Semester II

Basic Electronics

BBEE203

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Module-1

Semiconductor Diode

Module-1 (8 Hours)

Semiconductor Diodes: Introduction, PN Junction diode, Characteristics and Parameters, Diode Approximations, DC Load Line analysis.

Diode Applications: Introduction, Half Wave Rectification, Full Wave Rectification, Full Wave Rectifier Power Supply: Capacitor Filter Circuit, RC **π** Filter (includes numerical)

Zener Diodes: Junction Breakdown, Circuit Symbol and Package, Characteristics and Parameters, Equivalent Circuit, Zener Diode Voltage Regulator.

1.1. Introduction

Semiconductors are materials whose conductivity lies between conductors and insulators. Semiconductors are classified as intrinsic semiconductors and extrinsic semiconductors. Extrinsic semiconductors are further classified as N-type and P-type semiconductors. The P-N junction is formed between the p-type and the n-type semiconductors. In this session, let us know more about the P-N Junction.

P-N JUNCTION

A **p-n junction** is formed by joining p-type and n-type semiconductors together in very close contact. The term junction refers to the boundary interface where the two regions of the semiconductor meet. If they were constructed of two separate pieces this would introduce a grain boundary, so p-n junctions are created in a single crystal of semiconductor by doping, for example, by ion implantation, diffusion of dopants, or by epitaxy (growing a layer of crystal doped with one type of dopant on top of a layerof crystal doped with another type of dopant).

P-n junctions are elementary "building blocks" of almost all semiconductor electronicdevices such as diodes, transistors, solar cells, LEDs, and integrated circuits; they are theactive sites where the electronic action of the device takes place. For example, a common charge. The regions nearby the p-n interfaces lose their neutrality and become charged,forming the space charge region or depletion layer.

The electric field created by the space charge region opposes the diffusion process forboth electrons and holes. There are two concurrent phenomena: the diffusion process that tends to generate more space charge, and the electric field generated by the space chargethat tends to counteract the diffusion. The carrier concentration profile at equilibriumis shown in Fig. 1.1

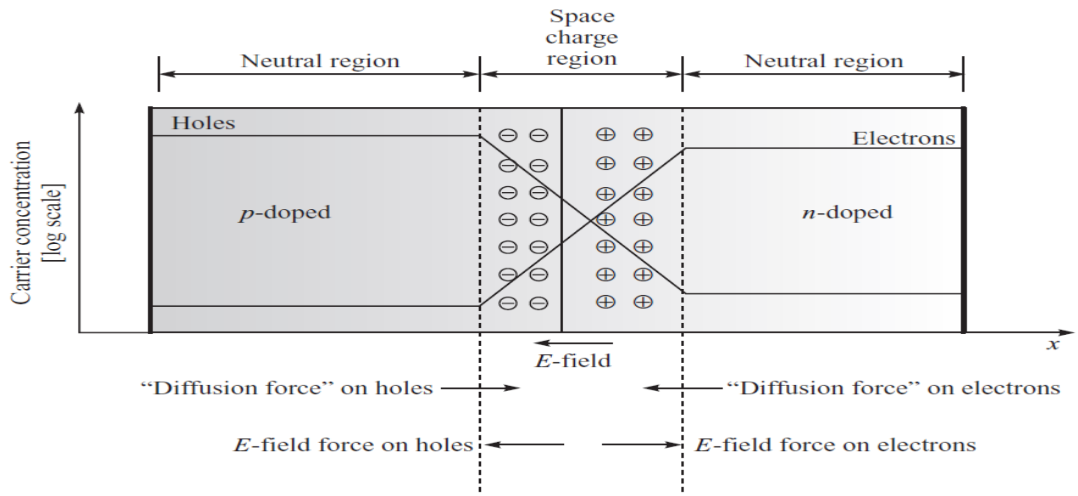


Figure 1.1 A p-n junction in thermal equilibrium with zero bias voltage applied

The space charge region is a zone with a net charge provided by the fixed ions (donors or acceptors) that have been left uncovered by majority carrier diffusion. When equilibrium is reached, the charge density is approximated by the displayed step function. In fact, the region is completely depleted of majority carriers (leaving a chargedensity equal to the net doping level), and the edge between the space charge region and the neutral region is quite sharp. The space charge region has the same charge on both sides of the p-n interfaces, thus it extends farther on the less doped side.

1.2.1 FORWARD BIASING AND REVERSE BIASING

Forward Biasing

When external voltage applied to the junction is in such a direction that it cancelsthe potential barrier, thus permitting current flow is called forward biasing. To apply forward bias, connect +ve terminal of the battery to p-type and –ve terminal to n-typeas shown in Fig. 1.2. The applied forward potential establishes the electric field which acts against the field due to potential barrier. Therefore, the resultant field is weakened and the barrier height is reduced at the junction as shown in Fig. 1.2 Since the potential barrier voltage is very small; a small forward voltage is sufficient to completely eliminatethe barrier. Once the potential barrier is eliminated by the forward voltage, junction resistance becomes almost zero and a low resistance path is established for the entire circuit. Therefore, current flows in the circuit. This is called forward current.

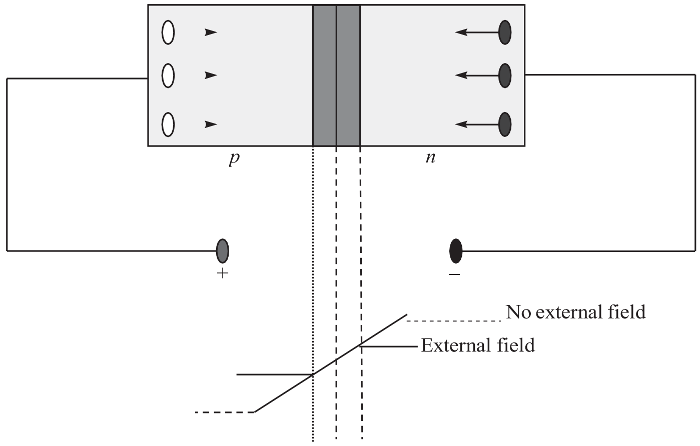


Figure 1.2 Forward biasing of p-n junction

Reverse Biasing

When the external voltage applied to the junction is in such a direction the potential barrier is increased it is called reverse biasing. To apply reverse bias, connect –ve terminal of the battery to p-type and +ve terminal to n-type as shown in Fig. 1.3.

The applied reverse voltage establishes an electric field which acts in the samedirection as the field due to potential barrier. Therefore, the resultant field at the junctionis strengthened and the barrier height is increased as shown in Fig. 1.3. The increased potential barrier prevents the flow of charge carriers across the junction. Thus, a high resistance path is established for the entire circuit and hence current does not flow.

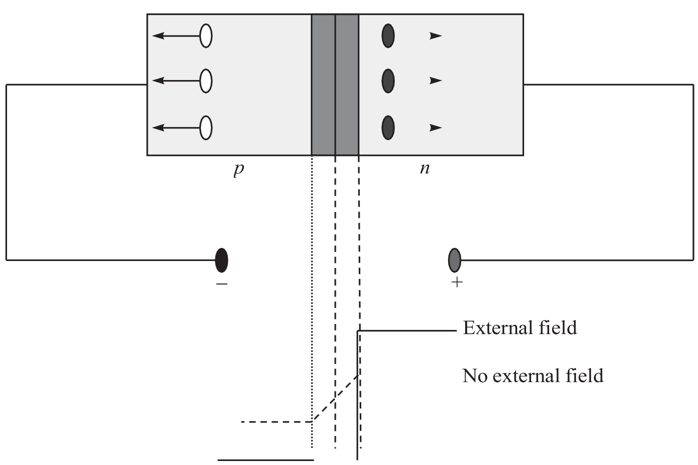


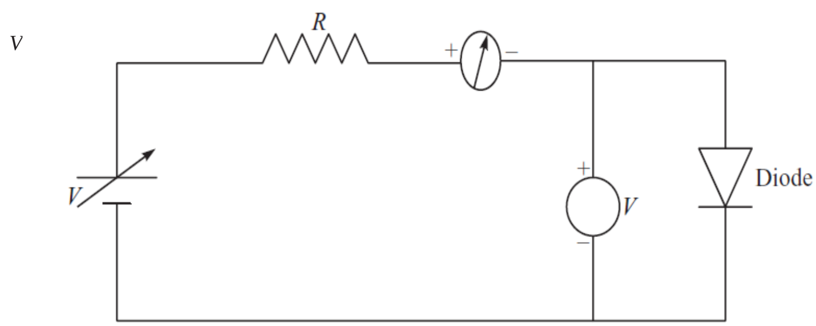
Figure 1.3 Reverse biasing of p-n junction

1.2.2. VOLT-AMPERE (V-I) CHARACTERISTICS OF P-N JUNCTION DIODE

The V-I characteristics of a semiconductor diode can be obtained with the help of the circuit shown in Fig. 1.4 (i). The supply voltage V is a regulated power supply; the diode is forward biased in the circuit shown. The resistor R is a current limiting resistor.The voltage across the diode is measured with the help of voltmeter and the current is recorded using an ammeter.

By varying the supply voltage different sets of voltage and currents are obtained. By plotting these values on a graph, the forward characteristics can be obtained. It can be noted from the graph the current remains zero till the diode voltage attains the barrier potential.

For silicon diode, the barrier potential is 0.7 V and for germanium diode, it is 0.3 V. The barrier potential is also called knee voltage or cut-in voltage. The reverse characteristics can be obtained by reverse biasing the diode. It can be noted that at a particular reverse voltage, the reverse current increases rapidly. This voltage is called breakdown voltage.



(i)

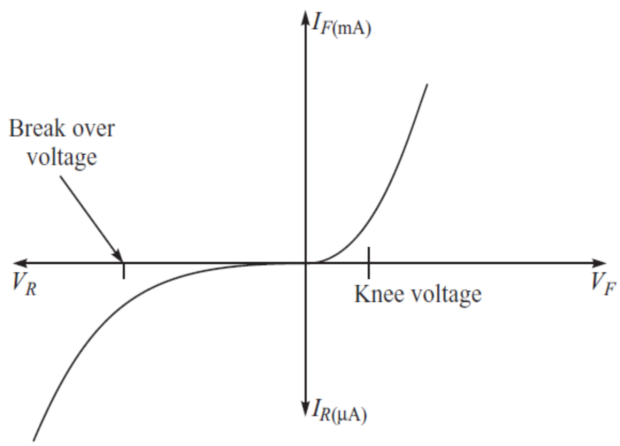


Figure 1.4 V-I characteristics of p-n junction diode.

(i) Circuit diagram

(ii) Characteristics

1.2.3. DIODE CURRENT EQUATION

The current in a diode is given by the diode current equation

$$I = I_o(e^{V/hV_T} - 1) \tag{1.1}$$

where, I = Diode current

I_o = Reverse saturation current

V = Diode voltage

h = Semiconductor constant

= 1 for Ge

= 2 for Si.

V_T = Voltage equivalent of temperature = T/11,600 (temperature T is in kelvin)

Note: If the temperature is given in °C then it can be converted to kelvin with the helpof the following relation, °C + 273 = K

1.2.4. STATIC AND DYNAMIC RESISTANCE OF A DIODE

DC or Static Resistance

When diode is forward biased, it offers a definite resistance in the circuit. This resistanceis known as dc resistance or static resistance (R_F). It is simply the ratio of the dc voltage (V_D) across the diode to the dc current (I_D) flowing through it as shown in Fig. 1.5.

$$R_F = \frac{V_D}{I_D} \tag{1.2}$$

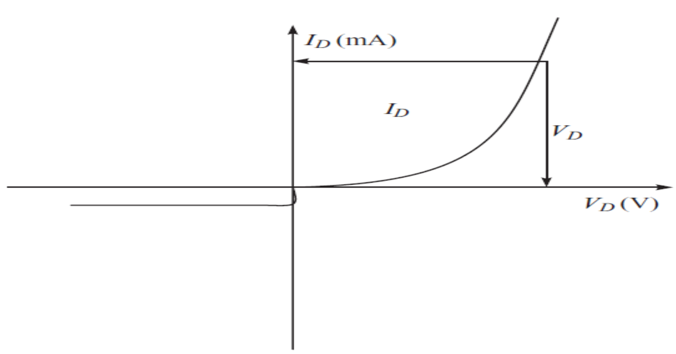


Figure 1.5 Determining the dc resistance of a diode at a particular operating point

PROBLEM 1.1: Determine the dc resistance level for the diode of Fig. 1.6 at

(a) I_D = 2 mA

(b) I_D = 20 mA

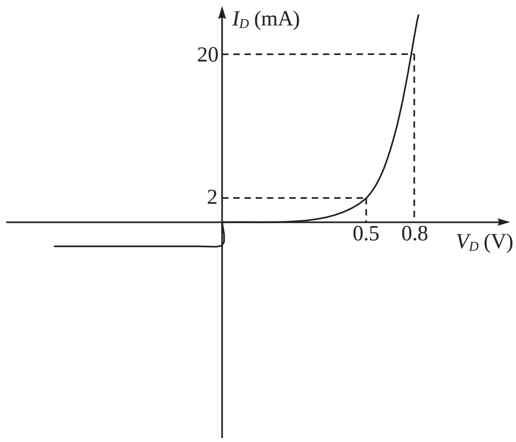


Figure 1.6

(a) At I_D = 2 mA, V_D = 0.5 volt (from the curve)

$$R_F = \frac{V_D}{I_D} = \frac{0.5\text{ V}}{2\text{ mA}} = 250\ \Omega$$

(b) At I_D = 20 mA, V_D = 0.8 volt from the curve)

$$R_F = \frac{V_D}{I_D} = \frac{0.8\text{ V}}{20\text{ mA}} = 40\ \Omega$$

AC or Dynamic Resistance

The ac or dynamic resistance of a diode, at a particular dc voltage, is equal to thereciprocal of the slope of the characteristics at that point, as shown in Fig. 1.7.

$$r_f = \frac{\Delta V_D}{\Delta I_D} \qquad (1.3)$$

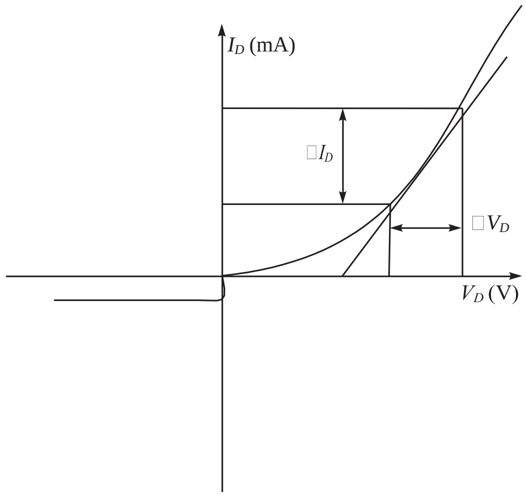


Figure 1.7 Determining the ac resistance of a diode at a particular operating point

1.3. DIODE CHARACTERISTICS AND DIODE PARAMETERS

1.3.1. DIODE CHARACTERISTICS

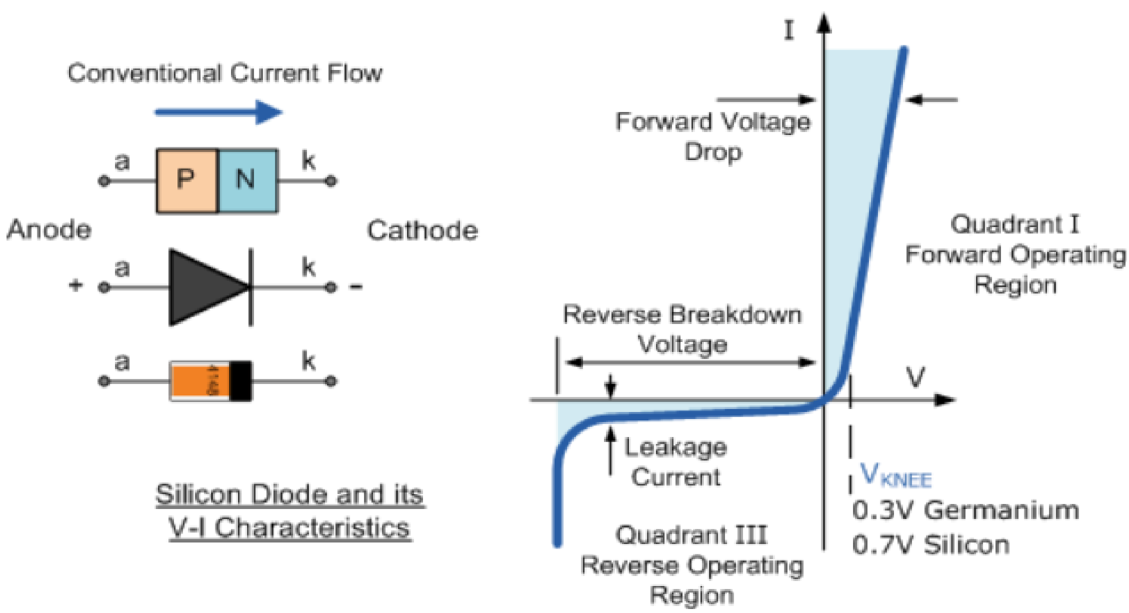


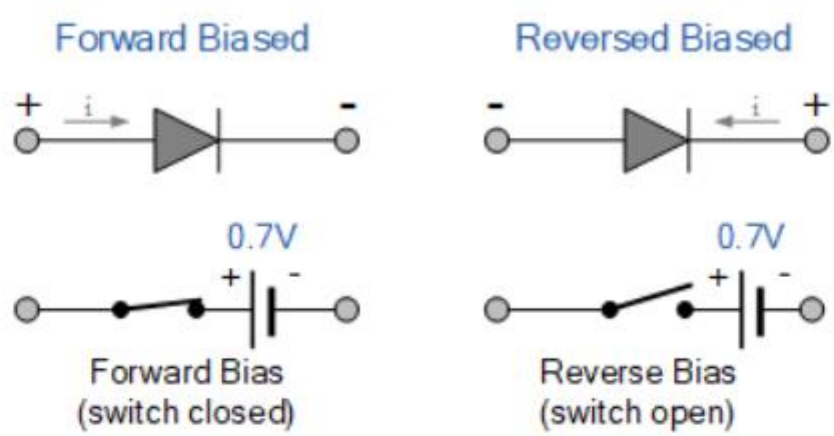
Figure 1.8 V-I Characteristics of P-N Junction Diode

The characteristics of a signal point contact diode are different for both germanium and silicon types and are given as:

1. Germanium Signal Diodes – These have a low reverse resistance value giving a lower forward volt drop across the junction, typically only about 0.2 to 0.3v, but have a higher forward resistance value because of their small junction area.

2. Silicon Signal Diodes – These have a very high value of reverse resistance and give a forward volt drop of about 0.6 to 0.7v across the junction. They have fairly low values of forward resistance giving them high peak values of forward current and reverse voltage.

The arrow always points in the direction of conventional current flow through the diode meaning that the diode will only conduct if a positive supply is connected to the Anode, (a) terminal and a negative supply is connected to the Cathode (k) terminal thus only allowing current to flow through it in one direction only, acting more like a one way electrical valve, (Forward Biased Condition). If we connect the external energy source in the other direction the diode will block any current flowing through it and instead will act like an open switch, (Reversed Biased Condition) as shown below.



1.3.2. DIODE PARAMETERS

Signal Diodes are manufactured in a range of voltage and current ratings and care must be taken when choosing a diode for a certain application. There are a bewildering array of static characteristics associated with the humble signal diode but the more important ones are.

1. **Maximum Forward Current ($I_{F(max)}$)**

The Maximum Forward Current ($I_{F(max)}$) is as its name implies the *maximum forward current* allowed to flow through the device. When the diode is conducting in the forward bias condition, it has a very small "ON" resistance across the PN junction and therefore, power is dissipated across this junction (Ohm´s Law) in the form of heat.

2. Forward Voltage Drop (VF).

The diode is said to be forward biased when the anode is more positive than the cathode. The ideal diode will have zero resistance when forward biased, however real diodes require that the forward bias exceed a threshold voltage V_F before forward conduction begins. When the diode is in forward conduction, the voltage drop across the diode is constant. The forward voltage drop is an intrinsic property of the semiconductor material used to make the pn junction and is related to the band gap. Thus V_F is the same for all silicon diodes.

3. Reverse saturation current (IR)

The reverse saturation current is the part of the reverse current in a semiconductor diode caused by diffusion of minority carriers from the neutral regions to the depletion region. This current is almost independent of the reverse voltage.

4. **Reverse Breakdown Voltage (VBR)**

Due to the flow of reverse current the width of the junction barrier increases. When this applied reverse bias voltage is increased gradually at a certain point a rapid increase in the reverse current can be observed. This is known as Junction breakdown. The corresponding applied reverse voltage at this point is known as Breakdown Voltage of the PN junction diode. This is also known as Reverse Breakdown Voltage.

5. **Dynamic resistance (r_f)**

It is defined as the resistance offered by the diode semiconductor device when an AC supply biases it.

$$r_f = \frac{\Delta V_D}{\Delta I_D}$$

1.3.3. DIODE APPROXIMATION

Diode permits only unidirectional conduction. It conducts well in forward directionand poorly in reverse direction. It would have been ideal if a diode acted as a perfect conductor (with zero voltage across it) when forward-biased, and as a perfect insulator (with no current through it) when reverse-biased. The V-I characteristics of such an idealdiode would be as shown in Fig. 1.9. An ideal diode acts like an automatic switch. Whenthe current tries to flow in the forward direction, the switch is closed. On the other hand,when the current tries to flow in the reverse direction, the switch is open.

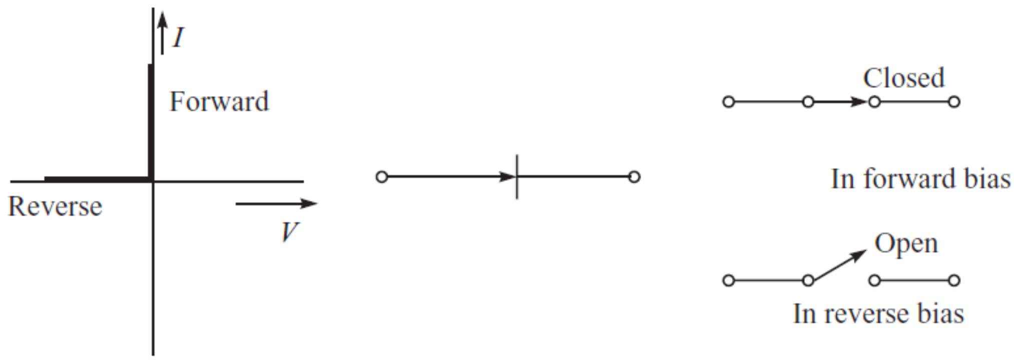


Figure 1.9 Ideal diode characteristics and switch analogy

DIODE EQUIVALENT CIRCUIT

It is generally profitable to replace a device or system by its equivalent circuit. Oncethe device is replaced by its equivalent circuit, the resulting network can be solved by traditional circuit analysis technique.

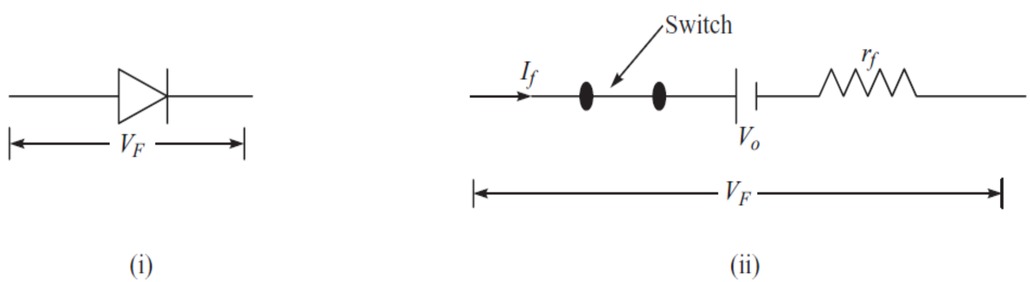


Figure 1.10

Diode equivalent circuit. (i) Symbol (ii) equivalent circuit

The forward current I_f flowing through the diode causes a voltage drop in its internalresistance, r_f. Therefore, the forward voltage V_F applied across the actual diode has to overcome

1. Potential barrier V_o
2. internal drop I_f r_f

$$V_f = V_o + I_f r_f \qquad (1.4)$$

For silicon diode V_o = 0.7 V whereas for germanium diode V_o = 0.3 V.For ideal diode r_f = 0.

1.4. DC Load Line Analysis of Semiconductor Diode

Figure 1.11(a) shows a DC Load Line Analysis of Semiconductor Diode in series with a 100 Ω resistance (R_1) and a supply voltage (E). The polarity of E is such that the diode is forward biased, so a diode forward current (I_F) flows. As already discussed, the circuit current can be determined approximately by assuming a constant diode forward voltage drop (V_F). When the precise levels of the diode current and voltage must be calculated, graphical analysis (also termed DC Load Line Analysis of Semiconductor Diode) is employed.

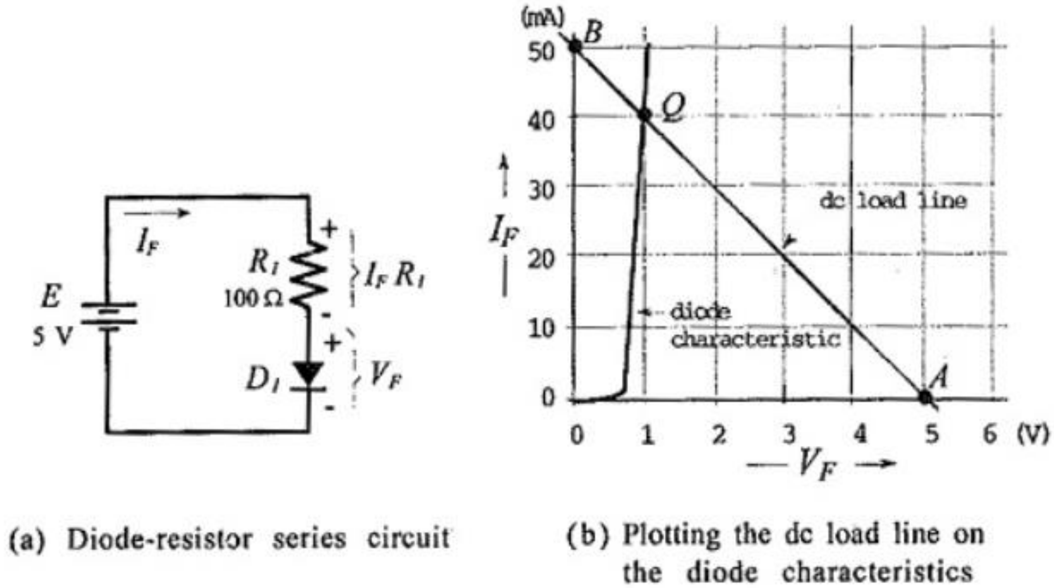


Figure 1.11 Ideal diode characteristics and switch analogy

For graphical analysis, a dc load line is drawn on the diode forward characteristics, [Fig. 1.11(b) This is a straight line that illustrates all dc conditions that could exist within the circuit. Because the load line is always straight, it can be constructed by plotting any two corresponding current and voltage points and then drawing a straight line through them. To determine two points on the load line, an equation relating voltage, current, and resistance is first derived for the circuit. From Fig. 1.11(a),

$$\boldsymbol{E = (I_F R_1) + V_F} \qquad \textbf{(1.5)}$$

Any convenient two levels of I_F can be substituted into Eq. 1.5 to calculate corresponding V_F levels, or vice versa.

Q-Point:

The relationship between the diode forward voltage and current in the circuit in Fig. 1.11(a) is defined by the device characteristic. Consequently, there is only one point on the dc load line where the diode voltage and current are compatible with the circuit conditions. That is point Q, termed the quiescent point or dc bins point, where the load line intersects the characteristic. This may be checked by substituting the levels of I_F and V_F at point Q into Eq. 1.5. From the Q point on Fig. 1.11(b), I_F = 40 mA and V_F = 1 V. Equation 1.5 states that E = (I_F R_1) + V_F. Therefore,

$$\boldsymbol{E = (40mA * 100\Omega) + 1V}$$

E=5V

So, with E = 5 V and R_1 = 100 Ω, the only levels of I_F and V_F that can satisfy Eq. 2-3 on the diode characteristics in Fig. 2-13(b) are I_F = 40 mA and V_F= 1 V.

Note that, although V_F = 0 and V_F = 5 V were used when, drawing the dc load line, no functioning semiconductor diode would have such forward voltage drops. These are simply convenient theoretical levels for constructing the DC Load Line Analysis of Semiconductor Diode.

Slope of the line is given by

$$\frac{V}{R_L} = I_F + \frac{V_F}{R_L}$$

$$I_F = -\frac{V_F}{R_L} + \frac{V}{R_L}$$

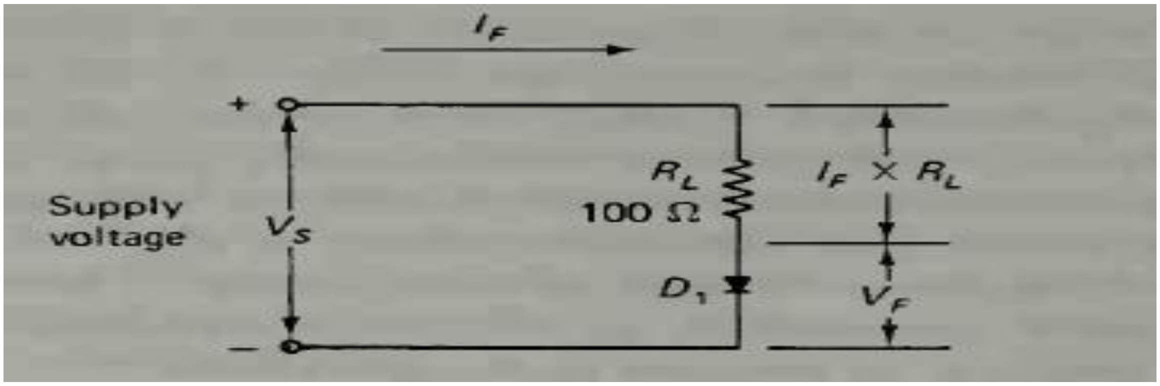
Comparing the above equation with equation of straight line

Y=mx +c, we get

C=$\frac{V}{R_L}$ and slope =$-\frac{1}{R_L}$

Problem

1. Draw the DC Load line of circuit below



solution

From Eq. (3-1),

$$V_S = I_F R_L + V_F$$

When $I_F = 0$,

$$V_S = 0 + V_F$$

Therefore, the diode voltage is

$$V_F = V_S = 5\ \text{V}$$

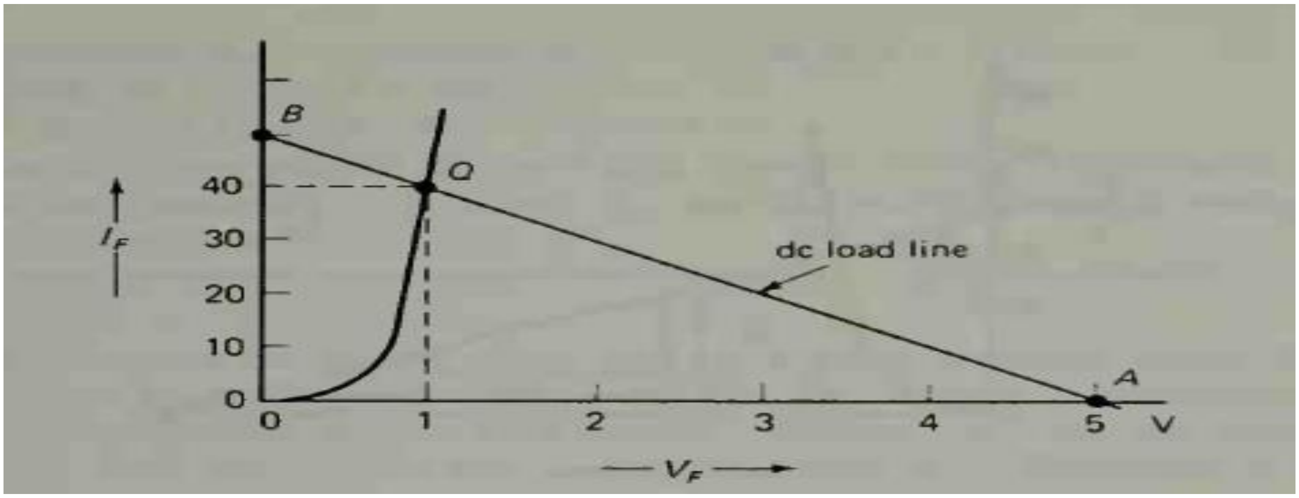
Plot point A on the diode characteristics at $I_F = 0$ *and* $V_F = 5$ V.
When $V_F = 0$.

$$V_S = I_F R_L + 0$$

$$I_F = \frac{V_S}{R_L}$$

$$= \frac{5\text{V}}{100\Omega} = 50\ \text{mA}$$

Plot point B on the diode characteristic at $I_F = 50$ mA *and* $V_F = 0$. *Now draw the dc load line through points A and B.*



1.5. Rectifier

- Rectifiers are the circuits which converts a.c voltage to pulsating d.c voltage.
- Rectifiers can be grouped into two types:

  i) Half-wave Rectifier

  ii) Full-wave Rectifier

i) Half-wave Rectifier

The simplest form of rectifier circuit makes use of a single diode and, since it operates on only either positive or negative half-cycles of the supply, it is known as a half-wave rectifier. Fig. 1.3 shows a simple half-wave rectifier circuit.

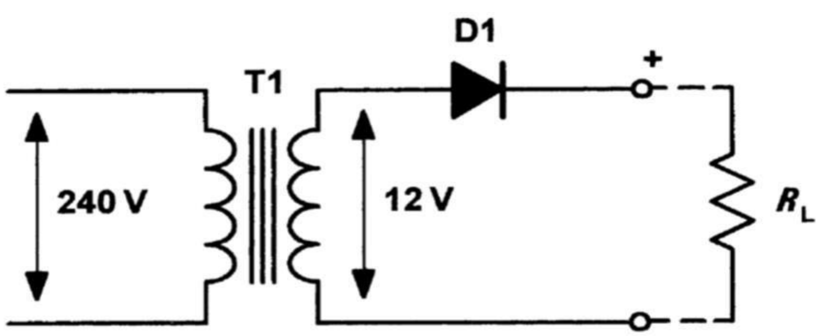


Figure 1.12 A simple half-wave rectifier circuit

- The mains voltage (220 to 240 V) is applied to the primary of a step-down transformer (T1).
- The secondary of T1 steps down the 240 V r.m.s. to 12 V r.m.s.

Diode D1 will only allow the current to flow in the direction shown (i.e. from cathode to anode). D1 will be forward biased during each positive half-cycle and will effectively behave like a closed switch as shown in Fig. 1.4.

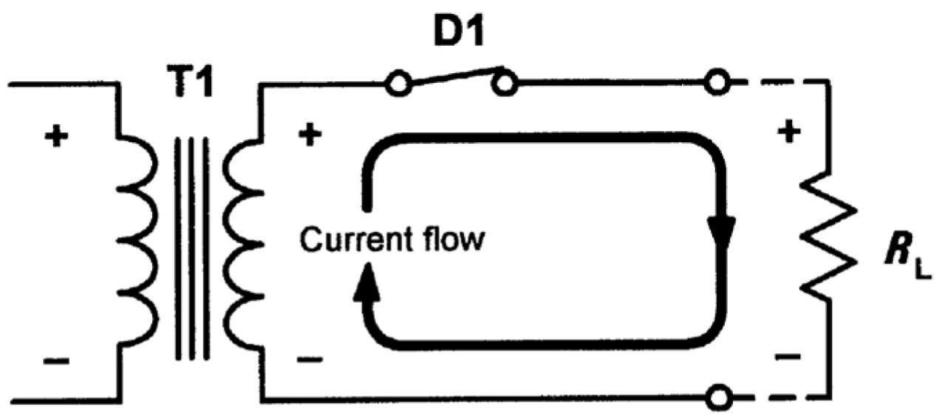


Figure 1.13 Half-wave rectifier circuit with D1 conducting (positive-going half-cycles of secondary voltage)

When the circuit current tries to flow in the opposite direction, the voltage bias across the diode will be reversed, causing the diode to act like an open switch as shown in Fig. 1.5.

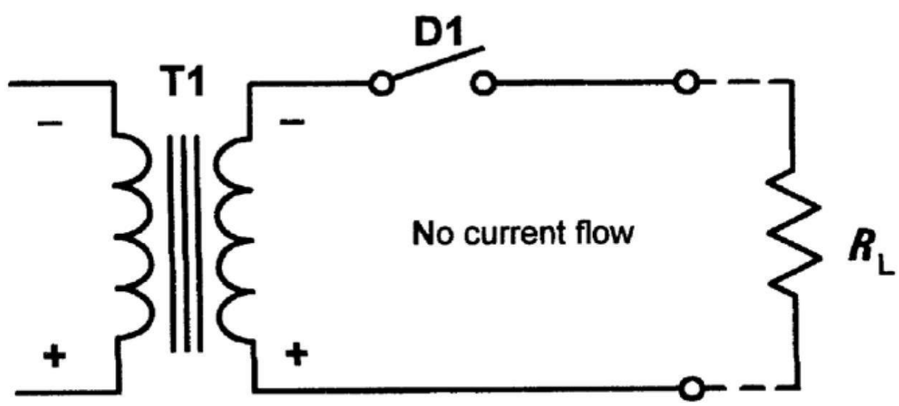


Figure 1.14 half-wave rectifier with D1 not conducting (negative-going half- cycles of secondary voltage)

During positive half cycle, the diode D1 is forward biased, thus the current flows through the load RL and voltage is developed across it.

During negative half cycle, the diode D1 is reverse biased, thus there will be no flow of current through the load RL, thereby the output voltage is zero.

The input and output voltage waveform of a half-wave rectifier is shown in Fig. 1.6.

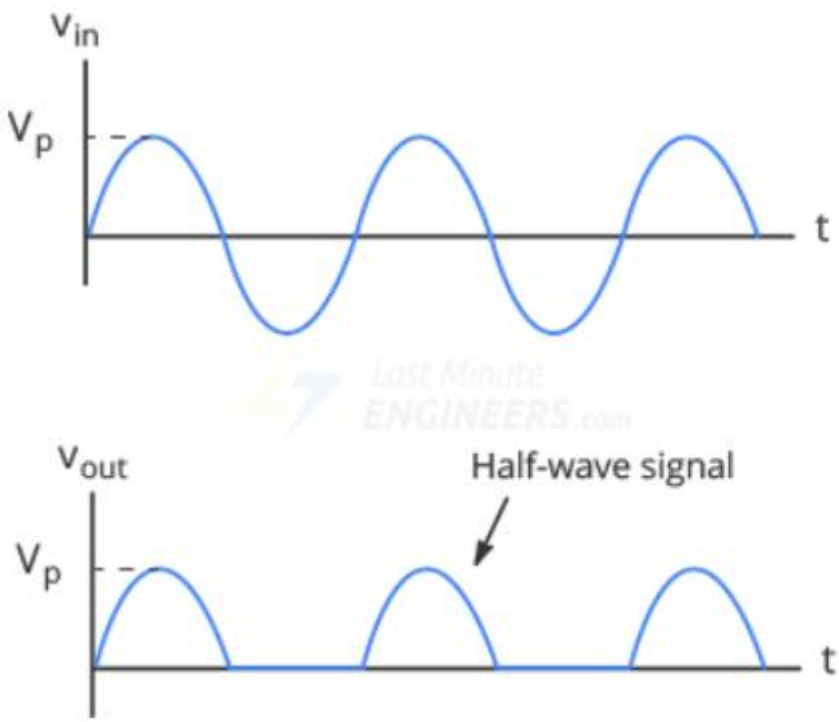


Figure 1.15 Half wave rectifier waveform

When the diode is forward biased, the voltage drop across it is V_F and output voltage is (input voltage) -V_F, the peak output voltage is

$$V_{po} = V_{pi} - V_F ----------- (1.6)$$

Note $V_{pi} = 1.414V_i$, where V_i is the rms level of the sinusoidal input voltage to the rectifier circuit.

The diode peak forward current is

$$I_p = \frac{V_{po}}{R_L} --------------- (1.7)$$

During negative half cycle

$$-V_o = -I_R R_L$$

When the diode is reverse biased the peak voltage of the negative half cycle of the input is applied to terminals. Thus, the peak reverse voltage or peak inverse voltage (PIV), applied to the diode is

$$V_R = PIV = V_{pi} ---------(1.8)$$

The average and rms values of half wave rectified waveform can be determined as

$$V_{o(ave)} = 0.318V_{po} -------- (1.9)$$

$$V_{o(rms)} = 0.5V_{po} -------- (1.10)$$

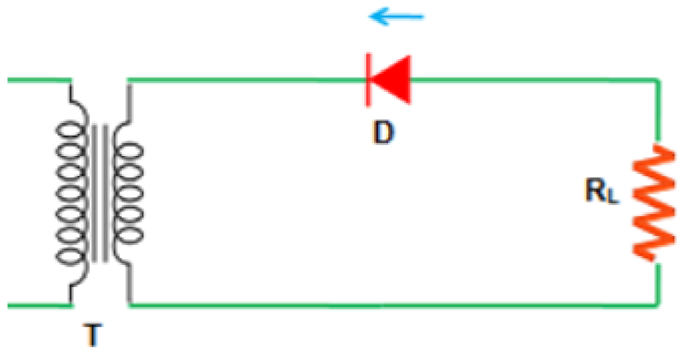
Problem

1. A diode with $V_F = 0.7V$ is connected as half wave rectifier. The load resistance is 500**Ω**, and the rms ac input is 22V. Determine the peak output voltage, the peak load current, and the diode peak reverse voltage.

$$V_{pi} = 1.414\ V_i = 1.414 \times 22\ V$$
$$= 31.1\ V$$
$$V_{po} = V_{pi} - V_F = 31.1\ V - 0.7\ V$$
$$= 30.4\ V$$
$$I_P = \frac{V_{po}}{R_L} = \frac{30.4\ V}{500\ \Omega}$$
$$= 60.8\ mA$$
$$PIV = V_{pi} = 31.1\ V$$

Negative Half Wave Rectifier

Unlike the positive half wave rectifier, the negative half wave rectifier allows electric current during the negative half-cycle of input AC signal and blocks electric current during the positive half-cycle of the input AC signal. When the diode in reverse bias condition, the half-wave rectifier circuit passed through it only negative half-cycle and block the positive half-cycle, this configuration is known as a **Negative half-wave rectifier**. In this rectifier circuit Cathode or negative terminal of the diode connected to the transformer and the Anode or positive terminal connected to the load resistor. So, the diode is in reverse bias condition.



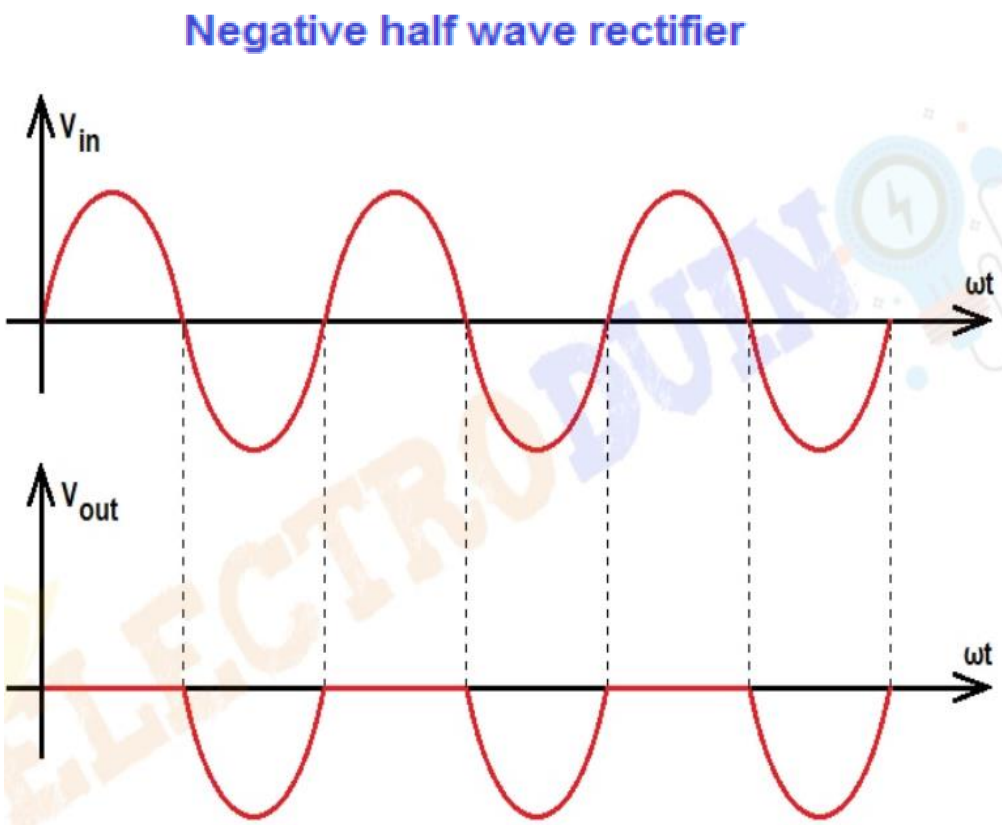


Fig 1.16 Input and output waveform of negative half wave rectifier

Half-wave Rectifier power Supply

Capacitor filter circuit

- when a Sinusoidal alternating voltage is rectified the resulting output waveform is a Series of positive (or negative) half cycles of the input
- To convert to direct voltage a Smoothing circuit or filter must be employed.
- Below figure Shows HWR circuit with a single capacitor filter (C_1) and a load resistor (R_L) and o/p waveform.
- The Capacitor termed a reservoir capacitor

$$\therefore V_C = V_{Pi} - V_F \quad — 1.17$$

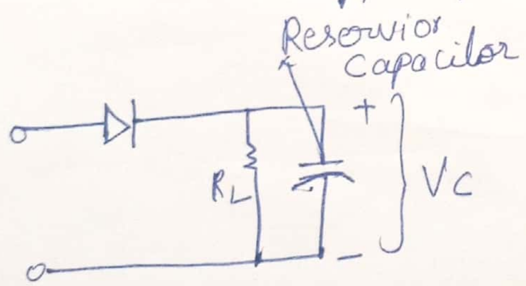
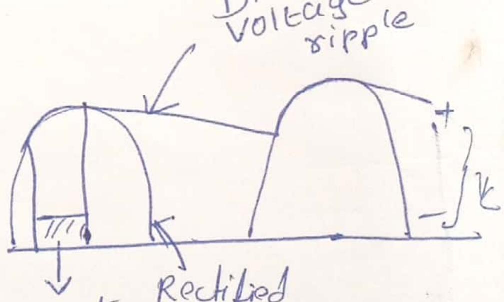


Fig 1.18(a) HWR with Capacitor



(b) output waveform

Ripple Amplitude and Capacitance

- The amplitude of ripple voltage is affected by load current, resevoir capacitor value, and capacitor discharge time.
- The discharge time depends on frequency of ripple waveform.
- The ripple amplitude can be calculated from the load current, and the capacitor capacitor value, discharge time.

The ripple amplitude is inversly proportional to capacitance.

E_{ave} = average dc o/p v/g

$E_{o(max)}$: Max. o/p v/g

$E_{o(min)}$: Min o/p V/g

V_r = Ripple v/g p-p amp

T = time period of ac i/p w/f

t_1 : Capacitor discharging time

t_2 = capactor charge time

θ_1 = Phase angle of i/p wave from zero to $E_{o(min)}$

θ_2 : Phase angle of i/p wave from $E_{o(min)}$ to $E_{o(max)}$

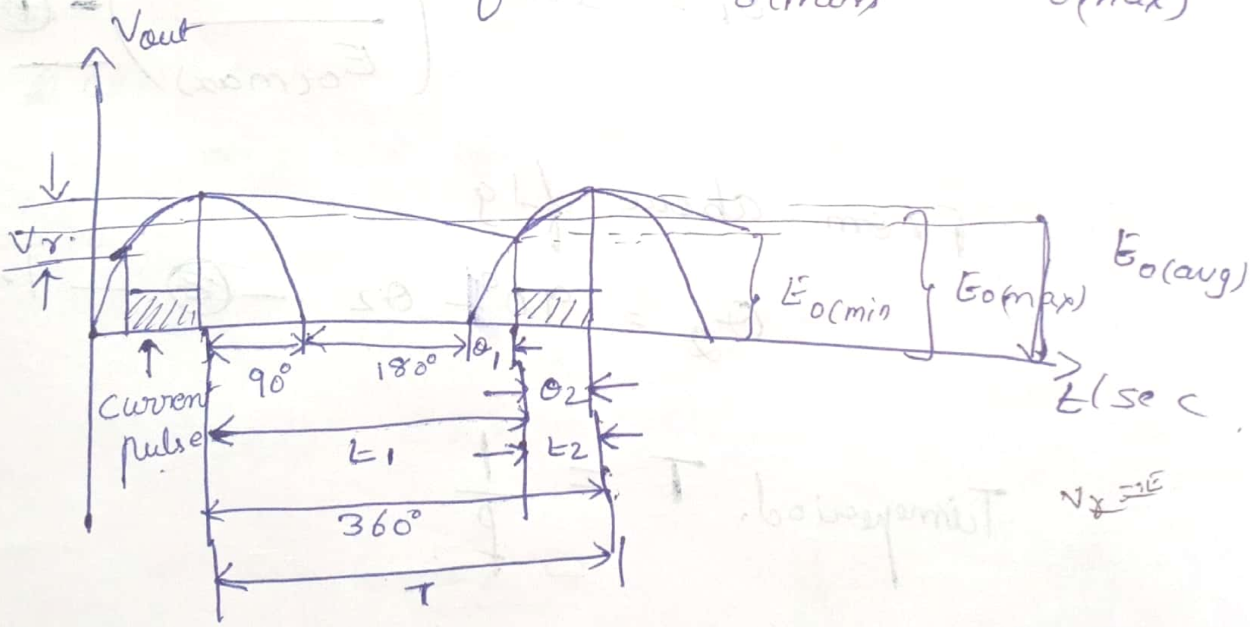
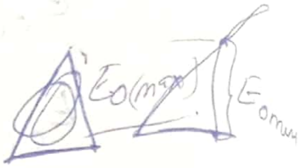
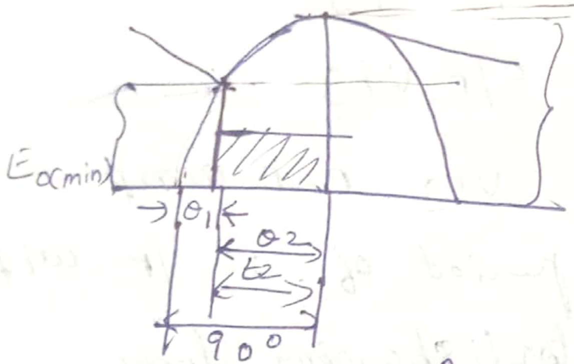


Fig1.7 Capacitor w/f Amplitude, angle & times

Relation Ship b/w $E_{o(min)}$ & $E_{o(max)}$





From above fig

$$\sin\theta_1 = \frac{opp.}{hyp} = \frac{E_{o(min)}}{E_{o(max)}} \quad — 1.11$$

$$E_{o(min)} = E_{o(max)} \sin\theta_1$$

$$\theta_1 = \sin^{-1}\left(\frac{E_{o(min)}}{E_{o(max)}}\right) — (1) — 1.12$$

From above fig

$$\theta_2 = 90^\circ - \theta_2 \quad — (2) — 1.13$$

Timeperiod. $T = \frac{1}{f}$

Time per degree is

$$t/\text{degree} = \frac{T}{360^\circ}$$

$$\therefore t_2 = \theta_2 \frac{T}{360^\circ} \quad — (3) — 1.14$$

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and $t_1 = T - t_2$ (from graph) —1.15

Taking the current as constant

$$C_1 = \frac{I_L t_1}{V_r} \quad — 1.16$$

eq (3) to (5) is used to cal C

Capacitance value

we can also approximate $t_1 \approx T$ to calculate discharge time

<u>Prob</u>

Determine the P-P ripple V/g for HWR and filter ckt which has 680 μF reservoir Capacitor an avg O/P of 28V & 200Ω R_L. ($f = 60$ Hz) ← always

Soln Given.

$C = 680\ \mu F$, $V_r = ?$

$E_{o(ave)} = 28\ V$.

$$C_1 = \frac{I_L t_1}{V_r}$$

$$V_r = \frac{I_L t_1}{C_1}$$

$t_1 \approx T = t_1 = 16.7\ mS$

$$V_r = \frac{140\ mA \times 16.7\ mS}{680\ \mu S}$$

$V_r = 3.4\ V$

$I_L = \frac{V}{R_L}$ ($V \to E_{o(avg)}$)

$= \frac{28}{200}$

$I_L = 140\ mA$

$T = \frac{1}{f}$

$T = \frac{1}{60} = 16.7\ mS$

cont HWR)

(3) A HWR dc power supply is to provide 20V to 500Ω load. The P-P V/g is not exceed 10% of the avg o/p V/g, and the ac i/p freq is 60Hz. calculate the required reservoir capacitance

Given

$R_L = 500\Omega$

$V_r \ngtr 10\% \, E_{o(ave)}$

$f = 60Hz$

$C = ?$

Soln

$$T = \frac{1}{f} = 16.7mS$$

$$t_1 \approx T = 16.7mS$$

$$V_r = 10\% \text{ of } E_o(ave)$$

$$= 10\% \text{ of } 20$$

$$V_r = 2V$$

$$I_L = \frac{E_{o(ave)}}{R_L} = \frac{20}{500\Omega}$$

$$= 40mA$$

$$C_1 = \frac{I_L t_1}{V_r}$$

$$= \frac{40mA \times 16.7mS}{2}$$

$$C_1 = 334\mu F$$

(4) Determine the charging time t_1 & discharge time t_2 for HWR power supply. and calculate C_1 (P-P ripple v/g does not exceed 10% of avg o/p v/g)

Soln

$V_r = 10\%$ of $E_{o(ave)}$

$V_r = 2V$

From graph $E_{o(avg)} = E_{omin} + 0.5 V_r$

$E_{o(min)} = E_{o(ave)} - 0.5 V_r$

$= 20 - (0.5 \times 2)$

$E_{o(min)} = 19V$

$E_{o(ave)} = E_{o(max)} - 0.5 V_r$

$E_{o(max)} = E_{o(ave)} + 0.5 V_r$

$= 20 + 0.5(2)$

$E_{o(max)} = 21 V$

$\theta_1 = \sin^{-1} \dfrac{(E_{o(min)})}{E_{o(max)}}$

$= \sin^{-1}\left(\frac{19}{21}\right)$

$= 65^\circ$

$\theta_2 = 90^\circ - \theta_1 =$

$= 25^\circ$

$t_2 = \dfrac{\theta_2 T}{360} =$

$t_2 = 1.16ms$

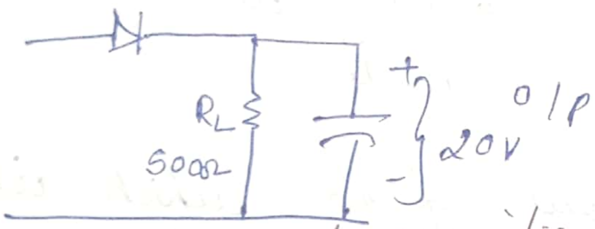
$t_1 = T - t_2 = 16.7ms - 1.16 ms$

$= 15.54ms$

$C_1 = \dfrac{I_L t_1}{V_r} = 310\mu F$

Capacitor Selection

- when a capacitance value is determined for a Specified ripple, a Suitable capacitor has to be chosen from manufacturer's list of available Standard value
- The calculated capacitance for reservoir capacitor is always the lowest



1.19 polarized capacitor

- The maximum voltage that may be Safely applied to capacitor is Stated in terms of its dc working voltage. This can be quite Small for large value of capacitors.

Capacitor Polarity

- It is very important that polarized capacitor be connected with the correct polarity.
- The positive terminal Should be connected to more positive of the two points in the circuit where the capacitor is to be installed
- The Straight bar on capacitor in above figure represents positive terminal
- polarized capacitors can Sometimes explode when incorrectly connected

Diode Specification

- Rectifier diode must be specified in terms of the current and voltages that they are subjected to.
- The diodes selected must be able to survive higher levels than the calculated maximum for a given circuit
- Consider below figure which illustrates the situation when the a.c. input wave is at its negative peak voltage ($-V_P$)

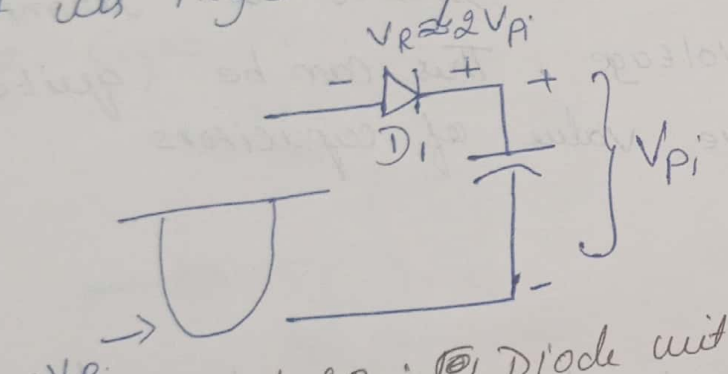


Fig 1.20 ; Diode with surge limiting resistor

- The capacitor has already been charged upto approximately the positive peak level of the input ($+V_P$).
- Consequently, the diode has $-V_P$ at its anode and $+V_P$ at its cathod, and so the diode peak reverse V/g is

$$V_R = 2V_P$$

The average forward rectified current ($I_{F(ave)}$) that the diode must pass is equal to dc o/p current $I_{F(ave)} = I_L$

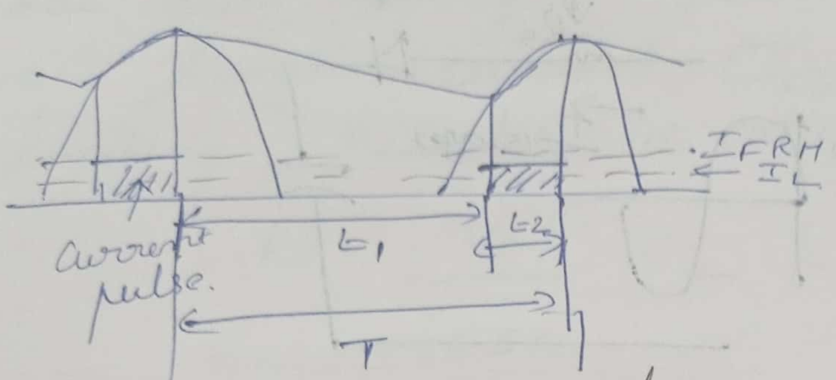


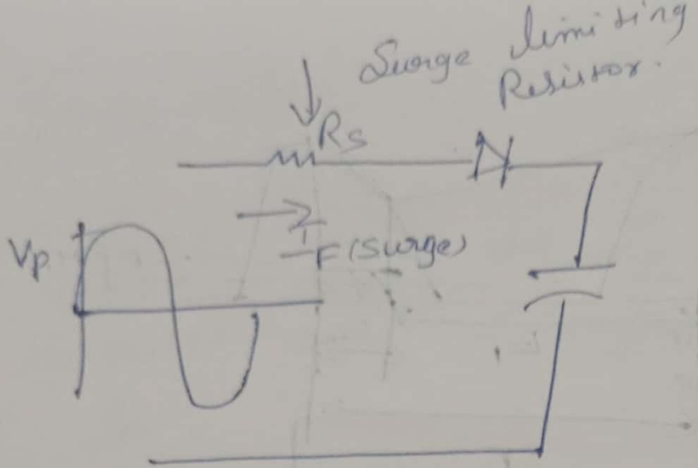
Fig 1.21: output waveform

- The diode in HWR with capacitor does not conduct continuously, but repeatedly passes pulses of current to recharge the capacitor each time diode is FB.
- The current pulse is known as repetitive surge current and is designated as I_{FRM}
- I_{FRM} is spike shaped, but it can be thought of as rectangular for calculation purpos
- The I_{FRM} averaged over time period T equals I_L

$$I_L = \frac{I_{FRM} t_2}{t_1 + t_2} \quad — 1.18$$

$$\text{i.e. } I_{FRM} = \frac{I_L (t_1 + t_2)}{t_2} \quad — 1.19$$

- The I_{FRM} is important quantity that must be known when a rectifier diode is being selected for particular application.



The above HWR with Rs connected in series with diode, this is low resistance component known as Surge limiting resistor.

The purpose of Rs is to limit any surge current that might pass through the diode.

The highest surge current occurs when ac supply is first switched on to the rectifier.

Before switch-on, the reservior capacitor normally contains no charge, thus it behaves as short circuit.

If switched on when ac i/p is at its peak level, the surge current is

$$I_{F(surge)} = \frac{V_p}{R_s} \quad — 1.20$$

For diode with specified maximum non-repetitive surge current (I_{FSM}), the surge limiting resistor is calculated as

$$R_S = \frac{V_P}{I_{FSM}} \quad - 1.21$$

- As the transformer normally used at i/p of rectifier circuit, and secondary winding has resistance greater than the required value of R_S, an additional ~~Eq~~ R_S may not be required.

Problem

① A HWR power supply circuit ~~with~~ is providing 20V supply and 500Ω load. Select suitable device and calculate required surge limiting resistance ($V_r = 10\%$ of $E_{o\,ave}$, $t_2 = 1.16ms$, $I_{FSurge} = 30A$)

Soln

$$E_{o(ave)} = 20V$$

$$V_P = E_{o(max)} + V_F$$

$$E_{omax} = E_{ave} + 0.5\, V_r$$

$$= 20 + (0.5 \times 2)$$

$$E_{omax} = 21V$$

$$V_P = 21 + 0.7$$

$$= 21.7V$$

$V_r = 10\%$ of 20
$= 2V$

$V_R \simeq 2 V_p$

$\simeq 2 \times 21.7V$

$V_R = 43.4V$

~~$I_{F(ave)} = I_L = 400mA$~~

$I_{F(ave)} = I_L = \frac{E_{o(ave)}}{R_L}$

$= \frac{20}{500}$

$= 40mA$

$I_L = I_{Fave}$

$I_{FRM} = \frac{I_L(t_1+t_2)}{t_2}$

$t_2 = T = \frac{1}{f} = \frac{1}{60Hz} = 16.7ms$

~~$t_1 = T \simeq 16.7ms$~~

~~$T = t_1 + t_2$~~

~~$t_2 =$~~

$I_{FRM} = \frac{40mA \times 16.7mS}{1.16mS}$

$= 576mA$

$I_{FSM} = I_{F(surge)}$

~~$I_{F(surge)}$~~ =

$$R_s = \frac{V_p}{I_{FSM}} = \frac{21.7}{30}$$

$$R_s = 0.7\Omega$$

Transformer Selection

- A power supply transformer is normally defined in terms of its rms i/p & o/p v/g & current.
- The transformer peak output voltage is calculated by adding the rectifier voltage drop to the power supply peak output.
- The peak voltage is then converted to rms to give the secondary value.

$$V_{S(rms)} = 0.707 (E_{o(max)} + V_p) \quad -1.22$$

- The rms current ~~of resistive~~ is given by (without filter)

$$I_{rms} = 2.2 I_{L(dc)} \quad - 1.23$$

- HWR with capacitor filter.

$$I_{Ldc} = 0.28 I_{S(rms)} \quad -1.24$$

- Transformer primary current is

$$I_{p(rms)} = \frac{V_{S(rms)} \times I_{S(rms)}}{V_{p(rms)}} \quad -1.25$$

1.1.4 Full-wave rectifiers

- Unfortunately, the half-wave rectifier circuit is relatively inefficient as conduction takes place only on alternate half-cycles.
- A better rectifier arrangement would make use of both positive and negative half-cycles. These full-wave rectifier circuits offer a considerable improvement over their half-wave counterparts.
- They are not only more efficient but are significantly less demanding in terms of the reservoir and smoothing components.
- There are two basic forms of full wave rectifier:
  - i) Bi-phase rectifier
  - ii) Bridge rectifier

i) Bi-phase rectifier circuits

Fig. 1.10 shows a simple bi-phase rectifier circuit.

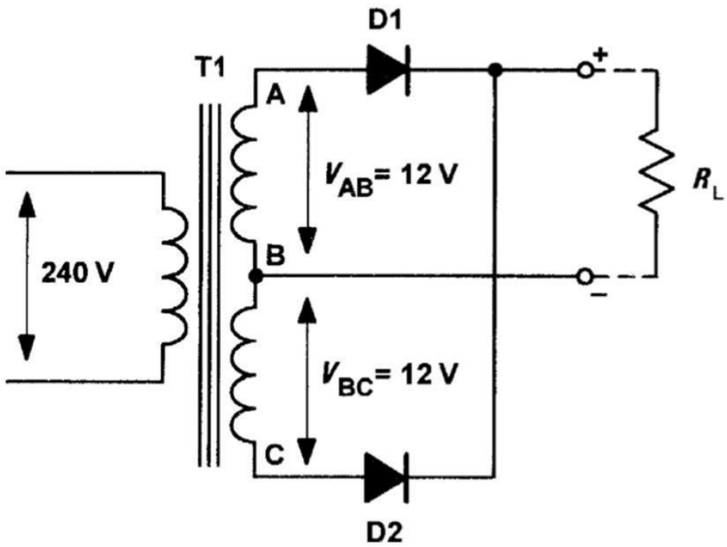
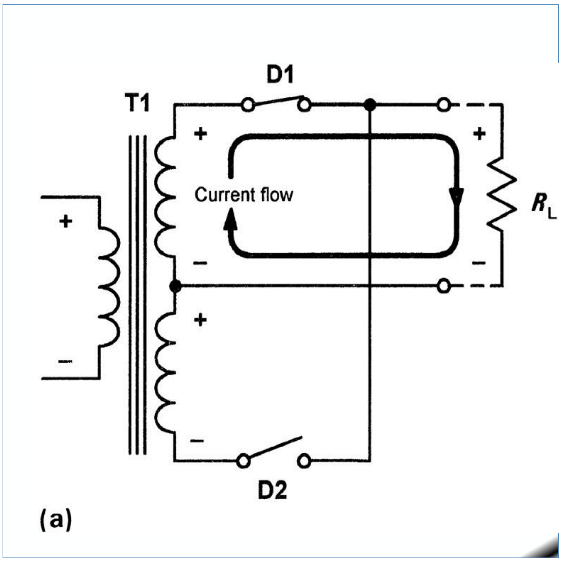


Figure 1.10 Bi-phase rectifier circuit

- Mains voltage (240 V) is applied to the primary of the step-down transformer (T1) which has two identical secondary windings, each providing 12 V r.m.s. (the turns ratio of T1 will thus be 240/12 or 20:1 for each secondary winding).
- On positive half-cycles, point A will be positive with respect to point B. Similarly, point B will be positive with respect to point C. In this

condition D1 will allow conduction (its anode will be positive with respect to its cathode) while D2 will not allow conduction (its anode will be negative with respect to its cathode). Thus D1 alone conducts on positive half-cycles.

- On negative half-cycles, point C will be positive with respect to point B. Similarly, point B will be positive with respect to point A. In this condition D2 will allow conduction (its anode will be positive with respect to its cathode) while D1 will not allow conduction (its anode will be negative with respect to its cathode). Thus D2 alone conducts on negative half-cycles.
- Fig. 1.10 shows the bi-phase rectifier circuit with the diodes replaced by switches. In Fig. 1.11 (a) D1 is shown conducting on a positive half-cycle while in Fig. 1.11 (b) D2 is shown conducting.



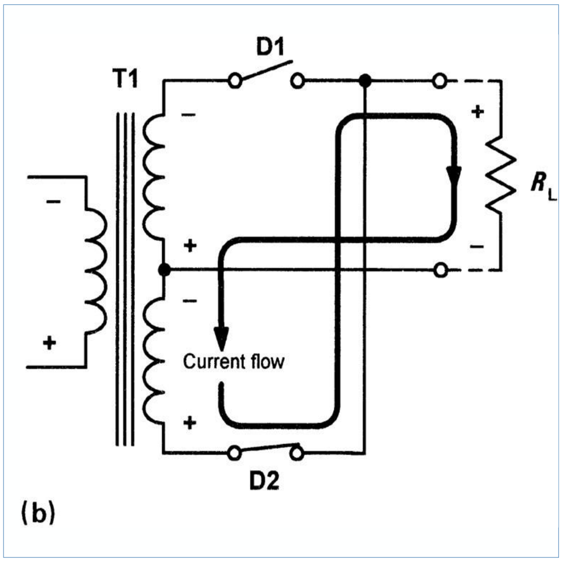


Figure 1.11 (a) Bi-phase rectifier with D1 conducting and D2 non-conducting (b) bi-phase rectifier with D2 conducting and D1 non-conducting

- The result is that current is routed through the load in the same direction on successive half-cycles.
- Furthermore, this current is derived alternately from the two secondary windings. As with the half-wave rectifier, the switching action of the two diodes results in a pulsating output voltage being developed across the load resistor (R_L).

- However, unlike the half-wave circuit the pulses of voltage developed across RL will occur at a frequency of 100 Hz (not 50 Hz).
- This doubling of the ripple frequency allows us to use smaller values of reservoir and smoothing capacitor to obtain the same degree of ripple reduction.
- As before, the peak voltage produced by each of the secondary windings will be approximately 17 V and the peak voltage across RL will be 16.3 V (i.e. 17 V less the 0.7 V forward threshold voltage dropped by the diodes).
- Fig. 1.12 shows how a reservoir capacitor (C1) can be added to ensure that the output voltage remains at, or near, the peak voltage even when the diodes are not conducting.

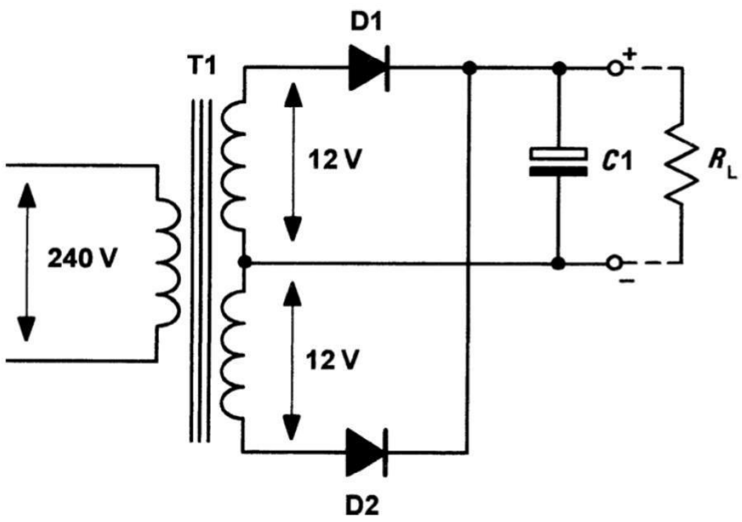


Figure 1.12 Bi-phase rectifier with reservoir capacitor

- This component operates in exactly the same way as for the half-wave circuit, i.e. it charges to approximately 16.3 V at the peak of the positive half-cycle and holds the voltage at this level when the diodes are in their non-conducting states.
- The time required for C1 to charge to the maximum (peak) level is determined by the charging circuit time constant (the series resistance multiplied by the capacitance value).
- In this circuit, the series resistance comprises the secondary winding resistance together with the forward resistance of the diode and the

(minimal) resistance of the wiring and connections. Hence C1 charges very rapidly as soon as either D1 or D2 starts to conduct.

- The time required for C1 to discharge is, in contrast, very much greater. The discharge time contrast is determined by the capacitance value and the load resistance, R_L. In practice, R_L is very much larger than the resistance of the secondary circuit and hence C1 takes an appreciable time to discharge. During this time, D1 and D2 will be reverse biased and held in a non-conducting state.
- As a consequence, the only discharge path for C1 is through R_L. Fig. 1.13 shows voltage waveforms for the bi-phase rectifier, with and without C1 present.

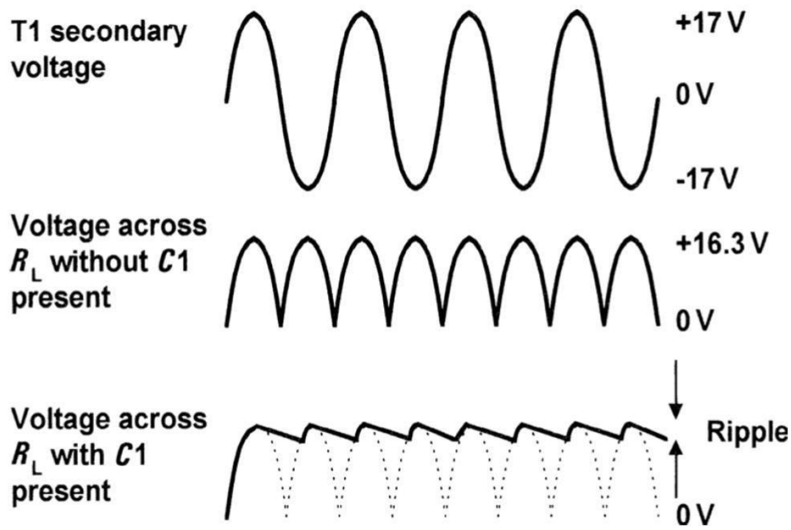


Figure 1.13 Waveforms for the bi-phase rectifier Note that the ripple frequency (100 Hz) is twice that of the half-wave circuit shown previously in Fig. 1.7.

ii) Bridge rectifier circuits

- An alternative to the use of the bi-phase circuit is that of using a four-diode bridge rectifier.
- A full-wave bridge rectifier arrangement is shown in Fig. 1.14.

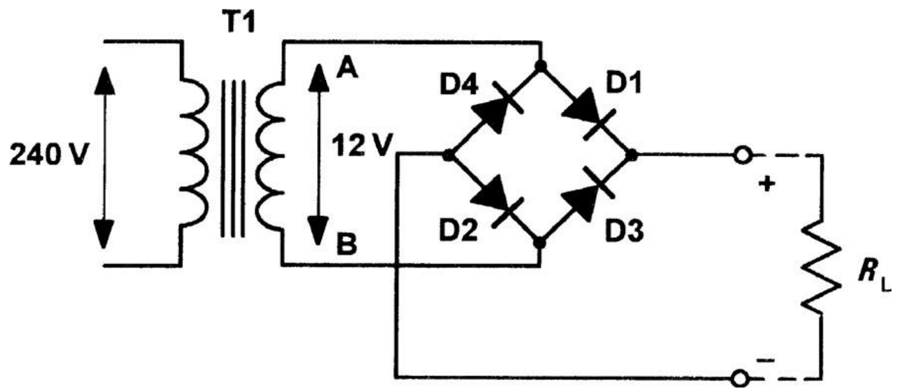


Figure 1.14 Full-wave bridge rectifier circuit

- Mains voltage (240 V) is applied to the primary of a step-down transformer (T1). The secondary winding provides 12 V r.m.s. (approximately 17 V peak) and has a turns ratio of 20:1, as before.
- On positive half-cycles, point A will be positive with respect to point B. In this condition D1 and D2 will allow conduction while D3 and D4 will not allow conduction.
- On negative half-cycles, point B will be positive with respect to point A. In this condition D3 and D4 will allow conduction while D1 and D2 will not allow conduction.
- Fig. 1.15 shows the bridge rectifier circuit with the diodes replaced by four switches. In Fig. 1.15(a) D1 and D2 are conducting on a positive half-cycle while in Fig. 1.15(b) D3 and D4 are conducting.

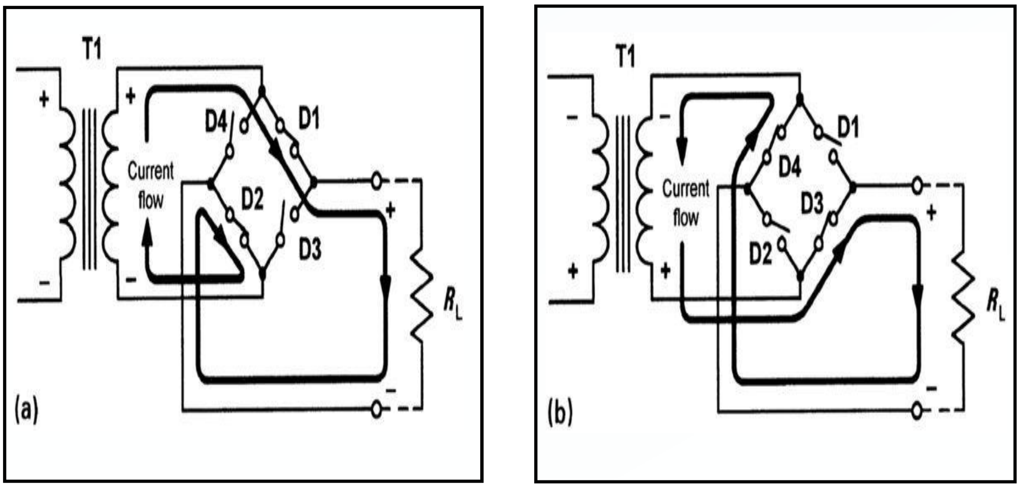


Figure 1.15 (a) Bridge rectifier with D1 and D2 conducting, D3 and D4 non-conducting (b) bridge rectifier with D1 and D2 non-conducting, D3 and D4 conducting

Problem

① Specify the transformer for HWR power circuit Supply circuit. ($E_{omax} = 21V$, $I_{L(dc)} = 40mA$, $V_{P(rms)} = 115V$)

Soln

$$V_{S(rms)} = 0.707 (E_{o(max)} + V_F)$$

$$= 0.707 (21 + 0.7)$$

$$V_{S(rms)} = 15.3V$$

$$I_{S(rms)} = 3.6 I_{Ldc}$$

$$= 3.6 \times 40mA$$

$$I_{S(rms)} = 144mA$$

$$I_{P(rms)} = \frac{V_{S(rms)} \times I_{S(rms)}}{V_{P(rms)}}$$

$$= \frac{15.3 \times 144mA}{115}$$

$$I_{P(rms)} = 19.2mA$$

Full wave rectifier power Supply

Below figure Shows FWR with reservoir capacitor and Surge limiting resistor.

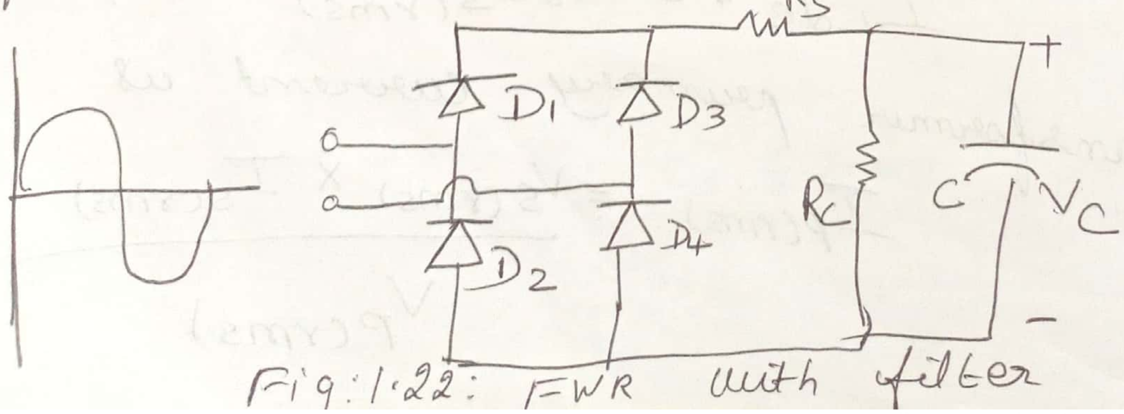


Fig: 1.22: FWR with filter

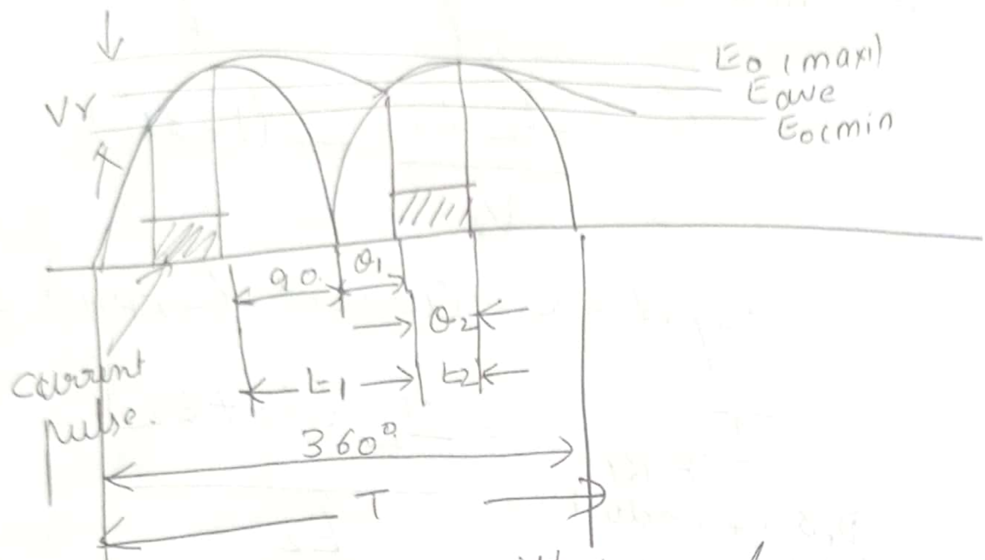


Fig 1.23: FWR with waveform

Applying pythogorous theorem

$$\sin\theta = \frac{opp}{hyp} \quad — 1.26$$

$$= \frac{E_{o(min)}}{E_{o(max)}}$$

$$\theta_1 = \sin^{-1}\left(\frac{E_{o(min)}}{E_{o(max)}}\right) \quad — 1.27$$

$$\theta_2 = 90^\circ - \theta_1 \quad — 1.28$$

$$t_2 = \frac{\theta_2 T}{360} \quad — 1.29$$

Comparing Fig 1.23 and Fig 1.17 shows that the capacitor discharge time t_1 for HWR circuit is approximately equal to the w/f time period T, while for the FWR t_1 is T/2

$$t_1 = \left(\frac{T}{2}\right) - t_2 \quad — 1.30$$

The Reservior capacitance for FWR is

$$C = \frac{I_L t_1}{V_r} \quad \text{—} (1.31)$$

The repetitive current (I_{FRM}) is

$$I_{FRM} = \frac{I_L (t_1 + t_2)}{t_2}$$

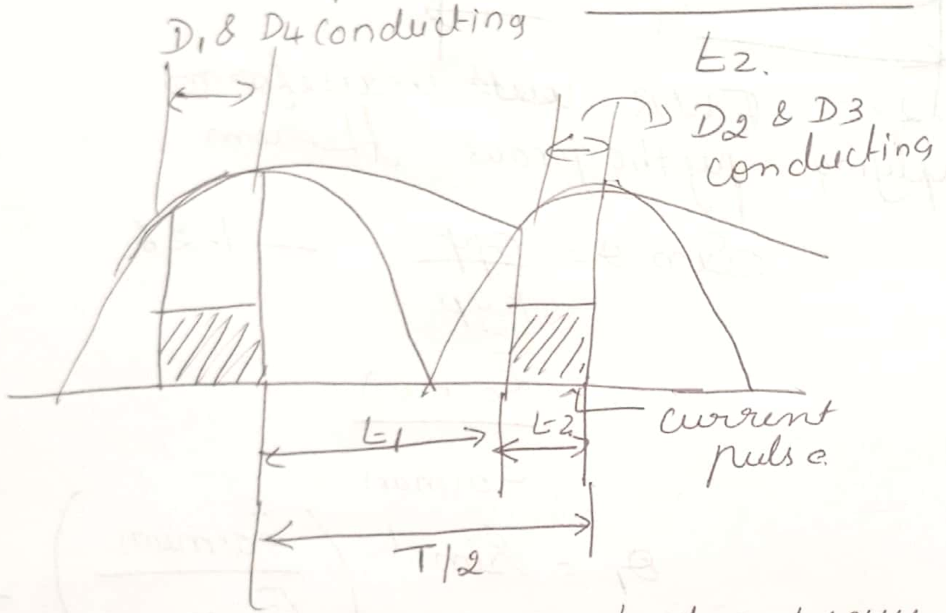


Fig 1.24: Diodes in bridge wave rectifier.

The average forward current passed by the bridge rectifier circuit is load current

$$I_{F(ave)} = \frac{I_L}{2} \quad \text{—} (1.32)$$

The reverse voltage across D3 is

$$V_R = V_P - V_F$$

$$V_R \approx V_P$$

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Problems

1) The fullwave rectifier dc power supply is to supply 20V to a 500Ω load. The peak to peak ripple voltage is not to exceed 10% of the average output voltage. and the ac input frequency is 60 HZ. Calculate reservior capacitor, calculate Surge limiting resistance

$$V_r = 10\% \text{ of } E_{o(ave)}$$

$$= 10\% \text{ of } 20$$

$$V_r = 2V$$

$$R_L = 500\Omega$$

$$f = \frac{1}{T} = T = 16.ms$$

$$t_2 = 1.16ms$$

$$t_1 = \frac{T}{2} - t_2$$

$$= \frac{16.7m}{2} - 1.16m$$

$$t_1 = 7.19ms$$

$$C_1 = \frac{I_L t_1}{V_r} = \frac{40mA \times 7.19ms}{2}$$

$$C_1 = 144\mu F$$

(24)

$$V_P = E_{o(max)} + 2V_F$$

$$= 21 + (2 \times 0.7)$$

$$V_P = 22.4V$$

$$I_{F(ave)} = \frac{I_L}{2} = \frac{40mA}{2}$$

$$I_{F(ave)} = 20mA$$

$$I_{FRM} = \frac{I_L(t_1+t_2)}{t_2}$$

$$= \frac{40mA \times 8.35ms}{1.16ms}$$

$$I_{FRM} = 288mA$$

Transformer Selection

The transformer Specification of FWR power Supply is determined by

$$V_{S(rms)} = 0.707(E_{o(max)} + 2V_F) \quad - 1.33$$

$$I_{L(dc)} = 0.62\, I_{S(rms)} \quad - 1.34$$

$$I_{S(rms)} = 1.6\, I_{L(dc)} \quad - 1.35$$

$$I_{P(rms)} = \frac{V_{S(rms)} \times I_{S(rms)}}{V_{P(rms)}}$$

~~Problem~~

① Calculate current in primary coil for.

$E_{o(max)} = 21V$, $I_L = 40mA$, $V_{p(rms)} = 115V, 60Hz$

Soln

$V_{s(rms)} = 0.707 (E_{o(max)} + 2V_F)$

$= 0.707 (21 + 1.4)$

$V_{s(rms)} = 15.8V$

$I_{s(rms)} = 1.6 I_{Ldc}$

$= 1.6 \times 40mA$

$I_{s(rms)} = 64mA$

$I_{p(rms)} = \frac{V_{s(rms)} \times I_{s(rms)}}{V_{p(rms)}}$

$= \frac{15.8 \times 64mA}{115}$

$I_{p(rms)} = 8.8mA$

~~RC~~ ~~π~~

RC π filter

- The ripple voltage that appears across the reservoir capacitor in a rectifier power supply can be attenuated by the use of additional resistor and capacitor, which together function as an ac voltage divider.

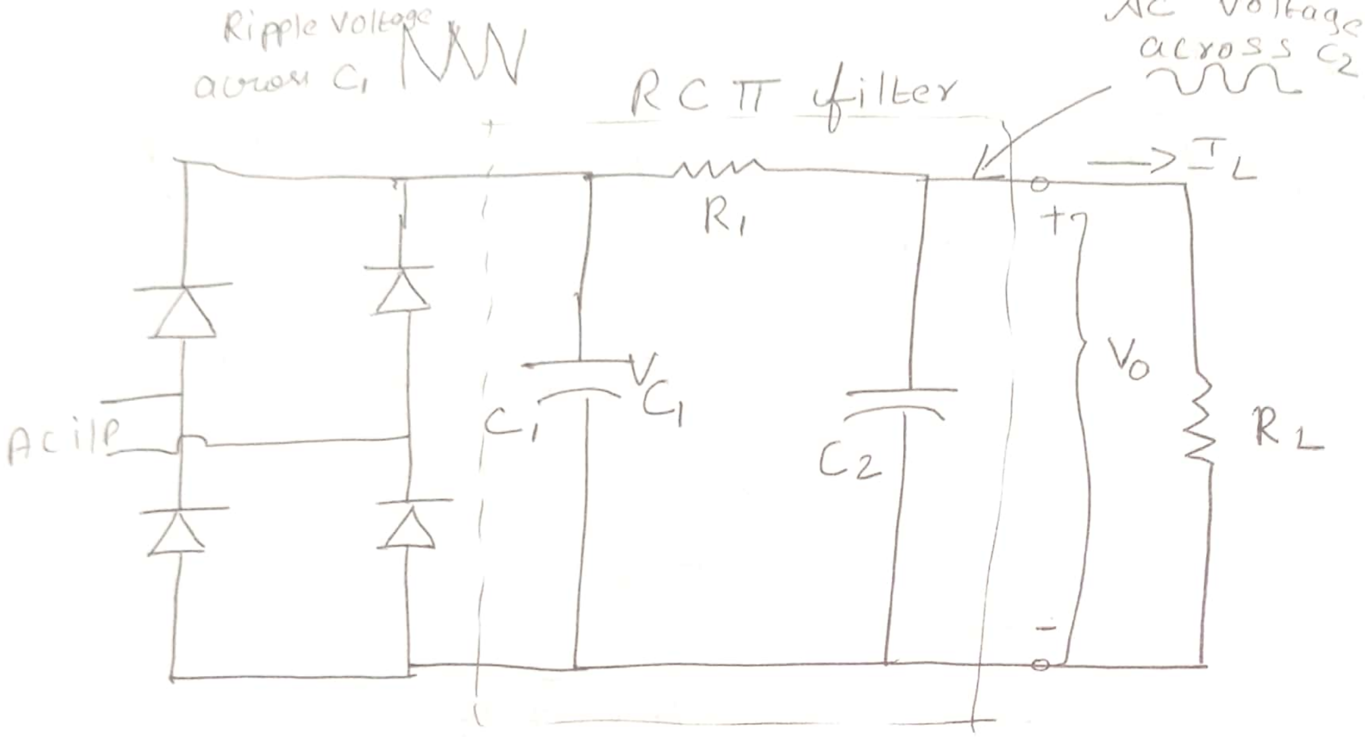

Fig 1.25: RC π filter circuit

- Fig 1.25 shows the circuit, C_1 being the reservoir capacitor, and R_1 and C_2 the additional components.
- The combination of C_1, R_1 and C_2 is referred to as a π-filter, because of the π-shaped arrangement of the circuit components.
- The reservoir capacitor continues to charge and discharge, producing sawtooth (ripple) waveform across C_1 regardless of the presence of the additional components.

The sawtooth waveform is composed of a fundamental ac voltage and a number of smaller amplitude, higher frequency harmonic components.

- Due to their higher frequencies, the harmonic components are more severely attenuated than the fundamental frequency component by the voltage division across R_1 and C_2.

- This combined with the smaller input amplitude of the harmonics means that the waveform developed across C_2 is the essentially an attenuation version of the sinusoidal fundamental component.

- By fourier analysis, the peak value of the fundamental component of the sawtooth waveform can be shown to be

$$V_p = \frac{V_r}{\pi} \quad \text{— } 1.33$$

- where V_r = ripple voltage peak to peak amplitude

- The ac voltage developed across C_2 is the filter ac output and is given by

$$V_o = \frac{V_i \, X_{C2}}{\sqrt{R_1^2 + X_{C2}^2}} \quad \text{— } 1.34$$

where V_i is filter ac input voltage applied across capacitor C_1

$$X_{C2} = \frac{R_1}{\sqrt{(V_i / V_o)^2 - 1}} \quad \text{— } 1.35$$

If $(V_i/V_o)^2 >> 1$

$$X_{C2} \approx \frac{R_1}{(V_i/V_o)} \quad \text{------ } 1.36$$

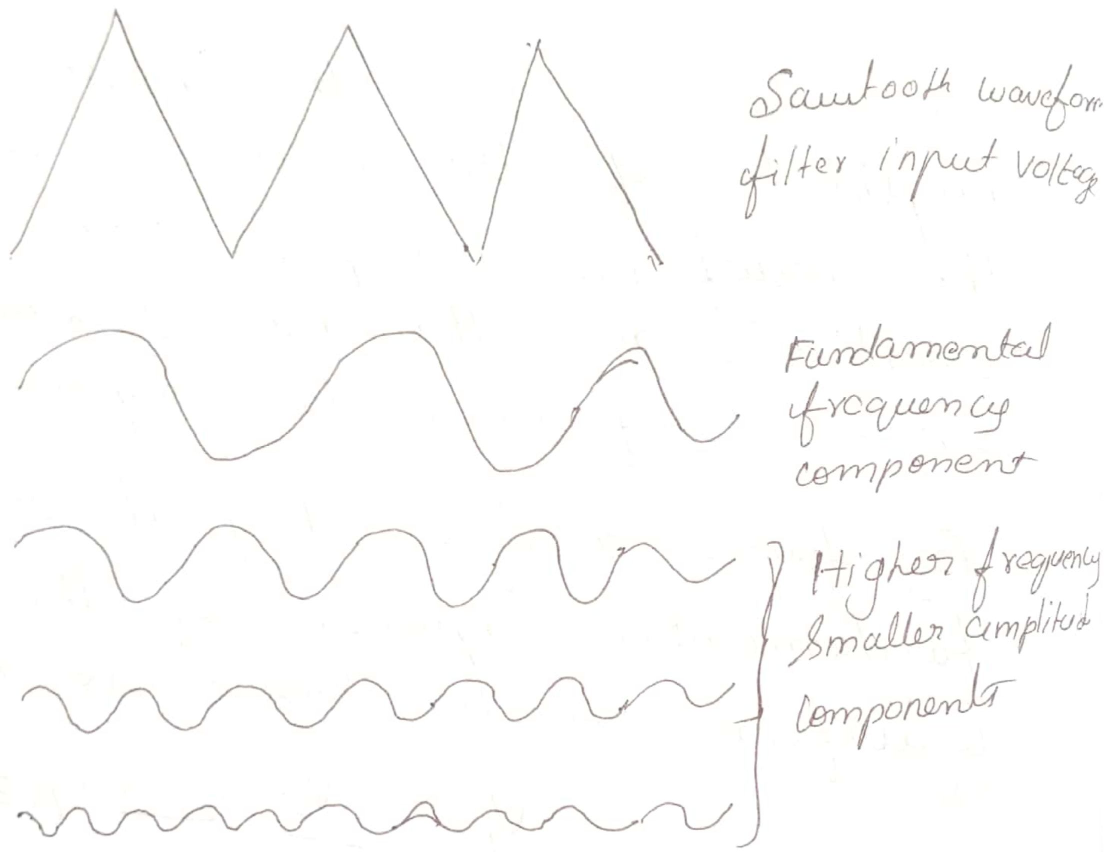

Fig 1.26: Π filter attenuates ac components that constitutes the ripple voltage

Problem

(1) The 2 V ripple waveform across capacitor C_1 is to be further attenuated by the use of an additional resistor and capacitor. If $R_1 = 22\Omega$, $C_1 = C_2 = 150\mu F$, $E_{o(ave)} = 20V$, $V_r = 2V$, $f_r = 120 Hz$

Soln

$$V_{o(dc)} = E_{o(ave)} - (I_L R_1)$$

$$= 19.12 V$$

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$$V_i = V_p = \frac{V_r}{\pi} = \frac{2V}{\pi}$$

$$V_i = 637 mV$$

$$X_{C2} = \frac{1}{2\pi f_r C_2}$$

$$X_{C2} = \frac{1}{2\pi \times 120 Hz \times 150 \mu F}$$

$$X_{C2} = 8.84 \Omega$$

$$V_o = \frac{V_i \times X_{C2}}{\sqrt{R_1^2 + X_{C2}^2}}$$

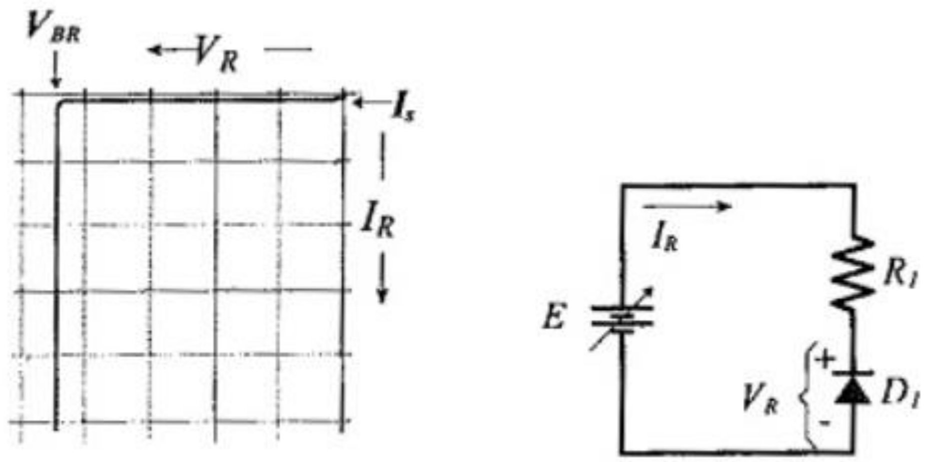
$$= \frac{637 mV \times 8.84 \Omega}{\sqrt{(22\Omega)^2 + (8.84)^2}}$$

$$V_o = 238 mV$$

ZENER DIODE

Junction Breakdown

- A Semiconductor Diode blocks current in the reverse direction, but will suffer from premature breakdown or damage if the reverse voltage applied across becomes too high.



(a) Diode reverse characteristic

(b) Diode-resistor circuit

Fig.1.27. Zener diode with current limiting resister

- When a PN junction is reversed biased it allows very small current to flow through it. This current is due to the movement of minority charge carriers and it is almost independent of the voltage applied.
- If reverse bias is made too high, the current through PN junction increases abruptly and the voltage at which this phenomenon occurs is called ***junction breakdown voltage*** and large current flows.
- The resistor connected in series limits the reverse current, thus the power dissipated in the diode can be kept at level that will not destroy the device. In this case the diode may be operated continuously in reverse breakdown.
- The reverse current returns to its normal level when the voltage is reduced below the reverse breakdown level.
- There are two processes which causes junction breakdown. One is ***zener breakdown*** and another one is ***avalanche breakdown*** .

- The high intensity electric field causes breakdown in a reverse biased pn-junction The high intensity electric field cause electron to break away from their atoms, thus converting the depletion region from insulating material into conductor. This is ionization by electric field, also called Zener breakdown, and it usually occurs with reverse bias voltages less than 5V.
- A Zener Diode, also referred to as a breakdown diode, is a specially doped semiconductor device engineered to function in the reverse direction. When the voltage across a Zener diode's terminals is reversed and reaches the Zener Voltage (also known as the knee voltage), the junction experiences a breakdown, allowing current to flow in the opposite direction. This phenomenon, known as the Zener Effect, is a key characteristic of Zener diodes.
- In case of avalanche breakdown, the increased electric field causes increase in the velocities of the minority carriers. These high energy carriers break covalent bonds, thereby generating more carriers. Again these generated carriers are accelerated by electric field. They break more covalent bonds during their travel. A chain is thus established, creating a large number of carriers. This gives rise to a high reverse current. This mechanism of breakdown is called ***avalanche breakdown*** .
- Avalanche breakdown is normally produced by reverse voltage levels above 5V.

Circuit Symbol and Package

- The circuit symbol for a Zener Diodes Characteristics in Fig. 1.28(a) is the same as that for an ordinary diode, but with the cathode bar approximately in the shape of a letter Z.
- The arrowhead on the symbol still points in the (conventional) direction of forward current when the device is forward biased. As illustrated, for operation in reverse bias, the voltage drop (V_Z) is + on the cathode, – on the anode.
- Low-power Zener diodes are available in a variety of packages. For the device package shown in Fig. 1.28(b), the coloured band identifies the cathode terminal, as in the case of an ordinary low-current diode. High-current Zener diodes are also available in the type of package that allows for mounting on a heat sink.

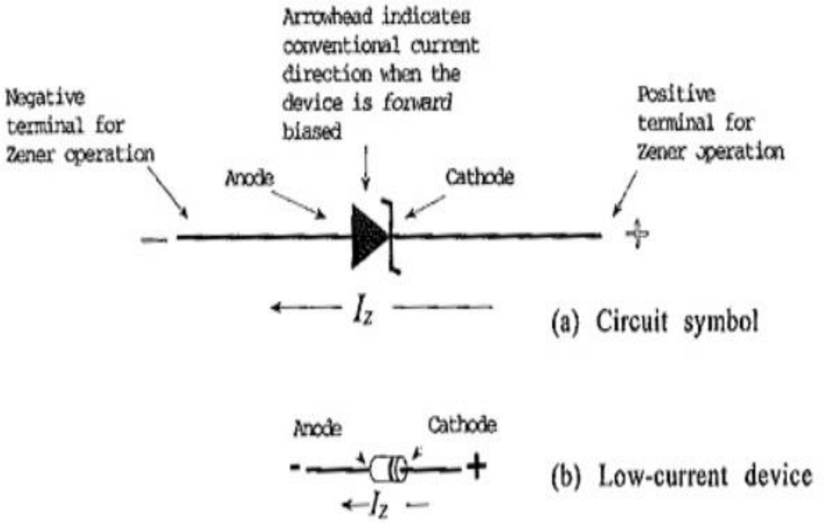


Fig.1.28. Zener circuit symbol and low current zener diode package

Characteristics and Parameters:

- The typical Zener Diodes Characteristics are shown in detail in Fig. 1.29. Note that the forward characteristic is simply that of an ordinary forward-biased diode. Some important points on the reverse characteristic are:
- **V_Z – Zener breakdown voltage**
- **I_{ZT} – Test current for measuring V_Z**
- **I_{ZK} – Reverse current near the knee of the characteristic; the minimum reverse current to sustain breakdown**
- **I_{ZM} – Maximum Zener current; limited by the maximum power dissipation.**
- The dynamic impedance (Z_Z) is another important parameter that may be derived from the characteristics. As illustrated in Fig. 1.29,
- Z_Z defines how V_Z changes with variations in diode reverse current. When measured at I_{ZT}, the dynamic impedance is designated (Z_{ZT}). The dynamic impedance measured at the knee of the characteristic (Z_{ZK}) is substantially larger than Z_{ZT}.

$$Z_Z = \frac{\Delta V_Z}{\Delta I_Z}$$

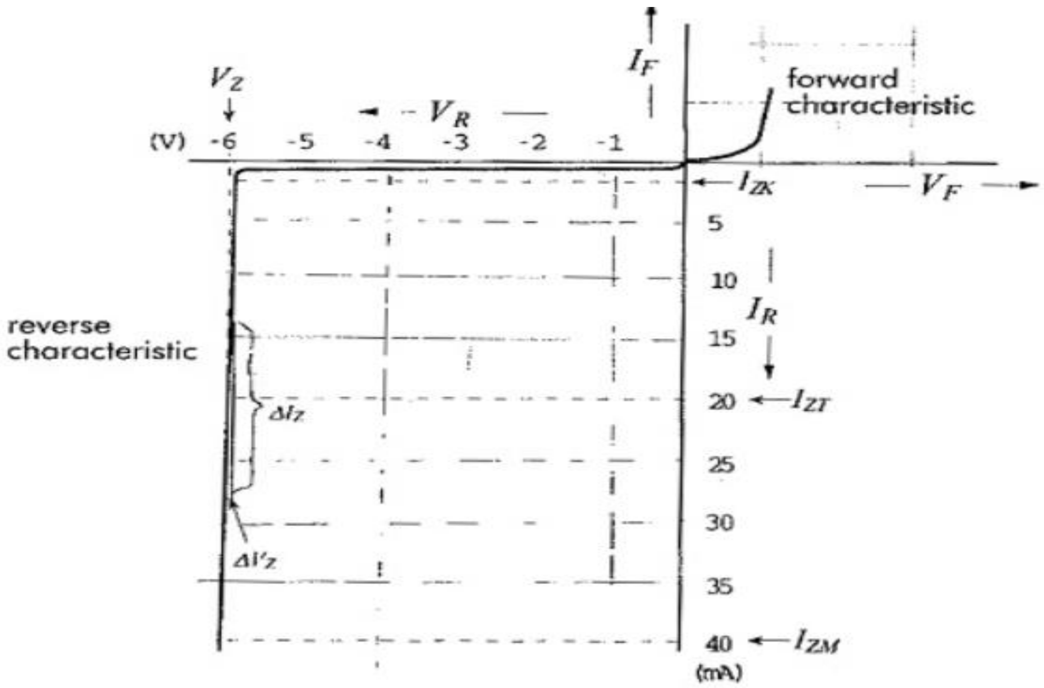


Fig.1.29. Zener circuit symbol and low current zener diode package

Equivalent Circuit

- The dc equivalent circuit for a Zener diode is simply a voltage cell with a voltage V_Z, as in Fig. 1.30(a). This is the complete equivalent circuit for the device for all dc calculations.
- For the ac equivalent circuit [Fig. 1.30(b)], the dynamic impedance is included in series with the voltages cell. The ac equivalent circuit is used in situations where the Zener current is varied by small amounts.
- It must be understood that these equivalent circuits apply only when the Zener diode is maintained in reverse breakdown. If the device becomes forward biased, then the equivalent circuit for a forward-biased diode must be used.

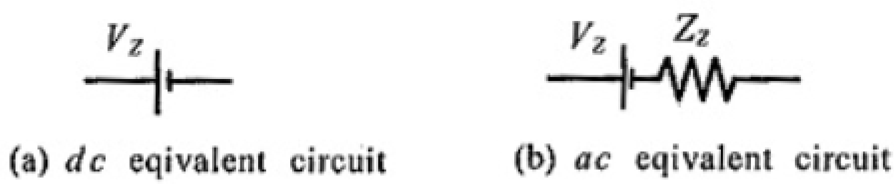


Fig.1.30. Equivalent circuit for Zener diode

Zener diode as voltage regulator circuit

Regulator Circuit with No load

- The most important application of Zener Diode Voltage Regulator Circuit is dc voltage regulator circuits. These can be the simple regulator circuit shown in Fig. 1.30, or the more complex regulators.
- The circuit in Fig. 1.30 is usually employed as a voltage reference source that supplies only a very low current (much lower than I_Z) to the output. Resistor R_1 in Fig. 1.30 limits the Zener diode current to the desired level.

$$I_Z = \frac{E_S - V_Z}{R_1}$$

- The Zener current may be just greater than the diode knee current (I_{ZK}). However, for the most stable reference voltage, I_Z should be selected as I_{ZT} (the specified test current).

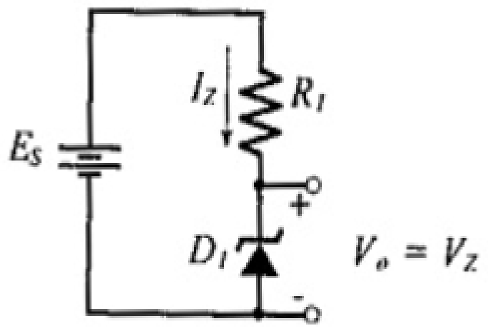


Fig.1.30. Zener Diode used as reference voltage source

Loaded Regulator:

- When a Zener diode regulator is required to supply a load current (I_L), as shown in Fig. 1.31, the total supply current (flowing through resistor R_1) is the sum of I_L and I_Z Care must be taken to ensure that the minimum Zener diode current is large enough to keep the diode in reverse breakdown.

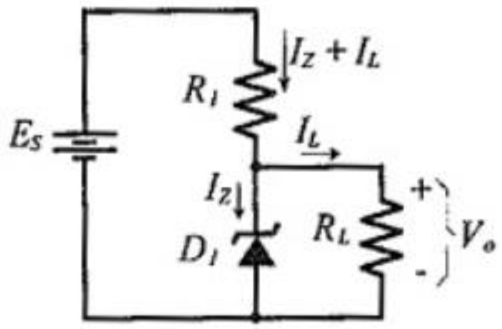


Fig.1.31. Zener Diode Voltage regulator

- The zener diode is connected with its cathode terminal connected to the positive rail of the DC supply so it is reverse biased and will be operating in its breakdown condition. Resistor R_S is selected so to limit the maximum current flowing in the circuit.
- With no load connected to the circuit, the load current will be zero, ($I_L = 0$), and all the circuit current passes through the zener diode which in turn dissipates its maximum power.
- Also a small value of the series resistor R_1 will result in a greater diode current when the load resistance R_L is connected and large as this will increase the power dissipation requirement of the diode so care must be taken when selecting the appropriate value of series resistance so that the zener's maximum power rating is not exceeded under this no-load or high-impedance condition.
- The load is connected in parallel with the zener diode, so the voltage across R_L is always the same as the zener voltage, ($V_R = V_Z$).
- There is a minimum zener current for which the stabilisation of the voltage is effective and the zener current must stay above this value operating under load within its breakdown region at all times. The upper limit of current is of course dependent upon the power rating of the device. The supply voltage V_S must be greater than V_Z.
- One small problem with zener diode stabiliser circuits is that the diode can sometimes generate electrical noise on top of the DC supply as it tries to stabilise the voltage. Normally this is not a problem for most applications but the addition of a large value decoupling capacitor across the zener's output may be required to give additional smoothing.
- The zener voltage regulator consists of a current limiting resistor R_1 connected in series with the input voltage E_S with the zener diode connected in parallel with the load R_L in

this reverse biased condition. The stabilised output voltage is always selected to be the same as the breakdown voltage V_o which is equal to V_Z of the diode.

- The circuit current equation is given by,

$$I_Z + I_l = \frac{E_S - V_Z}{R_1}$$

- In some cases, the load current in the type of circuit shown in Fig. 1.31 may be reduced to zero. Because the voltage drop across R_1 remains constant, the supply current remains constant at,

$$I_{R1} = I_Z + I_L$$

- All of this current flows through the Zener diode when R_L is disconnected. The circuit design must ensure that the total current does not exceed the maximum Zener diode current.

Problems

1. A 5.0V stabilised power supply is required to be produced from a 12V DC power supply input source. The maximum power rating P_Z of the Zener diode is 2W. Using the Zener regulator circuit above calculate:

Solution:

a). The maximum current flowing through the Zener diode.

$$\text{Maximum Current} = \frac{\text{Watts}}{\text{Voltage}} = \frac{2w}{5v} = 400mA$$

b). The minimum value of the series resistor, R_S

$$R_S = \frac{V_S - V_Z}{I_Z} = \frac{12 - 5}{400mA} = 17.5\Omega$$

c). The load current I_L if a load resistor of 1kΩ is connected across the Zener diode.

$$I_L = \frac{V_Z}{R_L} = \frac{5v}{1000\Omega} = 5mA$$

d). The Zener current I_Z at full load.

$$I_Z = I_S - I_L = 400mA - 5mA = 395mA$$