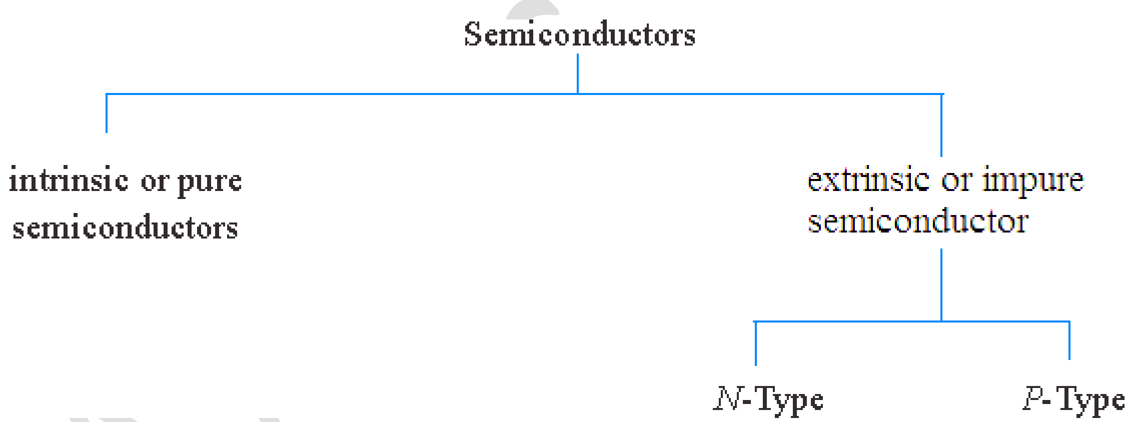
Introduction to semiconductor

Semiconductors : -

A semiconductor material is one whose electrical properties lie in between those of insulators and good conductors.
Examples are: germanium and silicon.
In terms of energy bands, semiconductors can be defined as those materials which have almost an empty conduction band and almost filled valence band with a very narrow energy gap (of the order of 1 eV) separating the two.



Types of Semiconductors:

Semiconductor may be classified as under:

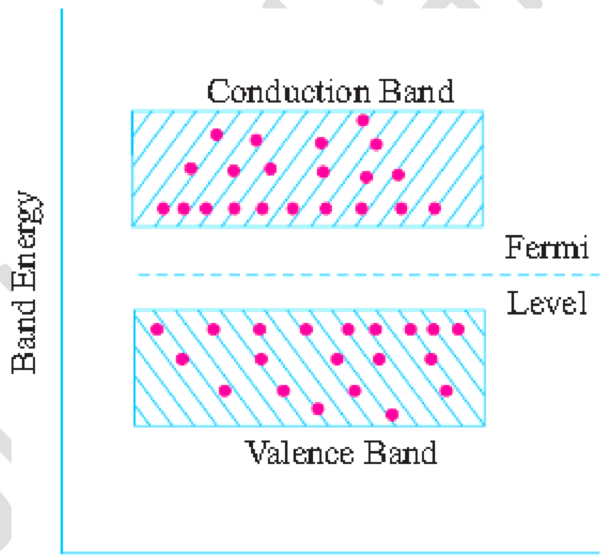
A . Intrinsic Semiconductors

An intrinsic semiconductor is one which is made of the semiconductor material in its extremely pure form.

Examples of such semiconductors are: pure germanium and silicon which have forbidden energy gaps of 0.72 eV and 1.1 eV respectively. The energy gap is so small that even at ordinary room temperature; there are many electrons which possess sufficient energy to jump across the small energy gap between the valence and the conduction bands. 2

Alternatively, an intrinsic semiconductor may be defined as one in which the number of conduction electrons is equal to the number of holes.

Schematic energy band diagram of an intrinsic semiconductor at room temperature is shown in Fig. below.



B . Extrinsic Semiconductors:

Those intrinsic semiconductors to which some suitable impurity or doping agent or doping has been added in extremely small amounts (about 1 part in 108) are called extrinsic or impurity semiconductors.

Depending on the type of doping material used, extrinsic semiconductors can be sub-divided into two classes:

(i) N-type semiconductors and

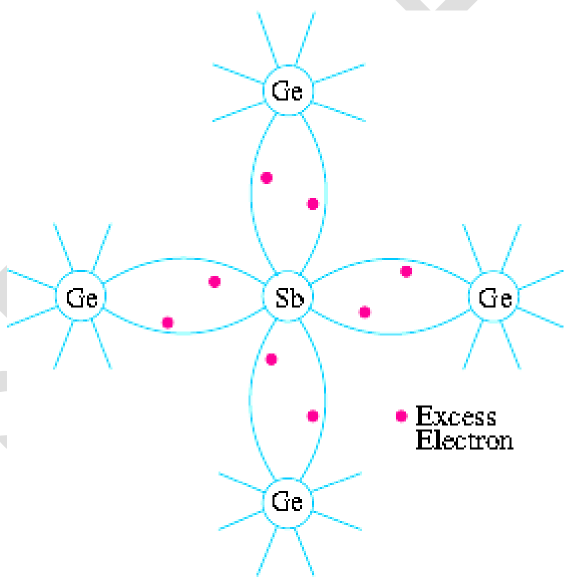
(ii) P-type semiconductors.

(i) N-type Extrinsic Semiconductor:

This type of semiconductor is obtained when a pentavalent material like antimonty (Sb) is added to pure germanium crystal. As shown in Fig. below, each antimony atom forms covalent bonds with the surrounding four germanium atoms with the help of four of its five electrons. The fifth electron is superfluous and is loosely bound to the antimony atom.

Hence, it can be easily excited from the valence band to the conduction band by the application of electric field or increase in thermal energy. It is seen from the above 3

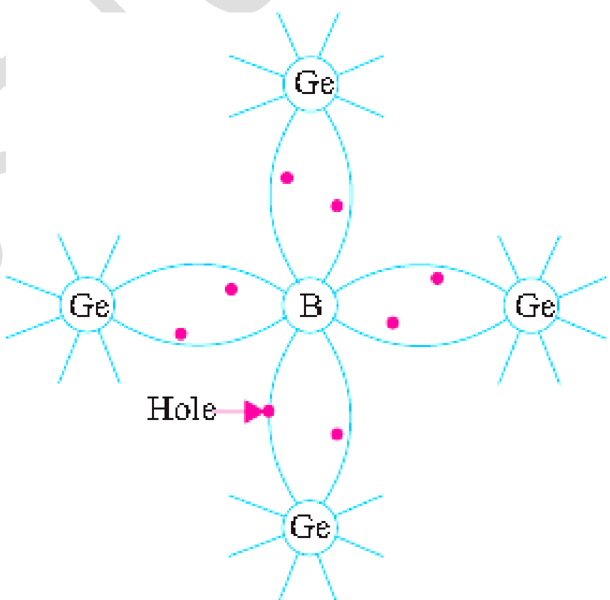
description that in N-type semiconductors, electrons are the majority carriers while holes constitute the minority carriers.



(ii) P-type Extrinsic Semiconductor:

This type of semiconductor is obtained when traces of a trivalent like boron (B) are added to a pure germanium crystal. In this case, the three valence electrons of boron atom form covalent bonds with four surrounding germanium atoms but one bond is left incomplete and gives rise to a hole as shown in Fig. below. Thus, boron which is called an acceptor impurity causes as many positive holes in a germanium crystal as there are boron atoms thereby producing a P-type (P for positive) extrinsic semiconductor.

In this type of semiconductor, conduction is by the movement of holes in the valence band.



Majority and Minority Carriers :

In a piece of pure germanium or silicon, no free charge carriers are available at 0ºK.

However, as its temperature is raised to room temperature

some of the covalent bonds are broken by heat energy and as a resultelectron-hole pairs are

Produced. These are called thermally-generated charge carriers.

They are also known as intrinsically-available charge carriers.

Ordinarily, their number is quite small. An intrinsic of pure germanium

can be converted into a P-type semiconductor by the addition of an acceptor impurity

which adds a large number of holes to it. Hence, a P-type material contains following charge carriers:

(A) Large number of positive holes—most of them being the added impurity holes with only a very small number of thermally generated ones.

(B) A very small number of thermally-generated electrons (the companions of the thermally generated holes mentioned above).

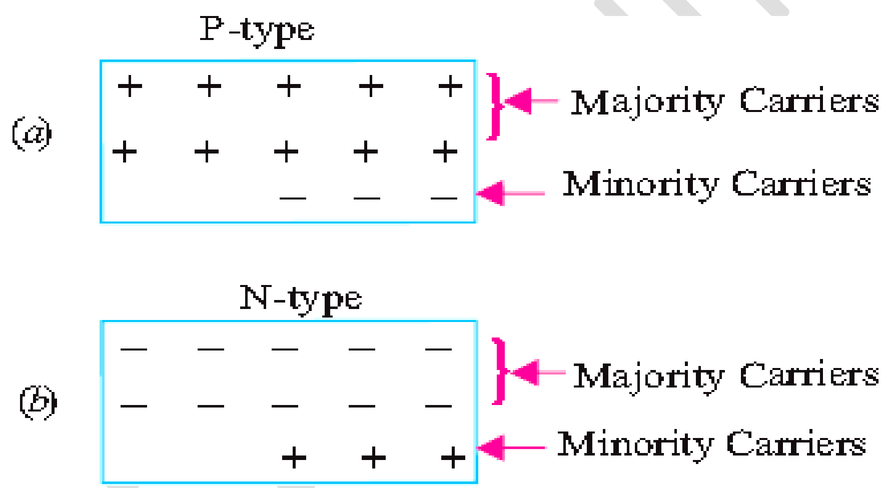
Obviously, in a P-type material, the number of holes (both added and thermally- generated)

is much more than that of electrons. Hence, in such a material

holes constitute majority carriers and electrons form minority carriers as shown in Fig. below (a). Similarly, in an N-type material, the number of electrons

(both added and thermally-generated) is much larger than the number of thermally-generated holes. Hence, in such a material

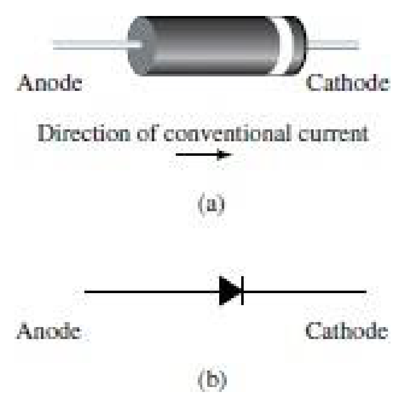
electrons are majority carriers whereas holes are minority carriers as shown in Fig. below (b).



P-N Junction Diode

1. Construction

It is two terminal devices consisting of a P-N junction formed either in Ge or Si crystal. It is circuit symbol is shown in fig. (1-a). The P and N type regions are referred to as anode and cathode respectively. In fig. (1-b) arrowhead indicates the conventional direction of current flow when forward biased. It is the same direction in which hole flow takes place.



2. Working

A P-N junction diode is a one way device offering low resistance when forward biased and behaving almost as an insulator when reverse biased.

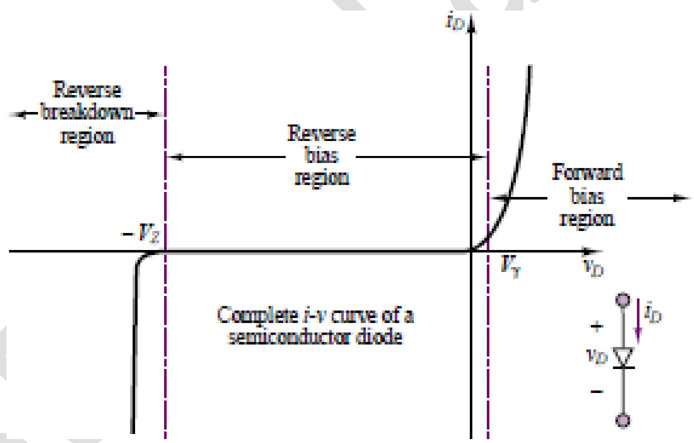
Hence such diodes are mostly used as rectifiers

for converting alternating current into direct current.

3. V/I Characteristic

Fig.2 shows the static voltage current characteristics

for a low power P-N junction diode.



3.1 Forward characteristic

When the diode is forward biased and applied voltage is increased from zero hardly any current flows through the device in the beginning. It is so because the external voltage is being opposed by the internal barrier voltage VB whose value is 0.7 V for Si and 0.3 V for Ge. As soon as VB is neutralized, current through the diode increases rapidly with increasing applied battery voltage. It is found that as little a voltage as 1.0 V produces a forward current of about 50 mA.

3.2 Reverse characteristic

When the diode is reverse biased majority carriers are blocked and only a small current (due to minority carriers) flows through the diode. As the reverse voltage is increased from zero, the reverse current very quickly reaches its maximum or saturation value I0 which is also known as leakage current. It is of order of nano ampers (nA) for Si and micro ampers (μA) for Ge. As seen from fig.2 when reverse voltage VBR, the leakage current suddenly and sharply increases, the curve indicating zero resistance at this point.

4. Diode Parameters

4.1 Bulk resistance (rB)

It is the sum of the resistance values of the P and N type semiconductor materials of which the diode is made of

$$r_{B=}\, r_P + r_N$$

Usually, it is very small, it is given by

$$r_B = \frac{V - V_K}{I_F}$$

It is the resistance offered by the diode well above the knee

voltage when current resistance is large.

Obviously, this resistance is offered in the forward direction.

4.2 Junction resistance (rj)

It is value for forward biased junction depends on the magnitude of forward dc current.

$$r_j = \frac{25\ mV}{I_F mA} \ \ldots\ldots\ldots\ldots\ldots \quad for\ Ge$$

$$r_j = \frac{50\ mV}{I_F\ mA} \ \ldots\ldots\ldots\ldots\ldots\ for\ Si$$

4.3 Dynamic or ac resistance

rac or rd = rB + rj

For large values of forward current, rj is negligible. Hence, rac = rB for small values of IF, rB is negligible as compared to rj

rac = rj

4.4 Forward voltage drop

It is given by the relation

$$forward\ voltage\ drop = \frac{power\ dissipated}{forward\ dc\ current}$$

Reverse saturation current (I_0) Reverse

breakdown voltage (V_{BR}) Reverse dc

resistance (R_R)

$$R_R = \frac{reverse\ voltage}{reverse\ current}$$

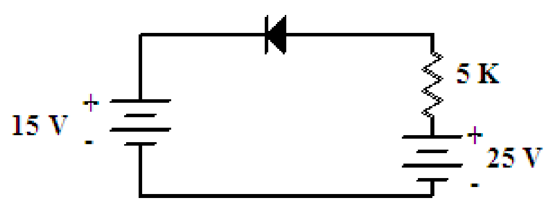
5. Equation of diode current

The analytical equation which describes both the forward and reverse characteristics is called the Boltzmann's diode equation given

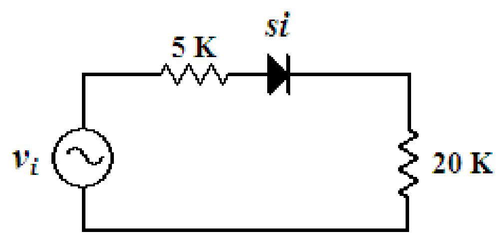
$$I = I_0(e^{40V} - 1) \ldots\ldots\ldots\ldots for\ Ge$$
$$I = I_0 e^{40V} \quad if\ V > 1\ volt.$$
$$I = I_0(e^{20V} - 1) \ldots\ldots\ldots for\ Si$$
$$I = I_0 e^{20V} \quad if\ V > 1\ volt.$$

Where I_0 reverse saturation current. V voltage across the diode .

EX 1 : For the diode shown in the following circuit calculate the current through the resistor ?

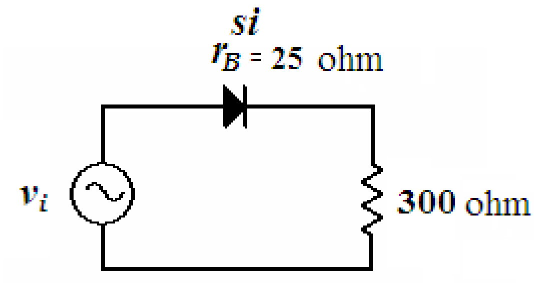


EX 2 : For the diode shown in the following circuit calculate the current ? if V_i = 5 v , V_o = ?



EX 3 : For the diode shown in the following circuit calculate the current ? if V_i = 10 v

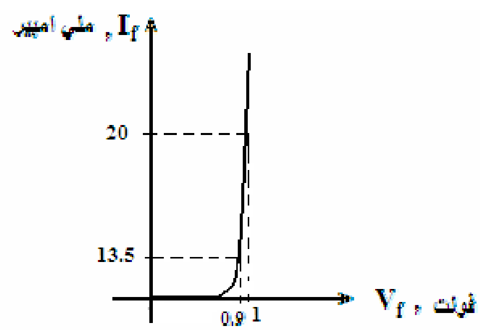
Vo = ? at (300 hom)



EX 4 : A silicon diode has a forward current of (30 Ma) & (1 V)

What is the approximate total resistance ? (*)

EX 5 : From the curve, calculate the total resistance



EX 6 : If the resistance of the P area (5Ω) & resistance of the N area (3Ω)

What is the total resistance ?

Rectifier

It is a circuit which employs one or more diodes to convert ac voltage into pulsating dc voltage.

We will consider the following circuits :

(i) Half wave rectifier.

(ii) Full wave rectifier.

(iii) Full wave bridge circuits.

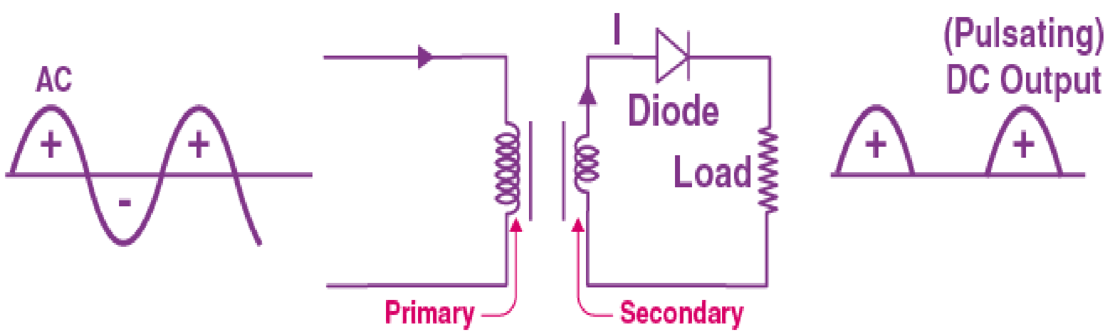
(iv) Voltage multiplier circuits

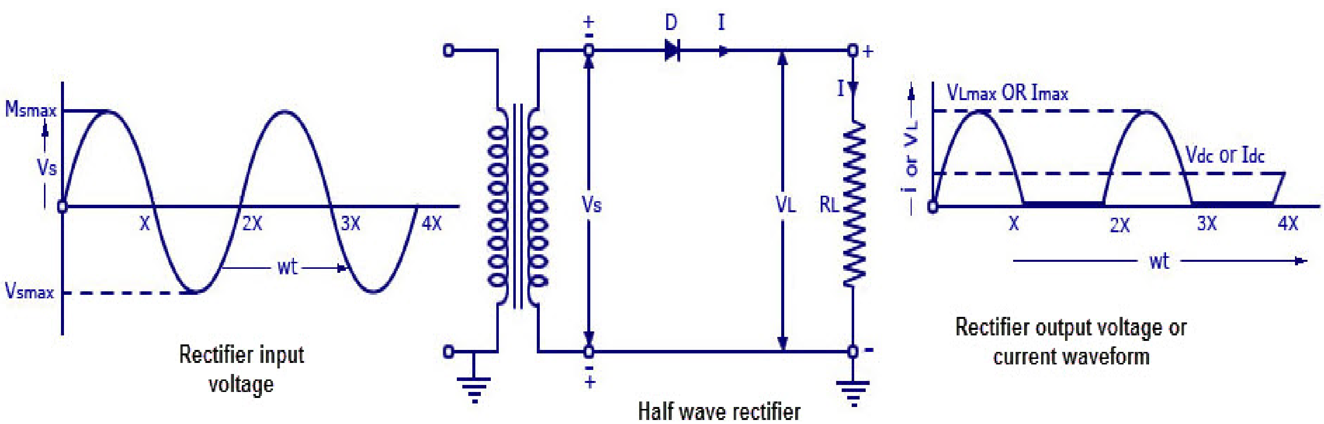
Half wave rectifier

Basic half wave rectifier circuit is shown in fig.1 along with its input and output waveforms. An alternating voltage is applied to a single diode connected in a series with a load resistor RL.

Working:

during the positive half cycle of the input ac voltage the diode D is forward biased (ON) and conducts while conducting the diode acts as a short circuit so that circuit current flows and hence, positive half cycle of the input ac voltage is dropped across RL.





During the negative half cycle, the diode is reversing biased (off), and so does not conduct. There is no current flow, hence there is no voltage drop across RL, ID=0 and VL=0.

Let the equation of the input supply voltage of fig.1 be

$V = V_m \sin\theta$

V_m= maximum value of supply voltage in fig.1

$= \sqrt{2}V$

V= rms value of supply voltage.

I_m= maximum value of diode or load current.

V_{dc}= average dc voltage across load.

I_{dc}= average dc current through load.

I_{rms}= rms current through load.

Then it can be proved that

(i) $V_{dc} = \frac{V_m}{\pi} = 0.318\, V_m$

(ii) $I_{dc} = \frac{V_{dc}}{R_L} = \frac{V_m}{\pi R_L}$

$$= 0.318 \frac{V_m}{R_L}$$

$$= 0.318\, I_m$$

$$= 0.45\, \frac{V}{R_L}$$

$$I_{rms} = \frac{I_m}{2} = 0.5\, I_m$$

(iii) Form Factor

$$F = \frac{rms\ value}{average\ value} = \frac{0.5\ I_m}{0.318\ I_m} = 1.57\ \ for\ sinusoidal\ ac\ wave$$

(iv) PIV

It is the maximum voltage across the diode in the reverse direction.

(v) Ripple Factor (γ)

The ripple factor of a single phase half wave rectifier is

$$\gamma = \frac{V_{rms}}{V_{dc}}$$

$$= \frac{0.385\ V_m}{0.318\ V_m} = 1.21$$

The relation between V_m and V_{dc} is given by

$$\frac{V_m}{V_{dc}} = 1 + \sqrt{3}.\gamma$$

(iii) Efficiency (η)

It is given by the ratio of the output dc power to the total amount of input power supplied to the circuit

$$\therefore\ \eta = \frac{P_{out}}{P_{in}}$$

$$now, P_{out} = I_{dc}^2 R_L$$

$$P_{in} = I_{rms}^2 (r_d + R_L)$$

$$\therefore\ \eta = \frac{I_{dc}^2 R_L}{I_{rms}(r_d + R_L)} \times 100$$

substituting and simplifying we get

$$\eta = \frac{0.406}{1 + \frac{r_d}{R_L}}$$

$$= \frac{40.6}{1 + \frac{r_d}{R_L}} \quad percent$$

If diode resistance r_d is neglected, then

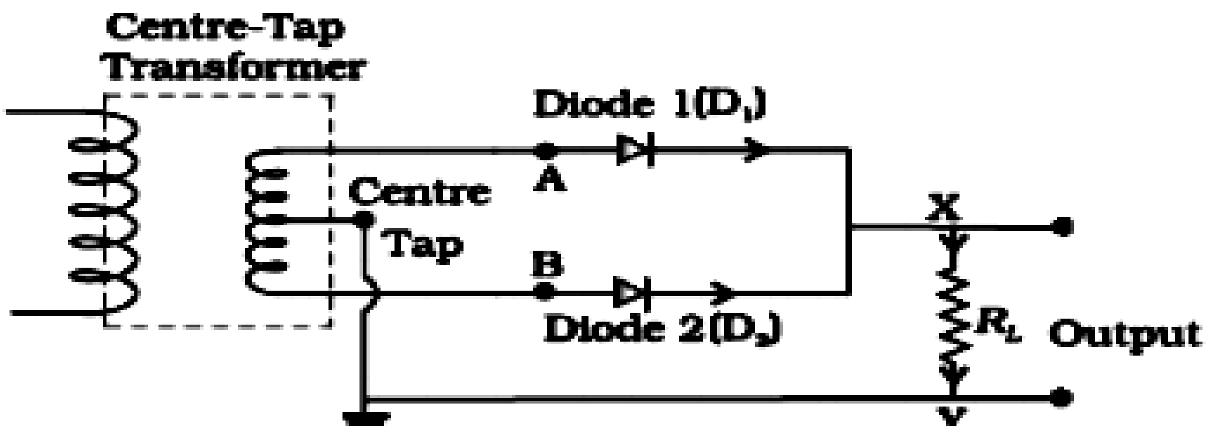
$$\eta = 40.6\,\% \qquad \textit{it is the maximum possible efficiency.}$$

Full -wave Rectifier

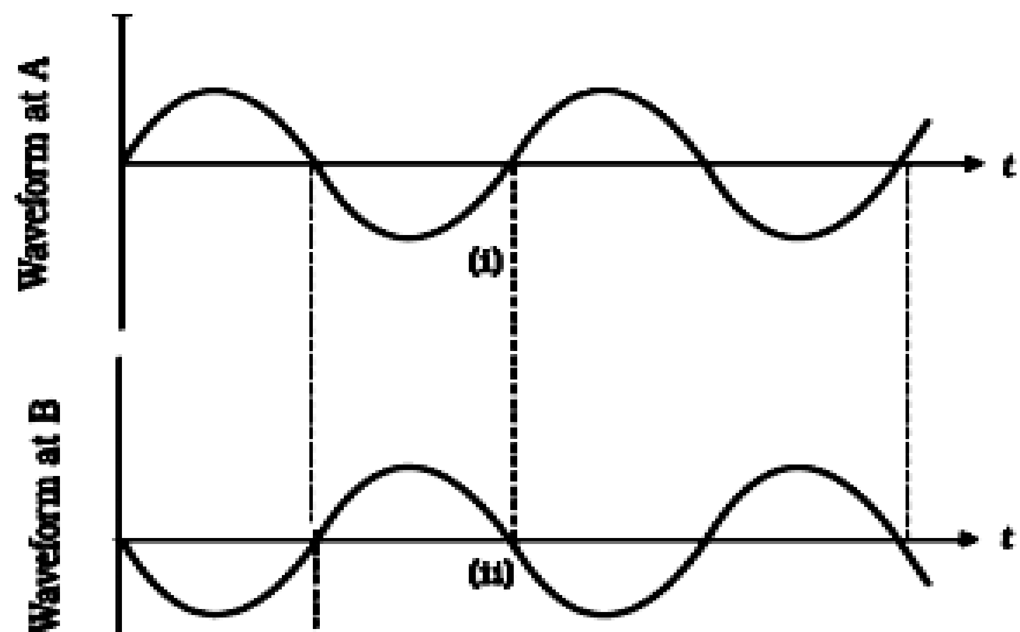
The full wave rectifier circuit using two diodes and a center tapped transformer is shown in fig.3. The centers tap. is usually taken as the ground or zero voltage reference point.

(a) Working:

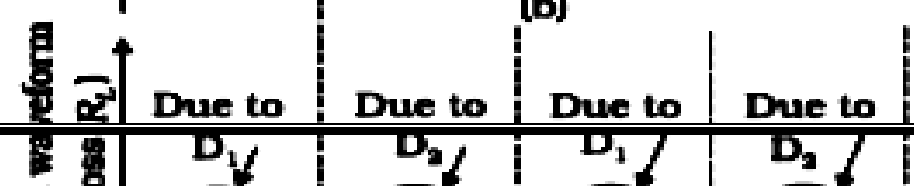
When input ac supply is switched on, the ends of the transformer secondary become +Ve and negative alternately. During the positive half cycle of the ac input. Hence, being forward biased diode D1 conducts (but not D2 which is reverse biased). As a result, positive half cycle of the voltage appears across RL. In the negative half cycle D2 conducts (but not D1). So we find that current keeps of following through RL in the same direction in both half cycles of the ac input. Also, the frequency of the rectified output voltage is twice the supply frequency.


Centre-Tap
Transformer
Diode 1(D_1)
A
Centre
Tap
B
Diode 2(D_2)
X
R_L
Output
Y

(a)


Waveform at A
t
(i)
Waveform at B
t
(ii)

(b)


Due to
D_1
Due to
D_2
Due to
D_1
Due to
D_2

(b) Average values:

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

$$= 0.636\,V_m \quad twice\ the\ half\ wave\ recifier\ value$$

$$= \frac{2\sqrt{2}V}{\pi} = 0.9\,V$$

Where V_m is the maximum voltage across each half of the secondary winding

=rms voltage across each half of the secondary winding.

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

$$= 0.636\,I_m$$

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

$$= \frac{V_{dc}}{R} = \frac{2.\sqrt{2}}{\pi} . \frac{V}{R_L}$$

$$= 0.9 \frac{V}{R_L}$$

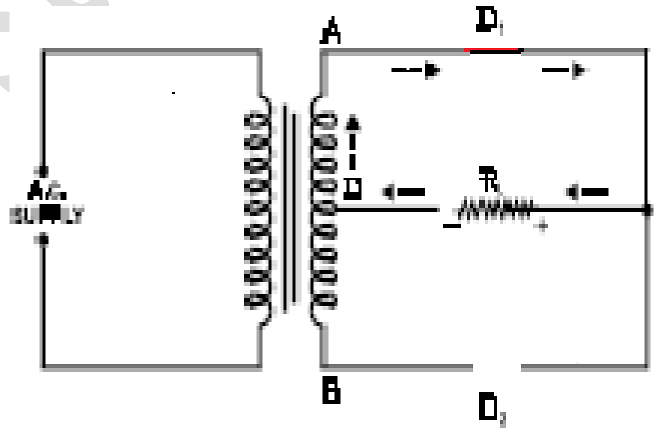
(iii) $I_{rms} = 0.707\, I_m$

(iv) $form\ factor, F = \frac{I_{rms}}{I_{av}} = \frac{I_{rms}}{I_{dc}}$

$$= \frac{0.707\, I_m}{0.636\, I_m} = 1.11$$

(a) PIV:

In this case, PIV rating of each diode is 2 Vm. consider the positive half cycle of the input ac supply when D1 acts as short and D2 acts as open since it is reverse biased. A voltage Vm develops across RL. As seen from fig. below, voltage across D2 is equal to the sum of voltages across the lower half GN of the transformer secondary and the load resistor. Hence PIV of D2=2 Vm.



(b) Ripple factor (γ):

$$\gamma = \frac{V_r(rms)}{V_{dc}} = \frac{0.305\, V_m}{0.636\, V_m} = 0.482$$

For full wave rectifier circuit

Is much less than that of half wave rectifier. The relation between Vm and Vdc is the same as HW rectifier.

(a) **<u>Efficiency:</u>**

$$\eta = \frac{P_{out}}{P_{in}}$$

$$= \frac{{I_{dc}}^2 * R_L}{{I_{rms}}^2 (r_d + R_L)}$$

Substituting and simplifying, we get

$$\eta = \frac{81.2\%}{1 + \frac{r_d}{R_L}} = 81.2\% \quad if\ r_d = 0$$

It is twice the value for half wave rectifier.

- Prove the solution to the following equation?

$$\eta = \frac{40.6}{1 + \frac{r_d}{R_L}} \text{ Percent}$$

Sol /

$$\eta = \frac{P_{out,dc}}{P_{in,ac}} * 100 \quad \text{-----} \ (1)$$

$$P_{out,dc} = I_{dc}^2 * R_L \quad \text{.....} \ (2)$$

$$P_{in,ac} = I_{rms}^2 (R_L + r_d) \quad \text{-----} \ (3)$$

Sub (3) and (2) in (1)

$$\eta = \frac{I_{dc}^2 * R_L}{I_{rms}^2 (R_L + r_d)} * 100$$

$$I_{dc} = \frac{V_{dc}}{R_L} \quad , \quad V_{dc} = \frac{V_m}{\pi}$$

$$\eta = \frac{\frac{I_m^2}{\pi^2} * R_L}{\frac{I_m^2}{4} (R_L + r_d)} * 100$$

$$\eta = \frac{4}{\pi^2} * \frac{R_L}{(R_L + r_d)} * 100$$

$$\eta = \frac{4}{\pi^2} * \frac{R_L}{R_L\left(1 + \frac{r_d}{R_L}\right)} * 100$$

$$\eta = \frac{0.406}{1 + \frac{r_d}{R_L}} * 100$$

$$\eta = \frac{40.6}{1 + \frac{r_d}{R_L}}$$

If diode resistance is neglected, then

$$\eta = 40.6\ \%$$

Tutorial

-Prove the solution to the following equation?

$$\eta = \frac{40.6}{1 + \frac{r_d}{R_L}} \text{ Percent}$$

Sol /

$$\eta = \frac{P_{out,dc}}{P_{in,ac}} * 100 \quad \text{.....} (1)$$

$$P_{out,dc} = I_{dc}^2 * R_L \quad \text{.....} (2)$$

$$P_{in,ac} = I_{rms}^2 (R_L + r_d) \quad \text{.....} (3)$$

Sub (3) and (2) in (1)

$$\eta = \frac{I_{dc}^2 * R_L}{I_{rms}^2 (R_L + r_d)} * 100$$

$$I_{dc} = \frac{V_{dc}}{R_L} \quad , \quad V_{dc} = \frac{V_m}{\pi}$$

$$\eta = \frac{\frac{I_m^2}{\pi^2} * R_L}{\frac{I_m^2}{4} (R_L + r_d)} * 100$$

$$\eta = \frac{4}{\pi^2} * \frac{R_L}{(R_L + r_d)} * 100$$

$$\eta = \frac{4}{\pi^2} * \frac{R_L}{R_L\left(1 + \frac{r_d}{R_L}\right)} * 100$$

$$\eta = \frac{0.406}{1 + \frac{r_d}{R_L}} * 100$$

$$\eta = \frac{40.6}{1 + \frac{r_d}{R_L}}$$

If diode resistance is neglected, then

$$\eta = 40.6\ \%$$

Example 1 : for the following circuit

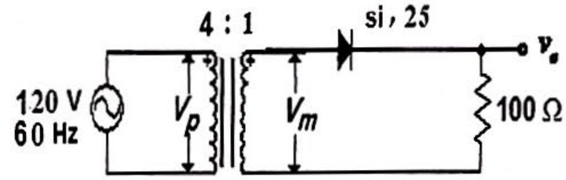
Calculate :

- (Vdc, Idc, PIV, Pac, Pdc, η%, r. f)

Is the diode used suitable

- if it is For Rectifier

VB = 60 V, IF max = 180 mA



Sol :-

- $V_p = \sqrt{2}\, V_{rms} = 168\ V$

$V_m = V_p * \frac{N_2}{N_1} = 42\ V$

$V_{dc} = \frac{V_m}{\pi} = 13.7\ V$

$I_{dc} = \frac{I_m}{\pi} = \frac{V_{dc}}{R_L} = 137\ mA$

$PIV = V_m = 42\ V$

$P_{ac} = \frac{V_m^2}{4(R_L + r_D)} = 3.53\ W$

$P_{dc} = \frac{V_m^2}{\pi^2\ R_L} = 1.79\ W$

$\eta\% = \frac{P_{dc}}{P_{ac}} * 100\% = 50.7\ \%$

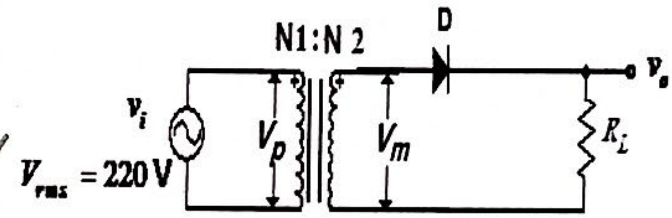
- Yes, it works ⇒ $I_{dc}\ (137\ mA) < I_{F\,max}\ (180\ mA)$

⇒ $PIV\ (42\ V) < V_B\ (60\ V)$

3

Example 2 : for the following circuit (Si , 25 Ω)
N1/N2 = 10/1 , RL = 100 Ω
Calculate :
(Vdc, Idc, PIV, Pac, Pdc, η%, r. f)

Sol :-



$V_p = \sqrt{2}\, V_{rms} = 310V$

$V_m = V_p * N_2/N_1 = 31V$

$V_{dc} = \frac{V_m}{\pi} = 9.87V$

$I_{dc} = \frac{V_{dc}}{R_L} = 98.72$ mA

$PIV = V_m = 31$ V

$P_{ac} = \frac{V_m^2}{4(R_L + r_D)} = 1.922$ W

$P_{dc} = \frac{V_m^2}{\pi^2 * R_L} = 0.9746$ W

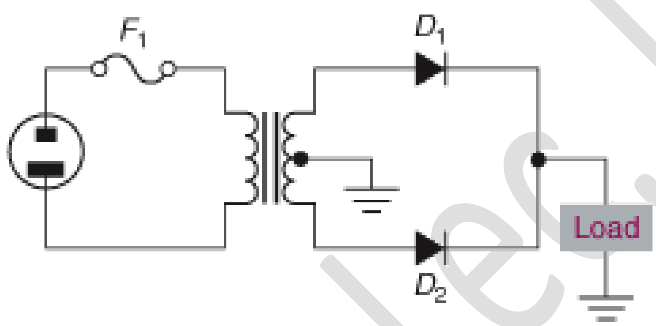
$\eta \% = \frac{P_{dc}}{P_{ac}} * 100\% = 50.7\%$

H.W.1 :

An electronic circuit with an input resistance of 500 ohms and requiring a continuous voltage of 12 volts to supply it. A half-wave rectifier was designed between the available source of 120 volts and 60 Hz and the circuit .

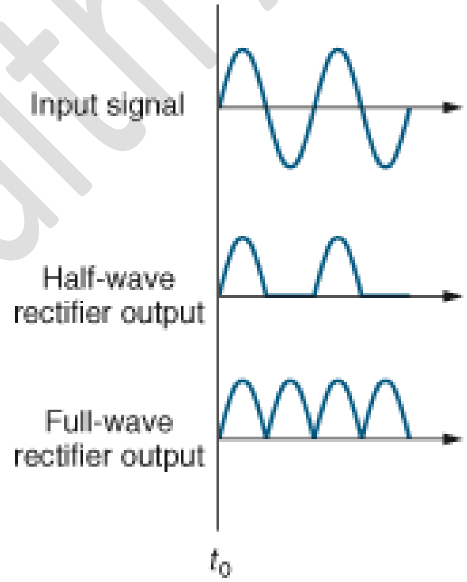
Tutorial

(ii) Full wave rectifier.



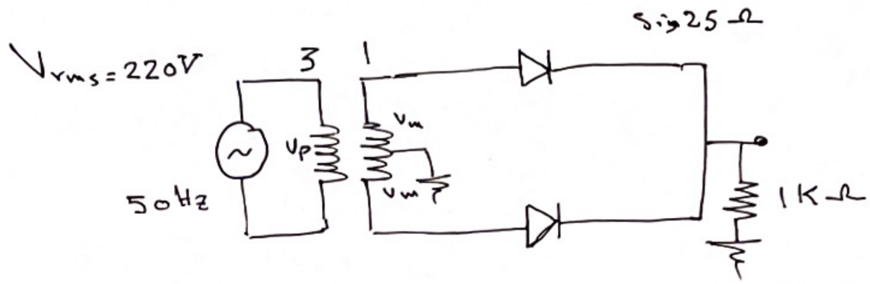
A full-wave rectifier

(a)



Typical rectifier waveforms

(b)



Determine :- (V_{dc} , I_{dc} , F_o , PIV , P_{ac} , P_{dc} , η)

Sol/ $V_p = \sqrt{2}\, V_{rms}$, $\frac{V_p}{2V_m} = \frac{N_1}{N_2}$

$V_{dc} = \frac{2V_m}{\pi} \Rightarrow V_{dc} = 24.7\,V$

$I_{dc} = \frac{V_{dc}}{R} \Rightarrow I_{dc} = 24.7\ mA$

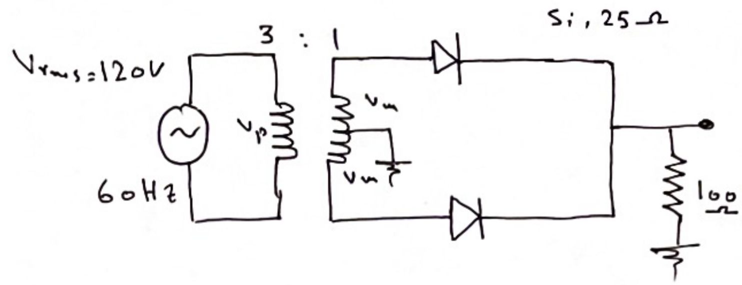
$F_o = 2F_i \Rightarrow F_o = 100\ Hz$

$PIV = 2V_m \Rightarrow PIV = 77.75\ V$

$P_{ac} = \frac{V_m^2}{2(R_L + r_D)} \Rightarrow P_{ac} = 0.74\ W$

$P_{dc} = \frac{4(V_m)^2}{\pi^2 R_L} \Rightarrow P_{dc} = 0.613\ W$

$\eta = \frac{P_{dc}}{P_{ac}} * 100\% \Rightarrow \eta = 82.8\ \%$



Q / Is this diode suitable for rectification? if it was:

$I_{f\,max} = 250\ mA$

$V_B = 80\ V$

Sol / $V_P = \sqrt{2}\ V_{rms} \Longrightarrow V_P = 168V$

$\frac{N_1}{N_2} = \frac{V_P}{2V_m} \Longrightarrow V_m = 28V$

$V_{dc} = \frac{2V_m}{\pi} \Longrightarrow V_{dc} = 17.8\ V$

$I_{dc} = \frac{V_{dc}}{R_L} \Longrightarrow I_{dc} = 178\ mA$

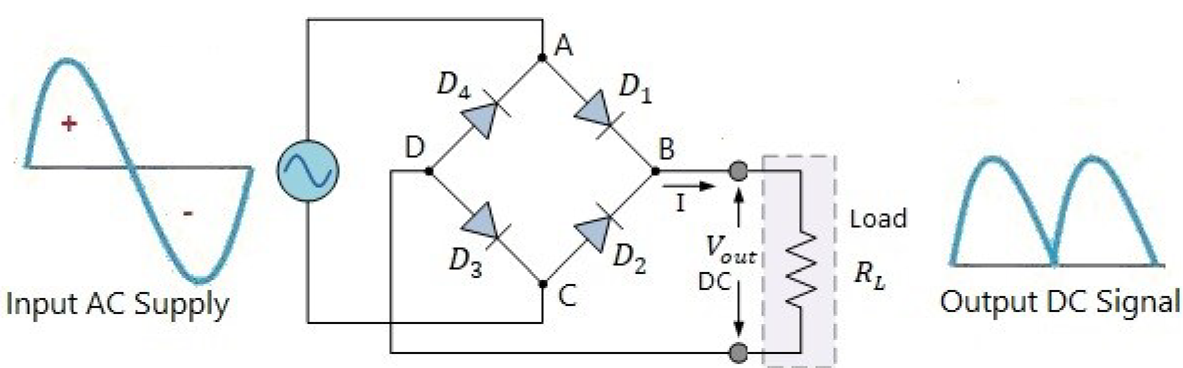
$PIV = 2V_m \Longrightarrow PIV = 56V$

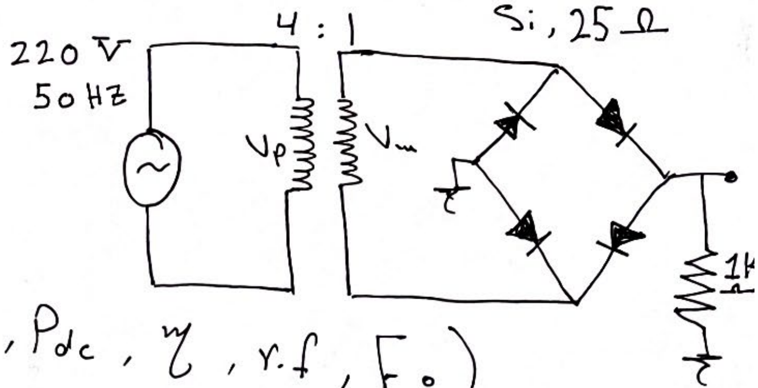
$I_{f\,max} = 250\ mA > I_{dc} = 178\ mA$ ✓

$V_B = 80\ V > PIV = 56\ V$ ✓

Tutorial

(iii) Full wave bridge circuits.





Determine :-

(V_{dc}, I_{dc}, PIV, P_{ac}, P_{dc}, η, r.f, F_o)

Sol :-

$$V_p = \sqrt{2}\, V_{rms} \Longrightarrow V_p = 311\,V$$

$$\frac{N_1}{N_2} = \frac{V_p}{V_m} \Longrightarrow V_m = 77.75\,V$$

$$V_{dc} = \frac{2V_m}{\pi} \Longrightarrow V_{dc} = 49.5\,V$$

$$I_{dc} = \frac{V_{dc}}{R_L} \Longrightarrow I_{dc} = 49.5\,mA$$

$$PIV = V_m \Longrightarrow PIV = 77.75\,V$$

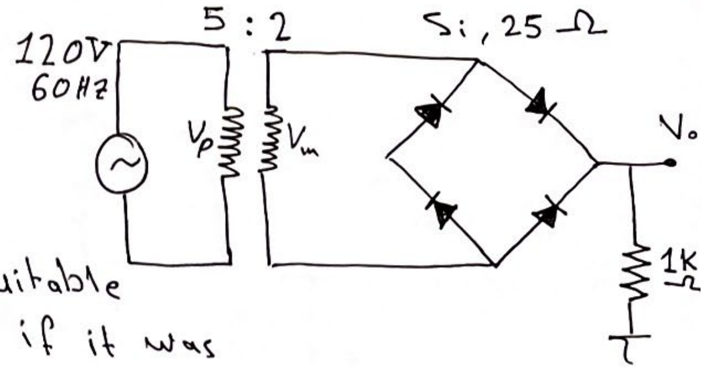
$$P_{ac} = \frac{V_m^2}{2(R_L + r_D)} \Longrightarrow P_{ac} = 2.95\,W$$

$$P_{dc} = \frac{4V_m^2}{\pi^2 R_L} \Longrightarrow P_{dc} = 2.45\,W$$

$$\eta = \frac{P_{dc}}{P_{ac}} * 100\% \Longrightarrow \eta = 83\,\%$$

$$r.f = \frac{V_r}{V_{dc}} \Longrightarrow r.f = 0.482$$

$$F_o = 2F_i \Longrightarrow F_o = 100\,Hz$$



Q / Is this diode suitable for rectification ? if it was

$I_{f\,max} = 100\ mA$, $V_B = 80\ V$

Sol :

$$V_p = \sqrt{2} * V_{rms} \Longrightarrow V_p = 168\ V$$

$$\frac{N_1}{N_2} = \frac{V_p}{V_m} \Longrightarrow V_m = 67.2\ V$$

$$V_{dc} = \frac{2V_m}{\pi} \Longrightarrow V_{dc} = 42.8\ V$$

$$I_{dc} = \frac{V_{dc}}{R_L} \Longrightarrow I_{dc} = 42.8\ mA$$

$$PIV = V_m \Longrightarrow PIV = 67.2\ V$$

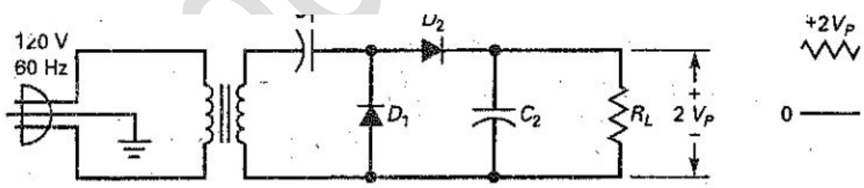
$$\underset{100\ mA}{I_{f\,max}} > \underset{42.8\ mA}{I_{dc}}$$

$$\underset{80\ V}{V_B} > \underset{67.2\ V}{PIV}$$

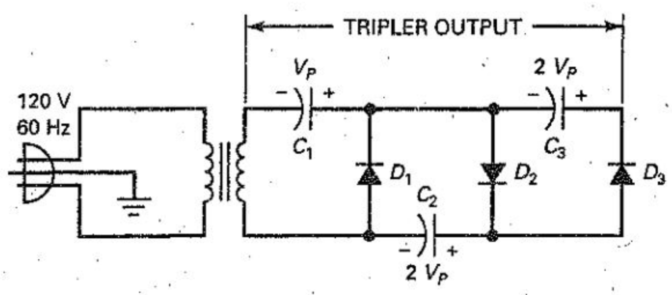
Voltage-Multiplier Circuits

Basic Concepts:

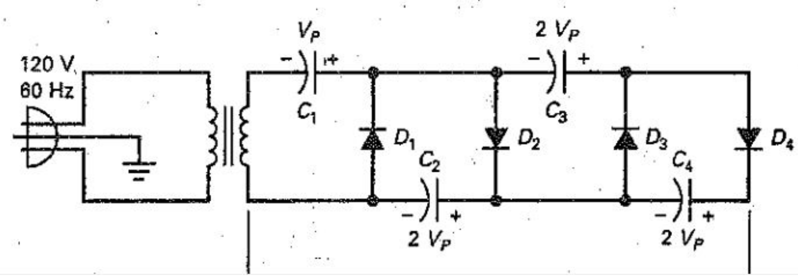
Diodes and capacitors can be connected in various configurations to produce filtered, rectified voltages that are integer multiples of the peak value of an input sine wave. The principle of operation of these circuits is similar to that of the clamping circuits discussed previously. By using a transformer to change the amplitude of an ac voltage before it is applied to a voltage multiplier, a wide range of dc levels can be produced using this technique. One advantage of a voltage multiplier is that high voltages can be obtained without using a high-voltage transformer.



(a)



(b)



Voltage Doubler

1. Half-Wave Voltage Doubler :

Figure 6-1 shows a half-wave voltage doubler circuit.

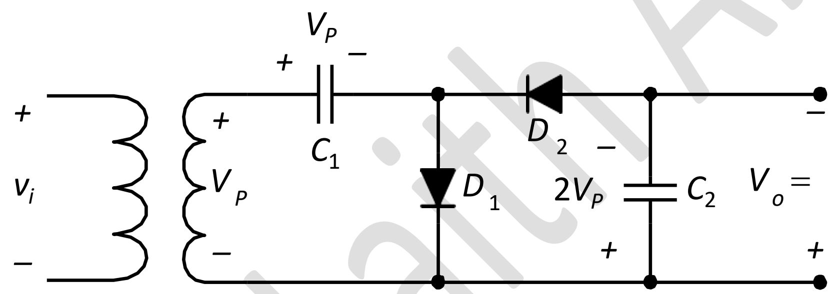


Fig. 6-1

Operation: $V_O = V_{C2} = |2V_p|$

◀ During the positive half-cycle,

D1 ON and *D2* OFF => Charging *C1* up to *VP*.

◀ During the negative half-cycle,

D2 ON and *D1* OFF => Charging *C2* to 2*VP*.

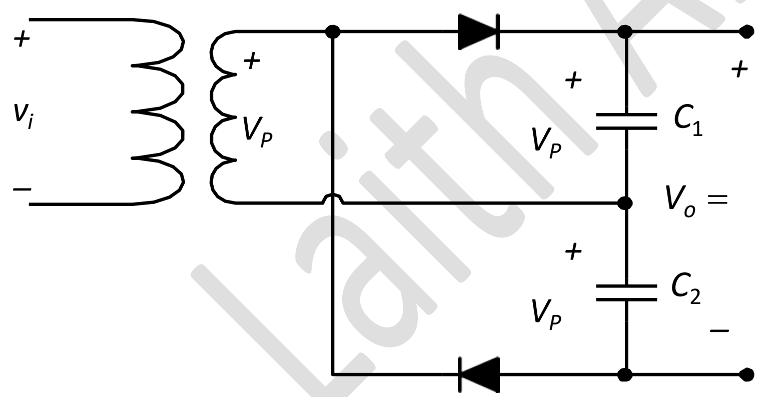
◀ The output (*Vo*) of the half-wave voltage doubler is [6.1]

If a load is connected to the output of the half-wave voltage doubler, the voltage across capacitor *C2* drops during the positive half-cycle (at the input) and the capacitor is recharged up to 2*VP* during the negative half-cycle. The output waveform across capacitor *C2* is that of a half-wave signal filtered by a capacitor filter.

The peak inverse voltage (*PIV*) rating of each diode in the half-wave voltage doubler circuit must be at least 2*VP*.

2. Full-Wave Voltage Doubler:

Figure 6-2 shows a full-wave voltage doubler circuit.



Operation:

Fig. 6-2

◀ During the positive half-cycle,

D1 ON and *D2* OFF => Charging *C1* up to *VP*.

◀ During the negative half-cycle,

D2 ON and *D1* OFF => Charging *C2* up to *VP*.

◀ The output (*Vo*) of the full-wave voltage doubler is

$$V_O = V_{C1} + V_{C2} = 2V_p$$

If load current is drawn from the full-wave voltage doubler circuit, the voltage across the capacitors *C1* and *C2* is the across a capacitor fed by a full-wave rectifier. One difference is that of *C1* and *C2* in series, which is less than capacitance of either *C1* and *C2* alone. The lower capacitor value will provide poorer filtering action than the single-capacitor filter circuit.

The peak inverse voltage across each diode is 2*VP*, as it is for filter capacitor circuit.

3.Voltage Tripler and Quadrupler :

Figure 6-3 shows an extension of the half-wave voltage doubler, which develops three and four times the peak input voltage. It should be obvious from the pattern of the circuit connection how additional diodes and capacitors may be connected so that the output voltage may also be five, six, seven, and so on, times the basic peak voltage (*VP*)

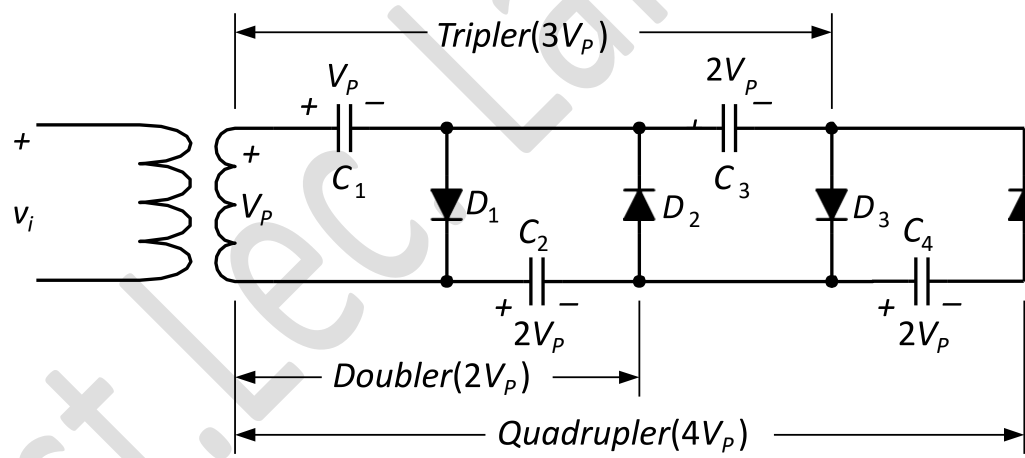


Fig. 6-3

Operation:

◀ During the positive half-cycle,

D1 ON and *D2*, *D3*, *D4* OFF => Charging *C1* up to *VP*.

◀ During the negative half-cycle,

D2 ON and *D1*, *D3*, *D4* OFF => Charging *C2* to 2*VP*.

◀ During the next positive half-cycle,

D1, *D3* ON and *D2*, *D4* OFF => *C2* charges *C3* to 2*VP*.

◀ During the next negative half-cycle,

D2, *D4* ON and *D1*, *D3* OFF => *C3* charges *C4* to 2*VP*.

◀ **The voltage across the combination of *C1* and *C3* is 3*VP* and that across *C2* and *C4* is 4*VP*.**

The *PIV* rating of each diode in the circuit must be at least 2*VP*.

SPECIAL DIODES

Zener Diode

It is a reverse-biased heavily-doped silicon (or germanium) P-N junction diode which is operated in the breakdown region where current is limited by both external resistance and power dissipation of the diode. Silicon is preferred to Ge because of its higher temperature and current capability.

When a diode breaks down, both Zener and avalanche effects are present although usually one or the other predominates depending on the value of reverse voltage. At reverse voltages less than 6 V, Zener effect predominates whereas above 6 V, avalanche effect is predominant. Strictly speaking, the first one should be called Zener diode and the second one as avalanche diode but the general practice is to call both types as Zener diodes.

Zener breakdown occurs due to breaking of covalent bonds by the strong electric field set up in the depletion region by the reverse voltage. It produces an extremely large number of electrons and holes which constitute the reverse saturation current (now called Zener current, Iz) whose value is limited only by the external resistance in the circuit. It is independent of the applied voltage.

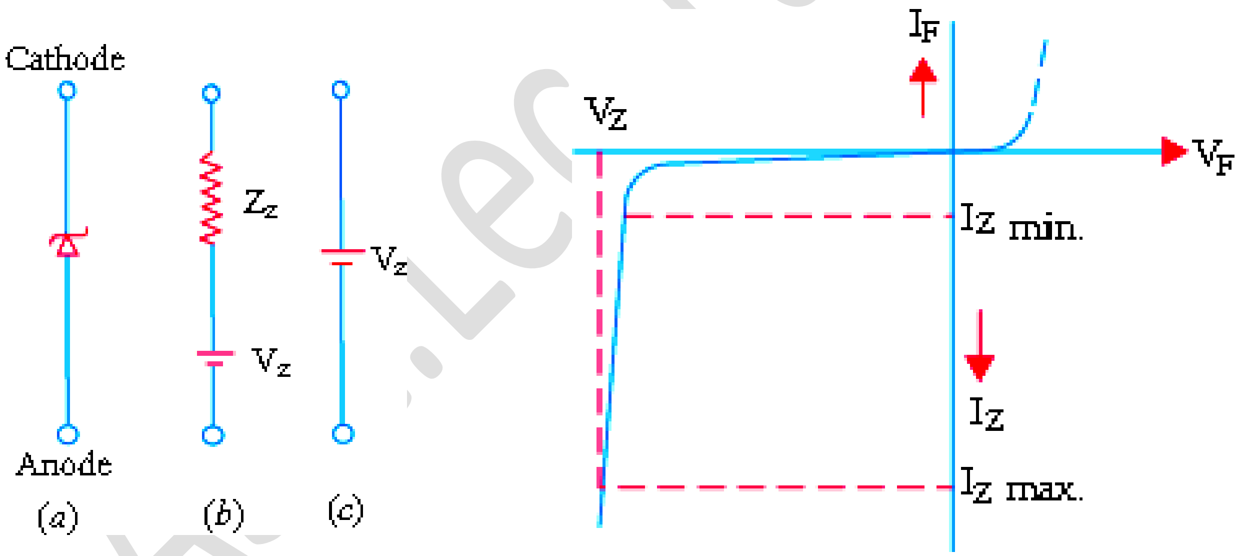
V/I Characteristic

A typical characteristic is shown by Fig. below in the negative quadrant. The forward characteristic is simply that of an ordinary forward-biased junction diode. The important points on the reverse characteristic are:

Vz = Zener breakdown voltage

Iz min = minimum current to sustain breakdown

Iz max = maximum Zener current limited by maximum power dissipation.



The schematic symbol of a Zener diode and its equivalent circuit are shown in Fig. below.

Zener Voltages

Zener diodes are available having Zener voltages of 2.4 V to 200 V. Their power dissipation is given by the product $V_z I_z$. Maximum ratings vary from 150 mW to 50 W.

Zener Biasing

For proper working of a Zener diode in any circuit

it is essential that it must :

1. be reverse-biased
2. Have voltage across it greater than V_z.
3. be in a circuit where current is less than $I_{z\,max}$.

Uses

Zener diodes find numerous applications in transistor circuitry. Some of their common uses are:

1. as voltage regulators.

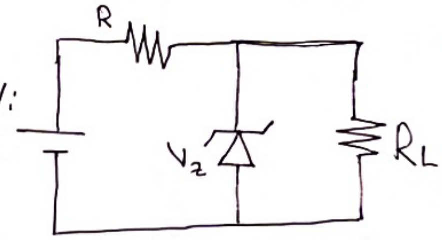
2. as a fixed reference voltage in a network for biasing and comparison purposes and for calibrating voltmeters.

3. as peak clippers or voltage limiters.

4. for meter protection against damage from accidental application of excessive voltage.

5. for reshaping a waveform.

Zener Diode



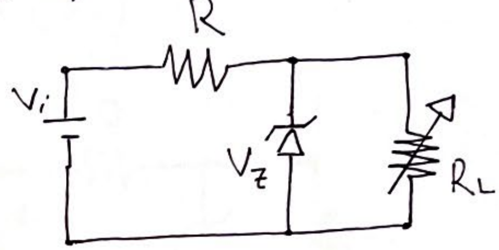
1- Fixed (V_i) and fixed (R_L)

$$I_L = \frac{V_L}{R_L} \Longrightarrow \text{if } V_L < V_z \text{ The diode is off}$$

$$I_R = \frac{V_i - V_L}{R} \qquad V_L > V_z \text{ The diode is on}$$

$$V_L = V_z \quad \text{if} \quad V_L > V_z$$

2- Fixed (V_i) and Variable (R_L)



$$R_{min} = \frac{R * V_z}{V_i - V_z}$$

$$I_{min} = \frac{V_L}{R_L}$$

$$I_Z = I_R - I_L$$

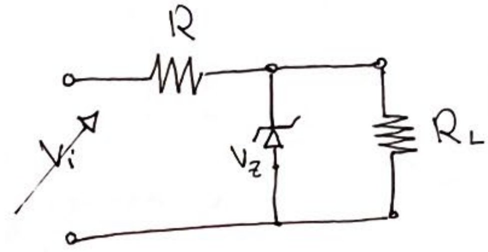
$$I_{L\,min} = I_R - I_{Z\,max}$$

$$I_{L\,min} = \frac{V_Z}{R_{L\,max}}$$

$$I_{L\,max} = \frac{V_Z}{R_{L\,min}}$$

3- Fixed (R_L) and Variable (V_i)

$$V_{in(min)} = \frac{(R_L + R) V_Z}{R_L}$$

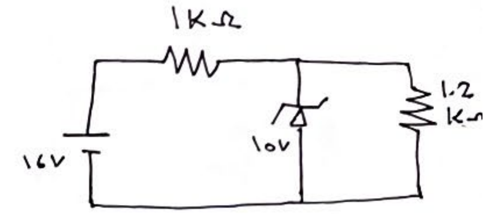


$$V_{in(max)} = I_{R(max)} * R + V_Z$$

$$I_{R(max)} = I_{Z(max)} + I_L$$

Determine :-

(V_L, V_R, I_z)



Sol :-

$$V_L = \frac{V_i * R_L}{R + R_L} \Longrightarrow V_L = 8.72\,V$$

$V_L < V_z \Rightarrow$ The diode is off .

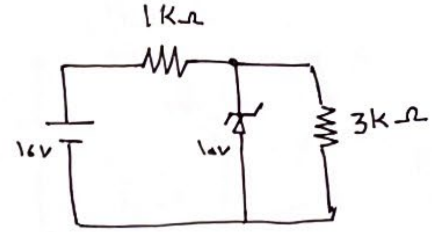
$16 - V_R - 8.72 = 0$

$V_R = 7.28\ V$

$I_z = 0\ V$

Determine:

(V_L, V_R, I_Z)



Sol:

$$V_L = \frac{V_i * R_L}{R + R_L} \Rightarrow V_L = 12\,V$$

$V_L > V_Z \Rightarrow$ The diode is on.

$$V_L = V_Z \Rightarrow V_L = 10\,V$$

$$16 - V_R - 10 = 0$$

$$V_R = 6\,V$$

$$I_R = I_Z + I_L$$

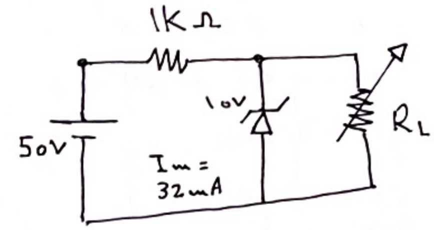
$$I_R = \frac{V_R}{R} \Rightarrow I_R = 6\ mA$$

$$I_L = \frac{V_L}{R_L} \Rightarrow I_L = 3.33\,mA$$

$$I_Z = 2.67\,mA$$

Determine :-

The Range of R_L and I_L



Sol :-

$$R_{min} = \frac{1 * 10}{50 - 10} \Rightarrow R_{min} = 0.25$$

$$I_{L(min)} = I_R - I_{Z(max)}$$

$$50 - V_R - 10 = 0$$

$$V_R = 40\ V$$

$$I_R = \frac{V_R}{R} \Rightarrow I_R = 40V$$

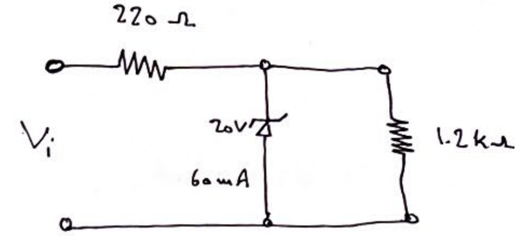
$$I_{L(min)} = 40 - 32 \Rightarrow I_{L(min)} = 8\ mA$$

$$I_{L(max)} = \frac{V_Z}{R_{min}} = \frac{10}{0.25} \Rightarrow I_{L(max)} = 40\ mA$$

$$R_{L(max)} = \frac{V_Z}{I_{Lmin}} = \frac{10}{8} \Rightarrow R_{L(max)} = 1.25\ K\Omega$$

Determine:-

The Range of V_{in}



Sol:-

$$V_{in(min)} = \frac{(1.2+0.22)*20}{1.2} \Rightarrow V_{in(min)} = 23.67\,V$$

$$I_{R(max)} = I_{Z(max)} + I_L$$

$$I_L = \frac{V_L}{R} \Rightarrow I_L = \frac{20}{1.2} \Rightarrow I_L = 16.6\ mA$$

$$I_{R(max)} = 76.6\ mA$$

$$V_{in(max)} = I_{R(max)} * R + V_Z$$

$$V_{in(max)} = 76.6 * 0.22 + 20$$

$$V_{in(max)} = 36.85\ V$$

Tutorial

- Prove the Solution to the following equation?

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

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

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

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

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

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

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

$$V_{rms} = \frac{V_m}{2} \Longrightarrow V_{rms} = 0.5\, V_m \Longleftarrow Q$$

$$V_{rms} = \sqrt{\frac{1}{2\pi} \int_0^{\pi} V_m^2 \sin^2 wt \; dwt}$$

$$V_{rms} = \sqrt{\frac{V_m^2}{2\pi} \int_0^{\pi} \frac{1-\cos 2wt}{2} \; dwt}$$

$$V_{rms} = \sqrt{\frac{V_m^2}{4\pi} \left[wt - \frac{1}{2} \sin 2wt \right]_0^{\pi}}$$

$$V_{rms} = \sqrt{\frac{V_m^2}{4\pi} \left[\pi - \frac{1}{2} \sin 2\pi + \frac{1}{2} \sin 0 \right.}$$

$$V_{rms} = \sqrt{\frac{V_m^2}{4} \cdot \frac{1}{\pi} \left[\pi - 0 \right]}$$

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

$$V_{rms} = 0.5\, V_m$$

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

$$I_{dc} = \frac{V_{dc}}{R_L}$$

$$I_{dc} = \frac{V_m}{\pi} * \frac{1}{R_L}$$

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

Filters

What are filters ?

It is an electrical circuit that controls the output signal according to the frequency of the input signal by selecting the desired frequency band to transmit and receiveand attenuating or eliminating unwanted frequencies.

Filters can also be used as circuits that block the frequency to which the filter circuit is tuned, and allow other frequencies to pass through. In communications systems, filters are used to separate the desired signal from other signals in order to limit the effect of interference between adjacent channels.

A device or process that removes certain unwanted components or features from a signal and is able to pass or amplify certain frequencies while attenuating others. Filtering is a category of signal processing. The distinguishing feature of filters is the complete or partial suppression of some aspect of the signal. This also means removing some Frequencies or frequency ranges, however filters do not only work in the frequency domain especially in image processing where there are many other targets for filtering.

Types of filters :

Classification of filters according to the range passed by the filter

Filters can be classified according to the range passed by the filter into four types:

1 - Low Pass Filter : **LPF**

2 - High Pass Filter : **HPF**

3 - Band Pass Filter : **BPF**

4 - Band-Stop Filters : **BSF**

Types of filters:

There are several types of filters:

1- Low-pass filters:

It allows signals to pass from zero frequency (constant current) up to a frequency with Foh – high cutoff frequency. Notice the following picture:

2- High-pass filters:

It allows the passage of signals whose frequency is higher than the Fol – low cutoff frequency and prevents the passage of signals whose frequency is lower. Therefore, it can be said that high-pass filters are opposite to low-pass filters.

Note the following:

3- Band-pass filters:

It allows signals to pass within a specific frequency range (the range between Fol and Foh) and prevents signals from passing outside this band or range.

4- Band-stop filters:

They are filters that prevent the passage of signals in a specific band or range of frequencies (the range between the frequencies FL and FL-) and allow signals to pass outside this range. This means that this type is completely opposite to band-pass filters. Note that H is for High and L is for Low.

Classification of filters based on the electrical circuit structure and the elements used

Filters can also be classified based on the electrical circuit installation and the elements used into several types, including:

1 - Passive Filters

2 - Active Filters

3 - Quartz Crystal Filters

4 - Ceramic Filters

Filters applications

These filters are used in several fields, the most important of which are:

1 - Used in analogue and digital communications systems.

2 - Used in radio and television broadcasting.

3 - Used in various electronic systems

4 - Used in The tuner is on the radio

5 - Used in Anti-aliasing

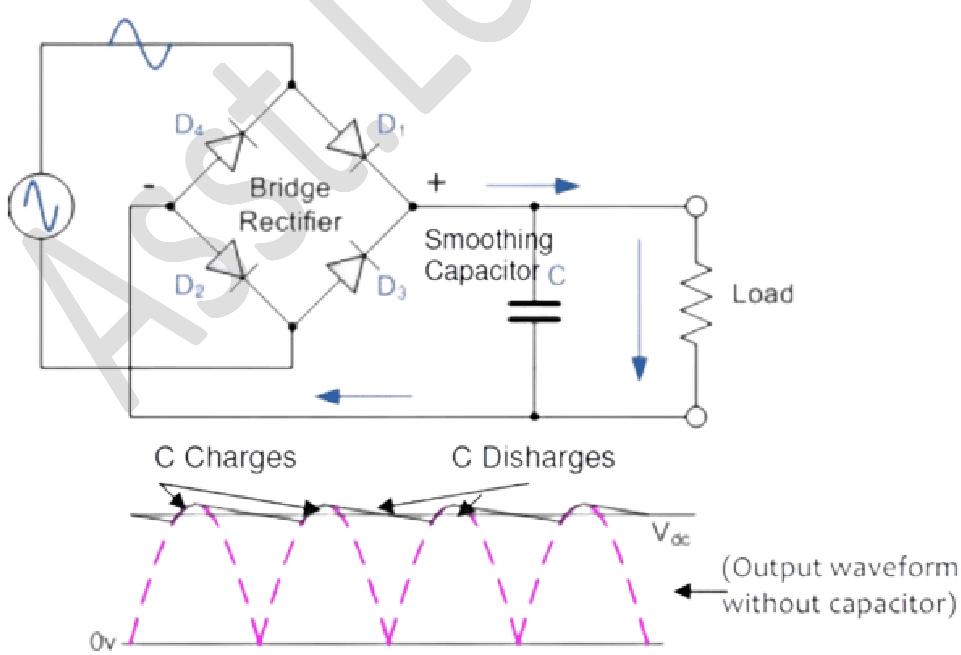
6 - Used in Uniformity of power supply

7 - Used in Noise suppression

1 . The mechanism of action of the filter

A capacitive circle

As for the gantry-type full-wave combiner with the middle point and connected to the capacitive filter, it produces better wave rectification because the amplitude is charged twice for the same time (note the two output signals). As a result, the ripple is smaller and the continuous output voltage approaches the peak voltage. Therefore, this type of filter is more widely used.



We notice from the figure above that the output signal is an almost constant voltage, and its difference from constant voltages is the small ripple resulting from charging and discharging the capacitor. The smaller the ripple, the better the uniformity.

In full-wave circuits with a capacitive filter, we need a long time constant Te to increase the capacitor discharge time, which is equal to 10 Te.

In full-wave circuits with a frequency of 50 Hz, the output time is:

For a long time constant, the time constant must be ten times greater than the output time:

$TC = Rl \times C \geq 100\ mS$

When the load current is large, it is difficult to obtain a long time constant (why?), and if it is a time constant

Long and sufficient for a light load current, the output of the capacitive filter is approximately equal to the input voltage and there is a ripple

The output is very small

Q : From the full wave rectifier circuit with the following filter, if you know that the peak voltage on the secondary file is equal,

Vp = 30 V the capacitance is equal C = 470 μF,

and the load resistance is equal RL = 220 Ω.

Find :

1 – $V_{dc.out}$

2 – $V_{r.out}$

3 – r%

4 – C_{min} if r% = 2 %

solution :

$$R_L \times C = 220 \times 470 \times 10^{-6} = 103 \times 10^{-3} = 103mS$$

$$T = \frac{1}{2\,F_{in}} = \frac{1}{2 \times 50} = 10mS$$

$$R_L \times C \geq 10 \times T$$

$$103 \times 10^{-3} \geq 10 \times 10 \times 10^{-3}$$

$$103 \geq 100$$

2 . The mechanism of action of the filter

A Inductive circle

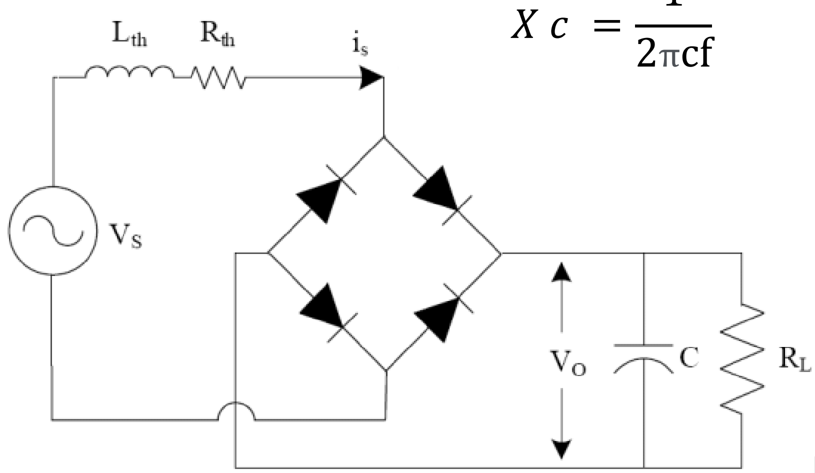
This filter consists of a choke coil, a capacitor, and a load resistance. The principle of the filter's work is to allow the continuous signal to pass through the coil because the resistance of the coil approaches zero at a continuous signal and prevents the signal from passing.

AC because its impedance is very large with an AC signal, as the resistance value depends on the frequency:

$XL = 2\pi fL$

As for the capacitor, it works to pass the alternating component and withdraw it from the output signal because its impedance is almost zero (short circuit), and its resistance is large relative to the continuous component (open circuit) so the continuous signal appears.

On load resistance



$$X\,c = \frac{1}{2\pi cf}$$

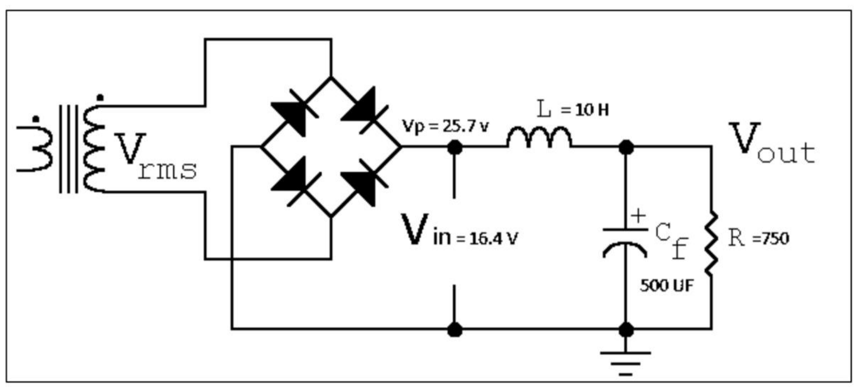
Q : From the following complete vector circuit if you know that the resistance of the coil > Rcoil = 25 Ω

Calculate the following :

1 – V dc.out

2 – V r.out

3 – r %



Solution :

1- $$V_{dc.out} = \frac{R_L}{R_L + R_{coil}} \times V_{dc.in}$$

$$V_{dc.out} = \frac{750}{750 + 25} \times 16.4 = 15.9V$$

2- $$V_{r.out} = 5.28 \times 10^{-7} \times \frac{V_p}{L.C}$$

$$V_{r.out} = 5.28 \times 10^{-7} \times \frac{25.7}{\ldots} = 2.71\,mV$$