BASIC ELECTRICAL & ELECTRONICS ENGINEERING
(23HES0201)

ANNAMACHARYA
INSTITUTE OF TECHNOLOGY AND SCIENCES
(AUTONOMOUS)
KADAPA

BASIC ELECTRICAL & ELECTRONICS ENGINEERING

(Common to All branches of Engineering)

PART A: BASIC ELECTRICAL ENGINEERING

UNIT I DC & AC Circuits

DC Circuits: Electrical circuit elements (R, L and C) – Ohm's Law and its limitations – Kirchhoff's Voltage Law (KVL) – Kirchhoff's Current Law (KCL) – Simple Numerical Problems to determine Equivalent Resistance in series, parallel, series-parallel circuits – DC Voltage Source – DC Current Source.

AC Circuits: Equations of AC Voltage and AC Current –Waveform – Cycle – Time Period – Frequency – Amplitude – Phase – Phase Difference – Maximum Value, Average Value, RMS Value, Form Factor, Peak Factor of Sine Waveform – Simple Numerical Problems – Definitions of Impedance, Active Power, Reactive Power, Apparent Power and Power Factor – Voltage and Current relationship along with phasor diagrams in Pure Resistance, Pure Inductance and Pure Capacitance Circuits.

UNIT II Machines and Measuring Instruments

Machines: Construction, Principle and Operation of (i) DC Motor (ii) DC Generator (iii) Single Phase Transformer (iv) Three Phase Induction Motor (v) Alternator – Applications of Electrical Machines.

Measuring Instruments: Construction and Working Principle of Permanent Magnet Moving Coil (PMMC) and Moving Iron (MI) Instruments – Wheat Stone Bridge.

UNIT III Energy Resources, Electricity Bill & Safety Measures

Energy Resources: Conventional and non-conventional energy resources; Layout and operation of various Power Generation systems: Hydel, Nuclear, Solar & Wind power generation.

Electricity bill: Power rating of household appliances including air conditioners, PCs, Laptops, Printers, etc. Definition of “unit” used for consumption of electrical energy, two- part electricity tariff, calculation of electricity bill for domestic consumers.

Equipment Safety Measures: Working principle of Fuse and Miniature circuit breaker (MCB), merits and demerits. Personal safety measures: Electric Shock, Earthing and its types, Safety Precautions to avoid shock.

Textbooks:

1. Basic Electrical Engineering, D. C. Kulshreshtha, Tata McGraw Hill, 2019,First Edition
2. Power System Engineering, P.V. Gupta, M.L. Soni, U.S. Bhatnagar and A.Chakrabarti,Dhanpat Rai & Co, 2013
3. Fundamentals of Electrical Engineering, Rajendra Prasad, PHI publishers, 2014,Third Edition

PART B: BASIC ELECTRONICS ENGINEERING

UNIT I SEMICONDUCTOR DEVICES

Introduction - Evolution of electronics – Vacuum tubes to nano electronics -Characteristics of PN Junction Diode — Zener effect — Zener Diode and its Characteristics
Diode Applications: Diode as clipper Diode as clamper, Bipolar Junction Transistor input and output characteristics of CB, CE, & CC Configurations.

UNIT II BASIC ELECTRONIC CIRCUITS AND INSTRUMENTATION

Rectifiers and power supplies: Block diagram description of a dc power supply, working ofa full wave bridge rectifier, capacitor filter (no analysis), working of simple zener voltage regulator. Amplifiers: Block diagram of Public Address system, Circuit diagram and working of common emitter (RC coupled) amplifier with its frequency response. Concept of Voltage divider biasing. Operational Amplifier: Block diagram of Op-Amp.

Inverting and non inverting. Pin configuration of IC 741.

UNIT III DIGITAL ELECTRONICS

Overview of Number Systems, Logic gates including Universal Gates, BCD codes, Excess-3 code, Gray code, Hamming code. Boolean Algebra, Basic Theorems and properties of Boolean Algebra, Truth Tables and Functionality of Logic Gates – NOT, OR, AND, NOR, NAND, XOR and XNOR. Simple combinational circuits–Half Adder and Full Adder, Introduction to sequential circuits, Flip flops, Registers and counters (Elementary Treatment only)

Textbooks:

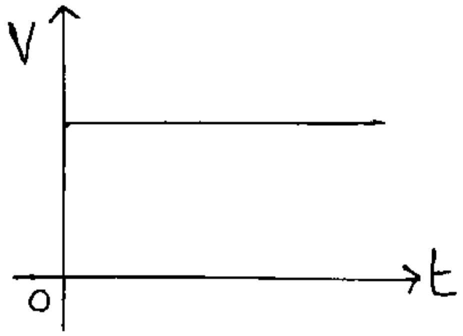
1. R. L. Boylestad & Louis Nashlesky, Electronic Devices & Circuit Theory,Pearson Education, 2021.
2. R. P. Jain, Modern Digital Electronics, 4th Edition, Tata Mc Graw Hill, 2009

UNIT – 1 CHAPTER – 1 DC Circuits

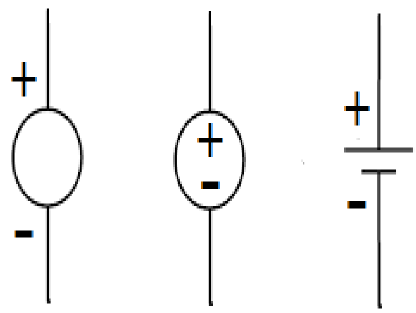
DC Voltage Source
DC Current Source
Ohm's Law
Resistor & Resistance
Inductor & Inductance
Capacitor & Capacitance
Kirchhoff's Voltage Law (KVL)
Kirchhoff's Current Law (KCL)
Network Reduction

DC Voltage Source:

- DC Voltage Source is a Voltage Source which has constant magnitude at any instant of time.



Characteristics

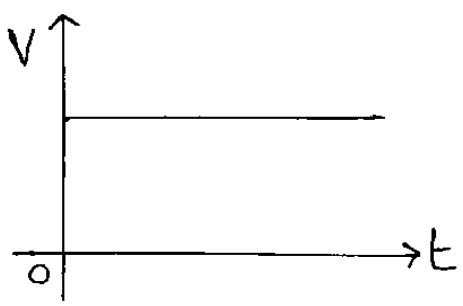


Representation

- DC Voltage Source is of two types.
  (i) Ideal DC Voltage Source (ii) Practical DC Voltage Source

(i) Ideal DC Voltage Source:

Ideal DC Voltage Source is a DC Voltage Source which has no internal resistance and it supplies the voltage which is equal to the actual voltage value.



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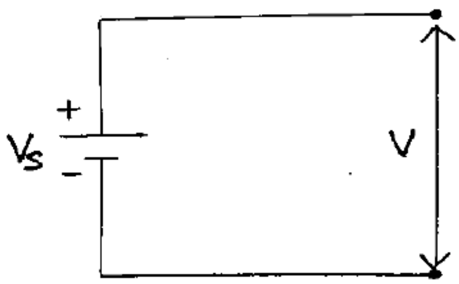
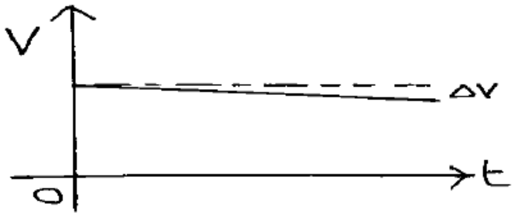


$V = V_S$

(ii) Practical DC Voltage Source:

Practical DC Voltage Source is a DC Voltage Source which has some internal resistance and it supplies the voltage which is less than the actual voltage value.



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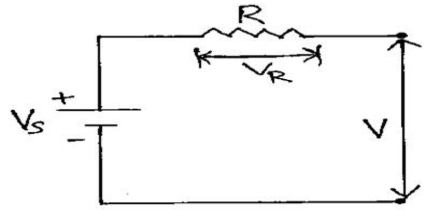
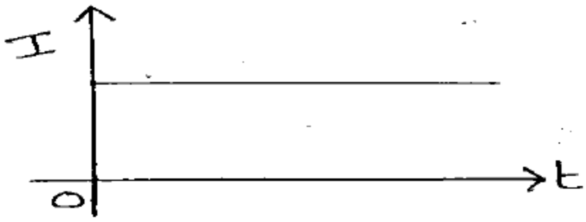


$V = V_S - V_R$

DC Current Source:

- DC Current Source is a Current Source which has constant magnitude at any instant of time.



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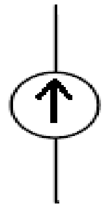
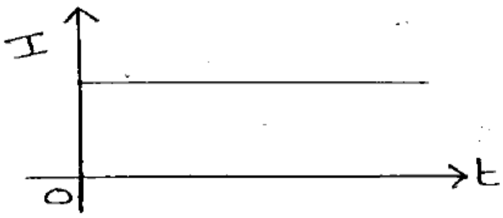


Representation

- DC Current Source is of two types.
  (i) Ideal DC Current Source (ii) Practical DC Current Source

(i) Ideal DC Current Source:

Ideal DC Current Source is a DC Current Source which has no internal resistance and it supplies the current which is equal to the actual current value.



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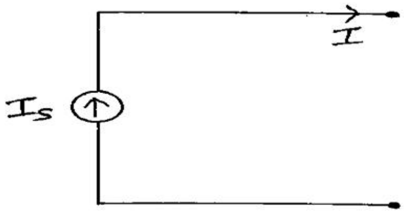
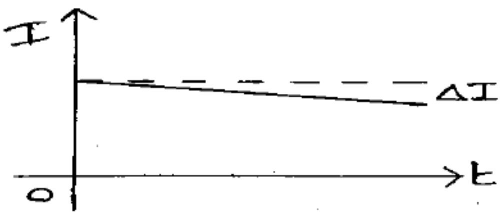


$I = I_S$

(ii) Practical DC Current Source:

Practical DC Current Source is a DC Current Source which has some internal resistance and it supplies the current which is less than the actual current value.



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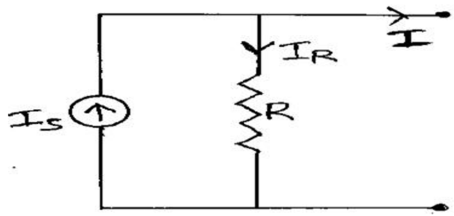


$I = I_S - I_R$

Ohm’s Law:

- Ohm’s Law states that the Current passing through a conductor is directly proportional to the Potential Difference or Voltage between the two ends of the conductor, when the Temperature, Pressure and other Physical Parameters of the conductor remains constant or unchanged.

$$I \propto V$$

$$\implies I = G * V$$

$$\implies I = \frac{1}{R} * V$$

$$\implies V = IR$$

Here, V = Voltage
I = Current
R = Resistance
G = Conductance

- Georg Simon Ohm, a Physicist and Mathematician from Germany proposed the Ohm’s Law in the year 1827.

- For any conductor, $R = \frac{\rho L}{A}$

Here, R = Resistance of the Conductor
ρ = Resistivity or Specific Resistance of the Conductor
L = Length of the Conductor
A = Area of Cross-Section of the Conductor

- Parameters which are assumed to be constant while defining Ohm’s Law are
  - Temperature
  - Pressure
  - Physical Parameters
    - Length of the Conductor
    - Area of Cross-Section of the Conductor

- Limitations of Ohm’s Law are
  - It is not applicable when the Temperature is changed.
  - It is not applicable when the Pressure is changed.
  - It is not applicable when the Physical Parameters are changed (Length of the Conductor and Area of Cross-Section of the Conductor).

Resistor and Resistance:

- Resistor is an electrical device which controls the flow of current and allows the required amount of current in an electrical circuit.

- In electrical circuits, the Resistor will be represented as

- Resistance is the property of Resistor.

- Resistance is denoted by R.

- The unit of Resistance is Ohm (Ω).

- Ohm was named as the unit of Resistance in the honour of Georg Simon Ohm, a Physicist and Mathematician from Germany.

- Resistance can be measured with Ohmmeter.

- According to Ohm's Law, the Current passing through a conductor is directly proportional to the Potential Difference or Voltage between the two ends of the conductor, when the Temperature, Pressure and other Physical Parameters of the conductor remains constant or unchanged.

$$I \propto V$$

$$\Longrightarrow \quad I = G * V$$

$$\Longrightarrow \quad I = \frac{1}{R} * V$$

$$\Longrightarrow \quad V = IR$$

Here, V = Voltage

I = Current

R = Resistance

G = Conductance

- For any conductor, $R = \frac{\rho L}{A}$

  Here, R = Resistance of the Conductor

  ρ = Resistivity or Specific Resistance of the Conductor

  L = Length of the Conductor

  A = Area of Cross-Section of the Conductor

- The Power absorbed by the Resistor will be dissipated in the form of Heat.
- In Electrical Circuits, Wire Wound Resistors are used. Wire Wound Resistor consists of a Metal Wire (made up of Nickel and Chromium Alloy) wound on Tube (made up of Ceramic or Fiber Glass).
- In Electronic Circuits, Carbon Resistors are used. Carbon Resistor consists of a Carbon Film placed around a Ceramic Rod.

Problem: Determine the specific resistance of a metal wire of 2m length and 0.6mm diameter, if the resistance of the wire is 50Ω.

Solution:

Given Data,

Length = L = 2 m

Diameter = d = 0.6 mm = $(0.6 * 10^{-3})$ m

Resistance = R = 50 Ω

Radius $r = \frac{d}{2} = \frac{(0.6 * 10^{-3})}{2} = (0.3 * 10^{-3})$ m

Area of Cross-Section $A = \pi r^2 = 3.14 * (0.3 * 10^{-3})^2 = (0.28 * 10^{-6})\ m^2$

Resistance $R = \frac{\rho L}{A}$

==> $50 = \frac{\rho * 2}{(0.28 * 10^{-6})}$

==> $\rho = (7 * 10^{6})$

∴ Specific Resistance $\rho = (7 * 10^{6})$ Ω - m

Inductor and Inductance:

- Inductor is an electrical device which stores Electrical Energy in the form of Magnetic Field, when the current passes through it in an electrical circuit.
- In electrical circuits, the Inductor will be represented as 
- Inductance is the property of Inductor.
- Inductance is denoted by L.
- The unit of Inductance is Henry (H).
- Henry was named as the unit of Inductance in the honour of Joseph Henry, a Scientist from America.
- Inductance can be measured with LCR Meter.
- Inductor is also called as Coil, Choke.
- Inductor consists of a Conducting Material (Copper Wire) wound on a Magnetic Material (Iron or Silicon-Steel).
- According to Faraday's Law of Electro Magnetic Induction, the Voltage across an Inductor is directly proportional to the rate of change of Current passing through the Inductor.

$$V \propto \frac{dI}{dt} \quad ==> \quad V = L\,\frac{dI}{dt} \quad ==> \quad I = \frac{1}{L}\int V\,dt$$

$\therefore$ Voltage across Inductor is $\quad V = L\,\frac{dI}{dt}$

$\therefore$ Current flowing through Inductor is $\quad I = \frac{1}{L}\int V\,dt$

- Power $\quad P = VI \quad ==> \quad P = L\,\frac{dI}{dt}\,I \quad ==> \quad P = LI\,\frac{dI}{dt}$

- Power $= \frac{\text{Energy}}{\text{Time}} \quad ==> \quad P = \frac{E}{t}$

$$==> \quad P = \frac{dE}{dt}$$

$$==> \quad \int P = \int \frac{dE}{dt}$$

$$==> \quad \int LI\,\frac{dI}{dt} = \int \frac{dE}{dt}$$

$$==> \quad \int LI\,dI = \int dE$$

$$==> \quad \int dE = \int LI\,dI$$

$$==> \quad \int dE = L\int I\,dI$$

$$==> \quad E = L\frac{I^2}{2}$$

$$==> \quad E = \frac{LI^2}{2}$$

$$==> \quad E = \frac{1}{2}\,LI^2$$

∴ Energy stored in Inductor $E = \frac{1}{2}\,LI^2$

Problem: Find the energy stored in an inductor which has 10mH inductance when a current of 2A is passing through it.

Solution:

Given Data,

Inductance = L = 10 mH = $(10 * 10^{-3})$ H

Current = I = 2 A

Energy stored in Inductor is

$$E = \frac{1}{2}\,LI^2 = \frac{1}{2} * (10 * 10^{-3}) * (2)^2 = 0.02 \text{ Joules}$$

∴ E = 0.02 J

Problem: If 150 coulombs of charge is supplied to an inductor of 8H in 10 seconds, then find (i) Current passing through inductor (ii) Energy stored in inductor.

Solution:

Given Data,

Charge = Q = 150 C

Inductance = L = 8 H

Time = t = 10 seconds

Current passing through inductor is

$$I = \frac{Q}{t} = \frac{150}{10} = 15 \text{ Amperes}$$

∴ I = 15A

Energy stored in Inductor is

$$E = \frac{1}{2}\,LI^2 = \frac{1}{2} * (8) * (15)^2 = 900 \text{ Joules}$$

∴ E = 900 J

Capacitor and Capacitance:

- Capacitor is an electrical device which stores Electrical Energy in the form of Electric Field, when the current passes through it in an electrical circuit.
- In electrical circuits, the Capacitor will be represented as 
- Capacitance is the property of Capacitor.
- Capacitance is denoted by C.
- The unit of Capacitance is Farad (F).
- Farad was named as the unit of Capacitance in the honour of Michael Faraday, a Scientist from England.
- Capacitance can be measured with LCR Meter.
- Capacitor is also called as Condenser.
- Capacitor consists of two parallel plates or electrical conductors (made up of Aluminium or Brass or Copper etc.) separated by insulating material or dielectric material (Air or Glass or Plastic or Paper etc.).
- According to Faraday's Law and Coulomb's Law, the Charge in a Capacitor is directly proportional to the Voltage across the Capacitor.

  $$Q \propto V \quad ==> \quad Q = CV \quad ==> \quad C = \frac{Q}{V}$$

  Current passing through Capacitor is

  $$I = \frac{Q}{t} \quad ==> \quad I = \frac{dQ}{dt} \quad ==> \quad I = \frac{d}{dt}(Q)$$

  $$==> \quad I = \frac{d}{dt}(CV) \quad ==> \quad I = C\frac{d}{dt}(V) \quad ==> \quad I = C\frac{dV}{dt}$$

  $\therefore$ Current passing through Capacitor is $I = C\frac{dV}{dt}$

  $\therefore$ Voltage across Capacitor is $V = \frac{1}{C} \int I \, dt$

- Power $P = VI \quad ==> \quad P = V\,C\,\frac{dV}{dt} \quad ==> \quad P = CV\,\frac{dV}{dt}$
- $\text{Power} = \frac{\text{Energy}}{\text{Time}} \quad ==> \quad P = \frac{E}{t}$

  $$==> \quad P = \frac{dE}{dt}$$

  $$==> \quad \int P = \int \frac{dE}{dt}$$

  $$==> \quad \int CV\,\frac{dV}{dt} = \int \frac{dE}{dt}$$

$$\Longrightarrow \quad \int CV\, dV = \int dE$$

$$\Longrightarrow \quad \int dE = \int CV\, dV$$

$$\Longrightarrow \quad \int dE = C \int V\, dV$$

$$\Longrightarrow \quad E = C\frac{V^2}{2}$$

$$\Longrightarrow \quad E = \frac{CV^2}{2}$$

$$\Longrightarrow \quad E = \frac{1}{2}\, CV^2$$

∴ Energy stored in Capacitor $E = \frac{1}{2}\, CV^2$

Problem: Find the energy stored in a capacitor which has 10μF capacitance when a voltage of 20V is applied across it.

Solution:

Given Data,

Capacitance = C = 10 μF = $(10 * 10^{-6})$ F

Voltage = V = 20 V

Energy stored in Capacitor is

$$E = \frac{1}{2}\, CV^2 = \frac{1}{2} * (10 * 10^{-6}) * (20)^2 = (2 * 10^{-3}) = 2 \text{ Milli Joules}$$

∴ E = 2 mJ

Problem: A charge of 400C is supplied to a capacitor of 60F by applying the energy. Find Voltage across capacitor and Energy stored in capacitor.

Solution:

Given Data,

Charge = Q = 400 C

Capacitance = C = 60 F

Voltage across Capacitor is

$$V = \frac{Q}{C} = \frac{400}{60} = 6.67 \text{ Volts}$$

∴ V = 6.67 Volts

Energy stored in Capacitor is

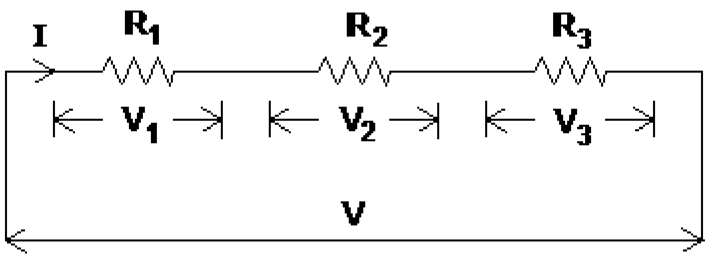
$$E = \frac{1}{2}\, CV^2 = \frac{1}{2} * (60) * (6.67)^2 = 1335 \text{ Joules}$$

∴ E = 1335 Joules

Kirchhoff 's Voltage Law (KVL):

- Kirchhoff's Voltage Law states that the algebraic sum of voltages in a closed circuit is zero. $\Sigma V = 0$

- Kirchhoff's Voltage Law states that the sum of voltage gains is equal to the sum of voltage drops in a closed circuit. $V = V_1 + V_2 + V_3$



In the above circuit, Voltage Gain is V and Voltage Drops are V_1, V_2, V_3.

- In a resistor, $V = IR$

  $V_1 = IR_1$

  $V_2 = IR_2$

  $V_3 = IR_3$

- According to KVL, the sum of voltage gains is equal to the sum of voltage drops

  $V = V_1 + V_2 + V_3$

  ==> $IR = IR_1 + IR_2 + IR_3$

  ==> $R = R_1 + R_2 + R_3$

  Here, R is the equivalent resistance (R_{eq}).

- Example:

  $R_1 = 10\ \Omega$, $R_2 = 20\ \Omega$, $R_3 = 30\ \Omega$

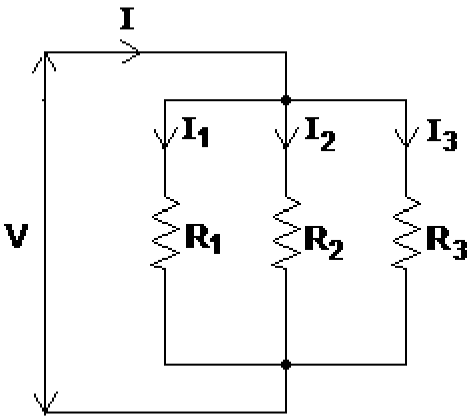
  $R = R_1 + R_2 + R_3 = 10 + 20 + 30 = 60\ \Omega$

.

- The applications of Kirchhoff's Voltage Law (KVL) are
  - KVL is used in DC Circuits and AC Circuits.
  - KVL is used for calculation of Voltage and Current in any circuit.
  - KVL is used Mesh Analysis.

Kirchhoff 's Current Law (KCL):

- Kirchhoff's Current Law states that the algebraic sum of currents at a junction or node is zero. $\Sigma I = 0$
- Kirchhoff's Current Law states that the sum of currents entering is equal to the sum of currents leaving at a junction or node. $I = I_1 + I_2 + I_3$



In the above circuit, entering current is I and leaving currents are I_1, I_2, I_3.

- In a resistor, $I = \frac{V}{R}$ $\therefore$ $I_1 = \frac{V}{R_1}$ $I_2 = \frac{V}{R_2}$ $I_3 = \frac{V}{R_3}$

- According to KCL, the sum of currents entering is equal to the sum of currents leaving.

$$I = I_1 + I_2 + I_3$$

$$\Longrightarrow \frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$\Longrightarrow \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Here, R is the equivalent resistance (R_{eq}).

- Example: $R_1 = 10\ \Omega$, $R_2 = 20\ \Omega$, $R_3 = 30\ \Omega$

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \Longrightarrow \frac{1}{R} = \frac{1}{10} + \frac{1}{20} + \frac{1}{30} = 0.1 + 0.05 + 0.033 = 0.183$$

$$\Longrightarrow R = \frac{1}{0.183} = 5.46 \qquad \therefore R = 5.46\ \Omega$$

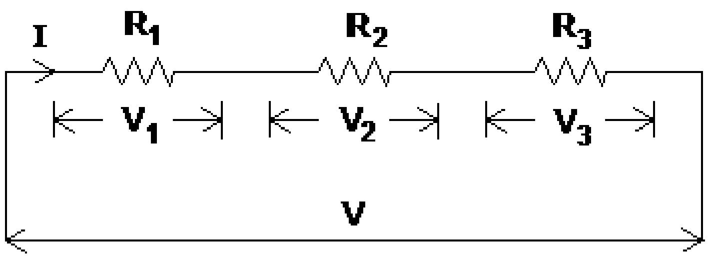
- The applications of Kirchhoff's Current Law (KCL) are
  - KCL is used in DC Circuits and AC Circuits.
  - KCL is used for calculation of Voltage and Current in any circuit.
  - KCL is used Nodal Analysis.

Network Reduction

Problem: Draw the circuit diagrams and determine the equivalent resistance when three resistors 10Ω, 20Ω and 30Ω are connected in (i) Series with each other (ii) Parallel with each other

Solution:

(i) Series Connection

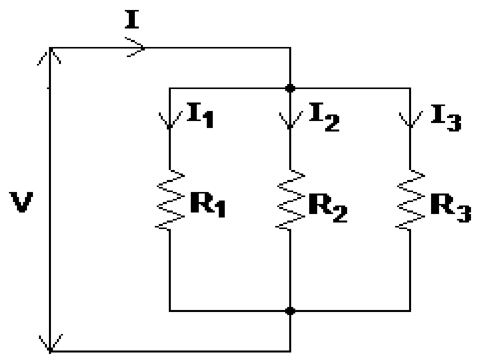


$R_1 = 10\ \Omega$, $R_2 = 20\ \Omega$, $R_3 = 30\ \Omega$

Equivalent Resistance = R = ?

$R = R_1 + R_2 + R_3 = 10 + 20 + 30 = 60\ \Omega$

(ii) Parallel connection



$R_1 = 10\ \Omega$, $R_2 = 20\ \Omega$, $R_3 = 30\ \Omega$

Equivalent Resistance = R = ?

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

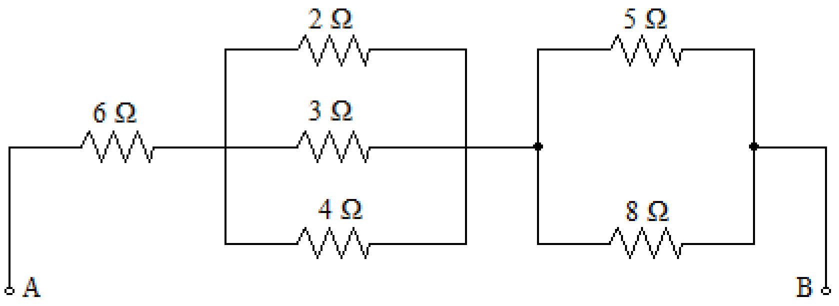
==> $\frac{1}{R} = \frac{1}{10} + \frac{1}{20} + \frac{1}{30} = 0.1 + 0.05 + 0.033 = 0.183$

==> $\frac{1}{R} = 0.183$

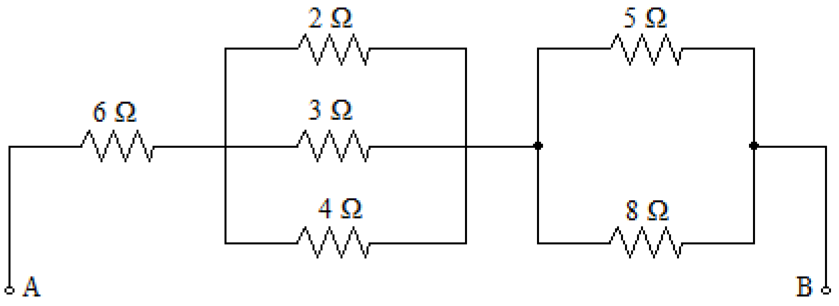
==> $R = \frac{1}{0.183} = 5.46$

$\therefore\ R = 5.46\ \Omega$

Problem: Find the equivalent Resistance between the terminals A and B



Solution:



Resistors 2Ω, 3Ω, 4Ω are in parallel

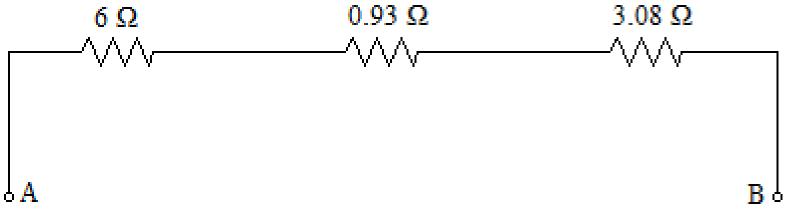
$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{2} + \frac{1}{3} + \frac{1}{4} = 1.08$$

R = 0.93Ω

Resistors 5Ω, 8Ω are in parallel

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{5} + \frac{1}{8} = 0.325$$

R = 3.08Ω

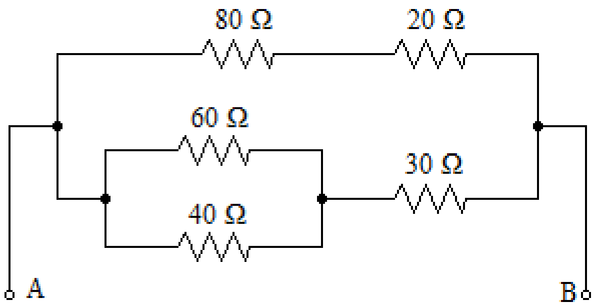


Resistors 6Ω, 0.93Ω, 3.08Ω are in series

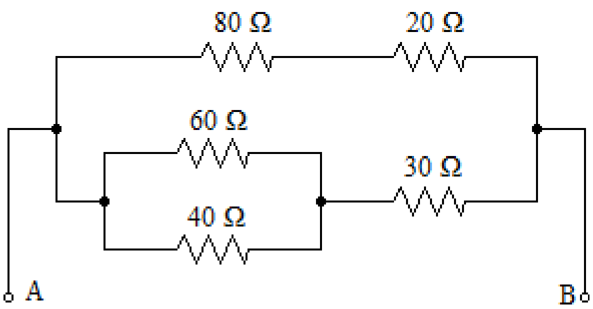
$R = R_1 + R_2 + R_3 = 6 + 0.93 + 3.08 = 10.01$

∴ **R = 10.01 Ω**

Problem: Find the equivalent Resistance between the terminals A and B



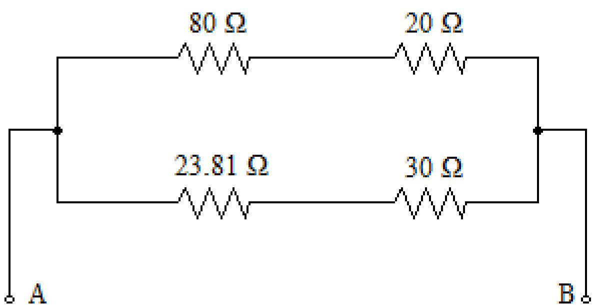
Solution:



Resistors 60Ω, 40Ω are in parallel

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{60} + \frac{1}{40} = 0.042$$

$R = 23.81\Omega$

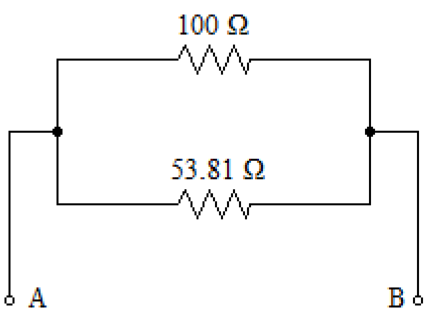


Resistors 80Ω, 20Ω are in series

$R = R_1 + R_2 = 80 + 20 = 100\Omega$

Resistors 23.81Ω, 30Ω are in series

$R = R_1 + R_2 = 23.81 + 30 = 53.81\Omega$

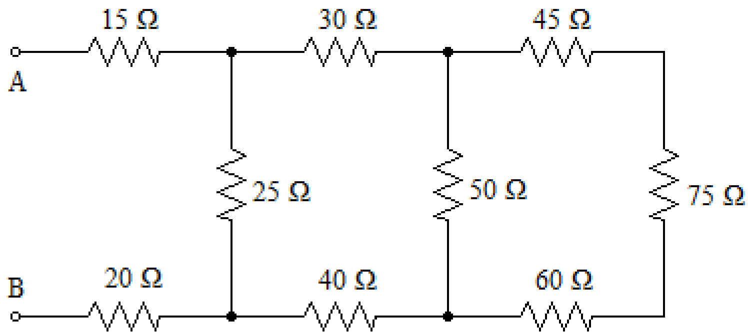


Resistors 100Ω, 53.81Ω are in parallel

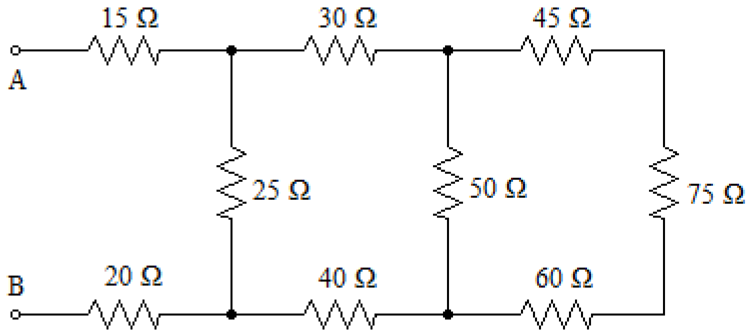
$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{100} + \frac{1}{53.81} = 0.029$$

$\therefore$ **R = 34.48Ω**

Problem: Find the equivalent Resistance between the terminals A and B

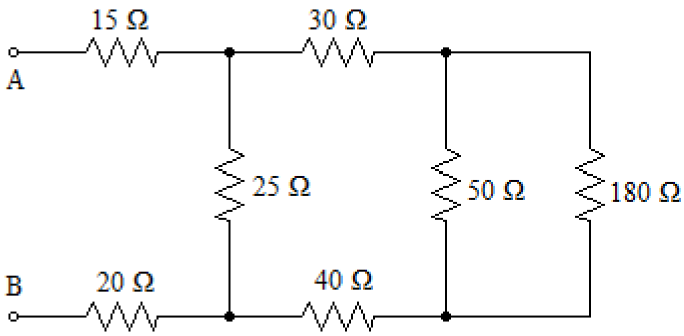


Solution:



Resistors 45Ω, 75Ω, 60Ω are in series

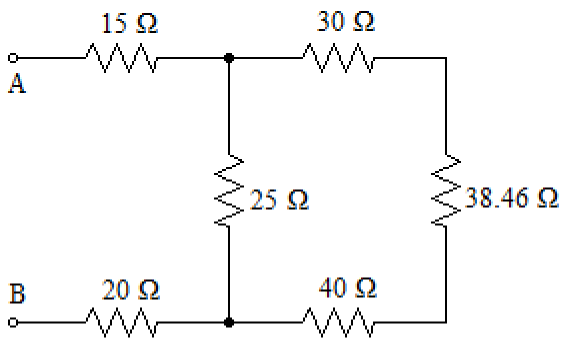
$R = R_1 + R_2 + R_3 = 45 + 75 + 60 = 180\Omega$



Resistors 50Ω, 180Ω are in parallel

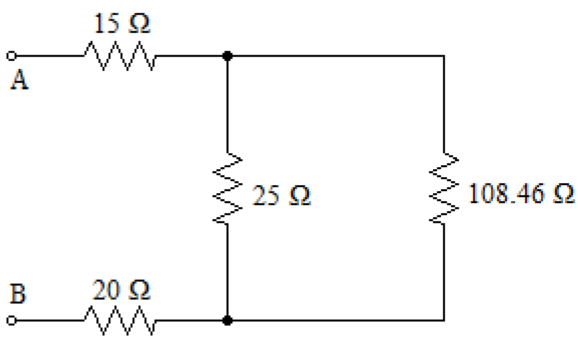
$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{50} + \frac{1}{180} = 0.026$$

$R = 38.46\Omega$



Resistors 30Ω, 38.46Ω, 40Ω are in series

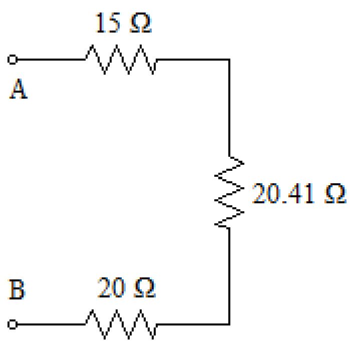
$R = R_1+R_2+R_3 = 30 + 38.46 + 40 = 108.46\Omega$



Resistors 25Ω, 108.46Ω are in parallel

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{25} + \frac{1}{108.46} = 0.049$$

$R = 20.41\Omega$



Resistors 15Ω, 20.41Ω, 20Ω are in series

$R = R_1 + R_2 + R_3 = 15+20.41+20 = 55.41$

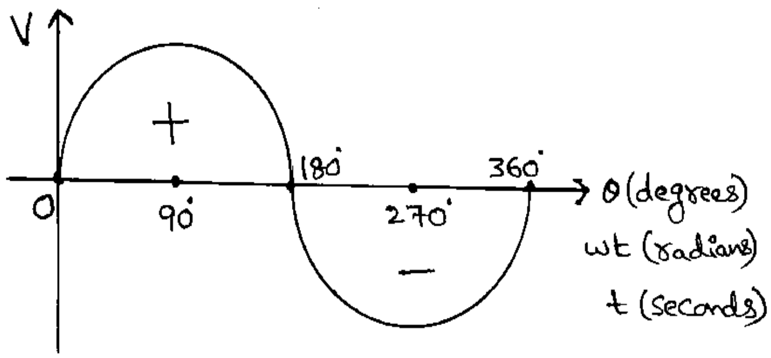
$\therefore$ **R = 55.41Ω**

UNIT – 1 CHAPTER – 2 AC Circuits

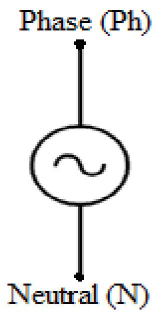
AC Voltage Source, AC Current Source
Types of AC Waveforms
Cycle, Time Period and Frequency
Maximum Value, Average Value and RMS Value
Peak Factor and Form Factor
Amplitude, Phase and Phase Difference
Power Factor, Active Power, Reactive Power and Apparent Power
Impedance, Inductive Reactance and Capacitive Reactance
Behaviour of Pure Resistance to AC Supply
Behaviour of Pure Inductance to AC Supply
Behaviour of Pire Capacitance to AC Supply

AC Voltage Source:

- AC Voltage Source is a Voltage Source whose magnitude and direction changes with respect to time.



Waveform

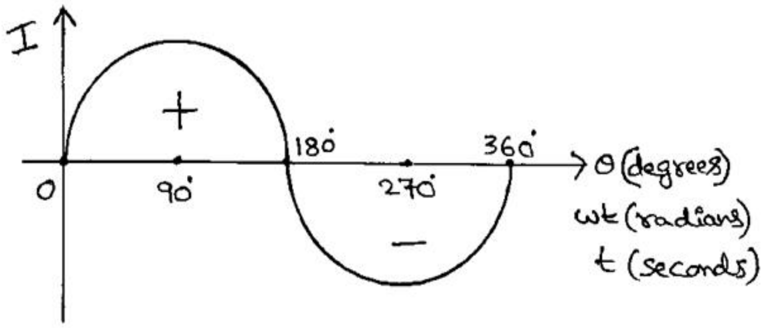


Representation

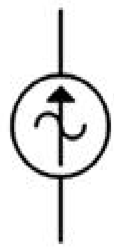
The equation for AC Voltage Source is $V = V_m \, Sin\,(wt)$ or $V = V_m \, Sin\theta$

AC Current Source:

- AC Current Source is a Current Source whose magnitude and direction changes with respect to time.



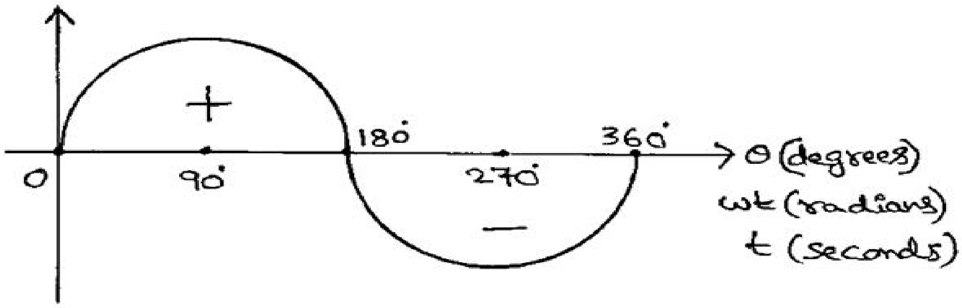
Waveform



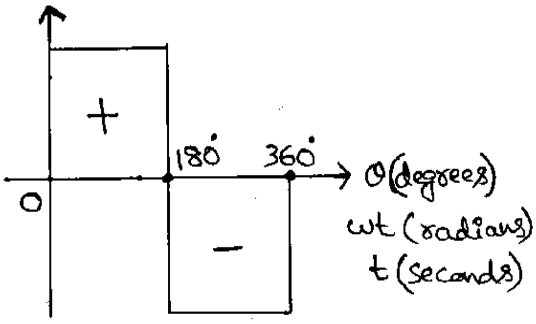
Representation

The equation for AC Current Source is $I = I_m \, Sin\,(wt)$ or $I = I_m \, Sin\theta$

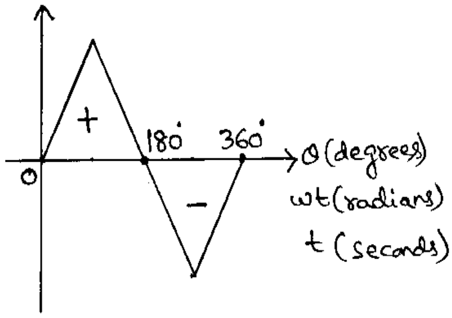
Types of AC Waveforms:



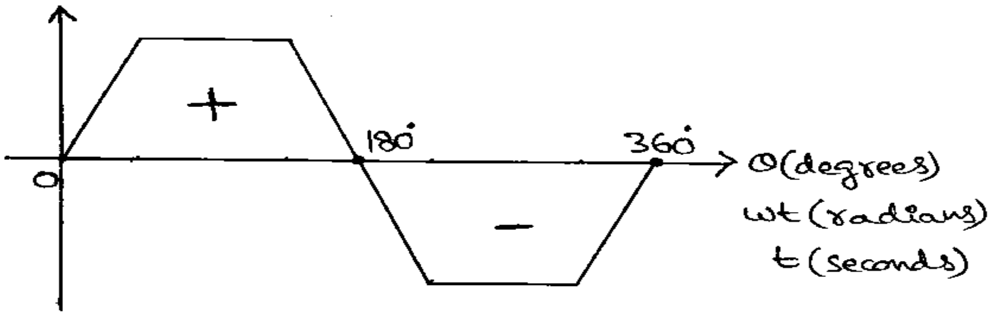
Sine Waveform



Square Waveform



Triangle Waveform



Trapezoid Waveform

Advantages of Sine Waveform:

- It is easy to generate Sine Waveform by using AC Generator.
- It is easy to analyse Sine Function by using Fourier Analysis.
- The Differentiation of Sine Function is also a Sine Function.

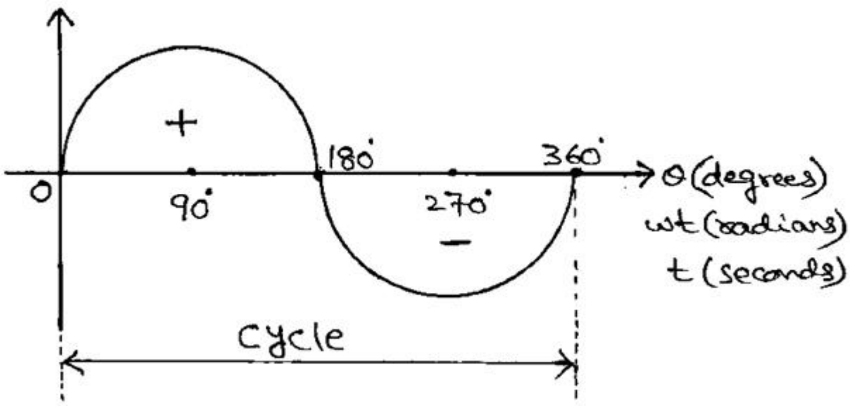
$$\frac{d}{d\theta}(\mathrm{Sin}\theta) = \mathrm{Cosine}\theta$$

- The Integral of Sine Function is also a Sine Function.

$$\int(\mathrm{Sin}\theta\ d\theta) = -\mathrm{Cosine}\theta$$

Cycle:

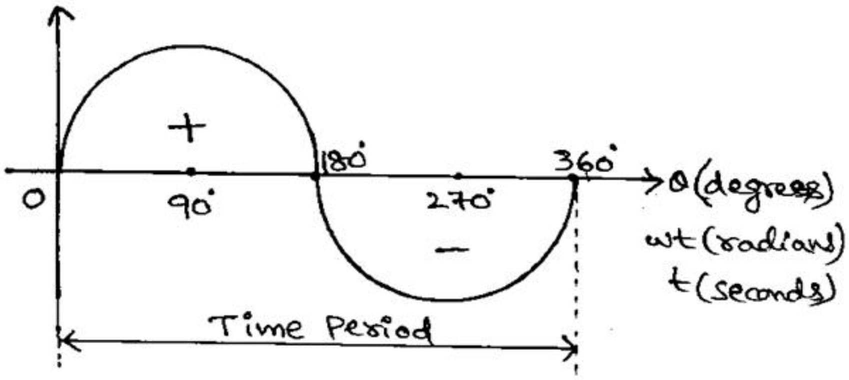
- The Complete Set of Positive Instantaneous Values and Negative Instantaneous Values of a Sine Wave is called as Cycle.



- A Cycle consists of two Half Cycles i.e. Positive Half Cycle and Negative Half Cycle.
- In Positive Half Cycle, the Instantaneous Values are Positive.
- In Negative Half Cycle, the Instantaneous Values are Negative.

Time Period:

- The Time taken by a Sine Wave to complete one Cycle is called as Time Period.

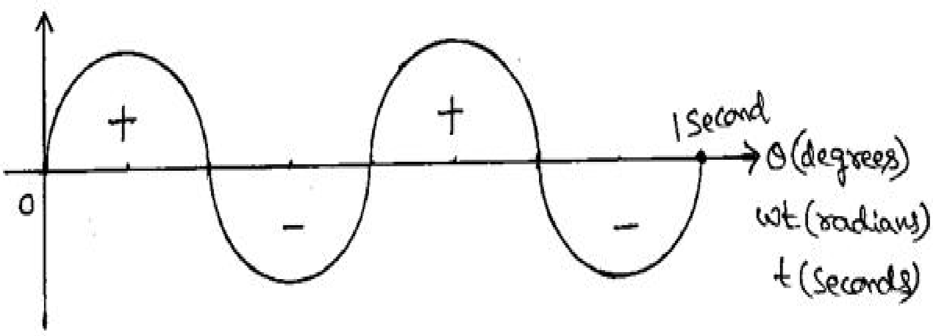


- Time Period is denoted by T.
- The unit of Time Period is Seconds.
- Time Period $= \frac{1}{\text{Frequency}}$
- $T = \frac{1}{f}$ where f = Frequency (in Hertz or Hz)
- For Example, Frequency f = 50Hz

$$\therefore \quad \text{Time Period } T = \frac{1}{f} = \frac{1}{50} = 0.02 \text{ Seconds}$$

Frequency:

- The Number of Cycles that a Sine Wave completes in One Second is called as Frequency.



- Frequency is denoted by f.
- The unit of Frequency is Hertz (Hz).
- $\text{Frequency} = \frac{1}{\text{Time Period}}$
- $f = \frac{1}{T}$ where T = Time Period (in Seconds)
- For Example, Time Period T = 0.05 Seconds

  ∴ Frequency $f = \frac{1}{T} = \frac{1}{0.05} = 20$ Hz

Problem: Determine Frequency of a Sine Wave when the Time Period is 20 milli Seconds.

Solution:

Given Data,

Time Period T = 20 milli Seconds = 0.02 Seconds

∴ Frequency $f = \frac{1}{T} = \frac{1}{0.02} = 50$ Hz

Problem: Determine Time Period of a Sine Wave when the Frequency is 60 Hz.

Solution:

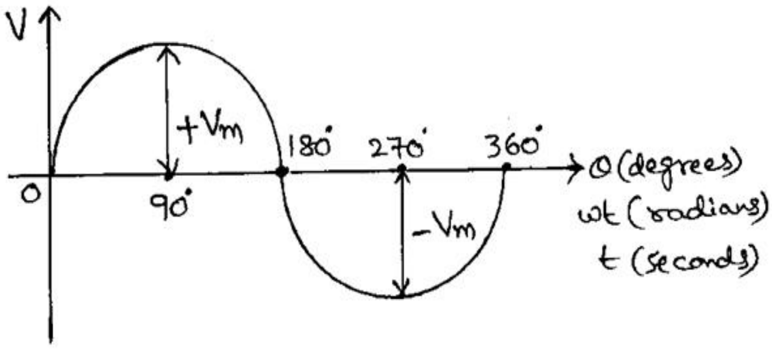
Given Data,

Frequency f = 60Hz

∴ Time Period $T = \frac{1}{f} = \frac{1}{60} = 0.0167$ Seconds

Maximum Value:

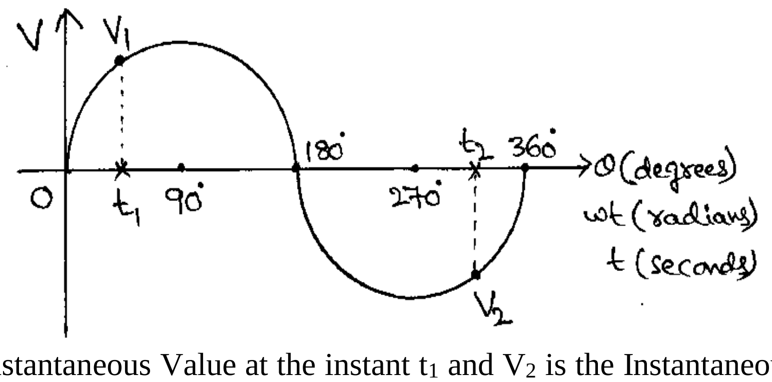
- The maximum Instantaneous Value during Positive Half Cycle (or) during Negative Half Cycle of a Sine Wave is called as Maximum Value.



- For Voltage Wave, Maximum Value is $+V_m$ in Positive Half Cycle and $-V_m$ in Negative Half Cycle.
- For Current Wave, Maximum Value is $+I_m$ in Positive Half Cycle and $-I_m$ in Negative Half Cycle.
- Maximum Value is also called as Peak Value (V_p and I_p).

Instantaneous Value:

- The Value of a Sine Wave at a particular Instant of Time is called as Instantaneous Value.
- The Instantaneous Values are Positive in Positive Half Cycle and Negative in Negative Half Cycle.



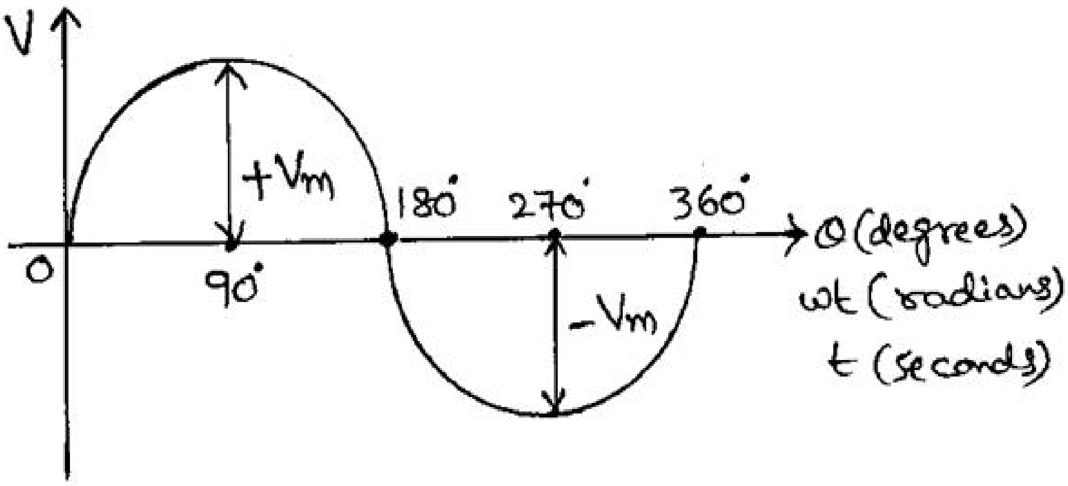
- V_1 is the Instantaneous Value at the instant t_1 and V_2 is the Instantaneous Value at the instant t_2.
- For Voltage Wave, the equation for Instantaneous Value is

$V = V_m \text{ Sin } (wt)$ where V_m = Maximum Value
$w = 2\pi f$
f = Frequency

- For Current Wave, the equation for Instantaneous Value is $I = I_m \text{ Sin } (wt)$

Average Value:

- The Average or Mean of different Instantaneous Values of a Sine Wave is called as Average Value.
- Average Value is also called as Mean Value.



- For Voltage Wave, the Average Value is V_{avg}

$$V_{avg} = \frac{2\ Vm}{\pi}$$

- For Current Wave, the Average Value is I_{avg}

$$I_{avg} = \frac{2\ Im}{\pi}$$

- The Average Value of One Complete Cycle of Sine Wave is ZERO.
    - In Sine Wave, the Positive Half Cycle Instantaneous Values are exactly same as the Negative Half Cycle Instantaneous Values.
    - If Average Value of Positive Half Cycle Instantaneous Values is (V_X) then, Average Value of Negative Half Cycle Instantaneous Values will be ($-V_X$).

∴ Average Value of One Complete Cycle $= \frac{Vx + (-Vx)}{2} = \frac{(Vx - Vx)}{2} = 0$

∴ Only One Half Cycle has to be considered to determine the Average Value of Sine Waveform.

- Derivation:

Consider a Voltage Wave $V = V_m \text{ Sin } (wt)$

$$V_{avg} = \frac{1}{\text{Time Period}} \int_{\text{Lower Limit}}^{\text{Upper Limit}} \text{(Waveform Equation)}$$

$$V_{avg} = \frac{1}{\pi} \int_0^{\pi} \text{Vm Sin (wt) } d(wt)$$

$$V_{avg} = \frac{Vm}{\pi} \int_0^{\pi} \text{Sin (wt) } d(wt)$$

$$V_{avg} = \frac{-Vm}{\pi} [\text{ Cos (wt)}_0^{\pi}]$$

$$V_{avg} = \frac{-Vm}{\pi} [(\text{Cos } \pi - \text{Cos } 0)]$$

$$V_{avg} = \frac{-Vm}{\pi} [(-1 - 1)]$$

$$V_{avg} = \frac{-Vm}{\pi} [(-2)]$$

$$V_{avg} = \frac{Vm}{\pi} [2]$$

$$\therefore \quad V_{avg} = \frac{2\ Vm}{\pi}$$

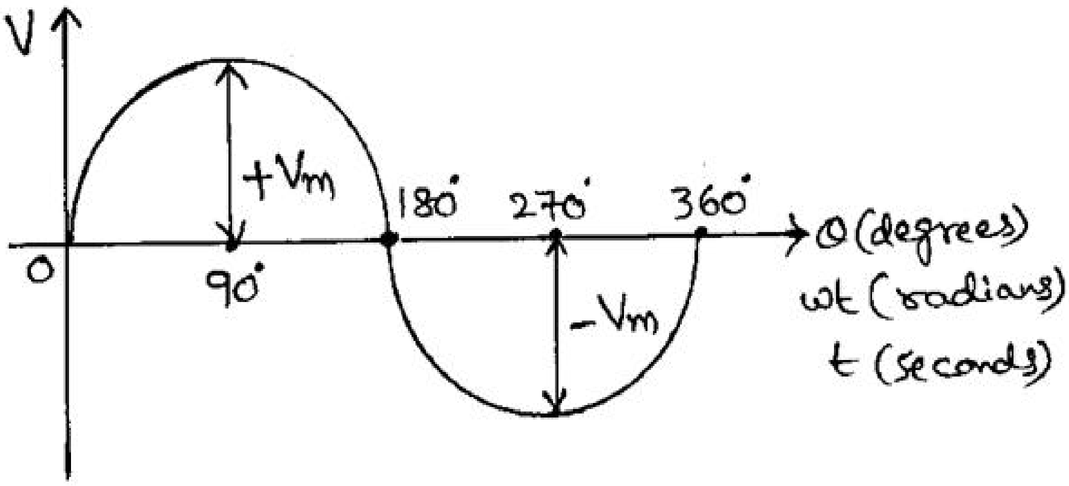
Similarly, for a Current Wave

$I = I_m \text{ Sin } (wt)$

$$I_{avg} = \frac{2\ Im}{\pi}$$

RMS Value:

- The Square Root of Mean of Square of different Instantaneous Values of an AC Wave is called as RMS Value.
- RMS Value is also called as Root Mean Square Value.



- For Voltage Wave, the RMS Value is V_{rms}

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

- For Current Wave, the RMS Value is I_{rms}

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

- Derivation:

Consider a Voltage Wave $V = V_m \text{ Sin (wt)}$

$$V_{rms} = \sqrt{\frac{1}{\text{Time Period}} \int_{\text{Lower Limit}}^{\text{Upper Limit}} (\text{Waveform Equation})^2}$$

$$V_{rms} = \sqrt{\frac{1}{2\pi} \int_0^{2\pi} (\text{Vm Sin wt})^2 \, d(wt)}$$

$$V_{rms} = \sqrt{\frac{1}{2\pi} \int_0^{2\pi} (\text{Vm}^2 \text{ Sin}^2 \text{wt}) \, d(wt)}$$

$$V_{rms} = \sqrt{\frac{Vm^2}{2\pi}\int_0^{2\pi}(Sin^2 wt)\ d(wt)}$$

$$V_{rms} = \sqrt{\frac{Vm^2}{2\pi}\int_0^{2\pi}\left(\frac{1 - Cos\ 2wt}{2}\right)\ d(wt)}$$

$$V_{rms} = \sqrt{\frac{Vm^2}{4\pi}\int_0^{2\pi}(1\ -\ Cos\ 2wt)\ d(wt)}$$

$$V_{rms} = \sqrt{\frac{Vm^2}{4\pi}\left[\int_0^{2\pi} 1\ d(wt) - \int_0^{2\pi} Cos\ 2wt\ d(wt)\right]}$$

$$V_{rms} = \sqrt{\frac{Vm^2}{4\pi}\left[(wt)_0^{2\pi} - \left(\frac{Sin\ 2wt}{2}\right)_0^{2\pi}\right]}$$

$$V_{rms} = \sqrt{\frac{Vm^2}{4\pi}\left[(2\pi - 0)\ - \left(\frac{Sin\ 2 * 2\pi}{2} - \frac{Sin\ 2 * 0}{2}\right)\right]}$$

$$V_{rms} = \sqrt{\frac{Vm^2}{4\pi}\left[(2\pi - 0)\ - \left(\frac{Sin\ 4\pi}{2} - \frac{Sin\ 0}{2}\right)\right]}$$

$$V_{rms} = \sqrt{\frac{Vm^2}{4\pi}\left[(2\pi - 0)\ - (0 - 0)\right]}$$

$$V_{rms} = \sqrt{\frac{Vm^2}{4\pi}\left[2\pi\right]}$$

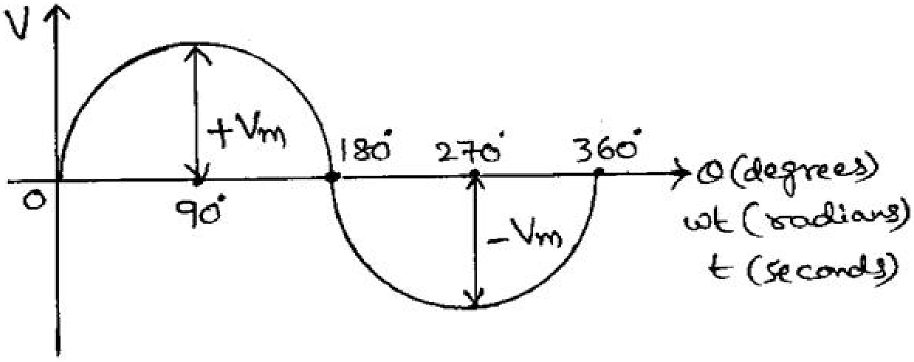
$$V_{rms} = \sqrt{\frac{Vm^2}{2}}$$

$$\therefore \qquad V_{rms} = \frac{Vm}{\sqrt{2}}$$

Similarly, for a Current Wave $I = I_m\ Sin\ (wt)$ $I_{rms} = \frac{Im}{\sqrt{2}}$

Peak Factor:

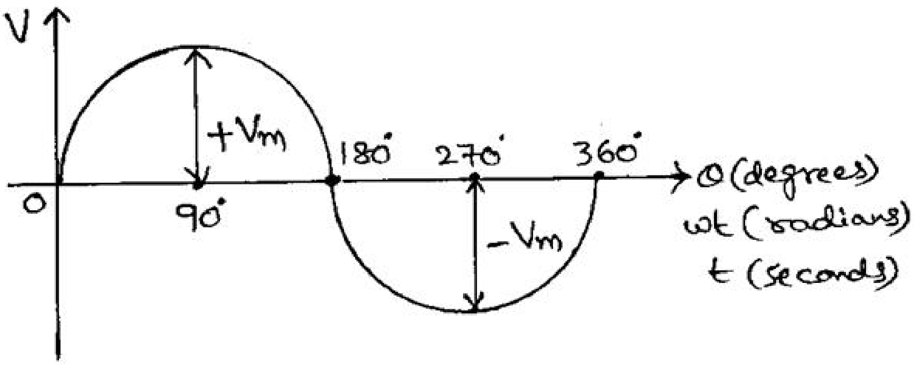
- The Ratio of Maximum Value to RMS Value of a Sine Wave is called as Peak Factor.



- For Voltage Wave, Peak Factor = $\frac{Vm}{Vrms}$
- For Current Wave, Peak Factor = $\frac{Im}{Irms}$
- For Sine Wave, Peak Factor = $\frac{Vm}{Vrms} = \frac{Vm}{Vm/\sqrt{2}} = \sqrt{2} = 1.414$

Form Factor:

- The Ratio of RMS Value to Average Value of a Sine Wave is called as Form Factor.



- For Voltage Wave, Form Factor = $\frac{Vrms}{Vavg}$
- For Current Wave, Form Factor = $\frac{Irms}{Iavg}$
- For Sine Wave, Form Factor = $\frac{Vrms}{Vavg} = \frac{Vm/\sqrt{2}}{2Vm/\pi} = \frac{\pi}{2\sqrt{2}} = 1.11$

Problem: A Sine Wave has the Maximum Voltage value of 325V. Determine (i) Average Value (ii) RMS Value (iii) Peak Factor (iv) Form Factor.

Solution:

Given Data, Maximum Value = V_m = 325 Volts

(i) Average Value = $V_{avg} = \frac{2\,Vm}{\pi} = \frac{2 * 325}{\pi} = 207$ Volts

(ii0 RMS Value = $V_{rms} = \frac{Vm}{\sqrt{2}} = \frac{325}{\sqrt{2}} = 230$ Volts

(iii) Peak Factor = $\frac{Vm}{Vrms} = \frac{325}{230} = 1.414$

(iv) Form Factor = $\frac{Vrms}{Vavg} = \frac{230}{207} = 1.11$

Problem: For an AC Voltage of V = 300 Sin (314t) Volts, determine (i) Average Value (ii) RMS Value (iii) Peak Factor (iv) Form Factor (v) Frequency (vi) Time Period.

Solution:

Given Data, V = 300 Sin (314t) Volts

This is in the form of V = V_m Sin (wt)

∴ Maximum Value = V_m = 300 Volts and w = 314

(i) Average Value = $V_{avg} = \frac{2\,Vm}{\pi} = \frac{2 * 300}{\pi} = 191$ Volts

(ii) RMS Value = $V_{rms} = \frac{Vm}{\sqrt{2}} = \frac{300}{\sqrt{2}} = 212.13$ Volts

(iii) Peak Factor = $\frac{Vm}{Vrms} = \frac{300}{212.13} = 1.414$

(iv) Form Factor = $\frac{Vrms}{Vavg} = \frac{212.13}{191} = 1.11$

(v) w = 2πf = 314 ==> $f = \frac{w}{2\pi} = \frac{314}{2\pi} = 50$ Hz

∴ Frequency = f = 50 Hz

(vi) Time Period = $T = \frac{1}{f} = \frac{1}{50} = 0.02$ Seconds

Problem: The Average Value of an AC Voltage is 200V. Determine (i) Maximum Value (ii) RMS Value (iii) Peak Factor (iv) Form Factor.

Solution:

Given Data, Average Value = V_{avg} = 200 Volts

(i) Average Value = $V_{avg} = \frac{2\,Vm}{\pi}$

==> $200 = \frac{2\,Vm}{\pi}$ ==> $V_m = \frac{200 * \pi}{2}$ = 314 Volts

∴ Maximum Value = V_m = 314 Volts

(ii) RMS Value = $V_{rms} = \frac{Vm}{\sqrt{2}} = \frac{314}{\sqrt{2}}$ = 222 Volts

(iii) Peak Factor = $\frac{Vm}{Vrms} = \frac{314}{222}$ = 1.414

(iv) Form Factor = $\frac{Vrms}{Vavg} = \frac{222}{200}$ = 1.11

Problem: The RMS Value of an AC Voltage is 250V. Determine (i) Maximum Value (ii) Average Value (iii) Peak Factor (iv) Form Factor.

Solution:

Given Data, RMS Value = V_{rms} = 250 Volts

(i) RMS Value = $V_{rms} = \frac{Vm}{\sqrt{2}}$

==> $250 = \frac{Vm}{\sqrt{2}}$ ==> $V_m = 250 * \sqrt{2}$ = 353.55 Volts

∴ Maximum Value = V_m = 353.55 Volts

(ii) Average Value = $V_{avg} = \frac{2\,Vm}{\pi} = \frac{2 * 353.55}{\pi}$ = 225.08 Volts

(iii) Peak Factor = $\frac{Vm}{Vrms} = \frac{353.55}{250}$ = 1.414

(iv) Form Factor = $\frac{Vrms}{Vavg} = \frac{250}{225.08}$ = 1.11

Problem: A Sine Wave has the Maximum Current value of 50A. Determine (i) Average Value (ii) RMS Value (iii) Peak Factor (iv) Form Factor.

Solution: Given Data, Maximum Value = I_m = 50 Amperes

(i) Average Value = $I_{avg} = \frac{2\,Im}{\pi} = \frac{2 * 50}{\pi} = 31.83$ Amperes

(ii) RMS Value = $I_{rms} = \frac{Im}{\sqrt{2}} = \frac{50}{\sqrt{2}} = 35.36$ Amperes

(iii) Peak Factor = $\frac{Im}{Irms} = \frac{50}{35.36} = 1.414$

(iv) Form Factor = $\frac{Irms}{Iavg} = \frac{35.36}{31.83} = 1.11$

Problem: For an AC Current of I = 60 Sin (250t) Amperes, determine (i) Average Value (ii) RMS Value (iii) Peak Factor (iv) Form Factor (v) Frequency (vi) Time Period.

Solution:

Given Data, I = 60 Sin (250t) Amperes

This is in the form of $I = I_m \sin(wt)$

∴ Maximum Value = I_m = 60 Amperes and w = 250

(i) Average Value = $I_{avg} = \frac{2\,Im}{\pi} = \frac{2 * 60}{\pi} = 38.2$ Amperes

(ii) RMS Value = $I_{rms} = \frac{Im}{\sqrt{2}} = \frac{60}{\sqrt{2}} = 42.43$ Amperes

(iii) Peak Factor = $\frac{Im}{Irms} = \frac{60}{42.43} = 1.414$

(iv) Form Factor = $\frac{Irms}{Iavg} = \frac{42.43}{38.2} = 1.11$

(v) $w = 2\pi f = 250$ ==> $f = \frac{w}{2\pi} = \frac{250}{2\pi} = 40$ Hz ∴ Frequency = f = 40 Hz

(vi) Time Period = $T = \frac{1}{f} = \frac{1}{40} = 0.025$ Seconds

Problem: The Average Value of an AC Current is 30A. Determine (i) Maximum Value (ii) RMS Value (iii) Peak Factor (iv) Form Factor.

Solution: Given Data, Average Value = I_{avg} = 30 Amperes

(i) Average Value = $I_{avg} = \frac{2\,Im}{\pi}$ ==> $30 = \frac{2\,Im}{\pi}$ ==> $I_m = \frac{30 * \pi}{2} = 47.12$

∴ Maximum Value = I_m = 47.12 Amperes

(ii) RMS Value = $I_{rms} = \frac{Im}{\sqrt{2}} = \frac{47.12}{\sqrt{2}}$ = 33.32 Amperes

(iii) Peak Factor = $\frac{Im}{Irms} = \frac{47.12}{33.32}$ = 1.414

(iv) Form Factor = $\frac{Irms}{Iavg} = \frac{33.32}{50}$ = 1.11

Problem: The RMS Value of an AC Current is 25A. Determine (i) Maximum Value (ii) Average Value (iii) Peak Factor (iv) Form Factor.

Solution: Given Data, RMS Value = I_{rms} = 25 Amperes

(i) RMS Value = $I_{rms} = \frac{Im}{\sqrt{2}}$ ==> $25 = \frac{Im}{\sqrt{2}}$ ==> $I_m = 25 * \sqrt{2}$ = 35.36

∴ Maximum Value = I_m = 35.36 Amperes

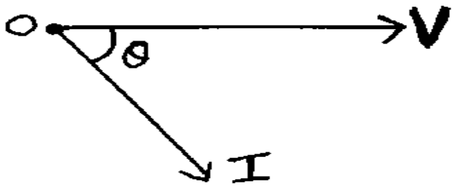
(ii) Average Value = $I_{avg} = \frac{2\,Im}{\pi} = \frac{2 * 35.36}{\pi}$ = 22.51 Amperes

(iii) Peak Factor = $\frac{Im}{Irms} = \frac{35.36}{25}$ = 1.414

(iv) Form Factor = $\frac{Irms}{Iavg} = \frac{25}{22.51}$ = 1.11

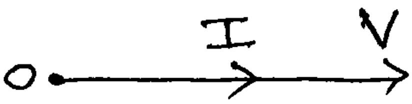
Amplitude:

- The magnitude or value of Voltage Vector or Current Vector is called as Amplitude.

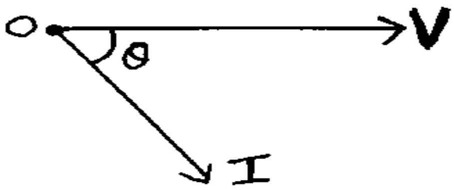


Phase:

- If there is no angle between Voltage Vector and Current Vector, then they are said to be In-Phase with each other.



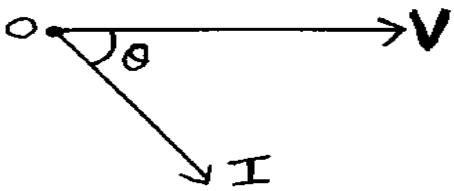
- If there is an angle (θ) between Voltage Vector and Current Vector, then they are said to be Out-of-Phase with each other.



Here, I is lagging with V by an angle (θ) and V is leading with I by an angle (θ)

Phase Difference (or) Phase Angle:

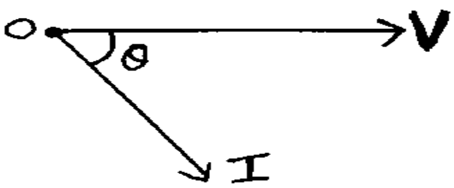
- The angle between Voltage Vector and Current Vector in an AC Circuit is called as Phase Angle.



Power Factor:

- The Cosine of the Phase Angle between Voltage Vector and Current Vector in an AC Circuit is called as Power Factor.

- Power Factor = Cos θ

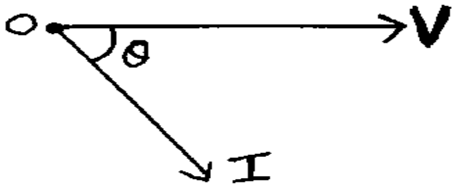


Active Power:

- The Useful Power which is consumed by an Electrical Load in an AC Circuit is called as Active Power.
- Active Power is denoted by P.
- The unit of Active Power is Watts.
- Active Power is also called as Useful Power, True Power, Real Power etc.
- The Product of RMS Value of Voltage, RMS Value of Current and Power Factor is called as Active Power.

$$P = V_{rms} * I_{rms} * \cos\theta \quad \text{(or)} \quad P = V\,I\,\cos\theta$$

where θ is the Phase Angle between Voltage and Current.

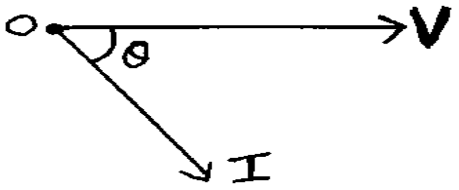


Reactive Power:

- The Unused Power which is not consumed by an Electrical Load in an AC Circuit is called as Reactive Power.
- Reactive Power is denoted by Q.
- The unit of Reactive Power is Volt Ampere Reactive (VAR).
- The Product of RMS Value of Voltage, RMS Value of Current and Sinθ is called as Reactive Power.

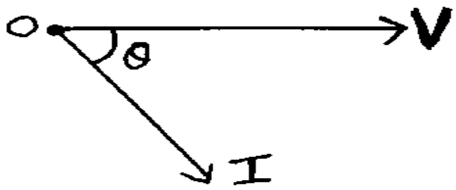
$$Q = V_{rms} * I_{rms} * \sin\theta \quad \text{(or)} \quad Q = V\,I\,\sin\theta$$

where θ is the Phase Angle between Voltage and Current.



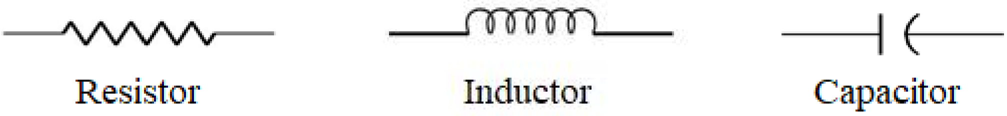
Apparent Power:

- The Product of RMS Value of Voltage and RMS Value of Current is called as Apparent Power.
- Apparent Power is denoted by S.
- The unit of Apparent Power is Volt Ampere (VA).
- $S = V_{rms} * I_{rms}$ (or) $S = V\ I$



Impedance:

- Impedance is the property of opposing or controlling the flow of current in an AC Circuit due to Resistor, Inductor and Capacitor.



- Impedance is denoted by Z.
- The unit of Impedance is Ohm (Ω).
- Impedance = Resistance + Reactance

$$Z = (R) + (X)$$

- Impedance = Resistance + Inductive Reactance + Capacitive Reactance

$$Z = (R) + (J\ X_L) + (-J\ X_C)$$

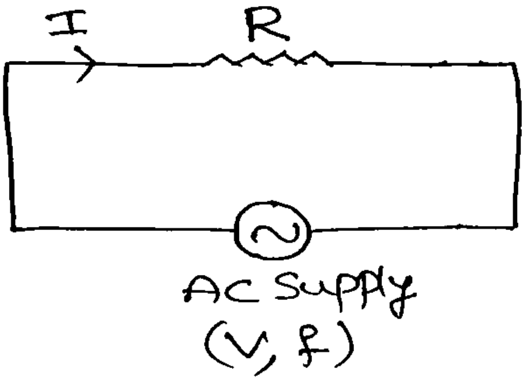
$$Z = R + J\ X_L - J\ X_C$$

Here $X_L = 2\ \pi\ f\ L$ where f = Frequency (in Hz) L = Inductance (in Henries)

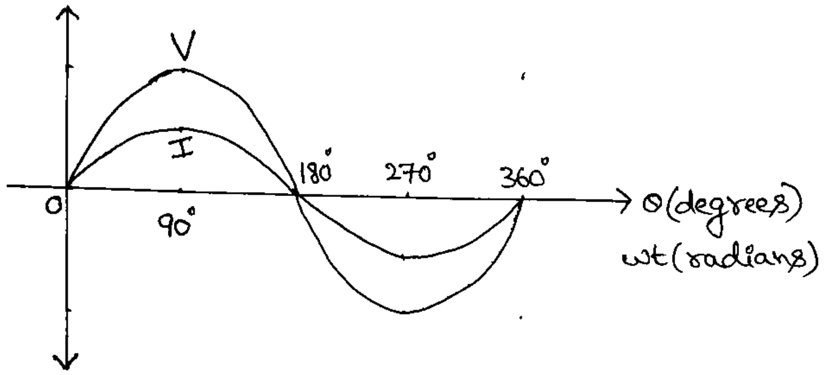
$X_C = \dfrac{1}{2\ \pi\ f\ C}$ where f = Frequency (in Hz) C = Capacitance (in Farads)

Behaviour of Resistor (Pure Resistance Circuit) to AC Supply:

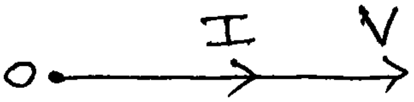
Circuit Diagram



Waveforms



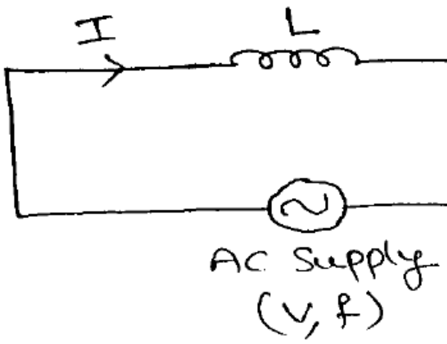
Phasor Diagram



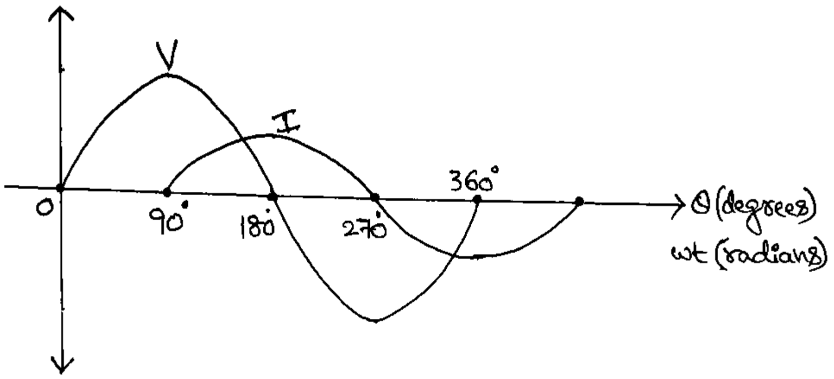
- Current and Voltage will be In-Phase with each other.
- Phase Angle = θ = 0
- Power Factor = Cos θ = Cos (0) = 1
- Impedance = Z = R Ω
- Current $I = \frac{V}{Z}$

Behaviour of Inductor (Pure Inductance Circuit) to AC Supply:

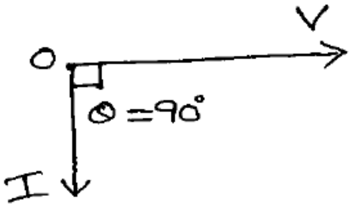
Circuit Diagram



Waveforms



Phasor Diagram



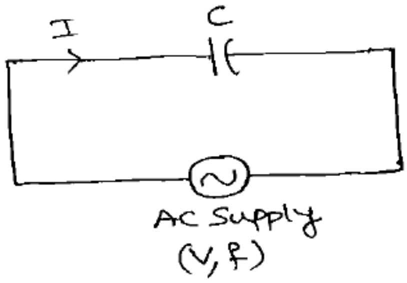
- Current and Voltage will be Out-of-Phase with each other.
- Current will be Lagging with Voltage by an angle of 90^0
- Phase Angle = $\theta = 90^0$
- Power Factor = $\cos\theta = \cos(90) = 0$
- Impedance = $Z = (J\ X_L)\ \Omega$ where X_L = Inductive Reactance (in Ω)

  $X_L = 2\ \pi\ f\ L$ where f = Frequency (in Hz)

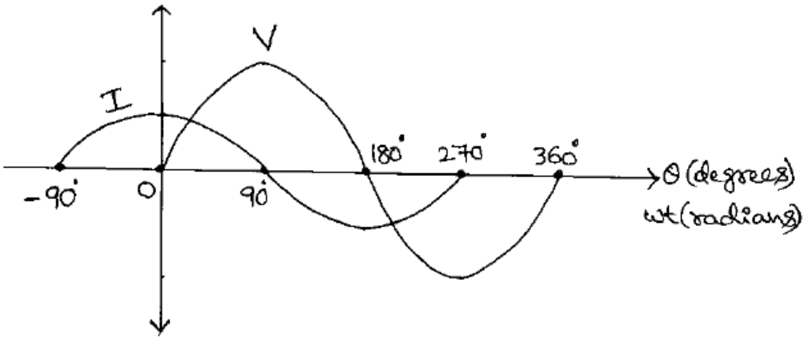
  L = Inductance (in Henries)
- Current $I = \frac{V}{Z}$

Behaviour of Capacitor (Pure Capacitance Circuit) to AC Supply:

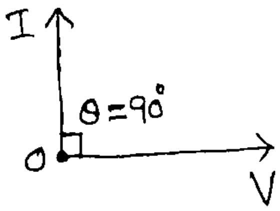
Circuit Diagram



Waveforms



Phasor Diagram



- Current and Voltage will be Out-of-Phase with each other.
- Current will be Leading with Voltage by an angle of 90^0
- Phase Angle = $\theta = 90^0$
- Power Factor = $\text{Cos } \theta = \text{Cos } (90) = 0$
- Impedance = $Z = (-J X_C)\ \Omega$ where X_C = Capacitive Reactance (in Ω)

$$X_C = \frac{1}{2\pi f C}$$

where f = Frequency (in Hz)
C = Capacitance (in Farads)

- Current $I = \frac{V}{Z}$

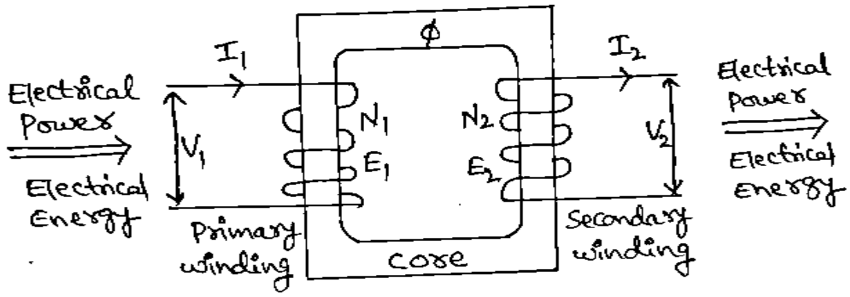
UNIT – 2 Chapter – 1 Electrical Machines

Transformer
Induction Motor (AC Motor)
Alternator (AC Generator)
DC Motor
DC Generator

Transformer

Main Function of Transformer

Transformer is a Static Electrical Machine which transforms or transfers Electrical Power and Electrical Energy from one circuit to another circuit without any change in Frequency.



Applications of Transformer

Core Type Transformers are used in Generating Stations, Sub-Stations and Residential Areas

Shell Type Transformers are used in Battery Chargers (Cell Phone, Laptop), Power Supplies (UPS, Inverter) and Electronic Circuits (TV, Radio)

Construction of Transformer

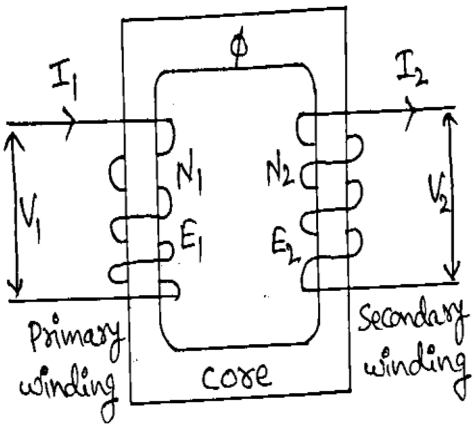
Transformer is a Static Electrical Machine which transforms or transfers Electrical Power and Electrical Energy from one circuit to another circuit without any change in Frequency.

The Main Parts of Transformer are (i) Core (ii) Coil or Winding

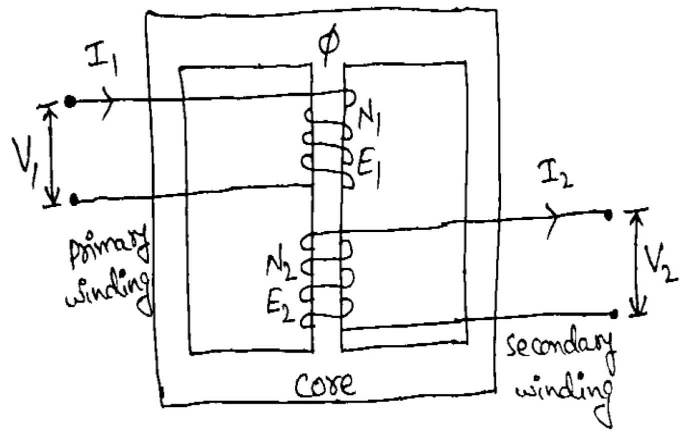
(i) Core:

- The purpose of Core is to hold the Coil or Winding.
- Another purpose of Core is to produce the magnetic field.
- Core is made up of High Grade Silicon Steel (Magnetic Material).
- Core is laminated with thin sheets of L shape or E shape.
- There are two types of Cores. They are Core Type and Shell Type.
- The Transformer which has "Core Type" Core is called as Core Type Transformer. The Transformer which has "Shell Type" Core is called as Shell Type Transformer.

Core Type Transformer



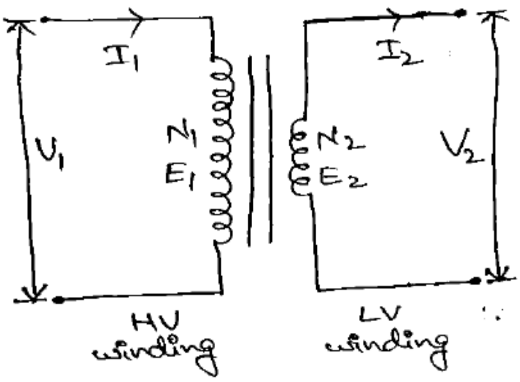
Shell Type Transformer



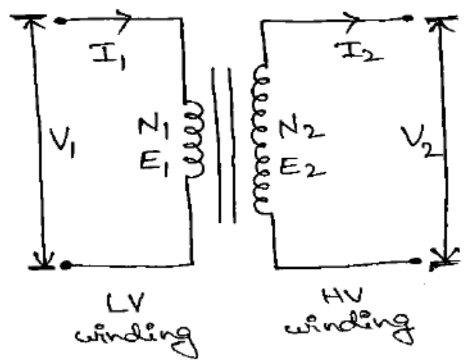
(ii) Coil or Winding:

- The purpose of Winding is to Transfer Electrical Power and Electrical Energy from One Circuit to Another Circuit.
- Winding will be placed on the Core.
- Winding Consists of Primary Winding and Secondary Winding.
- Winding is made up of Copper.
- The Winding which takes Electrical Power and Electrical Energy is called as Primary Winding. The Winding which gives Electrical Power and Electrical Energy is called as Secondary Winding.
- HV Winding will have more number of Turns and LV Winding will have less number of Turns.

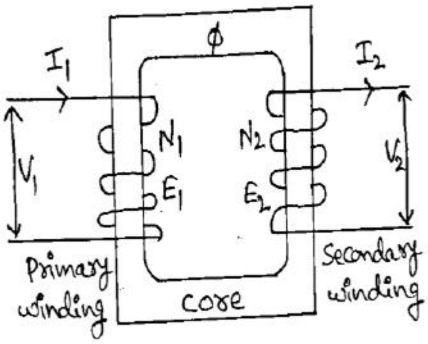
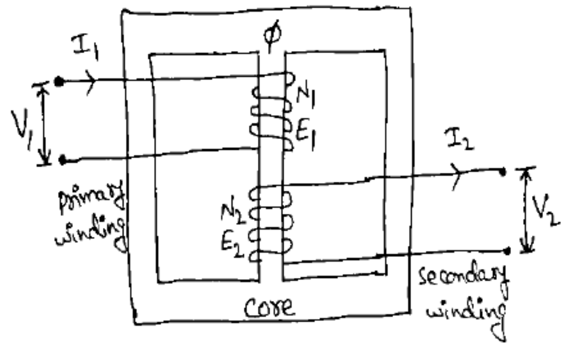
Step Down Transformer



Step Up Transformer

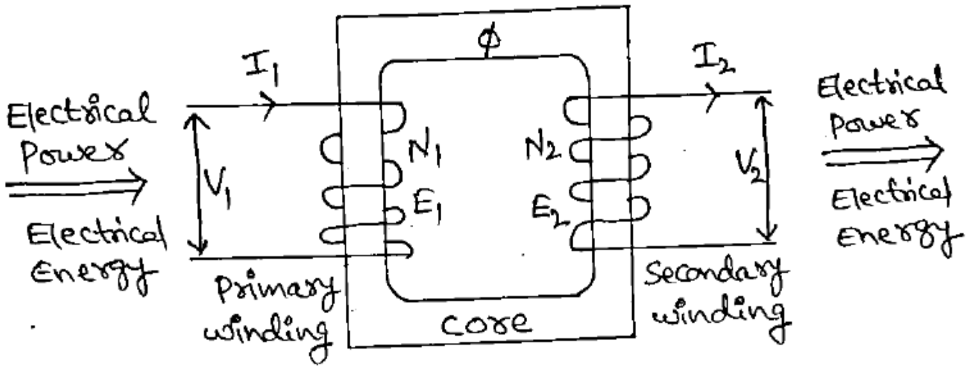


Comparison between Core Type Transformer and Shell Type Transformer

Sl. No.	Core Type Transformer	Shell Type Transformer
1		
2	The Transformer which has "Core Type" Core is called as Core Type Transformer.	The Transformer which has "Shell Type" Core is called as Shell Type Transformer.
3	It has two Limbs. (Left Side Limb and Right Side Limb).	It has three Limbs. (Left Side Limb, Centre Limb and Right Side Limb).
4	Primary Winding will be placed on Left Side Limb and Secondary Winding will be placed on Right Side Limb.	Both Primary Winding and Secondary Winding will be placed on Centre Limb.
5	The Winding can be easily removed for maintenance purpose.	The Winding cannot be easily removed for maintenance purpose
6	The Winding can be easily cooled.	The Winding cannot be easily cooled
7	The Thin Sheets of Lamination will be in L Shape.	The Thin Sheets of Lamination will be in E Shape.
8	Core Type Transformers are used in Generating Stations, Sub-Stations and Residential Areas.	Shell Type Transformers are used in Battery Chargers (Cell Phone, Laptop), Power Supplies (UPS, Inverter) and Electronic Circuits (TV, Radio)

Working Principle of Transformer

Transformer is a Static Electrical Machine which transforms or transfers Electrical Power and Electrical Energy from one circuit to another circuit without any change in Frequency.



Here, V = Voltage
I = Current
E = EMF
N = Number of Turns
Ø = Magnetic Flux

Step1: V_1 ==> I_1 ==> Production of Magnetic Field due to MMF ==> E_1

When a Voltage (V_1) is applied across Primary Winding, then,

- Current (I_1) passes through Primary Winding.
- Magneto Motive Force (MMF) produces Magnetic Field around the Primary Winding.
- The amount of Magnetic Field is called as Magnetic Flux (Ø).
- According to Faraday's Law of Electro Magnetic Induction, an EMF (E_1) will be induced in Primary Winding due to alternating Magnetic Flux around the Winding.

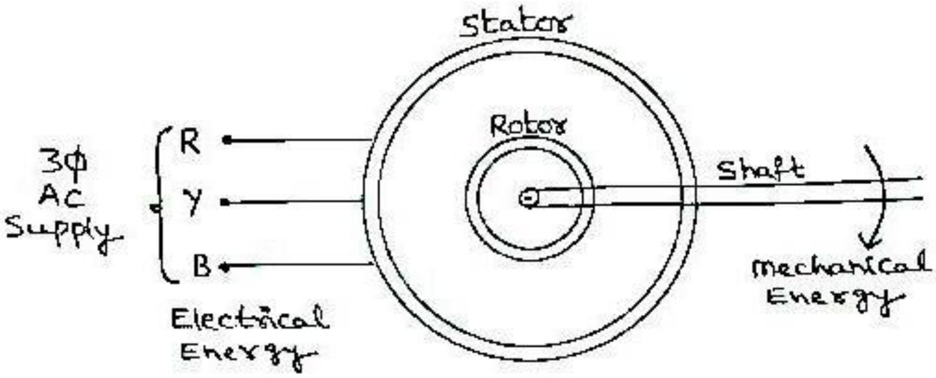
Step2: Production of Magnetic Field due to Mutual Induction ==> E_2 ==> I_2 ==> V_2

- According to Mutual Induction, as the Secondary Winding is placed near the magnetic field of Primary Winding on a same Core, a Magnetic Field will be produced around the Secondary Winding.
- The amount of Magnetic Field is called as Magnetic Flux (Ø).
- According to Faraday's Law of Electro Magnetic Induction, an EMF (E_2) will be induced in Secondary Winding due to alternating Magnetic Flux around the Winding.
- Current (I_2) passes through Secondary Winding.
- Voltage (V_2) will be produced across the Secondary Winding.

Induction Motor (AC Motor)

Main Function of Induction Motor

Induction Motor is a Rotating Electrical Machine which converts Electrical Energy (AC Supply) into Mechanical Energy.



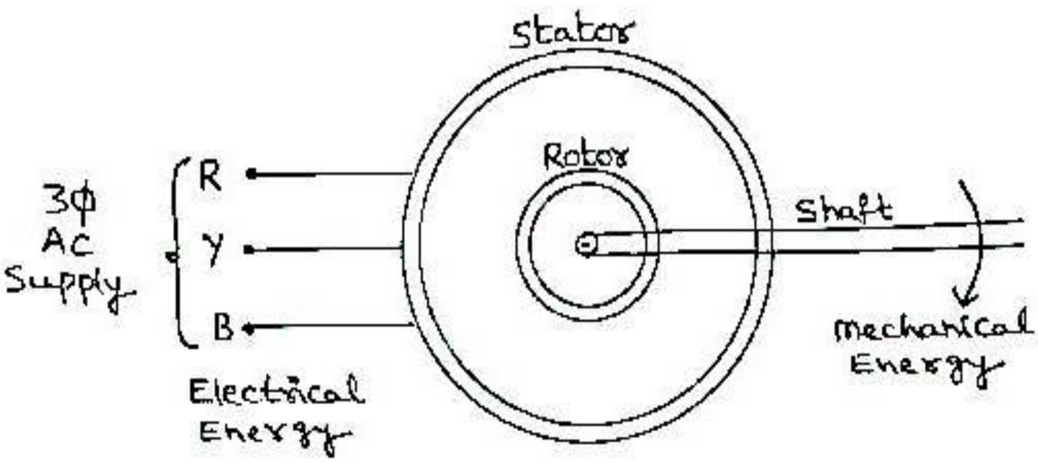
Applications of Induction Motor

Squirrel Cage Induction Motors are used in Water Pumps, Grinding Machines, Printing Machines, Fans etc.

Slip Ring Induction Motors are used in Electric Trains, Lifts, Cranes, Stone Crushers etc.

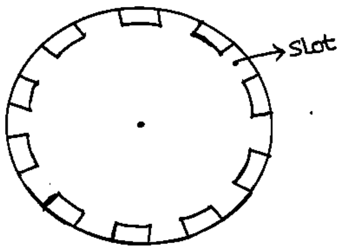
Construction of Induction Motor

Induction Motor is a Rotating Electrical Machine which converts Electrical Energy (AC Supply) into Mechanical Energy.

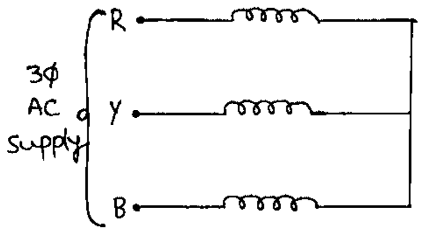


The Main Parts of Induction Motor are (i) Stator (ii) Rotor

(i) Stator:



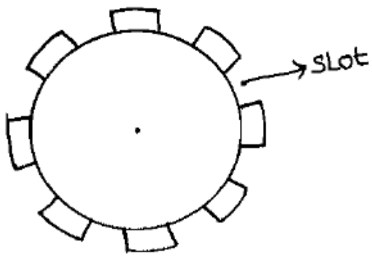
Stator Core



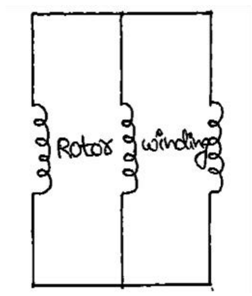
Stator Winding

- Stator is a stationary part of the Induction Motor.
- Stator consists of Core and Coil (Winding).
- Stator Core is made up of High Grade Silicon Steel (Magnetic Material).
- Stator Core is laminated.
- Stator Core consists of Slots.
- Stator Winding will be placed in the Slots.
- Stator Winding is made up of Copper (Conducting Material).
- Stator Winding will take 3Φ AC Supply.

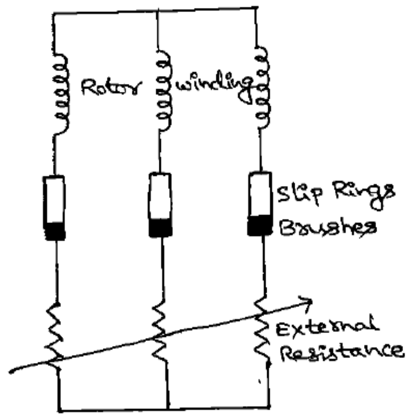
(ii) Rotor:



Rotor Core



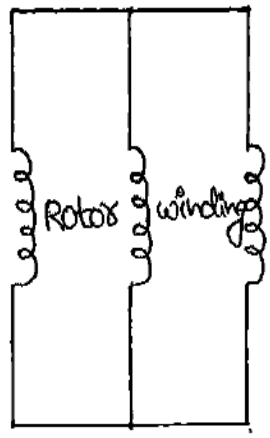
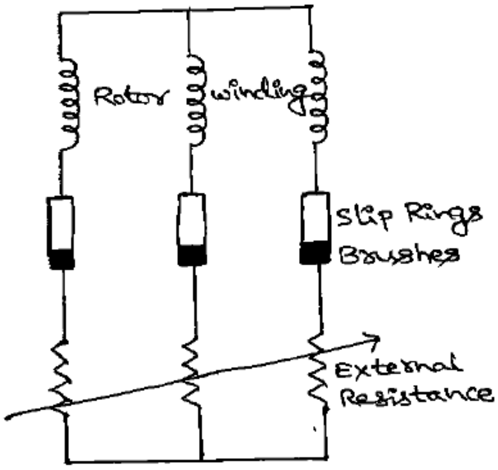
Squirrel Cage Rotor



Slip Ring Rotor

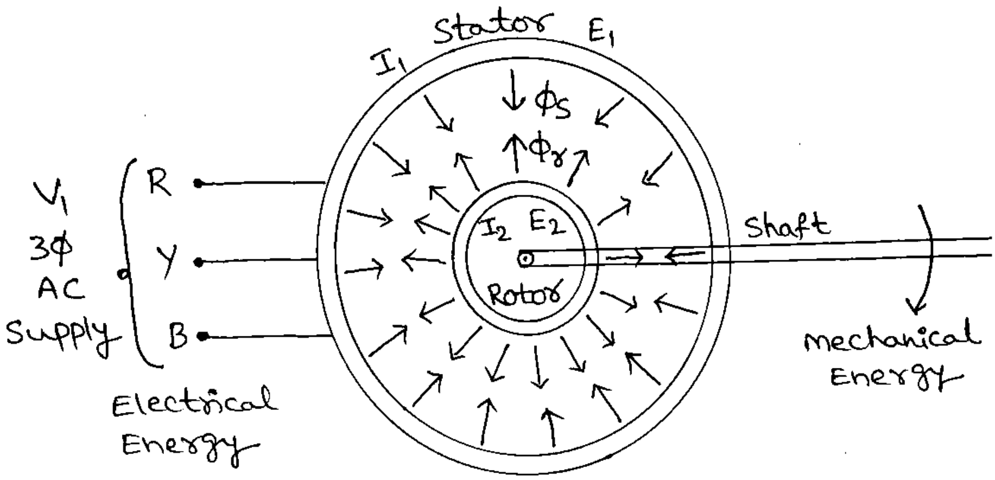
- Rotor is a rotating part of the Induction Motor.
- Rotor consists of Core and Coil (Winding).
- Rotor Core is made up of High Grade Silicon Steel (Magnetic Material).
- Rotor Core is laminated.
- Rotor Core consists of Slots.
- Rotor Winding will be placed in the Slots.
- Rotor Winding is made up of Copper (Conducting Material)
- There are two types of Rotors. (1) Squirrel Cage Rotor (2) Slip Ring Rotor.
- The Induction Motor which has “Squirrel Cage Rotor” is called as “Squirrel Cage Induction Motor”.
- The Induction Motor which has “Slip Ring Rotor” is called as “Slip Ring Induction Motor”.

Comparison between Squirrel Cage Rotor and Slip Ring Rotor
Comparison between Squirrel Cage Induction Motor and Slip Ring Induction Motor

Sl. No.	Squirrel Cage Rotor / Squirrel Cage Induction Motor	Slip Ring Rotor / Slip Ring Induction Motor
1		
2	In Squirrel Cage Rotor, the ends of Rotor Winding will be short circuited.	In Slip Ring Rotor, one end of Rotor Winding will be short circuited and other end will be connected to Slip Rings, Brushes and External Resistance.
3	The Induction Motor which has Squirrel Cage Rotor is called as Squirrel Cage Induction Motor.	The Induction Motor which has Slip Ring Rotor is called as Slip Ring Induction Motor.
4	Squirrel Cage Induction Motors are used in Water Pumps, Grinding Machines, Printing Machines, Fans etc.	Slip Ring Induction Motors are used in Electric Trains, Lifts, Cranes, Stone Crushers etc.
5	Slip Rings, Brushes and External Resistance are not required.	Slip Rings, Brushes and External Resistance are required.
6	Construction is simple and Cost is less	Construction is not simple and Cost is more
7	Losses are less and Efficiency is more	Losses are more and Efficiency is less
8	95% of practical applications use the Squirrel Cage Induction Motor	Only 5% of practical applications use the Slip Ring Induction Motor
9	Speed Control is not easy	Speed Control is easy
10	Low Starting Torque	High Starting Torque

Working Principle of Induction Motor

Induction Motor is a Rotating Electrical Machine which converts Electrical Energy (AC Supply) into Mechanical Energy.



Step1:

V_1 ==> I_1 ==> Production of Magnetic Field due to MMF ==> E_1

When a Voltage (V_1) is applied to Stator Winding, then,

* Current (I_1) passes through Stator Winding.
* Magneto Motive Force (MMF) produces Magnetic Field around the Stator Winding.
* The amount of Magnetic Field is called as Magnetic Flux ($Ø_S$).
* According to Faraday's Law of Electro Magnetic Induction, an EMF (E_1) will be induced in Stator Winding due to alternating Magnetic Flux around the Winding.

Step2:

Production of Magnetic Field due to Mutual Induction ==> E_2 ==> I_2

* According to Mutual Induction, as the Rotor Winding is surrounded by the Magnetic Field of Stator Winding, a Magnetic Field will be produced in the Rotor Winding.
* The amount of Magnetic Field is called as Magnetic Flux ($Ø_r$).
* According to Faraday's Law of Electro Magnetic Induction, an EMF (E_2) will be induced in Rotor Winding due to alternating Magnetic Flux around the Winding.
* Current (I_2) passes through Rotor Winding.

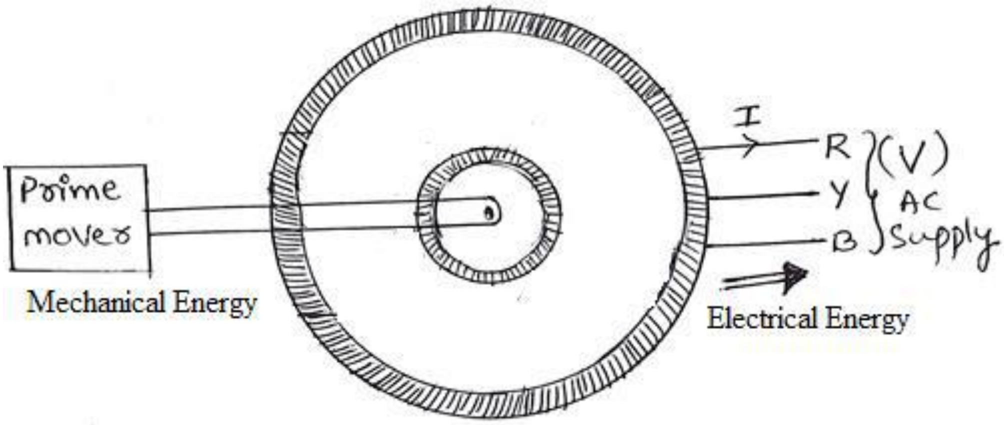
Step3:

* The directions of Stator Magnetic Flux ($Ø_S$) and Rotor Magnetic Flux ($Ø_r$) are opposite to each other.
* Due to the opposite directions of $Ø_S$ and $Ø_r$, both repel with each other and the rotor rotates in clockwise direction.

Alternator (AC Generator)

Main Function of Alternator

Alternator is a Rotating Electrical Machine which converts Mechanical Energy into Electrical Energy (AC Supply).



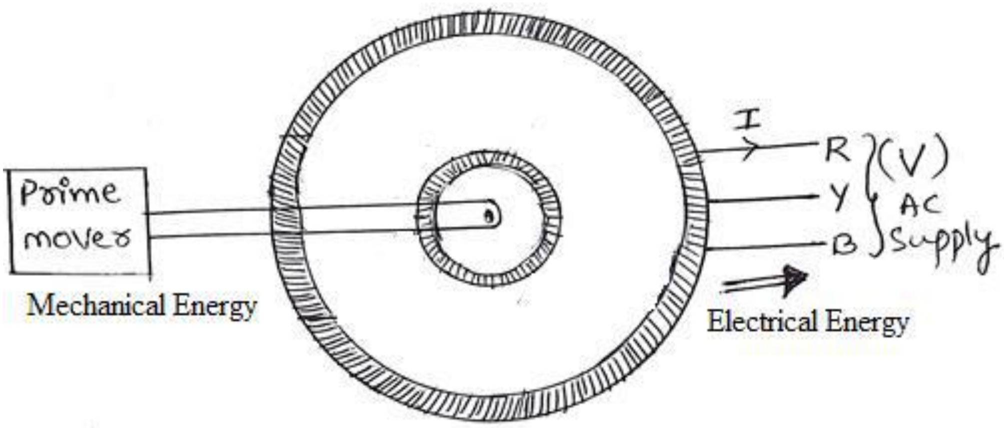
Applications of Alternator

Salient Pole Alternators are used in Hydel Power Plants.

Non-Salient Pole Alternators are used in Thermal Power Plants, Gas Power Plants, Nuclear Power Plants, Banks, Hospitals etc.

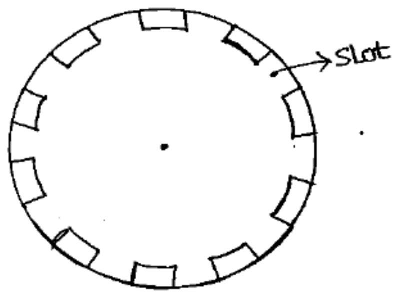
Construction of Alternator

Alternator is a Rotating Electrical Machine which converts Mechanical Energy into Electrical Energy (AC Supply).

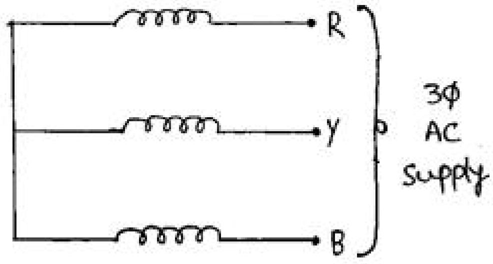


The Main Parts of Alternator are (i) Stator (ii) Rotor

(i) Stator:



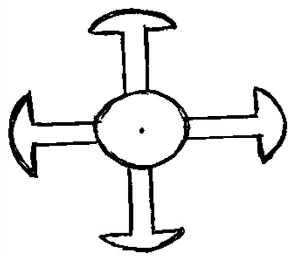
Stator Core



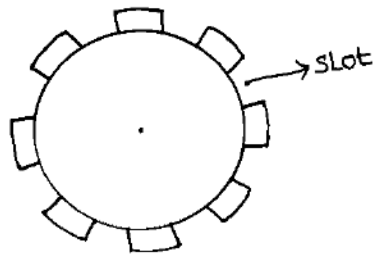
Stator Winding

* Stator is a stationary part of the Alternator.
* Stator consists of Core and Winding.
* Stator Core is made up of High Grade Silicon Steel (Magnetic Material).
* Stator Core is laminated.
* Stator Core consists of Slots.
* Stator Winding will be placed in the Slots.
* Stator Winding will generate 3Φ AC Supply.

(ii) Rotor:



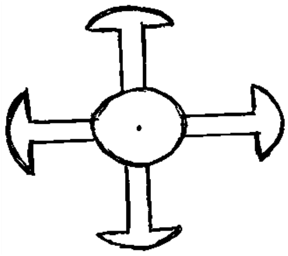
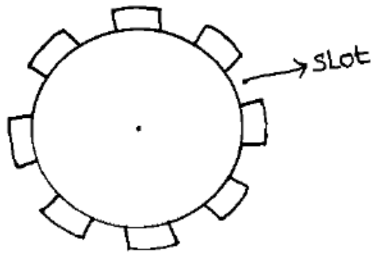
Projected Pole Rotor
(Salient Pole Rotor)



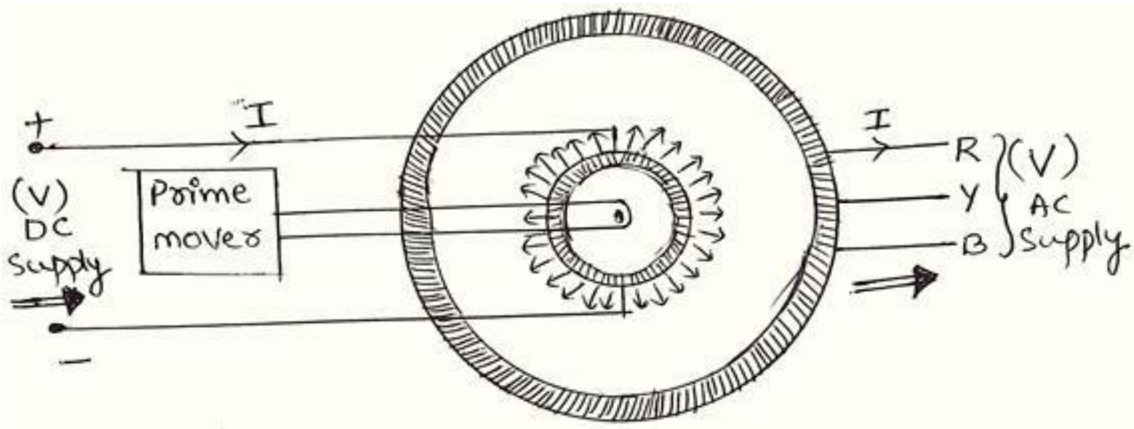
Cylindrical Rotor
(Non-Salient Pole Rotor)

* Rotor is a rotating part of the Alternator.
* Rotor consists of Core and Winding.
* Rotor Core is made up of High Grade Silicon Steel (Magnetic Material).
* Rotor Core is laminated.
* Rotor Winding will be placed on the rotor core.
* Rotor Winding is made up of Copper (Conducting Material)
* There are two types of Rotors (or) Rotor Cores. (1) Projected Pole Rotor (or) Salient Pole Rotor (2) Cylindrical Rotor (or) Non- Salient Pole Rotor.
* The Alternator which has "Salient Pole Rotor" is called as "Salient Pole Alternator".
* The Alternator which has "Non-Salient Pole Rotor" is called as "Non-Salient Pole Alternator".

Comparison between Salient Pole Rotor and Non-Salient Pole Rotor
Comparison between Salient Pole Alternator and Non-Salient Pole Alternator

Sl. No.	Salient Pole Rotor / Salient Pole Alternator	Non-Salient Pole Rotor / Non-Salient Pole Alternator
1		
2	Poles will be projected outside.	Poles will not be projected outside.
3	Winding will be placed on the poles	Winding will be placed in the slots
4	Larger diameter & smaller axial length	Smaller diameter & larger axial length
5	Salient Pole Rotor has to be rotated in low speed	Non-Salient Pole Rotor can be rotated in low speed and high speed also.
6	Preferred for Low and Medium Power Applications.	Preferred for High Power Applications
7	Prime Movers used for this rotor are Diesel Engine, Petrol Engine etc.	Prime Movers used for this rotor are Steam Engines.
8	Salient Pole Alternators are used in Hydel Power Plants	Non-Salient Pole Alternators are used in Thermal Power Plants, Gas Power Plants, Nuclear Power Plants, Banks, Hospitals etc.

Working Principle of Alternator



Step1: V ==> I ==> Production of Magnetic Field due to MMF ==> E

When the rotor is rotated with a Prime Mover (Diesel Engine, Petrol Engine, Steam Engine, Water Turbine and Wind Turbine) and When a DC Voltage is applied to Rotor Winding through Slip Rings, then,

- Current passes through Rotor Winding.
- Magneto Motive Force (MMF) produces Magnetic Field around the Rotor Winding.
- The amount of Magnetic Field is called as Magnetic Flux.
- According to Faraday's Law of Electro Magnetic Induction, an EMF (E) will be induced in Rotor Winding due to alternating Magnetic Flux around the Winding.

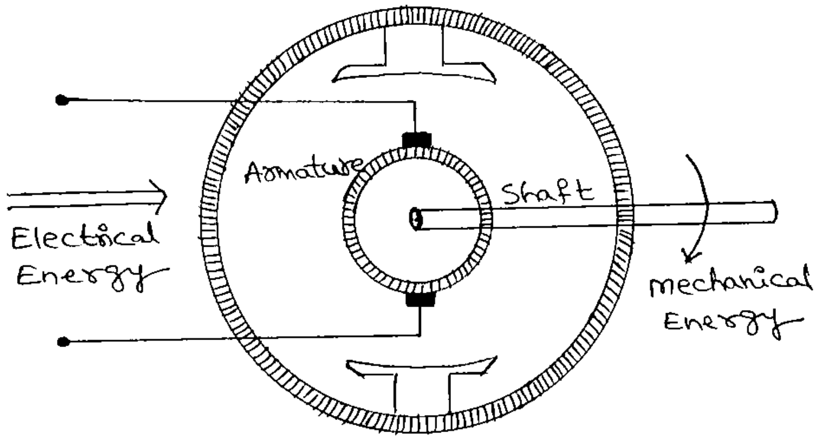
Step2: Production of Magnetic Field due to Mutual Induction ==> E ==> I ==> V

- According to Mutual Induction, as the Stator Winding is surrounded by the Magnetic Field of Rotor Winding, a Magnetic Field will be produced in the Stator Winding.
- The amount of Magnetic Field is called as Magnetic Flux (Ø).
- According to Faraday's Law of Electro Magnetic Induction, an EMF (E) will be induced in Stator Winding due to alternating Magnetic Flux around the Winding.
- Current passes through Stator Winding.
- AC Voltage will be generated from Stator Winding.

DC Machines

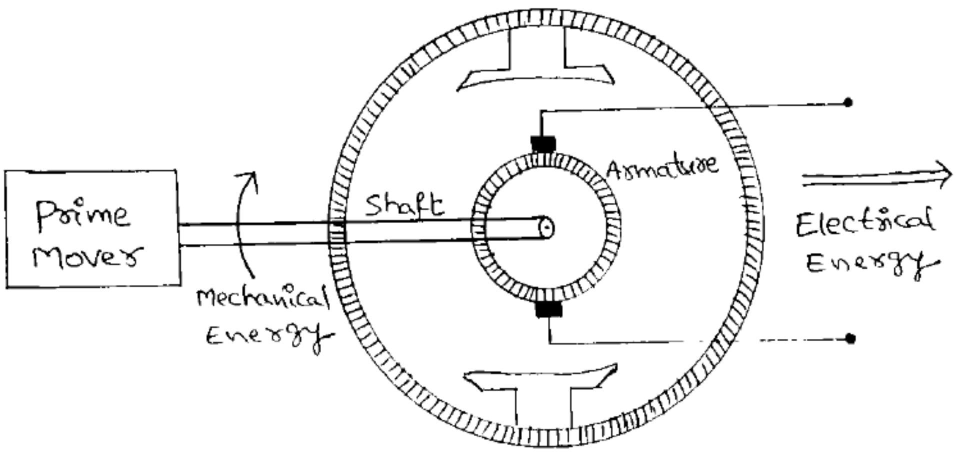
Main Function of DC Motor

DC Motor is a Rotating Electrical Machine which converts Electrical Energy (DC Supply) into Mechanical Energy.



Main Function of DC Generator

DC Generator is a Rotating Electrical Machine which converts Mechanical Energy into Electrical Energy (DC Supply).

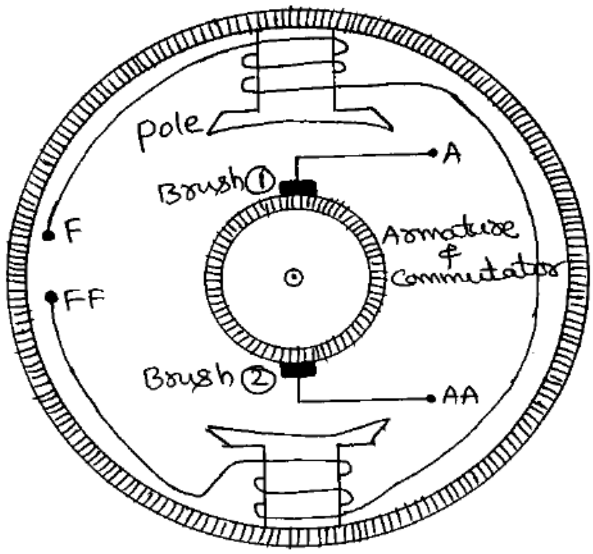


Applications of DC Machines

DC Motors are used in Electric Trains, Lifts, Cranes, Stone Crushers, Water Pumps, Grinding Machines, Printing Machines, Fans.

DC Generators are used in Electric Trains, Battery Charging, Power Supplies.

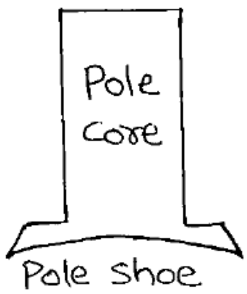
Construction of DC Machine (or) DC Generator (or) DC Motor



The main parts of DC Machine are

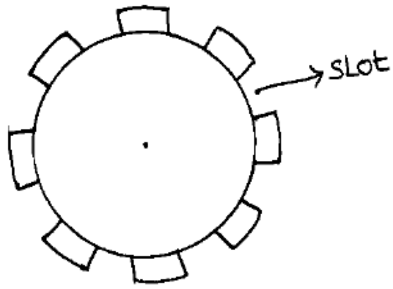
(1) Poles & Field Winding (2) Armature & Armature Winding (3) Commutator & Brushes

(1) Poles and Field Winding:



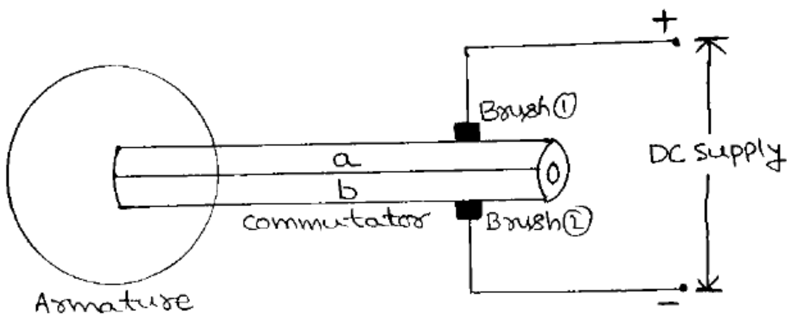
- Pole is a stationary part of the DC Machine.
- Pole consists of Pole Core and Pole Shoes.
- Pole Core is made up of High Grade Silicon Steel (Magnetic Material).
- Pole Core is laminated.
- Field Winding will be placed on the Pole Core.
- Field Winding is made up of Copper.
- When the current passes through the Field Winding, a Magnetic Field will be produced around the Field Winding.
- Pole Shoe distributes or spreads the Magnetic Field.

(2) Armature and Armature Winding:



* Armature is a rotating part of the DC Machine.
* Armature consists of Armature Core and Armature Winding.
* Armature Core is made up of High Grade Silicon Steel (Magnetic Material).
* Armature Core is laminated.
* Armature Core consists of Slots.
* Armature Winding will be placed in the Slots.
* Armature Winding is made up of Copper.

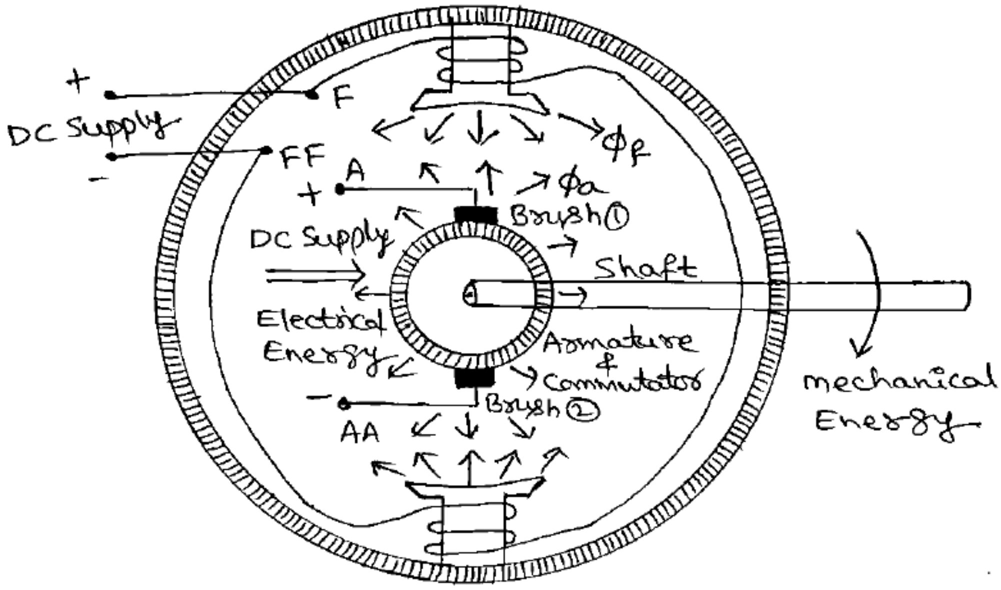
(3) Commutator:



* Commutator is a rotating part of the DC Machine.
* Commutator consists of Commutator Segments (a & b).
* Commutator Segments are made up of Copper.
* Commutator Segments are separated by insulating medium (Mica).
* Commutator Segments are connected to Armature Winding.
* Brushes are the stationary part of the DC Machine.
* Brushes are made up of Carbon.
* In DC Motor, Armature takes the DC Supply through Commutator and Brushes. Commutator converts DC to AC.
* In DC Generator, Armature generates the DC Supply through Commutator and Brushes. Commutator converts AC to DC.

Working Principle of DC Motor

DC Motor is a Rotating Electrical Machine which converts Electrical Energy (DC Supply) into Mechanical Energy.



Step1:

When a DC Voltage is applied to the Field Winding (F – FF), then,

* Current passes through the Field Winding.
* Magneto Motive Force (MMF) produces Magnetic Field around the Field Winding.
* The amount of Magnetic Field is called as Magnetic Flux ($Ø_f$).

Step2:

When a DC Voltage is applied to the Brushes, then,

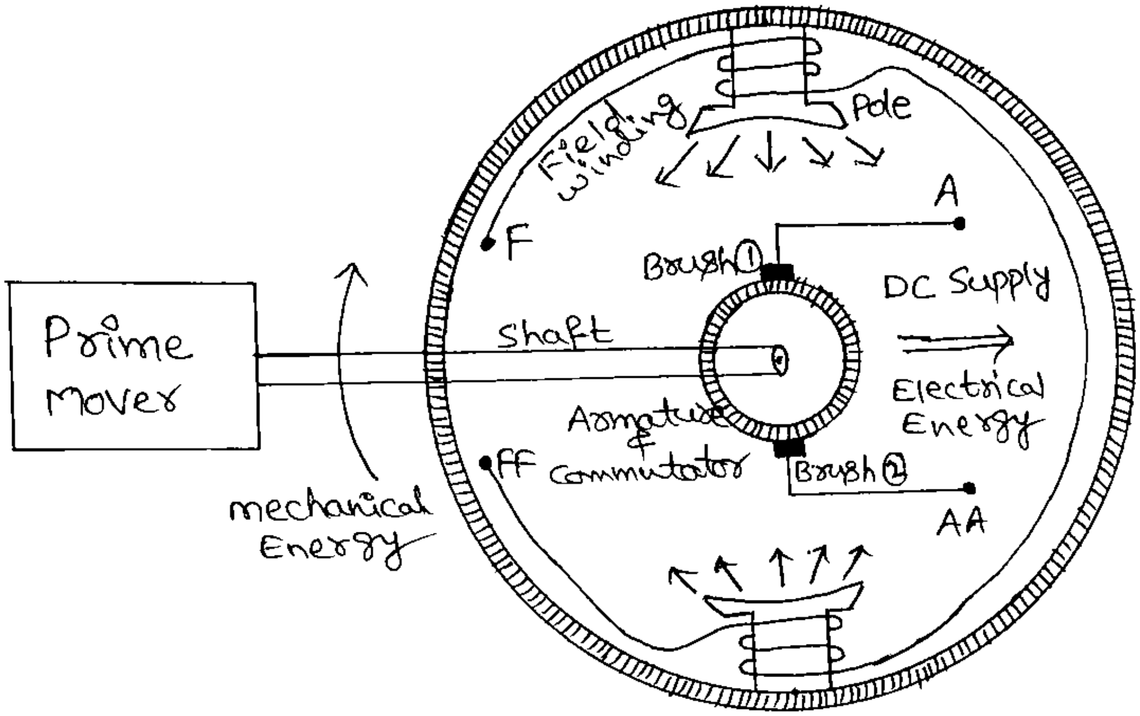
* Commutator collects the DC Voltage from Brushes
* Commutator converts DC Voltage into AC Voltage.
* Armature Winding collects the AC Voltage from Commutator.
* Current passes through the Armature Winding.
* Magneto Motive Force (MMF) produces Magnetic Field around the Armature Winding.
* The amount of Magnetic Field is called as Magnetic Flux ($Ø_a$).

Step3:

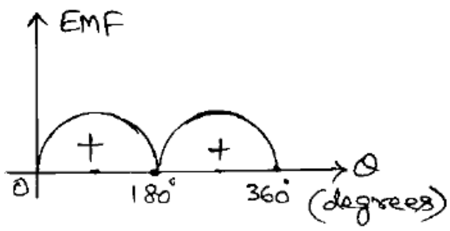
* The directions of $Ø_f$ and $Ø_a$ are opposite to each other.
* Due to the opposite directions of $Ø_f$ and $Ø_a$, both repel with each other and the armature rotates in clockwise direction.

Working Principle of DC Generator

DC Generator is a Rotating Electrical Machine which converts Mechanical Energy into Electrical Energy (DC Supply).

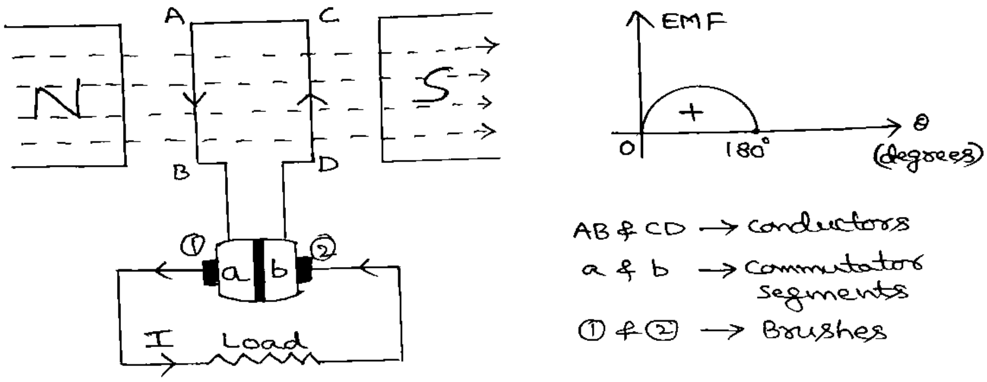


* The examples of Primer Movers are Diesel Engine, Petrol Engine, Steam Engine etc.
* Prime Mover rotates the Shaft, Armature and Commutator.
* When a DC Voltage is applied to Field Winding (F – FF), then, Current passes through Field Winding and Magneto Motive Force (MMF) produces Magnetic Field around the Field Winding
* When the Armature Winding is rotated in the Magnetic Field, an EMF will be induced in the Armature Winding.
* This EMF is AC EMF. But, DC Generator has to generate DC EMF.
* Hence, Commutator is connected to Armature Winding to convert AC to DC.



* As the Commutator is rotating, it is not possible to collect the EMF and Current through wires.
* So, two brushes are placed on the Commutator.
* As the brushes are stationary, it is easy to collect the EMF and Current through wires.

➢ When the Armature Winding rotates from 0^0 to 180^0



- Conductor AB is under North Pole, Therefore, Current direction is downwards.
- Conductor CD is under South Pole, Therefore, Current direction is upwards.
- Current Path is
  AB ==> a ==> 1 ==> Load ==> 2 ==> b ==> CD
- Here, Current is passing through the load from left side to right side which is our assumption. So, Waveform is positive.

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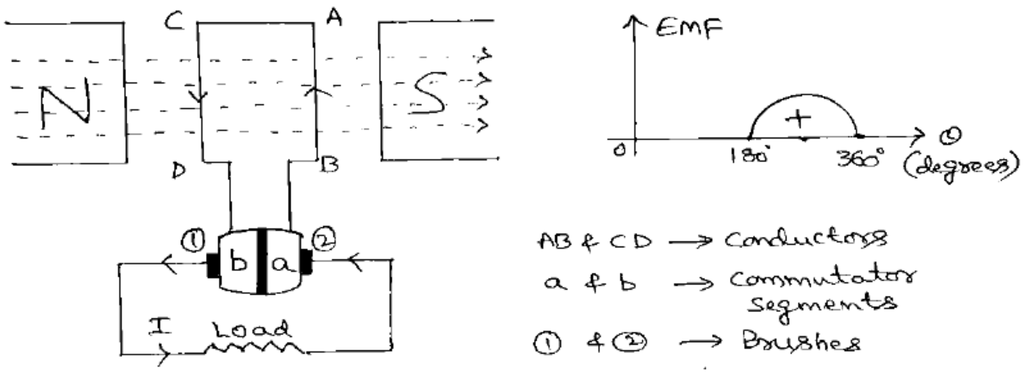
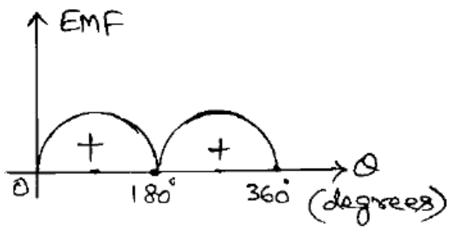
➢ When the Armature Winding rotates from 180^0 to 360^0



- Conductor CD is under North Pole, Therefore, Current direction is downwards.
- Conductor AB is under South Pole, Therefore, Current direction is upwards.
- Current Path is
  CD ==> b ==> 1 ==> Load ==> 2 ==> a ==> AB
- Here, Current is passing through the load from left side to right side which is our assumption. So, Waveform is positive.

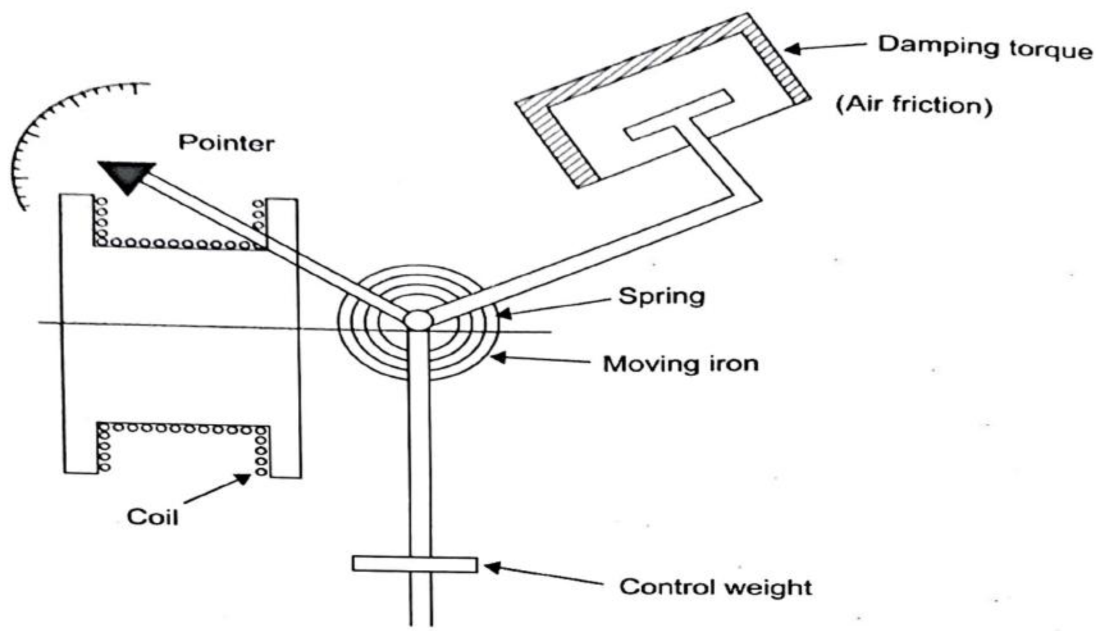
➢ The complete Waveform of Generated EMF is



UNIT – 2 Chapter – 2 Electrical Measurements

Attraction Type MI Meter (Moving Iron Meter)
Repulsion Type MI Meter (Moving Iron Meter)
Advantages and Disadvantages of MI Meters
MC Meter (Permanent Magnet Moving Coil PMMC Meter)
Advantages and Disadvantages of MC Meters
Wheatstone Bridge

Attraction Type MI Meter

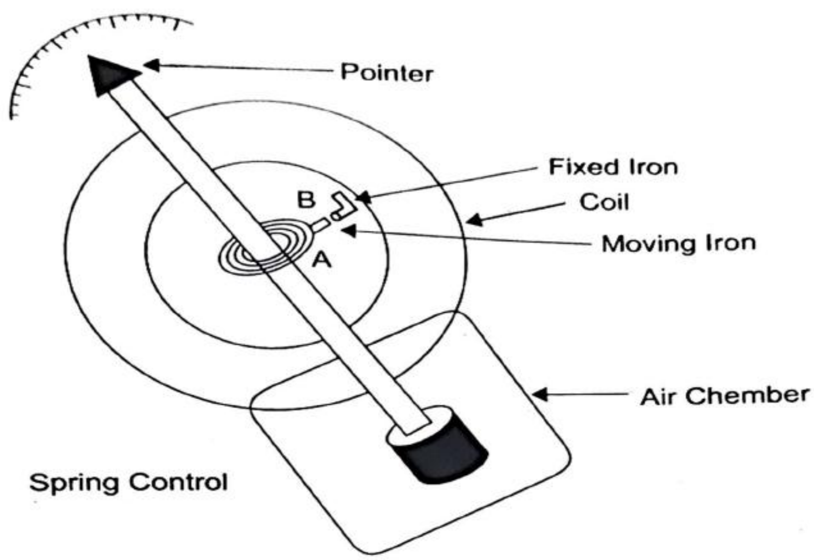


Principle: These instruments are based on the principle that when an unmagnified soft iron piece is placed near the current carrying coil (conductor), then the iron piece is attracted towards the coil. Damping torque is provided by air friction.

Construction: Figure (4.7) shows the constructional details of attraction type moving iron instrument. It mainly consists of a hollow cylindrical coil or solenoid. An oval shaped soft iron piece and a pointer are attached to the spindle, which is supported between two jeweled bearings near the coil. The soft iron piece is free to move in or out of the coil, and then the pointer also deflects on the scale with the motion of the iron piece. This is provided with spring control and air friction damping.

Working: When the instrument is connected to the circuit, the operating current flows through the sta- tionary coil. A magnetic field is set up and the soft iron piece is magnetized, which is attracted towards the centre of the coil. Thus the pointer attached to the spindle is deflected over the calibrated scale. If the current in the coil is reversed, the direction of the magnetic field pro- duced will reverse and the magnetism produced in the soft iron piece will also reverse. Hence, the direction of the deflecting torque remains unchanged. These instruments can, thus, be used on DC as well as AC systems.

Repulsion Type MI Meter



Principle: These instruments are based on the principle that the repulsive force will act, when two similarly magnetized iron pieces are placed nearer to each other.

Construction: It consists of a fixed cylindrical hollow coil, which carries the operating current. Inside the coil there are two vanes placed parallel to each other, one fixed and the other movable, connected to the spindle. In this instrument, controlling torque is provided by spring control method and damping torque is provided by air friction damping,

Working: If current flows through the coil, a magnetic field is set up along the axis of the coil. This field magnetizes both the vanes and attains similar polarity. A force of repulsion acts between the two vanes. Therefore movable vane moves away from the fixed vane. Thus, the pointer attached to the spindle deflects over the calibrated scale.

Advantages and Disadvantages of MI Meter

Advantages: The various advantages of MI instruments are

(i) These instruments can be used for both AC and DC circuits.

(ii) They are quite robust in construction.

(iii) They are comparatively cheaper.

(iv) As the torque to weight ratio is high, errors due to the friction are very less.

(v) They give sufficiently accurate readings, especially when they are used in AC circuits.

(vi) These can withstand large loads and are not damaged under sever over load conditions.

Disadvantages: The various disadvantages of MI instruments are

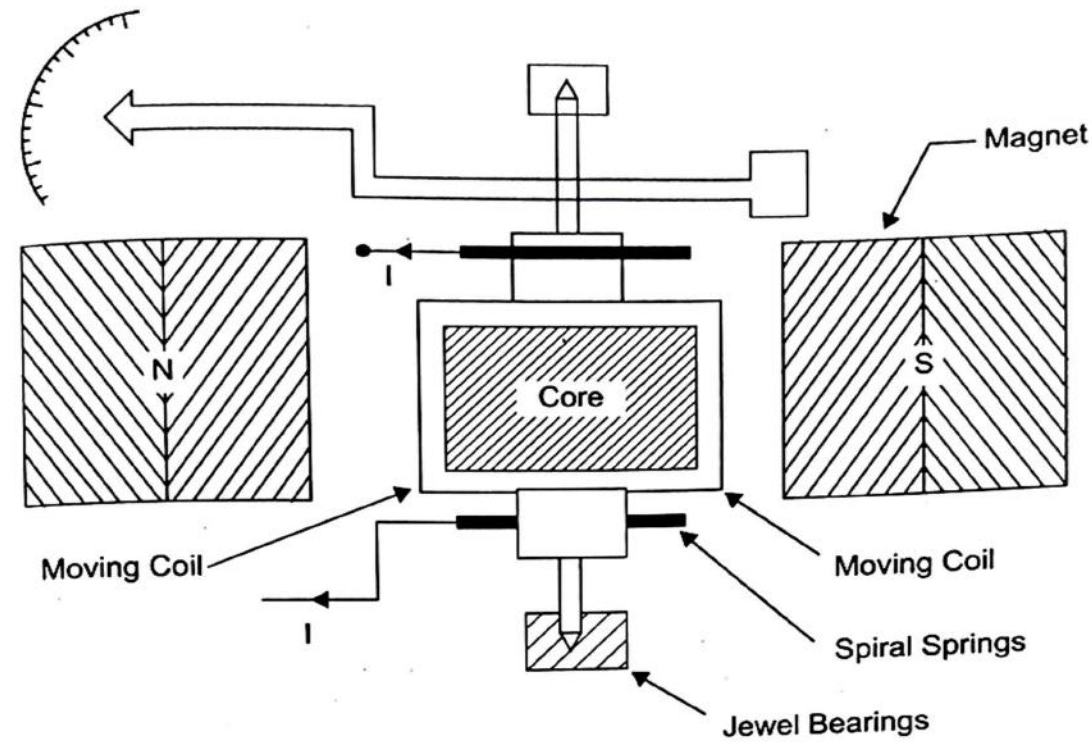
(i) The scale of MI instrument is non uniform ($\theta \propto I^2$ *or* V^2) and is cramped at the lower end. Hence, accurate readings are not possible at this end.

(ii) There are serious errors due to hysteresis, frequency changes, and stray magnetic fields.

(iii) The calibration is different for AC and DC because of the effect of inductance of meter.

(iv) Power consumption is high.

MC Meter (Permanent Magnet Moving Coil PMMC Meter)



Principle: It is based on the principle that, whenever a current carrying conductor is placed in a magnetic field, a mechanical force acts on the conductor.

Construction: A PMMC instrument consists of a permanent magnet and a rectangular coil, which can move about a central axis in the air gap, in between the poles N and S of the magnet as shows in figure (4.9). The coil consists of a number of turns of copper wire and it is mounted on a aluminium former and the rectangular coil lies in the narrow air gaps between the poles and cylinder. The coil is mounted on the spindle and acts as a moving element. The purpose of the aluminium former is to provide the necessary damping torque.

Working: When the instrument is connected in the circuit, operating current flows through the coil, which is mounted on the spindle. Since the coil is placed in the strong magnetic field, a force acts on the coil which produces deflecting torque (T_d). Thus pointer attached to the spindle deflected over the scale. If the current in the coil is reversed, the direction of the deflecting torque will be reversed, because filed produced by the permanent magnet does not change. This change will give wrong direction of rotation. So this instrument can not be used for AC supply.

Advantages and Disadvantages of MC Meter

Advantages: The various advantages of PMMC instruments are:

(i) It has uniform scale

(ii) The sensitivity is high

(iii) Power consumption is very low

(iv) It is very accurate and reliable

(v) No hysteresis loss

(vi) Damping is very simple and effective

(vii) Extension of instrument range is possible

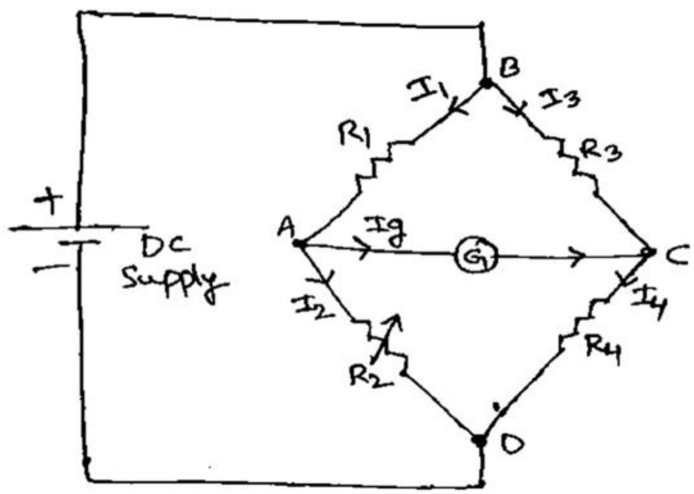
Disadvantages: The various disadvantages of PMMC instruments are:

(i) Suitable for DC measurements only

(ii) The cost is high due to delicate construction

(iii) Errors are present due to friction at the bearings and temperature variations

Wheatstone Bridge



- Wheatstone Bridge is used to measure unknown resistance.
- Wheatstone Bridge was invented by Charles Wheatstone in the year 1843.
- Wheatstone Bridge consists of 4 arms.
- Arm AB consists of fixed resistance R_1.
- Arm BC consists of fixed resistance R_3.
- Arm AD consists of variable resistance R_2.
- Arm CD consists of unknown resistance R_4.
- Arm AC consists of Galvanometer.
- By applying KCL at Node A, $I_1 = I_2 + I_g$ --------> Eqn 1
- By applying KCL at Node C, $I_3 + I_g = I_4$ --------> Eqn 2
- By applying KVL for the loop ABC, $I_1R_1 + I_gR_g = I_3R_3$ --------> Eqn 3
- By applying KVL for the loop ADC, $I_2R_2 = I_4R_4 + I_gR_g$ --------> Eqn 4
- Adjust the variable resistor R_2 to get null deflection in the galvanometer i.e. $I_g = 0$
- Eqn 1 becomes $I_1 = I_2$
- Eqn 2 becomes $I_3 = I_4$
- Eqn 3 becomes $I_1R_1 = I_3R_3$ ==> $R_1 = R_3$ --------> Eqn 5
- Eqn 4 becomes $I_2R_2 = I_4R_4$ ==> $R_2 = R_4$ --------> Eqn 6
- $\frac{\text{Eqn 5}}{\text{Eqn 6}}$ ==> $\frac{R_1}{R_2} = \frac{R_3}{R_4}$
- From the above equation, the unknown resistance R_4 can be calculated.

Energy Resources, Electricity Bill & Safety Measures

5

LEARNING OUTCOMES

After reading this chapter, the reader will be able to

- Outline the importance of electrical energy
- List various conventional and non-conventional energy sources
- Compare conventional and non-conventional energy sources
- Illustrate hydroelectric, nuclear, solar and wind power plants
- Explain different types of tariffs
- Outline the power rating of household appliances
- Illustrate first-aid for electric shock
- Explain the necessity of earthing/grounding
- Illustrate various methods of earthing
- Differentiate fuse and circuit breaker
- Outline the energy consumption calculations

5.1 INTRODUCTION

Energy is the necessity for the economic development of any country. The greater the per capita consumption of energy in a country, the higher is the standard of living of its people. The demand for energy resources are increasing day by day in the development of industries, transportation and agricultural activities. Power and energy are buzzwords in today's world. Energy exists in different forms in nature but the most important form is the electrical energy. The survival of industrial undertakings and our social structures depends primarily on low cost and uninterrupted supply of electrical energy. Electricity is emerged as basic necessity with food, shelter and clothing for human being. Infact, life without electricity has become highly unimaginable. Electric locomotives, heating, cooling, fans, blowers, motors, illumination are some applications that converts electrical energy into useful work.

5.2 ENERGY RESOURCES

Energy resources refer to the various natural sources or technologies used to obtain, produce, and convert energy for various purposes, such as electricity generation, transportation, heating, and industrial processes. Energy resources are classified into two types; such as (*i*) conventional energy resources, and (*ii*) non-conventional resources.

5.2.1 Conventional Energy Resources

Conventional energy resources refer to traditional sources of energy that have been widely used for many years to generate electricity and power in various aspects of modern life. These resources are typically non-renewable, which means they are limited and will eventually exhaust. The most common conventional energy resources include:

(i) Fossil Fuels

(a) Coal: Coal is a black or brownish-black sedimentary rock that is primarily composed of carbon. It has been used for centuries as a source of heat and energy and is burned to produce electricity in coal-fired power plants.

(b) Oil (Petroleum): Crude oil is refined to produce various products, including gasoline, diesel fuel, and jet fuel. These fuels are used in transportation and for power generation.

(c) Natural Gas: Natural gas is a hydrocarbon gas composed primarily of methane. It is used for heating, power generation, and as a fuel for vehicles and industrial processes.

(ii) Nuclear Energy: Nuclear power is generated by harnessing the heat produced during nuclear fission reactions. It is considered a conventional energy source because it has been in use for several decades. Nuclear power plants use uranium or plutonium as fuel.

(iii) Hydropower: Although often considered a renewable energy source, hydropower can also be classified as conventional when it involves large-scale dams and reservoirs. Water is used to turn turbines, generating electricity. This is a mature technology and has been widely used for many years.

(iv) Biomass: Biomass energy is derived from organic materials such as wood, crop residues, and animal waste. It can be burned directly for heat or converted into biofuels like ethanol and biodiesel for transportation and power generation.

These conventional energy sources have been the backbone of the global energy industry for many years. However, they have several drawbacks, including environmental concerns (e.g., greenhouse gas emissions, air and water pollution, and habitat disruption) and the fact that they are finite resources. As a result, there has been a growing emphasis on transitioning to cleaner and more sustainable energy sources, such as renewable energy (e.g., solar, wind, and hydro) and improving energy efficiency to reduce our reliance on conventional energy resources and mitigate their negative impacts on the environment.

5.2.2 Non-conventional Energy Resources

Non-conventional energy resources, also known as alternative or renewable energy resources, because they are typically sustainable, environmentally friendly, and have an unlimited supply. These resources are obtained by using natural processes, which can be replenished in a short amount of time. Here are some examples of non-conventional energy resources:

(i) Solar Energy: Solar power is generated by capturing energy from the sun using photovoltaic cells or solar panels. It is a clean and virtually unlimited source of energy that can be used for electricity generation and heating. Solar panels can be installed on rooftops, in solar farms, and even integrated into building materials.

(ii) **Wind Energy:** Wind turbines convert the kinetic energy of moving air into electricity. Wind power is considered a renewable resource because wind is a natural occurrence that will continue as long as the sun shines. Wind farms are often located in areas with consistent wind patterns.

(iii) **Hydropower (Small-Scale):** In addition to conventional large-scale hydropower, there are smaller-scale hydropower systems that can be installed in rivers or streams to generate electricity. These micro-hydro or mini-hydro systems are less disruptive to ecosystems than large dams.

(iv) **Geothermal Energy:** Geothermal power plants use heat from within the Earth to generate electricity. This heat can be sourced from hot water reservoirs, geysers, or even hot rocks deep underground. Geothermal energy is reliable and has a low environmental impact.

(v) **Biomass Energy (Sustainable Sources):** While conventional biomass can have negative environmental impacts, non-conventional biomass energy sources come from sustainably managed forests and agricultural residues. These materials can be used to generate heat, electricity, or biofuels.

(vi) **Ocean Energy:** Ocean energy includes tidal energy, wave energy, and ocean thermal energy. These technologies harness the power of the ocean's movements and temperature differences to generate electricity. They are still in the early stages of development but have great potential.

(vii) **Hydrogen Energy:** Hydrogen can be produced through various methods, including electrolysis of water using renewable electricity. It can be used as a clean fuel for vehicles and power generation when produced using non-polluting energy sources.

(viii) **Biofuels:** Non-conventional biofuels are produced from organic materials like algae or non-food crops. They can be used to replace traditional fossil fuels in transportation and are considered more environmentally friendly.

(ix) **Waste-to-Energy:** This involves converting municipal solid waste or organic waste into energy through processes like incineration or anaerobic digestion. It not only reduces waste but also produces energy.

Non-conventional energy resources are seen as more sustainable and environmentally responsible alternatives to conventional energy sources like coal, oil, and natural gas. They play a crucial role in reducing greenhouse gas emissions, mitigating climate change, and transitioning to a cleaner and more sustainable energy future.

5.2.3 Comparison between Conventional and Non-conventional Energy Resources

S.No.	Parameter	Conventional energy resources	Non-conventional energy resources
1.	Source	Derived from fossil fuels (coal, oil, natural gas), nuclear, and large hydropower sources.	Derived from renewables such as sun, wind, water, geothermal, and sustainably sourced biomass.
2.	Availability	Limited and finite; fossil fuel reserves are depleting.	Virtually unlimited, relying on ongoing natural processes.
3.	Environmental Impact	High environmental impact, including greenhouse gas emissions, pollution, habitat disruption, and ecosystem damage.	Low environmental impact, minimal emissions and pollution in generation.

4.	Sustainability	Often unsustainable due to finite reserves and environmental harm.	Sustainable, relying on natural replenishment.
5.	Technology Maturity	Mature and well-established technologies.	Evolving advancing technologies with ongoing R&D
6.	Energy Security	Vulnerable to price, supply, and geopolitics.	Enhanced security from decentralized, domestic production.
7.	Economic Considerations	Historically cheaper with long-term costs.	Becoming cost-competitive, potential for savings and less external impact.
8.	Energy Independence	Often rely on imports, leading to energy dependence on other countries.	Promote energy independence by harnessing local and domestic resources.
9.	Climate Change Mitigation	Contribute significantly to climate change through greenhouse gas emissions.	Crucial for climate mitigation, reducing emissions, and providing clean energy alternatives.
10.	Job Creation	Create extractive jobs, limited long-term employment.	Generate more jobs, including in manufacturing and maintenance with potential for long-term employment.

In summary, conventional energy resources are associated with environmental concerns, finite availability, and economic vulnerabilities, while non-conventional energy resources are characterized by sustainability, lower environmental impact, and increasing economic viability. The transition from conventional to non-conventional energy sources is driven by the need for environmental protection, energy security, and a sustainable energy future.

5.3 IMPORTANCE OF ELECTRICAL ENERGY

Electrical energy is superior to all other forms of energy due to the following reasons:

(i) **Cheapness/Economy:** Electrical energy is much cheaper than other forms of energy. So, it is very economical for domestic, commercial and industrial purposes.

(ii) **Cleanliness:** Electrical energy does not produce smoke, fumes or poisonous gases and therefore, its usage ensures cleanliness and healthy conditions.

(iii) **Convenient form:** Electrical energy is a very convenient form of energy. It can be easil converted into other forms of energy like heat, light, mechanical, sound or chemical.

(iv) **Easy control**: The electrically operated machines have simple and convenient startin control and operation. For example, the speed of electric motors can be easily varie over the desired range with simple arrangements.

(v) **Greater flexibility:** Electrical energy offers greater flexibility as it can be easi transported from one place to another with the help of solid or stranded conductors.

(vi) **High transmission efficiency**: The consumers of electrical energy are general situated far away from the generating stations. The electrical energy can be transmitt conveniently and efficiently from the centres of generation to the consumers with t help of transmission lines.

5.4 HYDROELECTRIC POWER PLANT

Hydroelectric power is the power obtained from the energy of falling water whereas hydroelectric power plant is the power plant utilizing the potential of water at a high level for the generation of electrical energy. Hydroelectric power stations are generally located in hilly areas where dams can be built conveniently and large water reservoirs can be obtained.

In a hydroelectric power station, water head is created by a construction of a dam across a river or lake. The pressure head or potential energy of water is utilized to drive the water turbine coupled to alternators, which generates electrical power.

In a hydropower station, water head is used to drive water turbine coupled to the generator. Water head may be available in hilly region naturally in the form of water reservoir (lakes etc.) at the hilltops. The potential energy of water can be used to drive the turbo generator set installed at the base of the hills through piping called penstock. Water head may also be created artificially by constructing dams on a suitable river.

5.4.1 Selection of site for hydroelectric power plant

The following points should be taken into account while selecting the site for a hydroelectric power station:

(i) **Availability of water:** The primary requirement of a hydroelectric power plant is the availability of huge quantity of water, so these plants should be built at a place, where adequate water is available at a good head.

(ii) **Storage of water:** The water supply from a river or canal varies during the year. This requires storage of water by constructing a dam in order to ensure the power generation throughout the year. The storage helps in equalizing the flow of water so that any excess quantity of water at a certain period of the year can be made available during times of very low flow in the river.

(iii) **Availability of land:** The land available should be cheap in cost and rocky in order to withstand the weight of the large building and heavy machinery.

(iv) **Water pollution:** Polluted water may cause excessive corrosive and damage to the metallic structures. Hence, availability of good quality of water is essential.

(v) **Transportation facility:** The site selected for a hydroelectric plant should be accessible by rail and road so that necessary equipment and machinery can be easily transported.

5.4.2 Layout diagram of hydroelectric power plant

The main components of a hydroelectric power plant as shown in figure (5.1) are as listed below:

(i) Dam

(ii) Reservoir

(iii) Penstock

(iv) Surge Tank

(v) Power House

(a) Hydraulic turbine (Prime mover)

(b) Generators and Step-up Transformers

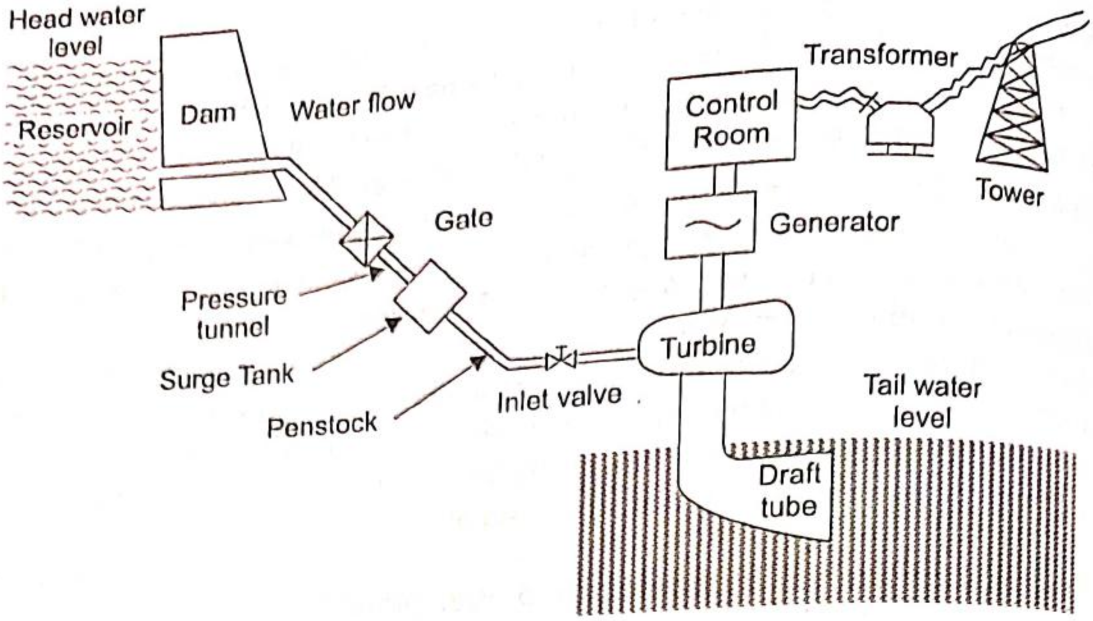


Figure (5.1): *Schematic diagram of hydroelectric power plant*

(i) Dam: A dam is a barrier which stores water and creates water head. The purpose of the dam is to store the water and to regulate the outgoing flow of water. The dam helps to store all the incoming water. It also helps to increase the head of the water.

(ii) Reservoir: It is a basic requirement of hydro electric power plant. Its purpose is to store water which may be used to run the prime mover to produce electrical power. It stores water during rainy season and supplies the water during dry season.

(iii) Penstock: Penstock is a closed pipe of steel or concrete for supplying water under pressure to the turbine. There are two types of penstock, low pressure and high pressure. The low pressure type consists of canal, a flume or pipe. The high pressure type consists of steel pipes, which can take water under pressure.

(iv) Surge tank: A surge tank is a small reservoir or tank in which water level rises or falls to reduce the pressure swings in the penstock. A surge tank is located near the beginning of the penstock. It reduces the distance between the free water surface in the dam and the turbine, thereby reducing the water-hammer effect on penstock.

Water-hammer effect: The water hammer is defined as the change in pressure rapidly above or below normal pressure caused by sudden change in the rate of water flow through the pipe, according to the demand of prime mover i.e. turbine.

(v) Power house: It is generally located at the foot of the dam and near the storage reservoir. If the power house is near the dam, the loss of head due to friction in the penstock would be less. A power house consists of two main parts, hydraulic and electric equipments.

(a) Hydraulic turbine (Prime mover): The hydraulic turbine converts the kinetic energy of water into mechanical energy. The mechanical energy (rotational) available on the turbine shaft is coupled to the shaft of an electric generator. The water after performing the work on turbine blades is discharged through the draft tube. The prime movers which are in common use are Pelton wheel, Francis turbine and Kaplan turbine.

Draft tube: It is connected to the outlet of the turbine. It allows the turbine to be placed above the tail water level. Tail water level is the water level after the discharge from the turbine. The discharged water is sent to the river, thus the level of the river is the tail water level.

(b) **Generators and step-up transformers:** As the water rushes through the turbine, it spins the turbine shaft, which is coupled to the electric generator. The generator has a rotating electromagnet called a rotor and a stationary part called a stator. The rotor creates a magnetic field that produces an electric charge in the stator. The charge is transmitted as electricity. The step-up transformer increases the voltage and current coming from the stator.

5.5 NUCLEAR POWER PLANT

A generating station in which nuclear energy is converted into electrical energy is known as a nuclear power station. In nuclear power station, heavy elements such as Uranium (U^{235}) or Thorium (Th^{232}) are used subjected to nuclear fission in the core of the reactor. The heat energy thus released is utilized in raising steam at high temperature and pressure. The steam runs the steam turbine, which converts steam energy into mechanical energy. The turbine drives the alternator which converts mechanical energy into electrical energy.

The most important feature of a nuclear power station is that huge amount of electrical energy can be produced from a relatively small amount of nuclear fuel as compared to other conventional types of power stations. 1 kg of Uranium U^{235} can produce as much energy as the burning of 4500 tonnes of high grade variety of coal or 2000 tonnes of oil.

5.5.1 Selection of site for nuclear power plant

The following points should be taken into account while selecting the site for a nuclear power station:

(i) **Availability of water:** As sufficient water is required for cooling purposes, therefore, the plant site should be located where ample quantity of water is available, e.g., across a river or by sea-side.

(ii) **Availability of space for disposal of waste:** The waste produced by fission in a nuclear power station is generally radioactive which must be disposed off properly to avoid health hazards. Therefore, the site selected for such a plant should have adequate arrangement for the disposal of radioactive waste.

(iii) **Distance from populated areas:** The site selected for a nuclear power station should be quite away from the populated areas as there is a danger of presence of radioactivity in the atmosphere near the plant. However, as a precautionary measure, a dome is used in the plant that does not allow the radioactivity to spread by wind or underground waterways.

(iv) **Transportation facilities:** The site selected for a nuclear power station should have adequate facilities in order to transport the heavy equipment during erection and to facilitate the movement of the workers employed in the plant.

From the above mentioned factors it becomes apparent that ideal choice for a nuclear power station would be near sea or river and away from thickly populated areas.

5.5.2 Layout Diagram of Nuclear Power Plant

The main components of a Nuclear power plant as shown in figure (5.2) are listed below.

(i) Nuclear reactor

(ii) Heat exchanger

(iii) Steam turbine

(iv) Alternator

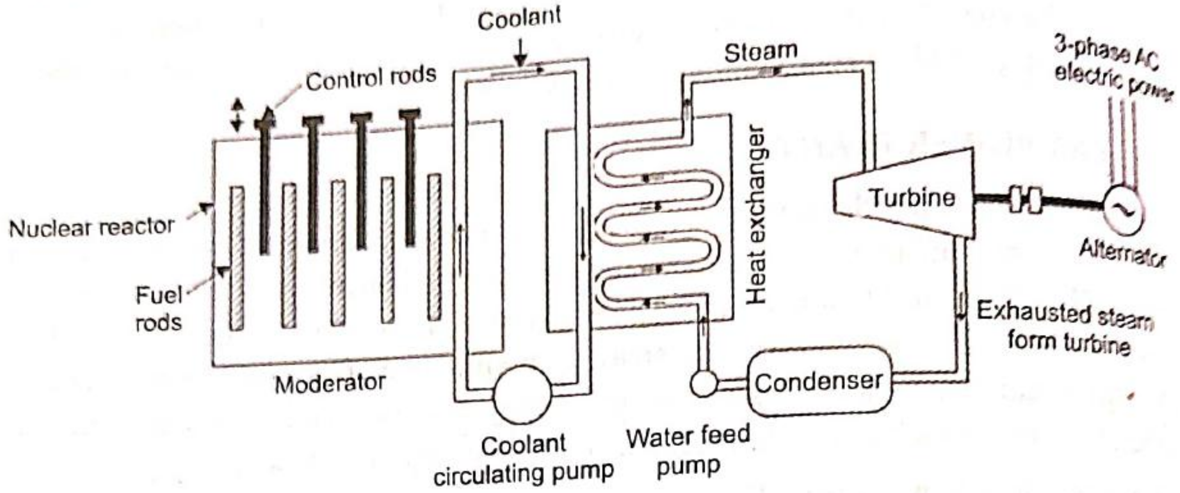


Figure (5.2): *Schematic diagram of Nuclear Power Plant*

(i) Nuclear reactor: A nuclear reactor is a cylindrical stout pressure vessel and houses fuel rods of Uranium, moderator and control rods. The present day atomic power plants work on the principle of nuclear fission of U^{235}. In the natural uranium, U^{235} constitutes only 0.72% and remaining parts is constituted by 99.27% of U^{238} and only about 0.05% of U^{234}. The concentration of U^{235} may be increased to 90% by gas diffusion process to obtain enriched U^{235}. When U^{235} is bombarded by neutrons a lot of heat energy along with additional neutrons are produced. These new neutrons further bombard U^{235} producing more heat and more neutrons. Thus a chain reaction sets up. However, the reaction is allowed to take place in a controlled manner inside a closed chamber called nuclear reactor. To ensure sustainable chain reaction, moderator and control rods are used. Moderators such as heavy water (deuterium) or very pure carbon C^{12} are used to reduce the speed of neutrons. To control the number neutrons, control rods made of cadmium or boron steel are inserted inside the reactor. The control rods can absorb neutrons. If we want to decrease the number neutrons, the control rods are lowered down further and vice versa. The heat generated inside the reactor is taken out of the chamber with the help of a coolant such as liquid sodium or some gaseous fluids.

(ii) Heat Exchanger: The coolant gives up heat to the heat exchanger to convert it to steam. After giving up heat, the coolant is again fed to the reactor.

(iii) Steam turbine: The steam produced in the heat exchanger is led to the steam turbine through a valve. After doing a useful work in the turbine, the steam is exhausted to condenser. The condenser condenses the steam, which is fed to the heat exchanger through feed water pump.

(iv) Alternator: The steam turbine drives the alternator, which converts mechanical energy into electrical energy. The output from the alternator is delivered to the bus-bars through transformer, circuit breakers and isolators.

5.6 SOLAR POWER GENERATION

Solar power generation is the process of converting sunlight into electricity or heat using photovoltaic (PV) panels or solar thermal systems. Solar power is a renewable and sustainable energy source that has gained popularity due to its environmental benefits and decreasing cost. The layout and operation of a solar power generation system can vary depending on its scale and purpose, but we will provide a general overview of the components and how they work together in a typical grid-tied solar power system.

5.6.1 Selection of Site for Solar Power Generation

Selecting the right site for solar power generation is critical to maximize the efficiency and effectiveness of solar energy system. Several factors should be considered when choosing a site for a solar power installation, whether it's a residential, commercial, or utility-scale project. The various factors are as listed below:

(i) **Solar resource potential:** The amount of sunlight a site receives throughout the year is a primary consideration. A location with a lot of direct sunlight and a high solar insolation is needed.

(ii) **Orientation and tilt:** The orientation and tilt angle of the solar panels significantly impact energy production. Solar panels should ideally face south for maximum sun exposure. The tilt angle should be optimized based on the site's latitude.

(iii) **Shading:** Avoid shading from nearby structures, trees, or other obstructions. Even small amounts of shading can reduce the efficiency of solar panels.

(iv) **Available space:** Assess the available space for solar panel installation. Rooftop systems utilize existing structures, while ground-mounted systems require open land.

(v) **Grid access:** If you plan to connect your solar power system to the electrical grid, ensure that there is a reliable grid connection available. Proximity to the grid connection point can affect installation costs.

(vi) **Land use and zoning:** Check local land use regulations and zoning codes to ensure that solar installations are allowed in the chosen area. Some areas may have restrictions on land use or may require permits for solar projects.

(vii) **Environmental impact:** Evaluate the potential environmental impact of solar installation. Ensure that it doesn't harm protected species, disrupt ecosystems, or violate environmental regulations. Environmental assessments and permits may be necessary.

(viii) **Topography and soil conditions:** The site's topography and soil conditions can affect the cost and feasibility of solar installation. Steep slopes, rocky terrain, or poor soil quality may require additional engineering and construction work.

(ix) **Weather conditions:** Consider local weather patterns and climate conditions. Extreme weather events, such as hurricanes or heavy snowfall, may impact the design and durability of the solar power system.

(x) **Accessibility:** Ensure that the site is easily accessible for equipment delivery, installation, and maintenance. Accessibility can affect installation costs and ongoing upkeep.

(xi) **Local incentives and regulations:** Research local incentives, tax credits, and regulatory policies that may impact the financial feasibility of solar project. Some regions offer incentives to encourage solar adoption.

(xii) Community and stakeholder support: Engage with the local community and stakeholders to address concerns and build support for the solar project. Public opinion and community support can influence the permitting process and project success.

(xiii) Long-term goals: Consider the long-term energy goals. Determine if the selected site can accommodate future expansions or additions to your solar power system.

5.6.2 Grid-tied Solar Power System

Grid-tied solar system generally consists of the following components as shown in figure (5.3).

(i) Solar Panels (Photovoltaic Cells)

(ii) Mounting Structure

(iii) Inverters

(iv) Electrical Panel

(v) Net Meter

(vi) Utility Grid Connection

(vii) Monitoring System

(i) Solar Panels (Photovoltaic Cells): Solar panels are the heart of a solar power system. They consist of photovoltaic cells made of semiconductor materials, typically silicon. When exposed to sunlight, these cells generate direct current (DC) electricity. Solar panels can be mounted on various surfaces, such as rooftops, ground mounts, or tracking systems to maximize sun exposure.

(ii) Mounting Structure: Solar panels are typically mounted on a structure that positions them at an optimal angle and orientation to the sun. Rooftop systems are attached to the roof, while ground-mounted systems are installed on the ground. Tracking systems follow the sun's path throughout the day to maximize energy production.

(iii) Inverters: The electricity generated by solar panels is in DC form, but most household appliances and the electrical grid operate on alternating current (AC). Inverters are used to convert the DC electricity produced by the solar panels into AC electricity.

(iv) Electrical Panel: The AC electricity produced by the inverter is then sent to the electrical panel or breaker box of the building. It can be used to power appliances and electrical loads within the building.

(v) Net Meter: If the solar power system is grid-tied (connected to the electrical grid), a net meter is installed. This bi-directional meter measures the electricity flowing both from the grid to the building and from the solar system to the grid. When the solar system generates more electricity than is needed, the excess is sent back to the grid, and the meter records this surplus.

(vi) Utility Grid Connection: A grid-tied solar power system remains connected to the local utility grid. During periods of high solar production, excess electricity is fed into the grid. Conversely, when solar production is low (e.g., at night), electricity is drawn from the grid.

(vii) Monitoring System: Many solar power systems come with monitoring equipment that allows homeowners or system operators to track the system's performance, energy production, and overall health. This helps identify issues and optimize system efficiency.

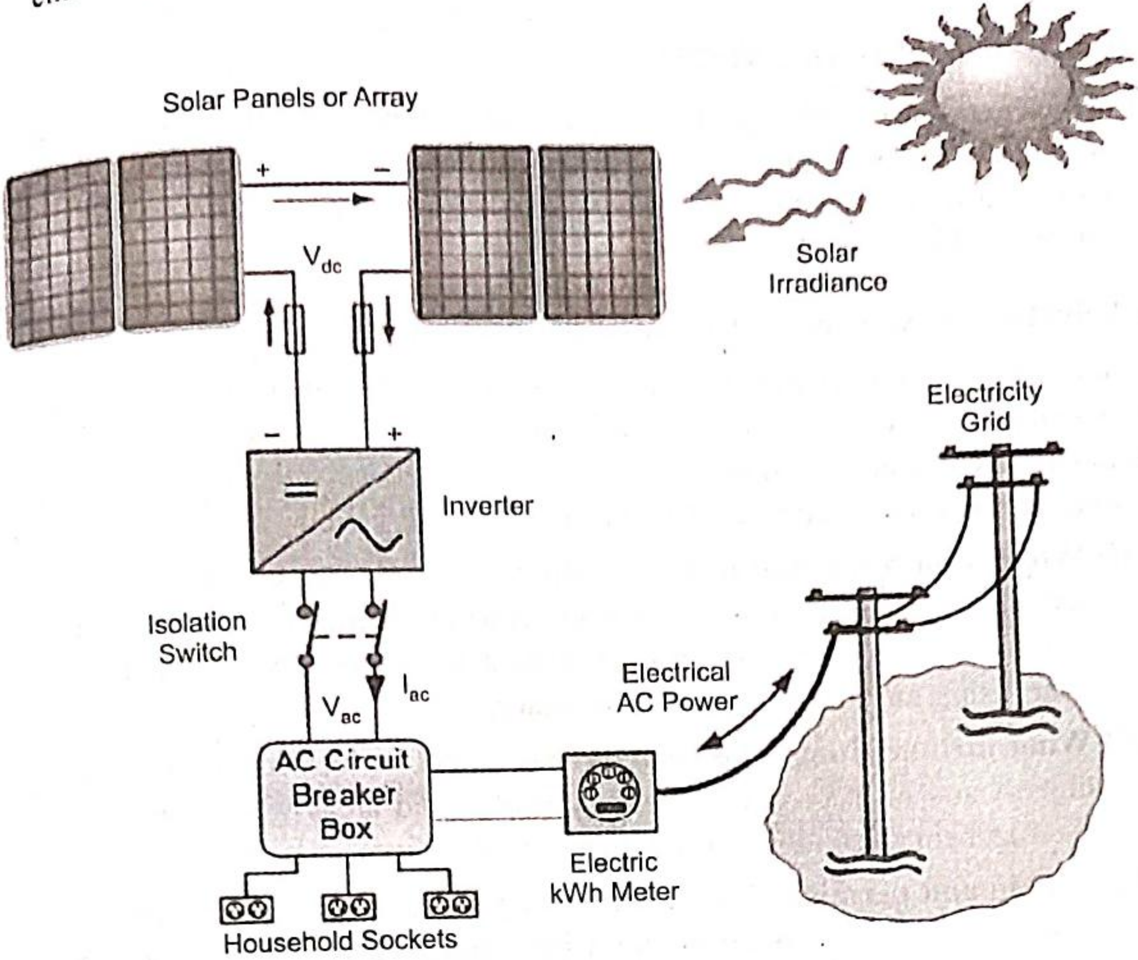


Figure (5.3): *Schematic diagram of grid tied solar system*

Operation of Grid-tied solar power system

Sunlight Capture: Solar panels capture sunlight and convert it into electricity through the photovoltaic effect. The more direct and intense the sunlight, the more electricity the panels generate.

Inverter Conversion: The DC electricity produced by the solar panels is sent to the inverter, where it is converted into AC electricity suitable for household use.

Power Consumption: The AC electricity produced by the inverter is used to power the building's electrical loads. If the solar system generates more electricity than the building consumes, the excess is exported to the grid.

Grid Interaction: In a grid-tied system, any excess electricity is sent to the utility grid, and the homeowner may receive credits or compensation for this surplus energy.

Night and Low Sunlight: During nighttime and periods of low sunlight, electricity is drawn from the grid to meet the building's power needs.

Monitoring and Maintenance: The system's performance is monitored to ensure it operates efficiently. Routine maintenance may include cleaning panels, checking connections, and addressing any issues.

Solar power generation systems offer renewable and clean energy, reduce electricity bills, and can have a positive environmental impact by reducing greenhouse gas emissions.

The operation of off-grid systems is similar but includes battery storage to provide electricity during periods of low or no sunlight.

5.7 WIND POWER GENERATION

Wind power generation, often referred to as wind energy or wind electricity, is the process of converting the kinetic energy of wind into electrical power. Wind turbines are the primary technology used for harnessing wind energy, and they have become an increasingly important source of renewable energy worldwide.

5.7.1 Selection of site for wind power generation

Site selection for wind power generation requires a thorough assessment of technical, environmental, regulatory, and social factors. It's often advisable to work with wind energy professionals and conduct a comprehensive wind resource assessment to ensure that the chosen site is suitable for your specific wind energy project. The various factors are as listed below:

(i) **Wind resource assessment:** The primary factor to assess is the wind resource at the site. We will need to gather data on wind speeds, directions, and turbulence at various heights above the ground. This data is typically collected over at least a year, using anemometers and wind vanes.

(ii) **Wind turbine siting:** The wind turbine should be located where it can capture the highest and most consistent wind speeds. Avoid areas with significant turbulence, such as behind buildings or near large obstructions.

(iii) **Zoning and permits:** Check local zoning regulations and permitting requirements. Ensure that the site is zoned for wind energy projects and obtain the necessary permits before proceeding.

(iv) **Environmental impact:** Assess the potential environmental impact of the wind energy project. Consider the effects on local wildlife, particularly birds and bats, as well as the impact on natural landscapes and ecosystems. Environmental assessments and permits may be required.

(v) **Access and infrastructure:** Ensure that the site is accessible for the delivery, installation, and maintenance of wind turbines and related infrastructure. Adequate road access, crane access, and electrical connections to the grid are essential.

(vi) **Grid connection:** Confirm the feasibility of connecting the wind energy system to the electrical grid. Analyze the capacity of the local grid to accommodate the energy produced and the requirements for grid interconnection.

(vii) **Meteorological data:** In addition to wind resource data, consider other meteorological factors such as temperature, humidity, and air density, as these can affect turbine performance and efficiency.

(viii) **Turbine height and size:** Choose an appropriate turbine height and size, based on the wind resource and site conditions. Taller turbines can access higher wind speeds, but they may have stricter permitting requirements and higher costs.

(ix) **Aviation and airspace considerations:** Ensure that the site complies with aviation and airspace regulations. Wind turbines can interfere with air traffic, so you may need to coordinate with aviation authorities.

(x) **Community and stakeholder engagement:** Engage with the local community and stakeholders to address concerns, build support, and foster positive relationships. Public opinion and local support can impact the permitting process and project success.

(xi) **Long-term viability:** Consider the long-term viability of the site. Assess how the wind resource may change over time, as well as the expected lifespan of the wind turbines. Plan for regular maintenance and potential repowering.

5.7.2 Layout and operation of wind power generation

Wind power generation system generally consists of the following components as shown in figure (5.4):

(i) Wind Turbines
(ii) Energy Conversion System
(iii) Electrical System
(iv) Grid Connection
(v) Energy Storage (Optional)
(vi) Monitoring and Control unit

(i) **Wind turbines:** Wind turbines are the primary components of a wind power generation system. They consist of large rotor blades mounted on a hub, which is connected to a generator. The kinetic energy of the wind causes the blades to rotate, which in turn drives the generator. Wind turbines are strategically placed in locations with a consistent and strong wind resource. Factors such as wind speed, direction, and turbulence are considered when determining optimal placement within a wind farm.

(ii) **Energy conversion system:** As the wind flows over the rotating blades, it causes them to turn, converting kinetic energy into mechanical energy. The mechanical rotation is used to turn a generator, typically an alternator, which converts mechanical energy into electrical energy.

(iii) **Electrical system:** The electricity generated by the wind turbine's generator is initially in the form of alternating current (AC). In many cases, wind turbines are connected to an electrical system that includes transformers, switchgear, and inverters to adjust voltage levels and convert AC power into a suitable form for transmission and distribution.

(iv) **Grid connection:** Wind power systems are often connected to the electrical grid, allowing the generated electricity to be distributed to homes, businesses, and industries. Grid-connected wind farms use transmission lines to transport electricity to consumers.

(v) **Energy storage:** Some wind power installations incorporate energy storage systems, such as batteries, to store excess electricity during periods of high wind. Energy storage helps ensure a consistent and reliable energy supply, even when the wind isn't blowing.

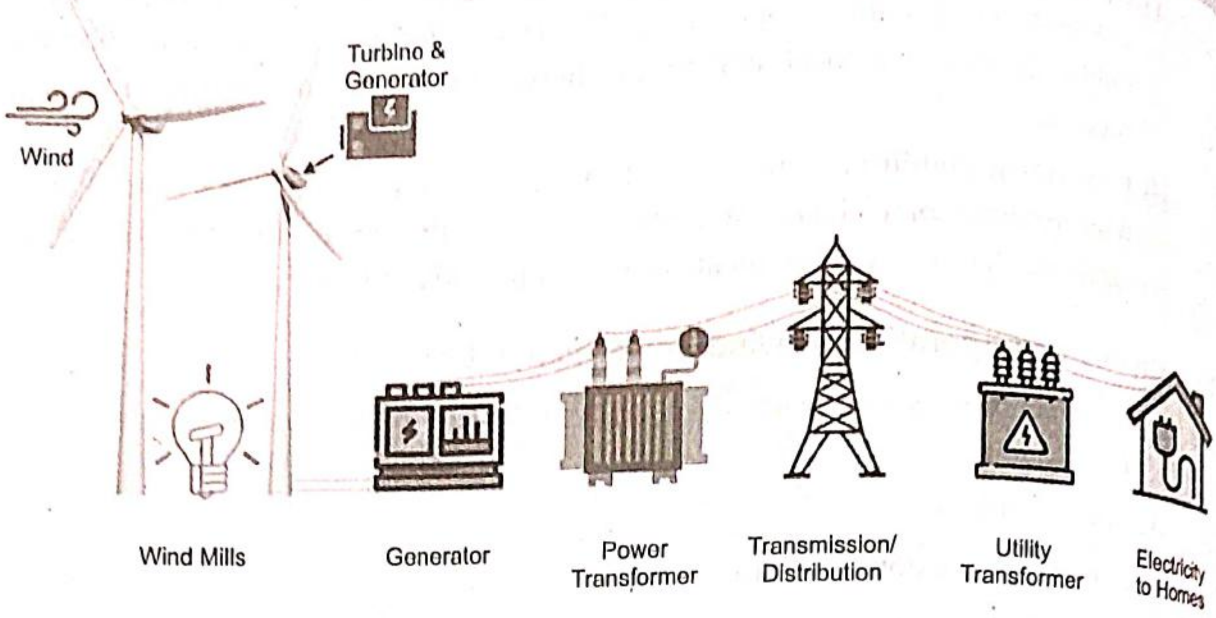


Figure (5.4): *Schematic diagram of wind power generation*

(vi) **Monitoring and control unit:** Wind power systems are equipped with monitoring and control systems that continuously track wind conditions, turbine performance, and overall system health. These systems optimize turbine operation and can diagnose issues for maintenance.

Operation of Wind Power Generation System

Wind Capture: As the wind blows, it flows over the blades of the wind turbine, causing them to rotate. The shape and design of the blades are engineered to efficiently capture the kinetic energy of the wind.

Mechanical Rotation: The mechanical rotation of the turbine's blades is transferred to the generator's rotor. This rotor is connected to a shaft, which spins inside the generator.

Energy Conversion: Within the generator, the mechanical energy is converted into electrical energy through electromagnetic induction. This process produces alternating current (AC) electricity.

Grid Interaction: In a grid-connected system, the AC electricity is synchronized with the grid's frequency and voltage and is fed into the electrical grid. This electricity is then distributed to consumers.

Energy Storage (If Applicable): If an energy storage system is present, excess electricity generated during periods of high wind can be stored for later use.

Monitoring and Control: The wind power system continuously monitors wind conditions, turbine performance, and electrical output. Automated control systems adjust the turbine's orientation (yaw), blade pitch, and other parameters to optimize energy capture and ensure safe operation.

Wind power generation offers numerous advantages, including sustainability, reduced greenhouse gas emissions, and renewable energy production. However, challenges such as intermittency, land use, and visual impact should be considered when planning and operating wind power projects. Wind power is becoming a more viable source of clean energy because of improvements in wind turbine technology, energy storage, and grid integration.

5.8 TARIFF

Today's interconnected power system, supply a number of consumers. With such a big organization management, economy and control come into account automatically. The supply companies (usually in the public sector) have to sell their electricity at such a rate that it covers the costs of generation, transmission, distribution, salaries of the employees, interest and depreciation and profit targeted by the company. The rate at which electrical energy is sold to the consumer is termed as 'tariff'. The cost of generation of electricity will depend upon various factors such as connected load, maximum demand, load factor, demand factor, diversity factor, plant capacity factor and plant use factor. These, in turn, will depend upon the type of load and load conditions. Hence, the tariff is different for different type of loads and hence different consumers. Therefore, while fixing the tariff, we have to consider various consumers (industrial, domestic, commercial, etc.) and their requirements.

5.8.1 Desirable Characteristics of a tariff

A tariff must have the following desirable characteristics or objectives:

- It should be such that the total cost of generation, transmission, and distribution is recovered.
- It should earn a reasonable profit.
- It must be fair and reasonable to the consumers.
- It should be simple and easy to apply.
- It should be attractive than a competitor.

Keeping in mind the above factors, various types of tariff have been designed.

5.8.2 Types of Tariff

There are several types of tariff. However, the following are the commonly used types of tariffs:

(i) Simple tariff

(ii) Flat rate tariff

(iii) Block rate tariff

(iv) Two part tariff

(v) Maximum demand tariff

(vi) Power factor tariff

(vii) Three part tariff

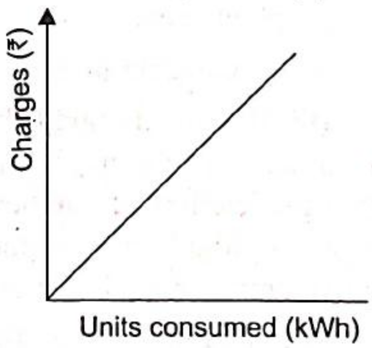


Figure (5.5): *Simple tariff*

(i) Simple tariff: In this type of tariff, a fixed rate is applied for each unit of the energy consumed. It is also known as a uniform tariff. The rate per unit of energy does not depend upon the quantity of energy used by a consumer. The price per unit (1kWh) of energy is constant. This energy consumed by the consumer is recorded by the energy meters. Graphically, it can be represented as shown in figure (5.5).

Advantages:

- Simplest method.
- Easily understandable and easy to apply.

- Consumer has to pay according to his utilization.

Disadvantages:

- No discrimination based on consumer types.
- Cost per unit is high.
- No incentives.

Applications:

- Generally applied to tube wells used for irrigation purposes.

(ii) Flat rate tariff: In this tariff, different types of consumers are charged at different rates of cost per unit (1kWh) of electrical energy consumed. Different consumers are grouped under different categories. Then, each category is charged money at a fixed rate similar to simple tariff. The different rates are decided according to the oonsumers, their loads and load factors. Graphically, it can be represented as shown in figure (5.6).

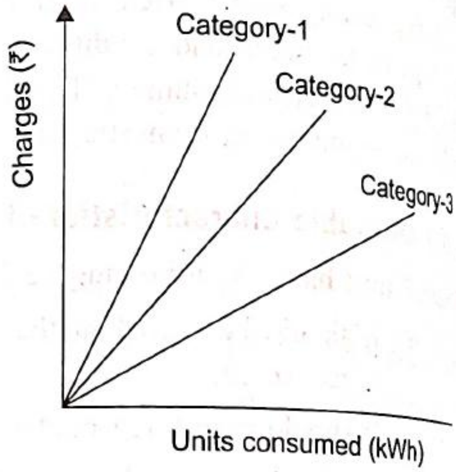


Figure (5.6): *Flat rate tariff*

Advantages:

- More fair to different consumers.
- Simple calculations.

Disadvantages:

- A specific consumer is charged a fixed rate with no incentives.
- Different load rates require separate meters, increasing complexity and cost.
- All consumers in one category pay equal rates, but it's fairer for high energy users to have lower fixed rates.

Applications:

- Applicable to domestic consumers

(iii) Block rate tariff: In this tariff, the first block of the energy consumed (consisting of a fixed number of units) is charged at a given rate and the succeeding blocks of energy (each with a predetermined number of units) are charged at progressively reduced rates. The rate per unit in each block is fixed.

For example, the first 60 units (1st block) may be charged at 4 rupees per unit; the next 40 units (2nd block) at 3.50 rupees per unit and the next 30 units (3rd block) at 3 rupees per unit. Graphically, it can be represented as shown in figure (5.7).

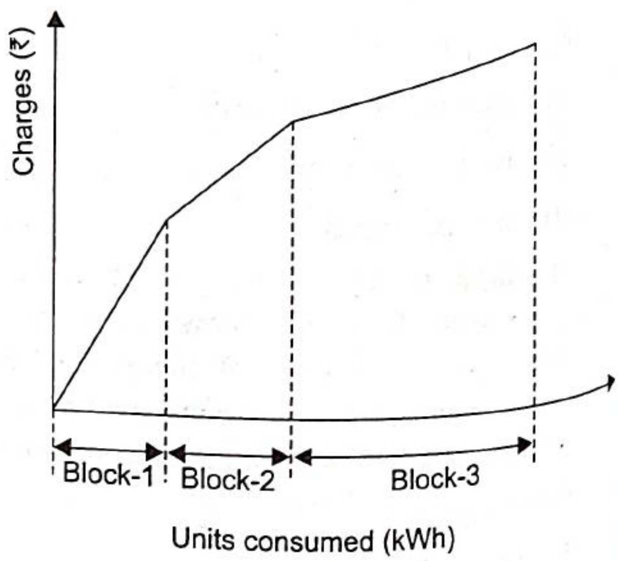


Figure (5.7): *Block rate tariff*

Advantages:

- Only one energy meter is required.
- Incentives for reduced rates increase energy usage, boosting load factor and lowering generation costs.

Disadvantages:

- No energy usage, no charges, despite the connection's maintenance costs.

Applications:

- Applicable to residential and small commercial consumers.

(iv) Two-part tariff: In this tariff, the total costs charged to the consumers consist of two components: fixed charges and running charges. It can be expressed as:

Total Cost = $[A \times \text{kW} + B \times \text{kWh}]$ ...(5.1)

Where, A = charge per kW of maximum demand

B = charge per kWh of energy consumed

The fixed charges will depend upon maximum demand of the consumer and the running charge will depend upon the energy (units) consumed. The fixed charges are due to the interest and depreciation on the capital cost of building and equipment, taxes and a part of operating cost which is independent of energy generated. On the other hand, the running charges are due to the operating cost which varies with variation in generated (or supplied) energy.

Disadvantages:

- Fixed charges must be paid regardless of energy consumption.
- Errors in assessing the maximum demand of the consumer.

Applications:

- Applicable to industrial consumers with appreciable maximum demand.

(v) Maximum demand tariff: In this tariff, the energy consumed is charged on the basis of maximum demand. The units (energy) consumed by him is called maximum demand. The max demand is calculated by a maximum demand meter. This removes any conflict between the supplier and the consumer as it were the two part tariff. It is similar to two-part tariff.

Applications:

- Applicable to large industrial consumers.

(vi) Power factor tariff: In this tariff, the power factor of the consumer's load is taken into consideration. The power factor is a very important parameter in power system. For optimal operation, the p.f must be high. Low p.f will cause more losses and imbalance on the system. Hence, the consumers which have low p.f loads will be charged more.

(vii) Three-part tariff: In this scheme, the total costs are divided into three sections: fixed costs, semi-fixed costs and running costs. It can be expressed as:

Total cost = $[\text{A} + \text{B} \times \text{kW} + C \times \text{kWh}]$ ...(5.2)

Where, A = fixed charges

B = charge per kW of maximum demand

C = charge per kWh of energy consumed

Applications:

- Applicable to big consumers.

5.9 POWER RATING OF HOUSEHOLD APPLIANCES

Household appliances have different power ratings, which are typically measured in watts (W) or kilowatts (kW). Here are approximate power ratings for some common household appliances, including air-conditioners, PCs, laptops, printers etc.:

(i) Air Conditioners

- Window Air Conditioner (1 ton): 1,000 W to 1,500 W
- Window Air Conditioner (2 tons): 2000 W to 3000 W
- Central Air Conditioner (varies by size and efficiency): 3000 W to 5000 W or more

(ii) Personal Computers (Desktops)

- Desktop PC (average): 250 W to 400 W
- Gaming Desktop PC (high-end): 600 W to 1000 W or more
- Monitor (average): 20 W to 60 W

(iii) Laptops

- Laptop (average): 30 W to 90 W (when charging)
- Laptop (in use, without charging): 15 W to 45 W

(iv) Printers

- Inkjet Printers: 30 W to 75 W (when printing)
- Laser Printers: 300 W to 800 W (when printing)

(v) Televisions

- LED/LCD TV (average): 50 W to 150 W (varies by size and model)
- Plasma TV: 100 W to 400 W (varies by size and model)

(vi) Refrigerators

- Refrigerator (average): 100 W to 800 W (varies by size and efficiency)
- Refrigerator (compressor starting): Higher power briefly during startup

(vii) Microwave Ovens

- Microwave Oven (average): 600 W to 1200 W (when cooking)
- Microwave Oven (standby): Around 3 W to 5 W

(viii) Washing Machines

- Washing Machine (average): 300 W to 500 W (varies by type and size)

(ix) Dishwashers

- Dishwasher (average): 1200 W to 1500 W (varies by model and cycle)

(x) Water Heaters

- Electric Water Heater (40-gallon tank): Around 4500 W (during heating)

(xi) Toasters and Coffee Makers

- Toaster: 800 W to 1200 W
- Coffee Maker: 800 W to 1500 W

Please note that these are approximate power ratings, and actual power consumption can vary depending on the make and model of the appliance, usage patterns, and settings. It's important to be aware of the power ratings of your household appliances to help. manage energy consumption and make informed decisions about energy efficiency. You can typically find the power rating (in watts) on a label or tag on the appliance or in the appliance's user manual.

5.10 ENERGY CONSUMPTION CALCULATION

Energy and power are closely related. Electrical energy can be measured only when electrical power is known. So, first, we understand the electrical power. Electrical power is the amount of electrical current that results from a certain amount of voltage or we can say that power is the rate at which energy is delivered. It is measured in watts. Mathematically it is written as

$$Power = Voltage \times Current \quad \text{...(5.3)}$$

The measurement of electrical energy is completely dependent on power which is measured in watt, kilowatts, megawatts, gigawatts, and time which is measured in an hour. Joule is the smallest unit of energy. But for some bigger calculation, some better unit is required. So, the unit used for electrical energy is watt-hour.

Electrical energy is the product of electrical power and time, and it is measured in joules. It is defined as "1 joule of energy is equal to 1 watt of power is consumed for 1 second". i.e.

$$Energy = Power \times Time \quad \text{...(5.4)}$$

$$1\ Joule = 1\ Watt \times 1\ sec$$

Watts are the basic unit of power in which electrical power is measured or we can say that rate at which electric current is being used at a particular moment.

Watt-hour is the standard used for measurement of energy, describing the amount of watts used over time. It shows how fast the power is consumed in the period of time.

$$Energy\ in\ Watt\ hours = Power\ in\ \text{Watts} \times Time\ in\ hours \quad \text{...(5.5)}$$

Kilowatt-hour is simply a bigger unit of energy when large appliances drawn power in kilowatts. It can be described as one kilowatt hour is the amount of energy drawn by the 1000 watts appliance when used for an hour.

Where, One kilowatt = 1000 watts

$$Energy\ in\ kiloWatt\ hours = Power\ in\ KiloWatts \times Time\ in\ hours \quad \text{...(5.6)}$$

The electrical supply companies take electric energy charges from their consumer per kilowatt hour unit basis.

5.10.1 Calculation of electricity bill for domestic consumers

The calculation of an electricity bill for domestic consumers typically involves a straightforward process based on the following components:

(i) Consumption: The primary factor is the amount of electricity consumed, measured in kilowatt-hours (kWh). This is determined by the electricity meter installed at your premises.

(ii) Tariff rate: The cost per unit of electricity (kWh) is specified by your electricity provider and may vary depending on your location and the tariff plan you are on. There might be different rates for different usage tiers or times of day.

Example: A consumer uses a 10kW geezer, a 6kW electric furnace and five 100W bulbs for 15 hours. How many units (kWh) of electrical energy have been used and what would be the electricity bill?

Explanation: Given that

Load-1 = 10 kW geezer

Load-2 = 6 kW electric furnace

Load-3 = 500 watt (five 100 watt bulbs)

Total load = 10 kW + 6 kW + 0.5 kW

Time taken = 10 hours

∴ *Energy Consumed* = *Power in* kW × *Time in hours*

For above electrical energy consumption, the tariff can be calculated as follows:

1 unit = 1kWh

So, the total energy consumption = 247.5 units

If the cost per unit is Rs.2.5, then the total electricity bill

= 247.5 × 2.5 = Rs.618.75/-

5.11 FUSE

The electrical equipment's are designed to carry a particular rated value of current normal conditions. Under abnormal conditions such as short circuit, overload or any the current raises above this value, damaging the equipment and sometimes resulting hazard. Fuses are come into operation under fault conditions.

A fuse is a short piece of metal, inserted in the circuit, which melts when exc current flows through it and thus breaks the circuit. Under normal operating conditio designed to carry the full load current. If the current increases beyond this designed due to any of the reasons mentioned above, the fuse melts and thus isolating the supply from the load.

(a) Desirable characteristics of a fuse element: The material used for fuse wire have the following characteristics:

- Low melting point e.g., tin, lead.
- High conductivity e.g., silver, copper.
- Free from deterioration due to oxidation e.g., silver.
- Low cost e.g., lead, tin, copper.

(b) Materials: Materials used are tin, lead or silver having low melting points. copper or iron is dangerous, though tinned copper may be used.

(c) Types of fuses: Fuses are classified into following types:

(i) Re-wireable or kit-kat fuse and

(ii) High rupturing capacity (HRC) cartridge fuse

5.11.1 Re-wireable or kit-kat fuse

Re-wireable fuse is used where low values of fault current are to be interrupted. The are simple in construction, cheap and available up to a current rating of 200A. T erratic in operation and their performance deteriorates with time. An image of re- fuse is as shown in figure (5.8).

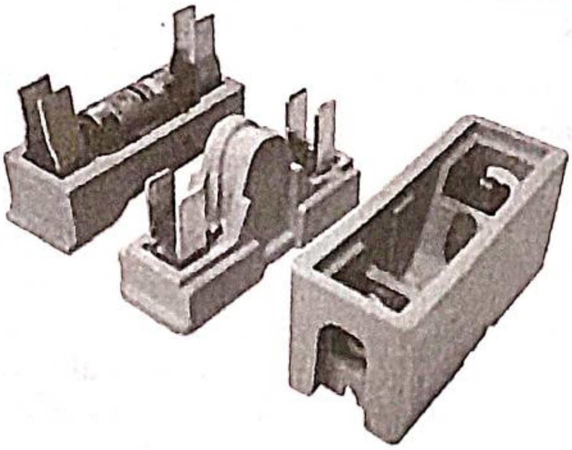


Figure (5.8): *Re-wireable or kit-kat fuse*

5.11.2 High Rupturing Capacity (HRC) Cartridge Fuse

Figure (5.9) shows an image of HRC cartridge fuse and figure (5.10) shows the essential parts of a typical HRC cartridge fuse. It consists of a heat resisting ceramic body having metal end-caps to which a silver current-carrying element is welded. The space within the body surrounding the element is completely packed with a filling powder. The filling material may be chalk, plaster of paris, quartz or marble dust and acts as an arc quenching and cooling medium. Therefore, it carries the normal current without overheating.

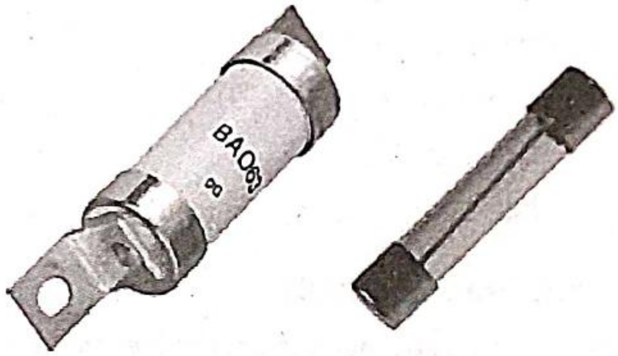


Figure (5.9): *HRC Cartridge fuse*

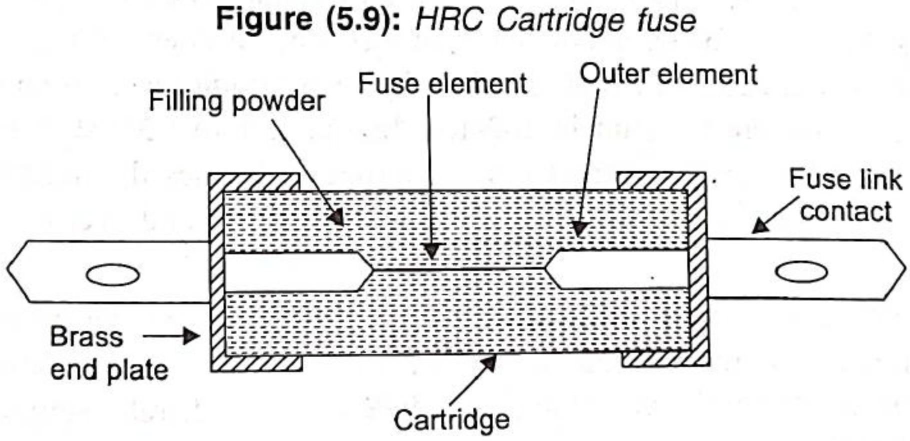


Figure (5.9): *Cross-section of HRC cartridge fuse*

Under normal loading conditions, the fuse element is at a temperature below its melting point. When a fault occurs, the current increases and the fuse element melts before the fault current reaches its first peak. The heat produced in the process vaporizes the melted silver element. The chemical reaction between the silver vapour and the filling powder results in the formation of a high resistance substance which helps in quenching the arc.

5.12 CIRCUIT BREAKER

Electrical circuit breaker is a switching device which can be operated manually and automatically for controlling and protection of electrical power system respectively. The modern power system deals with huge power network and huge numbers of associated electrical equipment. During short circuit fault or any other types of electrical fault, the equipment as well as the power network suffer a high stress of fault current, which in turn damage the equipment and networks permanently. For saving these equipment and the power networks the fault current should be cleared from the system as quickly as possible. Again after the fault is cleared, the system must come to its normal working condition as soon as possible for supplying reliable quality power to the receiving ends. The circuit breaker is the special device that does all the required switching operations during current carrying condition.

A circuit breaker essentially consists of fixed and moving contacts, called electrodes. Under normal operating conditions, these contacts remain closed and will not open automatically until and unless the system becomes faulty. The contacts can be opened manually or by remote control whenever desired. When a fault occurs on any part of the system, the trip coils of the breaker get energised and the moving contacts are pulled apart by some mechanism, thus opening the circuit.

The main types of circuit breakers are

(1) Miniature circuit breakers (MCB)

(2) Earth leakage circuit breakers (ELCB)

(3) Air blast Circuit Breaker (ACB)

(4) Molded Case Circuit Breaker (MCCB)

(5) Vacuum Circuit Breaker (VCB)

(6) SF_6 Circuit Breaker

5.12.1 Miniature Circuit Breaker (MCB)

Miniature Circuit Breakers are electromechanical devices that protect an electrical circuit from over currents. Over currents in an electrical circuit may result from short circuit, overload or faulty design. An MCB is a better alternative than fuse since it does not require replacement once an overload is detected. An MCB functions by interrupting the continuity of electrical flow through the circuit once a fault is detected. In simple terms MCB is a switch which automatically turns off when the current flowing through it passes the maximum allowable limit. Generally, MCB is designed to protect against over current and over temperature faults (over heating).

Working Principle: There are two contacts one is fixed and the other is moveable. When the current exceeds the predefined limit a solenoid forces the moveable contact to open (i.e., disconnect from the fixed contact) and the MCB turns off thereby stopping the current to flow in the circuit.

Operation: An image of MCB is as shown in figure (5.10) and internal parts of an MCB are shown in figure (5.11). It mainly consists of one bi-metallic strip, one trip coil and one hand operated on-off lever. Electric current carrying path of a MCB is as follows. First left hand side power terminal - then bimetallic strip - then current coil or trip coil - then moving contact- then fixed contact and - lastly right hand side power terminal and all are arranged in series.

If circuit is overloaded for a long time, the bi-metallic strip becomes over heated and deformed. This deformation of bi-metallic strip causes displacement of latch point. The moving contact of the MCB is so arranged by means of spring, with this latch point, that a little displacement of latch causes release of spring and makes the moving contact to move for opening the MCB. The current coil or trip coil is placed such a manner that during short circuit fault, the mmf of that coil causes its plunger to hit the same latch point and make the latch to be displaced. Hence, the MCB will open in the same manner. Again, when operating lever of the MCB is operated by hand, that means when we make the MCB at off position manually, the same latch point is displaced as a result moving contact separated from fixed contact in same manner. So, whatever may be the operating mechanism, that means, may be due to deformation of bi-metallic strip or may due to increased mmf of trip coil or may due to manual operation, actually the same latch point is displaced and same deformed spring is released, which ultimately responsible for movement of the moving contact. When the moving contact separated from fixed contact, there may be a high chance of arc. This arc then goes up through the arc runner and enters into arc splitters and is finally quenched. When we switch on the MCB, we actually reset the displaced operating latch to its previous on position and make the MCB ready for another switch off or trip operation.

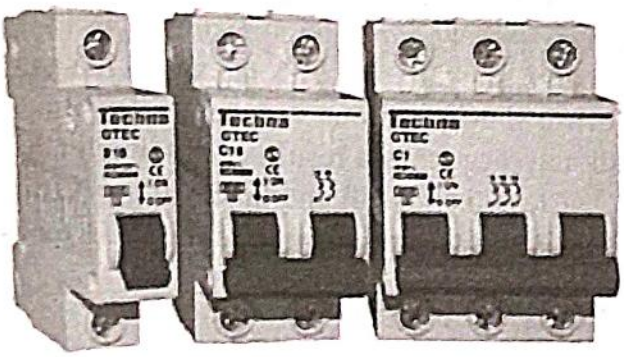


Figure (5.10): *Miniature Circuit Breaker*

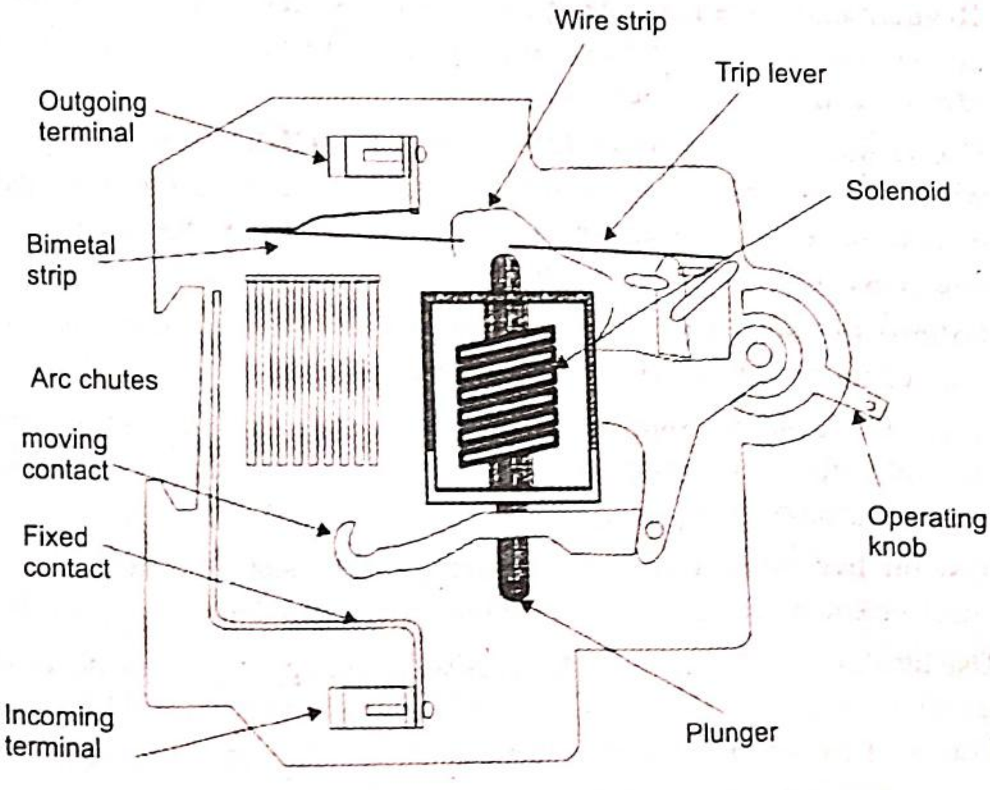


Figure (5.11): *Cross-section of MCB*

These are available in single pole, double pole, triple pole and four pole versions with neutral poles if required. The normal current ratings are available from 0.5 to 63 A with a symmetrical short circuit rupturing capacity of 3-10kA, at a voltage level of 230/440V. MCBs are generally designed to trip within 2.5 millisecond when an over current fault arises. In case of temperature rise or over heating it may take 2 seconds to 2 minutes for the MCB to trip

Advantages:

- MCBs replacing fuses in low-power domestic and industrial applications.
- High SC breaking capacity (10kA) overcomes fuse disadvantages i.e. low SC interrupting capacity (3kA).
- MCB combines switching, overload, and short circuit protection: bi-metallic strips for overload, solenoid for short circuit.

5.13 ELECTRIC SHOCK

Electric shock is a physiological reaction that occurs when an electric current passes through a person's body. This can happen when a person comes into contact with an electrical source; such as, an exposed wire, a faulty electrical appliance, or an electrical outlet. The severity of an electric shock can vary widely depending on several factors, including the voltage and current of the electrical source, the duration of contact, and the path the current takes through the body. Due to this electric shock, nervous structure, heart, lungs and brain are affected. If the current is large, death may occur. As a result, even though current is necessary, improper use will result in significant loss, i.e., death and financial loss. To avoid this electrical shock, we must be aware of preventive care and protective methods for safety precautions.

5.13.1 Preventive Methods to Avoid Electric Shock

Preventing electric shock is crucial for ensuring personal safety, whether at home or in a workplace. Here are some preventive methods to avoid electric shock:

(i) **Regular maintenance:** Keep your electrical system, including wiring, outlets, and appliances, well maintained. Regular inspections by a qualified electrician can identify and address potential hazards.

(ii) **Use Ground Fault Circuit Interrupters (GFCIs):** Install GFCIs in areas where water and electricity may come into contact, such as kitchens, bathrooms, and outdoor outlets. GFCIs can quickly disconnect power in the event of a ground fault, thus preventing from electric shocks.

(iii) **Follow the manufacturer's instructions:** Always read the manufacturer's instructions carefully before using a new appliance.

(iv) **Shut-off the power supply:** Always make sure that the power source should be shut-off before performing any work related to electricity. For example; inspecting, installing, maintaining or repairing.

(v) **Test for live wires:** Use a non-contact voltage tester or a multimeter to verify that wires or equipment are not live before touching them.

(vii) **Use insulated tools while working:** Always use appropriate insulated rubber gloves, goggles, protective clothes and shoes with insulated soles while working on any branch of circuit or any other electrical circuit. Use only tools and equipment with non-conducting handles when working on electrical devices.

(vii) **Follow safety guidelines:** Adhere to electrical safety guidelines and codes set by relevant authorities and organizations. These standards are designed to reduce the risk of electrical accidents.

(viii) **Outlet Covers:** Use outlet covers or childproof caps to prevent young children from inserting objects into electrical outlets.

(ix) **Inspect cords and cables:** Regularly inspect power cords, extension cords, and electrical cables for damage. Replace any frayed or damaged cords immediately.

(x) **Keep a safe distance:** Maintain a safe distance from overhead power lines, transformers, and other electrical equipment, as they can carry high voltage.

(xi) **Proper outlet usage:** Avoid overloading electrical outlets with too many devices or appliances. Use power strips with surge protection when necessary. Don't force plugs into outlets; they should fit snugly without excessive force.

(xii) **Extension cords:** Use extension cords as a temporary solution, not a permanent one. Avoid running them under carpets or in high-traffic areas where they can get damaged.

(xiii) **Stay dry:** Avoid working on electrical equipment with wet hands or in wet conditions. Water is an excellent conductor of electricity and increases the risk of shock.

(xiv) **Educate yourself:** If you're not knowledgeable about electrical systems, don't attempt electrical work on your own. Seek the assistance of a qualified electrician. Make sure extension cords are rated for the intended use and have no exposed wires.

(xv) **Use grounding:** Ensure that appliances and equipment that require grounding are properly connected to a grounded outlet.

(xvi) **Display danger board:** Danger board should be displayed at the work place. We should not allow any unauthorized person to enter in the working place and we should not put any new equipment into the service without necessary testing by the concern authority.

(xvii) **Avoid overhead power lines:** Stay away from overhead power lines, especially when using ladders, working on roofs, or using tall equipment. Contact with power lines can be extremely dangerous.

(xviii) **Emergency planning:** Have a plan in place for dealing with electrical emergencies. This should include knowing how to turn off power and having access to emergency contact information for electricians or utility companies.

5.13.2 First-aid for electric shock

If anyone suffers an electric shock, the electricity source should be cut-off immediately. Conduct the first-aid only after the victim is in a safe place. Check the victim's breath and pulse. If the person is unconscious but is breathing normally, he/she should be placed in a recovery position. If the victim is not breathing and has no pulse, cardiopulmonary resuscitation should be conducted.

Imp Note: Cardiopulmonary resuscitation should be carried out only by competent first-aid personnel.

Cardiopulmonary Resuscitation:

(i) Open the airway: Lift the jaw and tilt the head back to open the airway. Clear all obstacles.

(ii) Check the breaths:

See: Check to see if the chest rises and falls.

Listen: Listen for breathing.

Feel: Feel breathing on your cheek.

(iii) Check the pulse (circulation)

Use your fingers to feel the pulse.

(iv) Recovery position

If the casualty is unconscious but is breathing normally, place them in the recovery position (as shown in the figure below).

(v) **Mouth-to-mouth expired air resuscitation**

If the person is not breathing, mouth-to-mouth resuscitation should be used to help the resumption of breathing.

(vi) **External chest compression**

If the casualty has no pulse, cardiopulmonary resuscitation should be carried out (combining the expired air resuscitation and external chest compression).

5.14 EARTHING OR GROUNDING

The process of connecting the metallic frame (i.e. non-current carrying part) of electrical equipment or some electrical part of the system to earth (i.e. soil) is called grounding or earthing. The potential of the earth is to be considered zero for all practical purposes. Earthing is to connect any electrical equipment to earth with a very low resistance wire, making it to attain earth's potential. This ensures safe discharge of electric energy, due to failure of the insulation, line coming in contact with the casing etc. Earthing brings the potential of the body of the equipment to zero i.e. to the earth's potential, thus protecting the operating personnel against electrical shock.

The earth resistance is affected by the following factors:

(i) Material properties of the earth wire and the electrode.

(ii) Temperature and moisture content of the soil.

(iii) Depth of the pit.

(iv) Quantity of the charcoal used.

5.14.1 Necessity of Earthing

The following are the requirements for provision of earthing:

- To protect the operating personnel from the danger of shock.
- To maintain the line voltage constant under unbalanced load condition.
- To avoid risk of fire due to earth leakage current through unwanted path.
- Protection of the equipment.
- Protection of large buildings and all machines fed from overhead lines against lightning.

5.14.2 Methods of earthing

The various methods of earthing in common use are:

(i) Plate earthing

(ii) Pipe earthing

(iii) Rod earthing

(iv) Strip or wire earthing

(i) Plate earthing: In this type of earthing, plate either copper or GI is buried into the ground at depth of not less than 3m from the ground level as shown in figure (5.13). The plate electrode connects the electrical conductors to the earth. The earth plate is embedded in alternative layer of coke and salts for minimum thickness of about 15cm. The earth wire (copper wire for copper plate earthing and GI wire for GI plate earthing is securely bolted to an earth plate with the help of bolt nut and washer. A cement masonry chamber is built with a cast iron cover for easy regular maintenance. In this type of earthing the pipe earthing along with additional earth plate is provided at the bottom of the earth rod. If earth plate is made up of iron, size of earth plate is 60 cm × 60 cm × 6.3 mm. If it is made of copper size of earth plate is 60 cm × 60 cm × 3.15mm. The plate is placed at the depth of 3m and then alternative layers of charcoal and salt is put belw and top of earth plate.

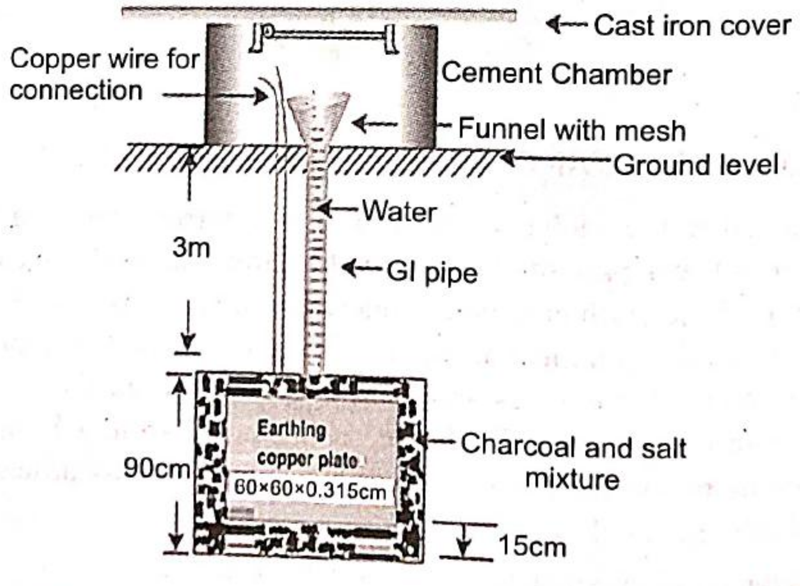


Figure (5.13): *Schematic diagram of plate earthing*

(ii) Pipe earthing: Pipe earthing is best form of earthing and cheap. In this earthing system, a GI pipe of 38mm diameter and 2.5m length is embedded vertically in ground to work as earth electrode as shown in figure (5.14), but depth depends on soil conditions. Wire is embedded upto the wet soil. The earth wire is fastened to the top section of the pipe with nut and bolts. The pit area around the pipe is filled with salt and coal mixture for improving soil condition and efficiency of earthing systems. It can take heavy leakage current for same electrode size in comparison to plate earthing. The earth wire connection with GI pipes being above the ground level can be checked for carrying out continuity test as and when desired where it is difficult for plate earthing. In summer season to have effective earthing 3 or 4 buckets of water is put through the funnel for better continuity of earthing. GI pipe of 38mm diameter, 2m length placed to depth of 4.75m. The depth depends on conditions of moisture. The size of pipe depends on the current to be carried and type of soil. The powdered charcoal salt is put 15cm around the pipe. A funnel is connected at the top of pipe and water is poured at regular period of for maintaining resistance as low as possible.

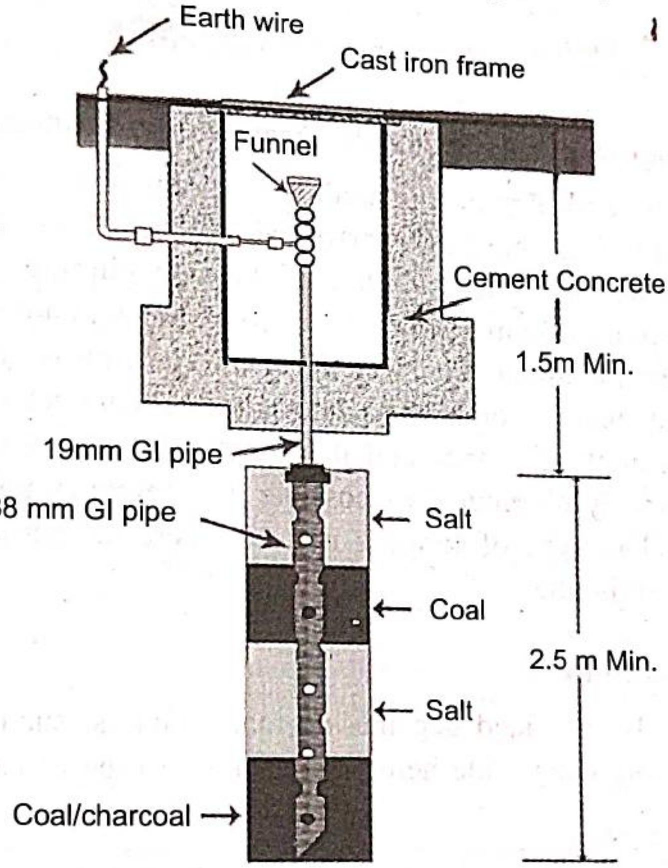


Figure (5.14): *Schematic diagram of pipe earthing*

(iii) Rod earthing: Rod earthing, also known as earth rod grounding or ground rod installation, is a common method used to establish a safe and effective electrical ground for various systems, such as electrical installations, buildings, and equipment. 12.5mm diameter copper rod, 16mm diameter galvanized steel rod, or hollow section GI pipe measuring 25mm and longer than 2.5 m must be buried upright in the ground using either a pneumatic hammer or by hand. The earth resistance is reduced to the desired value by the length of the embedded electrodes in the soil.

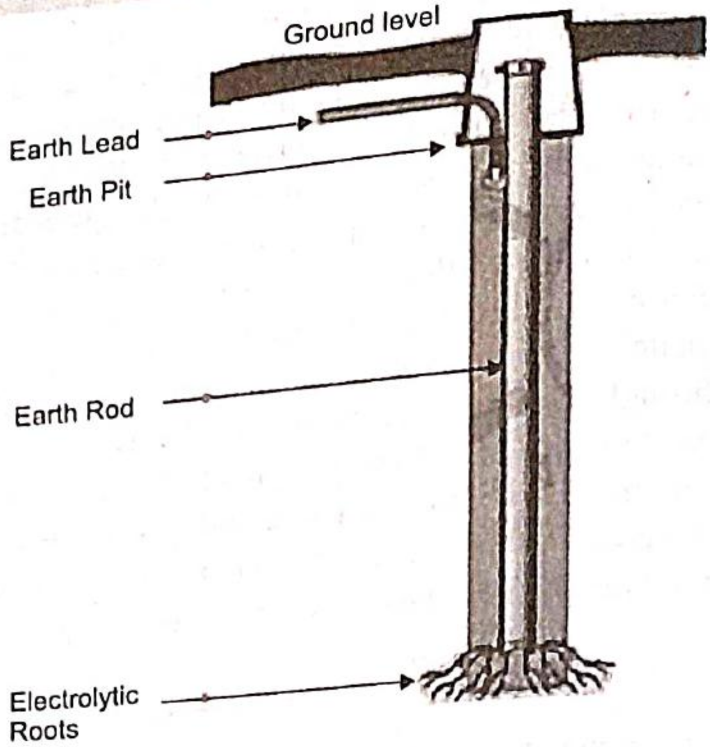


Figure (5.15): *Schematic diagram of rod earthing*

(iv) Strip or wire earthing: In this method of earthing, strip electrodes with a cross section of 25 mm × 1.6 mm are buried in horizontal trenches at a minimum depth of 0.5 m. If copper is used, it should have a cross-section of 25mm × 4mm, and if it's steel or iron, it should have a cross-section of 3mm × 3mm. If round conductors are used at all, their cross-section area shouldn't be too small; for example, if the material is galvanised iron or steel, it shouldn't be less than 6mm × 6mm. The length of the conductor buried in the ground would give a sufficient earth resistance and this length should not be less than 15m. The electrodes shall be as widely distributed as possible in a single straight or circular trenches radiating from a point. This type of earthing is used where the earth bed has a rocky soil and excavation work is difficult.

5.14.3 Selection of earthing

The type of earthing to be provided depends on many factors, such as, type of soil, type of installation etc. The following table helps in selecting a type of earhting for a particular application.

S.No	Type of earthing	Applications
01	Plate earthing	Large installations such as transmission towers, all sub-stations, generating stations
02	Pipe earthing	• For domestic installations such as heaters, coolers, refrigerators, geysers, electric iron etc. • For 11kV/400V distribution transformer • For induction motor rating up to 100HP • For conduit pipe in a wall, all wall brackets
03	Rod earthing	In areas where the soil is loose or sandy
04	Strip or wire earthing	In rocky areas

5.14.4 Earth Resistance

Earth resistance refers to the electrical resistance or impedance encountered when electrical current flows through the ground or earth in a grounding or earthing system. It is a crucial parameter in electrical engineering and safety, particularly in grounding systems. Measuring earth resistance helps ensure the effectiveness of grounding systems in safely dissipating electrical faults and preventing the buildup of dangerous voltages.

The earth resistance should be kept as low as possible so that the neutral of any electrical system, which is earthed, is maintained almost at the earth potential. The earth resistance for copper wire is 1 Ω and that of GI wire less than 3 Ω. The typical value of the earth resistance at large power stations is 0.5 Ω, major sub-stations is 1 Ω, small sub-stations is 2 Ω and in all other cases 5 Ω.

The resistance of the earth depends on the following factors:

- Condition of soil.
- Moisture content of soil.
- Temperature of soil.
- Depth of electrodes at which it is embedded.
- Size, material and spacing of earth electrode.
- Quality and quantity of coal and salt in the earth pit.

5.14.5 Difference between earth wire and neutral wire

S.No	Parameter	Earth wire	Neutral wire
1	Purpose	Earth wire provides a safe fault current path to the ground.	Neutral wire returns normal electrical currents from load to source.
2	Color coding	Earth wire is often green or green with yellow, labelled as "GND."	Neutral wire is usually white or gray, marked as "N".
3	Carrying current	Earth wire carries no current in normal conditions; it's for fault safety.	Neutral wire carries unbalanced current between the live or hot wire and the electrical load.
4	Connection	Earth wire connects to grounding system with rods/plates in earth.	Neutral wire connects the bus bar to earth ground at service panel.
6	Protection and safety	Earth wire is crucial for safety, preventing shocks and fires.	Neutral wire is essential for circuits provide a return path for current, not primarily for safety.

REVIEW QUESTIONS

1. What is a power generating station?
2. List the merits and demerits of a hydroelectric plant.

3. Draw a neat schematic diagram of a hydroelectric plant and explain the functions of various components.
4. Explain the essential factors which influence the choice of site for a hydroelectric plant.
5. Draw the schematic diagram of a nuclear power station and discuss its operation.
6. Discuss the factors for the choice of site for a nuclear power plant.
7. What do you understand by tariff? Discuss the objectives of tariff.
8. List the desirable characteristics of a tariff.
9. Explain some of the important types of tariffs commonly used.
10. What do you mean by earthing? Explain various methods of earthing.
11. What is a fuse? List the advantages and disadvantages of a fuse.
12. What is circuit breaker? Explain its operating principle.
13. Explain the construction and operation of a Miniature Circuit Breaker (MCB).
14. What is electric shock? Explain the first-aid for electric shock.
15. Differentiate earth wire and neutral wire.
16. Explain the procedure of energy consumption calculation.
17. Why ground wire is used in equipment ground?

BECE

UNIT-I

Semiconductor Devices

Introduction:

The word electronics is originated from the word electron which is a branch of science dealing with theory & use of devices in which the electrons travel through a vaccum, gas (or) a semiconductor medium.

* The electrons is that field of science which deals with the motion of electrons under the influence of applied electrons and magnectic field.

* The electrons has evolved around 3 components.

① Vaccum tubes
② Transistor
③ Integrated circuit (IC)

Era of vaccum Tubes Diode:

⇒ In 1883, Thomas Alva Edison discover that electrons will flow from one metal conductor to another through vaccum: this discovery of conductor is known as "Edison Effect".

⇒ In 1897, John Flemins applied Edison effect in inventing a 2-element ~~electrment~~ tube called "Diode".

⇒ In 1906, Leede ~~Flemins~~ Forest applied to utilized Edison effect to invent a 3-element tube called "Triode".

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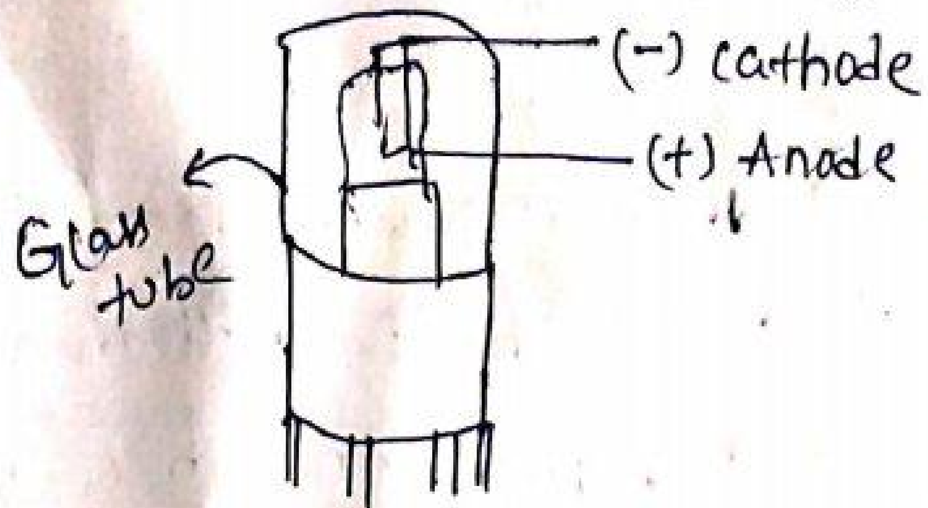
⇒ Diode & triode were instrument in amplification & transmission of electrical energy.

⇒ But vaccum tubes were bulky, fragile and high power consumption.

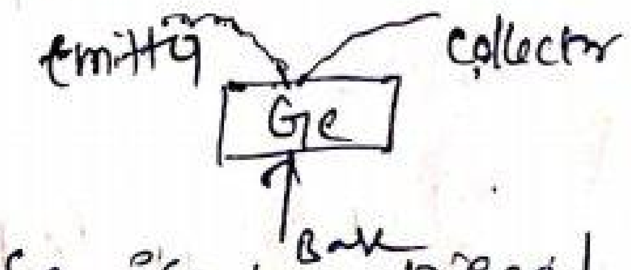


Triode: extra electrode placed btw anode and cathode.

(ii) Transistor Era:

In 1948, John Bardeen, Walter Brattain & William Shockly at Bell Laboratory developed Transistor & they received nobel prize for their creation in 1956.

⇒ The first transistor was a "point contact transistor"



* The modern transistor is a junction transistor & it is monolithic (in same semiconductor piece)

* The use of Ge & Si semiconductor materials made these transistor gain the popularity & usage in different electronic ckt.

* The transistor are compact in size, light in weight, low cost, less power consumption, fast & longer life if operated with in same operating conductors.

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Era of IC's:

The years 1958 to 1975 marked the introduction of IC with enlarged capabilities of over several thousand components on a single chip such as small scale integration, medium, large & very large scale Integration IC's.

Here the monochrome TV invented - 1930 and also colour TV invented 1950, IEEE - 1963
↓
Institute of electrical and Electronics Engineering

⇒ 1951 is commercial production of Transister. Trend carried out with JFET's & MOSFETs developed during 1951 to 1958 by improving the device design process & making them as powerful.

⇒ 1958 : Kilby (Texas institute in USA) gave idea of monolithic ckt (concept of Integrator device & ckt elements on to a single chip).

⇒ 1961 ⇒ fair child & Texas instrument commercially produced IC.

Evolution of IC's

1960 - Small scale Integration (< 100 comp/chip)

1966 - Medium scale Integration (>100 & <1000 comp/chip)

1969 - Large scale Integration (>1000 & < 10,000 comp/chip)

1975 - VLSI (Very large scale Integration)
↳ (> 10,000 comp/chip)

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Evolution of Nano Electronics:

Nano electronics has evolved in 1950's; with the invention of transistor by Bell Labs. This nano electronics has showed the way for the development of smaller, faster & more efficient electronic devices.

* Nano technology was introduced in 1960's. scientiest discovered that they could manipulate atoms & molecules to create new materials & devices at nano scale.

* In 1990's nano electronics came into commercial sector. companies began to incorporate nanoTech into their products leading to smaller, more powerful. electronic devices.

* At this era, microprocessor, the heart of modern computers was made possible by advances in nano electronics.

In early 2000's; nano electronics developed graphene a single layer of carbon atoms arranged in 2 Dimensional

Here in new technologies → nanowires, nanosensors, nano photonic devices.

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1. *Discuss the Fermi level in extrinsic semiconductors.* **Nov.-11, Set-1, 4, Marks 4**

1.11 Comparison between Intrinsic and Extrinsic Semiconductor

- The following table gives the comparison of intrinsic and extrinsic semiconductor materials.

Sr. No.	Intrinsic	Extrinsic
1.	Purest in form without any impurity.	Impurity is added hence not pure.
2.	Naturally available.	Obtained by the process called doping.
3.	Number of electrons and holes is always same.	Either electrons are more or holes are more depending on the type of the material.
4.	Conductivity is very poor.	Conductivity is high and can be controlled by doping level.
5.	Current flow is equal by electrons and holes.	Current flow is mainly because of majority carriers (electrons or holes) depending on the type n or p.
6.	Not used practically for manufacturing the devices.	Used for manufacturing of electronic devices.

Review Question

9.13. Differences between P-type and N-type Semiconductors

Sl.No.	N-type semiconductor	P-type semiconductor
1.	A small amount of pentavalent impurities such as arsenic or phosphorous is added to pure semi conductor to get N-type semiconductor.	A small amount of trivalent impurities such as gallium or aluminum is added to pure semi conductor to get P-type semiconductor.
2.	As the number of electrons is much greater than the number of holes in an N-type, electrons are called majority carriers and holes are called minority carriers.	As the number of holes is very much greater than the number of electrons in a P-type, holes are called majority carriers and electrons are called minority carriers.
3.	Current conduction is predominantly by electrons.	Current conduction is predominantly by holes.
4.	In N-type semiconductor the fermi level is just below the conduction band.	In P-type semiconductor the fermi level is just above the valence band.
5.	On increase in temperature it behaves as insulator.	On increase in temperature it behaves as insulator.
6.	In N-type semiconductor free electrons concentration is approximately equal to the density of donor atoms.	In P-type semiconductor free hole concentration is approximately equal to the density of acceptor atoms.

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⟹ Germanium has 32 electrons

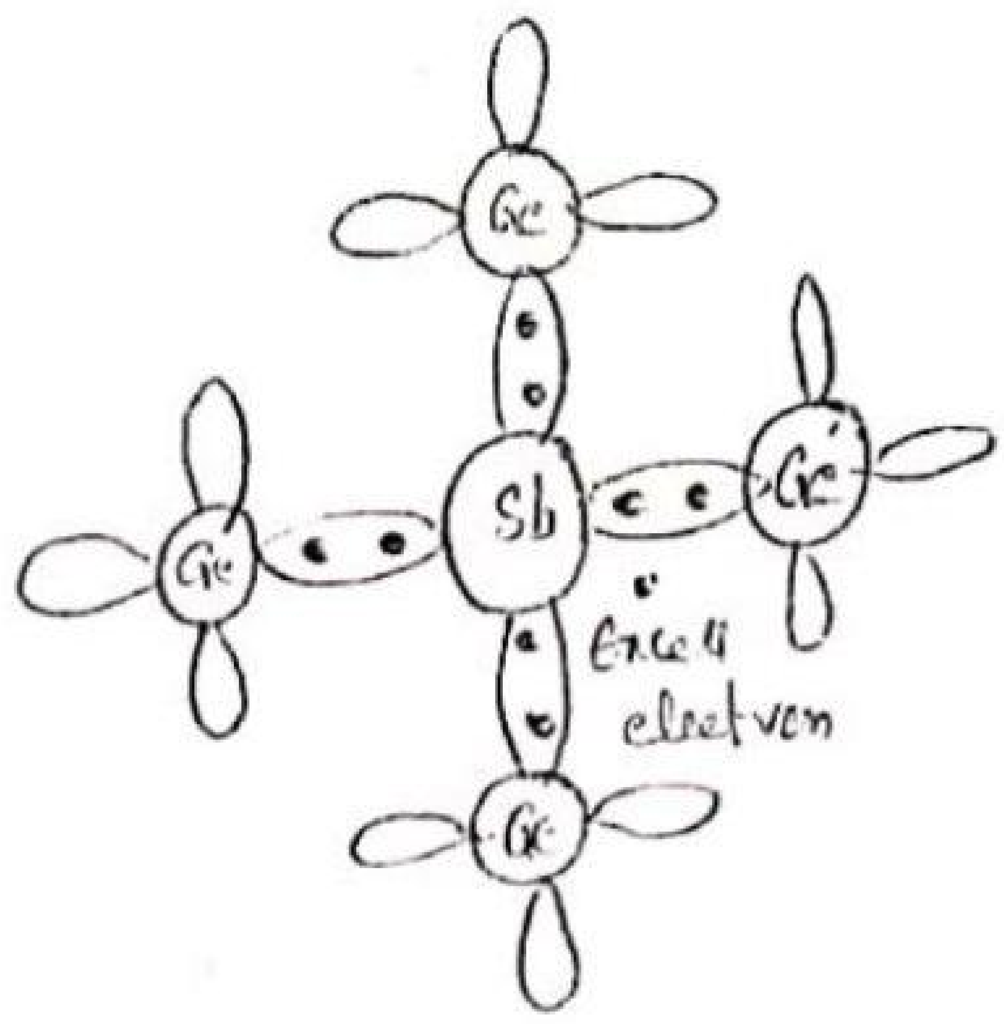
In K-orbit there are 2 e^-

L-orbit " " 8 e^-

M-orbit " " 18 e^-

N-orbit " " 4 e^-

Antimony (Sb) has 5 valence electrons.



⟹ each Antimony atom forms Co-valent bonds with the surrounding 4 Ge atoms with the help of 4 out of 5 e^-.

⟹ The 5th is superfluous & is loosely bound to the antimony atom. Hence it can be easily excited from valence band to the conduction band by the application of electric field.

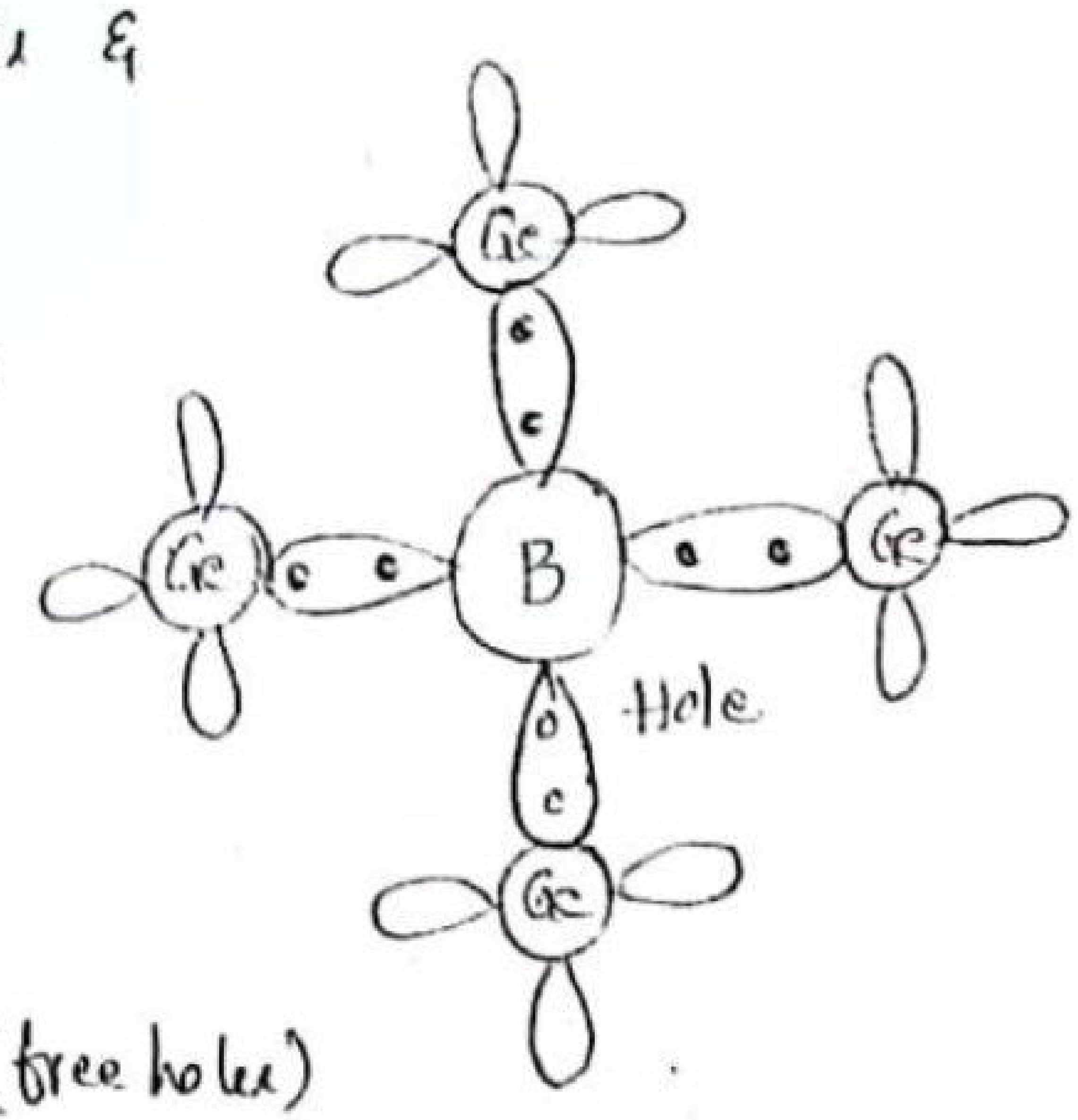
(ii) P (or) Acceptor-type Extrinsic Semiconductor :-

⟹ It obtained when a trivalent impurity like Boron (B) is added to pure Ge crystal

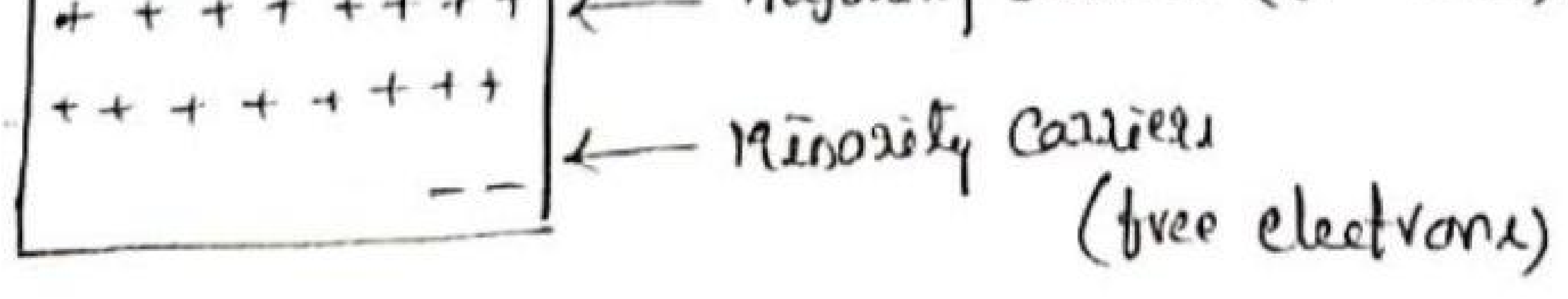
⟹ we know Ge has 4 valence electrons &

B " 3 " "

⟹ Each Boron atom forms Covalent bonds with 4 surrounding atoms but one bond is left incomplete which gives rise to a hole.



P-type



Pentavalent impurity adding → N region
Trivalent impurity adding → P region

N-type

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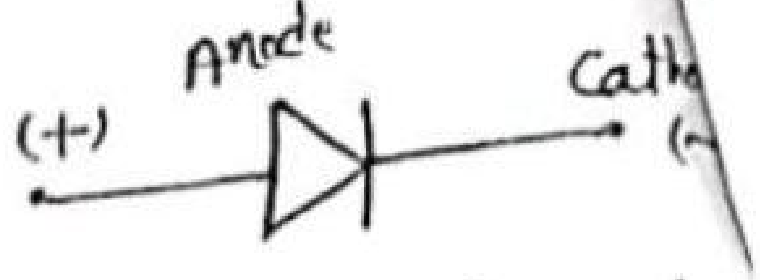
Semi-Conductor Diode :-

Diode :-

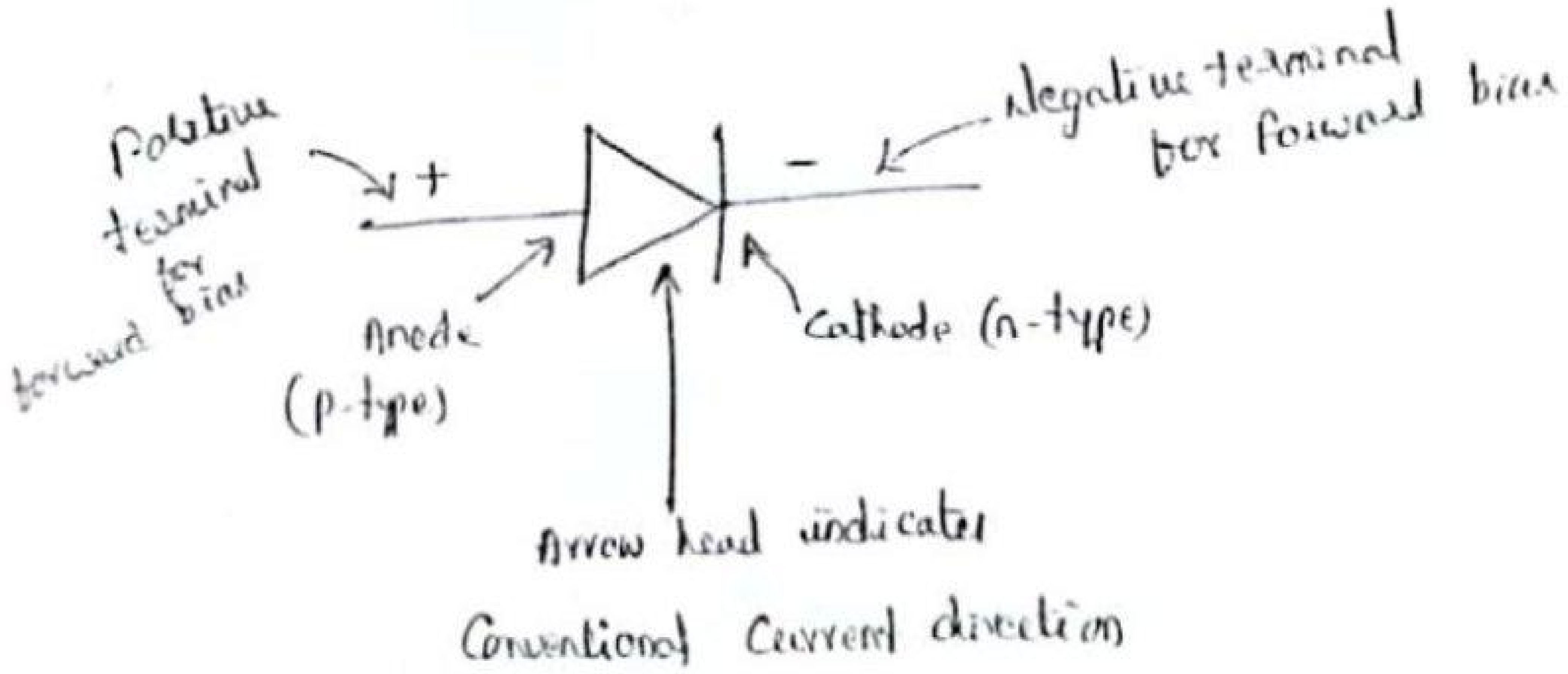
→ The joining of p-type material with an N-type material to a semiconductor device called "diode."

⇒ It represents two electrode device.



⇒ A diode is a device which only allow unidirectional flow of current if operated within a specified voltag level.

⇒ It blocks current in reverse direction while the reverse voltage is within a limited range, otherwise reverse barrier breaks & the volta at which this breakdown occurs is called Reverse breakdown voltage.



Biasing of diode :-

The process of applying an external voltage is called as biasing.

Zero bias :-

⇒ when no external voltage potential is applied to the PN junction diode called Zero biased Junction diode.

⇒ However, if the diodes terminals are shorted together, a few holes (majority carriers) in p-type material with enough

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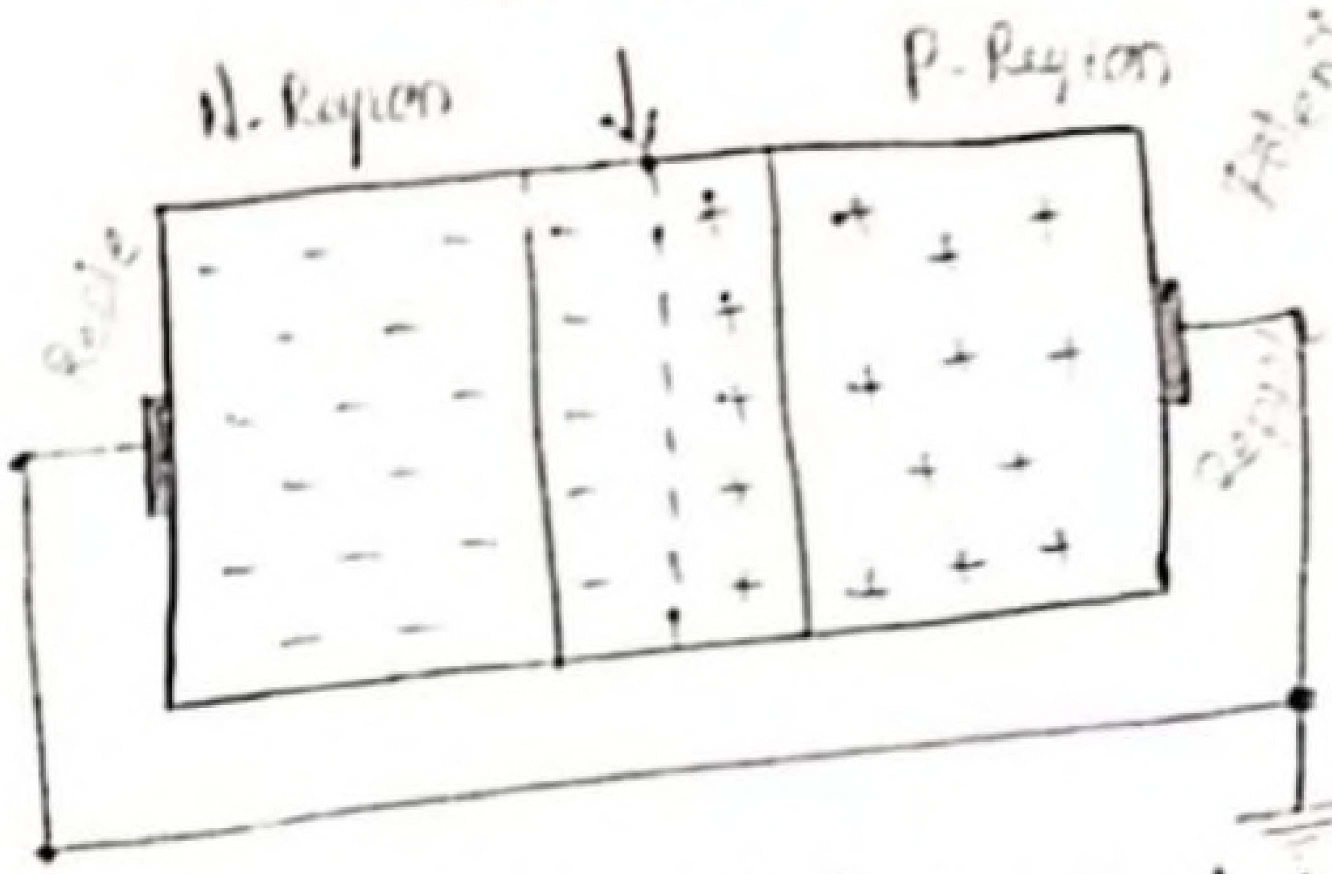
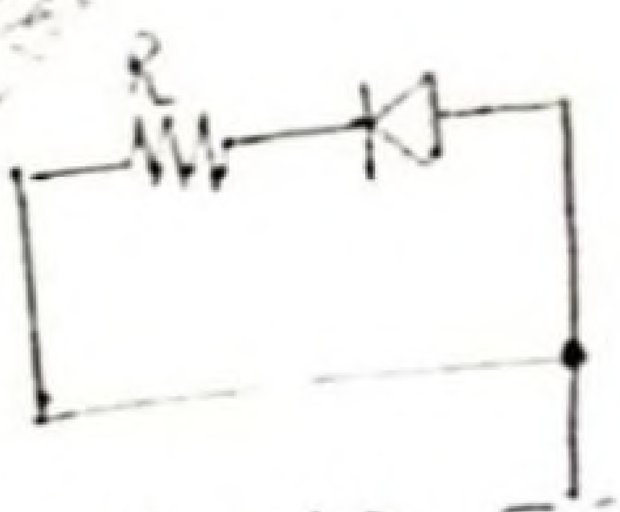
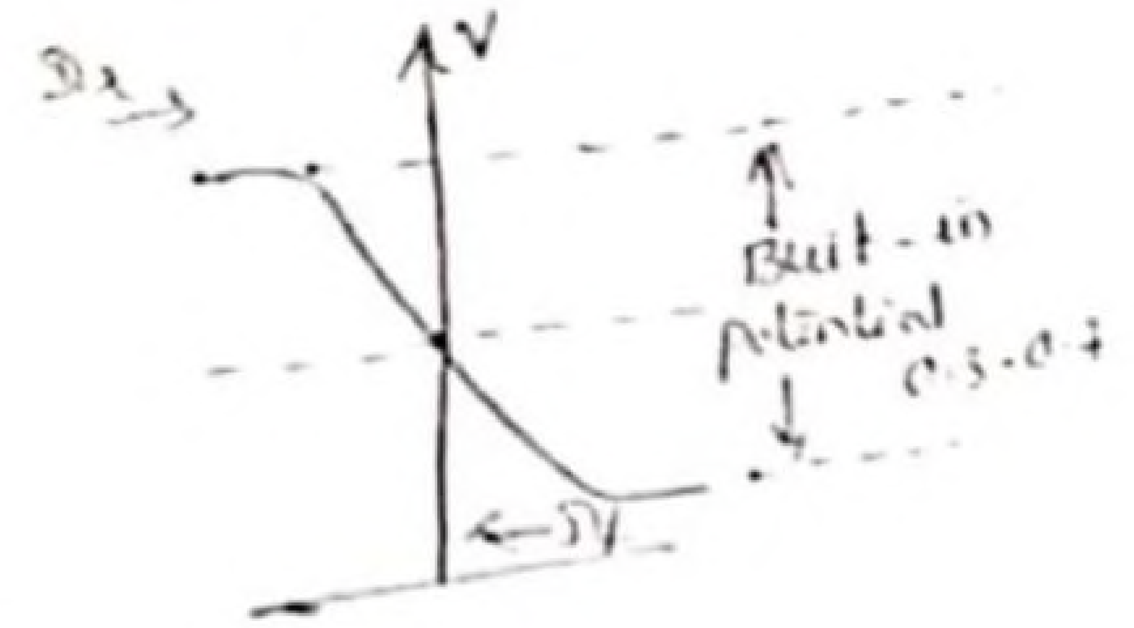




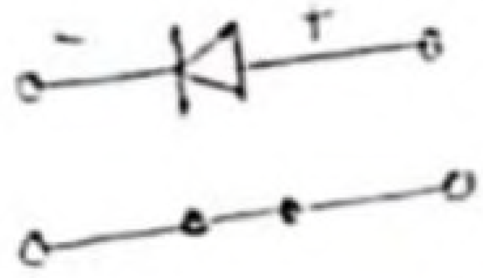


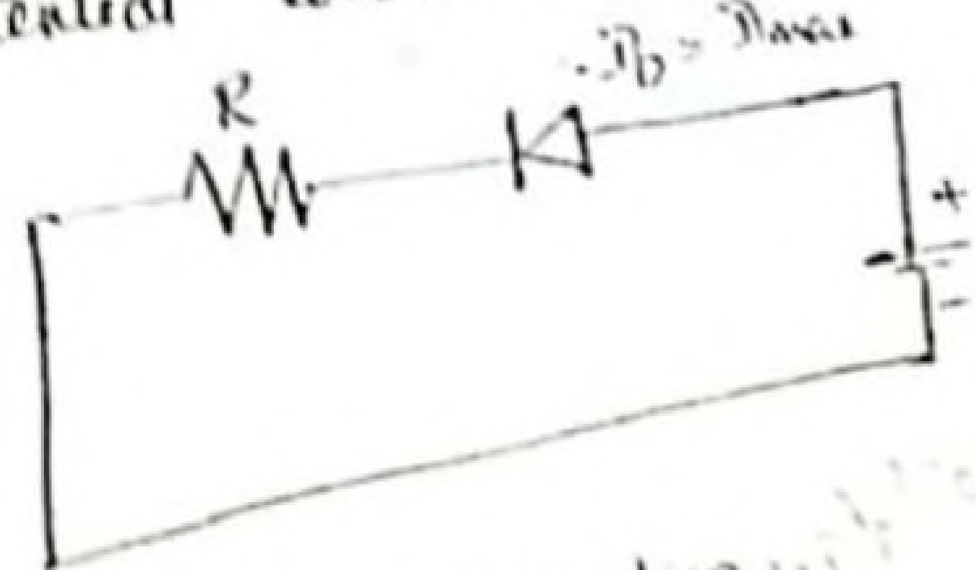
⟹ Likewise, holes are generated in the N-type material (minority carriers) & move across the junction in the opposite direction. This is known as Reverse Current (I_R).

⟹ This transfer of electrons & holes back & forth across the PN junction is known as diffusion. which is shown in fig. above.

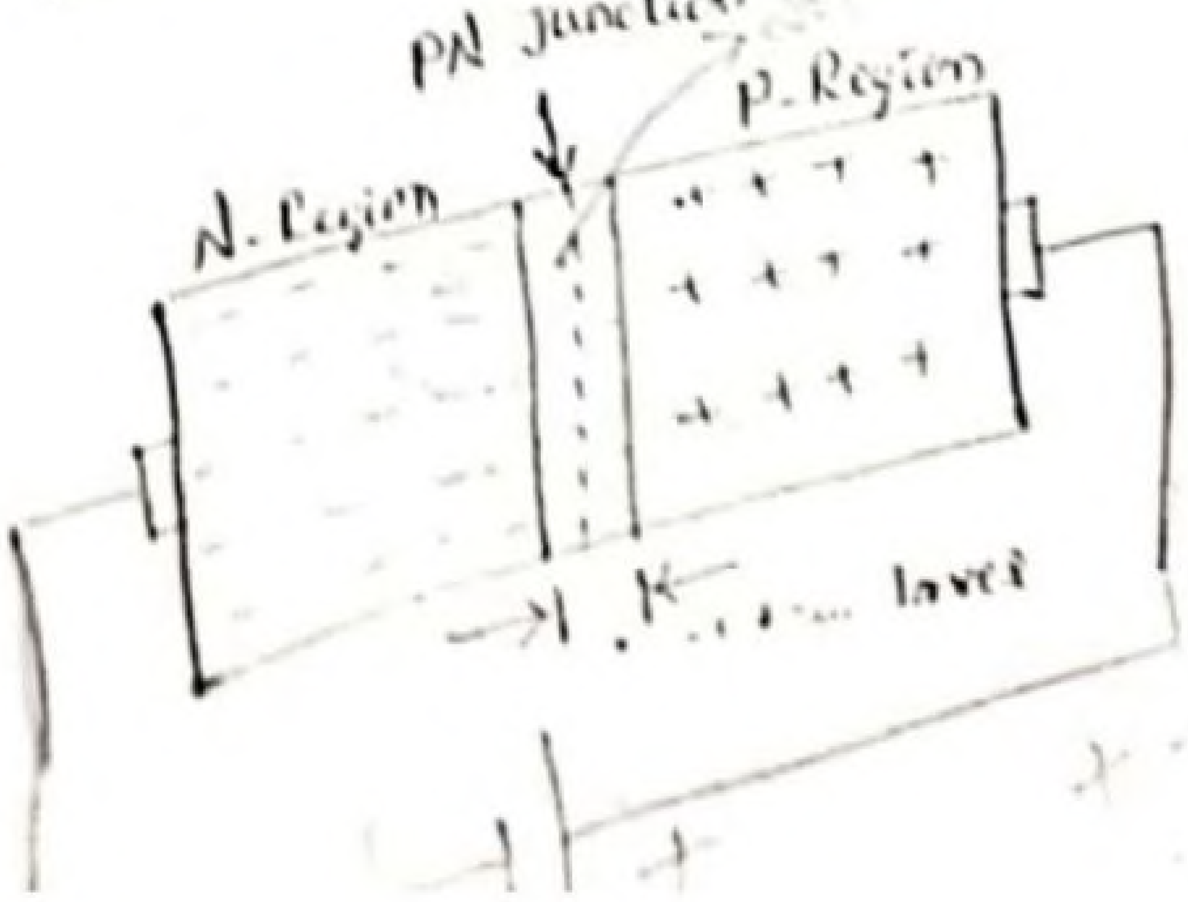
Forward Biased PN Junction diode :-

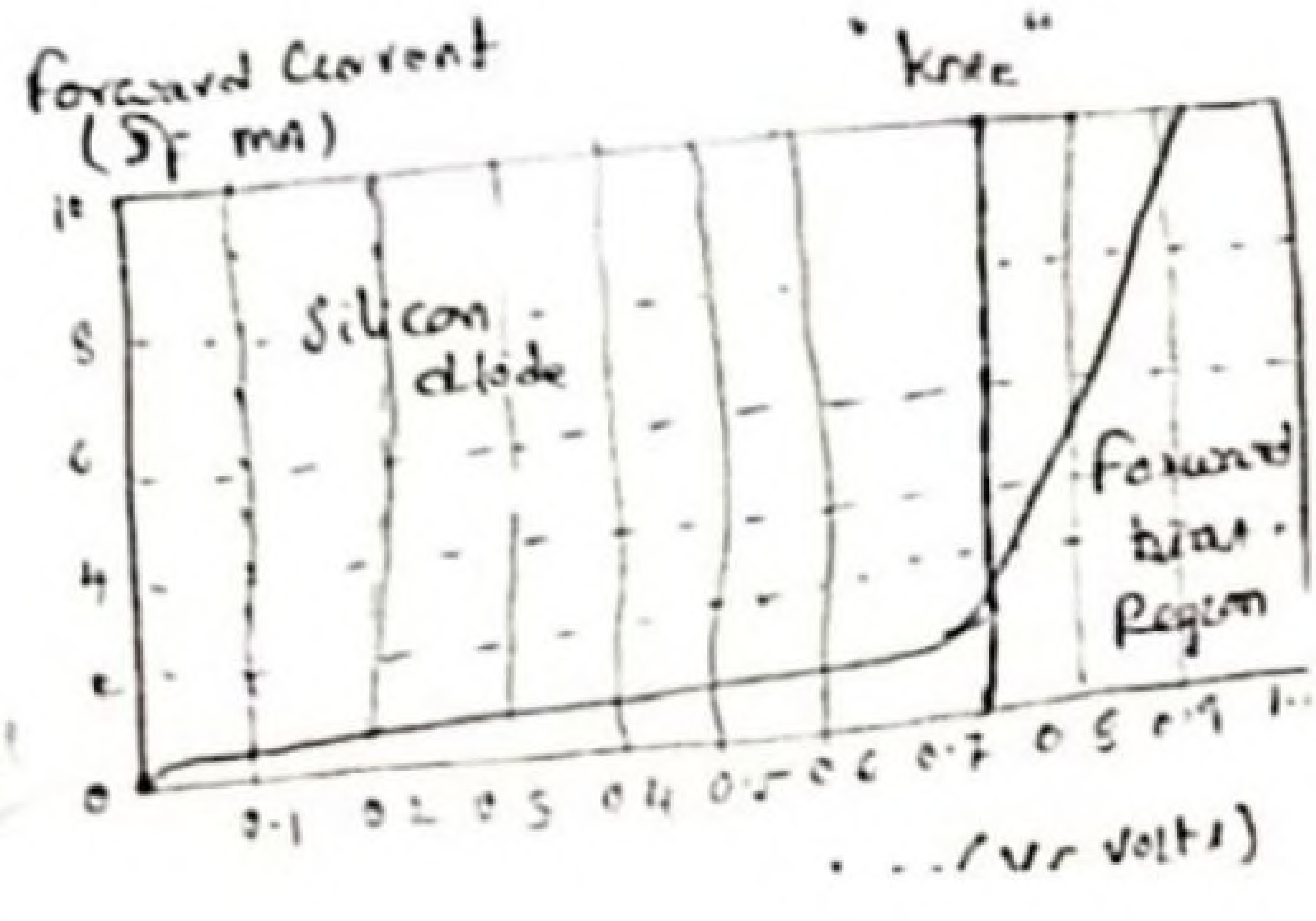
When a diode is connected in a forward Bias Condition, a negative voltage is applied to the n-type material & a +ve voltage is applied to the p-type material. If this external voltage becomes greater than the value of potential barrier, ≃ 0.7V for Si, & 0.3V for Ge., the potential barriers opposition will be overcome & current will start to flow





Diffusion Current flows in B





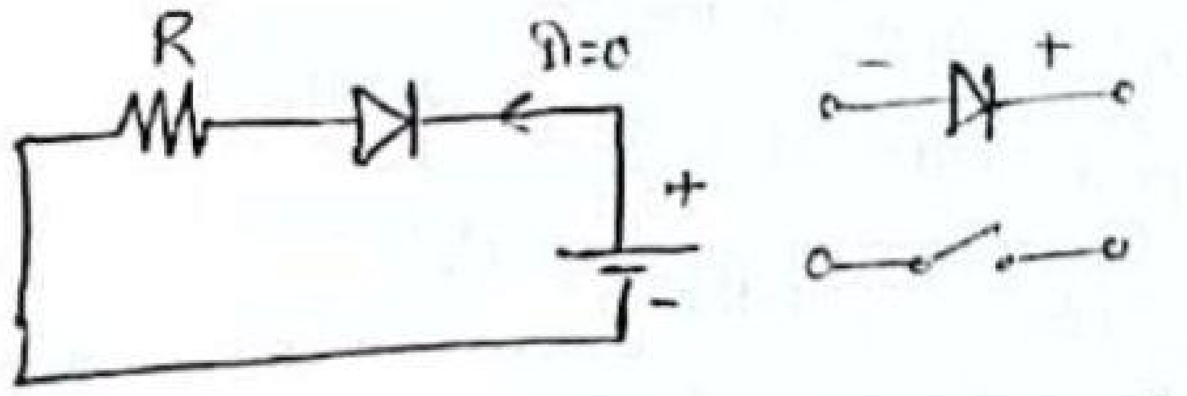
The application of a forward biasing voltage on the junction diode results,

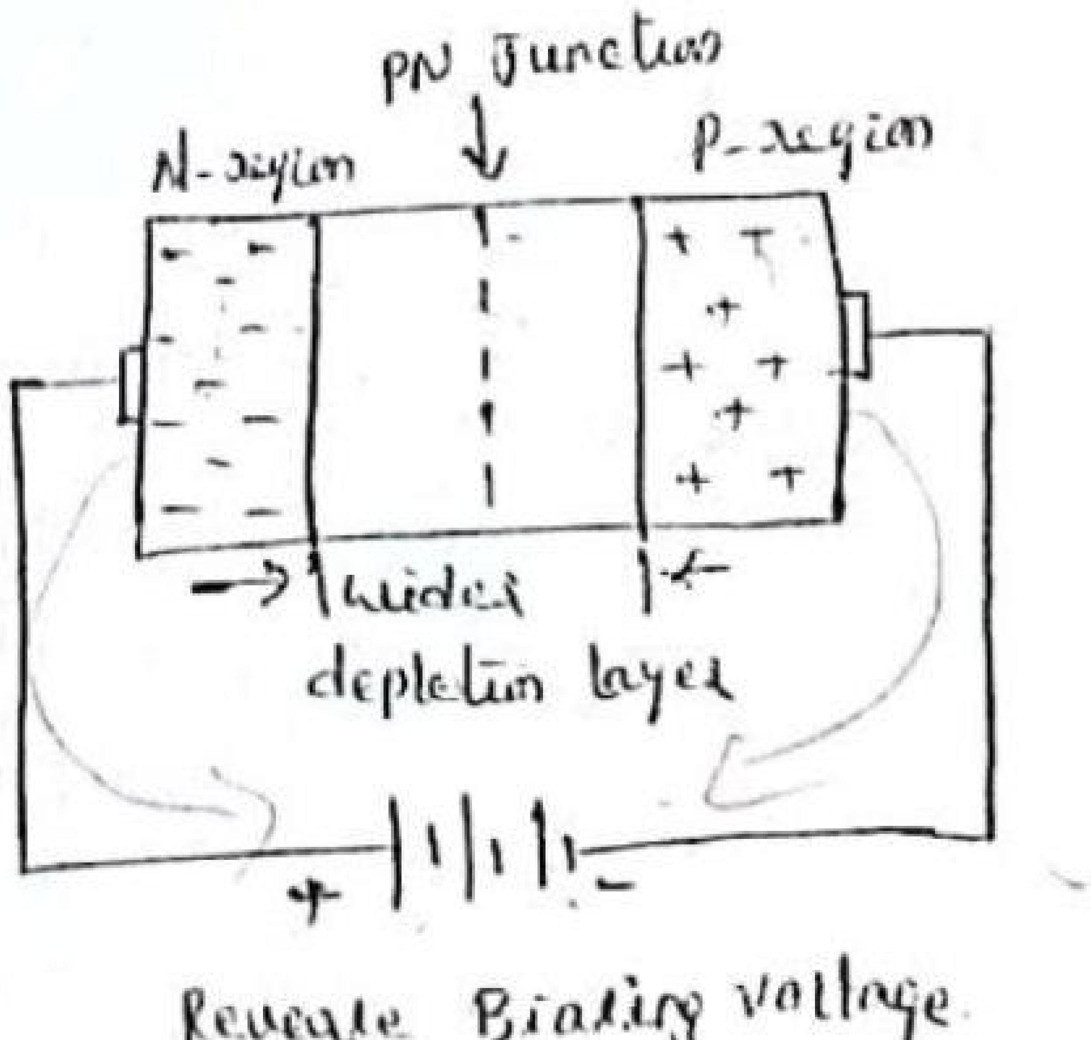
→ The depletion layer becoming very thin & narrow which represents a low impedance path through the junction thereby allowing high currents to flow.

→ The point at which this sudden increase in current takes place is represented on the static V-I characteristics curve above the "knee" point.

Reverse Biased PN Junction diode :-

When a diode is connected in a Reverse Bias Condition, a +ve voltage is applied to the N-type material & a '-ve' voltage is applied to the P-type material. The '+ve' voltage applied to the N-type material attracts e^- towards the '+ve' electrode & away from the junction, while the holes in the P-type end are also attracted away from the junction towards the '-ve' electrode.



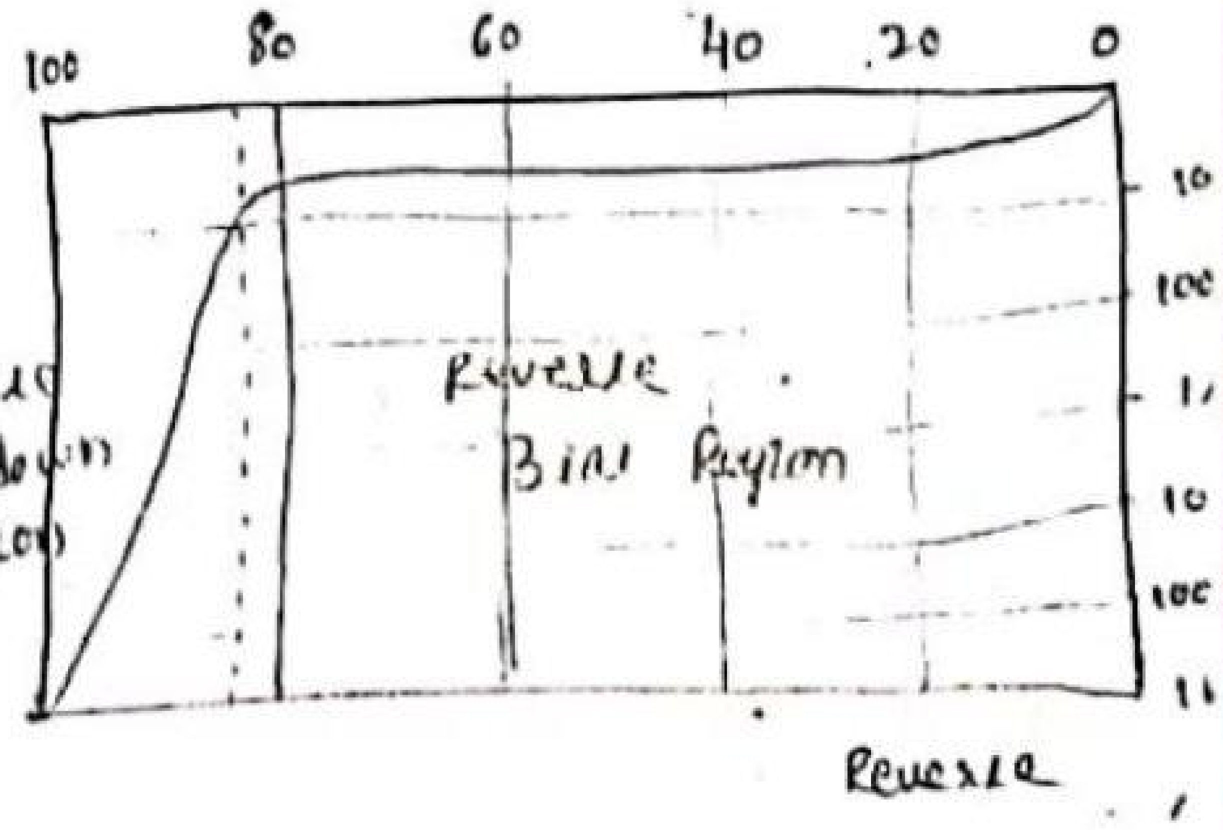


Reverse Biasing voltage.

→ Thus, the depletion layer grows wider due to lack of e^- & holes & presents a high impedance path, almost an insulator.

→ The result is that a high potential barrier is created thus preventing current from flowing through semiconductor material.

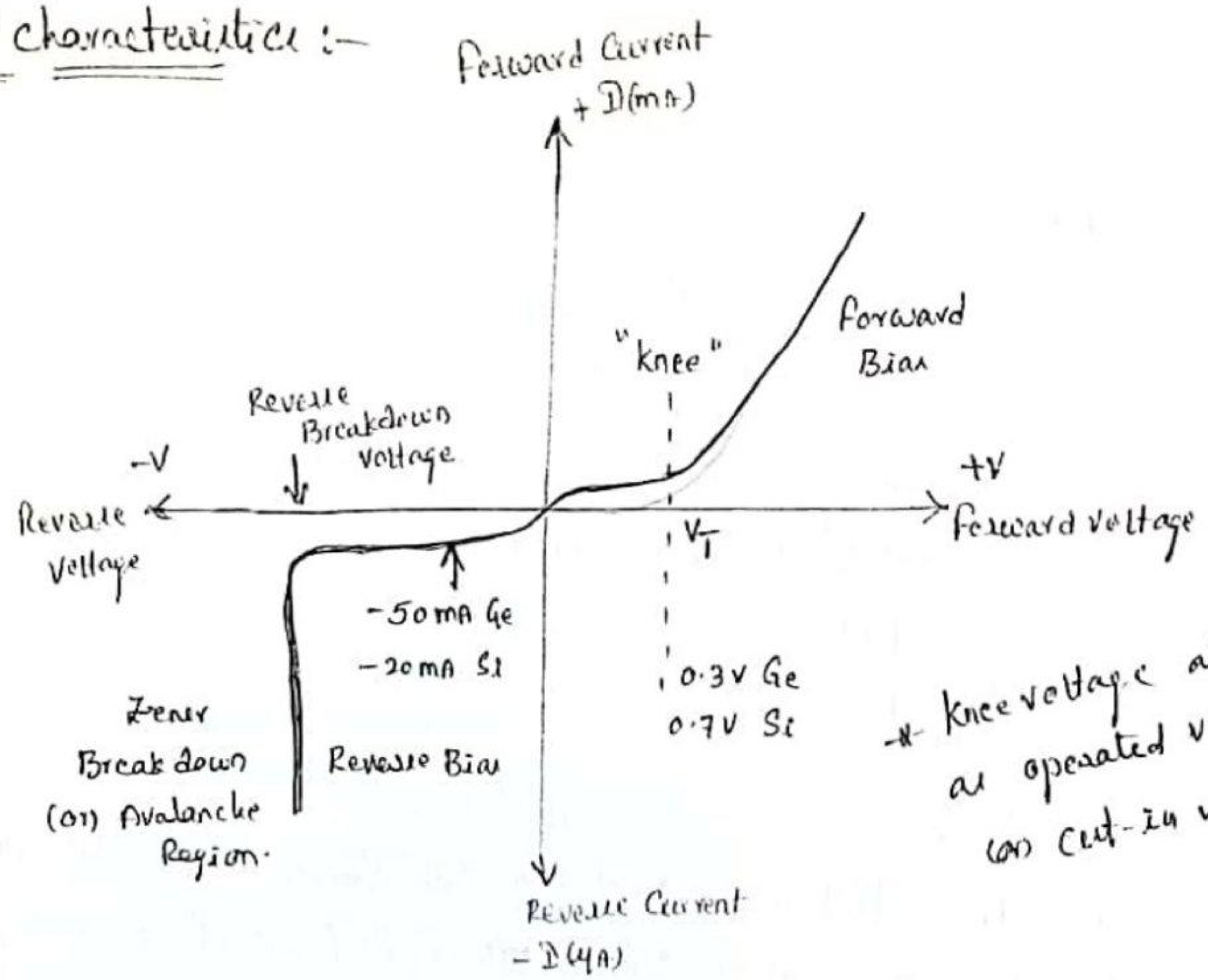
* Drift current flows in RB



→ A high resistance value to the PN junction & practically '0' current flows through the junction diode with an increase in bias voltage.

small leakage current

V-I characteristics :-



* knee voltage also known as operated voltage (or) cut-in voltage

Diode Relationship :-

It is a mathematical representation that shows us how does the applied voltage varies the current is given by the relation,

$$I_D = I_S \left(e^{V/\eta V_T} - 1\right)$$

where, $I_D \rightarrow$ Diode Current due to majority Carriers

$I_S \rightarrow$ Reverse Saturation Current.

$V \rightarrow$ applied voltage.

$V_T = \frac{KT}{q}$. i.e., Voltage equivalent of Temp.

$k =$ Boltzmann's Const. $= 1.38 \times 10^{-23}$ J/K

$q =$ charge on electron , $T \rightarrow$ Temp in °K.

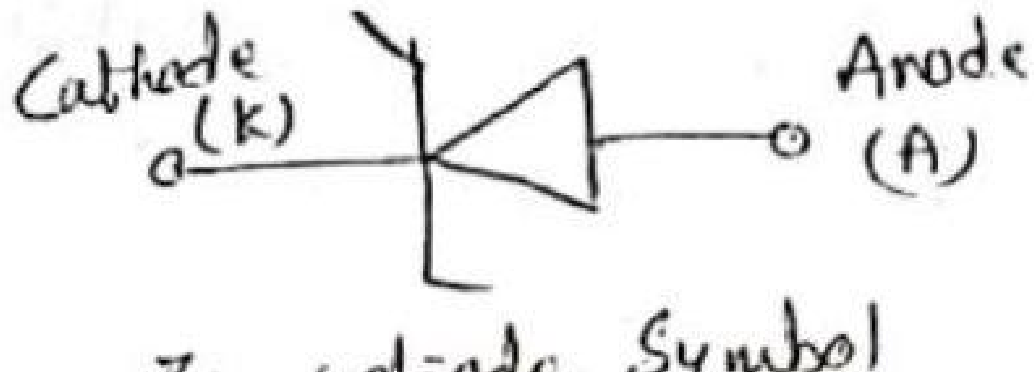
$V_T = 25.6$ mV

$\eta = 1 \rightarrow$ Ge

Zener diodes :-

The zener diode is like a general-purpose signal diode consisting of a silicon PN junction. when biased in the forward direction it behaves just like a normal signal diode passing the rated current, but as soon as a reverse voltage applied across the zener diode exceeds the rated voltage of the device, the diodes breakdown voltage V_B is reached at which point a process called "Avalanche Breakdown" occurs in the semiconductor depletion layer & a current starts to flow through the diode to limit this increase in voltage.

The current now flowing through the zener diode increases dramatically to the maximum circuit value (which is usually limited by a series resistor) & once achieved this reverse saturation current remains fairly constant over a wide range of applied voltages. This breakdown voltage point, V_B is called the "Zener voltage" for zener diodes & can range from less than one volt to hundreds of volts.



Zener diode Symbol

The point at which the zener voltage triggers the current to flow through the diode can be very accurately controlled (to less than 1% tolerance) in the doping stage of the diodes semiconductor construction giving the diode a specific 'zener breakdown voltage' (V_Z).

For Ex:- 4.3 V (or) 7.5V.

This zener breakdown voltage on the V-I curve is ... straight line.

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V-I characteristics of Zener diode :-

The Zener diode is used in its "reverse bias" (or) reverse breakdown mode, i.e., the diode anode connects to the -ve supply.

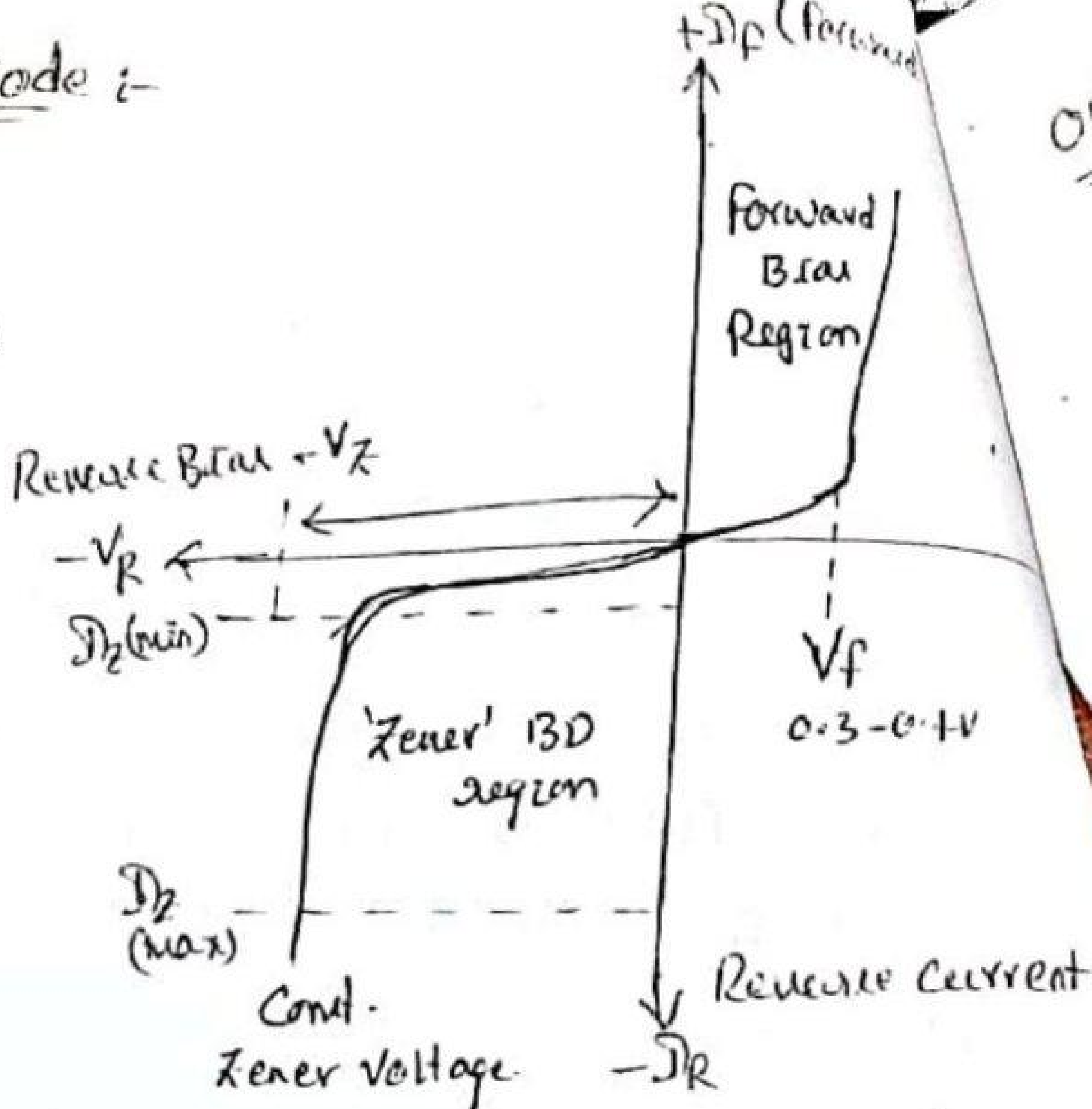

Fig:- Zener diode characteristics

From the V-I characteristics curve, we can see that the Zener diode has a region in its reverse bias characteristics of almost a Const. -ve voltage regardless of the value of the current flowing through the diode & remains nearly Const. even with large changes in current as long as the Zener diodes current remains b/w the breakdown current $I_Z(min)$ & the maximum current rating $I_Z(max)$.

This ability to control itself can be used to great effect to regulate (or) stabilize a voltage source against supply (or) load variations.

Applications :-

→ used for voltage regulation

⇒ used as reference elements

⇒ as surge suppressors

⇒ In switching applications

⇒ In clipper circuits.

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Diode as clipper:

The circuit for which the outputs are non-sinusoidal for sinusoidal inputs are called "Non linear wave shapping".

Eg: clippers and clamper circuits.

Clippers:

Def: It is an electronic circuit in which the waveform is shaped by removing (or) clipping a certain portion of the input signal without distorting the remaining part of the signal.

* It is also called as limiter, Amplitude selector (or) slicer.
* clippers are used in Radars, digital computers, Radio & TV receivers etc.

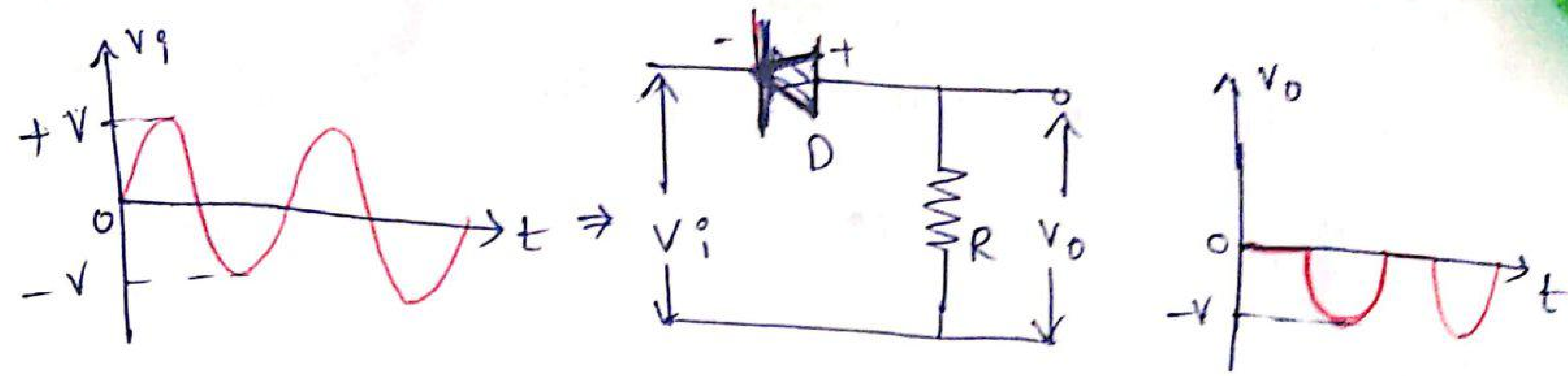
Types of clippers: four

1. positive clipper → shunt, series
2. Negative clipper → shunt, series
3. Biased clipper.
4. Combinational clipper.

(i) Positive clipper:

It is a circuit that clips off the positive half cycles of input signal.

It consists of a diode and resistor R.



* when $V_i \geq 0V$ diode D is reverse biase 'D' acts as open switch

Hence the positive halfcycle doesnot appear at the output.

ie $V_0 = 0V$

The positive halfcycle is clipped off.

* when $V_i < 0V$, diode 'D' is forward biased 'D' acts as short circuit (closed circuit).

The negative half cycle appears at the output.

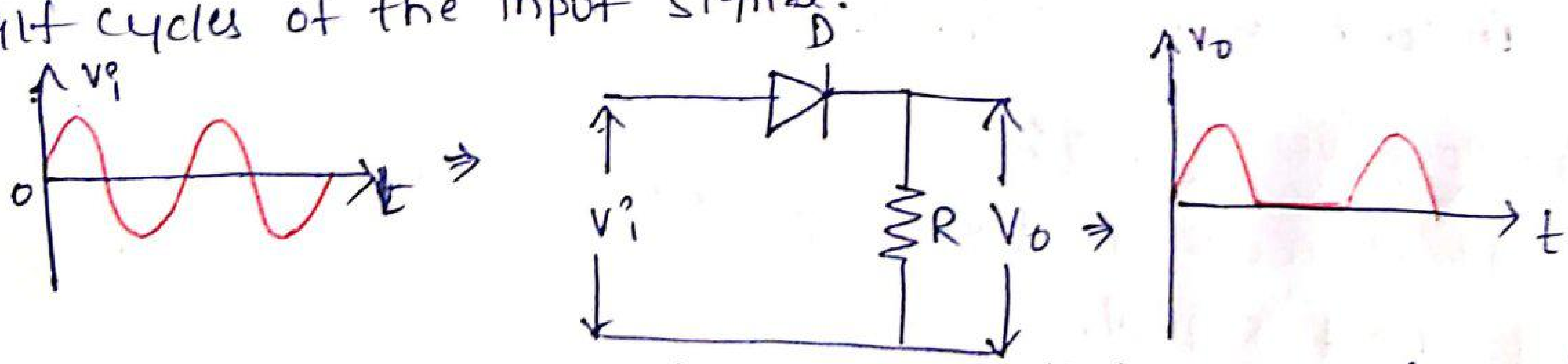
$V_0 = V_i$

Note:

The positive clippers act as "Half wave Rectifier".

(b) series Negative clipper:

Negative: It is a circuit that clips off the negative half cycles of the input signal.



* During positive half cycle ($V_i \geq 0V$), the diode 'D' is forward biased and acts as a closed switch.

$V_0 = V_i$

(*) During negative half cycle ($V_i < 0V$) 'D' is reverse biased and acts as open circuit.

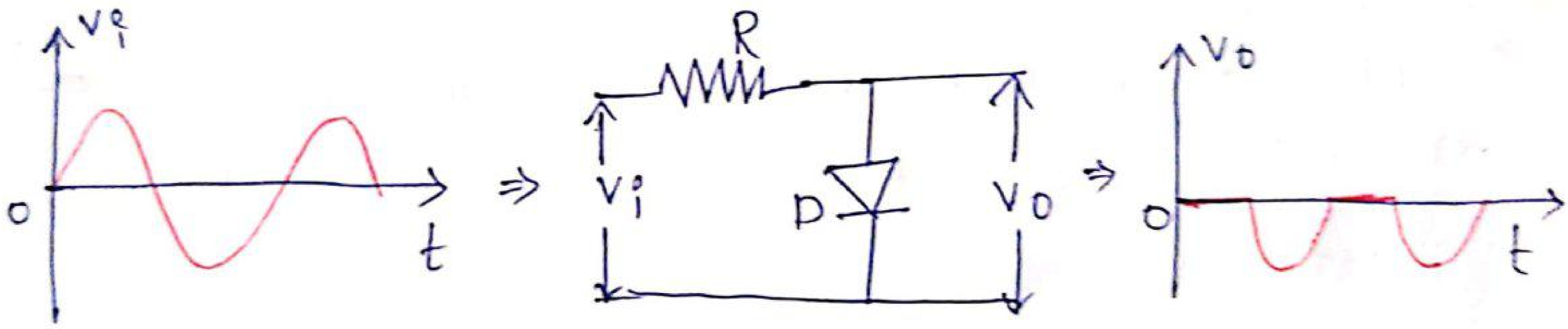
$$V_o = 0V$$

ie, the negative half cycles of the input signal are clipped off.

(ii) Shunt positive clipper:

→ It is a circuit that clips off the negative half cycles of input signal.

(*) When the diode is connected in parallel to the load, it is called as "parallel clipper".



(*) When $V_i \geq 0V$; Diode is forward biased and acts as closed switch

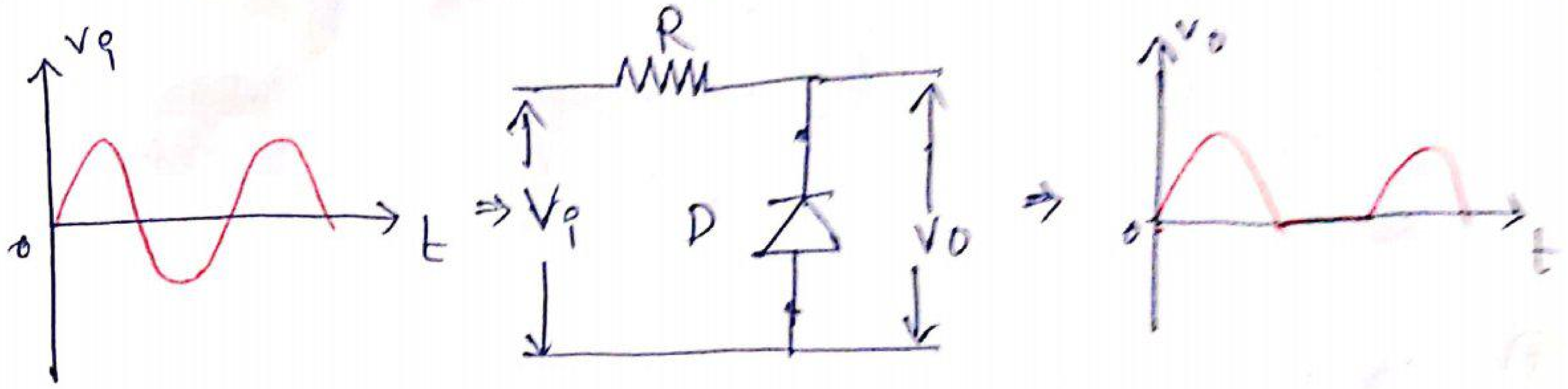
$$V_o = 0V$$

When $V_i < 0V$, (during negative cycles), the diode is reverse biased and acts as open switch.

$$V_o = V_i$$

Thus the positive half cycles of the input are clipped off is the output.

⊛ Shunt Negative clipper:



when vi · R·B (Vo = 0)

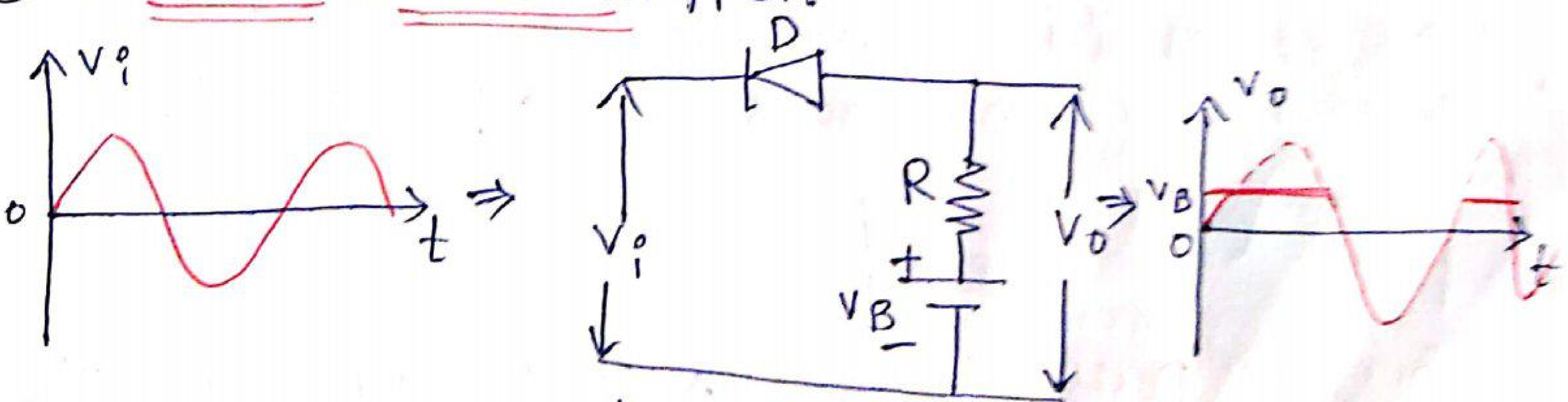
F·B (Vo = Vi)

(iii) Biased Clipper:

It is used to remove a small portion of the positive (or) negative half cycle of the input signal based on "biasing voltage".

* The clipping level can be shifted up (or) down by varying the bias voltage 'V_B'.

(i) Positive Biased clipper:

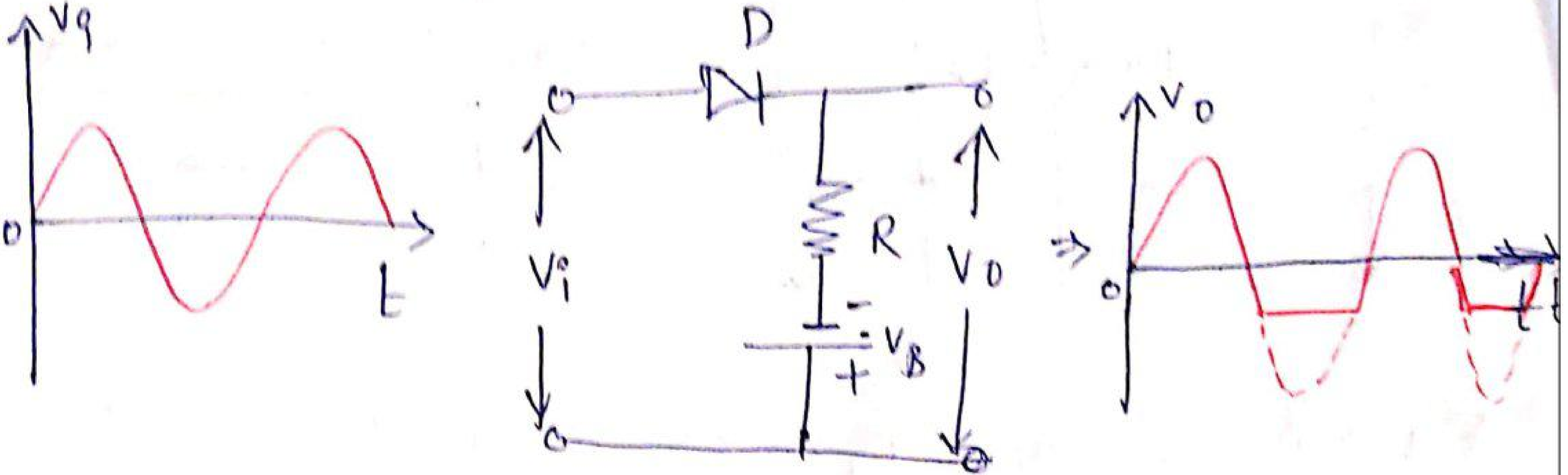


⊛ In this clipper, the diode doesnot conduct as long as input voltage is greater than 'V_B'.

ie, the output remains at V_B. [$V_i \geq V_B$]

when ($V_i < V_B$) the diode conducts and all the input signal having less than 'V_R' is also the negative half cycle appear at the output.

Negative Biased Clipper:

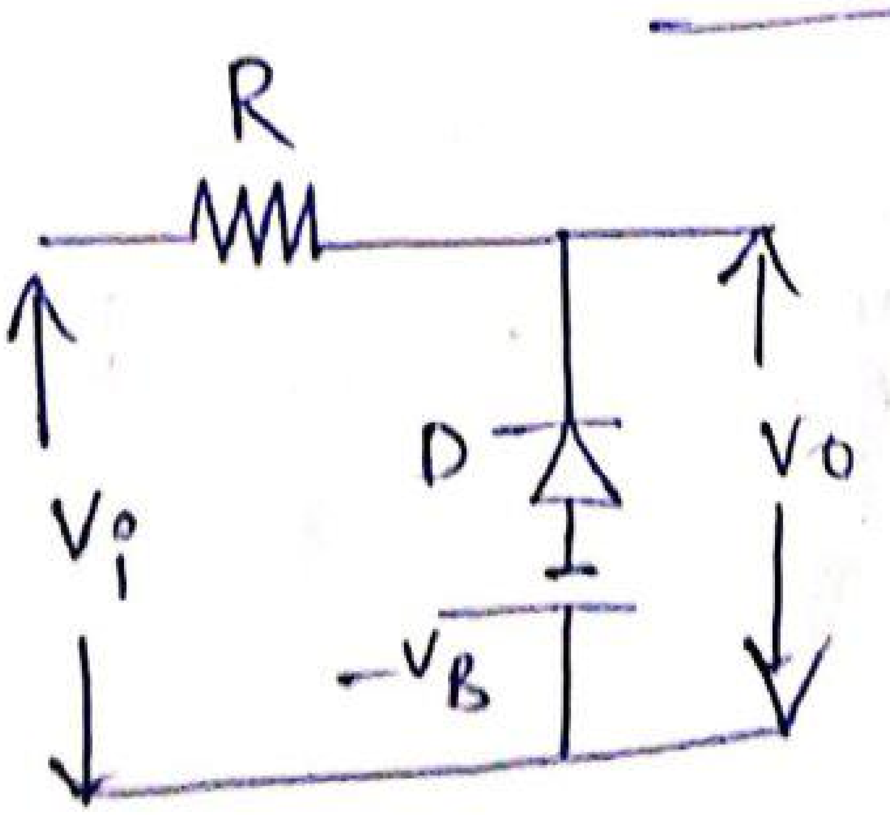


when the input voltage $V_i \leq -V_B$ the diode does not conduct and the output is

$$V_0 = -V_B$$

when the input voltage $V_i > -V_B$, the diode is ON & the output

$$V_0 = V_i$$ ~~is ON & the~~



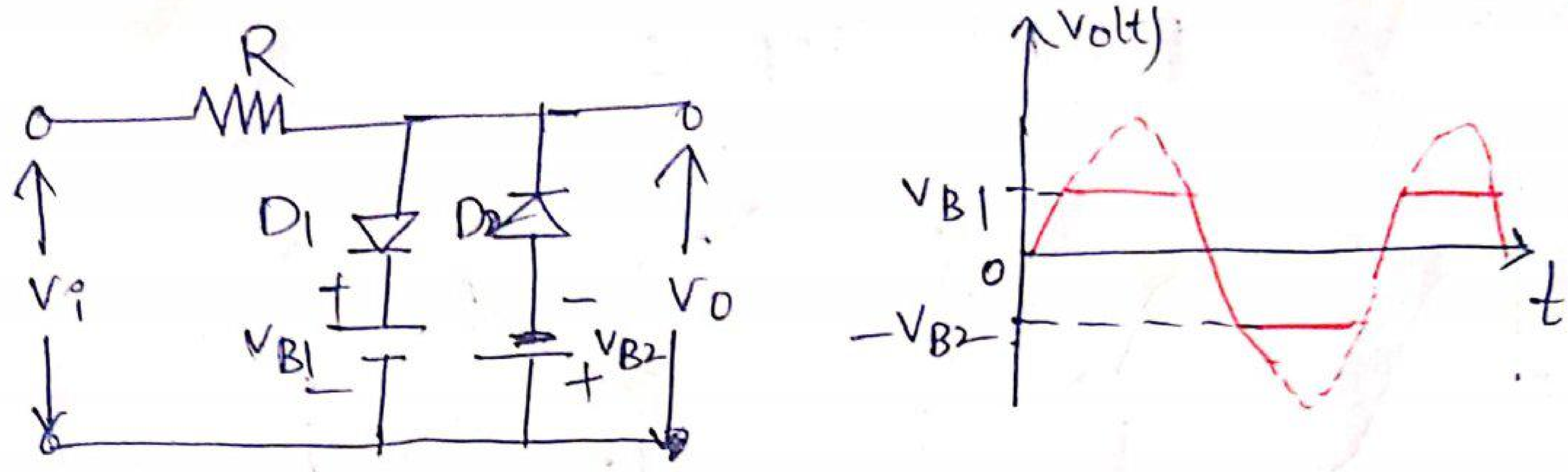
Biased shunt Negative clipper.

$$V_0 = \begin{cases} -V_B; & V_i \leq V_B; \text{ D-OFF} \\ V_i; & V_i \geq V_B; \text{ D is ON} \end{cases}$$

$$V_0 = \begin{cases} -V_B \\ \end{cases}$$

(iv) Combination clipper:

It is the combination of biased positive clipper and a biased negative clipper.



- When $V_i \geq V_{B1}$, D_1 is ON and D_2 is OFF

$$V_0 = V_{B1}$$

- When $V_i \leq -V_{B2}$, D_1 is OFF and D_2 is ON.

$$V_0 = -V_{B2}$$

- When V_i is between $-V_{B2}$ and V_{B1}, both Diodes D_1 and D_2 are OFF.

$$V_0 = V_i$$

- It can clip two independent levels depending on V_{B1} and V_{B2}.

Diode as clampers:

Def: A clamper circuit is a electronic circuit that adds (or) shifts a DC level to an AC signal.

(*) when a negative peak of the signal is raised above to the zero level, then the signal is said to be "positively clamped".

(*) when a positive peak of the signal is shifted below to the zero level, then the signal is said to be "negatively clamped".

→ As the DC level gets shifted, a clamper circuit is called "Level shifter".

* This clamper circuit is also known as "DC Restorer"

There are two types of clampers.

1. positive clamper
2. Negative clamper.

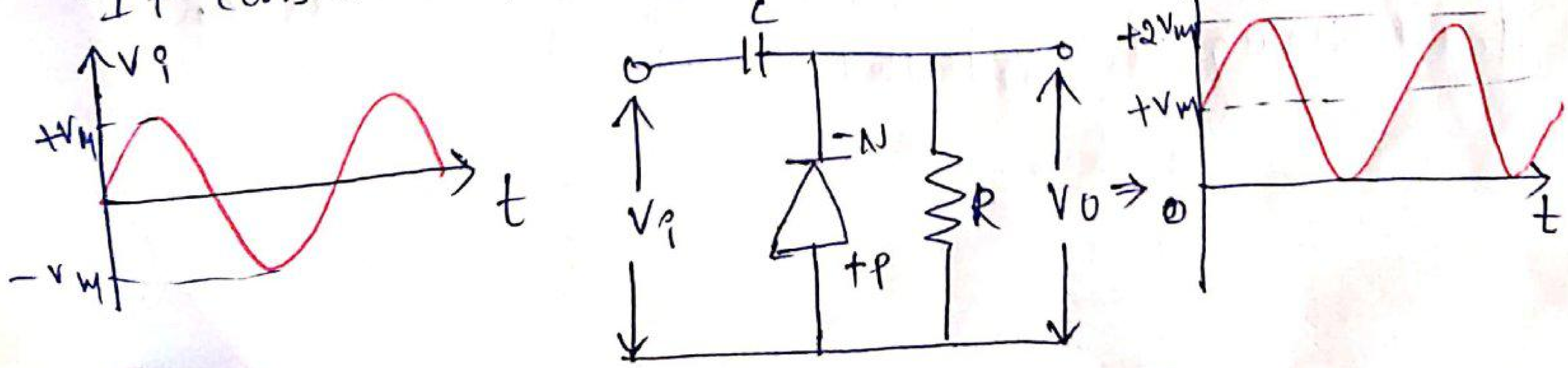
Assumption:

(i) Diode is an ideal one.

(ii) The time constant ($\tau = RC$) must be very large by selecting proper R & C value.

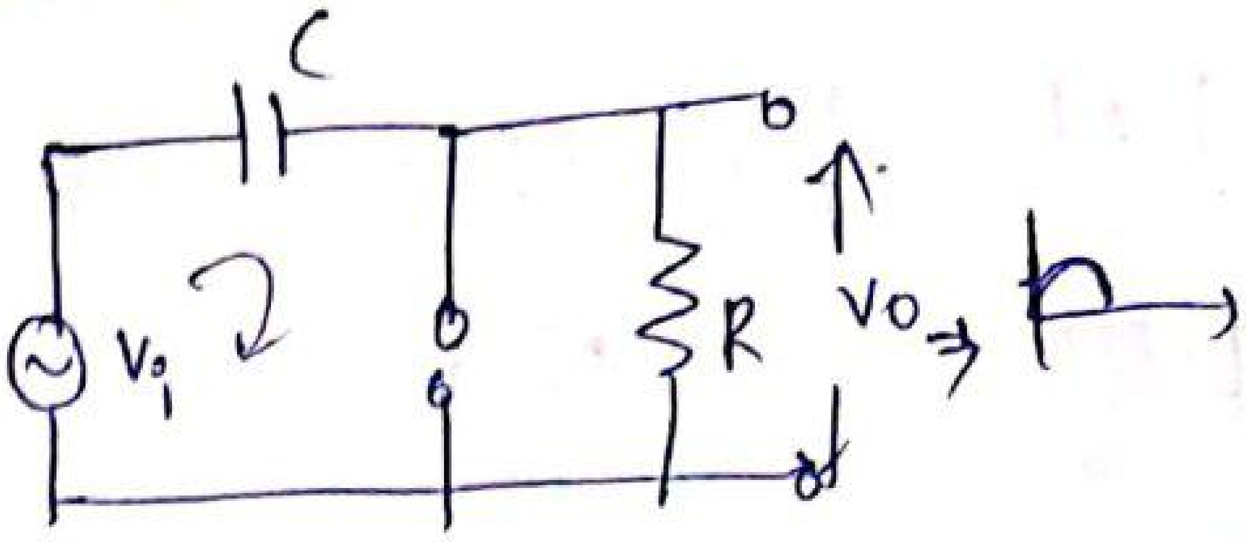
(1) positive clamper:

It consists of a diode, capacitor and resistor



This point '2'

(*) During the positive half cycle, the diode is reverse biased and the capacitor starts discharging through 'R'.

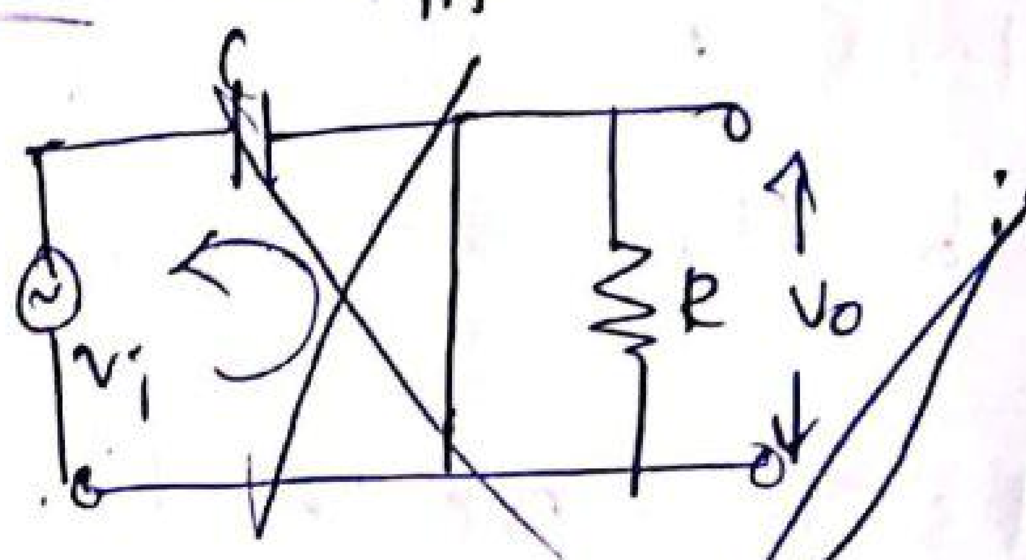


$$V_o = V_i + V_m$$

→ it allows only high-freq.

This one point '1'

~~(*) During the Negative half cycle of the input voltage 'V_i' diode gets forward biased and capacitor gets charged to the maximum value 'V_m'~~



(1) capacitor holds it's entire charge all the time due very high

$$V_o = V_i + V_m$$

when $V_i = V_m$ $\Rightarrow$ $V_o = V_m + V_m = 2V_m$

V_o is $2V_m$.

$$V_o = \begin{cases} V_m & ; V_i = 0 \\ 2V_m & ; V_i = V_m \\ 0 & ; V_i = -V_m \end{cases}$$

(*) During the negative half cycle of the input voltage 'V_i' diode gets forward bias and capacitor gets charged to the maximum vol 'V_m'. $V_o = V_i + V_m$

The total swing of the output is same as the total swing of the input.

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(ii) Negative clamper:

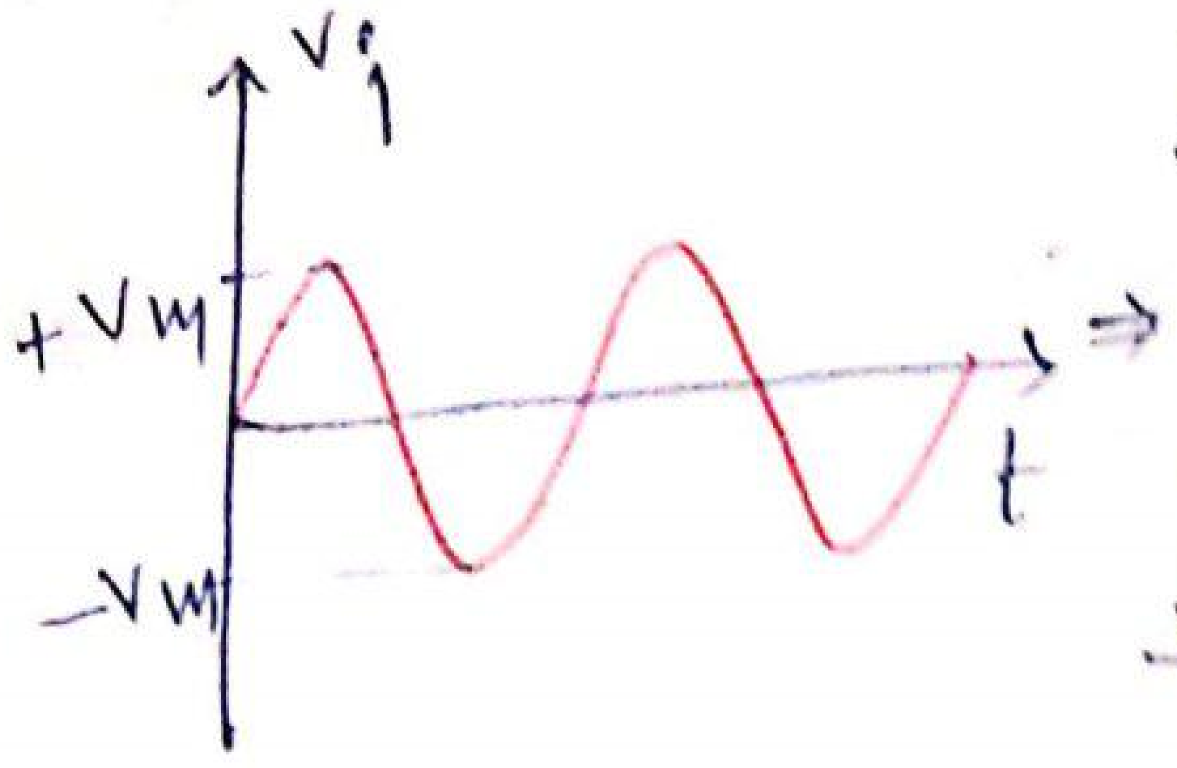

fig: Input wave form

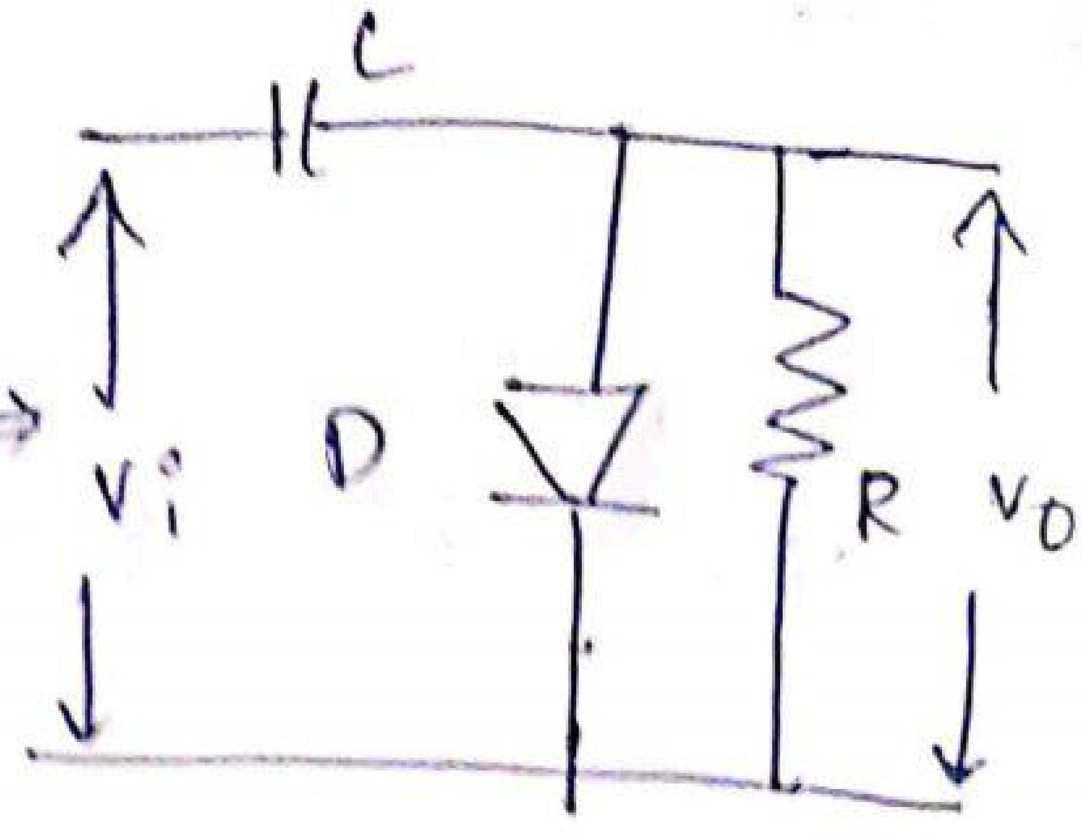

fig: Negative clamper circuit

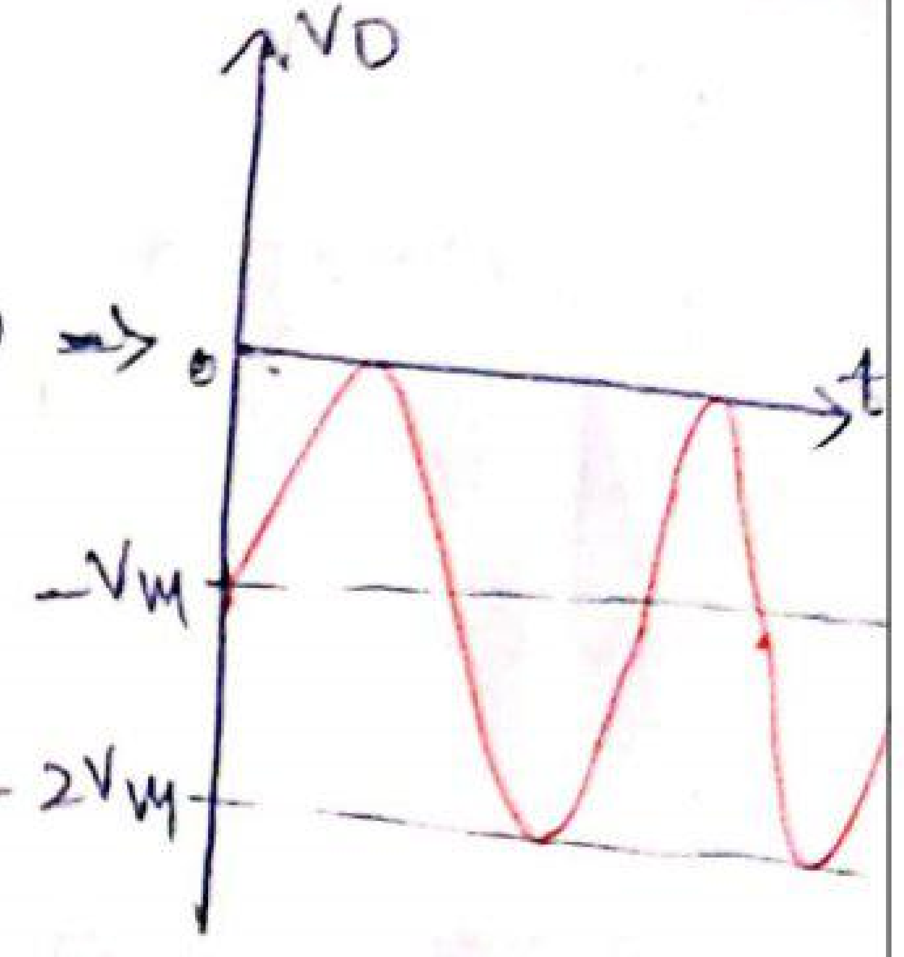

fig: output waveform

(*) During positive half cycle of the input signal, diode is forward biased and the capacitor gets charged upto the maximum value 'V_m'.

(*) when 'D' is forward biased, V_o is zero.

As the input voltage decreases often the positive peak value, the capacitor remains charged to 'V_m'

$$V_C = V_m$$

(*) As the time constant (τ) is very large, the capacitor holds all charges and remains charged to 'V_m'.

$$\boxed{V_o = V_i + V_m}$$

$$V_o = \begin{cases} -V_m \; ; & V_i = 0 \\ 0 \; ; & V_i = V_m \\ -2V_m \; ; & V_i = -V_m \end{cases}$$

* During the negative half cycle, the diode is open and the capacitor starts discharging the resistor 'R'.

In clamper circuit, the total swing of the output signal is equal to the total swing of the input signal.

Applications of clampers:

* It is ~~used~~ can be frequently used in removing the distortions.

* For improving the reverse recovery time, clampers are used.
* claming ckts can be used as voltage doublers and for modelling the existing waveforms to a required shape and range.
* Radar systems, sonar systems,
* used in TV receivers as a DC restorer.

Applications of clippers:

The main purpose of clipper circuit is to modify waveform of the signal which can be used in several applications such as in protection against overvoltage, noise removal, transmission etc.

* The clipper are used in transmitters and receivers of television.

Part-B → Transistors

1) Introduction :-

Transistor is Composition of two words i.e., Transfer and varistor (Variable Resistor). A transistor consists of 3 layers of Semiconductor material & each layer is having the capability of transferring current to the other layers.

This 3 layer Semiconductor device consisting of either two n-type & one-p type layers of materials (or) 2 p-type & one n-type layers of materials. The first type is called an NPN transistor, while the other is called PNP transistor respectively.

Ge & Si are the most preferable Semiconductor materials, which conducts electricity in semi-energetic way.

The difference b/w the diode & the transistor is

⇒ A diode is made up of 2 di layer & one junction.
⇒ A Transistor is made up of 3 layers with 2 junctions.

A transistor can acts as an ON/off Switch (OR) an amplifier. Amplifier :- it gives the strength of the weakest signal - It's using in trucks Receivers

Transistor :-

A transistor is a Semiconductor device which transfers a signal from a low resistance to high resistance.

Transistor
- Unipolar Junction Transistor (UJT)
- Bipolar Junction Transistor (BJT)

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UJT ⇒ In UJT, the current conduction is only due to one type of charge carriers i.e., majority carriers.

BJT ⇒ The current conduction is due to both majority & minority charge carriers.

Construction :-

BJT is a semiconductor device in which one type of semiconductor material is sandwitched b/w two opposite types of SC i.e., an n-type SC is sandwiched b/w 2 p-type SC (or) a p-type SC is sandwiched b/w 2 n-type SC.

Hence the BJT's are of 2 types. They are :

→ p-n-p Transistor
→ n-p-n Transistor.

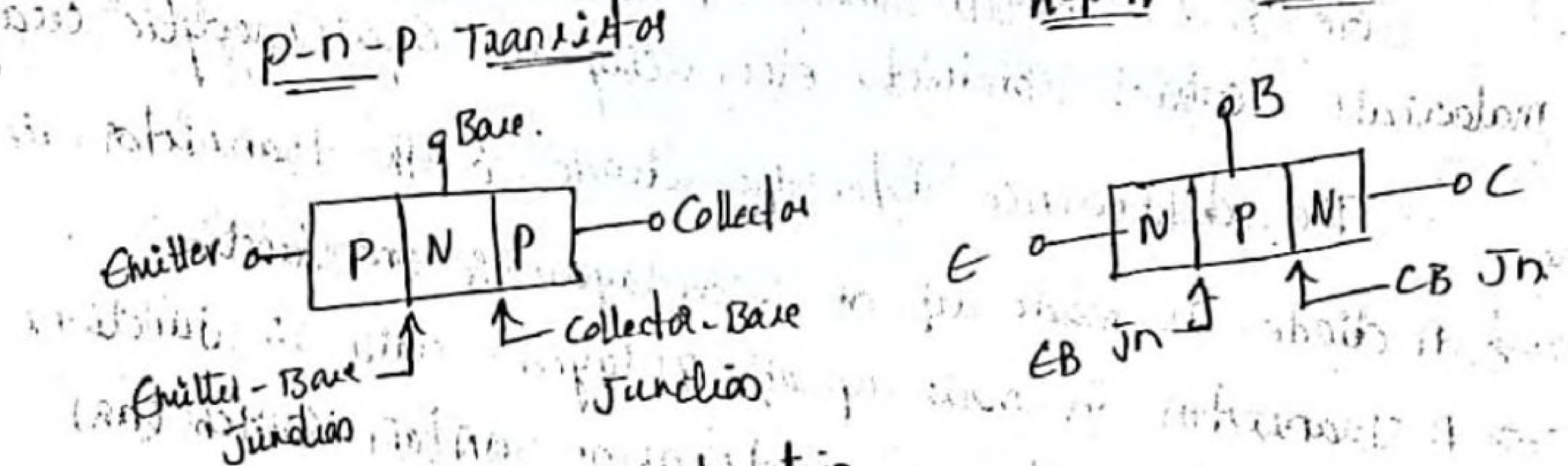


Fig (a) Construction

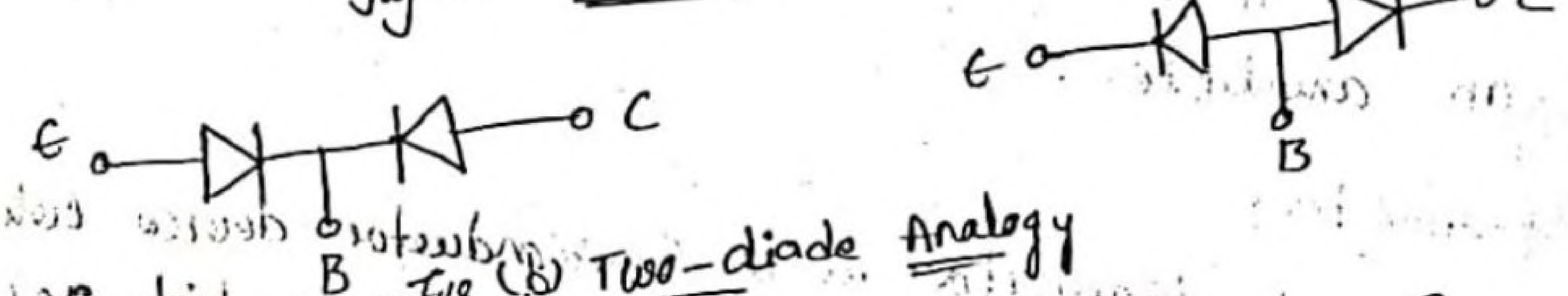


Fig (b) Two-diode Analogy

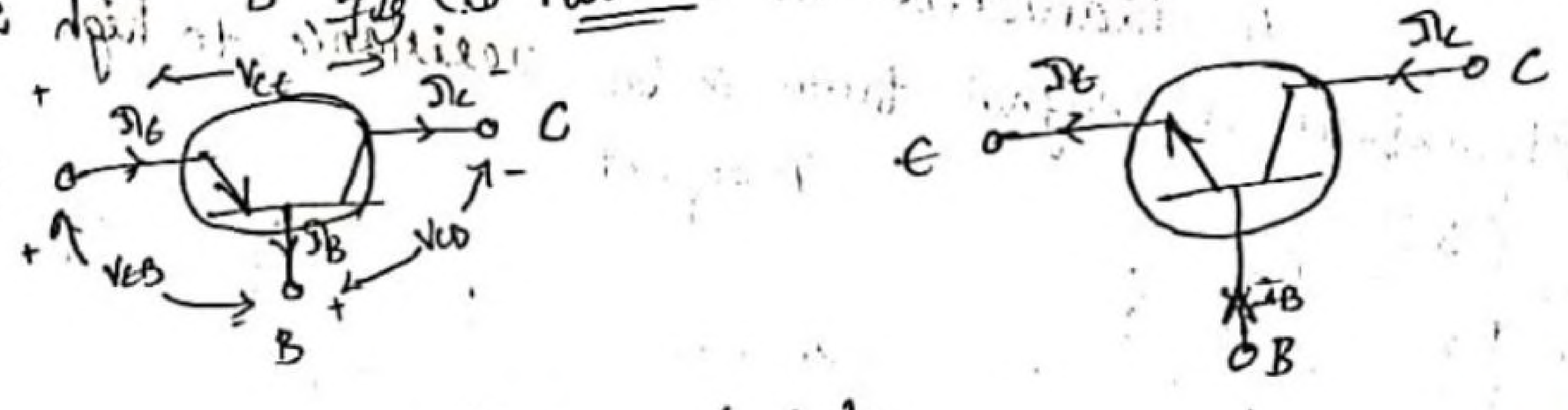


Fig (c) :- Symbols

Two types of BJT's are shown in fig.

Here, the arrow head represents the conventional current direction from p to n. Transistor has 3 terminals.

1) Emitter
2) Base
3) Collector

Emitter → Emitter is heavily doped because it is to emit the charge carriers.

Base → The charge carriers emitted by the emitter should reach collector passing through the base. Hence base should be very thin & to avoid recombination, & to provide more collector current base is lightly doped.

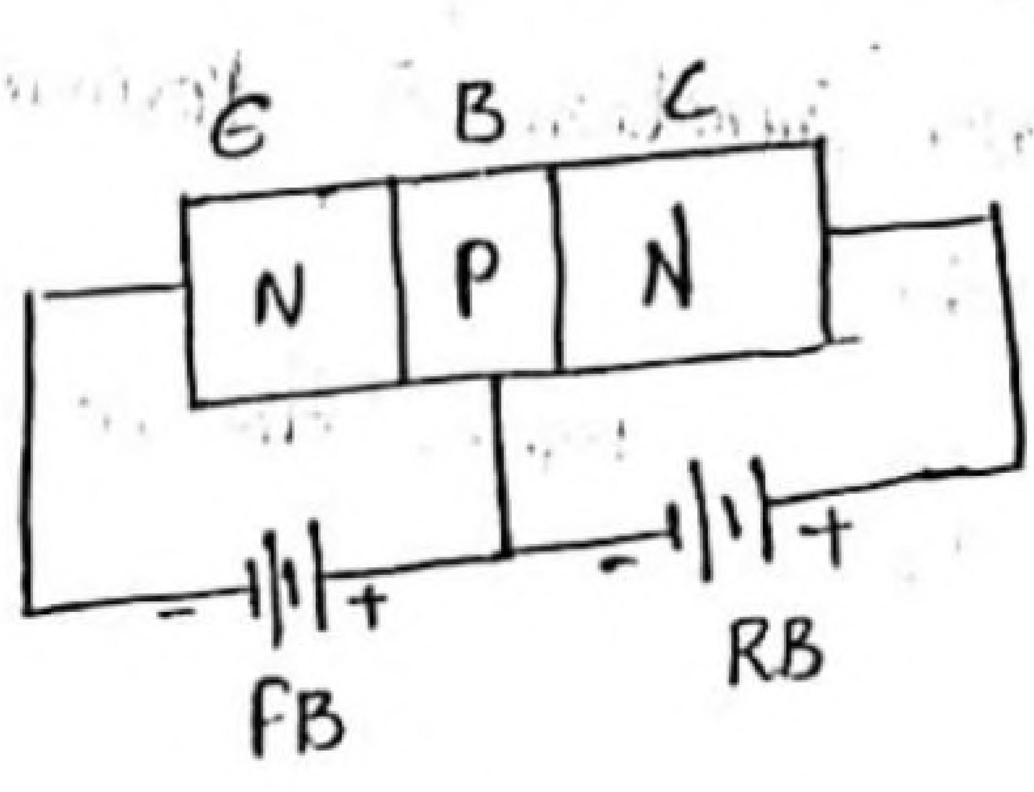
Collector → collector has to collect the most of charge carriers emitted by the emitter. Hence the cross section area of collector is more compared to emitter & is moderately doped.

Transistor can be operated in 4 Regions:-

Transistor operating modes :- → 1) Active mode.
→ 2) Saturation mode
→ 3) Cut-off mode
→ 4) Reverse Active Mode.

1) Active Mode :- for the transistor to operate in active region, base to emitter junction is forward biased & collector to base junction is reverse biased.

For the transistor to act as an amplifier, it should be operated in active region.



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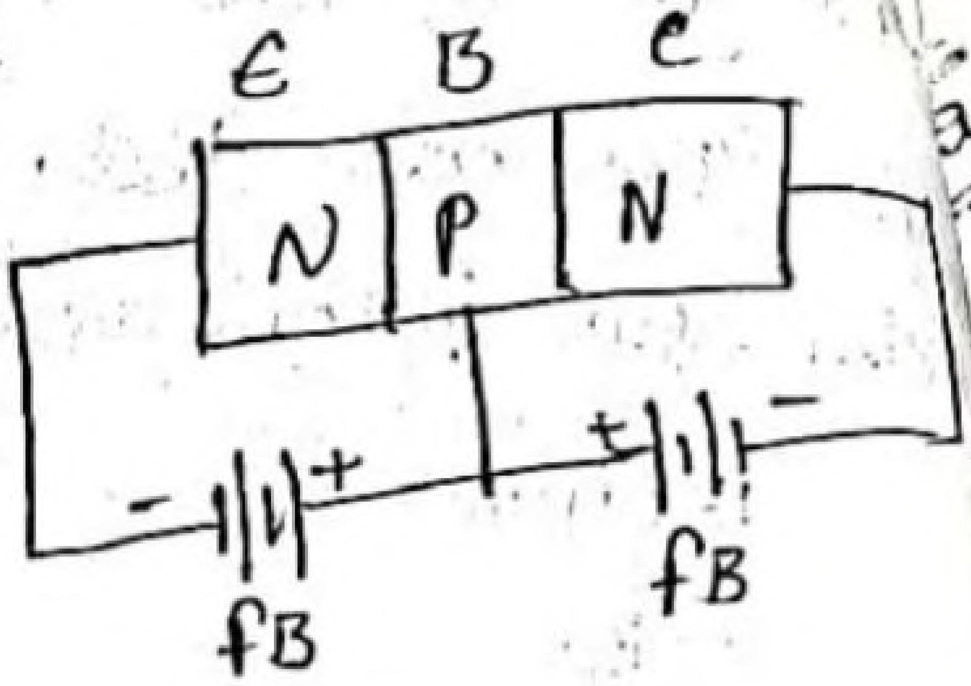
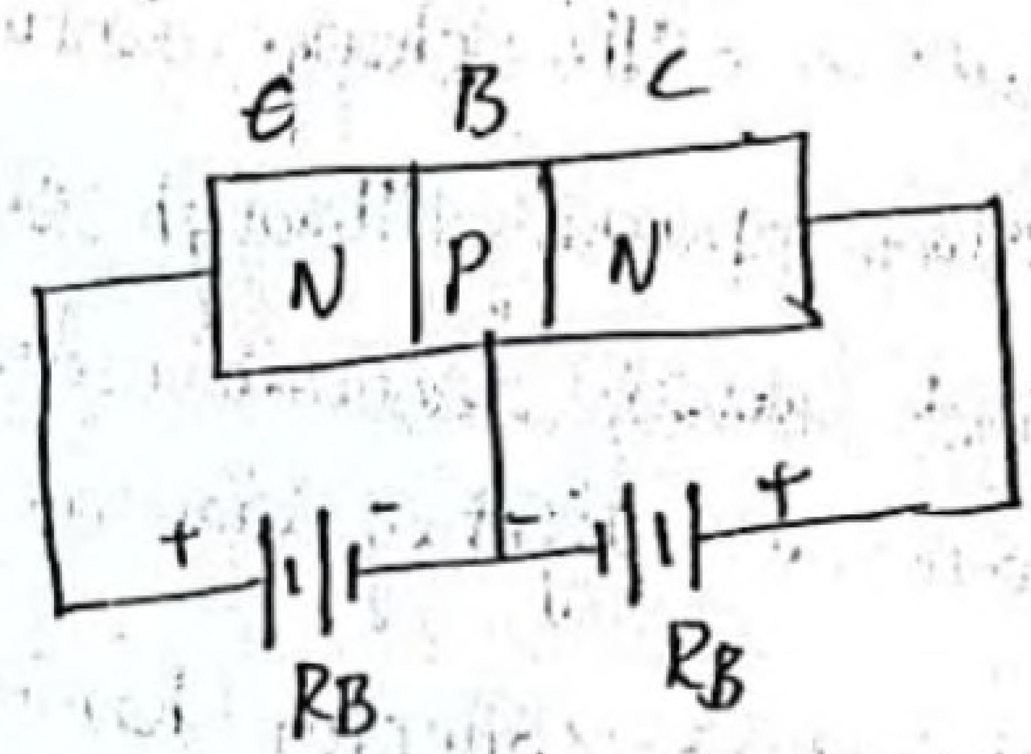
2> **Saturation Mode** :— For the transistor to be operated in saturation region if both the junctions i.e., collector to base junction & base to emitter junction are forward biased.



For the transistor to act as a Switch, it should be operated in Saturation region for "ON" State.

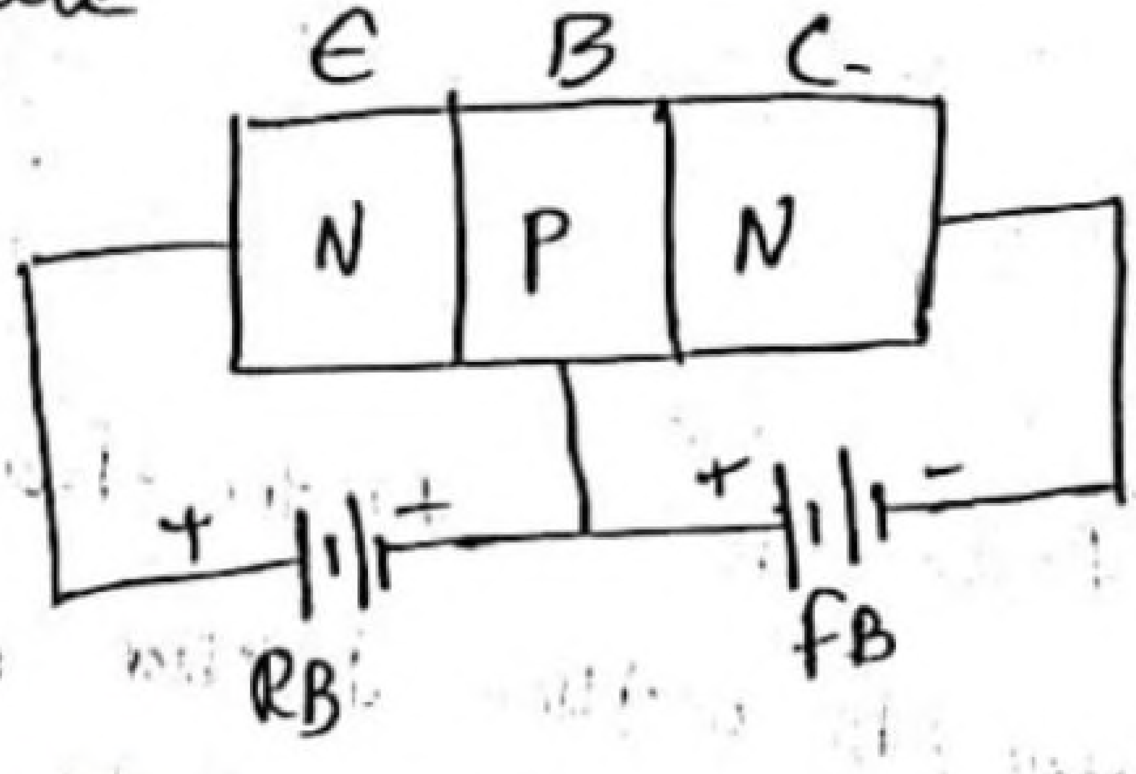
3> **Cut-off Mode** :— For the transistor to operate in cut-off region both the junctions i.e, base to emitter junction & collector to base junction are reverse biased.



For the transistor to act as switch, it should be operated in cut-off region for "OFF" State.

4> **Reverse Active Mode** :—

For the transistor to operate in reverse-Active region, base to emitter junction is reverse biased and base to collector junction is forward biased.



∴ Transistor can be used as 1> Amplifier
2> Switch.

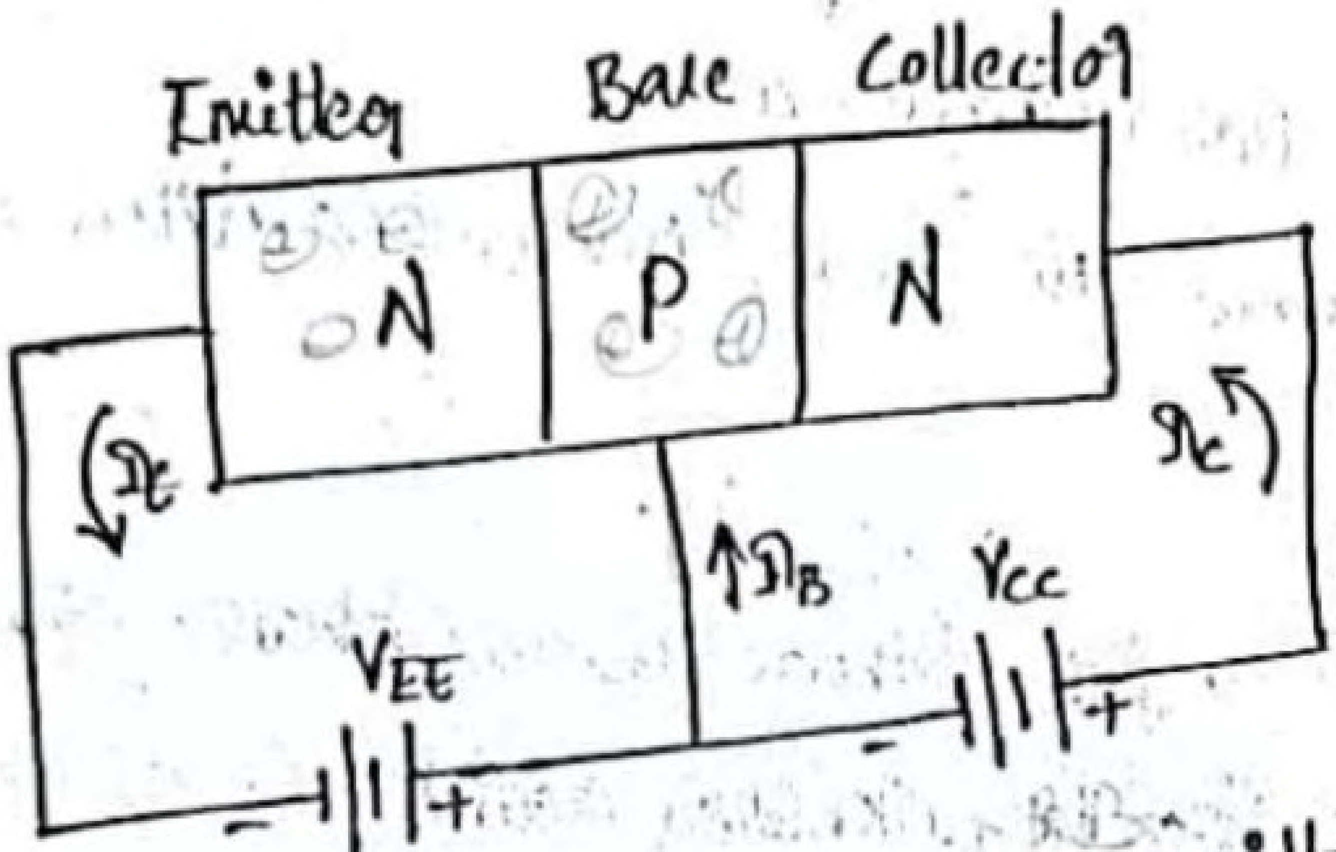
Transistor Operation:—

The transistor can be operated in two formats.

there are → 1) N-P-N transistor
→ 2) P-N-P transistor.

1) N-P-N Transistor Working:—

o/p current high
collector top high current
5% recombination
95% going to collector
so I_C current form



The n-p-n transistor with base to emitter junction forward biased & collector base junction reverse biased is as shown in fig. the majority carriers

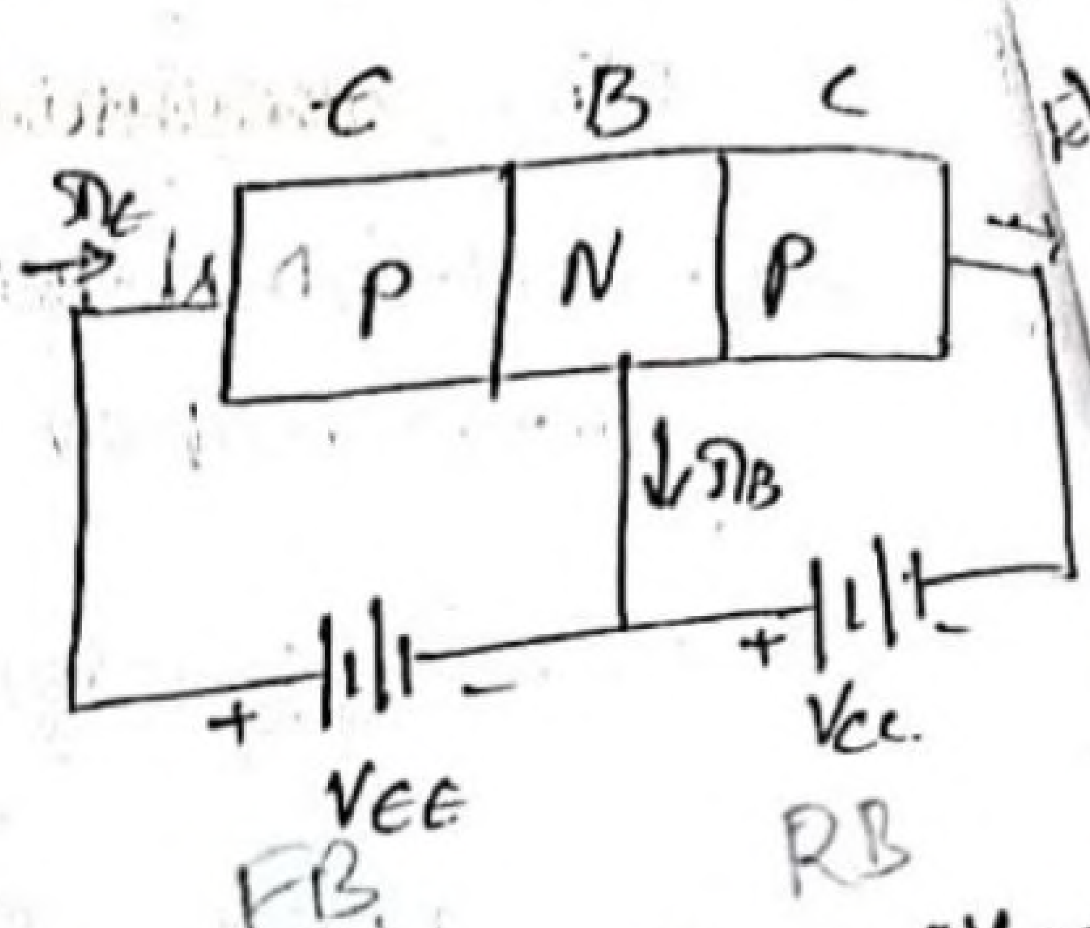
As the base to emitter Jn is FB, the majority carriers i.e., electrons have a tendency to emitted by the n-type emitter i.e, electrons have a tendency to flow towards the base which constitutes the emitter current I_E.

As the base is p-type there is chance of recombination of electrons emitted by the emitter with the holes in the p-type base. But as the base is very thin & lightly doped only few electron emitted by the n-type emitter less than 5% combines with the holes in the p-type base, the remaining more than 95% electrons emitted by the n-type emitter cross over into the collector region constitute the collector current.

The current distributions which is shown in fig is given by $I_E = I_B + I_C$.

22) Working of P-N-P Transistor :-

The p-n-p transistor with base to emitter junction is FB & collector to base Jn is RB as shown in fig.



As the base to emitter is FB the majority carriers emitted by the p-type emitter i.e., holes have a tendency to flow towards the base which constitutes the emitter current I_E.

As the base is n-type there is a chance of recombination of holes emitted by the electron emitter with the e^- in n-type base.

But as the base is very thin & lightly doped only few electrons less than 5% combine with the electrons holes emitted by the p-type emitter, the remaining 95% charge carriers cross over into collector region to constitute the collector current.

The current distribution which is shown in fig is given by

$$I_E = I_B + I_C.$$

Current Components in a Transistor :-

The fig. shows the various current components which flows across the FB emitter junction & RB collector junction in p-N-P transistor.

The emitter current consists of two parts.

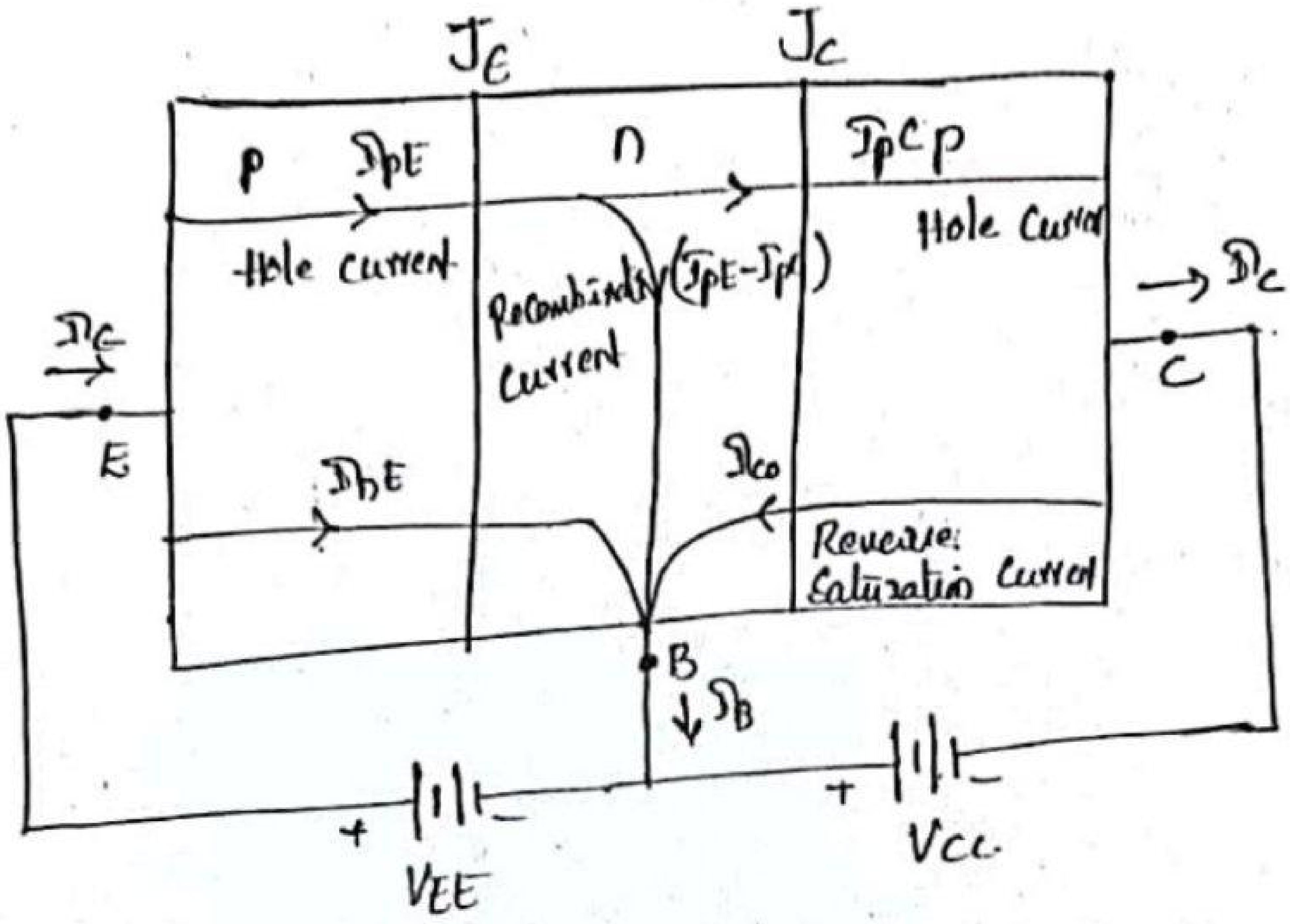
1 → Hole current (I_{pE})

2 → Electron current (I_{nE})

Hole current I_{pE} constituted by holes (holes crossing from E to B)

Electron current I_{nE} constituted by e^- (e^- crossing from B to E]

∴ Total emitter current, $I_E = I_{pE}$ (majority) $+ I_{nE}$ [minority]



⇒ The holes crossing the emitter base junction JE & reaching the collector base jn JC consists of collector current I_{pC}.

⇒ Not all the holes crossing the emitter base Jn JE reach collector base Jn Jc because of some of them combine with the e^- in n-type base. Since base width is very small, most of the holes cross Jc & very few recombine, constituting base current $[I_{pE} - I_{pC}]$.

⇒ when the emitter is open ckt'd, $I_E = 0$ & have $I_{pC} = 0$. under this condition, the base & collector together current I_C equals the reverse saturation current I_{co}.

⇒ when JE is FWB & JC is RB, the total collector current I_C will be the sum of hole current in collector I_{pC} & Reverse saturation I_C i.e, I_{co} ; $\boxed{I_C = I_{pC} + I_{co}}$

For PNP transistor $\boxed{I_E = I_B + I_C}$.

Transistor Configurations:—

When a transistor is to be connected in a ckt, one terminal is used as an i/p terminal, other terminal is used as an o/p terminal & the third terminal is common to the i/p & o/p.

Depending upon the i/p, o/p & common terminals, a transistor can be connected in 3 configurations.

→ 1. Common Base (CB) Configuration :—

It is also called as Grounded-base configuration. In this configuration, the emitter is the i/p terminal, the collector is the o/p terminal & base is the common terminal.

→ 2. Common Emitter (CE) Configuration :—

It is also called as Grounded-Emitter configuration. In this configuration, the base is the i/p terminal, the collector is the o/p terminal & the emitter is the common terminal.

→ 3. Common Collector (CC) Configuration :—

This is also called as Grounded-Collector configuration. In this configuration, base is i/p terminal, emitter is the o/p terminal & the collector is the common terminal.

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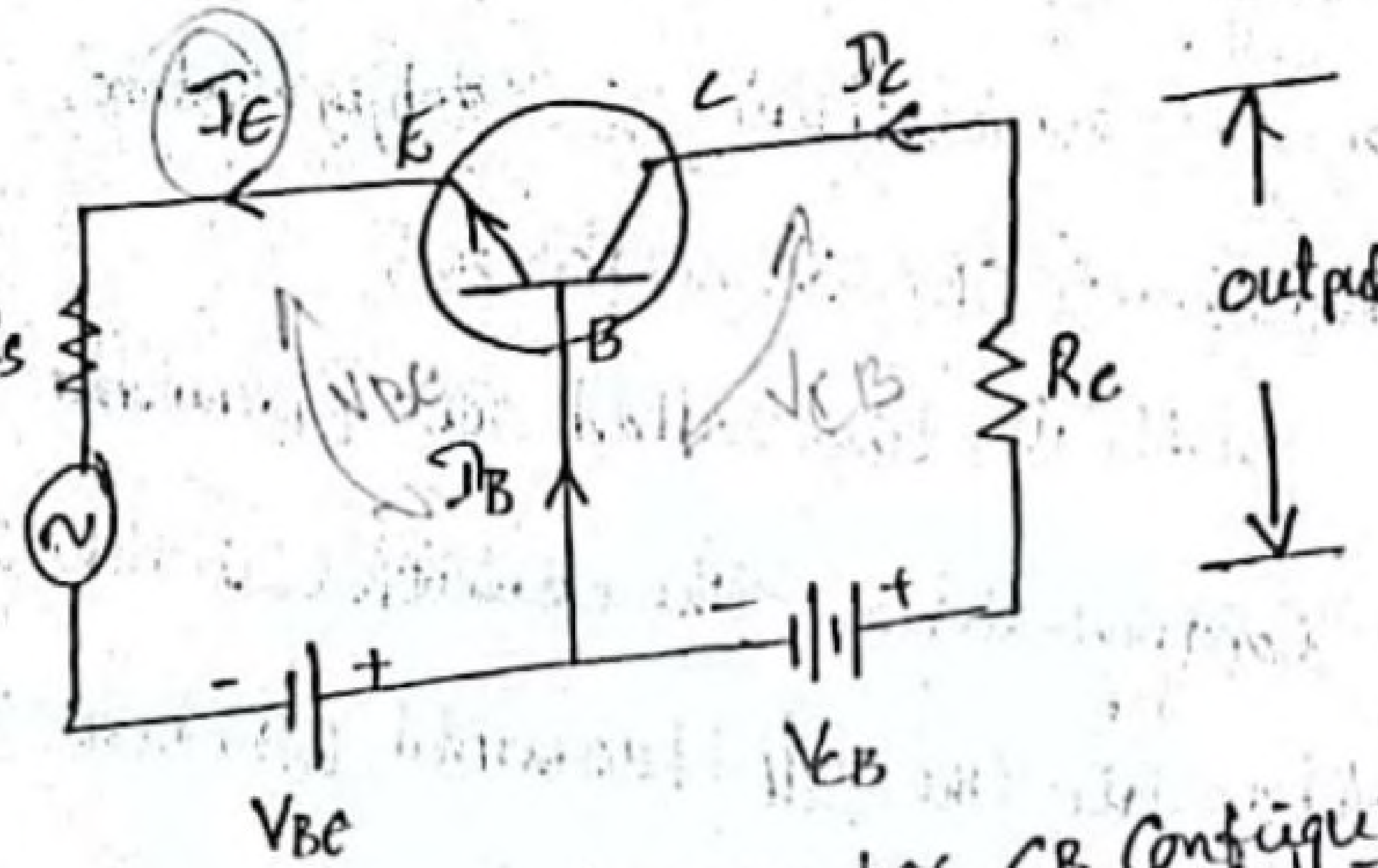
→ Common Base (CB) Configuration :-

In this Configuration, the i/p Signal is applied b/w emitter & base while the o/p is taken from collector & base i.e. A base is Common to input & o/p circuits. Hence the name Common - base Configuration



Fig(a) :- Circuit diagram for CB Configuration

When the emitter voltage is applied, as it is forward biased, the electrons from the negative terminal repel the emitter electrons & current flows through the emitter and base to the collector to contribute collector current.

The voltage VCB is kept constant throughout this.

In the CB Configuration, the i/p current is the emitter current I_E and the o/p current is the collector current I_C.

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Current Amplification Factor (α):–

The ratio of change in collector current ΔI_C to the change in emitter current ΔI_E when collector voltage V_{CB} is kept constant, is called as current amplification factor. It is denoted by α.

$$\alpha = \frac{\Delta I_C}{\Delta I_E} \quad \text{at constant } V_{CB}.$$

Expression for collector current

Along with the emitter current flowing, base current I_B flows through the base terminal due to e⁻-hole recombination. As collector base is reverse biased, leakage current ($I_{leakage}$) which is very small flows due to some minority charge carriers.

The emitter current that reaches the collector terminal is αI_E. Total collector current

$$I_C = \alpha I_E + I_{leakage}$$

$$I_C = \alpha I_E + I_{CBO} \rightarrow (1) \quad (I_{leakage} \text{ is termed as } I_{CBO})$$

The collector current

According to KCL, $I_E = I_C + I_B$

Sub. in eqn (1).

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

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

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

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

Hence, the above derived is the expression for collector current. The value of collector current depends on base current & leakage current along with current amplification factor of that transistor in use.

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()±yv p(^UP]R±yz Amplification factor (α) for CB can be calculated as below for the transistor operated in Active mode,

According to KCL, we know that,

$$I_E = I_C + I_B$$ Here, $V_{BE} = V_{EE}$

$V_{CB} = V_{CC}$

we have, $I_C = \alpha I_E + I_{CO}$

$= \alpha I_E + I_{CBO}$ $[\because I_{CBO} = I_{CO}]$ Reverse Saturation Current

$I_C = \alpha I_E$

$$\alpha = \frac{I_C}{I_E}$$ $[\alpha = 0.95 - 0.98]$

$[I_C \simeq I_E]$

where, α is the Common base current gain amplification factor

Characteristics of CB Configuration :—

⇒ This configuration provides voltage gain but no current gain.

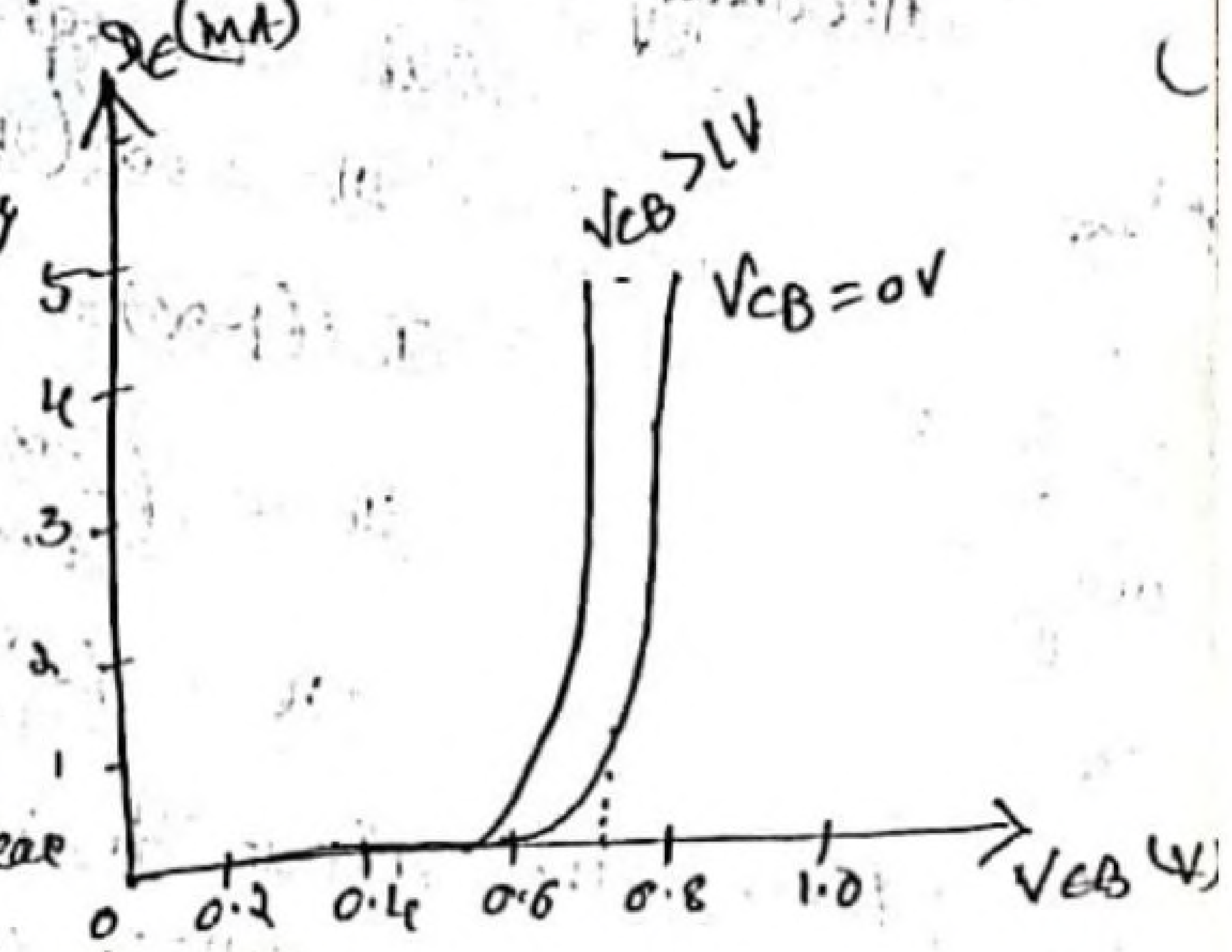
⇒ Being V_{CB} Constant, with a small increase in Emitter-base voltage V_{EB}, Emitter Current I_E gets increased.

⇒ Emitter current I_E is independent of Collector Voltage, V_{CB}.

⇒ when V_{CB} is zero, EB Jun is FWB so that I_E ↑'s rapidly with small increase in V_{EB}.

⇒ when V_{CB} is increased keeping V_{EB} Constant, the width of base region will ↓'s.

⇒ This effect results in an increase of I_E, Curve shift towards the left as V_{CB} is increased.

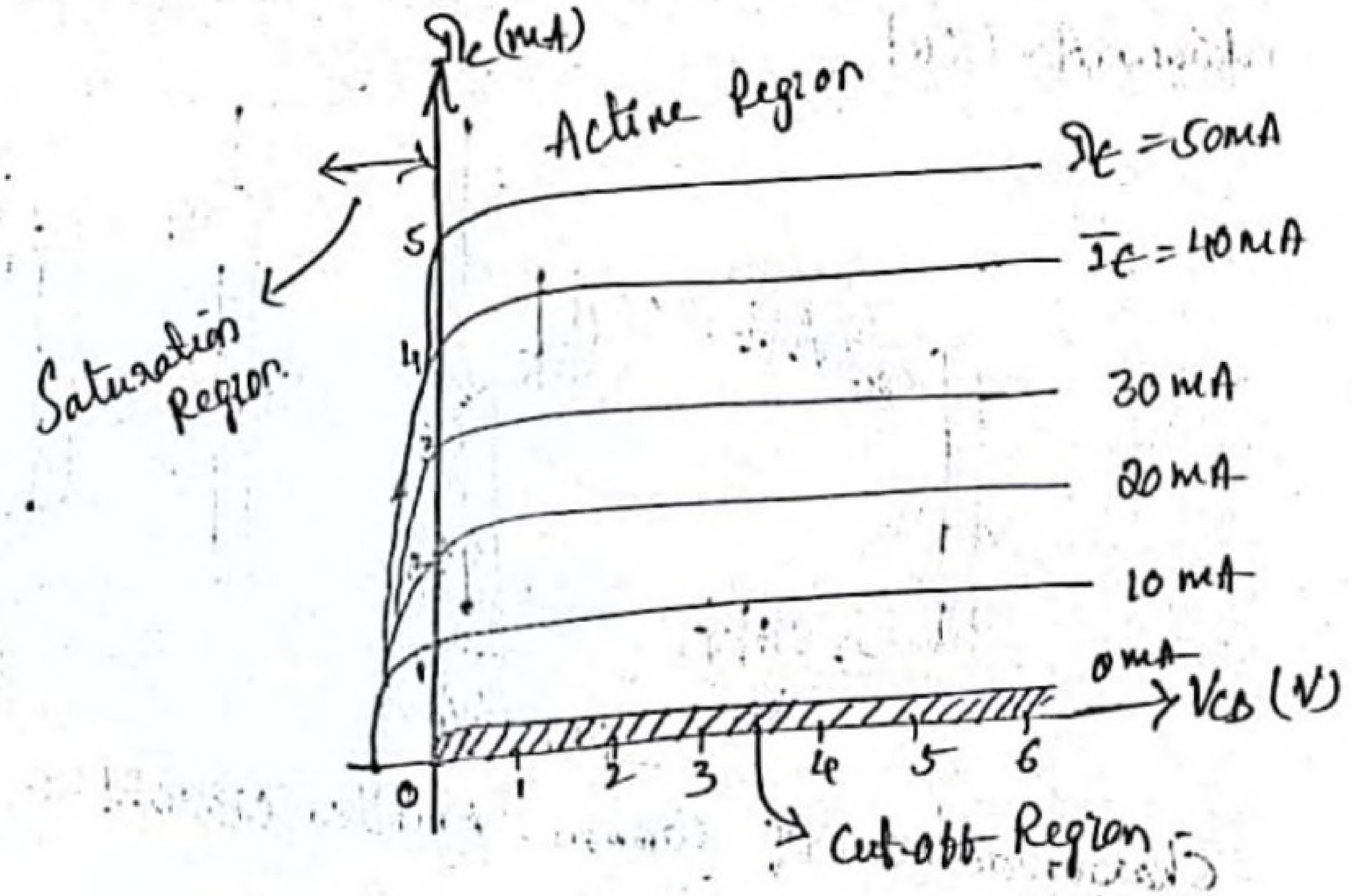


i/p characteristics Curve

put characteristics :- (O/P):

- The I_E is const. & V_{EB} is adjusting, then V_{CB} is increased & collector current is noted for each value of I_E. This is repeated for different fixed values of I_E.

⇒ Now the curve of I_C v/s V_{CB} plotted for constant values of I_E & o/p characteristics are obtained.



→ Cut-off Region →

→ Both junctions are reverse biased.

⇒ When EB-Jn is RB, the current due to majority carriers, I_E =

⇒ When CB Jn is RB, current due to minority carriers flows from collector-base as i.e., I_{CBO}.

→ Active Region :-

. The EB Jn is FwB & CB Jn is RB. As I_E ↑'s, I_C increases

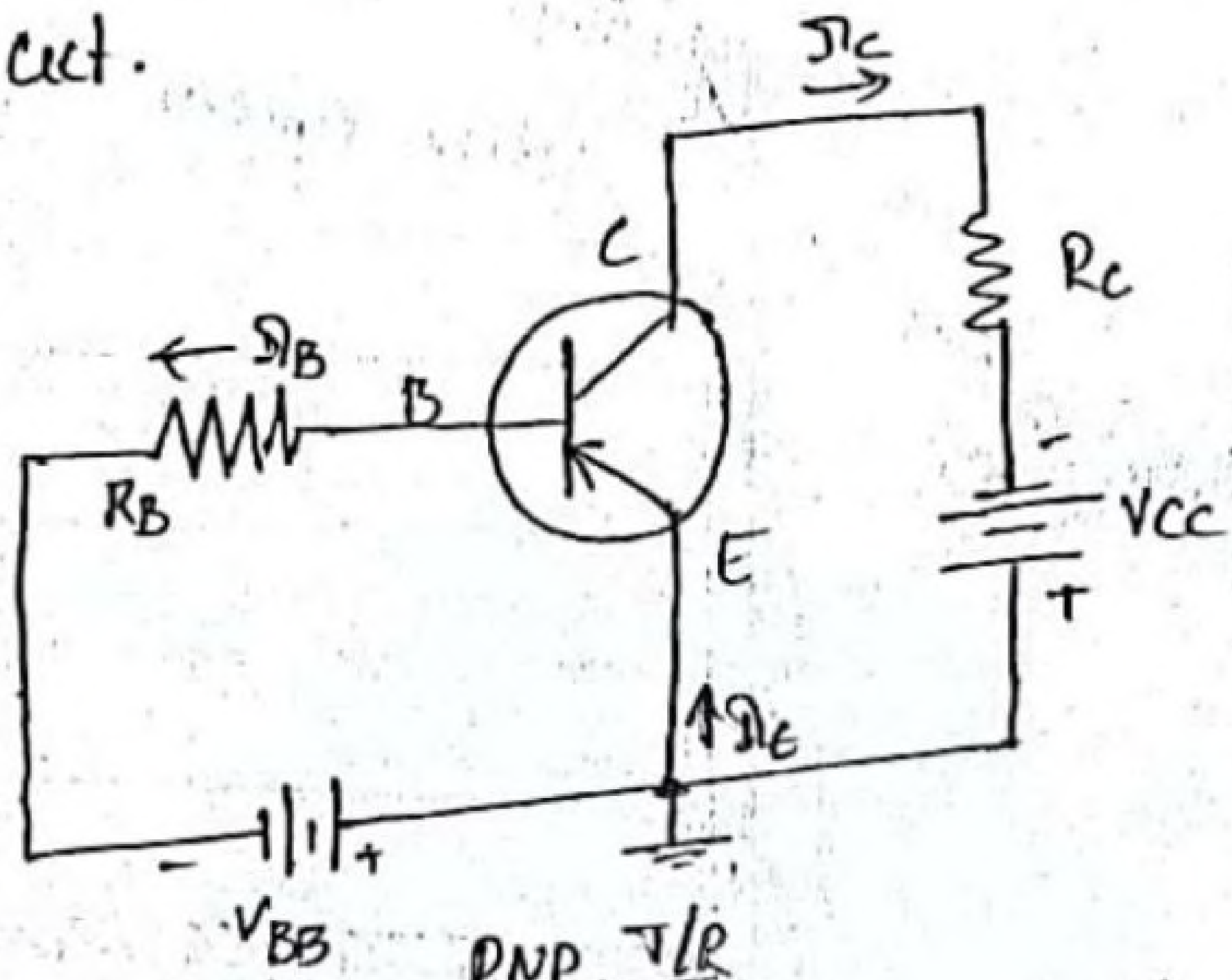
⇒ Saturation Region :-

Both Jn's are FwB, when V_{CB} is -Ve, the CB Jn is actually FwB, the graph drawn on -Ve side of V_{CB}

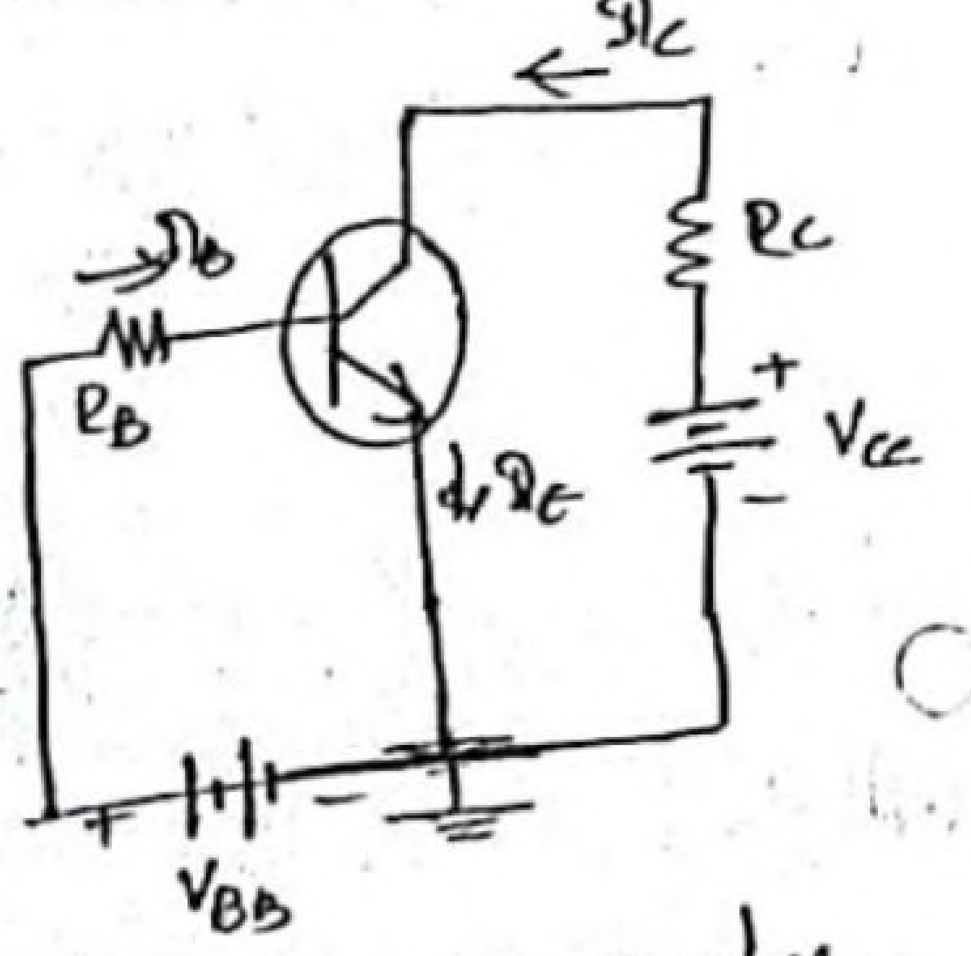
CE Configuration :-

In this Configuration, the i/p Signal is applied b/w base and emitter & the o/p is taken from collector & Emitter. As emitter is Common to i/p & o/p circuits, hence the name Common emitter Configuration.

The fig. below shows the Common emitter P-N-P & N-PN transistor ckt.



PNP T/R



NPN Transistor

Characteristics of Common-Emitter circuit :-

Input characteristics :-

To determine the i/p characteristics, the V_{CE} is kept Const. at zero Volts & base current I_B is increased from zero in equal steps by increasing V_{BE} in the Ckt.

The value of V_{BE} is noted for each setting of I_B.

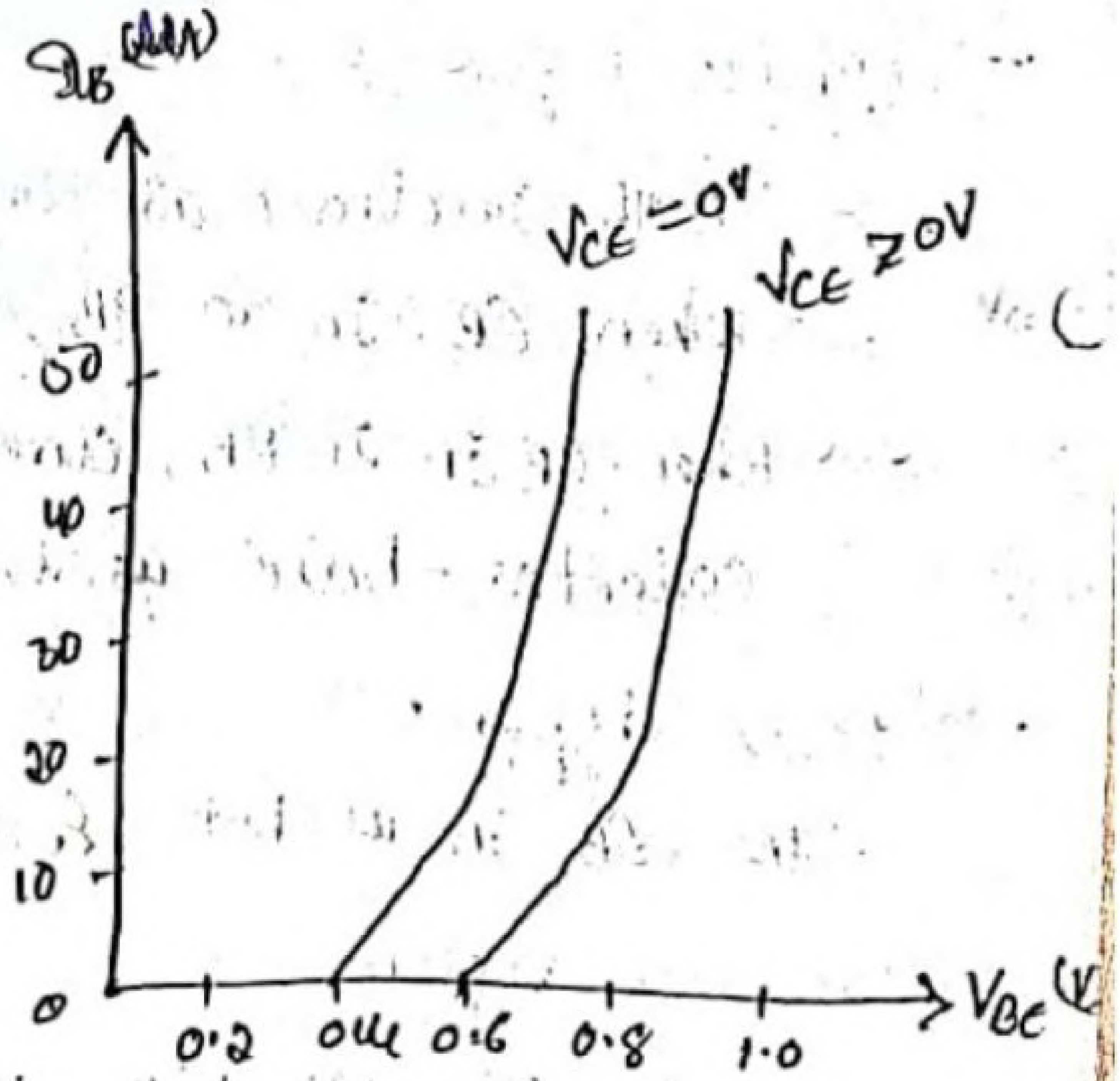


Fig :- CE Input characteristics

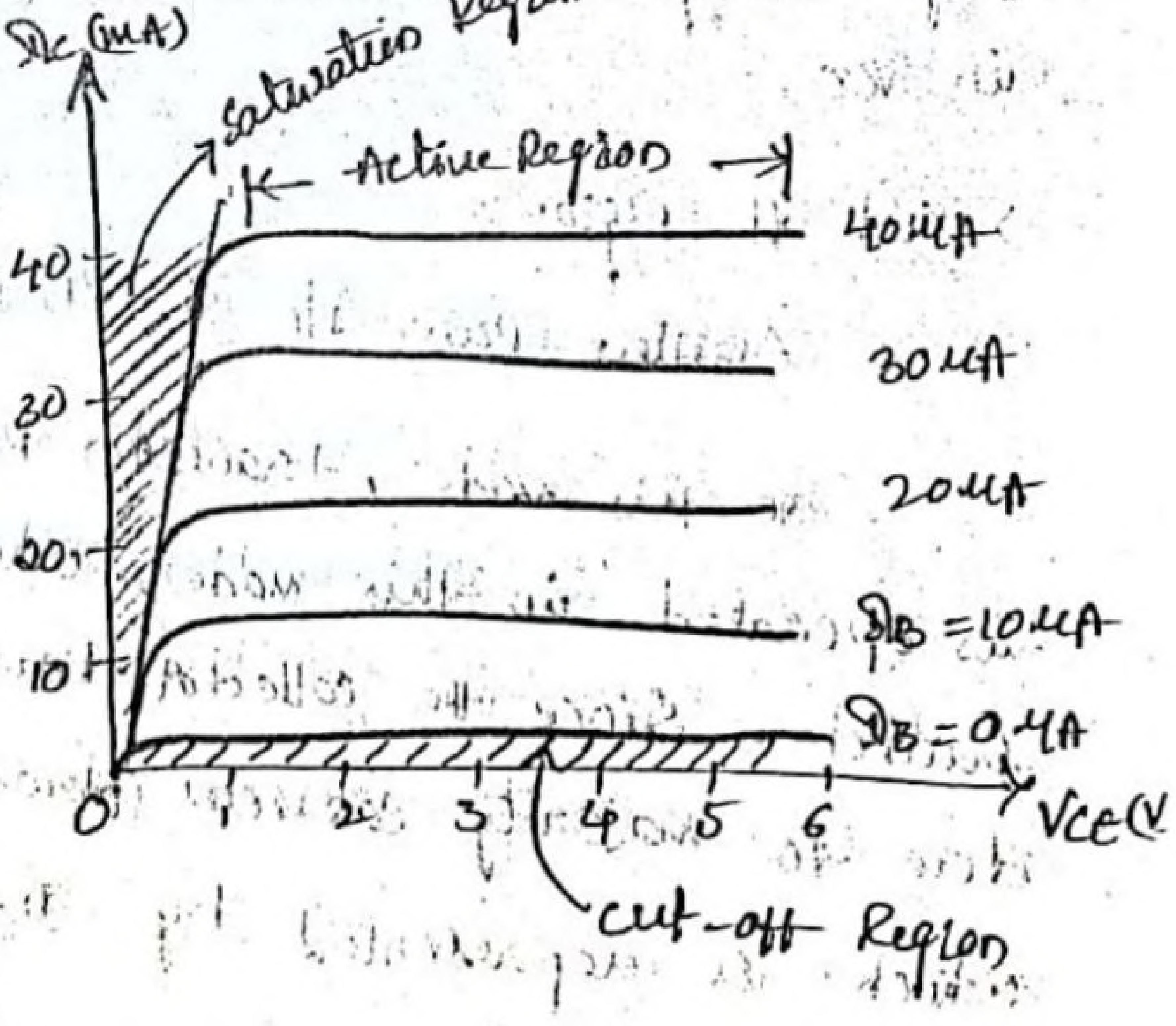
This procedure is repeated for higher fixed values of VCE, & the curves of IB V/S VBE are drawn.

When VCE=0, VBE is emitter-base Jn is FB & Jn behaves as a FB diode. When VCE is ↑ed, the width of depletion region at the RB collector base Jn will increase. Hence effective width of base will ↓'se. This effect causes a decrease in IB.

Hence, to get same value of IB as that of VCE=0, VBE should be increased. Therefore, the curve shifts to the right as VCE increases.

__Output characteristics :-__

It shows the relation b/w o/p current IC & o/p voltage VCE for different values of i/p current IB.



To determine the o/p characteristics, the base current IB kept constant at a suitable value by adjusting VBE.

The magnitude of VCE is increased in suitable equal steps from zero & the IC is noted for each setting of VCE.

Now the curves is plotted for different values of IB.

The O/p characteristics of CE Configuration Consist of 3 regions

⇒ Active Region :-

In this mode, the emitter-Base J/n is FB and Collector Base (CB) J/n is RB. As base current I_B is Constant, I_C increases as reverse bias voltage V_{CE} increases.

⇒ Saturation Region :-

Emitter-base J/n is FB & Collector-base J/n is FB.

In this mode, the transistor has a very large value of current. The transistor is operated in this mode, when it is used as a closed switch. Here, there is a large change in the collector current I_C with a small change in V_{CE}.

⇒ Cut-off Region :-

Emitter-Base J/n is RB & Collector-Base J/n is RB.

In this mode, transistor has zero current. The T/r is operated in this mode, when it is used as an open switch. Since the collector base J/n is RB, the current due to majority carriers flows from collector to emitter which is represented by I_{CEO}.

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Amplification factor :-

The ratio of change in collector current to the change in Base current. when the collector voltage is kept constant is called as current amplification factor.

The amplification factor β for CE can be calculated as,

$$I_E = I_B + I_C$$

we have, $I_C = \beta I_B + I_{CO}$

$$I_C = \beta I_B$$

$$\beta = \frac{I_C}{I_B}$$

where, β is the Common Emitter amplification factor.

Relationship b/w α & β :-

we know that, $I_E = I_B + I_C \rightarrow (1) \Rightarrow I_B = I_E - I_C$

$$\beta = \frac{I_C}{I_B} \rightarrow (2)$$

$$\therefore \beta = \frac{I_C}{I_E - I_C} \rightarrow (3)$$

Divide the above eqn by I_E on both numerator & denominator

$$\beta = \frac{I_C / I_E}{\frac{I_E}{I_E} - \frac{I_C}{I_E}}$$ we have, $\alpha = \frac{I_C}{I_E}$

$$\boxed{\therefore \beta = \frac{\alpha}{1-\alpha}}$$

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Collector Current (I_C) for CE :-

Apply KCL to the transistor

$$I_E = I_B + I_C \rightarrow (1)$$

The collector current has 2 components.

$$I_C = I_C \text{ majority} + I_C \text{ minority}$$

$$I_C = \alpha I_E + I_{CO} \rightarrow (2)$$

For general purpose transistors ;

$I_C \rightarrow$ measured in mA

$I_{CO} \rightarrow$ " in μA / nA.

Subs. eqn (1) in eqn (2).

$$I_C = \alpha(I_B + I_C) + I_{CO}$$

$$I_C = \alpha I_B + \alpha I_C + I_{CO}$$

$$I_C - \alpha I_C = \alpha I_B + I_{CO}$$

$$I_C (1-\alpha) = \alpha I_B + I_{CO}$$

$$I_C = \left(\frac{\alpha}{1-\alpha}\right) I_B + \left(\frac{1}{1-\alpha}\right) I_{CO} \rightarrow (3)$$

we have, $\beta = \frac{\alpha}{1-\alpha}$. Sub. in eqn (3)

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

$$\because 1+\beta = 1 + \frac{\alpha}{1-\alpha}$$

$$= \frac{1-\alpha+\alpha}{1-\alpha}$$

$$\boxed{1+\beta = \frac{1}{1-\alpha}}$$

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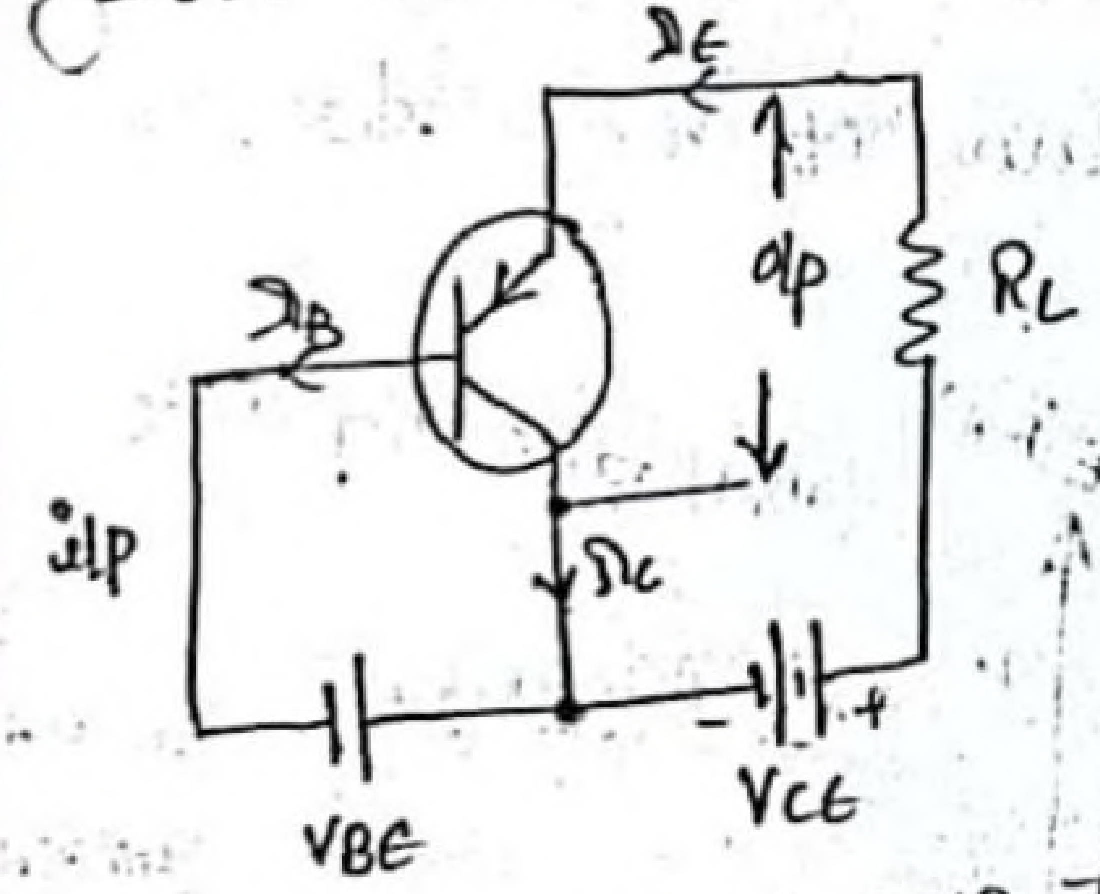
Common-Collector (CC) Configuration :-

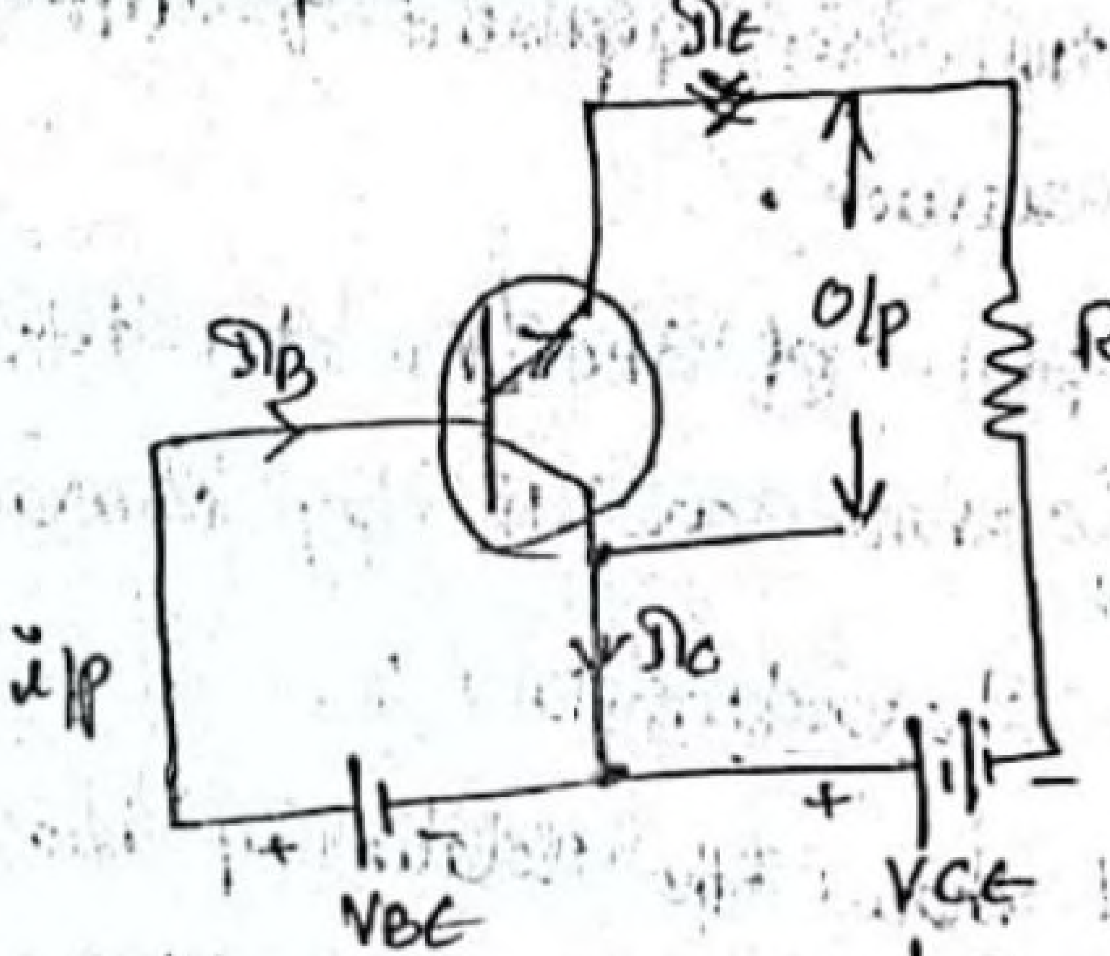
In common collector configuration, collector terminal is taken as common. So i/p is b/w base & collector terminals & o/p is taken from emitter & collector terminals.

It is also called emitter follower (or) voltage follower bcoz, the o/p emitter voltage always follows the base i/p voltage.

It has low voltage gain, high current gain & the power gain is medium. This configuration is mostly used for impedance matching. i.e., high impedance source is used for to drive low impedance load.



CC configuration of PNP T/R



NPN Transistor

Current Amplication factor (γ) :-

When no signal is applied, then the ratio of emitter current to the base current is called as dc gamma (γ_{dc}) of the transistor.

$$\gamma_{dc} = \gamma = \frac{I_E}{I_B}$$

$$\boxed{\gamma = \frac{I_E}{I_B}}$$

Characteristics of CC Configuration :-

Input characteristics :-

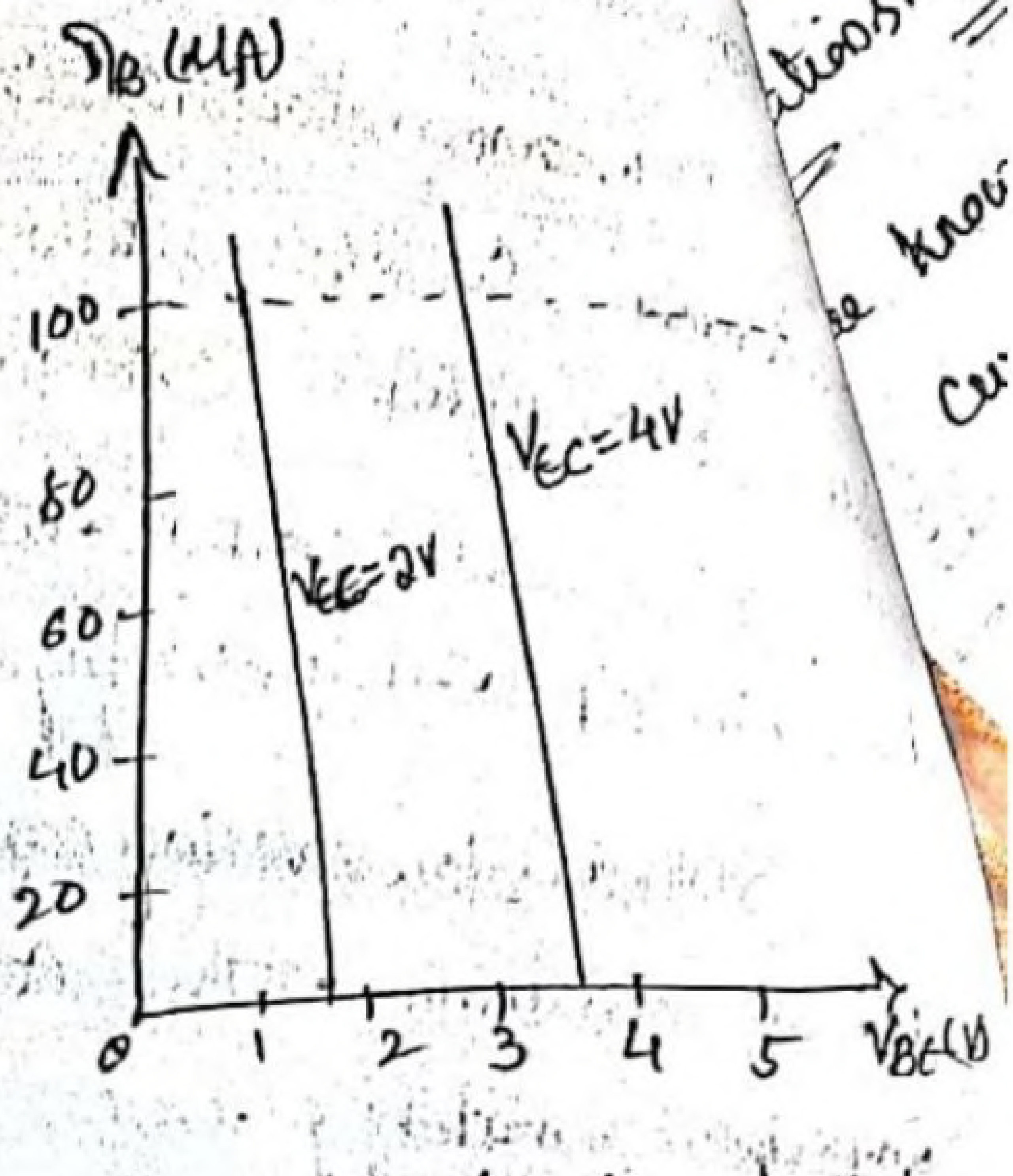


Fig:- CC i/p characteristics

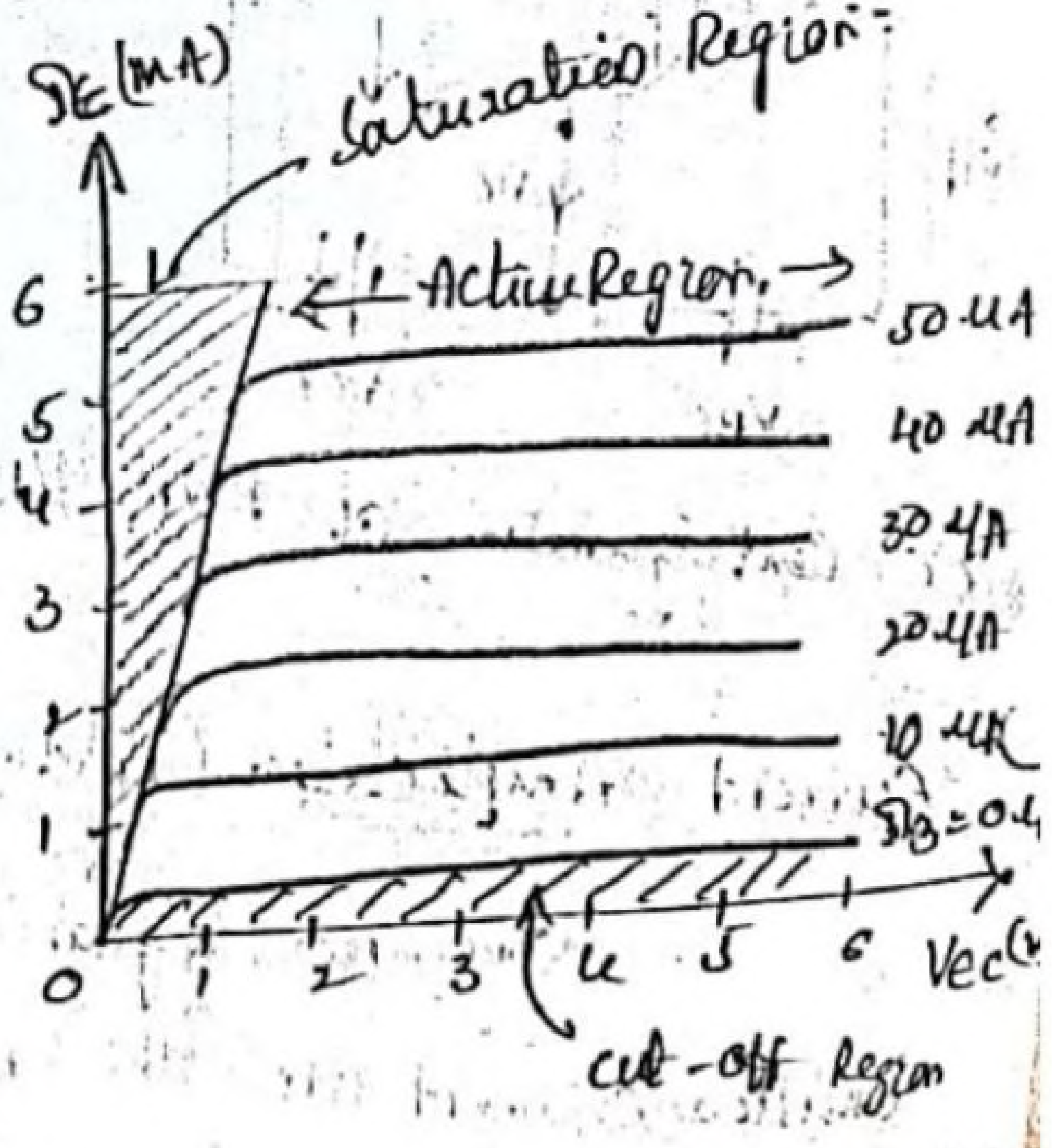
To determine the i/p characteristic, VEC is kept a suitable fixed value.

The base collector voltage VBC is fed in each equal steps & the corresponding the in IB is noted.

This is repeated for different fixed values.

plots of VBC / IB for different values of VEC is shown in in fig above are the i/p characteristics.

output characteristics :-



It shows the relationship b/w o/p current IE & o/p voltage VCE keeping i/p current IB const.

Initially IB is kept Const. at zero. & slowly i/p IB is increased like 10μA, 20μA & kept Const. & the o/p voltage VCE is fixed gradually from zero. & corresponding o/p current IE is noted.

C.R :- When i/p is zero, no current flows in T/R & it is called cut-off Region.

S.R :- When i/p is High & the current through the T/r is high & the t/r is in Saturation Region.

A.R :- The region where there is a change in o/p current for the change in o/p voltage is the Active region. Here Active Region almost looks flat.

Relationship b/w α, β & γ :-

We know that,

Current amplification factor for CB is

$$\alpha = \frac{I_C}{I_E}$$

Current amplification factor for CE is

$$\beta = \frac{I_C}{I_B}$$

Current amplification factor for CC is

$$\gamma = \frac{I_E}{I_B}$$

From KCL, we have, $I_E = I_B + I_C$

Divide I_B on both sides.

$$\frac{I_E}{I_B} = \frac{I_B}{I_B} + \frac{I_C}{I_B}$$

$$\boxed{\gamma = 1 + \beta}$$ WKT $\beta = \frac{\alpha}{1-\alpha}$.

Sub. $\beta = \frac{\alpha}{1-\alpha}$ in above eqn, we get

$$\gamma = 1 + \frac{\alpha}{1-\alpha} \Rightarrow \frac{1-\alpha+\alpha}{1-\alpha}$$

$$\boxed{\gamma = \frac{1}{1-\alpha}}$$

$$\therefore \boxed{\gamma = 1+\beta = \frac{1}{1-\alpha}}$$

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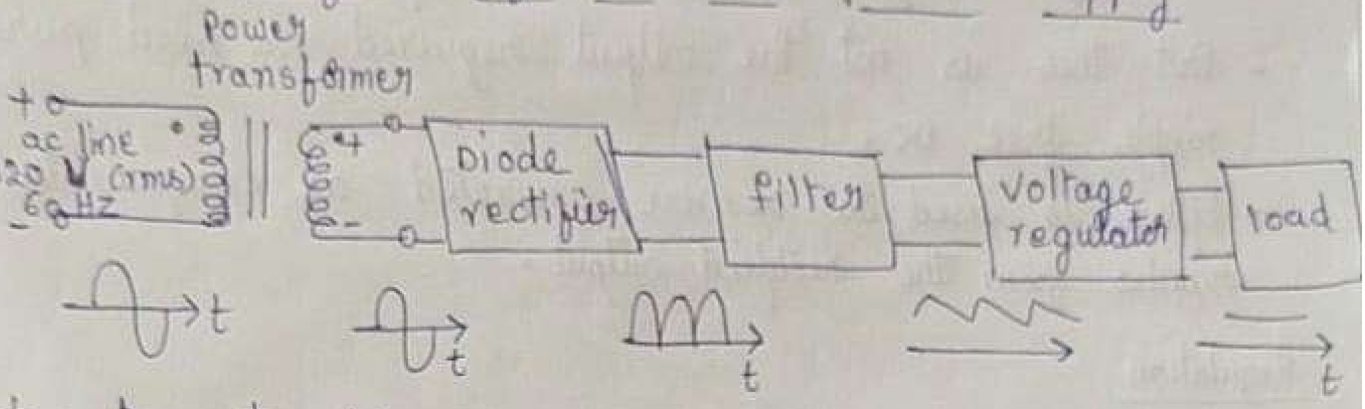
Comparison b/w CB, CE, CC Configuration :-

Characteristics	CB Configuration	CE Configuration	CC Configuration
1) Common terminal for I/p & O/p	Base terminal	Emitter terminal	Collector terminal
2) I/p voltage applied between	Emitter & Base terminal	Base & Emitter terminal	Emitter & Collector terminal.
3) O/p voltage taken across	Collector & Base termi	Collector & Emitter	Emitter & Collector
4) Input Impedance	Very low (50 to 500Ω)	Medium (500 to 5K Ω)	Very low (200 to 750KΩ)
5) O/p Impedance	Very High (1 to 10 MegaΩ)	Medium (50 to 500 KΩ)	Very low (upto 50 Ω)
6) I/p Current	Emitter Current (I_E)	Base current (I_B)	Base Current (I_B)
7) O/p current	Collector current (I_C)	Collector current (I_C)	Emitter Current (I_E)
8) Current Gain	$\alpha = \frac{I_C}{I_E}$ (less than unity)	$\beta = \frac{I_C}{I_B}$ (35 to 500)	$\gamma = I_E/I_B$ (high)
9) Voltage Gain	About 150	About 500	less than unity.
10) Leakage current	Very Small	Very Large	Very large
11) Power Gain	Medium	High	Medium
[illegible]	H-F [illegible] ckt	RF and [illegible]	Switching circuit [illegible]

unit - 2

Block diagram of a dc power supply



step down transformer :

→ A step down transformer will step down the voltage
→ from the ac mains to the required voltage level
→ The turn's ratio of the Transformer is so adjusted such as to obtain the required voltage value.

→ The output of transformer is given as input to the rectifier circuit.

Rectifier :

→ Rectifier is an electronic circuit consisting of diodes which carries out the rectification process.

→ Rectification is an the process of converting an alternating voltage or current into corresponding direct (DC) quantity. The i/p to the rectifier is ac whereas its output is unidirectional pulsating DC.

- usually a Full wave rectifier or a bridge rectifier is used to rectify both the half cycles of the ac supply

Filter

- The rectified voltage from the rectifier is a pulsating DC voltage having very high ripple content.
- But this is not the output required, we need pure ripple free DC.
- Filter is used to remove unwanted ac components or ripples from the rectified output.

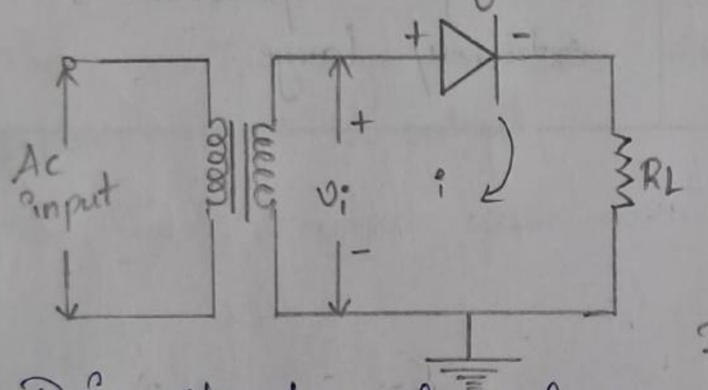
Regulation

- This is the last block of regulated dc power supply
- The output voltage or current will change or fluctuate when there is change in the input from ac mains or due to change in load current at the output of the regulated power supply.
- This problem can be eliminated by using a regulator. A regulator will maintain the output constant even when changes at the input or any other changes occur.

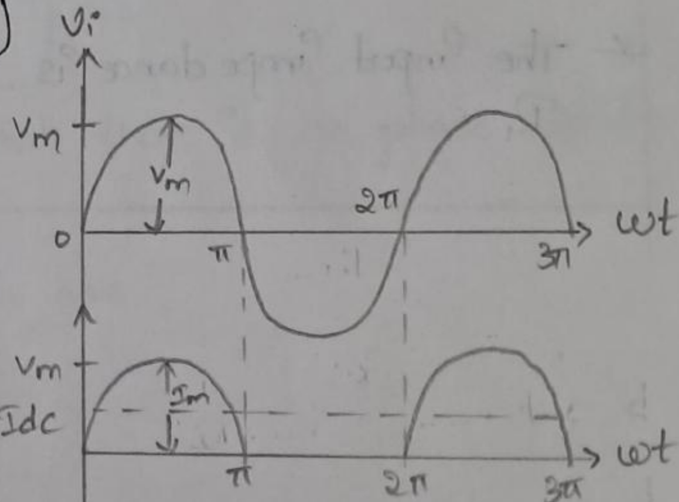
Rectifiers

One of the important applications of a diode is the rectifier circuits. Rectifier is an electric electronic device which converts a.c voltage into unidirectional voltage. The rectifier offers low resistance to the current in one direction but offers a high resistance to the opposite direction. Rectifier uses a unidirectional conductor device like a vaccum diode (or) PN junction diode. Rectifiers are classified depending upon the period of conductor as half wave rectifier and full wave Rectifiers.

Half wave Rectifier (HWR)



Basic structure of Halfwave Rectifier



Input - output waveforms of Halfwave rectifiers

Halfwave Rectifier:

It converts an ac voltage into a pulsating dc voltage using only one half of the applied ac voltage the rectifying device is usually a semiconductor diode and indicates that the device offers infinite resistance in the reverse direction and offers a small resistance R_f in the forward direction.

During the positive half cycle of the input, the diode D is forward biased and it acts as a closed path/switch and hence the diode conducts current through the load resistor R_L. During the negative half cycle of the input signal the diode D is heavily reverse biased and it acts as a open switch and hence it does not conducts the current through R_L.

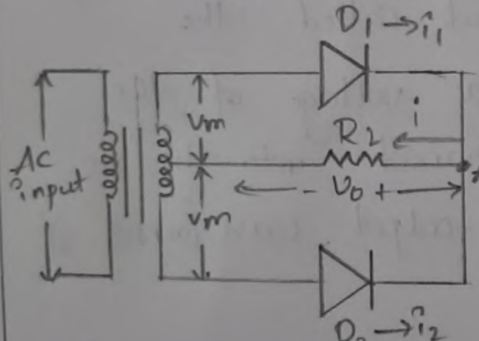
Full wave Rectifier:

A circuit which converts the alternating voltage (or) current into pulsating voltage (or) current during both half cycles of input is known as fullwave rectifier.

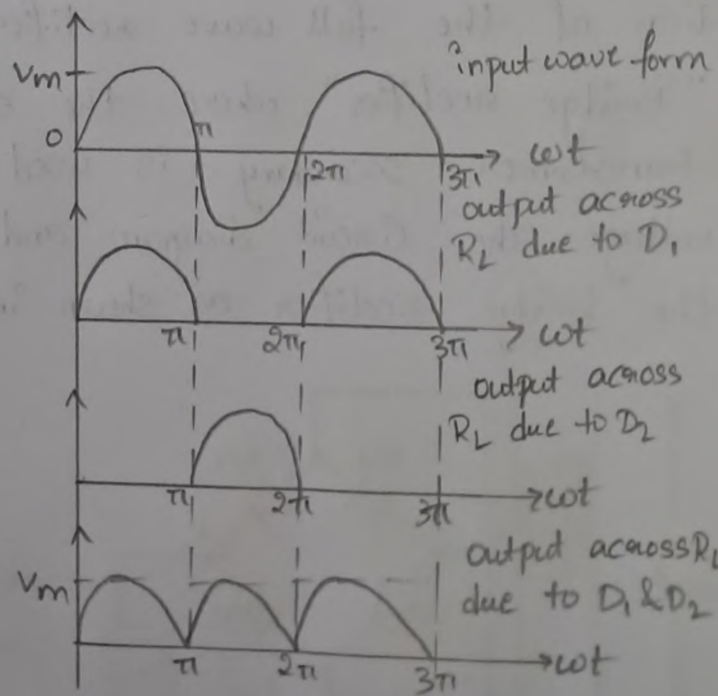
Two types of fullwave rectifiers

1) Center tapped FWR
2) Bridge rectifier

Centre tapped fullwave rectifier:



Fullwave Rectifier

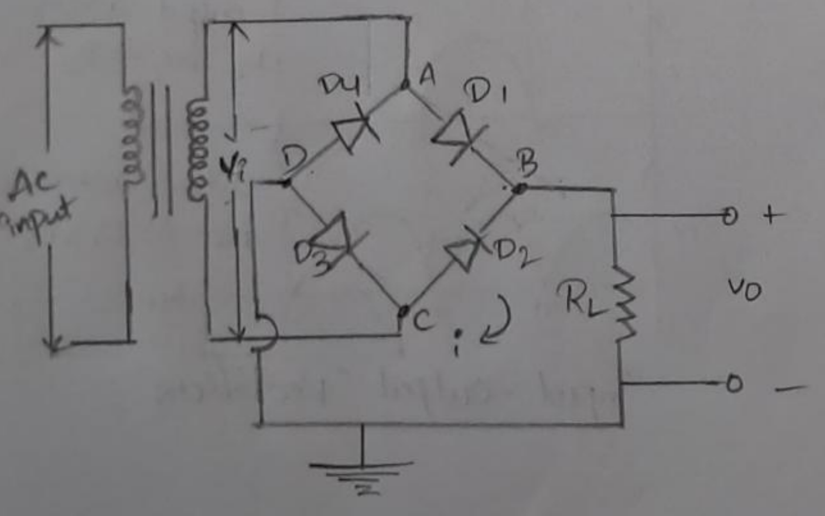


input - output Rectifiers.

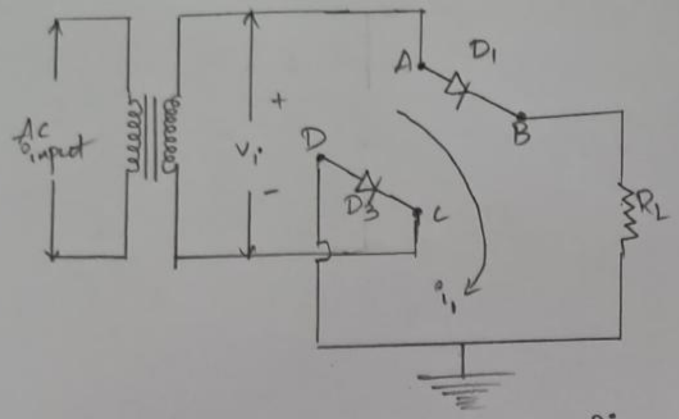
During positive half cycle of the input the Diode D_1 is forward biased and the diode D_2 is reverse biased. Thus diode D_1 Provides very low resistance and acts as a closed switch. As a result a current i_1 will flow. During Negative half cycle of input signal the diode D_2 is forward biased and the diode D_1 is reversed biased. So that the diode D_2 acts as a closed switch, as a result the current i_2 will flow. So that during both half cycles one of the diodes conducts and current will flow through the load resistor R_L.

Bridge Rectifier:

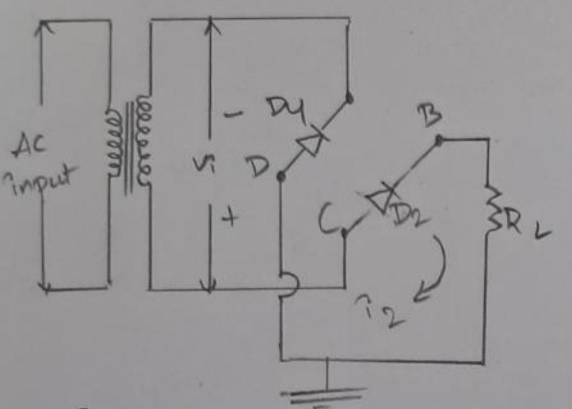
The fullwave rectifier requires a bulky center-tapped transformer where only one half of the total ac voltage of the transformer secondary winding is utilized to connect into dc input output. we now Consider a different different configuration of the full wave rectifier circuit called the "Bridge rectifier", where the entire ac voltage of the transformer secondary is used to connect into the dc voltage. the Circuit diagram and input-output wave-forms of the bridge rectifier as shown in fig.



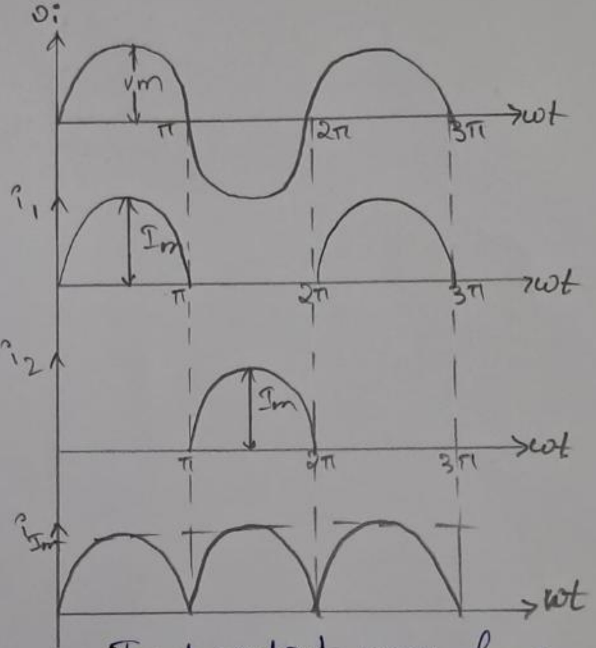
A bridge rectifier Circuit.



Equivalent circuit for +ve half cycle of input



Equivalent circuit for -ve half cycle of input



Input - output wave forms.

During +ve half cycle of the input the point A is +ve & C is -ve, so that diodes D_1 & D_3 conducts where as D_2 & D_2 are reverse biased. Hence current i_1 flows through the diodes D_1 & D_2 and the resistor R_L.

During the negative half cycle of the input signal the point A is -ve & C is +ve, so that Diodes D_2, D_4 gets forward biased where as diodes D_1, D_3 are reverse biased. Hence current i_2 flows through diodes D_2 & D_4 & the resistor R_L.

What is Zener Diode?

Zener diode is defined as

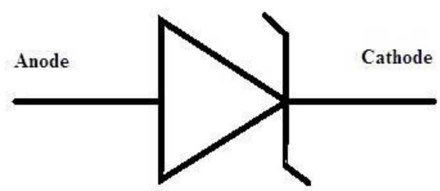
The semiconductor which is heavily doped to operate in reverse direction or in breakdown region.

The **Zener diode** behaves just like a normal general-purpose diode consisting of a silicon PN junction and when biased in the forward direction, that is Anode positive with respect to its Cathode, it behaves just like a normal signal diode passing the rated current.

However, unlike a conventional diode that blocks any flow of current through itself when reverse biased, that is the Cathode becomes more positive than the Anode, as soon as the reverse voltage reaches a pre-determined value, the zener diode begins to conduct in the reverse direction.

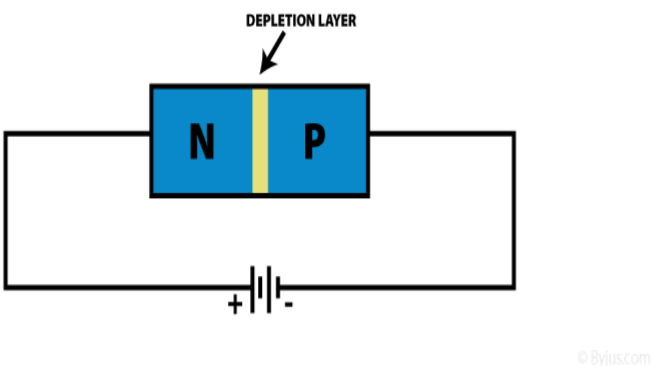
Zener Diode Symbol

The symbol for Zener diode is represented as below,



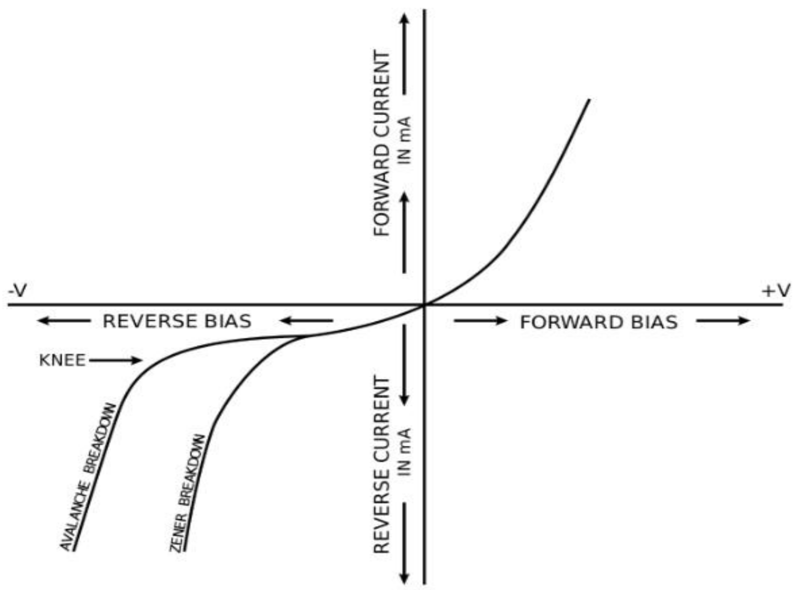
Zener Diode Circuit

We can define Zener diode as a single diode connected in a reverse bias. It can be connected in reverse bias positive as in the circuit shown below:



V-I Characteristics of Zener Diode

The diagram given below shows the V-I characteristics of the Zener diode. When the Zener diode is connected, in forward bias, diode acts as a normal diode. But Zener breakdown voltage occurs when the reverse bias voltage is greater than a predetermined voltage.



Working of Zener Diode

The basic principle behind Zener diode working is based on the cause of breakdown when the diode is in the reverse biased condition. For a Zener diode there are two types of breakdown:

- Zener breakdown
- Avalanche breakdown

Avalanche Breakdown

- A conventional reverse biased diode, when subjected to its breakdown voltage allows a significant amount of current. But when this reverse breakdown voltage is exceeded, the diode experiences an avalanche breakdown.
- When we increase the voltage through Zener in reverse bias mode, first current increases uniformly with it but after it reaches the breakdown state, the current increases massively for a very small or negligible change in voltage. The change is sharper in Zener than the normal diode.

Causes of Breakdown

- The breakdown is caused by two effects, the Avalanche effect and the Zener effect. The Zener effect is dominant in voltages up to 5.6 volts and the avalanche effect takes over above that.
- They are both similar effects, the difference being that Zener effect is a quantum phenomenon and the avalanche effect is the movement of electrons in the valence band like in any electric current.
- Avalanche effect also allows a larger current through the diode than the Zener effect.

Application of Zener Diode

Following are the applications of Zener diode:

Zener diode as voltage regulator:

Zener diode is used as Shunt voltage regulator for regulating voltage across small loads. The breakdown voltage of Zener diodes will be constant for a wide range of current. Zener diode is connected parallel to the load to make it reverse bias and once the Zener diode exceeds knee voltage, the voltage across the load will become constant.

Zener diode in over-voltage protection:

When the input voltage is higher than the Zener breakage voltage, the voltage across the resistor drops resulting in short circuit. This can be avoided by using Zener diode.

Zener diode in clipping circuits:

Zener diode is used for modifying AC waveform clipping circuits by limiting the parts of either one or both the half cycles of an AC waveform.

What are the advantages of Zener diode?

Following are the advantages of Zener diode:

- The size of the Zener diode is so small that it can be used in smaller circuits and also in cell phones.
- Zener diodes are less expensive when compared to other diodes.
- Zener diodes can be used for controlling, regulating, and stabilizing the voltage in the circuit.
- These diodes have a very high performance standard.
- The compatibility of the Zener diodes is good that they are used in regulating voltage.

What is Zener voltage?

Zener voltage is defined as the voltage at which the Zener diode breaks down.

How to control the breakdown voltage of Zener diode?

The breakdown voltage of Zener diode can be controlled either by adding impurities or by increasing the doping level.

When does the Zener Diode allow reverse flow of current?

It allows the current flow in the opposite direction when the voltage is above a certain value known as Zener Voltage or Avalanche Point or Breakdown Voltage.

State true or False. Zener Diode exhibit controlled breakdown.

True. Zener Diode does exhibit controlled breakdown.

How does breakdown occur?

The breakdown is caused by two effects, the Avalanche effect and the Zener effect.

What is the difference between the Zener effect and the avalanche effect?

The Zener effect is a quantum phenomenon whereas, the avalanche effect is the movement of electrons in the valence band like in the case of any electric current.

6.12.5 CC Amplifier (or) Emitter Follower

Figure 6.60 shows the CC amplifier circuit using a single power supply. Derivation of equations for input impedance, output impedance, voltage gain and current gain can be done similarly and the results are given below:

h-parameter model	r_e *model*
$Z_i = R_B \parallel Z_b$, where $Z_b = h_{ie} + h_{fe} R_E = h_{fe} R_E$	$Z_i = R_B \parallel Z_b$, where $Z_b = \beta(r_e + R_E) = \beta R_E$
$Z_o = R_E \parallel \dfrac{h_{ie}}{1 + h_{fe}}$	$Z_o = R_E \parallel \dfrac{\beta r_e}{1 + \beta}$
$A_V = \dfrac{R_E}{R_E + \left[\dfrac{h_{ie}}{1 + h_{fe}}\right]}$	$A_V = \dfrac{R_E}{R_E + r_e}$
$A_I = \dfrac{(h_{fe}) R_B}{R_B + Z_b}$	$A_I = \dfrac{\beta R_B}{R_B + Z_b}$

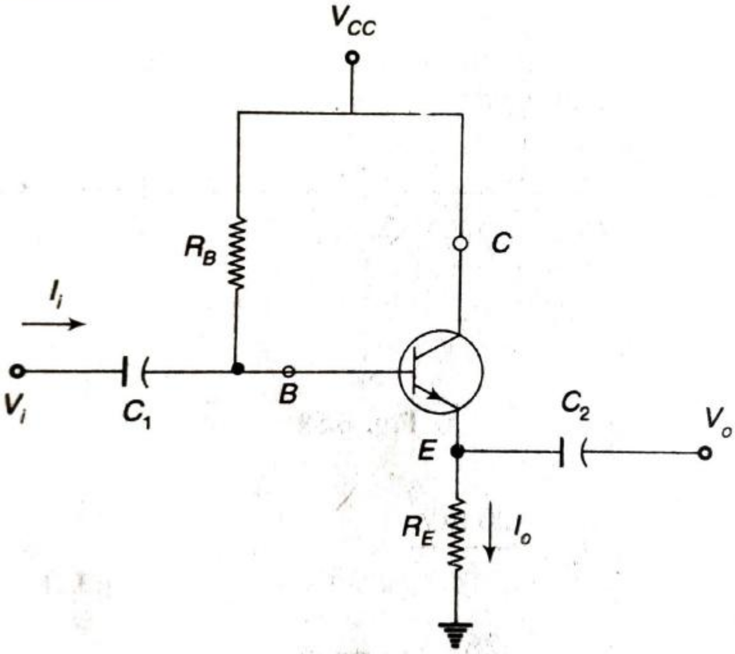


Fig. 6.60 Common Collector Amplifier

6.13 RC COUPLED AMPLIFIER

Figure 6.61 shows the two stage RC coupled common emitter amplifier. The two transistors are identical and a common power supply is used. R_C is the collector (load) resistor. Resistors R_1, R_2 and R_E provide the required bias. The bypass capacitor C_E prevents loss of amplification due to negative feedback. The output of the first stage gets coupled to the input of the second stage via coupling capacitor C_c which also serves as the blocking capacitor to keep the d.c. component of the output of the first stage from reaching the input of the second stage.

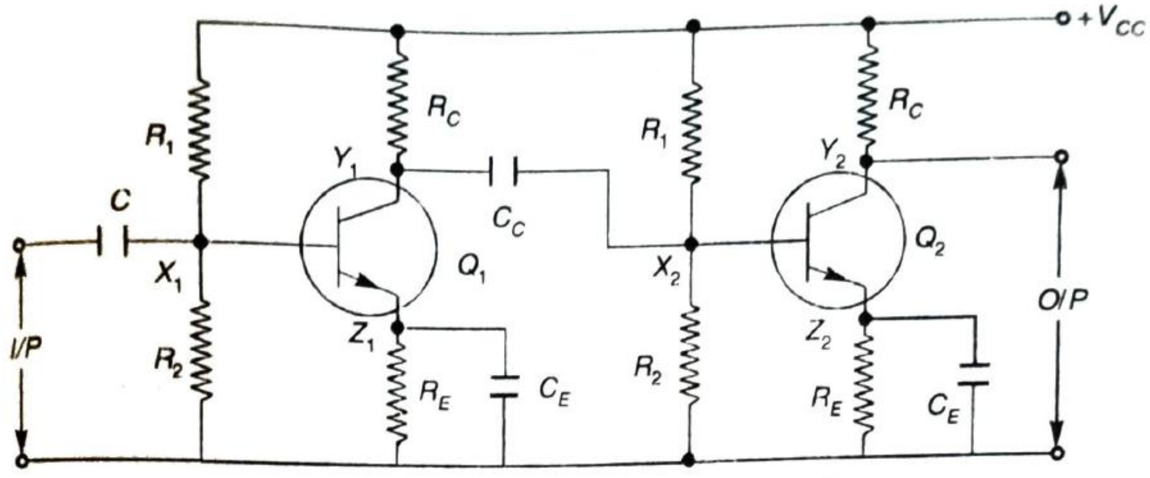


Fig. 6.61 A Two Stage RC Coupled Amplifier

Analysis of RC coupled CE amplifier For finding the response of the RC coupled amplifier, in the three frequency ranges, the transistor Q_1 of Fig. 6.61 is replaced by its high frequency π model yielding the equivalent circuit of Fig. 6.62. Here, C_{s1} and C_{s2} represent stray capacitances caused by wiring, proximity of components to chassis etc. $R_B = R_1 \parallel R_2$ is the biasing resistance of a particular stage.

The equivalent circuit of Fig. 6.62 may be modified by Miller's theorem by which the parallel combination of $r_{b'c}$ and $C_{b'c}$ are replaced by the corresponding impedances in the input circuit and the output circuit. The modified equivalent circuit is shown in Fig. 6.63.

As the equivalent circuit of the Fig. 6.63 is quite complicated, it may be simplified with a few assumptions as follows:

(i) Making use of the fact that in most cases the time constant of the output shunt circuit is negligible as compared with that of the input circuit, the capacitances $\dfrac{C_{b'c}(A-1)}{A}$, $C_{b'e}$ and C_{S2} may be omitted from the output circuit.

(ii) Since A is equal to $\dfrac{V_{ce}}{V_{b'e}}$, $|A| >> 1$. Hence, $r_{b'c}\left(\dfrac{A}{A-1}\right) \approx r_{b'c}$. But $r_{b'c} >> r_{ce}$. Hence, $r_{b'c}\left(\dfrac{A}{A-1}\right) \parallel r_{ce} \approx r_{ce}$ and $r_{b'c}\left(\dfrac{A}{A-1}\right)$ is omitted from the output circuit.

(iii) For typical values of transistor parameters and circuit components $\dfrac{r_{b'c}}{1-A} \gg r_{b'e}$. Hence, $\dfrac{r_{b'c}}{1-A} \parallel r_{b'e} \approx r_{b'e}$. Hence $\dfrac{r_{b'c}}{1-A}$ is neglected in the input circuit.

(iv) From Table 9.5,

$$g_{ce} = \frac{1}{r_{ce}} = h_{oe} - (1 + h_{fe})\, g_{b'c}$$
$$\approx h_{oe} - h_{fe}\, g_{b'c}$$

Substituting $A_{Vm} = \dfrac{-h_{fe} R_{c1}}{h_{ie}}$.

$$A_{Vh} = \frac{A_{Vm}}{1 + j2\pi f C r_{b'e}} \quad (6.140)$$

$$= \frac{A_{Vm}}{1 + j(f/f_H)}$$

where

$$f_H = \frac{1}{2\pi C r_{b'e}} \quad (6.141)$$

Also

$$|A_{Vh}| = \frac{|A_{Vm}|}{\sqrt{1 + (f/f_H)^2}}$$

At $f = f_H$,

$$|A_{Vh}| = \frac{|A_{Vm}|}{\sqrt{2}}$$

$$= 0.707\ |A_{Vm}|$$

Thus f_H forms the upper 3 dB frequency.

Since $f_H = \dfrac{1}{2\pi C r_{b'e}}$ in both cases, upper 3 dB frequencies of A_{Ih} and A_{Vh} are the same.

True mid-band A plot of $|A_V/A_{Vm}|$ in dB against frequency f on log scale is shown in Fig. 6.70.

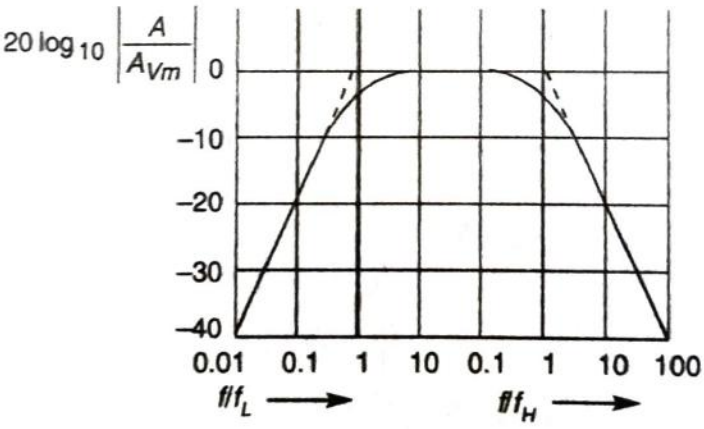


Fig. 6.70 Plot of Gain versus Frequency for an RC Coupled Amplifier

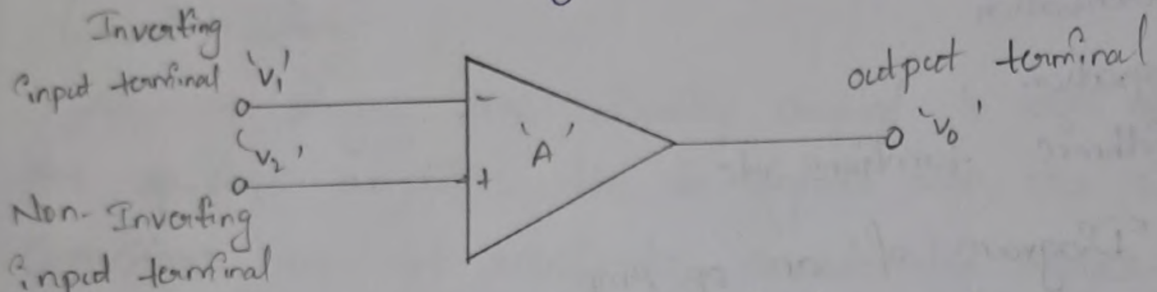
From the Fig. 6.70, the 3 dB bandwidth extends from f_L to f_H. Thus, 3 dB bandwidth equal to $f_H - f_L \approx f_H$. But the true midband in which the gain remains truly constant extends from $10\, f_L$ to $0.1\, f_H$. A plot of $|A_I/A_{Im}|$ in dB against frequency will result in a similar curve.

Gain bandwidth product Gain bandwidth product for the current gain is given by

Operational Amplifiers (op-Amps)

A direct coupled high-gain amplifiers comprising one (or) more differential amplifier circuit followed by a 'level shifter' & output circuit (push-pull amplifier) is called an op-Amp.

The circuit symbol of an op-Amp is shown below



It contains two input terminals and one output terminal. The terminal designated by '−' sign is inverting input terminal & it inverts the phase of the input signal applied to it. whereas the terminal designated by '+' sign is non-inverting terminal & it does not change the phase of the signal applied to it.

The voltage gain of the op-Amp is denoted by 'A' & is given by

$$V_0 = A(V_1 - V_2) \quad \text{—} ①$$

$$A = \frac{V_0}{V_1 - V_2} \quad \text{—} ②$$

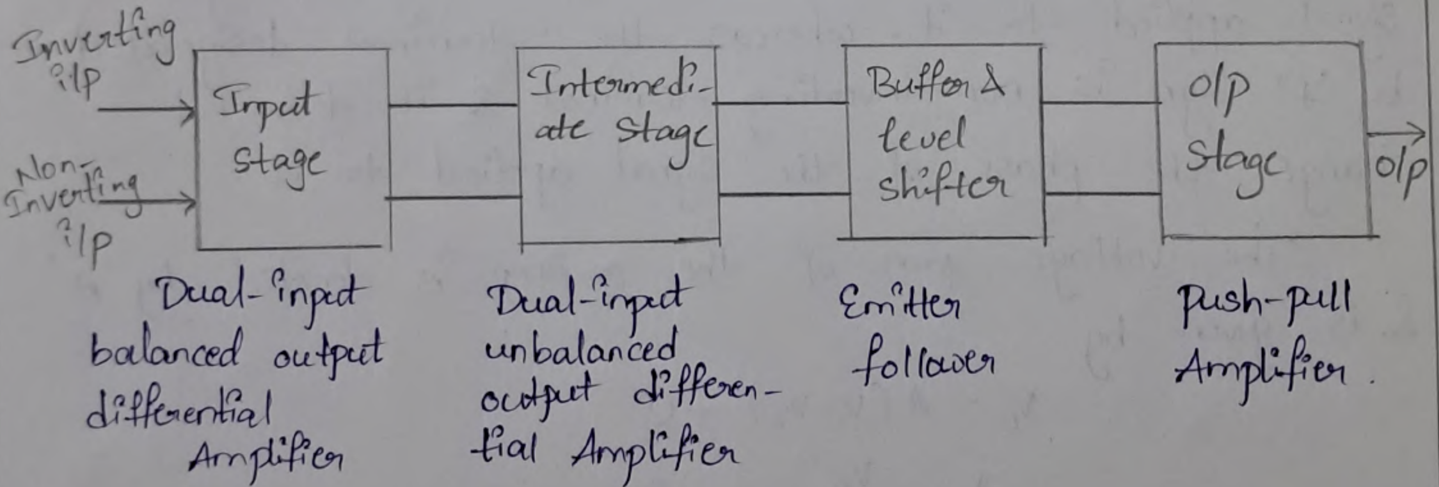
The output voltage is equal to the voltage gain times the difference of the two input voltages.

The basic function of an op-Amp is to amplify the difference between the two input signals. An op-Amp is widely used to amplify both AC as well as DC input signals. Not only for amplification, they are also designed to perform the various mathematical operations such as

1) Addition
2) Subtraction
3) Multiplication
4) Differentiation
5) Integration
6) Logarithmic functions etc.

Block Diagram of an op-Amp:

The block diagram of an IC 741 op-Amp is usually consists of four cascaded blocks as shown in fig.



Input Stage

* The input stage is basically a dual input balanced output differential amplifier.
* The function of the differential amplifier is to amplify the difference b/w the two input signals.

Intermediate stage:

* The intermediate stage is generally a dual-input unbalanced output differential amplifier.
* The overall gain requirement of an op-Amp is very high. The input stage alone cannot provide such a high gain. The main function of the intermediate stage is to provide an additional voltage gain required.

Level shifter:

All the stages are directly coupled to each other. As the op-Amp amplifies the dc signals also, the coupling capacitors are not used to cascade the stages. Hence the dc quiscent voltage level of previous stages get applied. as the i/p to the next ~~step~~ stage.

Hence stage by stage dc level increases well above ground potential such a high dc voltage level may drive the transistors into saturation. This may further causes distortion in the output due to clipping.

Output stage:

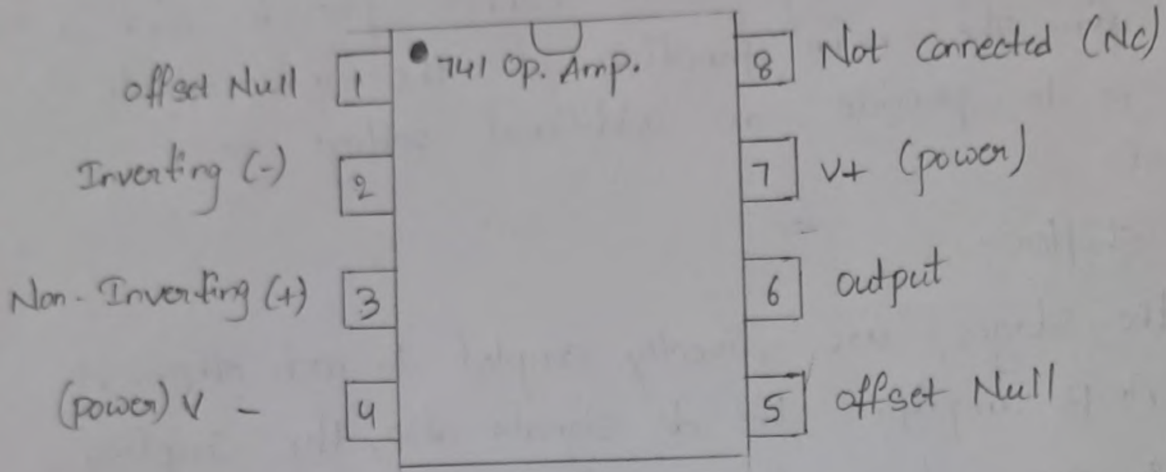
The basic requirement of o/p stage are

1) Low o/p impedence
2) Large ac o/p voltage swing.
3) High current sourcing & sinking capability

To obtain all above requirements, a push-pull complementary amplifier is used as an output stage.

IC 741 OP- Amp Pin Description

The pin diagram of the IC 741 op amp is shown below. It consists of 8 pins where each pin having some functionality which is discussed in the following.



IC 741 OP-Amp Pin Configuration

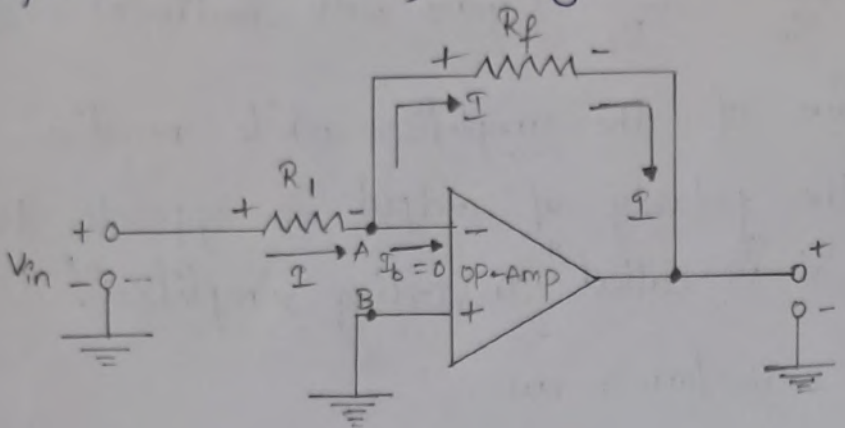
Pin configuration of IC 741 opamp is shown above

* pin 1 is offset Null
* pin 2 is Inverting input terminal
* pin 3 is a non-Inverting input terminal
* pin 4 is negative voltage supply (vcc)
* pin 5 is offset Null
* pin 6 is the output voltage.
* pin 7 is positive voltage supply (+vcc)
* Pin 8 has no connection.

The 741 op-amp is used in two ways such as an inverting & a non-inverting.

Ideal Inverting Amplifier:

As the name suggests the output as such an amplifier is inverted as compared to the input signal. The inverted output signal means having a phase shift of 180° as compared to the input signal.



So, an amplifier which provide a phase shift of 180° between input and output is called inverting amplifier the basic circuit diagram of an inverting amplifier using op amp is shown in fig.

Derivation of closed loop gain:

As node B is grounded, node A is also at ground potential, from the concept of virtual ground, so $V_A = 0$

$$\therefore I = \frac{V_{in} - V_A}{R_1}$$

$$I = \frac{V_{in}}{R_1} \quad -(1)$$

Now from the output side, considering the direction of current I we can write

$$I = \frac{V_A - V_0}{R_f}$$

$$\therefore I = \frac{-V_0}{R_f} \quad -(2)$$

Entire current I passes through R_f as op-amp input is zero.

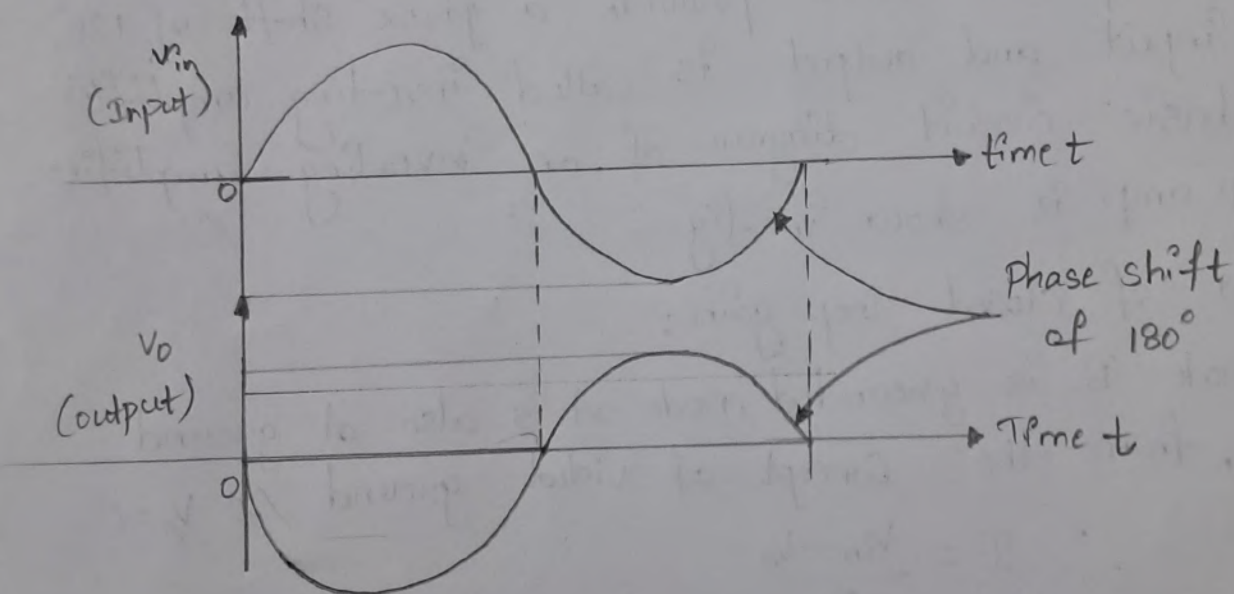
Equating equating ① & ② we get,

$$\frac{V_{in}}{R_1} = \frac{-V_0}{R_f}$$

$$\therefore A_{V_F} = \frac{V_0}{V_{in}} = -\frac{R_f}{R_1} \quad \text{(Gain with feedback)}$$

The $\frac{R_f}{R_1}$ is the gain of the amplifier while negative sign indicates that the polarity of output is opposite to that of input. Hence it is called "Inverting Amplifier".

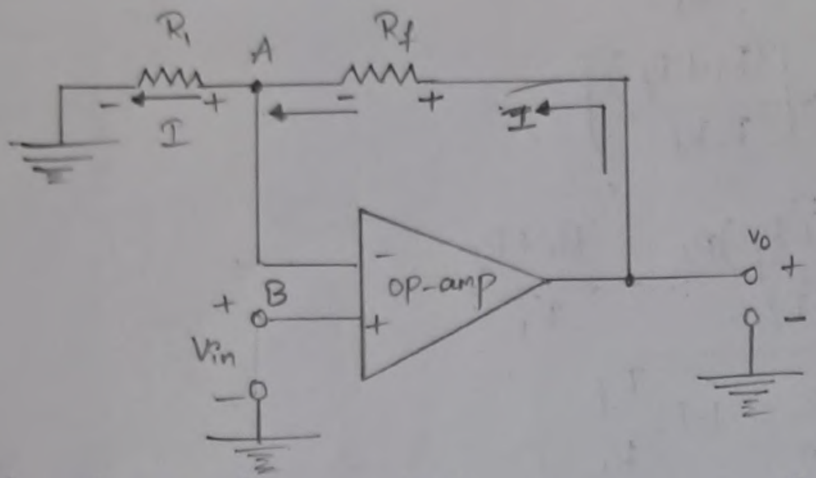
The input & output wave-forms are



wave forms of Inverting amplifier.

Ideal Non-inverting amplifier:

An amplifier which amplifies the input without producing any phase shift ~~between~~ input & output is called "non-inverting amplifier". The basic circuit diagram of a non inverting amplifier using op amp as shown in fig.



The input is applied to the non-inverting input terminal of the op-amp.

Derivation of closed loop gain:

The node B is at potential V_{in}, hence the potential of point A is same as B which is V_{in}, from the concept of virtual state

$$\therefore V_A = V_B = V_{in} \quad -(1)$$

from output side we can write,

$$I = \frac{V_0 - V_A}{R_f}$$

$$\therefore I = \frac{V_0 - V_{in}}{R_f} \quad -(2)$$

At the inverting terminal

~~$I = \frac{V_0 - V_A}{R_1}$~~ $I = \frac{V_A - 0}{R_1}$

$$\therefore I = \frac{V_{in}}{R_1} \quad -(3)$$

Entire current passes through R_1 as input current of op-amp is zero. Equating eqns (2) & (3),

$$\therefore \frac{V_o - V_{in}}{R_f} = \frac{V_{in}}{R_1}$$

$$\frac{V_o}{R_f} = \frac{V_{in}}{R_f} + \frac{V_{in}}{R_1}$$

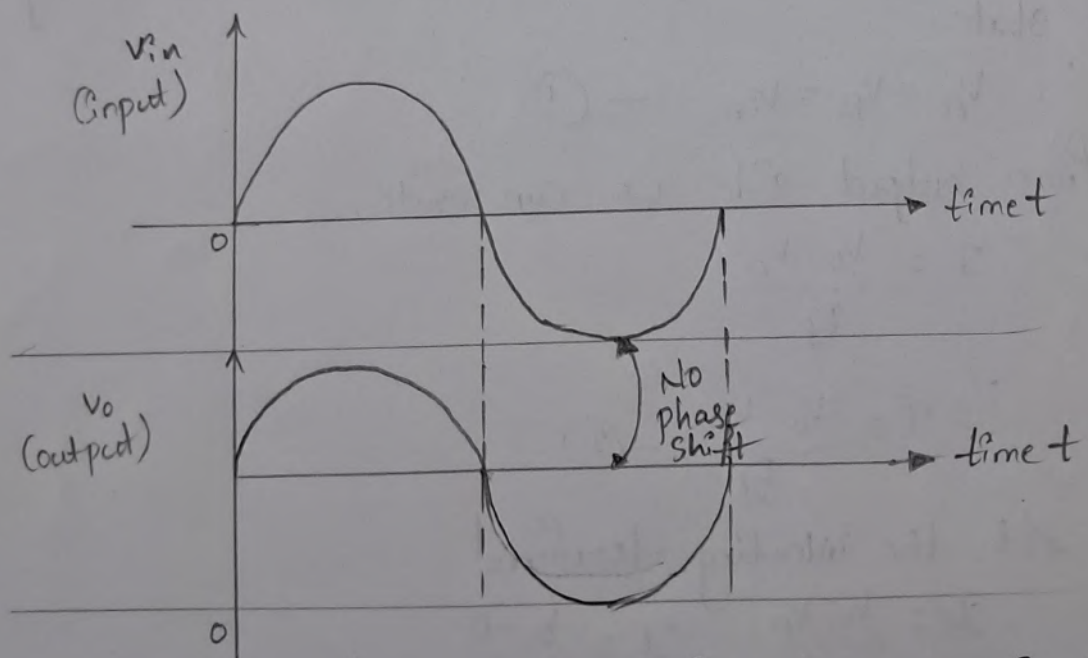
$$\therefore \frac{V_o}{R_f} = V_{in}\left[\frac{(R_1 + R_f)}{R_1 R_f}\right]$$

$$\therefore \frac{V_o}{V_{in}} = \frac{(R_1 + R_f) R_f}{R_1 R_f} = \frac{R_1 + R_f}{R_1}$$

$$\therefore A_{vf} = \frac{V_o}{V_{in}} = 1 + \frac{R_f}{R_1}$$

The positive sign indicates that there is no phase shift between input & output.

The input & output wave forms are



wave forms of non-inverting terminal.

Comparison:

Comparison between the ideal inverting & non-inverting amplifier op-amps circuits.

Ideal Inverting amplifier	Ideal Non-Inverting amplifier
* Voltage gain $= -R_f / R_1$	* Voltage gain $= 1 + (R_f / R_1)$
* The output is inverted with respect to input	* No phase shift between input & output
* The voltage gain can be adjusted as greater than, equal to (or) less than one.	* The voltage gain is always greater than one
* The input impedance is R_1	* The input impedance is extremely large.

UNIT - 1
NUMBER SYSTEMS & BOOLEAN ALGEBRA

- Introduction about digital system
- Philosophy of number systems
- Complement representation of negative numbers
- Binary arithmetic
- Binary codes
- Error detecting & error correcting codes
- Hamming codes

INTRODUCTION ABOUT DIGITAL SYSTEM

A Digital system is an interconnection of digital modules and it is a system that manipulates discrete elements of information that is represented internally in the binary form.

Now a day's digital systems are used in wide variety of industrial and consumer products such as automated industrial machinery, pocket calculators, microprocessors, digital computers, digital watches, TV games and signal processing and so on.

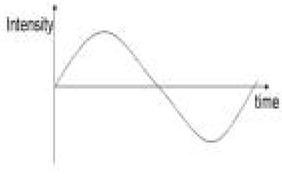
Characteristics of Digital systems

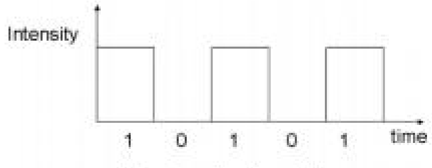
- Digital systems manipulate discrete elements of information.
- Discrete elements are nothing but the digits such as 10 decimal digits or 26 letters of alphabetsand so on.
- Digital systems use physical quantities called signals to represent discrete elements.
- In digital systems, the signals have two discrete values and are therefore said to be binary.
- A signal in digital system represents one binary digit called a bit. The bit has a value either 0 or 1.

Analog systems vs Digital systems

Analog system process information that varies continuously i.e; they process time varying signals that can take on any values across a continuous range of voltage, current or any physical parameter.

Digital systems use digital circuits that can process digital signals which can take either 0 or 1 for binary system.





Abrupt amplitude variations

Advantages of Digital system over Analog system

1. Ease of programmability

The digital systems can be used for different applications by simply changing the program without additional changes in hardware.

2. Reduction in cost of hardware

The cost of hardware gets reduced by use of digital components and this has been possible due to advances in IC technology. With ICs the number of components that can be placed in a given area of Silicon are increased which helps in cost reduction.

3. gh speed

Digital processing of data ensures high speed of operation which is possible due to advances in Digital Signal Processing.

4. High Reliability

Digital systems are highly reliable one of the reasons for that is use of error correction codes.

5. Design is easy

The design of digital systems which require use of Boolean algebra and other digital techniques is easier compared to analog designing.

6. Result can be reproduced easily

Since the output of digital systems unlike analog systems is independent of temperature, noise, humidity and other characteristics of components the reproducibility of results is higher in digital systems than in analog systems.

Disadvantages of Digital Systems

- Use more energy than analog circuits to accomplish the same tasks, thus producing more heat as well.
- Digital circuits are often fragile, in that if a single piece of digital data is lost or misinterpreted the meaning of large blocks of related data can completely change.
- Digital computer manipulates discrete elements of information by means of a binary code.
- Quantization error during analog signal sampling.

NUMBER SYSTEM

Number system is a basis for counting varies items. Modern computers communicate and operate with binary numbers which use only the digits 0 &1. Basic number system used by humans is Decimal number system.

For Ex: Let us consider decimal number 18. This number is represented in binary as 10010.

We observe that binary number system take more digits to represent the decimal number. For large numbers we have to deal with very large binary strings. So this fact gave rise to three new number systems.

i) Octal number systems

ii) Hexa Decimal number system

iii) Binary Coded Decimal number(BCD) system

To define any number system we have to specify

- Base of the number system such as 2,8,10 or 16.
- The base decides the total number of digits available in that number system.
- First digit in the number system is always zero and last digit in the number system is always base-1.

Binary number system:
The binary number has a radix of 2. As r = 2, only two digits are needed, and these are 0 and 1. In binary system weight is expressed as power of 2.

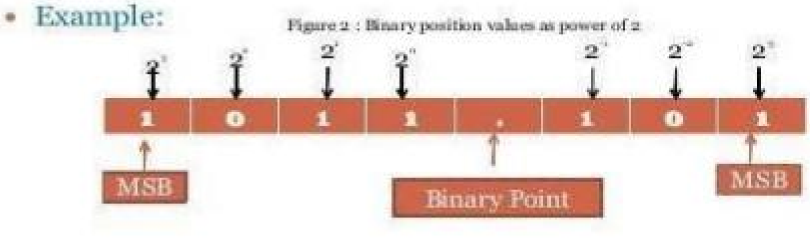


Figure 2 : Binary position values as power of 2

The left most bit, which has the greatest weight is called the Most Significant Bit (MSB). And the right most bit which has the least weight is called Least Significant Bit (LSB).

For Ex: $\mathbf{1001.01_2 = [\ (1) \times 2^3\ ] + [\ (0) \times 2^2\ ] + [\ (0) \times 2^1\ ] + [\ (1) \times 2^0\ ] + [\ (0) \times 2^{-1}\ ] + [\ (1) \times 2^2\ ]}$

$\mathbf{1001.01_2 = [\ 1 \times 8\ ] + [\ 0 \times 4\ ] + [\ 0 \times 2\ ] + [\ 1 \times 1\ ] + [\ 0 \times 0.5\ ] + [\ 1 \times 0.25\ ]}$

$\mathbf{1001.01_2 = 9.25_{10}}$

Decimal Number system

The decimal system has ten symbols: 0,1,2,3,4,5,6,7,8,9. In other words, it has a base of 10.

Octal Number System

Digital systems operate only on binary numbers. Since binary numbers are often very long, two shorthand notations, octal and hexadecimal, are used for representing large binary numbers. Octal systems use a base or radix of 8. It uses first eight digits of decimal number system. Thus it has digits from 0 to 7.

Hexa Decimal Number System

The hexadecimal numbering system has a base of 16. There are 16 symbols. The decimal digits 0 to 9 are used as the first ten digits as in the decimal system, followed by the letters A, B, C, D, E and F, which represent the values 10, 11,12,13,14 and 15 respectively.

Decimal	Binary	Octal	Hexadecimal
0	0000	0	0
1	0001	1	1
2	0010	2	2
3	0011	3	3
4	0100	4	4
5	0101	5	5
6	0110	6	6
7	0111	7	7
8	1000	10	8
9	1001	11	9
10	1010	12	A
11	1011	13	B
12	1100	14	C
13	1101	15	D
14	1110	16	E
15	1111	17	F

Number Base conversions

The human beings use decimal number system while computer uses binary number system. Therefore it is necessary to convert decimal number system into its equivalent binary.

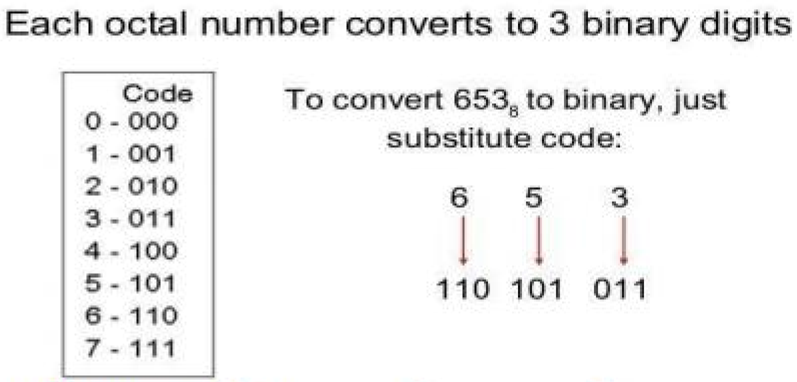
i) Binary to octal number conversion

ii) Binary to hexa decimal number conversion

The binary number:	001	010	011	000	100	101	110	111
The octal number:	1	2	3	0	4	5	6	7

The binary number:	0001	0010	0100	1000	1001	1010	1101	1111
The hexadecimal number:	1	2	5	8	9	A	D	F

iii) Octal to binary Conversion



iv) Hexa to binary conversion

v) Octal to Decimal conversion

Ex: convert 4057.06_8 to octal

$=4x8^3+0x8^2+5x8^1+7x8^0+0x8^{-1}+6x8^{-2}$

=2048+0+40+7+0+0.0937

$=2095.0937_{10}$

vi) Decimal to Octal Conversion

Ex: convert 378.93_{10} to octal

378_{10} to octal: Successive division:

```
8 | 378
  |____
8 |47 ---   2
  |________
8 |5  ---   7      ↑
  |_______
   0  ---   5
```

$=572_8$

0.93_{10} to octal :

0.93x8=7.44

0.44x8=3.52 ↓

0.53x8=4.16

0.16x8=1.28

$=0.7341_8$

$378.93_{10}=572.7341_8$

vii) Hexadecimal to Decimal Conversion

Ex: $5C7_{16}$ to decimal

$=(5x16^2)+(C\ x16^1)+ (7\ x16^0)$

=1280+192+7

$=147_{10}$

viii) Decimal to Hexadecimal Conversion

Ex: 2598.67510

```
1 6 |2598
    |_____
16 162____    -6
    10        -2
```

= $A26_{(16)}$

0.67510=0.675x16 -- 10.8

=0.800x16 -- 12.8 ↓

=0.800x16 -- 12.8

=0.800x16 -- 12.8

$=0.ACCC_{16}$

$2598.675_{10} = A26.ACCC_{16}$

ix) Octal to hexadecimal conversion:

The simplest way is to first convert the given octal no. to binary & then the binary no. to hexadecimal.

Ex: 756.603_8

7	5	6	.	6	0	3
111	101	110	.	110	000	011
0001	1110	1110	.	1100	0001	1000
1	E	E	.	C	1	8

x) Hexadecimal to octal conversion:

First convert the given hexadecimal no. to binary & then the binary no. to octal.

Ex: B9F.AE16

B	9	F	.	A	E		
1011	1001	1111	.	1010	1110		
101	110	011	111	.	101	011	100
5	6	3	7	.	5	3	4

=5637.534

Complements:

In digital computers to simplify the subtraction operation & for logical manipulation complements are used. There are two types of complements used in each radix system.

i) The radix complement or r's complement

ii) The diminished radix complement or (r-1)'s complement

Representation of signed no.s binary arithmetic in computers:

- Two ways of rep signed no.s
  1. Sign Magnitude form
  2. Complemented form
- Two complimented forms
  1. 1's compliment form
  2. 2's compliment form

Advantage of performing subtraction by the compliment method is reduction in the hardware.(instead of addition & subtraction only adding ckt's are needed.)
i.e, subtraction is also performed by adders only.

Instead of subtracting one no. from other the compliment of the subtrahend is added to minuend. In sign magnitude form, an additional bit called the sign bit is placed in front of the no. If the sign bit is 0, the no. is +ve, If it is a 1, the no is _ve.

Ex:

0	1	0	1	0	0	1

↓

Sign bit =+41 magnitude

↑

1	1	0	1	0	0	1

= -41

Note: manipulation is necessary to add a +ve no to a –ve no

Representation of signed no.s using 2's or 1's complement method:

If the no. is +ve, the magnitude is rep in its true binary form & a sign bit 0 is placed in front of the MSB.I f the no is _ve , the magnitude is rep in its 2's or 1's compliment form &a sign bit 1 is placed in front of the MSB.

Ex:

Given no.	Sign mag form	2's comp form	1's comp form
01101	+13	+13	+13
010111	+23	+23	+23
10111	-7	-7	-8
1101010	-42	-22	-21

Special case in 2's comp representation:

Whenever a signed no. has a 1 in the sign bit & all 0's for the magnitude bits, the decimal equivalent is -2^n , where n is the no of bits in the magnitude .
Ex: 1000= -8 & 10000=-16

Characteristics of 2's compliment no.s:

Properties:

1. There is one unique zero
2. 2's comp of 0 is 0
3. The leftmost bit can't be used to express a quantity . it is a 0 no. is +ve.
4. For an n-bit word which includes the sign bit there are $(2^{n-1}-1)$ +ve integers, 2^{n-1} –ve integers & one 0 , for a total of 2^nuniquestates.
5. Significant information is containd in the 1's of the +ve no.s & 0's of the _ve no.s
6. A _ve no. may be converted into a +ve no. by finding its 2's comp.

Signed binary numbers:

Decimal	Sign 2's comp form	Sign 1's comp form	Sign mag form
+7	0111	0111	0111
+6	0110	0110	0110
+5	0101	0101	0101
+4	0100	0100	0100
+3	0011	0011	0011
+2	0010	0010	0010
+1	0011	0011	0011
+0	0000	0000	0000

-0	--	1111	1000
-1	1111	1110	1001
-2	1110	1101	1010
-3	1101	1100	1011
-4	1100	1011	1100
-5	1011	1010	1101
-6	1010	1001	1110
-7	1001	1000	1111
8	1000	--	--

Methods of obtaining 2's comp of a no:

- In 3 ways
  1. By obtaining the 1's comp of the given no. (by changing all 0's to 1's & 1's to 0's) & then adding 1.
  2. By subtracting the given n bit no N from 2^n
  3. Starting at the LSB , copying down each bit upto & including the first 1 bit encountered , and complimenting the remaining bits.

  Ex: Express -45 in 8 bit 2's comp form

+45 in 8 bit form is 00101101

I method:

1's comp of 00101101 & the add 1

00101101

11010010

+1

11010011 is 2's comp form

II method:

Subtract the given no. N from 2^n

2^n = 100000000

Subtract 45= -00101101

+1

11010011 is 2's comp

III method:

Original no: 00101101

Copy up to First 1 bit 1

Compliment remaining : 1101001

---

bits 11010011

Ex:

-73.75 in 12 bit 2'compform

I method

01001001.1100
10110110.0011
+1

10110110.0100 is 2's

II method:

2^8 = 100000000.0000

Sub 73.75=-01001001.1100

10110110.0100 is 2's comp

III method :

Orginalno : 01001001.1100

Copy up to 1'st bit 100

Comp the remaining bits: 10110110.0

10110110.0100

2's compliment Arithmetic:

- The 2's comp system is used to rep –ve no.s using modulus arithmetic . The word length of a computer is fixed. i.e, if a 4 bit no. is added to another 4 bit no . the result will be only of 4 bits. Carry if any , from the fourth bit will overflow called the Modulus arithmetic.
  Ex:1100+1111=1011
- In the 2's compl subtraction, add the 2's comp of the subtrahend to the minuend . If there is a carry out , ignore it , look at the sign bit I,e, MSB of the sum term .If the MSB is a 0, the result is positive.& it is in true binary form. If the MSB is a ` (carry in or no carry at all) the result is negative.& is in its 2's comp form. Take its 2's comp to find its magnitude in binary.

Ex: Subtract 14 from 46 using 8 bit 2's comp arithmetic:

+14 = 00001110
-14 = 11110010 2's comp

+46 = 00101110
-14 =+11110010 2's comp form of -14

-32	(1)00100000	ignore carry

Ignore carry , The MSB is 0 . so the result is +ve. & is in normal binary form. So the result is +00100000=+32.

EX: Add -75 to +26 using 8 bit 2's comp arithmetic

+75	= 01001011	
-75	=10110101	2's comp
+26	= 00011010	2's comp form of -75
-75	=+10110101	
-49	11001111	No carry

No carry , MSB is a 1, result is _ve & is in 2's comp. The magnitude is 2's comp of 11001111. i.e, 00110001 = 49. so result is -49

Ex: add -45.75 to +87.5 using 12 bit arithmetic

+87.5 = 01010111.1000
-45.75=+11010010.0100

-41.75 (1)00101001.1100 ignore carry
MSB is 0, result is +ve. =+41.75

1's compliment of n number:

- It is obtained by simply complimenting each bit of the no,.& also , 1's comp of a no, is subtracting each bit of the no. form 1.This complemented value rep the –ve of the original no. One of the difficulties of using 1's comp is its rep o f zero. Both 00000000 & its 1's comp 11111111 rep zero.
- The 00000000 called +ve zero& 11111111 called –ve zero.

Ex: -99 & -77.25 in 8 bit 1's comp

+99	=	01100011
-99	=	10011100

+77.25 =	01001101.0100
-77.25 =	10110010.1011

1's compliment arithmetic:

In 1's comp subtraction, add the 1's comp of the subtrahend to the minuend. If there is a carryout , bring the carry around & add it to the LSB called the **end around carry.** Look at the sign bit (MSB) . If this is a 0, the result is +ve & is in true binary. If the MSB is a 1 (carry or no carry), the result is –ve & is in its is comp form .Take its 1's comp to get the magnitude inn binary.

Ex: Subtract 14 from 25 using 8 bit 1's EX: ADD -25 to +14

25	=	00011001	+14	= 00001110
-45	=	11110001	-25	=+11100110
+11		(1)00001010	-11	11110100
	+1			
			No carry	MSB =1
		00001011		result=-ve=-11_{10}

MSB is a 0 so result is +ve (binary)

=+11_{10}

Binary codes

Binary codes are codes which are represented in binary system with modification from the original ones.

- Weighted Binary codes
- Non Weighted Codes

Weighted binary codes are those which obey the positional weighting principles, each position of the number represents a specific weight. The binary counting sequence is an example.

Decimal	BCD 8421	Excess-3	84-2-1	2421	5211	Bi-Quinary 5043210			5	0	4	3	2	1	0
0	0000	0011	0000	0000	0000	0100001		0		X					X
1	0001	0100	0111	0001	0001	0100010		1		X				X	
2	0010	0101	0110	0010	0011	0100100		2		X			X		
3	0011	0110	0101	0011	0101	0101000		3		X		X			
4	0100	0111	0100	0100	0111	0110000		4		X	X				
5	0101	1000	1011	1011	1000	1000001		5	X						X
6	0110	1001	1010	1100	1010	1000010		6	X					X	
7	0111	1010	1001	1101	1100	1000100		7	X				X		
8	1000	1011	1000	1110	1110	1001000		8	X			X			
9	1001	1111	1111	1111	1111	1010000		9	X		X				

Reflective Code

A code is said to be reflective when code for 9 is complement for the code for 0, and so is for 8 and 1 codes, 7 and 2, 6 and 3, 5 and 4. Codes 2421, 5211, and excess-3 are reflective, whereas the 8421 code is not.

Sequential Codes

A code is said to be sequential when two subsequent codes, seen as numbers in binary representation, differ by one. This greatly aids mathematical manipulation of data. The 8421 and Excess-3 codes are sequential, whereas the 2421 and 5211 codes are not.

Non weighted codes

Non weighted codes are codes that are not positionally weighted. That is, each position within the binary number is not assigned a fixed value. Ex: Excess-3 code

Excess-3 Code

Excess-3 is a non weighted code used to express decimal numbers. The code derives its name from the fact that each binary code is the corresponding 8421 code plus 0011(3).

Gray Code

The gray code belongs to a class of codes called minimum change codes, in which only one bit in the code changes when moving from one code to the next. The Gray code is non-weighted code, as the position of bit does not contain any weight. The gray code is a reflective digital code which has the special property that any two subsequent numbers codes differ by only one bit. This is also called a unit- distance code. In digital Gray code has got a special place.

Decimal Number	Binary Code	Gray Code	Decimal Number	Binary Code	Gray Code
0	0000	0000	8	1000	1100
1	0001	0001	9	1001	1101
2	0010	0011	10	1010	1111
3	0011	0010	11	1011	1110
4	0100	0110	12	1100	1010
5	0101	0111	13	1101	1011
6	0110	0101	14	1110	1001
7	0111	0100	15	1111	1000

Binary to Gray Conversion

- Gray Code MSB is binary code MSB.
- Gray Code MSB-1 is the XOR of binary code MSB and MSB-1.
- MSB-2 bit of gray code is XOR of MSB-1 and MSB-2 bit of binary code.
- MSB-N bit of gray code is XOR of MSB-N-1 and MSB-N bit of binary code.

8421 BCD code (Natural BCD code):

Each decimal digit 0 through 9 is coded by a 4 bit binary no. called natural binary codes. Because of the 8,4,2,1 weights attached to it. It is a weighted code & also sequential . it is useful for mathematical operations. The advantage of this code is its case of conversion to & from decimal. It is less efficient than the pure binary, it require more bits.

Ex: 14→1110 in binary

But as 0001 0100 in 8421 ode.

The disadvantage of the BCD code is that , arithmetic operations are more complex than they are in pure binary . There are 6 illegal combinations 1010,1011,1100,1101,1110,1111 in these codes, they are not part of the 8421 BCD code system . The disadvantage of 8421 code is, the rules of binary addition 8421 no, but only to the individual 4 bit groups.

BCD Addition:

It is individually adding the corresponding digits of the decimal no,s expressed in 4 bit binary groups starting from the LSD . If there is no carry & the sum term is not an illegal code , no correction is needed .If there is a carry out of one group to the next group or if the sum term is an illegal code then 6_{10}(0100) is added to the sum term of that group & the resulting carry is added to the next group.

Ex: Perform decimal additions in 8421 code

(a)25+13

```
In BCD       25=  0010   0101
In BCD      +13  =+0001 0011
            ___    __________
             38    0011 1000
```

No carry , no illegal code .This is the corrected sum (b). 679.6 + 536.8

```
679.6    =   0110        0111        1001   .0110 in BCD
+536.8   =   +0101       0011        0010    .1000 in BCD
____ _ _     _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _
1216.4       1011        1010        0110   . 1110       illegal codes
             +0110     + 0011       +0110   . + 0110     add 0110 to each
                   ______________________________
      (1)0001    (1)0000      (1)0101   . (1)0100     propagate carry
      /          /            /              /
       +1         +1           +1            +1
      ____________________________________________
      0001       0010         0001         0110  .  0100

       1          2             1            6    .   4
```

BCD Subtraction:

Performed by subtracting the digits of each 4 bit group of the subtrahend the digits from the corresponding 4- bit group of the minuend in binary starting from the LSD . if there is no borrow from the next group , then 6_{10}(0110)is subtracted from the difference term of this group.

(a)38-15

```
In BCD      38=  0011     1000
In BCD     -15 = -0001    0101
           ___   __________

            23    0010    0011
```

No borrow, so correct difference.

.(b) 206.7-147.8

```
206.7    =   0010   0000   0110  .     0111                in BCD
-147.8 =     -0001  0100   0111  .     0110                in BCD
___ _ _      ___ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _
58.9         0000   1011   1110  .     1111          borrows are present
       -0110 -0110 .       -0110       subtract 0110
             ____________________________________

                    0101   1000  .     1001
```

BCD Subtraction using 9's & 10's compliment methods:

Form the 9's & 10's compliment of the decimal subtrahend & encode that no. in the 8421 code . the resulting BCD no.s are then added.

EX: 305.5 – 168.8

305.5 =	305.5	
-168.8=	+83.1	9's comp of -168.8
	(1)136.6	
	+1	end around carry
	136.7	corrected difference

305.5_{10} =	0011	0000 0101	.	0101	
$+831.1_{10}$=	+1000	0011 0001	.	0001	9's comp of 168.8 in BCD
	+1011	0011 0110	.	0110	1011 is illegal code
	+0110				add 0110
	(1)0001	0011 0110	.	0110	
				+1	End around carry
	0001	0011 0110	.	0111	
				= 136.7	

Excess three(xs-3)code:

It is a non-weighted BCD code .Each binary codeword is the corresponding 8421 codeword plus 0011(3).It is a sequential code & therefore , can be used for arithmetic operations..It is a self-complementing code.s o the subtraction by the method of compliment addition is more direct in xs-3 code than that in 8421 code. The xs-3 code has six invalid states 0000,0010,1101,1110,1111.. It has interesting properties when used in addition & subtraction.

Excess-3 Addition:

Add the xs-3 no.s by adding the 4 bit groups in each column starting from the LSD. If there is no carry starting from the addition of any of the 4-bit groups , subtract 0011 from the sum term of those groups (because when 2 decimal digits are added in xs-3 & there is no carry , result in xs-6). If there is a carry out, add 0011 to the sum term of those groups(because when there is a carry, the invalid states are skipped and the result is normal binary).

EX: 37 0110 1010

+28 +0101 1011

---

65 1011 (1)0101 carry generated

+1 ← propagate carry

1100 0101 add 0011 to correct 0101 &

-0011 +0011 subtract 0011 to correct 1100

1001 1000 $=65_{10}$

Excess -3 (XS-3) Subtraction:

Subtract the xs-3 no.s by subtracting each 4 bit group of the subtrahend from the corresponding 4 bit group of the minuend starting form the LSD .if there is no borrow from the next 4-bit group add 0011 to the difference term of such groups (because when decimal digits are subtracted in xs-3 & there is no borrow , result is normal binary). I f there is a borrow , subtract 0011 from the differenceterm(b coz taking a borrow is equivalent to adding six invalid states , result is in xs-6)

Ex: 267-175

267 = 0101 1001 1010

-175= -0100 1010 1000

0000 1111 0010

+0011 -0011 +0011

0011 1100 +0011 $=92_{10}$

Xs-3 subtraction using 9's & 10's compliment methods:
Subtraction is performed by the 9's compliment or 10's compliment
Ex:687-348 The subtrahend (348) xs -3 code & its compliment are:

9's comp of 348 = 651
Xs-3 code of 348 = 0110 0111 1011
1's comp of 348 in xs-3 = 1001 1000 0100
Xs=3 code of 348 in xs=3 = 1001 1000 0100

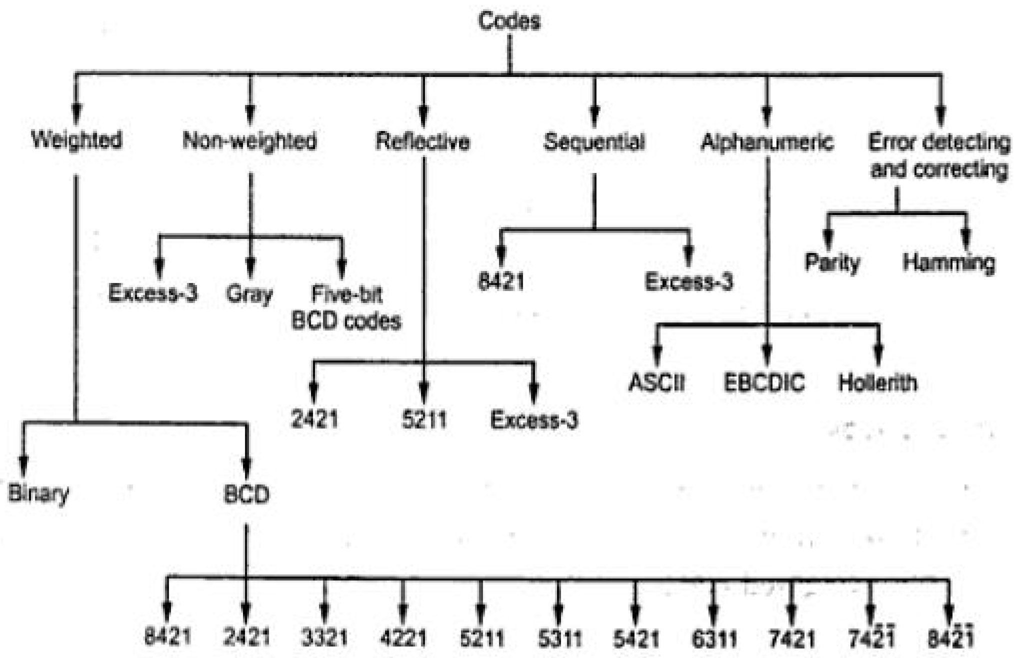
```
  687              687
 -348      →     +651 9's compl of 348
______
  339            (1)338
                    +1 end around carry
                 ____
                  339        corrected difference in decimal

    1001        1011        1010        687 in xs-3
   +1001        1000        0100        1's comp 348 in xs-3
   ___________________________
   (1)0010   (1)0011       1110      carry generated

 +1            +1                       propagate carry
 ______________________________
 (1)0011       0010    1110
                              +1        end around carry
 ______________________________

    0011        0011        1111        (correct 1111 by sub0011 and
   +0011       +0011       +0011        correct both groups of 0011 by
   ____        ____        ____      adding 0011)

    0110        0110        1100        corrected diff in xs-3 = 330₁₀
```

The Gray code (reflective –code):

Gray code is a non-weighted code & is not suitable for arithmetic operations. It is not a BCD code . It is a cyclic code because successive code words in this code differ in one bit position only i.e, it is a unit distance code.Popular of the unit distance code.It is also a reflective code i.e,both reflective & unit distance. The n least significant bits for 2^n through 2^{n+1}-1 are the mirror images of thosr for 0 through 2^n-1.An N bit gray code can be obtained by reflecting an N- 1 bit code about an axis at the end of the code, & putting the MSB of 0 above the axis & the MSB of 1 below the axis.

Reflection of gray codes:

Gray Code				Decimal	4 bit binary
1 bit	2 bit	3 bit	4 bit		
0	00	000	0000	0	0000
1	01	001	0001	1	0001
	11	011	0011	2	0010
	10	010	0010	3	0011
		110	0110	4	0100
		111	0111	5	0101
		101	0101	6	0110
		110	0100	7	0111
			1100	8	1000
			1101	9	1001
			1111	10	1010
			1110	11	1011
			1010	12	1100
			1011	13	1101
			1001	14	1110
			1000	15	1111



Binary codes block diagram

Error – Detecting codes: When binary data is transmitted & processed,it is susceptible to noise that can alter or distort its contents. The 1‘s may get changed to 0‘s & 1‘s .because digital systems must be accurate to the digit, error can pose a problem. Several schemes have been devised to detect the occurrence of a single bit error in a binary word, so that whenever such an error occurs the concerned binary word can be corrected & retransmitted.

Parity: The simplest techniques for detecting errors is that of adding an extra bit known as parity bit to each word being transmitted.Two types of parity**:** Oddparity**,** evenparity forodd parity, the parity bit is set to a _0‘ or a _1‘ at the transmitter such that the total no. of 1 bit in the word including the parity bit is an odd no.For even parity, the parity bit is set to a _0‘ or a _1‘ at the transmitter such that the parity bit is an even no.

Decimal	8421 code	Odd parity	Even parity
0	0000	1	0
1	0001	0	1
2	0010	0	1
3	0011	1	0
4	0100	0	1
5	0100	1	0
6	0110	1	0
7	0111	0	1
8	1000	0	1
9	1001	1	0

When the digit data is received . a parity checking circuit generates an error signal if the total no of 1's is even in an odd parity system or odd in an even parity system. This parity check can always detect a single bit error but cannot detect 2 or more errors with in the same word.Odd parity is used more often than even parity does not detect the situation. Where all 0's are created by a short ckt or some other fault condition.

Ex: Even parity scheme

(a) 10101010 (b) 11110110 (c)10111001

Ans:

(a) No. of 1's in the word is even is 4 so there is no error
(b) No. of 1's in the word is even is 6 so there is no error
(c) No. of 1's in the word is odd is 5 so there is error

Ex: odd parity

(a)10110111 (b) 10011010 (c)11101010

Ans:

(a) No. of 1's in the word is even is 6 so word has error
(b) No. of 1's in the word is even is 4 so word has error
(c) No. of 1's in the word is odd is 5 so there is no error

Checksums:

Simple parity can't detect two errors within the same word. To overcome this, use a sort of 2 dimensional parity. As each word is transmitted, it is added to the sum of the previously transmitted words, and the sum retained at the transmitter end. At the end of transmission, the sum called the check sum. Up to that time sent to the receiver. The receiver can check its sum with the transmitted sum. If the two sums are the same, then no errors were detected at the receiver end. If there is an error, the receiving location can ask for retransmission of the entire data, used in teleprocessing systems.

Block parity:

Block of data shown is create the row & column parity bits for the data using odd parity. The parity bit 0 or 1 is added column wise & row wise such that the total no. of 1's in each column & row including the data bits & parity bit is odd as

Data	Parity bit
10110	0
10001	1
10101	0
00010	0
11000	1
00000	1
11010	0

data
10110
10001
10101
00010
11000
00000
11010

Error –Correcting Codes:

A code is said to be an error –correcting code, if the code word can always be deduced from an erroneous word. For a code to be a single bit error correcting code, the minimum distance of that code must be three. The minimum distance of that code is the smallest no. of bits by which any two code words must differ. A code with minimum distance of 3 can't only correct single bit errors but also detect (can't correct) two bit errors, The key to error correction is that it must be possible to detect & locate erroneous that it must be possible to detect & locate erroneous digits. If the location of an error has been determined. Then by complementing the erroneous digit, the message can be corrected , error correcting , code is the Hamming code , In this , to each group of m information or message or data bits, K parity checking bits denoted by P1,P2, ---------pk located at positions 2^{k-1} from left are added to form an (m+k) bit code word. To correct the error, k parity checks are performed on selected digits of each code word, & the position of the error bit is located by forming an error word, & the error bit is then complemented. The k bit error word is generated by putting a 0 or a 1 in the 2^{k-1}th position depending upon whether the check for parity involving the parity bit P_k is satisfied or not.Error positions & their corresponding values :

Error Position	For 15 bit code $C_4 C_3 C_2 C_1$	For 12 bit code $C_4 C_3 C_2 C_1$	For 7 bit code $C_3 C_2 C_1$
0	0 0 0 0	0 0 0 0	0 0 0
1	0 0 0 1	0 0 0 1	0 0 1
2	0 0 1 0	0 0 1 0	0 1 0
3	0 0 1 1	0 0 1 1	0 1 1
4	0 1 0 0	0 1 0 0	1 0 0
5	0 1 0 1	0 1 0 1	1 0 1
6	0 1 1 0	0 1 1 0	1 1 0
7	0 1 1 1	0 1 1 1	1 1 1
8	1 0 0 0	1 0 0 0	
9	1 0 0 1	1 0 0 1	
10	1 0 1 0	1 0 1 0	
11	1 0 1 1	1 0 1 1	
12	1 1 0 0	1 1 0 0	
13	1 1 0 1		
14	1 1 1 0		
15	1 1 1 1		

7-bit Hamming code:

To transmit four data bits, 3 parity bits located at positions 2^0 21&2^2 from left are added to make a 7 bit codeword which is then transmitted.

The word format

P_1	P_2	D_3	P_4	D_5	D_6	D_7

D—Data bits P-
Parity bits

Decimal Digit	For BCD P1P2D3P4D5D6D7	For Excess-3 P1P2D3P4D5D6D7
0	0 0 0 0 0 0 0	1 0 0 0 0 1 1
1	1 1 0 1 0 0 1	1 0 0 1 1 0 0
2	0 1 0 1 0 1 1	0 1 0 0 1 0 1
3	1 0 0 0 0 1 1	1 1 0 0 1 1 0
4	1 0 0 1 1 0 0	0 0 0 1 1 1 1
5	0 1 0 0 1 0 1	1 1 1 0 0 0 0
6	1 1 0 0 1 1 0	0 0 1 1 0 0 1
7	0 0 0 1 1 1 1	1 0 1 1 0 1 0
8	1 1 1 0 0 0 0	0 1 1 0 0 1 1
9	0 0 1 1 0 0 1	0 1 1 1 1 0 0

Ex: Encode the data bits 1101 into the 7 bit even parity Hamming Code

The bit pattern is

P1P2D3P4D5D6D7

1 1 0 1

Bits 1,3,5,7 (P_1 111) must have even parity, so P_1 =1

Bits 2, 3, 6, 7(P_2 101) must have even parity, so P_2 =0

Bits 4,5,6,7 (P_4 101)must have even parity, so P_4 =0

The final code is 1010101

EX: Code word is 1001001

Bits 1,3,5,7 (C_1 1001) →no error →put a 0 in the 1's position→C1=0

Bits 2, 3, 6, 7(C_2 0001)) → error →put a 1 in the 2's position→C2=1

Bits 4,5,6,7 (C_4 1001)) →no error →put a 0 in the 4's position→C3=0

15-bit Hamming Code: It transmit 11 data bits, 4 parity bits located $2^0\ 2^1\ 2^2\ 2^3$

Word format is

P_1	P_2	D_3	P_4	D_5	D_6	D_7	P_8	D_9	D10	D11	D12	D13	D14	D15

12-Bit Hamming Code: It transmit 8 data bits, 4 parity bits located at position $2^0\ 2^1\ 2^2\ 2^3$

Word format is

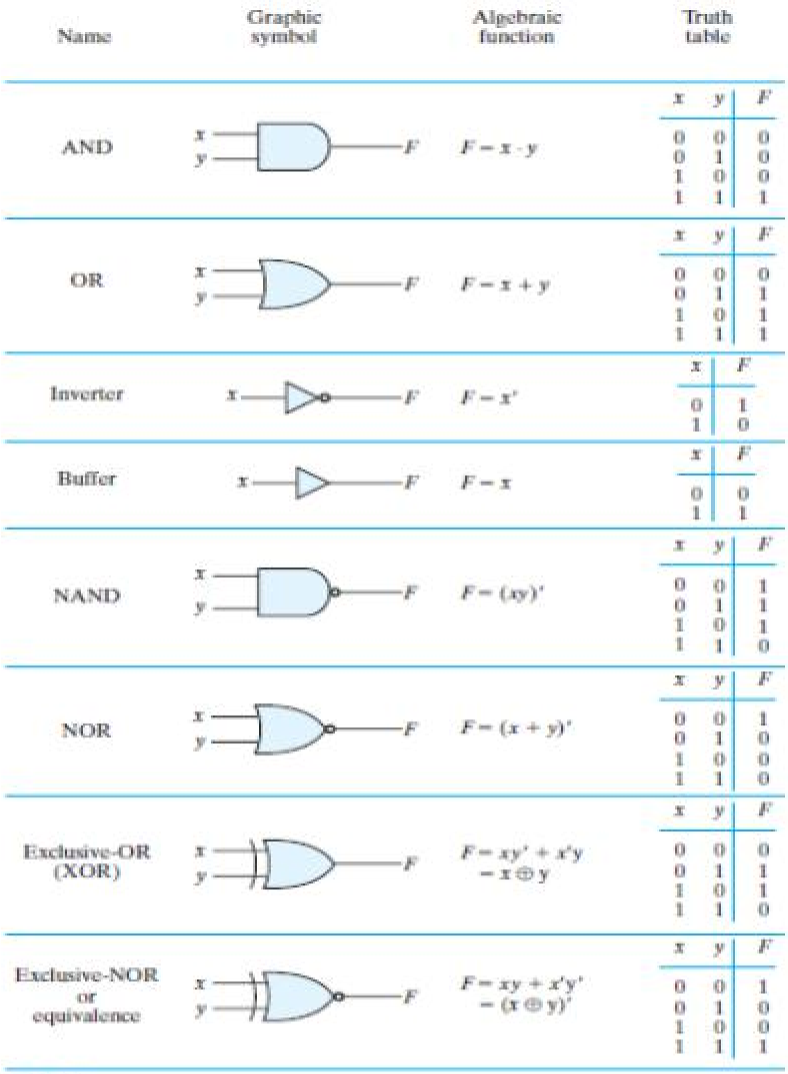
P_1	P_2	D_3	P_4	D_5	D_6	D_7	P_8	D_9	D10	D11	D12

Alphanumeric Codes:

These codes are used to encode the characteristics of alphabet in addition to the decimal digits. It is used for transmitting data between computers & its I/O device such as printers, keyboards & video display terminals.Popular modern alphanumeric codes are ASCII code & EBCDIC code.

Digital Logic Gates

Boolean functions are expressed in terms of AND, OR, and NOT operations, it is easier to implement a Boolean function with these type of gates.



Properties of XOR Gates

- XOR (also ⊕) : the “not-equal” function
- XOR(X,Y) = $X \oplus Y = X'Y + XY'$
- Identities:
  - $X \oplus 0 = X$
  - $X \oplus 1 = X'$
  - $X \oplus X = 0$
  - $X \oplus X' = 1$
- Properties:
  - $X \oplus Y = Y \oplus X$
  - $(X \oplus Y) \oplus W = X \oplus (Y \oplus W)$

Universal Logic Gates

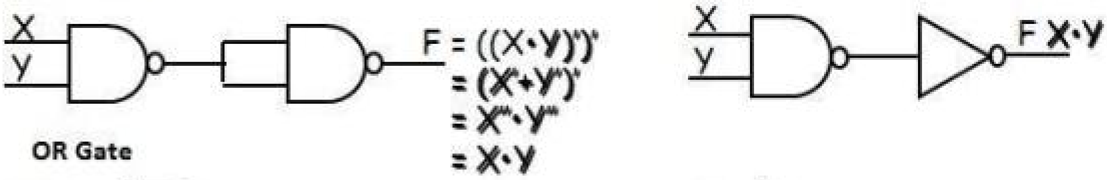
NAND and NOR gates are called Universal gates. All fundamental gates (NOT, AND, OR) can be realized by using either only NAND or only NOR gate. A universal gate provides flexibility and offers enormous advantage to logic designers.

NAND as a Universal Gate

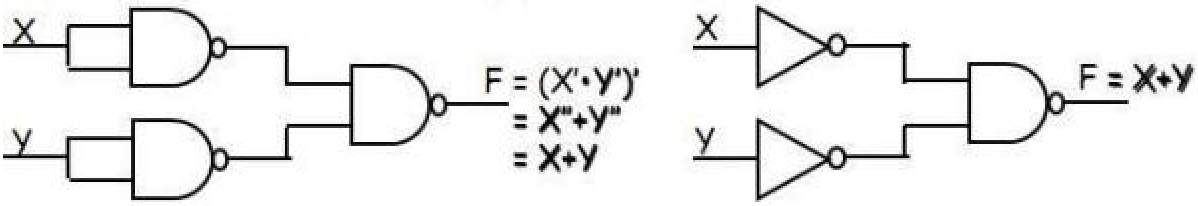
NAND Known as a “universal” gate because ANY digital circuit can be implemented with NAND gates alone.
To prove the above, it suffices to show that AND, OR, and NOT can be implemented using NAND gates only.

NOT Gate

AND Gate



OR Gate



Boolean Algebra: In 1854, George Boole developed an algebraic system now called Boolean algebra. In 1938, Claude E. Shannon introduced a two-valued Boolean algebra called switching algebra that represented the properties of bistable electrical switching circuits. For the formal definition of Boolean algebra, we shall employ the postulates formulated by E. V. Huntington in 1904.

Boolean algebra is a system of mathematical logic. It is an algebraic system consisting of the set of elements (0, 1), two binary operators called OR, AND, and one unary operator NOT. It is the basic mathematical tool in the analysis and synthesis of switching circuits. It is a way to express logic functions algebraically.

Boolean algebra, like any other deductive mathematical system, may be defined with aset of elements, a set of operators, and a number of unproved axioms or postulates. A *set* of elements is anycollection of objects having a common property. If **S** is a set and ***x*** and ***y*** are certain objects, then **x Î S**denotes that ***x*** is a member of the set **S**, and ***y*** **ÏS** denotes that ***y*** is not an element of **S**. A set with adenumerable number of elements is specified by braces: **A** = {1,2,3,4}, *i.e.* the elements of set **A** are thenumbers 1, 2, 3, and 4. A *binary operator* defined on a set S of elements is a rule that assigns to each pair ofelements from S a unique element from S._ Example: In *a*b=c*, we say that * is a binary operator if it specifies a rule for finding *c* from the pair (*a*,*b*)and also if *a*, *b*, *c* Î S.

Axioms and laws of Boolean algebra

Axioms or Postulates of Boolean algebra are a set of logical expressions that we accept without proof and upon which we can build a set of useful theorems.

	AND Operation	OR Operation	NOT Operation
Axiom1 :	0.0=0	0+0=0	0=1
Axiom2:	0.1=0	0+1=1	1=0
Axiom3:	1.0=0	1+0=1	
Axiom4:	1.1=1	1+1=1	

AND Law

Law1: A.0=0 (Null law)
Law2: A.1=A (Identity law)
Law3: A.A=A (Impotence law)

OR Law

Law1: A+0=A
Law2: A+1=1
Law3: A+A=A (Impotence law)

CLOSURE: The Boolean system is *closed* with respect to a binary operator if for every pair of Boolean values,it produces a Boolean result. For example, logical AND is closed in the Boolean system because it accepts only Boolean operands and produces only Boolean results.

_ A set *S* is closed with respect to a binary operator if, for every pair of elements of *S*, the binary operator specifies a rule for obtaining a unique element of *S*.

_ For example, the set of natural numbers N = {1, 2, 3, 4, … 9} is closed with respect to the binary operator plus (+) by the rule of arithmetic addition, since for any *a*, *b* Î N we obtain a unique *c* Î N by the operation *a* + *b* = c.

ASSOCIATIVE LAW:

A binary operator * on a set S is said to be associative whenever $(x * y) * z = x * (y * z)$ for all x, y, z Î S, forall Boolean values x, y and z.

COMMUTATIVE LAW:

A binary operator * on a set S is said to be commutative whenever $x * y = y * x$ for all $x, y, z \in S$

IDENTITY ELEMENT:

A set S is said to have an identity element with respect to a binary operation * on S if there exists an element $e \in S$ with the property $e * x = x * e = x$ for every $x \in S$

BASIC IDENTITIES OF BOOLEAN ALGEBRA

- *Postulate 1(Definition)*: A Boolean algebra is a closed algebraic system containing a set K of two or more elements and the two operators · and + which refer to logical AND and logical OR •$x + 0 = x$
- $x \cdot 0 = 0$
- $x + 1 = 1$
- $x \cdot 1 = 1$
- $x + x = x$
- $x \cdot x = x$
- $x + x' = x$
- $x \cdot x' = 0$
- $x + y = y + x$
- $xy = yx$
- $x + (y + z) = (x + y) + z$
- $x (yz) = (xy) z$
- $x (y + z) = xy + xz$
- $x + yz = (x + y)(x + z)$
- $(x + y)' = x' y'$
- $(xy)' = x' + y'$

- $(x')' = x$

DeMorgan's Theorem

(a) $(a + b)' = a'b'$

(b) $(ab)' = a' + b'$

Generalized DeMorgan's Theorem

(a) $(a + b + \ldots z)' = a'b' \ldots z'$
(b) $(a.b \ldots z)' = a' + b' + \ldots z'$

Basic Theorems and Properties of Boolean algebra Commutative law

Law1: A+B=B+A Law2: A.B=B.A

Associative law

Law1: A + (B +C) = (A +B) +C Law2: A(B.C) = (A.B)C

Distributive law

Law1: A.(B + C) = AB+ AC Law2: A + BC = (A + B).(A +C)

Absorption law

Law1: A +AB =A Law2: A(A +B) = A

Solution: A(1+B)
A

Solution: A.A+A.B
A+A.B
A(1+B)
A

Consensus Theorem

Theorem1. AB+ A'C + BC = AB + A'C Theorem2. (A+B). (A'+C).(B+C) =(A+B).(A'+C)

The BC term is called the consensus term and is redundant. The consensus term is formed from a PAIR OF TERMS in which a variable (A) and its complement (A') are present; the consensus term is formed by multiplying the two terms and leaving out the selected variable and its complement

Consensus Theorem1 Proof:

AB+A'C+BC=AB+A'C+(A+A')BC
=AB+A'C+ABC+A'BC

=AB(1+C)+A’C(1+B)

= AB+ A’C

Principle of Duality

Each postulate consists of two expressions statement one expression is transformed into the other by interchanging the operations (+) and (·) as well as the identity elements 0 and 1. Such expressions are known as duals of each other.
If some equivalence is proved, then its dual is also immediately true.
If we prove: (x.x)+(x’+x’)=1, then we have by duality: (x+x)·(x’.x’)=0

The Huntington postulates were listed in pairs and designated by part (a) and part (b) in below table.

Table for Postulates and Theorems of Boolean algebra

Part-A	**Part-B**
A+0=A	A.0=0
A+1=1	A.1=A
A+A=A (Impotence law)	A.A=A (Impotence law)
$A+\bar{A}=1$	$A.\bar{A}=0$
$\bar{\bar{A}}=A$ (double inversion law)	--
Commutative law: A+B=B+A	A.B=B.A
Associative law: A + (B +C) = (A +B) +C	A(B.C) = (A.B)C
Distributive law: A.(B + C) = AB+ AC	A + BC = (A + B).(A +C)
Absorption law: A +AB =A	A(A +B) = A
DeMorgan Theorem: $\overline{(A+B)} = \bar{A}\ .\ \bar{B}$	$\overline{(A.B)} = = \bar{A}\ + \bar{B}$
Redundant Literal Rule: $A+\bar{A}B=A+B$	$A.(\bar{A}+B)=AB$
Consensus Theorem: AB+ A’C + BC = AB + A’C	(A+B). (A’+C).(B+C) =(A+B).(A’+C)

Boolean Function

Boolean algebra is an algebra that deals with binary variables and logic operations.
A Boolean function described by an algebraic expression consists of binary variables, the constants 0 and 1, and the logic operation symbols.
For a given value of the binary variables, the function can be equal to either 1 or 0.

F(vars) = *expression*

↓ Set of binary Variables

→ Operators (+, •, ‘)
Constants (0, 1)
Groupings (parenthesis)
Variables

Consider an example for the Boolean function

F1 = x + y’z

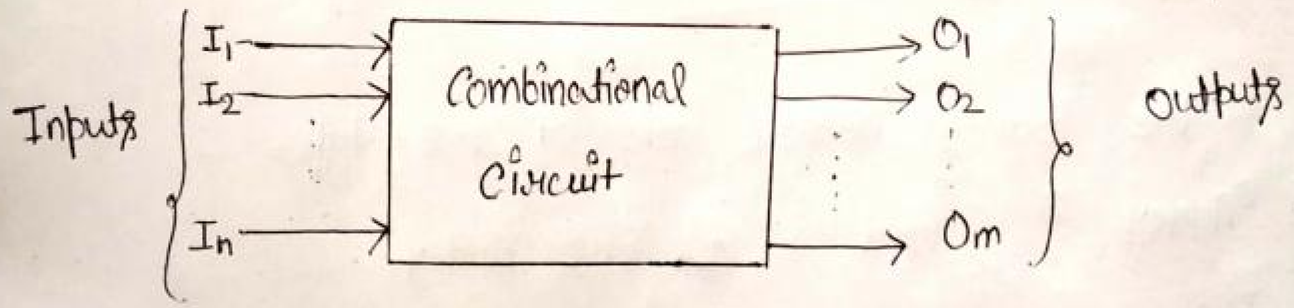
Digital Electronics

BCA - 2nd sem

Combinational Logic Circuits

Combinational Circuit :- Combinational logic circuits are memoryless digital logic circuits whose output at any instant in time depends only on the combination of its inputs.

A combinational circuit can have a number of inputs and a number of outputs. The block diagram of combination circuit having n inputs and m outputs are as -



— The sequence in which the inputs are being applied has no effect on the output of a combinational circuit.

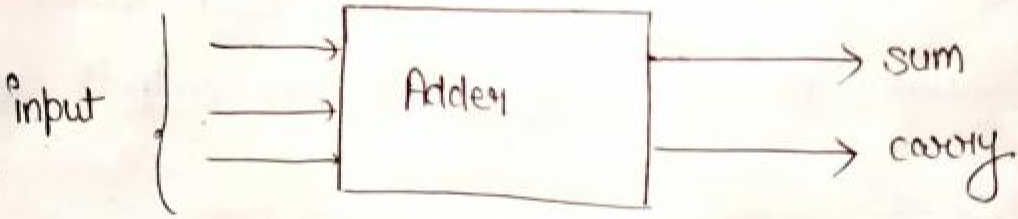
Example - Following are the examples of some combinational circuits —

Adders subtractors, multiplexers, demultiplexers, decoder, encoders etc.

Note – The combinational circuits do not use any memory because it works only on current input.

Binary Adder

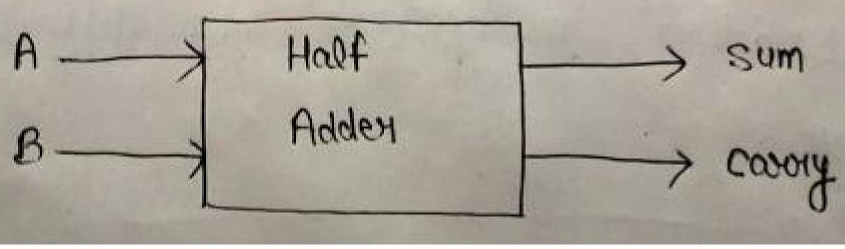
Binary adder is a combinational circuit that performs addition of binary numbers. It takes two or more binary bits as an input and produces sum and carry as output.



The binary adders are of two types –

1) Half Adder and 2) Full Adder

1) Half Adder :– Half adder is a combinational logic circuit that accepts two inputs in form of binary bit and produces two outputs namely 'sum' and 'carry'. Block diagram of half adder is as shown -



Truth table of half adder is —

Input		Output	
A	B	Sum	Carry
0	0	0	0
0	1	1	0
1	0	1	0
1	1	0	1

Now, K-map and simplified expression for outputs —

K-map for sum — Total input variables = 2

∴ No. of blocks = $2^2 = 4$

A \ B	$\overline{B}$ 0	B 1
$\overline{A}$ 0		1
A 1	1	

$\text{sum} = \overline{A}B + A\overline{B}$

$\boxed{\text{Sum} = A \oplus B}$

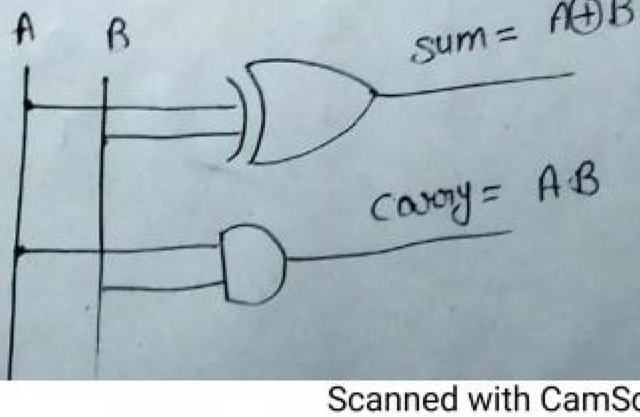
K-map for Carry — Two input is used

∴ No of cells = $2^2 = 4$

A \ B	$\overline{B}$ 0	B 1
$\overline{A}$ 0		
A 1		1

$\boxed{\text{Carry} = AB}$

Logic Diagram —



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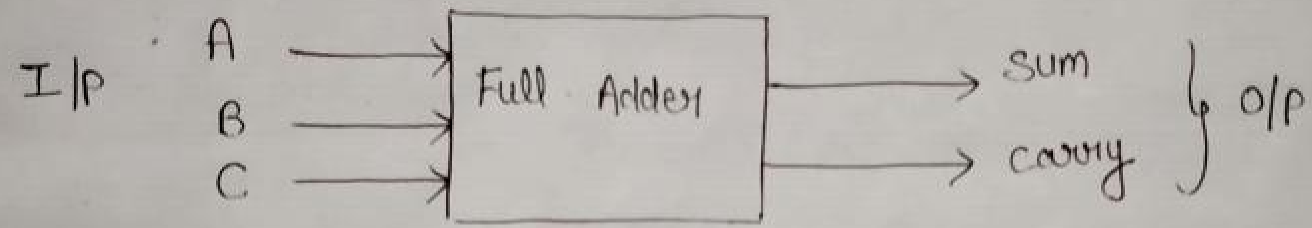
Full Adder:- To overcome the drawback of half adder circuit, a single bit adder circuit called full adder is developed.

That means a combinational circuit which accept three binary bits (0 & 1) as an input and generate sum & carry as an output. Block diagram are as—



Truth table of Full Adder is given as—

Input			Output	
A	B	C	sum	carry
0	0	0	0	0
0	0	1	1	0
0	1	0	1	0
0	1	1	0	1
1	0	0	1	0
1	0	1	0	1
1	1	0	0	1
1	1	1	1	1

K map for the sum output —

$\because$ Total no of variables = 3

$\therefore$ Total no of blocks = $2^3 = 8$

A \ BC	$\bar{B}\bar{C}$ 00	$\bar{B}C$ 01	BC 11	$B\bar{C}$ 10
$\bar{A}$ 0		1		1
A 1	1		1	

$$Sum = \bar{A}\bar{B}C + \bar{A}B\bar{C} + A\bar{B}\bar{C} + ABC$$

$$= \bar{A}(\bar{B}C + B\bar{C}) + A(\bar{B}\bar{C} + BC)$$

$$= \bar{A}(B\oplus C) + A\overline{(B\oplus C)}$$

$$= A\oplus B\oplus C$$

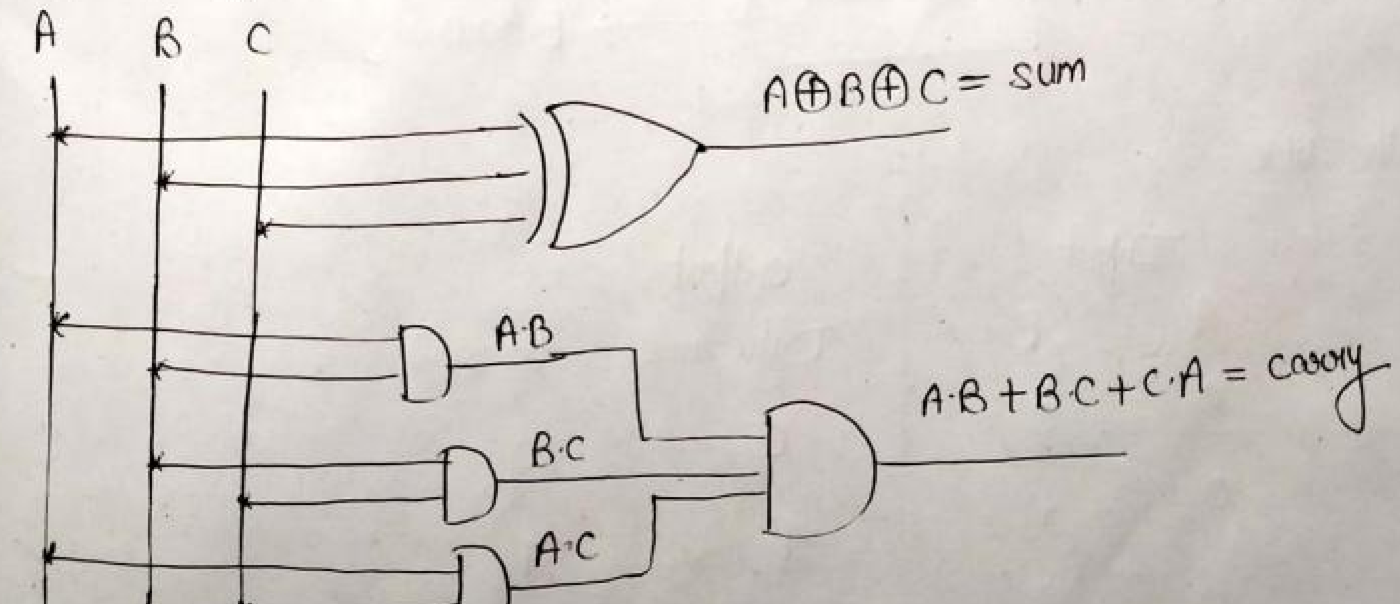
$(\because \bar{A}X + A\bar{X} = A\oplus$

K map for carry output-

A \ BC	$\bar{B}\bar{C}$ 00	$\bar{B}C$ 01	BC 11	$B\bar{C}$ 10
$\bar{A}$ 0			1	
A 1		1	1	1

$$Carry = AB + BC + CA$$

Logic Diagram



Unit 3 : Sequential Circuit

Lesson 1 : Sequential Logic Circuit

1.1. Learning Objectives

On completion of this lesson you will be able to :

- define sequential circuit
- know the different types of sequential circuit
- understand clock and its classification
- know about flip-flop and latches.

1.2. Sequential Circuits

In sequential logic circuit, "the present values of outputs are dependent on both present values of the inputs and the past values of inputs.

We already know that the combinational circuits implements the essential functions of a digital computer. *"A circuit known as combinational as long as its steady state outputs depend only on its current inputs".* In these circuits, there is no ability to retain the information regarding the state of the circuit and any prior input level conditions have no effect on the present outputs because they provide no memory. So for the later purposes, sequential circuit is used. *In sequential logic circuit, the present values of outputs are dependent on both present values of the inputs and the past values of inputs.* A sequential logic circuit consist of two parts.

- *the memory elements* i.e. flip-flop which is made up of an assembly of logic gates.
- *the combinational logic circuits* needed to produce the excitation inputs to the memory elements and to produce the required outputs.

Sequential circuits find wide application in digital systems as counters, registers, control logic, memories and other complex functions.

Examples,

- The elevator control.
- The traffic light system.
- automatic lock - which remember the combination of numbers and also their sequence.

Basic Block

A general model of a sequential circuit is shown in the following Fig.3.1.

Output depends on present state and input.

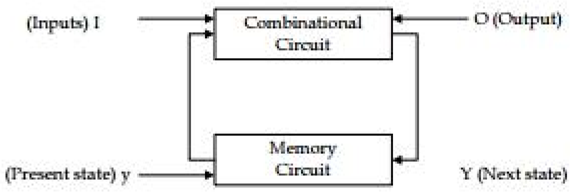


Fig. 3.1 : Block diagram of sequential circuit logic.

So, from the block diagram, we can find.

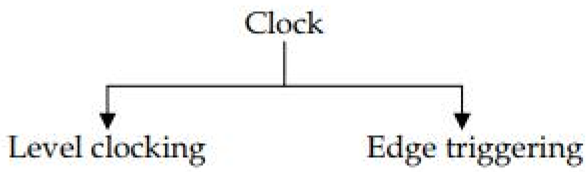
Output depends on present state and input i.e.

output O = f (I, y)
next state Y = f (I, y)
present state y = f (Y)

1.3. Clock

Clock is periodic sequence of pulses. Clock can be classified as level clocking and edge triggering.

Clock is periodic sequence of pulses.



Purposes

The purposes of clock is to synchronize the over-all action and to prevent the flip-flop from changing states until the right time.

a) ***Level clocking :*** The Flip-flop responds to the level (high or low) of the clock signal. Level clocking is of two types.

i) positive clocking

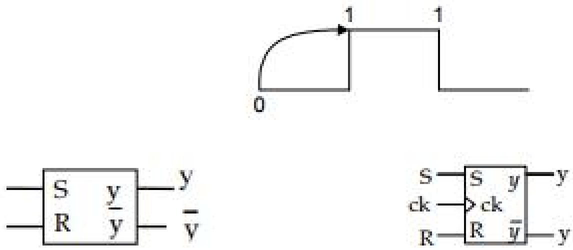


Fig. 3.2(a) : Basic block of latch (SR).

ii) negative clocking

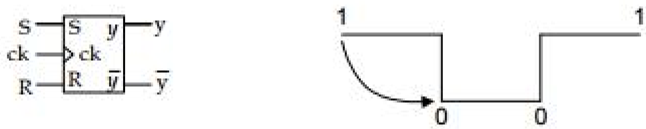


Fig. 3.2 (b) : negative clocking.

b) ***Edge Triggering :*** The flip-flop responds only on the rising or falling edge of the clock. Edge triggering is of two types. These are as follows :

The flip-flop responds only on the rising or falling edge of the clock.

i) positive edge triggering

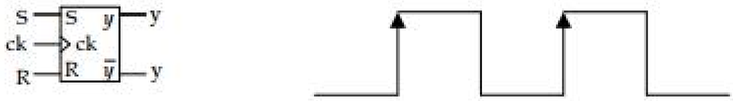


Fig. 3.3 (a) : positive edge triggering.

ii) negative edge or falling (trailing edge)

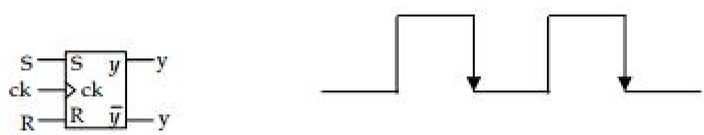


Fig. 3.3 (b) : negative edge triggering.

1.4. Types of Sequential Logic Circuits

Depending upon the timing of sequential circuit signal, the sequential logic circuits can be divided into two classes.

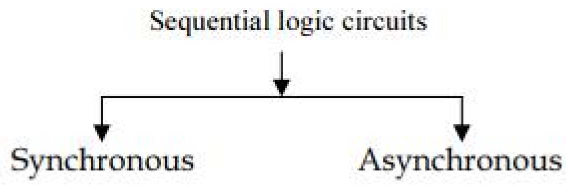


Fig. 3.4: Classes of sequential logic circuits.

Synchronous Sequential Circuits

> *A synchronous sequential circuits is one in which the contents of the memory can change only at discrete instants time or on the of transitions of a clock.*

A synchronous sequential circuits is one in which the contents of the memory can change only at discrete instants time or on the of transitions of a clock. Since all the circuit action will take place under the control of a clock, so these circuits are known as clocked sequential circuit.

Advantage

They are easier to troubleshoot and design because its outputs can change only at specific instants of time i.e. every thing is synchronized to the clock signal transition.

Asynchronous Sequential Logic Circuits

> *An asynchronous sequential logic circuits is one whose outputs can change state at any instant of time with the change of one or more of the inputs.*

An asynchronous sequential logic circuits is one whose outputs can change state at any instant of time with the change of one or more of the inputs. The memory elements used in these systems are delay type memory elements. It can be regarded as combinational circuit with feed back.

Disadvantage

It is difficult to design and troubleshoot and used only for simple configuration.

1.5. Flip-flops (FF)

A FF is an electronic device that has two stable states. One state is assigned the logic 1 value and the other is the logic 0. In other words, the memory elements used in sequential circuits are the flip flop. These circuits are binary cells capable of storing one bit of information.

Latch

> *A latch is a bistable circuit that is the fundamental building block of a flip-flop.*

A latch is a bistable circuit that is the fundamental building block of a flip-flop. It exists in one of the two states (e.g. 1 and 0), and in the absence of the input, it remains in that state. It has two output y and $\bar{y}$.

The following Fig. 3.5 illustrate a simple FF or 1 bit memory (i.e. it can store one bit of information y = 0 or y = 1) and since this information is locked or latched so, this FF is known as a latch.

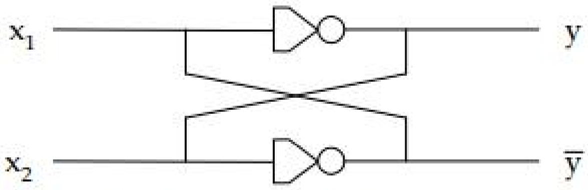


Fig. 3.5 : Simple FF or latch.

1.6. Exercise

1.6.1. Multiple choice questions

a) In sequential logic circuit the present values of outputs are dependent on

i) past values of input
ii) present values of input
iii) both present values of the inputs and the past values of inputs
iv) none of them.

b) The purpose of clock is to

i) synchronize the overall action and to prevent the FF from changing state until the right time
ii) synchronize the overall action
iii) respond the clock signal
iv) none of the above.

c) In synchronous sequential logic circuit, contents of the memory can change

i) only at discrete instants of time
ii) at any instant of time
iii) continuously
iv) none of the above.

1.6.2. Questions of short answers

a) What do you mean by sequential logic circuit and combinatioal logic circuits?
b) What do you mean by latch and FF?
c) What are the main differences between synchronous and asynchronous sequential logic circuit?

d) List some of the advantages of synchronous sequential logic circuit and disadvantages of asynchronous sequential logic circuit?

e) Distinguish between combinational and sequential Logic Circuit?

1.6.3. Analytical questions

a) i) What is clock? Describe different types of clock? ii) What is the purpose of clock signal?

b) How many types of sequential logic circuits? Describe briefly.

Lesson 2 : SR (Set - Reset) Flip-Flop

2.1. Learning Objectives

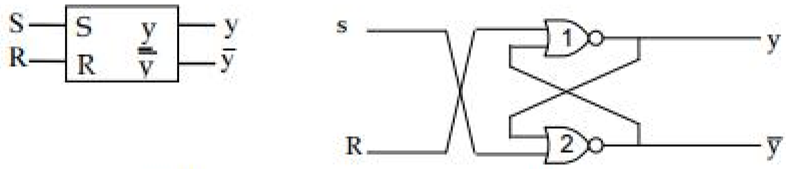
On completion of this lesson, you will be able to :

- understand the design and working principle of S-R flip-flop
- understand the design and working principle of clocked S-R flip-flop.

2.2. S-R FF

S-R flip-flop. The circuit as two input Set (S) and Reset (R) and two outputs.

The following Fig. 3.6(a) is known as S-R flip-flop. The circuit as two input Set (S) and Reset (R) and two outputs. As the starting point, assume that S=0, R=0 and y=0. The input to the gate 2 are R=0, $\bar{y}$=0, so output y = 1. The inputs to gate1 are S=0, $\bar{y}$=1, which has the output $\bar{y}$= 0. Now the state of the circuit is internally consistent and remains stable as long as S=R=0.



(a) (b)

Fig. 3.6(a) : Symbol of S-R FF. Fig. 3.6(b) : S-R FF using NOR gate.

At time t_1, if S goes to 1 i.e. inputs to the gate 2 are S=1, y=0, then after a delay of Δt_2, the output of gate 2 will $\bar{y}$=0. At this point, the input to the gate 1 become R=0, $\bar{y}$=0 and after another delay Δt_1, the output of gate 1 will be y=1. This condition is stable and FF is said to be Set. If S goes to 0, the output will remain y=1, $\bar{y}$=0 i.e. unchanged. When R goes to 1 and while S=0, it forces y=0 and y=1 and the circuit is said to be Reset. So, this flip-flop is called Set (S) Reset (R) flip-flop. The input combination S=R=1 is an indeterminate condition which gives y= $\bar{y}$=0 and is not allowed. The S-R FF can be defined with a truth table called transition table for the various input combinations and denoting present state by y and next state by $\bar{y}$. (Fig. 3.6). An equation describing the relationship for the next state in terms of present inputs and present states of the FF is known as characteristics equation of the FF. The characteristics equation can be got by its K-map (Fig. 3.6(c) using transition table (Fig. 3.6(e). The equation is

$Y = S + \bar{R}y$

SR \ y	0	1
00	0	1
01	0	0
11	x	x
10	1	1

$Y = S + \bar{R}y$

Fig. 3.6(c) : K-map.

The SR FF Circuit using *Nand* Gate

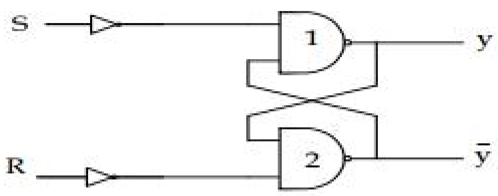


Fig. 3.6(d) : SR FF using NAND gates.

SR FF using NAND gates.

S	R	y	Y
0	0	0	0
0	0	1	1
0	1	0	0
0	1	1	0
1	0	0	1
1	0	1	1
1	1	0	X
1	1	1	X

Transition Table

→

S	R	Y	(output)
0	0	y	(no change)
0	1	0	
1	0	1	
1	1	X	(indeterminate)

Simplified Transition Table

Fig. 3.6(e) : Transition Table for S-R FF.

2.3. Clocked S-R FF

The FFs that we have discussed before are asynchronous S-R FF, because the output changes after a brief time delay in response to a change in the input. As the events in the digital computer are synchronized to a clock pulses, so it is required to set or reset a FF in synchronism with clock pulses i.e. changes occur only when a clock pulse occurs. This is done by adding two inputs NAND gates (gate 3 and gate 4 in the Fig. 3.6(g)) with the clock pulse to the inputs of the asynchronous S-R FF as shown in Fig 3.6(g). In order to operate these devices effectively, the following conditions must be met:

- The FF inputs should be allowed to change only when CK =0.
- The clock input should stay long enough time so that the outputs will be able to reach steady state.
- The condition S=R=1 must not be allowed to occur when CK=1.

Note : The circuit action can occur only when CK=1, when CK=0, the FF outputs do not change.

Logic symbol and NAND gate circuit.

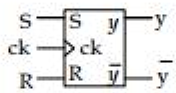


Fig. 3.6(f) : Logic symbol.

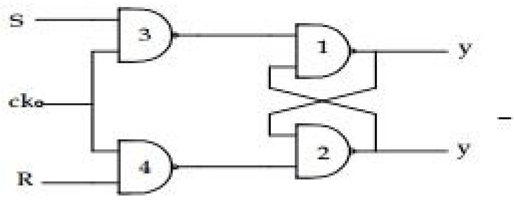


Fig. 3.6(g) : NAND gate circuit.

Input			Output	
CK	S	R	Mode	Y
O	-	-	No action	y
∏	0	0	Hold	y
∏	0	1	Reset	0
∏	1	0	Set	1
∏	1	1	Invalid	-

Fig. 3.6(h) : Truth Table for clocked S-R FF.

2.4. Exercise

2.4.1. Multiple choice questions

a) Which one of following statement in true?

i) In synchronous S-R FF, the output changes after a brief time delay in response to a change in the input.

ii) In asynchronous S-R FF time delay in response to a change in the input.

iii) The clocked S-R FF outputs should be allowed to change only when CK = 1.

iv) none of the above.

b) Which one is the true statement?

i) When S = R = 0, output is unchanged
ii) When S = 0, R = 1, then output is 1
iii) When S = 1, R = 1, then output is 1
iv) When S = 1, R = 0, then output is indeterminate condition.

2.4.2. Questions of short answers

a) Why is the S-R FF called Set-Reset FF? Deduce the transition table for the S-R FF.
b) What do you mean by characteristic equation? Write K-map of S-R FF and characteristics equation.
c) What are the conditions that must be met in clocked S-R FF?
d) Deduce the restrictions which must be imposed upon the inputs S and R for correct operation of the bistable.

2.4.3. Analytical questions

a) Draw S-R FF using NAND gate, explain its operation.
b) What will be the state of y and $\bar{y}$ after FF has been cleared?
c) Draw S-R FF using NOR and explains its operation.

Lesson 3 : J-K Flip-Flop

3.1. Learning Objectives

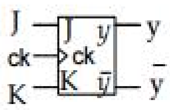
On completion of this lesson, you will be able to :

- understand the design and working principle of J-K FF
- describe race around condition
- know how can race around condition can be avoided
- illustrate master-slave J-K FF.

3.2. J-K Flip-flop

Refined FF is known as the JK FF.

We saw that the clock SR FF has an indeterminate state when S=R=1. When using clocked SR FFs the designer is required to be cautious about the FF inputs. This troublesome restrictions S=R=1 can be removed by modifying the SR FF. This refined FF is known as the JK FF. This modifications involves feeding the outputs of the FF back into the inputs of circuit shown in Fig. 3.7(b). The J input alone performs *set* function causing the output (next state) to be 1. The K input alone performs *reset* function causing the output (next state) to be 0. When both J and K are 1, the next state of the FF is the complement of the present state i.e. output (next state) is reversed. When J=K=0, then output is unchanged. The block diagram, FF circuit, transition table and K map of JK FF are shown in the following (Fig. 3.7(a), 3.7(b), 3.7© and 3.7(d).



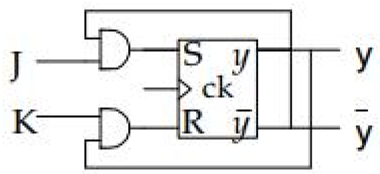


Fig. 3.7(a) : logic symbol. Fig. 3.7(b) : Modification of S-R into J-K FF.

J	K	y	Y
0	0	0	0
0	0	1	1
0	1	0	0
0	1	1	0
1	0	0	1
1	0	1	1
1	1	0	1
1	1	1	0

→

J	K	Y	
0	0	y	(Hold)
0	1	0	Reset
1	0	1	Set
1	1	$\bar{y}$	Toggle (complements)

Simplified Transition Table

Fig. 3.7© : Transition Table.

JK \ Y	0	1
00	0	1
01	0	0
11	1	0
10	1	1

Fig. 3.7(d) : K - map of J-K FF.

$Y = J\,\bar{y} + \bar{K}y$ is the characteristic equation of JK.

3.3. Characteristic Equation of JK from Characteristic Equation of S-R FF

We know that characteristic equation of S-R FF is $Y = S + \bar{R}y$.

Substitute $S = J\,\bar{y}$ and $R = Ky$

Characteristic equation of S-R FF.

$Y = J\,\bar{y} + \overline{Ky}.y$

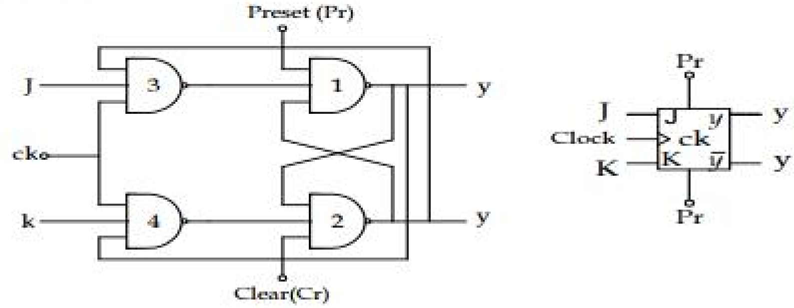
$= J\,\bar{y} + (\bar{K} + \bar{y}).y$ (from Demorgan law $\overline{x_2x_1} = \bar{x}_1 + \bar{x}_2$)

$= J\,\bar{y} + \bar{K}y + \bar{y}.y$

$= J\,\bar{y} + \bar{K}y + 0$ (Because $\bar{y}.y = 0$)

$\therefore Y = J\,\bar{y} + \bar{K}y$. This is the characteristics equation of J-K FF.

So, J-K FF can be constructed out of S-R FF and two NAND gates as shown in Fig. 3.7(e).



(e)

Fig. 3.7(e) : Logic circuit of J-K flip-flop.

The initial state of the flip-flop can be assigned by addition of two inputs namely preset and clear.

The initial state of the flip-flop can be assigned by addition of two inputs namely preset and clear as shown in Fig. 3.7(e) allows the initial state of the flip-flop to be assigned. The flip-flop can be cleared by setting C_r=0, P_r=1, C_k=0, as the output of gate 2 becomes 1 and the flip-flop can be preset with P_r=0, C_r=1, C_k=0. The FF can be enabled with P_r=1, C_r=1.

These inputs are called asynchronous inputs, and are not in synchronism with the clock and may be applied any time in between clock pulses.

3.4. Exercises

3.4.1. Multiple choice question

a) Which one of the following statement is true?

i) The K input alone performs Reset function.
ii) The K input alone performs Reset function causing the output to be 0.
iii) The J input alone performs Reset function.
iv) None of the above.

3.4.2. Question for short answers

a) Why J-K FF used?
b) What are the modification of S-R FF ? Illustrate with diagram.
c) Describe the working principle of J-K FF.
d) Draw the circuit diagram of J-K FF.
e) How can characteristic equation of J-K FF be got from that of S-R FF?

3.4.3. Analytical question

a) What is master slave J-K FF? Illustrate its operation.

Lesson 4 : D Flip Flop and T Flip Flop

4.1. Learning Objectives

On completion of this lesson, you will be able to :

- understand the design and working principle of D FF
- understand the design and working principle of T FF
- conversion of D from T and T from D.

4.2. D Flip Flop

The following Fig. 3.8(a) is the D Flip-flop.

The delay flip-flop or D flip-flop.

The delay flip-flop or D flip-flop Fig. 3.8(a) which gives a unit time delay between the input and output. The input is transferred to the output at the next clock pulse. The symbol, transition table and the K-map for D-type flip-flop are shown in Fig. 3.8(a), Fig. © and Fig. (d) respectively. The next state of the D-type flip-flop is given by

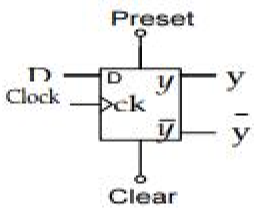


Fig. : 3.8(a) : Symbol.

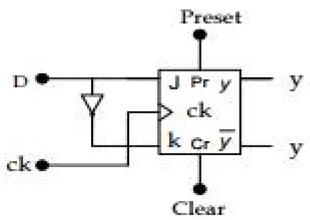


Fig. : 3.8(b) : J-K to D conversion.

D	y	Y
0	0	0
0	1	0
1	0	1
1	1	1

D	Y
0	0
1	1

Y=D

y \ d	0	1
0	0	1
1	0	1

Y=D

Fig. 3.8© : Transition table. Fig. 3.8(d) : K-map.

D From J-K FF

A D-type flip-flop can be constructed from a J-K flip-flop by putting J = D and K = $\bar{D}$ in equation Y = J $\bar{y}$+ $\bar{K}$y.
we can get

$$Y = D\bar{Y} + \bar{\bar{D}}$$
$$= D\bar{Y} + DY$$

$= D(\bar{y} + y)$
$= D.1$ (Because y + y = 1)
$= D.$

4.3. The T Flip-Flop

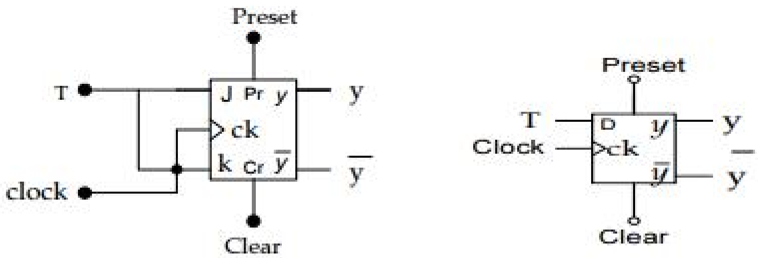
T flip-flop or trigger flip-flop has a single input terminal.

The T flip-flop or trigger flip-flop has a single input terminal. When a clock pulse appears at its input, the state of the T flip-flop is complemented each time irrespective of the present state. Fig. 3.9(b), Fig.3.9(c) and Fig. 3.9(d) represent the symbol, transition table and K-map of the T flip-flop, the characteristic equation of the T flip-flop is given by

$$Y = T\bar{y} + \bar{T}y$$

The T flip-flop can be obtained from a J-K flip-flop when both the inputs are connected together as shown in Fig. 3.9(a).

The T flip-flop can be obtained from a J-K flip-flop when both the inputs are connected together.



(a) (b)

T	y	Y	
0	0	0	] Unchanged
0	1	1	0
1	0	1	] ← Toggle
1	1	0	

(c)

y \ T	0	1
0	0	0
1	1	1

Y=D (d)

$Y = T\bar{y} + \bar{T}y$
$= T \oplus y$

Fig. 3.9 : T flip-flop; (a) J-K to T conversion, (b) Symbol of T flip-flop, (c) Transition table, (d) K-map.

4.4. Excitation Requirements of Flip-flops

One of the problems in the synthesis of sequential circuits is to find the inputs to the flip-flop for effecting a specified change in its state. All the possible changes in state and the corresponding excitation requirements for various FFs are given in the following excitation requirement table.

Data Transmission in Shift Registers

A number of FFs connected together such that data may be shifted into and shifted out of them is called a *shift register*. Data may be shifted into or out of the register either in serial form or in parallel form. So, there are four basic types of shift registers: serial-in, serial-out; serial-in, parallel-out; parallel-in, serial-out; and parallel-in, parallel-out. The process of data shifting in these registers is illustrated in Figure 6.53. All of these configurations are commercially available as TTL MSI/LSI circuits. Data may be rotated left or right. Data may be shifted from left to right or right to left at will, i.e. in a bidirectional way. Also, data may be shifted in serially (in either way) or in parallel and shifted out serially (in either way) or in parallel.

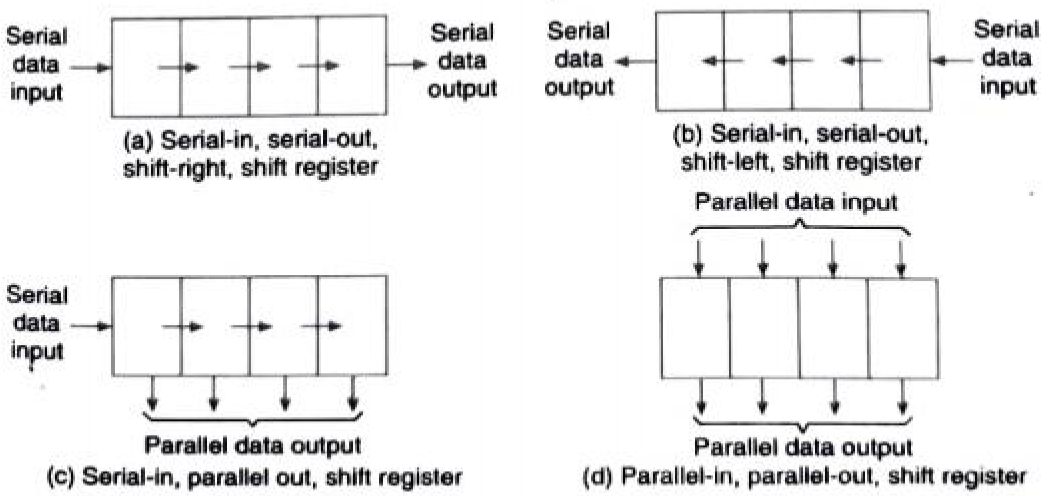
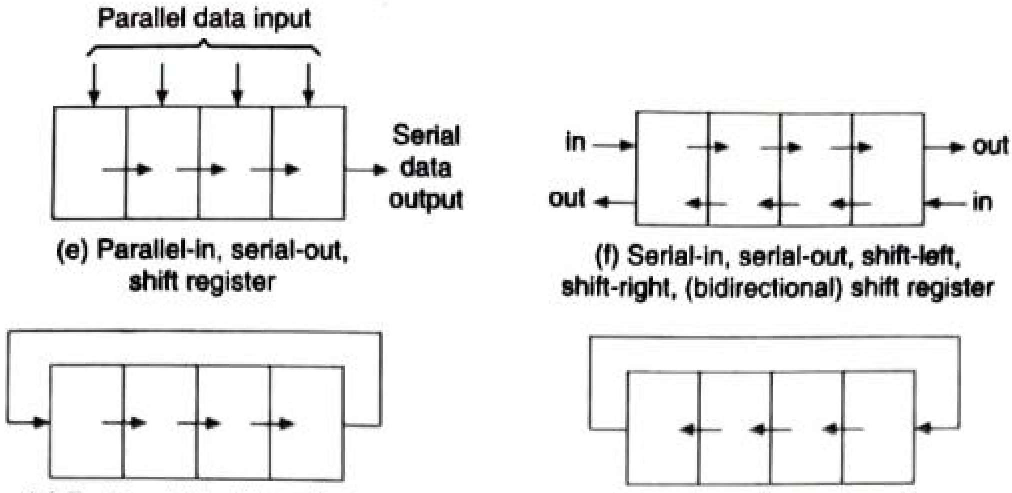


Figure 6.53 Data transfer in registers *(Contd.)*



(e) Parallel-in, serial-out, shift register

(f) Serial-in, serial-out, shift-left, shift-right, (bidirectional) shift register

(g) Rotate-right shift register

(h) Rotate-left shift register

Figure 6.53 Data transfer in registers.

Serial-in, Serial-out, Shift Register

This type of shift register accepts data serially, i.e. one bit at a time, and also outputs data serially.

The logic diagram of a 4-bit serial-in, serial-out, shift-right, shift register is shown in Figure 6.54. With four stages, i.e. four FFs, the register can store upto four bits of data. Serial data is applied at the D input of the first FF. The Q output of the first FF is connected to the D input of the second FF, the Q output of the second FF is connected to the D input of the third FF and the Q output of the third FF is connected to the D input of the fourth FF. The data is outputted from the Q terminal of the last FF.

When serial data is transferred into a register, each new bit is clocked into the first FF at the positive-going edge of each clock pulse. The bit that was previously stored by the first FF is transferred to the second FF. The bit that was stored by the second FF is transferred to the third FF, and so on. The bit that was stored by the last FF is shifted out.

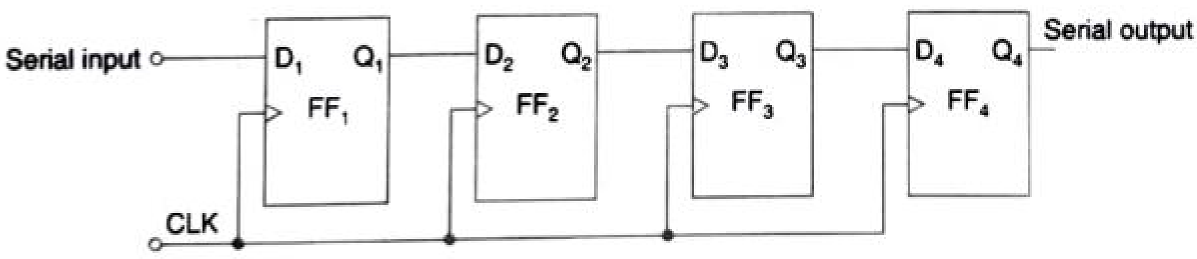
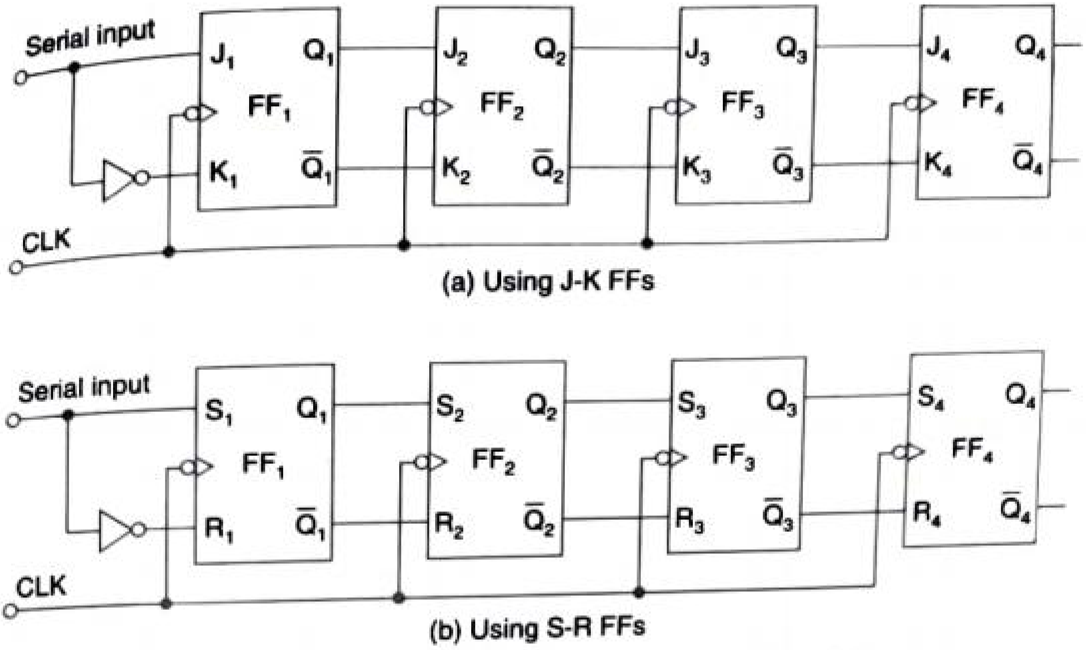


Figure 6.54 4-bit serial-in, serial-out, shift-right, shift register.

A shift register can also be constructed using J-K FFs or S-R FFs as shown in Figures 6.55a and 6.55b, respectively. The data is applied at the J(S) input of the first FF. The complement of this is fed to the K(R) terminal of the first FF. The Q output of the first FF is connected to J(S) input of the second FF, the Q output of the second FF to J(S) input of the third FF, and so on. Also, $\bar{Q}_1$ is connected to K_2 (R_2), $\bar{Q}_2$ is connected to K_3 (R_3), and so on.

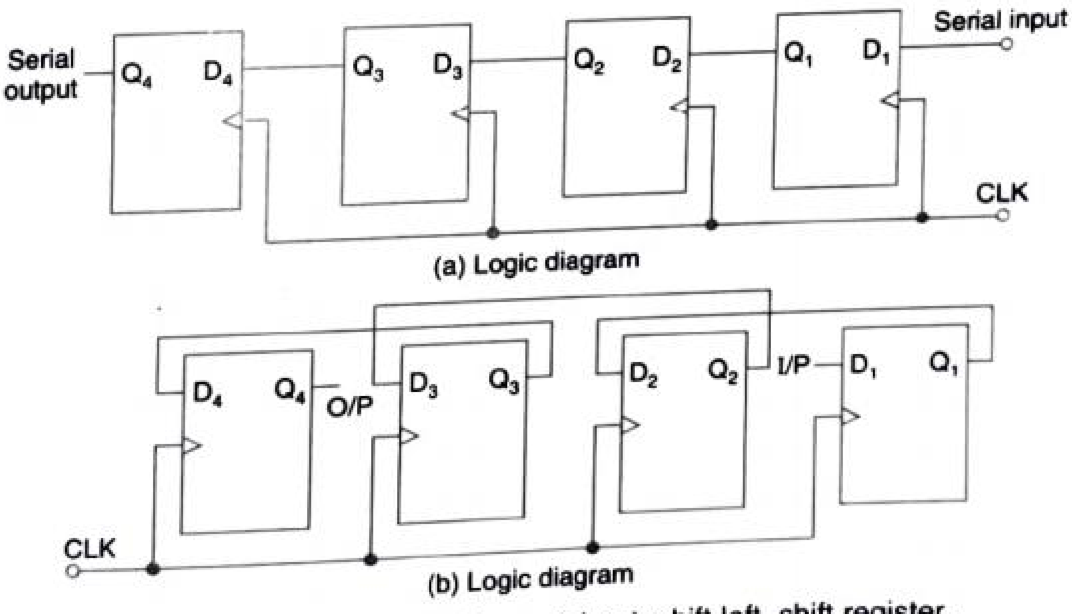


(a) Using J-K FFs

(b) Using S-R FFs

Figure 6.55 A 4-bit serial-in, serial-out, shift register.

Figure 6.56 shows the logic diagrams of a 4-bit serial-in, serial-out, shift-left, shift register.



(a) Logic diagram

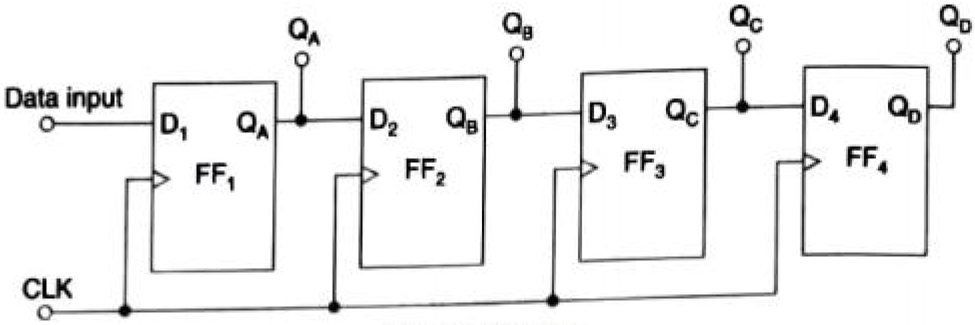
(b) Logic diagram

Figure 6.56 A 4-bit serial-in, serial-out, shift-left, shift register.

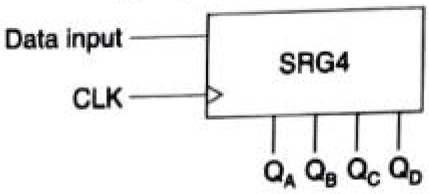
Serial-in, Parallel-out, Shift Register

Figure 6.57 shows the logic diagram and the logic symbol of a 4-bit serial-in, parallel-out, shift register. In this type of register, the data bits are entered into the register serially, but the data stored in the register is shifted out in parallel form.

Once the data bits are stored, each bit appears on its respective output line and all bits are available simultaneously, rather than on a bit-by-bit basis as with the serial output. The serial-in, parallel-out, shift register can be used as a serial-in, serial-out, shift register if the output is taken from the Q terminal of the last FF.



(a) Logic diagram



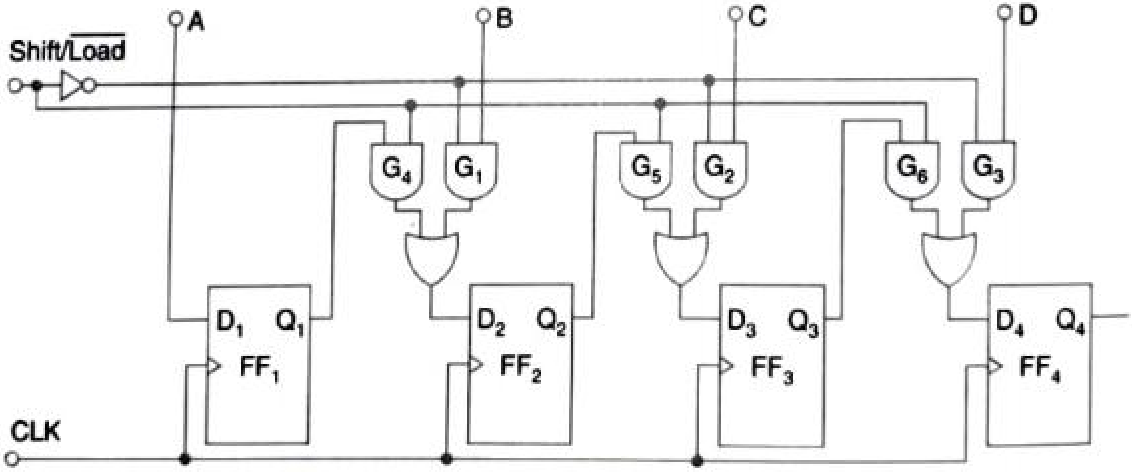
(b) Logic symbol

Figure 6.57 A 4-bit serial-in, parallel-out, shift register.

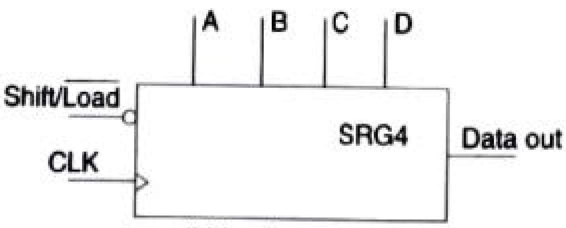
Parallel-in, Serial-out, Shift Register

For a parallel-in, serial-out, shift register, the data bits are entered simultaneously into their respective stages on parallel lines, rather than on a bit-by-bit basis on one line as with serial data inputs, but the data bits are transferred out of the register serially, i.e. on a bit-by-bit basis over a single line.

Figure 6.58 illustrates a 4-bit parallel-in, serial-out, shift register using D FFs. There are four data lines A, B, C, and D through which the data is entered into the register in parallel form. The signal Shift/$\overline{\text{LOAD}}$ allows (a) the data to be entered in parallel form into the register and (b) the data to be shifted out serially from terminal Q_4.



(a) Logic diagram



(b) Logic symbol

Figure 6.58 A 4-bit parallel-in, serial-out, shift register.

When Shift/$\overline{LOAD}$ line is HIGH, gates G_1, G_2, and G_3 are disabled, but gates G_4, G_5, and G_6 are enabled allowing the data bits to shift-right from one stage to the next. When Shift/$\overline{LOAD}$ line is LOW, gates G_4, G_5, and G_6 are disabled, whereas gates G_1, G_2, and G_3 are enabled allowing the data input to appear at the D inputs of the respective FFs. When a clock pulse is applied, these data bits are shifted to the Q output terminals of the FFs and, therefore, data is inputted in one step. The OR gate allows either the normal shifting operation or the parallel data entry depending on which AND gates are enabled by the level on the Shift/$\overline{LOAD}$ input.

Parallel-in, Parallel-out, Shift Register

In a parallel-in, parallel-out, shift register, the data is entered into the register in parallel form, and also the data is taken out of the register in parallel form. Immediately following the simultaneous entry of all data bits, the bits appear on the parallel outputs.

Figure 6.59 shows a 4-bit parallel-in, parallel-out, shift register using D FFs. Data is applied to the D input terminals of the FFs. When a clock pulse is applied, at the positive-going edge of that pulse, the D inputs are shifted into the Q outputs of the FFs. The register now stores the data. The stored data is available instantaneously for shifting out in parallel form.

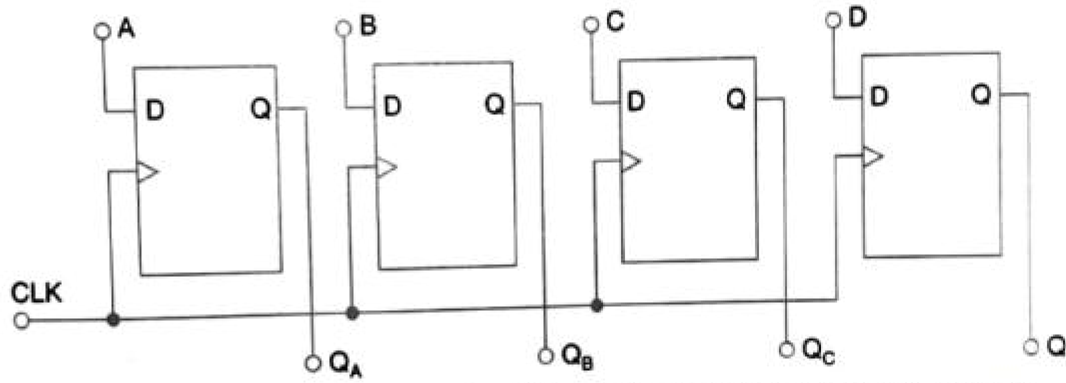
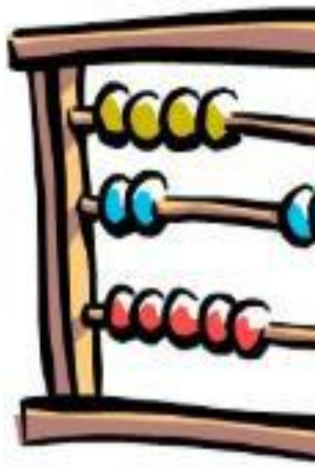


Figure 6.59 Logic diagram of a 4-bit parallel-in, parallel-out, shift register.

Index

- What are counters
- Ripple (Asynchronous Counters)
  - Full Sequence
  - Truncated
- Synchronous Counters



Counters

- Counters are sequential logic circuits that procee
through a well defined sequence of states after
application of clock pulses.
- Special type of registers with a capability of co
with the application of clock pulse
- Counters are used for a counting pulses
- Counters are constructed using Flipflops and log
- Counters are classified into two categories
  - Ripple (or Asynchronous) Counters
  - Synchronous Counters

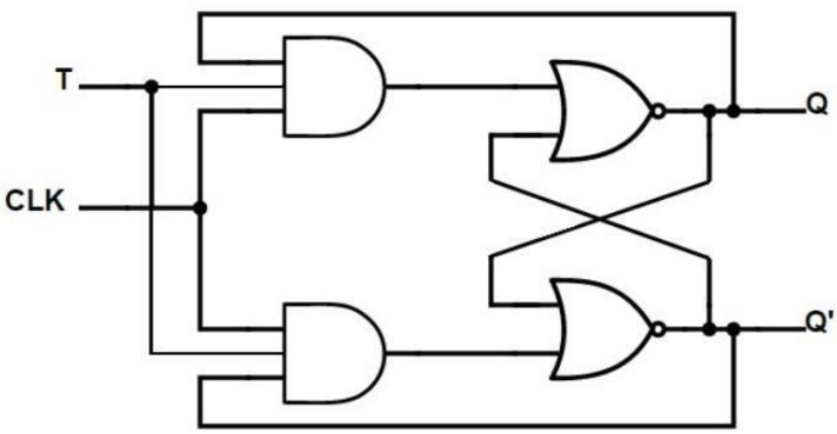
Ripple Counters (Asynchronous Counters)

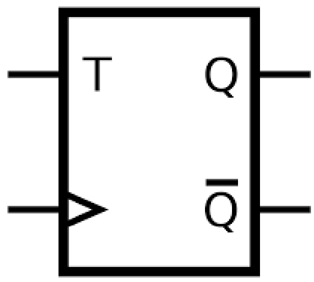
- Clock connected to the flip-flop clock input on the LSB bit flip-flop
- For all other bits, a flip-flop output is connected to the clock input, thus circuit is not truly synchronous!
- Output change is delayed more for each bit toward the MSB.
- An n-bit **Asynchronous counter** can have 2^n possible counting states e.g. MOD-8 for a 3-bit counter have (0-7) states

- But it is also possible to use the basic asynchrono counter configuration to construct special counte counting states less than their maximum output nu
- This is achieved by forcing the counter to reset it zero at a pre-determined value producing a typ asynchronous counter that has truncated sequen
- Then an n-bit counter that counts up to its maxim modulus (2^n) is called a **full sequence counter** n-bit counter whose modulus is less than the max possible is called a **truncated counter**.

Recap

- **T Flip flop**

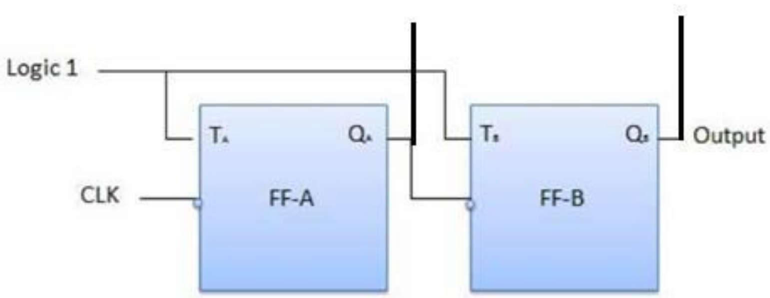




Clk	T	Q(t+1)	
0	X	Q(t)	No ch
0→1	0	Q(t)	No ch
1→1	1	Q'(t)	Comp

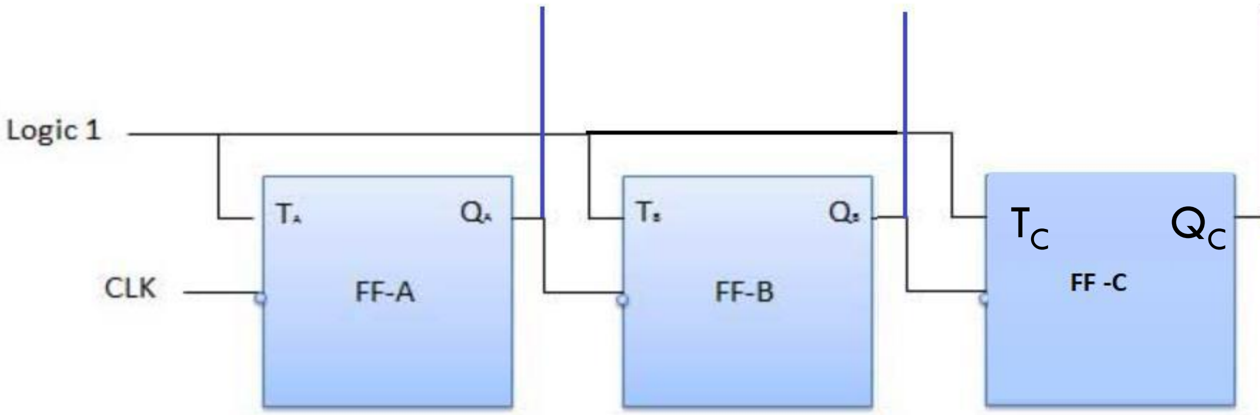
2-bit Ripple Up Counter (MOD

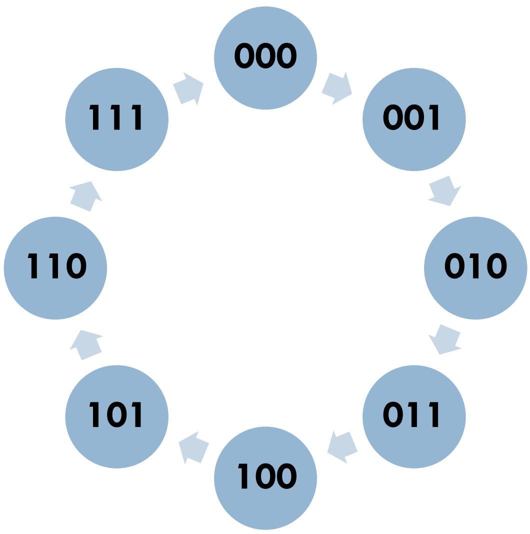
- The toggle (T) flip-flop are being used. But we c the JK flip-flop also with J and K connected permanently to logic 1. External clock is appliec clock input of flip-flop A and Q_A output is applie the clock input of the next flip-flop i.e. FF-B.



Clock	Counter output		State number	C
	Q_B	Q_A		
Initially	0	0	—	
1st	0	1	1	
2nd	1	0	2	
3rd	1	1	3	
4th	0	0	4	

3-bit Ripple Up Counter (MOD



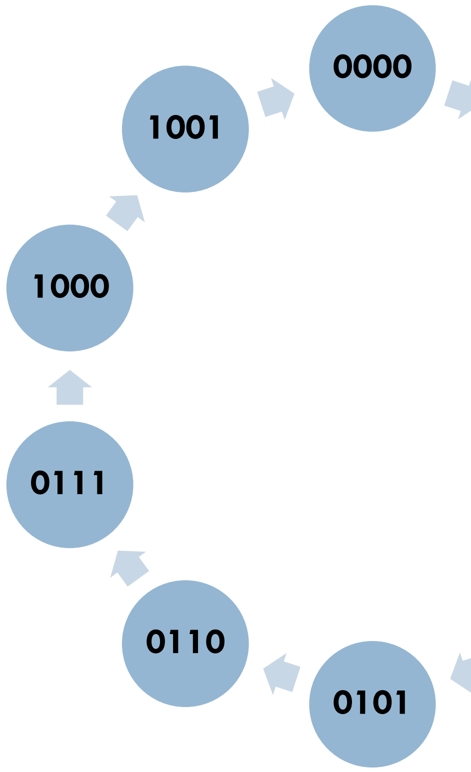


Exercise 1

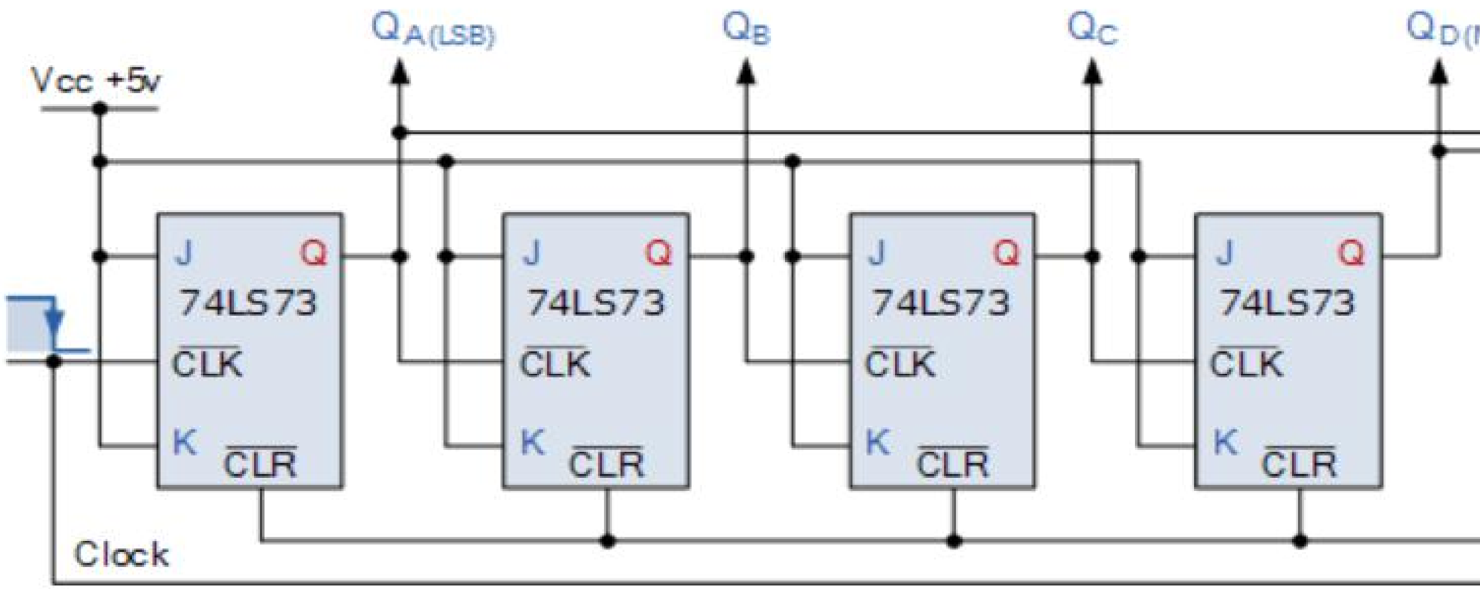
- A) Design and explain MOD-16 Asynchronou counter.
- B) Design and explain MOD-16 Asynchronou counter using D Flipflops

Ripple Counter (Truncated) Decade Counter

- **Decade Counter (MOD-10)**
- Also called BCD counter
- For a counter to count from 0000 to 1001, four flip flops are required. But we need to mechanism to restrict the count to 1001 and thereafter reset the counter to 0000 again otherwise our counter (with 4 flip flops) will continue to 1111 making it MOD-16 counter instead of MOD-10.



Decade Counter



https://www.electronics-tutorials.ws/counter/count_2.html

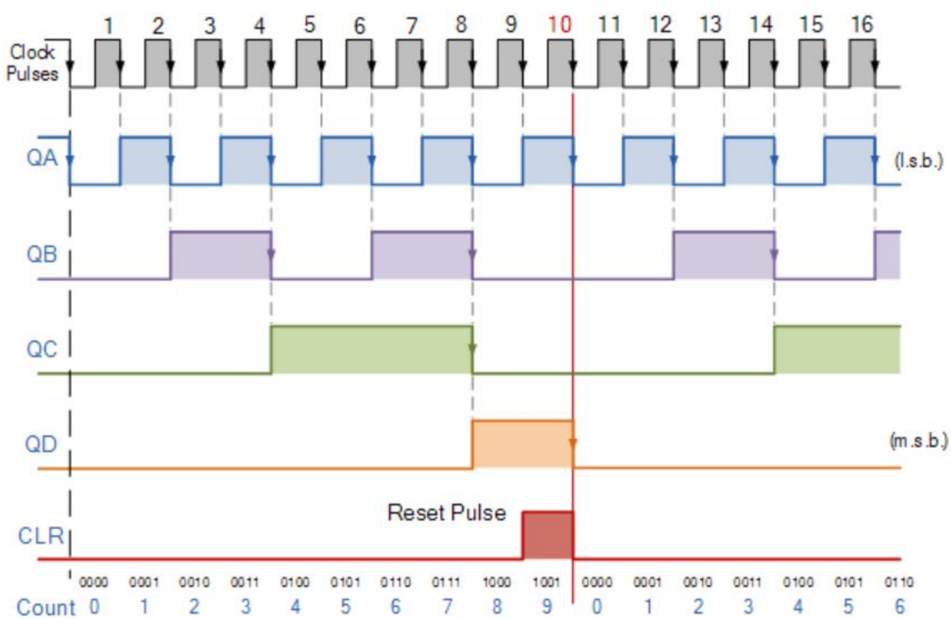
- This type of asynchronous counter counts upwards on each trailing ed input clock signal starting from 0000 until it reaches an output 1001 9). Both outputs QA and QD are now equal to logic "1". On the appl of the next clock pulse, the output from the 74LS10 NAND gate chan from logic "1" to a logic "0" level.

Decade Counter

- As the output of the NAND gate is connected CLEAR (CLR) inputs of all the 74LS73 J-K Fli flops, this signal causes all of the Q outputs t reset back to binary 0000 on the count of 1(

- As outputs QA and QD are now both equal t "0" as the flip-flop's have just been reset, the of the NAND gate returns back to a logic lev and the counter restarts again from 0000. W have a decade or Modulo-10 up-counter.

Decade Counter

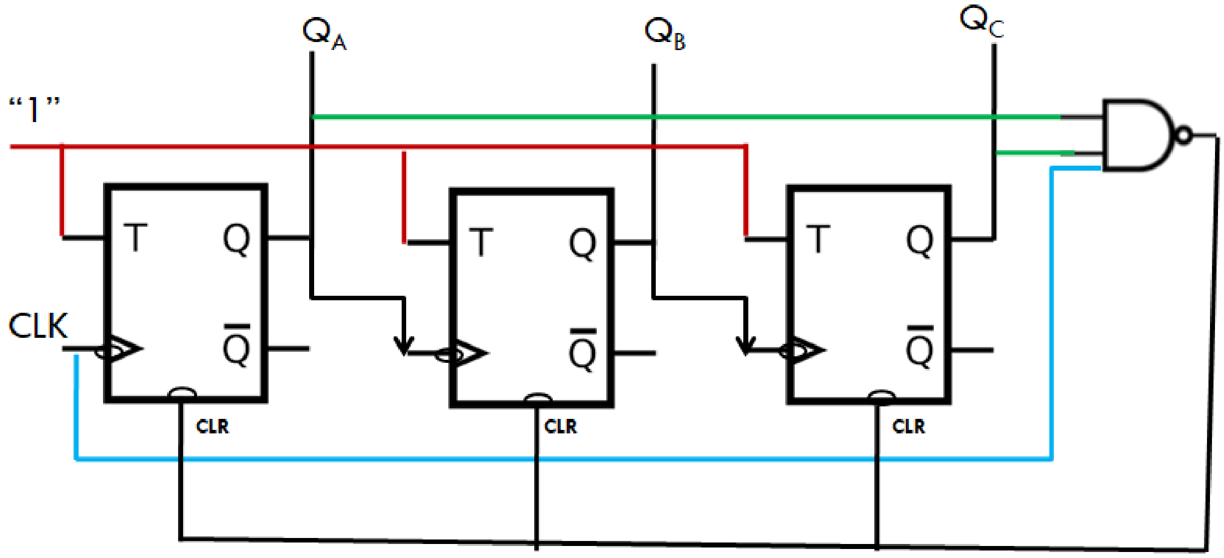


Clock Count	Output bit Pattern		
	QD	QC	QB
1	0	0	0
2	0	0	0
3	0	0	1
4	0	0	1
5	0	1	0
6	0	1	0
7	0	1	1
8	0	1	1
9	1	0	0
10	1	0	0
11	Counter Resets its Outputs		

- By using the same idea of truncating counter sequences, the above circuit could easily be adapted to other counting cycles be simply changing the connections to the inputs of the NAND gate or by using other logic gate combinations.

MOD-6 Asynchronous Up Coun

- MOD 6 asynchronous counter will require 3 flip flops and will count from 000 to 101.

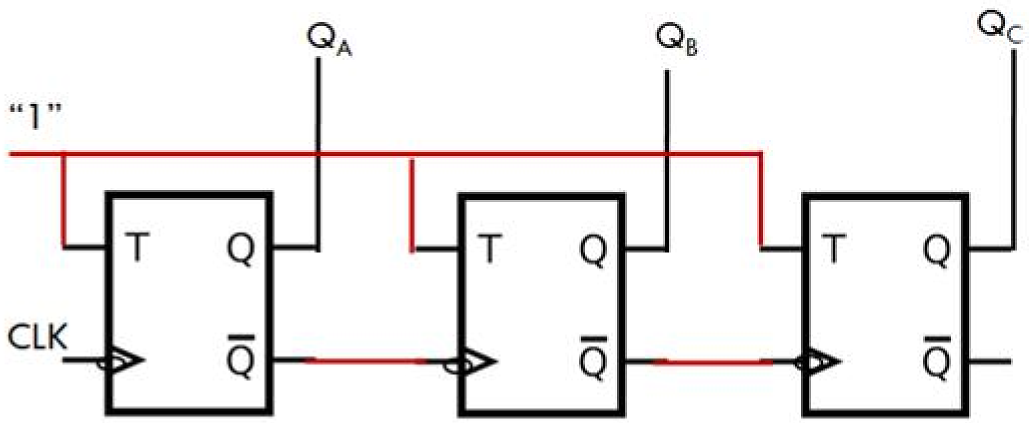


Q_C
0
0
0
0
1
1

- Once the Counter reaches 101, next positive ed the clock will make all three inputs of NAND gat and will set its output to 0 which is connected to all the flipflops thereby forcing all the flipflops t to 0. With the result counter is reset to 000.

Asynchronous Down Counter

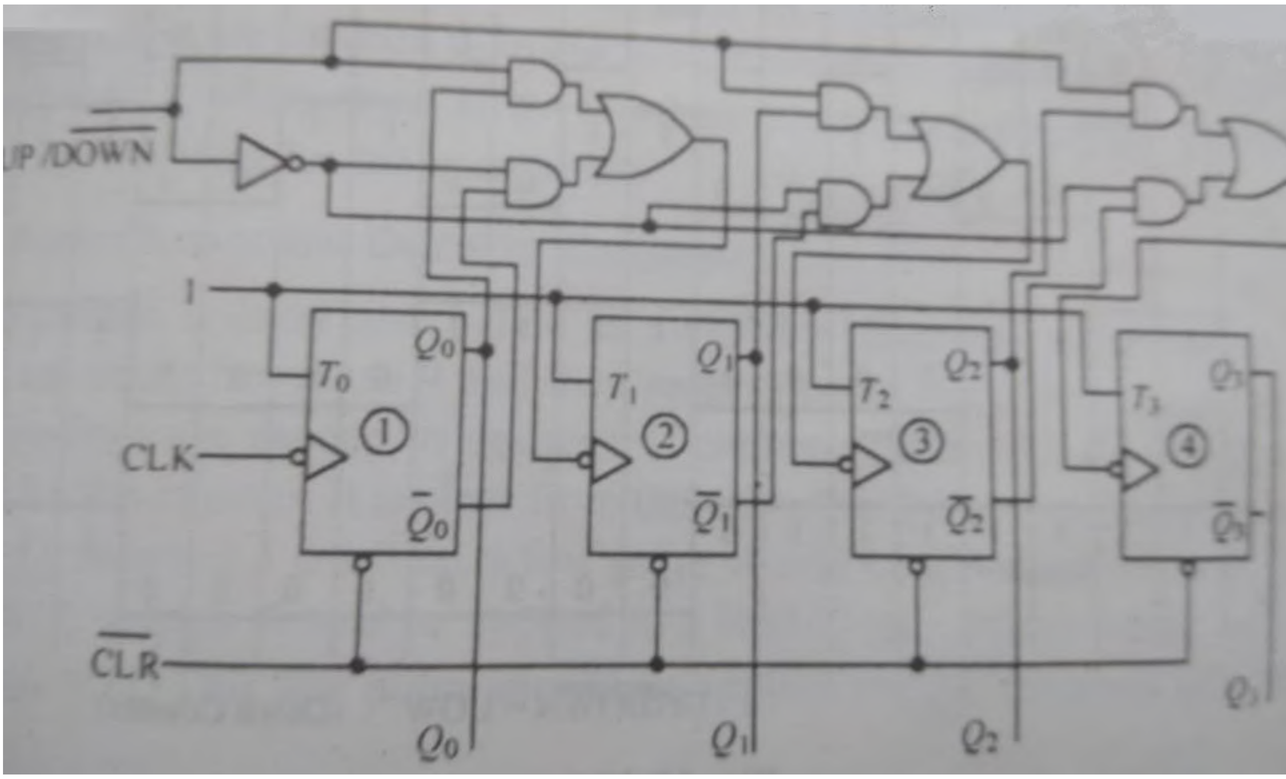
- MOD 8 Down Counter



Q_C
1
1
1
1
0
0
0
0

Asynchronous UP-Down Counter

- MOD-16 UP-DOWN counter

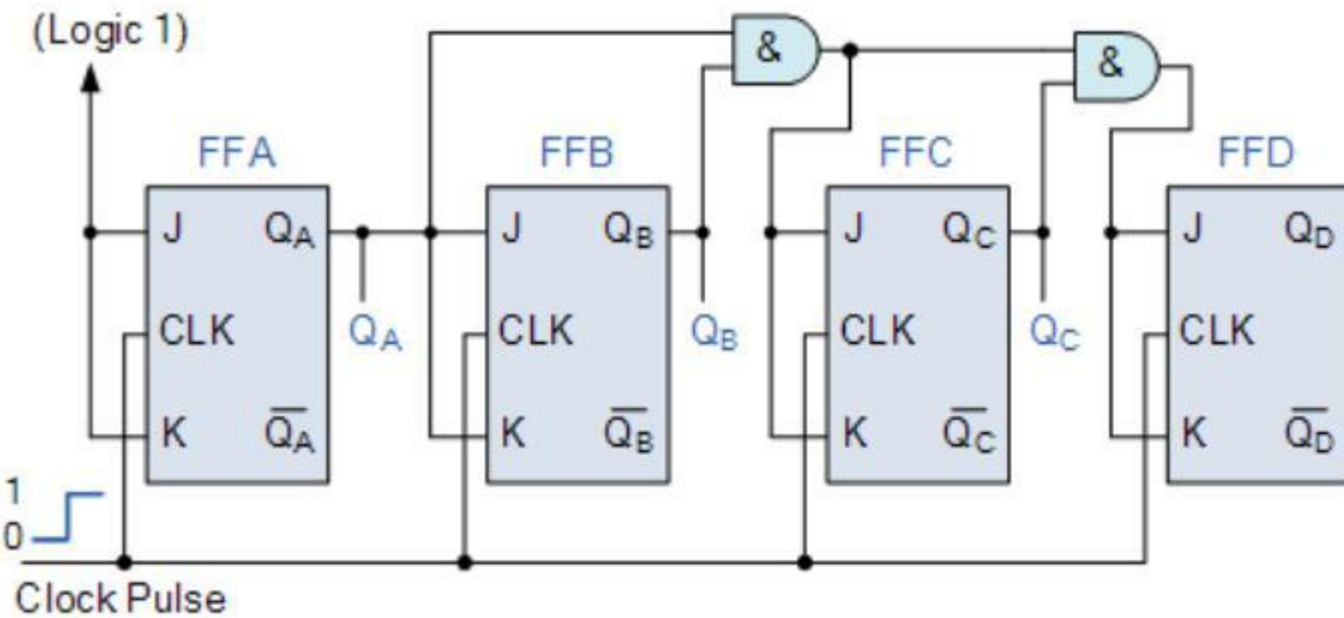


UP/Down = 1 → UP Counter
UP/Down = 0 → Down Counter

Synchronous Counters

- In **Synchronous Counter**, the external clock sig connected to the clock input of EVERY individual flop within the counter so that all of the flip-flop clocked together simultaneously (in parallel) at t same time giving a fixed time relationship. In oth words, changes in the output occur in "synchronis with the clock signal.
- The result of this synchronisation is that all the in output bits changing state at exactly the same ti response to the common clock signal with no ripp effect and therefore, no propagation delay.

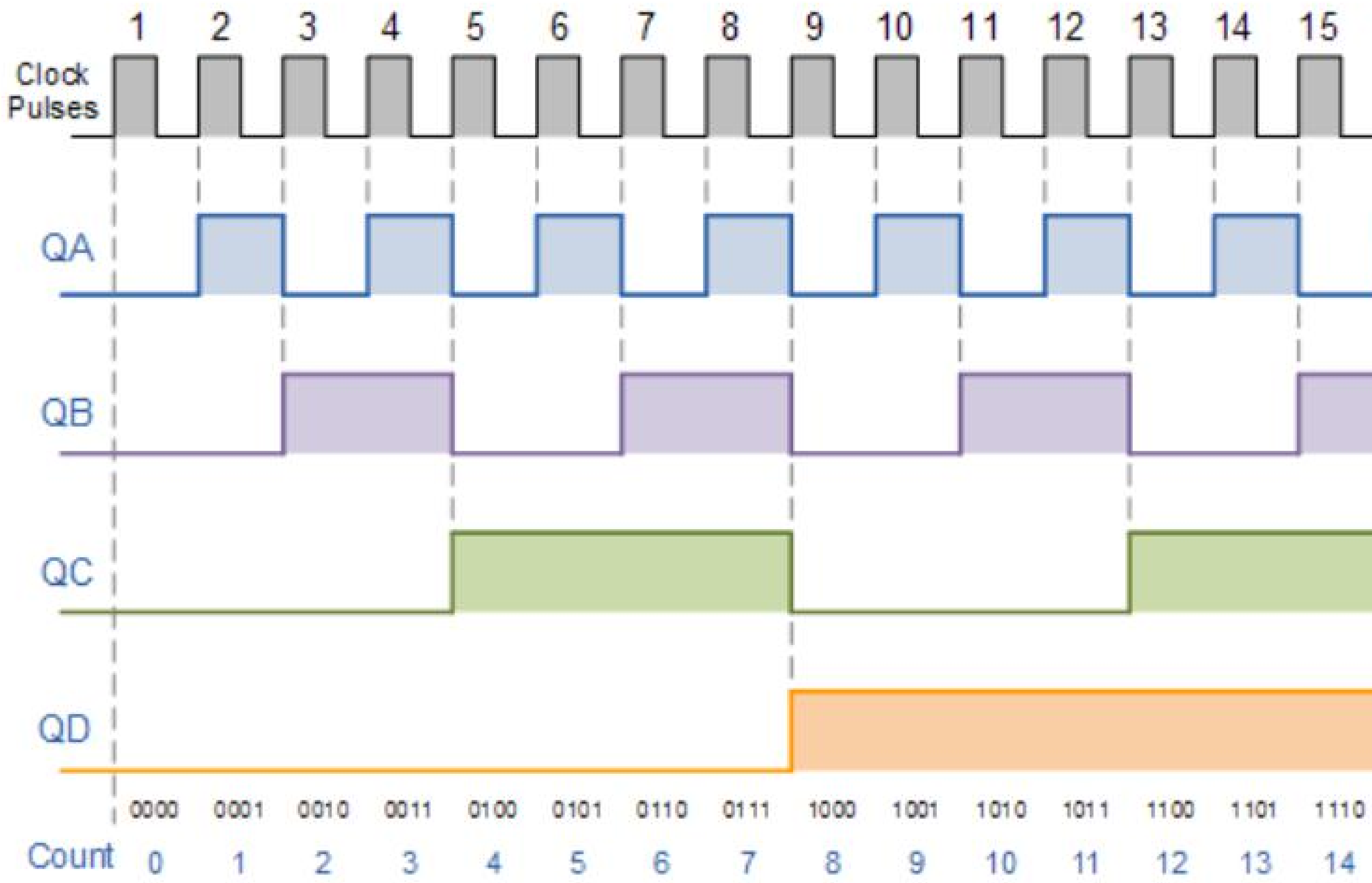
Binary 4-bit Synchronous Up Counter



- External clock pulses (pulses to be counted) are fed directly of the **J-K flip-flops** in the counter chain and that both the J and K inputs are all tied together in toggle mode (Hig only in the first flip-flop, FFA (LSB) allowing the flip-flop to every clock pulse. Then the synchronous counter follows a predetermined sequence of states in response to the comm signal, advancing one state for each pulse.
- The J and K inputs of flip-flop FFB are connected directly t output Q_A of flip-flop FFA, but the J and K inputs of flip-flops FFC and FFD are driven from separate AND gates wh also supplied with signals from the input and output of the stage. These additional AND gates generate the required the JK inputs of the next stage.

- If we enable each JK flip-flop to toggle based o whether or not all preceding flip-flop outputs (Q "HIGH" we can obtain the same counting sequen with the asynchronous circuit but without the ripp effect, since each flip-flop in this circuit will be c at exactly the same time.
- Then as there is no inherent propagation delay i synchronous counters, because all the counter sta triggered in parallel at the same time, the maxim operating frequency of this type of frequency c is much higher than that for a similar asynchrono counter circuit.

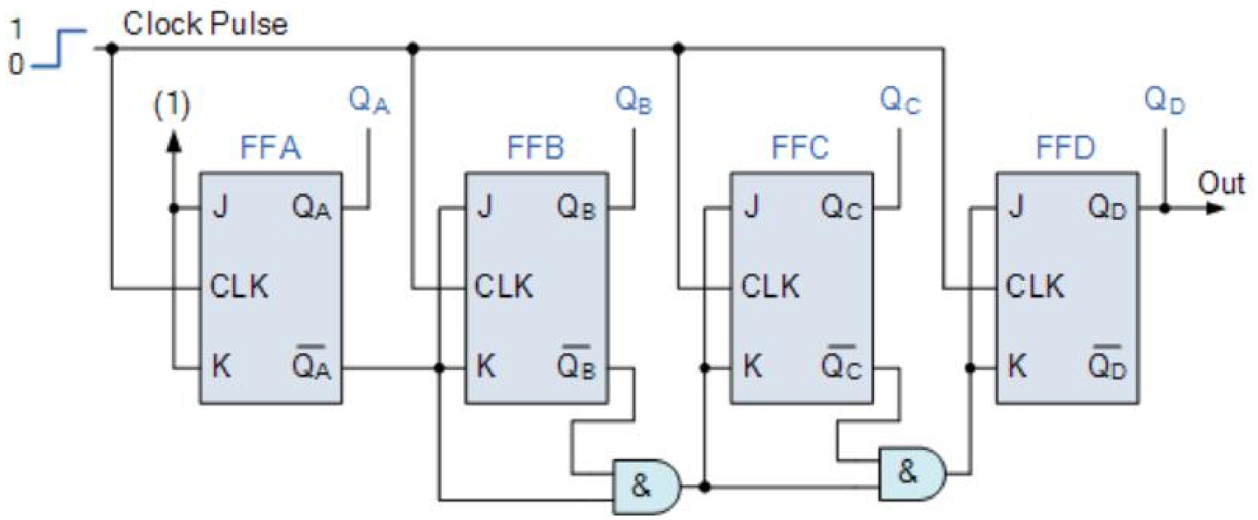
4-bit Synchronous Counter Waveform Timing Diagr



Synchronous Down Counter

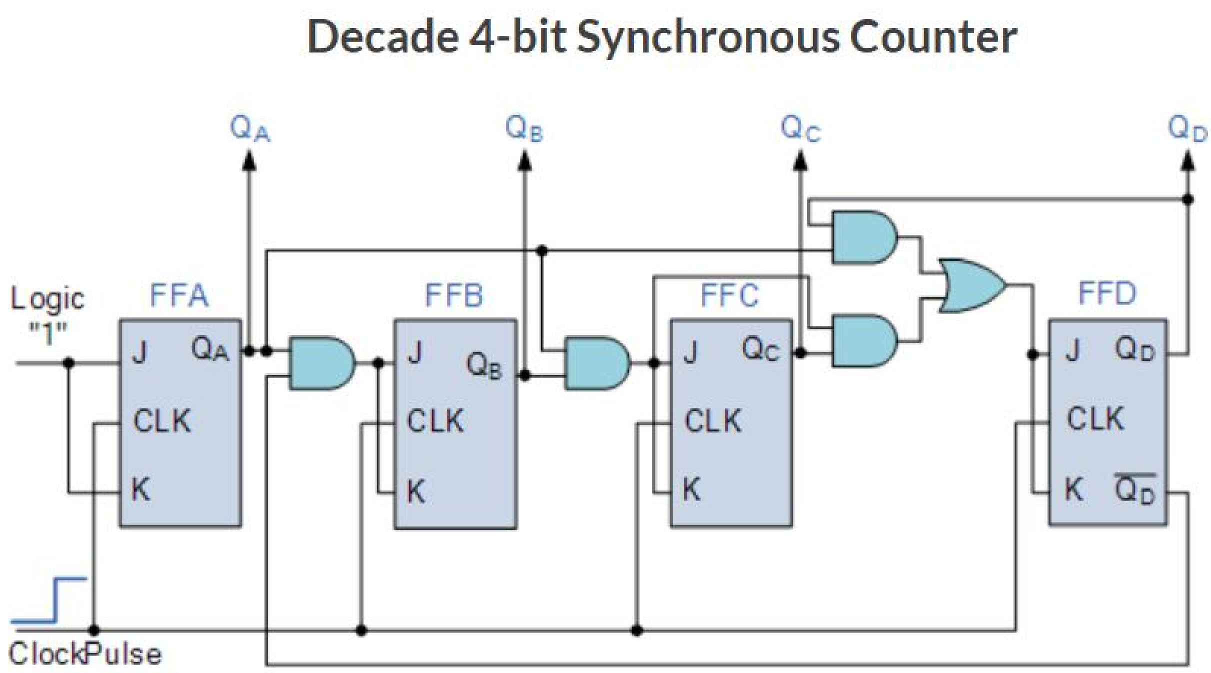
- we can easily construct a **4-bit Synchronous Down Counte** connecting the AND gates to the Q output of the flip-flops to produce a waveform timing diagram the reverse of the Here the counter starts with all of its outputs HIGH (1111) counts down on the application of each clock pulse to zero, before repeating again.

Binary 4-bit Synchronous Down Counter



Synchronous Decade Counter

- A 4-bit decade synchronous counter can also be built using synch binary counters to produce a count sequence from 0 to 9. A stand binary counter can be converted to a decade (decimal 10) count aid of some additional logic to implement the desired state sequ reaching the count of “1001”, the counter recycles back to “000 now have a decade or **Modulo-10** counter.



Synchronous Decade Counter

- The additional AND gates detect when the count sequence reaches “1001”, (Binary 10) and caus flop FF3 to toggle on the next clock pulse. Flip-flop FF0 toggles on every clock pulse. Thus, the reset and starts over again at “0000” producing synchronous decade counter.

Exercise

- 1. Design a synchronous Mod-10 counter to c
the sequence 0,2,4,5,6,8
- 2. Design a Synchronous Mod-8 counter. A co
input may be used that allow the counter to c
the up sequence or down sequence.

Reference

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Thankyou