Semiconductor Diodes and Applications

Introduction:

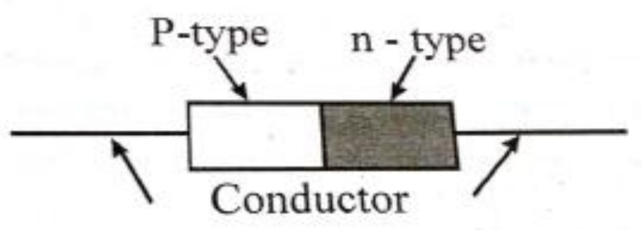
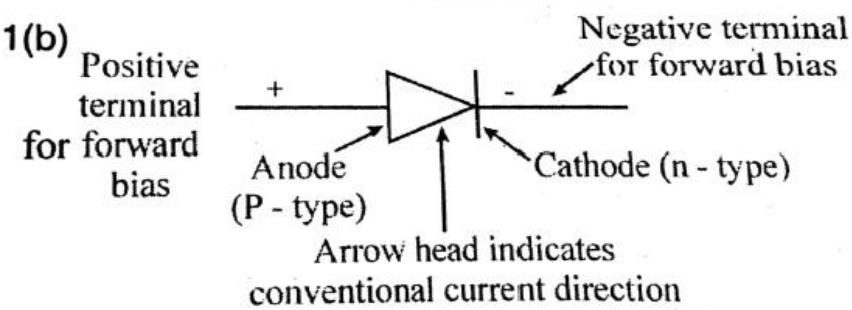


fig 1(a)

A p-n junction has the ability to permit substantial current flow when forward biased and to block current when reverse biased. The P-side of the diode is always the positive terminal for forward bias and is termed as anode. The n-side called the cathode is the negative terminal when the device is forward biased.

fig 1(b)



When it is forward biased, it offers a low resistance to the flow of current and acts as a closed condition of a switch. The current flowing in this direction is called as Forward Current I_F. Fig.1 (C)

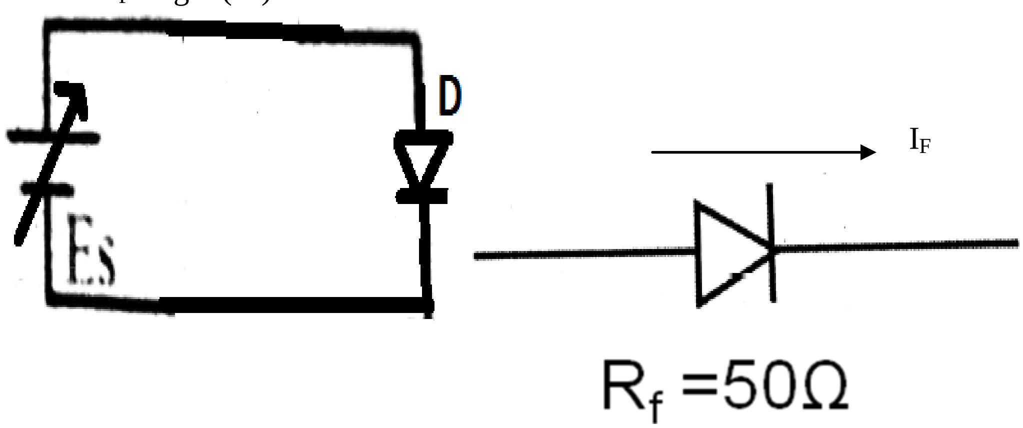


Fig 1 (c)

When it is Reverse biased, it offers a high resistance to the flow of current and acts as a open condition of a switch. The current flowing in this condition is known as reverse current I_R. Fig.1(d)

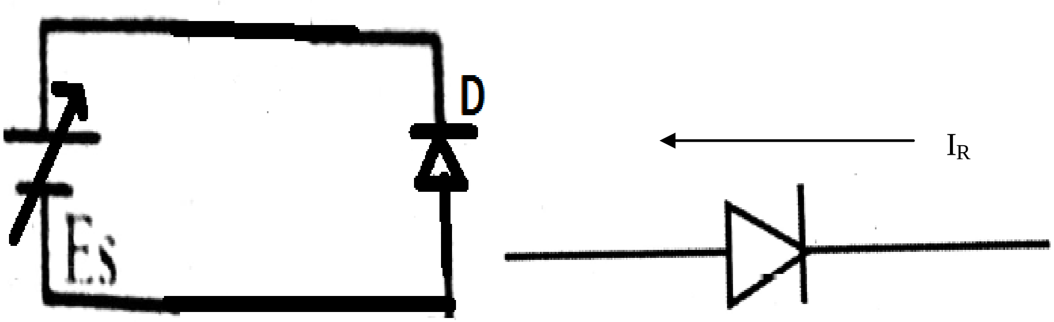
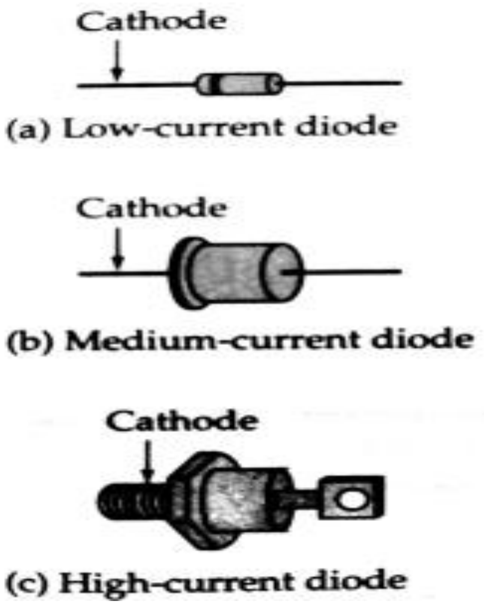


Fig 1 (d)

$$R_r = 1M\Omega$$

1.1 Classification of diodes based on size and appearance:



- Low current diode is usually capable of passing a maximum forward current of approximately 100mA. It can survive about 75V reverse bias without breaking down.
- Medium current diode can usually pass a forward current about 400mA and survive over 200V reverse bias.
- High current diodes, or power diodes, generate a lot of heat. It can pass forward currents of many amperes and can survive several hundred volts of reverse bias.

1.2 Forward and Reverse characteristics of silicon diode:

- Forward current (I_F) remains very low until the diode forward bias voltage (V_F) exceeds approximately 0.7V. Above 0.7V, I_F increases almost linearly with increase in V_F.
- A diode conducts a much smaller reverse current I_R when reverse biased with its anode at a negative potential with respect to its cathode.
- When reverse biased, a very small current, I_R which is less than 100nA flows through the silicon diode until the p-n junction breaks down at a reverse voltage of about 75V.

- This voltage of 75V at which the p-n junction breaks down is called the reverse break down voltage.

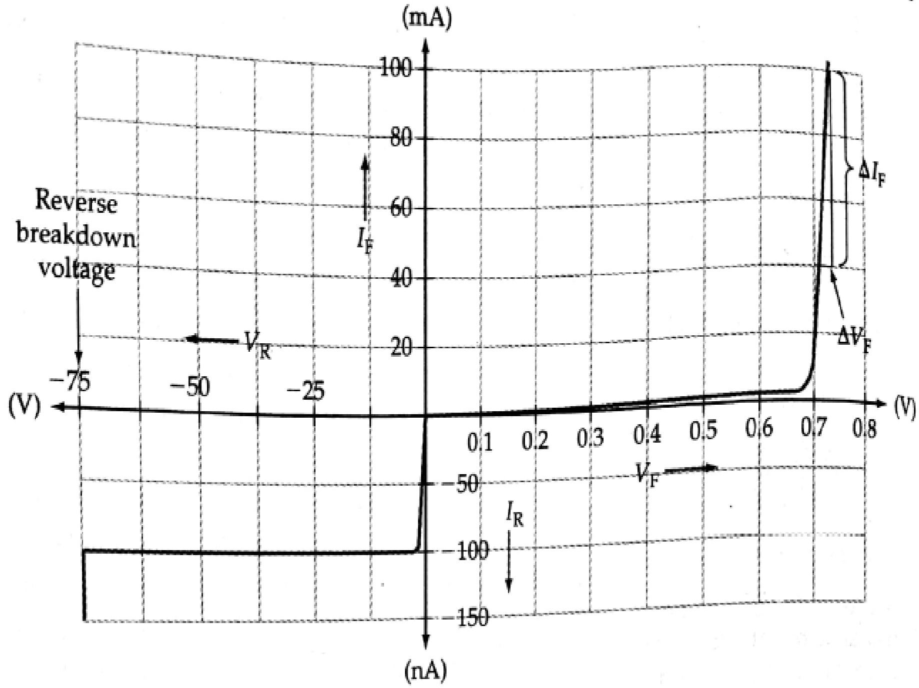
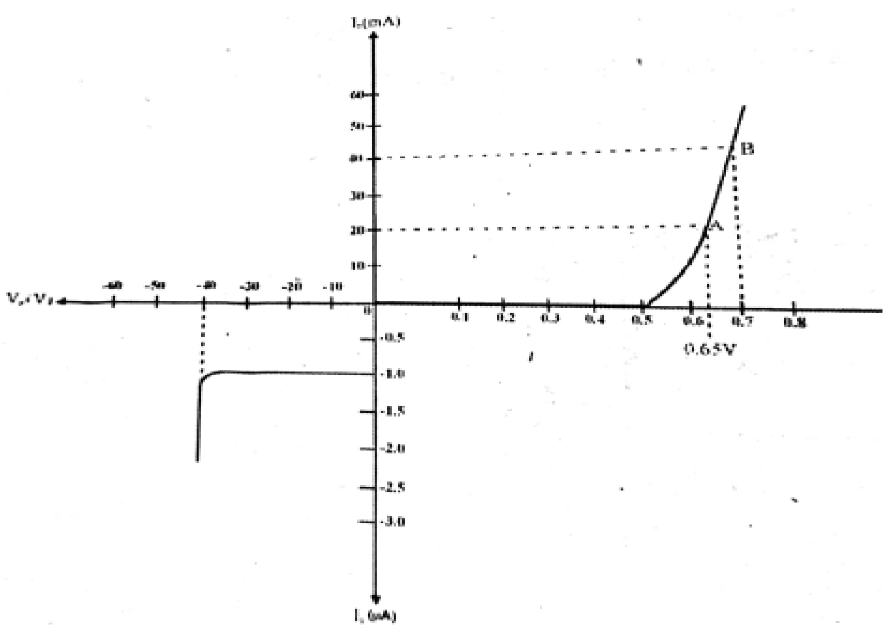


Fig.2 Forward and Reverse characteristics of a silicon diode

Problem: Plot the forward & reverse characteristics of a diode, given the following data

- Cut in voltage =0.6 V
- Reverse break down voltage =40V
- Nominal reverse current =1µA
- Forward current =20mA at a forward voltage of 0.65V
- Forward current =60mA at a forward voltage of 0.7V

Solution:



1.3 Forward and Reverse characteristics of Germanium diode

- The Forward voltage drop of a Ge diode is typically 0.3V.
- The reverse saturation current at 25^0C may be around 1µA

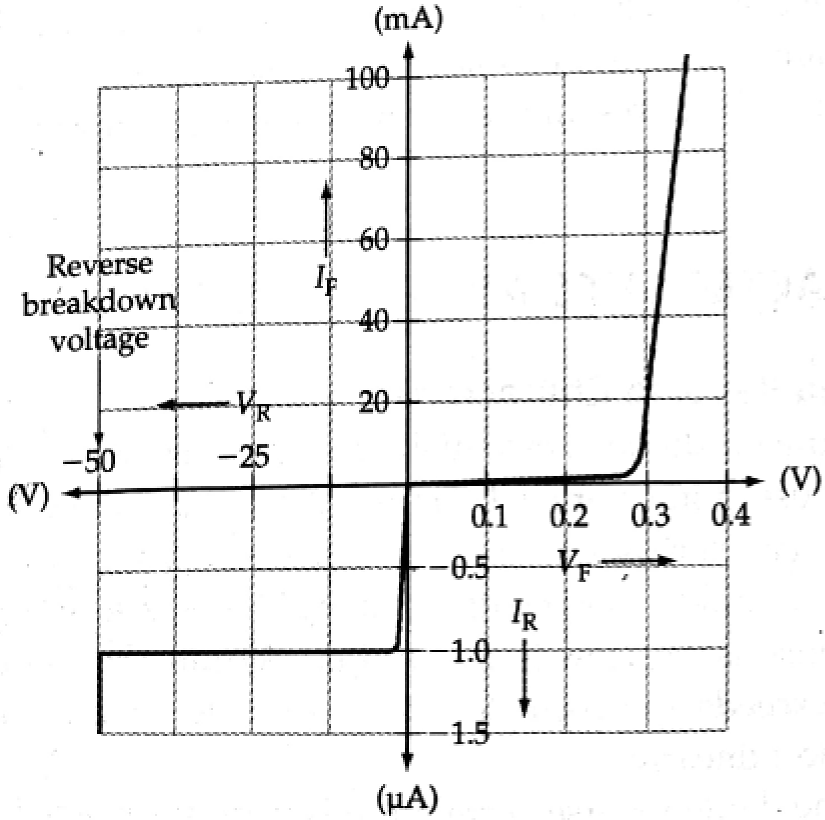


Fig.3 Forward and Reverse characteristics of a Germanium diode

1.4 Comparison of Si & Ge diodes

Parameters	Silicon diode	Germanium diode
Forward voltage drop or cut in voltage	0.6 v	0.3 v
Nominal reverse current	Few n A	Few µA
Reverse break down voltage	< 50V	up to 100 v
Application	Rectification	Small signal like detectors

1.5 Diode Current Equation

- When a diode is subjected to bias there will be a current flow through the diode depending on bias conditions.

- Diode conducts when it is forward biased and there will be a large majority charge carriers crossing the junction resulting in large current.
- Diode stops conduction when it is reverse biased and there will be only minority charge carriers crossing the junction resulting in a reverse saturation current.

The equation relating pn junction current and voltage levels is called Shockley equation and is represented as

$\mathbf{I_{F}= I_R[e^{(V_F / \eta V_T)} -1]}$

Where

I_R –Reverse Saturation Current

V_F- Applied bias voltage across the diode

η - Constant that depends on material

V_T – Thermal voltage called voltage equivalent of temperature

$$V_T = K_T/q$$

Where

K-Boltzman's constant=$1.38*10^{-23}$ J/K

T- Absolute Temperature=$(273+T^0C)K$

q-change of electron=$1.6*10^{-19}$ C

Problems:

Q2. Calculate the thermal voltage V_T at a temperature of 27^0C.

Soln: T = $273+27^0$C=300K

WKT $V_T=KT/q=(1.38*10^{-23}*300)/1.602*10^{-19}$

V_T=25.8mv or 26mv

Q3. A silicon pn junction diode has a reverse saturation current of I_O=30nA at a temperature of 300K. Calculate the junction current when the applied bias voltage is (a) 0.7v Forward Bias (b)10v reverse bias (η=2)

Soln:

(a) 0.7V Forward Bias

$I_F= I_R[e^{(V_F / \eta V_T)} -1]$

$V_F/\eta V_T$ =0.7 / (2*26mv)=13.46

$I_F=30nA[e^{13.46}-1]$

I_F=21mA

(b)10V Reverse Bias

$V_F/\eta V_T$ =-10/(2*26mv)= -192

$I_F=30nA[e^{1-192}-1]$

I_F= -30nA

1.6 Diode Parameters

1. Forward voltage drop (V_F): it is the voltage drop across a diode when it conducts. It is referred to as cut in voltage $V\gamma$ and is about 0.6V to 0.7V for Si diodes and about 0.2V to 0.3V for Ge diodes.

2. Reverse saturation current (I_R): is the nominal current which flows through the diode when it is reverse biased. It is in the order of nA for Si diodes and in the order of µA in case of Ge diodes.

3. Reverse Breakdown voltage (V_{BR}): is the reverse bias voltage at which p-n junction breaks down and permanently damages the diode.

4.Dynamic resistance (r_d): is also known as incremental resistance or ac resistance is the reciprocal of slope of the forward characteristic beyond the knee.

$r_d = \Delta V_F / \Delta I_F$ ----------- (1)

The dynamic resistance can also be calculated from the equation.

$r_d = 26mV / I_F$ --------(2)

5.Maximum forward current ($I_{F(max)}$: It is the maximum current a diode can pass under forward bias condition.

6. Power dissipation (P_D): It is the product of the current through diode and voltage across the diode.

$P_D = V_F I_F$-----------(3)

7. Reverse Recovery time (t_{rr}): It is the time required for the current to decrease to the reverse saturation current level

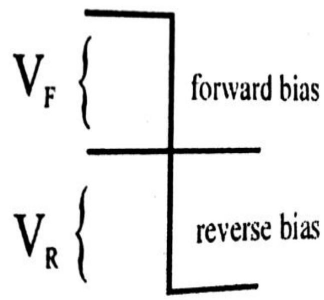
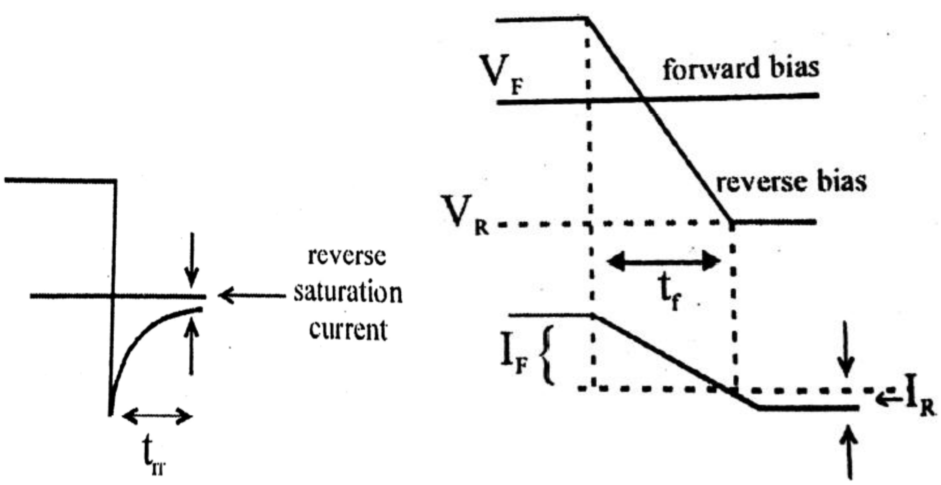


Fig.4



- When the pulse switches from positive to negative, the diode conducts in reverse instead of switching off sharply.
- The reverse current (I_R) initially equals the forward current (I_F), then it gradually reduces toward zero.
- The high level of reverse current occurs because at the instant of reverse bias there are charge carriers crossing the junction depletion region and these must be removed.
- To keep the diode reverse current to a minimum, the fall time (t_f) of the applied voltage pulse must be much larger than the diode t_{rr}. That is $t_f(min) = 10\, t_{rr}$.

1.6.1 Expressing r_d in terms of V_T and I_D

WKT $I_F= I_R[e^{V_F/\eta V_T} -1]$

Differentiate I_F w.r.t V_F

$d I_F/ d V_F= d (I_R[e^{V_F/\eta V_T} -1])/ d V_F$

$d I_F/ d V_F= I_R[e^{V_F/\eta V_T} *1/ \eta V_T -0]$

$d I_F/ d V_F= I_R\, e^{V_F/\eta V_T} * 1/ \eta V_T$

$I_F /I_R +1 =e^{V_F/\eta V_T}$

$d I_F/ d V_F= I_R/ \eta V_T (I_F /I_R +1)$

$d I_F/ d V_F= I_F/ \eta V_T$

WKT r=V/I

Therefore $d V_F/ d I_F= \eta V_T/ I_F$

put $\eta =1$ & V_T=26mV, we get

r_d=26mv/I_F= V_T/ I_F

Reverse Recovery time (t_{rr})

Problems

Q4. Find the minimal fall time for voltage pulses applied to a diode with reverse recovery time of 4ns.

Soln:

t_{rr} =4ns

$t_{f\ (min)}$ =10t_{rr} =10 X 4ns =40ns

Q5. Estimate the maximum reverse recovery time for a diode for an input pulse with 0.5µs fall time.

Soln:

$t_{rr\ (max)} = t_f$ / 10 = 0.5µs /10 =0.05µs

1.7 Diode Approximations

1.7.1 Ideal Diode Characteristics (shown in Fig.5a)

a) Zero forward voltage drop
b) The forward resistance (R_F) is zero
c) The reverse resistance (R_R) infinity

d) The diode readily conducts when forward biased and it blocks conduction when reverse biased. The reverse saturation current is zero (I_R)

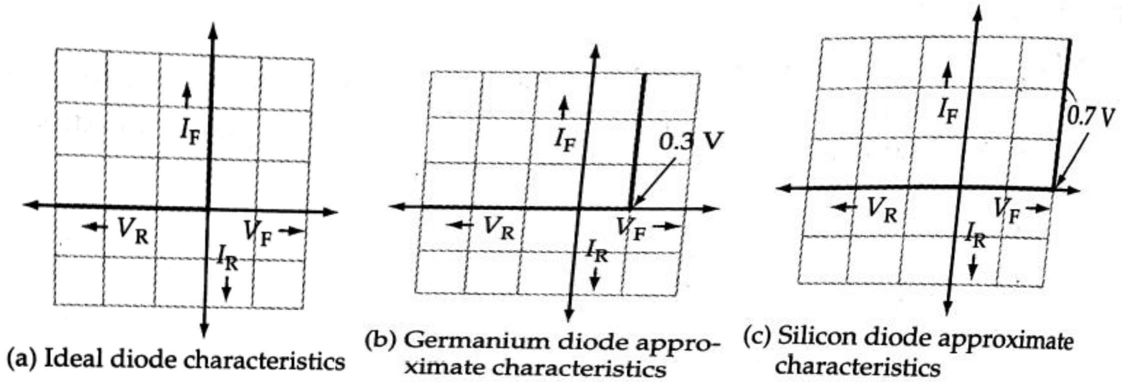


Fig.5

1.7.2. Approximate characteristics of a Si & Ge diode (shown in Fig. 5b and 5c)

a) V_F can be assumed constant in circuits with supply voltages much larger than the diode forward voltage drop.
b) The reverse saturation current is negligible to the forward current, so it can be ignored.
c) V_F is assumed to be 0.7V for Si diode & 0.3V for Ge diode.

Problems:

Problem Q6: For the diode circuits of Fig. 2, find the value of I. Use approximate model of the diode.

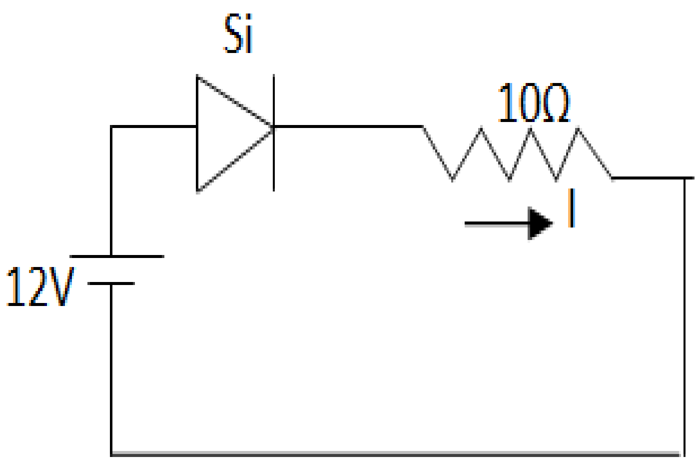


Fig.6

Soln:The Si diode is forward biased by 12V. So it conduct.
Apply KVL i.e 12-0.7-10I = 0
I = (12-0.7)/10 = 1.13A

Problem Q7: For the diode circuits of Fig. 7, find the value of I. Use approximate model of the diode.

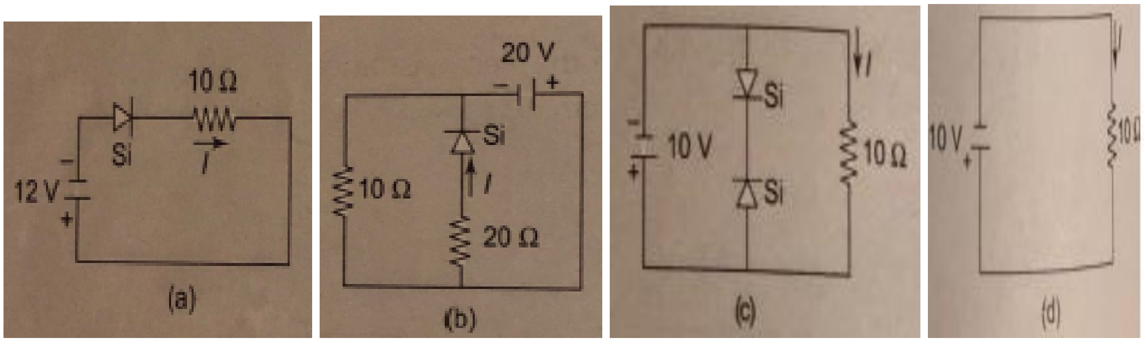


Fig.7

a) The Si diode is reverse biased by 12V. So it does not conduct. I = 0
b) The voltage across diode branch is 20V independent of 10Ω resistance. Therefore, the diode conducts. [20 – 20*I - 0.7 =0]
   I = (20-0.7)/20 = 19.3/20 =0.965A
c) The two diodes are in opposition and cannot conduct (open circuit).Thus, I = -10/10 = -1A (shown in Fig.7d)

Problem Q8: For the diode circuits of Fig.8 , determine I_D and V_O using approximate model of the diode.

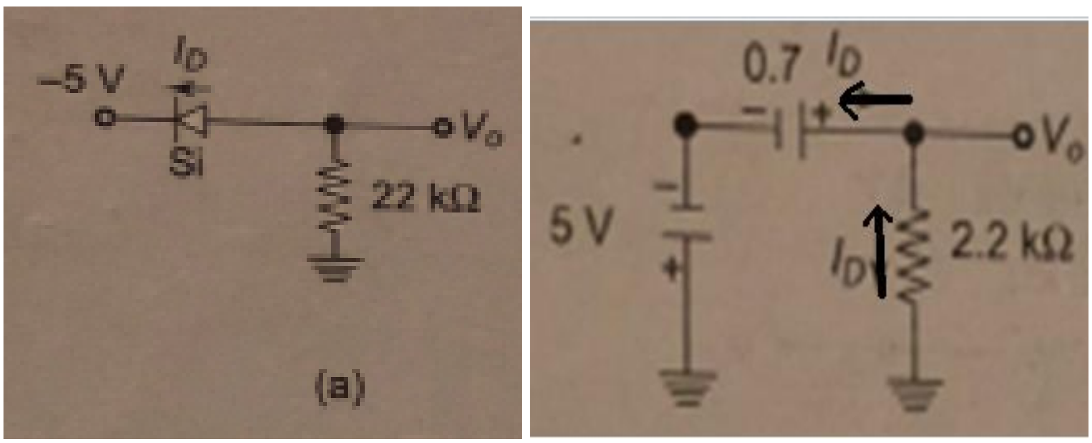


Fig.8

The equivalent circuit is drawn, shown in Fig.8b.
Apply KVL i.e $5+2.2K*I_D-0.7=0$
$I_D = (5-0.7)/2.2K = 4.3/2.2 = 1.95mA$
$V_O = -2.2*I_D = -2.2 X(4.3/2.2) = -4.3$ V
or directly, $V_O = -5+0.7 = -4.3V$

Problem Q9: For the diode circuits of Fig.9 , determine I_D and V_O using approximate model of the diode.

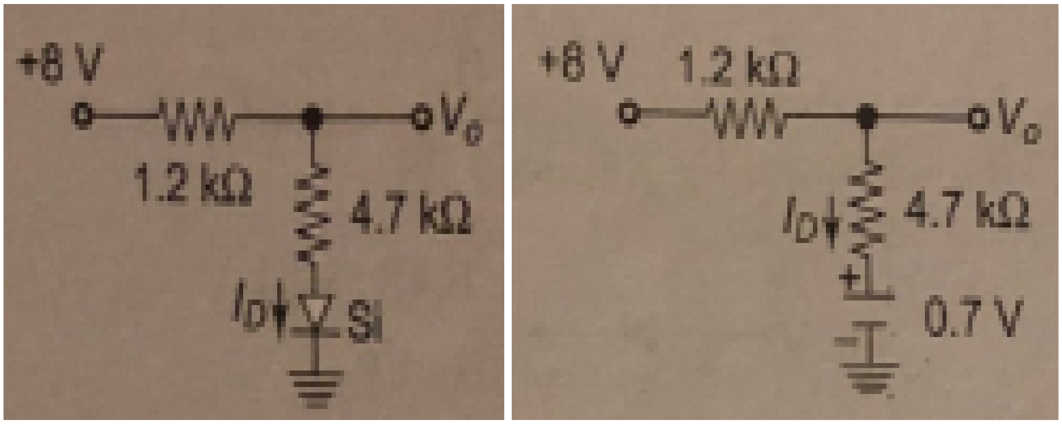


Fig.9

The equivalent circuit is drawn, shown in Fig.9b
I_D = (8-0.7)/(1.2K+4.7K) = 7.3/5.9 =1.237mA
V_O = 4.7K*I_D + 0.7 = 4.7X1.237 + 0.7 = 6.51 V

Problem Q10: For the diode circuits of Fig.10 , determine I_D and V_O

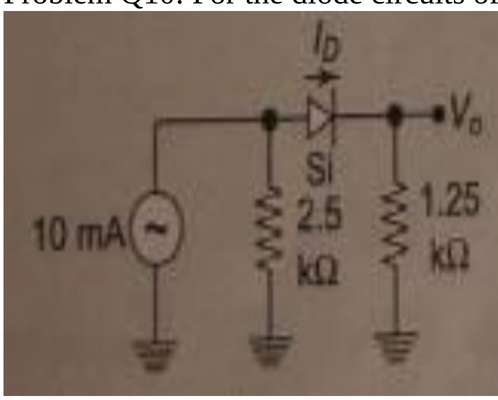


Fig.10(a)

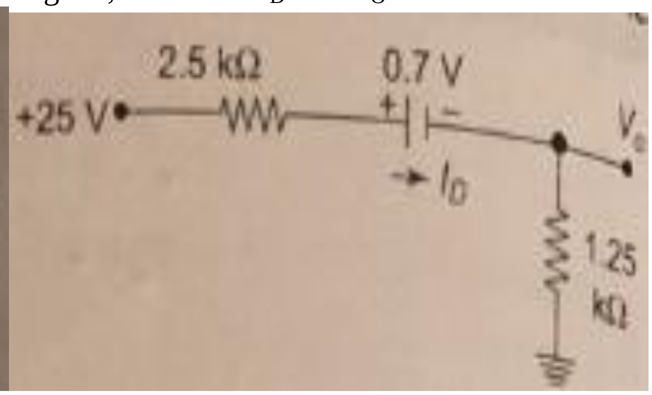


Fig.10(b)

Soln: Converting current source to voltage source and diode by its circuit model shown in Fig.10b.
I_D = (25-0.7)/(2.5+1.25) = 6.48mA
V_O = 1.25*I_D = 1.25X6.48 = 8.1 V

Problem Q11: For the diode circuits of Fig.11, determine I_D and V_O.

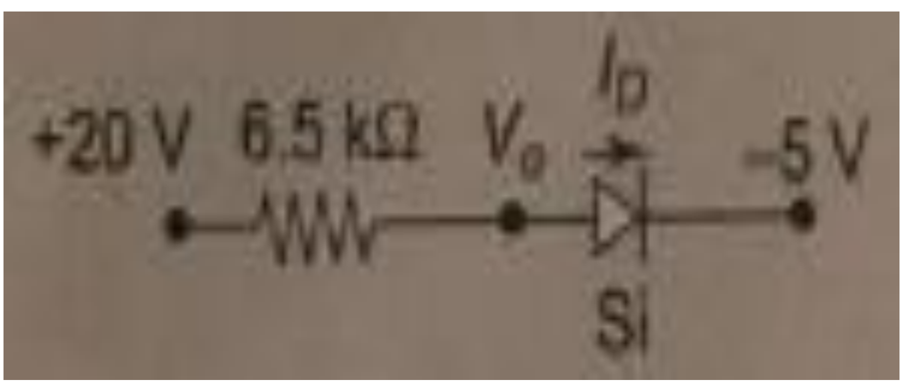


Fig.11

Soln: Apply KVL i.e $20=6.5K*I_D +0.7 -5$
$I_D = (20-0.7+5)/(6.5K) = 3.738mA$
$V_O = 20-3.738 X 6.5 = -4.3$ V
or $V_O = -5 + 0.7= -4.3$ V

Problem Q12: For the network of Fig.12 , determine V_{O1} V_{O2} and I_D .

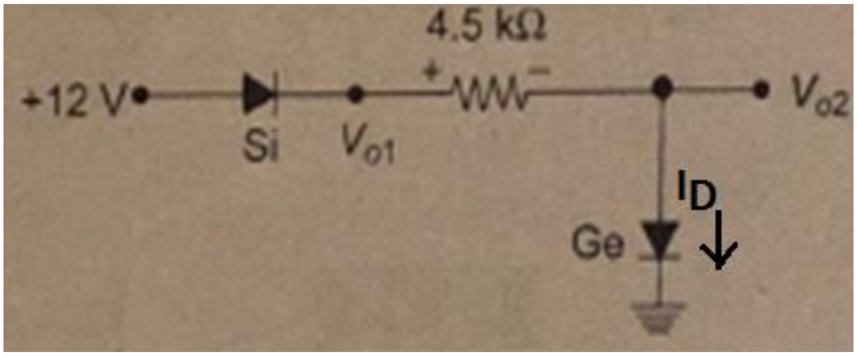


Fig.12
Soln: $V_{O1} = 12 – 0.7 =11.3V$
$V_{O2} = 0.3V$ when conducting
$I_D = (11.3-0.3)/4.5K =2.44mA$

Problem Q13: For the diode network of Fig.13 , determine V_O .

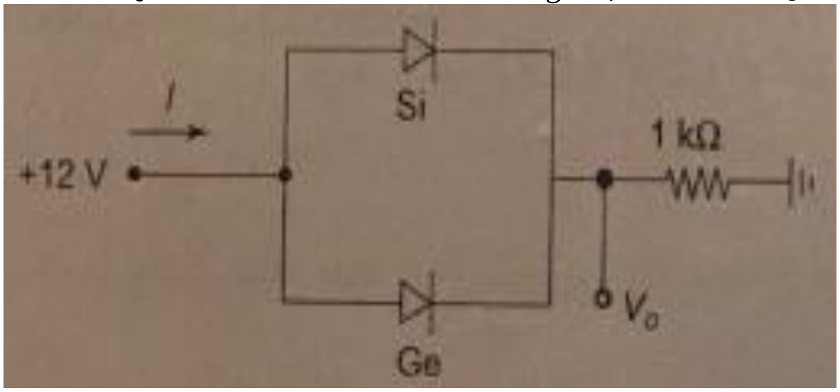


Fig.13
Soln: Diode Ge conducts, holding voltage at V_F =0.3V.
Therefore, diode Si does not conduct as its V_F =0.7V.
I = (12-0.3)/1K = 11.7mA ;V_O = 1 X 11.7 = 11.7V.

Problem Q14: For the diode network of Fig.14 , determine I_D and V_O
Soln: Converting current source to voltage source and diode by its circuit model shown in Fig.14b
$I_D = (4.4-0.7)/(2.2K+1.2K) = 1.08mA$
$V_O = 1.2K*I_D = 1.2K X 1.08m = 1.30$ V

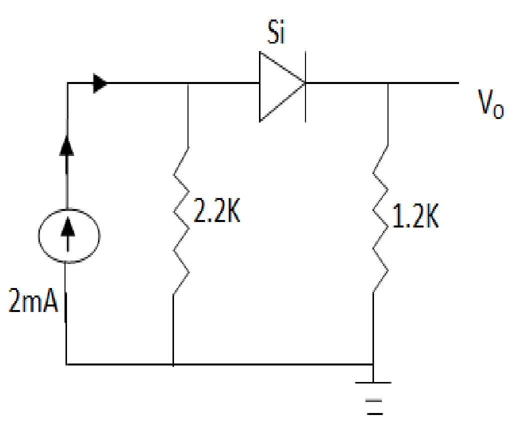


Fig.14(a)

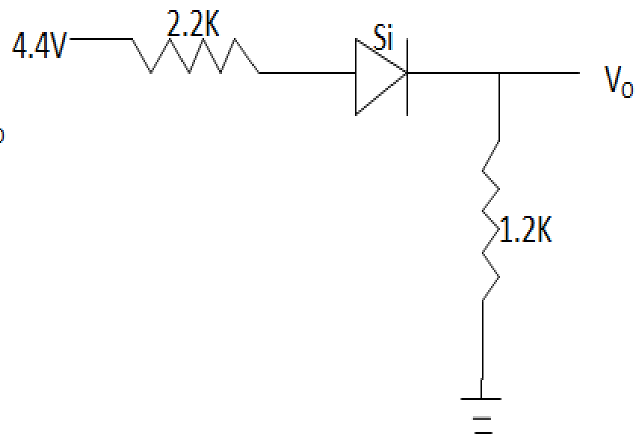


Fig.14(b)

Problem Q15: For the diode network of Fig.15 , determine I_D and V_O

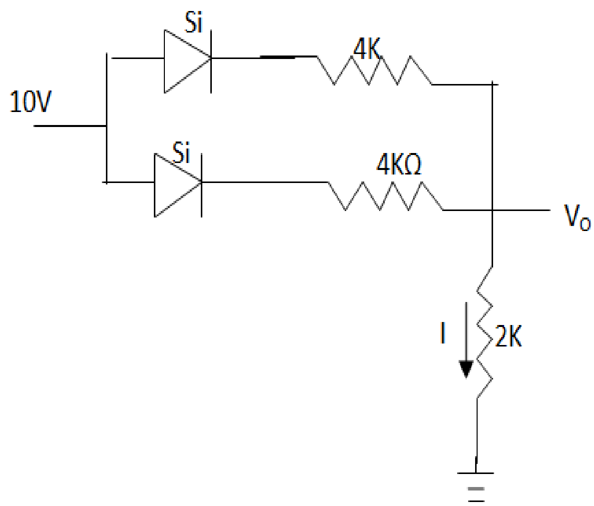


Fig.15(a)

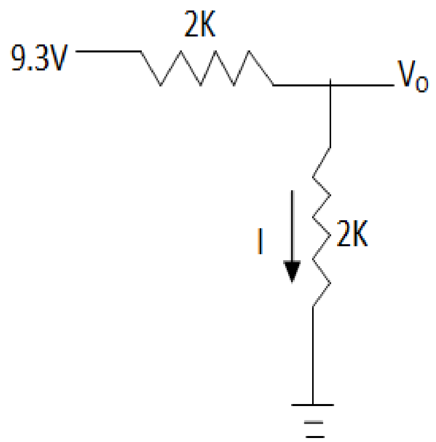


Fig.15(b)

Soln: The equivalent circuit is drawn, shown in Fig.15b

I = (9.3)/(4K) = 2.325mA

V_O = 2K*I_D = 2K X 2.32m = 4.65 V

Problem Q16: For the diode network of Fig.16 , determine I_1, I_2 and V_O

Soln: I_1 =(9-4.4)/2.2K =2.09mA

I_2 =(3-(-6))/(4.7K+3.3K) =1.125mA

V_O= (3.3K * 1.125mA) – 6 = -2.28V

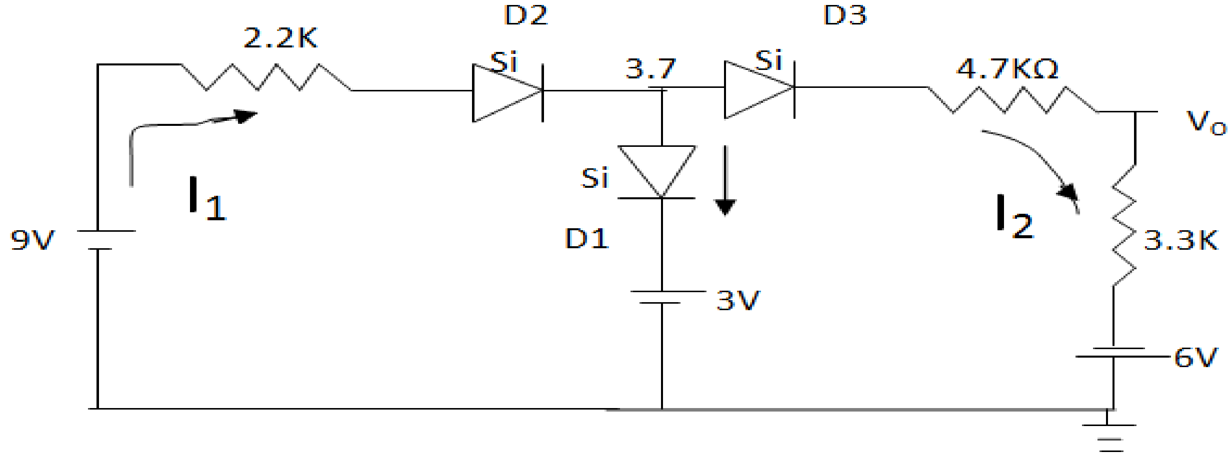
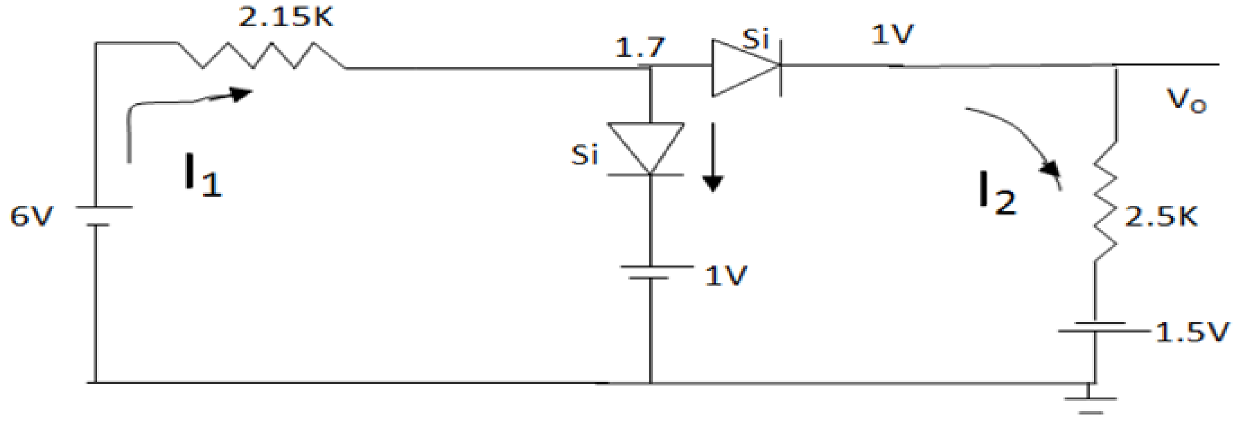


Fig.16

Problem Q17: For the diode network of Fig.17 , determine I_1, I_2 and V_O

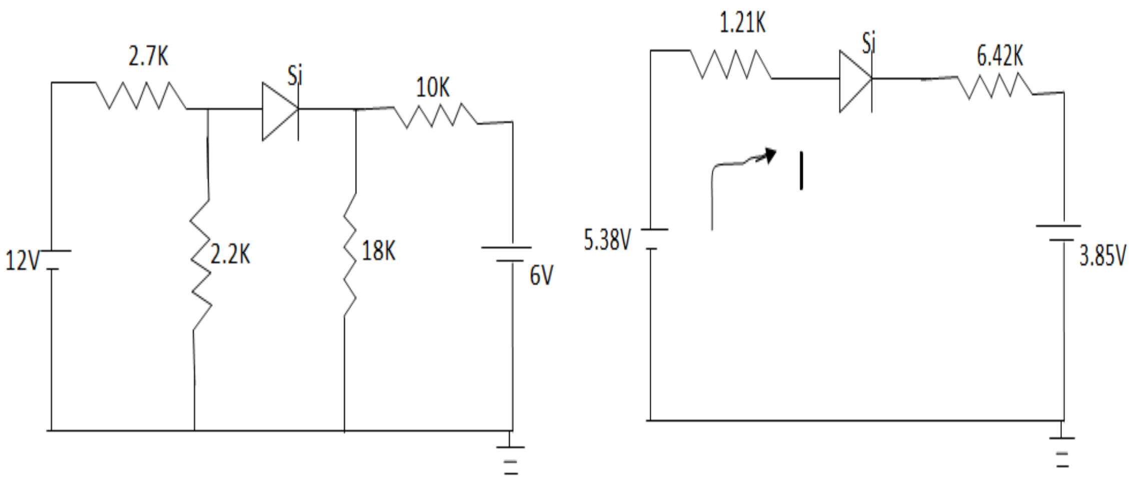


Soln: I_1 =(6-1.7)/2.15K =2mA

I_2 =(1-(-1.5))/2.5K =1mA

V_O= (2.5K * 1mA) - 1.5 = 1V

Problem Q17: For the diode network of Fig.17 , determine I.



Soln: V_{th} =(12*2.2K)/(2.2K+2.7K)=5.38V
R_{th}=(2.2K*2.7K)/(2.2K+2.7K) =1.21K
V_{th} =(6*18K)/(18K+10K)=3.85V
R_{th}=(10K*18K)/(10K+18K) =6.42K
The equivalent circuit is drawn, shown in Fig.14b
5.38-1.2K*I -0.7 -6.4K*I -3.85 =0; 5.38-3.85 =7.63*I; I =1.53/7.63=0.2mA.

Problem Q18: Determine V_O for the positive logic AND gate.

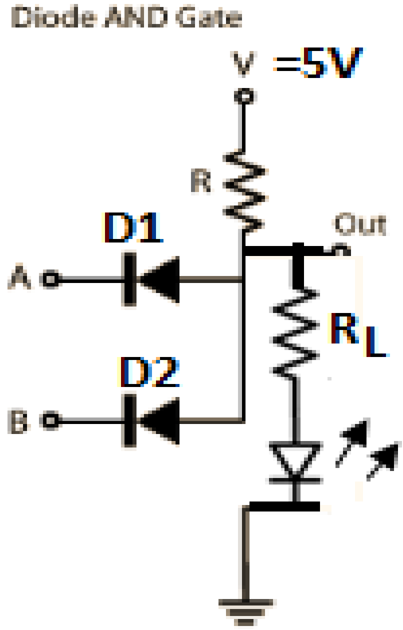


Fig.18

Case 1: When A=0V & B=0V, the cathode of each diode is grounded. Therefore, the positive supply V forward biases both diodes in parallel. The output voltage "out" is low.
Case 2: A is low & B is high. Since A is low, the diode D1 is forward biased, pulling the output down to a low voltage, with the B input HIGH, the diode D2 gets reverse biased, & therefore the output "out" is low.
Case 3: A is HIGH & B is low. Because of symmetry of the circuit, the circuit operation is similar to case 2. The diode D2 is ON & D1 OFF, hence the output "out" is low
Case 4: A is HIGH & B is HIGH. In this case both diodes are reverse biased. Hence there is no current through R & the output is pulled up to the supply voltage. Therefore, the output, "out" is HIGH.

Problem Q19: Determine V_O for the positive logic OR gate.
Case 1: When A=0V & B=0V, The output voltage "Y" is low. In this case both diodes are non-conducting. Hence Y is low.
Case 2: A is low & B is high. The high B input forward biases the diode D2 producing an output voltage +5V provided the diodes are ideal. If we consider the voltage drop across the diode (0.7V), then the output voltage produced is +4.3V.

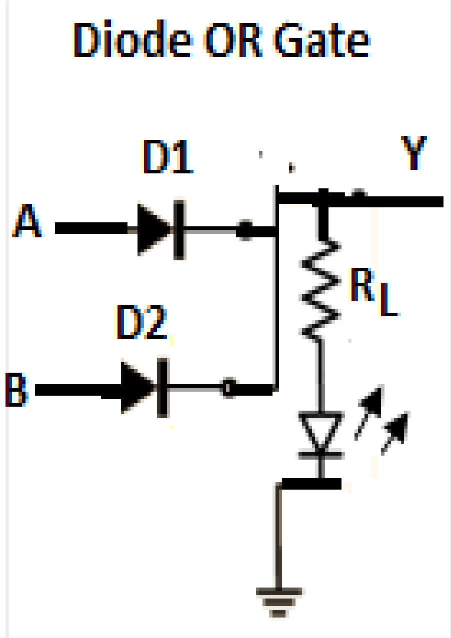


Fig.19

Case 3: When A=5V & B=0V, In this case the diode D1 is ON, & the diode D2 is OFF. Because of symmetry of the circuit, the circuit operation is similar to case 2. hence the output, Y is high.

Case 4: A= +5V & B =+5V with both inputs at +5V both diodes D1 & D2 are forward biased. The input voltages are parallel and therefore output voltage is +5V.

1.7.3 Piecewise Linear Characteristics

a) When the forward characteristics of a diode is not available, a straight line approximation called piecewise linear characteristics may be employed.

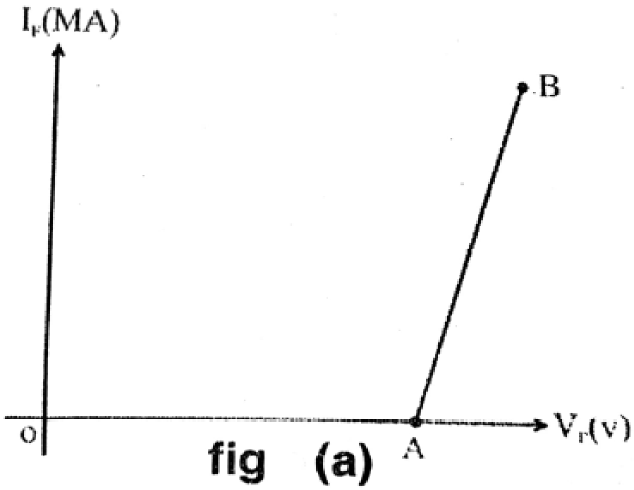
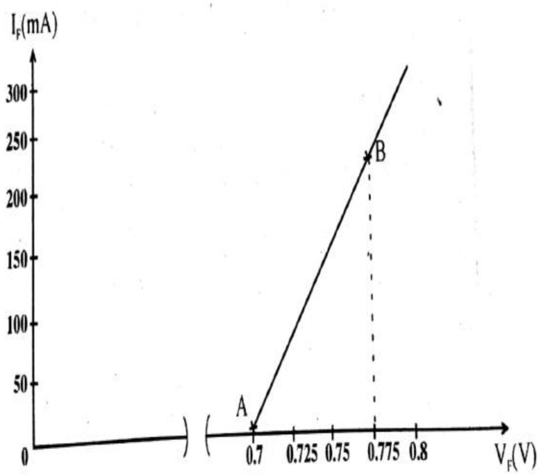


Fig.20

b) To construct piece wise linear characteristics, V_F is first marked on the horizontal axis. Then starting at V_F, straight line is drawn with a slope is equal to diode dynamic resistance. The advantage of this approach is that calculation becomes much simpler.

Problem 20: Plot the piecewise-linear characteristic of a silicon diode with a dynamic resistance of 0.3Ω and a maximum forward current of 250mA.

Soln=$r_d=\Delta V_F/\Delta I_F$;$\Delta I_F$=250mA
ΔV_F = r_d X ΔI_F =0.075V.
V_F = V_F + ΔV_F =0.7+0.075 V_F =0.775V(At point B)
V_F =0.7V(At point A). Join AB. (Shown in Fig.21)



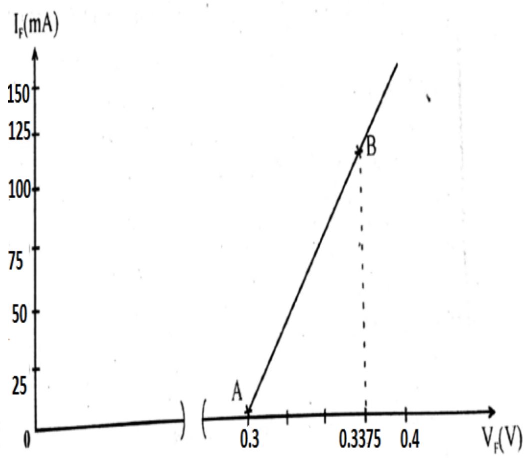


Fig.21 **Fig.22**

Problem 21: obtain the piecewise linear characteristic of a germanium diode with a dynamic resistance of 0.3Ω and maximum forward current of 125mA

Soln= $r_d=\Delta V_F/\Delta I_F$;$\Delta I_F$ =125mA
ΔV_F = r_d X ΔI_F = 0.0375V.
V_F = V_F + ΔV_F =0.3+0.0375 V_F =0.3375V(At point B)
V_F =0.3V(At point A). Join AB. (Shown in Fig.22)

1.8 DC Equivalent circuit of a diode

An equivalent circuit for a device is a circuit that represents the device behavior. It is made up of a number of components such as resistors & voltage cells.

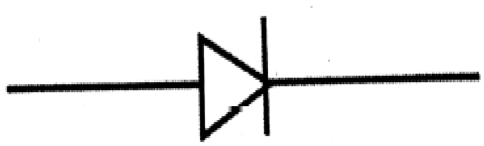


Fig.23(a)

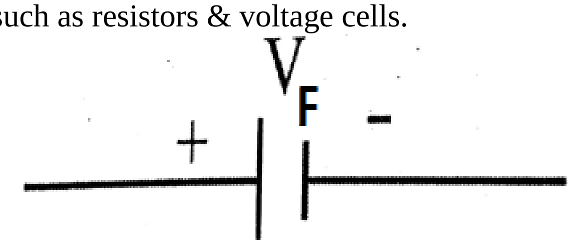


Fig.23(b)

A forward biased diode (Fig.23a) is assumed to have a constant forward voltage drop (V_F) & negligible series resistance. In this case, the dc equivalent circuit is assumed to be a voltage cell with a voltage V_F (Fig.23b).
The diode dynamic resistance (r_d) in series with the voltage cell, as shown in Fig.23c. This takes account of small variation in V_F that occurs with change in forward

current. An ideal diode is also included to show that current flows only in one direction.

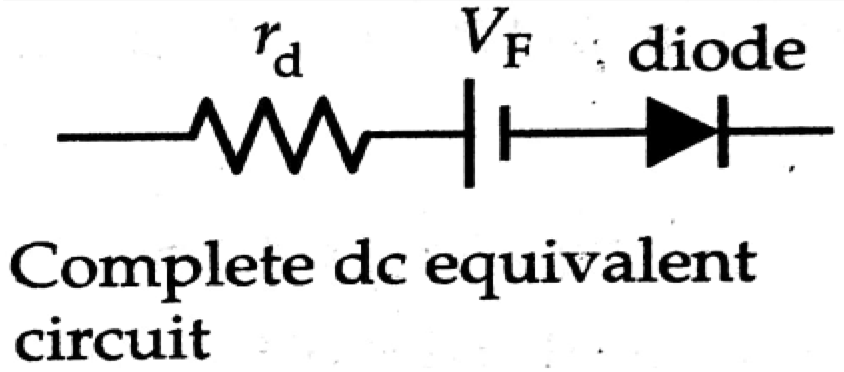


Fig.23(c)

Problem 22: Calculate I_F for the diode circuit in Fig.24a assuming that the diode has V_F=0.7V and r_d=0. Then recalculate the current taking r_d=0.25Ω.

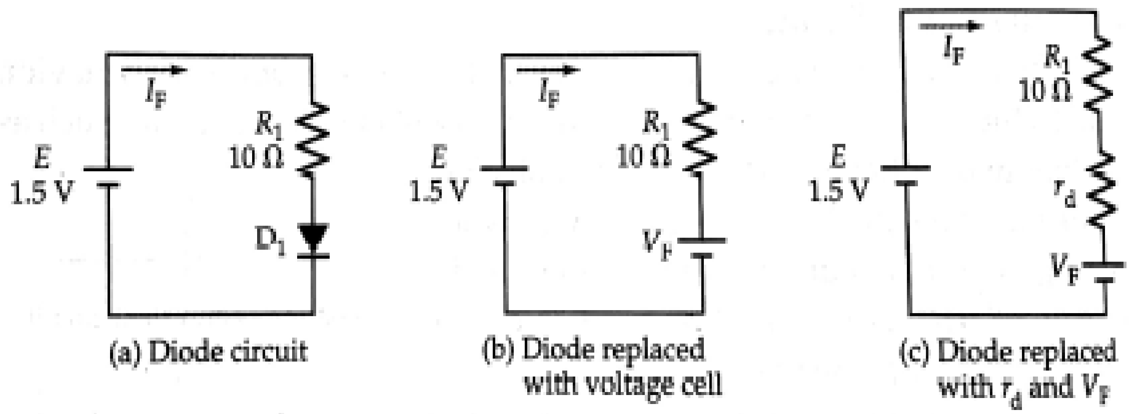


Fig.24

Soln: Substituting V_F as the diode equivalent circuit shown in Fig.24b.

$I_F = (E-V_F)/R_1 = (1.5-0.7)/10\Omega = 80mA$

Substituting V_F and r_d as the diode equivalent circuit shown in Fig.24c.

$I_F = (E-V_F)/(R_1+ r_d)= (1.5-0.7)/(10\Omega+0.25\Omega) = 78mA$

1.9 AC Equivalent circuit of a diode

1.9.1 Capacitance effects in a p-n junction

1. The depletion layer capacitance or transition capacitance which occurs at the junction of a reverse biased diode
2. The diffusion capacitance which occurs at the junction of a forward- biased diode.

1.9.1.1 Ac equivalent circuits (Reverse –Biased)

A reverse biased diode can be simply represented by the reverse resistance R_R in parallel with the depletion layer capacitance C_{pn}.(Fig.25)

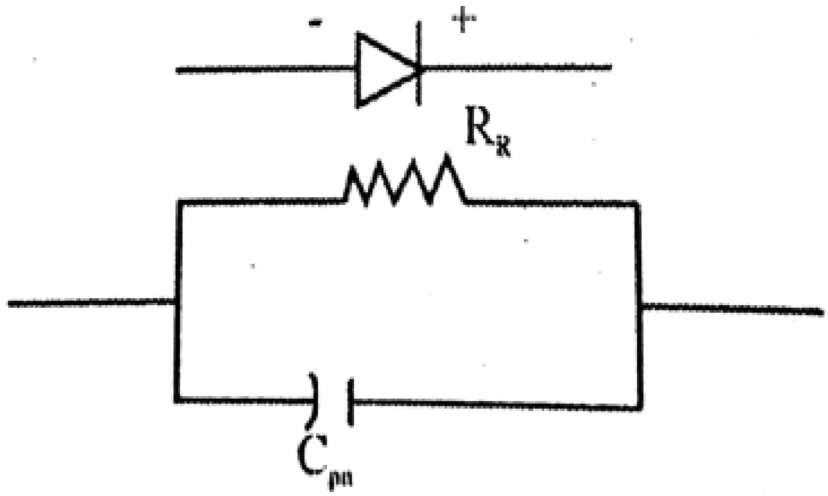


Fig.25

Depletion layer capacitance

- When a diode is reverse biased the depletion region around the junction behaves like a di-electric as this region is free of carriers.
- Further, the width of the depletion region increases with increase in reverse bias voltage.
- WKT a dielectric between 2 conducting plates acts as a capacitor given by,

C = (εA)/d -------(1)

The Depletion layer capacitance, C_{Pn} can be calculated using the equation of a parallel plate capacitor as given in equation (1).

1.9.1.2 ac equivalent circuits (Forward –Biased)

Forward biased diode consists of dynamic resistance r_d in series with a voltage cell representing V_F. To allow for the effect of diffusion capacitance, C_d is included in parallel. (Fig.26a)

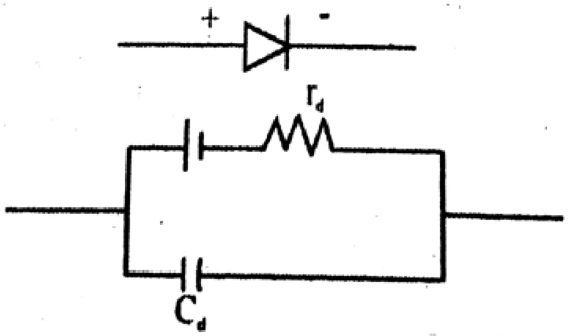


Fig.26(a)

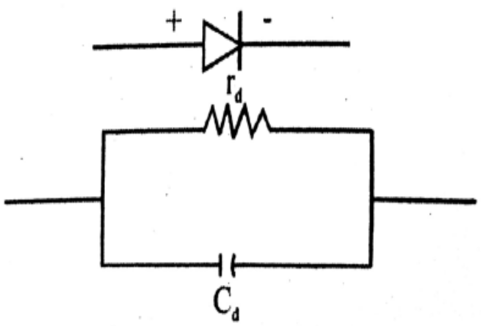


Fig.26(b)

The ac equivalent circuit is created by removing the voltage cell V_F from the complete equivalent circuit.(Fig.26b)

Diffusion capacitance

- When the voltage applied to a forward biased p-n junction is suddenly reversed, a large reverse current initially flows, which decreases gradually to the reverse saturation value of the current.
- The effect is similar to that of the discharge of a capacitor and is represented by a capacitance called diffusion capacitance, C_d.
- Thus, Diffusion capacitance is defined as the incremental capacitance given by the rate of change of injected charge with voltage i.e $C_d = dQ/dV$ -------(2)

1.20 Temperature effects on the power dissipation

The power dissipation in a diode is simply calculated as the device terminal voltage multiplied by the current level.

$P = V_F I_F$ -------(3)

Device manufacturers specify a maximum power dissipation for each type of diode. If the specified level is exceeded, the device will over heat and may short circuit or open circuit.

The maximum power that may be dissipated in a diode is normally specified for an ambient temperature of 25^0C.

Figure 27 shows the type of power versus temperature graph, then the maximum forward current level is calculated from equation ----(3).

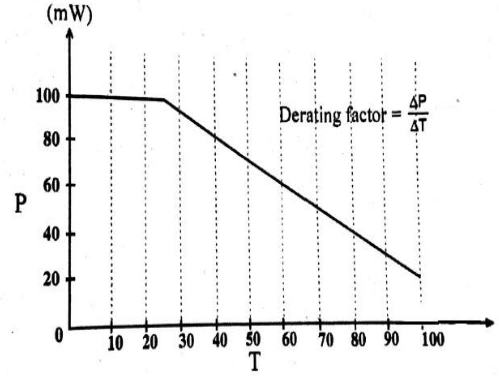


Fig.27

The derating factor defines the slope of the power versus temperature graph.

The equation for the maximum power dissipation when the temperature changes involves the specified power at the specified temperature (P_1 at T_1), the derating factor (D), and the temperature change (ΔT).

$P_2 = (P_1 \text{ at } T_1) – (D \text{ X } \Delta T)$ ------(4)

Problem 23:A diode maximum power dissipation at 25°C is 5W and the derating factor is 20mW/°C. what is the maximum power dissipation at 60°C.

Soln:

$P_2 = (P_1 \text{ at } T_1) – (D \times \Delta T)$ ------(4)

P_2=5-[(60-25)*20mW]
P_2=4.3W.

Problem 24:Find the maximum forward current at 25^0C and 75^0C of a diode with 500mW maximum power dissipation at 25^0C and a derating factor of 5mW/^{0}C, Assume that the forward voltage drop remains constant at 0.6V.
Soln: $P_1 = V_1 I_1$
When V_1 = forward voltage drop at $T_1{}^0$C and
I_1 = forward current at $T_1{}^0$C
$I_1 = P_1/V_1$ = 500mW/0.6V =0.5W/0.6 = 0.833A
$P_2 = (P_1 \text{ at } T_1) – (D \times \Delta T)$ ------(4)
P_2 = 500 – (75-25)5 = 250mW
$I_2 = P_2/V_2$ = 250mW/0.6V = 0.416A.

Problem 25:The power-temperature curve for a diode with a constant 0.65V forward voltage drop is shown in Fig 9. Find the maximum forward current at temperature at 25^0C.
Soln: $V_1 = V_2$ =0.65V
From the given power-temp curve.
P_1 =80mW
P_2=30mW
$I_1 = P_1/V_1$ = 80mW/0.65V =123mA
$I_2 = P_2/V_2$ = 30mW/0.65V = 46mA

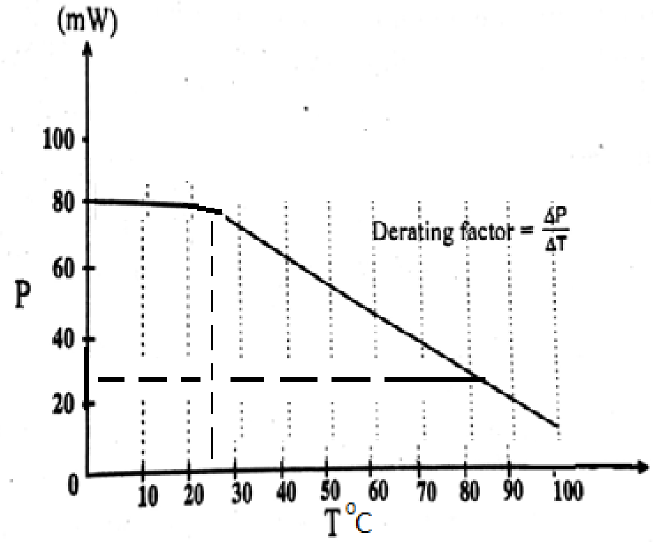


Fig.28

Problem 26:Find the maximum temperature at which a diode with a maximum power dissipation of 1000mW at 25^0C can withstand an average forward current of 500mA.Assume a forward voltage drop of 0.8V & power derating factor of 10mW/^{0}C.

b) Find the maximum forward current at 75^0C.

Soln: T_1 = 25^0C T_2 =? P_1 = 1000mW ; $I_1 = I_2$ =500mA

$V_1 = V_2 = 0.8V$ & $D = 10mW/^0C$
$P_2 = V_2 I_2 = 0.8 * 500mA = 400mW$
$P_2 = (P_1 \text{ at } T_1) - (D \text{ X } \Delta T)$ ------(4)
400 1000 – $(T_2$-25)10
b)Find the maximum forward current at 75^0C

Soln: $(T_2-25) = (1000-400)/10 = 60$;$(T_2-25)=60$;$T_2 = 85^0C$
$T_1 = 25^0C$, $T_2 = 75^0C$, $P_1 = 1000mW$,D= $10mW/^0C$
$P_2 = (P_1 \text{ at } T_1) - (D \text{ X } \Delta T)$ ------(4)
$P_2 = 1000 - (75-25)10 = 500mW$

1.21 Temperature effects on the Forward voltage drop

$V_{F2} = (V_{F1} \text{ at } T_1) + [(\Delta T \text{ X}(\Delta V_F/^0C)]$------(5)
The voltage drop across a forward biased p-n junction changes with temperature by approximately -1.8mv/^{0}C for Si diode and by -2.02mv/^{0}C.

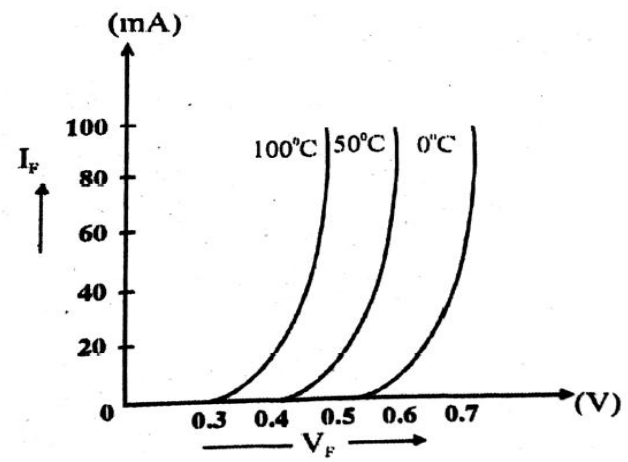


Fig.29

1.22 Temperature effects on Dynamic Resistance

The dynamic resistance of a forward biased diode can be obtained by applying the following equation for Temperature at 25^0C.
$r_d = 26mV / I_F$ ---- (A)
For higher temperature, the equation is
$r'_d = 26mV / I_F [(T+273^0C)/298^0K]$---- (6)
T is the junction temperature in degree Celsius.
Note: As temperature, V_T increases & therefore dynamic forward resistance increases.

Problem 27: It is required to operate a silicon diode with a forward voltage drop of 0.6V at 25^0C with a constant forward current up to 100^0C.
Find a) Forward voltage drop at 100^0C
b) Dynamic resistance at 25^0C & 100^0C if the forward current is kept constant at 26mA.

Soln: $V_{F2} = V_{F1} + (T_2 - T_1)V$; $V_{F1} = 0.6V$

V_{F2} = (V_{F1} at T_1) +[(ΔT X(Δ V_F/^{0}C)]------(5)
V_{F2} = 600 +[(100-25) X(-1.8)]= 465mV

b)Dynamic resistance at 25^{0}C & 100^{0}C if the forward current is kept constant at 26mA.
r'_d =26/I_F [(T + 273)/298]Ω
T=25^{0}C
r'_d =26/26 [(25 + 273)/298] =1Ω
T=100^{0}C
r'_d =26/26 [(100 + 273)/298] =1.25Ω

1.23 Zener Diode

Zener diode is a silicon p-n junction semiconductor device, which is generally operate in its reverse breakdown region.

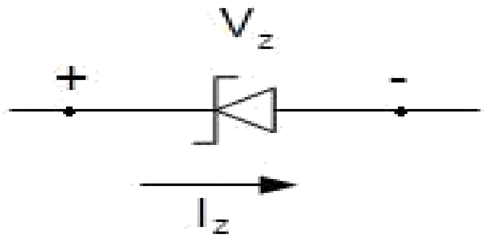


Fig.30

- Junction breakdown: There are two types of breakdown in a reverse biased pn junction.

a) Zener Breakdown
b) Avalanche breakdown

Differences between Zener and Avalanche breakdown

Sl No	Zener breakdown	Avalanche breakdown
1.	Breakdown occurs for zener diode with Vz<6V	Breakdown occurs for zener diode with Vz>6V
2.	Temperature coefficient is negative	Temperature coefficient is positive
3.	Breakdown occurs due to high electric field	Breakdown occurs due to high kinetic energy
4.	The VI curve is very sharp.	The VI curve is not as sharp as zener.

1.24 Zener Diode as voltage regulator

1.24.1 **Regulator circuit with no load**

The resistor R_1 limits the zener diode current to the desired level. I_Z is calculated as (shown in Fig.31) follows: $I_Z = (E_S - V_Z)/R_1$ -----(1)
The zener current may be just greater than the diode knee current (I_{ZK}).

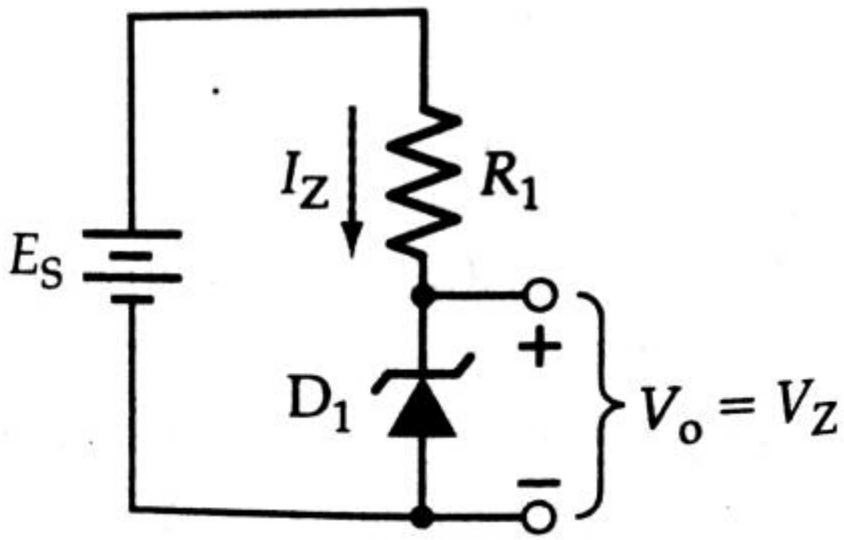


Fig.31 : Regulator ckt without load

Problem 28: A 9.1V reference source is to be designed using a series connected zener diode & resistor connected to a 30V supply. Calculate the circuit current when the supply voltage drops to 27V. Given I_{ZT} =20mA.

Soln: Given E_S =30V, V_Z =9.1V and I_Z =20mA
$R_1 = (E_S - V_Z)/I_Z$ = (30-9.1)/20mA =1.05KΩ =1KΩ
$P_{R1} = I_1^2 R_1 = (20mA)^2 * 1KΩ$ =0.4W
When E_S = 27V
$I_Z = (E_S - V_Z)/R_1$ = (27-9.1)/1KΩ =17.9mA

Problem 29: Design a 12V dc reference source (consisting of a zener diode & series connected resistor) to operate from a 25V supply. Determine the effect on the diode current when supply drops to 22V. Given I_{ZT} =20mA.

Soln: Given E_S =25V, V_Z =12V and I_Z =20mA
$R_1 = (E_S - V_Z)/I_Z$ = (25-12)/20mA =650Ω
$P_{R1} = I_1^2 R_1 = (20mA)^2 * 650$ =0.260W
When E_S = 22V
$I_Z = (E_S - V_Z)/R_1$ = (22-12)/680=14.7mA

1.24.2 Regulator circuit with load

- When a zener diode regulator is required to supply a load current, the total supply current (flowing through resistor R_1) is the sum of I_L & I_Z.(shown in Fig.32)
- The minimum zener diode current should be large enough to keep the diode in reverse breakdown.
- The circuit current equation is

$I_Z+I_L = (E_S-V_Z)/R_1$ -----(2)

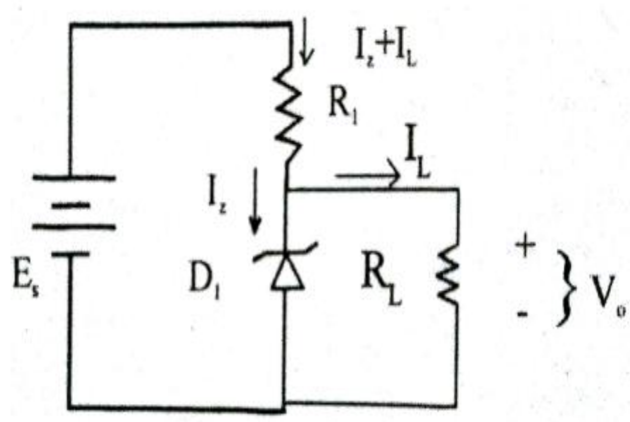


Fig.32

Problem 30: Design a 6.2V dc reference source to operate from a 16V supply. The circuit is to use a low-power zener diode and is to produce maximum possible load current. Calculate the maximum load current that can be produced by the circuit. Given P_D=400mW.

Soln: $I_{ZM} = P_D/V_Z$ = 400mW/6.2V =64.5mA
$I_{L(max)}+I_{Z(min)} = I_{ZM}$ =64.5mA
$R_1 = (E_S-V_Z)/I_{ZM}$ = (16-6.2)/64.5mA =152Ω

Problem 31: An 8V dc reference source is to be designed to produce the maximum possible output current from a low-power Zener diode. The supply voltage is 20V. Design the circuit & determine the maximum load current. Given P_D =400mW.

Soln: $I_{ZM} = P_D/V_Z$ = 400mW/8V =50mA
$I_{L(max)}+I_{Z(min)} = I_{ZM}$ =50mA
$R_1 = (E_S-V_Z)/I_{ZM}$ = (20-8)/50mA =240Ω

$P_{R1} = I_1^2 R_1 = (50mA)^2 * 240$ =0.6W.

1.24.3 Regulation with varying input voltage: (shown in Fig.33)

- From the above figure $V_0 = V_Z$= constant. $I_L = V_0/R_L=V_Z/R_L$= constant. We can write $I=I_L+I_Z$.

- If we increase input voltage V_{in} then the current I increases, but WKT current through the load is constant. Hence current through Zener increases to keep I_L constant.
- As long as I_Z is in between $I_{Z(min)}$ and $I_{Z(max)}$ the V_Z i.e. the output voltage V_0 is constant i.e. how the change in input voltage is getting compensated and constant output is maintained.
- When V_{in} decreases the current I decrease. But WKT the current through load is constant, the current through zener decreases. Iz will be in between $I_{z(max)}$ to $I_{z(min)}$ to keep the output voltage constant.

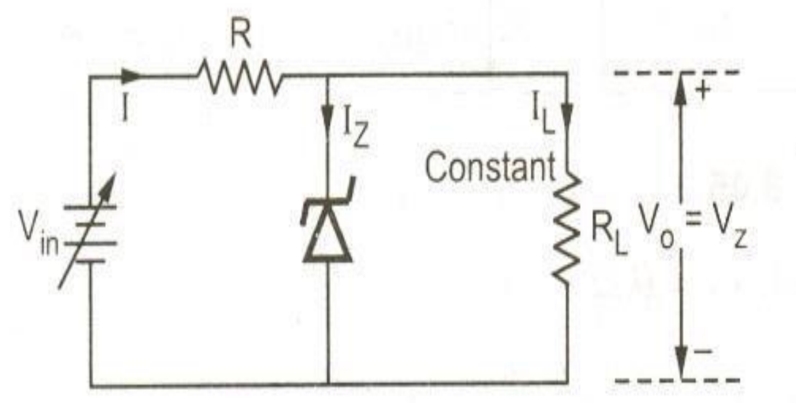


Fig 33: Varying input condition

Problem 32: Determine the range of V_{in} in which the zener diode of Fig. 34 Conducts.

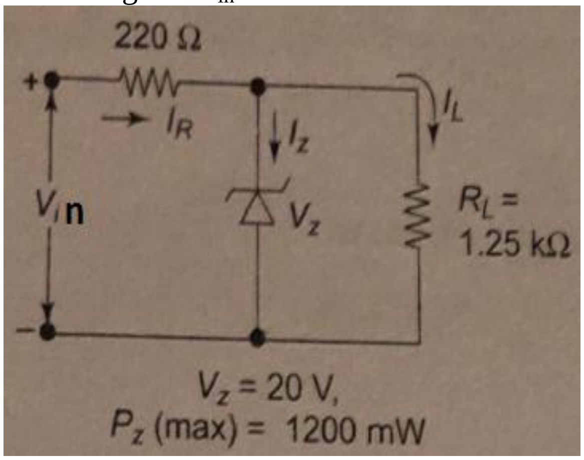


Fig.34

a) V_Z just in conducting state

V_Z =20V, I_Z =0

I_R=I_L =V_Z/R_L = V_L/R_L =20/1.25 =16mA

$V_{in(min)}$ =20+220 X 16mA =23.52V

b) I_Z=$I_{Z(max)}$ = P_D/V_Z = 1200/20 =60mA

I_L=16mA

I_R=I_Z+I_L = 60mA + 16mA =76mA

$V_{in(max)}$ =20 + 220 X 76mA =36.72V

The input voltage V_{in} is ranging from $V_{in(min)}$ to $V_{in(max)}$ i.e from 23.52V to 36.72V.

1.24.4 Regulation with varying load (shown in Fig.35)

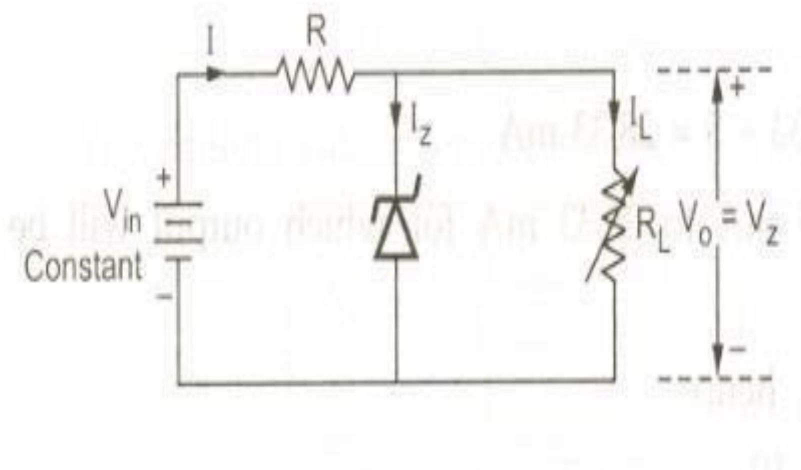


Fig.35

- In the above figure the input voltage V_{in} is kept constant whereas load is varying. Here V_{in} is constant and V_0 is also Constant.
- If R_L increases then current through load I_L decreases, to keep constant I, I_Z increases but as long as I_Z is in between $I_{Z(min)}$ and $I_{Z(max)}$ output voltage will be constant.
- If R_L decreases then current through load I_L increases, to keep constant I, I_Z decreases but as long as I_Z is in between $I_{Z(min)}$ and $I_{Z(max)}$ output voltage will be constant.

Problem 33: For Network of Fig.36 determine the range of $R_L < I_L$ that will result in V_{RL} being maintained at 10V. Also determine wattage rating of diode.

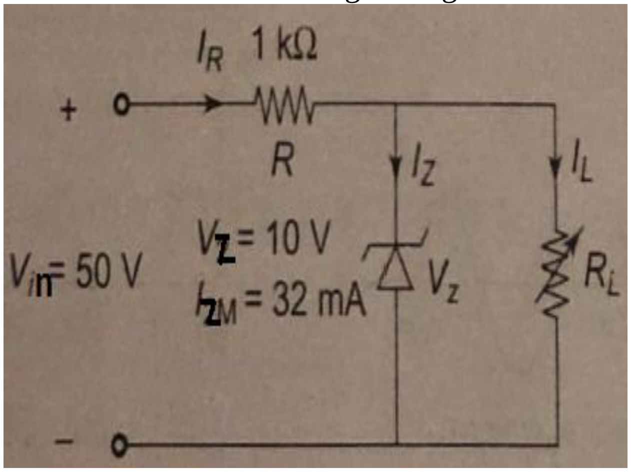


Fig.36

Soln: Value of R_L that will turn Zenerdiode on

R_{Lmin} =(R X V_Z)/(V_{in} –V_Z)
R_{Lmin} =(1000 X 10)/(50-10)=250Ω

- Voltage across R, i.e $V_R = V_{in} – V_Z$

V_R = 50-10 = 40V
$I_R = V_R/R$ =40/1000 =40mA
$I_{Lmin} = I_R – I_{ZM}$ = 40mA -32mA =8mA
$R_{Lmax} = V_Z/I_{Lmin} = V_L/I_{Lmin}$ = 10/8mA =1.2KΩ

- $P_{max} = V_Z$ X I_{ZM} = 10 x 32mA = 320mW
- **The laod resistance R_L is ranging from $R_{L(min)}$ to $R_{L(max)}$ i.e from** 250Ω **to** 1.2KΩ.

1.24.5 Design of Zener regulator when both Supply voltage and load are varying (Fig.37)

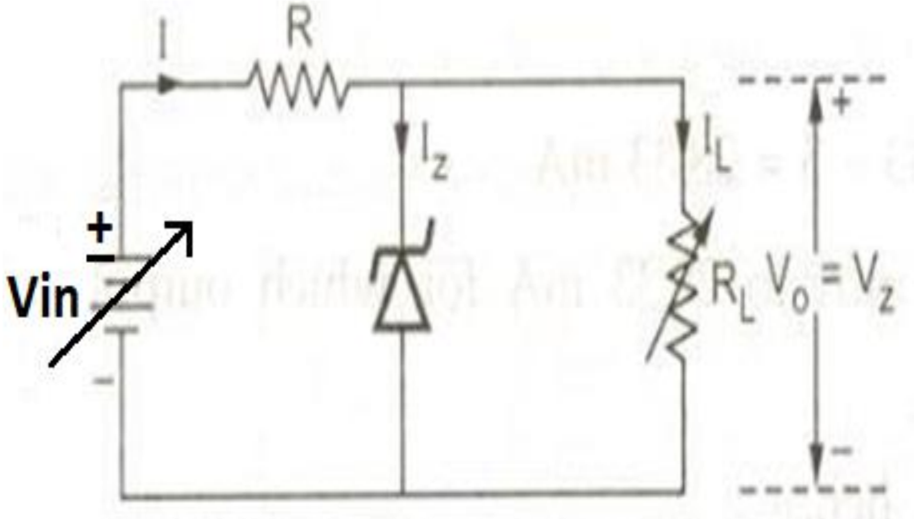


Fig:37

- In the above Fig.37 both input voltage Vin and load RL are varying.
- When we need to design a zener regulator, the parameters like R, V_{in} I_L has to be considered.
- Here V_{in} varies between $V_{in(min)}$ to $V_{in(max)}$ and the load current I_L varies from $I_{L(min)}$ to $I_{L\ (max)}$.
- The calculation of R should be such that zener should operate between $I_{Z(min)}$ and $I_{Z\ (max)}$.
- The current through zener must be more than $I_{Z(min)}$,where $I_{Z(min)}$ is the minimum zener current required to operate in the breakdown region.
- $[(V_{in(min)}- V_Z)/R]- I_{L\ (max)} > I_{Z(min)}$ -----------------------(1)
- Maximum zener current flows when $V_{in}= V_{in(max)}$ and $I_L = I_{L(min)}$.the current through zener must be less than $I_{Z\ (max)}$.where $I_{Z\ (max)}$ is the maximum allowable zener current for safe operation.
- $[(V_{in(max)} – V_Z)/R]- I_{L(min)} < I_{Z(max)}$ ---------------(2)
- Where $I_{Z(max)}=P_D/V_Z$
  P_D is the maximum allowable power dissipation in zener diode.

Problem 34: Design zener regulator for given specification. (Fig.38)

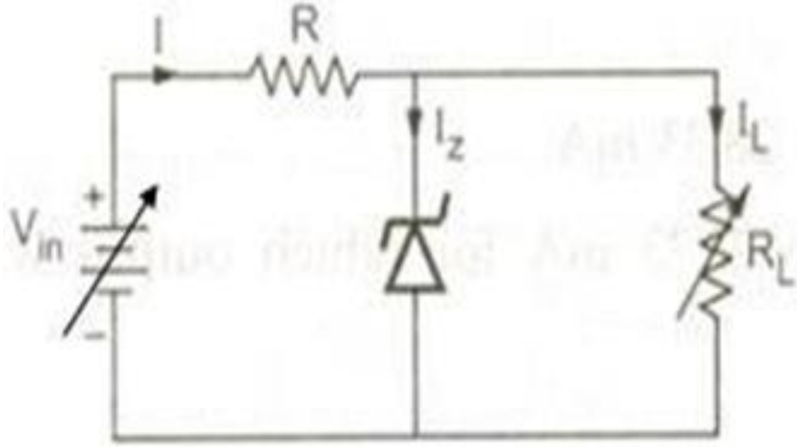
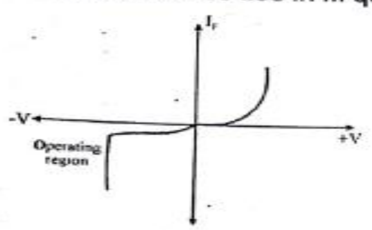
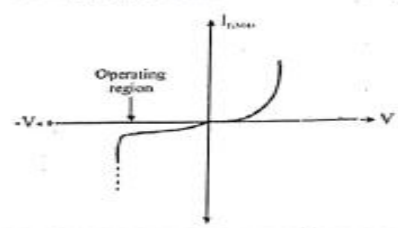


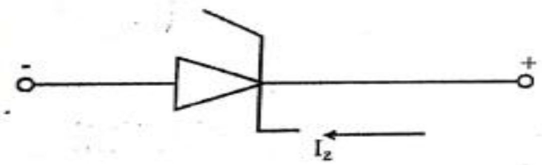
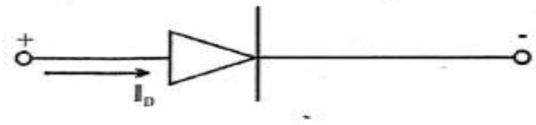
Fig.38

V_{in} varies from 12V to 18V
R_L varies from 225Ω to 1.8KΩ
V_Z=9V
I_Z(min)=10mA
$P_{d(max)}$=4.5W.

Soln: $I_{L(max)} = V_Z / R_{L(min)} = 40mA$
$I_{L(min)} = V_Z / R_{L(max)} = 5mA$
When V_{in}=12V
$[(V_{in(min)} - V_Z)/R] - I_{L(max)} > I_{Z(min)}$
(12-9)/R - 40mA>10mA ; 3/R=50mA; R<60Ω
When V_{in}=18V
$[(V_{in(max)} – V_Z)/R] - I_{L(min)} < I_{Z(max)}$
(15-9)/R - 5mA>500mA;6/R=505mA; R<11.88Ω
11.88Ω <R<60Ω

1.25 Compare Zener Diode & p-n junction diode

Zener diode	PN Junction diode
1. Operated in reverse breakdown con-dition	1. Operated in forward biased condition & never operated in reverse biased condition.
2. The Characteristics lies in III quadrant 	2. The characteristics lies in I quadrant 
3. Dynamic Zener resistance is very small in reverse breakdown condition	3. Diode resistance in reverse biased condition is v. high

Zener diode	PN Junction diode
4. Zener diode symbol is 	4. P - n Junction diode symbol is 
5. Conduction in zener is opposite to that of the arrow in symbol as operated in breakdown region	5. Conduction in p - n Junction diode is in same direction as that of arrow in symbol when forward biased
6. Power dissipation capability is very high	6. Power dissipation capability is very low
7. Zener diode will be available many voltage ranges ex : 3V, 5.6V, 8V, 11V	7. Pn Junction diode wi.: be availabe at only 0.7V
8. Application of Zener diode are voltage regulator, protection circuits, voltage limiters	8. Application of P - n Junction diode are rectifiers, voltage multipliers, clippers, clampers & many electronic devices

1.26 Rectifiers

A device which converts ac voltage in to dc voltage is called a rectifier or rectifier is an electrical device which offers a low resistance to the current in one direction but a high resistance to the current in opposite direction.

The following three rectifiers circuits can be used

1. Half-wave rectifier
2. Full-wave rectifier
3. Full-wave bridge rectifier

1.26.1 Half-wave rectifier

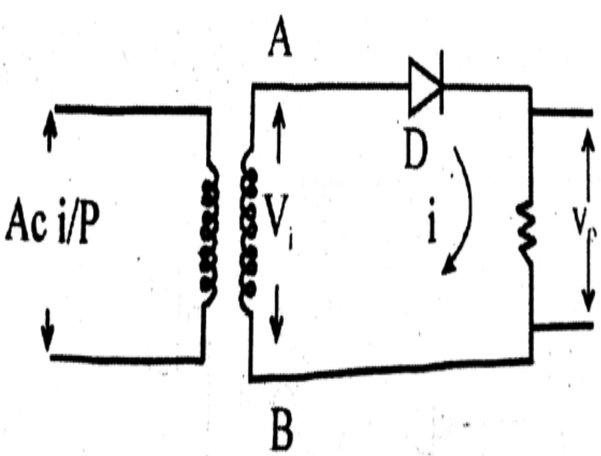


Fig.39 (a)

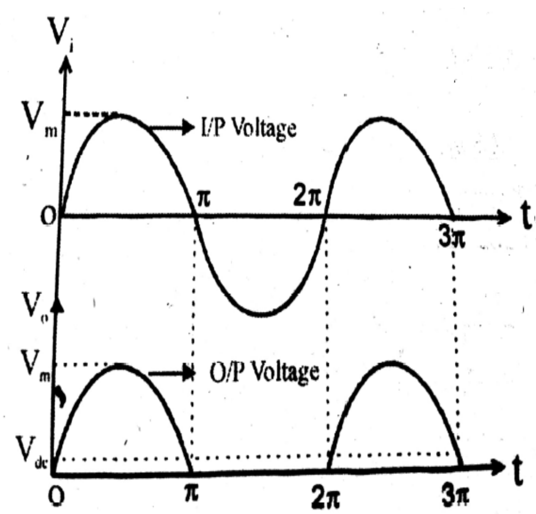


Fig.39(b)

In half wave rectification, the rectifier conducts current only during the positive half cycle of input a.c supply.

Operation:

- During the positive half-cycle of input a.c voltage, end A becomes positive with respect to end B. This makes the diode forward biased and hence it conducts current.
- During the negative half cycle, end A is negative with respect to end B. Under this condition, the diode is reverse biased and it conducts no current..
- Therefore, current flows through the diode during positive half cycle of input a.c voltage only and it is blocked during the negative half cycles.
- The output across the load is pulsating DC. These are further smoothened with the help of filter circuits.

- Let $V = V_m Sin\omega t = V_m Sin\theta$ be the instantaneous sinusoidal voltage appearing at the secondary winding of a transformer.
- During positive half cycle from 0 to π
  $i=I_m Sin\theta$ for $0<= \theta <= \pi$
- Similarly during negative half cycle from π to 2π
  $i =0$ for $\pi <= \theta<= 2\pi$
- The maximum load current is given by
  $I_m = V_m/ (R_F+R_S+R_L)$
- where R_F is forward resistance of a diode.
  R_S is transformer secondary resistance
  R_L is load resistance

1.26.1.1 DC or Average Current I_{DC}

$$I_{dc} = \frac{1}{2\pi}\int_0^{2\pi} i\,d(\omega t)$$

$$= \frac{1}{2\pi}\left[\int_0^{\pi} I_m \sin\omega t\, d(\omega t) + \int_{\pi}^{2\pi} .0.\,d(\omega t)\right]$$

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

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

$$= \frac{I_m}{\pi} \quad \text{(or)} \quad 0.318\ I_m$$

Substituting the value of I_m, we get $I_{dc} = \dfrac{V_m}{\pi \ \ R_f + R_L}$

If $R_L >> R_f$ then $I_{dc} = \dfrac{V_m}{\pi R_L} = 0.318\dfrac{V_m}{R_L}$

1.26.1.2 DC or Average Voltage V_{DC}

The average dc voltage is given by

$$V_{dc} = I_{dc} \times R_L = \frac{I_m}{\pi} \times R_L = \frac{V_m R_L}{\pi \; R_f + R_L}$$

$$\Rightarrow V_{dc} = \frac{V_m R_L}{\pi \; R_f + R_L}$$

If $R_L >> R_f$ then $V_{dc} = \frac{V_m}{\pi} = 0.318\ I_m$ $\quad \therefore V_{dc} = \frac{V_m}{\pi}$

1.26.1.3 RMS value of load current I_{rms}

The value of the R.M.S. current is given by

$$I_{rms} = \left[\frac{1}{2\pi} \int_0^{2\pi} i^2 d(\omega t) \right]^{\frac{1}{2}}$$

$$= \left[\frac{1}{2\pi} \int_0^{\pi} I_m^2 \sin^2 \omega t . d(\omega t) + \frac{1}{2\pi} \int_{\pi}^{2\pi} .0. d(\omega t) \right]^{\frac{1}{2}}$$

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

$$= \left[\frac{I_m^2}{4\pi} \left\{ (\omega t) - \frac{1}{2} \sin \omega t \right\}_0^{\pi} \right]^{\frac{1}{2}}$$

$$= \left[\frac{I_m^2}{4\pi} \left\{ (\omega t) - \frac{1}{2} \sin \omega t \right\}_0^{\pi} \right]^{\frac{1}{2}}$$

$$= \left[\frac{I_m^2}{4\pi} \left\{ \pi - 0 - \frac{\sin 2\pi}{2} + \sin 0 \right\} \right]^{\frac{1}{2}}$$

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

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

$$\therefore I_{rms} = \frac{I_m}{2} \quad \text{(or)} \quad I_{rms} = \frac{V_m}{2\ R_f + R_L}$$

1.26.1.4 RMS value of load Voltage V_{rms}

R.M.S. voltage across the load is given by

$$V_{rms} = I_{rms} \times R_L = \frac{V_m R_L}{2\ R_f + R_L} = \frac{V_m}{2\left(1 + \frac{R_f}{R_L}\right)}$$

$$\text{If } R_L >> R_f \text{ then } V_{rms} = \frac{V_m}{2}$$

1.26.1.5 DC power output P_{DC}

$P_{DC} = V_{DC} X I_{DC} = I_{DC}^2 X R_L$
$P_{DC} = I_{DC}^2 X R_L = (Im/\pi)^2 x R_L$
$P_{DC} = (1/\pi^2) x Im^2 R_L$
$I_m = (V_m/(R_S+R_f+R_L))$
$P_{DC} = (V_m^2 X R_L) / \pi^2(R_S+R_f+R_L)^2$

1.26.1.6 AC power output P_{AC}

$I_{rms} = I_m/2$
$P_{AC} = I_{rms}^2 \times (R_f + R_s + R_L)$
$P_{AC} = (I_m/2)^2 \times (R_f + R_s + R_L)$
$P_{AC} = I_m^2/4 \; [R_f + R_s + R_L]$

1.26.1.7 Rectifier Efficiency (η)

The rectifier efficiency is defined as the ration of d.c. output power to the a.c. input power i.e.,

$$\therefore \eta = \frac{P_{dc}}{P_{ac}}$$

$$P_{dc} = I_{dc}^2 R_L = \frac{I_m^2 R_L}{\pi^2}$$

$$P_{ac} = I_{rms}^2 \; R_L + R_f \; = \frac{I_m^2}{4} \; R_L + R_f$$

$$\therefore \eta = \frac{P_{dc}}{P_{ac}} = \frac{I_m^2 R_L}{\pi^2} \times \frac{4}{I_m^2 \; R_L + R_f} = \frac{4}{\pi^2}\left(\frac{R_L}{R_L + R_f}\right)$$

$$\Rightarrow \eta = \frac{4}{\pi^2} \cdot \frac{1}{\left(1 + \frac{R_f}{R_L}\right)} = \frac{0.406}{1 + \frac{R_f}{R_L}}$$

$$\Rightarrow \% \eta = \frac{40.6}{1 + \frac{R_f}{R_L}}$$

Theoretically the maximum value of rectifier efficiency of a half-wave rectifier is 40.6% when $\frac{R_f}{R_L} = 0$.

1.26.1.8 Ripple factor (γ)

$$\text{Ripple factor (r)} = \frac{\text{R.M.S value of a.c. component of o/p}}{\text{Average or d.c. component of o/p}}$$

$$I^2_{rms} = I^2_{dc} + I^2_{ac}$$

$$I^2_{ac} = I^2_{rms} - I^2_{dc}$$

$$I_{ac} = \sqrt{I^2_{rms} - I^2_{dc}}$$

$$\gamma = \frac{\sqrt{I^2_{rms} - I^2_{dc}}}{I_{dc}}$$

The ripple factor γ is given by

$$\therefore \gamma = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1} \quad \text{(or)} \quad \therefore \gamma = \sqrt{\left(\frac{V_{rms}}{V_{dc}}\right)^2 - 1}$$

$$\therefore \gamma = \sqrt{\left(\frac{I_m/2}{I_m/\pi}\right)^2 - 1} = \sqrt{\left(\frac{\pi}{2}\right)^2 - 1} = 1.21$$

$$\Rightarrow \gamma = 1.21$$

1.26.1.9 Voltage regulation

% Regulation =

V_{NL} = No load Voltage i.e with out any losses at the output. The total Average voltage is the no load voltage.

$$V_{NL} = V_{dc} =$$

V_{FL} = Full load voltage is the output DC voltage under full load condition.

V_{FL} = No-load Voltage – Full load losses

$$V_{FL} =$$

$$\% \text{ Regulation} = \frac{\frac{Vm}{\pi} - [\frac{Vm}{\pi} - I_{DC}R_f]}{\frac{Vm}{\pi} - I_{DC}R_f}$$

$$= \frac{\frac{Vm}{\pi} - \frac{Vm}{\pi} + I_{DC}R_f}{\frac{Vm}{\pi} - I_{DC}R_f}$$

$$= \frac{I_{DC}R_f}{\frac{Vm}{\pi} - I_{DC}R_f}$$

$$= \frac{1}{\frac{Vm}{\pi I_{DC}R_f} - 1}$$

We know that

$$I_{DC} = \frac{Vm}{\pi(R_f + R_L)}$$

By substituting I_{DC} in the above equation

$$= \frac{1}{\frac{Vm}{\pi} * \frac{\pi}{V_m} * \frac{R_f+R_L}{R_f} - 1}$$

$$\%Regulation = \frac{R_f}{R_L} * 100$$

1.26.1.10 Peak Inverse voltage

- It is maximum reverse voltage that a diode can withstand without destroying the junction.
- If the reverse voltage across a diode exceeds this value, the reverse current increases sharply and breakdown the junction due to excessive heat.
- PIV is extremely important when diode is used as a rectifier.
- For HWR under reverse bias condition is Vm. i.e PIV =Vm.

The PIV may be between 10V & 10KV depending upon the type of diode.

1.26.1.11 Half wave rectifier Advantages and Disadvantages

Advantages

1. The circuit is simpler and requires only one diode
2. PIV is only V_m.

Disadvantages

1. Ripple factor γ =1.21. i.e 121%
2. Efficiency is very low about 40.6%

Problem 35:

The I / p to a halfwave rectifier is $V = 230 \sin 314 t$, If $R_f = 50\,\Omega$ & $R_L = 1\,K\,\Omega$ Determine

a. peak load current
b. DC load current
c. AC load current or RMS load current
d. DC o / p voltage
e. AC power Input (i/p)
f. DC power output (o/p)
g. Rectifier effielency
h. percentage Regulation

Soln:

a. peak load current

$$I_m = \frac{V_m}{R_f + R_L} = \frac{230}{50 + 1K\Omega} = 219mA$$

b. DC load current

$$I_{dc} = \frac{I_m}{\pi} = \frac{219mA}{3.14} = 69.74mA$$

c. AC load current

$$I_{rms} = \frac{I_m}{2} = \frac{219mA}{2} = 109.5mA$$

d. DC o / p voltage

$$V_{dc} = I_{dc} \times R_L$$
$$= 69.74mA \times 1\,K\Omega$$
$$= 69.74\,V$$

e. AC power input (i/p)

$$P_{ac} = (I_{rms})^2 \times (R_L + R_F)$$
$$= (109.5)^2 \times (1000 + 50)$$
$$= 12.58\,W$$

f. DC power O / P (output)

$$P_{dc} = (I_{dc})^2 \times R_L$$
$$= (69.74)^2 \times 1000$$
$$= 4.86\,W$$

g. Rectifier effieiency

$$=\frac{P_{dc}}{P_{ac}}x100$$

$$=\frac{4.86}{12.58}x100$$

$$=38.63\%$$

h. percentage Regulation

$$\frac{R_f}{R_L}x100=\frac{50}{1000}x100=5\%$$

Problem 36:

A diode with V_F= 0.7V is connected as a half wave rectifier. The load resistance is 600 Ω and the (rms) as input is 24V. Determine the peak output voltage, the peak load current and the diode peak reverse voltage.

Given V_F = 0.7 v, R_L = 600 Ω

V(rms) = 24 v

* $V_m = \sqrt{2}\ V(rms) = \sqrt{2} \times 24$ v

V_m= 33.941 v

* $I_m = \frac{V_m - V_F}{R_L} = \frac{33.941 - 0.7}{600}$

I_m = 55.4016 mA

* Peak output voltage = $I_m \times R_L$

$= 55.4016 \times 10^{-3} \times 600$

= 33.240 v

* PIV = V_m = 33.941 v

Problem 37:

A half wave rectifier is used to convent 230 V AC in to DC across a load of 1 kΩ. The transformer used is 230 V/12 volts. The DC resistance of the transformer used is 12 Ω and the resistance of the diode is 22 Ω. Compute:

i. DC output voltage **ii. The rms value of the output voltage**

iii. Ripple factor **iv. Rectification efficiency.**

Soln:

Given $V_m = 12V$, $R_L = 1K\Omega$, $R_s = 12\Omega$, $R_f = 22\Omega$

$$V_m = \sqrt{2} \times 12 = 16.97V$$

$$I_m = \frac{V_m}{R_f + R_s + R_L} = \frac{16.97V}{(1\times10^3 + 12 + 22)} = \boxed{16.419mA}$$

$$I_{dc} = \frac{I_m}{\Pi} = \frac{16.419\times10^{-3}}{\Pi} = \boxed{5.22mA}$$

$$V_{dc} = I_{dc}.R_L = (5.22\times10^{-3})\ (1\times10^{3})$$

$$\boxed{V_{dc} = 5.22V}$$

$$V_{rms} = \frac{V_m}{2} = \frac{16.97}{2} = \boxed{8.485V}$$

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

$$\gamma = \sqrt{\frac{(8.2035\times10^{-3})}{(5.22\times10^{-3})} - 1}$$

$$= \sqrt{1.473}$$

$$\boxed{\gamma = 1.2138 \quad \Rightarrow \text{Ripple factor}}$$

$$I_{rms} = I_m/2$$

$$= \frac{16.419\times10^{-3}}{2}$$

$$= 8.2095mA$$

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

$$P_{dc} = (I_{dc})^2 . R_L = (5.22 \times 10^{-3})\ (1 \times 10^3)$$

$$P_{dc} = 27.24mw$$

$$P_{ac} = (I_{rms})^2\ (R_f + R_s + R_L)$$

$$P_{ac} = (8.20295 \times 10^{-3})^2\ \ (1 \times 10^3 + 12 + 22)$$

$$\boxed{P_{ac} = 69.68mw}$$

$\%\eta$ = 27.24mW/ 69.68mW = 39.09%

Problem 38

A half wave rectifier with $R_L = 1$ kΩ is given an input of 10V peak from step down transformer. Calculate D.C. voltage and load current for ideal and silicon diode.

Solution : Given values are $R_L = 1$ kΩ, $V_m = 10$ V peak

Case i) Ideal diode

Cut-in voltage $V_\gamma = 0$ V, $R_f = 0\ \Omega$

$$\therefore \quad V_{DC} = \frac{V_m}{\pi} = \frac{10}{\pi} = 3.18 \text{ V}$$

$$\therefore \quad I_{DC} = \frac{V_{DC}}{R_L} = \frac{3.18}{1 \times 10^3} = 3.18 \text{ mA}$$

Case ii) Silicon diode

Cut-in voltage $V_\gamma = 0.7$ V

$$\therefore \quad V_{DC} = \frac{V_m - V_\gamma}{\pi} = \frac{10 - 0.7}{\pi} = 2.96 \text{ V}$$

$$\therefore \quad I_{DC} = \frac{V_{DC}}{R_L} = 2.96 \text{ mA}$$

1.26.2 Full-wave Rectifier

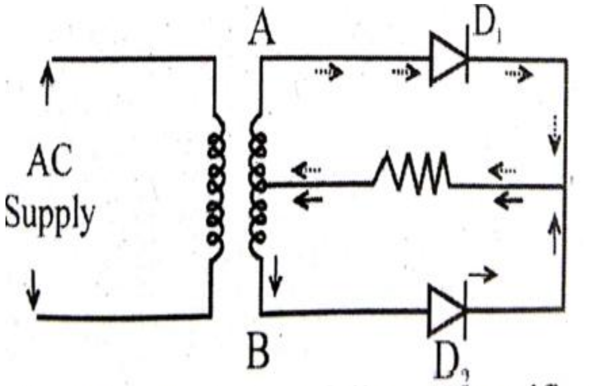


fig40(a) centre tap full wave rectifier

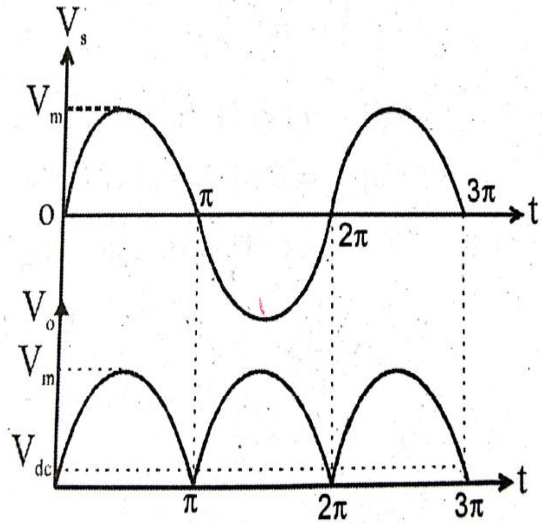


Fig. 40(b) Waveforms

Operation:

- During the positive half-cycle of input a.c voltage, end A becomes positive with respect to end B. This makes the diode D1 forward biased and diode D2 is reverse biased. Therefore Diode D1 conducts current.
- The conventional current flow is through diode D1, load resistor RL and the upper half of secondary winding as shown by the dotted arrows.
- During the negative half cycle, end A is negative with respect to end B. Under this condition, the diode D2 is forward biased and diode D1 is reverse biased. Therefore Diode D2 conducts current.
- The conventional current flow is through diode D2, load resistor RL and the lower half of secondary winding as shown by the solid arrows.
- The output across the load is pulsating DC. These are further smoothened with the help of filter circuits.

- Let $V = V_m Sin\omega t = V_m Sin\theta$ be the instantaneous sinusoidal voltage appearing at the secondary winding of a transformer.
- During positive half cycle from 0 to π
  $i=I_m Sin\theta$ for $0<= \theta <= \pi$
- Similarly during negative half cycle from π to 2π
  $i =I_m Sin\theta$ for $\pi <= \theta<= 2\pi$
- The maximum load current is given by
  $I_m = V_m/ (R_F+R_S+R_L)$
- where R_F is forward resistance of a diode.
  R_S is transformer secondary resistance
  R_L is load resistance

1.26.2.1 DC or Average Current I_{DC}

DC or average current I_{dc}

$$I_{dc}=\frac{1}{2\pi}\left[\int_0^{\pi} i\,d\theta+\int_{\pi}^{2\pi} i\,d\theta\right]$$

Since by definate intgral Property the above equation can be written as

$$I_{dc}=\frac{1}{2\pi}\left[2\int_0^{\pi} i\,d\theta\right]$$

$$I_{dc}=\frac{1}{\pi}\int_0^{\pi} i\,d\theta$$

$$I_{dc}=\frac{1}{\pi}\int_0^{\pi} I_m \sin\theta\, d\theta$$

$$I_{dc}=\frac{I_m}{\pi}[-\cos\theta]_0^{\pi}$$

$$I_{dc}=\frac{-I_m}{\pi}[\cos\pi-\cos 0]$$

$$I_{dc}=\frac{-I_m}{\pi}[-1-1]$$

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

1.26.2.2 DC or Average Voltage V_{DC}

$$V_{dc}=I_{dc}.R_L.=\frac{2I_m}{\pi}.R_L \quad \text{We know } I_m=\frac{V_m}{R_S+R_f+R_L}$$

$$\therefore V_{dc}=\frac{2.V_m.R_L}{\pi(R_S+R_f+R_L}$$

$$If\,(R_s+R_f)<<R_L$$

$$V_{dc}=\frac{2V_m}{\pi}=0.637V_m.$$

$$V_{dc}=0.637V_m.$$

1.26.2.3 RMS value of load current

$$I_{rms} = \sqrt{\frac{1}{\pi}\int_0^{\pi} i^2\, d\theta}$$

$$I_{rms} = \sqrt{\frac{1}{\pi}\int_0^{\pi} I_m^2 sin^2\ \theta d\theta}$$

$$I_{rms} = \sqrt{\frac{I_m^2}{\pi}\int_0^{\pi} sin^2\theta d\theta}$$

$$I_{rms} = \sqrt{\frac{I_m^2}{\pi}\int_0^{\pi} \left(\frac{1 - cos2\theta}{2}\right) d\theta}$$

$$I_{rms} = \sqrt{\frac{I_m^2}{\pi}\left[\frac{1}{2}\int_0^{\pi} d\theta - \frac{1}{2}\int_0^{\pi} cos2\theta d\theta\right]}$$

$$I_{rms} = \sqrt{\frac{I_m^2}{\pi}\left[\frac{\pi}{2} - \frac{1}{2}[sin2\pi - sin0]\right]}$$

$$I_{rms} = \sqrt{\frac{I_m^2 \pi}{2\pi}}$$

$$I_{rms} = \sqrt{\frac{I_m^2}{2}} = \frac{I_m}{\sqrt{2}}$$

1.26.2.4 RMS value of load voltage V_{rms}

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

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

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

$$\frac{1}{\sqrt{2}}\left[\frac{V_m}{R_f + R_L}\right] R_L$$

$$\boxed{V_{rms} = \frac{V_m/\sqrt{2}}{1 + R_f/R_L}}$$

for an ideal diode $V_{rms} = \dfrac{Vm}{\sqrt{2}}$

1.26.2.5 DC power output P_{DC}

$P_{DC} = V_{DC} \text{ X } I_{DC} = I_{DC}^2 \text{ X } R_L$
$P_{DC} = I_{DC}^2 \text{ X } R_L = (2Im/\pi)^2 \text{ x } R_L$
$P_{DC} = (4/\pi^2) \text{ x } Im^2 R_L$
$I_m = (V_m/(R_S+R_f+R_L))$
$P_{DC} =(4/\pi^2) \text{ X } (V_m^2/(R_S+R_f+R_L)) \text{ x } R_L$

1.26.2.6 AC power input P_{AC}

$P_{AC} = I_{rms}^2 \text{ X } (R_f + R_s + R_L)$
$P_{AC} = (I_m/\sqrt{2})^2 \text{ X } (R_f + R_s + R_L)$
$P_{AC} = (I_m^2 \text{ X } (R_f + R_s + R_L))/2$
Substituting the value of I_m we get
$I_m = (V_m/(R_S+R_f+R_L))$
$P_{AC} =(1/2) \text{ X } (V_m^2/(R_S+R_f+R_L)^2) \text{ x } (R_f + R_s + R_L)$ $P_{AC} = (V_m^2/2(R_S+R_f+R_L))$

1.26.2.7 Rectifier Efficiency (η)

The rectifier efficiency is defined as the ratio of output d.c. power to input a.c power

$$\eta = \frac{P_{DC}}{P_{AC}} = \frac{\text{D.C o/p power}}{\text{A.C i/p power}}$$

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

$$P_{ac} = I^2_{rms}\left(R_f + R_s + R_L\right)$$

$$\eta = \frac{I^2_{dc} R_L}{I^2_{rms}\left(R_f + R_s + R_L\right)}$$

$$\eta = \frac{\left(\frac{2I_m}{\pi}\right)^2 R_L}{\left(I_m/\sqrt{2}\right)^2\left(R_f + R_s + R_L\right)}$$

$$\eta = \frac{8}{\pi^2}\left(\frac{R_L}{R_f + R_s + R_L}\right)$$

$$\eta = 0.812\left(\frac{R_L}{R_f + R_s + R_L}\right)$$

$$\eta = \frac{0.812}{\frac{R_f + R_s + R_L}{R_L}}$$

If $(R_f + R_s) << R_L$ then maximum theoretical efficiency of FWR

$\%\eta$ max = 0.812 x 100 = 81.2%

1.26.2.8 Ripple factor (γ)

$$\text{Ripple factor (r)} = \frac{\text{R.M.S value of a.c. component of o/p}}{\text{Average or d.c. component of o/p}}$$

$$I^2_{rms} = I^2_{dc} + I^2_{ac}$$

$$I^2_{ac} = I^2_{rms} - I^2_{dc}$$

$$I_{ac} = \sqrt{I^2_{rms} - I^2_{dc}}$$

$$\gamma = \frac{\sqrt{I^2_{rms} - I^2_{dc}}}{I_{dc}}$$

$$\gamma = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1}$$ ———————— (A)

Substitute $I_{rms} = \frac{I_m}{\sqrt{2}}, \quad I_{dc} = \frac{2I_m}{\pi}$ ....(A)

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

$$\gamma = \sqrt{\left(\frac{\pi}{2\sqrt{2}}\right)^2 - 1} = \sqrt{(1.11)^2 - 1}$$

$$\boxed{\gamma = 0.482}$$

A
G

1.26.2.9 Voltage regulation

% Regulation =

V_{NL} = No load Voltage i.e with out any losses at the output. The total Average voltage is the no load voltage.

$$V_{NL} = V_{dc} =$$

V_{FL} = Full load voltage is the output DC voltage under full load condition.

V_{FL} = No-load Voltage – Full load losses

$$V_{FL} =$$

$$\% \text{ Regulation} = \frac{2\frac{Vm}{\pi} - \left[2\frac{Vm}{\pi} - I_{DC}R_f\right]}{2\frac{Vm}{\pi} - I_{DC}R_f}$$

$$= \frac{2\frac{Vm}{\pi} - 2\frac{Vm}{\pi} + I_{DC}R_f}{2\frac{Vm}{\pi} - I_{DC}R_f}$$

$$= \frac{I_{DC}R_f}{2\frac{Vm}{\pi} - I_{DC}R_f}$$

$$= \frac{1}{\frac{2Vm}{\pi I_{DC}R_f} - 1}$$

We know that

$$I_{DC} = \frac{2Vm}{\pi(R_f + R_L)}$$

By substituting I_{DC} in the above equation

$$= \frac{1}{\frac{2Vm}{\pi} * \frac{\pi}{2V_m} * \frac{R_f + R_L}{R_f} - 1}$$

$$\%Regulation = \frac{R_f}{R_L} * 100$$

1.26.2.10 Peak Inverse voltage

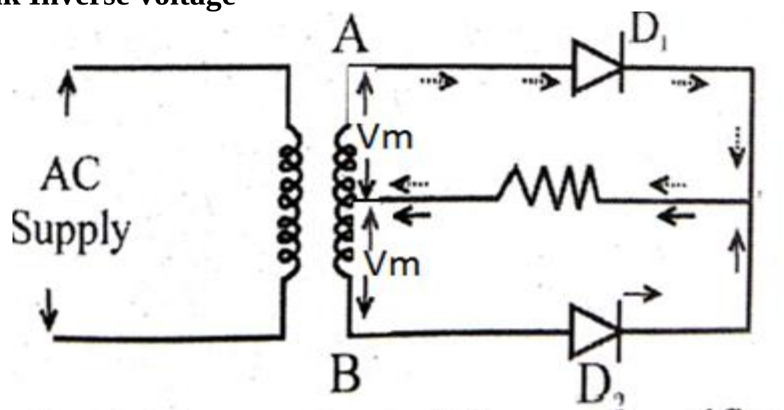


fig 41 centre tap full wave rectifier

- Suppose V_m is the maximum voltage across the half secondary winding.
- Fig.41 shows the circuit at the instant secondary voltage reaches its maximum value in the +ve direction.
- At this instant. Diode D_1 is conducting while diode D_2 is non conducting.
- Therefore, whole of the secondary voltage appears across the non-conducting diode.
- Consequently the PIV is twice the maximum voltage across the half secondary winding i.e PIV $=2V_m$

1.26.2.11 Full wave rectifier

Advantages

1. Low ripple γ =48.2%
2. Efficiency is high η =81.2%
3. Requires only two diodes.

Disadvantages

1. It is difficult to locate the centre tap on the secondary winding.
2. The DC output is small as each diode utilizes only one-half of the transformer secondary voltage.
3. The diodes used must have high PIV.

Problem 39

In a full wave rectifier the input is from a 100-0-100V transformer. The load & diode forward resistance are 1000 Ω & 20 Ω respectively calculate the

a) peak value of load current

b) rms value of load current

c) DC load current

d) Average output voltage

e) Rectification efficiency

f) Percentage regulation

g) Ripple factor

h) If capacitor is connected across R_L = 500 μF find μ?

given : $R_L = 1000\,\Omega$ & $R_f = 20\,\Omega$

$V_m = 100 \times \sqrt{2} = 141.42$ v

a) Peak value of load current $I_m = \frac{V_m}{R_f + R_L} = \frac{141.42}{20+1000} = 138.6\text{mA}$

b) rms value of load current $I_{rms} = \frac{I_m}{\sqrt{2}} = \frac{138.6\text{mA}}{\sqrt{2}} = 98.0\text{mA}$

c) DC load current $I_{dc} = \frac{2I_m}{\pi} = \frac{2\text{x}138.6\text{mA}}{\pi} = 88.22\text{mA}$

d) Average output voltage

$$V_{dc}=\frac{2V_m/\pi}{1+\frac{R_f}{R_L}}=\frac{2x141.42/3.142}{1+\frac{20}{1000}}$$

$$V_{dc}=88.24V$$

e) Rectification efficiency

$$\eta=\frac{0.812}{1+\frac{R_f}{R_L}}x100=\frac{0.812}{1+\frac{20}{1000}}=79.60\%$$

f) Percentage regulation

$$\frac{R_f}{R_L}x100=\frac{20}{1000}x100=2\%$$

g) Ripple factor

$$\gamma=\sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2-1}=\sqrt{\left(\frac{98.0}{88.22}\right)^2-1}$$

$$=0.483$$

h) with capacitor connected across R_L C=500 μF

$$\gamma=\frac{1}{4\sqrt{3}fCR_L}=\frac{1}{4\sqrt{3}x50x500x10^{-6}x1000}$$

$$\gamma=5.77\ x\ 10^{-3}$$ Assuming $f=50H_z$

Problem 40

: *A full wave rectifier uses a diode with forward resistance of 1 Ω. The transformer secondary is centre tapped with output 10-0-10 V_{rms} and has resistance of 5 Ω for each half section. Calculate*

i) No-load d.c. voltage

ii) D.C. output voltage at 100 mA

iii) % Regulation at 100 mA

Soln:

Solution:

$$R_f = 1\,\Omega,\ V(rms) = 10\ V,\ R_s = 5\,\Omega$$

$$V_m = \sqrt{2}\ V(rms) = \sqrt{2} \times 10 = 14.1421\ V$$

i) $$V_{DC}(NL) = \frac{2\ V_m}{\pi} = 2 \times \frac{14.1421}{\pi}$$

$$= \mathbf{9.0031\ V}$$

ii) $$I_{DC} = 100\ mA = \frac{2I_m}{\pi}$$

$\therefore$ $$I_m = \frac{\pi \times 100}{2} = 157.079\ mA$$

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

$\therefore$ $$157.079 \times 10^{-3} = \frac{14.1421}{1 + 5 + R_L}$$

$$R_L = 84.0317\ \Omega$$

$\therefore$ $$V_{DC}(\text{on load}) = I_{DC} R_L = 100 \times 10^{-3} \times 84.0317$$

$$= \mathbf{8.4031\ V}$$

iii) $$\%\ \text{Regulation} = \frac{V_{DC}(NL) - V_{DC}(\text{on load})}{V_{DC}(\text{on load})} \times 100$$

$$= \frac{9.0031 - 8.4031}{8.4031} \times 100$$

$$= \mathbf{7.14\ \%}$$

Problem 41

In a full wave rectifier, the input is from a 30 - 0 - 30 V transformer. The load and diode forward resistance are 100 Ω and 10 Ω respectively. Calculate the average voltage, rectification efficiency and percentage regulation.

Soln: Tranformer is 30 - 0 - 30 V.

It is full wave rectifier with input from center tap transformer. So r.m.s. value of secondary across each half of secondary is 30 V

$$\therefore \quad V_m = \sqrt{2}\times 30 = 42.4264 \text{ V} \quad \text{and} \quad R_f = 10\,\Omega,\ R_L = 100\,\Omega$$

$$I_m = \frac{V_m}{R_f + R_L} = \frac{42.4264}{(100+10)} = 0.3856 \text{ A}$$

$$\therefore \quad I_{DC} = \frac{2I_m}{\pi} = \frac{2\times 0.3856}{\pi} = 0.2455 \text{ A}$$

$$P_{AC} = I_{RMS}^2(R_f + R_L) = \left(\frac{I_m}{\sqrt{2}}\right)^2 (R_f + R_L) = 8.1778 \text{ W}$$

$$\%\,\eta = \frac{P_{D.C.}}{P_{A.C.}} \times 100 = \frac{6.027}{8.1778}\times 100 = \mathbf{73.69\ \%}$$

$$\%\ \text{Regulation} = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100$$

$$V_{DC}\ \text{no load} = V_{NL} = \frac{2}{\pi}\times V_m = \frac{2}{\pi}\times 42.4264 = 27.0094 \text{ V}$$

$$V_{DC}\ \text{full load} = V_{FL} = I_{DC}\times R_L = 0.2455\times 100 = 24.55 \text{ V}$$

$$\%\ \text{Regulation} = \frac{27.0094 - 24.55}{24.55} \times 100 = \mathbf{10.016\ \%}$$

Problem 42 : *In a two diode F.W.R. circuit, the voltage across each half of the transformer secondary is 100 V. The load resistance is 950 Ω and each diode has a forward resistance of 50 Ω. Find the load current and the r.m.s. value of the input current.*

Soln : Given data,

$$V_S = 100\text{ V},\ R_f = 50\ \Omega,\ R_L = 950\ \Omega$$

$$V_m = \sqrt{2} \times 100 = 141.42\text{ V} \qquad \ldots V_S = 100\text{ V is r.m.s.}$$

$$I_m = \frac{V_m}{R_S + R_L + R_f} = \frac{141.42}{950 + 50 + 0} = 0.141\text{ Amps}$$

$$I_{rms} = \frac{I_m}{\sqrt{2}} = \frac{0.141}{\sqrt{2}} = \mathbf{0.0997A} \qquad \ldots \text{RMS value of input current}$$

$$I_{DC} = \frac{2I_m}{\pi} = \frac{2 \times 0.141}{\pi} = \mathbf{0.0897A} \qquad \ldots \text{Load current}$$

1.26.3 Full wave Bridge rectifier

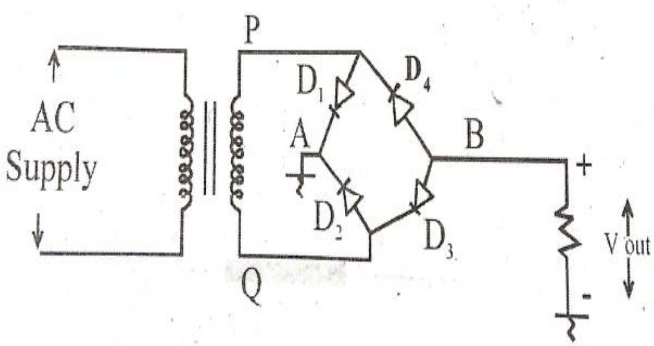


Fig.42(a) FWBR

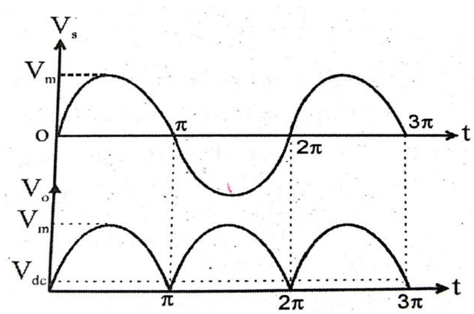


Fig.42(b) waveforms

Operation:

- During the positive half cycle of secondary voltage, the end P of the secondary winding becomes positive and end Q is negative.
- This makes diodes D_1 and D_3 forward biased while diodes D2 and D4 are reverse biased.

- Therefore, only diodes D_1 and D_3 conduct. These two diodes will be in series through the load R_L. It may see that current flow from A to B through the load R_L.
- During the negative half cycle of secondary voltage, the end P of the secondary winding becomes negative and end Q is positive.
- This makes diodes D_2 and D_4 forward biased while diodes D_1 and D_3 are reverse biased.
- Therefore, only diodes D_2 and D_4 conduct. These two diodes will be in series through the load R_L. It may see that current flow from A to B through the load R_L.
- Therefore, DC output is obtained across load R_L.

1.26.3.1 Full-wave Bridge Rectifier

1) DC or Average current I_{DC}

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

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

2) RMS value of load current

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

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

3) Rectifier efficiency

η =81.2%

4) Ripple factor

γ =48.2%

5) Regulation

$\%R = 2R_f/R_L * 100$

6) PIV $=V_m$

Where $I_m = V_m / (R_S+2R_f+R_L)$

1.26.3.2 Peak Inverse Voltage

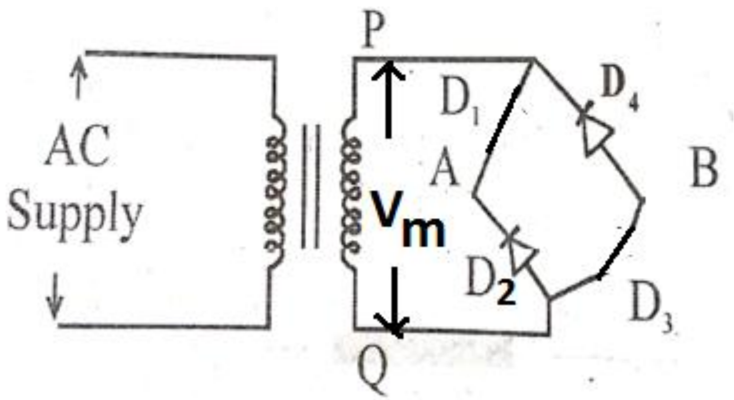


Fig.43

- Referring to Fig.43 it is clear that two reverse biased diodes (D_2 & D_4) & secondary of transformer are in parallel.
- Hence PIV of each diode (D_2 & D_4) is equal to the maximum voltage V_m across the secondary.
- Similarly, during the next half cycle, D_2 & D_4 are forward biased while D_1 & D_3 will be reverse biased.
- It is easy to see that reverse voltage across D_1 & D_3 is equal to V_m.

1.26.3.3 Full wave Bridge Rectifier

Advantages

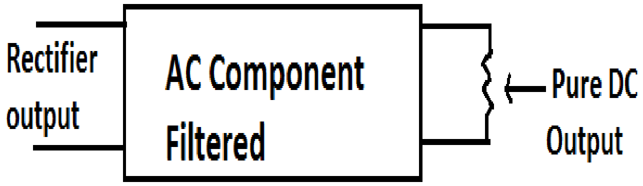
1. The need for centre-tapped transformer is eliminated.
2. The output is twice that of the centre tap circuit for the same secondary voltage.
3. The PIV is one-half that of the centre tap circuit.

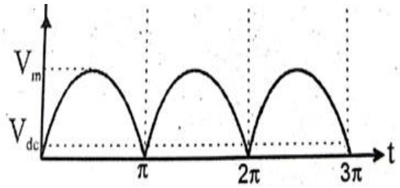
Disadvantages

1. It requires four diodes.
2. Power loss in bridge network is higher than that of center tap because two diodes conduct at a time.

1.26.3.4 C-Filter

A filter circuit is a device which removes the AC component of rectifier output but allows the DC component to reach the load shown in Fig.44.





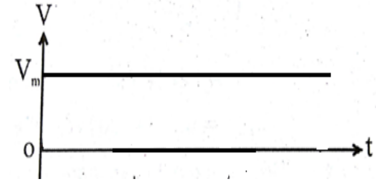


Fig.44

- The Fig.45 shows a typical Capacitor filter circuit.
- It consists of a capacitor 'C' placed across the rectifier output in parallel with load R_L.
- The pulsating direct voltage of the rectifier is applied across the capacitor.
- As the rectifier voltage increases, it charges the capacitor and also supplies current to the load.
- At the end of quarter cycle, the capacitor is charged to the peak value Vm of the rectifier voltage.
- Now, the rectifier voltage starts to decrease.
- As this occurs, the capacitor discharges through the load and voltage across it decreases.
- The voltage across load will decrease only slightly because immediately the next voltage peak comes and recharges the capacitor.
- This process is repeated again and again and the output voltage waveform shown in Fig 45.

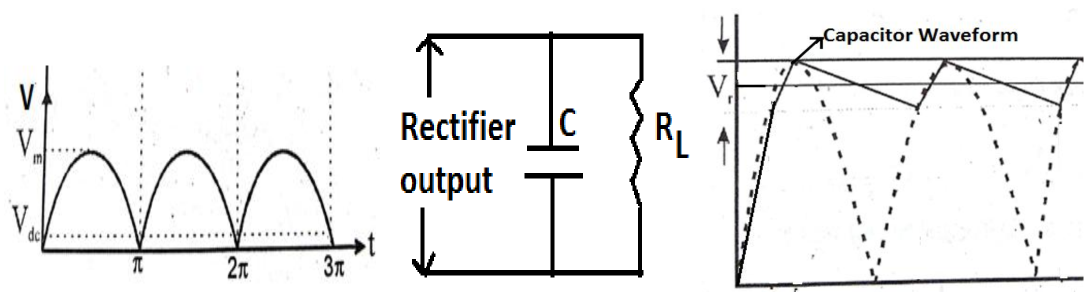


Fig.45

- The 'C' filter CKT is extremely popular because of its Low cost, small size, little weight & good characteristics.
- For small load currents (say up to 50mA), this type of filter is preferred.
- It is commonly used in transistor radio battery eliminators.

1.26.3.4.1 Full-wave Bridge Rectifier with C filter

It is assumed that the o/p voltage wave form for a full wave ckt with a capacitor filter may be approximated by a broken curve made up of portions of straight lines as shown is fig 46 . The peak value of this wave is Vm.

If the total discharge voltage of capacitor is denoted by v_r then from the diagram average value of the voltage is

$$V_{dc} = V_m - \frac{V_r}{2} \quad ....(1)$$

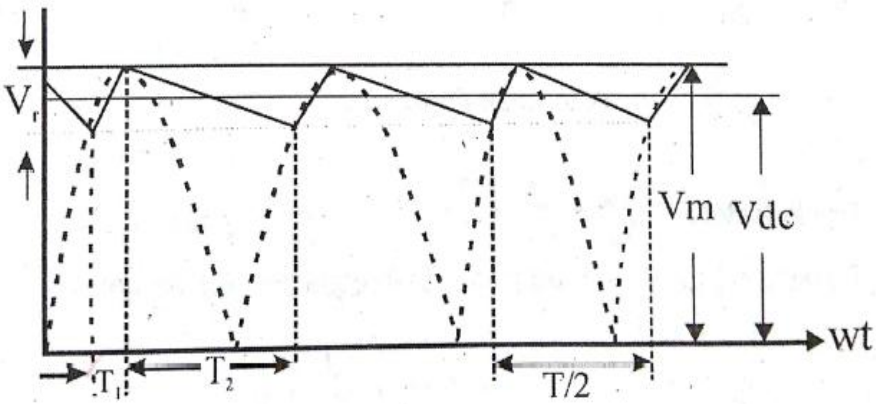


Fig.46

It is known mathematically that rms value of a triangular wave is

$$V_{rms} = \frac{V_r}{2\sqrt{3}} \quad ....(2)$$

During the time interval T_2, capacitor C is discharging through the load resistor

R_L

charge lost is

$Q=CV_r$ ....(3)

But $i = \frac{dQ}{dt}$

$$Q = \int_0^{T_2} i\,dt = I_{dc} T_2$$

$$\therefore \; I_{dc} T_2 = CV_r$$

$$V_r = \frac{I_{dc} T_2}{C} \quad ....(4)$$

Now $T_1 + T_2 = \frac{T}{2}$

$\therefore \; T_1 + T_2 \approx T_2 = \frac{T}{2}$ Where $T = \frac{1}{f}$

$$V_r = \frac{I_{dc}}{C}\left[\frac{T}{2}\right] = \frac{I_{dc}}{2fC}, \text{ But } I_{dc} = \frac{V_{dc}}{R_L}$$

$$\therefore V_r = \frac{V_{dc}}{2fCR_L} \text{ ....peak to peak ripple voltage ....(5)}$$

$$\text{Ripple factor } \gamma = \frac{V_{rms}}{V_{dc}} = \frac{V_r}{2\sqrt{3}} x \frac{1}{V_{dc}} \text{ ....(6)}$$

Substituting for V_r from equation (5) in equations (6) we get,

$$\gamma = \frac{\frac{V_{dc}}{2fCR_L}}{2\sqrt{3}} x \frac{1}{V_{dc}}$$

$$\therefore \boxed{r = \frac{1}{4\sqrt{3}fCR_L}}$$

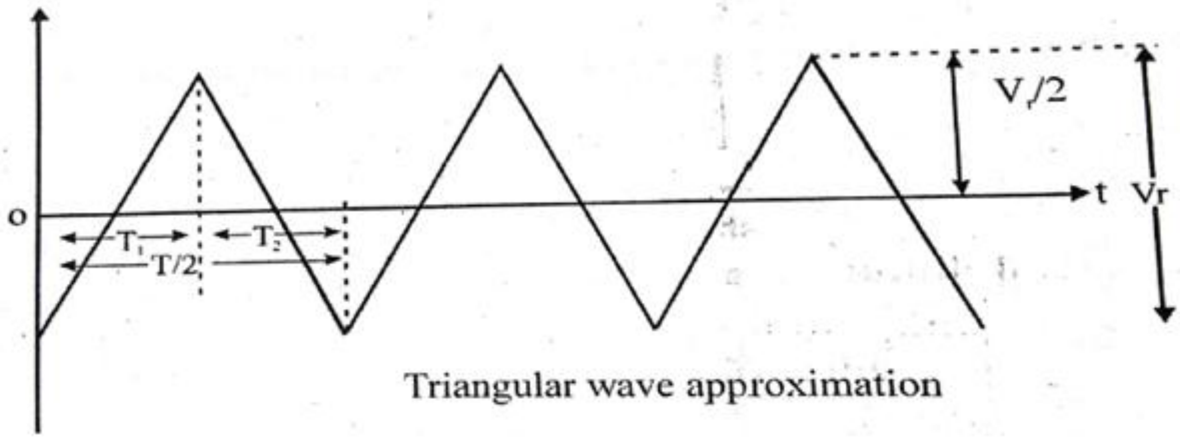


Fig.47

The triangular wave approximation is shown in Fig.47

The DC output voltage of the capacitor filter is given by

$$Vdc = V_m - \frac{V_r}{2}$$

$$\text{But } V_r = \frac{V_{dc}}{2fCR_L}$$

$$\therefore V_{dc} = V_m - \frac{V_{dc}}{4fCR_L}$$

$$V_{dc}\left[1+\frac{1}{4fCR_L}\right] = V_m$$

$$\therefore \boxed{V_{dc} = \frac{V_m}{1+\frac{1}{4fCR_L}}}$$

1.27 Comparison

Quantity	Half wave rectifier	Full wave rectifier	
		center tapped	Bridge
I_{dc}	I_m/π	$2I_m/\pi$	$2I_m/\pi$
I_{rms}	$I_m/2$	$I_m/\sqrt{2}$	$I_m/\sqrt{2}$
Ripple factor	1.21	0.48	0.48
Efficiency	40.6%	81.2%	81.2%
Center tapped tansformer	Not required	required	Not required
Number of diodes used	one	two	four
PIV	V_m	$2V_m$	V_m
Ripple factor with 'c' filter	$\frac{1}{2\sqrt{3}fCR_L}$	$\frac{1}{4\sqrt{3}fCR_L}$	$\frac{1}{4\sqrt{3}fCR_L}$
DC output voltage with 'c' filter V_{dc}	$\frac{V_m}{1+\frac{1}{2fCR_L}}$	$\frac{V_m}{1+\frac{1}{4fCR_L}}$	$\frac{V_m}{1+\frac{1}{4fCR_L}}$

Problem 43

A 1KΩ load is fed from a bridge rectifier connected across a transformer secondary whose primary is connected to 230V, 50 Hz supply. The ration of number of primary turns to secondary turns is 15:1 & forward resistance of each diode is 20 Ω. Calculate

a) Peak diode current
b) DC load current
c) DC current through each diode
d) RMS current through each diode

e) DC output voltage
f) DC power output
g) AC power input
h) Efficiency of rectification
i) Ripple factor
j) PIV
k) Percentage regulation

Soln:

Assume N_1/N_2 =15

$V_1/V_2 = N_1/N_2$ or $V_2 = (N_2/N_1)V_1$ = (1/15)230 =15.33V

V_m =15.33 X √2 =21.684V

a) Peak diode current

$I_m = V_m/(2R_f+R_L)$ =21.684/ (2(20)+1000) =20.85mA

b)DC load current

$I_{DC} = 2I_m/\pi$ =(2 X 20.85)/ π =13.27mA

c)DC current through each diode

$I_{DC(diode)} = I_{DC} / 2$ = 13.27/2 =6.63mA

d)RMS current through each diode

$I_{rms(diode)} = I_m / 2$ = 10.425mA

e) DC output voltage

$V_{dc} = I_{dc}$ X R_L =13.27 * 1000 X 10^3 =13.27V

f)DC power output

$P_{DC} = I^2_{dc}$ X $R_L = (13.27)^2$ X 1000 X 10^3 =0.176W

g)AC power input

$P_{AC(diode)} = (I^2_m / 2)$ X $(2R_f+R_L)$= $((20.85)^2/2)$ X (40X1000)

$P_{AC(diode)}$ =0.226W

h)Efficiency of rectification

η = (0.812) /(1+ 2(R_f / R_L)) = (0.812) / (1+ 2(20 / 1000

η =78.07%

i) ripple factor

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

$V_{rms} = (V_m/\sqrt{2}) / (1 + (2R_f/R_L))$

V_{rms} = (21.684/1.41) / (1 + (40/1000))

V_{rms} = 14.74V

V_{DC} = 13.27V

$$\gamma = \sqrt{\left(\frac{14.74}{13.27}\right)^2 - 1}$$

γ =0.484

j) PIV across non conducting diode =V_m

V_m = 21.684V

k)Percentage regulation

%R = ($2R_f$ / R_L) X 100 = (2*20) / (1000) X 100 =4%

Problem 44

A Full wave bridge rectifier using ideal diodes is supplied from a secondary of 10:1 transformer whose primary is connected to 240V, 50Hz main supply. The output of the rectifier is connected to resistance of 500Ω, in parallel with a capacitor filter C. Calculate the value of 'C' required so that the ripple factor is 2%. Also determine the dc output voltage, peak to peak ripple voltage and load regulation.

Soln:

Assume $N_1/N_2 = 10$
$V_1/V_2 = N_1/N_2$ or $V_2 = (N_2/N_1)V_1 = (1/10)240 = 24V$
$V_m = 24 \times \sqrt{2} = 33.84V$.

a)

$$\boxed{r = \frac{1}{4\sqrt{3}fCR_L}}$$

$$C = \frac{1}{4\sqrt{3} \times 50 \times 0.02 \times 500}$$

$$C = 288.67\mu F$$

b)

$$\boxed{V_{dc} = \frac{V_m}{1 + \frac{1}{4fCR_L}}}$$

$$V_{dc} = \frac{33.84}{1 + \frac{1}{4 \times 50 \times 288.67 \times 10^{-6} \times 500}}$$

$$V_{DC} = 32.70V$$

C) $V_{r(P-P)} = V_{DC} / 2fCR_L$

$V_{r(P-P)} = 32.70 / (2 \times 50 \times 288.67\mu F \times 500)$

$V_{r(P-P)} = 2.2655V$

d)Load regulation = $1 / 4fCR_L$

Load regulation = 1 /(4 X 50 X 288.67µF X 500)

% Load regulation =0.0346 X 100 = 3.46%

Problem 45: *The four semiconductor diodes used in a bridge rectifier circuit each having a forward resistance of 0.1 Ω and infinite reverse resistance, feed a d.c. current of 10 A to a resistive load from a sinusoidally varying alternating supply of 30 V (r.m.s). Determine the resistance of the load and the efficiency of the circuit.*

Soln: The given values are,

$$R_f = 0.1\,\Omega,\ I_{DC} = 10\text{ A},\ R_s = 0\,\Omega,\ V(\text{R.M.S.}) = 30\text{ V}$$

Now $$V_m = V(\text{R.M.S.}) \times \sqrt{2} = \sqrt{2} \times 30$$

$$= 42.4264\text{ V}$$

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

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

$$\therefore \quad I_m = \frac{\pi \times I_{DC}}{2} = \frac{\pi \times 10}{2}$$

$$= 15.7079\text{ A}$$

Now $$I_m = \frac{V_m}{2R_f + R_s + R_L}$$

$$\therefore \quad 15.7079 = \frac{42.4264}{2 \times 0.1 + R_L}$$

$\therefore \quad R_L + 0.2 = 2.7$

$\therefore \quad R_L = \mathbf{2.5\ \Omega}$

Now $\quad P_{DC} = I_{DC}^2 R_L = (10^2) \times 2.5 = 250\ W$

$P_{AC} = I_{RMS}^2 (2R_f + R_s + R_L)$

and $\quad I_{RMS} = \frac{I_m}{\sqrt{2}} = \frac{15.7079}{\sqrt{2}} = 11.1071\ A$

$\therefore \quad P_{AC} = (11.1071)^2\ [2 \times 0.1 + 2.5] = 333.092\ W$

$$\therefore \quad \%\ \eta = \frac{P_{DC}}{P_{AC}} \times 100 = \frac{250}{333.092} \times 100$$

$$= \mathbf{75.05\ \%} \qquad \text{... Rectifier efficiency}$$

Problem 46 : *A bridge rectifier is driving a load resistance of 100 Ω. It is driven by a source voltage of 230 V, 50 Hz. Neglecting diode resistances, calculate :*

i) Average D.C. voltage ii) Average direct current iii) Frequencey of output waveform.

Soln: Given, $R_L = 100\ \Omega$, $V(rms) = 230\ V$, $R_f = 0$, $f = 50\ Hz$

$$V_m = \sqrt{2} \times V(rms) = \sqrt{2} \times 230 = 325\ V$$

i) Average DC voltage $\quad V_{DC} = \frac{2V_m}{\pi} = \frac{2 \times 325}{\pi} = \mathbf{206.9\ V} \quad \text{... As } R_f = 0$

ii) Average direct current $\quad I_{DC} = \frac{2I_m}{\pi}$ where $I_m = \frac{V_m}{R_L + 2R_f + R_s}$

$$I_m = \frac{325}{100 + 0 + 0} = 3.25\ A$$

$$I_{DC} = \frac{2 \times 3.25}{\pi} = \mathbf{2.06\ A}$$

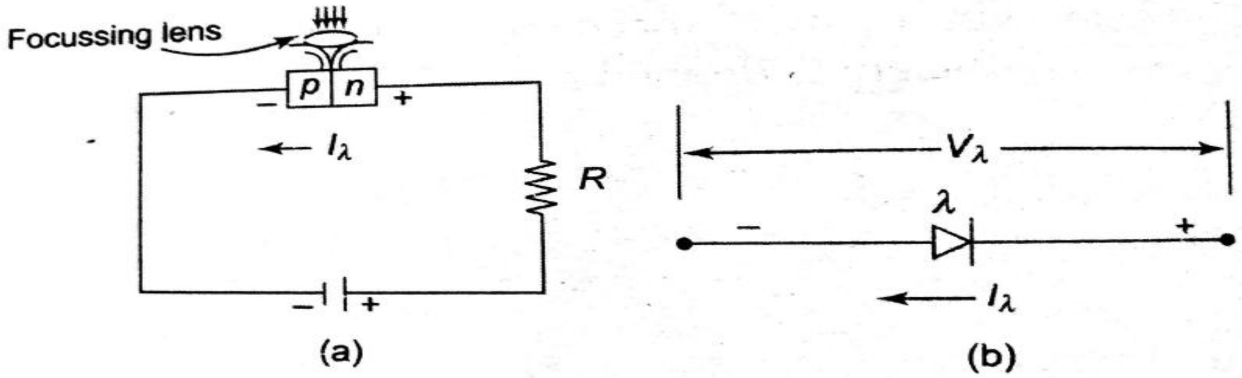
iii) Frequency of output waveform

$$= 2f = 2 \times 50 = \mathbf{100\ Hz}$$

1.28 Introduction to Photo diode, LED & Photo coupler

- Photo Diode, LED and Photo couplers are optoelectronic devices.
- Optoelectronic devices are devices that emit light, modify light, have their resistances affected by light or produce currents and voltages proportional to light intensity.

1.28.1 Photo Diode

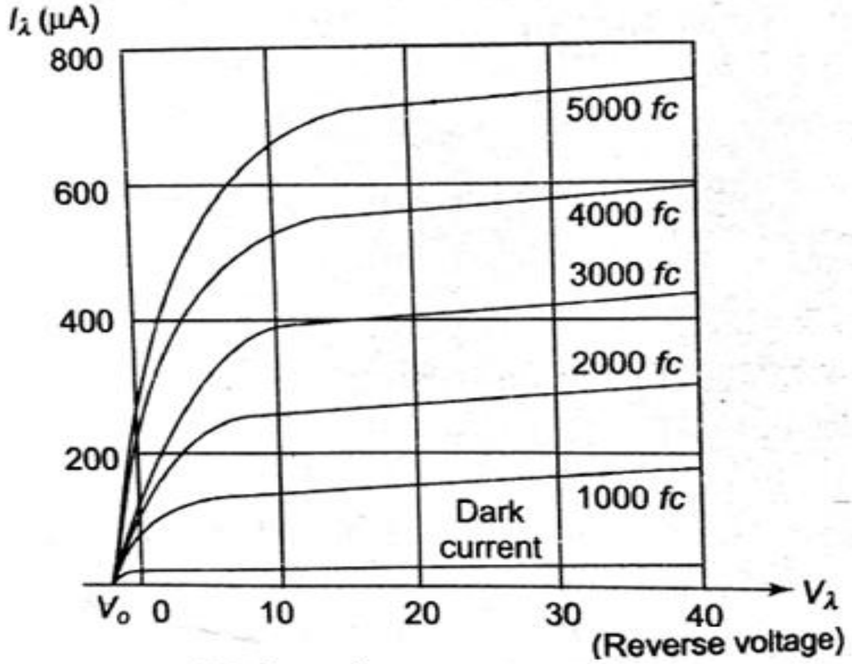


(a) Photodiode in reverse bias (b) Symbol

Fig.48

- A Photo diode is a PN junction (Si/Ge), in which light controls the diode current. It is operated in the reverse bias region.
- The reverse saturation current I_λ(μA) is limited by the availability of thermally generated minority carriers. This current is called dark current(current in the absence of light)
- As light is made to impinge on the junction, the light photons impart energy to the valence electrons causing more electron hole pairs to be released.
- The concentration o f the minority a carrier increase and so does the current I_λ.Thus a photo diode can be used as a photoconductive device.
- When the reverse bias voltage across a photo diode is removed, minority carriers flow back to their original sides, with an external circuit connected across the diode terminals.
- The electrons that had crossed the junction from p to n, will now flow out through the n-terminal and in to the p-terminal. This means that the device is behaving as a voltage cell.
- A Photodiode is thus a photoconductive device (in presence of light under reverse bias) as well as photo-voltaic device (when reverse bias is removed).
- The IV characteristics for various values of light intensity (fc) are shown in Fig.49
- The dark current characteristic corresponds to no light impingement ($I_\lambda = I_S$).

- By examining the characteristics it is found that at certain V_λ (say 20V), I_λ increases almost linearly with fc.



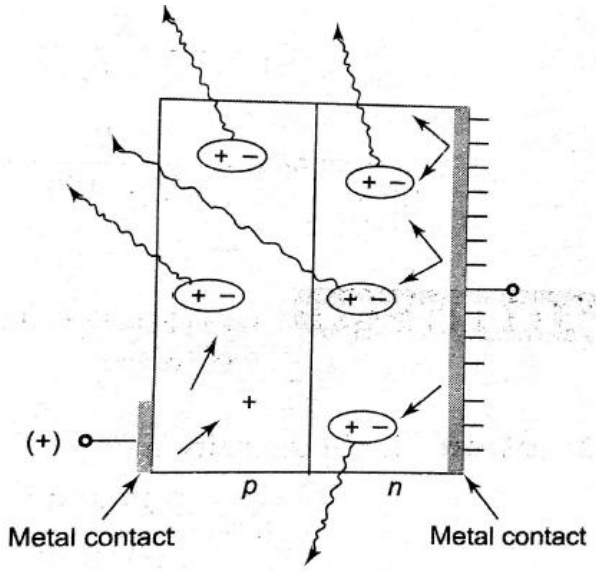
IV characteristics of photodiode

Fig.49

- G_e Photodiodes has more overlaps as compared to Si, which is in the range of light frequencies to which human eye is sensitive. G_e is, therefore more suitable for infra-red (IR) light sources like laser.

1.28.2 LED

- In a forward biased PN-junction, recombination of electrons and holes takes place at the junction and within the body of the crystal.
- Upon capture of a free electron by a hole, the electron goes in to a new state and its kinetic energy is given off as heat and a light photon.
- In a silicon diode, most of the energy is given off as heat, but in other materials such as gallium arsenide (GaAs) or gallium phosphide sufficient number of photons (light) are generated so as to create a visible source.
- This process of light emission in PN junction of such materials is known as electroluminescence which is depicted in the following figure 50.
  The metal contact of P material is made small to permit the emergence of maximum number of photons so that in an LED, the light lumens generated per watt of electric power is quite high.

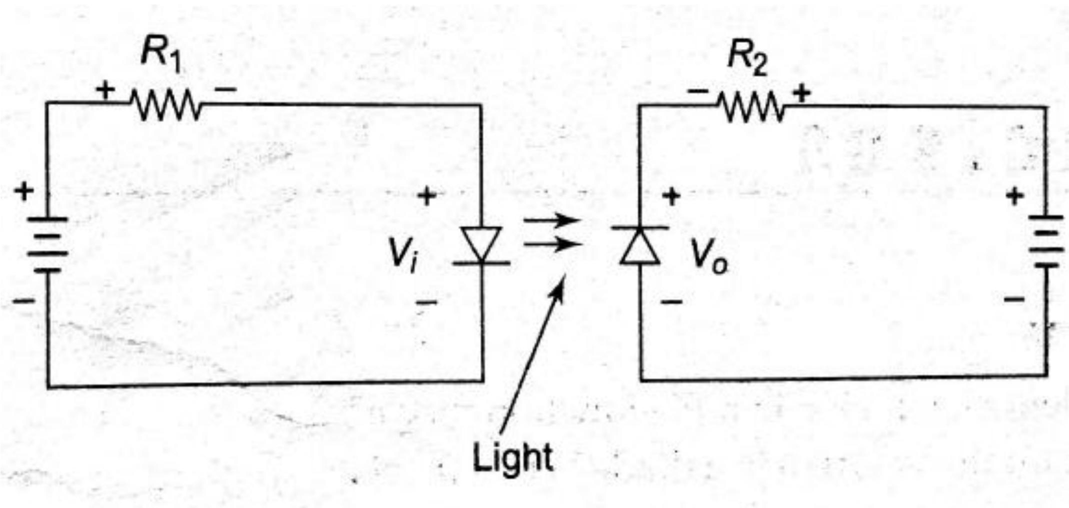


Light emission in PN-junction

Fig.50

1.28.3 Photo Coupler

- It is a package of an LED and photodiode.
- The LED is forward biased and photodiode is reverse biased.
- The output is available across R_2 as shown in Fig.51



Photocoupler

Fig.51

- The Key advantage of the photo coupler is the electrical isolation between two circuits.

1.29 Introduction to regulators

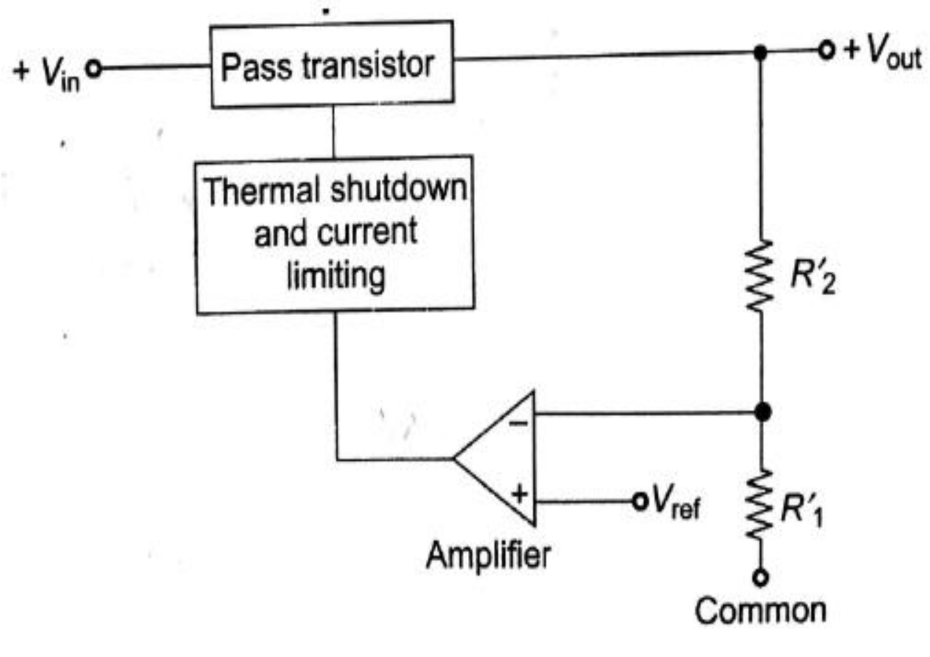
- Most IC voltage regulators have one of the types of output voltage: Fixed positive, fixed negative or adjustable.
- The fixed positive or negative voltage IC regulator provide fixed voltages with magnitudes from about 5 to 24V.
- IC regulators with an adjustable output can vary the regulated output voltage from 2 to 40V.

1.29.1 Advantages of IC voltage Regulators

2. Compact in size & rugged
3. Most efficient & reliable
4. It is very cheap due to mass production & easily available.
5. Has features like built in protection, thermal shut down, current limiting.

1.29.2 The LM78XX series

- The LM78XX series (where XX=05,06,08,10,12,15,18 or 24) are three terminal voltage regulators.
- The 7805 produces an output of +5V, the 7806 produces +6V, the 7808 produces +8V and so on up to 7824 which produces an output of +24V



Functional block diagram of three-terminal IC regulator

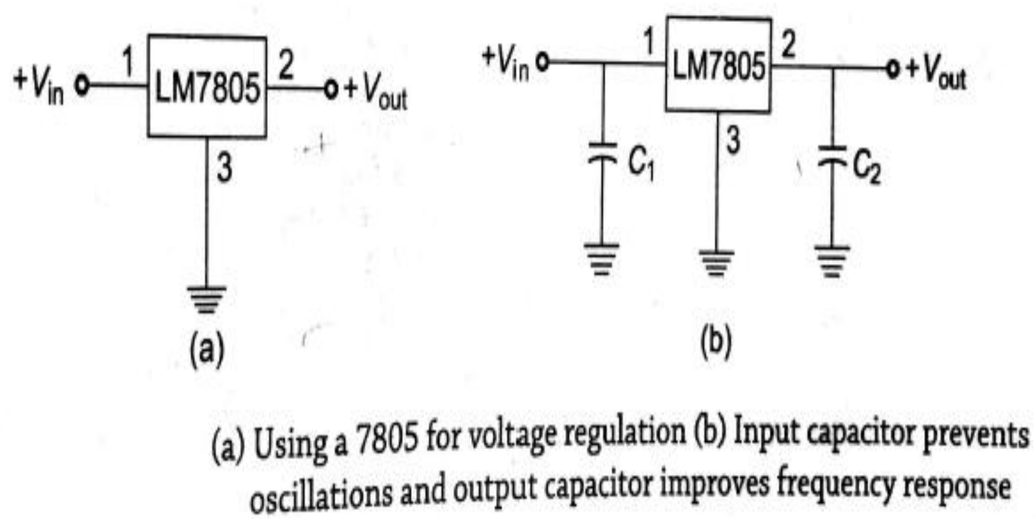
Fig.52

- Fig.52 shows the functional block diagram for the 78XX series.
- A built in reference voltage V_{ref} drives the non-inverting input of an amplifier.

- The voltage divider consisting of **R'$_1$ & R'$_2$** samples the output voltage & returns a feedback voltage to the inverting input of a high-gain amplifier.
- The output voltage is given by
  $V_{out} = (R'_1 + R'_2)/R'_1 \times V_{ref}$ -------(A)
- The **R'$_1$ & R'$_2$** indicate that these resistors are inside the IC itself, rather than being external resistors.
- These resistors are factory trimmed to get the different output voltages (5 to 15V) in the 78XX series.
- The tolerance of the output voltage is +/-4%.
- The Pass transistors of LM78XX series can handle a load current of 1A, with adequate heat sinking.
- Thermal shutdown and current limiting circuit is also included.
- Thermal shutdown is achieved when the chip shuts itself off when the internal temperature becomes too high, around 175^0C. This is a precaution against excessive power dissipation.

1.29.3 Fixed Regulator

The following figure 53 shows an LM7805 connected as a fixed voltage regulator.



Fig,53

- Pin 1 is the input, pin2 is the output & pin3 is ground.
- The LM7805 has an output voltage of +5V and a maximum load current over 1A.
- The typical load regulation is 10mV for a load current between 5mA and 1.5A.
- The typical line regulation is 3mV for an input voltage of 7 to 25V.
- Load regulation =ΔV_{out} for a range of load current
- Line regulation = ΔV_{out} for a range of input voltage
- When an IC is more than 6 from the filter capacitor of the unregulated power supply, the inductance of the connecting wire may produce oscillations inside the IC.
- This is why manufacturers recommend using a bypass capacitor C_1 on pin1.

- To improve the transient response of the regulated output voltage, a bypass capacitor C_2 is sometimes used on pin2.
- 0.22µF for the input capacitor
- 0.1µF for the output capacitor
- Any regulator in the 78XX series has a drop-out voltage of 2 to 3V, depending on the output voltage.
- This means that the input voltage must be at least 2 to 3V greater than the output voltage.
- Otherwise, the chips stops regulating.
- LM7805 will regulate over an input range of approximately 8 to 20V.

1.29.4 Regulated power Supply (Shown in Fig.54)

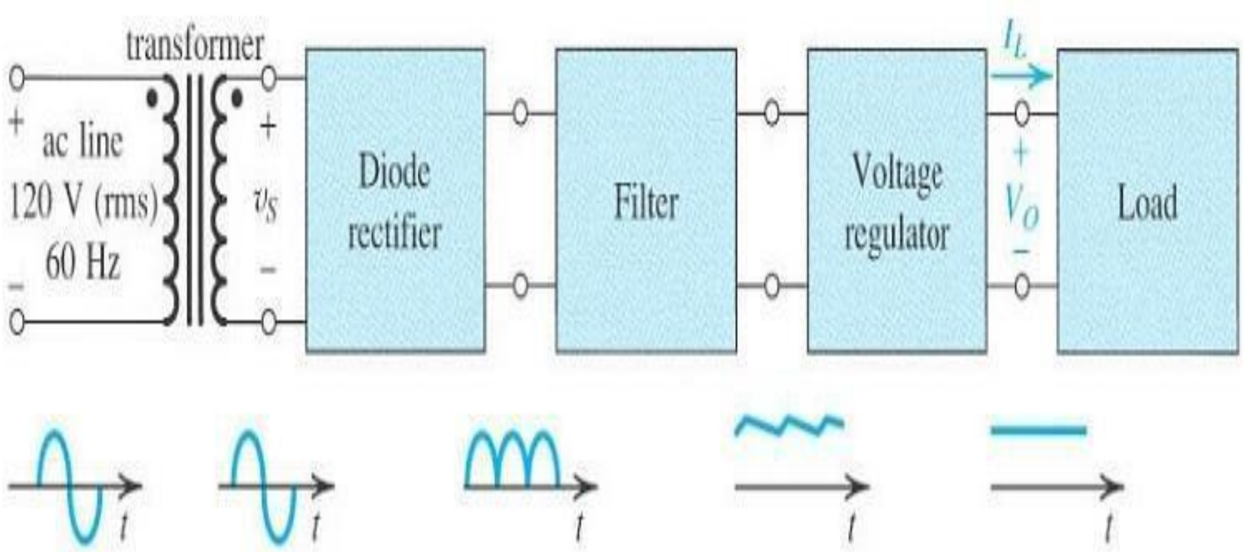


Fig.54

- The AC voltage is connected to the primary of the transformer.
- The transformer steps down to the AC voltage for the desired DC output.
- Pulsating DC voltage contains ripples. To reduce the ripple, filter is used after the rectifier circuit, which reduces the ripple content in the pulsating DC and tries to make it smoother. But still the output of filter contains some ripples and this output is called unregulated DC.
- A circuit used after the filter is a regulator circuit which is not only makes the dc voltage smooth and almost ripple free but it also keeps the dc output voltage constant though input DC voltage varies under certain conditions.
- The regulator also keeps dc voltage constant under variable load conditions.
- The output of the regulator is pure DC and to which the load can be connected

--------------------------End of Module-1-----------------------