ELECTRONICS DEVICES AND CIRCUITS

UNIT I

DIODE CHARACTERISTICES AND APPLICATIONS

Presented by

Mrs. G.Sujana ,Assistant professor

Miss. P.Bhagyalakshmi, Assistant professor

Electronics and Communication Engineering

Narsimha Reddy Engineering College (Autonomous)

Secunderabad, Telangana, India- 500100.

SEMICONDUCTOR

A **semiconductor** is a material that has an electrical conductivity between a conductor and an insulator. Its conductivity can be **controlled or modified** by temperature, light, electric field, or the addition of impurities (a process known as **doping**).

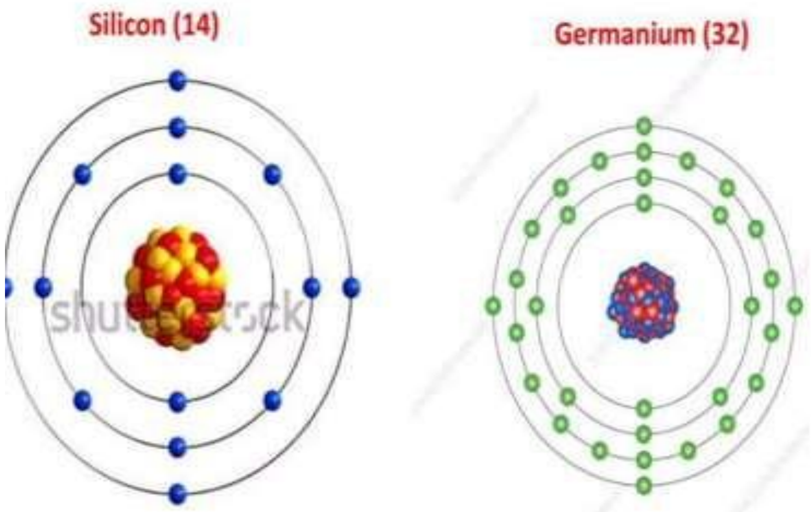
Semiconductor materials are the foundation of modern electronics. They are essential components in devices like transistors, diodes, solar cells, LEDs, and integrated circuits.

Examples:

1. **Gallium Arsenide (GaAs)** – high-speed devices

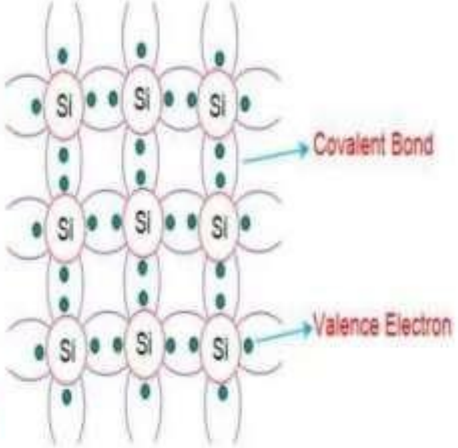
2. **Gallium Nitride (GaN)** – power electronics, LEDs

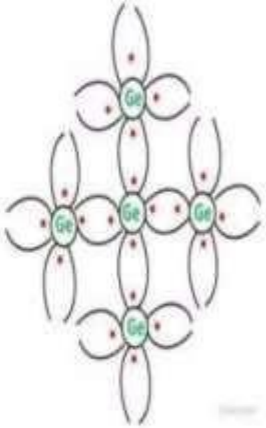
3. **Indium Phosphide (InP)** – high-frequency applications



Intrinsic Semiconductor

- A pure form of Semiconductor
- The concentration of electrons (n_i) in the conduction band = concentration of holes (p_i) in the valance band. (**$n_i = p_i$**)
- Conductivity is poor
- Eg. Pure Silicon, Pure Germanium (Tetravalent)





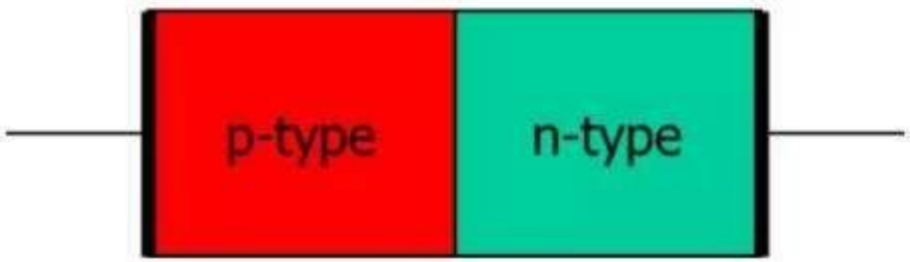
Extrinsic Semiconductor

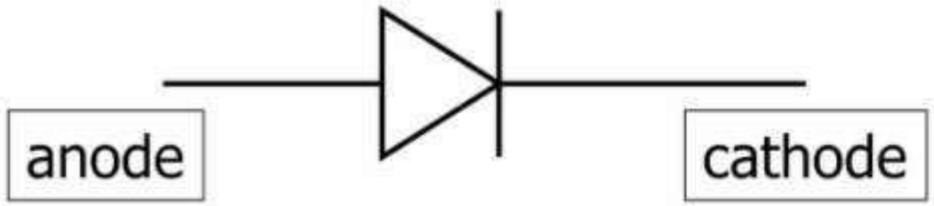
- A Impure form of Semiconductor
- To increase the conductivity of intrinsic semiconductor, a small amount of impurity (Pentavalent or Trivalent) is added.
- This process of adding impurity is known as **Doping**.
- 1 or 2 atoms of impurity for 10^6 intrinsic atoms.
- Electron concentration ≠ Hole concentration
- One type of carrier will predominate in an extrinsic semiconductor

Classification of Extrinsic Semiconductor

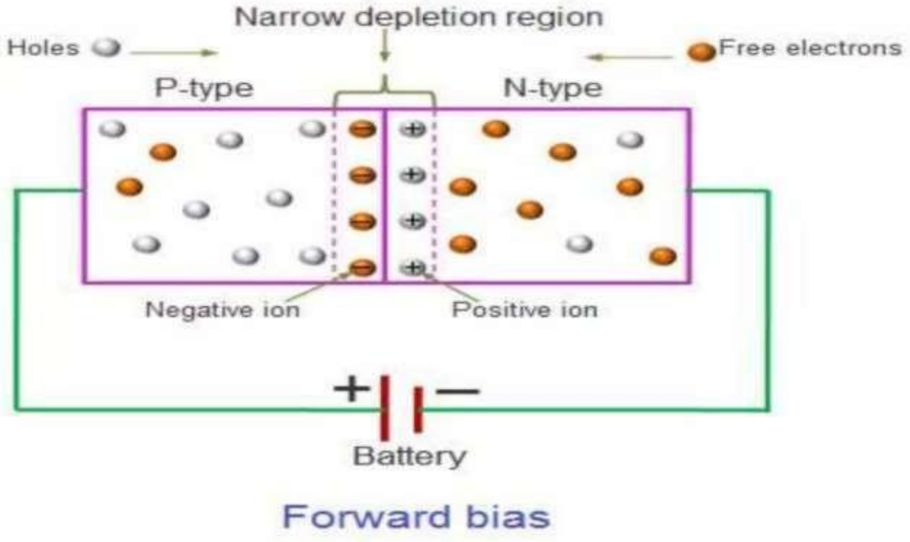
- N Type Semiconductor
- P Type Semiconductor

PN Junction Diode

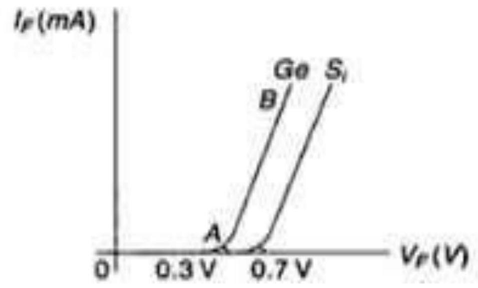




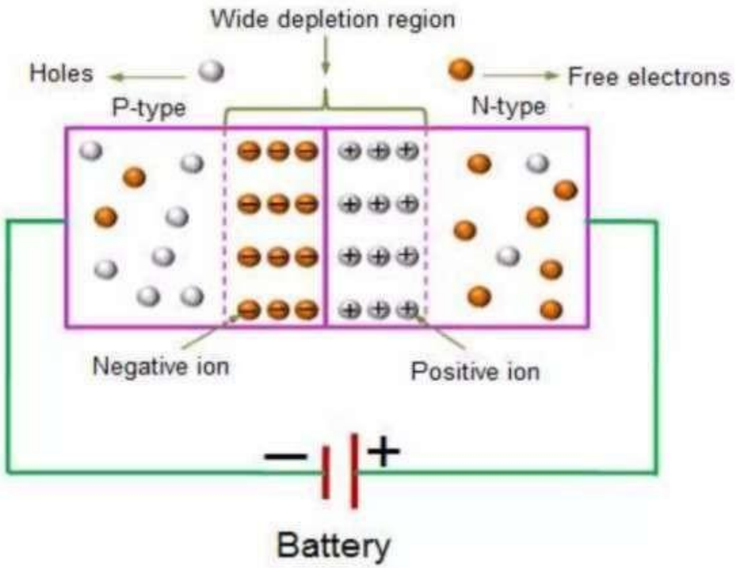
PN Junction Forward bias



Forward bias Characteristics

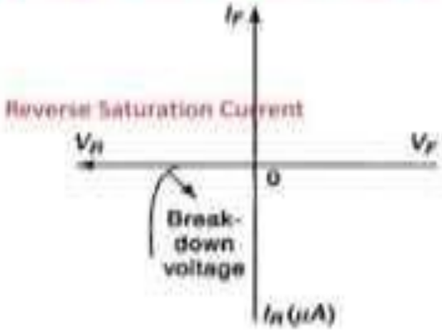


PN Junction Reverse bias

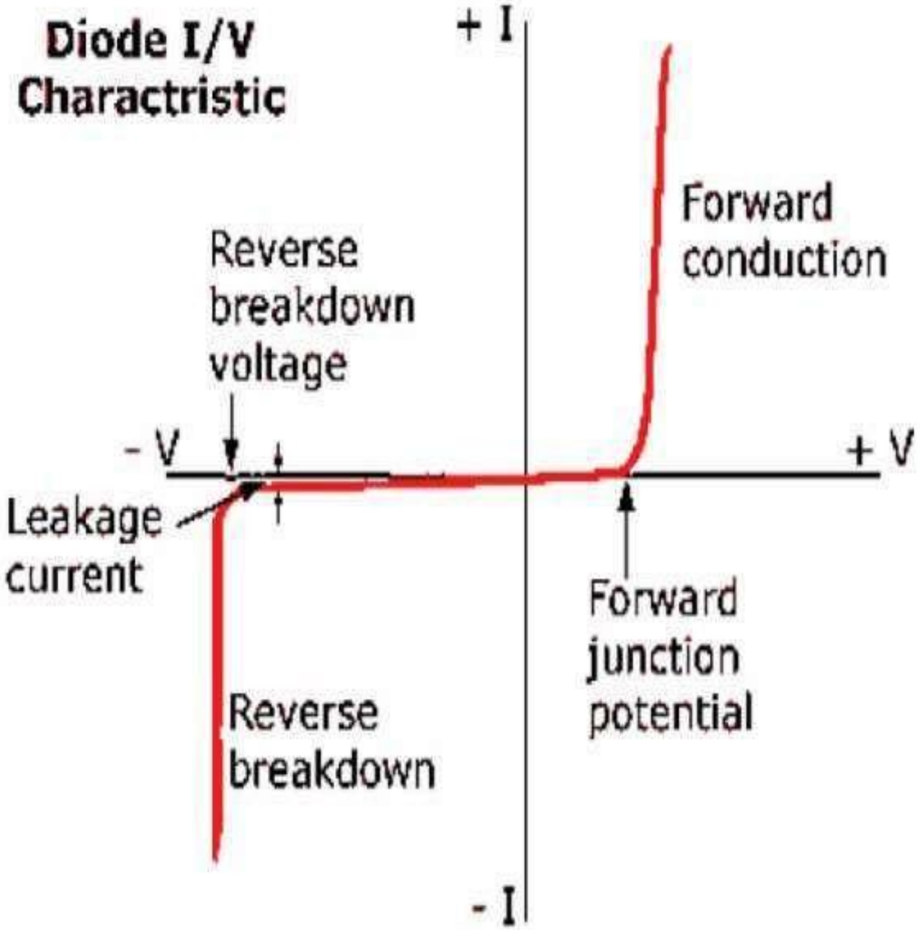


Reverse bias

Reverse bias Characteristics



Characteristics of PN Junction



DIODE RESISTANCE

The resistance of a diode isn't constant , It varies depending on whether the diode is **forward-biased** or **reverse-biased**, and even within the forward-biased condition, it changes with current. There main types of diode resistance:

1.Static (DC) Resistance : The Static resistance is calculated using Ohm's Law at a specific operating point. Its defined as the Ratio of Voltage to the Current i.e. V/I

2. **Dynamic (AC) Resistance**: The Dynamic resistance is defined as change in voltage to change in Current i.e dv/di

3. REVERSE RESISTANCE : The reverse resistance of a PN junction diode is the resistance of a diode when its connected in reverse-biased — i.e., when the p-side is connected to negative and the n-side to positive of the power supply.

TRANSITION CAPACITANCE :

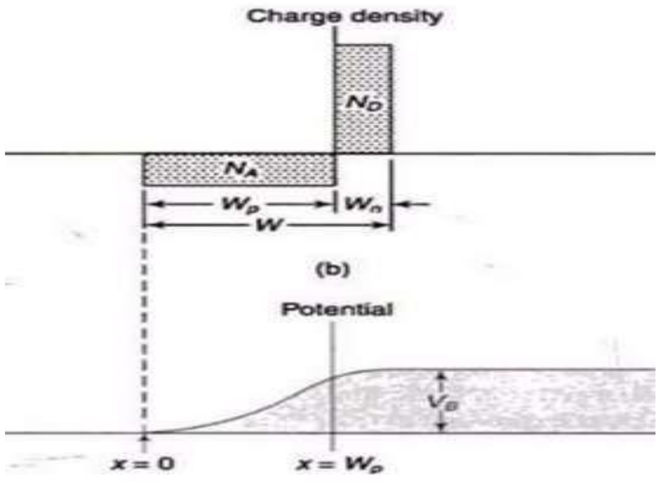
- The parallel layers of oppositely charged immobile ions on the two side of the junction form the capacitance C_T
- C_T is Transition or Space charge or depletion region capacitance.

$$C_T = \left|\frac{dQ}{dV}\right|$$

Where dQ is the increase in charge and dV is the change in voltage.

- The Total Charge density of a p type material with area of the junction A is given by,

$$Q = q\,N_A\,W\,A$$



- The relation between potential and charge density is given by the Poisson's equation.

$$\frac{d^2V}{dx^2} = -\frac{\rho}{\varepsilon_o\,\varepsilon_r}$$

$$\frac{d^2V}{dx^2} = \frac{qN_A}{\varepsilon_o\varepsilon_r}$$

$$V = \frac{qN_A x^2}{2\varepsilon_o\,\varepsilon r}$$

- At $x = W_p$, $V = V_B$,

$$V_B = \frac{qN_A W^2}{2\varepsilon}$$

- Differentiating w.r.to V, we get .

$$1 = \frac{qN_A\,2W}{2\varepsilon}\left|\frac{dW}{dV}\right|$$

$$\left|\frac{dW}{dV}\right| = \frac{\varepsilon}{qN_A W}$$

$$C_T = \left|\frac{dQ}{dV}\right| = A\,q\,N_A\left|\frac{dW}{dV}\right|$$

$$= A\,q\,N_A\,\frac{\varepsilon}{qN_A W}$$

$$C_T = \frac{\varepsilon A}{W}.$$

DIFFUSION CAPACITANCE :

- The capacitance that exists in a forward biased junction is called a diffusion or storage capacitance (C_D)
- $C_D >> C_T$

$$C_D = \frac{dQ}{dV},$$

Where dQ represents change in the number of minority carrier when change in voltage.

$$Q = \int_0^{\infty} AeP_n(0)e^{-x/L_p}\,dx = \left[\frac{AeP_n(0)e^{-x/L_p}}{1/L_p}\right]_0^{\infty}$$

$$= L_p AeP_n(0)$$

$$C_D = \frac{dQ}{dV} = AeL_p\frac{d[P_n(0)]}{dV}$$

$$C_D = \frac{dQ}{dV} = AeL_p\frac{d[P_n(0)]}{dV}$$

Diffusion hole current in the N side $I_{pn}(x)$

$$I_{pn}(x) = \frac{AeD_pP_n(0)}{L_p}e^{-x/L_p}$$

At, x = 0

$$I_{pn}(0) = \frac{AeD_pP_n(0)}{L_p}$$

$I_{pn}(0) = I$

$$I = \frac{AeD_pP_n(0)}{L_p}$$

$$P_n(0) = \frac{IL_p}{AeD_p}$$

Diff. w.r.to V

$$\frac{d[P_n(0)]}{dV} = \frac{dI}{dV}\frac{L_p}{AeD_p}$$

$$C_D = \frac{dQ}{dV} = \frac{dI}{dV}\frac{L_p^2}{D_p}$$

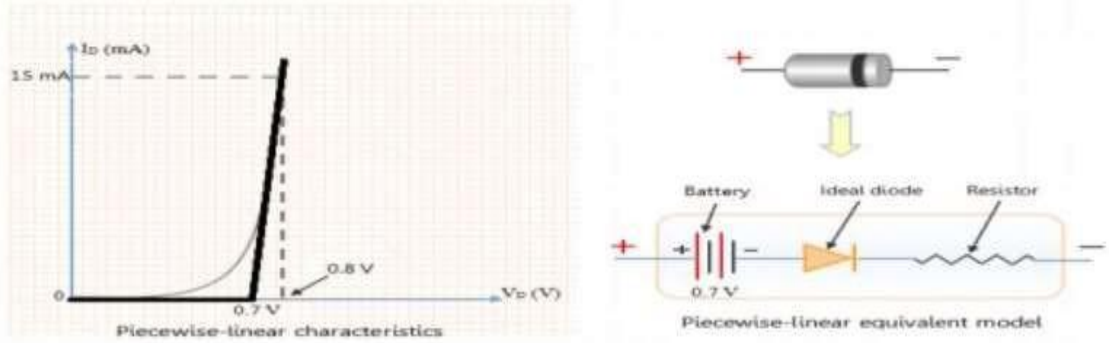
$$C_D = g\tau \qquad g = \frac{dI}{dV} \qquad \tau = \frac{L_p^2}{D_p}$$

$$C_D = \frac{\tau I}{\eta V_T}$$

From diode current equation, $g = \frac{I}{\eta V_T}$

Diode Equivalent Circuit:

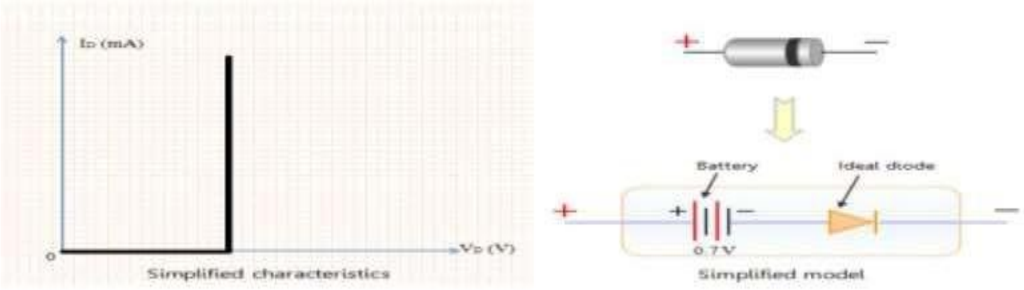
Piecewise-Linear Equivalent Circuit : A technique for obtaining an equivalent circuit for a diode is to approximate the characteristics of the device by straight-line segments



Piecewise-Linear Equivalent Circuit

2.SIMPLIFIED EQUIVALENTCIRCUIT :

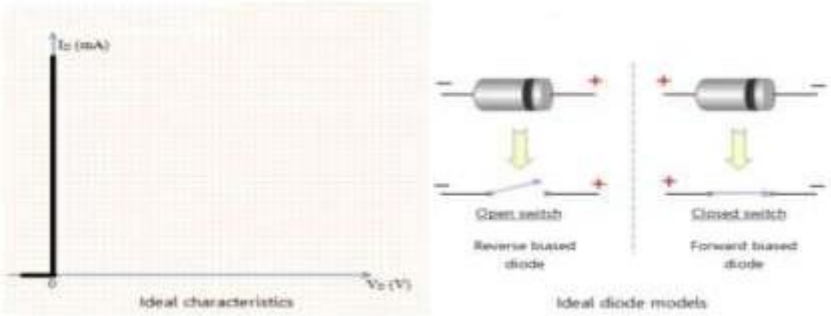
The battery simply indicates that it opposes the flow of current in forward direction until 0.7 V. As the voltage becomes larger than 0.7 V, the current starts flowing in forward direction. The horizontal line indicates that the current flowing through diode is zero for voltages between 0 and 0.7 V



Simplified Equivalent Circuit

3. IDEAL DIODE MODEL :

1. Ideal diode allows the flow of forward current for any value of forward bias voltage. Hence, Ideal diode can be modeled as closed switch under forward bias condition. This is shown in the figure.
2. Ideal diode allows zero current to flow under reverse biased condition. Hence it can be modeled as open switch. This is indicated in the figure.



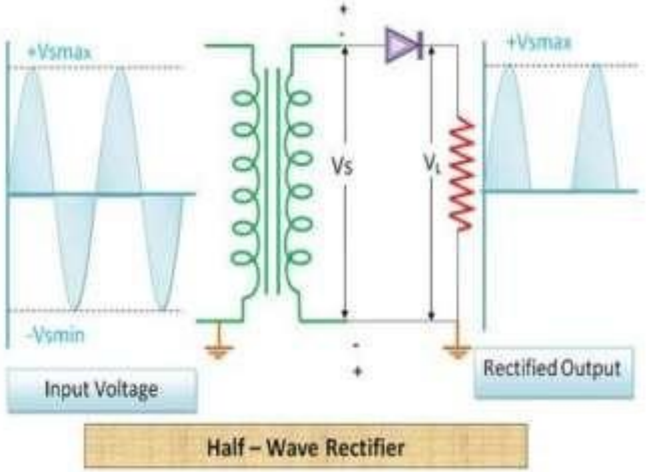
Ideal Diode Model

RECTIFIER:

A rectifier is a device which converts ac voltage (Bi-directional) to pulsating DC Voltage(Uni-directional). Any Electrical Device which offers a low resistance to the current in one direction but a high resistance to the current in the opposite direction is called rectifier

HALF WAVE RECTIFIER:

Half wave rectifier is that in which the half cycle of AC voltage gets converted into pulsating DC voltage. The remaining half cycle of AC is suppressed by rectifier circuit or the output DC current for remaining half cycle is zero.



Let V_i be the voltage to the primary of the transformer and given by the equation

$$V_i = V_m \sin \omega t;\ V_m >> V_\gamma$$

Ripple factor **(Γ)** The ratio of rms value of a.c. component to the d.c. component in the output is known as *ripple factor* (Γ).

$$\Gamma = \frac{\text{rms value of a.c. component}}{\text{d.c. value of component}} = \frac{V_{r,\,rms}}{V_{d.c.}}$$

where $$V_{r,\,rms} = \sqrt{V_{rms}^2 - V_{d.c.}^2}$$

$$\Gamma = \sqrt{\left(\frac{V_{rms}}{V_{d.c.}}\right)^2 - 1}$$

If the values of diode forward resistance (r_f) and the transformer secondary winding resistance (r_s) are also taken into account, then

$$V_{d.c.} = \frac{V_m}{\pi} - I_{d.c.}(r_s + r_f)$$

$$I_{d.c.} = \frac{V_{d.c.}}{(r_s + r_f) + R_L} = \frac{V_m}{\pi(r_s + r_f + R_L)}$$

The rms voltage at the load resistance can be calculated as

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

$$= V_m \left[\frac{1}{4\pi}\int_0^{\pi} (1 - \cos 2\,\omega t)\, d(\omega t)\right]^{\frac{1}{2}} = \frac{V_m}{2}$$

Therefore, $$\Gamma = \sqrt{\left[\frac{V_m/2}{V_m/\pi}\right]^2 - 1} = \sqrt{\left(\frac{\pi}{2}\right)^2 - 1} = 1.21$$

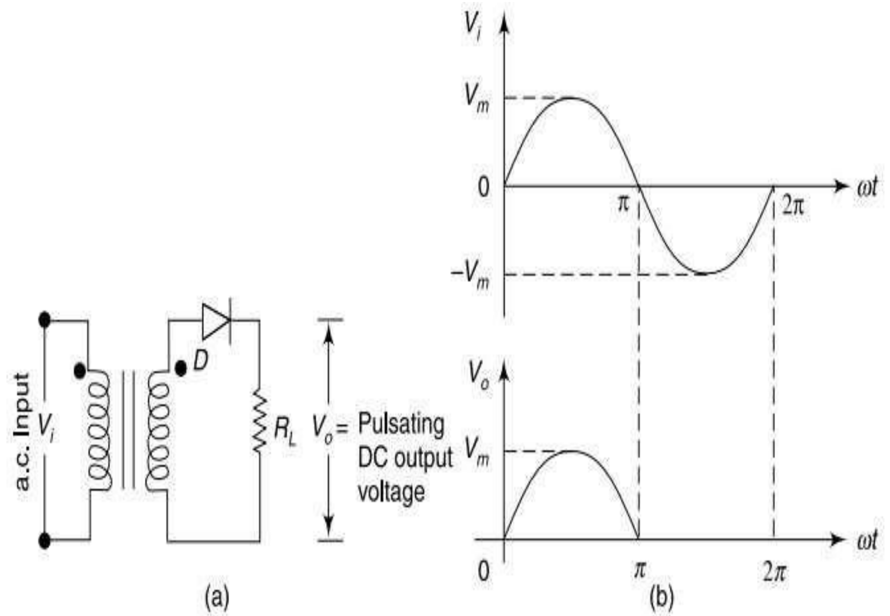


Fig. 3.3 *(a) Basic structure of a half-wave rectifier, (b) Input output waveforms of half wave rectifier*

V_{av} is the average or the d.c. content of the voltage across the load and is given by

$$V_{av} = V_{\text{d.c.}} = \frac{1}{2\pi}\left[\int_0^{\pi} V_m \sin \omega t d(\omega t) + \int_{\pi}^{2\pi} 0.d(\omega t)\right]$$

$$= \frac{V_m}{2\pi}[-\cos \omega t]_0^{\pi} = \frac{V_m}{\pi}$$

Therefore,
$$I_{\text{d.c}} = \frac{V_{\text{d.c.}}}{R_L} = \frac{V_m}{\pi R_L} = \frac{I_m}{\pi}$$

Efficiency (η) The ratio of d.c. output power to a.c. input power is known as *rectifier efficiency* (η).

$$\eta = \frac{\text{d.c. output power}}{\text{a.c. input power}} = \frac{P_{\text{d.c.}}}{P_{\text{a.c.}}}$$

$$= \frac{\dfrac{(V_{\text{d.c.}})^2}{R_L}}{\dfrac{(V_{\text{rms}})^2}{R_L}} = \frac{\left(\dfrac{V_m}{\pi}\right)^2}{\left(\dfrac{V_m}{2}\right)^2} = \frac{4}{\pi^2} = 0.406 = 40.6\%$$

The maximum efficiency of a half-wave rectifier is 40.6%.

Peak Inverse Voltage (PIV) It is defined as the maximum reverse voltage that a diode can withstand without destroying the junction. The peak inverse voltage across a diode is the peak of the negative half cycle. For half-wave rectifier, PIV is V_m.

Transformer Utilisation Factor (TUF) In the design of any power supply, the rating of the transformer should be determined. This can be done with a knowledge of the d.c. power delivered to the load and the type of rectifying circuit used.

$$\text{TUF} = \frac{\text{d.c. power delivered to the load}}{\text{a.c. rating of the transformer secondary}}$$

$$= \frac{P_{\text{d.c.}}}{P_{\text{a.c.}} \text{ rated}}$$

FULL WAVE RECTIFIER

Full wave rectifier is the semiconductor device which convert complete cycle of AC into pulsating DC. Unlike half wave rectifiers which uses only half wave of the input AC cycle, full wave rectifiers utilize full wave

Ripple factor (Γ)

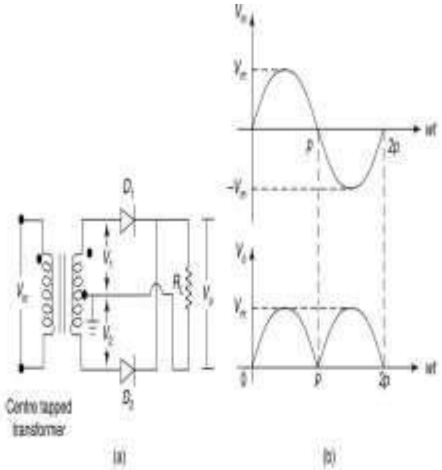
$$\Gamma = \sqrt{\left(\frac{V_{\text{rms}}}{V_{\text{d.c.}}}\right)^2 - 1}$$

The average voltage or d.c. voltage available across the load resistance

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

$$= \frac{V_m}{\pi}[-\cos \omega t]_0^{\pi} = \frac{2V_m}{\pi}$$

$$I_{\text{d.c.}} = \frac{V_{\text{d.c.}}}{R_L} = \frac{2V_m}{\pi R_L} = \frac{2I_m}{\pi} \text{ and } I_{\text{rms}} = \frac{I_m}{\sqrt{2}}$$



If the diode forward resistance (r_f) and the transformer secondary winding resistance (r_s) are included in the analysis, then

$$V_{\text{d.c}} = \frac{2V_m}{\pi} - I_{\text{d.c.}}(r_s + r_f)$$

$$I_{\text{d.c}} = \frac{V_{\text{d.c}}}{(r_s + r_f) + R_L} = \frac{2V_m}{\pi(r_s + r_f + R_L)}$$

RMS value of the voltage at the load resistance is

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

Therefore,

$$\Gamma = \sqrt{\left(\frac{V_m/\sqrt{2}}{2V_m/\pi}\right)^2 - 1} = \sqrt{\frac{\pi^2}{8} - 1} = 0.482$$

Efficiency (η) The ratio of d.c. output power to a.c. input power is known as rectifier efficiency (η).

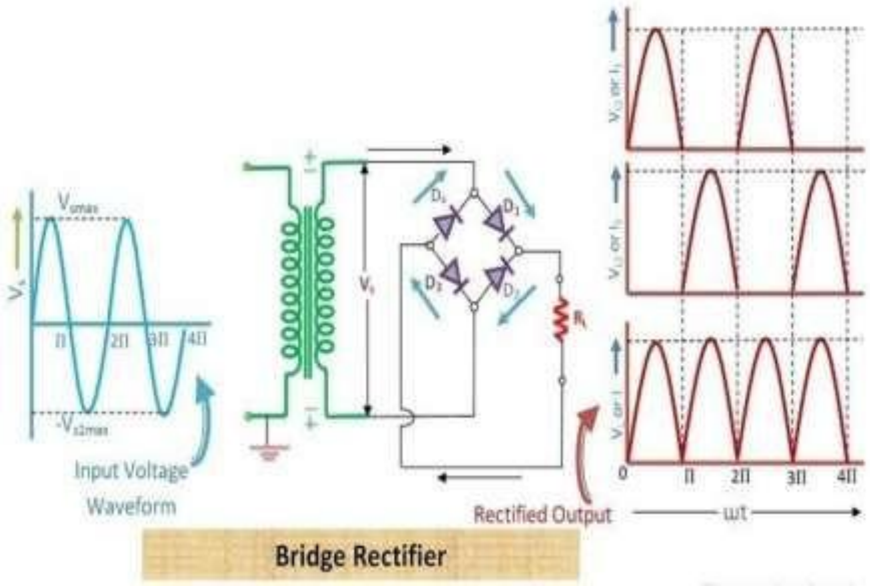
$$\eta = \frac{\text{d.c. output power}}{\text{a.c. input power}} = \frac{P_{\text{d.c.}}}{P_{\text{a.c.}}}$$

$$= \frac{(V_{\text{d.c.}})^2/R_L}{(V_{\text{rms}})^2/R_L} = \frac{\left[\frac{2V_m}{\pi}\right]^2}{\left[\frac{V_m}{\sqrt{2}}\right]^2} = \frac{8}{\pi^2} = 0.812 = 81.2\%$$

The maximum efficiency of a full-wave rectifier is 81.2%.

FULL WAVE BRIDGE WAVE RECTIFIER:

1. Bridge rectifier is formed by connecting four diodes in the form of a Wheatstone bridge. It also provides full wave rectification.
2. During the first half of AC cycle, two diodes are forward biased and during the second half of AC cycle, the other two diodes become forward biased



COMPARISION OF RECTIFIERS:

Particulars	*Type of rectifier*		
	Half-wave	*Full-wave*	*Bridge*
No. of diodes	1	2	4
Maximum efficiency	40.6%	81.2%	81.2%
$V_{d.c.}$ (no load)	V_m/π	$2V_m/\pi$	$2V_m/\pi$
Average current/diode	$I_{d.c.}$	$I_{d.c.}/2$	$I_{d.c.}/2$
Ripple factor	1.21	0.48	0.48
Peak inverse voltage	V_m	$2V_m$	V_m
Output frequency	f	$2f$	$2f$
Transformer utilisation factor	0.287	0.693	0.812
Form factor	1.57	1.11	1.11
Peak factor	2	$\sqrt{2}$	$\sqrt{2}$

CAPACITOR FILTER:

An inexpensive filter for light loads is found in the capacitor filter which is connected directly across the load

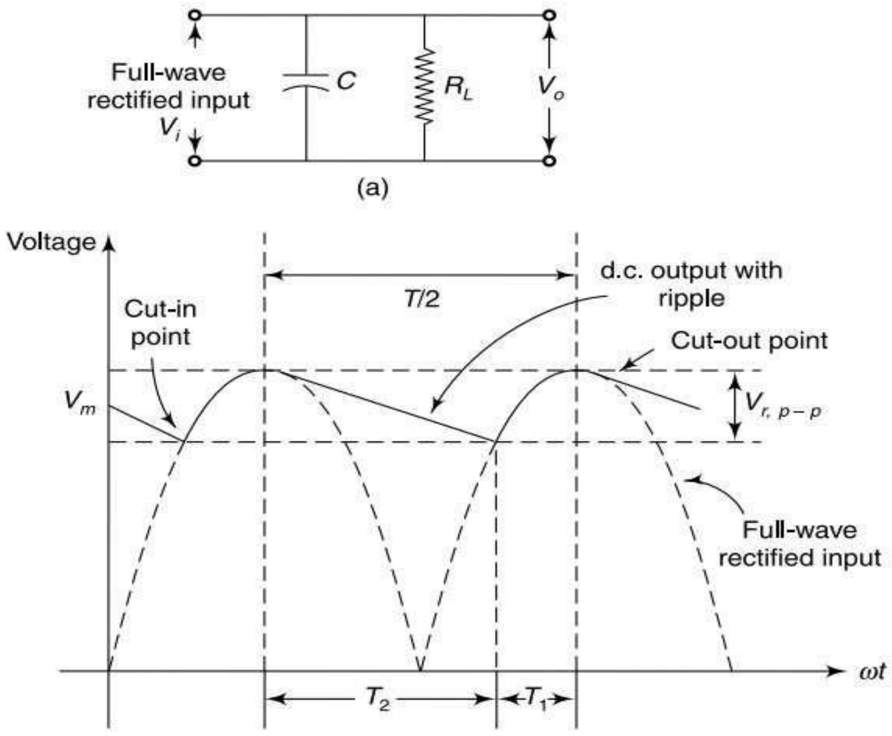


Fig. 3.10 *(a) Capacitor filter (b) Ripple voltage triangular waveform*

The charge it has acquired $= V_{r,\,p\text{-}p} \times C$

The charge it has lost $= I_{\text{d.c.}} \times T_2$

Therefore. $= I_{\text{d.c.}} \times T_2$

i.e. $T_2 = \dfrac{T}{2} = \dfrac{1}{2f}$, then $V_{r,\,p-p} = \dfrac{I_{\text{d.c.}}}{2fC}$

With the assumptions made above, the ripple waveform will be triangular in nature and the rms value of the ripple is given by

$$V_{r,\,\text{rms}} = \frac{V_{r,\,p-p}}{2\sqrt{3}}$$

Therefore from the above equation, we have

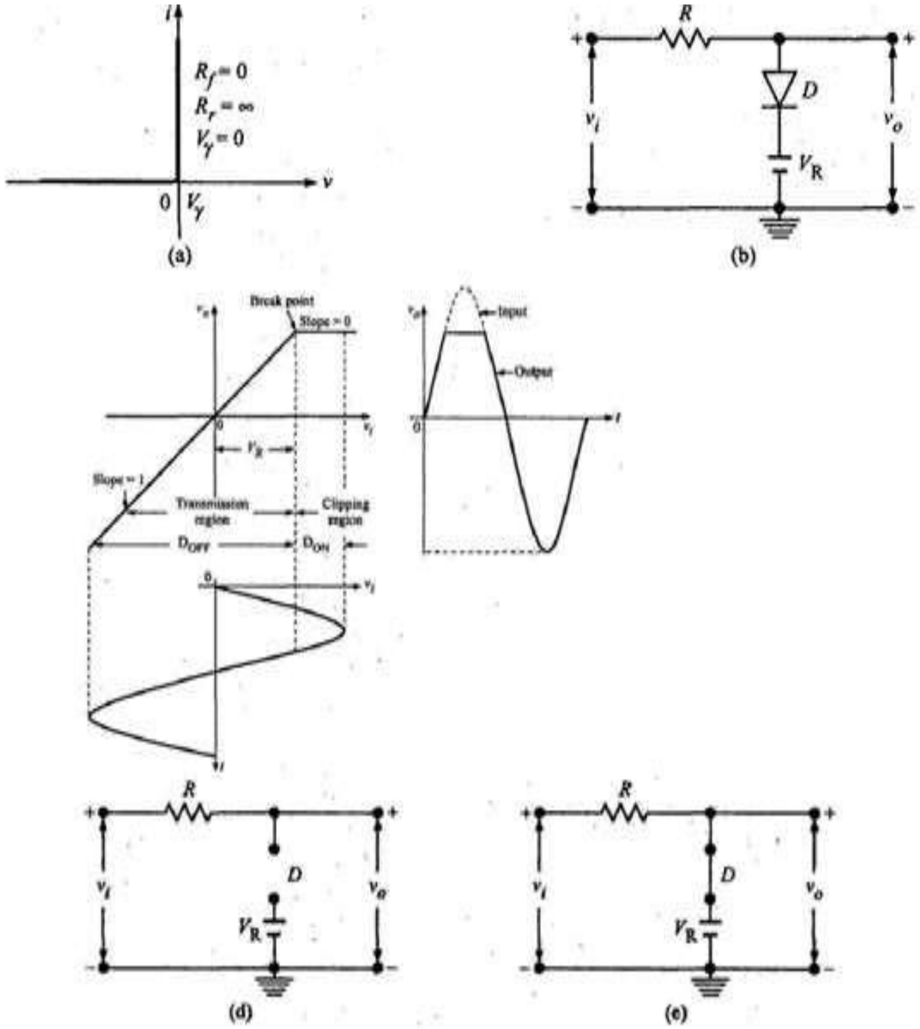
$$V_{r,\,\text{rms}} = \frac{I_{\text{d.c.}}}{4\sqrt{3}\,fC}$$

$$= \frac{V_{\text{d.c.}}}{4\sqrt{3}\,fCR_L}, \text{ since } I_{\text{d.c.}} = \frac{V_{\text{d.c.}}}{R_L}$$

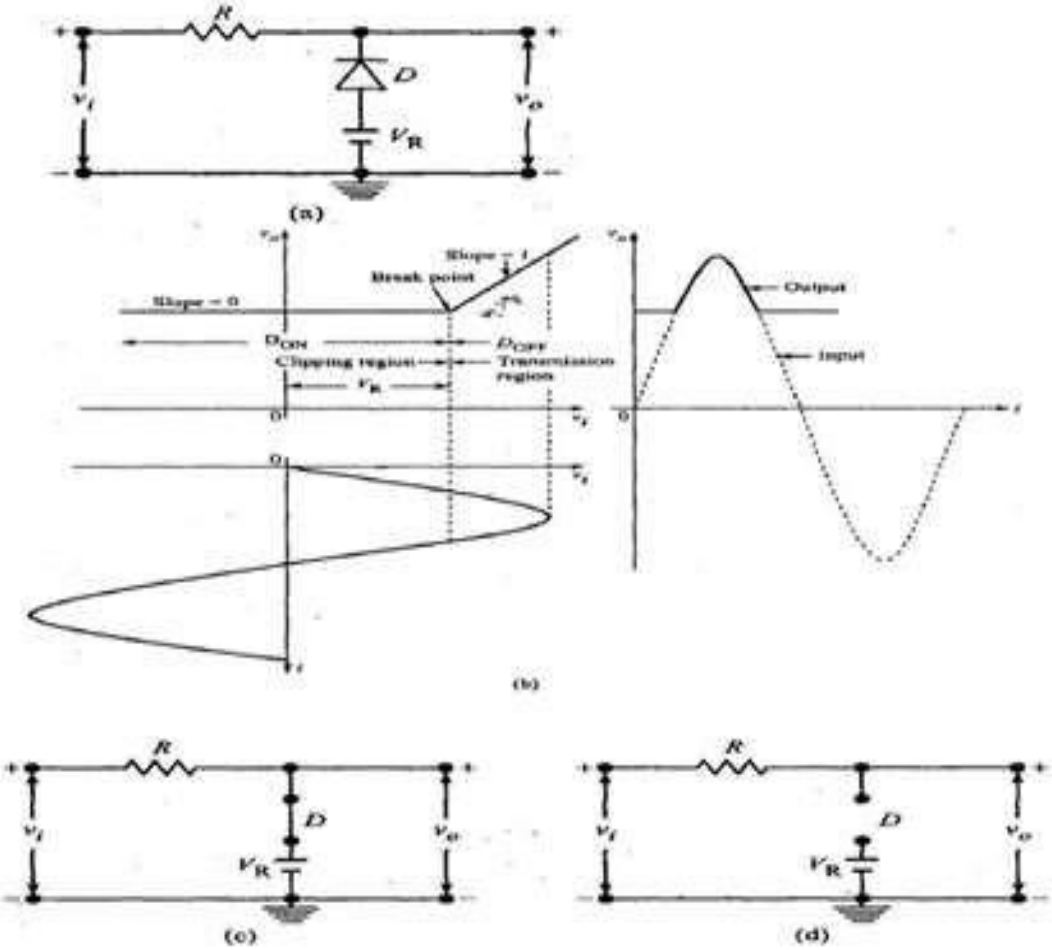
Therefore, ripple factor $\Gamma = \dfrac{V_{r,\,\text{rms}}}{V_{\text{d.c.}}} = \dfrac{1}{4\sqrt{3}\,fCR_L}$

Shunt Clipper:

a)Clipping Above Reference Level

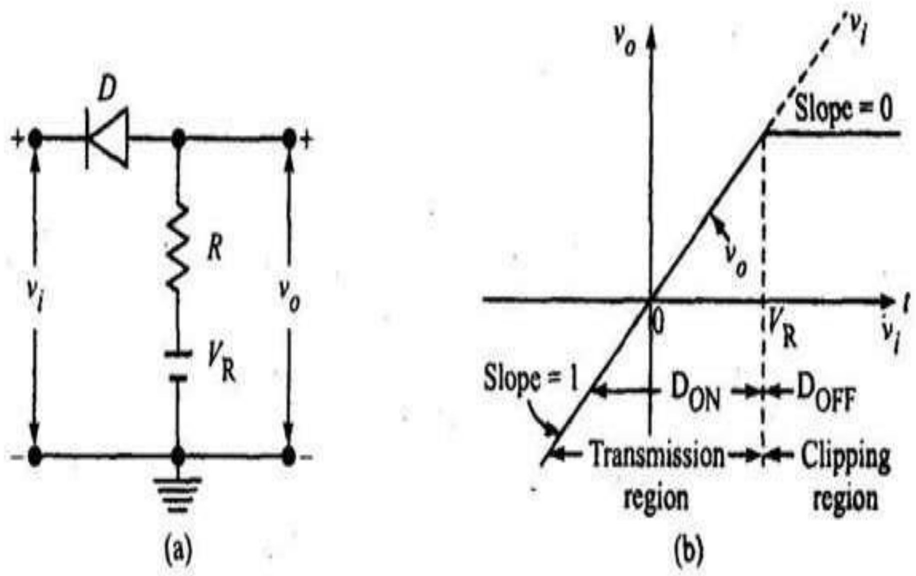


b)Clipping below Reference Level



Series Clipper:

a)Clipping Above Reference Level



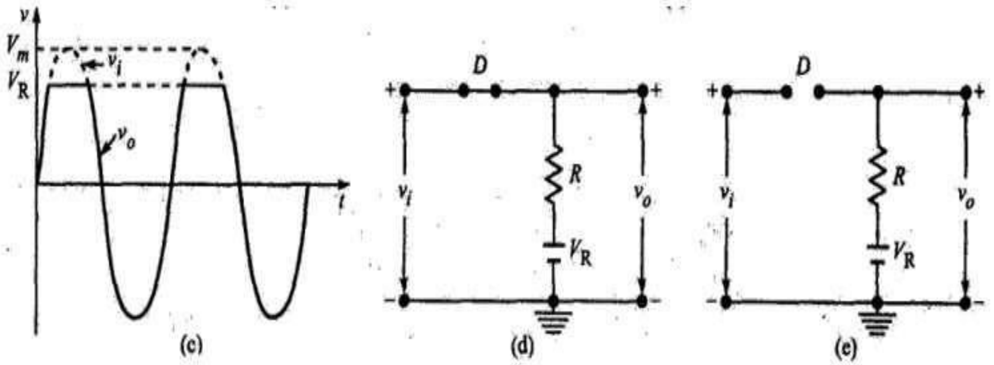
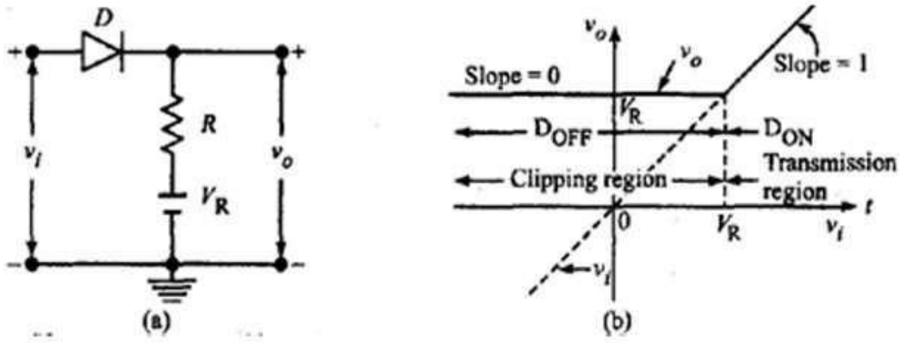


Figure 2.4 (a) Diode series clipper circuit diagram, (b) transfer characteristic, (c) output waveform for a sinusoidal input, (d) equivalent circuit for $v_i < V_R$, and (e) equivalent circuit for $v_i > V_R$.

b)Clipping below Reference Level



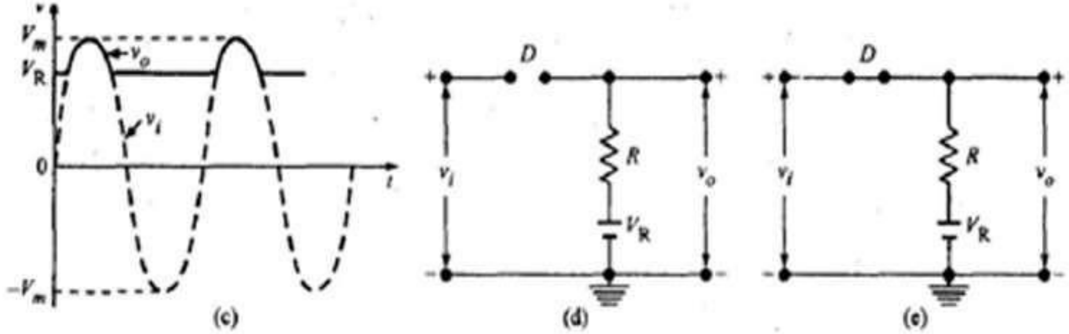
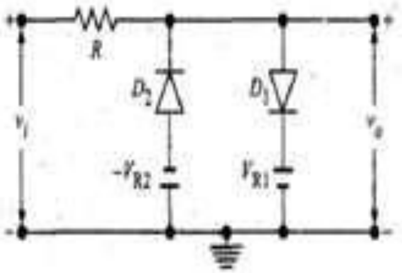


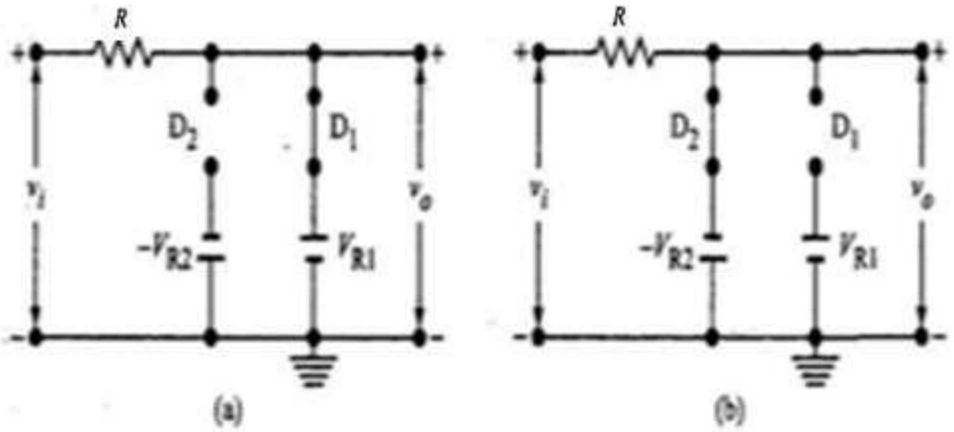
Figure 2.5 (a) Diode series clipper circuit diagram, (b). transfer characteristics, (c) output for a sinusoidal input, (d) equivalent circuit for $v_i < V_R$, and (e) equivalent circuit for $v_i > V_R$.

The circuit works as follows:

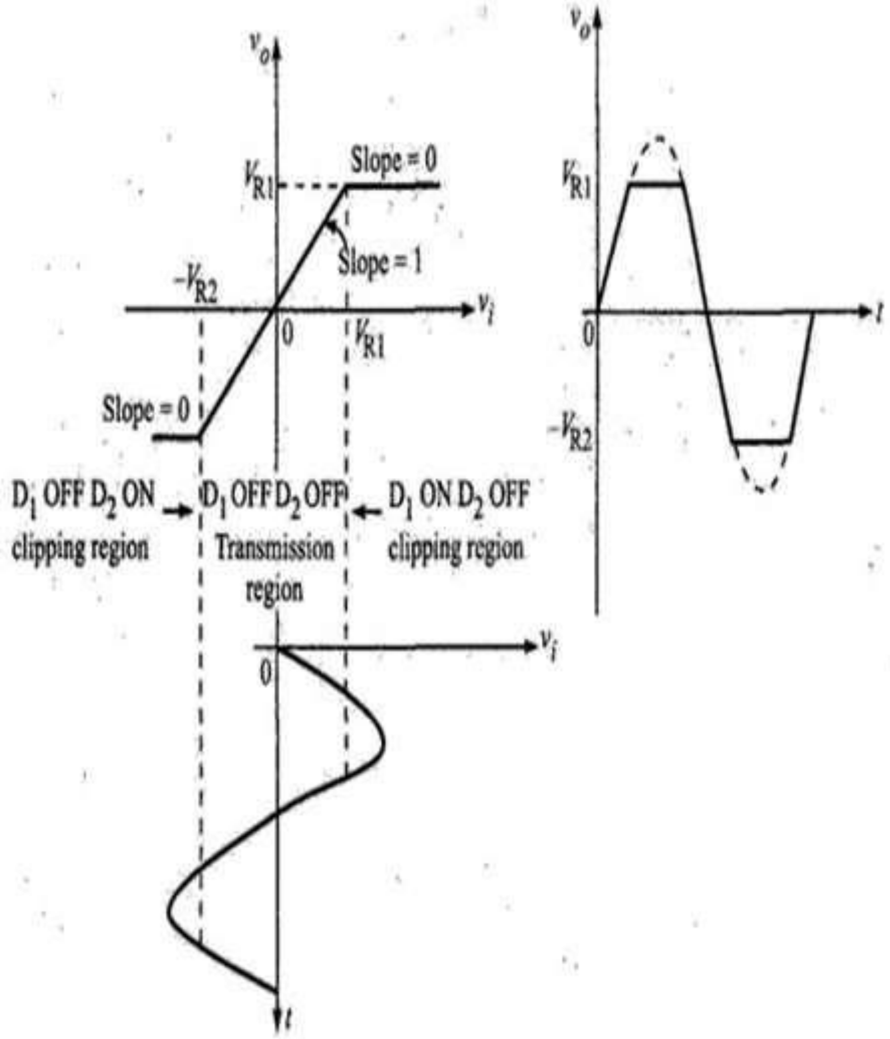
CLIPPING AT TWO INDEPENDENT LEVELS

Input v_i	*Output* v_o	*Diode status*
$v_i > V_{R1}$	$v_o = V_{R1}$	D_1 ON, D_2 OFF
$-V_{R2} < v_i < V_{R1}$	$v_o = v_i$	D_1 OFF, D_2 OFF
$v_i < -V_{R2}$	$v_o = -V_{R2}$	D_1 OFF, D_2 ON





(a) Equivalent circuit for $v_i > V_{R1}$ and (b) equivalent circuit for $v_i < -V_{R2}$



The piece-wise linear transfer curve, the input sinusoidal waveform and the corresponding output for the clipper

CLAMPING CIRCUITS :

The clamping circuit is often referred to as dc restorer or dc reinserter.In fact, it should be called a dc inserter, because the dc component introduced may be different from the dc component lost during transmission

Classification of clamping circuits

Basically clamping circuits are of two types:

1.positive-voltage clamping circuits

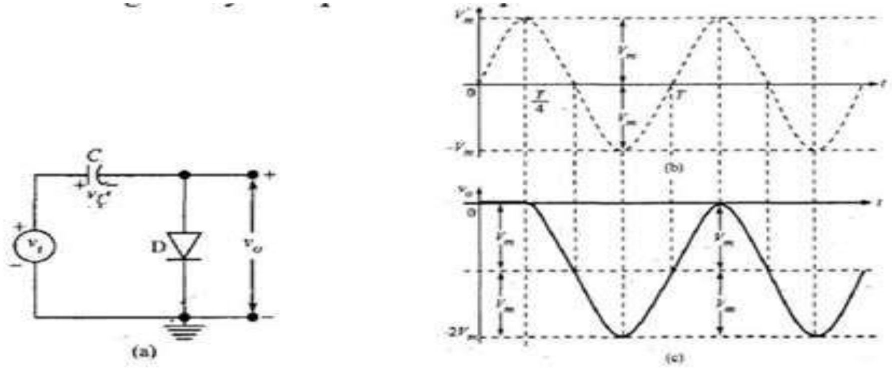
2.negative-voltage clamping circuit

NEGATIVE CLAMPER(POSITIVE PEAK CLAMPER):

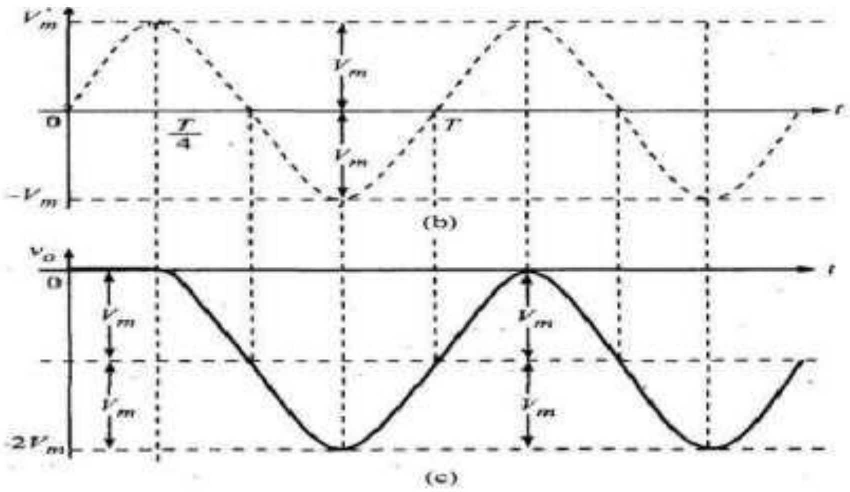
1.In negative clamping, the positive extremity of the waveform is fixed at the reference level and the entire waveform appears below the reference, i.e. the output waveform is negatively clamped with respect to the reference level .

2.At -the end of the first quarter cycle, the voltage across the capacitor, vc = Vm after the first quarter cycle, here is no path for the capacitor to discharge. Hence, the voltage across the capacitor remains constant at vc = Vm

3.After the first quarter cycle, the output is given by v0 = vi - Vm. During the succeeding cycles, the positive extremity of the signal will be clamped or restored to zero and the output

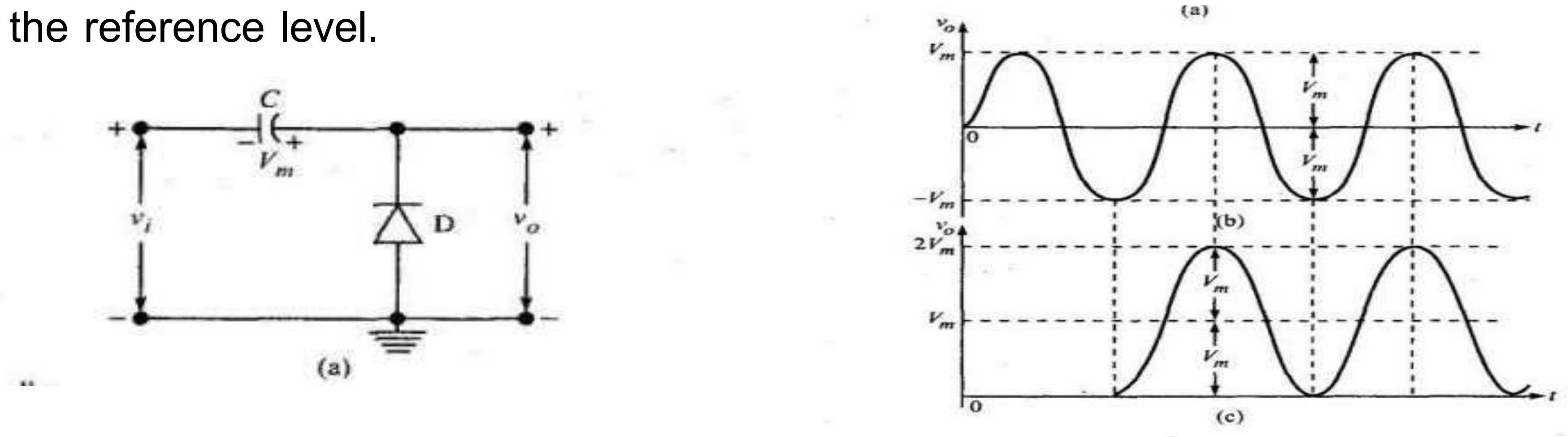


(a) A negative clamping circuit, (b) a sinusoidal input, and (c) a steady-state clamped output.



POSITIVE CLAMPER(NEGATIVE PEAK CLAMPER):

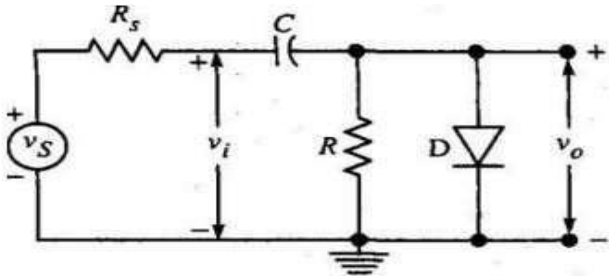
In positive clamping, the negative extremity of the waveform is fixed at the reference level and the entire waveform appears above the reference level, i.e. the output waveform is positively clamped with reference to the reference level.



(a) A positive clamping circuit, (b) a sinusoidal input, and (c) a steady-state clamped output.

CLAMPING CIRCUIT THEOREM

The clamping circuit theorem states that, for any input waveform under steady-state conditions, the ratio of the area Af under the output voltage curve in the forward direction to that in the reverse direction Ar is equal to the ratio Rf/R



Clamping circuit considering the source resistance & the diode forward resistance

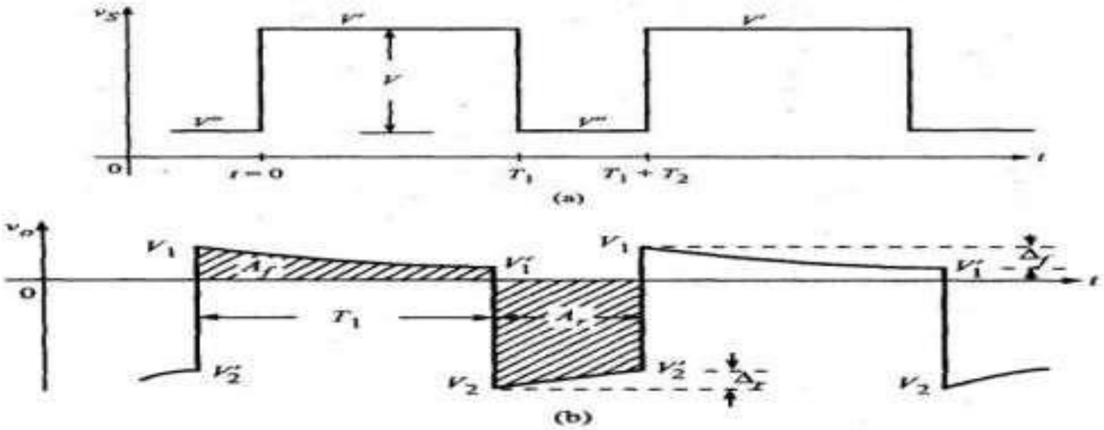
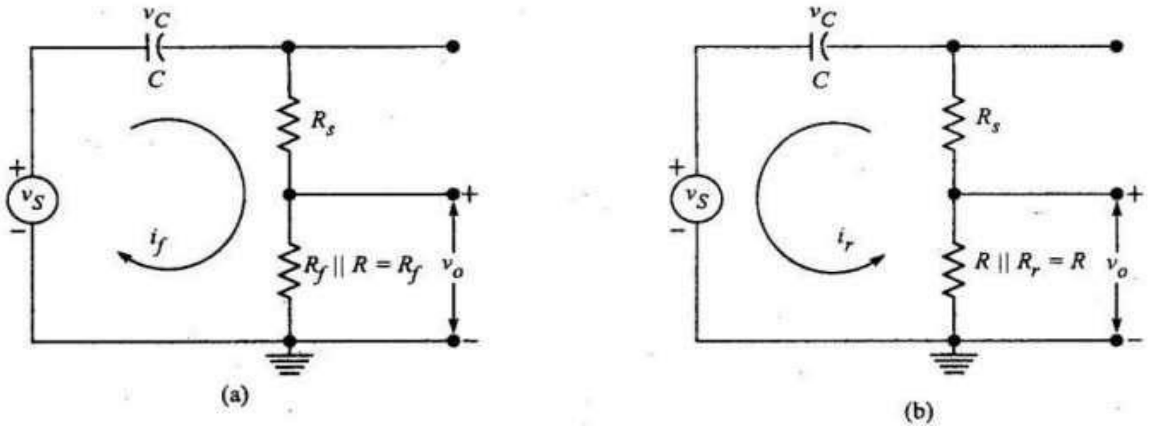


Figure : (a) A square wave input signal of peak-to-peak amplitude V, (b) the general form of the steady-state output of a clamping circuit with;' the input as in (a).

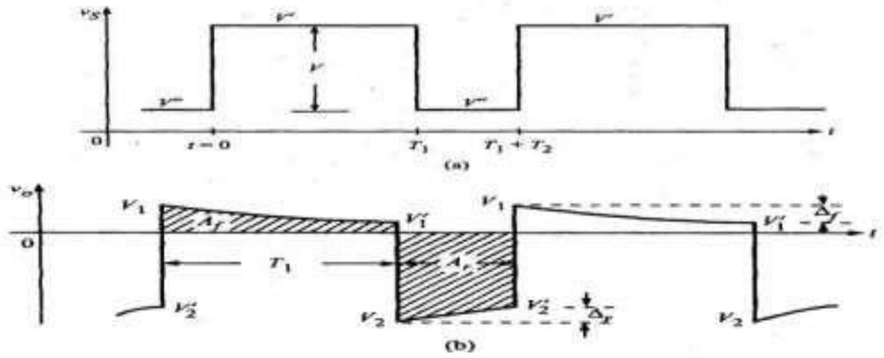


In the interval 0 < t < T, the input is at its upper level, the diode is ON,

If v/(f) is the output waveform in the forward direction, then the capacitor charging current is

$$i_f(t) = \frac{v_f(t)}{R_f}$$

$$Q_g = \int_0^{T_1} i_f(t)dt = \frac{1}{R_f}\int_0^{T_1} v_f(t)dt = \frac{A_f}{R_f}$$



Under steady-state the charge acquired by the Capacitor over one cycle must be equal to zero Therefore, the charge gained in the interval 0 < t < T1, will be equal to the charge lost in the interval

T1 < t< T1 + T2, i.e. Qg = Ql

$$Q_l = \int_{T_1}^{T_1+T_2} i_r(t)\,dt = \frac{1}{R}\int_{T_1}^{T_1+T_2} v_r(t)\,dt = \frac{A_r}{R}$$

$$Q_g = \int_{0}^{T_1} i_f(t)\,dt = \frac{1}{R_f}\int_{0}^{T_1} v_f(t)\,dt = \frac{A_f}{R_f}$$

$$\frac{A_f}{R_f} = \frac{A_r}{R} \qquad \text{i.e.} \qquad \frac{A_f}{A_r} = \frac{R_f}{R}$$