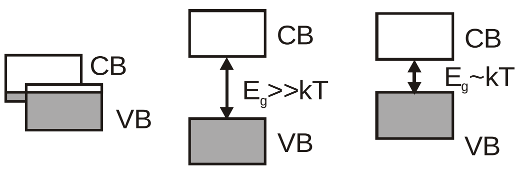
13. SEMICONDUCTOR DEVICES

Synopsis:

1. Solids are classified into two categories.
   a) Crystalline solids
   b) Amorphous solids
2. **Crystalline solids :** Crystalline solids have orderly arrangement of atoms with regularity and periodicity. They have sharp melting points. They have different physical properties in different directions. They are called anisotropic. Eg : Metals, sodium chloride, Germanium, Silicon.
3. **Amorphous solids :** In amorphous substances, atoms are arranged randomly and they do not have sharp melting points and are isotropic in nature. Eg : Glass, rubber, plastic.
4. Based upon electrical properties, crystalline solids are classified as (i) conductors, (ii) semiconductors, (iii) insulators.
   (i) **Conductors :** In conductors, large number of free electrons move randomly in the body. When an electrical field is applied, free electrons experience force due to the field and acquire drift speed resulting in electric current.
   (ii) **Semiconductors :** Semiconductors do conduct electricity when an electric field is applied. But their conductivity is in between that of conductors and insulators. They behave like insulators at 0 K. As temperature increases, their conductivity increases.
   (iii) **Insulators :** In insulators electrons are tightly bound to some nucleus or the other. In insulators even at very high electric field, current is almost zero.
5. The conductivity of solids can be explained by **Band Theory of solids.**
6. **Band Theory of solids :** A solid is a periodic arrangement of atoms. In case of isolated atom the energy levels are discrete or well separated. For a particular atom in the solid, neighbouring atoms influence the energies of the outer electrons. The discrete energy levels spread into band of energy levels. The highest filled band is called **valance band**. The next higher unfilled band is called **conduction band**. The valance band and conduction band are separated by certain forbidden energy region called **forbidden energy gap** (E_g).
7. The energy bands which are completely filled at 0 K are called valance bands. The bands with higher energies are called conduction bands.
8. Based on band theory of solids, solids are classified as conductors, semiconductors and insulators.



Conductor Insulator Semiconductor

9. **Conductors :**
   a) If the conduction band and valence band overlap one over the other then such substances are called as conductors.
   Eg : metals (Na crystal)
   b) The characteristic feature of a conductor is having partially filled energy bands. Na is a conductor because in Na, 3s is partially filled but Mg is a conductor because of overlapping of 3s and 3p energy bands.

c) For conductors forbidden energy gap is 0 eV.

10. **Insulators :**

a) If the conduction band and valence band are well separated (about 5 eV) by forbidden gap then such substances are called as insulators. Eg : Diamond.

11. **Semi-conductors :**

a) If the forbidden energy gap between the conduction band and valence band is small (about 1 eV) then such substances are called semiconductors. Eg : Silicon & Germanium.

b) For silicon forbidden energy gap is 1.1 eV and for germanium 0.72 eV.

c) At absolute zero, semiconductors behave as perfect insulators.

d) Semiconductors are of two types.

1) Intrinsic 2) Extrinsic

12. **Hole :**

a) A hole is an unfilled covalent bond (or) A vacant energy state in the valance band of a semiconductor is called hole.

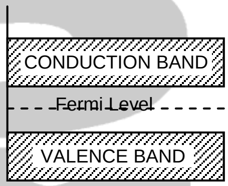
b) The existence of energy level of a hole can be observed in valence band of a semiconductor.

c) Hole acts like a positive charge but not a particle. Hole drifts in opposite direction to electrons with lesser speed.

13. **Fermi energy :** The highest energy level which an electron can occupy at 0 k is called Fermi level. For intrinsic semiconductors this level lies in the middle of the forbidden gap. It can also taken as average energy of charge carriers.

14. **Intrinsic semiconductors :**

a) Pure form of Si or Ge crystals are called intrinsic semiconductors (tetravalent).



Intrinsic semiconductor

b) The responsible charge carriers for conduction are both the free electrons and holes.

c) The number of holes and the number of free electrons are equal ($n_e=n_h$) and increase with increase of temperature.

d) Even though the responsible charge carriers are both the free electrons and holes the current contributed by the electrons is more than that of holes because of their higher mobility.

e) Mobility of electrons is nearly twice to that of holes in Germanium and 4 times in silicon.

f) Fermi-energy level lies exactly at the mid point of the forbidden gap.

15. **Extrinsic semiconductors :**

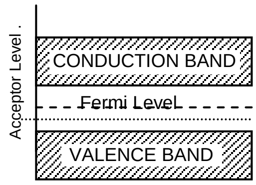
a) The conductivity of intrinsic semiconductor is relatively less. To increase their conductivity pure semiconductors are doped with trivalent or pentavalent substances.

b) **Doping :** Adding of selected impurities to a semiconductor to increase its conductivity is called doping.

c) The doped semiconductors are called as extrinsic semiconductors. They are of two types. i) p-type, ii) n-type.

d)

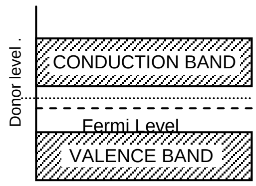
16. **p-type semiconductor :**



p-type semiconductor

   a) When a trivalent substance (III group elements) like Boron, Aluminium, Gallium, Indium etc., are added in sufficient quantities (1 in 10^6 or less) to the pure form of Si or Ge crystal then it is said to be p-type.
   b) In p-type semiconductor, holes are majority carriers and electrons are minority carriers ($n_h > n_e$)
   c) The fermi-energy level lies nearer to the valence band.
   d) It is electrically neutral.
   e) The energy level formed slightly above (about 0.01 eV) the valence band due to acceptor impurities is called acceptor energy level.

17. **n-type semiconductor :**



n-type semiconductor

   a) When a pentavalent substance (V group elements) like Phosphorous, Arsenic, Antimony etc., are added in sufficient quantities to the pure form of Si or Ge crystal then it is said to be n-type.
   b) In n-type semiconductor, electrons are majority carriers and holes are minority carriers. ($n_e > n_h$).
   c) The fermi-energy level in nearer to the conduction band.
   d) It is electrically neutral.
   e) The energy level formed slightly below (about 0.01 eV) the conduction band due to donor impurities is called donor energy level.
      1) Conductivity of n-type > p-type > intrinsic.
      2) With the increase of temperature fermi level moves down.

18. **p-n junction :** When a semi conducting material such as silicon or germanium is doped with impurity in such a way that one side has a large number of acceptor impurities and the other side has a large number of donor impurities. The resulting semiconductor is called p-n junction.

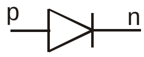
19. **p-n junction diode :**
   a) A p-n junction diode cannot be obtained by simple contact of p-type and n-type semiconductor.
   b) Near the junction, the free electrons from n-region migrate towards p-region and the holes in p-region migrate towards n-region. This process is known as diffusion. This diffusion is due to concentration gradient.
   c) Due to diffusion, positive ions are left over in n-region and negative ions are left over in p-region, near the junction. These ions are immobile.
   d) Due to the immobile ions on either side of the junction an internal electric field is formed at the junction which is directed from n to p.
   e) The no charge carrier region formed at p-n junction due to the combination of electrons and holes is called **depletion layer**.
   f) The thickness of the depletion layer is of the order of 10^{-6} m.
   g) When the depletion layer is sufficient by built up, it prevents the electrons diffusion from n to p side and hole diffusion from p to n side i.e., it acts as a barrier.
   h) The potential difference across the barrier which is set up to prevent diffusion of charge carriers through the junction is called **potential barrier** or **contact potential**.
   i) The potential barrier for silicon is 0.7 volts and for germanium is 0.3 volts.

j) The potential barrier value lies in between 0.1 to 0.7 volts, which depends on the nature of semiconductor, doping concentration and temperature of the junction.

k) It can be presumed to be equivalent to a condenser in which the depletion layer act as a dielectric.

l) p-n junction diode can be used as rectifiers, detectors.

m) In a circuit p-n junction diode is represented as. Here arrow mark represents the direction of current in forward bias. It represents 'p' side.



Drift current :

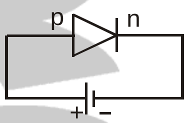
n) Due to thermal collisions, electron-hole pairs are created in the depletion region. The electron is quickly pushed by the electric field towards the n-side and the hole towards the p-side. As electron-hole pairs are continuously created in the depletion region, there is a regular flow of electrons towards the n-side and of holes towards the p-side. This makes a current from the n-side to the p-side. This current is called the drift current.

a) **Diffusion current :** When a p-n junction is formed, because of the concentration difference, holes try to diffuse from the p-side to n-side. Similarly, electrons try diffuse from n-side to p-side. This diffusion results in an electric current from the p-side to the n-side known as diffusion current.

v) The drift current and the diffusion current are in opposite directions. In unbiased junction, in steady state, the diffusion current equals the drift current in magnitude there is no net transfer of charge at any cross-section.

20. **Forward Bias :**

a) In a p-n junction diode, if p-region is connected to +ve terminal (relatively higher potential) of the battery and n-region is connected to –ve terminal (relatively lower potential) of the battery then it is said to be forward biased.



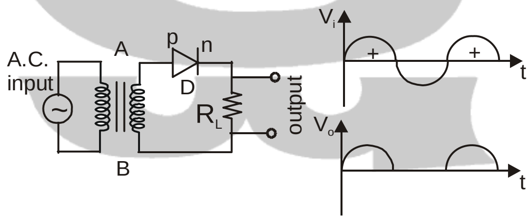
b) In forward biased condition, the width of depletion layer and barrier potential decrease.

c) It is a low resistance connection.

d) The resistance of an ideal diode in forward biased condition is zero.

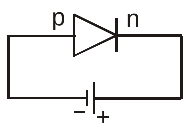
e) In forward biased condition, the flow of current is mainly due to the diffusion of electrons.

f) The direction of current is from p to n.



21. **Reverse Bias :**

a) In a p-n junction diode, if p-region is connected to –ve terminal (relatively low potential) of the battery and n-region is connected to the +ve terminal (relatively high potential) of the battery then it is said to be reverse biased.



b) In reverse biased condition, the width of the depletion layer and barrier potential increase.

c) It is a high resistance connection.

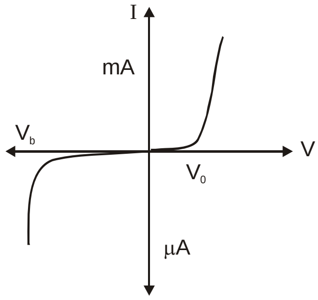
d) The resistance of an ideal diode in reverse bias condition is infinity.

e) In reverse biased condition, the flow of current is mainly due to the drift of charges.

f) The direction of current in it is from n to p.

i-v relation of diode is $i = i_0[e^{\frac{qv}{KT}} - 1]$ where i_0 is reverse saturation current, KT is thermal energy and q is charge of electron. In forward bias $i = i_0 e^{\frac{qv}{KT}}$, in reverse bias $i = -i_0$.

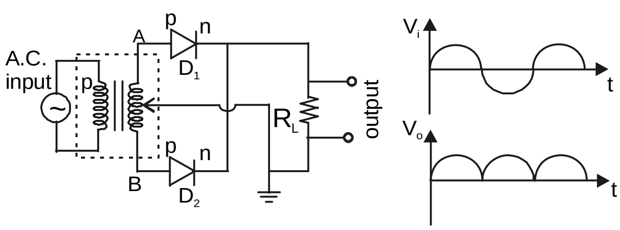
I-V characteristics :



V_b-break down voltage
V_0-barrier potential

Diode is unidirectional. It allows current in forward bias when applied potential is greater than the barrier potential.

22. **Rectifier :**
    a) The conversion of A.C. voltage to D.C. voltage is called **rectification**.
    b) A p-n junction diode is used as a rectifier.
    c) When a single diode is used as a rectifier, the rectification of only one half of the A.C. wave form takes place. Such a rectification is called **half wave rectification**.
23. **Efficiency of half wave rectifier :**
    a) The ratio of D.C. power output to the applied input A.C. power is known as rectifier efficiency.
    b) Rectifier efficiency $\eta = \frac{P_{dc}}{P_{ac}} = \frac{0.406R_L}{R_L + r_f}$ where R_L - load resistance, r_f - diode resistance.
24. In half wave rectification, a maximum of 40.6% of A.C. power is converted into D.C. power.
    In a half wave rectifier, if input frequency is n Hz A.C., then the output pulse frequency is n Hz D.C.
    a) maximum current $i_m = \frac{V_m}{r_f + R_L}$ where V_m = maximum voltage, r_f = internal resistance of the diode, R_L = load resistance.
    b) Average current $I_{dc} = \frac{I_m}{\pi}$
    c) rms current $i_{rms} = \frac{i_m}{\sqrt{2}}$.
    d) a.c power input $= i_{rms}^2 \text{ x } (r_f + R_L)$
    e) d.c power output $P_{dc} = (I_{dc})^2 \text{x} R_L$
25. When two diodes are used, then the rectification of both halves of the alternating voltage or current can be obtained. Such a rectification is called **full wave rectification**.



    a) In a full wave rectifier, if input frequency is n Hz A.C., then the output pulse frequency is 2n Hz pulsated D.C.
26. **Filter circuit :** The output current either from half wave rectifier or full wave rectifier, though unidirectional is not steady. It also contains A.C. components which are undesirable and are to be

removed by using filter circuit. Filter circuit is a device which removes the A.C. component of rectifier output and allows the D.C. component to reach the load.

27. **Efficiency of fullwave rectifier :**

a) The ratio of D.C. power output to the applied input A.C. power is known as rectifier efficiency.

b) Full wave rectifier efficiency $\eta = \frac{P_{dc}}{P_{ac}} = \frac{0.812R_L}{r_f + R_L}$ where r_f - diode resistance, R_L - load resistance.

28. In full wave rectifier a maximum of 81.2% of A.C. power is converted into D.C. power.

a) maximum current $I_m = \frac{V_m}{r_f + R_L}$ where V_m = maximum voltage, r_f = internal resistance of the diode, R_L = load resistance.

b) Average current $i_{av} = \frac{2I_m}{\pi}$ where I_m = maximum current

c) rms current $i_{rms} = \frac{I_m}{\sqrt{2}}$.

d) A.C. power input $= i_{rms}^2 \, x \, (R_L + r_f)$;

e) D.C. power output $P_{dc} = (I_{dc})^2 x R_L$

29. **Advantages of Semiconductor diodes** :

a) p-n junction diodes are minute (very small in size). Therefore these are used in microcircuits.

b) As they are solid state devices, no evacuation is needed as in vacuum tubes.

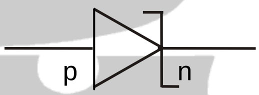
c) They are also quite strong and sturdy.

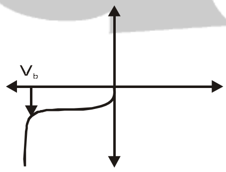
d) Usually they have long life.

e) There is no filament heating and consequent power loss.

f) These can be prepared to function over wide voltage ranges and to give very large rectified currents.

30. Zener diode :





V_b-break down voltage

a) It is a heavily doped p-n junction diode which is operated in the breakdown region in reverse bias mode.

b) Zener diode has a sharp breakdown voltage in the reverse bias because of heavy doping. This voltage is called Zener Voltage (V_Z).

c) Because of heavy doping width of the depletion layer decreases, the electric intensity in the depletion layer increases Zener breakdown is pulling the electrons from valence bonds by the action of this strong electric field.

d) In forward bias, zener diode act like an ordinary p-n junction diode.

e) Zener diode is used as a voltage regulator.

f) Output voltage (V_O)=Zener voltage (V_Z)

g) Current through load resistance (I_L)= $\frac{V_Z}{R_L}$.

h) Voltage across series resistance (V)=input voltage – zener voltage. $V=V_i-V_Z$

i) Current through series resistance (R) is $I=\frac{V}{R} = \frac{V_i - V_Z}{R}$.

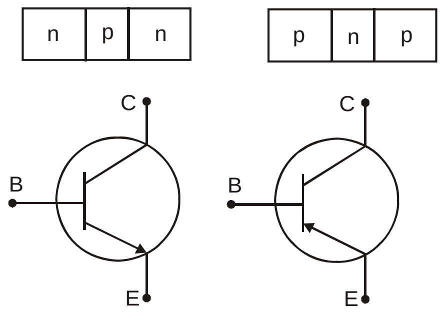
j) Current through zener diode (I_Z)=$I-I_L$.

k) Series resistance absorbs voltage fluctuations and zener diode absorbs current fluctuations.

l) The maximum reverse bias potential that can be applied before commencement of zener region is called the Peak Inverse Voltage [PIV].

31. Transistors : A transistor is formed by sandwiching a thin layer of a p-type semiconductor between two layers of n-type semiconductors or by sandwiching a thin layer of an n-type semiconductor between two layers of p-type semiconductors.

32. Transistor means “Transfer of resistance” and is invented by John Bardeen, W.H. Brattain and William Schockely in 1948.



33. Transistors are of two types i) n-p-n, ii) p-n-p

34. Transistor will mainly consists of three sections i) emitter, ii) base, iii) collector.

35. Emitter :

a) It is heavily doped to get more number of majority charge carriers.
b) Width of this region is slightly less than that of collector region.
c) Its function is to supply majority carriers to the base.

36. Base :

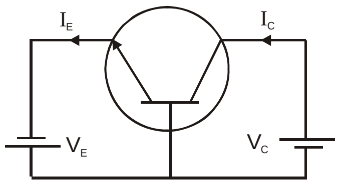
a) It is the middle section of the transistor.
b) It is slightly doped.
c) Width of this region is very thin (of the order of 10^{-6} m)
d) Its function is to inject majority carriers to the collector.

37. Collector :

a) It is moderately doped.
b) Width of this region is moderant of all regions to get large number of charge carriers.
c) Its function is to collect majority carriers from the base.
d) In a transistor emitter region and collector region cannot be interchanged.
   In a circuit p-n-p, n-p-n transistors are represented as follows :
e) In a transistor, the arrowhead should always be at the emitter base junction, which represents the direction of flow of conventional current.
f) In a transistor, emitter-base junction should be forward biased and collector-base junction should be reverse biased.
g) In an n-p-n transistor, the direction of current is from base to emitter.
h) In a p-n-p transistor, the direction of current is from emitter to base.
i) **Emitter current & Collector current :** The electrons going from the battery V_E to the emitter constitute the electric current I_E in the opposite direction. This is known as emitter current. Similarly, the electrons going from the collector to the battery V_C constitute the collector current I_C. Similarly for the holes which move in the opposite direction but result in the current in the same direction in p-n-p transistor.

Working of a transistor :

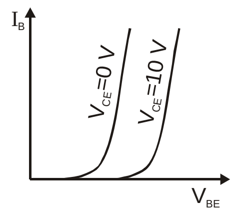
38. Consider a n-p-n transistor connected to the proper biasing. The emitter base junction is forward biased, so electrons are injected by the emitter into the base. The thickness of the base region is so small that most of the electrons diffusing into the base region cross over into the collector region. The reverse bias at the base collector junction helps this process, because as the electrons appear near this junction they are attracted by the collector. These electrons go through the batteries V_C and V_E and are then back to the emitter.



39. Cross sectional area of base is very large as compared to emitter. Cross sectional area of collector is less than base but greater than emitter.

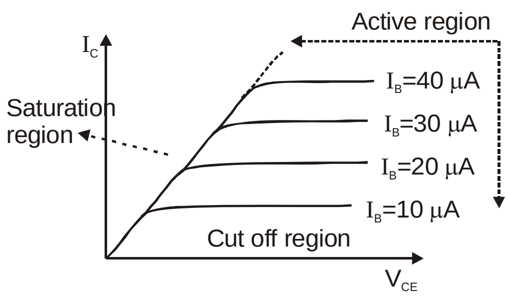
40. Transistor can be connected in three different configurations.
    i) Common base configuration
    ii) Common emitter configuration
    iii) Common collector configuration
    a) In any transistor circuit $I_E=I_B+I_C$.
    b) In common base configuration transistor, the current gain is $\alpha_{a.c} = \frac{\Delta I_C}{\Delta I_E}$.
    c) In common base configuration transistor α value is less than 1 ($\alpha<1$).
    d) The practical value of α lies between 0.95 to 0.995.
    e) In common-emitter configuration transistor, the current gain is $\beta_{a.c} = \frac{\Delta I_C}{\Delta I_B}$.
    f) The value of β is greater than one ($\beta>1$).
    g) The practical value of β lies in between 20 to 500.
    h) Relation between α, β : $\beta = \frac{\alpha}{1-\alpha}$; $\alpha = \frac{\beta}{1+\beta}$.

41. **Characteristic Curves :**
    a) For a common emitter configuration transistor, the curves showing the variation of base current (I_B) with base-emitter voltage (V_{BE}) at constant collector voltage (V_{CE}) are called as input characteristic curves.
    b) Input characteristic curve :



    c) Input resistance in CE configuration transistor is $R_i = \left(\frac{\Delta V_{BE}}{\Delta I_B}\right)_{V_{CE}}$

    d) For a common-emitter configuration transistor, the curves showing the variation of collector current (I_C) with collector-emitter voltage (V_{CE}) keeping base current (I_B) constant are called output characteristics curves.
    e) Output characteristic curve :



f) The output resistance in C-E configuration transistor is $R_o = \left(\frac{\Delta V_{CE}}{\Delta I_C}\right)_{I_B}$

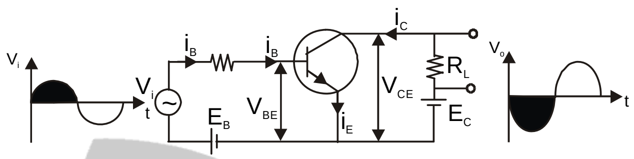
42. The collector set of characteristics has three regions of interest.

a) **Saturation region :** In this region the collector current becomes almost independent of base current. This happens when both junctions are forward biased.

b) **Cut off region :** In this region the collector current is almost zero. This happens when both junctions are reverse biased.

c) **Active region :** In this region collector current I_c is may times greater than base current (I_b). A small change in input current (ΔI_b) produces a large change in the output current (ΔI_c). This happens when emitter junction is forward biased and collector junction is reverse biased. The transistor works an amplifier when operated in the active region.

43. C-E configuration transistors are widely used as amplifiers because of its higher efficiency over the other configurations.



44. The process of raising the strength of weak signal is known as amplification and the device which accomplishes this job is called amplifier. The phenomenon of amplification is necessary in radio communication systems.

45. Figure shows an amplifier circuit using n-p-n transistor in common emitter mode. The battery E_B provides the biasing voltage (forward) V_{BE} for the base-emitter junction. The potential difference V_{CE} (reverse bias) is maintained between collector and the emitter by the battery E_C. The base - emitter junction is forward biased and so the electrons of the emitter flow towards the base. As the base region is very thin (of the order of micrometre) and the collector is also maintained at a positive potential, most of the electrons cross the base region and move into the collector. The current i_C is about $0.95i_E$ to $0.99i_E$. A small change in the current i_B in the base circuit controls the larger current i_C in the collector circuit. This is the basis of amplification with the help of a transistor.

46. The input signal, to be amplified, is connected in series with the biasing battery E_B in the base circuit and output is taken across load resistor (R_L).

47. **Current gain β :**

Current gain $\beta = \frac{\Delta i_C}{\Delta i_B}$

β lies between 20 to 500.

48. **Voltage gain A_V** : The voltage gain is the ratio of change in output voltage (ΔV_{CE}) to the change in input voltage (ΔV_{BE}).

Voltage gain $A_V = \frac{\Delta V_{CE}}{\Delta V_{BE}}$

49. **Power gain A_P** : Power gain is the ratio of output signal power to the input signal power.

A_P = current gain x voltage gain.

50. **Amplification factor A** $= \frac{e_o}{e_i}$ where e_i = input voltage, e_o = output voltage

51. The performance of a transistor amplifier depends upon input resistance, output resistance, collector load, current gain, voltage gain and power gain.

52. **Hybrid or 'h' parameters** : The performance of a transistor is usually studied with the constants of a transistor known as hybrid parameters. In the case of common emitter transistor circuit, they are defined in the following ways.

a) **Input impedance (h_{ie}) :** It is defined as the ratio of a small change in the base to emitter voltage to the corresponding change in base current when the collector voltage is kept constant.

$$h_{ie} = \left[\frac{\Delta V_{be}}{\Delta I_b}\right]_{V_{ce}}$$

Unit for h_{ie} is ohm (same as resistance).

b) **Reverse voltage ratio (h_{re}) :** It is defined as the ratio of a small change in the base to emitter voltage to the corresponding change in collector to emitter voltage keeping the base current constant.

$$h_{re} = \left[\frac{\Delta V_{be}}{\Delta V_{ce}}\right]_{I_b}$$

It is dimensionless constant.

c) **Forward current ratio (h_{fe}) :** The forward current ratio is defined as the ratio of a small change in the collector current to the corresponding change in the base current keeping the collector emitter voltage constant.

$$h_{fe} = \left[\frac{\Delta I_c}{\Delta I_b}\right]_{V_{ce}}$$

It is dimensionless constant.

d) **Output admittance (h_{oe}) :** The output admittance is defined as the ratio of a small change in the collector current to the corresponding small change in the collector emitter voltage keeping the base current constant.

$$h_{oe} = \left[\frac{\Delta I_c}{\Delta V_{ce}}\right]_{I_b}$$

Unit for h_{oe} is siemen.

These parameters can be calculated from the characteristic curves of a transistor. In the above notation, the first subscript indicates the nature of parameter and second subscript indicates the type of the circuit.

53. Transistors are heat-sensitive.

54. Transistors can be used as oscillators, electronic switches in computers and also in other circuits.

Comparative study of CB, CE and CC Amplifiers

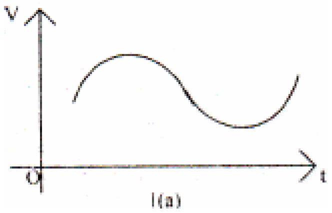
Parameter	CB Amplifier	CE Amplifier	CC Amplifier
1. Input Resistance	Minimum (50 – 200KΩ)	Less (1-2KΩ)	Maximum (150 – 800KΩ)
2. Output Voltage	Maximum (1-2MΩ)	More (5-50KΩ)	Minimum (1KΩ)
3. Current gain	Minimum	More (5-50KΩ)	Minimum (1KΩ)
4.Voltage gain	Medium	High	Minimum
5. Power gain	Medium (20-30)	Maximum (30-40)	Minimum (10)
6. Phase reversal	No	Yes	No

55. Logic Gates

1. The electronic circuits are of two types. They are analog and digital circuits.
2. Analog circuits:

   The waveforms are continuous and a range of values of voltages are possible

   ex: amplifier, oscillator circuits.

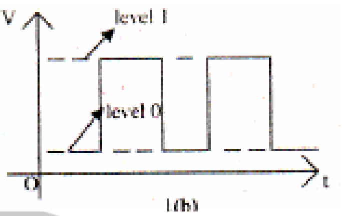


I(a)

3. Digital circuits

   The waveforms are pulsated and only descrete values of voltages are possible.

   ex: logic gates

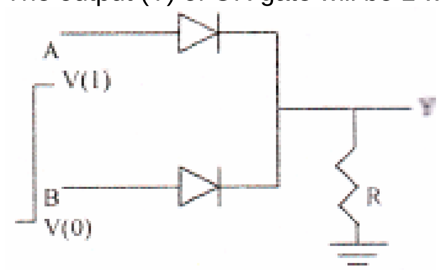


I(b)

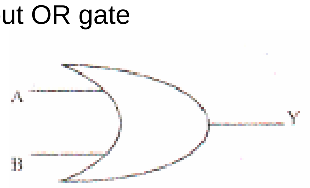
4. In the decimal system, there are ten digits. They are 0,1,2,3,4,5,6,7,8,9.
5. In the binary system, there are only two digits 0 and 1.
6. Digital electronics is devloped by representing the low and high levels of voltages in pulsated waveform with binary digits 0 and 1 (called bits).
7. The basic building blocks of digital circuits are called as logic gates, since they perform logic operations.
8. Generally the level 1 or high level is at $4 \pm 1V$ and level 0 or low level is at $0.2 \pm 0.2V$.

ORGATE

1. An OR gate has two or more inputs with one output.
2. The Boolean expression is Y = A+B.
3. The output (Y) of OR gate will be 1 when the inputs A or B or both 1.



a) two input OR gate



A	B	Y
0	0	0
0	1	1
1	0	1
1	1	1

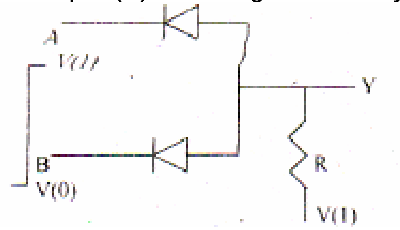
b) circuit symbol c) truth table

AND GATE

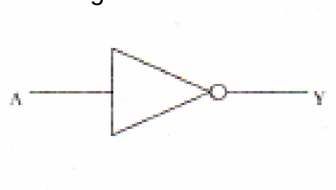
1. An AND gate has two or more inputs with one output.
2. The Boolean expression is Y=A.B.

(Y equals A and B)

3. The output (Y) of AND gate is 1 only when all the inputs are simultaneously 1.



a) two input AND gate



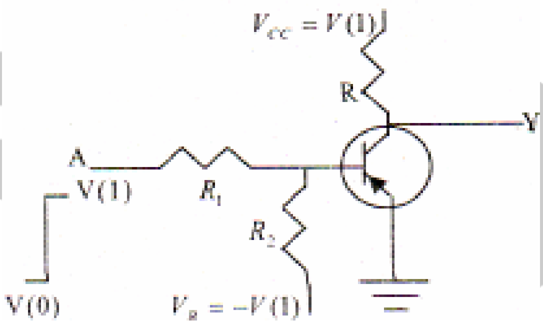
A	Y
0	1
1	0

b) circuit symbol c) truth table

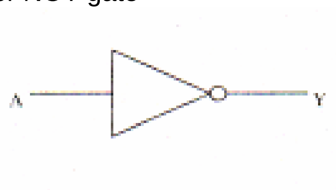
NOT GATE

1. It has a single input and a single output.
2. The Boolean expression is $Y = \overline{A}$.

   (Y equals not A)
3. The output of NOT gate is the inverse of the input or it performs nagation operation



a) Trasistor NOT gate



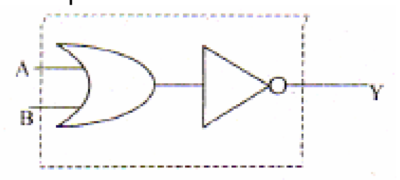
A	Y
0	1
1	0

b) circuit symbol c) truth table

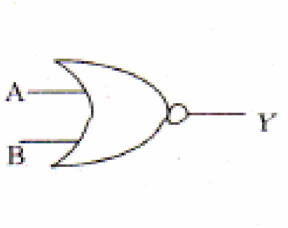
NOR GATE

1. It has two or more inputs and one output. A negation (NOT operation) applied after OR gate, gives a NOT-OR gate or simply NOR gate.
2. NOR gate output is inverse of OR gate output.

   The output of NOR gate is 1 only when all the inputs are simultaneously 0.
3. The Boolean expression is $Y = \overline{A+B}$.



a) two input NOR gate

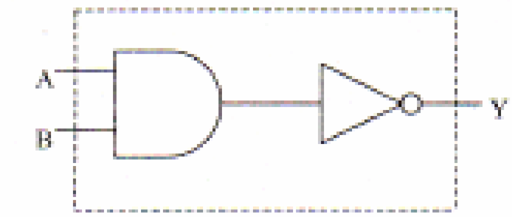


A	B	Y
0	0	1
0	1	0
1	0	0
1	1	0

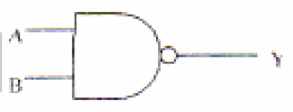
b) circuit symbol c) truth table

NAND GATE

1. It has two or more inputs and one output. A negation (NOT operation) applied after AND gate, gives a NOT-AND gate.
2. NAND gate output is inverse of AND gate output.
3. The Boolean expression is $Y = \overline{A.B}$.
4. The output of NAND gate is 1 only when atleast one input is 0.
5. The NOR and NAND gates are considered as universal gates, because we can obtain all the gates like OR, AND and NOT by using either NOR or NAND gaes repeatedly.



a) two input NAND gate

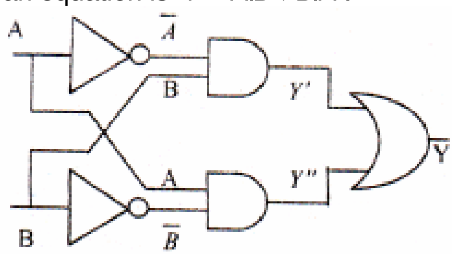


A	B	Y
0	0	1
0	1	1
1	0	1
1	1	0

b) circuit symbol c) truth table

XOR GATE

1. XOR gate is obtained by using OR, AND and NOT gates.
2. The output of a two input XOR gate is 1 only when the two inputs are different.
3. The Boolean equation is $Y = A.\overline{B} + B.\overline{A}$.



a) two input XOR gate

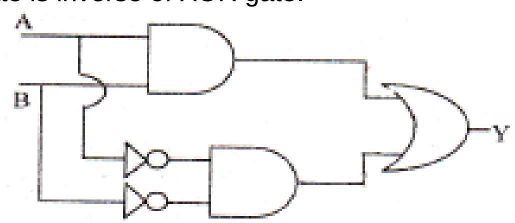
A	B	Y
0	0	0
0	1	1
1	0	1
1	1	0

b) circuit symbol c) truth table

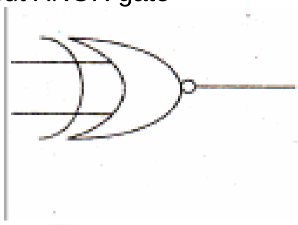
XNOR GATE

1. XNOR gate is obtained by using OR, AND and NOT gates.
2. It is also called exclusive NOR gate.
3. The output of a two input XNOr gate is 1 only when both the inputs are same.
4. The Boolean equation is $Y = A.B + \bar{A}.\bar{B}$.

XNOR gate is inverse of XOR gate.



a) two input XNOR gate



A	B	Y
0	0	1
0	1	0
1	0	0
1	1	1

b) circuit symbol c) truth table

The basic relations for OR gate.

i) A +0 = A ii) A +1 =1

iii) A +A = A iv) A+ $\bar{A}$ =1

The basic relations for AND gate.

i) A . 0 = 0 ii) A .1 = A

iii) A . A = A iv) A. $\bar{A}$ =0

De-Morgan's Theorems

i) $\overline{A + B} = \bar{A}.\bar{B}$ ii) $\overline{A.B} = \bar{A} + \bar{B}$

iii) $\bar{\bar{A}} + \bar{\bar{B}} = \bar{\bar{A}} + \bar{\bar{B}}$ iv) $\bar{\bar{A}}.\bar{\bar{B}} = \bar{\bar{A}} + \bar{\bar{B}} = A + B$

Example : Verification of theorems with truth table