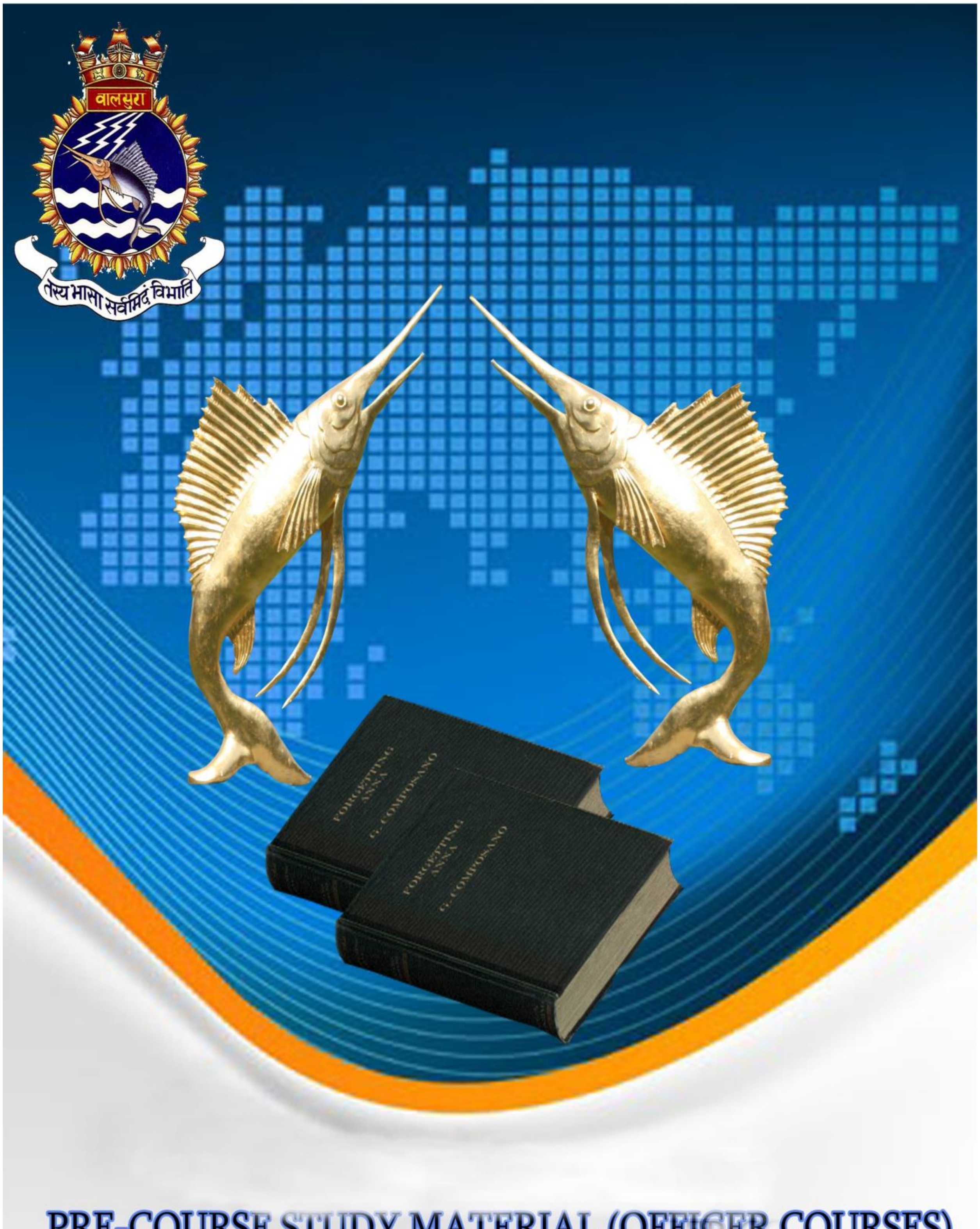


PRE-COURSE STUDY MATERIAL (OFFICER COURSES)

INS VALSURA

CONTENTS

PURPOSE AND SCOPE

1. **Purpose.** This document has been compiled as a Pre Course Material and a source of information for Officers undergoing Electrical specialisation course. The requirement of the document was felt to bring at par; prior to the above-mentioned course, Officers with different and varied backgrounds of engineering disciplines. Accordingly, the document acquaints Officers with certain topics which might not have been covered during their engineering studies. The coverage of the topics has been restricted to an introductory level to familiarise the trainee Officers with the basic concepts / technologies/ terms. The pre-course material only serves as a pre-cursor to further reading and must not be misconstrued as reference material in itself.

2. **Scope.** Based on instructor feedback and experience, the pre-course material has been compiled to cover the following topics:-

- (a) Electrical Machines
- (b) Power Electronics
- (c) Radar Engineering
- (d) Communication Engineering
- (e) Control Engineering

3. **Utilisation&Assessment.** The booklet is to be used as a preparatory document, to be read and understood prior to the corresponding subject being taught as part of the Electrical Specialisation course. Each chapter/ section is followed by a few basic questions which represent the expected knowledge level prior to undertaking the particular subject. The trainee may use his / her ability to answer them as a good measure of self assessment and refer to reference books indicated at the end of each chapter to be able to cope up with the course.

CHAPTER-1

ELECTRICAL MACHINES

1.1. Introduction

1.1.1. Electrical machine is the generic name for a device that converts mechanical energy to electrical energy, converts electrical energy to mechanical energy, or changes alternating current from one voltage level to a different voltage level.Electrical machines are divided into three main categories based on how they convert energy. Generators convert mechanical energy to electrical energy. Motors convert electrical energy to mechanical energy. Transformers change the voltage of alternating current.

1.1.2. Electrical machines form the building blocks for commencement of any study in electrical systems on board ships. The generation of electricity is carried by the onboard generators; the motors are used as basic prime movers for variety of systems varying from capstan to steering gear and from air blowers to drives for weapon systems. These systems are supplemented by their control circuitry such as Automatic Voltage Regulator (AVR), Governor, speed control units etc. for autonomous functioning. Further,habitability onboard ships is improved by use of refrigeration systems and air conditioning units. This chapter covers basic thumb rules of electricity and essential electrical machines that are used at various locations on a ship.

Remember: LM-RGi.e **L**eft Hand (Rule) for **M**otor &**R**ight Hand for **G**enerator

1.1.3. The functioning of electrical machines can be explained using the Fleming's rules. Fleming's left hand rule (for motors), and Fleming's right hand rule (for generators) is a pair of visual mnemonics that is used for working out which way an electric motor will turn, or which way the electric current will flow in an electric generator.

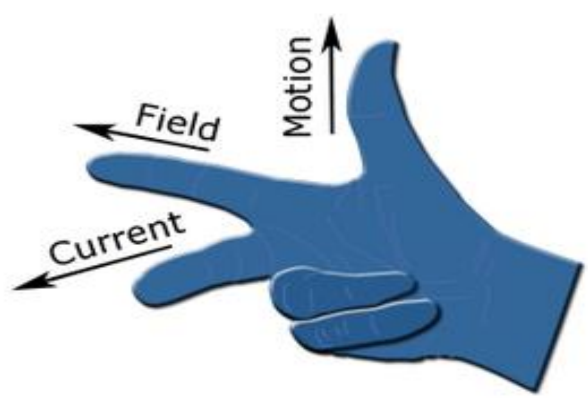
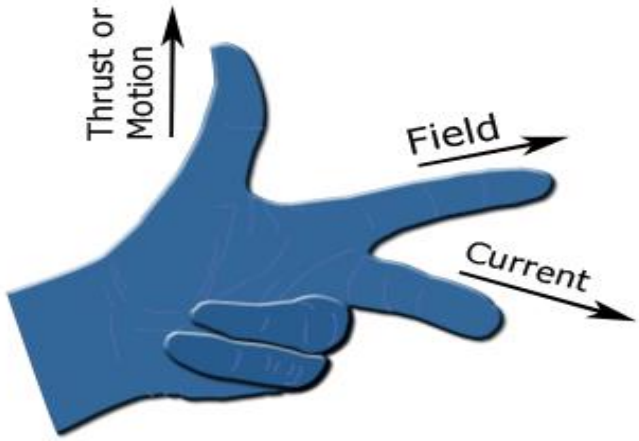


Fig 1.1FLEMING'S RIGHT HAND RULE: Middle finger gives the direction of flow of current in a generator



.

Fig 1.2FLEMING'S LEFT HAND RULE: Thumb gives the direction of motion of the motor.

1.2. **Generator**

1.2.1. An electric generator is a device that converts mechanical energy to electrical energy. A generator forces electrons to flow through an external electrical circuit. It is analogous to a water pump, which creates a flow of water but does not create the water inside. The source of mechanical energy, the prime mover, may be a reciprocating or turbine steam engine, water falling through a turbine or waterwheel, an internal combustion engine, a wind turbine, a hand crank, compressed air or any other source of mechanical energy.

1.2.2. There are two main parts of a generator which can be described in either mechanical or electrical terms. In mechanical terms the rotor is the rotating part of an electrical machine, and the stator is the stationary part of an electrical machine. In electrical terms the armature is the power-producing component of an electrical machine and the field is the magnetic field component of an electrical machine. The armature can be on either the rotor or the stator. The magnetic field can be provided by either electromagnets or permanent magnets mounted on either the rotor or the stator. Generators are classified into two types, AC generators and DC generators.

1.2.3. **AC Generator**

1.2.3.1. An AC generator converts mechanical energy into alternating current electricity. Generally, AC generators have the field winding on the rotor and the armature winding on the stator.

1.2.3.2. AC generators are classified into several types. The first is asynchronous or induction generators, in which stator flux induces currents in the rotor. The prime mover then drives the rotor above the synchronous speed, causing the opposing rotor flux to cut the stator coils producing active current in the stator coils, thus sending power back to the electrical grid. The second type is synchronous generators or alternator, in which the current for the magnetic field is provided by a separate DC current source.

1.2.3.3. The turning of a coil in a magnetic field produces rotational EMFs in both sides of the coil which add. Since the component of the velocity perpendicular to the magnetic field changes sinusoidally with the rotation, the generated voltage is sinusoidal or AC. This process can be described in terms of Faraday's law when you see that the rotation of the coil continually changes the magnetic flux through the coil and therefore generates a voltage.

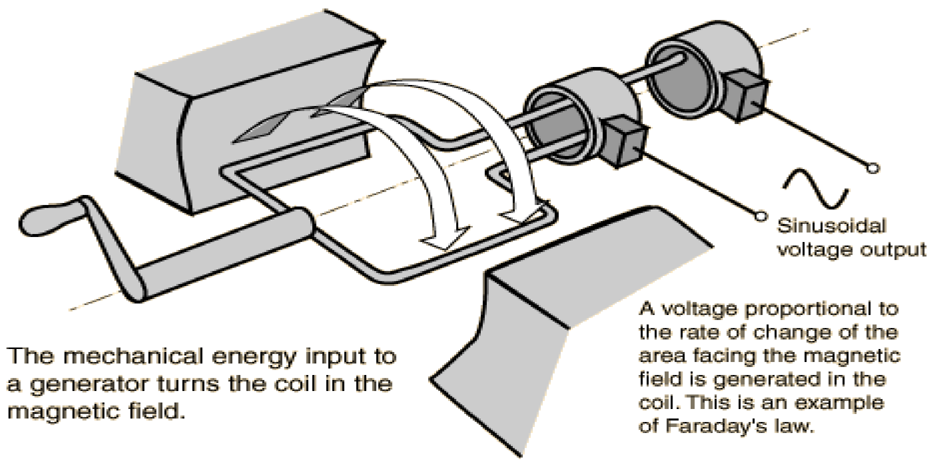


Fig 1.3 An AC Generator
Note: In AC Generators Slip Rings Are Used

1.2.4. **DC Generator**

1.2.4.1. A DC generator produces direct current electrical power from mechanical energy. A DC generator can operate at any speed within mechanical limits and always output a direct current waveform. Direct current generators known as dynamos work on exactly the same principles as alternators, but have a commutator on the rotating shaft, which converts the alternating current produced by the armature to direct current.

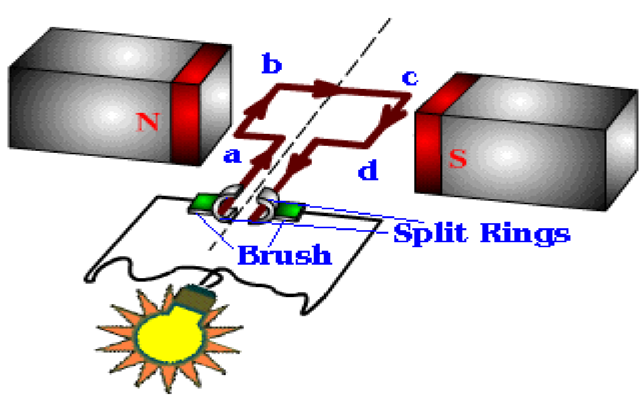


Fig 1.4 DC Generator

1.2.4.2. In DC generators the ends of the coil connect to a split ring (Fig 1.5), whose two halves are contacted by the brushes. Note that the brushes and split ring 'rectify' the EMF produced: the contacts are organised so that the current will always flow in the same direction, because when the coil turns past the dead spot, where the brushes meet the gap in the ring, the connections between the ends of the coil and external terminals are reversed.

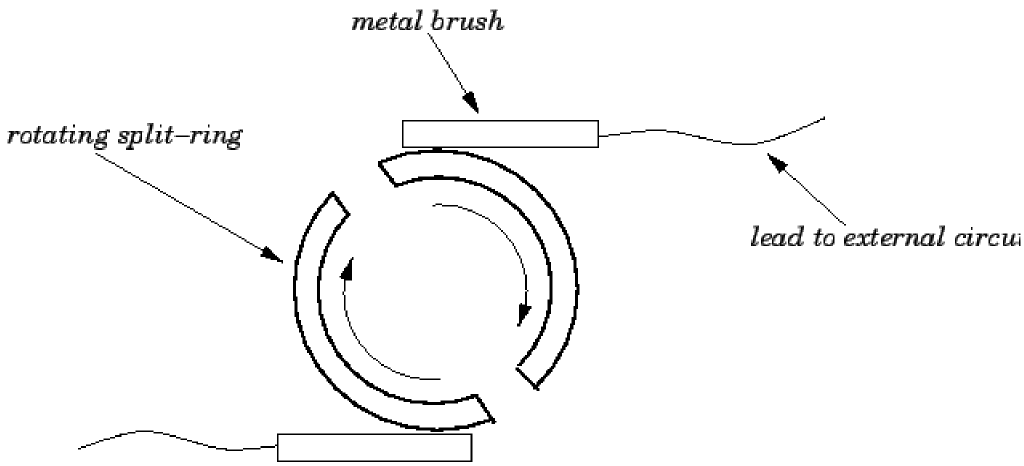


Fig 1.5 Split Ring Commutator

1.2.5. **Commutator**

1.2.5.1. A commutator is a rotary electrical switch in certain types of electric motors or electrical generators that periodically reverses the current direction between the rotor and the external circuit. In a motor, it applies power to the best location on the rotor, and in a generator, picks off power similarly. As a switch, it has exceptionally long life, considering the number of circuit makes and breaks that occur in normal operation.

1.2.5.2. A commutator is a common feature of direct current rotating machines. By reversing the current direction in the moving coil of a motor's armature, a steady rotating force (torque) is produced. Similarly, in a generator, reversing of the coil's connection to the external circuit provides unidirectional direct current to the external circuit.

1.3. **Motor**

1.3.1. An electric motor converts electrical energy into mechanical energy. The motor functions in the reverse process of electrical generators. They operate through interacting magnetic fields and current-carrying conductors to generate rotational force. Motors and generators have many similarities and many types of electric motors can be run as generators, and vice versa.They may be powered by direct current or by alternating current which leads to the two main classifications: AC motors and DC motors. Classification of motors is shown in Fig 2.6

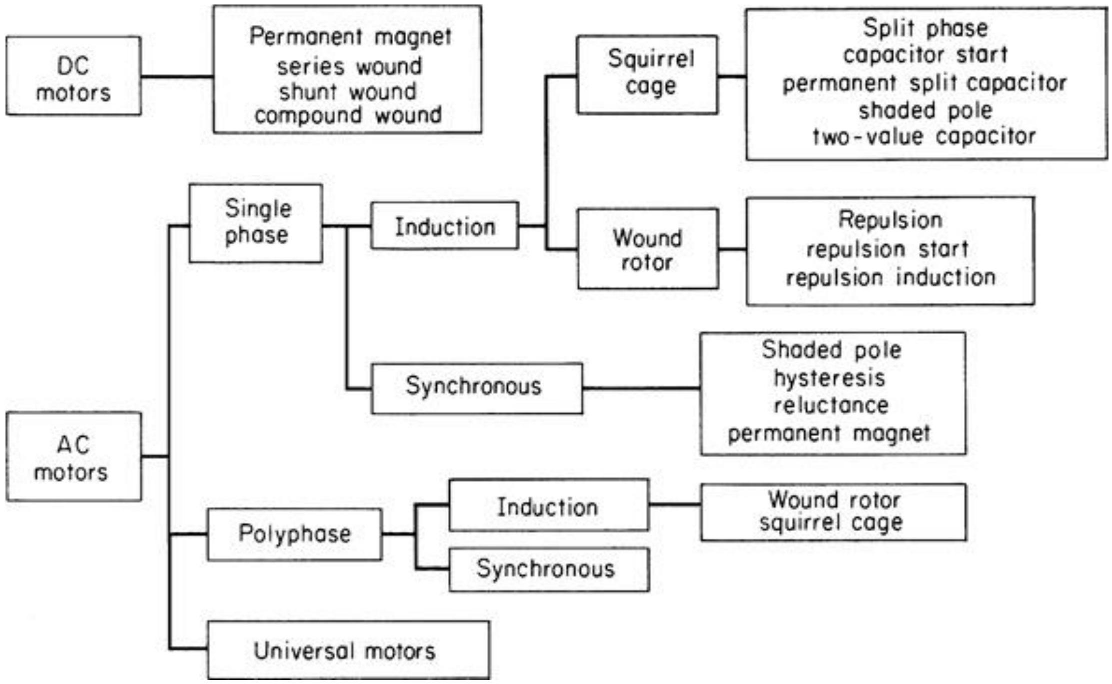


Fig 1.6 Classification of motors

1.3.1. **<u>AC Motor</u>**

1.3.1.1. An AC motor converts alternating current into mechanical energy. It commonly consists of two basic parts, an outside stationary stator having coils supplied with alternating current to produce a rotating magnetic field, and an inside rotor attached to the output shaft that is given a torque by the rotating field.

1.3.1.2. There are two main types of AC motors, depending on the type of rotor used. The first type is the induction motor, which only runs slightly slower or faster than the supply frequency. The magnetic field on the rotor of this motor is created by an induced current. The second type is the synchronous motor, which does not rely on induction and as a result, can rotate exactly at the supply frequency or a sub-multiple of the supply frequency. The magnetic field on the rotor is either generated by current delivered through slip rings or by a permanent magnet.

1.3.1.3. Induction motors are more widely used because of the following reasons:

(a) Induction motors are self-starting whereas synchronous motors are not self-starting.

(b) Speed control of Induction motor is easier as compared to synchronous motors.

(c) Maintenance of Squirrel cage induction motor is much easier than cylindrical or salient pole motors

1.3.2 **Induction Motor**

1.3.2.1. An induction or asynchronous motor is a type of AC motor where power is supplied to the rotor by means of electromagnetic induction, rather than by slip rings and commutators as in slip-ring AC motors. These motors have no friction caused by brushes, and their speed can be easily controlled.

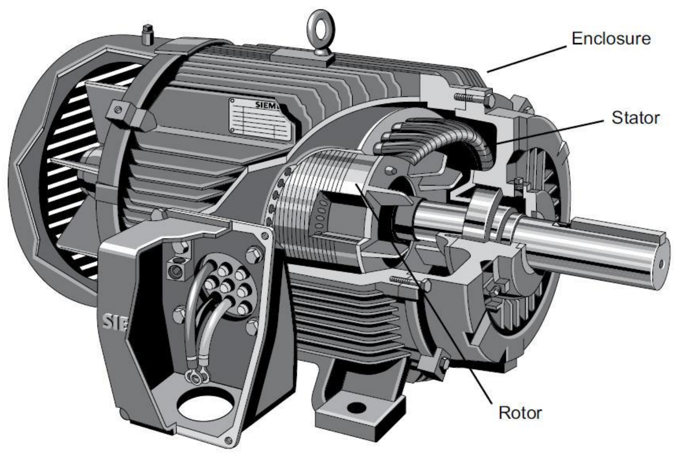


Fig 1.7 Induction Motor

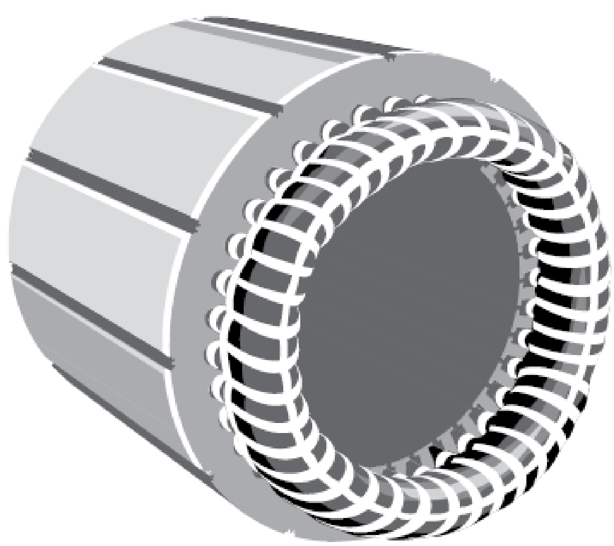


Fig 1.8 Stator with windings

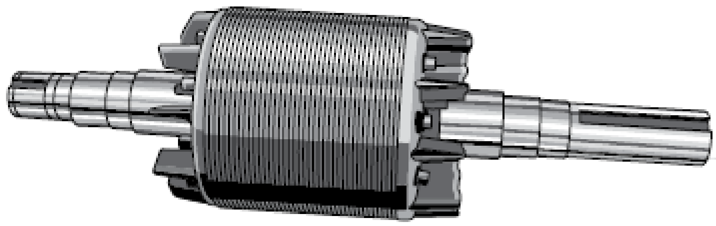


Fig 1.9 Rotor

1.3.2.2. An induction motor has a current induced in the rotor. Stator windings are arranged so that when energised with a polyphase supply they create a rotating magnetic field that induces current in the rotor conductors. These currents interact with the rotating magnetic field, causing rotational motion of the rotor.

1.3.2.3. For these currents to be induced, the speed of the physical rotor must be less than that of the stator's rotating magnetic field (ns), or else the magnetic field will not be moving relative to the rotor conductors and no currents will be induced. If this happens while the motor is operating, the rotor slows slightly until a current is re-induced, and it continues as before. The ratio between the speed of the magnetic field as seen by the rotor (slip speed) to the speed of the rotating stator field is unitless and is called the slip; due to this, induction motors are sometimes referred to as asynchronous machines. As well as generating rotary motion, induction motors may be run as generators or modified to directly generate linear motion.

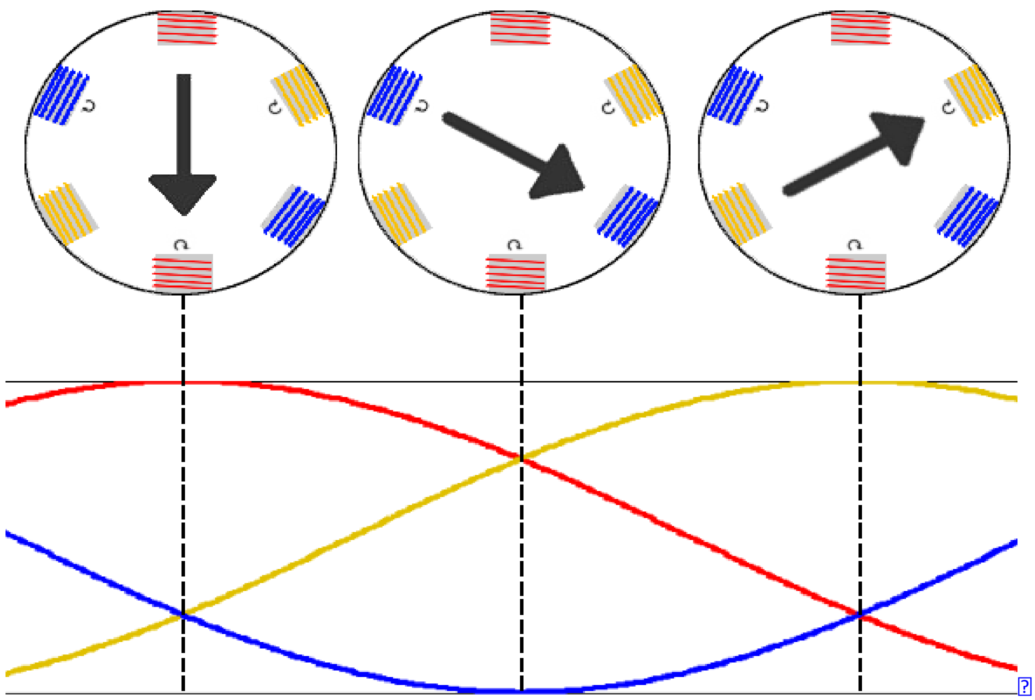


Fig 1.10 Rotating Magnetic field in a 3-phase induction motor

1.3.2.4. The stator of an induction motor consists of poles carrying supply current to induce a magnetic field that penetrates the rotor. To optimize the distribution of the magnetic field, the windings are distributed in slots around the stator, with the magnetic field having the same number of north and south poles. Induction motors are most commonly run on single-phase or three-phase power, but two-phase motors exist; in theory, induction motors can have any number of phases. Many single-phase motors having two windings and a capacitor can be viewed as two-phase motors, since the capacitor generates a second power phase 90 degrees from the single-phase supply and feeds it to a separate motor winding. Single-phase power is more widely available in residential buildings, but cannot produce a rotating field in the motor, so they must incorporate some kind of starting mechanism to produce a rotating field. There are three types of rotor: squirrel cage rotors made up of skewed (to reduce noise) bars of copper or aluminum that span the length of the rotor, slip ring rotors with windings connected to slip rings replacing the bars of the squirrel cage, and solid core rotors made from mild steel.

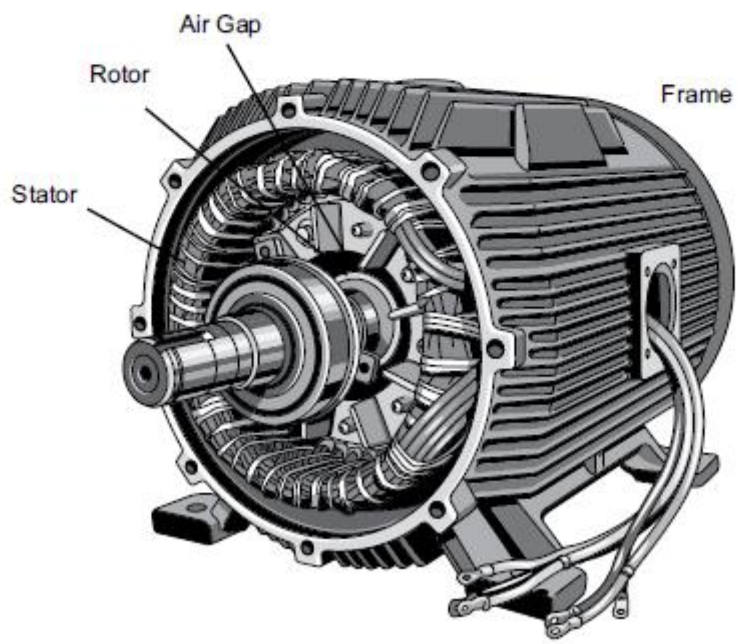


Fig 1.11 Partially assembled motor

1.3.3. **Synchronous Motors**

1.3.3.1. A synchronous electric motor is an AC motor distinguished by a rotor spinning with coils passing magnets at the same rate as the power supply frequency and resulting rotating magnetic field which drives it.

1.3.3.2. Synchronous motors do not rely on slip under usual operating conditions and as a result, produces torque at synchronous speed. Synchronous motors can be contrasted with an induction motor, which must slip in order to produce torque. They operate synchronously with line frequency. The speedof such motors is determined by the number of pairs of poles and the line frequency. The synchronous speed of the motor is given by the formula

$$V = 120*f/p$$

where v is the speed of the rotor (in rpm), f is the frequency of the AC supply (in Hz) and p is the number of magnetic poles

1.3.4. **DC Motor**

1.3.4.1. The brushed DC electric motor generates torque directly from DC power supplied to the motor by using internal commutation, stationary permanent magnets, and rotating electrical magnets. Brushes and springs carry the electric current from the commutator to the spinning wire windings of the rotor inside the motor. Brushless DC motors use a rotating permanent magnet in the rotor, and stationary electrical magnets on the motor housing. A motor controller converts DC to AC. This design is simpler than that of brushed motors because it eliminates the complication of transferring power from outside the motor to the spinning rotor.

1.3.4.2. An example of a brushless, synchronous DC motor is a stepper motor which can divide a full rotation into a large number of steps. The motor's position can be controlled precisely without any feedback mechanism as long as the motor is carefully sized to the application.

1.4 **Back EMF**

1.4.1. Back Electromotive Force (BackEMF)is the voltage, or electromotive force, that pushes against the current which induces it. Back EMF is caused by a changing electromagnetic field. It is represented by Lenz's Law of electromagnetism. Back electromotive force is a voltage that occurs in electric motors where there is relative motion between the armature of the motor and the external magnetic field. One practical application is to use this phenomenon to indirectly measure motor speed and position.

1.4.2. In a motor using a rotating armature and, in the presence of a magnetic flux, the conductors cut the magnetic field lines as they rotate. The changing field strength produces a voltage in the coil; the motor is acting like a generator (Faraday's law of induction). This voltage opposes the original applied voltage; therefore, it is called "back-electromotive force". (by Lenz's law.) With a lower overall voltage across the armature, the current flowing into the motor coils is reduced.

1.5 **Automatic Voltage Regulator**

1.5.1. Automatic Voltage Regulators (AVR's) are normally used in the Generators to control the output voltage depending upon load connected, such that, the load will not cause any voltage fluctuation and damage to the DG. Automatic Voltage Regulator is important part in Synchronous Generators; it controls the output voltage of the generator by controlling its excitation current. Thus it can control the output Reactive Power of the Generator.It is a device used to maintain a constant voltage at the alternators terminals. It functions by maintaining the excitation required to maintain the terminal voltage of the alternator with change in the load.

1.5.2. The Voltage Regulation Systemconsists of the voltage regulator, Voltage adjust potentiometer and power transformer. The voltage regulator senses and controls the generator output voltage which is operator adjustable within the design limits by use of the voltage adjust potentiometer. The power transformer provides operating power to the voltage regulator. The output voltage is indicated by the AC voltmeter on the control panel.

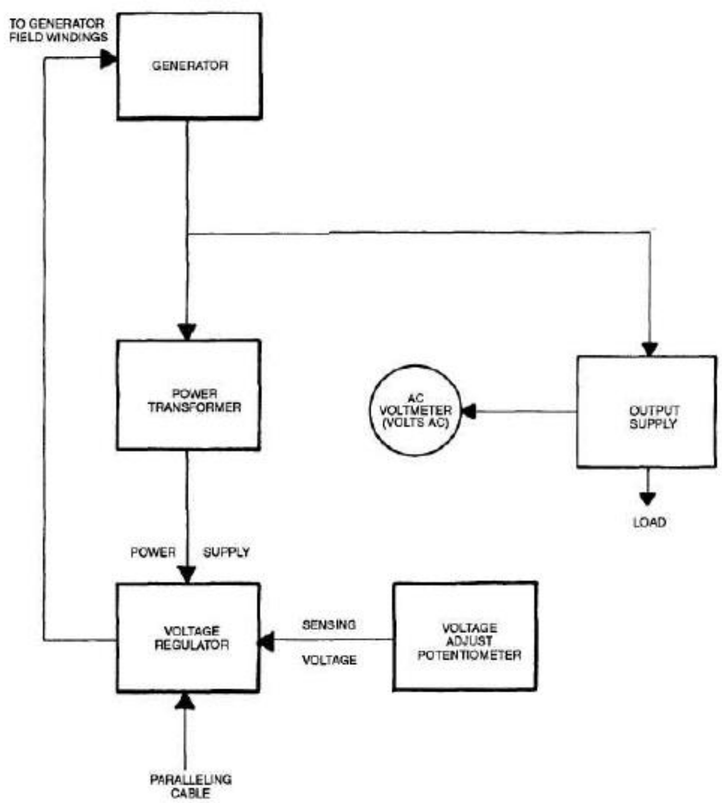


Fig 1.12 Automatic Voltage Regulator

1.6. **Governor**

1.6.1. A governor, or speed limiter, is a device used to measure and regulate the speed of a machine, such as agenerator or an engine. The Governor Control System includes the electronic governor control, governor actuator, magnetic pickup, load measuring unit, frequency transducer, frequency meter, fuel injection pumpand frequency adjust potentiometer. The governor actuator is a linear electromechanical actuator which controls the output of the fuel injection pump in response to the electrical input from the electronic governor control. The frequency adjust potentiometer, located on the control panel and adjusted by the operator, provides a signal representing the desired engine speed/generator frequency to the electronic governor control. A signal representative of the actual engine speed/generator frequency is sent to the electronic governor control by the magnetic pickup. Any change in engine speed from that selected by the operator, as sensed by the magnetic pickup, causes the electronic governor control to increase or decrease the fuel injection pump output to maintain the desired speed. The load measuring unit senses changes in external load demand and provides a change signal to the electronic governor control allowing the control to start its response prior to any actual change in engine speed.

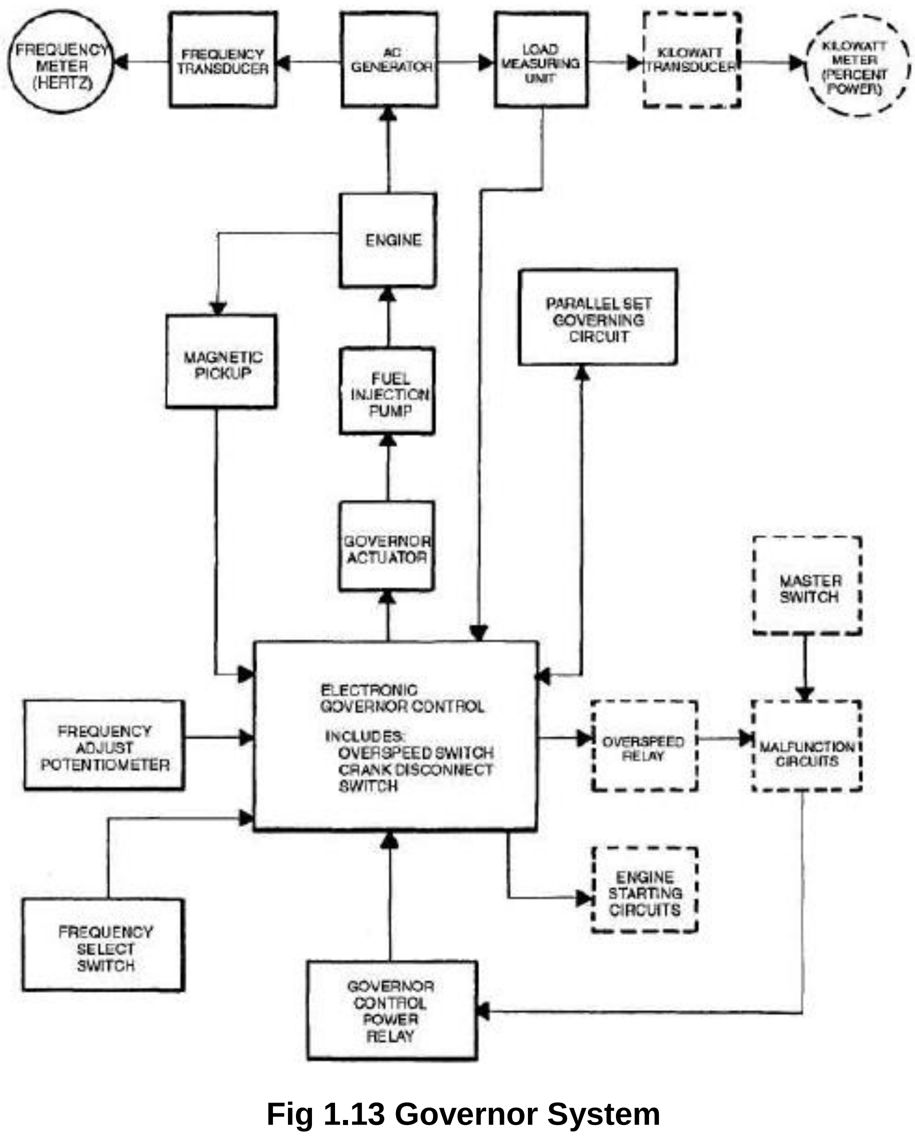


Fig 1.13 Governor System

1.7 **Refrigeration**

1.7.1 **Refrigeration** is a process in which work is done to move heat from one location to another. This work is traditionally done by mechanical work, but can also be done by magnetism, laser or other means. Refrigeration has many applications, including, but not limited to: household refrigerators, industrial freezers, cryogenics, air conditioning, and heat pumps.

1.7.2. **Vapor-compression cycle**

1.7.2.1. The vapor-compression cycle is used in most household refrigerators as well as in many large commercial and industrial refrigeration systems. Fig 2.14provides a schematic diagram of the components of a typical vapor-compression refrigeration system.

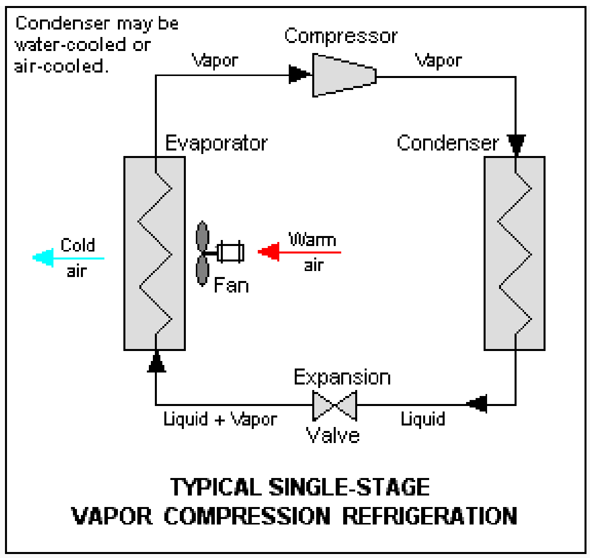


Fig1.14 Vapor compression refrigeration

1.7.2.2. The thermodynamics of the cycle can be analyzed on a diagram as shown in Figure 2.15. In this cycle, a circulating refrigerant such asFreon enters the compressor as a vapor. From point 1 to point 2, the vapor is compressed at constant entropy and exits the compressor as a vapor at a higher temperature, but still below the vapor pressure at that temperature. From point 2 to point 3 and on to point 4, the vapor travels through the condenser which cools the vapor until it starts condensing, and then condenses the vapor into a liquid by removing additional heat at constant pressure and temperature. Between points 4 and 5, the liquid refrigerant goes through the expansion valve (also called a throttle valve) where its pressure abruptly decreases, causing flash evaporation and auto-refrigeration of, typically, less than half of the liquid.

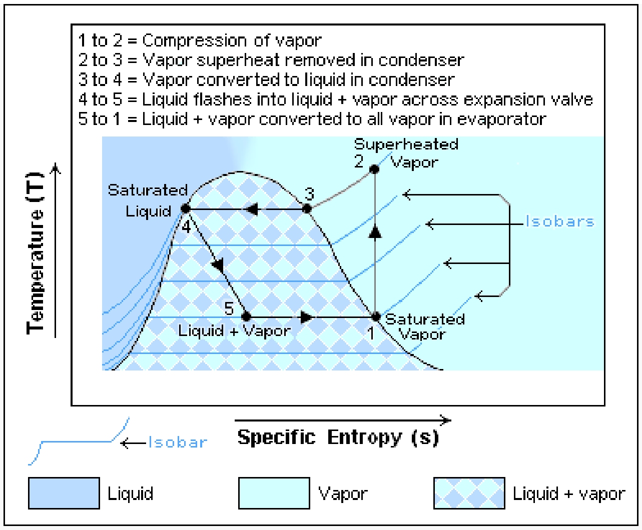


Fig 1.15 Temperature–Entropy diagram

1.7.2.3. This results in a mixture of liquid and vapor at a lower temperature and pressure as shown at point 5. The cold liquid-vapor mixture then travels through the evaporator coil or tubes and is completely vaporized by cooling the warm air (from the space being refrigerated) being blown by a fan across the evaporator coil or tubes. The resulting refrigerant vapor returns to the compressor inlet at point 1 to complete the thermodynamic cycle.

1.7.3. **Air Conditioning**

1.7.3.1. An air conditioner (often referred to as AC) is a system, or mechanism designed to dehumidify and extract heat from an area. The cooling is done using a simple refrigeration cycle. In construction, a complete system of heating, ventilation and air conditioning is referred to as "HVAC".

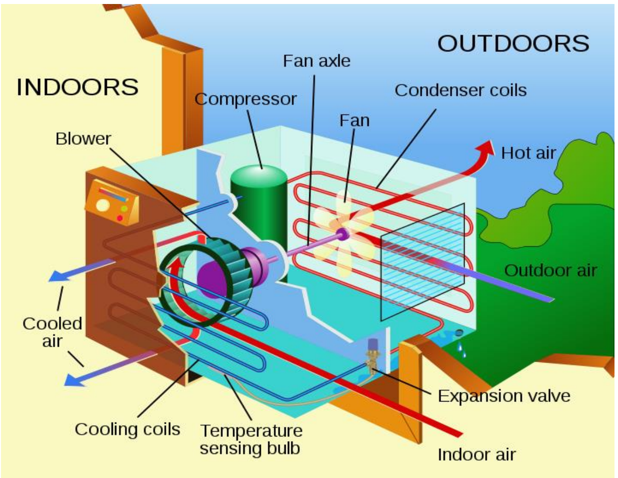


Fig 1.16 Typical Air Conditioner

1.7.3.2. In the refrigeration cycle of air conditioner, a heat pump transfers heat from a lower-temperature heat source into a higher-temperature heat sink. Heat would naturally flow in the opposite direction. This cycle takes advantage of the way phase changes work, where latent heat is released at a constant temperature during a liquid/gas phase change, and where varying the pressure of a pure substance also varies its condensation/boiling point.

1.7.3.3. The most common refrigeration cycle uses an electric motor to drive a compressor. In an automobile, the compressor is driven by a belt over a pulley, the belt being driven by the engine's crankshaft. Whether in a car or building, both use electric fan motors for air circulation. Since evaporation occurs when heat is absorbed, and condensation occurs when heat is released, air conditioners use a compressor to cause pressure changes between two compartments, and actively condense and pump a refrigerant around. A refrigerant is pumped into the evaporator coil, located in the compartment to be cooled, where the low pressure causes the refrigerant to evaporate into a vapor, taking heat with it. At the opposite side of the cycle is the condenser, which is located outside of the cooled compartment, where the refrigerant vapor is compressed and forced through another heat exchange coil, condensing the refrigerant into a liquid, thus rejecting the heat previously absorbed from the cooled space.

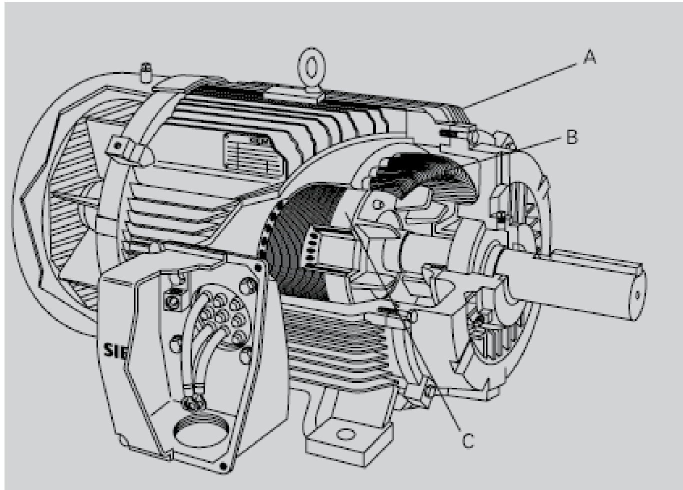
1.7.3.4. By placing the condenser (where the heat is rejected) inside a compartment, and the evaporator (which absorbs heat) in the ambient environment (such as outside), or merely running a normal air conditioner's refrigerant in the opposite direction, the overall effect is the opposite, and the compartment is heated. This is usually called a heat pump, and is capable of heating a home to comfortable temperatures (25 °C; 70 °F), even when the outside air is below the freezing point of water (0 °C; 32 °F).’

1.7.3.5. Cylinder unloaders are a method of load control used mainly in commercial air conditioning systems. On a semi-hermetic (or open) compressor, the heads can be fitted with unloaders which remove a portion of the load from the compressor so that it can run better when full cooling is not needed.

1.8. **Questions**

1.8.1. Briefly explain: brushes, split rings and commutator.
1.8.2. What isbackEMF?
1.8.3. How is DC generated in DC generators?
1.8.4. Identify the following components from the illustration:

A. ________
B. ________
C. ________



1.8.5. The ________ is the stationary part of an AC motor's electromagnetic circuit.
1.8.6. The ________ is the rotating electrical part of an AC motor.
1.8.7. The ________ rotor is the most common type of rotor used in three-phase AC motors.
1.8.8.The ________ protects the internal parts of the motor from water and other environmental elements.
1.8.9. What is a synchronous motor? How is it different from Induction Motor?
1.8.10.What are various methods of speed control in a motor?
1.8.11.What is meant by slip of a motor?
1.8.12.What is the purpose of a starter for a motor?
1.8.13. What are different types of Induction motors?
1.8.14.What is the need of an AVR and governor? Are they interchangeable?

1.9. <u>Suggested Reading</u>

Electrical TechnologyVol II – B.L. Thareja
Chapter 25
Chapter 26
Chapter 29

VP –174 :- Power Generation and Distribution

CHAPTER-2

POWER ELECTRONICS

2.1 Introduction

2.1.1. Power electronics is the application of solid-state electronics for the control and conversion of electric power. Power electronic converters can be found wherever there is a need to modify a form of electrical energy (i.e. change its voltage, current or frequency). The power range of these converters is from some milli-watts (as in a mobile phone) to hundreds of megawatts (e.g. in a HVDC transmission system). With "classical" electronics, electrical currents and voltage are used to carry information, whereas with power electronics, they carry power. Thus, the main metric of power electronics becomes the efficiency. Such convertors are widely used onboard ships and form the basic components of rectifiers, speed control devices, voltage conversion/ amplification, switching devices etc.

2.1.2. The first very high power electronic devices were mercury arc valves. In modern systems the conversion is performed with semiconductor switching devices such as diodes, thyristors and transistors. An AC/DC converter (rectifier) is the most typical power electronics device found in many consumer electronic devices, e.g. television sets, personal computers, battery chargers, etc. The power range is typically from tens of watts to several hundred watts. On ships the most common application is the speed control of motors, e.g., speed control of DC motors of ECM antenna in an EW system. The latest Soft starters for motors use such devices as their primary component.

2.1.3. The power conversion systems can be classified according to the type of the input and output power

(a) AC to DC (rectifier) - are used every time an electronic device is connected to the mains (computer, television etc.). These may simply change AC to DC or can also change the voltage level as part of their operation

(b) DC to AC (inverter) - are used primarily in UPS or emergency lighting systems. When mains power is available, it will charge the DC battery. If the mains fails, an inverter will be used to produce AC electricity at mains voltage from the DC battery.

(c) DC to DC (DC to DC converter) - are used in most mobile devices (mobile phones, PDA etc.) to maintain the voltage at a fixed value whatever the voltage level of the battery is. These converters are also used for electronic isolation and power factor correction

(d) AC to AC (AC to AC converter) - converters are used to change either the voltage level or the frequency (international power adapters, light dimmer). In power distribution networks AC/AC converters may be used to exchange power between utility frequency 50 Hz and 60 Hz power grids.

2.2. **Diode**

2.2.1. Diode is a type of two-terminal electronic component with a nonlinear current–voltage characteristic. A semiconductordiodeis a crystalline piece of semiconductor material connected to two electrical terminals. A vacuumtubediode (now rarely used except in some high-power technologies) is a vacuum tube with two electrodes: a plate and a cathode.

2.2.2. The most common function of a diode is to allow an electric current to pass in one direction (called the diode's *forward* direction), while blocking current in the opposite direction (the *reverse* direction). Thus, the diode can be thought of as an electronic version of a check valve. This unidirectional behavior is called rectification, and is used to convert alternating current to direct current, and to extract modulation from radio signals in radio receivers.

2.2.3. Semiconductor diodes have nonlinear electrical characteristics, which can be tailored by varying the construction of their P–N junction. These are exploited in special purpose diodes that perform many different functions. For example, diodes are used to regulate voltage (Zener diodes), to protect circuits from high voltage surges (Avalanche diodes), to electronically tune radio and TV receivers (varactor diodes), to generate radio frequency oscillations (tunnel diodes, Gunn diodes, IMPATT diodes), and to produce light (light emitting diodes). Tunnel diodes exhibit negative resistance, which makes them useful in some types of circuits.

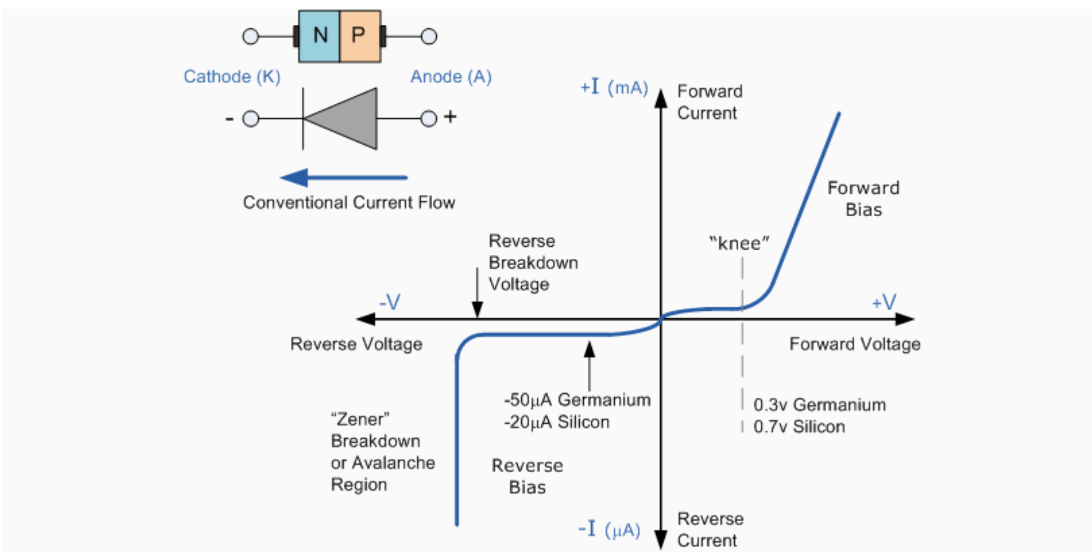


Fig 2.1 Diode and Static I-V Characteristics of Diode

2.3 **The PN Junction**

2.3.1. When the N and P-type semiconductor materials are joined together a very large density gradient exists between both sides of the junction so some of the free electrons from the donor impurity atoms begin to migrate across this newly formed junction to fill up the holes in the P-type material producing negative ions. However, because the electrons have moved across the junction from the N-type silicon to the P-type silicon, they leave behind positively charged donor ions (N_D) on the negative side and now the holes from the acceptor impurity migrate across the junction in the opposite direction into the region where there are large numbers of free electrons. As a result, the charge density of the P-type along the junction is filled with negatively charged acceptor ions (N_A), and the charge density of the N-type along the junction becomes positive. This charge transfer of electrons and holes across the junction is known as diffusion.

2.3.2. This process continues back and forth until the number of electrons which have crossed the junction have a large enough electrical charge to repel or prevent any more carriers from crossing the junction. The regions on both sides of the junction become depleted of any free carriers in comparison to the N and P type materials away from the junction. Eventually a state of equilibrium (electrically neutral situation) will occur producing a **"**potential barrier**"** zone around the area of the junction as the donor atoms repel the holes and the acceptor atoms repel the electrons. Since no free charge carriers can rest in a position where there is a potential barrier the regions on both sides of the junction become depleted of any more free carriers in comparison to the N and P type materials away from the junction. This area around the junction is now called the Depletion Layer.

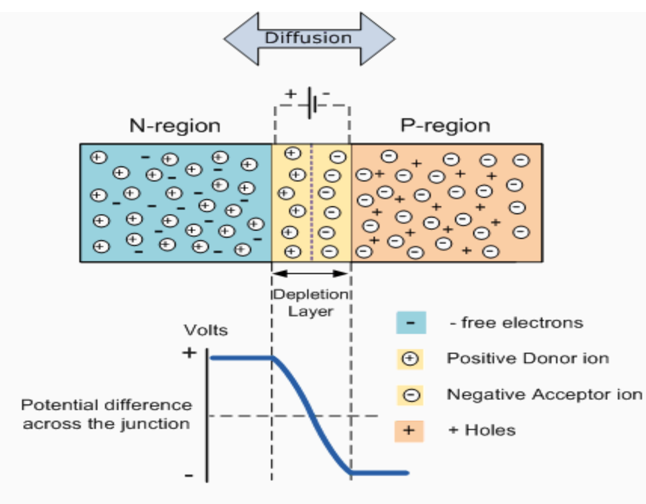


Fig 2.2A PN Junction

2.3.3. The total charge on each side of the junction must be equal and opposite to maintain a neutral charge condition around the junction. If the depletion layer region has a distance D, it therefore must therefore penetrate into the silicon by a distance of D_p for the positive side, and a distance of D_n for the negative side giving a relationship between the two of $D_p.N_A = D_n.N_D$ in order to maintain charge neutrality also called equilibrium.

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

2.4 Zener Diode

2.4.1. A **Zener diode** is a special kind of diode which allows current to flow in the forward direction same as an ideal diode, but will also permit it to flow in the reverse direction when the voltage is above a certain value known as the breakdown voltage, Zener knee voltage or Zener voltage. The device was named after Clarence Zener, who discovered this electrical property.

2.4.2. A conventional solid-state diode will not allow significant current if it is reverse-biased below its reverse breakdown voltage. When the reverse bias breakdown voltage is exceeded, a conventional diode is subject to high current due to avalanche breakdown. Unless this current is limited by circuitry, the diode will be permanently damaged due to overheating. In case of large forward bias (current in the direction of the arrow), the diode exhibits a voltage drop due to its junction built-in voltage and internal resistance. The amount of the voltage drop depends on the semiconductor material and the doping concentrations.

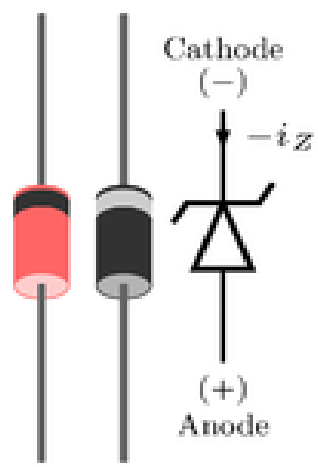


Fig 2.3 Zener Diode

2.4.3. A Zener diode exhibits almost the same properties, except the device is specially designed so as to have a greatly reduced breakdown voltage, the so-called Zener voltage. By contrast with the conventional device, a reverse-biased Zener diode will exhibit a controlled breakdown and allow the current to keep the voltage across the Zener diode close to the Zener breakdown voltage.

2.4.4. The Zener diode's operation depends on the heavy doping of its p-n junction allowing electrons to tunnel from the valence band of the p-type material to the conduction band of the n-type material. In the atomic scale, this tunneling corresponds to the transport of valence band electrons into the empty conduction band states; as a result of the reduced barrier between these bands and high electric fields that are induced due to the relatively high levels of doping on both sides.

2.4.5. Another mechanism that produces a similar effect is the avalanche effect as in the avalanche diode. The two types of diode are in fact constructed the same way and both effects are present in diodes of this type. In silicon diodes up to about 5.6 volts, the Zener effect is the predominant effect and shows a marked negative temperature coefficient. Above 5.6 volts, the avalanche effect becomes predominant and exhibits a positive temperature coefficient.

2.5 <u>**Questions**</u>

2.5.1. What do you mean by Trivalent and Pentavalent impurities? Define N-Type and P-Type semiconductors.
2.5.2. If there are extra electrons in N-Type semiconductors, then are they electrically neutral? Give reasons.
2.5.3. Define Doping.
2.5.4. Define Conductors, Insulators and Semiconductors based on Energy Band Diagram.
2.5.5. What do you mean by biasing? What are various types of Biasing?
2.5.6. Define Potential Barrier.
2.5.7. How does the flow of electron takes place through the junction?
2.5.8. Study about the V-I characteristics of the PN junction or a diode.

2.6 <u>**Transistor**</u>

2.6.1. A transistor is a semiconductor device used to amplify and switch electronic signals. It is composed of a semiconductor material with at least three terminals for connection to an external circuit. A voltage or current applied to one pair of the transistor's terminals changes the current flowing through another pair of terminals. Because the controlled (output) power can be much more than the controlling (input) power, a transistor can amplify a signal. Today, some transistors are packaged individually, but many more are found embedded in integrated circuits.

2.6.2. The transistor is the fundamental building block of modern electronic devices, and is ubiquitous in modern electronic systems. Following its release in the early 1950s the transistor revolutionized the field of electronics, and paved the way for smaller and cheaper radios, calculators, and computers, among other things.

2.6.3. The basic construction of a transistor consists of two PN-junctions connected back to back giving rise to three terminals, viz., the Emitter (E), Base (B) and Collector (C) respectively.

2.6.4 **<u>Unijunction Transistor (UJT)</u>**

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

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

2.6.4.3. In addition to its use as the active device in relaxation oscillators, one of the most important applications of UJTs or PUTs is to trigger thyristors (SCR, TRIAC, etc.). A DC voltage can be used to control a UJT or PUT circuit such that the "on-period" increases with an increase in the DC control voltage. This application is important for large AC current control.

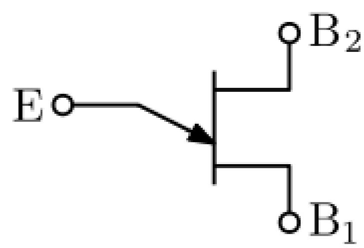


Fig 2.4 Uni Junction Transistor

2.6.5. **<u>Bipolar Transistor</u>**

2.6.5.1. A Bipolar (junction) transistor (BJT) is a three-terminal electronic device constructed of doped semiconductor material and may be used in amplifying or switching applications. *Bipolar* transistors are so named because their operation involves both electrons and holes. Charge flow in a BJT is due to bidirectional diffusion of charge carriers across a junction between two regions of different charge concentrations. This mode of operation is contrasted with *unipolar transistors,* such as field-effect transistors, in which only one carrier type is involved in charge flow due to drift. By design, most of the BJT collector current is due to the flow of charges injected from a high-concentration emitter into the base where they are minority carriers that diffuse toward the collector, and so BJTs are classified as *minority-carrier* devices.

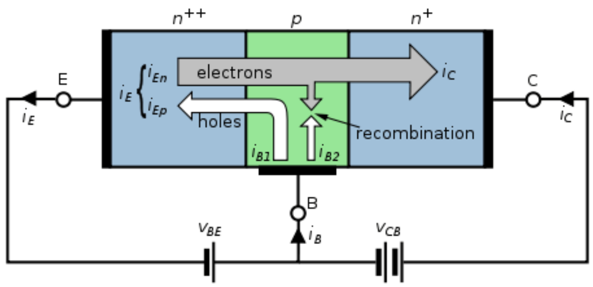


Fig 2.5 NPNBJT with forward-biased E–B junction and reverse-biased B–C junction

2.6.5.2. Bipolar Transistors are current regulating devices that control the amount of current flowing through them in proportion to the amount of biasing voltage applied to their base terminal acting like a current-controlled switch. The principle of operation of the two transistor types PNP and NPN, is exactly the same the only difference being in their biasing and the polarity of the power supply for each type.

2.6.5.3. As the Bipolar Transistor is a three terminal device, there are basically three possible ways to connect it within an electronic circuit with one terminal being common to both the input and output. Each method of connection responding differently to its input signal within a circuit as the static characteristics of the transistor varies with each circuit arrangement. These configurations are:

(a) Common Base Configuration - has Voltage Gain but no Current Gain.

(b) Common Emitter Configuration - has both Current and Voltage Gain.

(c) Common Collector Configuration - has Current Gain but no Voltage Gain.

2.6.7. **Field-effect Transistor (FET)**

2.6.7.1. The Field-Effect Transistor (FET) is a transistor that relies on an electric field to control the shape and hence the conductivity of a channel of one type of charge carrier in a semiconductor material. FETs are sometimes called *unipolar transistors* to contrast their single-carrier-type operation with the dual-carrier-type operation of bipolar (junction) transistors (BJT). The concept of the FET predates the BJT, though it was not physically implemented until afterBJTs due to the limitations of semiconductor materials and the relative ease of manufacturing BJTs compared to FETs at the time.

2.6.7.2. The FET controls the flow of electrons (or electron holes) from the source to drain by affecting the size and shape of a "conductive channel" created and influenced by voltage (or lack of voltage) applied across the gate and source terminals. This conductive channel is the "stream" through which electrons flow from source to drain.

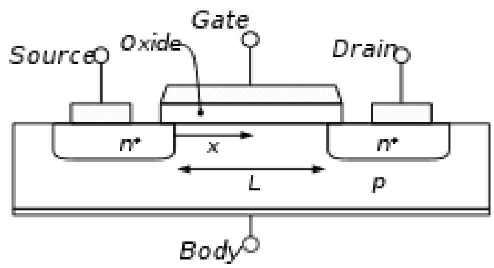


Fig 2.6 FET

2.6.7.3. In an n-channel *depletion-mode* device, a negative gate-to-source voltage causes a *depletion region* to expand in width and encroach on the channel from the sides, narrowing the channel. If the depletion region expands to completely close the channel, the resistance of the channel from source to drain becomes large, and the FET is effectively turned off like a switch. Likewise a positive gate-to-source voltage increases the channel size and allows electrons to flow easily.

2.6.7.4. **<u>JFET</u>**

2.6.7.4.1. The J-FET (Junction Field Effect Transistor) is a voltage controlled device. That is a small change in input voltage causes a large change in output current. FET operation involves an electric field which controls the flow of a charge (current) through the device. In contrast, a bipolar transistor employs a small input current to control a large output current. The source, drain, and gate terminal of the FET are analogous to the emitter, collector, and base of a bipolar transistor. The terms n-channel and p-channel refer to the material which the drain and source are connected. The schematic symbol for the p-channel and n-channel JFET are shown in fig 2.7.

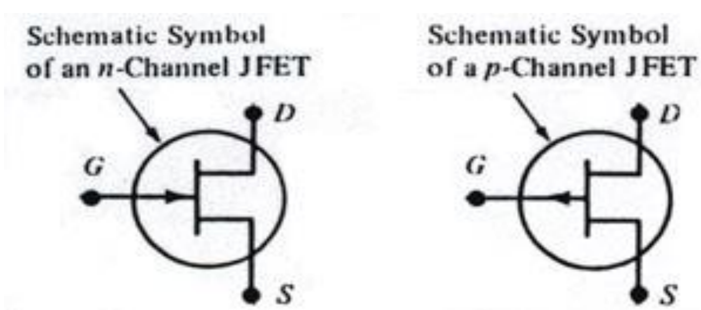


Fig 2.7 Schematic Symbol for the P-channel and N-channel JFET

2.6.7.4.2. A simplified n-channel JFET construction is shown below. Note that the drain and source connections are made to the n-channel and the gate is connected to the p material. The n material provides a current path from the drain to the source. An n-channel JFET is biased so that the drain is positive in reference to the source. On the other hand, a p-channel JFET with n material gate would be biased in reverse.

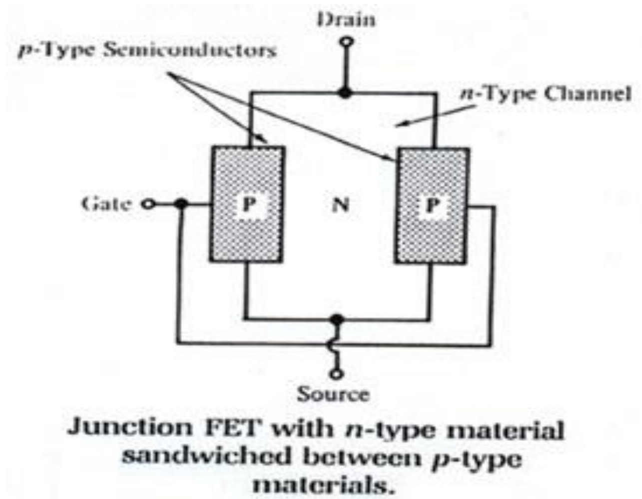


Fig 2.8 Junction FET with N-type material sandwiched between P-type materials

2.6.7.5. **<u>MOSFET</u>**

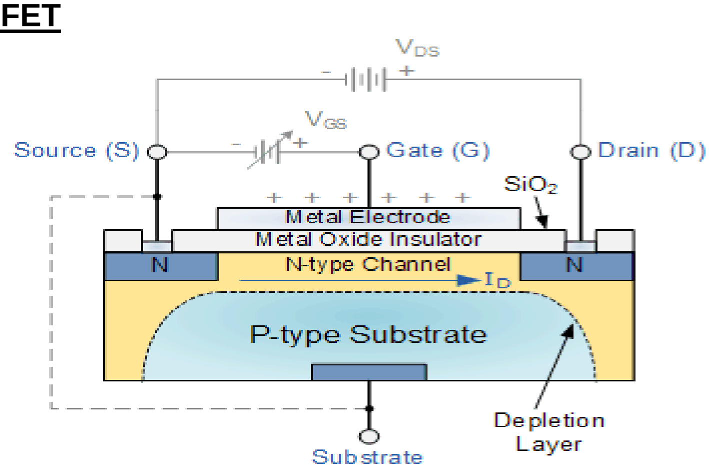


Fig 2.9 Basic MOSFET Structure

2.6.7.5.1. The construction of the Metal Oxide Semiconductor FET is very different to that of the Junction FET. Both the Depletion and Enhancement type MOSFETs use an electrical field produced by a gate voltage to alter the flow of charge carriers, electrons for N-channel or holes for P-channel, through the semi-conductive drain-source channel. The gate electrode is placed on top of a very thin insulating layer and there are a pair of small N-type regions just under the drain and source electrodes. The gate of a JFET must be biased in such a way as to forward-bias the PN-junction but with a insulated gate MOSFET device no such limitations apply so it is possible to bias the gate of a MOSFET in either polarity, positive or negative. This makes MOSFETs especially valuable as electronic switches or to make logic gates because with no bias they are normally non-conducting and this high gate input resistance means that very little or no control current is needed as MOSFETs are voltage controlled devices. Both the P-channel and the N-channel MOSFETs are available in two basic forms, the Enhancement type and the Depletion type.

2.7 **Thyristor**

2.7.1. The thyristor is a four-layer, three terminal semiconducting device, with each layer consisting of alternately N-type or P-type material, for example P-N-P-N. The main terminals anode and cathode, are across the full four layers, and the control terminal, called the gate, is attached to p-type material near to the cathode. (A variant called an SCS—Silicon Controlled Switch—brings all four layers out to terminals.) The operation of a thyristor can be understood in terms of a pair of tightly coupled bipolar junction transistors, arranged to cause the self-latching action:

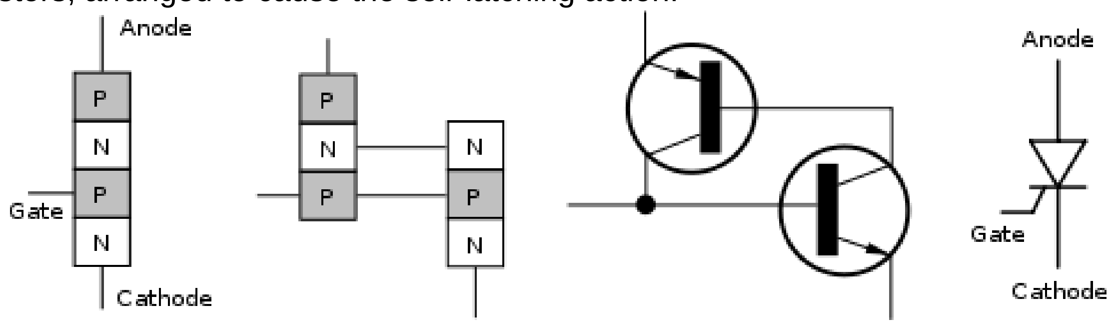


Fig 2.10 Symbol and Construction of a Thyristor

2.7.2. Thyristors have three states:

(a) Reverse blocking mode — Voltage is applied in the direction that would be blocked by a diode

(b) Forward blocking mode — Voltage is applied in the direction that would cause a diode to conduct, but the thyristor has not yet been triggered into conduction

(c) Forward conducting mode — Thethyristor has been triggered into conduction and will remain conducting until the forward current drops below a threshold value known as the "holding current"

2.7.3. The thyristor has three p-n junctions (serially named J_1, J_2, J_3 from the anode) as shown in Fig 2.11.

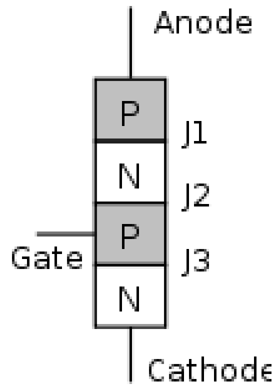


Fig 2.11 Layer Diagram of Thyristor.

2.7.4. When the anode is at a positive potential V_{AK} with respect to the cathode with no voltage applied at the gate, junctions J_1 and J_3 are forward biased, while junction J_2 is reverse biased. As J_2 is reverse biased, no conduction takes place (Off state). Now if V_{AK} is increased beyond the breakdown voltage V_{BO} of the thyristor, avalanche breakdown of J_2takes place and the thyristor starts conducting (On state).

2.7.5. If a positive potential V_G is applied at the gate terminal with respect to the cathode, the breakdown of the junction J_2 occurs at a lower value of V_{AK}. By selecting an appropriate value of V_G, the thyristor can be switched into the on state suddenly. Once avalanche breakdown has occurred, the thyristor continues to conduct, irrespective of the gate voltage, until: (a) the potential V_{AK} is removed or (b) the current through the device (anode−cathode) is less than the holding current specified by the manufacturer.

2.7.6. Thyristors are mainly used where high currents and voltages are involved, and are often used to control alternating currents, where the change of polarity of the current causes the device to switch off automatically; referred to as Zero Cross operation. The device can be said to operate *synchronously* as, once the device is open, it conducts current in phase with the voltage applied over its cathode to anode junction with no further gate modulation being required to replicate; the device is biased *fully on*. This is not to be confused with symmetrical operation, as the output is unidirectional, flowing only from cathode to anode, and so is asymmetrical in nature.

2.7.7. Thyristors are used as the control elements for phase angle triggered controllers, also known as phase fired controllers. They can also be found in power supplies for digital circuits, where they are used as a sort of circuit breaker or crowbar to prevent a failure in the power supply from damaging downstream components. A thyristor is used in conjunction with a zener diode attached to its gate, and when the output voltage of the supply rises above the zener voltage, the thyristor will conduct, then short-circuit the power supply output to ground (and in general blowing an upstream fuse).

2.7.8. Thyristors associated with triggering DIAC are used in stabilized power supplies within color television receivers Thyristors have been as lighting dimmers in television, motion pictures, and theater, where they replaced inferior technologies such as autotransformers and rheostats. They have also been used in photography as a critical part of flashes (strobes).

2.8 **DIAC**

2.8.1. The DIAC (diode for alternating current) is a diode that conducts current only after its breakovervoltage has been reached momentarily.

2.8.2. When this occurs, diode enters the region of negative dynamic resistance, leading to a decrease in the voltage drop across the diode and, usually, a sharp increase in current through the diode. The diode remains "in conduction" until the current through it drops below a value characteristic for the device, called the holding current. Below this value, the diode switches back to its high-resistance (non-conducting) state. This behavior is bidirectional, meaning typically the same for both directions of current.

2.8.3. Most DIACs have a three-layer structure with breakover voltage around 30 V. DIACs have no gate electrode, unlike some other thyristors that they are commonly used to trigger, such as TRIACs. Some TRIACs, like Quadrac, contain a built-in DIAC in series with the TRIAC's "gate" terminal for this purpose.

2.8.4. DIACs are also called *symmetrical trigger diodes* due to the symmetry of their characteristic curve. Because DIACs are bidirectional devices, their terminals are not labeled as *anode* and *cathode* but as A1 and A2 or MT1 (Main Terminal) and MT2.

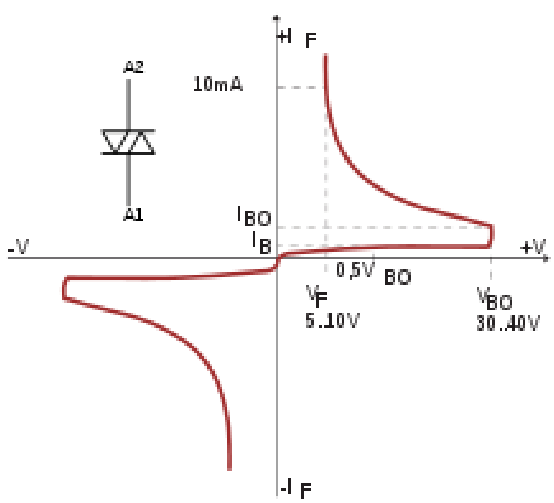
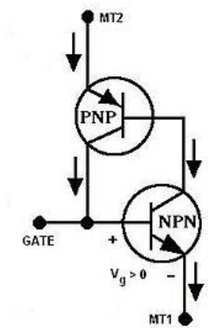


Fig 2.12 V-I Characteristics of DIAC

2.9 **TRIAC**

2.9.1. TRIAC (Triode for Alternating Current)isan electronic component which can conduct current in either direction when it is triggered (turned on), and is formally called a bidirectional triode thyristor or bilateral triode thyristor.

2.9.2. A TRIAC is approximately equivalent to two complementary unilateral thyristors (one is anode triggered and another is cathode triggered SCR) joined in anti-parallel



(paralleled but with the polarity reversed) and with their gates connected together. It can be triggered by either a positive or a negative voltage being applied to its *gate* electrode (with respect to A1, otherwise known as MT1). Once triggered, the device continues to conduct until the current through it drops below a certain threshold value, the holding current, such as at the end of a half-cycle of alternating current (AC) mains power. This makes the TRIAC a very convenient switch for AC circuits, allowing the control of very large power flows with milliampere-scale control currents. In addition, applying a trigger pulse at a controllable point in an AC cycle allows one to control the percentage of current that flows through the TRIAC to the load (phase control).

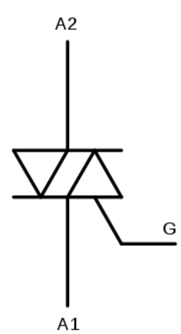


Fig 2.13 TRIAC

2.9.3. Low power TRIACs are used in many applications such as light dimmers, speed controls for electric fans and other electric motors, and in the modern computerized control circuits of many small and major household appliances.

2.10 **Questions**

2.1. What do you mean by current operated and voltage operated devices? Give examples.
2.2. How are FETs and MOSFETs used as switches?
2.3. What do you mean by Depletion mode and Enhancement mode MOSFETs?
2.4. List down 03 possible applications of a thyristor/ SCR onboard ships.

2.5. **Suggested Reading**

Power Electronics – PS Bhimraw
Chapter 2
Chapter 4

CHAPTER-3

RADAR ENGINEERING

3.1 Introduction

Radar is an object-detection system which uses radio waves to determine the range, altitude, direction, or speed of objects. It can be used to detect aircraft, ships, spacecraft, guided missiles, motor vehicles, weather formations, and terrain. The radar dish or antenna transmits pulses of radio waves or microwaves which bounce off any object in their path. The object returns a tiny part of the wave's energy to a dish or antenna which is usually located at the same site as the transmitter. Radar was developed in secret in nations across the world during World War II. The term radar is derived from the phrase "*Radio Detection and Ranging*". The modern uses of radar are highly diverse, including air traffic control, radar astronomy, air-defense systems, antimissile systems; marine radars to locate landmarks and other ships; aircraft anti-collision systems; ocean surveillance systems, outer space surveillance and rendezvous systems; meteorological precipitation monitoring; altimetry and flight control systems; guided missile target locating systems; and ground-penetrating radar for geological observations. High tech radar systems are associated with digital signal processing and are capable of extracting objects from very high noise levels. A radar system has a transmitter that emits radio waves called *radar signals* in predetermined directions. When these come into contact with an object they are usually reflected and/or scattered in many directions. Radar signals are reflected especially well by materials of considerable electrical conductivity—especially by most metals, by seawater, by wet land, and by wetlands. The radar signals that are reflected back towards the transmitter are the desirable ones that make radar work. If the object is *moving* either closer or farther away, there is a slight change in the frequency of the radio waves, caused by the Doppler effect. Although the reflected radar signals captured by the receiving antenna are usually very weak, these signals can be strengthened by the electronic amplifiers. The weak absorption of radio waves by the medium through which it passes is what enables radar sets to detect objects at relatively long ranges—ranges at which other electromagnetic wavelengths, such as visible light, infrared light, and ultraviolet light, are too strongly attenuated. The maximum range of conventional radar can be limited by a number of factors including:-

(a) Line of sight, which depends on height above ground.

(b) The maximum non-ambiguous range which is determined by the pulse repetition frequency. The maximum non-ambiguous range is the distance the pulse could travel and return before the next pulse is emitted.

(c) Radar sensitivity and power of the return signal as computed in the radar equation. This includes factors such as environmental and the size (or radar cross section) of the target.

3.2 The distance or range to the target is determined by measuring the time T_R taken by the pulse to travel to the target and return. Since electromagnetic energy propagates at the speed of light c=3 x 10^8 m/s, the range R is

$$R = c\, T_R/2$$

The factor 2 appears in the denominator because of the two-way propagation of radar. With the range in kilometers or nautical miles, and TR in microseconds, the equation becomes

$$R\ (\text{km}) = 0.15\ T_R\ (\mu\text{sec}) \quad \text{or} \quad R\ (\text{nm}) = 0.081\ TR\ (\mu\text{sec})$$

Each microsecond of round-trip travel time corresponds to a distance of 0.081 nautical mile, 0.093 statute mile, 150 meters, 164 yards, or 492 feet.

3.3 The basic principle of radar is illustrated in Figure 3.1. A transmitter generates an electromagnetic signal (such as short pulse of sine wave) that is radiated into space by an antenna. A portion of the transmitted energy is intercepted by the target and reradiated in many directions. The re-radiation directed back towards the radar is collected by the radar antenna, which delivers it to a receiver. There, it is processed to detect the presence of the target and determine its location. A single antenna is usually used on a time shared basis for both transmitting and receiving when the radar waveform is a repetitive series of pulses. The range, or distance, to a target is found by measuring the time it takes for the radar signal to travel to the target and return back to the radar. The target's location in angle can be found out from the direction the narrow-beam width radar antenna points when the received echo signal is of maximum amplitude.

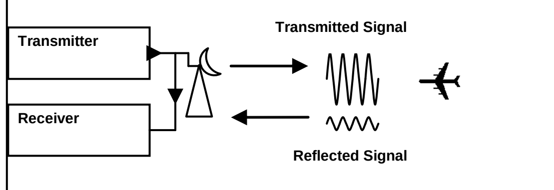


Figure 3.1: Basic Principle of Radar

3.4 **Classification Of Radars**

3.4.1 **Based On Operation:** Depending on the principle of their operation the radars may be classified into:-

a) Pulse Radar

i. Search Radar
ii. Tracking Radar

b) <u>CW Radar</u>

i. CW Doppler Radar
ii. FMCW Radar

c) <u>Moving Target Indication Radar</u>

i. MTI Radar
ii. Pulse Doppler Radar

d) <u>Array Radars</u>

i. Phased array
ii. Planar array

3.4.2 **Based On Application:** Radars in Navy may be classified based on their application

(a) Surveillance or Early Warning Radar

(b) Navigation Radar

(c) Gunnery Radar and tracking radar

3.5 Radar Frequencies

3.5.1 Conventional radars generally operate in what is called the microwave region (a term not rigidly defined. Operational radars in the past have been at frequencies ranging from about 100 MHz to 36 GHz, which covers more than eight octaves. These are not necessarily the limits. Operational HF over the horizon of radar does operate at frequencies as low as a few megahertz. At the other end of the spectrum, experimental millimeter wave radars have been at frequencies higher than 240 GHz.

3.5.2 Initially, letter codes such as S, X and L were used to designate the distinct frequency bands at which microwave radar was being developed. The original purpose was to maintain military secrecy; but the letter designations were continued as convenient shorthand means to readily denote the region of the spectrum at which radars operated. The list of Radar frequency letter band designations approved by IEEE standard is given in the table. These are related to the specific frequency allocations assigned by the International Telecommunications Union (ITU) for radiolocation, or radar. For example, L band officially extends from 1000 MHz to 2000 MHz, but L-band radar is only allowed to operate within the region from 1215 to 1400 MHz since that is the band assigned by the ITU.

3.5.3 **<u>List Of Radar Frequencies</u>**

(i) The Radar frequencies are classified as follows:

Band Designation	**Nominal Frequency Range**	**Specific Frequency Ranges for Radar based on ITU**
L	1 – 2 GHz	1215 – 1400 MHz
S	2 – 4 GHz	2300 – 2500 MHz 2700 – 3700 MHz
C	4 – 8 GHz	5250 – 5925 MHz
X	8 – 12 GHz	8500 – 10,680 MHz
Ku	12 – 18 GHz	13.4 – 14.0 GHz 15.7 – 17.7 GHz

(ii) The New Radar frequencies band has been introduced as below: -

Band Designation	**Nominal Frequency Range**
A	0 – 250 MHz
B	250 – 500 MHz
C	500 – 1000 MHz
D	1 – 2 GHz
E	2 -3 GHz
F	3 – 4 GHz
G	4 – 6 GHz
H	6 – 8 GHz
I	8 – 10 GHz
J	10 – 20 GHz
K	20 – 40 GHz
L	40 – 60 GHz
M	60 – 100 GHz

3.6 **Block Diagram For Pulse Radar**The operation of a pulse radar may be described with the aid of the simple block diagram as shown in the figure 3.2. The Block diagram may be divided into different sections namely Transmitter, Receiver, Display and Antenna assembly. The functions of different blocks are covered in the succeeding paragraphs

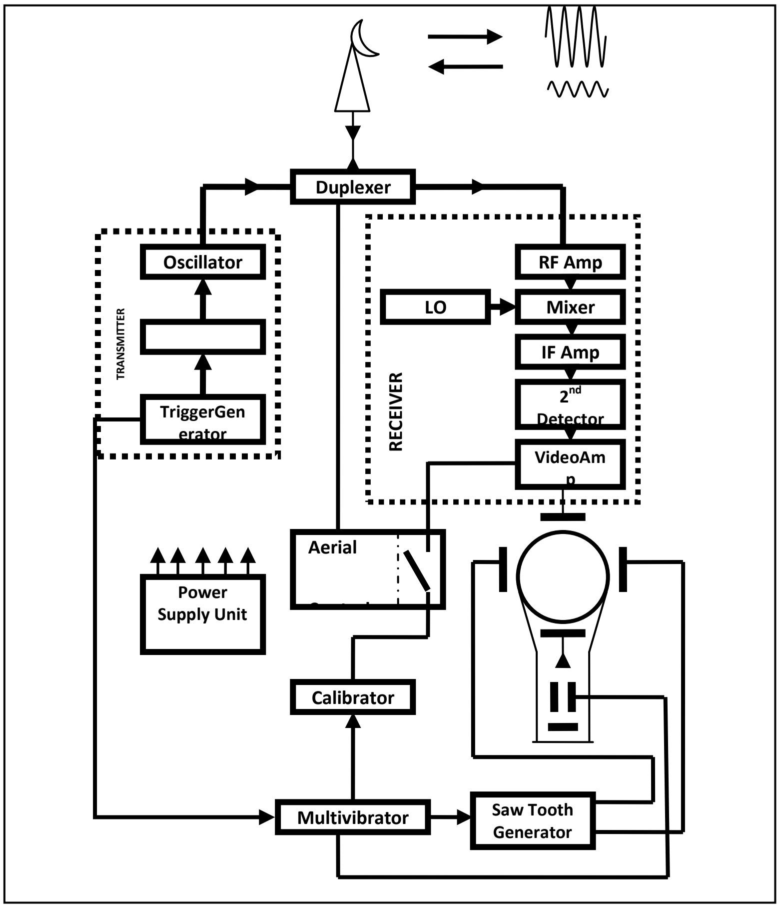


Figure 3.2 Basic Block Diagram of Pulse

3.6.1 **Transmitter** The transmitter in radar generates High power pulses of short duration that are fed to antenna through duplexer for transmission into free space. The transmitter consists of mainly three units viz. Trigger Unit, Modulator and Oscillator.

(a) **Trigger Unit:** The trigger unit generates impulses of very short duration which are used to trigger the modulator. The trigger is also applied to the display which initiates the saw tooth generator through a multivibrator. The trigger unit is also called as the Synchroniser. It is the main unit that synchronises all the sub units of a radar system.

(b) **Modulator:** The modulators main function is to turn the transmitter (High Power Oscillator or Power Amplifier) on or off in synchronism with the trigger pulses. In pulse radar, a modulator block decides the pulse width of the transmitted pulse. In pulse radar the modulator is more specifically known as Pulse Modulator. A modulator converts low power pulses of trigger unit into high power flat pulses that are used to turn the transmitter on and off.

(c) **Oscillator:** The oscillator is a high power, high frequency oscillator, such as magnetron. It is switched on and off by a modulator. A power amplifier is preferred over an oscillator when high average power is necessary, when other than simple pulse waveforms are required, or when good performance is needed in detecting moving targets.

3.6.2 **Antenna Assembly** An Antenna assembly is considered as having two main units namely Antenna and T/R Switch.

(a) **T/R Switch:** A transmit-receive switch controls the transmitting and receiving operations, permitting the use of only one antenna for both transmitting and receiving purposes and is more commonly known as Duplexer. During transmission, it connects the transmitter to the antenna and isolates the sensitive receiver from the damage due to high power transmitter pulses. In the interval between the pulses, during which the reflected energy is being received, the duplexer connects the antenna to the receiver. A T/R switch is generally located near the transmitter unit, and not near the antenna.

(b) **Antenna:** Antenna is a device that matches the impedance of the EM waves to the atmosphere. The antenna is used to radiate the EM waves from Oscillator or power amplifier into the air. The same antenna is used to receive the reflected echo of the target and feed it to the receiver.

3.6.3 **Receiver** The receiver is almost always a super heterodyne. This section of radar does most of the signal processing on the received echo to identify the target to its best. The receiver consist of various stages namely RF Amplifier, Mixer, IF amplifier, 2nd Detector, Video amplifier and a local oscillator. The function of different modules in a receiver follows in the succeeding paragraphs:

(a) **RF Amplifier:** The first stage of a super heterodyne receiver for radar application can be a transistor amplifier. An RF stage is a low noise amplifier that improves the weak signal received by the antenna. In some of the radar systems (mostly older ones) this stage is seldom employed, instead the signal is directly fed to the mixer stage. However, achieving a low noise amplifier is no longer the problem it once was, and now almost all the modern radars include the first stage as RF amplifier.

(b) **Mixer:** Whether or not it is used as the front-end, the mixer is a key element in super heterodyne receiver. The mixer converts RF signal to IF signal. It receives two inputs, one form RF amplifier and the other from Local Oscillator, and provides a beat frequency of the two. The desired beat frequency is called the Intermediate Frequency or more commonly as IF.

(c) **Local Oscillator:** A Reflex Klystron is usually used as a local oscillator in radar system. It is a low power, high frequency oscillator. The local oscillator frequency is made almost always higher (Why?) than the received RF.

(d) **IF Amplifier:** This stage is employed to amplify the weak IF signal from mixer stage. It generally employs two or three stages to improve the echo level.

(e) **2^{nd} Detector:** The 2^{nd} detector is used to detect the presence or absence of the signal. It is called 2^{nd} detector as the mixer is in fact the first detector stage.

(f) **Video Amplifier:** The video amplifier amplifies the detected signal and feeds it to the Display.

(g) **Indicator:** Different types of Indicators are available for viewing various parameters of the target through the received echo. Choice of display is one of the important factors in design of Radar.

3.6.4 **Display** A display unit is an essential part in itself. It is a different technology in itself. The Radar provides a video output which is further processed by Display system. It consists of few supporting units to view the echo of the screen of a CRT. Modern displays often employ LCD screen for Presentation of target echo. A display using CRT is assisted by a Multivibrator that produces square or rectangular pulses, a Saw tooth generator to produce the trace on the CRT screen and sometimes a calibrator to generate range rings or range markers on the display. There are various other units used in the Display system that assist in giving the best possible information from the received echo.

3.7 The different Radar parameters are defined as under:-

(a) **Range to a Target** The time for the signal to travel to a target located at a range R and return back to the radar is 2R/c. The range to a target is then

$$R = \frac{cT_R}{2}$$

With range in kilometers or in nautical miles, and T is microseconds, it becomes

R (km) = 0.15 $\mathbf{T_R}$ (μsec) or R (nmi) = 0.081 $\mathbf{T_R}$ (μsec)

Therefore it follows that

(i) 150 meters = 164 yards = 492 feet = 0.081 nmi = 0.093 statute mile.

(ii) It takes 12.35 μsec for radar Pulse to travel a nautical mile and back.

(b) **Range Ambiguity:** Once a signal is radiated into space by radar, sufficient time must elapse to allow all echo signals to return to the radar before the next pulse is transmitted. The rate at which pulses may be transmitted, therefore, is determined by the longest range at which targets are expected. If the time between pulses, say T_p, is too short, an echo signal from a long range target might arrive after the transmission of the next pulse and be mistakenly associated with that pulse (the next pulse) rather than the actual pulse transmitted earlier. This results in **Range Ambiguity** i.e. doubtful range.

(c) **Second time echoes:** Echoes that arrive after the transmission of the next pulse are called **second-time-around** echoes (or multiple-time-around echoes)

(d) **Maximum Unambiguous Range:** The range beyond which targets appear as second-time-around echoes is the **maximum unambiguous range**, R_{unamb} and is given by

$$R_{unamb} = \frac{cT_p}{2} = \frac{c}{2f_p}$$

(e) **Pulse Length:** In a Pulse Radar, the transmitter is switched ON and OFF alternately to measure the range of a target. The time for which the Radar Transmitter is kept ON is called the Pulse Length. It is specified in seconds

(f) **Pulse Repetition Time:** The time between two consecutive pulses is termed as Pulse Repetition Time or simply PRT. It is measured in seconds

(g) **Pulse Repetition frequency:** The number of pulses transmitted in one second is called as the Pulse Repetition Frequency or simply PRF. It is given in Hertz(Hz)

(h) **Peak Power:** The peak amplitude of the transmitted pulse is called the peak Power of the Radar. It is calculated in Watts.

(j) **Average Power:** The transmitter peak power averaged over the Pulse Repetition Time (PRT). It is also measured in watts and can be calculated by

$$\textbf{Average Power } (P_{avg}) = \frac{\textbf{Peak Power } (P_p) \textbf{ x Pulse Width (PW)}}{\textbf{Pulse Repetition Time (PRT)}}$$

(k) **Duty Cycle:** The ratio of the total time the radar is radiating to the total time it could have radiated is termed as Duty Cycle. The duty cycle can be found by:

$$\textbf{Duty Cycle} = \frac{\textbf{Pulse Length } (\tau) \text{ OR } \tau \times f_p}{\textbf{Pulse Repetition Time } (T_p)}$$

OR

$$\frac{\textbf{Average Power } (P_{avg})}{\textbf{Peak Power } (P_p)}$$

(l) **Data Rate:** Data Rate is the Hits per Scan.

(m) **Antenna Rotation Rate:** It is the number of rotation taken by Radar Antenna in one second. It is declared in RPM.

(n) **Echo**: The reflected signal from the target is termed as the echo signal that is processed by the radar receiver. It is given in Watts.

(p) **Minimum Detectable Signal**: It is the minimum power of the reflected signal at which the radar is able to identify the presence of a target. It is given in watts.

(q) **Frequency:** Cycles per Second

(r) **Range Resolution:** It is the ability of Radar systems to separate (distinguish) two targets whose distance from each other differs only slightly. If a pulse of 1 μsec is used this means that echoes returning from separate targets that are 1μsec apart in time (I.e. about 300 m in distance) will merge into one returned pulse and will not be separated. It is seen that the range resolution is no better that 300 mtrs.

(s) **Bearing Resolution:** It is the ability of Radar systems to separate (distinguish) two targets whose angular distance from each other differs only slightly. That is the targets are at same distance but different bearing. It is also called as the angular resolution and is dictated by the beamwidth of the antenna. IF the beamwidth is 2^0, then two separate targets that are less than 2^0 apart will appear as one target and will therefore not be resolved.

3.8 Factors Governing Pulse Characteristics

(a) **Pulse Shape Requirement:** An ideal radar pulse is expected to have vertical sides and flat tops. The Leading edge of the transmitted pulse must be vertical to ensure that the leading edge of the received pulse is also close to vertical. Otherwise, ambiguity will exist as to the precise instant at which the pulse has been returned, and therefore inaccuracies will creep into the exact measurement of the target range. A flat top is required for the voltage pulse applied to the magnetron anode; otherwise its frequency will be altered. It also is needed because the efficiency of the magnetron, multicavity klystron or other amplifier drops significantly if the supply voltage is reduced. A steep trailing edge is needed for the transmitted pulse, so that the duplexer can switch the receiver over to the antenna as soon as the body of the pulse has passed. It may sometime therefore limit the minimum range of the radar.

(b) **PRF Requirement:** To achieve maximum unambiguous range the Radar should not only be able to detect pulses returning from distant targets but also allow them time to return before the next pulse is transmitted. However, this is also true that the greater the number of pulses reflected from a target, the greater is the probability of distinguishing this target from noise (Ambiguous range). Since the antenna moves at a significant speed in many types of radar and yet it is necessary to receive several pulses from a given target, a lower limit on the pulse repetition frequency clearly exists.

(c) **Pulse Width Requirement**: If a short minimum Range (Dead Range) is required, then short pulses must be transmitted. A shorter pulse also improves range resolution. However, short pulses cannot travel longer distances and moreover the receiver bandwidths must be increased as pulses are made narrower. It is found that if τ is the pulse length in μsec then the bulk of pulse energy is contained in a frequency bandwidth of $2/\tau$MHz. Larger receiver bandwidth means more noise. A longer pulse is therefore sometimes suitable though with a poor range resolution. Further, for a pulse to travel a longer distance it needs larger power. It may be achieved by increasing the peak pulse power, but only at the expense of cost, size and power consumption. It is revealed that the maximum range depends on the pulse energy rather than on its peak power. Therefore, increase in range can be achieved by increasing the pulse width and thus additionally resulting in reduction of receiver bandwidth. Briefly, a shorter pulse length means good range resolution, good minimum range, less pulse power however, shorter range and larger receiver bandwidth. Whereas, a longer pulse length though have higher power requirement and poor range resolution/minimum range it is advantageous for larger range and lower receiver bandwidth.

3.9 Factors influencing maximum range

(a) **Effect of Transmitted power (Pt)**: The maximum range is proportional to the fourth root of the peak transmitted pulse power. The peak power must be increased sixteen fold, all else being constant, if a given maximum range is to be doubled.

(b) **Effect of Minimum Detectable Signal (S_{min})**: An alternative to above is to reduce the minimum detectable signal. This may make the receiver more susceptible to jamming and interference, because it now relies more on its ability to amplify weak signals (which could include the interference), and less on the sheer power of the transmitted and received pulses.

(c) **Effect of Antenna Aperture:** It can be seen the radar range equation that the maximum range is proportional to antenna diameter if the wavelength remains constant. It is thus apparent that possible the most effective means of doubling a given maximum range is to double the effective diameter of the antenna. Alternatively, a reduction in the wavelength i.e. increase the frequency will also give the same effect. But it is not as easy as it sounds. There is a limit here also, any increase in diameter-to-wavelength ratio will reduce the beam width which may be good for gunnery radar but is disadvantageous for a Surveillance or search radar.

(d) **Effect of Target Area:** The maximum radar range depends on the target area as might be expected. However, this is not under the control of either the designer, or maintainer or the user.

3.9 Some important terms used in Radar include:-

(a) **<u>Polarization</u>.** In the transmitted radar signal, the electric field is perpendicular to the direction of propagation, and this direction of the electric field is the polarization of the wave. Radars use horizontal, vertical, linear and circular polarization to detect different types of reflections. For example, circular polarization is used to minimize the interference caused by rain. Linear polarization returns usually indicate metal surfaces. Random polarization returns usually indicate a fractal surface, such as rocks or soil, and are used by navigation radars.

(b) **<u>Noise</u>**. Signal noise is an internal source of random variations in the signal, which is generated by all electronic components. Noise typically appears as random variations superimposed on the desired echo signal received in the radar receiver. The lower the power of the desired signal, the more difficult it is to discern it from the noise. Noise figure is a measure of the noise produced by a receiver compared to an ideal receiver, and this needs to be minimized.

(c) **<u>Interference</u>.** Radar systems must overcome unwanted signals in order to focus only on the actual targets of interest. These unwanted signals may originate from internal and external sources, both passive and active. The ability of the radar system to overcome these unwanted signals defines its signal-to-noise ratio (SNR). SNR is defined as the ratio of a signal power to the noise power within the desired signal.

(d) **<u>Clutter</u>** Clutter refers to radio frequency (RF) echoes returned from targets which are uninteresting to the radar operators. Such targets include natural objects such as ground, sea, precipitation (such as rain, snow or hail), sand storms, animals (especially birds), atmospheric turbulence, and other atmospheric effects, such as ionosphere reflections, meteor trails, and three body scatter spike. Clutter may also be returned from man-made objects such as buildings and, intentionally, by radar countermeasures such as chaff.Radar multipath echoes from a target cause ghosts to appear.Clutter may also originate from multipath echoes from valid targets caused by ground reflection, atmospheric ducting or ionospheric reflection/refraction (e.g. Anomalous propagation).

(e) **Jamming.** Radar jamming refers to radio frequency signals originating from sources outside the radar, transmitting in the radar's frequency and thereby masking targets of interest. Jamming may be intentional, as with an electronic warfare tactic, or unintentional, as with friendly forces operating equipment that transmits using the same frequency range. Jamming is considered an active interference source, since it is initiated by elements outside the radar and in general unrelated to the radar signals.

3.10 Questions

3.10.1. List the bands and their frequency ranges commonly used in Radar.

3.10.2. What are the components required for design of a Radar.

3.10.3. Classify Radars on the basis of mode of operation and mode of application.

3.10.4. Explain the basic working of Radar with block diagram.

3.10.5. Define Duty Cycle, Average power and Peak power.

3.10.6. Explain Range and Bearing resolution.

3.10.7. What are the pulse requirements for better range resolution?

3.10.8. List down factors affecting maximum range of Radar.

3.10.9. What is noise and clutter?

3.10.10. How does polarization help improve Radar performance?

3.11 Suggested Reading

Introduction to Radar Systems – ML Skolnik
Chapter 1

VP 132:- Basic Radar

CHAPTER-4

COMMUNICATION ENGINEERING

4.1 Introduction

4.1.1 The term Communications in a broad sense refers to the sending, receiving and processing of information by electronic means. The process started with wire telegraphy in the eighteen forties, developing with Telephony some decades later and Radio at the beginning of last century. Communication was made possible by the invention of the triode tube and was greatly improved in terms of technology, by the work done during World War II. Subsequently, it became even more widely used and refined through the invention and use of the transistor, integrated circuits and other semiconductor devices. More recently, the use of digital technology, including digital signal processing and computerized algorithms have made Communications even more widespread, with an increasing emphasis on computer and other data communications. The fall out of all these advancements in the Defence field has led the technology to the realm of 'Network Centric Warfare', which has the communication as it backbone.

4.1.2 A modern Communications system is first concerned with the sorting, processing and sometimes storing of information before its transmission. The actual transmission then follows, with further processing and the filtering of noise. Finally we have reception, which may include processing steps such as decoding, storage and interpretation.

4.2. Communication System

4.2.1. A communication system can be divided into three broad categories: transmitting equipment, receiving equipment, and terminal equipment. Transmitting equipment generates, amplifies, and modulates a transmitted signal. Receiving equipment receives a radio wave, then amplifies and demodulates it to extract the original intelligence. Terminal equipment is used primarily to convert the audio signals of encoded or data transmission into the original intelligence. The transmitting equipment creates a radio-frequency (RF) carrier and modulates it with audio intelligence to produce an RF signal. This RF signal is amplified and fed to the transmitting antenna, which converts it to electromagnetic energy for propagation. The receiving antenna converts the portion of the electromagnetic wave it receives into a flow of alternating RF currents. The receiver then converts these currents into the intelligence that was contained in the transmission. Terminal equipment is used primarily where coded transmissions are employed, to convert the modulated signal into the original intelligence. Figure 4.1 represents basic communication equipment.

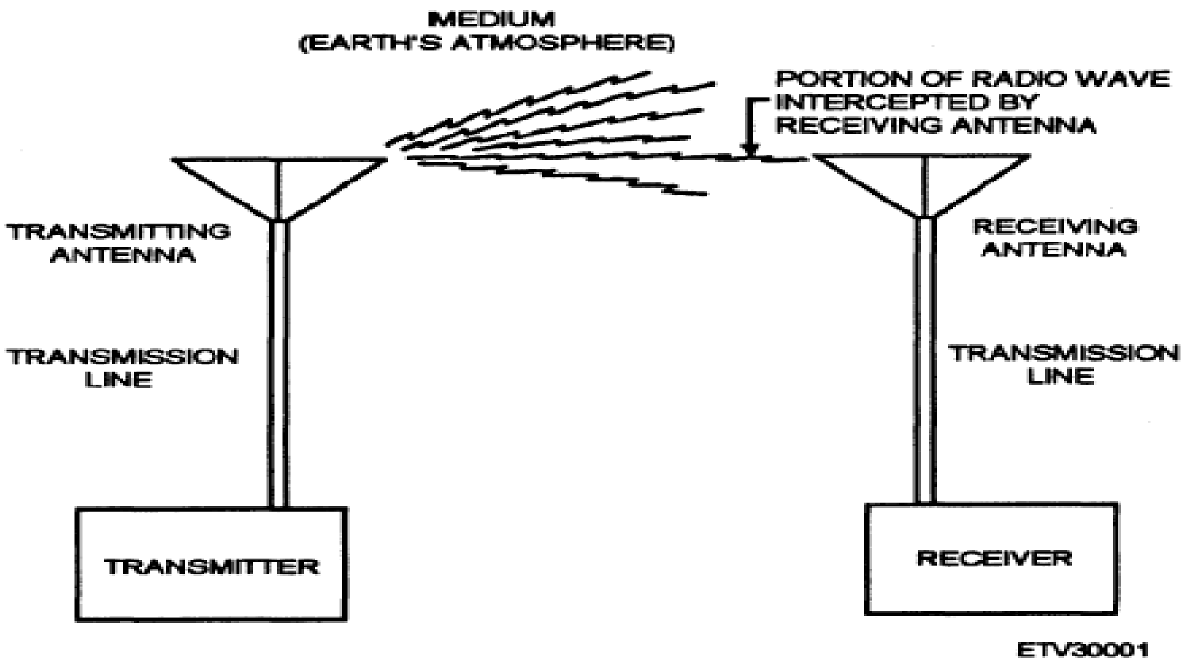


Fig 4.1 Basic Communication system Block Diagram

4.2.2. **Transmitter**For RF communications to take place, a signal has to be generated. Generating the signal is the job of the transmitter. Equipment used for generating, amplifying, and transmitting an RF carrier is collectively called a radio transmitter. Transmitters may be simple, low-power units, for sending voice messages a short distance or highly sophisticated, using thousands of watts of power for sending many channels of data (voice, teletype, telemetry, etc) over long distances. Basic transmitters are identified by their method of modulation: Continuous Wave (CW), Amplitude Modulation (AM), Frequency Modulation (FM), or Single Side Band (SSB). The basic Transmitter block diagram is explained in Figure 4.2.

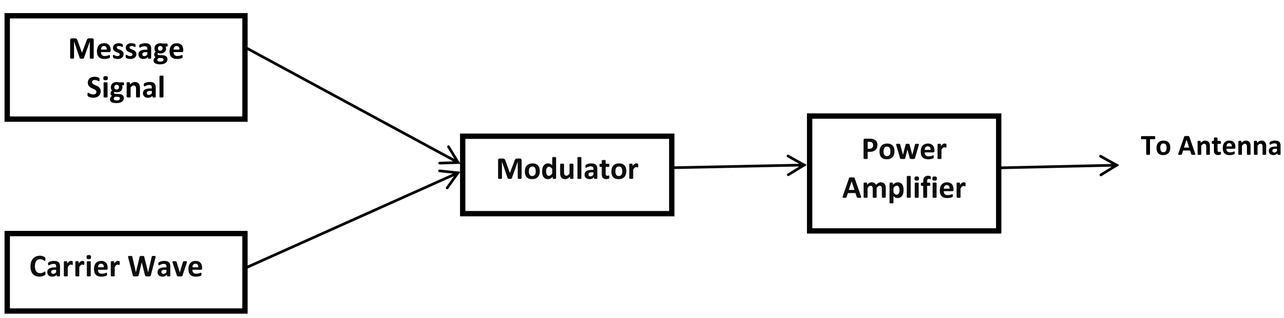


Fig 4.2 Basic Transmitter Block Diagram

4.2.3. **Receiver**

4.2.3.1. A receiver processes modulated signals and delivers, as an output, a reproduction of the original intelligence. The signal can then be applied to a reproducing device, such as a loudspeaker or a teletypewriter. To be useful, a receiver must perform certain basic functions. These functions are reception, selection, detection, and reproduction. Reception occurs when a transmitted electromagnetic wave passes through the receiver antenna and induces a voltage in the antenna. Selection is the ability to distinguish a particular station's frequency from all other station frequencies appearing at the antenna. Detection is the extraction of the modulation from an RF signal. Circuits that perform this function are called detectors. Different forms of modulation require different detector circuits. Reproduction is the action of converting the electrical signals to sound waves that can be interpreted by the ear. The basic Superhetrodyne receiver is explained in Figure 4.3.

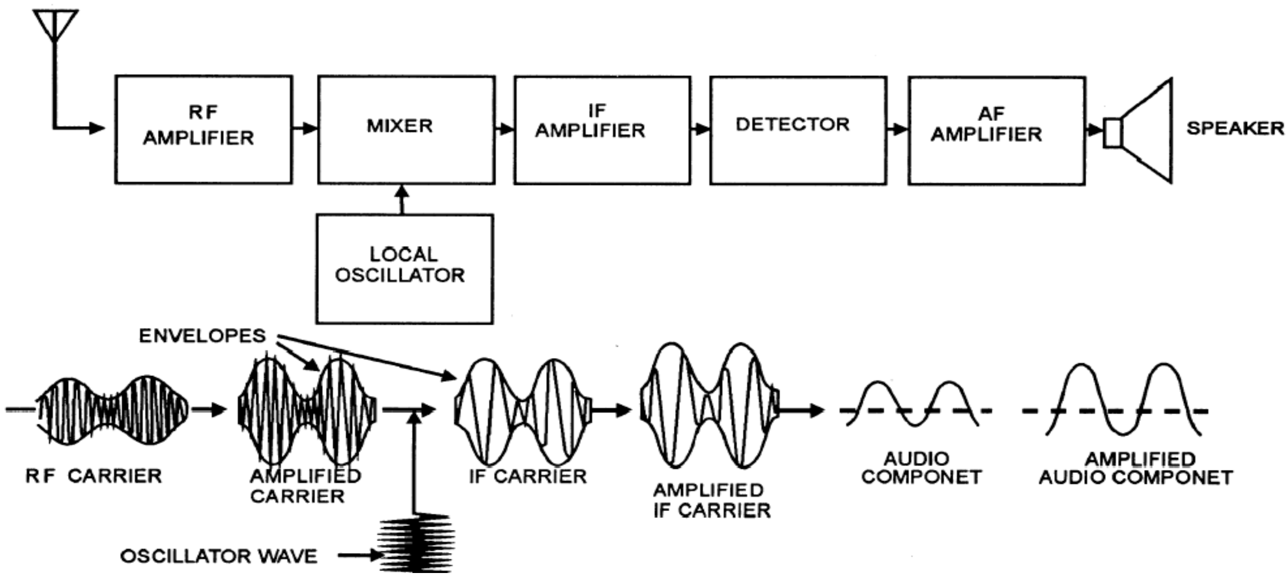


Fig 4.3 Basic SuperhetrodyneReceiver

4.2.3.2 The reasons for use of superheterodyne receiver is that the received frequency will be the same as transmitted frequency and therefore would be of a higher range in the order of hundreds of MHz or GHz. Signal processing and demodulation is extremely complicated at such high frequencies since it is cumbersome to design the electronics with clock synchronisation at such high frequencies. The superheterodyne receiver ensures down-conversion of received frequencies so as to enable easy signal processing and filtering process at nominal Intermediate frequency.One problem, which has to be contended within the superheterodyne receiver, is its ability to pick up a second or imagefrequency removed from the signal frequency by a value

> **Remember:** Image Frequency is the frequency available at Mixer input arising due to combination of harmonics of LO and received frequencies. This image frequency gives rise to distortion in IF stage signal processing since it will have spurious amplitudes in IF frequency range.

equal to twice the IF. To illustrate the point, refer Figure 4.4. In this example, we have a signal frequency of 1 MHz which mix to produce an IFof455kHz. A second or image signal, with a frequency equal to 1 MHz plus (2 x 455) kHz or 1.910 MHz, can also mix with the 1.455 MHz to produce the 455 kHz. Reception of an image signal is obviously undesirable and a function of the RF tuned circuits (ahead of the mixer), is to provide sufficient selectivity to reduce the image sensitivity of the receiver to tolerable levels.

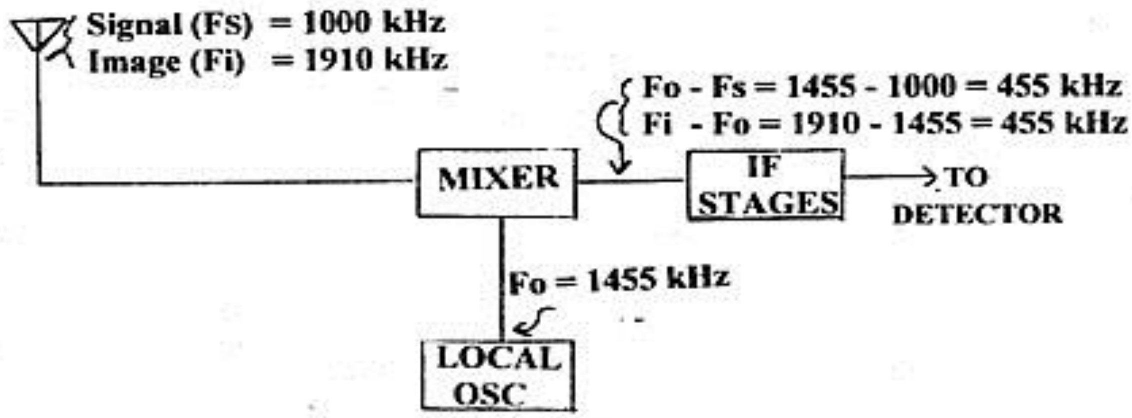


Figure 4.4 An illustration of how image frequency provides a second mixing product.

4.2.3.3 **Receiver Characteristics** Understandingreceiver characteristics are mandatory in determining operational condition and for comparing receivers. Important receiver characteristics are sensitivity, noise, selectivity, and fidelity.

(a) Sensitivity. Sensitivity is a measure of receiver's ability to reproduce very weak signals. The weaker the signal that can be applied and still produce a certain signal-to-noise (S/N) ratio, the better that receiver's sensitivity rating. Usually, sensitivity is specified as the signal strength in microvolts necessary to cause a S/N ratio of 10 dB.

(b) Noise. All receivers generate noise. Noise is the limiting factor on the minimum usable signal that the receiver can process and still produce a usable output. Expressed in decibels, it is an indication of the degree to which a circuit deviates from the ideal; a noise figure of 0 decibels is ideal.

(c) Selectivity. Selectivity is the ability of a receiver to distinguish between a signal at the desired frequency and signals at adjacent frequencies. The better the receiver's ability to exclude unwanted signals, the better its selectivity. The degree of selectivity is determined by the sharpness of resonance to which the frequency determining components (bandpass filters) have been engineered and tuned. Measurement of selectivity is usually done by taking a series of sensitivity readings in which the input signal is stepped along a band of frequencies above and below resonance of the receiver's circuits. As the frequency to which the receiver is tuned is approached, the input level required to maintain a given output will fall. As the tuned frequency is passed, the input level will rise. Input levels are then plotted against frequency. The steepness of the curve at the tuned frequency indicates the selectivity of the receiver.

(d) Fidelity. Fidelity is a receiver's ability to reproduce the input signal accurately. Generally, the broader the bandpass, the greater the fidelity. Measurement is taken by modulating an input frequency with a series of audio frequencies and then plotting the output measurements at each step against the audio input. The curve will show the limits of reproduction. Good selectivity requires a narrow bandpass. Good fidelity requires a wider bandpass to amplify the outermost frequencies of the sidebands. Knowing this, you can see that most receivers are a compromise between good selectivity and high fidelity.

4.3 **The Frequency Spectrum**

4.3.1. Table 3.1 shows the overall electromagnetic frequency spectrum as defined by the International Telecommunications Union. Pay particular attention to the part used for communications. Rapid growth in the quantity and complexity of communications equipment and increased worldwide international requirements for radio frequencies have placed large demands upon the RF spectrum. These demands include military and civilian applications, such as communications, location and ranging, identification, standard time, industrial, medical, and other scientific uses.

4.3.2. The military has modified the frequency spectrum for its use as shown in Table 4.1. A few general characteristics are:-

(a) The extremely-low-frequency (ELF), very-low frequency (VLF), and low-frequency (LF) bands require high power and long antennas for efficient transmission(antenna length varies inversely with the frequency). Transmission of these frequencies is normally limited to shore stations.

(b) The commercial broadcast band extends from about 550 kHz to 1700 kHz. This limits naval use to the upper and lower ends of the medium frequency (MF) band. Long-range shipboard communications were conducted exclusively in the high-frequency (HF) band, so a large percentage of shipboard transmitters and receivers are designed to operate in this band. A significant portion of the very-high-frequency (VHF) band is assigned to the commercial television industry. Some naval uses of the VHF band are mobile communications, repeater operation, navigation, amphibious and special operations, short range line-of-sight (LOS) communications, and satellite communications.

FREQUENCY	DESCRIPTION
30-300 GHz	extremely-high-frequency
3-30 GHz	super-high-frequency
300 MHz-3 GHz	ultra-high-frequency
30-300 MHz	very-high-frequency
3-30 MHz	high-frequency
300 kHz-3 MHz	medium-frequency
30-300 kHz	low-frequency
3-30 kHz	very-low-frequency
300 Hz-3 kHz	voice frequency
Up to 300 Hz	extremely-low-frequency

Table 4.1 Frequency Bands

(c) The ultra-high-frequency (UHF) band is used extensively by the Navy for LOS and satellite communications. Mobile communications, radar (over 400 MHz), and special operations are some other uses.

(d) The super-high-frequency (SHF) band is the workhorse of microwave communications. LOS communications, terrestrial, and satellite relay links, radar, and special operations are some other uses. Experimental use of the extremely-high frequency (EHF) band is ending. The Fleet Satellite (FLTSAT) EHF Package (FEP) is attached to two modified uhf FLTSATs. The FEP is currently providing ehf communications capability to Army, Navy, and Air Force ground, airborne, and oceangoing terminals.

4.4 **Modulation**

4.4.1. Modulation is a process of mixing a signal with a sinusoid to produce a new signal. This new signal, conceivably, will have certain benefits over an un-modulated signal, especially during transmission. If we look at a general function for a sinusoid $f(t) = A\sin(\omega t + \varphi)$, we can see that this sinusoid has three parameters that can be altered, to affect the shape of the graph. A is the magnitude, or amplitude of the sinusoid; ω is the frequency, and φ is the phase angle. All these parameters can be altered to transmit data. The sinusoidal signal that is used in the modulation is known as the carrier signal, or simply "the carrier". The signal that is used in modulating the carrier signal (or sinusoidal signal) is known as the "data signal" or the "message signal". It is important to notice that a simple sinusoidal carrier contains no information of its own.

4.4.2. Some types of modulation include:

(a) Amplitude Modulation**.** A type of modulation where the amplitude of the carrier signal is modulated (changed) in proportion to the message signal while the frequency and phase are kept constant.

(b) Frequency Modulation. A type of modulation where the frequency of the carrier signal is modulated (changed) in proportion to the message signal while the amplitude and phase are kept constant.

(c) Phase Modulation. A type of modulation where the phase of the carrier signal is modulated (changed) in proportion to the message signal while the amplitude and frequency are kept constant.

(d) Frequency Shift Keying. Frequency-shift keying is considered a form of FM. It is a digital mode of transmission commonly used in radioteletype applications. In FSK the carrier is present all the time. In a keyed condition, the carrier frequency changes by a predetermined amount calledthe mark frequency. The unkeyed state is called a space.

(e) Phase Shift Keying. Phase-shift keying is similar to FSK except that the phase, not the frequency, is shifted. The primary advantage of PSK is that it can be accomplished in an amplifier stage.

(f) Pulse Modulation. Pulse modulation is accomplished by varying the characteristics of a series of pulses. This can be done by varying the amplitude, duration, frequency, or position of the pulses. It can also be done through coding. Pulse modulation is especially suited for use with communications systems incorporating time-division multiplexing.

4.5 **Analog and Digital Systems**

4.5.1. **Analog.** Analog signals are signals with continuous values. Analog signals are used in many systems, although the use of analog signals has declined with the advent of cheap digital signals.Analog systems are less tolerant to noise, make good use of bandwidth, and are easy to manipulate mathematically. However, analog signals require hardware receivers and transmitters that are designed to perfectly fit the particular transmission. If you are working on a new system, and you decide to change your analog signal, you need to completely change your transmitters and receivers.

4.5.2. **Digital.** Digital signals are signals that are represented by binary numbers, "1" or "0". The 1 and 0 values can correspond to different discrete voltage values, and any signal that doesn't quite fit into the scheme just gets rounded off. Digital signals are more tolerant to noise, but digital signals can be completely corrupted in the presence of excess noise. In digital signals, noise could cause a 1 to be interpreted as a 0 and vice versa, which makes the received data different than the original data. Imagine if the army transmitted a position coordinate to a missile digitally, and a single bit was received in error. This single bit error could cause a missile to miss its target by miles. Luckily, there are systems in place to prevent this sort of scenario, such as checksums and Cyclic Redundancy Checks, which tell the receiver when a bit has been corrupted and ask the transmitter to resend the data. The primary benefit of digital signals is that they can be handled by simple, standardized receivers and transmitters, and the signal can be then dealt with in software (which is comparatively cheap to change).

4.6 **Noise.** In communication systems, the noise is an error or undesired random disturbance of a useful information signal, introduced before or after the detector and decoder. The noise is a summation of unwanted or disturbing energy from natural and sometimes man-made sources. There are various types of noises, viz., Thermal noise, Shot noise, Flicker noise, Burst noise etc.

4.7. **Basic Antenna Theory**

4.7.1. Radio waves are generated by electrons accelerating in the antenna. Consider a transmitter perpendicular to the ground. The electrons in the antenna, when a signal is applied, are changing their velocities continuously (i.e. moving up and down very quickly) in response to the applied signal

4.7.1 **Dipole Antenna:-**A dipole antenna is a radioantenna that can be made of a simple wire, with a center-fed driven element. It consists of two metal conductors of rod or wire, oriented parallel and collinear with each other (in line with each other), with a small space between them. The radio frequency voltage is applied to the antenna at the center, between the two conductors. These antennas are the simplest practical antennas from a theoretical point of view. They are used alone as antennas, notably in traditional "rabbit ears" television antennas, and as the driven elementin many other types of antennas, such as the Yagi.

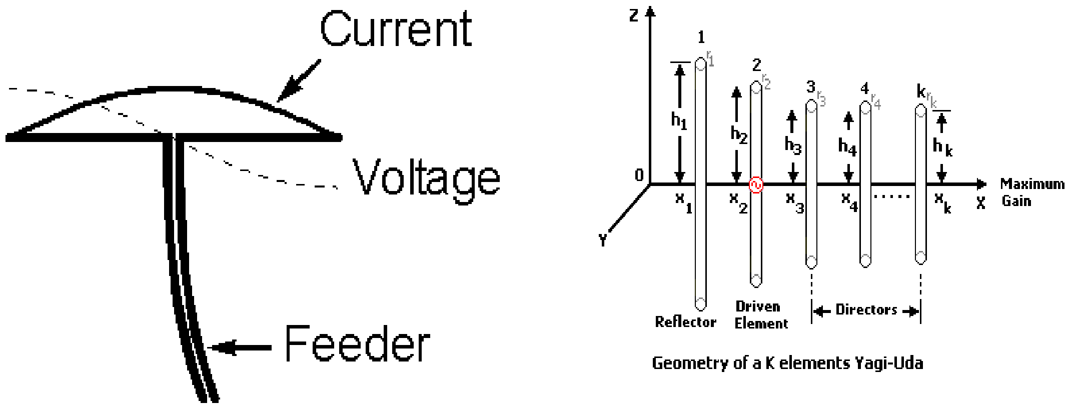
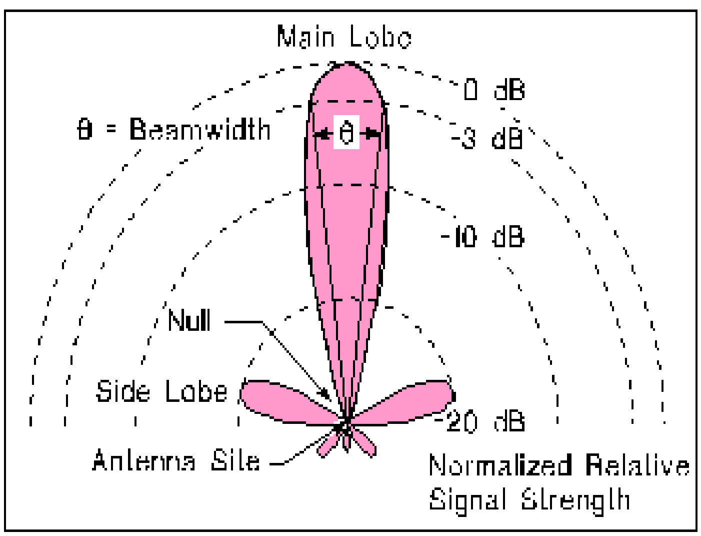


Fig 4.5 Half Wave Dipole and Yagi-uda antenna

4.7.2. There is only one part of a receiving aerial that is *active*, i.e. does the receiving and is connected to the TV/radio set. This active element is called the *dipole*. The simplest design of antenna would consist of a dipole only. Figure 4.6 shows the radiation pattern of a half-wave dipole.We can change the directivity of the aerial by adding other *elements*. Any other elements that we add to the basic half-wave dipole are called *passive* elements and are not connected electrically to the dipole.



side lobe

Fig 4.6 Radiation pattern of antenna

4.7.3. **<u>Monopole Antenna</u>** A monopole antenna is a class of radio antenna consisting of a straight rod-shaped conductor, often mounted perpendicularly over some type of conductive surface, called a ground plane. The driving signal from the transmitter is applied, or for receiving antennas the output voltage is taken, between the lower end of the monopole and the ground plane. One side of the antenna feedline is attached to the lower end of the monopole, and the other side is attached to the ground plane, which is often the Earth. This contrasts with a dipole antenna which consists of two identical rod conductors, with the signal from the transmitter applied between the two halves of the antenna. Common types of monopole antenna are the whip, rubber ducky, helical, random wire, mast radiator, and ground plane antennas.Like a dipole antenna, a monopole has an omni-directionalradiation pattern. That is it radiates equal power in all azimuthal directions perpendicular to the antenna, but the radiated power varies with elevation angle, with the radiation dropping off to zero at the zenith, on the antenna axis.A monopole can be visualized as being formed by replacing one half of a dipole antenna with a ground plane at right-angles to the remaining half. If the ground plane is large enough, the radio waves reflected from the ground plane will seem to come from an image antenna forming the missing half of the dipole, which adds to the direct radiation to form a dipole radiation pattern. So the pattern of a monopole with a perfectly conducting, infinite ground plane is identical to the top half of a dipole pattern, with its maximum radiation in the horizontal direction, perpendicular to the antenna

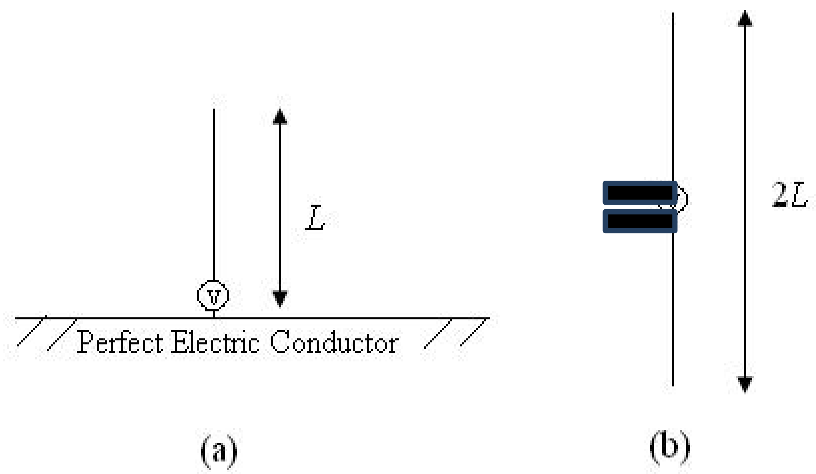


Fig 4.7 Monopole antenna and its equivalent

4.8. <u>Fiber Optics</u>

4.8.1. **Fiber-Optic Communication** is a method of transmitting information from one place to another by sending pulses of light through an optical fiber. The light forms an electromagnetic carrier wave that is modulated to carry information. The process of communicating using fiber-optics involves the following basic steps: Creating the optical signal involving the use of a transmitter, relaying the signal along the fiber, ensuring that the signal does not become too distorted or weak, receiving the optical signal, and converting it into an electrical signal.

4.8.2. An **optical fiber** is a flexible, transparent fiber made of very pure glass (silica) not much wider than a human hair that acts as a waveguide, or "light pipe", to transmit light between the two ends of the fiber.Fibers are used instead of metal wires because signals travel along them with less loss and are also immune to electromagnetic interference.

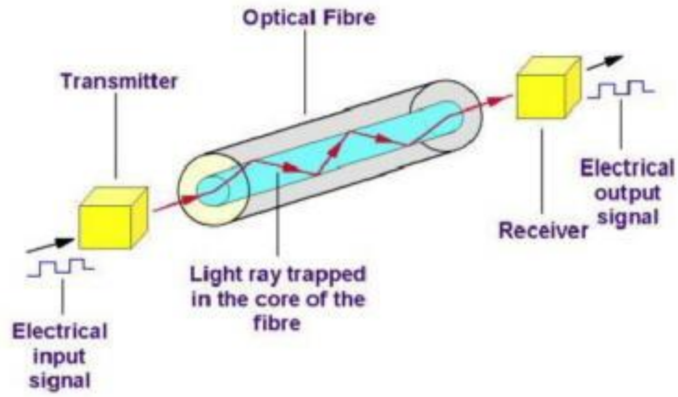


Fig 4.8 Fiber optic transmission

4.8.3. Optical fiber typically consists of a transparent core surrounded by a transparent cladding material with a lower index of refraction. Light is kept in the core by total internal reflection. This causes the fiber to act as a waveguide.

4.9. **Questions**

4.9.1 What is the requirement for modulation?
4.9.2 What are the various RF frequency bands and there applications?
4.9.3 What do you mean by ground waves and sky waves and what are the atmospheric effects on the propagation of sky waves?
4.9.4 How does an antenna radiate/function? Where the feed horn of an antenna should be kept in order to obtain a parallel beam? Relate this theory to optical mirrors/ lenses.
4.9.5 List down the various types of digital modulation schemes.
4.9.6 What are the various atmospheric phenomena that affect propagation of radio waves?
4.9.7 What are the receiver characteristics which need to be taken care of while designing a communication system?
4.9.8 What is the difference between analog, digital and discrete signals?
4.9.9 Why are optical fibers used to transmit for long distance communication?
4.9.10 What are the uses and disadvantages of Superhetrodynereceivers.

4.10 **Suggested Reading**

Electronic Communication Systems – Kennedy
Chapter 1
Chapter 2

VP 206:- Communication Systems

CHAPTER-5

CONTROL SYSTEMS

5.1 Introduction

5.1.1. The complexity of the problems of man's existence is growing at an ever-increasing rate and it may be expected to continue to do so in future. As such, constantly, human effort and capacity are replaced by machines and control systems, wherever possible, so that they may be applied to other problems.

5.1.2. For the past few decades, the trend of modern civilization has been in the direction of greater control. Its importance has grown tremendously in almost every field of technical endeavor. Thermostats regulate temperature in air-conditioners, refrigerators, ovens and furnaces. Numerous control arrangements find their ways into industrial and military applications, for the control of position, speed, tension, temperature, humidity, pressure flow etc. Some specific examples are tension controllers of sheet rolls in paper mills, thickness controller of sheet metals in rolling mills, pressure controller in boilers, concentration controllers, reaction controllers etc, in chemical processes, radar, antenna sweeping control, gun direction, missile control and control in space etc.

5.2. Control System

5.2.1. A Control System is a device, or a collection of devices that manage the behavior of other devices. Some devices are not controllable. A control system is an interconnection of components connected or related in such a manner as to command, direct, or regulate itself or another system.

(a) **Controller** A controller is a control system that manages the behavior of another device or system.

(b) **Compensator** A compensator is a control system that regulates another system, usually by conditioning the input or the output to that system. Compensators are typically employed to correct a single design flaw, with the intention of affecting other aspects of the design in a minimal manner.

5.3 Feedback

5.3.1. Feedback describes the situation when output from (or information about the result of) an event or phenomenon in the past will influence an occurrence or occurrences of the same (i.e. same defined) event / phenomenon (or the continuation / development of the original phenomenon) in the present or future. When an event is part of a chain of cause-and-effect that forms a circuit or loop, then the event is said to "feedback" into itself.

5.3.2. A feedback loop is a common and powerful tool when designing a control system. Feedback loops take the system output into consideration, which enables the system to adjust its performance to meet a desired output response.

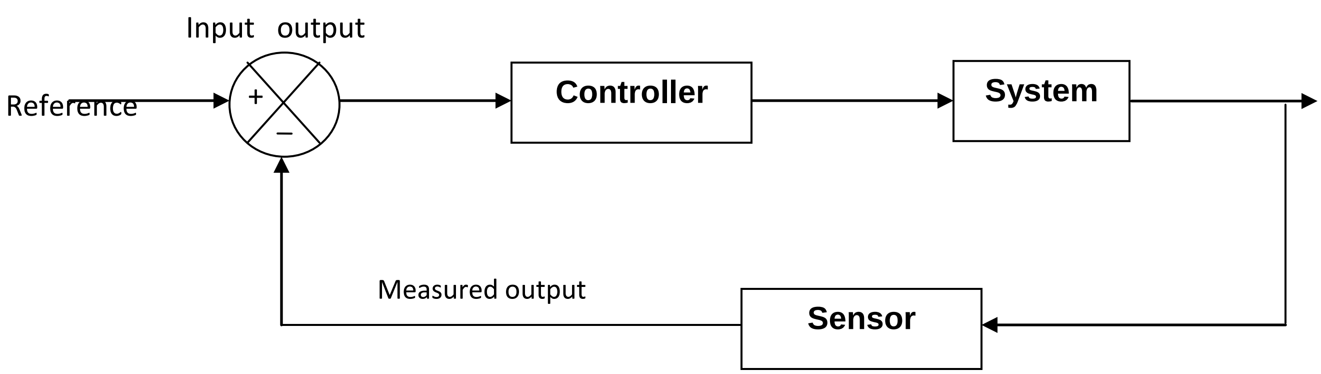


Fig 4.1An example of a Negative Feedback

5.3.3. This is a basic feedback structure. Here, we are using the output value of the system to help us prepare the next output value. In this way, we can create systems that correct errors. Here we see a feedback loop with a value of one. we call this a unity feedback.

5.3.4. In systems containing an input and output, feeding back part of the output so as to increase the input is *positive feedback* (*regeneration*); feeding back part of the output in such a way as to partially oppose the input is *negative feedback* (*degeneration*).

5.4 <u>Servomechanism</u>

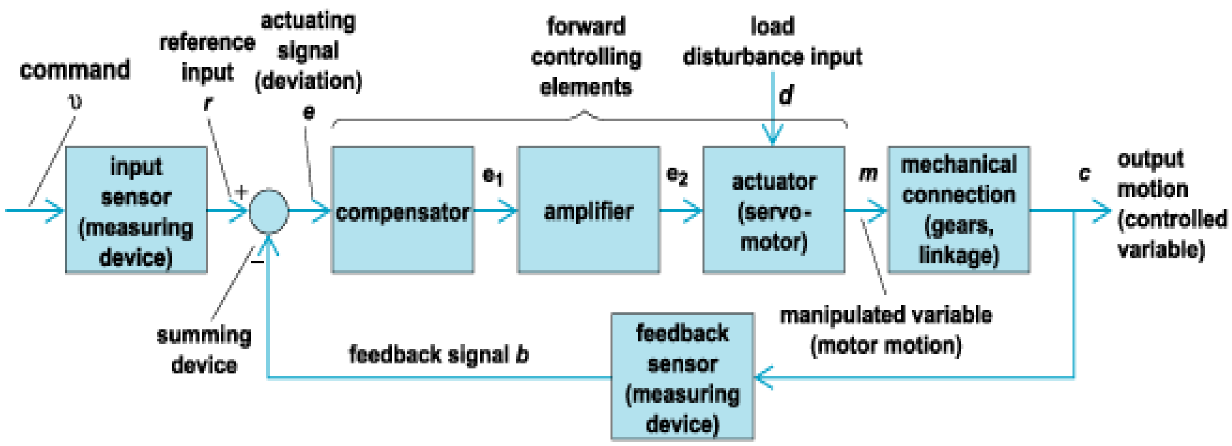


Fig 4.2Servomechanism

5.4.1. A servomechanism, or servo, is an automatic device that uses error-sensing negative feedback to correct the performance of a mechanism. The term correctly applies only to systems where the feedback or error-correction signals help control mechanical position, speed or other parameters. A servomechanism may or may not use a servomotor. For example, a household furnace controlled by a thermostat is a servomechanism, yet there is no motor being controlled directly by the servomechanism.

5.4.2. A common type of servo provides *position control*. Servos are commonly electrical or partially electronic in nature, using an electric motor as the primary means of creating mechanical force. Other types of servos use hydraulics, pneumatics, or magnetic principles. Servos operate on the principle of negative feedback, where the control input is compared to the actual position of the mechanical system as measured by some sort of transducer at the output. Any difference between the actual and wanted values (an "error signal") is amplified and used to drive the system in the direction necessary to reduce or eliminate the error. This procedure is one widely used application of control theory.

5.5 <u>Transfer Function</u>

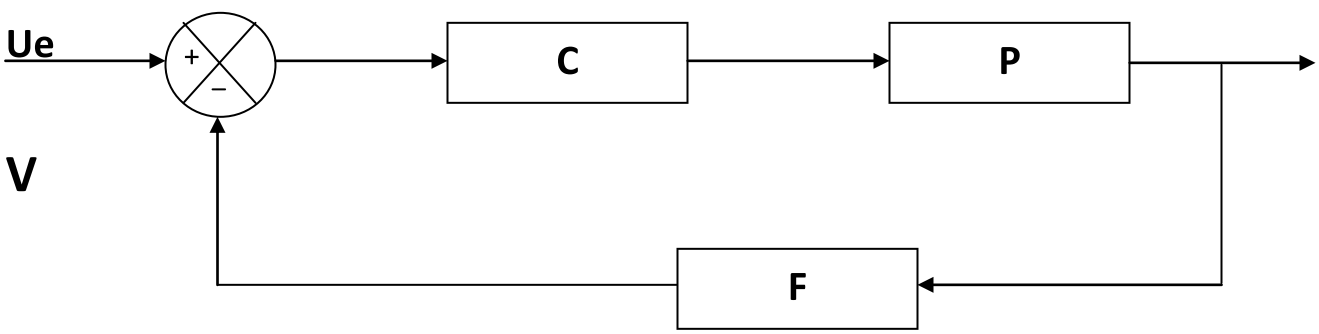


Fig 4.3A Negative Feedback Loop

Here r = Reference Signal
e = Measured Error
U = System Input
V = System Output
C = Controller
P = System
F = Sensor

5.5.1. If we assume the controller *C*, the plant *P*, and the sensor *F* are linear and time-invariant (i.e.: elements of their transfer function *C(s)*, *P(s)*, and *F(s)* do not depend on time), the systems above can be analysed using the Laplace transform on the variables. This gives the following relations:

$$Y(s) = P(s)U(s)$$
$$U(s) = C(s)E(s)$$

$$E(s) = R(s) - F(s)Y(s).$$

Solving for *Y*(*s*) in terms of *R*(*s*) gives:

$$Y(s) = \left(\frac{P(s)C(s)}{1 + F(s)P(s)C(s)}\right) R(s) = H(s)R(s).$$

5.5.2. The expression $H(s) = \frac{P(s)C(s)}{1 + F(s)P(s)C(s)}$ is referred to as the *closed-loop transfer function* of the system. The numerator is the forward (open-loop) gain from *r* to *y*, and the denominator is one plus the gain in going around the feedback loop, the so-called loop gain. If $|P(s)C(s)| \gg 1$, i.e. it has a large norm with each value of *s*, and if $|F(s)| \approx 1$, then *Y(s)* is approximately equal to *R(s)* and the output closely tracks the reference input.

5.6. **Poles and Zeroes**

5.6.1. Poles and Zeros of a transfer function are the frequencies for which the value of the transfer function becomes infinity or zero respectively. The values of the poles and the zeros of a system determine whether the system is stable, and how well the system performs. Control systems, in the simplest sense, can be designed simply by assigning specific values to the poles and zeros of the system.

5.6.2. Physically realizable control systems must have a number of poles greater than or equal to the number of zeros. Systems that satisfy this relationship are called proper. Let's say we have a transfer function defined as a ratio of two polynomials:

$$H(s) = \frac{N(s)}{D(s)}$$

5.6.3. Where, *N(s)* and *D(s)* are simple polynomials. Zeros are the roots of *N(s)* (the numerator of the transfer function) obtained by setting *N(s) = 0* and solving for *s*.Poles are the roots of *D(s)* (the denominator of the transfer function), obtained by setting *D(s) = 0* and solving for *s*. Because of our restriction above, that a transfer function must not have more zeros then poles, we can state that the polynomial order of *D(s)* must be greater than or equal to the polynomial order of *N(s)*. The polynomial order of a function is the value of the highest exponent in the polynomial.

5.7. **Synchros**

5.7.1. A synchro is a type of rotary electrical transformer that is used for measuring the angle of a rotating machine such as an antenna platform. In its general physical construction, it is much like an electric motor. The primary winding of the transformer, fixed to the rotor, is excited by an alternating current, which by electromagnetic induction, causes currents to flow in three star-connected secondary windings fixed at 120 degrees to each other on the stator. The relative magnitudes of secondary currents are measured and used to determine the angle of the rotor relative to the stator, or the currents can be used to directly drive a receiver synchro that will rotate in unison with the synchro transmitter.

5.7.2. Synchros are used primarily for the rapid and accurate transmission of information between equipment and stations. Examples of such information are changes in course, speed, and range of targets or missiles; angular displacement (position) of the ship's rudder; and changes in the speed and depth of torpedoes. This information must be transmitted quickly and accurately. Synchros can provide this speed and accuracy. They are reliable, adaptable, and compact.

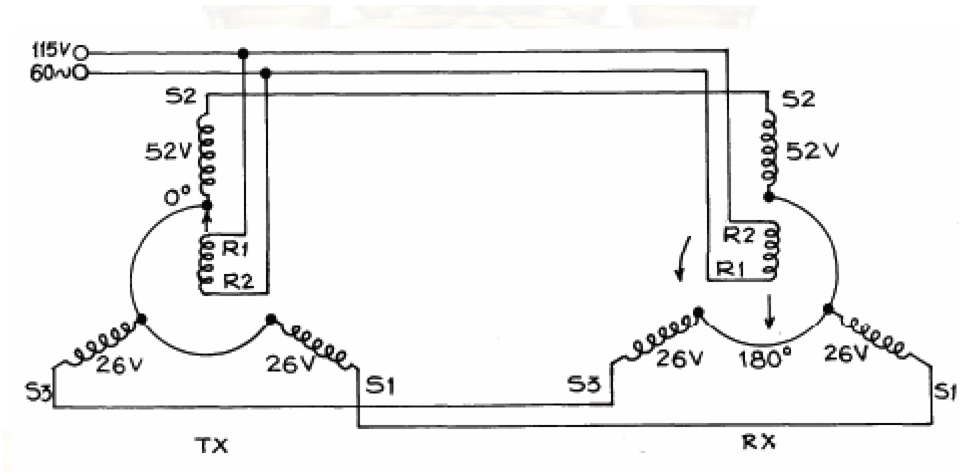


Fig 4.4A Simple Synchro System

5.7.3. Synchros, as stated earlier, are simply variable transformers. They differ from conventional transformers by having one primary winding (the rotor), which may be rotated through 360º and three stationary secondary windings (the stator) spaced 120º apart. It follows that the magnetic field within the synchro may also be rotated through 360º. If an iron bar or an electromagnet were placed in this field and allowed to turn freely, it would always tend to line up in the direction of the magnetic field. This is the basic principle underlying all synchro operations.

5.8 **Test Inputs**

5.8.1 **Step.** This represents a sudden change in input position. It is simulates the throw off due to gun recoil and is used to assess stability.

Information obtained:

Time to first crossover
Overshoot ratio
Steady state accuracy
Damped natural frequency

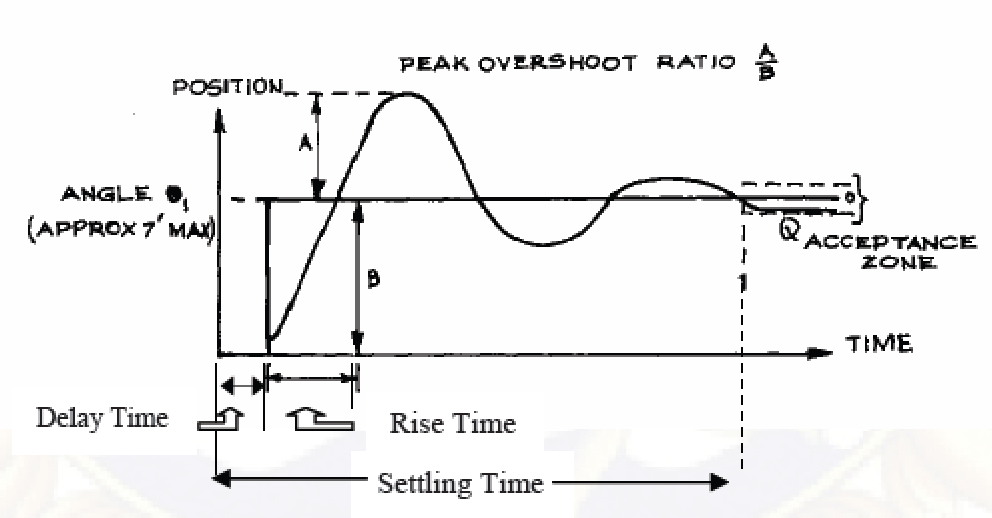


Fig.1.15(a)

5.8.2 **Ramp or constant speed**. A constant speed input will reveal the extent of any lag in output position and also cyclic errors due to mechanical defects. It simulates steady targets tracking and is used to eliminate static friction when "step tuning" a servo.

Information obtained;

Steady state accuracy
Indication of resonant frequency
Presence of cyclic errors

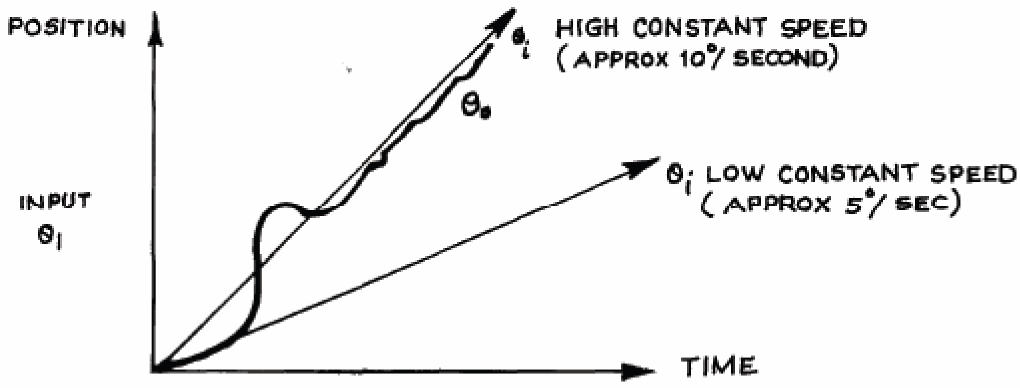


Fig.1.15 (b)

5.8.3 **SHM (Simple Harmonic Motion).** This represents a sinusoidal change of input position over the operational range. This input is used to assess the overall accuracy of the servo which will be indicated by the peak error magnitude. Stability can also be assessed by the smoothness of the trace.

Information obtained:

Phase lag
Magnification

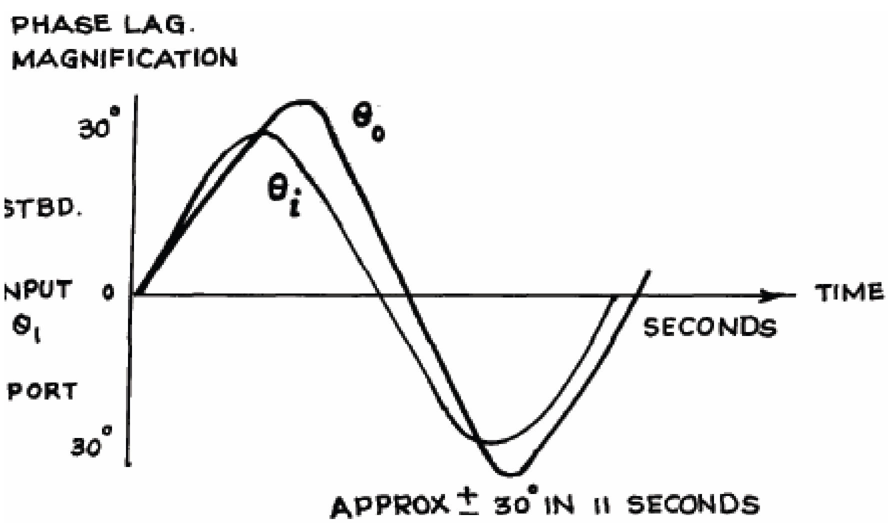
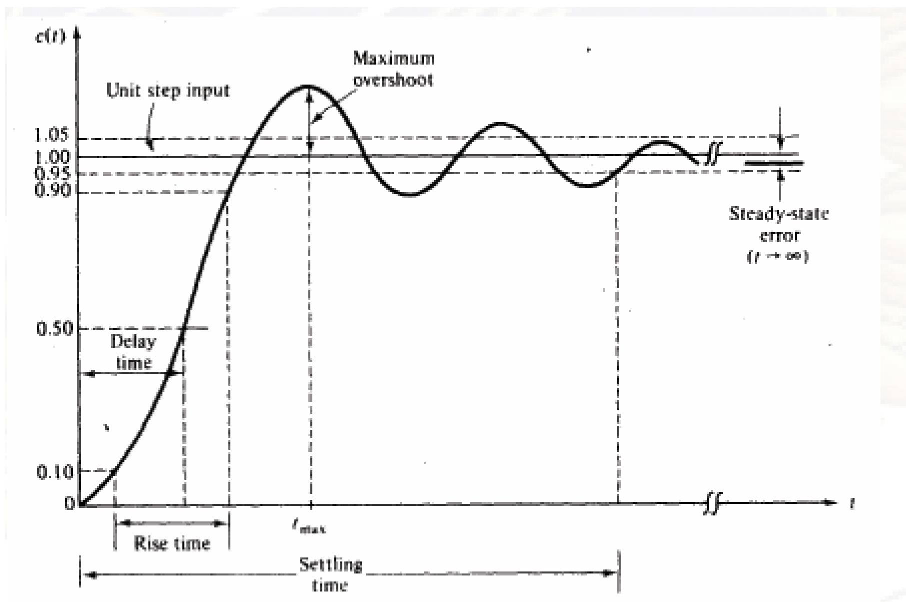


Fig. 1.15(c)

5.9**Time response specifications**:Control system is generally designed with damping less than one, i.e., oscillatory step response. Higher order control systems usually have a pair of complex conjugate poles with damping less than unity that dominate over the other poles .therefore the time response of second and higher order control system to a step input is generally of damped oscillatory nature as shown in figure next.

In specifying the transient –response characteristics of control system to a unit step input, we usually specify the following:

1. Delay time, t_d
2. Rise time, t_r
3. Peak time, t_p
4. Peak overshoot, m_p
5. Settling time, t_s
6. steady-state error, e_{ss}



1. **Delay time**, t_d: It is the required for the response to reach 50% of the final value in the first attempt.
2. **Rise time**, t_R: It is the time required for the response to rise from 0 to 100% of the final value for the understanding system.
3. **Peak time**, t_p: It is the time required for the response to reach the peak of time response or the peak overshoot.
4. **Settling time**, t_s: It is the time required for the time response to reach and stay within a specified tolerance band (2% or5%) of its final value.

5. **Peak overshoot**,m_p: It is the normalized difference between the time response peak and the steady output and is defined as,

$$\%M_p = \frac{c(t_p)-c(\infty)}{c(\infty)} * 100\%$$

6. **Steady-state error**, E_{ss}: It indicates the error between the actual output and the desired output as ‘t’ tends to infinity.

$$e_{ss}=\lim_{t\to\infty}[r(t)-c(t)].$$

5.10**Modes of Control**. An automatic temperature control might consist of a valve, actuator, controller and sensor detecting the space temp in the room. The control system is said to be ‘in balance’ when the space temp sensor does not register more or less temp than the required by the control system. What happens to the control valve when the space sensor register a change in temperature (a temp deviation) depends on the type of the control system used. The relationship between the movement of the valve and the change of temperature in the controlled medium is known as the mode of control or control actionDerivative of both these modes exist which will now be examined in greater detail. There are two basic modes of control:

(a)**On/ Off-** The valve is either fully open or fully closed, with no intermediate state.

(b)**Continuous-**The valve can move between fully open or fully closed, or be held at any intermediate position.

5.11 **On/ off control**. Occasionally known as two steps or two position control, this is the most basic control mode. Considering the tank of water shown in figure 5.2.1, the objective is to hit the water in the tank using the energy given of a simple steam coil. In the flow pipe of the coil, a two port valve and actuator is fitted, complete with a thermostat, placed in the water in the tank.

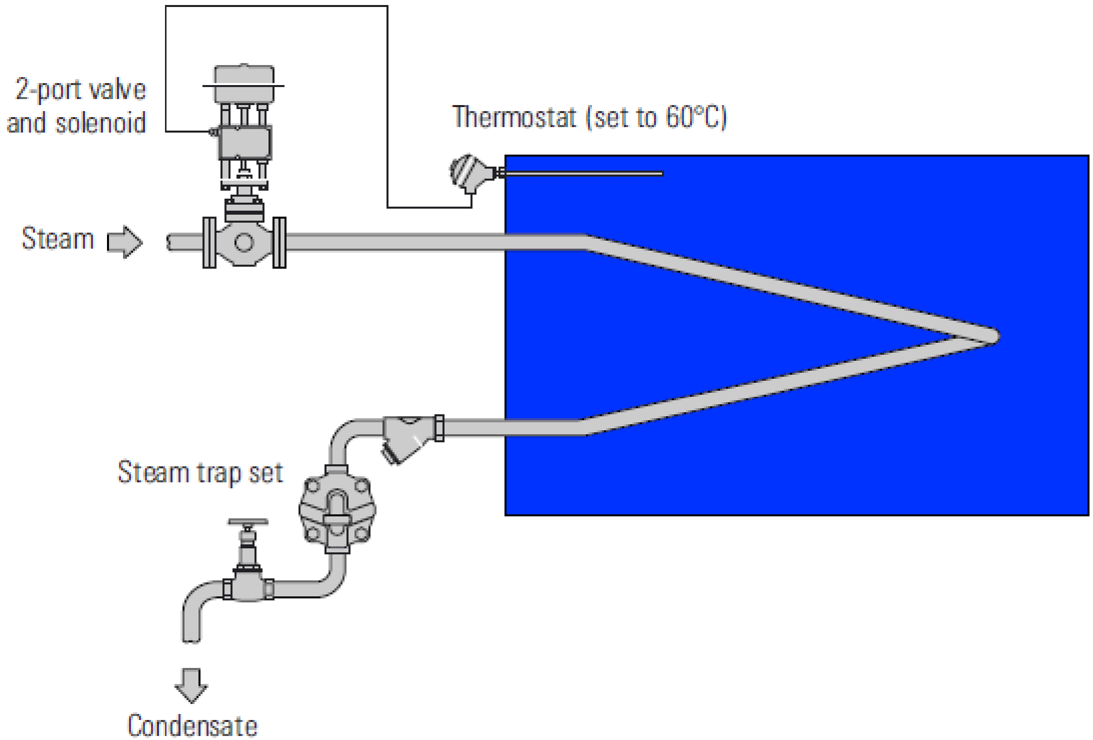


Fig. 5.2.1 On/off control of a tank

5.11.1. The thermostat is set to 60^o C, which is the required temp of the water in the tank. Logic dictates that the switching point were actually at 60^o C, the system would never operate properly, because the valve would not know whether to be open or close at 60^o C. From then on it could open and shut rapidly, causing wear.

5.11.2. For this reason, the thermostat would have an upper and lower switching point. This is initial to prevent over rapid cycling (this is often referred to as 'hunting' and is explained in detail later in the model). In this case the upper switching point might be 61^o C (the point at which the thermostat tells the valve to shut) and the lower switching point be 59^o C (the point when the valve is told to open). Thus there is an inbuilt switching difference in the thermostat of +/- 1^o C about the 60^o C set point.

5.11.3.This 2^o C (+/- 1^o C) is known as the switching differential. (This will vary between thermostats). a diagram of the switching action of the thermostat would look like the graph shown in fig 5.2.2, where it is illustrated that the temp of the tank contents will fall to 59^o C before the valve is asked to open and will raise to 61^o C before the valve is instructed to close.

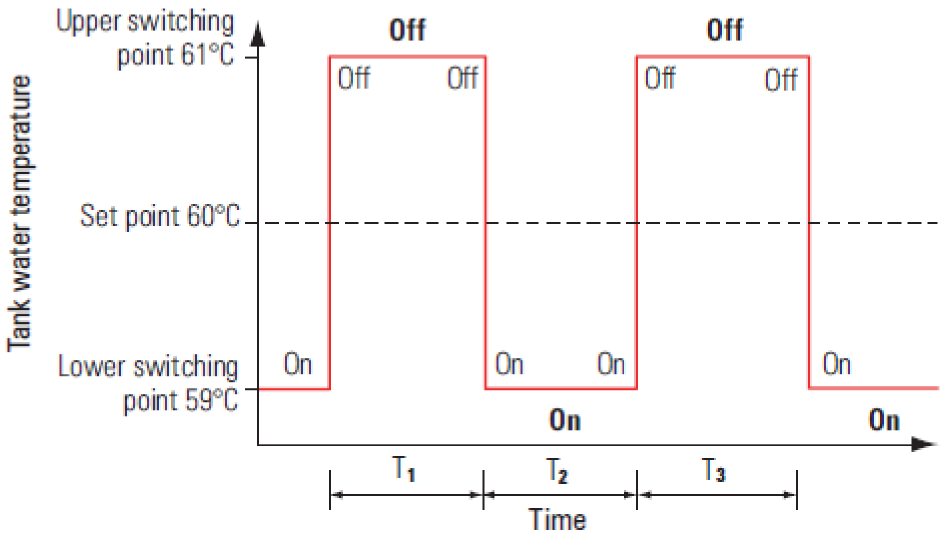


Fig. 5.2.2 On/off switching action of the thermostat

5.11.4.Figure 5.2.2 shows straight switching lines but the effect on heat transfer from coil to water will not be immediate. it will take time for the steam in the coil to effect the temp of the water I the tank. Not only that, but the water in the tank will rise above the 61^o C upper limit and fall below the 59^o C lower limit. This can be explained cross referencing fig 5.2.2 and 5.2.3. First however it is necessary to describe what is happening.

5.11.5. At point **A** (59^o C, fig 5.2.3) the thermostat directs the valve wide open. It takes time for the transfer of heat from the coil to affect the water temp, as shown by the slope of the rise in temp in fig 5.2.3. At point **B** (61^o C) the thermostat shuts the valve. However the coil is still full of steams, which continuous condense and give up its heat. Hence the water temp continuous to rise above the upper switching temp, and' overshoots' at **C**.

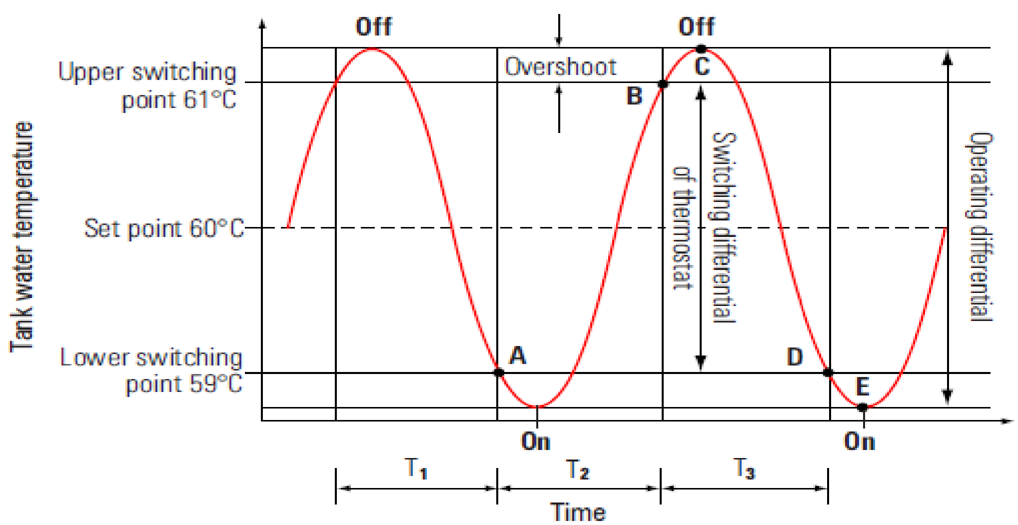


Fig. 5.2.3 Tank temperature versus time

5.11.6. From this point onwards, the water temp in the tank begins to fall until, at point **D** (59^o C), the thermostat tells the valve to open. Steam is admitted through the coil but again, it take time to have an effect and the water temp continuous to fall for a while, reaching its trough of undershoot at point **E**.

5.11.7. The difference between the peak and the trough is known as the operating differential. The switching differential of the thermostat depends on the type of thermostat used. The operating differential of the thermostat depends on the characteristics of the application such as the tank, its contents, and the heat transfer characteristics of the coil and so on.

5.11.8.Essentially, with on/off control, there are upper and lower switching limits and the valve is either fully open or fully closed- there is no intermediate state.The main advantages of on/off control are that it is simple and very low cost. This is why it is frequently found on domestic type applications such as central heating boilers and heater fans.Its major advantage is that the operating differential might fall outside the control tolerance required by the process. For example, on a food production line, where the taste and the repeatability of the taste are determined by precise temp control, on/ off control could well be unsuitable.

5.11.9. By contrast, in the case of space heating there are often large storage capacities (a large area to heat or cool that will respond to temp change slowly and slight variation inthe desired value is acceptable. In many cases on/off control is quite appropriate for this type of application.If on/off control is unsuitable because more accurate temp control is required, the next option is continuous control.

5.12**<u>Continuous control</u>**. Continuous control is often called modulating control. It means that the valve is capable of moving continually to change the degree of the valve opening or closing. It does not just move to either fully open or fully closed, as with on/ off control. There are three basic control actions that can apply to Continuous control:

(a) Proportional (P)
(b) Integral (I)
(c) Derivative (D)

It is also necessary to consider these I combination such as P+1, P+D, P+I+D. Although it is possible to combine the different actions, and all help to produce the required response, it is important to remember that both the integral and the derivative actions are usually corrective functions of a basic proportional control action.

The three control actions are considered below:

5.12.1.**<u>Proportional Control</u>**. This is most basic of the continuous control modes and is usually referred to by use of the letter 'P'. The principle aim of proportional control is to control the process as the condition change.

This section shows that:

(a) The larger the proportional band, the more stable the control, but the greater the offset.

(b) The narrower the proportional band, the less stable the process, but the smaller the offset.

5.12.2. The aim, therefore, should be introduce the smallest acceptable proportional band that will always keep the process stable the minimum offset.In explaining proportional control, several new terms must be introduced.

5.12.3. To define these, a simple analogy can be considered- cold water is supplied with water via a float operative valve and with a stop valve on the outlet pipe, as shown in fig both valves are the same size and having the same flow capacity. The desired water level in the tank is at point **B** (equivalent to the set point of a level controller).

5.12.4. It can be assumed that, with valve 'V' half open, (50% load) there is just the right flow rate of the water entering via the float operated valve to provide the desired flow out through the discharge pipe, and to maintain the water level in the tank at point at **B.**

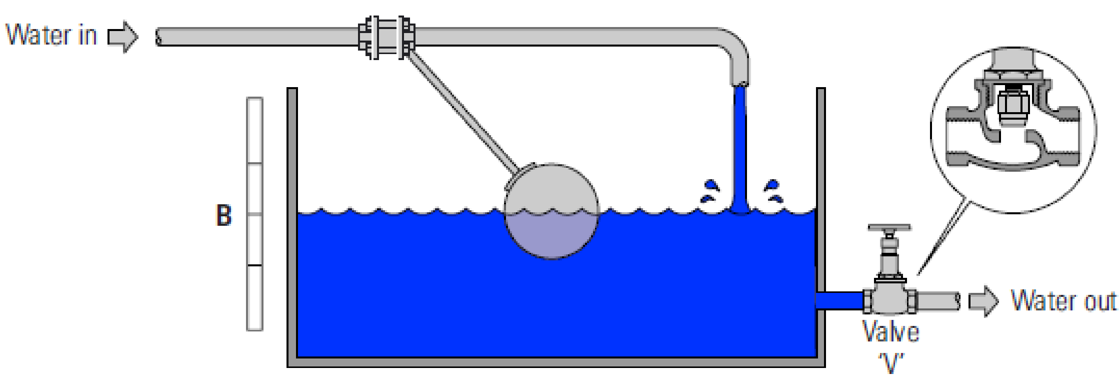


Fig. 5.2.4 Valve 50% open

5.12.5 The system can be said to be open in balance (the flow rate of water entering and leaving the tank is the same); under control, in a stable condition (the level is not varying) and at precisely the desired water level (**B**); giving the required outflow.With the valve 'V' closed, the level of water in the tank rises to point **A** and the float operated valve cuts off the water supply (see fig 5.2.5 below)(next page).

5.12.6. The system is still under control and stable but the control is above level **B**. The difference between level **B** and the actual control level **A** is related to the proportional band. Once again, if valve 'V' is half opened to give 50% load, the water level in the tank will return to the desired level, point **B**.

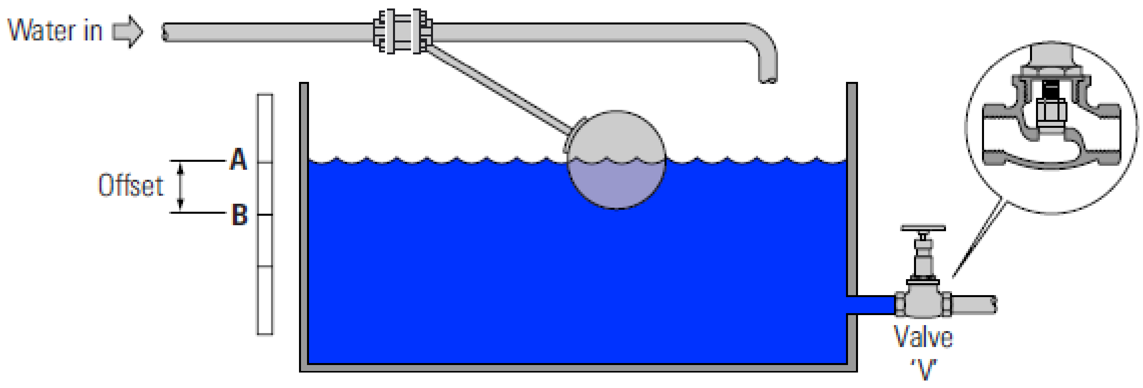


Fig. 5.2.5 Valve closed

5.12.7. In the fig 5.2.6 below, the valve 'V' is fully opened (100 % load). The float operated valve will need to drop to open the inlet valve wide and admit a higher flow rate of water to meet the increased demand from the discharge pipe. When it reaches level **C**, enough water will be entering to meet the discharge needs and the water level will be maintained at point **C**.

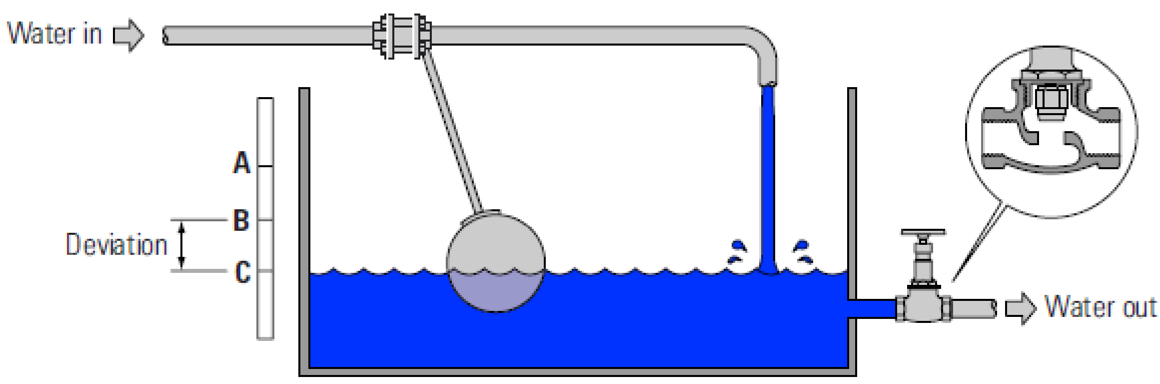


Fig. 5.2.6 Valve open

5.12.8. The system is under control and stable, but there is an offset; the deviation in level between point **B** and **C**. Fig 5.2.7 combines the three conditions used in this example.The difference in level between point **A** and **C** is known as the proportional band of P-band, since this is the change in level (or temp in the case of a temp control) for the valve to move from fully open or fully close.The recognized symbol for the proportional band is Xp.

5.12.9. The analogy illustrates several basic and important points relating to proportional control:

(a) The valve is moved in proportional to the error in the water level (or the temp deviation, in the case of a temp control) from the set point.
(b) The set point can only be maintained for one specific load condition.
(c) Whilst stable control will be achieved between points **A** and **C**, any load causing a difference I level to that of **B** will always provide an offset.

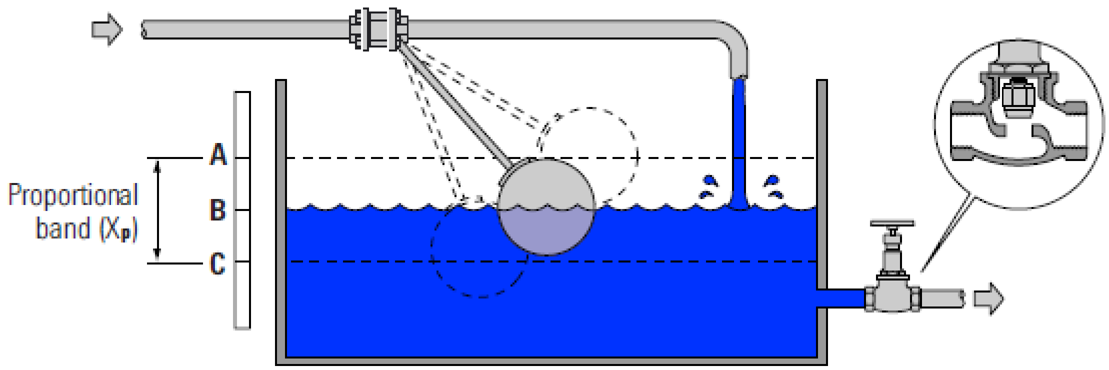


Fig. 5.2.7 Proportional band

Note: By altering the length of the float arm, the system Proportional band changes. A shorter arm gives a narrower P- band, and a longer arm gives a wider P- band. Fig 5.2.8 illustrate why this is so. A shorter arm needs less change in water level to move the angle of the arm from fully open to fully close. in both cases, it can be seen that level **B** represents the 50 % load level, **A** represents the 0% load level, and **C** represents the 100 % load level. It can also be seen how the offset is greater at any same load with the wider Proportional band.

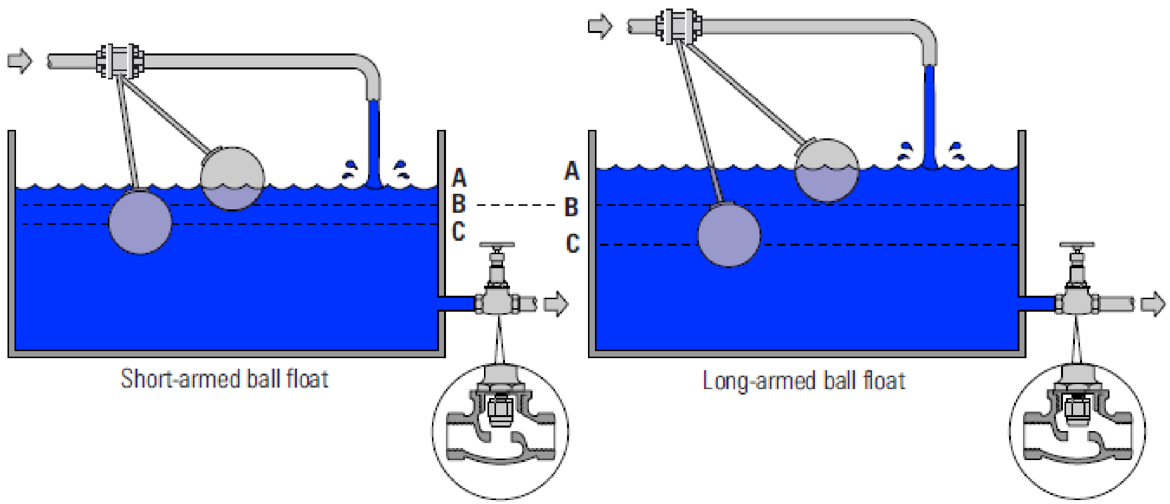


Fig. 5.2.8 Demonstrating the relationship between P-band and offset

5.12.10. For electrical and pneumatic controllers, the set value is at the middle of the Proportional band. The effect of changing the P-band for an electrical and pneumatic system can be described with a slightly different example, by using a temp control.The space temp of a building is controlled by a water (radiator type) heating system using a proportional action control by a valve driven with an electrical actuator, and an electronic controller and room sensor. The control selected has a proportional band (P-band or Xp) of 6^{o} C and the desired internal space temp is 18^{o} C. Under certain load conditions, the valve is 50% open and the required temp is correct at 18^{o} C.

5.13**Summary of modes of control**. A three- term controller contains three modes of control:

(a) Proportional (P) action with adjustable gain to obtain stability.

(b) Reset (Integral) (I) action to compensate for load changes.

(c) Rate (Derivative) (d) action to speed up valve movement when rapid load changes take places.

The various characteristics can be summarized, as shown in fig 5.2.17.

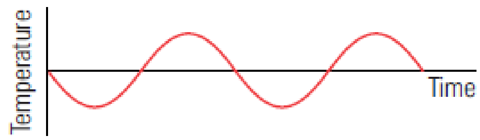
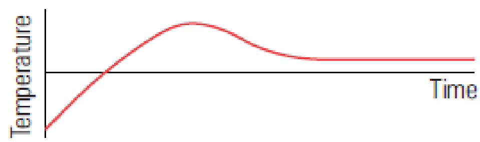
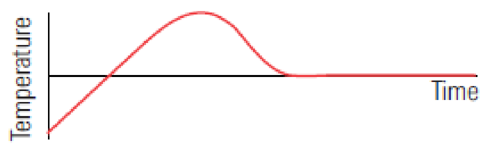
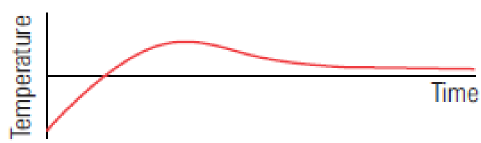
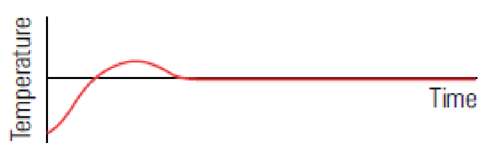
Control mode	Typical system responses	Advantages/disadvantages
On/off		▪ Inexpensive ▪ Simple ▪ Operating differential can be outside of process requirements
Proportional P		▪ Simple and stable ▪ Fairly high initial deviation (unless a large P-band is chosen), then sustained offset ▪ Easy to set up ▪ Offset occurs
Proportional plus Integral P + I		▪ No sustained offset ▪ Increase in proportional band usually required to overcome instability ▪ Possible increased overshoot on start-up
Proportional plus Derivative P+D		▪ Stable ▪ Some offset ▪ Rapid response to changes
Proportional plus Integral plus Derivative P+I+D		▪ Will give best control, no offset and minimal overshoot ▪ More complex to set up manually but most electronic controllers have an 'autotune' facility. ▪ More expensive where pneumatic controllers are concerned

Fig. 5.2.17 Summary of control modes and responses

Finally the control engineer must try to avoid the danger of using unnecessarily complicated controls for a specific application. The least complicated control action, which will provide the degree of control required, should always be selected.

5.14. **Questions**

5.14.1. What do understand by servo mechanism? What is feedback? How is it advantageous or disadvantageous?

5.14.2. What do you mean by test signals? What are the various types of test signals?

5.14.3. What are synchros? What is the advantage of synchro transmission?

5.14.4. What do you mean by control transformer and differential synchros?

5.14.5. What do you mean by metadyne?

5.14.6. What is a servo chain? Where would it find application onboard?

5.14. **Suggested Reading**

VP 193:- Control Systems
Modern Control Engineering By Katsuhiko Ogata

CHAPTER-6

INSTRUMENTATION AND TEST EQUIPMENT

6.1 Introduction

6.1.1 Maintenance and repair of various electrical equipment involves use of test equipment. Proper use of these test equipment reduces time of repair/maintenance, resulting reduced system down time. Knowledge of using test equipment is enhanced by regular use of these test equipment. Mastering on electrical equipment can only be achieved by mastering on the required test equipment.

6.1.2 Electronic measurements involve the fundamental electrical quantities of voltage and current and the inherent characteristics of resistance, capacitance, and inductance. In circuits being tested, voltage and current are dependent upon resistance, capacitance, and inductance for their distribution; therefore, voltage and current measurements are valuable aids in determining circuit component conditions and in the evaluation of symptoms. Practically any reading obtained from the use of test equipment will depend on these basic measured quantities of resistance, capacitance, and inductance.

6.2 Various Instruments and Test Equipment

6.2.1 DIGITAL MULTIMETER

The Digital Multimeter (DMM) displays measurement of DC and AC voltages as discrete numerals instead of a pointer deflection on a continuous scale. It is also used for measuring the continuity of wire or a circuit. Numerical readout is advantageous in many applications because it reduces human reading and interpolation errors, eliminates parallax error, increases reading speed and provides output in digital form which is suitable for further processing or recording.

Fig 6.2.1 Digital Multimeter

6.2.1.1 **Operation of Digital Multi Meter**

(a) Voltage Measurement. Select the appropriate function DC or AC and the voltage button, V. Now select the required range on the rotary range switch. Apply the input to the sockets labelled (+) and (-). It is advisable, where possible, to connect the low input to the lowest impedance with respect to ground. This will reduce common mode voltages. To measure a voltage above 1 KV, the HV probe is availed. For RF voltage measurement use the probe with the BNC to 4mm adaptor.

(b) Current Measurement. Select the appropriate function, DC or AC along with the current button. Now select the required range on the rotary range switch. Apply the input to the (+) and (-) sockets for ranges up to 2 Amp. For the 10 Amp range, connect the high input to the separate 10 Amps terminal. The maximum continuous overload is 2 Amp and the fuse, provides protection for sustained overloads in case of excess current. The 10 Amps range is not protected.

(c) Resistance Measurement. Select the function button to ohms and the appropriate range with the rotary range switch. Connect the resistance to be measured between the (+) & (-) socket. The internal current sources for measurement, give a negative voltage at the (+) socket. The input is protected up to 250 V rms on all ranges.

6.2.2 **SHOCK PULSE TESTER T-2000**

Shock pulse tester T-2000 combines the function of a Shock Pulse meter, a vibration meter, and a tachometer. The instrument is used to check the operating condition of rotating machines in order to detect mechanical faults and provides data for effective preventive maintenance. With the T2000, maintenance personnel can monitor all significant aspects of mechanical machine condition during a single inspection, such as:

(a) The mechanical condition of rolling bearings (bearing damage development).

(b) General machine condition (the effect of structural looseness, misalignment and out-of-balance on machine vibration).

Fig 6.2.2 Shock pulse tester

6.2.3 **ELECTRICAL MOTOR CHECKER EMC-22**

6.2.3.1 **Introduction** EMC-22 provides a fast and easy means to detect electrical faults- short circuits, open circuits, damaged insulation etc, in motor and other three phase machines. EMC-22 is used on stationary motors. The motor has to be isolated from its power supply before testing. There is no need to disconnect the supply cable, provided the power is switched off. Readings can be taken at any point along the motor power supply. The basic test can be made on site without disconnecting the phase windings.

6.2.3.2 **The Basic Test**. On any three-phase machines, an electrical fault can be detected in the following manner:-

(a) Measuring insulation resistance to earth.

(b) Measuring and comparing the resistance of different phases of stator winding.

(c) Measuring and comparing the inductance of different phases of stator winding.

Fig 6.2.3.2 EMC-22

6.2.3.3 Resistance and inductance values of each phase are measured and compared with each other. They should be equal or any difference between the values should be within acceptable tolerance limits. Measurements should be made in the above sequence. The sequence can be interrupted as soon as fault is detected.

6.2.4 **TONG TESTER**

6.2.4.1 **Introduction** This instrument is used to measure current. Two basic versions which are available are for D.C. and the other for A.C measurement. The advantage of this instrument over other current measuring devices such as an AVO is that there is no requirement to break a circuit, to introduce the meter in series for the measurement. It is however less accurate. It is ideal for measuring the current in damage control cables and current drawn by motors, large transformers, etc.

Fig 6.2.4.1 Tong tester

6.2.4.2 **Operating Procedure** Clip ON ammeter around each cable in turn and measure current. Select the highest scale reading initially to prevent damage to needle.

6.2.5 **NEON TESTER**

6.2.5.1 **Introduction** Neon Tester (N.T) is small and handy test equipment which is used to check whether the circuit is alive or dead. It is used to measure an approximate AC and DC voltage between 110 V and 700 V. It is also used to check whether three phase supply is available in the supply cables. A picture of a neon tester is shown below.

Fig 6.2.5.1 Neon tester

6.2.5.2 **Description** This instrument consists of two, rubber hand assemblies with PVC insulated brass probes. One hand assembly incorporates a NEON LAMP and a solenoid, which can be actuated by AC or DC supply (red scale for DC and yellow scale for AC). To check the voltage, the switch (ring push button which is housed within the PVC insulated probe) must be pressed. When measuring AC voltages the frequency should be 60 Hz. Other frequencies will give inaccurate reading on scale.

6.2.5.3 **Use of Neon Lamp** The neon lamp is used to indicate the voltage and polarity. If an AC voltage is measured the neon will burn over its full length. If it is used on DC it will burn at one end only.

6.2.6 **STROBO SCOPE**

6.2.6.1 **Introduction** Stroboscope is test equipment, which is used to measure r.p.m of the running machinery. The equipment has a flashing lamp whose frequency can be varied. When the flashing frequency of stroboscope is synchronised with running machinery's r.p.m, the r.p.m is displayed on the seven-segment display available on the stroboscope.

Fig 6.2.6.1 Stroboscope

6.2.7 **MEGGER**

6.2.7.1 **Introduction** Wee Megger is a type of self contained high generator, used to find the high resistance and insulation of the equipment. When very high resistance is to be measured the current produced with batteries are too small to be measured. It is therefore necessary to use much higher voltage. Another reason for using high voltage is to check the breakdown of insulation of cable.

6.2.7.2 **Operation**

(a) Connect the load across Megger connections and rotate the hand wheel i.e. +ve terminal to inner conductor and -ve terminal to ground.

(b) The scale should not show zero. It should be in mega ohms. e.g. for good insulation it must read more than 100 m ohm.

(c) Testing capacitor:- Connect the capacitor under test to Megger. Rotate the hand wheel. If capacitor is charging, needle will start showing increasing resistance which means capacitor is good. If meter is steady, the capacitor is bad (not getting charged).

(d) Testing insulation:- Connect the load across Megger connections and rotate the hand wheel i.e. +ve terminal to inner conductor and -ve terminal to ground. The scale should not show zero. It should be in mega ohms. e.g. for good insulation it must read more than 100 m ohm.

Fig 6.2.7.1 Wee Megger

6.2.8 **SPECTRUM ANALYSER**

6.2.8.1 **Introduction** Spectrum analysis is defined as the study of energy distribution across the frequency spectrum of a given electrical signal. The study gives valuable information about bandwidth, effects of different types of modulation and spurious signal generation. The knowledge of the above quantities and phenomena are useful in the design and testing of radio frequency (RF) and pulse circuitry.

Fig 6.2.7.1 Spectrum Analyser

6.2.8.2 Spectrum analysis is divided into two major categories on account of instrumentation limitations and capabilities. These are:-

(a) Audio frequency (AF) analysis

(b) Radio frequency (RF) spectrum analysis

RF spectrum analysis covers a frequency range of 10 MHz to 40 GHz, and hence is more important, because it includes majority of communication, navigation, radar, and industrial instrumentation frequency bands. Spectrum analyzers are sophisticated instruments which are capable of portraying graphically, amplitude of the signal as a function of frequency. These instruments find wide applications for measurement of attenuation, FM deviation and frequency.

6.2.9 **DIGITAL OSCILLOSCOPE**

6.2.9.1 **Introduction** The oscilloscope is probably the most versatile tool for the development of modern electronic circuits and systems. This device allows the amplitude of electrical signal, such as voltage, current, power etc. to be displayed primarily as a function of time. The oscilloscope depends on the movement of an electron beam, which is then made visible by allowing the beam to impinge on a phosphor surface, which produces a visible spot. A view of **Digital Oscilloscope TDS 220** from **Tektronix** is shown below and is discussed subsequently.

Fig 6.2.8.1 Digital Oscilloscope

6.2.9.2 **Function of oscilloscope**. The oscilloscope is used to find out the following:-

(a) The amplitude of the signal (Voltage AC/DC)

(b) Frequency of the signal

(c) Phase difference of two signals

(d) Wave form analysis or pulse measurement of quantities such as :-

(i) Rise time of the pulse

(ii) Fall time of the pulse

(iii) Over rising of pulse

(iv) Pulse width

6.2.10 SIGNAL GENERATOR

6.2.10.1 **Introduction** The signal generator is used to provide known test conditions for the performance evaluation of various electronic systems and for replacing missing signals in systems which are being analyzed for repairs. The standard signal generator is a source of sine wave voltage with an appreciable range of frequency and amplitude both of which are known to a high degree of accuracy. The instrument is provided with means of modulating the carrier frequency which is indicated by the dial setting. The modulation is indicated by a meter. Modulation may be sine wave, square wave and triangular wave. The output signal may be amplitude modulated (AM) or frequency modulated (FM). Usually amplitude modulation is employed.

Fig 6.2.9.1Signal generator

6.2.11 **TIME AND FREQUENCY COUNTER**

6.2.11.1 **Introduction** The time and frequency counter is used to measure the frequency generated from an oscillator/sine-wave generator. The signal whose frequency is to be measured is fed to the frequency counter. The counter measures the signal and displays on LCD display.

Fig 6.2.10.1 Time and Frequency Counter

6.2.10.2 **Principle of Operation** The signal whose frequency is to be measured is divided into a train of pulses with duration of one cycle for the signal. Thereafter, the number of pulses which are applied in a definite interval of time are counted by means of electronic counter. Since the pulse represents the cycle of unknown signal, the number appearing on the counter is a direct indication of the frequency of the unknown signal.

6.3 **Questions**

6.3.1 What do you understand by CRETE? Which all test equipment come under CRETE?

6.3.2 What all precautions must be taken when measuring the insulation of a motor?

6.3.3 Where will you find the bearing diameter before entering the value into shock pulse tester?

6.3.4 What is the basic principle behind Tong Tester?

6.3.5 What all precautions must be taken when using Megger?

6.3.6 What device sweeps a band of frequencies to determine frequencies and amplitudes of each frequency component?

6.3.7 Name two instruments used to analyze waveforms?

6.3.8 How do you measure the continuity of a wire or circuit and which test equipment will you use?

6.4 **Suggested Reading**

VP 204:- Instrumentation and controls

VP 191:- Common Test Equipment

CHAPTER 7

COMPUTER AND IT

7.1 Introduction

7.1.1 Digital and Analog System

In a digital system information is represented and processed in discrete rather than continuous forms. Systems based on continuous forms of information are called analog systems. For example, information on traditional audio cassette tapes is recorded as a continuous analog signal. Same signal can be sampled at uniform time intervals and converted to a set of discrete values to be recorded in a digital form.

7.1.1.1 Advantages of the Digital system

(a) Digital computers offer more flexibility than analog computers, i.e., they are easy to program to perform any desired algorithm.

(b) It is relatively easier to design high speed digital circuits.

(c) Numeric information can be represented digitally with greater precision and range than it can with analog signals.

(d) Given the same set of inputs, a properly designed digital circuit always produces precisely the same results. The outputs of an analog circuit may vary with temperature, supply voltage, component aging, and other factors.

(e) Information storage and retrieval functions are much easier to implement in digital form than in analog.

(f) Digital techniques allow the use of built-in error detection and correction mechanisms.

(g) Digital systems lend themselves to miniaturization more than do analog systems. They can provide a lot of functionality in a small space.

7.1.1.2 What is Computer

Computer is a device which takes input, Process it as per the stored instructions and give us required output. The input to computer is data and the instructions used to process this data are software and programmes which are stored in the memory and finally the output is information in the form of numbers, words, picture etc.

7.1.1.2.1 **Main components of the computer**

(a) **Central processing unit** This part of the computer system collects the raw data from the input devices and converts it to useful information which can then be used by the output devices. The CPU can be a single microchip, or on bigger systems, the CPU can be formed from a number of chips working together. The CPU has various registers to store data, ALU to perform arithmetic and logical operations, instruction decoders, counters and control lines. CPU reads instructions from the memory and performs the tasks specified. Timing of the communication process is controlled by the group of circuits known as control unit.

(b) **Main memory** Instructions and data are held in main memory, which is divided into millions of individually-addressable storage units called bytes. One byte can hold one character, or it can be used to hold a code representing, for example, a tiny part of a picture, a sound, or part of a computer program instruction. The total number of bytes in main memory is referred to as the computer's memory size. Types of memory are:-

(i) **Random Access memory (RAM)** Used for storing programs which are currently running and data which is being processed. This type of memory is volatile - it loses all its contents as soon as the machine is switched off.

(ii) **Read Only Memory (ROM)** Non-volatile, with contents permanently etched into the memory chip at the manufacturing stage Used for example to hold the bootstrap loader, the program which runs as soon as the computer is switched on and instructs it to load the operating system from disk into memory.

(iii) **Programmable read-only memory (PROM)** A memory chip on which data can be written only once. Once a program has been written onto a PROM, it remains there forever. Unlike RAM, PROMs retain their contents when the computer is turned off. The difference between a PROM and a ROM (read-only memory) is that a PROM is manufactured as blank memory, whereas a ROM is programmed during the manufacturing process. To write data onto a PROM chip, you need a special device called a PROM programmer or PROM burner. The process of programming a PROM is sometimes called burning the PROM.

(iv) **Erasable Programmable Read-Only Memory (EPROM)** It is a special type of PROM that can be erased by exposing it to ultraviolet light. Once it is erased, it can be reprogrammed.

(v) **Cache memory** Very fast memory used to improve the speed of a computer, doubling it in some cases. Acts as an intermediate store between the CPU and main memory. Stores the most frequently or recently used instructions and data for rapid retrieval. Generally between 1Kb and 512Kb.Much more expensive than normal RAM.

(vi) **Virtual memory** Space on a hard disk used to temporarily store data and swap it in and out of RAM as needed.

7.2 Operating System

7.2.1 The purpose of an operating system is to organize and control hardware and software so that the device it lives in behaves in a flexible but predictable way. All desktop computers have operating systems. The most common are the Windows family of operating systems developed by Microsoft, the Macintosh operating systems developed by Apple and the UNIX family of operating systems. At the simplest level, an operating system does two things, It manages the hardware and software resources of the system. In a desktop computer, these resources include such things as the processor, memory, disk space, etc and It provides a stable, consistent way for applications to deal with the hardware without having to know all the details of the hardware. Structure of Operating System is shown in the figure 7.1.

7.2.2 Structure of Operating System

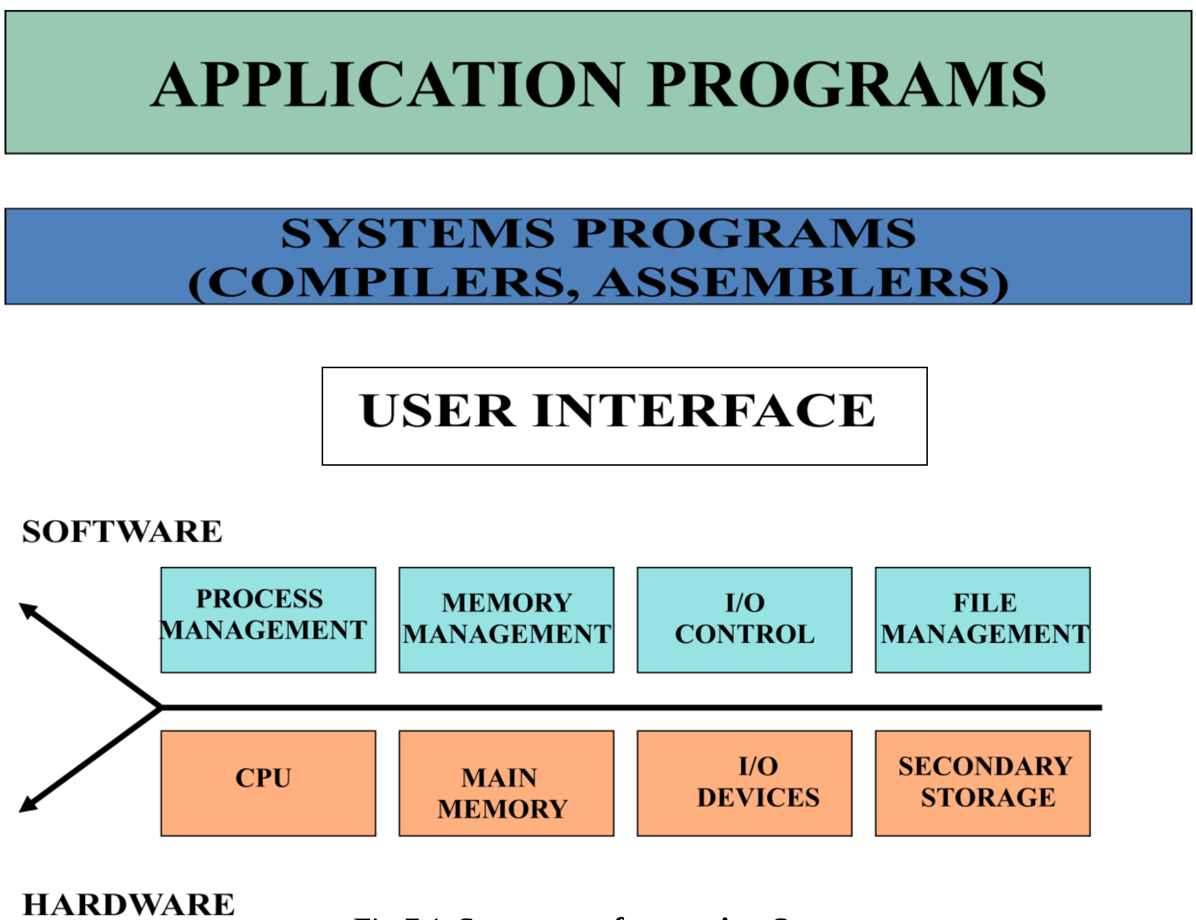


Fig.7.1 **Structure of operating System**

7.1.2.3 **Different kind of Operating Systems**

(a) **Real-time operating system (RTOS)** - Real-time operating systems are used to control machinery, scientific instruments and industrial systems. A very important part of an RTOS is managing the resources of the computer so that a particular operation executes in precisely the same amount of time every time it occurs.

(b) **Single-user, single task** - As the name implies, this operating system is designed to manage the computer so that one user can effectively do one thing at a time. The Palm OS for Palm handheld computers is a good example of a modern single-user, single-task operating system.

(c) **Single-user, multi-tasking** - This is the type of operating system most people use on their desktop and laptop computers today. Microsoft's Windows and Apple's Mac OS platforms are both examples of operating systems that will let a single user have several programs in operation at the same time. For example, it's entirely possible for a Windows user to be writing a note in a word processor while downloading a file from the Internet while printing the text of an e-mail message.

(d) **Multi-user** - A multi-user operating system allows many different users to take advantage of the computer's resources simultaneously. The operating system must make sure that the requirements of the various users are balanced, and that each of the programs they are using has sufficient and separate resources so that a problem with one user doesn't affect the entire community of users. UNIX, VMS and mainframe operating systems, such as MVS, are examples of multi-user operating systems.

7.2.4 **Tasks of Operating Systems**

(a) Processor management

(b) Memory management

(c) Device management

(d) Storage management

(e) Application interface

(f) User interface

7.2.5 **Concept of Process**

The ‘process’ can be defined as the execution of a program or that which a processor executes. Thus each copy of programme and each separate execution of one programme are identified by a unique ‘process’ within the operating system. There can be more than one copy of the same programme in the memory at any time. One programme may be under execution more than once simultaneously or the programme is re-entrant. With each process the OS creates a data structure called process control block (PCB) which gives substance to it and controls it. Each process is identified with a unique id called process id(PID) which can be referenced by the operating system and other process.

7.2.6 **Scheduling**

The task of determining the optimum sequence and timing of assigning ‘process’ to the processor is called scheduling. This task is performed by the operating system. Scheduling can be thought of to be exercised at three levels.

7.2.6.1 **Objectives of Scheduling**

(a) Maximise the system throughput.

(b) Be fair to all users/processes.

(c) Provide tolerable response.

(d) Degrade gracefully.

(e) Be consistent and predictable.

7.2.6.2 **Scheduling Algorithm**

(a) **First Come First Served Scheduling (FCFS)** First process to request the CPU gets it. When CPU is free next process is selected from the head of the queue and allowed to run. Process requesting I/O wait is added to the tail of the list when it moves back to READY state.

(b) **Short Job First Scheduling (SJF)** CPU is allocated to the Job which has the shortest expected CPU burst. It is difficult to predict the next cycle CPU burst time. If two jobs have same burst time then FCFS is adopted. It can be both Preemptive and Non Preemptive.

(c) **Priority Scheduling** A priority is assigned to each job and the CPU is assigned to the process in priority order, those with equal order are handled on FCFS basis. SJF is a case of Priority Scheduling with Priority equal to reciprocal of CPU burst.

(d) **Round-Robin Scheduling** CPU is allocated to the Jobs which are arranged in a circular queue, and the scheduler moves from one process to the next at the end of the time slice or when I/O wait occurs if sooner. This scheduling is Preemptive. Each job gets 1/n of the CPU time.

(e) **Multi Level Queue Scheduling** Jobs are divided into different queues based on their types (interactive, batch), priority, etc. Each queue follows its own scheduling algorithm. There is scheduling of queues as well, generally preemptive with fixed priority.

(f) **Multilevel feedback Queue Scheduling** Jobs may be moved between the queues in order to provide flexibility. Typically a CPU bound job may be relegated to a low priority queue and an I/O bound job may be promoted to a high priority queue. The flexibility provided by this type of algorithm increases its complexity.

7.3 Networking

7.3.1 Introduction

Networking is the term that describes the processes involved in designing, implementing, upgrading, managing and otherwise working with networks and network technologies. A network is simply a collection of computers or other hardware devices that are connected together, either physically or logically, using special hardware and software, to allow them to exchange information and cooperate.

7.3.2 Computing Models

The following computing models are used to categorize the way networking services are provided:-

(a) **Peer to Peer** This is a network environment that allows each user to control access to resources on their computers. It implies that all systems have the same status on the network. No system is a "slave" to another as shown in Figure 7.2

Fig 7.2 **Peer to Peer Network**

(b) **Client Server** In a client server network environment one or more computers provide services to clients which request services. The 'server' works for the client by providing a variety of network services. The server may control network activities or may be passive, and just provide services when requested. Applications used in a client/server network can be split into a front end that runs on the client and a back end that runs on the server. The network operating system provides the mechanism to integrate all the components of the network and allow multiple users to simultaneously share the same resources irrespective of physical location as shown in Figure 7.3.

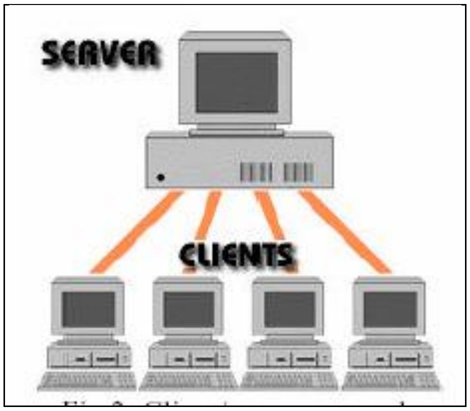


Fig 7.3 **Server-Client Network**

7.3.3 **Transmission Media**

In a network of computers, the transmission media provide the physical path for communication among the nodes and the manner in which the nodes are geometrically interconnected is known as its topology. The common topology used are Ring, bus, Star as shown in figure 7.4.

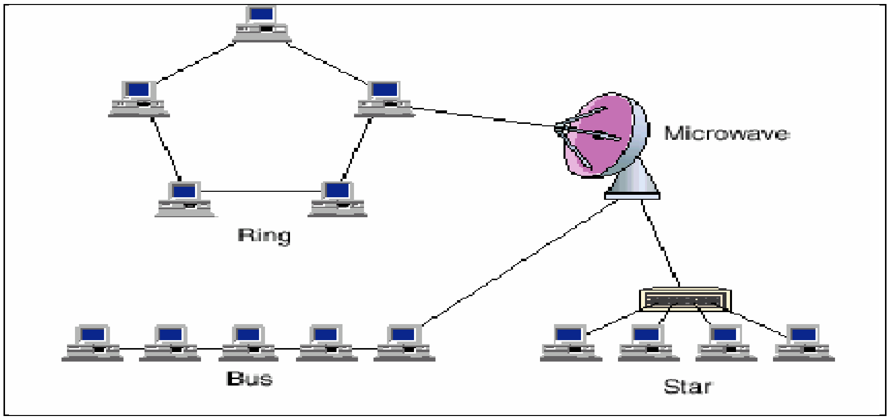
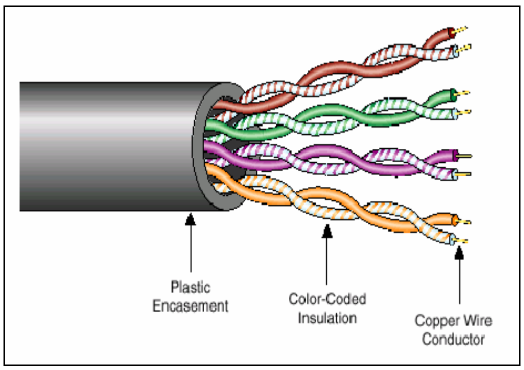


Fig 7.4 **Common Topologies**

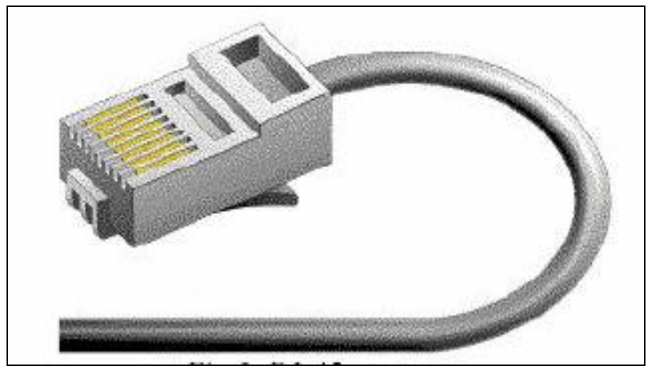
7.3.3.1 **Cable Media**

Various types of cables used are:-

(a) **Twisted Pair cable** These cable uses copper wire as telecommunication cable. Twisted pair can be used for both Analog and Digital communication. Twisting the copper wires reduces cross talk and signal emissions. Each intertwined strand conducts a current whose emitted waves are cancelled out by the other wire's emissions. There are two types of cables in this category, shielded twisted pair cable and unshielded twisted pair cable as shown in Figure 7.5.



Shielded Twisted pair Cable



Unshielded twisted pair Cable

Fig 7.5 **Various Twisted Pair Cable**

(b) **Coaxial Cable** It is made of two conductors that share a common axis the centre of the cable is a relatively stiff solid copper wire or stranded wire encased in insulating plastic foam The foam is surrounded by the second conductor, a wire mesh tube (some include conductive foil wrap), which serves as a shield from interference and signal capture A tough, insulating plastic tube forms the cover of the cable as shown in fig 7.6

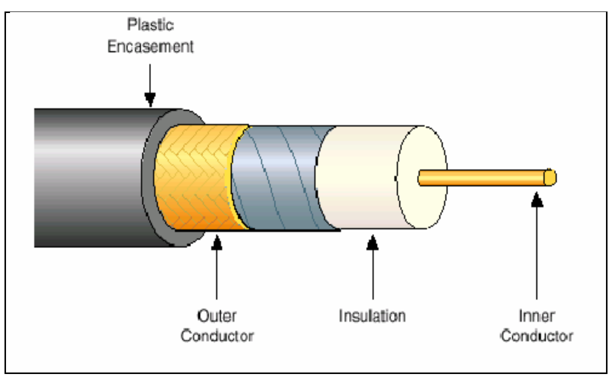


Fig 7.6 **Coaxial cable**

(c) **Fiber Optic Cable** Fiber optic cables can be composed of a single jacketed strand, but often multiple strands are bundled in the centre of a cable. Some fiber optic cables also provide an additional metallic, or fiber glass wire to increase cable strength. Optical fibers can be multimode or single mode in nature. Single-mode fiber has been optimized to allow only one light path, multimode fiber allows various light paths. Single-mode fiber has a higher capacity but costs more to produce and use than multimode fiber as shown in Fig 7.7.

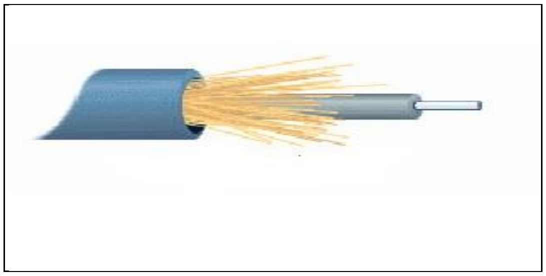


Fig 7.7 **Fiber Optic Cable**

7.3.4 Fundamental parts of Network

(a) **Network** - A network is a group of computers connected together in a way that allows information to be exchanged between the computers.

(b) **Node** - A node is anything that is connected to the network. While a node is typically a computer, it can also be something like a printer or CD-ROM tower.

(c) **Segment** - A segment is any portion of a network that is separated, by a switch, bridge or router, from other parts of the network.

(d) **Backbone** - The backbone is the main cabling of a network that all of the segments connect to. Typically, the backbone is capable of carrying more information than the individual segments.

(e) **Topology** - Topology is the way that each node is physically connected to the network (more on this in the next section).

(f) **Local Area Network (LAN)** - A LAN is a network of computers that are in the same general physical location, usually within a building or a campus. If the computers are far apart (such as across town or in different cities), then a Wide Area Network (WAN) is typically used.

(g) **Network Interface Card (NIC)** - Every computer (and most other devices) is connected to a network through an NIC. In most desktop computers, this is an Ethernet card (normally 10 or 100 Mbps) that is plugged into a slot on the computer's motherboard.

(h) **Media Access Control (MAC) address** - This is the physical address of any device -- such as the NIC in a computer -- on the network. The MAC address, which is made up of two equal parts, is 6 bytes long. The first 3 bytes identify the company that made the NIC. The second 3 bytes are the serial number of the NIC itself.

(j) **Unicast** - A Unicast is a transmission from one node addressed specifically to another node.

(k) **Multicast** - In a multicast, a node sends a packet addressed to a special group address. Devices that are interested in this group register to receive packets addressed to the group. An example might be a Cisco router sending out an update to all of the other Cisco routers.

(m) **Broadcast** – In a broadcast, a node sends out a packet that is intended for transmission to all other nodes on the network.

7.3.5 **Protocol**

A networking protocol defines a set of rules, algorithms, messages and other mechanisms that enable software and hardware in networked devices to communicate effectively. A protocol usually describes a means for communication between corresponding entities at the same OSI Reference Model layer in two or more devices. The most common protocols are:

(a) Ethernet

(b) Local Talk

(c) Token Ring

(d) FDDI

7.3.6 **Network Technologies**

Networks are differentiated by the method they use to determine a path between devices.

(a) **Circuit Switching**: A method of communication in which a dedicated communications path is established between two devices through one or more intermediate switching nodes as shown in fig 7.8

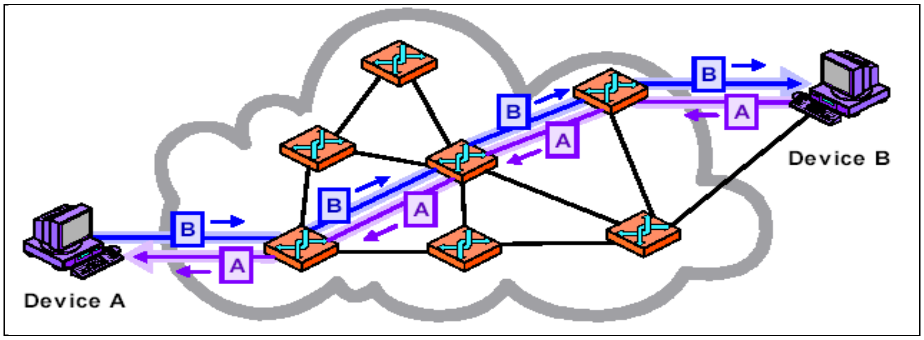


Fig 7.8 **Circuit Switching**

(b) **Packet switching** A method of transmitting messages through a communication network, in which long messages are subdivided into short packets. Each packet is passed from source to destination through intermediate nodes. At each node the entire message is received, stored briefly, and then passed on to the next node as shown in the Fig 7.9.

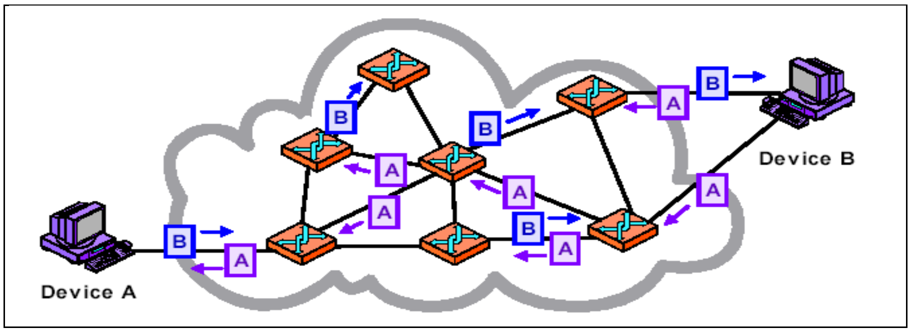


Fig 7.9 **packet Switching**

7.3.7 Network Hardware

Some of the Networking hardware are listed below:-

(a) **Modem** - A modem is a device that converts digital data into analog signal for transmission over telephone line. It involves modulation at the transmitting end and demodulation at the receiving end. The same device can be used to connect remote computers over telephone networks. In some instances, modems can take the place of NICs in connecting a device to a network as shown in Fig 7.10.

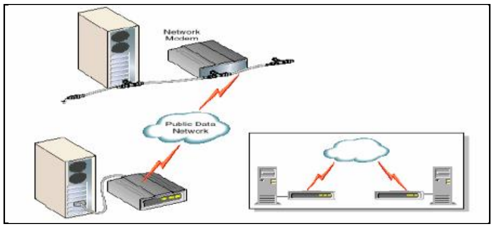


Fig 7.10 **Modem**

(b) **Repeaters** - A repeater is a device that boosts a network's signal as it passes through the transmission medium by electrically amplifying the signal it receives and re-broadcasting it. They are used when the total length of your network cable exceeds the standards set for the type of cable being used as shown in the Fig 7.11.

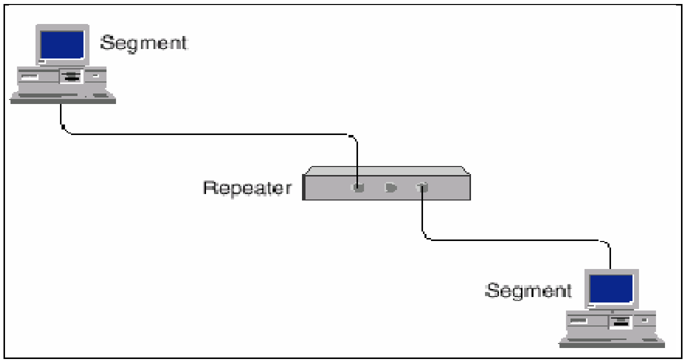


Fig 7.11 **Repeaters**

(c) **Concentrators/ Hubs** - Hubs receive transmissions from connected devices and transmit the signals to the other connected devices. The hub organizes the cables and transmits incoming signals to the other media segments. Some network implementations require a central point of connection between media segments. These central points are referred to as hubs, multiport repeaters, or concentrators. Cables from network devices plug in to the ports on the hub. A passive hub connects medium segments together, does not regenerate or amplify signals. It is not a repeater. The distance limitations on each segment connected to a passive hub are different than those applied to segments connected by active hubs. An active hub, connects medium segments together, regenerates or amplifies signals. In effect active hubs can extend the maximum cable length. All computers connected by active hubs still receive signals from all other computers as shown in the Fig 7.12.

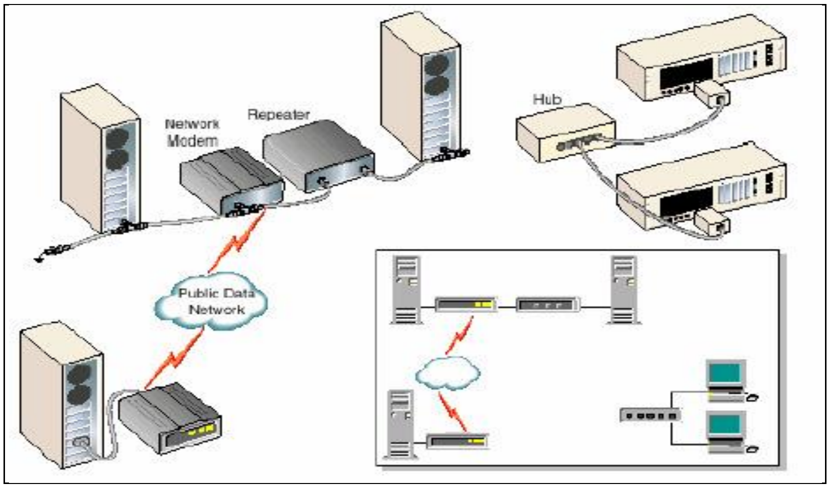


Fig 7.12 **Concentrators/Hub**

(d) **Transceivers**- A Transceiver is not a repeater. The function of a transceiver is to connect a single device to the network. There are four types of transceivers, they are:-

(i) Thick wire transceiver

(ii) Thin co-axial transceiver

(iii) Twisted pair transceiver

(iv) Fibre optic transceiver

(e) **Switches** - Switches allow you to avoid the congestion of a shared Ethernet network by permitting you to create individual segments. The improvement in network performance can be dramatic as shown in the Fig 7.13.

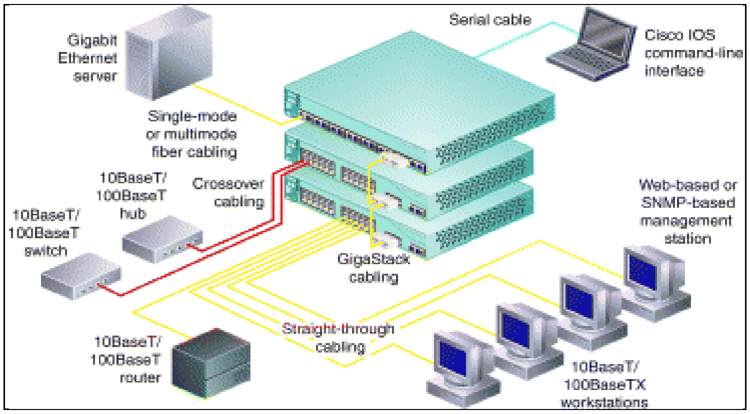


Fig 7.13 **Switches**

(f) **Routers** - A router translates information from one network to another; it is similar to a super intelligent bridge. Routers connect two or more logically separate networks. Each network is identified by its network address, a logical name assigned to it. Each network in an internet work must be assigned a unique network address as shown in the Fig 7.14.

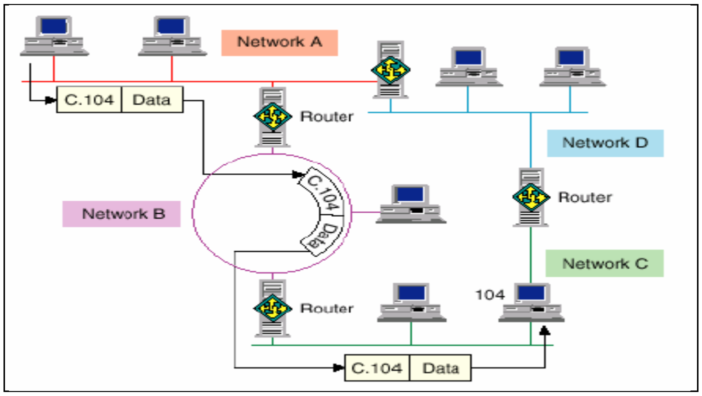


Fig 7.14 **Routers**

(g) **Multiplexers** - A transmission media that provides more capacity than a signal can use. To efficiently use the entire transmission media bandwidth, you can install multiplexers. A multiplexer combines two or more separate signals on a transmission media segment as shown in the Fig 7.15.

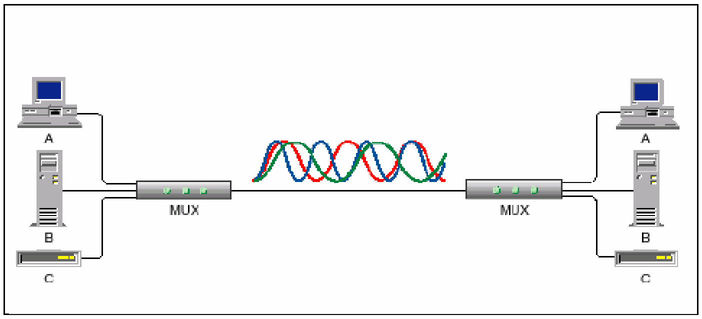


Fig 7.15 **Multiplexers**

(h) **Bridges** - A bridge is a device that allows you to segment a large network into two smaller, more efficient networks. A bridge extends the maximum distance of your network by connecting separate network segments. Bridges selectively pass signals from one segment to another based on the physical location of the destination device as shown in the fig 7.16.

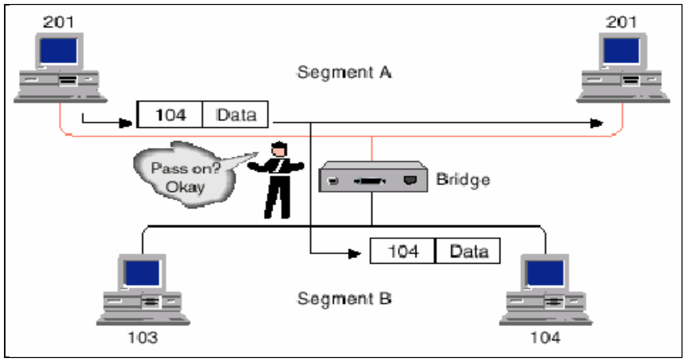


Fig 7.16 **Bridges**