كلية المنصور الجامعة

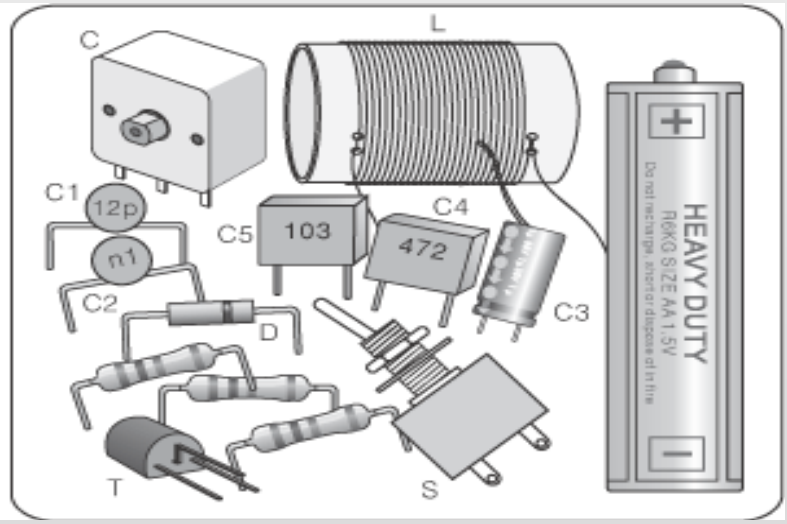
قسم
هندسة اتصالات
المرحلة الاولى

Electronic Physics Lectuers

2017 – 2018

الفيزياء الالكترونية

P-1



5000

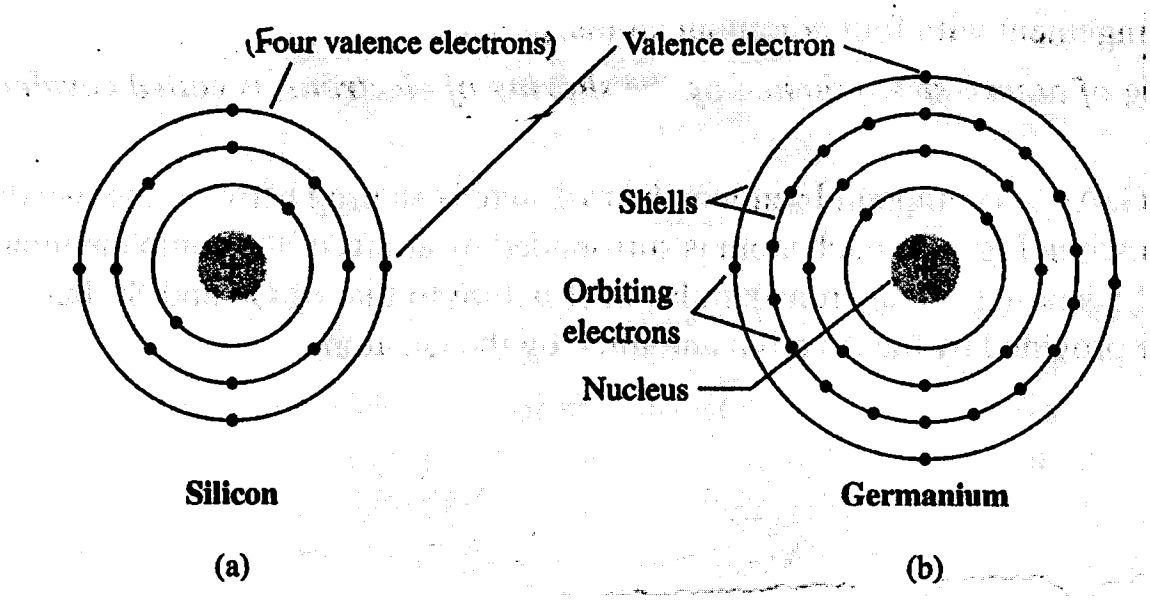
Lec.
Salah Y. H

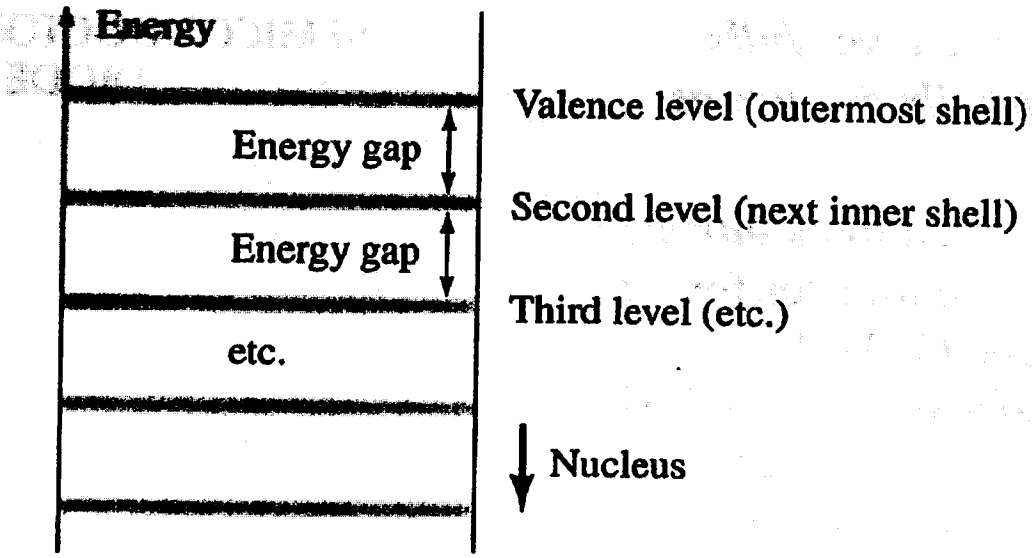
Introduction

Structure of the Atom:

The atom is a basic unit of material that consists of central nucleus surrounded by a cloud of negatively charged electrons. The atomic nucleus contains a mix of positively charges called (**PROTONS**) and uncharged particles called (NEUTRONS). The electron is the basic unit of the negative charge in atom. An atom containing an equal number of protons and electrons is electrically neutral. A group of atoms remain bound to each other forming a molecule.

- The total charge of the atom is (ZERO) .
- No. of electron (e_s) = No. of proton in atom.
- When an atom gets additional electron (or more) then it will be a negative (- Ve) ion .
- When the atom loss an electron (or more), it will be a positive (+ Ve) ion.
- Electron (e_s) orbiting around the nucleus in an atom have different orbits with different energies, and electron energy is higher for higher orbit.
- Electron energies are represented by (Energy level) so the higher orbit is at higher energy level .
- The outermost electron are called (Valence e_s).
- The No. of e_s (or protons) is called the atomic number (Z) , so for Germanium : **Z=32** , and for Silicon **Z= 14** . as shown.


(Four valence electrons)
Valence electron
Shells
Orbiting electrons
Nucleus
Silicon
Germanium
(a)
(b)


Energy
Energy gap
Energy gap
etc.
Valence level (outermost shell)
Second level (next inner shell)
Third level (etc.)
Nucleus

Insulators, Conductors, Semiconductors

Materials may be classified into three types according to the energy band model, Insulators, Conductors, and Semiconductors.

Insulator:

Insulator material has an energy- band diagram with a very wide forbidden energy band is so wide , as shown . The forbidden energy band is so wide that practically no electrons can be given sufficient energy to jump the gap from the valence band to the conduction band .

Conductor

Conductor is a solid containing many electrons in the conduction band at room temperature.In fact there is no forbidden region between the valence and conduction bands on a good conductors energy-band diagram. The two bands actually overlap as shown. So it is very easy for an electron in valence band to be in the conduction band.

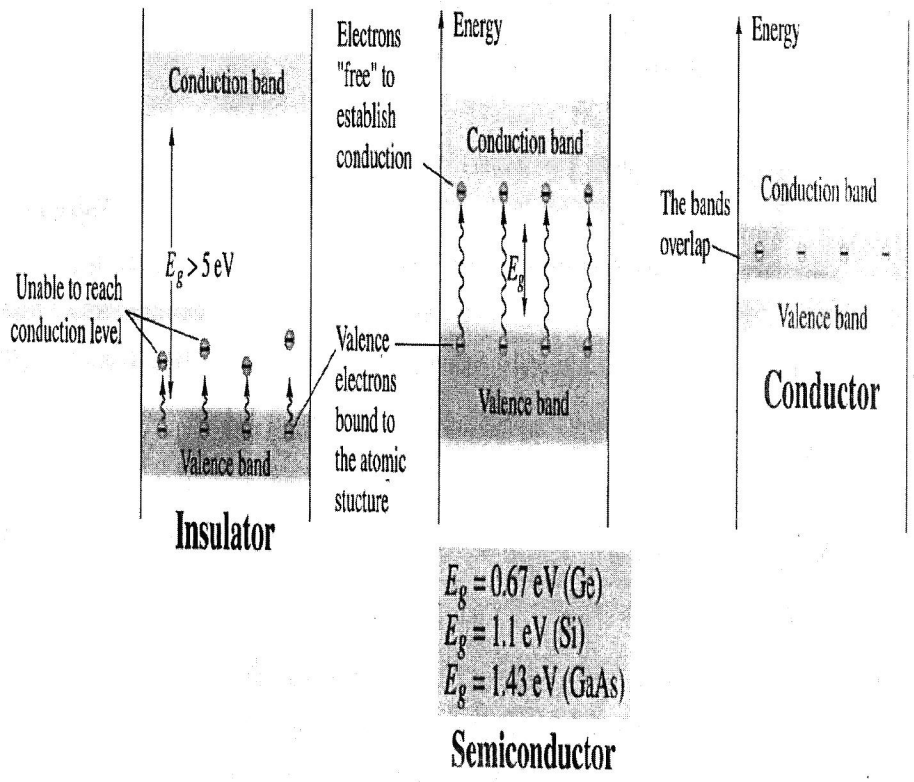
Semiconductor

In semi conductor the energy gap is much smaller than that of an insulator, but larger than that of conductor as shown. Basically, there is no (e_s) in the conduction band but since (Eg) is small, some valence (e_s) may get enough energy (by the heat of the room) so that they may jump to the conduction band through the energy gap.

- At room temperature , semiconductors can conduct some electric current . while at absolute zero temperature, there is no (e_s) in the conduction band of the semiconductor.

Note: Silicon Eg = 1.1 ev
Germanium Eg = 0.67 ev
(ev) ⟶ (electron – volt)

1 ev = $1.6*10^{-19}$ J.

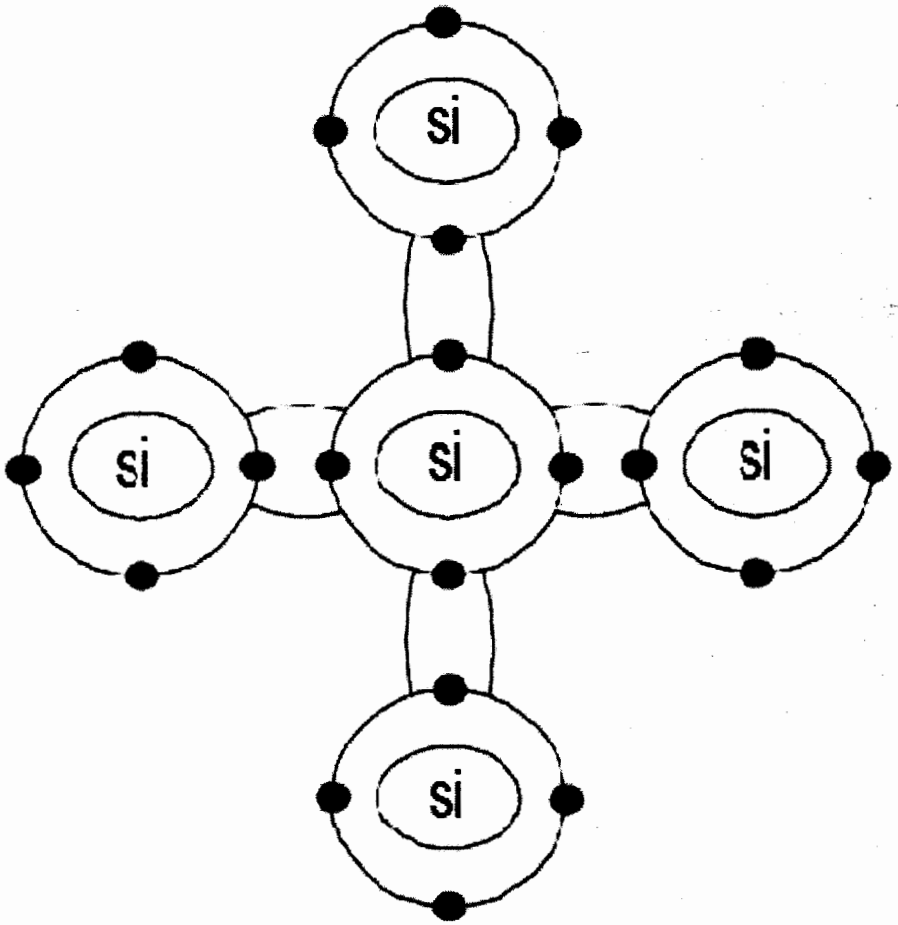


Semiconductor Material

Semi conductor are a special class of elements having conductivity between that of a good conductor and that of an insulator .

The two semiconductor are used most frequently in the construction of electronic devices are Germanium (Ge) and Silicon(Si).

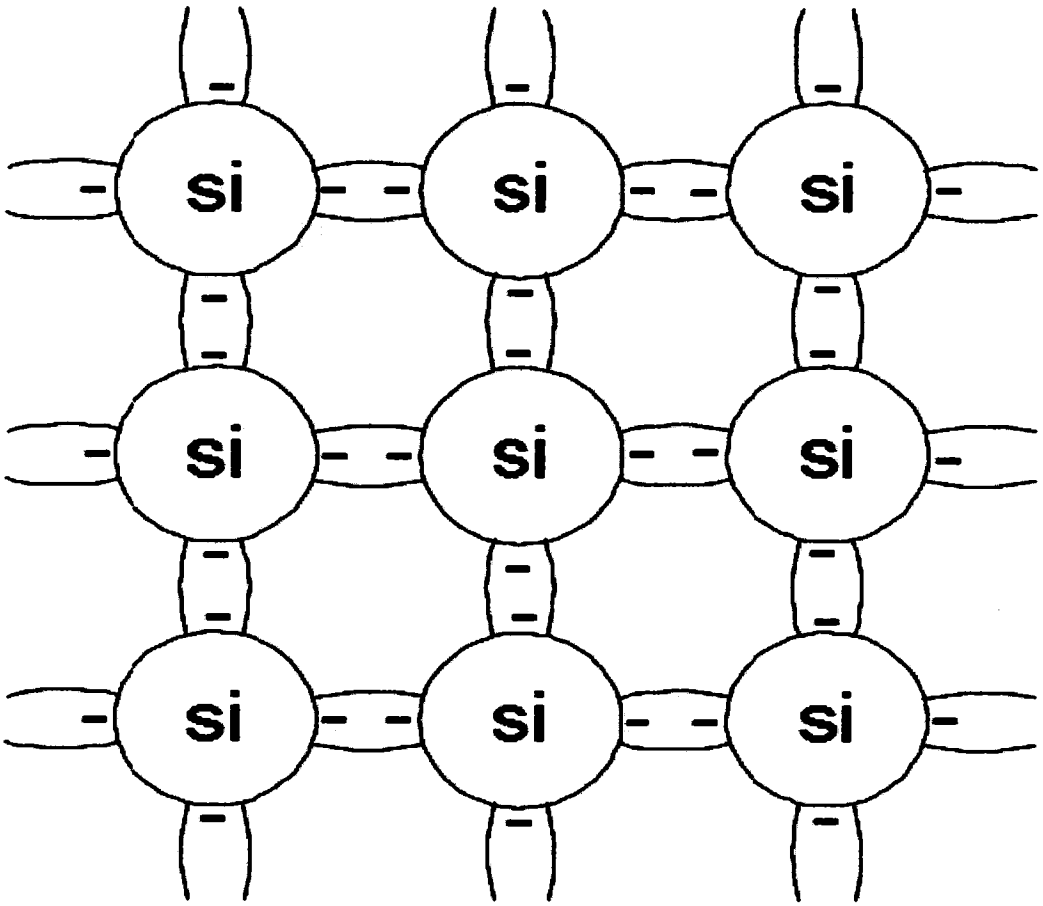
- Both (Si) and (Gi) have four valence (e_s) as shown below .
- In solid form : the atoms are arranged in a crystalline manner , so that each atoms surrounded by (4 atoms).
- Each atom shares its (4) valence (e_s) to form covalent bonds with (4 atoms) as shown.



Si- atoms arranged in crystalline solid

1-Intrinsic Semiconductors

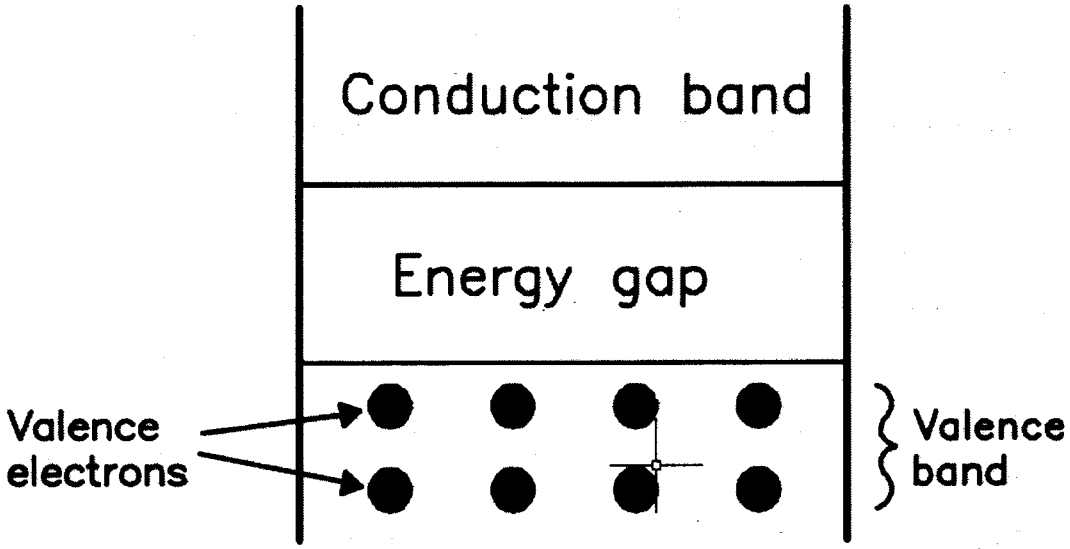
Intrinsic semiconductors are of pure materials with no impurities In intrinsic semiconductors all the(e_s),forming the covalent bonds are bonded to their atoms, they are not free (e_s), unless some energy is provided as shown .



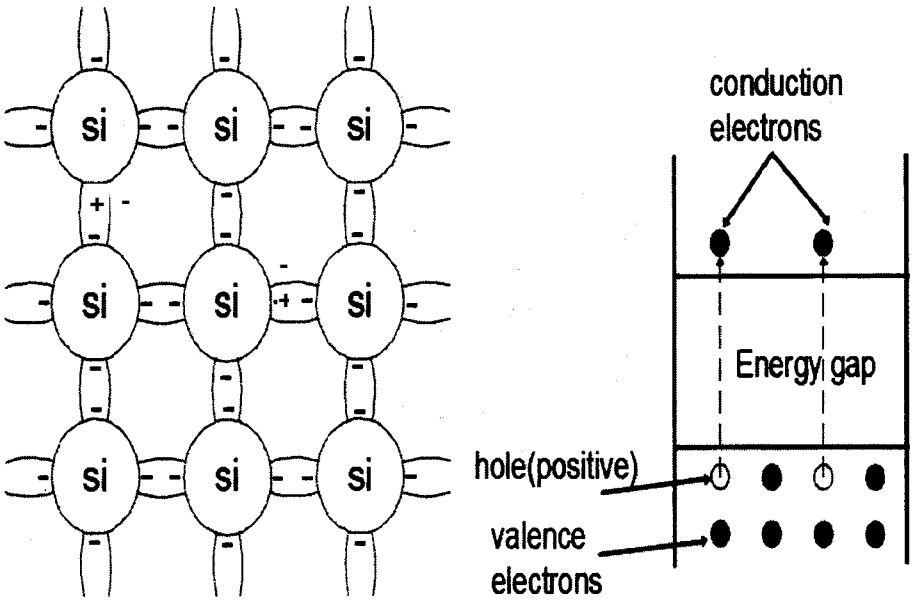
Representation of crystalline arrangement of Si-atoms in a solid

This means that all(e_s) are in the valence band and no (e_s) in the conduction band. (This is at absolute zero temp.).

(absolute zero temp = -273c or - 460 F)



- If temp is raised , some valence (e_s) get enough energy to jump to the conduction band and become free (e_s) .
- In this process , the (e_s) breaks the covalent bond and escape from its atom as shown .

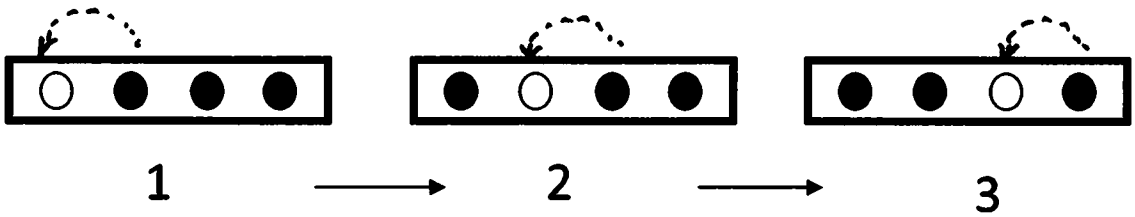


- From above fig, No. of (e_s) in conduction band = No of holes in valence band (e_s- hole pairs).
- As temp increased , the No. of (e_s- hole) pairs increases . thus temp . affects the electrical properties of semiconductors .

- Thermally- generated (e_s) are free from the atoms and can produce electric current if a potential difference (voltage) is applied to the semiconductor

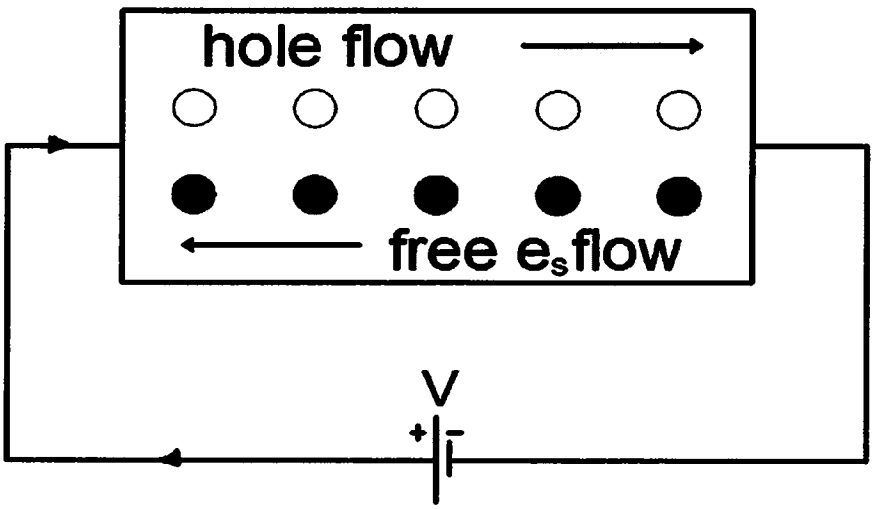
So the conductivity of a semiconductor increase with increasing temperature.

- Free (e_s) can move through the conduction band Also the (+Ve holes) can move through the valance band .
- The movement of (+Ve holes) in a valence band as shown below :



From the fig: movement of a hole to the right is in fact a movement of an (e_s) to the left in the valence band .

- Both (e_s) and (holes) are called (current carriers).
- Current in a semiconductor consist of two parts :-free (e_s) moving in one direction , and (hole) moving in the opposite direction, as shown .and total current is the sum of the two parts ($e_s$and holes) .



2 – Extrinsic semiconductors:

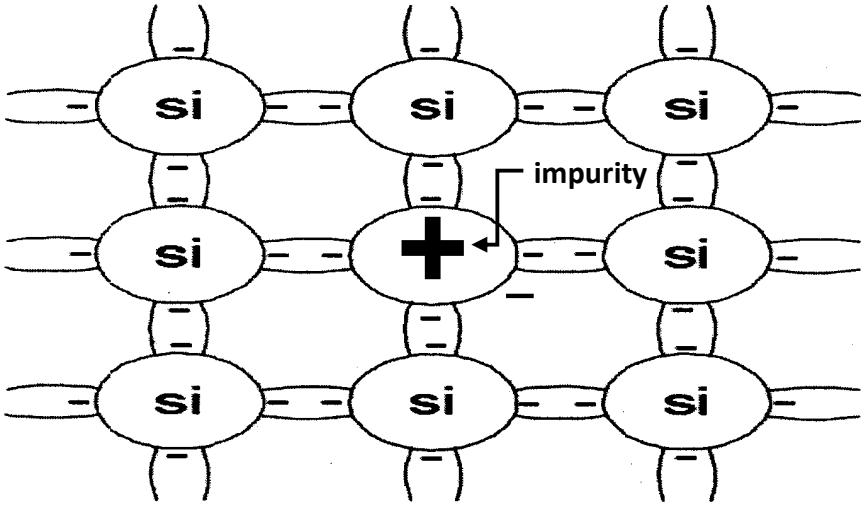
Extrinsic semiconductor is a material by an addition of specific **impurity atoms** to the pure (intrinsic)semiconductor.this will change the properties of the semiconductor material.

- The process of impurity addition is called (**Dopping**)
- The added impurities are called (**Dopants**)
- The concentration of the dopant is very small (≈ 1 part : 10 million parts of pure semiconductor material).
- There are two extrinsic material importance to semiconductor device **N**-type & **P**-type .

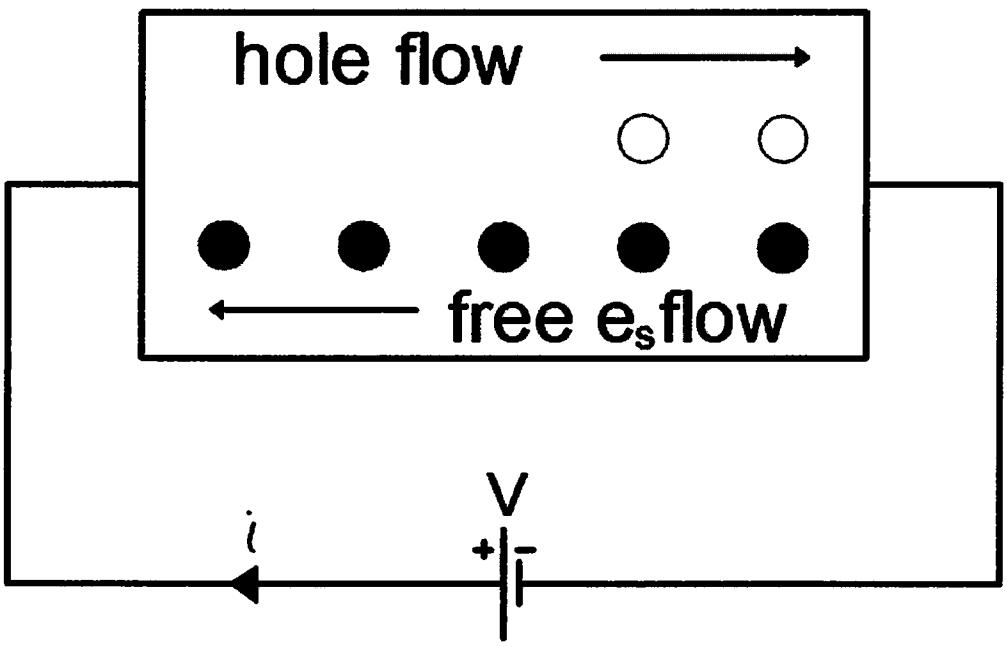
1- N-type semiconductor

N-type semiconductor is created by adding impurity elements that have five (5) valence (e_s) (pentavalent) ((such as arsenic , phosphorus and antimony)). Those impurities are added to the (Si) or (Ge) base

- An impurity atom becomes a +ve ion when it donates its e.
- These +ve ions are locked into the crystal structure and can not move to conduct current.



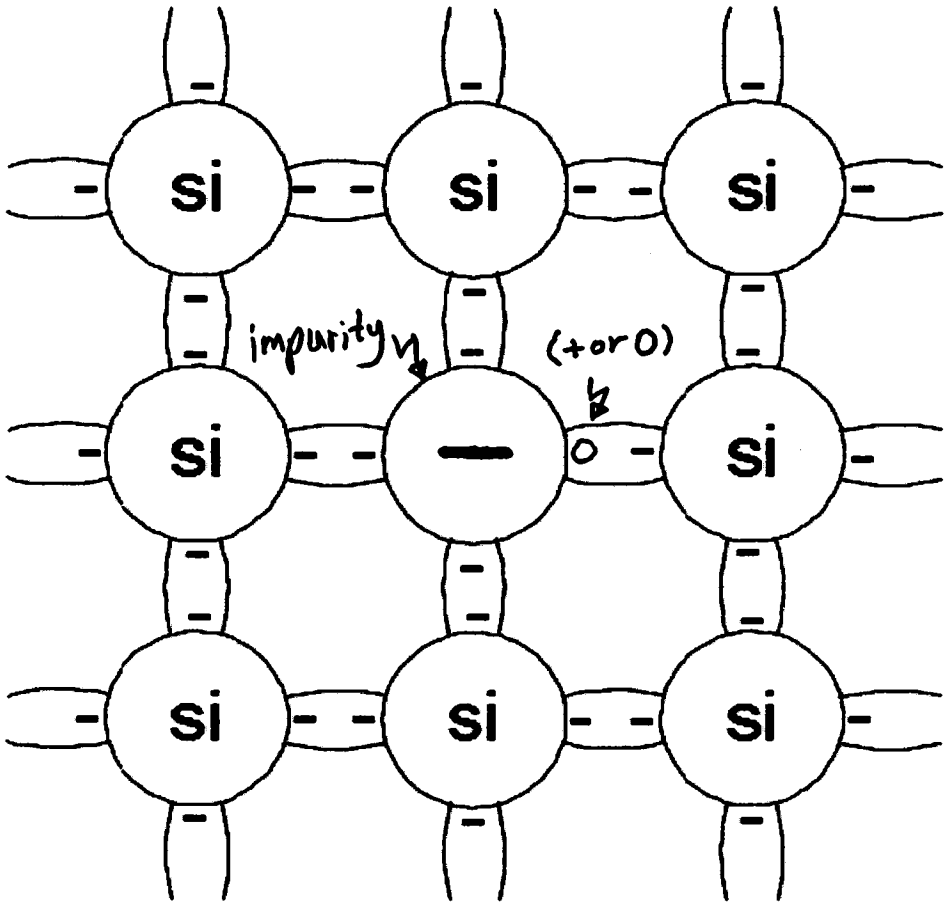
- Only (4) of the impurities valence (e_s) are required in the covalent bond.
- The fifth valence (e) does not enter a covalent bond , and it is loosely bounded to its atom.
- Only a small amount of energy is needed to remove this (e) from its atom , making it a free , conduction electron.
- The impurity atoms are called (Donors) or (Donor impurity) because each gives one e to the semiconductor material .
- For N-type : No. of free e_s in the conduction band is greater than the No. of holes in the valence band.
- The free e_s are called (the **Majority current carriers**)
- The holes are called (**Minority current carriers**).
- The resistivity of N-type semiconductor is lower than that of the intrinsic semiconductor .
- In N-type :the current is mostly created by free e_s



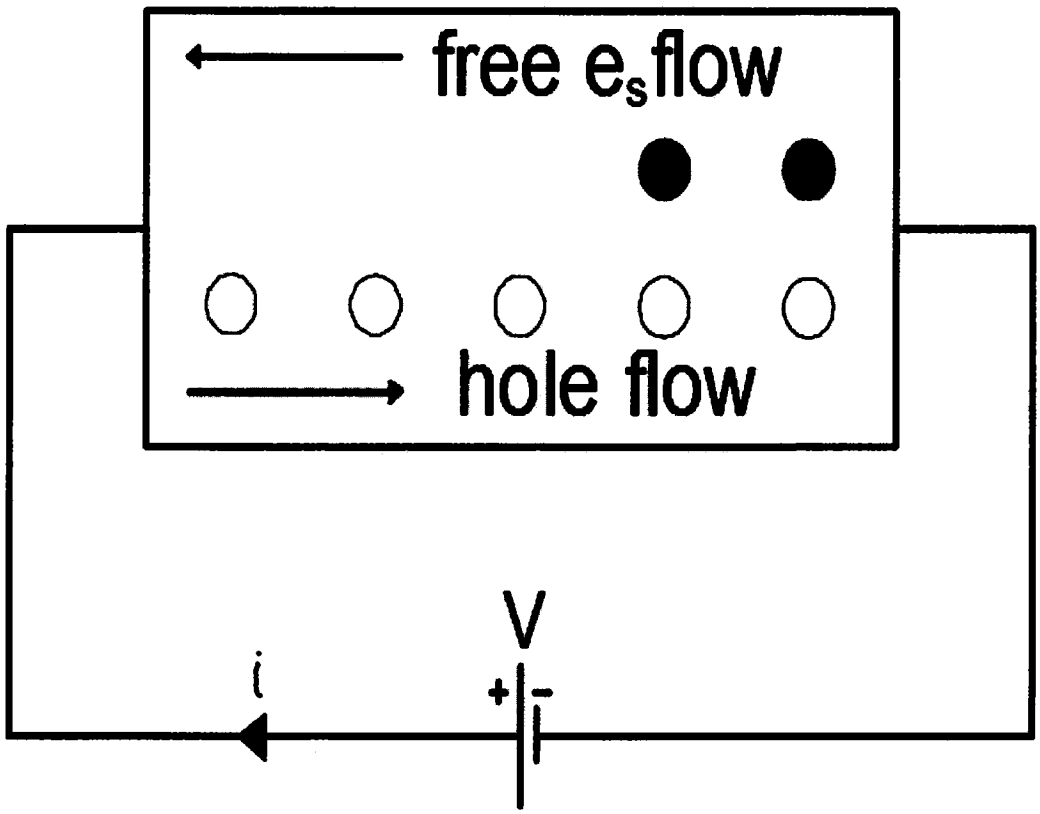
2 – P-Type semiconductor

The p-type material is formed by doping a pure (Ge) or (Si) with impurity atoms having (3) three valence electrons for example (Boron,Gallium,and Indium).

- Here , there is no enough e_s to complete the convalent bonds for the impurity atoms .
- The acceptor atom become a (-ve) ion when its empty covalent bond is filled by a neighboring valence e.
- The impurity atoms are called (**Acceptors**) because they accept e_s from other atoms.



- In P- type semiconductor : No. of holes in valence band is greater than the No. of free (e_s) in conduction band .
- For p- type semiconductors:
  - The holes are called **(Majority carriers)**
  - The free (e_s) are called **(minority carriers)**
- Also the resistivity is lower than that for intrinsic semiconductor .
- The current is mostly created by (+Ve holes)



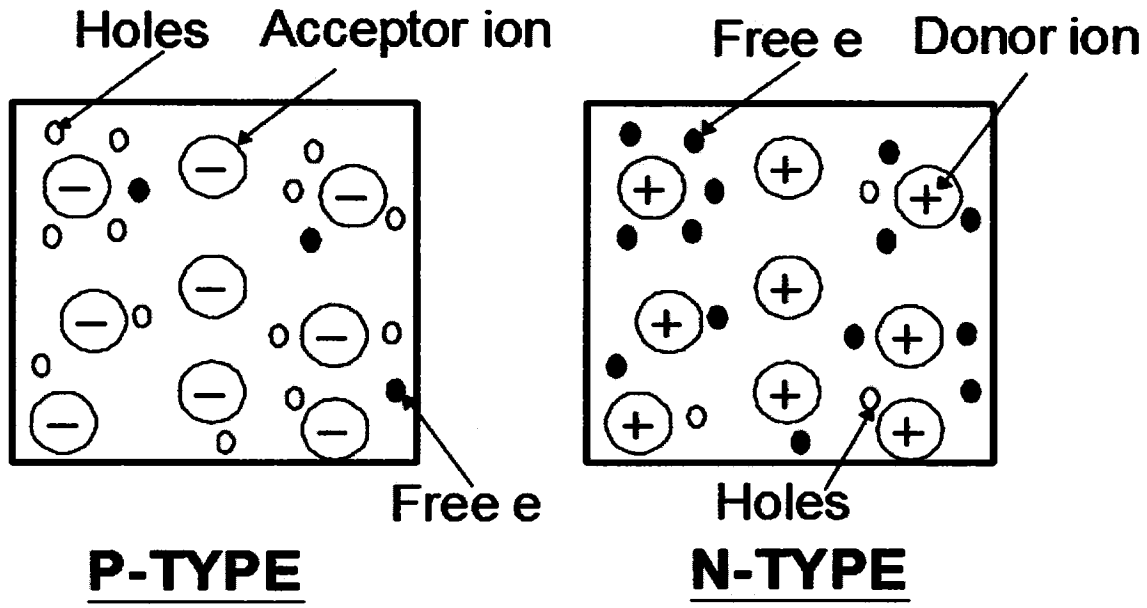
Summary of N-type & P-type semiconductor

Characteristics	N-type	P-type
No.of valence(e_s) of impurity atom	Greater than 4	Less than 4
Name of impurity	Donor	Acceptor
Typical impurities	Arsenic ,phosphorus ,Antimony	Indium, boron, aluminum
Majority carrier	Electron	Hole
Minority carrier	Hole	Electron
Energy band in which majority carrier move	Conduction band	Valence band

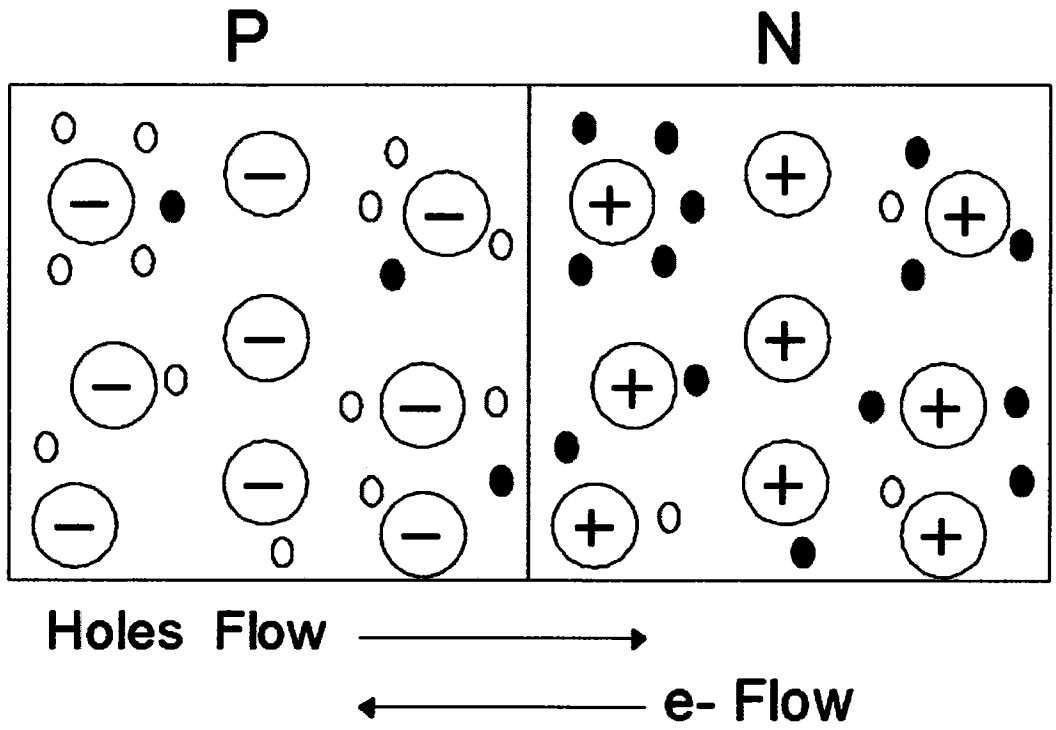
Note: in P –or – N- type semiconductors :

1- No . of majority carriers depend on the No. of impurity atom.
2- No. of minority carrier depend on temperature.

P-N Junction



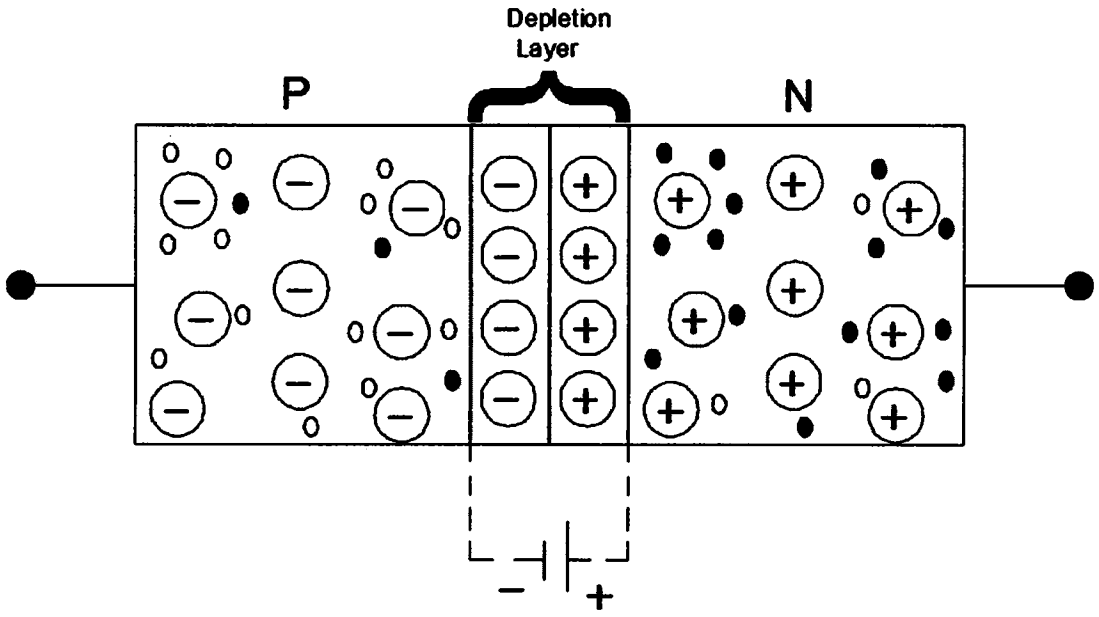
At the moment when P & N regions are joined to gather in a continues crystal structure:



- In P-region , there is a high concentration of holes (majority carriers). But across the junction , in N- region there is a very low concentration of holes (minority carrier).
- This difference in hole concentration causes the holes to diffuse from P region to N region across the junction (Diffusion current).
- Similarly in N-region there is a high concentration of e_s(majority carrier) but across the junction in the P- region there is a very low concentration of e_s (minority carrier).
- There will be a diffusion of e_s from N to P-region across the junction (Diffusion current).

Formation of Depletion Layer (or, space, charge region)

- When holes diffuse from P side to N side they recombine with free e_s in the N side .
- Also , when $e_s$diffuse from N side to P side they recombine with (+Ve) holes in the P side .
- In both cases , recombination cases (e_s) and holes to disappear .



- After some diffusion of e_s& holes:
- Near the junction: only the fixed ions remain(-Ve on the P side and +Ve on the N side as shown).
- There is no charge carrier in the region around the junction.
- These fixed charges near the junction tend to prevent further diffusion.
- Holes moving from P to N side are repelled by (+Ve ions) of the N side .
  Also (e_s) moving from N to P side are repelled by (-Ve ions) on the P side .
- These repulsion forces are small at first but become greater during diffusion.
- Eventually , the repelling force become greater enough to stop further diffusion of majority carriers.
- The region near the junction which contains the fixed ionic charges and no current carriers is called the (depletion region or space – charge region) .

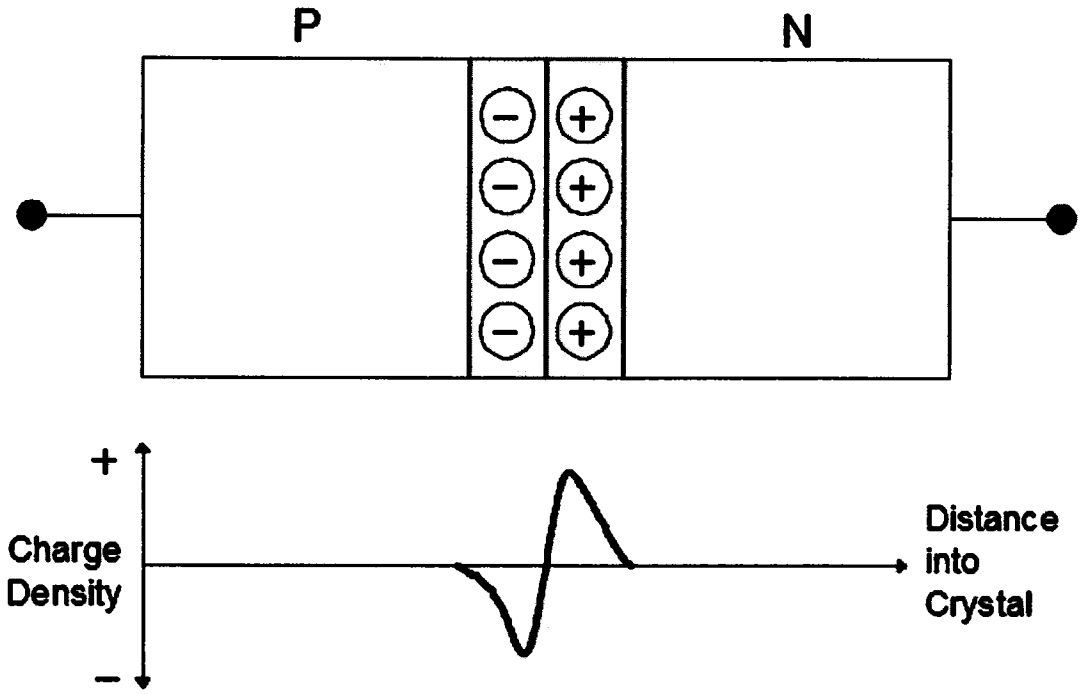
Potential Barrier

- The repelling force of the depletion layer is an electrical force .
- The fixed charges (ions) on both sides of the junction produce a potential barrier , the same as would be produced a battery.
- This potential barrier is about :

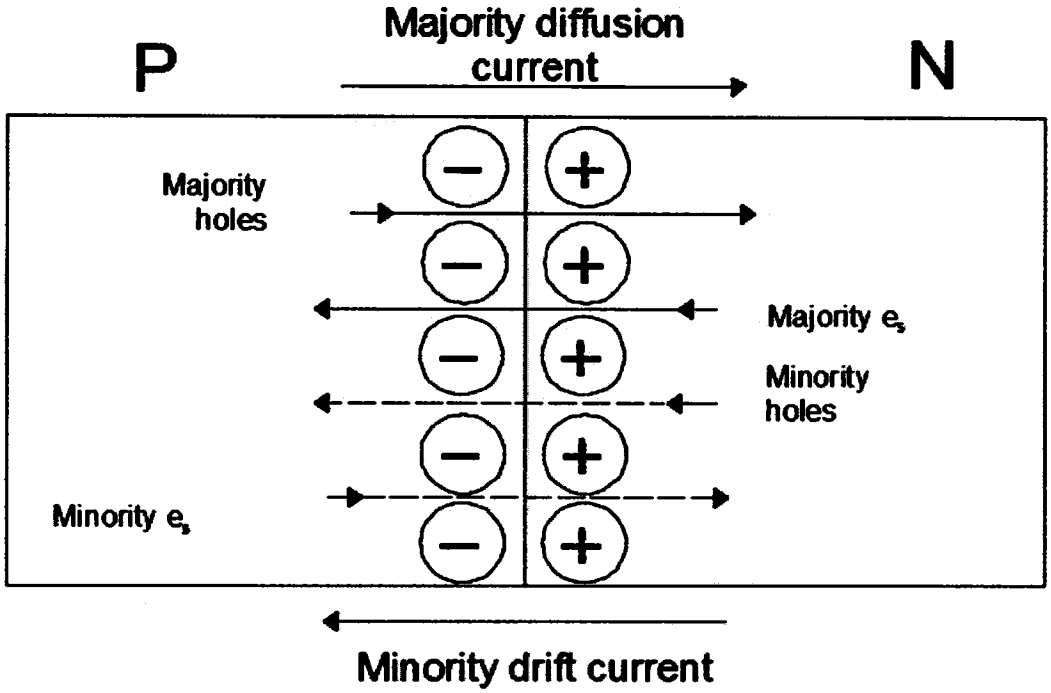
(0.3 volt) for (Ge) .

(0.7 volt) for (Si).

* outside the depletion layer (+Ve) &(-Ve) charges are equally distributed.(net charge$\simeq$zero).



- The depletion layer represents a potential barrier to any
- majority carriers that attempt to diffuse across the junction .
- Majority carriers must gain enough energy to over come this potential barrier.
- At room temp. few majority carriers will be able to over come this barrier . this small diffusion results in a majority carrier diffusion current (the sum of the holes and $e_s$currents) across the P-N junction .
- In addition , there is a reverse current due to the minority carriers, it is called the minority carrier drift current , which results due to attraction between the minority carriers in one side with the ions in the other side .
- These two currents cancel each other (when there is no external connections to the P-N crystal) and the total (net) current is zero.

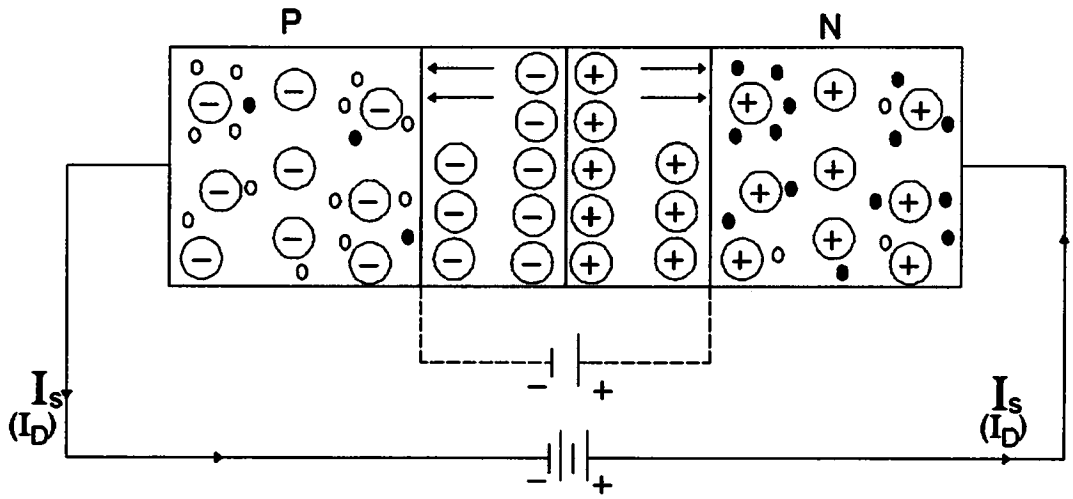


currents across a P-N junction that has no external connections (net current is zero)

Biasing

1- Reverse Biasing:

Reverse biasing take place when the voltage source (such as a battery) is applied across a P-N junction as shown :



- The (+Ve) terminal in connected to the N-type side , and (-Ve) terminal to the P-type side .

- This will increase the width of the depletion layer:

  - **In N-side :** the free e_s will be attracted to the (+Ve) potential of the applied voltage .
  - **In P-side :** the holes will be attracted the (-Ve) potential of the applied voltage.

- This widening of the depletion region will produce a greater potential barrier for the majority carrier.
- In this case the majority carrier current will be reduce to zero.
- The minority current will not change because each minority carrier interring depletion region will flow across the junction (as in the case of no – biasing).
- The current that exist under these condition is called the (reverse saturation current (I_s)).
- The saturation current I_s reaches its maximum value quickly and does not change much with increasing the reverse bias voltage.
- In reverse biasing: the majority diffusion current will drop to zero , and the minority drift current will increase quickly to the max-value(I_s).

- In reverse biasing: the current is due to minority carriers.

- The value of (I_s) depends on the No. of minority carrier (which are thermally generated)

∴ (I_s) depends on temperature

- (I_s) is about few nano amperes (10^{-9}A) in Si at room temp.(it is about 10 nano amperes).
- For (Ge) ,(I_s) is greater because (Ge) has a lower potential barrier across the P-N junction (0.3 volt).
- (I_s) is about a few micro ampers(10^{-6}A) in Ge at room temp.
- The resistance is very high in reverse biasing.

Note : in side the depletion region :

- In N-side : ⊕ : Donor ions (uncovered +Ve ions).
- In P-side : ⊖ : Acceptor ions (uncovered –Ve ions).

Reverse Break-down of P-N Junction

- If the reverse bias voltage exceeds a certain critical value called ((Reverse breakdown voltage (VBD))), than the reverse current will increase very rapidly for small increase in the reverse voltage.
- This will produce a reverse breakdown of the P-N junction.
- Why reverse breakdown: Increasing the reverse voltage causes the minority carriers to move at very high speeds across the junction. They can ionize the crystal atoms by collisions with them any many free (e_s) may be produced (also many holes).

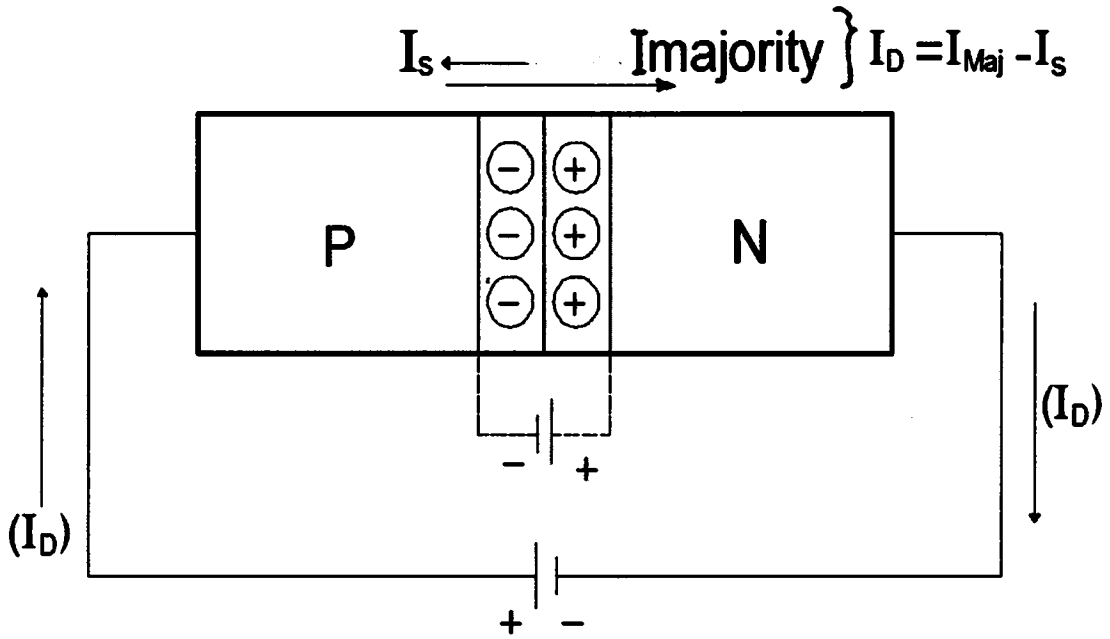
  The generated (e_s) may be accelerated by the reverse voltage and cause other ionizations of other atoms (breaking the covalent bonds).

  This will creates more and more charge carriers (free (e_s) and holes) (Avalanching process), hence increasing the reverse current of minority carriers.

- The process of reverse break down is also called ((avalanche breakdown)).
- The reverse breakdown voltage (V_{BD}) depends on temp. And impurity concentration.
- V_{BD} is also denoted on V_Z (Z:Zener).

2- Forward Biasing

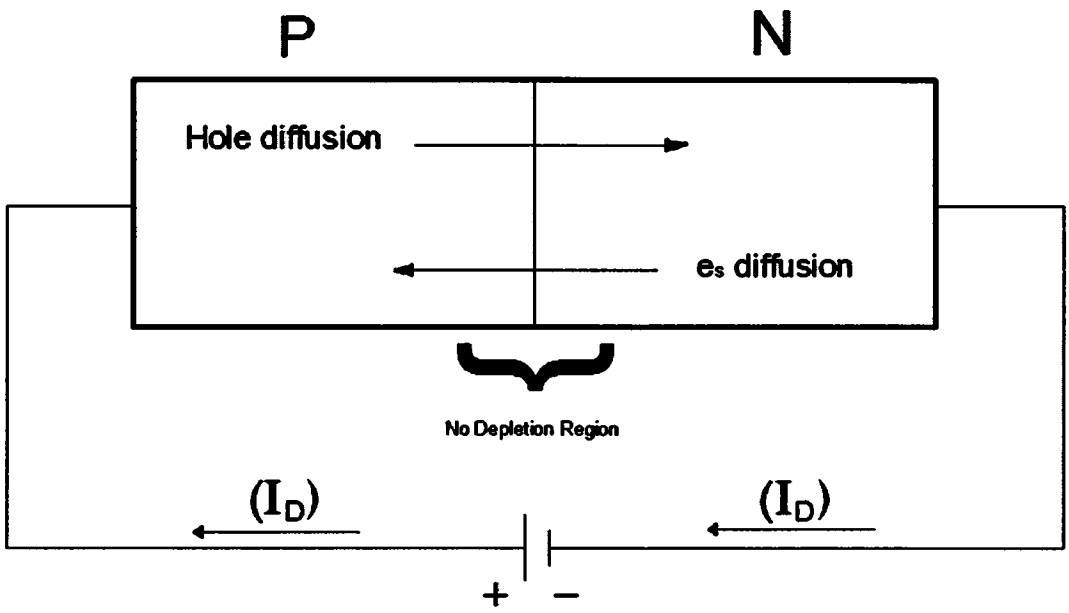
Forward biasing take place when the voltage source (such us a battery) is applied across a P-N junction as shown



Note : (I_s) also denoted as (reverse leakage current) .

- The minority current has not changed in magnitude.
- The majority current is increased due to the reduction in the width of the depletion region(how?).

- If the forward bias is made large enough , the depletion region is reduced and vanishes (disappear) (or the potential barrier is reduced to zero) so this will produce large forward current.
- Typical values of forward bias required to do this are (0.3V) for Ge, and (0.7V) for Si(the value of potential barriers).
- The forward current increases rapidly with increasing the forward bias.



Note: from the above fig,(I_s) is not represented

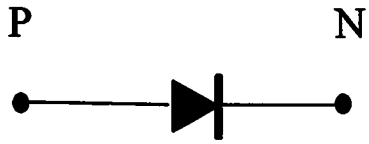
Summary

Forward biasing of P-N junction acts t completely neutralize the P-N junction potential barrier , allowing majority carriers to diffuse freely across the junction. This produces a forward current which increases sharply for small increases in this forward bias.

The P-N junction is also called a (Diode) , A(diode) is a simple electrical device that allows the flow of current only in one

direction (forward bias). So it can be act somewhat like a (SWITCH). A specific arrangement of (Diodes) can convert (A-C) voltage to pulsating (D-C) voltage , hence it sometimes also called a (rectifier).

** The P-N junction (Diode) is denoted by :-



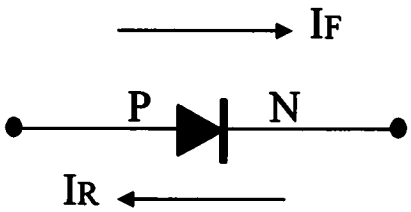
Anode cathode

⟶ Diode current (I_D).

⟶ Diode voltage (V_D).

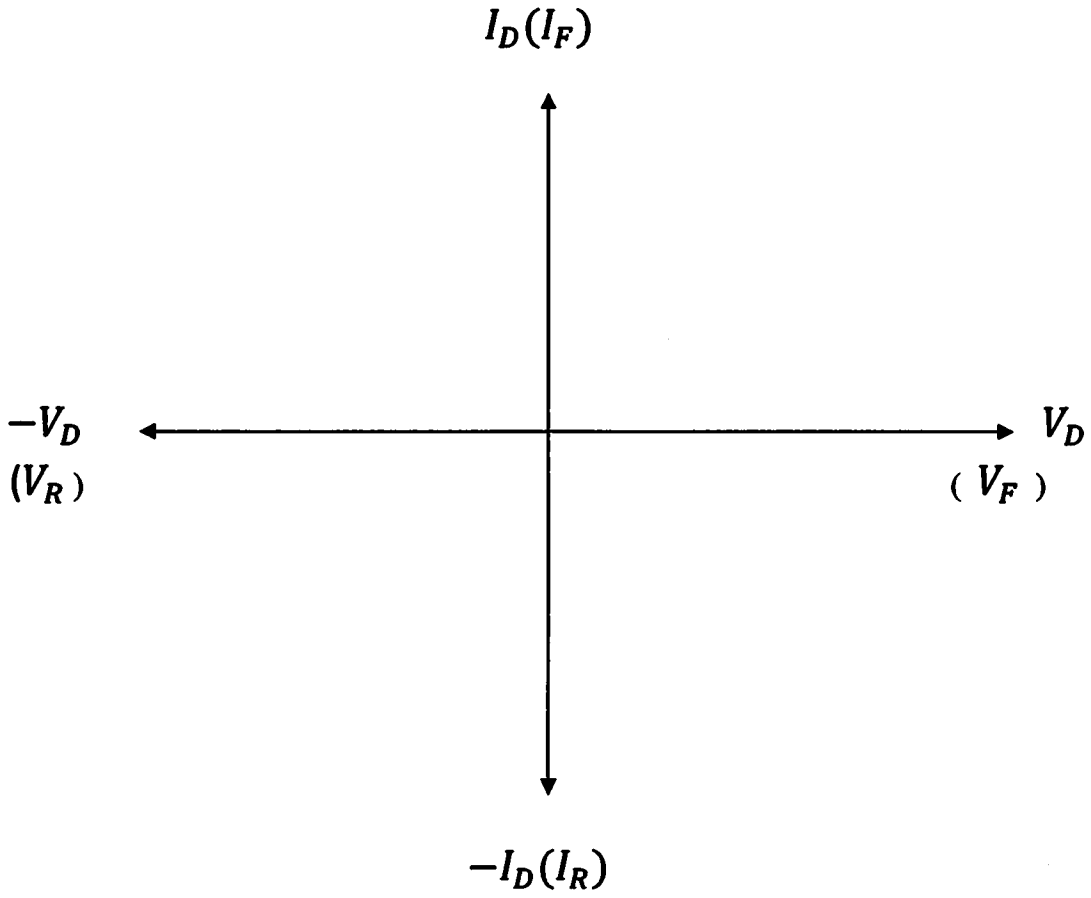
But I_D ⟨ IF : forward Biasing / IR: Reverse Biasing

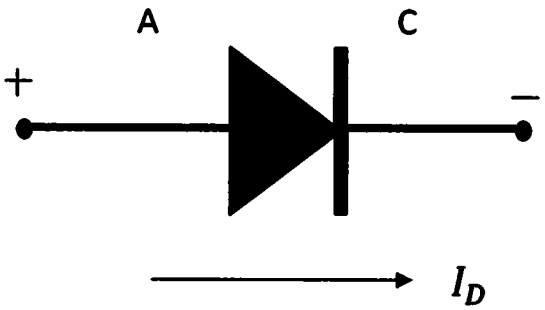
Also V_D: ($V_F$and V_R).



IF ⟶ +Ve (I_D)& I_R ⟶ - Ve (I_D).

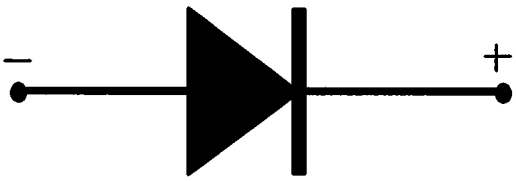
VF ⟶ +Ve (V_D).& V_R ⟶ -Ve (V_D).





I_D

+Ve(V_D &I_D)



I_D

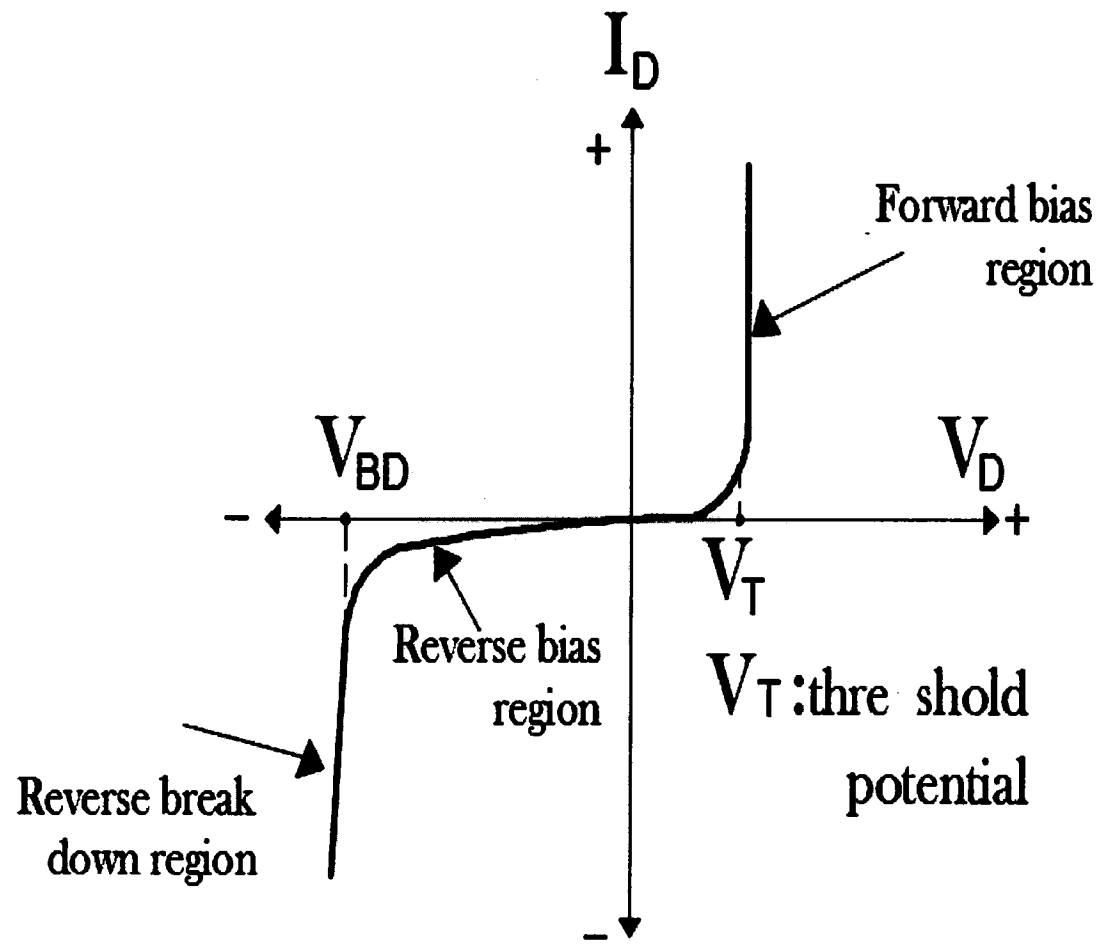
-Ve(V_D &I_D)

V-I characteristic of P-N Junction

The V – I char. Of a P-N junction (or diode) is the relation ship between V_D & I_D (the applied voltage on the diode and the current flowing through it).

Forward Biasing

- When VD is (+Ve) ,the anode is (+Ve) with respect to (W.r.t) the cathode .
- Here forward current flows from anode to cathode, and I_D is (+Ve) as shown



V-I characteristic of P-N Junction

- From fig. the forward region shows that(I_D) is very small until the forward voltage (V_D) be near than the value (V_T)
- V_T is the forward voltage needs to completely neutralize the potential barrier .

VT ≃0.3v for Ge

VT ≃0.7v For Si

* when (V_D) is above (V_T) , the forward current (ID) increases rapidly with increase in forward voltage.

** in forward biasing , the P-N diode conducts very well (**very low resistance)**

Reverse biasing

* when (VD) is made (-Ve) , the anode is (-Ve) (W.r.t) the cathode . this reverse biasing the P-N junction (Diode).

* the reverse current flows from cathode to anode

(I_D is –Ve).as shown in fig.

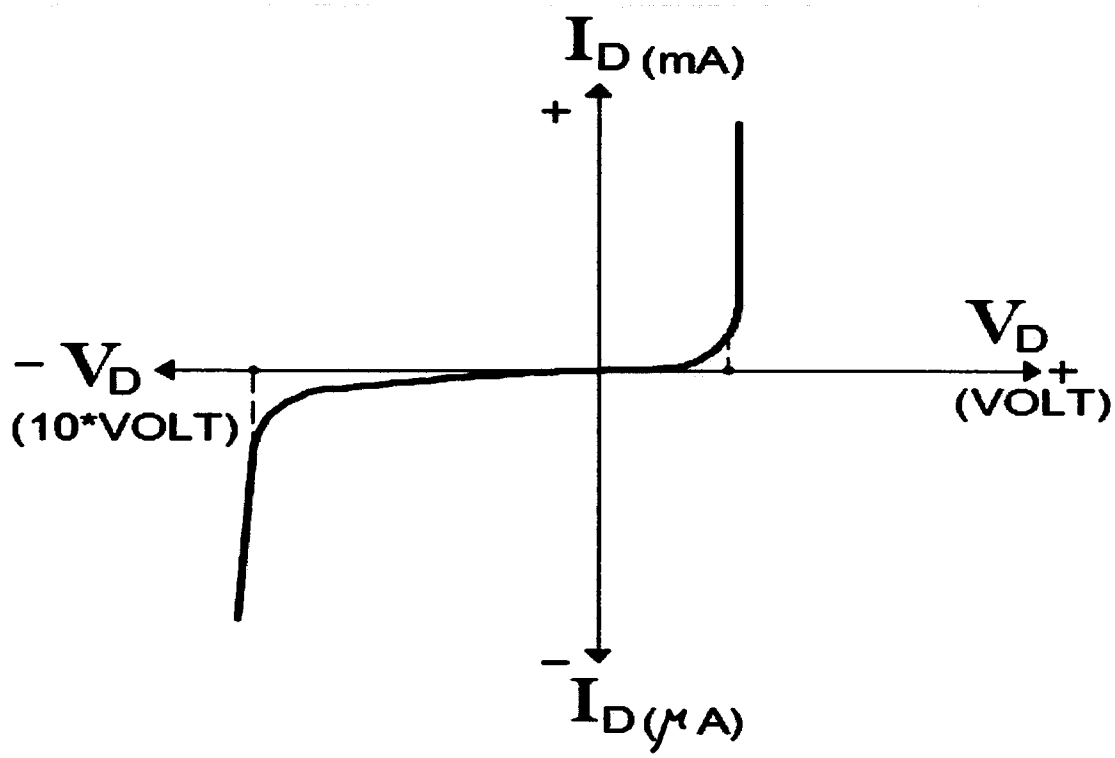
* the reverse current is very small until . the reverse voltage reaches the reverse breakdown voltage(VBD).

* After (VBD) ,the reverse current increases rapidly

(VBD is usually high≃30v⟶ thousands of volts in P-N diode)

** In reverse biasing the P-N diode conducts very poorly (**high resistance**), except at breakdown.

* usually , the V_D & I_D scales are not the same in forward and reverse biasing:



Zener Region

* In addition to the (avalanche breakdown) there another breakdown mechanism called (zener breakdown).

*zener breakdown occurs in diode know as (zener diodes).

*in zener diodes the avalanche region (Vz) is made closer to the vertical axis (current axis) by increasing the doping levels in the N and P type materials.

* zener breakdown occurs because there is a strong electric field in the region of junction that can produce ionization in many atoms and generate more carriers.

* the maximum (max) reverse bias potential that can be applied before intering the zener region is called (**the peak inverse voltage**) (**PIV**) or the peak reverse voltage (PRV).

Mathematical Representation of Diode Current

*From solid _ state physics, the diode current can be related to temperature (T) and applied bias voltage (V) as

$$I_D = I_S\,(e^{KV/T}-1)$$

Where:

I_S : Reverse saturation current.

K: Constant =11600/ {in Ge → =1 / Si → =2}

T: in kelvin units.

T= Tc + 273.

Ex 1: For Si _ diode, find the forward current (I_D) At room temp. (25°) for the for ward bias voltage of 0.5 v, Given I_S equal to 1X 10^{-6} Amp?

Solution:

T = 25+273 = 298 K

K(Si) = 11600/2 = 5800

$I_D = I_S\ (e^{KV/T}-1)$

KV/T = 5800 X 0.5/298 = 9.732

$I_D = 10^{-6}(e^{9.732}-1) = 16.898*10^{-3}$ Amp.

EX2: for Si diode , in what temp. that the forward current is (18mA) , for the forward bias voltage of (0.6v) ,given I_S equal to (900 nAmp)?

Solution:

We have

$I_D = I_S (e^{KV/T}-1)$

$I_D = 18X10^{-3}$ Amp , $I_S = 900nA = 0.9X10^{-6}$Amp

$18X10^{-3} = 0.9X10^{-6} (e^{11600*0.6/2T} - 1)$.

$18X10^{-3} = 0.9X10^{-6}\ e^{3480/T} - 0.9X10^{-6}$

$18X10^{-3} + 0.9X10^{-6} = 0.9X10^{-6}\ e^{3480/T}$

$0.0180009 = 0.9X10^{-6}\ e^{3480/T}$

$20001 = e^{3480/T}$

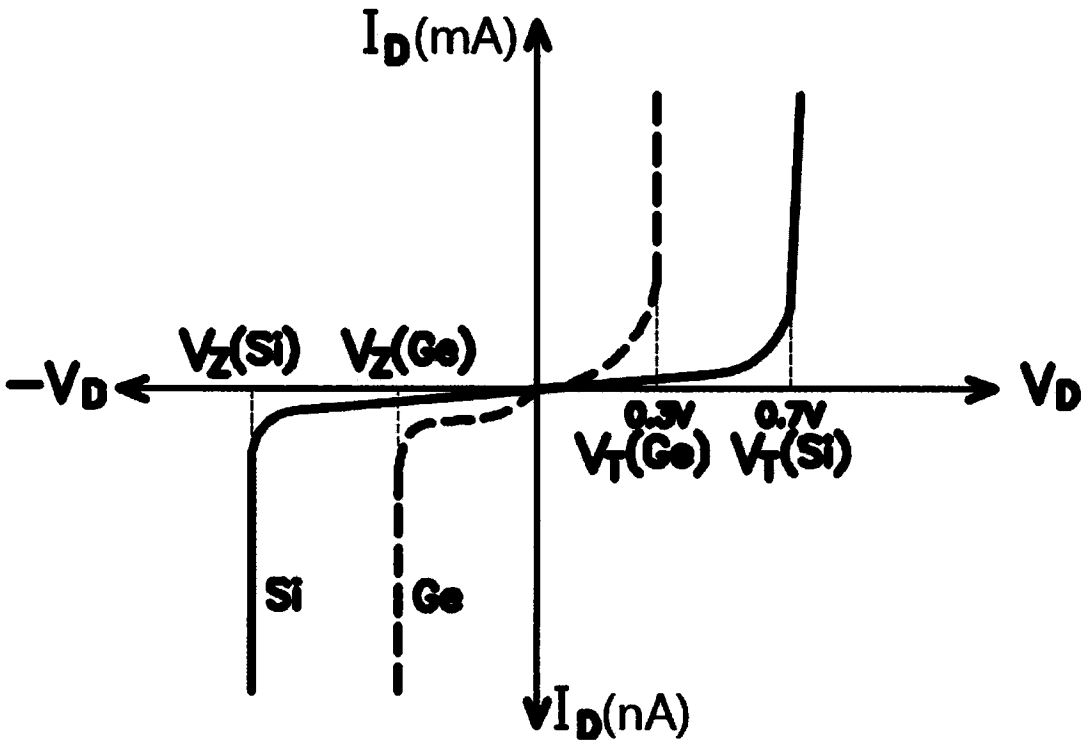
Ln 20001 = 3480/T = 9.9035

T = 3480 / 9.9035 = 351.38

But T = Tc+273°

Tc = 351.38 – 273 = 78.38°

Silicon versus Germanium



Comparision of Si and Ge semiconductor diodes

* things to remember

- Si has a larger forbidden energy gap than Ge (lower No. of minority carrier (e-hole pairs))

Eg(Si) = 1.1eV , Eg (Ge) = 0.67ev

- Si has a larger potential barrier than Ge (0.7 volt for Si & 0.3V for Ge). From the fig.

- Si diodes have a higher (PIV) because of lower No. of minority carriers in Si.

- Si diodes have wider temp. Ranges than Ge diodes (because Eg is larger for Si compared with Ge , hence increasing the temp. produces fewer minority carriers in Si than in Ge) .

- Ge has a larger saturation current (I_s) (revere leakage current) compared with Si (because Ge has a larger No. of minority carriers compared with Si)

- Si diodes have higher values of threshold potential (VT) (a disadvantage of Si diode) . (because Si diodes have higher potential barrier compared with Ge diodes).

Diode Resistance

In general:

--- Forward biasing (when VD>VT):

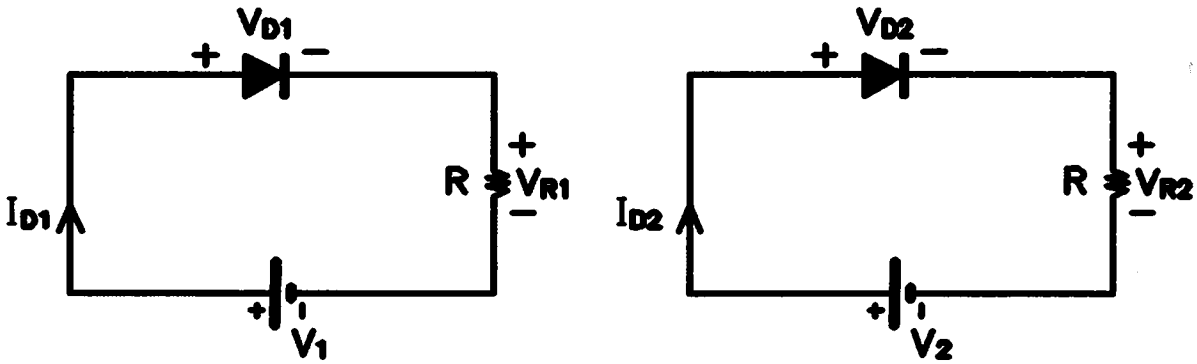
low diode resistance ⟶ high currents

--- reverse biasing :

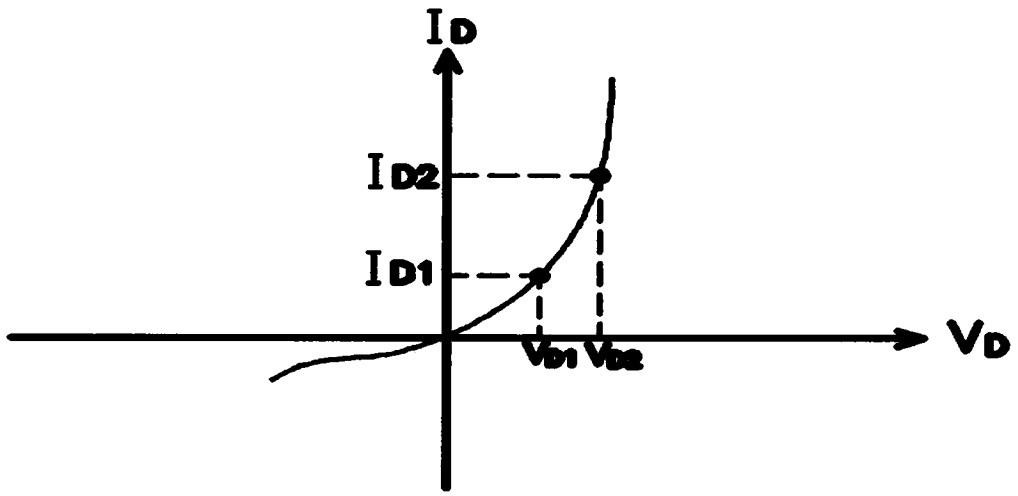
very high diode resistance ⟶ very low currents

① (D-C) resistance (Static resistance)(Rdc)

It is the diode resistance when the applied voltage (VD) on the diode is constant (D-C) voltage.

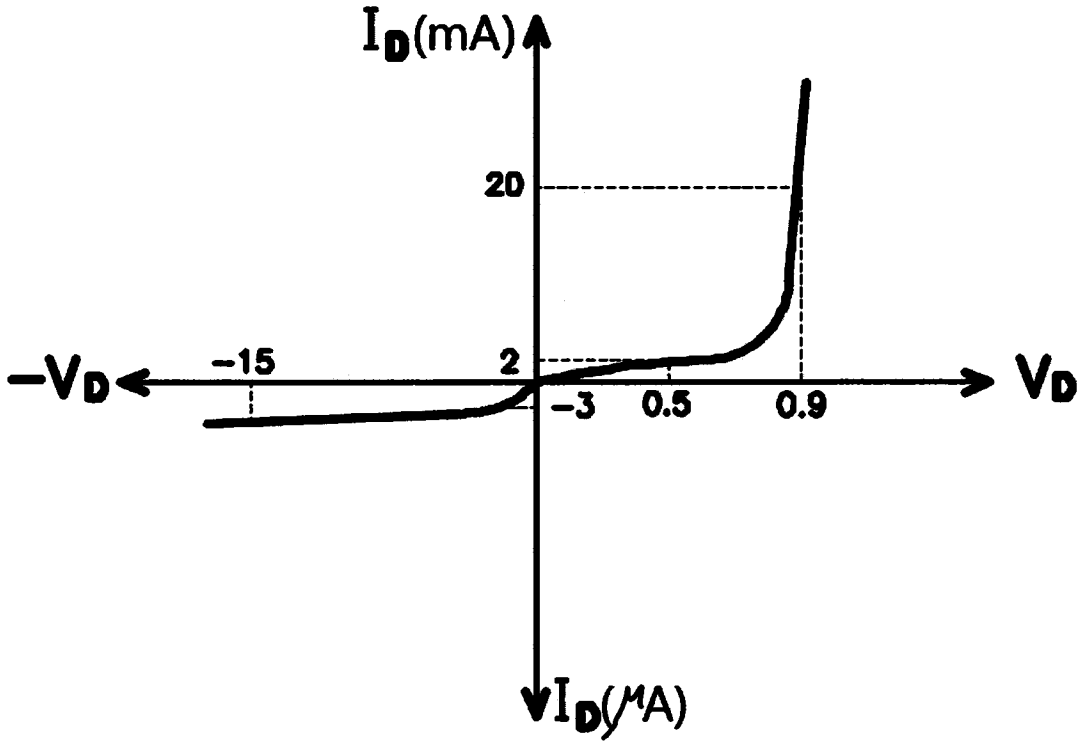


If V2>V1



EX use V-I char. Of Si – diode to calculate its D-C resistance for the following cases

VD = 0.5V b) VD = 0.9V c) VD = -15V .



Solution:

a) When VD = 0.5 V

From fig. ⟶ I_D = 2mA

$$Rdc = \frac{VD}{ID} = \frac{0.5}{2*10^{-3}} = 0.25 *10^3 \Omega = 250\ \Omega$$

b) When VD = 0.9V

ID= 20mA

$$Rdc = \frac{VD}{ID} = \frac{09}{20*10^{-3}} = 45\Omega$$

a) When VD = -15V

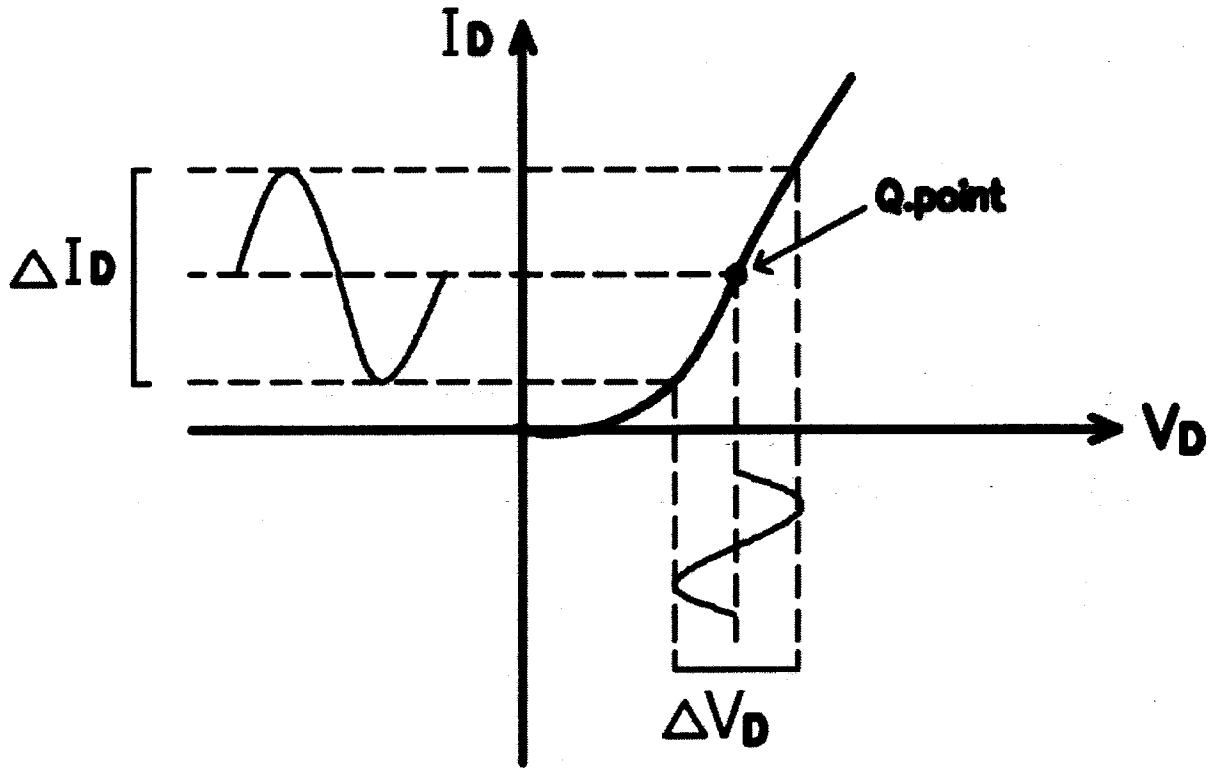
$I_D = -3$ A

$Rdc = \frac{-15}{-3*10^{-6}} = 5*10^6\Omega$

$= 5000000\Omega$ why high?

② (A-C) resistance (Dynamic resistance)(rac)

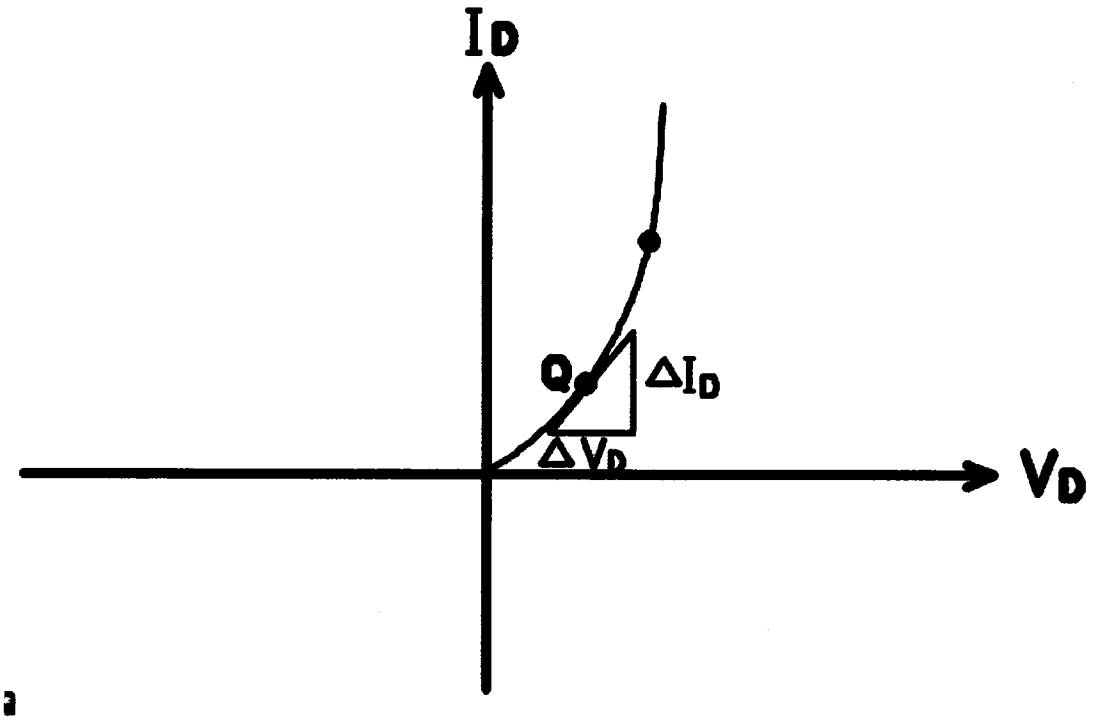
* it is the diode resistance when it is applied to an (A-C) voltage (voltage variation is not large).



* A change in diode voltage (△VD) is associated with a change in diode current (△ ID).

* Q- point : Quiescent – point .

*rac is determined by the inverse of the slope to the V-I curve at Q – point .



a

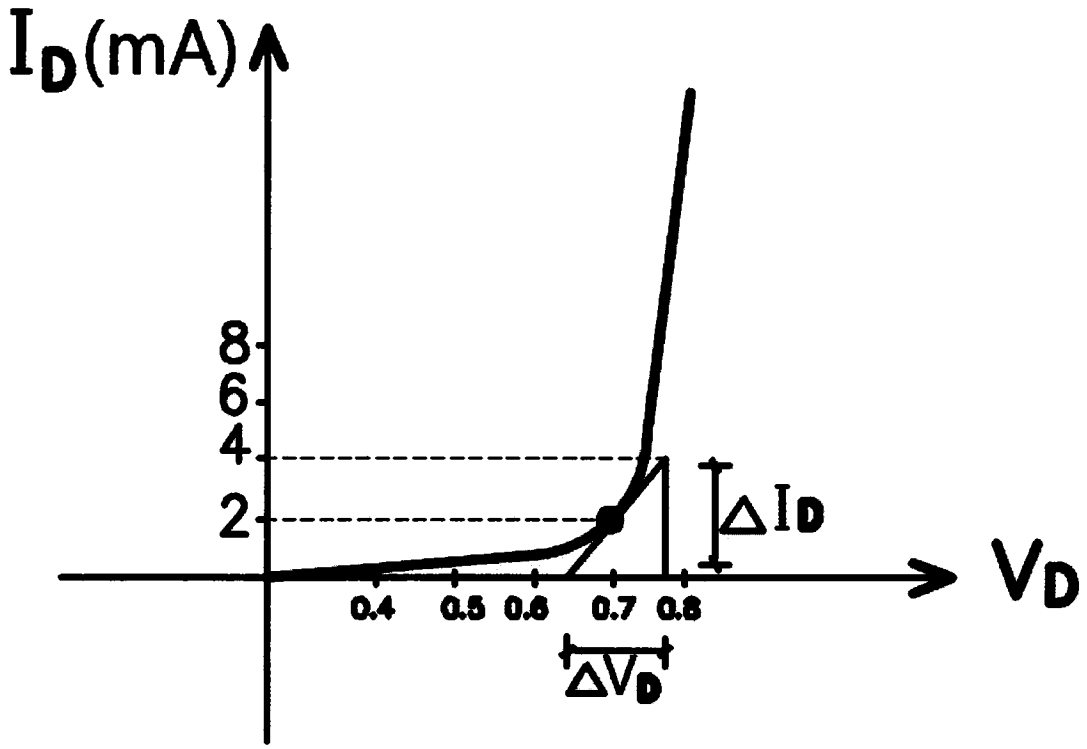
Slope = $\frac{\triangle ID}{\triangle VD}$

rac = $\frac{1}{slope}$

rac = $\frac{\triangle VD}{\triangle ID}$ (ohms low)

{△VD is not large}.

Ex : For the V-I char as shown , find the a-c resistance at I_D = 2 mAmp.



For I_D = 2 mAmp the tangent line at I_D = 2 mAmp was drawn as shown in fig, then draw the triangle as shown :

At I_D =4mA ⟶ VD =0.76 volt.

And I_D =0 mA ⟶ VD = 0.65 volt.

$$r_{ac} = \frac{\Delta VD}{\Delta ID} = \frac{0.76-0.65}{(4-0)X10^{-3}}$$

$$= \frac{0.11}{4\,X\,10^{-3}}$$

=27.5 (ohm)

③ Average Resistance (rav)

* It is the diode resistance when the applied voltage is too large.

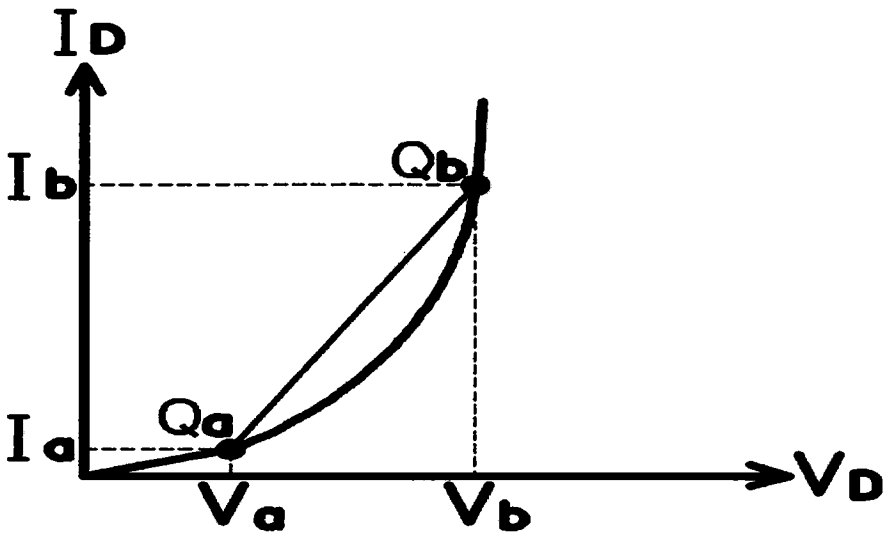
*Here a chord is used instead of the tangent as before.

Also rav $= \frac{1}{slope}$

& slope $= \frac{Ib-Ia}{Vb-Va} = \frac{\Delta ID}{\Delta VD}$.

rav $= \frac{Vb-Va}{Ib-Ia}$

rav $= \frac{\Delta VD}{\Delta ID}$ | point to piont

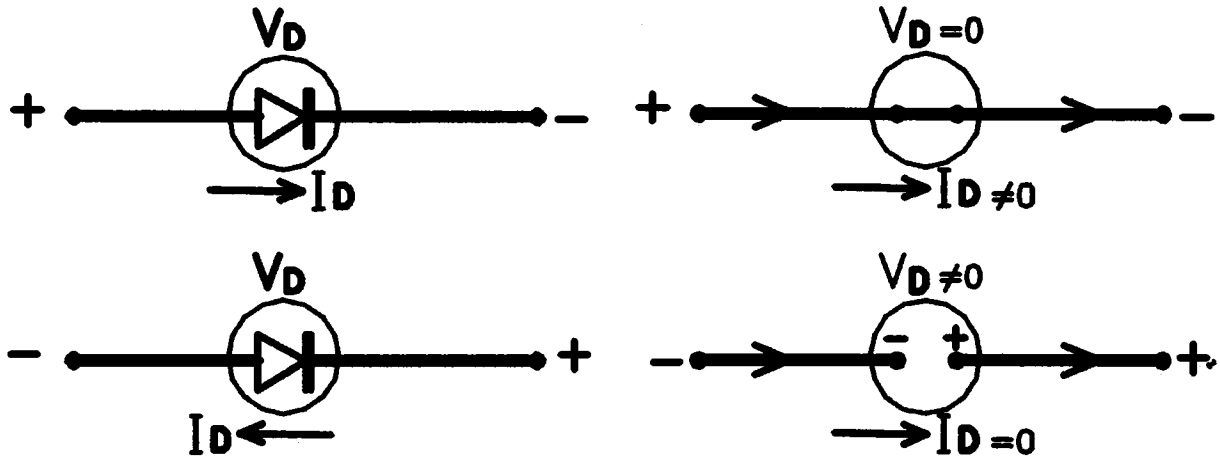


* For all the three type of diode resistance, the resistance is lower for higher voltages and currents.

The Concept of Ideal Diode

* An ideal diodes is a diode that has a **zero** resistance in forward biasing, and very high (in finity) resistance in reverse biasing (also this is not a real diode) .

* The ideal diode is an (Short) circuit in forward biasing and (Open) circuit in reverse biasing as shown:-



Equivalent Circuit For Diode (Diode Models)

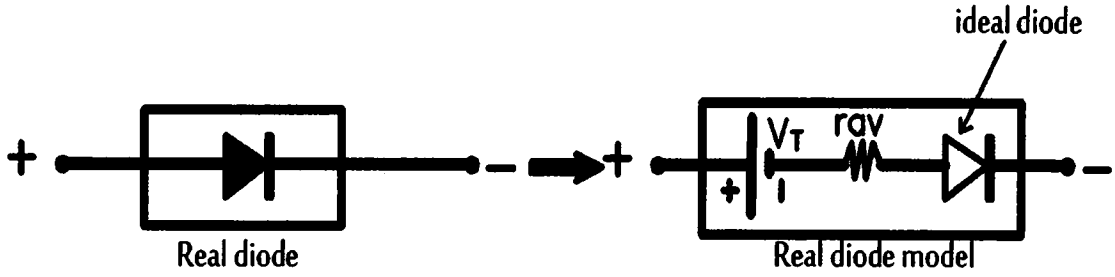
*This is approximate representation of a real diode.

*In general, a real diode is composed of three components:

1- Threshold potential (VT).

2-Diode resistance (usually rav).

3-An ideal diode.



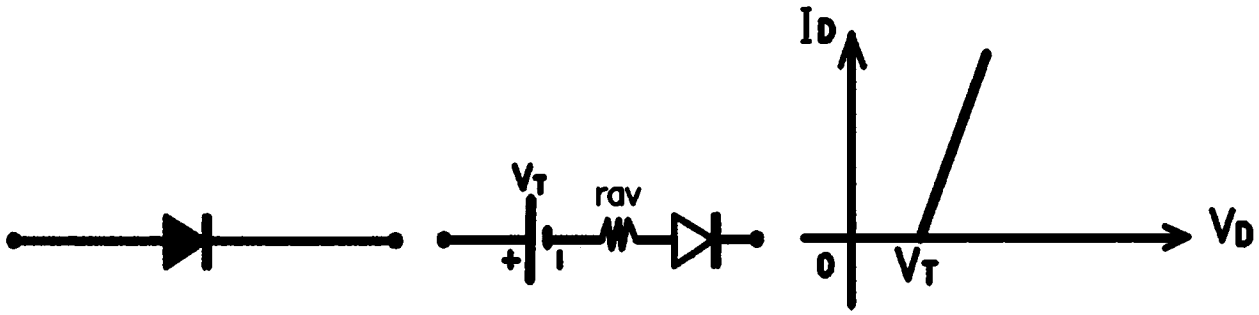
*Important Notes

1-In most networks , rav many be neglected when it is too small compared by other resistance in the network.

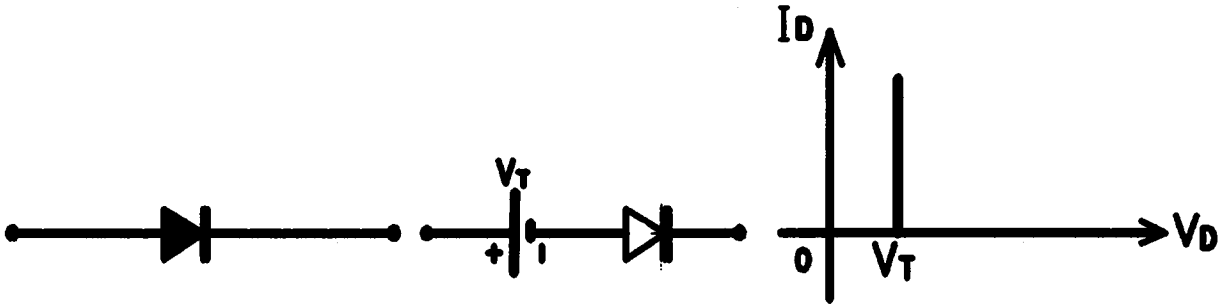
2-In some application , VT may be neglected when it is too small compared with other voltage in the network.

In Summary :

1-Complete:

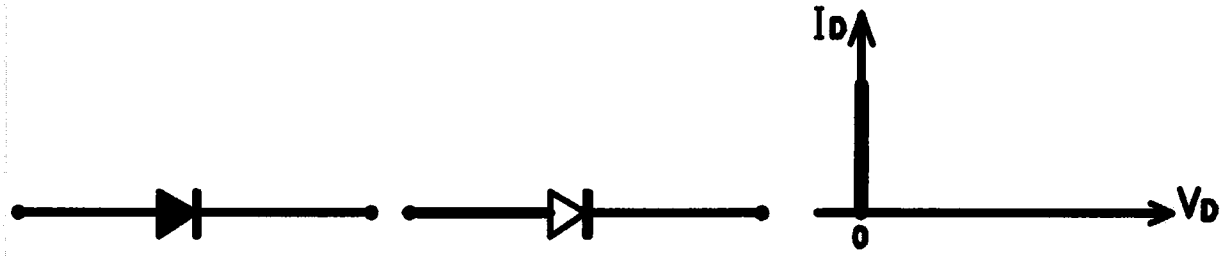


2-R network>> rav

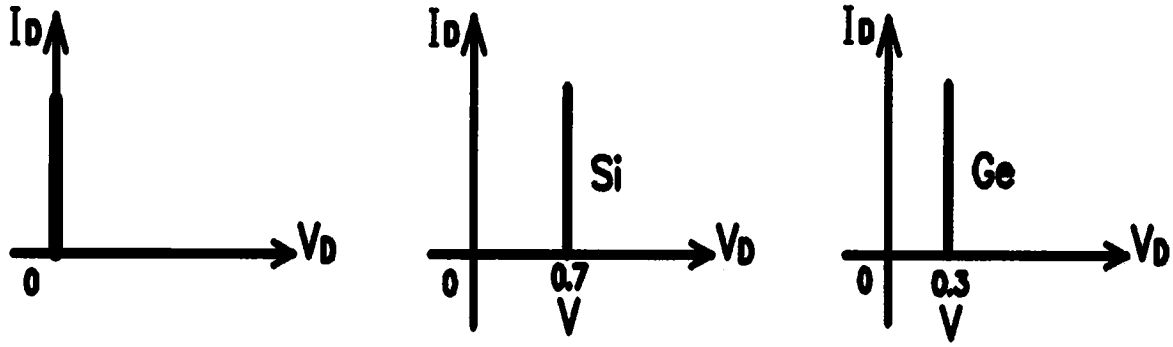


3-R network >>rav

V network >> VT

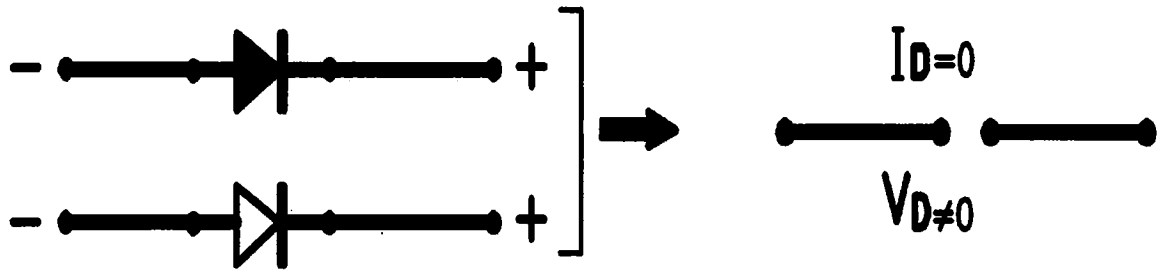


*we shall use the 2nd model for real diode and 3rd model for ideal diodes.



*For diode operation , we have the following cases:

* VD < 0 (Reverse biasing).



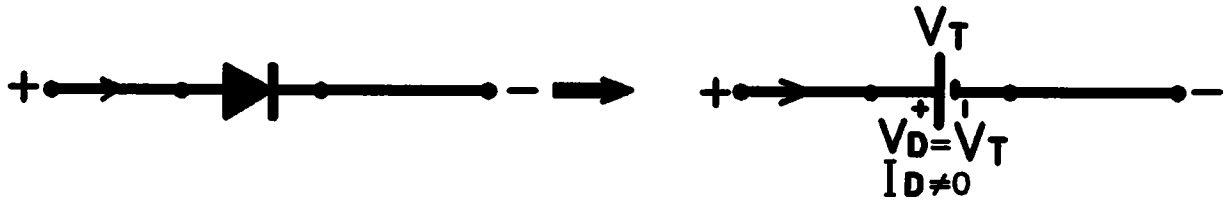
* VD > 0 (Forward biasing).

1-Ideal Diode

2-Real Diode

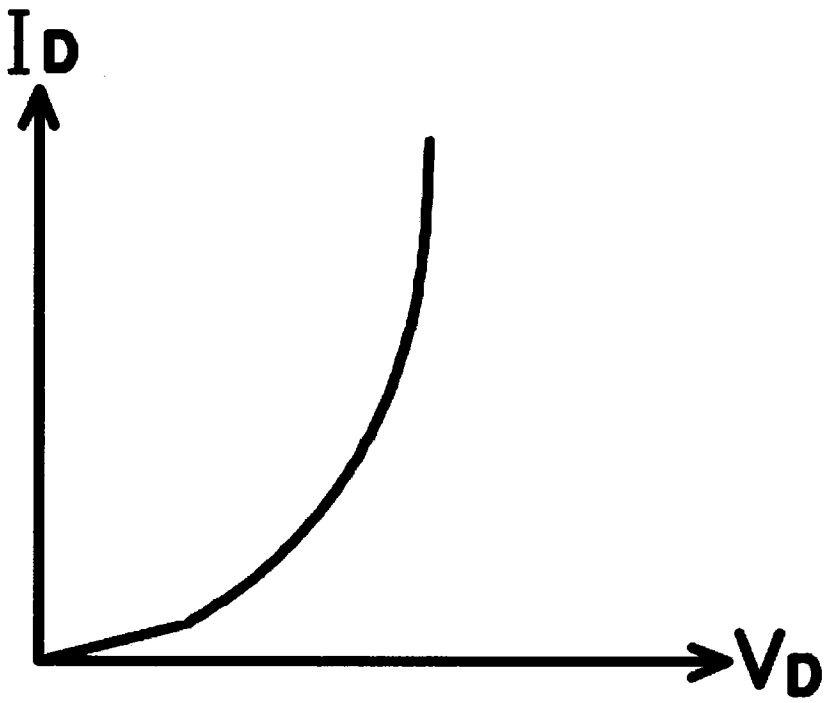
(a) VD<VT

(b) VD>VT

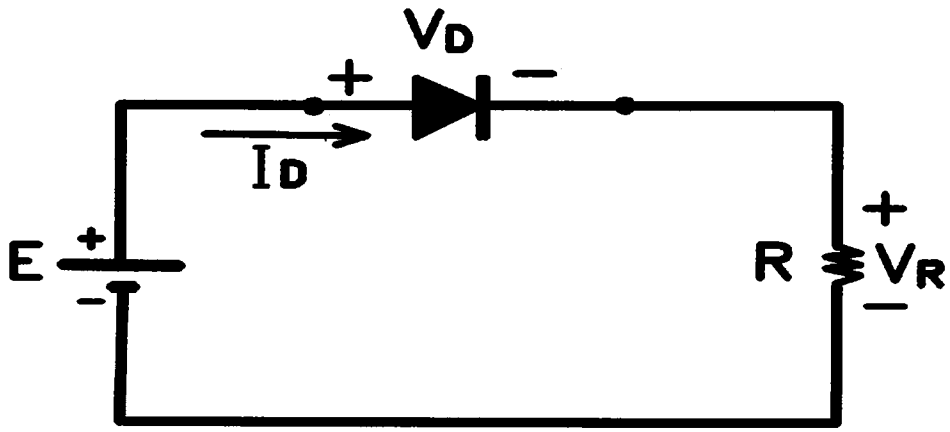


Load Line Analysis

Since the V-I char .is shown as:



And if we take a simple series circuit as shown



from (K.V.L)

$$E=VD+VR$$

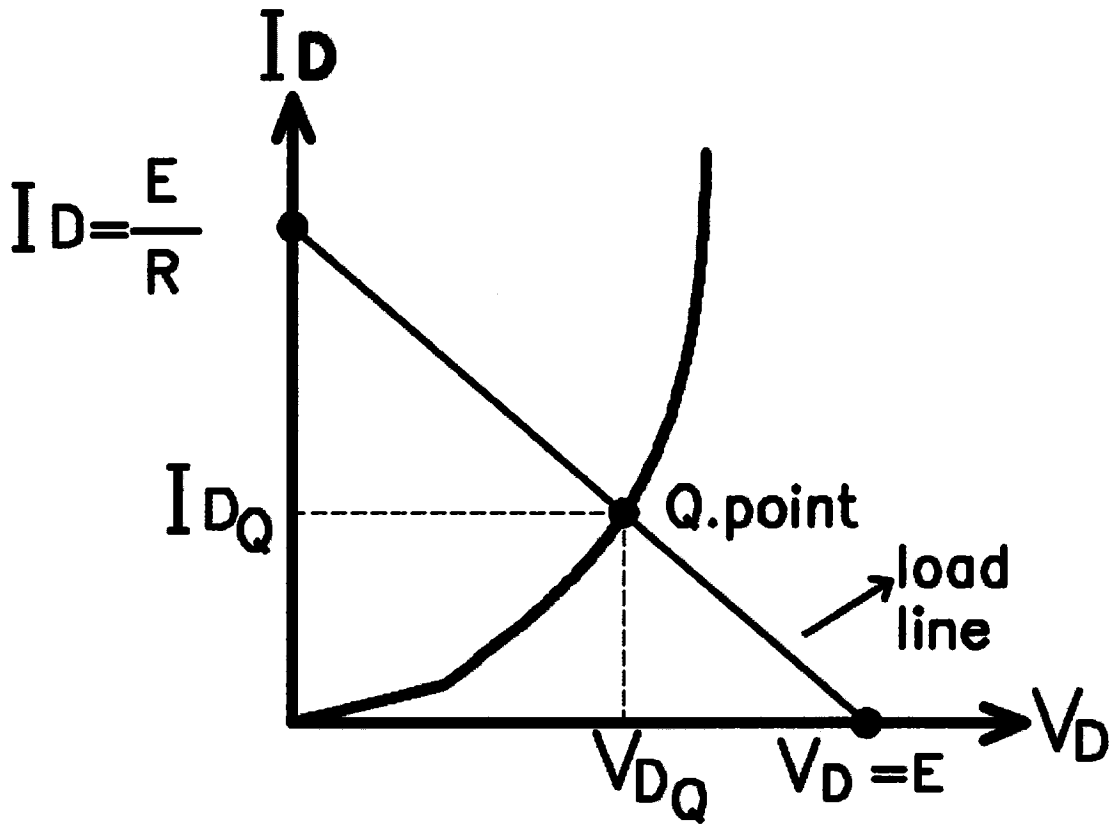
$$=VD+ID*R$$

From this equation.

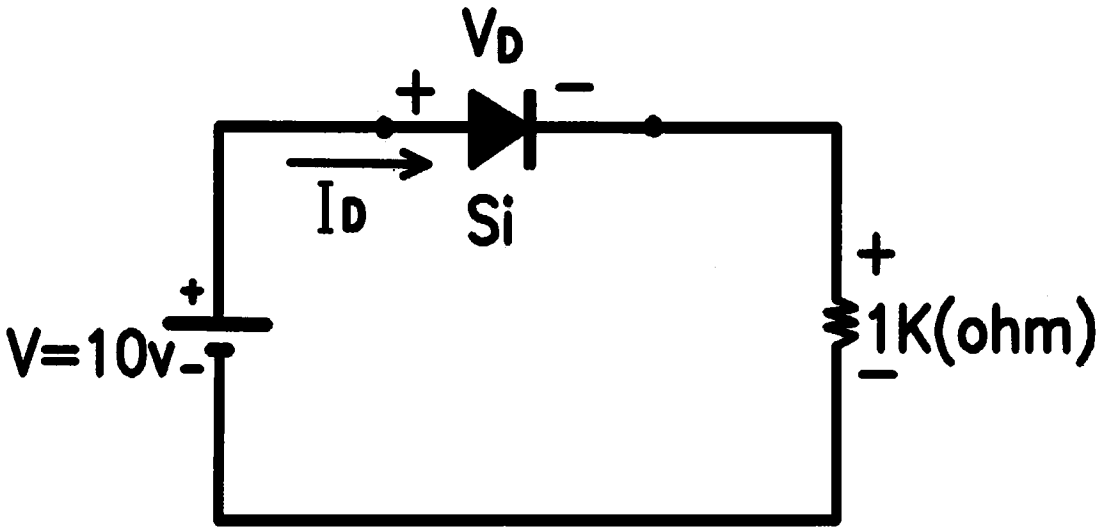
$$ID=\frac{E}{R}\Big|_{VD=0}$$

$$\text{And } VD=E\Big|_{ID=0}$$

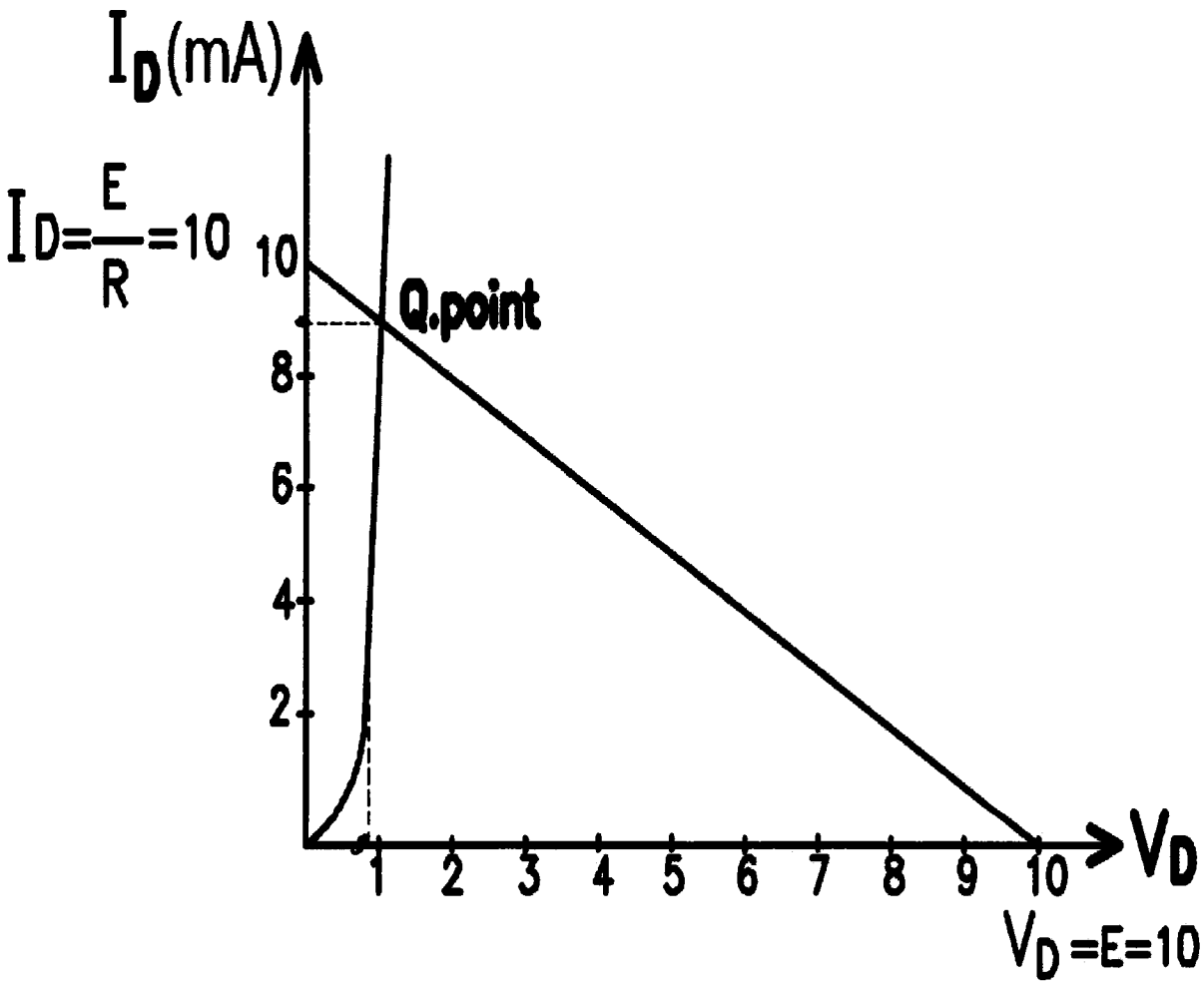
Then load line can be drawn as shown.



Ex : For a series diode configuration as shown find VDQ ,IDQ , VR.



Solution :



$$ID = \frac{E}{R}\Big|_{VD=0}$$

$$= \frac{10V}{1 * 10^3} = 10\text{mA}.$$

And $VD = E\Big|_{ID=0}$

$= 10$ volt .

From these result we can draw the load line as shown above.

From the fig :

a) $VD_Q \cong 0.78$ volt.

$ID_Q \cong 9.25\ mA$.

b) $VR = IR \times R = ID \times R = 9.25 \times 10^{-3} \times 1 \times 10^3 = 9.25v$.

OR

$VR = E - VD = 10 - 0.78 = 9.22$ volt.

AND/OR Gates

* These basic networks represent a computer logic circuits.

* In computer, the digitals (0) and (1) are used.

* usually (0) represented the (off) state , and (1) represent the (ON) state.

* In these gates, there are input and output terminal (for input and output voltage) , here we consider only two input terminals and one output terminal.

OR Gate

There is an output voltage if there is an input voltage on either input terminal or on both of then.

If there is no input on both terminals , there will be no output .

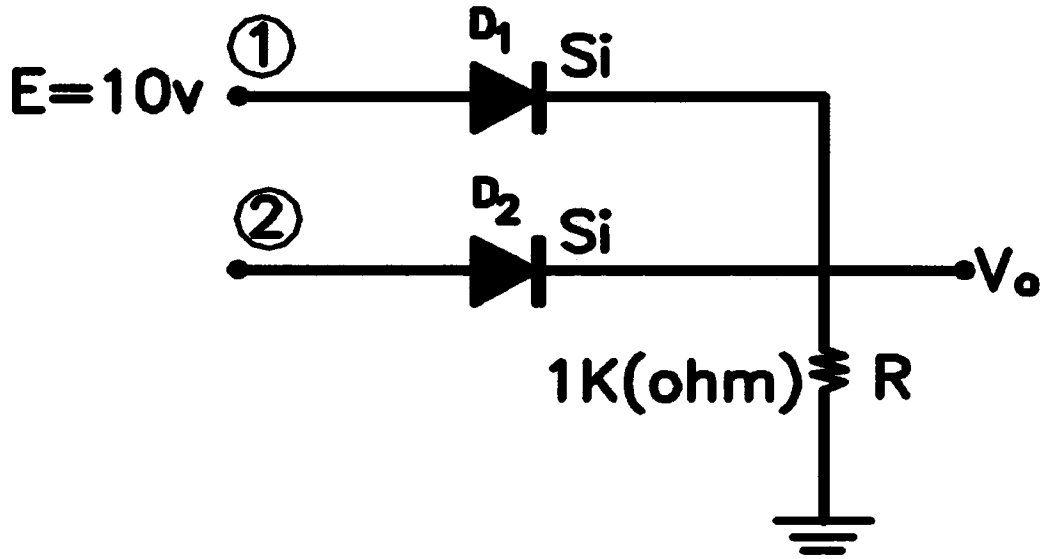
AND Gate

The output is (on) when both input terminals have input voltage ,if one (or both) of the input terminals has no input voltage , then there will be no output.

Note:

In some cases ,small output voltage are considered as (0) or (off) state

EX : (OR) .. for the circuit shown

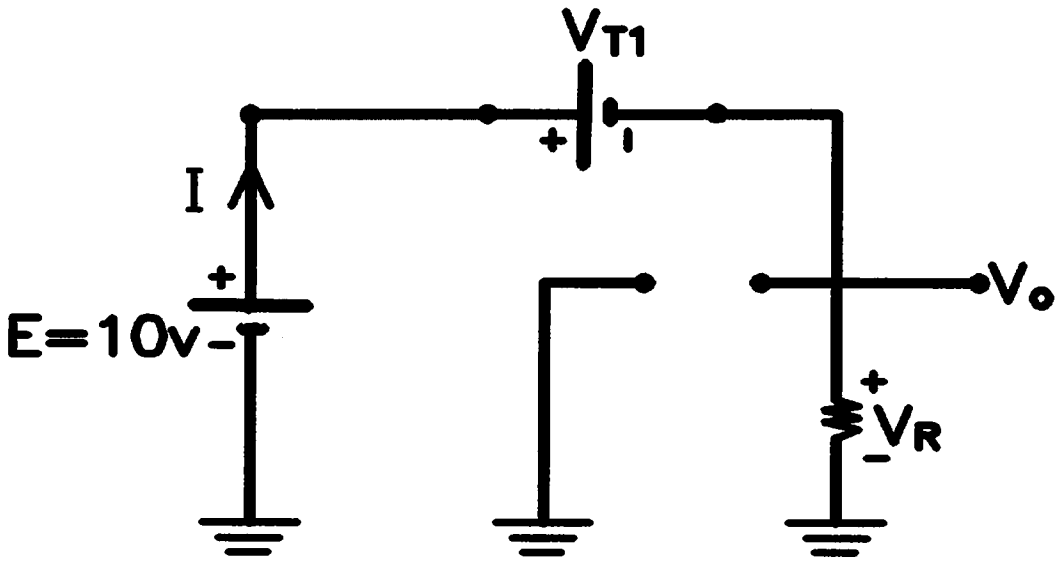


* there is an input voltage on terminal (1) ➡ 10 volt

*Terminal (2) has zero input , so it is at (ground) potential

** D1 will be in the (on) state , while D2 in the (off) state.

The equivalent network is



Vo = VR

And (K.V.L)

$E = V_{T1} + V_R$

$V_R = E - V_{T1}$

$V_R = 10 - 0.7 = 9.3$ volt

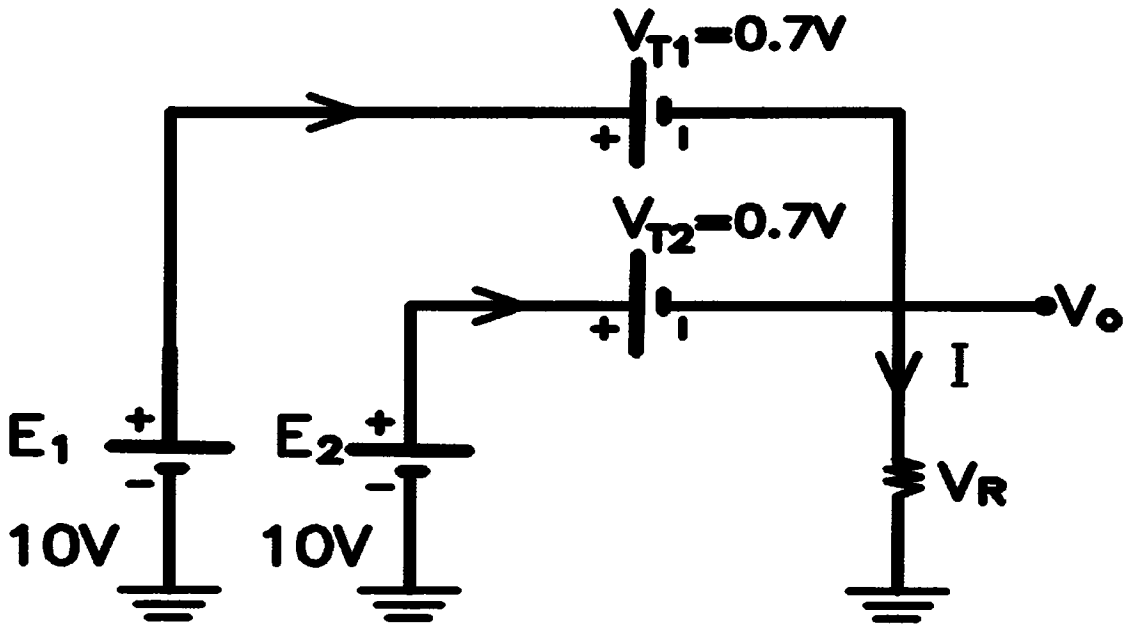
∴ Vo=9.3 volt {(on) or (1) state}

And to find the current through R

$$I = \frac{V_R}{R} = \frac{9.3}{10^3} = 9.3 * 10^{-3} = 9.3\ mA$$

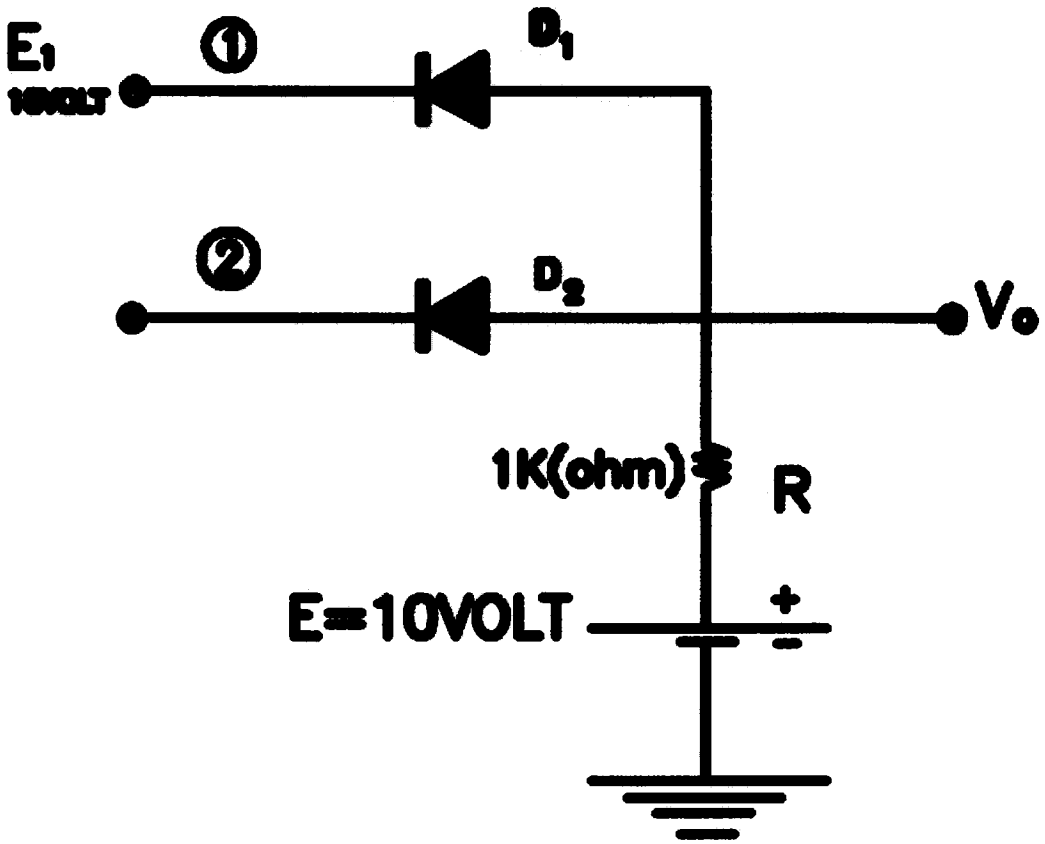
** if the input voltage (10v) applied on terminal (2) then D1 will be in the (off) state and D2 in the (ON) state , so will have the same output voltage and current (same results)

** if input voltages were applied on both terminals we shall also have the same result. (D1 & D2) are in the (ON) state.



Note: the same voltage (9.3v) will be applied on (R) since the two input terminals are parallel

EX: AND



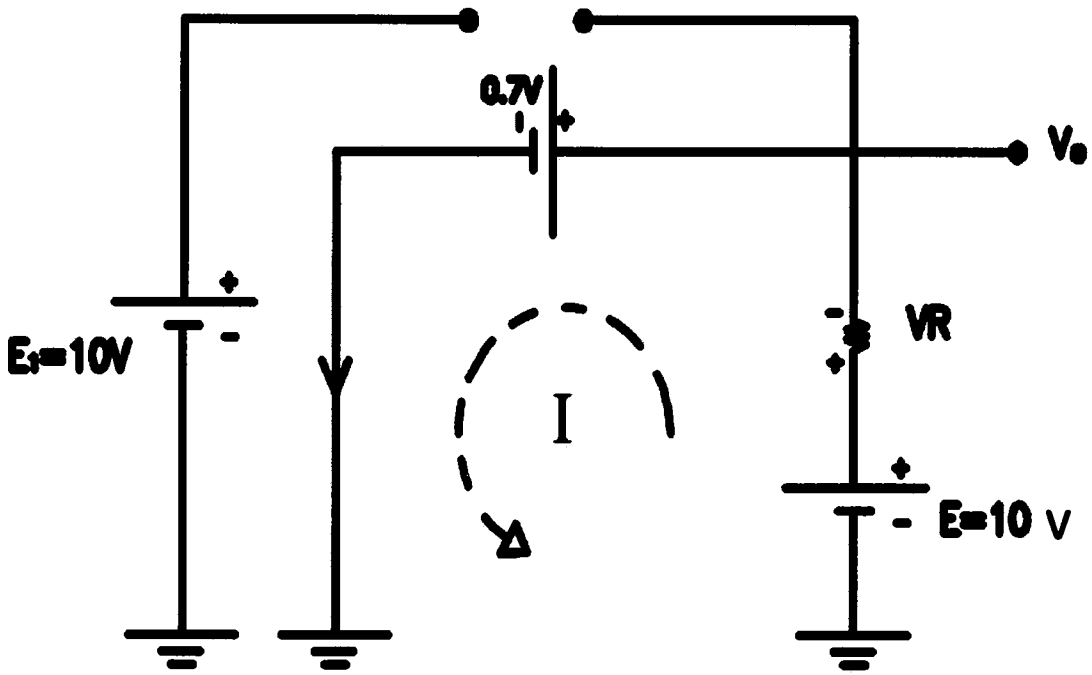
* Here there is a voltage source in this network.

* If input voltage is applied on terminal (1) only, D_1 will be in (off) state and D_2 in (ON) state.

– D_1 is off because there is no voltage difference between its anode and cathode , it mean (p _ and N . potential are equal) .

– D_2 is (ON) due to the voltage source in the network.

So the equivalent network is:



To find (V_0):

$V_0 = V_{T2}$ = 0.7 V (par allel).

OR

Take (KVL):

E = 10 V = $V_R + V_{T2}$

$\therefore$ $V_R = 10 - V_{T2} = 10 - 0.7 = 9.3$ volt.

But E = $V_R + V_0$.

V_0 = E - V_R = 10 – 9.3 = 0.7 volt (same result).

** This output voltage (V_0 = 0.7 v) is considered as a small value and represents the (0) state.

** The same result is obtained if the input voltage in applied on terminal (2) only, in this case (D_2) will be (off) and (D_1) will be (ON).

** But if the input voltages are applied on both input terminals, then D_1 & D_2 will be in the (off) state, and the current through resistance (R) will be zero (I =0).

Since I = 0 $\rightarrow$ V_R=0.

Applying (KLV) on the output loop :

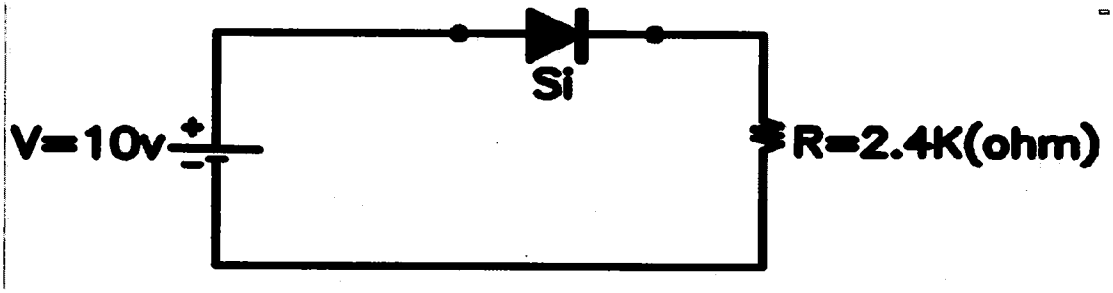
E = 10 = V_R + V_0

V_0 = E = 10 volt

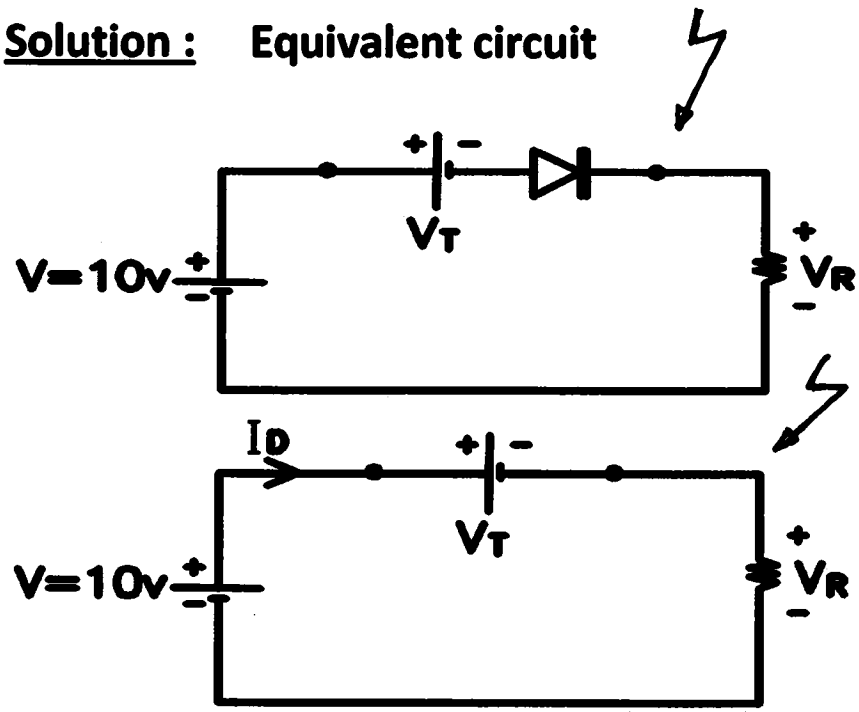
Which is considered to be the ((1)) state.

D-C voltage Diode Applications

EX 1:- For the circuit shown , find V_D ,V_R and I_D



Solution : Equivalent circuit



We have Vd = V_T= 0.7 volt

By using Kirchhoff voltage method (KVL)

$$V=VT+VR$$

∴ VR = V-VT = 10-0.7 = 9.3 volt

$$\text{But} \quad ID = IR = \frac{VR}{R}$$

$= \frac{9.3}{2.4x10^3} =$ 3.875mA = 3.875x 10^{-3} Amp

Note: if the diode is reversed find (VD, VR , ID)

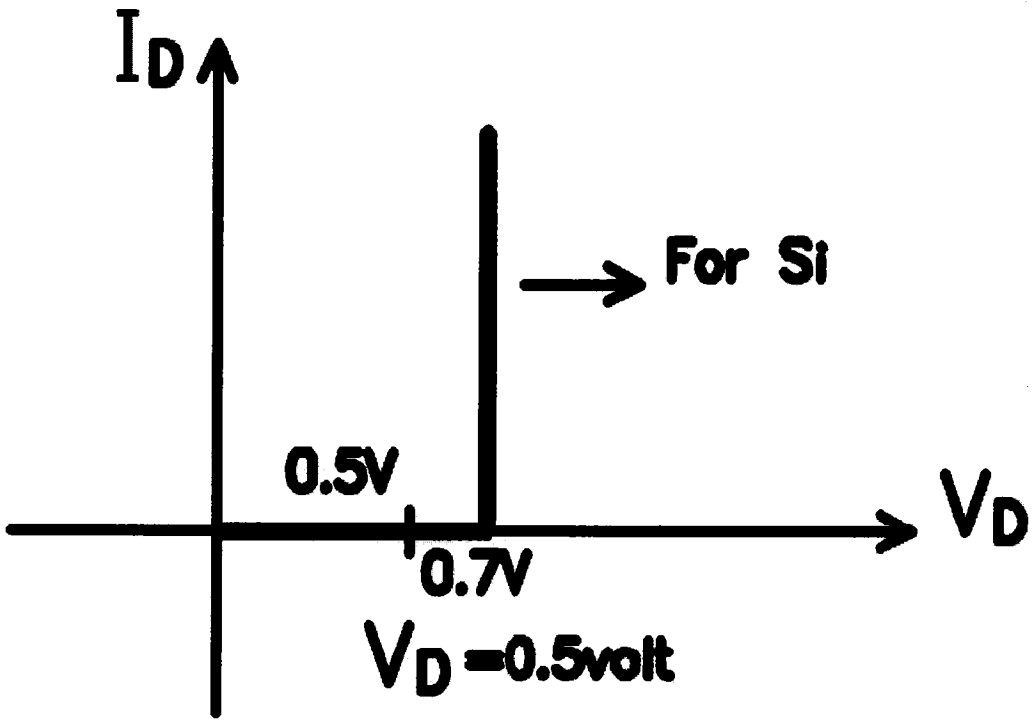
VD = 10 V , VR=0 , ID = 0 (Why)

EX2: for the same circuit of (EX1) ,if V=0.5vol

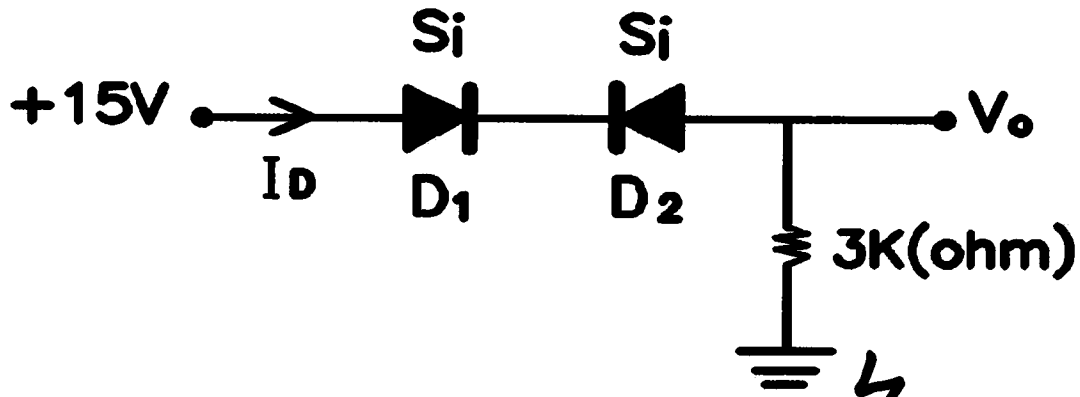
find V_D ,V_R and I_D ?

Solution ID = 0 , VR =0 , VD= V = 0.5 volt

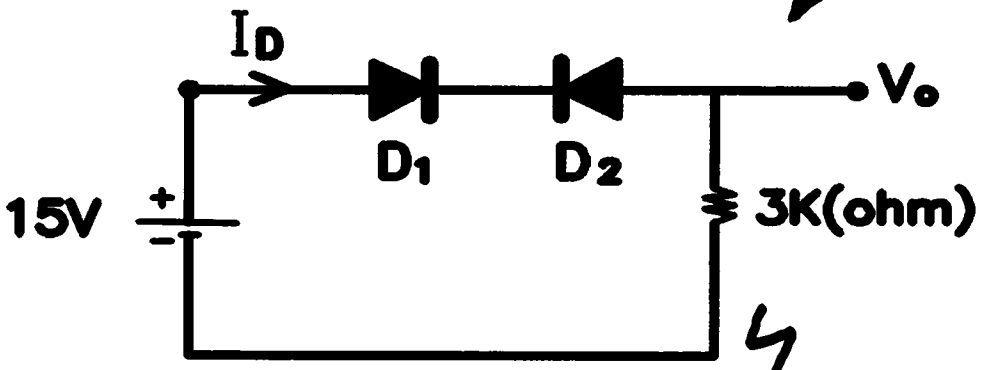
(because the level of applied voltage is in sufficient to turn silicon diode (ON) , the point of operation on the characteristic is shown below ,establishing the (open) circuit equivalent as appropriate approximation)

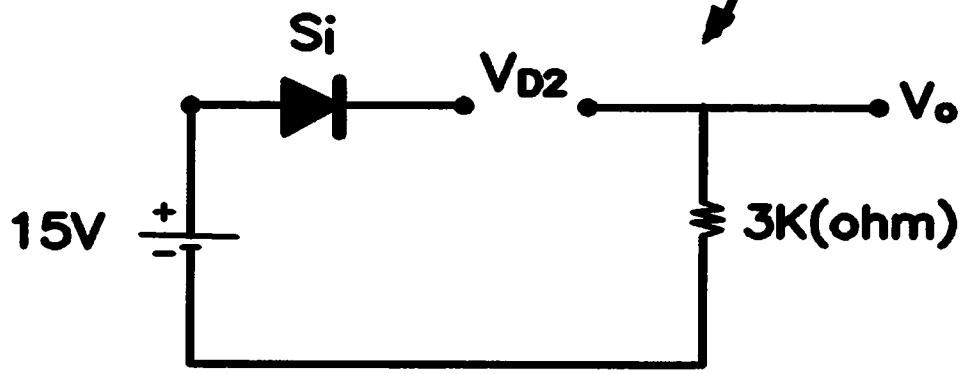


EX3: for the circuit shown , find V_O, I_D V_{D2}



Solution:





ID = 0 (open circuit)

$v_o = I \times 3\ k\Omega = 0$ volt

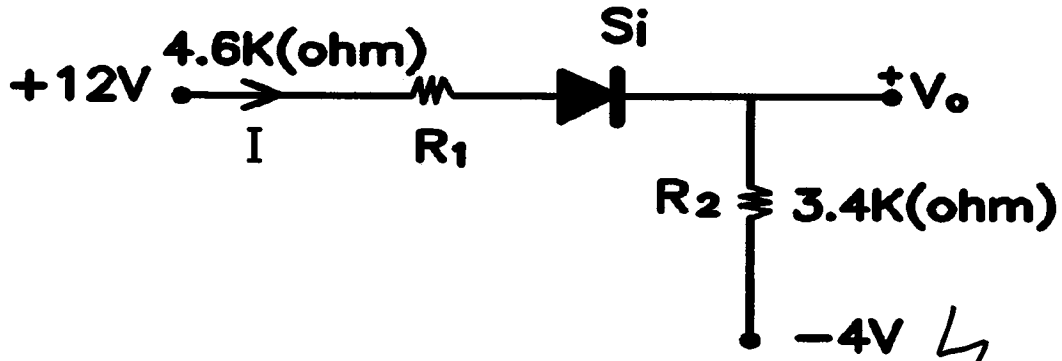
v_{D2} = 15 volt = voltage supply

OR : By using (KVL)

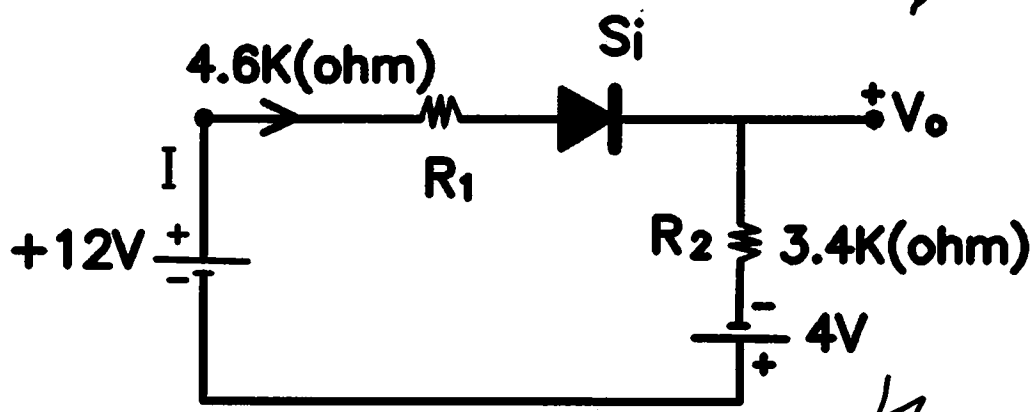
$V = 15 = V_{D1} + V_{D2} + V_R$

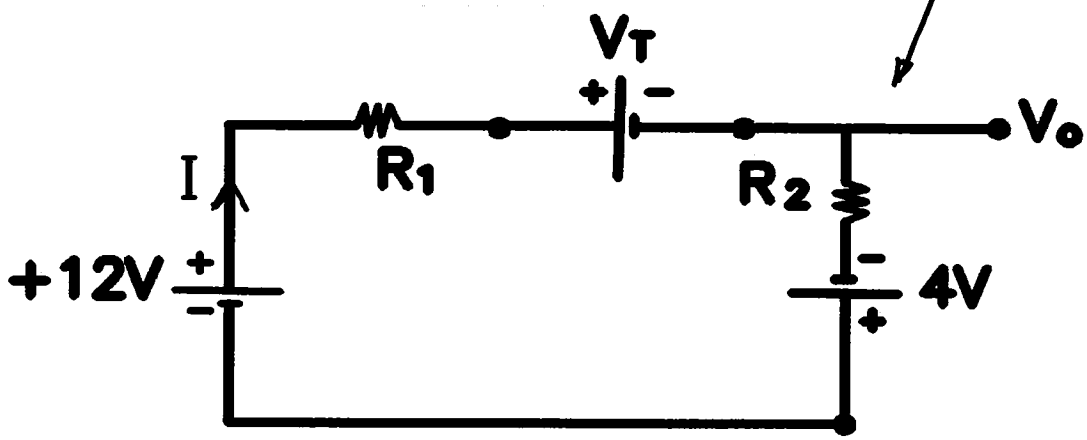
$15 = 0 + V_{D2} + 0$

EX 4: For the circuit shown , find I,V1,V2 and V_o



Solution :





$V_T = V_D = 0.7 Volt$

By (KVL) :

$12+4 = V_1 + V_2 + V_T$

$\therefore \quad 15.3 = V_1 + V_2$

$15.3 = I\,(R_1 + R_2)$

$$I = \frac{15.3}{R1+R2} = \frac{15.3}{(4.6+3.4)x10^3} = 1.912\text{mA}$$

$V_1 = 1.912 \times 10^{-3} \times 4.6 \times 10^3$

$= 8.797$ volt

$V_2 = 1.912 \times 10^{-3} \times 3.4 \times 10^3 = 6.5$ volt

By (KVL)

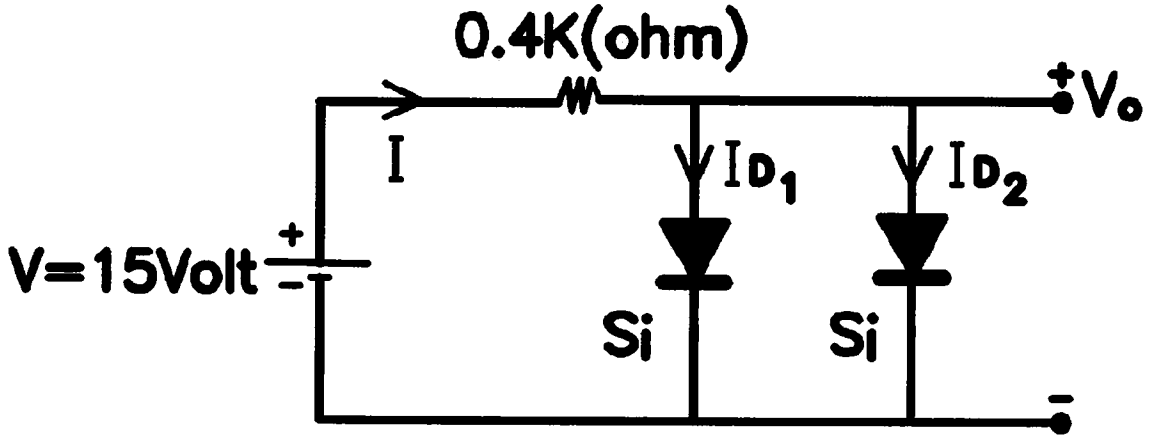
$12 = V_1 + V_T + V_O$

$V_O = 12 - 8.797 - 0.7 = 2.5$ Volt

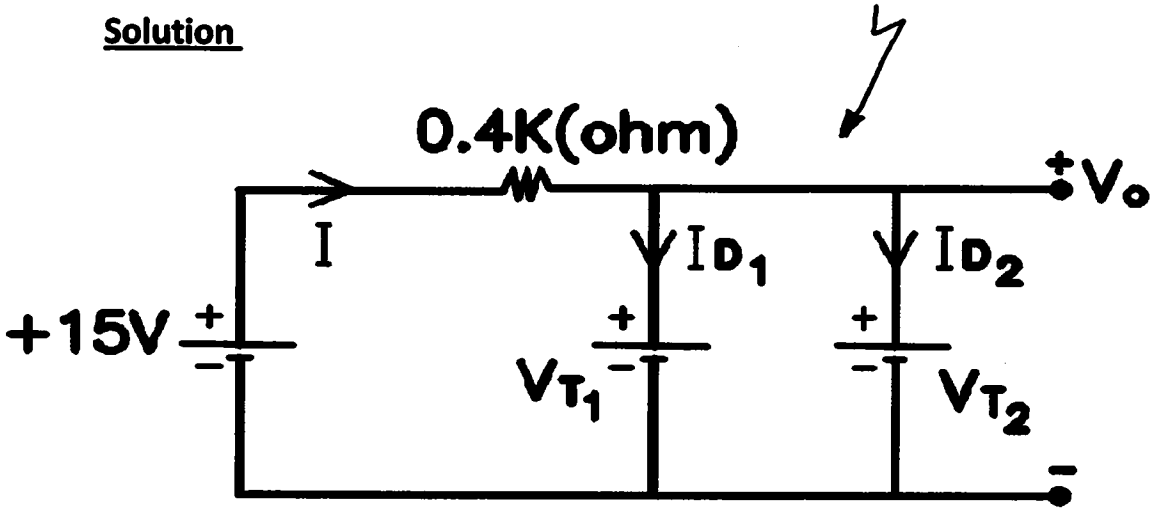
OR

$V_O = V_2 - 4 = 6.5 - 4 = 2.5$ Volt

EX 5: Find v_o, I ,I_{D1} , I_{D2} for the circuit shown ?



Solution



$V_T = V_{T2} = V_O$ = 0.7 Volt (parallel)

By using (KVL)

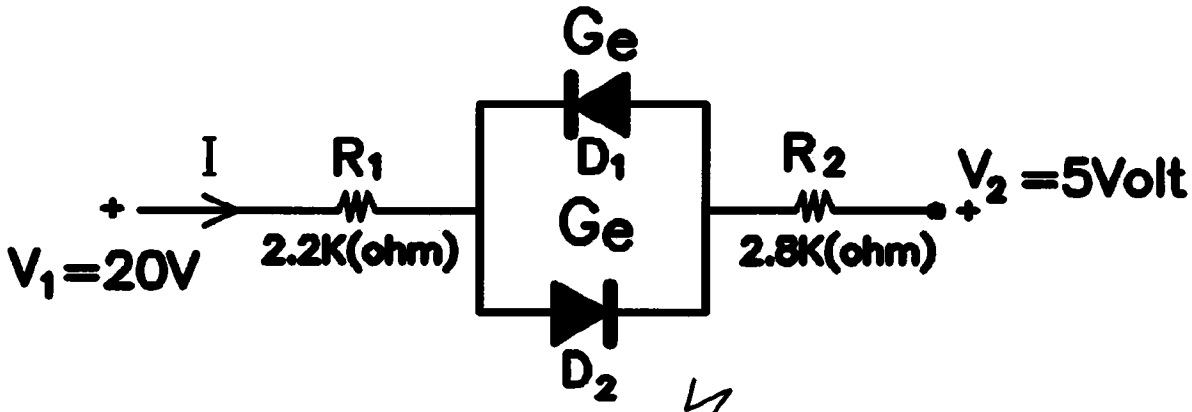
$15 = I \times 0.4 \times 10^3 + 0.7$

$14.3 = I \times 0.4 \times 10^3$

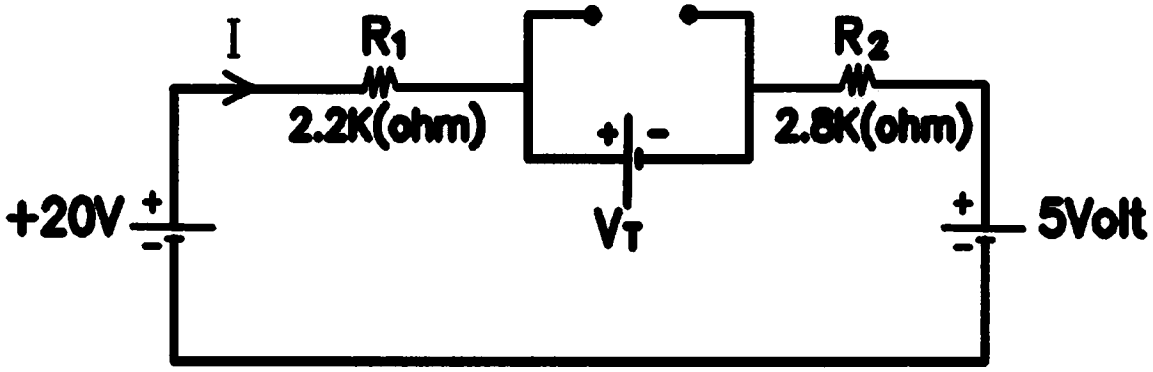
$\therefore \quad I = \frac{14.3}{0.4 \times 10^3} = 35.75$ mA

$I_{D1} = I_{D2} = \frac{I}{2} = 17.875$ mA

EX 6 : Find the current (I) for the circuit shown ?



Solution



(D1) become (open – circuit) (why)

By using (KVL)

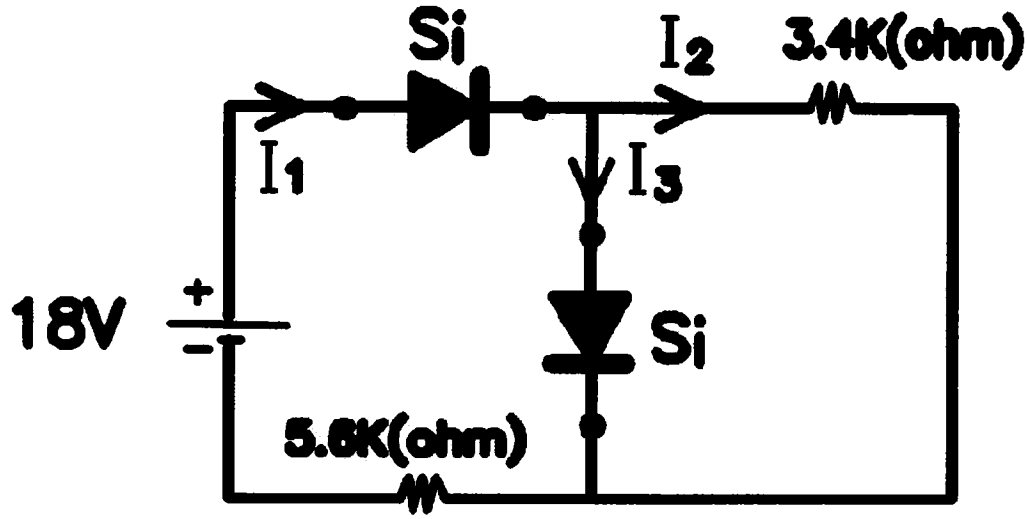
$20 = 5 + 2.2 \times 10^3 \times I + 2.8 \times 10^3 \times I + V_T$

But $V_T = V_D = 0.3$ v (for Ge).

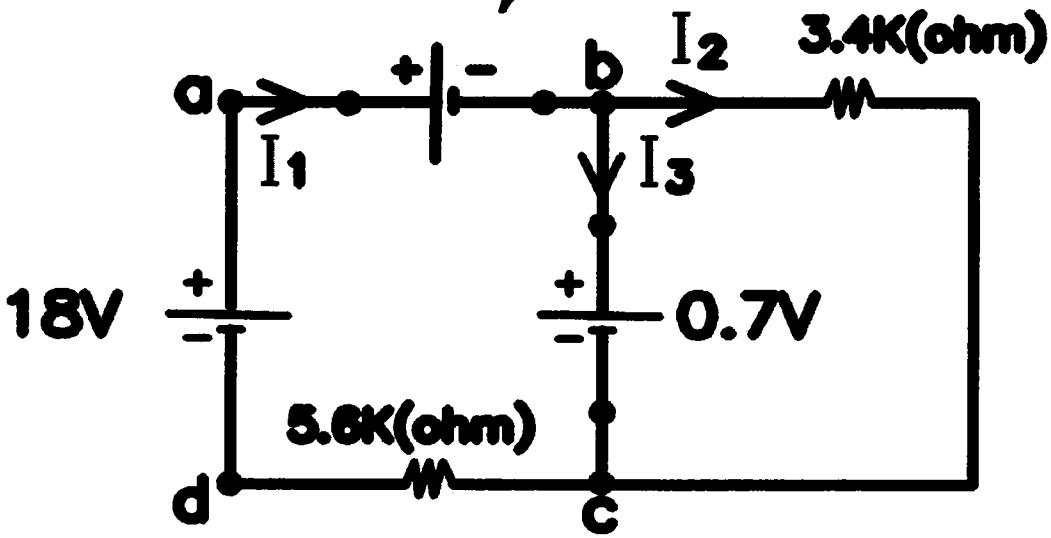
$14.7 = I(5 \times 10^3)$

$\therefore \quad I = \frac{14.7}{5x10^3} = 2.94$m Amp

EX 7 : Find the current I_1 , I_2 and I_3 for the circuit shown ?



Solution



$$I_2 = \frac{0.7}{3.4x\ 10^3} = 0.205 \text{ mA}$$

Use (KVL) for the circuit (ABCD)

$$18 = 0.7 + 0.7 + I_1 x\ 5.6x\ 10^3$$

$I_1 = \frac{16.6}{5.6 * 10^3}$ = 2.964 mA

But $I_1 = I_2 + I_3$ (K.C.L)

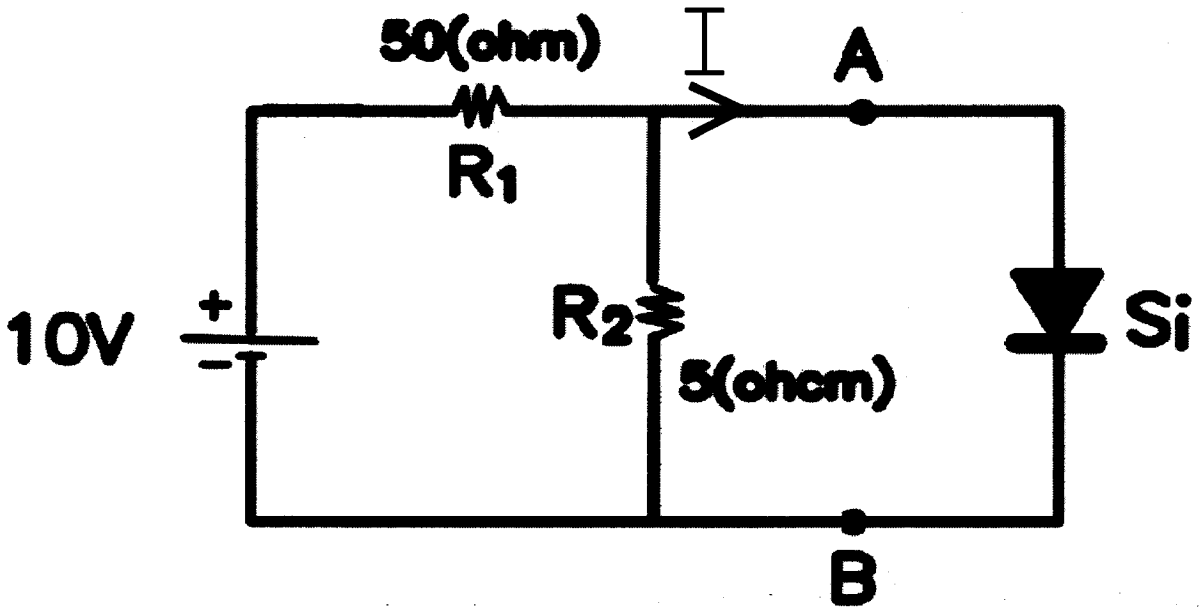
$I_3 = I_1 - I_2$

= 2.964 – 0.205 = 2.759 mAmp

Check if the voltage supply (18v) is reversed find (I_1 , I_2 and I_3)

$I_1 = I_2 = I_3 = 0$ (why)

Ex 8: Find the current (I) for the circuit ?



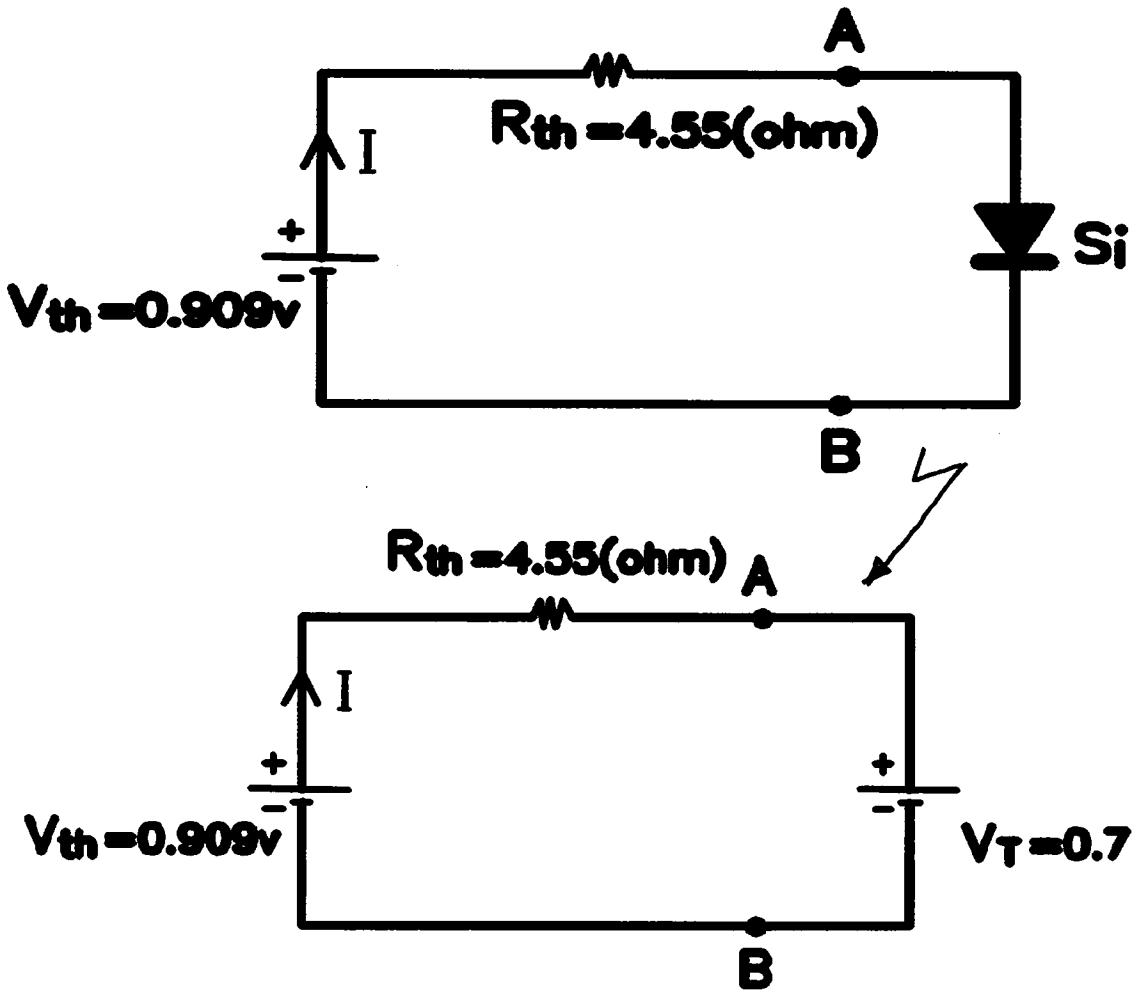
Solution use the thevenin theorem to find (R_{th} , V_{th}) across the point A & B

$R_{th} = R_1 // R_2 = \frac{R_1 x R_2}{R_1 + R_2} = \frac{50x5}{50+5}$ = 4.55 Ω

V_{th} = the voltage across A&B with diode removed

$= \frac{10}{50+5} * 5 = 0.909$ volt

The circuit becomes

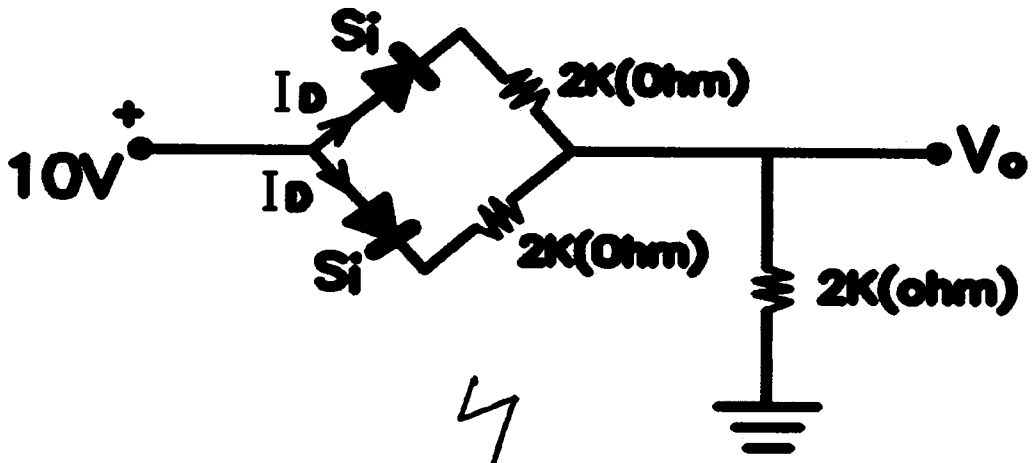


$\therefore \quad I = \frac{0.909-0.7}{4055} = 0.0459$ Amp

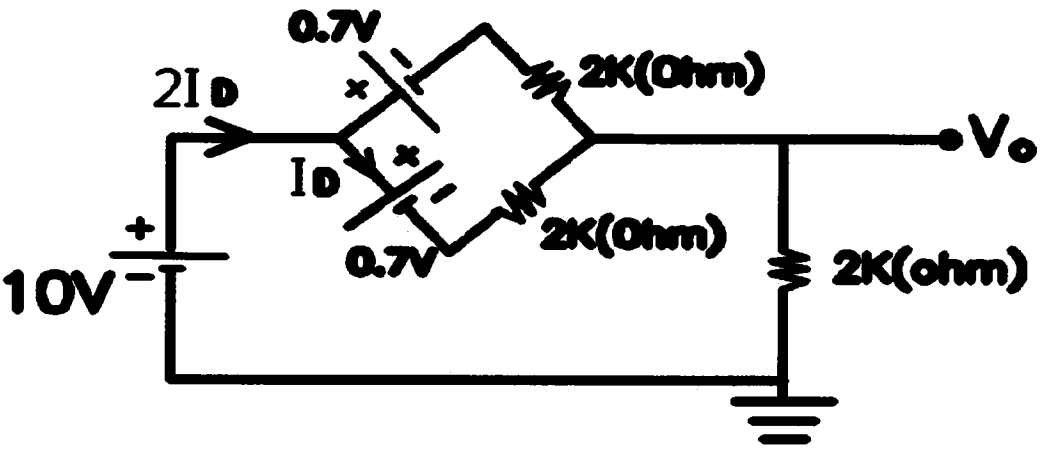
<u>Note</u> if the diode replaced by ideal diode , find the current .

I = 0.2 Amp (how) ?

Ex 9: For the circuit shown find v_o and I_D ?



Solution :



By using (KVL) :-

$10 = 0.7 + 2I_D + 2X2\ I_D$

$9.3 = 6I_D$

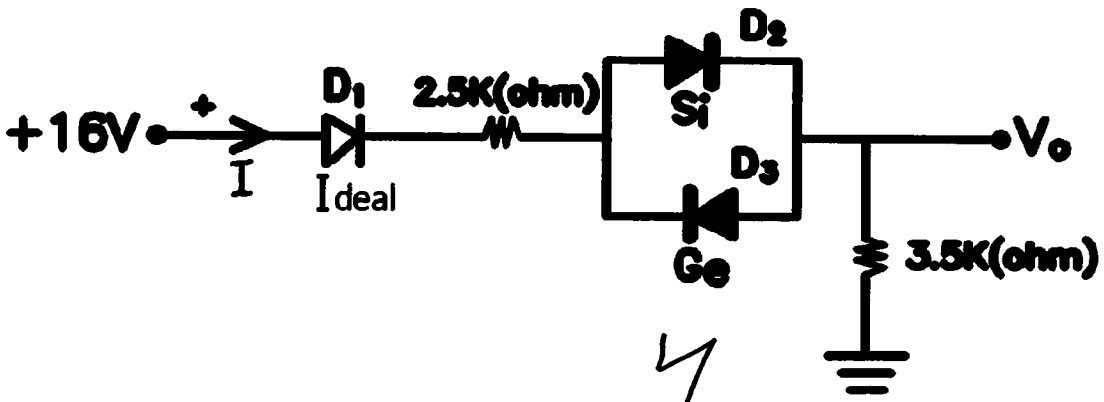
$\therefore \quad I_D = \frac{9.3}{6} = 1.55$ mAmp

And

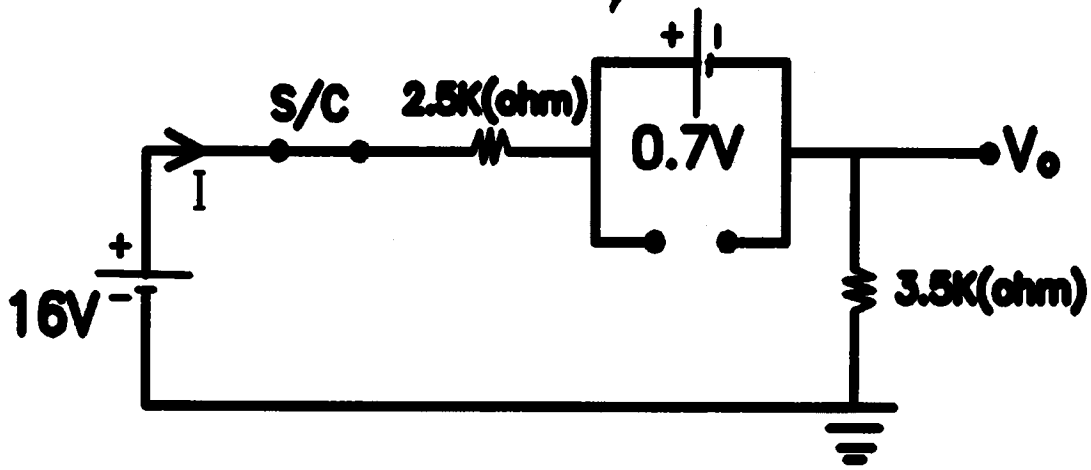
$v_o = 2I_D \text{ X } 2 \text{ X} 10^3$

$= 6.2$ volt

EX 10: For the circuit shown , find I, V_{D2}, V_{D3} & V_O ?



Solution



By (KVL) :-

$16 = 0.7 + I(2.5 + 3.5) \times 10^3$

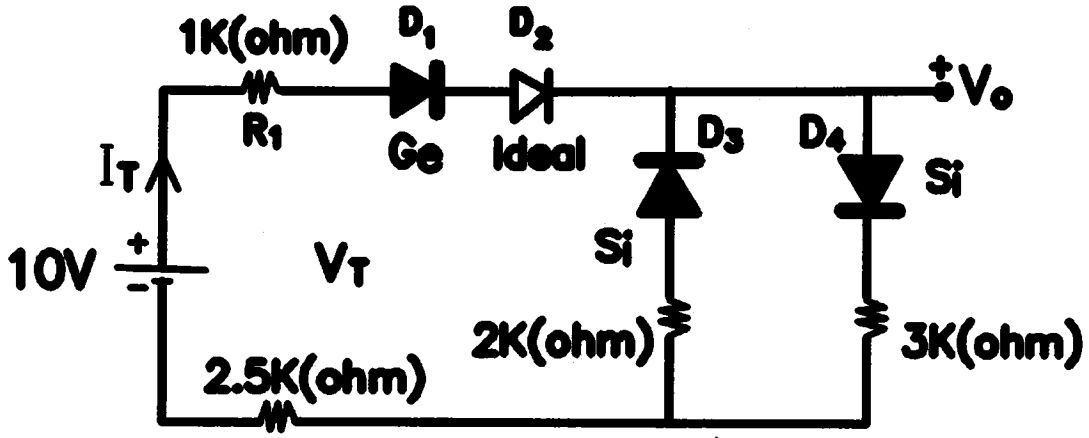
$\therefore \quad I = \frac{15.3}{6X10^3} = 2.55$ mA

$\therefore \quad V_o = I \times 3.5 \times 10^3 = 2.55 \times 10^{-3} \times 3.5 \times 10^3 = 8.925$ volt

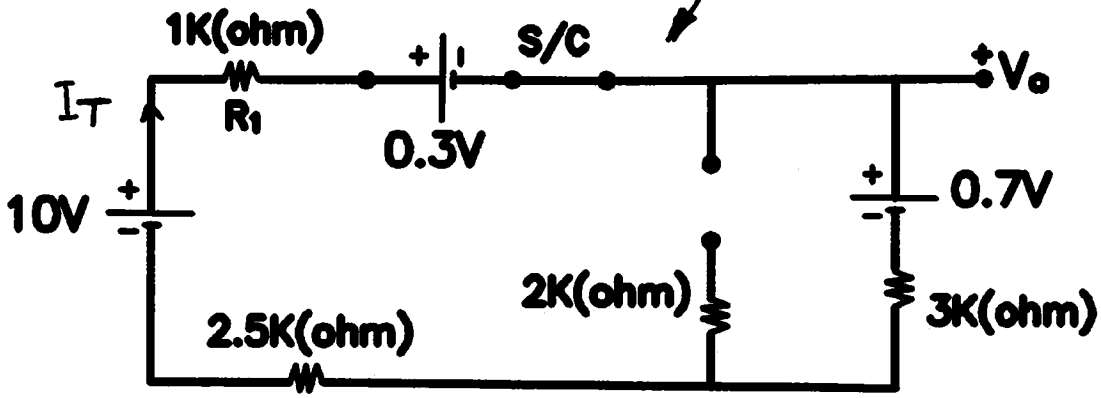
$V_{D2} = V_{D3} = 0.7$ volt (parallel)

Note: if the voltage supply is reversed find I, V_o ?

Ex 11: For the circuit find I_T , V_{R1} , and V_o ?



Solution :



By using (KVL) :-

$10 = I_T (1+3+2.5) +0.3+0.7$

$9 = 6.5 I_T$

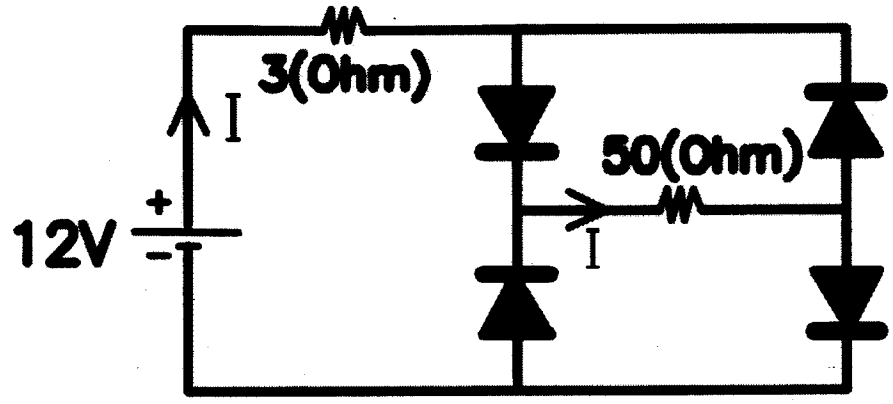
$\therefore \quad I_T = \frac{9}{6.5} = 1.384$ mAmp

And

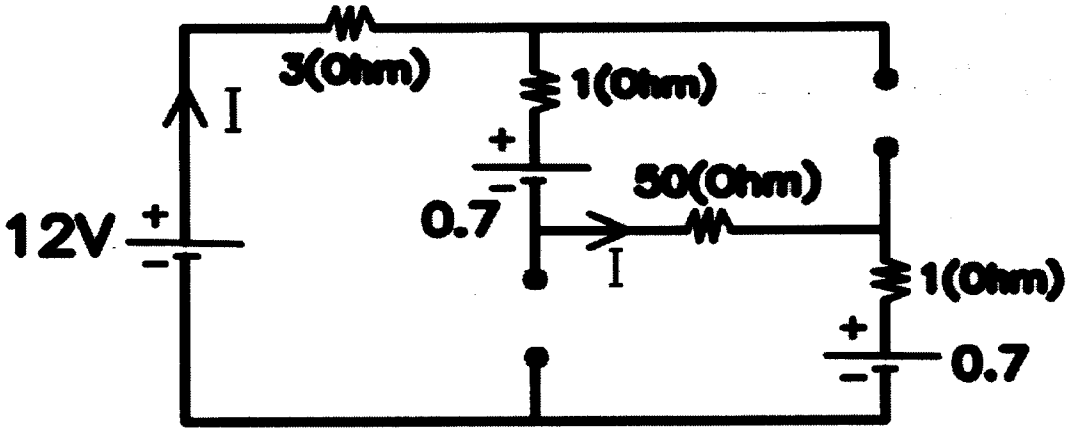
$\therefore \quad V_{R1} = 1.384 \times 10^{-3} \times 10^{3} = 1.384$ volt

$V_o = 0.7 + 3 \times 10^{3} \times 1.384 \times 10^{-3} = 4.853$ volt .

EX 12 : find the current in (50Ω) , assume all diode (Si) having a forward resistance is (1 Ω) .



Solution :



From the equivalent circuit that the circuit is series connection

$12 = I \times 3 + 1 \times I + 0.7 + 50 \times I + 1 \times I + 0.7$

$10.6 = 55\ I$

$I = \frac{10.6}{55} = 0.1927$ Amp

Note : Find the current in (50 Ω) , if the voltage (12) is reversed

(I = + 0.1927 Amp). (how) .

v_0= -5 + 0.3 = -4.7 Volt.

OR

10 = 1.47 X 10 X 10^3+ V_0

V_0=-4.7Volt.

b) also by (KVL) the current (ID) is the same (1.47 mA).

But V_0=14.7 – 5 = 9.7 volt

OR

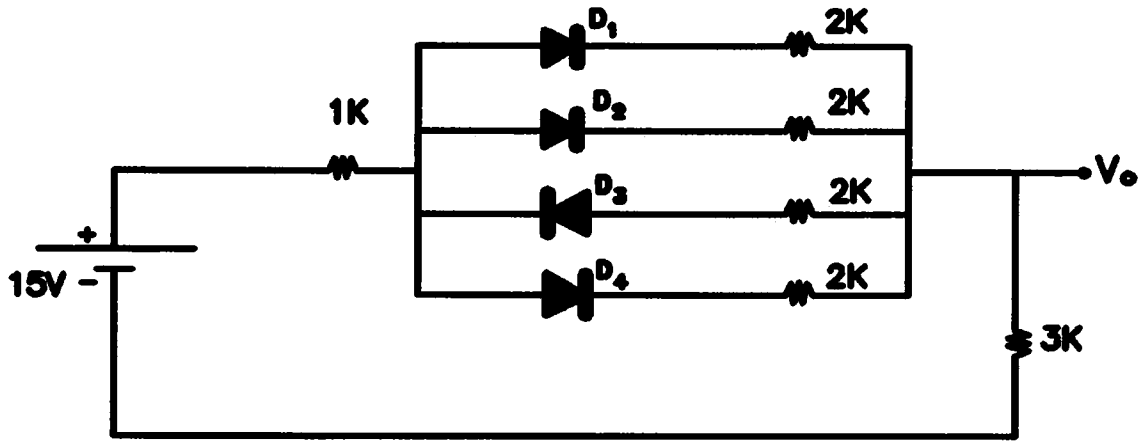
V_0 =10 – 0.3 = 9.7 volt.

c) Since the diode is reversal

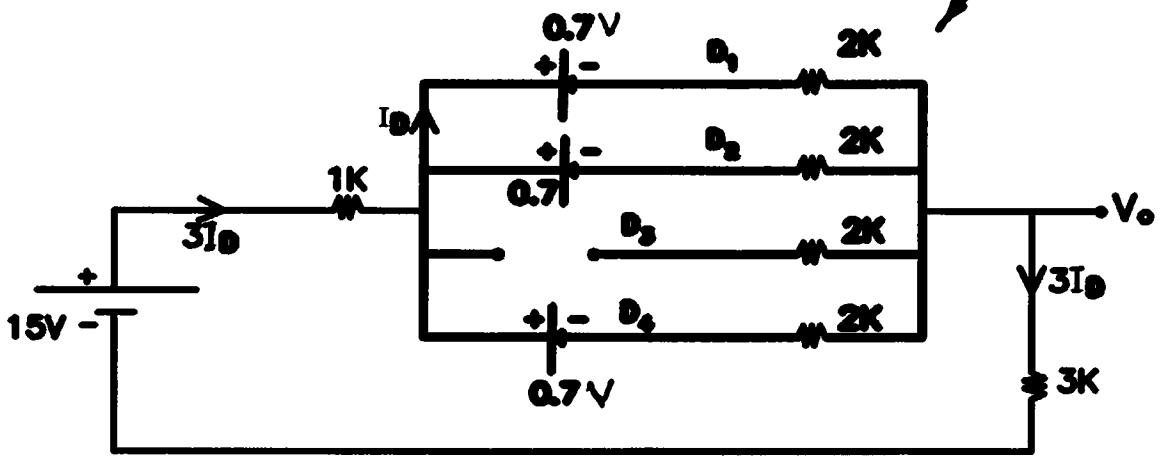
ID = 0

V_0= + 5 +10 = 15 volt.

Ex 13: Find I_D and V_o for the circuit shown , all diode are (Si) ?



Solution



By using (K.V.L)

$15 = 3\,I_D \times 10^3 + 0.7 + I_D \times 2\times10^3 + 3\,I_D \times 3 \times 10^3$

$14.3 = 14\times10^3\,I_D$

$\therefore \quad I_D = \frac{14.3}{14\times10^3} = 1.021$ mAmp

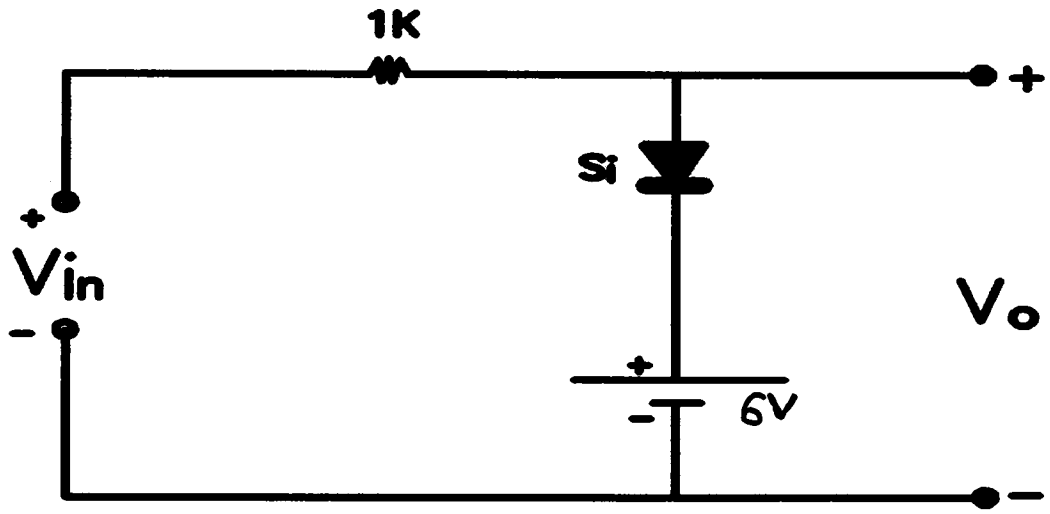
$\therefore \quad V_o = 3\,I_D \times 3 \times 10^3 = 9\times1.021 = 9.192$ volt .

Note: find I_D if the diode (D3) is reversed .

Ans : I_D = 0.794 mAmp

EX 14: For the circuit shown find V_O at

V_{in} =–2 volt , 3 volt , 5 volt , 6.7 volt , 15 volt



Solution :

When V_{in} = –2 volt ⟶ V out =–2 volt

V_{in} = 3 volt ⟶ Vout = 3 volt

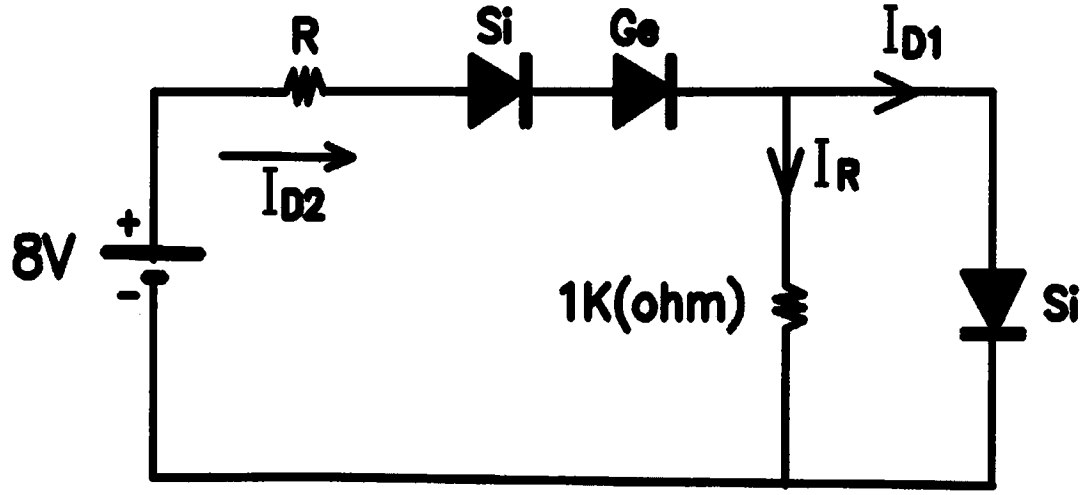
V_{in} = 5 volt ⟶ V out = 5 volt

V_{in} = 6.7 volt ⟶ V out = 6.7 volt

V_{in} = 15 volt ⟶ V out = 6.7 volt

Explain the result .

EX15: For the circuit show , find the value of (R) required such that (ID_1) is one-half of (ID_2) and find (ID_1,ID_2)?



Solution:

Since ID_2=2ID_1

$\therefore$ ID_1=IR = $\frac{0.7}{1000}$=0.7 mAmp.

ID_2=1.4 mAmp

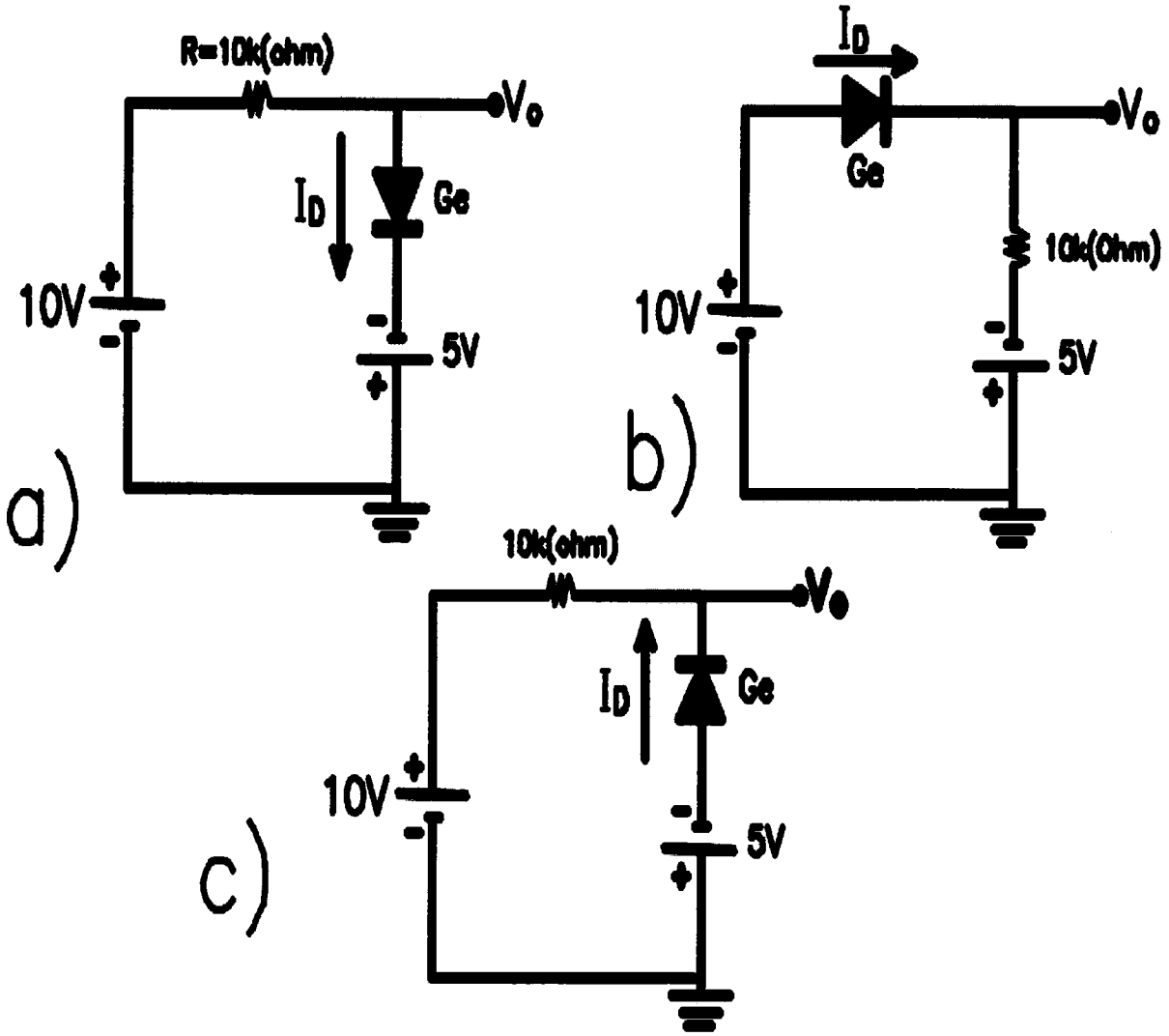
By (KVL) :-

8=ID_2*R+0.7+0.3+0.7

$\therefore$ 6.3=ID_2*R

R=$\frac{6.3}{1.4*10^{-3}}$=4.5*10^{+3}=4.5K(ohm)

EX16: For the circuit shown ,find ID, V_0 ?



Solution:

→ (a) By (KVL):-

$10+5=0.3+ID\times10X10^3$

$14.7=ID\ X\ 10\ X\ 10^3$

$\therefore \quad ID = \frac{14.7}{10X10^3} = 1.47\ X10^{-3} = 1.47\ mA.$

v_0=–5 + 0.3 =–4.7 Volt.

OR

$10 = 1.47 \times 10 \times 10^3 + V_0$

V_0=-4.7Volt.

→ (b) also by (KVL) the current (ID) is the same (1.47 mA).

But V_0=14.7 – 5 = 9.7 volt

OR

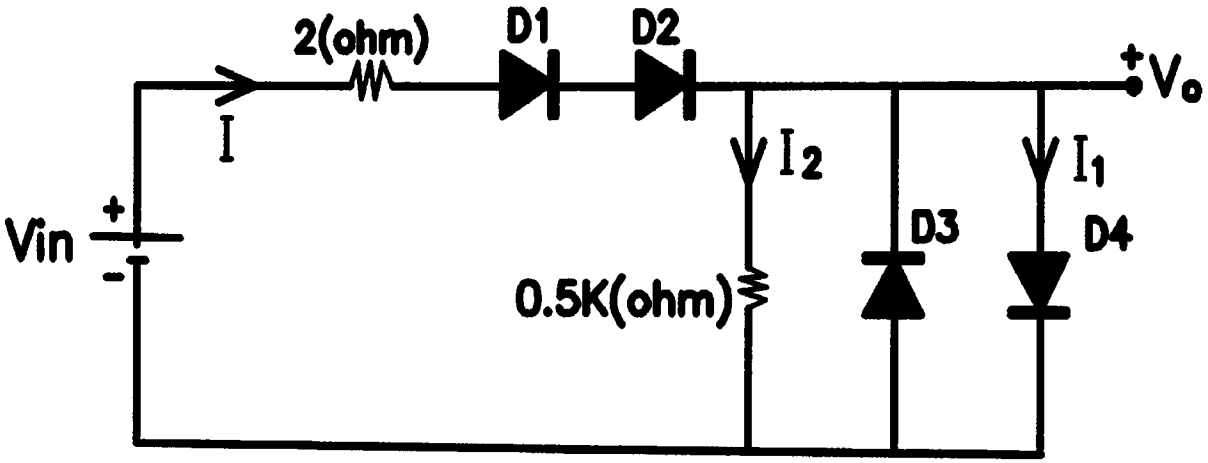
V_0 =10 – 0.3 = 9.7 volt.

→ (c) Since the diode is reversal

ID = 0

V_0= –5 -10 = -15 volt.

EX17: For the circuit show , the reverse – saturation current of each diode is (I_S= 2 X 10^{-13} A) . Find the (Vin) required to produce output voltage of (V_0 = 0.6 volt). If (K= 11600 , T = 300 K)?



Solution:

$I_1 = ID_4 = I_S\,(e^{\frac{kv}{T}} - 1)$

$= 2 \text{ X } 10^{-13}(e^{\frac{11600x0.6}{300}} - 1)$

$= 2 \text{ x } 10^{-13} \text{ x } 1.19 \text{ x} 10^{10} = 2.38$ mAmP.

$I_2 = \frac{0.6}{0.5} = 1.2$ mAmp.

But

$I = I_1 + I_2 \rightarrow$ (C.D.R).

$= 2.38 + 1.2 = 3.58$ mAmp.

For D_1 or D_2

$ID_1 = I_S\ (e^{\frac{kv}{T}} - 1)$.

$3.58\ X10^{-3} = 2X10^{-13}(\ e^{\frac{11600xV}{300}} - 1)$.

$\frac{3.58\ X10^{3}}{2\ X\ 10^{-13}} = e^{38.66v} - 1$

$1.79\ x\ 10^{10} = e^{38.66v}$ (1) niggled. (why)

Ln $1.79\ x\ 10^{10} = 38.66\ V$.

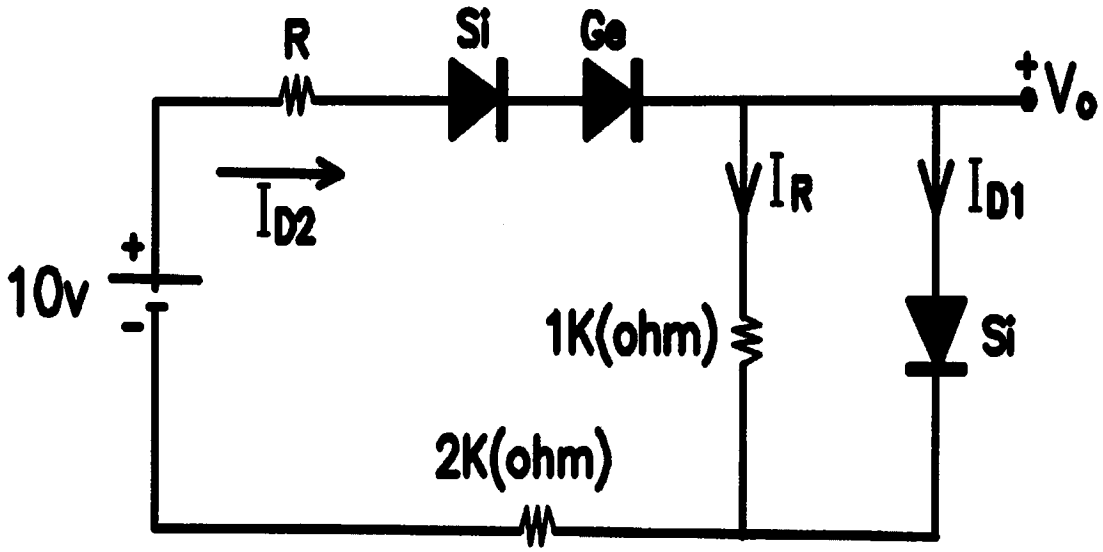
$23.6 = 38.66\ V$

$V = 0.61$ volt

By kirsch .Law .

Vin = 0.6 + 0.61 +0.61+ $2x3.58x10^{-3}$ = 1.827 volt.

EX 18: find R for the circuit shown , also ID1 is one half of ID2



solution:

$I_R = \frac{VD}{1*10^3} = \frac{0.7}{1*10^3} = 0.7\ mA$

$I_{D1} = \frac{1}{2} I_{D2} \longrightarrow I_{D2} = 2I_{D1}$

$I_{D1} = I_R = 0.7mA$

$I_{D2} = 1.4mA$

$10 = (0.7+0.3+0.7) + R*I_{D2} + 2 * 10^3 * I_{D2}$

$8.3 = 1.4*10^{-3} * R + 2 * 10^3 * 1.4*10^{-3}$

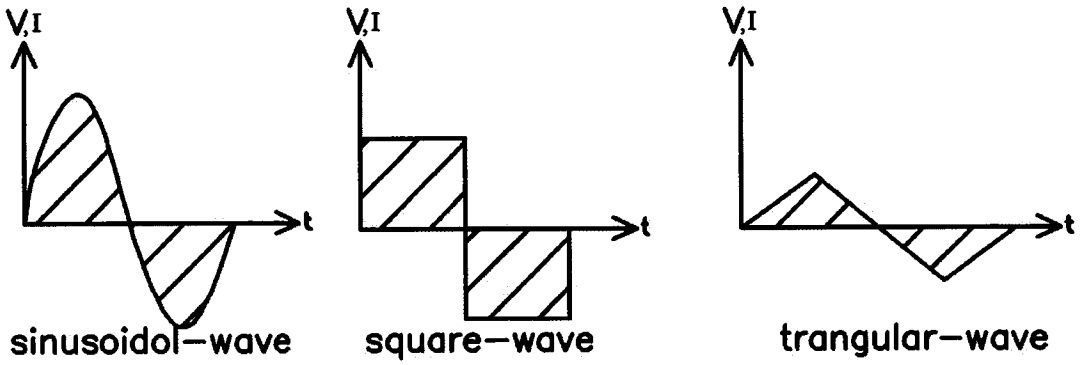
$8.3 = 2.8 + 1.4*10^{-3} * R$

$\therefore \quad 5.5 = 1.4*10^{-3} * R$

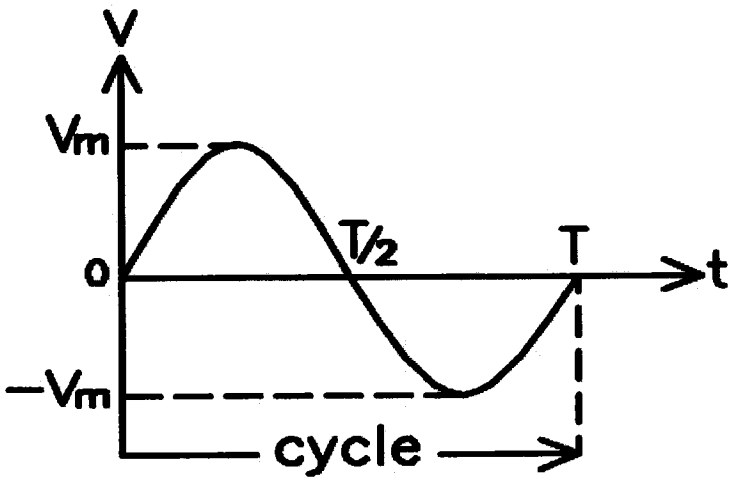
$\therefore \quad R = \frac{5.5}{1.4*10^{-3}} = \underline{3.93k\Omega}$

Alternating current (A.C) circuits

The analysis of network in which the magnitude of the source of (e.m.f) varies in a set manner.



The term alternating indicates only that the wave form alternates between two prescribed level , the term sinusoidal, square ,triangular, must also be applied . the pattern of particular interest is the sinusoidal (a.c) voltage.



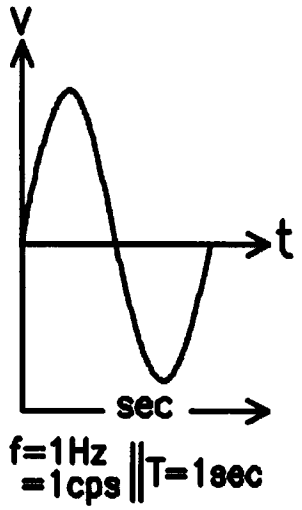
Where

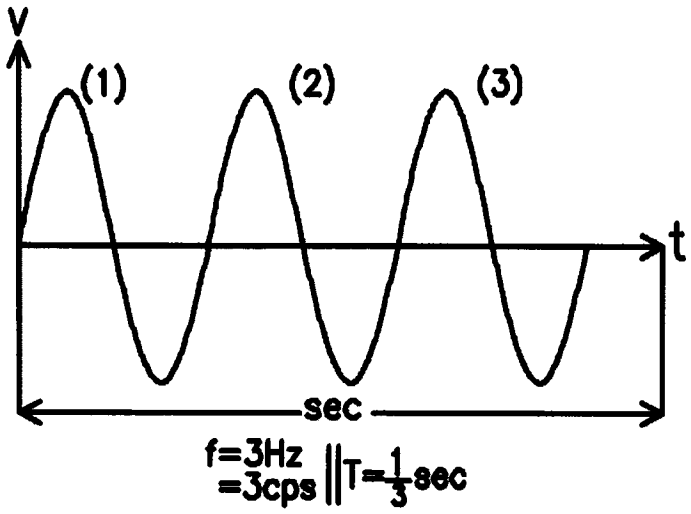
* t: time(s)

* T : the time interval between two successive repetitions of a periodic wave form.

* f (frequence) :No. of complete cycles in one second

(unit :Hz or (cps) or $\frac{1}{s} = S^{-1}$





From the above fig. and from the definitions of the period (T) and frequency (f) we get:

$$F=\frac{1}{T}$$

* W : angular velocity = $\frac{distance\ (\deg or\ rad)}{Time}$

$\frac{2\pi}{T}$ = 2πf (rad /sec)

* Vm : maximum or peak value of waveform .

So the sinusoidal voltage can be written as:

V =Vm sin(Wt).

Or = VmSin(2πft) .

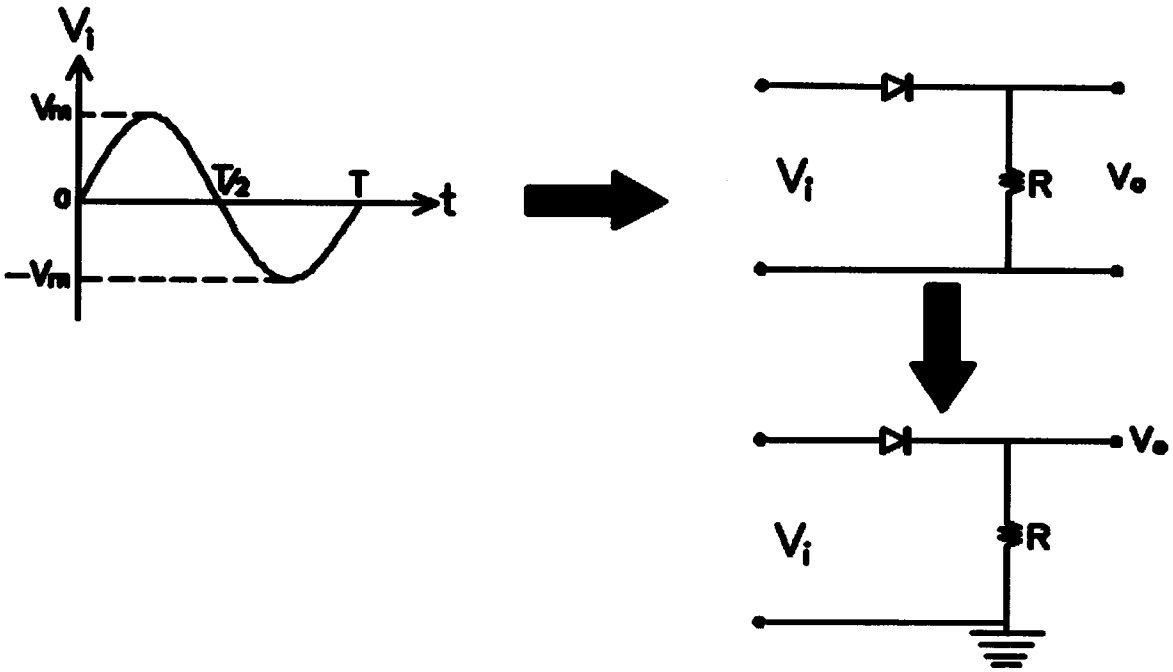
2

Diode application

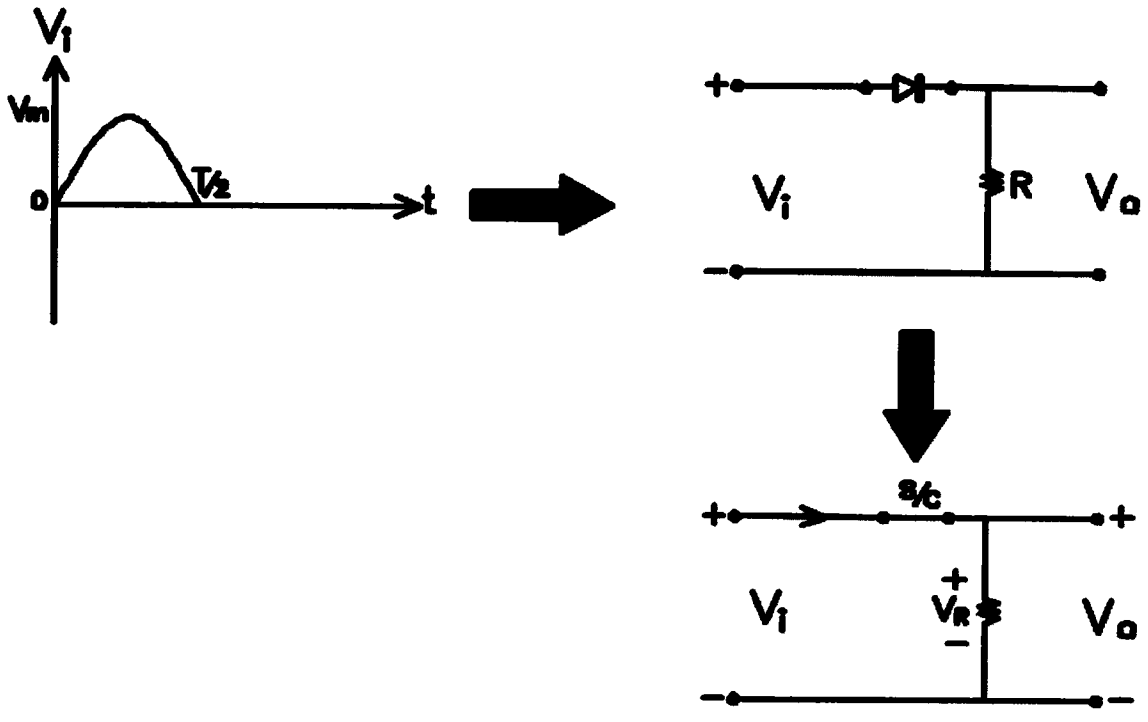
(A-C) voltage

A- Rectifiers

1- Half-wave Rectifiers



a) at t:0 ⟶ T/2

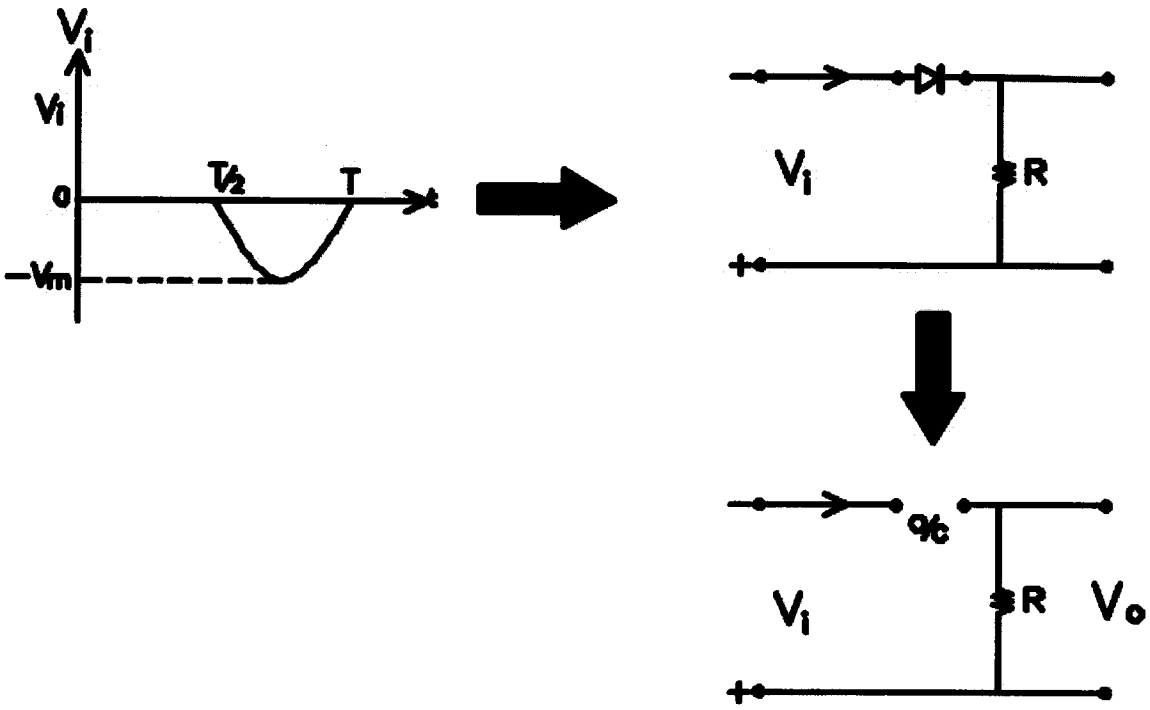


in this period the diode are in forward bias

(short circuit). As shown.

So Vin = Vr =Vo (parallel).

b) at t:T/2 ⟶ T

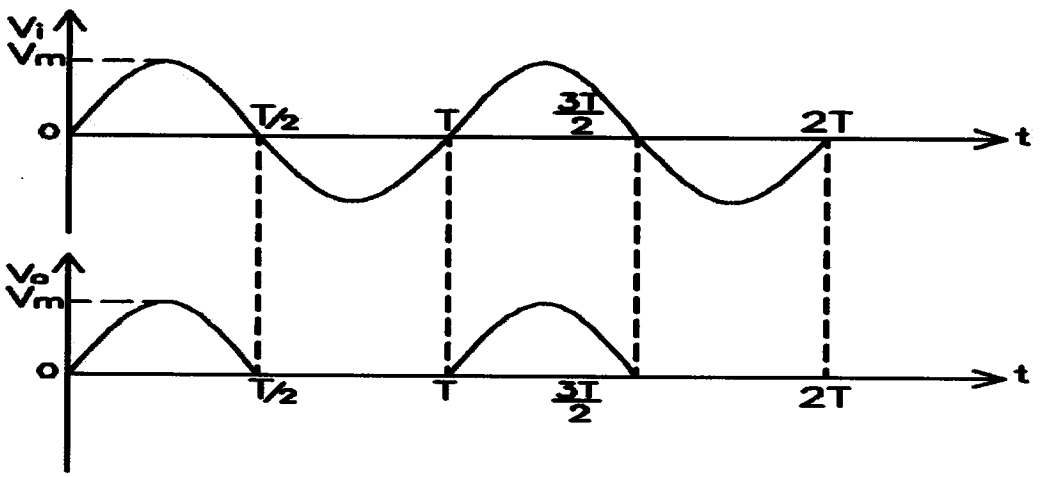


in this period the diode acts as (open circuit)(reverse bias)

as shown

since (I=0) ⟶ open circuit (o/c). **Vo = VR = 0**

The output voltage wave form(vo)



Average (mean) value

The average value of any current or voltage is the value indicated on a (D.C) meter.

V or I (average value) = $\frac{algebriac\ sum\ of\ areas}{length\ of\ curve}$

Or

$V_{av} = \frac{1}{T} \int_0^T V dt$

$I_{av} = \frac{1}{T} \int_0^T i dt$

.:The average (d-c) value of a half-wave rectifier sine-wave voltage (Vd-c) is :

$V_{d-c} = \frac{1}{T} \int_0^T V_{o(wt)} dwt$

$= \frac{1}{2\pi} [\int_0^{\pi} V_o \ \ dwt + \int_{\pi}^{2\pi} 0\ dwt\ ]$

$= \frac{1}{2\pi} \int_0^T V_m \sin(wt)\ dwt$

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

$= -\frac{V_m}{2\pi} [\ \cos(\pi) - \cos(0)\ ]\ .$

$= -\frac{V_m}{2\pi} (-1-1) = -\frac{V_m}{2\pi} (-2)$

$$V_{av} = V_{d-c} = \frac{V_m}{\pi} = 0.318\ V_m$$

5

And , the root mean square (r.m.s) value of the load voltage ($V_{r.m.s}$) for half wave rectifier sin-wave is :

$$V_{r.m.s}= \sqrt{\frac{1}{T}\int_0^T V_m^2 \, sin^2_{(wt)} dwt}$$

$$= \sqrt{\frac{V_m^2}{2\pi}\int_0^{\pi} sin^2_{(wt)} dwt}$$

We have : $\int_0^{\pi} sin^2 \, x \, dx = \frac{\pi}{2}$

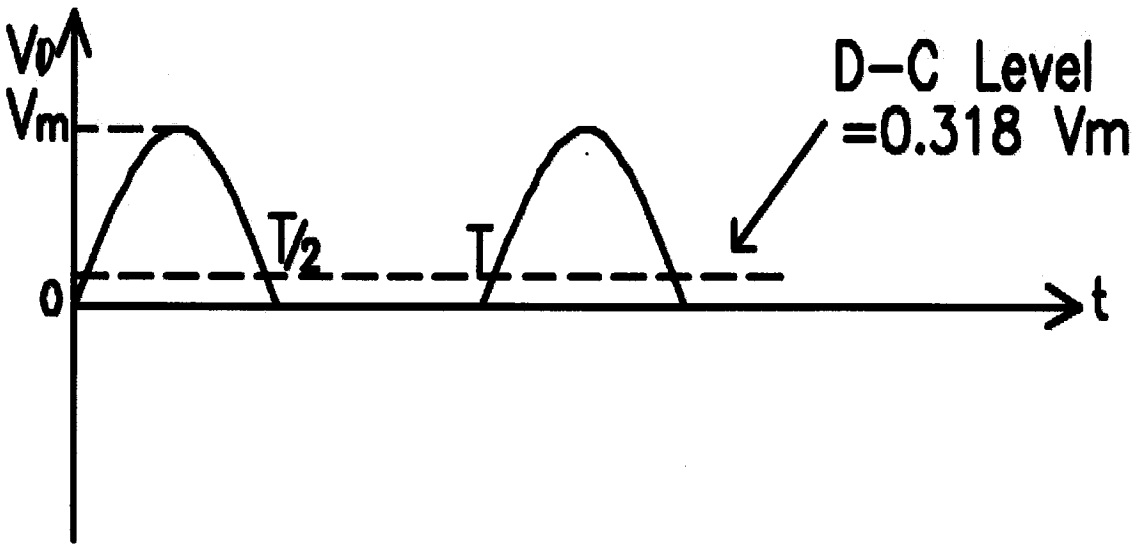
$$\int_{\pi}^{2\pi} sin^2 \, x \, dx = \frac{\pi}{2}$$

$$V_{r.m.s} = \sqrt{\frac{V_m^2}{2\pi} * \frac{\pi}{2}}$$

$$= \sqrt{\frac{V_m^2}{4}} = \boxed{\frac{V_m}{2} \text{ (half – wave rectifier)}}$$

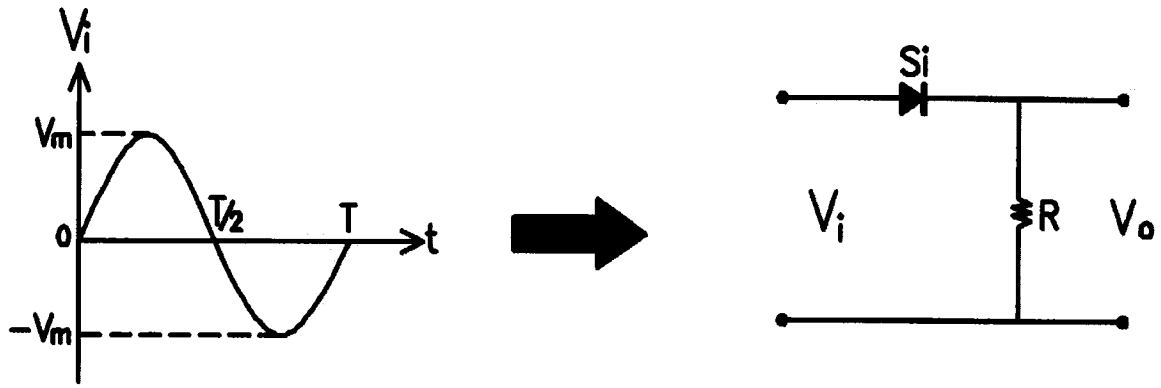
Note : the average value of asine – wave is always is (zero)

Prove why?



For a real – diode (Si for example) :

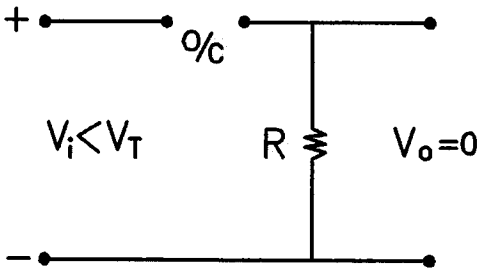
The input voltage (Vi) must exceed (0.7V) (VT) before the diode conducts:



a) at t: 0 ⟶ T/2

i) For V:< VT ⟶ the diode is off

so i = 0 & Vr=Vo=0

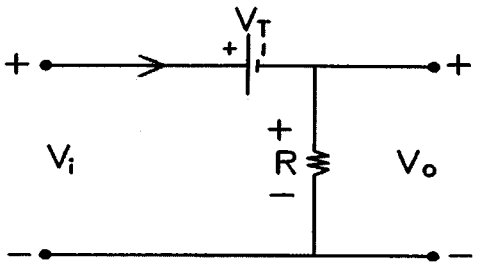


ii) for Vi>Vt ➞ the diode is on

By (K.v.l) (forward bias)

Vi= VT+Vo

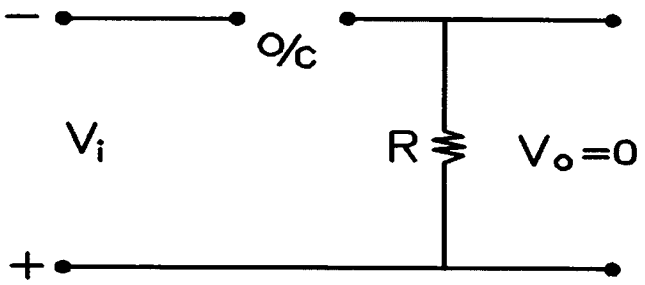
Vo= Vi – VT



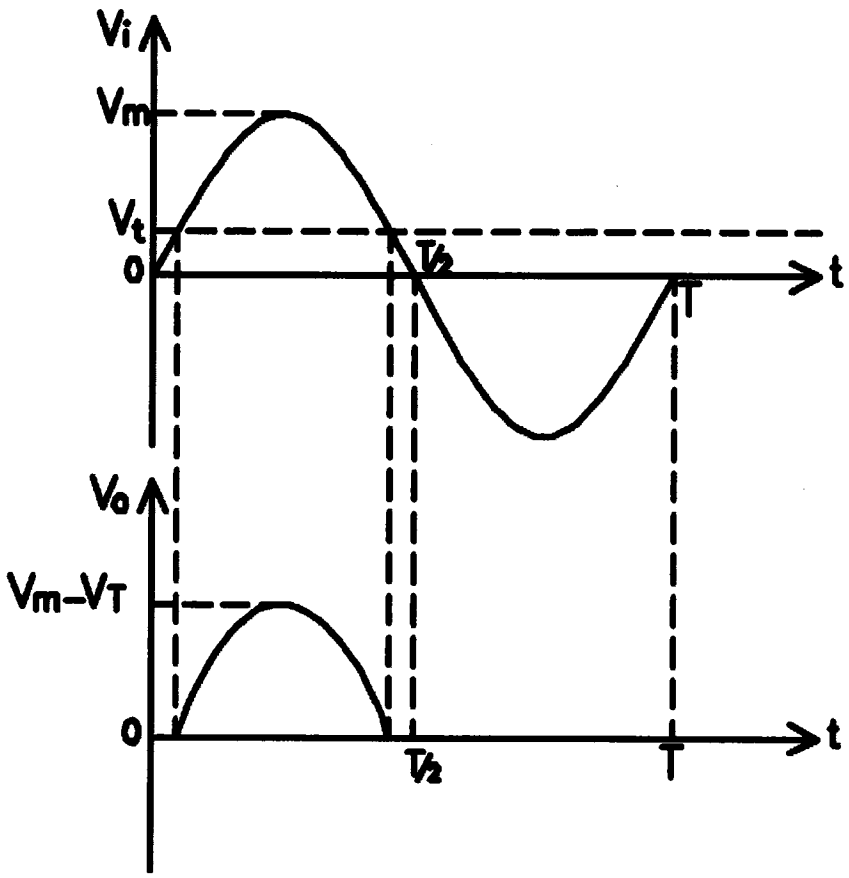
& Vo max = Vm- VT

b) at :t ⟶ T/2 ⟶ T

the diode is off (reverse bias) , i= 0 &vo=0



* Vo – waveform



And

Vd-c = 0.318 (Vm –VT).

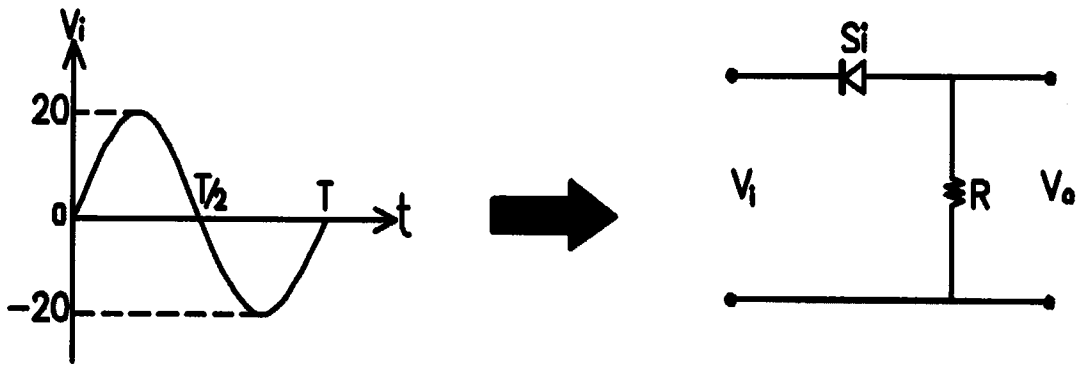
If Vm>>VT

Vd-c = 0.318Vm

EX: For the network shown, find

1- Find and draw the value of (V_0) , also determine its (d-c) level.

2-Repeat (1) with the ideal diode replaced by a silicon diode, What the required (PIV) should be for this diode.



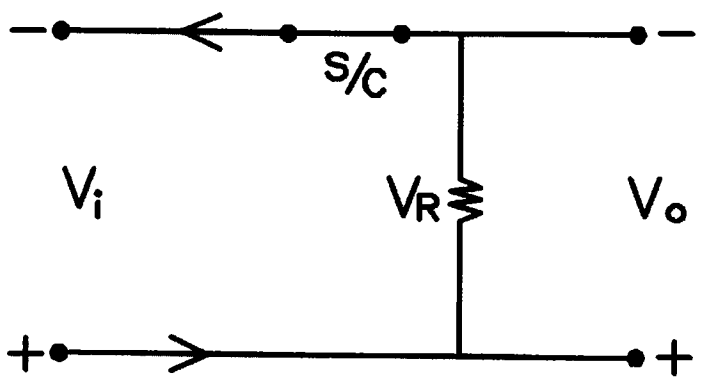
Solution:

1)

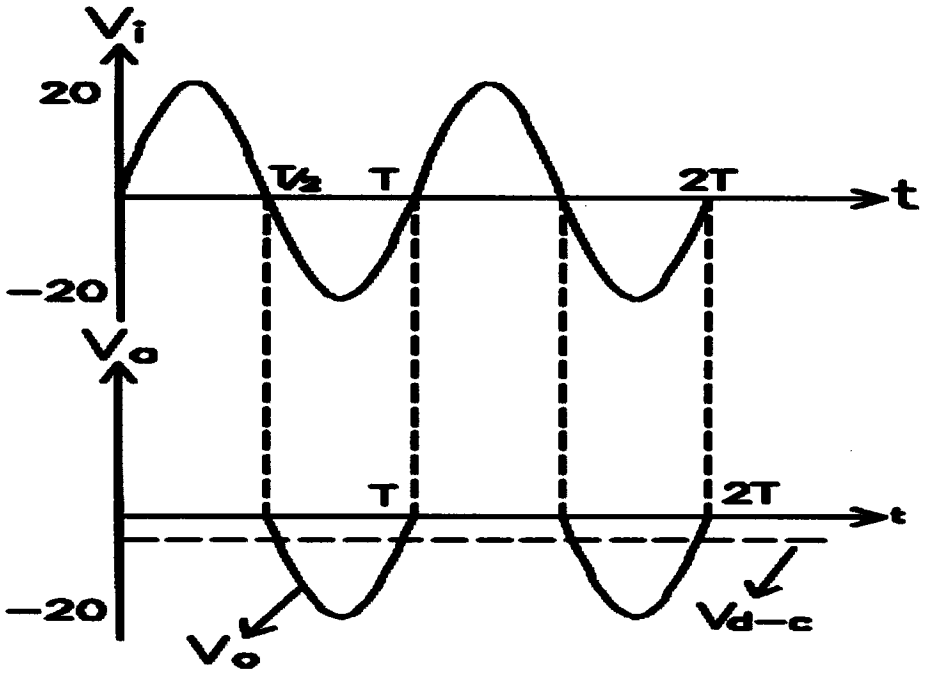
a) at t : 0 → $\frac{T}{2}$ → The diode act as a reverse then i = 0 & V_0=0 .

b) at t : $\frac{T}{2}$ → T → The diode act as forward Bias (ON) or (s/c).

$\therefore V_i = V_0$



∴ V_0_ wave form :-



∴ V_0 = -20 volt = -Vm.

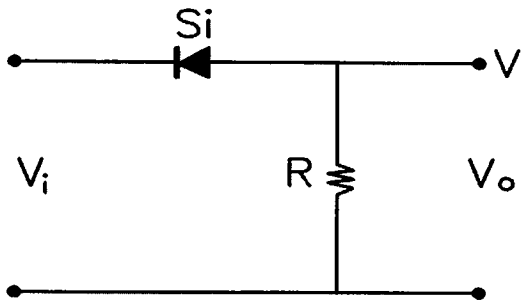
And $V_{d-c} = \frac{V_m}{\pi}$

$= \frac{-20}{\pi} = -0.318Vm$

=-0.318 x 20

= - 6.36 volt.

2) for Si-diode .

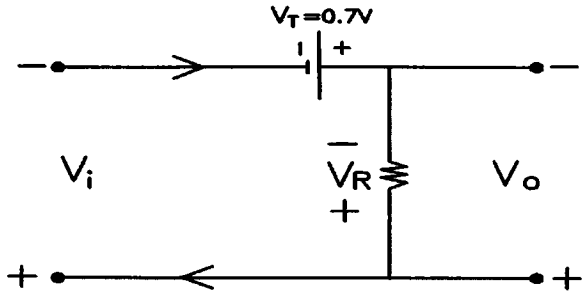


a) at t : $0 \rightarrow {}^{T}/_{2} \rightarrow$ also diode (off) i=0 & V_0=0.

b) at t : $\frac{T}{2} \rightarrow$ T

when $V_i < V_T \rightarrow$ The diode (off) i=0 , V_0=0.

But at $V_i > V_T \rightarrow$ The diode (ON)



By (KVL):

$$V_i = V_0 + V_T$$

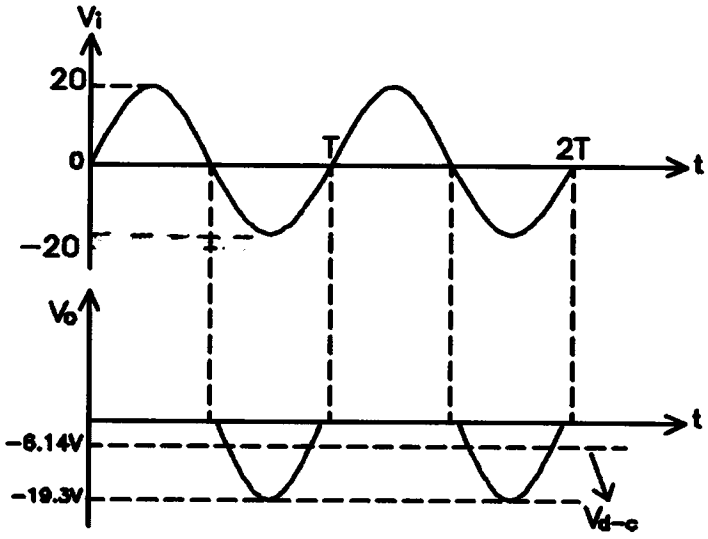
$\therefore V_0 = V_i - V_T$

OR

$$V_{0\,max} = V_{i\,max} - V_T$$

=20 – 0.7 = 19.3 volt . (negative voltage).

$\therefore V_0$ _ wave form :-



$$V_{d-c} = \frac{V_0}{\pi}$$

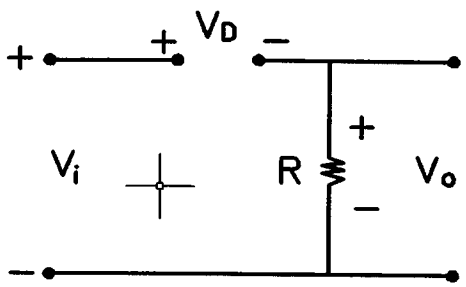
$$= \frac{-19.3}{\pi}$$

= -6.14 volt.

(PIV) Required:

This value measured at reverse biasing (Diode is off) as :

Here: i=0 & V_0=V_R=0.



∴ V_i=V_D=20 volt.

(here We take the max value of V_i)

∴ Required PIV > 20 volt .

(OR (PIV) min = 20 volt).

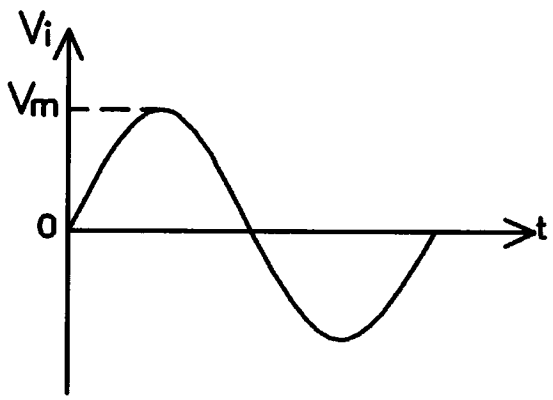
Efficiency of half-wave rectifier

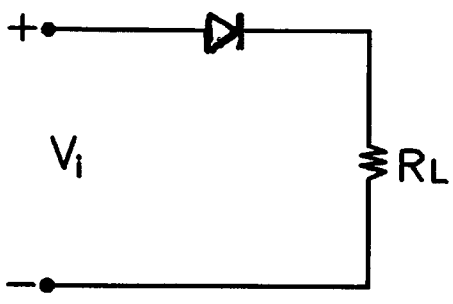
Rectifier efficiency is define as the ratio of (D-C) output power to the input (A-C) power.

$$\text{Rectifier efficiency } \eta\ \% = \frac{D.C\ out\ put\ power}{A.C\ input\ power}$$

For example:

Vi = Vm sinwt





$$I_m = \frac{V_m}{rd+Rl}$$

where :rd is (diode resistce)

* $I_{av} = I_{D.C} = \frac{I_m}{\pi}$
* $I_{r.m.s} = \frac{I_m}{2}$

} as derived before

We have (D.C) output power = $(I_{D.c}^2)$ .RL

$P_{d-c} = (\frac{I_m}{\pi})^2$ *RL

The input(a.c)power = $P_{a.c} = (I_{r.m.s})^2$(rd+RL).

$P_{a.c} = (\frac{I_m}{2})^2$ (rd+RL)

Rectifier effi = $\frac{P_{d-c}\ output}{P_{a.c} input}$ * 100%

$$\frac{(\frac{I_m}{\pi})^2 * RL}{(\frac{I_m}{2})^2 (rd+RL)} * 100\%$$

$$= \frac{(0.406) * RL}{(rd+RL)} * 100\%$$

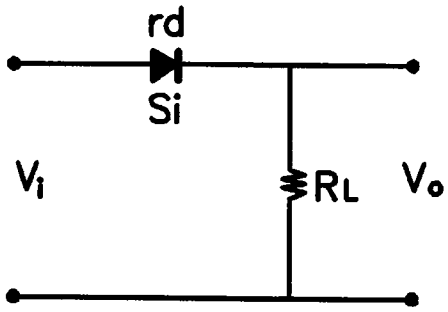
If (rd) is very small and can be negligible .

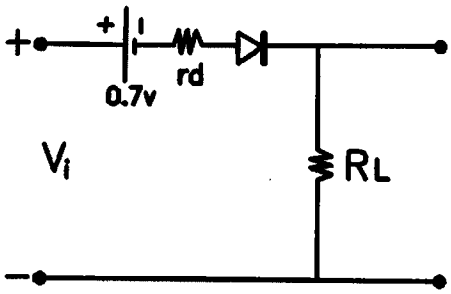
:.Max – Rectifier efficiency = 40.6%

This shows that in half –wave rectification . a maximum of (40.6%) of (A.C) power is converted into(D.C) power .

EX: For the circuit shown , find the value of diode efficiency , and max. efficiency if Rl= 1500Ω , rd = 120Ω , Vin= 30sinwt (volt)

14





Solution

$I_m = \frac{V_m - 0.7}{R_T} = \frac{V_m - 0.7}{rd + RL}$

$I_m = \frac{30 - 0.7}{120 + 1500}$ = 18.08 mA

$I_{av} = I_{d.c} = \frac{I_m}{\pi} = \frac{18.08}{3.14}$ = 5.76 mA

$I_{r.m.s} = \frac{I_m}{2} = \frac{18.08}{2}$ = 9.04 mA

$P_{in} = I_{r.m.s}^{\ 2}$ * RT

$= (9.04)^2 * (120+1500)$ = 0.132 watt

$P_{av} = P_{d.c} = I_{av}^{\ 2}$ *RL

$= (5.76)^2 * 1500$ = 0.049 watts

$\eta\ \% = \frac{P_{d-c\ output}}{P_{a.c\ input}} = \frac{0.049}{0.132}$ = 37.1%

And max. efficiency take place when rd = 0

η % (max) = 40.6% .

2- Full -wave Rectifier

In full-wave rectifier, current flow through the load in the same direction for both half- cycles of input (A-C) voltage. This can be achieved with two diodes working alternately. For the positive half-cycle of input voltage, one diode supplies current to the load and for the negative half-cycle the other diode does so, current being always in the same direction through the load.

Also this type of rectification is use to **improve** the d-c level obtained at the output.

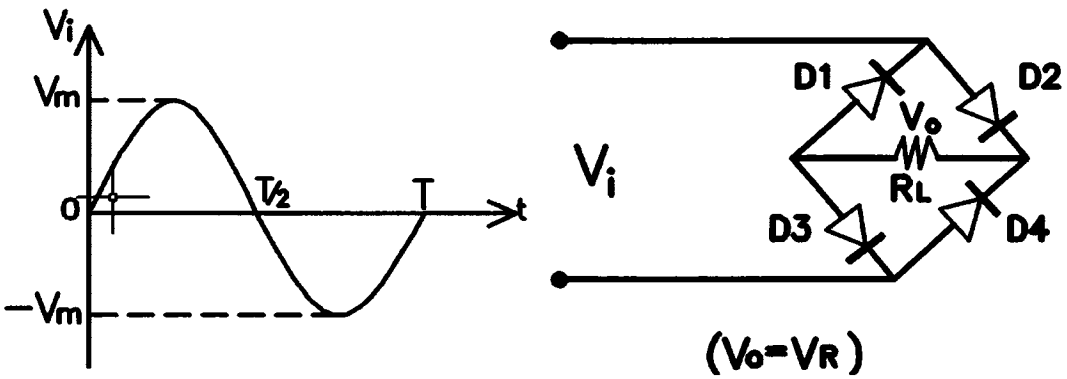
Two circuits are commonly used for full-wave rectification:

a-Full-wave bridge rectifier.

b-Center-tap full-wave rectifier.

a-Full-wave bridge Rectifier

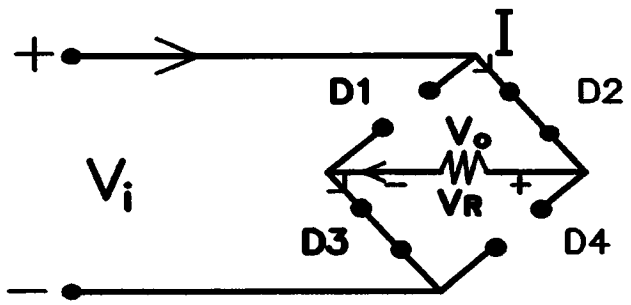
It contains four diode (D_1 , D_2 , D_3 & D_4) connect to form bridge as shown below.



a- at t:0 $\rightarrow \frac{T}{2}$

(D_1 , D_4)⟶OFF

(D_2 , D_3)⟶ON



(Vo=VR)

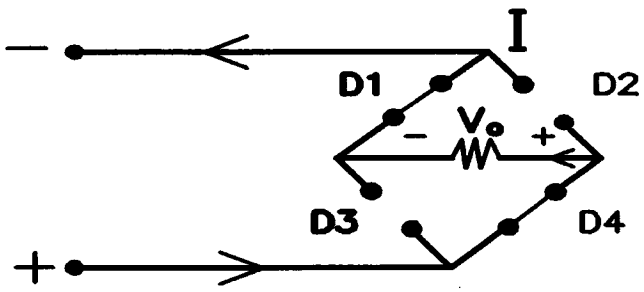
By (KVL):

$V_0 = V_i$ & $V_{0\,max} = V_m$.

b-at t : $\frac{T}{2}$ → T

(D_2 , D_3)⟶OFF

(D_1 , D_4)⟶ON



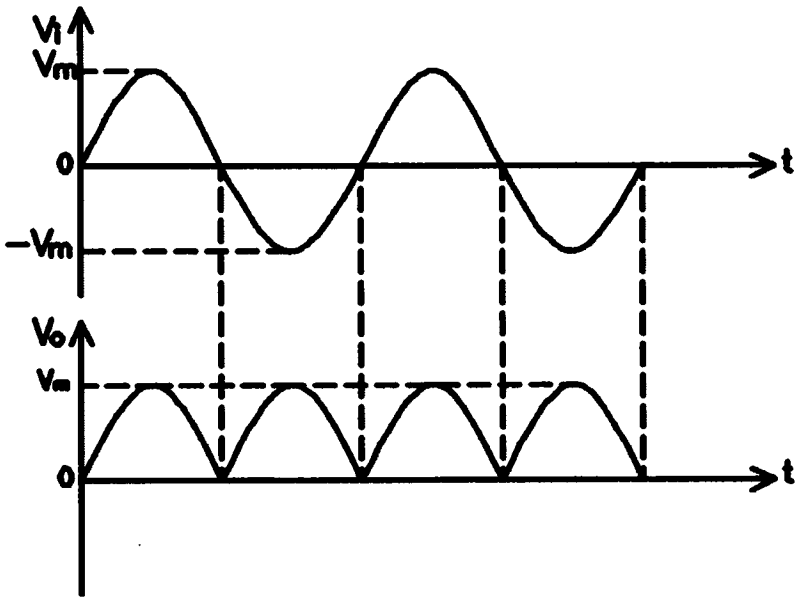
(Vo=VR)

Also: $V_0 = V_i$ & $V_{0\,max} = V_m$.

**Note: The polarity across the load resistance (R) is the same for the two periods : ((0→$\frac{T}{2}$) and ($\frac{T}{2}$ →T)).

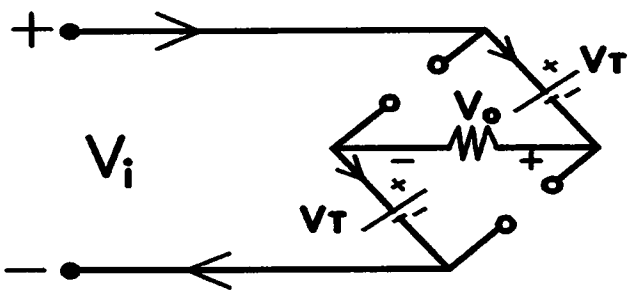
*V_0- wave form

V_{d-c} = 0.636 Vm. ??why



For a Real diode

a- at t :0$\longrightarrow\frac{T}{2}$



By (KVL)

V_i=V_0+V_T+V_T

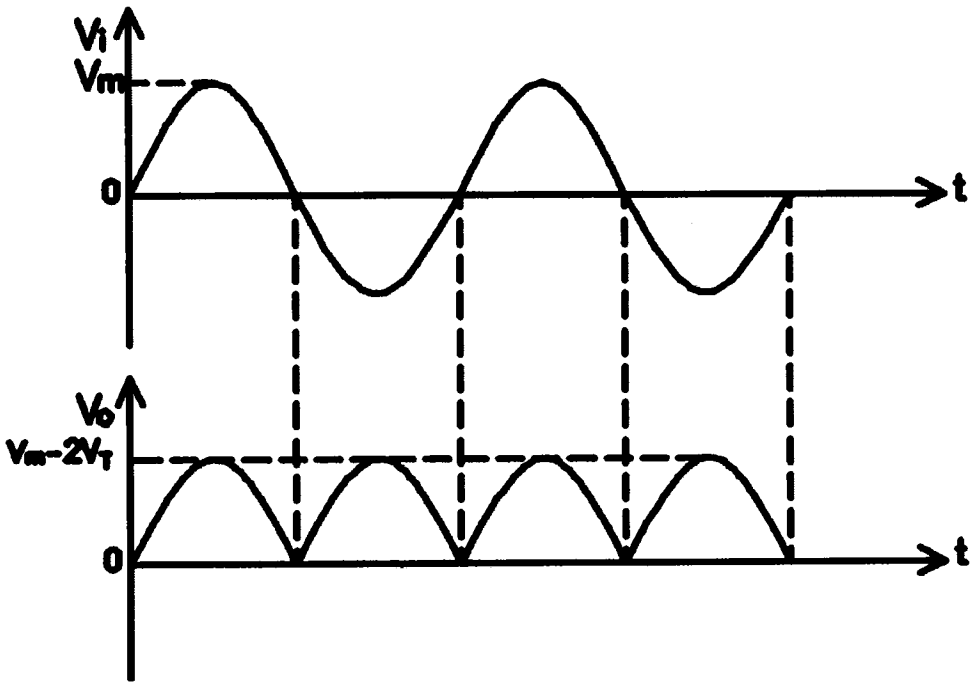
V_i=V_0+2V_T

$\therefore V_0$=V_i-2V_T and $\boxed{V_{0\,max}=V_m\text{-}2V_T.}$

b- at t: $\frac{T}{2} \rightarrow T$

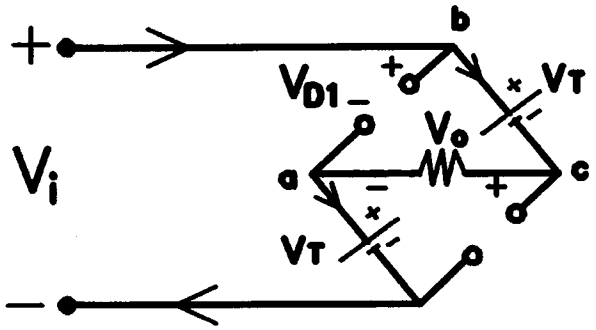
we will have the same result.

V_{d-c}=0.636 (V_m-2V_T).



(PIV) Required:

We choose a diode in reverse biasing (diode (D_1) in the interval t:0 $\rightarrow \frac{T}{2}$ for example).



By (K.V.L) in (abca)

V_{D1}=V_0+V_T 1

But we have

$V_0=V_i-2V_T$ 2

Put the value of (V_0) in eq(2) to eq(1).

$\therefore V_{D1}=V_T+(V_i-2V_T)$.

$\therefore V_{D1}=V_i-V_T$.

Considering max. voltage:

$\therefore (V_{D1})max=V_m-V_T$.

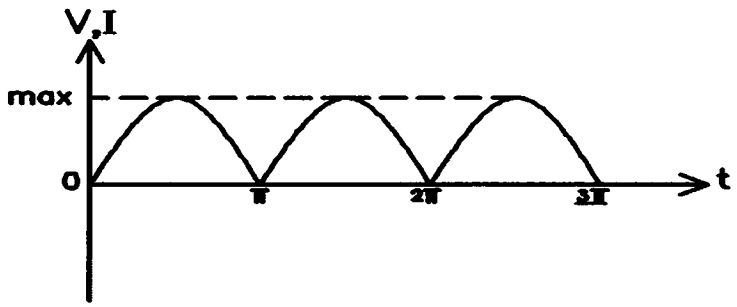
The voltage $((V_{D1})max$ is the maximum reverse biasing voltage on diode D_1

$\therefore$ Required PIV > V_m-V_T

$\cong$ PIV > V_m

Efficiency of Full-wave Rectifier

Since the output voltage or current of full-wave rectifier as shown



Then:

I or V (av)

$=\frac{1}{T}\int_0^T Vor\ I\ dt$.

$$\therefore V_{av} = \frac{1}{2\pi}\left[\int_0^{\pi} V_t\, dt + \int_{\pi}^{2\pi} V_t dt\right]$$

$$= \frac{1}{2\pi}\left[\int_0^{\pi} V_m \sin wt\ dt + \int_{\pi}^{2\pi} V_m \sin wt\, dt\right].$$

$$= \frac{V_m}{2\pi}\left[(-\cos wt\,\{_0^{\pi}) + (-\cos wt\,\{_{\pi}^{2\pi})\right]$$

$$= \frac{V_m}{2\pi}[-(-1-1) + |(-(1+1))]|$$

$$\boxed{= \frac{V_m}{2\pi}(2+2) = \frac{4V_m}{2\pi} = \frac{2V_m}{\pi}}$$

& $\boxed{I_{av} = \frac{2I_m}{\pi} = 0.636\, I_m.}$

The Root – mean – square (R.M.S) of full-wave rectifier is :

$$I_{r.m.s} = \sqrt{\frac{1}{T}\int_0^T i(t)^2\, dt.}$$

$$\therefore I_{r.m.s} =$$

$$\sqrt{\frac{1}{2\pi}\left[\int_0^{\pi} I_{m^2}\ sin^2\,(wt)^2\, dt + \int_{\pi}^{2\pi} I_{m^2} sin^2\,(wt)^2\, dt\right]}$$

But we have : $\int_0^{\pi} \sin x^2\ dx = \frac{\pi}{2}$

And $\int_{\pi}^{2\pi} \sin x^2\ dx = \frac{\pi}{2}$

$$\therefore I_{r.m.s} = \sqrt{\frac{I_{m^2}}{2\pi}\left(\frac{\pi}{2} + \frac{\pi}{2}\right)} = \sqrt{\frac{I_{m^2}}{2\pi}(\pi)}$$

$$\boxed{\therefore I_{r.m.s} = \frac{I_m}{\sqrt{2}}} \quad \rightarrow \text{sinusoidal wave.}$$

∴ The efficiency of Full-wave rectifier is

$$\eta\% = \frac{D-C\ output\ power}{A-C\ input\ power} \times 100\%.$$

Power (D-C) output = $(I_{d-c})^2 \times RL$

Power (A-C) input = $(I_{r.m.s})^2(rd + RL)$

$$\therefore \eta\% = \frac{(\frac{2Im}{\pi})^2 \ x\ RL}{(\frac{Im}{\sqrt{2}})^2\ (rd+RL)} \times 100\%.$$

$$= \frac{8}{\pi^2} \times \frac{RL}{rd+RL} \times 100\%.$$

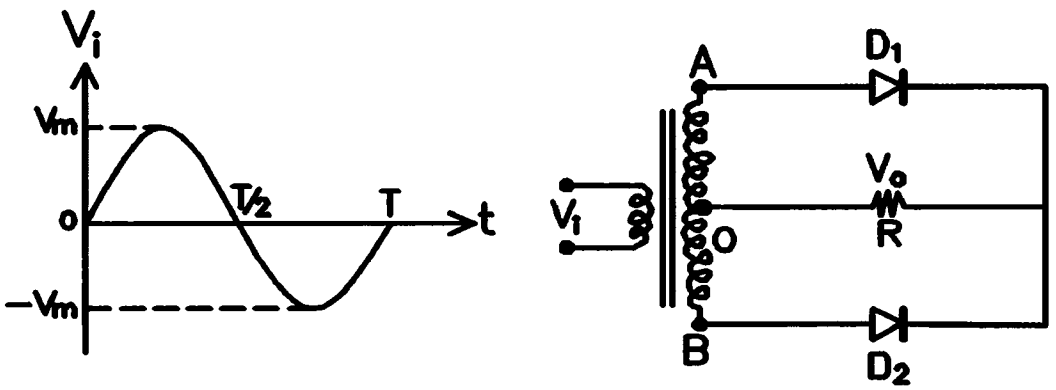
$$= \frac{(0.81)RL}{(rd+RL)} \times 100\%.$$

If (rd) is very small and can be negligible as in case of ideal diode then the efficiency.

$$\eta\% = 81\%$$

b- center-tap full-wave rectifier

The circuit employs two diode (D_1) and (D_2) as shown a center tapped secondary winding (AB) is used with two diodes connected so that each uses one half – cycle of input (A-C) voltage . In other words , diode (D_1) utilizes the (A-C) voltage appearing a cross the upper half(OA) of secondary winding for rectification while diode (D_2) uses the lower half winding (OB).



*at t: $0 \longrightarrow \frac{T}{2}$

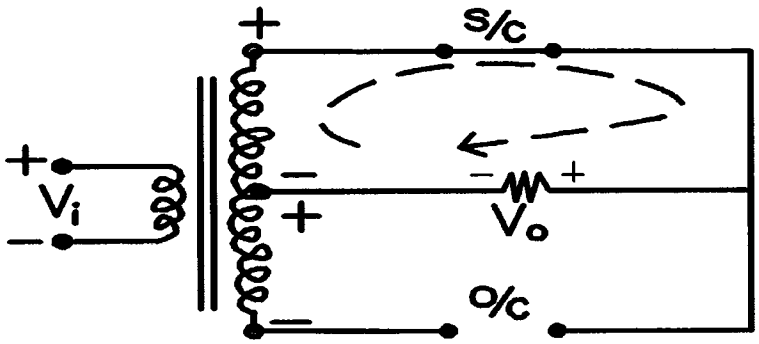
$D_1 \rightarrow ON$

$D_2 \rightarrow OFF$

By (K.V.L)

$$V_0 = V_i$$

$$V_{0\,max} = V_m$$



At t: $\frac{T}{2} \longrightarrow$ T

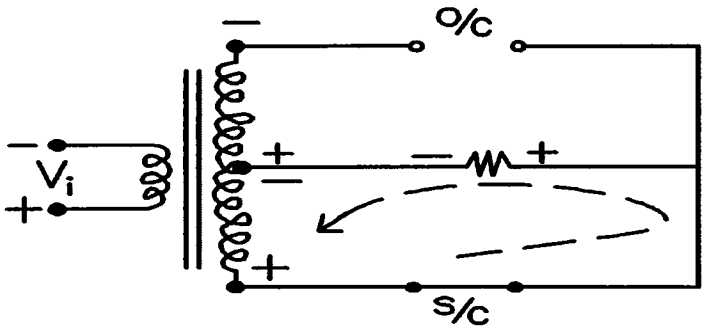
$D_1 \rightarrow$ OFF

$D_2 \rightarrow$ ON

We take the same Result.

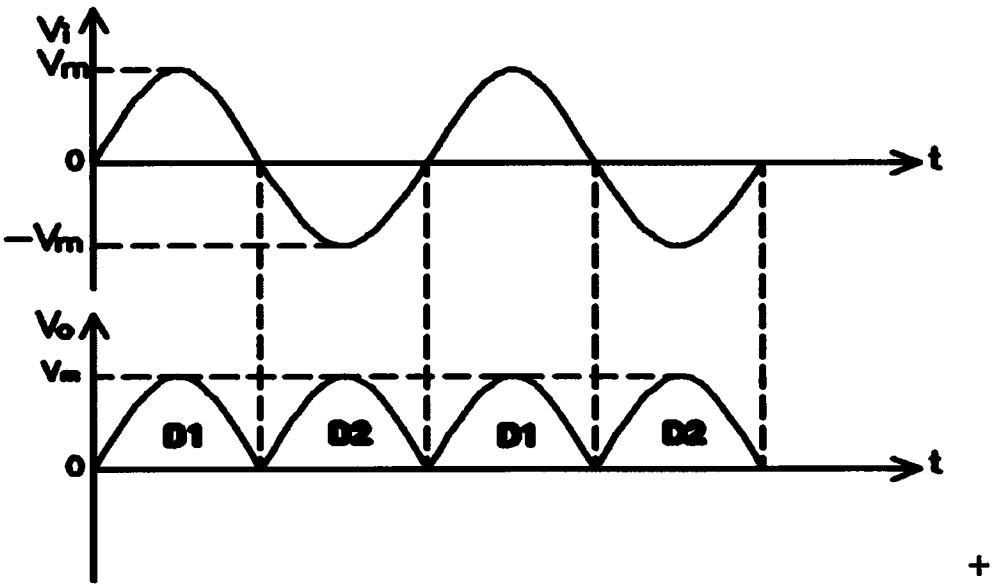
$$V_0 = V_i$$

$$V_{0\,max} = V_m$$



Note: The polarity a cross (R) is the same for the two periods.

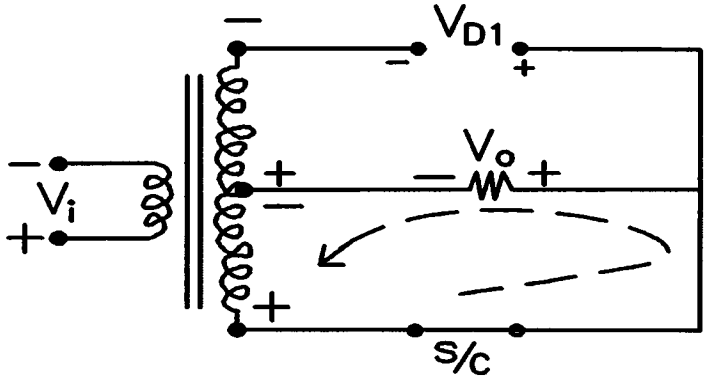
∴ V_0-wave from



***Required PIV**

****Here we shall neglect (V_T) of real diode.

****Taking a load of reverse biased diode (D_1 for example).



By (K.V.L):

$V_{D1} = V_i + V_0$

But $V_0 = V_i$

$\therefore V_{D1} = 2V_i$

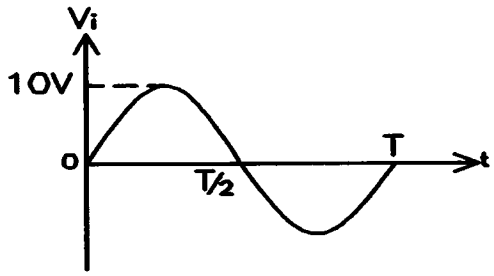
*Taking max . voltages :

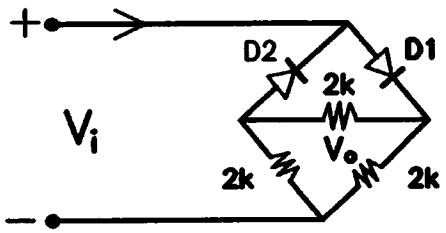
$\therefore V_{D1} = 2V_m$

$\therefore$Required PIV > $2V_m$

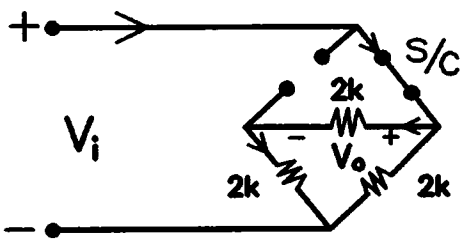
Note: check that in full-wave bridge rectifier the (PIV)> V_m ,while in cenfre-tap the (PIV)>2 V_m this mean that the diodes must have high inverse voltage this is one of dies a advantages of this type.

EX: For the circuit shown , find the output wave form and the d-c output level and the required (PIV)





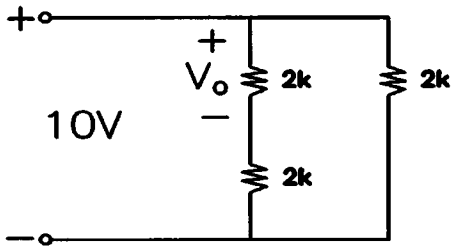
solution:



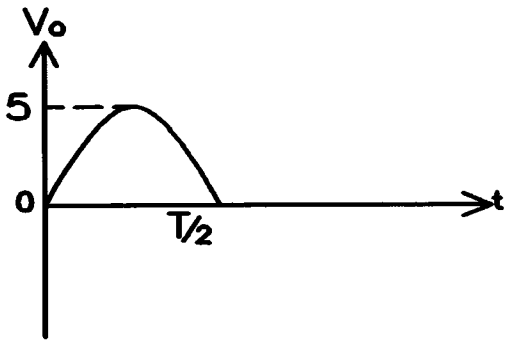
At t:0 → $\frac{T}{2}$

D_1→ ON

D_2→OFF



$\therefore V_0 = \frac{10}{2K+2K} X2K$ = 5 volt.

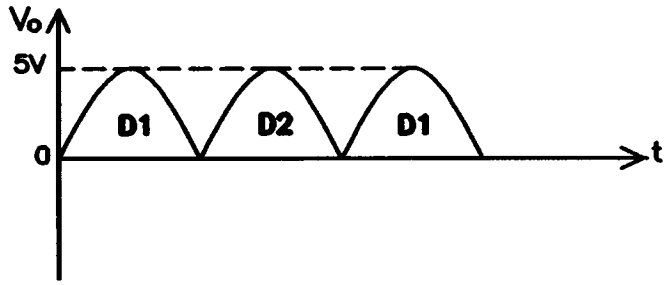


At t: $\frac{T}{2} \rightarrow$ T

$D_1 \rightarrow$ OFF

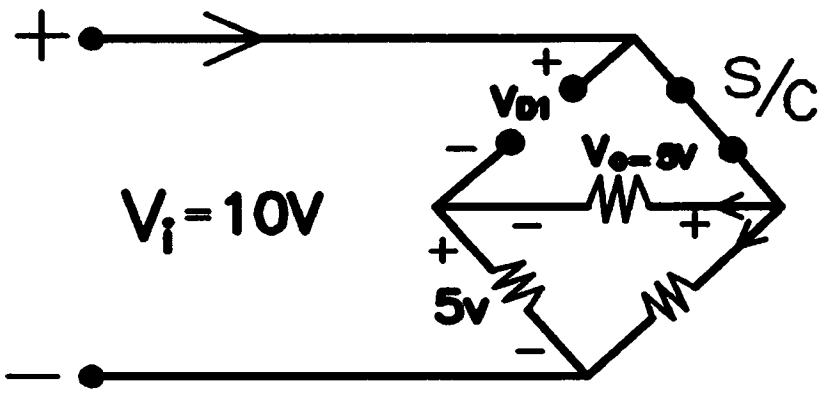
$D_2 \rightarrow$ ON and also V_0 = 5 volt.

$\therefore V_0$- **wave form**



$V_{(d-c)}$ or V_{av}

$= V_m \frac{2}{\pi}$ = 0.636 Vm = 0.636 x 5 = 3.18 volt &PIV > 5 volt .



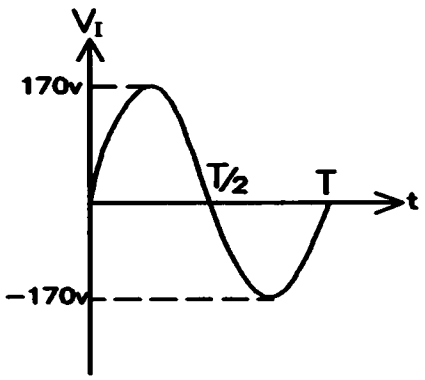
We see that $V_i = V_{D1} + 5$ volt

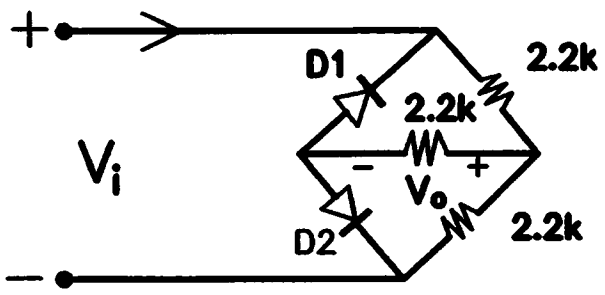
$10 = V_{D1} + 5$

$\therefore V_{D1} = 5$volt

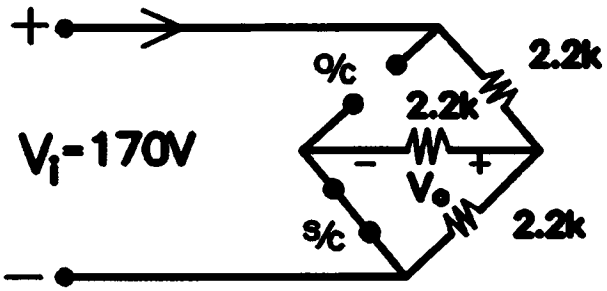
$\therefore$ PIV >5volt

EX: For the circuit shown , find the output wave form and the d-c output level.





Solution:



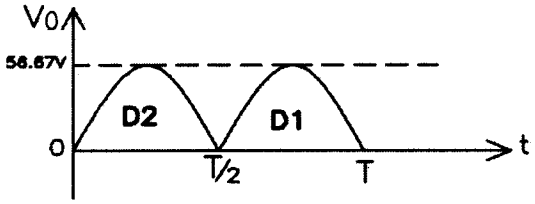
At t: $0 \rightarrow \frac{T}{2}$

$D_1 \rightarrow$OFF

$D_2 \rightarrow$ON

$$I = \frac{170}{2.2+(2.2//2.2)} = \frac{170}{3.3} = 51.51 \text{ mA}$$

$\therefore V_0 = 51.51 \text{ X } 1.1 = 56.67$ volt.



At $t: \frac{T}{2} \rightarrow T$

$D_1 \rightarrow$ ON

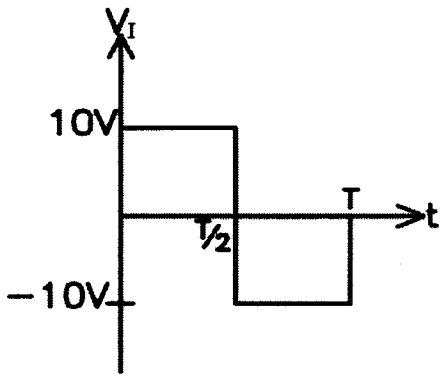
$D_2 \rightarrow$ OFF

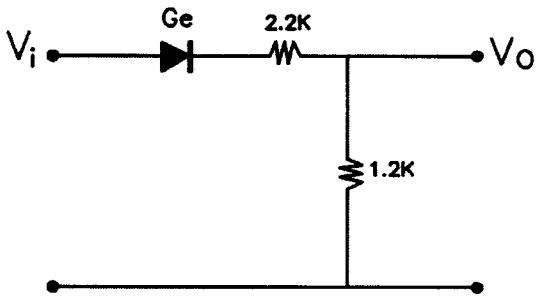
$\therefore V_0$ also equal to (56.67) volt.

$\therefore V_{d-c}$ or V_{av}

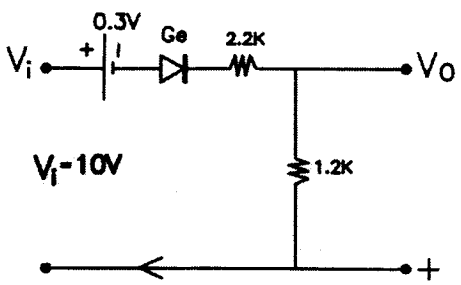
$= V_m \frac{2}{\pi} = 0.636 \times 56.67 \quad = 36.04$ volt.

EX: For the circuit , find the value of (V_0)





Solution:



At $t: 0 \rightarrow \frac{T}{2}$

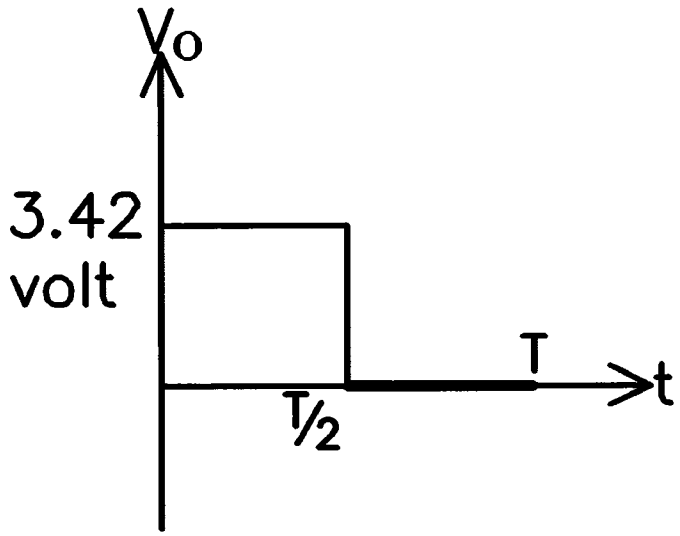
$V_0 = V_{(1.2)K\Omega}$

$I = \frac{10-0.3}{2.2+1.2}$ = 2.85 mAmp.

$\therefore V_0 = 2.85 \times 10^{-3} \times 1.2 \times 10^3$ = 3.42 volt.

And at $t: \frac{T}{2} \rightarrow T$

The diode is reverse basic and $V_0 = 0$.



Clippers

*There is a variety of diode networks called (clippers) that have the ability to (clip) off apportion of the input signal without distorting the remaining part of the alternating wave form.

*Clipping circuit also known as (**Limiters , amplitude selectors & slicers**) are used to remove the part of a signal that is above or below some defined reference level.

*There are two general categories of clippers

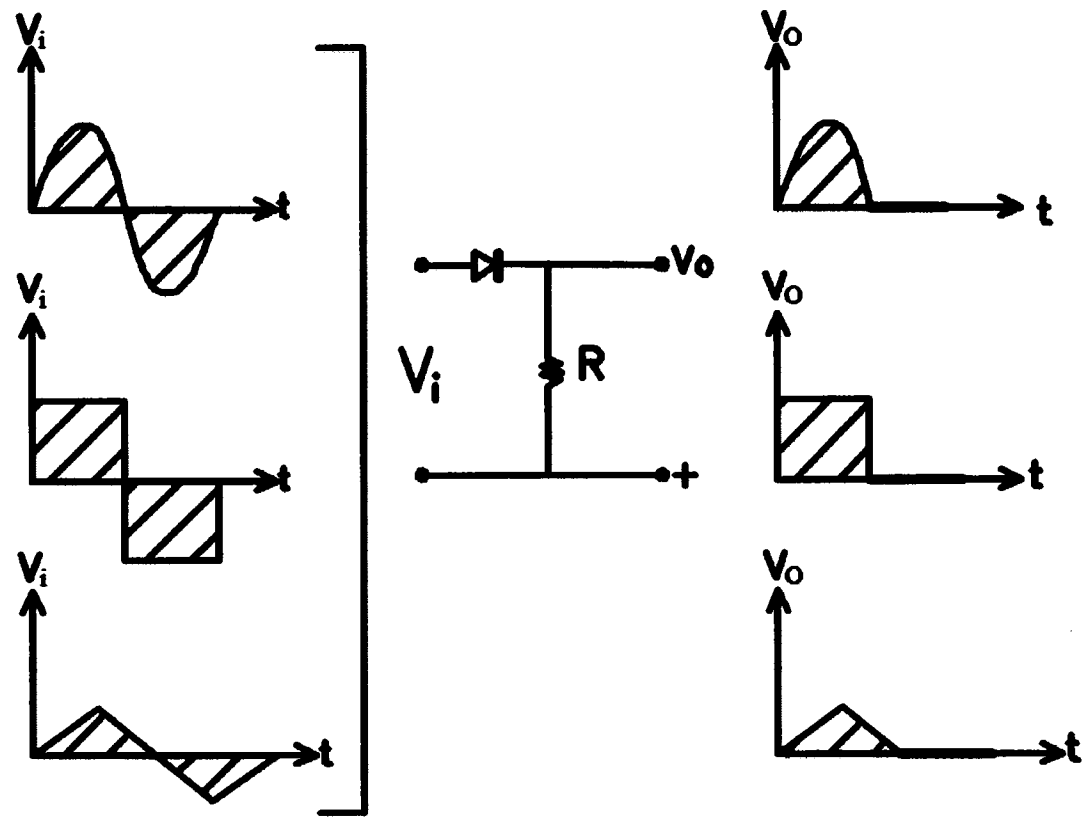
_Series .

_Parallel .

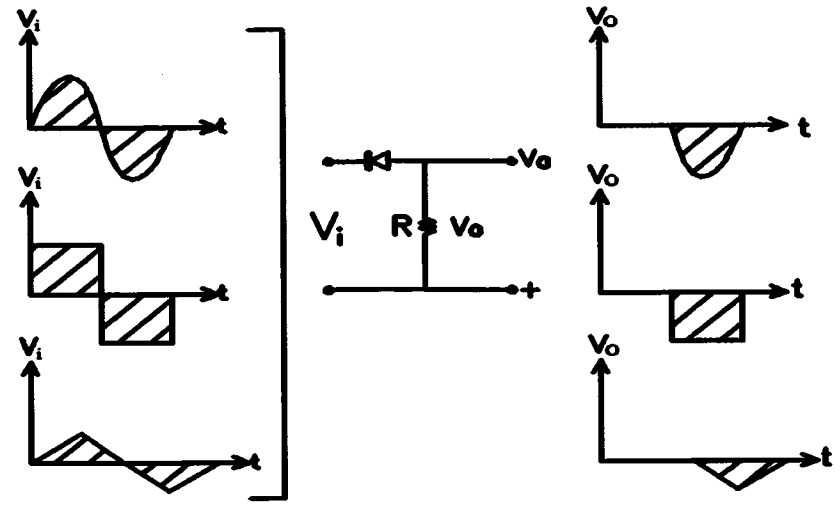
*Half-wave rectifiers are examples of clippers networks.

Half-wave Rectifier.

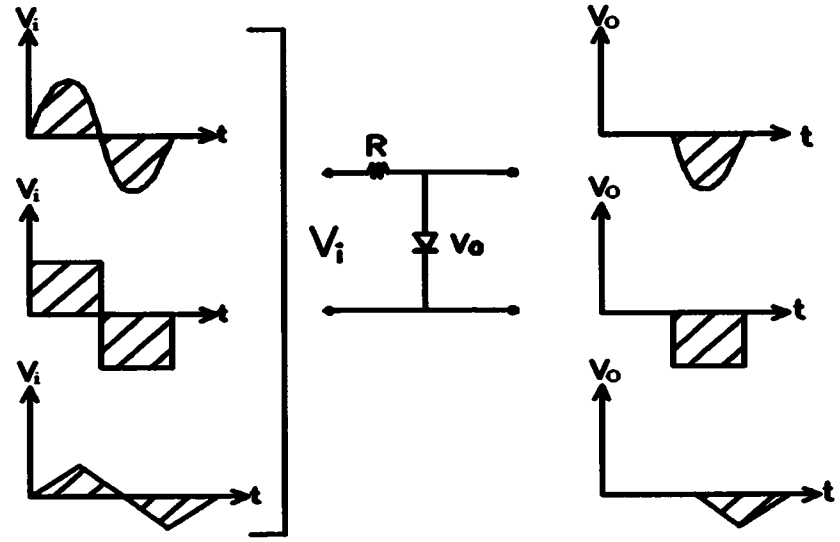
1)

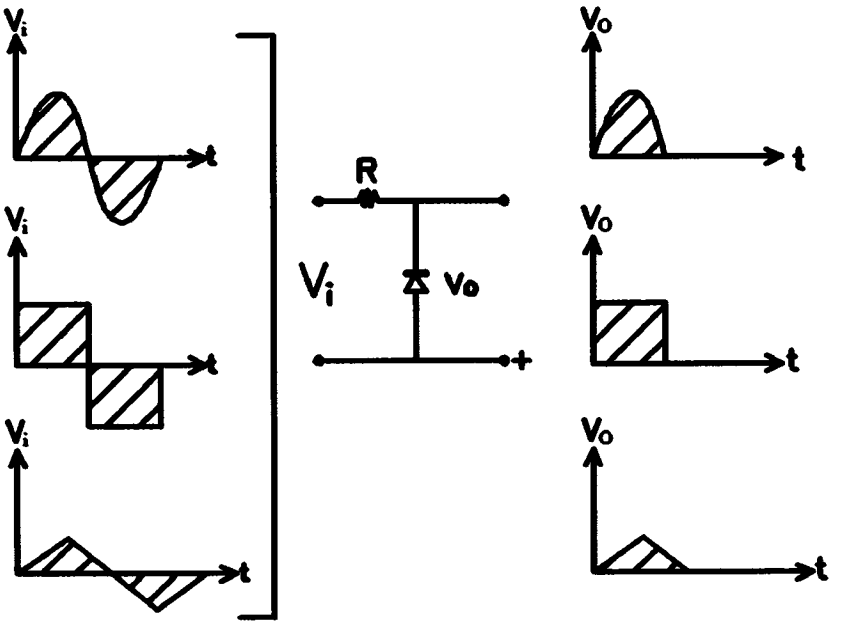


2)


Vi
t
Vi
t
Vi
t
Vi R Vo
+
Vo
t
Vo
t
Vo
t

3)

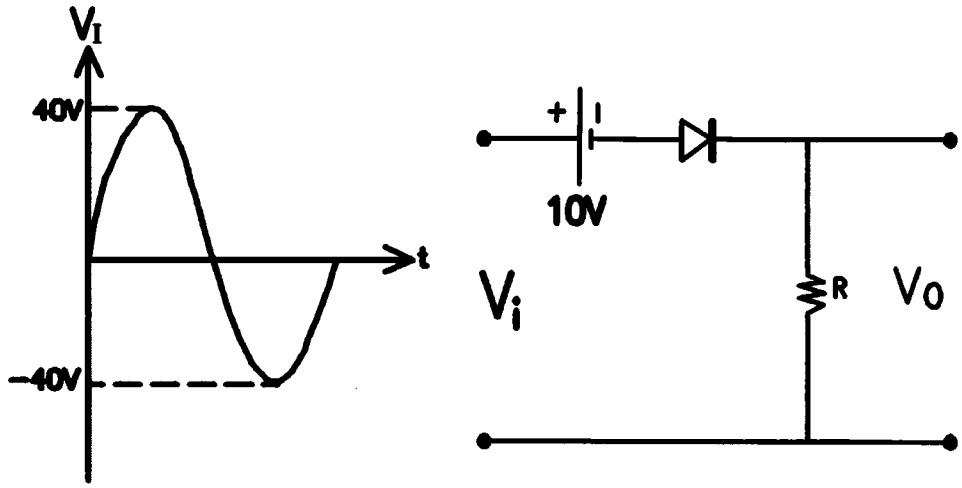

Vi
t
Vi
t
Vi
t
R
Vi Vo
Vo
t
Vo
t
Vo
t


Vi
t
Vi
t
Vi
t
R
Vi Vo
+
Vo
t
Vo
t
Vo
t

Note: To solve the problems either in series or parallel , first we must check or find the voltage which makes the diode in (ON or OFF).

1- Series: It means that the diode connected in series with load.

EX 1 : Determine and plot the output wave form for the circuit shown (the diode is ideal).



Solution: due to the above Note.

V_i > 10 v → Diode (ON) .

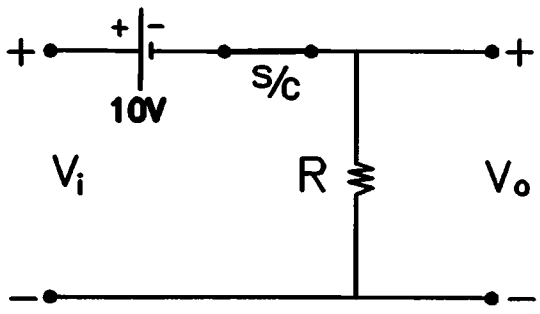
V_i < 10 v → Diode (OFF) .

at V_i > 10 volt :

$V_i = 10 + V_0$

$\therefore V_0 = V_i - 10$

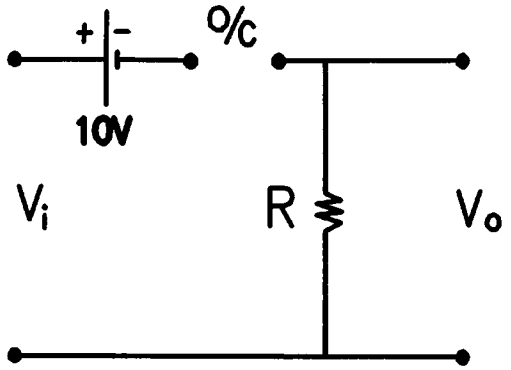
= 40 – 10 = 30 volt.

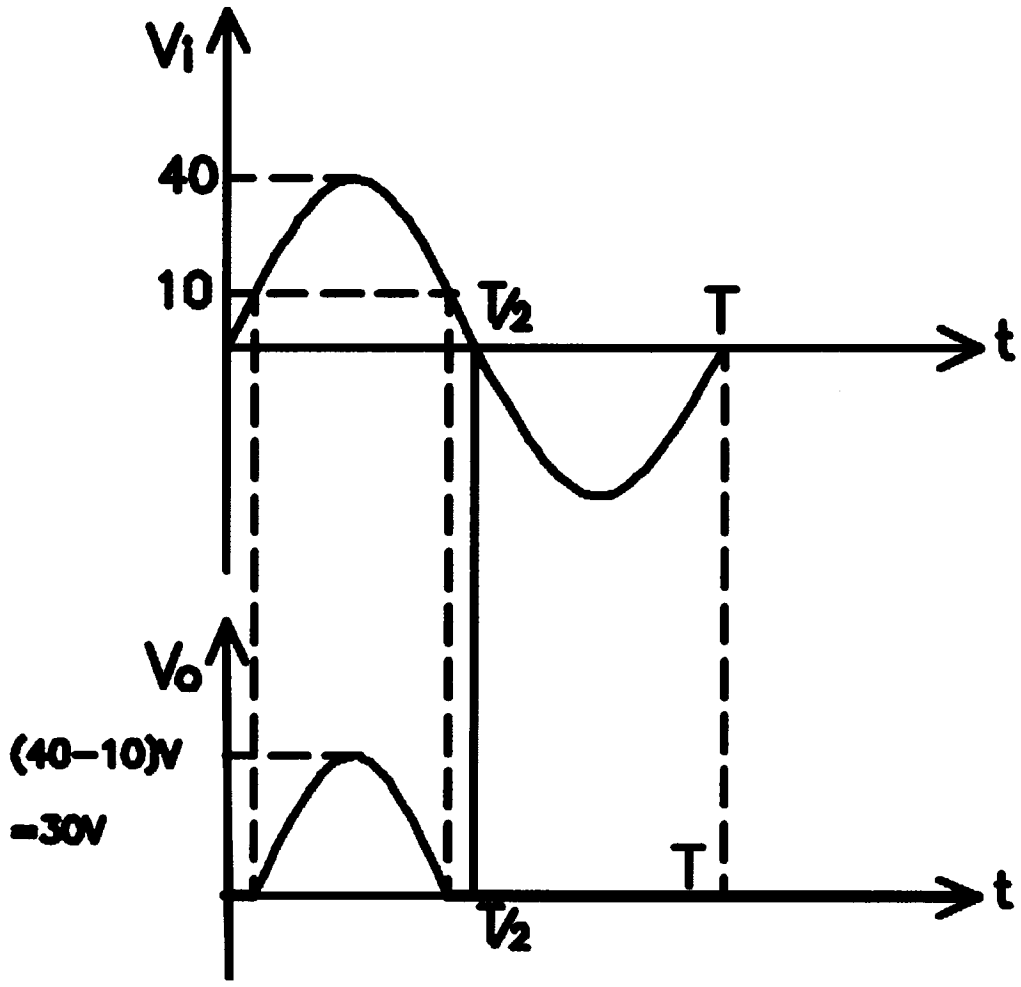


at $V_i < 10$ volt.

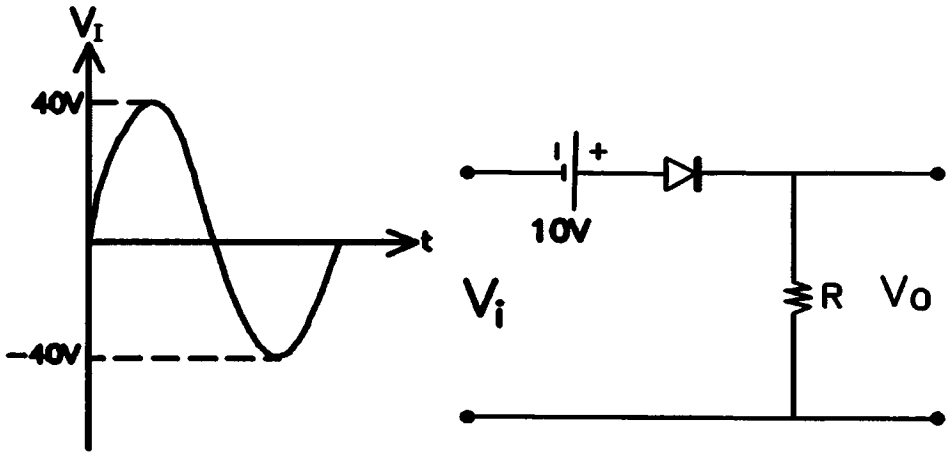
$i = 0$

$\therefore V_0 = 0$





EX 2: For the circuit shown find the output wave form.



Solution: $V_i > -10 \longrightarrow$ Diode (ON)

$V_i < -10 \longrightarrow$ Diode (OFF)

1) At $V_i > -10$

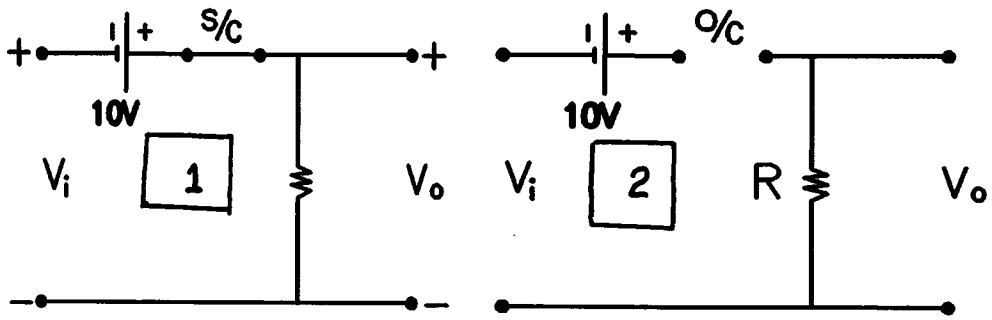
$V_i + 10 = V_0$

$\therefore V_0 = V_i + 10 = 50$ v.

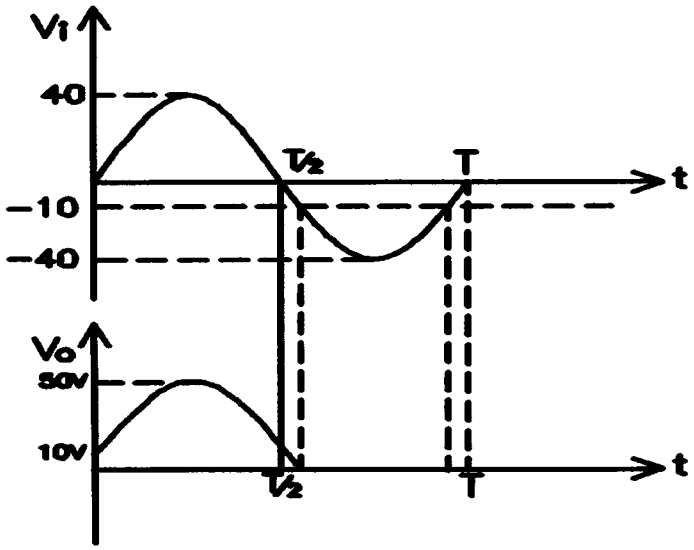
2) at $V_i < -10$

$i = 0$

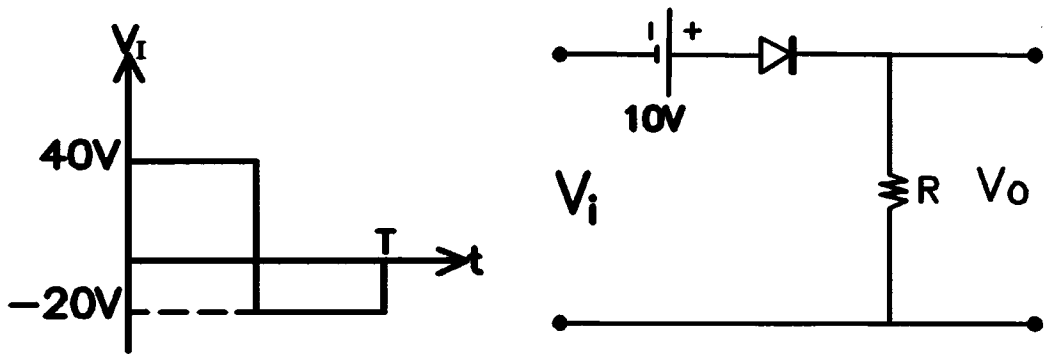
$V_0 = 0$



Vo-wave form:



EX 3 : For the circuit shown , find the output wave form.



Solution : also at V_i > -10 v ⟶ Diode (ON)

V_i < -10 v ⟶ Diode (OFF)

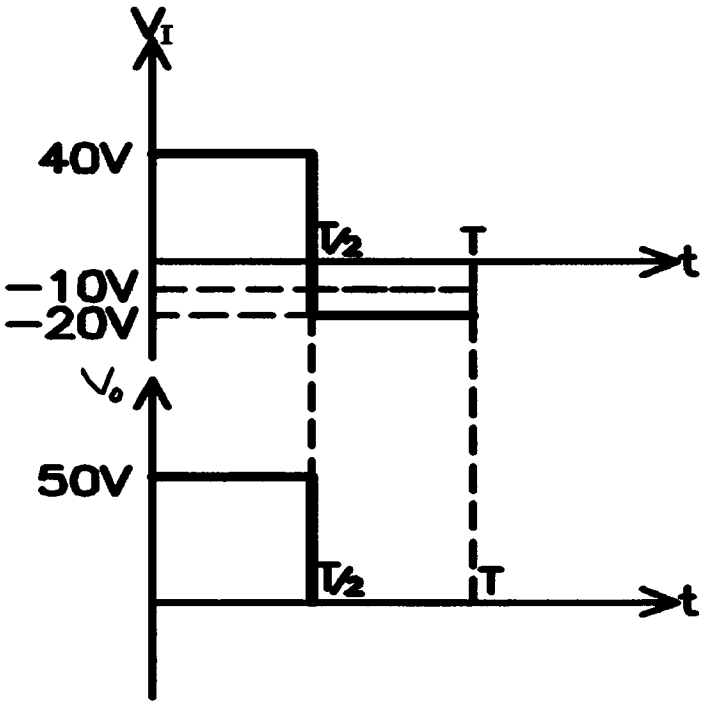
at V_i > -10 v

$V_0 = V_i + 10$

=40 +10 = 50 v.

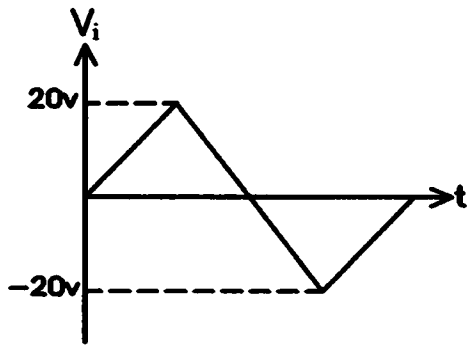
at V_i < -10

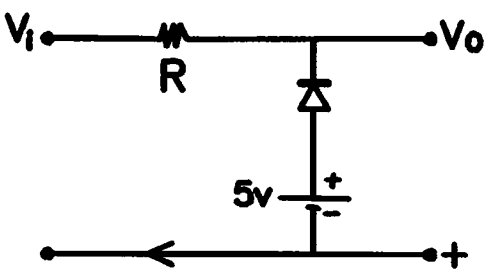
$V_0 = 0$.



2- Parallel: It means that the diode connected in parallel with the output (load)

EX 4: For the circuit plot (V_0).





Solution:

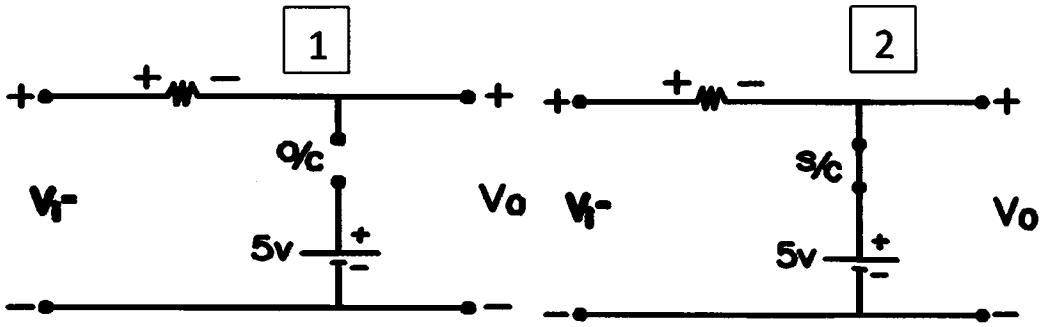
$V_i < 5 \rightarrow$ Diode (ON)

$V_i > 5 \rightarrow$ Diode (OFF)

1) $\therefore$ at $V_i > 5$ $\quad i = 0 \quad V_R = 0$ $\quad \boxed{\therefore V_i = V_0 \text{ Parallel.}}$

2) at $V_i < 5$

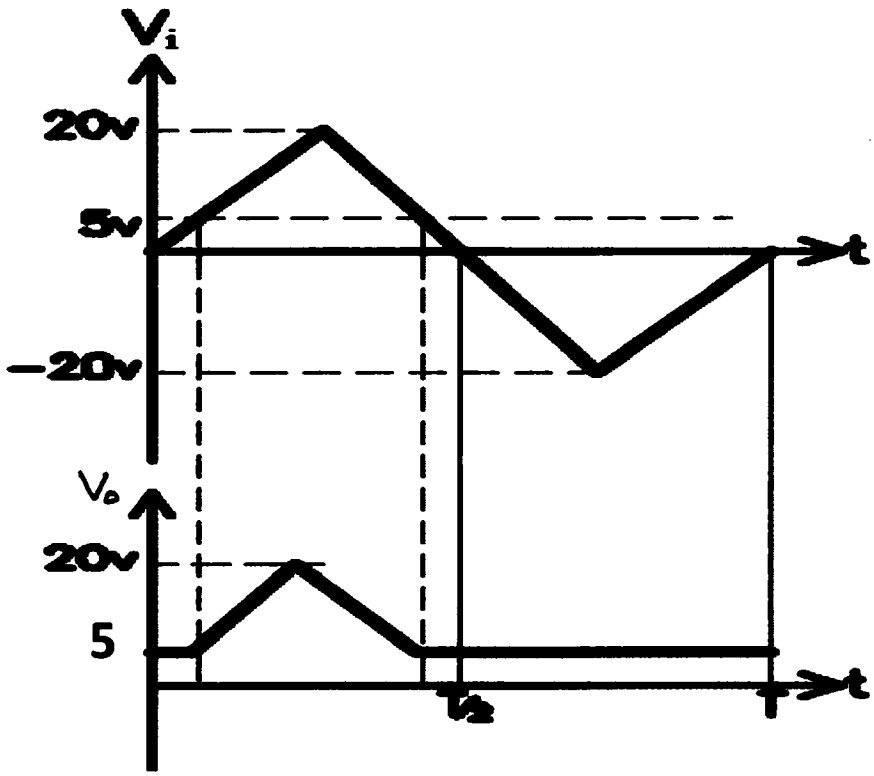
$\boxed{V_0 = 5 \text{ volt}}$



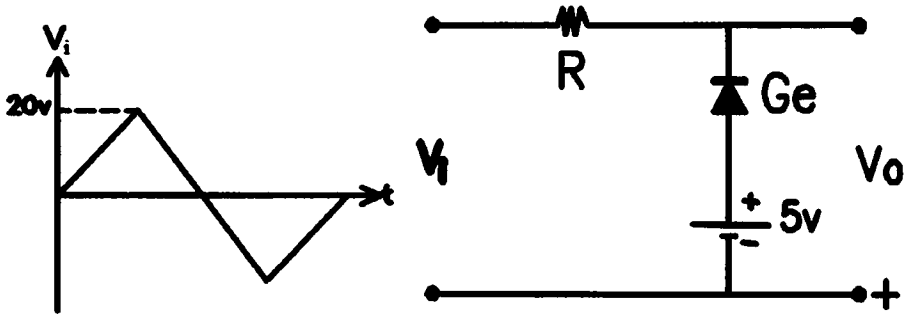
Then the output wave form

V_i > 5 volt → $V_i = V_0$

V_i < 5 volt → V_0= 5 volt.



EX 5: Repeat EX.4 , using the (Ge) diode.

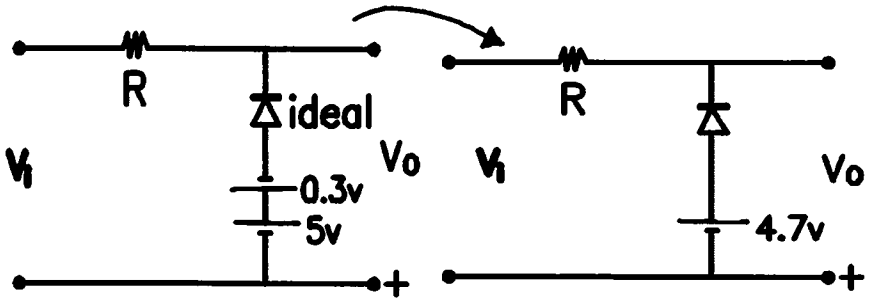


Solution: also:

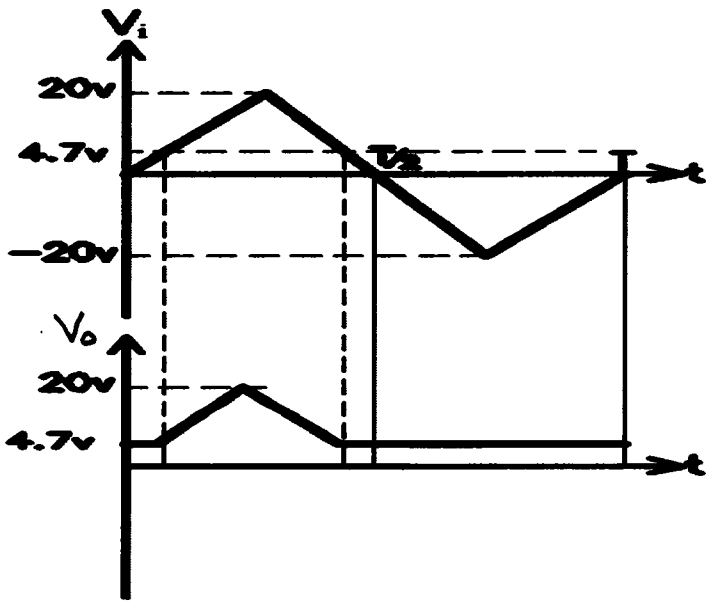
V_i > 4.7 v. →Diode (OFF) V_i < 4.7 v. →Diode (ON)

and : V_i > 4.7 v. ⟶ $V_0 = V_i$

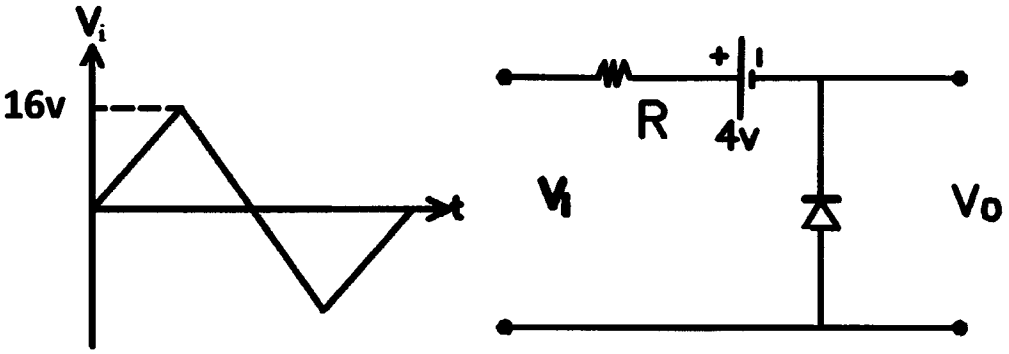
V_i < 4.7 v. ⟶ V_0 = 4.7 volt.



then the output wave form is



EX 6: For the circuit shown find the output wave form

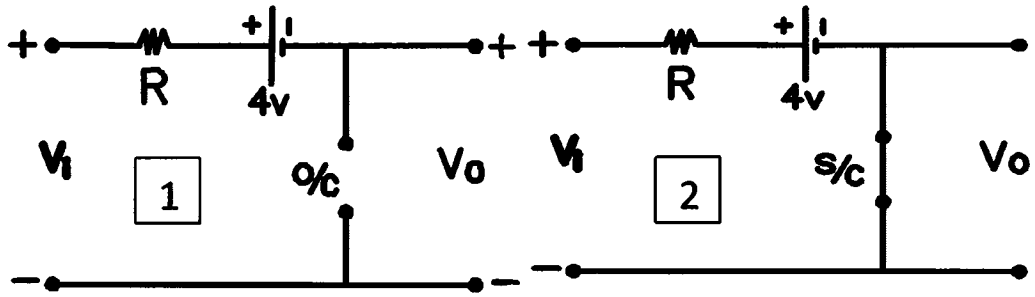


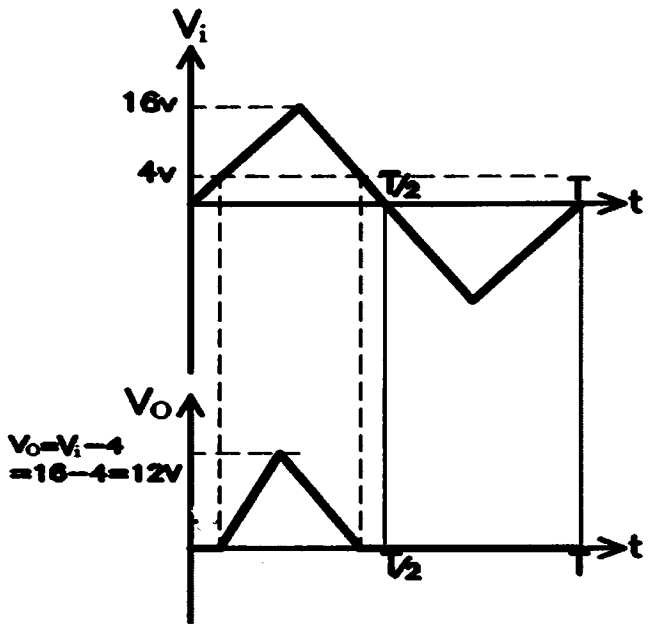
Solution:

$V_i > 4$ v.⟶ Diode (OFF) $V_i < 4$ v.⟶ Diode (ON)

1) at $V_i > 4$ v. $V_i = V_0 + 4$ $\therefore V_0 = V_i - 4$

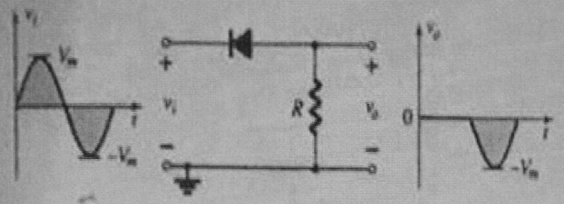
2) at $V_i < 4$ volt. $\therefore V_0 = 0$ (short-circuit).



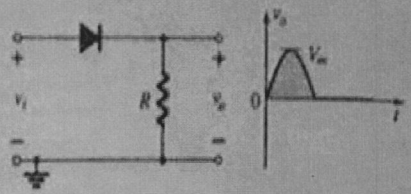


Simple Series Clippers (Ideal Diodes)

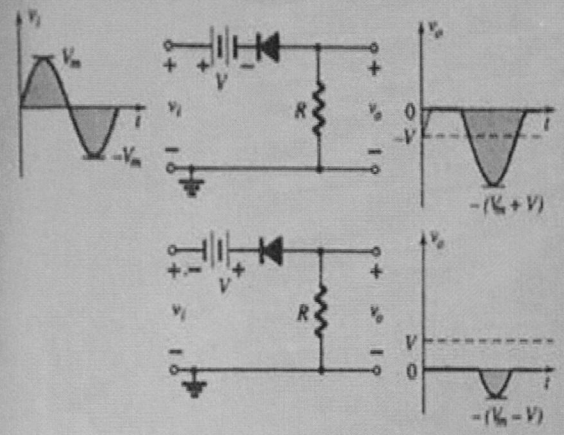
POSITIVE

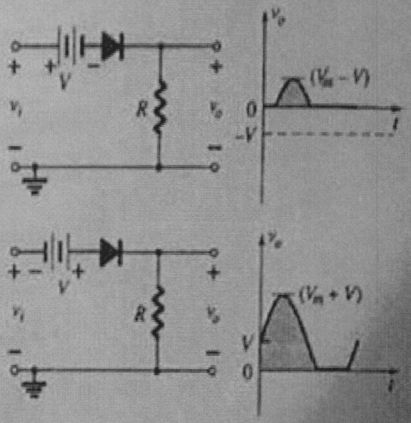


NEGATIVE

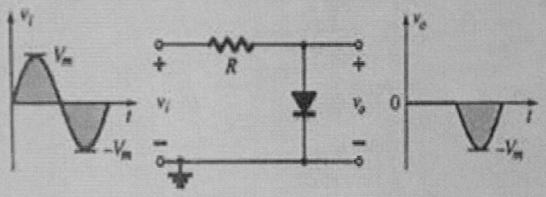


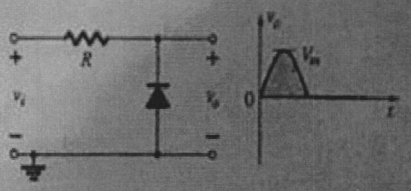
Biased Series Clippers (Ideal Diodes)



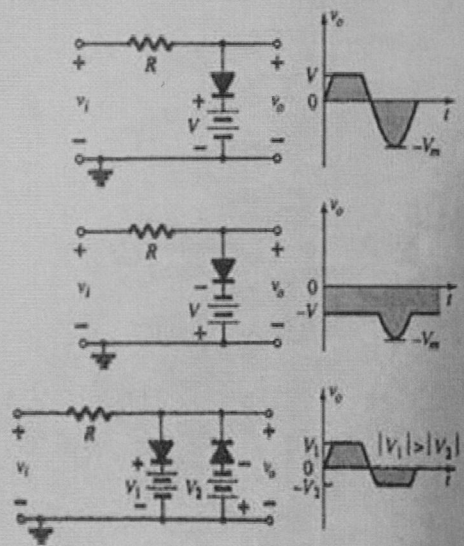


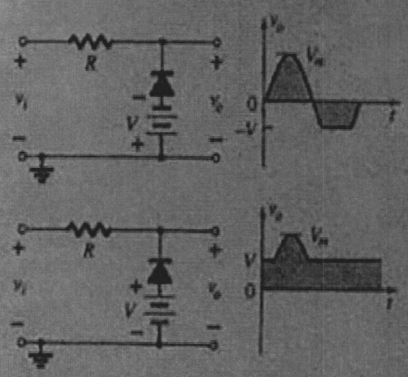
Simple Parallel Clippers (Ideal Diodes)





Biased Parallel Clippers (Ideal Diodes)





Clampers

The clamping network will clamp a signal to different (d-c) level.

*clamping network has a **diode , a capacitor (c) and a resistor (R)** , it may also have a (d-c) supply.

*we will assume that for all practical purposes the capacitor will fully charges or discharge in (five (5) times time constant **(ϯ)) (5ϯ)** ,where

ϯ = time constant = R x C

Brief Notes on Capacitors

Capacitor: •—||—• •—|(—•

Its unit is (Farad)

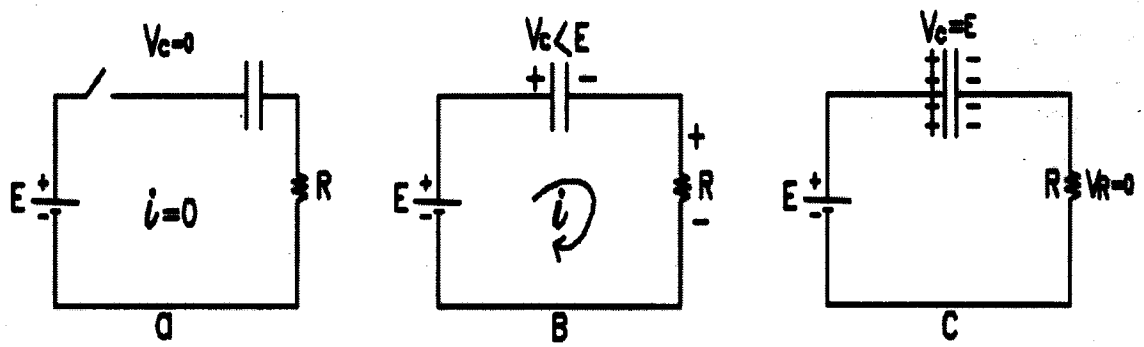
$C = \frac{Q}{V}$ where.

C: capacitor.

Q: charge on capacitor.

V: potential difference across capacitor.

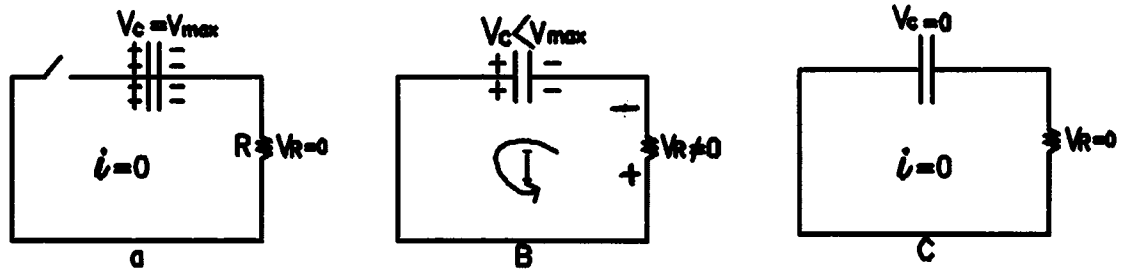
Charging a capacitor



Time of charging ∝ R.C

Discharging a capacitor

also time of discharge ∝ R.C

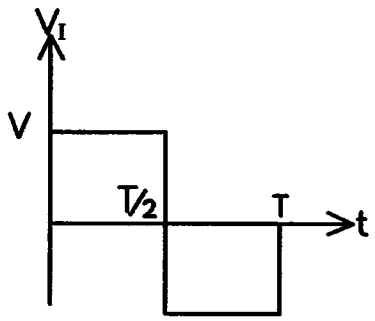


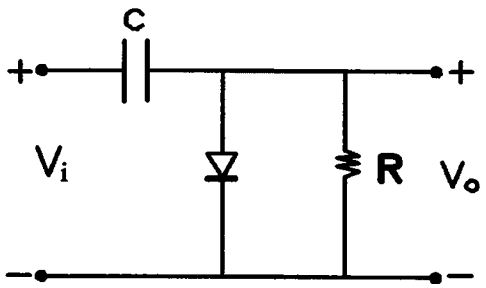
Assumptions

1- When charging the capacitor (at the 1st time), the charging time is **too** small (RC is very small) or, the capacitor will be charged to the maximum value of voltage very quickly.

2- Discharging the capacitor: the time of discharge is very large (R.C) is very large so that the capacitor may maintain its max. Value of voltage for a time long enough.

EX 1: For the circuit shown, explain and draw the output wave form.





Solution:

At t: 0 $\rightarrow \frac{T}{2}$

a- The diode is in for word bias (s/c).

b- The current will not flow through (R) → why?

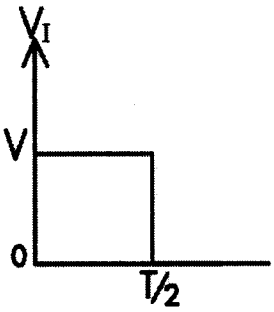
c- Then the time constant (ϛ) is very small (ϛ = R_N C). where

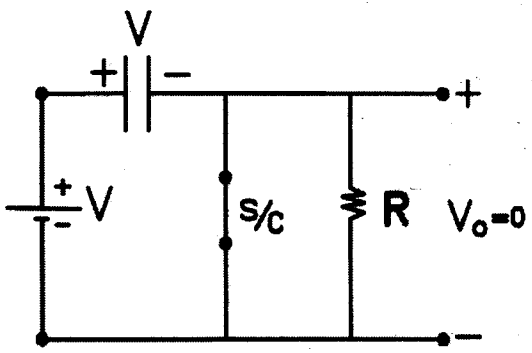
R_N = Inherent resistance of network (contact wire).

d- The capacitor (C) will be charged to voltage (V) very quickly during this interval ($0 \rightarrow \frac{T}{2}$).

e- The (V_0) is zero (parallel to short – circuit).

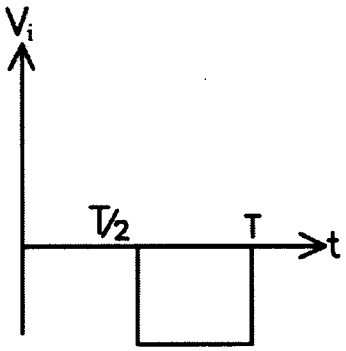
f- During the capacitor charging to the max-voltage (V), the output voltage is zero (V_0=0).

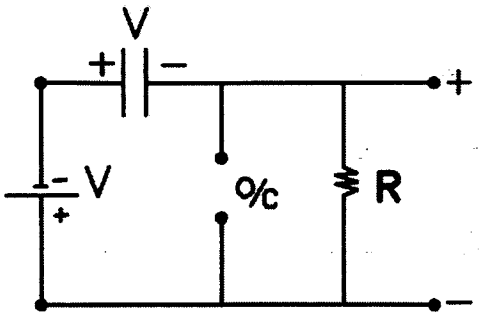




At t : $\frac{T}{2} \rightarrow$ T

a- The diode is in reverse bias (O/C) or (OFF) as shown





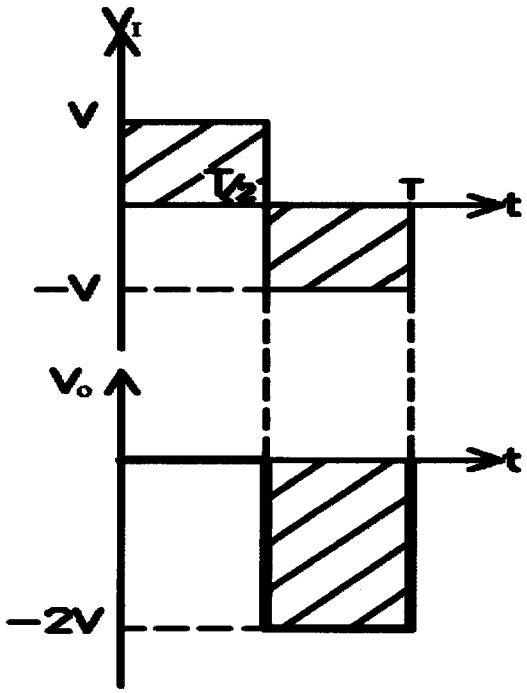
b- The current will flow through resistor (R) then the time constant (ζ = RC) is large and the discharge time of capacitor is large.

c- The time (5 RC) is much greater than the time interval ($\frac{T}{2} \rightarrow T$). It means that the capacitor maintains all its charge (voltage) at (V) during this interval.

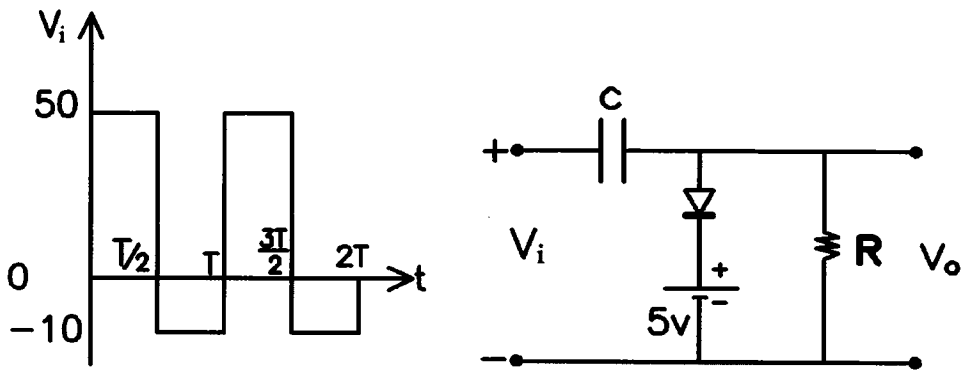
d- By using (KVL).

$V_0 + V + V = 0.$ Or V_0 =-2V.

Output wave form→



EX 2: For the circuit shown , determine the output wave form



Solution

1) at t: $0 \rightarrow \frac{T}{2}$

The diode is (ON)

V_0= 5v (parallel).

By (KVL).

50 =V_C + 5 $\therefore V_C$ = 45 → charging voltage of (c).

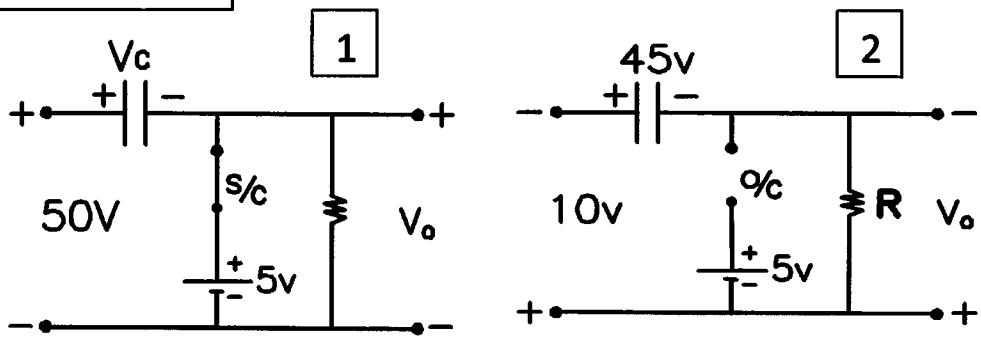
2) at t: $\frac{T}{2} \rightarrow$ T.

The diode is (OFF).

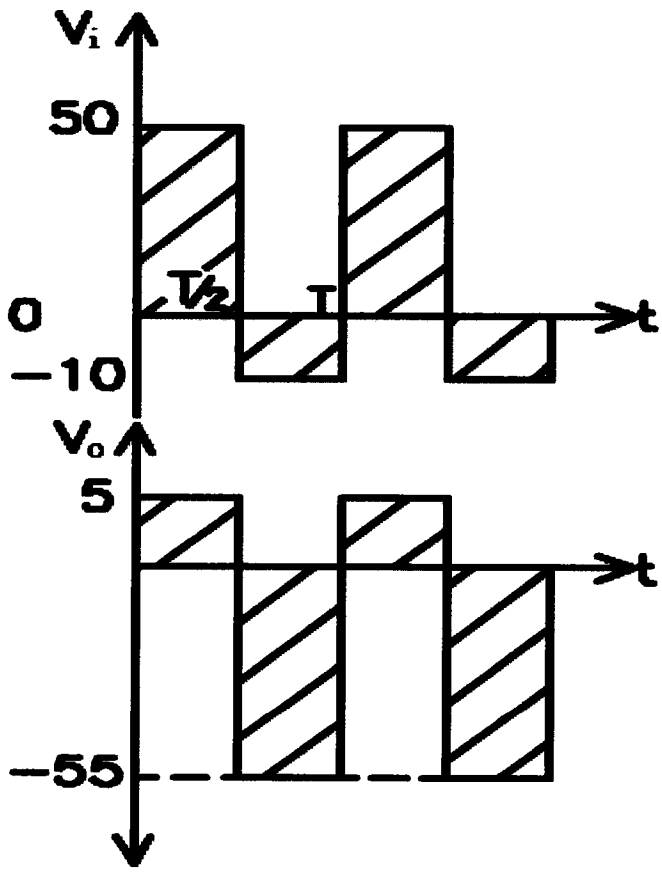
By (KVL)

V_0+ 45 +10 = 0.

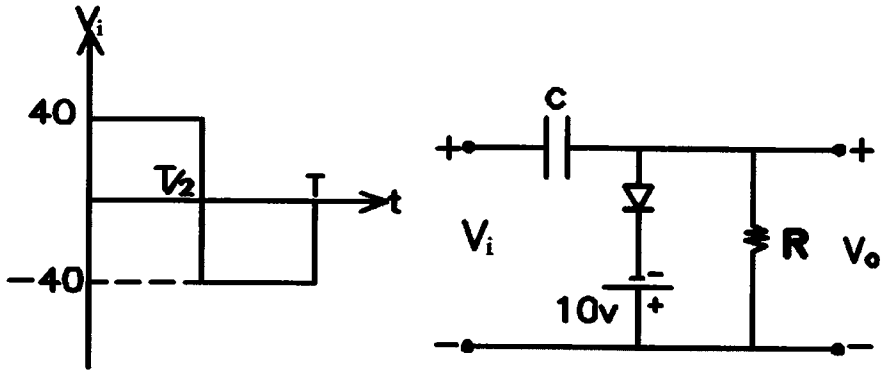
$\therefore V_0$= -55 volt.



output wave form:



EX 3: For the circuit shown , determine the output wave form.



Solution

1) at t: $0 \rightarrow \frac{T}{2}$ The diode is (ON).

V_0= -10 v (parallel)

By (KVL)

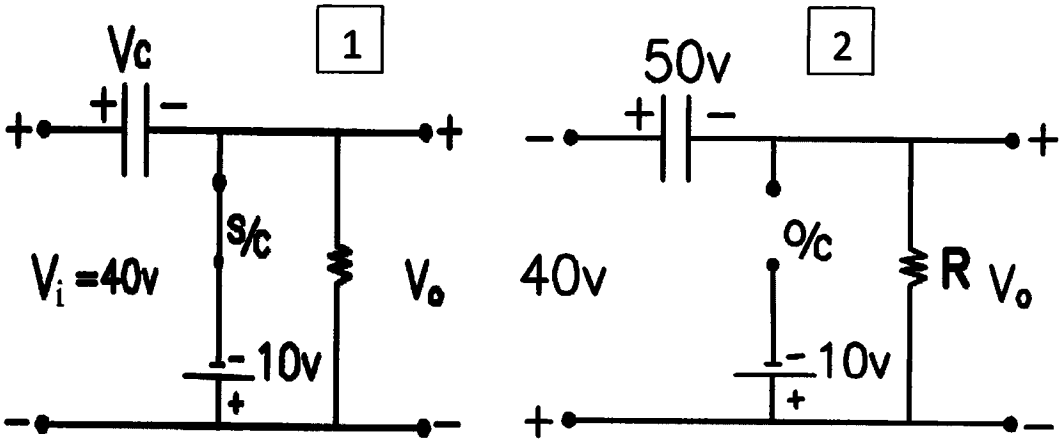
$10+V_i=V_C$.

$\therefore V_C$= 40 + 10 = 50 volt.

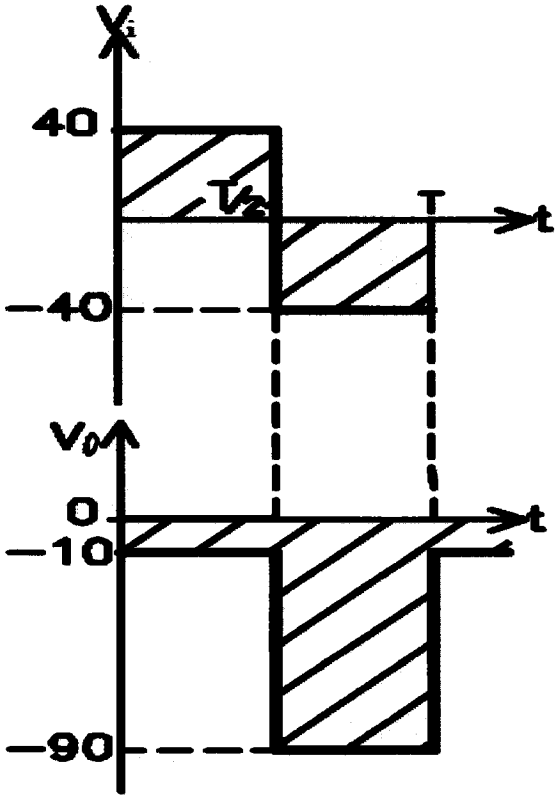
2) at t: $\frac{T}{2} \rightarrow$T The diode is (OFF)

By (KVL) $V_0+50+40=0$

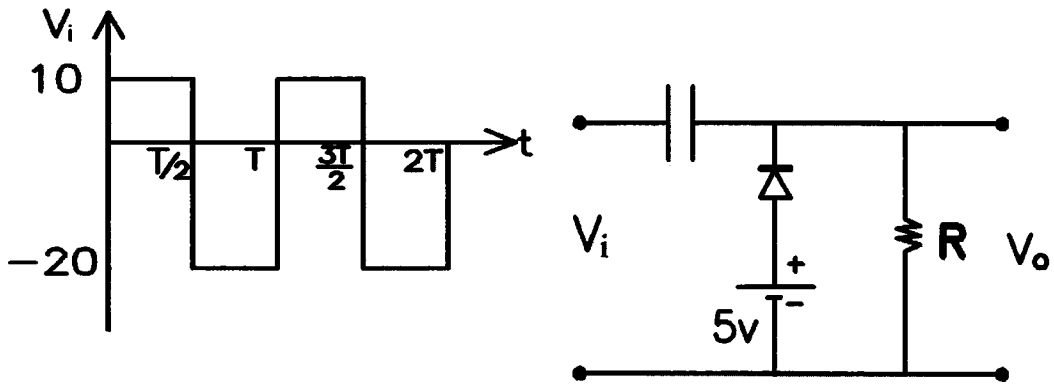
Or V_0=-90 volt.



∴ Output wave form →



EX 4: For the circuit shown, find (V_0).



Solution

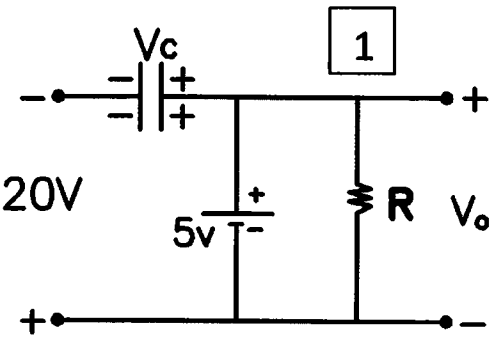
1) at t: $\frac{T}{2} \rightarrow$T The diode is (ON).

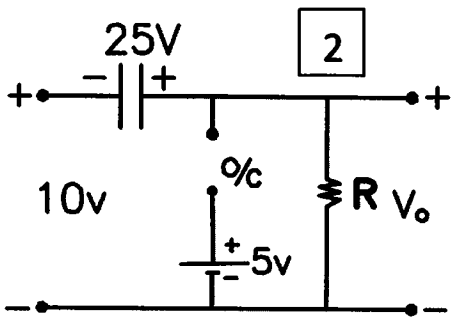
V_0=5 v (parallel) .

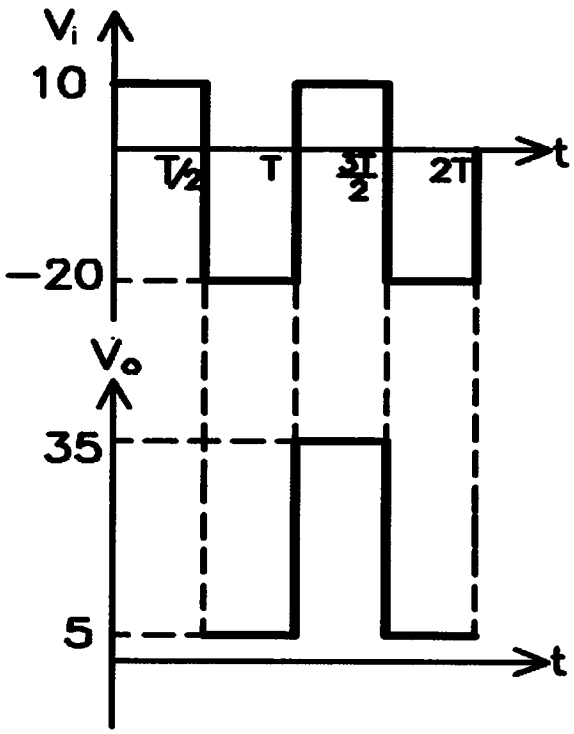
By (KVL) V_C-20-5=0 V_C=25 volt.

2) at t: $T \rightarrow \frac{3T}{2}$ The diode (OFF) .

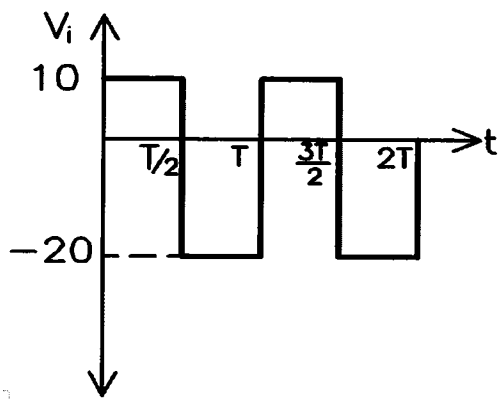
By (KVL) V_0=10+25=35 volt.

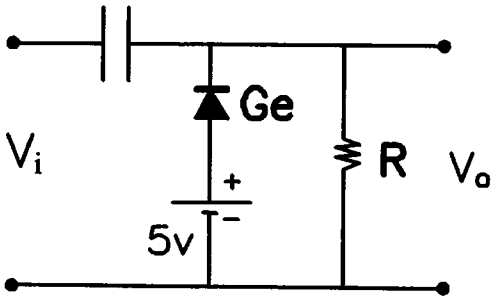






EX 5: Find (V_0) if the diode is (Ge) .





49

Solution

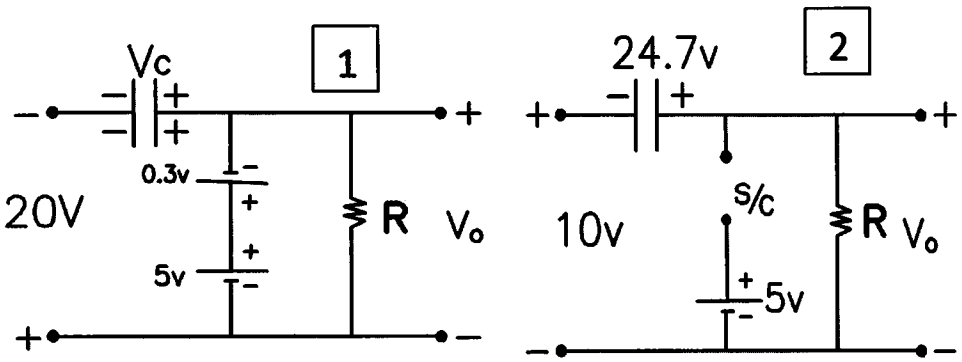
1) at t:$\frac{T}{2}$ →T The diode is (ON).

V_0=5 – 0.3 = 4.7 volt.

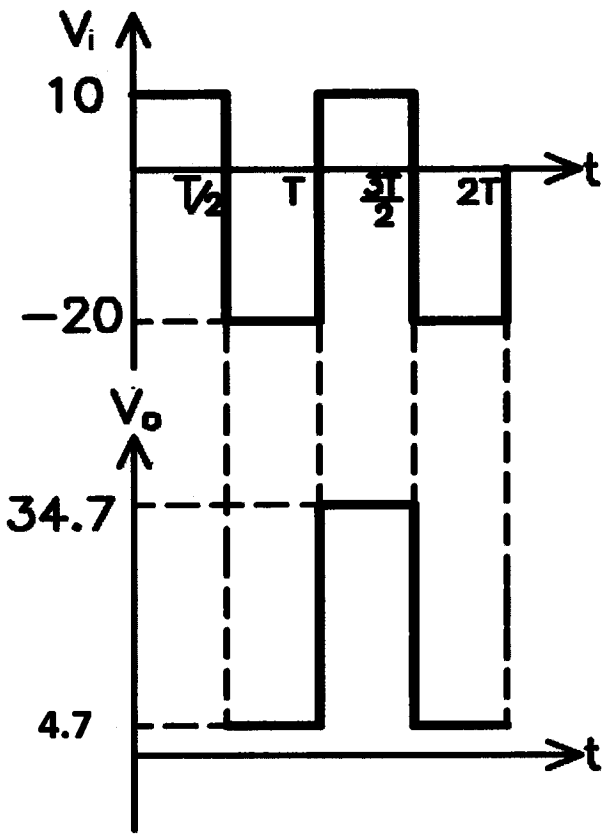
By (KVL) V_C +0.3 = 20+5 V_C=24.7 volt

2) at t: T → $\frac{3T}{2}$ The diode is (OFF).

V_0= 10 + 24.7 = 34.7 volt.



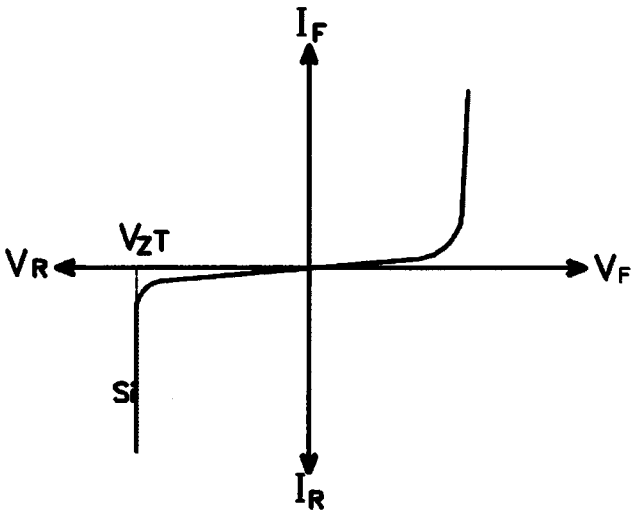
∴(V_0) waveform→



Zener Diodes

Break down region (V_{BD})(or zener region V_{ZT}) occurs in a semiconductor diode at a reverse bias potential.

*Zener diode is a device that is designed to make full use of the zener region (at voltage V_{ZT}).



Where : T→ test

So (V_{ZT} → Zener test voltage).

*Any voltage from (0→V_{ZT}) will result in an open circuit (on current)→ approximation.

*when V_{ZT} is reached, then zener diode starts conducting → approximation.

* V_{ZT} is also called (reverse off set voltage).

*** V_{ZT} depends on temperature and doping level.**

* Increasing the doping decrease the (V_{ZT}).

* (Si) is usually preferred in zeners.

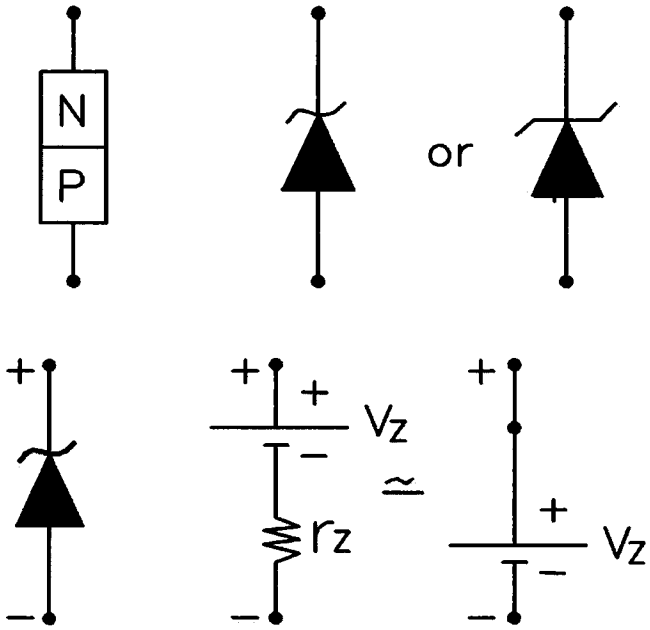
* A zener diode is like an **ordinary** diode except that it is properly doped so as to have a sharp break down voltage.

** A zener diode is **always reverse connected** , it is always reverse biased.

* A zener diode has sharp breakdown voltage , called zener voltage (V_Z).

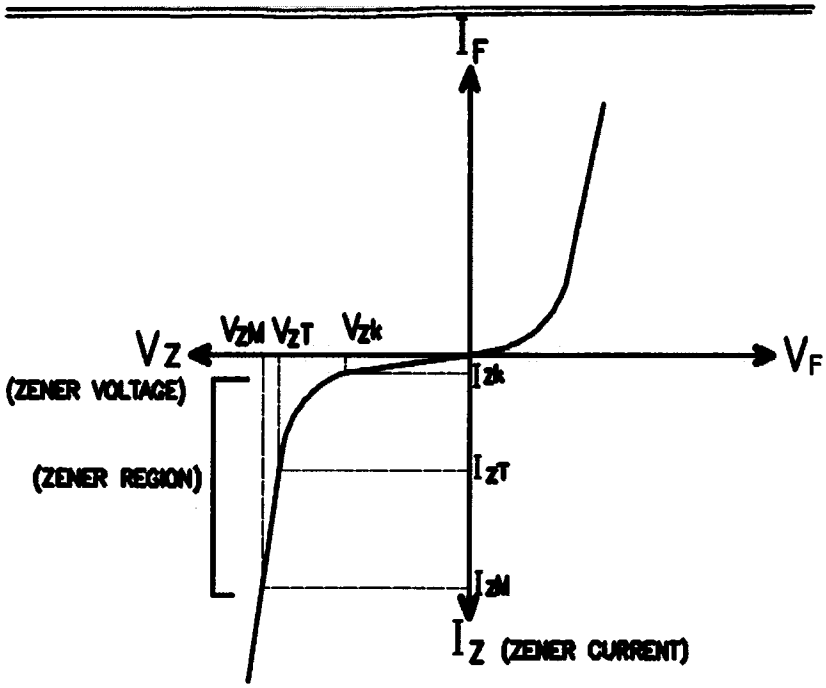
* When forward biased , its characteristics are just those of **ordinary diode**.

* The symbol of zener diode as shown below.



where (rz:Dynamic resistance)

Zener Diode Specification and Rating



ZENER diode char. curve

Where:

Zener knee → The portion of the reverse curve where the diode just begins going into breakdown.

IZK → The zener current at the zener knee (It is the minimum current needed to make the diode operate at breakdown region). As shown in fig.

Zener region → It is the breakdown region in zener diode (aftar zener knee). In this region the voltage is approximately constant over a wide variation in current.

I_{ZT} → Zener test current

V_{ZT} → zener test voltage (nominal zener voltage).

I_{ZM} → **Maximum allowable** zener current (max zener current which can be safely conducted by the zener diode) .

Effect of Temperature

*(V_{ZT}) may increase or decrease with increasing the tem perature. (This depends on doping).

KT → Zener voltage temperature coefficient ,(KT) indicates the percentage change in nominal zener voltage (V_{ZT}) for each degree centigrade in diode temperature , its units is :% / c°.

$$\therefore \mathbf{KT} = \frac{\Delta V_{ZT}}{V_{ZT}(T_1 - T_0)} \; x\; 100$$

Where:

ΔV_{ZT} : Resulting change in zener potential due to temperature variation. (T_1- T_0).

T_0 : Temperature at which (V_{ZT}) is given (usually T room).

T_1 : The new temperature.

Form above equation.

$$\Delta V_{ZT} = \frac{KT\ X\ V_{ZT}\ X\ (T_1 - T_0)}{100} \text{ ... volt.}$$

$$\Delta V_{ZT} = V_{ZT1} - V_{ZT}$$

V_{ZT} at T_1 | V_{ZT} at T_0

Note: +ve KT → V_{ZT} increase with temp.

-ve KT → V_{ZT} decrease with temp

EX: A given zener diode of a nominal zener voltage (V_{ZT}=10 volt) at room temperature (25 c°). Find the nominal voltage at a temperature of (100c°). Given that KT = 0.072% / c°.

Solution : we have

$$\Delta V_{ZT} = \frac{KT\ X\ V_{ZT}\ X\ (T_1 - T_0)}{100}$$

$$= \frac{0.072\ X\ 10\ X\ (100-25)}{100} = 0.0072\ X\ 75 = 0.54.$$

$\therefore\ \Delta V_{ZT} = 0.54.$

But $\Delta V_{ZT} = V_{ZT1} - V_{ZT}$

$\therefore 0.54 = V_{ZT1} - 10$

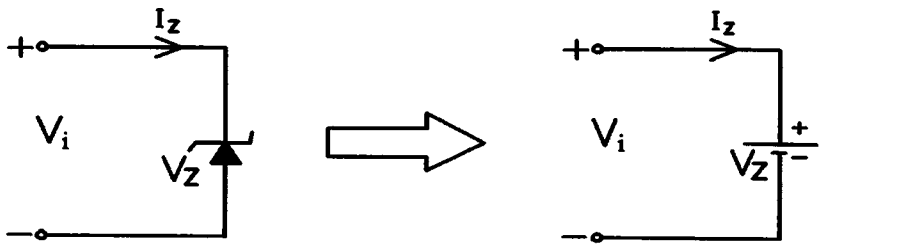
$\therefore V_{ZT1} = 10 + 0.54 = 10.54\ volt.$ (This is the value of V_Z at temp. of 100 c°).

Equivalent Circuit of Zener diode

The analysis of circuits using zener diodes can be made quite easily by replacing the zener diode by its equivalent circuit.

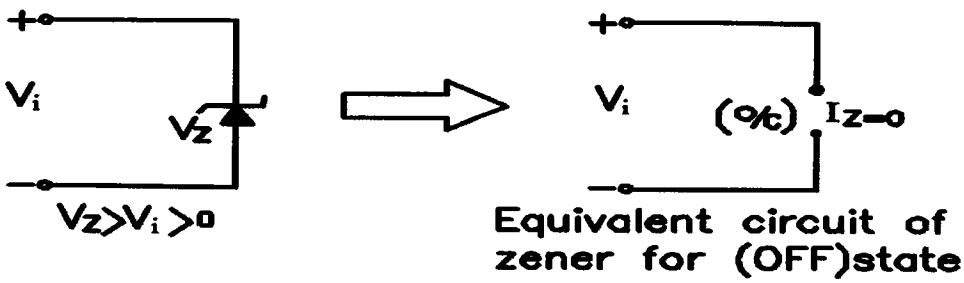
1-(ON) state : When reverse voltage a cross a zener diode is equal to **or** more than breakdown voltage (V_Z), the current increase very sharply. In this region the curve is almost vertical as shown in fig (1).

It means the voltage a cross zener diode is constant at (V_Z) even though the current through it changes. Therefore in the breakdown region , an ideal zener diode can be represented by a **battery** of voltage (V_Z) as shown below ,under this condition the zener is said to be in (ON) state.



Equivalent circuit of zener for (ON)state

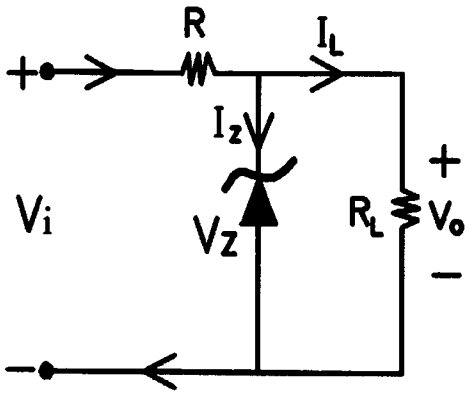
2- (OFF) state : When the reverse voltage a cross the zener diode is less than (Vz) but greater than (O), the zener diode is in the (OFF) state , the zener diode can be represented by an **open-circuit** as shown below.



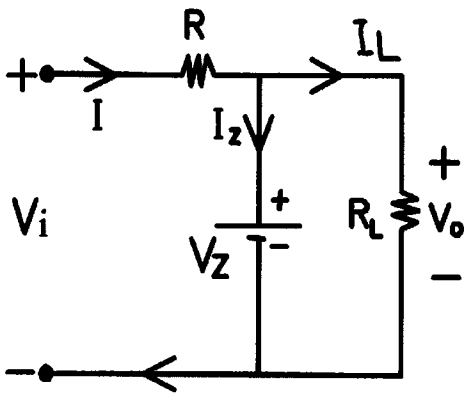
Equivalent circuit of zener for (OFF)state

Zener Diode as Voltage Stabilizer

A zener diode can be used as a voltage regulator to provide a constant voltage from a source whose voltage may vary over sufficient range. The circuit arrangement is shown in fig (1).The zener diode at zener voltage (V_Z) is reverse connected a cross the load (R_L) a cross which constant output is desired. It may be noted that the zener will maintain a constant voltage ($V_Z = V_0$) a cross the load so long as the input voltage does not fall below (V_Z).



Fig(1)



Fig(2)

When the circuit is properly designed, the load voltage (V_0) remains constant equal (V_Z), even though the input voltage (V_i) and (R_L) may vary over a wide range.

a-Suppose the input voltage increases. Since the zener is in the breakdown region, the zener diode is equivalent to a battery (V_Z) as shown in fig (2).

It is clear that output voltage remains constant at ($V_Z = V_0$). The excess voltage is dropped a cross the series resistance (R). This will cause an increase in total current (I). The zener will conduct the increase of current in (I) while the load current

remains constant hence output (V_0) remains constant irrespective of the changes in input voltage (V_i).

b- Now suppose that (V_i) input is constant but (R_L) decreases. This will cause an increase in (I_L). The extra current cannot come from the source because drop in(R) and hence source current (I) will not change as the zener is within its regulating range. The additional (I_L) will come from a decrease in (I_Z). Consequently the out put voltage stays at constant value.

Voltage drop across(R) = $V_i - V_0$

Current through R,

$$I = I_Z + I_L \rightarrow \text{KCL}$$

∴By ohms Law

$$R = \frac{V_i - V_0}{I_Z + I_L}$$

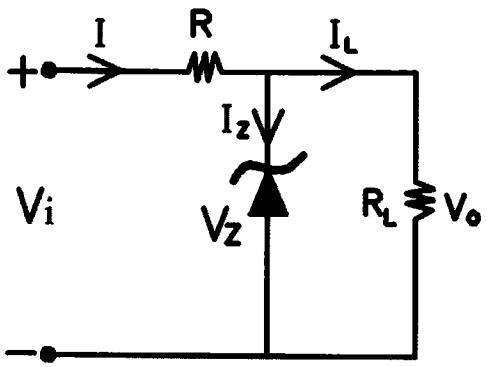
Solving Zener Diode Circuits

The analysis of zener diode circuits is quite similar to that applied to the analysis of semi conductor diodes. The first step is to determine the state of zener diode i .e , whether the zener is in the (ON) state. Or (OFF) state . Next the zener is replaced by its appropriate model. Finally the unknown quantities are determined from the resulting circuit.

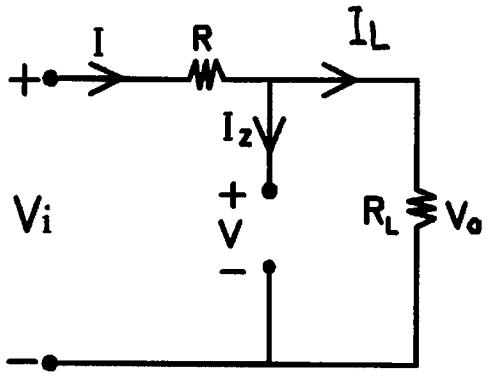
1- If (V_i and R_L)fixed:

This is the simplest case and is shown in fig (3), Here the applied voltage (V_i) and (R_L) is fixed. The first step is to find the state of zener diode. This can be determined by **removing the**

zener diode from the circuit and calculate the voltage (V) a cross the resulting (open-circuit) as shown in fig (4).



Fig(3)



Fig(4)

From fig(4)

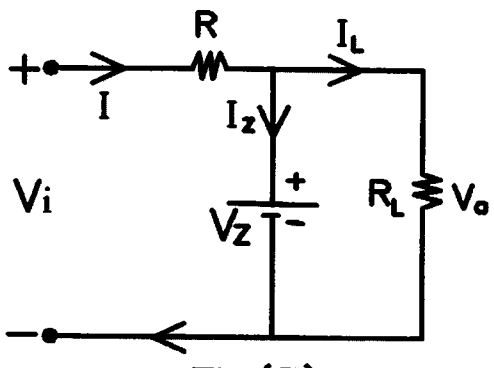
$$V = V_0 = \frac{V_i \, X \, R_L}{R + R_L}$$

Now: If $V \geq V_Z$, the zener diode is in the (ON) state.

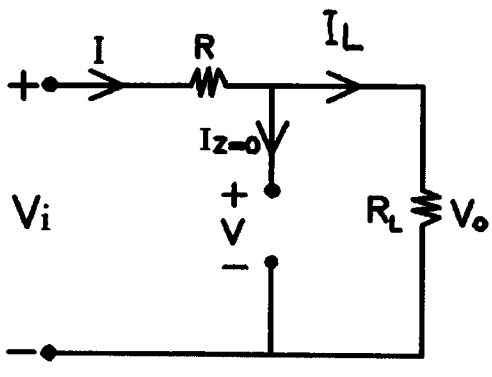
And its equivalent model can be as shown in fig (5) and If

$V < V_Z \rightarrow$ The diode is in (OFF) state as shown in fig(6).

a- (ON) state as in fig (5)



Fig(5)



Fig(6)

from fig(5) :

$$V_Z = V_0$$

$I_L = \frac{V_0}{R_L} = \frac{V}{R_L}$ & $I = \frac{V_i - V_0}{R}$

$\therefore I_Z = I - I_L \rightarrow$ (KCL)

and power dissipated in zener $P_Z = V_Z I_Z$ watts .

b- (OFF) state as in fig (6).

$I_Z = 0 \rightarrow \therefore I = I_L$

$V_R = V_i - V_0$ And V =V_0

and $P_Z = V X I_Z = V_{(0)} = 0$

2- If (V_i fixed & R_L variable):

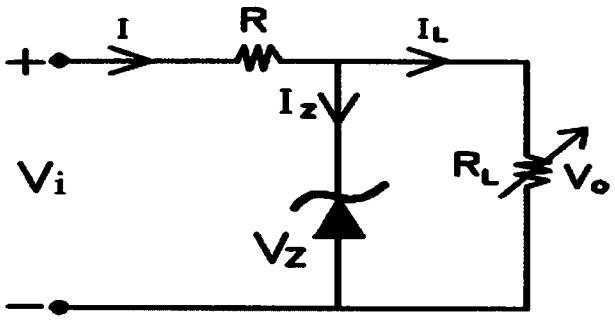
This case is shown in fig (7), here (V_i) fixed and (R_L) and hence (I_L) is changes. Note that there is a definite range of (R_L) values (and hence I_L) which will ensure the zener diode to be in (ON) state.

a-$R_{L\,(min)}$ and $I_{L\,(max)}$:

Once the zener is in (ON) state Load voltage ($V_0 = V_Z$) is constant. As a result, when load resistance is minimum ($R_{L\,min}$), load current will be maximum ($I_L = \frac{V_0}{R_L}$). In order to find the min. load resistance that will turn the zener (ON), we simply calculate (R_L) that will result in ($V_0 = V_Z$).

$\therefore V_0 = V_Z = \frac{V_i R_L}{R + R_L} \rightarrow (V.D.R).$

$\therefore R_{L\,min} = \frac{R V_Z}{V_i - V_Z}$



Fig(7)

This is the ($R_{L\,min}$) that will ensure that zener is in the (ON) state. Any value of load resistance less than this value will result in a voltage (V_0) a cross the load less than (V_Z) and the zener will be in the (OFF) state.

$$\therefore I_{L\,max} = \frac{V_0}{R_{L\,min}} = \frac{V_Z}{R_{L\,min}}$$

b- $R_{L\,(max)}$ and $I_{L\,(min)}$: It is easy to see that when $R_{L\,(\max\ )}$, the $I_{L\,(\min\ )}$.

$$I_Z = I - I_L$$

When zener is in the (ON) state, (I) remains fixed . This means that when ($I_{L\,(\max\ )}$), (I_Z) will be minimum on the other hand, when ($I_{L(\min\ )}$), (I_Z) is maximum If the maximum current that a zener can carry safely is (I_{ZM}) then.

$$I_{L(\min\ )} = I - I_{ZM}$$

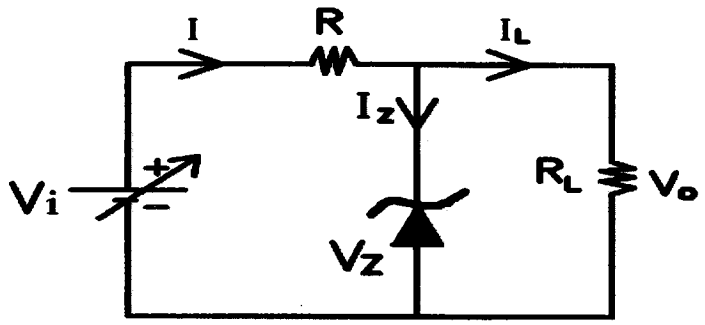
AND:

$$R_{L(\max\ )} = \frac{V_0}{I_{L(\min\ )}} = \frac{V_Z}{I_{L(\min\ )}}$$

Note: If the load resistance exceeds this limiting value, the current through zener will exceed (I_{ZM}) and the device may burn out.

3- IF (V_i *variable and* R_L *fixed*) :

This case is shown in fig (8), Here (R_L) fixed, while the applied voltage (V_i) changes.



Fig(8)

Note that there is a definite range of (V_i) values that will ensure that zener diode is in (ON) state. Let us calculate that range of values.

a- $V_{i(min)}$: To find the $V_{i\,(\min\ )}$ that will turn the zener(ON), simply calculate (V_i) as:

$$V_0 = V_z = \frac{R_L V_i}{R + R_L} \rightarrow V.D.R$$

$$\therefore V_{i(\min\ )} = \frac{V_Z(R + R_L)}{R_L}$$

b- $V_{i\,(max)}$: Now, current through R

$$I = I_Z + I_L$$

Since $I_L = \frac{V_0}{R_L} = \frac{V_Z}{R_L}$ is fixed

$\therefore I$ Will maximum when I_Z is maximum

$$\therefore I_{max} = I_{ZM} + I_L$$

But $V_i = I * R + V_0$. $V_0 = V_Z =$ constant .

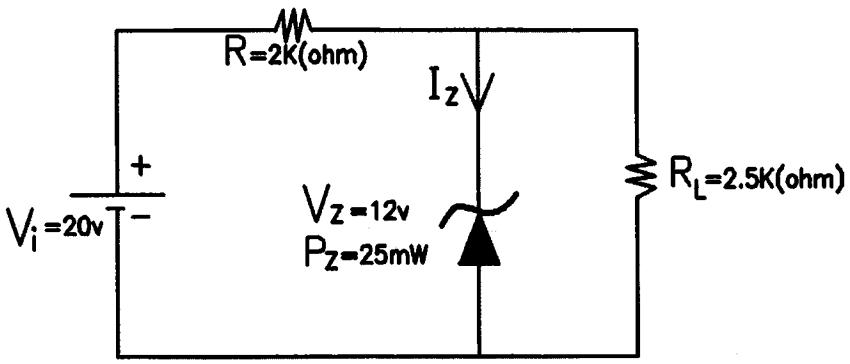
$$\therefore V_{i(\max)} = I_{max}\, x\, R + V_Z$$

$$V_{i(max)} = I_{max}\, x\, R + V_0 .$$

EX 1: For the circuit shown,

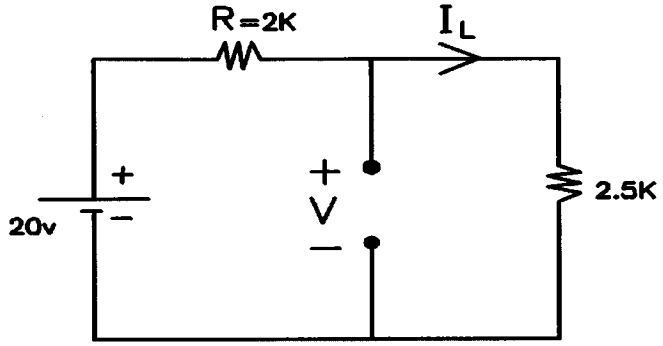
a) Find V_L , V_R , I_Z and P_Z

b) Repeat part (a) with R_L = 4 KΩ.



Solution:

a)



a)V = $\frac{20\ x\ 2.5}{2+2.5}$ = 11.11 volt.

* Since V = 11.11 volt Less than V_Z= 12 volt.

∴ Diode is (OFF) state.

∴ V_L = 11.11 volt.

And $V_R = V_i - V_L$ = 20 – 11.11 = 8.88 volt.

$I_Z = 0\ (open\ circuit)$.

$P_Z = V_Z\ X\ I_Z = 0\ watt.$

b) $V = \frac{V_i\ R_L}{R+R_L} = \frac{20\ X\ 4}{2+4} = 13.33\ volt.$

Since $V > V_Z = 12\ volt. \rightarrow Diode\ is\ (ON) state.$

∴ $V_L = V_Z = 12\ volt.$

$V_R = 20 - 12 = 8\ volt.$

$I_L = \frac{V_L}{R_L} = \frac{12}{4\ K\Omega} = 3mA.$

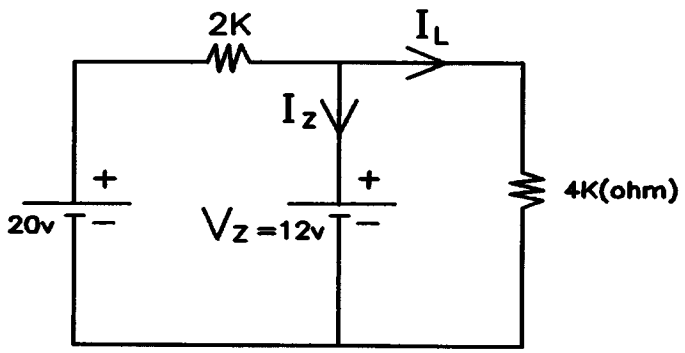
$I_R = \frac{V_R}{R} = \frac{8}{2\ K} = 4\ mA.$

$I_Z = I_R - I_L$

= 4-3 = 1 mAmp.

$P_Z = V_Z\ I_Z = 12\ X\ 1 = 12\ m\ watt.$

b)

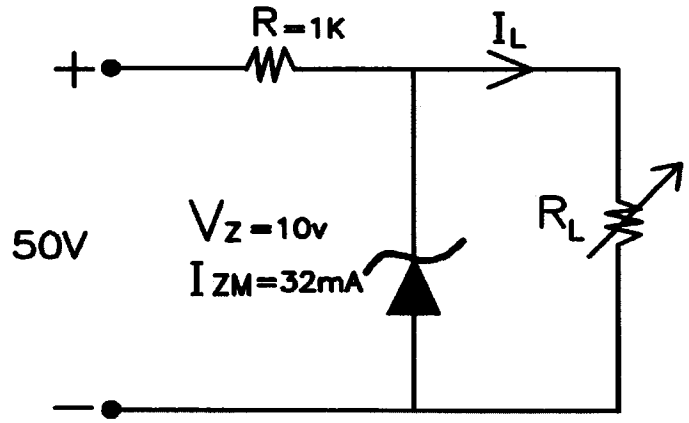


Note: P_Z = 12 m watt is less than specified P_Z = 25 mw.

EX 2: For the circuit shown,

a) Find the range of R_L & I_L that will result in V_{RL} is maintained at 10 volt.

b) The maximum (P_Z) of the diode.



Solution:

a) $R_{L\,min} = \frac{R\,V_Z}{V_i - V_Z} = \frac{1\,K * 10\,V}{50-10} = 250\,\Omega.$

$I_{L\,max} = \frac{V_Z}{R_{L\,min}} = \frac{10}{250} = 40\,mA.$

$V_R = V_i - V_Z = 50 - 10 = 40\,volt.$

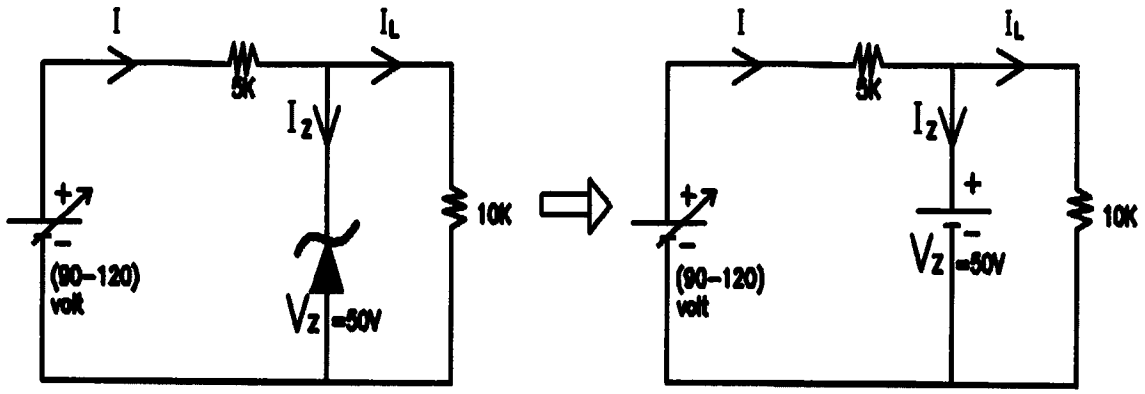
$I_R = \frac{V_R}{R} = \frac{40}{1\,K} = 40\,mA.$

$\therefore\ I_{L\,min} = I_R - I_{ZM} = 40 - 32 = 8\,mA.$

$\therefore\ R_{L\,max} = \frac{V_Z}{I_{L\,min}} = \frac{10\,V}{8\,mA} = 1250\,\Omega.$

b) $P_{Z\,max} = V_Z\ X\ I_{ZM} = 10\ X\ 32 = 320\,m\,watt.$

EX 3 : For the circuit shown, find the maximum & minimum of zener diode current.



Solution: The zener diode is (ON) state because

at $V_i = 90\ v \rightarrow V_L = \frac{90}{5+10} X\ 10 = 60\ v. > 50$ volt.

$V_i = 120$ v $\rightarrow V_L = \frac{120}{5+10} X\ 10 = 80$ v. >50 volt.

*Max zener current at V_i= 120 v.

$V_R = V_{5\ K\Omega} = 120 - 50 = 70$ volt.

$I = \frac{70}{5\ K} = 14\ mAmp.$

$I_L = \frac{50}{10\ K} = 5\ mA.$

$\therefore\ I_Z = I - I_L = 14 - 5 = 9\ mAmp.$

* Min zener current at V_i = 90 volt.

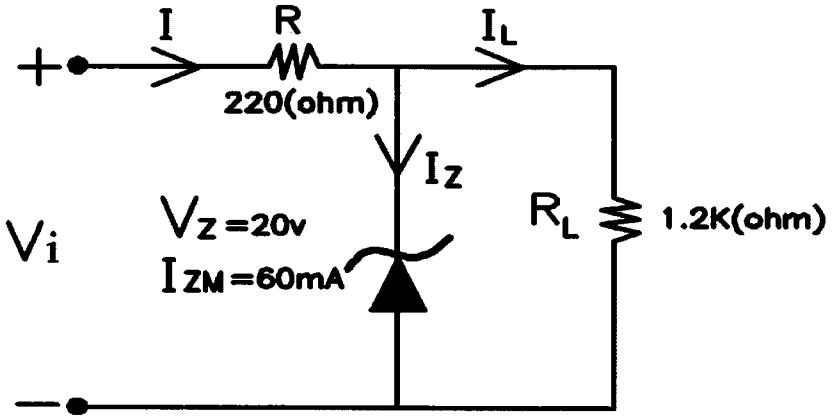
$V_R = 90 - 50 = 40\ volt.$

$I = \frac{V_R}{5\ K} = \frac{40}{5} = 8\ mA.$

$I_L = \frac{50}{10} = 5\ mA.$

$\therefore\ I_Z = 8 - 5 = 3\ mA.$

EX 4: For the circuit shown, find the range of (V_i) that will maintain the zener diode at (ON) state.



Solution:

$$V_{i\,min} = \frac{(R_L + R)V_Z}{R_L} = \frac{(1200+220)X\ 20}{1200} = 23.67v.$$

$$I_L = \frac{V_L}{R_L} = \frac{V_Z}{R_L} = \frac{20}{1200} = 16.67\ mA.$$

$$I_{R\,max} = I_{ZM} + I_L$$

= 60 + 16.67 = 76.67 mAmp.

By (KVL)

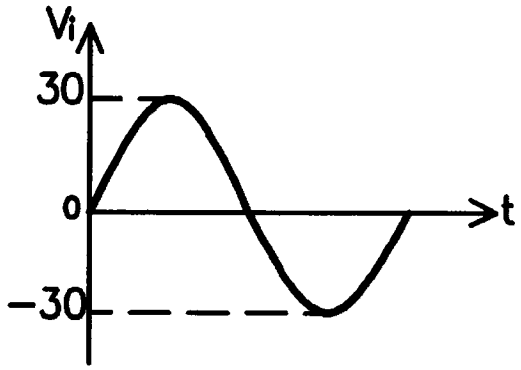
$$V_{i\,max} = I_{R\,(\max)}\ X\ R + V_Z$$

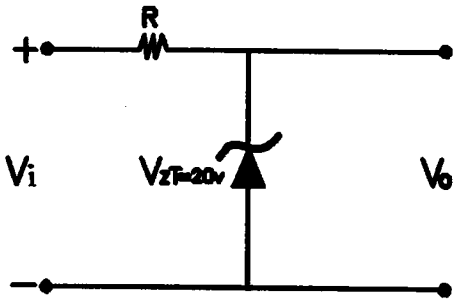
$$\therefore\ V_{i\,max} = 76.6\ X\ 0.22 + 20$$

= 16.87 + 20 = 36.87 volt.

Clipping Network by Using Z-Diode

EX 1: Draw the value of (V_0) for the circuit shown.



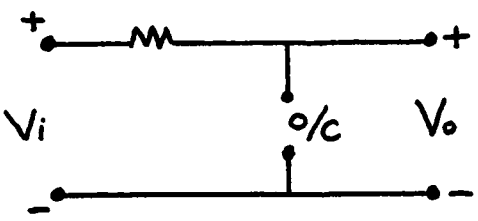


Solution:

a) at $V_i > 0$.

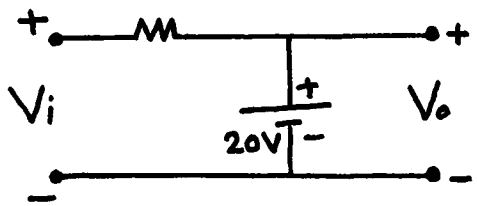
1- If $V_i < 20\ v$.

$\boxed{V_0 = V_i}$

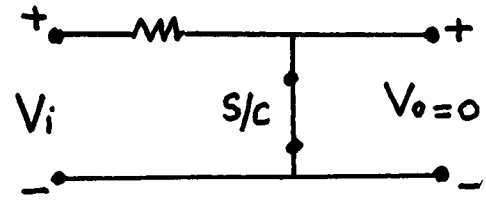


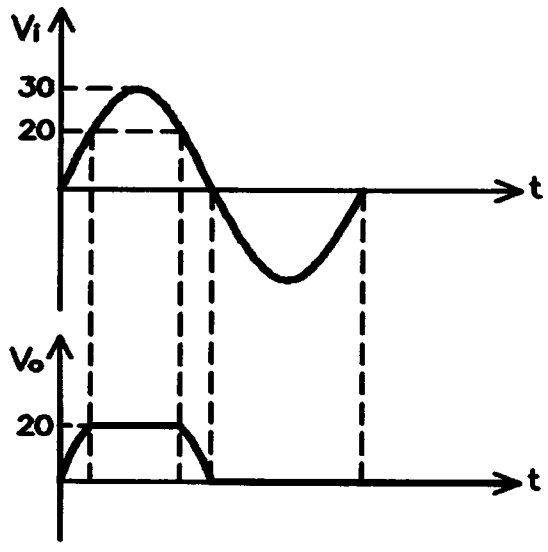
2- If $V_i > 20$

$\underline{V_0 = 20\ v. \rightarrow zener.}$

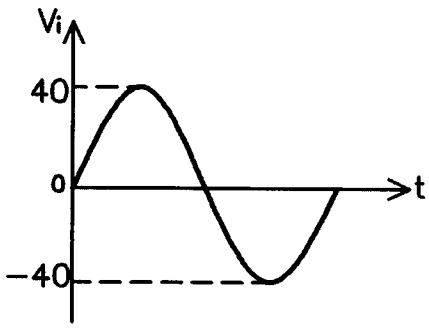


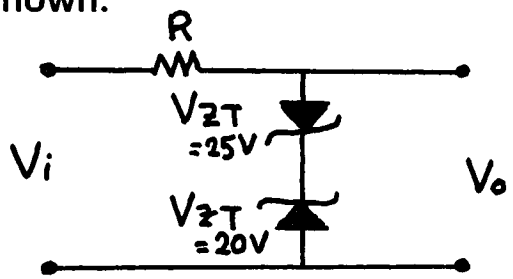
b) at $V_i < 0 \rightarrow$ *Forward bising (short circuit).*





EX 2: Draw the (V_0) for the circuit shown.





Solution:

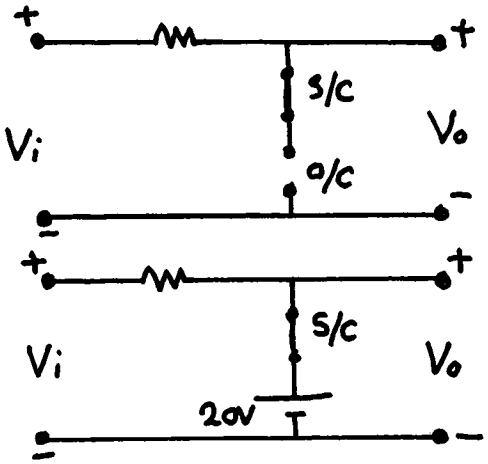
a) $V_i > 0$

1- $V_i < 20$

$V_0 = V_i$

2- $V_i > 20$

$V_0 = 20\ v$



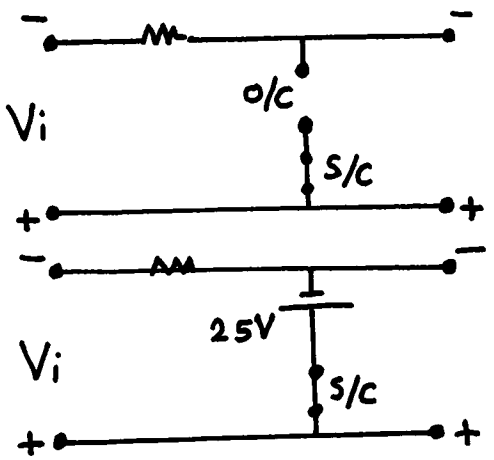
b) $V_i < 0$

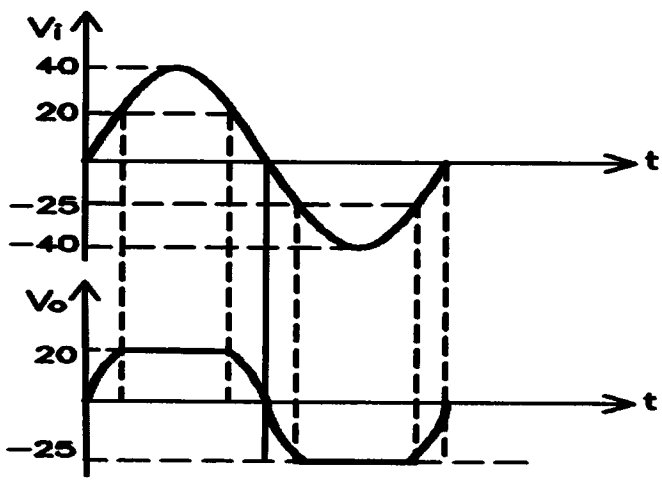
1- $V_i > -25\ v$

$V_0 = V_i$

2- $V_i < -25$

$V_0 = -25V$



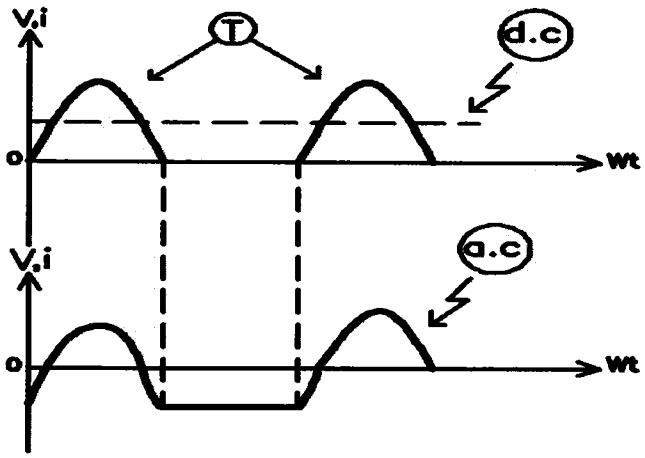


Ripple Factor

In general, it can be said that any varying voltage (or current) has a (d-c) component and an (a-c) component.

$\therefore i_T = I_{d-c} + i_{a-c}.$

$V_T = V_{d-c} + V_{a-c}.$



Ripple factor (r):-

$$r = \frac{Effective\ value\ of\ the\ (a-c) component}{(d-c) value}$$

OR

r = The ratio of the varying component to the steady component.

* $I_{r.m.s}$:- RMS – value for the whole varying current (i_T).

* $I_{r.m.s}^{\prime}$:- RMS – value for the (a-c) component of the whole varying current .

Since : $i_T = i_{ac} + I_{d-c}$

$\therefore i_{ac} = i_T - I_{d-c}.$

$i_{ac}^{\ 2} = (i_T - I_{dc})^2.$

$$\therefore i_{ac}^{\,2} = i_T^{\,2} - 2 i_T I_{dc} + I_{dc}^{\,2}$$

$$\frac{1}{2\pi}\int_0^{2\pi} i_{ac}^{\,2}\, dwt = \frac{1}{2\pi}\int_0^{2\pi} i_T^{\,2}\, dwt - \frac{2 I_{dc}}{2\pi}\int_0^{2\pi} i_T\, dwt + \frac{I_{dc}^{\,2}}{2\pi}\int_0^{2\pi} dwt.$$

$$\therefore I'^{2}_{r.m.s} = I^2_{r.m.s} - 2 I_{dc}\, x\, I_{dc} + \frac{I_{dc}^2}{2\pi} 2\pi$$

$$I'^{2}_{r.m.s} = I^2_{r.m.s} - 2 I_{dc}^2 + I_{dc}^2.$$

$$\therefore I'^{2}_{r.m.s} = I^2_{r.m.s} - I_{dc}^2$$

OR

$$\boxed{I'_{r.m.s} = \sqrt{I^2_{r.m.s} - I_{dc}^2}}$$

But $r = \frac{I'_{r.m.s}}{I_{dc}}$

$$\boxed{\therefore r = \frac{\sqrt{I_{rms}^2 - I_{dc}^2}}{I_{dc}} = \sqrt{\frac{I_{rms}^2 - I_{dc}^2}{I_{dc}^2}}}$$

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

* For half – wave rectifiers :

$I_{rms} = \frac{I_m}{2}$ / $I_{dc} = \frac{I_m}{\pi}$ →Proved before

$$\therefore r = \sqrt{\left(\frac{I_m}{2}\, x\, \frac{\pi}{I_m}\right)^2 - 1}$$

$$r = \sqrt{\frac{\pi^2}{4} - 1} \cong 1.21$$

r > 1 →The varying component is greater than the steady component.

* For half – wave rectifiers

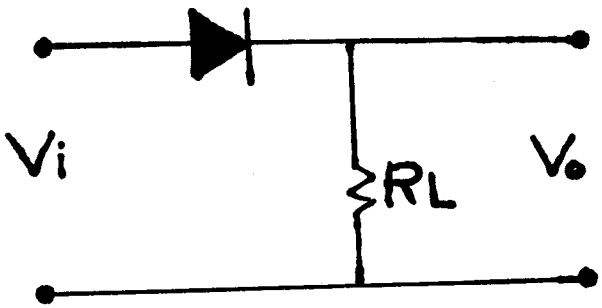
$I_{rms} = \frac{I_m}{\sqrt{2}}$ / $I_{dc} = \frac{2\,I_m}{\pi}$ →Proved before

$\therefore r = \sqrt{(\frac{I_m}{\sqrt{2}}\ x\ \frac{\pi}{2\,I_m})^2 - 1}$

$r = \sqrt{\frac{\pi^2}{8} - 1} \quad \cong 0.48$

r< 1 →The steady component is greater than the varying component.

EX: For the circuit shown, find I_m , I_{dc} , I_{rms}, Input power, Pout (I_{dc}) , efficiency & ripple factor.



$R_L = 1100\Omega.$

rf = 90Ω.

$V_i = 25\sin(100\pi\ t) volt$.

Solution:

$I_m = \frac{V_m - 0.3}{R_L + rf} = \frac{25-0.3}{1100+90} = 20.58\ mA.$

$I_{dc} = \frac{I_m}{\pi} = \frac{20.58}{\pi} = 6.55\ mA.$

$I_{rms} = \frac{I_m}{2} = \frac{20.58}{2} = 10.29\ mA.$

$Pinput = I_{rms}^2\ x\ (R_L + rf)$

$= (10.29 \times 10^{-3})^2 \times 1200 = 0.127$ watts

$P_{dc} = I_{dc}^2\ x\ R_L = (6.55\ x\ 10^{-3})^2\ x\ 1100 = 0.047\ watts.$

$\eta\% = \frac{P_{dc}}{P_{in}} = \frac{0.047}{0.127}\ x\ 100\% = 37\%$

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

$$= \sqrt{\left(\frac{10.29}{6.55}\right)^2 - 1}$$

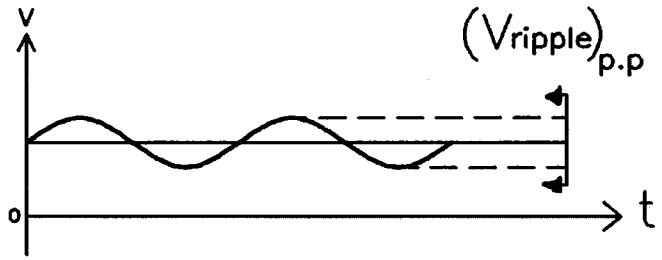
$$= 1.211$$

Power Supplies

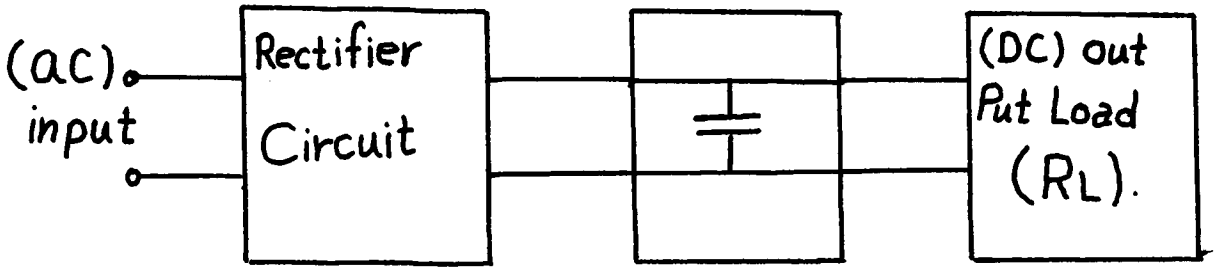
Ripple

$$(V_{ripple})\ p.p = (V_r)p.p$$

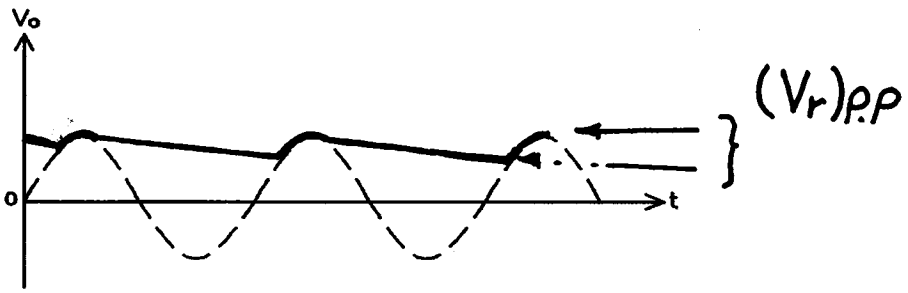
$$r = \frac{ripple\ voltage\ (rms)}{d.c\ voltage} = \frac{(V_r)rms}{V_{dc}}.$$

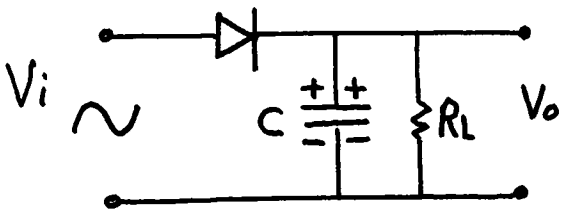


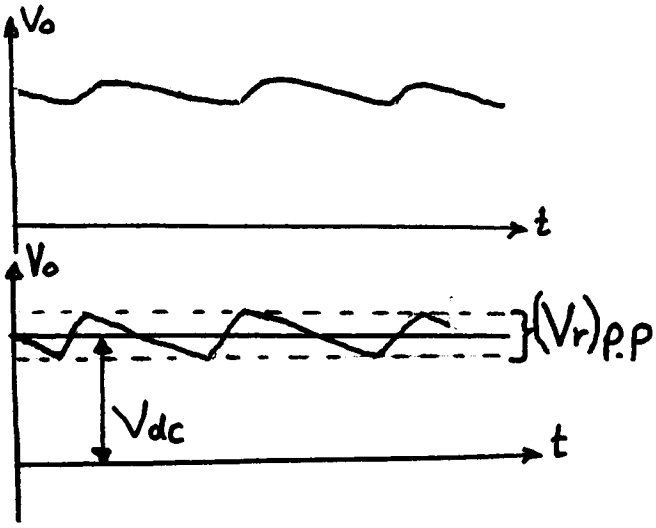
Filters : Simple capacitor Filters



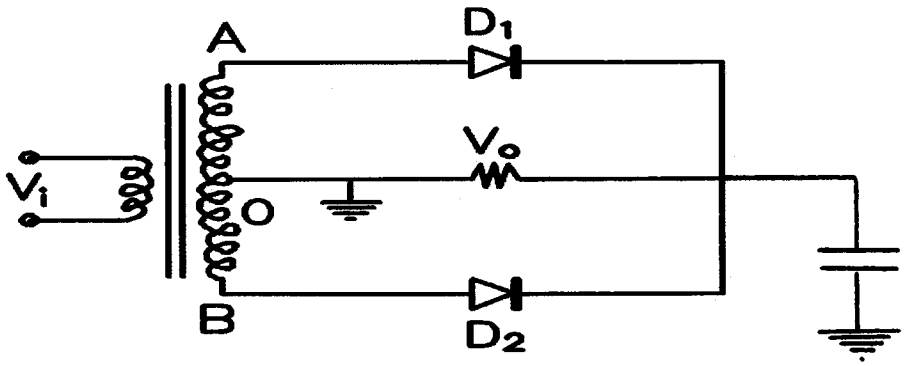
a) Half –wave rectifiers

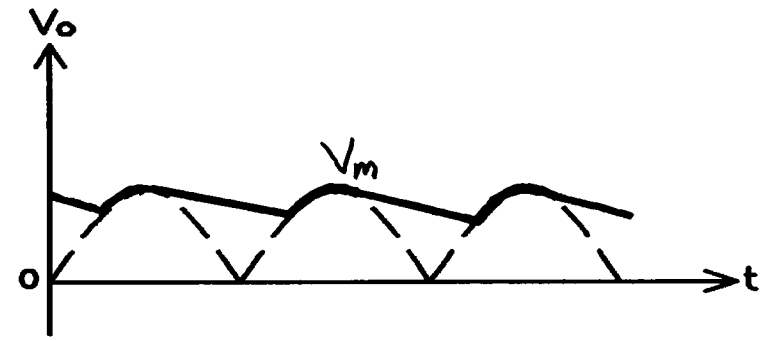


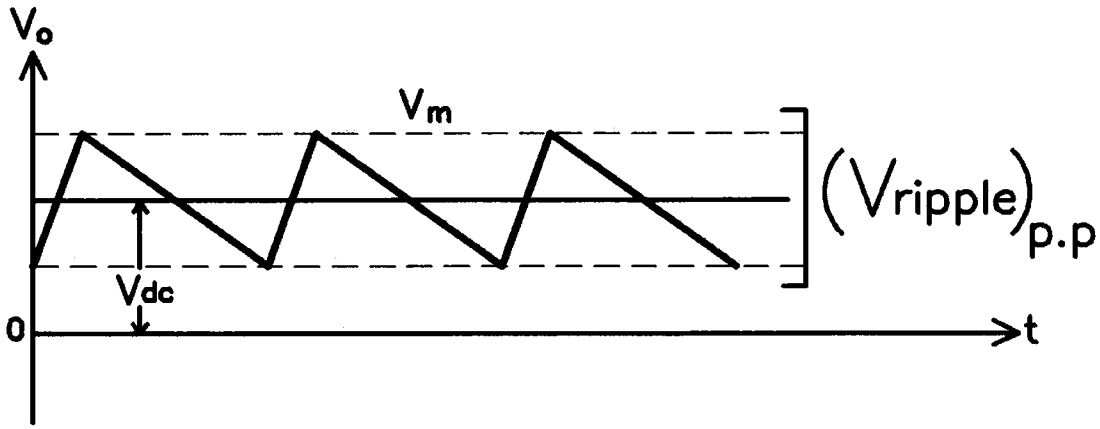




b) Full – wave rectifiers







Note: For Light Load ($I \ll or\ R_L \gg$) the capacitor will charge to a voltage ≅ V_m(nearly No ripple).

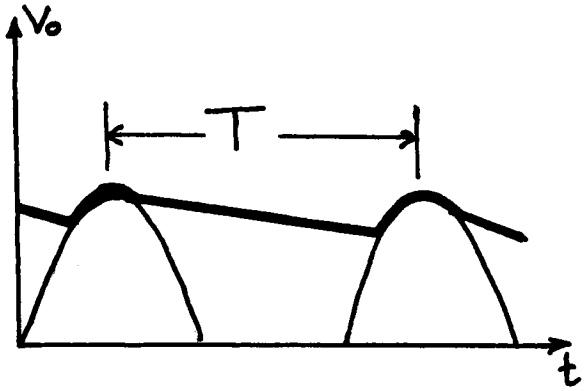
***For Half and Full wave:** we have:-

$$V_{dc} = V_m - \frac{(V_r)pp}{2} \dots\dots\dots\dots 1$$

$$(V_r)rms = \frac{(V_r)pp}{2\times\sqrt{3}} \dots\dots\dots\dots 2$$

Note: we have charging ≪ Dis charge time.

***For Half – wave



Approximately the

Capacitor discharges

During a period (T)

*If the amount of charge that the capacitor losses during one period (T) are (Q), then:

$$I_{dc} = \frac{\Delta Q}{\Delta t} = \frac{Q}{T} \rightarrow \therefore Q = I_{dc}.T.$$

Or $Q = \frac{I_{dc}}{f}$ $\quad where\ T = \frac{1}{f}\ (proved\ before)$

We have in general: - Q = C.V.

∴ The change in voltage on capacitor is $(V_r)pp$.

$$\therefore (V_r)pp = \frac{Q}{C} = \frac{I_{dc}}{fc} \dots\dots\dots 3 \text{ (half – wave) (H-W)}$$

Using eq (2):

$$(V_r)_{rms} = \boxed{\frac{(V_r)pp}{2\times\sqrt{3}} = \frac{I_{dc}}{2\times\sqrt{3}\ fc} \dots\dots\dots 4 \text{ (H-W)}}$$

For light load ($V_{dc} \cong V_m$)

The more exact relation

$$(V_r)_{rms} = \frac{I_{dc}}{2\sqrt{3}\,fc}\; x\; \frac{V_{dc}}{V_m}$$

OR $(V_r)_{rms} = \frac{V_{dc}}{2\sqrt{3}\,fc\,x\,R_L}$.

& we have $r = \frac{(V_r)_{rms}}{V_{dc}}$.

$$\therefore r = \frac{I_{dc}}{2\sqrt{3}\,fc\,V_{dc}} = r = \frac{1}{2\sqrt{3}\,fc\,R_L} \ldots\ldots\ldots 5 \quad (H.W)$$

Form eq(1): $V_{dc} = V_m - \frac{(V_r)_{pp}}{2}$

$$\therefore Using\ eq(3)\ V_{dc} = V_m - \frac{I_{dc}}{2\,fc} \ldots\ldots\ldots .6$$

more exact

$$V_{dc} = V_m - \frac{I_{dc}}{2\,fc} \cdot \frac{V_{dc}}{V_m}$$

***For Full – Wave

Here the capacitor discharges during a half period (T/2).

$\therefore f \rightarrow 2f$.

So, we will have:

$$(V_r)_{pp} = \frac{I_{dc}}{2\,fc} \ldots\ldots\ldots .7\ (F.W).$$

$$(V_r)_{rms} = \frac{I_{dc}}{4\sqrt{3}\,fc} \ldots\ldots\ldots .8\ (F.W).$$

$$r = \frac{I_{dc}}{4\sqrt{3}\,fc\,.V_{dc}} \ldots\ldots\ldots .9$$

OR $$r = \frac{1}{4\sqrt{3}\,fc\,R_L} \ldots\ldots\ldots .10$$

$$V_{dc} = V_m - \frac{I_{dc}}{4\,fc} \ldots\ldots\ldots 11$$

EX (1): Calculate the ripple voltage (rms), of a full-wave rectifier with a 100MF filter capacitor, connected to a load of (50 mA), f= 50Hz.

Solution:

$$(V_r)_{rms} = \frac{I_{dc}}{4\sqrt{3}fc} = \frac{50 \times 10^{-3}}{4\sqrt{3} \times 50 \times 100 \times 10^{-6}}$$

$$\therefore (V_r)_{rms} = 1.443\ volt.$$

EX (2): If the peak rectified voltage for the filter of the previous example is (30 v), calculate the filter-dc voltage.

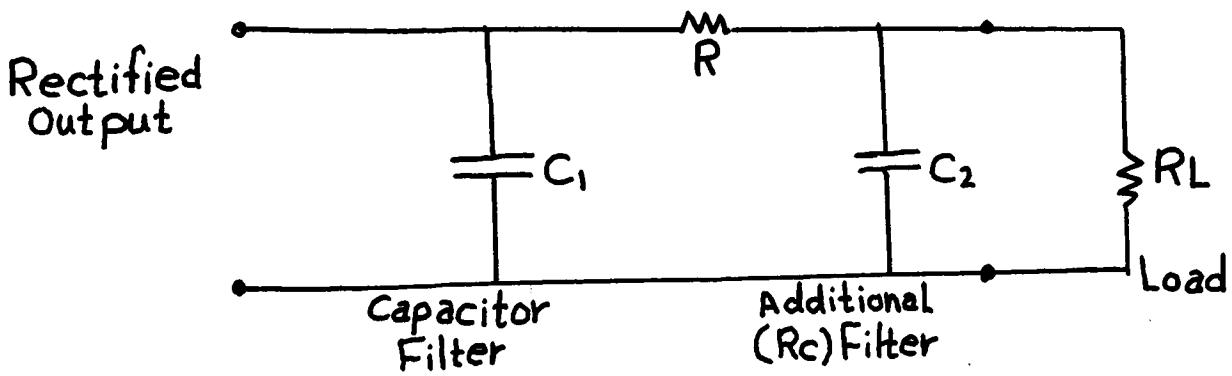
Solution:

$$V_{dc} = V_m - \frac{I_{dc}}{4fc}$$

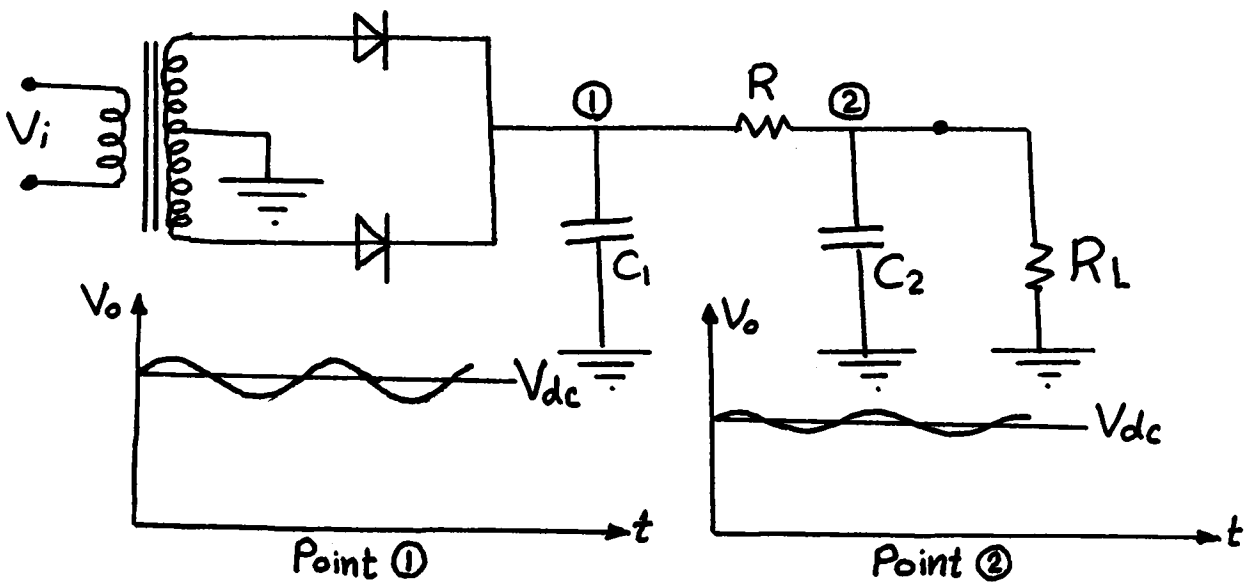
$$= 30 - \frac{50 \times 10^{-3}}{4 \times 50 \times 100 \times 10^{-6}}$$

$$= 27.5\ volt.$$

R-C filter



The purpose of this filter is to pass the (dc) component of the voltage on (C_1) and attenuate. The ac voltage (on C_1).



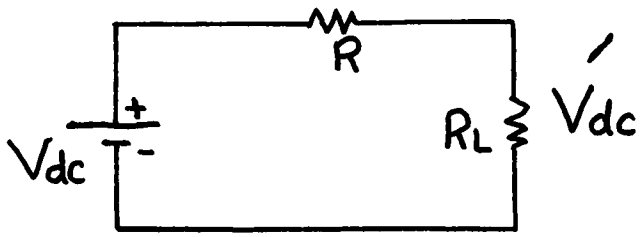
Form fig, the ripple at (2) is less than that at (1)

*The (dc) voltage at(2) is somewhat less than the voltage at (1) because of voltage drop on (R)

*The (RC) circuit acts on the (dc – level) of the voltage on (C_1) and on the ac (ripple) voltage on (C_1).

DC operation of RC Filter

Form fig →



$$V'_{dc} = \frac{V_{dc}}{R+R_L} X\ R_L \text{ ——→ } (V.D.R)$$

OR $$\boxed{V'_{dc} = \frac{R_L}{R+R_L} V_{dc} \dots\dots\dots 12}$$

EX: The addition of an (RC) filter section with R=125Ω, reduces the (d-c) voltage a cross the initial filter capacitor from 65v (dc), If the load resistance is (1kΩ), find the output (dc) voltage (V'_{dc}) from the filter circuit, the drop a cross the resistor, and load current.

Solution: From eq (12). $V'_{dc} = \frac{R_L}{R+R_L} V_{dc}$

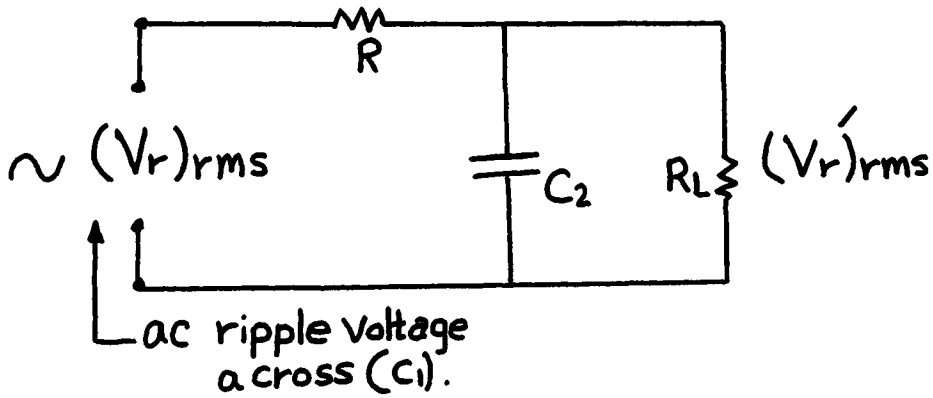
$\therefore V'_{dc} = \frac{1000}{125+1000} x\ 65 = 57.8\ volt.$

Drop voltage at (R) $= V_{dc} - V'_{dc}$

$= 65 - 57.8 = 7.2\ volt.$

$I_{dc} = \frac{V'_{dc}}{R_L} = \frac{57.8}{1000} = 57.8\ mA$

AC operation of RC filter



*Here we will assume that the ripple voltage (V_r) is sinusoidal.

* For the filter capacitor (C_2).

$X_c = \frac{1}{W_c} = \frac{1}{2\pi fc}\ \Omega \rightarrow For\ Half - wave.$

$X_c = \frac{1}{2W_c} = \frac{1}{4\pi fc}\ \Omega \rightarrow For\ Full - wave.$

Where f= line frequency.

C_2 in parallel with $R_L \rightarrow C_2//R_L$ then the resulting impedance (Z) is: $Z = \frac{R_L X_c}{\sqrt{R_L^2 + X_c^2}}$.

Assumption:

Load resistance + capacitive impedance ≅ capacitive impedance.

OR $Z \cong X_c$.

∴ The resulting (ac) component from the filter:-

$$(V_r')_{rms} = \frac{X_c}{\sqrt{R^2 + X_c^2}} (V_r)_{rms} \dots\dots\dots 13$$

For example → $Z \cong X_c$

For a filter capacitor value of (10 μF) at ripple voltage frequency of (60Hz), find impedance of the capacitor.

$$X_c = \frac{1}{W_c} = \frac{1}{2\pi fc} = \frac{1}{2 \times \pi \times 60 \times 10^{-6} \times 10} = 0.265\ k\Omega$$

If we use for example load resistance ($R_L = 2K\Omega$) then:

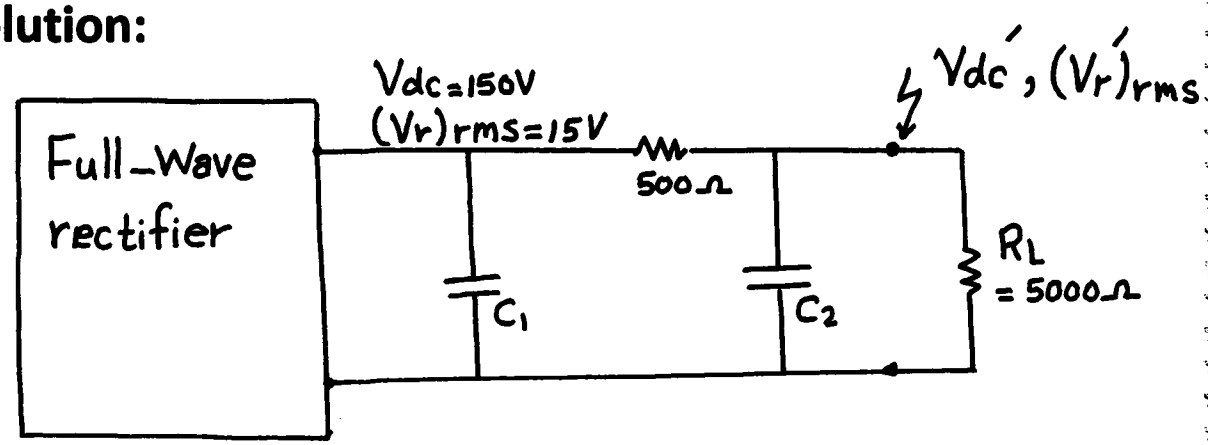
$$Z = R//X_c = \frac{X_c}{\sqrt{R^2 + X_c^2}}$$

$$= \frac{2 \times 0.265}{\sqrt{2^2 + 0.265^2}} = 0.263\ K\Omega$$

$\therefore Z \cong X_c$

EX : The output of a full-wave rectifier and capacitor filter is further filtered by an (RC) filter. The components values of the (RC) section are R = 500Ω, and C = 10 μF. If the initial capacitor filter develops 150 v (dc) with (15v) ac ripples voltage. Calculate the resulting (dc) and ripple voltage across the (5KΩ) load. Line frequency = 60Hz.

Solution:



Use eq(12) : $V'_{dc} = \frac{R_L}{R+R_L} V_{dc}$.

$$= \frac{5000}{500+5000} \; x \; 150 = 136.4 \; volt.$$

From eq(13) : $(V'_r)_{rms} = \frac{X_c}{\sqrt{R^2+X_c^2}} (V_r)_{rms}$.

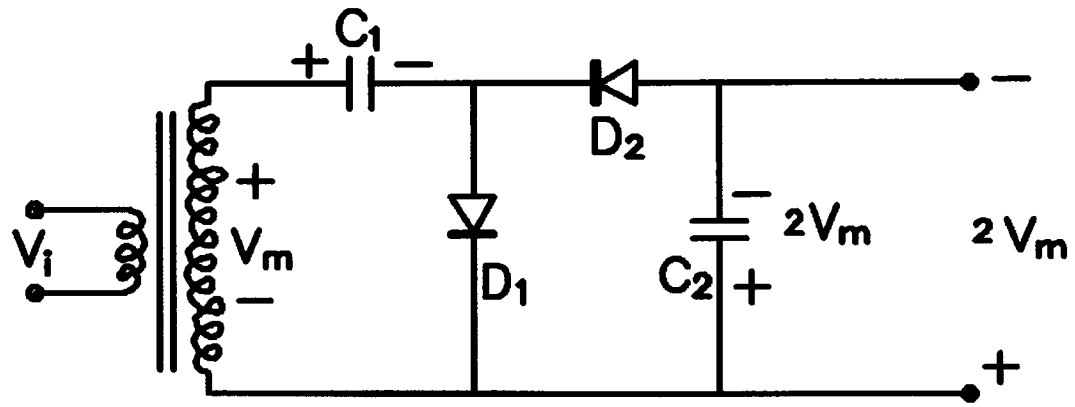
for Full-wave

$$X_c = \frac{1}{4\pi fc} = \frac{1}{4 \; x \; \pi \; x \; 60 \; x \; 10 \; x 10^{-6}} = 132.7 \; \Omega.$$

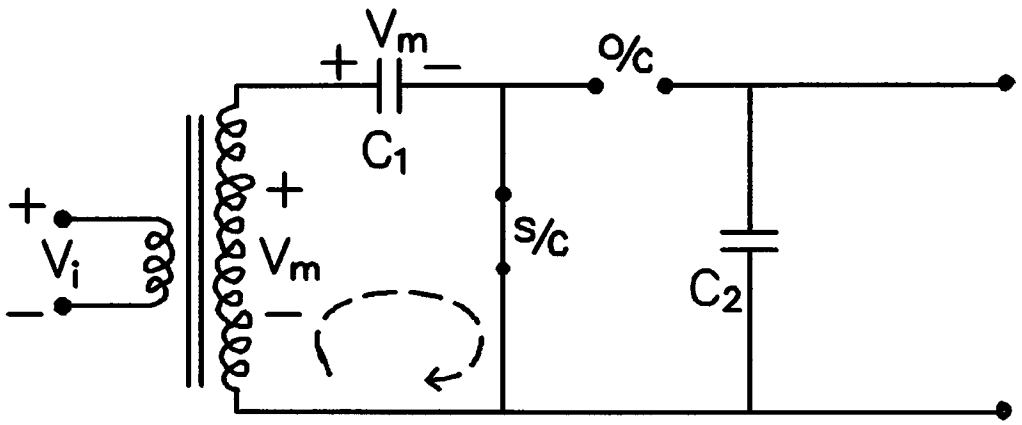
$$\therefore \; (V'_r)_{rms} = \frac{132.7}{\sqrt{500^2+152.7^2}} \; x \; 15 = 3.84 \; volt.$$

Voltage Doubler

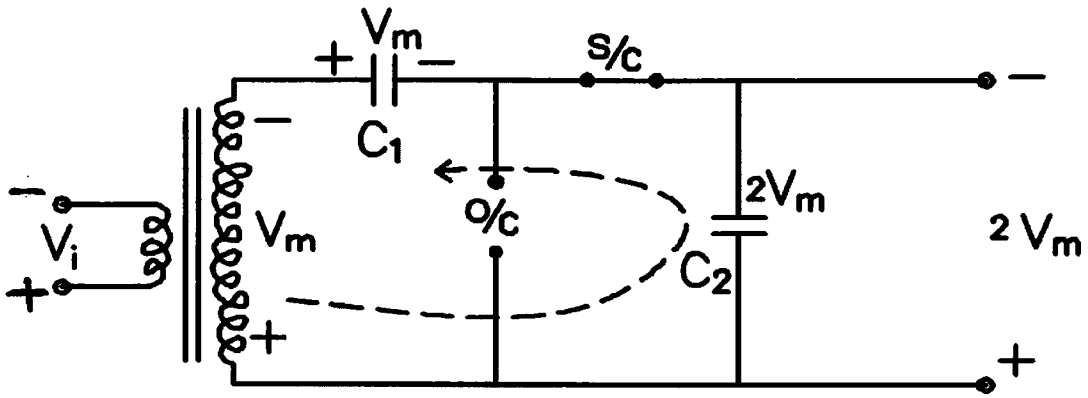
1- Half-wave voltage doubler



*at (+ve) half cycle:



*at (-ve) half cycle:



By (KVL): $V_{c2} = V_m + V_{C1}$ But $V_{c1} = V_m$

$\therefore V_{c2} = 2\,V_m$

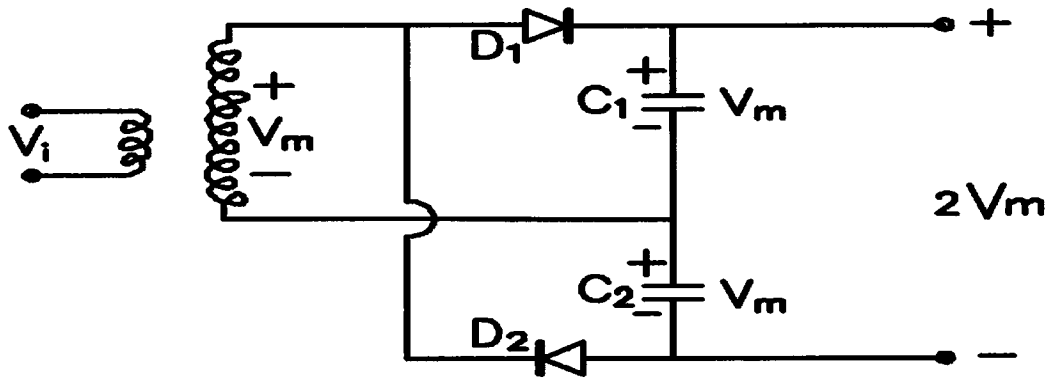
*on the next (+ve) half cycle (D_2) is (off) & C_2 will discharge through the load.

*If there is no-load, both capacitors stay charged:- C_1 at (V_m) & C_2 at ($2V_m$).

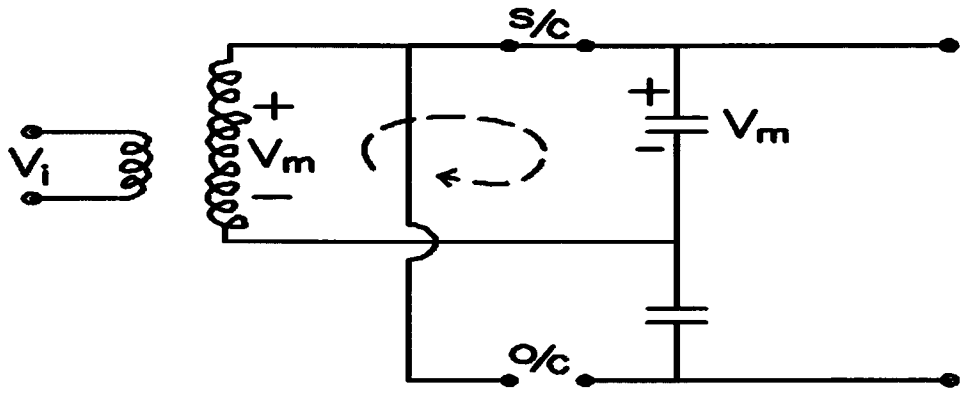
*with the load: The voltage a cross (C_2) will drops during the (+ve) half cycle and reach's the voltage ($2V_m$) during the (-ve) half cycle.

*The peak in verse voltage (PIV) a cross each diode is ($2V_m$).

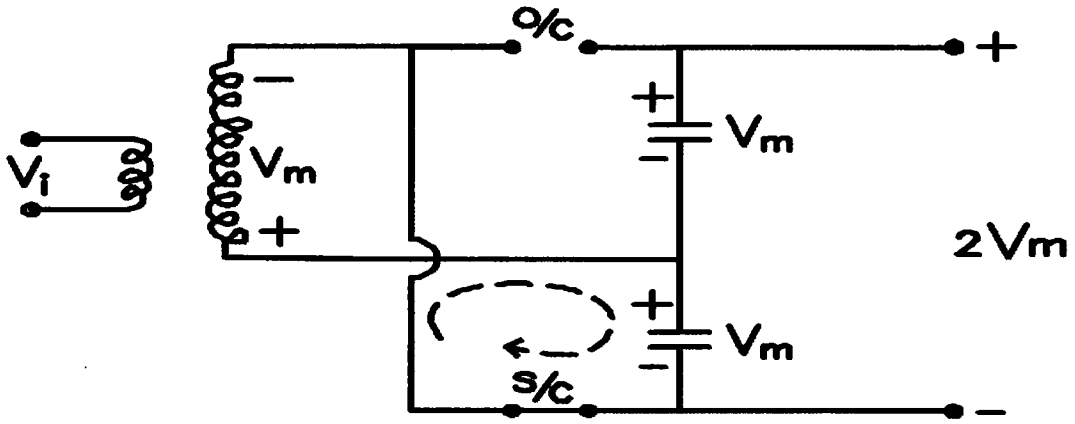
2- Full-wave voltage doubler



*at (+ve) half cycle.



*at (-ev) half cycle.



*with no-load, the voltage across both C_1 & C_2 is $(2V_m)$.

*with the load, the voltage a cross both C_1 & C_2 is that of a full wave rectifier with a capacitor filter (C_1&C_2).

*Here C_1 & C_2 are in series the resulting capacitance is less than the capacitance of either C_1 or C_2 alone.

*The lower capacitor value will provide poorer filtering than the single capacitor filter circuit.

*(PIV) across each diode is $(2V_m)$.

* The half-wave or full-wave voltage doubler provides twice the peak voltage $(2V_m)$, while requiring no. center-tapped transformer and only $(2V_m)$ (PIV) .