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ENGINEERS ACADEMY

# RPSC - A.En.

## Assistant Engineering

## ELECTRICAL

**Rajasthan Public Service Commission (RPSC)**

## Volume - 5

## Analog Electronics

SIERRA
INNOVATIONS

# 1

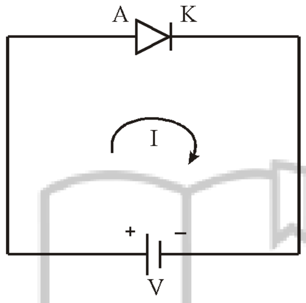
# DIODES CIRCUITS

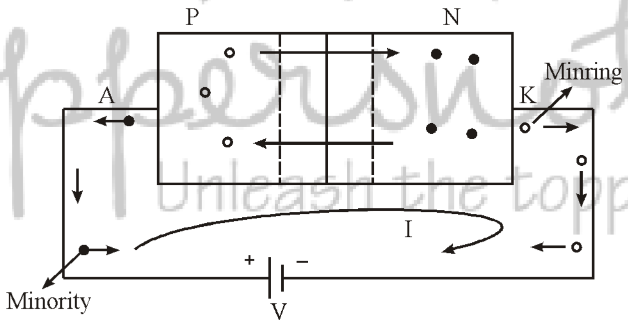
## THEORY

### 1.1 BIASING

A diode can be biased in 2 ways, i.e., forward bias and reverse bias.

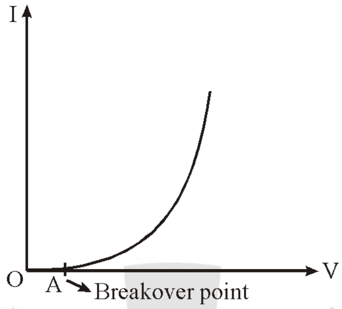
**Forward Bias :**





- The anode is connected to the positive terminal and cathode is connected to the negative terminal of the supply.
- The free carriers can cross over to the other side of the depletion layer when the applied forward bias voltage is just above the knee voltage.
- In this the free carrier are diffused across the junction and minority carriers are moving towards the battery.
- The depletion layer width, can become minimum.
- For a small change in the forward bias volume, there is a larger recombination of free carriers and there by the current is increasing exponentially.
- The forward bias voltage not only increase the energy of the free carriers, but also make the covalent bonds to break on both sides of the junction.

- With the applied forward bias, the number of free carriers less due to recombination can be generated due to breakage of covalent bonds.
- The diode can act like a closed switch.
- The V-I characteristics of the diode is a exponential growth and it can out like a non-linear device.



Forward current

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

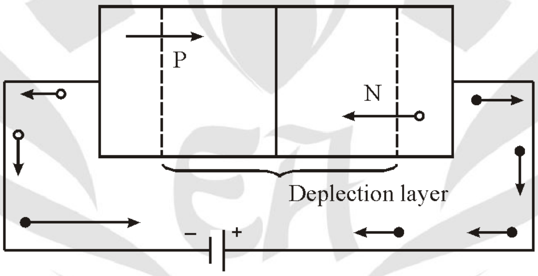
$$V_T = \frac{kT}{q} = \frac{T}{11600}$$

$$I_f \simeq I_0 e^{V_d/\eta V_T}$$

where $v_d$ = voltage across diode

$\eta$ = 1 for Ge, 2 for Si

**Reverse Bias :**



- The anode is converted to the negative terminal and the cathode connected to the positive terminal of the supply.
- The free carriers, i.e., $e^-$ s on n-side and holes on p-side are depleted (moving away) from the junction and move towards battery.
- The width of the depletion layer is increasing as increase in the reverse bias voltage.
- The minority carriers, i.e., holes on n-side and electrons on p-side can diffuse towards the junction.
- The current due to the free carriers is zero.
- The current is flowing due to the recombination of minority carriers and is of the order of 'μA' for Si.
- This minority current is also called reverse saturation current '$I_o$' (or) '$I_s$'.
- The reverse current is independent of reverse bias volume and depend on temperature strongly.
- The reverse current doubles for every 10°C increase in temperature in Ge, where as in Si, it almost doubles for every 6°C increase in temperature
- In a R.B. the diode can out like a open switch.

- Equation of current in reverse bias

$\because$ $$I_f = I_0\left[e^{V_d/\eta V_T} - 1\right]$$

where $V_d$ = Voltage across diode
= positive for forward bias
= negative for reverse bias

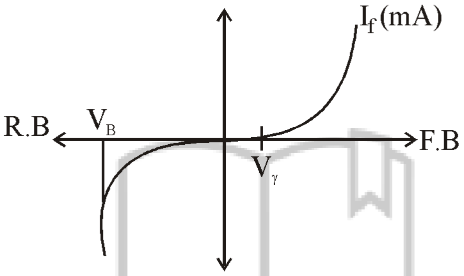
$$I_r = I_0(e^{-V/\eta V_T} - 1)$$

$\because$ $$e^{-V/\eta V_T} << 1$$

$$I_r \approx - I_0$$

(–) sign indicates that it is reverse bias and the current in reverse bias is independent of reverse bias voltage and depending strongly on temperature.

**V-I characteristics :**



**Temperature Dependence of V-I characteristics :** Reverse saturation current approximately doubles for every 10° rise in temperature if $I_0 = I_{01}$ at $T = T_1$, then at temperature T, $I_0$ is

$$I_0(T) = I_{01} \times 2^{(T-T_1/10)}$$

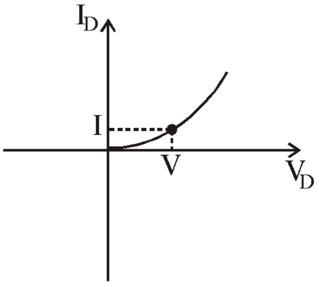
## 1.2 DIODE RESISTANCE

A resistance of a diode can be expressed in terms of static and dynamic.

**Static (or) DC Resistance :** It is expressed as the ratio of the voltage to the corresponding current at a given point of characteristic.

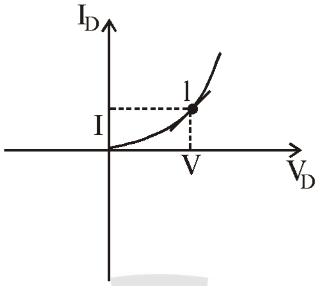
$$R_{DC} = \frac{V}{I}(\Omega)$$

The static resistance is valid only for linear devices, but diode is a non linear device.



**Dynamic (or) AC Resistance :** The dynamic resistance is not constant and mainly depending on the operating voltage region.

The dynamic resistance is expressed as the reciprocal of the slope of the characteristic.



$$V_c = \frac{1}{\text{slope}} = \frac{1}{dI/dV} = \frac{dv}{dI}\Omega$$

$$V_{AC} = \frac{dv}{dI} = \frac{\eta KT}{qI} = \frac{\eta rT}{I}\Omega$$

$$\therefore \qquad r_{AC} \propto \frac{1}{I}$$

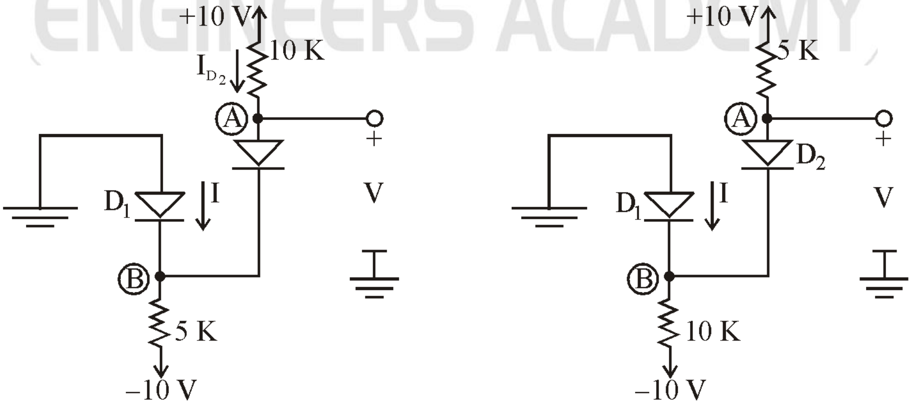
For Ge at T = 300 k (room temperature)

$$r_{AC} = \frac{26}{I}\Omega \qquad [\because \eta = 1, T = 300k, V_T = 26\,mv]$$

For Si at T = 300 k

$$\therefore \qquad r_{AC} \propto \frac{52}{I}\Omega \qquad [\because \eta = 2]$$

**Example 1 :** Assume the Diode to be ideal, find the values of I and V in the circuit.



(a) (b)

**Note :** In these circuits it might not be obvious at first sight whether none, one or both diode are conducting. In such cases we make a possible assumption, proceed with analysis, and then check whether we end up with consistent solution.

**Solution :** (a) Here we assume that both diodes are conducting. It follows that $V_B = 0$ and V= 0. The current through $D_L$ can now be determined from

$$I_{D_2} = \frac{10-0}{10K} = 1\text{ mA}$$

Writing a node equation at B,

$$I + 1 = \frac{0-(-10)}{5}$$

results in I = 1 mA.

Thus $D_1$ is conducting as originally assumed and final result is I = 1 mA and V = 0 V.

(b) For this circuit, if we assume that both diodes are conducting, then $V_B = 0$ and V = 0. The current in $D_2$ is obtained from,

$$I_{D_2} = \frac{10-0}{5} = 2\text{mA}$$

node equation at B is,

$$I + 2 = \frac{0-(-10)}{10}$$

$$I = -1\text{ mA}$$

Which is not possible as this would mean that current in $D_1$ flows from n to p.

So, we start again, assuming that $D_1$ is OFF and $D_2$ is ON. The current $I_{D2}$ is given by,

$$I_{D_2} = \frac{10-(-10)}{15} = 1.33\text{ mA}$$

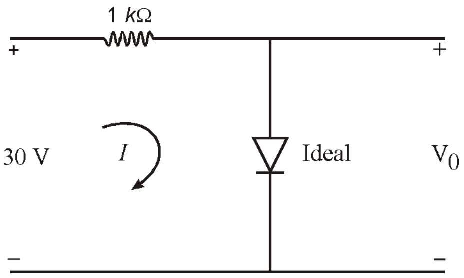
and voltage at node B is

$$V_B = -10 + 10 \times 1.33 = +3.3\text{ V}$$

Thus, $D_1$ is reverse biased and I = 0 and V = 3.3 V.

**Example 2 :** Find I and $V_o$, ideal diode is forward bias and short circuit.

**Solution :**

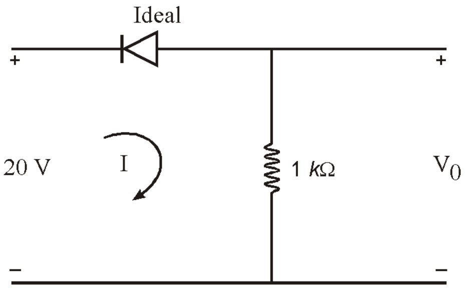


$$I = \frac{30}{1K} = 30\text{ mA}$$

$$V_0 = 0\text{ Volt}$$

**Example 3 :** Find I and $V_o$, ideal diode is forward bias and short circuit.

**Solution :**

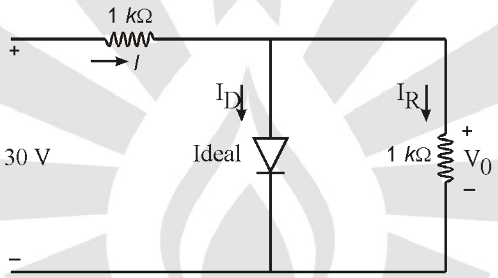


$$V_0 = -20V$$

$$I = \frac{-20}{1K} = -20\,mA$$

**Example 4 :** Find $V_o$, I, $I_D$ and $I_R$, Ideal diode is forward bias and short circuit.

**Solution :**



$$V_0 = 0$$

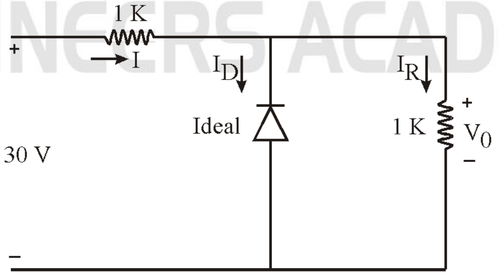
$$I_R = 0$$

$$I_D = \frac{30\,V}{1K} = 30\,mA$$

$$I = I_D = 30\,mA$$

**Example 5 :** Find $V_o$, I, $I_D$ and $I_R$, ideal diode is reverse bias and output current.

**Solution :**



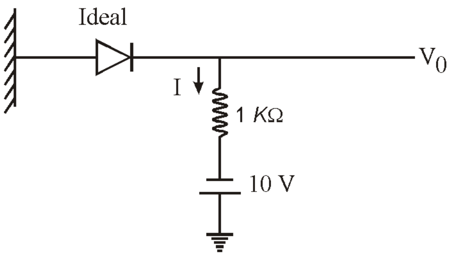
$$I_D = 0$$

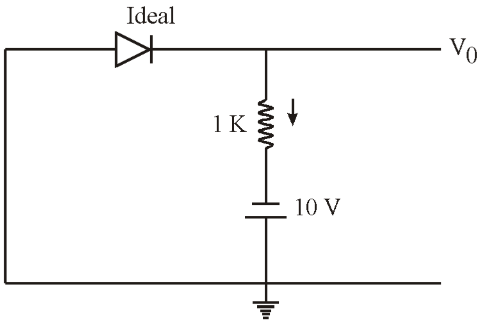
$$I = I_R = \frac{30}{1K + 1K} = 15\,mA$$

$$V_0 = 30 \times \frac{1}{1+1} = 15V$$

**Example 6 :** Find I and $V_o$. Ideal diode forward bias and SC.

**Solution :**





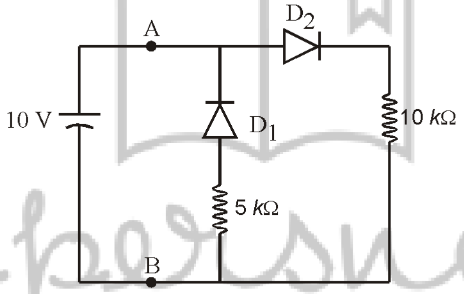
$\because$ Ideal diode is forward bias and short circuit

$\therefore$ $V_0 = 0$

and $0 - I \times 1K + 10V = 0$

$$I = \frac{10}{1K} = 10mA$$

**Example 7 :** Find $Z_{AB}$



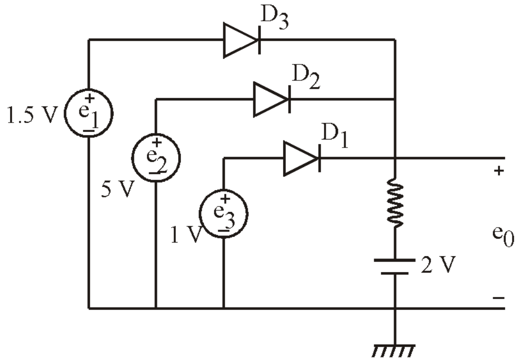
**Solution :** A is positive w.r.t. B.

$D_1$ is reverse bias and open circuit

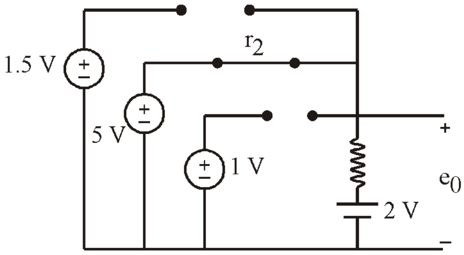
$D_2$ is forward bias and short circuit.

$Z_{AB} = 10k\Omega$

**Example 8 :** Find which diode is conducting in the given circuit and also find $e_0$.



**Solution :**

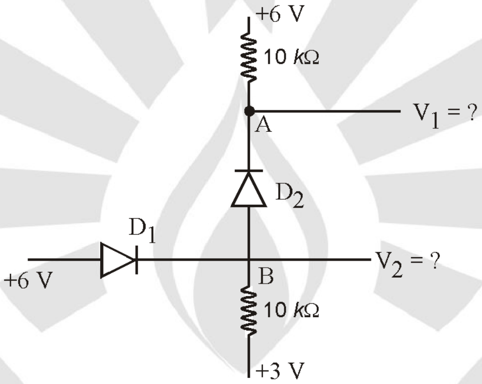


$D_1$ and $D_3$ are in reverse bias.

$D_2$ is forward bias and conducting.

$$e_0 = 5V$$

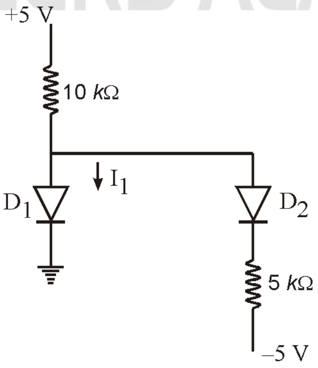
**Example 9 :** Find the voltage $V_1$ and $V_2$ of the arrangement given in the figure respectively :



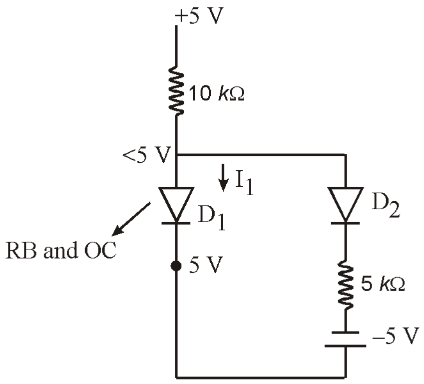
**Solution :** At node A voltage is less than 6 volt due to drop in resistor 10 kΩ. So diode $D_2$ is forward bias and SC.

$\therefore$ $$V_1 = V_2 = 6V$$

**Example 10 :** If $D_1$ and $D_2$ are ideal diode find the current $I_1$.



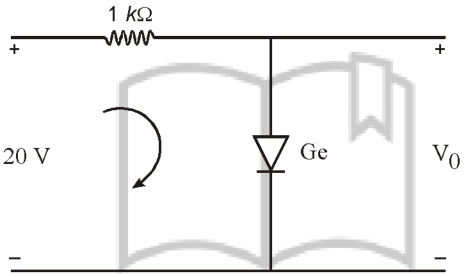
**Solution :**



From the figure $D_1$ is reverse bias and open circuit.

$\therefore$ $I_1 = 0$

**Example 11 :**



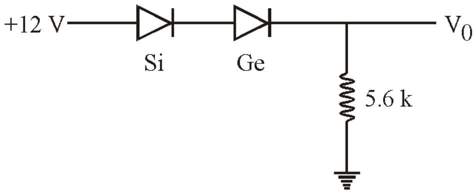
Find I and $V_0$

Find I and $V_0$, Ge diode is forward bias.

**Solution :** $V_0 = V_{Ge} = 0.2V$

$$I = \frac{20 - V_{Ge}}{1\,K} = \frac{20 - 0.2}{1\,K} = 19.8\ mA$$

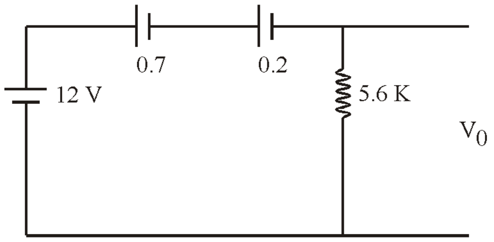
**Example 12 :** Find I and $V_0$.



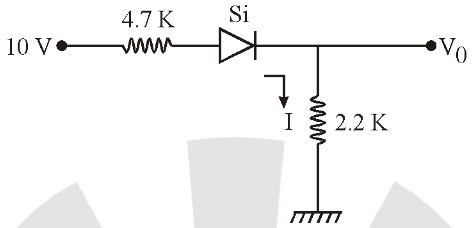
**Solution :**

$$I = \frac{12 - 0.7 - 0.2}{5.6\ K} = 1.982\ mA$$

$$V_0 = 12 - 0.7 - 0.2 = 11.1\ \text{Volt}$$

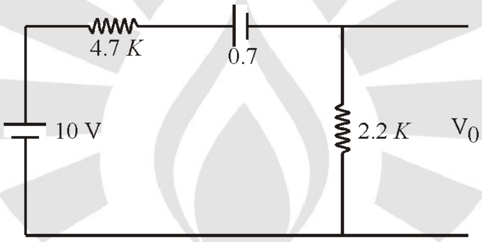


**Example 13 :** Find I and $V_0$.



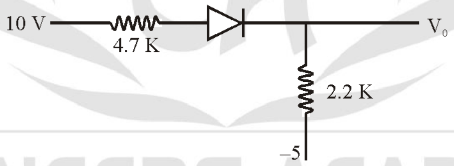
**Solution :**

$$I = \frac{10 - V_r}{4.7\,K + 2.2\,K} = \frac{10 - 0.7}{4.7K + 2.2\,K} = 1.347\text{ mA}$$



$$V_0 = 1.347 \times 2.2 = 2.965\text{ V}$$

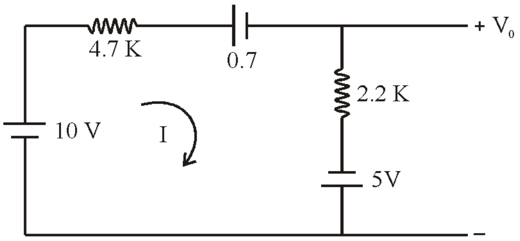
**Example 14 :** Find I and $V_0$.



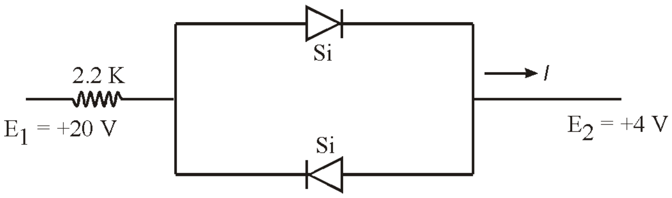
**Solution :**

$$I = \frac{10 - 0.7 + 5}{(4.7 + 2.2)K} = 2.072\text{ mA}$$

$$V_0 = I \times (2.2\text{ K}) - 5 = 2.072\text{ mA} \times 2.2\text{K} - 5 = -0.4416\text{ Volt}$$

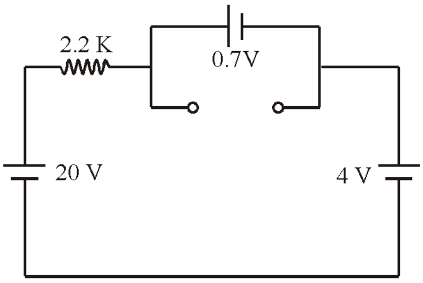


**Example 15 :** Find I

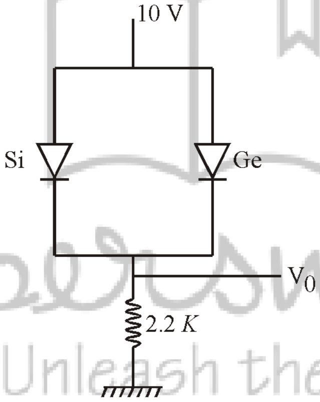


**Solution :** Since $E_1 > E_2$. Bottom diode is reverse bias and open circuit upper diode is forward bias and SC.

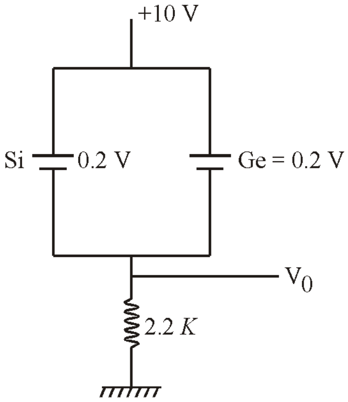
$$I = \frac{20 - 0.7 - 4}{2.2K} = 6.95 \text{ mA}$$



**Example 16 :** Find $V_0$.



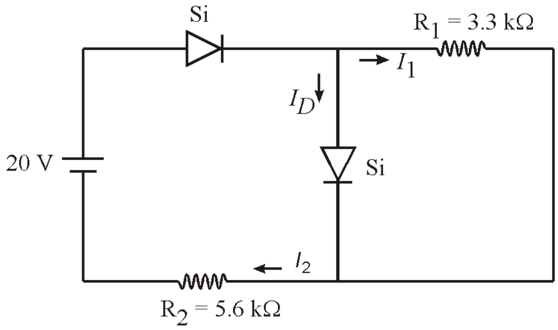
**Solution :** When 10 V is applied both Ge and Si diode both are forward bias and due to smaller cut in voltage Ge will enter into conduction.



$$V_0 = 10 - V_{Ge} = 10 - 0.2 = 9.8V$$

Si diode is forward bias but not conducting as the forward voltage is less than cut in voltage.

**Example 17 :** Find $I_D$.

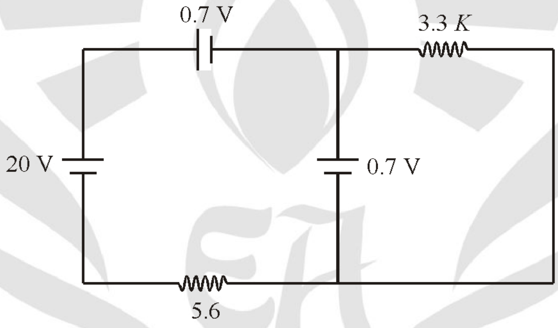


**Solution :**

$$V_{R_1} = V_{rSi} = 0.7V$$

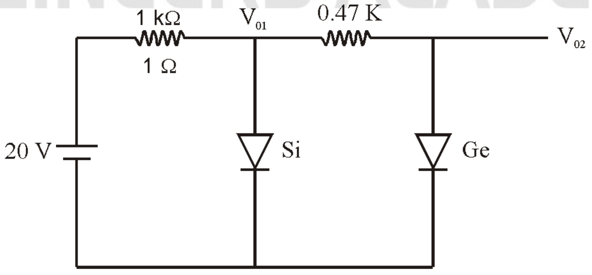
$$I_1 = \frac{0.7}{3.3K} = 0.212\ mA$$

$$I_2 = \frac{20 - 0.7 - 0.7}{5.6} = 3.321\ mA$$



$$I_D = I_2 - I_1 = 3.321 - 0.212 = 3.109\ mA$$

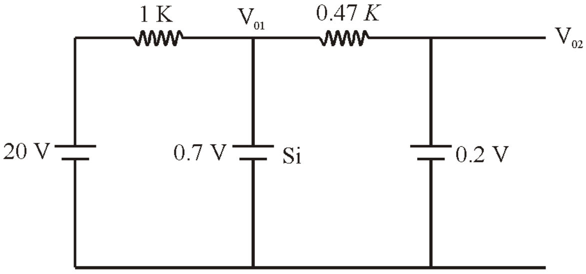
**Example 18 :** Find $V_{01}$ and $V_{02}$.



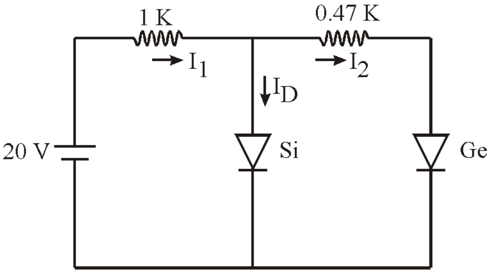
**Solution :**

$$V_{01} = 0.7V = V_{rSi}$$

$$V_{02} = 0.2V = V_{rGe}$$

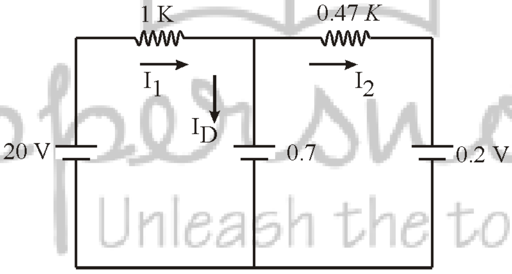


**Example 19 :** Find $I_1$, $I_2$ and $I_D$.



**Solution :**

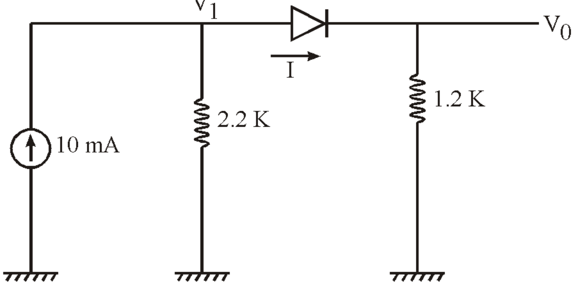
$$I_1 = \frac{20-0.7}{1K} = 19.3 \text{ mA}$$



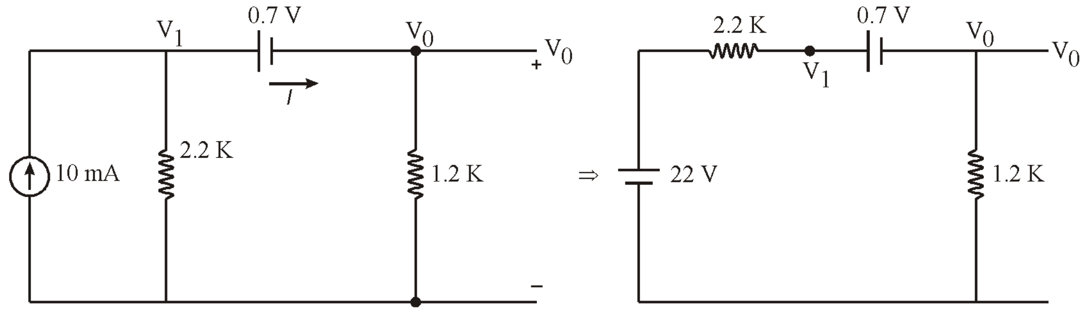
$$I_2 = \frac{0.7-0.2}{0.47K} = 1.063 \text{ mA}$$

$$I_D = 19.3 \text{ mA} - 1.063 \text{ mA} = 18.237 \text{ mA}$$

**Example 20 :** Find I, $V_1$ and $V_0$.



**Solution :**



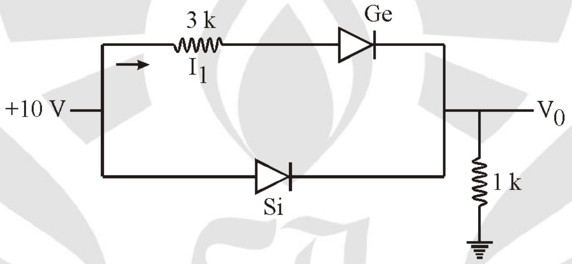
$$I = \frac{22 - 0.7}{2.2K + 1.2K} = 6.26\,\text{mA}$$

$$V_0 = I \times 1.2\text{ K} = 6.26 \times 1.2 = 7.51 \text{ Volt}$$

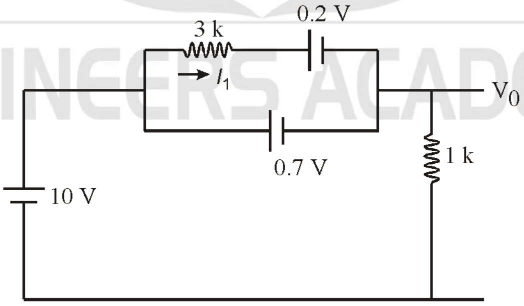
$$V_1 = 22 - (2.2 \times 6.26) = 8.228 \text{ Volt}$$

or $$V_0 = V_1 - V_{rSi} = 8.228 - 0.7 = 7.51 \text{ Volt}$$

**Example 21 :** Find $V_0$ and $I_1$.



**Solution :**

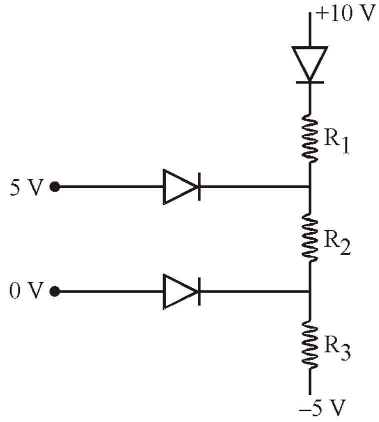


$$V_{rSi} = V_{rGe} + 3 \times I_1 \Rightarrow 0.7V = 0.2V + 3 \times I_1$$

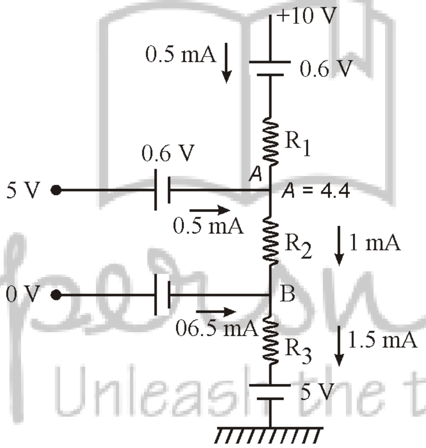
$$I_1 = \frac{0.5}{3} = 0.166\,\text{mA}$$

$$V_0 = 10 - V_{rSi} = 10 - 0.7 = 9.3 \text{ Volt}$$

**Example 22 :** The cut in voltage for each diode is 0.6 volt and each diode current is 0.5 mA. Find the values of $R_1$, $R_2$ and $R_3$.



**Solution :**



$$V_A = 5 - V_r = 5 - 0.6 = 4.4 \text{ Volt}$$

$$V_B = 0 - 0.6 = -0.6 \text{ Volt}$$

$$V_{AB} = V_A - V_B = 4.4 - (-0.6) = 5V$$

$$R_1 = \frac{10 - V_r - V_A}{0.5\,\text{mA}} = \frac{10 - 0.6 - 4.4}{0.5\,\text{mA}} = 10\,\text{k}\Omega$$

$$R_2 = \frac{V_A - V_B}{1\,\text{mA}} = \frac{5V}{1\text{mA}} = 5\,\text{k}\Omega$$

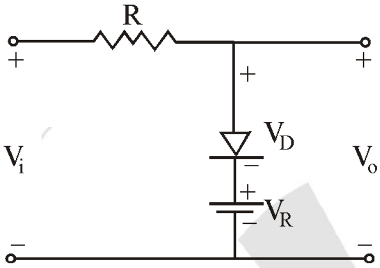
$$R_3 = \frac{V_B - (-5)}{1.5} = \frac{-0.6 + 5}{1.5} = 2.93\,\text{k}\Omega$$

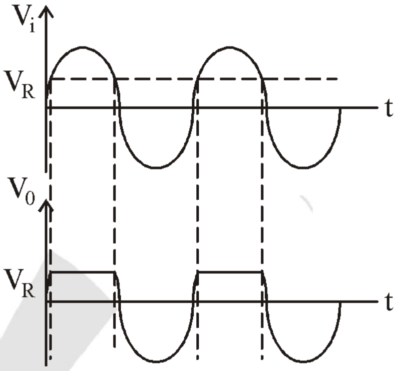
## 1.3 CLIPPERS

Clippers are networks that employ diodes to “clip” away a portion of an input signal without distorting the remaining part of the applied waveform.

**(i) Positive Clippers :**

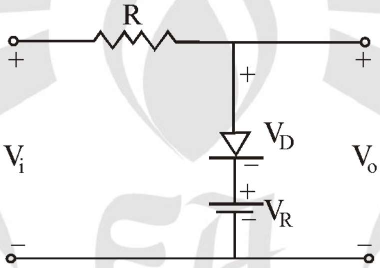
**Circuit - 1 :**





| $V_i$ | Diode | $V_0$ |
|---|---|---|
| $V_i < V_R$ | OFF | $V_i$ |
| $V_i > V_R$ | ON | $V_R$ |

**Circuit - 2 :**

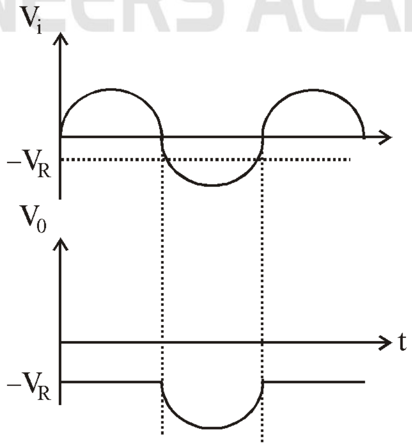


When $V_D > 0$ or $V_i < -V_R$, Diode → OFF

$V_0 = V_i$

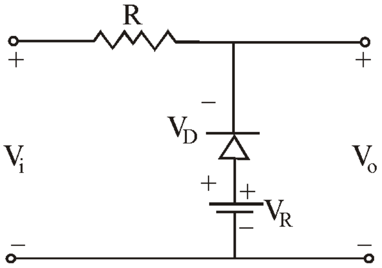
When $V_D < 0$ or $V_i > -V_R$, Diode → ON

$V_0 = -V_R$



**(ii) Negative Clippers :**

**Circuit - 1 :**

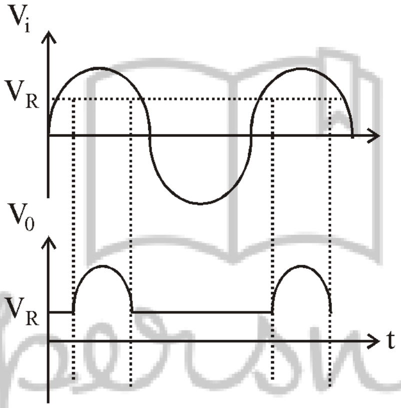


When $V_i > V_R$ Diode → OFF

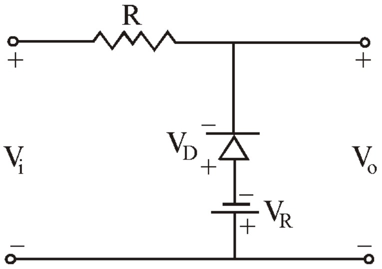
$V_0 = V_i$

When $V_i < V_R$ Diode → ON

$V_0 = V_R$



**Circuit - 2 :**

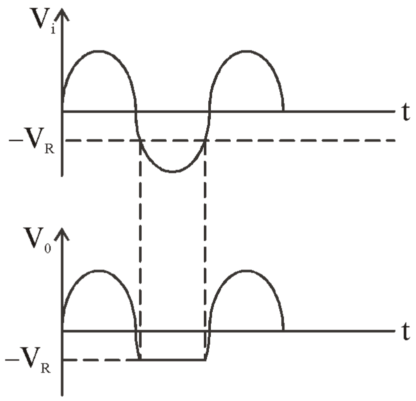


When $V_i < -V_R$, Diode → ON

$V_0 = -V_R$

When $V_i > -V_R$ Diode → OFF

$V_0 = V_i$

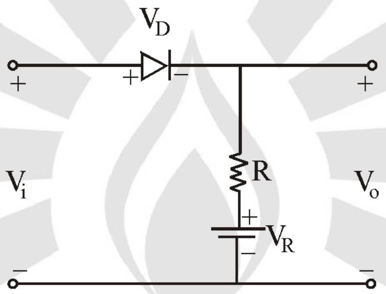


**Some other types of Clipper Circuit :**

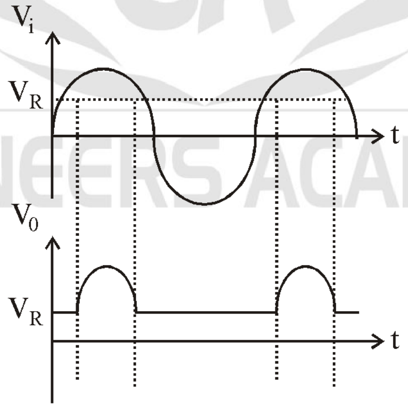
**Type - 1 :**

When $V_i > V_R$ Diode → ON $V_0 = V_i$

When $V_i < V_R$ Diode → OFF $V_0 = V_R$



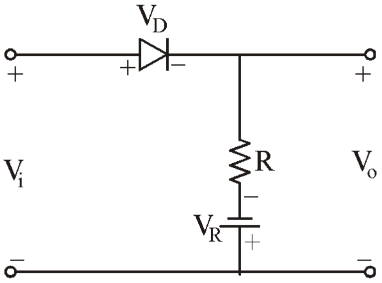
$$V_i = V_D + V_R$$
$$V_D = V_i - V_R$$

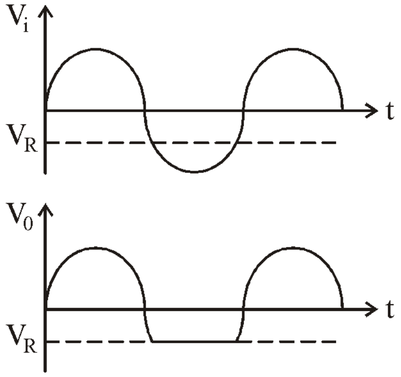


**Type - 2 :**

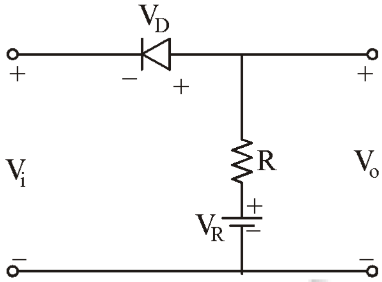
When $V_i > -V_R$, Diode → ON $V_0 \to V_i$

When $V_i < -V_R$, Diode → OFF $V_0 \to -V_R$



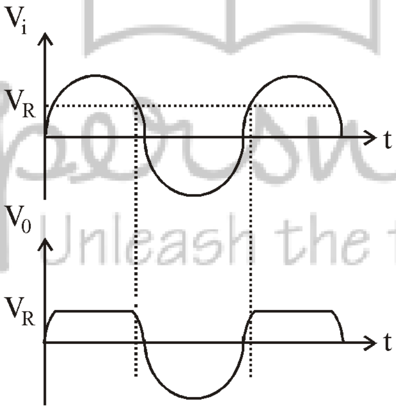


**Type - 3 :**

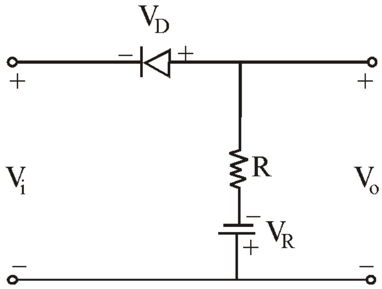


When $V_i < V_R$, Diode → ON, $V_0 = V_i$

When $V_i > V_R$, Diode → OFF, $V_0 = V_R$

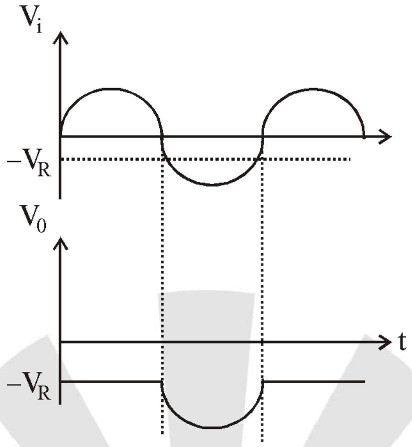


**Type - 4 :**

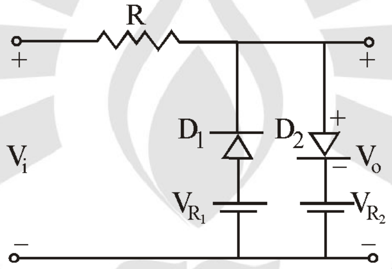


When $V_i < -V_R$, Diode → ON, $V_0 = V_i$

When $V_i > -V_R$, Diode → OFF, $V_0 = -V_R$



**Type - 5 :**

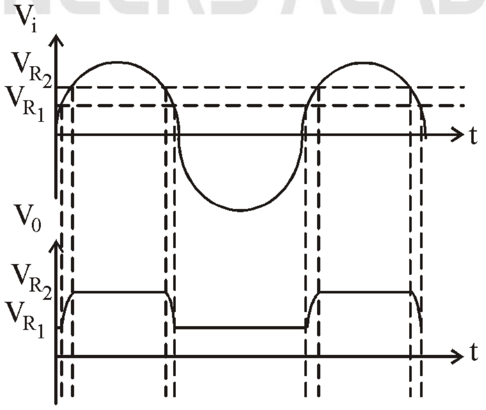


Let $V_{R1} < V_{R2}$

When $V_i < V_{R1}$, $D_1$ → ON, $D_2$ → OFF, $V_0 = V_{R1}$

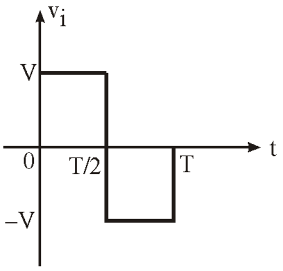
When $V_{R2} > V_i > V_{R1}$, $D_1$ → OFF, $D_2$ → OFF, $V_0 = V_i$

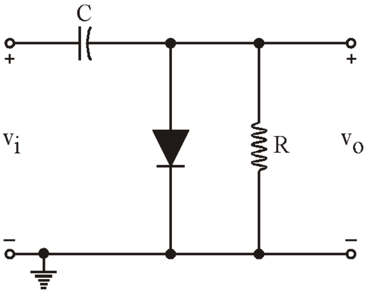
When $V_i < V_{R2}$, $D_1$ → OFF, $D_2$ → ON, $V_0 = V_{R2}$



## 1.4 CLAMPERS

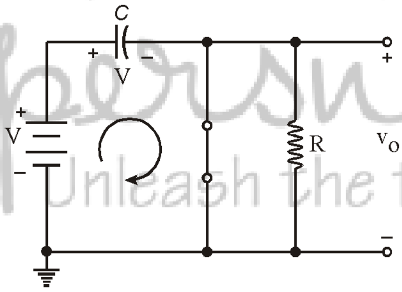
- A Clamper is a network constructed of a diode, a resistor, and a capacitor that shifts a waveform to a different dc level without changing the appearance of the opplied signal.
- Additional shifts can also be obtained by introducing a DC Supply to the basic structure. The chosen resistor and capacitor of the network must be chosen such that the time constant determined by $\tau = RC$ is sufficiently large to ensure that the voltage across the capacitor does not discharge significantly during the interval the diode is nonconducting. throughout the analysis we assume that for all practical purposes the capacitor fully charges or discharges in five constants.
- Clamping networks have a capacitor connected directly form input to output with a resistive element in parallel with the output signal. the diode is also in parallel with the output signal but may or may not have a series DC supply as an added element.





There is a sequence of steps that can be applied to help make the analysis straight forward. It is not the only approach to examining clampers, but it does offer an option if difficulties surface.

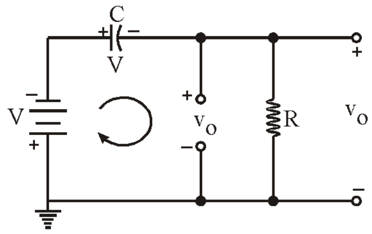
- **Step 1 :** Start the analysis by examining the response of the portion of the input signal that will forward bias the diode.
- **Step 2 :** During the period that the diode is in the "on" state. assume that the capacitor will charge up instantaneously to a voltage level determined by the surrounding network.



**Diode "on" and the capacitor charging to V volts.**

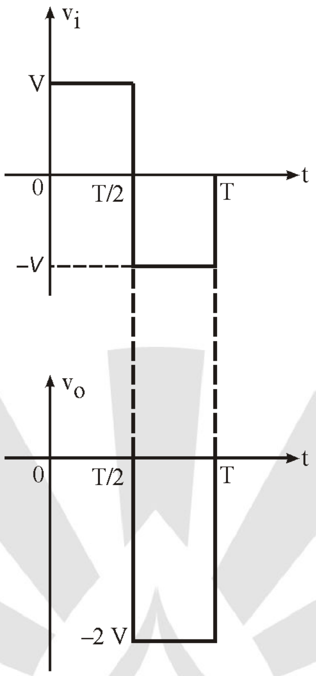
- **Step 3 :**Assume that during the period when the diode is in the "off" state the capacitor holds on to its established voltage level.
- **Step 4 :** Throughout the analysis, maintain a continual awareness of the location and defined polarity for Vo to ensure that the proper levels are obtained.

$$-V - V - v_0 = 0 \Rightarrow v_0 = -2V$$



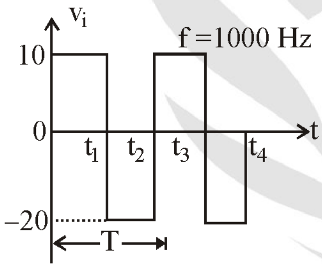
**Determining $v_0$ with the diode "off"**

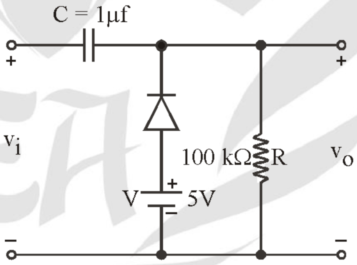
- **Step 5 :** Check that the total swing of the output matches that of the input. This is a property that applies for all clamping networks, giving an excellent check on the results obtained.



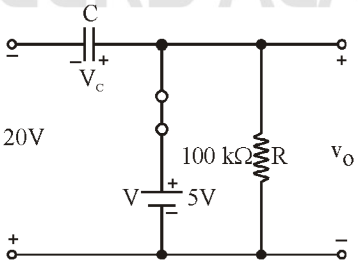
**Sketching Vo for the network**

**Example 1 :** Determine $V_0$ for the given network.





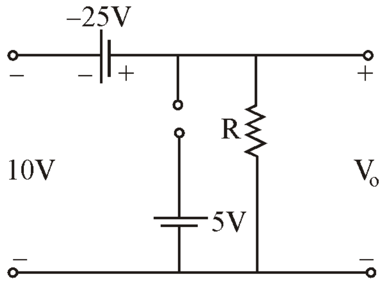
**Solution :** For period $t_1 \rightarrow t_2$, Diode D → ON



$$-20 + V_C - 5V = 0$$

$$V_C = 25V \text{ and } V_0 = +5V$$

For the period $t_2 \rightarrow t_3$



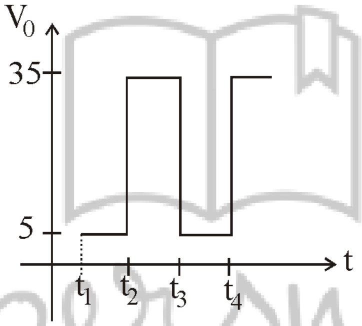
$$+\ 10V + 25V - V_0 = 0$$

$$V_0 = 35V$$

**Time Constant :** $\tau = RC = (100\ k\Omega)\ (0.1\ \mu F) = 10\ ms$

The Total discharge time is $5\tau = 5\ (10\ ms) = 50\ ms$

Since, the interval $t_2 \rightarrow t_3$ will only last for 0.5 ms, it is certainly a good approximation that the capacitor will holds its voltage during the discharge period between pulses of the input signal.

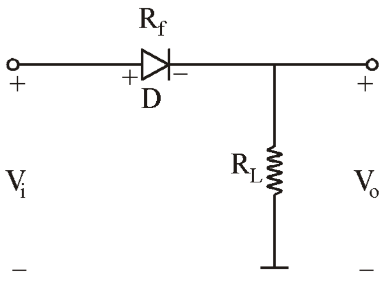


## 1.5 RECTIFIERS

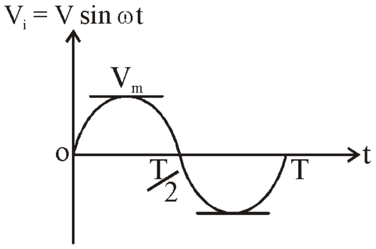
Rectifier is a device which converts the sinusoidal AC voltage into either positive or negative pulsating DC.

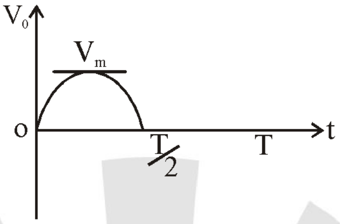
Rectifiers may be either half-wave or full wave type.

**1. Half-wave Rectifiers :**



$R_f \rightarrow$ Resistance of forward biased diode. For ideal case $\rightarrow R_f \rightarrow 0$





Period 0 → T/2, D → ON, $V_0 = V_i$

Period T/2 → T, D → OFF, $V_0 = 0$

**(i) Average value of output voltage :**

$$V_{avg.} = \frac{1}{T}\int_0^T V_0(t)dt = \frac{1}{T}\int_0^{T/2} V_m \sin \omega t dt$$

$$\because \quad T = 2\pi \quad = \frac{V_m}{2\pi}(-\cos t)_0^{\pi}$$

$$V_{avg.} = \frac{V_m}{\pi}$$

**(ii) Average value of output current:**

$$I_{avg.} = \frac{1}{T}\int_0^T i_0(t)dt = \frac{1}{T}\int_0^{T/2} I_m \sin \omega t dt \qquad [\omega t \to t, \because T = 2\pi]$$

$$= \frac{1}{2\pi}\int_0^{\pi} I_m \sin t dt = \frac{I_m}{2\pi}(-\cos t)_0^{\pi}$$

$$I_{avg.} = \frac{I_m}{\pi}$$

**(iii) RMS value of output voltage :**

$$V_{rms} = \left[\frac{1}{T}\int_0^T V_0^2(t)dt\right]^{1/2} = \left[\frac{1}{T}\int_0^{T/2} V_m^2 \sin^2 t dt\right]^{1/2} \quad \text{for } T = 2\pi,\ \omega t \to t$$

$$= \left[\frac{1}{2\pi}\int_0^{\pi} V_m^2\left(\frac{1-\cos 2t}{2}\right)dt\right]^{1/2}$$

$$V_{rms} = \frac{V_m}{2}$$

**(iv) RMS value of output current :**

$$I_{rms} = \left[\frac{1}{T}\int_0^T I_0^2 dt\right]^{1/2} = \left[\frac{1}{T}\int_0^{T/2} I_m^2 \sin^2 t\,dt\right]^{1/2} \quad \text{for } T = 2\pi,\ \omega t \to t$$

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

**(v) Form factor and peak factor :**

**Form Factor :** It is defined as the ratio of rms value to average value.

$$\text{(Form Factor) } (K_f) = \frac{\text{RMS Value}}{\text{Average Value}} = \frac{I_{rms}}{I_{avg.}} = \frac{I_m / 2}{I_m / \pi} = \frac{\pi}{2} = 1.57$$

**Peak Factor ($K_p$) :** It is defined as the ratio of Peak value to rms value.

$$K_p = \frac{\text{Peak value}}{\text{rms value}} = \frac{V_m}{V_m / 2} = 2$$

**(vi) Ripple factor ($\gamma$) :**

$$I^2 = I_{dc}^2 + I_1^2 + I_2^2 + \ldots$$

$$I^2 = I_{dc}^2 + I_{ac}^2$$

$$\gamma = \frac{I_{ac}}{I_{dc}} = \frac{\sqrt{I^2 - I_{dc}^2}}{I_{dc}} = \sqrt{\left[\frac{I_{rms}}{I_{dc}}\right]^2 - 1} = \sqrt{k_f^2 - 1} = \sqrt{(1.57)^2 - 1} = 1.21$$

**(vii) Peak Inverse Voltage (PIV) :** PIV is the rating of diode. It is defined as the maximum reverse voltage, diode can withstand.

$$PIV = \gamma_m$$

**(viii) Rectification Efficiency :** It is defined as the ratio of dc output power to the AC input power.

$$\eta = \frac{\text{output dc power}}{\text{input ac power}} = \frac{P_{odc}}{P_{iac}}$$

$$P_{odc} = I_{o\,avg.}^2 . R_L$$

$$P_{iac} = I_{irms}^2 (R_L + R_f)$$

$$\because \quad I_{orms} = I_{irms}$$

$$P_{iac} = I_{orms}^2 R_f + I_{orms}^2 R_L$$

$$\eta = \frac{I_{oavg.}^2 . R_L}{I_{orms}^2 R_f + I_{orms}^2 R_L} = \frac{\left(\frac{I_m}{\pi}\right)^2 R_L}{\left(\frac{I_m}{2}\right)^2 R_f + \left(\frac{I_m}{2}\right)^2 R_L}$$

$$\eta = \frac{4}{\pi^2} \cdot \frac{R_L}{R_f + R_L} = \frac{0.405}{1 + \frac{R_f}{R_L}} = 0.405 \text{ or } 40.5\%$$

**(ix) Voltage Regulation :** The variation of dc output voltage as a function of dc load current is called "Regulation". Percentage Regulation is given by

$$\text{(V.R.) \% Regulation} = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100$$

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

$$V_{FL} = \frac{V_m}{\pi} - I_{av.}R_f \;;\; I_{av.} = I_{FL}$$

$$\text{V.R.} = \frac{I_{av.}R_f}{\frac{V_m}{\pi} - I_{av.}R_f} \times 100$$

$$\because \quad I_{avg.} = \frac{I_m}{\pi} = \frac{V_m}{\pi}\left[\frac{1}{R_f + R_L}\right]$$

$$\therefore \quad \text{V.R.} = \frac{R_f}{R_L} \times 100$$

For ideally, $R_f = 0$

$\therefore$ V.R. $= 0$

**(x) Transformer Utilization Factor (TUF) :** It is defined by the ratio of Power delivered to the load and volt-ampere delivered by secondary side of transformer.

$$\text{TUF} = \frac{I_{0avg.}^2 \cdot R_L}{V_{irms} \cdot I_{irms}}$$

$$\because \quad I_{0rms} = I_{irms}$$

$$= \frac{\left[\frac{V_m}{\pi(R_f + R_L)}\right]^2 \times R_L}{\frac{V_m}{\sqrt{2}} \cdot \frac{I_m}{2}}$$

$$\text{TUF} = \frac{2\sqrt{2}}{\pi^2} \cdot \frac{R_L}{R_f + R_L}$$

For ideally, $R_f = 0$

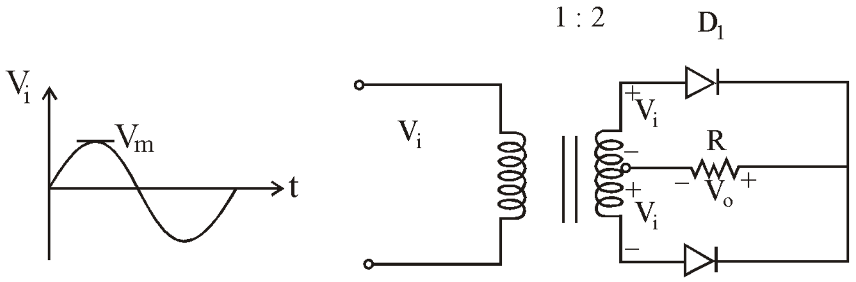
$$\text{TUF} = \frac{2\sqrt{2}}{\pi^2} = 0.286$$

**2. Full Wave Rectifier :**

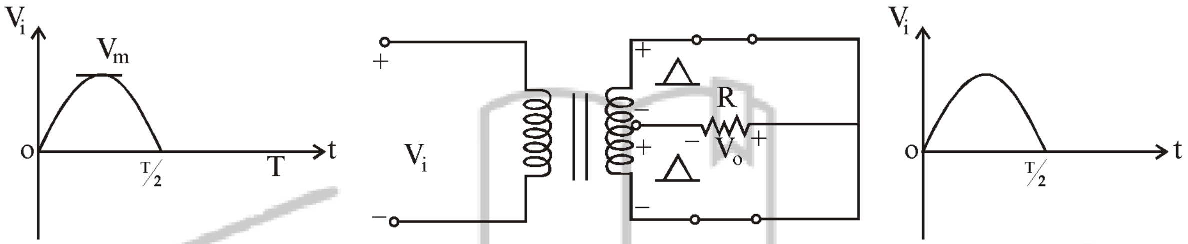
(a) Center-Tapped full-wave Rectifier

(b) Bridge Rectifier

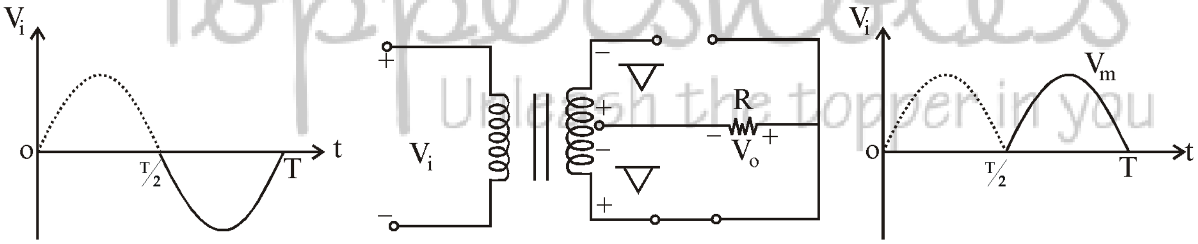
**(a) Center-Tapped full-wave Rectifier :**



For positive portion of input waveform :

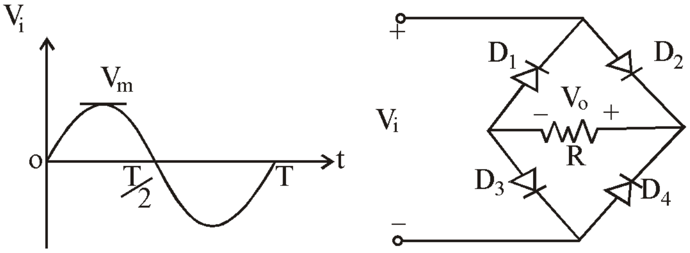


For negative portion of input waveform :

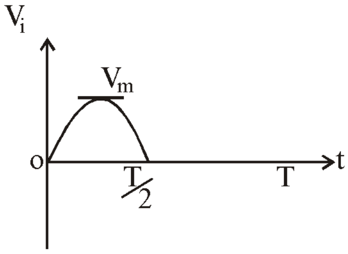


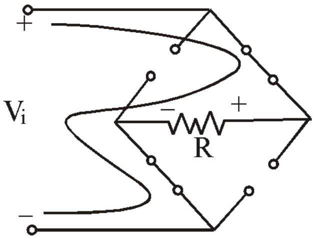
**Peak Inverse Voltage :** PIV ≥ $2V_m$

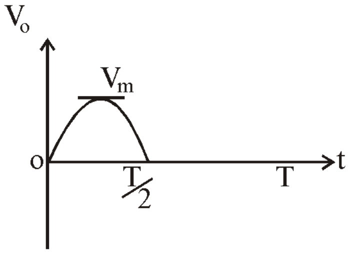
**(b) Bridge type full-wave rectifier :**



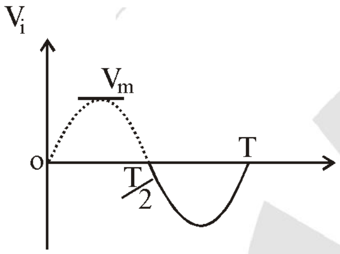
For positive portion of input waveform :

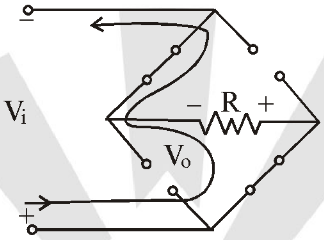


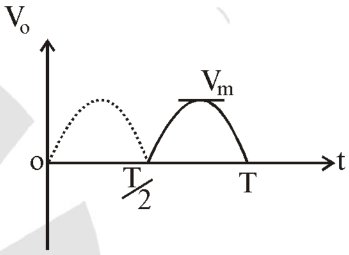




For negative portion of input waveform :







**1. Average Output Voltage :**

$$V_{oavg.} = \frac{2}{T}\int_0^{T/2} V_m \sin\omega t dt$$

$$V_{oavg.} = \frac{2V_m}{\pi}$$

**2. Average Output Current :**

$$I_{oavg.} = \frac{2I_m}{\pi}$$

**3. RMS Value of Output Voltage :**

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

**4. RMS Value of Input Voltage :**

$$V_{irms} = \frac{V_m}{\sqrt{2}}$$

**5. RMS Value of Output Current :**

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

**6. RMS Value of Input Current :**

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

**7. Form Factor and Peak Factor :**

$$\text{Form factor } (k_f) = \frac{\text{RMS Value}}{\text{Average Value}}$$

$$k_f = \frac{I_{rms}}{I_{dc}} = \frac{I_m/\sqrt{2}}{2I_m/\pi} = \frac{\pi}{2\sqrt{2}} = 1.11$$

**8. Ripple Factor (γ) :**

$$\gamma = \sqrt{(k_f)^2 - 1} = \sqrt{(1.11)^2 - 1}$$

$$\gamma = 0.482$$

**9. Voltage Regulation :**

$$\text{V.R. (Bridge Type)} = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100 = \frac{\frac{2v_m}{\pi} - \left(\frac{2v_m}{\pi} - 2I_{oavg.}R_f\right)}{\frac{2v_m}{\pi} - 2I_{oavg.}R_f} \times 100$$

$$\text{V.R.} = \frac{2R_f}{R_L} \times 100$$

**Note :** For Center Tapped

$$2R_f \to R_f$$

$$\therefore \qquad \text{V.R.} = \frac{R_f}{R_L} \times 100$$

**10. Rectifier Efficiency :**

$$\eta = \frac{P_{odc}}{P_{iac}} = \frac{I_{0avg.}^2 R_L}{I_{0rms}^2 R_L + I_{0rms}^2 \times 2R_f} \times 100$$

$$\eta = \frac{8}{\pi^2} \times \frac{R_L}{R_L + 2R_f} \times 100$$

Ideally, $R_f = 0$

$$\eta = 81.2\%$$

**Note :** For Center Tapped

$$2R_f \to R_f$$

$$\therefore \qquad \eta = \frac{8}{\pi^2} \times \frac{R_L}{R_L + 2R_f} \times 100$$

Ideally, $R_f = 0$

$$\eta = 81.2\%$$

**11. Transformer Utilization Factor (TUF) :**

$$\text{TUF} = \frac{P_{odc}}{\text{Voltage-Ampere rating of primary}} = \frac{I_{odc}^2 R_L}{V_{irms} I_{irms}}$$

$$\text{TUF} = \frac{\left(\dfrac{2v_m}{\pi} \times \dfrac{1}{2R_f + R_L}\right)^2 \times R_L}{\dfrac{V_m}{\sqrt{2}} \times \dfrac{I_m}{\sqrt{2}}}$$

$$\text{TUF} = \frac{8}{\pi^2} \cdot \frac{R_L}{R_L + 2R_f} \qquad \left[\because I_m = \frac{V_m}{R_L + 2R_f}\right]$$

Ideally $R_f \to 0$

$$\text{TUF} = 0.812$$

**Note :** For Center Tapped

$$\text{TUF} = \frac{8}{\pi^2} \cdot \frac{R_L}{R_L + R_f}$$

Ideally, $R_f = 0$

$$\text{TUF} = 0.812$$

**Difference between Bridge Rectifier and Center-Tapped Rectifier**

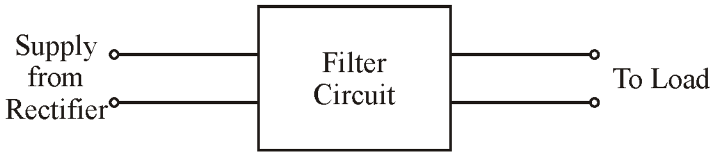
| | **Bridge** | | **Center-Tapped** |
|---|---|---|---|
| 1. | Size of Transformer required is smaller | 1. | Size of Transformer required is larger |
| 2. | PIV → $V_m$ | 2. | PIV → $2V_m$ |
| 3. | Cheap | 3. | Costly |
| 4. | TUF is better | 4. | Transformer utilization factor (TUF) is not good as compare to bridge rectifier |

**Difference between Half-wave Rectifier and Full-wave Rectifier**

| | **Half-wave Rectifier** | | **Full-wave Rectifier** |
|---|---|---|---|
| 1. | It gives lower output voltage and power | 1. | It gives higher output voltage and power |
| 2. | Rectification efficiency is low | 2. | Rectification efficiency is double that of a Half-wave |
| 3. | Ripple voltage is higher | 3. | Ripple voltage is lower |
| 4. | Ripple frequency is low | 4. | Ripple frequency is twice that of half wave |

## 1.6 RECTIFIER FILTERS

- A filter is used to reduce the ripples which is present in the wave form.
- A filter removes the AC component and allows only the DC component to reach the load.
- A filter circuit should be placed between the rectifier and the load.

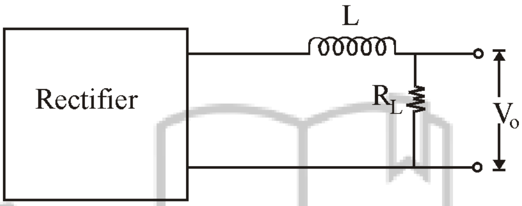


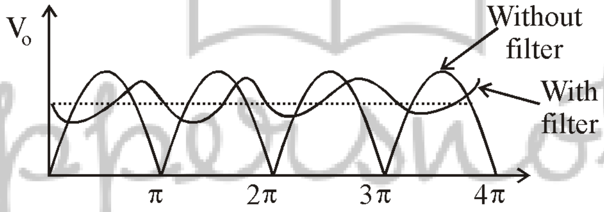
- A filter circuit generally a combination of inductors L and capacitors C.

**Commonly Used Filters are :**

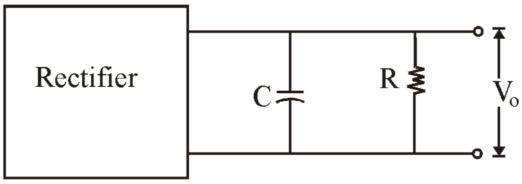
1. Series Inductor
2. Shunt Capacitor
3. Choke input or L-section filter
4. Capacitor input or $\pi$-filter
5. R-C Filters

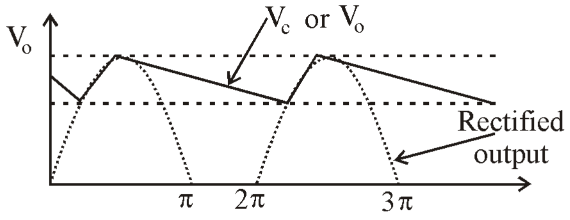
**1. Series Inductor Filter :**



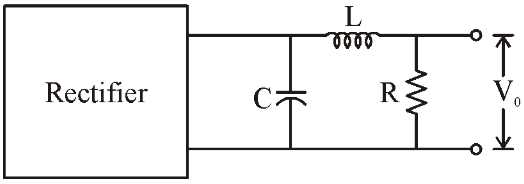


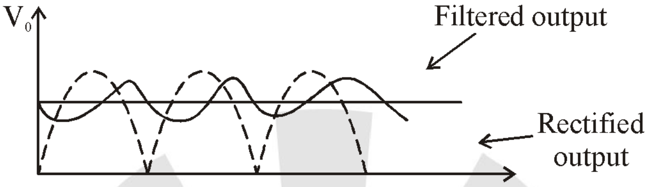
**2. Shunt Capacitor Filter :**



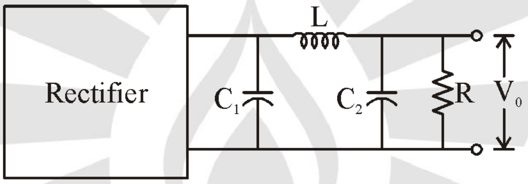


### 3. Choke-input or L-section Filter :

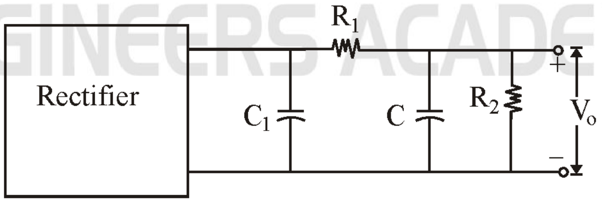




### 4. Capacitor-input or π-Filter :



### 5. R–C Filter :



The drawbacks of π-Filters are the comparatively larger cost, more weight, bigger size and external field developed by the series inductor. These drawbacks can be overcome by a series Resistor R, such a circuit is called the “R–C” Filter.

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