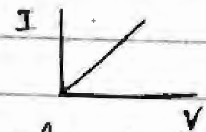
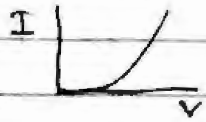
CHAPTER-1 (BASIC ELECTRONICS)
(By Amir A. Patel)

DIODE THEORY & APPLICATIONS

* **Linear device:** graph of current & voltage is a straight line then device is linear device. Simple resistor is a linear device.



* **Non-linear device:** Graph of current & voltage is not a straight line, then device is nonlinear device. Diode is non linear device.



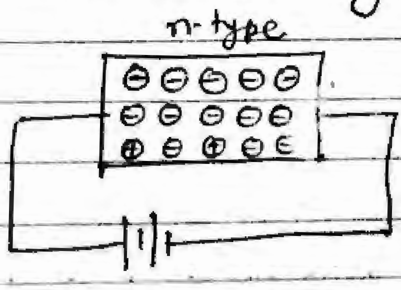
Intrinsic Semiconductor:

It is a pure semiconductor. A silicon crystal is an intrinsic semiconductor if every atom in the crystal is a silicon.

* **Extrinsic Semiconductor:**

If semiconductor is doped with impurities to have excess of free electrons or holes is called extrinsic semiconductor

→ **n-type Semiconductor:** If silicon is doped with penta valent impurities is called n-type semiconductor, where n stands for negative. Here there are number of free electrons ie. majority charge carriers and less amount of holes are called minority charge carriers.



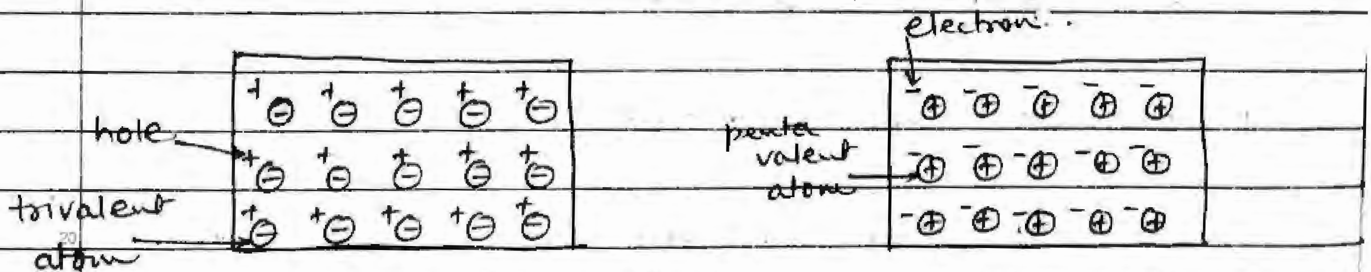
→ p-type Semiconductor:

Silicon has been doped with trivalent impurity is called p-type semiconductor. Holes are more in number, so majority charge carrier & electrons are minority charge carrier.

UNBIASED DIODE

A p-type semiconductor & n-type semiconductor are joined together with the help of special fabrication technique to form a p-n junction.

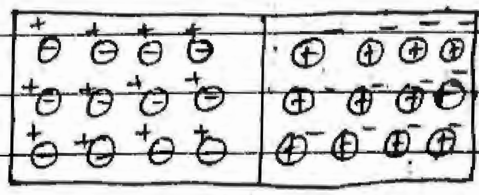
→ piece of p-type semiconductor has trivalent impurities, so it has hole in its valence orbit.



p-type Semiconductor. n-type semiconductor

→ piece of n-type semiconductor has pentavalent impurties, so it has electron int its valance orbit. electrons as majority charge carriers.

→ When p-type & n-type material joined it forms p-n-junction. This semiconductor device is called diode.



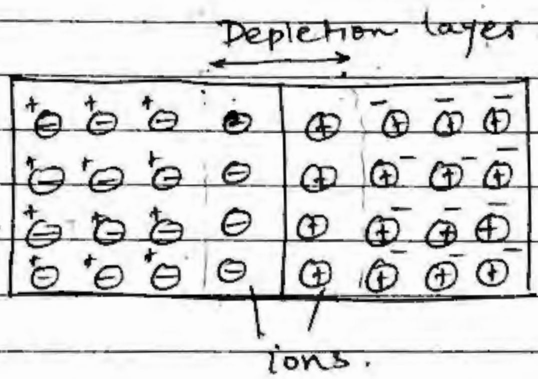
pn junction

→ Free electrons on n-side has repulsion for each other, so they tend to spread in all directions. Some of free electrons diffuse (spread) across the juction. when free electrons enters the p-region (electrons are minority charge carrier in p-region), it recombines with a hole.

→ when electron diffuse across junction, it creates a pair of ions. On n-side near junction large number of positive ions generated (As electron leaves n-side, pentavalent atom becomes positive ion).

→ on p side. electron recombines with holes of trivalent atoms, it generates negative ions near juction.

→ This is shown in the figure below.



Depletion layer: (Depletion Region):

→ Region on both the side of junction, which contains only immobile ions & no free carriers (electrons or holes) is called depletion region.

→ Depletion Region is also known as "space charge Region."

Due to depletion region electrons or holes can not diffuse (spread) to the other side. So, depletion region acts as barrier.

→ width of depletion region is very small, of the order of 0.5 to 1 μm.

→ electric field generated near junction by positive & negative ions.

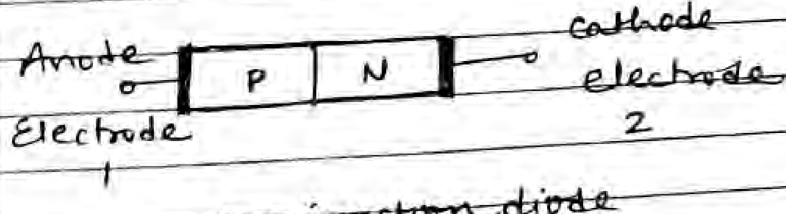
→ electric field between the ions is equivalent to a difference of potential called barrier potential.

→ At 25°C, the barrier potential equals to approximately 0.3 V for Ge (germenium) & 0.7 V for Si (Silicon).

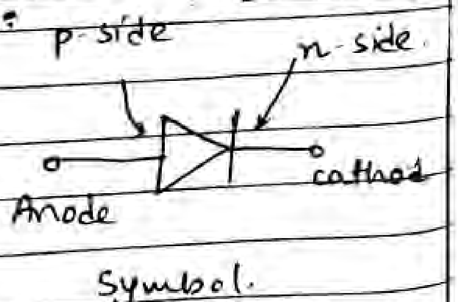
Q.1 Give Basic idea about forward bias and reverse bias of p-n junction diode.

Q. Biasing of a p-n junction diode. (Short note.) (5 or 7 marks)

A. p-n junction diode :



pn junction diode



Symbol.

→ when p-n junction is formed, depletion region gets created and movement of electron & holes through junction stops.

→ Thus current flowing to unbiased (not connected to power supply) p-n junction is zero.

→ To make current to flow we have to bias (Give external supply) the p-n junction diode.

→ Biasing is the process of applying d-c supply (voltage) to semiconductor diode

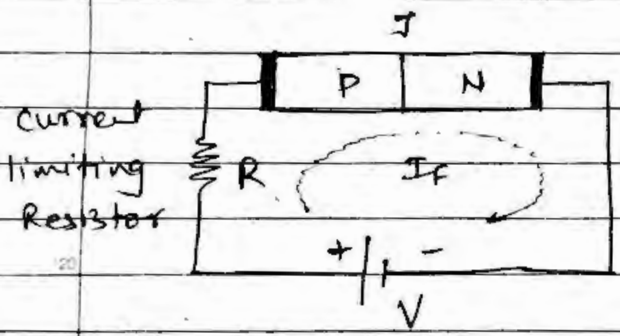
→ when no external voltage applied, diode will remain in the state of equilibrium. So, no current flowing through it.

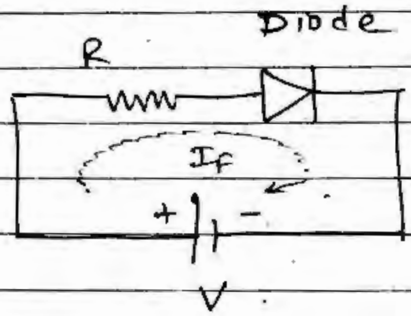
→ Biasing can be of two types:

1) Forward Bias. 2) Reverse Bias.

1) FORWARD BIAS.

→ If the p-side (anode) connected to the positive terminal of the external DC supply & n-side (cathode) is connected to negative terminal of dc supply then biasing is said to be "forward biasing".



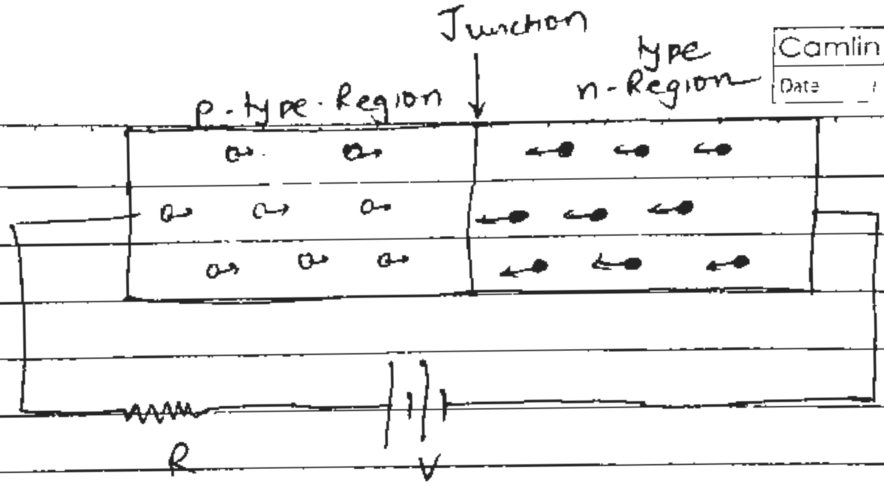


→ When battery is connected to diode it pushes electrons & holes towards junction.

→ if battery voltage is less than barrier potential depletion layer will not allow them to pass through it & junction.

→ But if battery voltage is greater than barrier potential, electrons will pass through junction & recombines with holes.

→ Large number of majority charge carriers crossing the junction constitute a current called a forward current.



→ electrons from n side will move towards the positive end of battery & holes will move towards junction.

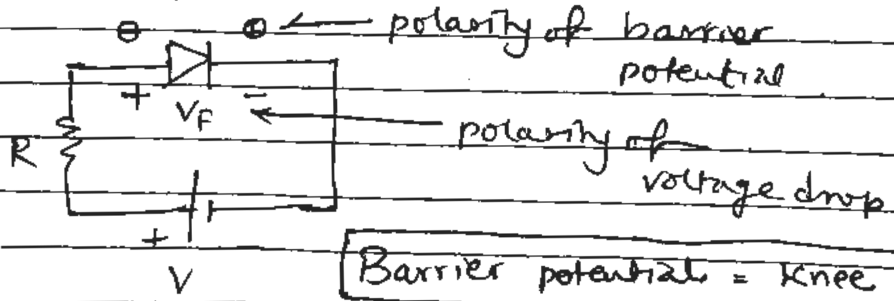
→ Movement of carriers will cause current & that is due to majority charge carriers. (electrons in n-type Region & holes in p-type region)

→ Forward current of diode (I_F) is due to majority carriers.

→ Due to large forward current (I_F), forward resistance of diode is very small.

Voltage drop across forward Bias Diode (V_F)

→ There is a potential drop across conducting forward bias diode to overcome barrier potential, which has opposite polarities to barrier potential & has value equal to barrier potential.

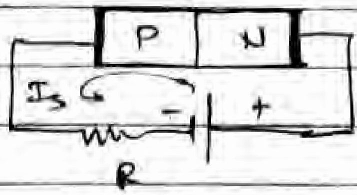


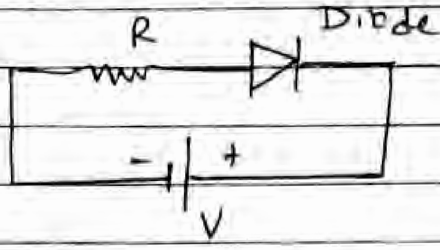
$\boxed{\text{Barrier potential = Knee voltage}}$

Knee Voltage: In forward region, the voltage at which the current starts to increase rapidly is called the knee voltage.

2) REVERSE BIAS :

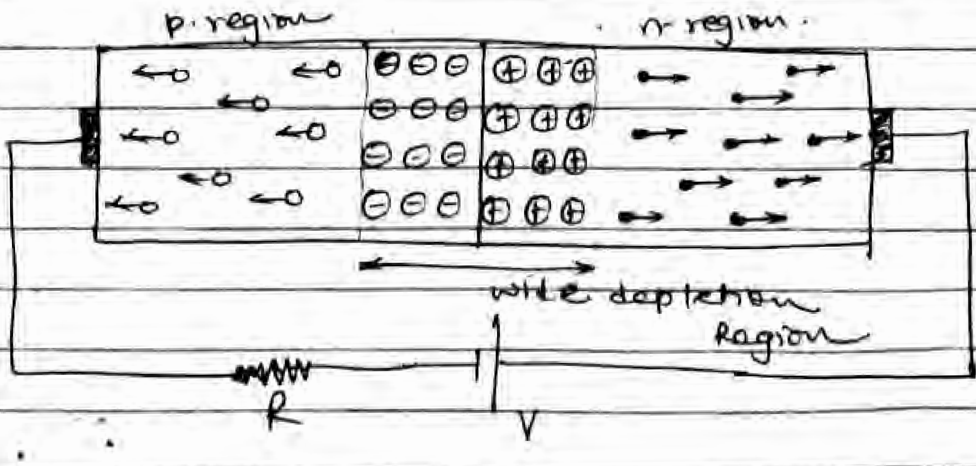
If p-region of diode is connected to the negative terminal of the external DC supply & n-region is connected to the positive terminal of DC supply then diode is said to be reverse bias.





→ When diode is reverse biased holes in p-region attracted to -ve terminal of battery & electrons in n-type region attracted towards +ve terminal of battery. So majority carriers of both region try to move away from junction. This will widen the depletion region.

→ As carriers try to move away from junction more number of ions present near junction on both the side (no carriers near junction), so barrier potential will increase.



* Minority carrier current (Reverse Saturation current)

→ p. region consists of a small number of electrons & n. region contains a small number of holes. These are minority carriers generated thermally.

→ Minority electrons in p-region are attracted by positive end of the dc supply. These electrons will cross the junction & constitute the reverse current I_s of the diode.

→ Reverse current is also called Reverse saturation current.

→ These current is due to the minority carriers. for Ge it is of the order of μA & for Si it is in nano ampere range.

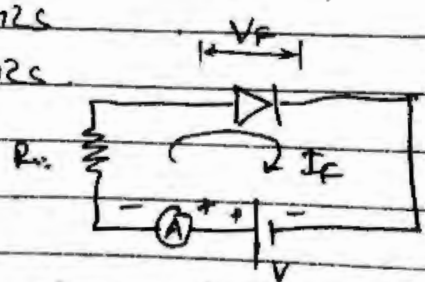
→ Reverse saturation current increases with temperature increase.

Q. Write short Note on: V-I characteristics of P-N Junction diode: (JAN. '19, 7 marks)

A. VI characteristics of p-n junction diode is graph of voltage across the diode verses the current flowing through it.

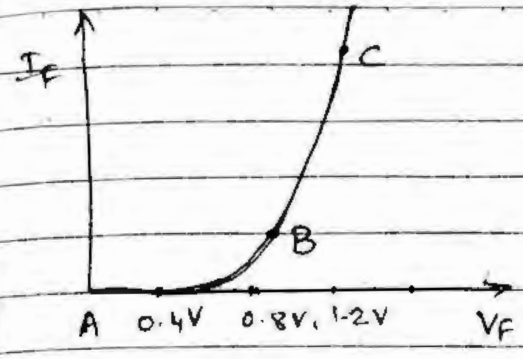
→ V-I characteristics can be divided into two parts:

1. Forward Characteristics
2. Reverse Characteristics



Forward Characteristics:

→ Forward characteristic is shown in the fig.



→ Current flowing through diode is approximately 0 until the diode voltage approches the barrier potential.

V_F = voltage across forward bias diode

I_F = current flowing through diode.

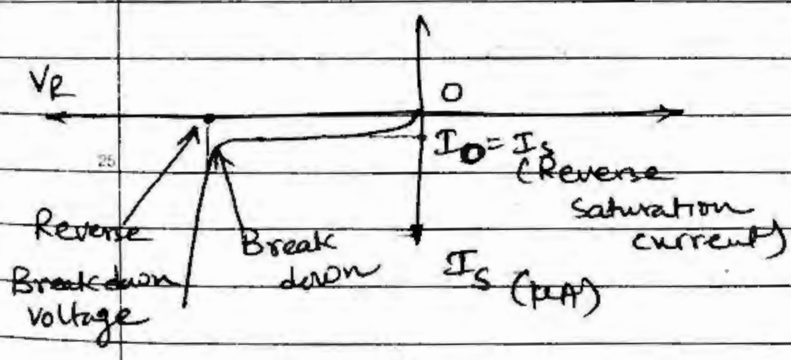
→ When diode voltage reaches 0.6 to 0.7V, diode current increases.

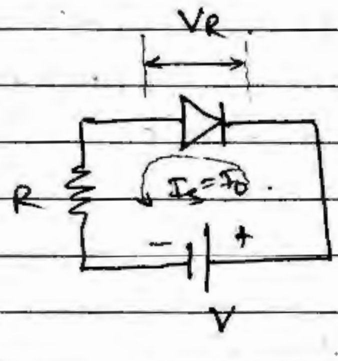
→ when diode voltage is greater than 0.7V diode current is significant & then graph is almost linear.

Cut in Voltage (knee voltage):

The voltage at which the forward diode current starts increasing rapidly is known as the cut in (knee) voltage.

Reverse Characteristics:



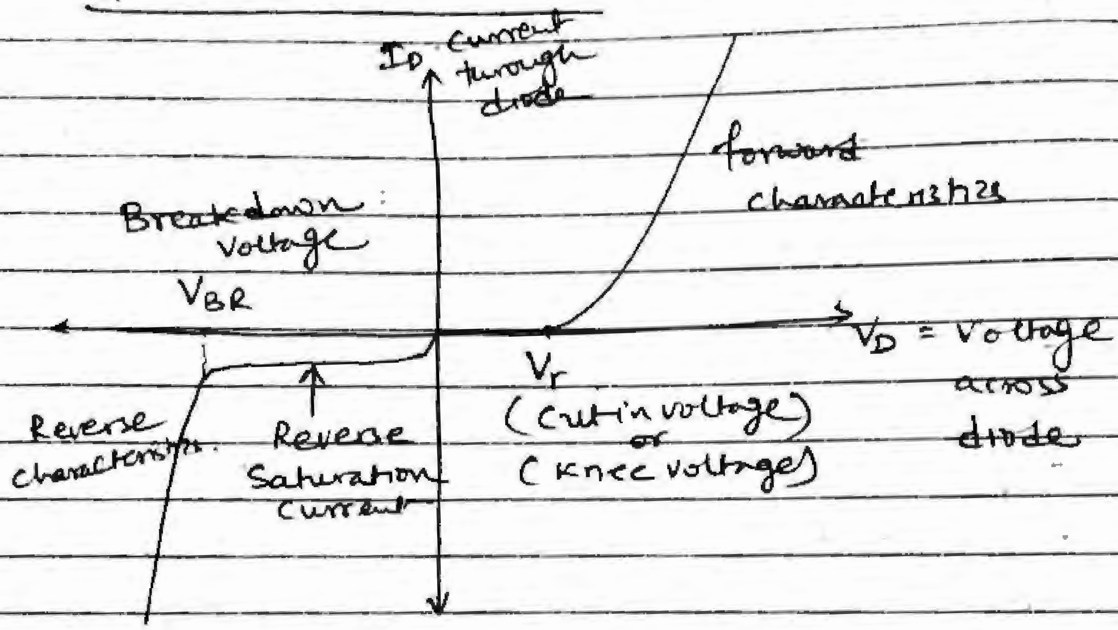


→ Current flowing through a diode in the reverse biased state is the reverse saturation current which flows due to minority carriers.

→ As reverse voltage is increased, reverse saturation current remains constant equal to I_0 if the temperature is constant.

→ As reverse voltage reaches breakdown voltage value, large current flows through diode and diode may get damaged.

Complete V-I characteristics.



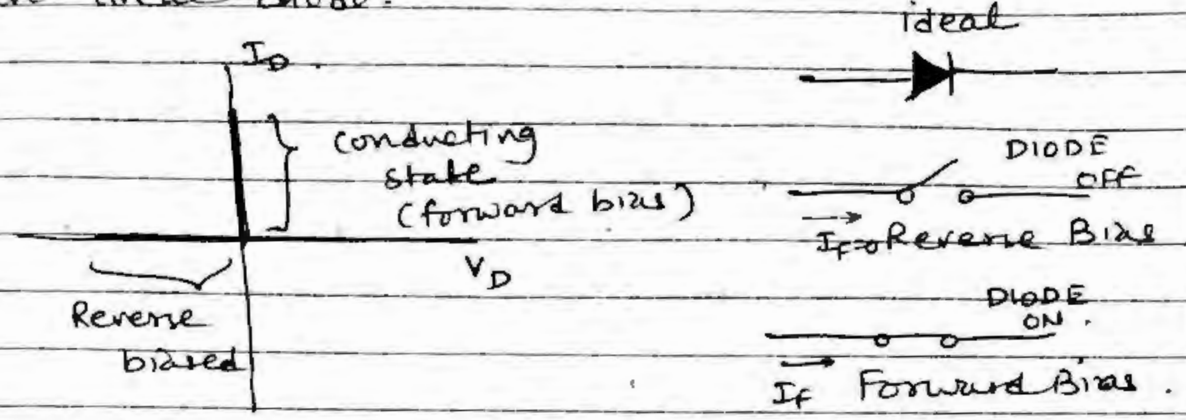
Q. Write short note on ideal diode.
(ideal approximation of diode) (3 or 4 marks)

→ Ideal diode is the simplest approximation of diode.

→ "What does a diode do?" It conducts well in the forward direction and poorly in the reverse direction.

→ Ideally diode acts like a perfect conductor (zero resistance) when forward biased and perfect insulator in reverse biased condition.

Below figure shows the current-voltage graph of an ideal diode.



→ When diode is in forward biased condition it acts as closed switch with zero resistance.

→ When diode is in Reversed Bias condition it acts as open switch with infinite resistance.

→ So ideal diode behave as switch.

Q. Define following terms: (1-mark each)

1) Reverse Saturation current: Current flowing through diode in reverse biased state due to minority carriers is called reverse saturation current.

Reverse saturation current for Ge is few μA
" " " " Si is few nA.

2) Surface Leakage Current: It is a reverse current at the surface of the crystal.

Surface leakage current is directly proportional to the reverse voltage.

Surface leakage current is due to surface impurities & imperfections in the crystal structure.

3) Cut in voltage (knee voltage): When diode is forward biased, voltage across diode at which current starts flowing through diode is called cut in voltage or knee voltage.

4) Bulk Resistance: When diode is in forward biased condition, above cut in (knee) voltage current starts rapidly. Above knee voltage, all that impedes current is ohmic resistance of the p & n regions.

Sum of ohmic Resistance of p-type & n-type material is called bulk resistance

$$R_B = R_p + R_N.$$

R_B — Bulk Resistance
R_p — Ohmic Resistance of p-type material
R_N — Ohmic Resistance of n-type material

5) Barrier Potential:

When diode is unbiased, due to presence of immobile positive & negative ions on both side of junction an electric field is created across junction. This electric field is known as barrier potential.

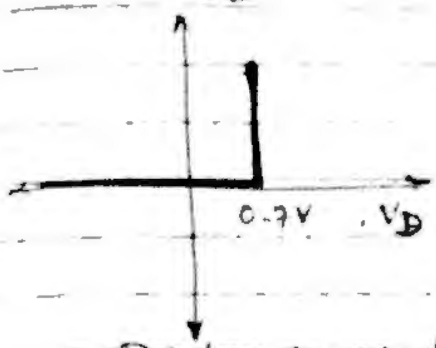
Q. Write short note on second & third approximation of diode (5 or 7 marks)

SECOND APPROXIMATION.

A Ideal diode approximation is used for trouble shooting applications. But for some other applications we need more accurate equivalent circuit.

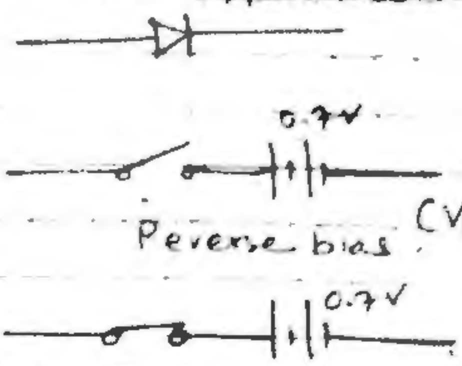
→ Graph of current versus voltage for second approximation is shown in fig.

→ Graph says no current exists until 0.7V appears across diode.



Diode curve for second approximation.

2nd approximation



→ Here in 2nd approximation we consider diode as a switch in series with a barrier potential of 0.7V.

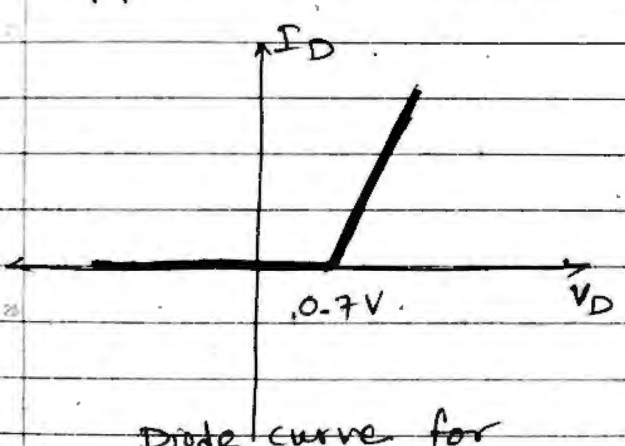
→ if diode voltage $V_D > 0.7$ it acts as closed switch.

→ if diode voltage $V_D < 0.7$ " " " open "

THIRD APPROXIMATION.

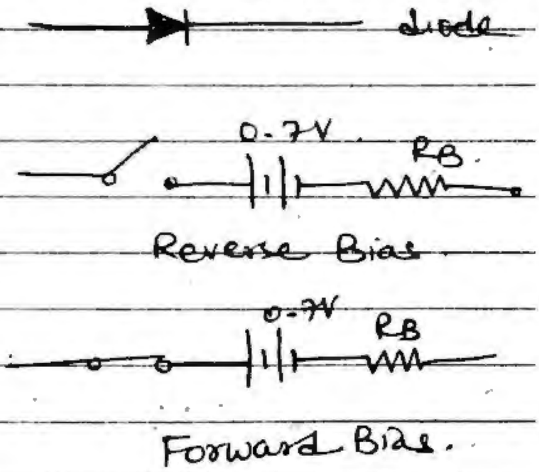
→ In third approximation of a diode, we include the bulk resistance R_B.

→ V-I characteristics of diode considering third approximation is shown bel.



Diode curve for third approximation

3rd approximation diode



→ After diode turn on, voltage increases linearly with an increase in current.

→ equivalent circuit for the third approximation is a switch in series with barrier potential

0.7V & bulk resistance R_B.

→ When diode voltage is greater than 0.7V diode conducts & voltage across diode is

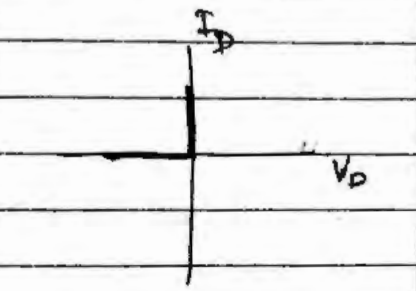
$$V_D = 0.7V + I_D R_B .$$

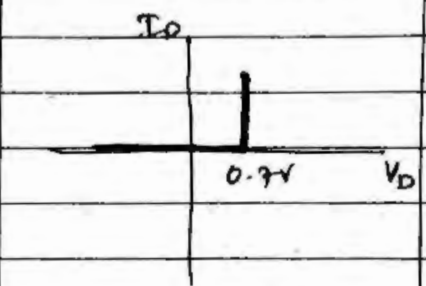
→ often bulk resistance is of the order of 1Ω.

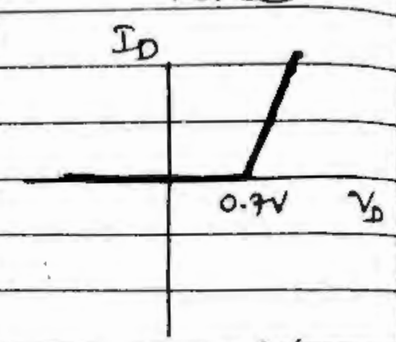
Diode Approximations Summary.

	First or Ideal	Second or Practical	Third.
When used	trouble shooting or quick analysis	Analysis at technician level	High level or Engineering level

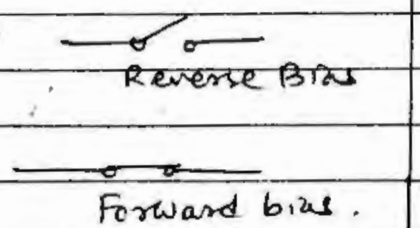
Diode Curve

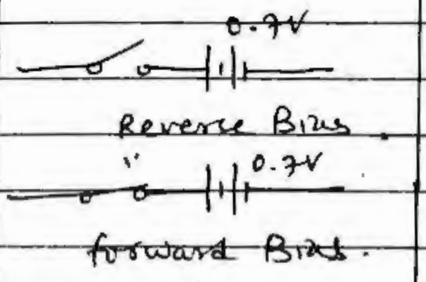


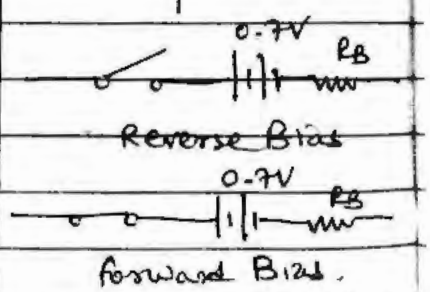




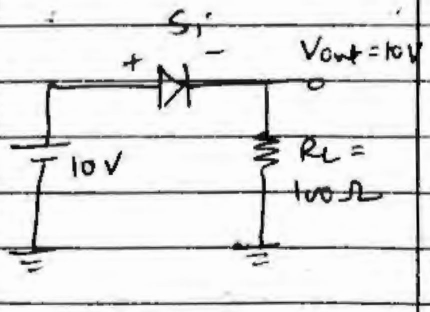
Equivalent Circuit

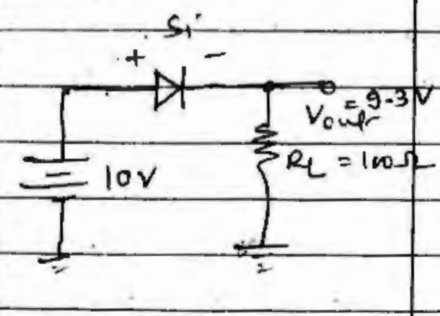


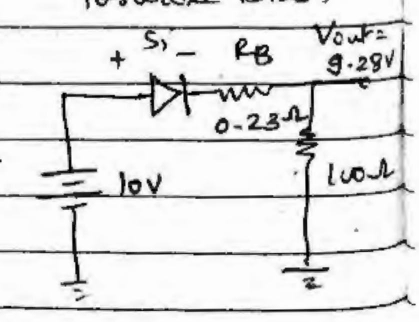




Circuit Example







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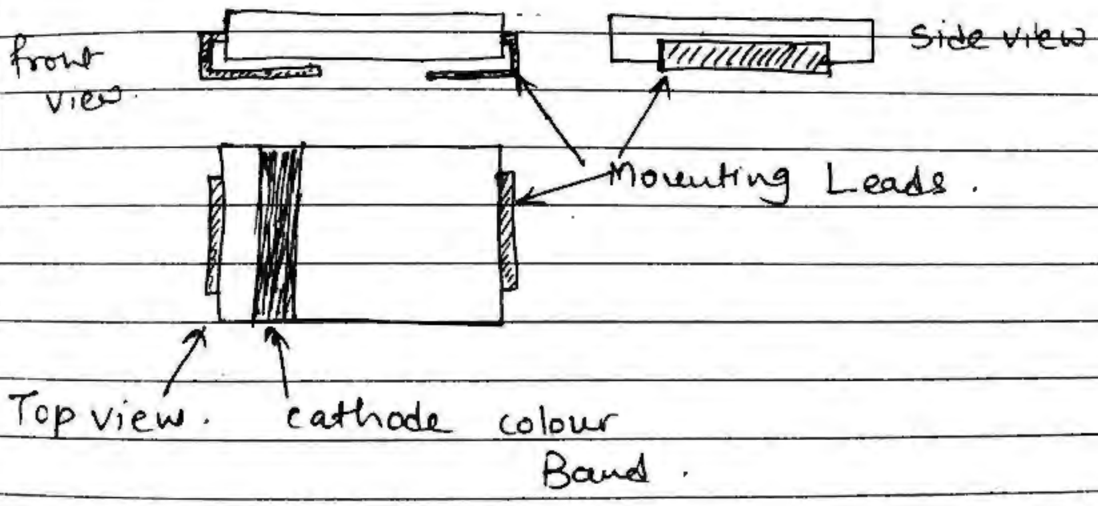
Q. Write short note on Surface mount diodes.

→ Surface mounted (SM) diodes can be used in almost all the applications of diodes.
→ surface mount diodes have following advantages over conventional diode.
- They are small
- They are efficient
- They are easy to test, remove & replace on circuit board.

→ Two most popular package types are.
1) SM (Surface Mount)
2) SOT (Small outline transistor)

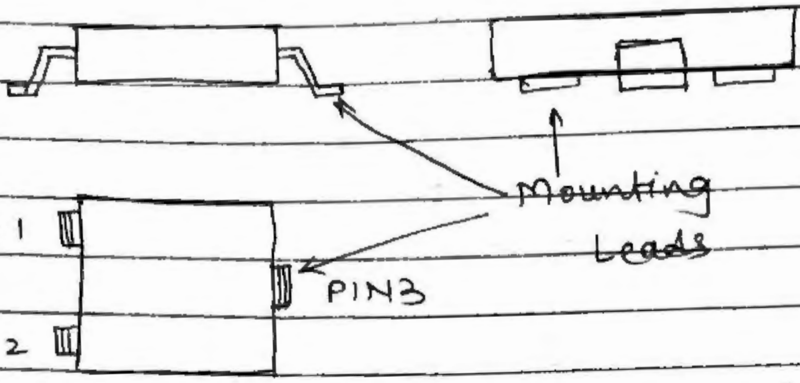
1) SM Package:



→ above figure shows SM style package for SM diode. It has two L-bend leads & a coloured band on one end of body to identify the cathod terminal.
→ dimention of SM diodes depends on current ratings.
→ as surface area of diode increase then current goes on increasing.

→ with increase in the surface area of SM style package, ability to dissipate heat also increases.

2) SOT Package :



SOT-23 style package for SM diodes

→ SOT-23 package has three gull-wing terminals.
→ PIN numbers are shown in fig. (It is three
→ terminal packages)
→ There is no marking for anode & cathode, to identify, we need to refer manufacturer's datasheet (databook).
→ Some SOT - style package includes two diodes, which have common cathod or common anode.
→ Diodes in SOT-23 packages are small, no dimention being greater than 0.1 inch.
→ It's small size makes it difficult to dissipate large amount of heat, so diodes are rated at less than 1A.

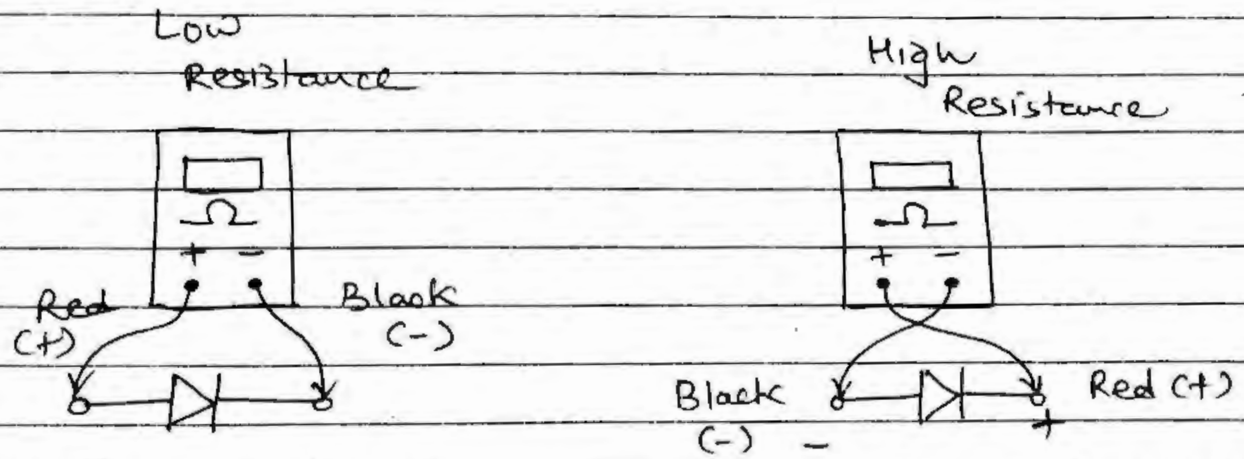
Q. Write short Note on Testing of diode with multimeter.

→ We know that Forward resistance of a pn junction diode is small as compared to its reverse bias resistance.

→ We use this principle in testing diode using multimeter.

→ step for testing diode using a multimeter is as follows.

1) Put multimeter on the resistance range.
2) Select highest Range.
3) connect the positive (Red) probe of multimeter to one end of the diode & negative probe to the other end of the diode. Measure Resistance
4) Now interchange the probes & measure the resistance again.
5) By following above step 3&4, we are forward biasing & reverse biasing the diode, so once resistance should be low & after interchanging resistance should be high.
6) If diode is faulty then in both step 3&4 resistance would be low.
7) Same procedure can be used for identification of diode terminals.



a) Forward biased Diode

b) Reverse biased diode

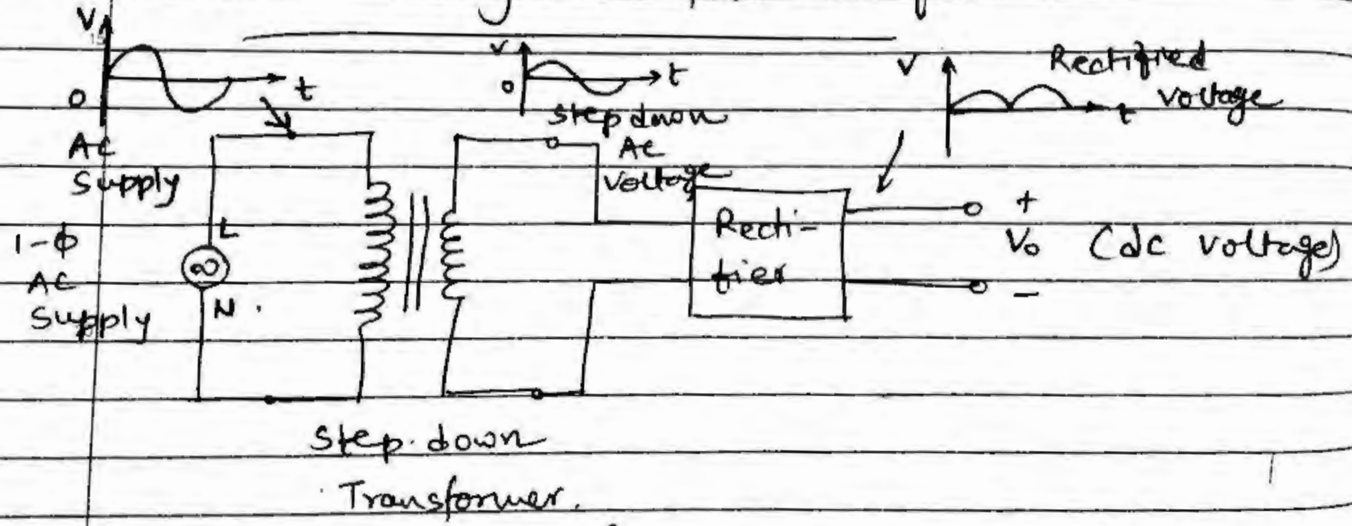
* Rectification:

→ Rectification is the process of converting the alternating voltage or current into corresponding direct (dc) quantity. (Direct voltage or current)

* Rectifiers:

→ Rectifier is an electronic device which is used for converting an alternating (AC) voltage or current into a unidirectional (dc) voltage or current.

Block Diagram for Rectifier:



→ Step down transformer is used to reduce the ac mains voltage to adequately small value.

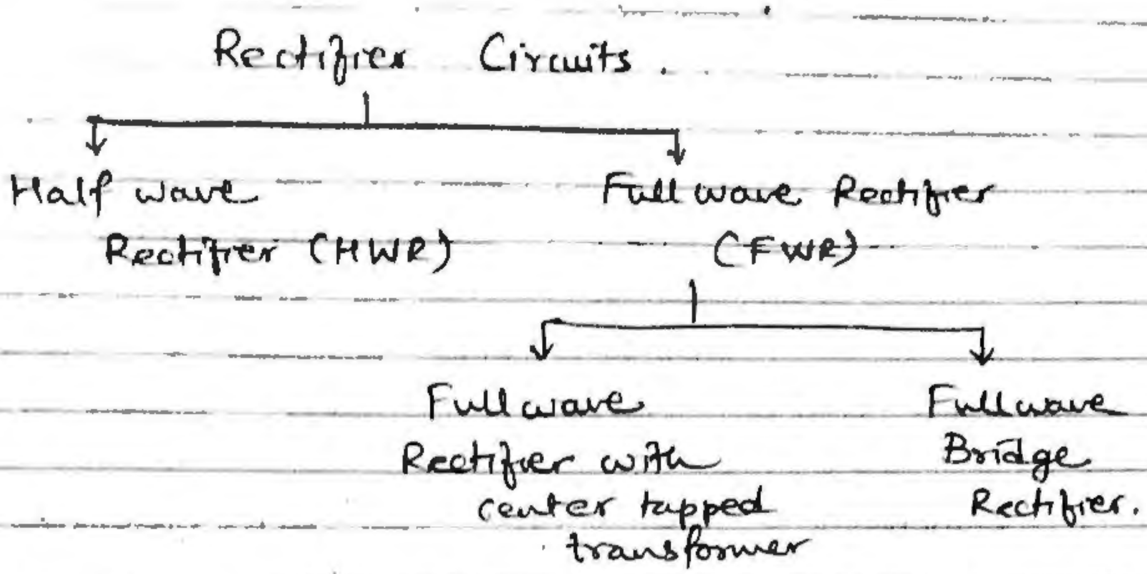
→ This voltage is converted into a pulsating dc voltage by the rectifier.

→ Types of Rectifiers used are halfwave rectifier, full wave rectifier or Bridge rectifier.

→ Every Electronic circuit such as amplifiers needs a dc power supply for its operation.

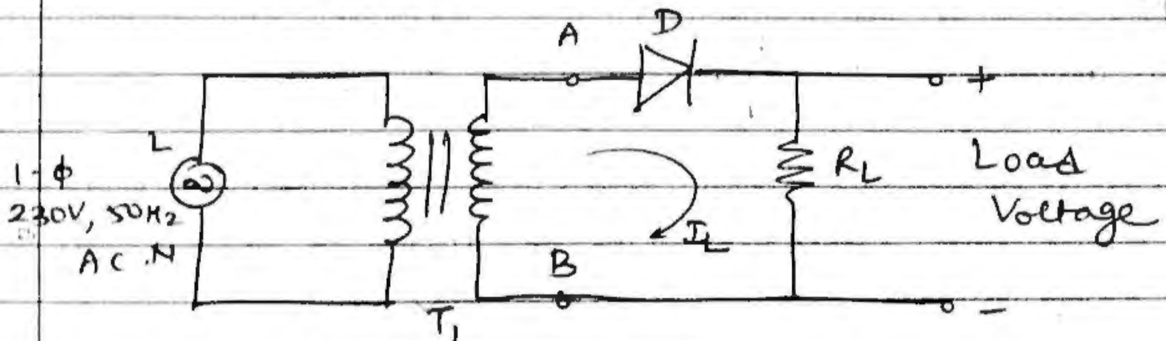
→ This dc voltage has to be obtained from the ac supply. So rectification process is require.

Types of Rectifiers:



Q. Write short note on "Half wave Rectifier".

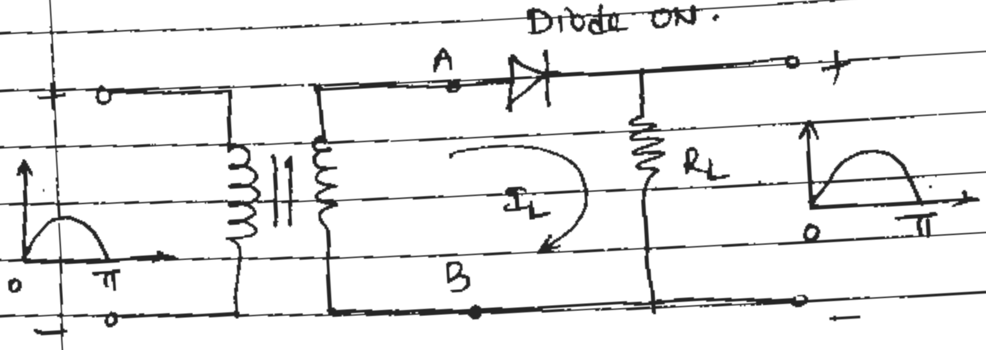
Circuit Diagram:



→ In half wave Rectifier, the rectifier is on only during one half cycle of the AC supply.

→ So output is produced in half cycle only, output is zero in other half cycle, so name is Half wave Rectifier.

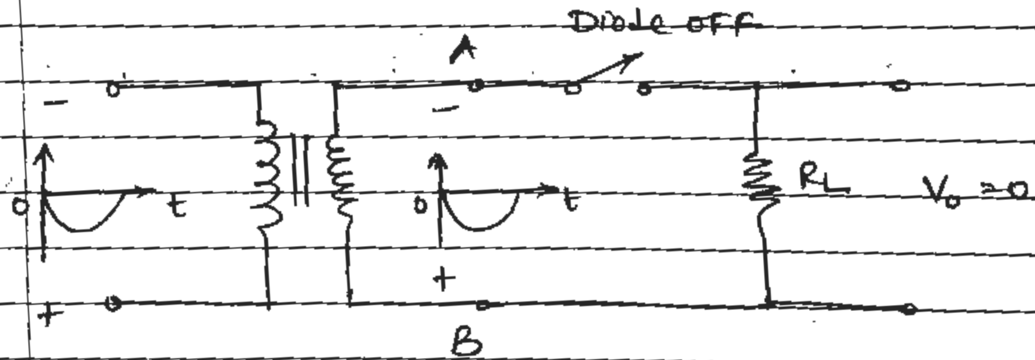
Operation in positive half cycle of supply: Cont



→ In positive half cycle of ac supply, terminal A is positive with respect to B, so Diode is in forward bias, & starts conducting.

→ V_{AB} is secondary voltage, and it appears almost as it is across load resistance. (As voltage drop across conducting diode is very small.

Operation in negative half cycle of supply.

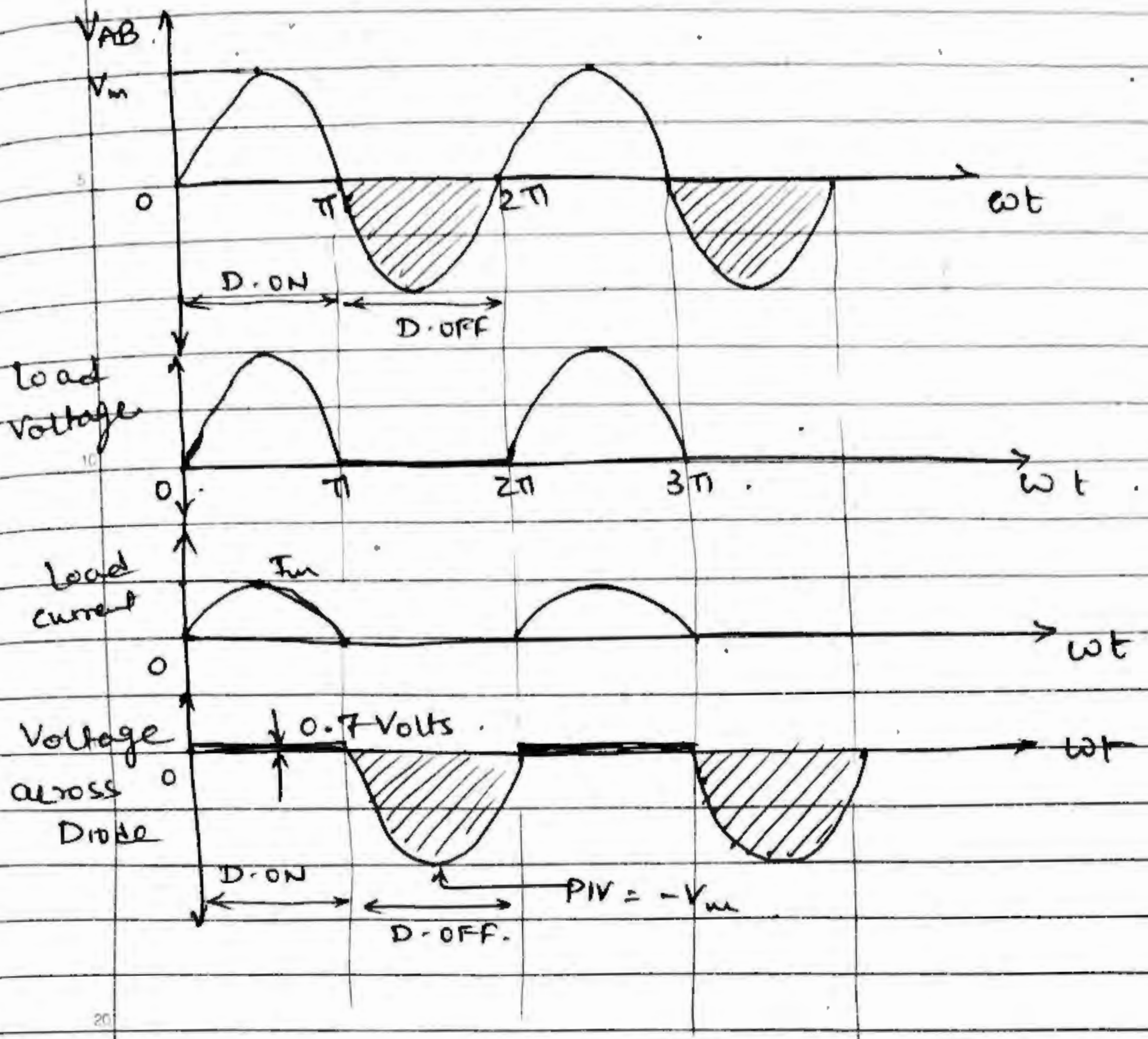


→ In negative half cycle of the ac supply (π to 2π) secondary voltage V_{AB} is negative, i.e. A terminal is negative with respect to B.

→ Hence diode is reverse biased and offers a very high resistance. Hence we can replace it by open circuited switch.

→ Load is disconnected from the secondary hence the load voltage & load current both are zero.

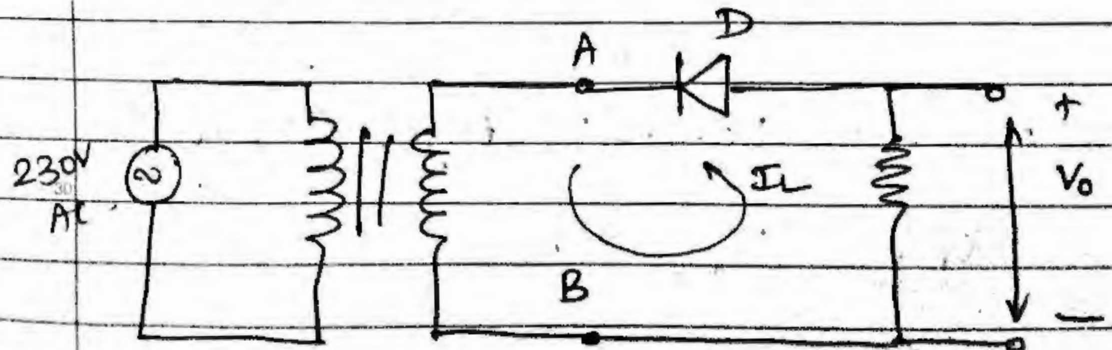
Wave forms :



* Negative Halfwave Rectifier :

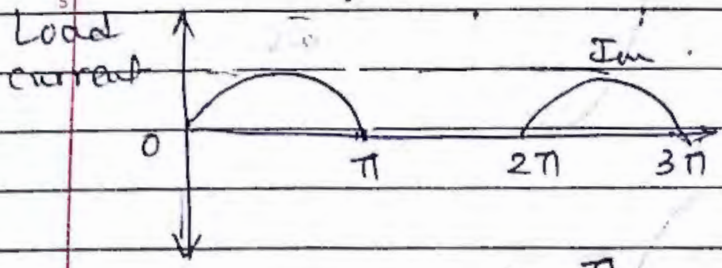
→ In Half wave rectifier if diode conducts only during negative half cycle of the ac supply, then it is called negative halfwave Rectifier.

→ Circuit Diagram is shown below.



Analysis of Halfwave Rectifier:

1) DC or Average Load Current (I_{Ldc})



$$I_{av} = I_{Ldc} = \frac{1}{2\pi}\int_0^{\pi} I_m \sin\omega t \; d\omega t$$

$$= \frac{-I_m}{2\pi}\left[\cos\omega t\right]_0^{\pi}$$

$$= -\frac{I_m}{2\pi}\left(\cos\pi - \cos 0\right)$$

$$= -\frac{I_m}{2\pi}\left(-1-1\right)$$

$$\boxed{I_{Ldc} = \frac{I_m}{\pi}}$$

$$I_m = \frac{V_m}{R_S + R_F + R_L}$$

R_S = Transformer secondary resistance

R_F = Diode forward Resistance

V_m = Maximum or peak Secondary voltage

R_L = load Resistance.

2. DC or Average Load Voltage. (V_{Ldc})

$$V_{Ldc} = I_{Ldc} \times R_L$$

$$V_{Ldc} = \frac{I_m}{\pi} \times R_L$$

$$V_{dc} = \frac{V_m}{\pi(R_s + R_L + R_f)} \times R_L \quad \underline{\text{exact}}$$

usually R_s & R_f are small.

$$R_s + R_f << R_L$$

so. $(R_s + R_f + R_L) \approx R_L$

$$V_{dc} = \frac{V_m}{\pi \cdot R_L} \times R_L$$

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

3) AC or RMS Load Current (I_{Lrms})

$$I_{Lrms} = \left[\frac{1}{2\pi}\int_0^{\pi} I_m^2 \sin^2\omega t \, d\omega t\right]^{1/2}$$

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

$$= \frac{I_m}{2}\left[\frac{1}{\pi}\left(\pi - \frac{1}{2}\sin 2\pi\right)\right]^{1/2}$$

$$= \frac{I_m}{2}\left[\frac{1}{\pi} \times \pi\right]^{1/2}$$

$$\boxed{I_{Lrms} = \frac{I_m}{2}}$$

4) AC or RMS value of Load Voltage: (V_{Lrms})

$$V_{Lrms} = I_{Lrms} \times R_L = \frac{I_m}{2} \times R_L$$

$$= \frac{V_m}{2(R_S + R_F + R_L)} \times R_L$$

$$(R_S + R_F) << R_L$$

So, $\boxed{V_{Lrms} \approx \frac{V_m}{2}}$

5) Ripple Factor (RF):

Ripple Factor

→ Ripple factor indicate how close rectified output is to the pure dc.

→ Ripple factor is amount of AC component present in DC output.

$$\text{Ripple factor} = \sqrt{\left(\frac{V_{Lrms}}{V_{Ldc}}\right)^2 - 1}$$

$$r = \sqrt{\left(\frac{V_{Lrms}^2 - V_{Ldc}^2}{V_{Lrms}^2}\right)}$$

$$r = \sqrt{\frac{(V_m/2)^2 - (V_m/\pi)^2}{(V_m/\pi)^2}}$$

$$r = 1.21 \text{ or } 121\%$$

Camlin Page
Date / /

6) DC output Power P_{Ldc}:

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

But, $I_m = \dfrac{V_m}{(R_S+R_L+R_F)}$

$(R_S+R_L) << R_L$ so, $I_m = \dfrac{V_m}{R_L}$

$$\text{So, } P_{Ldc} = \frac{V_m^2}{\pi^2 R_L} \cdot R_L = \frac{V_m^2}{\pi^2 R_L}$$

$$P_{Ldc} = \frac{V_{Ldc}^2}{R_L}$$

7) AC Input Power (P_{ac})

$$P_{ac} = I_{Srms}^2 \times (R_S + R_F + R_L)$$

$I_{S\,rms}$ = RMS value of secondary current.

$$I_{Srms} = I_{Lrms} = \frac{I_m}{2}$$

$$P_{ac} = \frac{I_m^2}{4}(R_S+R_F+R_L)$$

8) Rectification Efficiency or Power Conversion Efficiency:

$$\eta = \frac{\text{DC output power}}{\text{AC input power}} = \frac{P_{Ldc}}{P_{ac}}.$$

$$\eta = \frac{I_{Ldc}^2 R_L}{I_{Srms}^2 (R_S+R_F+R_L)}$$

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

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

$$(R_s + R_f) << R_L$$

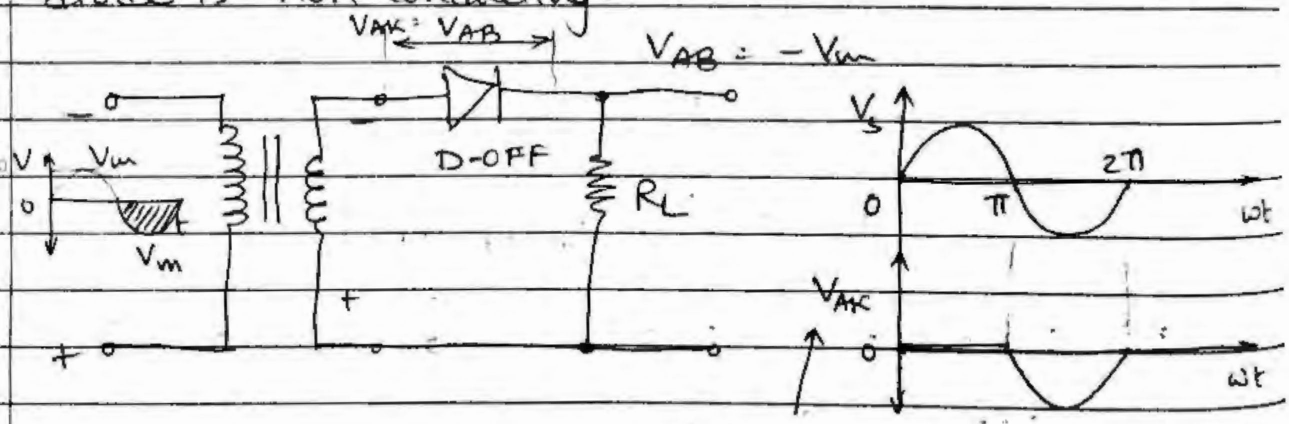
$$\eta = \frac{4}{\pi^2} = 0.4 \text{ or } 40\%.$$

→ Efficiency of Rectifier should be as high as possible.

g) Peak Inverse voltage (PIV):

→ This is the maximum negative voltage which appears across a non conducting reverse biased diode.

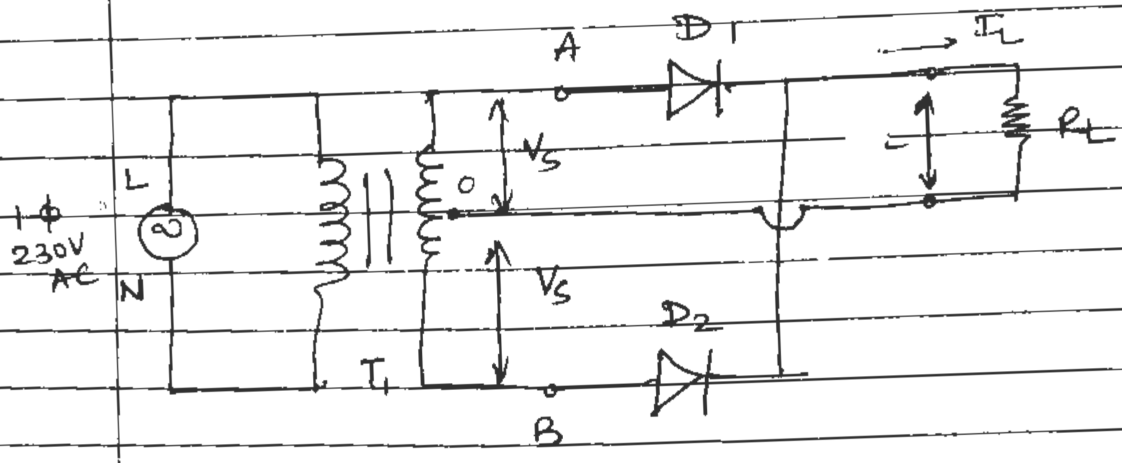
→ As shown in figure, the maximum negative voltage across the diode is $-V_m$ volt, when diode is non conducting.



Voltage across diode

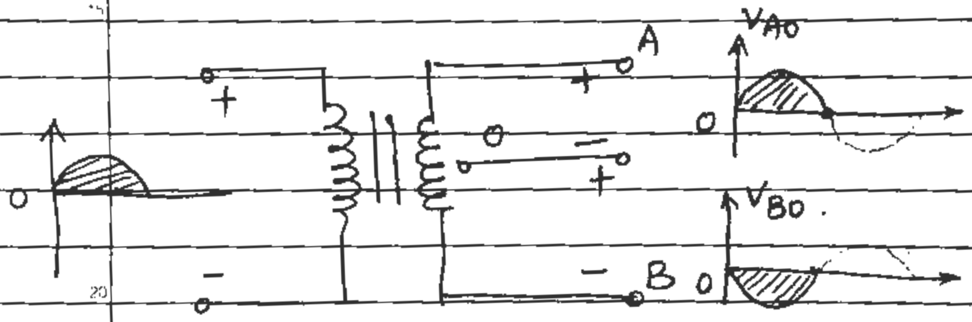
→ PIV has been used to denote the maximum reverse voltage capability of a diode.

Q. Write short note on Fullwave Rectifier.

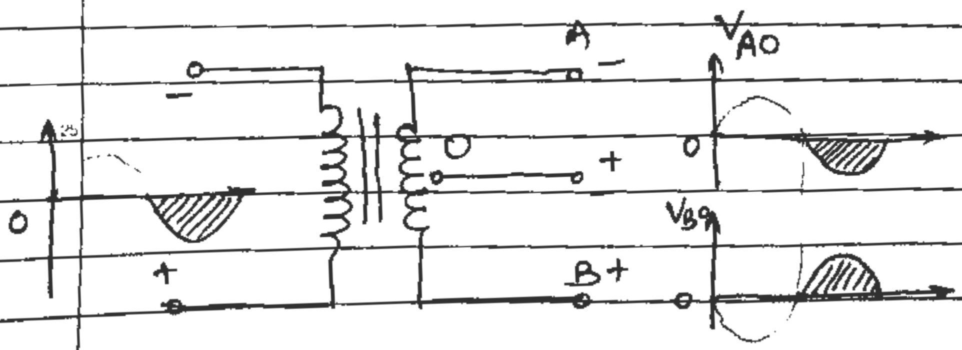


→ In Fullwave rectifier Load current flows in both half cycle of an AC supply.

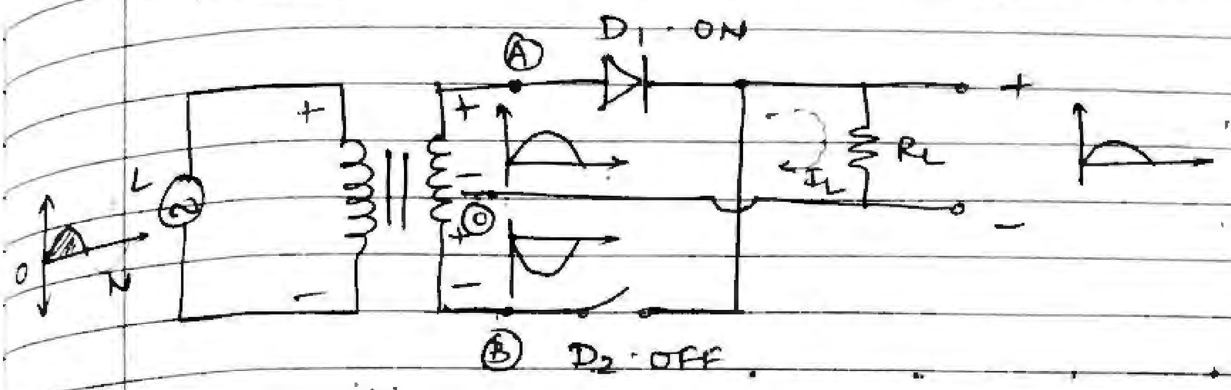
1) Center tapped Transformer:



During positive half cycle

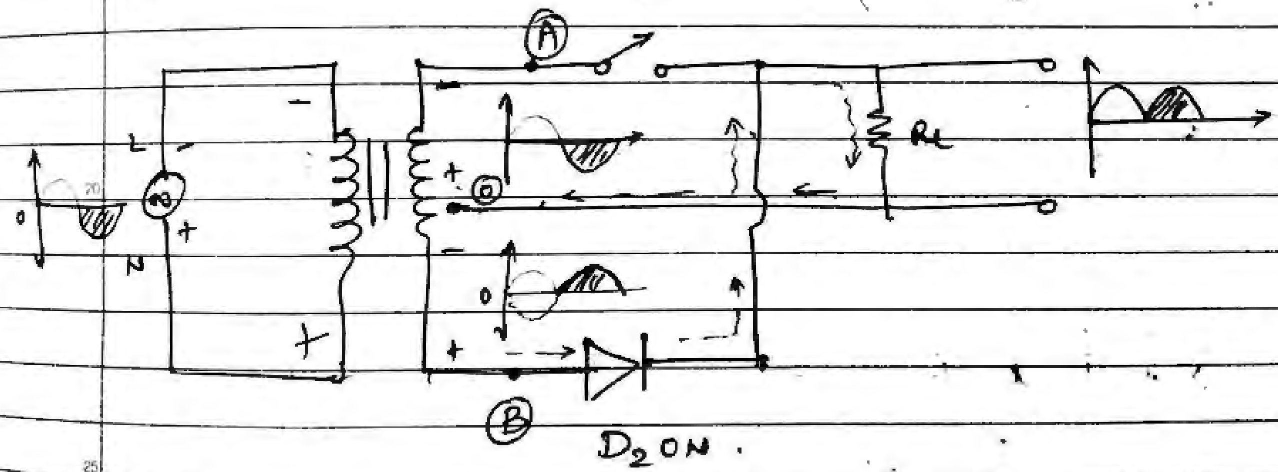


Operation in positive half cycle: (0 to π)



→ Due to center tapped transformer, V_{AO} & V_{BO} are always equal & opposite to each other.
→ So, D_1 is forward biased & D_2 is reverse biased, Load current starts flowing from A through D_1, through R_L & back to point O.

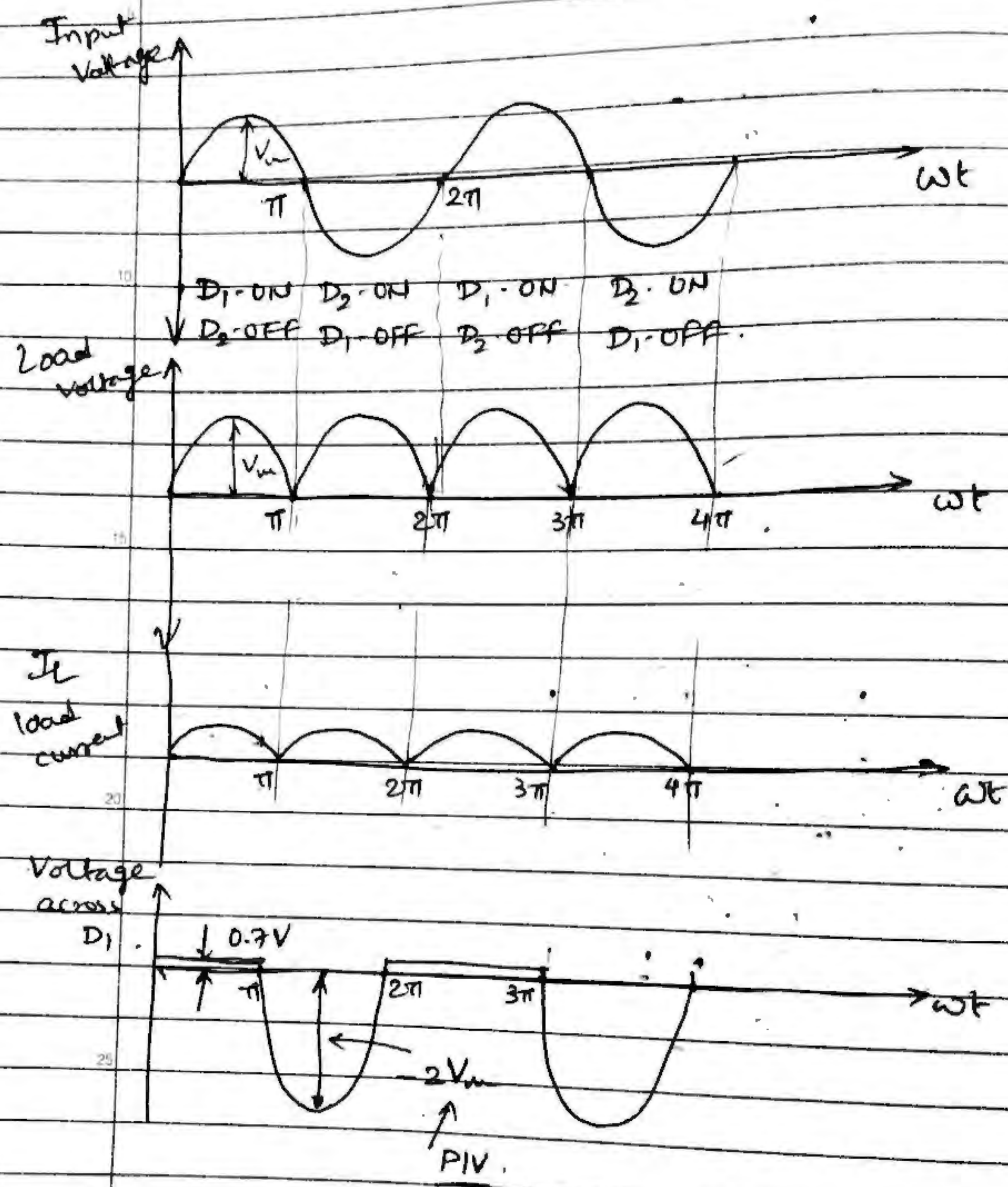
Operation in Negative half cycle:



→ for negative half cycle of supply, polarities for secondary induced voltages are shown in fig.
→ Diode D_1 is reverse biased & D_2 is forward biased.
→ So current flows from B, through D_2, then Resistor to terminal O, Current through

Load is in same direction as in positive half cycle.

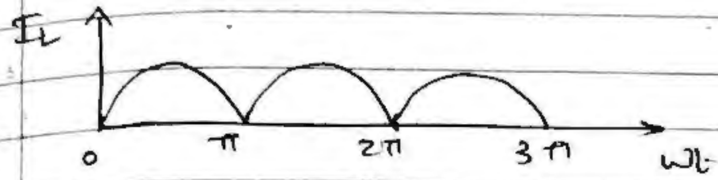
Waveforms:



→ Full wave rectifier consist of two halfwave rectifiers, which work independantly & feed the common Load.

Analysis of the Fullwave Rectifier.

1) Average Load Current (I_{Ldc})



$$I_{Ldc} = \frac{1}{\pi}\int_0^{\pi} I_m \sin\omega t \, d\omega t$$

$$= \frac{I_m}{\pi}\Big[-\cos\omega t\Big]_0^{\pi} = \frac{-I_m}{\pi}(\cos\pi - \cos 0)$$

$$= -\frac{I_m}{\pi}(-1-1)$$

$$\boxed{I_{Ldc} = \frac{2I_m}{\pi}}$$

2) Average load Voltage: (V_{Ldc})

→ As Load is purely Resistive

$$V_{Ldc} = I_{Ldc} \times R_L$$

$$V_{Ldc} = \frac{2I_m}{\pi} \times R_L$$

$$I_m = \frac{V_m}{(R_s + R_f + R_L)}$$

$$V_{Ldc} = \frac{2V_m}{\pi(R_s + R_f + R_L)} \times R_L = \frac{2V_m \cancel{R_L}}{\pi \cdot \cancel{R_L}}$$

$(R_s + R_f) << R_L$ so, $V_{Ldc} \approx \frac{2V_m}{\pi}$

Camlin Page
Date / /

3) RMS Load Current (I_{Lrms}):

$$I_{Lrms} = \left[\frac{1}{\pi}\int_0^{\pi} (I_m \sin\omega t)^2 \, d\omega t\right]^{1/2}$$

$$= \left[\frac{I_m^2}{2\pi}\int_0^{\pi} (1-\cos 2\omega t) \, d\omega t\right]^{1/2}$$

$$= \left[\frac{I_m^2}{2\pi}\left\{(\omega t)_0^{\pi} - \left(\frac{\sin 2\omega t}{2}\right)_0^{\pi}\right\}\right]^{1/2}$$

$$= \frac{I_m}{\sqrt{2}}\left[\frac{1}{\pi}\left\{(\pi) - \frac{1}{2}(0)\right\}\right]^{1/2}$$

$$\boxed{I_{Lrms} = \frac{I_m}{\sqrt{2}}}$$

4) RMS Load Voltage: (V_{Lrms})

$$V_{Lrms} = I_{Lrms} R_L$$

$$= \frac{I_m}{\sqrt{2}} \times R_L$$

$$V_m = V_m R_L$$

$$\boxed{V_{Lrms} = \frac{V_m}{\sqrt{2}}}$$

5) Ripple Factor:

$$\text{Ripple factor (RF)} = \sqrt{\left(\frac{V_{Lrms}}{V_{LDC}}\right)^2 - 1}$$

$$= \sqrt{\frac{(V_{Lrms})^2 - (V_{LDC})^2}{(V_{LDC})^2}}$$

$$= \sqrt{\frac{(V_m/\sqrt{2})^2 - \left(\frac{2V_m}{\pi}\right)^2}{\left(\frac{2V_m}{\pi}\right)^2}}$$

$$= \sqrt{\frac{\frac{1}{2} - \frac{4}{\pi^2}}{4/\pi^2}}$$

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

$$= 48\%$$

Value of Ripple factor for Full wave rectifier is much less (i.e. 0.48) than halfwave Rectifier (i.e. 1.21)

6) DC Output Power (P_{Ldc}):

$$P_{Ldc} = I_{Ldc}^2 \times R_L$$

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

$$P_{Ldc} = \frac{2V_m}{\pi} \times R_L$$

Camlin Page
Date / /

7) AC Input Power (P_{ac}) :-

$$P_{ac} = I_{S\,rms}^2 \times R_L$$

$$I_{S\,rms} = I_{L\,rms}$$

$$P_{ac} = I_{L\,rms}^2 \times R_L$$

$$= \left(\frac{I_m}{\sqrt{2}}\right)^2 \times R_L$$

$$P_{ac} = \frac{I_m^2}{2} R_L$$

8) Rectifier Efficiency :

$$\eta = \frac{P_{Ldc}}{P_{ac}} = \frac{I_{Ldc}^2 \times R_L}{I_{L\,rms}^2 \times R_L}$$

$$= \frac{\left(2 I_m/\pi\right)^2 \times \cancel{R_L}}{\left(I_m/\sqrt{2}\right)^2 \times \cancel{R_L}}$$

$$= \frac{4/\pi^2}{1/2} = \frac{8}{\pi^2}$$

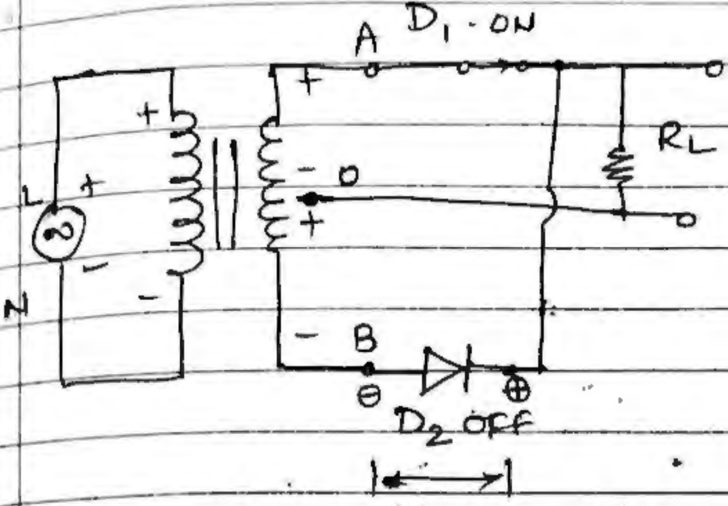
$$\eta = \frac{8}{\pi^2} = 0.812 = 81.2\,\%$$

→ FWR efficiency is almost twice the HWR efficiency.

Camlin Page
Date / /

9) Peak Inverse Voltage (PIV)

→ To obtain PIV consider circuit shown below.
→ It is FWR in positive half cycle.



$V_{BA} = -2V_m$.

→ above figure shows in positive half cycle, D_1 is ON, so closed switch and D_2 is off, in reverse biased.

→ Voltage across D_2 is V_{BA} and i.e. $-2V_m$

So PIV = $2V_m$.

→ In FWR, PIV is high $2V_m$, as compare to HWR (i.e. V_m); we need to select diodes of higher PIV ratings, which are costly.

Applications of FWR:

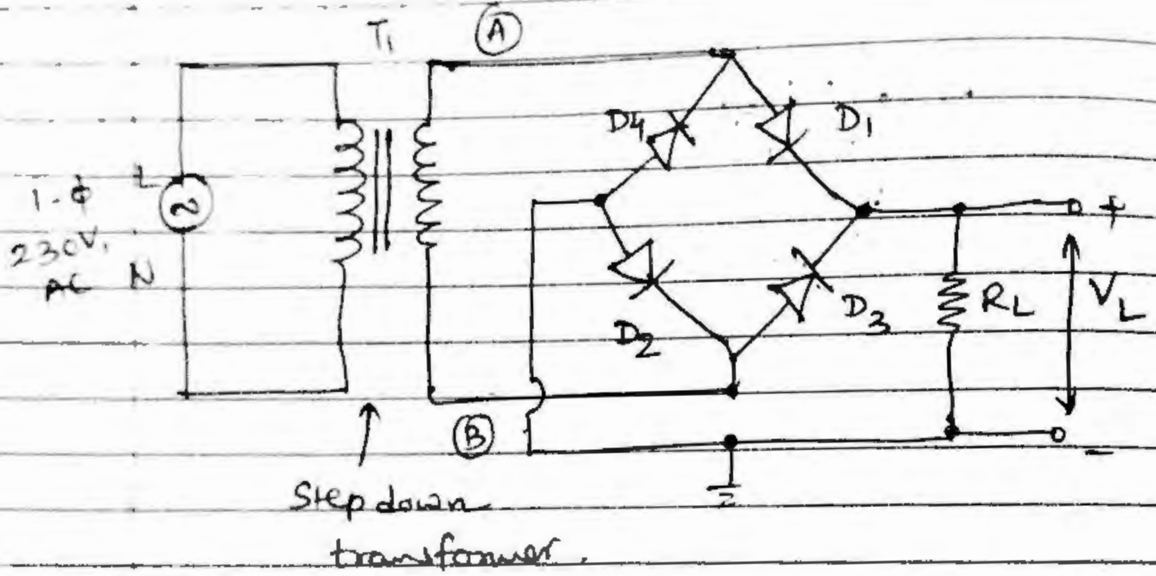
→ Laboratory power supply
→ High current power supply
→ Battery chargers
→ Power supplies for various electronics circuits.

Q. Write short Note on: Bridge Rectifier.

→ Disadvantages of Fullwave rectifier are high PIV & compulsory use of center tapped transformer.

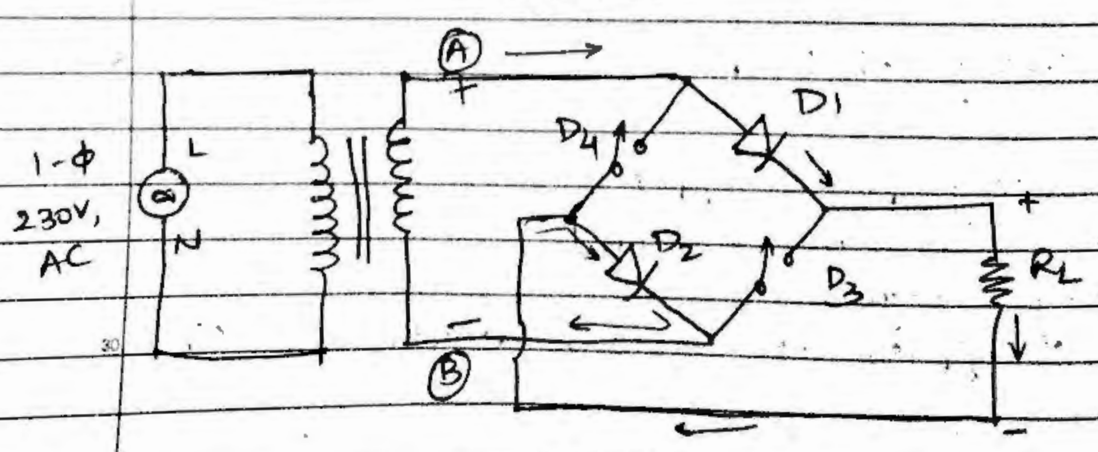
→ Above disadvantages are overcome in Bridge rectifier.

Circuit Diagram:



→ Center tapped transformer is not required

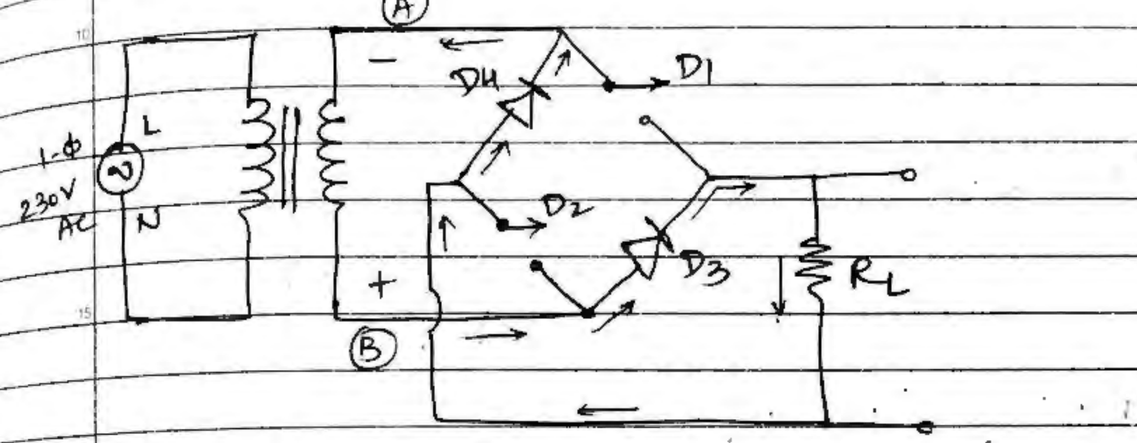
* Operation of Bridge Rectifier during positive half cycle ($0 \leq \omega t \leq \pi$):



→ During positive half cycle of the ac supply, secondary voltage V_{AB} is positive. Therefore diodes D_1 & D_2 are forward biased & Diodes D_3 & D_4 are reverse biased.

→ Load current & Load voltage are positive.

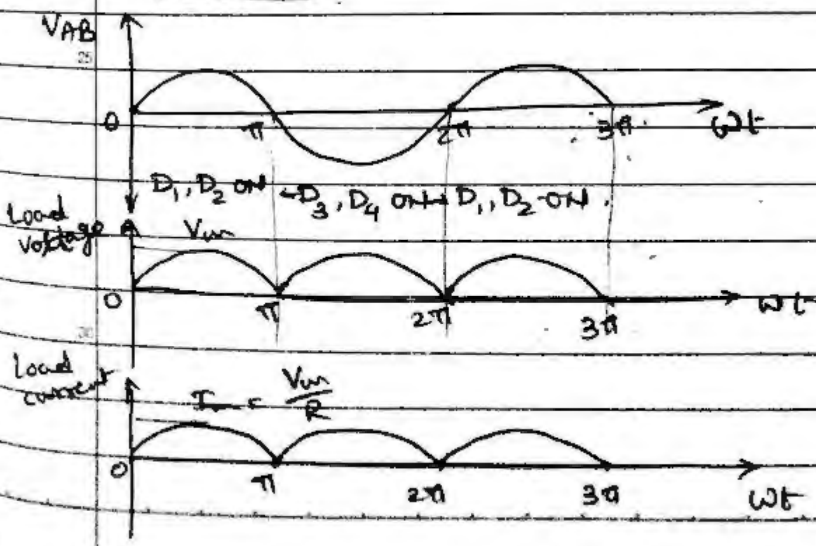
* **Operation of Bridge Rectifier During negative half cycle:** $(\pi \leq \omega t \leq 2\pi)$.



→ During negative half cycle secondary voltage V_{AB} is negative.

→ Diode D_1 & D_2 are reverse biased & D_3 & D_4 are forward biased.

Waveforms.



Camlin Page
Date / /

Performance Parameters of a Bridge Rectifier

→ Bridge rectifier is fullwave rectifier only. So, V_{Ldc}, I_{Ldc}, V_{Lrms} & I_{Lrms} have expressions as FWR

→ only change in $I_m = \dfrac{V_m}{(R_s + 2R_f + R_L)}$

1) DC output voltage:

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

2) DC output Current:

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

3) RMS output voltage:

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

4) RMS output current:

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

5) Ripple factor:

$$r = \left[\left(\frac{V_{Lrms}}{V_{Ldc}}\right)^2 - 1\right]^{1/2}$$

$$= 0.482 = 48.2\%$$

6) Rectification Efficiency:

$$\eta = \frac{P_{Ldc}}{P_{ac}}$$

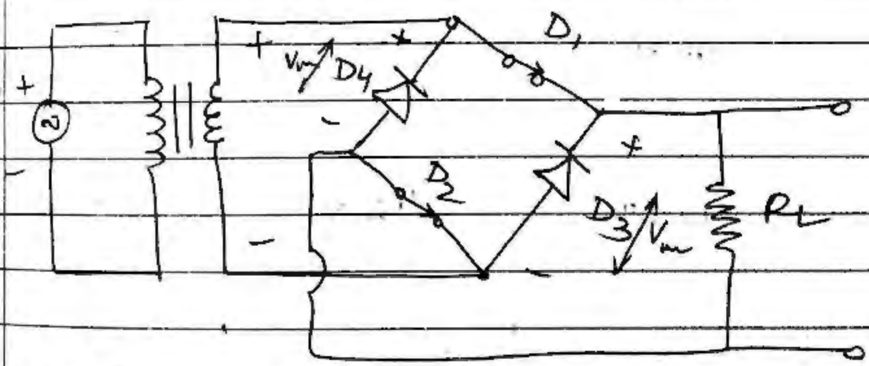
$$= \frac{I_{Ldc}^{2} R_L}{I_{srms}^{2} (R_L + R_f + R_L)}$$

$$\eta_{max} = \frac{I_{Ldc}^{2} \cdot \cancel{R_L}}{I_{Lrms}^{2} \cdot \cancel{R_L}}$$

$$= \frac{(2I_m/\pi)^2}{(I_m/\sqrt{2})^2} = \frac{8}{\pi^2} = 0.812$$

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

7) Peak Inverse Voltage (PIV):



$$\boxed{PIV = V_m}$$

Applications of Bridge Rectifier:

→ Laboratory dc power supply.
→ High current power "
→ Battery charger
→ DC power supply for various electronic circuits.

Camlin Page
Date

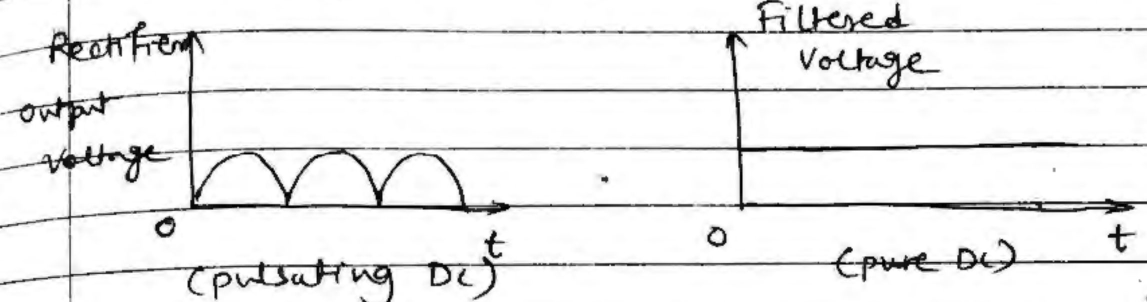
Q. Comparision of the Rectifier Circuits.

	Parameters	HWR	FWR	Bridge Rectifier
1.	DC or Average load Current	$\frac{I_m}{\pi}$	$\frac{2I_m}{\pi}$	$\frac{2I_m}{\pi}$
2.	Maximum average load voltage	$\frac{V_m}{\pi}$	$\frac{2V_m}{\pi}$	$\frac{2V_m}{\pi}$
3.	RMS load current I_{Lrms}	$\frac{I_m}{2}$	$\frac{I_m}{\sqrt{2}}$	$\frac{I_m}{\sqrt{2}}$
4.	RMS load Voltage V_{Lrms}	$\frac{V_m}{2}$	$\frac{V_m}{\sqrt{2}}$	$\frac{V_m}{\sqrt{2}}$
5.	DC Load Power P_{dc}	$\frac{I_m^2}{\pi^2} R_L$	$\frac{4I_m^2 R_L}{\pi^2}$	$\frac{4I_m^2 \cdot R_L}{\pi^2}$
6.	Rectification efficiency	40 %	81.2 %	81.2 %
7.	Ripple factor	121 %	48 %	48 %
8.	No. of diodes used	one	two	four
9.	Center tap transformer	Not required	required	Not required
10.	Peak Inverse Voltage (PIV)	V_m	$2V_m$	V_m

Filters:

→ Filters are electronic circuits used along with rectifiers in order to get a pure (ripple free) DC output.

→ Till now we have seen that all rectifiers's output is "pulsating" DC voltage. But we want pure DC voltage, so we use filters.



Types of Filters:

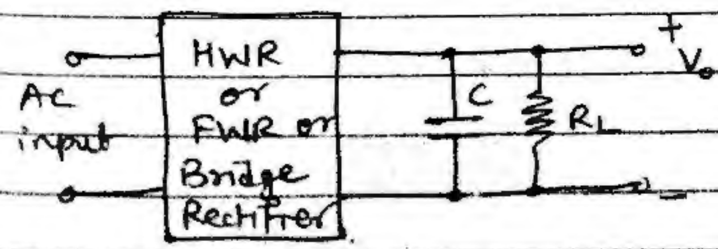
1) RC filters (Capacitor input filters).

2) LC filters.

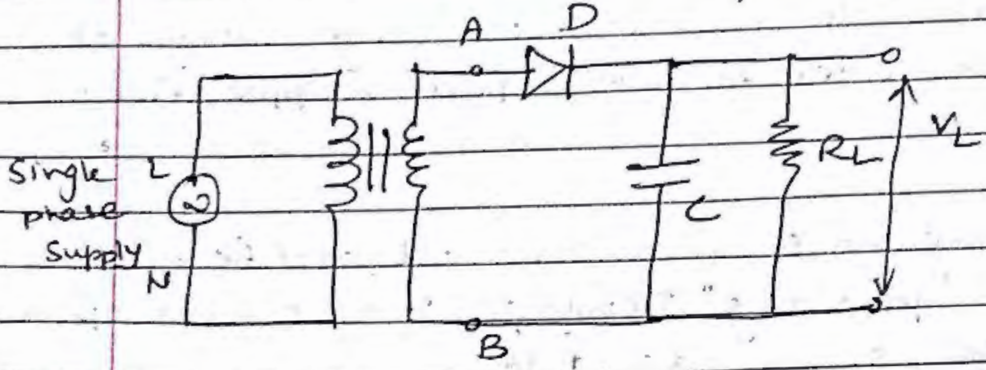
Q. Write short Note on "RC filters".

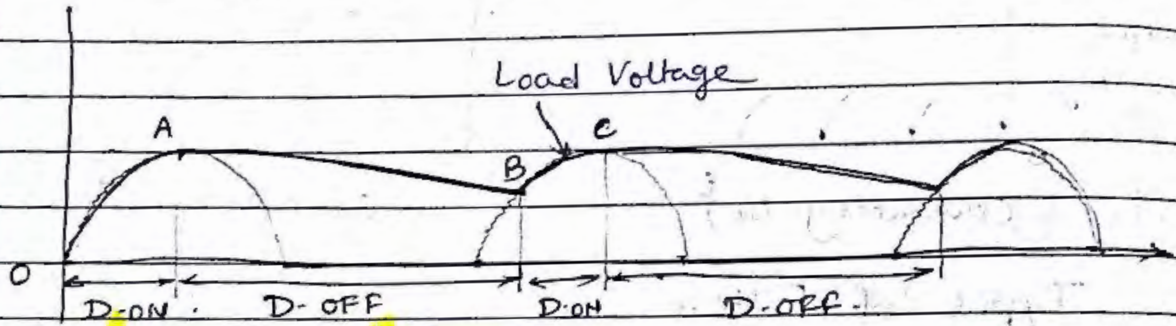
→ Shunt capacitor filter (RC filter) is used to reduce the ripple contents in the output of a rectifier, to obtain pure DC.

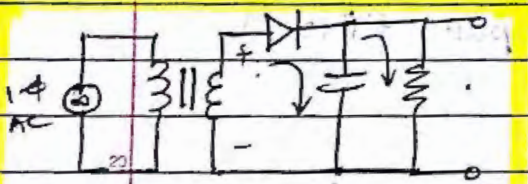
Connection of RC filter.



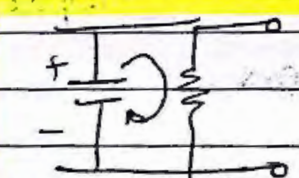
Halfwave Rectifier with capacitor Input Filter (RC filter)







0 to A:
Capacitor charge to V_m



A to B.
D. is OFF
as cathode voltage (capacitor voltage) is higher than anode (input voltage) voltage

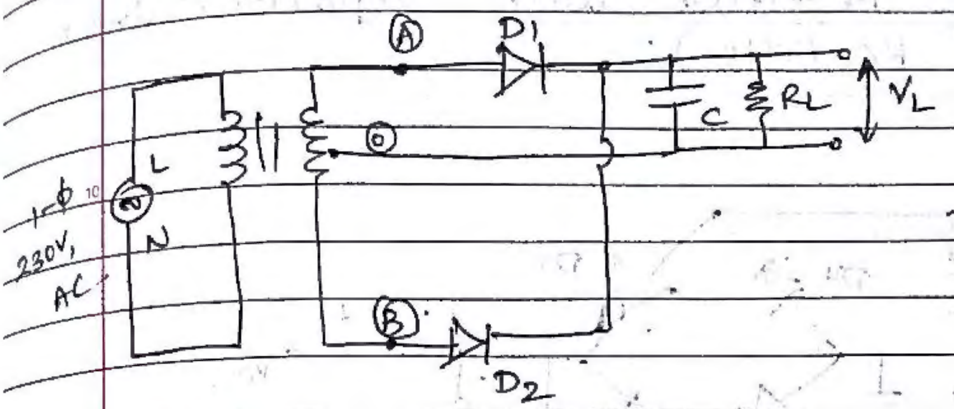
→ For interval 0 to A diode is in forward bias & capacitor will charge to V_m

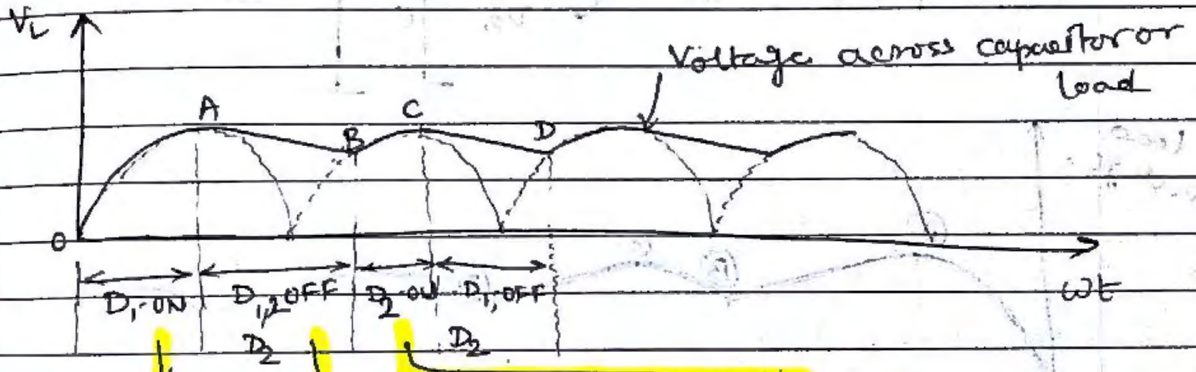
→ for A to B. diode anode voltage is less than capacitor voltage (due to negative half cycle) so diode is in reverse bias condition, so capacitor will discharge through Resistor.

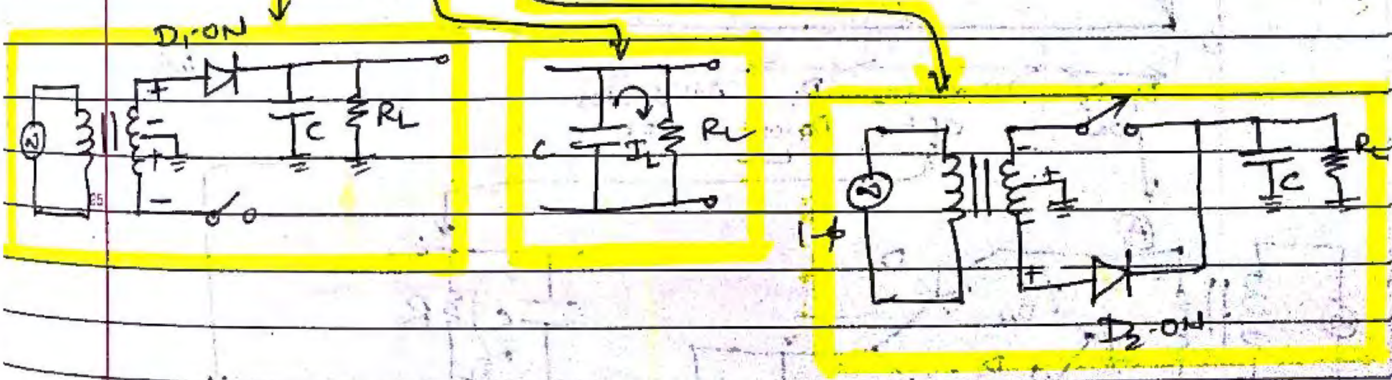
→ from B to C, capacitor, diode is in forward bias & capacitor charge.

→ Output voltage (Load Voltage) is shown in figure

* Fullwave Rectifier with Capacitor filter







→ from 0 to A, D_1 is in forward bias & D_2 is in reverse biased; capacitor will charge to V_m

→ from A to B, D_1 is in reverse bias & D_2 is also in reverse biased condition so, capacitor will discharge the load Resistor.

Camlin Page
Date / /

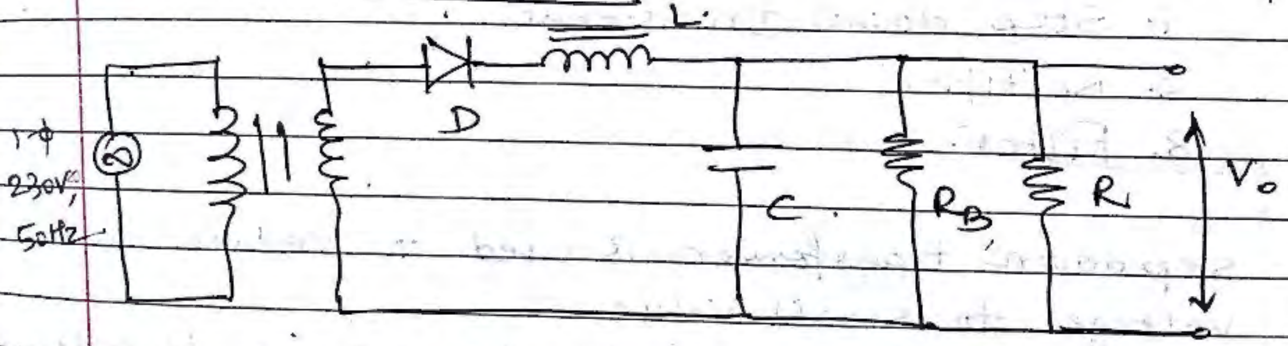
LC Filters:

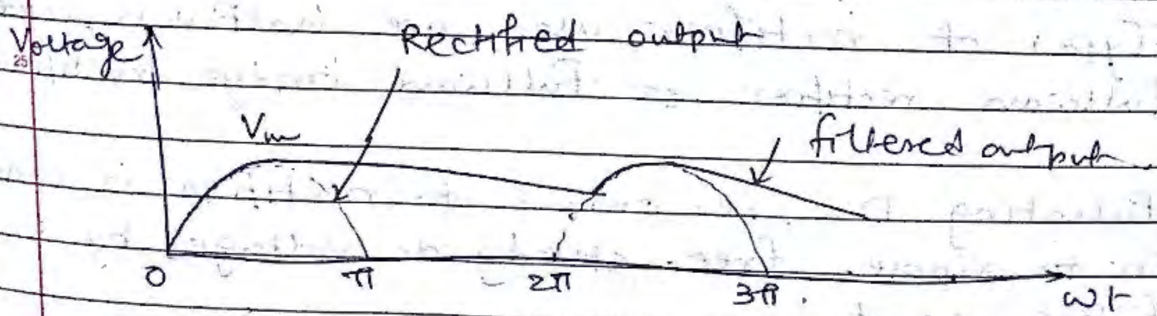
→ When the Load current is large, LC filter are an improvement or RC filters.
→ Using LC filter we can reduce the ripples so low ripple factor.
→ Diode donot have to carry surge currents.

Surge Current:

"The initial rush of current when power is turned on is called surge current". so, diodes must be selected with enough current rating to with stand surge current.

* LC filter with HWR:

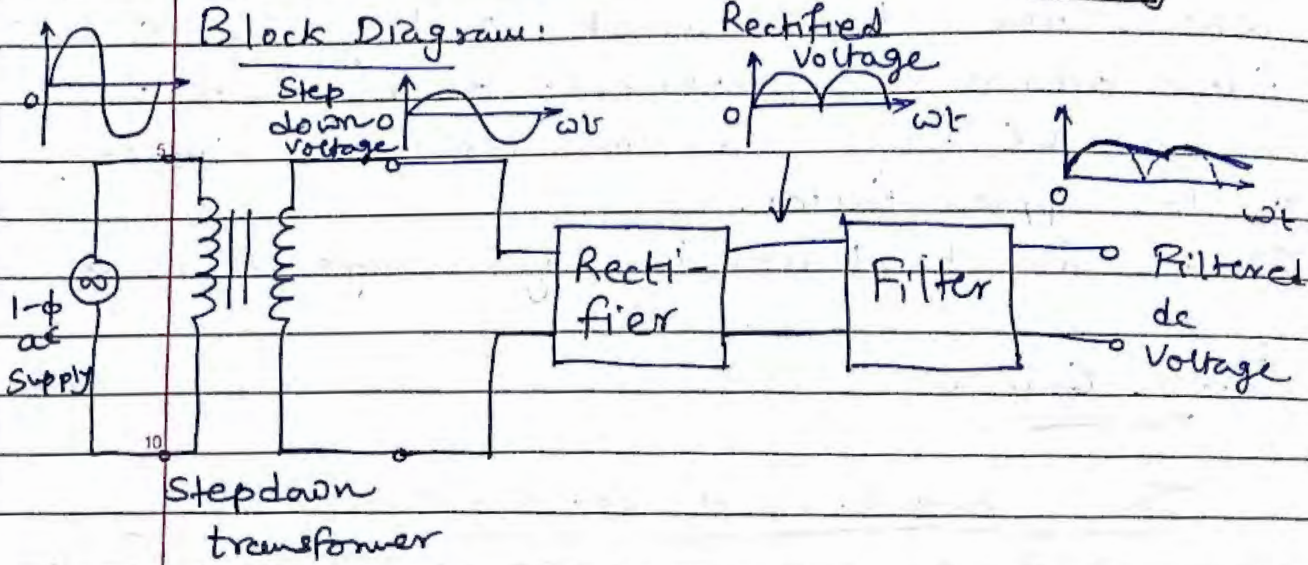




→ R_B is called bleeder resistance, it is used to maintain continuous current through inductor.

Q. Write Short note on "Unregulated Power Supply"

Block Diagram:



Basic Building blocks of an unregulated dc power supply are:

1. Step down transformer
2. Rectifier
3. Filter.

→ Stepdown transformer is used to reduce ac mains Voltage to small value.

→ Then rectifier converts AC to pulsating dc. Types of rectifier used are halfwave rectifier, fullwave rectifier or Fullwave bridge rectifier.

→ Pulsating DC, i.e. output of rectifier is converted in to ripple free steady dc voltage by filter circuit.

→ filtered output is very close to pure dc.

Clippers or Limiter:

→ A diode clipper or limiter is a wave shaping circuit that takes the input waveform & cutoff or clips its top half or bottom half or both.

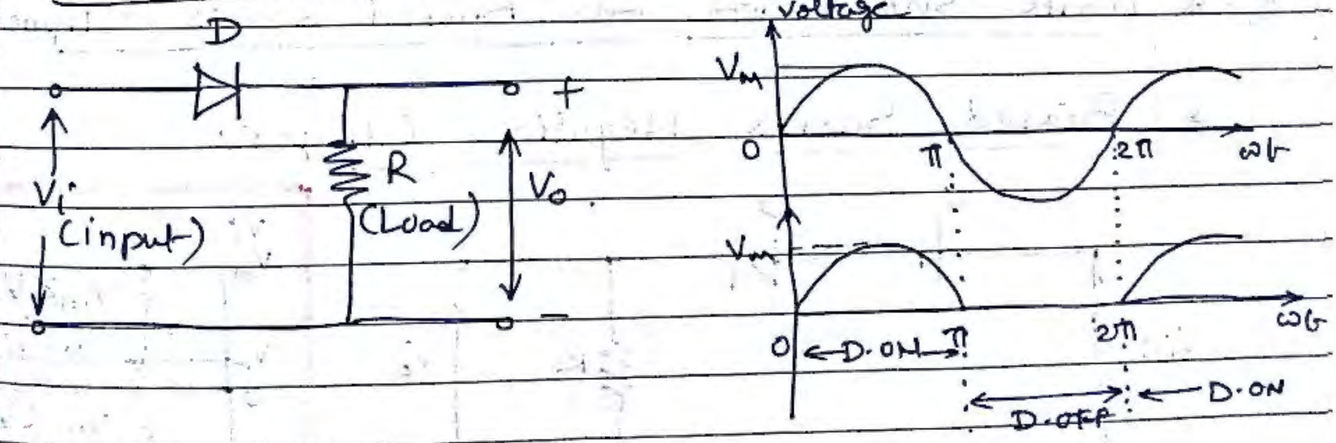
Classification of Clippers

Clippers

- Unbiased Clipper
  - Series Cripper
  - Parallel Clipper
- Biased Clipper.
  - Series Clipper
  - Parallel Clipper.

Q. Write short note on Series clipper.

Series Negative Clipper:

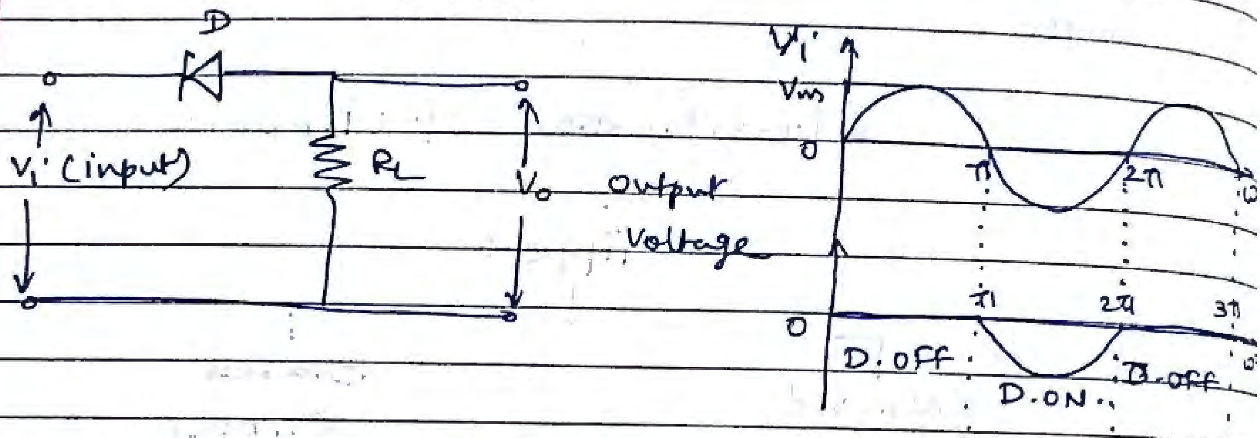


→ Negative clipper is same as half wave rectifier.

→ During the half cycle of input D is on. & output V_o is Same as V_i.

→ During Negative half cycle of input Diode is off (reverse bias) and output voltage is 0.
→ So negative cycle of input is clipped off.

* Series Positive Clipper:

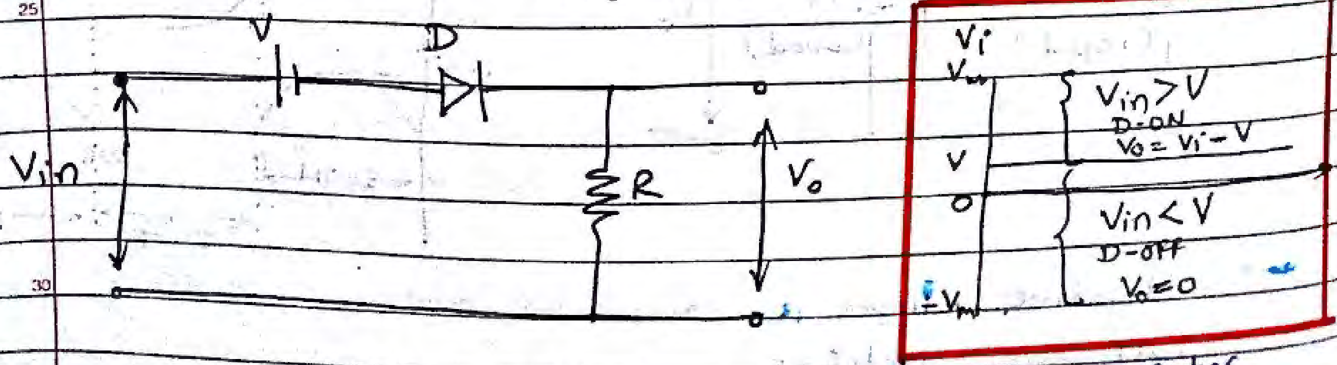


→ When positive half cycle of input is there, diode is in reversed bias, so Diode is open circuited & output voltage is zero.

→ When negative half cycle of input, diode is in forward biased condition, so diode is closed circuited & output voltage is same as input.

Q. * Write short note on Biased series Clipper.

* Biased Series Negative Clipper:



Just to remember.

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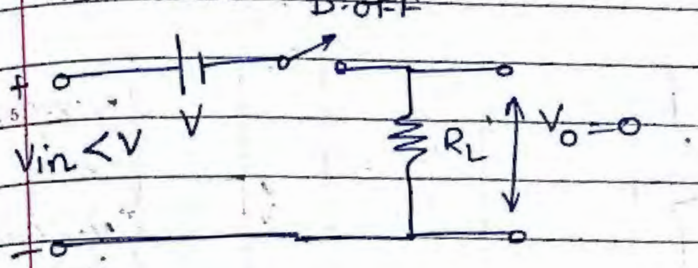
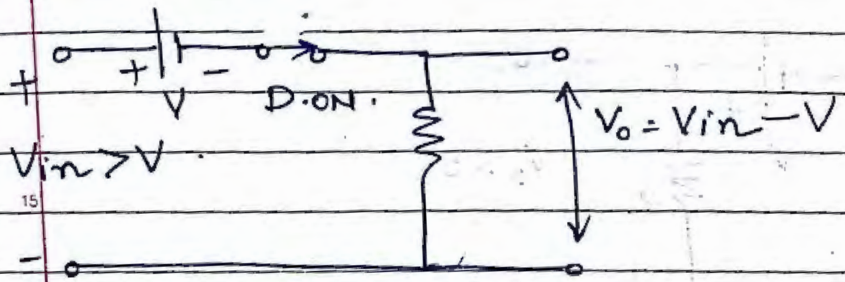
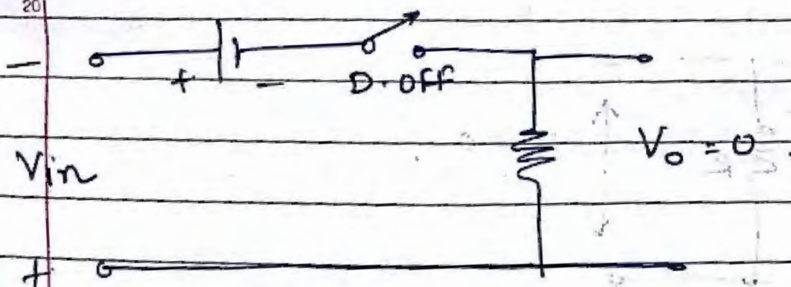
→ When V_{in} is positive, But $V_{in} < V$, then diode is in reverse bias condition and output voltage is zero.



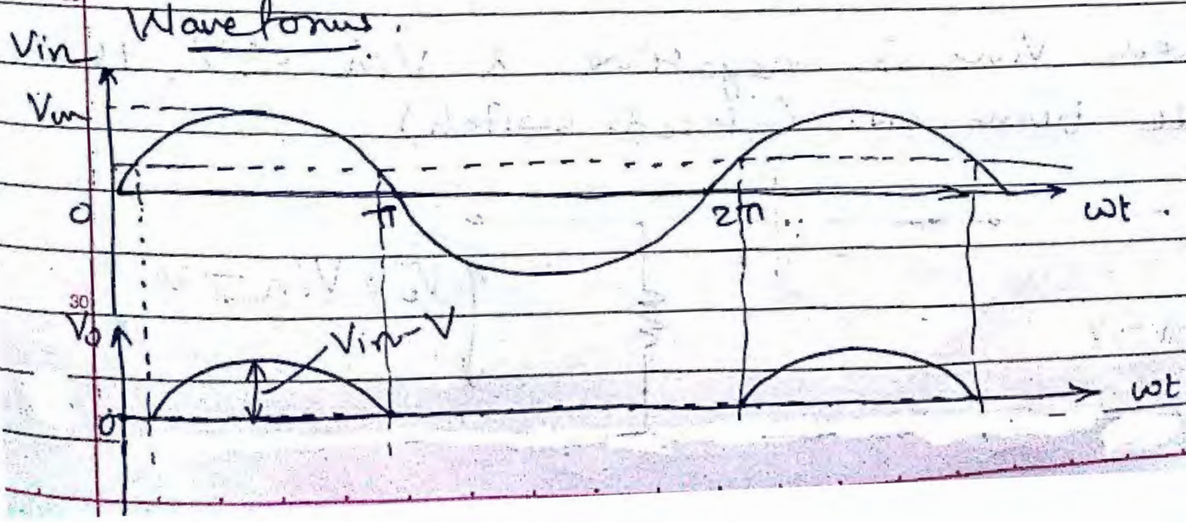
→ When V_{in} positive, But $V_{in} > V$, then diode is forward bias and so output voltage is same as input



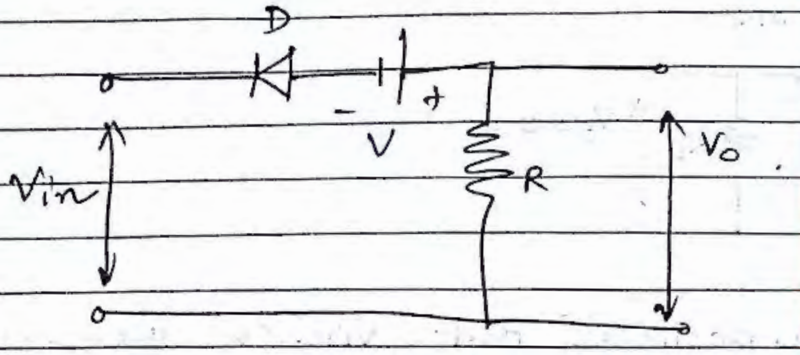
→ When V_{in} is negative, Diode is in reverse bias condition, so diode is open circuit.



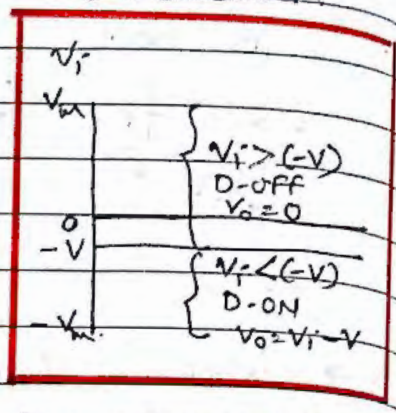
Waveforms.



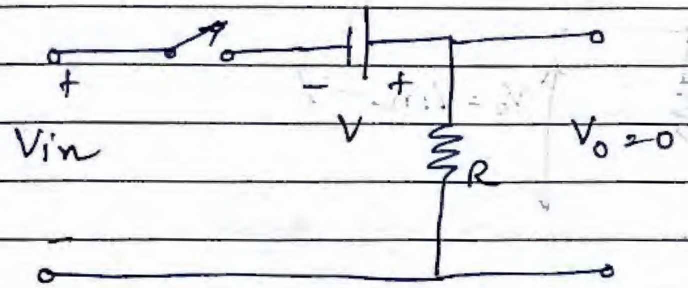
* Biased Series positive clipper



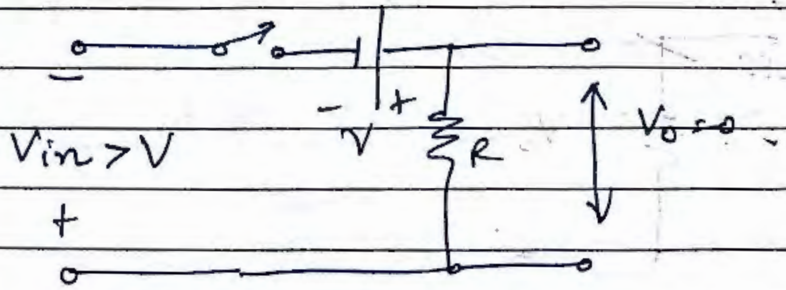
To Remember



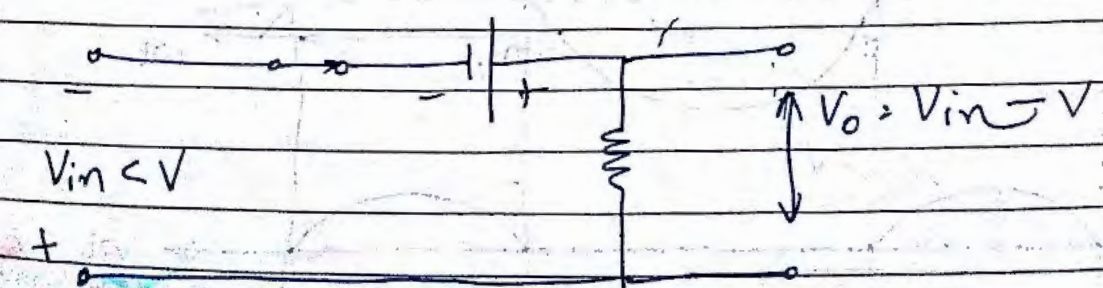
→ when Vin positive diode is in reverse bias so $V_o = 0$.

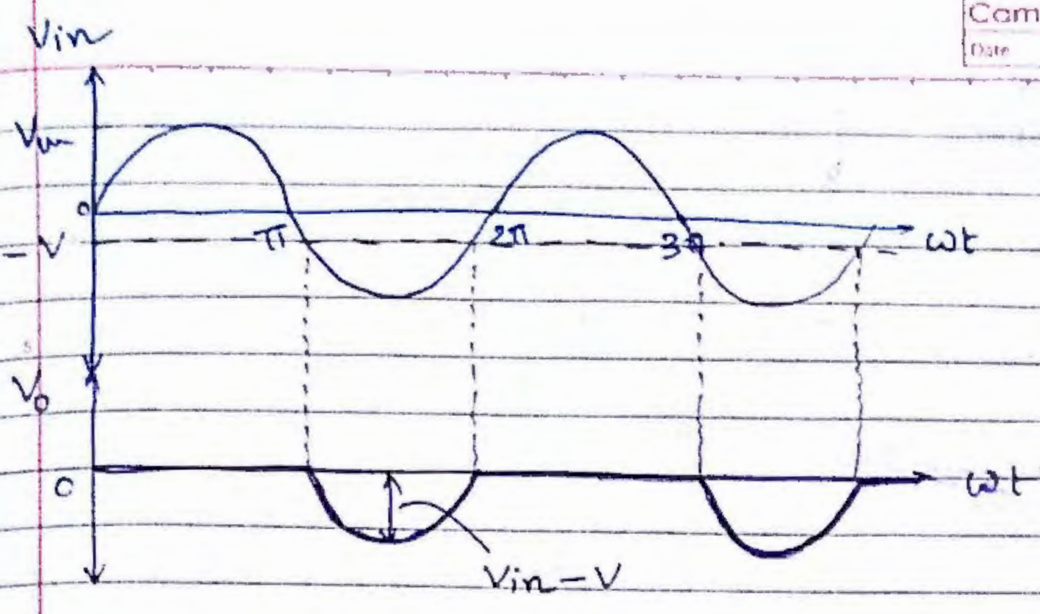


→ when Vin is negative but Vin > V then diode with remains OFF



→ when Vin is negative & Vin < V, then diode turn ON. (closed switch)

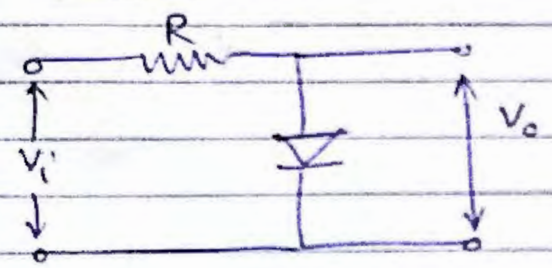




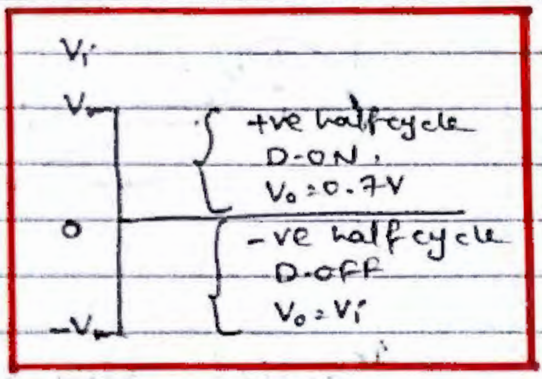
* Parallel Clipper Circuit :

(Parallel Positive Clipper)

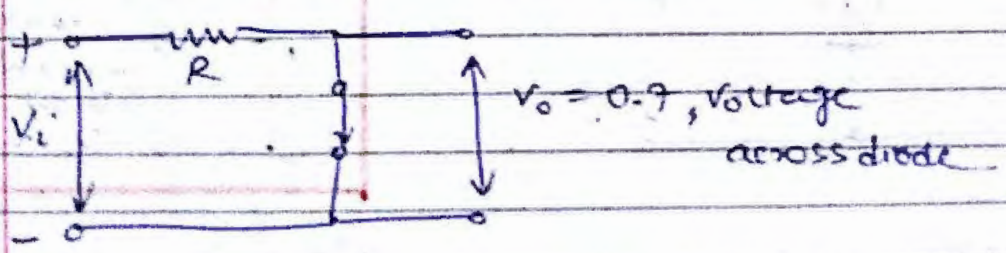
Circuit Diagram.



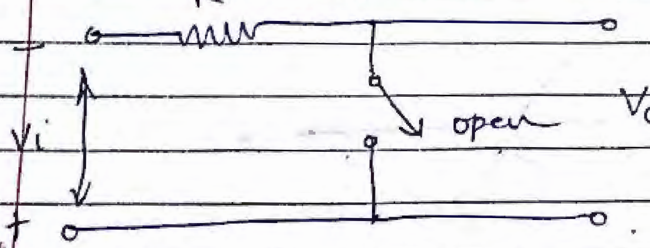
To Remember.



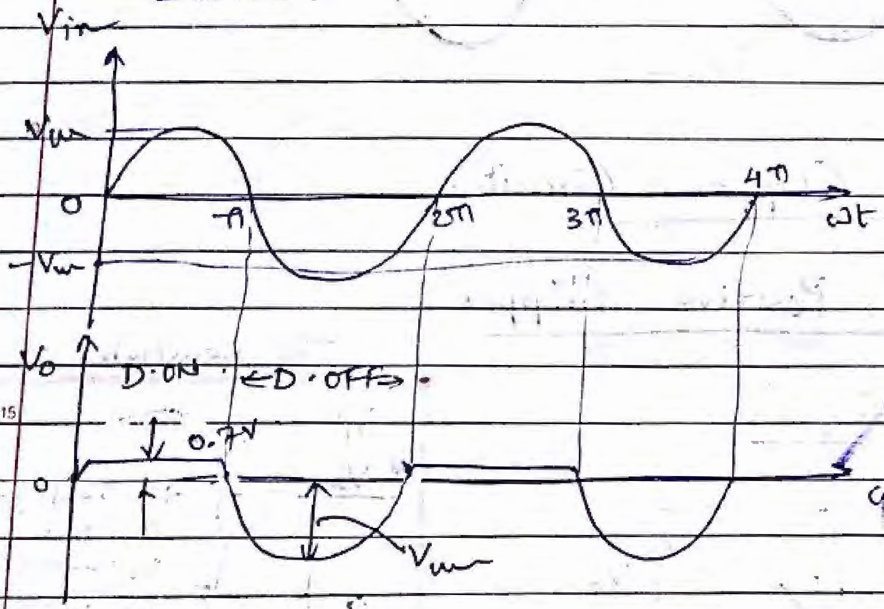
→ Operation with positive half cycle :
when Vin is positive diode is in forward bias (diode is ON).



→ Operation with Negative half cycle
when Vin is negative, diode is in reverse bias (diode is off).

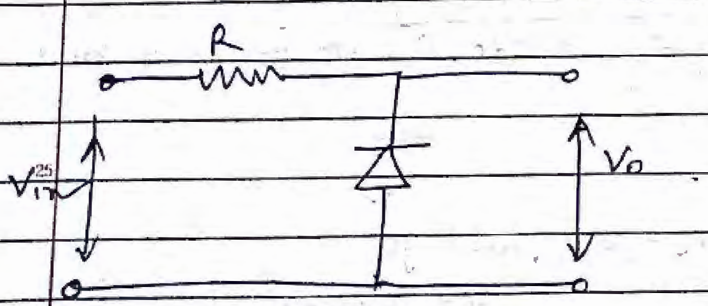


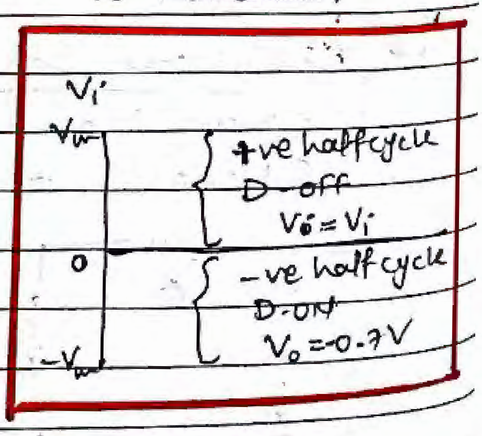
Waveforms.



Parallel Negative Clipper :

To Remember.

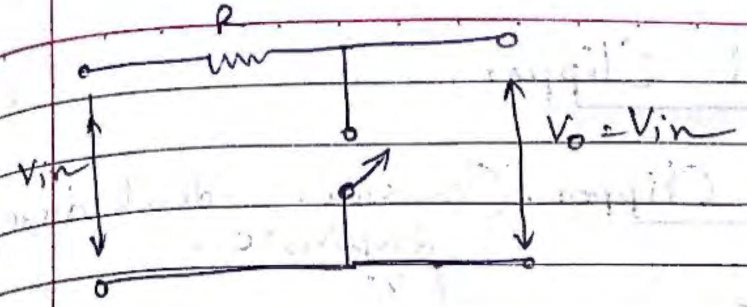




→ Operation During positive half cycle

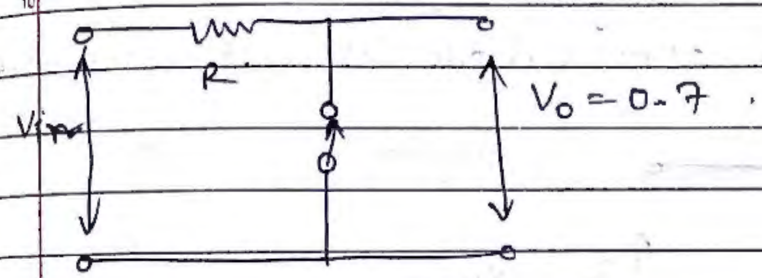
→ When Vin is +ve, Diode is off

So, $V_0 = V_{in}$

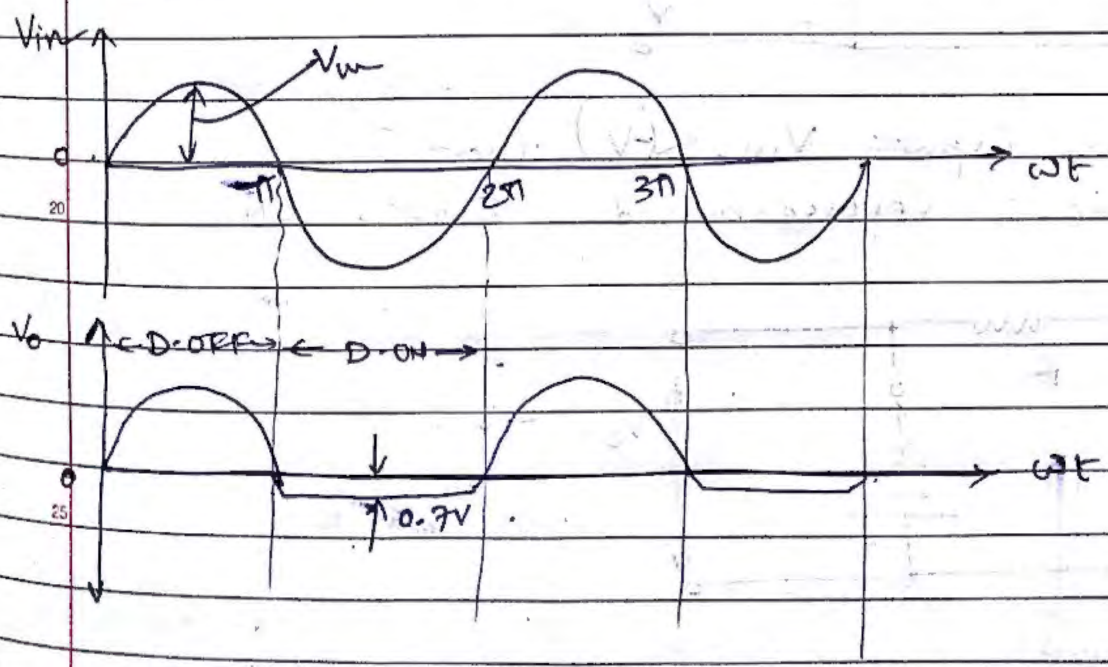


→ Operation During Negative half cycle:

When V_{in} is $-ve$ diode is ON. & $V_o = 0.7$ i.e. voltage across diode



Waveforms:



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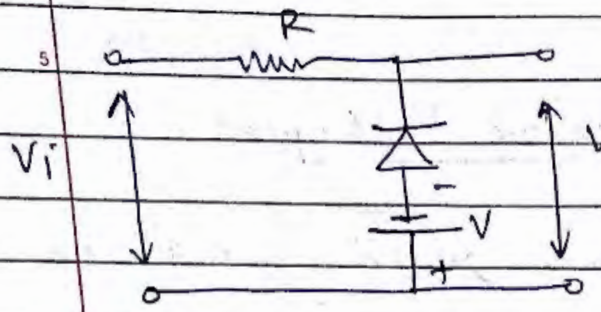
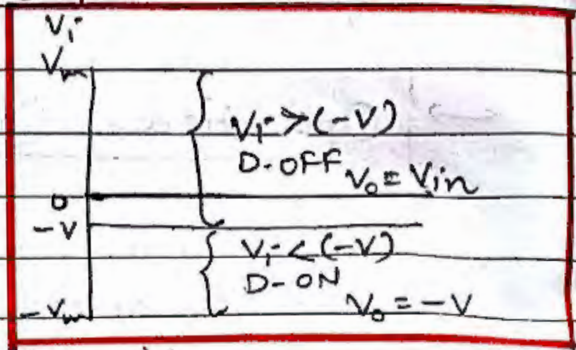
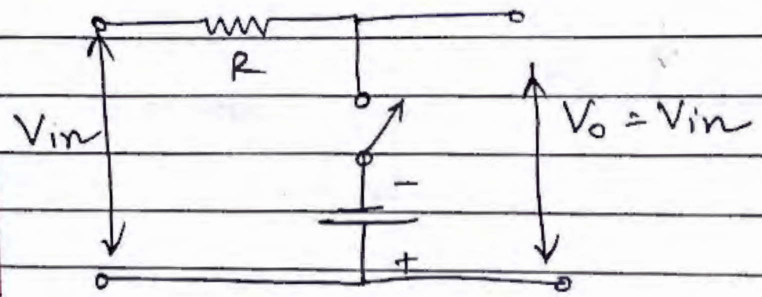
* Biased Parallel Clipper.

* Biased Negative Clipper. (consider ideal diode drop $V_D = 0$.)

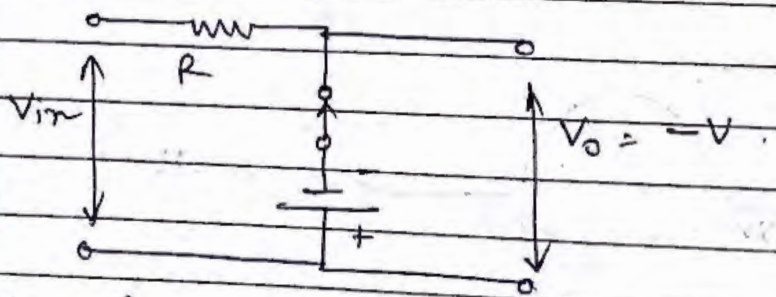




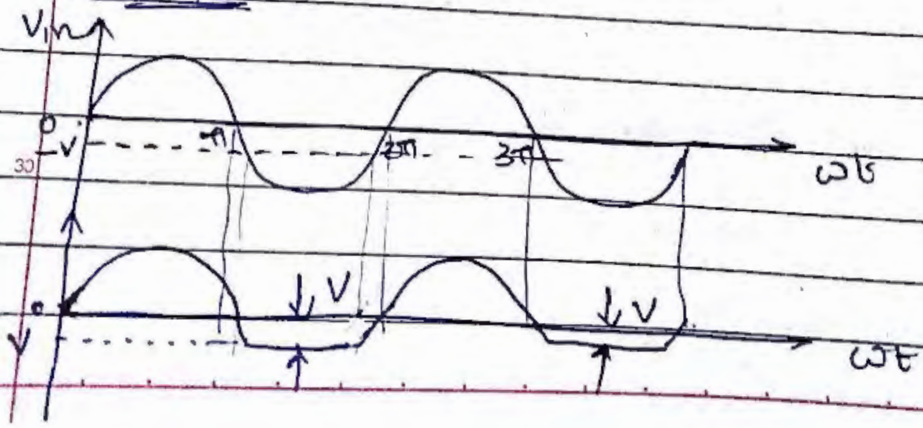
→ When input Vin is greater than V. (Vin > (−V)) diode off (diode is in Reverse Biased)
so,



→ When input Vin < (−V) then
Diode is forward biased Diode - ON.
so,

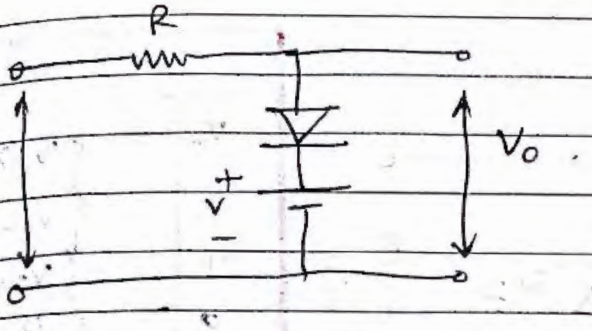


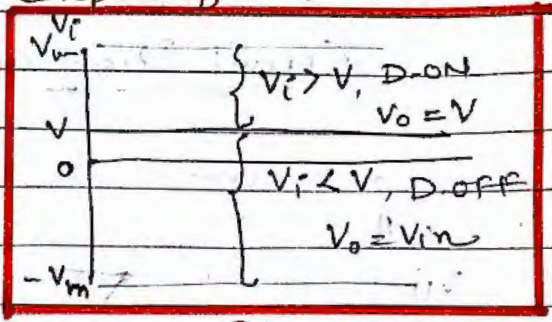
Waveforms:



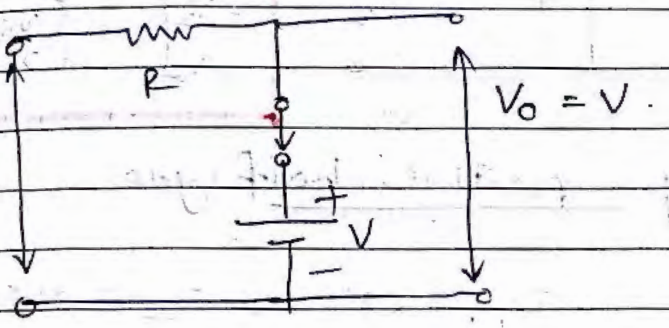
Camlin Page
Date / /

Biased Positive Clipper: (Consider ideal diode drop. $V_D = 0$.)

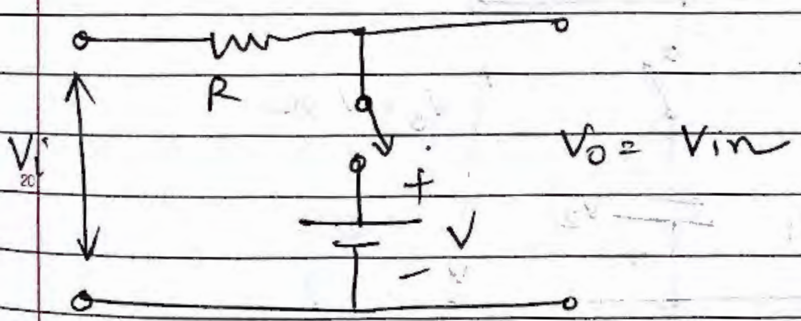




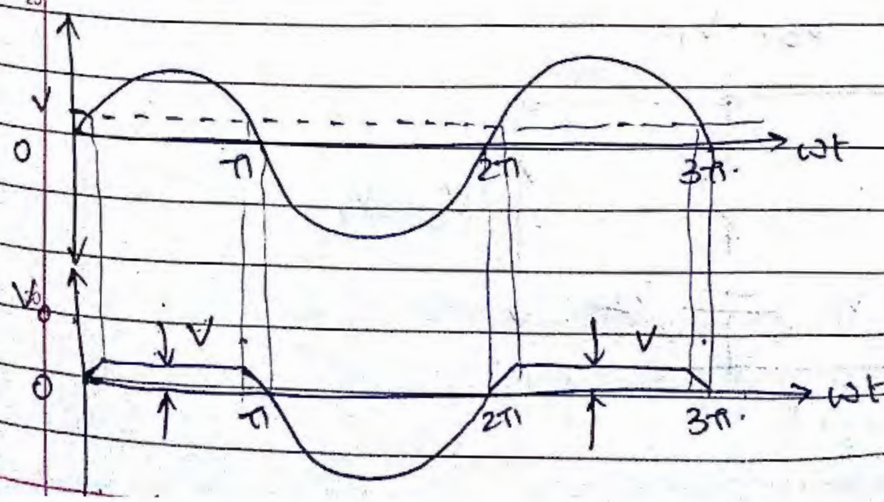
→ When $V_{in} > V$ then diode is ON. (forward bias)



→ When $V_{in} < V$ then diode is in Reverse bias.



Waveform:



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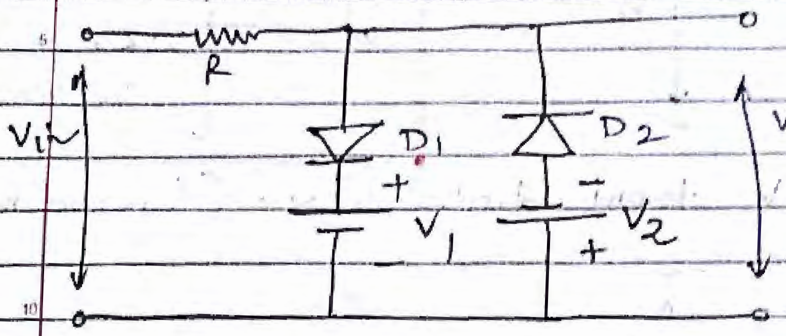
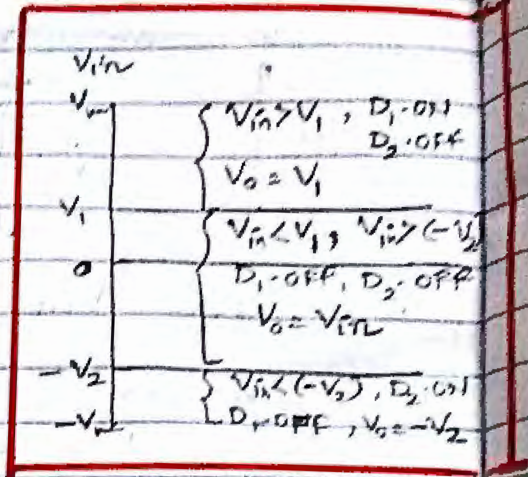
Two Way Parallel Clipper Circuit:

Circuit Diagram:

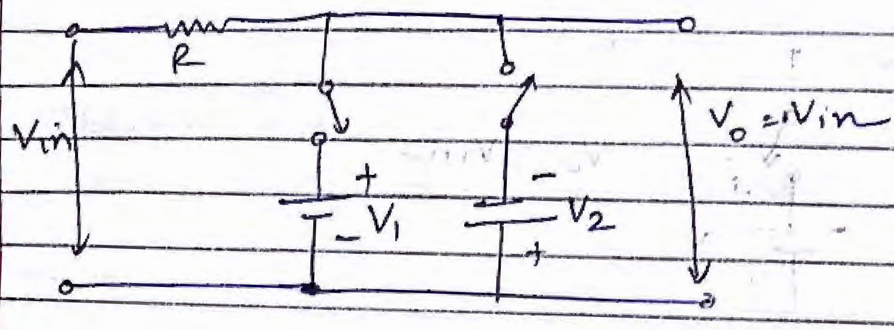




→ Operation during positive half cycle:

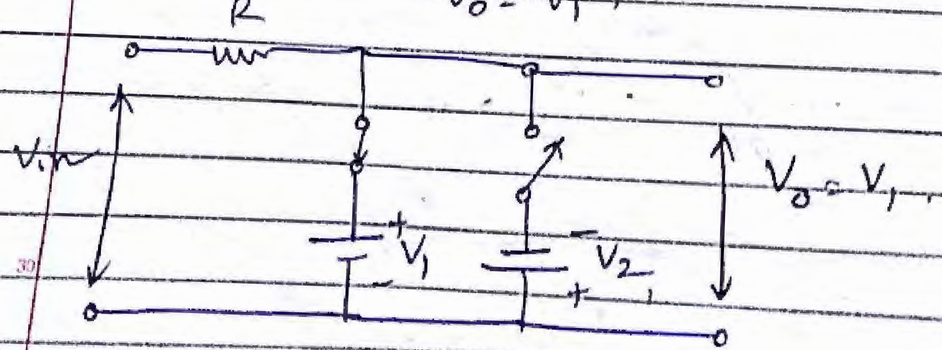
When $V_i < V_1$, D_1 is OFF & D_2 is OFF.

So, $V_0 = V_{in}$



When $V_i \geq V_1$, D_1 is ON, D_2 OFF.

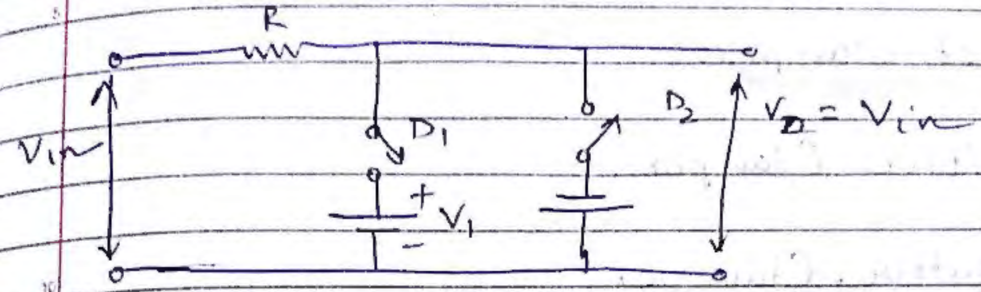
$V_0 = V_1$,



* Operation during Negative half cycle

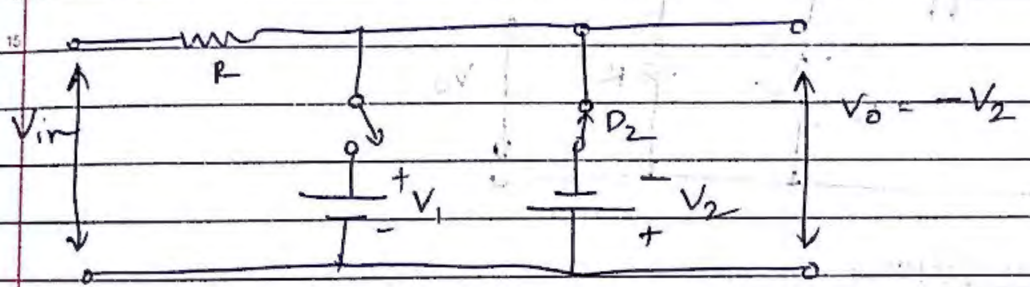
→ when $V_{in} > (-V_2)$,

D_1 - OFF, D_2 - OFF. $V_o = V_{in}$.

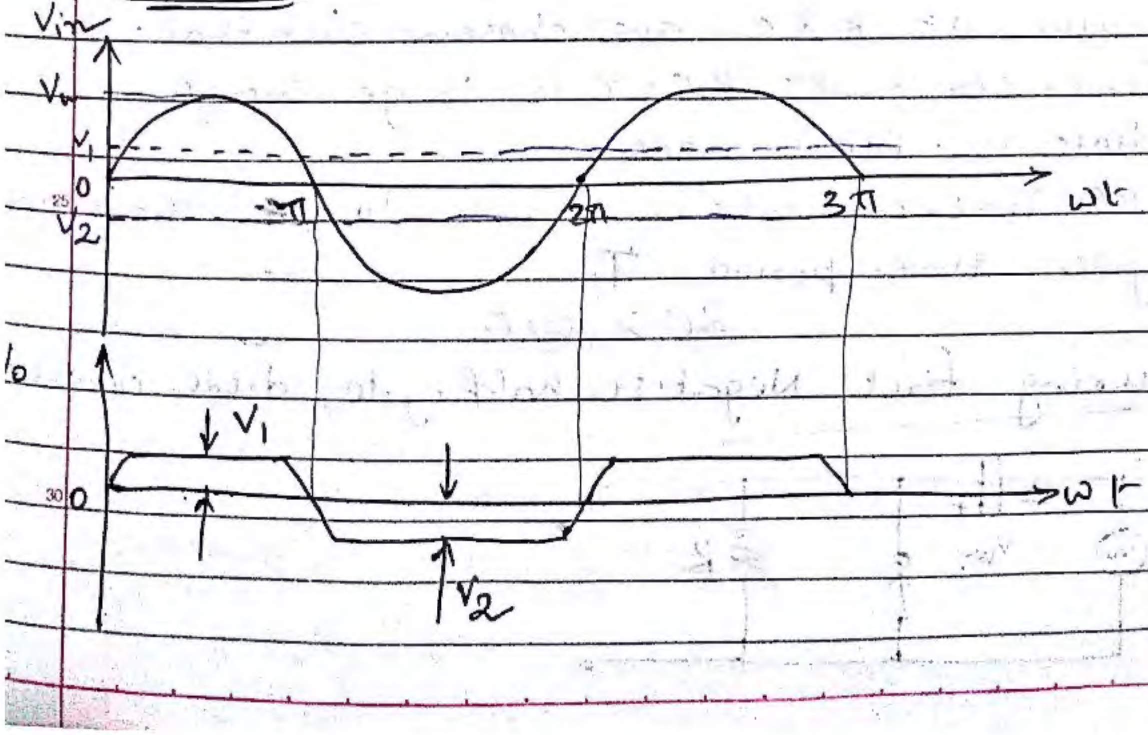


→ when $V_{in} < (-V_2)$.

D_1 - OFF, D_2 - ON. $V_o = -V_2$.



Waveforms:



Clamper Circuit Using Diode

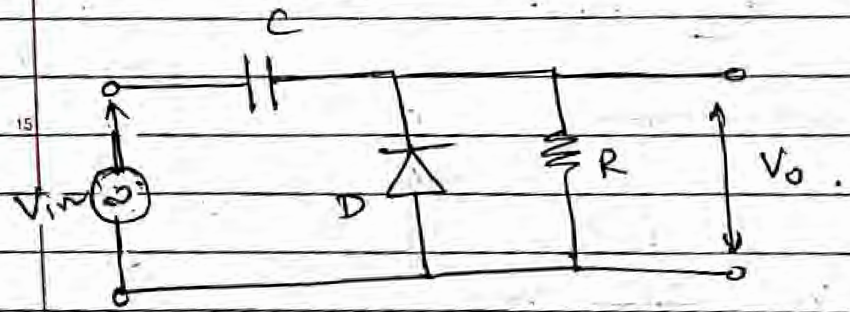
→ Clamper is the circuit which is used to clamp the input signal to a different dc level.

Types of Clampers:

1) Positive Clamper

2) Negative Clamper.

*. Positive Clamper:



Assumptions:

→ input is a perfect sine waveform

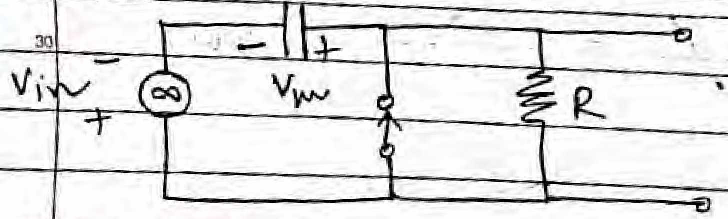
→ Value of R & C are chosen such that the Time constant $RC = \tau$ is large enough.

→ diode is ideal diode

→ RC Time constant is much longer than one cycle time period. T.

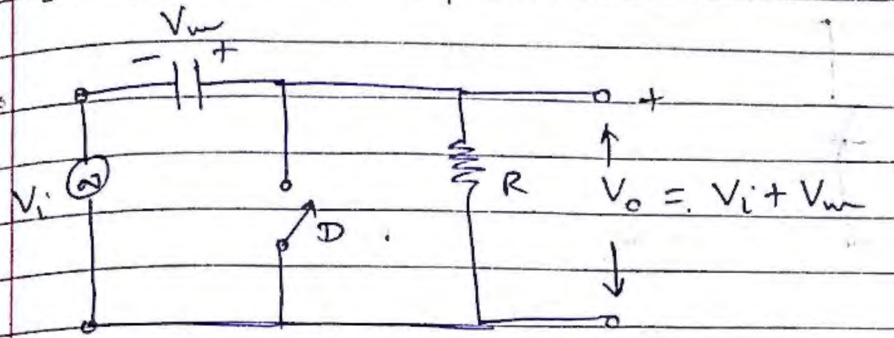
$$RC > 100T.$$

→ During first Negative half cycle diode conducts.



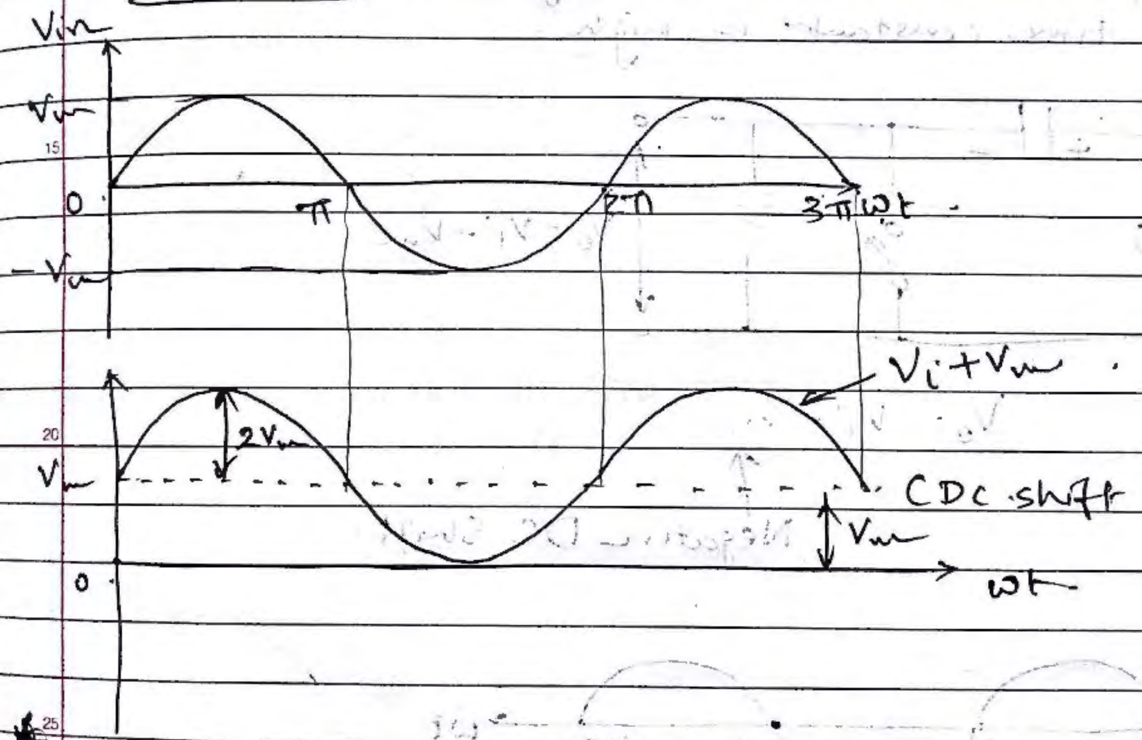
→ Once capacitor charge to V_m, diode will remain in Reverse bias condition.

→ So for rest of operation D.OFF & $V_o = V_i + V_m$ ↑ positive dc shift.



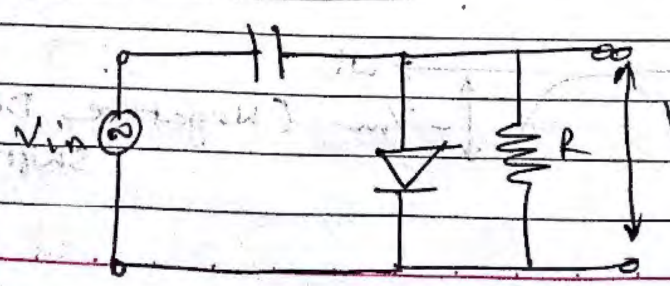
(equivalent circuit for rest operation)

Wave forms:



Negative Clamper:

Circuit Diagram:



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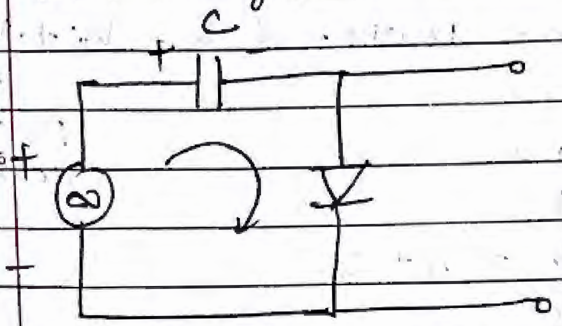
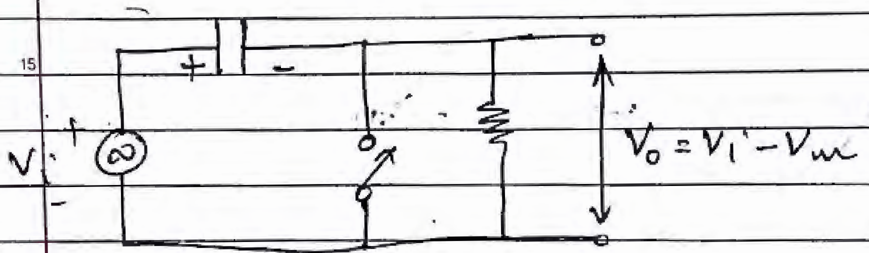
→ During first Positive half cycle capacitor will charge as diode will be in forward bias



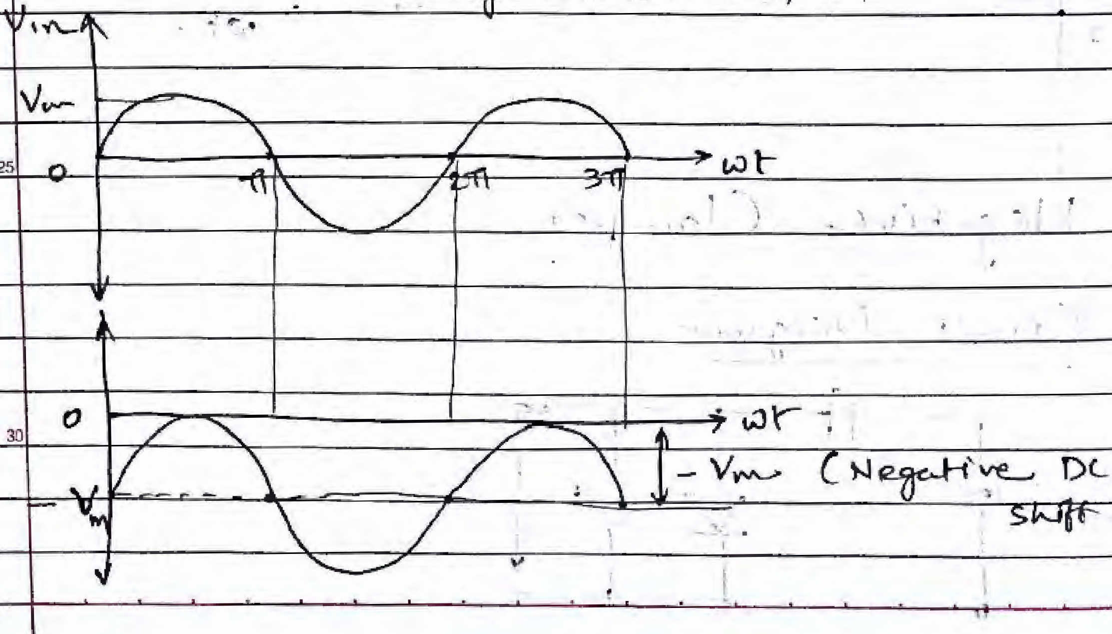
→ For Rest of the operation diode will become reverse bias due to charge of capacitor, and capacitor will not discharge through resistor as RC time constant is high.



$$V_o = V_i - V_m$$

↑

Negative DC Shift.



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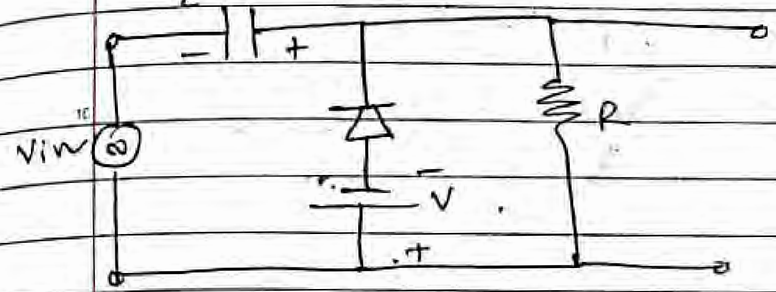
Biased Clamper:

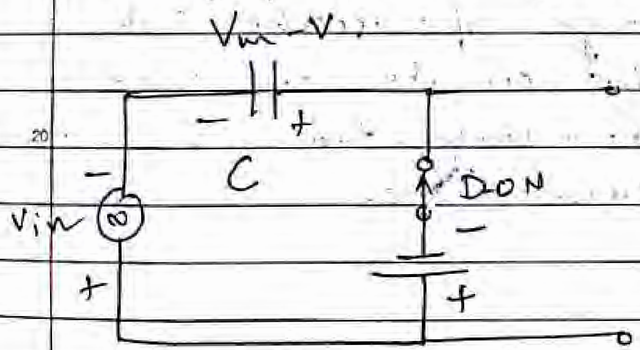
→ It is possible to obtain DC level shift which is different from V_m. For this we need to use additional DC source.

Positive biased Clamper:

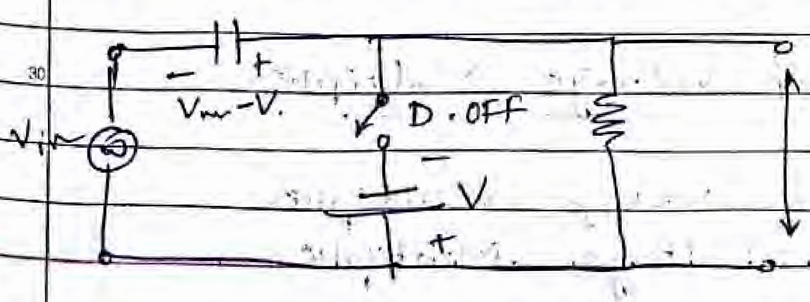
$V_c = V_m - V$.



→ During Negative half cycle of input, diode will be forward biased & capacitor gets charged to voltage $(V_m - V)$, with polarities shown bellow.

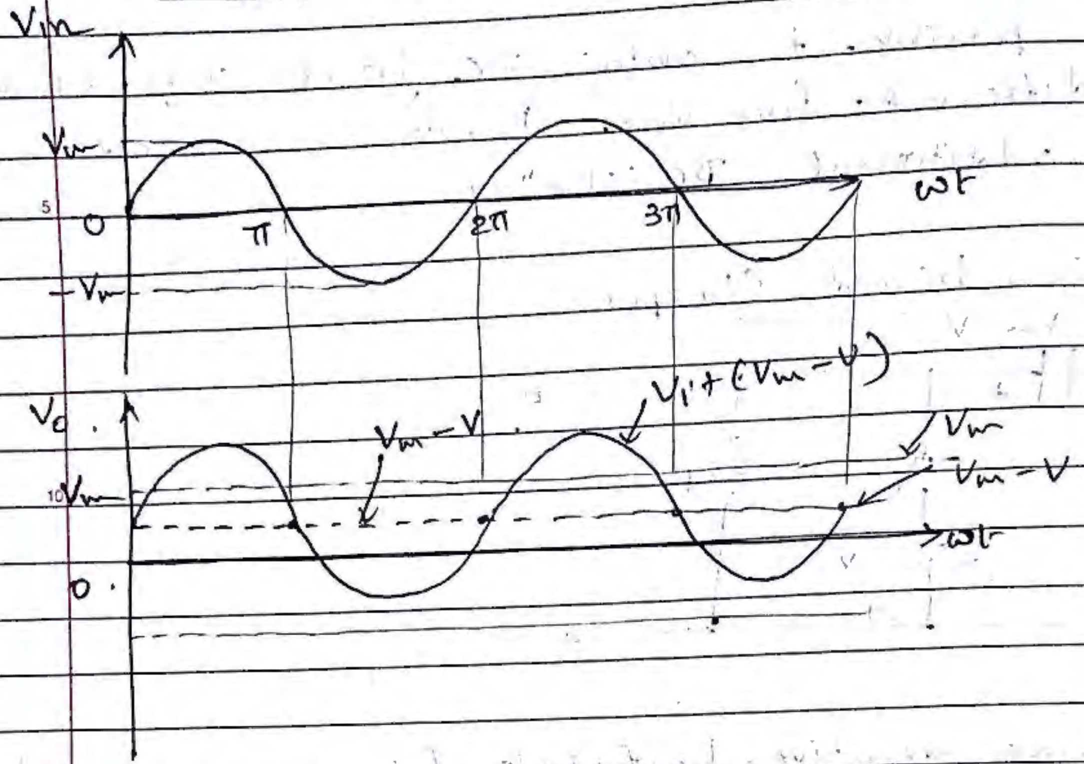


→ for rest of the operation, capacitor is fully charged to $V_m - V$, and acts as battery, diode will remain permently reverse biased condition. Circuit is as bellow.



$V_o = V_i + (V_m - V)$.

Waveforms:



Voltage Multiplier Circuits:

→ Maximum output voltage of rectifier is Vm.

→ The voltage multiplier circuits are used to obtain higher output voltage than Vm without changing transformer turns ratio.

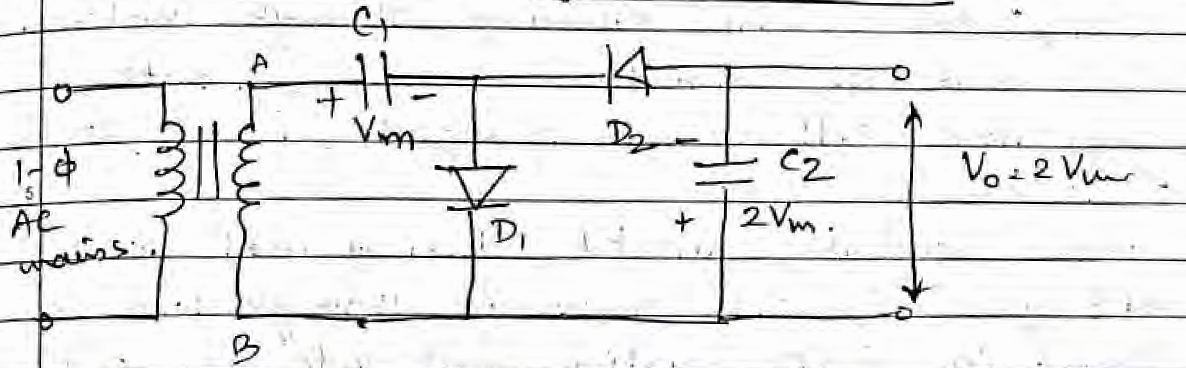
Definition:

Voltage multiplier is an electrical circuit that converts AC electrical power from lower voltage to higher DC voltage using network of capacitors & diodes.

Classification of Voltage Multiplier:

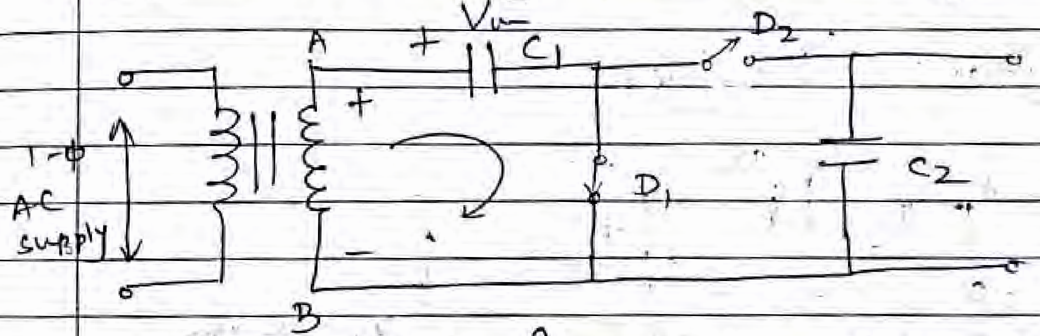
1. Half wave voltage Multiplier
2. Full wave voltage Multiplier

✱ Half wave Voltage Doubler Circuit:



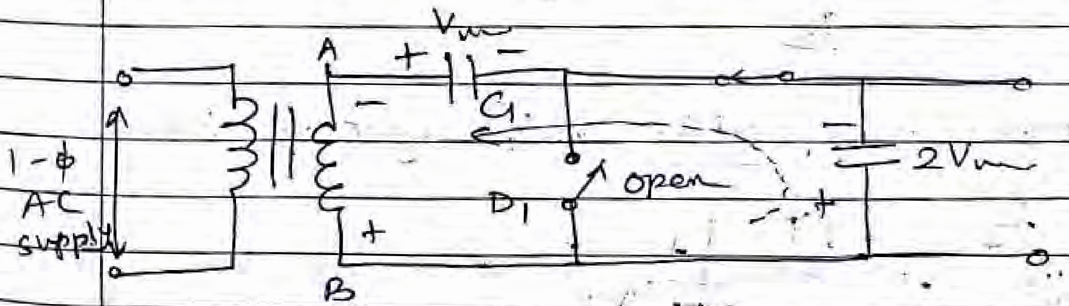
→ Halfwave voltage doubler is shown above.

→ Operation during positive half cycle



→ Diode D_1 is forward bias & D_2 reverse bias & C_1 will charge to V_m

→ Operation during Negative half cycle of input:



→ Here V_{AB} is negative, so D_1 turn OFF, & D_2 turn ON.

→ Capacitor C_2 will aquire a voltage of $2V_m$ with polarities shown in figure.

→ C_1 holds the voltage across it constant during the complete negative half cycle.

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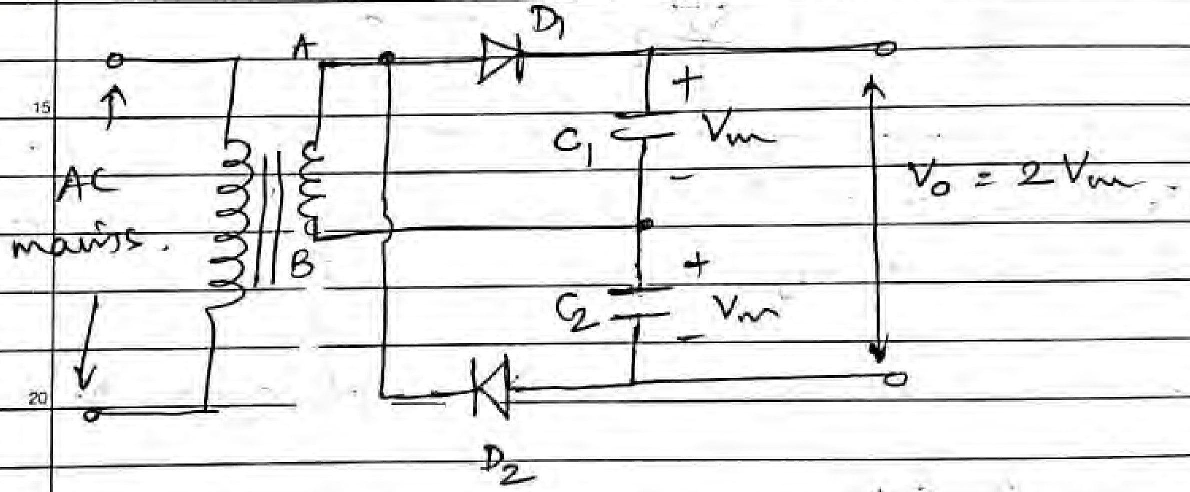
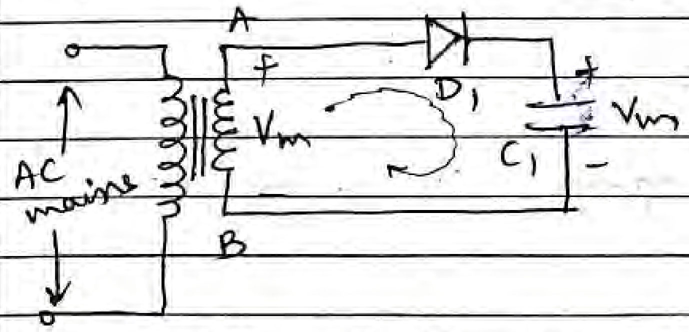
→ In next positive half cycle D_2 is non conducting & capacitor C_2 will discharge through the load. If Load is not connected across C_2, both capacitor will remain charged, i.e. C_1 to V_m & C_2 to $2V_m$.

→ when load is connected during next positive half cycle C_2 will discharge through load & then in next negative half cycle C_2 will charge to $2V_m$, PIV Rating of D_1 & D_2 is $2V_m$.

* Full wave Doubler:

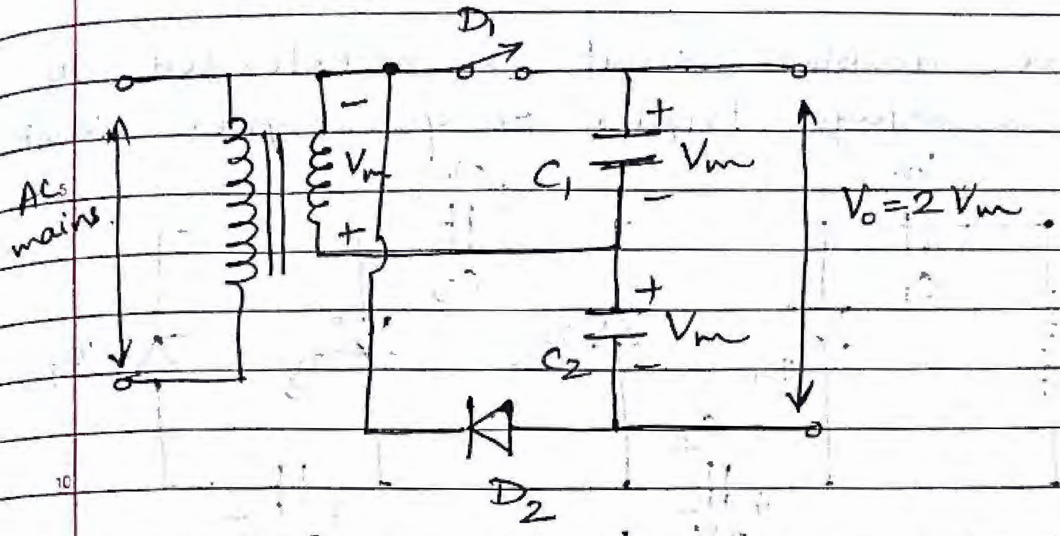


Operation in positive half cycle of input:



→ In positive half cycle V_{AB} is positive
→ Diode D_1, turn on & D_2 turn off, C_1 charges through D_1 to V_m.

Operation in negative half cycle of the input



→ During negative half cycle of the input, the secondary voltage V_{AB} is negative

→ D_1 is reverse biased, D_2 is forward biased & C_2 charges to V_m

→ $V_0 = 2V_m$ i.e. voltage across two capacitors.

→ When load is connected, series combination of C_1 & C_2 will yield a capacitance C

i.e. $$C_{eq} = \frac{C_1 C_2}{C_1 + C_2}$$

This will supply load current.

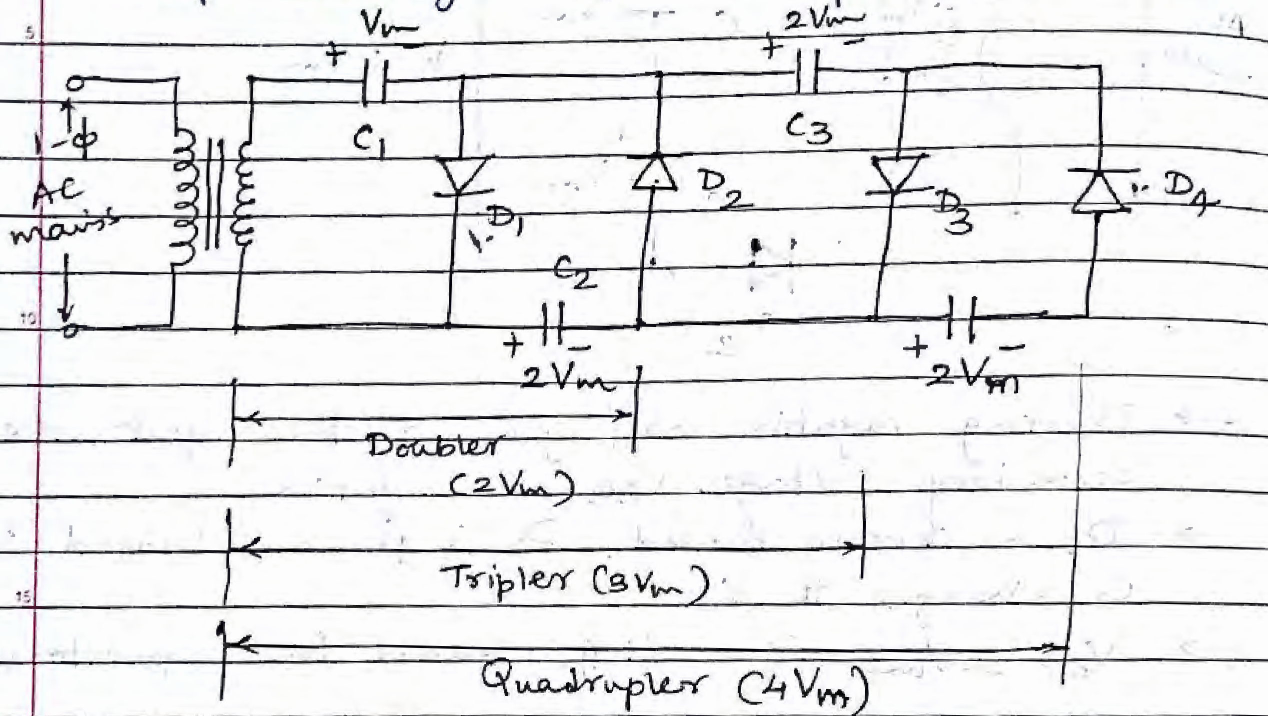
→ C_{eq} is lower than C_1 as well as C_2, so this filter action is poorer than a single capacitor filter circuit.

PIV Rating of Diode

→ PIV rating of diode connected in full wave is $2V_m$

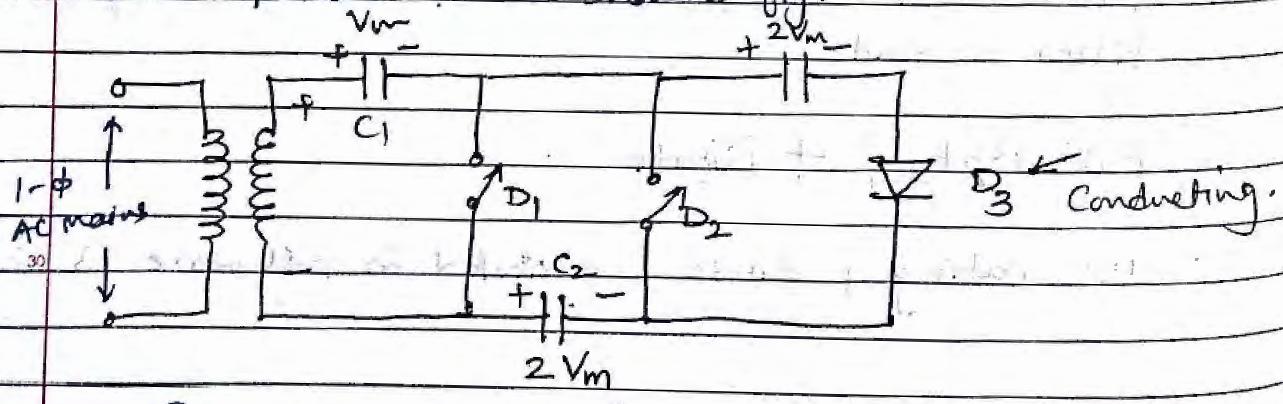
* Voltage Tripler & Quadrupler:

→ Half wave doubler circuit can be extended to develop a voltage tripler or quadrupler circuit.



→ In the positive half cycle of the input, capacitor C_1 is charged to V_m through diode D_1 with the polarities as shown.

→ In the next negative half cycle, the secondary voltage V_{AB} is −ve, which turns D_2 on. The capacitor C_2 will charge to $2V_m$ with the polarities as shown fig.

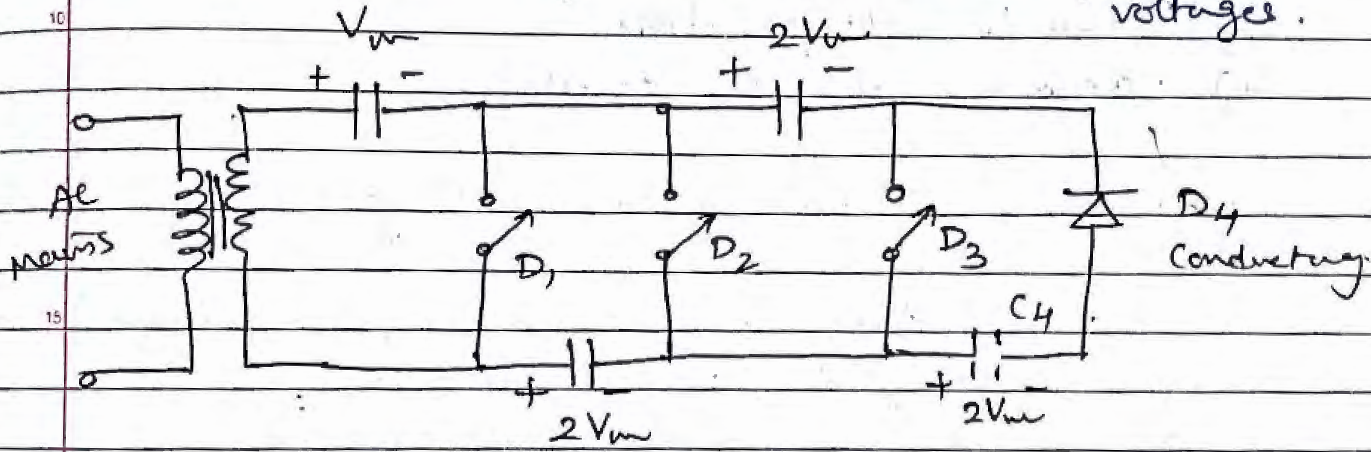


Equivalent Circuit for second positive half cycle

→ In next positive half cycle of input, diode D_3 is turn ON, As V_{AB} is +ve. This will charge the capacitor C_3 to $2V_m$ as shown in fig.

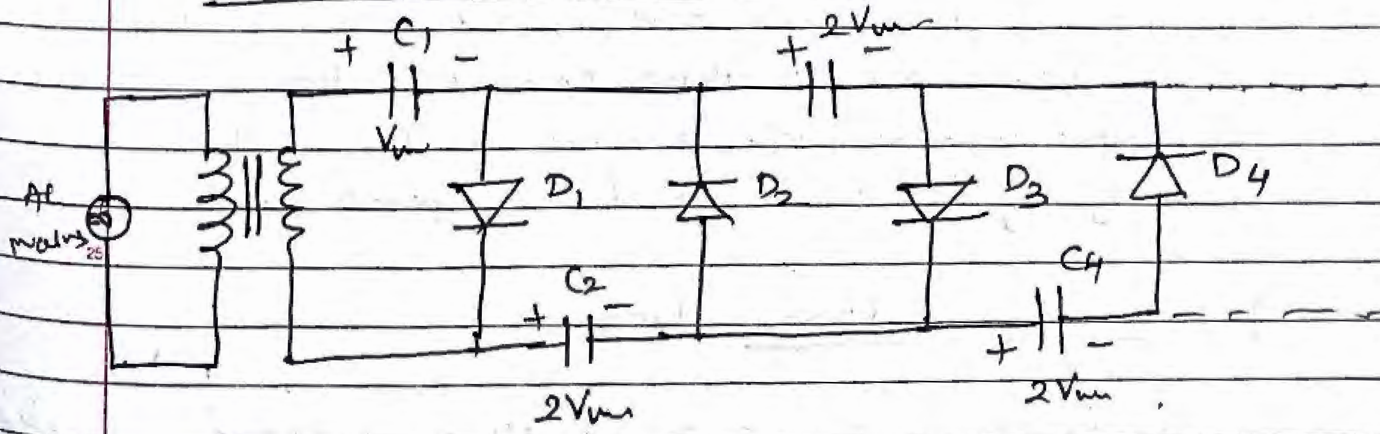
→ In next positive half cycle, diode D_4 is turned ON, which will charge C_4 to $2V_m$ as shown in fig.

→ After charging all capacitors we can tap suitable points to get double, triple or quadruple voltages.



Equivalent Circuit for second negative half cycle.

N - Fold Voltage Multiplier:



* Reading Datasheet of diode.

→ The manufacturers of electronic components list the device specifications in datasheets.

→ Some of the specifications of p-n junction diode are as follows.

1) Reverse Breakdown Voltage
2) Maximum forward current
3) Forward voltage drop
4) Maximum reverse current.

1) Reverse Break Down Voltage:

It is a maximum reverse peak voltage that can be applied across diode.
it is same as peak Inverse voltage.

2) Maximum forward current:

It is defined as the maximum value of forward current that can be allowed to pass through a forward biased diode without damaging it at specific temperature.

3) Forward Voltage drop:

It is the anode to cathod voltage measured across forward biased diode, it is denoted by V_F.

→ typically V_F for Si diode is between 0.7 V to 0.9 V

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4) Maximum Reverse current:

This is the reverse current at maximum reverse dc. rated voltage.

→ This reverse current includes thermally produced saturation current, & surface leakage current.