

UNIT-1

Diodes and Applications

Junction diode characteristics:

open circuited p-n junction:

Under open-circuited conditions the net hole current must be zero.

If donor impurities are introduced into one side and acceptors into the other side of a single crystal of a semiconductor, a p-n junction is formed.

The donor ion is represented by a plus sign because,

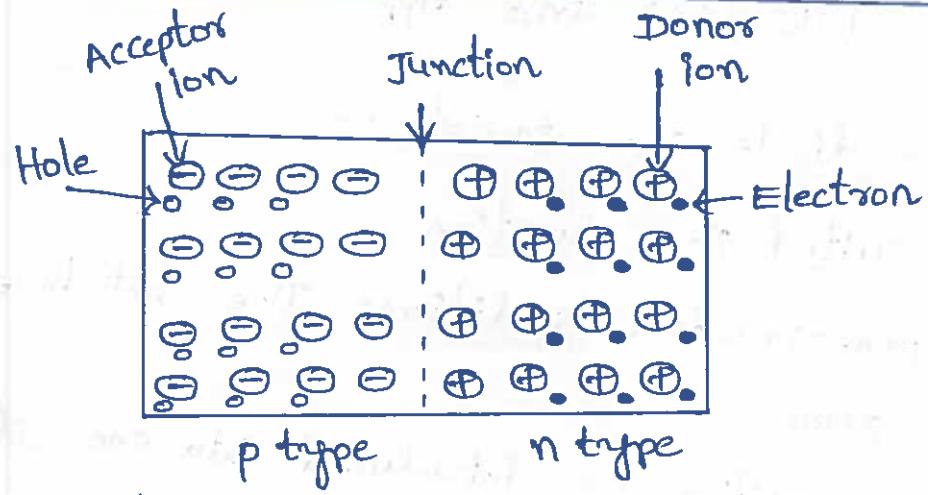
after this impurity atom "donates" an electron, it becomes a positive ion. The acceptor ion is indicated by

a minus sign because, after this atom "accepts" an electron, it becomes a negative ion. Initially,

there are nominally only p-type carriers to the left of the junction and only n-type carriers to the right

space-charge region:

The region of the junction is depleted of mobile charges, it is called the depletion region, the space-charge region, or the transition region. The thickness of this region is of the order of the wavelength of visible light ($0.5 \text{ micron} = 0.5 \mu\text{m}$).

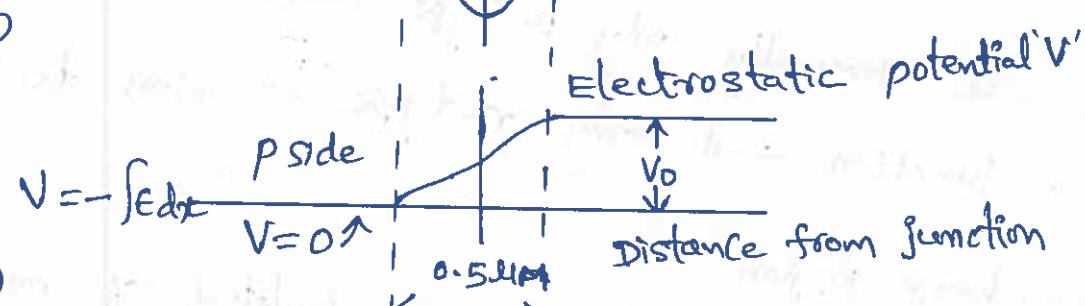


$$\frac{d^2V}{dx^2} = -\frac{\rho}{\epsilon}$$

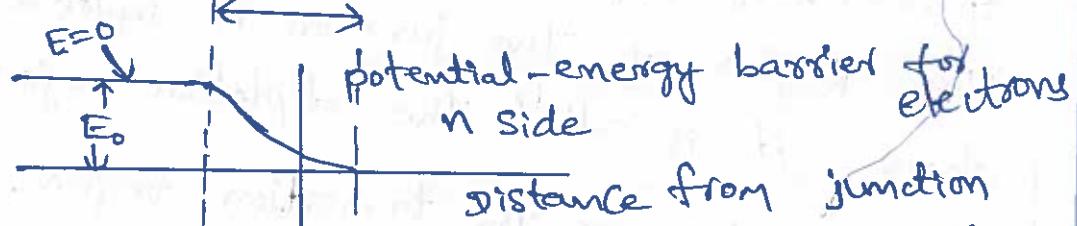
(b)



(c)



(d)



(e)

fig 3.1 A schematic diagram of a p-n junction, including the charge density, electric field intensity and potential-energy barriers at the junction.

within this very narrow space-charge layer these are no mobile carriers. To the left of this region the carrier concentration is $p \approx N_A$, and to its right it is $n \approx N_D$.

Electric Field Intensity

The space-charge density p is zero at the junction. It is positive to the right and negative to the left of the junction. This distribution constitutes an electrical dipole layer, giving rise to electric lines of flux from right to left, corresponding to negative field intensity E as depicted in fig 3.1C. Equilibrium is established when the field is strong enough to restrain the process of diffusion. There is no steady-state movement of charge across the junction.

The field intensity curve is proportional to the integral of the charge density curve. This statement follows from poisson's equation

$$\frac{d^2V}{dx^2} = -\frac{P}{\epsilon} \quad \text{--- (1)}$$

where ϵ is the permittivity. If ϵ_r is the (relative) dielectric constant and ϵ_0 is the permittivity of

free space, then $\epsilon = \epsilon_0 \epsilon_0$.

Integrating equation ① and remembering that

$$\epsilon = -\frac{dV}{dx} \text{ gives } \epsilon = \int_{x_0}^x \frac{P}{\epsilon} dx \quad \rightarrow ②$$

where $\epsilon = 0$ at $x = x_0$. Therefore the curve plotted in fig 3.1c is the integral of the function drawn in fig. 3.1b
~~(divided by ϵ)~~.

potential:

The electrostatic-potential variation in the depletion region is shown in fig. 3.1d, and is the negative integral of the function ϵ of fig. 3.1.c. This variation constitutes a potential-energy barrier against the further diffusion of holes across the barrier.

The form of the potential-energy barrier against the flow of electrons from the n side across the junction is shown in fig. 3.1e. It is similar to that shown in fig. 3.1d, except that it is inverted, since the charge on an electron is negative.

The p-n junction as a Rectifier:

If a junction is formed between a sample of p-type and one of n-type semiconductor, this combination possesses the properties of a rectifier. We consider now, qualitatively, how this diode rectifier action comes about.

Reverse Bias:

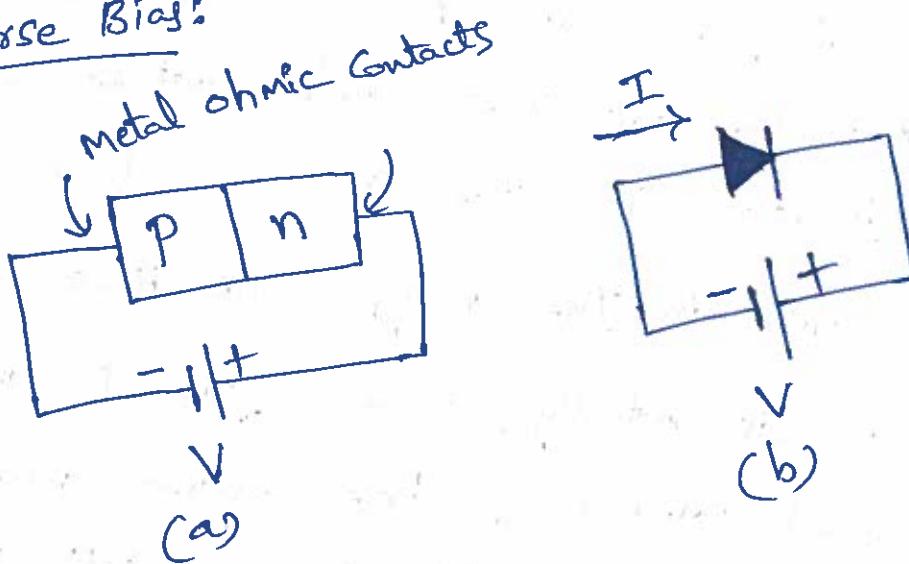


Fig 3.2 (a) A p-n junction biased in the reverse direction.

(b) The rectifier symbol is used for the p-n diode

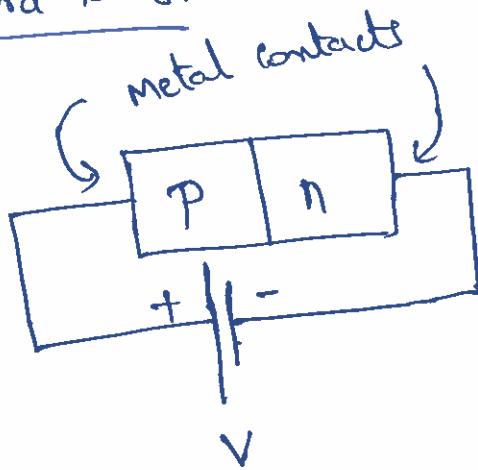
In above fig 3.2, a battery is shown connected across the terminals of a p-n junction. The negative terminal of the battery is connected to the p side of the junction.

and the positive terminal to the n side. The polarity of connection is such as to cause both the holes in the p-type and the electrons in the n-type to move away from the junction. Consequently, the region of negative-charge density is spread to the left of the junction (Fig. 3.1b), and the positive-charge-density region is spread to the right. However, this process cannot continue indefinitely, because in order to have a steady flow of holes to the left, these holes must be supplied across the junction from the n-type silicon. And there are very few holes in the n-type side. Hence, normally, zero current results. Actually, a small current does flow because a small number of hole-electron pairs are generated throughout the crystal as a result of thermal energy.

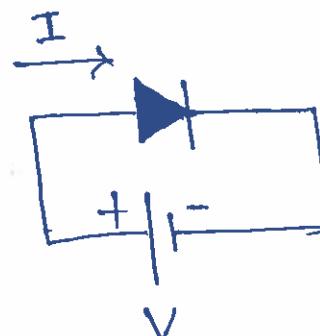
The holes so formed in the n-type silicon will wander over to the junction. A similar remark applies to the electrons thermally generated in the p-type silicon. This small current is the diode reverse saturation current, and its magnitude is designated by I_0 .

This reverse current will increase with increasing temperature, and hence the back resistance of a crystal diode decreases with increasing temperature. From the argument presented here, I_0 should be independent of the magnitude of the reverse bias.

Forward Bias:



(a)



(b)

Fig 2.2 (a) A p-n junction biased for the forward direction.

(b) The rectifier symbol is used for the p-n diode

unit-11 8/59

V-I (volt-ampere) characteristic.

For a p-n junction, the current I is related to the voltage V by the equation

$$I = I_0 (e^{V/nV_T} - 1) \quad \text{--- ①}$$

A positive value of I means that current flows from the p to the n side. The diode is forward-biased if V is positive, indicating that the p side of the junction is positive with respect to the n side.

The symbol ~~stands for the~~ η is unity for germanium and approximately 2 for silicon at rated current.

The symbol V_T stands for the volt equivalent of temperature, and is given by

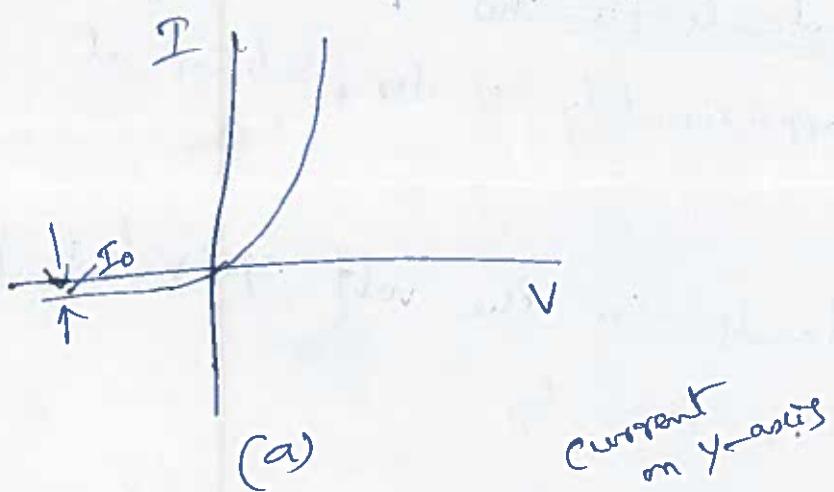
$$V_T = \frac{T}{11,600} \quad \text{--- ②}$$

At room temperature ($T = 300^\circ\text{K}$), $V_T = 0.026\text{V} = 26\text{mV}$.

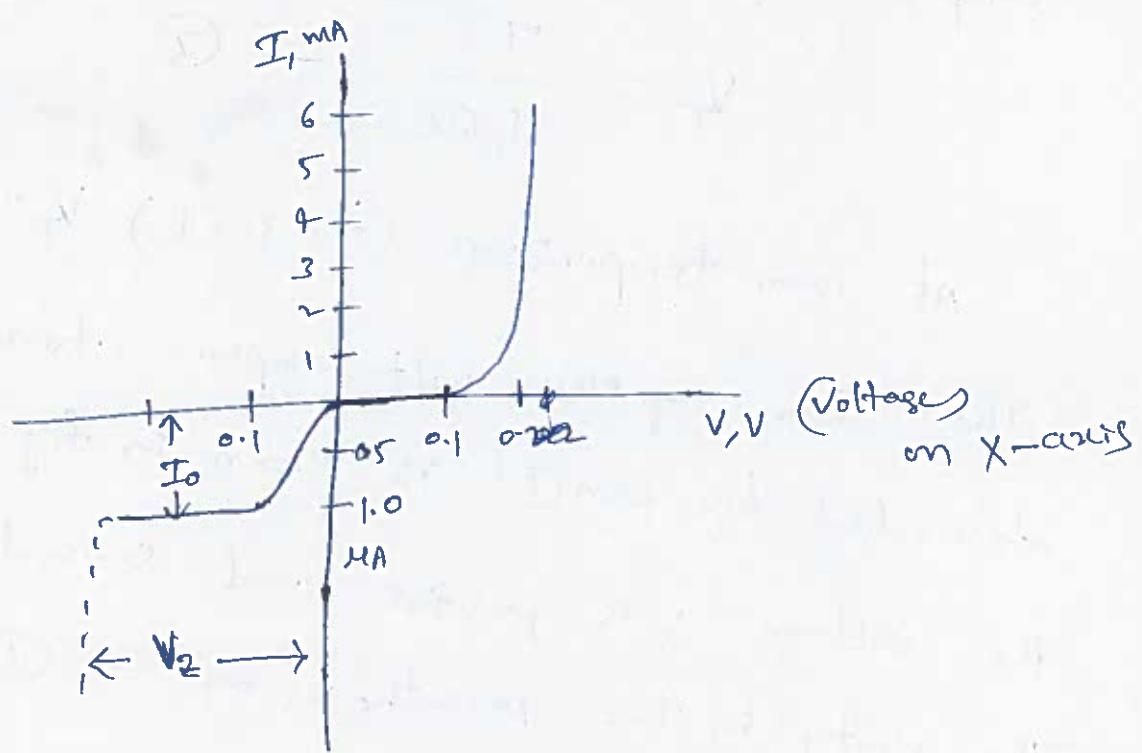
The form of the volt-ampere characteristic described by eqn ① is shown in fig. 3.6a. When the voltage V is positive and several times V_T , the unity in the parentheses of eqn ① may be neglected.

When the diode is reverse-biased and (V) is several times V_T , $I \approx -I_0$. The reverse current is therefore constant, independent of the applied reverse bias. Consequently, I_0 is referred to as the reverse saturation current.

The volt-ampere characteristic shown in the fig. has a forward-current scale in milliamperes and a reverse scale in microamperes.



Current on Y-axis



(a)
(b)

The volt-ampere characteristic of an ideal p-n diode. The volt-ampere characteristic for a germanium unit-1, 10/59

The temperature dependence of the V/I characteristics:

~~feature~~

$$\text{The volt-ampere relationship } I = I_0 (e^{\frac{V}{V_T}} - 1)$$

Contains the temperature implicitly in the two symbols V_T and I_0 .

The leakage component is independent of temperature, we may expect to find a smaller rate of change of I_0 with temperature than that predicted above.

From experimental data we observe that the reverse saturation current increases approximately 7 percent/°C for both silicon and Germanium.

The reverse saturation current approximately doubles

for every 10°C rise in temperature.

If $I = I_{01}$ at $T = T_1$, then at a temperature T ,

I_0 is given by

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

If the temperature is increased at a fixed voltage, the current increases. If we now reduce V , then I may be brought back to its previous value.

Diode Resistance:

The static resistance R of a diode is defined as the ratio V/I of the voltage to the current. At any point on the volt-ampere characteristic of the diode, the resistance R is equal to the reciprocal of the slope of a line joining the operating point to the origin.

The static resistance varies widely with V and I and is not a useful parameter.

For a small-signal operation the dynamic, or incremental, resistance r is an important parameter and is defined as the reciprocal of the slope of the volt-ampere characteristic.

The dynamic resistance varies inversely with current.

Diffusion Capacitance:

For a forward bias a capacitance which is much larger than the transition capacitance C_T

considered. The origin of this larger capacitance lie in the injected charge stored near the junction outside the transition region.

It is convenient to introduce an incremental capacitance, defined as the rate of change of injected charge with voltage, called the diffusion, or storage, capacitance C_D .

static derivation of C_D :

we now make a quantitative study of C_D

$$C_D = \frac{dQ}{dV} = \gamma \frac{dI}{dV} = \gamma g = \frac{\gamma}{\gamma V_T}$$

where the diode incremental conductance $g = \frac{dI}{dV}$, substituting the expression for the diode incremental resistance $\rho = 1/g$,

$$\rho \approx \frac{\gamma V_T}{I}$$

$$C_D = \frac{\gamma I}{\gamma V_T}$$

The diffusion capacitance is proportional to the current I .

Diffusion Capacitance for a Sinusoidal Input:

for the special case where the excitation varies sinusoidally with time, C_D' may be obtained from a solution of the equation of continuity.

$$\text{At low frequencies } C_D' = \frac{1}{2} T g \text{ if } \omega T \ll 1$$

~~which is half the~~

For high frequencies, C_D' decreases with increasing frequency and is given by

$$C_D' = \left(\frac{T}{2\omega} \right)^{\frac{1}{2}} g \text{ if } \omega T \gg 1$$

Diode ~~Switching~~ Switching Times

When a diode is driven from the reversed condition to the forward state or in the opposite direction, the diode response is accompanied by a transient and an interval of time elapses before the diode recovers to its steady state.

The forward recovery time t_{fr} is the time difference between the 10 percent point of the diode voltage and the time when

~~1. In the following diagram, if the flow is
in the same direction, then the flow is
laminar. If the flow is turbulent, then
the flow is unsteady.~~

~~2. If the flow is laminar, then the flow is
unsteady. If the flow is turbulent, then
the flow is steady.~~

~~3. If the flow is steady, then the flow is
laminar. If the flow is unsteady, then
the flow is turbulent.~~

~~4. If the flow is unsteady, then the flow is
turbulent. If the flow is steady, then
the flow is laminar.~~

~~5. If the flow is laminar, then the flow is
unsteady. If the flow is turbulent, then
the flow is steady.~~

~~6. If the flow is steady, then the flow is
turbulent. If the flow is unsteady, then
the flow is laminar.~~

~~7. If the flow is unsteady, then the flow is
turbulent. If the flow is steady, then
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~~8. If the flow is laminar, then the flow is
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~~9. If the flow is steady, then the flow is
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~~10. If the flow is unsteady, then the flow is
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~~11. If the flow is laminar, then the flow is
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the flow is steady.~~

~~12. If the flow is steady, then the flow is
turbulent. If the flow is unsteady, then
the flow is laminar.~~

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turbulent. If the flow is steady, then
the flow is laminar.~~

~~14. If the flow is laminar, then the flow is
unsteady. If the flow is turbulent, then
the flow is steady.~~

~~15. If the flow is steady, then the flow is
turbulent. If the flow is unsteady, then
the flow is laminar.~~

~~16. If the flow is unsteady, then the flow is
turbulent. If the flow is steady, then
the flow is laminar.~~

~~17. If the flow is laminar, then the flow is
unsteady. If the flow is turbulent, then
the flow is steady.~~

~~18. If the flow is steady, then the flow is
turbulent. If the flow is unsteady, then
the flow is laminar.~~

~~19. If the flow is unsteady, then the flow is
turbulent. If the flow is steady, then
the flow is laminar.~~

unit-1 15159

this voltage reaches and remains within 10 percent of its final value. It turns out that t_{fr} does not usually constitute a serious practical problem, and hence we here consider only the more important

situation of reverse recovery.
storage and transition time:

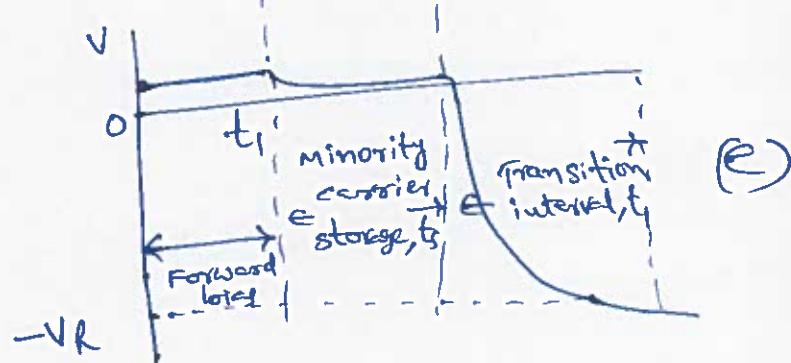
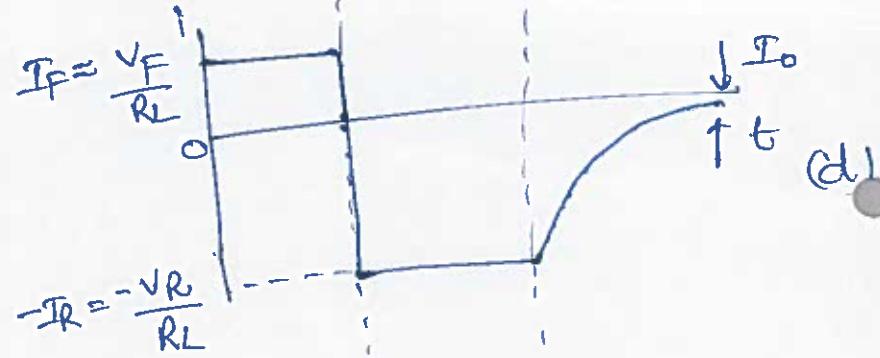
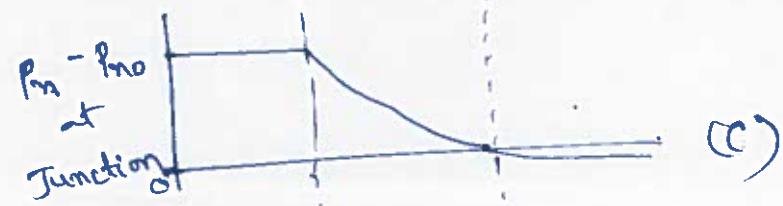
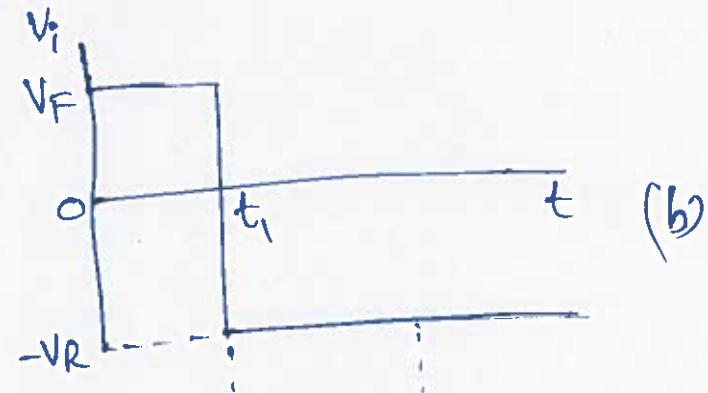
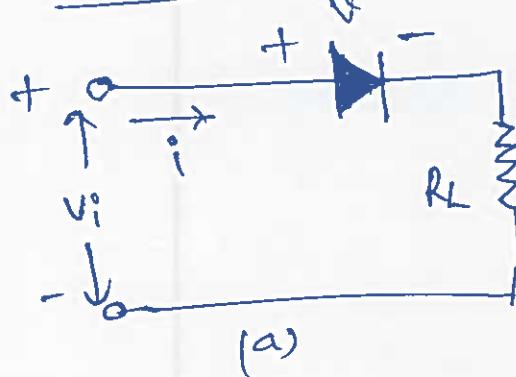
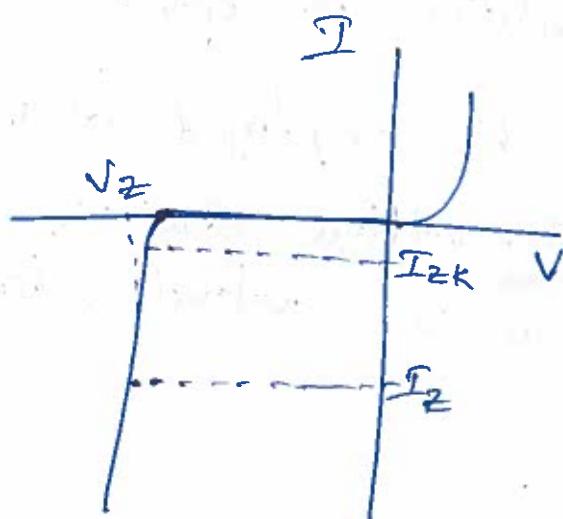
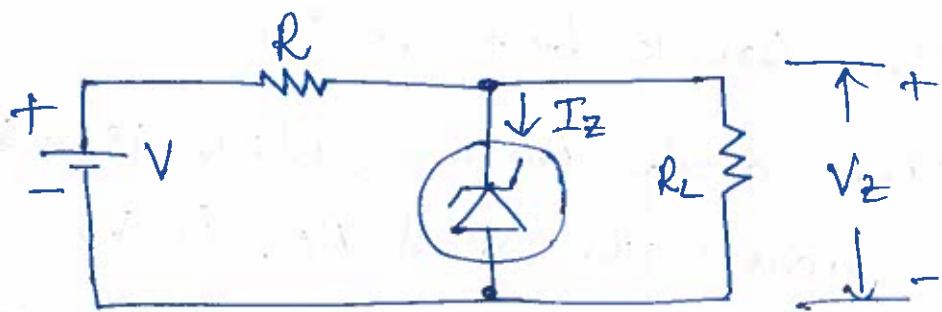


Fig: The waveform in (b) is applied to the diode circuit in (a); (c) the excess carrier density at the junction; (d) the diode current; (e) the diode voltage.

Breakdown Diodes:



(a)



(b)

Fig : (a) The volt-ampere characteristic of an avalanche, or zener, diode.
 (b) A circuit in which such a diode

is used to regulate the voltage across R_L against changes due to variations in load current and supply voltage.

The reverse-Voltage characteristic of a semiconductor diode, including the breakdown region is redrawn in fig (a)

Diodes which are designed with adequate power-dissipation capabilities to operate in the breakdown region may be employed as voltage-referance (or) constant-voltage devices. Such diodes are known as avalanche, breakdown or zener diodes.

The source V and resistor R are selected so that, initially, the diode is operating in the breakdown region.

Here the diode voltage, which is also the voltage across the load R_L , is V_Z as by fig (v). and the diode current is I_Z .

The diode will now regulate the load voltage against variation in load current and against variations in supply voltage V because, in the breakdown region, large changes in diode current produce only small changes in diode voltage.

Moreover, as load current (or) supply voltage changes, the diode current will accommodate itself to these changes to maintain a nearly constant load voltage.

Tunnel diode is a heavily doped p-n junction diode. It displays a negative resistance behaviour in a specific region in its characteristic curve. By negative resistance we mean that in that region, the current flowing through the diode decreases as the voltage is increased.

Characteristics of a Tunnel Diode!

• Tunnel diode is an excellent conductor in the forward direction. Also, for small forward voltages (up to 50 mV for Ge), the resistance remains small. At the peak current I_p corresponding to the voltage V_p , the slope $\frac{dI}{dV}$ of the characteristic is zero. If V is increased beyond V_p , the current decreases.

The tunnel diode exhibits a negative resistance characteristic between the peak current I_p and the minimum value I_V , called the valley current.

At the valley voltage V_V at which $I = I_V$, the conductance is again zero, and beyond this point the resistance becomes and remains positive. At the so-called peak forward voltage V_F the current again reaches the value I_p . For larger voltages the current increases beyond this value.

The Tunnel Diode!

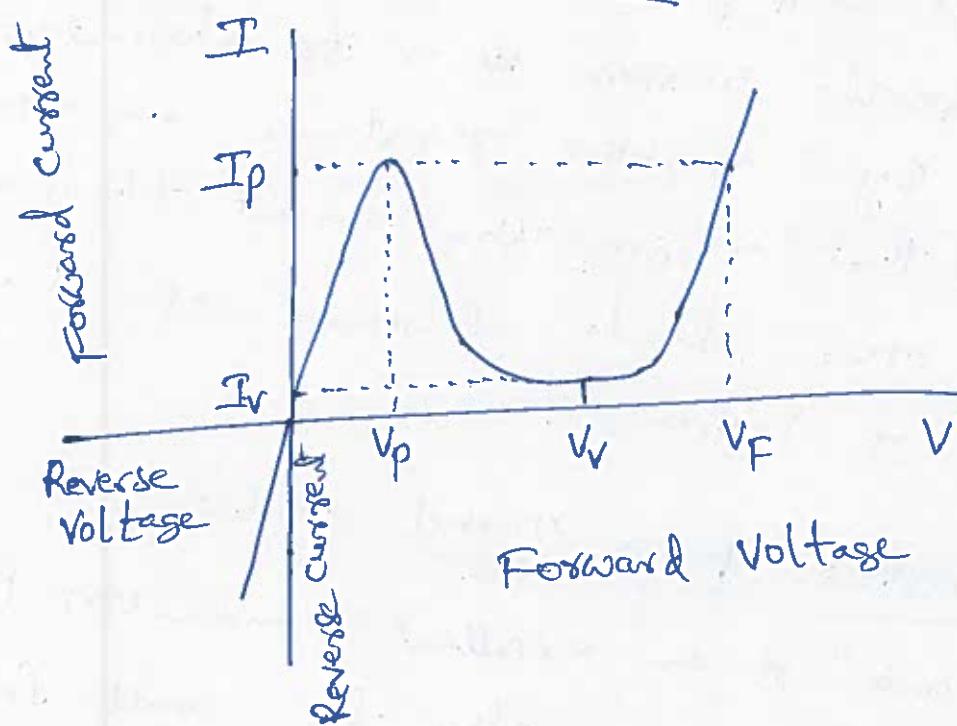


Fig: volt-ampere characteristic of a tunnel diode.

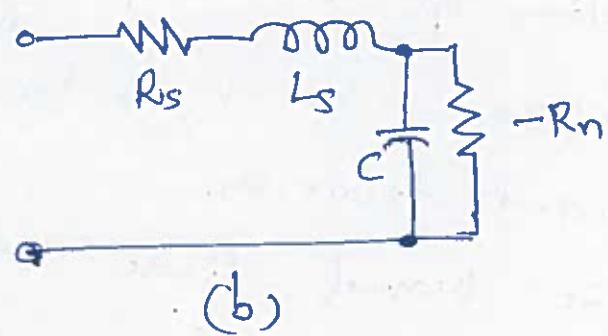
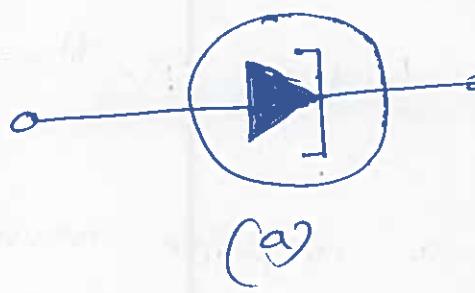
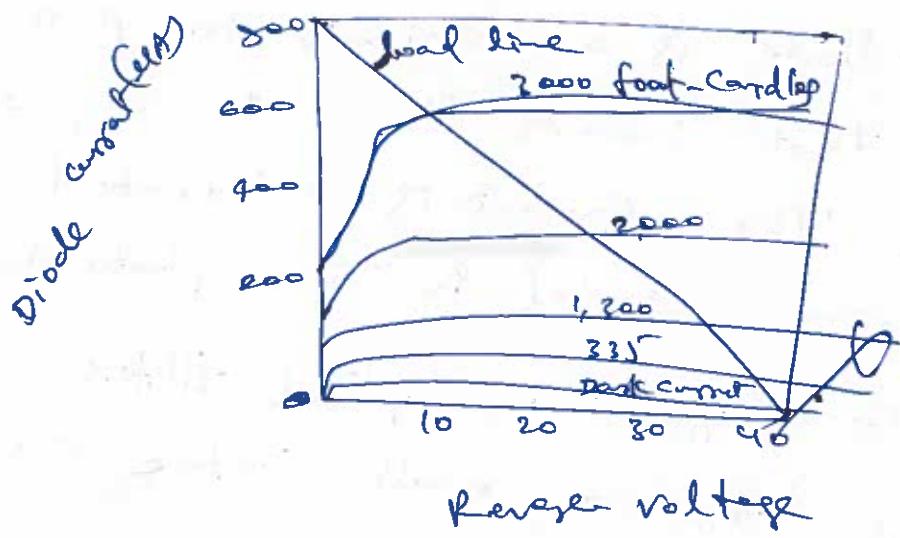


Fig: (a) symbol for a tunnel diode
 (b) small-signal model in the negative-resistance region.

applications:

- ① It is used as a switching device with very high speed.
- ② It is used as ~~for~~ a microwave oscillator with high frequency.
- ③ This diode is used as an oscillatory amplifier and switch.

Volt-ampere characteristic:



for the
fig: volt-ampere characteristic
germanium photodiode

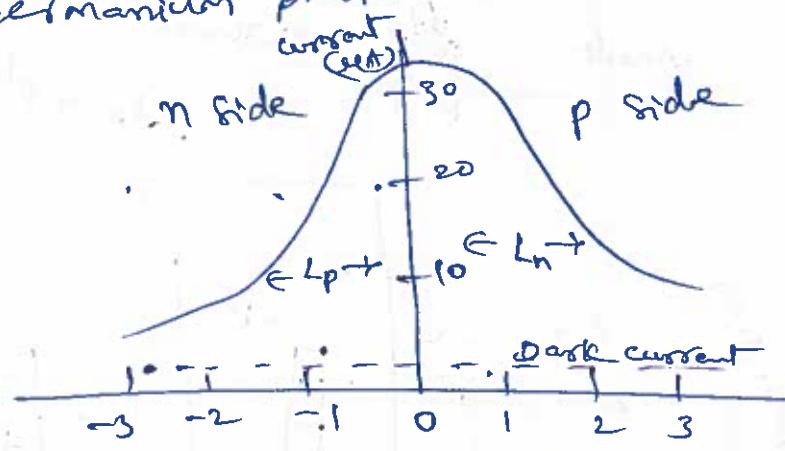


fig: Sensitivity of ~~the~~ a semi conductor
photodiode as a function of the distance
of the light spot from the junction.

The Semiconductor photo diode.

A photodiode is a semiconductor p-n junction device that converts light into an electrical current. The current is generated when photons are absorbed by the photodiode. Photodiodes may contain optical filters, and may have large or small surface areas.

photodiode symbol

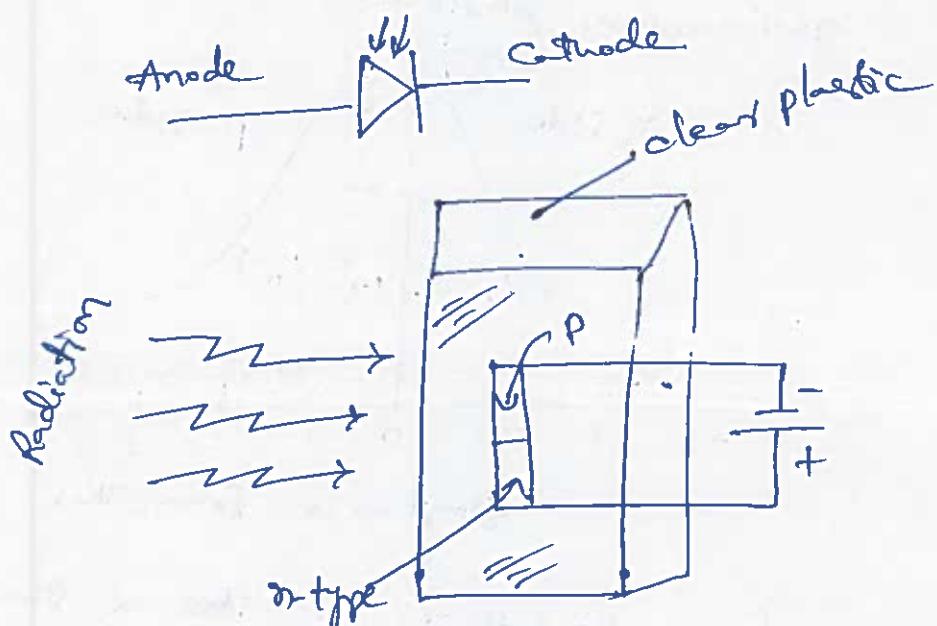
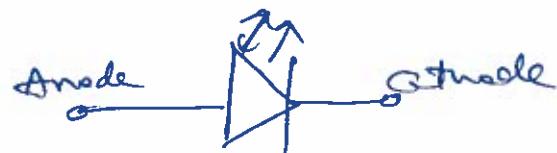


fig: The construction of a semiconductor
photo diode

If a reverse-biased p-n junction is illuminated, the current varies almost linearly with the light (fixed) flux. This device consists of a p-n junction embedded in a clear plastic, as given in fig. Radiation is allowed to fall upon one surface across the junction. The remaining sides of the plastic are either painted black or enclosed in a metallic cage.

Light-emitting Diode

A light emitting diode (LED) is a semiconductor light source that emits light when current flows through it. Electrons in the semiconductor combine with electron holes, releasing energy in the form of photons (i.e. light). It is operated in the forward biased condition.



ex: GaAs, AlGaAs, GaNp

The efficiency of the process of light generation increases with the injected current and with a decrease in temperature.

(The light is concentrated near the junction because most of the carriers are to be found within a diffusion length of the junction.)

Types of LEDs

When forward biased, minority carriers are injected across the p-n junction - one across the junction these minority carriers recombine with majority carriers and give up energy in the form of light.

clipping circuits:

A clipper (or limiter) is used to clip off ~~off~~ or remove a portion of an a.c. signal. It is called Clipper. These clippers can remove signal voltages above or below a specified level.

The important diode clippers are (i) positive clipper (ii) biased clipper (iii) combination clipper

(i) positive clipper:

positive clipper removes the positive half-cycles of the input voltage.

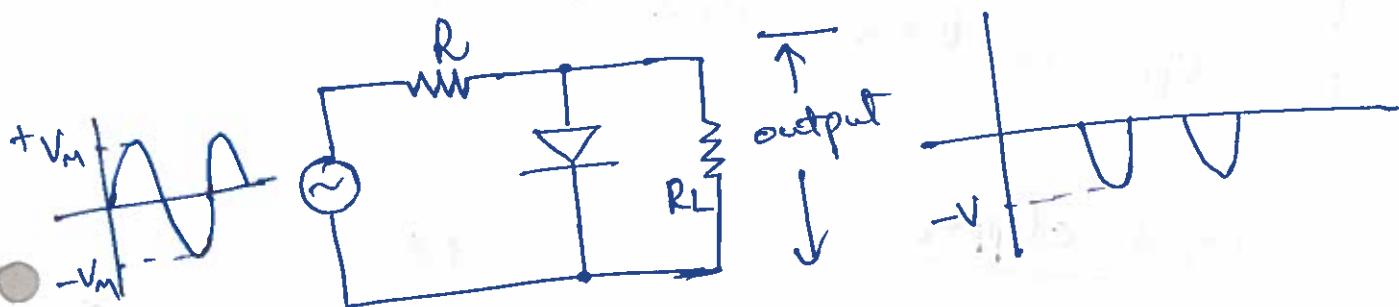


fig: positive clipper

The circuit action is as follows. During the positive half cycle of the input voltage, the diode is forward biased and conducts heavily. Therefore, the voltage across the diode and hence across the load R_L is zero. Hence + output voltage during positive half cycles is zero.

During the negative half-cycle of the input voltage, the diode is reverse biased and behaves as an open. In this condition, the circuit behaves as a voltage divider with an output of

$$\text{output voltage} = \frac{R_L}{R+R_L} V_m$$

R_L is greater than R .

$$\therefore \text{output voltage} = -V_m.$$

It may be noted that if it is desired to remove the negative half-cycle of the input, the only thing to be done is to reverse the polarities of the diode in the circuit. ~~it is called~~ It's clipper is then called a negative clipper.

(ii) Biased clipper:

Sometimes it is desired to remove a small portion of positive (or) negative half-cycle of the signal voltage. For this purpose, biased clipper is used.

The circuit action is as follows. The diode will conduct heavily so long as input voltage is greater than $+V$. When input voltage is greater

②

than $+V$, the diode behaves as a short and the output equals $+V$. The output will stay at $+V$ so long as the input voltage is greater than $+V$. During the period $+V$, the diode is reverse biased and behaves as an open. Therefore, most of the input voltage appears across the output. In this way, the biased positive clipper removes input voltage above $+V$. During the negative half cycle of the input voltage, the diode remains reverse biased. Therefore, almost entire negative half-cycle appears across the load.

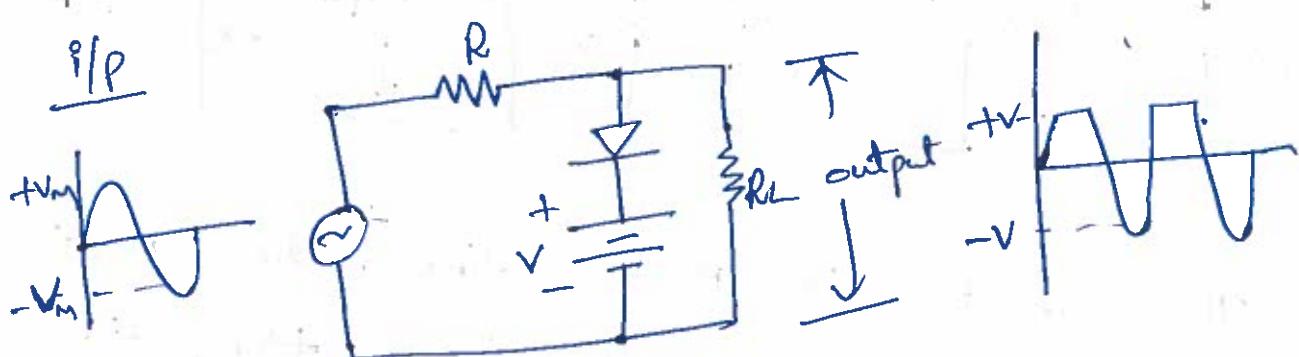
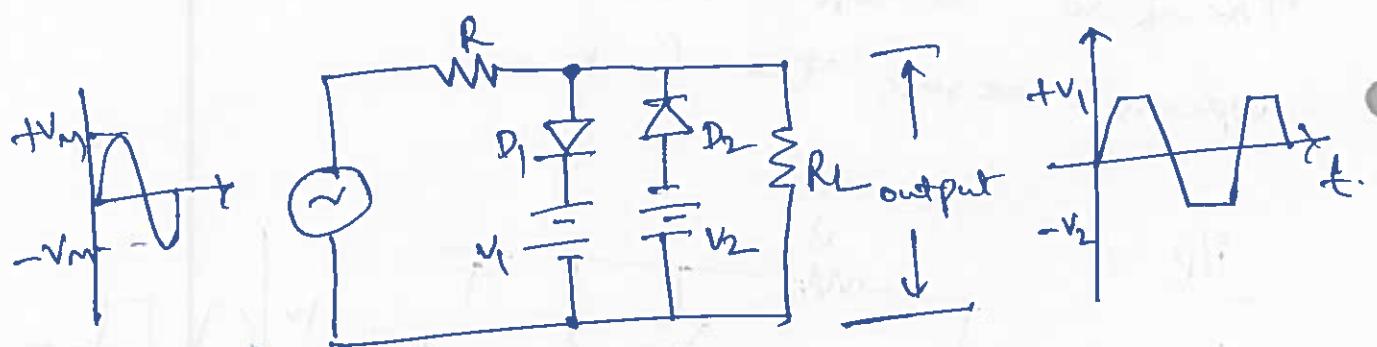


fig: Biased positive clipper.

If it is desired to clip a portion of negative half-cycles of input voltage, the only thing to be done is to reverse the polarities of diode or battery. Such a circuit is then called a biased negative clipper.

(iii) Combination clipper:

It is a combination of biased positive and negative clippers. with a combination clipper, a portion of both positive and negative half-cycles of input voltage can be removed or clipped as shown in fig.



The circuit action is as follows. When positive input voltage is greater than $+V_1$, diode D_1 conducts heavily while diode D_2 remains reverse biased.

(3)

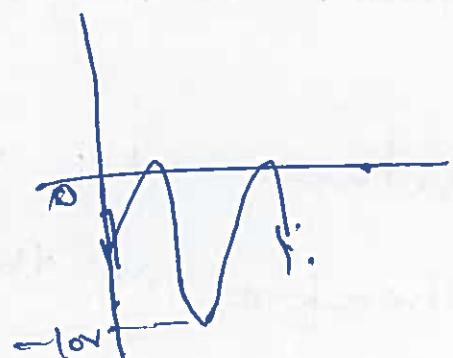
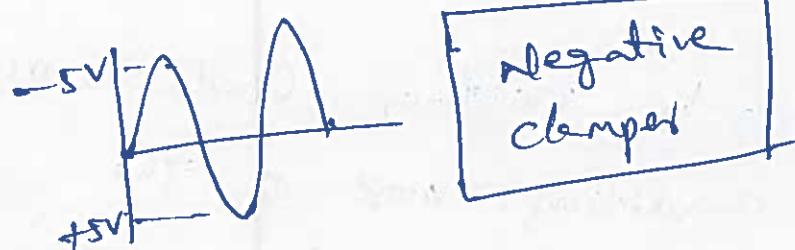
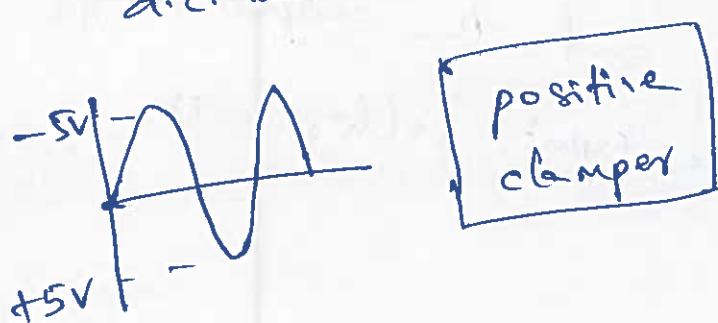
Therefore, a voltage $+V_1$ appears across the load. This output stays at $+V_1$ so long as the input voltage exceeds $+V_1$. On the other hand, during the negative half-cycle, the diode D_2 will conduct heavily and the output stays at $-V_2$ so long as the input voltage is greater than $-V_2$.

Between $+V_1$ and $-V_2$ neither diode is on. Therefore, in this condition, most of the input voltage appears across the load. It is interesting to note that this clipping circuit can give square wave output if V_{xy} is much greater than the clipping levels.

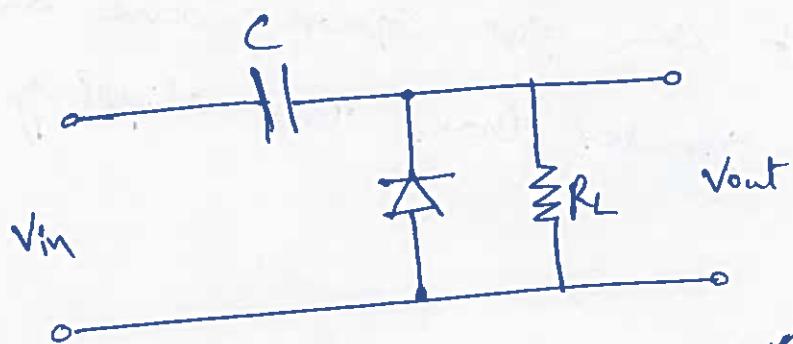
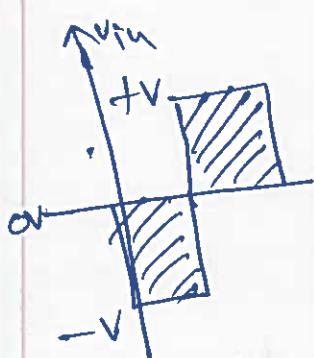
Clippers find extensive use in radar, digital and other electronic systems.

Clamping circuits!

A circuit that places either the positive or negative peak of a signal at a desired d.c. level is known as a clamping circuit.



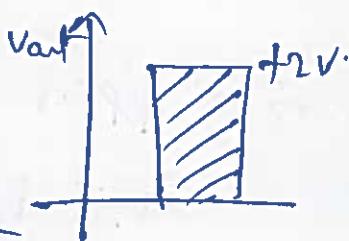
positive clamer!



fig①

operation!

- During the negative halfcycle of the input signal, the diode is forward biased. Therefore, the diode behaves as a short as shown in fig②



(4)

The charging time constant ($= CR_f$ where R_f = forward resistance of the diode) is very small so that the capacitor will charge to V volts very quickly. It is easy to see that during this interval, the output voltage is directly across the short circuit. Therefore, $V_{out} = 0$.

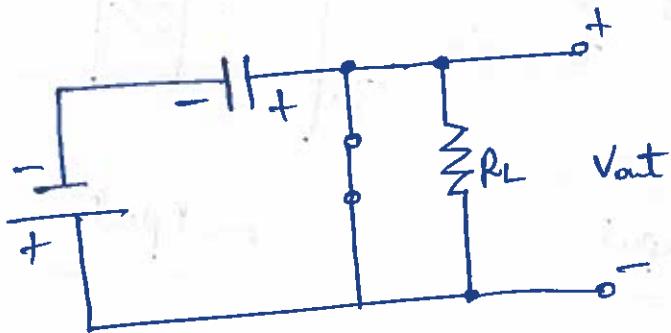


fig. ②

(ii) when the input switches to $+V$ (i.e. positive half-cycle), the diode is reverse biased and behaves as an open \circ . Since the discharging time constant ($= CR_L$) is much greater than the time period of the input signal, the capacitor remains almost fully charged to V volts during the off time of the diode.

Referring to fig. ③ and applying Kirchhoff's voltage law to the input loop, we have,

$$V + V - V_{out} = 0$$

$$V_{out} = 2V$$

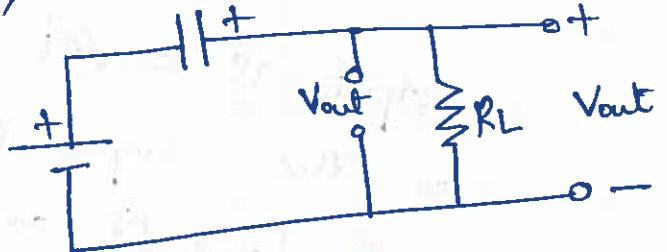
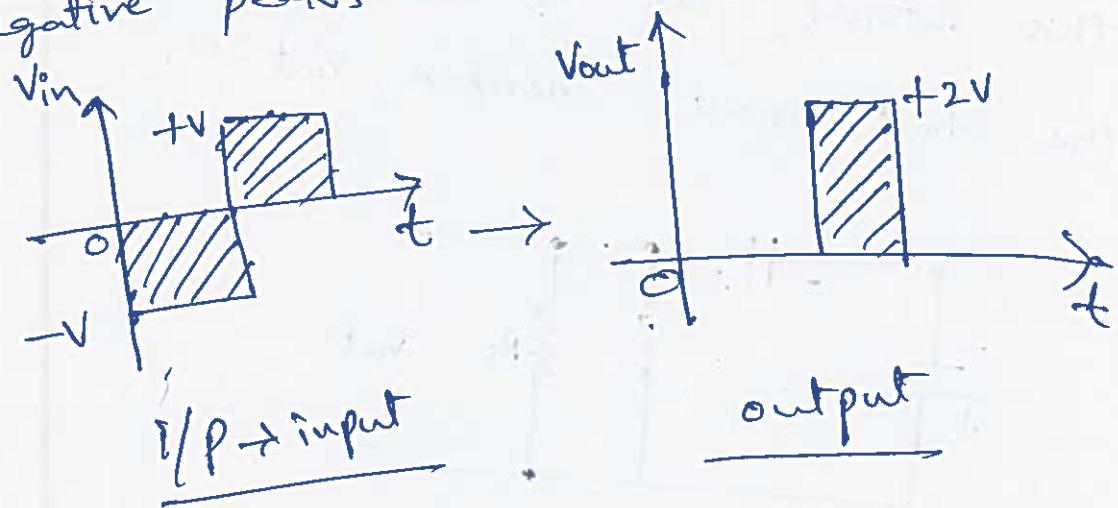


fig: ③

The resulting waveform is shown by fig ④. It is clear that it is a positively clamped output. That is to say the input signal has been pushed upward by V Volts so that negative peaks fall on the zero level.



* Comparators! (Diode Comparators)

- An amplitude Comparator is a circuit that tells the time instant at which the input amplitude has reached a reference level.
- Using an ideal diode, as long as, $V_i < V_F$, $V_o = V_F$. If $V_i \geq V_F$, $V_o = V_i$ up to $t = t_1$, $V_o = V_F$ and the slope of the output is 0. (At $t = t_1$, output suddenly rises as the input (the slope at the output has changed) and this is the time instant at which the input reaches the ~~reference~~ reference level).

reference level V_R . The point P' where the slope changes when the diode conducts is called the break point. The diode in this case is called a "pick-off" diode.

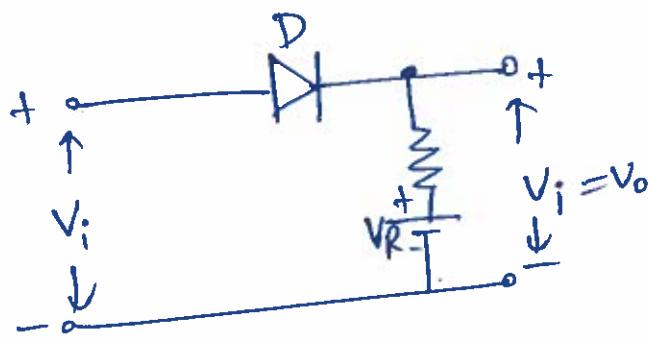


fig. (a)

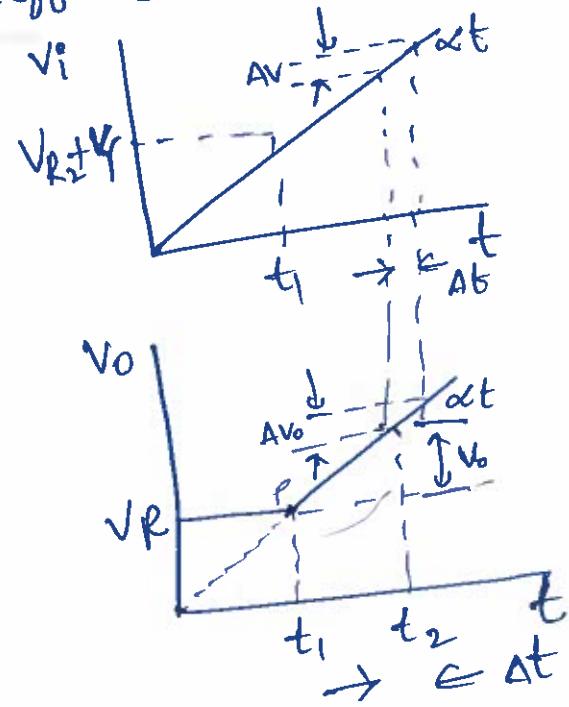


fig. (b)

Fig(a) diode comparator.

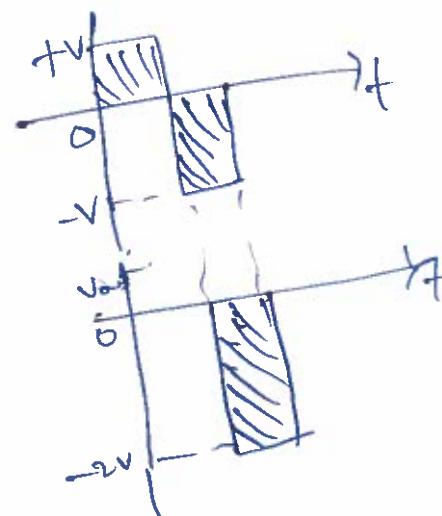
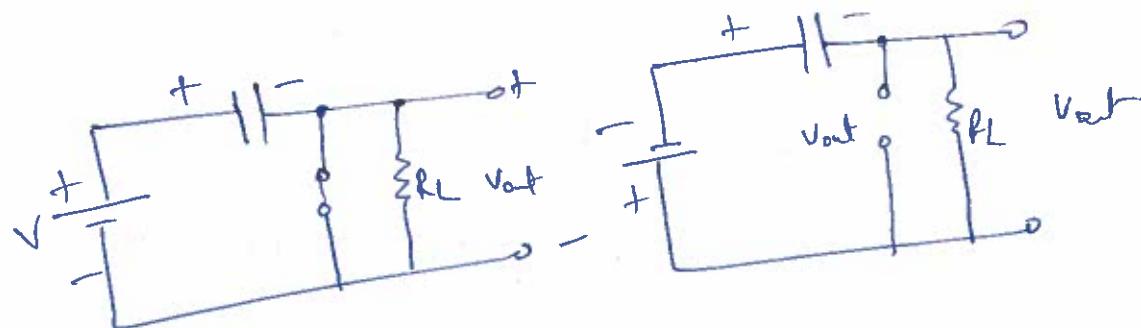
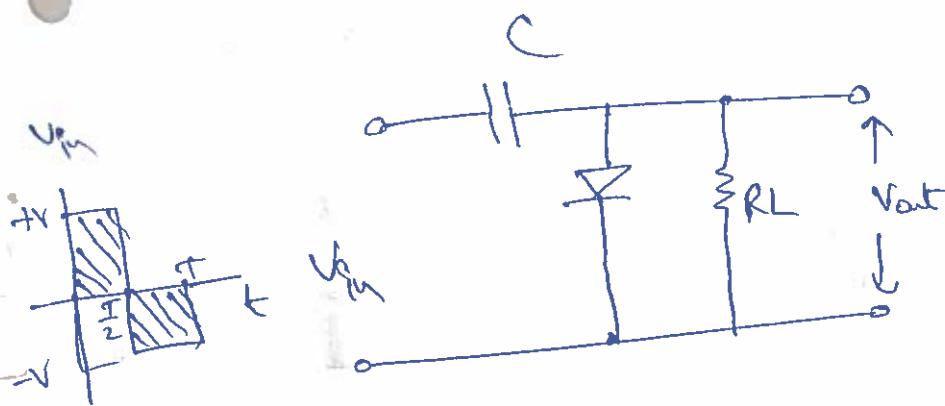
Fig(b) the comparison operation is illustrated with a ramp input signal V_i and the corresponding output waveform is indicated.

Unit-1, 34/59

clamping circuit (positive clamped)

A circuit that places either the positive or negative peak of a signal at a desired d.c level is known as a clamping circuit.

Negative clamped:



The charged output is taken across R_L .

- ① During the positive half-cycle of the input signal the diode is forward biased, the diode behaves as a short as shown in fig. The charging time constant ($= C_{ff} R_L$) is very small so that the capacitor will charge to V volts very quickly. During this interval, the output voltage is directly across the short circuit. Therefore $V_{out} = 0$.
- ② When the input switches to $-V$ state (ie negative half-cycle), the diode is reverse biased and behaves as an open as shown in fig. Since the discharging time constant ($= C_{ff} R_L$) is much greater than the time period of the input signal, the capacitor almost remains fully charged to V volts during the off time of the diode and applying Kirchhoff's Voltage law to the input loop we have

$$-V - V - V_{out} \rightarrow 0$$

$$V_{out} = -2V$$

: total swing of the output signal is equal to the total swing of the input signal.

Introduction to Rectifiers:

Why we go for rectifiers?

Basically all electronic equipment [devices] needs d.c power supply. In previous days for d.c supplies we are using batteries.

Battery: Battery is a series or parallel combination of cells can be divided into 2 types.

- * primary cells
- * secondary cells.

primary cells → They are non-rechargeable

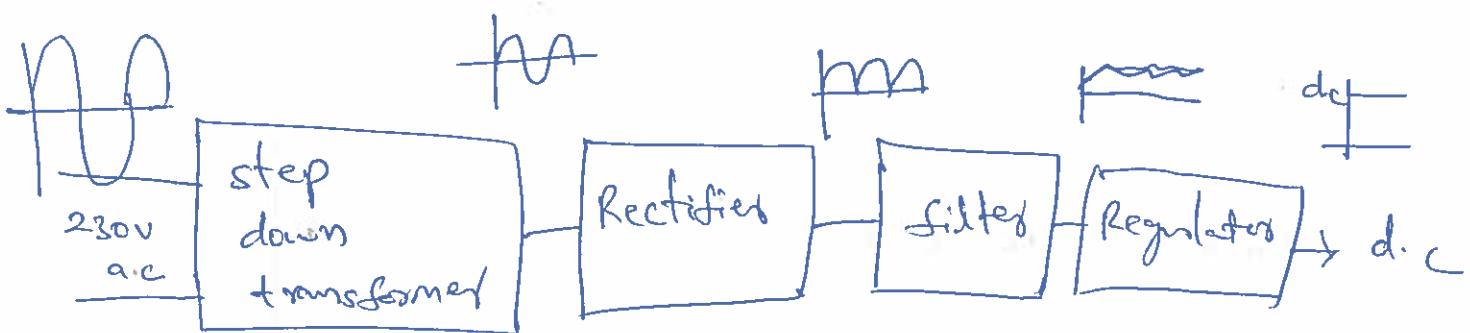
secondary cells → They are rechargeable [cars]

But to recharge these batteries we need D.C

But D.C cannot be generated directly but A.C can generate by all power stations so, to operate any electronic device we want D.C. This can be obtained

from A.C. This is called A.C to D.C converter (or) regulated D.C power supply (or) linear mode power supply [LMPS].

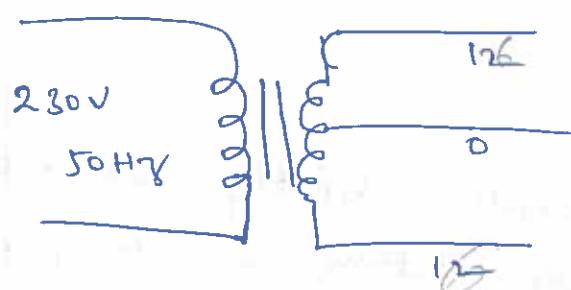
Block diagram of LMPS or regulated D.C power supply.



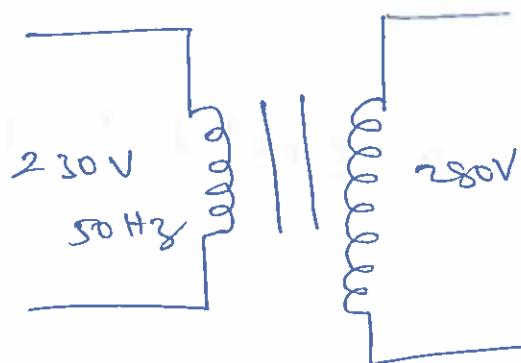
Transformers: Transformer is a device which transforms only A.c. signal. They can be divided into 3 types.

- * Center tapped transformer
- * step up transformer
- * step down transformers

* centre tapped transformer: Here center of the transformer is tapped to get particular voltages like 12v , 9v , 16v .

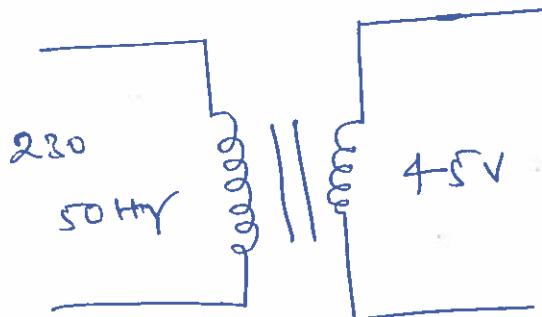


* step up transformer: In this case number of turns of the secondary coil is greater than the no. of turns for the primary coil. so we can get step up voltage.



②

step down transformer: In this case number of turns of the secondary coil is less than that of turns in the primary coil. So we can get step down voltage.



Rectifiers!

Rectifier is a device which convert AC into pulsating DC. Rectifier can be divided into several types. Based on A-C power supply they are of two types.

- * Single phase rectifiers

- * Poly phase rectifiers

Based on the type of connection rectifiers are divided into 2 types

- * Half wave rectifier

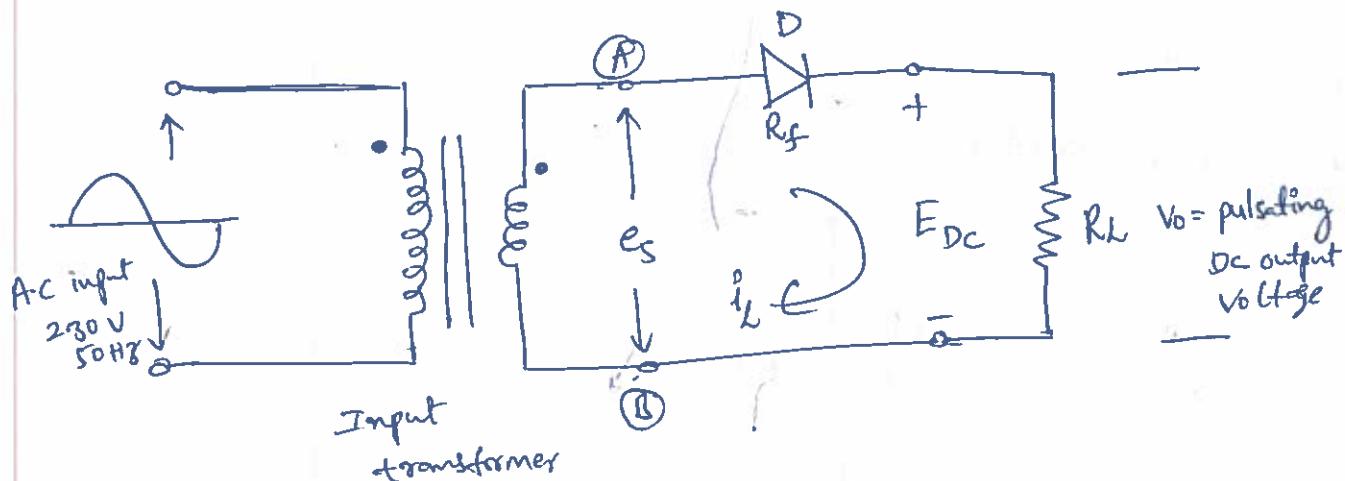
- * Full wave rectifier

Full wave rectifier again divided into 2 types

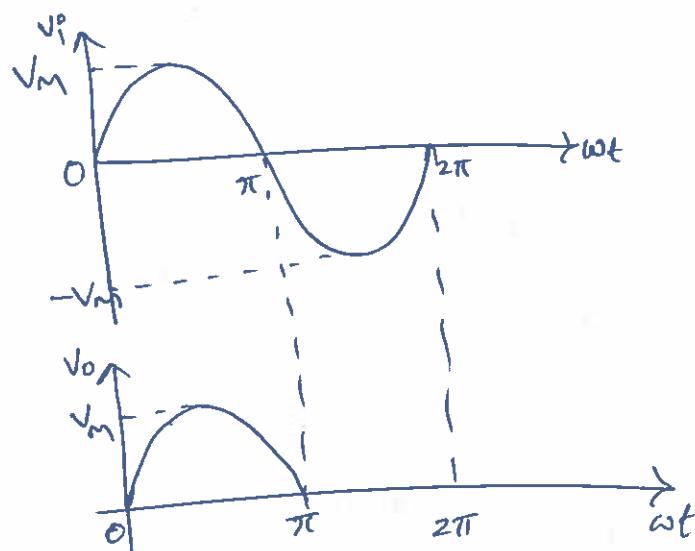
- * Center tapped rectifier

- * Bridge full wave rectifier.

operation of Half wave Rectifier:



(a) Basic structure of a half-wave rectifier



(b) Input and output waveform of half wave rectifier

In the above diagram we used step down transformer which is given to the diode for positive half cycle & it is positive and B is negative. so diode is ON [due to the forward bias]

so the output is same as input In the case of negative half cycle 'A' is negative and B is positive so there is no conduction [for ideal diode conduction is zero (0)].

H.W
find value of total off voltage

$$V_{rms} = \left[\frac{\int_{-\pi}^{2\pi} v_i^2 d(\omega t)}{2\pi} \right]^{1/2}$$

$$= \left[\frac{1}{2\pi} \int_0^\pi v_0^2 d(\omega t) + \int_\pi^{2\pi} v_i^2 d(\omega t) \right]$$

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

$$= \left[\frac{V_m^2}{2\pi} \int_0^\pi \left(\frac{1 - \cos 2\omega t}{2} \right) d(\omega t) \right]^{1/2} \quad \begin{matrix} \sin^2 \theta = \\ \frac{1 - \cos 2\theta}{2} \end{matrix}$$

$$= \left[\frac{V_m^2}{2\pi} \left(\frac{\omega t - \frac{\sin 2\omega t}{2}}{2} \right)_0^\pi \right]^{1/2} \quad \begin{matrix} \theta = \omega t \\ 0 = \omega t \end{matrix}$$

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

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

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

Ques

$$V_{avg} = \left[\frac{1}{\pi} \int_0^\pi v_m \sin \omega t d(\omega t) \right]^{1/2}$$

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

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

H-W

$$V_i = V_m \sin \omega t; V_o > V_i$$

$$V_o = V_m \sin \omega t \text{ for } 0 \leq \omega t \leq \pi$$

$$= 0 \text{ for } \pi \leq \omega t \leq 2\pi$$

Area under the curve \rightarrow to 2π

$$\text{Area} = \frac{1}{2\pi} \int_0^{2\pi} V_o d(\omega t)$$

$$= \frac{1}{2\pi} \int_0^{\pi} V_o d(\omega t) + \underbrace{\int_{\pi}^{2\pi} V_o d(\omega t)}_0$$

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

$$= \frac{1}{2\pi} \left[V_m \left[-\cos \omega t \right]_0^{\pi} \right]$$

$$= \frac{1}{2\pi} V_m \left[-\cos \pi - (-\cos 0) \right]$$

$$= V_m \left[-(-1) - (-1) \right]$$

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

F.W.R

$$V_o = V_m \sim \sin \omega t \quad 0 \leq \omega t \leq \pi$$

$$V_{av} > V_{de} = \frac{\text{Area under the curve}}{\text{Base}}$$

$$= \int_0^{\pi} V_o d(\omega t)$$

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

$$= \frac{V_m}{\pi} \left[-\cos \omega t \right]_0^{\pi} = \frac{V_m}{\pi} \left[-\cos \pi - (-\cos 0) \right]$$

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

(3)

when diode is ON output same as input. It means input is transferred through the output. That's why this is called active elements.

Efficiency of the Half wave rectifier:

Let V_i be the voltage to the primary of the transformer and given by the equation

$$V_i = V_m \sin \omega t; V_m \gg V_r$$

Here V_r is the cut-off voltage of the diode.

Ripple factor (Γ): The ratio of rms value of a.c component to the d.c component in the output is known as ripple factor (Γ)

$$\Gamma = \frac{\text{rms value of a.c component}}{\text{d.c value of component}} = \frac{\sqrt{V_{rms}^2 - V_{d.c}^2}}{V_{d.c}}$$

$$\text{Here } V_{rms} = \sqrt{V_{rms}^2 - V_{d.c}^2}$$

$$\Gamma = \sqrt{\left(\frac{V_{rms}}{V_{d.c}}\right)^2 - 1}$$

V_{av} is the average or the d.c content of the voltage across the load and is given by

$$\begin{aligned} V_{av} &= V_{d.c} = \frac{1}{2\pi} \left[\int_0^\pi V_m \sin \omega t \, d(\omega t) + \int_0^{2\pi} 0 \cdot d(\omega t) \right] \\ &= \frac{V_m}{2\pi} \left[-\cos \omega t \right]_0^\pi = \frac{V_m}{\pi} \end{aligned}$$

$$\text{Therefore } I_{dc} = \frac{V_{dc}}{R_L} = \frac{V_m}{\pi R_L} = \frac{I_m}{\pi}$$

If the values of diode forward resistance (r_f) and the transformed secondary winding resistance (r_s) are also taken into account, then.

$$V_{d.c} = \frac{V_m}{\pi} - I_{d.c} (r_s + r_f)$$

$$I_{d.c} = \frac{V_{d.c}}{(r_s + r_f) + R_L} = \frac{V_m}{\pi (r_s + r_f + R_L)}$$

Rms voltage at the load resistance can be calculated as

$$V_{rms} = \left[\frac{1}{2\pi} \int_0^{\pi} V_m^2 \sin^2 \omega t d(\omega t) \right]^{1/2}$$

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

$$\therefore \text{Therefore } \Gamma = \sqrt{\left[\frac{V_m/2}{V_m/\pi} \right]^2 - 1} = \sqrt{\left(\frac{\pi}{2} \right)^2 - 1} = 1.21$$

From this expression it is clear that the amount of a.c present in the output is 121% of the d.c. Voltage so the half wave rectifier is not practically useful in converting a.c. into d.c

Efficiency (η): The ratio of d.c output power to a.c input power is known as rectifier efficiency (η).

$$\eta = \frac{\text{d.c output power}}{\text{a.c input power}} = \frac{P_{d.c}}{P_{a.c}}$$

$$= \frac{\left(\frac{V_{d.c}}{R_L} \right)^2}{\left(\frac{V_{rms}}{R_L} \right)^2} = \frac{\left(\frac{V_m}{\pi} \right)^2}{\left(\frac{V_m}{2} \right)^2} = \frac{4}{\pi^2} = 0.406$$

= 40.6%

Peak Inverse Voltage (PIV): it is defined as the maximum reverse voltage that a diode can withstand without destroying the junction. The peak Inverse voltage across a diode is the peak of the negative half cycle. for halfwave rectifier, PIV is V_m

Transformer Utilisation Factor (TUF): In the design of any power supply, the rating of the transformer should be determined. This can be done with a knowledge of the d.c power delivered to the load and the type of rectifying circuit used.

$$TUF = \frac{\text{d.c power delivered to the load}}{\text{a.c rating of the transformer Secondary.}}$$

$$= \frac{P_{d.c}}{P_{a.c \text{ rated.}}}$$

In the half wave rectifying circuit, the rated voltage of the transformer secondary is $V_m/\sqrt{2}$, but the actual rms current flowing through the winding is only $\frac{I_m}{2}$, not $\frac{I_m}{\sqrt{2}}$.

$$TUF = \frac{\frac{I_m^2}{\pi^2} R_L}{\frac{V_m \times I_m}{\sqrt{2}} \times \frac{1}{2}} = \frac{\frac{V_m^2}{\pi^2} \frac{1}{R_L}}{\frac{V_m}{\sqrt{2}} \frac{V_m}{2R_L}} = \frac{2\sqrt{2}}{\pi^2} \approx 0.287$$

The TUF for a half wave rectifier is 0.287.

Form Factor

$$\text{form factor} = \frac{\text{Vms Value}}{\text{average Value}}$$

$$= \frac{V_m/\sqrt{2}}{V_m/\pi} = \frac{\pi}{2} = 1.57$$

peak Factor:

$$\text{peak factor} = \frac{\text{Peak Value}}{\text{Vms Value}}$$

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

full wave rectifiers:

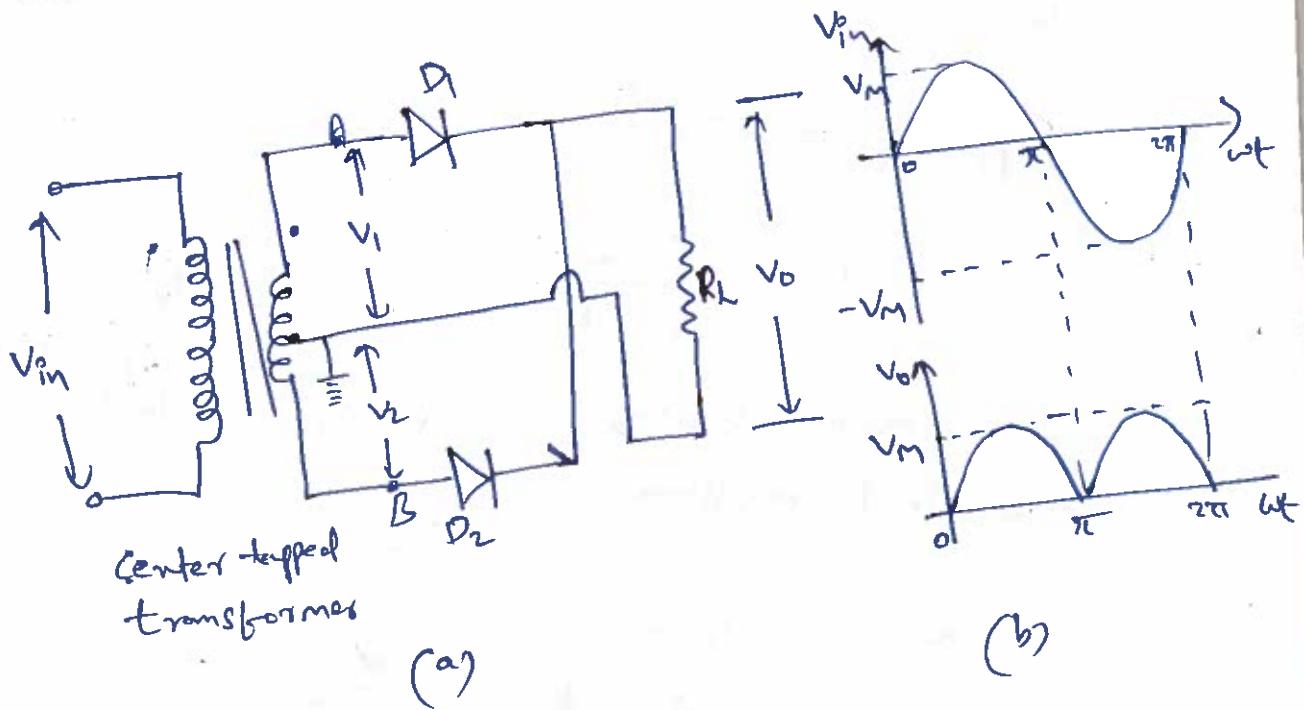
Disadvantages:

- ① Efficiency (η) is low [40%]
- ② Utilization of Ac power is low [because only we are getting positive half cycle].

(1)

Center tapped full wave Rectifier:

To overcome the disadvantage of half-wave rectifier we go for centre tapped full wave rectifier.



Here we are using centre tapped transformer [it is used to select particular voltages] 606, 909. So it is called centre tapped full wave rectifier.

For positive half cycle A is positive and B is negative. so D_1 is forward bias and D_2 is reverse bias. The entire input voltage will be ^{comes} appeared across load. Here output voltage is same as input.

unit-1, 47/59

If we apply the negative half cycle then "A" is negative and B is positive so diode D₂ is in forward bias and diode D₁ is reverse bias.

Again entire input voltage will be appeared across load.

Ripple Factor (Γ):

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

The average voltage or dc voltage available across the load resistance is

$$V_{dc} = \frac{1}{\pi} \int_0^T V_m \sin \omega t d(\omega t)$$

$$= \frac{V_m}{\pi} [-\cos \omega t]_0^T = \frac{2V_m}{\pi}$$

$$I_{dc} = \frac{V_{dc}}{R_L} = \frac{2V_m}{\pi R_L} = \frac{2I_m}{\pi} \text{ and } I_{rms} = \frac{I_m}{\sqrt{2}}$$

If the diode forward resistance (r_f) and the transformer secondary winding resistance (r_s) are included in the analysis, then

$$\underline{V_{dc}} = \underline{\frac{2V_m}{\pi}} - \underline{I_{dc}(r_s + r_f)}$$

$$I_{dc} = \frac{V_{dc}}{(r_s + r_f) + R_L} = \frac{2V_m}{\pi(r_s + r_f + R_L)}$$

RMS value of the voltage at the load resistance is

$$V_{rms} = \sqrt{\left[\frac{1}{\pi} \int_0^{\pi} V_m \sin \omega t d(\omega t) \right]} = \frac{V_m}{\sqrt{2}}$$

$$\therefore F = \sqrt{\left(\frac{V_m / \sqrt{2}}{2V_m / \pi} \right)^2 - 1} = \sqrt{\frac{\pi^2}{8} - 1} = 0.482$$

Efficiency (η): The ratio of dc output power to ac input power is known as rectifier efficiency (η).

$$\eta = \frac{\text{dc output power}}{\text{ac input power}} = \frac{P_{dc}}{P_{ac}}$$

$$= \frac{(\sqrt{dc})^2 / R_L}{(\sqrt{rms})^2 / R_L} = \frac{\left[\frac{2V_m}{\pi} \right]^2}{\left[\frac{V_m}{\sqrt{2}} \right]^2}$$

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

The maximum efficiency of a full-wave rectifier is 81.2%.

Transformer Utilization factor (TUF): The average TUF for a full-wave rectifying circuit is determined by considering the primary and secondary winding separately and it gives a value of 0.693.

Form Factor

form factor = $\frac{\text{rms value of the output voltage}}{\text{average value of the output voltage}}$

$$= \frac{V_m/\sqrt{2}}{2V_m/\pi} = \frac{\pi}{2\sqrt{2}} = 1.11$$

Peak Factor:

peak factor = $\frac{\text{peak value of the output voltage}}{\text{rms value of the output voltage}}$

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

Peak Inverse Voltage: peak inverse voltage for full-wave rectified is $2V_m$ because the entire secondary voltage appears across the non-conducting diode.

Disadvantages of Centre tapped full wave Rectifier:

* location of centre tapped transformer is very difficult process.

* it is better to have minimum peak inverse voltage, in this full wave rectifier we are having high peak inverse i.e. $2V_m$.

(5)

Bridge Rectifier

To overcome previous problems we go for Bridge full wave rectifier.

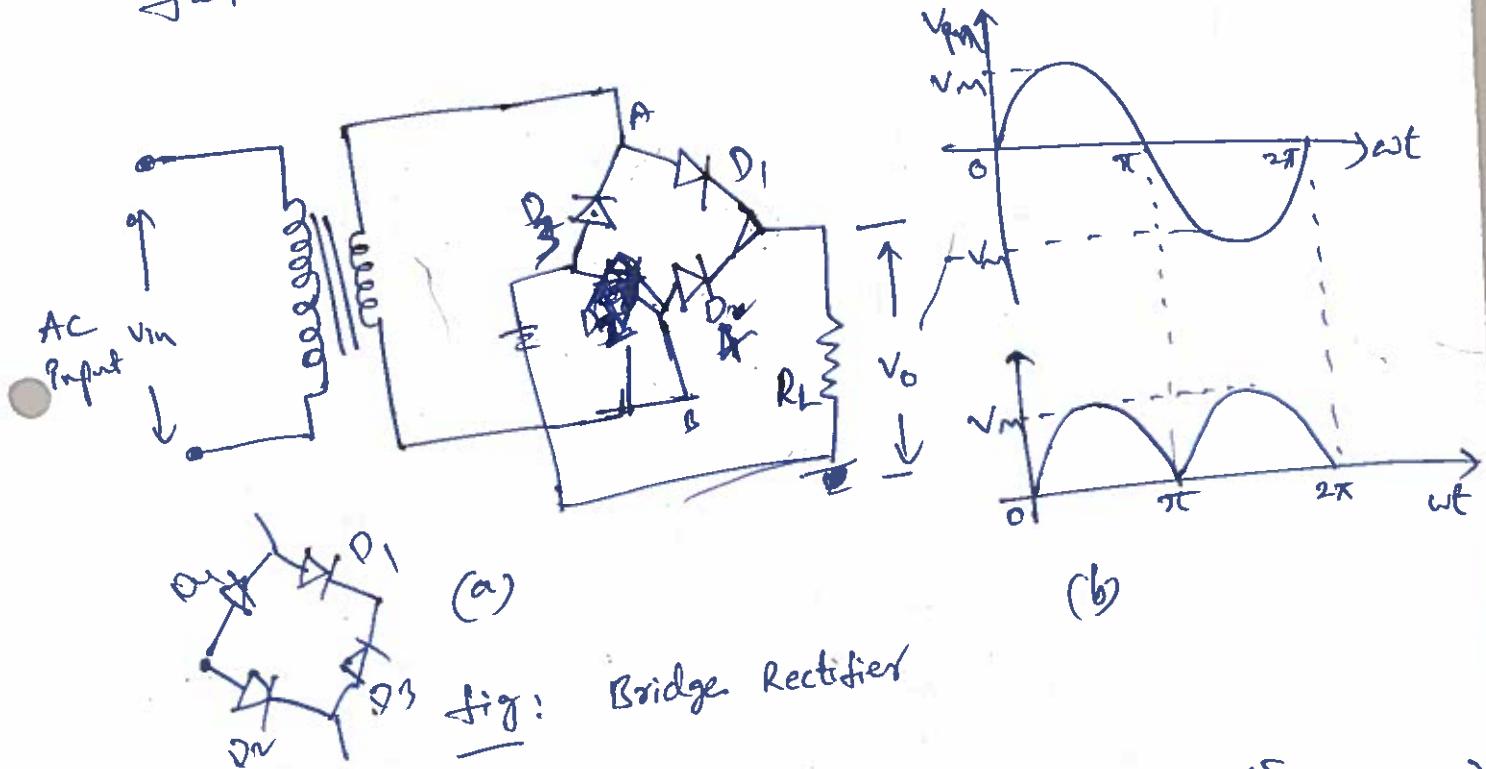


fig: Bridge Rectifier

In this case we see using four diodes [D_1, D_2, D_3, D_4] which are connected in the form of bridge so this is called bridge full wave rectifier

for positive half cycle A is positive if B is negative. so D_1 and D_2 are in forward bias and D_3, D_4 are in reverse biased.

In the same way for negative half cycle A is negative if B is positive so D_3, D_4 are in forward bias and D_1 and D_2 are in reverse bias

unit-1, 51/59

In this case its efficiency (81%) is same as a centre tapped full wave rectifier. But we are not using any centre tapped transformer [which is difficult to use] and in this peak reverse voltage is V_m . The average values of output voltage and load current for bridge rectifier are the same as for a centre-tapped full wave rectifier and the ripple factor is 0.98.)

Advantages:

- (i) The need for centre-tapped transformer is eliminated
- (ii) The output is twice that of the centre-tap circuit for the same secondary voltage
- (iii) The PIV is one-half that of the centre-tap circuit.

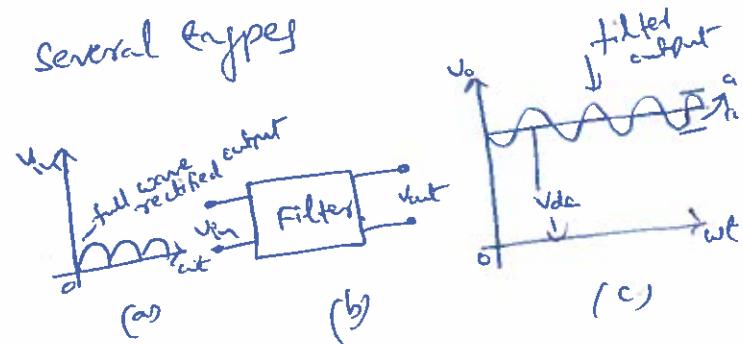
Filters:

After rectifier we are having pulsating DC (AC with DC). Here AC components are called ripples so these ripples are unwanted things. They are eliminated by the device called filter.

Definition: Filter is a device which removes unwanted components. Here AC components are unwanted filter will be inserted between the output of rectifier and load.

filters are classified into several types

- * Inductor filter
- * Capacitor filter
- * LC or L-section filter
- * CLC or π -type filter



Inductor filter:

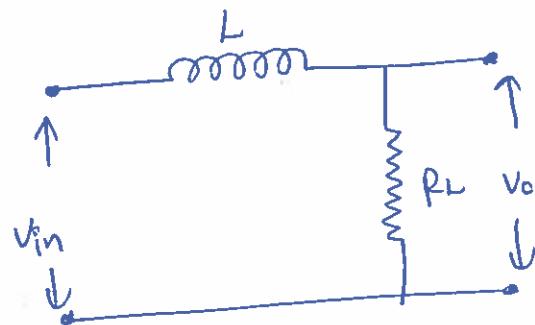


fig: Inductor filter

fig. shows the inductor filter. When the output of the rectifier passes through an inductor, it blocks the AC component and allows only the DC component to reach the load.

The ripple factor of the Inductor filter is given by

$$\Gamma = \frac{R_L}{3\sqrt{2} \omega L}$$

The ripple factor will decrease when L is increased and R_L is decreased. The Inductor filter is more effective only when the load current high (small R_L).

The operation of the Inductor filter depends on its well known fundamental property to oppose any change of current passing through it.

This analyse this filter for a full-wave, the Fourier series can be written as

$$V_o = \frac{2V_m}{\pi} - \frac{4V_m}{\pi} \left[\frac{1}{3} \cos 2\omega t + \frac{1}{15} \cos 4\omega t + \frac{1}{35} \cos 6\omega t + \dots \right]$$

The dc component is $\frac{2V_m}{\pi}$

Assuming the third and higher terms contribute little output, the output voltage is

$$V_o = \frac{2V_m}{\pi} - \frac{4V_m}{3\pi} \cos 2\omega t$$

\therefore The dc component of current $I_m = \frac{V_m}{R_L}$

The impedance of series combination of L and R_L at 2ω is

$$Z = \sqrt{R_L^2 + (2\omega L)^2} = \sqrt{R_L^2 + 4\omega^2 L^2}$$

\therefore for the ac component,

$$I_m = \frac{V_m}{\sqrt{R_L^2 + 4\omega^2 L^2}}$$

(2)

i. The resulting current i is given by

$$i = \frac{2V_m}{\pi R_L} - \frac{4V_m}{3\pi} \cdot \frac{\cos(2wt-\phi)}{\sqrt{R_L^2 + 4\omega^2 L^2}}$$

where

$$\phi = \tan^{-1}\left(\frac{2\omega L}{R_L}\right)$$

The ripple factor, which can be defined as the ratio of the rms value of the ripple to the dc value of the wave is

$$\Gamma = \frac{\frac{4V_m}{3\sqrt{2}\sqrt{R_L^2 + 4\omega^2 L^2}}}{\frac{2V_m}{\pi}} = \frac{2}{3\sqrt{2}} \times \frac{1}{\sqrt{1 + \frac{4\omega^2 L^2}{R_L^2}}}$$

if $\frac{4\omega^2 L^2}{R_L^2} \gg 1$, then a simplified expression for

$$\Gamma \approx \Gamma = \frac{R_L}{3\sqrt{2}\omega L}$$

In case, the load resistance is infinity, i.e. the output is an open circuit, then the ripple factor is

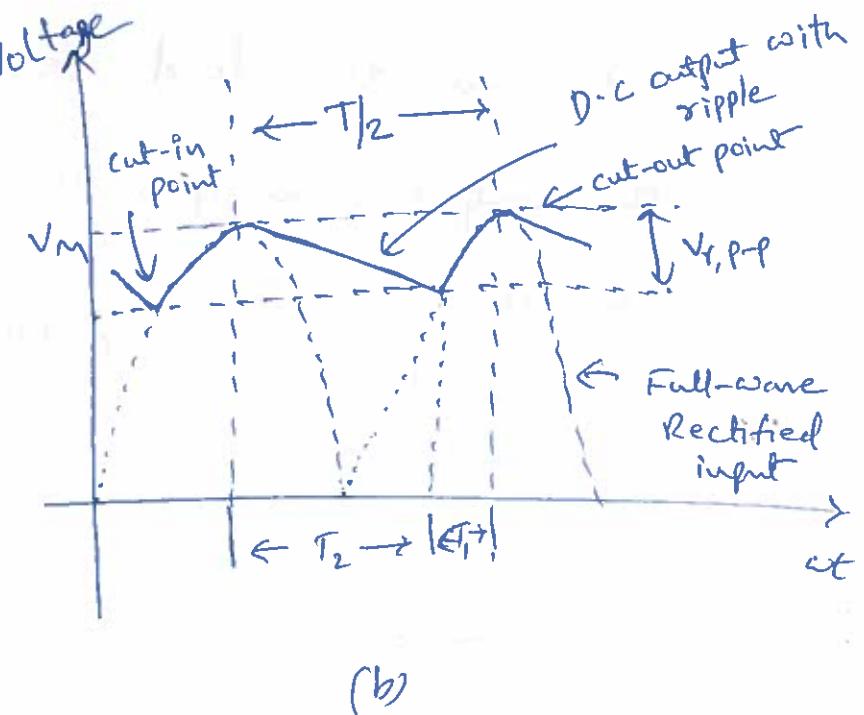
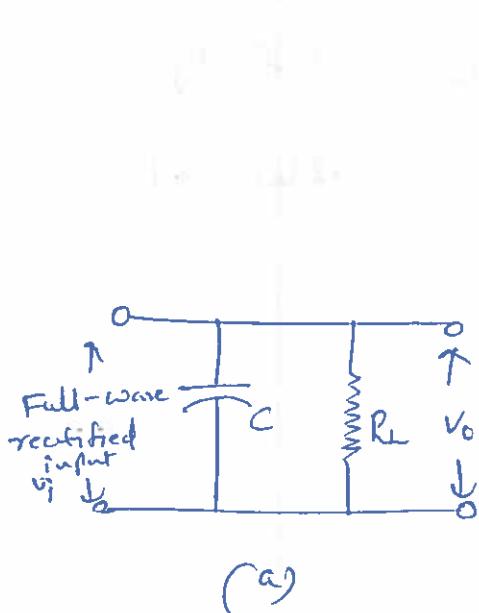
$$\Gamma = \frac{2}{3\sqrt{2}} = 0.471.$$

* Capacitor filter:

The property of a capacitor is that it allows ac component and blocks the dc component. The operation of a capacitor filter is to short the ripple to ground but leave the dc to appear at the output when it is connected across a pulsating dc voltage.

During the positive half-cycle, the capacitor charges up to the peak value of the transformer secondary voltage V_m , and will try to maintain this value as the full wave input drops to zero.

The diode will conduct when the transformer secondary voltage becomes more than the 'cut-in' voltage of the diode. The diode stops conducting when the transformer voltage becomes less than the diode voltage. This is called cut-out voltage.



(a) capacitor filter

(b) Ripple Voltage Triangular waveform

The charge it has acquired = $V_{r,p-p} \times C$

~~Therefore~~ The charge it has lost = $I_{dc} \times T_2$

Therefore $V_{r,p-p} = I_{dc} \times T_2$

If the value of the capacitor is fairly large, or the value of the load resistance is very large, then it can be assumed that the time, T_2 is equal to half the periodic time of the waveform.

$$\text{i.e. } T_2 = \frac{T}{2} = \frac{1}{2f}, \text{ then } V_{r,p-p} = \frac{I_{dc}}{2fc}$$

with the assumptions made above, the ripple waveform will be triangular in nature and the rms value of the ripple is given by

$$V_{r,\text{rms}} = \frac{V_{r,p-p}}{2\sqrt{3}}$$

∴ from the above equation, we have

$$V_{r,\text{rms}} = \frac{I_{dc}}{4\sqrt{3} fc}$$

$$= \frac{V_{dc}}{4\sqrt{3} fc R_L}, \text{ since } I_{dc} = \frac{V_{dc}}{R_L}$$

$$\therefore \text{ripple factor } F = \frac{V_{r,\text{rms}}}{V_{dc}} = \frac{1}{4\sqrt{3} fc R_L}$$

The ripple may be decreased by increasing C or R_L (or both) with a resulting increase in dc output voltage.

Lc Filter (or) L-section Filter

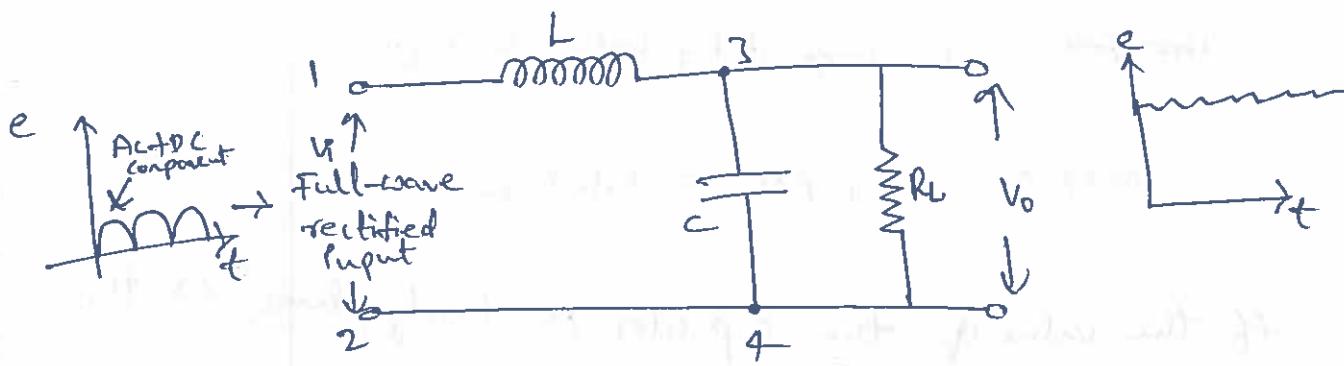


Fig shows the a typical choke input filter circuit. It consists of a choke ^(Inductor) _L connected in series with the rectifier output and a filter capacitor ^(Inductor) _C across the load.

The pulsating output of the rectifier is applied across terminals 1 and 2 of the filter circuit. The pulsating output of rectifier contains a.c. and d.c. components. The Inductor offers high opposition to the passage of a.c. component but negligible opposition to the d.c. component.

The result is that most of the a.c. component appears across the Inductor while whole of d.c. component passes through the Inductor on its way to load.

At terminal 3, (the rectifier output contains d.c. component and the remaining part of a.c. component ^{which} has managed to pass through the Inductor.) the low reactance of filter capacitor bypasses the a.c. component but prevents the d.c. component to flow through it. Therefore, only d.c. component reaches the load. In this way, the filter circuit has filtered out the a.c. component from the rectifier output, allowing d.c. component to reach the load.

$$\text{Ripple factor} = \frac{1}{6\sqrt{2}\omega RC}$$

Here Hence ripple factor for choke-input filter does not depend upon the load resistance unlike the capacitor input filter.

PN junction diode applications:-

An ideal pn junction diode is a two terminal polarity sensitive device that has zero resistance (diode conducts) when it is forward biased and infinite resistance (diode does not conduct) when reverse biased. Due to this characteristic the diode finds a number of applications as follows.

- a) rectifier for dc power supplies.
- b) switch in digital logic circuits used by computers
- c) clamping network used as dc restorer for TV receivers and voltage multipliers.
- d) clipping circuits used as wave shaping circuits used in Computers, radars, radio and TV Receivers.
- e) demodulation (detector) circuits

The same pn junction with different doping concentration finds ~~special~~ following applications.

- a) detectors (APD, PIN photodiode) in optical communication circuits
- b) Zener diodes for voltage regulators
- c) varactor diodes for tuning circuits of radio and TV Receivers.
- d) light emitting diodes for digital displays
- e) LASER diodes for optical communication
- f) Tunnel diodes as oscillator at microwave frequencies

waterloo king, which I've

broken because out of the box it was
damaged and had some scratches
so I had to replace it with another
one which cost me \$10.00. I am
not sure if it will work but I
will try it.

I have also been working on
my keyboard which I have been
building with my dad.

It's not finished yet but we have
most of the parts and it's
working well.

It's made of wood and has
been painted black. It's
about 10 inches wide and
12 inches tall.

It's not finished yet (including my logo) and it's
still being worked on.

The logo is made of wood and
is painted black. It's about 10
inches wide and 12 inches tall.

It's not finished yet (including my logo) and it's
still being worked on.