Module 1

Semiconductor Diodes & Applications

p-n Junction diode, equivalent circuit of diode
Zener Diode, Zener diode as a voltage
regulator, Rectification - Halfwave rectifier,
Full wave rectifier, Bridge rectifier.
Capacitor filter circuit [2.2, 2.3 2.4 of Text 1)

photodiode, LED, photo Coupler. (2.7.4 . 2.7.5 & 2.7.6
of Text 1)

78 XX series & 7805 Fixed IC Voltage Regulator
(8.4.4 & 8.4.5 of Text 1).

(RBT Levels L1, L2 & L3)

Semiconductor Diodes :-

Diode approximation :-

The Diode approximations are

(i) Ideal diode approximation

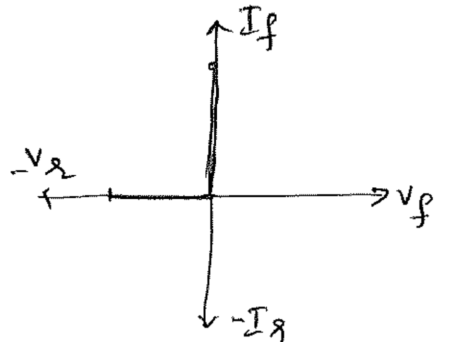
(ii) Second approximation

(iii) linear piecewise approximation or Third approximation.

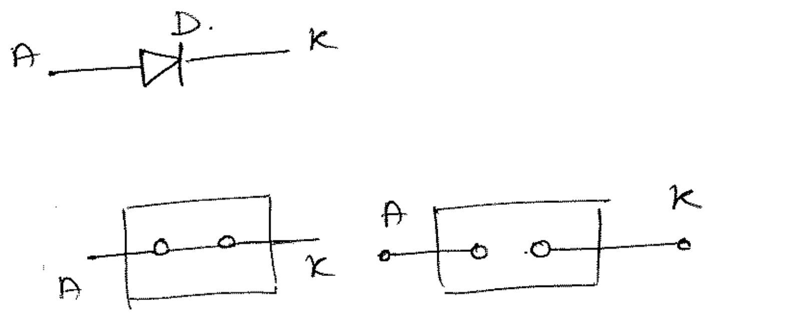
Ideal Diode approximation

An equivalent circuit is defined as a combinational network of passive elements, voltage source etc. It is used to replace the active device for the purpose of mathematical & Analytical Analysis.

In ideal diode equivalent Circuit, the diode is as switch. When diode is forward biased. it is treated as short circuit, with no resistance being offered, i,e $R = 0\,\Omega$. But when it is reverse biased treated as open circuit. Ideal characteristics are shown below. When reverse biased Resistance is infinity.



Ideal characteristics



Forward Biased. Closed circuit

Reverse Biased. open circuit

Second approximation

It is also called as modified equivalent circuit. practically no diode is ideal. Hence for analysing some circuit more accurate approximation is required. & is called second approximation.

To an ideal equivalent circuit, add the cut in (or knee) voltage V_K (for Si Diode = 0.7 V, Ge Diode = 0.3 V). This will shift the characteristics towards right by an amount equal to V_K. modified equivalent circuit is shown below.

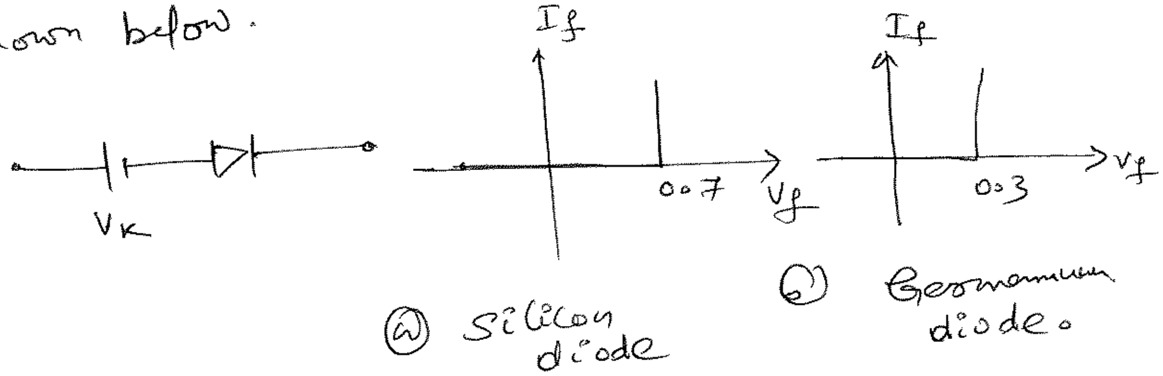


Fig (2) second approximation.

piecewise linear equivalent (approximation) circuit.

The approximation of characteristics with the help of pieces of straight line is called linear piecewise approximation. To the modified equivalent circuit, a forward resistance of r_d is added as shown in figure. Due to addition of r_d the vertical straight characteristics of modified equivalent line will bend towards right resulting in a slope as shown in figure below. when diode is forward biased. The current starts flowing only after V_K (volts). The current then increases linearly with voltage having a slope of $\frac{1}{r_d}$ when diode is reverse biased the diode acts as open circuit offering infinite resistance.

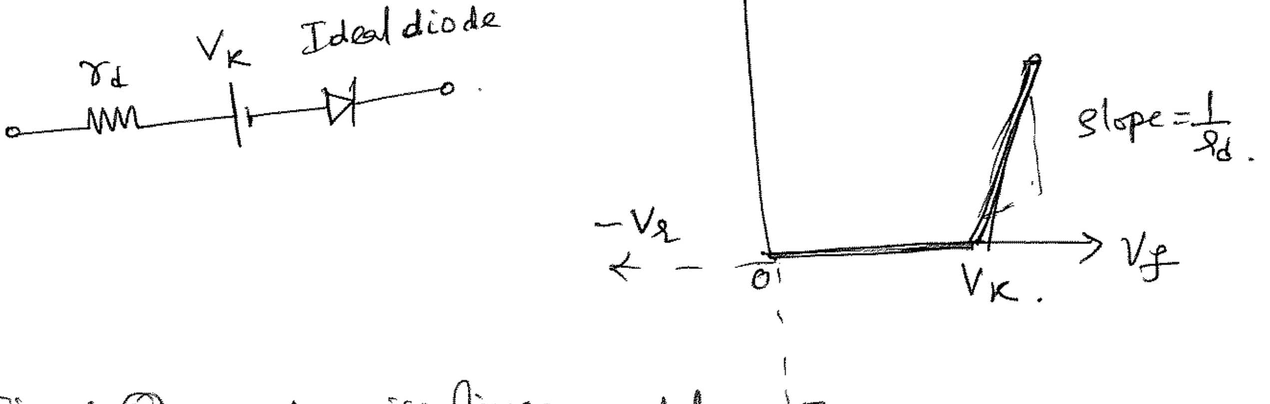


Figure (3). piecewise linear model

Semiconductor Diodes & Applications.

pn-Junction Diode :-

pn junctions Diodes are semiconductor devices which conduct only in one direction.

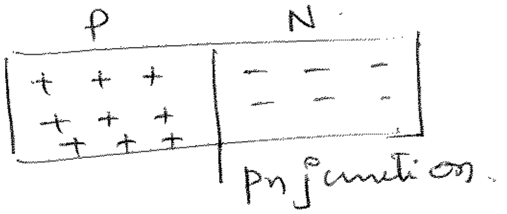
The pn junction ~~can formed~~ be defined as the junction formed by attaching a p-type & an N-type semiconductor. Once the pn junction is formed, the charge carriers are subjected to movement across the pn junction. This process is Transport phenomenon.

Transport phenomenon is defined as the process of movement of charge carriers across the p-n junction in the absence of any external electric field.

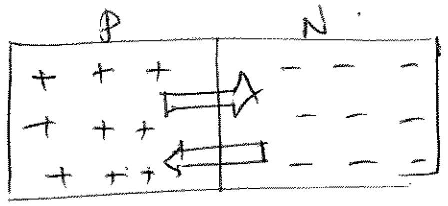
Diffusion process :- It can be defined as the process of movement of majority charge carriers across the junction when there is no external voltage applied.

Due to diffusion process, the majority charge carriers cross the junction & then meets a charge of opposite polarity on the other side of the pn-junction & the charge gets neutralized. The process of charge cancellation is called recombination.

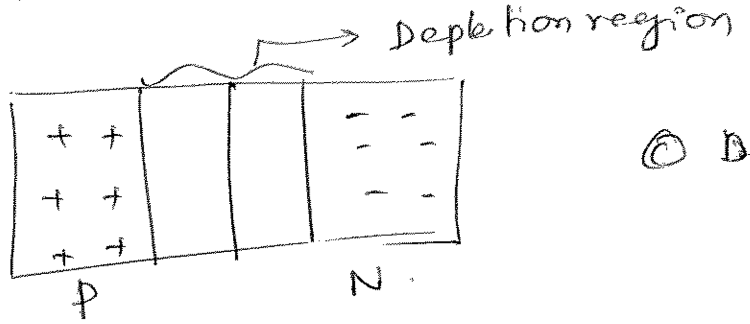
Due to recombination process on either side of junction a region exists without any charge carriers is called depletion region. This region contains neither electrons nor holes.



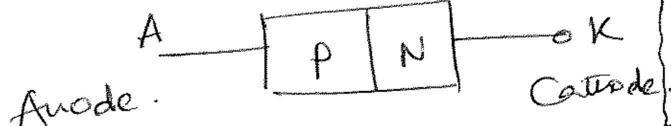
(a) pn-junction.



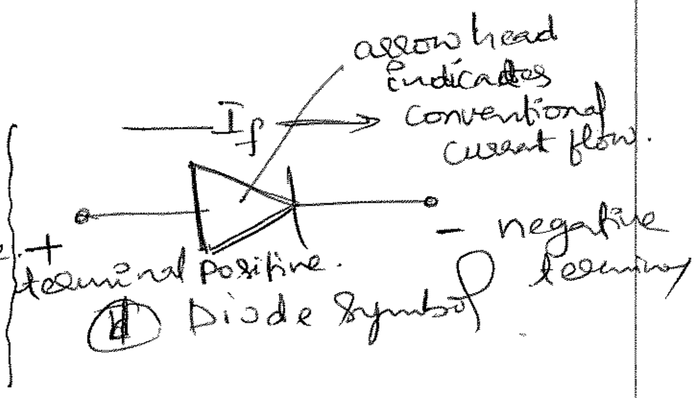
(b) Diffusion.



(c) Depletion region.



(e) p-n junction.



(d) Diode symbol

Diode terminals :-

The device formed by the formation of the pn junction is called a diode. The diode has two terminals. They are Anode, Cathode.

A p-type material is called anode. & n-type is called Cathode.

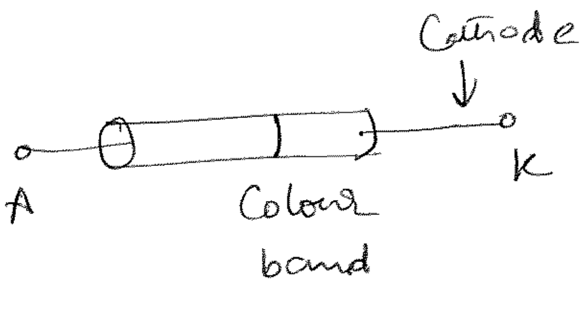
Biasing of pn junction Diode

- Applying external D.C voltage to any electronic device is called biasing.
- p-n junction allows current flow only in one direction, under biased condition.
- Depending upon the polarity of the d.c voltage externally applied to it, the biasing is classified as Forward biasing & Reverse biasing.

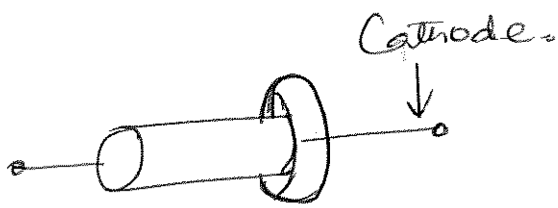
Explain the Types of Diodes.

The diodes classified based on
(1) Forward current carrying capacity
(2) Reverse voltage withstanding capacity.

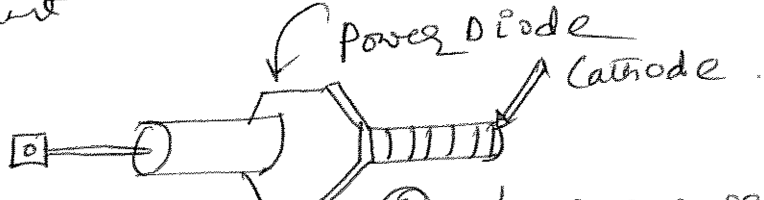
Sl.no.	Diode	Forward current capacity	Reverse voltage capacity.
1.	Low current	upto 100 mA	upto 75 V
2.	medium current	upto 400 mA	upto 200 V
3.	large current	Few amperes	several 100 volts.



(a) Low current



(b) medium current



(c). Large current

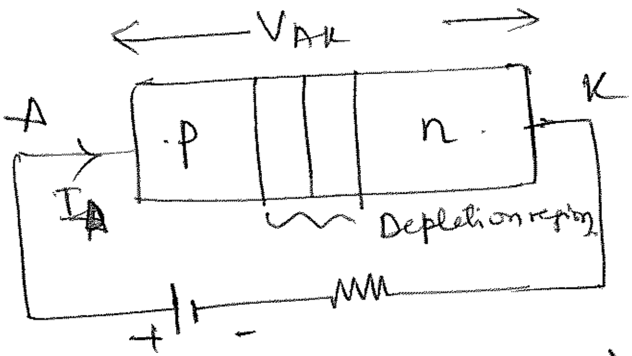
- Low and medium current diodes are connected in circuit by soldering their leads to the connecting terminal. The heat generated by these diodes is not very high & easily carried away by convection to the surroundings.

- The heat generated in case of high current diodes is very high and hence these diodes are stud mounted and provided with head sinks made of metals like copper or aluminium. The heat sinks provide large surface area so that heat can be easily transferred to the surroundings.

Characteristics and parameters.

Forward and Reverse characteristics :-

- If Anode (p-side) is connected to +ve terminal of external voltage source (battery) and cathode to negative terminal of external voltage source. Then Diode is said to be forward biased.



(a) Diode under forward biased Condition.

The holes of p type semiconductor move towards the junction. And the electrons in the n-type semiconductor are pushed towards the junction because of the external supply voltage. These movement of charge carriers contribute flow of current and diode is known as conducting.

- The width of depletion region decreases due to movement of majority charge carrier towards the junction.
- The minimum voltage required for the majority charge carriers to cross the junction is called barrier potential.

  for Si diode barrier potential is 0.7 Volts.

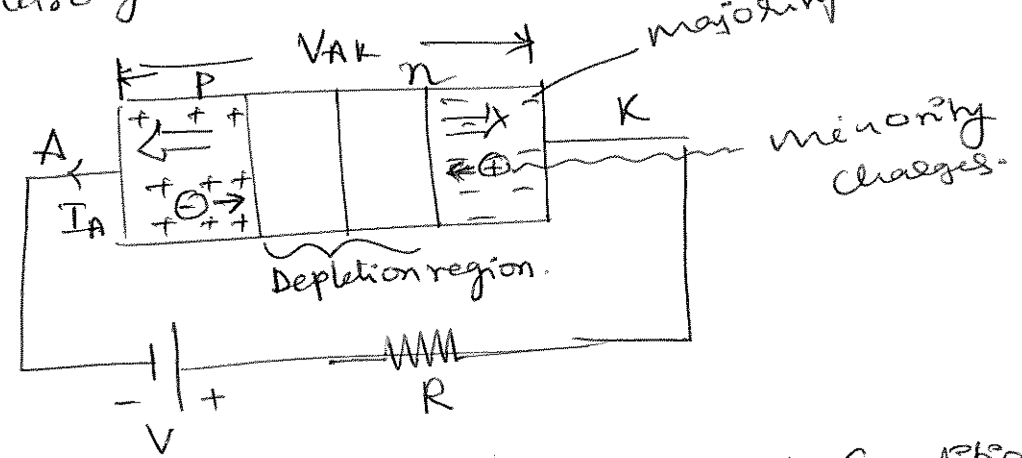
  Ge diode " " is 0.3 Volts

- As voltage V_{AK} increases beyond barrier potential more number of charge carrier are pushed across junction & hence the current through the diode increases exponentionally. as shown in V-I curve (1)

Reverse characteristics.

The diode is said to be reverse biased when the anode voltage is negative with respect to cathode. i,e Anode connected negative terminal of power supply & cathode to positive terminal of the power supply.

V_{AK} is the voltage across the diode & I_A is the current through the diode.



(b) Diode under reverse biased condition.

The majority charge carrier from ~~both~~ sides are pulled away from the junction. This is because of force exerted by the external voltage on the charge carriers.

Since majority charges moves away from junction they doesn't contribute to the flow of current & diode is said to be not conducting.

Even though the small number of minority charge carriers are pushed towards the pn-junction by the external voltage.

The movement of minority charges results in the current through the diode.

Since the minority charges are small in number, the current through the diode is very small & is called reverse saturation current.

Since current is small, it is neglected and the diode is said to be in OFF condition.

. The variation of current is shown below. reverse biasing increases the depletion region widen. when a reverse voltage increases beyond specific value, the pn junction breaks down & current decrease drastically (or increases in reverse direction).

The reverse voltage at which the p-n junction breaks down is called reverse breakdown voltage or peak inverse voltage. (PIV).

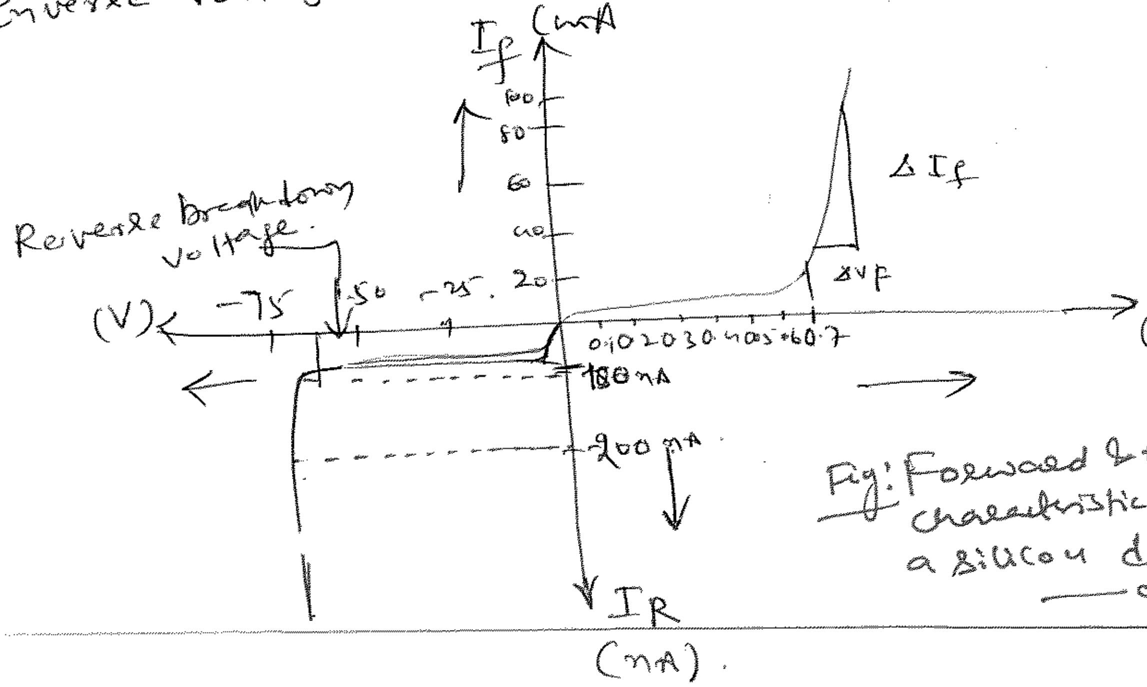
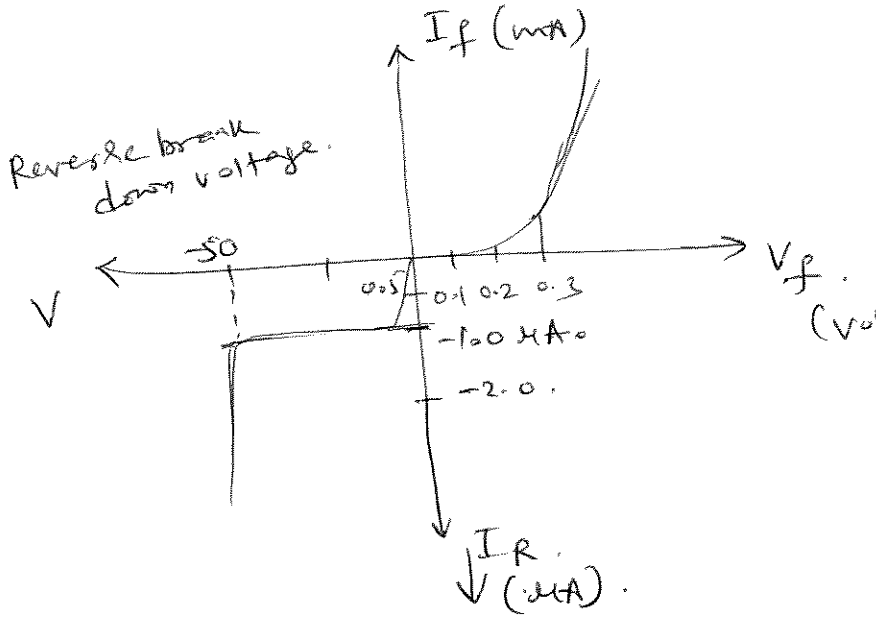


Fig: Forward & Reverse characteristics for a silicon diode.



Typical forward & Reverse Characteristics curve for germanium Diode.

Diode parameters :-

① **Barrier potential** :- It is defined as the minimum voltage under the forward biased condition, at which the diode starts conducting. It is also called cut-in voltage or knee voltage.

② **Forward Voltage drop (V_F).** It is defined as the voltage drop across the diode, when the diode is forward biased. The typical value $V_F = 0.7V$ silicon.
$V_F = 0.3V$ germanium.

③ **Forward Resistance (R_f).**
It is defined as the resistance of the diode when the diode is forward biased. For ideal diode $R_f = 0\Omega$.
For practical diode R_f = few ohms (very low).

④ **Reverse saturation current**
It is defined as the current through the diode when the diode is under the reverse biased condition.

- **peak Inverse voltage (PIV)** - It is defined as the reverse voltage at which the p-n junction breaks down & the diode starts conducting heavily. Once p-n junction break down. the device gets damaged.
It is called as PIV rating of Diode.

Diode Equations :- (Relationship)

The diode relationship refers to diode current & its dependance on the Voltage across diode.

The relationship between diode current & diode voltage is called diode current equation.

The equation is.

$$I = I_0\left[e^{\frac{V}{\eta V_T}} - 1\right]$$

Where :

$I \rightarrow$ current flowing through the diode.

$I_0 \rightarrow$ reverse saturation current of the diode.

$V \rightarrow$ Voltage applied across the diode.

$V = +ve$ for forward biasing

$V = -ve$ for reverse biasing.

$\eta \rightarrow$ Constant. it value $\eta = 1$ or 2.

V_T - voltage equivalent of Temperature.

$= \frac{KT}{q}$ where $K \rightarrow$ Boltzmann Constant

$= 1.38 \times 10^{-23}$ J/K.

$T \rightarrow$ Temperature in ^{o}K.

$T = 273 +$ temperature in $^{\circ}C$.

q — magnitude of electronic charge $= 1.6 \times 10^{-19}$ Columbs.

$$V_T = \frac{1.38 \times 10^{-23}}{1.6 \times 10^{-19}} \times (273 + t^{\circ}C) = (8.625 \times 10^{-5})(273 + t^{\circ}C)$$

$$\boxed{V_T = \frac{273 + t^{\circ}C}{11,600}}$$

for $t^{\circ}C = 27$ $V_T = \underline{0.026}$

$$\boxed{V_T = 26\,mVolts}$$

Nature of V-I characteristics from Equation of Diode

Consider a diode equation

$$I = I_0\left(e^{V/\eta V_T} - 1\right).$$

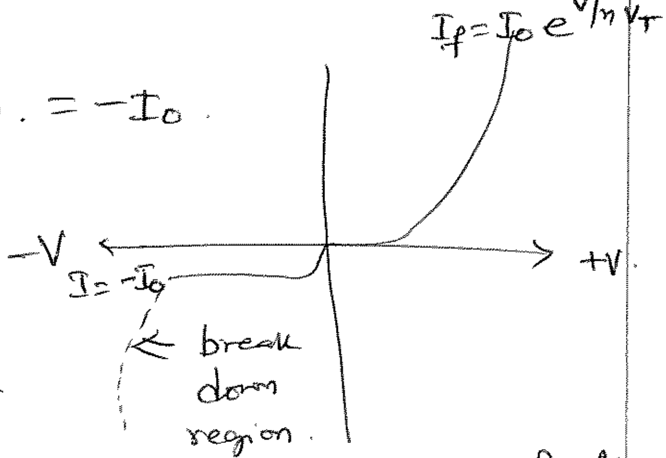
Now for a forward biased condition, the bias voltage V is considered positive & hence exponential index has positive sign. Due to this $1 << e^{V/\eta V_T}$. hence neglecting 1.

$$\boxed{I_f = I_0 \, e^{V/\eta V_T}}$$

It shows that once bias voltage exceeds cut-in voltage, the forward current increases exponentially.

In reverse biased condition, the bias voltage V is treated negative & due to this exponential index has negative sign. So $e^{-V/\eta V_T} << 1$. hence neglecting exponential term. we get

$$I_R = I_0(-1) = -I_0$$



V-I characteristics of p-n junction Diode

(1). A silicon diode operates at low values of current. The diode is under forward biased condition. The reverse saturation current of diode is 10 nA. The voltage across the diode is 0.5 V. Find the current through the diode

given:- $I_0 = 10\,nA$ $\quad V = 0.5\,V$ $\quad t = 25°C$ $\quad \eta = 2$ (Si diode at low currents)

$$V_T = \frac{t° + 273}{11600} = 25.68 \times 10^{-3}\,V = 0.02568\,V$$

Find $I = ?$

$$I = I_0 \left[e^{V/\eta V_T} - 1 \right]$$

$$= 10 \times 10^{-9} \left[e^{\frac{0.5}{2(0.02568)}} - 1 \right]$$

$$= 0.169 \times 10^{-3}\,A = 0.169\,mA$$

(2). A germanium diode operates at room temperature of 22°C with a forward current of 40mA. The forward voltage across diode is 0.25V. Find the reverse saturation current of the diode.

given. $t = 22°C$.

$I = 40\times10^{-3}A$. for germanium diode $\underline{\underline{\eta = 1}}$.

$V = 0.25V$.

$I_0 = ?$

$$V_T = \frac{273+22}{11600} = \underline{0.025}.$$

$$I = I_0\left[e^{V/\eta V_T} - 1\right]$$

$$I_0 = \frac{I}{e^{V/\eta V_T} - 1} = \frac{40\times10^{-3}}{\left(e^{0.25/0.025\times1} - 1\right)}$$

$$= \frac{40\times10^{-3}}{22025} =$$

$$\boxed{I_0 = 1.816 \simeq 1.82\,\mu A}$$

(3) In an application the germanium diode carries a current of 57mA under forward biased Condition The diode operates at a temperature of 100°C. The reverse saturation current of the diode is 5μA. Find the voltage across the diode.

given :- $\underline{\eta = 1}$ (ge) $t = 100°C$

$I_0 = 5\mu A$.

$I = 57\mu A = 0.057A$.

$V = ?$

$$V_T = \frac{273+100}{11600} = 0.032$$

$$I = I_0\left[e^{\frac{V}{\eta V_T}} - 1\right]$$

$$\frac{I}{I_0} = \left[e^{\frac{V}{\eta V_T}} - 1\right]$$

$$\frac{I}{I_0} + 1 = e^{\frac{V}{\eta V_T}}$$

$$\log_e\left[\frac{I}{I_0} + 1\right] = \frac{V}{\eta V_T}$$

$$\log_e\left[\frac{0.057}{5\times10^{-6}} + 1\right] = \frac{V}{0.032}$$

$$\ln\left[11,401.\right] = \frac{V}{0.032}$$

$$\boxed{V = 0.299V}$$

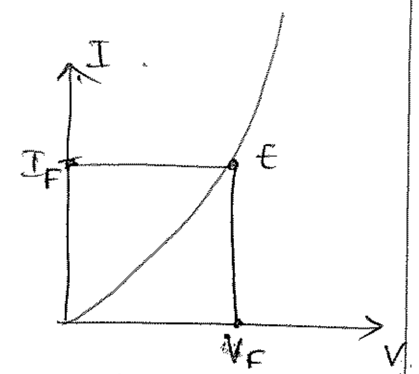
Static and Dynamic resistance.

Static resistance:-

It is also called as DC resistance is defined as a ratio of DC voltage across the diode to the resulting DC forward current through it.

$$R_{dc} = \frac{\text{forward DC voltage}}{\text{forward DC current}} \text{ in } \Omega = \frac{V_F}{I_F}$$

R_{dc} – Varies from $40\Omega - 70\Omega$.



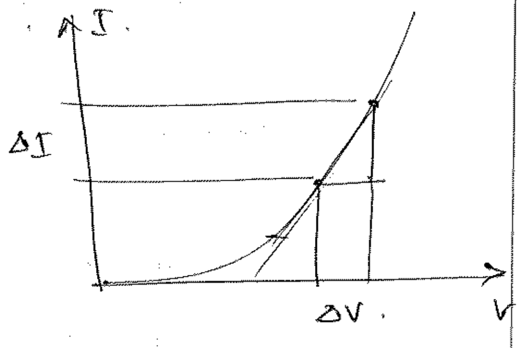
Dynamic forward resistance

when an alternating voltage is applied to diode, then the resistance offered by the diode under forward bias is called dynamic or AC forward resistance

It is defined as ratio of change in forward AC voltage to the change in diode current.

$$R_d = \frac{\Delta V}{\Delta I} = \frac{1}{\text{slope of tangent}}$$

$$\text{slope of tangent} = \frac{\Delta I}{\Delta V}$$



W.K.T the current through the diode is given by

$$I = I_0 \left[e^{\frac{V}{\eta V_T}} - 1 \right]$$

$$I = I_0 \, e^{V/\eta V_T} \rightarrow (2) \qquad e^{V/\eta V_T} \text{ is very large}$$

differentiating eq^n (2) ~~on the~~ with respect to V.

$$\frac{dI}{dV} = \frac{d}{dV}\left\{ I_0 \, e^{\frac{V}{\eta V_T}} \right\} = I_0 \frac{d}{dV}\left\{ e^{\frac{V}{\eta V_T}} \right\}$$

$$\frac{dI}{dV} = I_o\, e^{V/\eta V_T} \cdot \frac{1}{\eta V_T}$$

$$\frac{dI}{dV} = I \cdot \frac{1}{\eta V_T}$$

$$\frac{dV}{dI} = \frac{\eta V_T}{I} \longrightarrow (3)$$

$\eta = 1$ and temperature $t = 27^\circ C$.

$$V_T = \frac{t^\circ C + 273}{11600} = \frac{300K}{11600} = 0.026$$

$$\boxed{r_d = \frac{0.026}{I} = \frac{26\,mV}{I_F}}$$

* A silicon diode operates at low values of current. The diode is under forward biased condition. The reverse saturation current of the diode is 10nA. The voltage across the diode is 0.5V. Find the current through the diode, static & dynamic resistance of the diode. Consider $t^\circ = 25^\circ C$.

given Data :- $I_o = 10\,nA$ $\quad I = ?$

$V = 0.5\,V$

$\eta = 2$ (Si. diode at low currents).

$V_T = \frac{t^\circ C + 273}{11600}$

$= \frac{25 + 273}{11600}$

$= 0.0256$.

$$I = I_o\left[e^{V/\eta V_o} - 1\right)$$

$$= 10 \times 10^{-9}\left[e^{\frac{0.5}{2 \times 0.0256}} - 1\right]$$

$$= 10 \times 10^{-9}\left[e^{9.765} - 1\right]$$

$$= 1.743 \times 10^{-4}$$

$$\boxed{I = 0.1743\,mA} \quad \simeq 0.17\,mA.$$

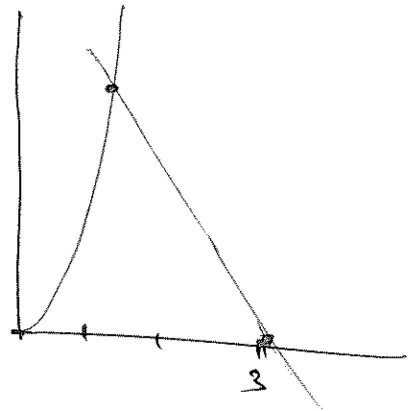
Static resistance $R_f = \frac{V}{I} = \frac{0.5}{0.17m} = 2.9\,K\Omega$

Dynamic resistance $r_d = \frac{0.026}{I} = 0.15\,K\Omega$.

$V_f = V_{in} - I_f R_L$

$I_f = 25mA$ $I_Q = 25mA$.

$I_f = 0$ $V_f = V_{in} = 3V$. is point B.



$$\text{Slope} = \frac{\Delta I_f}{\Delta V_f}.$$

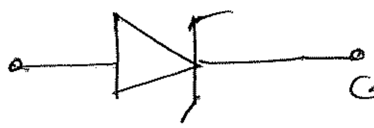
$\Delta I_f = 10mA$ $\Delta V_f = 0.9V$.

$$\text{slope} = \frac{10 \times 10^{-3}}{0.9} = 0.0111$$

$$R_L = \frac{1}{\text{slope}} = \underline{\underline{90\Omega}}.$$

Zener Diode:-

Zener Diodes are Constructed by heavily doped N & p type semiconductors. The symbol shown below.



(a) Zener diode

Operation:-

- In the forward bias direction, the zener diode behaves like an ordinary diode

- In Reverse bias Condition, no current flows untill the breakdown voltage is reached.

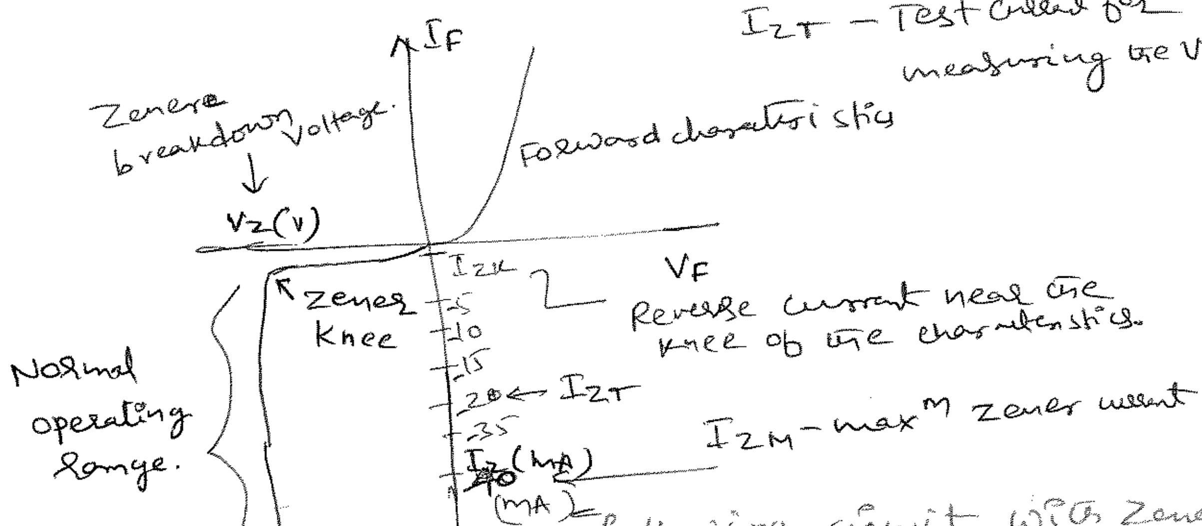
- The zener diode undergoes a process of breakdown when the reverse voltage increase to a specific value called Zener voltage, then diode starts Conducting simultaneously current increases in Zener diode.

- After breakdown, the voltage across the zener diode will remain constant & the current controlled by external resistance.

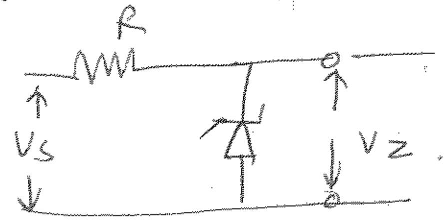
Break down voltage of Zener 2.4 to 200V power rating from 1W to 50W.

V_Z depends on Doping.

V-I characteristics of Zener diode



① Find the value of R in the following circuit with Zener diode of voltage rating of 4.7 V. The power rating of Zener diode is 400 mW. $V_S = V_{in} = 12$ V.



given :- $V_Z = 4.7$ V $P_Z = 400$ mW

$V_S = 12$ V.

find. $R_S = ?$

$$P_Z = V_Z I_Z$$

$$I_Z = \frac{P_Z}{V_Z} = \frac{400\,m}{4.7} = 85\,mA.$$

To Find R. apply ohm's law.

$$R = \frac{V_S - V_Z}{I_Z} = \frac{12 - 4.7}{85 \times 10^{-3}} = 8.5\,\Omega \quad 85\,\Omega$$

②. A zener diode has voltage rating of 5 V, & the current rating of 20 mA. Find the static resistance of the zener diode. If the voltage across the zener diode changes by 0.5 V, the current through the zener diode is found to vary by 10 mA. Find the dynamic resistance of the zener diode.

given $V_Z = 5$ V $I_Z = 20$ m. change in $V_Z = 0.5$ V

change in $I_Z = 10$ mA.

$$\text{Static resistance} = \frac{V_Z}{I_Z} = \frac{5}{20 \times 10^{-3}} = 250\,\Omega.$$

$$\text{dynamic resistance } r_d = \frac{\text{change in } V_Z}{\text{change in } I_Z} = \frac{0.5}{10\,m} = 50\,\Omega$$

Zener diode as a Voltage regulator

Voltage regulators are the devices used to maintain constant voltage across a load despite of fluctuations in the input voltage and load currents.

The zener diode in its reverse bias region is widely used as a voltage regulator as it continuous to operate till the magnitude of current becomes less than $I_{Z(min)}$.

The typical voltage regulator is shown in figure ①.

The zener diode of breakdown voltage V_Z is connected to the supply voltage in reverse direction.

For all the values of current within the breakdown region the voltage across the diode will remain fixed at V_Z, giving a constant supply across its load.

The resistance R_S controls the current flowing in the circuit.

Case (i). When no load is connected ($I_L = 0$).

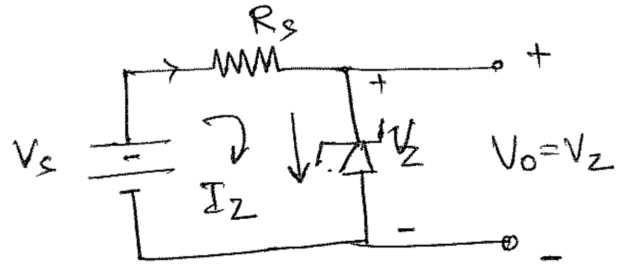
When there is no load resistance R_L, then $I_L = 0$. The current flowing in the circuit entirely passes through Zener diode.

The diode dissipates maximum power. Series resistor is selected carefully to maintain the power dissipation with in the range of maximum power dissipating capability of the diode.

Apply KVL to the circuit.

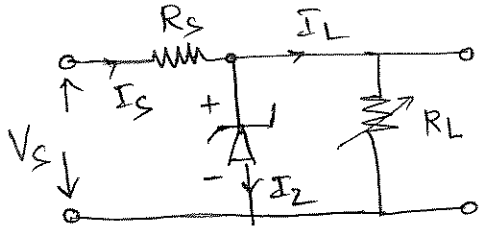
$$V_S - I_Z R_S - V_Z = 0.$$

The current I_Z flowing in the Resistor is given by



$$\boxed{I_Z = \frac{V_S - V_Z}{R_S}} \quad R_S = \frac{V_S - V_Z}{I_Z}.$$

Case ②. When load resistance R_L is connected across the diode.



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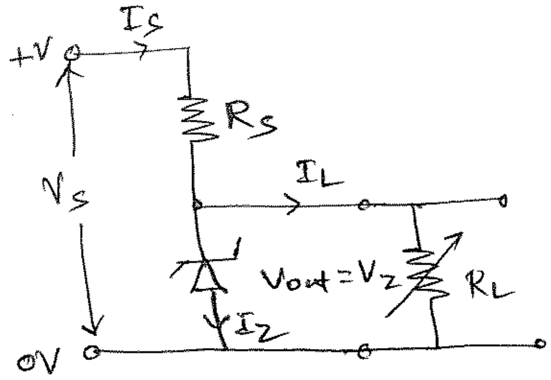


Zener diode as a voltage regulator.

Here, since the load is parallel to zener diode, the output voltage will be equal to V_Z.

The zener current must always be above $I_{Z(min)}$ [current for which the stabilization of voltage is effective]. The higher limit of current allowed to flow in the circuit depends upon the power dissipating capability of the components used.

Apply KVL to the above circuit.

$$I_Z + I_L = \frac{V_S - V_Z}{R_S}$$

$$I_S = I_Z + I_L$$

The voltage regulation can be done through two techniques.

1 line regulation.

2. Load regulation.

Line Regulation :— In this case, series resistance and load resistance are kept constant and it is assumed that all the variations in voltage arise due to fluctuations in input power supply.

The regulated output voltage is achieved for input voltage above certain minimum level. The percentage of regulation is given by

$$\frac{\Delta V_o}{\Delta V_{IN}} \times 100$$

Where V_o is the output voltage, V_{IN} is the input voltage, and ΔV_o is the change in output voltage for a particular change in input voltage ΔV_{IN}.

2. Load Regulation :-

Here, the input voltage is fixed while the load resistance is varied. The constant output voltage is obtained as long as the load resistance is maintained above a minimum value. The percentage of regulation is given by.

$$\left(\frac{V_{NL} - V_{FL}}{V_{NL}}\right) \times 100$$

Where V_{NL} is the voltage across the Zener diode when no load is applied ($R_L = 0$).

V_{FL} Full Load voltage across the Zener diode when R_L value is maximum.

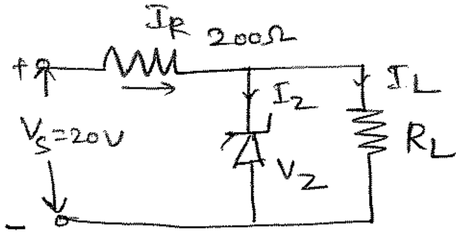
3. Series resistance Also varies, & it is given by

$$R_{max} = \frac{V_{i(min)} - V_Z}{I_{L(max)} + I_{Z(min)}}$$

$$R_{min} = \frac{V_{i(max)} - V_Z}{I_{L(min)} + I_{Z(max)}}.$$

$$R_{min} < R < R_{max}.$$

The circuit of figure has a Zener diode connected across the load.



(a) For $R_L = 180\Omega$, determine all currents and voltages

(b). Repeat part (a) for $R_L = 450\Omega$

(c). Find the value of R_L for the zener to draw maximum power

$V_Z = 10V$, $R_Z = 0$.

$P_{Z(max)} = 350mW$

(d). Find the minimum value of R_L for the Zener to be just in on-state.

Solution:-

(a). as R_L is small, Assume zener diode not conduct i.e $I_Z = 0$.

$$I_R = I_Z + I_L = \frac{V_s - V_Z}{R_s + R_L}$$

$$I_R = I_Z = \frac{20 - 0}{200 + 180} = 52.6mA.$$

$$V_Z = V_L = V_s - I_R * R_s = 20 - (52.6 \times m \times 200) = 9.48 < 10V.$$

(b). $R_L = 450\Omega$.

Assume that the Zener Conducts.

$$V_L = V_Z = 10V$$

$$I_L = \frac{V_Z}{R_L} = 0.0222 = 22.2mA.$$

$I_R = \frac{V_s - V_Z}{R_s} = \frac{20-10}{200} = 50mA$, $I_Z = I_R - I_L = 27.8mA$.

$P_Z = I_Z * V_Z = 27.8m * 10 = 278mW \le 350mW$ rating

(c). when Zener draws maximum power

$I_R = \frac{V_s - V_Z}{R_s} = \frac{20-10}{200} = 50mA$

$I_Z = \frac{P_Z}{V_Z} = \frac{350m}{10} = 35mA.$

$I_L = I_R - I_Z = 50 - 35 = 15mA.$ $R_L = \frac{V_Z}{I_L} = \frac{10}{15m} = 667\Omega.$

(d). $I_Z = 0$ (just on state)

$I_R = 50mA = I_L$

$V_L = V_Z = 10V$ $R_{L(min)} = \frac{V_o}{I_R} = \frac{10}{50m} = 200\Omega.$

(1) Design a zener diode voltage Regulator to meet the following specifications.

Unregulated dc output voltage V_i : 8-12 V.

Regulated dc output Voltage V_o : 5 V.

Minimum Zener current ; I_{Zmin} : 5 mA

maximum zener current, I_{Zmax} : 80 mA

Load current : 0 – 20 mA.

given Data:-

$V_{imin} = 8V$ $V_{imax} = 12V$ $V_o = 5V$.

$I_{Lmin} = 0mA$ $I_{Lmax} = 20mA$. $I_{Zmin} = 5mA$

$I_{Zmax} = 80mA$. $V_Z = \underline{5V} = V_o$.

select a zener diode with a reverse. breakdown voltage of 5V.

$$R_L = \frac{V_Z}{I_L} = \frac{V_o}{I_{Lmax}} = \frac{5V}{20mA}.$$

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

$$\frac{V_{imin} - V_Z}{I_{Zmin} + I_{Lmax}} > R$$

$$\frac{8-5}{5mA + 20mA} > R.$$

$$120 > R.$$

$$\boxed{R < 120\Omega} \rightarrow (1)$$

$$\frac{V_{imax} - V_Z}{I_{Zmax} + I_{Lmin}} < R$$

$$= \frac{12-5}{(80mA + 0)} < R. \qquad \boxed{R > 87.5\Omega} \rightarrow (2)$$

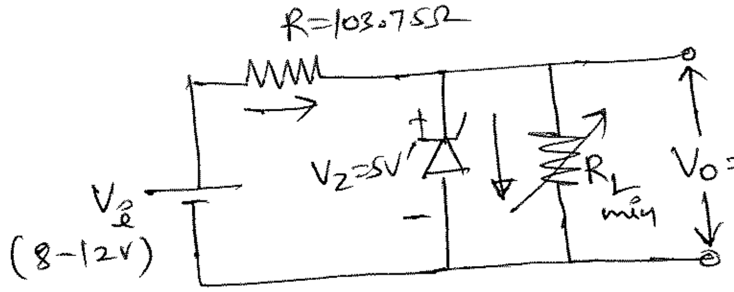
Combining the results of eqn ① & ②

$$\boxed{87.5\Omega < R < 120\Omega}$$

Let us take average.

$$R = \frac{87.5 + 120}{2}$$

$$\boxed{R = 103.75\Omega}$$



$R_{Lmin} = 250\Omega$.

Zener diode voltage regulator.

② Design a zener diode voltage regulator to meet the following requirements.

Unregulated dc input voltage V_i : 13 – 17V.

load current, I_L = 10mA.

Regulated output voltage V_o : 10V.

minimum Zener current : I_{Zmin} = 5mA.

maximum power dissipation in zener P_{Zmax} = 500mW.

given : $V_{imin} = 13V$.

$V_{imax} = 17V$.

$I_L = I_{Lmax} = 10mA$

$I_{Lmin} = 0$ (not given)

$V_o = 10V$

$I_{Zmin} = 5mA$.

$$P_{zmax} = P_D = V_z I_{zmax}.$$

$$I_{zmax} = \frac{P_D}{V_z} = \frac{500\times10^{-3}}{10} = \underline{50mA}.$$

$$\frac{V_{imin} - V_o}{I_{zmin} + I_{Lmax}} > R.$$

$$\frac{13-10}{5m + 10mA} \geq R$$

$$200 > R$$

$$\boxed{R \not> 200\ \Omega}$$

$$\frac{V_{imax} - V_o}{I_{zmax} + I_{Lmin}} < R.$$

$$\frac{17-10}{50m + 0} < R$$

$$140 < R$$

$$\boxed{R > 140\Omega}$$

Then $R = \frac{140+200}{2} = \underline{170\ \Omega}.$

$$R_L = \frac{V_o}{I_L}$$

$$R_{Lmin} = \frac{V_o}{I_{Lmax}} = \frac{10}{10\times10^{-3}} = \underline{\underline{1000\ \Omega}}.$$

$$\boxed{R_{Lmin} = 1000\ \Omega}$$

① . A 9V reference source is to be designed using a series connected zener diode and a resistor connected to a 30V supply. Select suitable components and calculates the circuit current when supply voltage drops to 27V. Choose $I_Z = 20mV$.

Given data:- $V_S = 30V$.

$$R_S = \frac{V_S - V_Z}{I_Z}$$

$$R_S = \frac{30 - 9.1}{20mA}$$

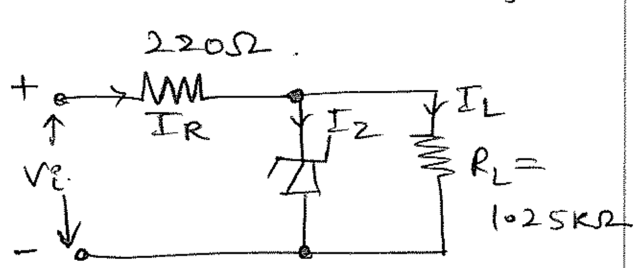
$$= 1.05 K\Omega$$

$$P = (I_Z)^2 * R_S = (20 \times 10^{-3})^2 * 1 K\Omega$$

$$= 0.4 W.$$

when $V_S = 27V$, $I_Z = \frac{V_S - V_Z}{R_S} = \frac{27 - 9.1}{1 K\Omega} = 17.9 mA$.

② Determine the range of V_i in which zener diode of figure conducts.



$V_Z = 20V$

$P_Z(max) = 1200 mW$

(i) V_Z just in conducting state.

$V_Z = 20V$, $I_Z = 0$.

$$I_R = I_L = \frac{20}{1.25K} = \frac{V_Z}{R_L} = 16mA.$$

$$V_i = 20 + (220 \times 16 \times 10^{-3}) = 23.52V.$$
$$= V_Z + (I_R * R)$$

ⓑ. $I_Z = I_{Z(max)} = \frac{P_{Z(max)}}{V_Z} = \frac{1200m}{20} = 60mA$.

$I_L = 16mA$.

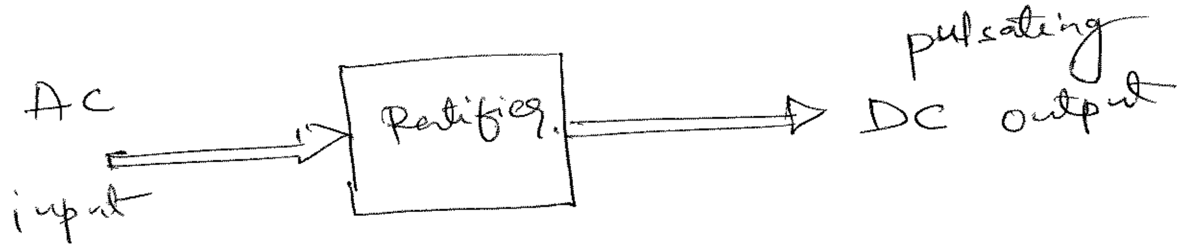
$I_R = I_Z + I_R = 76mA$.

$$V_i = V_Z + (R * I_{R\,max})$$
$$= 20 + (220 * 76mA) = 36.72V.$$

For input voltage from 23.52V to 36.72V, V_L will remain constant at 20V.

Rectifiers.

A rectifier is defined as an electronic circuit that converts alternating current (AC), which periodically reverses direction into a direct current (DC) which flows in only one direction. This process is known as rectification.



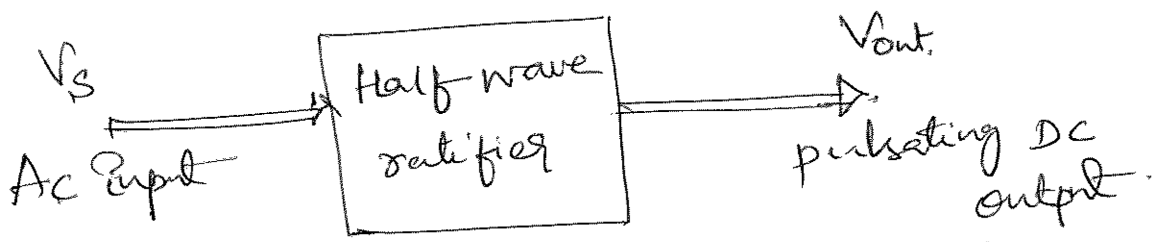
Classification of rectifier.

Rectifier.

- Half wave Rectifier
- Full wave Rectifier.
  - Rectifier with Centre tapped Transformer.
  - Bridge Rectifier.

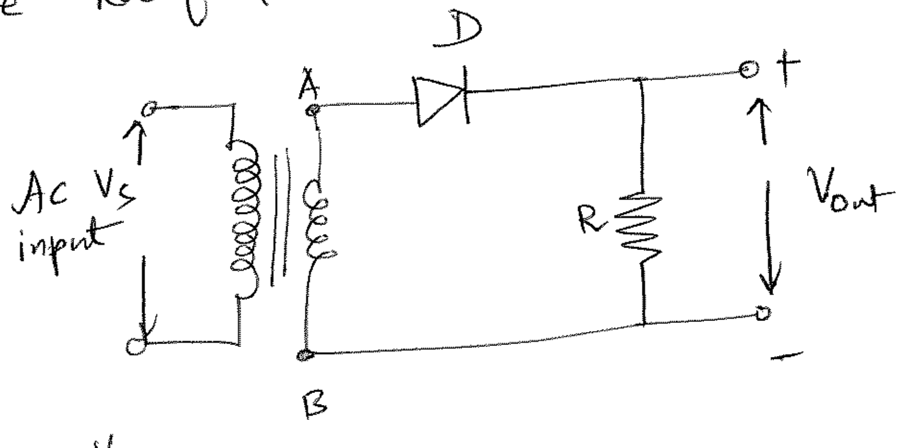
Half wave Rectifier :-

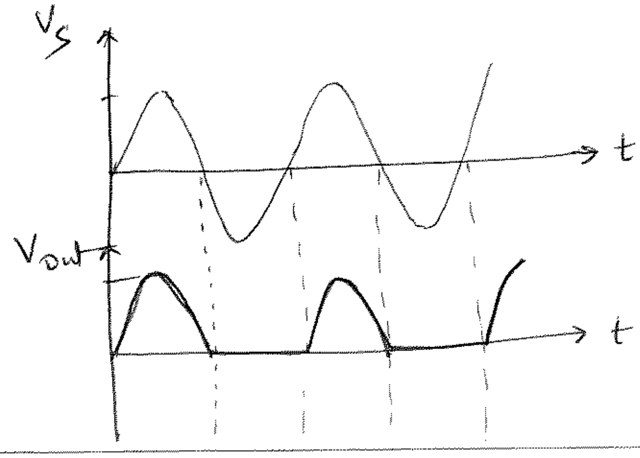
Half wave rectifier is a circuit which provides an output only during one half cycle of the input and zero output for the other half cycle.



The half wave rectifier using the diode is shown below.

The transformer is used to either step-up or step down, the ac input voltages, A diode in series with the transformer and load is used in half wave Rectifier.



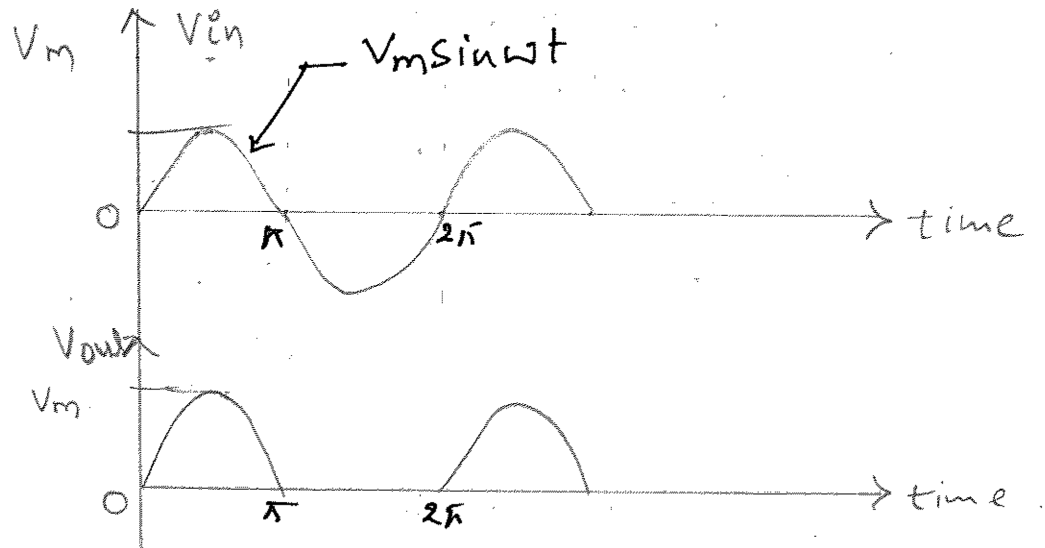


Working. During positive half cycle of the input signal (ac), the Diode Anode terminal becomes positive with respect to the other end. The Diode D is forward biased and acts as short circuit, Thus current flows in the circuit.

$$V_D = I_L R_L$$

During negative half cycle of the AC input. The diode Anode terminal becomes negative with respect to end B. The diode D is reverse biased and acts as open circuit thus no current flows.

$$V_D = 0 \text{ volt}.$$



Analysis of half wave rectifier

we use performance parameter.

- DC output voltage. (V_{DC})
- RMS output voltage (V_{rms})
- Ripple factor (γ)
- Efficiency: (η)
- DC output current (I_{dc})
- RMS output current (I_{rms})
- peak Inverse voltage. (PIV)
- ac power (P_{ac})
- DC power (P_{DC})

To find an expression for dc output voltage

Dc output voltage is also known as the average value of the output voltage.

$$V_{DC} = \frac{\text{area under one cycle}}{\text{period of one cycle}}$$

$$\begin{cases} V_o = V_m \sin\omega t & \text{for } 0 \text{ to } \pi \\ V_o = 0 & \text{for } \pi \text{ to } 2\pi . \end{cases}$$

V_{DC} is defined as the ratio of area enclosed under one cycle of the output waveform to the period of one cycle.

$$V_{DC} = \frac{\text{area under one cycle}}{\text{period of one cycle.}}$$

$$V_{DC} = \frac{\int_0^{2\pi} V_o \, d\omega t}{2\pi} = \frac{\int_0^{\pi} V_m \sin\omega t . d\omega t.}{2\pi}$$

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

$$V_{DC} = \frac{V_m.}{2\pi} \left[-\cos\pi + \cos 0 \right]$$

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

$$\boxed{V_{DC} = \frac{V_m.}{\pi}} = \boxed{V_{av} = \frac{V_m}{\pi}}$$

Similarly.

$$I_{DC} = \frac{I_m.}{\pi} \text{ or } I_{av} = \frac{I_m.}{\pi}.$$

$$I_{DC} = \frac{V_{dc}}{R_L} = \frac{V_m.}{\pi} * \frac{1}{R_L} = \frac{1}{\pi} \frac{I_m.}{\cancel{R_L}} * \cancel{R_L} = \frac{I_m.}{\pi}.$$

To find an expression for RMS output voltage.

The rms voltage is also called effective voltage. It is found as square root of the ratio of area enclosed under one cycle of the squared output waveform to the period.

Here one cycle is form 0 to 2π.

$$\underbrace{V_{rms}}_{\text{root mean square}} = \sqrt{\frac{\int_0^{2\pi} V_o^2 . d\omega t}{2\pi}} = \sqrt{\frac{\int_0^{\pi} V_o^2 d\omega t}{2\pi}}$$

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

$$\sin^2\omega t = \frac{1-\cos 2\theta}{2}$$

$$= \sqrt{\frac{V_m^2}{4\pi}} \sqrt{\left[\omega t - \frac{\sin 2\omega t}{2}\right]_0^{\pi}}$$

$$= \sqrt{\frac{V_m^2}{4\pi}} \sqrt{\pi - \frac{\sin 2\pi}{2}}$$

$$= \sqrt{\frac{V_m^2}{4\pi}} \, 2\sqrt{\pi}$$

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

$$I_{rms} = \frac{V_{rms}}{R_C} = \frac{V_m}{2R_L} = \frac{I_m R_L}{2R_L} = \frac{I_m}{2}$$

$$P_{dc} = I_{dc}^2 * R_L$$

$$= \left(\frac{I_m}{\pi}\right)^2 * R_L = \frac{I_m^2}{\pi^2} * R_L$$

$$P_{dc} = \frac{1}{\pi^2} \frac{V_m^2}{R_L^2} * R_L = \frac{V_m^2}{\pi^2 R_L}$$

$$P_{ac} = I_{rms}^2 * R_L$$

$$= \left(\frac{I_m}{2}\right)^2 * R_L = \frac{1}{4} * \frac{V_m^2}{R_L^2} * R_L = \frac{V_m^2}{4R_L}$$

(1) Ripple factor.

It is defined as the measure of ac component in the output of the rectifier.

$$\text{Ripple factor} = \gamma = \frac{\text{rms value of ac component}}{\text{dc component of output}}$$

$V_{ac} \rightarrow$ rms value of ac component in the rectifier output.

$V_{DC} \rightarrow$ is the DC value of Rectifier output.

$V_{rms} \rightarrow$ rms value of the Combibed waveforms.

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

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

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

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

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

$$= \sqrt{\left(\frac{\frac{V_m}{2}}{\frac{V_m}{\pi}}\right)^2 - 1} = \sqrt{\left(\frac{\pi}{2}\right)^2 - 1}$$

$$\boxed{\gamma = 1.21} \text{ or } 121\%$$

Efficiency :-

Efficiency is defined as the ratio of dc power delivered to the load to the total input power to the rectifier.

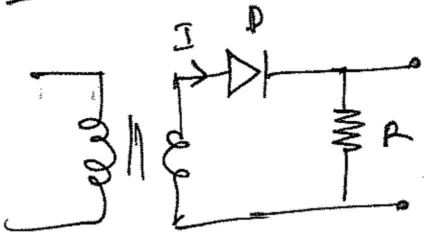
$$\eta = \frac{\text{dc output power}}{\text{Total input power}}$$

$$\eta = \frac{P_{dc}}{P_{ac}} = \frac{\dfrac{V_m^2}{\pi^2 * R_L}}{\dfrac{V_m^2}{4R_L}} = \frac{4}{\pi^2} = 40.5\%$$

$$\boxed{\eta = 0.405}$$

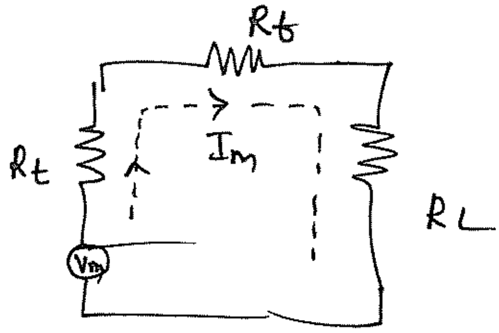
or

<u>Equivalent circuit of Half wave ratifier</u>



Half wave ratifier.

≡



Equivalent circuit
Of Half wave ratifier

From <u>circuit</u>.

$$P_{dc} = I_{dc}^2 R_L .$$

$$P_t = I_{rms}^2 (R_f + R_t + R_L).$$

$$\eta = \frac{P_{dc}}{P_t} = \frac{I_{dc}^2 R_L}{I_{rms}^2 (R_f + R_t + R_L)}$$

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

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

$$\eta = \frac{\left[\frac{I_m}{\pi}\right]^2 R_L}{\left[\frac{I_m}{2}\right]^2 (R_f + R_t + R_L)}$$

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

$$= 0.405 . \frac{R_L}{R_L}$$

$R_f = 0$
$R_t = 0.$

$$\boxed{\eta = 0.405 .}$$

An half wave ratifier supplies power to a load of 500 Ω. The input voltage to the circuit is 100V (peak value). Find the rms & average value of the load voltage, load current, rms & average value of the ripple factor, efficiency of ratifier. given forward resistance of the diode to be 10 Ω.

given. Data :- $V_m = 100V$ $R_L = 500\,\Omega$ $R_f = 10\,\Omega$

$I_{DC} = ?$ $I_{rms} = ?$ $V_{DC} = ?$ $V_{rms} = ?$ Ripple factor = ?

$\eta = ?$

We know :- $I_m = \frac{V_m}{R_f + R_t + R_L} = \frac{100}{(10+0+500)} = 0.196\,A.$

$$I_{DC} = \frac{I_m}{\pi} = \frac{0.196}{\pi} = 0.062\,A$$

$$I_{rms} = \frac{I_m}{2} = \frac{0.196}{2} = 0.098\,A$$

$$V_{DC} = I_{DC} * R_L$$

$$= 0.062 * 500$$

$$= 31V.$$

$$V_{rms} = I_{rms} * R_L$$

$$= 0.098 * 500 = 49V.$$

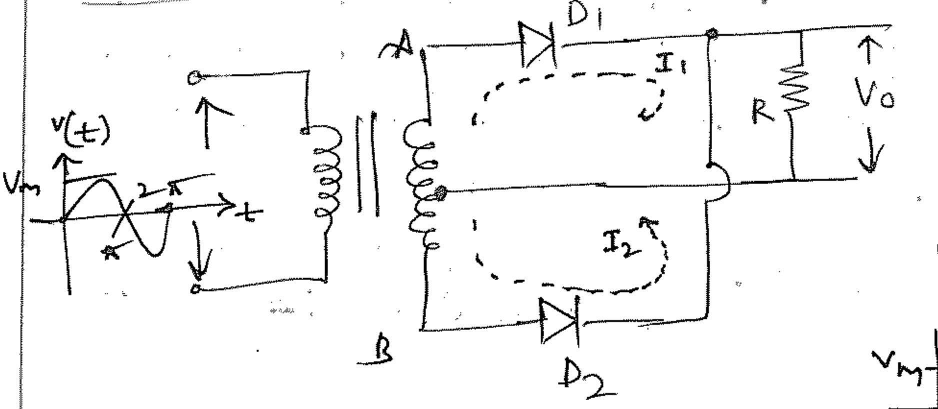
ripple factor = 1.21.

$$\text{Efficiency} = \eta = 0.405\left(\frac{R_L}{R_f + R_t + R_L}\right)$$

$$= 0.405\left(\frac{500}{10+0+500}\right) = \underline{0.397}$$

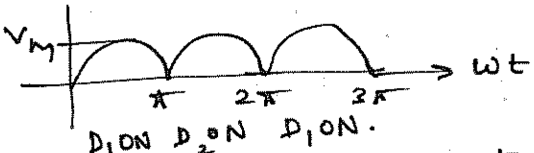
Full wave Rectifiers :-

Full wave rectifier with Centre tapped transformer

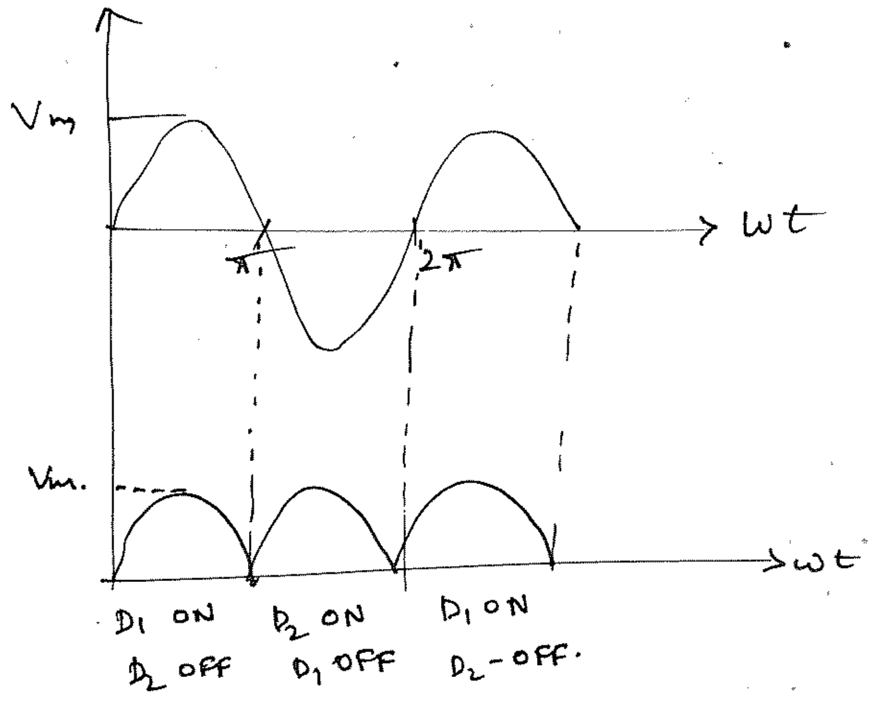


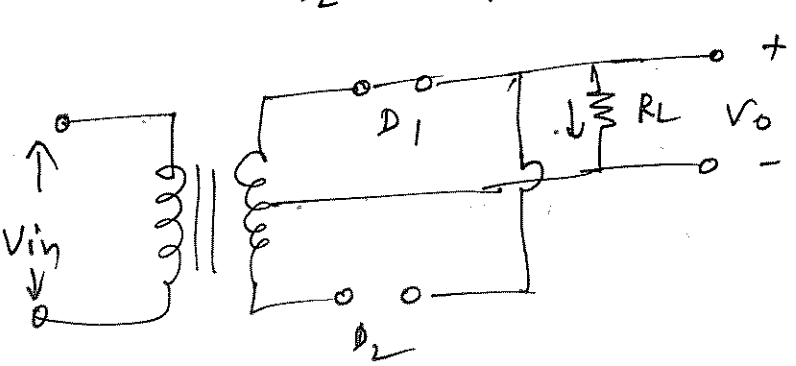
Current flows when D1 Conducts

Current flows when D2 Conducts.

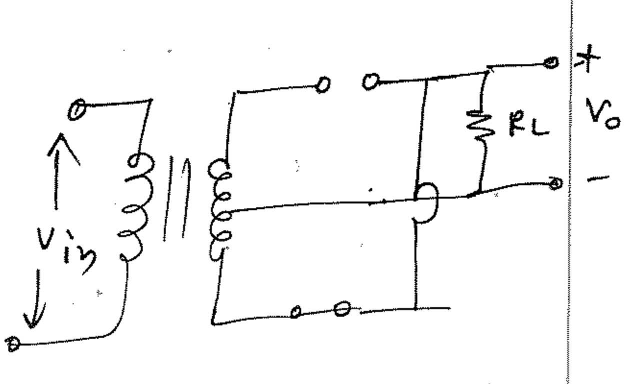


The full wave rectifier using two diodes and a Centre tapped transformer is shown in fig ①.
The Transformer is used to either step-up or step down the ac input voltage. Two diodes are Connected on the secondary side of the Transformer as shown in fig ② along with the load.





ⓐ During +ve half cycle



ⓑ During Negative cycle.

Operation:- During +ve half cycle of the ac input Voltage end A becomes positive with respect to end B The diode D_1 is forward biased & Conducts, diode D_2 is reverse biased and acts as open circuit and will not Conduct as shown fig②.

Thus Diode D_1 supplies the load current. The Conventional current flow is through diode D_1, load resistor R_L.

During -ve half cycle of the AC input voltage end A becomes -ve with respect to end B, the diode D_2 is forward biased and Conducts while diode D_1 is reverse biased and acts as open circuit and will not Conduct. The Diode D_2 supplies the load current the Conventional Current is through diode D_2, Load resistor R_L.

Therefore for both the half cycles the current flows through load in the same direction. Hence we get two half cycles for one input signal.

Analysis of the full wave rectifier:-

The performance parameters are

① DC output Voltage

② RMS output Voltage

③ Ripple factor

④ Efficiency.

DC output voltage:-

The dc output voltage can also be Called the average value of the output voltage.

The dc output voltage is defined as the ratio of area enclosed under one cycle of the output waveform. one cycle is from 0 to π.

let the output voltage of the rectifier be expressed as $V_0 = V_m \sin \omega t$.

$$V_{DC} = \frac{\text{area under one cycle}}{\text{period of one cycle.}}$$

$$V_{DC} = \frac{\int_0^{\pi} V_0 \cdot d\omega t}{\pi} = \frac{\int_0^{\pi} V_m \sin \omega t}{\pi}$$

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

$$V_{DC} = \frac{V_m}{\pi} \left[-\cos \pi + \cos 0 \right]$$

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

$$\boxed{V_{DC} = \frac{2V_m}{\pi}}$$

Expression for RMS output voltage

The rms voltage is also called effective voltage. The RMS value of a continuous-time waveform is the square root of the airthmetic mean (average) of the squares of the original values.

. let the output of the rectifier is $V_0 = V_m \sin \omega t$.

The rms output voltage is found as square root of the ratio of area enclosed under one cycle of the squared output waveform to the period of one cycle.

In above waveform, one cycle is from 0 to π.

$$V_{rms} = \sqrt{\frac{\text{area enclosed under one cycle of the squared output waveform}}{\text{period of one cycle}}}$$

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

$$= \sqrt{\frac{V_m^2}{\pi}} \sqrt{\int_0^{\pi} \left[\frac{1 - \cos 2\omega t}{2}\right] \cdot d\omega t}$$

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

$$= \sqrt{\frac{V_m^2}{2\pi}} \sqrt{\pi - \frac{\sin 2\pi}{2}}$$

$$V_{RMS} = \sqrt{\frac{V_m^2}{2\pi}} \cdot \sqrt{\pi}$$

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

Ripple factor :-

Ripple factor is measure of ac component in the output of the rectifier.

Mathematically, the ripple factor found as the ratio of rms value of ac component to dc value in the output of the rectifier.

$$\text{Ripple factor} = \gamma = \frac{\text{rms value ac component}}{\text{dc component}}$$

let V_{ac} is the rms value of ac component in the o/p Rectifier

V_{DC} is the dc value of the output of the rectifier.

V_{rms} is the rms value of the combined waveforms.

The rms voltage can be.

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

$$V_{ac} = \sqrt{V_{Rms}^2 - V_{DC}^2}$$

Ripple factor $= \gamma = \dfrac{V_{ac}}{V_{dc}}$.

$$\gamma = \frac{\sqrt{V_{rms}^2 - V_{dc}^2}}{V_{DC}}$$

$$= \sqrt{\left[\frac{V_{rms}}{V_{dc}}\right]^2 - 1} = \sqrt{\left[\frac{\frac{V_m}{\sqrt{2}}}{\frac{2V_m}{\pi}}\right]^2 - 1}$$

here $V_{rms} = \dfrac{V_m}{\sqrt{2}}$.

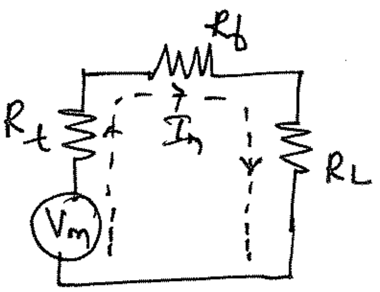
$$= \sqrt{\left(\frac{\pi}{\sqrt{2}}\right)^2 - 1} = \underline{\underline{0.483}}.$$

$V_{dc} = 2\dfrac{V_m}{\pi}$.

Efficiency:- It is defined as the ratio of dc power delivered to the load to the total ~~input~~ input power to the rectifier.

$$\eta = \frac{\text{dc output power}}{\text{total input power}}.$$

$$\eta = \frac{P_{dc}}{P_i}.$$



In the circuit V_m is peak value of secondary voltage.

I_m is the peak value of current through the circuit.

By applying Ohm's law peak current I_m can be expressed as follows.

peak load current $I_m = \dfrac{V_m}{R_f + R_t + R_L}$

Here I_{dc} is the dc load current

$$P_{dc} = I_{dc}^2 R_L$$

Here $P_i = I_{rms}^2 (R_f + R_t + R_L)$ - - - - -

where R_f - resistance of the forward biased diode
R_t - is the resistance of secondary winding of the transformer.

$$\eta = \frac{P_{dc}}{P_i} = \frac{I_{dc}^2 R_L}{I_{rms}^2 (R_f + R_t + R_L)}.$$

$I_{dc} = \dfrac{2 I_m}{\pi}$

$I_{rms} = \dfrac{I_m}{\sqrt{2}}$

$$= \frac{\left[\frac{2 I_m}{\pi}\right]^2 R_L}{\left[\frac{I_m}{\sqrt{2}}\right]^2 (R_f + R_t + R_L)}.$$

$$= \frac{8}{\pi^2}\left[\frac{R_L}{R_f + R_t + R_L}\right]$$

$$= 0.81 \frac{R_L}{R_f + R_t + R_L}$$

we get maximum efficiency when $R_f = 0$ & $R_t = 0$,

$$\boxed{\eta = 0.81}$$

Note :- $I_{DC} = \dfrac{2 I_m}{\pi}$ $\quad I_{rms} = \dfrac{I_m}{\sqrt{2}}$ $\quad V_{DC} = \dfrac{2 \cdot V_m}{\pi}$

$V_{rms} = \dfrac{V_m}{\sqrt{2}}$ $\quad V_{DC} = I_{DC} \cdot R_L$.

$V_{RMS} = I_{RMS} \cdot R_L$.

peak Load current $I_m = \dfrac{V_m}{R_f + R_t + R_L}$

$\eta = 0.81 \cdot \dfrac{R_L}{(R_f + R_t + R_L)}$ $\quad \eta = 0.483$.

A full wave rectifier (centre taped rectifier) with a centre tapped secondary supplies power to a load of 500Ω. The input voltage to the circuit is 100V (peak value). Find the rms & average value of the load current, rms & average value of load voltage, ripple factor. & Efficiency of the rectifier. Consider the forward resistance of the diode to be 10Ω.

given data:- $V_m = 100V$, $R_L = 500\Omega$, $R_f = 10\Omega$.

Find $I_{DC} = ?$ $I_{rms} = ?$ $V_{DC} = ?$, $V_{rms} = ?$

Ripple factor = ? $\eta = ?$

Ans:- $I_m = \dfrac{V_m}{(R_f + R_t + R_L)} = \dfrac{100}{(10+0+500)} = 0.196A$

$I_{DC} = \dfrac{2 I_m}{\pi} = \dfrac{2 * 0.196}{\pi} = 0.124A$

$I_{rms} = \dfrac{I_m}{\sqrt{2}} = \dfrac{0.196}{\sqrt{2}} = 0.1386A$

$V_D = I_{DC} * R_L = 0.124 * 500$

$= 62V$

$V_{rms} = I_{rms} * R_L$

$= 0.1386 \times 500$

$= 69.3V$

Ripple factor $= 0.483$

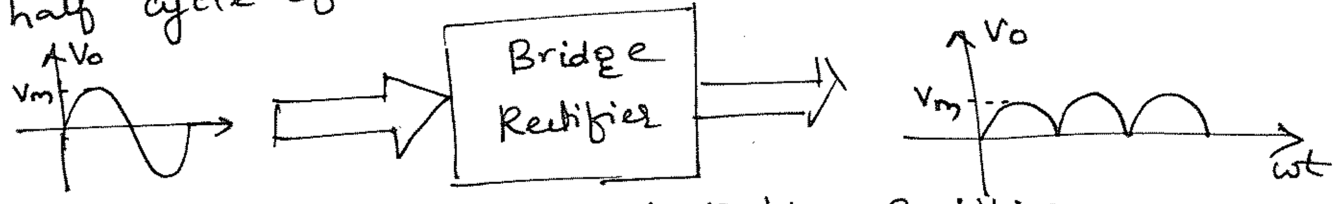
Efficiency $= \eta = 0.81 * \dfrac{R_L}{(R_f + R_t + R_L)}$

$= 0.81 * \dfrac{500}{(10+0+500)}$

$\boxed{\eta = 0.7941}$

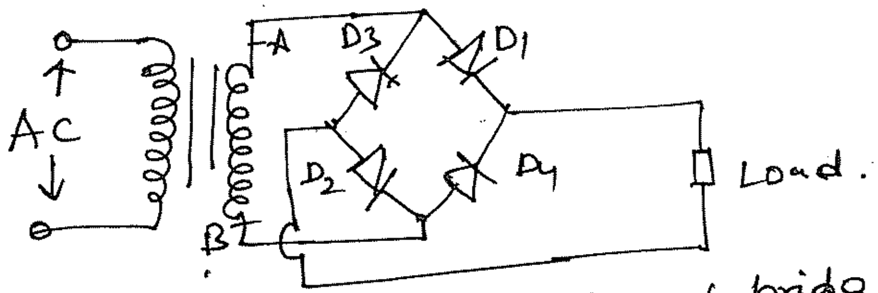
Bridge Rectifier :-

Is a circuit which provides output during both half cycle of the input.



Block diagram of Bridge Rectifier.

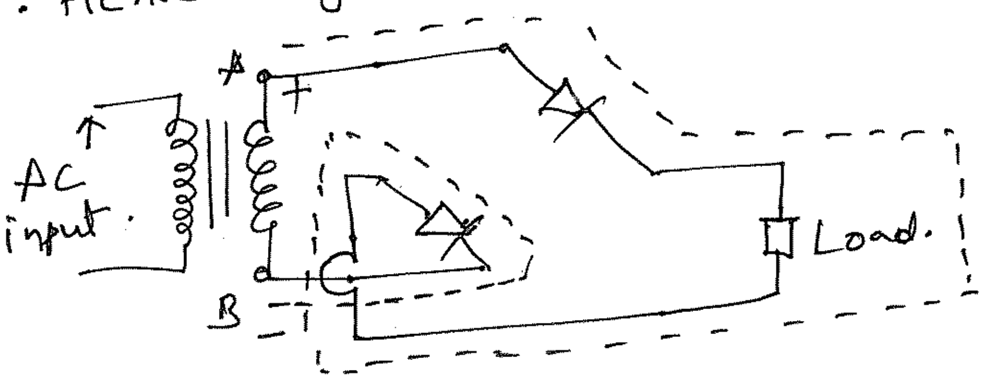
The bridge Rectifier using the four diodes and a transformer is shown. The Transformer in the given is used to either step-up or step-down the ac input voltages. Four diodes are connected to the Secondary windings of the transformer.



circuit diagram of bridge Rectifier.

Working :-

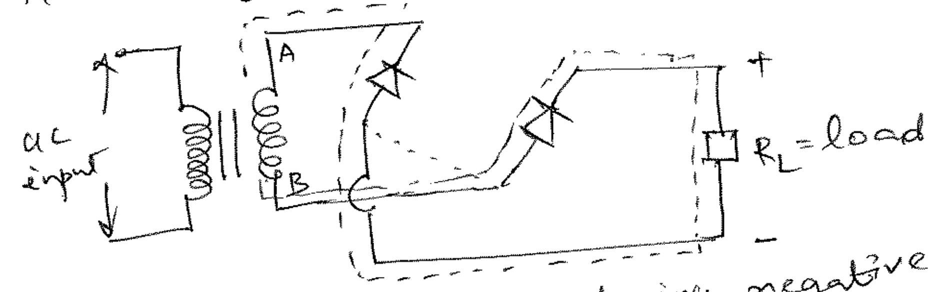
During The positive half cycle of the input signal let the terminal A becomes positive & the terminal B becomes negative. The diode D1 & D2 are forward biased & D3 & D4 are reverse biased. The current flows through the diode D1, D2 and the load. Hence we get the voltage across the load.



bridge Rectifier during positive half cycle.

During negative half cycle of the input signal, the terminal A becomes negative & the Terminal B becomes positive. D_3 & D_4 Forward biased.
D_2 & D_1 Reverse biased.

The current flows through the diode D_3, D_4 & the load. Hence we get the voltage across the load.



Bridge Rectifier during negative half cycle.

Note: Since two diodes conduct during any of the half cycles For efficiency & peak current Calculation $2R_f$ will be used.

In analysis bridge rectifier is same as that of full wave Rectifier with Centre tapped transformer.

Formulae

DC output current $I_{DC} = \frac{2I_m}{\pi}$

rms output Current $I_{rms} = \frac{I_m}{\sqrt{2}}$

No load DC output Voltage $V_{DC} = \frac{2V_m}{\pi}$

No load Rms output Voltage $V_{rms} = \frac{V_m}{\sqrt{2}}$

When the resistance of transformer & Diode is considered then $V_{DC} = I_{DC} * R_L$ & $V_{rms} = I_{rms} \times R_L$

peak load current $I_m = \dfrac{V_m}{(2R_f + R_L + R_L)}$

ripple factor (γ) $= 0.483$.

efficiency $= \eta = 0.81 \dfrac{R_L}{2R_f + R_L + R_L}$

A Full wave Rectifier with a Centre tapped secondary transformer supplies power 5W to a load of 100Ω. Find the input voltage to the circuit. The Transformer has a secondary resistance of 25Ω. Consider $R_f = 20\Omega$.

Soln: given.

$R_L = 100\,\Omega$

$R_f = 20\Omega$ $\quad$ $P = 5W$.

$R_t = 25\,\Omega$ $\quad$ Find $V_m = ?$

We know that

$$\text{Output power} = I_{dc}^2 \times R_L$$

$$5 = I_{dc}^2 \times 100$$

$$I_{dc}^2 = 5/100$$

$$I_{dc} = \sqrt{5/100}$$

$$\boxed{I_{dc} = 0.2236A}$$

W.K.T. $I_{dc} = \frac{2I_m}{\pi} \Rightarrow I_m = \frac{I_{dc} \times \pi}{2}$.

$$= \frac{0.2236 \times \pi}{2}$$

$$\boxed{I_m = 0.35135A}$$

peak load current $I_m = \frac{V_m}{(R_f + R_t + R_L)}$

$$V_m = I_m(R_f + R_t + R_L)$$

$$= 0.35135(20 + 100 + 25)$$

$$= 0.35135 \times 145$$

$$\boxed{V_m = 50.94V}$$

(1) A Bridge Rectifier has Input voltage of 100sinωt. The diode resistance is 50Ω & the load resistance is 950Ω. Find the dc output voltage, ripple factor, & efficiency.

given :- $V_m = 100$, $R_f = 50\Omega$ $R_t = 0$ $R_L = 950\Omega$

Find. V_{DC}, V_{rms}, Ripple factor, $\eta = ?$

$$I_m = \frac{V_m}{2R_f + R_t + R_L} = \frac{100}{1000} = 0.1A$$

Find I_{DC}:

$$I_{DC} = \frac{2I_M}{\pi} = \frac{0.2}{\pi} = 0.06366 A$$

$$I_{RMS} = \frac{0.1}{\sqrt{2}} = 0.071 A$$

$$V_{DC} = I_{DC} \cdot R_L = 0.0636 * 950$$
$$= 60.42V$$

$$V_{RMS} = I_{RMS} * R_L$$
$$= 0.071 \times 950 = 67.45V$$

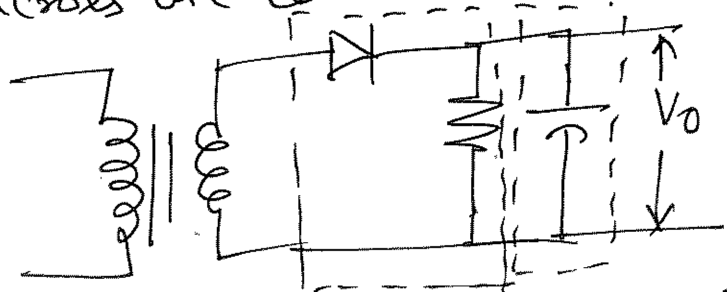
ripple factor $= 0.483$

$$\eta = 0.81 * \frac{R_L}{(2R_f + R_t + R_L)} = 0.81 * \frac{950}{1000} = 0.77$$

Filters :- Half wave rectifier with a Capacitor filter

A filter is a circuit that removes the ac component present in the output of a rectifier.

Consider a half wave rectifier with a capacitor C connected across the load. as shown below.



Half wave rectifier with Capacitor filter.

The output of the rectifier is the input to the filter. When diode reverse biased or forward biased. Depending on that filter works.

<u>When</u> $V_i > V_C$.

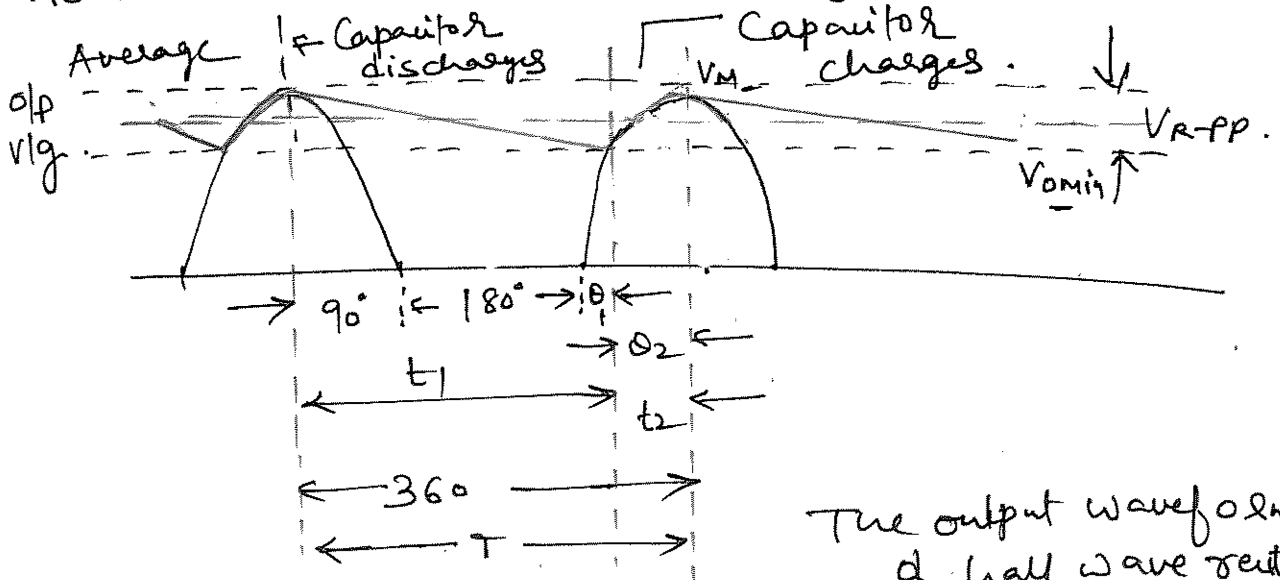
The diode is in forward bias condition & conducts current through the load ~~current~~ resistor R_L. Hence the current produces an output voltage across the load resistor R_L, which has the similar output to that of half wave rectifier.

. At the same time the capacitor is charged. At the end quarter cycle, when the input voltage reaches the maximum value, capacitor also charges to the maximum input value.

<u>When input voltage falls below peak value.</u>

$V_i < V_C$.

- The Diode reverse biased. Anode voltage less than capacitor (cathode) voltage. ∴ No current flows through the Diode.
- The capacitor which has been already charged starts discharging through the load resistor.
- As capacitor discharges, the capacitor voltage & hence the output voltage magnitude decreases.



The output waveform of half wave rectifier with capacitor filter.

Full wave rectifier with a capacitor filter

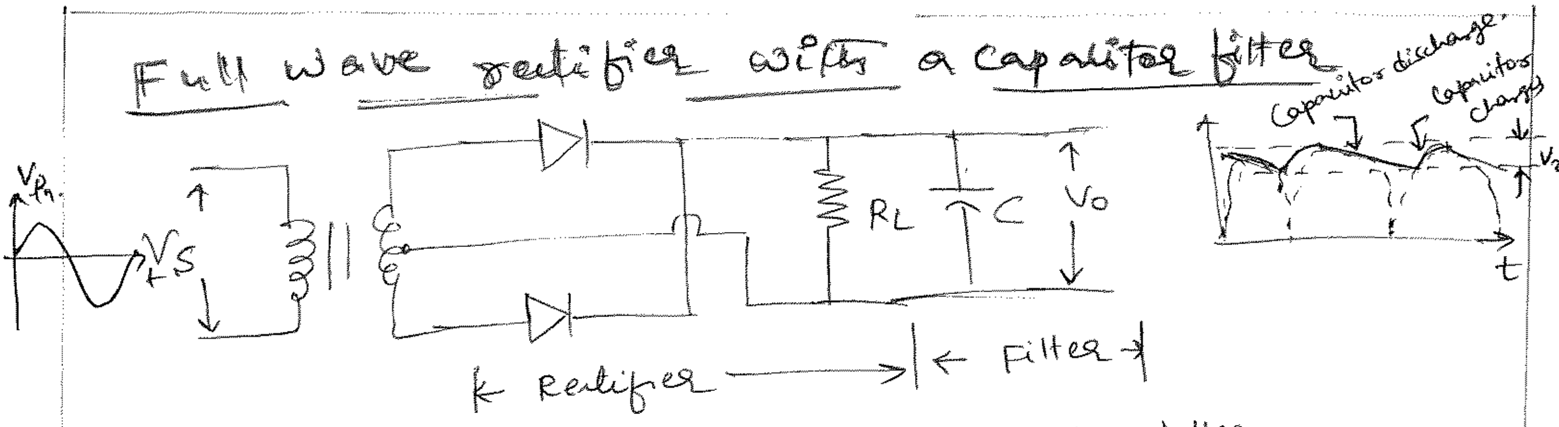


Fig: Fullwave rectifier with capacitor filter.

Case ①: $V_{in} > V_C$

when Diode is forward biased & conducts current through the Load resistor R_L. Hence the current produces an output voltage across the Load resistor R_L, which has the same shape as the initial input.

· During this time, the capacitor is charged. when the input voltage reaches the maximum value, the capacitor charged to the maximum value of the input voltage.

Case ② $V_{in} < V_p$. when the input voltage falls below the peak value.

The diode is reverse biased since anode voltage (input voltage) becomes less than the ~~diode~~ cathode voltage (capacitor voltage). ∴ no current through the diode.

During reverse biasing of Diode, the capacitor starts discharging through the Load resistor.

· The discharge current of the capacitor produces voltage across the load resistor; hence we get the output voltage.

The.

A Full wave Rectifier with a centre tapped secondary transformer supplies power 5W to a load of 100Ω. Find the input voltage to the circuit. The transformer has a secondary resistance of 25Ω. Take the $R_f = 20\,\Omega$.

Soln:- given $R_L = 100\,\Omega$ $\quad R_f = 20\,\Omega \quad R_t = 25\,\Omega$.

$P = 5\,W$

Find V_m.

we know that

$$\text{output power} = I_{dc}^2 * R_L$$

$$5 = I_{dc}^2 * 100$$

$$I_{dc}^2 = \frac{5}{100}$$

$$I_{dc} = \sqrt{\frac{5}{100}} = 0.2236\,A$$

$$\frac{2I_m}{\pi} = I_{dc} \Rightarrow I_m = \frac{I_{dc} * \pi}{2}$$

$$= \frac{0.2236 * \pi}{2}$$

$$I_m = 0.35135\,A.$$

peak load current $I_m = \dfrac{V_m}{R_f + R_t + R_L}$

$$V_m = I_m(R_f + R_t + R_L)$$

$$= 0.35135 * 145$$

$$\boxed{V_m = 50.94\,V}$$

Problems on Full Wave Rectifier

A Full wave rectifier with a centre tapped transformer. The secondary supplies power to a load of 100Ω. The input voltage to the circuit is 10V (rms value) through a transformer having a secondary resistance of 25Ω. Find DC & rms output voltages, ripple factor, output power, input power & efficiency of the rectifier. forward resistance of the diode to be 10Ω.

given. $V_m = 10 * \sqrt{2}$ $\quad R_L = 100\Omega,\ R_f = 10\Omega,\ R_t = 25\Omega.$

$= 14.14$

Find. $I_{dc} = ?\quad I_{rms} = ?\quad V_{dc} = ?\quad V_{rms} = ?\quad \eta = ,\ P_{in},\ P_{out}$

Sol^n

W.K.T the peak load current $I_m = \dfrac{V_m}{R_t + R_f + R_L} = \dfrac{14.14}{100+10+25}$

$= 0.1047\ A$

$$I_{dc} = \frac{2I_m}{\pi} = \frac{2 * 0.1047}{\pi} = 0.0666\ A.$$

$$I_{rms} = \frac{I_m}{\sqrt{2}} = \frac{0.1047}{\sqrt{2}} = 0.0740\ A$$

$$V_{DC} = I_{dc} * R_L = 0.0666 * 100 = 6.66\ V.$$

$$V_{rms} = I_{rms} * R_L = 0.0740 * 100 = 7.4\ V.$$

$$P_{out} = I_{DC}^2 R_L = (0.0667)^2 * 100 = 0.444 W.$$

$$P_{in} = I_{rms}^2 (R_L + R_f + R_t) = (0.0740)^2 * (135) = 0.739\ W.$$

Ripple factor $(\gamma) = 0.483$

$$\eta = 0.812 * \frac{R_L}{R_L + R_f + R_t}$$

$$= 0.812 * \frac{100}{135} = \underline{0.6014}$$

$$\boxed{\%\ \eta = 60.14}$$

A Full wave Rectifier is supplied power through a step down transformer with a primary input voltage of 250V. The turns-ratio of the transformer is 10. The load resistance is 1kΩ. The resistance to the secondary windings of the transformer is 12Ω & that of diode is 13Ω. Calculate the dc & rms value of the output Voltage. Find Regulation.

given, $V_p = 250V$ turns ratio $= 10$, $R_L = 1k\Omega$, $R_t = 12\Omega$, $R_f = 13\Omega$

Find, V_{dc}, V_{rms}, Regulation.

Solution:- Secondary voltage $= \frac{V_P}{\text{turn-ratio}} = \frac{250}{10} = 25V$.

$$V_m = \sqrt{2}\, V_s = \sqrt{2} \times 25$$
$$= 35.35V$$

peak load current $I_m = \frac{V_m}{R_f + R_L + R_t} = \frac{35.35}{1025} = 0.0345A$

$$I_{dc} = \frac{2I_m}{\pi} = \frac{2 \times 0.0345}{\pi} = 0.022A$$

$$I_{rms} = \frac{I_m}{\sqrt{2}} = \frac{0.0345}{\sqrt{2}} = 0.02439A$$

$$V_{dc} = I_{dc} \times R_L = 0.022 \times 1000 = 21.95V = 22V$$

$$V_{rms} = I_{rms} \times R_L = 0.02439 \times 1000 = 24.39 = 25V$$

$$\text{Regulation} = \frac{R_t + R_f}{R_L} = \frac{25}{1000} = 0.025$$

Problem on half wave Rectifier :-

(2) A half wave rectifier is supplied power through a step down transformer with a primary input voltage of 250V. The primary to secondary turns ratio of the transformer is 10. The Load resistance is 1kΩ. The resistance of the secondary winding of the transformer is 12Ω & that of diode is 13Ω. Calculate the dc & rms value of the output voltage. Also Find the Regulation.

Solⁿ :- $V_p = 250V$. turns ratio = 10. $R_L = 1k\Omega$ $R_t = 12\Omega$ $R_f = 13\Omega$

$V_{dc} = ?$

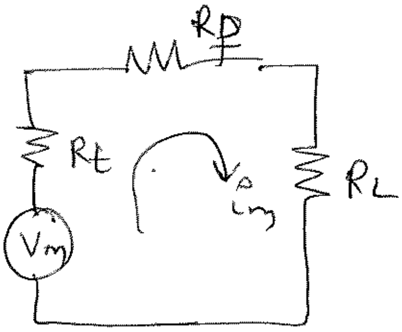
$V_{rms} = ?$

Regulation = ?

$$V_s = \frac{V_p}{\text{turns ratio}} = \frac{\text{Primary i/p voltage}}{\text{turns ratio}}$$

$$= \frac{250}{10}$$

$$= 25.$$



$$V_m = \sqrt{2} * V_s$$

$$= 35.35V$$

The peak Load current

$$I_m = \frac{V_m}{(R_f + R_t + R_L)} = \frac{35.35}{1025}$$

$$= 0.0345A.$$

$$I_{dc} = \frac{I_m}{\pi} = \frac{0.0345}{\pi} = 0.0109A$$

$V_{dc} = I_{dc} \times R_L = 10.97V$.

$$I_{rms} = \frac{I_m}{2} = 0.0172A.$$

$V_{rms} = I_{rms} \times R_L = 17.2V$.

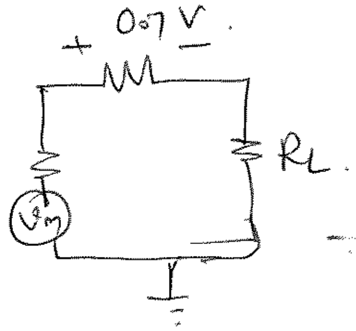
$$\text{Regulation} = \frac{I_{dc}(R_f + R_t)}{V_{dc}} = \frac{0.0109 \times (25)}{10.97}$$

$$= 0.0248.$$

$\boxed{\% \text{Regulation} = 2.48\%}$

(3). A diode in a half wave rectifier has $V_F = 0.7V$. The Load resistance is 600Ω. & the ac input Voltage is 25V (rms). Determine dc & rms output voltage.

given:- $V_f = 0.7$ $R_L = 600\Omega$, $V_s = 25V$ $V_{dc} = ?$, $V_{rms} = ?$



$V_m = \sqrt{2} * V_s$

$= \sqrt{2} * 25$

$V_m = 35.35V$.

$I_m = \dfrac{V_m - V_F}{R_f + R_t + R_L}$

$= \dfrac{35.35 - \cancel{0.7}}{(600+0+0)}$

$\boxed{I_m = 0.0588 A}$.

$R_f = 0$
$R_t = 0$.

$I_{dc} = \dfrac{I_m}{\pi} = 0.0187A = \dfrac{0.058}{\pi} = 0.0187A$.

$I_{rms} = \dfrac{I_m}{2} = 0.0294 A. = \dfrac{0.058}{2} = 0.0294$

$V_{DC} = I_{DC} * R_L = 0.018 * 600 = 10.8V$

$V_{Rms} = I_{Rms} \times R_L = 0.029 \times 600 = 17.4V$.

Photo Diode:-

Light definition and units.

According to the quantum theory, light is in the form of photons and each photon delivers an energy packet to the surface on which it falls.

$$W = hf \text{ joules.}$$

where, h = planck's constant 6.624×10^{-34} Joules seconds

f = frequency of light waves in Hz.

Another important information is that light also behaves as travelling wave.

The frequency of light is directly related to its wavelength, as

$$f = V/\lambda$$

where V = velocity of light (3×10^8 m/s)

λ = Wavelength in meters, A° or μm.

1 angstrom (A°) = 10^{-10} m.

1 micrometer (μm) = 10^{-6} m

Intensity of light is measured in units of luminous flux incident on unit area.

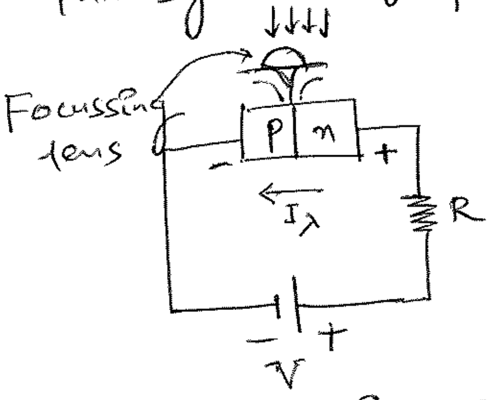
Unit of luminous flux are lumens.

$$1\ lm = 1.496 \times 10^{-10}\ W$$

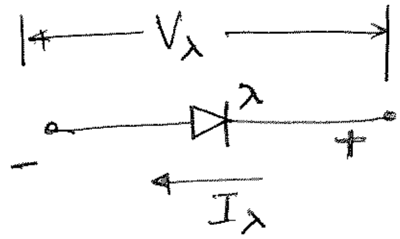
Intensity of light can be measured with the following practical unit. $1\ lm/ft^2$, called foot-Candle ($fc = 1.609 \times 10^{-9}\ W/m^2$

A photodiode is a PN junction (silicon/ germanium) operates in reverse-bias region as shown in figure 1(a)

The symbol of photodiode is also shown in figure 1(b)



1 (a). photo diode in reverse bias Condition.



1 (b) symbol

A light is made to impinge on the junction (pn), the light photons impart energy to the valence electrons Causing more electron-hole pairs to be released.

As a result, the Concentration of minority Carriers increases and current I_λ also increases.

The reverse saturation current I_λ is limited by the availability of thermally generated minority carrier.

The VI characteristics for various values of light intensity (fc) are draw in figure 2.

The dark current characteristic corresponding to no-light impingement ($I_\lambda = I_s$).

Here for the certain V_λ (say 20V), I_λ increases almost linearly with fc

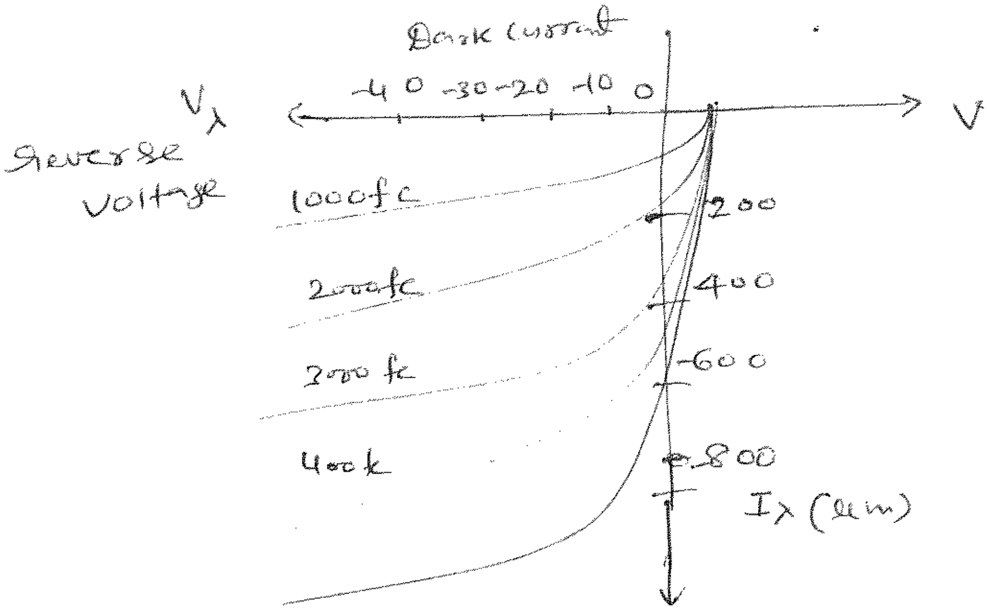


Fig (2). VI Characteristics of photo diode

Generally Ge photo diode has more overlaps compared to Si, which is the range of light frequencies to which the human eye is sensitive.

Ge is, therefore, more suitable for infra-red (IR) light sources like laser.

Light Emitting Diode (LED)

In a forward biased PN Junction diode recombination of electrons & holes takes place at the junction and within the body of the crystal, extactly at the location of a crystal defect.

The free electrons will be Captured by holes, the electron goes into a new state & its kinetic energy is given off as heat & as light photons.

In silicon diode, most of this energy is given off as heat but in other materials such as gallium arsenide (GaAs) or Gallium phosphide (GaP) sufficient number of photons (light) are generated so as to create a visible source.

This process of light emission in PN Junctions of such materials is shown in fig (B) & it is called as electroluminescence.

The metal contact of p-material is made much small to permit the emergence of maximum number of photons so that in an LED, the light lumens generated per watt of electric power is quite high.

Intensity of light increases almost linearly with forward Current, depending on the material used.

The voltage levels of LEDs are 1.7V & to 3.3V.

It is compitable with solid-state circuits.

The response time is short few ns (nanoseconds) and light contrast is good.

LED emit light in

red
green. orange or blue color.

Applications

used in Display appliations.

(1) 8 segment display. of numbers 0 to 9.

(2) LED TV's.

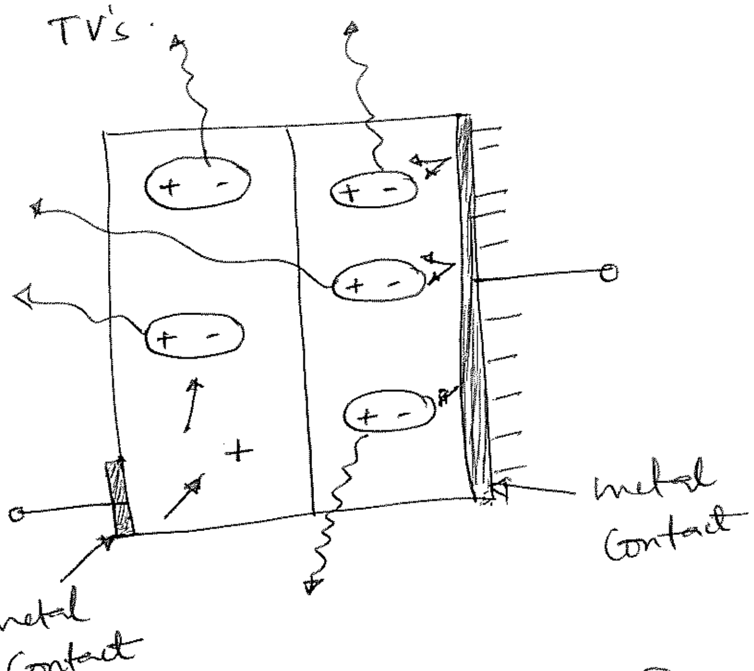


Figure ③. Light emission in PN Junction

For a photodiode, determine I_λ if $V_\lambda = 30V$ and intensity of light is $3.22 \times 10^{-6} W/m^2$. given $I_\lambda = 300 \mu A$ for 30V in figure ②.

light intensity in fc

$$f_c = \frac{3.22 \times 10^{-6}}{1.609 \times 10^{-9}}$$

$$= 2000.$$

photo Coupler

It is a package of an LED and photodiode whereas circuits are electrically isolated as in figure (4). The LED is forward biased & the photodiode is reverse biased. The output is available across R_2.

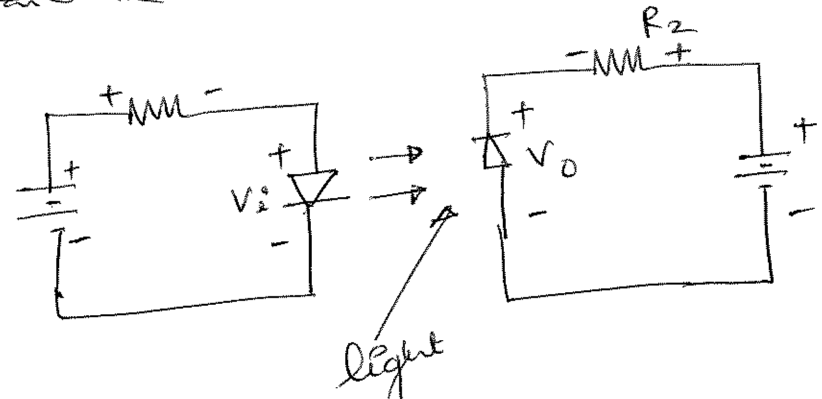


Figure (4) photo Coupler

Advantage of photo Coupler is electrical isolation between two circuits.

It is employed to couple circuits whose voltage level may differ by several thousand volts.

78XX Series & 7805 Fixed IC Voltage Regulator

We learnt in previous topic that Zener diode can be used as voltage regulator. Similarly we have Integrated circuits are also called as monolithic linear regulators namely

LM 7800 series

LM 7805 Fixed Regulator

LM7800 series

The LM78XX series (where XX = 05, 06, 08, 10, 12, 15, 18 or 24) is a typical three terminal voltage Regulators.

The 7805 produces an output of +5V
7806 produces +6V
7808 produces +8V & so on upto
& 7824 produces an output of +24V

The Functional block diagram of 78XX series voltage regulator is shown in figure 5.

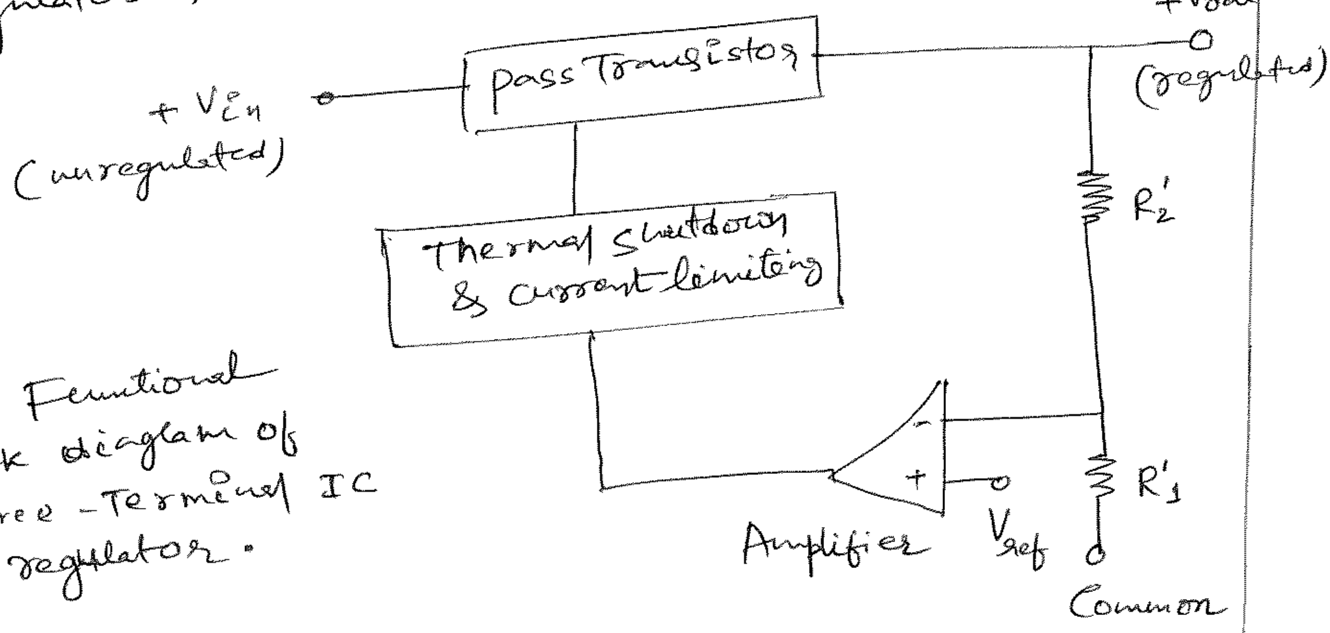


Fig 5. Functional block diagram of Three-Terminal IC regulator.

IC regulators are series regulator because they are more efficient than the shunt regulator.

IC regulator will have three pins

1. unregulated input voltage pin
2. regulated output voltage pin
3. Ground.

Available in plastic or metal packages, These are popular because they are inexpensive & easy to use.

The output voltage of IC regulator may be

fixed positive
fixed negative or
adjustable.

A built in reference voltage Vref drives the non-inverting input of an amplifier.

A voltage divider circuit consisting of R_1' and R_2' samples the output voltage and returns a feedback voltage to the inverting input of a high gain amplifier.

The output voltage is given by

$$V_{out} = \frac{R_1' + R_2'}{R_1'} V_{ref}.$$

The reference voltage is similar to zener voltage.

The primes attached to R_1' & R_2' indicate that these resistors are inside the IC itself, rather than being external resistors, rather than being external resistor.

These resistors are factory trimmed to get the different output voltages (5 to 15V) in the 78XX series.

The tolerance of the output voltage is ±4 percent.

The LM78XX includes a pass transistor, it can handle 1A of load current, provided that adequate heat sinking is used.

Thermal shutdown & current limiting circuit included. Thermal shutdown means that the chip will shut itself off when the internal temperature becomes too high, around 175°C.

This is a precaution against excessive power dissipation, which depends on the ambient temperature type of heat sinking & other variables.

Because of thermal shutdown & current limiting, devices in the 78XX series are almost indestructible.

LM7805 Fixed IC Regulator

LM7805 is a fixed Voltage Regulator IC. It has three pins pin 1 is the input, pin 2 is the output and pin 3 is ground.

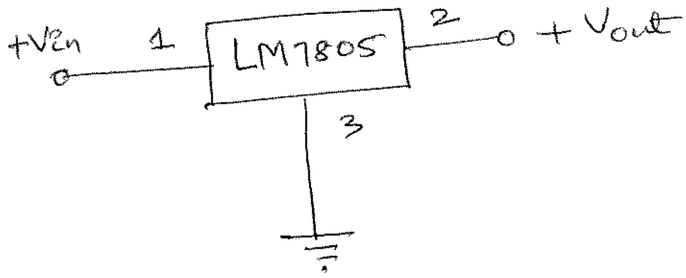
LM7805 has an output voltage of +5V and a maximum load current over 1A.

The typical load regulation is 10 mV for a load current between 5 mA & 1.5 A.

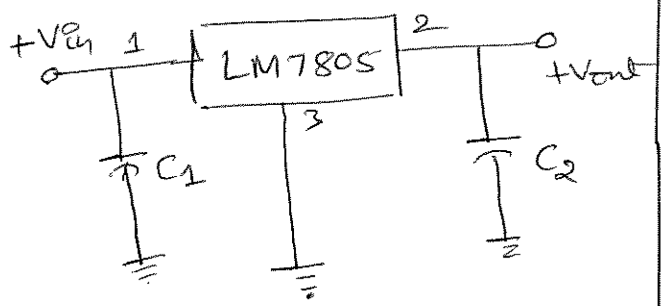
The typical line regulation is 3 mV for an input voltage of 7 to 25 V.

LM 7805 has a ripple rejection of 80dB, which means that it will reduce the input ripple by a factor of 10,000.

LM7805 is a very stiff voltage source to all loads within its current rating with output resistance of 0.01Ω.



ⓐ using a 7805 as voltage Regulator.



ⓑ Input Capacitor prevents oscillations and output Capacitor improves frequency response

When an IC is more than 6 from the filter capacitor of the unregulated power supply, oscillations will be produced because of the inductance of the connecting wires. hence to avoid oscillations bypass capacitor C_1 is used near p1. The value suggested by manufacture in data sheet will be 0.22μF for 78xx series IC.

A bypass capacitor C_2 is sometimes used on pin 2 to improve the transient responses of the regulated output voltage. The C_2 output capacitor value is 0.1μF.

78xx series Regulator has a drop-out voltage of 2 to 3 V depending on the output voltage. It means that input voltage is 2 to 3 V greater than that of output voltage.

otherwise, the chip stop regulating. Also there is a maximum input voltage because of excessive power dissipation.

For instance, the LM7805 will regulate over an input range of approximately 8 to 20 V.

The data sheet for the 78xx series gives the minimum and maximum input voltages for the other preset output voltages.

A half wave