Lecture 1 ENGINEERING

Unit 1 PN Junction Diode

Contents

- Introduction to Electronics
- Semiconductor Materials.
- Energy Bands
- Types of Semiconductors

Introduction to Electronics

Electronics Engineering deals with the study of electronic devices.

Electronic device is a device in which conduction takes place by the movement of electron through a semiconductor.

The further advancement in this field depends on three factors :

- quality of semiconductor material.
- Network design technique
- quality of manufacturing and processing equipment.

Semiconductor Material

The construction of electronic devices or integrated circuit depends on the quality of semiconductor material used.

Semiconductors : special class of elements having conductivity between that of a conductor and insulator.

Semiconductor Materials
- Single Crystal (Ge, Si)
- Compound (GaAs, CdS, GaN, GaAsP)

(constructed of two or more semiconductor materials of different atomic structures)

Most frequently used Semiconductors :

→ Ge
→ Si } → single

→ GaAs → compound.

Their structures are such that doping can be done easily and hence are chosen as frequently used semiconductors from group IV

Q Why is Si preferred over Ge?

→ Si is abundant on earth.

→ The leakage current is less in Si (nA) than that of Ge. (μA)

Atomic Number of Ge – 32 (2, 8, 18, 4)

Atomic Number of Si – 14 (2, 8, 4)

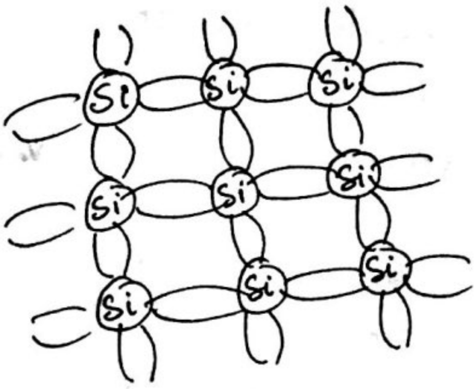
Valence electrons of Ge are in 4th shell and that of Si are in 3rd shell. Valence electrons of Ge are less tightly bound to Nucleus and will require very small amount of energy to escape from the atom.
Hence at every small temperature, the leakage current is more in Ge.
Therefore Ge is more unstable at high temperatures.

GaAs → results in the speed of operation upto 5 times that of Si.

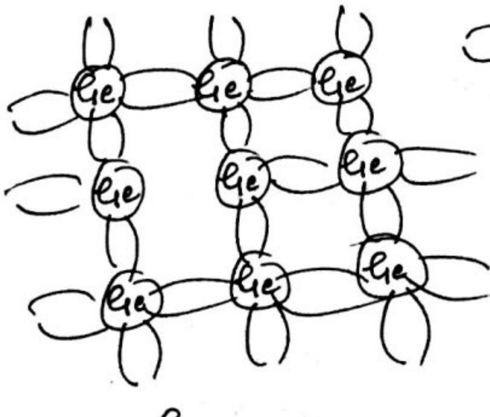
Atomic Numbers

Ge - 32	2, 8, 18, 4
Si - 14	2, 8, 4
Ga - 31	2, 8, 18, 3
As - 33	2, 8, 18, 5

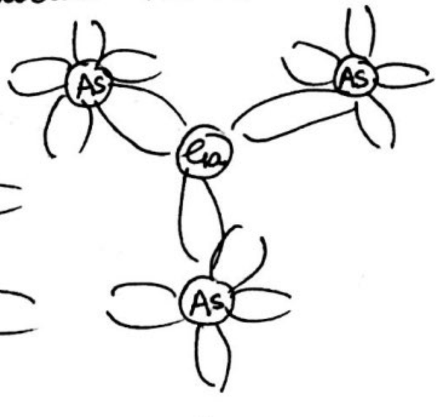
Covalent Bonding exist in Semiconductor materials.



Si



Ge



GaAs.

each atom (Ga) surrounded by an atom of complementary type

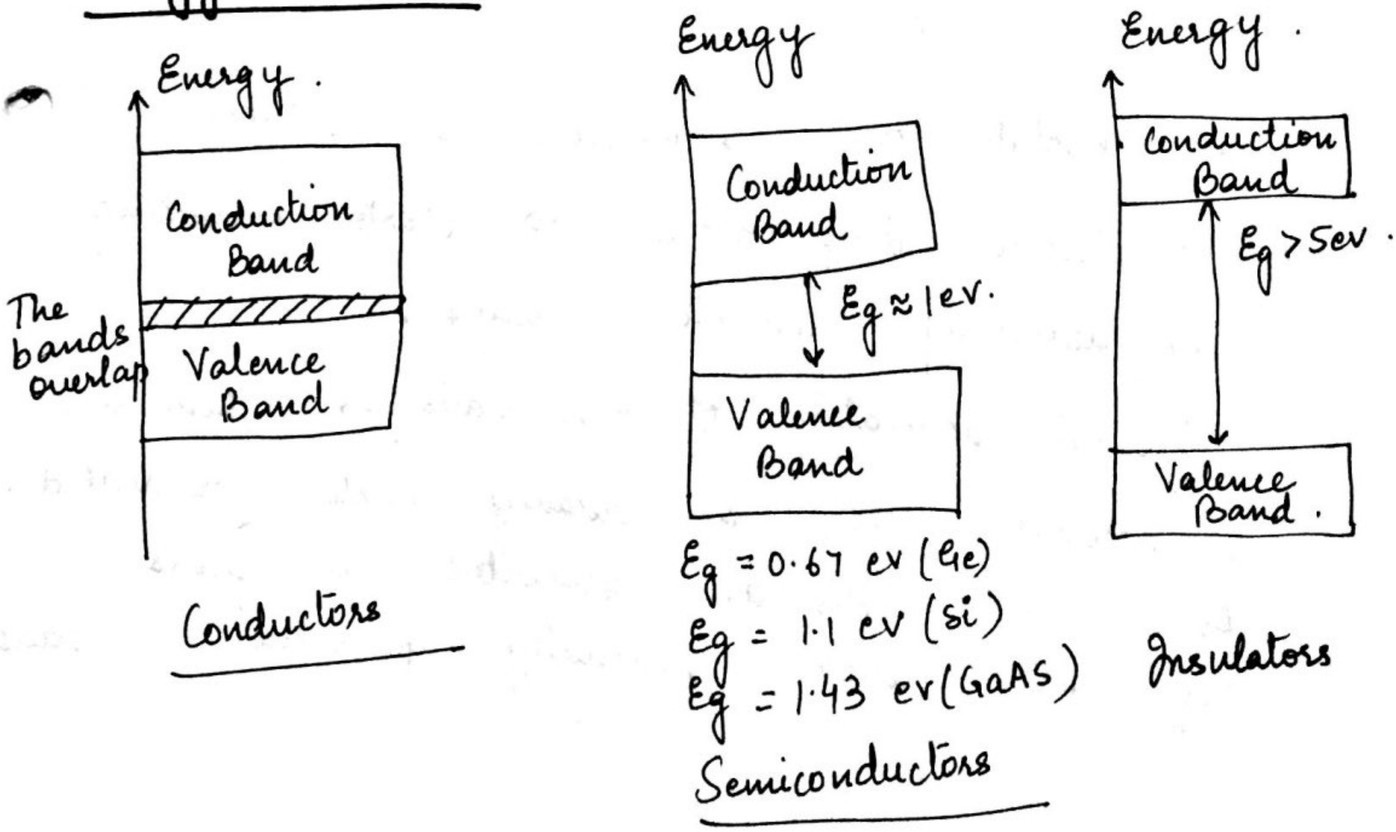
Q What is the difference between Semiconductors and Conductors?

→ Semiconductors have negative temperature coefficient of resistance. i.e Resistance decreases with increase in temperature. Conductivity can be increased by doping. Conductors have positive temperature coefficient of resistance i.e resistance increases with increase in temperature.

Q What is doping?

→ Doping is the process of addition of impurities to a pure semiconductor to increase its conductivity.

Energy Bands



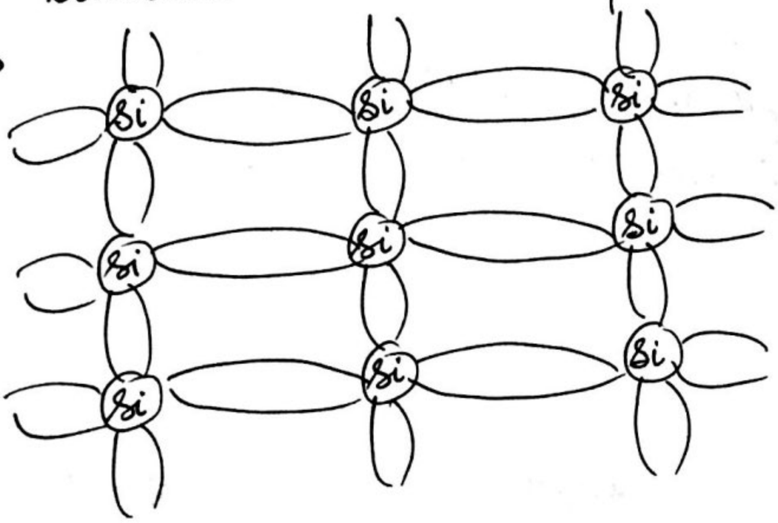
Types of Semiconductors

- Semiconductors
  - Intrinsic
  - Extrinsic
    - N type
    - P type

Intrinsic Semiconductor

→ semiconductor in its purest form.

→



→ At Absolute 0 K → Behaves as insulator.

→ At Room Temp (300 K) → Starts conducting by absorbing thermal energy.

→ Thermal generation of e-h pairs → When an e^- becomes free, a vacancy (hole) is created. As e^- and holes are generated in pairs, they are called thermally generated e-h pairs.

→ Recombination → The process in which a free electron combines with a hole.

Lifetime of charge Carriers → The duration for which the charge carriers exist before recombination (τ).

Extrinsic Semiconductor

→ A semiconductor material that has been subjected to the doping process.

Two Types.

N Type

P Type.

Summary:

- Semiconductors have negative temperature coefficient
- Si is preferred over Ge.
- Doping increases conductivity .

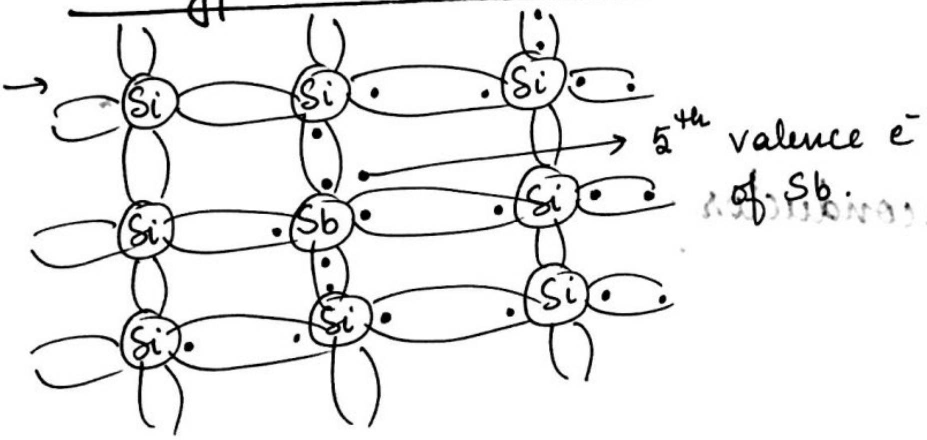
Lecture 2.

Unit 1 : PN Junction Diode

Contents

- N Type Semiconductor
- P Type Semiconductor
- Introduction to semiconductor diode.
- Formation of Depletion Region.

N Type Semiconductor



→ Pentavalent impurity like As, P, Sb added.

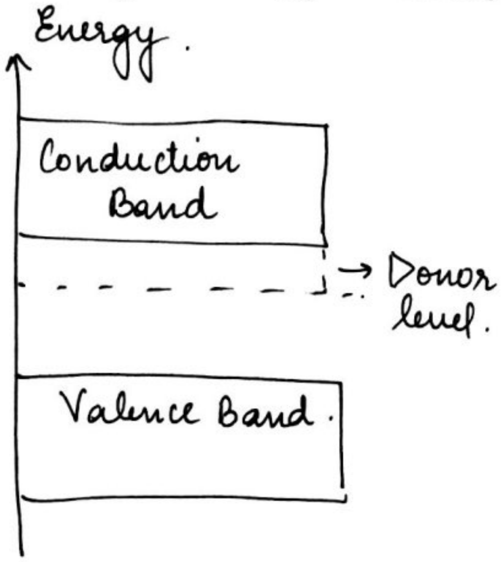
→ 5^{th} valence e^- is loosely bound to parent atom., Thus the impurity has donated an extra e^-.

→ Pentavalent impurity also called donor impurity

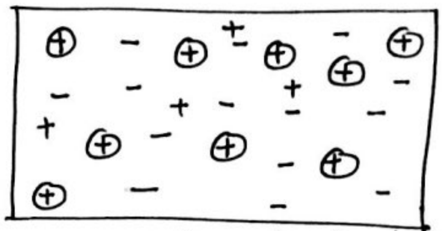
→ Electrons are majority charge carriers, holes are minority charge carrier.

→ N Type Semiconductor is electrically neutral as the number of protons in nucleus is still equal to free $\bar{e}$ and $\bar{e}$ in orbit.

→ Resulting energy Band



Representation of N Type Semiconductor

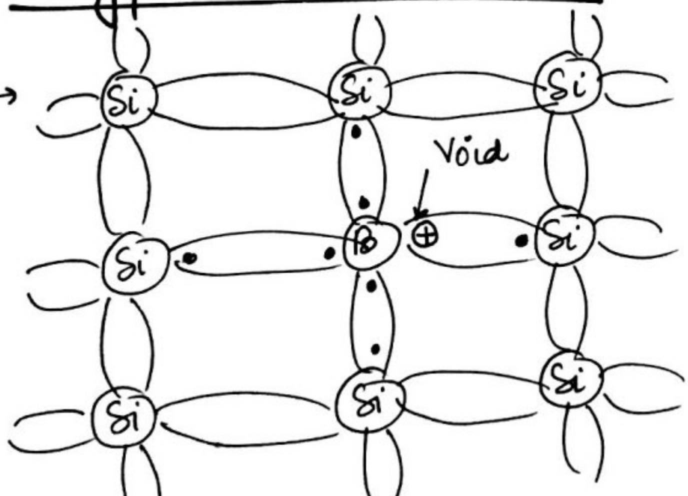


− → electrons (Majority carriers)
+ → holes (Minority carriers)
⊕ → Ac. Donor Ions.

→ At very small temp, (Room temperature), conductivity increases to a great extent.

P type Semiconductor

→



→ Trivalent impurity like B, Ga, In added

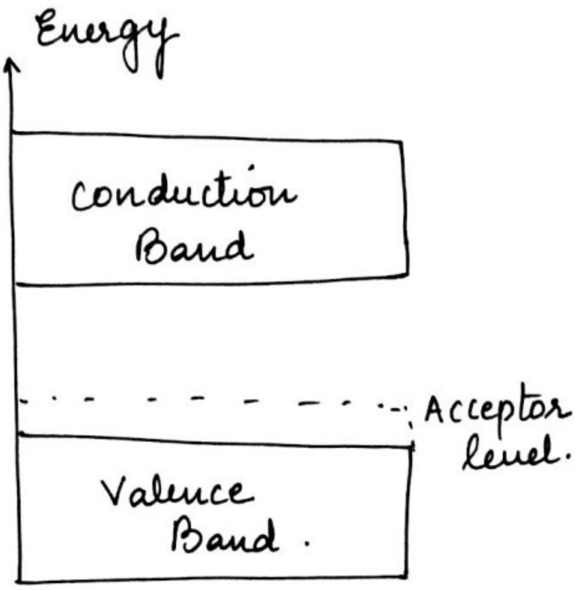
→ A hole or vacancy is present, which has tendency to accept an electron.

→ Trivalent impurity also called acceptor type impurity

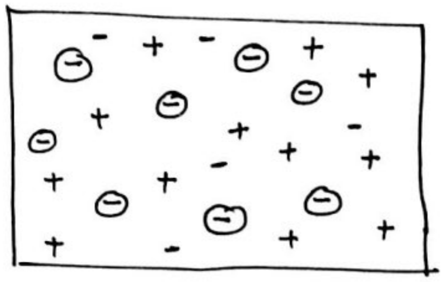
→ Holes are majority charge carriers, Electrons are minority charge carriers.

→ P type semiconductor is also electrically neutral.

→ Resulting Energy Band Diagram



Representation of P type Semiconductor

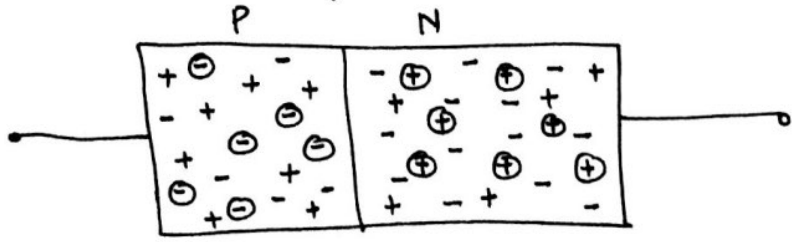


+ → holes (Majority carriers)
- → electrons (Minority carriers)
⊖ → Acceptor ion

→ At very small temperature (Room temperature), conductivity increases to a great extent.

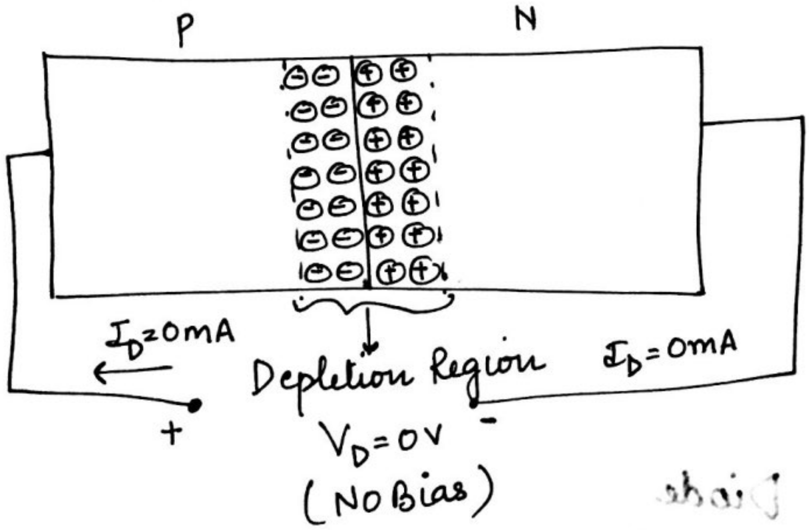
Semiconductor Diode

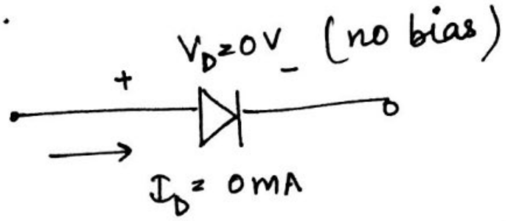
When N Type semiconductor is joined to a P type semiconductor by special fabrication technique, then a semiconductor diode or PN diode or junction diode is formed.



PN Diode

Formation of Depletion layer

- Electrons from 'N type' diffuse into 'P type' and recombine with the holes.
- Holes from 'P type' diffuse into 'N type' and recombine with the electrons.
- The maximum recombination takes place near the junction and thus only ions are left uncovered in this region.
- This region is called depletion region or space charge region.
- 

- The net current flow under no bias condition is zero.
- 

Symbol of PN Diode

- Potential Barrier → The Electric field set up by immobile positive and negative ions on opposite sides of junction that oppose the flow of electrons and holes across the junction.

University Questions

Q1. Define Depletion layer and Potential Barrier (2 marks)
(2015-16)

Summary

- Pentavalent Impurity / Donor type impurity is added to N type material.
- Electrons are majority carriers in N type and holes are minority carriers.
- Trivalent impurity / Acceptor type impurity is added to P type material.
- Holes are majority and Electrons are minority charge carriers in P type.
- Depletion Region / Space charge region does not contain any charge carrier.

Lecture 3

Unit1 : PN Diode

Contents

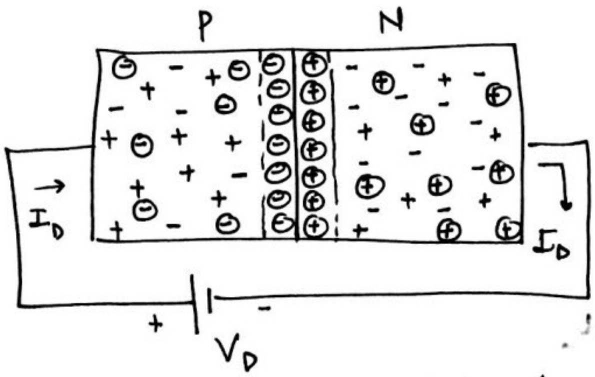
Biasing

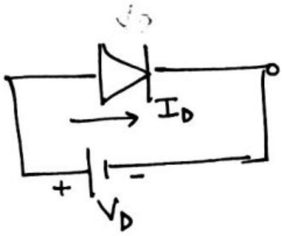
The process of applying an external voltage across the two terminals of a device.

Biasing can be of two types:

- Forward Biasing
- Reverse Biasing.

Forward Biasing ($V_D > 0$)

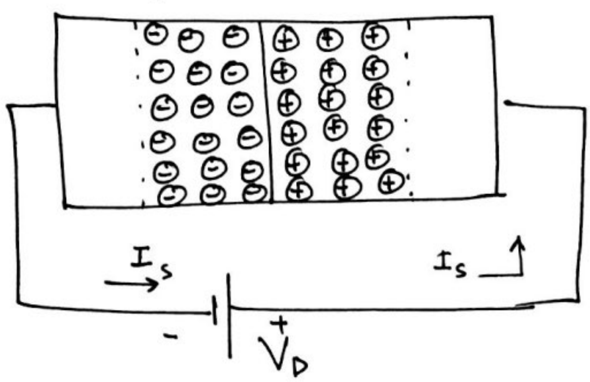
- 

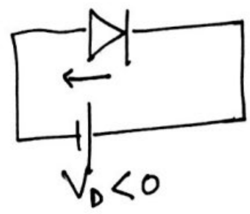


- Depletion layer width decreases.
- Barrier Potential decreases
- Forward current is maximum
- Forward Resistance is minimum.
- Potential Barrier for Si is 0.7V and for Ge is 0.3V

- As soon as the applied voltage overcomes the potential barrier, current starts flowing.

Reverse Biasing ($V_D < 0$)





- Depletion layer width increases
- The current due to majority carriers is zero.
- A small current due to minority carriers flow. This current is called reverse saturation current, I_s.
- Potential Barrier increases.
- Reverse Resistance is very high.
- The term saturation comes from the fact that it reaches its maximum level quickly and does not change with change in applied voltage.
- I_s depends on temperature. The reverse saturation current doubles its value for 10°C rise in temperature.

Diode Current Equation

$$I_D = I_s\left(e^{V_D/\eta V_T} - 1\right)$$

$I_D \rightarrow$ Diode current
$I_s \rightarrow$ reverse saturation current
$V_D \rightarrow$ applied forward voltage
η = constant 1 for Ge, 2 for Si.

V_T = thermal voltage $= \frac{KT}{q}$

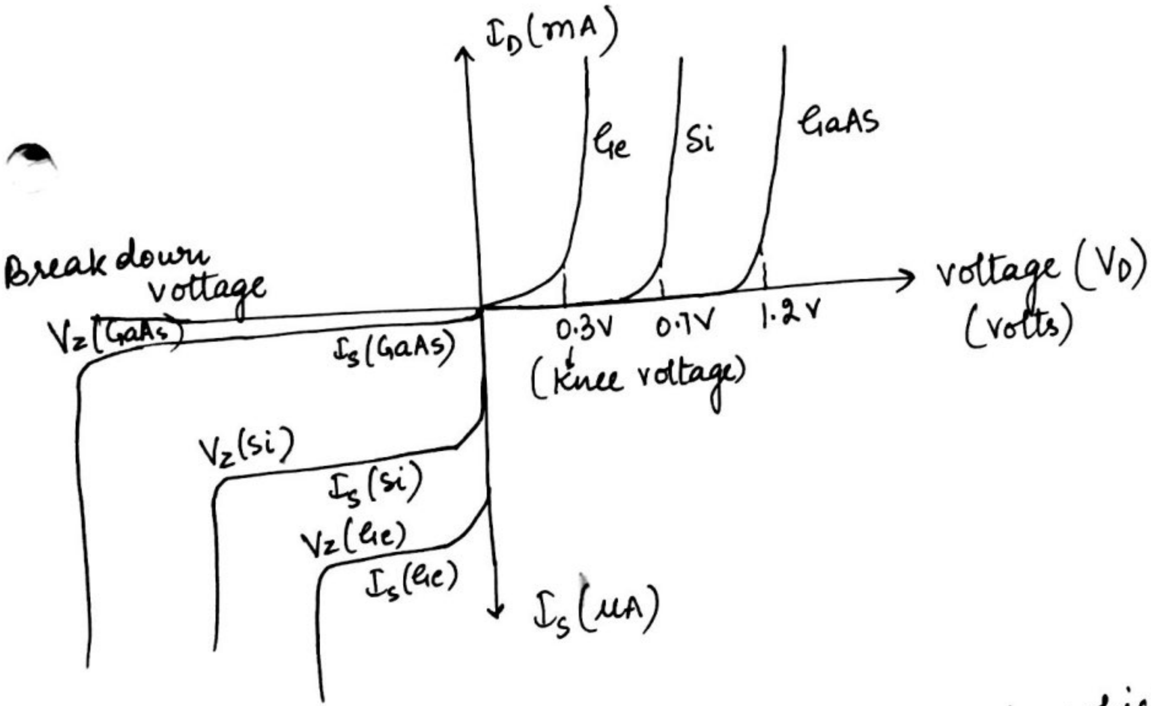
K = Boltzmann's constant = 1.38×10^{-23} J/K

T = Temp in K = 273 + temp in °C

$q = 1.6 \times 10^{-19}$ C.

$V_T = 26$ mV for room temp (300 K)

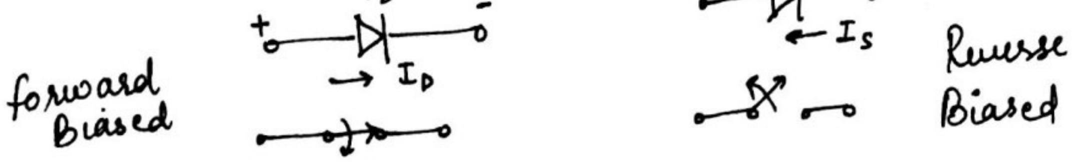
V-I Characteristics of Diode



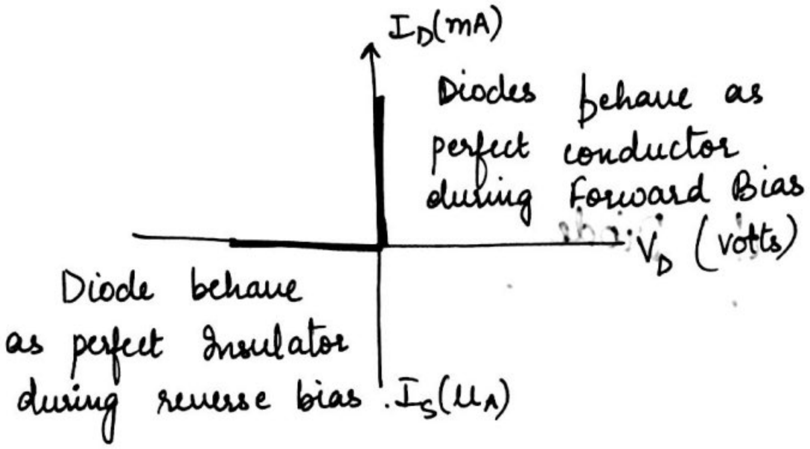
Knee voltage / cut in voltage: The voltage at which current starts rising rapidly. It is 0.3 V for Ge, 0.7V for Si and 1.2 V for GaAS.

Breakdown voltage: The reverse voltage at which the junction collapse and reverse current increases is called breakdown voltage.

Ideal Diode Characteristics



An ideal diode behaves as a closed switch during forward bias and as a open switch during reverse bias.



Note: Relation of Depletion layer width with the Doping level

$$\text{Depletion layer width} \propto \frac{1}{\text{doping level}}$$

More (Heavy) doping → lesser depletion layer width.

Less (Light) doping → Thicker depletion layer.

University Questions

- Explain V-I Characteristics of Diode. (2014-15) (5 Marks)
- Define depletion layer and Potential Barrier.
- The reverse saturation current of a Si PN junction diode is 10 μA at 300 K. Determine the forward bias voltage to be applied to obtain diode current of 100 mA. (2017-18)

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Summary (Lecture - 3).

- Depletion layer decreases in forward biasing.
- Depletion layer increases in reverse biasing.
- Forward Biasing means

  p → positive terminal of battery

  n → negative terminal of battery

  or

  $p > n$.

- Reverse Biasing means

  p → negative terminal of battery.

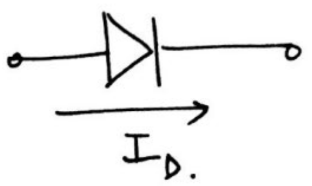
  n → positive terminal of battery

  or

  $p < n$.

- Current is maximum in forward biasing.
- Current is minimum in reverse biasing.
- Reverse Saturation current flows in reverse biasing, which depends on temperature. It doubles its value for every 10°C rise in temperature.

- The reverse saturation current is more in Ge (μA) than in Si (nA).
- In a diode, current flows from p to N.



- Depletion layer width $\propto \frac{1}{\text{level of doping}}$.

More doping → lesser depletion layer width.
less doping → More / Thicker depletion layer.

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Lecture 4

Unit 1 : PN Diode

Contents :

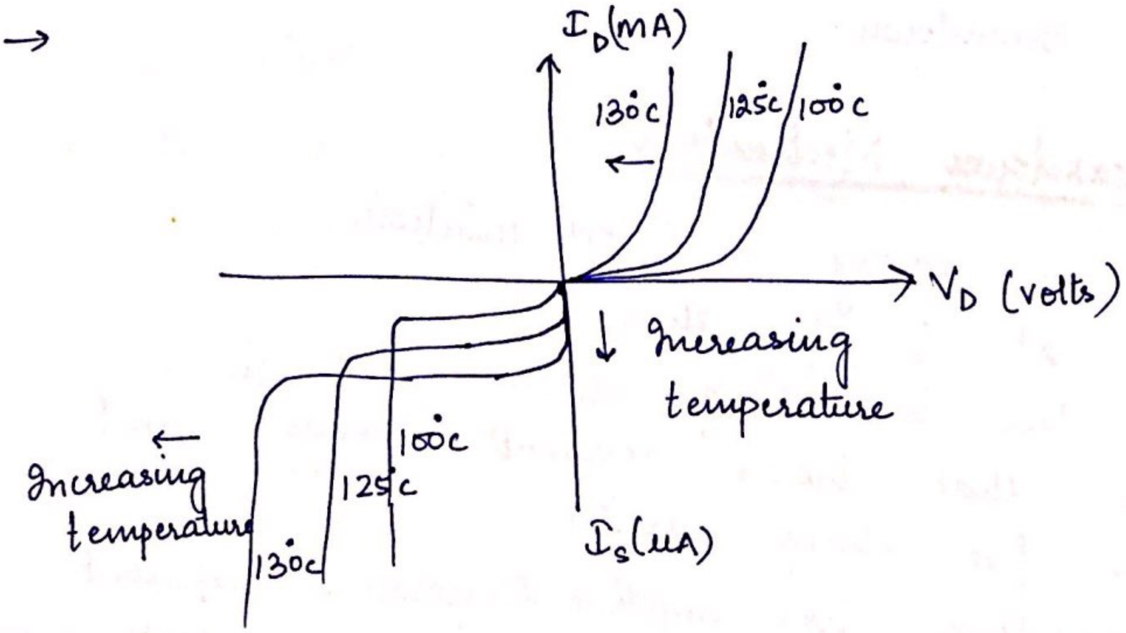
- Effect of Temperature on V-I Characteristics
- Breakdown Mechanisms
- Zener Breakdown Mechanism
- Avalanche breakdown Mechanism.

Effect of Temperature on Characteristics of Diode

- Knee voltage decreases
- Breakdown voltage increases
- Reverse Saturation current increases for every 10°c rise in temperature.

Q. Draw the V-I characteristics of diode at 100°c, 125°c and 130°c.

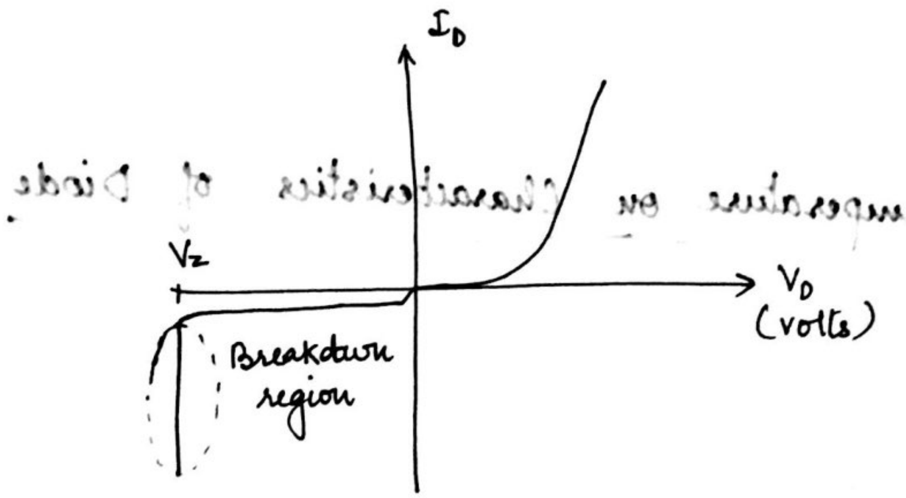
→



Breakdown Mechanisms

If excessive reverse voltage is applied to a PN junction, a point comes when the junction collapse and the reverse current rises sharply, this voltage is called breakdown voltage (V_Z).

Note: In breakdown region V_z remains constant, I_z varies.

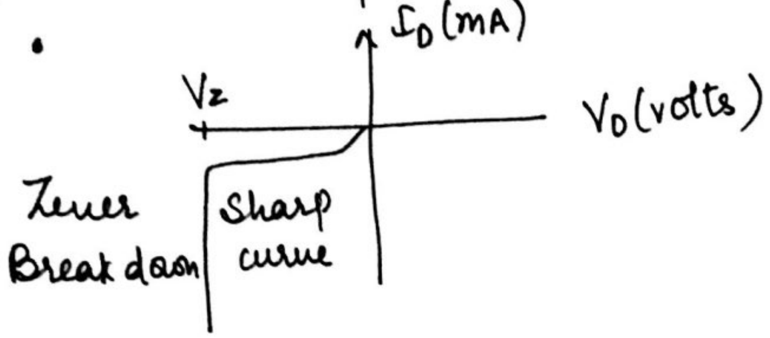


Breakdown Mechanisms are of two types:

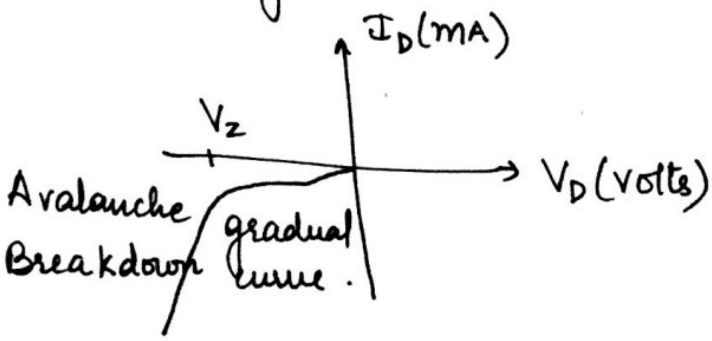
- Zener Breakdown
- Avalanche Breakdown.

Zener Breakdown Mechanism

- occurs in heavily doped PN junctions.
- occurs at V_z less than -5 V
- occurs due to strong electric field in the junction, that breaks covalent bonds and generate free charge carriers.
- Zener breakdown has negative temperature coefficient i.e breakdown voltage V_z decreases as temperature increases

- Has Sharp Characteristic
- 

Avalanche Breakdown Mechanism

- occurs in lightly doped junctions.
- occurs for $V_z > -5\,V$
- It occurs due to the fact that as the reverse voltage increase, the velocity of minority carriers increase, and thereby the associated kinetic energy increases. These carriers with high kinetic energy when collide with atoms, result in generation of carriers. It is a multiplication process.
- Avalanche breakdown has positive temperature coefficient i.e V_Z increases with increase in temperature.
- It has gradual curve.
- 

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University Questions

Q 1. Differentiate Zener and Avalanche breakdown Mechanism. (2 marks) (2013-14)

Q 2. Explain the V-I characteristics of diode (2014-15) (5 Marks.

Q 3. Describe breakdown mechanisms of diode (2 marks) (2015-16)

Q 4. Explain the effect of temperature on conductivity of semiconductor (2 marks) (2015-16)

Lecture 5

Unit I : PN Diode

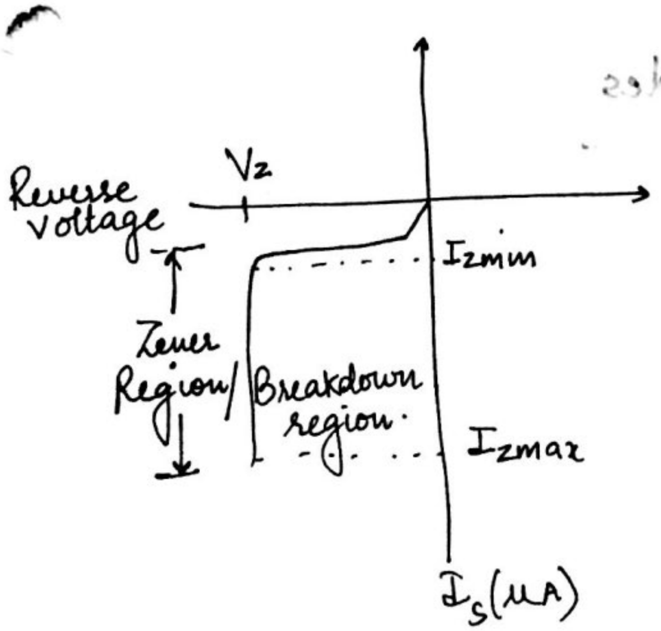
Contents :

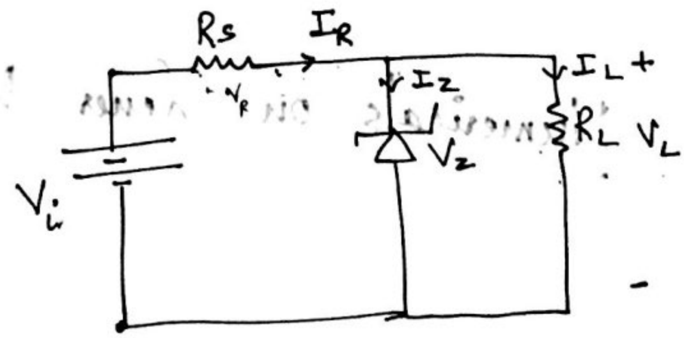
- Zener Diode as shunt regulator
- Numericals on Zener diode as shunt Regulator.

Zener Diode as shunt Regulator

Zener diodes are the specially designed diodes which employs the breakdown region (Zener region) of diode characteristic.

The voltage across a Zener diode remains constant equal to V_z when it is operated in the breakdown region or Zener region.





$$I_R = \frac{V_i - V_z}{R_s} \quad \text{--- (1)}$$

$$V_L = I_L R_L \Rightarrow I_L = \frac{V_L}{R_L}$$

$$I_L = \frac{V_z}{R_L} \quad \text{--- (2)}$$

$$I_R = I_z + I_L \quad \text{--- (3)}$$

Case 1: V_i variable R_L fixed

According to eq ①, if V_i changes I_R will change. If V_i increases I_R will increase. According to equation ② I_L will remain fixed as V_Z and R_L are constant.

Therefore according to eq ③ when I_R will increase I_Z will increase.

V_o will remain constant as long as I_Z is maintained between $I_{Z min}$ to $I_{Z max}$.

Case 2: V_i fixed, R_L variable.

According to eq ① I_R remains constant as V_i, V_Z, R_S are's fixed. According to eq ② if R_L increases, I_L decreases. Therefore according to eq ③ only I_Z decreases, and V_Z and hence V_L continues to remain constant.

Numericals on Zener Diodes

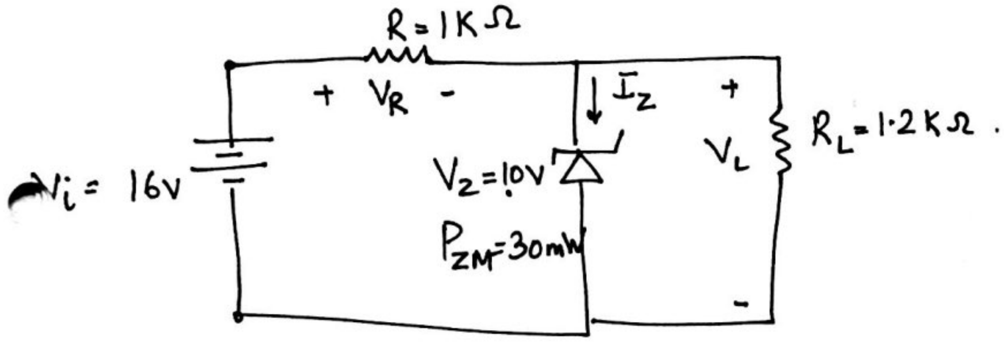
The numericals on Zener diodes are discussed for three cases:

(i) fixed V_i, fixed R_L
(ii) Fixed V_i, Variable R_L
(iii) Variable V_i, fixed R_L

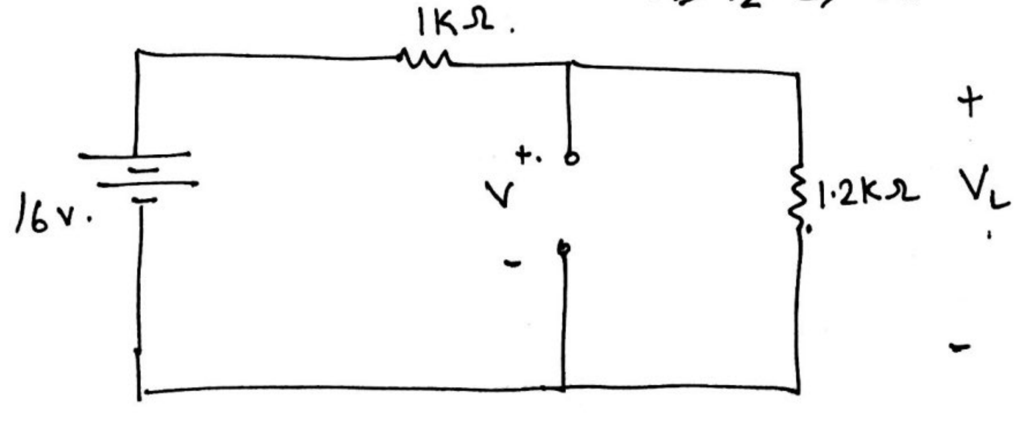
Fixed Vi, Fixed R_L

Q1. (i) For the given Zener diode network, Calculate V_L, V_R, I_Z, P_Z.

(ii) Repeat (i) with $R_L = 3\,k\Omega$. (2010-11 UPTU) (5 Marks)



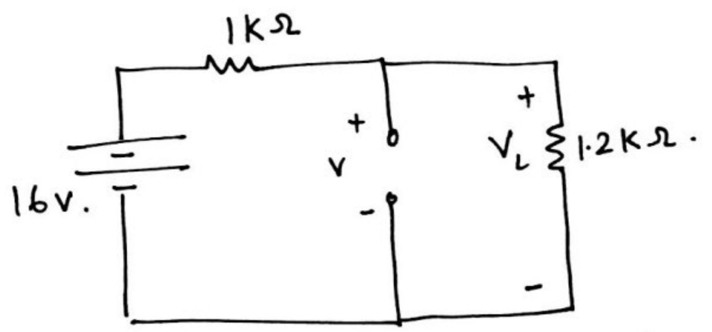
Step 1 Determine the state of Zener diode whether it is "ON" or "OFF" by removing it and calculating the voltage across the open circuit. If $V < V_Z \Rightarrow$ "OFF"
$V \geq V_Z \Rightarrow$ "ON"



$$V = V_L = \frac{16 \times 10^3 \times 1.2}{2.2 \times 10^3} = 8.73\,V$$

Hence $\boxed{\text{Zener diode is OFF}}$

Step2 Replace the diode according to the result of step 1 and solve the circuit.



$\boxed{I_Z = 0\ A}$

$P_Z = V_Z I_Z$

$\boxed{P_Z = 0\ W}$

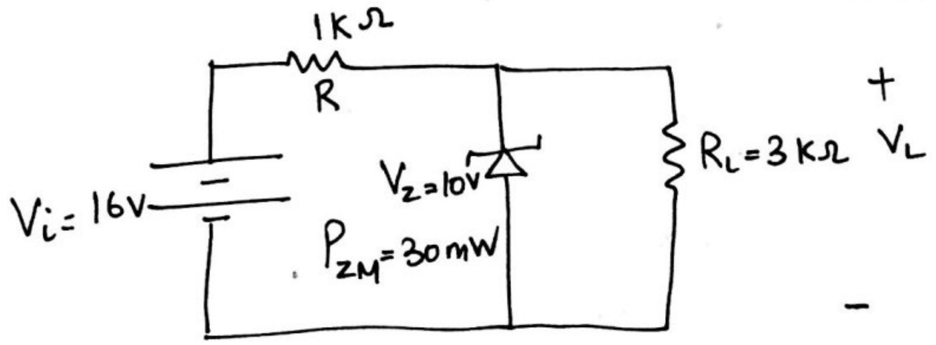
$\boxed{V_L = V = 8.73\ V}$

$V_R = V_i - V$

$= 16 - 8.73$

$\boxed{V_R = 7.27\ V}$

(ii). Repeat (i) with $R_L = 3K\Omega$.



Follow the same steps as in (i)

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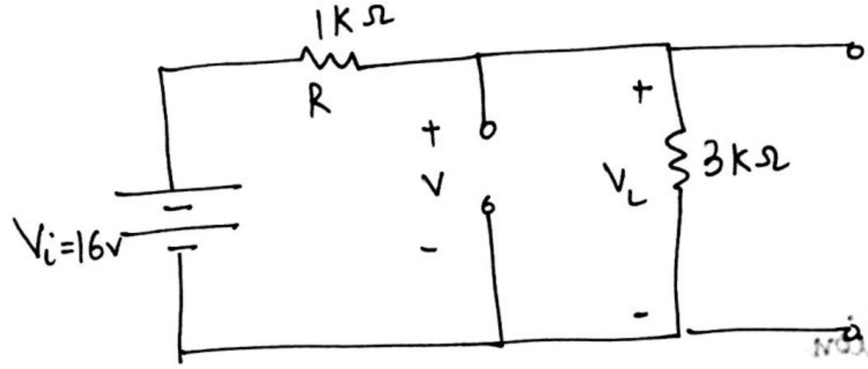
step 1

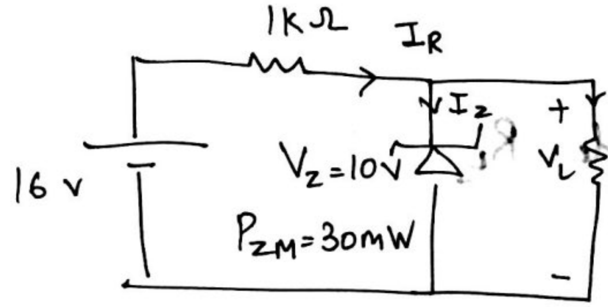


$$V = V_L = \frac{16 \times 3 \times 10^3}{(3+1) \times 10^3}$$

$$\boxed{V = 12\,V}$$

$$V > V_Z \Rightarrow \text{"ON"}$$

step 2



$$\boxed{V_L = V_Z = 10V}$$

$$V_R = V_i - V_Z$$

$$= 16 - 10V$$

$$\boxed{V_R = 6V}$$

$$I_R = \frac{V_R}{R} = \frac{6}{1 \times 10^3} = 6mA$$

$$\boxed{I_R = 6mA} \qquad I_L = \frac{V_L}{R_L} = \frac{V_Z}{R_L} = \frac{10}{3 \times 10^3} = 3.33\,mA$$

$$\boxed{I_Z = I_R - I_L} \qquad \boxed{I_Z = 2.67\,mA}$$

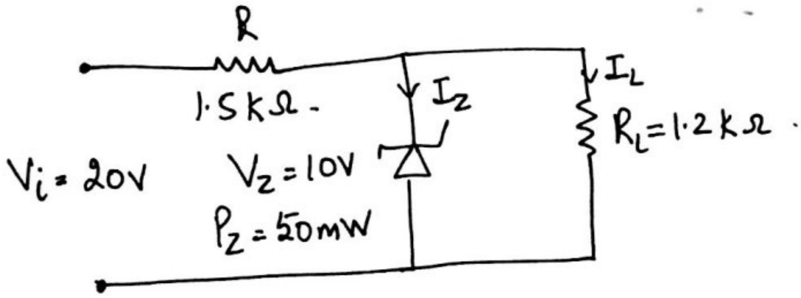
$$P_Z = V_Z I_Z$$

$$= 10 \times 2.67 \text{ mA}$$

$$\boxed{P_Z = 26.7 \text{ mW}}$$

University Question

Q For the given Zener diode network, determine V_L, V_R, I_L, I_R (5 Marks) (2015-16) (2013-14).



V = 8.8 V 'OFF'

$V_L = 8.8$ V

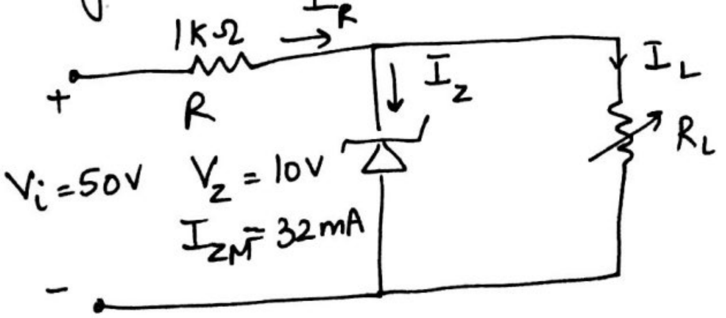
$V_R = 11.2$ V

$I_R = 7.4$ mA

$I_L = 7.4$ mA

Fixed Vi, Variable R_L

Q2. For the given network, determine the range of R_L and I_L that will result in V_{RL} being maintained at 10V. Determine the maximum wattage rating of the diode (2011-12) (5 Marks) UPTU (2017-18) (7 marks)



→ R_{Lmin} R_{Lmax} I_{Lmin} I_{Lmax} } → are to be calculated 'step 1' R_{Lmin} will be calculated as

$$V_L = V_Z = \frac{R_L V_i}{R_L + R} \Rightarrow \frac{R_{Lmin} V_i}{R_{Lmin} + R}$$

$$\Rightarrow \boxed{R_{Lmin} = \frac{R V_Z}{V_i - V_Z}}$$

$$R_{Lmin} = \frac{10^3 \times 10}{50 - 10} = 250\Omega$$

$$\boxed{R_{Lmin} = 250\Omega}$$

step 2 $\quad I_{Lmax} = \frac{V_L}{R_{Lmin}} = \frac{V_Z}{R_{Lmin}}$

$$I_{Lmax} = \frac{10}{250} = 0.04$$

$$\boxed{I_{Lmax} = 40\,mA}$$

step 3. $\quad \boxed{I_R = I_{ZM} + I_{Lmin}}$

$$I_R = \frac{V_R}{R} = \frac{V_i - V_Z}{R}$$

$$I_R = \frac{50 - 10}{10^3} = 40\,mA$$

$$I_{Lmin} = 40\,mA - 32\,mA$$

$$\boxed{I_{Lmin} = 8\,mA}$$

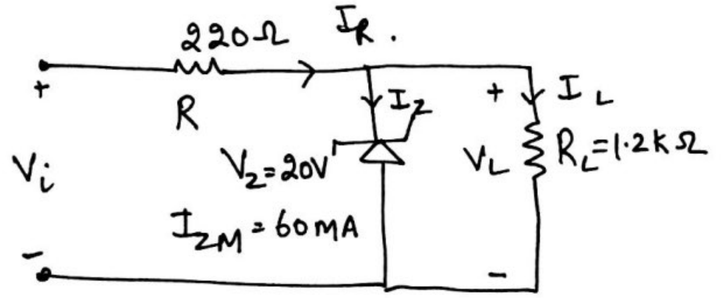
Step 4 $R_{Lmax} = \frac{V_L}{I_{min}} = \frac{V_z}{I_{min}} = \frac{10}{8 \times 10^{-3}} = 1.25k\Omega$

Answer. Range of $R_L \rightarrow 250\Omega$ to $1.25k\Omega$.

Range of $I_L \rightarrow 8mA$ to $40mA$

Variable V_i, fixed R_L

Q3. Determine the range of values of V_i, that will maintain Zener diode of the network in the "ON" state.



→ V_{imin} to V_{imax} are to be calculated.

Step 1 V_{imin} will be calculated as

$$V_L = V_z = \frac{R_L V_i}{R + R_L} \Rightarrow V_z = \frac{R_L V_{imin}}{R + R_L}$$

$$\boxed{V_{imin} = \frac{V_z}{R_L}(R + R_L)}$$

$$V_{imin} = \frac{20 \times (220 + 1.2 \times 10^3)}{1.2 \times 10^3}$$

$\boxed{V_{imin} = 23.67V}$

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step 2 Vimax

$$I_{Rmax} = \frac{V_{imax} - V_Z}{R}$$

$$I_{Rmax} = I_{ZM} + I_L$$

$$I_L = \frac{V_Z}{R_L} = \frac{20}{1.2 \times 10^3} = 16.67\ mA$$

$$\Rightarrow I_{Rmax} = 60\,mA + 16.67\,mA$$

$$\boxed{I_{Rmax} = 76.67\,mA}$$

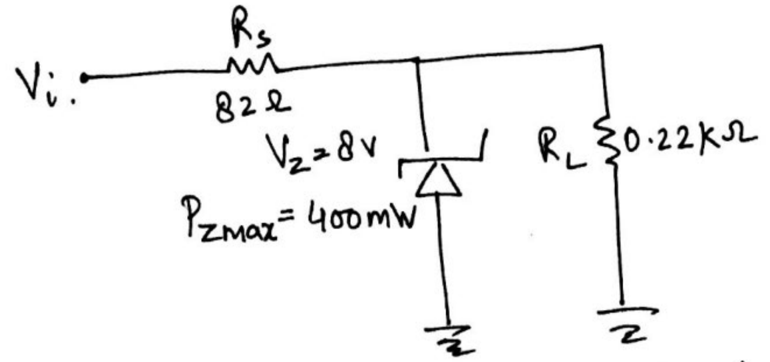
$$76.67 \times 10^{-3} = \frac{V_{imax} - 20}{220}$$

$$\boxed{V_{imax} = 36.87V}$$

Ans. $\boxed{23.67\,V \text{ to } 36.87\,V}$

University Questions

Q2

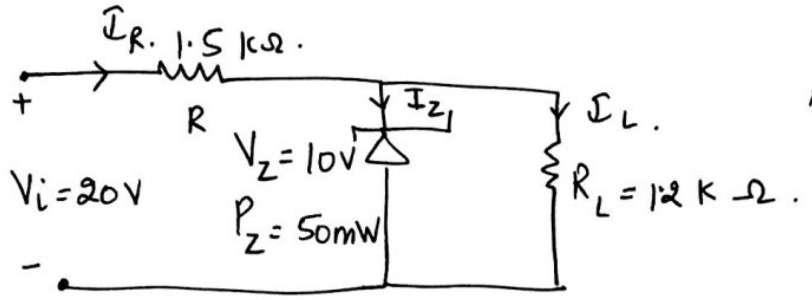


(2015-16 UPTU)
(5 Marks)

For the above Network, determine the range of V_i that will maintain V_L at 8V and not exceed maximum power rating of diode. (Ans: 10.98 to 15.08 V)

Q. Explain Zener diode as shunt regulator. (5 Marks)

Q. For the Zener diode network, determine V_L, V_R, I_L, I_R.



Ans: $V_L = 8.88\ V$

$I_z = 0$

$V_R = 11.12\ V$

$I_L = I_R = 7.4\ mA$.

Lecture 7

Unit 1 : PN Junction Diode

Contents :

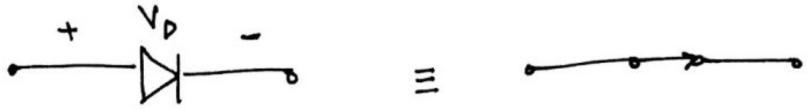
- Diode Equivalent Circuits
- Series Diode Configuration .

Diode Equivalent Circuits

There are 3 approximations.

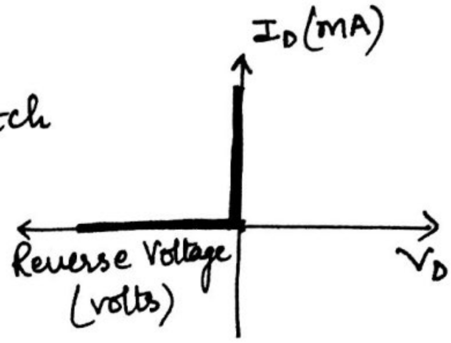
- First approximation → Ideal Diode .
- Second approximation → Simplified Equivalent Circuit .
- Third approximation → Piecewise Linear Equivalent circuit .

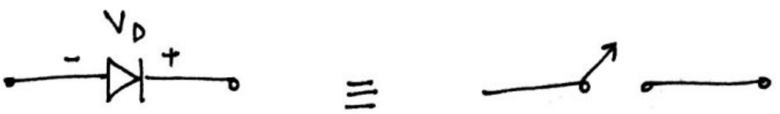
First approximation



Forward Bias

closed switch
(Diode ON)

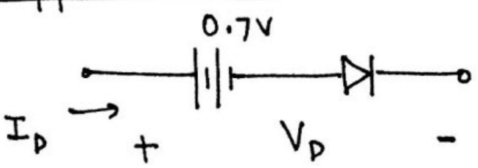


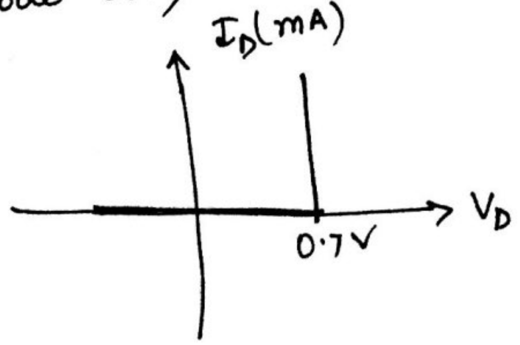


Reverse Bias

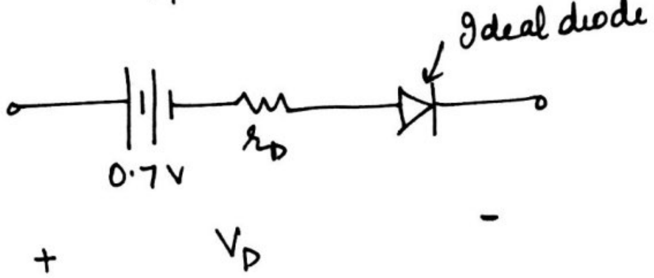
open switch
(Diode OFF)

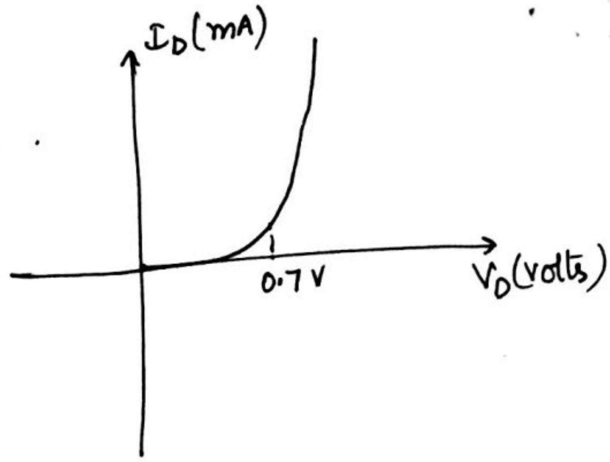
Second approximation





Third approximation

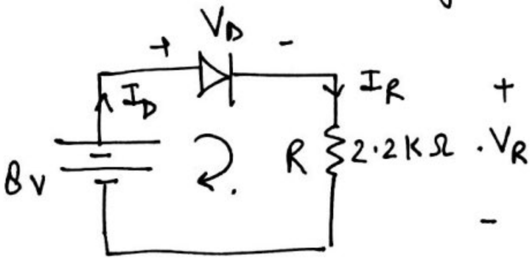




Series Diode Configuration

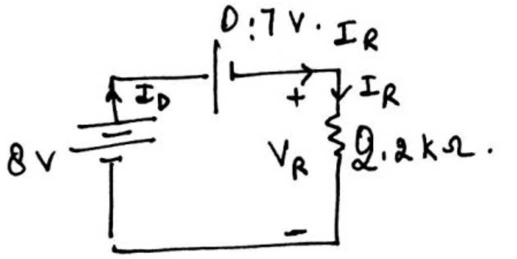
- If the diode is forward biased, replace
  - Si diode → 0.7 V battery
  - Ge diode → 0.3 V
  - GaAs diode → 1.12 V.

Q.1. For the series diode configuration, determine V_D, V_R, I_D.



→ Diode is forward biased

→



$$I_D = I_R = \frac{V_R}{R}$$

$$= \frac{7.3}{2.2 \times 10^3}$$

$$\boxed{I_D = 3.32 \text{ mA}}$$

$$\boxed{V_D = 0.7 \text{ V}}$$

$$V_R - 8 + 0.7 \text{ V} = 0$$

$$\boxed{V_R = 7.3 \text{ V}}$$

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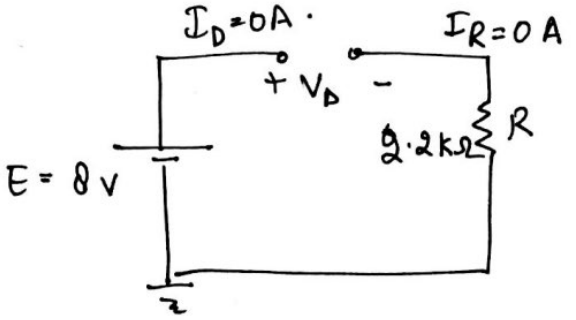
Q2. Repeat Q1. if the diode is reverse biased.

→ If the diode is reverse biased, replace it with open circuit.



$$\boxed{I_D = 0 \text{ A}}$$

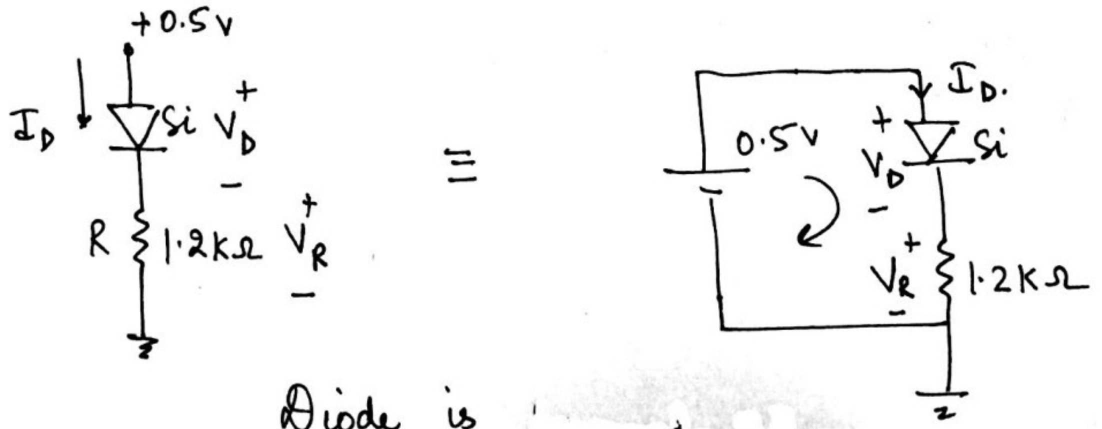
$$V_D = E - V_R$$

$$V_R = I_R R = 0$$

$$\boxed{V_D = 8V}$$

$$\boxed{V_R = 0 \text{ V}}$$

E3. For the series diode configuration, determine V_D, V_R, I_D



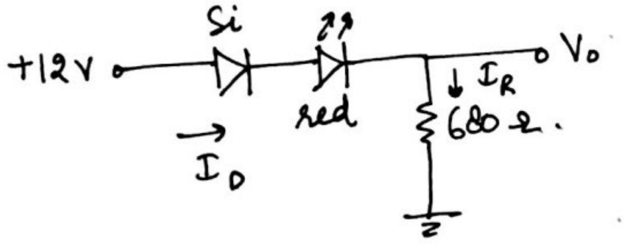
Diode is

$V_D = 0.7$ V .

$V_D = 0.5$ V

$V_R = 0$ V.

Q.3. Determine V_o and I_D for the series circuit.

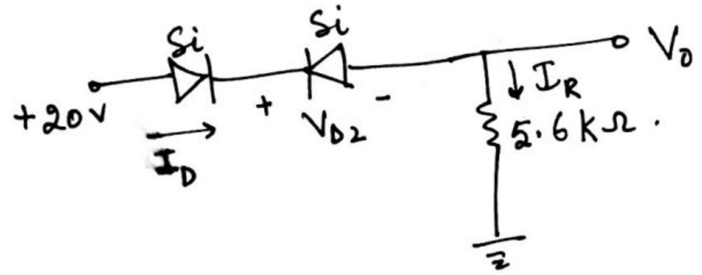


[red diode → 1.8 V if "ON"]

Ans: $V_o = 9.5\,V$

$I_D = 13.97\,mA$.

Q.4. Determine I_D, V_{D2} and V_o for the circuit:



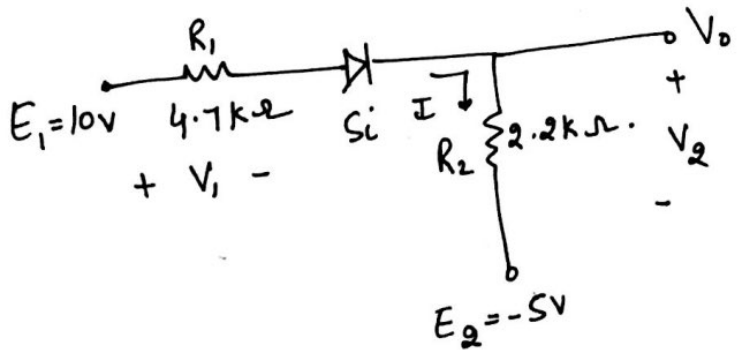
Ans: $I_D = 0\,A$.

$V_o = 0\,V$

$V_{D2} = 20\,V$

⇒

Q.5. Determine I, V_1, V_2 and V_o



Ans: $V_1 = 9.73\,V$

$V_2 = 4.55\,V$.

$V_o = -0.45\,V$

$I \approx 2.07\,mA$

Lecture 8

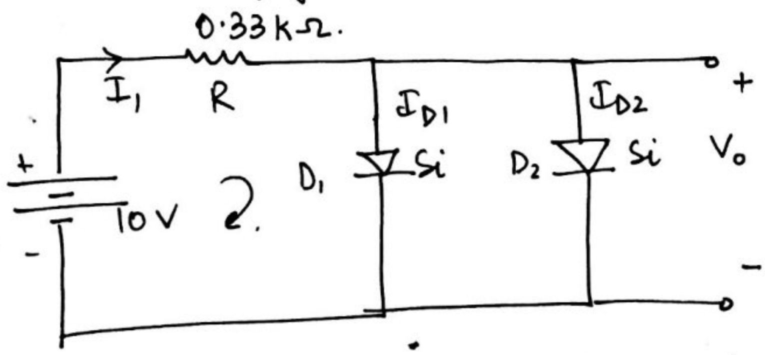
Unit 1 : PN Junction Diode

Contents :

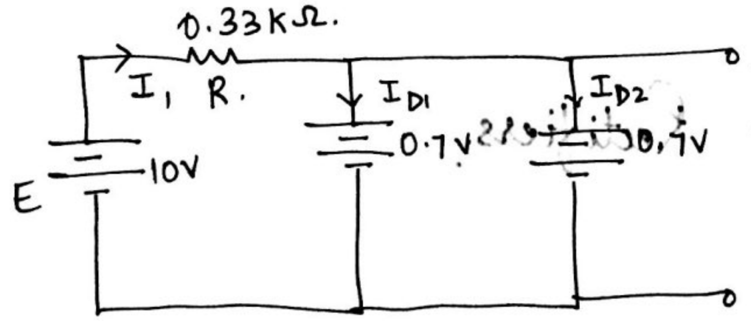
- Parellel diode Configuration
- Series parellel diode configuration.
- Introduction to Rectifiers

Parellel diode Configuration

Q1. Determine V_o, I_1, I_{D1} and I_{D2} for the parellel diode configuration.



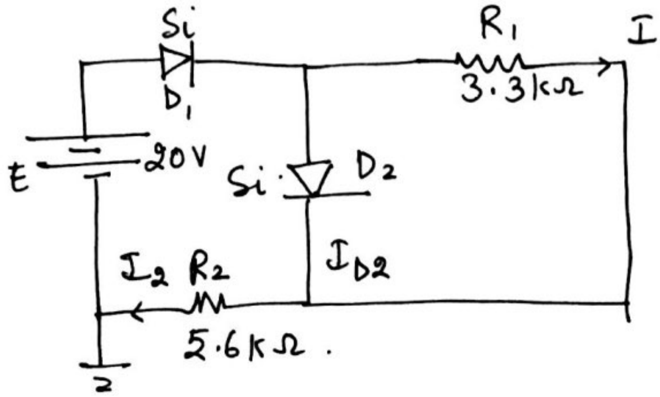
D_1 and D_2 → Forward Biased.



$V_o = 0.7\ V$ $\qquad I_1 = \dfrac{E - V_D}{R} = \dfrac{10 - 0.7}{0.33 \times 10^3} = 28.18\ mA$

$$\boxed{I_{D1} = I_{D2} = \frac{I_1}{2} = \frac{28.18}{2} = 14.09\ mA}.$$

Q2.



Determine the currents I_1, I_2, I_{D2} for the above network.

Ans: $I_1 = 0.212\ mA$
$I_2 = 3.32\ mA$.
$I_{D2} = 3.11\ mA$.

Diode Applications

1. Rectifiers
2. Clippers
3. Clampers.
4. Voltage Multipliers
5. Zener diodes.

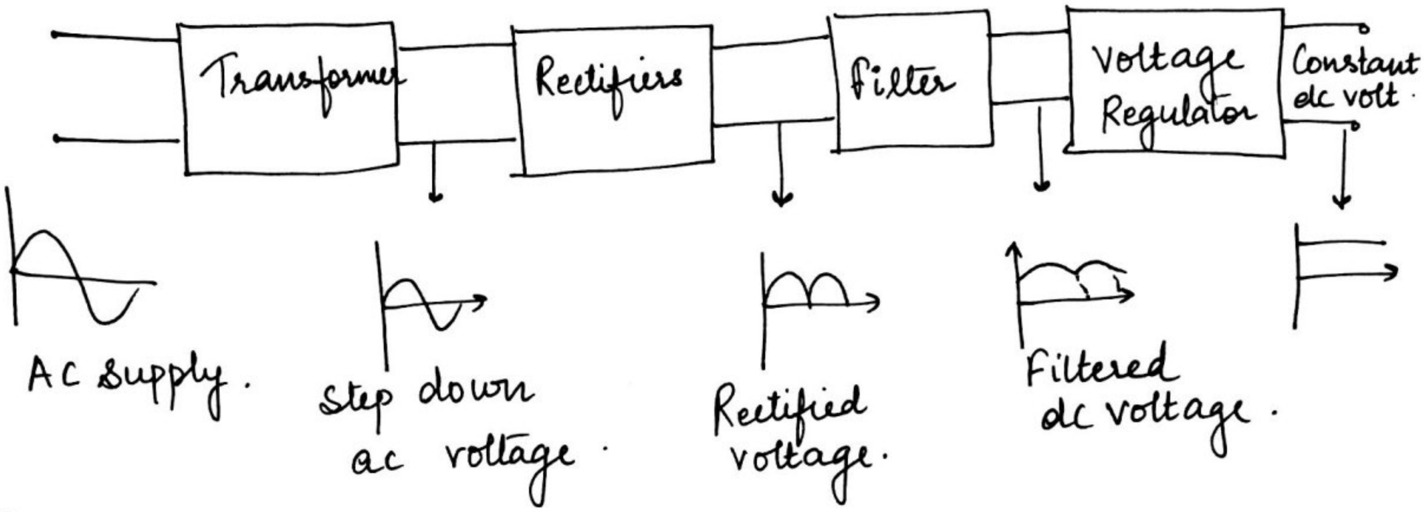
Introduction to Rectifiers.

Rectifiers convert a.c to pulsating d.c.

Rectifiers are of two types:

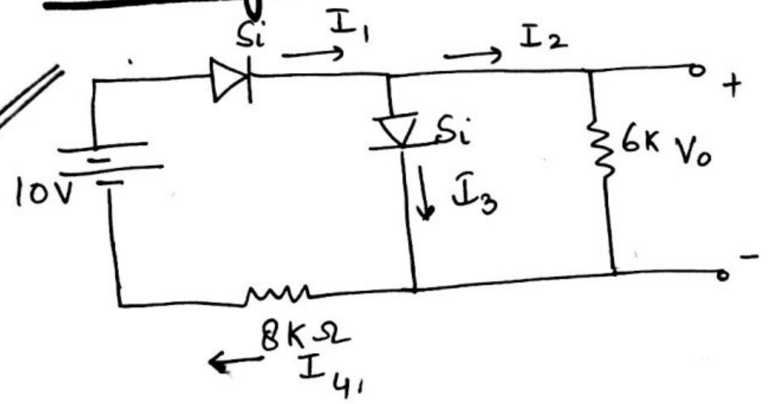
- Half wave rectifier
- Full wave rectifier.

Block diagram of a regulated Power supply.



University Question

Q.



(2016-17' odd sem)

Determine I_1, I_2, I_3, I_4, V_o.

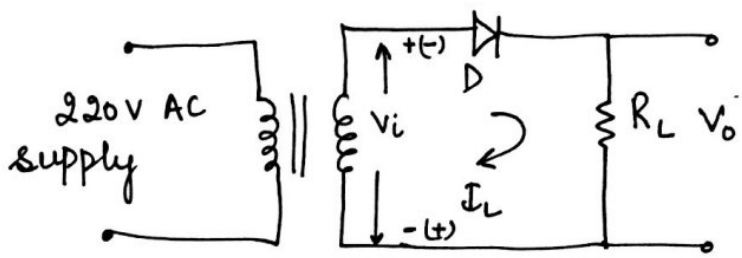
Lecture 9

Unit 1 : PN Junction Diode

Contents :

- Half Wave Rectifier
- Average / DC value of Half Wave Rectifier.
- Rms / AC value for Half Wave Rectifier
- full wave Rectifier

Half Wave Rectifier



$V_i = V_m \sin \omega t$.

During positive half cycle

D is forward biased

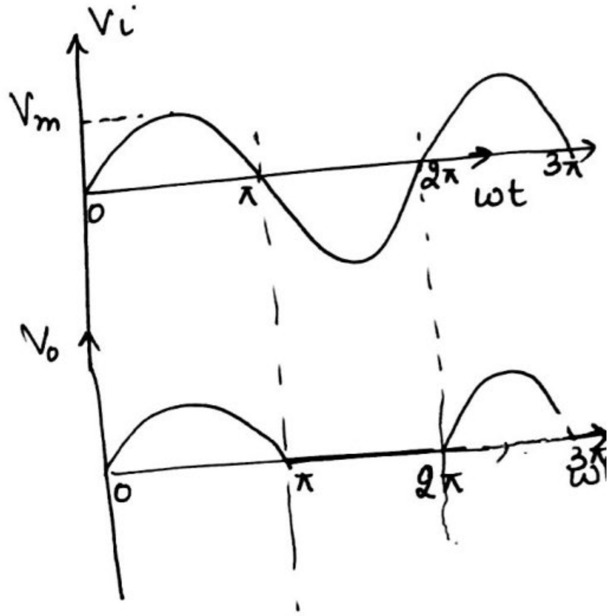
$V_o = V_i$

During negative half cycle

D is reverse biased

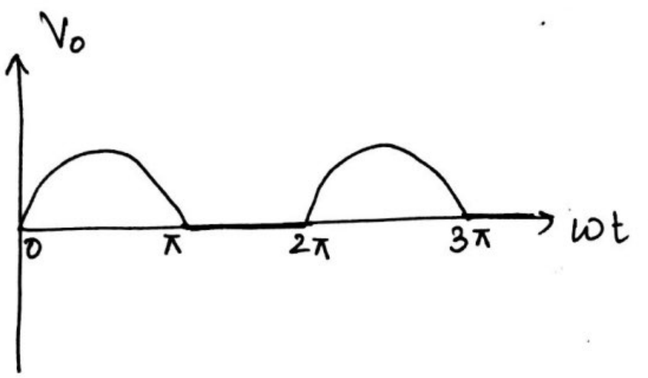
$V_o = 0$

Half wave rectifier is so called because it delivers power to the load only during one half cycle of ac supply voltage.



Input and output Waveforms of Half Wave rectifier

Dc / Average value of output Voltage (V_o) for half Wave Rectifier



$$V_{dc} / V_{avg} = \frac{\text{Area under one cycle}}{\text{Base}}$$

$$= \frac{\int_0^{2\pi} V_o \, d\omega t}{2\pi}$$

$$= \frac{\int_0^{\pi} V_m \sin\omega t \, d\omega t + \int_{\pi}^{2\pi} 0 . \, d\omega t}{2\pi}$$

$$\boxed{V_{dc} = \frac{V_m}{\pi}} \qquad \boxed{I_{dc} = \frac{I_m}{\pi}}$$

$V_{dc} = 0.318 \, V_m$ $\qquad$ $I_{dc} = 0.318 \, I_m$

AC / RMS value of Output Voltage (V_o) for Half Wave Rectifier

$$V_{rms} = \sqrt{\frac{1}{2\pi} \int_0^{2\pi} V_o^2 \, d\omega t}$$

$$V_{rms} = \frac{1}{\sqrt{2\pi}} \sqrt{\int_0^{\pi} V_m^2 \sin^2\omega t \, d\omega t}$$

$$V_{rms} = \frac{V_m}{\sqrt{2\pi}} \sqrt{\int_0^{\pi} \frac{1-\cos 2\omega t}{2} \, d\omega t}.$$

$$\boxed{V_{rms} = \frac{V_m}{2}} \qquad \boxed{I_{rms} = \frac{I_m}{2}}$$

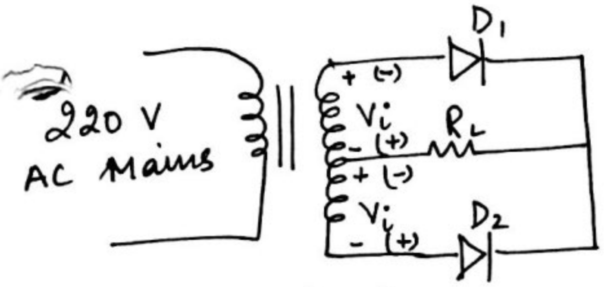
PIV of each diode $= V_m$.

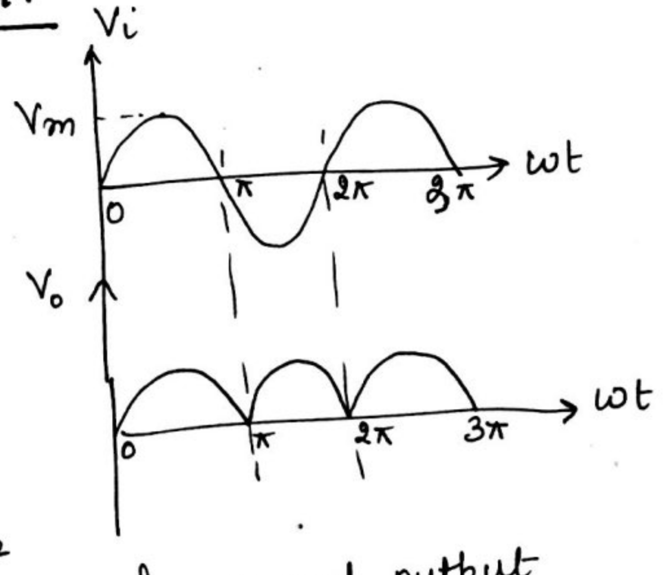
Full Wave Rectifier

Full wave rectifier is of 2 types:

- centre tapped Transformer
- Bridge Rectifier.

Center tapped Transformer.

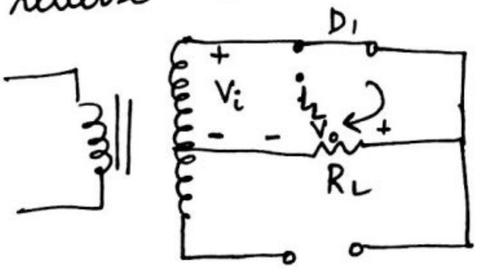




Input and output waveforms

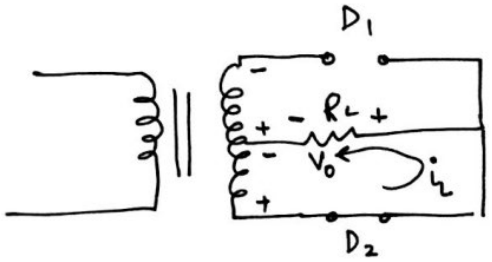
$V_i = V_m \sin\omega t$

During positive half cycle D_1 is forward biased and D_2 is reverse biased.



$V_o = V_i$

During negative half cycle D_1 is reverse biased and D_2 is forward biased



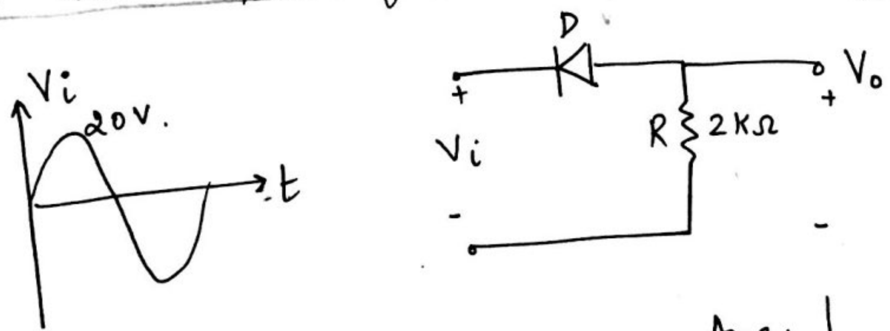
$\boxed{V_0 = V_i}$ PIV of each diode = $2V_m$.

University Questions

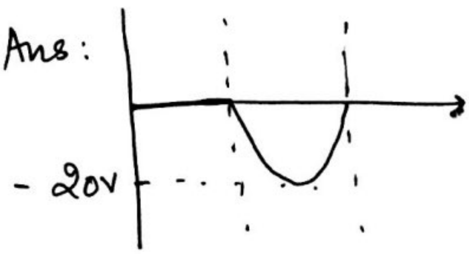
Q Explain the working of full wave rectifier. (2015-16) (5 Marks)

Q Explain the working of half wave rectifier.

Q Sketch the output V_0 and determine the dc level of the output for the network.



Ans:



$V_{dc} = -6.14V$.

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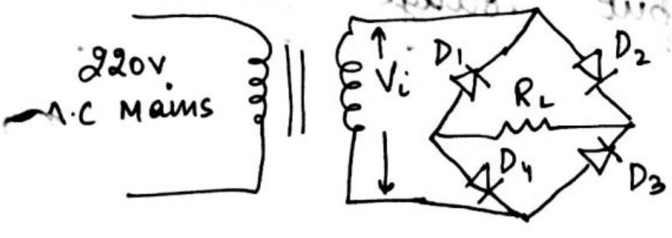
Lecture 10 — ELECTRONICS ENGG.

Unit 1 : PN Junction Diode.

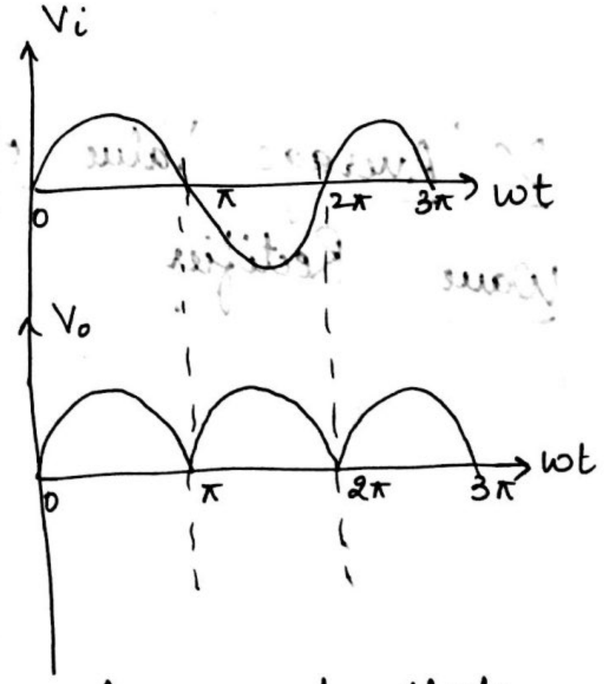
Contents :

- Bridge Rectifier
- Average / DC value of output voltage for full wave rectifier
- RMS / AC value of output voltage for full wave rectifier
- Ripple factor.

Bridge Rectifier



$V_i = V_m \sin\omega t$



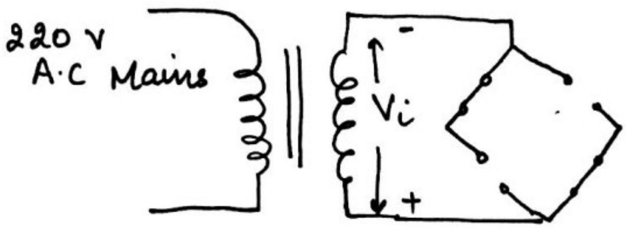
Input and output Waveforms

During positive half cycle D_2 and D_4 will be forward and D_1 and D_3 will be reverse biased.

$V_i = V_m \sin\omega t$

$\boxed{V_o = V_i}$

During negative half cycle, D_1 and D_3 will be forward biased and D_2 and D_4 will be reverse biased.

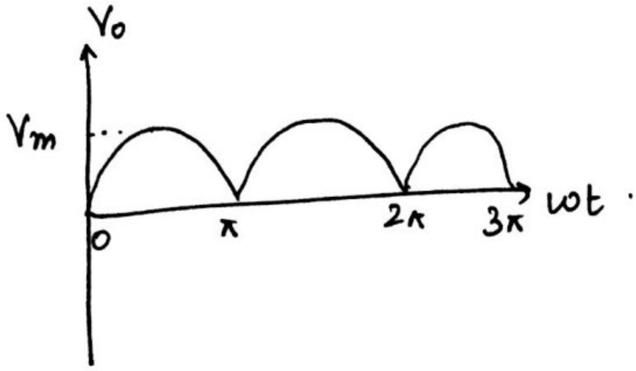


$V_i = V_m \sin\omega t$.

$\boxed{V_o = V_i}$

PIV of each diode $= V_m$.

DC / Average Value of Output Voltage for Full Wave Rectifier



$$V_{dc} / V_{avg} = \frac{\text{Area under one cycle}}{\text{Base}}$$

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$$V_{dc} = \frac{\int_0^{\pi} V_0 \, d\omega t}{\pi}$$

$$= \frac{\int_0^{\pi} V_m \sin\omega t \, d\omega t}{\pi}$$

$$\boxed{V_{dc} = \frac{2V_m}{\pi}} \qquad \boxed{I_{dc} = \frac{2I_m}{\pi}}$$

$$\boxed{V_{dc} = 0.636\, V_m} \qquad \boxed{I_{dc} = 0.636\, I_m}$$

AC / RMS Value for Full Wave Rectifiers

$$V_{rms} = \sqrt{\frac{1}{\pi}\int_0^{\pi} V_0^2 \, d\omega t}$$

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

$$\boxed{V_{rms} = \frac{V_m}{\sqrt{2}}} \qquad \boxed{I_{rms} = \frac{I_m}{\sqrt{2}}}$$

Ripple factor

The output of rectifier contain both a.c and d.c components. The ac component of the output voltage and current from rectifier is called ripple.

Ripple factor is the quantity to measure this ripple. More the ripple factor, lesser is the efficiency of rectifier and lesser the ripple factor, more is the efficiency of rectifier.

Ripple factor $r = \dfrac{\text{RMS value of ac component of output voltage}}{\text{dc component of output voltage}}$.

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

$$V_{rms} = \sqrt{V_{dc}^2 + V_{ac,\,rms}^2}$$

squaring both sides, and arranging the equation we get, (Dividing both sides by V_{dc})

$$\boxed{\sqrt{\left(\frac{V_{rms}}{V_{dc}}\right)^2 - 1} = \frac{V_{ac,\,rms}}{V_{dc}}} = \text{Ripple factor}.$$

Ripple factor for Half Wave Rectifiers

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

$$V_{rms} = \frac{V_m}{2} \qquad V_{dc} = \frac{V_m}{\pi}$$

$$\boxed{r = 1.21}$$

Ripple factor for Full wave Rectifiers

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

$$V_{rms} = \frac{V_m}{\sqrt{2}} \qquad V_{dc} = \frac{2V_m}{\pi}$$

$$\boxed{r = 0.48}$$

Efficiency of Rectifiers

$$\text{Efficiency } \eta = \frac{\text{Dc Power delived to the load}}{\text{AC Power input to the Transformer secondary.}}$$

$$= \frac{I_{dc}^2 R_L}{I_{rms}^2 (R_S + R_f + R_L)}$$

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$$\boxed{\eta = \frac{I_{dc}^2 R_L}{I_{rms}^2 (R_S + R_F + R_L)}}$$

$(R_S + R_f) << R_L$

Efficiency of half wave Rectifier

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

$$\eta = \frac{(I_m/\pi)^2 R_L}{(I_m/2)^2 (R_S + R_F + R_L)}$$

$= 0.405$

$$\boxed{\eta\% = 40.5\%}$$

Efficiency of Full Wave Rectifier

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

$$\eta = \frac{\left(\frac{2I_m}{\pi}\right)^2 R_L}{\left(\frac{I_m}{\sqrt{2}}\right)^2 (R_S + R_F + R_L)}$$

$\eta = 0.812$

$$\boxed{\eta\% = 81.2\%}$$

University Questions

Q. Explain full wave rectifier with circuit diagram. Also find ripple factor for it. (5 Marks) (2015-16)

Q. Differentiate between half wave and Full wave rectifiers (2015-16) (5 Marks).

Q. Elucidate the operation of half wave rectifier in detail and derive the expression for ripple factor (5 Marks) (2014-15).

Q. Draw and explain the working of a Bridge Rectifier with input and output waveforms. Calculate efficiency and ripple factor. (5 Marks) (2014-15)

Q. Prove that the efficiency of half wave rectifier is 40.5%.

Q. Explain operation of full wave bridge rectifier with the help of a circuit diagram. Also sketch input and output waveforms. Define its PIV. Also derive its ripple factor and rectification efficiency. (2017-18) (even).

Lecture 11

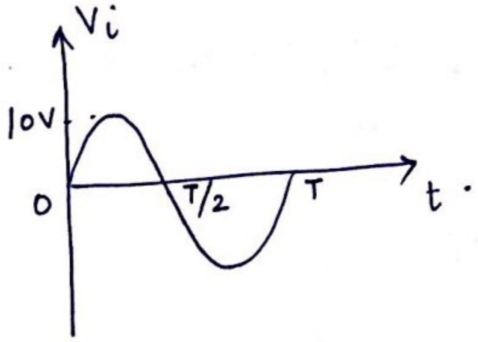
Unit 1: PN Junction Diode

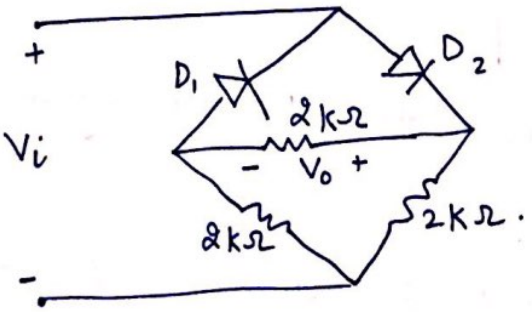
Contents :

- Numericals on Rectifiers
- Clippers
- Positive clipper
- Negative clipper.

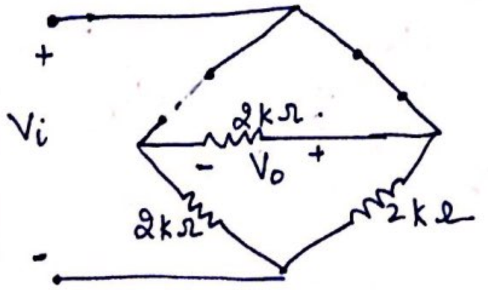
Numericals on Rectifiers

Q. Draw V_o for the following circuit. Also calculate the output dc level and required PIV of each diode. (2017-18) (even) (7 Marks).





→ During positive half cycle

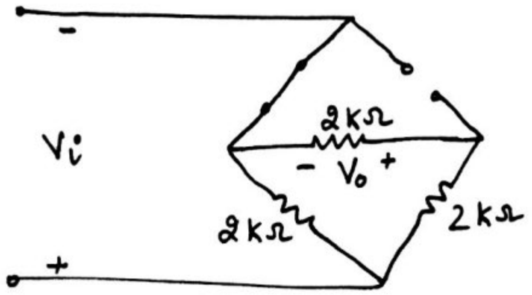


$$V_o = \frac{V_i \times 2K}{(2+2)K}$$

$$= \frac{V_i}{2}$$

$$\boxed{V_o = 5V}$$

During negative half cycle

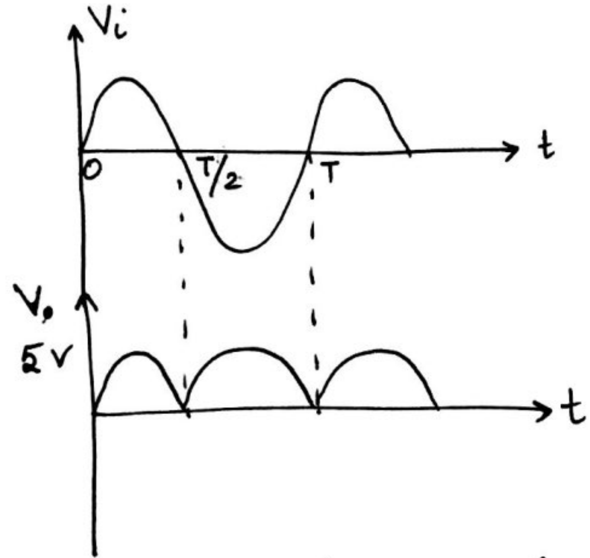


$$V_o = \frac{2K\,(V_i)}{(2+2)\,K}$$

$$V_o = \frac{V_i}{2}$$

$$\boxed{V_o = 5V}$$

Waveform



$$V_{dc} = \frac{2V_m}{\pi}$$

$$= \frac{2\times 5}{\pi} = \frac{10}{\pi}$$

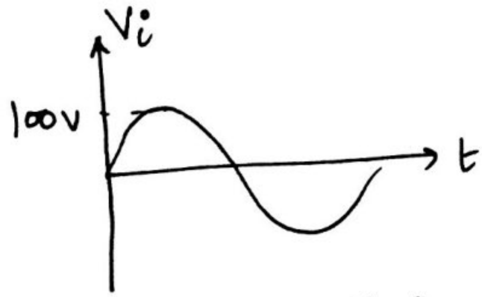
$$\boxed{V_{dc} = 3.18\,V}$$

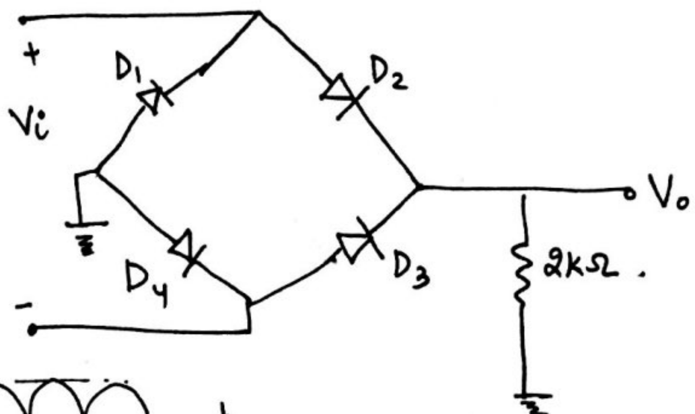
$$\boxed{PIV = 5V}$$

$$V_{dc} = \frac{\text{area of one cycle}}{\text{Base}} = \frac{2V_m}{\pi} = 3.18\ V.$$

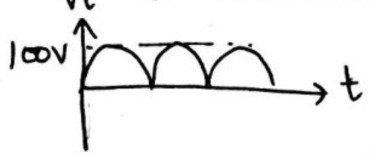
PIV of diode $= V_m = 5V$.

Q.

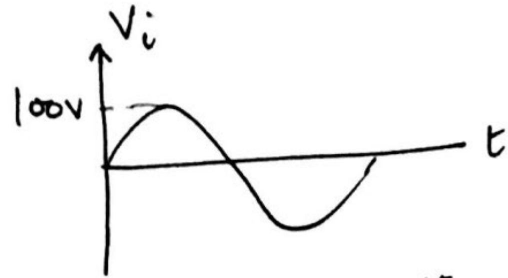


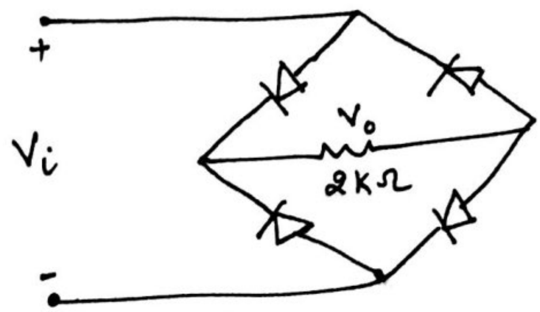


Draw the output voltage waveform.

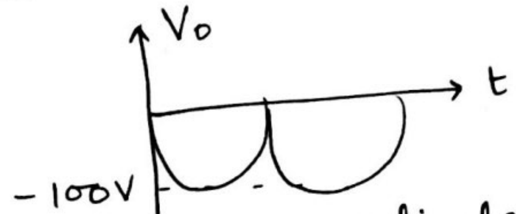


Q:





Draw the output voltage waveform.



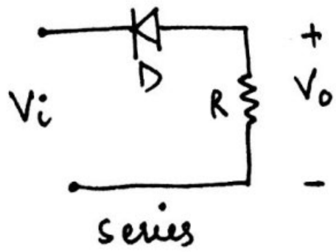
Clippers.

Clippers are the circuits that remove a particular portion of the input signal without distorting the remaining part.

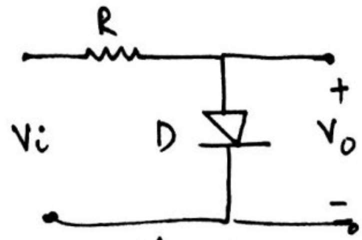
Clippers are of four types.

- Positive clipper
- Negative clipper
- Biased clippers
  - → Biased Positive clipper
  - → Biased Positive clipper with reverse polarity
  - → Biased Negative clipper
  - → Biased Negative clipper with reverse polarity.
- Combination clipper.

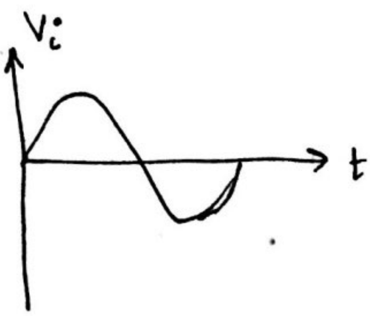
Positive clipper.



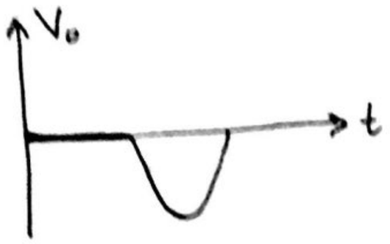
series



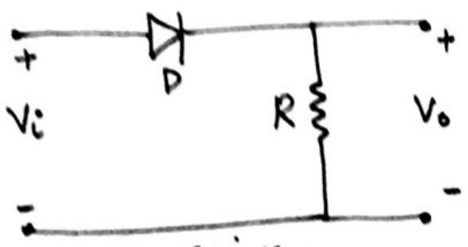
shunt.



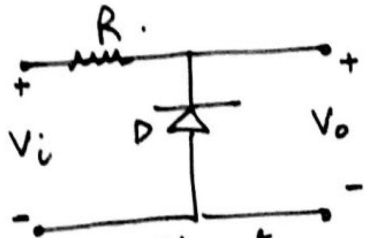
output waveform



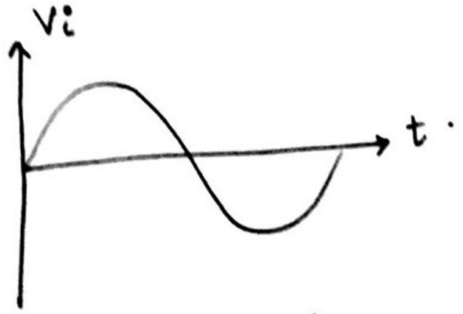
Negative clipper.



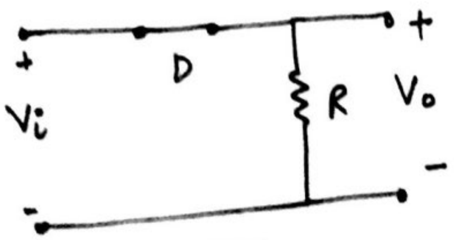
series.



Shunt

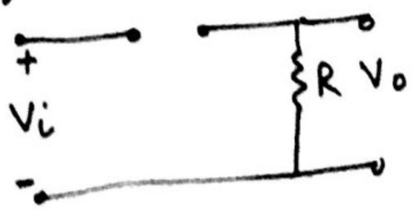


During positive half cycle D is forward biased.



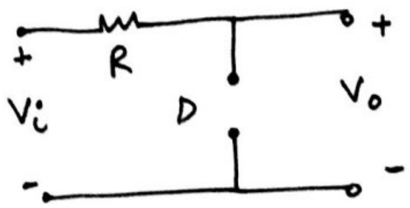
$\boxed{V_o = V_i}$

During negative half cycle D is reverse biased



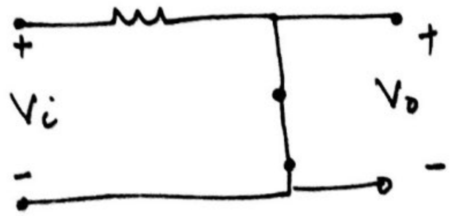
$\boxed{V_o = 0}$

During positive half cycle D is reverse biased.



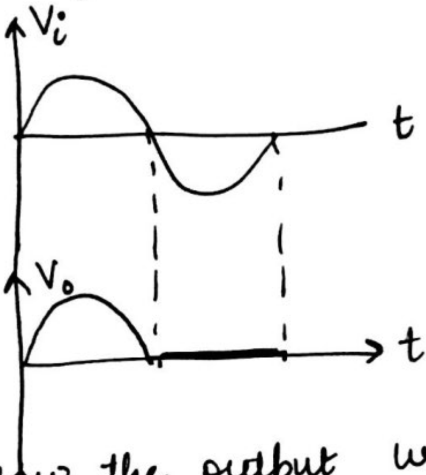
$\boxed{V_o = V_i}$

During negative half cycle D is forward biased.



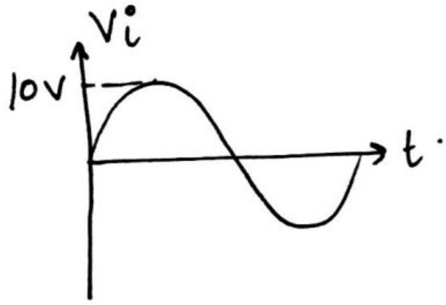
$\boxed{V_o = 0}$

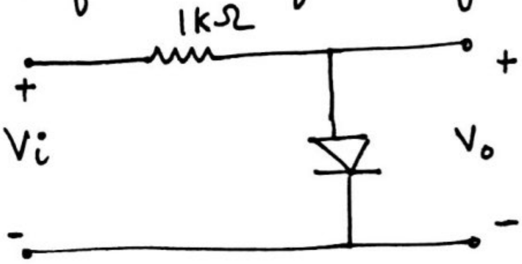
Waveforms



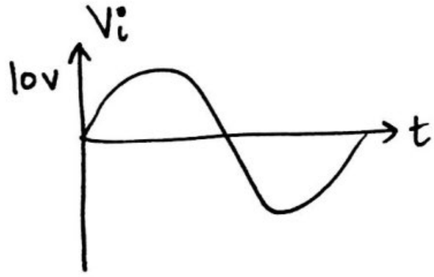
Draw the output waveforms for the following circuit.

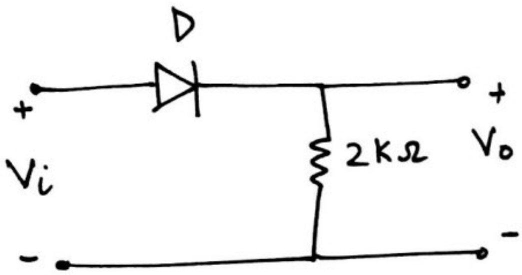
Q





Q





University Question

Q Draw a simple clipping circuit with suitable waveform and explain types of clippers (5 Marks)
(2014-15)

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Lecture 12

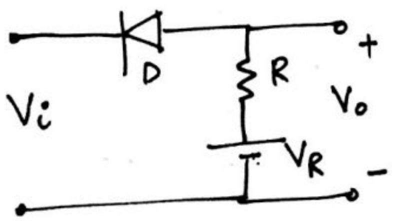
Unit 1: PN Junction Diode

Contents:

- Biased clippers
- Numericals on biased clippers.
- Combination clippers.
- Numericals on combination clipper.

Biased clippers

Biased positive clipper.



During positive half cycle

case 1 $p>n$ $V_R>V_i$ (Forward)

$V_o = V_i$

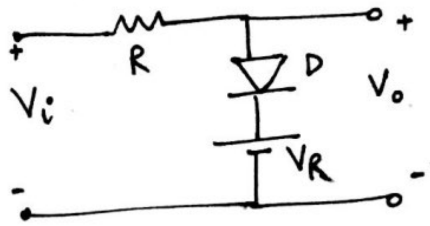
case 2 $p<n$ $V_R<V_i$ (Reverse)

$V_o = V_R$

During negative half cycle

D is forward biased

$\boxed{V_o = V_i}$



During positive half cycle

case 1 $p>n$ $V_i>V_R$ (Forward)

$V_o = V_R$

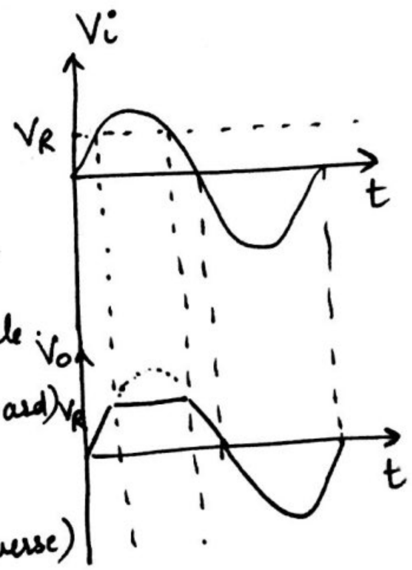
case 2 $p<n$ $V_i<V_R$ (Reverse)

$V_o = V_i$

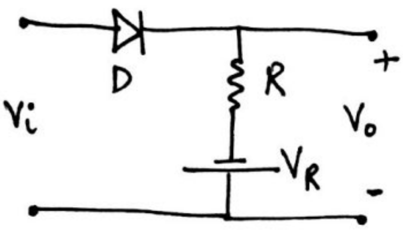
During negative half cycle

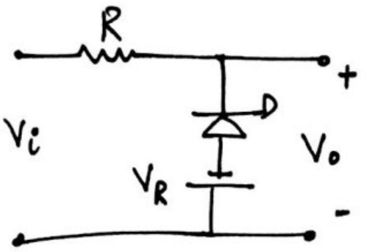
D is reverse biased.

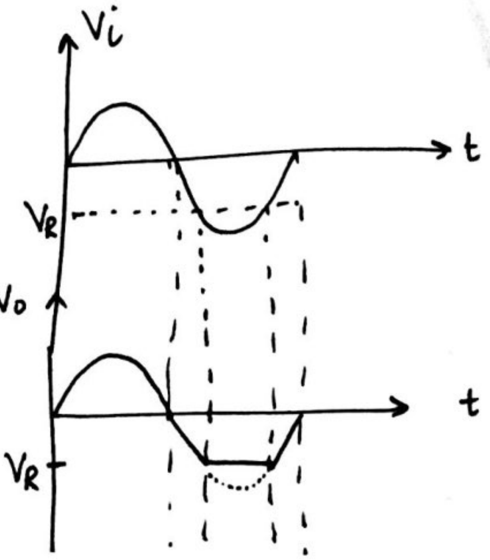
$\boxed{V_o = V_i}$



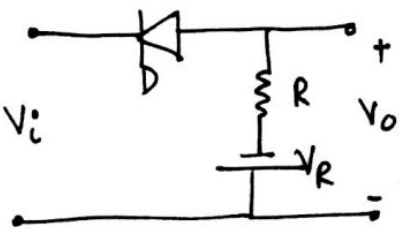
Biased Negative clipper.

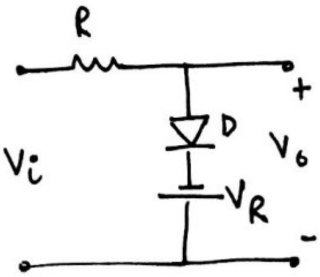


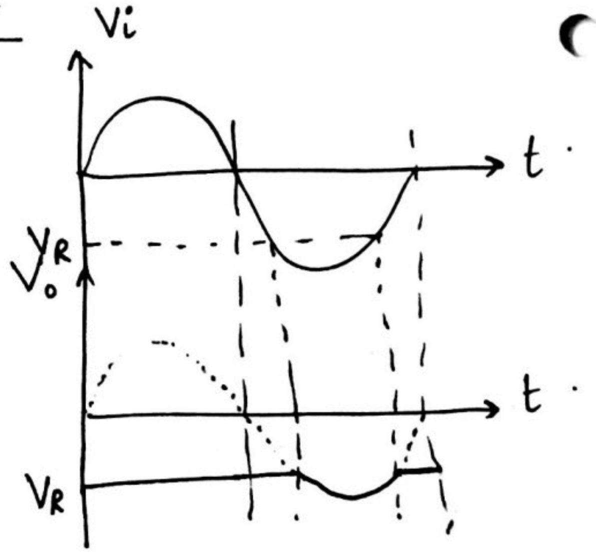




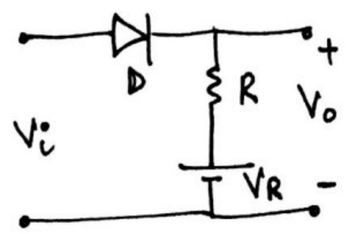
Biased positive clipper with reverse polarity of battery

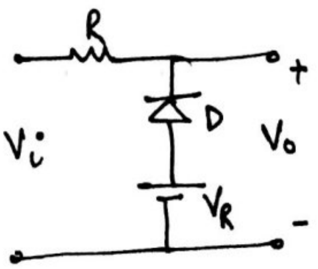


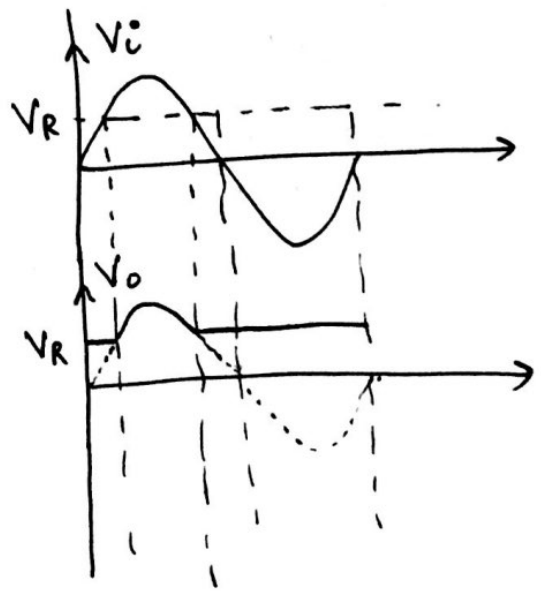




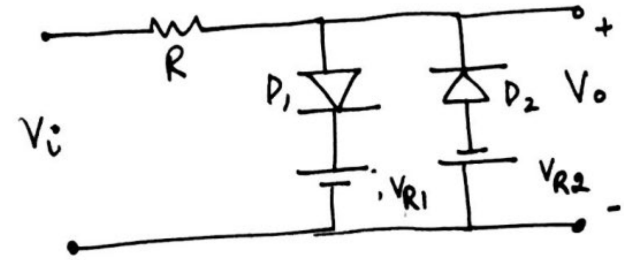
Biased Negative clipper with Reverse polarity of battery.

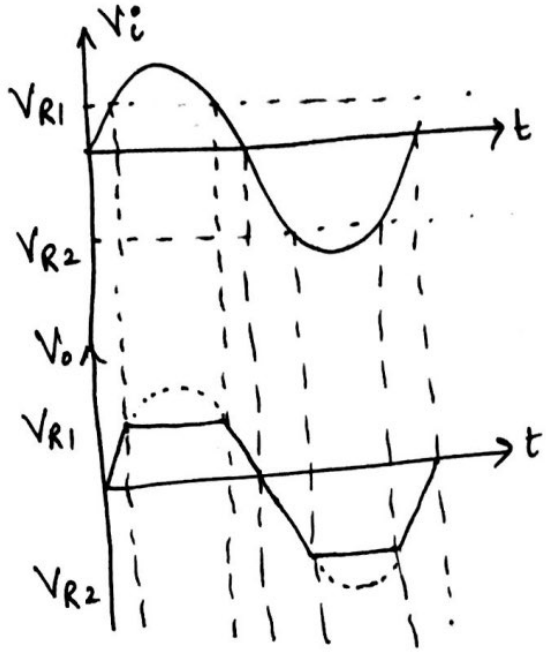






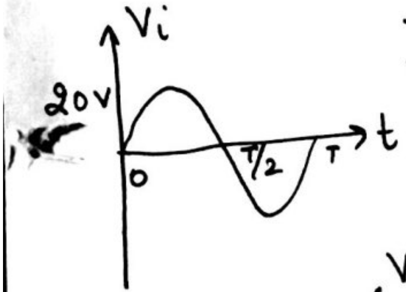
Combination Clipper.

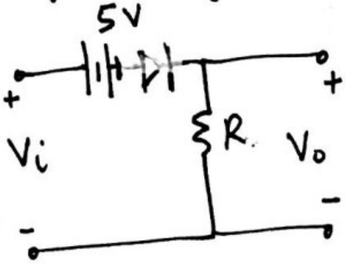




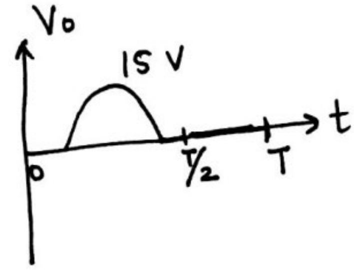
Draw the V_o for following circuits :

Q1.

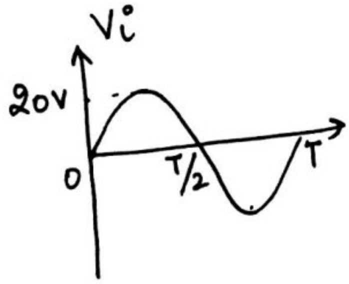


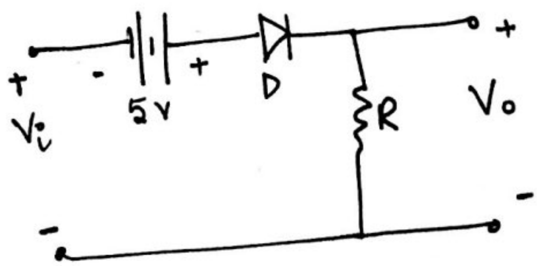


Ans:

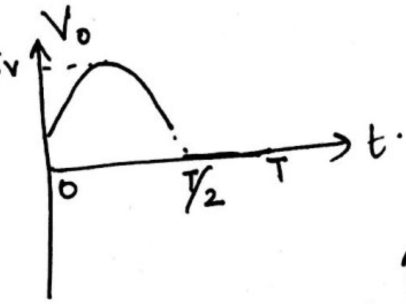


Q2.

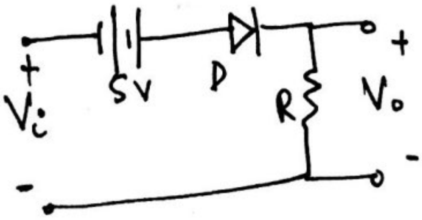


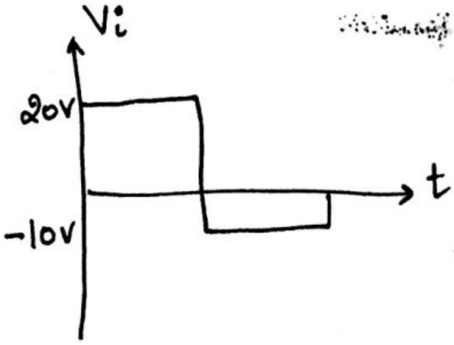


Ans :

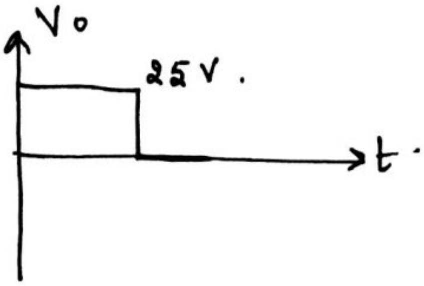


Q3.

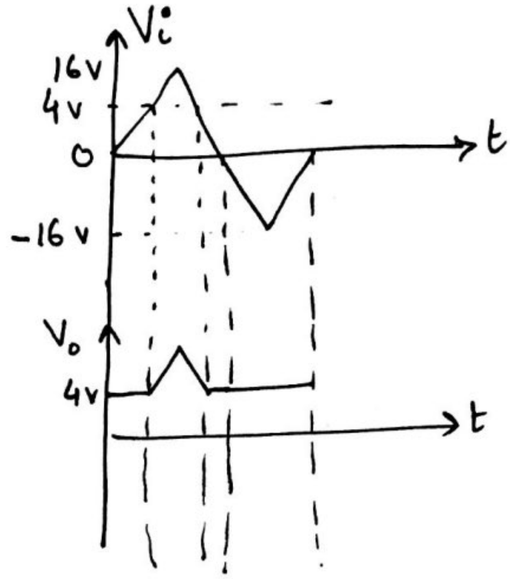


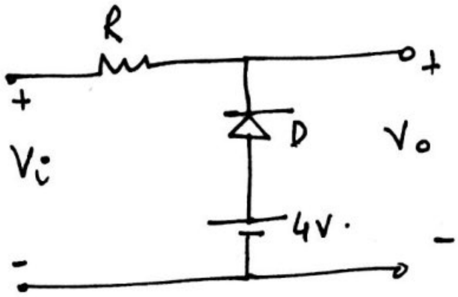


Ans :



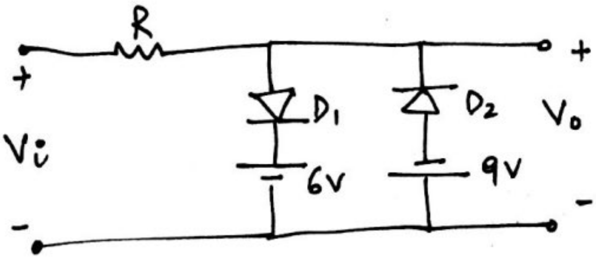
Q4.

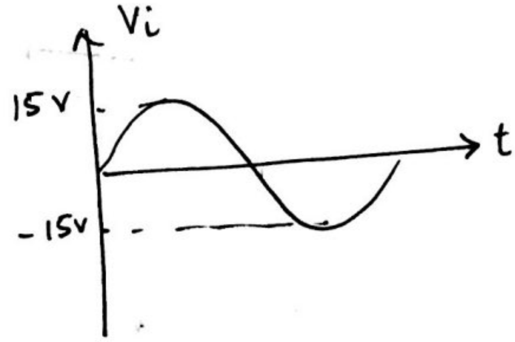




Ans.

Q5.





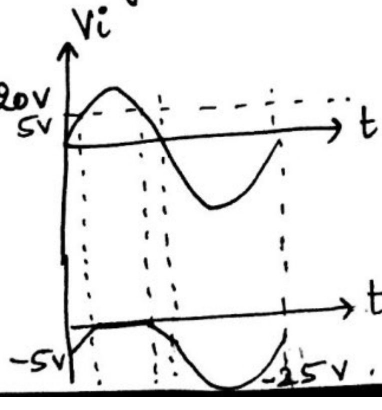
Consider the diodes to be ideal .

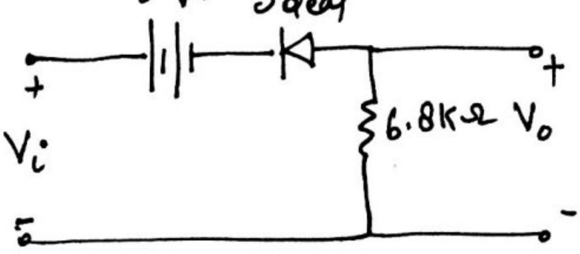
Q6. Repeat Q 5 considering the diodes to be nonideal .

<u>University Questions</u>

(5 Marks)
(2015-16)

Q 1.





Ans:

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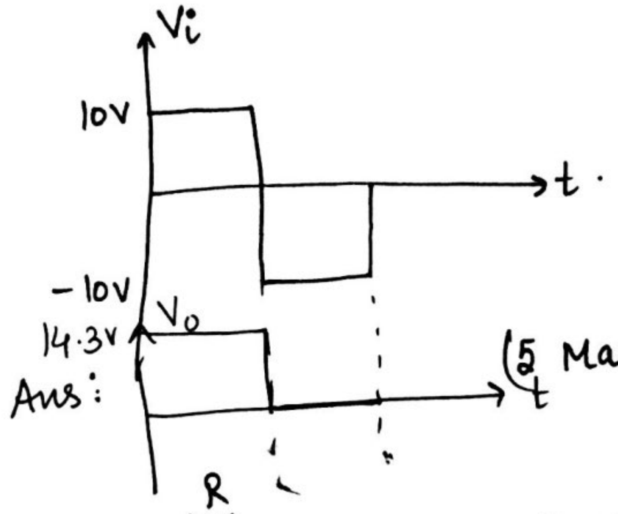
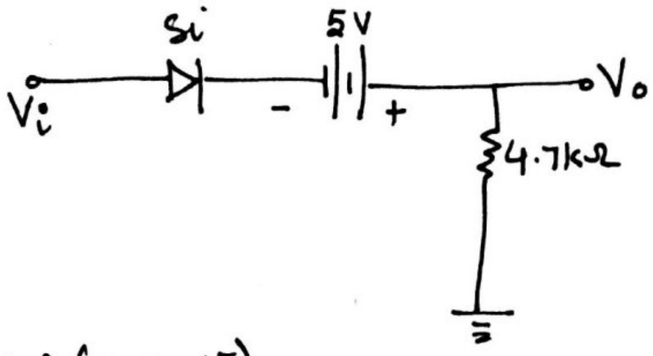
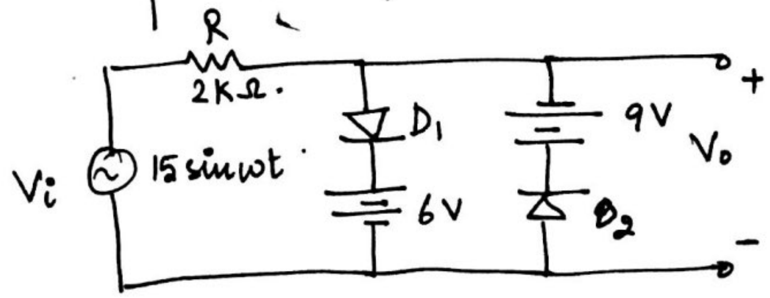
Q2.





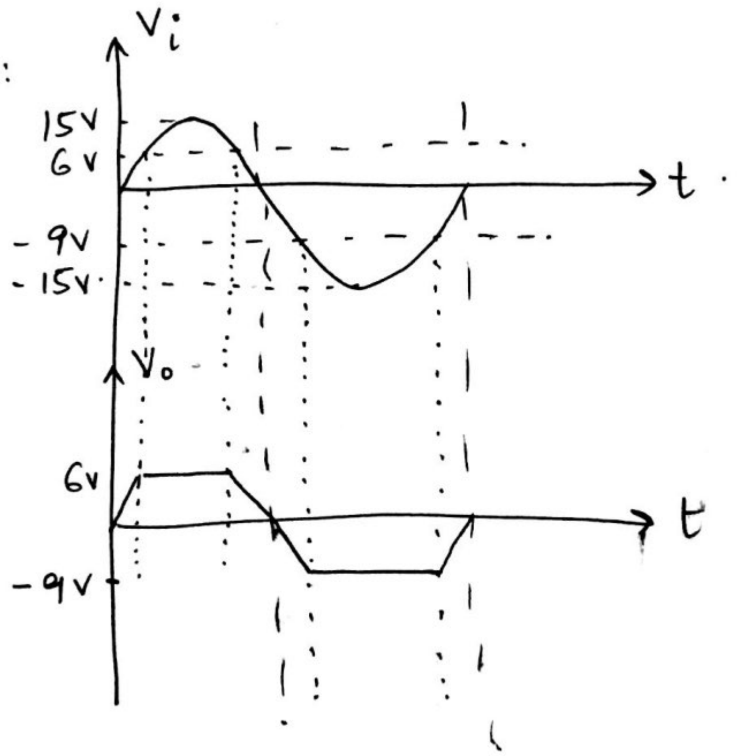
(5 Marks) (2014-15)

Q3.

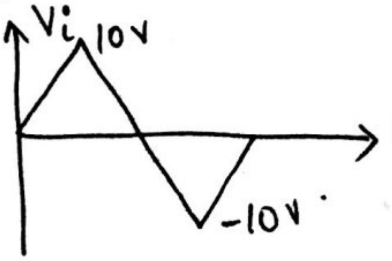


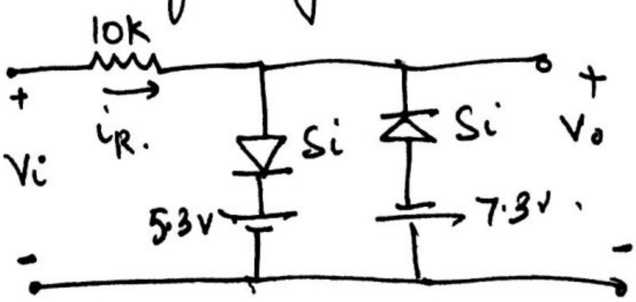
(5 Marks) (2012-13)

Ans:

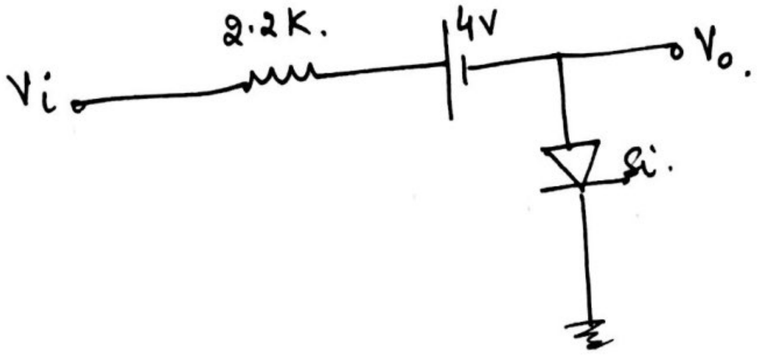


Q4. Define clipper circuit. Sketch the o/p waveform for the circuit shown below for given input.
(2017-18) (7 marks)





Q5. Sketch V_o: (2017-18) even (7 Marks).



Lecture 13

Unit1 : PN Junction Diode

Contents :

- Clampers
- Voltage Multipliers.

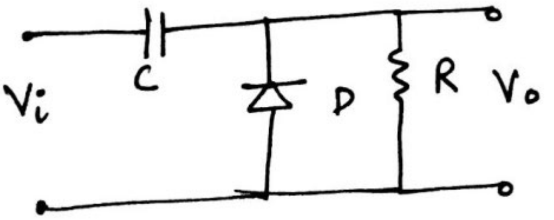
Clampers.

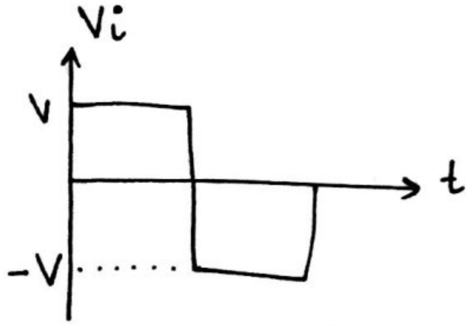
A clamper is a circuit that shifts the input signal to a different dc level without changing the appearance of the signal.

Clampers are of two types:

- Positive clamper
- Negative Clamper.

Positive Clamper.





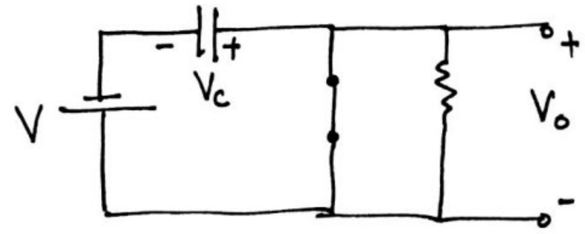
Follow three steps

step1 Always start from that cycle, that will forward bias the diode

step2 Calculate V_c (Voltage across capacitor)

step3 Calculate V_o in different half cycles.

Step1 Start from negative half cycle

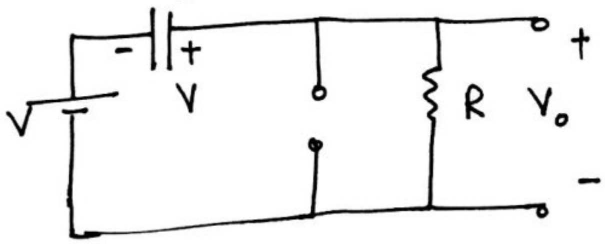


step2 $V_c - V = 0$

$\boxed{V_c = V}$

during negative half cycle $\boxed{V_o = 0}$

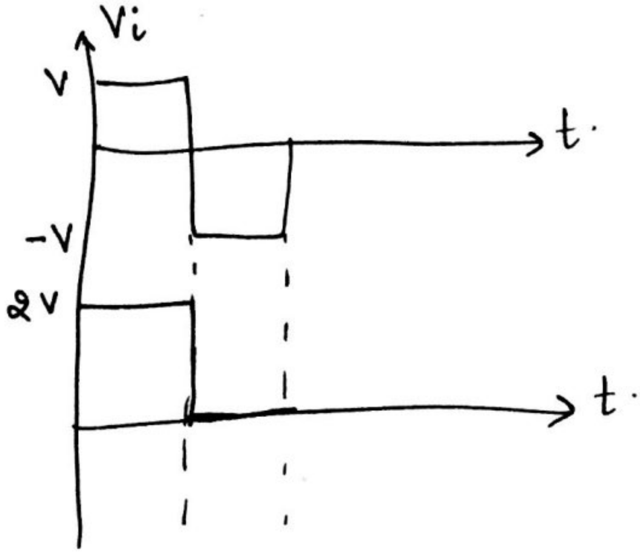
step 3 during positive half cycle.



$V_o - V - V = 0$

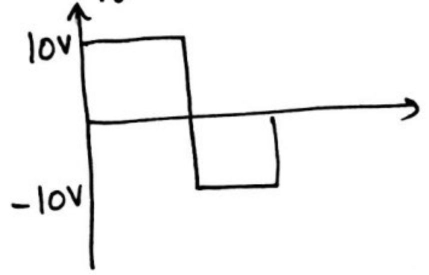
$\boxed{V_o = 2V}$

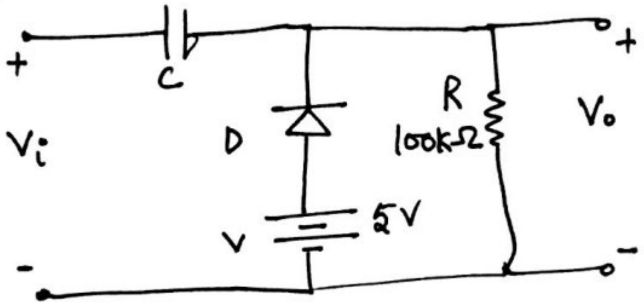
Waveforms



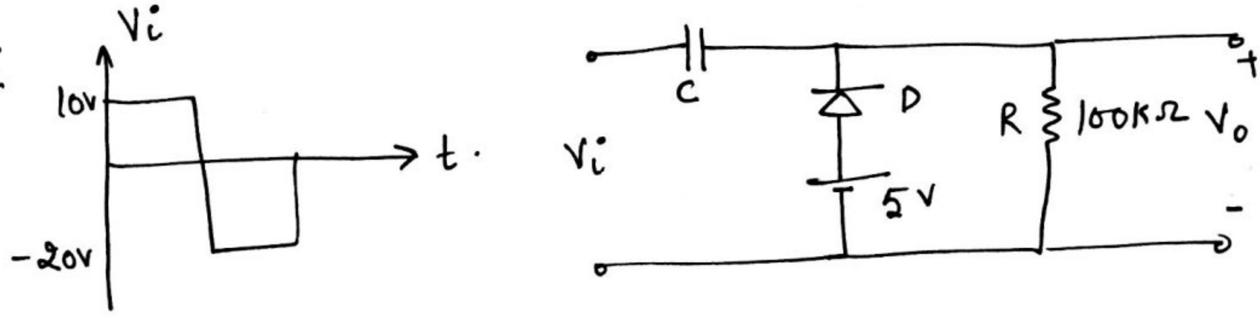
Draw the output voltage waveforms for the following circuits.

Q1.

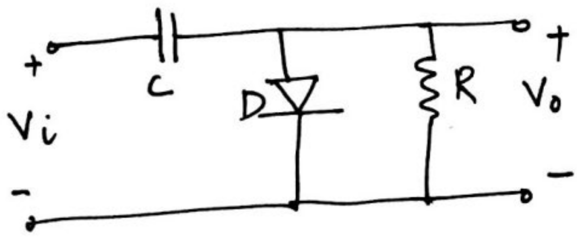


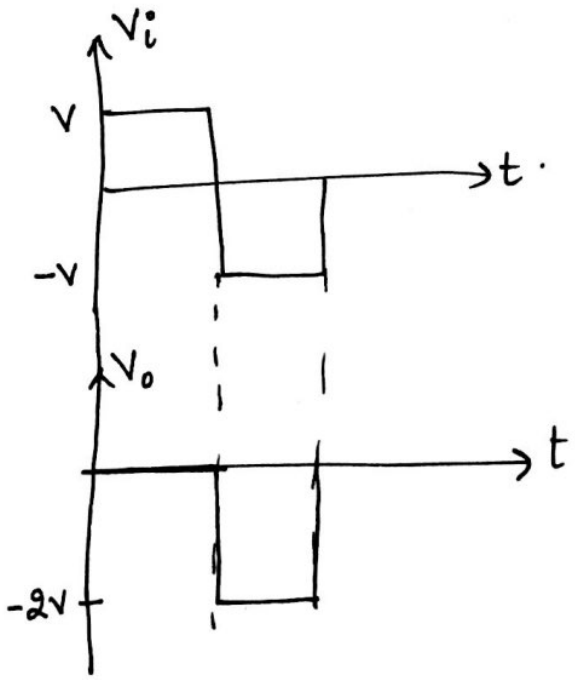


Q2.



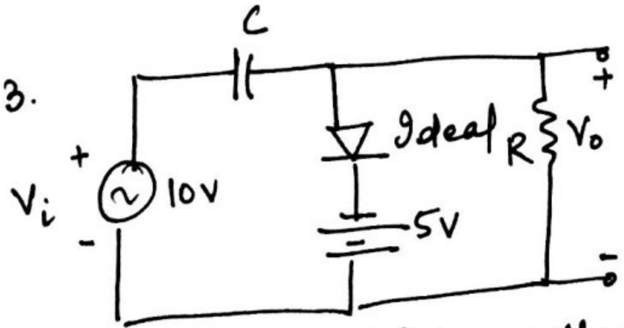
Negative clamper.





Follow the same steps as in positive clipper.

Q3.

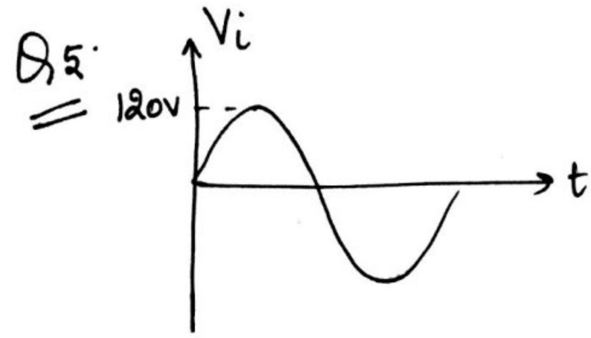


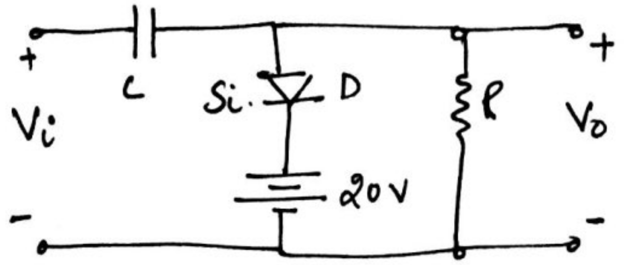
(5 Marks) (2015-16 UPTU)

Sketch and find output voltage of the circuit, when peak value of input voltage is 10 V.

Q4. Repeat Q3, considering the diode to be non ideal.

Q5.





(5 Marks) (2014-15) (2017-18) even, 7 Marks.

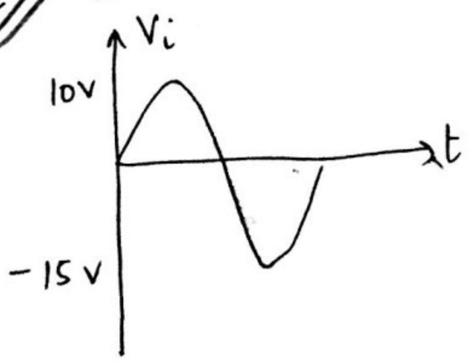
Voltage Multipliers

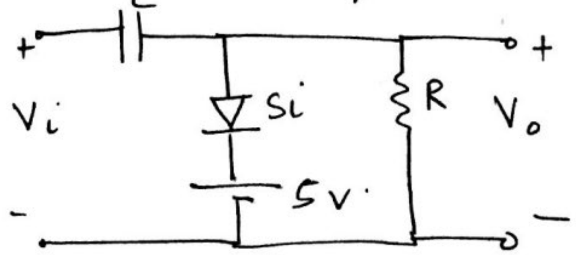
A voltage multiplier is a circuit which generates a dc output voltage whose value is the multiple of peak ac input voltage. There are different types of voltage multipliers.

- Voltage Doubler ($2V_m$)
- Voltage Tripler ($3V_m$)
- Voltage Quadrupler ($4V_m$).

University Question

Q. Determine V_o and draw its waveform (2016-17)





Ans. $V_C = 4.7\ V$

$V_o(\text{positive}) = 5.7\ V$.

$V_o(\text{negative}) = -19.3\ V$

Lecture 14

Unit 1 : PN Junction Diode

Contents :

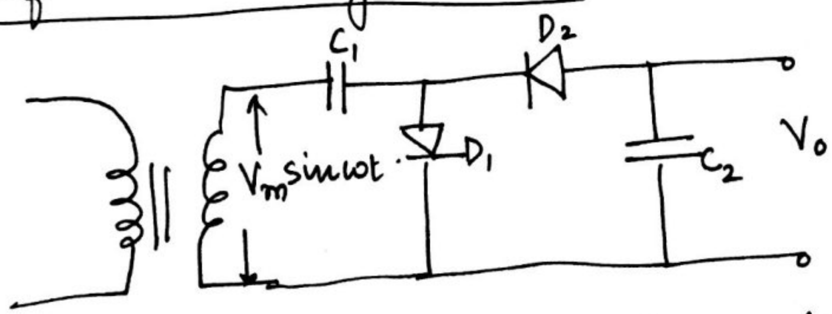
- Voltage Doubler
  - → Half wave doubler
  - → Full wave doubler.
- Voltage Tripler and Quadrupler.
- LED (Light Emitting Diode)

Voltage Doubler

Voltage doubler is a circuit whose dc output voltage is double the peak ac input voltage.

$V_o = 2V_m$.

Half Wave voltage Doubler

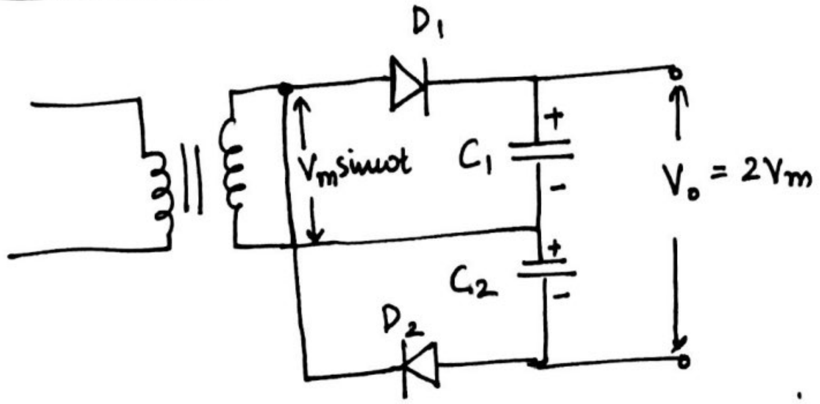


During the positive half cycle, D_1 is forward and D_2 is reverse biased. Capacitor C_1 is charged to the peak value of ac input.

During negative half cycle, D_1 is reverse and D_2 is forward biased. Capacitor C_2 is charged to $2V_m$.

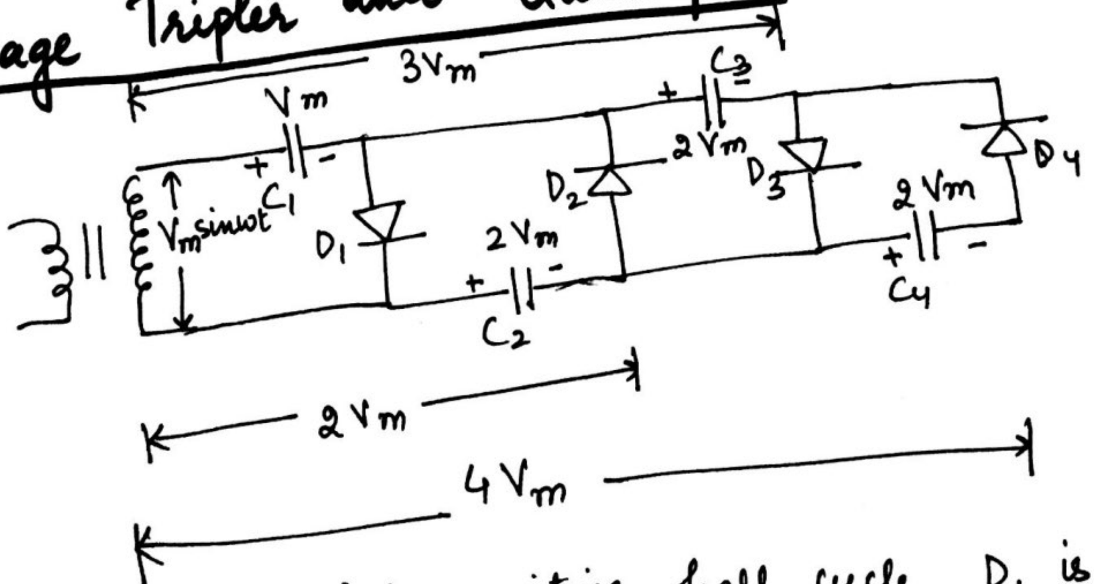
Hence $V_o = 2V_m$

Full Wave Voltage Doubler



During positive half cycle, D_1 is forward and D_2 is reverse biased. The capacitor C_1 is charged to V_m. During negative half cycle D_1 is reverse and D_2 is forward biased. The capacitor C_2 is charged to V_m. If there is no load, $V_o = 2V_m$.

Voltage Tripler and Quadrupler



During the first positive half cycle, D_1 is forward biased and C_1 is charged to V_m. During the first negative half cycle, D_2 is forward biased and C_2 is charged to $2V_m$.

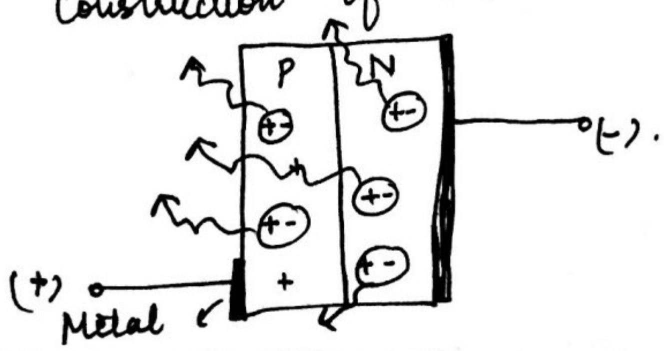
During the second positive cycle, D_3 is forward biased and C_3 is charged to $2V_m$. During the second negative cycle, D_4 is forward biased and C_4 is charged to $2V_m$.

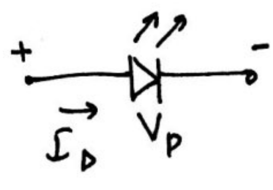
Thus voltage across C_2 is $2V_m$. Voltage across C_1 and C_3 are $3V_m$. Voltage across C_2 and C_4 is $4V_m$.

<u>Note</u>: If we go beyond $4V_m$, voltage regulation becomes poor. Although there is no upper limit.

LED (Light emitting diode)

- LED is a pn junction diode, that gives off visible or invisible (infrared) light when energised.
- When LED is forward biased, the recombination of majority carriers near the junction result in the emission of light.
- In case of Si and Ge, when recombination takes place, energy is dissipated in the form of heat. Therefore they are not used for LED.
- GaAsP is used for LED.
- Construction of LED.





The external metallic conducting surface connected to the p type material is smaller to permit the emergence of maximum number of photons of light energy when diode is forward biased.

- Light output of an LED is directly proportional to the forward current.
- The color of emitted light depends on the forbidden energy gap.

$$E_g = \frac{hc}{\lambda}.$$

Advantages of LED

- small size, light weight.
- Available in different spectral colors.
- Longer life.
- Better Linearity.
- suitable for high operating speeds.
- Low cost.

Disadvantages of LED

- output power is affected by changes in temperature
- Luminous efficiency of LED is low.
- overcurrent can damage it easily.
- requires high power.

University Questions : Explain principle of operation of LED (2017-18)

Q. Differentiate LED and LCD.

Q. Explain with suitable circuit that how diode acts as voltage multiplier? (5 Marks) (2014-15)

Q. Describe the working of voltage tripler (5 Marks) (2015-16)

Q. Explain voltage multipliers (5 Marks) (2015-16)

Q. Explain half wave and full wave voltage doublers. (5 Marks) (2013-14)

Lecture 15

Unit 1 : PN Junction Diode

Contents :

- Liquid Crystal Display (LCD)
- Varactor Diode
- Tunnel Diode.

Liquid Crystal Display.

A liquid crystal is a material that flows like a liquid but whose molecular structure has some properties normally associated with solids.

There are two major types of LCDs.

- Dynamic scattering LCDs.
- Field effect LCDs.

Advantages.

- Require less power
- low threshold voltage and require low operating voltage and current.
- low cost.

Disadvantages.

- Small operating temperature range
- low switching speeds
- Backlighting is necessary
- Require larger area.

University Questions.

Q. Differentiate between LED and LCD (5 Marks) (2015-16).

→

Parameters	LED	LCD
1. Power Required	More	less.
2. Speed	Fast	slow.
3. Life span	long	Short
4. Operating temp. Range.	wide	Small.
5. Viewing angle	wide	narrow.
6. operating voltage	low	low and moderate.
7. Ease of Mounting	very easy.	difficult
8. Applications	7 segment display.	watches, calculators.

Varactor Diode

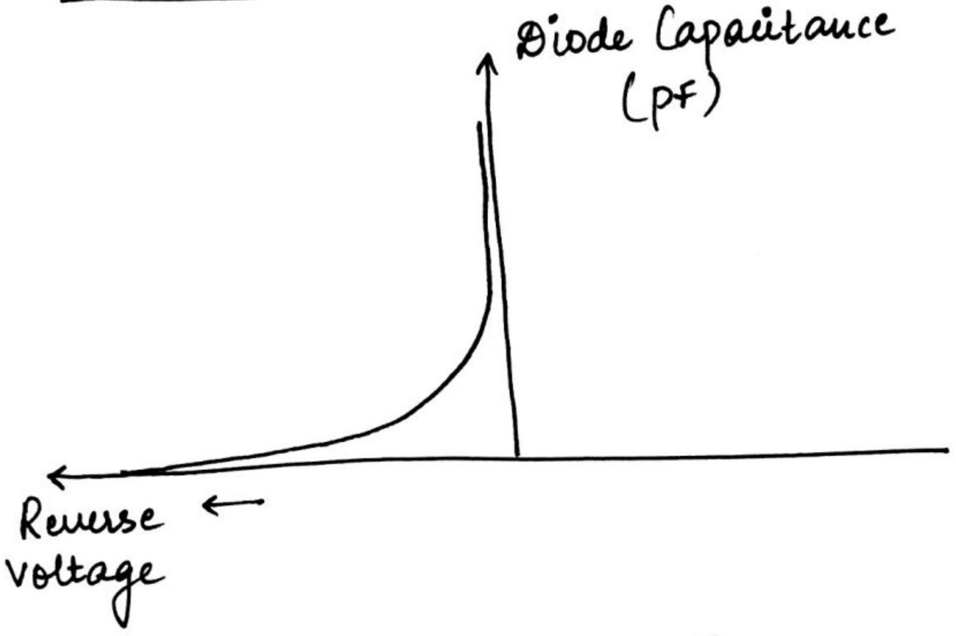
→ A varactor diode is a reverse biased PN junction which utilizes the inherent capacitance of depletion layer.

→ Also called as VVC (voltage variable capacitor), varicap, or tunning diode.

→ The depletion layer of reverse biased PN junction diode behaves as dielectric and P, N act as plates. $C = \frac{\epsilon A}{d}$

→ When reverse voltage increases, the width of depletion layer increases and hence capacitance decreases.

→ <u>Characteristics of Varactor Diode</u>



<u>Symbol</u>

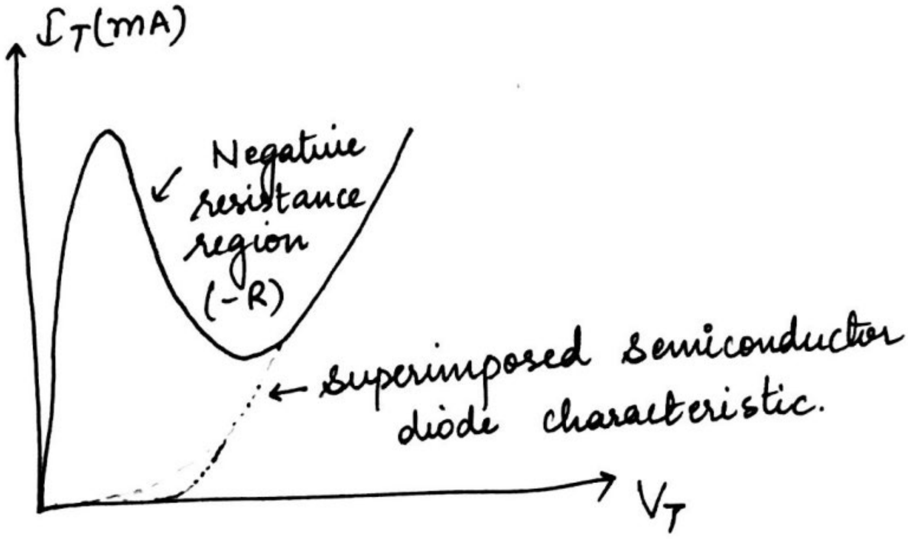
<u>Applications</u>

Tuning circuits, radio, television; automatic frequency control device,

<u>Tunnel Diode</u>

- The tunnel diode is fabricated by doping the semiconductor materials upto 100 to thousand times that of a normal pn diode.
- This results in greatly reduced depletion layer

Characteristics of Tunnel Diode



- The carriers can 'tunnel' through extremely thin depletion region, rather than overcome the potential barrier that accounts for peak in curve
- Tunnel diode is used in high speed applications such as in computers.
- Ge and GaAs are the most common materials to manufacture tunnel diode.
- The tunnel diode characteristics shows a <u>negative resistance region</u>. In this region, an increase in voltage results in reduction in diode current.

University Question

Q. Explain working and characteristics of Tunnel Diode with the help of neat diagram (5 Marks) (2015-16) (2017-18) even.

Q. Draw the capacitance versus voltage transfer characteristic for varactor diode (2 Marks) (2013-14)

Q. Explain the principle of operation of LED (2016-17). (2 Marks)

Q. Explain the principle of operation of LCD (5 Marks.) (2016-17)

Q. Explain the V-I Characteristics of Tunnel diode (5 Marks) (2016-17.