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ASPIRE TO EXCEL

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

EC T33 ELECTRONIC DEVICES AND CIRCUITS NOTES

II YEAR/ III SEM

UNIT 1

Semiconductor Diodes

1.1 INTRODUCTION

The aim of Electronic component is to act as switch.

The atom structure is show in fig.

Atom = Nucleus(Protons + Neutrons) **+ Electrons**

The outermost electron in the atom is called as valance electron.

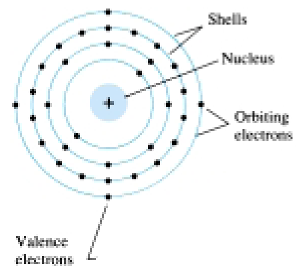


Fig: 1.1 Atom structure

Basically there are three material in nature. They are Conductor, Semiconductor and Insulator. Conduction in all this material starts when the electrons in conduction band moves to the valance band.

For conductor, the conduction and valance band already overlap, so without any external voltage it starts conducting due to normal room temperature (Noise).

For insulator, the conduction and valance band is separated with larger band gap which need very high energy to move the electron from conduction band to valance band. This will fulfill our aim to act as switch but with very high energy is need.

For Semiconductor, the conduction and valance band separated with small band gap which needs low energy to move the electron from conduction to valance band. In case of semiconductor this will act as switch with low energy which will fulfill our aim.

- Intrinsic semiconductor(Pure)
- Extrinsic semiconductor(Impure or Doped)
  - N-Type semiconductor(Electrons are majority carrier)
  - P- Type semiconductor(Holes are majority carrier)

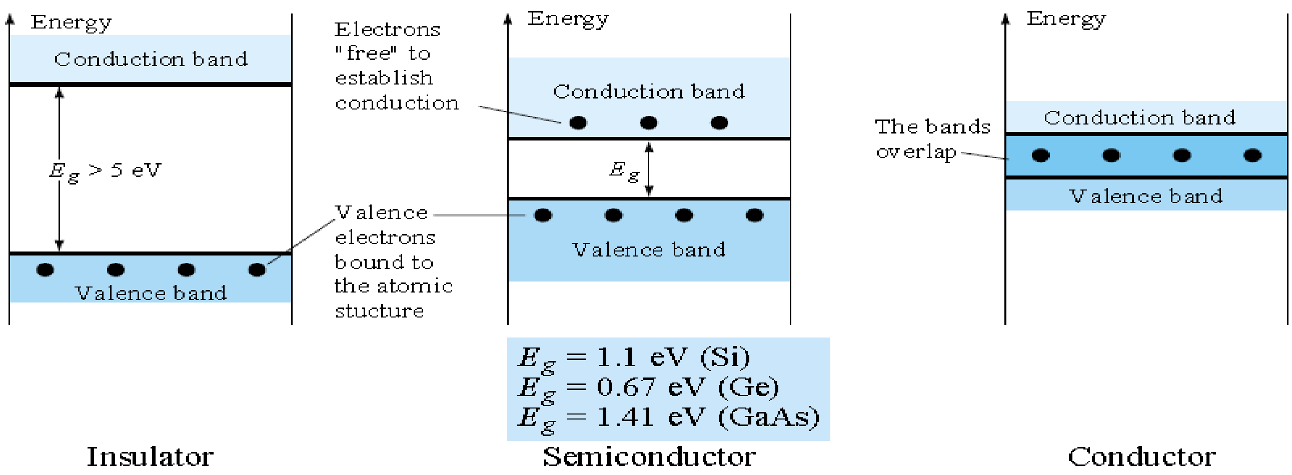


Fig:1.2 Conduction and Valance band of Insulator, Semiconductor and Conductor

1.2 INTRINSIC SEMICONDUCTOR

It is a Pure semiconductor without any impurities. Fig 1.2 shows the energy band diagram of intrinsic semiconductor. For Ge(Germanium) material electrons take 0.67 eV to reach conduction band from valance band and for Si(silicon) 1.1 eV. But silicon is cheaper than germanium. That's why silicon is used widly.

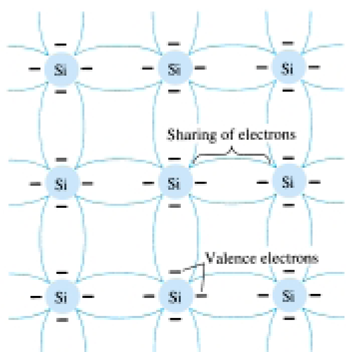


Fig: 1.3 Intrinsic Semiconductor

To reduce the energy further, should reduce the band gap. This is done by means of doping.

Doping- Process of adding impurities in intrinsic semiconductor.

1.3 EXTRINSIC SEMICONDUCTOR

All the dopped semiconductors are called as Extrinsic semiconductor.

If the dopped atom creats excess electron in the atom means then it is called as N- Type semiconductor. Electrons are majority carriers. Holes are minority carriers. (i.e.,) Pentavelant impurities are used for doping (Arsenic(As), Antimony(Sb), Phosphorous(P)).

If the dopped atom creats holes in the atom means then it is called as P-Type semiconductor. Holes are majority carriers. Electrons are minority carriers. (i.e.,) Trivalent impurities are used for doping (Boron(B), Gallium(Ga), Indium(In)).

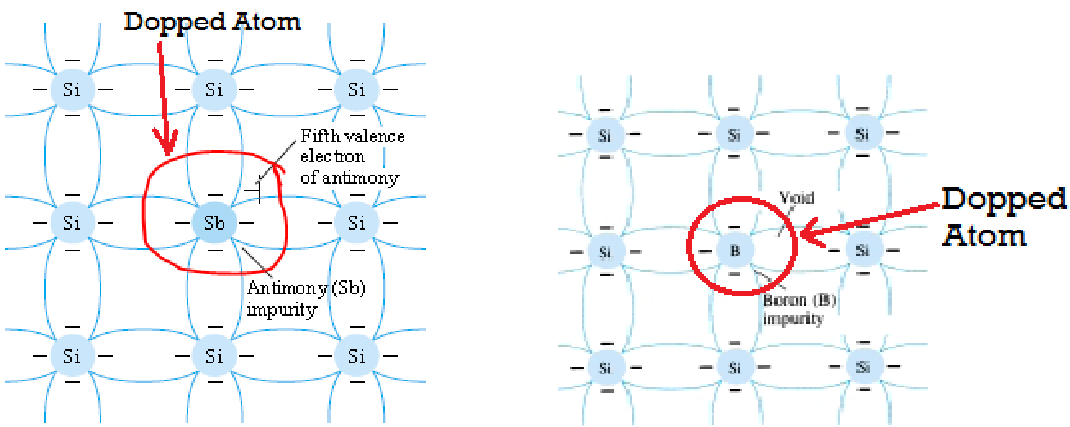


Fig: 1.4 (a) N-Type Semiconductor, (b) P-Type Semiconductor

This P-Type and N-Type Jointly form the PN doide.

1.4 PN JUNCTION DIODE

Combination of P and N type semiconductor is called as PN junction diode. It is lightly doped diode.

Symbol

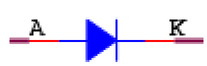


Fig: 1.5 Circuit symbol

Construction of PN Junction Diode

- P-Type and N-Type semicondutor combined to form the PN junction diode.

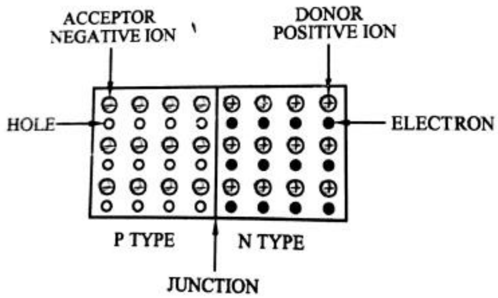


Fig: 1.6 PN Junction Diode

- In P side, each acceptor atom accepts one electron from semiconductor atom and the acceptor atom become immobile negative ion and semiconductor atom become hole. The P side has excess holes.
- In N side, each donor atom donate one electron and the donor atom become immobile positive ion, there is one free electron for each positive immobile ion. The N side has excess electrons.

Depletion Region

- Electrons move from N side to P side and recombine with holes in the P type material. Because of this movement and recombination, electrons in N type and holes in P type material disappear.

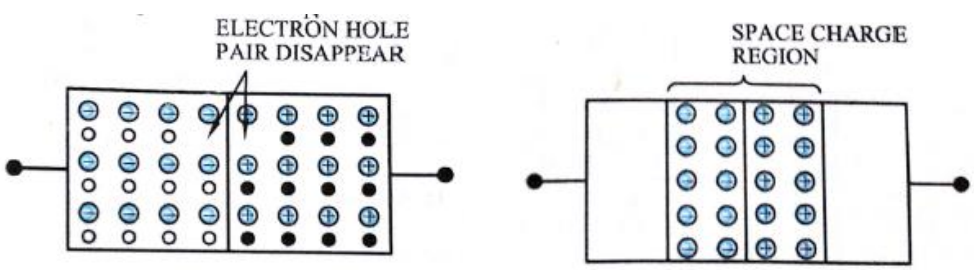


Fig: 1.7 Space Charge region (or) Depletion region

- Near the junction there will be an array of negative and positive immobile ions, which will block the electron hole mobility from one side to another. An equilibrium condition will be reached.
- This region near the junction, which consist of immobile ions, is called space charge region or transision region or depletion region(no mobile carriers).

Barrier Potential

- In depletion region there are positive charges in the N side and negative charges in the P side forms electric dipole layer, giving rise to a potential difference V_o. This potential difference is called barrier Potential.
- It prevent the movement of mobile carriers across the junction. V_o is 0.3 V for Ge and 0.7 V for Si.

Operation of PN Junction Diode(VI Characteristics)

- There are two main operation
    - Forward bias
    - Reverse bias
- Bias is nothing but applying external voltage.

Forward Bias

(Batteries Positive terminal is connected to P type and Negative terminal is connected to N type)

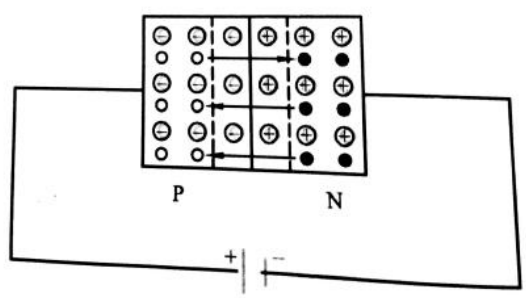


Fig: 1.8 Diode in Forward Bias

- When an external voltage is applied, the holes in the P type material are repelled by the positive terminal of the battery, and the electrons in the N type material are repelled by the negative terminal of the battery, Which will reduces the width of the depletion region. Further increase in external voltage above the barrier potential voltage, then the depletion region gets broken. Holes cross the junciton and move towards negative terminal of the battery and electrons moves towards positive terminal of the battery.
- Due to this movement of charges, produces a high forward current, which is show in the forward VI characteristics.
- When the applied voltage reaches the barrier potential then the junction break down occurs which increases the flow of electrons. The point at which diode starts conducting in forward bias is called as **knee voltage** or **cut in voltag**e or **threshold voltage**

Reverse Bias

(Batteries Positive terminal is connected to N type and Negative terminal is connected to P type)

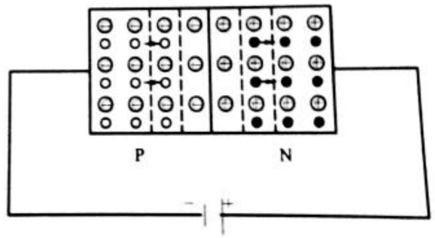


Fig: 1.9 Diode in Reverse Bias

- When an external voltage is applied, the holes in the P type material are attracted by the negative terminal of the battery, and the electrons in the N type material are attracted by the positive terminal of the battery, Which will increases the width of the depletion region and barrier potential. The high barrier potential will not allow charge carriers to move across the junction. Therefore in reverse bias no current flow through the junction.
- PN junction diode offers very low resistance in forward bias and very high resistance in reverse bias.
- When the voltage across the diode is increased, the depletion layer is strengthened, therefore the current through the diode is the reverse saturation current. Further increase in reverse voltage will suddenly increases the high reverse saturation current due to the breakdown of the diode. The minimum voltage at which the breakdown occurs is called breakdown voltage.

Diode Current Equation or Shockley Diode Equation

- The mathematical equation which describes the forward and reverse characteristic of a semiconductor diode is called diode current equation.

$$I = I_o\left(e^{\frac{V}{\eta V_T}} - 1\right)$$

Where, I = forward (reverse) diode current

I_o = reverse saturation current

V = external voltage, it is positive for forward bias and negative for reverse bias

η = 1 for Ge and 2 for Si

V_T = volt equivalent of temperature

Application

- Diode can be used as switch, because it offers very low resistance (Closed switch) in forward bias and very high resistance (open switch) in reverse bias.
- Diode can be used as rectifier to convert AC signal into DC signal.

1.5 **PN DIODE CURRENT EQUATION**

Consider a forward biased PN junction diode, holes are injected into N side and from P side. Holes are minority carrier in N side. The minority carrier holes concentration in N side decreases exponentially from the junction as shown in Fig: 1.10.

Similarly electrons are injected into P side from N side, electrons are minority carrier in P side. In N side, electron concentration decreases exponentially from the junction. In diode the current conduction is by both the charge carriers so it is called bipolar device.

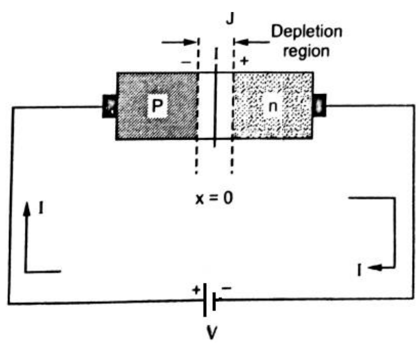


Fig: 1.10 PN Junction Diode

Let p_p – Hole concentration in P-type at the edge of depletion region

n_n – Electron concentration in N type at the edge of the depletion region

p_n – Hole concentration in N type at the edge of the depletion region

n_p – Electron concentration in P type at the edge of the depletion region

Under the biased condition, when holes moves from p-side to n-side due to diffusion their concentration behaves exponentially.

$$p_p = p_n e^{V_J/V_T} \qquad \text{----------} \quad (1)$$

Where V_J is barrier potential or junction potential

Now consider forward biased diode. The junction is at x=0.

Holes concentration in P region near the junction, $p_{p0} = p_n(0)e^{(V_J-V)/V_T}$ ---------- (2)

When V=0 (i.e., Unbiased condition) $p_{p0} = p_{n0}e^{V_J/V_T}$ ----------- (3)

Where p_{n0} is concentration of holes on n-side just near the junction.

As the concentration of holes in entire P- region is constant, equating (2) and (3) we get,

$$p_n(0)e^{(V_J-V)/V_T} = p_{n0}e^{V_J/V_T}$$

$$p_n(0) = p_{n0}e^{V/V_T} \quad \text{--------} \quad (4)$$

This equation represents boundary condition and called **law of junction.**

Similarly $n_p(0) = n_{p0}e^{V/V_T}$ --------- (5)

Now the difference between two concentrations at the junction under unbiased and biased concentration is called as **excess concentration.**

$$P_n(0) = p_n(0) - p_{n0} \quad \text{----------} \quad (6)$$

Using (4) in (6),

$$P_n(0) = p_{n0}e^{V/V_T} - p_{n0}$$

$$P_n(0) = p_{n0}\left(e^{V/V_T} - 1\right) \quad \text{-----------} \quad (7)$$

Similarly, $N_p(0) = n_{p0}\left(e^{V/V_T} - 1\right)$ --------- (8)

The hole current crossing the junction from p-side to n-side is given by,

$$I_{pn}(0) = \frac{qAD_p p_n(0)}{L_p} \quad \text{-----------} \quad (9)$$

While an electron current crossing the junction from n- side to p-side is given by,

$$I_{np}(0) = \frac{qAD_n N_p(0)}{L_n} \quad \text{-----------} \quad (10)$$

Where A= area of cross-section of junction

D_p = Diffusion constant for holes

D_n = Diffusion constant for electrons

L_p = Diffusion length for holes

L_n = Diffusion length for electrons

The total **diode current** I at the junction is the total conventional current flowing through the circuit.

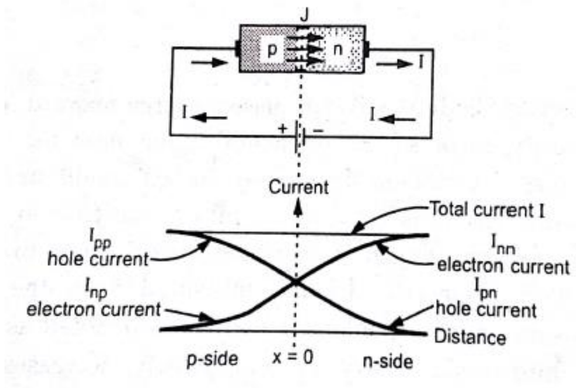


Fig: 1.11 Current components

Current on P side = $I_{pp}(x) + I_{np}(x) \approx I_{np}(x)$

Current on N side = $I_{nn}(x) + I_{pn}(x) \approx I_{pn}(x)$

Total current I is given by,

$$I = I_{pn}(0) + I_{np}(0) = \frac{qAD_p P_n(0)}{L_p} + \frac{qAD_n N_p(0)}{L_n}$$

$$= \left[\frac{qAD_p P_{n0}}{L_p} + \frac{qAD_n n_{p0}}{L_n}\right]\left(e^{V/V_T} - 1\right)$$

$$I = I_o\left(e^{\frac{V}{V_T}} - 1\right)$$

Where, $I_0 = \frac{qAD_p P_{n0}}{L_p} + \frac{qAD_n n_{p0}}{L_n}$ = reverse saturation current

$$I = I_o\left(e^{\frac{V}{\eta V_T}} - 1\right)$$

The value of η =1 for Ge diodes and η =2 for Si diodes.

1.6 TEMPERATURE EFFECTS OF PN JUNCTION DIODE

The rise in temperature increases the generation of electron-hole pairs in semiconductors and increases their conductivity. As a result, the current through the PN junction diode increases with temperature as given by the diode current equation.

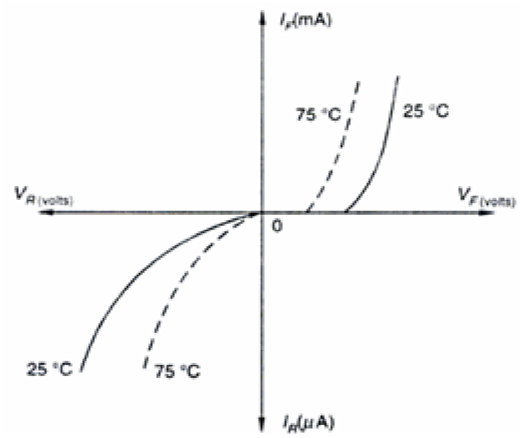


Fig: 1.12 Effect of temperature on the diode characteristics

The small conduction current makes forward bias and reverse bias breakdown earlier in the PN junction diode.

Temperature α Current

$$I = I_o\left(e^{-\frac{V}{\eta V_T}} - 1\right)$$

The reverse saturation current I_o, doubles with every 10^o C increase in temperature.

1.7 D.C OR STATIC RESISTANCE (R_F)

It is defined as the ratio of the voltage to the current, V/I, in the forward bias characteristics of the PN junction diode. In the forward bias characteristics of the diode as shown in Fig: 1.13**.** The d.c. or static resistance (RF) at the operating point can be determined by using the corresponding levels of voltage V and current I, i.e.

$$R_F = \frac{V}{I}$$

Here, the D.C resistance is independent of the shape of the characteristics in the region surrounding the point of interest. The D.C. resistance levels at the knee and below will be greater than the resistance levels obtained for the characteristics above the knee. Hence, the D.C. resistance will be low when the diode current is high. As the static resistance varies widely with V and I, it is not a useful parameter.

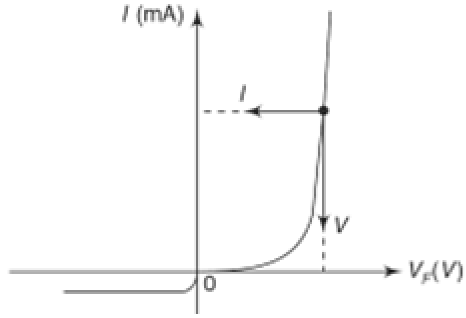


Fig: 1.13 Forward biasing of a diode

1.8 A.C. OR DYNAMIC RESISTANCE (R_F)

It is defined as the reciprocal of the slope of the volt-ampere characteristics

$$r_f = \frac{\text{Change in voltage}}{\text{resulting change in current}} = \frac{\Delta V}{\Delta I}$$

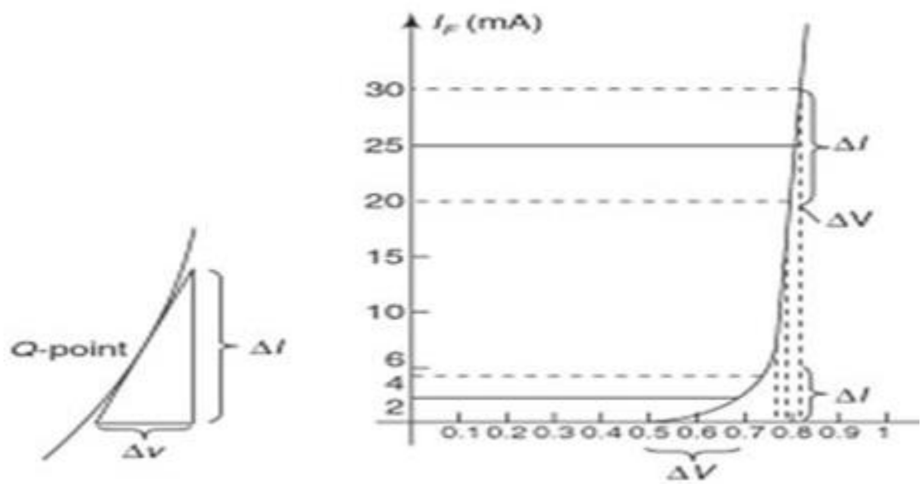


Fig: 1.14 Dynamic Resistance

The **Schokley's equation** for the forward and reverse bias region is defined by

$$I = I_o \left(e^{-\frac{V}{\eta V_T}} - 1 \right)$$

Taking the derivative of the above equation w.r.t the applied voltage, V, we get

$$\frac{dI}{dV} = \frac{d}{dV}[I_o\,(e^{V/\eta V_T} - 1)]$$

$$= I_o\left[\frac{1}{\eta V_T} \cdot e^{V/\eta V_T}\right]$$

$$= \frac{I_o e^{V/\eta V_T}}{\eta V_T}$$

$$= \frac{I + I_o}{\eta V_T}$$

Generally I>>I0 in the vertical-slope section of the characteristics. Therefore,

$$\frac{dI}{dV} \cong \frac{I}{\eta V_T}$$

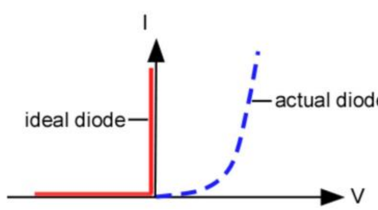
$$\frac{dV}{dI} = r_f = \frac{\eta V_T}{I}$$

The dynamic resistance varies inversely with current.

1.9 DIODE EQUIVALENT CIRCUIT

Ideal Diode

When the forward resistance is zero and reverse resistance is infinity then it is called as Ideal diode.



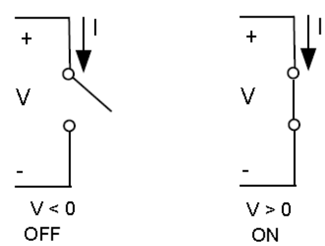


Fig: 1.15 V-I Characteristics of Ideal Diode. Reverse biased Forward biased

But practically it is not possible to get the zero resistance in any device.

Practical Diode

Practically it is impossible to get the resistance zero, some forward resistance (R_f) present in the circuit. The diode starts conducting after 0.6 V, that is represented by adding the voltage source in the practical diode model

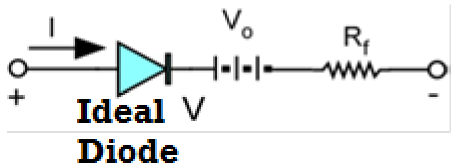


Fig: 1.16 Practical diode model

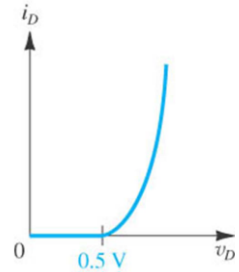


Fig: 1.17 V-I characteristics

Piecewise Linear Model of Diode

For analyzing purpose the VI characteristics of diode is approximated only by straight line i.e., linear relationship.

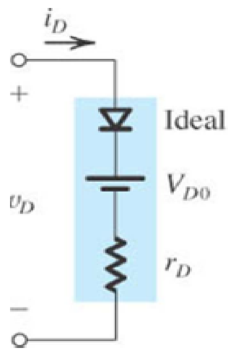


Fig: 1.18 Piecewise linear model

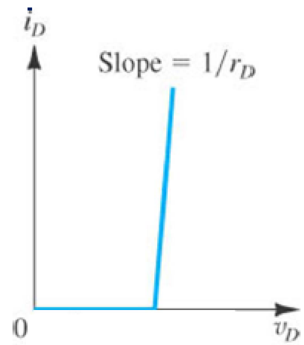


Fig: 1.19 V-I characteristics

1.10 TRANSITION OR SPACE CHARGE CAPACITANCE (C_T)

When a diode is reverse biased, the width of the depletion region increases. So, there are more positive and negative charges present in the depletion region. Due to this, the P region and N region act like parallel plate capacitor while depletion region acts like dielectric. There exists a capacitance called transition capacitance or junction capacitance or space charge capacitance or barrier capacitance or depletion region capacitance.

$$C_T = \frac{\varepsilon A}{W}$$

where ε is the permittivity of the material, A is the cross-sectional area of the junction and W is the width of the depletion layer over which the ions are uncovered.

This capacitance is is voltage dependent and is given by

$$C_T = \frac{k}{(V_k + V_R)^n}$$

V_k = Knee voltage,

1.11 DIFFUSION CAPACITANCE (C_D)

In forward biased condition, the width of the depletion region decreases and holes from P-side get diffused in N- side while electrons from N- side move into the P-side. As the applied voltage increases, concentration of injected charged particles increases. This rate of change of the injected charge with applied voltage is defined as a capacitance is called diffusion capacitance.

$$C_D = \frac{dQ}{dV},$$

The diffusion capacitance can be determined by the expression

$$C_D = \frac{\tau I}{\eta V_T}$$

Where τ is the mean life time for holes and electrons.

1.12 DIODE SWITCHING TIMES

Diodes are often used in a switching mode. When the applied bias voltage to the PN diode is suddenly reversed in the opposite direction, the diode response reaches a steady state after an interval of time, called the recovery time.

The forward recovery time, t_{fr}, is defined as the time required for forward voltage or current to reach a specified value (time interval between the instant of 10% diode voltage to the instant this voltage reaches within 10% of its final value) after switching diode from its reverse-to forward-biased state. Fortunately, the forward recovery time possess no serious problem. Therefore, only the reverse recovery time, t_{rr}, has to be considered in practical applications.

When the PN junction diode is forward biased, the minority electron concentration in the P-region is approximately linear. If the junction is suddenly reverse biased, at t1, then because of this stored electronic charge, the reverse current (I_R) is initially of the same magnitude as the forward current (I_F). The diode will continue to conduct until the injected or excess minority carrier density (p-p0) or (n-n0) has dropped to zero. However, as the stored electrons are removed into the N-region and the contact, the available charge quickly drops to an equilibrium level and a steady current eventually flows corresponding to the reverse bias voltage as shown in figure1.6(c).

As shown in fig.1.20 (b), the applied voltage V_i=V_F for the time up to t1 is in the direction to forward-bias the diode. The resistance R_L is large so that the drop across R_L is large when compared to the drop across the diode. Then the current is

$$I \approx \frac{V_F}{R_L} = I_F$$

Then, at time t=t_1, the input voltage is suddenly reversed to the value of –VR. Due to the reasons explained above, the current does not become zero and has the value until the time t=t_2. At t=t_2,

$$I = \frac{V_R}{R_L} = -I_R$$

when the excess minority carriers have reached the equilibrium state, the magnitude of the diode current starts to decrease, as shown in fig.1.20(d)

During the time interval from t_1 to t_2, the injected minority carriers have remained stored and hence this time interval is called the storage time (t_s).

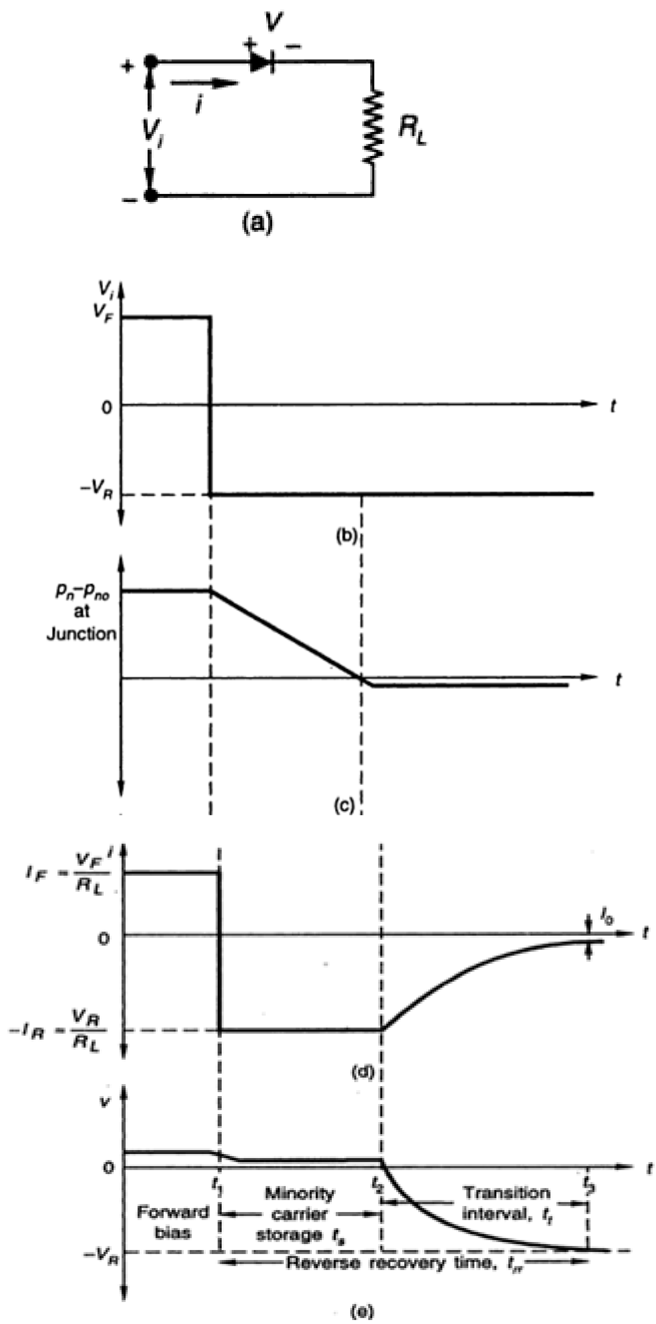


Fig: 1.20 Switching characteristics of PN junction diode

After the instant t=t2, the diode gradually recovers and ultimately reaches the steady-state. The time interval between t2 and the instant t3 when the diode has recovered nominally, is called the transition time, tt. The recovery is said to have completed (i) when even the minority carriers remote from the junction have diffused to the junction and crossed it, and (ii) when the junction transition capacitance, CT, across the reverse-biased junction has got charged through the external resistor RL to the voltage –VR.

The reverse recovery time (or turn-off time) of a diode, trr, is the interval from the current reversal at t=t1 until the diode has recovered to a specified extent in terms either of the diode current or of the diode resistance, i.e. trr=ts+tt.

For commercial switching type diodes the reverse recovery time, trr, ranges from less than 1ns up to as high as 1 μs. This switching time obviously limits the maximum operating frequency of the device. If the time period of the input signal is such that T=2.trr, then the diode conducts as much in reverse as in the forward direction. Hence it does not behave as a one way device. In order to minimise the effect of the reverse current, the time period of the operating frequency should be a minimum of approximately 10 times t_{rr}. For example, if a diode has t_{rr} of 2ns, its maximum operating frequency is

$$f_{max} = \frac{1}{T} = \frac{1}{10 \times t_{rr}} = \frac{1}{10 \times 2 \times 10^{-9}} = 50 \text{ MHz}$$

The t_{rr} can be reduced by shortening the length of the P-region in a PN junction diode. The stored charge and, consequently, the switching time can also be reduced by introduction of gold impurities into the junction diode by diffusion. The gold dopant, sometimes called a life time killer, increases the recombination rate and removes the stored minority carriers. This technique is used to produce diodes and other active devices for high speed applications.

1.13 ZENER DIODE

- Zener diode is a heavily doped PN junction diode.
- Depletion layer is very thin (due to heavy doping).
- Junction electric field is strong therefore lower applied reverse voltage is enough to cause the breakdown. Which is called as Zener breakdown.
- Zener breakdown is sharp

Symbol

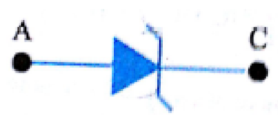


Fig: 1.21 Circuit symbol

V-I Characteristics

- Forward bias
- Reverse bias

Bias- applying external voltage

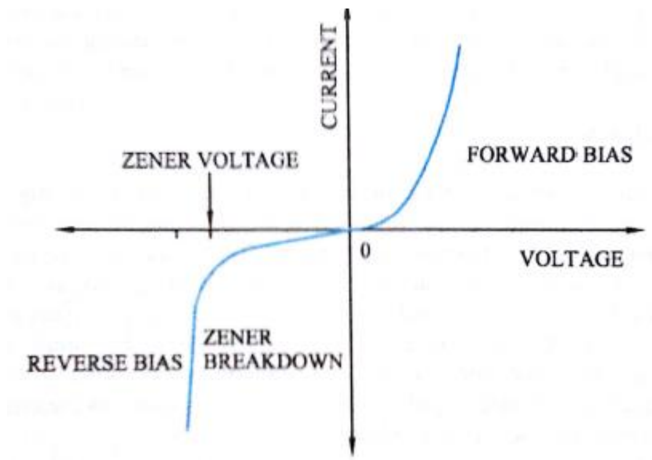


Fig: 1.21 V-I Characteristics of Zener diode

Forward Bias

(Batteries Positive terminal is connected to P type and Negative terminal is connected to N type)

In forward biased condition Zener diode acts as the ordinary PN junction diode.

- When an external voltage is applied, the holes in the P type material are repelled by the positive terminal of the battery, and the electrons in the N type material are repelled by the negative terminal of the battery, Which will reduces the width of the depletion region. Further increase in external voltage above the barrier potential voltage, then the depletion region gets broken. Holes cross the junciton and move towards negative terminal of the battery and electrons moves towards positive terminal of the battery.
- Due to this movement of charges, produces a high forward current, which is show in the forward VI characteristics.

Reverse Bias

(Batteries Positive terminal is connected to N type and Negative terminal is connected to P type)

- At a reverse voltage the electric field in the depletion layer will be strong enough to break the covalent bonds. This produces extremely large number of electrons and holes and heavy current flow through the junction causing breakdown. The zener breakdown voltage depends on the amount of doping.

Application

- In the zener breakdown region voltage across the diode remains constant over a wide range of current, therefore zener diode can be used as **Voltage regulator.**

1.14 BREAKDOWNS IN DIODE

In reverse bias, breakdown of the junction occurs by two mechanisms, they are Zener Breakdown and Avalanche Breakdown.

Zener Breakdown

Zener breakdown takes place in a heavily doped diode. In a heavily doped diode the depletion layer will be thin and the electric field in the depletion layer will be high. When a small reverse bias voltage is applied, a very strong electric field (about 10^7 V/m) is set up across the thin depletion layer. This field directly breaks or ruptures the covalent bonds. Now extremely large number of electrons and holes are produced and the current through the diode increases rapidly. This mechanism is called **Zener Breakdown**.

Avalanche Breakdown

Avalanche breakdown takes place in lightly doped diode, whose depletion layer is large and the electric field across the depletion layer is not so strong to break covalent bond. In the depletion layer thermally generated minority carriers are accelerated by the electric field. The minority carriers move with high speed and collide with atoms. Due to the collision covalent bonds are broken and electron hole pairs are generated. These new carries so produced are also accelerated by the field and they break more covalent bonds. This forms a cumulative process is called as **avalanche** (or flood) multiplication and the current through the diode increases rapidly. This breakdown is called as **avalanche breakdown**.

UNIT II

BJT and FET

2.1 BIPOLAR JUNCTION TRANSISTOR (BJT)

- Transistor is a two junction, three terminal device.
- Conduction due to both majority and minority charge carriers. (i.e., Bipolar).

Construction

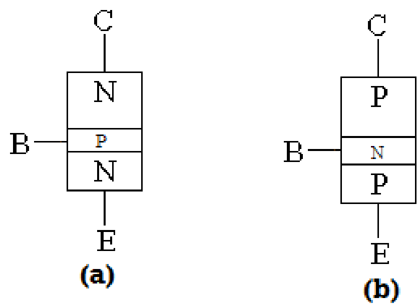


Fig: 2.1 Transistor (a) NPN & (b) PNP

- Transistor is simply a sandwich of one type semiconductor material between two layers of other type. There are two types of Transistor, they are
    - **NPN transistor –** P type material is sandwich between two layer of N type material.
    - **PNP transistor -** N type material is sandwich between two layer of P type material.

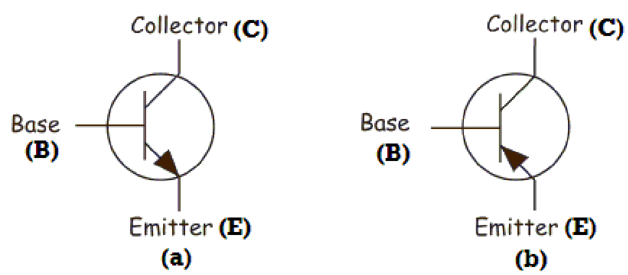


Fig: 2.2 Circuit symbol of (a) NPN & (b) PNP Transistor

- Arrowhead should be at the emitter terminal. It indicates the directional of current flow when emitter base junction is forward biased.

Terminals

Emitter: The main function of this region is to supply majority charge carriers to the base. Emitter region is more heavily doped when compared with other regions.

Base: The middle section of the transistor is known as base. Base region is very lightly doped and is very thin as compared to either emitter or collector. It is made very thin to reduce recombination of charge carriers in the base region.

Collector: The main function of the collector is to collect majority charge carriers through the base. Collector region is moderately doped. The collector region is made physically larger than the emitter region. This is due to the fact that collector has to dissipate much greater power. Due to this difference, collector and emitter are not interchangeable.

Operating Modes

Transistor can be considered as two diodes connected back to back. Consider current flowing from collector to emitter of an NPN. It is operated in three regions

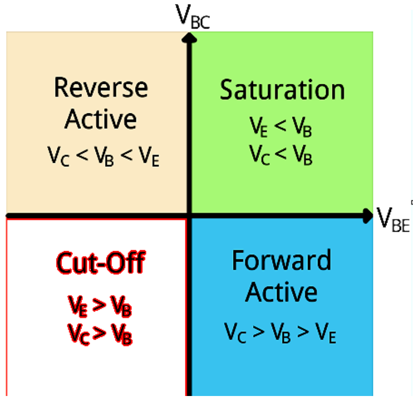


Fig: 2.3 Graphical representation of different regions with its voltages

- **Saturation** – The transistor acts like a short circuit. Current freely flows from collector to emitter. i.e., both collector base and emitter base junction are forward biased
- **Cut-off** – The transistor acts like an open circuit. No current flows from collector to emitter. i.e., both collector base and emitter base junction are Reverse biased
- **Active** - Emitter base junction is Forward biased and collector base junction is Reverse biased
- **Active – Forward Active:** The current from collector to emitter is proportional to the current flowing into the base.
- **Active – Reverse Active:** Like forward active mode, the current is proportional to the base current, but it flows in reverse. Current flows from emitter to collector.

2.2 TRANSISTOR BIASING

As shown in fig 2.4, usually the emitter-base junction is forward biased (F.B) and collector-base junction is reverse biased (R.B). Due to the forward bias on the emitter-base junction, an emitter current flows through the base into the collector. Though the collector-base junction is reverse biased, almost the entire emitter current flows through the collector circuit.

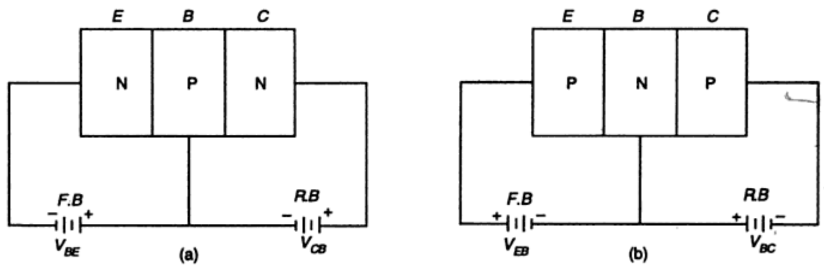


Fig: 2.4 Transistor biasing (a) NPN transistor and (b) PNP transistor

2.3 OPERATION OF NPN TRANSISTOR

As shown in fig 2.5, the forward bias applied to the emitter base junction of an NPN transistor causes a lot of electrons from the emitter region to crossover to the base region. As the base is lightly doped with P-type impurity, the number of holes in the base region is very small and hence the number of electrons that combine with holes in the P-type base region is also very small. Hence a few electrons combine with holes to constitute a base current IB. The remaining electrons (more than 95%) crossover into the collector region to constitute a collector current IC. Thus the base and collector current summed up gives the emitter current, i.e.

$$I_E = -(I_C + I_B).$$

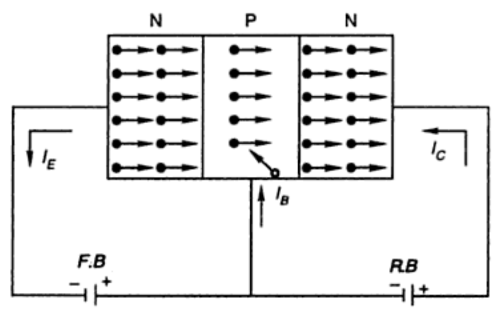


Fig: 2.5 Current in NPN transistor

In the external circuit of the NPN bipolar junction transistor, the magnitudes of the emitter current IE, the base current IB and the collector current IC are related by

$$I_E = I_C + I_B.$$

2.4 OPERATION OF PNP TRANSISTOR

As shown in fig 2.6, the forward bias applied to the emitter-base junction of a PNP transistor causes a lot of holes from the emitter region to crossover to the base region as the base is lightly doped with N-type impurity. The number of electrons in the base region is very small and hence the number of holes combined with electrons in the N-type base region is also very small. Hence a few holes combined with electrons to constitute a base current IB. The remaining holes (more than 95%) crossover into the collector region to constitute a collector current Ic. Thus the collector and base current when summed up gives the emitter current, i.e.

$$I_E = -(I_C + I_B).$$

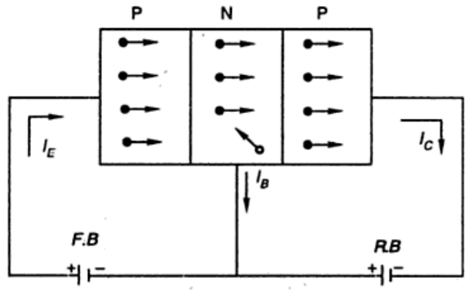


Fig: 2.6 Current in PNP transistor

In the external circuit of the PNP bipolar junction transistor, the magnitudes of the emitter current IE, the base current IB and the collector current Ic are related by

$$I_E = I_C + I_B$$

This equation gives the fundamental relationship between the currents in a bipolar transistor circuit. Also, this fundamental equation shows that there are current amplification factors α and β in common base transistor configuration and common emitter transistor configuration respectively for the static (D.C) currents, and for small changes in the currents.

2.5 TRANSISTOR CURRENT COMPONENTS

In the fig 2.7 shown the various components which flow across the forward-based emitter junction and the reverse-biased collector junction. The emitter current I_E consists of hole current I_{pE} (holes crossing from the emitter into base) and electron current I_{nE} (electron crossing from base into the emitter). The ratio of hole to electron currents, I_{pE} / I_{nE}, crossing the emitter junction is proportional to the ratio of the conductivity of the p material to that of the n material. In the commercial transistor the doping of the emitter is made much larger than the doping of the base. This future ensures (in a p-n-p transistor) that the emitter current consists almost entirely of the holes. Such a situation is desired since the current which results from electrons crossing the emitter junction from base to emitter does not contribute carriers which can reach the collector.

Not all the holes crossing the emitter junction J_E reach the collector junction J_c because some of them combine with the electrons in the n – type base. If I_{pc} is the hole current at J_c, there must be a bulk recombination current I_{pE} - I_{pC} leaving the base, as indicated in figure. (actually, electrons enter the base region through the base lead to supply those charges which have been lost by recombination with the holes injected into the base across $J_{E)}$.

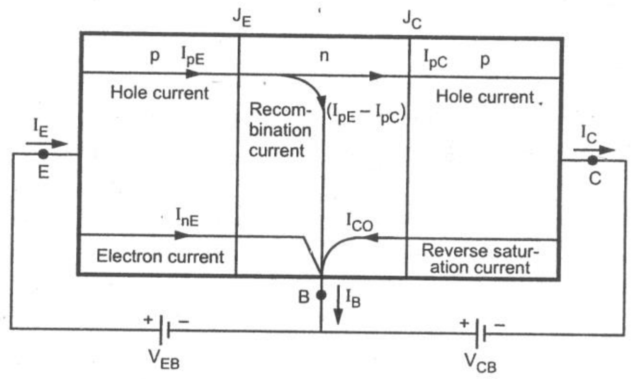


Fig: 2.7 Transistor current components

If the emitter were open-circuited so that $I_E = 0$, then I_{pC} would be zero. Under these circumstances, the base and collector would act as a reverse-biased diode, and the collector current I_c would equal the reverse saturation current I_{CO}. If $I_E \neq 0$, then, from figure, we note that

$$I_c = I_{co} - I_{pC}$$

For a p-n-p transistor, I_{co} consists of holes moving across J_c from left to right (base to collector) and electrons crossing J_c in the opposite direction. Since the assumed reference direction for I_{co} in figure is from right to left, then for a p-n-p transistor, I_{co} is negative. For an n-p-n transistor, I_{co} is positive.

Emitter Efficiency:- (γ)

The emitter, or injection, efficiency γ is defined as

$$\gamma \equiv \frac{\text{current of injected carriers at emitter junction}}{\text{Total emitter current}}$$

In the case of a p-n-p transistor, $\gamma = \frac{I_{pE}}{I_{pE} + I_{nE}} = \frac{I_{pE}}{I_E}$

Where I_{pE} is the injected hole diffusion current at emitter junction and I_{nE} is the injected electron diffusion current at emitter junction.

Transport Factor:- (β)

The transport factor β is defined as

$$\beta = \frac{\text{injected carrier current at the collector junction}}{\text{injected carrier current at the emitter junction}}$$

$$\beta = \frac{I_{pC}}{I_{pE}}$$

Large – signal current Gain:- (α)

We define the ratio of the negative of the collector-current increment to the emitter-current change from zero (cutoff) to IE as the large-signal currant gain of a common-base transistor, or

$$\alpha = -(I_c - I_{co})/I_E$$

since I_c and I_E have opposite signs, then α, as defined, is always positive Typical numerical values of α lie in the range of 0.90 to 0.995.

$$\alpha = I_{pC} / I_E$$
$$= (I_{pC} / I_{pE}).\ (I_{pE} / I_E)$$
$$\alpha = \beta\ \gamma$$

2.6 GENERAL TRNSISTOR EQUATION

In the active region of the transistor, the emitter is forward biased and the collector is reverse biased. The generalized expression for collector current I_C for collector junction voltage V_C and emitter current I_E is given by

$$I_C = -\alpha I_E + I_{CBO}(1 - e^{V_c/V_T})$$

If V_C is negative and $| V_C |$ is very large compared with V_T, then the above equation reduces to

$$I_C = -\alpha I_E + I_{CBO}$$

If V_C, i.e. V_{CB}, is few volts, I_C is independent of V_C. Hence the collector current Ic is determined only by the fraction α of the current I_E flowing in the emitter.

Relation among I_C, I_B and I_{CBO}

If V_C is negative and $| V_C |$ is very large compared with V_T, then the above equation reduces to

$$I_C = -\alpha I_E + I_{CBO}$$

since I_C and I_E are flowing in opposite directions,

$$I_E = -(I_C + I_B)$$

Therefore,
$$I_C = -\alpha [-(I_C + I_B)] + I_{CBO}$$
$$I_C - \alpha I_C = \alpha I_B + I_{CBO}$$
$$I_C (1 - \alpha) = \alpha I_B + I_{CBO}$$
$$I_C = \frac{\alpha}{1-\alpha} I_B + \frac{I_{CBO}}{1-\alpha}$$

Since $\beta = \frac{\alpha}{1-\alpha}$,

the above expression becomes

$$I_C = (1 + \beta)\ I_{CBO} + \beta I_B$$

2.6.1 RELATION AMONG I_C, I_B AND I_{CEO}

In this CE configuration of the transistor, the collector current Ic is the sum of the part of the emitter current I_E that reaches the collector, and the collector-emitter leakage current I_{CEO}. Therefore, the part of I_E, which reaches collector is equal to

$$(I_C - I_{CEO}).$$

Hence, the large-signal current gain ($\boldsymbol{\beta}$)is defined as,

$$\beta = \frac{(I_C - I_{CEO})}{I_B}$$

From the equation, we have

$$I_C = \beta I_B + I_{CEO}$$

2.6.2 RELATION BETWEEN I_{CBO} AND I_{CEO}

Comparing the I_C, we get the relationship between the leakage currents of transistor common-base (CB) and common-emitter (CE) configurations as

$$I_{CEO} = (1 + \beta)\, I_{CBO}$$

From this equation, it is evident that the collector-emitter leakage current (I_{CEO}) in CE configuration is (1+$\boldsymbol{\beta}$) times larger than that in CB configuration. As I_{CBO} is temperature-dependent, I_{CEO} varies by large amount when temperature of the junctions changes.

2.6.3 EXPRESSION FOR EMITTER CURRENT

The magnitude of emitter-current is

$$I_E = I_C + I_B$$

substituting I_C in the above equation, we get

$$I_E = (1 + \beta)\, I_{CBO} + (1 + \beta)\, I_B$$

substituting $\beta = \frac{\alpha}{1-\alpha}$, we have

$$I_E = \frac{1}{1-\alpha} I_{CBO} + \frac{1}{1-\alpha} I_B$$

2.6.4 DC current gain ($\boldsymbol{\beta}$dc or h_{FE})

The d.c. current gain is defined as the ratio of the collector current Ic to the base current I_B.

$$\beta_{dc} = h_{FE} = \frac{I_C}{I_B}$$

As I_C is large compared with I_{CEO}, the large signal current gain and the d.c. current gain (h_{FE}) are approximately equal.

2.7 TYPES OF CONFIGURATION

Depending upon the common terminal between the input and output of the transistor, three configurations are classified. They are: (i) Common base (CB) configuration, (ii) common emitter (CE) configuration, and (iii) common collector configuration.

(i) (CB) configuration

This is also called grounded base configuration. In this configuration, emitter is the input terminal, collector is the output terminal and base is the common terminal.

(ii) (CE) configuration

This is also called grounded emitter configuration. In this configuration, base is the input terminal, collector is the output terminal and emitter is the common terminal.

(iii) (CC) configuration

This is also called grounded collector configuration. In this configuration, base is the input terminal, emitter is the output terminal and collector is the common terminal.

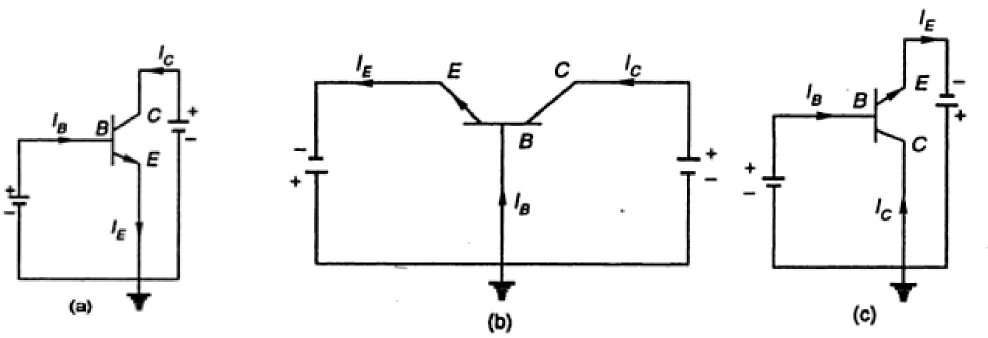


Fig: 2.8 Transistor configuration: (a) Common Base, (b) Common Emitter & (c) Common Collector

2.8 CB CONFIGURATION

The circuit diagram for determining the static characteristics curves of an NPN transistor in the common base configuration is shown in fig 2.9

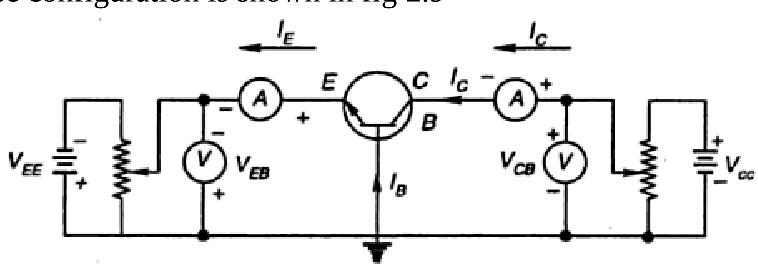


Fig: 2.9 Circuit to determine CB static characteristics

Input Characteristics

To determine the input characteristics, the collector-base voltage VCB is kept constant at zero volt and the emitter current IE is increased from zero in suitable equal steps by increasing VEB. This is repeated for higher fixed values of VCB. A curve is drawn between emitter current

IE and emitter-base voltage VEB at constant collector-base voltage VCB. The input characteristics thus obtained are shown in fig

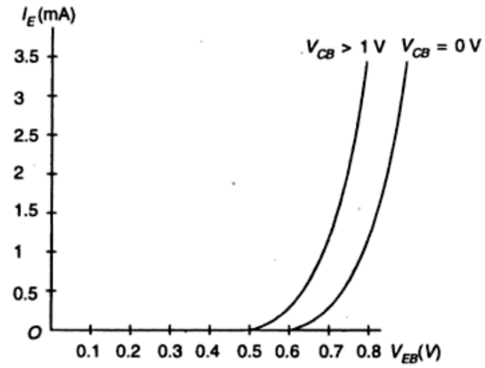


Fig: 2.10 CB Input Characteristics

When V_{CB} is equal to zero and the emitter-base junction is forward biased as shown in the fig 2.10 characteristics, the junction behaves as a forward biased diode so that emitter current I_E increases rapidly with small increase in emitter-base voltage V_{EB}. When V_{CB} is increased keeping V_{EB} constant, the width of the base region will decrease. This effect results in an increase of I_E. Therefore, the curves shift towards the left as V_{CB} is increased.

Output Characteristics

To determine the output characteristics, the emitter current I_E is kept constant at a suitable value by adjusting the emitter-base voltage V_{EB}. Then V_{CB} is increased in suitable equal steps and the collector current I_C is

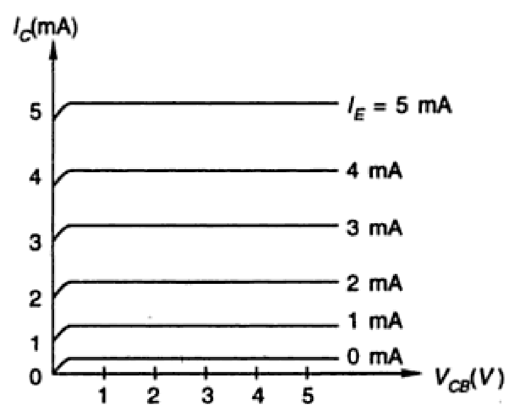


Fig: 2.11 CB Output Characteristics

Noted for each value of I_E. This is repeated for different fixed values of I_E, Now the curves of Ic versus V_{CB} are plotted for constant values of I_E and the output characteristics thus obtained is shown in Fig. 2.11

From the characteristics, it is seen that for a constant value of I_E, I_C is independent of V_{CB} and the curves are parallel to the axis of V_{CB}. Further, Ic flows even when V_{CB} is equal to zero. As the emitter-base junction is forward biased, the majority carriers, i.e. electrons, from the emitter are injected into the base region. Due to the action of the internal potential barrier at the reverse biased collector-base junction, they flow to the collector region and give rise to I_c even when V_{CB} is equal to zero.

2.8.1 EARLY EFFECT OR BASE-WIDTH MODULATION

As the output voltage V_{cc} increased, the collector base junction is more reverse biased, therefore the depletion layer width at the collector junction increases, which reduces the effective width of the base. This dependency of base-width on collector-to-emitter voltage is known as the **Early effect**.

This decrease in effective base-width has three consequences:

(i) There is less chance for recombination within the base region. Hence, α increases with increasing $|V_{CE}|$.

(ii) The charge gradient is increased within the base, and consequently, the current of minority carriers injected across the emitter junction increases,

(iii) For extremely large output voltage, the effective base-width may be reduced to zero, causing voltage breakdown in the transistor. This phenomenon is called the **punch through** or **Reach through**.

For higher values of *VCB,* due to Early effect, the value of α increases. For example, α changes, say from 0.98 to 0.935. Hence, there is a very small positive slope in the CB output characteristics and hence the output resistance is not zero.

2.8.2 THERMAL RUN AWAY

Flow of collector current produces heat in the collector junction which increases the reverse saturation current I_{CO}, again the I_C increases. This process goes in cumulative way, the heat at the junction increases and burns the transistor. The process of self-destruction of transistor is called **Thermal Run Away.**

2.9 TRANSISTOR PARAMETERS

The slope of the CB characteristics will give the following four transistor parameters. Since these parameters have different dimensions, they are commonly known as common base *hybrid parameters* or *h-parameters.*

***(i)* Input impedance (hib).** It is defined as the ratio of the change in (input) emitter voltage to the change in (input) emitter current with the (output) collector voltage V_{CB} kept constant. Therefore,

$$h_{ib} = \frac{\Delta V_{EB}}{\Delta I_E}, \ V_{CB} \text{ constant.}$$

(ii) Output admittance (hob): It is defined as the ratio of change in the (output) collector current to the corresponding change in the (output) collector voltage with the (input) emitter current I_E kept constant. Therefore,

$$h_{ob} = \frac{\Delta I_C}{\Delta V_{CB}}, \; I_E \text{ constant.}$$

(iii)Forward current gain (hfb): It is defined as a ratio of the change in the (output) collector current to the corresponding change in the (input) emitter current keeping the (output) collector voltage VCB constant. Hence,

$$h_{fb} = \frac{\Delta I_C}{\Delta I_E}, \; V_{CB} \text{ constant.}$$

(iv) Reverse voltage gain (h_{rb}): It is defined as the ratio of the change in the (input) emitter voltage and the corresponding change in (output) collector voltage with constant (input) emitter current, I_E.

$$h_{rb} = \frac{\Delta V_{EB}}{\Delta V_{CB}}, \; I_E \text{ constant}$$

2.10 CE CONFIGURATION

Input characteristics

To determine the input characteristics, the collector to emitter voltage is kept constant at zero volt and base current is increased from zero in equal steps by increasing *VBE* in the circuit shown in Fig. 2.12.

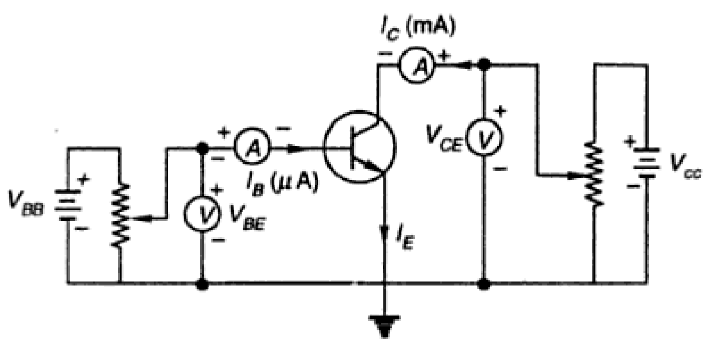


Fig: 2.12 Circuit to determine CE static characteristics

The value of *VBE* is noted for each setting *of* IB. This procedure is repeated for higher fixed values of VCE, and the curves of *IB* Vs. VBE are drawn. The input characteristics thus obtained arc shown in Fig. 2.13

When *VCE* =0, the emitter-base junction is forward biased and the junction behaves as a forward biased diode. Hence the input characteristic for *VCE* = 0 is

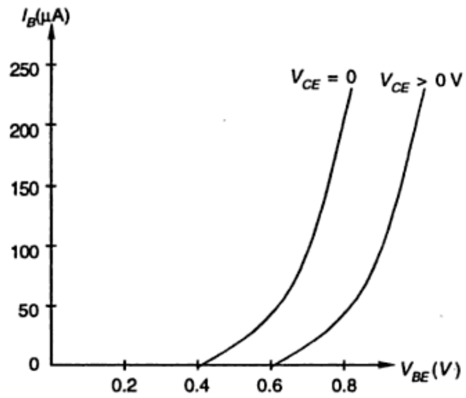


Fig: 2.13 CE Input Characteristics

Similar to that of a forward-biased diode. When V_{CE} is increased, the width of the depletion region at the reverse biased collector-base junction will increase. Hence the effective width of the base will decrease. This effect causes a decrease in the base current I_B. Hence, to get the same value of I_B as that for V_{CE} = 0, V_{BE} should be increased. Therefore, the curve shifts to the right as V_{CE} increases.

Output characteristics

To determine the output characteristics, the base current I_B is kept constant at a suitable value by adjusting base-emitter voltage, V_{BE}. The magnitude of collector-emitter voltage V_{CE} is increased in suitable equal steps from zero and the collector current Ic is noted for each setting $V_{CE.}$

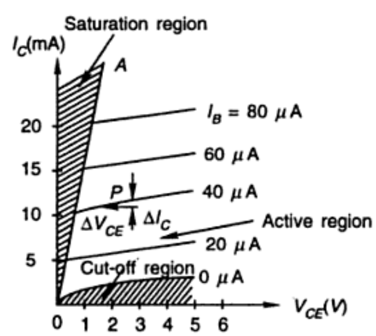


Fig: 2.14 CE Output Characteristics

$\beta = \dfrac{\alpha}{1-\alpha}$ and $I_C = (1+\beta)I_{CBO} + \beta I_B$

For larger values of V_{CE}, due to early effect, a very small change in α is reflected in a very large change in β. For example, when α=0.98, $\beta = \dfrac{0.98}{1-0.98} = 49$. If α increases to 0.985, then $\beta = \dfrac{0.985}{1-0.985} = 66$. Here, a slight increase in α by about 0.5 results in an increases in by β about 34%. Hence, the output characteristics of CE configuration show a larger slope when compared with CB Configuration.

The output characteristics have three regions, namely, saturation region, cutoff region and active region. The region of curves to the left of the line *OA* is called the *saturation region* (hatched), and the line *OA* is called the saturation line. In this region, both junctions are forward biased and an increase in the base current does not cause *a* corresponding large change in Ic. The ratio of V_{CE}*(sat) to* I_C region is called saturation resistance,

The region below the curve for I_B = 0 is called the *cut-off region* (hatched). In this region, both junctions are reverse biased. When the operating point for the transistor enters the cut-off region, the transistor is OFF. Hence, the collector current becomes almost zero and the collector voltage almost equals *Vcc*, the collector supply voltage. The transistor is virtually an open circuit between collector and emitter

The central region where the curves are uniform in spacing and slope is called the active region (unhatched). In this region, emitter-base junction is forward biased and the collector-base junction is reverse biased. If the transistor is to be used as a linear amplifier, it should be operated in the active region,

If the base current is subsequently driven large and positive, the transistor switches into the saturation region via the active region, which is traversed at a rate that is dependent on factors such as gain and frequency response. In this ON condition, large collector current flows and collector voltage falls to a very low value, called V_{CEsat}, typically around 0.2 V for a silicon transistor, the transistor is virtually a short circuit in this state.

High speed switching circuits are designed in such a way that transistors are not allowed to saturate, thus reducing switching times between ON and OFF times.

Transistor parameters

The slope of the CE characteristics will give the following four transistor parameters. Since these parameters have different dimensions, they are commonly known as common emitter *hybrid parameters* or *h-parameters,*

(i) Input impedance (hie): It is defined as the ratio of the change in (input) base voltage to the change in (input) base current with the (output) collector voltage V_{CE} kept constant. Therefore,

$$h_{ie} = \frac{\Delta V_{BE}}{\Delta I_B}, \ V_{CE} \text{ constant}$$

(ii) Output admittance (hoe): It is defined as the ratio of change in the (output) collector current to the corresponding change in the (output) collector voltage with the (input) base current I_B kept constant. Therefore,

$$h_{oe} = \frac{\Delta I_C}{\Delta V_{CE}}, \ I_B \text{ constant}$$

(iii) Forward current gain (hfe). It is defined as a ratio of the change in the (output) collector current to the corresponding change in the (input) base current keeping the (output) collector voltage V_{CE} constant. Hence,

$$h_{fe} = \frac{\Delta I_C}{\Delta I_B},\ V_{CE} \text{ constant}$$

(iv) Reverse voltage gain (hre): It is defined as the ratio of the change in the (input) base voltage and the corresponding change in (output) collector voltage with constant (input) base current, I_B. Hence,

$$h_{re} = \frac{\Delta V_{BE}}{\Delta V_{CE}},\ I_B \text{ constant}$$

2.11 CC CONFIGURATION

The circuit diagram for determining the static characteristics of an NPN transistor in the common collector configuration is shown in fig. 2.15.

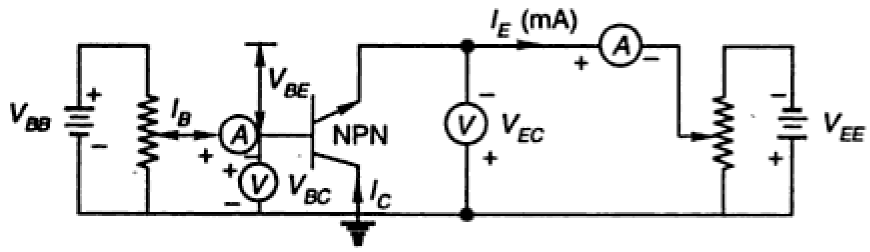


Fig: 2.15 Circuit to determine CC static characteristics

Input characteristics

To determine the input characteristics, V_{EC} is kept at a suitable fixed value. The base-collector voltage V_{BC} is increased in equal steps and the corresponding increase in I_B is noted. This is repeated for different fixed values of V_{EC}. Plots of V_BC versus I_B for different values of V_{EC} shown in Fig. 2.16 are the input characteristics.

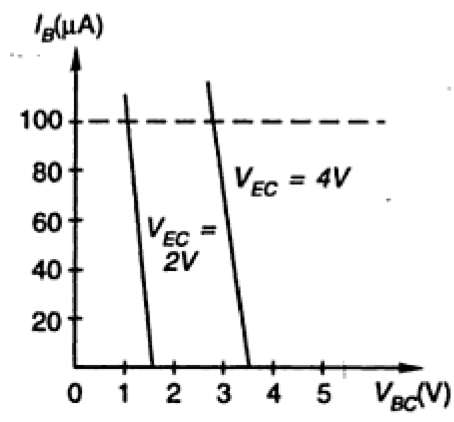


Fig: 2.16 Input Characteristics

Output characteristics

The output characteristics are the same as those of the common emitter configuration.

2.12 COMPARISON

Property	CB	CE	CC
Input resistance	Low (about 100 Ω)	Moderate (about 750 Ω)	High (about 750 KΩ)
Output resistance	High (about 450 KΩ)	Moderate (about 45 KΩ)	Low (about 25 Ω)
Current gain	1	High	High
Voltage gain	About 150	About 500	Less than 1
Phase shift between input & output voltages	0 or 360^o	180^o	0 or 360^o
Applications	For high frequency circuits	For audio frequency circuits	For impedance matching
Current amplification factor=(output current)/(input current)	$\alpha = \frac{\Delta I_C}{\Delta I_E}$	$\beta = \frac{\Delta I_C}{\Delta I_B}$	$\gamma = \frac{\Delta I_E}{\Delta I_B}$

RELATIONSHIP BETWEEN α AND β

We know that $\Delta I_E = \Delta I_C + \Delta I_B$

By definition, $\Delta I_C = \alpha \Delta I_E$

Therefore, $\Delta I_E = \alpha \Delta I_E + \Delta I_B$

i.e. $\Delta I_B = \Delta I_E (1-\alpha)$

Dividing both sides by ΔI_C, we get

$$\frac{\Delta I_B}{\Delta I_C} = \frac{\Delta I_E}{\Delta I_C}(1-\alpha)$$

Therefore,

$$\frac{1}{\beta} = \frac{1}{\alpha}(1-\alpha)$$

$$\beta = \frac{\alpha}{(1-\alpha)} \text{ and } \alpha = \frac{\beta}{(1+\beta)}, \text{ or } \frac{1}{\alpha} - \frac{1}{\beta} = 1$$

From this relationship, it is clear that as α approaches unity, β approaches infinity. The CE configuration is used for almost all transistor applications because of its high current gain, β

RELATIONSHIP AMONG α, β AND γ:

In the CC transistor amplifier circuit, I_B is the input current and I_E is the output current.

Current amplification factor for CC configuration is $\gamma = \frac{\Delta I_E}{\Delta I_B}$, substituting $\Delta I_B = \Delta I_E - \Delta I_C$, we get $\gamma = \frac{\Delta I_E}{\Delta I_E - \Delta I_C}$

Dividing the numerator and denominator on RHS by ΔI_E, we get

$$\gamma = \frac{\frac{\Delta I_E}{\Delta I_E}}{\frac{\Delta I_E}{\Delta I_E} - \frac{\Delta I_C}{\Delta I_E}} = \frac{1}{1-\alpha}$$

Therefore, $\gamma = \frac{1}{1-\alpha} = (1+\beta)$

2.13 EBERS MOLL TRANSISTOR MODEL

Consider two ideal diodes connected back to back and two dependent current sources. If emitter junction is forward biased and collector junction is reverse biased then the collector current will be $I_C = -\alpha_N I_E - I_{CO}\left(e^{\frac{V_C}{V_T}} - 1\right)$. α_N is current gain of CB configuration.

$\alpha_N = \alpha_I = 0$

If collector junction is forward biased and emitter junction is reverse biased then the emitter current will be $I_E = \alpha_I I_C$. α_I is the inverse current gain of CB configuration. It is called inverse because collector acts as emitter and emitter acts as collector. This is indicated by two current sources in Ebers Moll model.

When emitter base junction is reverse biased, the reverse saturation current through the diode is -I_{EO}. The emitter base junction can be considered as a diode with reverse saturation current I_{EO}.

When collector base junction is reverse biased, the reverse saturation current through the diode is –I_{CO}. The collector base junction can be considered as a diode with reverse saturation current I_{CO}. This is indicated by two diodes in Ebers Moll model. Fig shows the Ebers Moll model of PNP transistor.

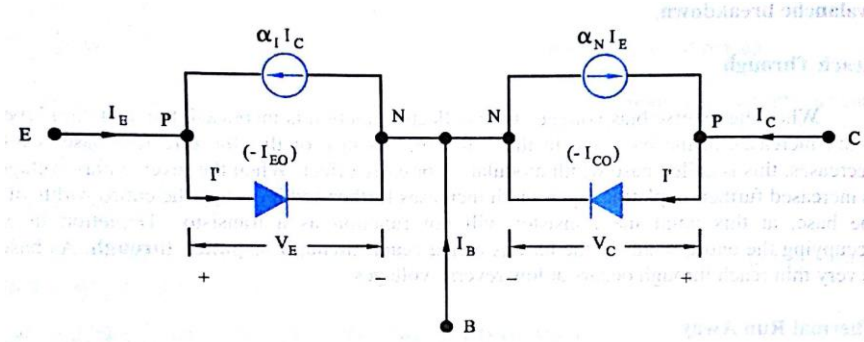


Fig: 2.17 Ebers Moll model for PNP transistor

The current through a diode is given by

$$I = I_o\left(e^{\frac{V}{V_T}} - 1\right)$$

Applying KCL to the collector node.

$$I_C = -\alpha_N I_E + I$$

$$I_C = -\alpha_N I_E - I_{CO}\left(e^{\frac{V_C}{V_T}} - 1\right)$$

Applying KCL to the emitter node

$$I_E = -\alpha_I I_C + I$$

$$I_E = -\alpha_I I_C - I_{EO}\left(e^{\frac{V_E}{V_T}} - 1\right)$$

The $\alpha_N, \alpha_I, I_{EO}, I_{CO}$ are related by the following equation

$$\alpha_N I_{CO} = \alpha_I I_{EO}$$

This model is valid for both forward and reverse voltages applied across the transistor junctions.

If $\alpha_N = \alpha_I = 0$, that is no minority carrier is transported through the base (when base width is large, all the carriers injected into base will recombine in the base and no carrier is transported to collector or emitter), therefore the transistor amplification factor become zero. Hence it is not possible to construct a transistor by connecting two diodes back to back.

Application of Transistor

- Transistor can be used as voltage and current amplifier.
- Transistor can be used in impedance matching.
- Transistor can be used as switch.

2.14 FIELD EFFECT TRANSISTORS

FET is a device in which the flow of current through the conducting region is controlled by an electric field. Hence it is called as Field Effect Transistor (FET).

Current conduction is only by majority carrier, therefore it is called as unipolar junction transistor.

Based on construction, it is classified into two types

- Junction Field Effect Transistor (JFET)
- Metal Oxide Semiconductor Field Effect Transistor (MOSFET) or Insulated Gate FET (IGFET) or Metal Oxide Silicon Transistor (MOST).

Advantages of FET:

- FET is a unipolar device, the current conduction is by majority carriers only. Transistor is a bipolar device, the current conduction is by both majority and minority carriers.
- FET has thermal stability.
- Input impedance is very high
- FET is less noisy
- FET is immune to radiation
- FET can be operated in wide range of frequencies
- Fabrication of FET in IC is simpler and occupy less space.

Disadvantages of FET

- The gain of the FET amplifier is low.
- The gain bandwidth product is relatively small.

2.15 JFET (JUNCTION FIELD EFFECT TRANSISTOR)

JFET has three terminals source, drain and gate.

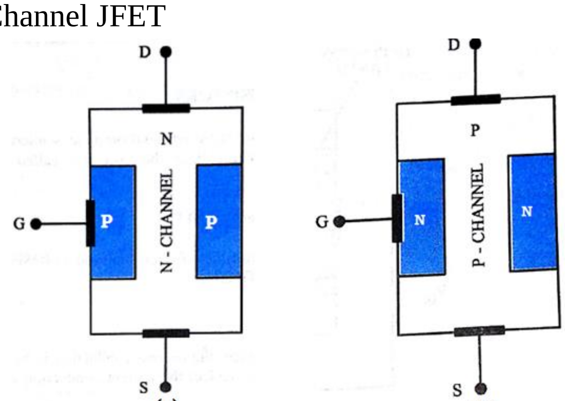
Source is the terminal through which majority carriers enter into the JFET.

Drain is the terminal through which majority carriers leave the JFET.

Gate is the terminal used to control the flow of majority carriers through JFET.

Depends on the type of material used in the gate region, JFET is classified into two types

- N Channel JFET
- P Channel JFET



(a) (b)

Fig: 2.18 Structure of (a) N channel JFET, (b) P channel JFET

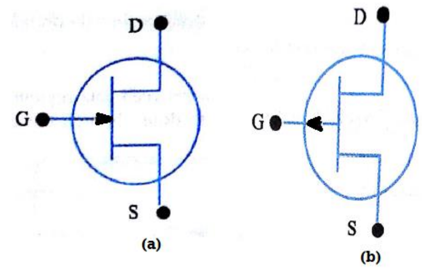


Fig: 2.19 Symbol of (a) N channel JFET, (b) P channel JFET

- Arrow head indicates the direction of current flow.

2.16 OPERATION OF N CHANNEL JFET

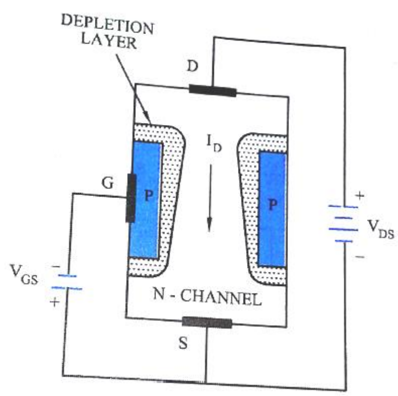


Fig: 2.20 Operation of N channel JFET

The gate junction is reverse biased by the battery V_{GS}. The positive terminal of the battery V_{DS} is connected to drain D and the negative terminal to source S. Through the channel, electrons move from the source to the drain. The current due to electrons is drain current (I_D).

For a fixed value of V_{DS}, as the gate source reverse voltage V_{GS} is increased the depletion layer width at the gate junction increases. The increases in the depletion layer width decreases the channel width and the area for the electrons movement. In JFET the drain current I_D depends on the gate source reverse voltage V_{GS}.

Static Characteristics

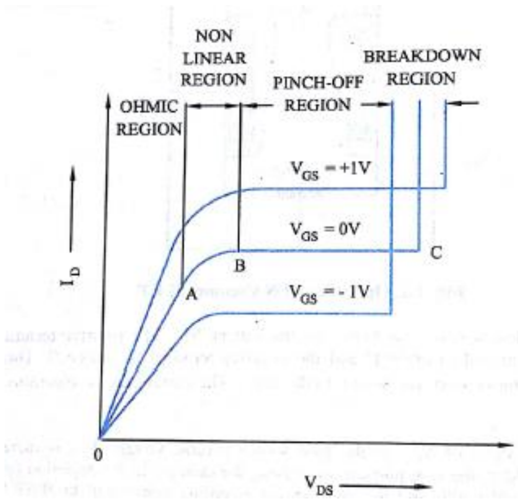


Fig: 2.21 Drain characteristics of N channel JFET

The graph between drain source voltage V_{DS} and drain current I_D for a constant gate source voltage V_{GS} is called static characteristics of JFET, it is also know as drain characteristics.

For plotting static characteristics, gate source voltage V_{GS} is kept constant, the change in drain current I_D is noted for change in drain source voltage V_{DS}. The variation of I_D with V_{DS} for different constant values of V_{GS} can be obtained and plotted on a graph.

When V_{GS}=0, the entire width of the channel is available for the movement of electrons. When V_{DS} is zero the drain current I_D is also Zero.

Graph shows three regions of operation.

Ohmic region:

As V_{DS} is increases from zero the drain current I_D also increases. The N type semiconductor acts as a resistor. V_{DS} and I_D follow ohms law up to the point A. From zero to the point A the region is called ohmic region. In ohmic region there exist a linear relationship between V_{DS} and I_D.

Non Linear Region:

As V_{DS} is increased, the voltage drop through the semiconductor bar. It is V_{DS} at the drain and decreases towards source and become zero at the source. The voltage drop in the semiconductor bar revere biases the junction, the depletion layer width at the junction increases. The voltage near drain is higher than the voltage at source; therefore the gate reverse biased less. Because of this the depletion layer width is more near the drain terminal. Now if the voltage V_{DS} from point A is increased, the drain current I_D, increases at reverse square law rate up to the point B. the region from A to B is called the nonlinear region.

Pinch off Region:

At the point B the channel is almost blocked by the depletion layer. Now the increase in drain current I_D is not possible. The drain current I_D reaches saturation and it remain constant up to point C. the drain source voltage V_{DS}, at which the channel is pinched off (the channel is almost blocked and current remain constant) is called Pinch off voltage V_P. The region over which the current remain constant is called pinch off or saturation region. In this region a JFET acts as a constant current device.

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$$

Where I_{DSS} = Drain current when V_{GS}=0.

V_{GS} = voltage between gate and source.

V_P = pinch off voltage.

Breakdown

After pinch off, if the voltage is increases beyond the point C avalanche breakdown of the reverse biased gate junction will occur and the current increases abruptly.

When the negative reverse bias voltage at the gate is increases, the resulting V_{DS}-I_D curve is similar to V_{GS}=0 curve but

- The ohmic region is decreased
- Pinch off occurs for lower values of voltage and
- Avalanche breakdown occurs for lower values of V_{DS}.

Transfer characteristics

The graph between gate source V_{GS} and drain current I_D for a constant drain source voltage V_{DS} is called transfer characteristics of JFET.

Drain current equation, is $I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$

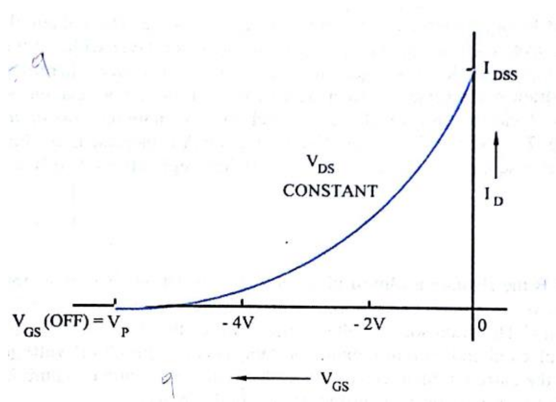


Fig: 2.22 Transfer characteristics of N channel JFET

When V_{GS}=0, the drain current I_D=I_{DSS}. As V_{GS} is increased, the channel width decreases and hence the drain current decreases. When V_{GS}=V_P the current width become zero and the drain current I_D become zero. The source voltage at which the drain current become zero is called V_{GS}(off) voltage.

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_{GS}(\text{off})}\right)^2$$

2.17 OPERATION OF P CHANNEL JFET

The gate junction is reverse biased by the battery V_{GS}. The negative terminal of the battery V_{DS} is connected to drain D and the positive terminal to source S. through the channel, holes move from the source to drain. The current due to holes is drain current I_D.

For a fixed value of V_{DS}, as the gate source reverse voltage V_{GS} is increased the depletion layer width at the gate junction increases. The increase in the depletion layer width decreases the channel width and the area for the holes movement. In JFET the drain current I_D depends on the gate source reverse voltage V_{GS}.

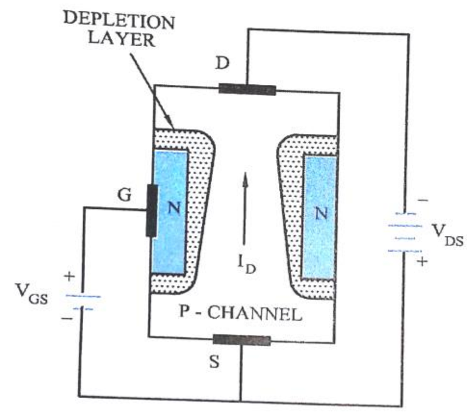


Fig: 2.23 Operation of P channel JFET

Characteristics

Drain and transfer characteristics of P channel JFET is same as N channel JFET except the reverse in V_{DS} and V_{GS} polarity.

2.18 FET PARAMETERS

- DC drain Resistance
- AC drain Resistance
- Transconductance
- Amplification Factor

DC Drain Resistance (R_{DS})

This is the static or ohmic resistance of the channel. It is given by

$$R_{DS} = \frac{V_{DS}}{I_D}$$

AC Drain Resistance (r_D)

$$r_d = \frac{\Delta V_{DS}}{\Delta I_D}, \; V_{GS} = 0 \text{ held constant.}$$

AC resistance between drain and source terminals when FET is operating in the Pinch-off region.

Transconductance or Mutual Conductance (g_m)

It is the measure of control of gate voltage over drain current

$$g_m = \frac{\Delta I_D}{\Delta V_{GS}} \text{ mho, } V_{DS} \text{ held constant}$$

It is the slope of transfer characteristic.

Amplification Factor (μ)

$$\mu = \frac{\Delta V_{DS}}{\Delta V_{GS}}, \; I_D \text{ held constant.}$$

The relation among ac drain resistance, transconductance and amplification factor is given by

$$\mu = r_d \times g_m$$

2.19 METAL OXIDE SEMICONDUCTOR FIELD EFFECT TRANSISTOR (MOSFET or IGFET)

There are two types of MOSFET, they are

- Enhancement MOSFET
- Depletion MOSFET

2.20 ENHANCEMENT MOSFET

In enhancement MOSFET, the drain current is increased by the gate voltage.

Construction

The N channel MOSFET consist of a lightly doped P type substrate. Two heavily doped N+ regions are formed into the substrate.

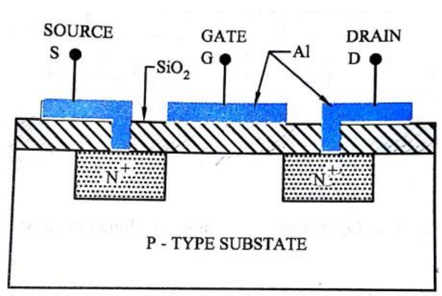


Fig: 2.24 N channel Enhancement MOSFET

One N+ region acts as source S and another N+ region acts as drain D. A thin layer of Silicon dioxide (SiO_2) is grown over the surface, and holes are made in the oxide layer to form metal contacts with source and drain. The region between the N+ source and drain is called Channel. The gate metal contact G is made on the SiO_2 layer, above the channel. The gate metal and the channel act as the two plates of a parallel plate capacitor and the SiO_2 layer acts as the dielectric.

OPERATION

The channel is lightly doped P type semiconductor, its resistance is high therefore electrons cannot move freely from source to drain. When a Positive voltage is applied at the gate, it induces negative charges in the channel.

These induced negative charge are called inversion layer. Now the channel has electrons as carriers, therefore the conductivity of the channel increases and electrons flow from source to drain. Thus the drain current is increased (enhanced) by the gate voltage.

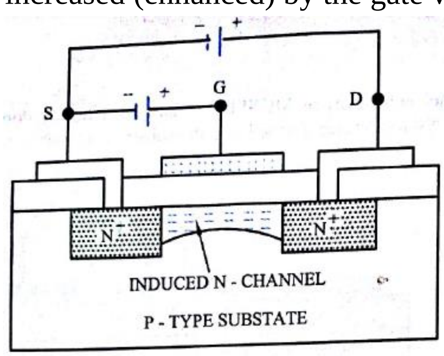


Fig: 2.25 Operation of N channel Enhancement MOSFET

Symbol

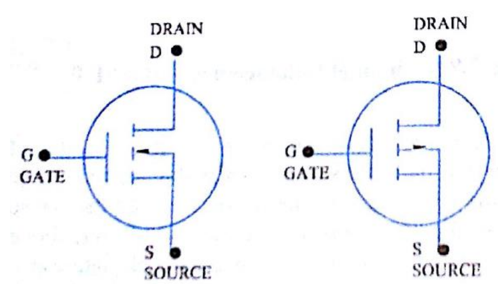


Fig: 2.26 Symbol of Enhancement N channel and P channel MOSFET

Drain characteristics

The graph between drain source voltage V_{DS} and drain current I_D for a constant gate source voltage V_{GS} is called the drain characteristics of MOSFET. For plotting drain characteristics, gate source voltage V_{GS} is kept constant, the change in drain current I_D is noted for change in drain source voltage V_{DS}. The variation of I_D with V_{DS} for different constant value of V_{GS} can be obtained and plotted on a graph.

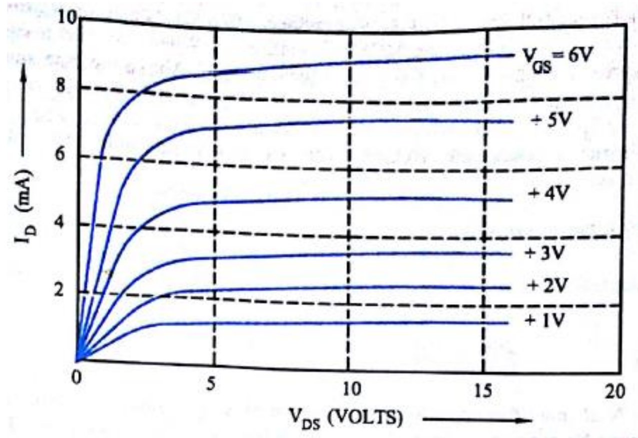


Fig: 2.27 Drain characteristics

When V_{GS} is zero, the drain current is zero. When V_{GS} is made positive, drain current increases.

Transfer characteristics

The graph between gate source voltage V_{GS} and drain current I_D for a constant drain and source voltage V_{DS} is called the transfer characteristics of MOSFET.

For a fixed drain source voltage V_{DS} voltage, when V_{GS} is zero or negative, very small saturation current flow through the MOSFET, called I_{DSS}. When V_{GS} is increased above zero, the drain current, remain at I_{DSS} for small values of V_{GS}. Above the gate source threshold voltage V_{GST} the current increases rapidly.

N channel enhancement MOSFET cannot be operated with gate voltage negative (depletion mode).

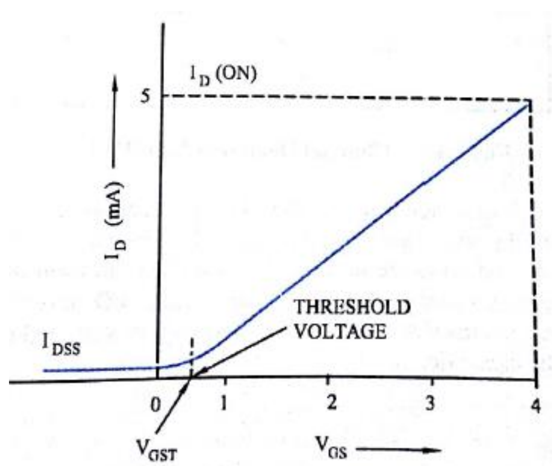


Fig: 2.28 Transfer characteristics

2.21 DEPLETION MOSFET

In depletion MOSFET, the drain current can be increased or decreased by the gate voltage.

Construction

The N channel depletion MOSFET consist of a lightly doped P type substrate. Two heavily doped N+ regions are formed into the substrate.

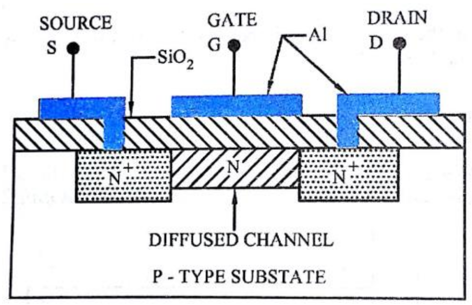


Fig: 2.29 N channel Depletion MOSFET

One N+ region acts as source S and another N+ region acts as drain D. A lightly doped N type channel is formed between source and drain. A thin layer of silicon dioxide (SiO_2) is grown over the surface, and holes are made in the oxide layer to form metal contacts with source and drain. The gate metal contact G is made on the SiO_2 layer, above the N type channel. The gate metal and the channel act as the two plates of a parallel plate capacitor and the SiO_2 layer act as the dielectric.

Operation

The channel is lightly doped N type semiconductor, therefore electrons can move from source to drain.

Enhancement mode

When a positive voltage is applied at the gate, it induces negative charges in the channel, therefore the conductivity of the channel increases and more electrons flow from source to drain. Thus the drain current is increases (enhanced) by the positive gate voltage.

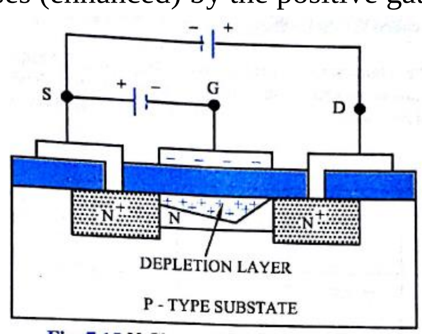


Fig: 2.30 N channel depletion MOSFET with Negative Gate Voltage

Depletion Mode

When the gate voltage is negative, it induces positive charges in the channel. The induced positive charges reduce the conductivity of the channel (prevent the movement of electrons from source to drain); therefore the drain current decreases for negative gate voltage.

Symbol

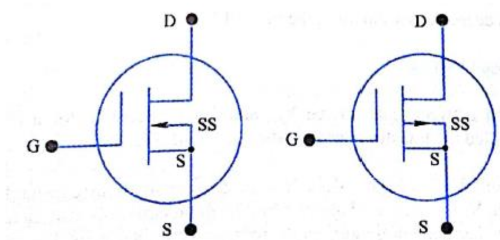


Fig: 2.31 Symbol of Depletion N channel and P channel MOSFET

Drain Characteristics

The graph between drain source voltage V_{DS} and drain current I_D for a constant gate source voltage V_{GS} is called the drain characteristics of MOSFET.

For plotting drain characteristics, gate source voltage V_{GS} is kept constant, the change in drain current I_D is noted for change in drain source voltage V_{DS}. The variation of I_D with V_{DS} for different constant values of V_{GS} can be obtained and plotted on a graph.

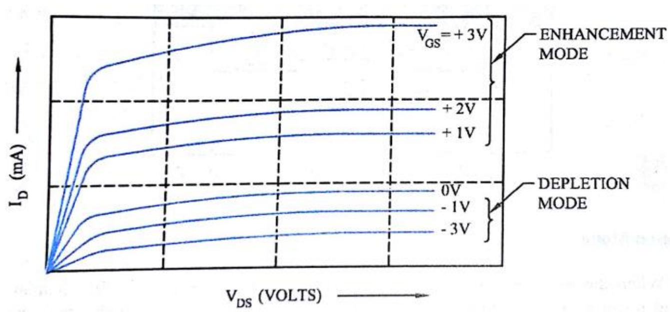


Fig: 2.32 Drain characteristics

When V_{GS} is zero, small drain current flow through the MOSFET. When V_{GS} is made positive, drain current is increases. When V_{GS} is made negative, the drain current is decreases.

Transfer Characteristics

The graph between gate source voltage V_{GS} and drain current I_D for a constant drain and source voltage V_{DS} is called the transfer characteristics of MOSFET.

For a fixed V_{DS} voltage, when V_{GS} is zero small drain current flow through the MOSFET. When V_{GS} is increased above zero, the drain current is also increased. When V_{GS} is reduced below zero, the drain current decreases and reaches zero. The gate source voltage V_{GS} at which the drain current become zero is called V_{GS}(off), at this voltage the current is completely occupied by the positive charges, therefore electrons cannot move from source to drain.

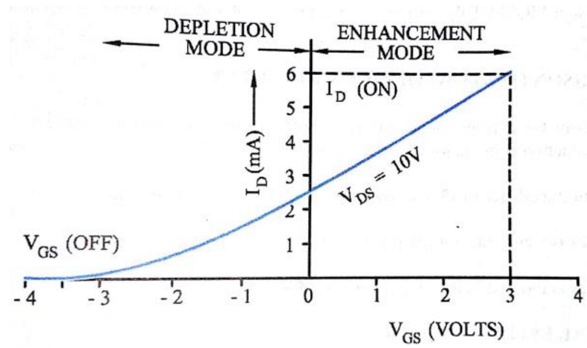


Fig: 2.33 Transfer Characteristics

N channel depletion MOSFET can be operated with gate voltage negative (depletion mode) and with gate voltage positive (enhancement mode).

2.22 VMOS OR VMOSFET (OR V- GROOVE MOSFET)

One of the major disadvantage of MOSFET is the reduced power handling level as compared to BJT. This can be overcome by changing construction mode.

The vertical-MOSFET is a component designed to handle much large drain currents. There is no physical connection between Source and drain. Thus VMOS is an enhancement type MOSFET.

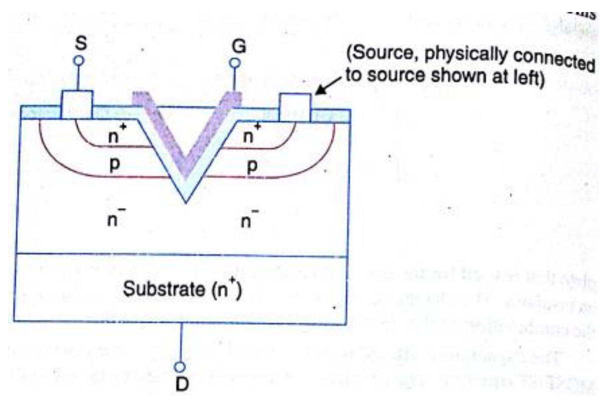


Fig: 2.34 VMOSFET

With the V-shaped gate, a larger channel is formed by a positive gate voltage. With a large channel, the device is capable of handeling a large amoun of drain current.

Operation

When a positive gate voltage is applied to the device, an N- Type channel forms in the P-type region. This effective channel connects the source and drain. The shape of the gate causes a wider channel, which allows much higher drain current.

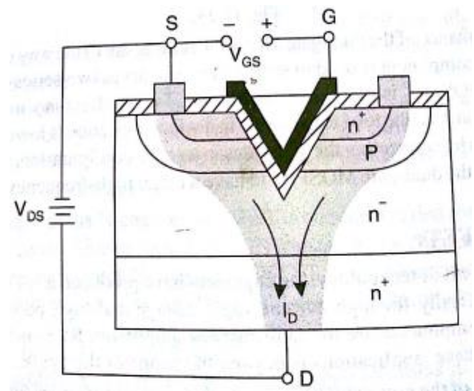


Fig: 2.35 Operation of VMOS

VMOS exhibit higher transconductance and a lower turn-on resistance. This devices is not harmful to thermal runaway and has Positive temperature coefficient. More than one V-groove is formed to increase the amount of drain current.

UNIT III

Special Semiconductor Devices

3.1 PRINCIPLE AND OPERATION OF SCHOTTKY DIODE

Schottky barrier diode is an extension of point contact diode. The Schottky diode is formed when a metal, such as Aluminum, is brought into contact with a moderately doped N-type. It is a unipolar device because it has electrons as majority carriers on both sides of the junction. Hence, there is no depletion layer formed near the junction.

There is no significant current from the metal to the semiconductor with reverse bias. Thus, the delay present in the junction diodes due to hole-electron recombination time is absent here. The forward resistance is lower, and so is noise.

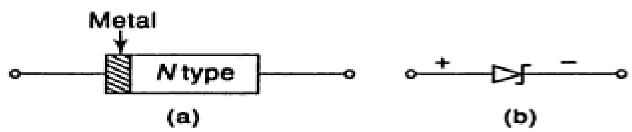


Fig: 3.1 SCHOTTKY DIODE a) metal-semiconductor contact and (b) circuit symbol

The forward current is dominated by electron flow from semiconductor to metal, and the reverse current is mainly due to election flow from metal to semiconductor. As there is very little minority carrier injection from semiconductor into metal, Schottky diodes are also said to be majority carrier devices.

The diode is also referred to as hot carrier diode because when it is forward biased, conduction of electrons on the N side gains sufficient energy to cross the junction and enter the metal. Since these electrons plunge into the metal with large energy, they are commonly called as hot carriers.

VI Characteristics

The current in a PN junction diode is controlled by the diffusion of minority carriers whereas the current in the Schottky diode results from the flow of majority carriers over the potential barrier at the metal-semiconductor junction. The reverse saturation current for a Schottky diode is larger than that of a PN junction diode. The storage time for a Schottky diode is theoretically zero. The Schottky diode has a smaller turn-on voltage and shorter switching time than the PN junction diode.

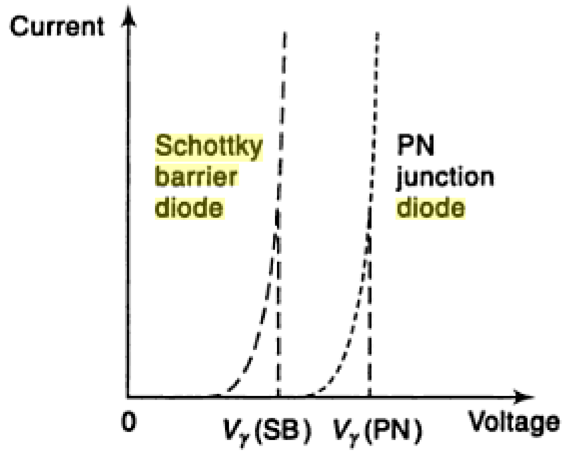


Fig: 3.2 V-l characteristics of schottky barrier diode and PN junction diode

Application:

- Schottky diode can be used for rectification of signals of frequencies even exceeding 300 MHz.
- It is commonly used in switching power supplies at frequencies of 20 GHz.
- Its low noise figure finds application in sensitive communication receivers like radars.
- It is also used in clipping and clamping circuits and in computer gating.

3.2 VARACTOR DIODE

The varactor also called a varicap, tuning or voltage variable capacitor diode, is a junction diode with a small impurity dose at its junction, which has the useful property that its junction or transition capacitance is easily varied electronically.

When any diode is reverse biased, a depletion region is formed. The larger the reverse bias applied across the diode, the width of the depletion layer "W" becomes wider. Conversely, by decreasing the reverse bias voltage, the depletion region width "W" becomes narrower. This depletion region is devoid of majority carriers and acts like an insulator preventing conduction between the N and P regions of the diode, just like a dielectric, which separates the two plates of a capacitor. The varactor diode with its symbol is shown in Fig 3.3 (b).

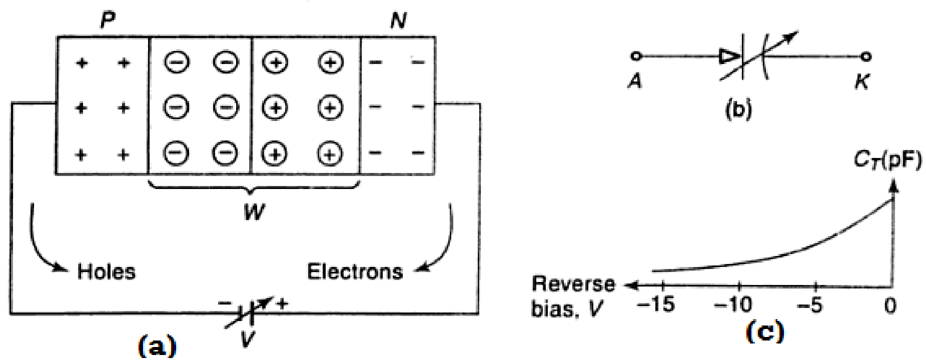


Fig: 3.3 (a) Deplection region in a reverse biased PN junction, (b) Circuit symbol of Varactor diode, (c) Characteristics of Varator diode

As the capacitance is inversely proportional to the distance between the plates ($C_T \propto 1/W$), the transition capacitance C_T varies inversely with the reverse voltage as shown in Fig 3.3 (c). Consequently, an increase in reverse bias voltage will result in an increase in the depletion region width and a subsequent decrease in transition capacitance C_T. At zero volt, the varactor depletion region *W* is small and the capacitance is large at approximately 600 pF. When the reverse bias voltage across the varactor is 15 V, the capacitance is 30 pF,

Application:

- The varactor diodes are used in FM radio and TV receivers, AFC circuits, self-adjusting bridge circuits and adjustable bandpass filters.
- Tuning of LC resonant circuit in microwave frequency multipliers and in very low noise microwave parametric amplifiers.

3.3 TUNNEL DIODE

The Tunnel or Esaki diode is a thin-junction diode which exhibits negative resistance under low forward bias conditions.

Construction:

An ordinary PN junction diode has an impurity concentration of about 1 part in 10^8. With this amount of doping the width of the depletion layer width is high (5 microns) and there exists a potential barrier across the junction. Due to this, Majority carrier flow blocked.

Tunnel diode is constructed by adding one impurity atom for every 10^{-3} semiconductor atoms. The depletion layer width is inversely proportional to the square root of impurity concentration. So depletion layer width is less than or equal to 100 A^0.

Tunneling Operation:

When the depletion layer is very thin electrons can move from filled state to empty state without any additional energy. This is called tunneling.

Condition for Tunneling:

- Diode should be heavily doped.
- Depletion layer width should be very thin (100 A^0).
- Filled state on one side and Empty state on other side.
- Filled and empty state should be on same energy level.

Symbol:

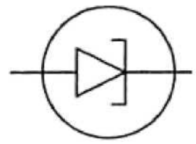


Fig: 3.4 Circuit symbol

VI Characteristics:

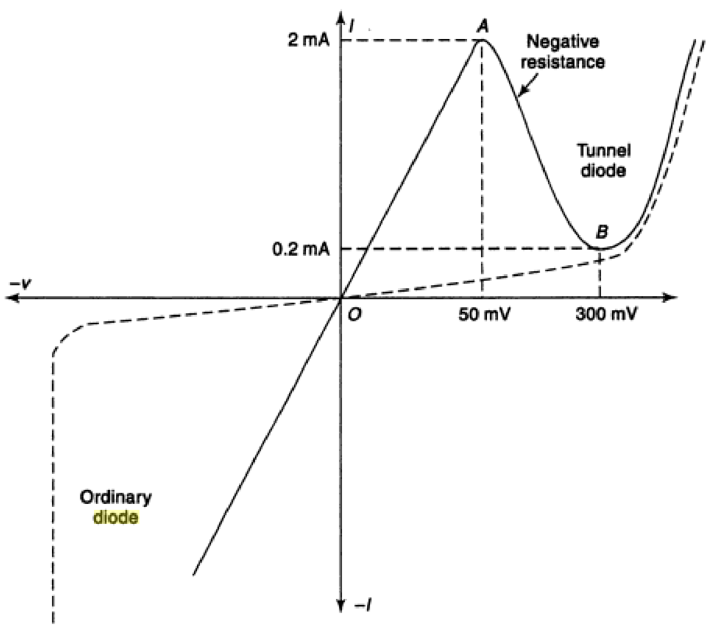


Fig: 3.5 V-I characteristics of Tunnel diode

When it is forward biased, the electrons in the N type starts tunneling to the P type semiconductor, this is because of the energy levels of N type conduction band and P type valence band are equal shown in fig 3.6 (a).

With this minimum voltage tunnel diode starts conducting without the help on excess external voltage which leads to current flow shown in VI characteristics fig from point O to A.

At some stage the electrons fully moved to the P side, no available free electron in the N side, which leads to decreases in current value called negative resistance region. Further increase in external voltage it acts as normal PN junction diode.

In reverse bias, It act as normal diode.

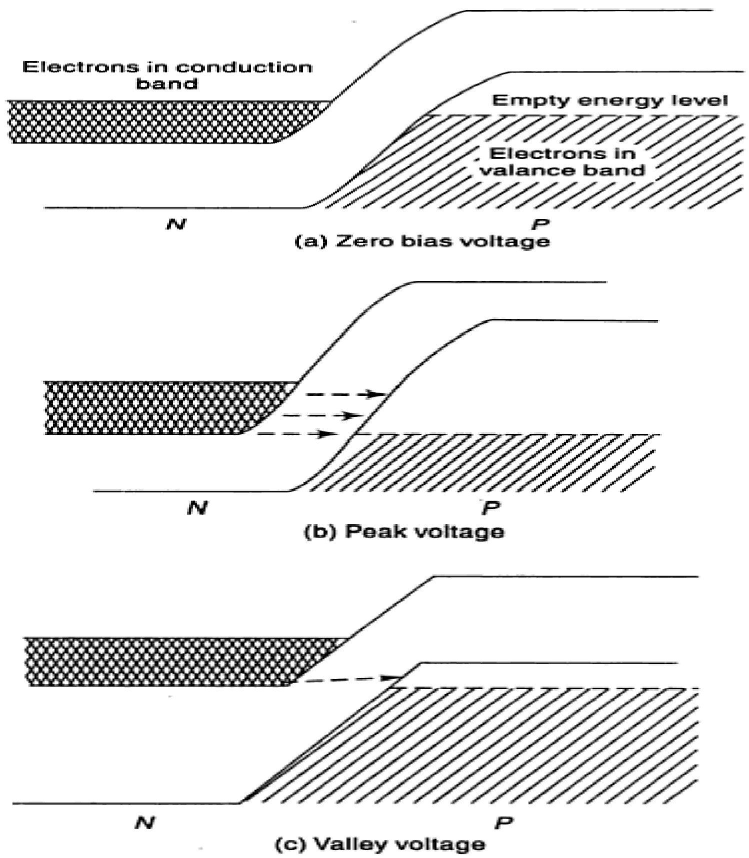


Fig: 3.6 Energy level diagram of Tunnel diode

Applications

1. Tunnel diode is used as an ultra-high speed switch with switching speed of the order of ns or ps
2. As logic memory storage device
3. As microwave oscillator
4. In relaxation oscillator circuit
5. As an amplifier.

Advantages

1. Low noise
2. Ease of operation
3. High speed
4. Low power

Disadvantages

1. Voltage range over which it can be operated is 1 V less
2. Being a two terminal device, there is no isolation between the input and output circuit.

3.4 PIN DIODE

It is composed of three regions. In addition to the usual N and P regions, an intrinsic layer (I region) is sandwiched between them, to form the PIN.

The intermediate layer offers relatively high resistance which gives it two advantages compared to an ordinary PN diode. They are

(1) Decrease in capacitance between P and N regions as it is inversely proportional to the separation between these regions. It allows a faster response time for the diode. Hence, PIN diodes are used at high frequencies (more than 300 MHz).

(2) Possibility of greater electric field between the P and N junctions, so that the charge carriers drift towards their majority carrier side. This enhances faster response of the diode.

It offers a variable resistance under forward bias condition as shown in Fig5.11 Forward resistance offered is given by r_{ac} α 50/I, where I is the d.c, current in mA.

Hence, for large d.c. currents, the diode will look like a short. In reverse biased condition it looks like an open, i.e. it offers an infinite resistance.

It is used as a switching diode for signal frequencies up to GHz range and as an AM modulator of very high frequency signals.

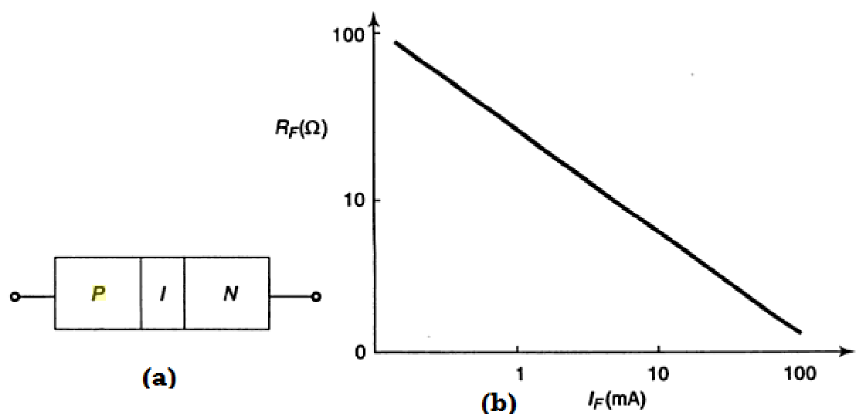


Fig: 3.7 (a) Structure of PIN diode, (b) variation of forward resistance in PIN diode

3.5 CONSTRUCTION AND OPERATION OF LIGHT EMITTING DIODE (LED)

The Light Emitting Diode (LED) is a PN junction device which emits light, when forward biased, by a phenomenon called electroluminescence. In silicon and germanium, greater percentage of energy is given out in the form of heat.

In other materials such as gallium phosphide (GaP) or gallium arsenide phosphide (GaAsP), the number of photons of light energy emitted is sufficient to create a visible light source. Here, the charge carrier recombination takes place when electrons from the N-side cross the junction and recombine with the holes on the P-side.

In forward biased, the difference of energy between the conduction band and the valance band is radiated in the form of light energy. Light is generated by recombination of electrons and holes whereby their excess energy is transferred to an emitted photon. The brightness of the emitted light is directly proportional to the forward bias current.

An N-type layer is grown on a substrate and a P-type is deposited on it by diffusion. Since carrier recombination takes place in the P-layer, it is kept uppermost. The metal anode connections are made at the outer edges of the P-layer so as to allow more central surface area for the light to escape.

LEDs are manufactured with domed lenses in order to reduce the reabsorption problem. A metal (gold) film is applied to the bottom of the substrate for reflecting as much light as possible to the surface of the device and also to provide cathode connection.

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

LEDs radiate different colours such as red, green, yellow, orange, blue and white. Some of the LEDs emit infrared (invisible) light also.

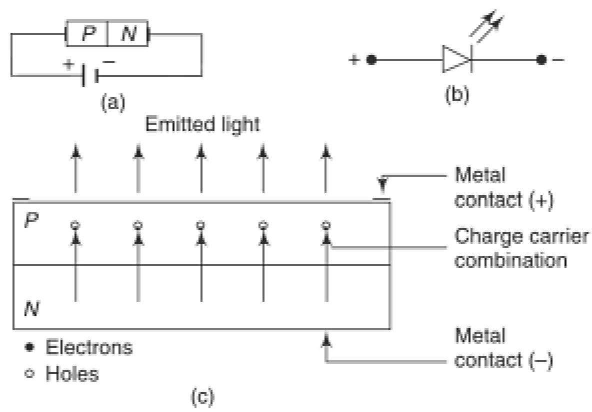


Fig: 3.9 LED (a) under forward bias, (b) Symbol, and (c) Recombinations and emission of light

Color of the emitted light (Wavelength) depends on the type of material used is given as follows.

Gallium arsenide (GaAs) – infrared radiation (invisible)

Gallium phosphide (GaP) – red or green

Gallium arsenide phosphide (GaAsP) - red or yellow

LEDs emit no light when reverse biased. LEDs operate at voltage levels from 1.5 to 3.3 V, with the current of some tens of milliamperes.

Application:

- They are used in burglar alarm systems, picture phones, multimeters, calculators, digital meters, microprocessors, digital computers, electronic telephone exchange, intercoms, electronic panels, digital watches, solid state video displays and optical communication systems.
- LED lamps.

3.5.1 INFRARED EMITTERS

The infrared emitting diodes arc PN junction gallium arsenide devices which emit a beam of light when forward biased. When the junction is energized, electrons from the N-region will recombine with the excess holes of the P-material in a specialty formed recombination region sandwiched between the P- and N-type materials. This recombination, which tends to restore the equilibrium carrier densities, can result in the emission of photons from the junction. The radiant energy from the device is infrared with a typical peak at 0.9 µm. which ideally matches the response of silicon photodiode and phototransistors.

3.6 LIQUID CRYSTAL DISPLAY (LCD)

The two liquid crystal materials which are commonly used in display technology are nematic and cholesteric. This liquid components have the fluidity of a liquid and the optical property of a solid.

Based on the construction. LCDs are classified into two types. They are

(3) Dynamic scattering LCD, and

(ii) Field effect LCD.

3.6.1 DYNAMIC SCATTERING TYPE

The display consists of two glass plates, each coated with tin oxide (SnO_2) on the inside with transparent electrodes separated by a liquid crystal layer, 5 to 50µm thick. Liquid crystal is transparent, light can pass through the crystal.

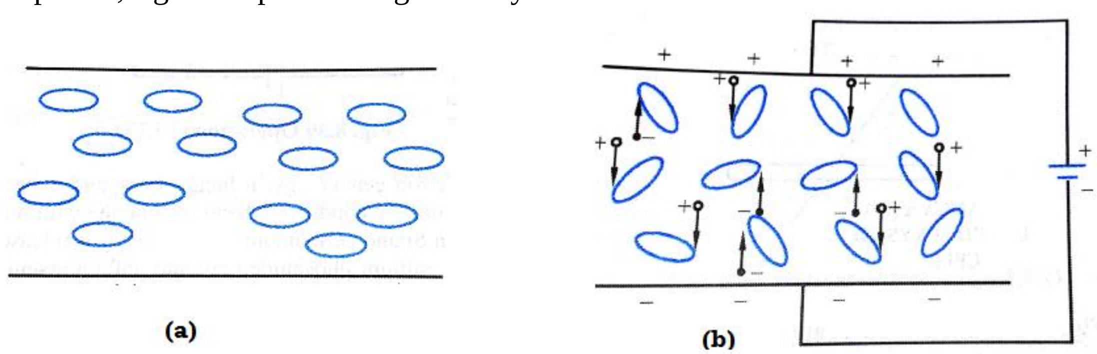


Fig: 3.10 (a)Molecular arrangement of Unactivated Liquid Crystal, (b)Molecular arrangement of Activated Liquid Crystal

When the liquid crystal is activated by applying an electric field, the carriers flowing through the crystal will disturb the molecular arrangement and the molecules are randomly oriented. Now the liquid crystal scatters the light in all direction and the activated area will appear brighter. This phenomenon is called **dynamic scattering**.

Construction

A liquid crystal consists of a layer of liquid crystal material sandwiched between two glass sheets. The inner side of the glass sheets is deposited with transparent metal film electrodes. When both the glass sheets are transparent the LCD is called transmittive type cell. When one glass in transparent and the other one is reflective, the LCD is called reflective type cell.

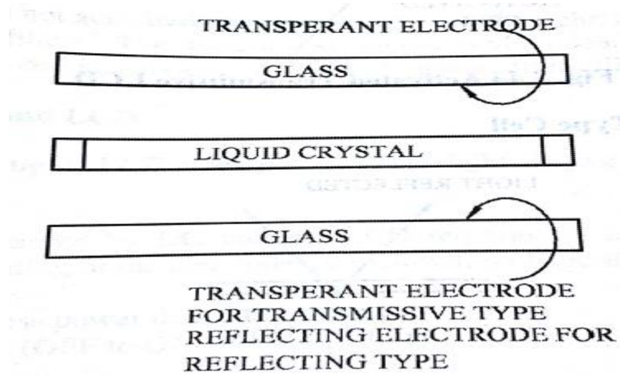


Fig: 3.11 Structure of LCD

Operation of Transmittive type Cell

In transmittive type the light falls on the cell from the back side of the cell. When the cell is not activated it is transparent so it allow light to pass through the cell. In this case the cell will not appear bright.

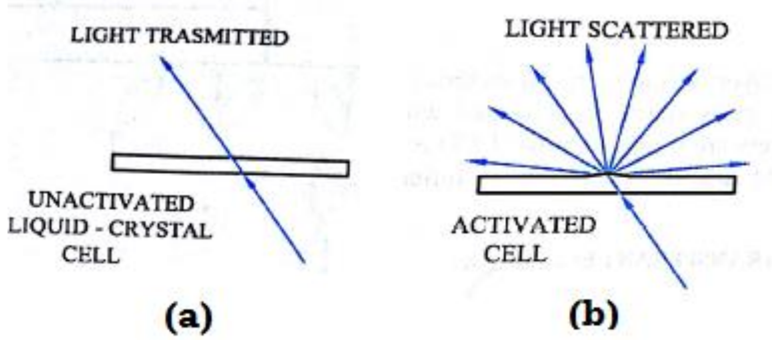


Fig: 3.12 (a)Unactivated Transmittive LCD, (b) Activated Transmittive LCD

When the cell is activated the incident light is scattered. In this case the cell will appear bright.

Operation of Reflective Type Cell

In reflective type the light falls on the cell from the front side of the cell. When the cell is unactivated the light passes through the crystal, the light is reflected by the back side reflective glass and again pass through the crystal. In this case the cell will not appear bright.

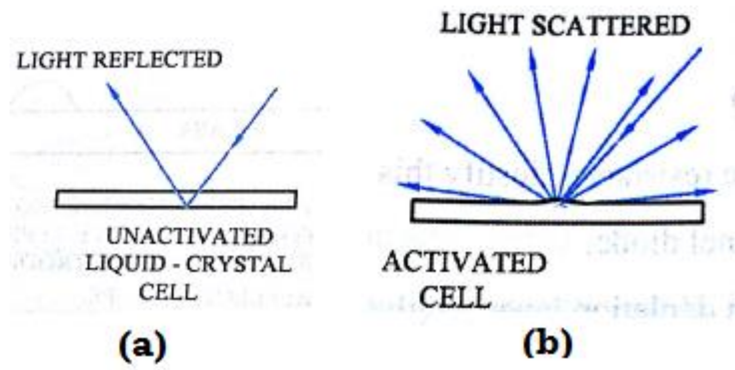


Fig: 3.13 (a)Unactivated Reflective LCD, (b) Activated Reflective LCD

When the cell is activated the incident light is scattered and reflected by the cell. In this case the cell will appear bright.

3.6.2 FIELD EFFECT LCD

The construction of a field effect LCD display is similar to that of the dynamic scattering type, with the exception that two thin polarising optical fillers arc placed at the inside of each glass sheet. The LCD material is of twisted nematic type which twists the light (change in direction of polarisation) passing through the cell when the latter is not energized. This allows light to pass through the optical filters and the cell appears bright. When the cell is energized, no twisting of light takes place and the cell appears dull.

Liquid crystal cells are of two types: (i) Transmittive type, and (ii) Reflective type. In the transmittive type cell, both glass sheets are transparent so that light from a rear source is scattered in the forward direction when the cell is activated.

The reflective type cell has a reflecting surface on one side of the glass sheet. The incident light on the front surface of the cell is dynamically scattered by an activated cell.

Advantages of LCD

(i) The voltages required are small.

(ii) They have a low power consumption. A seven segment display requires about 140 W (20 W per segment), whereas LEDs require about 40 mW per numeral.

{iii) They are economical.

Disadvantages of **LCD**

(i) LCDs are very slow devices. The turn ON and OFF times are quite large. The turn ON time is typically of the order of a few ms, while the turn OFF is 10 ms.

(ii) When used on d.c, their life span is quite small. Therefore, they are used with a.c supplies having a frequency less than 50 Hz.

(iii) They occupy a large area.

3.7 DIAC (DIODE A.C. SWITCH)

DIAC is a three layer, two terminal semiconductor device. MT_1 and MT_2 are the two main terminals which are interchangeable, It acts as a bidirectional Avalanche diode. It does not have any control terminal. It has two junctions J_1 and J_2. The structure of DIAC is like a transistor. Doping concentration of three layers of DIAC is identical.

At voltage less than the breakover voltage, a very small amount of current called the leakage current flows through the device and the device remains in OFF state. When the voltage level reaches the breakover voltage, the device starts conducting and it exhibits negative resistance characteristics, i.e. the current flowing in the device starts increasing and the voltage across it starts decreasing.

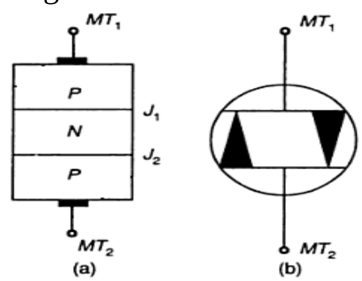


Fig. 3.14 Diac(a)Basic structure and (b)circuit symbol

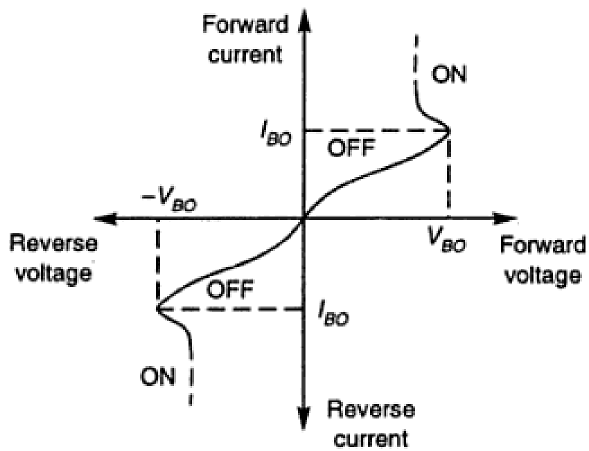


Fig: 3.15 Characteristics of DIAC

The Diac is not a control device. It is used as triggering device in Triac phase control circuits used for light dimming, motor speed control and heater control.

3.8 SILICON CONTROLLED RECTIFIER (SCR)

Diode and transistor cannot be used as switch in high current. Thyristors (SCR, DIAC & TRIAC) are semiconductor switch, made to operate in high current application.

Construction

SCR is a four layer semiconductor device, which consist of alternate P type and N type silicon. SCR consists of three junctions J_1, J_2 and J_3 and three terminals known as anode A, cathode K and Gate G.

The function of gate is to control the firing of SCR. SCR conducts only in one direction i.e., from anode to cathode and hence it is called unidirectional switch.

Symbol & Structure

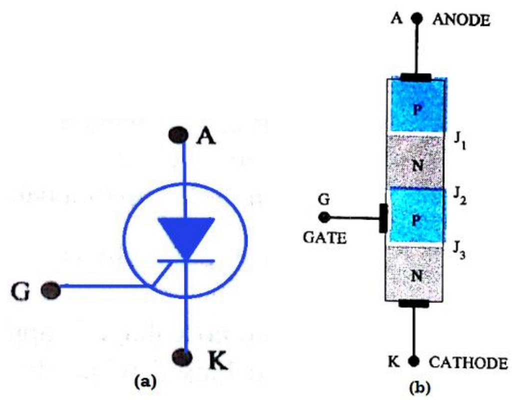


Fig: 3.16 (a) Symbol of SCR, (b) structure of SCR

Two Transistor analogy of SCR

The operation of SCR may be explained by dividing it into two transistors: a PNP transistor T_1 and another NPN transistor T_2. Collector of each transistor is coupled to the base of the other transistor.

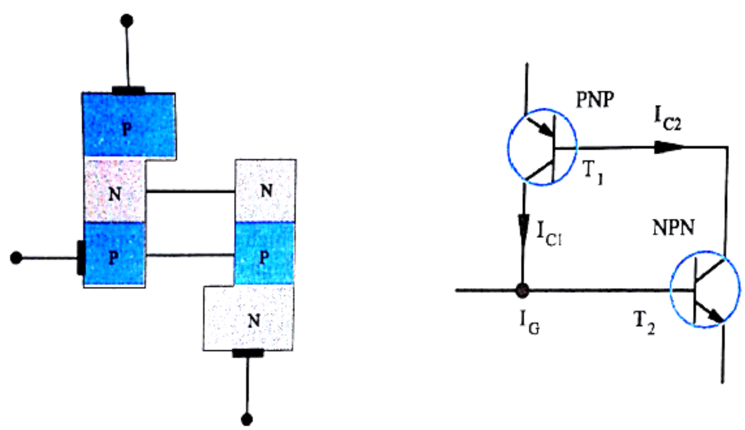


Fig: 3.17 Two transistor model of SCR

When gate is open and V_{AK} is positive and less than the break over voltage VBO, transistors T_1 and T_2 remain in cutoff. Therefore, no current flows through the SCR. When the gate is made positive, a small gate current flow through the base of T_2. This increase its collector current. As the collector current of T_2 is the base current of T_1, T_1 is switched ON and its collector current increases. The collector current of T_1 is base current of T_2. Therefore an increase in current of one transistor causes an increase in current of the other transistor. This process goes in an accumulative way and both transistors are driven into saturation. Now a heavy current flow through the load. The SCR is in ON condition.

Operation of SCR

SCR can be operated with gate open or with positive voltage at the gate. In SCR a load is connected in series with anode and anode is kept at positive potential with respect to cathode with the help of a battery.

I_G=0 and V_{AK} is positive

When no voltage is applied at the gate(I_G=0) and V_{AK} is positive, junctions J_1 and J_2 are forward biased while the junction J_2 is reverse biased. Due to the reverse bias of the junction J_2, no current flows through the load R_L. The current flowing through the SCR is very small reverse saturation current. SCR is said to be in cut-off condition.

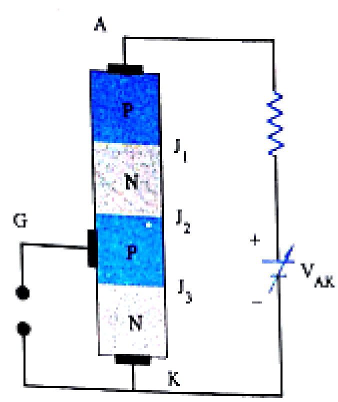


Fig: 3.18 SCR with open Gate

When positive voltage at the anode is increased, the reverse bias at the junction J_2 is also increases and at a particular voltage the junction J_2 breaks down. Now the SCR conducts heavily and is said to be in ON state. The resistance of SCR become low (0.01Ω to 1Ω) therefore the voltage across the SCR decreases.

The anode voltage at which the SCR start conducting is called **break over voltage.** The current at which SCR is switched ON is called the holding current I_H. Holding current is the minimum current required to keep the SCR in ON condition.

SCR can be used as a switch with V_{AK} positive.

I_G>0 and V_{AK} is positive

When V_{AK} is positive, junction J_1 and J_3 are forward biased while the junction J_2 is reverse biased. When the gate is made positive with respect to cathode, the gate voltage forward biases junction J_3. Electrons from N type material cross the junction J_3

and move into P type material, holes from P type material cross the junction J_3 and move in to the N type material. Electrons are the majority carriers in the P type material, which can cross the reverse biased junction J_2. More electrons that get energy from the positive voltage can create more carriers and break the junction J_2 for a low V_{AK}, and SCR conducts heavily. Once SCR starts conducting, the gate loses its control, SCR cannot be switched off by the gate voltage.

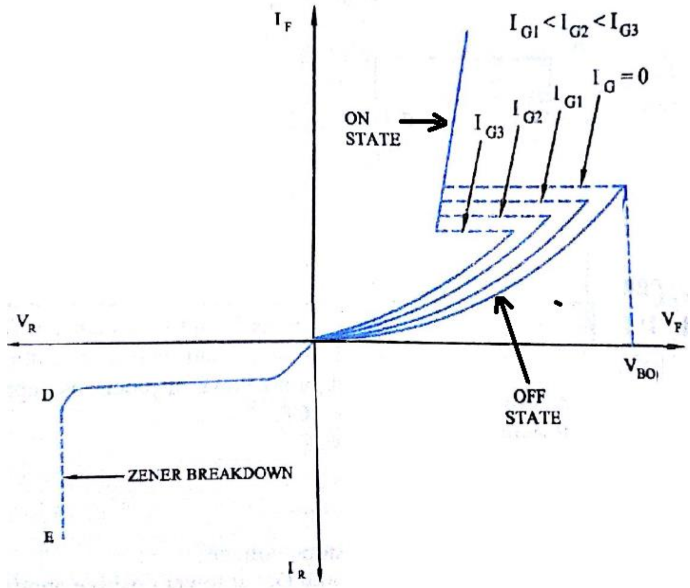


Fig: 3.19 VI characteristics of SCR

V_{AK} is negative

When V_{AK} is negative, junction J_1 and J_3 are reverse biased while the junction J_2 is forward biased. Due to the reverse bias of junction J_1 and J_3, no current flows through the load R_L. The current flowing through the SCR is very small reverse saturation current. When the negative voltage at the anode is increased, break down of junctions happens similar to zener breakdown which damages SCR. SCR cannot be used as switch with negative V_{AK}.

SCR Properties

- SCR can be switched ON by positive anode voltage.
- Positive gate voltage makes SCR to switch ON at lower positive anode voltages.
- When SCR is in ON condition it cannot be switched OFF by gate voltage.
- The anode voltage is to be reduced, to reduce the current below holding current in order to switch OFF the SCR.
- SCR cannot be used with negative anode voltage.
- SCR is unidirectional switch.

3.9 TRIAC (TRIODE A.C, SWITCH)

SCR can conduct current in one direction. Triac is the combination of 2 SCR in opposite direction. TRIAC is a three terminal, bidirectional semiconductor device.

Construction

TRIAC is a four layer semiconductor device with 3 terminals Anode1, Anode2 and gate. A positive or negative voltage at the gate can switch a triac from off state to on state.

(a) Two SCR model of Triac, (b) Structure of Triac and (c) symbol

Operation and characteristics:

- Positive bias
- Negative bias

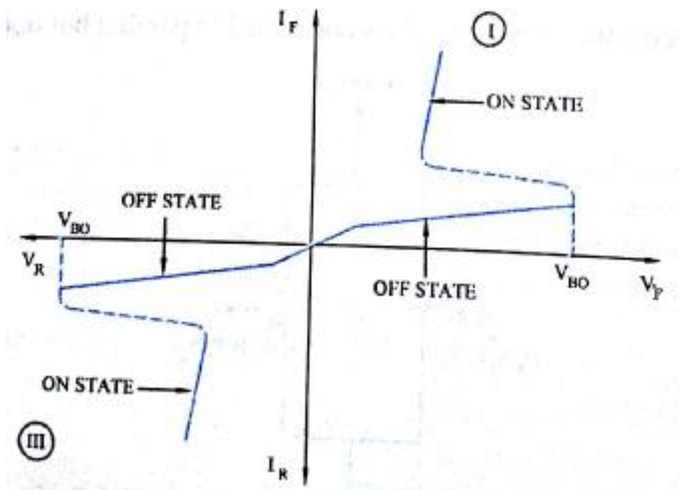


Fig: 3.20 VI characteristics

Positive Bias

When a positive voltage is applied between anode 1 and anode 2.

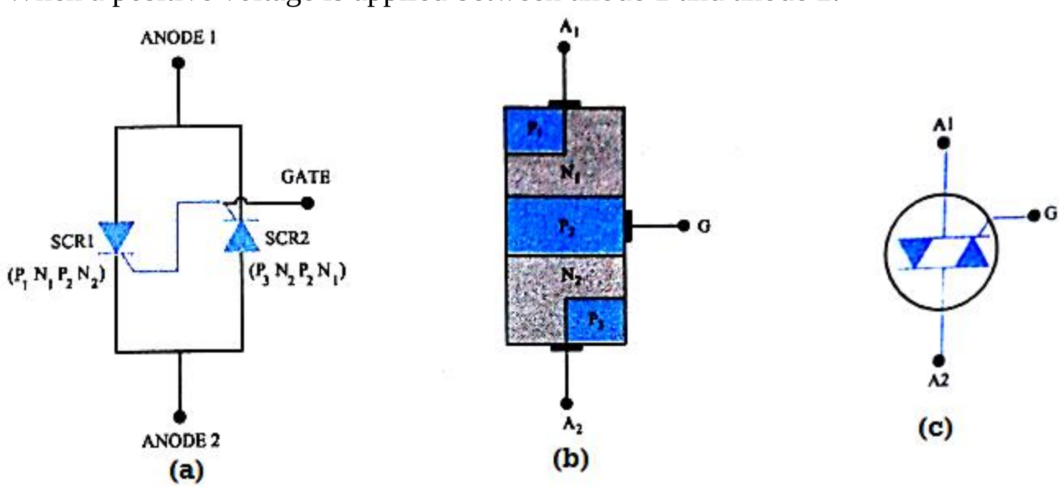


Fig: 3.21 (a) Two SCR structure, (b) Triac structure & (c) Triac Symbol

The P_1N_1 and P_2N_2 junctions are forward biased and P_2N_1 junction is reverse biased. When the positive voltage is increased above breakdown voltage V_{BO} the P_2N_1 junction breaks and the triac is switched ON and conduct current from anode1 to anode2. Triac can also be switched ON by applying positive voltage at the gate. When a positive voltage is applied at the gate, triac can switch ON for lower anode voltages.

Negative Bias

When a negative voltage is applied between anode 1 and anode 2. The P_3N_2 and P_2N_1 junctions are forward biased and P_2N_2 junction is reverse biased. When the negative voltage is increased above breakdown voltage V_{BO} the P_2N_2 junction breaks and the triac is switched ON and conduct current from anode2 to anode1. Triac can also be switched ON by applying a positive voltage at the gate. When a positive voltage is applied at the gate, triac switch ON for lower anode voltages.

3.10 UJT (UNIJUNCTION TRANSISTOR)

UJT is a three terminal semiconductor switching device. As it has only one PN junction and three leads, it is commonly called as Unijunction transistor.

The basic structure of UJT is shown in Fig. 4.19 (a). It consists of a lightly doped N-type Silicon bar with a heavily doped P-type material alloyed to its one side closer to B_2 for producing single PN junction. The circuit symbol of UJT is shown in Fig, 4.19 (b). Here the emitter leg is drawn at an angle to the vertical and the arrow indicates the direction of the conventional current.

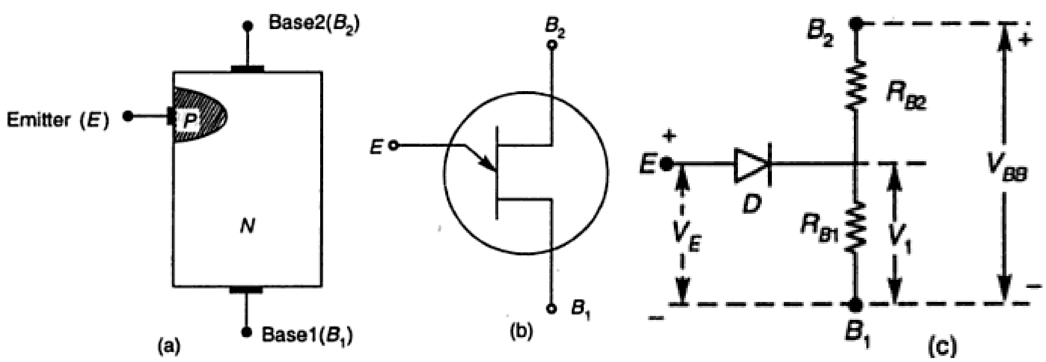


Fig: 3.22 UJT (a) Basic structure, (b) Circuit symbol and (c) Equivalent circuit

CHARACTERISTICS OF UJT

Referring to Fig. 3.22(c), the interbase resistance between B_2 and B_1 of the silicon bar is $R_{BB}=R_{B1}+R_{B2}$.With emitter terminal open, if voltage V_{BB} is applied between the two bases, a voltage gradient is established along the N-type bar.

The voltage drop across R_{B1} is given by $V_1=,\eta V_{BB}$ where the ***intrinsic stand-off ratio***

$$\eta = R_{B1}/(R_{B1} + R_{B2}).$$

The typical value of η ranges from 0.56 to 0.75. This voltage V_1 reverse biases the PN junction and emitter current is cut-off. But a small leakage current flows from B_2 to emitter due to minority carriers. If a positive voltage V_E is applied to the emitter the PN junction will remain reverse biased so long as V_E is less than V_1. If V_E exceeds V_1 by the cut-in voltage V_γ, the diode becomes forward biased. Under this condition, holes are injected into N-type bar. These holes are repelled by the terminal B_2 and are attracted by the terminal B_1 Accumulation of holes in E to B_1, region reduces the resistance in this section and hence emitter current I_E is increased and is limited by V_E. The device is now in the 'ON' state.

If a negative voltage is applied to the emitter PN junction remains reverse biased and the emitter current is cut off. The device is now in the 'OFF state.

Fig 3.23 shows a family of input characteristics of UJT, Here, up to the peak point *P*, the diode is reverse biased and hence, the region to the left of the peak point is called *cut-off region.* The UJT has a stable firing voltage *Vp* which depends linearly on V_{BB} and a small firing current I_p (≈ 25 μA). At P, the peak voltage $V_p = \eta V_{BB} + V_\gamma$, the diode starts conducting and holes are injected into N-layer Hence, resistance decreases thereby decreasing V_E For the increase in I_E So, there is a *negative resistance region* from peak point *P* to valley point V. After the valley point, the device is driven into saturation and behaves like a conventional forward biased PN junction diode. The region to the right of the valley point is called saturation region. In the valley point, the resistance changes from negative to positive. The resistance remains positive in the saturation region. For very large I_E, the characteristic asymptotically approaches the curve for $I_{B2} = 0$.

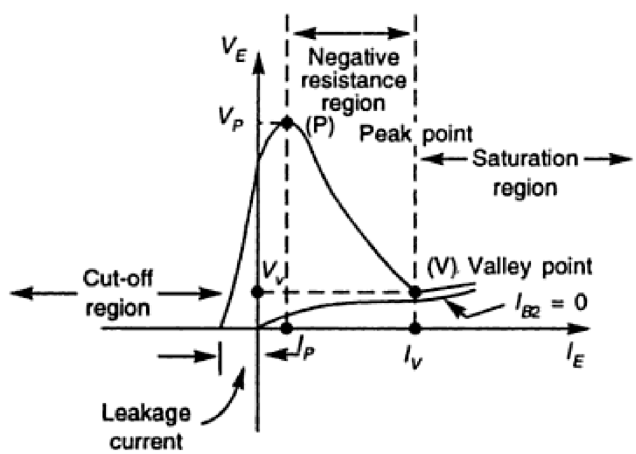


Fig: 3.23 Input characteristics of UJT

A unique characteristic of UJT is, when it is triggered, the emitter current increases regenerative until it is limited by emitter power supply. Due to this negative resistance properly, a UJT can be employed in a variety of applications, viz. sawtooth wave generator, pulse generator, switching, timing and phase control circuits.

3.11 UJT RELAXATION OSCILLATOR

The relaxation oscillator using UJT which is meant for generating sawtooth waveform is shown in Fig. 3.24. It consists of a UJT and a capacitor C_E which *is* charged through R_E as the supply voltage V_{BB} is switched ON

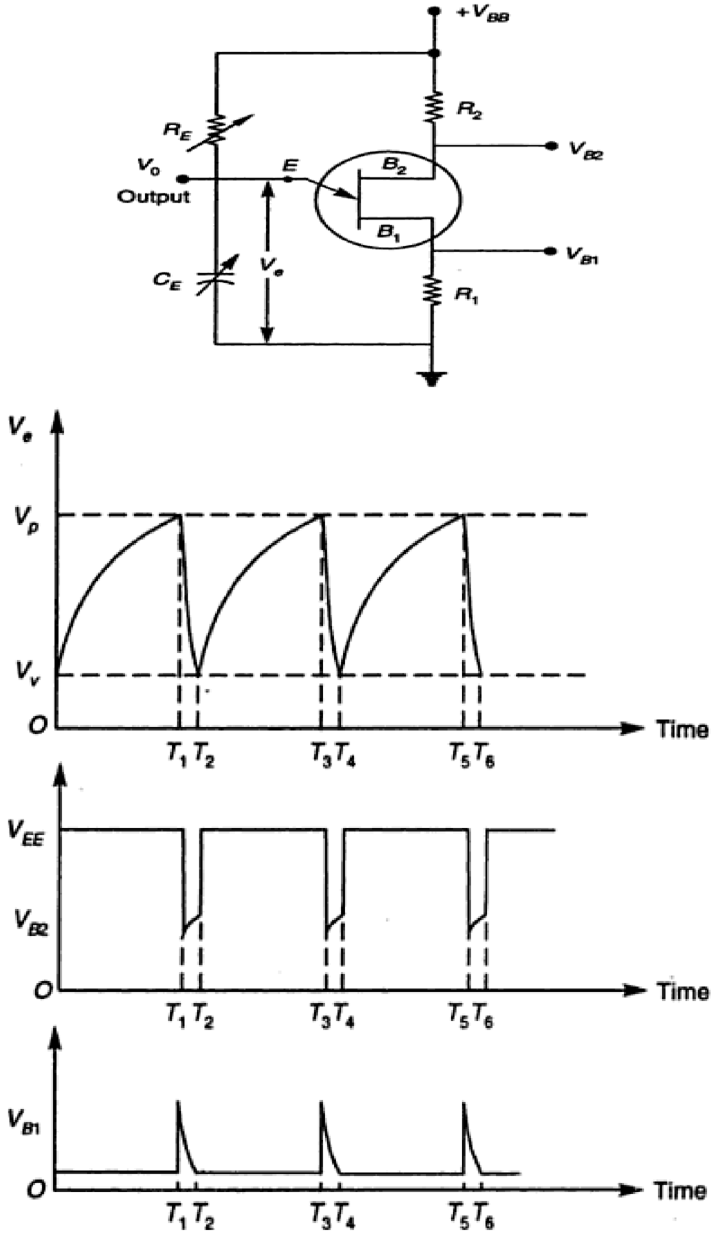


Fig: 3.24 UJT relaxation oscillator

The voltage across the capacitor increases exponentially and when the capacitor voltage reaches the peak point voltage *Vp* the UJT starts conducting and the capacitor voltage is discharged rapidly through E_{B1} and R_1. After the peak point voltage of UJT is reached, it provides negative resistance to the discharge path which is useful in the working of the relaxation oscillator. As the capacitor voltage reaches zero, the device then cuts off and capacitor C_E starts to charge again. This cycle is repeated continuously generating a *sawtooth waveform* across C_E.

The inclusion of external resistors R_2 *and* R_1 in series with B_2 and B_1 provides spike waveforms. When the UJT fires, the sudden surge of current through B_1 causes drop across R_1, which provides positive going spikes. Also, at the time of firing, fall of V_{EB1} causes I_2 to increase rapidly which generates negative going spikes across R_2

By changing the values of capacitance C_E or resistance R_E, frequency of the output waveform can be changed as desired, since these values control the time constant $R_E C_E$ of the capacitor changing circuit.

Frequency of Oscillation

Assuming that the capacitor is initially uncharged, the voltage V_c across the capacitor prior to breakdown is given by

$$V_c = V_{BB}(1 - e^{-t/R_E C_E})$$

where $R_E C_E$ = charging time constant of resistor-capacitor circuit, and t = time from the commencement of the waveform.

The discharge of the capacitor occurs when V_C is equal to the peak-point voltage V_P, i.e.

$$V_P = \eta V_{BB} = V_{BB}(1 - e^{-t/R_E C_E})$$

$$\eta = 1 - e^{-t/R_E C_E}$$

$$e^{-t/R_E C_E} = (1 - \eta)$$

Therefore,

$$t = R_E C_E \log_e \frac{1}{(1-\eta)}$$

$$= 2.303\ R_E C_E \log_{10} \frac{1}{(1-\eta)}$$

If the discharge time of the capacitor is neglected, then $t = T$, the period of the wave.

Therefore, frequency of oscillation of sawtooth wave,

$$f = \frac{1}{T} = \frac{1}{2.3\ R_E\ C_E\ \log_{10} \frac{1}{(1-\eta)}}$$

3.12 PHOTOCONDUCTIVITY

When light in the form of photons strikes the semiconductor, each photon delivers energy to the electrons. If the photon energy is greater than the energy hand gap of the semiconductor, free mobile charge carriers are liberated and, as a result, resistivity of the semiconductor is decreased, so conduction starts. This Process of generating electric current from incident light is called photoconductivity.

3.13 LIGHT DEPENDENT RESISTOR(LDR) OR PHOTORESISTOR:

It is a semiconductor device whose resistance varies inversely with the intensity of light falls upon it. It is also known as *photoresistive* cell or *photoresistor* because it operates on the principle of photoresistivity.

when light in the form of photons strikes the semiconductor, each photon delivers energy to the electrons. If the photon energy is greater than the energy hand gap of the semiconductor, free mobile charge carriers are liberated and, as a result, resistivity of the semiconductor is decreased, so conduction starts.

Photoconductive cells are generally made of cadmium compounds such as cadmium sulphide *{CdS)* and cadmium selenide (CdSe).

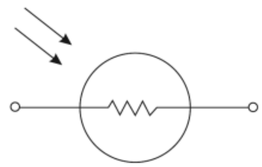


Fig: 3.25 circuit Symbol

A photoconductive cell is an inexpensive and simple detector which is widely used in OFF/ON circuits, light-measurement and light-detecting circuits.

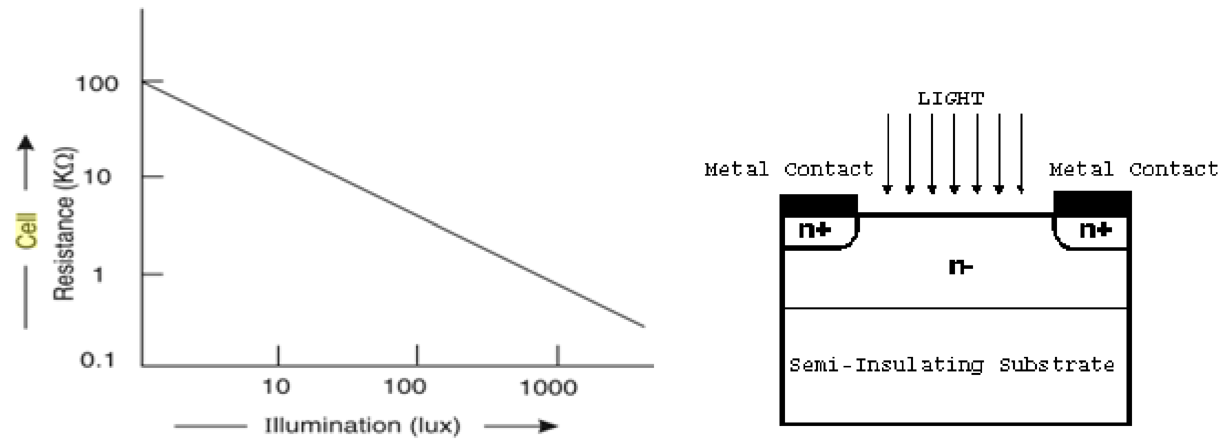


Fig: 3.26 (a) Characteristics curve of LDR, (b) Basic structure of LDR

There are two types of LDR

- Intrinsic photo resistor(Pure semiconductors are used for construction)
- Extrinsic photo resistor(Doped semiconductors are used for construction)

Application

- Light detector

3.14 PHOTODIODES

A photodiode is *a* type of photodetector capable of converting light into either current or voltage.

A photodiode is a two terminal PN junction device, which *operates in a* reverse *bias.* It has a small transparent window, which allows light to strike the PN junction.

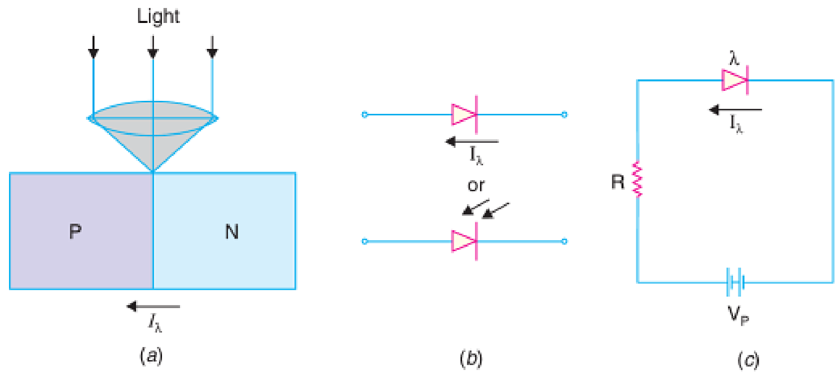


Fig: 3.27 Photodiode

Photodiode produces reverse current in the reverse bias by thermally generated electron-hole pairs in the depletion layer, which are swept across the junction by the electric field created by the reverse voltage.

Its reverse current increases with the light intensity at the PN junction When there is no incident light, the reverse current is almost negligible and is called the dark current. An increase in the amount of light energy produces an increase in the reverse current for a given value of reverse-bias voltage.

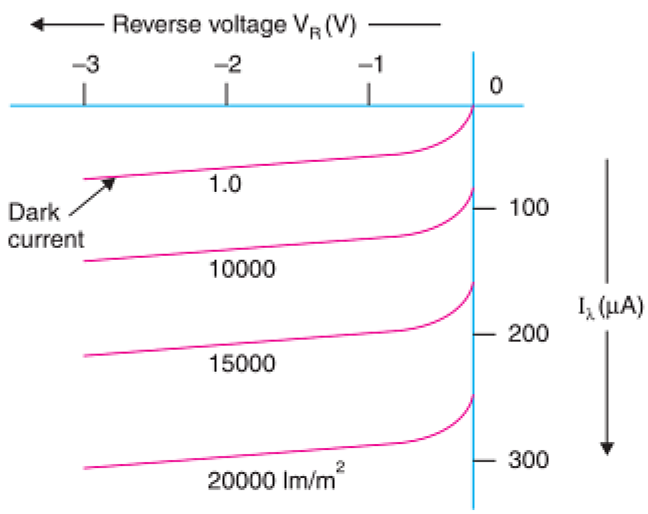


Fig: 3.28 Characteristic curve of a photodiode

Applications

1. Used in consumer electronic device such as compact disc (CD) players, smoke detectors, and the receivers for infrared remote control equipments from televisions to air-conditioners,
2. Used or accurate measurement of light intensity in science and industry. The photodiodes have more linear response than photo-conductors.
3. Widely used in medical applications such as detectors for computer tomography, instruments to analyze samples pulse oximeters.
4. Because of their fast switching speed, used for optical communication and in lighting regulation.

5. Optical communication systems
6. Character recognition
7. Encoders *etc.*

3.15 AVALANCHE PHOTO DIODE (APD)

ADP is used in optical communication for detection of light at the receiving end. It converts the input light energy into electrical energy.

It essentially consist of reverse biased PN junction. The depletion region in the reverse biased PN junction is formed by immobile positively charged donor atoms in the N-type semiconductor material and immobile negative charged acceptor atoms in the P-type material. The electric field in this depletion region is very high where most of the photons are absorbed and primary charge carriers (electron-hole pair) generated. There charge carriers acquire sufficient energy from the electric field to excite new electron hole pair by this process known as impact ionization.

These new carriers created by impact ionization can themselves produce additional carriers by the same mechanism. For this process, APD requires a high reverse bias voltage in the order of 100- 400 V. carrier multiplication factors as greater as 104 may be obtained using defect free materials. Electron-hole pair thus generated separate and drift under the influence of the electric field in the depletion region and diffuse outside the depletion region so that they are finally collected in the detector terminals. This leads to a flow of current in the external circuit whose magnitude is proportional to the intensity of light incident on APD.

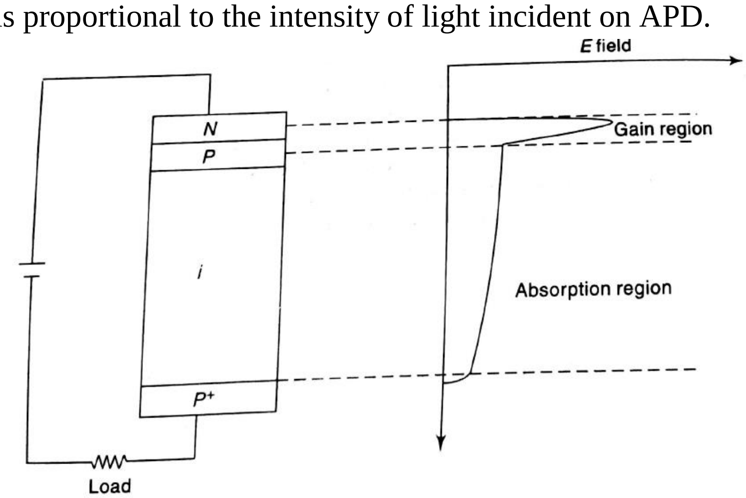


Fig: 3.29 Structure of APD

Due to the internal gain mechanism in an APD, a large electrical response is obtained even for a weak input signal. Quantum efficiency closer to 100% in the working region can be obtained.

3.16 PHOTOTRANSISTOR

It is light-sensitive transistor and is similar to an ordinary bipolar junction transistor (BJT) except that it has no connection to the base terminal. Its operation is based on the photodiode that exists at the CB junction. Instead of the base current, the input to the transistor is provided in the form of light.

Silicon NPN are mostly used as phototransistor. The device is usually packed with a lens on top although it is sometimes encapsulated in clear plastic. When there is no incident light on the CB junction, there is a small thermally-generated collector-to-emitter leakage current I_{CEO} which, in this case, is called dark current and is in the nA range

When light is incident on the CB junction, a base current I_{λ} is produced which is directly proportional to the light intensity. Hence, collector current $I_C=\beta I_{\lambda}$

The photo-transistor has the advantages of greater sensitivity and current capacity than photodiodes, However, photodiodes are faster of the two switching *in* less than *a* nanosecond.

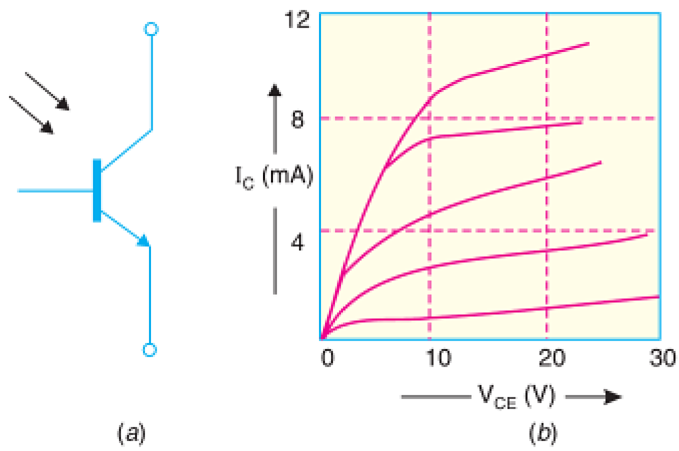


Fig: 3.30 (a) structure of phototransistor, (b) characteristic curve of Phototransistor

3.17 OPTOCOUPLER

An optocoupler is a solid-slate component in which the Light emitter, the light path and the light detector are all enclosed within the component and cannot be changed externally. As the optocoupler provides electrical isolation between circuits, it is also called *optoisolator*. An optoisolator allows signal transfer without coupling wires, capacitors or transformers. It can couple digital (ON/OFF) or analog (variable) signals.

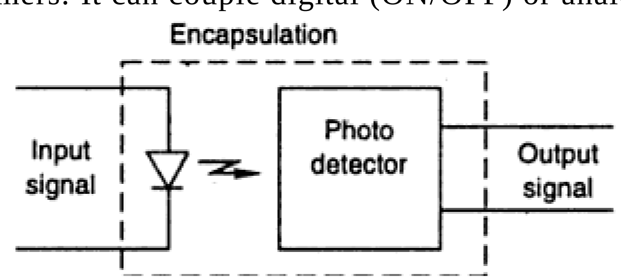


Fig: 3.31 Schematic representation of the optocoupler

Optoisolator consists of an infrared LED and a photodetector such as PIN photodiode for fast switching.

Optoisolators transduce input voltage to proportional light intensity by using LEDs. The light is transduced back to output voltage using light sensitive devices, GaAs.

The wavelength response of each device is made to be as identical as possible to permit the highest measure of coupling possible. There is a transparent insulating cap between each set' of elements embedded in the structure (not visible) permit the passage of light. They are designed with very small response times in such a way that they can be used to transmit data in the MHz range.

Optoisolator is used as an interface between high voltage and low voltage systems. Application for this device includes the interfacing of different types of logic circuits and their use in level-and- position-sensing circuits.

The switching time of an optoisolator decreases with increased current, while for many devices it is exactly the reverse.

3.18 SOLAR CELL

When sunlight is incident on a photovoltaic cell, it is converted into electric energy. Such an energy converter is called solar cell or solar. This cell consists of a single semiconductor crystal which has been doped with both P- and N-type impurities, thereby forming a PN junction.

An incident light photon at the junction may collide with *a* valence electron and impart sufficient energy to make a transition to the conduction band.

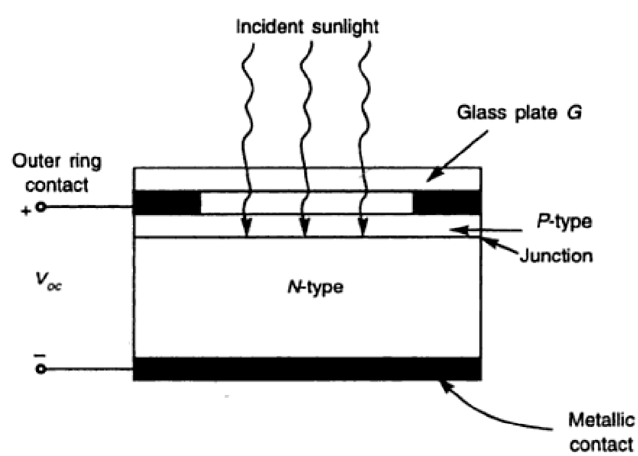


Fig: 3.32 Basic construction of a PN junction solar cell

As a result, an electron-hole pair is formed. The newly formed electrons are minority carriers in the P-region. They move freely across the junction. Similarly, holes formed in the N-region cross the junction in the opposite direction, The flow of these electrons and holes across the junction is in a direction opposite to the conventional forward current in a PN junction. Further, it leads to the accumulation of a majority carriers on both sides of the junction. This gives rise to a photovoltaic voltage across the junction in the open circuit condition. This voltage is a logarithmic function of illumination.

To increase the power output, large banks of cells are used in series and parallel combinations. The efficiency of the solar cell is measured by the ratio of electric energy output to the light energy input expressed as a percentage. Silicon and selenium arc the materials used widely in solar cells because of their excellent temperature characteristics.

3.19 LASER DIODE

Laser is a narrow beam of Photons emitted by specially made laser diodes. Laser diode is similar to an ordinary LED, but it generates a beam of high intensity light. A laser is a device in which a number of atoms vibrate to produce a beam of radiation in which all the waves have single wavelength and are in Phase with each other.

Laser light is Monochromatic and can be focused as a pencil beam The beam of a typical laser has 4×0.6mm widening at a distance of 15 meters. Like an LED, laser diode converts electrical energy into light energy.

Working

The most common laser diode generates semiconductor or injection laser. In these lasers, a population of Inversion Electrons is produced by applying a voltage across its p-n junction. Laser beam is then available from the semiconductor region. The p-n junction of laser diode has polished ends so that, the **emitted photons reflect back and forth and creates more electron-hole pairs**. The photons thus generated will be in phase with the previous photons. This will give a Pencil Beam and all the photons in the beam are Coherent and in phase.

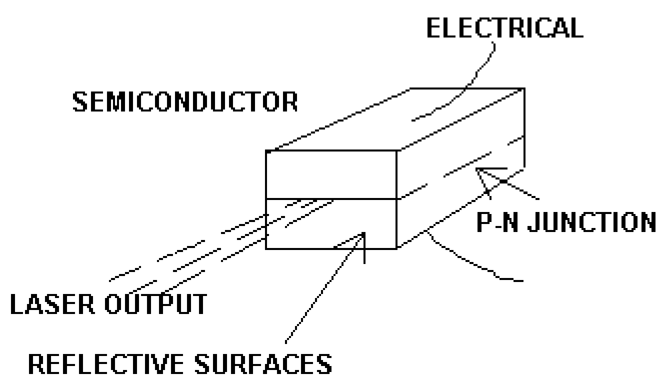


Fig: 3.33 LASER diode

Laser is a high intensity penetrating beam and is extremely dangerous when focused on to the Eye. A Laser pointer with output power higher than 5 mW is harmful.

Applications

Optical memories, Fiber optic communications, Military applications, surgical procedures, CD players, Printers etc.,

UNIT IV
BIASING AND STABILIZATION

4.1 INTRODUCTION

BIASING

In order to operate transistor in the desired region, external DC voltage is applied with correct polarity and magnitude to the two junctions of the transistor. The process of applying the DC voltage to the transistor is called Biasing or DC biasing.

Q-POINT OR OPERATING POINT(I_C AND V_{CE})

Certain voltage and current conditions are required to bias a transistor. These conditions are known as DC operating point or quiescent point (Q- point). Eg. $I_C = 0.5$ A, $V_{CE} = 12$ V.

The operating point must be stable for proper operation of the transistor. However, the operating point shifts with changes in transistor parameters such as β, I_{CO} and V_{BE}. As transistor parameters are temperature dependent, the operating point also varies with change in temperature.

To maintain the operating point stable two techniques are there. They are

(i) **Stabilization techniques**- refers to the use of resistive biasing circuits which allow I_B to vary so as to keep I_C relatively constant with variation in I_{CO}, β and V_{BE}.

(ii) **Compensation techniques-** refers to the use of temperature-sensitive devices such as diodes, transistors, thermistors, etc., which provide compensating voltages and currents to maintain the operating point stable.

4.2 STABILITY FACTOR (S)

The extent to which the collector current I_c is stabilised with varying I_{C0} is measured by a stability factor *S*. It is defined as the rate of change of collector current I_c with respect to the collector-base leakage current I_{CO}, keeping both the current I_B and the current gain $\boldsymbol{\beta}$ constant.

$$S = \frac{\partial I_C}{\partial I_{CO}} \approx \frac{dI_C}{dI_{CO}} \approx \frac{\Delta I_C}{\Delta I_{CO}}, \ \beta \text{ and } I_B \text{ constant}$$

For CE configuration, collector current is given as,

$$I_C = \beta I_B + I_{CEO} \qquad \text{or} \qquad I_C = \beta I_B + (1+\beta) I_{CBO}$$

Differentiating the above equation with respect to I_C, we get

$$1 = \beta \frac{\partial I_B}{\partial I_C} + (1+\beta)\frac{\partial I_{CBO}}{\partial I_C}$$

$$\frac{\partial I_{CBO}}{\partial I_C} = \frac{1-\beta\left(\frac{\partial I_B}{\partial I_C}\right)}{(1+\beta)}$$

$$S = \frac{\partial I_C}{\partial I_{CBO}} = \frac{(1+\beta)}{1-\beta\left(\frac{\partial I_B}{\partial I_C}\right)}$$

ADDITIONAL STABILITY FACTORS

Stability Factors S' and S'' The stability factor S' is defined as the rate of change of I_C with V_{BE}, keeping I_{CO} and β constant

$$S' = \frac{\partial I_C}{\partial V_{BE}} \approx \frac{\Delta I_C}{\Delta V_{BE}}$$

The stability factor S'' is defined as the rate of change of I_C with respect to β, keeping I_{CO} and V_{BE} constant

$$S'' = \frac{\partial I_C}{\partial \beta} \approx \frac{\Delta I_C}{\Delta \beta}$$

NEED FOR BIASING:

- To operate the transistor in the desired (Active) region.
- To get the output signal power greater than the input signal power. (i.e., Amplification of Transistor).

4.3 DC EQUIVALENT MODEL, LOAD LINE AND OPERATING POINT

DC LOAD LINE

CE configured circuit shown in fig 4.1 (a) with base emitter junction forward biased and collector base junction reverse biased.

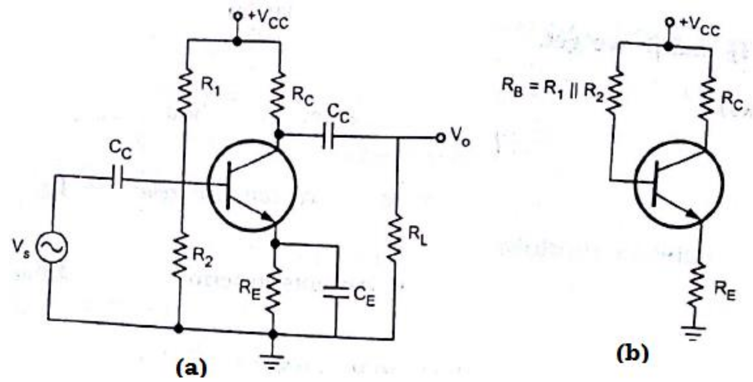


Fig: 4.1 (a) CE amplifier, (b) Equivalent circuit when AC signal is absent

When AC signal is absent the capacitor provides high impedance i.e., open circuit. Therefore the equivalent circuit is show in fig: 4.1(b). Applying Kirchhoff's voltage law to the collector circuit (b)

$$V_{CC} - I_C (R_C + R_E) - V_{CE} = 0$$

$$V_{CC} = I_C (R_C + R_E) + V_{CE}$$

$$I_C = \left[-\frac{1}{(R_C + R_E)}\right] V_{CE} + \frac{V_{CC}}{(R_C + R_E)}$$

$$= \left[-\frac{1}{R_{dc}}\right] V_{CE} + \frac{V_{CC}}{R_{dc}} \qquad \because R_{dc} = R_C + R_E$$

Compared to equation of straight line y=mx+c, m ($-1/R_{dc}$) is slope and c (V_{CC}/R_{dc}) is the intercept of Y axis.

When $V_{CE}=V_{CC}$; $I_C=0$ and we get a point A. When $V_{CE}=0$; $I_C= V_{CC}/R_{dc}$ and we get a point B.

The line drawn between points A and B is called **dc load line(**Plot I_C Vs V_{CE}**).** Knowing any one of I_C, I_B or V_{CE} it is easy to determine the other two from the load line.

Applying kirchhoff's law to the base circuit,

$$V_{CC} - I_B R_B - V_{BE} - I_E R_E = 0$$

$$V_{CC} - I_B R_B - V_{BE} - (1+\beta) I_B R_E = 0$$

$$I_B [R_B + (1+\beta) R_E] = V_{CC} - V_{BE}$$

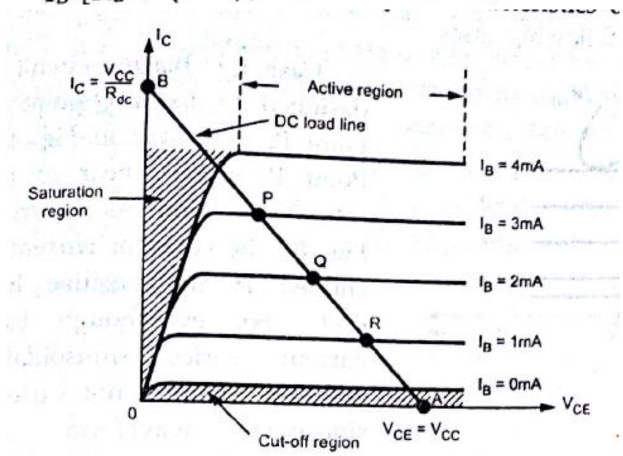


Fig: 4.2 Common emitter output characteristics with dc load line

$$I_B = \frac{V_{CC} - V_{BE}}{R_B + (1+\beta) R_E}$$

As $V_{CC} >> V_{CE}$

$$I_B = \frac{V_{CC}}{R_B + (1+\beta) R_E}$$

The intersection point of characteristic curve for I_B and dc load line is called operating point. For different values of I_B, different operating points P, Q and R are obtained. All these are Q points.

4.3.1 CRITERIA FOR FIXING OPERATING POINT

The operating points are selected in three different cases with respect of dc load line,

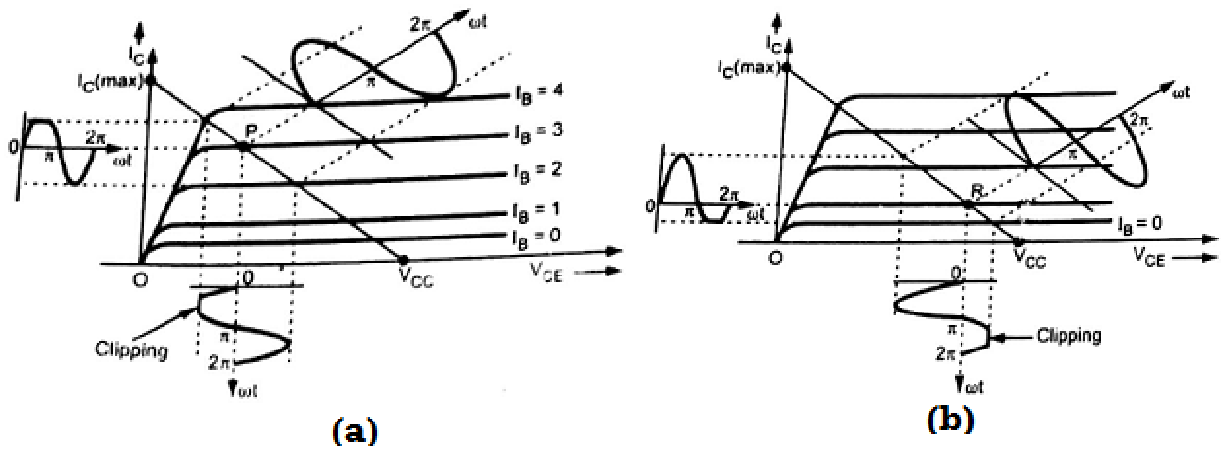


Fig: 4.3 (a) case 1: Operation point near saturation region, (b) case 2: operating point near cut-off region

Case 1: Operating point Near saturation region at point P, gives clipping at the positive peaks, so eventhough base current varies, collector current is not useful sinusoidal waveform (distortion is present at the output). Therefore point P is not a suitable operating point.

Case 2: Operating point Near cut-off region at point R, gives clipping at negative peak, point R is also not suitable operating point.

Case 3: Operating point At center of (active region) Q, the output signal is sinusoidal waveform without any distortion. Thus point Q is the best operating point.

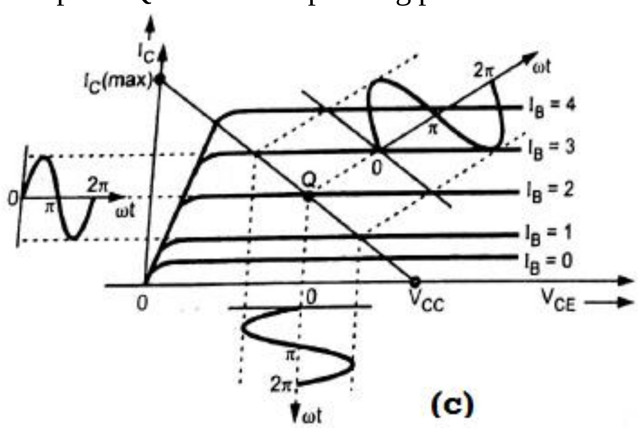


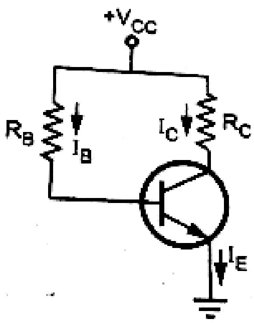
Fig: 4.3 (c) case 3: operating point at the center of active region

4.4 DIFFERENT TYPES OF BJT BIASING

It is always convenient and preferable to have an electronic circuit that works on a single battery. There are several biasing circuits are there. In particular

- Fixed or base bias
- Collector to base bias or base bias with collector feedback
- Self bias or voltage divider bias

4.5 FIXED BIAS OR BASE BIAS



Applying kirchhoff's law to the base circuit,

$$V_{CC} - I_B R_B - V_{BE} = 0$$

$$I_B = \frac{V_{CC} - V_{BE}}{R_B}$$

$$\therefore I_B \cong \frac{V_{CC}}{R_B} \quad \because V_{CC} >> V_{BE}$$

The supply voltage V_{CC} is of fixed value. Once the resistance R_B is selected, I_B is also fixed. Hence this circuit is called "Fixed bias circuit".

Fig: 4.4 Fixed bias circuit

Applying kirchhoff's voltage law to the collector current,

$$V_{CC} - I_C R_C - V_{CE} = 0$$

$$\therefore V_{CE} = V_{CC} - I_C R_C$$

$$V_{CC} = I_C R_C + V_{CE}$$

$$I_C = \frac{V_{CC} - V_{CE}}{R_C}$$

Voltage drop across R_C can never be more than V_{CC}.

$$I_C R_C < V_{CC}$$

$$\text{or } I_C < \frac{V_{CC}}{R_C}$$

If the transistor is replaced by another transistor, even though the type is same, their characteristic may differ slightly. In fixed bias circuit, the change in the characteristic of transistor changes the operating point.

So the fixed bias circuit is unsatisfactory if the transistor is replaced by another of the same type.

4.5.1 STABILITY FACTOR FOR FIXED BIAS CIRCUIT

$$S = \frac{(1+\beta)}{1-\beta\left(\frac{\partial I_B}{\partial I_C}\right)}$$

Collector current in CE configuration is given as

$$I_C = \beta I_B + I_{CEO} \text{ or } I_C \cong \beta I_B \text{ since } \beta I_B \gg I_{CEO}$$

From fixed bias I_C is given by $I_C \cong \frac{V_{CC}}{R_B} \cong I_B$

Differentiate I_B with respect to I_C, $\frac{\partial I_B}{\partial I_C} = 0$, change in I_B will not affect V_{CC} and V_{BE}

Substituting this value in S, $S = \frac{(1+\beta)}{1-0}$

$$S = 1 + \beta$$

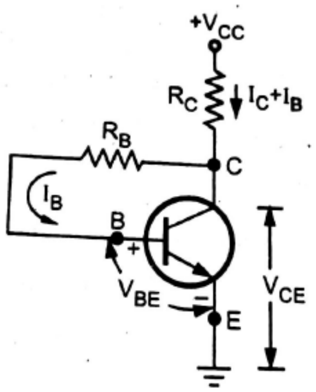
Advantages

- Simple circuit with few components
- Operating point is fixed anywhere in the active region by simply changing the R_B value. Thus it provides maximum flexibility in design.

Disadvantages

- Thermal stability is not provided by this circuit. So the operating point is not maintained.
- I_C depends on β, thus stabilization of operating point is very poor.

4.6 COLLECTOR TO BASE BIAS CIRCUIT OR BASE BIAS WITH COLLECTOR FEEDBACK



Because of poor stability in operating point, R_B is connected between collector and base. Hence the circuit is called "collector to base bias circuit". Thus I_B flows through R_B and $(I_C + I_B)$ flows through the R_C.

Applying voltage law to the base circuit,

$$V_{CC} - (I_B + I_C) R_C - I_B R_B - V_{BE} = 0$$

$$V_{CC} = (R_B + R_C) I_B + I_C R_C + V_{BE}$$

$$I_B = \frac{(V_{CC} - I_C R_C) - V_{BE}}{R_C + R_B}$$

$$\frac{I_C}{\beta} = \frac{(V_{CC} - I_C R_C) - V_{BE}}{R_C + R_B} \quad \because I_C = \beta I_B$$

$$I_C = \frac{\beta (V_{CC} - I_C R_C - V_{BE})}{R_C + R_B}$$

Fig: 4.5 Collector to base bias circuit

Applying Kirchhoff's voltage law to the collector circuit,

$$V_{CC} - (I_C + I_B) R_C - V_{CE} = 0$$

$$V_{CE} = V_{CC} - (I_C + I_B) R_C$$

$$= V_{CC} - I_C R_C - I_B R_C$$

$$V_{CC} - I_C R_C = V_{CE} + I_B R_C$$

Substituting this value of $V_{CC} - I_C R_C$ in I_B equation,

$$I_B = \frac{V_{CE} + I_B R_C - V_{BE}}{R_C + R_B}$$

Change in β and I_{CO} due to temperature, then I_C tends to increase, since $I_C = \beta I_B + I_{CEO}$. As a result, voltage drop across R_C increases. Since V_{CC} is constant V_{CE} decreases. Due to V_{CE}

reduction, I_B reduces. As I_C depends on I_B, decrease in I_B reduces the original increase in I_C. The result is that the circuit tends to maintain a stable value of I_C, keeping the Q point fixed.

A part of the output is fed back to the input through R_B, and increase in collector current decreases the base current. Thus negative feedback exists in the circuit, so this circuit is also called **Voltage feedback bias circuit.**

4.6.1 STABILITY FACTOR FOR COLLECTOR TO BASE BIAS CIRCUIT

$$S = \frac{1+\beta}{1-\beta\left(\frac{\partial I_B}{\partial I_C}\right)}$$

From collector to base bias circuit,

$$V_{CC} = I_C R_C + I_B (R_C + R_B) + V_{BE}$$

Differentiate the above equation with respect to I_C,

$$0 = \partial I_C R_C + \partial I_B (R_C + R_B)$$

$$\frac{\partial I_B}{\partial I_C} = \frac{-R_C}{R_C + R_B}$$

$$S = \frac{1+\beta}{1-\beta\left(-\frac{R_C}{R_C + R_B}\right)}$$

$$\boxed{S = \frac{1+\beta}{1+\beta\left(\frac{R_C}{R_C + R_B}\right)}}$$

Collector to base bias having less stability factor than fixed bias circuit. Hence this circuit provides better stability than fixed bias circuit.

4.6.2 STABILIZATION WITH CHANGES IN β

Stability factor S depends on β. But if we design the circuit with condition $\beta R_C \gg R_B$ then we can make stability factor independent of β.

We know that, $I_C = \beta I_B + (1+\beta) I_{CBO}$

Therefore, $$I_B = \frac{I_C - (1+\beta) I_{CO}}{\beta}$$

Applying KVL to base circuit, $-V_{CC} + (I_B + I_C) R_C + I_B R_B + V_{BE} = 0$

$$-V_{CC} + I_B (R_C + R_B) + I_C R_C + V_{BE} = 0$$

Substituting the value of I_B in above equation

$$-V_{CC} + \left[\frac{I_C - (1+\beta) I_{CO}}{\beta}\right](R_C + R_B) + I_C R_C + V_{BE} = 0$$

Multiplying by β on both side we get,

$$-\beta V_{CC}+I_C\left(R_C+R_B\right)-\left(1+\beta\right)I_{CO}\left(R_C+R_B\right)+\beta I_C R_C+\beta V_{BE}=0$$

$$I_C\left[R_C+R_B+\beta R_C\right]=\left[\beta V_{CC}+\left(1+\beta\right)I_{CO}\left(R_C+R_B\right)-\beta V_{BE}\right]$$

As $\beta >> 1$, $1+\beta \approx \beta$

$$I_C\left[\beta R_C+R_B\right] \approx \beta\left[V_{CC}-V_{BE}+I_{CO}\left(R_C+R_B\right)\right]$$

$$I_C \approx \frac{\beta\left[V_{CC}-V_{BE}+I_{CO}\left(R_C+R_B\right)\right]}{\left(R_B+\beta R_C\right)}$$

Here $\beta R_C >> R_B$, therefore

$$I_C \approx \frac{V_{CC}-V_{BE}+I_{CO}\left(R_C+R_B\right)}{R_C}$$

The collector current has become independent of β and hence stabilized against change in β.

If we provide stability against I_{CO} variations, we get stability against β variations also.

4.7 SELF BIAS OR VOLTAGE DIVIDER BIAS OR EMITTER BIAS

In this circuit, the biasing is provided by three resistors R_1, R_2 and R_E. The resistors R_1 and R_2 act as a potential divider giving a fixed voltage to point B which is base. If collector current increases due to change in temperature or change in β, the emitter current I_E also increases and V_{BE}.Due to reduction in V_{BE}, base current I_B and hence collector current I_C also reduces. Therefore, we can say that negative feedback exists in the emitter current I_C compensates for the original change in I_C.

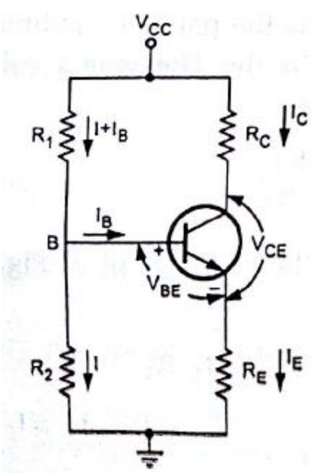


Fig: 4.6 Voltage Divider Bias Circuit

Voltage across R_2 is the base voltage V_B. Applying the voltage divider theorem to find V_B,

$$V_B = \frac{R_2\ (I)}{R_1\ (I+I_B)+R_2\ (I)} \times V_{CC}$$

$$V_B = \frac{R_2}{R_1+R_2} \times V_{CC} \qquad \because\ I >> I_B$$

Voltage across R_E (V_E) can be obtained as,

$$V_E = I_E R_E = V_B - V_{BE}$$

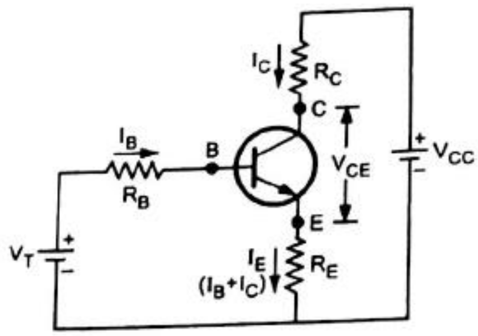
$$I_E = \frac{V_B - V_{BE}}{R_E}$$

Applying KVL to the collector circuit,

$$V_{CC} - I_C R_C - V_{CE} - I_E R_E = 0$$

$$V_{CE} = V_{CC} - I_C R_C - I_E R_E$$

4.7.1 STABILITY FACTOR FOR VOLTAGE DIVIDER BIAS



$$S = \frac{1+\beta}{1-\beta\left(\frac{\partial I_B}{\partial I_C}\right)}$$

Here thevenin's equivalent voltage V_T is given by,

$$V_T = \frac{R_2 \times V_{CC}}{R_1 + R_2} \quad \text{and} \quad R_B = \frac{R_1 R_2}{R_1 + R_2}$$

Applying KVL to the base circuit,

$$V_T = I_B R_B + V_{BE} + (I_B + I_C) R_E$$

Fig: 4.7 Thevenin's equivalent circuit for voltage divider bias

Differentiate w.r.t I_C,

$$0 = \frac{\partial I_B}{\partial I_C} \times R_B + \frac{\partial I_B}{\partial I_C} \times R_E + R_E$$

$$\frac{\partial I_B}{\partial I_C} = \frac{-R_E}{R_E + R_B}$$

$$\boxed{S = \frac{1+\beta}{1+\beta\left(\frac{R_E}{R_E+R_B}\right)}}$$

By simplifying the above

$$S = \frac{(1+\beta)(R_E + R_B)}{R_B + (1+\beta) R_E}$$

Dividing each term by R_E we get,

$$S = (1+\beta)\frac{1+ {}^{R_B}\!/\!_{R_E}}{(1+\beta) + {}^{R_B}\!/\!_{R_E}}$$

From this equation

1. The ratio R_B/R_E controls value of stability factor S. if R_B/R_E << 1 then the above equation reduces to $$S = (1+\beta).\frac{1}{(1+\beta)} = 1$$
   Practically $R_B/R_E \neq 0$. For better stability factor, keep the ratio R_B/R_E as small as possible.
2. To keep R_B/R_E small, it is necessary to keep R_B small. This means that R1$\|$R2 must be small. Due to small value of R1 and R2, potential divider circuit will draw more current from VCC reducing the life of the battery. So while designing if we make R2 much

smaller than R1 then parallel combination results small RB without drawing more current through VCC. Another important aspect is that reducing RB will reduce input impedance of the circuit, since RB comes in parallel with the input. This reduction of input impedance in amplifier circuits is not desirable and hence RB cannot be made very small.

3. Emitter resistance RE is the another parameter we can use to decrease ratio R_B/R_E. By increasing RE we can make R_B/R_E small. But as we increase RE, drop IE RE will also increase and since VCC is constant, drop across RC will reduce. This shifts the operating point Q which is not desirable and hence there is limit for increasing RE.

   Thus while designing voltage divider bias circuit we have to find compromising values:

S	– Small
RB	- Reasonably small
RE	- not very large

4. If ratio R_B/R_E is fixed, S increases with β. Therefore stability decreases with increasing β.
5. Stability factor S is essentially independent of β for small value of S.

Stability factor S for voltage divider bias or self bias is less as compared to other biasing circuits studied. So this circuit is most commonly used.

4.8 BIAS COMPENSATION

The various biasing circuits considered in the previous sections used some types of negative feedback to stabilise the operation point. Also, diodes, thermistors and sensistors can be used to compensate for variations in current.

4.8.1 DIODE COMPENSATION

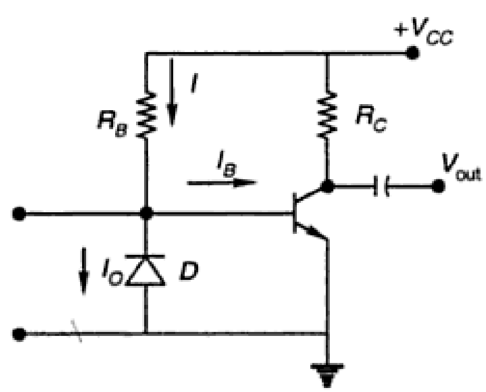


Figure 4.8 shows *a* transistor amplifier with a diode *d* connected across the base-emitter junction for compensation of change in collector saturation current I_{Co}. The diode is of the same material as the transistor and it is reverse biased by the base-emitter junction voltage V_{BE}, allowing the diode reverse saturation current I_0 to flow through diode D. The base current $I_B = I - I_0$

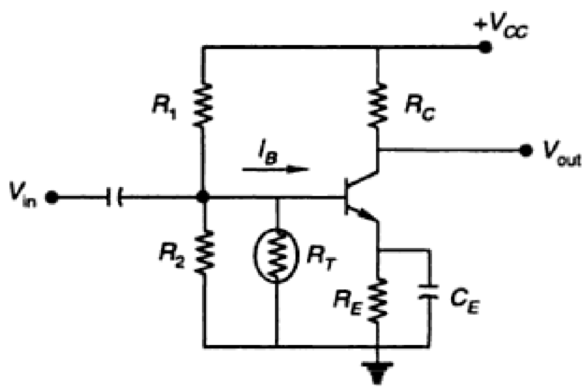
As long as temperature is constant, diode *D* operates as a resistor. As the temperature increases, I_{co} of the transistor increases-Hence, to compensate for this, the base current I_B should be decreased.

Fig: 4.8 Diode bias compensation

The increase in temperature will also cause the leakage current I_o through D to increase and thereby decreasing the base current I_B. This is the required action to keep I_c constant.

This method of bias compensation does not need a change in I_C to effect the change in I_B. as both I_o and I_{co} can track almost equally according to the change in temperature.

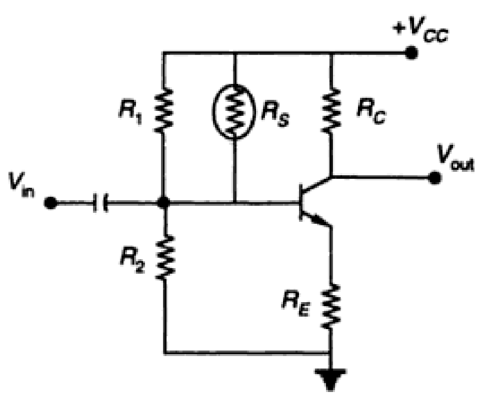
4.8.2 THERMISTOR COMPENSATION



In Fig. 4.9, a thermistor, R_T, having a negative temperature coefficient is connected in parallel with R_2. The resistance of thermistor decreases exponentially with increase of temperature. An increase in temperature will decrease the base voltage V_{BE}, reducing I_B and I_c. Bias stabilisation is also provided by R_E and C_E.

Fig: 4.9 Thermistor bias compensation

4.8.3 SENSISTOR COMPENSATION



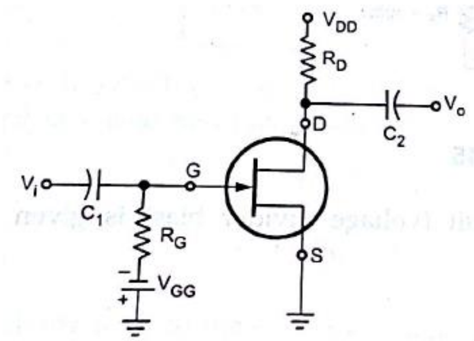
In Fig. 4.10, a sensistor, R_s, having *a* positive temperature coefficient is connected across R_1 (or R_E). R_s increases with temperature. As temperature increases, the equivalent resistance of the parallel combination of R_1 and R_s also increases and hence the base voltage V_{BE} decreases, reducing I_B and I_c. This reduced I_c compensates for the increased I_c caused by the increase in I_{C0}, V_{BE} and β due to temperature rise.

Fig: 4.10 Sensistor bias compensation

4.9 BIASING IN JFET

- Fixed or gate bias
- Voltage divider bias
- Self bias

4.9.1 FIXED-BIAS CIRCUIT



This is the simplest biasing arrangement. To make gate-source junction reverse-biased, a separate supply V_{GG} is connected such that gate is more negative than the source.

For DC analysis coupling capacitors are open circuits.

$I_G = 0$ A, So R_G is open circuit, shown in simplified fixed bias circuit.

Fig: 4.11 Fixed bias circuit for N-channel JFET

Applying KVL to the input circuit, $V_{GS} + V_{GG} = 0$

$$V_{GS} = -V_{GG}$$

Since V_{GG} is a fixed DC supply, the voltage V_{GS} is fixed in magnitude and hence the name fixed bias circuit.

Drain current is given by

$$I_D = I_{DSS}\left(1-\frac{V_{GS}}{V_p}\right)^2$$

The drain to source voltage of output circuit can be determined by applying KVL.

$$V_{DS} + I_D R_D - V_{DD} = 0$$

$$V_{DS} = V_{DD} - I_D R_D$$

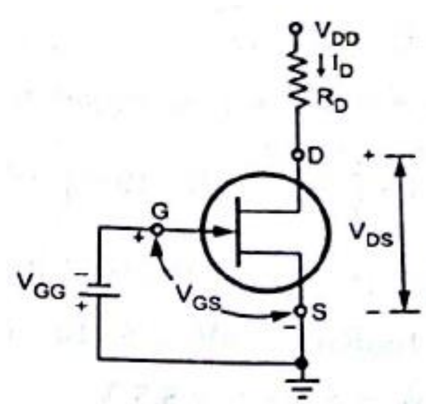


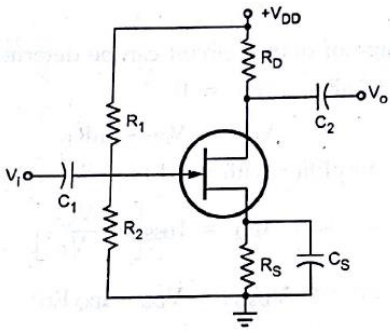
Fig: 4.12 Simplified Fixed Bias Circuit

The Q point of the JFET amplifier with fixed bias circuit is given by:

$$I_{DQ} = I_{DSS}\left[1 - \frac{V_{GS}}{V_P}\right]^2$$

$$V_{DSQ} = V_{DD} - I_{DQ} R_D$$

4.9.2 VOLTAGE DIVIDER BIAS CIRCUIT



The voltage at the source of the JFET must be more positive than the voltage at the gate in order to keep the gate-source junction reverse-biased. The source voltage is

$$V_S = I_D R_S$$

The gate voltage is set by resistors R1 and R2 as expressed by the following equation using the voltage divider formula:

$$V_G = \left(\frac{R_2}{R_1 + R_2}\right) V_{DD}$$

Fig: 4.13 Voltage divider bias for N-channel JFET

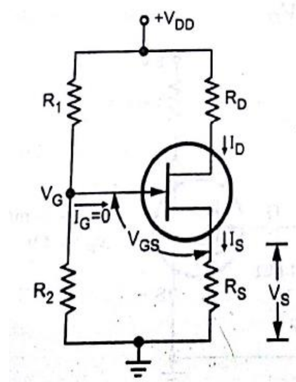


Fig: 4.14 simplified voltage Divider bias circuit

Applying KVL to the input circuit of simplified voltage divider bias circuit,

$$V_G - V_{GS} - V_S = 0$$

$$\therefore V_{GS} = V_G - V_S = V_G - I_S R_S$$

$$= V_G - I_D R_S \qquad \because I_D = I_S$$

$$\therefore V_{GS} = V_G - I_D R_S$$

Applying KVL to the output circuit,

$$V_{DS} + I_D R_D + V_S - V_{DD} = 0$$

$$\therefore V_{DS} = V_{DD} - I_D R_D - I_D R_S$$

$$= V_{DD} - I_D (R_D + R_S)$$

The Q point of a JFET amplifier using the voltage divider bias is given by:

$$I_{DQ} = I_{DSS}\left[1 - \frac{V_{GS}}{V_P}\right]^2$$

$$V_{DSQ} = V_{DD} - I_D (R_D + R_S)$$

4.9.3 SELF BIAS CIRCUIT

JFET must be operated such that the gate source junction is always reverse-biased. This condition requires a negative V_{GS} for an N-channel JFET and a positive V_{GS} for P- channel JFET. This can be achieved using the self bias arrangement shown in fig: . The gate resistor, R_C does not affect the bias because it has essentially no voltage drop across it; and therefore the gate remains at 0 V. R_G is necessarry only to isolate an AC signal from ground in amplifier applications. The voltage drop across resistor, R_S makes gate source junction reverse biased.

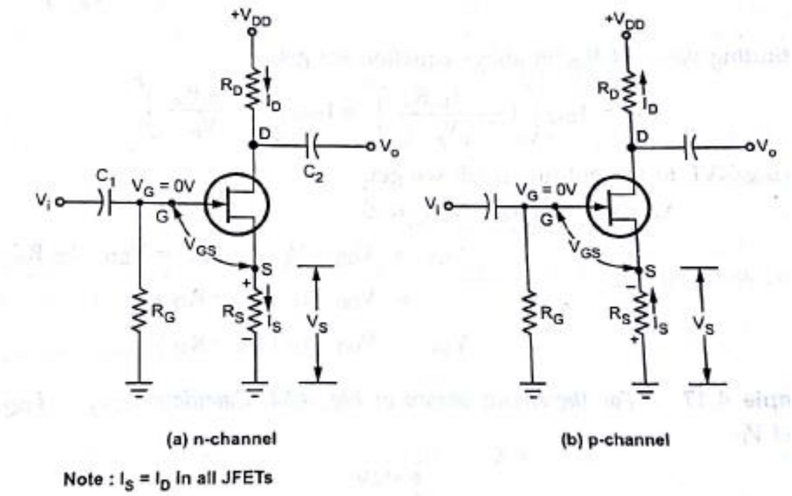


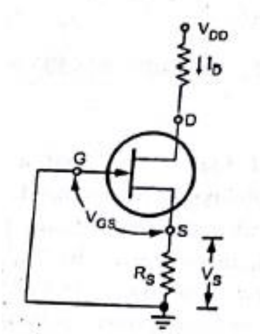
Fig: 4.15 Self Bias Circuit for JFET

For the N-channel FET in fig: 4.15 (a), I_S produces a voltage drop across R_S and makes the source positive with respect to ground. Since $I_S = I_D$ and $V_G = 0$, then $V_S = I_S R_S = I_D R_S$. The gate to source voltage is,

$$V_{GS} = V_G - V_S = 0 - I_D R_S = - I_D R_S$$

For the P-channel FET in fig: 4.15 (b), I_S produces a voltage drop across R_S and makes the source negative with respect to ground. Since $I_S = I_D$ and $V_G = 0$, then $V_S = - I_S R_S = - I_D R_S$. The gate to source voltage is,

$$V_{GS} = V_G - V_S = 0 - (- I_D R_S) = +I_D R_S$$



For DC analysis, capacitors are open circuited and R_G is short circuited, since $I_G = 0$.

The relation between I_D and V_{GS} is given by

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_p}\right)^2$$

Substituting the value of V_{GS} in the above equation,

$$I_D = I_{DSS}\left(1 - \frac{-I_D R_S}{V_p}\right)^2 = I_{DSS}\left(1 + \frac{I_D R_S}{V_p}\right)^2$$

Applying KVL to the output circuit,

Fig: 4.16 Simplified self-bias circuit for DC analysis

$$V_S + V_{DS} + I_D R_D - V_{DD} = 0$$
$$V_{DS} = V_{DD} - V_S - I_D R_D = V_{DD} - I_D R_S - I_D R_D$$
$$= V_{DD} - I_D (R_S + R_D)$$
$$V_{DS} = V_{DD} - I_D (R_S + R_D)$$

4.10 BIASING OF MOSFET

BIASING FOR DEPLETION TYPE MOSFET

Biasing circuits for depletion type MOSFET are quite similar to the circuits used for JFET biasing. The primary difference between the two is the fact that depletion type MOSFETs also permit operating points with positive value of V_{GS} for N-channel and negative values of V_{GS} for P-channel MOSFET. To have positive value of V_{GS} for N-channel and negative value of V_{GS} for P-channel self bias is unsuitable.

4.11 BIASING FOR ENHANCEMENT TYPE MOSFET

Biasing circuits for enhancement type MOSFET are similar to the circuit used for JEFT biasing. The primary difference between two is the fact that enhancement type MOSFET only permits operating points with positive values of VGS for N-channel and negative values or VGS for P-channel, for this self bias is unsuitable.

- Feedback bias
- Voltage divider bias

4.11.1 FEEDBACK BIAS CIRCUIT:

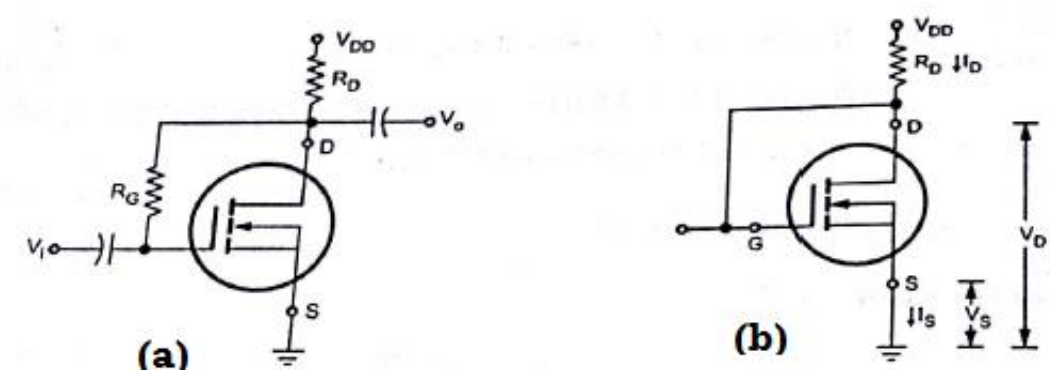


Fig: 4.17 (a) Feedback bias circuit, (b) simplified feedback circuit for DC analysis

For DC analysis, capacitors are open circuited and R_G is short circuited, since $I_G = 0$.

As drain and gate terminals are shorted

$$V_D = V_G$$
$$V_{DS} = V_{GS} \qquad \because \quad V_S = 0 .$$

Applying KVL to output circuit,

$$V_{DD} - I_D R_D - V_{DS} = 0$$

$$V_{DS} = V_{DD} - I_D R_D$$

$$V_{GS} = V_{DD} - I_D R_D \quad \because V_{DS} = V_{GS}$$

4.11.2 VOLTAGE DIVIDER BIAS

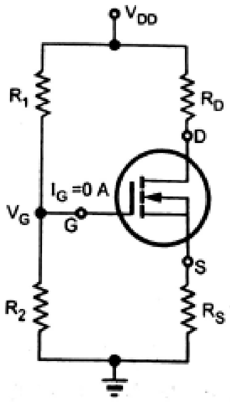


Fig: 4.18 Voltage Divider Bias

Here the biasing resistors R1 and R2 are designed to provide gate to source voltage.

DC Analysis :

As $I_G = 0$ A

$$V_G = \frac{R_2 V_{DD}}{R_1 + R_2}$$

Applying KVL to input circuit we get,

$$V_G - V_{GS} - V_S = 0$$

$$\therefore V_{GS} = V_G - I_S R_S = V_G - I_D R_S \quad \because I_D = I_S$$

$$\therefore V_{GS} = V_G - I_D R_S$$

Applying KVL to output circuit we get,

$$V_{DD} - I_D R_D - V_{DS} - I_S R_S = 0$$

$$\therefore V_{DS} = V_{DD} - I_D R_D - I_S R_S = V_{DD} - I_D R_D - I_D R_S$$

$$= V_{DD} - I_D (R_D + R_S) \quad \because I_D = I_S$$

UNIT V
POWER SUPPLIES

5.1 RECTIFIERS

Rectifier is defined as an electronic device used for converting (A.C) voltage into unidirectional voltage (D.C). i.e. A.C. voltage into a pulsating D.C. voltage

- Half wave Rectifier
- Full wave Rectifier

5.2 HALF-WAVE RECTIFIER (A.C. voltage into a pulsating D.C. voltage)

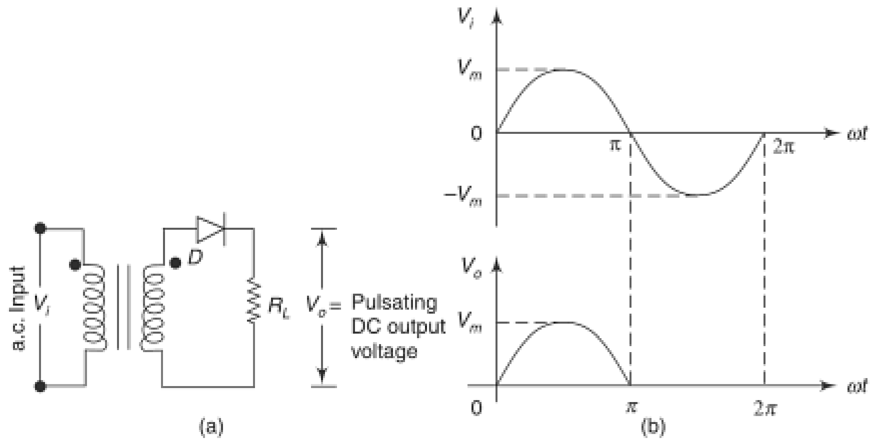


Fig: 5.1 (a) Basic structure of half-wave rectifier, and (b) input output waveforms of half wave rectifier

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

$$V_i = V_m \sin \omega t;\ V_m >> V_\gamma$$

where V_γ is the cut-in voltage of the diode.

During positive half cycle, the diode D is in Forward bias condition. Diode conduct.

During negative half cycle, the diode D is in reverse bias condition. Diode does not conduct.

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

$$\Gamma = \frac{\text{rms value of a.c. component}}{\text{d.c. value of component}} = \frac{V_{r,\text{rms}}}{V_{\text{d.c.}}}$$

where $$V_{r,\text{rms}} = \sqrt{V_{\text{rms}}^2 - V_{\text{d.c.}}^2}$$

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

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

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

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

Therefore, $$I_{\text{d.c}} = \frac{V_{\text{d.c.}}}{R_L} = \frac{V_m}{\pi R_L} = \frac{I_m}{\pi}$$

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

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

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

The rms voltage at the load resistance can be calculated as

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

$$= V_m \left[\frac{1}{4\pi}\int_0^{\pi} (1 - \cos 2\,\omega t)\, d(\omega t)\right]^{\frac{1}{2}} = \frac{V_m}{2}$$

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

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

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

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

$$= \frac{\dfrac{(V_{\text{d.c.}})^2}{R_L}}{\dfrac{(V_{\text{rms}})^2}{R_L}} = \frac{\left(\dfrac{V_m}{\pi}\right)^2}{\left(\dfrac{V_m}{2}\right)^2} = \frac{4}{\pi^2} = 0.406 = 40.6\%$$

The maximum efficiency of a half-wave rectifier is 40.6%.

Peak Inverse Voltage (PIV) It is defined as the maximum reverse voltage that a diode can withstand without destroying the junction. The peak inverse voltage across a diode is the peak of the negative half cycle. For half-wave rectifier, PIV is V_m.

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

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

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

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

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

Form Factor

$$\text{Form factor} = \frac{\text{rms value}}{\text{average value}}$$

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

Peak Factor

$$\text{Peak factor} = \frac{\text{peak value}}{\text{rms value}}$$

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

5.3 FULL-WAVE RECTIFIER (A.C. voltage into a pulsating D.C. voltage**)**

It uses two diodes of which one conducts during one half-cycle while the other diode conducts during the other half-cycle of the applied ac voltage. There are two types of full-wave rectifiers viz. (i) center tapped transformer full-wave rectifier and (ii) bridge rectifier.

During positive half-cycle, diode D_1 forward bias, conducts current and diode D_2 reverse bias, does not conduct.

During negative half-cycle, diode D_2 forward bias, conducts current and diode D_1 reverse bias, does not conduct.

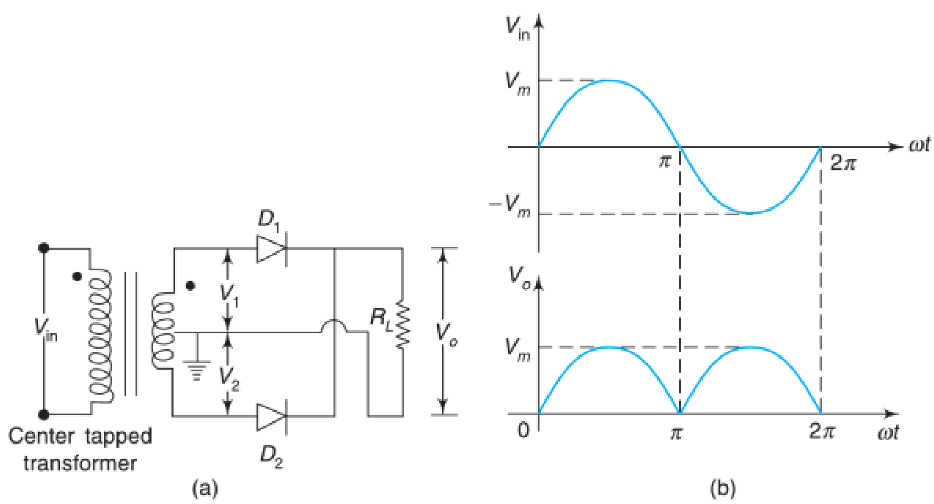


Fig. 4.23 Full-wave Rectifier

Fig: 5.2 (a) Full-wave Rectifier, (b) input and output waveform

RIPPLE FACTOR (Γ)

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

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

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

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

Therefore,

$$\Gamma = \sqrt{\left[\frac{V_m/\sqrt{2}}{2V_m/\pi}\right]^2 - 1} = \sqrt{\frac{\pi^2}{8} - 1} = 0.482$$

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

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

$$= \frac{(V_{dc})^2/R_L}{(V_{rms})^2/R_L} = \frac{\left[\frac{2V_m}{\pi}\right]^2}{\left[\frac{V_m}{\sqrt{2}}\right]^2} = \frac{8}{\pi^2} = 0.812 = 81.2\%$$

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

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

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

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

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

Transformer Utilisation Factor (TUF) The average TUF in a full-wave rectifying circuit is determined by considering the primary and secondary winding separately and it gives a value of 0.693

Form factor

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

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

Peak factor

$$\text{Peak factor} = \frac{\text{peak value of the output voltage}}{\text{rms value of the output voltage}} = \frac{V_m}{V_m/\sqrt{2}} = \sqrt{2}$$

Peak inverse voltage for full-wave rectifier is $2V_m$ because the entire secondary voltage appears across the non-conducting diode.

5.4 BRIDGE RECTIFIER (A.C. voltage into a pulsating D.C. voltage)

The need for a center tapped transformer in a full-wave rectifier is eliminated in the bridge rectifier.

For the positive half-cycle of the input ac voltage, diodes D_1, and D_3 conduct, whereas diodes D_2 and D_4 do not conduct. The conducting diodes will be in series through the load resistance R_L. So the load current flows through R_L.

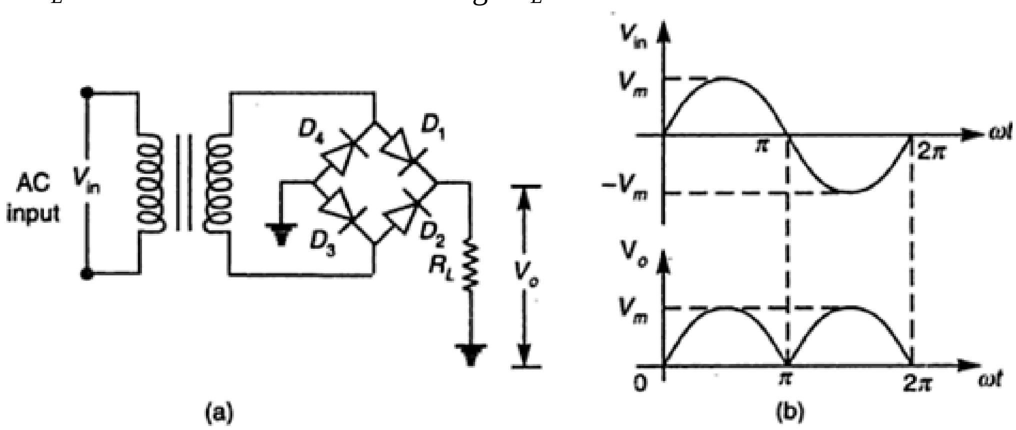


Fig: 5.3 (a) Bridge rectifier, (b) input and output waveforms

During the negative half-cycle of the input ac voltage, diodes D_2 and D_4 conduct, whereas diodes D_1 and D_3 do not conduct. The conducting diode D_2 and D_4 will be in series through the load R_L and the current flows through R_L in the same direction as in the previous half-cycle. Thus a bidirectional wave is converted into a unidirectional one.

The average values of output voltage and load current for bridge rectifier are the same as for a center-tapped full wave rectifier. Hence,

$$V_{d.c.} = \frac{2V_m}{\pi} \quad \text{and} \quad I_{d.c.} = \frac{V_{d.c.}}{R_L} = \frac{2V_m}{\pi R_L} = \frac{2I_m}{\pi}$$

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

$$V_{d.c.} = \frac{2V_m}{\pi} - I_{d.c.}(r_s + r_f)$$

$$I_{d.c.} = \frac{2I_m}{\pi} = \frac{2V_m}{\pi(r_s + r_f + R_L)}$$

The maximum efficiency of a bridge rectifier is 81.*2%* and the ripple factor is 0.48. The PIV is V_m

Advantages of the bridge rectifier

The ripple factor and efficiency of the rectification are the same as the full-wave rectifier. The bulky center tapped transformer is not required. Transformer utilization factor is considerably high. Since the current flowing in the transformer secondary is purely alternating, the TUF increases to 0.812.

Disadvantage is it requires four. But the diodes are cheaper. Apart from this, the PIV rating required for the diodes in a bridge rectifier is only half of that for a center tapped full-wave rectifier, this is a great advantage.

Comparison of Rectifiers

Particulars	*Type of rectifier*		
	Half-wave	*Full-wave*	*Bridge*
No. of diodes	1	2	4
Maximum efficiency	40.6%	81.2%	81.2%
V_{dc} (no load)	V_m/π	$2V_m/\pi$	$2V_m/\pi$
Average current/diode	I_{dc}	$I_{dc}/2$	$I_{dc}/2$
Ripple factor	1.21	0.48	0.48
Peak inverse voltage	V_m	$2V_m$	V_m
Output frequency	f	2f	2f
Transformer utilisation factor	0.287	0.693	0.812
Form factor	1.57	1.11	1.11
Peak factor	2	$\sqrt{2}$	$\sqrt{2}$

5.5 FILTERS

The ripple in the rectified (contains dc and ac component) wave being very high, the factor being 48% in the full-wave rectifier; majority of the applications which cannot tolerate this. Filters are used to minimise the undesirable ac, i.e. ripple leaving only the dc component to appear at the output.

The full wave rectified output voltage is applied at filters input. The output of a filter is not exactly a constant dc level. But it also contains a small amount of ac component. Some important filters arc:

(a) Inductor filter

(b) Capacitor filter

(c) *LC* or L-section filter,

(d) and CLC or π-type filter

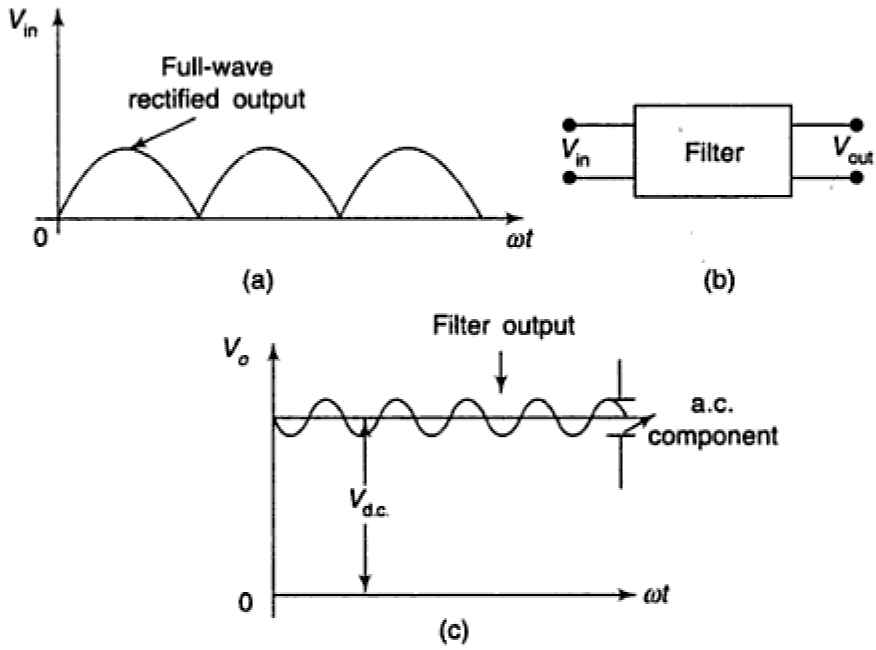


Fig: 5.4 concept of filter

5.6 INDUCTOR FILTER

When the output of the rectifier passes through an inductor, it blocks the ac component and allows only the dc component to reach the load.

The ripple factor of the Inductor filter is given by

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

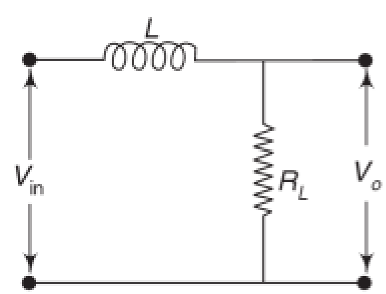


Fig: 5.5 Inductor Filter

It shows that the ripple factor will decrease when L is increased and R_L is decreased. Clearly, the inductor filter is more effective only when the load current is high (small R_L). The larger value of the inductor can reduce the ripple and al the same time the output dc voltage will be lowered as the inductor has a higher dc resistance.

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

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

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

The d.c. component is $\frac{2V_m}{\pi}$.

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

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

The diode, choke and transformer resistances can be neglected since they are very small as compared with R_L. Therefore, the d.c. component of current $I_m = \frac{V_m}{R_L}$.

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

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

Therefore, for the ac component,

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

Therefore, the resulting current i is given by,

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

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

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

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

If $\frac{4\omega^2 L^2}{R_L^2} >> 1$, then a simplified expression for Γ is

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

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

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

This is slightly less than the value of 0.482. The difference being attributable to the omission of higher harmonics as mentioned. It is clear that the inductor filter should only be used where R_L is consistently small.

5.7 CAPACITOR FILTER

An inexpensive filter for light loads is found in the capacitor filter which is connected directly across the load, as shown in Fig. 5.6 (a). The property of a capacitor is that it allows ac component and blocks the dc component.

During the positive half-cycle, the capacitor charges up to the peak value of the transformer secondary voltage, Vm, and will try to maintain this value as the full-wave input drops to zero. The capacitor will discharge through RL slowly until the transformer secondary voltage again increases to a value greater than the capacitor voltage. The diode conducts for a period which depends on the capacitor voltage (equal to the load voltage). The diode will conduct when the transformer secondary voltage becomes more than the 'cut-in' voltage of the diode. The diode stops conducting when the transformer voltage becomes less than the diode voltage. This is called cut-out voltage.

From the cut-in point to the cut-out point, what-ever charge the capacitor acquires is equal to the charge the capacitor has lost during the period of non-conduction.

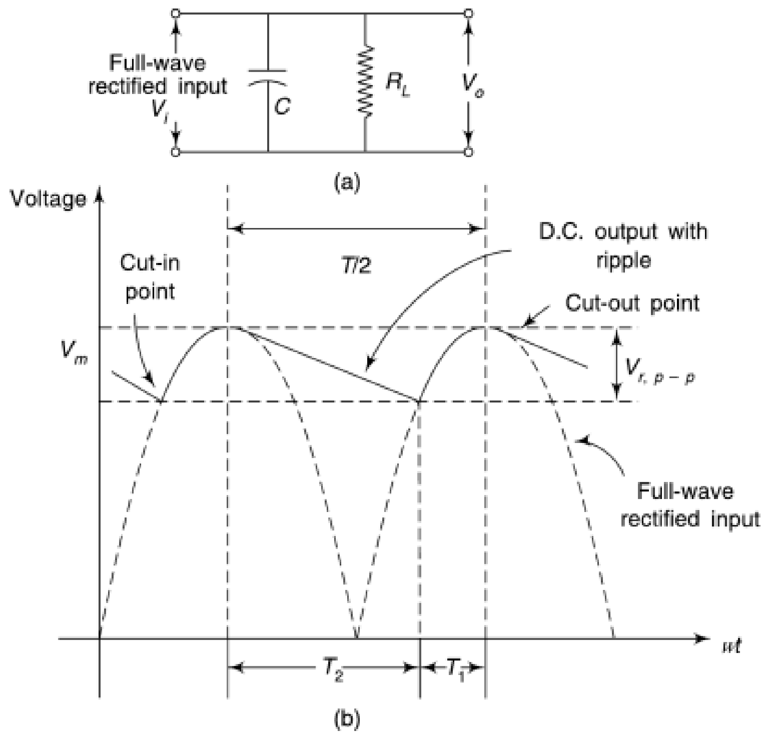


Fig: 5.6 (a) Capacitor filter, (b) Ripple voltage triangular waveform

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

The charge it has lost $= I_{\text{d.c.}} \times T_2$

Therefore, $V_{r,\,p\text{–}p} \times C = I_{\text{d.c.}} \times T_2$

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

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

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

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

Therefore, from the above equation, we have

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

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

Therefore, ripple factor $\Gamma = \frac{V_{r,\,rms}}{V_{dc}} = \frac{1}{4\sqrt{3}\, f\, C\, R_L}$.

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

If $f = 50$ Hz, C in μF and R_L in Ω, $\Gamma = \frac{2890}{CR_L}$.

5.8 L-SECTION OR LC FILTER

We know that the ripple factor is directly proportional to the load resistance R_L in the inductor filter and inversely proportional to R_L in the capacitor filter. Therefore, if these two filters are combined as LC filter or L-section filter, the ripple factor will be independent of R_L

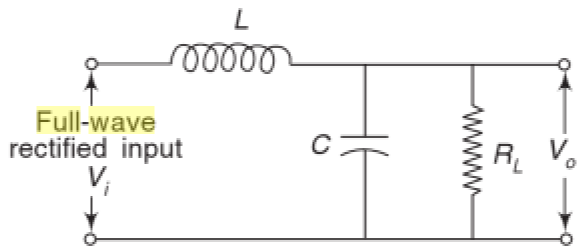


Fig: 5.7 LC filter

If the value of the inductance is increased, it will increase the time of conduction. At some critical value of inductance, one diode, either D_1 or D_2 in full-wave rectifier, will always be conducting.

From Fourier series, the output voltage can be expressed as

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

The d.c. output voltage, $V_{d.c.} = \frac{2V_m}{\pi}$

Therefore, $I_{rms} = \frac{4V_m}{3\pi\sqrt{2}} \cdot \frac{1}{X_L} = \frac{\sqrt{2}}{3} \cdot \frac{V_{dc}}{X_L}$

This current flowing through X_c creates the ripple voltage in the output.

Therefore, $V_{r,\,rms} = I_{rms} \cdot X_C = \frac{\sqrt{2}}{3} \cdot V_{dc} \cdot \frac{X_C}{X_L}$

The ripple factor, $\Gamma = \frac{V_{r,\,rms}}{V_{dc}} = \frac{\sqrt{2}}{3} \cdot \frac{X_C}{X_L}$

$$= \frac{\sqrt{2}}{3} \cdot \frac{1}{4\omega^2 CL}, \text{ since } X_C = \frac{1}{2\omega C} \text{ and } X_L = 2\omega L$$

If $f = 50$ Hz, C is in μF and L is in Henry, ripple factor $\Gamma = \frac{1.194}{LC}$.

LC filter with Bleeder resistor It was assumed in the analysis given above that for a critical value of inductor, either of the diodes is always conducting, i.e. current does not fall to zero. The incoming current consists of two components:

(a) $I_{dc}=\frac{V_{dc}}{R_L}$ and (b) a sinusoidal varying components with peak value of $\frac{4V_m}{3\pi X_L}$. The negative peak of the ac current must always be less than dc, i.e., $\sqrt{2} I_{rms} \leq \frac{V_{dc}}{R_L}$

We know that for LC filter, $I_{rms} = \frac{\sqrt{2}}{3}, \frac{V_{dc}}{X_L}$

Hence $\frac{2V_{dc}}{3X_L} \leq \frac{V_{dc}}{R_L}, i.e. X_L \geq \frac{2}{3} R_L$

i.e., $L_C = \frac{R_L}{3\omega}$, where LC is the critical inductance.

It should be noted that the condition $X_L \geq 2/3\ R_L$ cannot be satisfied for all load requirements. At no load, i.e. when the load resistance is infinity, the value of the inductance will also tend to be infinity. To overcome this problem, a bleeder resistor R_B, is connected in parallel with the load resistance as shown in Fig. *5.8*

Therefore, a minimum current will always be present for optimum operation of the inductor. It improves voltage regulation of the supply by acting as the pre-load on the supply. Also, it provides safety by acting as a discharging path for capacitor.

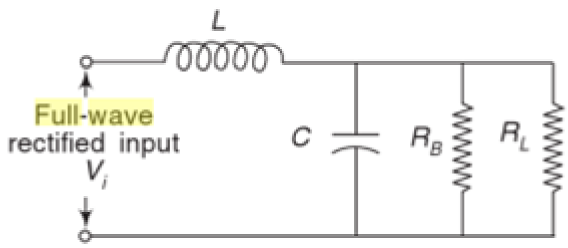


Fig: 5.8 Bleeder Resistor connected at the LC filter output

5. 9 CLC OR π-SECTION FILTER

Fig: 5.9 Shows the CLC or π -type filter which basically consists of a capacitor filter followed by an *LC* section.

This filter offers a fairly smooth output, and is characterized by a highly peaked diode currents and poor regulation. Proceeding the analysis in the same ways as that for the single L-section filter, we obtain

$$\Gamma = \sqrt{2} \cdot \frac{X_{C1}}{R_L} \cdot \frac{X_{C2}}{X_L}$$

The term 'R_L' in the above equation should be noted.

If $f = 50$ Hz, C in μF, L in H and R_L in Ω, then $\Gamma = \frac{5700}{LC_1C_2R_L}$.

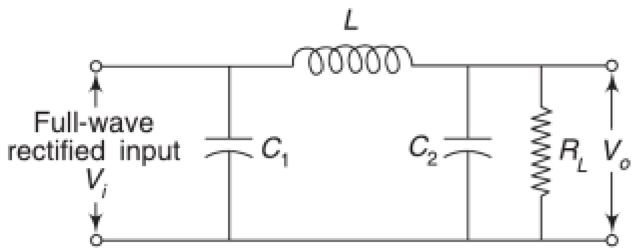


Fig: 5.9 CLC or π- type Filter

COMPARISON OF FILTERS

	Type of Filter				
	None	*L*	*C*	*L-Section*	*π-Section*
V_{dc} at no load	0.636 V_m	0.636 V_m	V_m	V_m	V_m
V_{dc} at load I_{dc}	0.636 V_m	0.636 V_m	$V_m - \frac{4170\, I_{dc}}{C}$	0.636 V_m	$V_m - \frac{4170\, I_{dc}}{C}$
Ripple factor Γ	0.48	$\frac{R_L}{16000\, L}$	$\frac{2410}{CR_L}$	$\frac{0.83}{LC}$	$\frac{3330}{LC_1C_2R_L}$
Peak inverse voltage (PIV)	$2V_m$	$2V_m$	$2V_m$	$2V_m$	$2V_m$

5.10 VOLTAGE REGULATION USING ZENER DIODE (Gives Constant Output Voltage)

A voltage regulator is an electronic circuit that provides a stable DC voltage independent of the load current, temperature and ac line voltage variations.

The quality of the regulation specified by (i) Line regulation and (ii) Load regulation. For a good regulator the line and load regulation should be minimum value.

LINE REGULATION

A change in input voltage to a regulator will cause a change in its output of load voltage. Line regulation is defined as the change in output voltage for a change in line supply voltage keeping the load current and temperature constant. Line regulation is given by

$$\text{Line regulation} = \frac{\text{change in output voltage}}{\text{change in input voltage}} = \frac{\Delta V_o}{\Delta V_{in}}$$

LOAD REGULATION

Voltage regulator will experience a slight change in output voltage when there is a change in load current demand (i.e., Full load voltage).

$$\text{Load regulation} = \frac{V_{\text{no load}} - V_{\text{full load}}}{V_{\text{full load}}}$$

5.11 TYPES OF VOLTAGE REGULATORS: There are two types of voltage regulators available namely,

i) Shunt voltage regulator

ii) Series voltage regulator

5.12 SHUNT VOLTAGE REGULATOR: The heart of any voltage regulator circuit is a control element. If such a control element is connected in shunt with the load, the regulator circuit is called shunt voltage regulator.

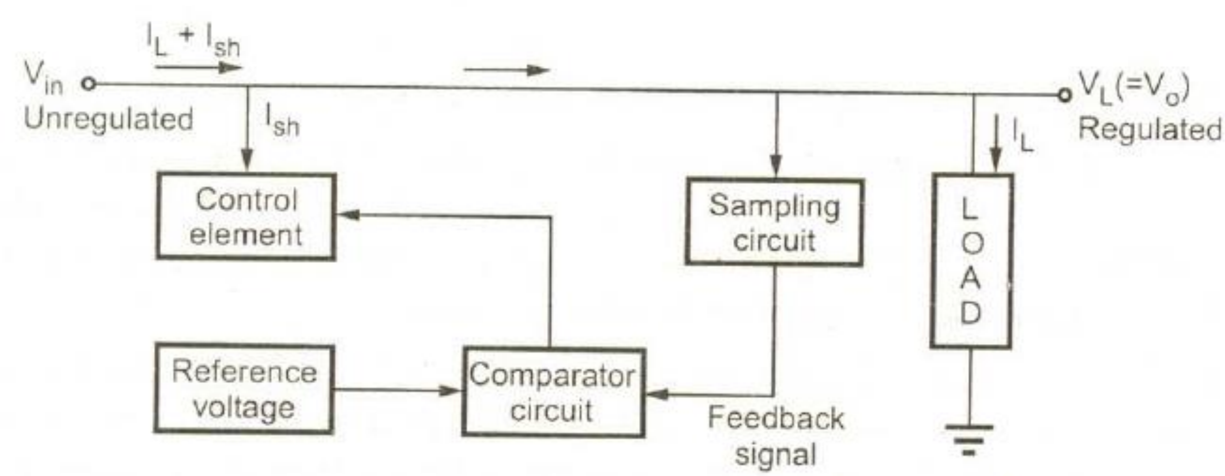


Fig: 5.10 Block diagram of shunt voltage regulator

The unregulated input voltage V_{in}, tries to provide the load current. But part of the current is taken by the control element, to maintain the constant voltage across the load. If there is any change in the load voltage, the sampling circuit provides a feedback signal to the comparator circuit. The comparator circuit compares the feedback signal with the reference voltage and generates a control signal which decides the amount of current required to be shunted to keep the load voltage constant.

5.12.1 ZENER DIODE SHUNT REGULATOR

The zener diode is selected with V_z equal to the voltage desired across the load. The zener diode has a characteristic that under reverse bias condition, the voltage across it practically remains constant, even if the current through it changes by a large extent. Under normal conditions, the input current $I_i = I_L + I_Z$ flows through resistor *R*. The input voltage V_i can be written as

$$V_i = I_i R + V_Z = (I_L + I_Z)R + V_Z$$

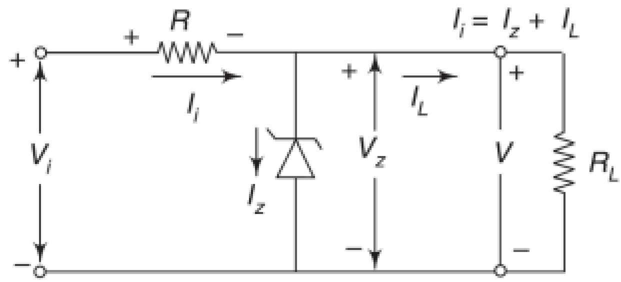


Fig: 5.11 Zener voltage Regulator

When the input voltage V_i increases (say due to supply voltage variations), as the voltage across zener diode remains constant, the drop across resistor *R* will increase with a corresponding increase in $I_L + I_z$. As V_z is a constant, the voltage across the load will also remain constant and hence, I_L will be a constant. Therefore, an increase in $I_L + I_Z$ will result in an increase in I_z which will not alter the voltage across the load.

It must be ensured that the reverse voltage applied to the zener diode never exceeds PIV of the diode and at the same time, the applied input voltage must be greater than the breakdown voltage of the zener diode for its operation. The zener diodes can be used as 'stand-alone' regulator circuits and also as reference voltage sources.

5.12.2 EMITTER-FOLLOWER TYPE REGULATOR

In the Zener voltage regulator, the zener current varies over a wide range as the input voltage and load current vary. As a result, the output voltage which is equal to V_Z also changes by a small amount. This change in the output voltage can be minimised by reducing the change in the zener current with the help of a circuit called emitter-follower type regulator.

Here, the load resistance, R_L, is not connected across the zener directly as in the zener regulator, but is connected through an amplifier/buffer circuit.

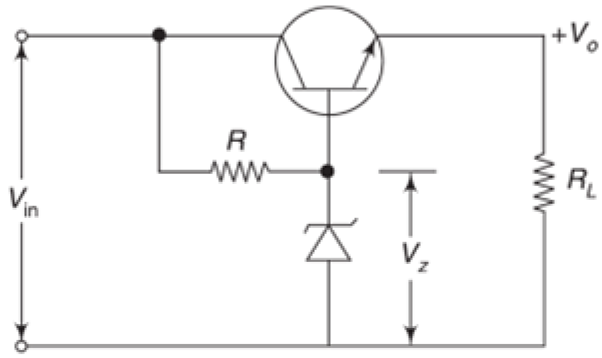


Fig: 5.12 Emitter Follower Typer Regulator

Transistor is connected as an emitter-follower. As can be seen, the output voltage, V_0= (V_Z-V_{BE})

However, the load current I_L is supplied by the transistor from the input voltage V_{in}, deriving its base current from the zener circuit. The base current I_B is equal to $\frac{I_L}{\beta}$

Where β is the current-gain of the transistor. As far as the zener circuit is concerned, it is supplying only the base current. Any change in the load current is reduced by *β* times i.e. change in the zener current.

5.12.3 TRANSISTORISED SHUNT REGULATOR

In the transistorised shunt voltage regulator shown in Fig. 5.13, the output voltage is determined by the voltage drop across series resistor R_s. If I_L increases due to a load change, V_0 will tend to decrease. However, the voltage across R_2 will also decrease, thereby reducing the forward bias on the transistor and driving it to cut-off. This results in less current flow through the transistor, thereby maintaining I_s almost constant, which keeps the voltage drop across R_s relatively unchanged. Thus, for a given input voltage, output voltage $V_0=V_i-I_sR_s$, remains substantially constant. The major drawback in this circuit is the large amount of power dissipated in R_s,

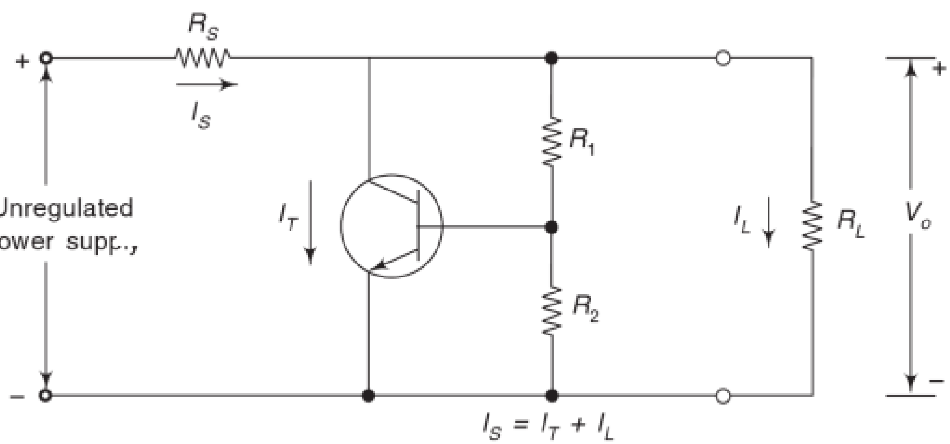


Fig: 5.13 Transistorised shunt Regulator

5.13 SERIES VOLTAGE REGULATOR:

If in a voltage regulator circuit, the control element is connected in series with the load, the circuit is called series voltage regulator circuit.

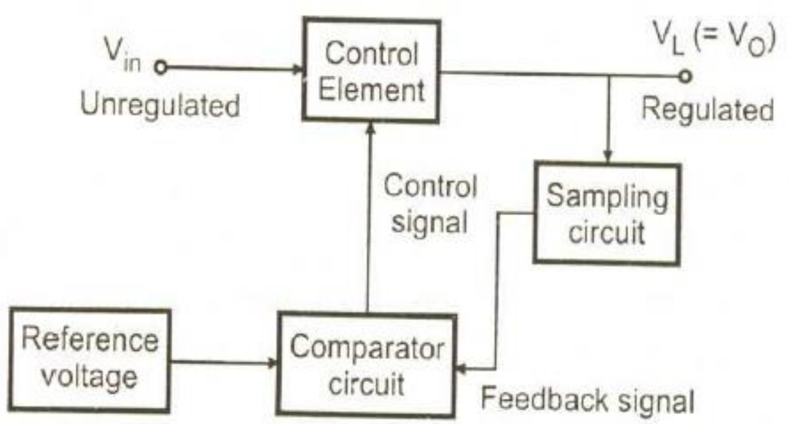


Fig: 5.14. Block diagram of series voltage regulator

The control element controls the amount of the input voltage that gets to the output. The sampling circuit provides the necessary feedback signal. The comparator circuit compares the feedback with the reference voltage to generate the appropriate control signal.

5.13.1 TRANSISTORISED SERIES REGULATOR

If R_s is replaced by a transistor as shown in Fig. 5.15, a more efficient circuit results which is more sensitive to voltage changes and provides better regulation.

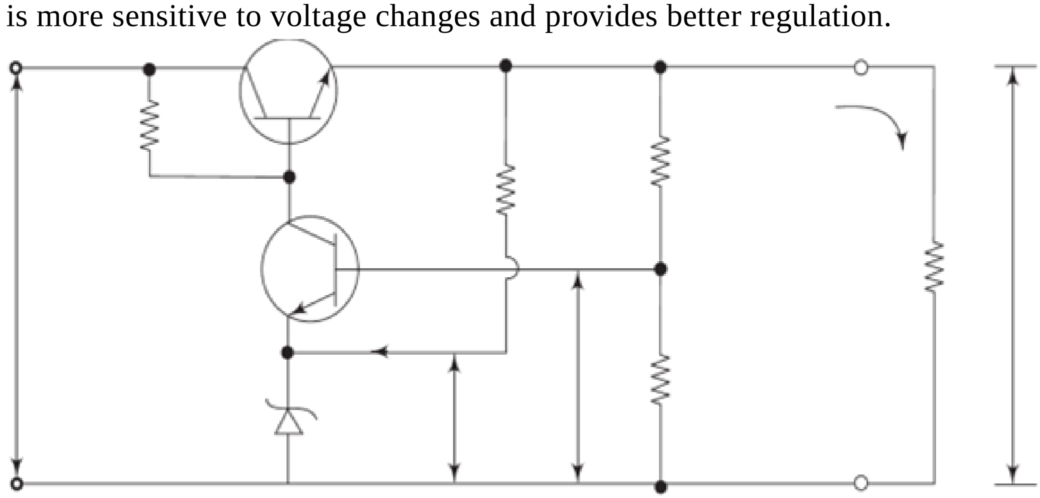


Fig: 5.15 Transistorised Series Regulator

Transistor Q_2, actually serves as a differential amplifier in which the fraction of the output voltage βV_o is compared with reference voltage V_Z.. The difference $(\beta V_0 - V_Z)$ is amplified by Q_2 and appears at the base of Q_1. This in turn determines the voltage drop that will occur across Q_1 . Because of the gain of Q_2, it requires only a small change in V_o to have a large effect on Q_1. Further, the output voltage may be varied over wide range using R_2 .The zener diode and transistor Q_2 can be chosen so that the temperature coefficients practically cancel.

If R_2 is adjusted for a lower output voltage, a greater voltage drop occurs across Q_1 Maximum dissipation in Q_1 thus takes place at high load currents and low output voltage in variable regulated power supplier employing a series regulator.

Drawback of transistorised series regulator

The output voltage available is restricted by the V_{CEO} of the series transistor used. The power rating of the transistor used, as a series loser, depends on the voltage difference between the input and output voltages. This difficulty can be minimised to a great extent by using thyristors. Thyristors have the ability to control large power with minimal control power, and this control power does not have to remain continuous as in the case of the base current of a transistor.

5.13.2 SHORT CIRCUIT PROTECTION OR OVERLOAD PROTECTION:

Fig: 5.16 (a) shows overload protection circuit in which a small sensing resistance R_{sc} is added in series with the load resistance and two diodes are connected from the base of the transistor to the output.

The emitter voltage is equal to $(V_Z - V_{BE})$. The voltage drop across the sensing resistance R_{sc} is equal to $(I_L \times R_{SC})$ As long as the voltage drop across R_{SC} is less than twice the cut-in voltage of the diode, the diodes are effectively as good as not connected in the circuit.

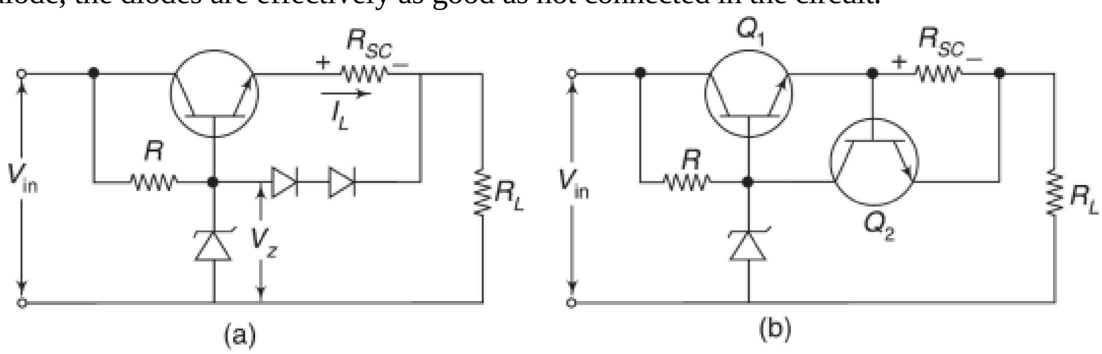


Fig: 5.16 (a) and (b) Overload Protection Circuit

If the voltage drop across R_{sc} increases suddenly due to over current in the load, then the diodes will be forward biased and will start conducting. This will divert apart of the base current, which will be directly led to the output, thus restricting the base current and hence, the transistor current. With a proper design, the transistor can be turned-off in the case of a short circuit.

The protective diodes can be replaced by another transistor Q_2 as shown in Fig. 5.16 (b). In this case, the voltage across R_{sc} is used in turning ON transistor Q_2, giving the same effect as before.

5.14 CURRENT LIMITING CIRCUIT OR TRANSISTOR CURRENT REGULATOR

The main function of a current regulator is to maintain a fixed current through the load despite variations in the terminal voltage. Such a circuit employing a zener diode and PNP transistor is shown in fig: 5.17.

Suppose due to drop in V_L, current $I_L(I_C)$ is decreased, then I_E ($\approx I_C$) will also decrease. Hence drop across R_E, i.e., V_{BE} will decrease,

$$-V_{RE} - V_{BE} + V_Z = 0 \text{ or } V_{BE} = V_Z - V_{RE}$$

Hence a decrease in V_{RE} will decrease V_{BE} and therefore the conductivity of the transistor will also decrease. This process keeps I_L at a fixed level.

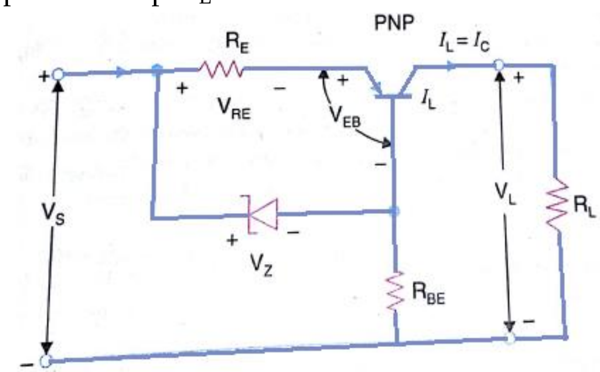


Fig: 5.17 Transistor current regulator circuit

5.15 LINEAR VOLTAGE REGULATOR

If the control element of a regulator operates in its linear region, then the regulator is called a linear regulator. Linear regulators are generally of series mode type. The regulator circuit using Zener diode *is* vulnerable to the variations in supply voltage since the current through the Zener diode also changes correspondingly.

Hence the linear regulator uses an op-amp as an error amplifier, and a pass transistor as a control element. The error output from the op-amp drives the control element, which allows current to the load accordingly and keeps the output voltage constant.

5.16 OP-AMP VOLTAGE REGULATOR

- Op-Amp Series Regulator
- Op-Amp Shunt Regulator

5.16.1 OP-AMP SERIES REGULATOR

The basic circuit of a linear voltage regulator or Op-Amp series Regulator *is* shown in Fig-5.18. The regulating circuit consists of a voltage reference (V_{ref}), a differential amplifier called *error amplifier* using op-amp and a series regulating clement Q_1 connected as an emitter follower.

The output voltage is sampled and fed back to the inverting input of the error amplifier through the potential divider R_2-R_3. The error amplifier produces an output voltage that in proportional to the difference between the reference voltage and the sampled output voltage and it may be written as $V_0' = A[V_{ref} - \boldsymbol{\beta} V_0]$,

where *A* is the gain of the amplifier and $\boldsymbol{\beta}$ is the feedback factor which is equal to $R_3/(R_2 + R_3)$. Since the drop across the base-emitter junction of transistor Q_1 is small, the output V_0 can be approximated to V'_0.

Thus $\quad V_o' = V_o = A[V_{ref} - \beta V_o]$

That is, $\quad V_o = AV_{ref}/(1 + A\beta)$

This equation implies that the output voltage is determined by the reference voltage and the feedback factor.

This equation implies that the output voltage is determined by the reference voltage and the feedback factor. The output voltage thus obtained is kept at a constant level by the control of series element connected with the error amplifier. For instance, an increase in output voltage causes a corresponding decrease in the error amplifier output, which biases the series control transistor with reduced base current. This action causes an increase in collector-to-emitter voltage and thus the increase in the output is reduced.

On the other hand, when the output voltage reduces, the output of the differential amplifier increases. Then, the series transistor is biased heavily at its base and as a consequence, the collector-to-emitter voltage decreases.

Thus the reduction in output is compensated and the output voltage is maintained constant.

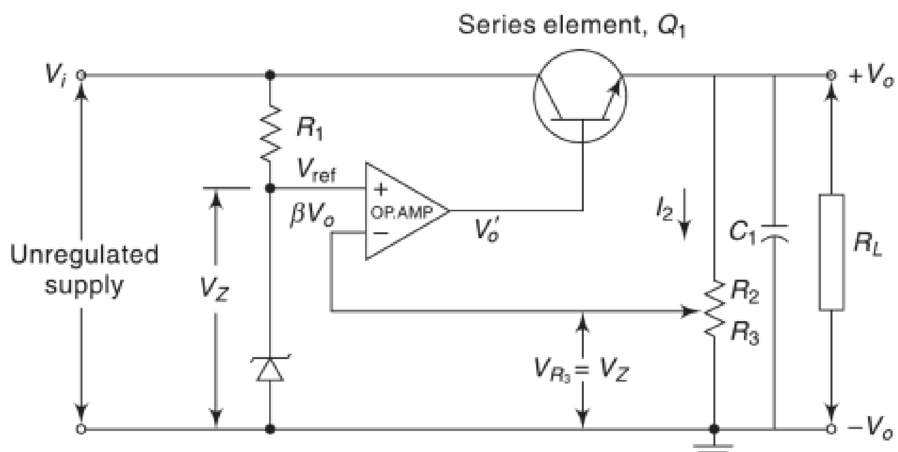


Fig: 5.18 Basic Circuit of a Op-Amp series Regulator

5.16.2 OP-AMP SHUNT REGULATOR

Here the control element is a series resistor R_2 and a transistor Q_1 in parallel with the load. In such a regulator, regulation is achieved by controlling the current through Q_1.

When output voltage tries to decrease due to change in either the input voltage or load current or temperature, the attempted decrease is sensed by R_3 and R_4 and applied to the non-inverting input of the op-amp. The resulting difference in voltage reduces the op-amp's output, driving Q_1 less thus reducing its collector current (shunt current), and increasing its collector-to-emitter resistance. Since collector-to emitter resistance act as a voltage divider with R_1, this action offsets the attempted decrease in output voltage and hence, maintains it at a constant value. The opposite action occurs when output voltage tries to increase. The shunt regulator is less efficient than the series type but offers inherent short-circuit protection.

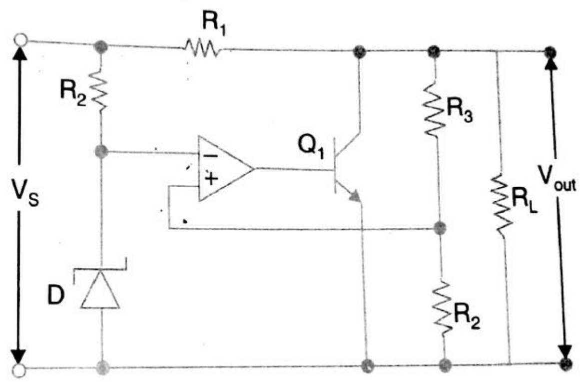


Fig: 5.19 Op-Amp shunt Regulator

5.17 SWITCHING REGULATOR

In the linear regulators considered so far, the control element i.e., the transistor conducts all the time, the amount of conduction varying with changes in output voltage or current. Due to continuous power loss, the efficiency of such a regulator is reduced to 50% or less.

A switching regulator is different because its control element operates like a switch i.e., either it is saturation (closed) or cut-off (open). Hence there is no unnecessary wastage of power which results in higher efficiency of 90% or more. There are three types.

(a) Step- down regulator
(b) Step- up regulator
(c) Inverting switching regulator

5.17.1 STEP- DOWN REGULATOR

In this regulator, V_{out} is always less than V_S. an unregulated positive DC voltage is applied to the collector of the NPN transistor. A series of pulse from oscillator is sent to the base of transistor T which gets saturated (closed) on each of the positive pulse. It is so because NPN transistor needs a positive voltage pulse on its base in order to turn ON. A saturated transistor acts as a closed switch, hence it allows V_S to send current through L and charge C to the value of output voltage during the on-time (T_{ON}) of the pulse. The diode D_1 is reverse- biased at this point and hence, does not conduct.

Eventually when positive pulse turns to zero, Q is cut-off and acts like an open switch during the off period (T_{OFF}) of the pulse. The collapsing magnetic field of the coil produces self-induced voltage and keeps the current flowing by returning energy to the circuit.

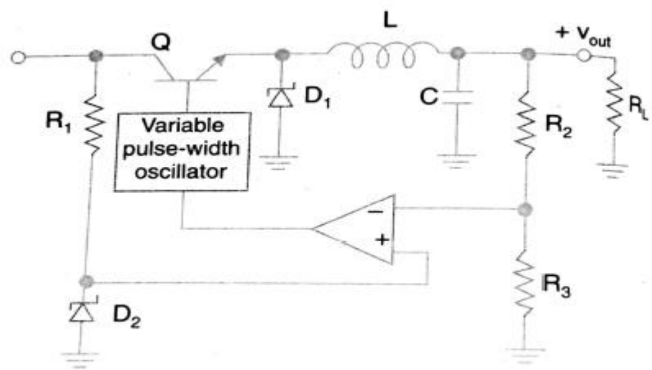


Fig: 5.20 Step- Down Regulator

The value of output voltage depends on input voltage and pulse width i.e., on-time of the transistor. When on time is increased relative to off- time, C charges more thus increasing V_{out}. When T_{ON} is decrease, C discharges more thus decreasing V_{out}. By adjusting the duty cycle (T_{ON}/T) of the transistor, V_{out} can be varied.

$$V_{out} = V_S (T_{ON}/T)$$

Where T is the period of the ON-OFF cycle of the transistor and is related to frequency by T= 1/f. Also, $T = T_{ON} + T_{OFF}$ and the ratio (T_{ON}/T) is called the duty cycle.

The regulating action of the circuit is explained as follows:

When V_{out} tries to decrease, on-time of the transistor is increased causing an addition charge on the capacitor C to offset the attempted decrease. When V_{out} tries to increase, TON of the transistor is decreased causing C to discharge enough to offset the attempted increase.

5.17.2 STEP- UP REGULATOR

When the transistor Q turns ON on the arrival of the positive pulse at its base, voltage across L increases quickly to V_S-$V_{CE(sat)}$ and magnetic field of L expands quickly. During on-time of the transistor, V_L keeps decreasing from its initial maximum value. The longer transistor is ON, the smaller V_L becomes.

When the transistor turns OFF, magnetic field of L collapses and its polarity reverses so that its voltage adds to the input voltage thus producing an output voltage greater than the input voltage. During Off- time of the transistor, D_2 is forward-biased and allows C to charge. The variations in V_{out} due to charging and discharging action are sufficiently smoothed by filtering action of L and C.

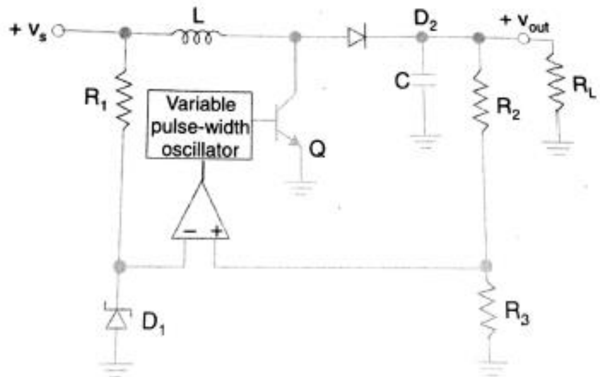


Fig: 5.21 Step-Up Regulator

It may be noted that shorter the on-time of the transistor, greater the inductor voltage and hence greater V_L adds to V_S. On the other hand, the longer the on-time, the smaller the inductor voltage and hence, lesser the output voltage (because smaller V_L adds to V_S).

The regulating action may be explained as follows:

When V_{out} tries to decrease (because of either increasing load or decreasing V_S), transistor on time decreases thereby offsetting attempted decrease in V_{out}, when V_{out} tries to increase, on time increase and attempted increase in V_{ou}t is offset.

As seen, the output voltage is inversely related to the duty cycle.

$$V_{out} = V_s\ (T/T_{ON})$$

2 MARKS QUESTIONS WITH ANSWERS

UNIT -I

1. What is Intrinsic Semiconductor?
   Pure form of semiconductors are said to be intrinsic semiconductor. Ex: germanium, silicon.

2. What is P-type Semiconductor?
   The Semiconductor which are obtained by introducing penta valent impurity atom (phosphorous, antimony) are known as P-type Semiconductor.

3. What is N-type Semiconductor?
   The Semiconductor which is obtained by introducing trivalent impurity atom (gallium, indium) are known as N-type Semiconductor.

4. Define Hall Effect.
   If a metal or semiconductor carrying current I is placed in a transverse magnetic field B, an electric field E is induced in the direction perpendicular to both I and B, This phenomenon is known as Hall Effect.

5. Give the expression for diffusion current density due to electron.
   $Jn = qDndn / dx$

   Where J_n - diffusion current density due to electron
   q - Charge of an electron
   D_n – diffusion constant for electron
   dn /dx – concentration gradient

6. What are conductors? Give examples.
   Conductors are materials in which the valence and conduction band overlap each other so there is a swift movement of electrons which leads to conduction. Ex. Copper, silver.

7. What are insulators? Give examples.
   Insulators are materials in which the valence and conduction band are far away from each other. So no movement of free electrons and thus no conduction. Ex glass, plastic.

8. What are Semiconductors? Give examples.
   The materials whose electrical property lies between those of conductors & insulators are known as Semiconductors. Ex: germanium, silicon.

9. What are the types of Semiconductor?
   - Intrinsic semiconductor

- Extrinsic semiconductor.

10. Give the expression for diffusion current density due to holes.

$$Jp = -qDpdp / dx$$

Where

J_p - diffusion current density due to holes

q - Charge of a hole

D_p – diffusion constant for hole

dn / dx – concentration gradient

11. What is depletion region in PN junction?

The region around the junction from which the mobile charge carriers are depleted is called as depletion region. since this region has immobile ions, which are electrically charged , the depletion region is also known as space charge region.

12. What is meant by biasing a PN junction?

Connecting a PN junction to an external voltage source is biasing a PN junction.

13. What is forward bias and reverse bias in a PN junction?

- When positive terminal of the external supply is connected to P region and negative terminal to N region ,the PN junction is said to be forward biased.
- Under forward biased condition the PN region offers a very low resistance and a large amount of current flows through it.

14. What is the total current at the junction of PN junction diode?

The total in the junction is due to the hole current entering the n material and the electron current entering the p material. Total current is given by

$I = Ipn(0) + Inp(0)$

Where,

I – Total current

$I_{pn}(0)$ - hole current entering the n material

$I_{np}(0)$ - electron current entering the p material.

15. What are break down diodes?

Diodes which are designed with adequate power dissipation capabilities to operate in the break down region are called as break down or zener diodes.

16. What is break down? What are its types?

- When the reverse voltage across the PN junction is increased rapidly at a voltage the junction breaks down leading to a current flow across the device.

- This phenomenon is called as break down and the voltage is break down voltage. The types of break down are

  i) zener break down
  ii) Avalanche breakdown

17. What is an ideal diode?

    An ideal diode is one which offers zero resistance when forward biased and infinite resistance when reverse biased.

18. What is depletion region in PN junction?

    The region around the junction from which the mobile charge carriers (electrons and holes) are depleted is called as depletion region. Since this region has immobile ions, which are electrically charged, the depletion region is also known as space charge region.

19. What is Reverse saturation current?

    The current due to the minority carriers in reverse bias is said to be reverse saturation current. This current is independent of the value of the reverse bias voltage.

20. Compare ideal diode as a switch.

    An ideal diode when forward biased is equivalent a closed (ON) switch and when reverse biased, it is equivalent to an open (OFF) switch.

    State the mathematical equation which relates voltage applied across the PN junction diode and current flowing through it.

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

21. Define knee/cut-in/threshold voltage of a PN diode.

    It is the forward voltage applied across the PN diode below which Practically no current flows.

22. Define breakdown voltage.

    It is the reverse voltage of a PN junction diode at which the junction breaks Down with sudden rise in the reverse current.

23. Define Zener diode.

    A zener diode is a properly doped crystal diode which has a sharp breakdown Voltage.

24. What is the effect of junction temperature on cut-in voltage of a PN diode?

    Cut-in voltage of a PN diode decreases as junction temperature increases.

25. What is the effect of junction temperature on forward current and reverse current of a PN diode

    For the same forward voltage, the forward current of a PN diode increases and reverse saturation current increases with increase in junction temperature.

26. Differentiate between breakdown voltage and PIV of a PN diode.

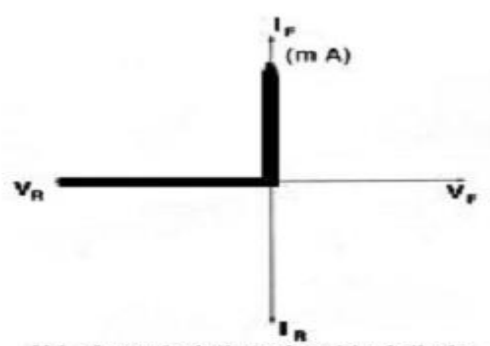
    The breakdown voltage of a PN diode is the reverse voltage applied to it at which the PN junction breaks down with sudden rise in reverse current. Whereas, the peak inverse voltage

(PIV) is the maximum reverse voltage that can be applied to the PN junction without damage to the junction.

27. Differentiate avalanche and zener breakdowns.

Zener Breakdown	Avalanche Breakdown
Breaking of covalent bonds is due to intense electric field across the narrow depletion region it generates large number of free electrons to cause breakdown	collision of thermally generated charge carriers having high velocity and kinetic energy with adjacent atom, this process is a cumulative process hence the charge carriers are multiplied hence it is known as carrier multiplication or avalanche multiplication.
The temperature coefficient is negative	The temperature Coefficients is positive
This occurs with breakdown voltage 6V or less than it.	This occurs with breakdown voltage above 6V
The reverse characteristics is very sharp in breakdown region	The reverse characteristics is not sharp in breakdown region.
Breakdown occurs due to heavily doped junction and applied strong electric field	Breakdown occurs due to avalanche multiplication between thermally generated ions.
Doping level is high.	Doping level is low.
Breakdown occurs at lower voltage compared to avalanche breakdown	Breakdown occurs at higher voltage.

28. Draw the V-I characteristics of an ideal diode.



V-I characteristics of an ideal diode

29. Define drift current?

When an electric field is applied across the semiconductor, the holes move towards the negative terminal of the battery and electron move towards the positive terminal of the battery. This drift movement of charge carriers will result in a current termed as drift current.

30. Define the term diffusion current?

A concentration gradient exists, if the number of either electrons or holes is greater in one region of a semiconductor as compared to the rest of the region. The holes and electron tend to move from region of higher concentration to the region of lower concentration. This process in called diffusion and the current produced due this movement is diffusion current.

31. What is depletion region.?

The region around the junction from which the charge carriers are completely depleted is known as depletion region. Since this region has immobile ions, which are electrically charged. This depletion region is known as space charge region.

32. List the uses of zener diode.

- It can be used as voltage regulator.
- It can be used as limiter in wave shaping circuits.
- It can be used in protection circuit against damage from accidental over voltage.
- It can be used as a fixed reference voltage in a network for calibrating voltmeters

33. Distinguish junction diode from Zener diode.

junction diode	Zener diode
It is never intentionally operated in the breakdown region because it may damage	It is operated in the breakdown region.
It have thick junction	It have thin junction
Power dissipation is less	Power dissipation is HIGH
Dynamic resistance is very small in reverse bias	Dynamic resistance is very high in reverse bias
Used as rectifiers, voltage multipliers, clippers and clampers	Used as voltage regulators, limiters etc.,

34. Differentiate between drift and diffusion currents.

Drift Current	Diffusion Current
It is developed due to potential gradient.	It is developed to charge concentration gradient.
This phenomenon is found both in metals and semiconductors.	It is found only in semiconductors.

35. List the PN diode parameters.

- Bulk Resistance.
- Static Resistance/Junction Resistance (or) DC Forward Resistance or

- Dynamic Resistance (or) AC Forward Resistance
- Reverse Resistance
- Knee Voltage
- Breakdown Voltage
- Reverse Current (or) Leakage Current
- State the PN diode ratings.
- Even PN-Junction has limiting values of maximum forward current,
- peak inverse voltage and maximum power rating.

36. Define reverse recovery time.

It is maximum time taken by the device to switch from ON to OFF stage.

38. List the PN diode switching times.

- Recovery Time
- Forward Recovery Time
- Reverse Recovery Time
- Storage and Transition Times

UNIT-II

1. What is a FET?

   A field effect transistor is a three terminal semiconductor device in which current conduction takes place by one type of carriers either the holes or electrons and is controlled by an electric field.

2. Why FET is called as unipolar device?

   The operation of FET depends upon the flow of majority carriers only either holes or electrons and hence FET is said to be unipolar device.

3. Define pinch off voltage.

   It is the voltage at which the channel is pinched off, (i.e) all the free charges from the channel get removed.

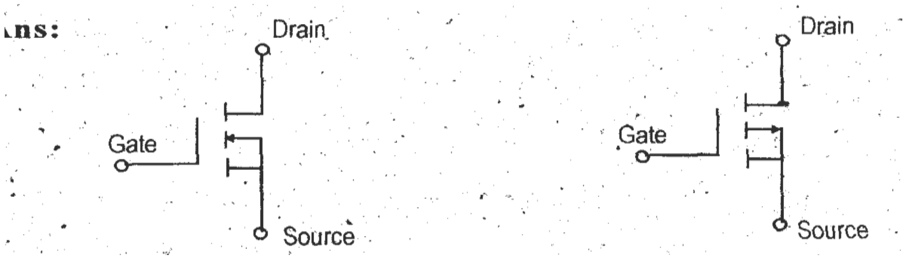
4. Compare N-channel and P-channel JFET.

N-Channel JFET	P-channel JFET
Current carriers are electrons	Current-carriers are holes
Low input noise	High input noise
High transconductance	Low transconductance
Mobility of electrons	Mobility of holes

5. What is a MOSFET?

MOSFET is metal oxide semiconductor field effect transistor. It is a three terminal semiconductor devices similar to FET with gate insulated from the channel.

6. Draw the current symbol for enhancement type MOSFET.



7. What is the application of MOSFET?

- It can be used as, input amplifiers -in oscilloscope, electronic voltmeters
- In computer memories.
- In logic circuits ,
- Phase shift oscillators,&
- In FM and TV receiver.

8. What is a bipolar junction transistor?
   A bipolar junction transistor is a three terminal semiconductor deice in which the operation depends on the interaction of both majority and minority carriers.

9. Define the different operating regions of transistor.
   Active Region: It is defined in which transistor function is biased in reverse direction and emitter function in forward direction.
   Cutoff Region: The region in which the collector and emitter functions are both reverse biased.
   Saturation Region: The region in which both the collector and emitter functions are forward biased.

10. Define NPN and PNP transistor.

NPN Transistor: In NPN transistor, P-type semiconductor is sandwiched between two n-type semiconductors. The emitter region is made up of n-type semiconductor base region is made of p-type semiconductor, collector region is made of n-type semiconductor.

PNP Transistor: In PNP transistor, n-type semiconductor is sandwiched between two P-type semiconductor. Emitter region is made of P-type, collector region is made of P-type and the base region is made of n-type, semiconductor.

11. What are the three types of configuration in transistors?
Depending on the input, output and .common terminal a transistor are connected in 3configurations;

- Common base configuration
- Common emitter configuration
- Common collector-Configuration.

12. What are early effect or base and the modulation?
As the collector by voltage Vcc is made to increase the reverse bias, the space charge width between collector and base tends to increase with the result that the effective width of the base decreases. This dependency of base width on collector to emitter -voltage is known as early effect.

13. What is thermal runaway?
The continuous increase in collector current due to poor-biasing causes the temperature at collector terminal to increase. If no stabilization i.e., done, the collector leakage current also increases. This further increases the temperature. This action becomes cumulative and. ultimately the transistor turns out. The self destruction of an unstabilized transistor ' is known as thermal runaway.

14. What are the types of breakdown in transistor?
The different types of breakdown in transistor are

- Avalanche multiplication,
- Reach through (or) Punch through.

15. Difference between BJT and FET?

FET	BJT
Voltage controlled device	Current controlled device
Unipolar device ;because in main current now only majority carrier participates	Bipolar device . it means current is due to both majority and minority current
Higher frequency response	frequency variation affects the performance
Good thermal stability because of Absence of minority carriers	temperature dependent, thermal runaway may cause
Costlier than bjt	relatively cheaper
No offset voltage, so it works better as a	there is always an offset voltage before

switch or chopper.	switching
Small gain bandwidth product	greater than FET
Fet has very high input impedance	Bjt has low input input impedance
Very less noisy in comparison to bjt	Noisy
. Doesn't require any threshold so it is a better chopper circuit	. Requires a threshold voltage to operate so cannot work as a good chopper
. Due to very high rd resistance as a switch it is not preferred	. Due to very less very low internal resistance so as a switch it performs better.
. At low frequencies, FET is an ideal amplifier but at high frequencies, its gain decreases rapidly with frequencies	. At high frequencies BJT is a good amplifier
. In the FET we don't see the thermal runaway	. Due to minority charge carriers and low input impedance it suffers form thermal runaway

16. List the static characteristic of FET?

- Three terminal device (source (S), drain(D) , gate(G))
- Current carried by one type of charge practical so it is unipolar devices
- Temperature dependent
- Very high input impedance
- Current control device
- It requires very less space compared to BJT
- Used as amplifier or switch

17. What is the active region in the transistor CB configuration?

When emitter to base junction is in forward bias and collector to base junction is in reverse bias the region of operation is active region.

18. What are the benefits of the h-parameters?

1. Real numbers at audio frequencies.
2. Easy to measure.
3. Can be obtained from the transistor static characteristic curves.
4. Convenient to use in circuit analysis and design.
5. Most of the transistor manufactures specify the h- parameters.

19. Define Transistor.

It consists of two PN Junctions formed by sandwiching either p-type or n-type semiconductor between a pair of opposite types.

20. Mention the types of transistor?

1. NPN Transistor
2. PNP Transistor

21. Define current amplification factor.

The ratio of change in output current to the change in input current at constant other side voltage is called current amplification factor.

22. Explain the input characteristics of transistor.

It is a graph drawn between output voltage and input current keeping other side voltage as constant.

23. Explain the output characteristics of transistor.

It is a graph drawn between output voltages and output current keeping other side current (I/P) as constant.

24. Mention the types of connection in a transistor.

1. Common base connection.
2. Common emitter connection
3. Common collector connection.

25. What are the biasing conditions to operate transistor in active region?

Emitter-base junction has to be forward biased and collector-base junction to be reverse biased.

26. In a transistor operating in the active region although the collector junction is reverse biased, the collector current is quite large. Explain.

Forward biasing the input side and reverse biasing the output side are the requirements of a transistor in the active region. The collector current is experimentally equal to the emitter current. Therefore the collector current will be large as emitter current is large on the other hand, in CE operation I_B is multiplied by β, hence we get large collector current.

27. Why CE configuration is considered to be the most versatile one?

The common emitter configuration provides very good voltage gain about 500CE configuration finds excellent usage in audio frequency applications, hence used in receivers and transmitter.

28. Write the junction transistor operation may be drawn from the analysis.

1. The major charge carriers in the PNP junction transistor are holes.
2. The major charge carriers in the NPN junction transistor are electrons.

29. Why transistor (BJT) is called current controlled device?

The output voltage, current or power is controlled by the input current in a transistor. So, it is called the current controlled device.

30. Why silicon type transistors are more often used than Germanium type?

Because silicon has smaller cut-off current I_{CBO} , small variations in I_{CBO} due to variations in temperature and high operating temperature as compared to those in case of Germanium.

31. Why collector is made larger than emitter and base?

Collector is made physically larger than emitter and base because collector is to dissipate much power.

32. Why the width of the base region of a transistor is kept very small as compared to other regions?

Base region of a transistor is kept very small and lightly doped so as to pass most of the injected charge carriers to the collector.

33. Why emitter is always forward biased with respect to base?
    To supply majority charge carrier to the base.
34. Why collector is always reverse biased with respect to base?
    To remove the charge carriers away from the collector-base junction.
35. Why CE configuration is most popular in amplifier circuits?
    Because it's current, voltage and power gains are quite high and the ratio of output impedance and input impedance are quite moderate
36. Why emitter is always forward biased with respect to base?
    To supply majority charge carrier to the base.
37. Why collector is always reverse biased with respect to base?
    To remove the charge carriers away from the collector-base junction.
38. Why CE configuration is most popular in amplifier circuits?
    Because it's current, voltage and power gains are quite high and the ratio of output impedance and input impedance are quite moderate
39. Why is CC configuration seldom used?
    Because its voltage gain is always less than unity.
40. Which of the BJT configuration is suitable for impedance matching application and why?
    CC configuration is suitable for impedance matching applications because of very high input impedance and low output impedance.
41. Why field effect transistor is called unipolar transistors?
    Because current conduction is by only one type of majority carriers.
42. Why FET's are so called? (or) Why FETs are voltage controlled devices?
    The output characteristics of a FET can be controlled by the applied electric field (voltage) and hence the name FET and are voltage controlled devices.
43. How is drain current controlled in a JFET?
    By controlling the reverse bias given to its gate, i.e., VGS
44. What is the pinch-off voltage in a JFET?
    The value of V_{DS} at which the channel is pinched-off, i.e., all the free charges from the channel get removed, is called the pinch-off voltage in a JFET.

45. What are the parameters that control the pinch-off voltage of JFET?
    Electron charge, donor/acceptor concentration density, permittivity of channel material and half-width of channel bar.

How does the FET behave (i) for small values of $|V_{DS}|$ and (ii) for large values of $|V_{DS}|$?

(i) FET behaves as an ordinary resistor for small values of $|V_{DS}|$, i.e., in ohmic region.

(ii) FET behaves as a constant current source for large values of $|V_{DS}|$ till breakdown occurs.

46. What is meant by saturation region?

The region of drain characteristic of a FET in which drain current remains fairly constant is called the saturation or pinch-off region.

47. What is meant by drain-source saturation current $I_{DSS?}$

The drain current in pinch-off region with $V_{DS} = 0$ is called I_{DSS}.

48. Why is the input impedance of FET very high?

Because it's input circuit (gate-to-source) is reverse biased and the input gate current is very small (nA).

49. Differentiate BJT and UJT.

BJT	UJT
1. It has two PN junctions	1. It has only one PN junctions
2. three terminals present are emitter, base,collector	2. three terminals present are emitter, base1,base2
3. basically a amplifying device	3. basically a switching device

UNIT-III

1. What is a varactor diode?
   A diode which is based on the voltage variable capacitance of the reverse biased p-n Junction is said to be varactor diode. It has other names such as varicaps, voltacaps.

2. What is a tunnel diode?
   The tunnel diode is a pn junction diode in which the impurity concentration is greatly Increased about 1000 times higher than a conventional PN junction diode thus yielding very thin depletion layer. This diode utilizes a phenomenon called tunneling and hence the diode is referred as tunnel diode.

3. What is tunneling phenomenon?
   The phenomenon of penetration of the charge carriers directly though the potential barrier instead of climbing over it is called as tunneling.

4. What is backward diode?
   The backward diode is a diode in which the doping level is moderate. The forward current in this case is very small, very much similar to that of the reverse current in the conventional diode.

5. what is a LED?
   A PN junction diode which emits light when forward biased is known as Light emitting diode (LED).

6. Explain the Advantages of photodiode?

   a. can be used as variable resistance device.

b. Highly sensitive to the light.

c. The speed of the operation is very high . the switching of current and hence the resistance value from high to low or other wise is very fast .

7. Explain the Disadvantages of photodiode?

(i) The dark current is temperature dependent .

(ii) The overall photo diode characteristics are temperature dependent

Hence have poor temperature stability

(iii) The current and change in current is in the range of TA which may not be sufficient to drive other circuits. Hence amplification is necessary

6. What is Pin diode ?

Pin diode is a high speed switching device, because its highly improved switching time in comparison with a PN diode. In this diode high resistivity intrinsic layer is sandwiched between the heavily doped P and N regions thus it is named as PIN diode.

7. What is a varactor diode ?

The varactor diode is a semiconductor, voltage dependent variable capacitor diode. This special diode which is made for the application utilization of voltage variable properly hence it is called varactor diode or Varicaps (or) voltage cap.It is operated under reverse biased conditions so as to yield a variable junction capacitance.

8. What is the significance of varactor diode ?

The varactor diode is a semiconductor, voltage deprndent ,variable capacitors diode.Their mode of operation depends on the capacitance that exists at the PN junction when it is reverse biased.

9. Why germanium instead of silicon is used for construction of SCR?

For the construction of SCR germanium is preferred than silicon because, more silicon per ampere current is required. Hence the current rating is increased, it require more silicon.

12. Write an two different characteristics of SCR ?

1. Forward characteristics
2. Reverse characteristics

13. Mention the application of SCR.

(i) It can be used as a speed control element in DC and Ac motors.

(ii)It can be used as an inverter.

(iii) It can be used as an Converter.

14. Define breakdown voltage of SCR.

It can be defined as the minimum forward voltage at which the SCR starts conducting heavily.

15. Define latching current.

It can be defined as the maximum anode current that an SCR capable of passing without destruction.

16. Define holding current of an SCR .

It can be defined as the minimum value of anode current required to keep the SCR in ON position.

17. What is DIAC ?

Diac is a two terminal ,bi-directional semiconductor switching depending upon the polarity of the voltage applied across its main terminals .In operation ,diac is equivalent to two 4 layer diodes connected in antiparallel.

18. List out the applications of DIAC.

(i) It is used as a trigger device in TRIAC power control systems.
(ii) It is used in lamp dimmer circuits
(iii) It is used in heater control circuits
(iv) It is used for speed control of universal motor.

19. A triac is considered as two SCRs connected in reverse parallel.Why?

The TRIAC is a bidirectional device.,i.e it conducts in both direction ,In order to achieve this characteristics two SCRs are connected in reverse and parallel.

20. Compare SCR with TRIAC.

SCR	TRIAC
It is a unidirectional device	It is a bidirectional device
It is triggered by a narrow positive pulse applied at the gate	It is triggered by a narrow pulse of the either polarity to the gate.
SCR are available only with large current rating.	Triac are available for both lower current and large current rating.
It has fast turn off	The turn off time is less than SCR
UJT is used for triggering	Diac is used for triggering
Applications: Phase control, Protection of power suppliers	Applications: Phase control, light dimmer

21. What is TRIAC ?

TRIAC is a three terminal bi-directional semiconductor switching device. It can conduct in both the directions for any desired period.In operation it is equivalent to two SCRs connected in antiparallel .

22. Give the applications of UJT.

(i) It is used in timing circuits

(ii)It is used in switching circuits.

(iii) It is used in phase control circuits.

(iv) It is used in saw –tooth generators.

(v)It is used in pulse generation.

23. Define dark current of a photo diode .

When there is no light ,the reverse biased photodiode carriers a current which is very small and is called as dark current.

24. What is photodiode ?

It is a light sensitive device used to convert light signal into electrical signal.

25. What is mean by solar cell ?

A solar cell is basically a PN junction diode which converts solar energy into electric energy. It is also called a solar energy converter.

26. What is Photo voltaic effect?

When the light is incident on the photodiode ,an internal voltage is generated, it causes the current flow through internal circuit even though no external source is applied. this generated emf is proportional to the frequency and the intensity of the incident light. This phenomenon is called photo voltaic effect.

27. What is known as photo conductive effect?

This is the absorption of incident light by an semiconductor resulting in increase in conductivity.

28. What is an LCD ?

LCD is a passive type display devices used for display of numeric and alphanumeric character in dot matrix and seven segment display. The main advantage of LCD is the low power consumption because no light generation is required .

29. On what factor does the color of the light emitted by a LED depend ?

(i) Energy gap of the material

(ii) The colour of the emitted light depends on the type of the material used.

30. Explain the Advantages of LED?

The various advantages of LED are.

(i) LED are small in size , and hence can be regarded as point source of light . because of their small size , several thousand of LEDs can be packed in one sq .metre area (ii)The brightness of light emitted by LED depends on the current flowing through LED. hence the brightness of light can be smoothly controlled by varying the current. This makes possible to operate LED displays under different ambient lighting conditions.

31. Explain the Disadvantages of LED ?

a. It draws considerable current requiring frequent replacement of battery in low power battery operated devices.

b. Luminous efficiency of LEDs is low which is about 1.5 lumen/watt.

c. The characteristics are affected by temperature

d. Need large power for the operation compared to normal p-n junction.

32. Write an application of LED?

a. All kind of visual display. In seven segment displays and alpha numeric displays. Such displays are commonly used in watches and calculators.

b. In the optical devices such as optocouplers .

c. As ON-OFF indicator in various types of electronic circuits.

d. LEDs useful in remote controls.

33. Different types of LCD ?

1. Dynamic scattering LCD
2. Field effect LCD

34. What does UJT stands for? Justify the name UJT..

UJT stands for unijunction transistor. The UJT is a three terminal semiconductor device having two doped regions. It has one emitter terminal (E) and two base terminals (B1andB2). It has only one junction, moreover from the out look, it resembles to a transistor hence the name unijunction transistor.

35. What is interbase resistance of UJT?

The resistance between the two bases (B1and B2) of UJT is called as interbase resistance.

Interbase resistance = RB1 + RB2

RB1- resistance of silicon bar between B1 and emitter junction.

RB2 - resistance of silicon bar between B2 and emitter junction

36. What are the regions in the VI characteristics of UJT?

1. Cut-off region
2. Negative resistance region.
3. Saturation region

37. What is meant by negative resistance region of UJT?

In a UJT when the emitter voltage reaches the peak point voltage, emitter current starts flowing. After the peak point any effort to increase in emitter voltage further leads to sudden increase in the emitter current with corresponding decrease in emitter voltage, exhibiting negative resistance. This takes place until the valley point is reached. This region between the peak point and valley point is called negative resistance region.

38. Mention the applications of UJT.

1. It is used in timing circuits

2. It is used in switching circuits
3. It is used in phase control circuits
4. It can be used as trigger device for SCR and triac.
5. It is used in saw tooth generator.
6. It is used for pulse generation.

39. What is a TRIAC?

TRIAC is a three terminal bidirectional semiconductor switching device. It can conduct in both the directions for any desired period. In operation it is equivalent to two SCR's connected in antiparallel.

40. Give the application of TRIAC.

1. Heater control
2. Motor speed control
3. Phase control
4. Static switches

41. What are the different operating modes of TRIAC?

1. Keeping MT2 and G positive
2. Keeping MT2 and G negative.
3. Keeping MT2 positive and G negative.
4. Keeping MT2 negative and G positive.

42. What is a DIAC?

DIAC is a two terminal bidirectional semiconductor switching device. . It can conduct in either direction depending upon the polarity of the voltage applied across its main Terminals. In operation DIAC is equivalent to two 4 layer diodes connected in antiparallel.

43. Give some applications of DIAC.

1. To trigger TRIAC
2. Motor speed control
3. Heat control
4. Light dimmer circuits

44. What is a SCR?

A silicon controller rectifier (SCR) is a three terminal, three junction semiconductor device that acts as a true electronic switch. It is a unidirectional device. It converts alternating current into direct current and controls the amount of power fed to the load.

45. Define break over voltage of SCR.

Break over voltage is defined as the minimum forward voltage with gate open at which the SCR starts conducting heavily.

46. Why SCR cannot be used as a bidirectional switch.

SCR can do conduction only when anode is positive with respect to cathode with proper gate current. Therefore, SCR operates only in one direction and cannot be used as bidirectional switch.

47. How turning on of SCR is done?

1. By increasing the voltage across SCR above forward break over voltage.
2. By applying a small positive voltage at gate.
3. By rapidly increasing the anode to cathode voltage.
4. By irradiating SCR with light.

48. How turning off of SCR is done?
1. By reversing the polarity of anode to cathode voltage.
2. By reducing the current through the SCR below holding current.
3.By interrupting anode current by means of momentarily series or parallel switching

49. Define holding current in a SCR.
Holding current is defined as the minimum value of anode current to keep the SCR ON.

50. List the advantages of SCR.
1. SCR can handle and control large currents.
2. Its switching speed is very high
3. It has no moving parts, therefore it gives noiseless operation.
4. Its operating efficiency is high.

51. List the application of SCR.
1. It can be used as a speed controller in DC and AC motors.
2. It can be used as an inverter.
3. It can be used as a converter
4. It is used in battery chargers.
5. It is used for phase control and heater control.
6. It is used in light dimming control circuits.

52. What is meant by latching.
The ability of SCR to remain conducting even when the gate signal is removed is called as latching.

53. Define forward current rating of a SCR.
Forward current rating of a SCR is the maximum anode current that it can handle without destruction.

54. List the important ratings of SCR.
1. Forward break over voltage
2. Holding current
3. Gate trigger current
4. Average forward current
5. Reverse break down voltage.

55. Compare SCR with TRIAC.

SCR	TRIAC
1. unidirectional current	1. bidirectional current
2. triggered by positive pulse at gate	2. triggered by pulse of positive or negative at gate
3. fast turn off time	3. Longer turn off time

4. large current ratings	4. lower current ratings

56. Give the various triggering devices for thyristors.
    1. SCR
    2. UJT
    3. DIAC
    4. TRIAC
57. Comparison between LED and LCD

Table *Comparison between LED and LCD*

LED	*LCD*
Consumes more power–requires 10–250 mW power per digit	Essentially acts as a capacitor and consumes very less power–requires 10–200 μW power per digit
Because of high power requirement, it requires external interface circuitry when driven from ICs	Can be driven directly from IC chips
Good brightness level	Moderate brightness level
Operable within the temperature range −40 to 85 °C	Temperature range limited to −20 to 60 °C
Life time is around 100,000 hours	Life time is limited to 50,000 hours due to chemical degradation
Emits light in red, orange, yellow, green blue and white	Invisible in darkness – requires external illumination
Operating voltage range is 1.5 to 5 V d.c. Response time is 50 to 500 ns	Operating voltage range is 3 to 20 V a.c. Has a slow decay time – response time is 50 to 200 ms
Viewing angle 150°	Viewing angle 100°

UNIT IV

1. What are the transistor parameters that vary with the temperature?

   β, I_{CO}, V_{Beo} are the parameters varying with the temperature.

2. What is Bias? What is the need for biasing?

   - The proper flow of zero signal collector current and the maintenance of proper collector emitter voltage during the passage of signal is know as transistor biasing.

   - When a transistor is biased properly, it works efficiently and produces no distortion in the output signal and thus operating point can be maintained stable.

3. What do you understand by DC & AC load line?

   DC Load Line

   It is the line on the output characteristics of a transistor circuit which gives the values of Ic & Vce corresponding to zero signal.

4.

AC Load Line

This is the line on the output characteristics of a transistor circuit which gives the values of Ic & Vce when signal is applied.

4. What is the meant by operating point Q?
The zero signal values of Ic & Vce are known as operating point. It is also called so because the variations of Ic and Vce take place about this point, when the signal is applied.

5. What are the types of biasing?
The different types of biasing are
- Fixed bias
- Collector to Base bias (or) Feedback bias
- Self bias (or) Voltage divider bias

6. Define stability factor 'S'.
The stability factor is defined as the rate of change of collector current Ic with respect to the reverse saturation collector current Ico, keeping 'Vbe' and β constant.

$$S = \frac{\Delta I_C}{\Delta I_{CO}}$$

7. What are the disadvantages of collector feedback bias?
- The collector current is high.
- If AC signal voltage gain feedback into the resistor Re, it will reduce the gain of the amplifier.

8. Define the stability factors S' and S''.
The Stability factor S' is defined as the rate of change of Ic with V_{BE} keeping I_{CO} and constant.
β

$$S' = \frac{\Delta I_C}{\Delta V_{BE}}$$

The Stability factor S'' is defined as the rate of change of Ic with V_{BE} keeping I_{CO} and constant.

$$S'' = \frac{\Delta I_C}{\Delta \beta}$$

9. Give the stability factor S for the fixed bias circuit.
The stability factor for the fixed bias circuit is,
$S = 1 + \beta$

10. Give the stability factor S for the Collector to base bias circuit.

The stability factor for the Collector to base bias circuit is,

$$S = \frac{1+\beta}{1-\beta\,[\,Rc/(Rc+Rb)\,]}$$

11. Give the stability factor S for the Voltage divider bias circuit.

The stability factor for the Voltage divider bias circuit is,

$$S = \frac{1+\beta}{1-\beta\,[\,Rc/(Rc+Re)\,]}$$

12. Why fixed bias circuit is not used in practice?

The stability of the fixed bias circuit is very less. Since the stability factor $S=1+\beta$ is a large quantity, therefore stability is less. So, it is not used in amplifier circuits.

13. What is all the compensation techniques used for bias stability?

Along with the negative feedback, the following techniques are used for the Q point stability.

- Diode compensation,
- Thermistor compensation,
- Sensistor compensation.

14. How FET is known as Voltage variable resistor?

In the region before pinch off, where V_{DS} small, the drain to source resistance r_d can be controlled by the bias voltage V_{GS}.Therefore FET is useful as voltage variable resistor (VVR)or Voltage dependent Resistor (VDR).

15. List the advantages of fixed bias method.

The advantages of fixed bias method are,

- The stability of the operating point is greatly improved when compared with the other circuits.
- Less cost and simple circuit.

UNIT V

1. What is a power supply?

Equipment, which converts the alternating waveform from the power lines into an essentially direct voltage, is known as power supply.

2. What are all the subsystems in a power supply?

A power supply consists of following three subsystems.

- Rectifier.
- Filter
- Voltage regulator.

3. What is the function of rectifier?
   Rectifier is capable of converting a sinusoidal input waveform. Its average value is zero, into a unidirectional waveform, with a non-zero average component.

4. What is half – wave rectifier?
   The rectifier circuit which converts only the positive half cycle of the AC input voltage input voltage into useful DC output voltage is known as half-wave rectifier.

5. Write down the average DC voltage across the load in a half-wave rectifier circuit.
   The average DC voltage is given by, π
   $Vdc = IdcRL = Vm/\{(1 + Rf/RL)$
   R_f = Diode forward resistance RL= Load resistance
   V_m = Maximum amplitude

6. Define ripple factor.
   A measure of the purity of the DC output of a rectifier circuit is called the ripple factor 'r' and is defined as,

$$r = \frac{\text{RMS value of AC components}}{\text{Average value of wave}}$$

7. What is meant by peak inverse voltage?
   The maximum reverse voltage capability of a diode is known as peak inverse voltage.

8. What is full-wave rectifier?
   A rectifier circuit, which converts both positive and negative half cycle of the input AC voltage into useful DC voltage, is known as full wave rectifier.

9. What are all the drawbacks of a full wave rectifier?
   The draw backs of full wave rectifier are,

- Centre tapped transformer is required.

- Diodes having twice the PIV rating are necessary in this rectifier.

10. What are all the advantages of bridge rectifier circuit?
    The advantages of bridge rectifier circuit are,

- The transformer utilization factor is high (0.812)
- It is suitable for large amount of DC power circuits.
- The peak inverse voltage across each diode is the peak V_m only not $2V_m$ as in the case of two diode rectifier.

11. Define rectifier efficiency.

It is defined as the ratio of DC power output to the applied AC power in put Rectifier efficiency.

12. What is the need for a filter in rectifier?

- Most of the rectifier circuits make use of transformer whose secondary feeds the AC power. The transformer rating is necessary to design a power supply.
- Transformer utilization factor (TF) defined as the ratio of DC power delivered to the load to the AC power rating of transformer secondary.

13. What is a rectifier-filter?

A filter circuit is a device which removes the AC component but allows the DC components of the rectifier to reach the load. Ripples can be removed by one of the following filtering methods.

- A capacitor, in parallel to the load, provides a easier by pass for the ripples due to low impedance to AC at ripple frequency and leave the DC appear across the load.
- An inductor, in series with the load, prevents the passage of ripples due to high impedance at ripple frequency, while allowing the DC due to low resistance to DC.

14. List some advantages and disadvantages of CLC filters.

- It can be used with both HWRs and FWRs.
- More output is obtained
- Output is almost pure DC.

15. What is the need for voltage regulators? What are the drawbacks of unregulated power supply?

An ordinary (unregulated) power supply from the following

Drawbacks: Poor regulation

- The DC output voltage varies with temperature, in case semiconductors are used.
- For certain applications the output of the filter even with small amount of ripples is not acceptable.

QUESTION BANK

UNIT-I

TWO MARKS

1. What is meant by semiconductor diodes?
2. What is the classification of semiconductor devices?
3. What is meant by Intrinsic semiconductor diodes?
4. What is meant by Extrinsic semiconductor?
5. What are the types of Extrinsic semiconductor?
6. What is meant by N-type semiconductor?
6. What is meant by N-type semiconductor?
7. How will you get P-type semiconductor?
8. Write about donor impurities?
9. Write about acceptor impurities?
10. What is meant by continuity equation?
12. Name the current that flows through a PN Junction diode?
13. What is meant by PN Junction diode?
14. What is meant by diffusion?
15. What is meant by depletion region?
16. What is meant by drift current?
17. What is meant by diffusion current?
18. Define-Reverse Resistance?
19. What is meant by diffusion capacitance (CD)?
20. What is the effect of Temperature on PN Junction diode?
21. What is a zener diode?
22. What is zener breakdown?

11 MARKS

1. Describe the operation of PN junction diode.
2. Explain about the energy band structure of insulator, semiconductors and conductors
3. Explain about in detail HALL EFFECT?
4. Explain about
   a) Drift and diffusion currents
   b) Fermi levels in extrinsic semiconductors
   c) Explain in detail of intrinsic semiconductors and extrinsic semiconductors.
5. Explain in details
   a) Diode equivalent circuit
   b) Diode switching times
6. Explain forward and reverse bias in PN junction and drift current.

7. Explain transition and diffusion capacitance.
8. Explain about Fermi Dirac distribution and energy band diagram.
9. Discuss about Transition and Diffusion capacitance
10. Explain in detail of intrinsic semiconductors and extrinsic semiconductors.

UNIT-II

TWO MARKS

1. What is a bipolar junction transistor?
2. Define the different operating regions of transistor.
3. Define NPN and PNP transistor.
4. Define Transistor current.
5. What are the three types of configuration in transistors?
6. What is early effect or base and the modulation?
8. What are the consequence effects of base width modulation?
9. What is thermal runaway?
10. List the uses of emitter follower circuit.
11. What are the types of breakdown in transistor?
12. What is a FET?
13. Why FET is called as unipolar device?
14. Define pinch off voltage.
15. What are the characteristic parameters of JFET?
16. What-are the applications of JFET.
17. What is a MOSFET?
18. Write short on the working principle of a MOSFET.
19. How the MOSFET's are protected from overload voltage?
20. What are the application of MOSFET?

11 MARKS

1. Explain ebber's moll equations with circuit diagram.
2. Discuss about
(a) the difference between MOSFET and JFET.
(b) The pinch off voltage.
3. Explain about enhancement mode of operation in MOSFET.
4. Explain about the EMOSFET, DMOSFET and VMOSFET.
5. Explain JFET with drain and transfer characteristics.
6. Explain early effect.
7. Explain characteristics of transistor in CB or CE or CC configurations.

8. Explain PNP or NPN transistor.

UNIT -III

TWO MARKS

1. What is a TRIAC?
2. Give the symbol and structure of TRIAC.
3. Give the equivalent circuit of TRIAC
4. Give the application of TRIAC.
5. What are the different operating modes of TRIAC?
6. Give the VI characteristics of TRIAC.
7. What is a DIAC?
8. Give some applications of DIAC
9. Give the VI characteristics of DIAC.
10. Give the basic construction and symbol of DIAC.
11. What is a SCR?
12. Define break over voltage of SCR.
13. Why SCR cannot be used as a bidirectional switch.
14. Give the construction and symbol of SCR.
15. How turning on of SCR is done?
16. How turning off of SCR is done?
17. Construction symbol of DIAC
18. Give the equivalent circuit of DIAC
19. Define holding current in a SCR.
20. List the advantages of SCR.
21. List the application of SCR.
22. What is meant by latching.
23. Define forward current rating of a SCR.
24. List the important ratings of SCR.
25. Compare SCR with TRIAC
26. What is Shockley diode (PNPN diode)?
27. What is a thyristor?
28. What are the types of thyristors?
29. Give the various triggering devices for thyristors.

11 MARKS

1. Construction, principle of operation and characteristics of
   (a) Schottky barrier diode
   (b) Varactor diode
   (c) Tunnel diode
   (d) SCR
   (e) DIAC
   (f) TRIAC

2. Explain PIN, LCD and LED.
3. Explain photodiode, optocoupler, solar cell.

UNIT – IV

TWO MARKS

1. What is Bias? What is the need for biasing?
2. What do you understand by DC& AC load line?
3. What is the meant by operating point Q?
4. What are the types of biasing?
5. What are all the factors that affect the stability of the operating point?
6. Define stability factor ‘S’?
7. What are the disadvantages of collector feedback bias?
8. Why voltage divider bias is commonly used in amplifier circuit?
9. Define the stability factors S’ and S’’ ?
10. Give the stability factor S for the fixed bias circuit, Collector to base bias and Voltage divider bias.
11. Why fixed bias circuit is not used in practice?
12. What are all the compensation techniques used for bias stability?
13. Why the input impedance of FET is more than that of a BJT?
14. How FET is known as Voltage variable resistor?
15. List the advantages of Fixed bias method?
16. How self-bias circuit is used as constant current source?
17. What is Thermal runaway?
18. What are the consideration factors that are used for the selection of an operating point for an FET amplifier?
19. Write the different types of FET biasing circuits.
20. What is meant by stabilization?

11 MARKS

1. Explain
    a. DC load line and Q-point
    b. Need for biasing
2. Explain types of BJT Biasing techniques.
3. Explain types of FET biasing techniques.
4. Explain MOSFET biasing.
5. Explain stability factor and bias compensation techniques.

UNIT- V

TWO MARKS

1. Define rectifier.

2. Types of rectifiers.
3. What are the basic elements of regulated power supply?
4. What is ripple factor(γ)?
5. What is a rectifier?
6. Define or what is Transformer utilization factor?
7. What is a filter and state its types?
8. What is regulated power supply?
9. What is the function of a voltage regulator?
10. What is the need of foldback current limiting?
11. Why series regulator called as linear voltage regulators?
12. What is switching regulator? List the four major components of the switching regulator.
13. Define PIV.
14. What is bleeder resistor?

11 MARKS

1. Explain in detail, the working of Bridge rectifiers with resistive load with necessary waveforms.
2. Explain the operation of FWR with a neat circuit diagram & waveforms and derive Idc, Irms, Vdc, Vrms
3. Define Irms, Vdc, Vrms, ripple factor, regulation, efficiency , PIV & TUF.
4. Explain foldback limiting.
5. Explain switching regulator.
6. Explain series and shunt voltage regulators.
7. Explain Half wave rectifier with necessary diagrams and derivation.
8. Explain Full wave with necessary diagram and derivation.
9. Explain bridge rectifier with necessary diagram and derivation.

UNIVERSITY QUESTION PAPERS

4623026

B.Tech. DEGREE EXAMINATION,
NOVEMBER/DECEMBER 2014.

Third Semester

Electronics and Communication Engineering

ELECTRON DEVICES

Time : Three hours — Maximum : 75 marks

PART A — (10 × 2 = 20 marks)

Answer ALL questions.

All questions carry equal marks.

1. Why semiconductor act as an insulator at ordinary temperature?

2. What are donor and acceptor impurities?

3. What is Depletion region in a PN junction diode?

4. State the relationship between diode capacitance and the reverse bias voltage.

5. Explain the significance of Base Width modulation.

6. What is meant by Gate – Source threshold voltage and pinch off Voltage?

7. What are the Applications of Tunnel diode?

8. What is an LCD? Mention its merits and demerits.

9. Compare SCR and TRIAC.

10. How does UJT differ from a FET?

PART B — ($5 \times 11 = 55$ marks)

Answer ALL questions, ONE from each Unit.

All questions carry equal marks.

UNIT I

11. Explain electrostatic and magnetic deflection in CRT.

Or

12. Explain Hall effect in detail.

UNIT II

13. Derive the PN diode current equation from the quantitative theory of diode currents.

Or

14. Derive the expression for transition capacitance and diffusion capacitance.

UNIT III

15. Explain the construction, operation and characteristics of a p-channel JFET. Explain how the various FET parameters are calculated from the above characteristics.

Or

16. Derive the Eber's Moll model for a PNP transistor.

UNIT IV

17. Explain the construction and working of Schottky barrier diode and give some applications of Schottky barrier diode.

Or

18. Explain the construction and working of seven segment display.

UNIT V

19. Explain with the equivalent circuit of a UJT, the characteristics and define intrinsic standoff ratio. How UJT is used as a relaxation oscillator?

Or

20. Explain how SCR is used for phase control. Write some applications of SCR.

UNIT V

19. With a neat diagram, explain the following.

(a) Shunt transistorized voltage regulators (6)

(b) Current limiting circuit. (5)

Or

20. (a) With a block diagram explain the various components of power supply with their functions. (7)

(b) Discuss the foldback limiting circuit with its use. (4)

5623026

B.Tech. DEGREE EXAMINATION, NOVEMBER/DECEMBER 2014.

Third Semester

Electronics and Communication Engineering

ELECTRONIC DEVICES AND CIRCUITS

Time : Three hours Maximum : 75 marks

PART A — ($10 \times 2 = 20$ marks)

Answer ALL questions.

All questions carry equal marks.

1. Draw the diode equivalent circuit.

2. How does the avalanche breakdown voltage vary with temperature?

3. What is Early effect?

4. Distinguish DMOSFET and EMOSFET.

5. List the name of regions in the VI characteristics of UJT.

6. What is optocoupler?

7. What is the need of biasing?

8. How the compensation is achieved in Diode compensation for V_{BE}?

9. Is the Capacitor filter suitable for heavy loads? Justify the reason.

10. What are the factors affecting the output voltage of a regulated power supply?

PART B — (5 × 11 = 55 marks)

Answer ALL questions, ONE from each Unit.

All questions carry equal marks.

UNIT I

11. Draw and explain the operation and characteristics of a PN junction diode. Also derive its Current equation.

Or

12. (a) Write short note on the following. (6)

(i) Diode switching time

(ii) Transition and Diffusion capacitance.

(b) Discuss the operation and reverse bias characteristics of Zener diode. (5)

UNIT II

13. (a) Explain why CE Configuration is popular in amplifier circuits? (6)

(b) Compare all the three configurations of a BJT in terms of their circuit parameters. (5)

Or

14. Explain the operation and VI characteristics of JFET.

UNIT III

15. What is SCR? Explain construction, operation and its VI characteristics.

Or

16. Discuss the following in brief

(a) Tunnel diode (4)

(b) Phototransistor (4)

(c) Solar cell. (3)

UNIT IV

17. Draw and explain the biasing circuit for MOSFET using common source configuration.

Or

18. Draw the circuit diagram of Collector -Base bias circuit using CE configuration and explain how it stabilizes operating point.

4623026

B.Tech. DEGREE EXAMINATION, APRIL/MAY 2014.

Third Semester

Electronics and Communication Engineering

ELECTRON DEVICES

Time : Three hours | Maximum : 75 marks

PART A — (10 × 2 = 20 marks)

Answer ALL questions.

All questions carry equal marks.

1. Define electric field.

2. What is Fermi Dirac distribution function?

3. Enumerate some of the applications of the diode?

4. What is the barrier potential for Ge and Si?

5. Draw the Ebers-Moll model of a transistor.

6. List out some of the differences between JFET and MOSFET.

7. How the seven segment displays are classified?

8. What are the applications of PIN diode?

9. Draw the equivalent circuit of UJT.

10. Define gate trigger current.

PART B — (5 × 11 = 55 marks)

Answer ALL questions, ONE from each Unit.

All questions carry equal marks.

UNIT I

11. Discuss about electrostatic deflection in cathode ray tube and derive an expression for its deflection sensitivity. (11)

Or

12. Explain briefly about Hall effect. (11)

UNIT II

13. Explain briefly about the characteristics and breakdown mechanisms of zener-diode. (11)

Or

14. (a) The reverse saturation current of a silicon PN junction diode is 10 μA. Calculate the diode current for the forward bias voltage of 0.6 V at 25°C. (6)

(b) With neat diagrams explain the operation of reverse biased PN junction. (5)

UNIT III

15. With neat circuit diagram explain t construction, operation, input and outp characteristics of common emitter configuration (

Or

16. Discuss in detail about the construction, operat and characteristics of enhancement MOSFET. (

UNIT IV

17. Explain the construction, operation and v characteristics and applications of pho transistors. (

Or

18. (a) Write a short note on seven segment displa

(b) Explain the construction and applications PIN diode.

UNIT V

19. (a) With V-I characteristics describe tl working principle of SCR. (

(b) Draw the structure, equivalent circuit an input characteristics of UJT. (

Or

20. Explain briefly about UJT relaxation oscillato and derive an expression for frequency o oscillation. (11

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B.Tech. DEGREE EXAMINATION, NOVEMBER 2013.

Third Semester

Electronics and Communication Engineering

ELECTRON DEVICES

Time : Three hours Maximum : 75 marks

PART A — ($10 \times 2 = 20$ marks)

Answer ALL questions.

All questions carry equal marks.

1. Give the energy band structure of conductor.
2. Define Hall effect.
3. Define reverse resistance.
4. What is break down? What are its types?
5. Why the input impedance of FET is more than that of a BJT?
6. Difference between MOSFET and FET.
7. Give the applications of Schottky diode.
8. What is a photo diode?

9. What is meant by latching?

10. What is intrinsic stand-off ratio of an UJT?

PART B — (5 × 11 = 55 marks)

Answer ALL questions, ONE from each unit.

All questions carry equal marks.

UNIT I

11. Explain the Force on a particle in magnetic field.

Or

12. Explain the position of Fermi level in extrinsic semiconductor using the energy band diagram and obtain relation for the same.

UNIT II

13. Explain the switching characteristics of a diode.

Or

14. Explain the following applications of Diode :

(a) Logic gates (4)

(b) Series clipper (4)

(c) Parallel clipper. (3)

UNIT III

15. Describe the characteristics of CB and C configuration.

Or

16. Explain the following in detail :

(a) Depletion MOSFET (

(b) Enhancement MOSFET. (

UNIT IV

17. Explain the construction, operatio characteristics, and applications of Tunnel diode.

Or

18. Write short notes on :

(a) Photo transistor (

(b) Solar cells (

UNIT V

19. Explain the operation, volt ampere characteristic and applications of SCR, also explain its tw transistor model.

Or

20. Explain the operation, equivalent circuit, vol ampere characteristics, and application of TRIAC.

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UNIT V

19. Describe the operation of UJT. What is the main application of UJT? Explain.

Or

20. Explain the characteristics of TRIAC and DIAC with neat sketches.

B.Tech. DEGREE EXAMINATION, APRIL 2013.

Third Semester

Electronics and Communication Engineering

ELECTRON DEVICES

Time : Three hours Maximum : 75 marks

SECTION A — (10 × 2 = 20 marks)

Answer ALL questions.

All questions carry equal marks.

1. Define Donor atom and Acceptor atom.

2. State the applications of PN junction diode.

3. Define Hall Effect.

4. What are the different configurations of BJT? Define PIV.

5. How FET is used as voltage variable resistor?

6. State Early effect.

7. Draw the circuit symbol and equivalent circuit of Varactor diode.

8. What is Avalanche effect in APD?

9. Why does UJT show negative resistance region?

10. What are the applications of TRIAC?

SECTION B — ($5 \times 11 = 55$ marks)

Answer ALL questions, ONE from each unit.

All questions carry equal marks.

UNIT I

11. (a) With relevant diagrams explain the motion of an electron in magnetic field. (6)

(b) An electron is accelerated through a potential of 40v before it enters a magnetic density of 0.91 wb/m^2 at an angle of 30° with field. Find the position of an electron after which it has completed one revolution in the field. (5)

Or

12. Derive continuity equation for the flow of carriers in a semiconductor.

UNIT II

13. Derive the expression for current PN junction diode in terms of applied po

Or

14. Write a note on zener diode VI characteristics.

UNIT III

15. Derive the expression for pinch off volt JFET and explain transfer an characteristics.

Or

16. Explain how breakdown occurs in a transi draw the CB, CE and CC characteristics of

UNIT IV

17. Explain about the working principl characteristics of Tunnel diode.

Or

18. Explain in detail the basic characteristics and photodiode.

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B.Tech. DEGREE EXAMINATION, NOVEMBER 2012.

Third Semester

Electronics and Communication Engineering

ELECTRON DEVICES

Time : Three hours — Maximum : 75 marks

PART A — ($10 \times 2 = 20$ marks)

Answer ALL questions.

All questions carry equal marks.

1. What is Electrostatic deflection sensitivity?

2. Give the energy band structure of Insulator.

3. Define the term transition capacitance.

4. Define transition time.

5. What are the main drawbacks in BJT?

6. State the two types of MOSFET. State also the modes in which they operate.

7. What is a varactor diode?

8. What is photo conductive effect?

9. Give some applications of DIAC.

10. Why SCR cannot be used as a bidirectional switch.

PART B — (5 × 11 = 55 marks)

Answer ALL questions, ONE from each Unit.

All questions carry equal marks.

UNIT I

11. Explain the Force on a particle and motion of a particle in electric field.

Or

12. Explain N-type and P-type semiconductor with their energy band diagram.

UNIT II

13. Explain P-N diode biasing? Also explain VI characteristics.

Or

14. (a) Explain the characteristics of Zener Diode. (6)

(b) What are the types of break down in diode? (5)

UNIT III

15. Discuss the operation of transistor as an Amplifier and transistor as a switch.

Or

16. Describe the construction and characteristics of JFET.

UNIT IV

17. Explain the construction, operation, characteristics and applications of Schottky barrier diode. **schottky barrier diode**

Or

18. Write short notes on :

(a) Photo transistor **Phototransistor** (5)

(b) Solar cells **solar cells** (6)

UNIT V

19. Explain the operation, equivalent circuit, volt ampere characteristics, and application of UJT.

Or

20. Explain the operation, volt ampere characteristics, and applications of DIAC.

REFERENCE

1. R.L.Boylestad and L.Nashelsky, - Electronic Devices and Circuit Theory, Pearson Education, Tenth Edition, 2009.
2. A. P. Godse and U. A. Bakshi “Electronic Devices and Circuits”, Technical publications Pune, First edition 2007.
3. S. Salivahanan, N.Suresh Kumar and A.Vallavaraj, Electronic Devices and Circuits, 2^{nd} Edition, TMH, 2007.
4. R.S. Sedha, Applied Electronics, Chand Publication.