SAMPLE STUDY MATERIAL

Instrumentation Engineering

IN

Postal Correspondence Course

GATE & PSUs

Analog Electronics

CONTENT

CHAPTER-1

DIODE APPLICATION

1. Rectifier: A diode rectifier (alternating to unidirectional converter) forms an essential building block of the dc power supplies required to electronic equipment.

Alternating (DC value = 0) **Unidirectional (Pulsating DC)**
(+ve DC value)

Important Terms

1. Ripple Factor: $r = \dfrac{\text{RMS value of AC component}}{\text{DC value}}$

$$\boxed{r = \frac{V_{ac\ rms}}{V_{dc}}}$$

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

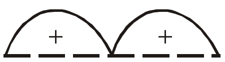
$$\left[\text{Form factor (F)} = \frac{\text{RMS value}}{\text{DC value}} = \frac{V_{rms}}{V_{dc}}\right]$$

Hence, $\boxed{r = \sqrt{F^2 - 1}}$

Note: Ideal value $r = 0$, F = 1 (AC component = 0)

2. Crest Factor: $C = \dfrac{\text{Peak value}}{\text{RMS value}}$

3. Ripple Voltage: Ripple voltage is defined as deviation of output voltage from it's DC value



Output of rectifier ⇒ Pulsating DC

DC value = V_{dc}

RMS value = V_{rms}

4. PIV (Peak Inverse Voltage)

It is maximum voltage applied to diode in reverse bias condition and decide voltage handling capacity of diode circuit.

Note: PIV should be low.

5. Transformer utilization factor: It shows the degree of utilization of the transformer in rectifier circuit.

It must be very high and decide cost of circuit

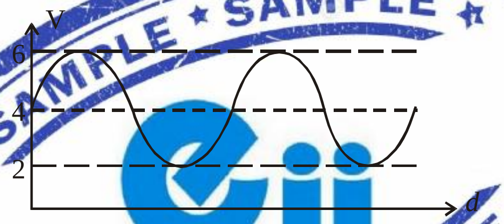
Output Rectifier

$$V = V_{DC} + V_{AC}$$

$$V_{rms} = \sqrt{(V_{DC})^2 + (V_{AC_{rms}})^2}$$

$$\Rightarrow \quad V_{AC_{rms}} = \sqrt{V_{rms}^2 - V_{DC}^2}$$

Example: Let $V = 4 + 2\sin\omega t$



- $V_{DC} = 4$
- $V_{AC_{rms}} = \dfrac{2}{\sqrt{2}}$
- $V_{rms} = \sqrt{4^2 + \left(\dfrac{2}{\sqrt{2}}\right)^2} = \sqrt{16+2} = \sqrt{18}$
- **Ripple Factor (*r*)** $= \dfrac{V_{AC_{rms}}}{V_{dc}} = \dfrac{\frac{2}{\sqrt{2}}}{4} = \dfrac{1}{2\sqrt{2}} = 0.35$
- Form Factor

$$F = \frac{V_{rms}}{V_{DC}} = \frac{\sqrt{18}}{4} = 1.06$$

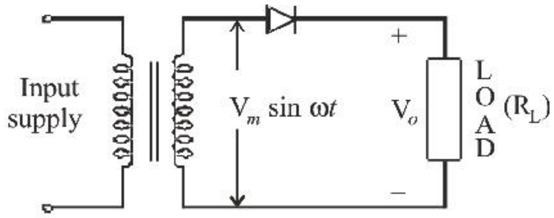
Rectifier

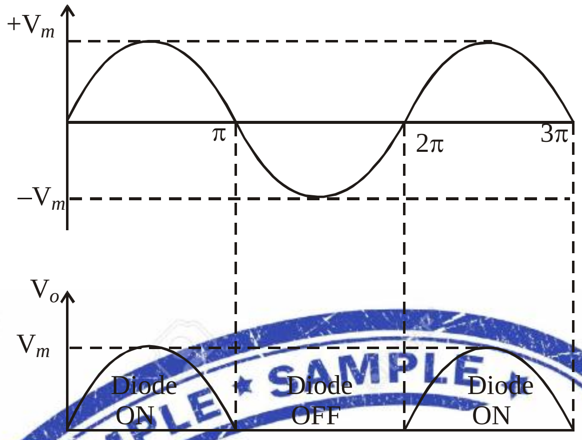
1. Half wave rectifier
2. Full wave rectifier

(*a*) Centre taped rectifier (*b*) Bridge rectifier

- **Half Wave Rectifier**

The half wave rectifier utilizes alternate half cycles of the input signal.





⇒ During +ve half cycle of supply voltage diode on and during –ve half it is off.

1. $V_{avg} = V_{DC}$

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

2. $$V_{rms} = \left[\frac{1}{2\pi}\int_0^{\pi} V_m^2 \sin^2 \omega t \, d(\omega t)\right]^{\frac{1}{2}} = \frac{V_m}{2}$$

3. Form Factor

$$\mathbf{F} = \frac{V_{rms}}{V_{DC}} = \frac{\frac{V_m}{2}}{\frac{V_m}{\pi}} = \frac{\pi}{2} = 1.58$$

4. Ripple Factor

$$r = \sqrt{F^2 - 1} = \sqrt{\left(\frac{\pi}{2}\right)^2 - 1} = 1.21$$

5. Crest Factor:

$$C = \frac{\text{Peak value}}{\text{RMS value}} = \frac{V_m}{\frac{V_m}{2}} = 2$$

6. Rectifier Efficiency:

$$\eta = \frac{\text{DC output power}}{\text{AC input power}} \times 100 = \frac{P_{dc}}{A_{AC}}$$

$$P_{dc} = V_o I_o = \frac{V_m}{\pi} \times \frac{I_m}{\pi} = \frac{V_m I_m}{\pi^2} \qquad \left(I_m = \frac{V_m}{R_L} \right)$$

RMS output voltage $V_{rms} = \frac{V_m}{2}$

RMS output current $I_{rms} = \frac{V_{rms}}{R_L} = \frac{V_m}{2R_L} = \frac{I_m}{2}$

$$P_{ac} = V_{rms}\, I_{rms} = \frac{V_m}{2}\frac{I_m}{2} = \frac{V_m I_m}{4}$$

$$\eta(\%) = \frac{P_{dc}}{P_{ac}} = \frac{\frac{V_m I_m}{\pi^2}}{\frac{V_m I_m}{4}} = \frac{4}{\pi^2} = 40.53\%$$

7. TUF : $= \frac{P_{dc}}{\text{VA rating of transformer}} = \frac{\frac{V_m I_m}{\pi^2}}{\frac{V_m I_m}{2\sqrt{2}}} = 0.286$

Voltage is available for full time period and current is available for half of time period

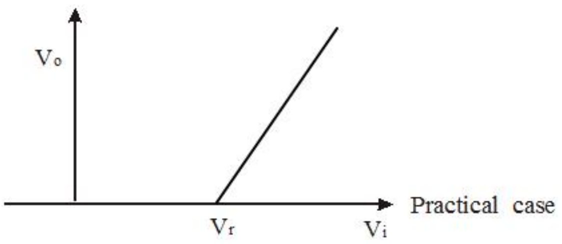
Note: Transformer is under utilized

8. PIV: Peak inverse voltage = V_m

9. Ripple Frequency: Source frequency

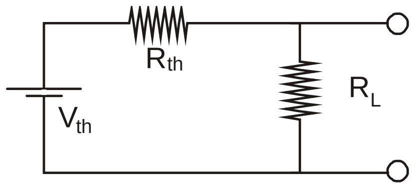
$$\boxed{f_r = r_s}$$

⇒ **Transfer curve of H.W.R.** (Diode is assumed ideal)



V_i	D	V_o
$V_i > 0$	ON	V_i
$V_i < 0$	OFF	0

Thevenin equivalent of half wave rectifier



$$I_{dc} = \frac{V_{TH}}{R_{TH} + R_L}$$

$$I_L = \frac{V_m \sin \omega t - V_r}{R_S + R_F + R_L} \cong \frac{V_m \sin \omega t}{R_S + R_F + R_L}$$

$$I_{dc} = \frac{1}{2\pi}\int_o^{\pi} I_L d(\omega t) \qquad I_m^{'} \sin \omega t \ \ where\ I_m^{'} = \frac{V_m}{R_S + R_F + R_L}$$

$$I_{dc} = \frac{1}{2\pi}\int_o^{\pi} I_L d(\omega t) = \frac{1}{2\pi}\int_o^{\pi} I_m^{'} \sin(\omega t) d(\omega t)$$

$$= \left(\frac{I_m^{'}}{\pi}\right) = \frac{V_m/\pi}{R_S + R_F + R_L} = \left(\frac{V_{Th}}{R_{Th} + R_L}\right)$$

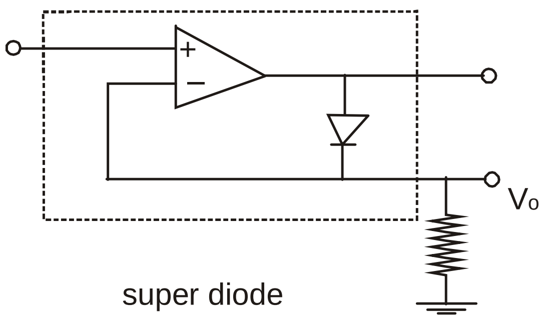
Thus $\boxed{V_{Th} = \frac{V_m}{\pi}}$

$\boxed{R_{Th} = R_S + R_F}$

Drawbacks :

- Excessive ripple factor =1.21
- Low rectifier efficiency
- Low TUF
- d.c. Saturation of transformer secondary

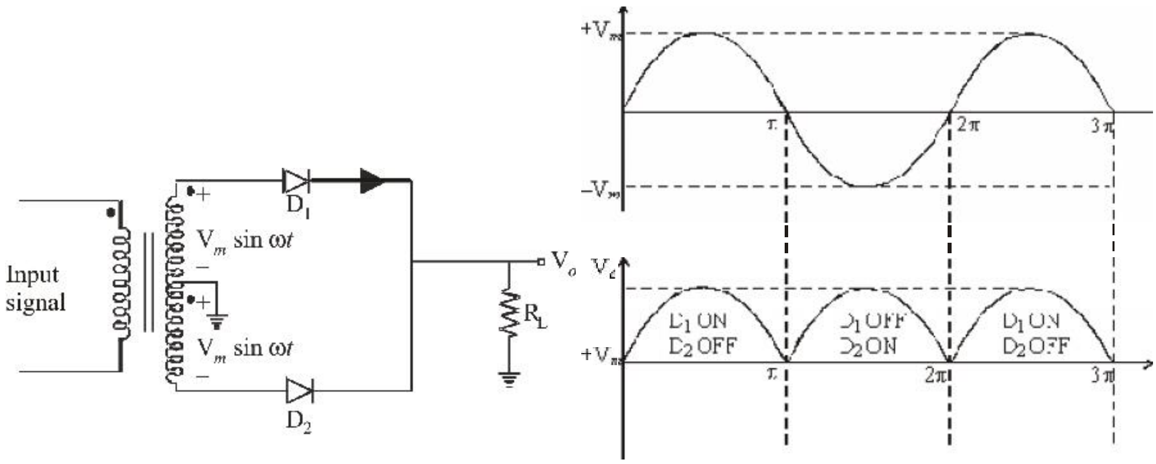
Precision Half wave rectifier :



10. Full Wave Rectifier

In the full wave rectifier, rectification takes place for both the half cycle of input signal.

1. Centre Tapped F.W.R. (Using Ideal Diodes)



Note: Ripple frequency = 2 (source frequency)

$$\boxed{f_r = 2 f_s}$$

(*i*) Average Value

$$V_{average} = V_{DC} = \frac{1}{\pi}\int_0^{\pi} V_m \sin \omega t \, . \, d(\omega t) = \frac{2V_m}{\pi}$$

(*ii*) RMS Value

$$V_{rms} = \left[\frac{1}{\pi}\int_0^{\pi} V_m^2 \sin^2 \omega t \, d(\omega t)\right]^{\frac{1}{2}} = \frac{V_m}{\sqrt{2}}$$

(*iii*) Form Factor

$$F = \frac{V_{rms}}{V_{DC}} = \frac{\frac{V_m}{\sqrt{2}}}{\frac{2V_m}{\pi}} = \frac{\pi}{2\sqrt{2}} = 1.11$$

(*iv*) Ripple Factor

$$r = \sqrt{F^2 - 1} = \sqrt{\left(\frac{\pi}{2\sqrt{2}}\right)^2 - 1} = 0.48$$

(*v*) Crest Factor

$$C = \frac{V_m}{\frac{V_m}{\sqrt{2}}} = \sqrt{2}$$

(*vi*) Rectifier Efficiency

$$\eta\% = \frac{P_{dc}}{P_{ac}} \times 100 = \frac{4}{\pi^2} \frac{V_m I_m}{\left(\frac{V_m I_m}{2}\right)}$$

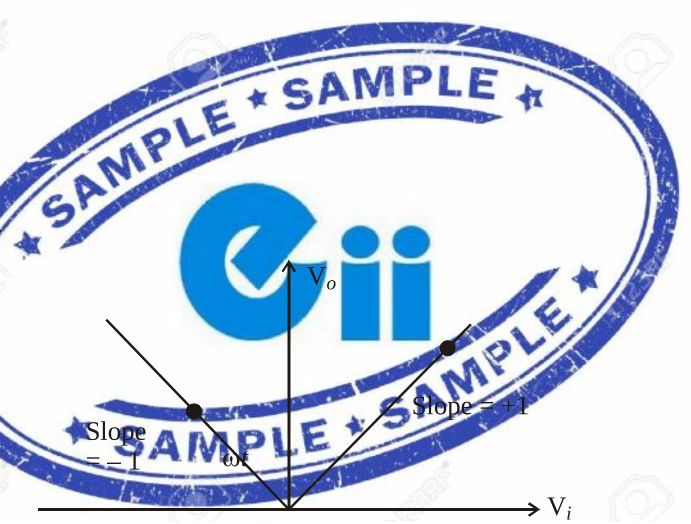
$$= \frac{8}{\pi^2} \qquad \left(I_m = \frac{V_m}{R_L} \right)$$

(*vii*) TUF = $\frac{P_{dc}}{\text{VA Rating of transformer}} = \frac{\frac{4}{\pi^2} V_m\ I_m}{0.6035\ V_m\ I_m} = 0.672$

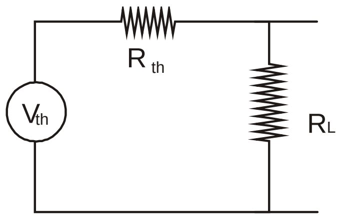
Note: In FWR case utilization of transformer takes place in both +ve and –ve half hence TUF increases.

(*viii*) PIV = $2V_m$; Higher PIV is disadvantages to circuit as it effect diode operation.

Transfer Curve of FWR



Thevenin equivalent of full wave rectifier



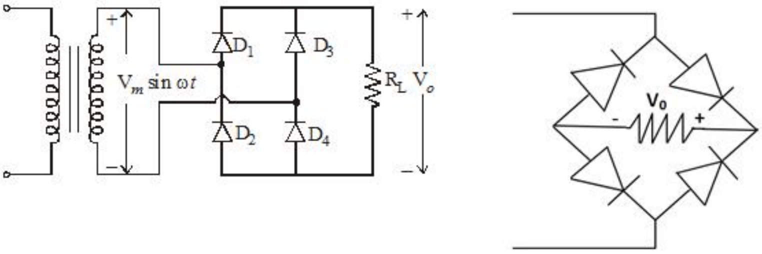
$$I_{th} = \frac{V_{th}}{R_L + R_{th}}$$

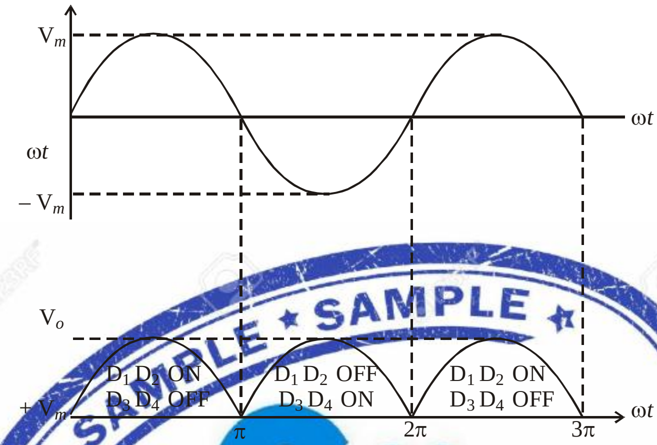
$$I_L = \frac{V_m \sin \mu t - V_r}{R_S + R_F + R_L} \cong \frac{V_m \sin \mu t}{R_S + R_F + R_L} = I_m^{'} \sin \mu t \quad \because I_m^{'} = \frac{V_m}{R_S + R_F + R_L}$$

$$I_{dc} = \frac{1}{2\text{®}} \int_o^{\text{®}} I_L d(\mu t) = \frac{2I_m^{'}}{\text{®}} = \frac{2V_m / \text{®}}{R_S + R_F + R_L}$$

$$\boxed{V_{th} = \frac{2V_m}{®}} \qquad \boxed{R_{Th} = R_S + R_F}$$

2. Bridge Type FWR (Using Ideal Diode):





Floating resistance may acquire stray charge from environment.

(*i*) Average value: $V_{average} = V_{DC} = \frac{2V_m}{\pi}$

(*ii*) RMS value: $V_{rms} = \frac{V_m}{\sqrt{2}}$

(*iii*) Form factor: $F = \frac{\pi}{2\sqrt{2}} = 1.11$

(*iv*) Ripple factor: $r = 0.48$

(*v*) Rectification efficiency = 81.06%

Note: As waveform is some for centre tapped and bridge type FWR hence above (*v*) quantities are same.

(*vi*) TUF: TUF = 0.812

Note: Transformer is proper utilized.

(*vii*) PIV = V_m

Key Points:

(*i*) Both full wave rectifiers are better than the half wave rectifier in so far as voltage ripple factor, rectification efficiency, TUF and crest factor are concerned.

(*ii*) TUF of bridge type FWR is better than centre tapped FWR therefore transforms required in the centre tapper FWR is bulky.

(*iii*) PIV of diodes in bridge rectifier is half of that of the diodes used in centre tapped FWR.

(*iv*) Overall, a bridge rectifier using four diodes is more economical.

Filter Circuits:

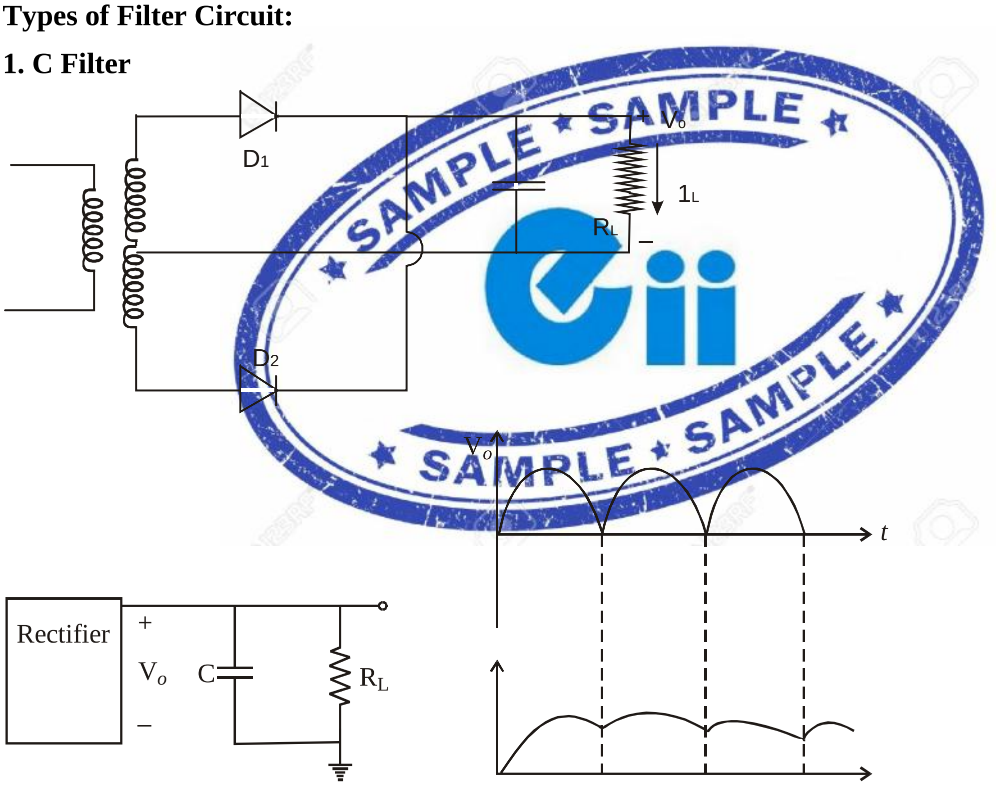
⇒ As the output of the rectifier circuit is pulsating DC containing AC and DC component filter circuits are used to suppress the AC component.

⇒ It reduces ripple factor to negligible value.

⇒ Important components of the filters are capacitor and inductor.

Types of Filter Circuit:

1. C Filter



Here, ripple voltage is approximated as triangular waveform and on this basis d.c. and r.m.s value is calculate.

$$V_{rpp} \begin{cases} dc \;\; value \rightarrow \dfrac{V_{rpp}}{2} \\ rms \;\; value \rightarrow \dfrac{V_{rpp}}{2\sqrt{3}} \end{cases}$$

⇒ A capacitor C across load R_L offers direct short circuit to AC component, these are therefore not allowed to reach the load. However dc gets stored in the form of energy in C and this allows the maintence of almost constant dc output voltage across the load.

⇒ C-filter is suitable for load having low current (High Load Resistance)

⇒ HWR with C-filter Ripple factor $r = \dfrac{1}{2\sqrt{3}\, f\, CR_L}$

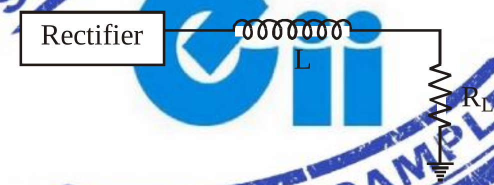
⇒ FWR with C-filter Ripple factor $r = \dfrac{1}{4\sqrt{3}\, f\, CR_L}$

$$V_{dc} = V_m - \frac{1}{2}V_{rpp}$$

$$V_{rpp} = \frac{V_{dc}}{F_C R_L}$$

$$\boxed{V_{rpp} = \frac{2V_m}{1+2F_C R_L}}$$

(*ii*) Inductor Filter (L-filter):



⇒ An inductor L in series with load R_L reduces the ac component or ac ripples because L in series with R_L offers high impedance to ac component but very low resistance to dc.

⇒ L-filter is suitable for loads requiring high load current (low value of R_L).

Note: In both C-filter and L-filter, time constant should be large for better waveform *i.e.*,

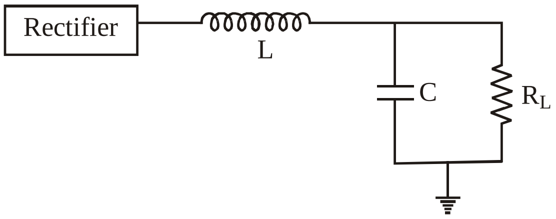
$\tau = \dfrac{L}{R_L} = CR_L$ should be high.

(*ii*) Ripple factor (*r*) = $\dfrac{2}{3\sqrt{2}} \dfrac{1}{\sqrt{1+\left(\dfrac{X_L}{R_L}\right)^2}}$

where, $X_L = \omega L$ for HWR

$= Z\,\omega\,L$ for FWR

(*iii*) L section or LC Filter:



⇒ An LC filter consists of inductor L in series with the load and capacitor C across the load. This filter possesses the advantage of both L filter and C filter.

⇒ Ripple factor $r = \dfrac{\sqrt{2}}{3}\dfrac{X_C}{X_L}$

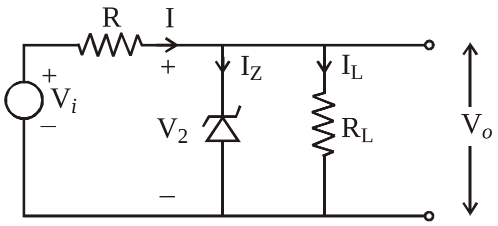
Note: (*i*) Ripple factor (*r*) is independent of R_L (*ii*) $r \propto \dfrac{1}{f^2}$

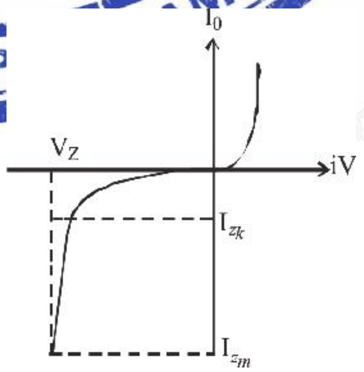
Voltage Regulator

⇒ Voltage regulator is a circuit whose purpose is to provide constant DC voltage between it's output terminals.

⇒ Voltage regulator circuits can be implemented using Zenner diode, transistors, etc.

1. Voltage Regulator Using Zener Diode:





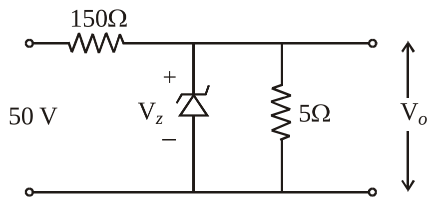
- V_i is output of the filter circuit.
- Zener diode should be RB and breakdown.
- I_{ZK} = KNEE current = The minimum current flowing through the zener diode when zener breakdown has just occurred.
- I_{Zm} = The maximum zener current.
- P_{Zm} = Maximum power dissipated in zener diode = $V_Z\, I_{Zm}$

- For satisfactory operation of circuit.

$$I \geq I_{ZK} + I_L$$

$$\frac{V_i - V_o}{R} \geq I_{ZK} + I_L$$

Example: Find P_Z Given $V_Z = 15V$



Solution: Voltage across reverse bias zener diode = $\frac{5}{150+5} \times 50 = 1.612$ V

This voltage is less than V_Z hence zener is off and $I_Z = 0$ hence $P_Z = V_Z I_Z = 0$

Example. If in the above problem $5\,\Omega$ resistor is replaced by $100\,\Omega$ resistor. Now find P_Z?

Solution: Voltage across RB zener diode

$$V_o = \frac{100}{150+100} \times 50 = 20\,V$$

Now $V_o > V_Z$

Hence, diode will go into breakdown mode.

Hence, $(V_o = V_Z = 15V)$

$$I = \frac{50-15}{150} = 0.23\,A$$

$$I_L = \frac{15}{100} = .15\,A$$

$$I_Z = I - I_L = 0.23 - 0.15 = 0.08\,A$$

$$P_Z = V_Z\, I_Z = 15 \times 0.08 \text{ watts}$$

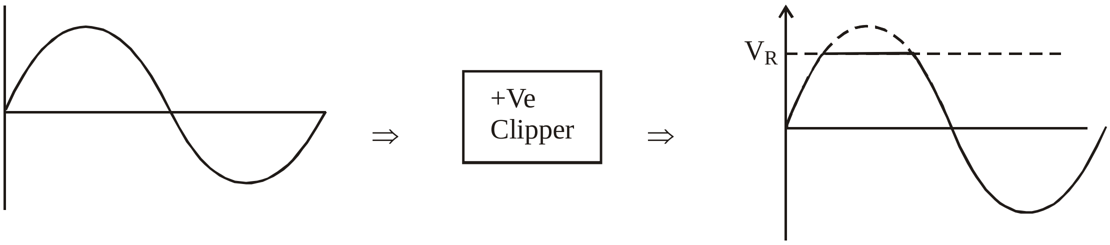
$$= 1.2 \text{ watts}$$

Clipping (Limiting) Circuits

⇒ These are used to select the part of waveform that lie above or below some reference level.

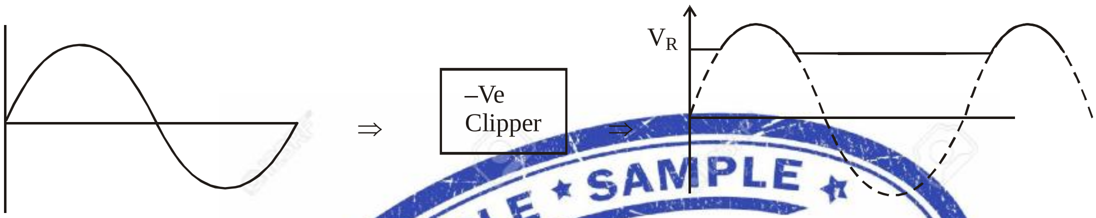
(*i*) Positive Clipper:

- Clipping above reference level.

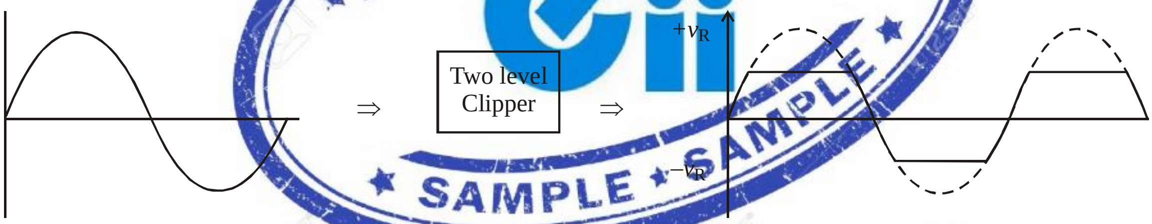


(*ii*) Negative Clipper:

- Clipping below reference level

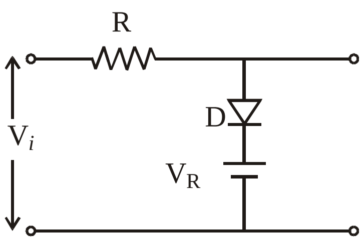


(*iii*) Two Level Clipper:



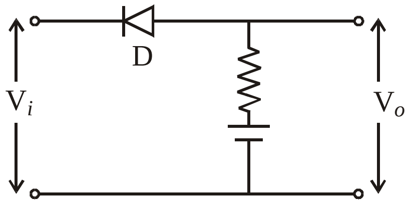
⇒ On the basis of position of diode w.r.t load

(*i*) Shunt Clipper



(Shunt +ve clipper)

(*ii*) Series Clipper

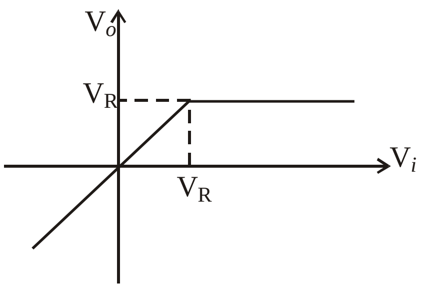


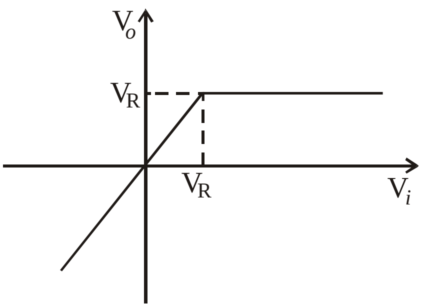
Series +ve clipper

Range of V_i	D	V_o
$V_i < V_R$	OFF	V_i
$V_i \geq V_R$	ON	V_R

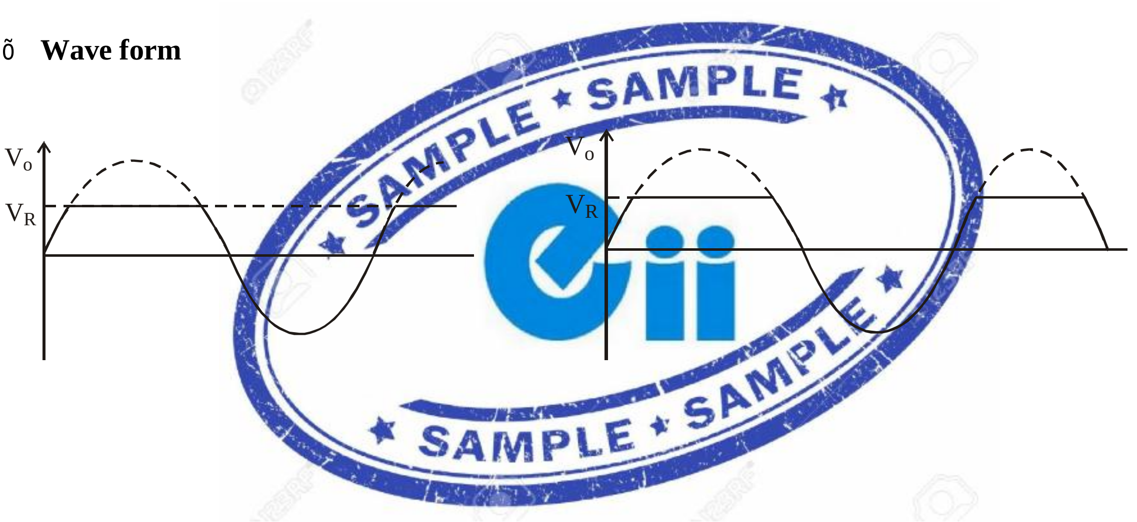
Range of V_i	D	V_o
$V_i < V_R$	ON	V_i
$V_i \geq V_R$	OFF	V_R

- **Transfer Curve**





õ **Wave form**



36	052187	ANOOP A	ECE
37	008233	ARPIT SHUKLA	ECE
38	106114	MANISH GUPTA	EE
41	018349	VINAY GUPTA	ECE
44	098058	LEENA P MARKOSE	EE
45	029174	NAVNEET KUMAR KANWAT	EE

9 Rank under AIR 100 in GATE 2015 (Rank 6,8,19,28,41,56,76,91,98)

and many more............................