Jaipur Engineering College & Research Centre, Jaipur

Lecture Notes

3EE4-06: Analog Electronics

ACADEMIC SESSION 2020-21

Prepared By:
Jisha Varghese

VISION OF ELECTRICAL ENGINEERING DEPARTMENT

Electrical Engineering Department strives to be recognized globally for outcome based knowledge and to develop human potential to practice advance technology which contribute to society.

MISSION OF ELECTRICAL ENGINEERING DEPARTMENT

M1. To impart quality technical knowledge to the learners to make them globally competitive Electrical Engineers.

M2. To provide the learners ethical guidelines along with excellent academic environment for a long productive career.

M3. To promote industry-institute relationship.

PROGRAM OUTCOMES

1. **Engineering knowledge:** Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems in Electrical Engineering.
2. **Problem analysis:** Identify, formulate, research literature, and analyze complex engineering problems reaching substantial conclusions using first principles of mathematics, natural sciences, and engineering sciences in Electrical Engineering.
3. **Design/development of solutions:** Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations using Electrical Engineering.
4. **Conduct investigations of complex problems:** Use research based knowledge and research methods including design of experiments, analysis and interpretation of data and synthesis of the information to provide valid conclusions using Electrical Engineering.
5. **Modern tool usage:** Create, select and apply appropriate techniques, resources, and modern engineering and EE tools including prediction and modeling to complex engineering activities with an understanding of the limitations in EE.
6. **The engineer and society:** Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice using EE.
7. **Environment and sustainability:** Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of EE and need for sustainable development in EE.
8. **Ethics:** Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice using EE.
9. **Individual and team work:** Function effectively as an individual and as a member or leader in diverse teams, and multi-disciplinary settings in EE.
10. **Communication:** Communicate effectively on complex engineering activities with the engineering community and society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations and give and receive clear instructions.
11. **Project management and finance:** Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage EE projects and in multi-disciplinary environments.
12. **Life-long learning:** Recognize the need for and have the preparation and ability to engage in independent and lifelong learning in the broadest context of technological changes needed in EE.

COURSE OUTCOMES:

On successful completion of the course, the students will be able to: -

CO1	Understand the characteristics of Diodes, concepts behind the Clippers, and Clampers. Design and analysis of various rectifier and amplifier circuits
CO2	Analyze the characteristics of current flow in a bipolar junction transistor and MOSFET & different electronic devices such as Amplifiers
CO3	Understand the dynamics of Linear & Non Linear Devices

Syllabus

RAJASTHAN TECHNICAL UNIVERSITY, KOTA

SYLLABUS

2nd Year - III Semester: B.Tech. (Electrical Engineering)

3EE4-06: Analog Electronics

Credit: 3 | **Max. Marks: 150 (IA:30, ETE:120)**

3L+0T+0P | **End Term Exam: 3 Hours**

SN		Hours
1.	**Diode circuits** P-N junction diode, I-V characteristics of a diode; review of half-wave and full-wave rectifiers, Zener diodes, clamping and clipping circuits.	4
2.	**BJT circuits** Structure and I-V characteristics of a BJT; BJT as a switch. BJT as an amplifier: small-signal model, biasing circuits, current mirror; common-emitter, common-base and common collector amplifiers; Small signal equivalent circuits, high-frequency equivalent circuits.	8
3.	**MOSFET circuits** MOSFET structure and I-V characteristics. MOSFET as a switch. MOSFET as an amplifier: small-signal model and biasing circuits, common-source, common-gate and common-drain amplifiers; small signal equivalent circuits - gain, input and output impedances, transconductance, high frequency equivalent circuit.	8
4.	**Differential, multi-stage and operational amplifiers** Differential amplifier; power amplifier; direct coupled multi-stage amplifier; internal structure of an operational amplifier, ideal op-amp, non-idealities in an op-amp (Output offset voltage, input bias current, input offset current, slew rate, gain bandwidth product)	8
5.	**Linear applications of op-amp** Idealized analysis of op-amp circuits. Inverting and non-inverting amplifier, differential amplifier, instrumentation amplifier, integrator, active filter, P, PI and PID controllers and lead/lag compensator using an op-amp, voltage regulator, oscillators (Wein bridge and phase shift). Analog to Digital Conversion.	8
6.	**Nonlinear applications of op-amp** Hysteretic Comparator, Zero Crossing Detector, Square-wave and triangular-wave generators, Precision rectifier, peak detector. Monoshot	6
	TOTAL	**42**

Office of Dean Academic Affairs
Rajasthan Technical University, Kota

Unit: 1

Chapter: Diode Circuits

Unit - 1

P-N-Junction Diodes

Basic introduction to semiconductors

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

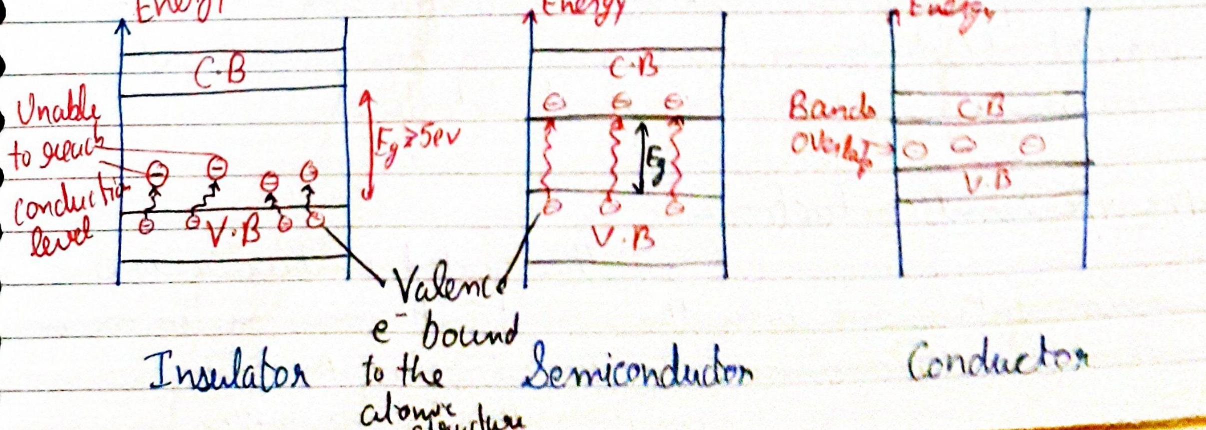
It can be pure as silicon or germanium or compounds such as gallium arsenide or cadmium selenide
→ Single-crystal semiconductor
→ compound semiconductor

* Most ~~commonly~~ frequently used are Ge, Si and GaAs.

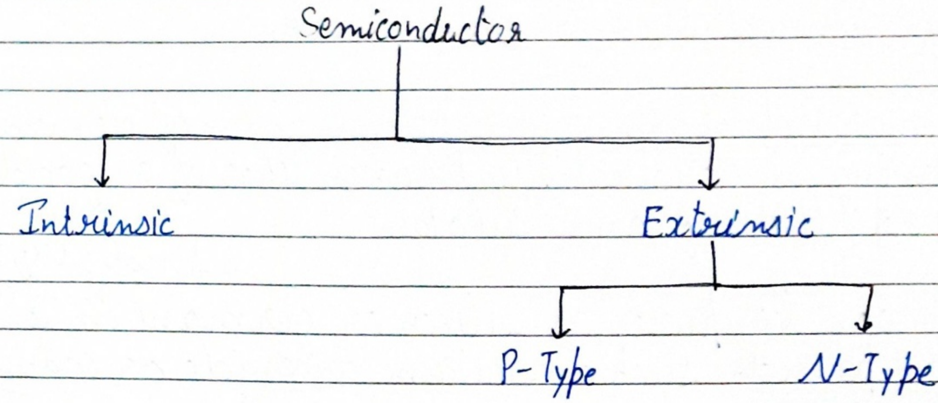
Insulator :- Material that does not conduct electrical current. eg:- paper, plastic, rubber etc

Conductor :- Material or substances which allow electricity to flow through them. eg → coppers etc.

Energy Levels :- $E_g = 0.67\,eV\,(Ge)$; $E_g = 1.1\,eV\,(Si)$; $E_g = 1.43\,eV\,(GaAs)$



Semiconductor Types:-



Intrinsic Semiconductor:- A pure form of semiconductors

- Conduction is either due to thermal excitation or crystal defects. example Si, Ge, GaAs (Gallium Arsenide) etc.
- Number of holes is equal to number of free electron

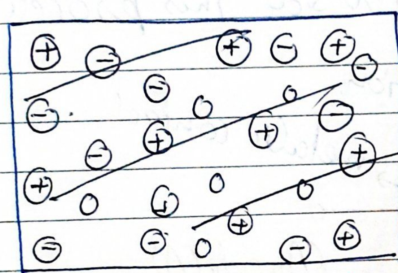
Extrinsic Semiconductor:- A semiconductor doped by a specific impurity which is able to deeply modify its electrical properties, making it suitable for electronic applications (diode, transistors etc) or optoelectronic applications (light emitters and detectors).

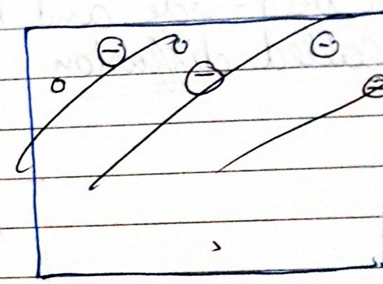
N-Type Semiconductor:- If the added impurity is a pentavalent atom then the resultant semiconductor is N-type semiconductor eg:- Phosphorus, Arsenic, Bismuth, Antimony etc.

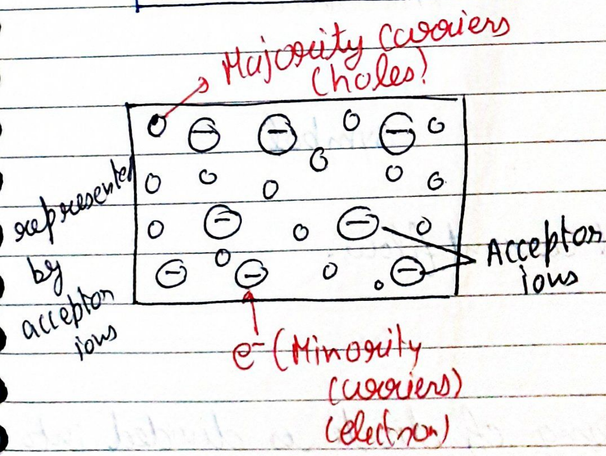
P-type Semiconductor:-

If the added impurity is a trivalent atom then the resultant semiconductor is called P-type Semiconductor. example:- Boron, Gallium, indium etc.

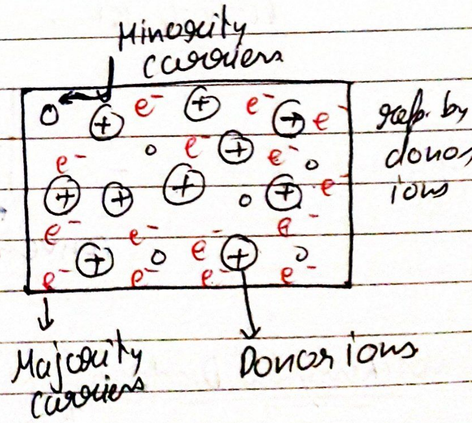
N-type & P-type:-







P-type



N-type.

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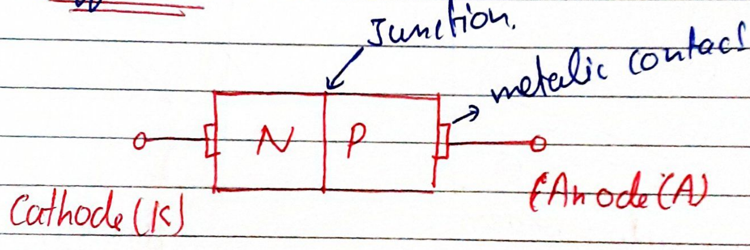
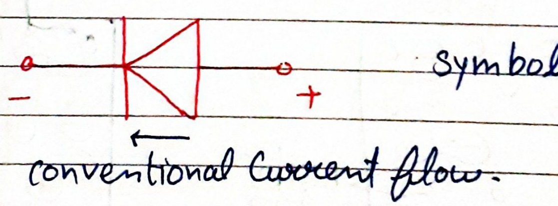
Semiconductor Diode (P-N Junction) diode -

Construction

When a P-type material is ~~Joined~~ diffused with an N-type material by using doping techinque. A Junction is formed and is called P-N Junction diode.

~~The working~~ N-type material has high concentration of free electrons, while P-type material has high concentration of holes. Hence at the junction there is a tendency of free electrons to diffuse over to the P-side and holes to the N side. This process is called diffusion.



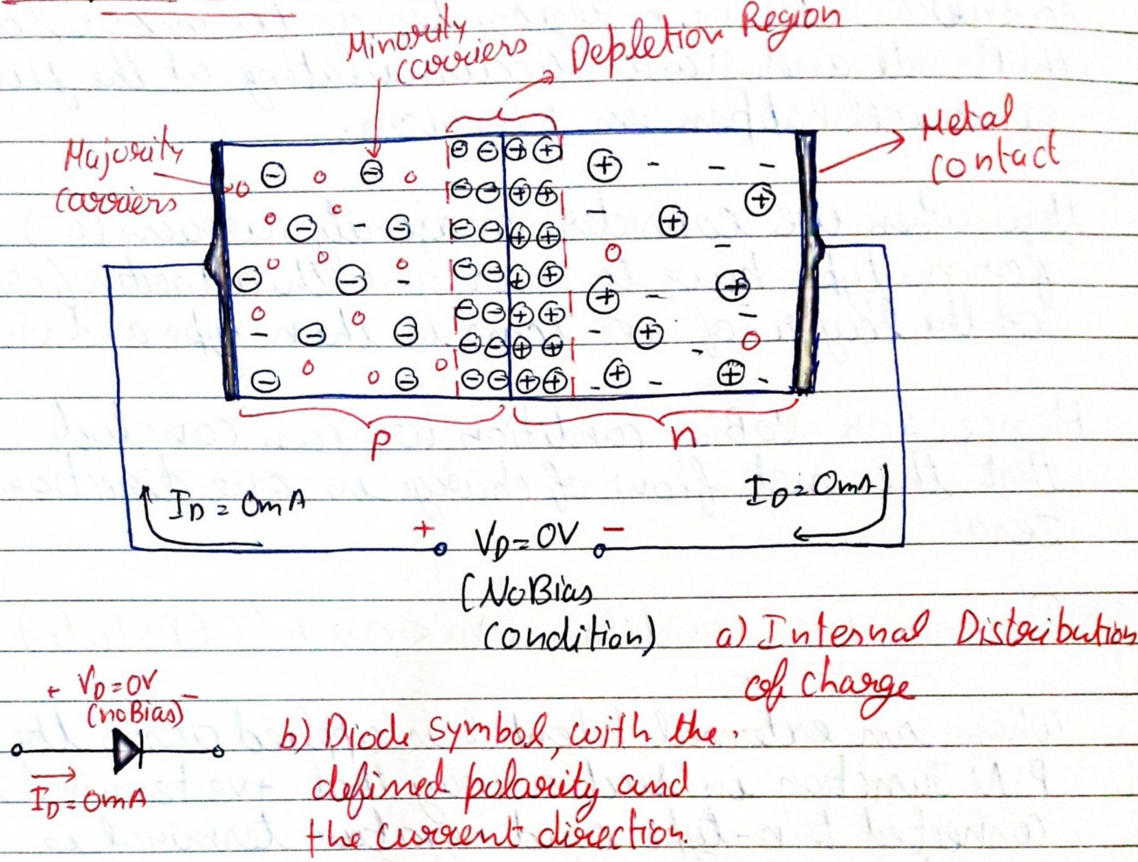


Working of Diode -

The working of diode is divided into 3 types

1. No Applied Bias ($V = 0V$)
2. Reverse Bias Condition ($V_D < 0V$)
3. Forward Bias Condition ($V_D > 0V$)

① No Applied Bias (V = 0 V)



From the above figure, when the two materials are joined, the electron and holes in the region of the junction will combine which results the lack of free carriers near the junction. The accumulation of charge carriers near the junction (ie negative ions on P-side and positive ions on n side) forms depletion region due to the depletion of free carriers in the region.

For No-Bias condition, no external voltage is applied ie V = 0v and the current (majority) is also zero. But

Biasing :- The setting of initial operating conditions (current and voltage) of an active device. in an amplifier

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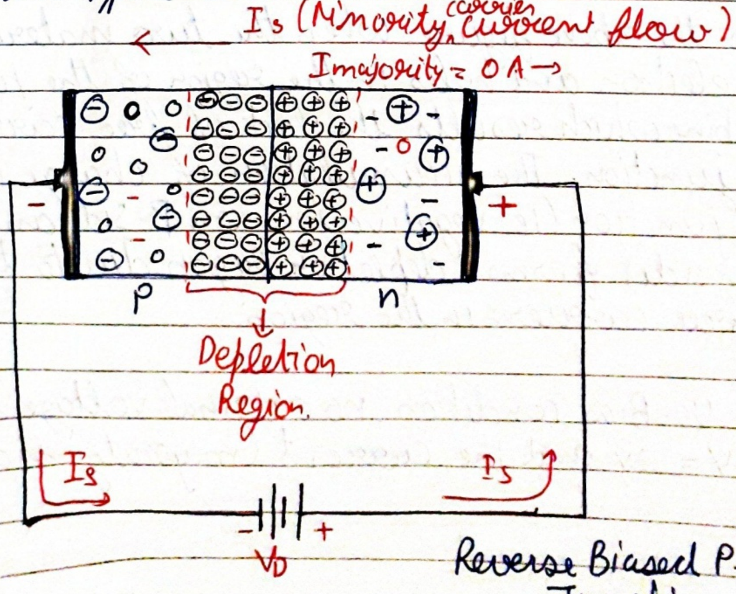
For the case of no-bias condition, minority carriers (holes) in n-region tends to move towards the P-side and starts accumulating at the junction. Same will happen on p-region.

Now when we consider majority carriers (e^-) for n-type have to overcome the attractive force of the layer of +ve ions in the n-type and viceversa.

Hence for No Bias condition we can conclude that the net flow of charge in one direction is zero.

② Reverse Bias Condition ($V_D < 0V$) (OFF state)

When an external potential is applied across the P-N Junction in such a way that +ve terminal is connected to n-type and negative terminal is connected to P-type as shown below :-



Reverse Biased P-N Junction

Biasing :- Biasing is referred to a fixed DC voltage or current applied to a terminal of an electronic component such that a proper operating condition can be obtained.

The number of ~~uncovered~~ +ve ions ~~in the~~ across the depletion region (near n-type) will start increase (same is the case with +ve ions near p-type region) due to the attractive forces across the positive & negative potential due to the applied voltage.

Due to which the thickness of depletion layer increases due to which the potential barrier across the junction increases and as a result it become difficult for majority carriers to overcome it. Hence, the majority carriers current for this reverse biased becomes zero.

However, the minority charge carriers can easily flow through this potential barrier and a minority current (uA) always flow during reverse biased condition.

The current which exists under reverse bias conditions is called the reverse saturation current (I_s)

③ Forward Bias condition ($V_D > 0V$) (ON State)

When a +ve voltage is applied across the diode in such a way that the +ve terminal is connected to P-type and -ve terminal is connected to N-type.

On applying a +ve potential, due to recombination the +ve and -ve ions across the depletion layer will ~~start getting~~ recombine and as a result the depletion layer will start ~~reducing~~ reducing and after a time period it will diminish completely. As a result their is a large flow of majority charge carriers across the junction. Due to this the majority current start flowing and the device is turned on.

Current Equation

$$I_D = I_S\left(e^{V_D/\eta V_T} - 1\right)$$ (For forward Bias)

$$I_D \cong I_S\, e^{V_D/\eta V_T}$$ (For +ve value $e^{V_D/\eta V_T} >> 1$)

I_S → reverse saturation current.

V_D → Applied forward-bias voltage across the diode.

η → ideality factor ($\eta = 1$)

V_T → Thermal voltage or Threshold Voltage.

$$V_T = \frac{K T_K}{q}$$

K → Boltzmann's constant $= 1.38\times10^{-23}$ J/K

T_K → Absolute Temp.

q → magnitude of e^- 1.6×10^{-19} C.

$$I_D = -I_S\left(e^{V_D/\eta V_T} - 1\right)$$ (For reverse Bias)

$$I_D = -I_S$$ V_D is −ve

$V_D = 0$ $I_D = I_S(e^0 - 1) = I_S(1-1) = 0\,mA$

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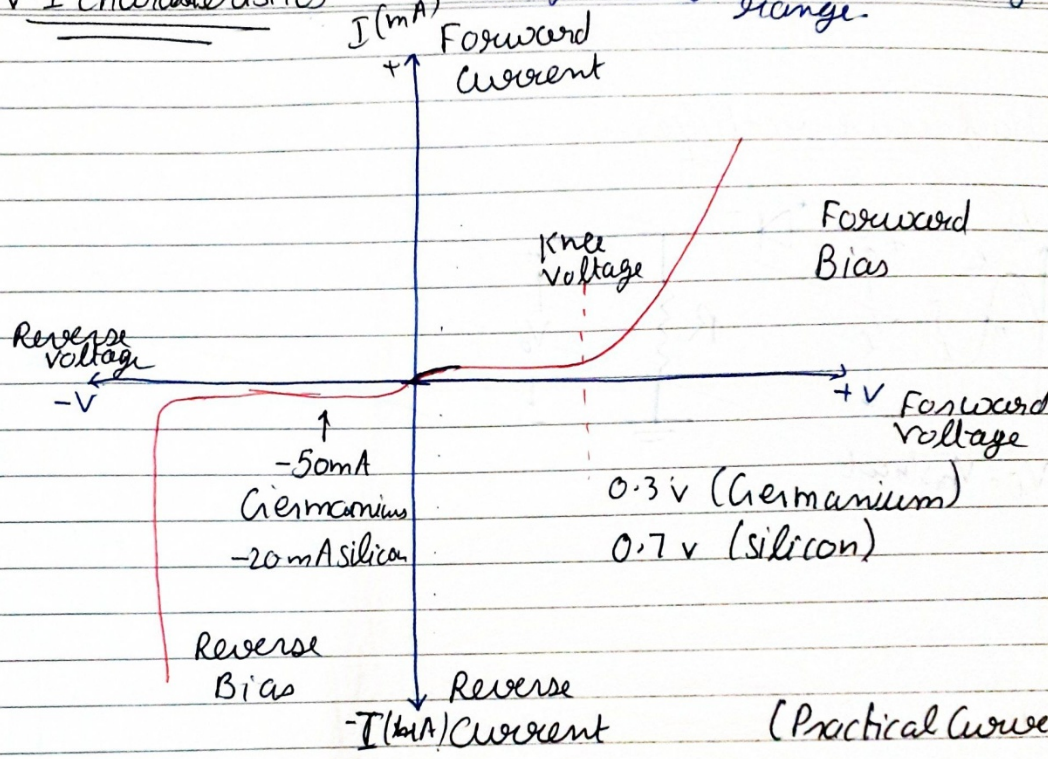
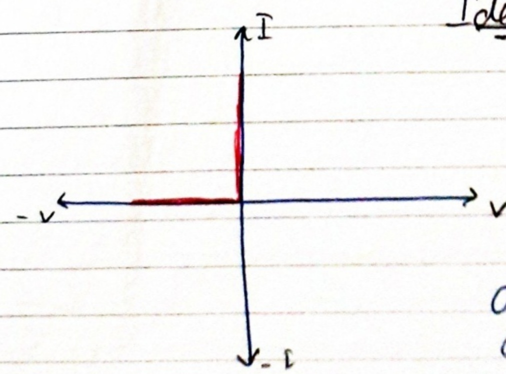
Q-point :- (operating point of a device).
It is important as it ensures that non linear components operates at optimal current and voltage throughout the operating range.

V-I Characteristics



(Practical Curve)



Ideal Diode:- A diode which acts as a perfect conductor when a forward biased voltage is applied and acts as an insulator when a reverse voltage is applied.

DC or static Resistance :- $R_D = \frac{V_D}{I_D}$

AC or Dyanamic Resistance :- $r_D = \frac{\Delta V_D}{\Delta I_D}$

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Rectification :-

Process of converting a.c voltage into d.c. voltage

It is achieved with

1) step-down Transformer
2) Rectifier
3) Filter
4) Voltage regulator circuits.

Block Diagram of a Regulated Power Supply System.

Transformer → Step down 230V AC mains to low voltage AC

Rectifier → Convert AC to DC, but with varying DC i.e $f \neq 0$.

Smoothing → Smooth the DC from varying greatly to small-ripple.

Regulator → Eliminates ripple by setting DC o/p to a fixed voltage.

Rectifier :-

A device which offers a low resistance to the current in one direction but a high resistance to the current in opposite direction.

- Converts sinusodial i/p waveform to unidirectional waveform.

→ A rectifier is a device which converts a.c voltage to pulsating dc voltage.

Characteristics of Rectifier Circuit :-

① Average or DC current :- Area of one cycle of curve divided by the base.

$$\text{Avg. value / DC / Mean value} = \frac{\text{Area over one period}}{\text{Total Time period}}$$

$$V_{dc} = \frac{1}{T}\int_0^T V_d(\omega t)$$

② Effective or RMS current :- Squared of a periodic function of time is given by area of one cycle of the curve which represent square of function divide by the base.

$$V_{rms} = \sqrt{\frac{1}{T}\int_0^T V_d^2 (\omega t)}$$

③ Peak Factor -:

Ratio of Peak value to rms value

$$\text{Peak Factor} = \frac{\text{Peak value}}{\text{rms Value}}$$

④ Form Factor -:

Ratio of RMS value to Average Value.

$$\text{Form Factor} = \frac{\text{RMS Value}}{\text{Average Value}}$$

⑤ Ripple Factor (Γ) -:

Ratio of RMS value of ac component to the dc component in the O/P.

$$\Gamma = \frac{V_{ac}}{V_{dc}}$$

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

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⑥ Efficiency :- (η)
Ratio of d.c o/p Power to AC i/p Power.

$$\eta = \frac{O/p\ Power}{I/p\ Power}$$

⑦ Peak Inverse Voltage (PIV) :-
Maximum reverse voltage that a diode can withstand without destroying the junction.

⑧ Transformer Utilization Factor (TUF)

D.C power to be delivered to the load in a rectifier circuit decides the rating of the transformer used in circuit.

$$TUF = \frac{P_{dc}}{P_{ac(rated)}}$$

⑨ % Regulation :-
Variation of d.c.-o/p voltage as a function of d.c.-load current.

$$\%\ Regulation = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100$$

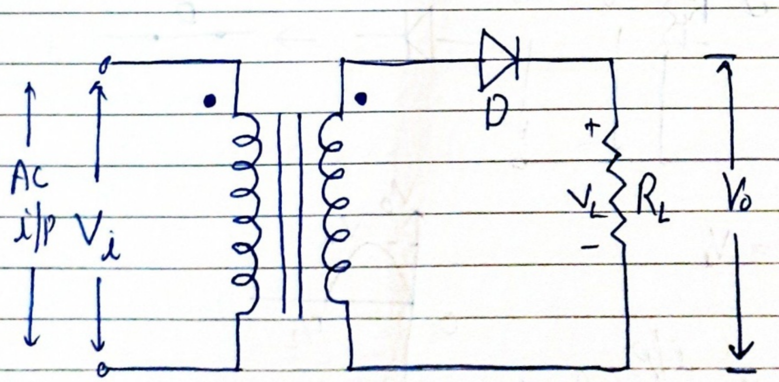
For an ideal power supply, % Regulation is zero.

Classification :-

1) Half-Wave Rectifier
2) Full-Wave Rectifier
3) Bridge Rectifier.

Half Wave Rectifier :-

converts a.c. voltage into a pulsating voltage using only one half cycle of the applied a.c. voltage.



Construction :-

AC(i/p) voltage is applied to the rectifier circuit using step-down transformer.

Let $V = V_m \sin(\omega t)$

where V_m is peak value of secondary a.c. voltage.

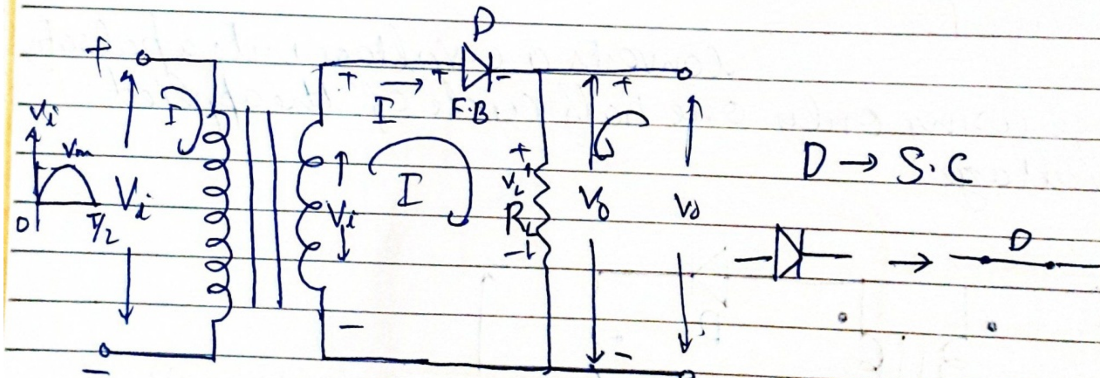
Operation:-

For +ve half cycle -

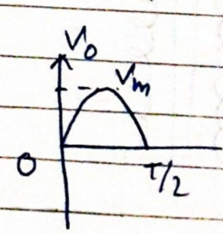
When a +ve half cycle of i/p a.c voltage is applied, the diode D is forward biased. (which is replaced by S.C) and starts conducting. The current starts flowing through the circuit and a voltage drop (V_L) appear across R_L.

Let (V_0) is the o/p voltage then

$$V_0 = V_L$$



o/p eq. $V_0 = V_i$



Applying KVL in the i/p loop

$$V_i - V_L = 0$$

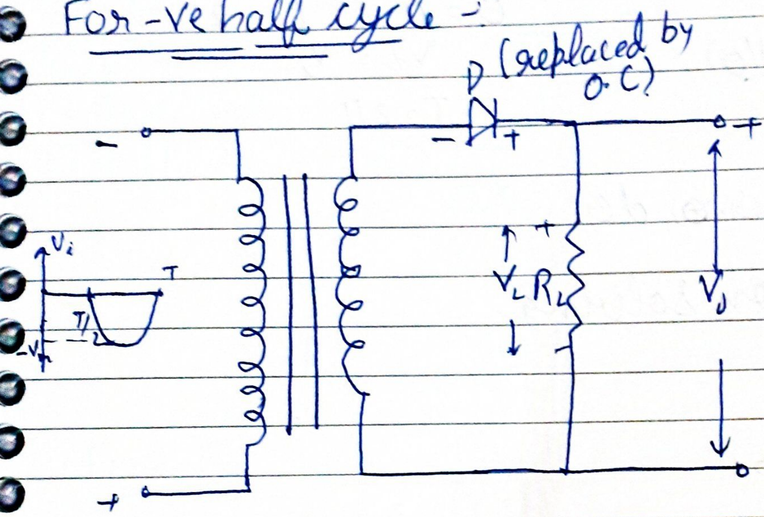
$$V_L = V_i$$

Applying KVL in the o/p loop.

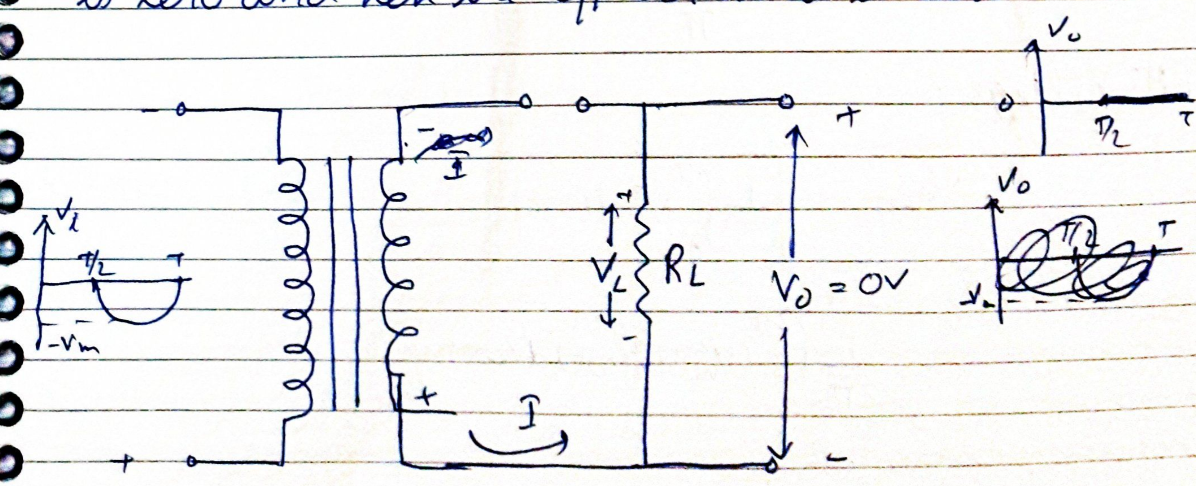
$V_0 = V_L$

$\therefore$ $\boxed{V_0 = V_i}$ for forward biased case.

<u>For -ve half cycle</u> :-



For the case of -ve half cycle diode (D) is reversed biased and is replaced by open circuit. Hence the current flowing through the circuit is zero and hen the o/p obtained is zero.



$\because I = 0$ $\quad V_L = I R_L = 0V$ $\quad V_0 = V_L = 0V$

① Average voltage :-

$\omega t = 2\pi$

$$V_{dc} = \frac{1}{T}\int_0^T V_d(\omega t)$$

Let $\omega t = \theta$

$\omega \rightarrow$ constant

$dt = d\theta$

$t = 0 \qquad t = T \qquad T = 2\pi$

$\theta = 0 \qquad \theta = 2\pi$

$V_d = V_i$

$T = 2\pi$

$$V_{dc} = \frac{1}{T}\int_0^{2\pi} V_d \, d(\theta)$$

$$\frac{1}{2\pi}\int_0^{2\pi} V_m \sin(\theta)\, d\theta$$

On solving.

$$\frac{V_m}{2\pi} \times 2$$

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

② Average current :-

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

③ RMS Voltage -

$$V_{rms} = \sqrt{\frac{1}{T}\int_0^T V^2 \, d(\omega t)}$$

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

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

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④ RMS Current

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

⑤ Peak Factor

$$= \frac{\text{Peak Value}}{\text{rms Value}}$$

$$= \frac{V_m}{V_m/2}$$

Peak Factor = 2

⑥ Form Factor :-

$$= \frac{\text{RMS Value}}{\text{avg. Value}}$$

$$= \frac{V_m/2}{V_m/\pi} = \pi/2.$$

Form Factor = 1.57

⑦ Ripple Factor :-

$$\Gamma = \frac{V_{ac}}{V_{dc}}$$

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

$$\Gamma = \frac{\sqrt{V_{rms}^2 - V_{dc}^2}}{V_{dc}} = \sqrt{\frac{V_{rms}^2}{V_{dc}^2} - 1} = 1.21$$

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⑧ Efficiency (η)

$$\eta = \frac{\text{o/p Power}}{\text{i/p Power}} * 100$$

$$= \frac{P_{ac}}{P_{dc}} * 100 = 40.8\%$$

⑨ TUF :-

$$TUF = \frac{P_{dc}}{P_{ac(rated)}}$$

$$TUF = 0.286$$

As TUF is low it shows that half wave circuit, transformer is not fully utilized.

⑩ PIV :-

Maximum reverse voltage that a diode can withstand without destroying the Junction.

$$PIV = V_m$$

Disadvantages

① Ripple factor is high.
② Efficiency is low
③ TUF is low
④

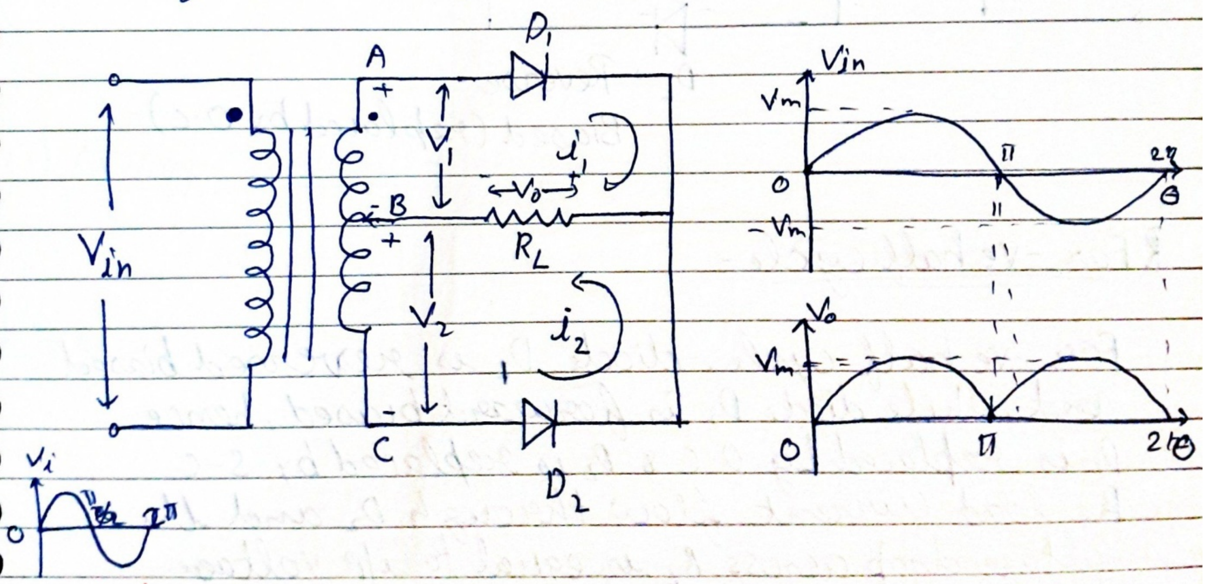
Full Wave Rectifier:-

Converts an ac voltage into a pulsating dc voltage using both half cycles of the applied ac voltage.

Two diodes are connected in the circuit through a common load R_L by using a center-tap transformer.

Center-tap transformer:-

It produces two sinusoidal waveforms of same magnitude and frequency but out of phase w.r.t to the ground in the secondary winding of the transformer.

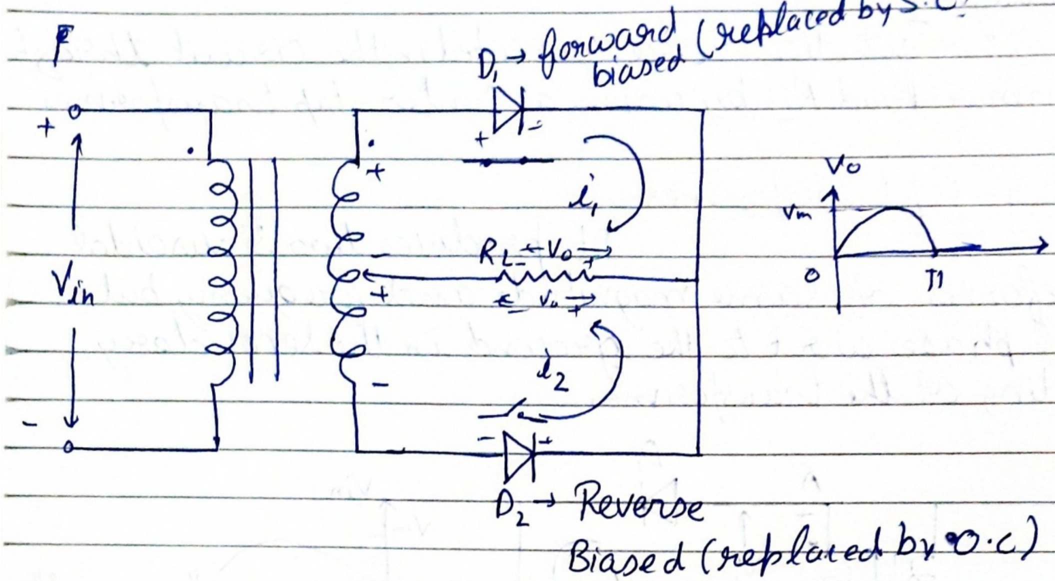


Working:-

For +ve half cycle

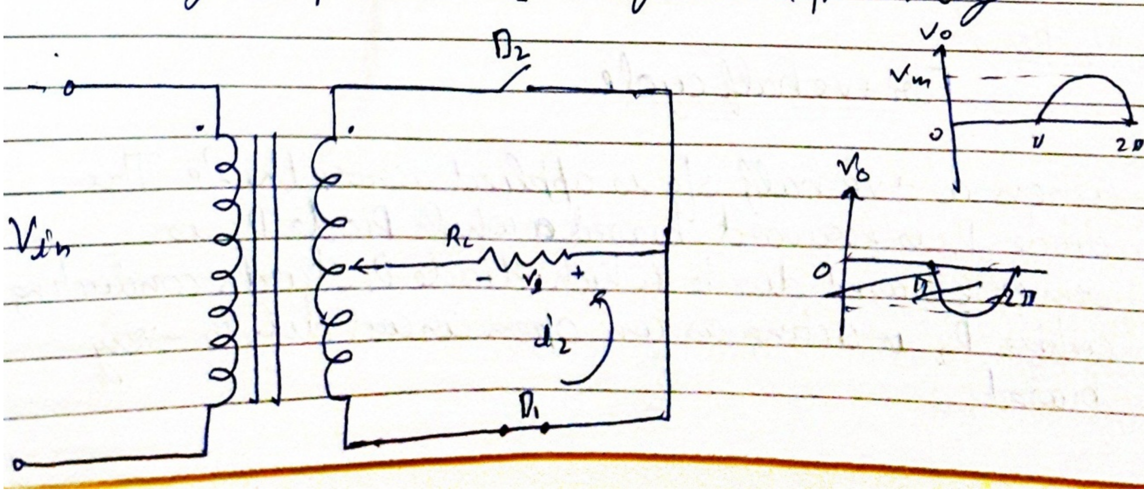
When a +ve half s/g is applied across the i/p. The diode D_1 is forward biased while Diode D_2 is reverse biased due to which diode D_1 starts conducting while D_2 is acting as an open circuit due to -vely biased.

The load current flows through D_1 and the voltage drop across R_L will be equal to the i/p voltage.



For -ve half cycle :-

For -ve half cycle, diode D_1 is reversed biased and while diode D_2 is forward biased, hence D_1 is replaced by O.C & D_2 is replaced by S-C. The load current flow through D_2 and the voltage drop across R_L is equal to i/p voltage.



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① **Average Voltage** :-

$$V_{dc} = I_{dc} R_L = \frac{2I_m}{\pi} R_L$$

where $I_m = \frac{V_m}{R_S + R_f + R_L}$

$$\therefore \quad V_{dc} = \frac{2 \cdot V_m R_L}{\pi (R_S + R_f + R_L)}$$

If $(R_S + R_f) << R_L$

$$V_{dc} = \frac{2V_m}{\pi} = 0.637 V_m$$

② **Average Current** :-

$$I_{av} = \frac{1}{2\pi} \int_0^{2\pi} i \, d\theta = \frac{1}{2\pi} \int_0^{2\pi} I_m \sin\theta \, d\theta$$

$$= \frac{I_m}{2\pi} \left[\int_0^{\pi} \sin\theta \, d\theta - \int_{\pi}^{2\pi} \sin\theta \, d\theta \right]$$

$$= \frac{I_m}{2\pi} \left[(-2)(-2) \right]$$

$$= \frac{I_m}{2\pi} (+4) = \frac{2I_m}{\pi} = 0.637 I_m$$

$$I_{dc} = 0.637 I_m$$

③ RMS Voltage :-

$$V_{rms} = \frac{1}{T}\int_0^T V^2 d(\theta)$$

$$= \sqrt{\frac{1}{2\pi}\int_0^{2\pi} (V_m^2 \sin^2\theta \, d\theta)}$$

on solving, we get

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

④ RMS Current :-

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

⑤ Peak Factor :-

$$= \frac{\text{Peak Value}}{\text{rms Value}}$$

$$= \frac{V_m}{V_m/2} = \frac{2}{2}$$

⑥ Form Factor :-

$$= \frac{\text{RMS Value}}{\text{Average Value}} = \frac{V_m/\sqrt{2}}{2V_m/\pi}$$

Form Factor = 1.11

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⑦ Ripple Factor :-

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

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

$$\gamma_{FWR} = \sqrt{\left(\frac{I_m}{\sqrt{2}} \Big/ \frac{2I_m}{\pi}\right)^2 - 1}$$

$$= 0.483$$

⑧ Efficiency (η) :-

$$\eta = \frac{O/P\ Power}{i/p\ Power} \times 100$$

$$= \frac{P_{dc}}{P_{ac}} \times 100$$

$P_{dc} = I_{dc}^2 \cdot R_L = \left(\frac{2}{\pi} \cdot I_m\right)^2 \cdot R_L$

$P_{ac} = I_{rms}^2 (R_f + R_s + R_L)$

$= \left(\frac{I_m}{\sqrt{2}}\right)^2 (R_f + R_s + R_L)$

$$\eta = \frac{\frac{I_m^2 \cdot 4}{\pi^2} \cdot R_L}{\frac{I_m^2}{2} \cdot (R_f + R_s + R_L)}$$

If $(R_f + R_s) << R_L$

$$\eta = \frac{4}{\pi^2} \cdot \frac{2}{1} = \frac{8}{\pi^2} = 0.812 = 81.2\%$$

(9) $TUF = \frac{P_{dc}}{P_{ac(rated)}}$

Since both winding are used $TUF_{FWR} = 2 TUF_{HWR}$

$= 2 \times 0.287 = 0.574$

(10) Peak Inverse Voltage (PIV) :-

Maximum reverse voltage that a diode can withstand without destroying the Junction.

$PIV = 2V_m$

Advantages :-

1) Ripple factor = 0.482 (against 1.21 for HWR)

2) Rectification efficiency is 0.812 or 81.2%.

3) Better TUF (secondary) is 0.574

4) No core saturation problem.

Disadvantages :-

1) Requires center tapped transformer.

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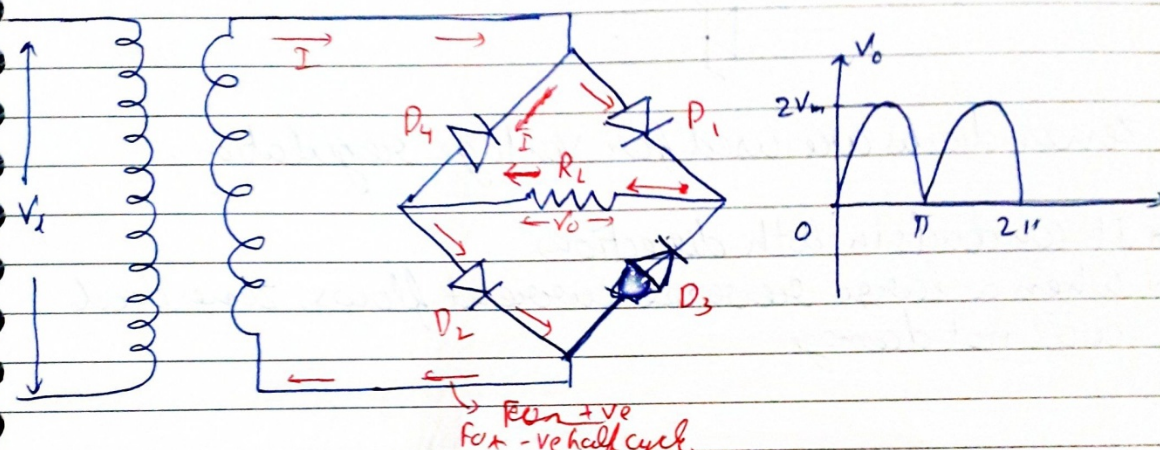
Bridge Rectifier:-

Main advantage of this bridge circuit is that it does not require a special center tapped transformer, hence reducing its size and cost.



The four diode D_1, D_2, D_3 & D_4 are arranged in such a way that $D_3 D_4$ & $D_1 D_2$ work together.

During +ve half cycle of supply, diode D_1 & D_2 conducts ie are replaced by short circuit while diodes D_3 & D_4 are reverse biased ie are replaced by open circuit.

For -ve half cycle of supply, diode D_3 & D_4 conduct while D_1 & D_2 are reverse biased, (OFF).

Average current $I_{dc} = \frac{2I_m}{\pi}$

Ripple Factor $\gamma = 0.482$

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

Rectification eff. $\eta = 0.812$

DC o/p voltage (no load) - $V_{DC} = \frac{2V_m}{\pi}$

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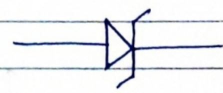
Zener Diode :- → highly doped diodes.

It is a special type of diode designed to reliably allow current to flow backwards when a certain set reverse voltage known as Zener voltage is reached.



Zener diodes are used for voltage regulation.

* It conducts in both directions
* When a large reverse current flows, zener diode will not damage.

Breakdown Voltage :-

Critical value of the voltage at which the breakdown of P-N Junction diode occurs.

It depends on the width of the depletion region which in turn depends on doping level.

Two mechanisms by which breakdown can occur are

(1) Avalanche Breakdown

(2) zener breakdown

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Avalanche breakdown :- (Avalanche Multiplication)

① It occurs in a diode which is lightly or moderately doped and has thick Junction (depletion layer width is high). It occurs under reverse biased condition.

② It occurs when we apply a high reverse voltage across the diode (higher than the zener breakdown voltage (6V) 5V)

③ It occurs because of the ionisation of e⁻ & hole pair. As when a reverse voltage applied is increased, there is a rise in temperature across the Junction. Due to this vibration of atoms ↑ and thus reduces the mean free path for e⁻. Hence Breakdown voltage increases with increase in temperature

④ It is +ve temperature coefficient.

⑤ The minority carriers, under reverse biased conditions, flowing through the Junction acquire a K.E which increases with the increase in reverse voltage. At high voltages, the K.E of minority carriers increases to a level that it knock out e⁻ from covalent bonds of semiconductor material. This is a chain reaction and it goes on like this. Hence the level of current increases.

Zener Breakdown:-

It occurs due to heavy doping and have narrow junction.
Valence e⁻ which break free under the influence of applied electric field can be accelerated enough due to which it dislocate the free e⁻ from valence Band to Conduction Band, resulting to a large number of free minority carriers which suddenly increase the reverse current.

* It occurs for low value of reverse voltage ($< 6V$).

* When reverse voltage across depletion layer increases the thickness of layer (t) increases.

$$t \propto \sqrt{V}$$ (where V is applied reverse voltage)

* Let Electric field intensity (E) inside depletion layer

$$= \frac{V}{t}$$

$$E \propto \frac{V}{t} \propto \sqrt{V} \qquad (\because t \propto \sqrt{V})$$

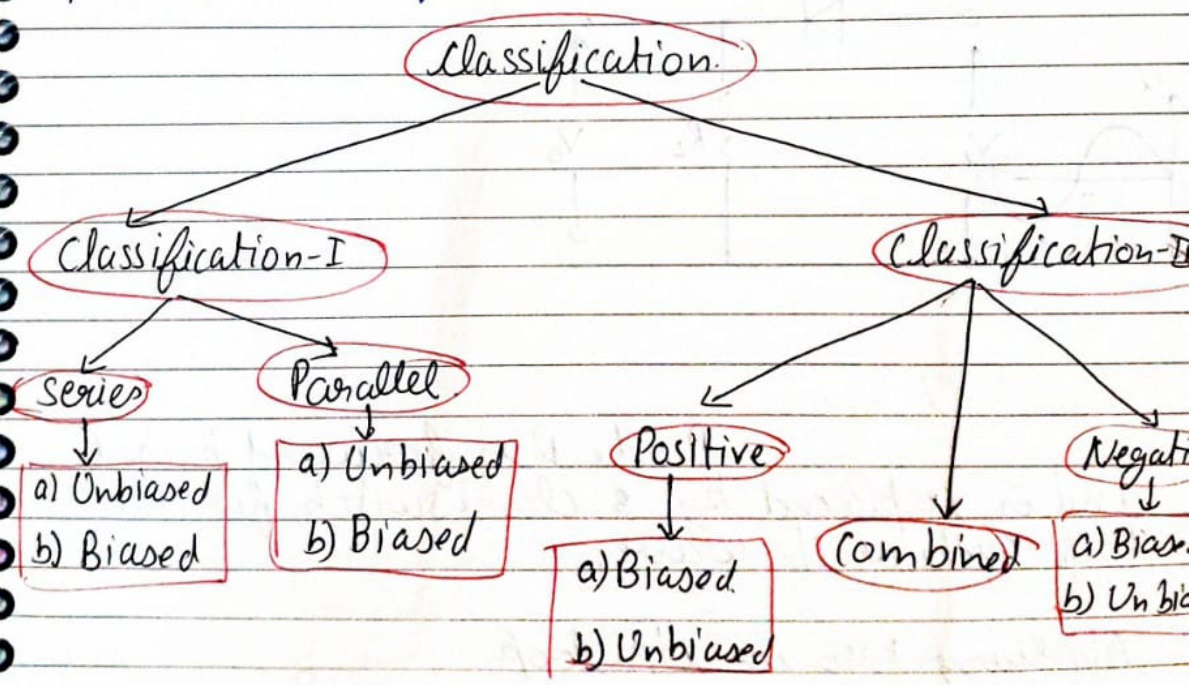
$$\boxed{E \propto \sqrt{V}}$$

The high electric field intensity causes field emission of e⁻ from immobile ions of depletion layer.
It creates a large no. of e⁻-hole pairs inside depletion layer. The external battery forces towards N-region and holes toward P-region.

So a large reverse current flows from N to P region. This phenomenon is known as zener breakdown. After breakdown the reverse current is independent of applied voltage and limited only by external resistance.

Clipping Circuits -

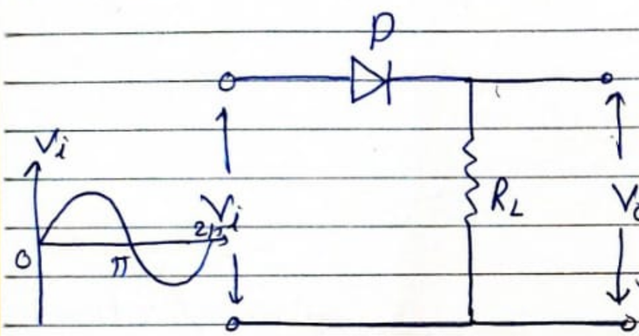
The ability to clip (cut) a portion of i/p without distorting the remaining part of Alternating waveform.



classification - I
On the basis of orientation of diode.

a) Series Clippers :- When a diode is connected in series with the load.

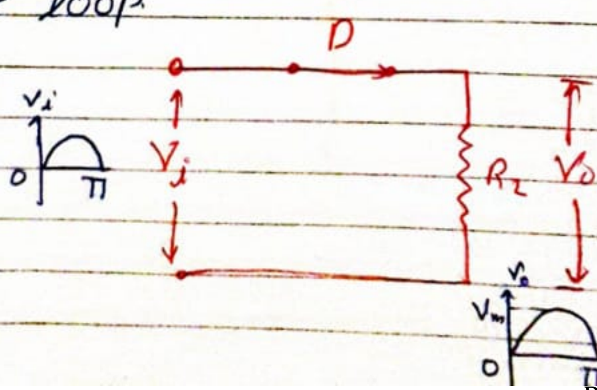
(i) Unbiased Series Clipper cuts the complete +ve or -ve half.



For +ve half cycle :- Diode D is forward biased and is replaced by a closed switch, for +ve half cycle of i/p wave.

Applying KVL in i/p loop

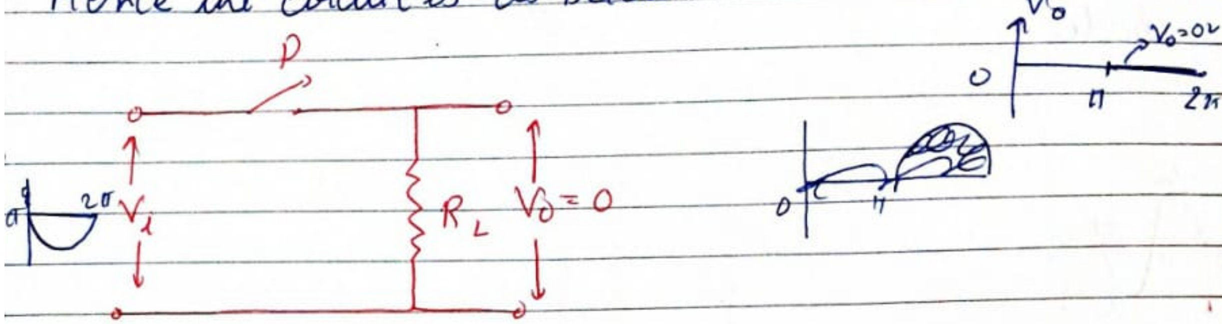
$V_0 = V_i$



For Negative half cycle:-

Diode is reverse biased and is replaced by an open circuit.

Hence the circuit is as below.



Applying KVL in the o/p loop

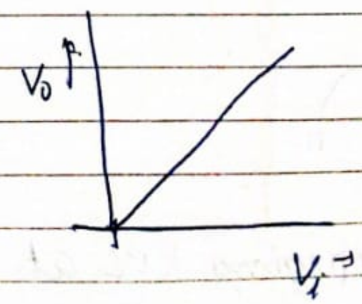
$$V_0 = 0 \quad (\text{as } i = 0)$$

Transfer characteristics:-

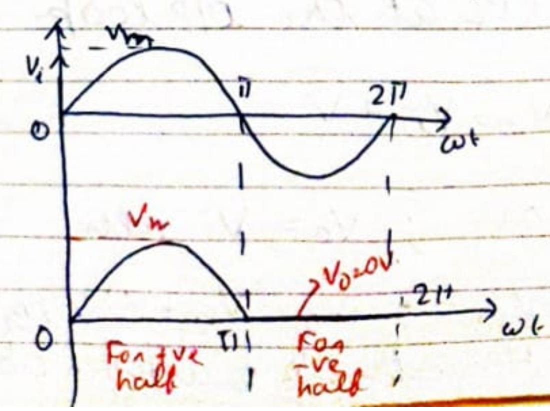
Variation of o/p voltage with i/p voltage.

If $V_i > 0$, $V_0 = V_i$

$V_i < 0$, $V_0 = 0$

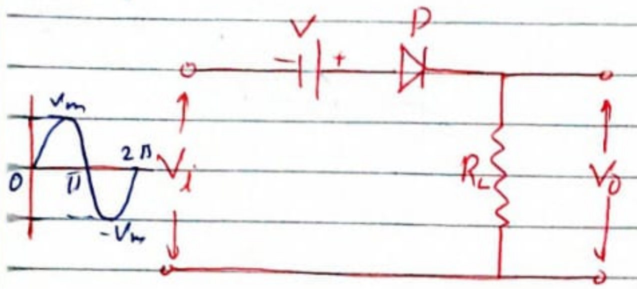


Final Waveform



(2) Biased Series Clippers :- It clips only a portion of wave (either +ve or -ve half)

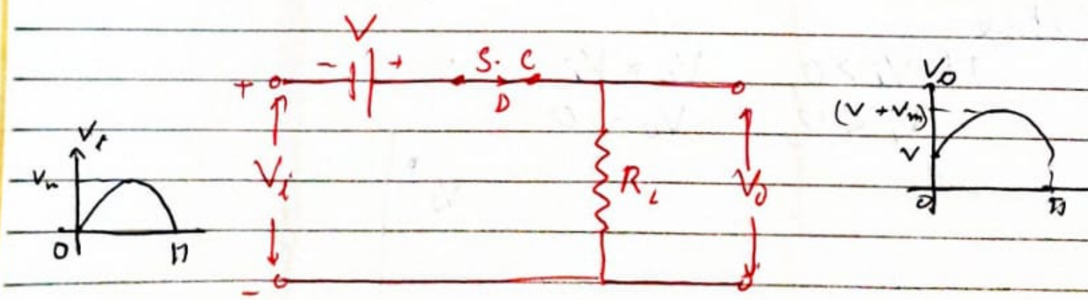
It contains a ~~series~~ DC battery in series with the diode.



For +ve half cycle :-

For complete +ve half cycle the diode D is forward biased and is replaced by S.C.

The circuit becomes



Applying KVL at the o/p loop.

$$V_o = V_i + V$$

When $V_i = 0V$; $V_o = V$ volts

$V_i = V_m$; ~~$V_o =$~~ $(V_m + V)$ volts

Hence the o/p waveform obtained is shown above

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For Negative Cycle:-

Diode D will be forward biased till $V_i + V$ is greater than cut in voltage of diode.

ie $V_i < V$, D is F.B ; $V_i > V$, D is R.B

For ideal diode cut in voltage is zero.

∴ When $V_i < V$, Diode D is forward biased

$V_0 = (-V_i + V)$ volts.

Let $V = 5V$, $V_i = 0$

Let $V_i = 0V$ $\quad V_0 = 0 + 5 = 5V$

$V_i = 1V$ $\quad V_0 = -1 + 5 = 4V$

$V_i = 2V$ $\quad V_0 = -2 + 5 = 3V$

$V_i = 3V$ $\quad V_0 = -3 + 5 = 2V$

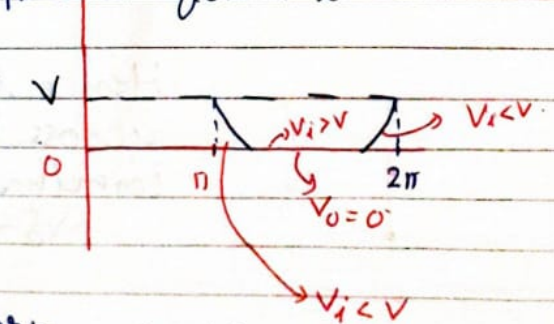
$V_i = 4V$ $\quad V_0 = -4 + 5 = 1V$

$V_i = 5V$ $\quad V_0 = -5 + 5 = 0V$

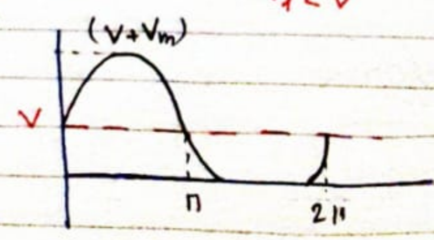
For $V_i > V$, Diode is reverse biased

Hence $V_0 = 0v$.

∴ The O/P waveform is



Final waveform



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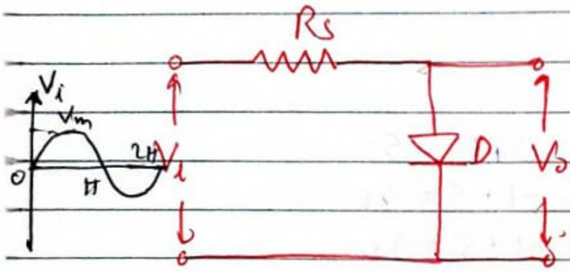
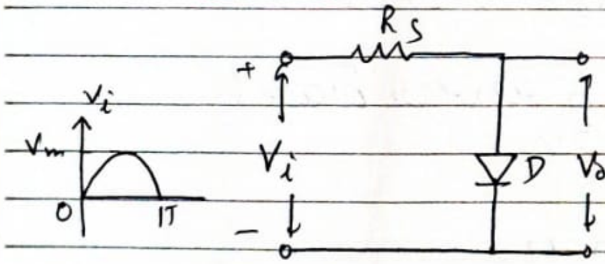
b) Parallel Clipper:- Diode is connected in parallel to load.

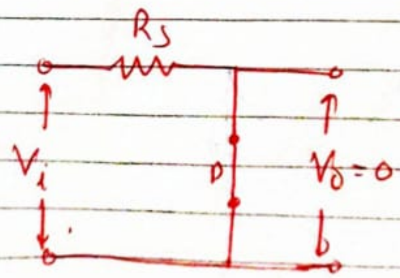
(1) Unbiased parallel clipper:- Either complete –ve or +ve half cycles are completely clipped off.



For +ve half cycle:-

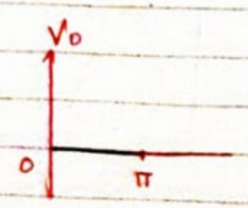


For +ve half cycle diode (D) is F.B hence replaced by S.C



Hence the ~~load~~ o/p voltage across the shorted terminal is zero.
$V_o = 0$

Hence o/p waveform



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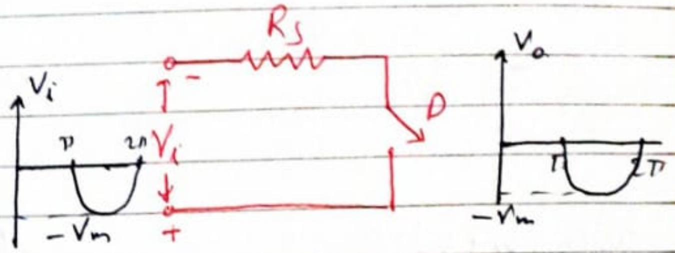
For -ve half cycle:-

Diode (D) is reversed biased and hence it is replaced by open circuit.

Applying KVL,

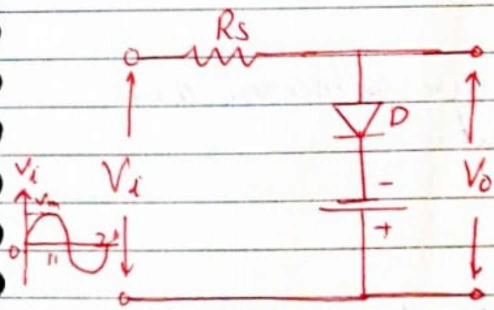
$V_0 = V_i$



② Biased Parallel Clipper:-

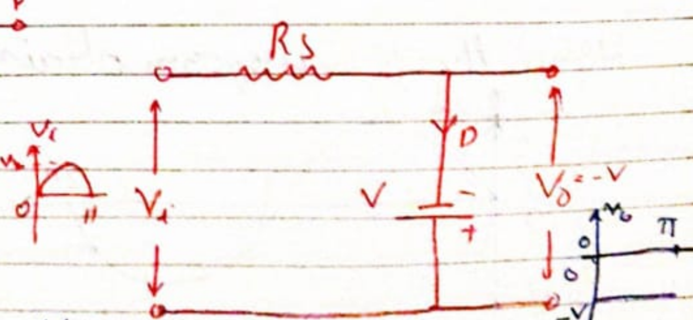
Only a portion of waveform is clipped off either from +ve half or -ve half cycle.

A DC battery is connected in series with Diode which is connected in parallel to load.



For +ve half cycle

For complete +ve half cycle diode is forward biased and is replaced by S.C.



Applying KVL in the o/p loop.

$V_0 = -V_i$

Hence the o/p waveform obtained is shown with the circuit.

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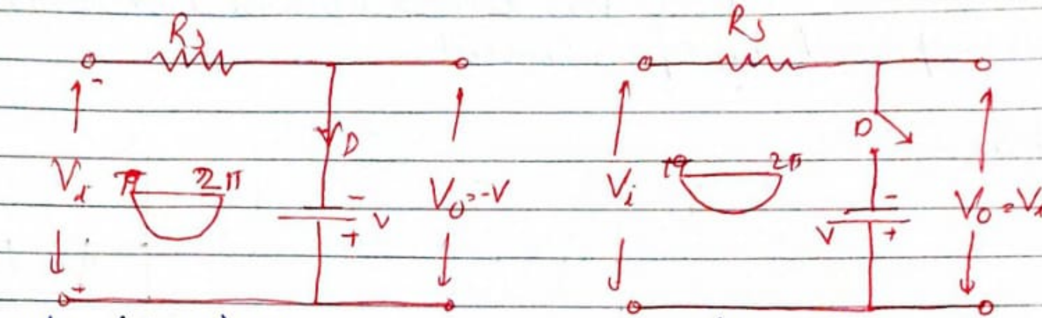
For -ve half cycle :-



when $(V_i + V) > 0$ when $(V_i + V) < 0$

For the case of -ve half cycle diode D is forward biased till $V_i < V$. Hence o/p

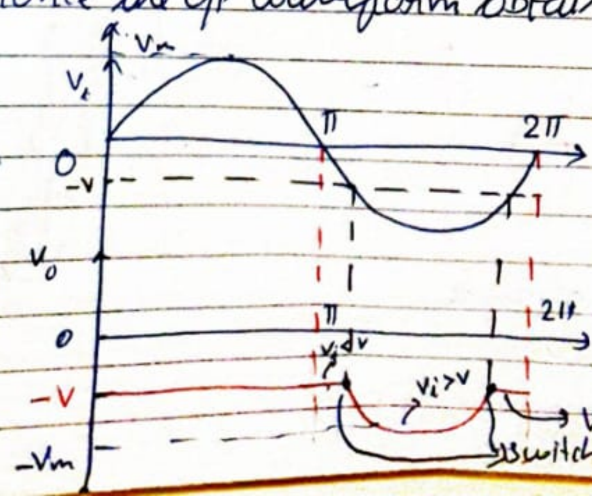
$$\boxed{V_o = -V} \quad (\text{for } V_i < V)$$

For $V_i = V$
Diode D is in switching state.

For $V_i > V$
Diode D is completely reverse biased and the o/p will follow the input

i.e. $\boxed{V_o = V_i}$

Hence the o/p waveform obtained is



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Classification - II

According to the ablity to clip off +ve or -ve portion of alternating wave

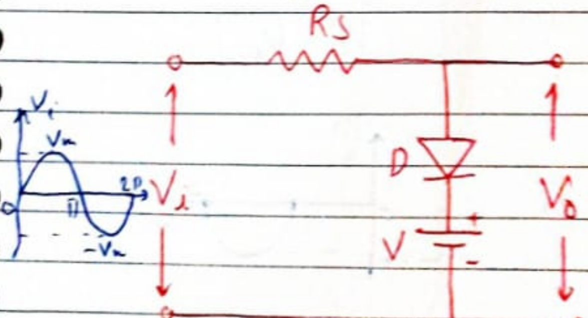
a) **Positive Clipper** - clips off ~~complete~~ +ve portion of the ~~half cycle~~ wave.

1) **Unbiased +ve clipper** - clips off complete +ve half & negative half is is unaffected

Same example as given in Unbiased parallel Clipper

2) **Biased +ve clipper** - clips off only a portion of +ve voltage, while keeping negative half cycle unaffected.

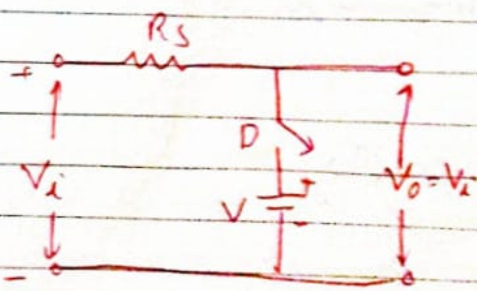
A DC Battery is connected in series with the diode.



For +ve half cycle -

When $V_i < V$, Diode D is reversed biased.

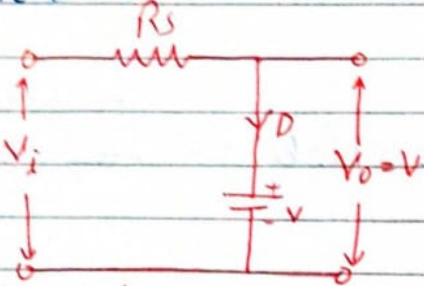
The circuit can be redrawn as.



Applying KVL along the loop

$$V_o = V_i$$

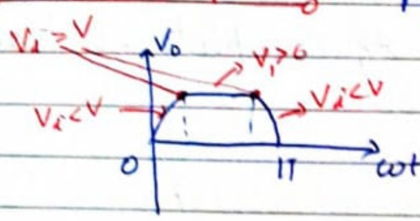
For $V_i \geq V$ diode D is forward biased and is replaced by short circuit or closed switch.



Applying KVL in o/p loop

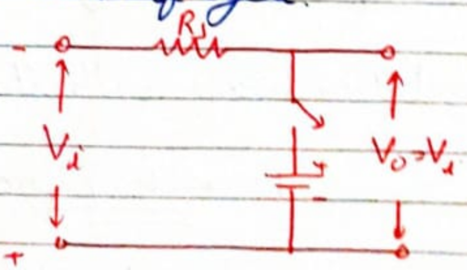
$$V_o = V$$

Hence the o/p waveform is



Negative half cycle:-

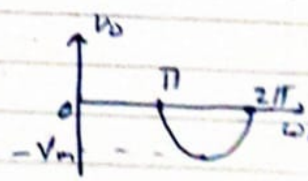
Diode is reverse biased for complete -ve half cycle.



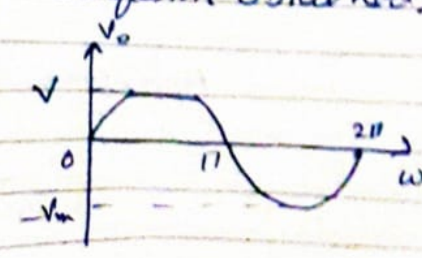
Applying KVL

$$V_o = V_i$$

Hence the o/p waveform is



The final o/p waveform obtained is

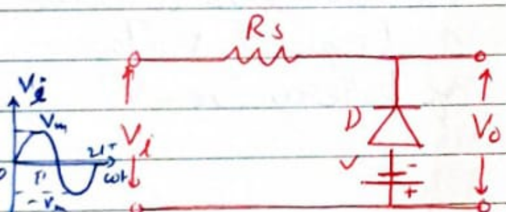


b) Negative clipper:- Clips off the negative portion of wave.

① Unbiased -ve clipper:- complete -ve half of wave is cut by while the +ve half remain unchanged.

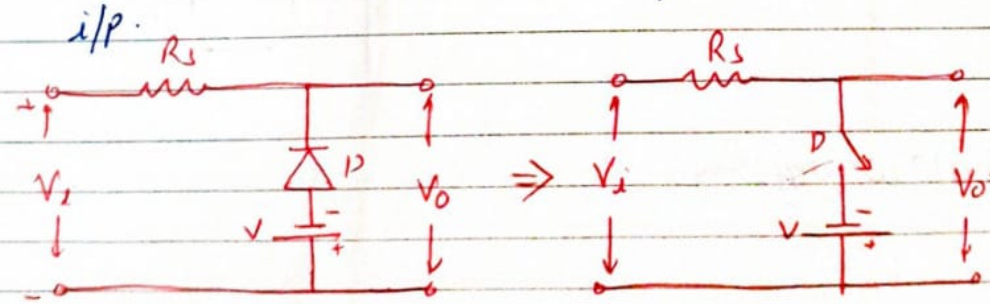
Example Half wave Rectifier.

② Biased Negative clipper:- Battery is connected in series with the diode.



For +ve half cycle:-

The diode D is reversed biased for complete +ve half cycle and the o/p will follow the i/p.



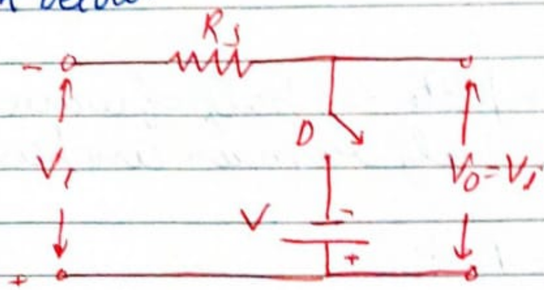
Applying KVL in the loop

$$V_0 = V_i$$

Hence the o/p waveform is

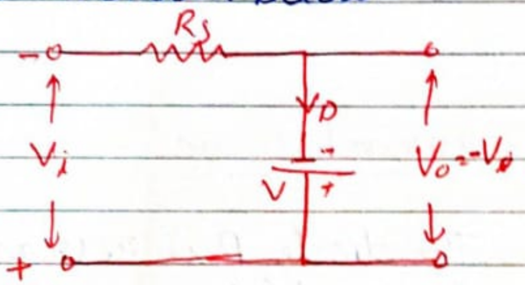
For -ve half cycle :-

For $|V_i| \leq |V|$, diode D is reversed biased. The ckt is shown below.



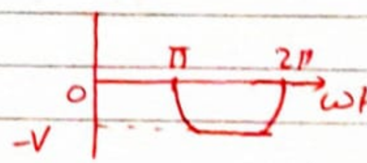
Hence
$V_0 = V_i$

For $|V_i| \geq |V|$, diode D is forward biased. The ckt is shown below:

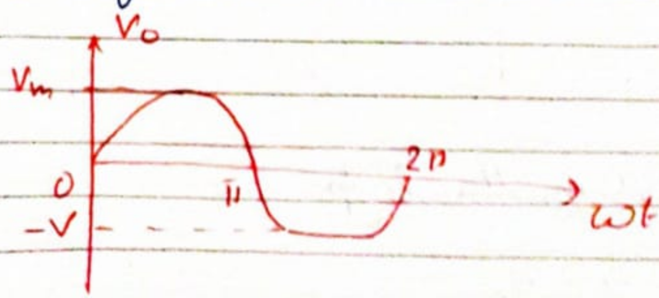


O/P voltage is constant and equal to voltage of battery (ie -V)

Hence the o/p wave form

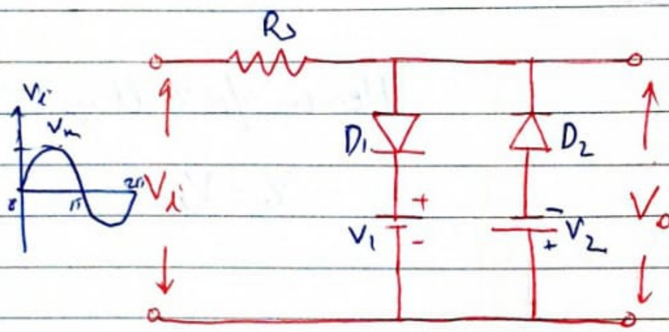


Final o/p waveform



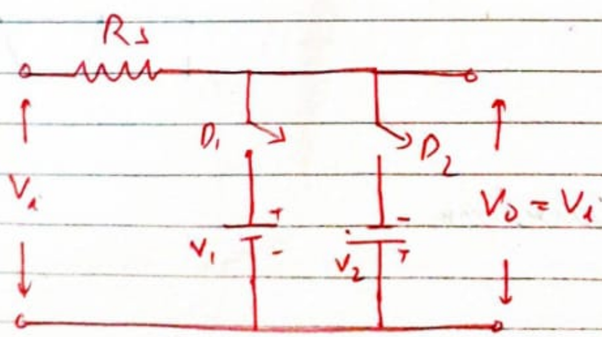
c) Combined Positive and Negative Clipper :

Batteries of opposite polarities are connected in parallel. Diode D_1 & D_2 are included in series with the batteries. ~~such that~~



For +ve half cycle :- Diode D_2 is reversed biased for whole +ve half cycle.

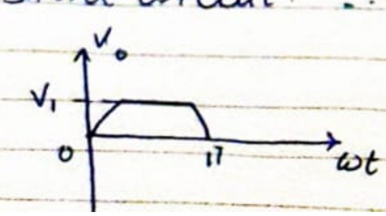
Diode D_1 is also reverse biased for $V_i < V_1$, Diode D_1 will be replaced by open circuit.



Applying KVL

$$V_0 = V_i$$

For $V_i \geq V_1$, diode D_1 is forward biased and is replaced by short circuit. $\therefore V_0 = V_i$



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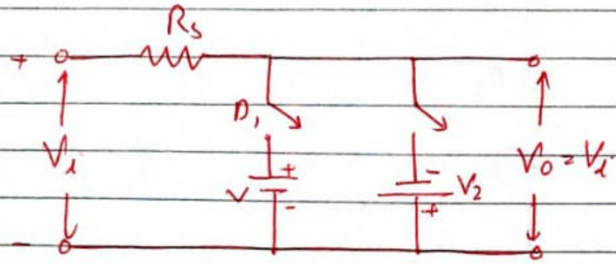
For -ve half cycle :-

For $|V_i| < |V_2|$

Diode D_1 is reverse biased for whole -ve cycle
Diode D_2 is reverse biased till $V_i < V_2$, hence replaced by open circuit.

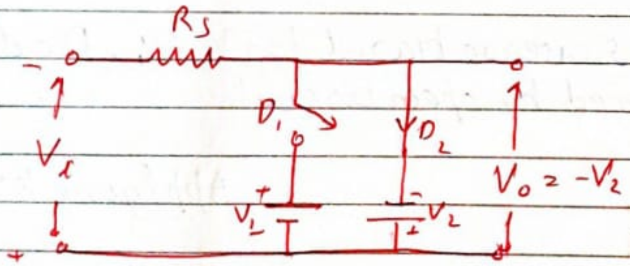


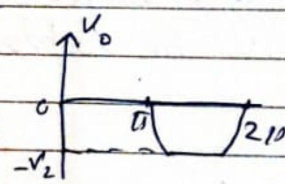
Hence o/p voltage

$V_0 = V_i$

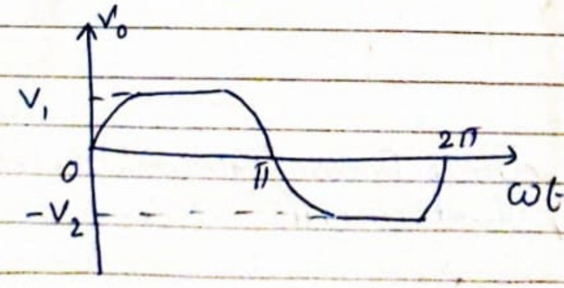
For $|V_i| > |V_2|$

D_2 is forward biased and D_1 is reversed biased.





Hence the overall waveform



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Clamping Circuits -

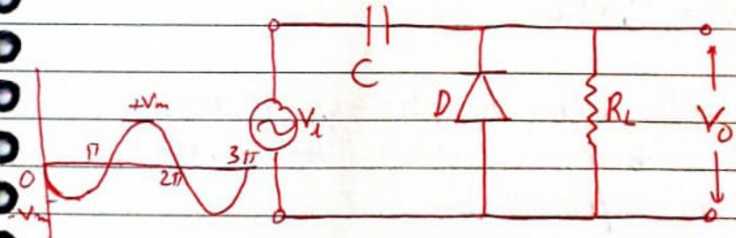
Shifts an AC S/g to a different DC level without clipping.

It must have a capacitor, a diode, a resistive element. It can also have DC battery source.

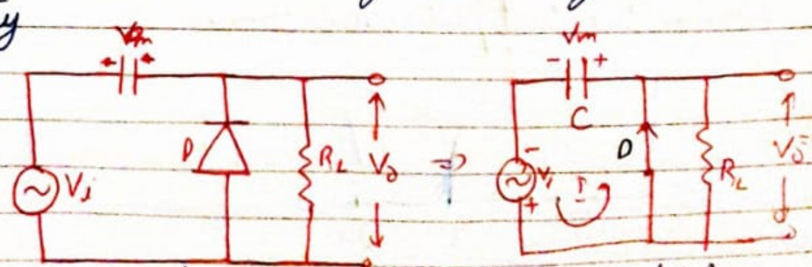
* The time constan (RC) of circuit should be high enough to ensure that voltage across capacitor doesnot change significantly when diode is reversed biased.

a) Positive Clamper

It raises the level of AC Signal by adding the DC component. This result in rising of the level of signal.



Negative half Cycle :- Diode D is F.B and due to which capacitor charges to voltage level V_m with polarity

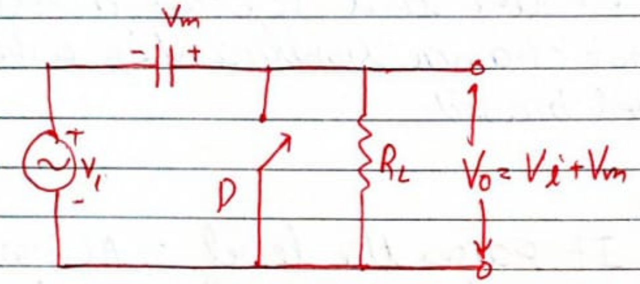


For this case the capacitor gets charged to Max. (V_m)

Hence $V_0 = 0$ volts (o/p (only for first cycle $\omega t = 0$ to π)

For Positive Half cycle :-

It is assumed that the charge across capacitor remains the same. Diode D is reverse biased for this case and hence is replaced by O.C.



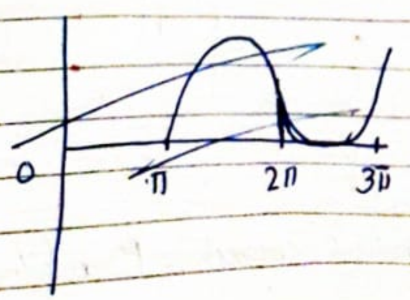
Applying KVL across the loop

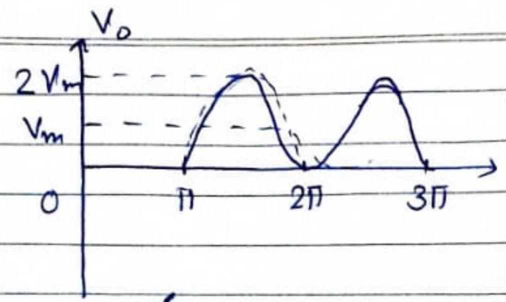
$$V_0 = V_i + V_m$$

For next -ve half cycle, due to charge across capacitor, Diode D will now always be reverse biased and hence is replaced by O.C.

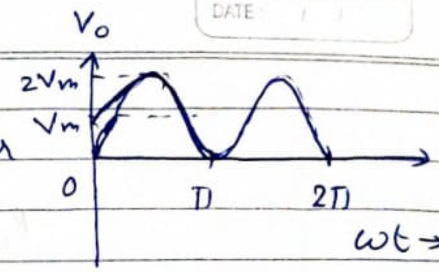
$$\therefore V_0 = V_i + V_m$$

Hence the output waveform is



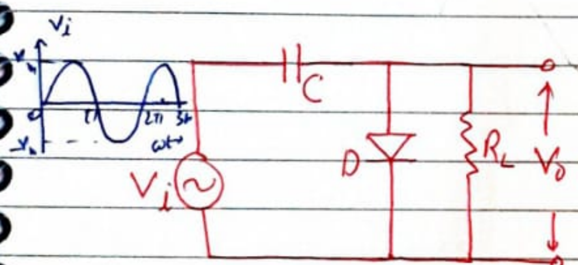


(Original Waveform)

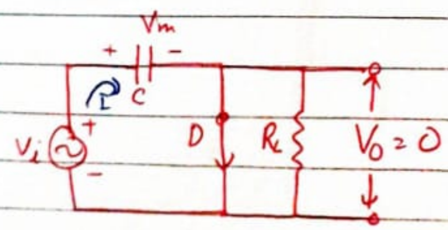


Or (Shifted Waveform) shown in book.

(b) Negative Clamper – Clamps the AC signal to a lower level.



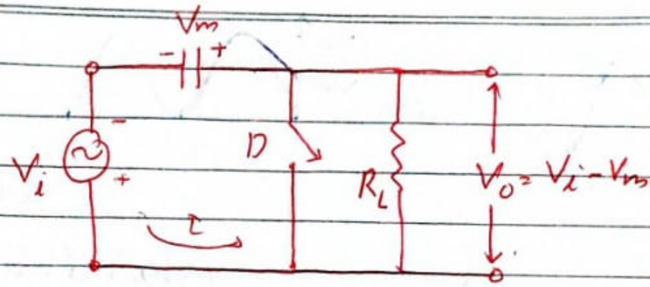
For +ve half cycle –



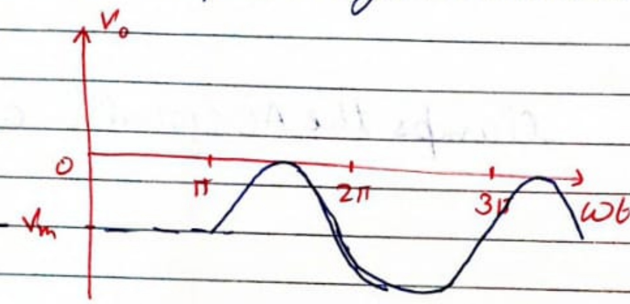
Diode D is forward biased & capacitor charges to Vm with the shown polarity.

For –ve half cycle – Diode D is reverse biased and is replaced by open circuit

$$V_o = V_i - V_m$$

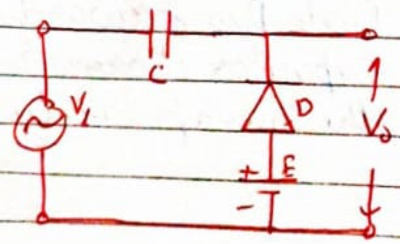


In this the o/p voltage is lowered by amount $-V_m$.

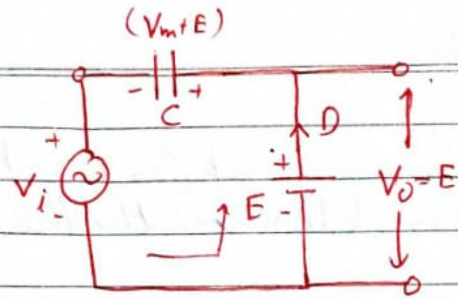


③ Biased Clampers :-

When a battery is included in series with the diode.



For -ve half cycle :-
Diode D is forward biased and the capacitor C charges to voltage $(V_m + E)$.

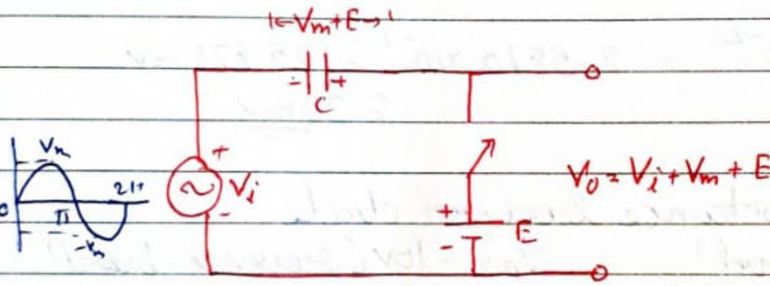


For +ve half cycle:-

Diode D is reverse biased

Applying KVL in loop

$$V_o = V_i + V_m + E$$



Hence the o/p waveform obtained