BEE303 ELECTRON DEVICES

UNIT I

ELECTRON DEVICES

Conduction of Electricity in solids, liquids and gases

Solids:

A solid conductive metal contains mobile, or free, electrons originating in the conduction electrons. These electrons are bound to the metal lattice but no longer to any individual atom. Even with no external electric field applied, these electrons move about randomly due to thermal energy but, on average, there is zero net current within the metal. Given a surface through which a metal wire passes, the number of electrons moving from one side to the other in any period of time is on average equal to the number passing in the opposite direction

When a metal wire is connected across the two terminals of a DCvoltage source such as a battery, the source places an electric field across the conductor. The moment contact is made, the free electrons of the conductor are forced to drift toward the positive terminal under the influence of this field. The free electrons are therefore the charge carrier in a typical solid conductor. For an electric current of 1 ampere, 1 coulomb of electric charge drifts every second through any given point in the conductor.

Liquids (Electrolytes):

Commonly, electrolytes are solutions of acids, bases or salts.

Pure water is a poor conductor of electricity. However, very small amounts of impurities, especially salts, greatly increase the electrical conductivity of water.

The main carriers of electrical current are dissolved ions. If a battery is connected to a container of water so that the (+) and (-) poles of the battery are immersed in the water, the positive ions will migrate toward the (-) pole and the negative ions will migrate toward the (+) pole (electrical opposites attract). This closes the "switch" and electric current flows through the solution.

Different ions can help carry the electric current, some more / some less, depending upon their electrical charge and their size. More highly charged, smaller ions are more efficient carriers of the electrical current.

The higher the concentration of ions, the greater is the conductance of the solution.

None of the ion electrical current carriers of salts dissolved in water are as mobile as "free" electrons in a metal are.

Gases and plasmas:

In air and other ordinary gases below the breakdown field, the dominant source of electrical conduction is via a relatively small number of mobile ions produced by radioactive gases, ultraviolet light, or cosmic rays. Since the electrical conductivity is low, gases are dielectrics or insulators. However, once the applied electric field approaches the breakdown value, free electrons become sufficiently accelerated by the electric field to create additional free electrons by colliding, and ionizing, neutral gas atoms or molecules in a process called avalanche breakdown. The breakdown process forms a plasma that contains a significant number of mobile electrons and positive ions, causing it to behave as an electrical conductor. In the process, it forms a light emitting conductive path, such as a spark, arc or lightning.

Plasma is the state of matter where some of the electrons in a gas are stripped or "ionized" from their molecules or atoms. A plasma can be formed by high temperature, or by application of a high electric or alternating magnetic field as noted above.

Due to their lower mass, the electrons in a plasma accelerate more quickly in response to an electric field than the heavier positive ions, and hence carry the bulk of the current.

Vacuum

Since a "perfect vacuum" contains no charged particles, it normally behaves as perfect insulator. However, metal electrode surfaces can cause a region of the vacuum to become conductive by injecting free electrons or ions through either field electron emission or thermionic emission.

Field emission

(FE) is emission of electrons induced by an electrostatic field. The most common context is FE from a solid surface into vacuum.
The classical example of thermionic emission is the emission of electrons from a hot cathode, into a vacuum in a vacuum tube

Thermionic emission

It is the heat-induced flow of charge carriers from a surface or over a potential-energy barrier. This occurs because the thermal energy given to the carrier overcomes the binding potential, also known as work function of the metal (typically >1000K (726˚C))

Externally heated electrodes are often used to generate an electron cloud as in the filament or indirectly heated cathode of vacuum tubes. Vacuum tubes are used in electronic switching and amplifying devices based on vacuum conductivity.

Motion in a uniform electric or magnetic field:

We want now to describe—mainly in a qualitative way—the motions of charges in various circumstances. Most of the interesting phenomena in which charges are moving in fields occur in very complicated situations, with many, many charges all interacting with each other. For instance, when an electromagnetic wave goes through a block of material or a plasma, billions and billions of charges are interacting with the wave and with each other. We will come to such problems later, but now we just want to discuss the much simpler problem of the motions of a single charge in a *given* field. We can then disregard all other charges—except, of course, those charges and currents which exist somewhere to produce the fields we will assume.

We should probably ask first about the motion of a particle in a uniform electric field. At low velocities, the motion is not particularly interesting—it is just a uniform acceleration in the direction of the field. However, if the particle picks up enough energy to become relativistic, then the motion gets more complicated. But we will leave the solution for that case for you to play with.

Next, we consider the motion in a uniform magnetic field with zero electric field. We have already solved this problem—one solution is that the particle goes in a circle. The magnetic force $qv\times Bqv\times B$ is always at right angles to the motion, so $dp/dtdp/dt$ is perpendicular to pp and has the magnitude $vp/Rvp/R$, where RR is the radius of the circle:
$F=qvB=vpR.F=qvB=vpR.$

The radius of the circular orbit is then

$R=pqBR$

That is only one possibility. If the particle has a component of its motion along the field direction, that motion is constant, since there can be no component of the magnetic force in the direction of the field. The general motion of a particle in a uniform magnetic field is a constant velocity parallel to BB and a circular motion at right angles to BB—the trajectory is a cylindrical helix . The radius of the helix is given by if we replace pp by $p\perp p\perp$, the component of momentum at right angles to the field.

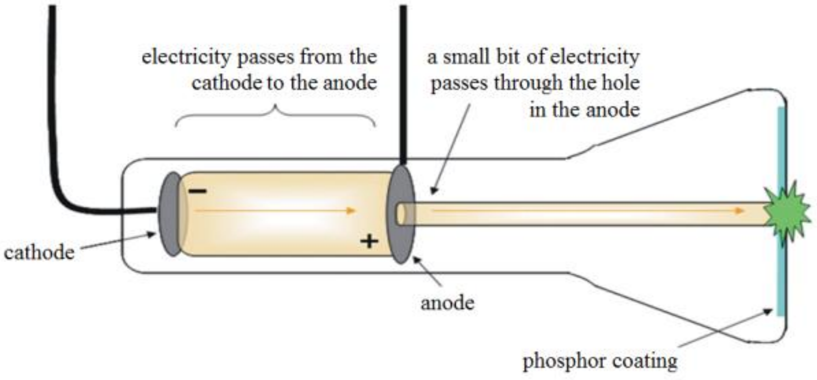
CATHODE RAY TUBE:

The **cathode ray tube** (**CRT**) is a vacuum tube that contains one or more electron guns and a phosphorescent screen, and is used to display images.[1] It modulates, accelerates, and deflects electron beam(s) onto the screen to create the images. The images may represent electrical waveforms (oscilloscope), pictures (television, computer monitor), radar targets, or others. CRTs have also been used as memory devices, in which case the visible light emitted from the fluorescent material (if any) is not intended to have significant meaning to a visual observer (though the visible pattern on the tube face may cryptically represent the stored data).

In television sets and computer monitors, the entire front area of the tube is scanned repetitively and systematically in a fixed pattern called a raster. An image is produced by controlling the intensity of each of the three electron beams, one for each additive primary colour (red, green, and blue) with a video signal as a reference. In all modern CRT monitors and televisions, the beams are bent by *magnetic deflection*, a varying magnetic field generated by coils and driven by electronic circuits around the neck of the tube, although electrostatic deflection is commonly used in oscilloscopes, a type of electronic test instrument.

A CRT is constructed from a glass envelope which is large, deep (i.e., long from front screen face to rear end), fairly heavy, and relatively fragile. The interior of a CRT is evacuated to approximately 0.01 Pa to 133 nPa.,evacuation being necessary to facilitate the free flight of electrons from the gun(s) to the tube's face. That it is evacuated makes handling an intact CRT potentially dangerous due to the risk of breaking the tube and causing a violent implosion that can hurl shards of glass at great velocity. As a matter of safety, the face is typically made of thick lead glass so as to be highly shatter-resistant and to block most X-ray emissions, particularly if the CRT is used in a consumer product.

Since the late 2000s, CRTs have been largely superseded by newer "flat panel" display technologies such as LCD, plasma display, and OLED displays, which in the case of LCD and OLED displays have lower manufacturing costs and power consumption, as well as significantly less weight and bulk. Flat panel displays can also be made in very large sizes; whereas 38" to 40" was about the largest size of a CRT television, flat panels are available in 60" and larger sizes.



Magnetic and electrostatic deflection:

Bending radii in magnetic fields:

A particle of rest mass m_0, momentum p and charge qe, where e is the electron charge and q an integer, that enters a uniform magnetic field, B, perpendicular to its velocity, will describe a circular orbit of radius, R; its ‘magnetic rigidity’, BR, is given by the expression:

Using the particle's rest energy E_o, the kinetic energy E_k and the Lorentz factor $\gamma \equiv 1 + E_k/E_o$, the above expression can be re-written as:

E_o

or, if E_k/E_o « 1, i.e. in the non-relativistic limit,

$ɿ_o)^{1/2}$

In both (la) and (lb), BR is in T·m, E_o and E_k are in MeV and m_o is in atomic mass units. See table below for some typical values.

Magnetic deflectors**:**
In the small deflection angle θ limit, tan $\theta \simeq \theta$, a magnetic deflector of length l in metres, and field strength B, in Tesla, will produce a deflection

E_o V)

or, in the non-relativistic approximation,

$ɿ_0)^{1/2}$ V, m_0, in a.u.)

Electrostatic deflectors:

For a particle of velocity v, perpendicular to the field of a parallel-plate deflector of length l, gap d and deflecting potential V, the deflection angle θ is given by:

where the other symbols are defined as before; it is assumed that tan $\theta \simeq \theta$.

For practical applications:

E_o in MeV)

or, in the non-relativistic limit,

E_k in MeV)

Table of magnetic rigidities, BR (in T·m) for different values of E_k (in MeV)

m)

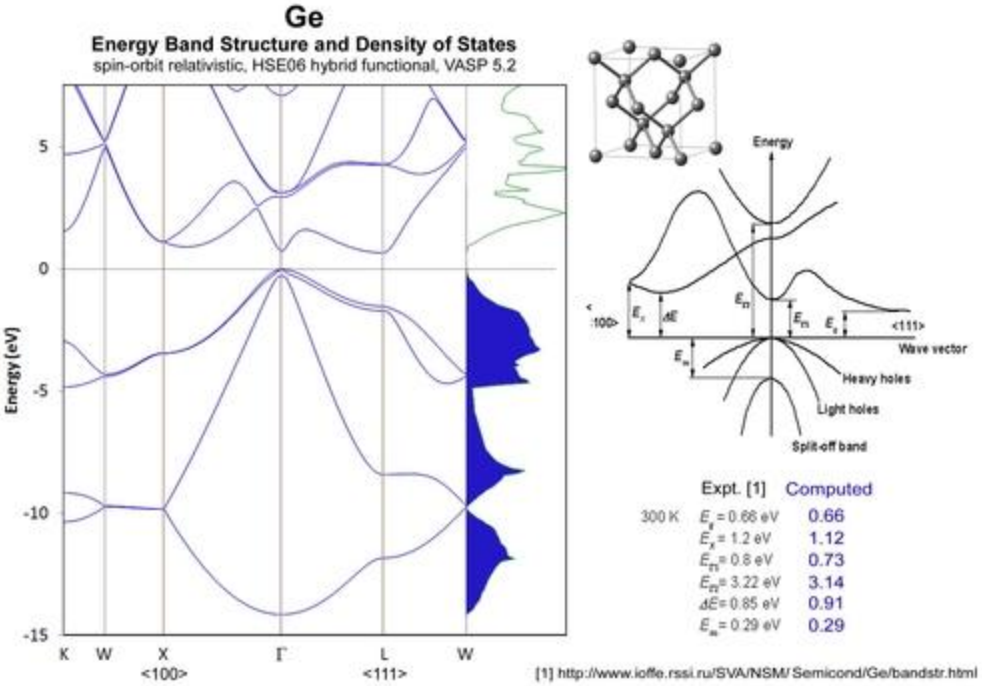
0^{-4}	$^{-3}$	$^{-3}$	$^{-2}$	$^{-1}$		^{1}
	$^{-2}$	$^{-1}$	$^{-1}$			^{1}
3	$^{-2}$	$^{-1}$	$^{-1}$			^{1}
	$^{-2}$	$^{-1}$	$^{-1}$			^{1}
	$^{-2}$	$^{-2}$	$^{-1}$	$^{-1}$		

UNIT II

SOLID STATE ELECTRONICS

ENERGY BAND STRUCTURE OF GERMANIUM:

Elemental germanium is a semiconductor with a measured indirect band gap of 0.66 eV. Using a hybrid functional as implemented in VASP 5.2, the computed value is 0.66 eV while standard density functional approaches incorrectly predict Ge to have no band gap. Other features of the band structure such as the direct gap at Γ are also well reproduced by the current level of theory, namely 0.8 eV (measured) and 0.73 eV (computed), thus demonstrating the reliability of this level of approach in predicting energy band structures. This sets the stage for using computations to modify the band structure for example by uniaxial strain to meet specific design criteria.



Energy Bands of Silicon:

Silicon is a semiconductor material whose number of free electrons is less than conductor but more than that of an insulator. For having this unique characteristic, silicon has a broad application in the field of electronics. There are two kinds of **energy band in silicon** which are conduction band and valence band. A series of energy levels having valence electrons forms the valance band in the solid. At absolute 0^{o}K temperature the energy levels of the valence band are filled with electrons. This band contains maximum amount of energy when the electrons are in valence band, no current flows due to such electrons. Conduction band is the higher energy level band which is the minimum amount of energy. This band is partially filled by the electrons which are known as the free electrons as they can move anywhere in the solid. These electrons are responsible for current flowing. There is a gap of energy between the conduction band and the valence band. This difference of energy is called forbidden energy gap. This gap determines the nature of a solid.

Whether a solid is metal, insulator or semiconductor in nature, the fact is determined by the amount of forbidden energy gap. Partially there is no gap for metals and large gap for insulators. For semiconductors, the gap is neither large nor the bands get overlapped. Silicon has forbidden gap of 1.2 eV at 300^{o}K temperature. We know that in a silicon crystal, the covalent bonds exist. Silicon is electrically neutral. When an electron breaks away from its covalent bond, a hole is created behind it. As temperature increases, more and more electrons jump into the conduction band, and more holes are created in the valence band.

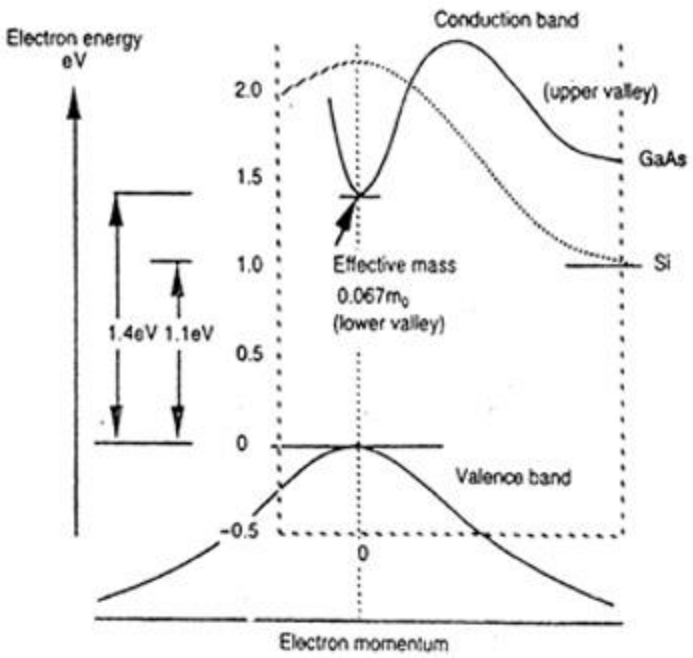
Energy Bands Diagram of Intrinsic Silicon

Energy Bands Diagram of Extrinsic Silicon

Gallium Arsenide (GaAs) – Energy Band Structure:

One of the important characteristics that is attributed to GaAs is its superior electron mobility brought about as the result of its energy band structure as shown in the figure below. Gallium Arsenide (GaAs) is a direct gap material with a maximum valence band and a minimum conduction band and is supposed to coincide in k-space at the Brillouin zone centers. In the graph shown below, we can see that the some valleys in the band structure are narrow and some are sharply curved. These curves and narrows differ corresponding to the electrons with low effective mass state, while valleys that are wide with gentle curvature are characterized by larger effective masses. The curvature that is seen in the graph of the energy versus electron momentum profile clearly shows the effective mass of electrons travelling through the crystal. The minimum point of gallium arsenide's conduction band is near the zero point of crystal-lattice momentum, as opposed to silicon, where conduction band minimum occurs at high momentum. Now, mobility, μ, depends upon

- Concentration of impurity, N
- Temperature, T
- And is also inversely related to the electron effective mass, m.



Energy band structure of silicon and gallium arsenide

Energy Band Strucure of GaAs

For GaAs, the effective mass of these electrons is 0.067 times the mass of free electron (that is, $0.067m_e$, where m_e is the free electron rest mass). Thus the shapes in the conduction band bring about a superior electron mobility. Due to this, the electrons travel faster in Gallium Arsenide (GaAs) than in Silicon. However the conduction of electrons of GaAs is very similar to that of Silicon in the higher valleys. The reason behind this is the high mass and strong inter-valley scattering which provide very low mobility. Furthermore, Gallium Arsenide is a direct-gap semiconductor. Its conduction band minimum occurs at the same wave vector as the valence band maximum, which means little momentum change is necessary for the transition of an electron from the conduction band, to the valence band. Since the probability of photon emission with energy nearly equal to the band gap is somewhat high, GaAs makes an excellent light-emitting diode. Silicon on the other hand, is an indirect-gap semiconductor since the minimum associated with its conduction band is separated in momentum from the valence band minimum. Therefore it cannot be a light-emitting device.

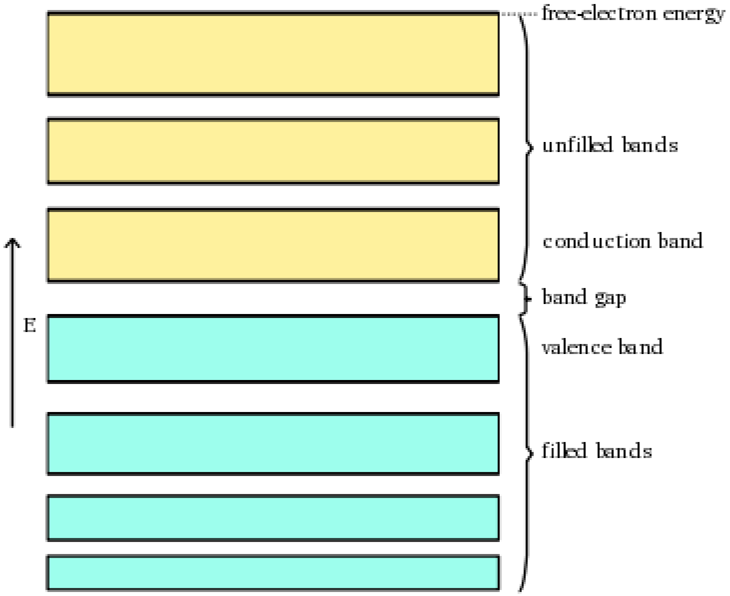
CARRIER GENERATION AND RECOMBINATION:

In the solid-state physics of semiconductors, **carrier generation** and **recombination** are processes by which mobile charge carriers (electrons and electron holes) are created and eliminated. Carrier generation and recombination processes are fundamental to the operation of many optoelectronic semiconductor devices, such as photodiodes, LEDs and laser diodes. They are also critical to a full analysis of p-n junction devices such as bipolar junction transistors and p-n junction diodes.

The **electron–hole pair** is the fundamental unit of generation and recombination, corresponding to an electron transitioning between the valence band and the conduction band where generation of electron is a transition from the valence band to the conduction band and recombination leads to a reverse transition.

Carrier generation and recombination occur when an electron makes transition from the valence band to conduction band in a semiconductor, as a result of interaction with other electrons, holes, photons, or the vibrating crystal lattice itself. These processes must conserve both quantized energy and momentum, and the vibrating lattice plays a large role in conserving momentum as photons carry very little momentum in relation to their energy.

Recombination and generation are always happening in semiconductors, both optically and thermally, and their rates are in balance at equilibrium. The product of the electron and hole densities (and) is a constant **at equilibrium**, maintained by recombination and generation occurring at equal rates. When there is a surplus of carriers (i.e.,), the rate of recombination becomes greater than the rate of generation, driving the system back towards equilibrium. Likewise, when there is a deficit of carriers (i.e.,), the generation rate becomes greater than the recombination rate, again driving the system back towards equilibrium.[1] As the electron moves from one energy band to another, the energy and momentum that it has lost or gained must go to or come from the other particles involved in the process (e.g. photons, electron, or the system of vibrating lattice atoms). The following models are used to describe generation and recombination, depending on which particles are involved in the process.



Drift and diffusion currents :-

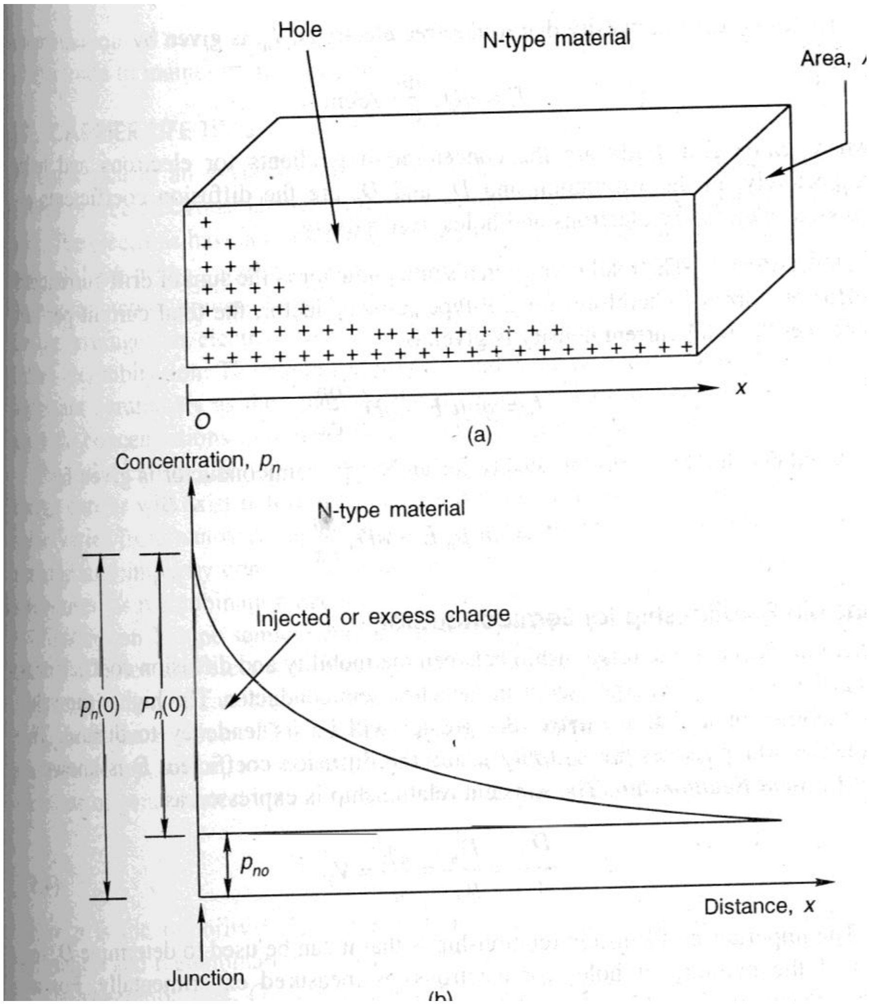
→ The flow of charge (ie) current through a semiconductor material are of two types namely drift & diffusion.

→ (ie) The net current that flows through a (PN junction diode) semiconductor material has two components

Drift current
Diffusion current

The **difference between drift current and diffusion current** is that **drift current**depends on the electric field applied: if there's no electric field, there's no **drift current**. **Diffusion current** occurs even though there isn't an electric field applied to the semiconductor. It does not have E as one of its parameters.

Drift current :-



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

Drift current density J_n , due to free electrons is given by
$J_n = q\ n\ \mu_n\ E$ A / cm^2

Drift current density J_P, due to holes is given by
$J_P = q\ p\ \mu_p\ E$ A / cm^2

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

P - Number of holes per cubic centimeter

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.

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.

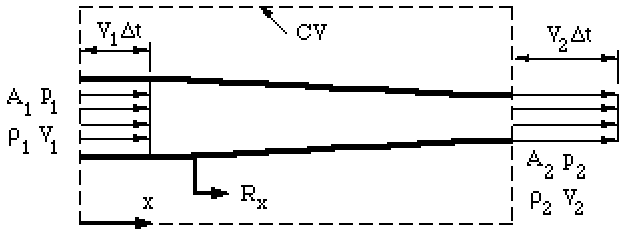
→ A concentration gradient exists if the number of either elements or holes is greater in one region of a semiconductor as compared to the rest of the Region.

→ 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.

CONTINUITY EQUATION:

One of the fundamental principles used in the analysis of uniform flow is known as the Continuity of Flow. This principle is derived from the fact that mass is always conserved in fluid systems regardless of the pipeline complexity or direction of flow.

If steady flow exists in a channel and the principle of conservation of mass is applied to the system, there exists a continuity of flow, defined as: "The mean velocities at all cross sections having equal areas are then equal, and if the areas are not equal, the velocities are inversely proportional to the areas of the respective cross sections." Thus if the flow is constant in a reach of channel the product of the area and velocity will be the same for any two cross sections within that reach. Looking a the units of the product of area (sq-ft) and velocity (fps) leads to the definition of flow rate (cfs). This is expressed in the Continuity Equation:



$$Q = A_1V_1 = A_2V_2$$

Where:

Q = the volumetric flow rate

A = the cross sectional area of flow

V = the mean velocity

Calculation of flow rate is often complicated by the interdependence between flow rate and friction loss. Each affects the other and often these problems need to be solved iteratively. Once flow and depth are know the continuity equation is used to calculate velocity in the culvert.

HALL EFFECT:

The **Hall effect** is the production of a voltage difference (the **Hall voltage**) across an electrical conductor, transverse to an electric current in the conductor and to an applied magnetic field perpendicular to the current. It was discovered by Edwin Hall in 1879.[1] For clarity, the original effect is sometimes called the **ordinary Hall Effect** to distinguish it from other "Hall Effects" which have different physical mechanisms.

The Hall coefficient is defined as the ratio of the induced electric field to the product of the current density and the applied magnetic field. It is a characteristic of the material from which the conductor is made, since its value depends on the type, number, and pr

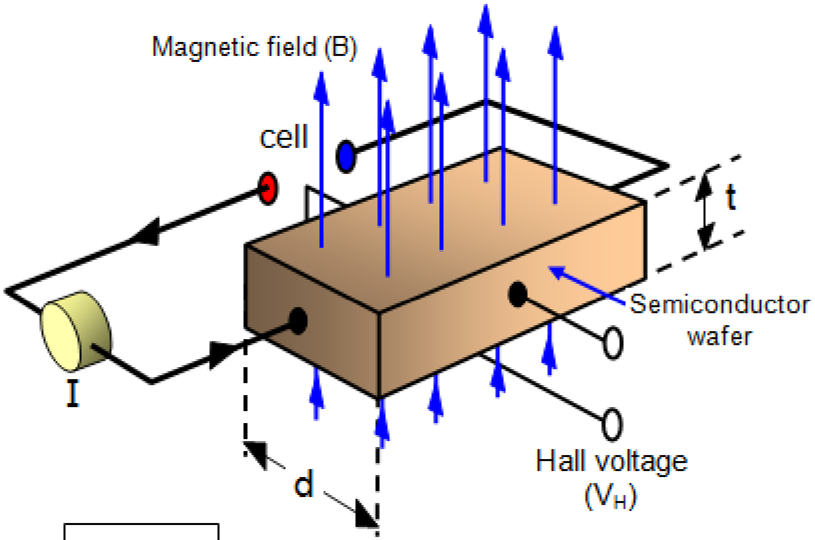


Figure 1

PN Junction Diode and its Characteristics:

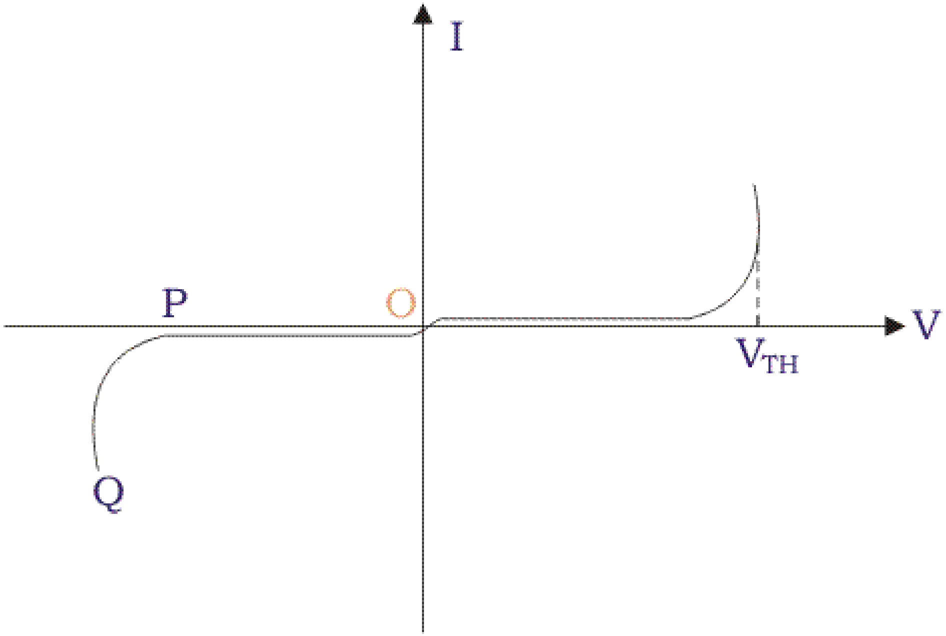
P-N junction diode is the most fundamental and the simplest electronics device. When one side of an intrinsic semiconductor is doped with acceptor i.e, one side is made p-type by doping with n-type material, a p-n junction diode is

formed. This is a two terminal device. It appeared in 1950’s.
P-N junction can be step graded or linearly graded. In step graded the concentration of dopants both, in n-side and in p-side are constant up to the junction. But in linearly graded junction, the doping concentration varies almost linearly with the distance from the junction. When the **P-N diode** is in unbiased condition that is no voltage is applied across it, electrons will defuse through the junction to p-side and holes will defuse through the junction to n-side and they combine with each other.

P-N Junction Diode Characteristics:
Let's a voltage V is applied across a **p-n junction** and total current I, flows through the junction. It is given as.

$$I = I_S \left[exp\left(\frac{eV}{\eta K_B T} \right) - 1 \right]$$

Here, I_S = reverse saturation current
e = charge of electron
η = emission co-efficient
K_B = Boltzmann constant
T = temperature The current voltage characteristics plot is given below.
The current voltage characteristics.

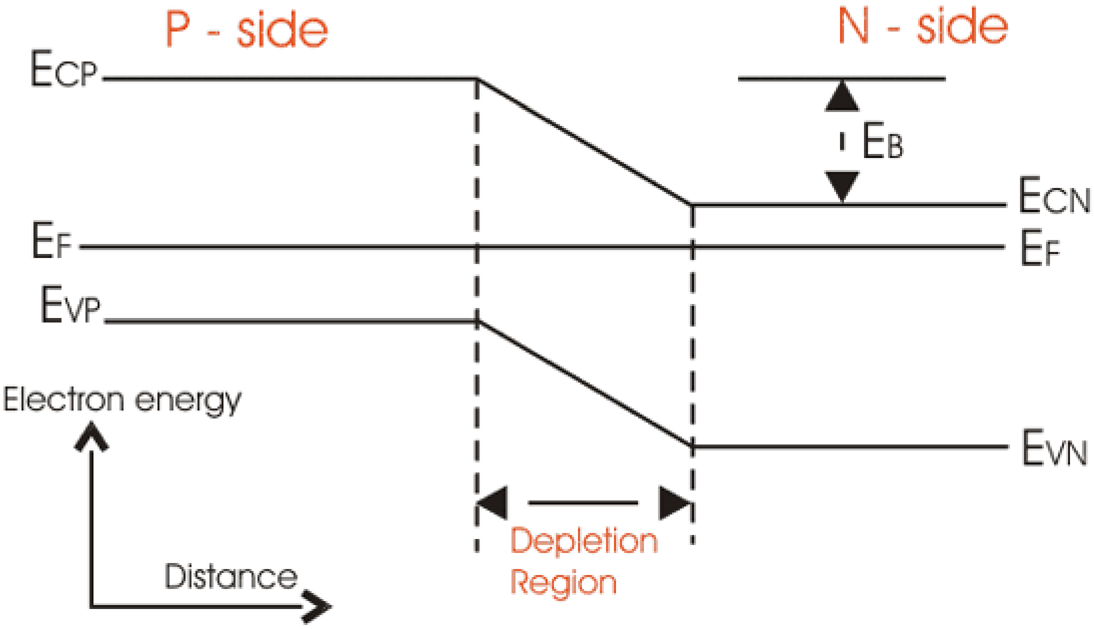


When, V is positive the junction is forward biased and when V is negative, the junction is reversing biased. When V is negative and less than V_{TH}, the current is very small. But when V exceeds V_{TH}, the current suddenly becomes very high. The voltage V_{TH} is known as threshold or cut in voltage. For Silicon diode V_{TH} = 0.6 V. At a reverse voltage corresponding to the point P, there is abrupt increment in reverse current. The PQ portion of the characteristics is known as breakdown region.

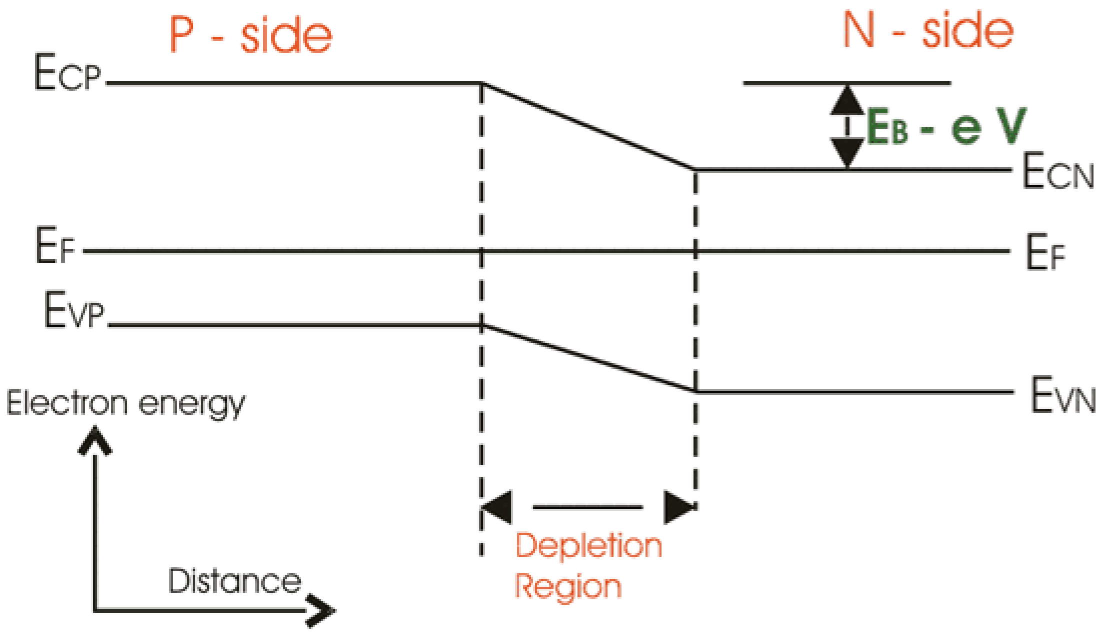
P-N Junction Band Diagram
For an n-type semiconductor, the Fermi level E_F lies near the conduction band edge. E_C but for an p-type semiconductor, E_F lies near the valance band edge E_V.

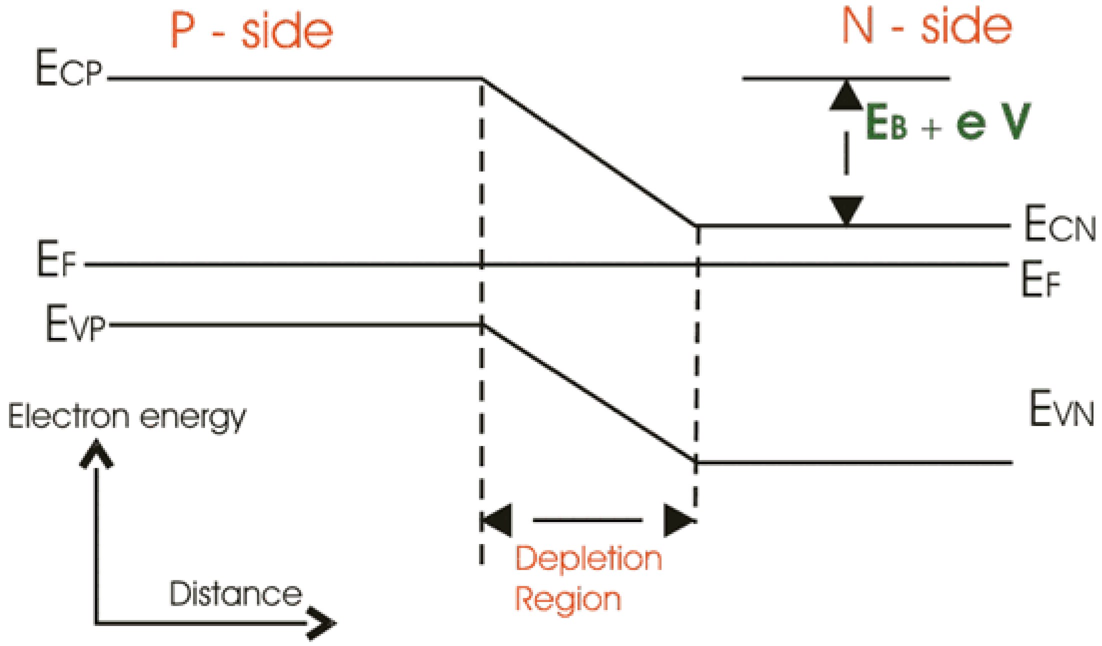
Now, when a p-n junction is built, the Fermi energy E_F attains a constant value. In this scenario the p-sides conduction band edge. Similarly n–side valance band edge will be at higher level than E_{cn}, n-sides conduction band edge of p-side. This energy difference is known as barrier energy. The barrier energy is

$$E_B = E_{cp} - E_{cn} = E_{vp} - E_{vn}$$



If we apply forward bias voltage V, across junction then the barrier energy decreases by an amount of eV and if V is reverse bias is applied the barrier energy increases by eV.





P-N Junction Diode Equation

The **p-n junction diode** equation for an ideal diode is given below

$$I = I_S \left[exp\left(\frac{eV}{K_B T} \right) - 1 \right]$$

Here, I_S = reverse saturation current

e = charge of electron

K_B = Boltzmann constant

T = temperature

For a normal p-n junction diode, the equation becomes

$$I = I_S\left[exp\left(\frac{eV}{\eta K_B T}\right) - 1\right]$$ Here, ɳ = emission co-efficient, which is a number between 1 and 2, which typically increases as the current increases.

Ideal Diodes

The diode equation gives an expression for the current through a diode as a function of voltage. The *Ideal Diode Law*, expressed as:

$$I = I_0\left(e^{\frac{qV}{kT}} - 1\right)$$

where:
I = the net current flowing through the diode;
I_0 = "dark saturation current", the diode leakage current density in the absence of light;
V = applied voltage across the terminals of the diode;
q = absolute value of electron charge;
k = Boltzmann's constant; and
T = absolute temperature (K).

The "dark saturation current" (I_0) is an extremely important parameter which differentiates one diode from another. I_0 is a measure of the recombination in a device. A diode with a larger recombination will have a larger I_0. An excellent discussion of the recombination parameter is in [1]

Note that:

- I_0 increases as T increases; and
- I_0 decreases as material quality increases.

At 300K, kT/q = 25.85 mV, the "thermal voltage".

Non-Ideal Diodes

For actual diodes, the expression becomes:

$$I = I_0\left(e^{\frac{qV}{nkT}} - 1\right)$$

where:
n = ideality factor, a number between 1 and 2 which typically increases as the current decreases.

The junction capacitance:

The junction capacitance is calculated using the expression for the parallel plate capacitance. This might at first seem unexpected since the charge is distributed throughout the depletion layer. However, when applying small voltage variations one finds that charge is only added and removed at the edge **of the depletion region so that the capacitance simply depends on the dielectric constant, the area and the depletion layer width, yielding:**

$$C_j = \frac{\varepsilon_s}{w} = \sqrt{\frac{q\varepsilon_s}{2(\phi_i - V_a)}\frac{N_a N_d}{N_a + N_d}}$$

PN JUNCTION BREAKDOWN CHARACTERISTICS:

Electrical break down of any material (say metal, conductor, semiconductor or even insulator) can occur due to two different phenomena. Those two phenomena are **1) Zener breakdown** and **2) Avalanche breakdown**

These two phenomena are quite like a natural occurrence. It even applies to our daily life while lightning. We all know air is an insulator under normal conditions. But when lightning occurs (an extremely high voltage), it charges the air molecules nearby and charges get transferred via air medium. Now that's a kind of electrical break down of an insulator. A similar kind of situation arises in zener and avalanche breakdown as well. Let see what's it all about!

Zener Breakdown

When we increase the reverse voltage across the pn junction diode, what really happens is that the electric field across the diode junction increases (both internal & external). This results in a force of attraction on the negatively charged electrons at junction. This force frees electrons from its covalent bond and moves those free electrons to conduction band. When the electric field increases (with applied voltage), more and more electrons are freed from its covalent bonds. This results in drifting of electrons across the junction and electron hole recombination occurs. So a net current is developed and it increases rapidly with increase in electric field.

Zener breakdown phenomena occurs in a pn junction diode with heavy doping & thin junction (means depletion layer width is very small). Zener breakdown does not result in damage of diode. Since current is only due to drifting of electrons, there is a limit to the increase in current as well.

Avalanche Breakdown

Avalanche breakdown occurs in a pn junction diode which is moderately doped and has a thick junction (means its depletion layer width is high). Avalanche breakdown usually occurs when we apply a high reverse voltage across the diode (obviously higher than the zener breakdown voltage,say Vz). So as we increase the applied reverse voltage, the electric field across junction will keep increasing.

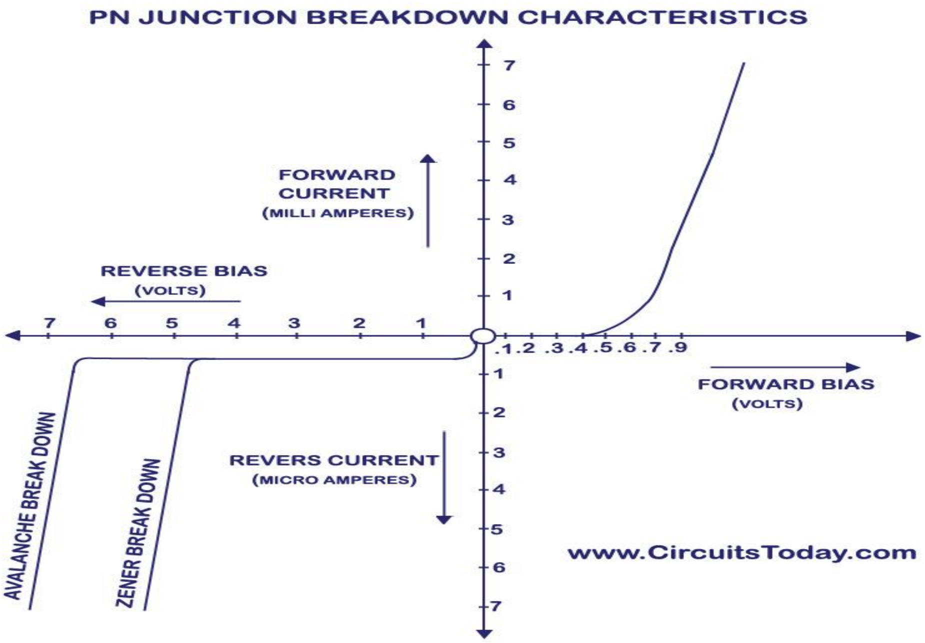
If applied reverse voltage is Va and the depletion layer width is d;

then the generated electric field can be calculated as Ea =Va/d

This generated electric field exerts a force on the electrons at junction and it frees them from covalent bonds. These free electrons will gain acceleration and it will start moving across the junction with high velocity. This results in collision with other neighboring atoms. These collisions in high velocity will generate further free electrons. These electrons will start drifting and electron-hole pair recombination occurs across the junction. This results in net current that rapidly increases.

We learned that avalanche breakdown occurs at a voltage (Va) which is higher than zener breakdown voltage (Vz). The reason behind this is simple. We know, avalanche phenomena occurs in a diode which is moderately doped and junction width (say d) is high. A zener break down occurs in a diode with heavy doping and thin junction (here d is small). The electric field that occur due to applied reverse voltage (say V) can be calculated as E = V/d.

So in a Zener breakdown, the electric field necessary to break electrons from covalent bond is achieved with lesser voltage than in avalanche breakdown. The reason is thin depletion layer width. In avalanche breakdown, the depletion layer width is higher and hence much more reverse voltage has to be applied to develop the same electric field strength (necessary enough to break electrons free)



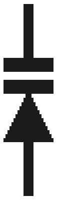
Varactor diode :

Varactor diodes or varicap diodes are semiconductor devices that are widely used in the electronics industry and are used in many applications where a voltage controlled variable capacitance is required. Although the terms varactor diode and varicap diode can be used interchangeably, the more common term these days is the varactor diode.

Although ordinary PN junction diodes exhibit the variable capacitance effect and these diodes can be used for this applications, special diodes optimised to give the required changes in capacitance. Varactor diodes or varicap diodes normally enable much higher ranges of capacitance change to be gained as a result of the way in which they are manufactured. There are a variety of types of varactor diode ranging from relatively standard varieties to those that are described as abrupt or hyperabrupt varactor diodes

Varactor diode symbol

As the primary function of a varactor diode is as a variable capacitor, its circuit symbol represents this. Sometimes they may be shown as ordinary diodes, whereas more usually the varactor diode circuit symbol shows the bar as a capacitor, i.e. two lines.



Varactor diode circuit symbol

Varactor diodes are always operated under reverse bias conditions, and in this way there is no conduction. They are effectively voltage controlled capacitors, and indeed they are sometimes called varicap diodes, although the term varactor is more widely used these days.

Varactor diodes, or as they are sometimes called, varicap diodes are a particularly useful form of semiconductor diode. Finding uses in many applications where electronically controlled tuning of resonant circuits is required, for items such as oscillators and filters, varactor diodes are an essential component within the portfolio of the electronics design engineer. However to be able to use varactor diodes to their best advantage it is necessary to understand features of varactor diodes including the capacitance ratio, Q, gamma, reverse voltage and the like. If used correctly, varactor diodes provide very reliable service particularly as they are a solid state device and have no mechanical or moving elements as in their mechanical variable capacitor counterparts.

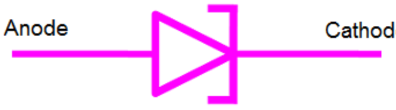
Tunnel diode:

A Tunnel diode is a heavily doped p-n junction diode in which the electric current decreases as the voltage increases.

In tunnel diode, electric current is caused by “Tunneling”. The tunnel diode is used as a very fast switching device in computers. It is also used in high-frequency oscillators and amplifiers.

Symbol of tunnel diode

The circuit symbol of tunnel diode is shown in the below figure. In tunnel diode, the p-type semiconductor act as an anode and the n-type semiconductor act as a cathode.

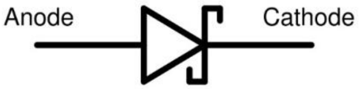


Tunnel diode symbol

We know that a anode is a positively charged electrode which attracts electrons whereas cathode is a negatively charged electrode which emits electrons. In tunnel diode, n-type semiconductor emits or produce electron so it is referred to as the cathode. On the other hand, p-type semiconductor attracts electrons emitted from the n-type semiconductor so p-type semiconductor is referred to as the anode.

FAST RECOVERY DIODES:

Rectification is the most popular use for diodes. Fast rectifiers convert alternating current (AC) to direct current (DC). They only allow one-way flow of electrons. Rectifiers have many uses and are often found serving as components of high-voltage direct current power transmission systems and DC power supplies. Fast rectifier diodes feature very low reverse recovery time, very low switching losses and low noise turn-off switching.

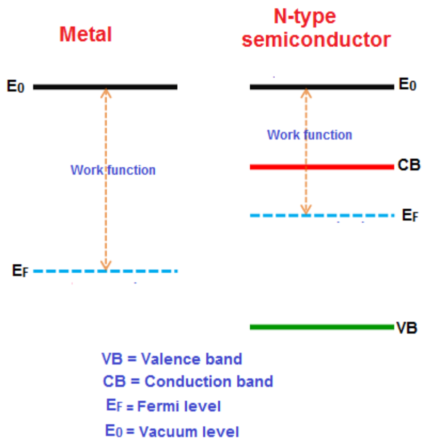


Schottky diode:
Schottky diode is a metal-semiconductor junction diode that has lessforward voltage drop than the P-N junction diode and can be used in high-speed switching applications.
Energy band diagram of schottky diode

The energy band diagram of the N-type semiconductor and metal is shown in the below figure.The vacuum level is defined as the energy level of electrons that are outside the material. The work function is defined as the energy required to move an electron from Fermi level (E_F) to vacuum level (E_0).

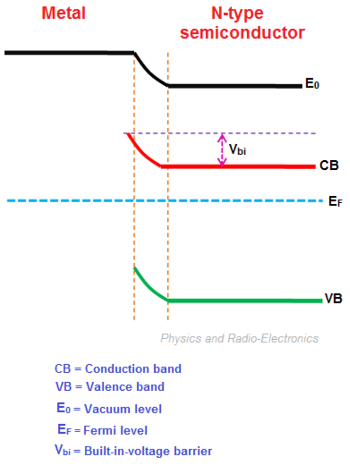
The work function is different for metal and semiconductor. The work function of a metal is greater than the work function of a semiconductor. Therefore, the electrons in the n-type semiconductor have high potential energy than the electrons in the metal.

The energy levels of the metal and semiconductor are different. The Fermi level at N-type semiconductor side lies above the metal side.



We know that electrons in the higher energy level have more potential energy than the electrons in the lower energy level. So the electrons in the N-type semiconductor have more potential energy than the electrons in the metal.

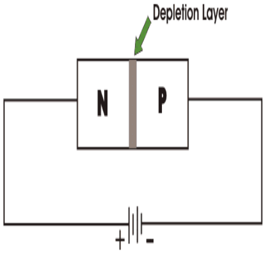
The energy band diagram of the metal and n-type semiconductor after contact is shown in the below figure.



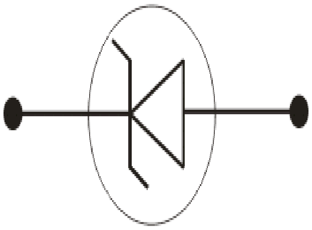
When the metal is joined with the n-type semiconductor, a device is created known as schottky diode. The built-in-voltage (V_{bi}) for schottky diode is given by the difference between the work functions of a metal and n-type semiconductor.

Zener Diode:

Zener Diode is nothing but a single diode connected in a reverse bias, we have already stated that. A diode connected in reverse bias positive in a circuit is shown below,

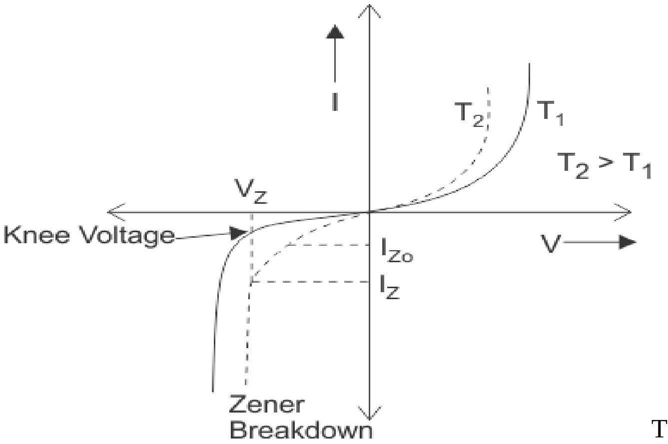


The circuit symbol of **Zener diode** is also shown below. For convenience and understanding, it is used normally



Characteristics of a Zener Diode

Now, discussing about the diode circuits we should look through the graphical representation of the operation of the **zener diode**. Normally it is called the V-I characteristics of a general p-n junction diode.



The above diagram shows the V-I characteristics of the zener diode. When the diode is connected in forward bias, this diode acts as a normal diode but when the reverse bias voltage is greater than a predetermined voltage zener breakdown voltage takes place. To make the breakdown voltage sharp and distinct, the doping is controlled and the surface imperfections are avoided. In the V-I characteristics above V_z is the zener voltage, we can say. It is also the knee voltage because at this point the current is the current is very rapid.

UNIT III

BIPOLAR JUNCTION TRANSISTOR

Ebers moll equation:

Introduction to Ebers moll model of transistor

Ebers Moll model is a simple and elegant way of representing the transistor as a circuit model. The Ebers Moll model of transistor holds for all regions of operation of transistor. This model is based on assumption that base spreading resistance can be neglected. It will be obvious that why two diodes connected back to back will not function as a transistor from the following discussion, as dependent current source term will be missing which is responsible for all the interesting properties of transistor.

Description of Ebers-moll model:

Ebers-moll model of transistor

The current equations derived above is interpreted in terms of a model shown in the figure. This model of transistor is known as Ebers Moll model of transistor.From the diagram applying Kirchhoff's current law at the collector node, we get

$I_C= -\alpha_N*I_E + I_{CO} *(1 – e^{V}{}_{CB}/V_t)$

Where $\boldsymbol{\alpha}_N$ is the current gain of common base transistor mentioned above in normal mode of operation,$\mathbf{V}_{BC}$ is the base to collector voltage, $\mathbf{I}_{co}$ is the reverse saturation current of base collector junction.Similarly at emitter and base node by applying Kirchhoff's current law

$I_E= -\alpha_I*I_C+I_{EO}(1 – e^{V}{}_{BE}/V_t)$, $I_E+I_B+I_C = 0$

Where $\boldsymbol{\alpha}_{\mathbf{I}}$ is the inverted current gain of common base transistor with roles of collector and emitter interchanged, $\mathbf{V}_{BE}$ is the base to Emitter voltage, $\mathbf{I}_{co}$ is the reverse saturation current of base Emitter junction. αI and αI are related through the reverse saturation currents of the diode as

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

The above equations are derived based on the assumption of low level minority carrier injection (the hole concentration injected into the base is very much less compared to the intrinsic electron concentration in base), in such a case emitter or collector current is mainly dominated by diffusion currents, drift current is negligible compared to drift currents.

The Base to emitter voltage and base to collector voltage in terms of currents can be derived as follows

$I_E= -\alpha_I*I_C+I_{EO}(1 – e^{V}{}_{BE}/V_t)$, $I_C= -\alpha_N*I_E + I_{CO} *(1 – e^{V}{}_{CB}/V_t)$

$I_E+\alpha_I*I_C=I_{EO}(1 – e^{V}{}_{BE}/V_t)$, $I_C+\alpha_N*I_E = I_{CO} *(1 – e^{V}{}_{CB}/V_t)$

$(I_E+\alpha_I*I_C)/I_{EO} = (1 – e^{V}{}_{BE}/V_t)$, $(I_C+\alpha_N*I_E)/I_{CO} = (1 – e^{V}{}_{CB}/V_t)$

$e^{V}{}_{BE}/V_t = 1 – ((I_E+\alpha_I*I_C)/I_{EO})$, $e^{V}{}_{CB}/V_t = 1 -((I_C+\alpha_N*I_E)/I_{CO})$

Applying anti log on both sides we get
$V_{BE}= V_t *\ln(1 – ((I_E+\alpha_I*I_C)/I_{EO}))$, $V_{CB} = V_t *\ln(1 -((I_C+\alpha_N*I_E)/I_{CO}))$
For example in cutoff region $I_E=0$ amps and $I_C = I_{CO}$ then the base to emitter voltage is
$V_{BE} = V_t*\ln(1-(\alpha_I*I_{CO})/I_{EO}))$
$V_{BE,cutoff} = V_t*\ln(1-\alpha_N)$

Transistor Characteristics:

Transistor Characteristics are the plots which represent the relationships between the current and the voltages of a transistor in a particular configuration. By considering the transistor configuration circuits to be analogous to two-port networks, they can be analyzed using the characteristic-curves which can be of the following types

1. **Input Characteristics:**
   These describe the changes in input current with the variation in the values of input voltage keeping the output voltage constant.
2. **Output Characteristics:**
   This is a plot of output current versus output voltage with constant input current.
3. **Current Transfer Characteristics:**
   This characteristic curve shows the variation of output current in accordance with the input current, keeping output voltage constant.

Common Base (CB) Configuration of Transistor
In CB Configuration, the base terminal of the transistor will be common between the input and the output terminals as shown by Figure 1. This configuration offers low input impedance, high output impedance, high resistance gain and high voltage gain.

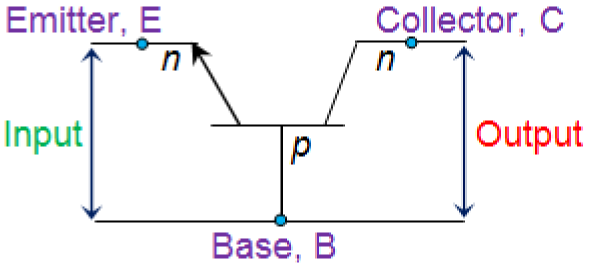


Figure 1 Common Base (CB) Configuration

Input Characteristics for CB Configuration of Transistor

Figure 2 shows the input characteristics of a CB configuration circuit which describes the variation of emitter current, I_E with Base-Emitter voltage, V_{BE} keeping Collector-Base voltage, V_{CB} constant.

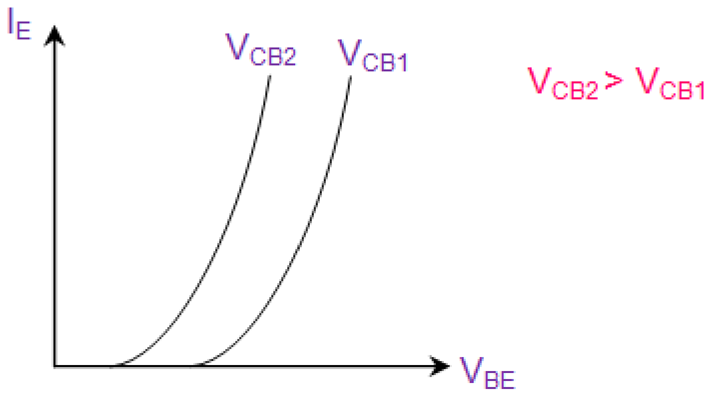


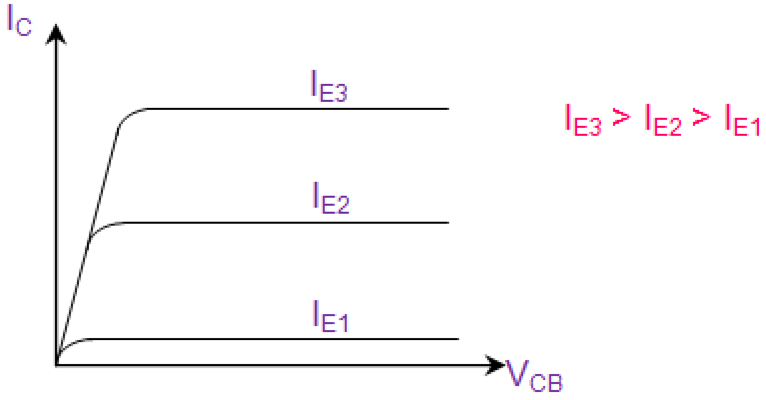
Figure 2 Input Characteristics for CB Configuration

This leads to the expression for the input resistance as

$$R_{in} = \left.\frac{\Delta V_{BE}}{\Delta I_E}\right|_{V_{CB}=constant}$$

Output Characteristics for CB Configuration of Transistor

The output characteristics of CB configuration (Figure 3) show the variation of collector current, I_C with V_{CB} when the emitter current, I_E is held constant. From the graph shown, the output resistance can be obtained as



$$R_{out} = \left.\frac{\Delta V_{CB}}{\Delta I_C}\right|_{I_E=constant}$$

Figure 3 Output Characteristics for CB Configuration

Current Transfer Characteristics for CB Configuration of Transistor

Figure 4 shows the current transfer characteristics for CB configuration which illustrates the variation of I_C with the I_E keeping V_{CB} as a constant. The resulting current gain has a value less than 1 and can be mathematically expressed as

$$\alpha = \left.\frac{\Delta I_C}{\Delta I_E}\right|_{V_{CB}=constant}$$

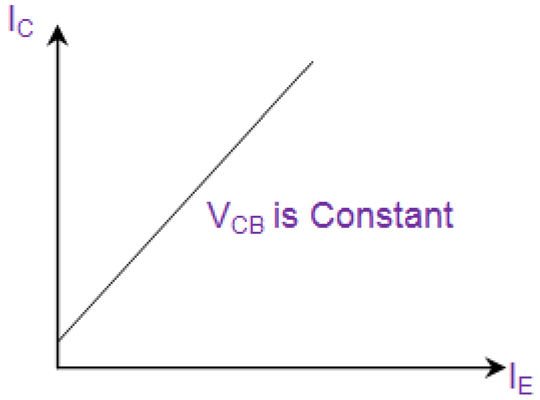


Figure 4 Current Transfer Characteristics for CB Configuration

Common Collector (CC) Configuration of Transistor

This transistor configuration has the collector terminal of the transistor common between the input and the output terminals (Figure 5) and is also referred to as emitter follower configuration. This offers high input impedance, low output impedance, voltage gain less than one and a large current gain.

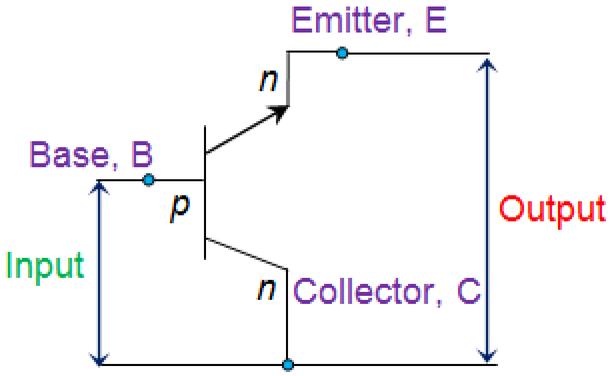


Figure 5 Common Collector (CC) Configuration

Input Characteristics for CC Configuration of Transistor

Figure 6 shows the input characteristics for CC configuration which describes the variation in I_B in accordance with V_{CB}, for a constant value of Collector-Emitter voltage, V_{CE}.

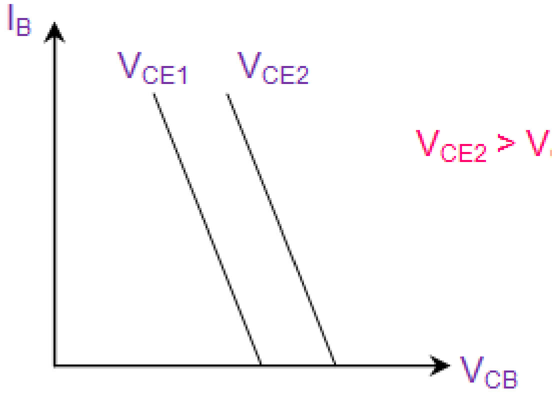


Figure 6 Input Characteristics for CC Configuration

Output Characteristics for CC Configuration of Transistor

Figure 7 shows the output characteristics for the CC configuration which exhibit the variations in I_E against the changes in V_{CE} for constant values of I_B.

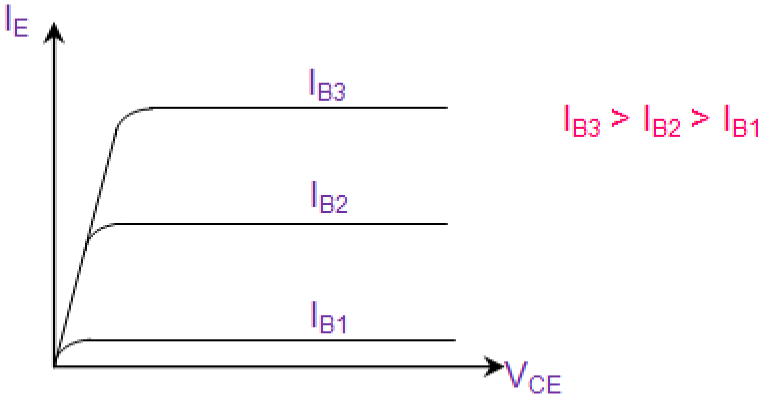


Figure 7 Output Characteristics for CC Configuration

Current Transfer Characteristics for CC Configuration of Transistor:

This characteristic of CC configuration (Figure 8) shows the variation of I_E with I_B keeping V_{CE} as a constant.

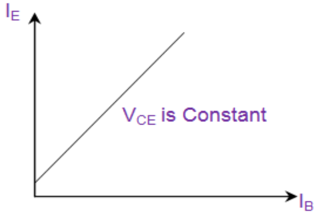


Figure 8 Current Transfer Characteristics for CC Configuration

Common Emitter (CE) Configuration of Transistor

In this configuration, the emitter terminal is common between the input and the output terminals as shown by Figure 9. This configuration offers medium input impedance, medium output impedance, medium current gain and voltage gain.

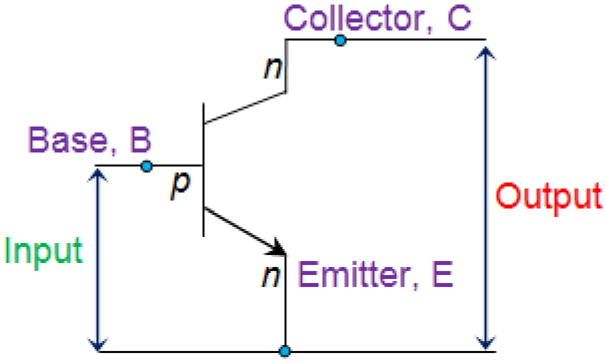


Figure 9 Common Emitter (CE) Configuration

Input Characteristics for CE Configuration of Transistor

Figure 10 shows the input characteristics for the CE configuration of transistor which illustrates the variation in I_B in accordance with V_{BE} when V_{CE} is kept constant.

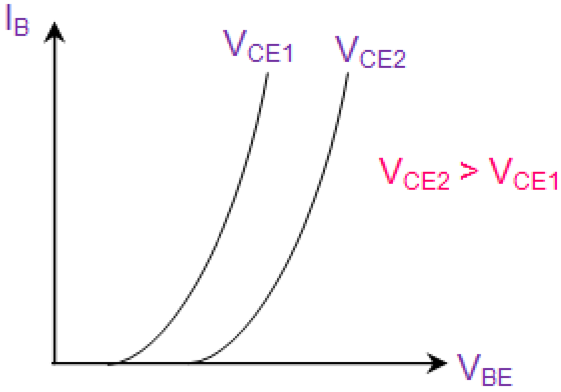


Figure 10 Input Characteristics for CE Configuration

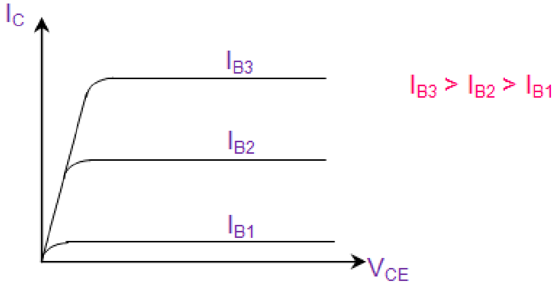
From the graph shown, the input resistance

$$R_{in} = \left.\frac{\Delta V_{BE}}{\Delta I_B}\right|_{V_{CE}=constant}$$

of the transistor can be obtained as

Output Characteristics for CE Configuration of Transistor

The output characteristics of CE configuration (Figure 11) are also referred to as collector characteristics. This plot shows the variation in I_C with the changes in V_{CE} when I_B is held constant. From the graph shown, the output resistance can be obtained



as

$$R_{out} = \left.\frac{\Delta V_{CE}}{\Delta I_C}\right|_{I_B=constant}$$

Figure 11 Output Characteristics for CE Configuration

Current Transfer Characteristics for CE Configuration of Transistor

This characteristic of CE configuration shows the variation of I_C with I_B keeping V_{CE} as a constant. This can be mathematically given by $\beta = \frac{\Delta I_C}{\Delta I_B}\Big|_{V_{CE}=constant}$ This ratio is referred to as common-emitter current gain and is always greater than 1.

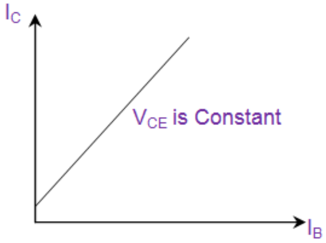
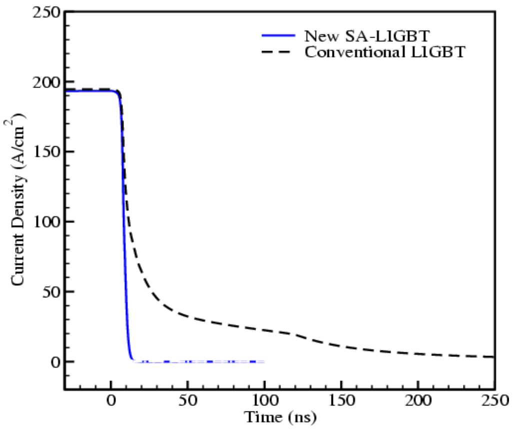


Figure 12 Transfer Characteristics for CE Configuration

Switching Characteristics:

The switching performance of conventional IGBTs is limited by the excess carrier recombination process producing a tail current. Additionally, hole injection is not stopped instantly leading to another extension of switching time. There are two distinct phases in the turn-off waveform of the conventional LIGBT. The first phase is characterized by a rapid fall in anode current, corresponding to the electron current flowing through the MOSFET, which is reduced to zero when the gate voltage drops below its threshold voltage. The second phase is dominated by the slowly decaying tail of the anode current. During the second phase, minority carriers (holes) stored in the drift region are removed by recombination processes and the decay of this stored charge is mainly determined by the minority carrier lifetime in the drift region. The reduction of the carrier lifetime of the drift region increases the on-resistance of the devices.



The n^+-anode short of the SA-LIGBT provides an electron extraction path during turn-off. It helps the fast decaying of excess carriers (holes) in the n-drift region, and provides a faster switching speed compared to the conventional LIGBT. Figure shows the turn-off characteristics of the proposed SOI SA-LIGBT and a conventional SOI LIGBT. Turn-off simulations were performed at an anode current density of 190A/ cm^2 , $V_A = 50$V, and $V_G = 12$V. The devices were turned off by ramping the gate voltage down from 12V to 0V in 10ns. A carrier lifetime of 10 μs for both electrons and holes was used in the simulation. As can be seen in the figure the turn-off tail of the proposed SA-LIGBT is extremely small in comparison to the conventional SOI-LIGBT. SA-LIGBT gives similar characteristics to that of SOI-LDMOSFETs, thus considerably reducing the turn-off time and the transient power losses .

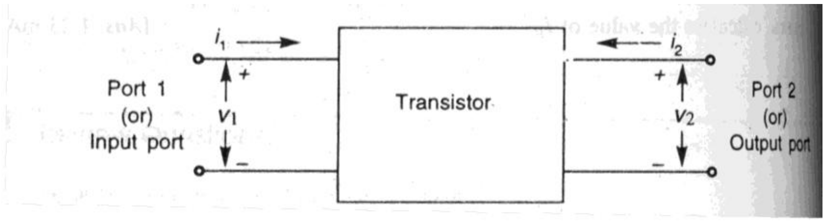
H – Parameter model :-

→ The equivalent circuit of a transistor can be dram using simple approximation by retaining its essential features.

→ These equivalent circuits will aid in analyzing transistor circuits easily and rapidly.

Two port devices & Network Parameters:-

→ A transistor can be treated as a two part network. The terminal behaviour of any two part network can be specified by the terminal voltages V_1 & V_2 at parts 1 & 2 respectively and current i_1 and i_2, entering parts 1 & 2, respectively, as shown in figure.



Two port network

→ Of these four variables V_1, V_2, i_1 and i_2, 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 part parameters out of which the following three are more important.

1. Z – Parameters (or) Impedance parameters
2. Y – Parameters (or) Admittance parameters
3. H – Parameters (or) Hybrid parameters.

Hybrid parameters (or) h – parameters:-

→ If the input current i_1 and output Voltage V_2 are takes as independent variables, the input voltage V_1 and output current i_2 can be written as

$V_1 = h_{11} i_1 + h_{12} V_2$

$i_2 = h_{21} i_1 + h_{22} V_2$

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

$h_{11} = [V_1 / i_1]$ with $V_2 = 0$

= Input Impedance with output part short circuited.

$h_{22} = [i_2 / V_2]$ with $i_1 = 0$

= Output admittance with input part open circuited.

$h_{12} = [V_1 / V_2]$ with $i_1 = 0$

= reverse voltage transfer ratio with input part open circuited.

$h_{21} = [i_2 / i_1]$ with $V_2 = 0$

= Forward current gain with output part short circuited.

The dimensions of h – parameters are as follows:

h_{11} - Ω

h_{22} – mhos

h12, h21 – dimension less.

→ as the dimensions are not alike, (ie) they are hybrid in nature, and these parameters are called as hybrid parameters.

I = 11 = input ; 0 = 22 = output ;

F = 21 = forward transfer ; r = 12 = Reverse transfer.

Notations used in transistor circuits:-

$h_{ie} = h_{11e}$ = Short circuit input impedance

$h_{0e} = h_{22e}$ = Open circuit output admittance

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

$h_{fe} = h_{21e}$ = Short circuit forward current Gain.

The Hybrid Model for Two-port Network:-

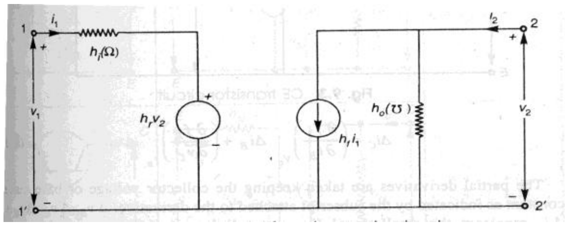
$V_1 = h_{11} i_1 + h_{12} V_2$

$I_2 = h_1 i_1 + h_{22} V_2$

↓

$V_1 = h_1 \, i_1 + h_r \, V_2$

$I_2 = h_f \, i_1 + h_0 \, V_2$

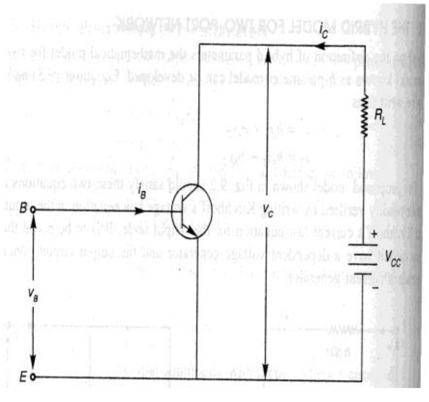


The Hybrid Model for Two-port Network

Transistor Hybrid model:-

Use of h – parameters to describe a transistor have the following advantages.

1. h – parameters are real numbers up to radio frequencies .
2. They are easy to measure
3. They can be determined from the transistor static characteristics curves.
4. They are convenient to use in circuit analysis and design.
5. Easily convert able from one configuration to other.
6. Readily supplied by manufactories.



CE Transistor Circuit

To Derive the Hybrid model for transistor consider the CE circuit shown in figure.The variables are $i_{B,}$ i_c, $v_{B(=v_{BE})}$ and $v_{c(=v_{CE}).}$ i_B and v_c are considered as independent variables.

Then , $v_B = f_1(i_{B,}\ v_c)$ ----------------------(1)

$i_C = f_2(i_{B,}\ v_c)$ ----------------------(2)

Making a Taylor's series expansion around the quiescent point $I_{B,}\ V_C$ and neglecting higher order terms, the following two equations are obtained.

$\Delta v_B = (\partial f_1/\partial i_B)V_c \,.\, \Delta\, i_B + (\partial f_1/\partial v_c)I_B \,.\, \Delta v_C$ ---------------(3)

$\Delta\, i_C = (\partial f_2/\partial i_B)V_c \,.\, \Delta\, i_B + (\partial f_2/\partial v_c)I_B \,.\, \Delta v_C$ ----------------(4)

The partial derivatives are taken keeping the collector voltage or base current constant as indicated by the subscript attached to the derivative.

Δv_B , Δv_C , $\Delta\, i_C$, $\Delta\, i_B$ represent the small signal(increment) base and collector voltages and currents,they are represented by symbols v_b , v_c , i_b and i_c respectively.

Eqs (3) and (4) may be written as

$V_b = h_{ie}\, i_b + h_{re}\, V_c$

$i_c = h_{fe}\, i_b + h_{oe}\, V_c$

Where $h_{ie} = (\partial f_1/\partial i_B)V_c = (\partial v_B/\partial i_B)V_c = (\Delta v_B/\Delta i_B)V_c = (v_b / i_b)V_c$

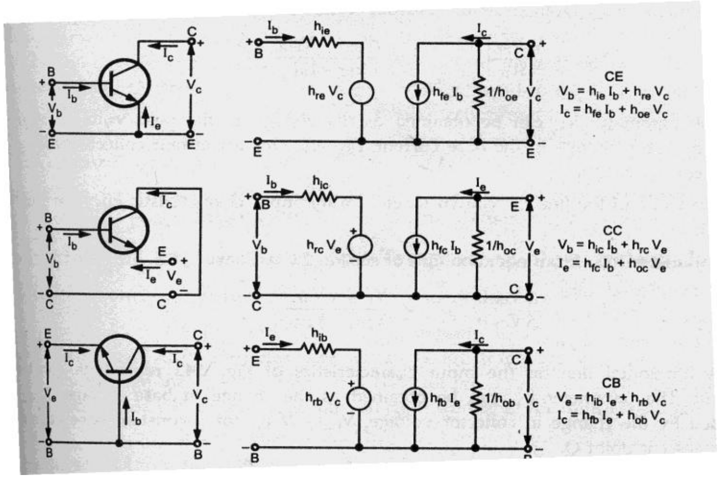
$h_{re} = (\partial f_1/\partial v_c)I_B = (\partial v_B/\partial v_c)\, I_B = (\Delta v_B/\Delta v_c)\, I_B = (v_b/v_c)\, I_B$

$h_{fe} = (\partial f_2/\partial i_B)V_c = (\partial i_c/\partial i_B)V_c = (\Delta\, i_c/\Delta i_B)V_c = (i_c / i_b)V_c$

$h_{oe} = (\partial f_2/\partial v_c)I_B = (\partial i_c/\partial v_c)\, I_B = (\Delta\, i_c/\Delta v_c)\, I_B = (i_c/v_c)\, I_B$

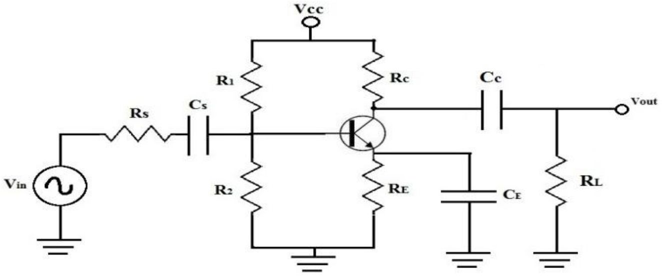
The above equations define the h-parameters of the transistor in CE configuration.The same theory can be extended to transistors in other configurations.

Hybrid Model and Equations for the transistor in three different configurations are are given below.



LOW FREQUENCY EQUIVALENT CIRCUITS:

Just like we did for the BJT configurations, we're going to start by looking at each of the basic amplifier stages in terms of analysis and finish with strategies for designing for a specific low frequency characteristic. All amplifiers are presented as capacitive-coupled to stages that may occur before and after. Recall that this is the easiest way to ensure dc isolation, but may not be feasible in certain circumstances or under certain conditions. Note: in the circuits that follow, the actual signal source (vS) and its associated source resistance (RSource) have been included. Previously, we knew that this source and resistance was there but we just started our investigations with the input to the transistor (vin). This should not cause too much heartburn – the analysis process is the same and the relationship between vS and vin is a voltage divider. Since we've already got an RS in FET circuits (in the source leg), don't get confused between the source of the transistor itself and the resistance associated with the signal source (shown as R).



RF TRANSISTOR:

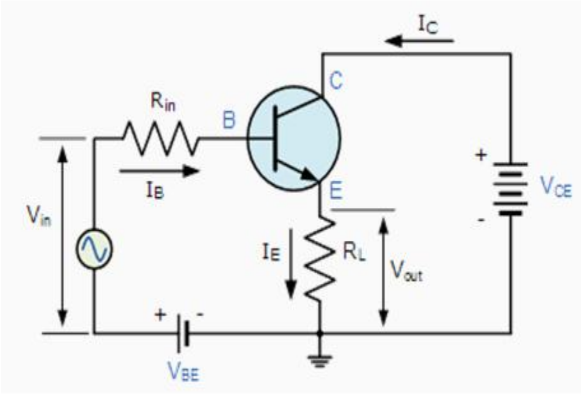
An RF Transistor, or radio frequency transistor, is a semiconductor device which is used in order to amplify and switch electronic signals and power. RF transistors contain at least three terminals for connection to an external circuit. A current or voltage applied to one pair of the RF transistor terminals changes the current flowing through another pair of terminals. A transistor can use a small signal applied between one pair of its terminals in order to control a much larger signal at another pair of terminals. This is called gain. A transistor has the ability to control its output in proportion to its input signal and therefore act as an amplifier. Also, a transistor can be used in order to turn current on or off in a circuit as an electrically controlled switch.

Types of RF Transistors:

There are several different kinds of RF transistors at Future Electronics. We stock many of the most common types categorized by several parameters including frequency range, CE voltage, polarity, gain, output power, channel type, D-S breakdown voltage and packaging type. Our parametric filters will allow you to refine your search results according to the required specifications.

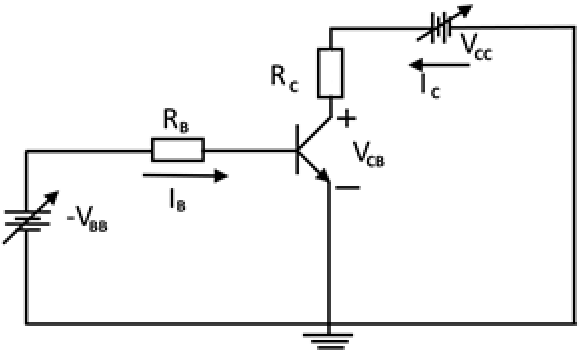
Applications for RF Transistors:

RF transistors can be found in several modern electronics including mobile radio and telecommunication applications, FM/TV broadcast, avionics, radar and defense communications as well as industrial, scientific, medical and broadcast applications.



POWER TRANSISTOR:

Power transistors are **transistors** that are used in high-**power** amplifiers and **power** supplies. **Power transistors** are suited for applications where a lot of **power** is being used- current and voltage. The collector of the **transistor** is connected to a metal base that acts as a heat sink to dissipate excess **power**.



UNIT IV

FET, UJT AND SCR

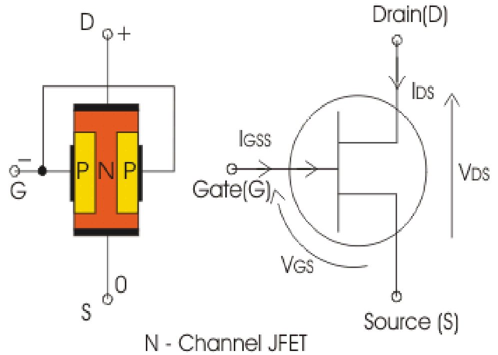
JFET or Junction Field Effect Transistor:

The **junction field effect transistor** or **JFET** is one of the simplest transistors from the structural point of view. It is a voltage controlled semiconductor device. In this, the currentis carried by only one type of carriers. So, it is a unipolar device. It has a very high input electrical resistance.

JFET consists of a doped Si or GaAs bar. There are ohmic contacts, the two ends of the bar and semiconductor junction on its two sides. If the semiconductor bar is n-type, the two sides of the bar is heavily doped with p-type impurities and this is known as n-channel JFET.

On the other hand if the semiconductor bar is p-type, the two sides of the bar is heavily doped with n-type impurities and this is known as p-channel JFET. When a voltage is applied between the two ends, a current which is carried by the majority carriers of the bar flows along the length of the bar.
There are several terminals in JFET. The terminal through which the majority carrier enter the bar and the terminal through which they leave are known as source (s) and drain (D) respectively. The heavily doped region on the two sides is known as the gate (G).
In **junction field effect transistor**, the junction is a reverse biased. As a result, depletion regions form, which extend to the bar. By changing gate to source voltage, the depletion width can be controlled. So, the effective cross section area decreased with increasing reverse bias. So, the drain current is a function of the gate to the source voltage: Now days JFET is obsolete. Its applicants are limited to circuit design. Where it can be used an amplifier and as a switch both.

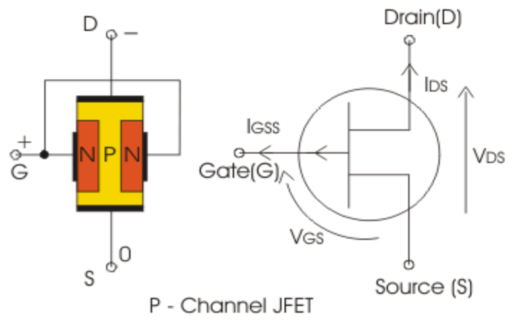
N-Channel JFET



N - Channel JFET

A semiconductor bar of n-type material is taken and ohmic contacts are made on either ends of the bar. Terminals are brought out from these ohmic contacts and named as drain and source as shown in the figure below. On the other two sides of the n-type semiconductorbar, heavily doped p-type regions are formed to create a p-n junction. Both these p-type regions are connected together via ohmic contacts and the gate terminal is brought out as seen below. Figure below shows the n-channel and p-channel JFET with symbols. The arrow on the gate indicates the direction of the current. Current flows through the length of the n-type bar (channel) due to majority charge carries which in this case are electrons. When a voltage is applied between the two ends, a current which is carried by the majority carriers electrons flows along the length of a bar. The majority carriers enter the bar through the source terminal and leave through the drain terminal. The heavily doped regions of the n-type bar are known as the gates.
The gate source junctions is reverse is biased as a result depletion regions from which extend to the bar by changing gate to source voltage effective cross sectional area decreases with the function of the gate to source voltage.

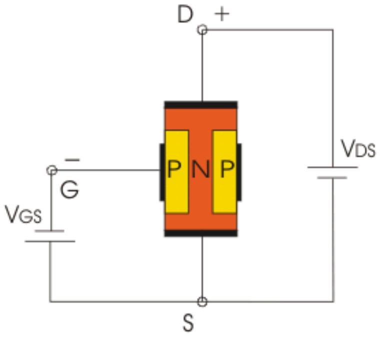
P-Channel JEFT



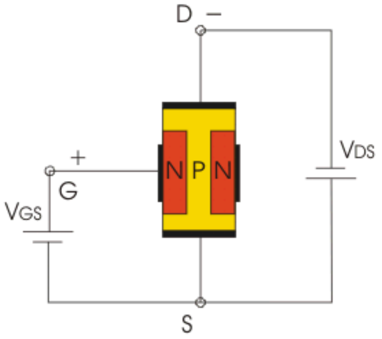
p-channel JFET consists of a p-type silicon or GaAs. Two sides of the bar is heavily doped with n-type impurities. When a voltage is applied between the two ends, a current which is carried by the majority carrier holes flow along the length of a bar. The gate source junction is reverse biased as a result depletion regions form, which extend to the bar by changing gate to extend to source voltage the depletion width can be controlled. The effective cross sectional area decreased with increasing reverse bias, so the drain current is the function of the gate to source voltage.

Biasing of JFET

The gate to source p-n junction of a JFET is always reverse biased and supply voltage is givenacross the drain to source terminal.



N - Channel JFET



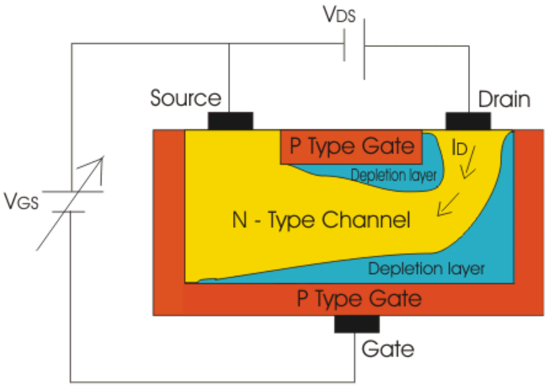
P - Channel JFET

Operation of Junction Field Effect Transistor or JFET

Operation with gate to source voltage = 0

If an n-channel JFET is biased as explained above and the gate to source voltage is kept zero, due to the positive drain to source voltage few electrons which are available for conduction in the n-type material will start flowing from the narrow passage (channel) from source to drain. This current is called as drain current. As the channel has some finite resistance it will cause some voltage drop across the channel. Hence the depletion region of the p-n junction starts increasing and penetrates more into the n-type material as it is lightly doped. Due to this the width of the channel available for conduction is reduced. The penetration of the depletion region into the n-type region depends on the reverse bias voltage. Maximum drain current

$I_{D(MAX)}$ will flow through the device when the channel is widest i.e. when V_{GS} is zero.



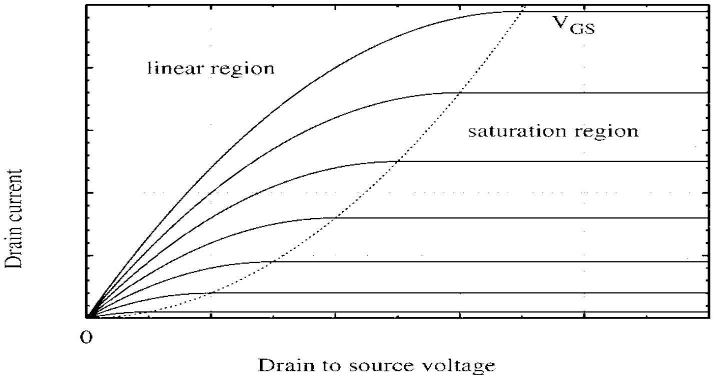
Operation with negative gate to source voltage As a negative voltage is applied to the gate to source pn junction the depletion region increases and penetration of the depletion region into the n-type channel further increases. If the negative gate to source voltage is further increased the depletion region spreads more and more inside the n-type bar. Due to this less and less number of charge carries (electrons) can pass through the channel and the drain current reduces. Hence, with increase in negative gate to source voltage drain current reduces. At a certain value of this voltage the depletion region from both the ends will increase and touch each other and the drain current will become zero. This gate to source voltage at which drain current is cutoff is called as $V_{GS(OFF)}$. As seen the V_{GS} controls I_D. Hence, JFET is a voltage controlled device. The relationship between I_D and V_{GS} is given by Shockley's equation

$$I_D = I_{D(MAX)}\left[1 - \frac{V_{GS}}{V_P}\right]^2$$

Where, V_P is the pinch off voltage which is the value of drain to source V_{DS} at which drain current reaches its constant saturation value. Any further increase in V_{DS} does not affect I_D.

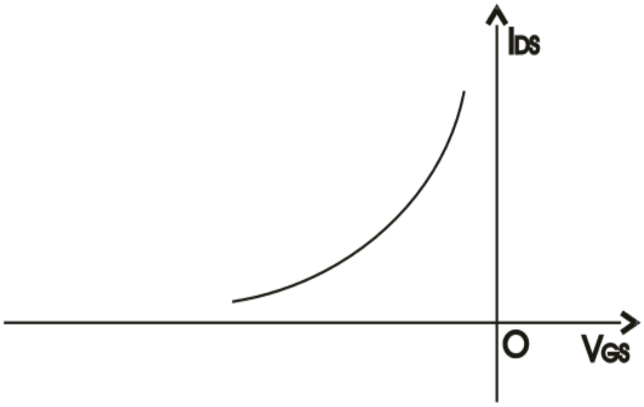
JEFT Characteristics or Junction Field Effect Transistor Characteristics
In this characteristics we can find three regions,

1. The linear or the ohmic region: Here the drain to source voltage is small and drain current in nearly proportional to the drain to source voltage. When a positive drain to source voltage is applied, this voltage increases from zero to a small value, the depletion region width remain very small and under this condition the semi conductor bar behaves just like a resistor. So, drain current increases almost linearly with drain to source voltage.



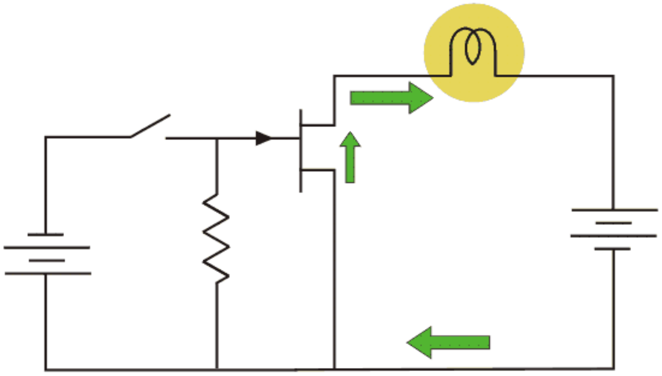
2. The saturation of the active region: Here the drain current is almost constant and it is not dependent on the drain to source voltage actually. When the drain to source voltage continuous to increase the channel resistance increases and at some point, the depletion regions meet near the drain to pinch off the channel. Beyond that pinch off voltage, the drain, current attains saturation.
3. The breakdown voltage: Here the drain current increases rapidly with a small increase of the drain to source voltage. Actually for large value of drain to source voltage, a breakdown of the gate junction takes place which results a sharp increase of the drain current.

Transfer Characteristics The graphical characteristics plot of the saturation drain current against the gate to source voltage is known as the transfer characteristics of JFET. It can be obtained from static characteristics very easily. The transfer characteristics of an n- channel is shown below



JFET as Switch

The junction field effect transistor (JFET) can be used as an electronically controlled switch to control electric power to a load. JFET's are normally on (NO) devices. They are normally saturated devices. When a reverse bias is applied between gate and source, the depletion regions of that junction expand and pinching off the channel through which current flowing takes place. If the channel is pinched the current does not flow the device will be in switched off condition. By this process junction field effect transistor can be used as switches. But now days their application is obsolete. An example of JFETs acting as a switch and the corresponding circuit is given below.

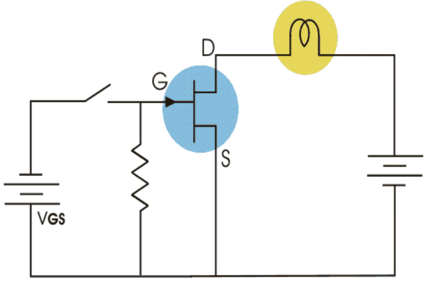


Applications of JFET

The **junction field effect transistor** has many application in the field of electronics and communication.
Some of these applications are stated below.

1. Low noise and high input impedance amplifier:- Noise is an undesirable disturbance which interferes with the signals information - greater the noise less the information. Energy electronics device cause some amount of noise. If FET s is used at the front end, we get less amount of amplified noise at the output. Now, it has very high input impedance. So, it can be used in high input impedance amplifier.
2. **Buffer Amplifier:-** Buffer amplifier should have very high input impedance and low output impedance. Because of high i/p impedance and low output impedance, FET acts as great buffer amplifier. the common drain mode can be used in this purpose.
3. **R.F.Amplifier:-** JFET is good in low current signal operation as it is a voltage controlled semiconductors device. It has very low noise level. So, it can be used as RF amplifier in receiver sections of communication field.
4. **Current Source:-** Here all the supply voltage appears across load. If the current tries to increase very much, the excessive load a current drives the JFET in to active region. Thus JFET acts as a current source.

5. **Switch:-** JFET may be used as an on/off switch controlling electrical power to load.

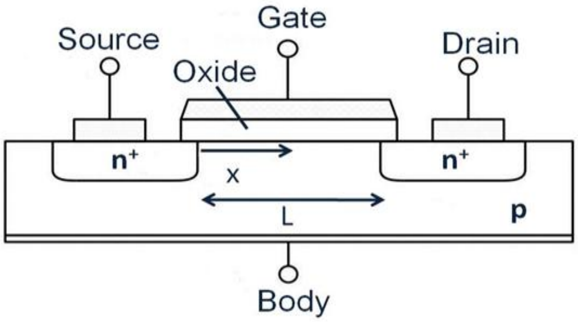


MOSFET:

Introduction:

The MOSFET (Metal Oxide Semiconductor Field Effect Transistor) transistor is a semiconductor device which is widely used for switching and amplifying electronic signals in the electronic devices. The MOSFET is a core of integrated circuit and it can be designed and fabricated in a single chip because of these very small sizes. The MOSFET is a four terminal device with source(S), gate (G), drain (D) and body (B) terminals. The body of the MOSFET is frequently connected to the source terminal so making it a three terminal device like field effect transistor. The MOSFET is very far the most common transistor and can be used in both analog and digital circuits.

The MOSFET works by electronically varying the width of a channel along which charge carriers flow (electrons or holes). The charge carriers enter the channel at source and exit via the drain. The width of the channel is controlled by the voltage on an electrode is called gate which is located between source and drain. It is insulated from the channel near an extremely thin layer of metal oxide. The MOS capacity present in the device is the main part



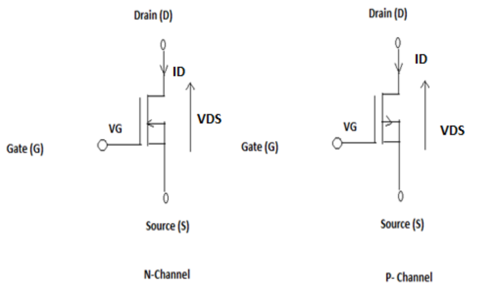
The MOSFET can function in two ways

Depletion Mode,Enhancement Mode

Depletion Mode:

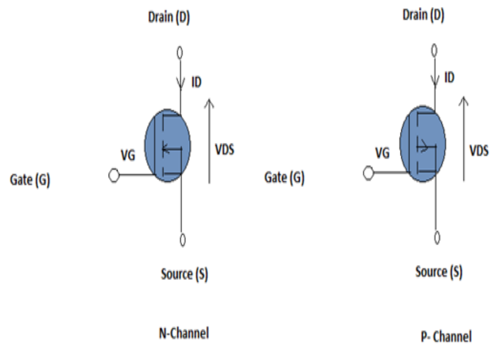
When there is no voltage on the gate, the channel shows its maximum conductance. As the voltage on the gate is either positive or negative, the channel conductivity decreases.

For example



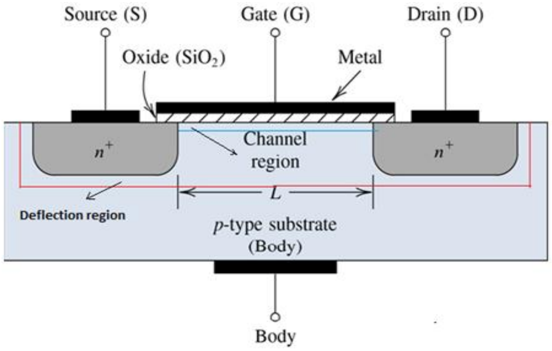
ENHANCEMENT MODE:

When there is no voltage on the gate the device does not conduct. More is the voltage on the gate, the better the device can conduct.



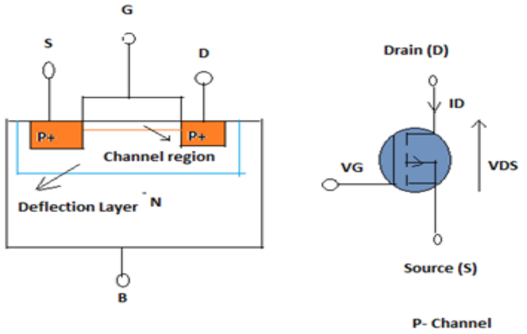
Working Principle of MOSFET:

The aim of the MOSTFET is to be able to control the voltage and current flow between the source and drain. It works almost as a switch. The working of MOSFET depends upon the MOS capacitor. The MOS capacitor is the main part of MOSFET. The semiconductor surface at the below oxide layer which is located between source and drain terminal. It can be inverted from p-type to n-type by applying a positive or negative gate voltages respectively. When we apply the positive gate voltage the holes present under the oxide layer with a repulsive force and holes are pushed downward with the substrate. The depletion region populated by the bound negative charges which are associated with the acceptor atoms. The electrons reach channel is formed. The positive voltage also attracts electrons from the n+ source and drain regions into the channel. Now, if a voltage is applied between the drain and source, the current flows freely between the source and drain and the gate voltage controls the electrons in the channel. Instead of positive voltage if we apply negative voltage , a hole channel will be formed under the oxide layer.



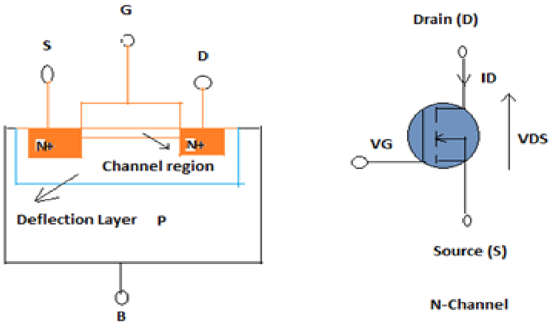
P-Channel MOSFET:

The P- Channel MOSFET has a P- Channel region between source and drain. It is a four terminal device such as gate, drain, source, body. The drain and source are heavily doped p+ region and the body or substrate is n-type. The flow of current is positively charged holes. When we apply the negative gate voltage, the electrons present under the oxide layer with are pushed downward into the substrate with a repulsive force. The depletion region populated by the bound positive charges which are associated with the donor atoms. The negative gate voltage also attracts holes from p+ source and drain region into the channel region.



N- Channel MOSFET:

The N-Channel MOSFET has a N- channel region between source and drain It is a four terminal device such as gate, drain , source , body. This type of MOSFET the drain and source are heavily doped n+ region and the substrate or body is P- type. The current flows due to the negatively charged electrons. When we apply the positive gate voltage the holes present under the oxide layer pushed downward into the substrate with a repulsive force. The depletion region is populated by the bound negative charges which are associated with the acceptor atoms. The electrons reach channel is formed. The positive voltage also attracts electrons from the n+ source and drain regions into the channel. Now, if a voltage is applied between the drain and source the current flows freely between the source and drain and the gate voltage controls the electrons in the channel. Instead of positive voltage if we apply negative voltage a hole channel will be formed under the oxide layer.



MOSFET CHARACTERISTICS:

MOSFETs are tri-terminal, unipolar, voltage-controlled, high input impedance devices which form an integral part of vast variety of electronic circuits. These devices can be classified into two types viz., depletion-type and enhancement-type, depending on whether they possess a channel in their default state or no, respectively. Further, each of them can be either p-channel or n-channel devices as they can have their conduction current due to holes or electrons respectively. However inspite of their structural difference, all of them are seen to work on a common basic principle which is explained in detail in the article "MOSFET and its Working". This further implies that all of them exhibit almost similar characteristic curves, but for differing voltage values.

In general, any MOSFET is seen to exhibit three operating regions viz.,

1. **Cut-OffRegion**
   Cut-off region is a region in which the MOSFET will be OFF as there will be no current flow through it. In this region, MOSFET behaves like an open switch and is thus used when they are required to function as electronic switches.
2. **OhmicorLinearRegion**
   Ohmic or linear region is a region where in the current I_{DS} increases with an increase in the value of V_{DS}. When MOSFETs are made to operate in this region, they can be used as amplifiers.
3. **SaturationRegion**
   In saturation region, the MOSFETs have their I_{DS} constant inspite of an increase in $V_{DS}$and occurs once V_{DS} exceeds the value of pinch-off voltage V_P. Under this condition, the device will act like a closed switch through which a saturated value of I_{DS} flows. As a result, this operating region is chosen whenever MOSFETs are required to perform switching operations.
   Having known this, let us now analyze the biasing conditions at which these regions are experienced for each kind of MOSFET.

n-channel Enhancement-type MOSFET:
Figure 1a shows the transfer characteristics (drain-to-source current I_{DS} versus gate-to-source voltage V_{GS}) of **n-channel Enhancement-type MOSFETs**. From this, it is evident that the current through the device will be zero until the V_{GS} exceeds the value of threshold voltage V_T. This is because under this state, the device will be void of channel which will be connecting the drain and the source terminals. Under this condition, even an increase in V_{DS}will result in no current flow as indicated by the corresponding output characteristics (I_{DS}versus V_{DS}) shown by Figure 1b. As a result this state represents nothing but the cut-off region of MOSFET's operation.
Next, once V_{GS} crosses V_T, the current through the device increases with an increase in I_{DS}initially (Ohmic region) and then saturates to a value as determined by the V_{GS} (saturation region of operation) i.e. as V_{GS} increases, even the saturation current flowing through the device also increases. This is evident by Figure 1b where I_{DSS2} is greater than I_{DSS1} as $V_{GS2}> V_{GS1}$, I_{DSS3} is greater than I_{DSS2} as $V_{GS3} > V_{GS2}$, so on and so forth. Further, Figure 1b also shows the locus of pinch-off voltage (black discontinuous curve), from which V_P is seen to increase with an increase in V_{GS}.

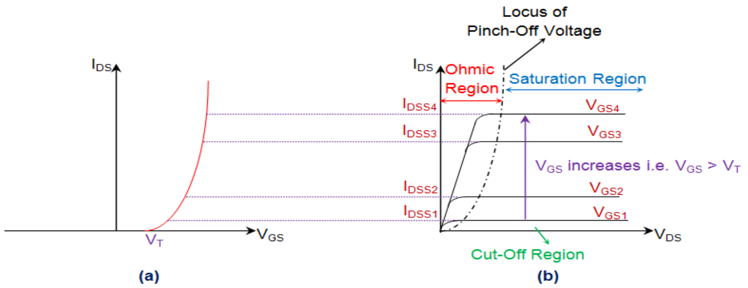
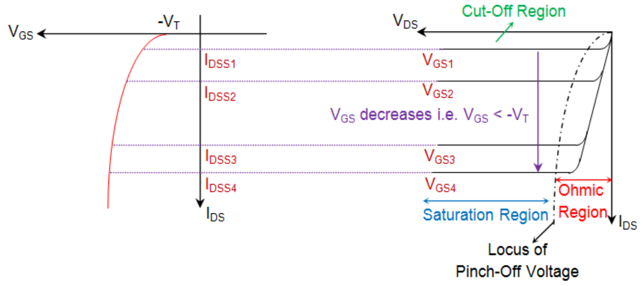


Figure 1 ***n*****-Channel Enhancement type MOSFET (a) Transfer Characteristics (b) Output Characteristics**

p-channel Enhancement-type MOSFET
Figure 2a shows the transfer characteristics of **p-type enhancement MOSFETs** from which it is evident that I_{DS} remains zero (cutoff state) untill V_{GS} becomes equal to $-V_T$. This is because, only then the channel will be formed to connect the drain terminal of the device with its source terminal. After this, the I_{DS} is seen to increase in reverse direction (meaning an increase in I_{SD}, signifying an increase in the device current which will flow from source to drain) with the decrease in the value of V_{DS}. This means that the device is functioning in its ohmic region wherein the current through the device increases with an increase in the applied voltage (which will be V_{SD}).

However as V_{DS} becomes equal to $-V_P$, the device enters into saturation during which a saturated amount of current (I_{DSS}) flows through the device, as decided by the value of V_{GS}. Further it is to be noted that the value of saturation current flowing through the device is seen to increase as the V_{GS} becomes more and more negative i.e. saturation current for V_{GS3} is greater than that for V_{GS2} and that in the case of V_{GS4} is much greater than both of them as V_{GS3} is more negative than V_{GS2} while V_{GS4} is much more negative when compared to either of them (Figure 2b). In addition, from the locus of the pinch-off voltage it is also clear that as V_{GS} becomes more and more negative, even the negativity of V_P also increases.



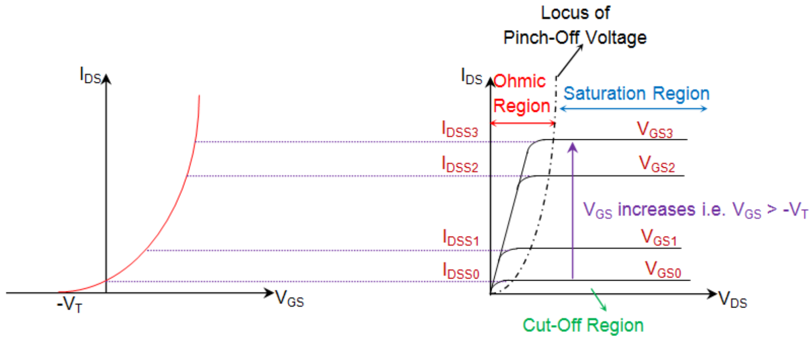
(a) (b)

Figure 2 ***p*-Channel Enhancement type MOSFET (a) Transfer Characteristics (b) Output Characteristics**

n-channel Depletion-type MOSFET

The transfer characteristics of **n-channel depletion MOSFET** shown by Figure 3a indicate that the device has a current flowing through it even when V_{GS} is 0V. This indicates that these devices conduct even when the gate terminal is left unbiased, which is further emphasized by the V_{GS0} curve of Figure 3b. Under this condition, the current through the MOSFET is seen to increase with an increase in the value of V_{DS} (Ohmic region) untill V_{DS}becomes equal to pinch-off voltage V_P. After this, I_{DS} will get saturated to a particular level I_{DSS} (saturation region of operation) which increases with an increase in V_{GS} i.e. $I_{DSS3} > I_{DSS2} > I_{DSS1}$, as $V_{GS3} > V_{GS2} > V_{GS1}$. Further, the locus of the pinch-off voltage also shows that V_P increases with an increase in V_{GS}.

However it is to be noted that, if one needs to operate these devices in cut-off state, then it is required to make V_{GS} negative and once it becomes equal to $-V_T$, the conduction through the device stops ($I_{DS} = 0$) as it gets deprived of its n-type channel



(a) (b)

Figure 3 ***n*-Channel Depletion type MOSFET (a) Transfer Characteristics (b) Output Characteristics**

p-channel Depletion-type MOSFET

The transfer characteristics of **p-channel depletion mode MOSFETs** (Figure 4a) show that these devices will be normally ON, and thus conduct even in the absence of V_{GS}. This is because they are characterized by the presence of a channel in their default state due to which they have non-zero I_{DS} for $V_{GS} = 0V$, as indicated by the V_{GS0} curve of Figure 4b. Although the value of such a current increases with an increase in V_{DS} initially (ohmic region of operation), it is seen to saturate once the V_{DS} exceeds V_P (saturation region of operation). The value of this saturation current is determined by the V_{GS}, and is seen to increase in negative direction as V_{GS} becomes more and more negative. For example, the saturation current for V_{GS3} is greater than that for V_{GS2} which is however greater when compared to that for V_{GS1}. This is because V_{GS2} is more negative when compared to V_{GS1}, and V_{GS3} is much more negative when compared to either of them. Next, one can also note from the locus of pinch-off point that even V_P starts to become more and more negative as the negativity associated with the V_{GS} increases. Lastly, it is evident from Figure 4a that inorder to switch these devices OFF, one needs to increase V_{GS} such that it becomes equal to or greater than that of the threshold voltage V_T. This is because, when done so, these devices will be deprived of their p-type channel, which further drives the MOSFETs into their cut-off region of operation.

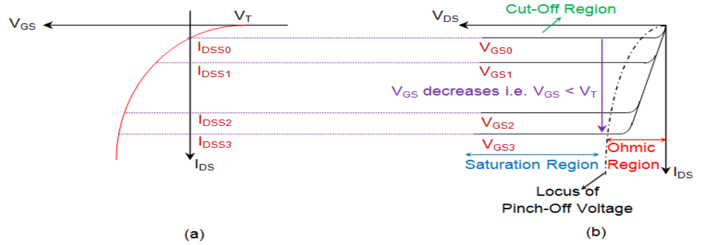


Figure 4 *p*-Channel Depletion type MOSFET (a) Transfer Characteristics (b) Output Characteristics

LOW FREQUENCY AND HIGH FREQUENCY EQUIVALENT CIRCUITS:

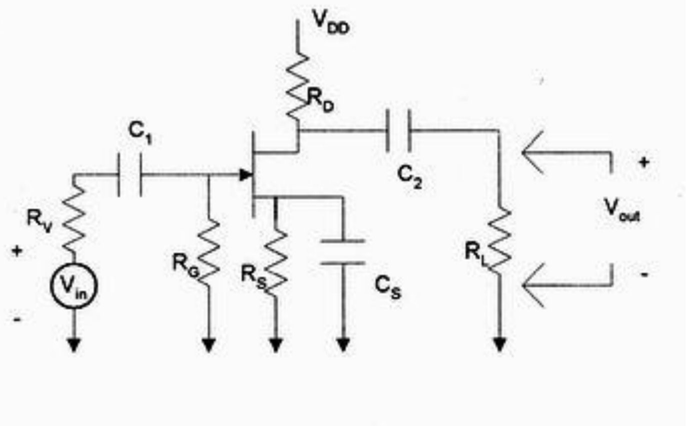


Figure 1

The Field Effect Transistor circuit low frequency response can be evaluated by analyzing the transfer functions of the elements which affect the response at frequencies below midband. If there is more then one transfer function, the resultant overall response can be determined from the product of the individual response; usually done graphically with a Bode plot.

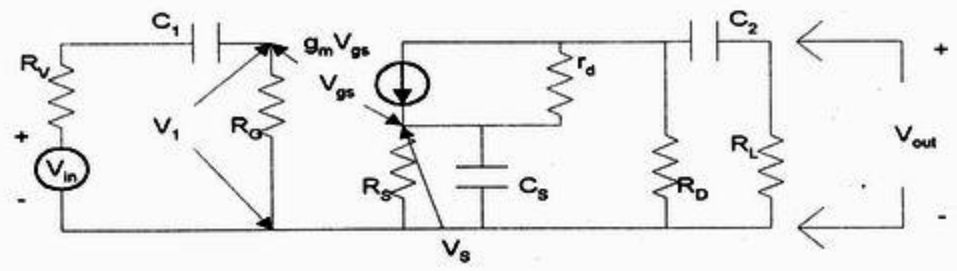


Figure 2

Figure 2 shows the low frequency equivalent of the circuit of the FET configuration in Figure 1. When examining the input circuit, the input transfer function is developed from C_1 , R_G , and R_V.

$$V1 = V_{in}R_G / (R_V + R_G) + (1/j\omega C_1)$$

$$V1 / V_{in} = R_G / R_V + R_G(1 / (1 - j (1 / \omega(R_V + R_G) C)))$$

$$V1 / V_{in} = R_G / R_V + R_G(1 / (1 - j (\omega_1(\text{input})) / \omega))$$

$$(R_V + R_G) C = 1 / \omega_1(\text{input}) = 1 / 2 \pi f_1(\text{input})$$

Examining this expression reveals a pole in the low frequency response produced by the input elements, C_1, R_G , and R_V at a frequency of $f_{1(input)} = 1 / 2 \pi (R_V + R_G) C_1$

The output elements of the circuit can also be expected to produce a low frequency pole. Evaluating the affect separately by assuming R_S in parallel with $C_S = Z_S = 0$. And r_d in parallel with $R_D = R$ the following equivalent circuit in Figure 3 can be produced.

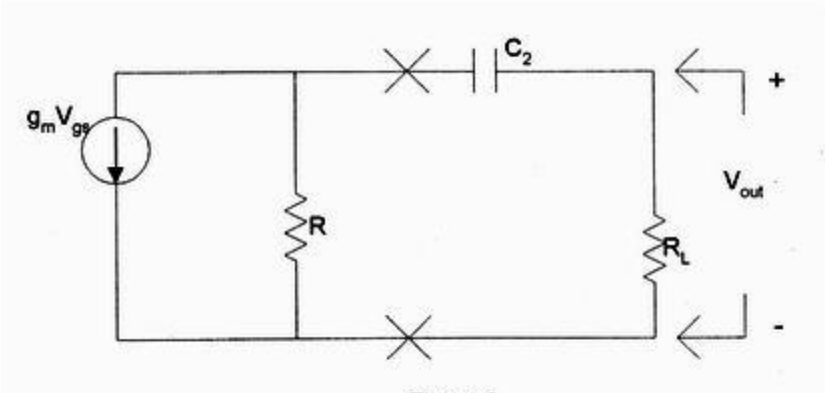


Figure 3

Applying a Theven solution to the left of X - X we can redraw the equivalent circuit in Figure 4.

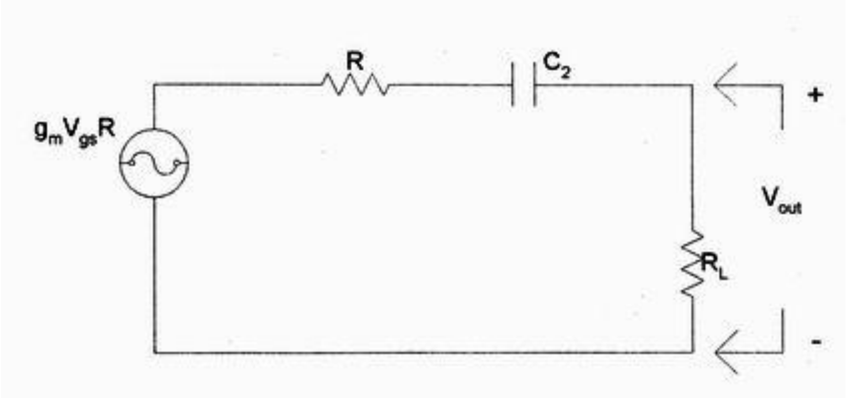


Figure 4

Therefore, the transfer function of Figure 4 becomes the following:

$V_{out} / V_{in} = V_{out} / g_m V_{gs} R = R_L / R + R_L [1 - (j / \omega (R + R_L)C_2]$

$V_{out} / V_{in} = R_L / R + R_L [1 / 1 - (j (\omega_{1output} / \omega))]$

So the transfer function becomes:

$\omega_{1output} = 1 / (R + R_L)C_2$

Notice that this transfer function reveals yet another Pole in the low frequency response, at a frequency determined by the output coupling capacitor C_2 and the resistance the capacitor sees is $(R + R_L)$. Now, by disregarding the affects of R_S and C_S, the low frequency response looks like Figure 5.

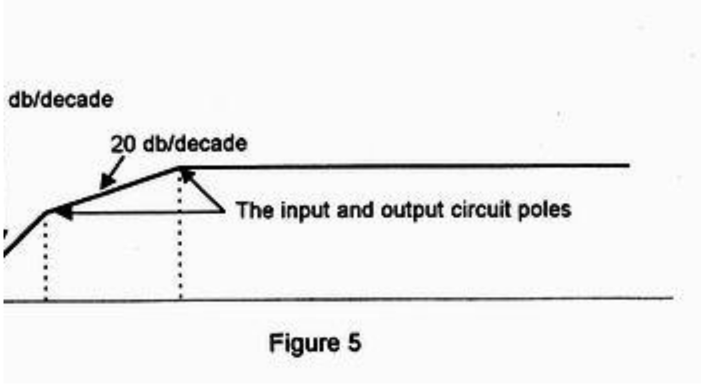


Figure 5

C_S in association with R_S must be assumed to also affect the low frequency response. It is possible to select values of R_S and C_S that remove their effects sufficiently to allow C_1 and C_2 to establish dominant poles. Note, this is not always the case.

Recall the gain equation (i.e. transfer function) of the drain loaded amplifier with source impedance:

$Av = -g_m Z_L / 1 + Z_S = -Z_L / (1 / g_m) + Z_S$

Sense only the effects of the source resistance R_S, and the source capacitance C_S are being considered, assume the load impedance Z_L to be resistive.

$Av = -R / (1 / g_m) + Z_S$

And,

$Z_S = R_S$ in Parallel with C_S

$Z_S = [R_S (1 / j \omega C_S)] / [R_S + (1 / j \omega C_S)]$

$Z_S = R_S / (1 + j \omega R_S C_S)$, substituting Z_S into the derived gain equation produces:

$Av = -R / [1 / g_m + (R_S / (1 + (1 / j \omega R_S C_S)))]$

Rearranging the derivation with some basic algebraic relations produces the complete transfer function:

$Av = - [R / (1 / g_m + R_S)] \cdot [(1 + j \omega R_S C_S) / (1 + j \omega (R_S 1 / g_m C_S) / (R_S + (1 / g_m)))]$

Examination of the completed transfer function result shows a zero at a frequency denoted with the mathematical expression of:

$\omega_{So} = 1 / R_S C_S$

And a pole at a frequency denoted as:

$\omega_{Sp} = 1 / (R_S 1 / G_m C_S) / (R_S + 1 g_m)$

The frequency response plot of the derived transfer function can be represented graphically as shown in Figure 6.

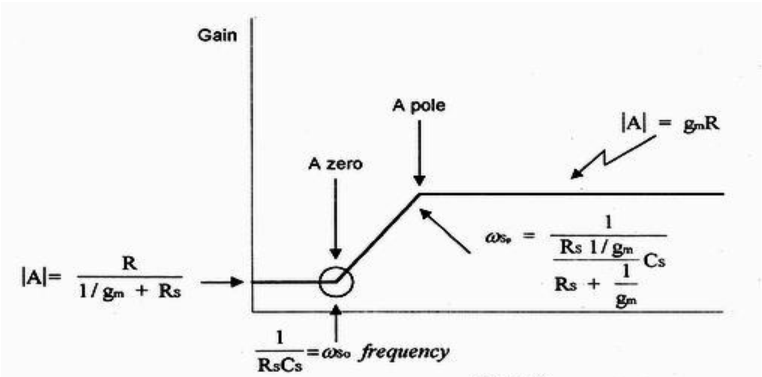


Figure 6

Engineering key words: frequency response, fet, low frequency, amplifier, amp, freq, bode plot, poles and zeros, bandwidth, bandpass, rolloff, transfer function, derivation, mathematical expression, gate, drain, source, gain, Av, specification, manufacture, input function, output, equivalent circuit, elements, Theven, substitution, load, dB, decade, semilog, log-log, nonlinear effect, circuit analysis.

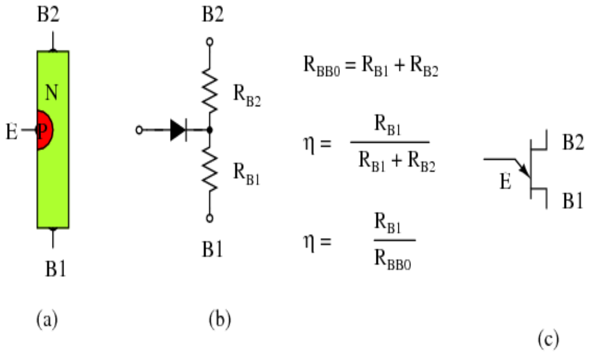
Uni-Junction Transistor(UJT):

A **unijunction transistor** (**UJT**) is an electronic semiconductor device that has only one junction. The UJT has three terminals: an emitter (E) and two bases (B1 and B2). The base is formed by lightly doped n-type bar of silicon. Two ohmic contacts B1 and B2 are attached at its ends. The emitter is of p-type and it is heavily doped. The resistance between B1 and B2, when the emitter is open-circuit is called interbase resistance.

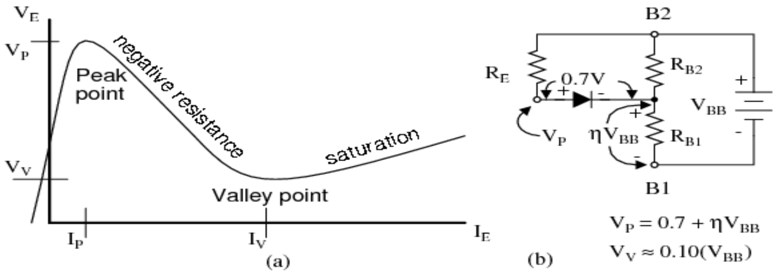
The UJT is biased with a positive voltage between the two bases. This causes a potential drop along the length of the device. When the emitter voltage is driven approximately one diode voltage above the voltage at the point where the P diffusion (emitter) is, current will begin to flow from the emitter into the base region. Because the base region is very lightly doped, the additional current (actually charges in the base region) causes conductivity modulation which reduces the resistance of the portion of the base betweenthe emitter junction and the B2 terminal. This reduction in resistance means that the emitter junction is more forward biased, and so even more current is injected. Overall, the effect is a negative resistance at the emitter terminal. This is what makes the UJT useful, especially in simple oscillator circuits.

Construction:

A *unijunction transistor* is composed of a bar of N-type silicon having a P-type connection in the middle. Shown in Figure below(a). The connections at the ends of the bar are known as bases B1 and B2; the P-type mid-point is the emitter. With the emitter disconnected, the total resistance R_{BBO},is the sum of R_{B1} and R_{B2} as shown in Figure below(b). The intrinsic standoff ratio η is the ratio of R_{B1} to R_{BBO}. It varies from 0.4 to 0.8 for different devices. The schematic symbol is Figure below(c)



The Uni-junction emitter current vs voltage characteristic curve (Figure below(a)) shows that as V_E increases, current I_E increases up I_P at the peak point. Beyond the peak point, current increases as voltage decreases in the negative resistance region. The voltage reaches a minimum at the valley point. The resistance of R_{B1}, the saturation resistance is lowest at the valley point. V_P is the voltage drop across R_{B1} plus a 0.7V diode drop; see Figure below(b). V_V is estimated to be approximately 10% of V_{BB}.



Silicon Controlled Rectifier (SCR)

Silicon Controlled Rectifier (SCR) is a unidirectional semiconductor device made of silicon which can be used to provide a selected power to the load by switching it ON for variable amount of time. These devices are solid-state equivalent of thyratrons and are hence referred to as thyristors or thyrode transistors. In fact, SCR is a trade name of General Electric (GE) to the thyristor. Basically **SCR** is a three terminal, four-layer (hence of three junctions J1, J2 and J3) semiconductor device consisting of alternate layers of p- and n-type material doping. Figure 1a shows the SCR with the layers pnpn which has the terminals Anode (A), Cathode (K) and the Gate (G). Further it is to be noted that the Gate terminal will generally be the p-layer nearer to the Cathode terminal. The symbol of the SCR used in case of circuit diagrams is shown in Figure 1b.

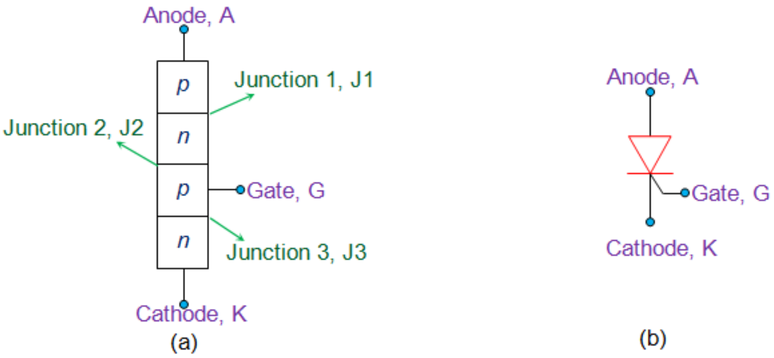


Figure 1 Silicon Controlled Rectifier (a) Layered Structure (b) Symbol

These SCRs can be considered equivalent to two inter-connected transistors as shown by the Figure 2.

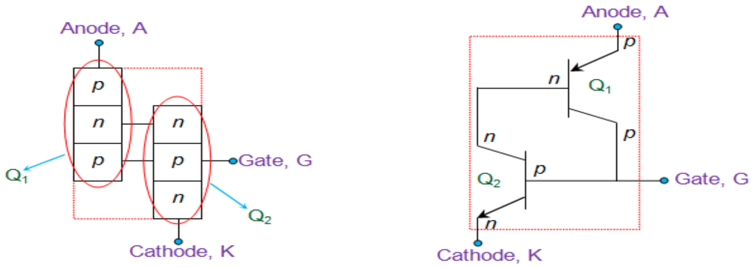


Figure 2 SCR realization interms of Bipolar Junction Transistors

Here it is seen that a single **SCR** is equal to a combination of pnp (Q_1) and npn (Q_2) transistors where the emitter of Q_1 will act as the anode terminal of the SCR while the emitter of Q_2 will be its cathode. Further, the base of Q_1 is connected to the collector of $Q_2$and the collector of Q_1 is shorted with the base of Q_2 to result in the gate terminal of the SCR.

The working of SCR can be understood by analyzing its behaviour in the following modes:

1. **Reverse Blocking Mode:** In this mode, the SCR is reverse biased by connecting its Anode terminal to negative end of the battery and by providing its Cathode terminal with a positive voltage (Figure 3a). This leads to the reverse biasing of the junctions J1 and J3, which inturn prohibits the flow of current through the device, inspite of the fact that the junction J2 will be forward biased. Further, in this state, the SCR behaviour will be identical to that of a typical diode as it exhibits both the flow of reverse saturation current (green curve in Figure 4) as well as the reverse break-down phenomenon (black curve in Figure 4).

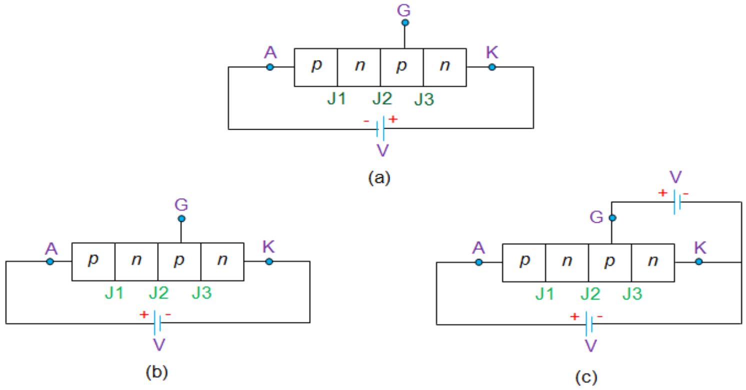


Figure 3 Biasing of Silicon Controlled Rectifier

2. **Forward Blocking Mode:** Here a positive bias is applied to the SCR by connecting its Anode to the positive of the battery and by shorting the SCR cathode to the battery's negative terminal, as shown by Figure 3b. Under this condition, the junctions J1 and J3 gets forward biased while J2 will be reverse biased which allows only a minute amount of current flow through the device as shown by the blue curve in Figure 4.

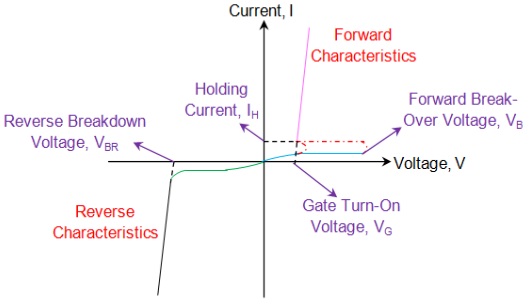


Figure 4 V-I Characteristics of SCR

3. **Forward Conduction Mode:** SCR can be made to conduct either (i) By Increasing the positive voltage applied between the Anode and Cathode terminals beyond the Break-Over Voltage, V_B or (ii) By applying positive voltage at its gate terminal as shown by Figure 3c. In the first case, the increase in the applied bias causes the initially reverse biased junction J2 to break-down at the point corresponding to Forward Break-Over Voltage, V_B. This results in the sudden increase in the current flowing through the SCR as shown by the pink curve in Figure 4, although the gate terminal of the SCR remains unbiased.

TRIAC:

CONSTRUCTION AND SYMBOL:

Triac is a three terminal AC switch which is different from the other silicon controlled rectifiers in the sense that it can conduct in both the directions that is whether the applied gate signal is positive or negative, it will conduct. Thus, this device can be used for AC systems as a switch.

This is a three terminal, four layer, bi-directional semiconductor device that controls AC power. The triac of maximum rating of 16 kw is available in the market.

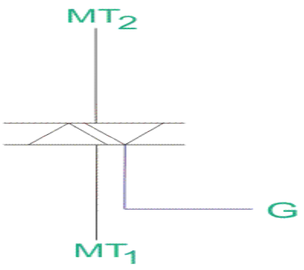


Figure shows the symbol of triac, which has two main terminals MT_1 and MT_2 connected in inverse parallel and a gate terminal.

Two SCRs are connected in inverse parallel with gate terminal as common. Gate terminals is connected to both the N and P regions due to which gate signal may be applied which is irrespective of the polarity of the signal. Here, we do not have anode and cathode since it works for both the polarities which means that device is bilateral. It consists of three terminals namely, main terminal 1(MT_1), main terminal 2(MT_2), and gate terminal G.

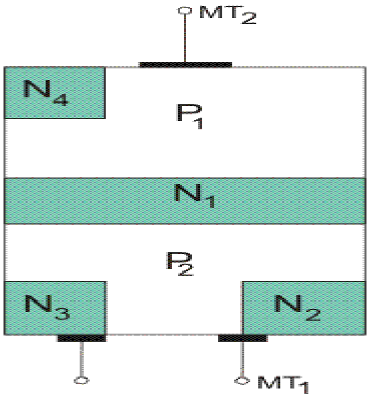


Figure shows the construction of a triac. There are two main terminals namely MT_1 and $MT_2$and the remaining terminal is gate terminal.

Operation of Triac

The triac can be turned on by applying the gate voltage higher than break over voltage. However, without making the voltage high, it can be turned on by applying the gate pulse of 35 micro seconds to turn it on. When the voltage applied is less than the break over voltage, we use gate triggering method to turn it on.

There are four different modes of operations, they are-

1. **When MT_2 and Gate being Positive with Respect to MT_1** When this happens, currentflows through the path P_1-N_1-P_2-N_2. Here, P_1-N_1 and P_2-N_2 are forward biased but N_1-$P_2$is reverse biased. The triac is said to be operated in positively biased region. Positive gate with respect to MT_1 forward biases P_2-N_2 and breakdown occurs.
2. **When MT_2 is Positive but Gate is Negative with Respect to MT_1** The current flows through the path P_1-N_1-P_2-N_2. But P_2-N_3 is forward biased and current carriers injected into P_2 on the triac.
3. **When MT_2 and Gate are Negative with Respect to MT_1** Current flows through the path P_2-N_1-P_1-N_4. Two junctions P_2-N_1 and P_1-N_4 are forward biased but the junction N1-P1 is reverse biased. The triac is said to be in the negatively biased region.

4. **When MT_2 is Negative but Gate is Positive with Respect to MT_1** P_2-N_2 is forward biased at that condition. Current carriers are injected so the triac turns on. This mode of operation has a disadvantage that it should not be used for high (di/dt) circuits. Sensitivity of triggering in mode 2 and 3 is high and if marginal triggering capability is required, negative gate pulses should be used. Triggering in mode 1 is more sensitive than mode 2 and mode 3.

Characteristics of a Triac

The **triac** characteristics is similar to SCR but it is applicable to both positive and negative triac voltages. The operation can be summarized as follows-

First Quadrant Operation of Triac

Voltage at terminal MT_2 is positive with respect to terminal MT_1 and gate voltage is also positive with respect to first terminal.

Second Quadrant Operation of Triac

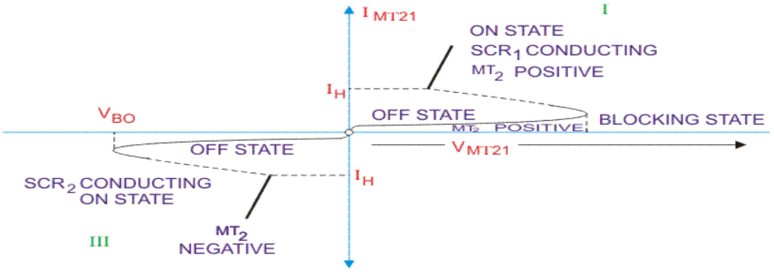
Voltage at terminal 2 is positive with respect to terminal 1 and gate voltage is negative with respect to terminal 1.

Third Quadrant Operation of Triac

Voltage of terminal 1 is positive with respect to terminal 2 and the gate voltage is negative.

Fourth Quadrant Operation of Triac

Voltage of terminal 2 is negative with respect to terminal 1 and gate voltage is positive.



V-I Characteristic of a Triac

When the device gets turned on, a heavy current flows through it which may damage the device, hence in order to limit the current a current limiting resistor should be connected externally to it. By applying proper gate signal, firing angle of the device may be controlled. The gate triggering circuits should be used for proper gate triggering. We can use diac for triggering the gate pulse. For firing of the device with proper firing angle, a gate pulse may be applied up to a duration of 35 micro seconds.

Advantages of Triac

1. It can be triggered with positive or negative polarity of gate pulses.
2. It requires only a single heat sink of slightly larger size, whereas for SCR, two heat sinks should be required of smaller size.
3. It requires single fuse for protection.
4. A safe breakdown in either direction is possible but for SCR protection should be given with parallel diode.

Disadvantages of Triac

1. They are not much reliable compared to SCR.
2. It has (dv/dt) rating lower than SCR.
3. Lower ratings are available compared to SCR.
4. We need to be careful about the triggering circuit as it can be triggered in either direction.

Uses of Triac

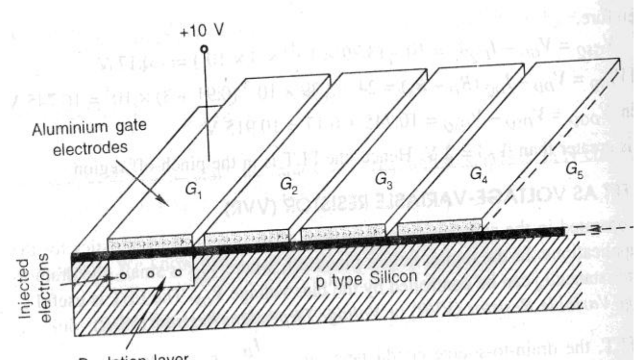
1. They are used in control circuits.
2. It is used in High power lamp switching.
3. It is used in AC power control.

UNIT V
CCD AND OPTOELECTRONIC DEVICES

CHARGE TRANSFER DEVICE

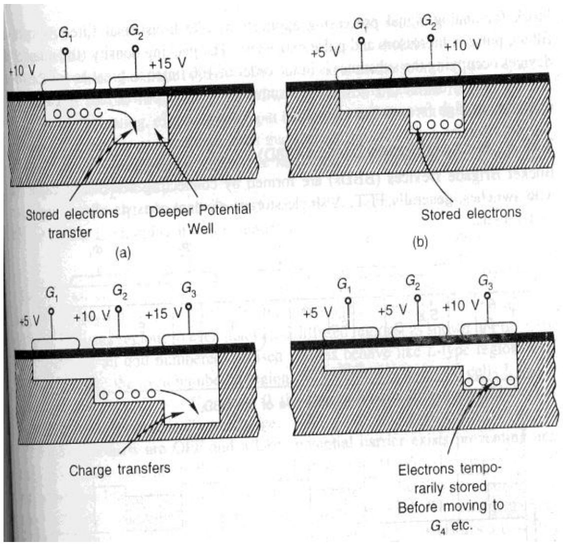
A charge transfer device is a semiconductor structure in which discrete charge packets are removed. it finds wide applications in shift registers imaging systems dynamic memories and high speed filtering . there are two main methods of constructing CTD namely 1. Charge coupled Device CDD 2.Bucket Brigade Device.

CHARGE COUPLED DEVICE (CCD)



A charge coupled device is a shift register formed by closely spaced Mos capacitors A CCD can store and transfer analog signals either electrons or holes which may be introduced electrically or optically . A cross sectional view of three phase charge coupled device is shown. the structure consists of a serial of metal gate electrodes separated from a p (or an N) type semiconducting silicon substrate (for an N channel) by a thin silicon dioxide layer on the top of silicon dioxide is an array of metallised electrodes which are connected to signal voltages V1,V2 and V3.

A three phase clocked voltage pulse system supplied to the gate ensures that the charge is transferred serially between gates and its direction is controlled as given below. the first phase connects a positive voltage V1 say + 10 V to G1 where V1 is greater than either V2 or V3 a depletion layer is formed in typically less than 1 microseconds. This produces the potential well into which information in the form of minority electrons is stored. During the second phase the adjacent gate G2 is biased to a greater voltage V2 say +15V to produce a deeper well under it is shown. The stored charge then transfers into the deeper potential well by diffusion down the potential gradient which incidentally can be a relatively slow process.the charge is stored in the well under G2 the voltage on G1 is reduced say + 5 V and that on G2 to a sustaining level of +10 V . A third phase transfers a + 15 V pulse to the next gate G2.and the charge is transferred from G2 to the well under it as shown the voltages on G2 and G3 can be relaxed to complete one cycle of frequency. The charge transferred from under G1 to under G3 in one cycle of the clocked three phase pulse which causes a series of voltages in the sequence of +15,+10,+5,+15 etc., to be applied to each. The charge in the substrate is transferred under one electrode to the next and so on. As charge is moved out of one set of three electrode G3 to G4 then the input gate is again put in a state to receive further bit of information .



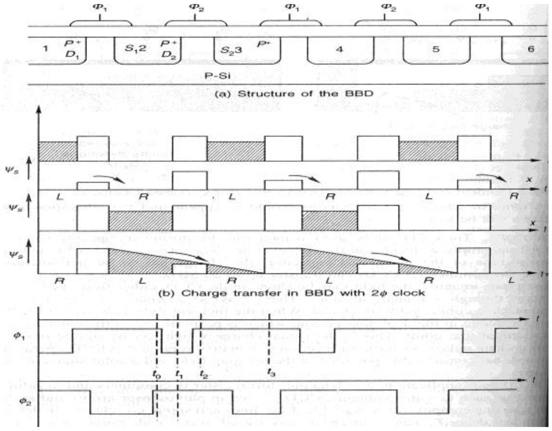
The CCD structure behaves as a dynamic shift register and charge as to be transferred to less than one ms.

Applications:-

CCDs can transferred up to 20 MHz.

Dynamic shift register in computers and solid state imaging video camera

BUCKET BRIGADE DEVICES (BBD) are formed by connecting a series of capacitors with switches FET. A single storage element consists of two capacitor switch units.



The BBD operates on the basis of charge transfer to the adjacent wells.the BBD structure cosists of a series of MOS transistors (MOSFET) as shown in fig. In which drain of the first transistor acts as the source of the adjacent transistor and so on. In a p channel BBD the source and drain regions are P+ of charge . the device is structured such that capacitance C associated with the left hand cell L is much larger due to the larger gate overlap than that of the right hand cell Cl >>Cr

Assume at time to when all channels are off a signal charge is stored in a diffused region L charging it to a potential VoQ = Cl Vo

If L has no charge to start with no charge transfer will take place.at t1 the phase 1 and phase 2 is low. The charge transfer takes place from all odd numbered diffused regions to even numbered diffused regions behave like L-type regions as shown

All odd numbered diffused regions behave like L type regions and transfer charge to the even numbered regions R. when phase 1 comes on cells L and R get connected. Since Cl >>Cr Ql =0 the charge flow will continue till the left hand cell L contains practically no charge.

At t2 all channels are off and large potential barrier exists preventing any carrier flow. At t3 the phase phase 2 is high and phase 1 is low.qll even numbered regions behave like L type region and tranfer charge to theR type regions.one pair of even and odd numbered regions constitute a bit or cell. The charge transfer takes place only from L to R not from R to L . since there is a potential barrier between them. During one complete clock period T charge is transferred by one bit.

BBDs operate on lower maximum frequencies than CCDs because of transfer speed is limited by the charge flow through the channel. BBDs have large cell area .BBDs are used in audio delay lines to implement reverberation.BBDs can transfer at 1 MHz.

LCD:

Basics of LCD Displays:-

The liquid-crystal display has the distinct advantage of having a low power consumption than the LED. It is typically of the order of microwatts for the display in comparison to the some order of milliwatts for LEDs. Low power consumption requirement has made it compatible with MOS integrated logic circuit. Its other advantages are its low cost, and good contrast. The main drawbacks of **LCD**s are additional requirement of light source, a limited temperature range of operation (between 0 and 60° C), low reliability, short operating life, poor visibility in low ambient lighting, slow speed and the need for an ac drive.

Basic structure of an LCD

A liquid crystal cell consists of a thin layer (about 10 u m) of a liquid crystal sandwiched between two glass sheets with transparent electrodes deposited on their inside faces. With both glass sheets transparent, the cell is known as *transmittive type cell.* When one glass is transparent and the other has a reflective coating, the cell is called *reflective type.* The LCD does not produce any illumination of its own. It, in fact, depends entirely on illumination falling on it from an external source for its visual effect

Types of LCD/Liquid Crystal Displays.

Two types of display available are dynamic scattering display and field effect display**.**

When *dynamic scattering display* is energized, the molecules of energized area of the display become turbulent and scatter light in all directions. Consequently, the activated areas take on a frosted glass appearance resulting in a silver display. Of course, the unenergized areas remain translucent.

Field effect LCD contains front and back polarizers at right angles to each other. Without electrical excitation, the light coming through the front polarizer is rotated 90° in the fluid.

Now, let us take a look at the different varieties of liquid crystals that are available for industrial purposes. The most usable liquid crystal among all the others is the nematic phase liquid crystals.

Nematic Phase LCD

The greatest advantage of a nematic phase liquid crystal substance is that it can bring about predictable controlled changes according to the electric current passed through them. All the liquid crystals are according to their reaction on temperature difference and also the nature of the substance.

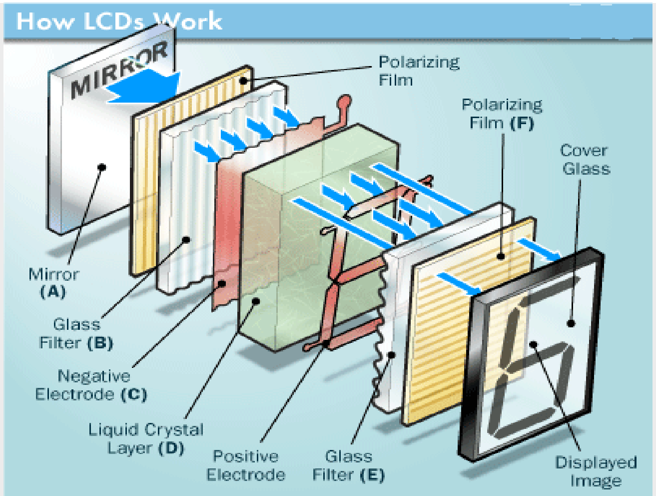
Twisted Nematics, a particular nematic substance is twisted naturally. When a known voltage is applied to the substance, it gets untwisted in varying degrees according to our requirement. This in turn is useful in controlling the passage of light. A nematic phase liquid crystal can be again classified on the basis in which the molecules orient themselves in respect to each other. This change in orientation mainly depends on the director, which can be anything ranging from a magnetic field to a surface with microscopic grooves. Classification includes Smectic and also cholesteric. Smectic can be again classified as smectic C, in which the molecules in each layer tilt at an angle from the previous layer. Cholesteric, on the other hand has molecules that twist slightly from one layer to the next, causing a spiral like design. There are also combinations of these two called Ferro-electric liquid crystals (FLC), which include cholesteric molecules in a smectic C type molecule so that the spiral nature of these molecules allows the microsecond switching response time. This makes FLCs to be of good use in advanced displays.

Liquid crystal molecules are further classified into thermotropic and lyotropic crystals. The former changes proportionally with respect to changes in pressure and temperature. They are further divided into nematic and isotropic. Nematic liquid crystals have a fixed order of pattern while isotropic liquid crystals are distributed randomly. The lyotropic crystal depends on the type of solvent they are mixed with. They are therefore useful in making detergents and soaps.

Making of LCD

- Though the making of LCD is rather simple there are certain facts that should be noted while making it.
- The basic structure of an LCD should be controllably changed with respect to the applied electric current.
- The light that is used on the LCD can be polarized.
- Liquid crystals should be able to both transmit and change polarized light.
- There are transparent substances that can conduct electricity.

To make an LCD, you need to take two polarized glass pieces. The glass which does not have a polarized film on it must be rubbed with a special polymer which creates microscopic grooves in the surface. It must also be noted that the grooves are on the same direction as the polarizing film. Then, all you need to do is to add a coating of nematic liquid crystals to one of the filters. The grooves will cause the first layer of molecules to align with the filter's orientation. At right angle to the first piece, you must then add a second piece of glass along with the polarizing film. Till the uppermost layer is at a 90-degree angle to the bottom, each successive layer of TN molecules will keep on twisting. The first filter will naturally be polarized as the light strikes it at the beginning. Thus the light passes through each layer and is guided on to the next with the help of molecules. When this happens, the molecules tend to change the plane of vibration of the light to match their own angle. When the light reaches the far side of the liquid crystal substance, it vibrates at the same angle as the final layer of molecules. The light is only allowed an entrance if the second polarized glass filter is same as the final layer. Take a look at the figure below.



working of lcd

The main principle behind liquid crystal molecules is that when an electric current is applied to them, they tend to untwist. This causes a change in the light angle passing through them. This causes a change in the angle of the top polarizing filter with respect to it. So little light is allowed to pass through that particular area of LCD. Thus that area becomes darker comparing to others.

For making an LCD screen, a reflective mirror has to be setup in the back. An electrode plane made of indium-tin oxide is kept on top and a glass with a polarizing film is also added on the bottom side. The entire area of the LCD has to be covered by a common electrode and above it should be the liquid crystal substance. Next comes another piece of glass with an electrode in the shape of the rectangle on the bottom and, on top, another polarizing film. It must be noted that both of them are kept at right angles. When there is no current, the light passes through the front of the LCD it will be reflected by the mirror and bounced back. As the electrode is connected to a temporary battery the current from it will cause the liquid crystals between the common-plane electrode and the electrode shaped like a rectangle to untwist. Thus the light is blocked from passing through. Thus that particular rectangular area appears blank.

Colour Liquid Crystal Display

Colour LCDs are those that can display pictures in colours. For this to be possible there must be three sub-pixels with red, green and blue colour filters to create each colour pixel. For combining these sub-pixels these LCDs should be connected to a large number of transistors. If any problem occurs to these transistors, it will cause a bad pixel.

One of the main disadvantages of these types of LCDs is the size. Most manufacturers try to reduce the height than gain it. This is because more transistors and greater pixels will be needed to increase the length. This will increase the probability of bad pixels. It is very difficult or also impossible to repair a LCD with bad pixels. This will highly affect the sale of LCDs.

LED:

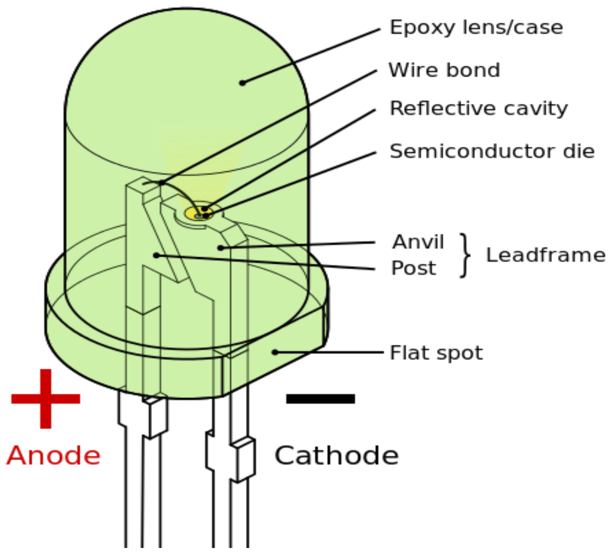
A **light-emitting diode** (**LED**) is a two-lead semiconductor light source. It is a p–n junction diode that emits light when activated.[5]When a suitable voltage is applied to the leads, electrons are able to recombine with electron holes within the device, releasing energy in the form of photons. This effect is called electroluminescence, and the color of the light (corresponding to the energy of the photon) is determined by the energy band gap of the semiconductor. LEDs are typically small (less than 1 mm^2) and integrated optical components may be used to shape the radiation pattern.[6]

Appearing as practical electronic components in 1962,[7] the earliest LEDs emitted low-intensity infrared light. Infrared LEDs are still frequently used as transmitting elements in remote-control circuits, such as those in remote controls for a wide variety of consumer electronics. The first visible-light LEDs were also of low intensity and limited to red. Modern LEDs are available across the visible, ultraviolet, and infrared wavelengths, with very high brightness.

Early LEDs were often used as indicator lamps for electronic devices, replacing small incandescent bulbs. They were soon packaged into numeric readouts in the form of seven-segment displays and were commonly seen in digital clocks. Recent developments have produced LEDs suitable for environmental and task lighting. LEDs have led to new displays and sensors, while their high switching rates are useful in advanced communications technology.

LEDs have many advantages over incandescent light sources, including lower energy consumption, longer lifetime, improved physical robustness, smaller size, and faster switching. Light-emitting diodes are used in applications as diverse as aviation lighting, automotive headlamps, advertising, general lighting, traffic signals, camera flashes, and lighted wallpaper. As of 2017, LED lights home room lighting are as cheap or cheaper than compact fluorescent lamp sources of comparable output.[8] They are also significantly more energy efficient and, arguably, have fewer environmental concerns linked to their disposal.[9][10]

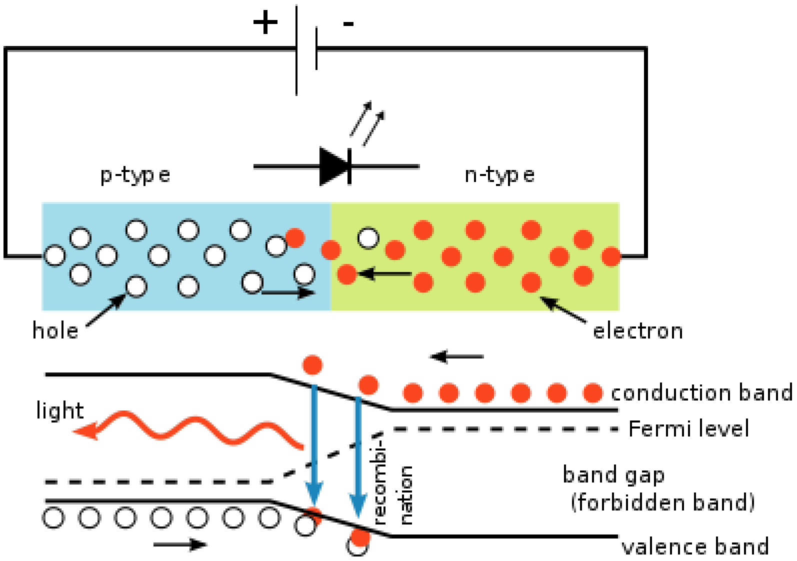
Unlike a laser, the color of light emitted from an LED is neither coherent nor monochromatic, but the spectrum is narrow with respect to human vision, and for most purposes the light from a simple diode element can be regarded as functionally monochromatic.



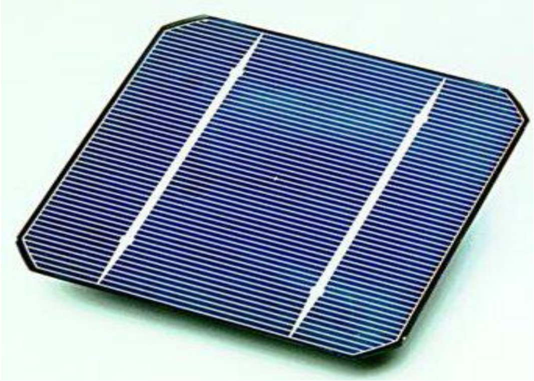
Working principle:

A P-N junction can convert absorbed light energy into a proportional electric current. The same process is reversed here (i.e. the P-N junction emits light when electrical energy is applied to it). This phenomenon is generally called electroluminescence, which can be defined as the emission of light from a semiconductor under the influence of an electric field. The charge carriers recombine in a forward-biased 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 is less than the energy levels of the electrons. Some portion of the energy must be dissipated 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 gallium arsenide phosphide (GaAsP) and gallium phosphide (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. However, when the junction is reverse biased, the LED produces no light and—if the potential is great enough, the device is damaged.



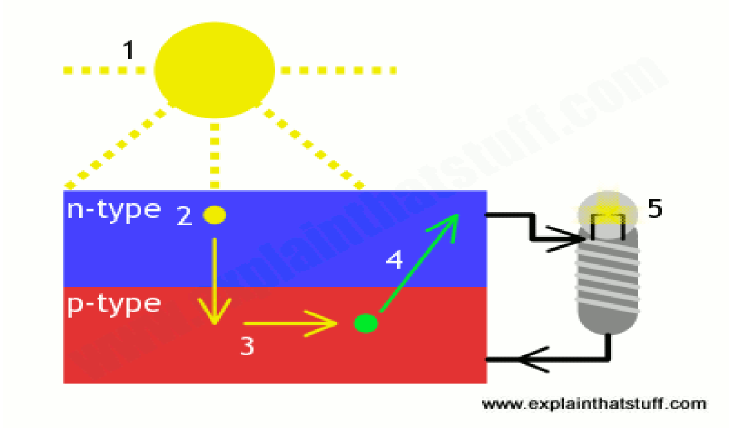
Solar cell:
A **solar cell** or **photovoltaic cell** is a device that converts light energy into electrical energy. Sometimes the term *solar cell* is reserved for devices intended specifically to capture energy from sunlight, while the term *photovoltaic cell* is used when the light source is unspecified. The device needs to fulfill only two functions: photogeneration of charge carriers (electrons and electron holes) in a light-absorbing material, and separation of the charge carriers to a conductive contact that will transmit the electricity. This conversion is called the *photovoltaic effect*, and the field related to solar cells is known as photovoltaics.



Working of solar cell:

A solar cell is a sandwich of n-type silicon (blue) and p-type silicon (red). It generates electricity by using sunlight to make electrons hop across the junction between the different flavors of silicon:

1. When sunlight shines on the cell, photons (light particles) bombard the upper surface.
2. The photons (yellow blobs) carry their energy down through the cell.
3. The photons give up their energy to electrons (green blobs) in the lower, p-type layer.
4. The electrons use this energy to jump across the barrier into the upper, n-type layer and escape out into the circuit.
5. Flowing around the circuit, the electrons make the lamp light up.



Solar cell applications:

Solar cells have many applications. They have long been used in situations where electrical power from the grid is unavailable, such as in remote area power systems, Earth-orbiting satellites and space probes, consumer systems, e.g. handheld calculators or wrist watches, remote radiotelephones and water pumping applications. More recently, they are starting to be used in assemblies of solar modules connected to the electricity grid through an inverter, often in combination with net metering.

Solar cells are regarded as one of the key technologies towards a sustainable energy supply.

LASER:

A **laser** is a device that emits light through a process of optical amplification based on the stimulated emission of electromagnetic radiation. The term "laser" originated as an acronym for "**light amplification by stimulated emission of radiation**".[1][2] The first laser was built in 1960 by Theodore H. Maiman at Hughes Research Laboratories, based on theoretical work by Charles Hard Townes and Arthur Leonard Schawlow. A laser differs from other sources of light in that it emits light *coherently*. Spatial coherence allows a laser to be focused to a tight spot, enabling applications such as laser cutting and lithography. Spatial coherence also allows a laser beam to stay narrow over great distances (collimation), enabling applications such as laser pointers. Lasers can also have high temporal coherence, which allows them to emit light with a very narrow spectrum, i.e., they can emit a single color of light. Temporal coherence can be used to produce pulses of light as short as a femtosecond.

Among their many applications, lasers are used in optical disk drives, laser printers, and barcode scanners; DNA sequencing instruments, fiber-optic and free-space optical communication; laser surgery and skin treatments; cutting and welding materials; military and law enforcement devices for marking targets and measuring range and speed; and laser lighting displays in entertainment.

Terminology

Laser beams in fog, reflected on a car windshield

The word *laser* started as an acronym for "light amplification by stimulated emission of radiation". In modern usage, the term "light" includes electromagnetic radiation of any frequency, not only visible light, hence the terms *infrared laser*, *ultraviolet* *laser*, *X-ray laser*, *gamma-ray laser*, and so on. Because the microwave predecessor of the laser, the maser, was developed first, devices of this sort operating at microwave and radio frequencies are referred to as "masers" rather than "microwave lasers" or "radio lasers". In the early technical literature, especially at Bell Telephone Laboratories, the laser was called an **optical maser**; this term is now obsolete.[5]

A laser that produces light by itself is technically an optical oscillator rather than an optical amplifier as suggested by the acronym. It has been humorously noted that the acronym LOSER, for "light oscillation by stimulated emission of radiation", would have been more correct.[6]With the widespread use of the original acronym as a common noun, optical amplifiers have come to be referred to as "laser amplifiers", notwithstanding the apparent redundancy in that designation.

The back-formed verb *to lase* is frequently used in the field, meaning "to produce laser light,"[7] especially in reference to the gain medium of a laser; when a laser is operating it is said to be "lasing." Further use of the words *laser* and *maser* in an extended sense, not referring to laser technology or devices, can be seen in usages such as *astrophysical maser* and *atom laser*.

WORKING:

"Laser" is an acronym for **l**ight **a**mplification by **s**timulated **e**mission of **r**adiation. A laser is created when the electrons in atoms in special glasses, crystals, or gases absorb energy from an electrical current or another laser and become "excited." The excited electrons move from a lower-energy orbit to a higher-energy orbit around the atom's nucleus. When they return to their normal or "ground" state, the electrons emit photons (particles of light).

These photons are all at the same wavelength and are "coherent," meaning the crests and troughs of the light waves are all in lockstep. In contrast, ordinary visible light comprises multiple wavelengths and is not coherent.

Laser light is different from normal light in other ways as well. First, its light contains only one wavelength (one specific color). The particular wavelength of light is determined by the amount of energy released when the excited electron drops to a lower orbit. Second, laser light is directional. Whereas a laser generates a very tight beam, a flashlight produces light that is diffuse. Because laser light is coherent, it stays focused for vast distances, even to the moon and back.

APPLICATIONS:

Laser has many applications in the modern world:

- Laser cutting.
- Laser welding.
- Laser drilling.
- Laser marking.
- Laser cladding, a surface engineering process applied to mechanical components for reconditioning, repair work or hardfacing.
- Photolithography. E.t.c
- In military
- In medicine
- In space studies e.t.c