ELECTRONIC DEVICES - EC8252

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ELECTRONIC DEVICES L T P C 3 0 0 3

OBJECTIVES:
The student should be made to:

- Be exposed to basic electronic devices
- Be familiar with the theory, construction, and operation of Basic electronic devices.

UNIT I SEMICONDUCTOR DIODE 9

PN junction diode, Current equations, Diffusion and drift current densities, forward and reverse bias characteristics, Switching Characteristics.

UNIT II BIPOLAR JUNCTION 9

NPN -PNP -Junctions-Early effect-Current equations – Input and Output characteristics of CE, CB CC-Hybrid -π model - h-parameter model, Ebers Moll Model- Gummel Poon-model, Multi Emitter Transistor.

UNIT III FIELD EFFECT TRANSISTORS 9

JFETs – Drain and Transfer characteristics,-Current equations-Pinch off voltage and its significance- MOSFET- Characteristics- Threshold voltage -Channel length modulation, D-MOSFET, E-MOSFET-,Current equation - Equivalent circuit model and its parameters, FINFET,DUAL GATE MOSFET.

UNIT IV SPECIAL SEMICONDUCTOR DEVICES 9

Metal-Semiconductor Junction- MESFET, Schottky barrier diode-Zener diode-Varactor diode –Tunnel diode- Gallium Arsenide device, LASER diode, LDR.

UNIT V POWER DEVICES AND DISPLAY DEVICES 9

UJT, SCR, Diac, Triac, Power BJT- Power MOSFET- DMOS-VMOS. LED, LCD, Photo transistor, Opto Coupler, Solar cell, CCD.

TOTAL: 45 PERIODS

OUTCOMES: At the end of the course, the student should be able to:

- Explain the theory, construction, and operation of basic electronic devices.
- Use the basic electronic devices

TEXT BOOKS

1. Donald A Neaman, “Semiconductor Physics and Devices”, Third Edition, Tata Mc GrawHill Inc. 2007.

REFERENCES:

1. Yang, “Fundamentals of Semiconductor devices”, McGraw Hill International Edition, 1978.

2. Robert Boylestad and Louis Nashelsky, “Electron Devices and Circuit Theory” Pearson Prentice Hall, 10th edition,July.

INTRODUCTION

ELECTRON

It is a stable elementary particle with a charge of negative electricity, found in all atoms and acting as the primary carrier of electricity in solids.

ELECTRONICS

- Electronics is the movement of electrons in a vacuum, gas, semiconductor, etc., in devices in which the flow is controlled and utilized.
- Electronics deals with electrical circuits that involve active electrical components such as vacuum tubes, transistors, diodes and integrated circuits, and associated passive interconnection technologies.

ELECTRON DEVICES

- An electronic component is any physical entity in an electronic system used to affect the electrons or their associated fields in a manner consistent with the intended function of the electronic system.
- Components are generally intended to be connected together, usually by being soldered to a printed circuit board (PCB), to create an electronic circuit with a particular function (for example an amplifier, radio receiver, or oscillator). Components may be packaged singly, or in more complex groups as integrated circuits.
- Some common electronic components are capacitors, inductors, resistors, diodes, transistors, etc. Components are often categorized as active (e.g. transistors and thyristors) or passive (e.g. resistors and capacitors).

ELECTRONIC CIRCUITS

Circuits and components can be divided into two groups: Analog and Digital. A particular device may consist of circuitry that has one or the other or a mix of the two types.

Analog circuits are constructed from combinations of a few types of basic circuits. Analog circuits use a continuous range of voltage as opposed to discrete levels as in digital circuits. The number of different analog circuits so far devised is huge, especially because a 'circuit' can be defined as anything from a single component, to systems containing thousands of components.

Digital circuits are electric circuits based on a number of discrete voltage levels. Digital circuits are the most common physical representation of Boolean algebra, and are the basis of all digital computers. To most engineers, the terms "digital circuit", "digital system" and "logic" are interchangeable in the context of digital circuits.

UNIT I SEMICONDUCTOR DIODE

1.1 SEMICONDUCTOR

A semiconductor is a material which has electrical conductivity to a degree between that of a metal (such as copper) and that of an insulator (such as glass). Semiconductors are the foundation of modern electronics, including transistors, solar cells, light-emitting diodes (LEDs), quantum dots and digital and analog integrated circuits.

DIODE

Diode – Di + ode

Di means two and ode means electrode. So physical contact of two electrodes is known as diode and its important function is alternative current to direct current.

1.2 REVIEW OF INTRINSIC AND EXTRINSIC SEMICONDUCTORS

1.2.1 INTRINSIC SEMICONDUCTOR

An intrinsic semiconductor is one, which is pure enough that impurities do not appreciably affect its electrical behaviour. In this case, all carriers are created due to thermally or optically excited electrons from the full valence band into the empty conduction band. Thus equal numbers of electrons and holes are present in an intrinsic semiconductor. Electrons and holes flow in opposite directions in an electric field, though they contribute to current in the same direction since they are oppositely charged. Hole current and electron current are not necessarily equal in an intrinsic semiconductor, however, because electrons and holes have different effective masses (crystalline analogues to free inertial masses).

The concentration of carriers is strongly dependent on the temperature. At low temperatures, the valence band is completely full making the material an insulator. Increasing the temperature leads to an increase in the number of carriers and a corresponding increase in conductivity. This characteristic shown by intrinsic semiconductor is different from the behaviour of most metals, which tend to become less conductive at higher temperatures due to increased phonon scattering.

Both silicon and germanium are tetravalent, i.e. each has four electrons (valence electrons) in their outermost shell. Both elements crystallize with a diamond-like structure, i.e. in such a way that each atom in the crystal is inside a tetrahedron formed by the four atoms which are closest to it. Each atom shares its four valence electrons with its four immediate neighbours, so that each atom is involved in four covalent bonds.

1.2.2 EXTRINSIC SEMICONDUCTOR

An extrinsic semiconductor is one that has been doped with impurities to modify the number and type of free charge carriers. An extrinsic semiconductor is a semiconductor that has been *doped*, that is, into which a doping agent has been introduced, giving it different electrical properties than the intrinsic (pure) semiconductor.

Doping involves adding doping atoms to an intrinsic semiconductor, which changes the electron and hole carrier concentrations of the semiconductor at thermal equilibrium. Dominant carrier concentrations in an extrinsic semiconductor classify it as either an n-type or p-type semiconductor.

A pure or intrinsic conductor has thermally generated holes and electrons. However these are relatively few in number. An enormous increase in the number of charge carriers can by achieved by introducing impurities into the semiconductor in a controlled manner. The result is the formation of an extrinsic semiconductor. This process is referred to as doping. There are basically two types of impurities: donor impurities and acceptor impurities. Donor impurities are made up of atoms (arsenic for example) which have five valence electrons. Acceptor impurities are made up of atoms (gallium for example) which have three valence electrons.

The two types of extrinsic semiconductor are

1.2.2.1 N-TYPE SEMICONDUCTORS

Extrinsic semiconductors with a larger electron concentration than hole concentration are known as n-type semiconductors. The phrase 'n-type' comes from the negative charge of the electron. In n-type semiconductors, electrons are the majority carriers and holes are the minority carriers. N-type semiconductors are created by doping an intrinsic semiconductor with donor impurities.

In an n-type semiconductor, the Fermi energy level is greater than that of the intrinsic semiconductor and lies closer to the conduction band than the valence band. Arsenic has 5 valence electrons, however, only 4 of them form part of covalent bonds. The 5th electron is then free to take part in conduction. The electrons are said to be the majority carriers and the holes are said to be the minority carriers.

1.2.2.2 P-TYPE SEMICONDUCTORS

As opposed to n-type semiconductors, p-type semiconductors have a larger hole concentration than electron concentration. The phrase 'p-type' refers to the positive charge of the hole. In p-type semiconductors, holes are the majority carriers and electrons are the minority carriers. P-type semiconductors are created by doping an intrinsic semiconductor with acceptor impurities. P-type semiconductors have Fermi energy levels below the intrinsic Fermi energy level.

The Fermi energy level lies closer to the valence band than the conduction band in a p-type semiconductor. Gallium has 3 valence electrons, however, there are 4 covalent bonds to fill. The 4^{th} bond therefore remains vacant producing a hole. The holes are said to be the majority carriers and the electrons are said to be the minority carriers.

1.3 PN JUNCTION

When the N and P-type semiconductor materials are first joined together a very large density gradient exists between both sides of the junction so some of the free electrons from the donor impurity atoms begin to migrate across this newly formed junction to fill up the holes in the P-type material producing negative ions.

However, because the electrons have moved across the junction from the N-type silicon to the P-type silicon, they leave behind positively charged donor ions (ND) on the negative side and now the holes from the acceptor impurity migrate across the junction in the opposite direction into the region are there are large numbers of free electrons.

As a result, the charge density of the P-type along the junction is filled with negatively charged acceptor ions (NA), and the charge density of the N-type along the junction becomes positive. This charge transfer of electrons and holes across the junction is known as diffusion.

This process continues back and forth until the number of electrons which have crossed the junction have a large enough electrical charge to repel or prevent any more carriers from crossing the junction.

The regions on both sides of the junction become depleted of any free carriers in comparison to the N and P type materials away from the junction. Eventually a state of equilibrium (electrically neutral situation) will occur producing a "potential barrier" zone around the area of the junction as the donor atoms repel the holes and the acceptor atoms repel the electrons. Since no free charge carriers can rest in a position where there is a potential barrier the regions on both sides of the junction become depleted of any more free carriers in comparison to the N and P type materials away from the junction. This area around the junction is now called the Depletion Layer.

THE PN JUNCTION

The total charge on each side of the junction must be equal and opposite to maintain a neutral charge condition around the junction.

If the depletion layer region has a distance D, it therefore must therefore penetrate into the silicon by a distance of Dp for the positive side, and a distance of Dn for the negative side giving a relationship between the two of Dp.NA = Dn.ND in order to maintain charge neutrality also called equilibrium.

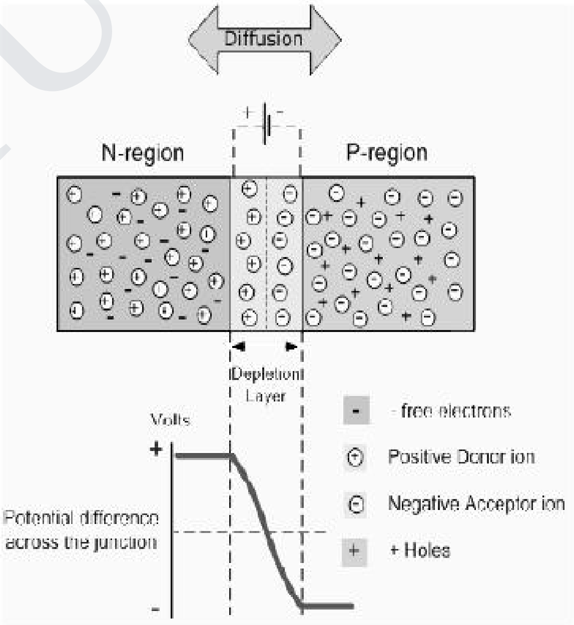


Figure 1.1 PN junction formations

.3.1 PN JUNCTION DISTANCE

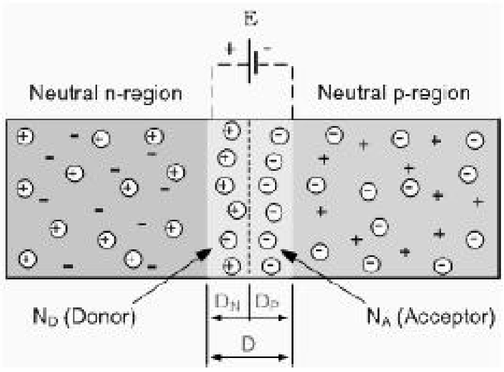


Figure 1.2 PN junction distance under built in potential E_0

As the N-type material has lost electrons and the P-type has lost holes, the N-type material has become positive with respect to the P-type. Then the presence of impurity ions on both sides of the junction cause an electric field to be established across t his region with the N- side at a positive voltage relative to the P-side.

The problem now is that a free charge requires some extra energy to overcome the barrier that now exists for it to be able to cross the depletion region junction. This electric field created by the diffusion process has created a "built-in potential difference" across the junction with an open-circuit (zero bias) potential of:

$$E_0 = V_T \ln\left(\frac{N_D . N_A}{n_i^2}\right)$$

Where: E_0 is the zero bias junction voltage, V_T the thermal voltage of 26mV at room temperature,

N_D and N_A are the impurity concentrations and

n_i is the intrinsic concentration.

A suitable positive voltage (forward bias) applied between the two ends of the PN junction can supply the free electrons and holes with the extra energy. The external voltage required to overcome this potential barrier that now exists is very much dependent upon the type of semiconductor material used and its actual temperature. Typically at room temperature the voltage across the depletion layer for silicon is about 0.6 - 0.7 volts and for germanium is about 0.3 - 0.35 volts. This potential barrier will always exist even if the device is not connected to any external power source.

The significance of this built-in potential across the junction is that it opposes both the flow of holes and electrons across the junction and is why it is called the potential barrier. In practice, a PN junction is formed within a single crystal of material rather than just simply joining or fusing together two separate pieces. Electrical contacts are also fused onto either side of the crystal to enable an electrical connection to be made to an external circuit. Then the resulting device that has been made is called a PN junction Diode or Signal Diode.

1.3.2 DEPLETION LAYER PN JUNCTION

If one side of crystal pure semiconductor Si(silicon) or Ge(Germanium) is doped with acceptor impurity atoms and the other side is doped with donor impurity atoms , a PN junction is formed as shown in figure. P region has high concentration of holes and N region contains large number of electrons.

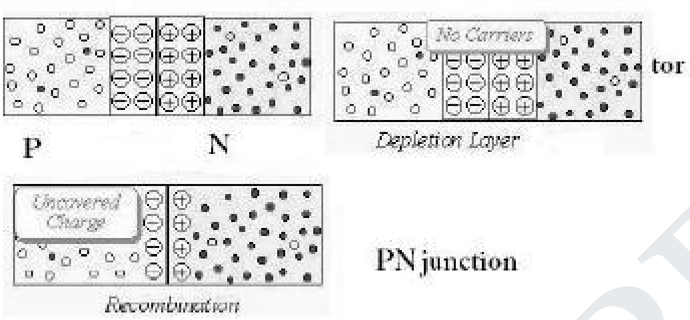


Figure1.3 Depletion Layer PN Junction

As soon as the junction is formed, free electrons and holes cross through the junction by the process of diffusion. During this process, the electrons crossing the junction from N-region into P-region , recombine with holes in the P-region very close to the junction. Similarly holes crossing the junction from the P-region into the N-region, recombine with electrons in the N- region very close to the junction. Thus a region is formed, which does not have any mobile charge very close to the junction. This region is called the depletion layer of PN junction.

In this region, on the left side of the junction, the acceptor atoms become negative ions and on the right side of the junction, the donor atoms become positive ions as shown in figure.

1.3.3 FUNCTION OF DEPLETION LAYER OF PN JUNCTION

An electric field is set up, between the donor and acceptor ions in the depletion layer of the pn junction .The potential at the N-side is higher than the potential at P-side. Therefore electrons in the N- side are prevented to go to the lower potential of P-side. Similarly, holes in the P-side find themselves at a lower potential and are prevented to cross to the N-side. Thus, there is a barrier at the junction which opposes the movement of the majority charge carriers.

The difference of potential from one side of the barrier to the other side of the barrier is called potential barrier. The potential barrier is approximately 0.7V for a silicon PN junction and 0.3V for germanium PN junction. The distance from one side of the barrier to the other side is called the width of the barrier, which depends on the nature of the material.

1.4 QUANTITATIVE THEORY OF P-N DIODE CURRENTS

To derive the expression for the total current as function of applied voltage (neglect the barrier width)When diode is forward biased, holes injected from the p to n material. The concentration p_n of holes in the n-side is increased above equilibrium value p_{no}

L_p is the diffusion length for holes in the N-material and the injected or excess concentration at x=0 is

$$P_n(0) = p_n(0) - p_{no} \quad \dots\dots\dots\dots\dots \quad (2)$$

Equation (2) shows the exponential decrease of density $p_n(x)$ with distance x into the N-material.

The diffusion hole current in the N-side is

$$I_{pn}(x) = \frac{-AeD_pP_n(0)}{L_p}\, e^{-x/L_p} \quad \dots\dots\dots\dots\dots \quad (3)$$

From equation 3 hole current decreases exponentially with distance. It is depending on $P_n(0)$, because it is a function of applied voltage. I_{pn} depends on applied voltage or injected concentration is a function of voltage.

Law of Junction

The hole concentration at the edges of the space charge region are p_p and p_n in the P and N materials and the barrier potential across the depletion layer is $V_B(= V_o - V)$

From Boltzmann relationship of kinetic gas theory

$$p_p = p_n\, e^{V_B/V_T} \quad \dots\dots\dots\dots\dots \quad (4)$$

Where, V_T is the volt- equivalent of temperature.

This equation is valid as long as the hole current is small compared with diffusion or drift current. This condition is called low level injection.

Under open circuit condition (i.e., V=0), $p_p = p_{po}$, $p_n = p_{no}$, and $V_B = V_o$

The equation (4) becomes

$$p_{po} = p_{no}\, e^{V_o/V_T} \quad \dots\dots\dots\dots\dots \quad (5)$$

When the junction is forward biased the barrier $V_B$is decreased from its equilibrium Vo by amount V

$$V_B = V_o - V \quad \dots\dots\dots\dots\dots \quad (6)$$

The hole concentration throughout the P-side is constant and equal to the thermal equilibrium value $(p_p = p_{po})$. The hole concentration varies exponentially with distance into the N-side.

$$At\ x = 0, p_n = p_n(0)$$

Then Boltzmann relation becomes

$$p_{po} = p_n(0)\, e^{(V_o - V)/V_T} \dots\dots\dots\dots (7)$$

Dividing Equation (7) by (5)

$$\frac{p_n(0)}{p_{no}} = \frac{e^{(-V_o+V)/V_T}}{e^{-V_o/V_T}} = e^{V/V_T}$$

$$p_n(0) = p_{no}\, e^{V/V_T}$$

The boundary condition is called law of junction, indicates when V>0, the $p_n(0)$ is greater than the equilibrium value p_{no}.

But from eq 2, $P_n(0) = p_n(0) - p_{no}$, then hole concentration injected into the n-side at the junction.

$$P_n(0) = p_{no}\, e^{V/V_T} - p_{no}$$

$$P_n(0) = p_{no}\, (e^{V/V_T} - 1) \ldots\ldots\ldots\ldots\ldots\ldots (8)$$

Forward currents

The hole current crossing the junction into n- side at x=0

$$I_{pn}(0) = \frac{AeD_pP_n(0)}{L_p} = \frac{AeD_pp_{n0}}{L_p}\,(e^{V/V_T} - 1)$$

The electron current crossing the junction into the P-side with x=0 is

$$I_{np}(0) = \frac{AeD_nN_p(0)}{L_n} = \frac{AeD_nn_{p0}}{L_n}\,(e^{V/V_T} - 1)$$

Total current $I = I_{pn}(0) + I_{np}(0)$

$$I = \frac{AeD_pp_{n0}}{L_p} + \frac{AeD_nn_{p0}}{L_n}\left[e^{V/V_T} - 1\right]$$

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

Where $I_0 = \frac{AeD_pp_{n0}}{L_p} + \frac{AeD_nn_{p0}}{L_n}$= reverse saturation current

If we consider carrier generation and recombination in space –charge region, the genaral equation of the diode current is approximately given by

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

Where V= external voltage applied to the diode and η= a constant, 1 for Ge and 2 for Si.

Reverse currents or reverse saturation current I_0

We know that $p_n = \frac{n_i^2}{N_D}$ and $n_p = \frac{n_i^2}{N_A}$. Applying these relationships in the above equation of reverse saturation current, I_0 we get

$$I_0 = Ae\left[\frac{D_p}{L_pN_D} + \frac{D_n}{L_nN_A}\right]n_i^2$$

1.4.1 DIODE CURRENT EQUATION

The diode current equation relating the voltage V and current I is given by

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

where

I – diode current

I_O – diode reverse saturation current at room temperature

V – External voltage applied to the diode

η - a constant, 1 for Ge and 2 for Si

V_T = kT/q = T/11600, thermal voltage

K – Boltzmann's constant (1.38066x10^-23 J/K)

q – Charge of electron (1.6x10^-19 C)

T – Temperature of the diode junction

At room temperature (T=300 K), V_T = 26mV. Substituting this value in current equation,

$$I = I_0 \left[e^{\left(40V/\eta \right)} - 1 \right]$$

For germanium diode,

$I = I_0 [e^{(40V)} - 1]$ Since η=1 for Ge

For silicon diode,

$I = I_0 [e^{(20V)} - 1]$ Since η=2 for Si

If the value of applied voltage is greater than unity, then the equation of diode current for germanium, $I = I_0 [e^{40V}]$ and for silicon, $I = I_0 [e^{20V}]$,

when the diode is reverse biased, its current equation may be obtained by changing the sign of voltage V.

Thus diode current with reverse bias is

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

If V >> V_T then the term $e^{\left(-V/\eta V_T \right)} << 1$ therefore $I = I_0$ termed as reverse saturation current, which is valid as long as the external voltage is below the breakdown value.

1.5 DRIFT AND DIFFUSION CURRENTS

- The flow of charge (ie) current through a semiconductor material are of two types namely drift & diffusion. (ie) The net current that flows through a (PN junction diode) semiconductor material has two components

(i) Drift current (ii) Diffusion current

1.5.1 DRIFT CURRENT

- When an electric field is applied across the semiconductor material, the charge carriers attain a certain drift velocity V_d , which is equal to the product of the mobility of the charge carriers and the applied Electric Field intensity E .
  Drift velocity V_d = mobility of the charge carriers X Applied Electric field intensity.
- Holes move towards the negative terminal of the battery and electrons move towards the positive terminal of the battery. This combined effect of movement of the charge carriers constitutes a current known as – the drift current.
- Thus the drift current is defined as the flow of electric current due to the motion of the charge carriers under the influence of an external electric field.
- Drift current due to the charge carriers such as free electrons and holes are the current passing through a square centimeter perpendicular to the direction of flow.

(i) Drift current density J_n , due to free electrons is given by

$$J_n = qn\mu_n EA \;\; A/cm^2$$

(ii) Drift current density J_P, due to holes is given by

$$J_p = qp\mu_p EA \;\; A/cm^2$$

Where, n - Number of free electrons per cubic centimetre.

P - Number of holes per cubic centimetre

μ_n – Mobility of electrons in cm^2 / Vs

μ_p – Mobility of holes in cm^2 / Vs

E – Applied Electric filed Intensity in V /cm

q – Charge of an electron = 1.6×10^{-19} coulomb.

1.5.2 DIFFUSION CURRENT

- It is possible for an electric current to flow in a semiconductor even in the absence of the applied voltage provided a concentration gradient exists in the material.

- A concentration gradient exists if the number of either elements or holes is greater in one region of a semiconductor as compared to the rest of the Region.

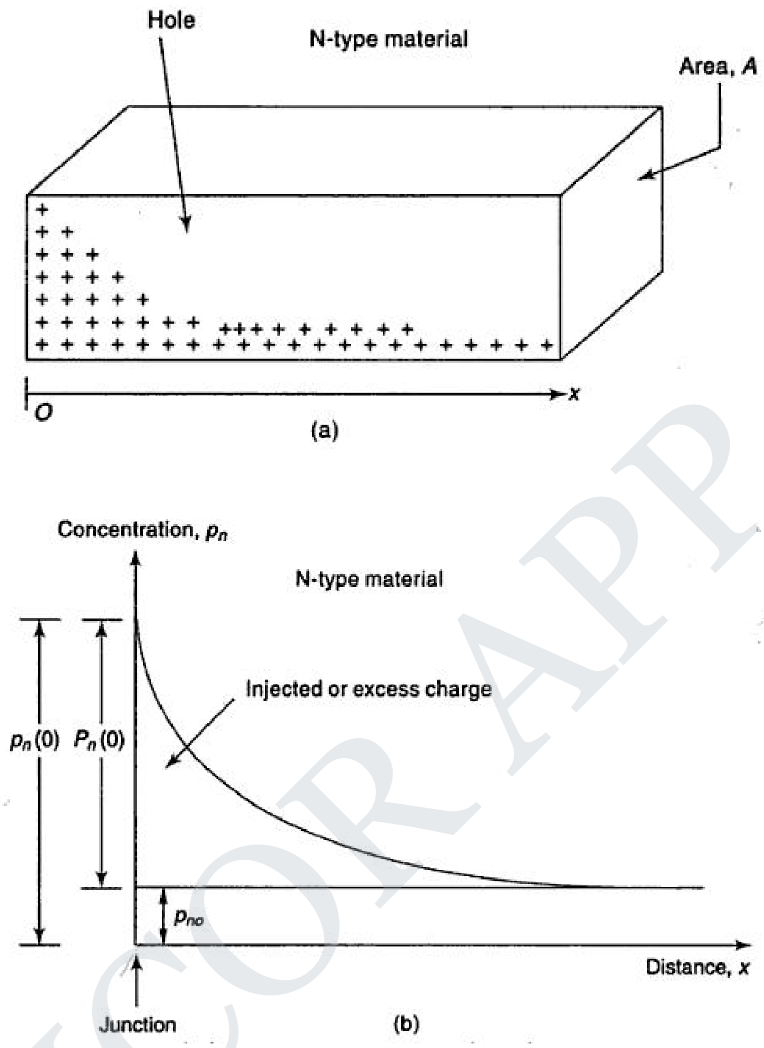


Figure 1.4 (a) Exess hole concentration varying along the axis in an N-type semiconductor bar, (b) The resulting diffusion current

→ In a semiconductor material the change carriers have the tendency to move from the region of higher concentration to that of lower concentration of the same type of charge carriers. Thus the movement of charge carriers takes place resulting in a current called diffusion current.

As indicated in fig a, the hole concentration p(x) in semiconductor bar varies from a high value to a low value along the x-axis and is constant in the y and z directions.

Diffusion current density due to holes J_P is given by

$$J_p = -qD_p \frac{dp}{dx} \; A/cm^2$$

Since the hole density p(x) decreases with increasing x as shown in fig b, dp/dx is negative and the minus sign in equation is needed in order that J_P has positive sign in the positive x direction.

Diffusion current density due to the free electrons is given by

$$J_n = -qD_n \frac{dn}{dx} \; A/cm^2$$

Where ,

$\frac{dn}{dx}$ – concentration gradient for electrons

$\frac{dp}{dx}$ - concentration gradient for holes

D_n and D_p – diffusion coefficient for electrons and holes

Total Current

The total current in a semiconductor is the sum of both drift and diffusion currents that is given by

$$J_p = qp\mu_p E - qD_p \frac{dp}{dx}$$

Similarly the total current density for an N type semiconductor is given by

$$J_n = qp\mu_n E + qD_n \frac{dn}{dx}$$

1.6 FORWARD BIAS CONDITION

When positive terminal of the battery is connected to the P-type and negative terminal to N-type of the PN junction diode that is known as forward bias condition.

Operation

The applied potential in external battery acts in opposition to the internal potential barrier which disturbs the equilibrium.

As soon as equilibrium is disturbed by the application of an external voltage, the Fermi level is no longer continuous across the junction.

Under the forward bias condition the applied positive potential repels the holes in P type region so that the holes move towards the junction and the applied positive potential repels the electrons in N type region so that the electrons move towards the junction.

When the applied potential is more than the internal barrier potential the depletion region and internal potential barrier disappear.

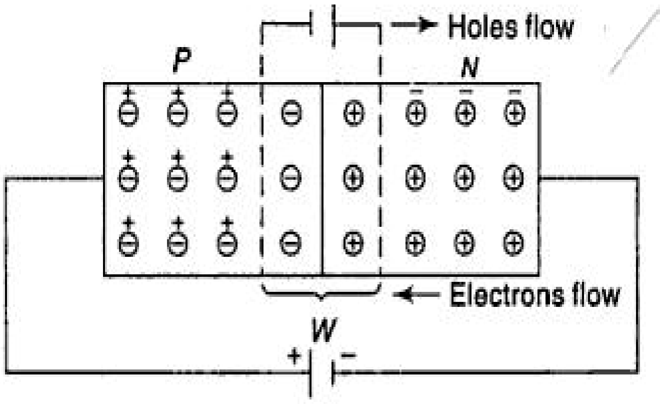


Figure 1.5 PN junctions under forward bias

V-I Characteristics

As the forward voltage increased for $V_F < V_o$, the forward current I_F almost zero because the potential barrier prevents the holes from P region and electrons from N region to flow across the depletion region in opposite direction.

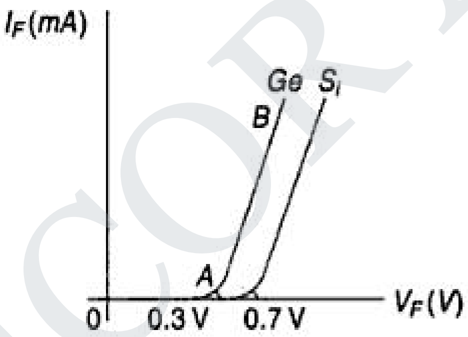


Figure 1.6 V-I characteristics of a diode under forward bias

For $V_F > V_o$, the potential barrier at the junction completely disappears and hence, the holes cross the junction from P to N type and electrons cross the junction to opposite direction, resulting large current flow in external circuit.

A feature noted here is the cut in voltage or threshold voltage V_F below which the current is very small.At this voltage the potential barrier is overcome and the current through the junction starts to increase rapidly.

Cut in voltage is 0.3V for germanium and 0.7 for silicon.

1.6.1 UNDER REVERSE BIAS CONDITION

When the negative terminal of the battery is connected to the P-type and positive terminal to N-type of the PN junction diode that is known as forward bias condition.

Operation

The holes from the majority carriers of the P side move towards the negative terminal of the battery and electrons which from the majority carrier of the N side are attracted towards the positive terminal of the battery.

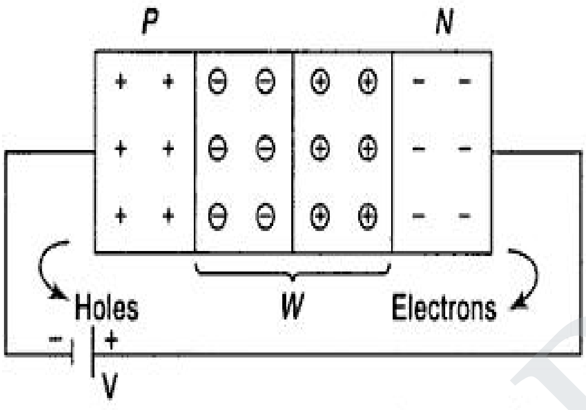


Figure 1.7 PN junctions under reverse bias

Hence, the width of the depletion region which is depleted of mobile charge carriers increases. Thus, the electric field produced by applied reverse bias, is in the same direction as the electric field of the potential barrier.

Hence the resultant potential barrier is increased which prevents the flow of majority carriers in both directions. The depletion width W is proportional to under reverse bias.

V-I characteristics

Theoretically no current flow in the external circuit. But in practice a very small amount of current of the order of few microamperes flows under reverse bias.

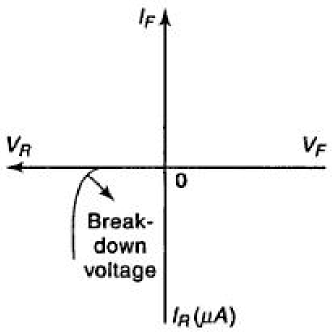


Figure 1.8 V-I characteristics under reverse bias

Electrons forming covalent bonds of semiconductor atoms in the P and N type regions may absorb sufficient energy from heat and light to cause breaking covalent bonds. So electron hole pairs continuously produced.

Consequently the minority carriers electrons in the P region and holes in the N region, wander over to the junction and flow towards their majority carrier side giving rise a small reverse current. This current is known as reverse saturation current Io.

The magnitude of this current is depends on the temperature because minority carr ier is thermally broken covalent bonds.

1.6.2 DIODE CHARACTERISTICS

1. Maximum Forward Current

The Maximum Forward Current (IF(max)) is as its name implies the maximum forward current allowed to flow through the device. When the diode is conducting in the forward bias condition, it has a very small "ON" resistance across the PN junction and therefore, power is dissipated across this junction (Ohm´s Law) in the form of heat. Then, exceeding its (IF(max)) value will cause more heat to be generated across the junction and the diode will fail due to thermal overload, usually with destructive consequences. When operating diodes around their maximum current ratings it is always best to provide additional cooling to dissipate the heat produced by the diode.

For example, our small 1N4148 signal diode has a maximum current rating of about 150mA with a power dissipation of 500mW at 25oC. Then a resistor must be used in series with the diode to limit the forward current, (IF(max)) through it to below this value.

2. Peak Inverse Voltage

The Peak Inverse Voltage (PIV) or Maximum Reverse Voltage (VR(max)), is the maximum allowable Reverse operating voltage that can be applied across the diode without reverse breakdown and damage occurring to the device. This rating therefore, is usually less than the "avalanche breakdown" level on the reverse bias characteristic curve. Typical values of VR(max) range from a few volts to thousands of volts and must be considered when replacing a diode.The peak inverse voltage is an important parameter and is mainly used for rectifying diodes in AC rectifier circuits with reference to the amplitude of the voltage were the sinusoidal waveform changes from a positive to a negative value on each and every cycle.

3. Forward Power Dissipation

Signal diodes have a Forward Power Dissipation, (PD(max)) rating. This rating is the maximum possible power dissipation of the diode when it is forward biased (conducting). When current flows through the signal diode the biasing of the PN junction is not perfect and offers some resistance to the flow of current resulting in power being dissipated (lost) in the diode in the form of heat. As small signal diodes are nonlinear devices the resistance of the PN junction is not constant, it is a dynamic property then we cannot use Ohms Law to define the power in terms of current and resistance or voltage and resistance as we can for resistors. Then to find the power that will be dissipated by the diode we must multiply the voltage drop across it times the current flowing through it: PD = VxI

4. Maximum Operating Temperature

The Maximum Operating Temperature actually relates to the Junction Temperature (TJ) of the diode and is related to maximum power dissipation. It is the maximum temperature allowable before the structure of the diode deteriorates and is expressed in units of degrees centigrade per Watt, (oC/W). This value is linked closely to the maximum forward current of the device so that at this value the temperature of the junction is not exceeded. However, the maximum forward current will also depend upon the ambient temperature in which the device is operating so the maximum forward current is usually quoted for two or more ambient temperature values such as 25oC or 70oC.

1.7 SWITCHING CHARACTERISTICS

Diodes are often used in switching mode. When the applied bias voltage to the PN diode is suddenly reversed in opposite direction and it reaches a steady state at a interval of time that is called the recovery time.

Forward recovery time is defined is the time required the forward voltage or current to reach a specified value after switching diode from its reverse to forward biased state.

When PN diode is forward biased the minority electrons concentration in P region is linear. If the junction is suddenly reversed at t1 then because of stored electronic charge, the reverse current I_R is initially of the same magnitude as forward current I_F.

The diode will continue to conduct until the injected or excess minority carrier density (p-po) or (n-no) has dropped to zero shown in fig. c.

In fig. b the applied voltage Vi = 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 diode. Then the current is I= V_F / R_L = I_F.

At time t=t1 the input voltage is reversed to the value of $-V_R$ current does not become zero and the value is I= V_R / R_L = I_R shown in fig d..

During the time interval from t1 to t2 the injected minority carriers have remained stored and hence this interval is called the storage time (t1).

After the instant t=t2, the diode gradually recovers and ultimately reaches the steady state. The time interval between t2 and instant t3 when the diode has recovered nominally is called the transition time t_t.

The recovery said to have completed (i) when even the minority carriers remote from the junction have difference to the junction and crossed it. (ii) when the junction transition capacitance C across the reverse biased junction has got charged through the external resistor R_L to the voltage $-V_R$.

For commercial switching type diodes the reverse recovery time t_{rr} ranges from less than 1ns up to as high as 1us. In order to minimize the effect of reverse current the time period of the operating frequency should be a minimum of approximately 10 times t_{rr}.

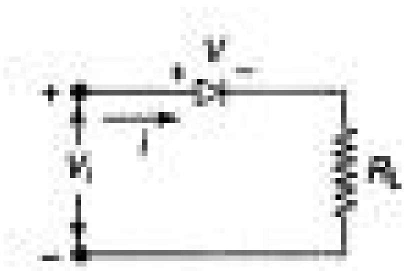


Figure 1.9 a) Switching characteristics of PN diode

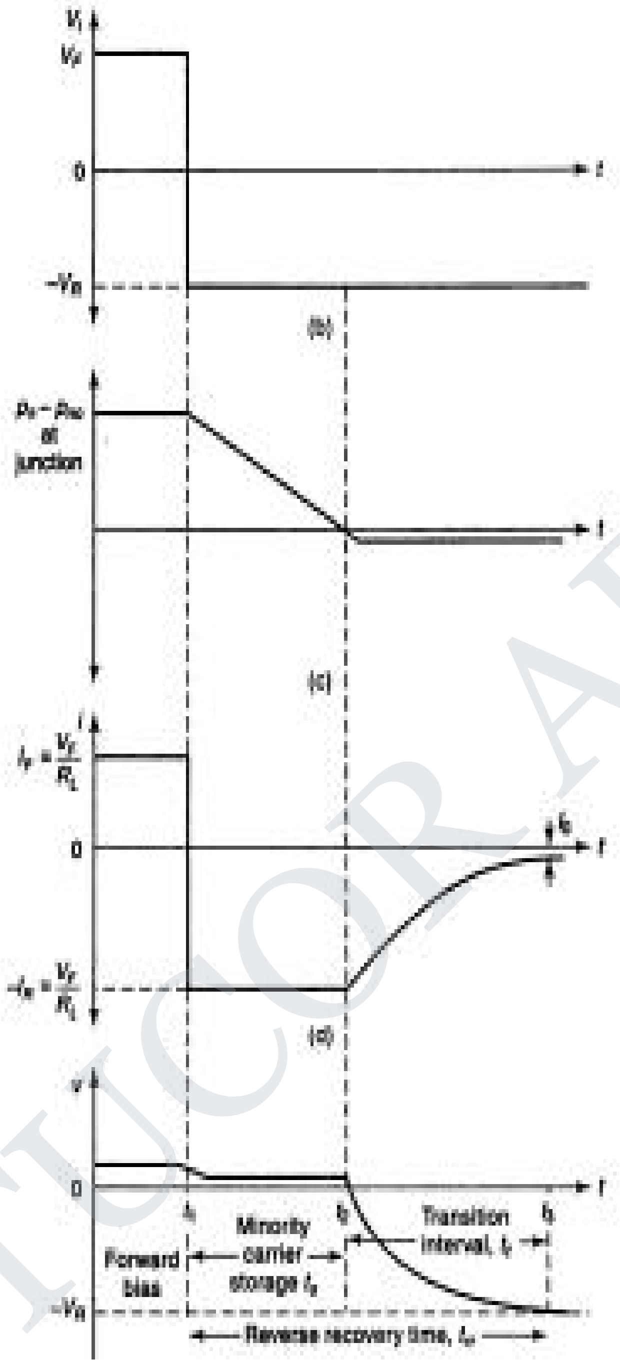


Figure 1.9 b) Switching characteristics of PN diode

For example if diode has t_{rr} of 2ns its 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 reverse recovery time can be reduced b shortening the length of the P region in a PN junction diode.

The stored storage and switching time can be reduced by introduction of gold impurities into junction diode by diffusion. The gold doping also 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.

1.8 APPLICATION OF PN DIODE

- Can be used as rectifier in DC Power Supplies.
- In Demodulation or Detector Circuits.
- In clamping networks used as DC Restorers
- In clipping circuits used for waveform generation.
- As switches in digital logic circuits.
- In demodulation circuits.

UNIT II BIPOLAR JUNCTION

2.1 INTRODUCTION

The transistor is the main building block "element" of electronics. It is a semiconductor device and it comes in two general types: the Bipolar Junction Transistor (BJT) and the Field Effect Transistor (FET).

It is named as transistor which is an acronym of two terms: "transfer-of-resistor." It means that the internal resistance of transistor transfers from one value to another values depending on the biasing voltage applied to the transistor. Thus it is called TRANSfer resISTOR: i.e. TRANSISTOR.

A bipolar transistor (BJT) is a three terminal semiconductor device in which the operation depends on the interaction of both majority and minority carriers and hence the name bipolar.

The voltage between two terminals controls the current through the third terminal. So it is called current controlled device. This is the basic principle of the BJT

It can be used as amplifier and logic switches. BJT consists of three terminals:

- Collector : C
- Base : B
- Emitter : E

2.1.1 TYPES

There are two types of bipolar transistors

- NPN transistor and
- PNP transistor.

2.1.2 TRANSISTOR CONSTRUCTION

PNP Transistor: In PNP transistor a thin layer of N-type silicon is sandwiched between two layers of P-type silicon.

NPN Transistor: In NPN transistor a thin layer of P-type silicon is sandwiched between two layers of N-type silicon. The two types of BJT are represented in figure 2.1

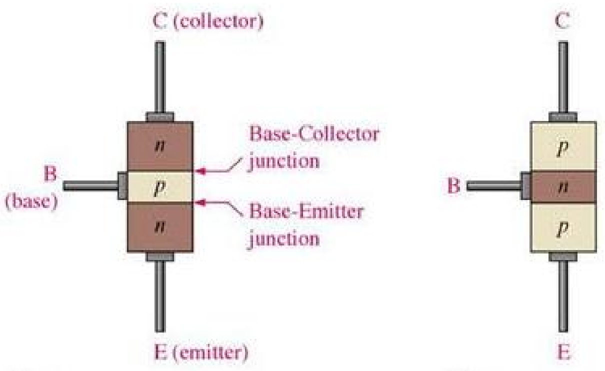


Figure 2.1 Transistors: NPN, PNP

The symbolic representation of the two types of the BJT is shown in figure 2.2

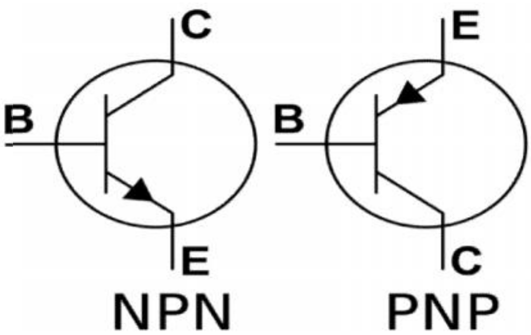


Figure 2.2 circuit symbol: NPN transistor ,PNP transistor

Area:[C>E>B]

- The area of collector layer is largest. So it can dissipate heat quickly.
- Area of base layer is smallest and it is very thin layer.
- Area of emitter layer is medium.

Doping level:[E>C>B]

- Collector layer is moderately doped. So it has medium number of charges.
- Base layer is lightly doped. So it has a very few number of charges.
- Emitter layer is heavily doped. So it has largest number of charges.

Junctions:

- There are two junctions in this transistor – junction J-1 and junction J-2.
- The junction between collector layer and base layer is called as collector-base junction or C-B junction.
- The junction between base layer and emitter layer is called as base-emitter junction or B-E junction. The two junctions have almost same potential barrier voltage of 0.6V to 0.7V, just like in a diode.

Equivalent diode representation:

- The transistor formed by back to back connection of two diodes.

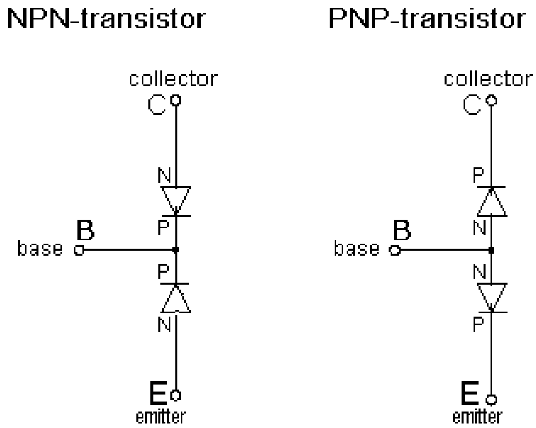


Figure 2.3 The equivalent diode representation for the NPN and PNP transistors

2.1.3 TRANSISTOR BIASING

The states of the two pn junctions can be altered by the external circuitry connected to the transistor. This is called biasing the transistor.

Usually the emitter- base junction is forward biased and collector –base junction is reverse biased. Due to 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.

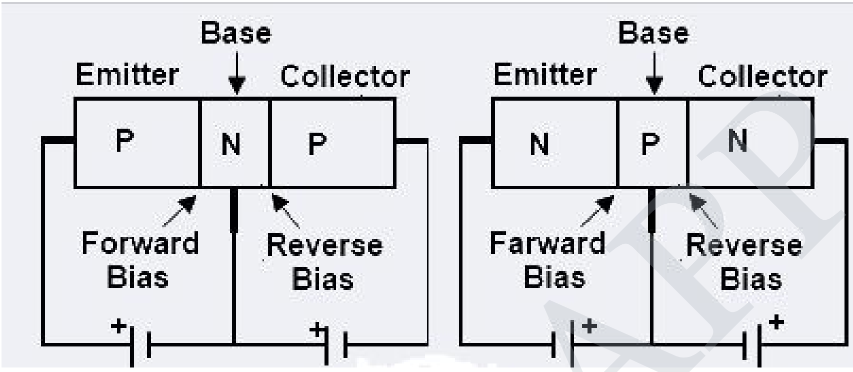


Figure 2.4 Transistor biasing: PNP transistor, NPN transistor

A single pn junction has two different types of bias:

- Forward bias
- Reverse bias

There are two junctions in bipolar junction transistor. Each junction can be forward or reverse biased independently. Thus there are four modes of operations:

Table 2.1 Modes of operation of transistor

Modes	Emitter-Base junction	Collector- Base junction
Cutoff	Reverse	Reverse
Active	Forward	Reverse
Saturation	Forward	Forward
Reverse active	Reverse	Forward

Forward Active

In this mode of operation, emitter-base junction is forward biased and collector base junction is reverse biased. Transistor behaves as a source. With controlled source characteristics the BJT can be used as an amplifier and in analog circuits.

Cut off

When both junctions are reverse biased it is called cut off mode. In this situation there is nearly zero current and transistor behaves as an open switch.

Saturation

In saturation mode both junctions are forward biased large collector current flows with a small voltage across collector base junction. Transistor behaves as an closed switch.

Reverse Active

It is opposite to forward active mode because in this emitter base junction is reverse biased and collector base junction is forward biased. It is called inverted mode. It is no suitable for amplification.However the reverse active mode has application in digital circuits and certain analog switching circuits.

2.1.4 TRANSISTOR CURRENTS

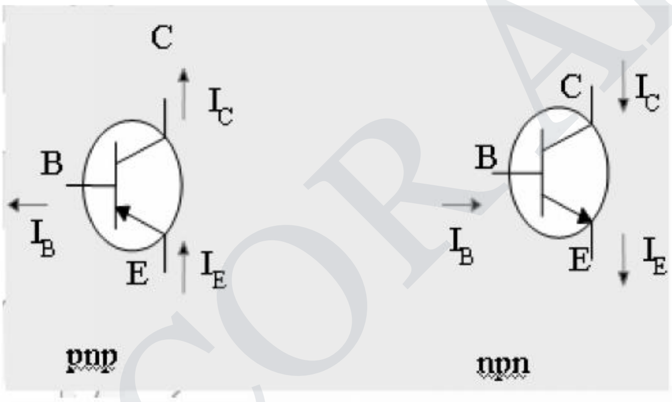


Figure 2.5 Transistor current flow directions

- The arrow is always drawn on the emitter The arrow always point toward the n-type

- The arrow indicates the direction of the emitter current:

pnp:E-> B

npn: B-> E

I_C = the collector current, I_B = the base current, I_E = the emitter current

2.2 OPERATION OF AN NPN TRANSISTOR

Emitter base junction is forward biased and collector base junction is reverse biased. Due to emitter base junction is forward biased lot of electrons from emitter entering the base region.

Base is lightly doped with P-type impurity. So the number of holes in the base region is very small.

Due to this, electron- hole recombination is less (i.e,) few electrons(<5%) combine with holes to constitute base current(I_B)

ELECTRONIC DEVICES The remaining electrons (>95%) crossover into collector region, to constitute collector current(I).

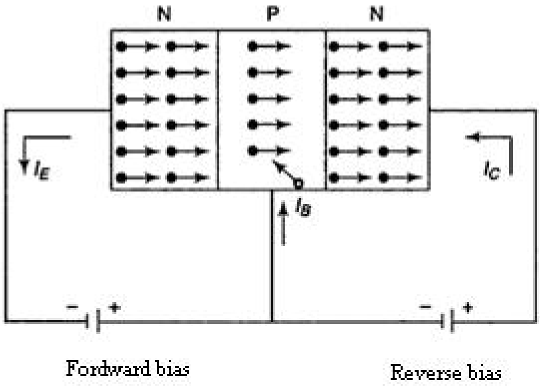


Figure 2.6 Current in NPN transistor

Total current In-terms of magnitude

$$I_E = I_C + I_B$$

2.2.1 OPERATION OF A PNP TRANSISTOR

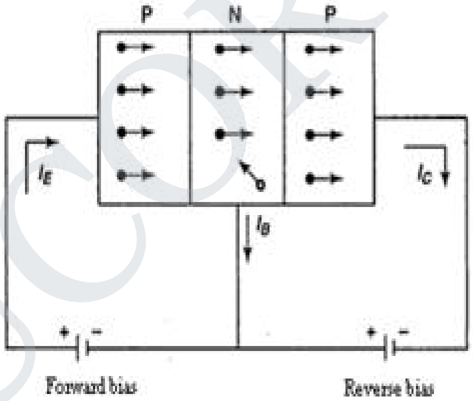


Figure 2.7 Current in PNP transistor

Emitter base junction is forward biased and collector base junction is reverse biased. Due to emitter base junction is forward biased lot of holes from emitter entering the base region and electrons from base to emitter region.

Base is lightly doped with N-type impurity. So the number of electrons in the base region is very small.

Due to this, electron- hole recombination is less (i.e,) few holes (<5%) combine with electrons to constitute base current(I_B)

The remaining holes (>95%) crossover into collector region to constitute collector current(I_C). Applying KCL to the transistor, the total current in terms of magnitude

$$I_E = I_C + I_B$$

2.3 CURRENT EQUATIONS

Let's consider the BJT *npn* structure shown on Figure 2.8

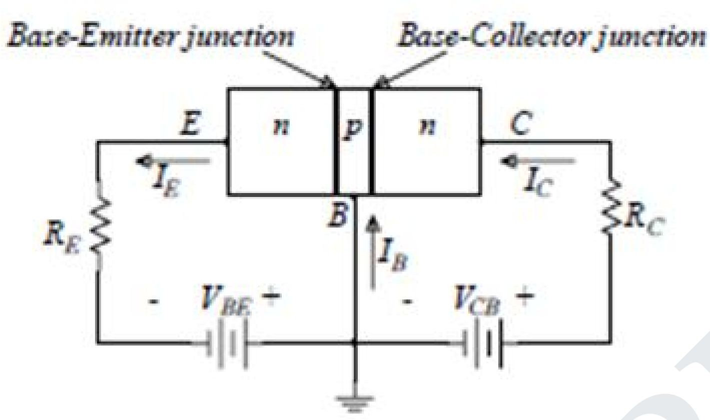


Figure 2.8 NPN transistor biasing

With the voltage VBE and VCB as shown, the Base-Emitter (B-E) junction is forward biased and the Base Collector (B-C) junction is reverse biased.

The current through the B-E junction is related to the B-E voltage as

$$I_E = I_s\left(e^{V_{BE}/V_T} - 1\right)$$

Due to the large differences in the doping concentrations of the emitter and the base regions the electrons injected into the base region (from the emitter region) results in the emitter current .

Furthermore the number of electrons injected into the collector region is directly related to the electrons injected into the base region from the emitter region.

Therefore, the collector current is related to the emitter current which is in turn a function of the B-E voltage.

The collector current and the base current are related by

$$I_C = \beta I_B \dots \dots \dots (1)$$

And by applying KCL we obtain

$$I_E = I_C + I_B \dots \dots \dots (2)$$

And thus from equations (1) & (2) the relationship between the emitter and the base currents is

$$I_E = \beta I_B + I_B =$$

$(1 + \beta)I_B$

$$I_E = (1 + \beta)I_B \dots \dots \dots \dots (3)$$

And equivalently

$$I_C = \left(\frac{\beta}{1+\beta}\right) I_E$$

The fraction $\left(\frac{\beta}{1+\beta}\right)$ is called α.

$$\alpha = \left(\frac{\beta}{1+\beta}\right)\ (or) \beta(1-\alpha)$$

For the transistors of interest β=100 which corresponds to α= 0.99 and Ic = IB

α and β Relationship in a NPN Transistor

$$\text{DC Current gain} = \frac{\text{output current}}{\text{input current}} = \frac{I_C}{I_B}$$

$$I_E = I_C + I_B \text{ (KCL) and } current\ amplification\ factor\ (or)\ current\ gain\ \alpha = \frac{I_C}{I_E}.$$

$$\text{Thus } I_B = I_E - I_C$$

$$I_B = I_E - \alpha I_E$$

$$I_B = I_E(1-\alpha)$$

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

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

2.4 EARLY EFFECT OR BASE WIDTH MODULATION

The early effect is the variation in the width of the base in a bipolar transistor due to a variation in the applied base-to-collector voltage. For example a greater reverse bias across the collector –base junction increases the collector-base depletion width. If V_{CE} increases V_{CB} increases too.

The decrease in the base width by V_{CB} has the following two consequences that affect the current:

- There is a lesser chance for recombination within the "smaller" base region.
- The charge gradient is increased across the base, and consequently, the current of minority carriers injected across the emitter junction increases.
- Punch through (or) Reach through:For extremely large reverse voltage is applied to the C-B junction, the “base width” is reduced to zero, causing voltage breakdown in a transistor. It is known as punch trough or reach through

Both these factors increase the collector or "output" current of the transistor with an increase in the collector voltage. This increased current is shown in Figure 2.9 Tangents to the characteristics at large voltages extrapolate backward to intercept the voltage axis at a voltage called the Early voltage, often denoted by the symbol $V_{A.}$

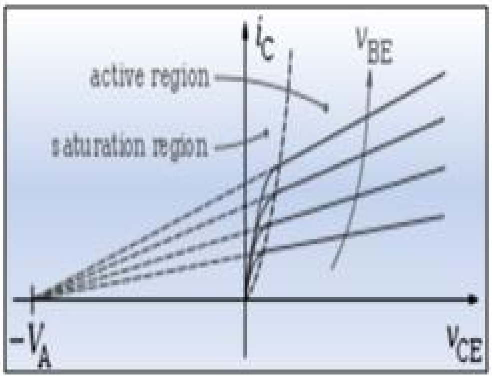


Figure 2.9 Collector current increase with an increase of the collector-emitter voltage due to the Early effect. The Early voltage, V_A, is also indicated on the figure.

2.5 CONFIGURATION OF TRANSISTOR CIRCUIT

A transistor is a three terminal device. But require '4' terminals for connecting it in a circuits.
(i.e.) 2 terminals for input, 2 terminals for output.
Hence one of the terminal is made common to the input and output circuits. Common terminal is grounded.

2.5.1 TYPES OF CONFIGURATIONS

Three types of configuration is available

1) Common base(CB) configuration
2) Common emitter (CE) configuration
3) Common collector (CC) configuration

2.5.2 COMMON BASE(CB) CONFIGURATION

In common base configuration circuit is shown in figure. Here base is grounded and it is used as the common terminal for both input and output.

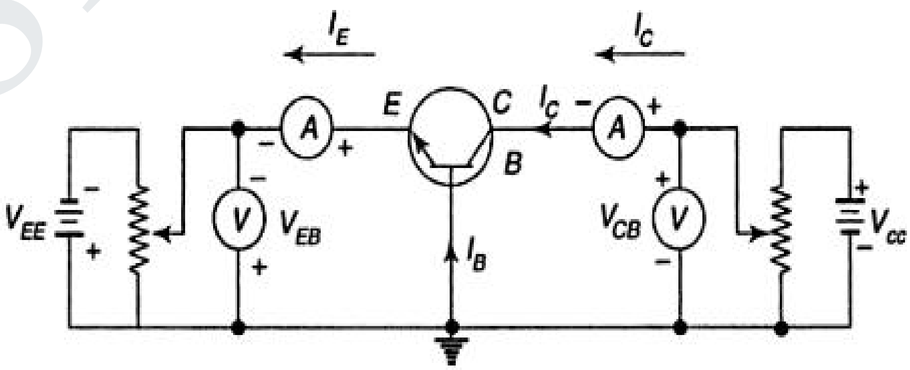


Figure 2.10 Circuit to determine CB static characteristics

It is also called as grounded base configuration. Emitter is used as a input terminal where as collector is the output terminal.

Input characteristics:

It is defined as the characteristic curve drawn between input voltage to input current whereas output voltage is constant.

To determine input characteristics, the collector base voltage V_{CB} is kept constant at zero and emitter current I_E is increased from zero by increasing V_{EB}.This is repeated for higher fixed values of V_{CB}.

A curve is drawn between emitter current and emitter base voltage at constant collector base voltage is shown in figure 2.11.When V_{CB} is zero EB junctions is forward biased. So it behaves as a diode so that emitter current increases rapidly.

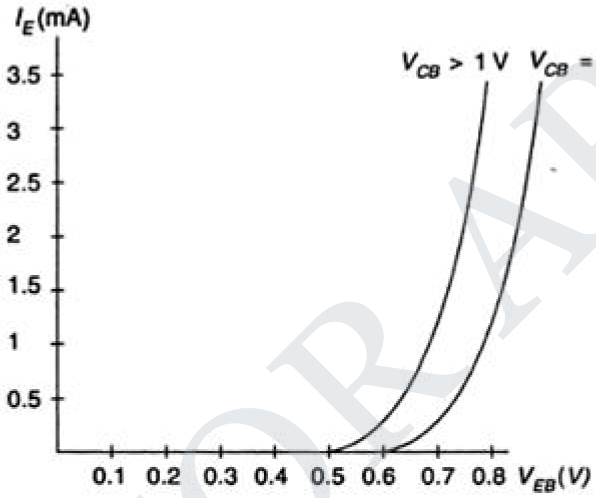


Figure 2.11 CB input characteristics

Output Characteristics

It is defined as the characteristic curve drawn between output voltage to output current whereas input current is constant.To determine output characteristics, the emitter current I_E is kept constant at zero and collector current Ic is increased from zero by increasing V_{CB}.This is repeated for higher fixed values of I_E.

From the characteristic it is seen that for a constant value of I_E, Ic is independent of V_{CB} and the curves are parallel to the axis of V_{CB}.As the emitter base junction is forward biased the majority carriers that is electrons from the emitter region are injected into the base region.

In CB configuration a variation of the base-collector voltage results in a variation of the quasi-neutral width in the base. The gradient of the minority-carrier density in the base therefore changes, yielding an increased collector current as the collector-base current is increased. This effect is referred to as the Early effect.

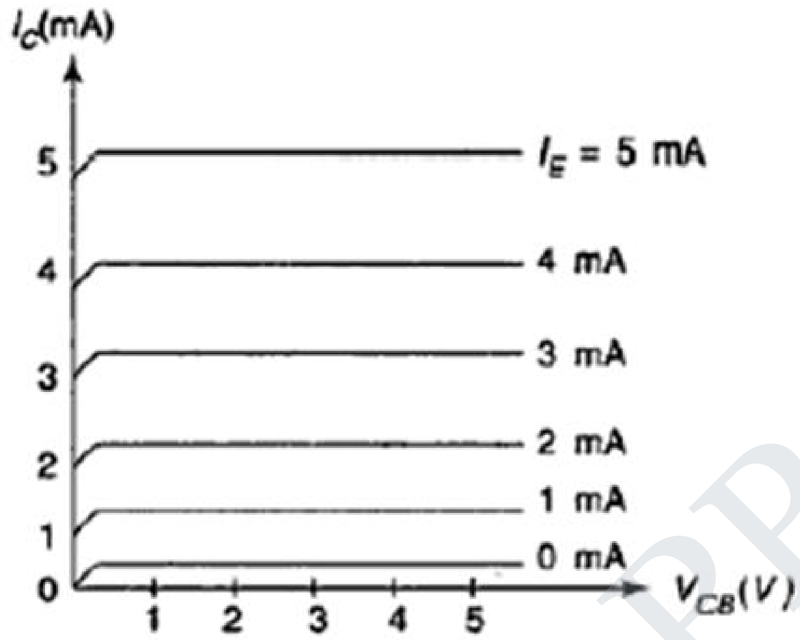


Figure 2.12 CB output characteristics

Transistor parameters in CB configuration

The slope of CB characteristics will give the following four transistor parameters. It is known as base hybrid parameters.

I. Input impedance (h_{ib}): It is defined as the ratio of change in input voltage (emitter voltage) to change in input current (emitter current) with the output voltage (collector voltage) is kept constant.

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

This ranges from 20ohms to 50ohms.

II. Output admittance (h_{ob}): It is defined as the ratio of change in output current (collector current) to change in output voltage (collector voltage) with the input current (emitter current) is kept constant.

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

This ranges from 0.1 to 10μ mhos.

III. Forward current gain (h_{fb}): It is defined as the ratio of change in output current (collector current) to change in input current (emitter current) with the output voltage (collector voltage) is kept constant.

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

This ranges from 0.9 to 1.0.

IV. Reverse voltage gain (h_{rb}): It is defined as the ratio of change in input voltage (emitter voltage) to change in output voltage (collector voltage) with the input current (emitter current) is kept constant.

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

This ranges from 10^{-5} to 10^{-4}.

2.5.3 CE CONFIGURATION

In common emitter configuration circuit is shown in figure. Here emitter is grounded and it is used as the common terminal for both input and output. It is also called as grounded emitter configuration. Base is used as a input terminal whereas collector is the output terminal.

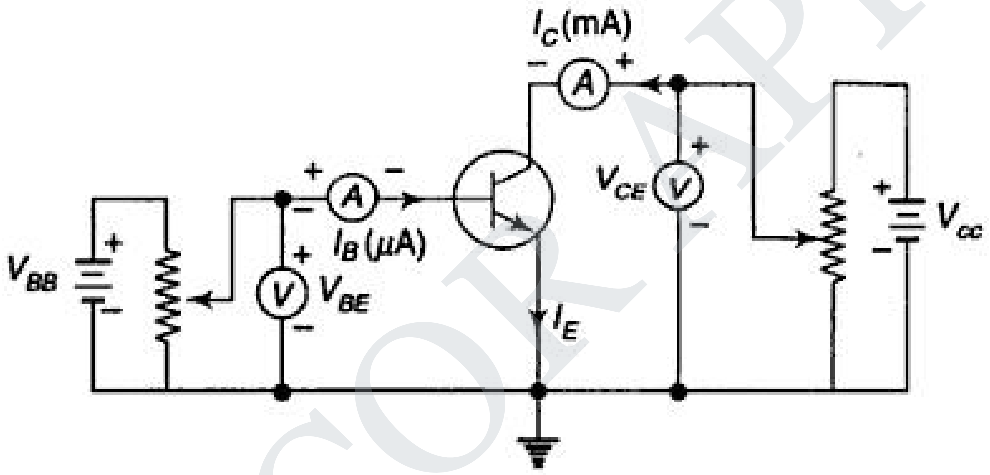


Figure 2.13 Circuit to determine CE static characteristics

Input Characteristics

It is defined as the characteristic curve drawn between input voltages to input current whereas output voltage is constant.

To determine input characteristics, the collector base voltage V_{CB} is kept constant at zero and base current I_B is increased from zero by increasing V_{BE}.This is repeated for higher fixed values of V_{CE}.

A curve is drawn between base current and base emitter voltage at constant collector base voltage is shown in figure2.14. Here the base width decreases. So curve moves right as V_{CE} increases.

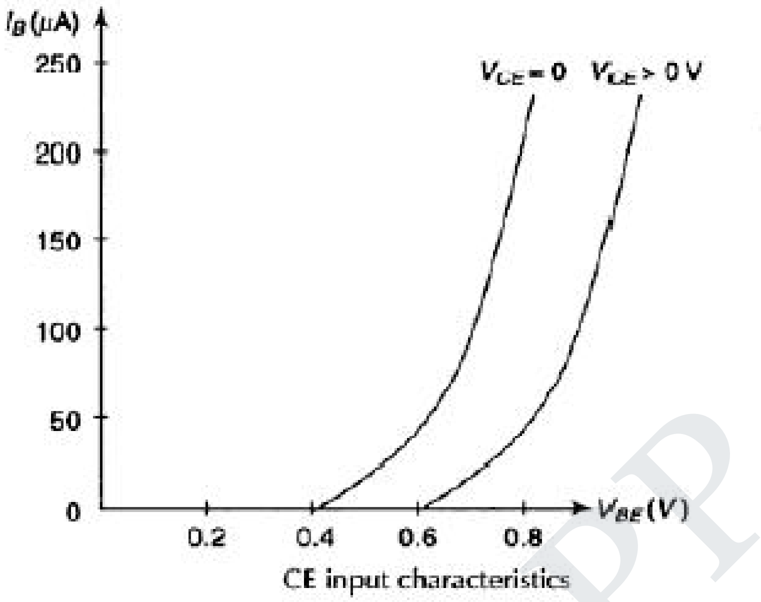


Figure 2.14 CE input characteristics

Output Characteristics

It is defined as the characteristic curve drawn between output voltage to output current whereas input current is constant.

To determine output characteristics, the base current I_B is kept constant at zero and collector current Ic is increased from zero by increasing V_{CE}.This is repeated for higher fixed values of I_B.

From the characteristic it is seen that for a constant value of I_B, Ic is independent of V_{CB} and the curves are parallel to the axis of V_{CE}.

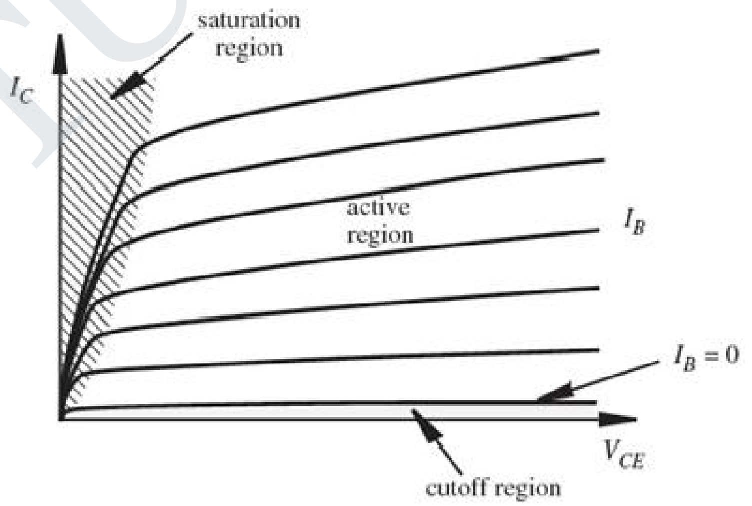


Figure 2.15 CE output Characteristics

The output characteristic has 3 basic regions:

- Active region –defined by the biasing arrangements.

- Cutoff region – region where the collector current is 0A

- Saturation region- region of the characteristics to the left of VCB = 0V.

Active region	**Saturation region**	**Cut-off region**
• I_E increased, I_C increased. • BE junction forward bias and CB junction reverse bias. • Refer to the graph, $I_C \approx I_E$ • I_C not depends on V_{CB} • Suitable region for the transistor working as amplifier.	• BE and CB junction is forward bias • Small changes in V_{CB} will cause big different to I_C • The allocation for this region is to the left of V_{CB}=0V.	• Region below the line of I_E=0 A • BE and CB is reverse biase • No current flow at collector, only leakage current.

Transistor parameters in CE configuration

The slope of CE characteristics will give the following four transistor parameters. It is known as emitter hybrid parameters.

I. Input impedance (h_{ie}): It is defined as the ratio of change in input voltage (base voltage) to change in input current (base current) with the output voltage (collector voltage) is kept constant.

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

This ranges from 500ohms to 2000ohms.

II. Output admittance (h_{oe}): It is defined as the ratio of change in output current (collector current) to change in output voltage (collector voltage) with the input current (base current) is kept constant.

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

This ranges from 0.1 to 10µ mhos.

III. Forward current gain (h_{fe}): It is defined as the ratio of change in output current (collector current) to change in input current (base current) with the output voltage (collector voltage) is kept constant.

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

This ranges from 20 to 200.

IV. Reverse voltage gain (h_{re}): It is defined as the ratio of change in input voltage (base voltage) to change in output voltage (collector voltage) with the input current (base current) is kept constant.

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

This ranges from 10^{-5} to 10^{-4}.

2.5.4 CC CONFIGURATION

In common collector configuration circuit is shown in figure. Here collector is grounded and it is used as the common terminal for both input and output. It is also called as grounded collector configuration. Base is used as a input terminal whereas emitter is the output terminal.

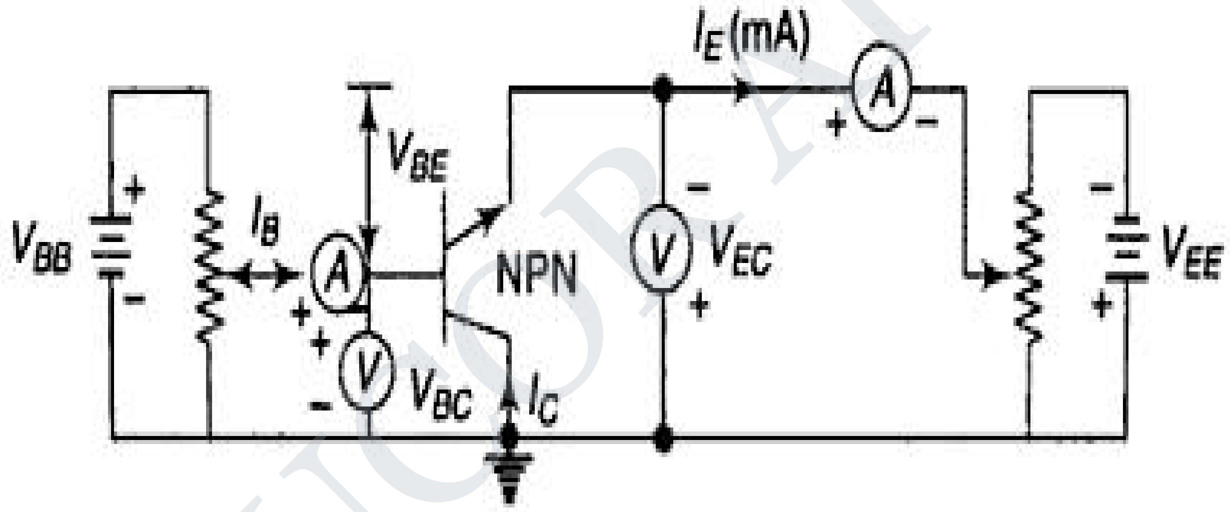


Figure 2.16 Circuits to determine CC static characteristics

Input Characteristics

It is defined as the characteristic curve drawn between input voltage to input current whereas output voltage is constant.

To determine input characteristics, the emitter base voltage V_{EB} is kept constant at zero and base current I_B is increased from zero by increasing V_{BC}.This is repeated for higher fixed values of V_{CE}.A curve is drawn between base current and base emitter voltage at constant collector base voltage is shown in figure2.17.

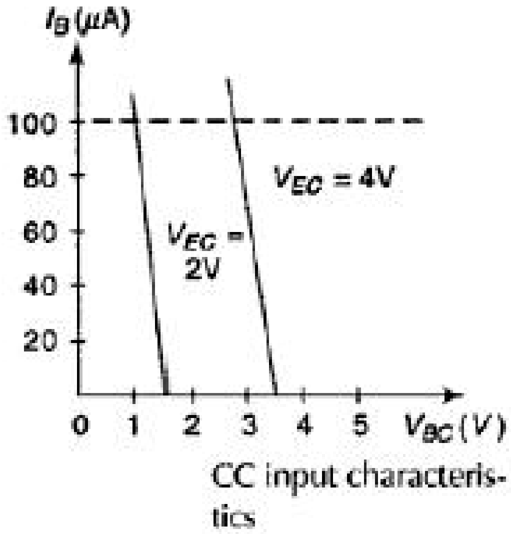


Figure 2.17 CC input characteristics

Output Characteristics

It is defined as the characteristic curve drawn between output voltage to output current whereas input current is constant.

To determine output characteristics, the base current I_B is kept constant at zero and emitter current I_E is increased from zero by increasing V_{EC}. This is repeated for higher fixed values of I_B.

From the characteristic it is seen that for a constant value of I_B, I_E is independent of V_{EB} and the curves are parallel to the axis of V_{EC}.

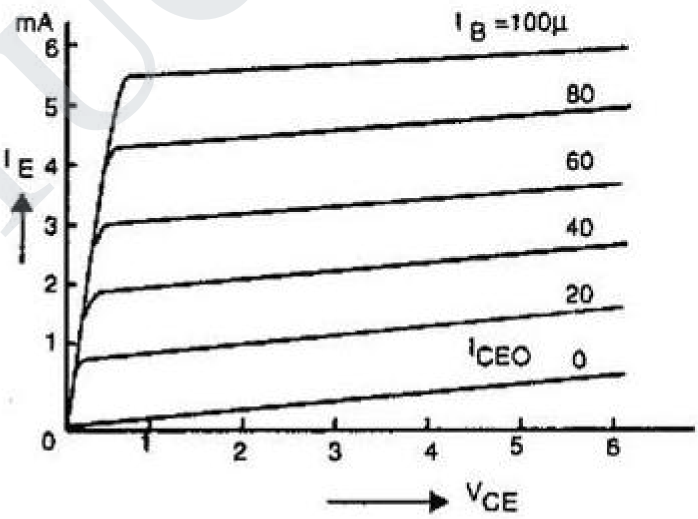


Figure 2.18 CC output characteristics

Transistor parameters in CC configuration

The slope of CC characteristics will give the following four transistor parameters. It is known as base hybrid parameters.

I. Input impedance (h_{ic}): It is defined as the ratio of change in input voltage (base voltage) to change in input current (base current) with the output voltage (emitter voltage) is kept constant.

$$h_{ic} = \frac{\Delta V_{BC}}{\Delta I_B}, \; V_{EC} \text{ constant}$$

II. Output admittance (h_{oc}): It is defined as the ratio of change in output current (emitter current) to change in output voltage (emitter voltage) with the input current (base current) is kept constant.

$$h_{oc} = \frac{\Delta I_E}{\Delta V_{EC}}, \; I_B \text{ constant}$$

III. Forward current gain (h_{fc}): It is defined as the ratio of change in output current (emitter current) to change in input current (base current) with the output voltage (emitter voltage) is kept constant.

$$h_{fc} = \frac{\Delta I_E}{\Delta I_B}, \; V_{EC} \text{ constant}$$

IV. Reverse voltage gain (h_{rc}): It is defined as the ratio of change in input voltage (base voltage) to change in output voltage (emitter voltage) with the input current (base current) is kept constant.

$$h_{rc} = \frac{\Delta V_{BC}}{\Delta V_{EC}}, \; I_B \text{ constant}$$

A comparison of CB, CE and CC Configurations

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°	180°	0 or 360°
Applications	for high frequency circuits	for audio frequency circuits	for impedance matching

2.6 Hybrid-Pi Model

The hybrid-pi model is a popular circuit model used for analyzing the small signal behavior of bipolar junction and field effect transistors. Sometimes it is also called *Giacoletto model*. The model can be quite accurate for low-frequency circuits and can easily be adapted for higher frequency circuits with the addition of appropriate inter-electrode capacitances and other parasitic elements.

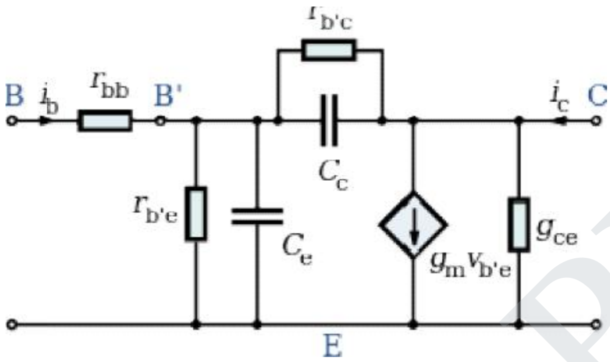


Figure 2.19 Hybrid π model for a transistor in the CE configuration

Where,

r_{bb}- base spreading resistance between the actual base B and virtual base B'. It represents the bulk resistance of the base. Its typical value is 100Ω.

- resistance between the virtual base B' and the emitter terminal E whose typical value is 1kΩ.

- Resistance between the virtual base B'and the collector terminal C whose typical value is 4MΩ.

- Diffusion capacitance of the normally forward biased base- emitter junction. It has a typical value of 100pF.

- Transistor capacitance of the normally reverse biased collector- base junction. It has a typical value of 3pF.

- output resistance with typical value of 80kΩ

- output current generator value where g_m is the transconductance of the transistor.

2.6.1 Hybrid-π conductance's

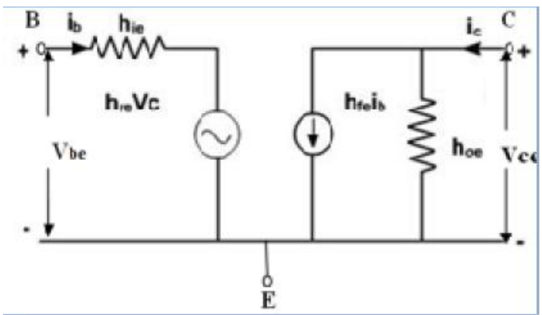


Figure 2.20 h-parameter model for a common-emitter transistor at low frequency

2.7 h-PARAMETER BJT MODEL

A transistor can be treated as a two port network. The terminal behavior of any two port network can be specified by the terminal voltage V_i and V_o at port 1 and port 2 respectively and currents I_i and I_o, entering ports 1 and 2 respectively. As shown in figure 2.20

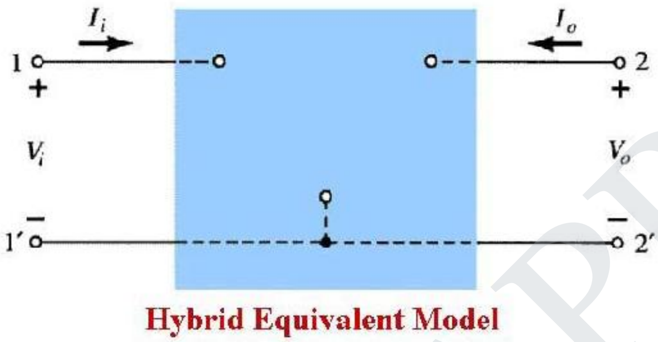


Figure 2.21 two port network

Of these four variables, V_i , V_o ,I_i and I_o two can be selected as independent variables and the remaining two can be expressed in terms of these independent variables. This leads to various two port parameters out of which the following are very important.

i. h-parameters or hybrid parameters
ii. Z-parameters or impedance parameters
iii. Y-parameters or admittance parameters

The h-parameter model is typically suited to transistor circuit modeling. Hence, both short-circuit and open-circuit terminal conditions are used. It is important because:

1. Its values are used on specification sheets
2. It is one model that may be used to analyze circuit behavior
3. It may be used to form the basis of a more accurate transistor model

The h parameter model has values that are complex numbers that vary as a function of:

1. Frequency
2. Ambient temperature
3. Q-Point

At low and mid- band frequencies, the h parameter values are real values. Other models exist because this model is not suited for circuit analysis at high frequencies.

If the input current and the output voltage are taken as independent variables, the input voltage and output current can be written as

$$\begin{bmatrix} V_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ V_2 \end{bmatrix}$$

$$V_1 = h_{11}I_1 + h_{12}V_2$$

$$I_2 = h_{21}I_1 + h_{22}V_2$$

The four hybrid parameters $h_{11}, h_{12}, h_{21}, and\ h_{22}$ are defined as follows:

When $V_1 = 0$ i.e., with output port short circuited,

$$h_{11} = \left[\frac{V_1}{I_1}\right] with\ V_2 = 0$$

= input impedance

$$h_{21} = \left[\frac{I_2}{I_1}\right] with\ V_2 = 0$$

= forward current gain or forward transfer ratio

When $I_1 = 0$ i.e., with input port open circuited.

$$h_{21} = \left[\frac{I_2}{V_2}\right] with\ I_1 = 0$$

= output admittance

$$h_{11} = \left[\frac{V_1}{V_2}\right] with\ I_1 = 0$$

= reverse voltage gain or reverse transfer ratio

The equivalent circuit of the h-parameter representation is shown in figure 2.. Here $h_{12}V_2$ is the controlled voltage source and $h_{21}I_2$ is the controlled current source.

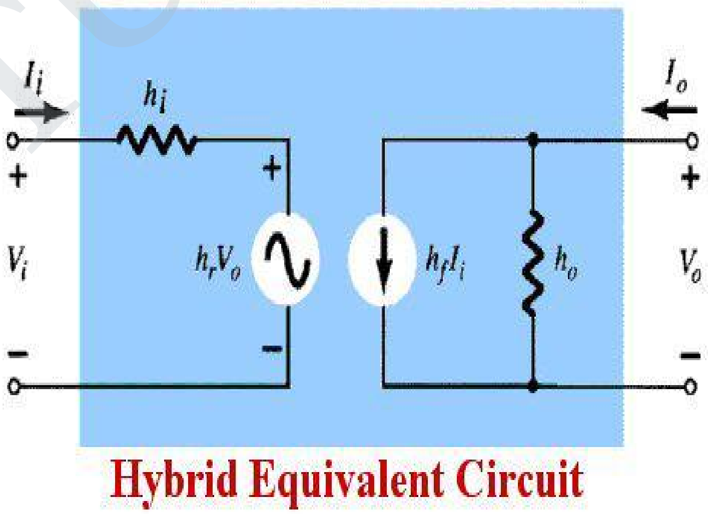


Figure 2.22 Equivalent circuit of h-parameter model

The dimensions of h-parameters are as follows:

$$h_{11} \rightarrow \Omega$$

$$h_{11} \rightarrow \mho$$

$$h_{12}, h_{21} \rightarrow dimensionless$$

The alternative subscript notations recommended by IEEE commonly used are

i=11=input, o=22=output

f=21=forward transfer, r=12=reverse transfer

When h-parameters are applied to transistors, it is a common practice to add a second subscript to designate the type of configuration. Considered –e for common emitter, b for common base and c for common collector. Thus, for a common emitter (CE) configuration,

$$h_{ie} = h_{11e} = short\ circuit\ input\ impedance$$

$$h_{oe} = h_{22e} = open\ \ circuit\ output\ admittance$$

$$h_{re} = h_{12e} = open\ \ circuit\ reverse\ voltage\ transfer\ ratio$$

$$h_{fe} = h_{21e} = short\ circuit\ forward - current\ gain$$

Conversion formulae for h-parameters

CC	CB
$h_{ic} = h_{ie}$	$h_{ib} = \frac{h_{ie}}{1 + h_{fe}}$
$h_{rc} = 1$	$h_{ib} = \frac{h_{ie} h_{oe}}{1 + h_{fe}} - h_{re}$
$h_{fc} = -(1 + h_{fe})$	$h_{fb} = \frac{-h_{fe}}{1 + h_{fe}}$
$h_{oc} = h_{oe}$	$h_{ob} = \frac{h_{oe}}{1 + h_{fe}}$

2.8 Ebers-Moll Model

The Ebers-Moll model, or equivalent circuit, is one of the classic models of the bipolar transistor. This particular model is based on the interacting diode junctions and applicable in any of the transistor operating modes.

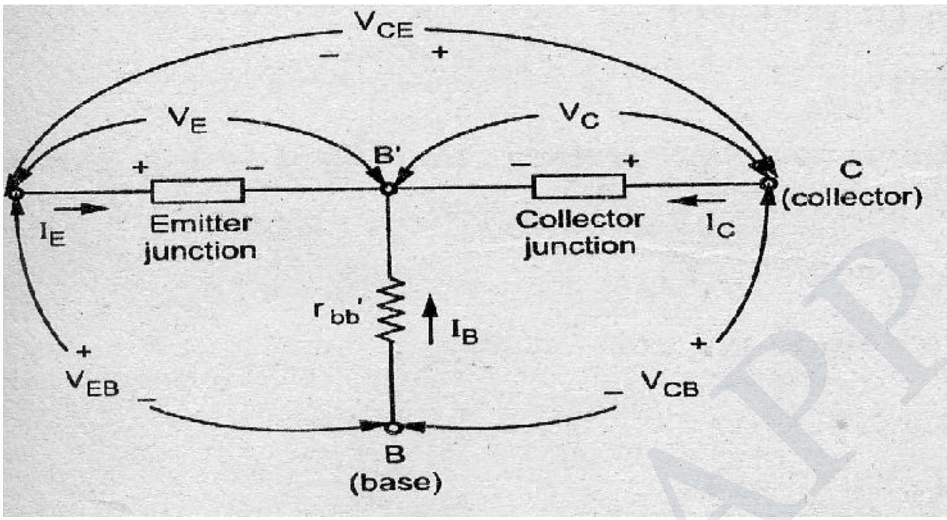


Figure2.23 Transistor currents and Voltages direction

The general expression for collector current I_C of a transistor for any voltage across collector junction V_C and emitter current I_E is

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

Where α_N is the current gain in normal operation and I_{CO} is the collector junction reverse saturation current.

In the inverted mode of operation, the above equation can be written as

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

Where α_I is the inverted common-base current gain and I_{EO} is the emitter junction reverse saturation current.

The above four parameters are related by the condition

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

For many transistors I_{EO} lies in the range 0.5 I_{CO} to I_{CO}

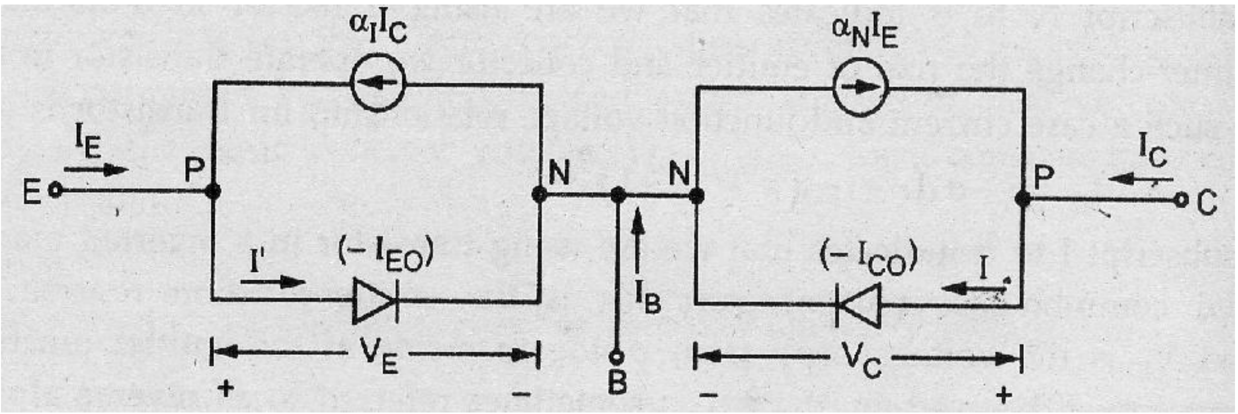


Figure 2.24 Ebers-moll models for a PNP transistor

In above figure, two separate ideal diodes are connected back to back with saturation currents- I_{EO} and -I_{CO} and there are two dependent current-controlled sources shunting the ideal diodes. The current sources account for the minority carrier transport across the base. An application of kirchhoff's current law to the collector node of the above figure gives

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

Where, I is the diode current. As I_O is the magnitude of reverse saturation current, then $I_O = -I_{CO}$. Substituting this value of I_O in above equation, we get

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

Which is nothing but the general expression for collector current of a transistor. Hence this model is valid for both forward and reverse static voltages applied across the transistor junctions.

2.9 Gummel-Poon Model

The DC and dynamic currents of the transistor in response to V_{BE} and V_{CE} can be represented accurately by BJT model used in circuit simulators such as Spice. The Gummel-Poon model of the BJT considers more physics of the transistor that the Ebers-Moll model. This model can be used if, for example, there is a non-uniform doping concentration in the base.

The Gummel–Poon model is a detailed charge-controlled model of BJT dynamics, which has been adopted and elaborated by others to explain transistor dynamics in greater detail than the terminal-based models typically do.This model also includes the dependence of transistor β-values upon the dc current levels in the transistor, which are assumed current-independent in the Ebers–Moll model.

A significant effect included in the Gummel–Poon model is the DC current variation of the transistor β_F and β_R.

– When certain parameters are omitted, the Gummel–Poon model reverts to the simpler Ebers–Moll model.

The Gummel–Poon model and modern variants of it are widely used via incorporation in the SPICE.The Gummel-Poon model is valid for both positive and negative values of V_{BE} and V_{CE} where as the ebers-moll model is limited to positive values of V_{BE} and $V_{CE.}$ Gummel –poon was an improvement over the ebers-moll model by taking into account the early effect and high level injection effects.

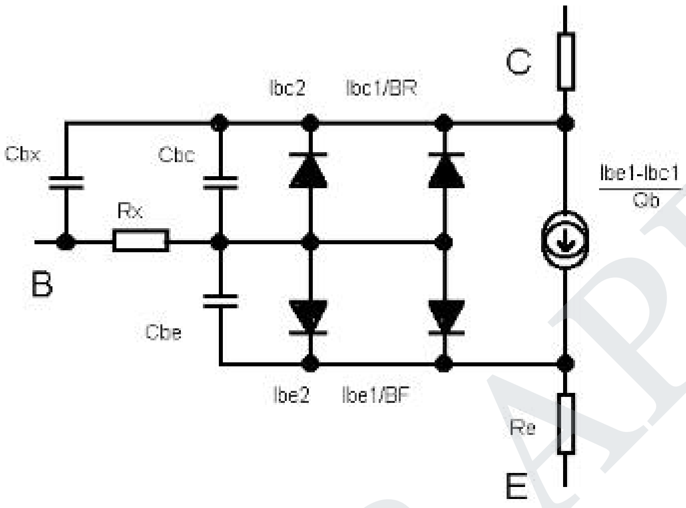
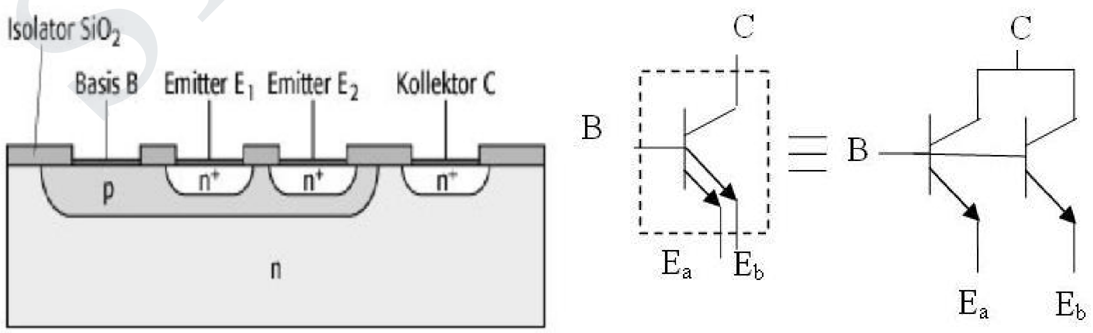


Figure 2.25 Gummel-Poon model with high-level injection effect and early effect

2.10Multi Emitter Transistors (Transistor Transistor Logic)

A Multiple-emitter transistor is a specialized bipolar transistor mostly used at the inputs of TTL NAND logic gates. Input signals are applied to the emitters. Collector current stops flowing only if all emitters are driven by the logical high voltage, thus performing an AND logical operation using a single transistor. Multiple-emitter transistors replace diodes of DTL and allow reduction of switching time and power dissipation.

TTL inputs are the emitters of a multiple-emitter transistor. This IC structure is functionally equivalent to multiple transistors where the bases and collectors are tied together. The output is buffered by a common emitter amplifier.



(a) (b)

Figure 2.26 Multi-emitter transistor (a) cross-sectional view, (b) symbol

Inputs both logical ones. When all the inputs are held at high voltage, the base–emitter junctions of the multiple-emitter transistor are reverse-biased. Unlike DTL, a small –collector‖ current (approximately 10µA) is drawn by each of the inputs. This is because the transistor is in reverse-active mode. An approximately constant current flows from the positive rail, through the resistor and into the base of the multiple emitter transistor. This current passes through the base- emitter junction of the output transistor, allowing it to conduct and pulling the output voltage low (logical zero).

An input logical zero. Note that the base-collector junction of the multiple-emitter transistor and the base-emitter junction of the output transistor are in series between the bottom of the resistor and ground. If one input voltage becomes zero, the corresponding base-emitter junction of the multiple-emitter transistor is in parallel with these two junctions.

A phenomenon called current steering means that when two voltage-stable elements with different threshold voltages are connected in parallel, the current flows through the path with the smaller threshold voltage. As a result, no current flows through the base of the output transistor, causing it to stop conducting and the output voltage becomes high (logical one). During the transition the input transistor is briefly in its active region; so it draws a large current away from the base of the output transistor and thus quickly discharges its base. This is a critical advantage of TTL over DTL that speeds up the transition over a diode input structure.

The main disadvantage of TTL with a simple output stage is the relatively high output resistance at output logical "1" that is completely determined by the output collector resistor. It limits the number of inputs that can be connected (the fanout). Some advantage of the simple output stage is the high voltage level (up to V_{CC}) of the output logical "1" when the output is not loaded.

2.14.1 Features of Multi-Emitter Structure

- Each emitter strip can be considered as the emitter of a separate transistor and each of these devices share a common base and collector.
- The lateral and vertical dimensions of the emitter can be scaled more easily.
- Aluminium contact spiking in the emitter base junction is minimized.
- The current gain is 3 to 7 times that of a conventional transistor.
- Higher cut off frequency - 17 to 30 Ghz
- Less delay - 50psec gate delay
- Component density of IC is enhanced by the efficient utilization of the chip area.
- It is used particularly in the first stages of the TTL family gates.
- Multi emitter transistor have been fabricated with more than 60 emitter strips.
- Multiple-emitter transistors allows reduction of switching time and power dissipation.

UNIT III FIELD EFFECT TRANSISTORS

3.1 INTRODUCTION

Flow of current through the conducting region controlled by an electric field. Hence the name field effect transistor (FET).

FET is said to be a uni-polar device because current conduction is only by majority carriers.

FET is Voltage controlled device because its output characteristics are determined by field which depends on the voltage applied.

It has three terminals named as

- Source (S)
- Drain(D)
- Gate(G)

3.1.1 CLASSIFICATION OF FET

FET is classified into two types as follows

- JFET (Junction Field Effect Transistor)
    - n-channel
    - p-channel
- MOSFET(Metal Oxide Semiconductor (or) Insulated Gate FET
    - Depletion type
        - ✓ n-channel
        - ✓ p-channel
    - Enhancement type
        - ✓ n-channel
        - ✓ p-channel

3.1.2 Advantages of JFET over BJT

1. Operation depends upon the flow of majority carriers only
2. It exhibits a high input resistance (mega ohm) because gate constitute no current but in BJT, base constitute a current.
3. Less noisy.
4. It has thermal stability

3.1.3 Disadvantages in JFET

1. Small gain bandwidth product.

3.2 JFET [Junction Field Effect Transistor]

- JFET can be used as a linear Resistor
- The drain current is controlled by gate voltage applied at the gate V_{GS} and $I_G \approx 0$. Therefore it is termed as " voltage controlled device".

3.2.1Types

1) N-channel JFET
2) P-channel JFET

3.2.2 Symbol

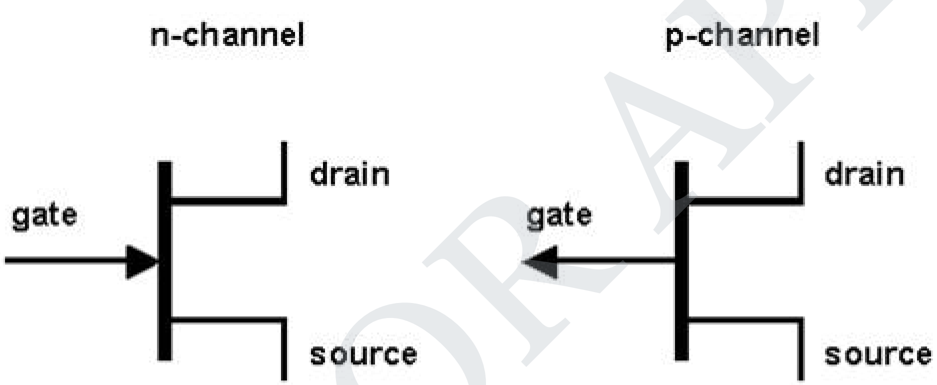
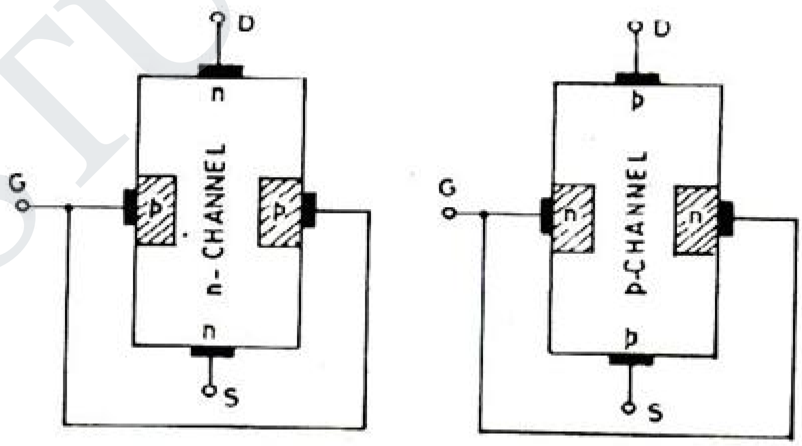


Figure 3.1 JFET symbol for n-channel and p-channel

3.2.3Construction



N-Channel JFET P-Channel JFET

Figure 3.2 JFET construction for n-channel and p-channel

- It consists of N-type or P-type base which is made of silicon.
- Ohmic contacts made at the two ends of base called source and drain.

Source(S):-

- Connected to negative pole of battery.
- Electrons enter the base through this terminal for N-channel JFET.

Drain(D):-

- Connected to postive pole of battery.
- Electrons leave the base through this terminal for N-channel JFET.

Gate(G):-

- Heavily doped P-type silicon is diffused on both sides of the N-channel base by which PN junction are formed.
- These layers are joined together and called gate.

Channel:-

- It is the space between the gate through which majority carriers pass.

3.3 Operation of N-channel JFET

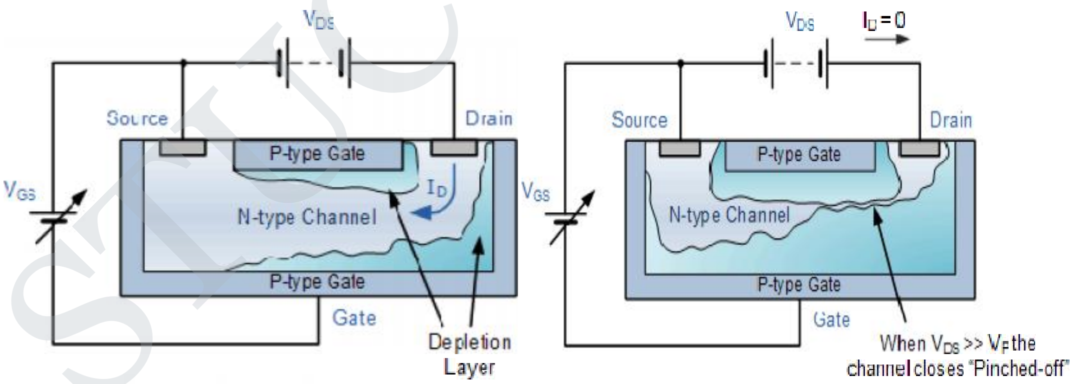


Figure 3.3 JFET under applied bias

Case (i) "when $V_{GS} = 0$ and V_{DS} is increased from zero"

- Here N-base (Drain) is connected to positive supply. It act as a reverse bias. Due to this, depletion region gets increases.
- At one point ,$(i.e.,V_{DS} = V_P)$ widths of the channel becomes zero and carriers doesnot flow from drain to source and current I reaches constant positions.
- When V_{DS} is increased, the current(I_D) gets linearly increased.

Pinch of voltage (V_P)

The pinch off voltage is the voltage at which the junction is depleted of charge carriers.

Case (ii) "when $V_{GS} = negative$ and V_{DS} is increased from zero"

- When JFET is operated under negative gate voltage is termed as "depletion mode of operation"
- When negative voltage of V_{GS} is incresed the pinch of voltage V_P decreased.
- When V_{GS} is further increased the channel is fully depleted and no current flows through it.

Case (iii) "when $V_{GS} = positive$ and V_{DS} is increased from zero"

- When V_{GS} is positive, it act like a forward biased PN diode.
- This mode of operation is called as a enhancement mode and this mode of operation is allowed to operate in this mode upto 0.7V.

Transfer and Drain Characteristics:-

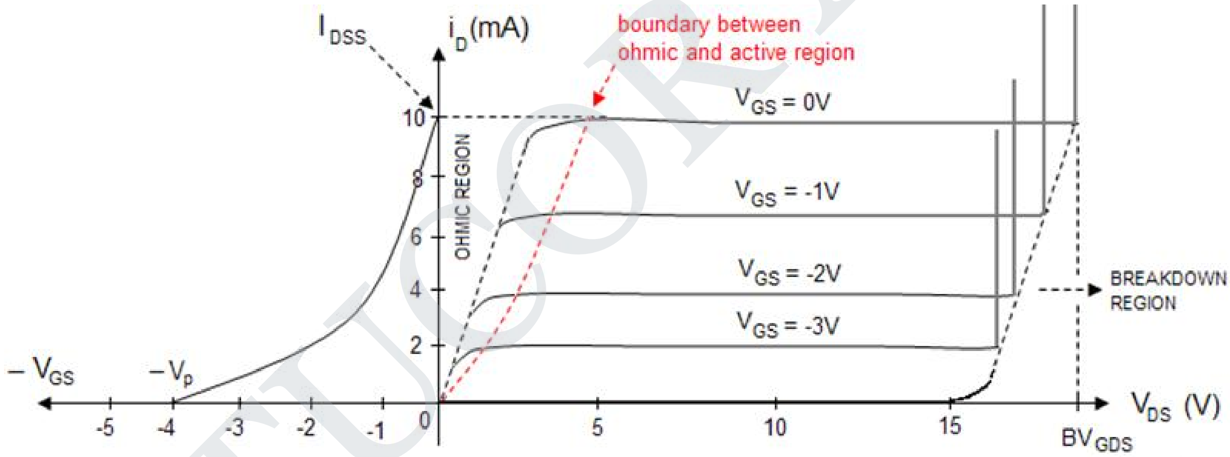


Figure 3.4 Transfer and Drain characteristics of N-channel JFET

Drain characteristics of N-channel JFET is the curve drawn between drain current $I_D\,(mA)$ and drain –source voltageV_{DS}.

A transfer characteristic of N-channel JFET is drawn between drain current $I_D\,(mA)$ and negative of gate source voltageV_{GS}.

3.4 Current Equations

The relation between I_D and V_{GS} is expressed by Shockley's equation

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

Where

V_{GS}- Gate to source voltage

V_P - Pinch off voltage

I_D- Drain current

I_{DSS}- I_D where $V_{GS} = 0$

From equation (1)

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

Differentiate equation (1) with respect to V_{GS}, we get

$$G_m = \frac{\Delta I_D}{\Delta V_{GS}} = I_{DSS} \times 2\left(1 - \frac{V_{GS}}{V_P}\right)\left(\frac{-1}{V_P}\right) \ldots\ldots\ldots\ldots(3)$$

Where

$$g_m = \frac{\Delta I_D}{\Delta V_{GS}} \rightarrow transconductance$$

From equation (2)

$$g_m = \frac{-2I_{DSS}}{V_P}\sqrt{\frac{I_D}{I_{DSS}}}$$

$$g_m = -2\frac{\sqrt{I_D I_{DSS}}}{V_P}$$

$$g_m = \frac{I_{DSS}}{-V_P/2}$$

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

Where $V_P = V_{GS(off)}$

3.4.1 Applications

1) Used as an amplifier
2) Used as voltage variable resistor in operational amplifiers
3) Used in mixer circuits in FM and TV receivers

 3.5 MOSFET (Metal Oxide Semiconductor Field Effect Transistor)

- Like JFET, it has a source, Drain and Gate.
- It is also called IGFET (Insulated Gate FET) because gate terminal is insulated from channel. Therefore it has extremely high input resistance.

3.5.1 Types of MOSFET

It has two types

- Depletion mode MOSFET
  - ✓ N-channel
  - ✓ P-channel
- Enhancement mode MOSFET
  - ✓ N-channel
  - ✓ P-channel

The enhancement-type MOSFET is usually referred to as an E-MOSFET, and the depletion type, a D-MOSFET. The drain current in a MOSFET is controlled by the gate-source voltage VGS.

3.5.2 Depletion mode-MOSFET [D-MOSFET]

In depletion mode of operation the bias voltage on the gate reduce the number of charge carriers in the channel and therefore reduce the drain current I_D. It operates in both depletion mode and enhancement mode.

3.5.2.1 Symbol

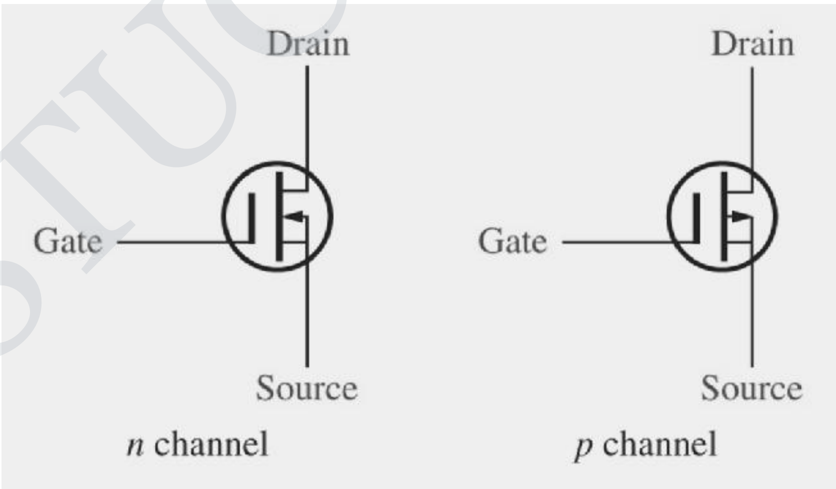


Figure 3.5 D-MOSFET symbol for n-channel and p-channel

3.5.2.2 Construction

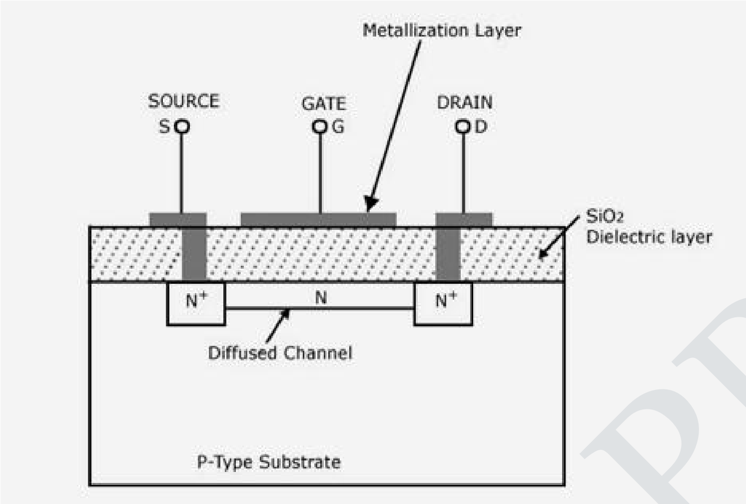


Figure 3.6 structure of n-channel D-MOSFET

- It consists of lightly doped p-type substrate in which two highly doped n-regions are diffused.
- The source and drain terminals are connected through metallic contacts to n-doped regions linked by an n-channel. The gate is also connected to a metal contact surface but remains insulated from the n-channel by a very thin silicon dioxide (SiO_2) layer. SiO_2 is a particular type of insulator referred to as a dielectric that sets up opposing (as revealed by the prefix di-) electric fields within the dielectric when exposed to an externally applied field.
- Then the thin layer of metal aluminium is formed over the Sio_2 layer. This metal overs the entire channel region and it forms the gate(G).

3.5.2.3 Operation of N-channel D-MOSFET

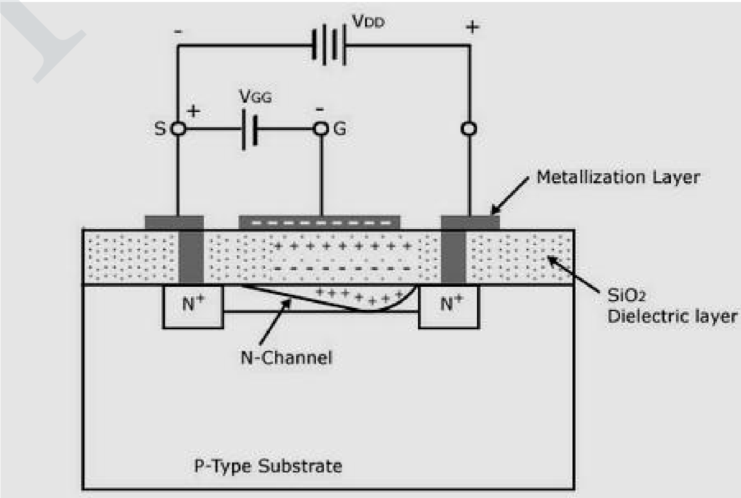


Figure 3.7 n-channel D-MOSFET under applied bias

Case (i) "when and is increased from zero"

- Here N-base (Drain) is connected to positive supply. It act as a reverse bias. Due to this, depletion region gets increases.
- Free electron from n-channel are attracted towards positive potential of drain terminal. This establishes current through channel flows from drain to source and denoted as I_{DSS}.

Pinch of voltage

The pinch off voltage is the voltage at which the junction is depleted of charge carriers.

Case (ii) "when and is increased from zero"

- The negative charge on gate repels conduction electrons from the channel and attract holes from the p-type substrate.
- Due to this electron-hole recombination occurs and reduce the number of free electrons in the channel available for conduction, reducing Drain current (I_D).
- When negative voltage of is incresed the pinch of voltage decreased.When is further increased the channel is fully depleted and no current flows through it.
- The negative voltage on the gate deplete the channel, the device is referred to as a depletion MOSFET.

Case (iii) "when and is increased from zero"

- Due to postive ,additional electrons are induced in the channel. Hence the conductivity of the channel increases and current (I_D) increases.
- This mode of operation is called as a enhancement mode and it is also called as dual mode MOSFET or ON-MOSFET.

3.5.2.4 Characteristics curve

Two types

- Drain characteristics [ ]
- Transfer characteristics [ ]

D-MOSFET's are biased to operate in two modes :depletion or enhancement mode.

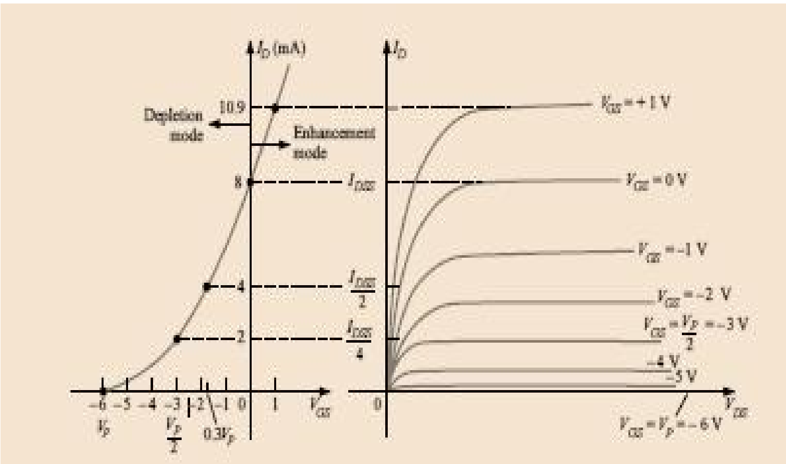


Figure 3.8 Drain and transfer characteristics

3.5.3 ENHANCEMENT- MODE MOSFET [E-MOSFET]

In this mode bias on the gate increases the number of charge carriers in the channel and increases the drain current (I_D).

It operates only in the enhancement mode and has no depletion mode of operation.It has no physical channel.

3.5.3.1Symbol of E-MOSFET

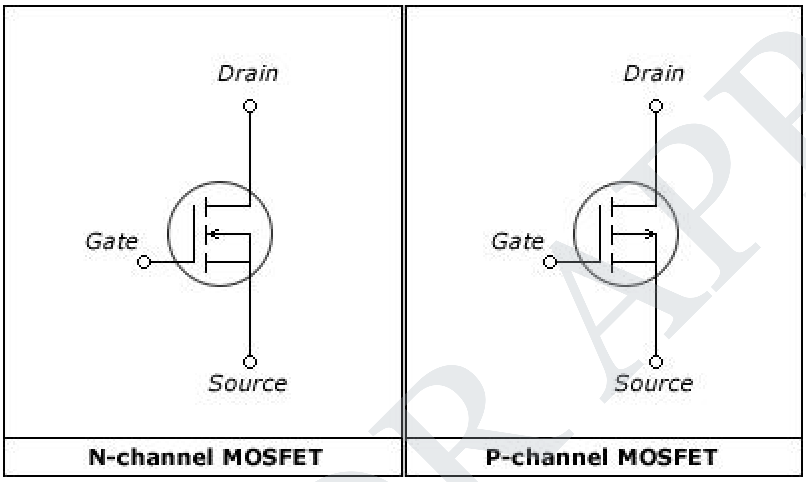


Figure 3.9 symbol of n-channel and p0channel E-MOSFET

3.5.3.2Basic Construction

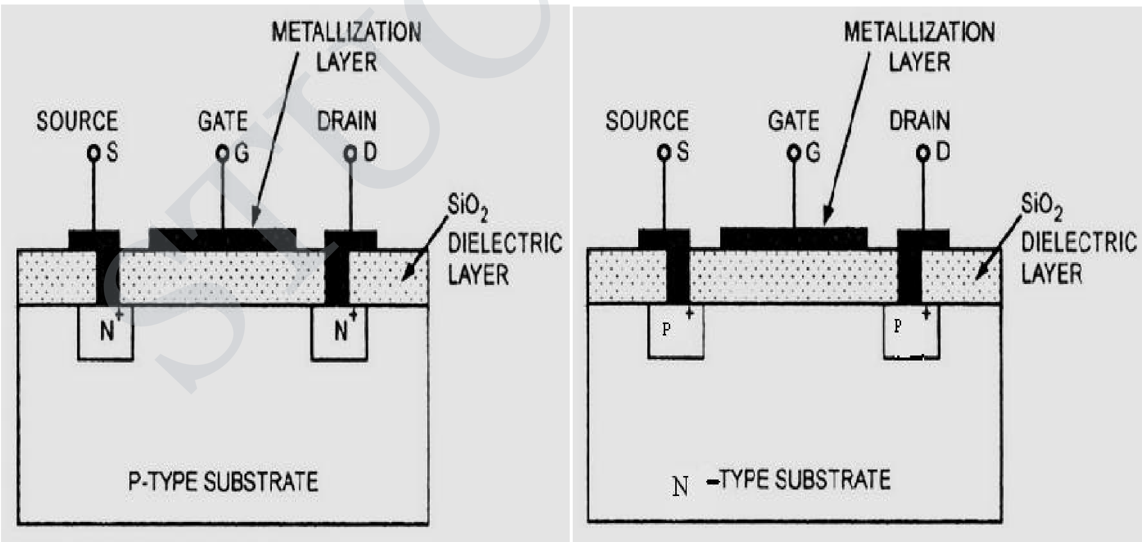


Figure 3.10 Construction of n-channel and p-channel E-MOSFET

In the basic construction of the n-channel enhancement-type MOSFET, a slab of p-type material is formed from a silicon base and is again referred to as the substrate. As with the depletion-type MOSFET, the substrate is sometimes internally connected to the source terminal, while in other cases a fourth lead is made available for external control of its potential level.

The SiO_2 layer is still present to isolate the gate metallic platform from the region between the drain and source, but now it is simply separated from a section of the p-type material.

In summary, therefore, the construction of an enhancement-type MOSFET is quite similar to that of the depletion-type MOSFET, except for the absence of a channel between the drain and source terminals.

3.5.3.3 Operation

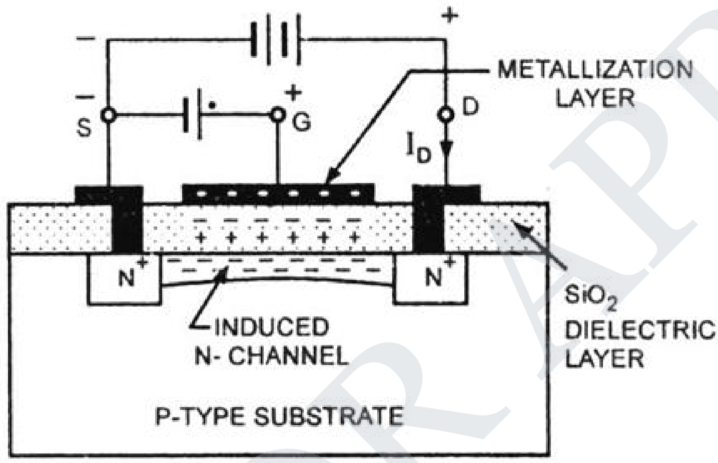


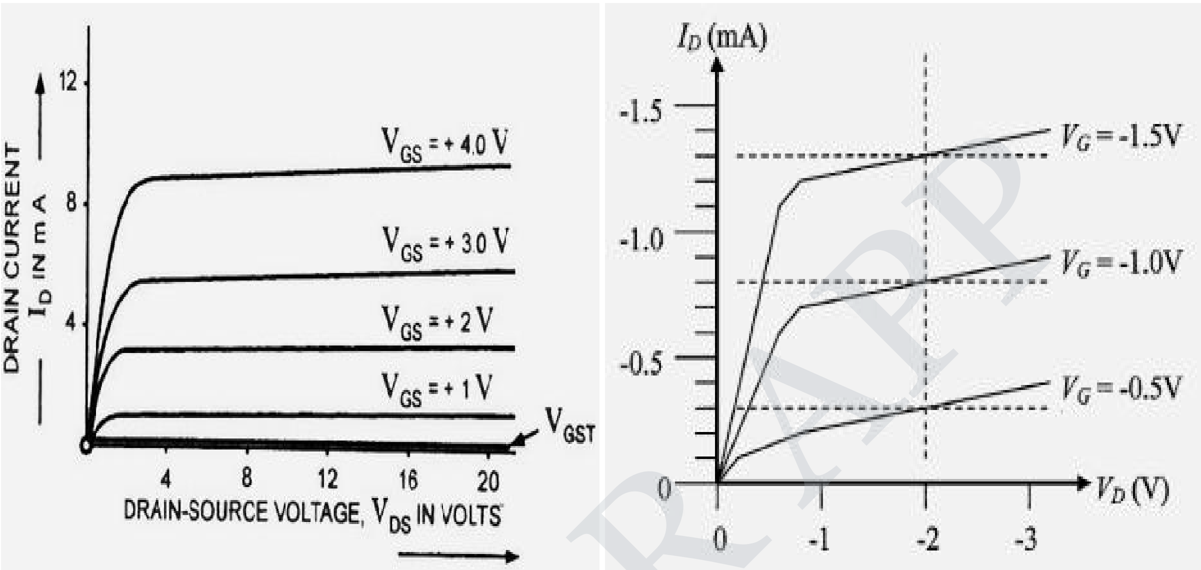
Figure 3.11 N-channel E-MOSFET under applied bias

- If V_{GS} is set at 0 V and a voltage applied between the drain and source of the device, the absence of an n-channel (with its generous number of free carriers) will result in a current of effectively zero amperes—quite different from the depletion- type MOSFET and JFET where I_D - I_{DSS}.
- It is not sufficient to have a large accumulation of carriers (electrons) at the drain and source (due to the n-doped regions) if a path fails to exist between the two. WithV_{DS} some positive voltage, V_{GS} at 0 V, and terminal SS directly connected to the source, there are in fact two reverse-biased p-n junctions between the n-doped regions and the p-substrate to oppose any significant flow between drain and source.
- When both V_{DS} and V_{GS} have been set at some positive voltage greater than 0 V, establishing the drain and gate at a positive potent ial with respect to the source. The positive potential at the gate will pressure the holes (since like charges repel) in the p-substrate along the edge of the SiO_2 layer to leave the area and enter deeper regions of the p-substrate.
- As V_{GS} is increased beyond the threshold level, the density of free carriers in the induced channel will increase, resulting in an increased level of drain current. However, if we hold V_{GS} constant and increase the level of V_{DS}, the drain current will eventually reach a saturation level as occurred for the JFET and depletion-type MOSFET.

- The conductivity of the channel is enhanced by the positive bias voltage on the gate, the device is known as enhancement MOSFET. E-MOSFET's are normally called as "OFF – MOSFET"

3.5.3.4 Characteristics of E-MOSFET

Drain characteristics curve



a) N-channel b) P-channel

Figure 3.12 Drain characteristics curve a) n-channel b) p-channel

Transfer characteristics curve

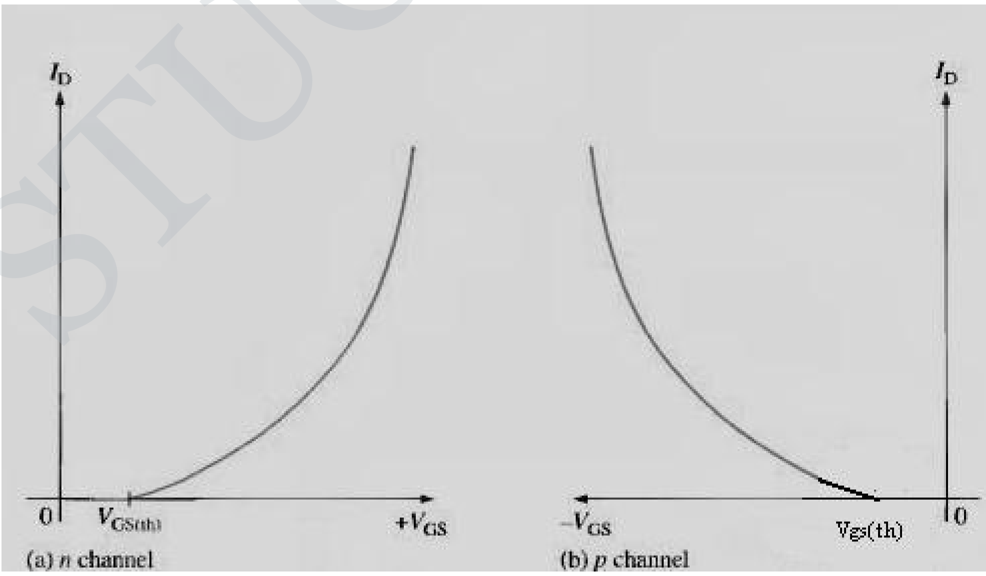


Figure 3.13 Transfer characteristics curve a) n-channel b) p-channel

For levels of $V_{GS} > V_T$, the drain current is related to the applied gate-to-source voltage by the following nonlinear relationship:

$$I_D = k\left(V_{GS} - V_{GS(th)}\right)^2$$

Where, k-constant depends upon type of MOSFET.

Again, it is the squared term that results in the nonlinear (curved) relationship between ID and $V_{GS.}$ The k term is a constant that is a function of the construction of the device. The value of k can be determined from the following equation where ID(on) and VGS(on) are the values for each at a particular point on the characteristics of the device.

$$k = \frac{I_{D(on)}}{\left(V_{GS(on)} - V_{GS(th)}\right)^2}$$

3.5.4 Applications:

1. Used in digital VLSI circuits
2. Used as amplifiers
3. Used in computer memories
4. Used as oscillator and in communication.

3.6 CHANNEL LENGTH MODULATION

One of several short-channel effects in MOSFET scaling, channel length modulation (CLM) is a shortening of the length of the inverted channel region with increase in drain bias for large drain biases. The result of CLM is an increase in current with drain bias and a reduction of output resistance. Channel length modulation occurs in all field effect transistors, not just MOSFETs.

To understand the effect, first the notion of pinch-off of the channel is introduced. The channel is formed by attraction of carriers to the gate, and the current drawn through the channel is nearly a constant independent of drain voltage in saturation mode. However, near the drain, the gate and drain jointly determine the electric field pattern. Instead of flowing in a channel, beyond the pinch-off point the carriers flow in a subsurface pattern made possible because the drain and the gate both control the current. In the figure at the right, the channel is indicated by a dashed line and becomes weaker as the drain is approached, leaving a gap of uninverted silicon between the end of the formed inversion layer and the drain (the pinch-off region).

As the drain voltage increases, its control over the current extends further toward the source, so the uninverted region expands toward the source, shortening the length of the channel region, the effect called channel-length modulation. Because resistance is proportional to length, shortening the channel decreases its resistance, causing an increase in current with increase in drain bias for a MOSFET operating in saturation. The effect is more pronounced the shorter the source-to-drain separation, the deeper the drain junction, and the thicker the oxide insulator.

In bipolar devices a similar increase in current is seen with increased collector voltage due to base-narrowing, known as the early effect. The similarity in effect upon the current has led to use of the term "Early effect" for MOSFETs as well, as an alternative name for "channel-length modulation".

Channel length modulation: the channel pinch-off point moves slightly away from drain as .The effective channel length L_{eff} reduces with .Electrons travel to pinch-off point will be swept to drain by electric field.

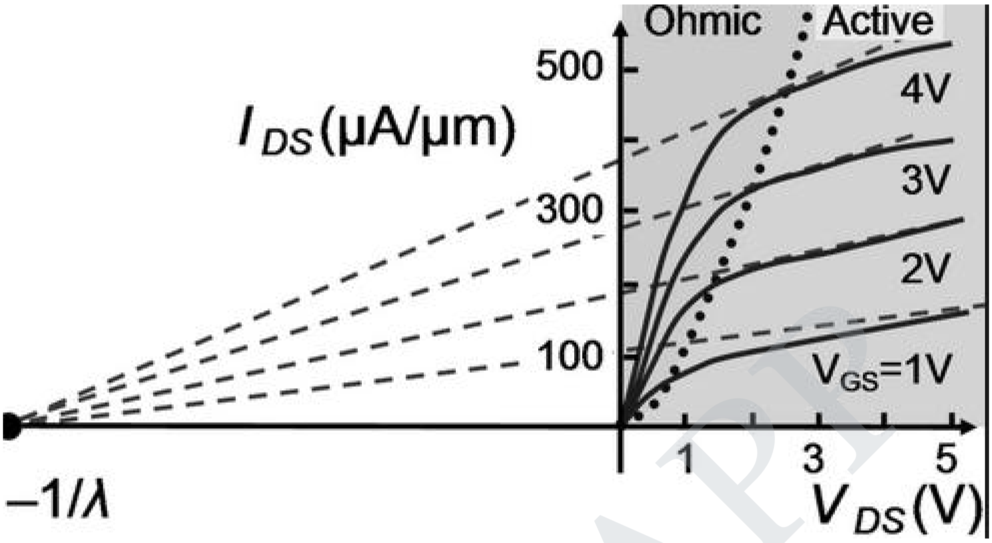


Figure 3.14 Effect of channel length modulation due to the non-zero slope in saturation region, resulting in a finite output resistance

For an N-channel device the slope of the curve in the saturation region can be expressed by using the drain current I_D given by

Where is appositive quantity called the Channel length modulation parameter or $^{-1}$ is analogous to the early voltage in bipolar transistor, is the conduction parameter and is the threshold voltage.
The output resistance due to channel length modulation is expressed by

The output resistance can be determined at the Q-point by

The output resistance is an important factor in the analysis of small signal equivalent circuit of MOSFET.

3.7 THRESHOLD VOLTAGE

The threshold voltage, commonly abbreviated as V_{th} or $V_{GS\,(th)}$, of a field-effect transistor (FET) is the minimum gate-to-source voltage differential that is needed to create a conducting path between the source and drain terminals.

At gate-to-source voltages above the threshold voltage ($V_{GS} > V_{th}$) but still below saturation (less than "fully on", $(V_{GS} - V_{th}) > V_{DS}$), the transistor is in its 'linear region', also known as ohmic mode, where it behaves like a voltage-controlled variable resistor.

In n-channel enhancement-mode devices, a conductive channel does not exist naturally within the transistor, and a positive gate-to-source voltage is necessary to create one. The positive voltage attracts free-floating electrons within the body towards the gate, forming a conductive channel. But first, enough electrons must be attracted near the gate to counter the dopant ions added to the body of the FET; this forms a region with no mobile carriers called a depletion region, and the voltage at which this occurs is the threshold voltage of the FET. Further gate-to-source voltage increase will attract even more electrons towards the gate which are able to create a conductive channel from source to drain; this process is called inversion.

In contrast, n-channel depletion-mode devices have a conductive channel naturally existing within the transistor. Accordingly, the term 'threshold voltage' does not readily apply to turn such devices 'on', but is used instead to denote the voltage level at which the channel is wide enough to allow electrons to flow easily. This ease-of-flow threshold also applies to p-channel depletion-mode devices, in which a positive voltage from gate to body/source creates a depletion layer by forcing the positively charged holes away from the gate-insulator/semiconductor interface, leaving exposed a carrier-free region of immobile, negatively charged acceptor ions.

3.8 DUAL GATE MOSFETS

MOSFET can be provided with two gates. Both gates can be used independently to control the drain current or the channel resistance.Dual gate MOSFET are normally of the n-channel depletion type. The dual-gate MOSFET has a tetrode configuration, where both gates control the current in the device.

3.8.1 Symbol and Construction

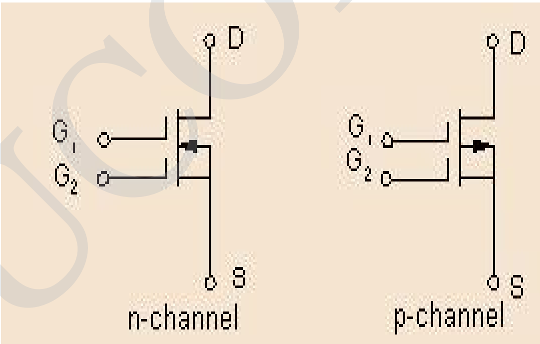


Figure 3.15 Symbol of dual gate MOSFET

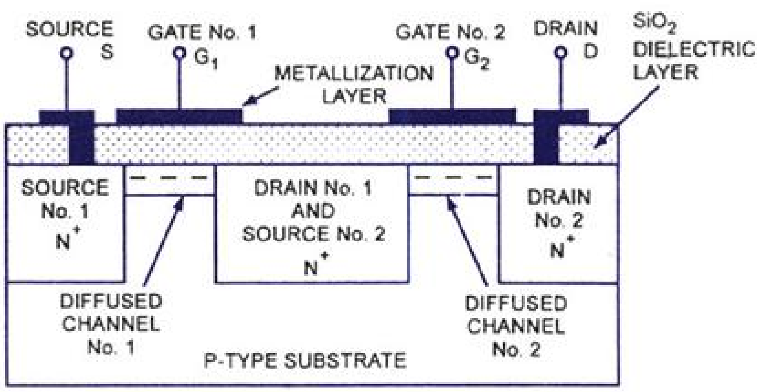


Figure3.16 N-channel Dual gate MOSFET

The output signal of the dual gate MOSFET is approximately proportional to the PRODUCT of the input voltages:

3.8.2 Applications :

- This makes this device suitable for applications where the multiplication of signals is required.E.g. modulation, mixing, demodulation, automatic gain control etc.
- It is also used as signal switch
- One gate serves as input for the signal to be amplified or transferred, the other as the control input. The advantage is, that the signal and the control voltage are fully separated.

3.9 FINFET

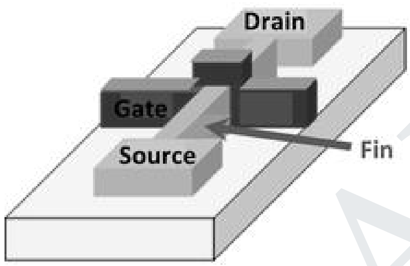


Figure 3.17 FinFET structure

The distinguishing characteristic of the FinFET is that the conducting channel is wrapped by a thin silicon "fin", which forms the body of the device. The thickness of the fin (measured in the direction from source to drain) determines the effective channel length of the device.

The "Omega FinFET" design is named after the similarity between the Greek letter omega (Ω) and the shape in which the gate wraps around the source/drain structure. It has a gate delay of just 0.39 picosecond (ps) for the N-type transistor and 0.88 ps for the P-type. FinFET can also have two electrically independent gates, which gives circuit designers more flexibility to design with efficient, low-power gates.

3.13.1 Applications:

The double gate FinFETs which are driven independently are used to construct low power logic gates, single transistor mixers and SRAMs

T V SPECIAL SEMICONDUCTOR DEVICES

UNIT IV SPECIAL SEMICONDUCTOR DEVICES 4.1

4.1 Semiconductor Field Effect Transistor (MESFETs)

Metal-Semiconductor Field Effect Transistor (MESFETs)

MESFET stands for metal–semiconductor field effect transistor. It is quite similar to a JFET in construction and terminology. The difference is that instead of using a p-n junction for a gate, a Schottky (metal-semiconductor) junction is used. MESFETs are usually constructed in compound semiconductor technologies lacking high quality surface passivation such as GaAs, InP, or SiC, and are faster but more expensive than silicon-based JFETs or MOSFETs. Production MESFETs are operated up to approximately 45 GHz, and are commonly used for microwave frequency communications and radar. From a digital circuit design perspective, it is increasingly difficult to use MESFETs as the basis for digital integrated circuits as the scale of integration goes up, compared to CMOS silicon based fabrication.

The Metal-Semiconductor-Field-Effect-Transistor (MESFET) consists of a conducting channel positioned between a source and drain contact region as shown in the Figure 4.1. The carrier flow from source to drain is controlled by a Schottky metal gate. The control of the channel is obtained by varying the depletion layer width underneath the metal contact which modulates the thickness of the conducting channel and thereby the current between source and drain.

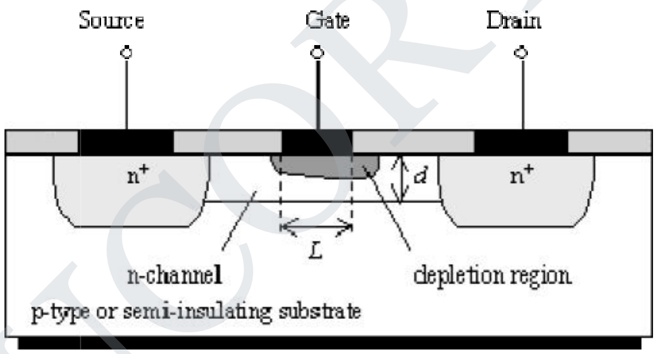


Figure 4.1 Structure of MESFET

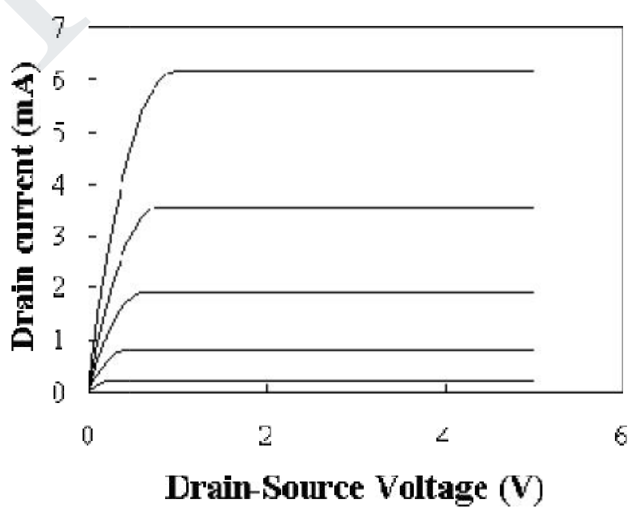


Figure 4.2 MESFETcharacteristics

4.1.1 Application

Numerous MESFET fabrication possibilities have been explored for a wide variety of semiconductor systems. Some of the main application areas are:

- military communications
- As front end low noise amplifier of microwave receivers in both military radar devices and communication
- commercial optoelectronics
- satellite communications
- As power amplifier for output stage of microwave links.
- As a power oscillator.

4.1.2 Advantage of the MESFET

- The higher transit frequency of the MESFET makes it particularly of interest for microwave circuits. While the advantage of the MESFET provides a superior microwave amplifier or circuit, the limitation by the diode turn-on is easily tolerated.
- Typically depletion-mode devices are used since they provide a larger current and larger transconductance and the circuits contain only a few transistors, so that threshold control is not a limiting factor.
- The buried channel also yields a better noise performance as trapping and release of carriers into and from surface states and defects is eliminated.
- The use of GaAs rather than silicon MESFETs provides two more significant advantages: first, the electron mobility at room temperature is more than 5 times larger, while the peak electron velocity is about twice that of silicon.
- Second, it is possible to fabricate semi-insulating (SI) GaAs substrates, which eliminates the problem of absorbing microwave power in the substrate due to free carrier absorption.

4.1.3 Disadvantage of the MESFET

- The disadvantage of the MESFET structure is the presence of the Schottky metal gate. It limits the forward bias voltage on the gate to the turn-on voltage of the Schottky diode. This turn-on voltage is typically 0.7 V for GaAs Schottky diodes.
- The threshold voltage therefore must be lower than this turn-on voltage. As a result it is more difficult to fabricate circuits containing a large number of enhancement-mode MESFET.

4.2 SCHOTTKY BARRIER (HOT-CARRIER) DIODES

A Schottky diode, also known as a hot carrier diode, is a semiconductor diode which has a low forward voltage drop and a very fast switching action. There is a small voltage drop across the diode terminals when current flows through a diode.

A normal diode will have a voltage drop between 0.6 to 1.7 volts, while a Schottky diode voltage drop is usually between 0.15 and 0.45 volts. This lower voltage drop provides better system efficiency and higher switching speed.

In a Schottky diode, a semiconductor–metal junction is formed between a semiconductor and a metal, thus creating a Schottky barrier. The N-type semiconductor acts as the cathode and the metal side acts as the anode of the diode. This Schottky barrier results in both a low forward voltage drop and very fast switching.

4.2.1 Symbol and Construction

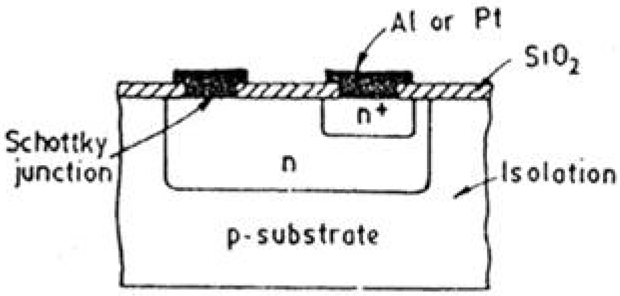


Figure 4.3 a)cross sectional view of Schottky diode b)Symbol

It can be seen from the circuit symbol that it is based on the normal diode one, but with additional elements to the bar across the triangle shape.

Its construction is quite different from the conventional p-n junction in that a metalsemiconductor junction is created such as shown in Figure 4.3. The semiconductor is normally n-type silicon (although p-type silicon is sometimes used), whiles a host of different metals, such as molybdenum, platinum, chrome, or tungsten, are used.

Different construction techniques will result in a different set of characteristics for the device, such as increased frequency range, lower forward bias, and so on. Priorities do not permit an examination of each technique here, but information will usually be provided by the manufacturer. In general, however, Schottky diode construction results in a more uniform junction region and a high level of ruggedness.

In both materials, the electron is the majority carrier. In the metal, the level of minority carriers (holes) is insignificant. When the materials are joined, the electrons in the n-type silicon semiconductor material immediately flow into the adjoining metal, establishing a heavy flow of majority carriers. Since the injected carriers have a very high kinetic energy level compared to the electrons of the metal, they are commonly called –hot carriers.

The additional carriers in the metal establish a —negative wall in the metal at the boundary between the two materials. The net result is a –surface barrier between the two materials, preventing any further current. That is, any electrons (negatively charged) in the silicon material face a carrier-free region and a –negative wall at the surface of the metal.

The application of a forward bias as shown in the first quadrant of Figure 4.2 will reduce the strength of the negative barrier through the attraction of the applied positive potential for electrons from this region. The result is a return to the heavy flow of electrons across the boundary, the magnitude of which is controlled by the level of the applied bias potential.

The barrier at the junction for a Schottky diode is less than that of the p-n junction device in both the forward- and reverse-bias regions. The result is therefore a higher current at the same applied bias in the forward- and reverse-bias regions. This is a desirable effect in the forward-bias region but highly undesirable in the reverse-bias region.

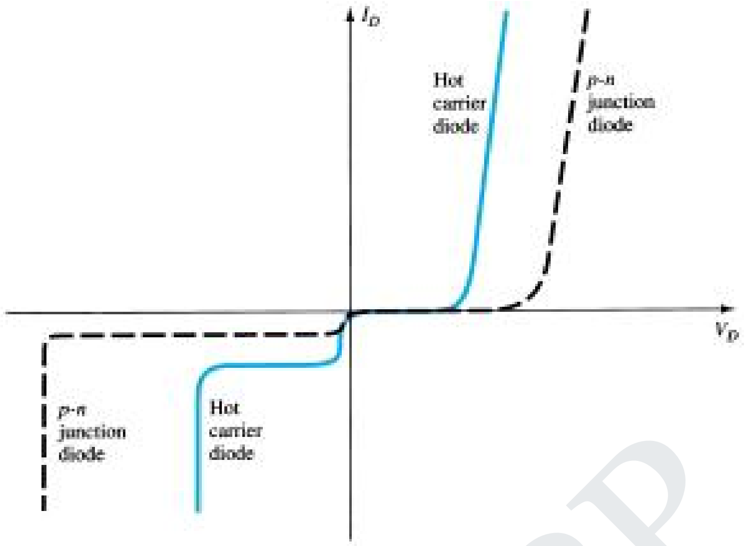


Figure 4.4 Comparison of characteristics of hot carrier and PN diode

4.2.2 Advantages

Schottky diodes are used in many applications where other types of diode will not perform as well. They offer a number of advantages:

- Low turn on voltage: The turn on voltage for the diode is between 0.2 and 0.3 volts for a silicon diode against 0.6 to 0.7 volts for a standard silicon diode. This makes it have very much the same turn on voltage as a germanium diode.
- Fast recovery time: The fast recovery time because of the small amount of stored charge means that it can be used for high speed switching applications.
- Low junction capacitance: In view of the very small active area, often as a result of using a wire point contact onto the silicon, the capacitance levels are very small.

The advantages of the Schottky diode, mean that its performance can far exceed that of other diodes in many areas.

4.2.3 Applications

The Schottky barrier diodes are widely used in the electronics industry finding many uses as diode rectifier. Its unique properties enable it to be used in a number of applications where other diodes would not be able to provide the same level of performance. In particular it is used in areas including:

- **RF mixer and detector diode:** The Schottky diode has come into its own for radio frequency applications because of its high switching speed and high frequency capability. In view of this Schottky barrier diodes are used in many high performance diode ring mixers. In addition to this their low turn on voltage and high frequency capability and low capacitance make them ideal as RF detectors.
- **Power rectifier:** Schottky barrier diodes are also used in high power applications, as rectifiers. Their high current density and low forward voltage drop mean that less power is wasted than if ordinary PN junction diodes were used. This increase in efficiency means

that less heat has to be dissipated, and smaller heat sinks may be able to be incorporated in the design.

- **Power OR circuits:** Schottky diodes can be used in applications where a load is driven by two separate power supplies. One example may be a mains power supply and a battery supply. In these instances it is necessary that the power from one supply does not enter the other. This can be achieved using diodes. However it is important that any voltage drop across the diodes is minimised to ensure maximum efficiency. As in many other applications, this diode is ideal for this in view of its low forward voltage drop. Schottky diodes tend to have a high reverse leakage current. This can lead to problems with any sensing circuits that may be in use. Leakage paths into high impedance circuits can give rise to false readings. This must therefore be accommodated in the circuit design.

- **Solar cell applications:** Solar cells are typically connected to rechargeable batteries, often lead acid batteries because power may be required 24 hours a day and the Sun is not always available. Solar cells do not like the reverse charge applied and therefore a diode is required in series with the solar cells. Any voltage drop will result in a reduction in efficiency and therefore a low voltage drop diode is needed. As in other applications, the low voltage drop of the Schottky diode is particularly useful, and as a result they are the favoured form of diode in this application.

- **Clamp diode** - especially with its use in LS TTL: Schottky barrier diodes may also be used as a clamp diode in a transistor circuit to speed the operation when used as a switch. They were used in this role in the 74LS (low power Schottky) and 74S (Schottky) families of logic circuits. In these chips the diodes are inserted between the collector and base of the driver transistor to act as a clamp. To produce a low or logic "0" output the transistor is driven hard on, and in this situation the base collector junction in the diode is forward biased. When the Schottky diode is present this takes most of the current and allows the turn off time of the transistor to be greatly reduced, thereby improving the speed of the circuit.

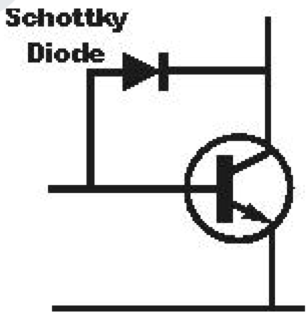


Figure 4.5 An NPN transistors with Schottky diode clamp

In view of its properties, the Schottky diode finds uses in applications right through from power rectification to uses in clamp diodes in high speed logic devices and then on to high frequency RF applications as signal rectifiers and in mixers.

Their properties span many different types of circuit making them almost unique in the variety of areas and circuits in which they can be used.

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4.3 ZENER DIODE

A Zener diode is a type of diode that permits current not only in the forward direction like a normal diode, but also in the reverse direction if the voltage is larger than the breakdown voltage known as "Zener knee voltage" or "Zener voltage". The device was named after Clarence Zener, who discovered this electrical property.

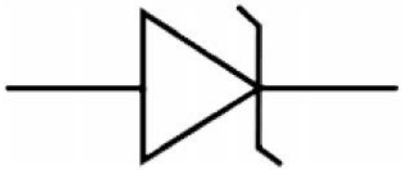


Figure 4.6 Diode symbol

However, the Zener Diode or "Breakdown Diode" as they are sometimes called, are basically the same as the standard PN junction diode but are specially designed to have a low pre-determined Reverse Breakdown Voltage that takes advantage of this high reverse voltage. The point at which a zener diode breaks down or conducts is called the "Zener Voltage" (Vz).

The Zener diode is like a general-purpose signal diode consisting of a silicon PN junction. When biased in the forward direction it behaves just like a normal signal diode passing the rated current, but when a reverse voltage is applied to it the reverse saturation current remains fairly constant over a wide range of voltages. The reverse voltage increases until the diodes breakdown voltage VB is reached at which point a process called Avalanche Breakdown occurs in the depletion layer and the current flowing through the zener diode increases dramatically to the maximum circuit value (which is usually limited by a series resistor). This breakdown voltage point is called the "zener voltage" for zener diodes.

Avalanche Breakdown*:* There is a limit for the reverse voltage. Reverse voltage can increase until the diode breakdown voltage reaches. This point is called Avalanche Breakdown region. At this stage maximum current will flow through the zener diode. This breakdown point is referred as “Zener voltage”.

The point at which current flows can be very accurately controlled (to less than 1% tolerance) in the doping stage of the diodes construction giving the diode a specific zener breakdown voltage, (Vz) ranging from a few volts up to a few hundred volts. This zener breakdown voltage on the I-V curve is almost a vertical straight line.

4.3.1 Zener diode characteristics

The Zener Diode is used in its "reverse bias" or reverse breakdown mode, i.e. the diodes anode connects to the negative supply. From the I-V characteristics curve above, we can see that the zener diode has a region in its reverse bias characteristics of almost a constant negative voltage regardless of the value of the current flowing through the diode and remains nearly constant even with large changes in current as long as the zener diodes current remains between the breakdown current IZ(min) and the maximum current rating IZ(max).

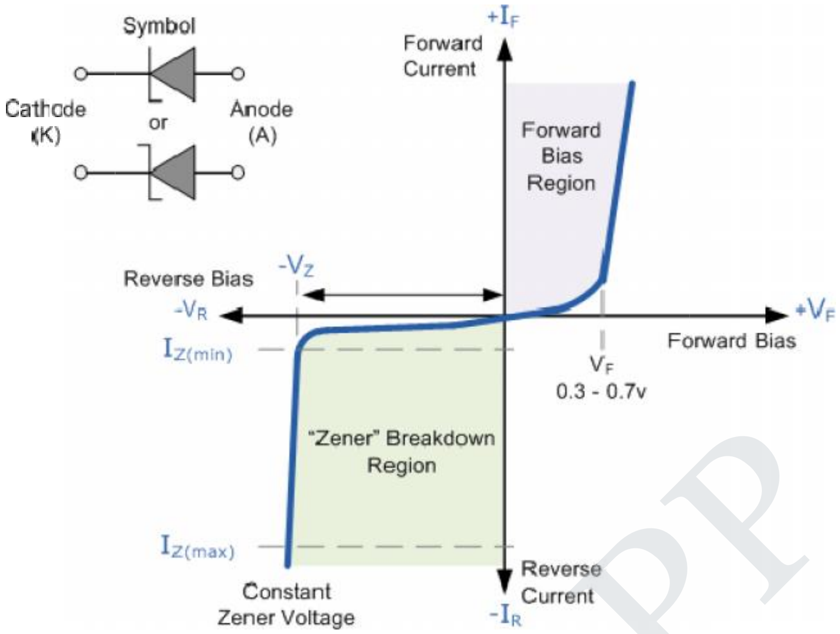


Figure 4.7 Zener diode characteristics

4.3.2 Applications of zener diode

1.The Zener Diode Regulator

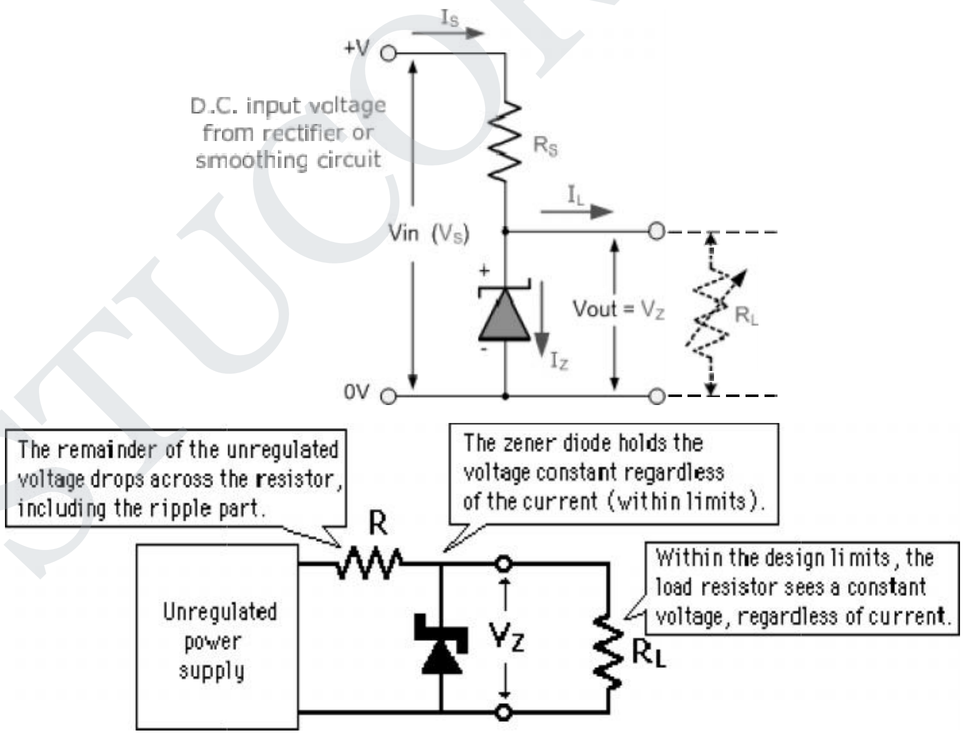
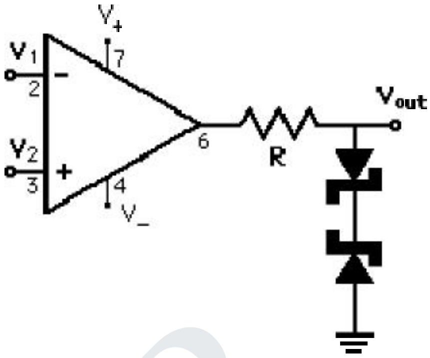


Figure 4.8 Zener diode act as voltage regulator

The constant reverse voltage V_Z of the zener diode makes it a valuable component for the regulation of the output voltage against both variations in the input voltage from an unregulated power supply or variations in the load resistance. The current through the zener will change to keep the voltage at within the limits of the threshold of zener action and the maximum power it can dissipate.

2. Zener-Controlled Output Switching

This comparator application makes use of the properties of the zener diode to cause the output to switch between voltages determined by the zener diodes when the input voltage difference $V_2 - V_1$ changes sign. The output circuit amounts to a zener regulator which switches from one zener voltage to the other on a transition.



3. Zener Limiter

A single Zener diode can limit one side of a sinusoidal waveform to the zener voltage while clamping the other side to near zero. With two opposing zeners, the waveform can be limited to the zener voltage on both polarities.

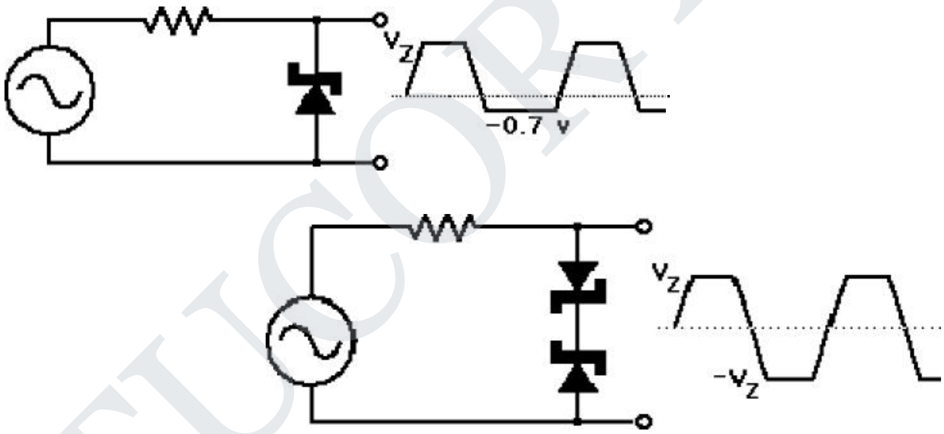


Figure 4.9 Zener limiter

4. Zener Role in Power Supplies

The zener diode is widely used as a voltage regulator because of its capacity to maintain a constant voltage over a sizeable range of currents. It can be used as a single component across the output of a rectifier or incorporated into one of the variety of one-chip regulators Basically there are two type of regulations such as:

a) Line Regulation

In this type of regulation, series resistance and load resistance are fixed, only input voltage is changing. Output voltage remains the same as long as the input voltage is maintained above a minimum value.

$$\text{Percentage of line regulation can be calculated by} = \frac{\Delta V_0}{\Delta V_{in}}$$

Where V_0 is the output voltage and V_{IN} is the input voltage and ΔV_0 is the change in output voltage for a particular change in input voltage ΔV_{IN}.

b) Load Regulation

In this type of regulation, input voltage is fixed and the load resistance is varying. Output volt remains same, as long as the load resistance is maintained above a minimum value.

$$\text{Percentage of load regulation} = \left[\frac{V_{NL} - V_{FL}}{V_{NL}}\right] * 100$$

where V_{NL} is the null load resistor voltage (ie. remove the load resistance and measure the voltage across the Zener Diode) and V_{FL} is the full load resistor voltage.

4.3.3 Difference between Zener breakdown from avalanche breakdown

Zener Breakdown	Avalanche breakdown
1.This occurs at junctions which being heavily doped have narrow depletion layers . 2.This breakdown voltage sets a very strong electric field across this narrow layer. 3.Here electric field is very strong to rupture the covalent bonds thereby generating electron-hole pairs. So even a small increase in reverse voltage is capable of producing large number of current carriers. i.e. why the junction has a very low resistance. This leads to Zener breakdown.	1.This occurs at junctions which being lightly doped have wide depletion layers. 2.Here electric field is not strong enough to produce Zener breakdown. 3.Her minority carriers collide with semi conductor atoms in the depletion region, which breaks the covalent bonds and electron-hole pairs are generated. Newly generated charge carriers are accelerated by the electric field which results in more collision and generates avalanche of charge Carriers. This results in avalanche breakdown.

4.4 VARACTOR DIODE

Varactors are operated in a reverse-biased state. No current flows, but since the thickness of the depletion zone varies with the applied bias voltage, the capacitance of the diode can be made to vary. Generally, the depletion region thickness is proportional to the square root of the applied voltage; capacitance is inversely proportional to the depletion region thickness. Thus, the capacitance is inversely proportional to the square root of applied voltage.

All diodes exhibit this phenomenon to some degree, but varactor diodes are manufactured specifically to exploit this effect and increase the capacitance (and thus the range of variability), whereas most ordinary diode fabrication strives to minimize the capacitance.

A varactor diode is best explained as a variable capacitor. Think of the depletion region as a variable dielectric. The diode is placed in reverse bias. Junction capacitance is present in all reverse biased diodes because of the depletion region.

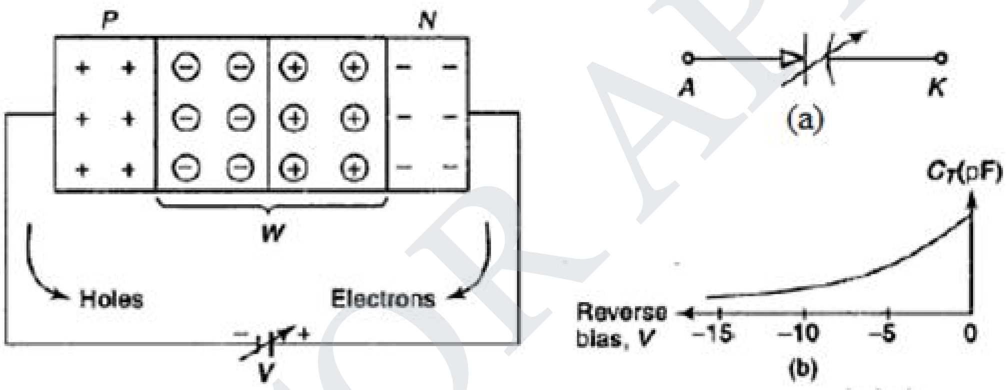


Figure 4.10 Depletion region in a reverse biased PN junction a) circuit symbol b) characteristics of varactor diode

They are also called voltage-variable capacitance diodes. A Junction diode which acts as a variable capacitor under changing reverse bias is known as VARACTOR DIODE.A varactor diode is specially constructed to have high resistance under reverse bias. Capacitance for varactor diode are Pico farad. (10-12) range.

$$C_T = {\epsilon A}/{W_d}$$

C_T =Total Capacitance of the junction

ϵ = Permittivity of the semiconductor material

A = Cross sectional area of the junction

W_d= Width of the depletion layer

Curve between Reverse bias voltage Vr across varactor diode and total junction capacitance C_T and C_T can be changed by changing Vr.

4.4.1 Applications

- Junction capacitance is optimized in a varactor diode and is used for high frequencies and switching applications.
- Varactor diodes are often used for electronic tuning applications in FM radios and televisions.
- Varactors are used as voltage-controlled capacitors. They are commonly used in voltage-controlled oscillators, parametric amplifiers, and frequency multipliers.

4.5 TUNNEL DIODE (ESAKI DIODE)

- A tunnel diode or Esaki diode is a type of semiconductor that is capable of very fast operation, well into the microwave frequency region, made possible by the use of the quantum mechanical effect called tunneling.
- It was introduced by Leo Esaki in 1958.Heavily-doped p-n junction.Impurity concentration is 1 part in 10^3 as compared to 1 part in 10^8 in p-n junction diode.Width of the depletion layer is very small (about 100 A). It is generally made up of Ge and GaAs.

4.5.1 Circuit symbol of tunnel diode

Figure 4.11 symbol of tunnel diode

4.5.2TunnelingPhenomenon:

According to classical mechanics theory, a particle must have an energy at least equal to the the height of a potential-energy barrier if it has to move from one side of the barrier to the other. In other words, energy has to be supplied from some external source so that the electrons on N side of junction climb over the junction barrier to reach the P-side. However if the barrier is thin such as in tunnel diode ,the Schrodinger equation(Quantum Mechanics) indicates that there is a large probability that an electron will penetrate through the barrier. This will happen without any loss of energy on the part of electron. This quantum mechanical behavior is referred to as tunneling and the high-impurity P-N junction devices are called tunnel-diodes. The tunneling phenomenon is a majority carrier effect.

4.5.2.1Forward bias operation

Under normal forward bias operation, as voltage begins to increase, electrons at first tunnel through the very narrow p–n junction barrier because filled electron states in the conduction band on the n-side become aligned with empty valence band hole states on the p-side of the p-n junction. As voltage increases further these states become more misaligned and the current drops – this is called negative resistance because current decreases with increasing voltage. As voltage increases yet further, the diode begins to operate as a normal diode, where electrons travel by conduction across the p–n junction, and no longer by tunneling through the p–n junction barrier. The most important operating region for a tunnel diode is the negative resistance region.

4.5.2.2Reverse bias operation

When used in the reverse direction, tunnel diodes are called back diodes (or backward diodes) and can act as fast rectifiers with zero offset voltage and extreme linearity for power signals (they have an accurate square law characteristic in the reverse direction). Under reverse bias, filled states on the p-side become increasingly aligned with empty states on the n-side and electrons now tunnel through the pn junction barrier in reverse direction.

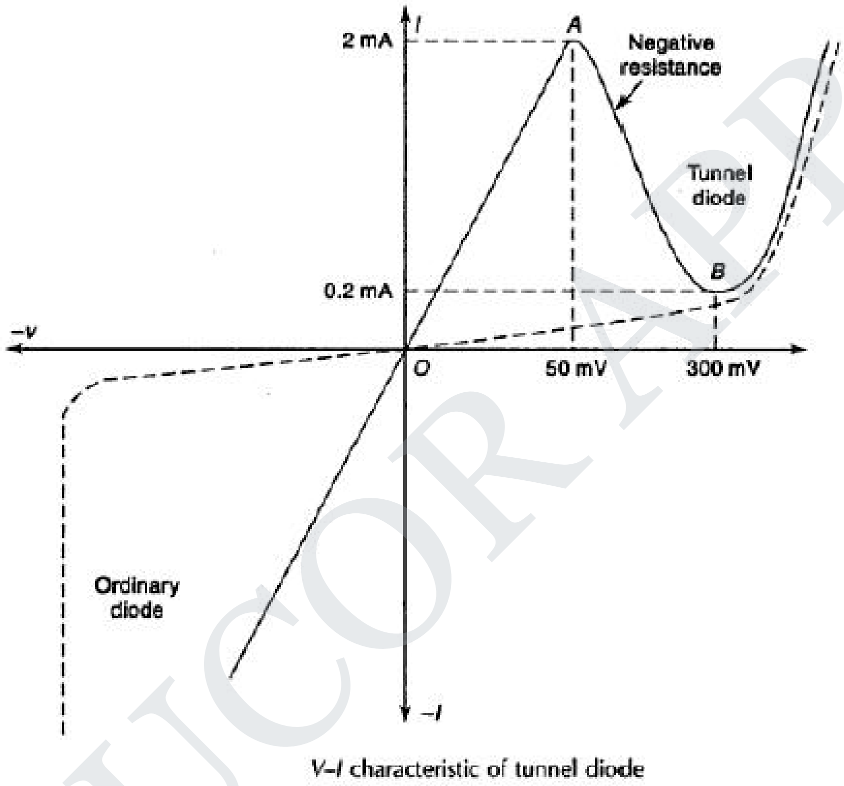


Figure 4.12 V-I characteristics of tunnel diode

4.5.3 Energy Band Diagram

Energy-band diagram of pn junction in thermal equilibrium in which both the n and p region are degenerately doped.

At Zero Bias

Simplified energy-band diagram and I-V characteristics of the tunnel diode at zero bias.

- Zero current on the I-V diagram;

- All energy states are filled below EF on both sides of the junction;

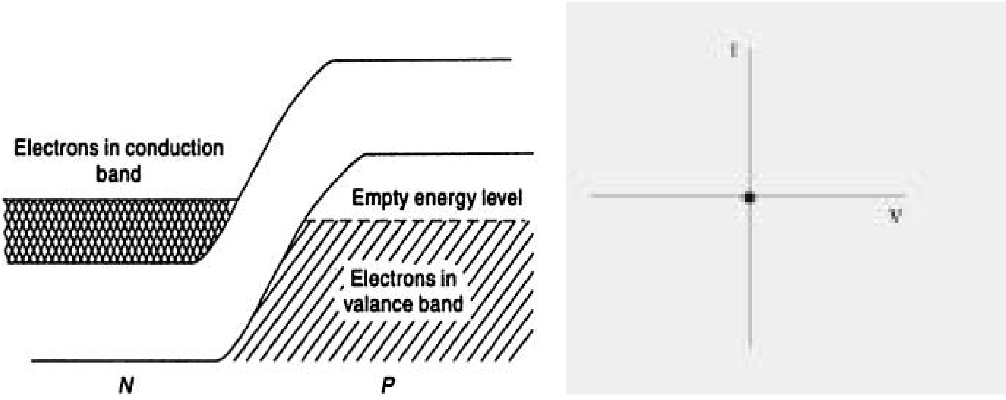


Figure 4.13 Energy Band Diagram at zero bias

At Small Forward Voltage

Simplified energy-band diagram and I-V characteristics of the tunnel diode at a slight forward bias

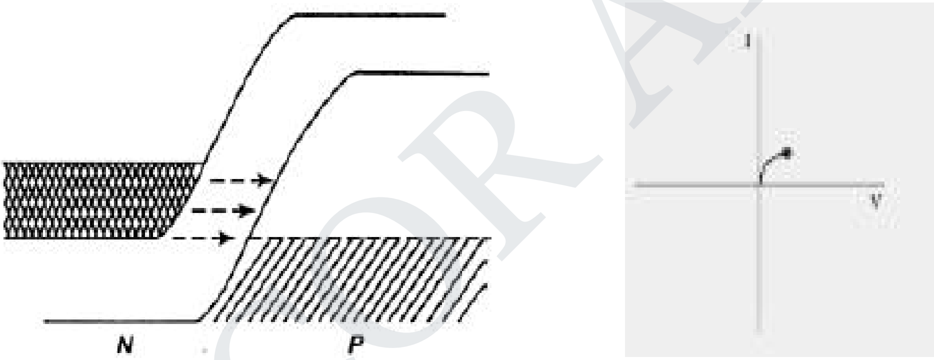


Figure 4.14 Energy Band Diagram at small forward bias

- Electrons in the conduction band of the n region are directly opposite to the empty states in the valence band of the p region.So a finite probability that some electrons tunnel directly into the empty states resulting in forward-bias tunnelling current.

At Maximum Tunnelling Current

Simplified energy-band diagram and I-V characteristics of the tunnel diode at a forward bias producing maximum tunnelling current.The maximum number of electrons in the n region are opposite to the maximum number of empty states in the p region.Hence tunneling current is maximum.

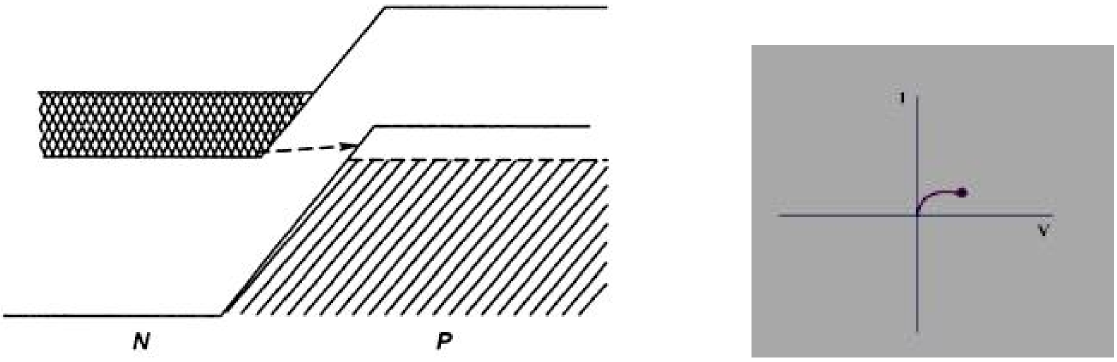


Figure 4.15 Energy Band Diagram at Maximum Tunnelling Current

4.5.4 Tunnel Diode Equivalent Circuit

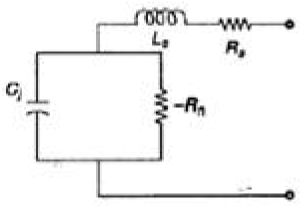


Figure 4.16 Equivalent circuit of tunnel diode

This is the equivalent circuit of tunnel diode when biased in negative resistance region.

- At higher frequency the series R and L can be ignored.
- Hence equivalent circuit can be reduced to parallel combination of junction capacitance and negative resistance.

4.5.5 Applications

- As logic memory storage device
- As microwave oscillator
- In relaxation oscillator circuit
- As an amplifier
- As an ultra-high speed switch

4.5.6 Advantages and disadvantages

The tunnel diode is not as widely used these days as it was oat one time. With the improvement in performance of other forms of semiconductor technology, they have often become the preferred option. Nevertheless it is still worth looking at a tunnel diode, considering its advantages and disadvantages to discover whether it is a viable option.

4.5.6.1 Advantages

- **Very high speed:** The high speed of operation means that the tunnel diode can be used for microwave RF applications.

- **Longevity:** Studies have been undertaken of the tunnel diode and its performance has been shown to remain stable over long periods of time, where other semiconductor devices may have degraded.

4.5.6.2 Disadvantages

- **Reproducibility:** It has not been possible to make the tunnel diode with as reproducible performance to the levels often needed.

- **Low peak to valley current ratio:** The negative resistance region and the peak to valley current is not as high as is often be required to produce the levels of performance that can be attained with other devices.

One of the main reasons for the early success of the tunnel diode was its high speed of operation and the high frequencies it could handle. This resulted from the fact that while many other devices are slowed down by the presence of minority carriers, the tunnel diode only uses majority carriers, i.e. holes in an n-type material and electrons in a p-type material.

The minority carriers slow down the operation of a device and as a result their speed is slower. Also the tunnelling effect is inherently very fast.

The tunnel diode is rarely used these days and this results from its disadvantages. Firstly they only have a low tunnelling current and this means that they are low power devices. While this may be acceptable for low noise amplifiers, it is a significant drawback when they are sued in oscillators as further amplification is needed and this can only be undertaken by devices that have a higher power capability, i.e. not tunnel diodes. The third disadvantage is that they are problems with the reproducibility of the devices resulting in low yields and therefore higher production costs.

4.6 GALLIUM ARSENIDE DEVICE:

Gallium arsenide (GaAs) is a compound of the elements gallium and arsenic. It is a III/V semiconductor, and is used in the manufacture of devices such as microwave frequency integrated circuits, monolithic microwave integrated circuits, infrared light-emitting diodes, laser diodes, solar cells and optical windows.GaAs is often used as a substrate material for the epitaxial growth of other III-V semiconductors including: InGaAs and GaInNAs.

Some electronic properties of gallium arsenide are superior to those of silicon. It has a higher saturated electron velocity and higher electron mobility, allowing gallium arsenide transistors to function at frequencies in excess of 250 GHz. Unlike silicon junctions, GaAs devices are relatively insensitive to heat owing to their wider bandgap. Also, GaAs devices tend to have less noise than silicon devices, especially at high frequencies. This is a result of higher carrier mobilities and lower resistive device parasitics. These properties recommend GaAs circuitry in mobile phones, satellite communications, microwave point-to-point links and higher frequency radar systems. It is used in the manufacture of Gunn diodes for generation of microwaves.

Another advantage of GaAs is that it has a direct band gap, which means that it can be used to emit light efficiently. Silicon has an indirect bandgap and so is very poor at emitting light. Nonetheless, recent advances may make silicon LEDs and lasers possible.

As a wide direct band gap material with resulting resistance to radiation damage, GaAs is an excellent material for space electronics and optical windows in high power applications.

Because of its wide band gap, pure GaAs is highly resistive. Combined with the high dielectric constant, this property makes GaAs a very good electrical substrate and unlike Si provides natural isolation between devices and circuits. This has made it an ideal material for microwave and millimetre wave integrated circuits, MMICs, where active and essential passive components can readily be produced on a single slice of GaAs.

4.7 LASER DIODE

Laser action (with the resultant monochromatic and coherent light output) can be achieved in a p-n junction formed by two doped gallium arsenide layers. The two ends of the structure need to be optically flat and parallel with one end mirrored and one partially reflective. The length of the junction must be precisely related to the wavelength of the light to be emitted. The junction is forward biased and the recombination process produces light as in the LED (incoherent). Above a certain current threshold the photons moving parallel to the junction can stimulate emission and initiate laser action.

Laser diodes and light emitting diodes have a number of elements in common with respect to their theory of operation. However the laser diode theory of operation incorporates more elements, taking in additional processes to provide the coherent light it produces.

4.7.1 Symbol

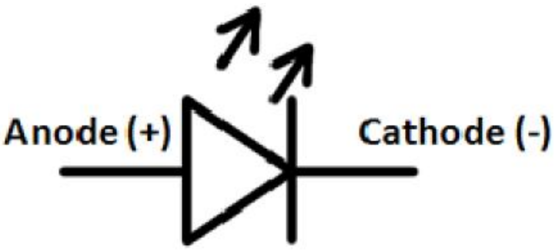
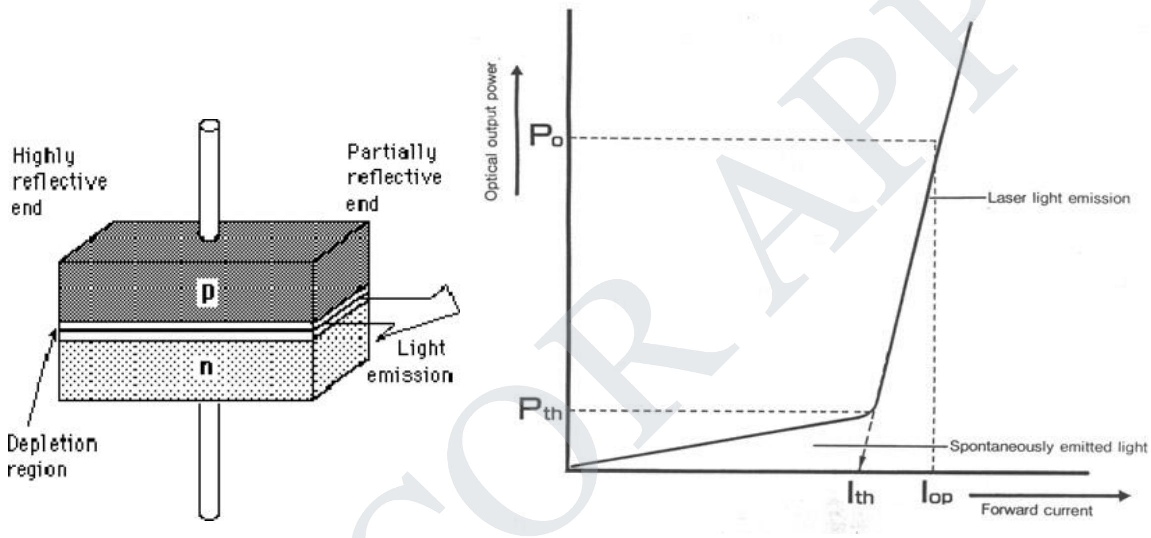


Figure 4.17 Symbol of laser diode

4.7.2 Structure and characteristic curve



(a) (b)

Figure 4.18 (a) Structure and (b) characteristic curve of laser diode

A laser diode, or LD, is an electrically pumped semiconductor laser in which the active medium is formed by a p-n junction of a semiconductor diode similar to that found in a emitting diode. The laser diode is the most common type of laser produced. Laser diodes have a very wide range of uses that include, but are not limited to, fibre optic communications, barcode readers, laser pointers, CD/DVD/Blu-ray reading, laser printing, scanning and increasingly directional lighting sources.

4.7.3 Laser diode theory basics

There are three main processes in semiconductors that are associated with light:

- **Light absorption:** Absorption occurs when light enters a semiconductor and its energy is transferred to the semiconductor to generate additional free electrons and holes. This effect is widely used and enables devices like to photo-detectors and solar cells to operate.

- **Spontaneous emission:** The second effect known as spontaneous emission occurs in LEDs. The light produced in this manner is what is termed incoherent. In other words the frequency and phase are random, although the light is situated in a given part of the spectrum.

- **Stimulated emission:** Stimulated emission is different. A light photon entering the semiconductor lattice will strike an electron and release energy in the form of another light photon. The way in which this occurs releases this new photon of identical wavelength and phase. In this way the light that is generated is said to be coherent.

The key to the laser diode operation occurs at the junction of the highly doped p and n type regions. In a normal p-n junction current flows across the p-n junction. This action can occur because the holes from the p-type region and the electrons from the n-type region combine. With an electromagnetic wave (in this instance light) in passing through the laser diode junction diode junction it is found that the photo-emission process occurs. Here the photons release further photons of light occurs when they strike electrons during the recombination of holes and electrons occurs.

Naturally there is some absorption of the light, resulting in the generation of holes and electrons but there is an overall gain in level.

The structure of the laser diode creates an optical cavity in which the light photons have multiple reflections. When the photons are generated only a small number are able to leave the cavity. In this way when one photon strikes an electron and enables another photon to be generated the process repeats itself and the photon density or light level starts to build up. It is in the design of better optical cavities that much of the current work on lasers is being undertaken. Ensuring the light is properly reflected is the key to the operation of the device.

4.8 LDR (**LIGHT DEPENDENT RESISTOR**):

A Light Dependent Resistor (LDR) or a photo resistor is a device whose resistivity is a function of the incident electromagnetic radiation. Hence, they are light sensitive devices. They are also called as photo conductors, photo conductive cells or simply photocells. They are made up of semiconductor materials having high resistance. There are many different symbols used to indicate a LDR, one of the most commonly used symbol is shown in the figure below. The arrow indicates light falling on it.

A photoresistor or light-dependent resistor (LDR) or photocell is a resistor whose resistance decreases with increasing incident light intensity; in other words, it exhibits photoconductivity. A photoresistor is made of a high resistance semiconductor. If light falling on the device is of high enough frequency, photons absorbed by the semiconductor give bound electrons enough energy to jump into the conduction band.

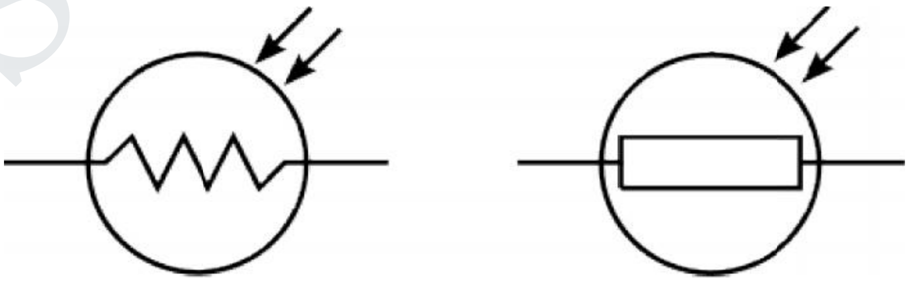


Figure 4.19 symbol of Photo-resistor

4.8.1 Working principle of LDR

A light dependent resistor works on the principle of photo conductivity. Photo conductivity is an optical phenomenon in which the materials conductivity (Hence resistivity) reduces when light is absorbed by the material.

When light falls i.e. when the photons fall on the device, the electrons in the valence band of the semiconductor material are excited to the conduction band. These photons in the incident light should have energy greater than the band gap of the semiconductor material to make the electrons jump from the valence band to the conduction band.

Hence when light having enough energy is incident on the device more & more electrons are excited to the conduction band which results in large number of charge carriers. The result of this process is more and more current starts flowing and hence it is said that the resistance of the device has decreased. This is the most common working principle of LDR

4.8.2 Characteristics of LDR

LDR's are light dependent devices whose resistance decreases when light falls on them and increases in the dark. When a light dependent resistor is kept in dark, its resistance is very high. This resistance is called as dark resistance. It can be as high as 1012 Ω.

If the device is allowed to absorb light, its resistance will decrease drastically. If a constant voltage is applied to it and intensity of light is increased the current starts increasing. Figure below shows resistance vs. illumination curve for a particular LDR.

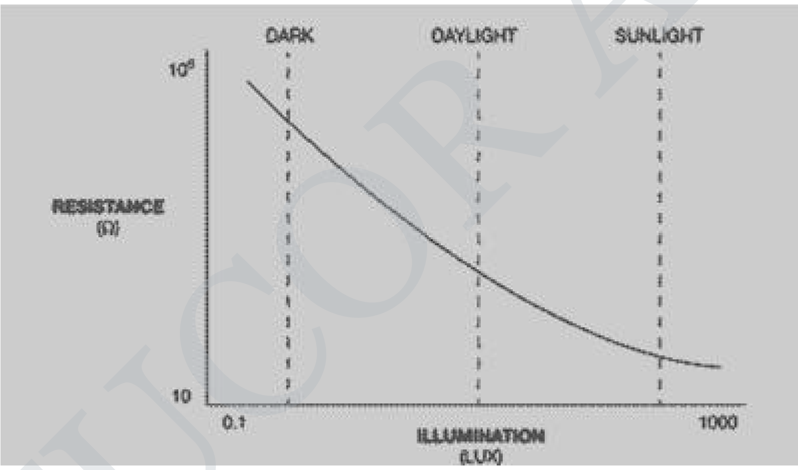


Figure 4.20 Characteristics of LDR

4.8.3 Applications of LDR

- LDR's have low cost and simple structure. They are often used as light sensors.
- They are used when there is a need to detect absences or presences of light like in a camera light meter.
- Used in street lamps, alarm clock, burglar alarm circuits, light intensity meters, for counting the packages moving on a conveyor belt, etc.

4.8.4 Advantages

LDR's are cheap and are readily available in many sizes and shapes. Practical LDRs are available in a variety of sizes and package styles, the most popular size having a face diameter of roughly 10 mm. They need very small power and voltage for its operation.

4.8.5 Disadvantages

Highly in-accurate with a response time of about tens or hundreds of milliseconds.

UNIT V POWER DEVICES AND DISPLAY DEVICES

5.1 UNI JUNCTION TRANSISTOR (UJT)

Unijunction transistor (abbreviated as UJT), also called the double-base diode is a 2-layer, 3-terminal solid-state (silicon) switching device. The device has-a unique characteristic that when it is triggered, its emitter current increases re generatively (due to negative resistance characteristic) until it is restricted by emitter power supply. Since the device has one pn junction and three leads it is commonly called UJT.

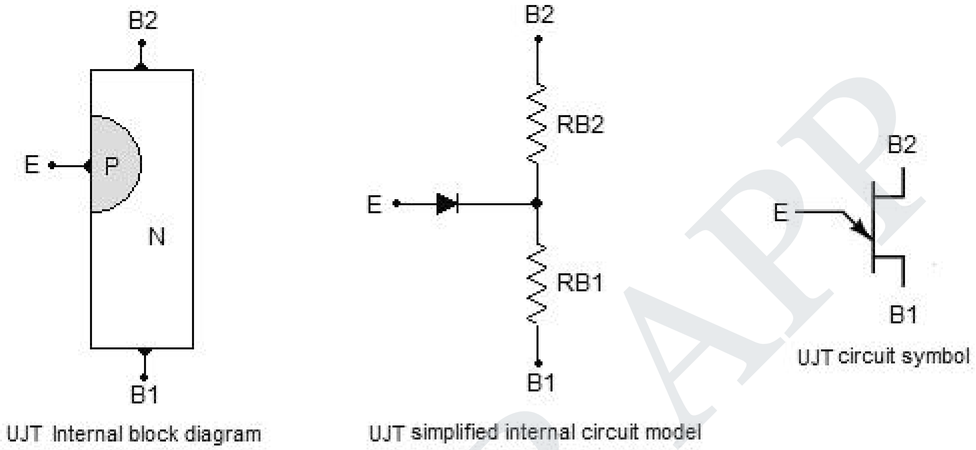


Figure 5.1 UJT structure, Equivalent circuit and Symbol

5.1.1 Construction of a UJT

The basic structure of a unijunction transistor is shown in figure. It essentially consists of a lightly-doped N-type silicon bar with a small piece of heavily doped P-type material alloyed to its one side to produce single P-N junction. The single P-N junction accounts for the terminology unijunction. The silicon bar, at its ends, has two ohmic contacts designated as base-1 (B_1) and base-2 (B_2), as shown and the P-type region is termed the emitter (E). The emitter junction is usually located closer to base-2 (B_2) than base-1 (B_1) so that the device is not symmetrical, because symmetrical unit does not provide optimum electrical characteristics for most of the applications.

The symbol for unijunction transistor is shown in figure. The emitter leg is drawn at an angle to the vertical line representing the N-type material slab and the arrowhead points in the direction of conventional current when the device is forward-biased, active or in the conducting state. The basic arrangement for the UJT is shown in figure.

A complementary UJT is formed by diffusing an N-type emitter terminal on a P-type base. Except for the polarities of voltage and current, the characteristics of a complementary UJT are exactly the same as those of a conventional UJT.

- The device has only one junction, so it is called the unijunction device.
- The device, because of one P-N junction, is quite similar to a diode but it differs from an ordinary diode as it has three terminals.
- The structure of a UJT is quite similar to that of an N-channel JFET. The main difference is that P-type (gate) material surrounds the N-type (channel) material in case of JFET and the gate surface of the JFET is much larger than emitter junction of UJT.

- In a unijunction transistor the emitter is heavily doped while the N-region is lightly doped, so the resistance between the base terminals is relatively high, typically 4 to 10 kilo Ohm when the emitter is open.
- The N-type silicon bar has a high resistance and the resistance between emitter and base-1 is larger than that between emitter and base-2. It is because emitter is closer to base-2 than base-1.
- UJT is operated with emitter junction forward- biased while the JFET is normally operated with the gate junction reverse-biased.
- UJT does not have ability to amplify but it has the ability to control a large ac power with a small signal. It exhibits a negative resistance characteristic and so it can be employed as an oscillator.

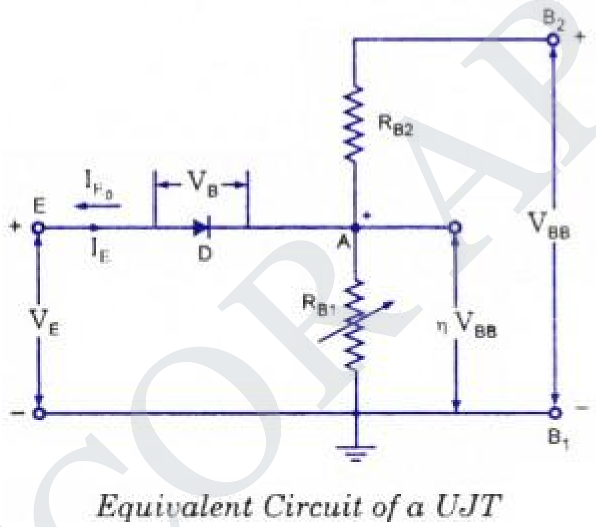


Figure 5.2 Equivalent circuit of UJT

5.1.2 UJT parameters

R_{BBO}: It is the resistance between the terminals B1 and B2. In simple words, it is the resistance of the N-Type bar when measured lengthwise. If RB1 is resistance of the bar from E to B1 and RB2 is the resistance of the bar from E to B2, then R_{BBO} can be expressed as R_{BBO}= RB1 +RB2. The typical range of R_{BBO} is from 4KΩ to 10KΩ.

Intrinsic standoff ratio (η) : It is the ratio of RB1 to the sum of RB1 and RB2. It can be expressed as η = RB1/(RB1+RB2) or η = RB1/R_{BBO}. The typical range of intrinsic standoff ratio is from 0.4 to 0.8

5.1.3 Operation of a UJT

Imagine that the emitter supply voltage is turned down to zero. Then the intrinsic stand-off voltage reverse-biases the emitter diode, as mentioned above. If V_B is the barrier voltage of the emitter diode, then the total reverse bias voltage is $V_A + V_B = \eta V_{BB} + V_B$. For silicon $V_B = 0.7$ V.

Now let the emitter supply voltage V_E be slowly increased. When V_E becomes equal to ηV_{BB}, I_{Eo} will be reduced to zero. With equal voltage levels on each side of the diode, neither reverse nor forward current will flow.

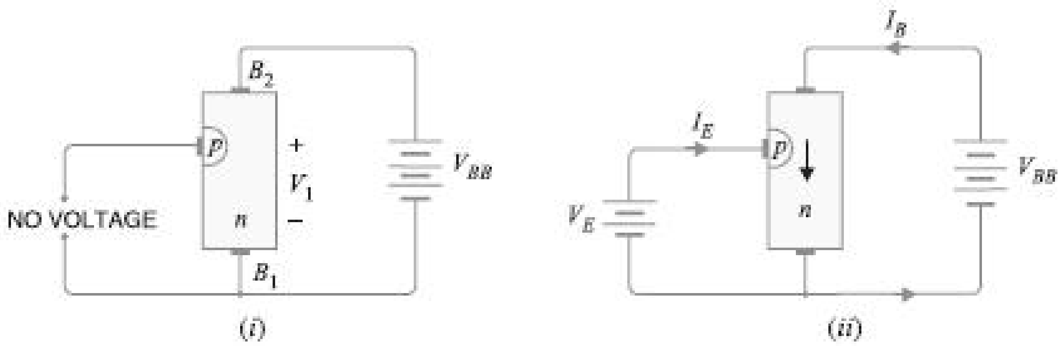
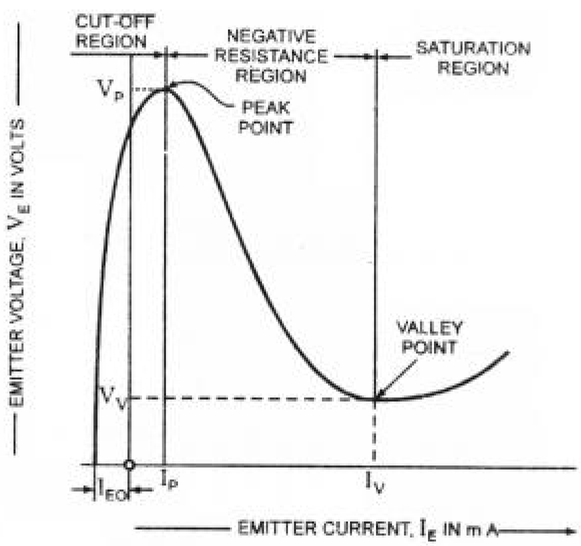


Figure 5.3 operation UJT under (i) V_E=0 (ii) applied V_E

When emitter supply voltage is further increased, the diode becomes forward-biased as soon as it exceeds the total reverse bias voltage ($\eta V_{BB} + V_B$). This value of emitter voltage V_E is called the peak-point voltage and is denoted by V_P. When $V_E = V_P$, emitter current I_E starts to flow through R_{B1} to ground, that is B_1. This is the minimum current that is required to trigger the UJT. This is called the peak-point emitter current and denoted by I_P. Ip is inversely proportional to the interbase voltage, V_{BB}.

Now when the emitter diode starts conducting, charge carriers are injected into the RB region of the bar. Since the resistance of a semiconductor material depends upon doping, the resistance of region RB decreases rapidly due to additional charge carriers (holes). With this decrease in resistance, the voltage drop across RB also decrease, cause the emitter diode to be more heavily forward biased. This, in turn, results in larger forward current, and consequently more charge carriers are injected causing still further reduction in the resistance of the RB region. Thus the emitter current goes on increasing until it is limited by the emitter power supply. Since VA decreases with the increase in emitter current, the UJT is said to have negative resistance characteristic. It is seen that the base-2 (B2) is used only for applying external voltage VBB across it. Terminals E and B1 are the active terminals. UJT is usually triggered into conduction by applying a suitable positive pulse to the emitter. It can be turned off by applying a negative trigger pulse.

5.1.4 UJT Characteristics



Static Emitter-Characteristic For a UJT

Figure 5.4 static Emitter Characteristics for a UJT

The static emitter characteristic (a curve showing the relation between emitter voltage V_E and emitter current I_E) of a UJT at a given inter base voltage V_{BB} is shown in figure. From figure it is noted that for emitter potentials to the left of peak point, emitter current I_E never exceeds I_{Eo} . The current I_{Eo} corresponds very closely to the reverse leakage current I_{Co} of the conventional BJT. This region, as shown in the figure, is called the cut-off region. Once conduction is established at $V_E = V_P$ the emitter potential V_E starts decreasing with the increase in emitter current I_E. This Corresponds exactly with the decrease in resistance R_B for increasing current I_E. This device, therefore, has a negative resistance region which is stable enough to be used with a great deal of reliability in the areas of applications listed earlier. Eventually, the valley point reaches, and any further increase in emitter current I_E places the device in the saturation region, as shown in the figure5.4.

Three other important parameters for the UJT are I_P, V_V and I_V and are defined below:

Peak-Point Emitter Current I_p : It is the emitter current at the peak point. It represents the rnimrnum current that is required to trigger the device (UJT). It is inversely proportional to the interbase voltage V_{BB}.

Valley Point Voltage V_V: The valley point voltage is the emitter voltage at the valley point. The valley voltage increases with the increase in interbase voltage V_{BB}.

Valley Point Current I_V: The valley point current is the emitter current at the valley point. It increases with the increase in inter-base voltage V_{BB}.

5.1.5 Special Features of UJT.

The special features of a UJT are :

1. A stable triggering voltage (V_P)— a fixed fraction of applied inter base voltage V_{BB}.
2. A very low value of triggering current.
3. A high pulse current capability.
4. A negative resistance characteristic.
5. Low cost.

5.1.6 Applications of UJT.

- Relaxation oscillators.
- Switching Thyristors like SCR, TRIAC etc.
- Magnetic flux sensors.
- Voltage or current limiting circuit.
- Bistable oscillators.
- Voltage or current regulators.
- Phase control circuits.

5.1.6.1 UJT relaxation oscillator.

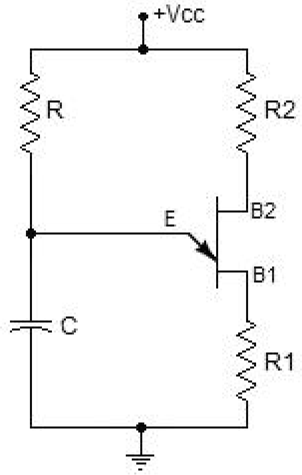


Figure 5.5 UJT relaxation oscillator

The circuit diagram of a UJT relaxation oscillator is given shown above. R1 and R2 are current limiting resistors. Resistor R and capacitor C determines the frequency of the oscillator.

The frequency of the UJT relaxation oscillator can be expressed by the equation

Where η is the intrinsic standoff ratio and *ln* stand for natural logarithm.

When power supply is switched ON the capacitor C starts charging through resistor R. The capacitor keeps on charging until the voltage across it becomes equal to 0.7V plus ηVbb. This voltage is the peak voltage point "Vp" denoted in the characteristics curve (Fig:2). After this point the emitter to RB1 resistance drops drastically and the capacitor starts discharging through this path. When the capacitor is discharged to the valley point voltage "Vv" (refer Fig : 1) the emitter to RB1 resistance climbs again and the capacitor starts charging. This cycle is repeated and results in a sort of sawtooth waveform across the capacitor. The saw tooth waveform across the capacitor of a typical UJT relaxation oscillator is shown in the figure below.

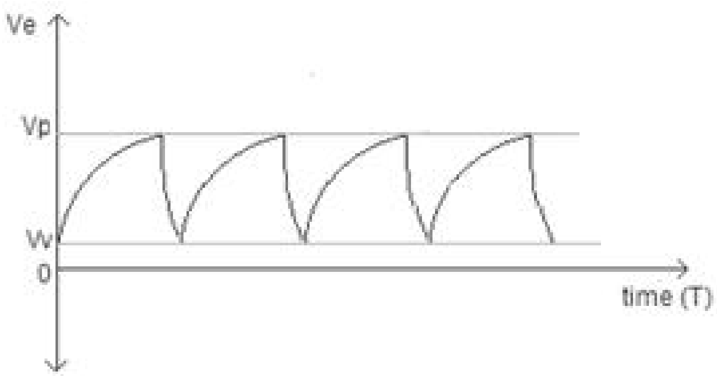


Figure 5.6 wave across the capacitor in a UJT relaxation oscillator

5.2 SILICON CONTROLLED RECTIFIER (SCR)

5.2.1Introduction

The SCR stand for Silicon Control Rectifier, it is used in industries because it can handle high values of current and voltage.

Three terminals

- Anode - P-layer
- Cathode - N-layer (opposite end)
- Gate - P-layer near the cathode

Three junctions - four layers

Connect power such that the anode is positive with respect to the cathode - no current will flow

A silicon controlled rectifier is a semiconductor device that acts as a true electronic switch. It can change alternating current and at the same time can control the amount of power fed to the load. SCR combines the features of a rectifier and a transistor.

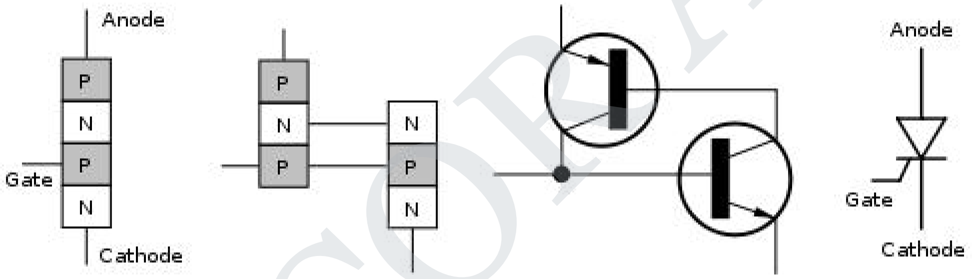


Figure 5.7 Basic Structure, equivalent transistor model and symbol of SCR

5.2.2 Construction

When a pn junction is added to a junction transistor the resulting three pn junction device is called a SCR. ordinary rectifier (pn) and a junction transistor (npn) combined in one unit to form pnpn device.

Three terminals are taken : one from the outer p- type material called anode a second from the outer n- type material called cathode K and the third from the base of transistor called Gate. GSCR is a solid state equivalent of thyratron. The gate anode and cathode of SCR correspond to the grid plate and cathode of thyratron SCR is called thyristor.

5.2.3 Working Principle

Load is connected in series with anode the anode is always kept at positive potential w.r.t cathode.

5.2.3.1 SCR Operation / Working

The Silicon Control Rectifier SCR start conduction when it is forward biased. For this purpose the cathode is kept at negative and anode at positive. When positive clock pulse is applied at the gate the SCR turns ON.

When forward bias voltage is applied to the Silicon Control Rectifier SCR, the junction J1 and J3 become forward bias while the junction J2 become reverse bias.

When we apply a clock pulse at the gate terminal, the junction J2 become forward bias and the Silicon Control Rectifier SCR start conduction.The Silicon Control Rectifier SCR turn ON and OFF very quickly, At the OFF state the Silicon Control Rectifier SCR provide infinity resistance and in ON state, it offers very low resistance, which is in the range of 0.01O to 1O.

5.2.3.2 SCR Firing & Triggering

The Silicon Control Rectifier SCR is normally operated below the forward break over voltage (VBO). To turn ON the Silicon Control Rectifier SCR we apply clock pulse at the gate terminal which called triggering of Silicon Control Rectifier, but when the Silicon Control Rectifier SCR turned ON, now if we remove the triggering voltage, the Silicon Control Rectifier SCR will remain in ON state. This voltage is called Firing voltage.

5.2.3.3 When Gate is Open

No voltage applied to the gate, j2 is reverse biased while j1 and j3 are FB . J1 and J3 is just in npn transistor with base open .no current flows through the load RL and SCR is cut off. If the applied voltage is gradually increased a stage is reached when RB junction J2 breakdown .the SCR now conducts heavily and is said to be ON state. the applied voltage at which SCR conducts heavily without gate voltage is called Break over Voltage.

5.2.3.4 When Gate is Positive w.r.to Cathode:-

The SCR can be made to conduct heavily at smaller applied voltage by applying small positive potential to the gate.J3 is FB and J2 is RB the electron from n type material start moving across J3 towards left holes from p type toward right. Electrons from j3 are attracted across junction J2 and gate current starts flowing. as soon as gate current flows anode current increases. the increased anode current in turn makes more electrons available at J2 breakdown and SCR starts conducting heavily. the gate loses all control if the gate voltage is removed anode current does not decrease at all. The only way to stop conduction is to reduce the applied voltage to zero.

Break over Voltage

It is the minimum forward voltage gate being open at which SCR starts conducting heavily i.e turned on.

Peak Reverse Voltage (PRV)

It is the maximum reverse voltage applied to an SCR without conducting in the reverse direction.

Holding Current

It is the maximum anode current gate being open at which SCR is turned off from on conditions.

Forward Current Rating

It is the maximum anode current that an SCR is capable of passing without destruction

Circuit Fusing Rating

It is the product of of square of forward surge current and the time of duration of the surge.

5.2.4 Turning OFF methods of Silicon Control Rectifier - SCR

There are two methods through which Silicon Control Rectifier SCR can be turned OFF,

5.2.4.1 Anode current interruption method

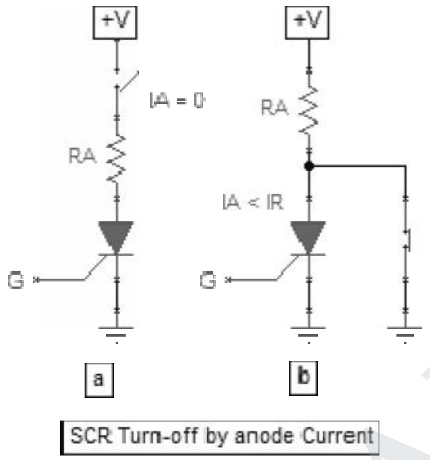


Figure 5.8 SCR turn-off by anode Current

In this method a parallel or a series switch is used to turn OFF the Silicon Control Rectifier (SCR electronics) by turning OFF the switch.

5.2.4.2 Forced Commutation method

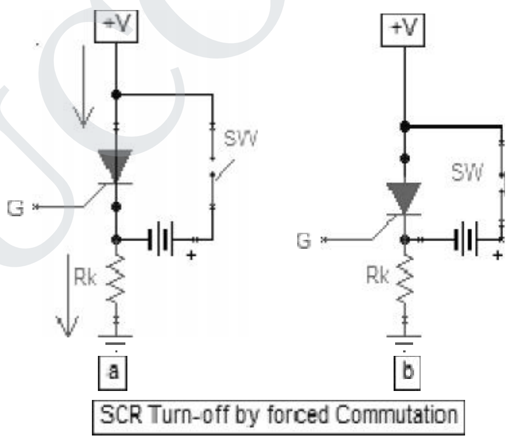


Figure 5.8 SCR turn-off by forced communication

In this method a reversed polarity battery is connected, so the current through the Silicon Control Rectifier SCR is reduced and it turn OFF.

5.2.5 V-I Characteristics of SCR

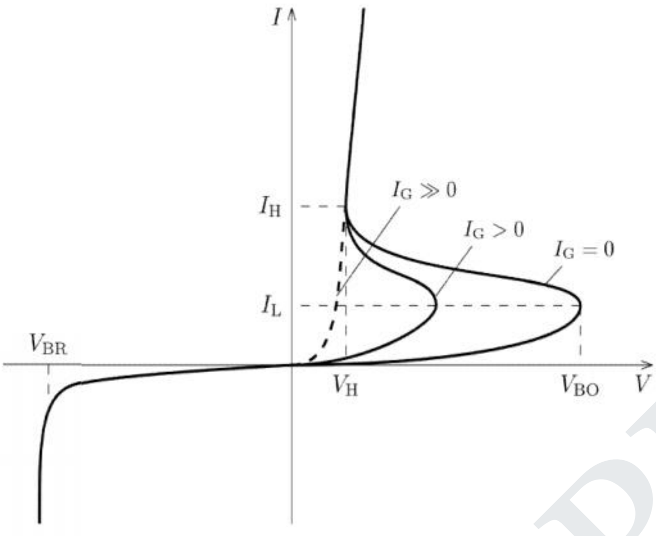


Figure 5.9 V-I Characteristics of SCR

5.2.5.1 Forward Characteristics

When anode is +ve w.r.t cathode the curve between V & I is called Forward characteristics. OABC is the forward characteristics of the SCR at Ig =0. if the supplied voltage is increased from zero point A is reached .SCR starts conducting voltage across SCR suddenly drops (dotted curve AB) most of supply voltage appears across RL

5.2.5.2 Reverse Characteristics

When anode is –ve w.r.t cathode the curve b/w V&I is known as reverse characteristics reverse voltage come across SCR when it is operated with ac supply reverse voltage is increased anode current remains small avalanche breakdown occurs and SCR starts conducting heavily is known as reverse breakdown voltage.

5.2.5.3 Application

- SCR as a switch
- SCR Half and Full wave rectifier
- SCR as a static contactor
- SCR for power control
- SCR for speed control of d.c.shunt motor
- Over light detector

5.3 DIAC (DIODE A.C. SWITCH)

The DIAC is a full-wave or bi-directional semiconductor switch that can be turned on in both forward and reverse polarities.The DIAC gains its name from the contraction of the words DIode Alternating Current.

The DIAC is widely used to assist even triggering of a TRIAC when used in AC switches. DIACs are mainly used in dimmer applications and also in starter circuits for florescent lamps.

A Diac is two terminal , three layer bi directional device which can be switched from its off state for either polarity of applied voltage.

5.3.1 Circuit symbol

The DIAC circuit symbol is generated from the two triangles held between two lines as shown below. In some way this demonstrates the structure of the device which can be considered also as two junctions

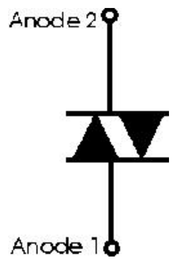


Figure 5.10 symbol of DIAC

The two terminals of the device are normally designated either Anode 1 and Anode 2 or Main Terminals 1 and 2, i.e. MT1 and MT2.

5.3.2 Construction

The DIAC can be constructed in either npn or pnp form. The two leads are connected to p regions of silicon separated by an n- region. The structure of DIAC is similar to that of a transistor differences are

- There is no terminal attached to the base layer
- The three regions are nearly identical in size. The doping concentrations are identical to give the device symmetrical properties.

The DIAC can e fabricated as either a two layer or a five layer structure. In the three layer structure the switching occurs when the junction that is reverse biased experiences reverse breakdown. The three layer version of the device is the more common and can have a break-over voltage of around 30 V. Operation is almost symmetrical owing to the symmetry of the device.

A five layer DIAC structure is also available. This does not act in quite the same manner, although it produces an I-V curve that is very similar to the three layer version. It can be considered as two break-over diodes connected back to back.

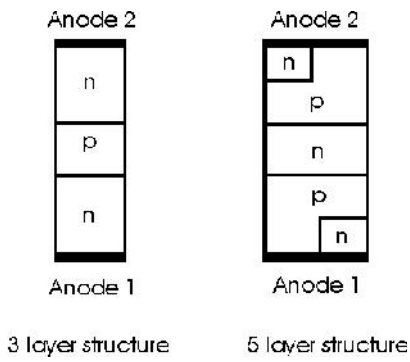


Figure 5.11 The structure of a DIAC

For most applications a three layer version of the DIAC is used. It provides sufficient improvement in switching characteristics. For some applications the five layer device may be used.

5.3.3 Operation

When a positive or negative voltage is applied across the terminals of Diac only a small leakage current Ibo will flow through the device as the applied voltage is increased , the leakage current will continue to flow until the voltage reaches breakover voltage Vbo at this point avalanche breakdown of the reverse biased junction occurs and the device exhibits negative resistance i.e current through the device increases with the decreasing values of applied voltage the voltage across the device then drops to break back voltage Vw.

5.3.4 V- I characteristics of a DIAC

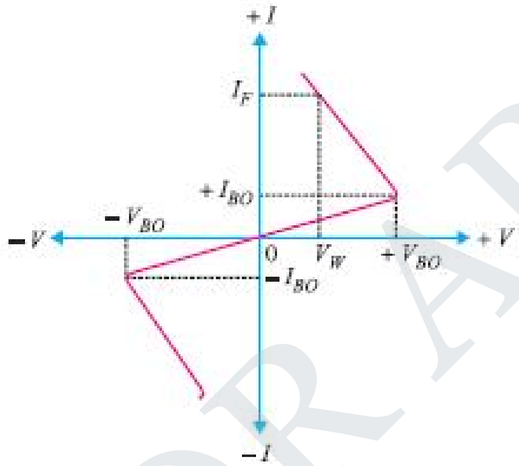


Figure 5.11 V- I characteristics of a DIAC

For applied positive voltage less than + Vbo and Negative voltage less than -Vbo , a small leakage current flows thrugh the device. Under such conditions the diac blocks flow of current and behaves as an open circuit. the voltage +Vbo and -Vbo are the breakdown voltages and usually have range of 30 to 50 volts.

When the positive or negative applied voltage is equal to or greater than tha breakdown voltage Diac begins to conduct and voltage drop across it beco mes a few volts conduction then continues until the device current drops below its holding current breakover voltage and holding current values are identical for the forward and reverse regions of operation.

5.3.5 Applications

Diacs are used for triggering of triacs in adjustable phase control of a c mains power. Applications are light dimming heat control universal motor speed control.Typically the DIAC is placed in series with the gate of a TRIAC. DIACs are often used in conjunction with TRIACs because these devices do not fire symmetrically as a result of slight differences between the two halves of the device. This results in harmonics being generated, and the less symmetrical the device fires, the greater the level of harmonics produced. It is generally undesirable to have high levels of harmonics in a power system.

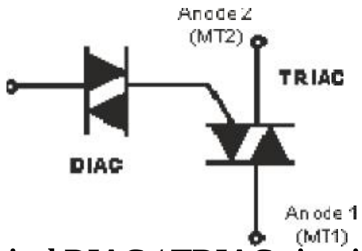


Figure 5.12 Typical DIAC / TRIAC circuit configuration

To help in overcoming this problem, a DIAC is often placed in series with the gate. This device helps make the switching more even for both halves of the cycle. This results from the fact that its switching characteristic is far more even than that of the TRIAC. Since the DIAC prevents any gate current flowing until the trigger voltage has reached a certain voltage in either direction, this makes the firing point of the TRIAC more even in both directions.

5.4 TRIAC

The TRIAC is a three terminal semiconductor device for controlling current. It gains its name from the term TRIode for Alternating Current.

It is effectively a development of the SCR or thyristor, but unlike the thyristor which is only able to conduct in one direction, the TRIAC is a bidirectional device.

5.4.1 TRIAC symbol

The circuit symbol recognises the way in which the TRIAC operates. Seen from the outside it may be viewed as two back to back thyristors and this is what the circuit symbol indicates.

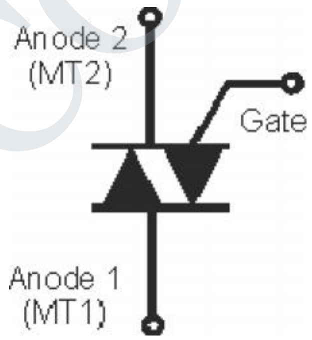


Figure 5.13 TRIAC symbol for circuit diagrams

On the TRIAC symbol there are three terminals. These are the Gate and two other terminals are often referred to as an "Anode" or "Main Terminal". As the TRIAC has two of these they are labelled either Anode 1 and Anode 2 or Main Terminal, MT1 and MT2.

5.4.2 TRIAC basics

The TRIAC is a component that is effectively based on the thyristor. It provides AC switching for electrical systems. Like the thyristor, the TRIACs are used in many electrical switching applications. They find particular use for circuits in light dimmers, etc., where they enable both halves of the AC cycle to be used.

This makes them more efficient in terms of the usage of the power available. While it is possible to use two thyristors back to back, this is not always cost effective for low cost and relatively low power applications.

It is possible to view the operation of a TRIAC in terms of two thyristors placed back to back.

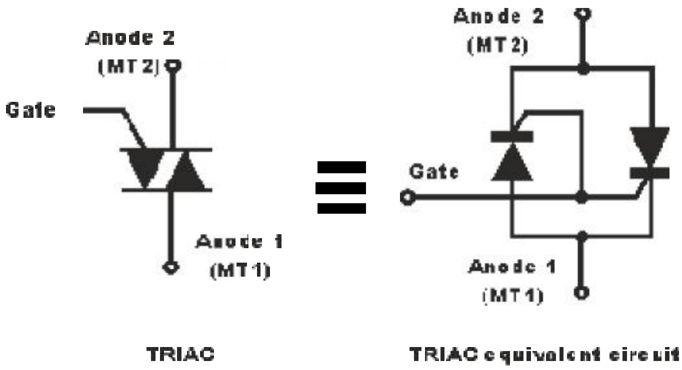


Figure 5.14 TRIAC symbol, equivalent as two thyristors

One of the drawbacks of the TRIAC is that it does not switch symmetrically. It will often have an offset, switching at different gate voltages for each half of the cycle. This creates additional harmonics which is not good for EMC performance and also provides an imbalance in the system

In order to improve the switching of the current waveform and ensure it is more symmetrical is to use a device external to the TRIAC to time the triggering pulse. A DIAC placed in series with the gate is the normal method of achieving this.

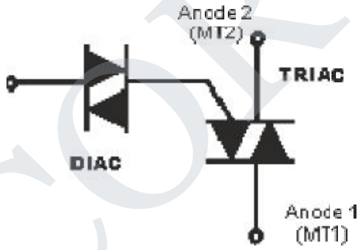


Figure 5.15 DIAC and TRIAC connected together

5.4.3 Operation

With switch S open, there will be no gate current and the triac is cut off. Even with no current the triac can be turned on provided the supply voltage becomes equal to the breakover voltage.

When switch S is closed, the gate current starts flowing in the gate circuit. Breakover voltage of triac can be varied by making proper currnt flow. Triac starts to conduct wheather MT2 is positive or negative w.r.t MT1.

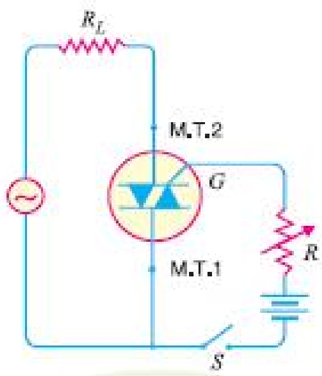


Figure 5.16 TRIAC operation under biasing

If terminal MT2 is positive w.r.t MT1 the TRIAC is on and the conventional current will flow from MT2 to MT1. If terminal MT2 is negative w.r.t MT1 the TRIAC is again turned on and the conventional current will flow from MT1 to MT2.

5.4.4Characteristics

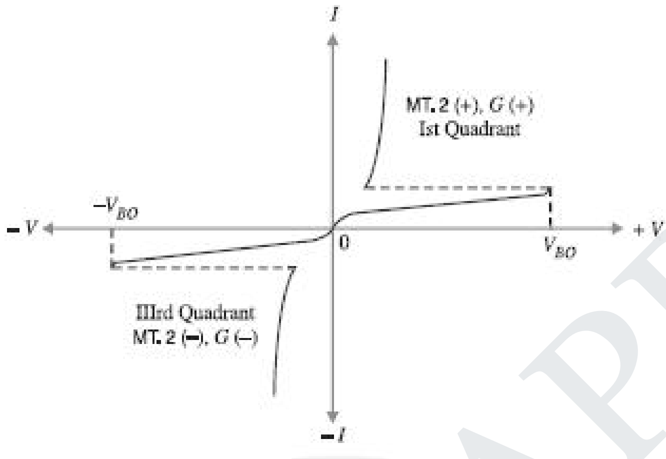


Figure 5.16 The V-I Characteristics curve for TRIAC

The V-I curve for triac in the Ist and IIIrd quadrants are essentially identical to SCR in the Ist quadrant.The triac can be operated with either positive or negative gate control voltage but in normal operation usually the gate voltage is positive in quadrant I and negative in quadrant III. The supply voltage at which the triac is ON depends upon gate current. The greater gate current and smaller supply voltage at which triac is turned on. This permits to use triac to control a,c. power in a load from zero to full power in a smooth and continuous manner with no loss in the controlling device.

5.4.5 Advantages and disadvantages

When requiring to switch both halves of an AC waveform there are two options that are normally considered. One is to use a TRIAC, and the other is to use two thyristors connected back to back - one thyristor is used to switch one half of the cycle and the second connected in the reverse direction operates on the other half cycle.As there are two options the advantages and disadvantages of using a TRIAC must be weighed up.

Advantages

- Can switch both halves of an AC waveform
- Single component can be used for full AC switching

Disadvantages

- A TRIAC does not fire symmetrically on both sides of the waveform
- Switching gives rise to high level of harmonics due to non-symmetrical switching
- More susceptible to EMI problems as a result of the non-symmetrical switching
- Care must be taken to ensure the TRIAC turns off fully when used with inductive loads.

5.4.6 Applications

TRIACs are used in a number of applications. However they tend not to be used in high power switching applications - one of the reasons for this is the non-symmetrical switching characteristics. For high power applications this creates a number of difficulties, especially with electromagnetic interference.

However TRIACs are still used for many electrical switching applications:

- Domestic light dimmers
- Electric fan speed controls
- Small motor controls
- Control of small AC powered domestic appliances

5.5 POWER BJT

5.5.1Introduction

Bipolar Junction Transistor (BJT) is a three terminal, three layer, two junction semiconductor device. Emitter(E), Base(B) and Collector(C) are the three terminals of the device.

Symbol: The symbol of the Power BJT is same as signal level transistor.

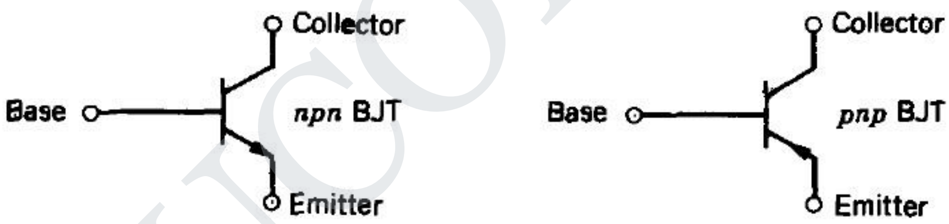


Figure 5.17 Symbol of power BJT

5.5.2 Structure

The construction of the Power Transistor is different from the signal transistor as shown in the following figure. The n- layer is added in the power BJT which is known as drift region.

- A Power BJT has a four layer structure of alternating P and N type doping as shown in above npn transistor.
- It has three terminals labeled as Collector, Base, Emitter.
- In most of Power Electronic applications, the Power Transistor works in Common Emitter configuration.
- ie, Base is the input terminal, the Collector is the output terminal and the Emitter is common between input and output.
- In power switches npn transistors are most widely used than pnp transistors.
- The thickness of the dirft region determines the breakdown voltage of the Power transistor.

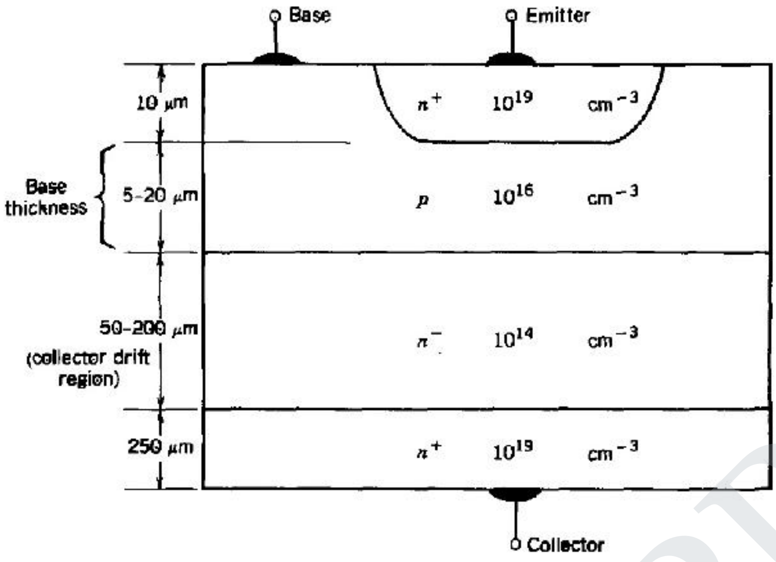


Figure 5.18 Structure of Power BJT

- The characteristics of the device is determined by the doping level in each of the layers and the thickness of the layers.

5.5.3 VI Characteristics

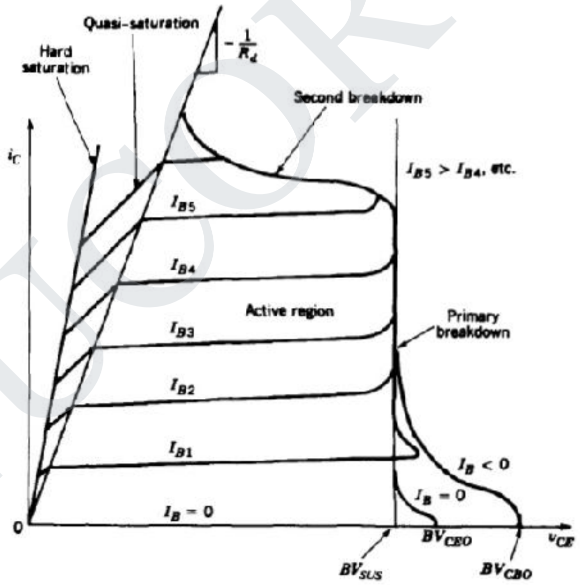


Figure 5.18 VI Characteristics Power BJT

- The VI characteristics of the Power BJT is different from signal level transistor.
- The major differences are Quasi saturation region & secondary breakdown region.
- The Quasi saturation region is available only in Power transistor characteristic not in signal transistors. It is because of the lightly doped collector drift region present in Power BJT.
- The primary breakdown is similar to the signal transistor's avalanche breakdown.
- Operation of device at primary and secondary breakdown regions should be avoided as it will lead to the catastrophic failure of the device.

5.6 POWER MOSFET

5.6.1Introduction:

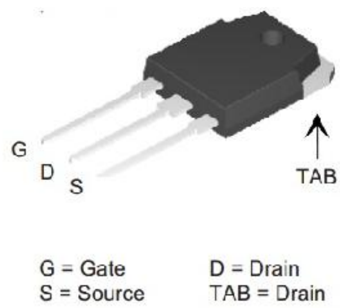


Figure 5.19 IC model for Power MOSFET

A metal-oxide-semiconductor field-effect transistor(MOSFET) is developed by combining the areas of field-effect concept and MOS technology.The Conventional planar MOSFET has the restriction of handling the high power. In high power applications, the Double-diffused vertical MOSFET or VMOS is used which is simply known as Power MOSFET.

5.6.2 Power MOSFET

The Power MOSFET is the three terminal (Gate, Drain and Source), four layer (n^+pnn^{+}),Unipolar (only majority carriers in conduction) semiconductor device.

- The MOSFET is a majority carrier device, and as the majority carriers have no recombination delays, the MOSFET achieves extremely high bandwidths and switching times.
- The gate is electrically isolated from the source, and while this provides the MOSFET with its high input impedance, it also forms a good capacitor.
- MOSFETs do not have secondary breakdown area, their drain to source resistance has a positive temperature coefficient, so they tend to be self protective.
- It has very low ON resistance and no junction voltage drop when forward biased. These features make MOSFET an extremely attractive power supply switching device.

5.6.3Symbol

The symbol for n-channel MOSFET is given below. The direction of the arrow on the lead that goes to the body region indicates the direction of current flow. As this is the symbol for n channel MOSFET, the arrow is inwards. For p-channel MOSFET, the arrow will be towards outside.

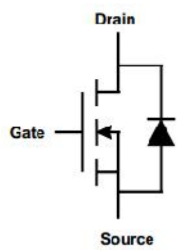


Figure 5.20 Symbol of Power MOSFET

5.6.4 Structure

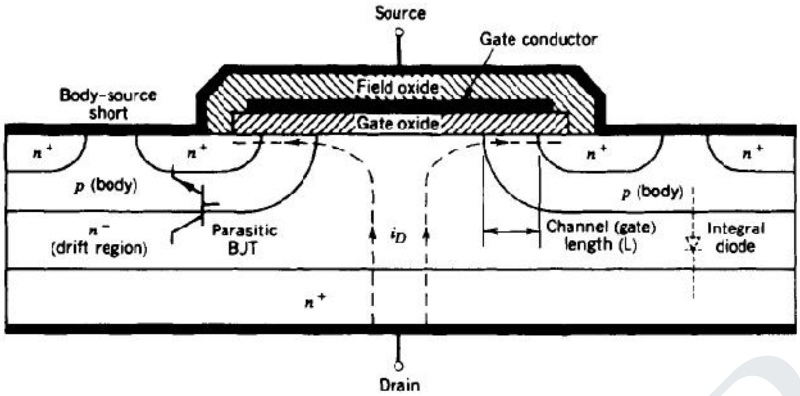


Figure 5.20 Structure of Power MOSFET

- The Power MOSFET has a vertically oriented four layer structure of alternating P and N type($n^+pn^-n^+$) layers.
- The P type middle layer is called as body of MOSFET. In this region , the channel is formed between source and drain.
- The n- layer is called as drift region,which determines the breakdown voltage of the device. This n- region is present only in Power MOSFETs not in signal level MOSFET.
- The gate terminal is isolated from body by silicon dioxide layer.
- When the positive gate voltage is applied with respect to source, the n-type channel is formed between source to drain. As shown in the figure 5.20 there is a parasitic npn BJT between source and drain.
- To avoid this BJT turns on, the p-type body region is shorted to source region by overlapping the source metallization on to the p type body. The result is a parasitic diode which is formed between drain to source terminals. This integral diode plays an important role in half and full bridge converter circuits.

5.6.5Characteristics

The VI characteristics of n-channel enhancement mode MOSFET.

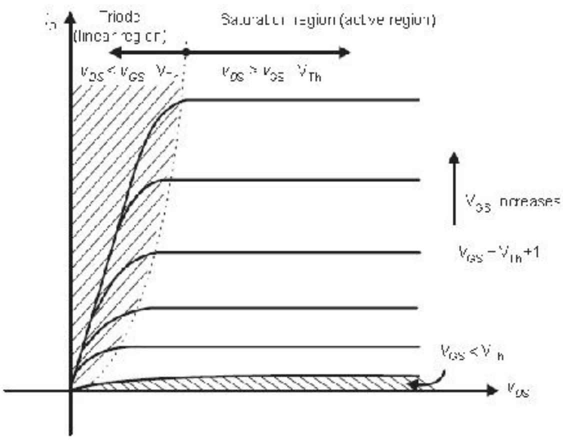


Figure 5.21 V-I characteristics of n-channel enhancement mode MOSFET

5.7 DOUBLE-DIFFUSED MOS (DMOS)

The figure5.22 shows a double-diffused MOS (DMOS) structure. The channel length, L, is controlled by the junction depth produced by the n^+ and p-type diffusions underneath the gate oxide. L is also the lateral distance between the n^+ p junction and the p-n substrate junction. The channel length can be made to a smaller distance of about 0.5 micro meters. Thus, this process is similar to the situation with respect to the base width of a double-diffused bipolar transistor. When a fairly large positive voltage is applied to the gate [$>V_{TH}$], it will cause the inversion of the p-substrate region underneath the gate to n- type , and the n-type surface inversion layer that is produced will act as a conducting channel for the flow of electrons from source to drain.

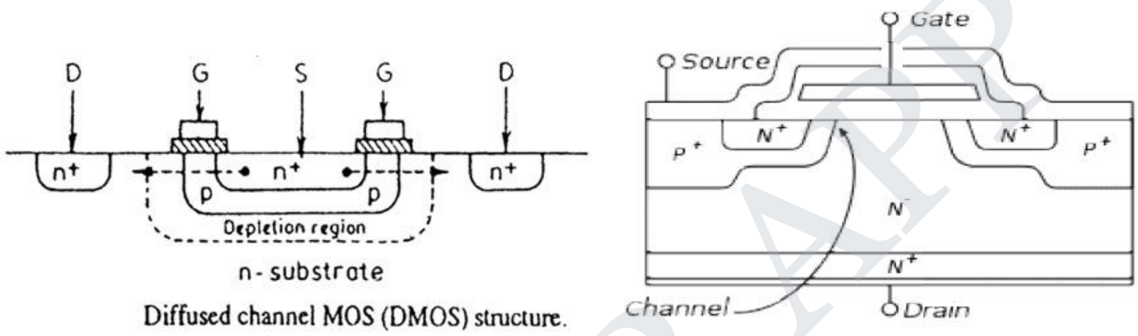


Figure 5.22 Double-Diffused MOS (DMOS) Structure

From the structure it is known that the n-type substrate is very lightly doped. This will help in making enough space for the expansion of the depletion region between the p-type diffusion region and the n^+ drain contact region. Due to this, the breakdown voltage will become higher between the drain and source

5.8 V-GROOVE MOS (VMOS)

5.8.1 VMOS Structure

The structure of VMOS is similar to short-channel power FET that is constructed as a vertical structure. The operation is same as that of a Double-Diffused MOS (DMOS) device. Take a look at the figure below to know more about the VMOS structure. This device, like a DMOS device has a channel length which is set by the difference between the p-type and n^+ diffusions.

In VMOS, the p-type epitaxial layer is lightly doped. Along with this, the space available for the expansion of the depletion region between the p^+ diffused layer and the n^+ substrate will cause a high breakdown voltage (BV_{DS}) and a low drain capacitance. That is, the breakdown voltage will be almost greater than or equal to 50 Volts. Due to the heavily doped n^+ substrate, the value of the drain series resistance is kept very small.

The outer wall of the VMOS has an SiO_2 insulation layer, which is covered by an aluminum layer. This aluminum layer acts as the gate for the device. In a VMOS device the thickness of the layer does not depend on the mask resolution. And due to the fact that a conventional mask lithographic process is used for its fabrication, the p-region is stretched as a channel above the substrate. Thus, it is easy to make a channel as short as 1micro meter, which is essential for high-speed MOSFETs.

Another unique feature of VMOS is the anisotropically-etched V-groove cut normally to the surface that extends through both the n^+, p regions and penetrates slightly through the epitaxial region. Due to this, it is easier for the gate to overlay the p-diffusion which acts as the current conducting channel. The packing density of such devices on a chip is more as the MOSFET's are formed on the slopes of the grooves.

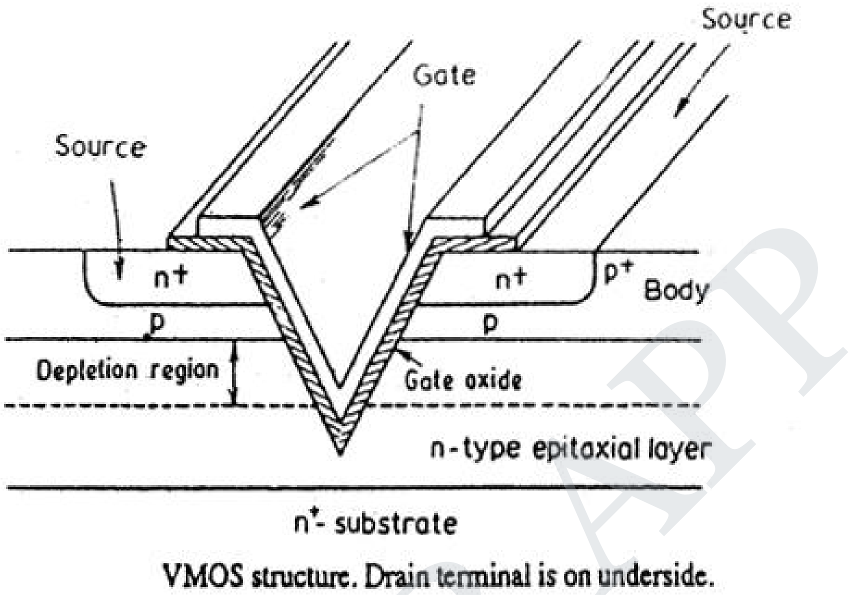


Figure 5.22 VMOS structure

The V-grooves are produced by an anisotropic or orientation – dependent etching (ODE) process. The etchant, which is usually KOH at (80 to 100)°C, attacks silicon very rapidly in the [100] crystallographic direction, but very slowly in the [111] direction. In the case of (100) oriented silicon substrates the result will be the production of V-shaped grooves that have (111) side walls as shown in the figure below.

The angle of the (111) groove side walls with respect to the (100) silicon surface will be 54.74°. The width of the opening in the oxide layer controls the width of the grooves, W. The oxide layer width is used as an etching mask since SiO_2 is attacked only very slowly by the etching solution.

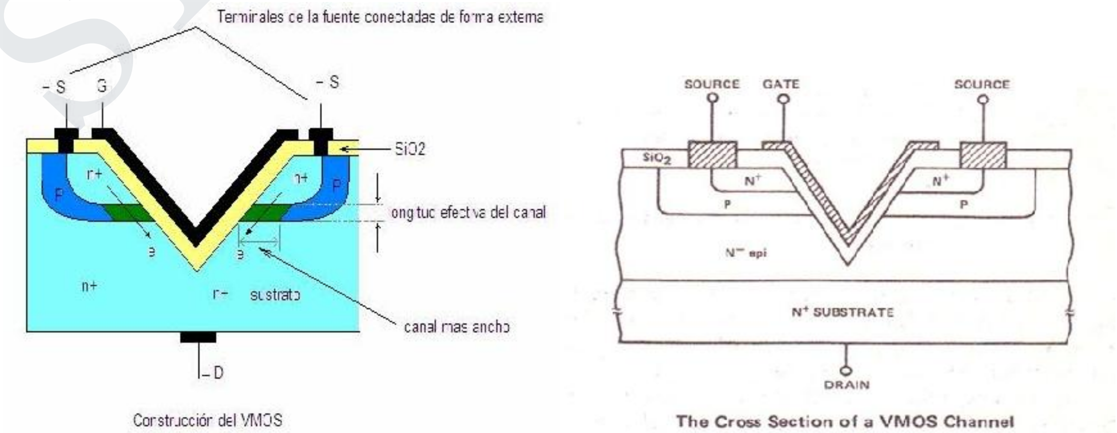


Figure 5.23 Cross sectional view of VMOS

There is also the existence of two conduction paths between drain and source, as shown in Fig., to further contribute to a higher current rating. The net result is a device with drain currents that can reach the ampere levels with power levels exceeding 10 W.

Compared with commercially available planar MOSFETs, VMOS FETs have reduced channel resistance levels and higher current and power ratings.VMOS FETs have a positive temperature coefficient that will combat the possibility of thermal runaway.

The reduced charge storage levels result in faster switching times for VMOS construction compared to those for conventional planar construction.

In fact, VMOS devices typically have switching times less than one-half that encountered for the typical BJT transistor.

5.8.2 VMOS Applications

- Hi-fi audio power amplifiers
- Broadband high-frequency amplifiers, and
- Switching power amplifiers which converts ac power sources into dc at arbitrary voltage.

Such power supplies made from VMOS will have lower cost, lighter weight, and smaller size than conventional power supplies.

5.9 LIQUID-CRYSTAL DISPLAYS (LCD)

Liquid crystal cell displays (LCDs) are used in similar applications where LEDs are used. These applications are display of numeric and alphanumeric characters in dot matrix and segmental displays.
The LCDs are of two types :

- Dynamic scattering type and
- Field effect type.

The liquid crystal material may be one of the several organic compounds which exhibit optical properties of a crystal though they remain In liquid form. Liquid crystal is layered between glass sheets with transparent electrodes deposited on the inside faces. When a potential is applied across the cell, charge carriers flowing through the liquid disrupt the molecular arrangement and produce turbulence.

When the liquid is not activated, it is transparent. When the liquid is activated the molecular turbulence causes light to be scattered in all directions and the cell appears to be bright. The phenomenon is called **dynamic scattering.**

The construction of a field effect liquid crystal display is similar to that of the dynamic scattering type, with the exception that two thin polarizing optical filters are placed at the inside of each glass sheet. The liquid crystal material in the field effect cell is also of different type from that employed in the dynamic scattering cell.

The material used is twisted nematic type and actually twists the light passing through the cell when the latter is not energized. This allows the 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.

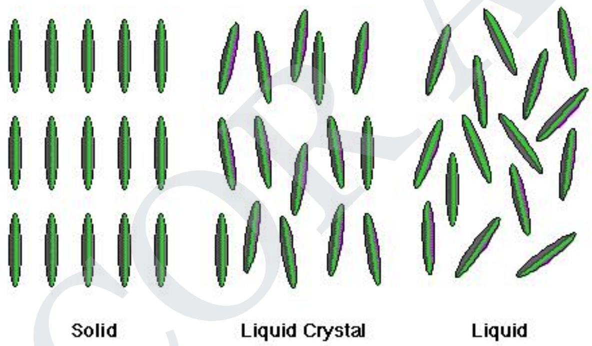
Liquid crystal cells are of two types. (i) Transmittive type and (ii) Reflective type.

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.

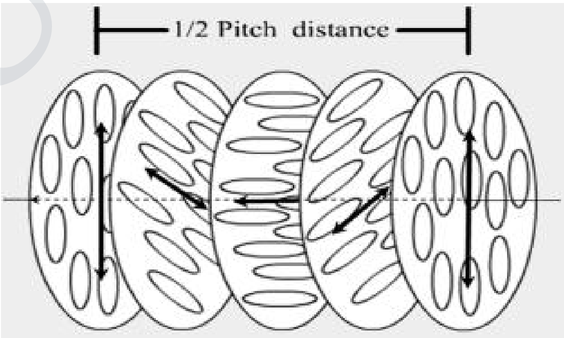
The reflective type cell has a reflecting surface on one side of glass sheets. The incident light on the front surface of the cell is dynamically scattered by an activatedcell. Both types of cells appear quite bright when activated even under ambient light conditions.

The liquid crystals are light reflectors or transmitters and therefore they consume small amounts of energy (unlike light generators). Unlike LEDs which can work on d.c. the LCDs require a.c. voltage supply. A typical voltage supply to dynamic scattering LCD is 30 V peak to peak with 50Hz.

The liquid-crystal display (LCD) has the distinct advantage of having a lower power requirement than the LED. It is typically in the order of microwatts for the display, as compared to the same order of milliwatts for LEDs. It does, however, require an external or internal light source and is limited to a temperature range of about 0° to 60°C. Lifetime is an area of concern because LCDs can chemically degrade. The types receiving the major interest today are the field-effect and dynamic-scattering units.



(i)



(ii)

Figure 5.24 Schematic arrangements of molecules in liquid crystal (i)Nematic, (ii) Cholesteric

A liquid crystal is a material (normally organic for LCDs) that will flow like a liquid but whose molecular structure has some properties normally associated with solids.

For the light-scattering units, the greatest interest is in the nematic liquid crystal, having the crystal structure shown in Figure 5.27

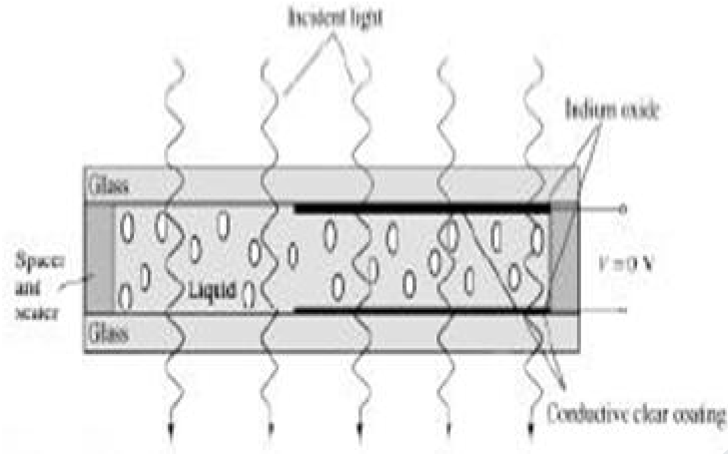


Figure 5.27 Nematic liquid crystal with no applied bias

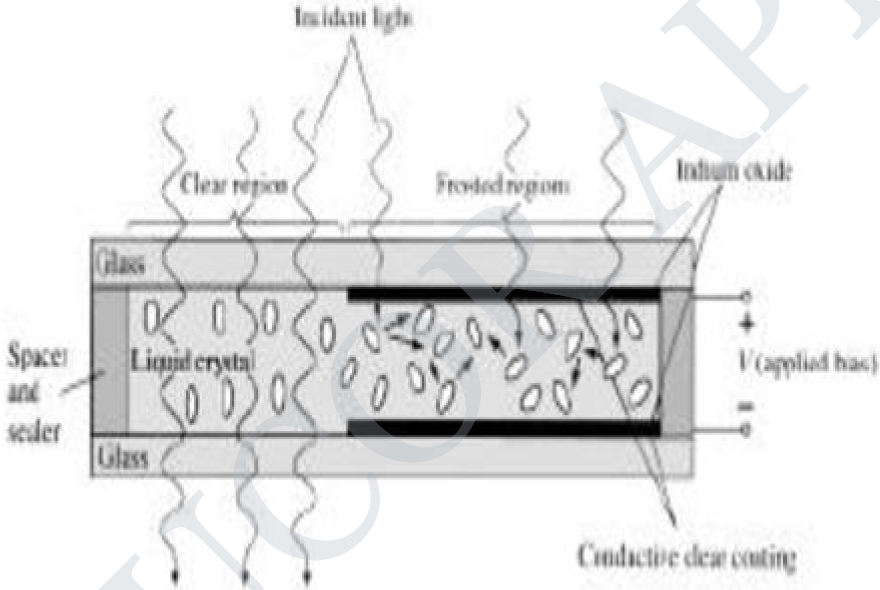


Figure 5.28 Nematic liquid crystal with applied bias

The field-effect or twisted nematic LCD has the same segment appearance and thin layer of encapsulated liquid crystal, but its mode of operation is very different.

Similar to the dynamic- scattering LCD, the field-effect LCD can be operated in the reflective or transmissive mode with an internal source.

The transmissive display appears in Figure 5.29 The internal light source is on the right, and the viewer is on the left.

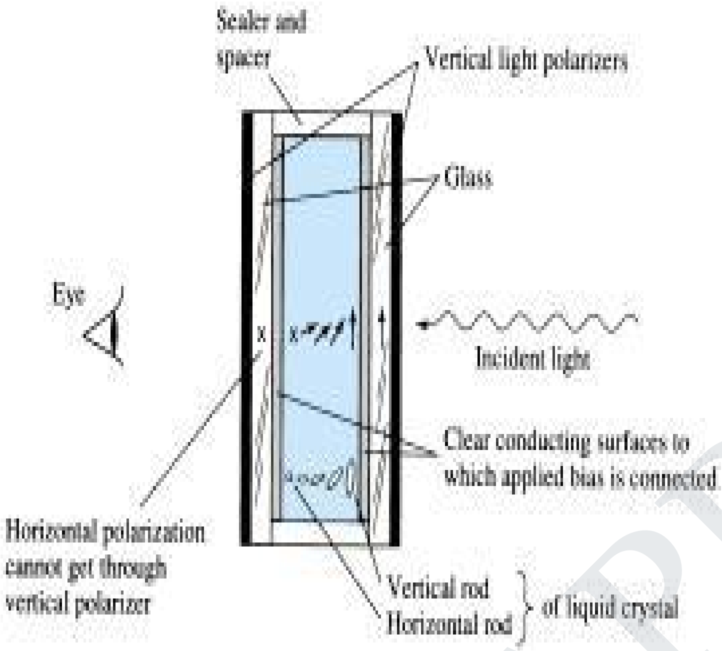


Figure 5.29 Transmissive field effect LCD with no applied bias

The reflective-type field-effect LCD is shown in Figure 5.30 In this case, the horizontally polarized light at the far left encounters a horizontally polarized filter and passes through to the reflector, where it is reflected back into the liquid crystal, bent back to the other vertical polarization, and returned to the observer.

If there is no applied voltage, there is a uniformly lit display. The application of a voltage results in a vertically incident light encountering a horizontally polarized filter at the left, which it will not be able to pass through and will be reflected.

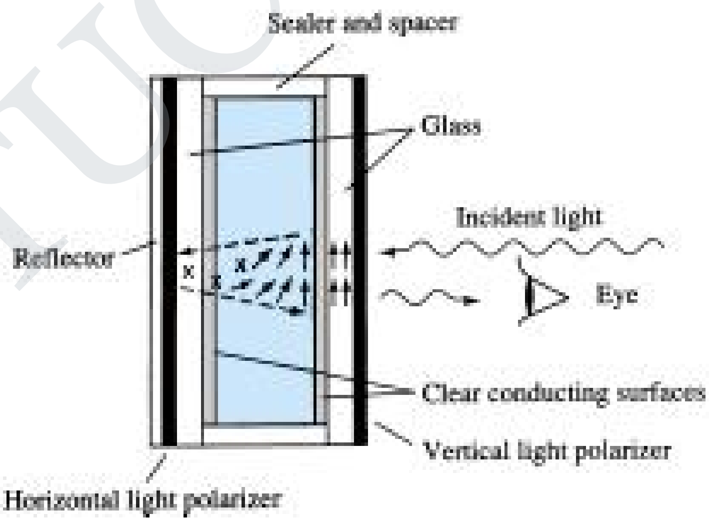


Figure 5.30 Reflective field effect LCD with no applied bias

5.9.2 Advantages of LCD

- Low power is required
- Good contrast
- Low cost

5.9.3Disadvantages of LCD

- Speed of operation is slow
- LCD occupy a large area
- LCD life span is quite small, when used on d.c. Therefore, they are used with a.c. suppliers.

5.9.4 Applications of LCD

- Used as numerical counters for counting production items.
- Analog quantities can also be displayed as a number on a suitable device. (e.g.) Digital millimeters.
- Used for solid state video displays
- Used for image sensing circuits.
- Used for numerical display in pocket calculators.

5.10 LIGHT EMITTING DIODE (LED)

A light emitting diode (LED) is known to be one of the best optoelectronic devices out of the lot. The device is capable of emitting a fairly narrow bandwidth of visible or invisible light when its internal diode junction attains a forward electric current or voltage.

The visible lights that an LED emits are usually orange, red, yellow, or green. The invisible light includes the infrared light. The biggest advantage of this device is its high power to light conversion efficiency. That is, the efficiency is almost 50 times greater than a simple tungsten lamp.

The response time of the LED is also known to be very fast in the range of 0.1 microseconds when compared with 100 milliseconds for a tungsten lamp. Due to these advantages, the device wide applications as visual indicators and as dancing light displays.

We know that a P-N junction can connect the absorbed light energy into its proportional electric current. The same process is reversed here. That is, the P-N junction emits light when energy is applied on it. This phenomenon is generally called electro luminance, which can be defined as the emission of light from a semi-conductor under the influence of an electric field.

The charge carriers recombine in a forward P-N junction as the electrons cross from the N-region and recombine with the holes existing in the P-region. Free electrons are in the conduction band of energy levels, while holes are in the valence energy band.

Thus the energy level of the holes will be lesser than the energy levels of the electrons. Some part of the energy must be dissipated in order to recombine the electrons and the holes. This energy is emitted in the form of heat and light.

The electrons dissipate energy in the form of heat for silicon and germanium diodes. But in Galium- Arsenide-phosphorous (GaAsP) and Galium-phosphorous (GaP) semiconductors, the electrons dissipate energy by emitting photons. If the semiconductor is translucent, the junction becomes the source of light as it is emitted, thus becoming a light emitting diode (LED). But when the junction is reverse biased no light will be produced by the LED, and, on the contrary the device may also get damaged.

The constructional diagram of a LED is shown below.

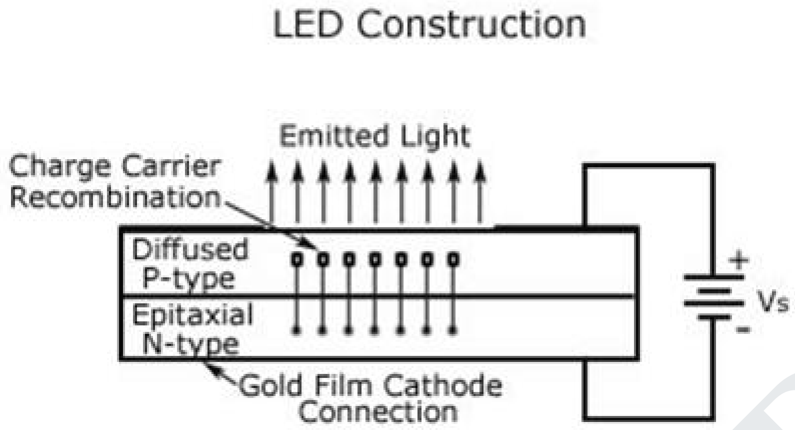


Figure 5.31 LED construction

All the semiconductors listed above can be used. An N-type epitaxial layer is grown upon a substrate, and the P-region is produced by diffusion. The P-region that includes the recombination of charge carriers is shown is the top. Thus the P-region becomes the device surface. In order to allow more surface area for the light to be emitted the metal anode connections are made at the outer edges of the P-layer.

For the light to be reflected as much as possible towards the surface of the device, a gold film is applied to the surface bottom. This setting also enables to provide a cathode connection. The re-absorption problem is fixed by including domed lenses for the device. All the wires in the electronic circuits of the device is protected by encasing the device.

The light emitted by the device depends on the type of semiconductor material used. Infrared light is produced by using Gallium Arsenide (GaAs) as semiconductor. Red or yellow light is produced by using Gallium-Arsenide-Phosphorus (GaAsP) as semiconductor. Red or green light is produced by using Gallium-Phosphorus (GaP) as semiconductor.

5.10.1 LED Circuit Symbol

The circuit symbol of LED consists of two arrow marks which indicate the radiation emitted by the diode.

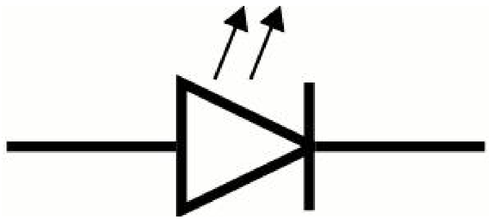


Figure 5.32 Symbol of LED

5.10.2 LED Characteristics

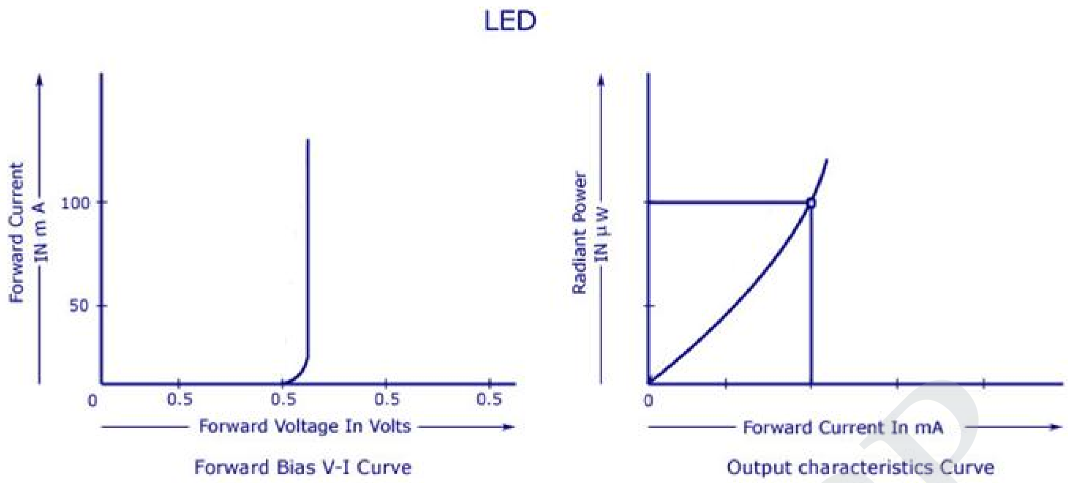


Figure 5.33 LED characteristics curve

The forward bias Voltage-Current (V-I) curve and the output characteristics curve is shown in the figure above. The V-I curve is practically applicable in burglar alarms. Forward bias of approximately 1 volt is needed to give significant forward current. The second figure is used to represent a radiant power-forward current curve. The output power produced is very small and thus the efficiency in electrical-to-radiant energy conversion is very less.

The figure 5.34 shows a series resistor R_{series} connected to the LED. Once the forward bias of the device exceeds, the current will increase at a greater rate in accordance to a small increase in voltage. This shows that the forward resistance of the device is very low. This shows the importance of using an external series current limiting resistor. Series resistance is determined by the following equation.

$$R_{series} = \left(V_{supply} - V\right)/I$$

V_{supply} – Supply Voltage

V – LED forward bias voltage

I – Current

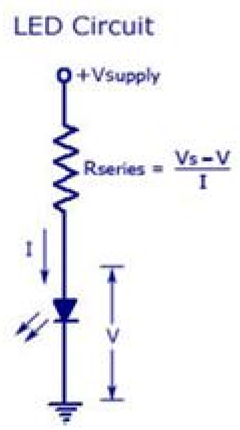


Figure 5.34 LED circuits

The commercially used LED's have a typical voltage drop between 1.5 Volt to 2.5 Volt or current between 10 to 50 milliamperes. The exact voltage drop depends on the LED current, colour, tolerance, and so on.

5.10.3 LED as an Indicator

The circuit shown below is one of the main applications of LED. The circuit is designed by wiring it in inverse parallel with a normal diode, to prevent the device from being reverse biased. The value of the series resistance should be half, relative to that o f a DC circuit.

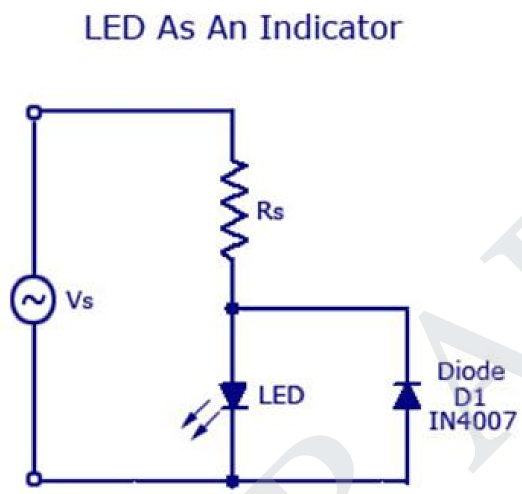


Figure 5.35 LED as an indicator

LEDS displays are made to display numbers from segments. One such design is the seven-segment display as shown below. Any desired numerals from 0-9 can be displayed by passing current through the correct segments. To connect such segment a common anode or common cathode cathode configuration can be used. Both the connections are shown below. The LED's are switched ON and OFF by using transistors.

5.10.4 Advantages of LED's

- Very low voltage and current are enough to drive the LED.
- Voltage range – 1 to 2 volts.
- Current – 5 to 20 milliamperes.
- Total power output will be less than 150 milliwatts.
- The response time is very less – only about 10 nanoseconds.
- The device does not need any heating and warm up time.
- Miniature in size and hence light weight.
- Have a rugged construction and hence can withstand shock and vibrations.
- An LED has a life span of more than 20 years.

5.10.5 Disadvantages of LED

- A slight excess in voltage or current can damage the device.
- The device is known to have a much wider bandwidth compared to the laser.
- The temperature depends on the radiant output power and wavelength.

5.11 Light Sensors

A Light Sensor generates an output signal indicating the intensity of light by measuring the radiant energy that exists in a very narrow range of frequencies basically called “light”, and which ranges in frequency from “Infra-red” to “Visible” up to “Ultraviolet” light spectrum.

The Light Sensor is a passive devices that convert this “light energy” whether visible or in the infra-red parts of the spectrum into an electrical signal output. Light sensors are more commonly known as “Photoelectric Devices” or “Photo Sensors” because the convert light energy (photons) into electricity (electrons).

Photoelectric devices can be grouped into two main categories, those which generate electricity when illuminated, such as Photo-voltaics or Photo-emissives etc, and those which change their electrical properties in some way such as Photo-resistors *or* Photo-conductors. This leads to the following classification of devices.

Photo-emissive Cells – These are photodevices which release free electrons from a light sensitive material such as caesium when struck by a photon of sufficient energy. The amount of energy the photons have depends on the frequency of the light and the higher the frequency, the more energy the photons have converting light energy into electrical energy.

Photo-conductive Cells – These photodevices vary their electrical resistance when subjected to light. Photoconductivity results from light hitting a semiconductor material which controls the current flow through it. Thus, more light increase the current for a given applied voltage. The most common photoconductive material is Cadmium Sulphide used in LDR photocells.

Photo-voltaic Cells – These photodevices generate an emf in proportion to the radiant light energy received and is similar in effect to photoconductivity. Light energy falls on to two semiconductor materials sandwiched together creating a voltage of approximately 0.5V. The most common photovoltaic material is Selenium used in solar cells.

Photo-junction Devices – These photodevices are mainly true semiconductor devices such as the photodiode or phototransistor which use light to control the flow of electrons and holes across their PN-junction. Photojunction devices are specifically designed for detector application and light penetration with their spectral response tuned to the wavelength of incident light.

5.12 PHOTOJUNCTION DEVICES

Photo junction Devices are basically PN-Junction light sensors or detectors made from silicon semiconductor PN-junctions which are sensitive to light and which can detect both visible light and infra-red light levels. Photo-junction devices are specifically made for sensing light and this class of photoelectric light sensors include the Photodiode and the Phototransistor.

5.12.1PHOTODIODE

5.12.1.1 Symbol and construction of photo diode

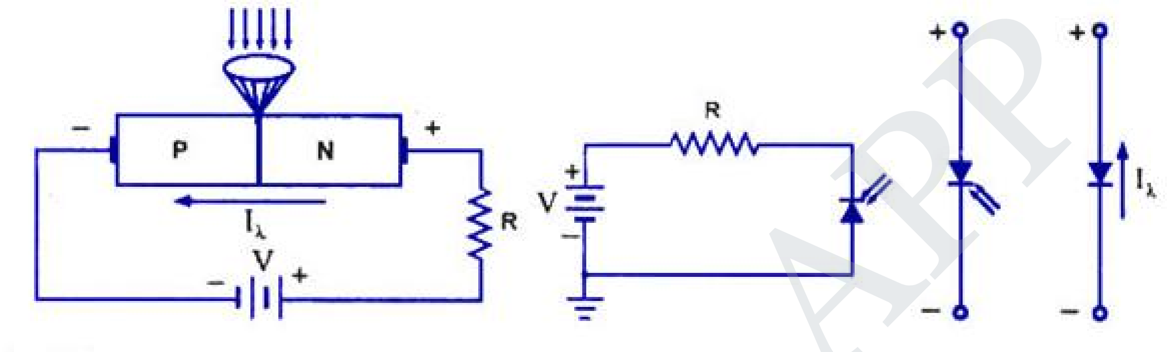


Figure 5.36 Biasing arrangement and construction of photodiode and Symbol

Photo-diode is a two-terminal semiconductor P-N junction device and is designed to operate with reverse bias. The basic biasing arrangement, construction and symbols for the device are given in figure. It is either mounted in translucent case or has its semiconductor junction mounted beneath an optical lens. The output voltage is taken from across a series-connected load resistor R. This resistance may be connected between the diode and ground or between the diode and the positive terminal of the supply, as illustrated in figure.

When the P-N junction is reverse-biased, a reverse saturation current flows due to thermally generated holes and electrons being swept across the junction as the minority carriers. With the increase in temperature of the junction more and more hole-electron pairs are created and so the reverse saturation current I_0 increases. The same effect can be had by illuminating the junction.

When light energy bombards a P-N junction, it dislodges valence electrons. The more light striking the junction the larger the reverse current in a diode. It is due to generation of more and more charge carriers with the increase in level of illumination. This is clearly shown in figure 5.37 for different intensity levels. The *dark current* is the current that exists when no light is incident. It is to be noted here that current becomes zero only with a positive applied bias equals to V_Q.

The almost equal spacing between the curves for the same increment in luminous flux reveals that the reverse saturation current I_0 increases linearly with the luminous flux as shown in figure. Increase in reverse voltage does not increase the reverse current significantly, because all available charge carriers are already being swept across the junction. For reducing the reverse saturation current I_0 to zero, it is necessary to forward bias the junction by an amount equal to barrier potential. Thus the photodiode can be used as a *photoconductive device.*

5.12.1.2 V-I characteristics of photodiode

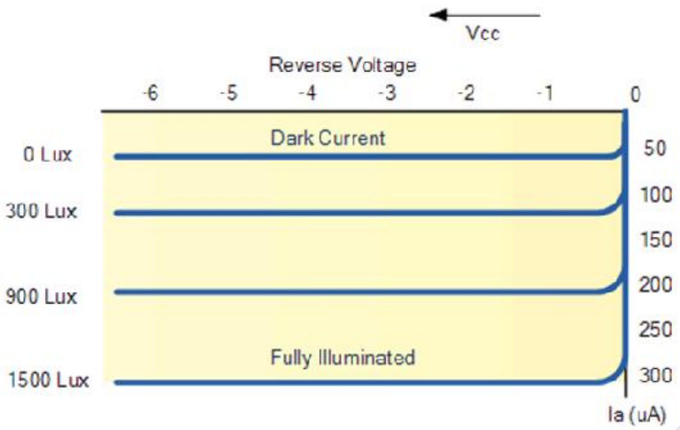


Figure 5.37 V-I characteristics of photodiode

The current-voltage characteristic (I/V Curves) of a photodiode with no light on its junction (dark mode) is very similar to a normal signal or rectifying diode. When the photodiode is forward biased, there is an exponential increase in the current, the same as for a normal diode. When a reverse bias is applied, a small reverse saturation current appears which causes an increase of the depletion region, which is the sensitive part of the junction. Photodiodes can also be connected in a current mode using a fixed bias voltage across the junction. The current mode is very linear over a wide range.

On removal of reverse bias applied across the photodiode, minority charge carriers continue to be swept across the junction while the diode is illuminated. This has the effect of increasing the concentration of holes in the P-side and that of electrons in the N-side But the barrier potential is negative on the P-side and positive on the N-side, and was created by holes flowing from P to N-side and electrons from N to P-side during fabrication of junction. Thus the flow of minority carriers tends to reduce the barrier potential.

When an external circuit is connected across the diode terminals, the minority carrier; return to the original side via the external circuit. The electrons which crossed the junction from P to N-side now flow out through the N-terminal and into the P-terminal This means that the device is behaving as a voltage cell with the N-side being the negative terminal and the P-side the positive terminal. Thus, the photodiode is & photovoltaic device as well as photoconductive device.

When used as a light sensor, a photodiodes dark current (0 lux) is about 10uA for geranium and 1uA for silicon type diodes. When light fall upon the junction more hole/electron pairs are formed and the leakage current increases. This leakage current increases as the illumination of the junction increases. Thus, the photodiodes current is directly proportional to light intensity falling onto the PN-junction.

5.12.1.3 Advantage of photodiodes

One main advantage of photodiodes when used as light sensors is their fast response to changes in the light levels.

5.12.1.4 Disadvantage of photodiodes

One disadvantage of this type of photo device is the relatively small current flow even when fully lit.

5.12.2 PHOTO TRANSISTORS

An alternative photo-junction device to the photodiode is the Phototransistor which is basically a photodiode with amplification. The Phototransistor light sensor has its collector-base PN-junction reverse biased exposing it to the radiant light source.

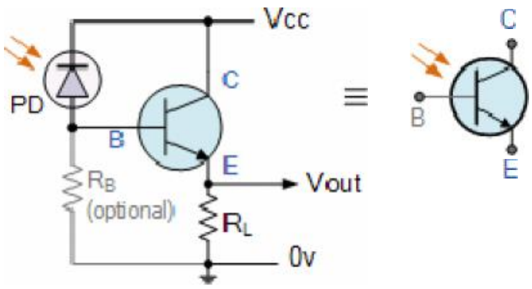


Figure 5.38 Photo-transistor Symbol

Phototransistors operate the same as the photodiode except that they can provide current gain and are much more sensitive than the photodiode with currents are 50 to 100 times greater than that of the standard photodiode and any normal transistor can be easily converted into a phototransistor light sensor by connecting a photodiode between the collector and base.

Phototransistors consist mainly of a bipolar NPN Transistor with its large base region electrically unconnected, although some phototransistors allow a base connection to control the sensitivity, and which uses photons of light to generate a base current which in turn causes a collector to emitter current to flow. Most phototransistors are NPN types whose outer casing is either transparent or has a clear lens to focus the light onto the base junction for increased sensitivity.

5.12.2.1 Photo-transistor Construction and Characteristics

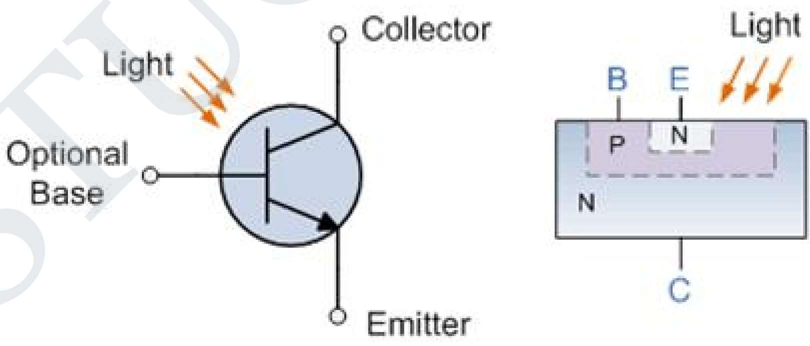


Figure 5.39 phototransistor construction

In the NPN transistor the collector is biased positively with respect to the emitter so that the base/collector junction is reverse biased. therefore, with no light on the junction normal leakage or dark current flows which is very small. When light falls on the base more electron/hole pairs are formed in this region and the current produced by this action is amplified by the transistor.

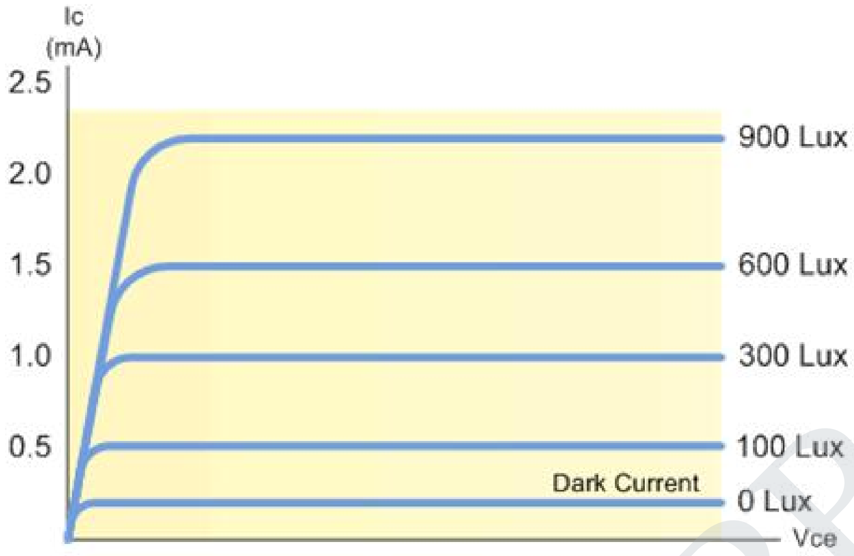


Figure 5.40 V-I characteristics of phototransistor

Usually the sensitivity of a phototransistor is a function of the DC current gain of the transistor. Therefore, the overall sensitivity is a function of collector current and can be controlled by connecting a resistance between the base and the emitter but for very high sensitivity optocoupler type applications, Darlington phototransistors are generally used.

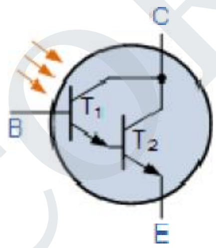


Figure 5.41 Darlington phototransistors symbol

5.12.2.2Applications

Phototransistors are used for a wide variety of applications. In fact, phototransistors can be used in any electronic device that senses light. For example, phototransistors are often used in smoke detectors, infrared receivers, and CD players. Phototransistors can also be used in astronomy, night vision, and laser range-finding.

Some of the areas of application for the phototransistor include punch-card readers, computer logic circuitry, lighting control (highways, etc.), level indication, relays, and counting systems.

5.12.2.3 Advantages

Phototransistors have several important advantages that separate them from other optical sensors. They produce a higher current than photodiodes and also produce a voltage, something that photoresistors cannot do. Phototransistors are very fast and their output is practically instantaneous. They are relatively inexpensive, simple, and so small that several of them can fit onto a single integrated computer chip.

5.12.2.4 Disadvantages

While phototransistors can be advantageous, they also have several disadvantages. Phototransistors made of silicon cannot handle voltages over 1,000 Volts. They do not allow electrons to move as freely as other devices, such as electron tubes, do. Also, phototransistors are also more vulnerable to electrical surges/spikes and electromagnetic energy.

5.13 PHOTOVOLTAIC CELLS

The most common type of photovoltaic light sensor is the Solar Cell. Solar cells convert light energy directly into DC electrical energy in the form of a voltage or current to a power a resistive load such as a light, battery or motor. Then photovoltaic cells are similar in many ways to a battery because they supply DC power.

However, unlike the other photo devices we have looked at above which use light intensity even from a torch to operate, photovoltaic solar cells work best using the suns radiant energy.

Solar cells are used in many different types of applications to offer an alternative power source from conventional batteries, such as in calculators, satellites and now in homes offering a form of renewable power.

5.13.1 Photovoltaic Cell

Photovoltaic cells are made from single crystal silicon PN junctions, the same as photodiodes with a very large light sensitive region but are used without the reverse bias. They have the same characteristics as a very large photodiode when in the dark.

When illuminated the light energy causes electrons to flow through the PN junction and an individual solar cell can generate an open circuit voltage of about 0.58v (580mV). Solar cells have a “Positive” and a “Negative” side just like a battery.

Individual solar cells can be connected together in series to form solar panels which increases the output voltage or connected together in parallel to increase the available current. Commercially available solar panels are rated in Watts, which is the product of the output voltage and current (Volts times Amps) when fully lit.

5.13.2 Characteristics of a typical Photovoltaic Solar Cell

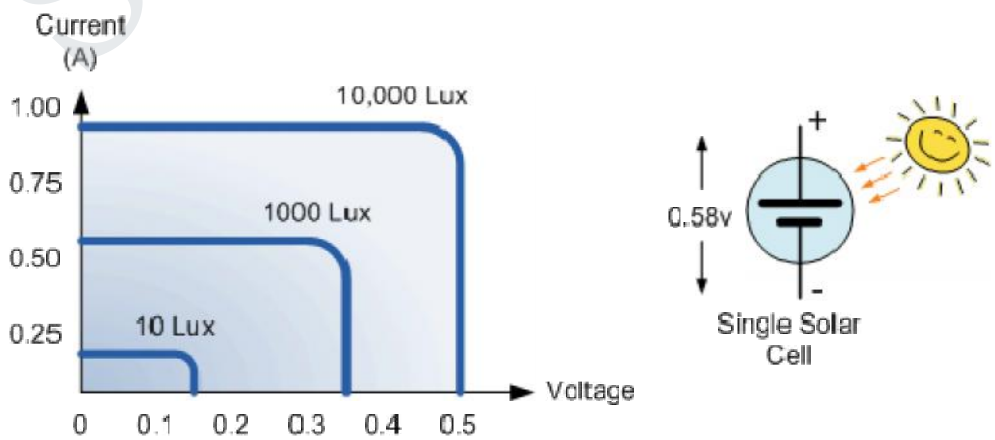


Figure 5.42 Characteristics of a typical Photovoltaic Solar Cell

The amount of available current from a solar cell depends upon the light intensity, the size of the cell and its efficiency which is generally very low at around 15 to 20%. To increase the overall efficiency of the cell commercially available solar cells use polycrystalline silicon or amorphous silicon, which have no crystalline structure, and can generate currents of between 20 to 40mA per cm^2.

Other materials used in the construction of photovoltaic cells include Gallium Arsenide, Copper Indium Diselenide and Cadmium Telluride. These different materials each have a different spectrum band response, and so can be "tuned" to produce an output voltage at different wavelengths of light.

In this tutorial about Light Sensors, we have looked at several examples of devices that are classed as Light Sensors. This includes those with and those without PN-junctions that can be used to measure the intensity of light.

In the next tutorial we will look at output devices called Actuators. Actuators convert an electrical signal into a corresponding physical quantity such as movement, force, or sound. One such commonly used output device is the Electromagnetic Relay.

5.13.3 SOLAR CELLS

In recent years, there has been increasing interest in the solar cell as an alternative source of energy. When we consider that the power density received from the sun at sea level is about 100 mW/cm^2 (1 kW/m2), it is certainly an energy source that requires further research and development to maximize the conversion efficiency from solar to electrical energy.

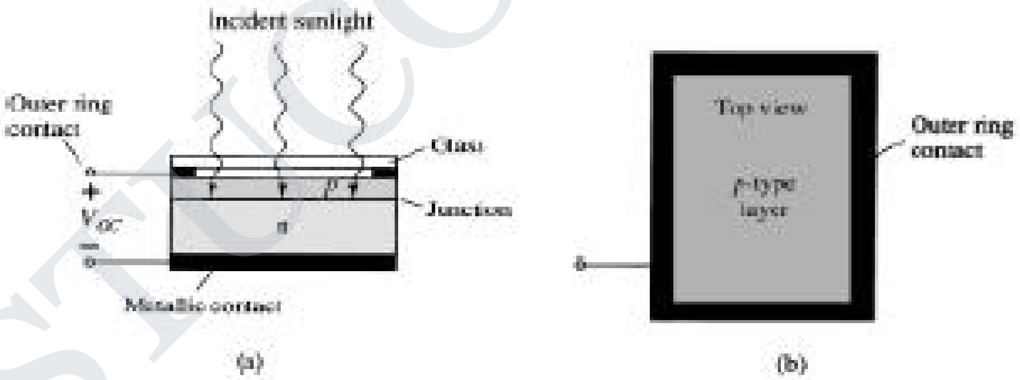


Figure 5.43 (a) cross section; (b) top view

The basic construction of a silicon p-n junction solar cell appears in Figurre 5.43. As shown in the top view, every effort is made to ensure that the surface area perpendicular to the sun is a maximum. Also, note that the metallic conductor connected to the p-type material and the thickness of the p-type material are such that they ensure that a maximum number of photons of light energy will reach the junction

A photon of light energy in this region may collide with a valence electron and impart to it sufficient energy to leave the parent atom. The result is a generation of free electrons and holes. This phenomenon will occur on each side of the junction.

In the p-type material, the newly generated electrons are minority carriers and will move rather freely across the junction as explained for the basic p-n junction with no applied bias. A similar discussion is true for the holes generated in the n-type material.

The result is an increase in the minority-carrier flow, which is opposite in direction to the conventional forward current of a p-n junction. This increase in reverse current is shown in Figure 5.44. Since V= 0 anywhere on the vertical axis and represents a short-circuit condition, the current at this intersection is called the short-circuit current and is represented by the notation I_{SC}.

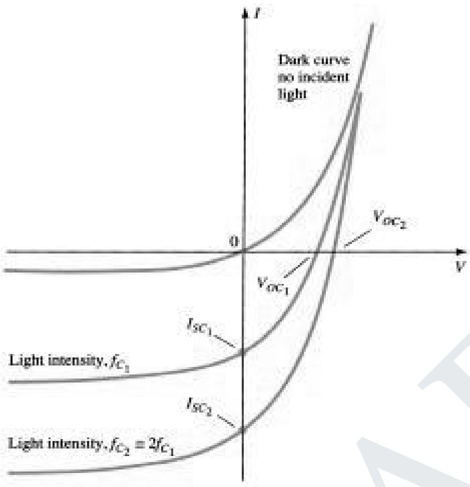


Figure 5.44 V-I curve for solar cell

Under open-circuit conditions (id = 0), the photovoltaic voltage V_{OC} will result. This is a logarithmic function of the illumination, as shown in Figure 5.45. V_{OC} is the terminal voltage of a battery under no-load (open-circuit) conditions. Note, however, in the same figure that the short- circuit current is a linear function of the illumination.

That is, it will double for the same increase in illumination (f_{C1} and $2f_{C1}$ in Figure 5.45) while the change in V_{OC} is less for this region. The major increase in V_{OC} occurs for lower-level increases in illumination. Eventually, a further increase in illumination will have very little effect on V_{OC}, although I_{SC} will increase, causing the power capabilities to increase.

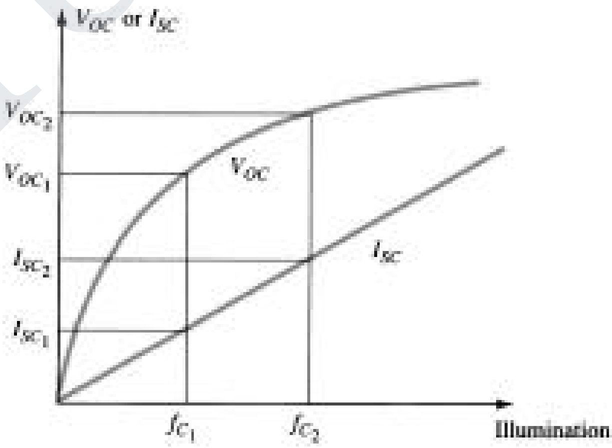


Figure 5.45 Voc and Isc versus illumination for solar cell

Selenium and silicon are the most widely used materials for solar cells, although gallium arsenide, indium arsenide, and cadmium sulfide, among others, are also used.

5.14 OPTOCOUPLER

In electronics, an opto-isolator, also called an optocoupler, photocoupler, or optical isolator, is a component that transfers electrical signals between two isolated circuits by using light. Opto - isolators prevent high voltages from affecting the system receiving the signal. Commercially available opto-isolators withstand input-to-output voltages up to 10 kV and voltage transients with poeds upto 10kV/μs. A common type of opto-isolator consists of an LED and a phototransistor in the same package. Opto-isolators are usually used for transmission of digital (on/off) signals, but some techniques allow use with analog (proportional) signals.

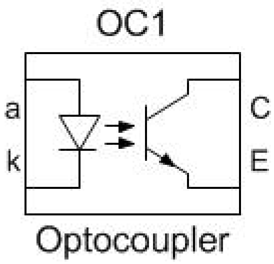


Figure 5.46 Optocoupler Symbol

An opto-isolator contains a source (emitter) of light, almost always a near infrared light-emitting diode (LED), that converts electrical input signal into light, a closed optical channel (also called dielectrical channel), and a photosensor, which detects incoming light and either generates electric energy directly, or modulates electric current flowing from an external power supply.The sensor can be a photoresistor, a photodiode, a phototransistor, a silicon-controlled rectifier (SCR) or a triac. Because LEDs can sense light in addition to emitting it, construction of symmetrical, bidirectional opto-isolators is possible.

An optocoupled solid state relay contains a photodiode opto-isolator which drives a power switch, usually a complementary pair of MOSFETs. A slotted optical switch contains a source of light and a sensor, but its optical channel is open, allowing modulation of light by external objects obstructing the path of light or reflecting light into the sensor.

5.15 CCD(CHARGE COUPLED DEVICE)

A charge-coupled device (CCD) is a device for the movement of electrical charge, usually from within the device to an area where the charge can be manipulated, for example conversion into a digital value. This is achieved by "shifting" the signals between stages within the device one at a time. CCDs move charge between capacitive *bins* in the device, with the shift allowing for the transfer of charge between bins.

The CCD is a major piece of technology in digital imaging. In a CCD image sensor, pixels are represented by p-doped MOS capacitors. These capacitors are biased above the threshold for inversion when image acquisition begins, allowing the conversion of incoming photons into electron charges at the semiconductor-oxide interface; the CCD is then used to read out these charges. Although CCDs are not the only technology to allow for light detection, CCD image sensors are widely used in professional, medical, and scientific applications where high-quality image data is required.

In applications with less exacting quality demands, such as consumer and professional digital cameras, active pixel sensors (CMOS) are generally used; the large quality advantage CCDs enjoyed early on has narrowed over time.

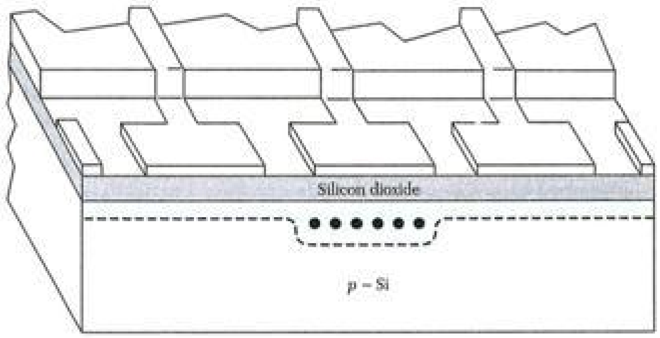


Figure 5. 47 Basic structure of CCD

In a CCD for capturing images, there is a photoactive region (an epitaxial layer of silicon), and a transmission region made out of a shift register (the CCD, properly speaking).An image is projected through a lens onto the capacitor array (the photoactive region), causing each capacitor to accumulate an electric charge proportional to the light intensity at that location.

A one- dimensional array, used in line-scan cameras, captures a single slice of the image, while a two- dimensional array, used in video and still cameras, captures a two-dimensional picture corresponding to the scene projected onto the focal plane of the sensor. Once the array has been exposed to the image, a control circuit causes each capacitor to transfer its contents to its neighbor (operating as a shift register).

The last capacitor in the array dumps its charge into a charge amplifier, which converts the charge into a voltage. By repeating this process, the controlling circuit converts the entire contents of the array in the semiconductor to a sequence of voltages. In a digital device, these voltages are then sampled, digitized, and usually stored in memory; in an analog device (such as an analog video camera), they are processed into a continuous analog signal (e.g. by feeding the output of the charge amplifier into a low-pass filter) which is then processed and fed out to other circuits for transmission, recording, or other processing.

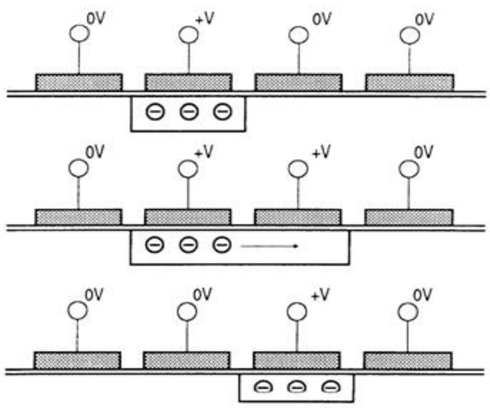


Figure 5.48 The mechanism of charge transfer in a CCD

15.1 Functional features

CCD can convert optical signals into digital signal directly to achieve the acquisition, storage, transmission and proceeding of images. The special characterizations are:

1. Small in size and light in weight.
2. Low power consumption, low working voltage.
3. Stable performance and long operational life, resistant of impact and vibration
4. High sensitivity, low noise and large dynamic range
5. Quick respond, with self-scanning function, small image distortion, non-residual image
6. Applicable to ultra-large scale integrated circuit, with high integration of pixel, accurate size, and low cost

5.15.2 Applications of CCD

Consequently, CCD shows wide applications in varied fields.

CCD device and its application technology have been developed, and remarkable progress, especially in the mage sensor and non-contact measurement have been made in the past decades years. With the theory development, CCD becomes a high-sensitivity device and used in many regions. Some of them are listed here in this report:

5.15.2.1 CCD digital camera

CCD cameras contain light-sensitive silicon chips that detect electrons excited by incoming light, and the micro circuitry that transfers a detected signal along a row of discrete picture elements or pixels, scanning the image very rapidly [9]. Two-dimensional CCD arrays with many thousands of pixels are used in these CCD cameras, and they are often used in machine vision applications.

CCD cameras can operate in both monochrome (black, white, and grayscale) and color. The range of colors is generated by varying combinations of different discrete colors, like red, green, and blue components (RGB), to create a wide spectrum of colors. Important performances of CCD cameras include horizontal resolution, maximum frame rate, shutter speed, sensitivity, and signal-to-noise ratio. Other parameters to consider when specifying CCD cameras include specialty applications, performance features, physical features, lens mounting, shutter control, sensor specifications, dimensions, and operating environment parameters.

The CCD camera can be applied in astronomy, medicine, optical scanner, etc., as its high quantum efficiencies, linearity of outputs and ease of use.

5.15.2.2 CCD image sensor

CCD image sensors are electronic devices which are capable of transforming a light pattern (image) into an electric charge pattern (an electronic image). The CCD consists of several individual elements that have the capability of collecting, storing and transporting electrical charge from one element to another, as described in the theory part. Together with the photosensitive properties of silicon, CCD is used to design image sensors.

With semiconductor technologies and design rules, one or more output amplifiers at the edge of the chip collect the signals from the CCD, and electronic images can be obtained by applying series of pulses that transfer the charge of one pixel after another to the output amplifier, line after line. The output amplifier converts the charge into a voltage, while external electronics will transform this output signal into a form suitable for monitors or frame grabbers. Thus CCDs have extremely low noise figures.CCD image sensors can also be a color sensor or a monochrome sensor, as the CCD camera.

Important image sensor performances include spectral response, data rate, quantum efficiency, dynamic range, and number of outputs. An important environmental parameter to consider is the operating temperature.

CCD image sensors have found important applications in many areas of society and science, like digital cameras, scanners, medical devices, satellite surveillance and in instrumentation for astronomy and astrophysics.

5.15.2.3Optical scanner

CCD used in fax machines forms images on the surface of arrayed capacitor. The brightness of images produces each capacity with charges, which can be transferred to amplifier and forms voltage at the edge of circuit. With the information of the voltage, the images can be stored and print out.

QUESTION BANK

UNIT- I SEMICONDUCTOR DIODE

1. **Give the value of Charge, Mass of an electron.**

   Charge of an electron – 1.6 x 10 -19 coloumbs. Mass of an electron - 9.11 x 10 -31 Kgs

2. **Define Potential.**

A potential of V volts at point B with respect to point A, is defined as the work done in taking unit positive charge from A to B , against the electric field.

3. **Define Current density.**

   It is defined as the current per unit area of the conducting medium. J = I / A

4. **Define Electron volts.**

If an electron falls through a potential of one volt then its energy is 1 electron volt. 1 eV = 1.6 x 10 -19 joules

5. **What is atomic number?**

   The number of protons or electrons in an atom is atomic number.

6. **What are valence electrons?**

   Electron in the outermost shell of an atom is called valence electron.

7. **What is forbidden energy gap?**

   The space between the valence and conduction band is said to be forbidden energy gap.

8. **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.

9. **What are insulators? Give examples?**

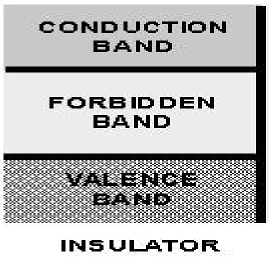
   Insulators are materials in which the valence and conduction band are far away from each other. So no movement of free electrons and thus no conduction. Ex glass, plastic.

10. **What are Semiconductors? Give examples?**

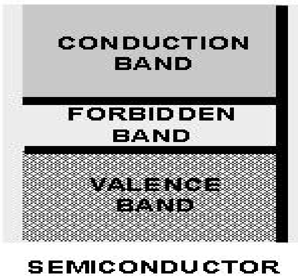
    The materials whose electrical property lies between those of conductors and insulators are known as Semiconductors. Ex germanium, silicon.

11. **Give the energy band structure of Insulator.**

    In Insulators there is a wide forbidden energy gap. So movement of valence electron from valence to conduction band is not possible.

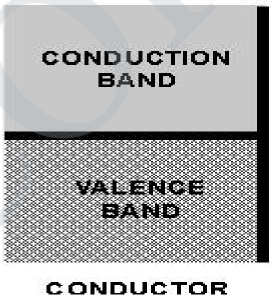


12. Give the energy band structure of Semi conductor.



In Semiconductors there is a small forbidden energy gap. So movement of valence electron from valence to conduction band is possible if the valence electrons are supplied with some energy.

13. **Give the energy band structure of conductor.**
In conductors there is no forbidden energy gap, valence band and conduction and overlap each other. so there is a heavy movement of valence electrons.



14. **What are the types of Semiconductor?**

1. Intrinsic semiconductor 2. Extrinsic semiconductor.

15. **What is Intrinsic Semiconductor?**

Pure form of semiconductors are said to be intrinsic semiconductor. Ex: germanium, silicon.

16. **What is Extrinsic Semiconductor?**

If certain amount of impurity atom is added to intrinsic semiconductor the resulting semiconductor is Extrinsic or impure Semiconductor.

17. **Define Mass – action law.**

Under thermal equilibrium the product of free electron concentration (n) and hole concentration (p) is constant regardless of the individual magnitude.

$$n.p = ni^2$$

18. **What are the types of Extrinsic Semiconductor?**

1.P-type Semiconductor 2. N- Type Semiconductor.

19. **What is P-type Semiconductor?**

The Semiconductor which are obtained by introducing pentavalent impurity atom (phosphorous, antimony) are known as P-type Semiconductor.

20. **What is N-type Semiconductor?**

The Semiconductor which is obtained by introducing trivalent impurity atom (gallium, indium) are known as N-type Semiconductor.

21. **What is doping?**

Process of adding impurity to a intrinsic semiconductor atom is doping. The impurity is called dopant.

22. **Which charge carriers is majority and minority carrier in N-type Semiconductor?**

Majority carrier: electron and minority carrier: holes.

23. **Which charge carriers is majority and minority carrier in P-type Semiconductor?**

Majority carrier: holes and minority carrier: electron

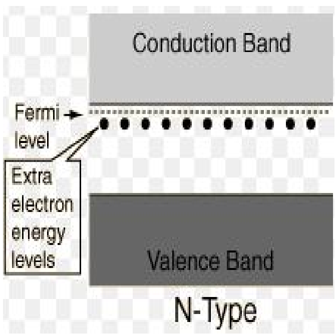
24. **Why n - type or penta valent impurities are called as Donor impurities?**

n- type impurities will donate the excess negative charge carriers (Electrons) and therefore they are reffered to as donor impurities.

25. **Why P – type or trivalent impurities are called as acceptor impurity?**

p- type impurities make available positive carriers because they create holes which can accept electron, so these impurities are said to be as acceptor impurity.

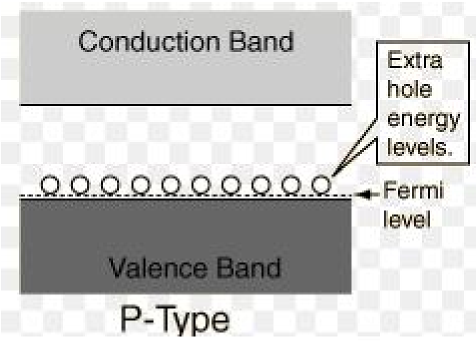
26. **Give the energy band structure of n- type semiconductor.**



27. 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.

28. **Give the energy band structure of P- type semiconductor.**



29. Give the expression for the Fermi level energy in n – type semiconductor.

$$E_F = E_C - kT \ln \frac{N_C}{N_D}$$

Where,

E_F - Fermi level energy

E_C – Conduction band energy

K – Boltzmann constant

T – Temperature

N_C – dimension of concentration in n – type

N_D - concentration of donor atoms

30. Give the expression for drift current density due to electron.

$$J_n = qn\mu_n E$$

Where,

Jn - drift current density due to electron, q- Charge of electron

μ_n - Mobility of electron , E - applied electric field

31. Give the expression for drift current density due to holes.

$$J_p = qp\mu_p E$$

Where, Jn - drift current density due to holes, q - Charge of holes

µp - Mobility of holes, E - applied electric field

32. **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.

33. Give the expression for diffusion current density due to electron.

$$J_n = qD_n \frac{dn}{dx}$$

Where

Jn - diffusion current density due to electron q - Charge of an electron
Dn – diffusion constant for electron dn / dx – concentration gradient

34. Give the expression for diffusion current density due to holes.

$$J_p = qD_p \frac{dp}{dx}$$

Where

Jp - diffusion current density due to holes q - Charge of a hole

Dp – diffusion constant for hole dn / dx – concentration gradient

35. **What is the other name of continuity equation? What does it indicate?**

The other name of continuity equation is equation of conservation of charge.This equation indicates that the rate at which holes are generated thermally just equals the rate at which holes are lost because of recombination under equilibrium conditions.

36. **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.

37. **Give some application of Hall Effect.**

i. hall effect can be used to measure the strength of a magnetic field in terms of electrical voltage.
ii. it is used to determine whether the semiconductor is p – type or n- type material
iii. it is used to determine the carrier concentration
iv. it is used to determine the mobility.

38. **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.

39. **Give the other names of depletion region?**

i.space charge region

ii.Transition region

40. **What is barrier potential?**

Because of the oppositely charged ions present on both sides of PN junction an electric potential is established across the junction even without any external voltage source which is termed as barrier potential.

41. **What is meant by biasing a PN junction?**

Connecting a PN junction to an external voltage source is biasing a PN junction.

42. **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.

43. **What is reverse bias in a PN junction?**

When positive terminal of the external supply is connected to N type and negative terminal to P type then the PN junction is said to be in reverse bias. Under reverse biased condition the PN region offers a very high resistance and a small amount of current flows through it.

44. **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.

45. **Why a contact difference of potential exist in PN junction?**

When a pn junction is formed by placing a p-type and n-type material in intimate contact, the Fermi level throughout the newly formed specimen is not constant at equilibrium. There will be transfer of electron and energy until Fermi levels in the two side did line up. But the valence and conduction band in pside cannot be at the at the same level as in n side .this shift in energy level results in contact difference of potential.

46. Give the expression of contact difference of potential?

$$E_0 = kT \ln \frac{N_D N_A}{n_i^2}$$

Where, E_0 - contact difference of potential, K – Boltzmann constant , T – Temperature

N_D - concentration of donor atoms ,N_A - concentration of acceptor atoms

n_i – intrinsic concentration

47. **Give the diode current equation?**

The diode current equation relating the voltage V and current I is given by

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

I – diode current, I_O – diode reverse saturation current at room temperature

V – External voltage applied to the diode, η - a constant, 1 for Ge and 2 for Si

V_T = kT/q = T/11600, thermal voltage,
K – Boltzmann‘s constant (1.38066x10^-23 J/K)
q – Charge of electron (1.6x10^-19 C)
T – Temperature of the diode junction

UNIT II BIPOLAR JUNCTION

1. **What is a transistor? What are the types?**

Transistor consists of two junctions formed by sandwiching either p type or n type semiconductor between a pair of opposite types.

Two types - *NPN transistor *PNP transistor

2. **Define BJT?**

A bipolar junction transistor is a three terminal semiconductor device in which the operation depends on the interaction of both majority and minority carriers and hence the name bipolar.

3. **Give the h_{ie} and h_{eo} equations of BJT?**

$h_{11} = h_{ie}$ - The input impedance of the transistor (corresponding to the emitter resistance r_e).Unit ohms Ω.

$$h_{11} = \left.\frac{V_i}{I_i}\right|_{V_o = 0}$$

$h_{22} = h_{oe}$ - The output impedance of transistor. This term is usually specified as admittance and has to be inverted to convert it to impedance. Units' siemans S.

$$h_{22} = \left.\frac{I_o}{V_o}\right|_{I_i = 0}$$

4. **Why is the transistor called a current controlled device?**

A transistor is called a current controlled device. This is because; collector current is controlled by base current. The changes in collector current are proportional to the corresponding changes in base current.

5. **Explain about the characteristics of a transistor?**

In common emitter configuration, input characteristics is the plot obtained by tracing the variation of input current I_B with the input voltage V_{BE}. Similarly, the variation of output current I_C with the Collector to emitter voltage V_{CE} is known as output characteristics.

6. **Define h parameters?**

One of a set of four transistor equivalent-circuit parameters that conveniently specify transistor performance for small voltages and currents in a particular circuit. Also known as hybrid parameter.

7. **Why we use h-parameters to describe a transistor?**

Any linear circuit can be analyzed by four parameters (input resistance, reverse voltage gain, forward current gain and output admittance) of mixed dimensions. Since the dimensions of the parameters have mixed units they are referred as h-parameters. The h-parameters are determined by both open circuit and short circuit terminations.

8. **What is operating point?**

The Q point or quiescent point or operating point where DC load line intersects proper base current curve. The coordinates of Q point decides the zero values of IC and VCE in a common emitter transistor.

9. **In a bipolar transistor which region is wider and which region is thinner? Why?**

The middle region of bipolar junction transistor is called as the base of the transistor. Input signal of small amplitude is applied to the base. This region is thin and lightly doped. The magnified output signal is obtained at the collector. This region is thick and heavily doped.

10. **What do you understand by thermal runaway?**

The excess heat produced at the collector base junction may even burn and destroy the transistor. The self destruction of an unbiased transistor is known as thermal runaway. To avoid thermal run away the operating point of the circuit is to be stabilized.

11. **Define the delay time and rise time in the switching characteristics of transistor?**

In the transistor switching characteristics the delay time is the time that elapses the application of the input pulse and current to rise to 10 percent of its maximum value. The time required for IC to reach 90% of its maximum level from 10% level is called the rise time.

12. **Differentiate FET and BJT (any two)?**

FET	**BJT**
Unipolar device (that is current conduction by only one type of either electron or hole).	Bipolar device (current conduction by both electron and hole).
High input impedance due to reverse bias.	Low input impedance due to forward bias.
Gain is characterized by trans conductance	Gain is characterized by voltage gain
Low noise level	High noise level

13. **When a transistor is used as a switch, in which region of output characteristics it is operated?**

When a transistor is used as a switch it is operated alternately in the cut off region and saturation region of the output characteristics.

14. **When does a transistor act as a switch?**

A transistor should be operated in saturation and cut off regions to use it as a switch. While operating in saturation region, transistor carry heavy current hence considered as ON state. In cut-off, it carries no current and it is equivalent to open switch.

15. **Why do the output characteristics of a CB transistor have a slight upward slope?**

The emitter and collector are forward biased under the saturation region. Hence a small change in collector voltage causes a significant change in collector current. Therefore the slight upward slope is found in output characteristics.

16. **Define transport factor, β?**

It is the ratio of injected carrier current reaching at collector base junction to injected carrier current at emitter base junction.

$$\beta = I_{pC} / I_{PE}$$

17. **Define rise time?**

The time required for I_C to reach 90% of its maximum level from 10% level is called rise time, t_r

18. **Define current gain in CE configuration?**

The current gain (β) of common emitter configuration is defined as the ratio of change in collector current to change in base current when collector emitter voltage is kept constant.

I_C / I_B **β** is also referred as $\mathbf{h_{fe}}$.

19. **What is meant by biasing a transistor?**

Process of maintaining proper flow of zero signal collector current and collector emitter voltage during the passage of signal. Biasing keeps emitter base junction forward biased and collector base junction reverse biased during the passage of signal.

20. What are the various methods used for transistor biasing? Which one is popular?

Base resistor method

Biasing with feedback resistor

Voltage divider bias

Voltage divider bias is wide popular because it offers excellent stabilization to the circuit.

21. What are the limitations of h-parameters?

Obtaining the exact value of h-parameters for a particular transistor is quite difficult. Highly suitable only for small ac signals.

22. What is the basic difference between bias compensation and stabilization?

Stabilization is the process of making operating point independent of temperature variations or changes in transistor parameters using dc biasing circuits. In the case of compensation technique, in order to stabilize the Q point, we use temperature sensitive devices like diodes, thermistors, transistors instead of DC biasing circuits.

23. List the 3 sources of instability of collector current?

- Individual variations
- Temperature dependence of collector
- current Thermal runaway

24. Define Current Amplification Factor for CE, CC, CB Configuration

The current amplification factor for CB configuration is given by,

$$\alpha = \frac{\text{change in collector current at constant } V_{CB}}{\text{change in emitter current}} = \frac{\Delta I_C}{\Delta I_E} \text{ for constant } V_{CB}$$

The current amplification factor for CE configuration is given by,

$$\beta = \frac{\text{change in collector current}}{\text{change in base current at constant } V_{CE}} = \frac{\Delta I_C}{\Delta I_B} \text{ for constant } V_{CE}$$

The current amplification factor for CC configuration is given by,

$$\gamma = \frac{\text{change in emitter current}}{\text{change in base current at constant } V_{CE}} = \frac{\Delta I_E}{\Delta I_B} \text{ for constant } V_{CE}$$

25. Define punch through or reach through.

Extremely large collector voltage, the effective base width may be reduced to zero, resulting in voltage breakdown of a transistor. This phenomenon is known as punch through.

26. Define pinch off voltage

Pinch off voltage is defined as the drain to source voltage above which drain current becomes almost constant.

27. A)What happens to transistor when both the junctions are reverse biased?

B) Can transistor circuit be operated as a switch? State how?

A) The transistor operated in cut-off region and act as a open switch.

B) A Transistor can be operated as a closed or ON Switch, when both the junctions are forward bias and open or OFF switch when both junction are reverse biased.

UNIT III FIELD EFFECT TRANSISTORS

1. **Define FET?**

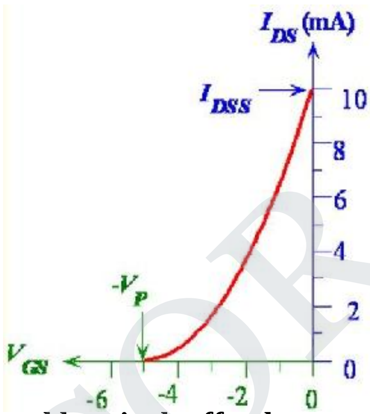
A field effect transistor (FET) is a three terminal semiconductor device which can be used as an amplifier or switch. The three terminals are Drain (D), Source (S), and Gate (G).

2. **Define channel?**

It is a bar like structure which determines the type of FET. Different types of N channel are FET and P channel FET.

3. **Draw the transfer characteristic for n-channel depletion type MOSFET?**

Transfer characteristic:



4. **What do you understand by pinch off voltage and out of voltage?**

As the reverse bias is further increased, the effective width of the channel decreases, the depletion region or the space charge region widens, reaching further into the channel and restricting the passage of electrons from the source to drain. Finally at a certain gate to source voltage $V_{GS} = V_P$.

5. **Why FET is called as "voltage operated device"?**

In FET the output current, I_D is controlled by the voltage applied between gate and source (V_{GS}). Therefore FET is said to be voltage controlled device.

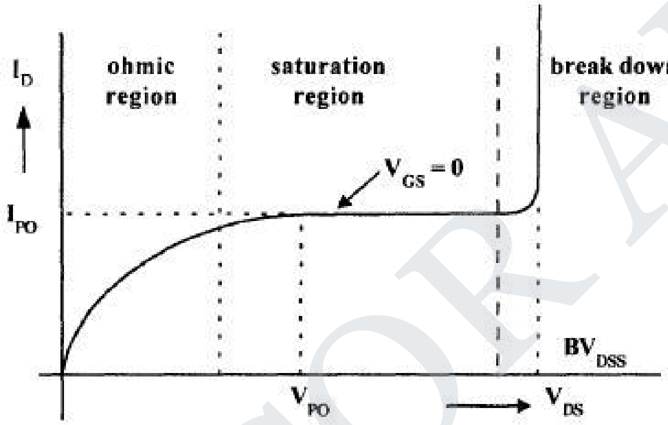
6. **Which MOSFET is called as Normally ON MOSFET and NORMALLY OFF MOSFET? Why?**

This is just one type of MOSFET, called **'normally -off'** because it is only the application of a positive gate voltage above the critical voltage which allows it to pass current between source and drain.Another type of MOSFET is the **'normally-on'**, which has a conductive channel of less heavily doped *n*-type material between the source and drain electrodes.

7. Compare BJT and MOSFET

S.No	BJT	MOSFET
1	CB,CE,CC configurations	CS,CG,CD configurations
2	Less input resistance compared to JFET	Very high input resistance
3	Input output relation is linear	Input output relation is non-linear
4	Gain bandwidth product is high	Gain bandwidth product is low
5	Thermal noise is more	Thermal noise is less
6	Thermal stability is less	Thermal stability is more
7	Bigger size than MOSFET	Smaller size

8. **Sketch the ohmic region in drain characteristics of JFET? Drain characteristics:**



9. **Define Amplification factor in JFET?**

It is defined as the ratio of change in drain-source voltage VDS to the change in gate-source voltage VGS at constant drain current ID. It is also called mutual conductance.

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

Amplification factor = Drain resistance X Trans conductance.

1. $= R_o \times g_m$

10. What are the advantages of FET over BJT?

- In FET input resistance is high compared to BJT Construction is smaller than BJT.
- Less sensitive to changes in applied voltage
- Thermal stability is more and Thermal noise is much lower Thermal runaway does not exist in JFET

11. Comparison between JFET and BJT.

S.No	BJT	JFET
1	Low input impedance	High input impedance
2	High output impedance	Low output impedance
3	Bipolar device	Unipolar device
4	Noise is more	Less noise
5	Cheaper	Costlier
6	Gain is more	Less gain
7	Current controlled device	Voltage controlled device

12. What are the important features of FET?

- The parameters of FET are temperature dependent. In FET, as temperature increases drain resistance also increases, reducing the drain current. Thus unlike BJT, thermal runaway does not occur with FET. Thus we can say FET is more temperature stable.
- FET has very high input impedance. Hence FET is preferred in amplifiers. It is less noisy.
- Requires less space.
- It exhibits no offset voltage at zero drain current.

13. Comparison between JFET and MOSFET.

S.No	JFET	MOSFET
1	Operated in depletion mode	Operated in depletion mode and enhancement mode
2	High input impedance(>10MΩ)	Very High input impedance(>10000MΩ)
3	Gate is not insulated from channel	Gate is insulated from channel by a layer of SiO_2
4	Channel exists permanently	Channel exists permanently in depletion type but not in enhancement type.
5	Difficult to fabricate than MOSFET	Easier to fabricate
6	Drain resistance is high	Drain resistance is less
7	Gate is formed as a diode	Gate is formed as a capacitor

14. **Explain the biasing of JFET?**

Input is always reverse biased and output is forward biased. (Note: In transistor input is forward biased and output is reverse biased).

15. **Define Drain resistance.**

It is the ratio of change in Drain – source voltage (ΔV_DS) to the change in Drain current (ΔI_D) at constant gate source voltage (V_{GS}).

16. **Define Tran's conductance?**

It is the ratio of change in drain current (ΔI_D) to the change in Gate – Source Voltage (ΔV_{GS}) at constant Drain – Source voltage (V_{DS}).

17. Write the advantages of JFET?

Input impedance of JFET is very high.

This allows high degree of Isolation between the Input and Output circuit.

Current carriers are not crossing the junction hence noise is reduced drastically

18. List the JFET parameters?

A.C drain resistance (r_d) Trans conductance (g_m) Amplification factor (μ)

19. **Explain the depletion node of operation in MOSFET?**

When the gate is at negative bias, the thickness of the depletion layer further increases owing to the further increase of the induced positive charge. Thus the drain current decreases, as the gate is made more negative. This is called depletion mode of operation.

20. **Explain the term Drain in FET?**

The drain is the terminal through which the current leaves the bar. Convention current entering the bar is designated as I_D.

21. **Define the term Gate in FET?**

The gate consists of either P^+ or N^+ impurity regions, heavily doped and diffused to the bar. This region is always reverse biased and in fact, controls the drain current I_D.

22. **Write the relative disadvantages of an FET over that of a BJT?**

1. The gain bandwidth product in case of a FET is low as compared with a BJT.

2. The category, called MOSFET, is extremely sensitive to handling therefore additional precautions have to be considered while handling.

23. Mention the methods used for biasing circuits in FET?

Self-bias and Potential divider bias.

24. Explain the term MOSFET?

In the insulated gate FET, conductivity is controlled by the potential on the insulated metal plate lying on the top of the channel the insulated gate field effect transistor is often called metallic oxide semiconductor FET.

25. Mention the three regions that are present in the drain source characteristics of JFET?

- Saturation region
- Break down region
- Ohmic region

26. List the characteristics of JFET.

- Drain characteristics
- Transfer characteristics.

27. **Give the drain current equation of JFET.**

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

Where

V_{GS}- Gate to source voltage
V_P - Pinch off voltage
I_D- Drain current
I_{DSS}- I_D Where $V_{GS} = 0$

28. **Why MOSFET is called IGFET?**

MOSFET is constructed with gate terminal insulated from the channel. So it is also called as insulated gate FET or IGFET.

29. **Comparison between JFET and MOSFET**

JFET	MOSFET
Gate is not insulated from channel	Gate is insulated from channel by a thin layer of SiO2
There are two types – N-channel and P-Channel	Four types - P-channel enhancement, P-channel depletion, N-channel enhancement, N-channel Depletion
Cannot be operated in depletion and enhancement modes	Can be operated in depletion and enhancement Modes
There is a continuous channel	There is a continuous channel only in depletion type, but not in enhancement type

30. Compare P channel and N channel JFET.

S.No	N- channel JFET	P-channel JFET
1	Current carriers are electrons	Current carriers are holes
2	Mobility of electrons is almost twice that of holes in p-channel	Mobility of holes is poor
3	Low input noise	Large input noise
4	Transconductance is very high	Transconductance is very small

UNIT- IV SPECIAL SEMICONDUCTOR DEVICES

1. What is a Thermistor?

Thermistor is a combination of thermal and resistance. A thermistor is a resistance with definite thermal characterisics. Thermistors are widely used for temperature compensation. ie cancelling the effect of temperature, liquid level, gas flow etc.

Thermistors are made in the shape of beads, probes, discs, washers etc.

2. Explain Tunneling principle?

The tunnel diode is PN junction device, which operates in certain regions of its IV characteristics by the quantum mechanical tunneling of electrons through the potential barrier of the junction.The tunneling process for reverse current is essentially the zener effect, although negligible reverse bias is needed to initiate the process in tunnel diodes.It is also called Esaki diode.

3. **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 a very thin depletion layer. This diode utilizes a phenomenon called tunneling and hence the diode is referred as tunnel diode.

4. What the applications of Tunnel diode?

High speed switching circuits

Logic circuits

5. **What is a schottky diode?**

A special type of diode which is manufactured for high frequency (> 10 MHZ) rectifying action and for fast switching is called as schottky diode. It is formed by connecting a metal and a semiconductor along with the ohmic contacts.

6. What are the other names of schottky diode?

- Rectifying metal semiconductor diode
- Surface barrier diodes.
- Hot carrier diodes

7. What are hot carriers?

The injected carrier from the semiconductor to the metal is termed as hot carriers. They are so called because they possess high kinetic energy.

8. List some applications of zener diode.

Zener diode find wide commercial and industrial applications. Some of their common applications are:

- As voltage regulators.
- As peak clippers or voltage limiters.
- For wave shaping.
- For meter protection against damage from accidental application of excessive voltage.
- As a fixed reference voltage in a network for biasing and comparison purposes and for calibrating voltmeters.

9. Give the applications of schottky diode.

1. It can switch off faster than bipolar diodes

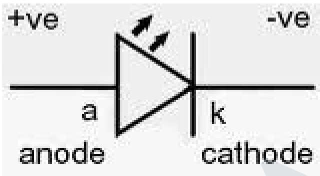
2. It is used to rectify very high frequency signals (>10 MHZ)

3. as a switching device in digital computers.

4. It is used in clipping and clamping circuits.

5. It is used in communication systems such as frequency mixers, modulators and detectors.

10. Draw symbol of Varactor diode.



UNIT –V POWER DEVICES AND DISPLAY DEVICES

1. Define Photovoltaic effect.

When Light is incident on a photodiode, an internal voltage is generated, it causes the current floe through internal circuit even though no external source is applied. This generated EMF is proportional to the frequency and intensity of the incident light.

2. Mention the applications of DIAC, SCR, LED and photoconductive cell.

DIAC:

1. It is used as a trigger device in TRAIC power control system.
2. It is used in Lamp dimmer circuit.
3. It is used in Heater control circuits
4. It is used for Speed control of universal motor.

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.

LED:

1. It is used in optical switching application.
2. It is used in seven segment and dot matrix displays.
3. It is used in the field of optical communication.
4. It is used in Digital watches and calculators.

Photoconductive Cell:

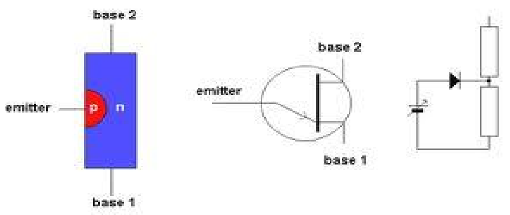
1. To measure the intensity of illumination.
2. As a voltage regulator.
3. As a volume controls that is itself controlled by light control.
4. As On-OFF switch.

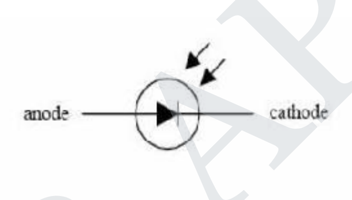
3. What is Photodiode?

The photo diode is a diode in which the current sensitivity to radiation can be made much larger by the use of the reverse biased PN junction. Thus this diode conducts heavily in the reverse bias when there is some radiation allowed to fall on the PN junction.

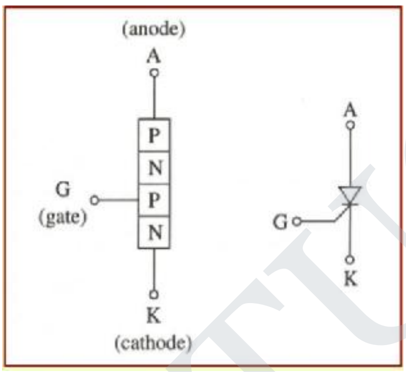
4. Draw the symbol of UJT, Photodiode, TRIAC, DIAC, LED and SCR.

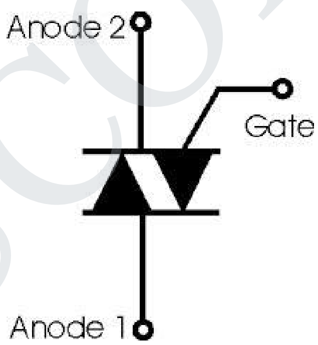
UJT PHOTODIODE

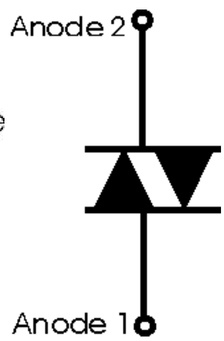




SCR TRAIC DIAC







5. Define intrinsic standoff ratio of UJT.

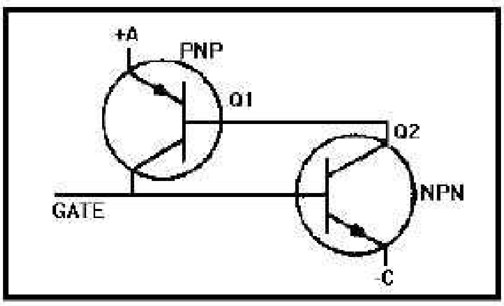
It is defined as the ratio of the voltage drop across R_{B1} (V_A) to the battery voltage (V_{BB})

$\frac{V_A}{V_{BE}} = \frac{R_{B1}}{R_{B1}+R_{B2}} = \eta$. Its value is generally lying in the range of 0.5 to .08.

6. Define holding current of SCR and draw the two transistor model of SCR.

Holding current is defined as the minimum value of anode current to keep the SCR ON.

Two Transistor Model of SCR



7. **Define dark current in photodiode.**

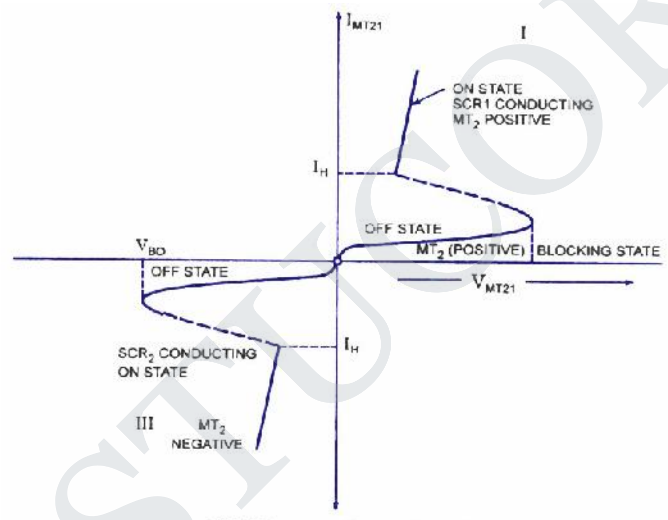
When there is no light the reveres e bias photodiode carries a current which is very small and is called dark current.

8. **Differentiate photodiode and phototransistor.**

Photodiode : It is a light sensitive device used to convert light signal into electrical signal. It is also called photo detector

Phototransistor: The photo transistor is a light detector, it combines a photodiode and phototransistor. The phototransistor cannot be directly used in control applications

9. **Draw the VI characteristics of TRIAC.**



V-I Characteristic of a Triac

10. **What are the regions in the VI characteristics of UJT?**

1. Cut-off region
2. Negative resistance region.
3. Saturation region

11. **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.

12. **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.

13. What is a Ohmic contact?

An ohmic contact is a low resistance junction providing conduction in both direction between metal and the semiconductor. Ohmic contact acts as contact between any semiconductor device and outside world.

14. What does UJT stands for? Justify the name UJT.

UJT stands for uni junction transistor. The UJT is a three terminal semiconductor device having two doped regions. It has one emitter terminal (E) and two base terminals (B1and B2). It has only one junction, moreover from the out look, it resembles to a transistor hence the name unijunction transistor.

15. **What is inter base resistance of UJT?**

The resistance between the two bases (B1and B2) of UJT is called as inter base resistance. Inter base resistance = RB1 + RB2

RB1- resistance of silicon bar between B1 and emitter junction.

RB2 - resistance of silicon bar between B2 and emitter junction

16. **Give the expression for peak point voltage for UJT?**

VP = ή VBB + VD

Where

VP - peak point voltage

ή - intrinsic stand -off ratio

VBB - voltage applied between the bases VD – barrier potential of UJT

17. **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.

18. **What is a LED?**

A PN junction diode which emits light when forward biased is known as Light emitting diode (LED).

19. **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.

20. **Give the application of TRIAC.**
- Heater control
- Motor speed control
- Phase control
- Static switches

21. **What are the different operating modes of TRIAC?**
- Keeping MT2 and G positive
- Keeping MT2 and G negative.
- Keeping MT2 positive and G negative.
- Keeping MT2 negative and G positive.

22. **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 anti parallel.

23. **Give some applications of DIAC.**
- To trigger TRIAC
- Motor speed control
- Heat control
- Light dimmer circuits

24. **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.

25. **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.

26. **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.

27. How turning on of SCR is done?

- By increasing the voltage across SCR above forward break over voltage.
- By applying a small positive voltage at gate.
- By rapidly increasing the anode to cathode voltage.
- By irradiating SCR with light.

28. **How turning off of SCR is done?**

- By reversing the polarity of anode to cathode voltage.
- By reducing the current through the SCR below holding current.
- By interrupting anode current by means of momentarily series or parallel switching

29. **Define holding current in a SCR.**

Holding current is defined as the minimum value of anode current to keep the SCR ON.

30. **List the advantages of SCR.**

- SCR can handle and control large currents.
- Its switching speed is very high
- It has no moving parts, therefore it gives noiseless operation.
- Its operating efficiency is high.

31. **List the application of SCR.**

- It can be used as a speed controller in DC and AC motors.
- It can be used as an inverter.
- It can be used as a converter
- It is used in battery chargers.
- It is used for phase control and heater control.
- It is used in light dimming control circuits.

32. **What is meant by latching.**

The ability of SCR to remain conducting even when the gate signal is removed is called as latching.

33. **Define forward current rating of a SCR.**

Forward current rating of a SCR is the maximum anode current that it can handle without destruction.

34. **Compare SCR with TRIAC.**

SCR	TRIAC
unidirectional current	bidirectional current
triggered by positive pulse at gate	triggered by pulse of positive or negative at gate
fast turn off time	Longer turn off time
large current ratings	lower current ratings

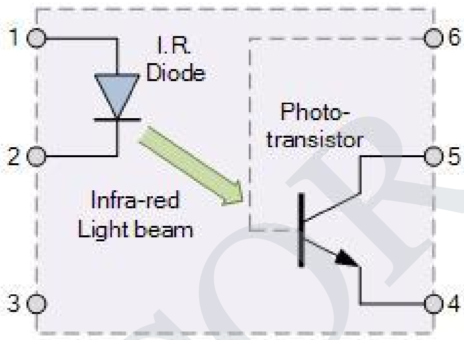
35. **Differentiate BJT and UJT.**

BJT	UJT
. It has two PN junctions	It has only one PN junctions
Three terminals present are emitter, Base, collector	Three terminals present are emitter, base1,base2
basically a amplifying device	basically a switching device

36. **Give the various triggering devices for thyristors.**

- SCR
- UJT
- DIAC
- TRIAC

37. **Draw the opto-coupler circuit?**



Reg. No. :

Question Paper Code : 57016

B.E./B.Tech. DEGREE EXAMINATION, MAY/JUNE 2014.

Second Semester

Electronics and Communication Engineering

EC 6201 — ELECTRONIC DEVICES

(Regulation 2013)

Time : Three hours Maximum : 100 marks

Answer ALL questions.

PART A — (10 × 2 = 20 marks)

1. Define mass action Law.
2. What is the principle operation of a PN Junction diode in reverse bias condition?
3. What is the need for biasing in the transistor?
4. Draw the h parameter model for CE transistor.
5. In which region JFET acts as a resistor and why?
6. Differentiate between JFET and BJT.
7. Draw the energy band diagram of metal and semiconductor before and after conduction is made.
8. List out the applications of tunnel diode.
9. Draw the basic structure of TRIAC and its symbol.
10. Write down the significance of Opto coupler.

PART B — (5 × 16 = 80 marks)

11. (a) Explain the theory of PN junction diode and derive its diode current equation. (16)

Or

(b) Explain and derive current components and switching characteristics of diode. (16)

12. (a) Explain the characteristics of BJT in CC, CE, CB compare the performance of a transistor in different configurations. (16)

Or

(b) Draw a voltage divider bias circuit and derive an expression for its stability factor. (16)

13. (a) (i) Discuss about FINFET and Dual Gate MOSFET. (8)

(ii) Explain the four distinct regions of the output characteristics of the JFET. (8)

Or

(b) (i) With the help of suitable diagrams explain the working of different types of MOSFET. (10)

(ii) Briefly describe some applications of JFET. (6)

14. (a) (i) Draw the VI characteristics of zener diode and explain its operation. (8)

(ii) Write short notes on Schottky diode. (8)

Or

(b) (i) Explain the principle behind the varactor diode and list out its application. (8)

(ii) Give the details about the Laser diode. (8)

15. (a) Explain the operation, characteristics and applications of SCR. (16)

Or

(b) Write short notes on :

(i) Solar cell (8)

(ii) CCD. (8)

Reg. No. :

Question Paper Code : 51392

B.E./B.Tech. DEGREE EXAMINATION, MAY/JUNE 2014.

Second Semester

Electronics and Communication Engineering

EC 2151 /EC 25/ 080290007/ EE 1152/ 10144 EC 205 — ELECTRIC CIRCUITS AND ELECTRON DEVICES

(Common to Computer Science and Engineering, Biomedical Engineering, Medical Electronics Engineering and Information Technology)

(Regulation 2008/2010)

Time : Three hours Maximum : 100 marks

Answer ALL questions.

PART A — (10 × 2 = 20 marks)

1. State Kirchoff's current law.
2. State Thevenin's theorem.
3. Write the expression for the quality factor of a resonant circuit.
4. If a coil has 500 turns linked with a flux of 50 mWb when carrying a current of 125A, calculate the inductance of the coil.
5. Define Electron volt.
6. Write any two applications of Zener diode.
7. Define α_{dc} and β_{dc} of a transistor.
8. Draw the structure and symbol for a n-channel JFET.
9. Mention any two applications of DIAC.
10. What is Photovoltaic effect?

PART B — (5 × 16 = 80 marks)

11. (a) (i) Find the current through each resistor of the circuit shown in Figure (a) using nodal-analysis. (10)

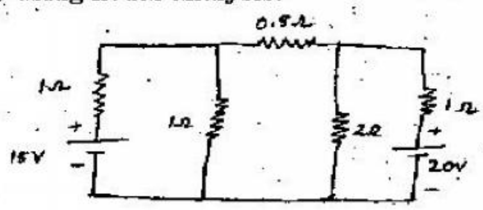


Figure (a)

(ii) State and prove maximum power transfer theorem. (6)

Or

(b) (i) Find the Thevenin's equivalent circuit for the network in Figure (b) at terminals AB. (10)

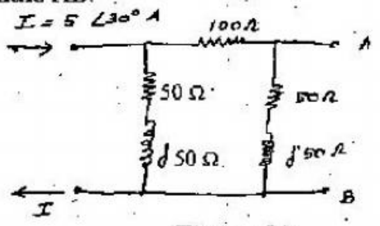


Figure (b)

(ii) Explain superposition theorem, assuming a suitable circuit. (6)

12. (a) (i) Derive expressions for resonant frequency and bandwidth of a series resonant circuit. Draw its frequency response. (8)

(ii) Discuss the response of a series RL circuit to sinusoidal input. (8)

Or

(b) With a neat sketch define the following terms in respect of step response of a second order system. (16)

(i) Delay time (ii) Rise time

(iii) Peak time (iv) Peak overshoot

(v) Settling time.

Also write the equation for the response.

13. (a) Explain the working of a PN junction diode derive the expression for the current through a PN junction diode and explain its VI characteristics.

Or

(b) (i) Define the following with respect to a diode

(1) Cut in voltage

(2) Reverse breakdown voltage

(3) Diffusion capacitance

(4) Transition capacitance.

(5) Intrinsic and extrinsic semiconductors. (10)

(ii) Distinguish between Zener breakdown and Avalanche breakdown. (6)

14. (a) (i) Explain the working of a CE transistor configuration. Explain its input and output characteristics. (10)

(ii) Compare the characteristics of CE, CB and CC configuration of transistors. (6)

Or

(b) (i) Explain the working of n-channel enhancement MOSFET. (10)

(ii) Compare the characteristics of BJT, JFET and MOSFET. (6)

15. (a) (i) Draw the VI characteristics of SCR and explain its operation. Explain the terms Holding current and Latching current. (10)

(ii) Explain the principle of operation of photo transistor. (6)

Or

(b) Write short notes on :

(i) Photodiode (5)

(ii) LED. (5)

(iii) UJT. (6)

Reg. No. :

Question Paper Code : 31350

B.E./B.Tech. DEGREE EXAMINATION, NOVEMBER/DECEMBER 2013.

Second Semester

Electronics and Communication Engineering

EC 2151/EC 25/10144 EC 205/080290007/EE 1152 — ELECTRIC CIRCUITS AND ELECTRON DEVICES

(Common to Computer Science and Engineering, Biomedical Engineering, Medical Electronics Engineering and Information Technology)

(Regulation 2008/2010)

Time : Three hours Maximum : 100 marks

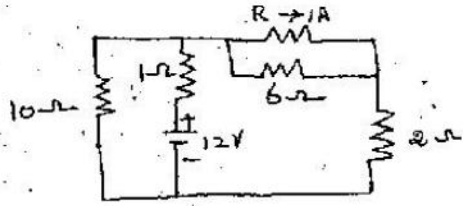
Answer ALL questions.

PART A — ($10 \times 2 = 20$ marks)

1. State Kirchoffs current and voltage laws.
2. State superposition theorem.
3. Define Q factor of series resonant circuit.
4. Draw frequency response of R-L network.
5. Draw energy band diagram of semiconductor.
6. Define diffusion capacitance.
7. Draw input characteristics of CB transistor.
8. Define drain to source resistance of JFET.
9. What is LED?
10. Write the principle of operation of photodiode.

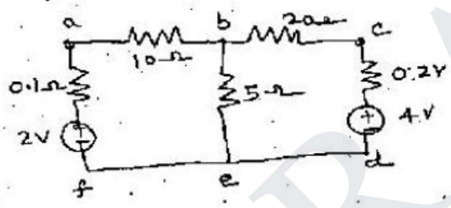
PART B — (5 × 16 = 80 marks)

11. (a) Find the value R so that 1A current would flow in it, for the network in the figure shown below. (16)



Or

(b) State Norton's theorem and find the current through branch b-e using Norton's theorem. (16)



12. (a) Obtain expression for the instantaneous current through the RLC series circuit with sinusoidal input. (16)

Or

(b) What is Q factor? Find value of Q factor for an inductor and capacitor, connected in series. (16)

13. (a) Draw and explain zener diode and its characteristics. (16)

Or

(b) What is transition capacitance and obtain expression for transition capacitance in PN junction diode. (16)

14. (a) Explain with neat diagram the operation of NPN transistor. (16)

Or

(b) Describe construction and operation of n-channel depletion type MOSFET. (16)

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15. (a) (i) With a neat sketch explain construction and VI characteristics of tunnel diode. (10)

(ii) Explain construction and operation of photoconductive cell. (6)

Or

(b) (i) Draw and describe the principle of operation and characteristics of SCR. (8)

(ii) Draw and explain the working and characteristics of UJT. (8)

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Reg. No. :

Question Paper Code : 21350

B.E./B.Tech. DEGREE EXAMINATION, MAY/JUNE 2013.

Second Semester

Electronics and Communication Engineering

EC 2151/EC 25/10144 EC 205/080290007/EE 1152 – ELECTRIC CIRCUITS AND ELECTRON DEVICES

(Common to Computer Science and Engineering, Biomedical Engineering, Medical Electronics Engineering and Information Technology)

(Regulation 2008/2010)

Time : Three hours Maximum : 100 marks

Answer ALL questions.

PART A — (10 × 2 = 20 marks)

1. State Kirchhoff's voltage law.
2. State Superposition theorem.
3. A series RL circuit, with R = 10 Ω and L = 1H, has a 100 V source applied at t = 0. Find the current for t>0.
4. What is the power factor of the circuit under series resonance?
5. Distinguish between intrinsic and extrinsic semiconductors.
6. Mention the two types of junction capacitances.
7. Give the biasing arrangement for an NPN transistor to operate in the active region.
8. Write the equation for drain current of JFET.
9. Draw the two transistor equivalent circuit of SCR.
10. Compare LED and LCD.

PART B — (5 × 16 = 80 marks)

11. (a) (i) For the circuit shown in Fig.1, calculate the value of resistor R, when then total current taken by the network is 1.5 A (8)

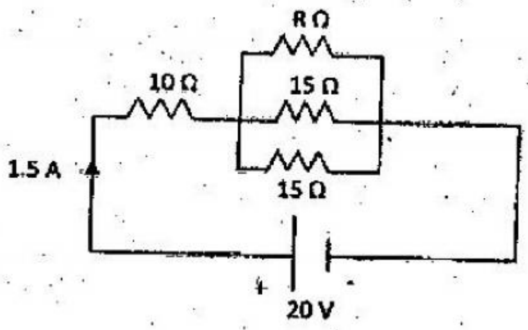

Fig. 1

(ii) Find the equivalent resistance between the terminals A and B of Fig. 2, using star-delta transformation. (8)

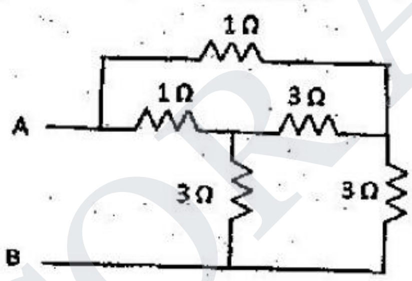

Fig. 2

Or

(b) (i) State Thevenin's and Norton's theorems. (6)

(ii) For the circuit shown in Fig. 3, determine the value of R_L to get the maximum power. Also find the maximum power transferred to the load. (10)

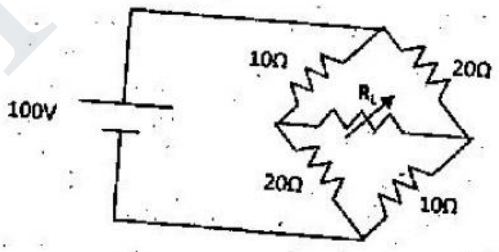

Fig. 3

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12. (a) (i) Describe the response of RC circuit to a pulse of duration T and height V_0. (8)

(ii) Obtain the expression for the current $i(t)$ from the differential equation $\frac{d^2i(t)}{dt^2}+10\frac{di(t)}{dt}+25i(t)=0$

with initial conditions

$i(0^+)=2\frac{di(0^+)}{dt}=0$ (8)

Or

(b) (i) Derive the expression for resonant frequency of a series RLC circuit. Also define Q factor and bandwidth and give the relation between resonant frequency, Q factor and bandwidth. (10)

(ii) Determine the quality factor and resonant frequency for the series circuit consisting of $R = 10\ \Omega$, $L = 0.1$ H and $C = 10\ \mu F$. (6)

13. (a) (i) Explain the theory of PN junction diode along with its V-I characteristic. (8)

(ii) Discuss the effect of temperature upon the characteristics of PN junction diode. (8)

Or

(b) (i) Distinguish between avalanche breakdown and zener breakdown. (8)

(ii) Draw and explain the characteristics of zener diode. (8)

14. (a) (i) Draw and explain the characteristics of PNP transistor in CB configuration. (8)

(ii) Compare CB, CE and CC transistor configurations. (8)

Or

(b) (i) Describe the construction, operation and characteristics of N-channel JFET. (8)

(ii) Draw the structure of N-channel depletion type MOSFET and explain its operation and characteristics. (8)

15. (a) (i) With energy band diagram, explain the theory and characteristics of tunnel diode. (10)

(ii) Write notes on varactor diode. (6)

Or

(b) (i) Describe the construction, operation and characteristics of UJT. (8)

(ii) Discuss the operation and characteristics of photodiode. Mention the applications of photodiodes and phototransistors. (8)

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