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IES/GATE

Electrical Engineering

Volume - 6

Analog Electronics

SIERRA INNOVATIONS

INDEX

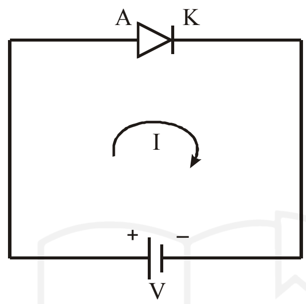
1 CHAPTER Diodes Circuits

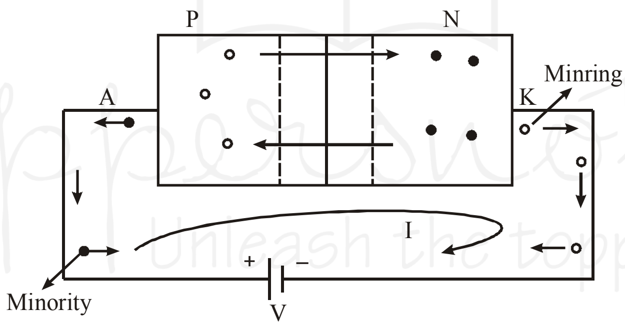
THEORY

1.1 BIASING

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

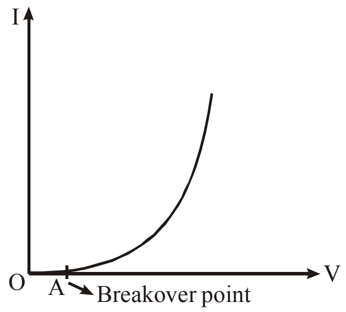
Forward Bias :





- 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

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

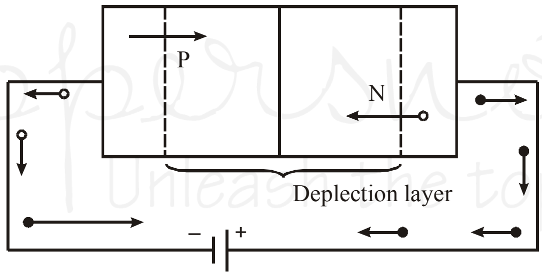
$$V_T = \frac{kT}{q} = \frac{T}{11600}$$

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

where v_d = voltage across diode

η = 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

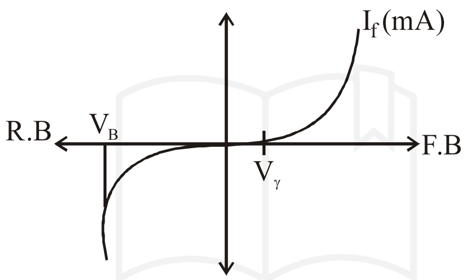
$$I_r = I_0(e^{-V/\eta V_T} - 1)$$

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

$$I_r \approx - I_0$$

(–) 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

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

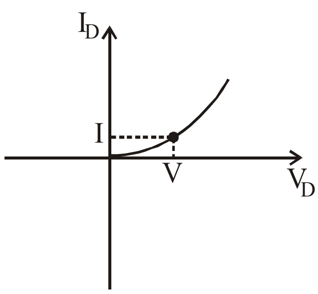
1.2 DIODE RESISTANCE

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.

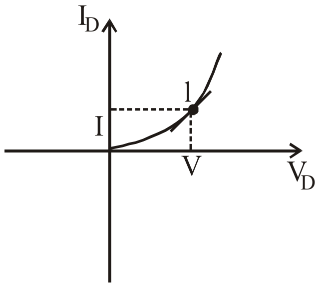
$$R_{DC} = \frac{V}{I}(\Omega)$$

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.



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

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

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

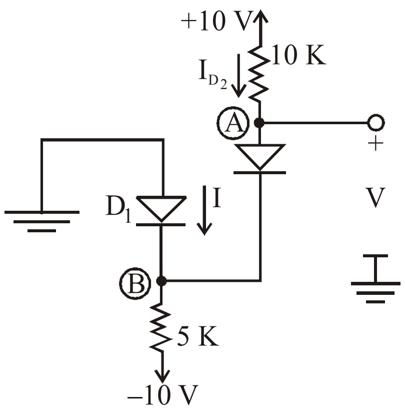
For Ge at T = 300 k (room temperature)

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

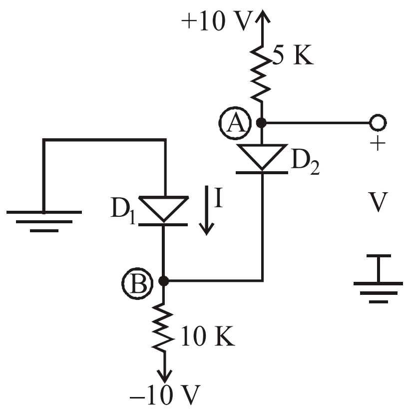
For Si at T = 300 k

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

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,

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

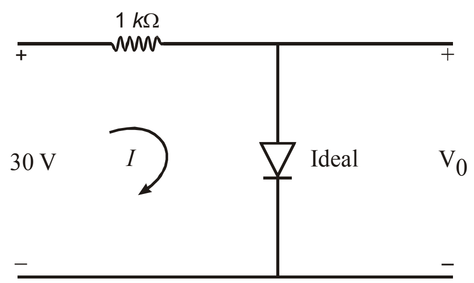
and voltage at node B is

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

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 :

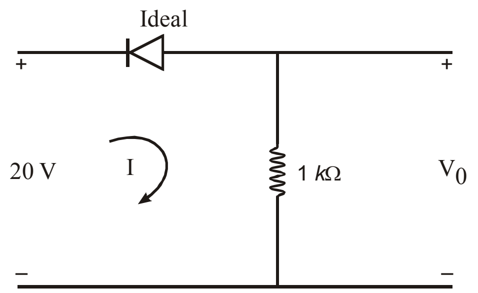


$$I = \frac{30}{1K} = 30 \text{ mA}$$

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

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

Solution :

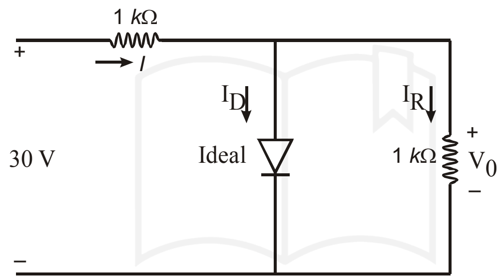


$$V_0 = -20V$$

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

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

Solution :



$$V_0 = 0$$

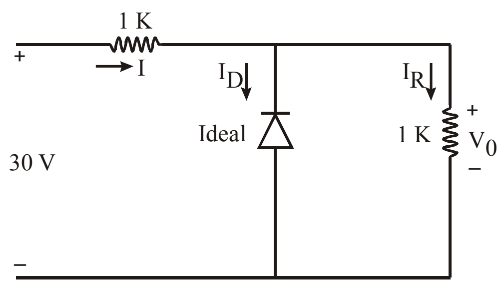
$$I_R = 0$$

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

$$I = I_D = 30 \text{ mA}$$

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

Solution :



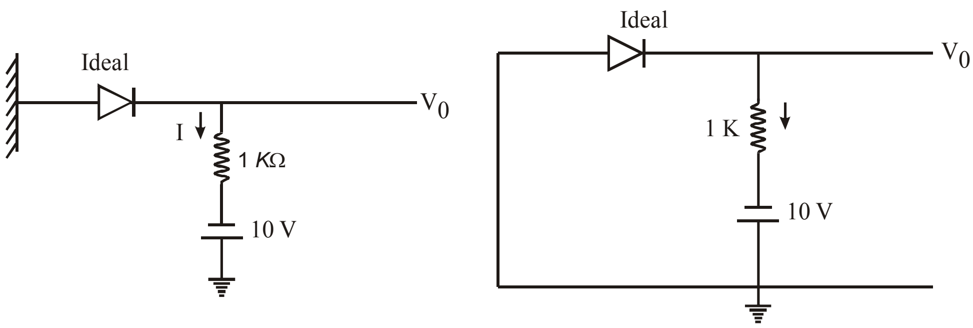
$$I_D = 0$$

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

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

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

Solution :



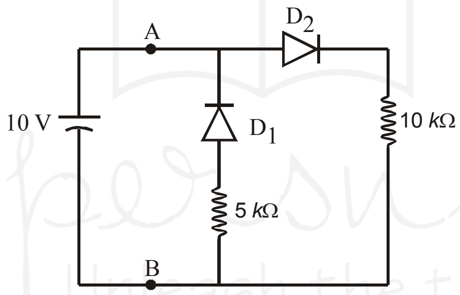
∵ Ideal diode is forward bias and short circuit

∴ $V_0 = 0$

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

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

Example 7 : Find Z_{AB}



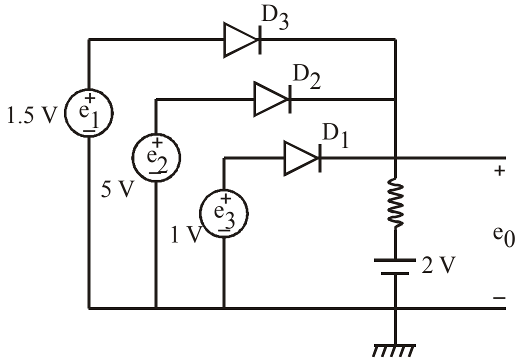
Solution : A is positive w.r.t. B.

D_1 is reverse bias and open circuit

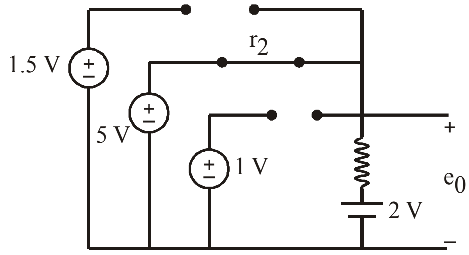
D_2 is forward bias and short circuit.

$$Z_{AB} = 10k\Omega$$

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



Solution :

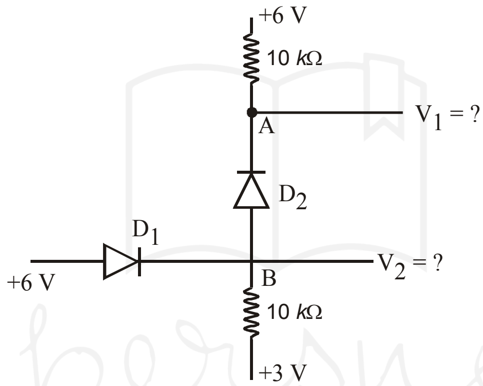


D_1 and D_3 are in reverse bias.

D_2 is forward bias and conducting.

$$e_0 = 5V$$

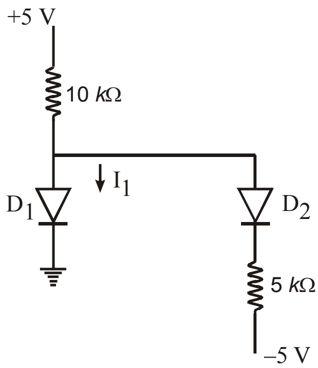
Example 9 : Find the voltage V_1 and V_2 of the arrangement given in the figure respectively :



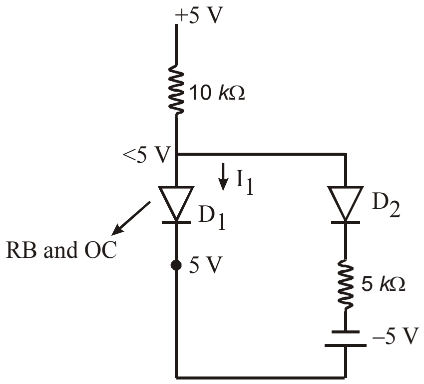
Solution : At node A voltage is less than 6 volt due to drop in resistor 10 kΩ. So diode D_2 is forward bias and SC.

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

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



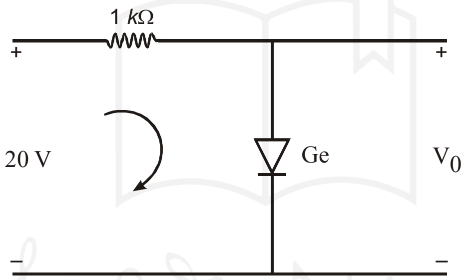
Solution :



From the figure D_1 is reverse bias and open circuit.

$\therefore \qquad I_1 = 0$

Example 11 :



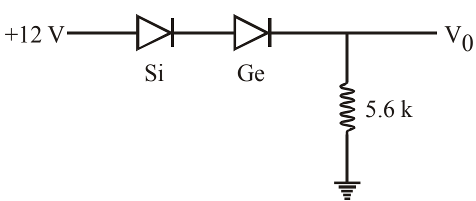
Find I and V_0

Find I and V_0, Ge diode is forward bias.

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

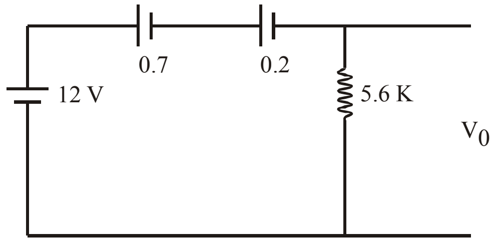
$$I = \frac{20 - V_{Ge}}{1\,K} = \frac{20 - 0.2}{1\,K} = 19.8\text{ mA}$$

Example 12 : Find I and V_0.

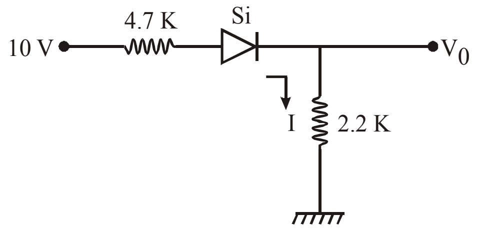


Solution : $$I = \frac{12 - 0.7 - 0.2}{5.6\,K} = 1.982\text{ mA}$$

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

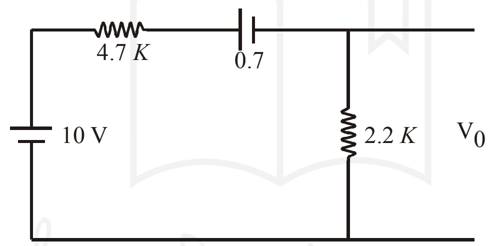


Example 13 : Find I and V_0.



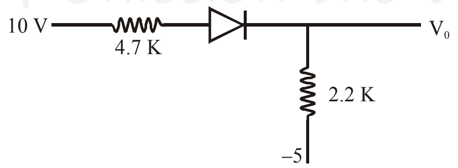
Solution :

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



$V_0 = 1.347 \times 2.2 = 2.965$ V

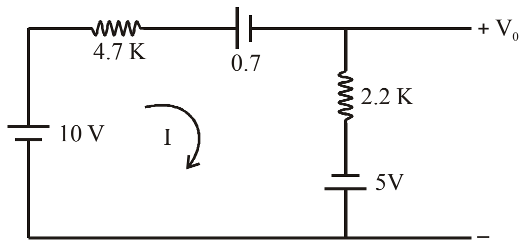
Example 14 : Find I and V_0.



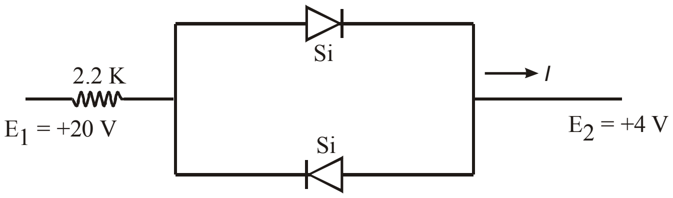
Solution :

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

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

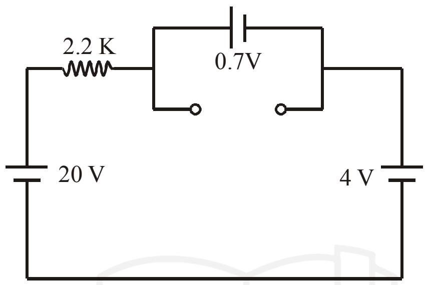


Example 15 : Find I

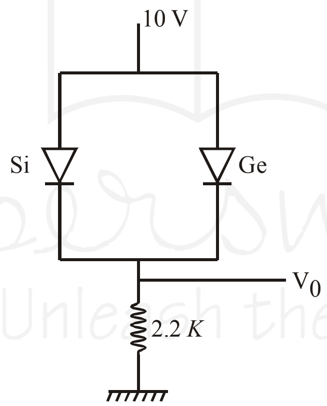


Solution : Since $E_1 > E_2$. Bottom diode is reverse bias and open circuit upper diode is forward bias and SC.

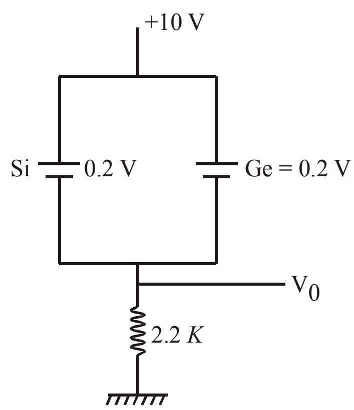
$$I = \frac{20 - 0.7 - 4}{2.2K} = 6.95 \text{ mA}$$



Example 16 : Find V_0.



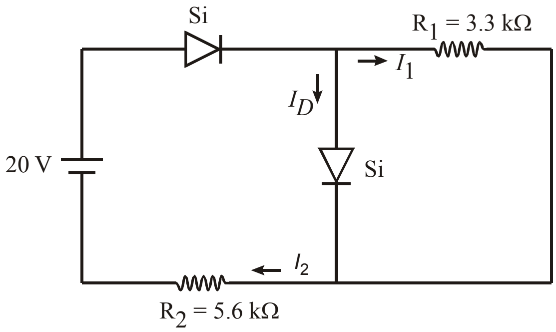
Solution : When 10 V is applied both Ge and Si diode both are forward bias and due to smaller cut in voltage Ge will enter into conduction.



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

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

Example 17 : Find I_D.

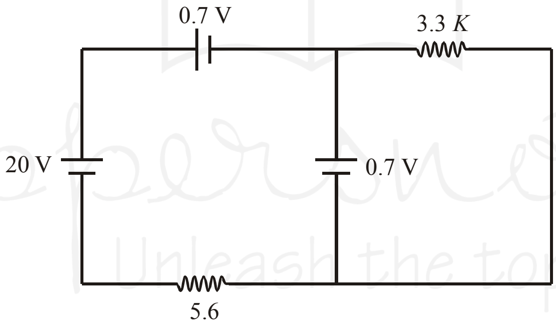


Solution :

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

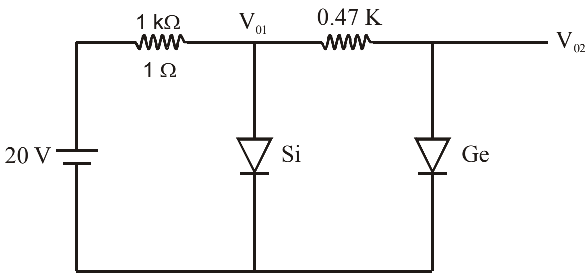
$$I_1 = \frac{0.7}{3.3K} = 0.212 \text{ mA}$$

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



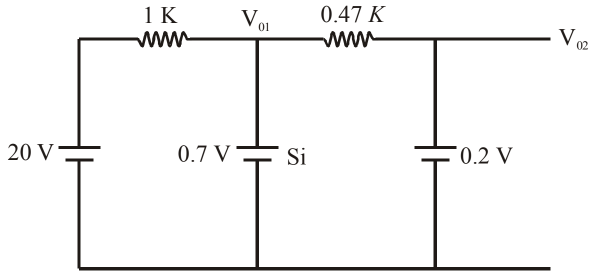
$$I_D = I_2 - I_1 = 3.321 - 0.212 = 3.109 \text{ mA}$$

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

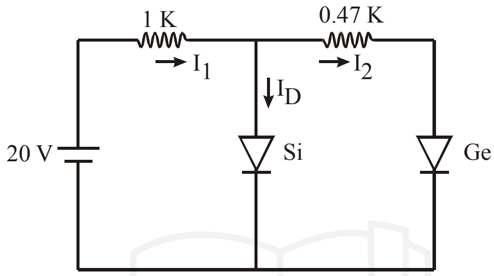


Solution :

$$V_{01} = 0.7V = V_{rSi}$$
$$V_{02} = 0.2V = V_{rGe}$$

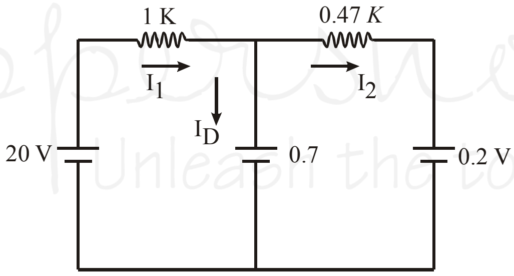


Example 19 : Find I_1, I_2 and I_D.



Solution :

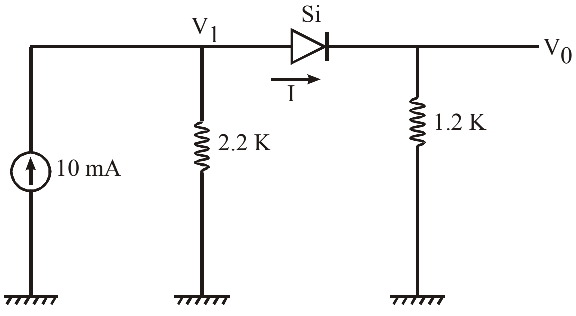
$$I_1 = \frac{20-0.7}{1K} = 19.3 \text{ mA}$$



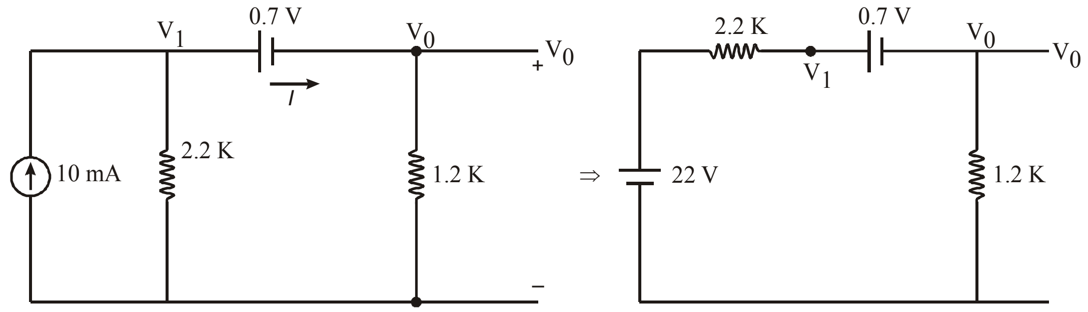
$$I_2 = \frac{0.7-0.2}{0.47K} = 1.063 \text{ mA}$$

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

Example 20 : Find I, V_1 and V_0.



Solution :



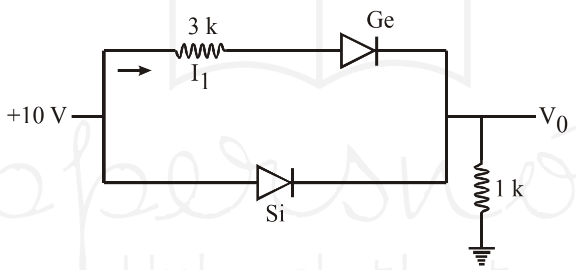
$$I = \frac{22 - 0.7}{2.2K + 1.2K} = 6.26\,mA$$

$$V_0 = I \times 1.2\ K = 6.26 \times 1.2 = 7.51\ Volt$$

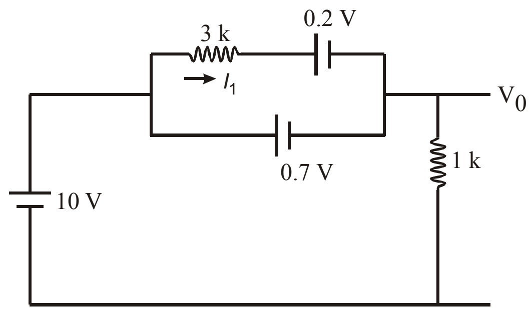
$$V_1 = 22 - (2.2 \times 6.26) = 8.228\ Volt$$

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

Example 21 : Find V_0 and I_1.



Solution :

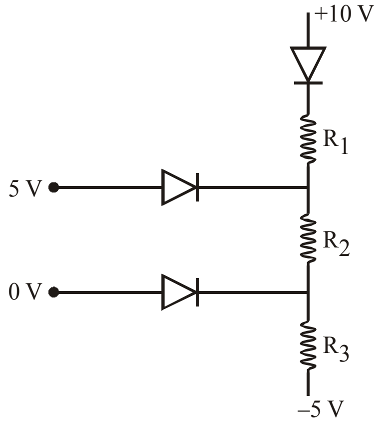


$$V_{rSi} = V_{rGe} + 3 \times I_1 \Rightarrow 0.7V = 0.2V + 3 \times I_1$$

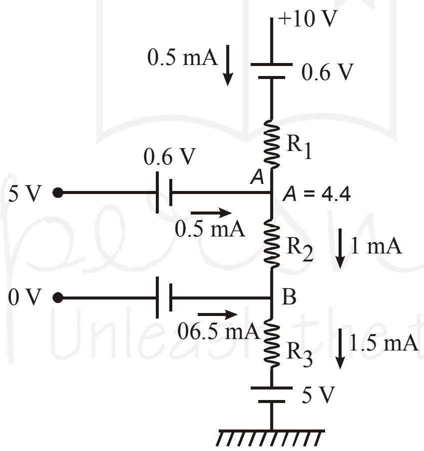
$$I_1 = \frac{0.5}{3} = 0.166\,mA$$

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

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 :



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

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

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

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

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

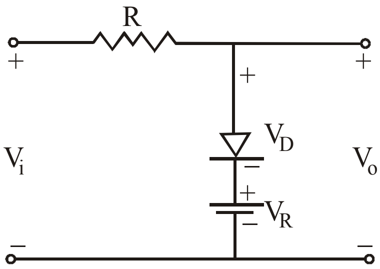
$$R_3 = \frac{V_B - (-5)}{1.5} = \frac{-0.6 + 5}{1.5} = 2.93\,k\Omega$$

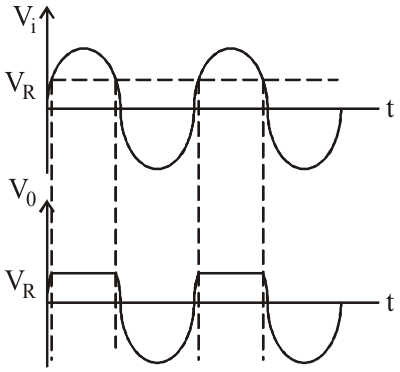
1.3 CLIPPERS

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 :

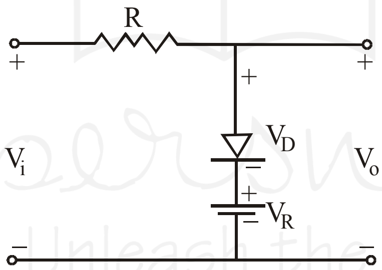
Circuit - 1 :





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

Circuit - 2 :

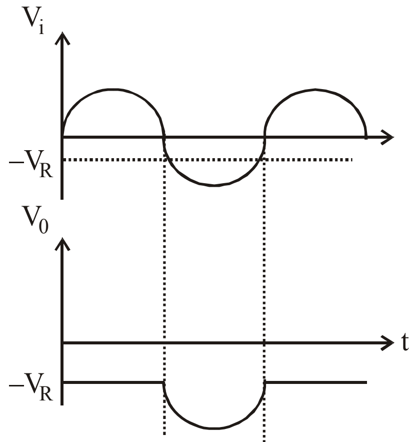


When $V_D > 0$ or $V_i < -V_R$, Diode $\rightarrow$ OFF

$V_0 = V_i$

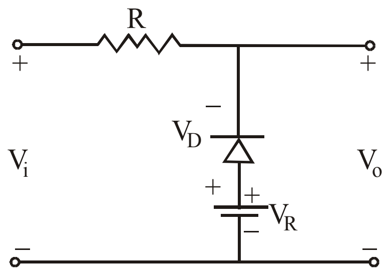
When $V_D < 0$ or $V_i > -V_R$, Diode $\rightarrow$ ON

$V_0 = -V_R$



(ii) Negative Clippers :

Circuit - 1 :

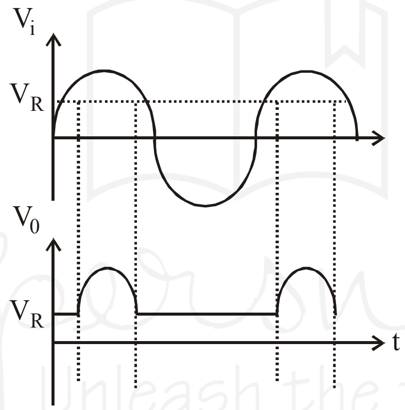


When $V_i > V_R$ Diode $\rightarrow$ OFF

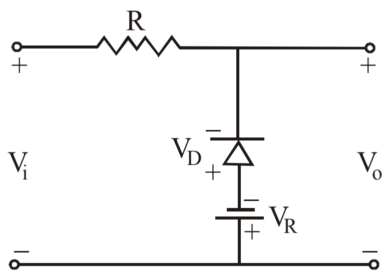
$V_0 = V_i$

When $V_i < V_R$ Diode $\rightarrow$ ON

$V_0 = V_R$



Circuit - 2 :

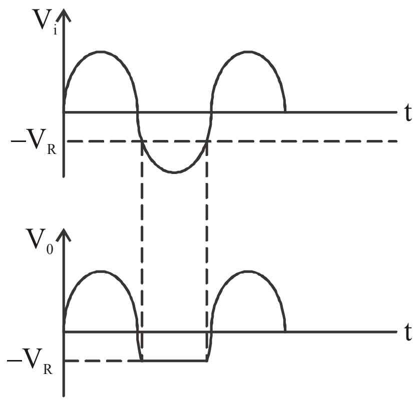


When $V_i < -\ V_R$, Diode $\rightarrow$ ON

$V_0 = -\ V_R$

When $V_i > -\ V_R$ Diode $\rightarrow$ OFF

$V_0 = V_i$

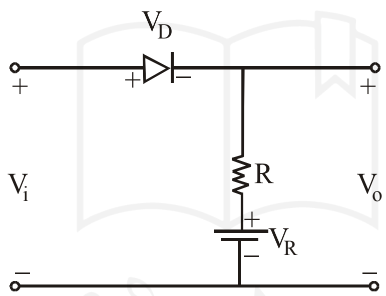


Some other types of Clipper Circuit :

Type - 1 :

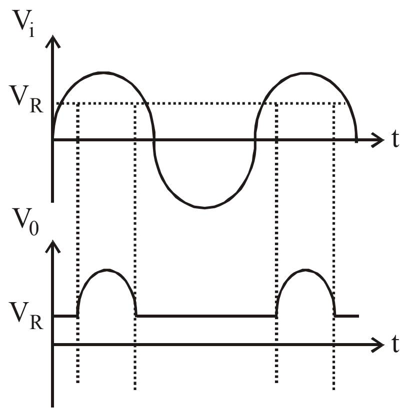
When $V_i > V_R$ Diode $\rightarrow$ ON $V_0 = V_i$

When $V_i < V_R$ Diode $\rightarrow$ 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 $\rightarrow$ ON $V_0 \rightarrow V_i$

When $V_i < -V_R$, Diode $\rightarrow$ OFF $V_0 \rightarrow -V_R$