# ELECTRONIC MECHANIC

## NSQF LEVEL - 5

## 3rd Semester

## TRADE THEORY

**SECTOR: Electronics & Hardware**

Directorate General of Training


DIRECTORATE GENERAL OF TRAINING
MINISTRY OF SKILL DEVELOPMENT & ENTREPRENEURSHIP
GOVERNMENT OF INDIA



NATIONAL INSTRUCTIONAL
MEDIA INSTITUTE, CHENNAI

Post Box No. 3142, CTI Campus, Guindy, Chennai - 600 032

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**Duration : 2 - Years**

**Trades : Electronic Mechanic 3rd Semester - Trade Theory NSQF Level 5**



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# FOREWORD

The Government of India has set an ambitious target of imparting skills to 30 crores people, one out of every four Indians, by 2020 to help them secure jobs as part of the National Skills Development Policy. Industrial Training Institutes (ITIs) play a vital role in this process especially in terms of providing skilled manpower. Keeping this in mind, and for providing the current industry relevant skill training to Trainees, ITI syllabus has been recently updated with the help of Mentor Councils comprising various stakeholder's viz. Industries, Entrepreneurs, Academicians and representatives from ITIs.

The National Instructional Media Institute (NIMI), Chennai, an autonomous body under the Directorate General of Training (DGT), Ministry of Skill Development & Entrepreneurship is entrusted with developing producing and disseminating Instructional Media Packages (IMPs) required for ITIs and other related institutions.

The institute has now come up with instructional material to suit the revised curriculum for **Electronic 3rd Semester Trade Theory NSQF Level - 5 in Electronic & Hardware Sector under Semester Pattern.** The NSQF Level - 5 Trade Theory will help the trainees to get an international equivalency standard where their skill proficiency and competency will be duly recognized across the globe and this will also increase the scope of recognition of prior learning. NSQF Level - 5 trainees will also get the opportunities to promote life long learning and skill development. I have no doubt that with NSQF Level - 5 the trainers and trainees of ITIs, and all stakeholders will derive maximum benefits from these IMPs and that NIMI's effort will go a long way in improving the quality of Vocational training in the country.

The Executive Director & Staff of NIMI and members of Media Development Committee deserve appreciation for their contribution in bringing out this publication.

Jai Hind



**RAJESH AGGARWAL**
Director General / Addl.Secretary
Ministry of Skill Development & Entrepreneurship,
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New Delhi - 110 001

# PREFACE

The National Instructional Media Institute (NIMI) was established in 1986 at Chennai by then Directorate General of Employment and Training (D.G.E & T), Ministry of Labour and Employment, (now under Directorate General of Training, Ministry of Skill Development and Entrepreneurship) Government of India, with technical assistance from the Govt. of the Federal Republic of Germany. The prime objective of this institute is to develop and provide instructional materials for various trades as per the prescribed syllabi under the Craftsman and Apprenticeship Training Schemes.

The instructional materials are created keeping in mind, the main objective of Vocational Training under NCVT/NAC in India, which is to help an individual to master skills to do a job. The instructional materials are generated in the form of Instructional Media Packages (IMPs). An IMP consists of Theory book, Practical book, Test and Assignment book, Instructor Guide, Audio Visual Aid (Wall charts and Transparencies) and other support materials.

The trade practical book consists of series of exercises to be completed by the trainees in the workshop. These exercises are designed to ensure that all the skills in the prescribed syllabus are covered. The trade theory book provides related theoretical knowledge required to enable the trainee to do a job. The test and assignments will enable the instructor to give assignments for the evaluation of the performance of a trainee. The wall charts and transparencies are unique, as they not only help the instructor to effectively present a topic but also help him to assess the trainee's understanding. The instructor guide enables the instructor to plan his schedule of instruction, plan the raw material requirements, day to day lessons and demonstrations.



IMPs also deals with the complex skills required to be developed for effective team work. Necessary care has also been taken to include important skill areas of allied trades as prescribed in the syllabus.

The availability of a complete Instructional Media Package in an institute helps both the trainer and management to impart effective training.

The IMPs are the outcome of collective efforts of the staff members of NIMI and the members of the Media Development Committees specially drawn from Public and Private sector industries, various training institutes under the Directorate General of Training (DGT), Government and Private ITIs.

NIMI would like to take this opportunity to convey sincere thanks to the Directors of Employment & Training of various State Governments, Training Departments of Industries both in the Public and Private sectors, Officers of DGT and DGT field institutes, proof readers, individual media developers and coordinators, but for whose active support NIMI would not have been able to bring out this materials.

**R. P. DHINGRA**
**EXECUTIVE DIRECTOR**

**Chennai - 600 032**

# ACKNOWLEDGEMENT

National Instructional Media Institute (NIMI) sincerely acknowledges with thanks for the co-operation and contribution extended by the following Media Developers and their sponsoring organisation to bring out this IMP **(Trade Theory)** for the trade of **Electronic Mechanic** under the **Electronic & Hardware** Sector for ITIs.

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NIMI records its appreciation of the Data Entry, CAD, DTP Operators for their excellent and devoted services in the process of development of this Instructional Material.

NIMI also acknowledges with thanks, the invaluable efforts rendered by all other staff who have contributed for the development of this Instructional Material.

NIMI is grateful to all others who have directly or indirectly helped in developing this IMP.

# INTRODUCTION

## TRADE THEORY

The manual of trade theory consists of theoretical information for the Fourth Semester course of the Electronic Mechanic Trade. The contents are sequenced according to the practical exercise contained in the manual on Trade practical. Attempt has been made to relate the theortical aspects with the skill covered in each exercise to the extent possible. This co-relation is maintained to help the trainees to develop the perceptional capabilities for performing the skills.

The Trade theory has to be taught and learnt along with the corresponding exercise contained in the manual on trade practical. The indicating about the corresponding practical exercise are given in every sheet of this manual.

It will be preferable to teach/learn the trade theory connected to each exercise atleast one class before performing the related skills in the shop floor. The trade theory is to be treated as an integrated part of each exercise.

The material is not the purpose of self learning and should be considered as supplementary to class room instruction.

## TRADE PRACTICAL

The trade practical manual is intented to be used in workshop . It consists of a series of practical exercises to be completed by the trainees during the Fourth Semester course of the Electronic Mechanic trade supplemented and supported by instructions/ informations to assist in performing the exercises. These exercises are designed to ensure that all the skills in compliance with NSQF LEVEL - 5

The manual is divided into Eight modules. The distribution of time for the practical in the Eight modules are given below.

| | | |
|---|---|---|
| Module 1 | Digital Storage Oscilloscope | 25 Hrs |
| Module 2 | Basic SMD (2,3,4 terminal components) | 125 Hrs |
| Module 3 | Protective devices | 25 Hrs |
| Module 4 | Electrical control circuits | 25 Hrs |
| Module 5 | Electronics cables & connectors | 50 Hrs |
| Module 6 | Communication Electronics | 75 Hrs |
| Module 7 | Microcontroller (8051) | 75 Hrs |
| Module 8 | Sensors, Transducers and applications | 75 Hrs |
| | Projects - Analog IC application | 50 Hrs |
| | Projects - Digital IC application | 50 Hrs |
| | Total | 575 Hrs |

The skill training in the shop floor is planned through a series of practical exercises centred around some practical project. However, there are few instances where the individual exercise does not form a part of project.

While developing the practical manual a sincere effort was made to prepare each exercise which will be easy to understand and carry out even by below average trainee. However the development team accept that there is a scope for further improvement. NIMI, looks forward to the suggestions from the experienced training faculty for improving the manual.

## CONTENTS

## LEARNING / ASSESSABLE OUTCOME

On completion of this book you shall be able to

- **Measure the various parameters by DSO and execute the result wiith standard one**
- **Rework on PCB after identifying defects from SMD soldering and desoldering**
- **Construct different electrical control circuits and test for their proper functioning with due care and safety**
- **Prepare, crimp, terminate and test various cables used in different electronics industries**
- **Assemble and test a commercial AM/FM receiver and evaluate performance**
- **Test, service and troubleshoot the various components of different domestic/industrial programmable systems.**
- **Execute the operation of different process sensors, identify wire & test various sensors of different industrial processes by selecting appropriate test instruments.**
- **Plan and carry out the selection of a project, assembly the project and evaluate performance for a domestic/commercial applications.**

## SYLLABUS FOR ELECTRONIC MECHANIC TRADE

**THIRD SEMESTER** **Duration: 06 Months**

| Week No. | Learning Outcome Reference | Professional Skills (Trade Practical) with Indicative hrs. | Professional Knowledge (Trade Practical) |
|---|---|---|---|
| 53 | • Measure the various parameters by DSO and execute the result with standard one. | Digital Storage Oscilloscope<br>180. Identify the different front panel control of a DSO. (5 hrs)<br>181. Measure the Amplitude, Frequency and time period of typical electronic signals using DSO. (7 hrs)<br>182.Take a print of a signal from DSO by connecting it to a printer and tally with applied signal. (6 hrs)<br>183.Construct and test function generator using IC 8038. (7 hrs) | Advantages and features of DSO. Block diagram of Digital storage oscilloscope (DSO)/ CRO and applications. Applications of digital CRO. Block diagram of function generator. Differentiate a CRO with DSO. |
| 54 | • Identify, place, solder and desolder and test different SMD discrete components and IC,s package with due care and following safety norms using proper tools/setup. | Basic SMD (2, 3, 4 terminal components)<br>184. Identification of 2, 3, 4 terminal SMD components. (5 hrs)<br>185. De-solder the SMD components from the given PCB. (5 hrs)<br>186. Solder the SMD components in the same PCB. (5 hrs)<br>187. Check for cold continuity of PCB. (3 hrs)<br>188. Identification of loose /dry solder, broken tracks on printed wired assemblies. (7 hrs) | Introduction to SMD technology Identification of 2, 3, 4 terminal SMD components. Advantages of SMD components over conventional lead components. Soldering of SM assemblies - Reflow soldering. Tips for selection of hardware, Inspection of SM. |
| 55-56 | • Identify, place, solder and desolder and test different SMD discrete components and IC,s package with due care and following safety norms using proper tools/setup. | SMD Soldering and De-soldering<br>189. Identify various connections and setup required for SMD Soldering station. (5 hrs)<br>190. Identify crimping tools for various IC packages. (3 hrs)<br>191. Make the necessary settings on SMD soldering station to de-solder various ICs of different packages (at least four) by choosing proper crimping tools (14 hrs)<br>192. Make the necessary settings on SMD soldering station to solder various ICs of different packages (at least four) by choosing proper crimping tools | Introduction to Surface Mount Technology (SMT). Advantages, Surface Mount components and packages. Introduction to solder paste (flux). Soldering of SM assemblies, reflow soldering. Tips for selection of hardware, Inspection of SM. Identification of Programmable Gate array (PGA) packages. Specification of various tracks, calculation of track width for different current ratings. Cold/ Continuity check of PCBs. Identification of lose / dry solders, broken tracks on printed wiring assemblies. |

| | | | |
|---|---|---|---|
| | | (14 hrs)<br>193. Make the necessary setting rework of defective surface mount component used soldering / de-soldering method. (14 hrs) | Introduction to Pick place Machine, Reflow Oven, Preparing stencil,& stencil printer |
| 57-58 | • Rework on PCB after identifying defects from SMD soldering and desoldering. | PCB Rework<br>194.Checked and Repair Printed Circuit Boards single, Double layer, and important tests for PCBs. (12 hrs)<br>195. Inspect soldered joints, detect the defects and test the PCB for rework. (8 hrs)<br>196. Remove the conformal coatings by different methods. (8 hrs)<br>197.Perform replacement of coating. (8 hrs)<br>198.Perform baking and preheating. (8 hrs)<br>199. Repair solder mask and damage pad. (6 hrs) | Introduction to Static charges, prevention, handling of static sensitive devices, various standards for ESD. Introduction to non soldering interconnections. Construction of Printed Circuit Boards (single, Double, multilayer), Important tests for PCBs. Introduction to rework and repair concepts. Repair of damaged track. Repair of damaged pad and plated through hole. Repair of solder mask. |
| 59 | • Construct different electrical control circuits and test for their proper functioning with due care and safety. | Protection devices<br>200. Identify different types of fuses along with fuse holders, overload (no volt coil), current adjust (Biometric strips to set the current). (9 hrs)<br>201. Test the given MCBs. (8 hrs)<br>202. Connect an ELCB and test the leakage of an electrical motor control circuit. (8 hrs) | Necessity of fuse, fuse ratings, types of fuses, fuse bases. Single/ three phase MCBs, single phase ELCBs. Types of contactors, relays and working voltages. Contact currents, protection to contactors and high current applications. |
| 60 | • Construct different electrical control circuits and test for their proper functioning with due care and safety | Electrical control circuits<br>203. Measure the coil winding resistance of the given motor. (6 hrs.)<br>204. Prepare the setup of DOL starter and Control an induction motor. (7 hrs)<br>205. Construct a direction control circuit to change direction of an induction motor. (6 hrs.)<br>206. Connect an overload relay and test for its proper functioning. (6 hrs) | Fundamentals of single phase Induction motors, synchronous speed, slip, rotor frequency. Torque-speed characteristics, Starters used for Induction motors. |
| 61-62 | • Prepare, crimp, terminate and test various cables used in different electronics industries. | Electronic Cables & Connectors<br>207. Identify various types of cables viz. RF coxial feeder, screened cable, ribbon cable, RCA connector cable, digital optical audio, video cable, RJ45, RJ11, | Cable signal diagram conventions Classification of electronic cables as per the application w.r.t. insulation, gauge, current capacity, flexibility etc. Different types of |

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| | | Ethernet cable, fiber optic cable splicing, fiber optic cable mechanical splices, insulation, gauge, current capacity, flexibility etc. used in various electronics products, different input output sockets (15 hrs)<br>208. Identify suitable connectors, solder/crimp /terminate & test the cable sets. (10 hrs)<br>209. Check the continuity as per the marking on the connector for preparing the cable set. (10 hrs)<br>210. Identify and select various connectors and cables inside the CPU cabinet of PC. (10 hrs)<br>211. Identify the suitable connector and cable to connect a computer with a network switch and prepare a cross over cable to connect two network computers. (5 hrs) | connector & their terminations to the cables. Male / Female type DB connectors. Ethernet 10 Base cross over cables and pin out assignments, UTP and STP, SCTP, TPC, coxoial, types of fibre optical Cables and Cable trays. Different types of connectors Servo 0.1" connectors, FTP, RCA,BNC,HDMI Audio/video connectors like XLR, RCA (phono), 6.3 mm PHONO, 3.5 / 2.5 mm PHONO, BANTAM, SPEAKON, DIN, mini DIN, RF connectors, USB, Fire wire, SATA Connectors, VGA, DVI connectors, MIDI and RJ45,RJ11 etc. |
| **63-65** | • Assemble and test a commercial AM/ FM receiver and evaluate performance. | Communication electronics<br>212. Modulate and Demodulate various signals using AM and FM on the trainer kit and observe waveforms (10 hrs)<br>213. Construct and test IC based AM Receiver (10 hrs)<br>214. Construct and test IC based FM transmitter (10 hrs)<br>215. Construct and test IC based AM transmitter and test the transmitter power. Calculate the modulation index. (10 hrs)<br>216. Dismantle the given FM receiver set and identify different stages (AM section, audio amplifier section etc) (10 hrs)<br>217. Modulate two signals using AM kit draw the way from and calculate percent (%) of modulation. (10 hrs)<br>218. Modulate and Demodulate a signal using PAM, PPM, PWM Techniques (15 hrs) | Radio Wave Propagation – principle, fading. Need for Modulation, types of modulation and demodulation. Fundamentals of Antenna, various parameters, types of Antennas & application. Introduction to AM, FM & PM, SSB-SC & DSB-SC. Block diagram of AM and FM transmitter. FM Generation & Detection. Digital modulation and demodulation techniques, sampling, quantization & encoding. Concept of multiplexing and de multiplexing of AM/ FM/ PAM/ PPM /PWM signals.<br>A simple block diagram approach to be adopted for explaining the above mod/ demod. techniques |
| **66-68** | • Test, service and troubleshoot the various components of different domestic/ industrial programmable systems. | Microcontroller (8051)<br>219. Identify various ICs & their functions on the given Microcontroller Kit. (5 hrs)<br>220. Identify the address range of RAM & ROM. (5 hrs)<br>221. Measure the crystal frequency, connect it to the controller. (5 hrs) | Introduction Microprocessor & 8051Microcontroller, architecture, pin details & the bus system. Function of different ICs used in the Microcontroller Kit. Differentiate microcontroller with microprocessor. Interfacing of memory to the |

| | | | |
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| | | 222.Identify the port pins of the controller & configure the ports for Input & Output operation. (7 hrs)<br>223.Use 8051 microcontroller, connect 8 LED to the port, blink the LED with a switch. (10 hrs)<br>224. Perform the initialization, load & turn on a LED with delay using Timer. (8 hrs)<br>225. Perform the use of a Timer as an Event counter to count external events. (10 hrs)<br>226. Demonstrate entering of simple programs, execute & monitor the results. (10 hrs)<br>227. Perform with 8051 microcontroller assembling language program, check the reading of an input port and sending the received bytes to the output port of the microcontroller, used switches and LCD for the input and output. (15 hrs) | microcontroller. Internal hardware resources of microcontroller. I/O port pin configuration. Different variants of 8051 & their resources. Register banks & their functioning. SFRs & their configuration for different applications.<br>Comparative study of 8051 with 8052. Introduction to PIC Architecture. |
| **69-71** | • Execute the operation of different process sensors, identify, wire & test various sensors of different industrial processes by selecting appropriate test instruments. | Sensors, Transducers and Applications<br>228. Identify sensors used in process industries such as RTDs, Temperature ICs, Thermocouples, proximity switches (inductive, capacitive and photo electric), load cells, strain gauge. LVDT PT 100 (platinum resistance sensor), water level sensor, thermostat float switch, float valve by their appearance (15 hrs)<br>229. Measure temperature of a lit fire using a Thermocouple and record the readings referring to data chart. (15 hrs)<br>230.Measure temperature of a lit fire using RTD and record the readings referring to data chart (15 hrs.)<br>231. Measure the DC voltage of a LVDT (15 hrs)<br>232. Detect different objectives using capacitive, inductive and photoelectric proximity sensors (15 hrs) | Basics of passive and active transducers. Role, selection and characteristics. Sensor voltage and current formats.<br>Thermistors / Thermocouples - Basic principle, salient features, operating range, composition, advantages and disadvantages.<br>Strain gauges/ Load cell – principle, gauge factor, types of strain gauges.<br>Inductive/ capacitive transducers - Principle of operation, advantages and disadvantages.<br>Principle of operation of LVDT, advantages and disadvantages.<br>Proximity sensors – applications, working principles of eddy current, capacitive and inductive proximity sensors |

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|---|---|---|---|
| **72-73** | • Plan and carry out the Selection of a project, assemble the project and evaluate performance for a domestic/commer cial applications. | Analog IC Applications<br>233-237<br>Make simple projects/ Applications using ICs 741, 723, 555, 7106, 7107 Sample projects:<br>• Laptop protector<br>• Mobile cell phone charger<br>• Battery monitor<br>• Metal detector<br>• Mains detector<br>• Lead acid battery charger<br>• Smoke detector<br>• Solar charger<br>• Emergency light<br>• Water level controller<br>• Door watcher<br>(Instructor will pick up any five of the projects for implementation) (50 Hrs) | Discussion on the identified projects with respect to data of the concerned ICs. Components used in the project. |
| **74-75** | • Plan and carry out the Selection of a project, assemble the project and evaluate performance for a domestic/commer cial applications | Digital IC Applications<br>238-242<br>Make simple projects/Applications using various digital ICs (digital display, event counter, stepper motor driver etc)<br>Duty cycle selector<br>• Frequency Multiplier<br>• Digital Mains Resumption Alarm<br>• Digital Lucky Random number generator<br>• Dancing LEDs<br>• Count down timer<br>• Clap switch<br>• Stepper motor control<br>• Digital clock<br>• Event counter<br>• Remote jammer<br>(Instructor will pick up any five of the projects for implementation) (50 Hrs) | Discussion on the identified projects with respect to data of the concerned ICs. Components used in the project. |
| 76-77 | Revision | | |
| 78 | Examination | | |
| | | | |

# Operate the front panel controls of a digital storage oscilloscope

**Objectives :** At the end of this lesson you shall be able to
- **define digital storage oscilloscope**
- **compare DSO and analog CRO**
- **draw the block diagram and explain the functions of each block**
- **list the functions of each control on the front panel.**

Electronic equipments can be divided into two types: analog and digital. Analog equipment works with continuously variable voltages, while digital equipment works with binary numbers (1 and 0's) that may represent voltage samples. For example, a conventional cassette player is an analog device; a compact disc player is a digital device.

Oscilloscopes also come in analog and digital types. An analog oscilloscope works by directly applying a voltage being measured to an electron beam moving across the oscilloscope screen. The voltage deflects the beam up and down proportionally, tracing the waveform on the screen. This gives an immediate picture of the waveform. In contrast, a digital oscilloscope samples the waveform and uses an analog-to-digital converter ( ADC) to convert the voltage being measured into digital information. Then uses this digital information to reconstruct the waveform on the screen. Some of the advantages of a digital oscilloscope over analog oscilloscope include the scope's ability to store digital data for later viewing, upload to a computer, generate a hard copy or store on a disk and its capacity to instantly make measurements on the digital data.

A digital oscilloscope also has the ability to examine digitized information stored in its memory and make automatic measurements based on the selected parameters of the user, such as voltage excursion, frequency and rise times.

**Digital Storage Oscilloscopes (DSO)**

Digital oscilloscopes are often referred to as digital storage oscilloscope (DSO) or digital sampling oscilloscopes (DSO).

The concept behind the digital oscilloscope is somewhat different to an analog scope.

Rather than processing the signals in an analog fashion, the DSO converts them into a digital format using an analog to digital converter (ADC), then it stores the digital data in the memory, and then processes the signals digitally, finally it converts the resulting signal in a picture format to be displayed on the screen of the scope.

Since the waveform is stored in a digital format, the data can be processed either within the oscilloscope itself, or even by a PC connected to it. One advantage of using the DSO is that the stored data can be used to visualize or process the signal at any time. The analog scopes do not have memory therefore the signal can be displayed only instantaneously. The transient parts of the signal (which may vanish even in milliseconds or microseconds) can not be observed using an analog oscilloscope. The DSO's are widely used in many applications in view of their flexibility and performance.

Figure 1 shows the block diagram of DSO as consists of,

1 Data acquisition

2 Storage

3 Data display.

Data acquisition is earned out with the help of both analog to digital and digital to analog converters, which is used for digitizing, storing and displaying analog waveforms. Overall operation is controlled by control circuit which is usually consists of microprocessor.

Data acquisition portion of the system consist of a Sample-and-Hold (S/H) circuit and an analog to digital converter (ADC) which continuously samples and digitizes the input signal at a rate determined by the sample clock and transmit the digitized data to memory for storage. The control circuit determines whether the successive data points are stored in successive memory location or not, which is done by continuously updating the memories.

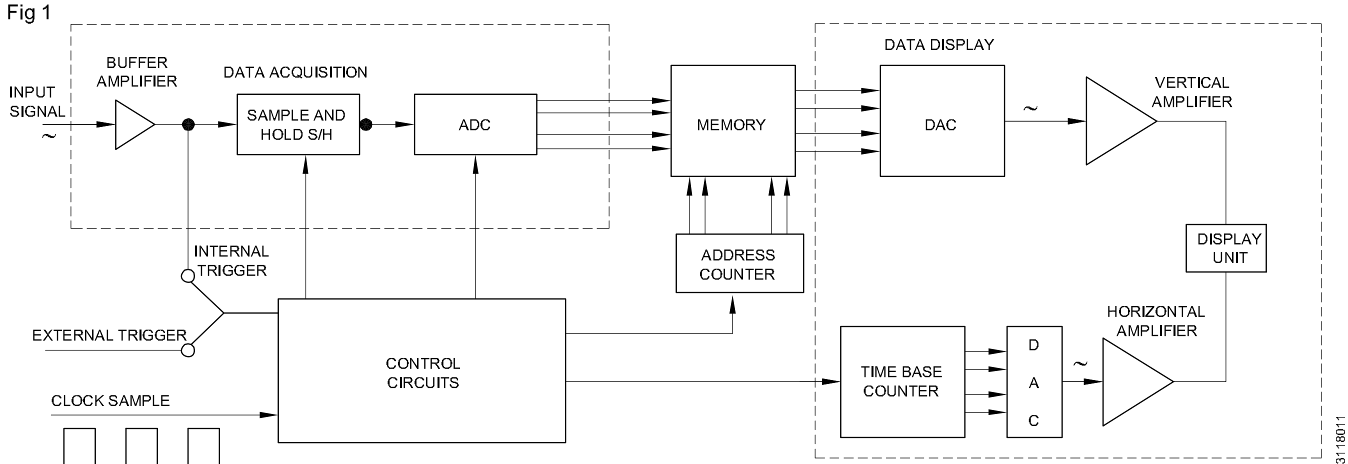
When the memory is full, the next data point from the ADC is stored in the first memory location writing over the old data. The data acquisition and the storage process is continues till the control circuit receive a trigger signal from either the input waveform or an external trigger source. When the triggering occurs, the system stops and enters into the display mode of operation in which all or some part of the memory data is repetitively displayed on the cathode ray tube.

In display operation, two DACs are used which gives horizontal and vertical deflection voltage for the CRT Data from the memory gives the vertical deflection of the electron beam, while the time base counter gives the horizontal deflection in the form of staircase sweep signal.

The screen display consist of discrete dots representing the various data points but the number of dot is very large as 1000 or more that they tend to blend together and appear to be a smooth continuous waveform.

The display operation ends when the operator presses a front-panel button and commands the digital storage oscilloscope to begin a new data acquisition cycle.

Fig 1




BLOCK DIAGRAM DSO

This chapter describes the menus and operating details associated with each front-panel menu button or control.

Digital Storage Oscilloscopes are small, lightweight, bench top packages that you can use to take ground-referenced measurements.

**Understanding Oscilloscope Functions**

This chapter contains information on what you need to understand before you use an oscilloscope. To use your oscilloscope effectively, you need to learn about the following oscilloscope functions:

- Setting up the oscilloscope
- Triggering
- Acquiring signals (waveforms)
- Scaling and positioning waveforms
- Measuring waveforms

**Setting Up the Oscilloscope**

You should become familiar with three functions that you may use often when operating your oscilloscope: Autoset, saving a setup, and recalling a setup. Using Autoset the function obtains a stable waveform display for you. It automatically adjusts the vertical scale, horizontal scale and trigger settings. Autoset also displays several automatic measurements in the graticule area, depending on the signal type.

**Saving a Setup**

The oscilloscope saves the current setup if you wait five seconds after the last change before you power off the oscilloscope. The oscilloscope recalls this setup the next time you apply power. You can use the SAVE/RECALL Menu to permanently save up to ten different setups.

**Recalling a Setup**

The oscilloscope can recall the last setup before power off, any of your saved setups or the default setup.

**Default Setup**

The oscilloscope is set up for normal operation when it is shipped from the factory. This is the default setup. To recall this setup, push the DEFAULT SETUP button.

**Triggering**

The trigger determines when the oscilloscope starts to acquire data and display a waveform. When a trigger is set up properly, the oscilloscope converts unstable displays or blank screens into meaningful waveforms.

When you push the RUN/STOP or SINGLE SEQ buttons to start an acquisition, the oscilloscope goes through the following steps:

- Acquires enough data to fill the portion of the waveform record to the left of the trigger point. This is also called the pretrigger.
- Continues to acquire data while waiting for the trigger condition to occur.
- Detects the trigger condition..
- Continues to acquire data until the waveform record is full.
- Displays the newly-acquired waveform.

For Edge and Pulse triggers, the oscilloscope counts the rate at which trigger events occur to determine trigger frequency and displays the frequency in the lower right corner of the screen.

**Source**

You can use the Trigger Source options to select the signal that the oscilloscope uses as a trigger. The source can be any signal connected to a channel BNC, to the EXT TRIG BNC or the AC power line (available only with Edge triggers).

**Types**

The oscilloscope provides three types of triggers: Edge, Video, and Pulse Width.

**Modes**

You can select a Trigger Mode to define how the oscilloscope acquires data when it does not detect a trigger condition. The modes are Auto and Normal. To perform a single sequence acquisition, push the SINGLE SEQ button.

**Coupling**

You can use the Trigger Coupling option to determine which part of the signal will pass to the trigger circuit. This can help you attain a stable display of the waveform.

To use trigger coupling, push the TRIG MENU button, select an Edge or Pulse trigger, and select a Coupling option.

Trigger coupling affects only the signal passed to the trigger system. It does not affect the bandwidth or coupling of the signal displayed on the screen.

To view the conditioned signal being passed to the trigger circuit, push and hold down the TRIG VIEW button. Trigger coupling affects only the signal passed to the triggersystem. It does not affect the bandwidth or coupling of the signal displayed on the screen.

**Position**

The horizontal position control establishes the time between the trigger and the screen center.

**Slope and Level**

The Slope and Level controls help to define the trigger. The Slope option (Edge trigger type only) determines whether the oscilloscope finds the trigger point on the rising or the falling edge of a signal. The TRIGGER LEVEL knob controls where on the edge the trigger point occurs.

**Acquiring Signals**

When you acquire a signal, the oscilloscope converts it into a digital form and displays a waveform. The acquisition mode defines how the signal is digitized and the time base setting affects the time span and level of detail in the acquisition.

**Acquisition Modes**

There are three acquisition modes: Sample, Peak Detect, and Average.

**Sample**

In this acquisition mode, the oscilloscope samples the signal evenly spaced intervals to construct the waveform. This mode accurately represents signals most of the time. However, this mode does not acquire rapid variations in the signal that may occur between samples. This can result in aliasing and may cause narrow pulses to be missed. In these cases, you should use the Peak Detect mode to acquire data.

**Peak Detect**

In this acquisition mode, the oscilloscope finds the highest and lowest values of the input signal over each sample interval and uses these values to display the waveform. In this way, the oscilloscope can acquire and display narrow pulses, which may have otherwise been missed in Sample mode. Noise will appear to be higher in this mode.

**Average**

In this acquisition mode, the oscilloscope acquires several waveforms, averages them, and displays the resulting waveform. You can use this mode to reduce random noise.

**Time Base**

The oscilloscope digitizes waveforms by acquiring the value of an input signal at discrete points. The time base allows you to control how often the values are digitized. To adjust the time base to a horizontal scale that suits your purpose, use the SEC/DIV knob.

**Scaling and Positioning Waveforms**

You can change the display of waveforms by adjusting their scale and position. When you change the scale, the waveform display will increase or decrease in size. When you change the position, the waveform will move up, down, right, or left. The channel reference indicator (located on the left of the graticule) identifies each waveform on the display. The indicator points to the ground level of the waveform record.

**Vertical Scale and Position**

You can change the vertical position of waveforms by moving them up or down in the display. To compare data, you can align a waveform above another or you can align waveforms on top of each other.

You can change the vertical scale of a waveform. The waveform display will contract or expand about the ground level.

**Horizontal Scale and Position;**

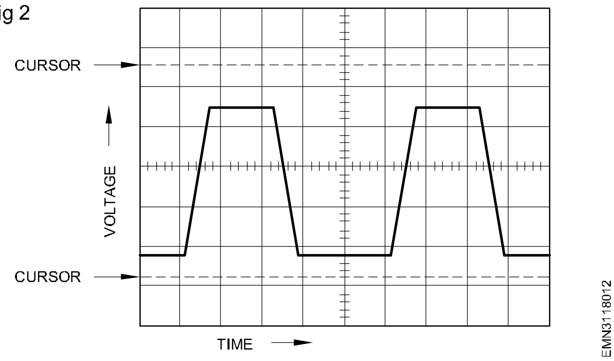
Pretrigger Information You can adjust the HORIZONTAL POSITION control to view waveform data before the trigger, after the trigger, or some of each. When you change the horizontal position of a waveform, you are actually changing the time between the trigger and the center of the display. (This appears to move the waveform to the right or left on the display.) For example, if you want to find the cause of a glitch in your test circuit, you might trigger on the glitch and make the pretrigger period large enough to capture data before the glitch. You can then analyze the pretrigger data and perhaps find the cause of the glitch. You change the horizontal scale of all the waveforms by turning the SEC/DIV knob. For example, you might want to see just one cycle of a waveform to measure the overshoot on its rising edge.

The oscilloscope shows the horizontal scale as time per division in the scale readout. Since all active waveforms use the same time base, the oscilloscope only displays one value for all the active channels, except when you use Window Zone.

## Taking Measurements

The oscilloscope displays graphs of voltage versus time as shown in fig. 2 and can help you to measure the displayed waveform. There are several ways to take measurements. You can use the graticule, the cursors, or an automated measurement.

Fig 2




## Graticule

This method allows you to make a quick, visual estimate. For example, you might look at a waveform amplitude and determine that it is a little more than 100 mV. You can take simple measurements by counting the major and minor graticule divisions involved and multiplying by the scale factor. For example, if you counted five major vertical graticule divisions between the minimum and maximum values of a waveform and knew you had a scale factor of 100 mV/division, then you could easily calculate your peak-to-peak voltage as follows: 5 divisions x 100 mV/division = 500 mV.

### Cursors

This method allows you to take measurements by moving the cursors, which always appear in pairs, and reading their numeric values from the display readouts. There are two types of cursors:

### Voltage and Time

When you use cursors, be sure to set the Source to the waveform on the display that you want to measure. To use cursors, push the CURSOR button.

### Voltage Cursors

Voltage cursors appear as horizontal lines on the display and measure the vertical parameters.

### Time Cursors

Time cursors appear as vertical lines on the display and measure the horizontal parameters.

### Automatic

The MEASURE Menu can take up to five automatic measurements. When you take automatic measurements, the oscilloscope does all the calculating for you. Because the measurements use the waveform record points, they are more accurate than the graticule or cursor measurements. Automatic measurements use readouts to show measurement results. These readouts are updated periodically as the oscilloscope acquires new data.

## Acquire

Push the Acquire button to set acquisition parameters

| Options | Settings | Comments |
|---|---|---|
| Sample | | Use to acquire and accurately display most waveforms; this is the default mode |
| Peak Detect | | Use to detect glitches and reduce the possibility of aliasing |
| Average | | Use to reduce random or uncorrelated noise in the signal display; the number of averages is selectable |
| Averages | 4<br>16<br>64<br>128 | Select number of averages |



**RUN/STOP Button:** Push the RUN/STOP button when you want the oscilloscope to continuously acquire waveforms. Push the button again to stop the acquisition.

**SINGLE SEQ Button:** Push the SINGLE SEQ button when you want the oscilloscope to acquire a single waveform and then stop. Each time you push the SINGLE SEQ button, the oscilloscope begins to acquire another waveform. After the oscilloscope detects a trigger it completes the acquisition and stop.

| Acquisition mode | Single Seq button |
|---|---|
| Sample, Peak Detect | Sequence is complete when one acquisition is acquired |
| Average | Sequence is complete when the defined number of acquisitions is reached |

**Scan Mode Display:** You can use the Horizontal Scan acquisition mode (also called Roll mode) to continuously monitor signals that change slowly. The oscilloscope displays waveform updates from the left to the right of the screen and erases old points as it displays new points.

A moving, one-division-wide blank section of the screen separates the new waveform points from the old. The oscilloscope changes to the Scan acquisition mode when you turn the SEC/DIV knob to 100 ms/div or slower, and select the Auto Mode option in the TRIGGER Menu.

To disable Scan mode, push the TRIG MENU button and set the Mode option to Normal.

Stopping the Acquisition. While the acquisition is running, the waveform display is live. Stopping the acquisition (when you push the RUN/STOP button) freezes the display. In either mode, the waveform display can be scaled or positioned with the vertical and horizontal controls.

**Auto set**

When you push the AUTOSET button, the oscilloscope identifies the type of waveform and adjusts controls to produce a usable display of the input signal.

| Function | Setting |
|---|---|
| Acquire mode | Adjusted to sample to peak detect |
| Display format | Set to YT |
| Display type | Set to dots for a video signal, set to vectors for an FFT spectrum; otherwise, unchanged |
| Horizontal position | Adjusted |
| Trigger coupling | Adjusted to DC, Noise reject , or HF reject |
| Trigger holdoff | Minimum |
| Trigger level | Set to 50% |
| Trigger mode | Auto |
| Trigger source | Adjusted; cannot use Autoset on the EXT TRIG signal |
| Trigger slope | Adjusted |
| Trigger type | Edge or Video |
| Trigger video sync | Adjusted |
| Trigger video standard | Adjusted |
| Vertical bandwidth | Full |
| Vertical coupling | DC (if GND was previously selected); AC for a video signal; otherwise, unchanged |

The Autoset function examines all channels for signals and displays corresponding waveforms. Autoset determines the trigger source based on the following conditions:

- If multiple channels have signals, channel with the lowest frequency signal
- No signals found, the lowest-numbered channel displayed when Autoset was invoked
- No signals found and no channels displayed, oscilloscope displays and uses channel 1

**Cursor**

Push the CURSOR button to display the measurement cursors and cursor menu.

| Options | Settings | Comments |
|---|---|---|
| Type* | Voltage<br>Time<br>Off | Select and display the measurement cursors; voltage measures amplitude and time measures time and frequency |
| Source | CH1<br>CH2<br>CH3**<br>CH4**<br>MATH<br>REFA<br>REFB<br>REFC**<br>REFD** | Choose the waveform on which to take the cursor measurements<br><br>The readouts display this measurement |
| Delta | | Displays the difference (delta) between the cursors |
| Cursor 1 | | Displays cursor 1 location (time is referenced to the trigger position, voltage is referenced to ground) |
| Coursor 2 | | Displays cursor 2 location (time is referenced to the trigger position, voltage is referenced to ground) |

*For a math FFT source, measures magnitude and frequency.

**Display**

Push the DISPLAY button to choose how waveforms are presented and to change the appearance of the entire display

| Options | Settings | Comments |
|---|---|---|
| Type | Vectors | Vectors fills the space between adjacent sample points in the display.<br>Dots displays only the sample points |
| Persist | OFF<br>1 sec<br>2 sec<br>5 sec<br>Infinite | Sets the length of time each displayed sample point remains displayed |
| Format | YT | YT format displays the vertical voltage in relation to time (horizontal scale )<br>XY format displays a dot each time a sample is acquired on channel 1 and channel 2<br>Channel 1 voltage determines the X coordinate of the dot (horizontal and the channel 2 voltage determines the Y coordinate (vertical) |
| Contrast Increase | | Darkness the display; makes it easier to distinguish a channel waveform from persistence. |
| Contrast Decrease | | Lightens the display |

For a math FFT source, measures magnitude and frequency

**Utility**

Push the UTILITY button to display the Utility Menu.

| Options | Settings | Comments |
|---|---|---|
| Systems status | | Displays summaries of the oscilloscope settings |
| Options | Display Style* | Displays screen data as black on white, or as white on black |
| | Printer Setup* | Displays the setup for the printer; see page 131 |
| | RS232 Setup** | Displays the setup for the RS-232 port; see page 134 |
| | GPIB Setup** | Displays the setup for the GPIB port; see page 143 |
| Do self cal | | Performs a self calibration |
| Error Log | | Displays a list of any errors logged This list is useful when contacting a Tektronix service center for help<br>This list is useful when contacting a Tektronix Service Center for help |
| Language | English<br>French<br>German<br>Italian<br>Spanish<br>Portuguese<br>Japanese<br>Korean<br>Simplified Chinese<br>Traditional Chinese | Selects the display language of the operating system |

## Capturing a single shot signal

**Objectives :** At the end of this lesson you shall be able to
- **capture a single shot signal**
- **optimizing the Acquisition**
- **measure the propagation delay.**

### Capturing

Some events which do not occur frequently, but occurs very rarely for short duration of time can be viewed with the help of digital storage oscilloscope. In other words, the transient part of the signal which vanish even in few milliseconds or microseconds can be observed using a digital oscilloscope.

### For example

The transient response of Rh, Rc circuits, A and E signal in microprocessors, switch bouncing signal etc.

The DSO can display captured data in various ways.

### Capturing a Single-Shot Signal

The reliability of a reed relay in a piece of equipment has been poor and you need to investigate the problem. You suspect that the relay contacts arc when the relay opens. The fastest you can open and close the relay is about once second so you need to capture the voltage across the relay as a single-shot acquisition.

### Optimizing the Acquisition

The initial acquisition shows the relay contact beginning to open at the trigger point. This is followed by a large spike that indicates contact bounce and inductance in the circuit. The inductance can cause contact arcing and premature relay failure. You can use the vertical, horizontal, and trigger controls to optimize the settings before the next single-shot event is captured. When the next acquisition is captured with the new settings (when you push the SINGLE SEQ button again), you can see more detail about the relay contact opening.

### Measuring Propagation Delay

You suspect that the memory timing in a microprocessor circuit is marginal. Set up the oscilloscope to measure the propagation delay between the chip-select signal and the data output of the memory device.

## Interface the DSO to external devices

**Objectives :** At the end of this lesson you shall be able to
- **state the applications of USB rear and host port**
- **uses of save/recall menu**
- **state the advantages of using a USB flash drive**
- **interface the USB port to the external device**
- **understand the printer setups before printing the waveforms .**

A typical DSO may come with two USB ports that allow flexible communications with a number of devices.

The USB host port on the front of the oscilloscope can transfer

- Wave form and setup data to and from a USB flash drive
- Screen images to a USB flash drive

The USB device port on the rear of the oscilloscope can transfer

- Waveform and setup data to and from a computer
- Screen images to a computer
- Screen images directly to a PictBridge compatible printer

The USB port Host port on the front of the oscilloscope is designed to support a single USB flash drive. The port will not support multiple USB flash drives by use of a USB hub.

The USB device port on the rear of the oscilloscope can either be connected to a computer or to a PictBridge compatible printer, but not both simultaneously.



**SAVE/RECALL waveforms**

You can use the SAVE/RECALL menu, Save Waveform options to save wave from data points and acquisition parameters information to a USB flash drive. You can use the Recall Waveform menu option to display saved waveforms. Also called as reference waveforms. Reference waveforms are displayed with a lower intensity than live waveforms

You can use Print button or SAVE /RECALL menu, Save option to save the current screen image to a file on a USB flash drive. The PRINT button is more versatile than the option button, because it can send to any menu

Saving setups on a USB flash drive has several advantages over savings setups in internal memory;

- A USB flash drive has much greater capacity then internal memory
- You can copy the setup into a word processing or spreadsheet program on a computer
- You can give the setup file a meaningful name.
- You can use the USB flash drive to copy the setup to a different oscilloscope

**You can set the print button to do the following**

- Send the current image to a Pictbridge compatible printer or computer to the rear USBport
- Save the current screen image to a USB flash drive choosing among a number of formats.
- Save the current image, the waveform data points of each displayed waveform, and the current set up parameters to a USB flash drive, with a single button push

**You can also set the following options before printing**

**Ink saver: ON** prints colour waveforms on a whites back round. **OFF** prints colour waveforms on a black background, as they appear on the screen

**Abort printing :** select to stop sending data to the printer and to end printing

**Layout:** Select the orientation of the screen image to be printed either portrait or landscape.

**Pape size:** (Select from a lot for paper sizes supported by your printer.) The default choice allows the printer to select its default paper size.

**Image size:** Select from a list of image sizes supported by your printer. The default choice is generally the largest image size which will fit on the default to allow the printer to control paper type.

**Print quality:** Select from a list of print qualities supported by your printer. Select default to allow the printer to control print quality

**Data print** : Select On to print the date and time on the hard copy. Some printer do not support this option.

The selected printer options will be saved when you turn off the oscilloscope power whenever you start a print, the oscilloscope compares your selected printer settings, and it changes them to Default.

## Differentiate a CRO with DSO

Diffrerence between Cathods Ray Oscilloscope (CRO) & Digital storage Oscilloscope (DSO):

The Following points will make you understand the basic diffrent between cathode ray oscilloscope and digitalstor -age oscilloscope.

- The advantage of the analong storage oscilloscope (CRO) is that it has a higher bandwidth and writing speed than a digital storage oscilloscope, being capable of operating speeds about 15 GHz.
- The digital storage oscilloscope is primarily limited in speed by the digistising capability of the analog to digital converter. Aliasing effects also limit the useful storage bandwith(usb) of the oscilloscope to a value given by the ratio.
- The Value of constant C is dependent on the interpolation method used between the dots. For a dot diaplay C should be about25, to give an eligible display: for straight line interpolation it should be about 10, and for sinusoidal interpolation C should be about 2.5.
- The digital storage oscilloscope has a CRT which is much cheaper than an anlong storage oscilloscope, making replacement, more economical. The digital storage time, using its digital memory.
- Furthermore, it can operate with a constant CRT refresh time, so giving a bright image even at very fast signal speeds. The digital storage oscilloscope is not, however, capable of functioning in a variable persistance storage mode.
- Th**e** time base in a digital storage oscilloscope is generated by a crystal clock so that it is more accurate and stable than a CRO, where the time base is generated by a ramp circuit.
- The analong to digital converter used in a digital storage oscilloscope also gives it a higher resolution than an anlong oscilloscope(CRO). For example, a twelve bit digitizer can resolve one part in 4096. A convertional analong oscilloscope typically resolves to about one part in 50, equivalnet to 6 bit resolution.
- Digital storage oscilloscopes are also capable of operting in a look back mode, as described for waveform recorders. An anlong oscilloscope(CRO) collects data after it has been triggered.
- A digital storage oscilloscope (DSO) is always collecting data, and trigger tells it when to stop. The oscilloscope can stop immediately on trigger, so that all the stored information is pretrigger, if the delay is longer than the storage capability of the oscilloscope, then all the stored information is post trigger, as for an analog oscilloscope.
- The digital storage oscilloscope is also able to operate in a babysitting mode. When the scope is trigered it print out the stored results onto a hard copy recorder ( or disc storage), and then re-arms itself ready for another reading .



Uses of Digital Storage Oscilloscope

- Used for testing signal voltage in circuit debugging.
- Testing in manufacturing
- Designing
- Testing of signals voltage in radio broadcasting equipment.
- In the field of research
- Audio and video recording equipment.

| Analog oscilloscope | Digital Oscilloscope |
|---|---|
| Directly reads voltage and displays its on screen. | Its reads the analong and converts it into digital form before being dispaly on the screen |
| Do not require ADC, microprocessor and acquision memory | Require ADC, microprocessor and acquisition memory |
| Can only analyze signal in real time as there is no storage memory available. | Can analyze signal in real time as well as can analyze previously acquired large sample of data with facility of storage available. |
| Can not analyze high frequency sharp rise time transients | Can not analyze high frequency transients due to advanced DSP algorithms available and ported on microprocessor with can operate on stored samples of input voltage. |

Fig 1

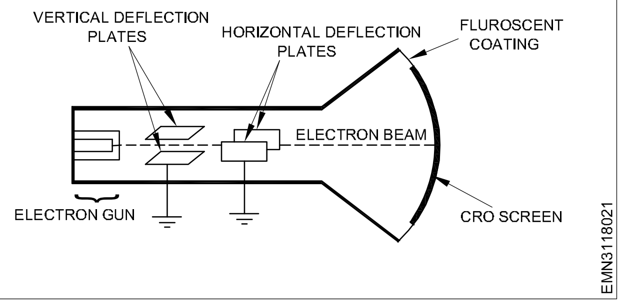



Fig 2


Fig 3

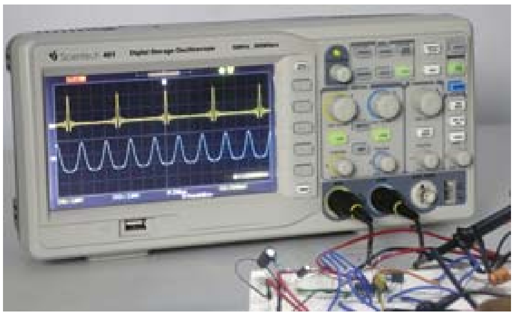
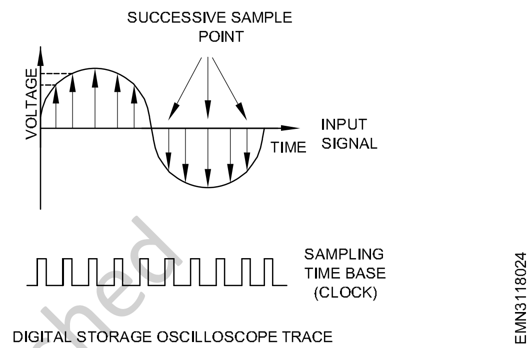



Fig 4



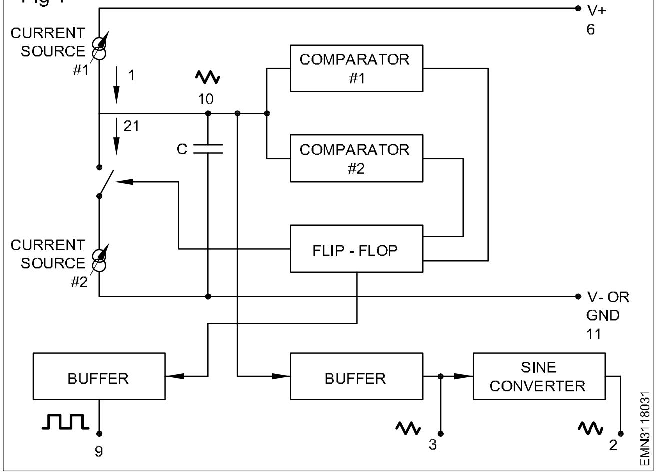
## Function generator using IC 8038

**Objectives :** At the end of this lesson you shall be able to
- **define features the IC 8038**
- **explain the working of IC 8038 as function generator**
- **draw the circuit of function generator and waveforms using IC 8038**
- **calculate the frequency of oscillation**
- **choose the values of R and C for a particular frequency.**

The IC 8038 waveform generator is a monolithic integrated circuit capable of producing high accuracy sine, square, triangular, sawtooth and pulse waveforms with a minimum of external components. The frequency (or repetition rate) can be selected externally from 0.001Hz to more than 300Hz using either resistors or capacitors, frequency modulation and sweeping can be accomplished with an external voltage. The IC 8038 is fabricated with advanced monolithic technology, using Schottky barrier diodes and thin film resistors, and the output is stable over a wide range of temperature and supply variations.

An external capacitor C is charged and discharged by two current sources as shown in fig.1. Current source #2 is switched on and off by a flip-flop, while current source #1 is continuously ON. Assuming that the flip-flop is in a state such that current source #2 is off, and the capacitor is charged with a current I, the voltage across the capacitor rises linearly with time. When this voltage reaches the level of comparator #1 (set at 2/3 of the supply voltage), the flip-flop is triggered, changes states, and releases current source #2. This current source normally carries a current 2I, thus the capacitor is discharged with a net-current I and the voltage across it drops linearly with time.When it has reached the level of comparator #2 (set at 1/3 of the supply voltage), the flip-flop is triggered into its original state and the cycle starts again. Four waveforms are readily obtainable from this basic generator circuit. With the current sources set at I and 2I respectively, the charge and discharge times are equal. Thus a triangle waveform is created across the capacitor and the flip-flop produces a square wave. Both waveforms are fed to buffer stages and are available at pins 3 and 9.

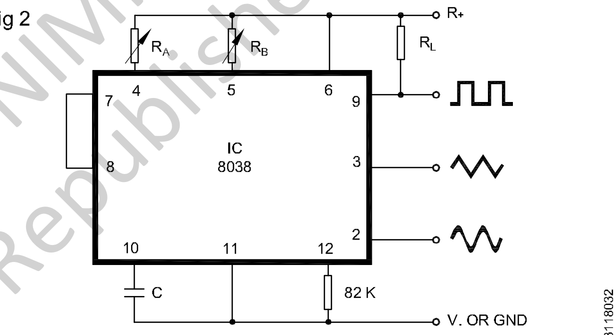
Fig 1




### IC 8038 function generator (fig. 2)

The levels of the current sources can, however, be selected over a wide range with two external resistors. Therefore, with the two currents set at values different from I and 2I, an asymmetrical sawtooth appears at Terminal 3 and pulses with a duty cycle from less than 1% to greater than 99% are available at Terminal 9. The sine wave is created by feeding the triangle wave into a nonlinear network (sine converter). This network provides decreasing shunt impedance as the potential of the triangle moves toward the two extremes.

Fig 2




IC 8038 FUNCTION GENERATOR

The figure.2 shows circuit diagram of function generator.Figure 3 and 4 shows the waveforms for 50% and 80 % duty cycles respectively.

### Waveform Timing

The symmetry of all waveforms can be adjusted with the external timing resistors. Two possible ways to accomplish this are shown in Figure. 3 and 4. Best results are obtained by keeping the timing resistors $R_A$ and $R_B$ separate (A). $R_A$ controls the rising portion of the triangle and sine wave and the 1 state of the square wave. The magnitude of the triangle waveform is set at 1/ 3 voltage supply; therefore the rising portion of the triangle is

$$t_1 = \frac{C \times V}{I} = \frac{C \times 1/3 \times V_{supply} \times R_A}{0.22 \times V_{supply}} = \frac{R_A \times C}{0.66}$$

The failling portion of the triangle and sine wave and the 0 state of the square wave is.

$$t_2 = \frac{C \times V}{I} = \frac{C \times 1/3 \times V_{supply} \times R_A}{2(0.22)\frac{V_{supply}}{R_B} - 022\frac{V_{supply}}{R_A}} = \frac{R_A \times R_B C}{0.66\,(2R_A - R_B)}$$

Fig 3

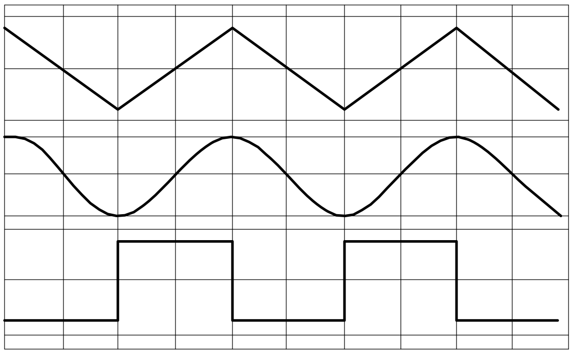
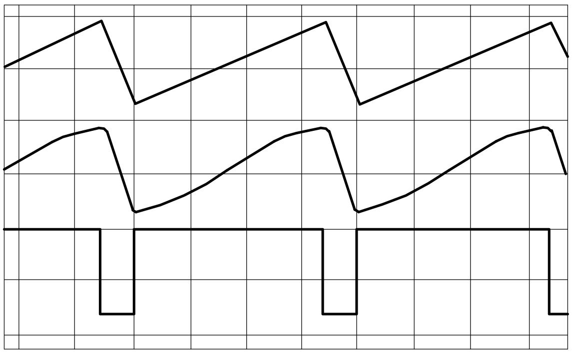


Fig 4




Thus a 50% duty cycle is achieved when $R_A = R_B$

With two separate timing resistors, the frequency is given by

$$f = \frac{1}{t_1 + t_2} = \frac{1}{\frac{R_A C}{0.66}\left(1 + \frac{R_B}{2R_A - R_B}\right)}$$

or, If $R_A = R_B = R$

$$f = \frac{0.33}{RC}$$

**Selecting $R_A$, $R_B$ and C**

For any given output frequency, there is a wide range of RC combinations that will work, however certain constraints are placed upon the magnitude of the charging current for optimum performance. At the low end, currents of less than 1µA are undesirable because circuit leakages will contribute significant errors at high temperatures. At higher currents (I > 5mA), transistor betas and saturation voltages will contribute increasingly larger errors. Optimum performance will, therefore, be obtained with charging currents of 10µA to 1mA. If pins 7 and 8 are shorted together, the magnitude of the charging current due to $R_A$ can be calculated from:

$$I = \frac{R_1 \text{ x } (V_+ - V_-)}{R_1 + R_2} \text{ x } \frac{1}{R_A} = \frac{0.22(V_+ - V_-)}{R_A}$$

R1 and R2 are shown as 11K and 39 KΩ

A similar calculation holds for $R_B$.

**The capacitor value should be chosen at the upper end of its possible range.**

# Introduction to ESD, SMT & SMD IC packages

**Objectives :** At the end of this lesson you shall be able to
- **the trainees will be able to acquire the knowledge on genral safety precautions to be followed in a SMD soldering lab**
- **the trainee will be able to acquire the knowledge about the precautions to be followed to avoid the damage of SMD components due electrostatic discharge (ESD).**

**General safety precautions to be followed while performing soldering and desoldering work in a laboratory or work place**

- Never touch the element or tip of the soldering iron. They are very hot (above 300°C) and will give you a nasty burn.
- Take great care to avoid touching the mains cable with the tip of the iron. The iron should have a heat proof cable for extra protection. Ordinary plastic cable melts immediately if touched by a hot iron and there is a risk of burns and electric shock.
- Always return the soldering iron to its stand when not in use. Never put it down on your workbench, even for a moment. Normally the trainees used to follow the bad practice of keeping the hot soldering iron on the top of work bench and burn the work bench and burn the power supply cable of CROs or function generator, and other costly equipments. So instructor should train the trainees from the beginning to follow the safe work habits
- Allow joints a minute or so to cool down before you touch them.
- Work in a well - ventilated area. The smoke formed as you melt solder is mostly from the flux and quite irritating. Avoid breathing it by keeping you head to the side of, not above, your work.
- Wash your hands after using solder. Solder contains lead.

**Preparing the soldering iron**

- Place the soldering iron in its stand and plug in. The iron will take a few minutes to reach its operating temperature of above 300°C.
- Dampen the sponge in the stand. The best way to do this is to lift it out the stand and wet it by using distilled water to avoid corrosion of soldering iron tip, and squeeze to remove excess water. It should be damp, not dripping wet.
- Wait a few minutes for the soldering iron to warm up. You can check if it is ready by trying to melt a little solder on the tip.
- Wipe the tip of the iron on the damp sponge. This will clean the tip.
- Melt a little solder on the tip of the iron. This is called 'tinning' and it will help the heat to flow from the iron's tip to the joint. It only needs to be done when you plug in the iron, and occasionally while soldering if you need to wipe the tip clean on the sponge.
- You are now ready to start soldering.

**ESD protection**

- Proper precautions in handling SMDs should also be observed to avoid ESD (Electrostatic - Discharge)
- Electronics components are becoming smaller and faster but they are also becoming more sensitive towards ESD.
- Electrostatic discharge (ESD) is the release of static electricity when two objects come into contact. Familiar examples of ESD include the shock we receive when we walk across a carpet and touch a metal doork nob and the static electricity we feel after drying clothes in a clothes dryer. A more extreme example of ESD is a lightning bolt. Most ESD events are harmless, it can be an expensive problem in many industrial environments.
- ESD first requires a build - up of an electrostatic charge. This occurs when two different materials rub together. One of the materials becomes positivity charged; the other becomes negatively charged. The positively - charged material now has an electrostatic charge. When that charge comes into contact with the right material, it is transferred and we have an ESD event. The heat from the ESD event is extremely hot, although we do not feel it when we are shocked. However, when the charge is released onto an electronic device such as an expansion card, the intense heat from the charge can melt or vaporize the tiny parts in the card causing the device to fail. Sometimes an ESD event can damage a device, but it continues to function. This is a called a latent defect, which is hard to detect and significantly shortens the life of the device.
- Synthetic carpeting - one can hardly move without generating a charge - avoid carpeting in your work area.
- Cathode ray tubes (oscilloscopes or monitors) can be dangerous sources of ESD- keep static sensitive components a safe distance away from the screen and avoid touching the screen.

- Many electronic devices are susceptible to low voltage ESD events. For example , hard drive components are sensitive to only 10 volts. For this reason, manufacturers of electronics devices incorporate measures to prevent ESD events throughout the manufacturing, testing, shipping, and handling processes. For example, an employee may wear a wrist strap when working with devices or many wear ESD control footwear and work on an ESD floor mat that causes the electrostatic charge to go into the ground instead of into the device. Sensitive devices can be packaged with materials that shield the product from a charge.
- The rework station needs to be specifically designed to minimise the effect of ESD, especially when various studies around the world have revealed that 60-90 percent of defective devices are damaged due to ESD, and 70 percent of these failures can be attributed to damage caused by ungrounded workers. So it becomes really important that you take ESD - control systems seriously, or otherwise, the losses can be astonishingly high.
- A basic ESD control rule is ground all conductors including workers at the rework station. Ground works very efficiently in ESD - control systems and reliably removes ESD to ground. For such a grounding system, it is important that the electrical wiring system of our lab should be correct. All electrical outlets in our lab need to be evaluated for correct wiring of live, neutral and ground wires.

A wrist strap is an effective method for ground the workers. The electrostatic discharge association's standard ANSI/ ESD SI.1-2006 defines a wrist strap as an assembled device consisting of a wrist cuff and ground cord that provides electrical connection of a pension's skin to the ground. The standard document completely describe the parameters for evaluation, acceptance and functional testing of wrist straps. While the document describes the whole set of mechanical and electrical parameters over which a wrist strap needs to be evaluated and accepted, the most important parameter amongst all is the wrist strap continuity and resistance, which should be 1 meg - ohm 20 percent, for acceptance. The document also suggests the testing procedure for the same. While you are buying grounding materials, do check if they comply with the above - mentioned standard and specification.

When you are working with sensitive electronics components you should consider buying all the equipment for your workstation that is tagged as anti- static or ESD - safe. The materials mentioned below are optional but can be used for better electrostatic protected area (EPA).

1 ESD- tables, chairs and stools

2 ESD- safe toll kit (cutter, plier, desoldering pump, etc)

3 ESD- safe equipment like soldering iron

4 ESD- safe brush

5 ESD -safe trays, bins and cabinets

**ESD safe workstation layout**

An ESD workstation is defined as work area with materials and equipment that limit electrostatic voltages and ESD (Electrostatic discharge) shown in fig.1.

Fig 1

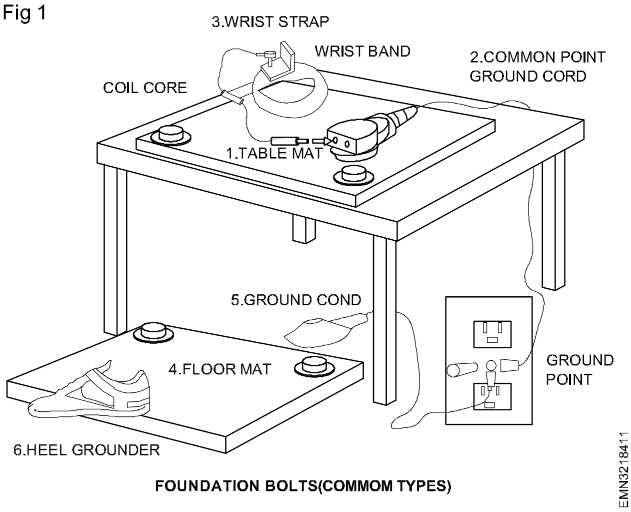
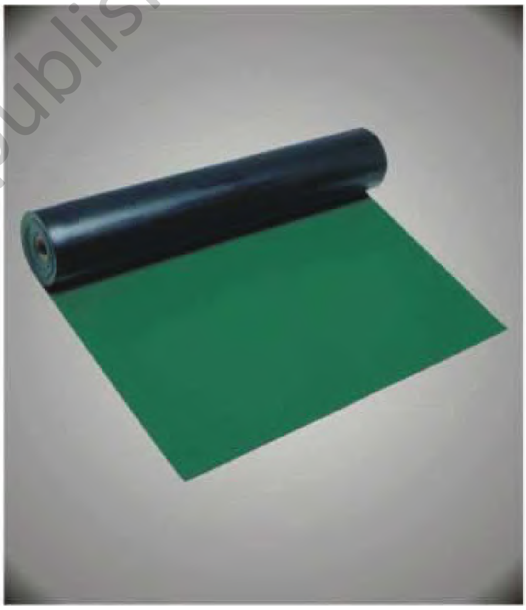



**Table Mat**

A work surface that dissipates static from conductive items placed on it shown in fig. 2.

Fig 2



**Common point ground cord**

A cable and connector that connect a table mat and one or two wrist straps to ground. shown in fig. 3 & 4.

Fig 3

Fig 4

**Wrist strap**

A two part device including a wrist band and a coil cord that connects a person's skin to ground. ESD wrist straps, also known as anti static wrist straps as show in fig.4, are used to prevent electrostatic discharge (ESD) by safety grounding a person working with electronics equipment or at an electronic assembly facility. It consists of a bend of fabric with fine conductive fibers woven into it. The fibers are usually made of carbon or carbon - filled rubber, and the strap is bound with a stainless steel clasp or plate. They are usually used in conjunction with an ESD table mat on the workbench, or a special static dissipating plastic laminate on the workbench surface.

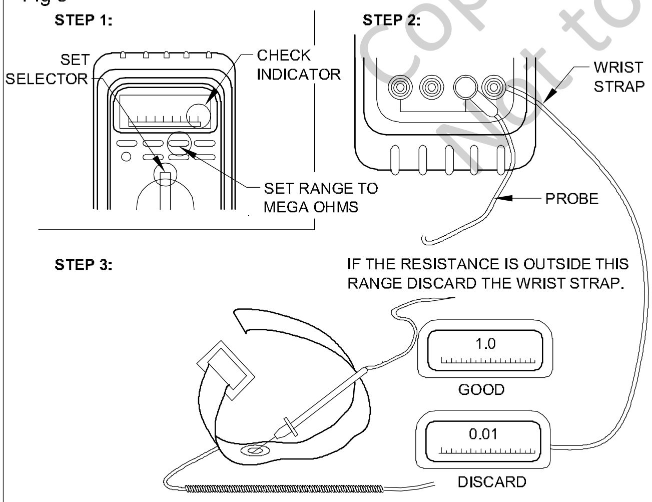
**ESD wrist strap testing using a multimeter**

Step 1 : Set the range of the multimeter to megohms (M )

Step 2 : Plug the wrist strap's banana jack into the voltage /ohm (V ) port on the multimeter. Connect a probe to the COM port on the multimeter.

Step 3 : Test the conductive metal button inside the wrist strap to verify that the resistance reading is between 0.9 M and 1.1 M as shown in fig. 5.

Fig 5




**STEP 1:**SET THE RANGE OF THE MULTIMETER TO MEGOHMS(MΩ)

**STEP 2:**PLUG THE WRIST STRAP'S BANANA JACK INTO THE VOLTAGE / OHM (VΩ) PORT ONTHE MULTIMETER.CONNEC A PROBE TO THE COM PORT ON THE MULTIMETER .

**STEP 3:**TEST THE CONDUCTIVE METAL BUTTON INSIDE THE WRIST STRAP TO VETIFYTHAT THE RESISTANCE READING IS BETWEEN 0.9 MΩ AND 1.1 MΩ.

**ESD WRIST STRAP TESTING USING A MULTIMETER**

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**Floor Mat**

A walking surface that dissipates static charge from conductive items placed on it. shown in fig. 6

Fig 6

ESD anti fatigue floor mats are made of 3/8" thick closed - cell expnaded polyvinyl chloride designed to provide comfort and reduce worker fatigue when used in static sensitive environment. Surface resistivity is $10^9$-$10^{10}$ Ohm. The construction design of the ESD floor mat allows for effective static charge removal at a non - damaging flow rate and emboss pattern make slip resistatn. At the same time the ESD anti fatigue mat is known to maintain a consistent discharge throughout the life of the mat with no noticeable deterioration of effectiveness. Resistant to degradation by inorganic acid, organic acids, detergent solutions, alcohol and mineral oil. Suggested service temperature of -20°F to +160°F.

**Floor mat ground cord**

A cable and connector that connect a floor mat to ground

**Heel grounder**

A device for connecting a walking or standing person to ground by using the moisture in the shoe as a body connection and a conductive rubber tread as a connection to a grounded mat or floor.

**ESD Heel grounders**

ESD heel grounders provide a continous ground path between the operator and properly grounded ESD protected flooring. They are designed for use in applications where user mobility is required, such as wave solder, kitting and quality control. "ESD protective flooring used with approved footwear, may be used as an alternative to the wrist strap system for standing operations." Heel grounders quickly and effectivley drain the static charges that are collected by the personnel during normal everyday activities. ESD heel straps help protect your electronic assembly plant. shown in fig. 7 & 8.

Fig 7

Fig 8

**Durable ESD slipper & Heel grounder**

**Conductive shoe covers**

Conductive shoe covers also known as polypropylene shoe covers, are non woven, spun bond fabric that helps filter particulates. They have a conductive strip that protects electronic devices from static charge. Covers are extra lightweight. For added safety, choose skid - free soles for improved traction. They are packaged as 100 pieces per bag and 3 bags per case. shown in fig.9

Fig 9

**ESD Finger cots**

ESD finger cots or pink ESD finger cots are commonly used in electronic assembly, photonics, medical and pharmaceutical manufacturing. Anti static finger cots are powder free and are made of 100% latex material. These finger cots meet MIL -STD - 105E for holes, tear, stains and electrostatic properties. Pink in color. Style is rolled. shown in fig. 10 & 11.

Fig 10

Fig 11

**Conductive gloves** (shown in fig.12)

Conductive gloves are made of seamless knit nylon and copper fiber yarns with urethane coating. The surface resistivity is below 7.5 x $10^7$. Electrostatic dissipative (ESD) fiber yarns blended with low lint nylon which reduces static build - up on the glove surface for improved performance in electronics assembly.

Fig 12

**ESD Aprons**

ESD jackets, also known as ESD smocks, are lightweight and provide durable static shielding for use where electrostatic charge is a concern. It has a lapel style collar and is 3/4 length with 3 pockets. New ECX-500 fabric gives low cost static - shielding during electronics assembly process. Available in blue and white color. shown in fig.13

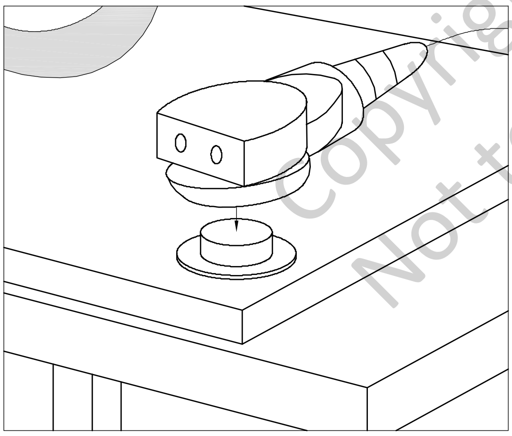
Fig 13

**To install ESD workstation**

1 Lay the table mat flat on the workbench with the snaps toward the operator. TIP. Mild heat (sun light) will remove creases caused by shipping.

2 Connect the common point ground cord to the table mat by snapping it to the left or right snap. shown in fig.14

Fig 14



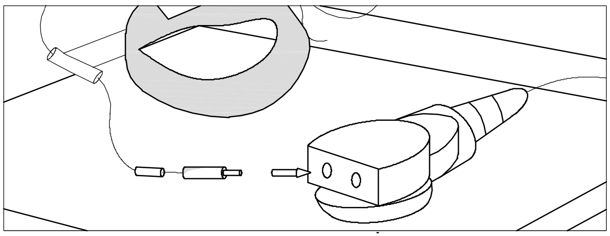

3 Connecting the coil cord to the common point ground cord by plugging the banana plug into one of the ground cord's banana nacks. shown in fig.15

4 Snap the wrist band to the coil cord. TIP : Make sure that the operator wears the wrist band on bare skin and tightens the band so that no gap exists between the skin and the band. shown in fig.16

5 Lay the floor mat on the floor in front of the workbench with the snaps toward the bench.

6 Connect the floor mat ground cord to one snap on the floor mat. shown in fig.17

Fig 15




FOUNDATION BOLTS(COMMOM TYPES)

Fig 16

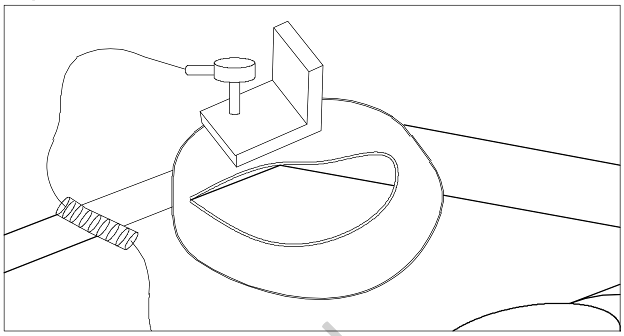
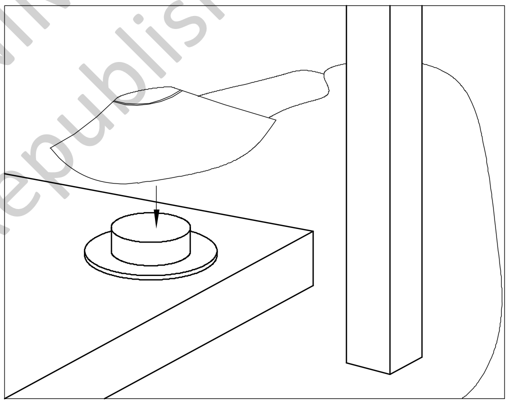



Fig 17



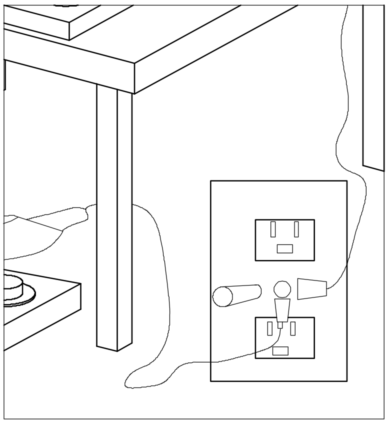

FOUNDATION BOLTS(COMMOM TYPES)

7 Connect the common point ground cord and floor mat ground cord to ground. Use the green wire building ground point as specified in EOS/ESD standard 6. Connection to this ground point most easily accomplished by removing the center AC outlet plate cover screw, placing the screw through the eyelets from both ground cords, and replacing the screw. The wires can be moved to the left and right sides of the screw so that they do not obstruct the outlet. shown in fig.18

**Cautionary notices**

**Warning :** only qualified personnel should work with exposed AC outlets. Consult with a qualified electrician to make ground connection if necessary. AC voltage is dangerous.

Fig 18



FOUNDATION BOLTS(COMMOM TYPES)

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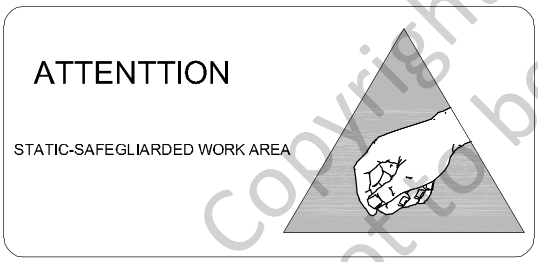
**Caution :** Exercise extreme care when using energized equipment at an ESD workstation. Ground fault current interrupters should be considered to avoid shock. Most static controll equipment is not desinged to be used near voltages greater than 250 volts.

8 Mount the ESD awareness sign above the work area where it is clearly visible to both the operator and anyone approaching the work area. Before hanging the sign, clean any dust or oil from the wall before application for better adhesion. Next, remove the cover tape from the back of the adhesive strips, place the sign on the wall, and press firmly across the entire sign so that all of the adhesive contacts the wall. shown in fig.19

Fig 19




FOUNDATION BOLTS(COMMOM TYPES)

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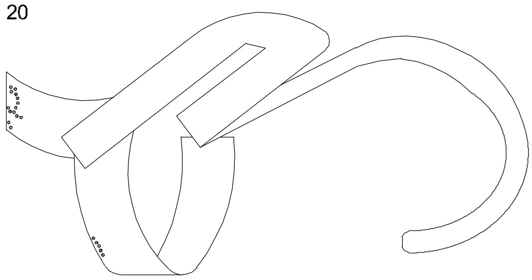
9 **Heel grounders :** Open the velcro strap. Remove foot from shoe and insert tab. Trim excess tab material with scissors if necessary. Place foot back into shoe and slip rubber cup onto the shoe's hell. Close velcro strap. Repeat procedure for other shoe. shown in fig.20

Fig 20



FOUNDATION BOLTS(COMMOM TYPES)

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Newly installed work stations should be tested for continuity. A surface resistivity meter with a "resistance to ground" founction can be used to test continuity from the ground point to all part of the workstation.

**Ionizers** (shown in fig.21)

Fig 21

Bench top Ionizers are used in many high tech manufacturing programs to control ESD (Electro Static Discharge) in the work environment. EDS ionizers neutralize a static charge via balancing the ions between the molecules in the gasses of the surrounding air. They are typiecally used to control static on isolated conductors that can't be grounded and insulative objects (like standard plastics). ESD ionizers are perfect for removing contaminant attraction caused by static as well as neutralizing static charges from wide, focused or hard to reach areas. Ionization is ideal when working with delicate electronic products or large more robust assemblies.

The required limit according to ANSI/ESD S20.20 is less than ± 50V offset voltage (balance). In addition to that, the discharge time to reduce + 1000V to +100 V and to reduce -1000V to - 100 V should also be measured. Faster the static elimination time, the better it is. Do look for one that strictly complies with the ANSI /ESD S20.20 standard.

**ESD bags** ( as shown in fig. 22)

Fig 22

ESD bags, also known as general purpose ESD bags or static shielding bags, have buried metal shielding that offers superior durability at a low cost. These ESD bags are recognized as the consistently reliable, readily available and most competitively priced static shielding bags in the electronics industry. General purpose antistatic bags are available in regular open top or zip lock. Light transmission of better than 50% allows for easy identification of static devices without removal.

ESD bags are constructed from an alloy electrostatic shield with a tough layer of polyester protection, providing a level of abrasion and puncture resistance never before possible in a transparent shielding bag.

**ESD Bins and containers** (shown in fig. 23 to 29)

Fig 23


ESD SHELF BINS WITH CORRUGATED BASE

Fig 24

ESD SHELF BIN

Fig 25

ESD SMALL PARTS DRAWERS

Fig 26


ESD STACKING BINS

Fig 27

ESD PICKING BINS

Fig 28

LARGE ESD STACKING BINS

Fig 29

ESD STORAGE BOXES

## Surface Mount Technology and Surface Mount Devices

**Objectives :** At the end of this lesson you shall be able to
- **explain briefly SMT & SMD**
- **state the need for SMD**
- **list the advantages of SMDs**
- **state the safety precautions required while handling SMDs**
- **list the tools and equipments used in SMT**
- **understand to perform test and measurement of the circuit.**Introduction

• Keep surface mount components away from children and pets.

### Introduction

Surface Mount Devices (SMDs) are used in a growing number of commercial and industrial products. Due to their small size, prototype manufacturing, rework and repair can be difficult and are best performed using specialized techniques specific to this technology. Learning these techniques will help you succeed when working with these small components. The SMT technique opens advantages and new applications through miniaturizing of the components and increasing of reliability.

Surface Mounted Devices (SMD) are active and passive electronic components without conventional connecting wires.

In the conventional through - hole technology (THT) the components are placed on the "components side" of the printed circuit board (PCB), wires inserted into holes, and soldered to the copper pads on the opposite, "solder side" of the PCB.

The SMD components will be placed on the 'solder side' of the PCB and their metal caps soldered to the copper pads of the PCB. Therefore both layers of the PCB could be used as active areas. A thickness of PCBs used for SMD is between 0.8 and 1.00mm. Historically roots of SMD are hybrid circuits on the ceramic substrates (middle of seventies) but a huge industrial applications of SMD started in the beginning of eighties.

The industrial standard unfortunately allows that most of the SMD components do not have a clear description. Since a tiny size of the components they are labeled with a code. Therefore a sure identification of the components is impossible without appropriate technical documentation. Moreover the polarity and pin-outs of different components could be not identified without data sheets. For these reasons SMD for beginners became a very hard job.

### Need of surface mount technology

SMDs have improved performance over through-hole components due to their smaller size, shorter internal leads, and smaller board layouts. These factors reduce the circuit's parasitic inductance and capacitance. SMDs can also be more cost effective than traditional through - hole components due to the smaller board size, fewer board layers, and fewer holes. SMDs can be challenging to solder, so it is best to learn general soldering skills on larger components before attempting to work with SMDs.



Advantages of SMDs are given below

1 PCBs area much smaller than by conventional through - hole components

2 Since the both layers of the PCB could be used for assembling, the final PCBs area for the same circuits could be decreased by 50%.

3 Simple assembling-no bending and cutting of the wires.

4 Automatic assembling very easy. Low cost of the assembling.

5 Small size of components makes very high packing density possible. For the same circuits a volume of a module assembled with SMD could be reduced to 30% of the device assembled with the conventional technique. Therefore a size of the whole instrument decreases, too.

6 Very high resistance to mechanical shock and vibration.

7 Low store and transport cost. Low store area and volume.

8 Lack of hole's drilling and metallization.

9 Thin pads.

10 For larger volumes, low manufacturing cost.

### SMD safety precautions

Surface mount components are very small, and therefore special precautions (in addition to those required when working with through - hole components) must be taken

- Do not eat or drink when working with surface mount components.
- Do not use cups, plates, or any food related items to hold or store surface mount components.
- Keep surface mount components away from children and pets.
- Always wear safety goggles.
- Work away from the edge of a desk or workbench to ensure that components will not fall on the floor.
- Keep a strong light and magnet available to search for components that have dropped on the floor.

**Work area for dealing with SMD**

Because SMDs are very small, it is important to make them "look" bigger. This can be accomplished by illuminating the work surface with a very bright light. A swing - arm desk lamp with a 100-watt frosted bulb positioned close to the work surface works very well. The lamp should be adjustable from 6 to 24 inches above the desktop. Regular room lighting or shop lights just are not bright enough. The second trick is to work on an absolutely clean, bright white surface. The SMD work tray works very well. The white paper gives contrast to the components and the small sides help prevent the SMDs from getting lost.

**Tools and Equipment required for SMD**

The tools and equipment required for SMD used are self - locking tweezers which work much better than regular tweezers. Vacuum pick-up tools can also be used, but are considerably more expensive. Select a low wattage (15 or 25 watt) or temperature controlled (600°F) pencil soldering iron with a pointed tip.

List of tools & equipments

1 Safety Goggles
2 Self locking tweezers (Fig.1)
3 600°F or low wattage soldering gun with sharply pointed tip
4 Small diameter solders wire (63/37)
5 RMA solder paste
6 Desoldering braid
7 Plastic scouring pads
8 Deco cement
9 Magnet
10 Flexible neck lamp with 100w frosted bulb.
11 Magnifying glass.

Fig 1


To clean the circuit board before soldering you will need a nonconductive abrasive pad. Don't use steel wool or a steel wool scouring pad, since they may leave small (almost microscopic) steel wires behind. A strong magnet is useful for finding dropped components. You will also need a magnifying glass. Use this to read the component markings on chip resistors and electrolytic capacitors.

**Types of SMD components**

Now a days, almost all active components are available in SMD packages for example diodes, transistors, FET, Triac etc. But in passive components only resistor and capacitors are available in different sizes and values. Due to size and mounting limitations -inductors and transformers are not available in SMDs. In active devices, some power electronic components are available in limited varieties due to large current drawing and problems for mounting heat sink on SMDs. Large surface space is required for mounting the heat sinks whereas SMDs are in small size.

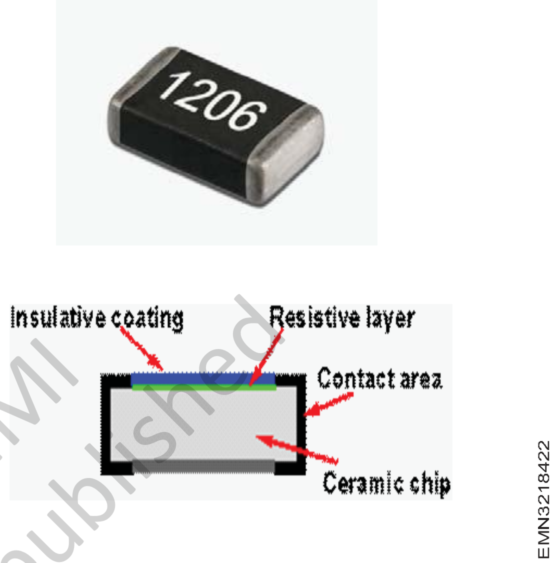
**SMD resistors**

SMD resistors are in shape of rectangle with metalized in both ends of body for convenient to solder on PCBs.

SMD resistors are constructed with use of the thick film technique on a ceramic substrate. They have metallic areas on the narrow ends of the chip, which allows soldering. The resistive path is covered wtih a protective glaze. Chip resistors could be soldered with all common soldering techniques:reflow, wave and solder iron. A sample of SMD resistor is shown in Fig 2.

Case forms of same SMD components ae tabulated table1.

Fig 2






**SMD resistor packages**

SMD resistors are available in different types of packages and they are mostly differ some part of specifications from manufacturer to manufacturer. The size of resistors are also reduced day by day due to technological enhancement. The most common packages and their sizes are shown in table 1.

**SMD resistor specifications**

SMD resistor specifications differ from one manufacturer to other. For selecting a SMD resistor, one needs to refer to manufacturer ratings.

Some most important specifications are shown below.

a. **Power rating:** The size of the resistor will increase by power rating and current drawn by it. The power rating of resistor should be always smaller than PCB layer current rating. Some power ratings are shown in table.

b. **Tolerance:** SMD resistors are mostly metal oxide film resistor which are having more accurate values. So they mostly having tolerance of 1% to 5%. But in some special applications they may available in less than 1% tolerance.

c. **Temperature coefficient:** SMD are having very good temperature coefficient than normal resistors due metal oxide film material. Generally they may available in 25 to 100 ppm/c.

SMD Resistors Code Table

| SMDC | 0201 | B | P | 4 | 2R2 |
|---|---|---|---|---|---|
| Product Type | Dimensions | Resistance Tolerance | Function Code | Package Code | Resistance Valve |
| | 01005<br>0201<br>0402<br>0603<br>0805<br>1206<br>1210<br>2010<br>2512 | B:±0.1%<br>C:±0.25%<br>D:±0.5%<br>F:±1%<br>J:±5% | L:Standard & High Precision<br>E: TC50<br>P: High Power<br>H: Ultra High Power | 0:7" Reel 15Kpcs<br>4:7" Reel 4Kpcs<br>6:7" Reel 10Kpcs<br>7:7" Reel 5Kpcs<br>9:10" Reel 8Kpcs<br>A:10" Reel 10Kpcs<br>B:10" Reel 20Kpcs<br>C:13" Reel 40Kpcs<br>D:13" Reel 20Kpcs<br>F: Bulk | ---1R2: 1.2Ω<br>---3K3: 3.3Ω<br>---10K:10KΩ<br>---100:100KΩ<br>--- to fill up 6 spaces |

Table 1

| Form | Power (watt) | Length (mm) | Width (mm) |
|---|---|---|---|
| 0402 | 0.063 | 1.0 | 0.5 |
| 0503 | 0.063 | 1.27 | 0.75 |
| 0505 | | 1.27 | 1.25 |
| 0603 | 0.062 | 1.60 | 0.80 |
| 0705 | | 1.91 | 1.27 |
| 0805 | 0.1 | 2.00 | 1.25 |
| 1005 | 0.125 | 2.55 | 1.25 |
| 1010 | | 2.55 | 2.55 |
| 1206 | 0.25 | 3.2 | 1.6 |
| 1210 | 0.25 | 3.2 | 2.6 |
| 1505 | | 3.8 | 1.25 |
| 2010 | 0.5 | 5.08 | 2.55 |
| 2208 | | 5.72 | 1.90 |
| 2512 | 1.0 | 6.5 | 3.25 |
| MELF | | 5.5 | 2.2 |
| MINIMELF | | 3.6 | 1.4 |
| MICROMELF | | 2.0 | 1.27 |

## SMD capacitors

SMD capacitors are mostly used components after SMD resistors in practical electronic circuits. SMD capacitors are similar to general capacitors in construction and the only difference is that instead of leads SMD capacitors have metalized connections at their both ends.

Advantages of SMD over a general capacitors

1. Due no leadless, manufacturers are using different techniques and they are available in small in size.
2. Easy to assemble and mount in automated manufacturing techniques.
3. Less effected by static field and electro-magnetic effects.

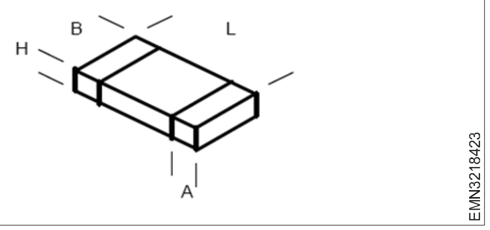
Types of SMD capacitors

1. SMD Ceramic capacitors
2. SMD tantalum capacitors
3. SMD electrolytic capacitors

## Ceramic multilayer chip capacitors

Ceramic multilayer chip capacitors are available with a very wide range of values, from 0.47pF to 1 F. This values are covered by seven cases forms. The forms depends of the capacitors values. The most popular case are 0805 and 1206.

Fig 3



Ceramic multilayer chip capacitors case forms.

**Table 2**

| CASE FORM | L (mm) | B (mm) | H (mm) | A (mm) |
|---|---|---|---|---|
| 0508 | 2.0 | 1.25 | 0.51 to 1.27 | 0.25 to 0.75 |
| 0603 | 1.6 | 0.8 | 0.80 | |
| 1206 | 3.2 | 1.6 | 0.51 to 1.6 | 0.25 to 0.75 |
| 1210 | 3.2 | 2.5 | 0.51 to 1.9 | 0.3 to 1.0 |
| 1808 | 4.5 | 2.0 | 0.51 to 1.9 | 0.3 to 1.0 |
| 1812 | 4.5 | 3.5 | 0.51 to 1.9 | 0.3 to 1.0 |
| 2220 | 5.7 | 5.0 | 0.51 to 1.9 | 0.3 to 1.0 |

**SMD tantalum capacitors**

SMD tantalum capacitors are available in different case forms, partly without printed values. The + polarity is marked by white line, or white "M". The case forms depend of capacitance value and nominal voltage.

SMD tantalum capacitors standard sizes are:

3.2 x 1.8 mm
3.5 x 2.8 mm
6.0 x 3.2 mm
7.3 x 4.3 mm

The values are coded with digits, or with alphanumerical characters.

Fig 4


EMN3218424

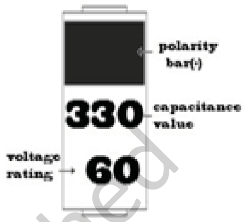
They are low cost and smaller size than general capacitors.

Electrolytic capacitors are now being used increasingly in SMD designs. SMD capacitors are available in two types are value marking

1. Direct value printing
2. Coding technique

Generally, SMD ceramic and tentalum capacitors are having coding technique for reading values and they may differ from one manufacturer to other. Most of Electrolytic capacitors are having values with their working voltage printed on their surface because of their large surface area.

Fig 5

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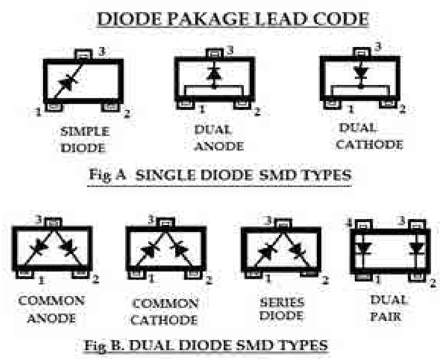
**SMD diodes and transistors**

SMD diodes and transistors are available mostly in similar packages. Diodes are avilable in mainly two forms as shown in below fig.

Those are

1. Single diode form
   a. Simple diode
   b. Dual anode
   c. Dual cathode
2. Dual diode form
   a. Common anode
   b. Common cathode
   c. Series diodes
   d. Dual pair

Fig 6

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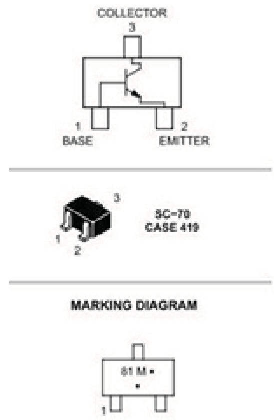
Almost all standard diodes and transistors are available as SMD components in SOT - 23, SOT - 89 and SOT - 143 cases. In general electrical parameters of SMD diodes and transistors are the same as comparable standard types in conventional cases. SOT - 23, and SOT - 143 cases are used for components with power dissipation 200 to 400 mW. SOT - 89 cases are used for power dissipation 500 mW to 1W. SMD LEDs are available in SOT - 23 cases. All SMD transistors are marked with codes.

Fig 7




| SMD code | Package | Device name | Manufacturer | Data |
|---|---|---|---|---|
| A7 | SOT-23 | BAV99 | National | Switching diodes |
| A7 | SOT-23 | BAV99 | Zowie | Switching diodes |
| A7 | SOT-323 | BAV99WT1 | Motorola | Switching diodes |
| A7 | SOT-523 | MMBD4448H TC | BL Galaxy Electrical | Switching diodes |
| A7 - | SOT-23 | BAV99 | NXP | Switching diodes |
| A7 | SOT-23 | BAV99 | National | Switching diodes |
| A7 | SOT-23 | BAV99 | National | Switching diodes |
| A7 | SOT-23 | BAV99 | Zowie | Switching diodes |
| A7 | SOT-323 | BAV99WT1 | Motorola | Switching diodes |
| A7 | SOT-523 | MMBD4448H TC | BL Galaxy Electrical | Switching diodes |
| A7 | SOT-23 | BAV99 | National | Switching diodes |



Similarly FET and MOSFET in SMD forms are shown in below figures.

Fig 8

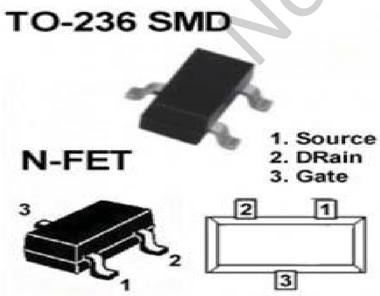



Fig 9

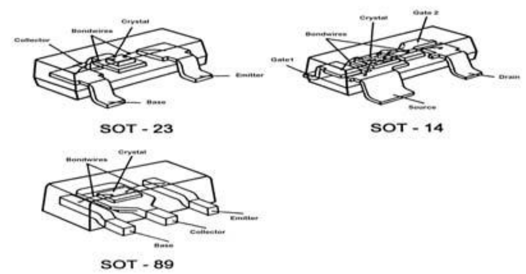
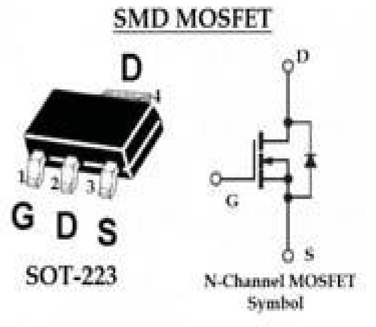


Fig 10




EMN321842A

Exmples of SMD transistors coding.

| MARK | COMPONENT | CASE |
|---|---|---|
| 1J | BC848A | SOT -23 |
| 4G | BC860C | SOT -23 |
| 1F* | MMBT5550 | SOT -23 |
| 1F* | BC847B | SOT -23 |
| AA* | BCW60A | SOT -23 |
| AA* | BCX51 | SOT -89 |

* Hint

The same mark does not means the same component!

If SMD transistors with the same marks have different case forms their technical specifications are different as well!

**SMD Integrated circuits**

The first SMD ICs were manufactured on begin 70' for hybrid technique. Nowadays (February 1999) are many of new ICs design manufactured in SMD only.

ICs in SMD cases are electrically fully compatible to types in DIL cases therefore both of them have the same marking. The different for SMD (SO-xx case )is only the last character of the mark; i.e. LM 324 N (DIL) = LM 324 D (SO).

SO cases are produced with two different pin forms:

1. pins bent outside of the case

2. pins bent under the case

Fig 11


EMN321842B

Pin 1 is marked by a white line on atop of the case or a cut on a front of the case.

Abbreviate the full form of term used in surface Mount technology

SMD **S**urface **M**ounted **D**evices (active, passive and electromechanical components)

SMT **S**urface **M**ounted **T**echnology (assembling and montage technology)

SMA **S**urface **M**ounted **A**ssembly.



**Solder paste and its Application in SMT**

Solder paste or solder cream is simply a suspension of fine solder particles in a flux vehicle. In electronic industry, solder paste is used in surface mount technology ( SMT ) to solder SMDs on to the printed circuit board, The composition of the particles can be tailored to produce a paste of the desired melting range. Additional metals can be added to change paste compositions for specialized applications. Particle size and shape, metal content and flux type can be varied to produce pastes to varying viscosity. Availability of solder paste

Solder paste is available in both leaded (with lead) and lead-free (with no lead) forms. It can be no-clean or water soluble. With no-clean solder paste, there is not need to clean the board after soldering. Water soluble solder paste is easily soluble in water with no harm.

How to Get the Best Solder Joints from Solder Paste Application

1. In order to achieve good solder paste printing results, a combination of the right solder paste material, the right tools and the right process are necessary. Kester is a trusted brand in manufacturing solder paste and other soldering material including solder wire, solder bar, solder flux etc. Although the supplier is essentialy responsible for providing the desired solder paste and screens or stencils and the squeegee blades, the user must control process and equipment variables to achieve good print quality. Even the best solder paste, equipment, and application methods are not sufficent by themselves to ensure acceptable results.

Using solder paste

Start by applying flux to the circuit board pads. Then apply solder paste on the all pads of the components you want to solder.

Using tweezers, place the component in its correct position and hold it there. Place the tip of the soldering iron onto each of the pads so that the solder melts and makes good connections between the component and the board Flood with solder

This method is for soldering chips.

As usual start by applying flux too the pads on the circuit board. Fasten one of the corner pins of the chip to its pad by using a bit of solder. Make sure the chip is properly aligned on the pads.

Hold the chip in place while touching the corner pad with the tip of the soldering iron so that the solder melts the pin and the pad together.

Check the alignment of the chip. if it is not in its place, use your soldering iron to loosen the pin chip and align the chip properly. Continue soldering on the opposite corner by putting a bit of solder on the soldering iron tip then touching the circuit board pad and pin at the same time. Do this for all the pins of the chip one by one.

After all the pins have been soldered you should inspect the solder joints carefully with microscope or loupe to check for bad joints or solder bridges.

**Reflow solder process Description**

The basic reflow solder process consists of: Application of a solder paste to the desired pads on a printed circuit board (PCB) Placement of the parts in the paste. Applying heat to the assembly which causes the solder in the paste to melt (reflow). wet to the PCB and the part termination resulting in the desired solder fillet connection.

A Solder paste the solder paste mixes are improving as the demands of reflow soldering of SMT increase. Selection and specification of the optimum paste is a key item in the reflow solder process.

B Placement of the parts in the paste is not difficult if the pad design considers all the application tolerances. (see KEMET Application Bulletin "Surface Mount- Mounting Pad Dimensions and Considerations"). Care should be taken during the transportaion of the PCB,s not to smear the solder paste or move parts. Inspection of palcement accuracies and subsequent to increase repair rates after soldering.

C Appplication of heat to result in the eventual solder joint must consists of the following discrete items:- Preheat cycle is intended to drive off most of the volatile solvents contained in the paste before the flux begains to work. This assists in intiating fluxing action on the solder powder and the metal surface to be joined.- Additional preheat time to elevate the temperature of the PCB, Solder paste, and terminations to a temperature near the melting point of the solder.- Additional heat transfer to elevate the temperature over the liquidous point of the solder.- Temperature to be achieved are the liquidous melting point of solder. Liquidous points for-60 Sn/40 Pb solder is... 188C 63 Sn/37 Pb solder is... 183C 62 Sn/36 Pb/2 Ag solder is 179C Additional heat is reuired to insure activation of the rosins. However, heat should be limited to minimize the time some parts are above critical temperature. As temperature cooldown to the solder solidification temperature, followed by gradual (static) cooling to temperature near cleaning temperature.Equipment unique to surface mounting in electronics has not matured yet. There are two main types of automated inspection equipment on the market: x-ray and laser. However, most electronic companies depend on visual inspection at 2 to 10x, using either microscope of magnifying lamp.

# Surface Mount Technology (SMT)

**Objectives :** At the end of this lesson you shall be able to
- **explain surface mount technology**
- **describe advantages and disadvantages surface mount components.**

**Surface-mount technology (SMT)** is a method for producing electronic circuits in which the components are mounted or placed directly onto the surface of printed circuit boards (PCBs). An electronic device so made is called a surface-mount device (SMD). In the industry it has largely replaced the through-hole technology construction method of fitting components with wire leads into holes in the circuit board. Both technologies can be used on the same board for components not suited to surface mounting such as large transformers and heat-sinked power semiconductors.

An SMT component as shown in fig.1 is usually smaller than its through-hole counterpart because it has either smaller leads or no leads at all. It may have short pins or leads of various styles, flat contacts, a matrix of solder balls (BGAs), or terminations on the body of the component.

Virtually all of today's mass produced electronics hardware is manufactured using surface mount technology, SMT. The associated surface mount devices, and SMDs provide many advantages over their leaded predecessors in terms of manufacturability and often performance.

It was not until the 1980's that surface mount technology, SMT became widely used. Once SMT started to be used, the change from conventional leaded components to surface mount devices, SMDs took place quickly in view of the enormous gains that could be made using SMT.

Fig 1

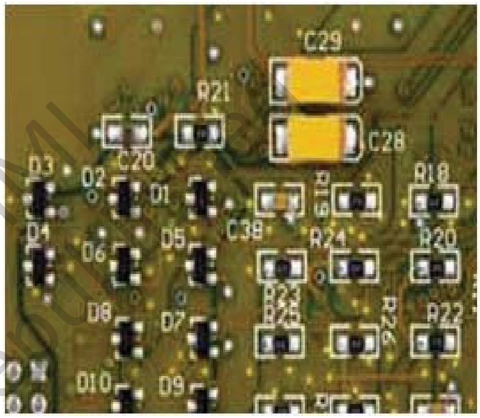
SMT COMPONENT

Mass produced electronic circuit boards need to be manufactured in a highly mechanized manner to ensure the lowest cost of manufacture. The traditional leaded electronic components do not lend themselves to this approach. Although some mechanisation was possible, component leads needed to be pre-formed. Also when the leads were inserted into boards automatically problems were often encountered as wires would often not fit properly slowing production rates considerably.

It was reasoned that the wires that had traditionally been used for connections were not actually needed for printed circuit board construction. Rather than having leads placed through holes, the components could be soldered onto pads on the board instead. This also saved creating the lead holes in the boards which added cost to the production of the bare PCBs.

As the components were mounted on the surface of the board, as shown in the fig. 2, rather than having connections that went through holes in the board, the new technology was called surface mount technology or SMT and the devices used were surface mount devices, SMDs. The idea for SMT was adopted very quickly because it enabled greater levels of mechanisation to be used, and it considerably saved on manufacturing costs.

Fig 2




TYPICAL SMT BOARD WITH TRANSISTORS, AND PASSIVE COMPONENTS

To accommodate surface mount technology, SMT, a completely new set of components was needed. New SMT outlines were required, and often the same components, e.g. ICs were sold as shown in fig. 3 in both traditional leaded packages and SMT packages. Despite this, the gains of using SMT proved to be so large that it was adopted very quickly.

Fig 3

ICS WERE SOLDERED IN PCB BOARD

**SMT board with typical IC packages**

**SMT Components**

Surface mount devices, SMDs by their nature are very different to the traditional leaded components. They can be split into a number of categories.

**Passive SMDs:** There is quite a variety of different packages used for passive SMDs. However the majority of passive SMDs are either resistors or capacitors for which the package sizes are reasonably well standardized. Other components including coils, crystals and others tend to have more individual requirements and hence their own packages.

Resistors and capacitors have a variety of package sizes. These have designations that include: 1812, 1206, 0805, 0603, 0402, and 0201. In other words the 1206 measures 12 hundreds by 6 hundreds of an inch. The larger sizes such as 1812 and 1206 were some of the first that were used. They are not in widespread use now as much smaller components are generally required. However they may find use in applications where larger power levels are needed or where other considerations require the larger size.

The connections to the printed circuit board are made through metallised areas at either end of the package.

**Transistors and diodes:** These components are often contained in a small plastic package. The connections are made via leads which emanate from the package and are bent so that they touch the board. Three leads are always used for these packages. In this way it is easy to identify which way round the device must go.

**Integrated circuits:** There is a variety of packages which are used for integrated circuits. The package used depends upon the level of interconnectivity required. Many chips like the simple logic chips may only require 14 or 16 pins, whereas other like the VLSI processors and associated chips can require up to 200 or more. In view of the wide variation of requirements there is a number of different packages available.

For the smaller chips, packages such as the SOIC (Small Outline Integrated Circuit) may be used. These are effectively the SMT version of the familiar DIL (Dual In Line) packages used for the familiar 74 series logic chips. Additionally there are smaller versions including TSOP (Thin Small Outline Package) and SSOP (Shrink Small Outline Package).

The VLSI chips require a different approach. Typically a package known as a quad flat pack is used. This has a square or rectangular footprint and has pins emanating on all four sides. Pins again are bent out of the package in what is termed a gull-wing formation so that they meet the board. The spacing of the pins is dependent upon the number of pins required. For some chips it may be as close as 20 thousandths of an inch. Great care is required when packaging these chips and handling them as the pins are very easily bent.

Other packages are also available. One known as a BGA (Ball Grid Array) is used in many applications. Instead of having the connections on the side of the package, they are underneath. The connection pads have balls of solder that melt during the soldering process, thereby making a good connection with the board and mechanically attaching it. As the whole of the underside of the package can be used, the pitch of the connections is wider and it is found to be much more reliable.

A smaller version of the BGA, known as the micro BGA is also being used for some ICs. As the name suggests it is a smaller version of the BGA.

**Advantages**

The main advantages of SMT over the older through-hole technique are:

- Smaller components. As of 2012 smallest was 0.4 × 0.2 mm (0.016 × 0.008 in: 01005). Expected to sample in 2013 are 0.25 × 0.125 mm (0.010 × 0.005 in, size not yet standardized)
- Much higher component density (components per unit area) and many more connections per component.
- Lower initial cost and time of setting up for production.
- Fewer holes need to be drilled.
- Simpler and faster automated assembly. Some placement machines are capable of placing more than 136,000 components per hour.
- Small errors in component placement are corrected automatically as the surface tension of molten solder pulls components into alignment with solder pads.
- Components can be placed on both sides of the circuit board.
- Lower resistance and inductance at the connection; consequently, fewer unwanted RF signal effects and better and more predictable high-frequency performance.
- Better mechanical performance under shake and vibration conditions.
- Many SMT parts cost less than equivalent through-hole parts.
- Better EMC performance (lower radiated emissions) due to the smaller radiation loop area (because of the smaller package) and the smaller lead inductance

**Disadvantages**

- Manual prototype assembly or component-level repair is more difficult and requires skilled operators and more expensive tools, due to the small sizes and lead spacings of many SMDs.
- SMDs cannot be used directly with plug-in breadboards (a quick snap-and-play prototyping tool), requiring either a custom PCB for every prototype or the mounting of the SMD upon a pin-leaded carrier. For prototyping around a specific SMD component, a less-expensive breakout board may be used. Additionally, strip board style proto boards can be used, some of which include pads for standard sized SMD components. For prototyping, "dead bug" bread boarding can be used.
- SMDs' solder connections may be damaged by potting compounds going through thermal cycling.

- Solder joint dimensions in SMT quickly become much smaller as advances are made toward ultra-fine pitch technology. The reliability of solder joints becomes more of a concern, as less and less solder is allowed for each joint. Voiding is a fault commonly associated with solder joints, especially when re- flowing a solder paste in the SMT application. The presence of voids can deteriorate the joint strength and eventually lead to joint failure.
- SMT is unsuitable for large, high-power, or high-voltage parts, for example in power circuitry. It is common to combine SMT and through-hole construction, with transformers, heat-sinked power semiconductors, physically large capacitors, fuses, connectors, and so on mounted on one side of the PCB through holes.
- SMT is unsuitable as the sole attachment method for components that are subject to frequent mechanical stress, such as connectors that are used to interface with external devices that are frequently attached and detached.

## Classification of SMD IC packages

**Objective :** At the end of this lesson you shall be able to
- **identify different types SMD IC packages depends upon their size & pin details.**

**Package classifications**

**Packaging trends**

Integrated circuits are classified into LSI, VLSI and ULSI is recent years

With increased functions and pin counts, IC packages have had to change significantly in the last few years in order to keep - up with the advancement in semiconductor development.

Functions required for conventional IC packages are as follows.

1 To protect IC chips from the external environment

2 To facilitatge the packaging and handling of IC chips

3 To dissipate heat generated by IC chips

4 To protect the electrical characteristics of the IC

Standard dual - in - line packages (DIP), which fulfill these basic requirements, have enjoyed wide usage in the electronics industry for a number of years

With increasing integration and higher speed ICs, and with the miniaturization of electronic equipment, newer packages have been requested by the industry which incorporate the functions listed below.

1 Multi- pin I/O

2 Ultra- miniature packages

3 Packages suited to high density ICs

4 Improved heat resistance for use with reflow soldering techniques.

5 High through put speed

6 Improved heat dissipation

7 Lower cost per pin

**Classification of ICS by the mounting method**

**Through - hole mount packages**

Through hole packages have a structure in which the lead pins are inserted and soldered into holes ( 0.8 to 1.0 mm in diameter) drilled through the printed circuit (PC) board, and find wide applications in elecrtronic equipment where board space is not at a premium or where costs are a constraint.

DIPs, and PGAs (pin grid array) are typical packages in this group.

**Surface mount packages**

Surface mount packages have a flat structure in which the lead pins are soldered directly to the soldered pattern (called the mount pad) provided on the PC board, and are used in high - pin - density IC package situations because devices can be mounted on both sides of the PC board. QFPs and QFJs (PLCC) are typical packages in this group.

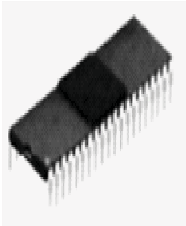
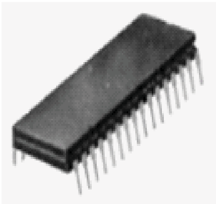
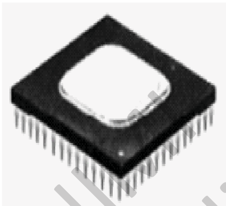
**Custom packages**

Memory modules are packages which have several memory ICs mounted on a PC board, Tape carrier packages (TCP ) using tape automated bonding (TAB) techniques, chip on board (COB) packages, or IC cad packages. TCP and COB packages are custom designs conforming to the customer’s specifications.

**Classication by package materials**

Packages are broadly classifed into ceramic and plastic packages. Package materials can be selected according to their application or operating environment.

Ceramic packages are known for thier high reliability, but plastic packages are becoming more popular due to their low cost (when compared to ceramic packages). Reliability has improved considerably in the last few years marking plastic a very attractive alternative to ceramic.

| Type | | Package types | | Package symbol | | Pin count |
|---|---|---|---|---|---|---|
| | | | | Old | New | |
| Through hole mounting type | Ceramic | Standard DIP |  | AS | AA | 16, 16, 18, 20, 22, 24, 28, 40, 42, 48 |
| | | CER- DIP |  | AS | AB | 8, 14, 16, 18, 22, 24,, 28, 32, 40, 42 |
| | | PGA |  | AS | BA | $73^{+2}$,$88133^{+2}$,$177^{+2}$, $209^{+2}$, $257^{+2}_{+1}$,$301^{+2}$, 240,$365^{+2}$, 400 |

The PGA pin count includes a pin for preventing incorrect insertion.

| Package Name | Characteristics |
|---|---|
| Dual in - line package | DIP packages are hermetic ceramic package. The lead pitch is 2.54mm (100 mil) and the package body is made of ceramics. Metal or glass may be used as a sealing material. |
| Dual in - line package (Glass sealed) | Dual in - line package are called “CER-DIP” package. The lead pitch is 2.54 mm ( 100 mil) and the package body is molded with powder ceramics. The sealing materials is glass. |
| Pin grid array | PGA packages are featured by the leads which are drawn out vertically from each package body and arranged on the spcfied grid. The package body is made of ceramic, and the standard lead pitch is 2.54 mm ( 100 mil). PGA packages are suited to multipin packaging. |



**SMD integrated circuits family**

Packages type for surface mount integrated circuits can be grouped into families.

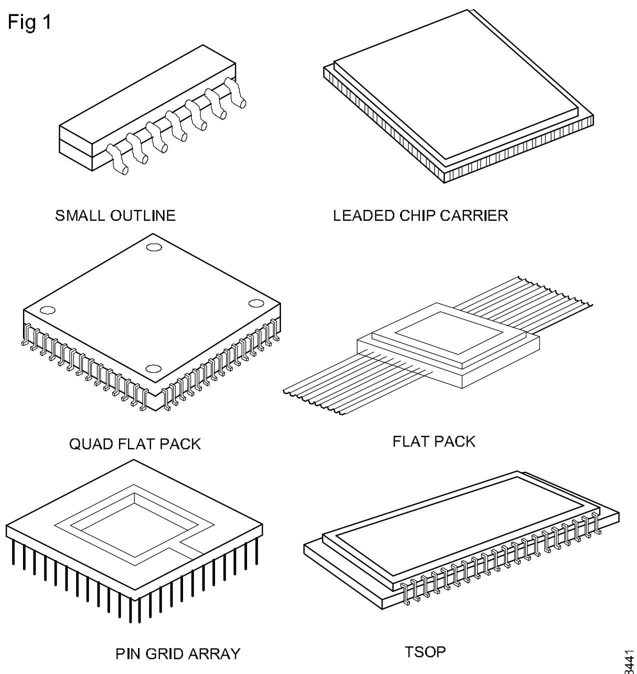
The flat pack is old technology.

The QUAD flat pack and TSOP use newer technology.

Each family has certain characteristics in common such as lead style, lead pitch, body size and case materials. as shown in fig. 1 & 2

## SMD IC family overview

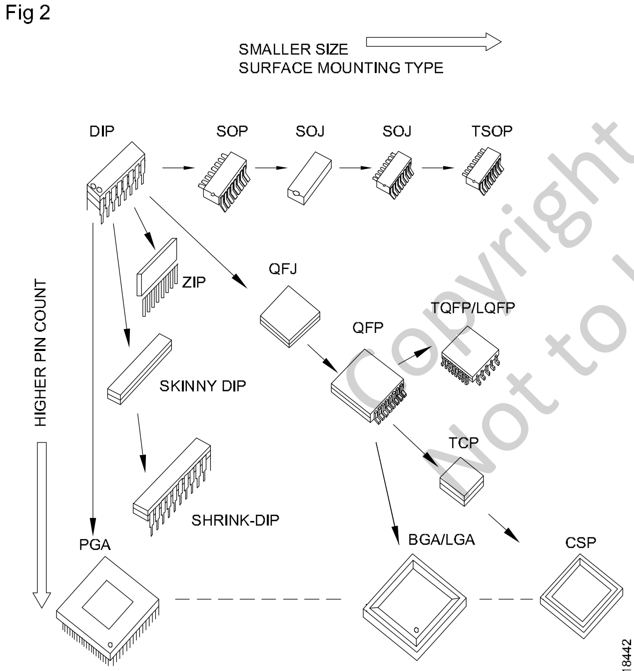
Fig 1




OVER VIEW
SMD IC FAMILY

## Package classifications

Fig 2




SMD IC FAMILY

## Lead styles

SMD integrated circuits have three types of basic leads. They have their name depends upon their shape.

Gull - wing leads are small and quite fragile. They can easily be damaged and must be handled with great care.

Gull - wing leads are used to get th highest number of leads onto an IC. It is possible to get 40 to 80 leads per linear inch ( 15 to 33 leads per cm) onto an IC using gull-wing leads. Gull - wing leads are easy to inspect after soldeirng.

J - leads are more sturdy than gull - wing leads, however, they take up more space. With J- leads, you can only get 20 leads per linear inch (8 leads per cm) on an IC package.

Flat leads are also used on ICs. Flat leads must be stored in special carriers to prevent lead damage.

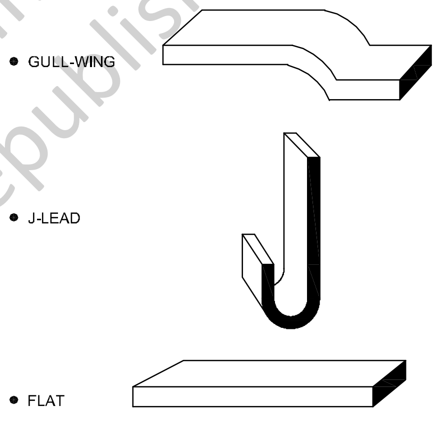
Just prior to use, IC's with flat leads are cut and bent into gull - wings by using lead forming equipment. Lead forming equipment is an extra expenses. Therefore, flat leads are the least popular type of IC lead.

The words lead pitch are synonymous with lead space



**Leads styles**

Fig 3




LEADS STYLES

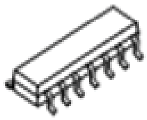
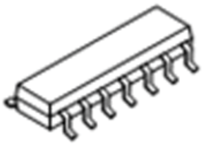
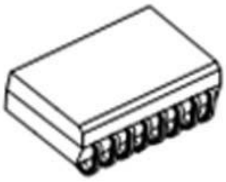
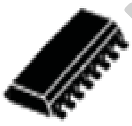
Heads system as shown in fig. 3.

Gull - wing

J- lead

Flat

**Small outline, Integrated circuit**

| Drawing | | Nomenclature | Body width | Lead type |
|---|---|---|---|---|
| 8-16 PIN |  | SO = Smal outline | 156 mil | |
| 8-16 PIN |  | SOM = Medium outline | 220 mil* | Gull 50 mil pitch |
| 16-32 PIN |  | SOL = “Large” outline<br>SOP = “Small” outline package | 300 mil | |
| 16-40 PIN |  | SOJ or SOL - J = “J” - Lead large outline | 300 mil* | J- Lead 50 mil |
| 32-56 PIN |  | VSOP = Very small outline package | 300 mil | Gul wing 25 mil |
| 8-30 PIN |  | SSOP= Shrink small outline package | 208 mil | Gull wing 25 mil |
| 20-56 PIN |  | QSOP = Quarter small outline package | 156 mil | Gull wing 25 mil |

Note : The length of the body is determined by the number of leads.

**SOIC packaging**

13 inch (330 mm) reels are standard for SOICs. The carrier tape is always plastic and measures 12 mm to 32 mm in width depending on the IC package size.

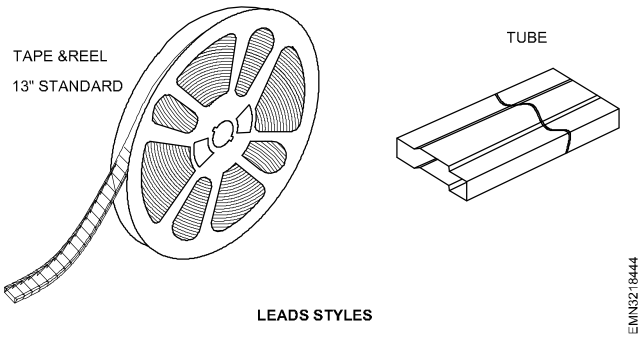
SOIC's are also readily available in plastic tubes. These tubes are sometimes called magazines or sticks. as shown in fig. 4

**Tape & Reel 13" standard**

**Tube**

**TSOP thin small outline package**

Fig 4




The TSOP (Thin small outline package ) combines a low profile package (1.0 mm high) with fine - pitch 19.7 mils ( .5mm) leads.

The TSOP provides a package which accommodates a large silicon chip in a high density package.

TSOP's are usually shipped in trays; however, tape and reel and tubes are available on special request.

The overall dimensions of TSOPs include the leads (total footprint). as shown in fig. 5 & 6.

Fig 5

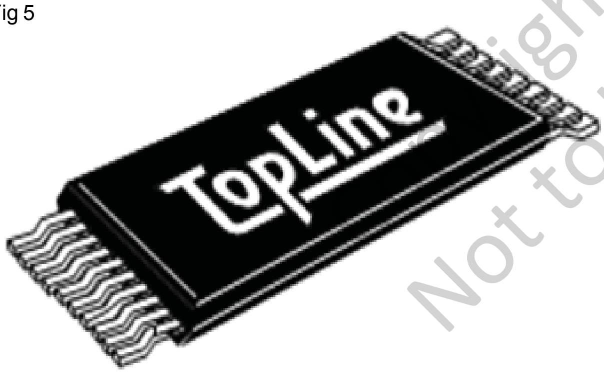
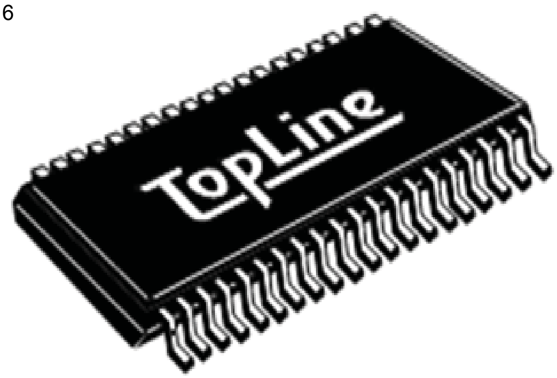



Fig 6




**Type 11 20 to 56 lead 0.5 mm pitch**

**Type 12 20 leads 1.27 mm pitch**

**PLCC leaded chip carrier**

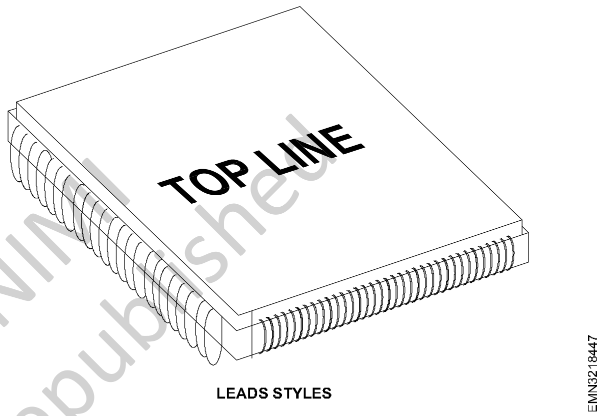
The plastic body PLCC is the most popular leaded chip carrier. Its J - leads are always 50 mil ( 1.27 mm ) pitch. They are commonly available from 18 to 100 leads. PLCC's are usually supplied in tubes or on tape and reel.

As an alternative to the plastic case, leaded chip carriers are available in ceramic, known as CLCC, and metal, known as MLCC.

PLCCs fit into IC sockets and can be easily replaced in the field.

PLCCs have been in use for over a decade and are now a common item. as shown in fig.7

Fig 7



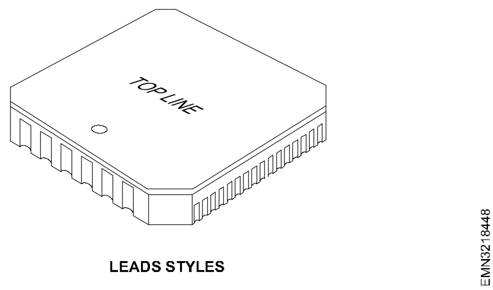

- Fits into IC sockets
- T & R or tubes
- Trends - PLCC is common item to new development

**LCC (leadless chip carrier)**

The ceramic LCC is one of the most rugged packages since it has no leads. LCCs are soldered direclty to PC boards by their solder pads, known as castellations. Most LCCs come with 50 mil pitch gold castellations which must be pre - coated with solder before mounting. as shown in fig. 8

LCCs are usually designed for mill spc, aerospace and high temperature applications.

Fig 8



LCC's are shipped in either trays or tubes.

Sometimes LCC's are called LCCC (Leadless ceramic chip carrier)

- LCC
- Solderable castellation pads
- 16 Pin to 44 pin ( up to 124 pin)
- Rugged, no leads to bend
- Ceramic body
- High temp & mil spec. applications
- Usually tubes or trays

**Quad flat pack nomenclature**

There are many variations of quad flat packs depending on package materials (plastic, ceramic or metal) and other standards.

**Nomenclature**

- QFP - Quad Flat Pack
- PQFP - Plastic Quad Flat Pack
- CQFP - Ceramic Multilayer QFP
- CERQUAD - Ceramic Quad Flat Pack
- MQUAD - Metal Quad Flat Pack
- MQFP - Metric Quad Flat Pack
- TQFP - Thin Quad Flat Pack
- TAPEPAK - Molded Carrier Ring
- BQFP - Bumpered Quad Flat Pack
- LQFP - Low Quad Flat Pack

**BQFP - Bumpered Quad Flat Pack**

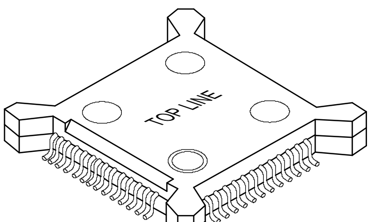
The bumpered quad flat pack is built to American JEDEC standards using true inch measurements. This means that 25 mil lead pitch is truly 5 mils (.636 mm not .65 mm) as shown in fig. 9.

The purpose of the bumepred corners is to protect the leads during shipping, handling and assembly.

BQFPs are constructed in a plastic package; however, they are also available with metal case, known as the BMQUAD.

BQFPs always have gull - wing leads and are shipped in trays, tubes or on tape and reel.

Fig 9




LEADS STYLES

EMN3218449

- JEDEC standard (USA)
- Bumpered corners - Protects leads
- Gull - wing
- Up to 196 leads
- Package options - Trays, tubes and T & R
- True 25 mil (.636 mm) pitch

**TAPEPAK molded carrier ring**

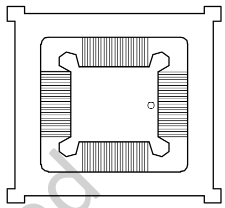
Tapepak was invented by national semiconductor and is now licensed for production by several manufacturers.

Know for its molded carrier ring, the leads remain safe from damage. The molded carrier ring allows the device to be tested before the need to cut and form the leads.

Leads up to 304 are now available with Tapepak. as shown in fig.10.

The main disadvantage with Tapepak is the added expense to provide lead forming equipment.

Fig 10



LEADS STYLES

EMN321844A

- Molded crrier ring keeps leads flat prior to use
- Allows automated testing
- 120 pins to 304 pins
- Coin stack in tubes
- Requires lead forming equipment

**Flip chips**

Flip chips are bare die with small solder bumps on the bottom which serve as "leads".

The flip chip is soldered directly to a PC board (FR4 or ceramic) by placing the component on the board and applying heat. The solder bumps melt to corresponding pads on the PC board.

The following solder type (Eutectic) is used for the bumps:

FR4 boards 63% - 37% low melt ( 183°C)

Ceramic boards : 95% - 5% requires high temp.

Bump on the die are around the perimeter and also in the middle.

Since the parts are small, dimensions are specified in "microns" not millimeters.

100µm = 1 millimeter

Important package specifiers

A Die size

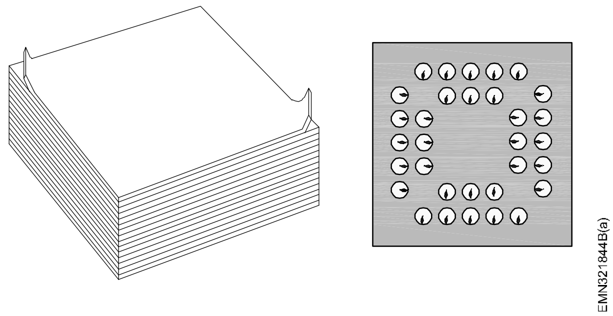
B Number bumps

C Diameter of bumps

D Solder composition of bumps

E Bump pitch

Fig 11 a




### Package symbols and codes

1) Package code (New package code)

The package codes given onthe outline view are those specfied in ED - 7303 (General rules for integrated circuits package name and code) established by electronic industries association of Japan (EIAJ) as shown below

□-□□□ □□□ □□□□-□□□□x□□□□-□□□□-□□□
1 2 3 4 5 6 7

1 Package material

2 Package structure characteristics

3 Package name

4 Number of package leads

5 Reference package dimensions

6 Lead pitches

**Examples**

1 P-HQFP 208-40 x 40-0.65 - K (HQFP 208- P-4040-0.65-K) this indicates a plastic QFP type package with a heat sink, consistingof 208 leads with a package body size of 40 mm x 40 mm and a normal bending lead pitch of 0.65 mm.

2 P-DIP 42-13.7 x 51.98-2.54 (DIP42-P-600-2.54) This indicates a plastic DIP type package consistingof 42 leads with package body width of 13.7mm package body length of 51.98 mm and a lead pitch of 2.54 mm.

**Package Names**

| Code | Package Name |
|---|---|
| QFP | Quad Flat Package |
| QFJ | Quad Flat J-Leaded Package |
| DIP | Dual in -line Package |
| SOP | Small Out-Line Package |
| SOJ | Small Out-line J-Leaded Package |
| ZIP | Zigzag in- line Package |
| PGA | Pin Grid Array |
| BGA | Ball Grid Array |
| LGA | Land Grid Array |

**Number of Package Leads (Typical Example)**

| Code | Package Name |
|---|---|
| 0008 | 8 |
| 0014 | 14 |
| 0064 | 64 |
| 0144 | 144 |
| 0256 | 256 |

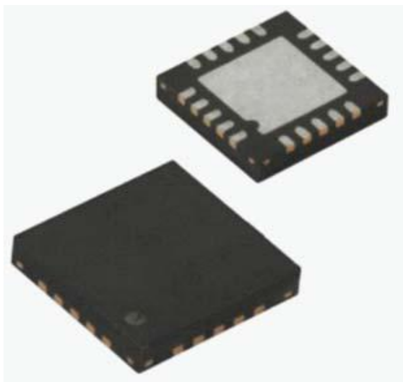
**Package Material**

| Code | Material | Applicable Package |
|---|---|---|
| C | Ceramic | Multi-layer ceramic package |
| G | Ceramic | Hermetic ceramic package sealed with glass |
| P | Plastric | Package molded with resin |

### QFN - Quad flat no leads

The Quad flat no leads package, or QFN is a very small square - shaped or rectangular surface - mount plastic package with no leads. It is basically a quad flat package, except for the absence of leads protruding from its sides. Meta pads or lands around the periphery of the bottom of the QFN package service as electrical connection points to the outside world. Because the QFN has no leads an has shorter bond wire lengths, it exhibits less inductance than leaded packages and therefore provides a higher electrical performance. The QFN package also includes an exposed thermal pad at the package bottom to facilitate heat dissipation from the die. as shown in fig. 11a & 11b.

Fig 11b



### Ceramic package, or cerpack

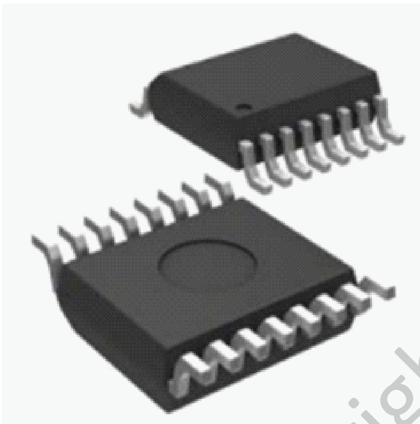
The ceramic package, or cerpack, is a hermetically sealed rectangular ceramic package that has leads extending from both of its longer sides, thus forming two sets of in - line pins. It is therefore a type of dual -in-line package (DIP) like the CerDIP. as shown in fig.12.

Fig 12

**QSOP Quarter size outline package**

The quarter size outline package, or QSOP is a small rectangular surface - mount plastic package with gull wing leads protruding out of its longer sides. The QSOP comes in two standard body widths; the narrow body QSOP which has a nominal body thickness of 150 mils and the wide body QSOP which has a nominal body thickness of 300 mils. Typical QSOP lead counts range from 16 to 28 leads for the narrow body and 36 to 44 leads for the wide body. The QSOP lead pitch is typically 25 mils. as shown in fig. 13.

Fig 13

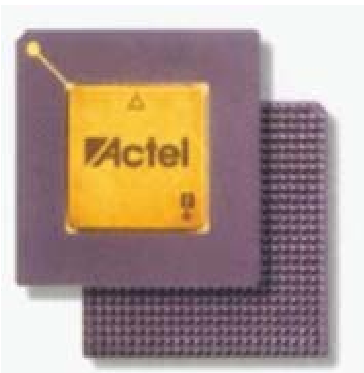


**General notes on IC packages**

**Ceramic column grid array, or CCGA**

The Ceramic column grid array, or CCGA is a square - shaped or rectangular ceramic package that uses solder columns for external electrical connection instead of leads or solder balls. These solder columns are arranged in a grid or array at the bottom of the ceramic package body, hence the name 'ceramic column grid array. The CCGA is basically just a CBGA package that has solder columns instead of solder balls. as shown in fig. 14

Fig 14




**PSOP - Power small outline package**

The power small outline package, or PSOP is a rectangular small outline IC package developed by amkor that integrates a copper heat slug in its plastic body. The die is attached to this heat slug, increasing the chip's ability to dissipate heat and thus handle more power. as shown in fig. 15

Fig 15


**CLCC or LCC - Ceramic leadless chip carrier**

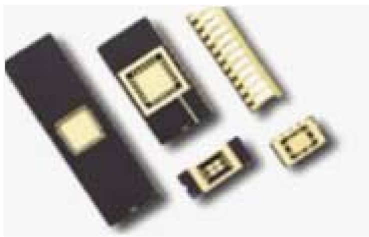
The ceramic leadless chip carrier, or CLCC or LCC, is a square or rectangular surface mount ceramic package that has no leads. For electrical connection to the outside world, the LCC instead uses flat metal contacts (or metallized castellations) known as pads around the four sides of the package bottom. as shown in fig. 16

Fig 16


**Sidebraze package**

The sidebraze package, is one of the most mature IC packages still in use today. It is a rectangular ceramic package that has leads extending from both of its longer sides, thus forming two sets of in-line pins. It is therefore a type of dual - in line package (DIP). Two other widely used DIP's are the PDIP and the CerDIP. as shown in fig. 17.

Fig 17

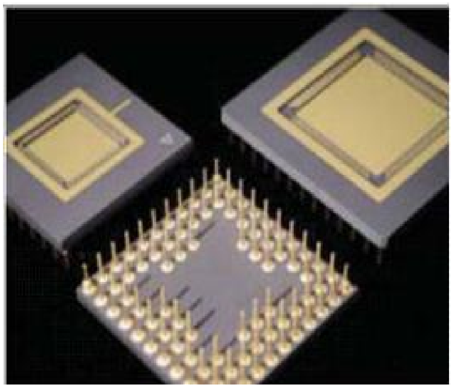


**CPGA Ceramic pin grid array**

The ceramic pin grid array, or CPGA is a square or rectangular through- hole ceramic package whose pins or leads are arranged in a square array at the bottom of the package body. The CPGA can either have a first - sealed ceramic lid or a solder - sealed metal lid. The CPGA is just one of several types of the PGA package.

The PGA is a popular choice for devices with high I/O counts such as microprocessors because of its high pin density. as shown in fig. 18.

Fig 18



**DFN- Dual flat no leads**

The Dueal flat no leads package, or DNF is a very small square - shaped or rectangular surface - mount plastic package with no leads. Metal pads or lands along two sides of the bottom of the DFN package serve as electrical connection points to the outside world. The DFN is similiar to the QFN, except that the latter has lands all around the periphery of the package instead of just two sides like the DFN. as shown in fig. 19.

Fig 19

**DPAK - Decawatt package**

The Decawatt package, or DPAK is an IC package developed by motorola to encase discrete high - power deviecs. The DPAK is also known as the TO-252. The acronym 'DPAK' can also stand for the term 'Discrete package' DPAKs can have 3 or 5 terminals. as shown in fig. 20.

Fig 20

**JLCC- J-Leaded ceramic chip carrier**

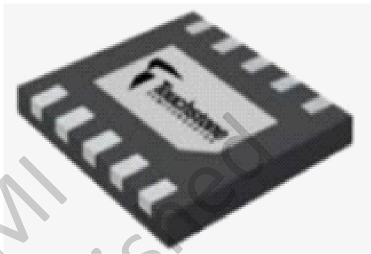
The J-leaded ceramic chip carrier, or JLCC, is a square or rectangular surface - mount ceramic package that has J-formed leads around its periphery. The plastic molded equivalent of the JLCC is the PLCC. as shown in fig. 21.

Fig 21

**TDFN- Thin Dual flat no leads**

The thin dual flat no leads package, or TDFN, is a very small and thin square - shaped or rectangular surface - mount plastic package with no leads. Instead of leads, it uses metal pads along two sides of the package body for electrical connection to the outside world. It is basically a thinner version of the dual flat no leads (DFN) package. as shown in fig. 22.

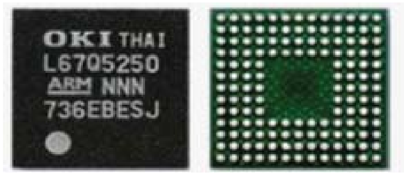
Fig 22



**LFBGA - Low profile fine- pitch ball grid array**

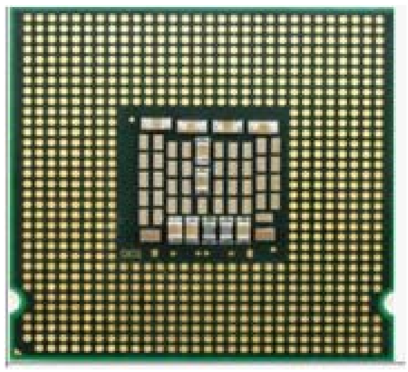
The low profile fine pitch ball grid array, or LFPBGA, is a smaller version of the ball grid array (BGA) package. It is basically an FBGA package that has a package height ranging from 1.2 mm and 1.7 mm. It is therefore thicker than the TFBGA and the VFBGA. as shown in fig. 23

Fig 23




**LGA - Land grid array (Fig.24)**

Fig 24

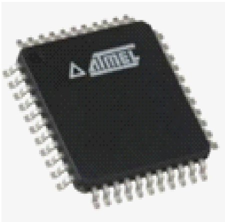


The land grid array or LGA is a package that uses metal pads for external electrical connection instead of leads (as in the pin grid array) or solder balls ( as in the ball grid array). These metal pads, which are called 'lands' are arranged in a grid or array at the bottom of the package body hence the name land grid array. The grid arrangement of the lands of the LGA package allows it to have a high land count, making it a popular packaging option for devices with high I/O requirements.

**TQFP Thin quad flat pack**

The thin quad flat pack, or TQFP is a surface - mount IC package with gull wing leads on all foru sides of the package body. It is basically a thinner version of the MQFP and LQFP. as shown in fig. 25

Fig 25



**LQFP - Low profile quad flat pack**

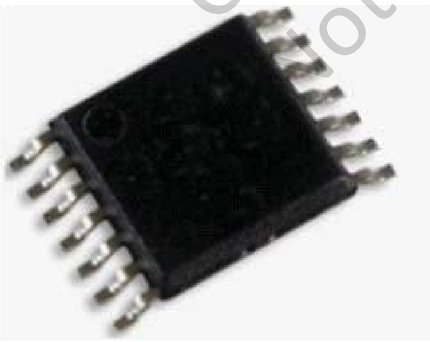
The low profile quad flat pack or LQFP, is a surface - mount IC package with leads extending from all four sides of the package body. as shown in fig. s26.

Fig 26


**TSSOP - Thin shrink small outline package**

The thin shrink small outline package, or TSSOP, is a rectangular surface mount plastic package with gull wing leads. It has a smaller body and smaller lead pitch than the standard SOIC package. It is also smaller and thinner than a TSOP with the same lead count. as shown in fig. 27

Fig 27



**MQFP- Metric quad flat pack**

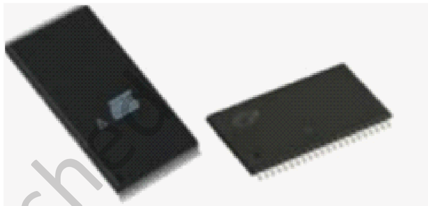
The metric quad flat pack, or MQFP is a surface - mount IC package with gull wing leads on all four sides of the package body. as shown in fig. 28

Fig 28


**TSOP -Thin small outline pacakge**

The thin small outline package, or TSOP is a rectangular IC package with a thickness of 1.0 mm. There are two typs of TSOPs. The type I TSOP has its leads protruding from the shorter edges of the package. The type II TSOP has its leads protruding from the longer edges of the package. as shown in fig. 29

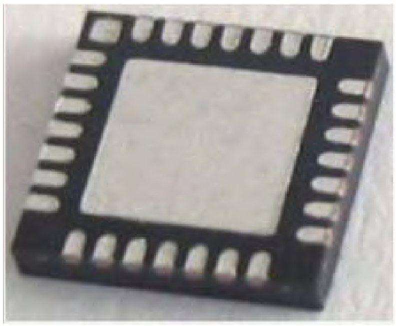
Fig 29



**MLP- Micro lead frame package**

The micro lead frame package, or MLP is a JEDEC compliant, very thin, near - CSP square - shaped or rectangular surface - mount plastic package uses metal padsinstead of leads for the electrical connection to the outside world. The MLP belongs to the same 'no leads' package family as the QFN and the DFN. as shown in fig. 30

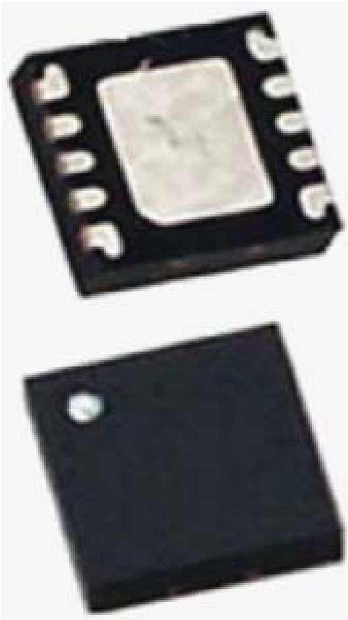
Fig 30



**UTDFN - Ultra thin dual flat no leads**

The ultra thin dual flat no leads package, or UTDFN is a very small and thin square - shaped or rectangular surface - mount plastic package with no leads. Instead of leads, it uses metal pad as long two sides of the package body for electrical connection to the outside world. It is basically a thinner version of the thin dual flat no leads (TDFN) package. as shown in fig. 31.

Fig 31



**MSOP - Micro small out line package**

The micro small outline package, or micro- SOP or MSOP, is a very small rectangular plastic package with guall wing leads protruding out of its longer sides. The MSOP is a miniaturized version of the SSOP package, having a smaller footprint than the latter. as shown in fig. 32.

Fig 32

**UTQFN- Ultra thin quad flat no leads**

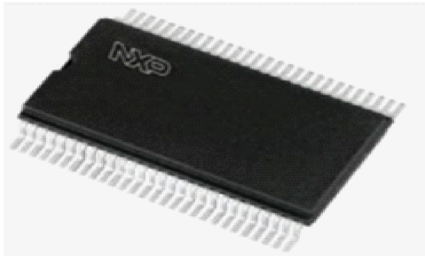
The ultra thin quad flat no leads package, or UTQFN is avery small and thin square- shaped or rectangular surface - mount plastic package with no leads. Instead of leads, it uses metal pads around the periphery of the package body for electrical connection to the outside world. It is basically a thinner version of the thin quard flat no leads (TQFN) package. as shown in fig.33.

Fig 33

**VSOP- Very small outline package**

The very small out line package, or VSOP is one of several smaller versions of the SOIC package, having a compressed body and a tightened pitch for its gull wing leads. Another smaller version of the SOIC is the SSOP. as shown in fig. 34

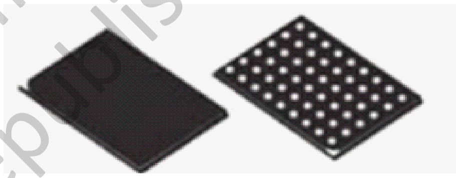
Fig 34




**TFBGA - Thin profile fine ptich ball grid array**

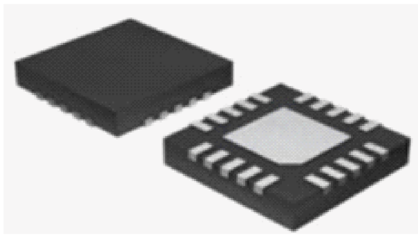
The thin profile fine pitch ball grid array or TFBGA, is a thinner version of the FBGA package like all BGA packages. TFBGA's use solder balls that are arranged in a grid or array at the bottom of the package body for external electrical connection. The TFBGA is near - chip - scale in size and features ball pitch values that are even tighter than those of the FBGA. as shown in fig. 35.

Fig 35



**TQFN - Thin quad flat no leads**

Fig 36



The thin quad flat no leads package, or TQFN is a very small and thin square - shaped or rectangular surface mount plastic package with no leads. Instead of leads, it uses metal pads around the periphery of the bottom of the package body for electrical connection to the outside world. It is basically a thinner version of the quad flat no leads (QFN) package. as shown in fig. 36

**FBGA- Fine pitch ball grid array**

The fine pitch ball grid array, for FPBGA or FBGA is a smaller version of the ball grid array (BGA) package. As in all BGA packages, FBGA's use solder balls that are arranged in a grid or array at the bottom of the package body for external electrical connection. However, the FBGA is near chip -scale in size, with a smaller and thinner body than the standard BGA package. As its name implies, it also features a finer ball pitch (smaller distance between balls) as shown in fig. 37.

Fig 37

**SSOP-Shrink small outline package**

The shrink small outline package or SSOP is a smaller or 'shrunk' version of the SOIC package having a compressed body and a tightened lead pitch. as shown in fig. 38.

Fig 38


**D3PAK - Decawatt package 3**

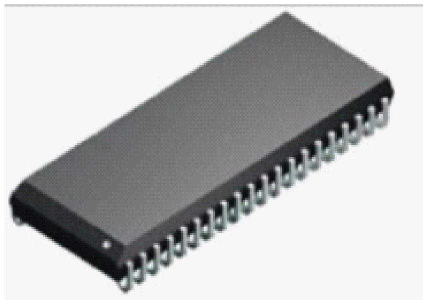
The decawatt package 3 or D3PAK is a bigger version of the D2PAK package. Just like the D2PAK ( and the DPAK the D2PAK's predecessor) the D3PAK is a surface - mount plastic - molded package intended for high - power discrete devices. The D3PAK is also known by other names such as 'TO-268' and discrete package 3. as shown in fig. 39

Fig 39

**SOJ : Small outline J- lead package**

The small outline J-lead package or SOJ is a small rectangular surface - mount plastic molded integrated circuit package with J-formed leads. The leads protrude from the longer edge of the package. The SOJ is also sometimes referred to as SOJ or J- leaded small outline IC package. as shown in fig. 40

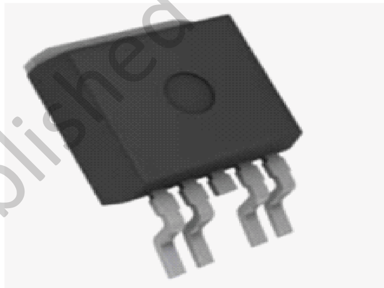
Fig 40



**D2PAK or DDPAK- Double decawatt package**

The Double decawatt package, or D2PAK or DDPAK is the successor to the DPAK package which was designed by Motorola to encase discrete high power devices. The D2PAK is bigger than the DPAK and comes in several versions with different terminal counts. The D2PAK which has a flat heat sink at the back is basically the surface - mount equivalent of the TO-220 through- hole package and its therefore sometimes referred to as 'SMD-220'. The D2PAK is also known as 'TO-263'. as shown in fig. 41.

Fig 41

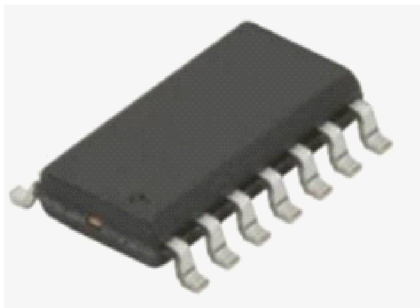




**SOIC - Small outline integrated circuit**

The small outline integrated circuit or SOIC is a small rectangular surface mount plastic molded integrated circuit package with gull wing leads. The leads protrude from the longer edge of the package. It is one of the most commonly used surface mount packages today as show in fig. 42

Fig 42



**Small outline Transistor (SOT) package**

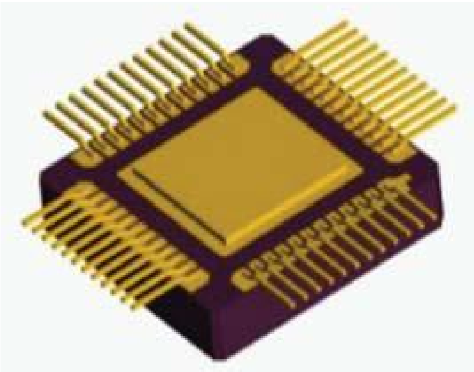
Small outline transistor (SOT) packages are very small, inexpensive surface mount plastic - modled packages with leads on their two long sides. Due to their low cost and low profile. SOT's are widely used in consumer electronics. The SOT - 23 and the SC-70 packages are two of the most widely used SOT packages today. Note that a side from these two, there are many other SOT package types used in the IC industry. as shown in fig. 43

Fig 43

**CQFP - Ceramic quad flat pack**

The ceramic quad flat pack, or CQFP is a ceramic IC package with leads extending from all four sides of the package body. CQFP's are predominantly square in shape, although rectangualr variants do exist. The CQFP is just one of the many types of the quad flat pack (QFP) package. as shown in fig. 44

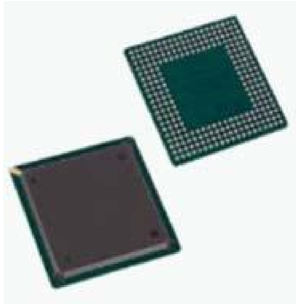
Fig 44



**Ball grid array aka BGA**

BGA packages are used to permanently surface mount devices such as microprocessors. A BGA can provide more interconnection pins than can be put on a dual in - line or flat package. The whole bottom surface of the device can be used, instead of just the perimeter. The leads are also one average shorter than with a perimeter only type, leading to better performance at high speeds. soldering of BGA devices requires precise control and is usually done by automated processes. A BGA device is never mounted in socket in use. as shown in fig.45

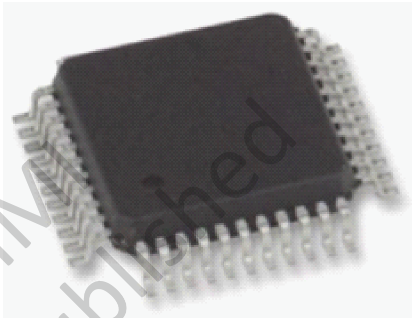
Fig 45



**Plastic quad flat package aka PQFP**

The plastic quad flat pack, or PQFP is an IC package with leads extending from all four sides of the package body. PQFP's are predominantly square in shape, although rectangular variants do exist. The PQFP is just one of the many types of the quad flat pack (QFP) package. as shown in fig. 46.

Fig 46



**PLCC- Plastic leaded chip carrier**

The plastic leaded chip carrier, or PLCC is a four - sided plastic package that has "J" leads around its periphery. These "J" leads, occupy less board space than the gull - wing leads that other packages like the SOIC have. PLCC lead counts range from 18 to 84. PLCC packages can either be square or rectangular in shape. The ceramic equivalent of the PLCC is the JLCC. as shown in fig. 47

Fig 47

# Explanation about different types of tools & equipments & raw materials required for SMD soldering and desoldering work

**Objectives :** At the end of this lesson you shall be able to
- **trainees will be familiar to use the tools and raw materials used to avoid the damage of costly SMD devices and components and ICs due to electrostatic discharge**
- **trainees will be familiar to use tools and equipments and raw materials required to do soldering and desoldering work of SMD components and ICs.**

**Tools and equipments required for SMD soldering**

**Hot air station solder blower**

Fig 1


Fig 2

**Hot air gun soldering station iron tool solder**

It is used to solder and de solder the fine and narrow terminals of SMD components, by setting the suitable temperature and air pressure of hot air blower as per the pad size of the PCB and package size of SMD components. shown in fig. 1 & 2.

**Working of SMD Rework station**

Rework station is an antistatic soldering station with soldering iron and hot air gun. Rework station recommended. Thermal sensitive electronic component like (QFP, PLCC, SOP etc) Air complessior is located in side the sttion etc.,) It is useful for the soldering and desoldering the SMD components. shown in fig.3, 4, & 5

**SMD rework system with different temperature profiles and digital display**

Fig 3


Fig 4

VARIOUS SOLDERING TIPS

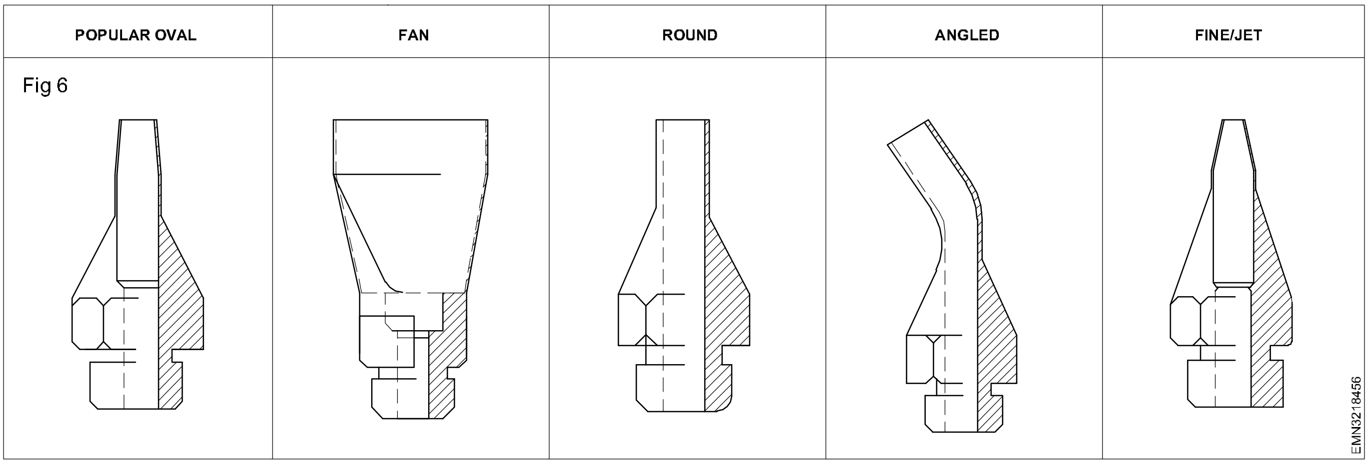
Fig 5

DIFFERENT SHAPES OF HOT AIR TIPS

The hot air pencil has many advantages of the traditional soldering iron : First and foremost, the hot air pencil is completely non - invasive providing precision, pin- pointed, non - contact, low- velocity hot air directly to the individual components leads. as show in fig. 6

Optional : 5 Distinct stainless steel air tip styles are available for all SMD's

Fig 6




**Heated Tweezers : (Optional)**

Heated tweeezers have more targeted heat transfer than the hot - air rework stations. They provide a fast and efficient method to solder and de-solder SMDs such as chip resistors, chip capacitors, SOTs, flat packs and DIP ICs. as shown in fig. 7

Fig 7


**Solder suckers de - soldering pumps**

A 'desoldering pump' or more generically referred to as a "solder sucket", is a tool that vaccums molten solder from circuit board assemblies during circuit repairs or component removal. shown in fig. 8

Fig 8

Anti - Static Desoldering Pump / Solder Sucker

**Monocle Magnifier -Illuminated**

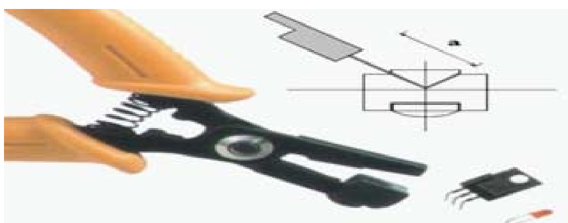
This loop magnifier set itself apart in your eyes because of the little LED on the side. Trying to view SMD connections is hard enough - the LED on the side is huge help for those want to inspect the connections very closely for proper solder connection. shown in fig. 9 & 10.



Fig 9

**90° forming tool**

Fig 10



**Tool cut kink forming**

Fig 11

Special tool that cuts and pre-form the component wire in one operation. Length setting is carried out by means of a sliding stop. as shown in fig.11

**90° SMD tweezer**

Parallel blades ideal to lift & align chips. Also winding coils & hairsprings. as shown in fig 12

Fig 12

**Curved tweezer**

Curved (eagle) tweezer for general assembly, permits resting hand on bench. Fine points. as shown in 13

Fig 13

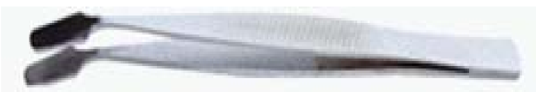
Reverse action tweezer grips and hold parts with less pressure than traditional tweezers. shown in fig.14.

Fig 14

**Parallel paddle tweezer**

Smooth, tlat, angled parallel paddle tweezer. Great at gripping and lifting IC's & small parts. as shown in fig.15

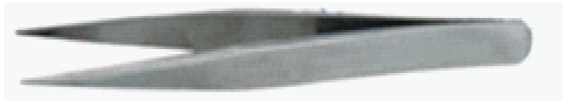
Fig 15



**Rounded points tweezer**

Round points prevent scratch to delicate parts silicon, crystal & germanium water chips. as shown in fig. 16

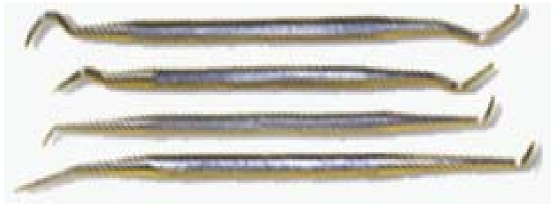
Fig 16



**SMD probers & spudgers**

Align, straighten chip leads or test solder joint. as shown in fig.17

Fig 17



**Integrated circuit (IC) extractor J - leaded, PLCC, PLCC socket, connector & PGA extractors**

Fig 18

Removes IC's PGA's, thru- hole connectors after de-soldering easily and quickly. Compression steel spring with insulated, cushioned grips permits single handed squeezingthe hooks up underneath the device for simple lifting up and out of the PC board. as shown in fig. 18

**PLCC socket extraction tool**

Fig 19

ESD safe works with all JEDED, J- leaded, SOJ or PLCC SMD packages and PLCC sockets. This helpful, universal tool removes PLCC chips and sockets with as few as 18 leads / pins up to 124 leds /pin. Spring - loaded and self - opening, the tool reduces hand fatigue and permits single hand operation. Insert the hooks into the corner and lift.

Helps in preventing lead /pin damage. A PCB benchtop essential. as shown in fig.19

**Micro shears, flush cutters and pliers**

Fig 20


SHORT SNUB NOSE PLIERS

Cuts cable and wire ties with 20° head angle. as shown in fig. 20 & 21.

Fig 21

LONG REACH NEEDLE NOSE PLIERS

Shears PCB chip leads & wire to 20A WG, cables & wire ties. as shown in fig. 22.

Fig 22

WIRE, CABLE, WIRE TIE CUTTER

Grip and hold while twisting or tugging. Good for wire forming. Smooth jaws stop nicking/scoring tiny wires to 1 mil. Spring - loaded "return". as shown in fig.23

Fig 23

PCB LEADS FLUSH CUTTER & CLIP

**Quard flat pack pin & lead straightening tool**

This is an essential quality control (QC) tool for pin number verification along with body size and pitch of unknown QFP components. as shown inf ig. 24 & 25.

Fig 24

RESHAPES, RE-ALIGNS, STRAIGHTENS QFP, TQFP & LQFP PACKAGES TO ULTRA - FINE PITCH.

Fig 25

It reworks and align bent pins of all sizes of QFP and TQFP's and correct co-planarity problems. The lead straightner handles chip with lead / pin pitches from 0.4 mm to 1.0 mm.

The template accommodates 46 different QPF patterns and is ideal for component recovery or salvage of expensive QPF, TQPF and LQPF packages /chips. Use standard hand tools like dental picks and tweezers to adjust the QPF pins to match recessed template slots.

**Hobby knife**

Fig 26

We use these extensively when working with PCBs. These small knife work well for cutting traces, scraping ground pours, and guiding hair - like wires into their proper place. Excel knife comes with aluminum handle, one ultra - sharp blade, and safety cap. as shown in fig. 26

**Pana vise junior clamp**

PCB holder : (Opitonal)

Fig 27

A small, sturdy clamp that can be rotated to almost any angle to hold work or tools. The jaws of this clamp are heat - resistant, open to 2 7/8", and have embedded grooves to help hold circuit boards. For extra stability, it can be secured to a work bench with mounting screws. as shown in fig.27

ESD safe vacuum pen (optional)

**Suction & vacuum lifting & halding SMD's, glass wafers & small parts**

Vaccum handling tool that features with silicon vaccum cups for lifting small parts and components. Vacuum from the pen vac is generated by simply pressing and releasing the vaccum release button. as shown in fig.28, 29, 30.

Fig 28

ESD - SAFE PEN VACUUM HANLDING TOOL THAT FEATURES

Fig 29

PEN VAC KITS INCLUDE 6 OR 10 SUCTION CUPS

Fig 30

**Digital multimeter**

Smart tweezer (optional) : Measure accurately and easily your SMT components. LCR measurement using smart tweezers. Measure resistance from 0.05 ohm to 10 mega ohm, capacitance 10pF to 5 mF and inductance 1 uH to 1H. It automatically recognize for LCR measure mode. Continiuty or open test, Diode test. DC/AC voltae upto +/ - 8 volt, reading of main and parasitic impedance components. Measurement of dissipation and quality factors. as shown in fig. 31.

Fig 31


SOLDERING & DESOLDERING TIP TEMPERUTE THERMOMETER (OPTIONAL)

**Soldering and desoldering tip temperature thermometer (Optional)**

Measure tip temperature quickly, with high accuracy. as shown in fig.32

Fig 32

Bench fume absorber (optional) as shown in fig.33

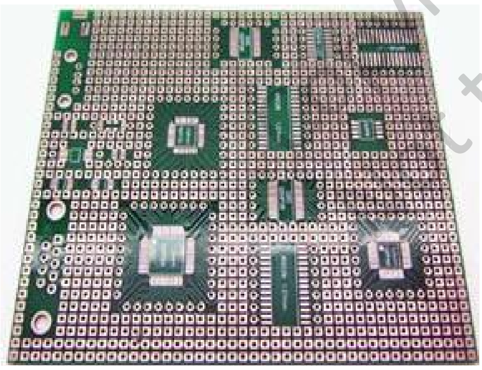
Fig 33

Help to remove harmful fume in soldering area

**Raw materials**

SMD PCB board (single sided and double sided) as shown fig. 34 & 35

Fig 34



This prototype board supports most kinds of SMD IC package.

TQFP 32 (0.65 mm)

TQFP 48 (0.5 mm)

TQFP 64 (0.5 mm)

SOP 28, SO- 8, SO-14, SO- 16, SOT - 25

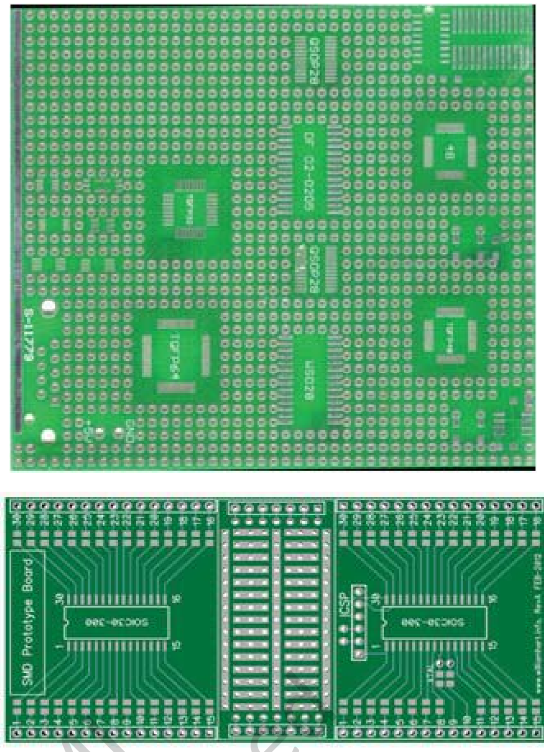
QSOP - 28 (0.65 mm)

DB 9

MSOP - 8, etc

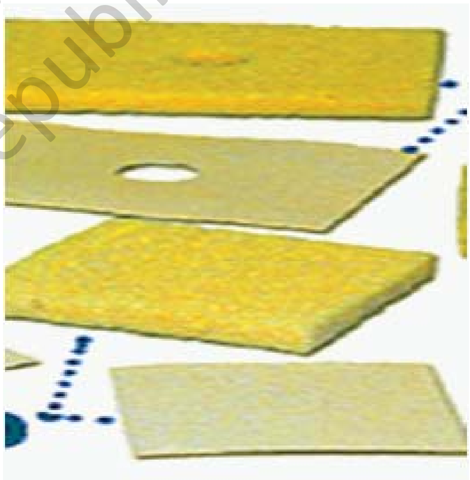
Size : 90 * 110* 1.5 mm

Fig 35



**Damp sponge with a hole**

Fig 36



A hole in the middle gives you an edge to wipe the iron tip on, and also a place for the used solder to fall into so you are not trying to clean the tip on older debris. We should wet the sponge using distilled water to avoid corrosion of the soldering iron bit. as shown in fig.36

**Dry tip cleaner**

A sponge replacement, these soft, metal coils are coated with flux and clean soldering iron tips without thermally shocking them like a wet sponge does. This helps to prolong tip life. Also, this cleans more effectively than a sponge. To clean, thrust the iron into the coils a few times. as shown in fig. 37

Do not scrape the tip on the coils because this can fling molten solder.

Fig 37

**Flux : The key to surface mount soldering**

Flux removes oxides from metal that prevent solder from bonding to it, and also helps to distribute heat. During typical soldering with flux - cored, solder wire, all the flux you need is contained in the solder. When the wire touches a hot connection, the flux flows out, cleans the joint and prevents further oxidation. However, in surface mount soldering, (brace yourself) oftentimes solder is melted on the iron, and then transferred to the joint. During this time, the flux quickly boils off and becomes useless, so additional flux is needed on the connection. If transferring solder in this manner sems questionable, bare in mind that a common process in industry, called wave soldering, is similar. Fluxed boards are slowly passed over a giant wave of moten solder that wicks into the connectios.

Flux comes in a large variety of different types and applicatiors. It is recommend using a rosinbased, RMA (Rosin Mildly activated), clean the flux soon afte soldering because the residues quickly harden. “No - clean” fluxes have very low activation levels, and are therefore less effective than activated fluxes, but will work fine on clean parts. as shown in fig. 38.

Use no - clean flux if you are making circuits space applications or if you use water solube flux, the residues are corrosive, and should be removed with warm water.

Fig 38


**Solder wire spool holder, soldering wire rack, solder wire dispenser**

No clean solder wire has a no - clean flux core and is terrific for all your PCB soldering including both through-hole and surface mount. Ideal for prototyping, low - volume runs, and printed circuit board rework at the bench.

**Solder paste with lead**

Fig 39

Zerolead - solder paste is your RoHs compliant, as shown in fig. 39 lead - free solder paste perfectly harmonizing its rich tin, silver and copper alloy with an effective no - clean flux ‘carrier’ yielding simply superb wetting characteristics and premium solder joints with an attractive satin finish.

Zero lead solder paste was developed specifically for the electronic bench top and is ideal for rework, low volume prodcution. This consists of tiny solder balls floating in gel - like flux. Once paste is applied to the pads, chips are placed on top, and the board is “reflowed” (paste melted) in a toaster oven or with hot air. Paste can be applied using the syringes shown or with a squeegee and stencil. Note that paste in syringes usually has slightly less metal content to help it flow through small needles. Get paste in a air if you are using a stencil. The main choice to make is between no - clean or water soluble paste. No clean flux is recommended unless you have reason to believe your components are difficult to solder old and possibly corroded. The residues from water - soluble paste are corrosive, so be sure to clean them with warm water.

If you get a syringe, you will likely have to buy a needle and plunger, too A 22 gauge needle is a good starting place, and you can always lay a thicker bead of paste just by pushing more out.

**Alcohol dispensing pump bottle (optional)**

Fig 40


This ESD safe bottle pumps a small amount of isopropyl alcohol into a dish on the lid when pressed down by a brush. as shown in fig. 40. It is designed to keep the rest of the alcohol from evaporating, and helps conserve use. If you want to clean flux residues, use an acid brush with isopropyl alcohol. Be sure two wipe up the residues with a lint - free wipe (like kim wipes) and not just over them around on the board.

**Foam swabs, Anti - static**

Fig 41

Acid brushes, scrub brushes for PC board repair & rework through- hole, plated through cleaner brushes, flux brushes. as shown in fig. 41.

Fig 42


Applicator brushes ( acid brushes) are essential tools in labs and at the bench for cleaning and scrubbing away flux from the circuit board with solvents to remove flux, especially with plated through - hole chips. as shown in fig. 42,43,44,45 &46.

Fig 43

CLEANING BGA CHIPS

Fig 44

Fig 45

CLEANING PC BOARDS SOLDER JOINTS AFTER REWORK

Fig 46

SCRUBBING OLD FLUX AWAY WITH SOLVENT OFF I.C LEADS

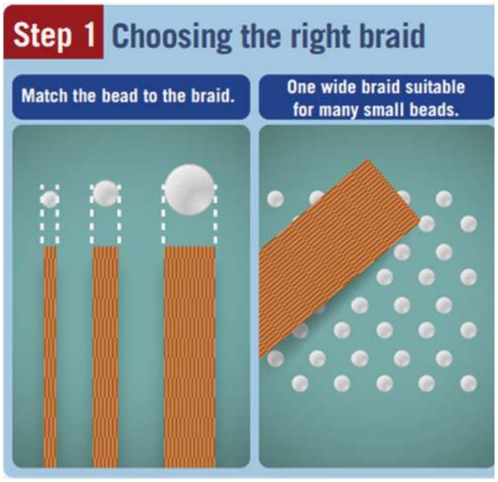
**Desoldering braid**

De - soldering is required when electronic components need to be removed from a circuit, usually because they are faulty. It may sometimes be necessary during testing or assembly, if a wrong parts has been fitted or a modification has to be made. To professionally remove solder from a circuit, you will need for the following materials. as shown in fig. 47

1 De -soldering barid

2 Soldering iron

Fig 47




Step 1 : Choosing the right braid

- Choose a braid width the matches the size of the solder bead to be removed.
- If there are many small beads, choosing a wider braid will also speed up the desoldering process.

Step 2 : Using the braid

a. Heat up soldering iron as shown in fig. 48

b. Place super wick on to solder bead

c. Place heated solder iron on to braid

Molten solder is drawn up by capillary action into the braid. Careful not to overheat, or 'drag whiskers' of solder over the board, not let the braid solidity on the joint. Always remove braid and solder iron together in a vertical motion.

Fig 48


a) Heat up soldering iron

b) Place super wick on to solder bead

c) Place heated solder iron on to braid

- The desoldering braid is treated with a flux coating that once used will no longer draw in the molten solder, so you will need to unspool new braid as you desoder several joints.
- Always hold the braid by the bobbin on which it is spooled because the copper does conduct heat and can cause burns if handled directly.



## Soldering guns and its types

**Objectives :** At the end of this lesson you shall be able to

- **explain soldering guns and its types**
- **describe the selection of soldering guns**
- **define tips and its types .**

**Soldering guns**

A **soldering gun** is an approximately pistol-shaped, electrically powered tool for soldering metals using tin-based solder to achieve a strong mechanical bond with good electrical contact. The tool has a trigger-style switch so it can be easily operated with one hand. The body of the tool contains a transformer with a primary winding connected to mains electricity when the trigger is pressed, and a single-turn secondary winding of thick copper with very low resistance. A soldering tip, made of a loop of thinner copper wire, is secured to the end of the transformer secondary by screws, completing the secondary circuit. When the primary of the transformer is energized, several hundred amperes of current flow through the secondary and very rapidly heat the copper tip. Since the tip has a much higher resistance than the rest of the tubular copper winding, the tip gets very hot while the remainder of the secondary warms much less. A tap on the primary winding is often used to light a pilot lamp which also lights the work piece.

**Soldering iron types**

- Simple iron
- Cordless iron

- Temperature-controlled soldering iron
- Soldering station
- Soldering tweezers

**Simple iron**

For electrical and electronics work, a low-power iron, a power rating between 15 and 35 watts, is used. Higher ratings are available, but do not run at higher temperature; instead there is more heat available for making soldered connections to things with large thermal capacity, for example, a metal chassis Some irons are temperature-controlled, running at a fixed temperature in the same way as a soldering station, with higher power available for joints with large heat capacity. Simple irons run at an uncontrolled temperature determined by thermal equilibrium; when heating something large their temperature drops a little, possibly too much to melt solder.

**Cordless iron**

Small irons heated by a battery, or by combustion of a gas such as butane in a small self-contained tank, can be used when electricity is unavailable or cordless operation is required. The operating temperature of these irons is not regulated directly; gas irons may change power by adjusting gas flow. Gas-powered irons may have interchangeable tips including different size soldering tips, hot knife for cutting plastics, miniature blow-torch with a hot flame, and small hot air blower as shown in fig 1 for such applications as shrinking heat shrink tubing.

Fig 1


DIFFERENT TYPES OF GAS FLOW IRON

**Temperature-controlled soldering iron**

Simple irons reach a temperature determined by thermal equilibrium, dependent upon power input and cooling by the environment and the materials it comes into contact with. The iron temperature will drop when in contact with a large mass of metal such as a chassis; a small iron will lose too much temperature to solder a large connection. More advanced irons for use in electronics have a mechanism with a temperature sensor and method of temperature control to keep the tip temperature steady; more power is available if a connection is large. Temperature-controlled irons may be free-standing, or may comprise a head with heating element and tip, controlled by a base called a soldering station, with control circuitry and temperature adjustment and sometimes display is as shown in the fig. 2.

Fig 2

TEMPERATURE CONTROLLED SOLDERING IRON

A variety of means are used to control temperature. The simplest of these is a variable power control, much like a light dimmer, which changes the equilibrium temperature of the iron without automatically measuring or regulating the temperature. Another type of system uses a thermostat, often inside the iron's tip, which automatically switches power on and off to the element. A thermal sensor such as a thermocouple may be used in conjunction with circuitry to monitor the temperature of the tip and adjust power delivered to the heating element to maintain a desired temperature.



**Soldering station**

A soldering station (fig. 3), invariably temperature-controlled, consists of an electrical power supply, control circuitry with provision for user adjustment of temperature and display, and a soldering iron or soldering head with a tip temperature sensor. The station will normally have a stand for the hot iron when not in use, and a wet sponge for cleaning. It is most commonly used for soldering electronic components. Other functions may be combined; for example a rework station, mainly for surface-mount components may have a hot air gun, vacuum pickup tool, and a soldering head; a desoldering station will have a desoldering head with vacuum pump for desoldering through-hole components, and a soldering iron head.

Fig 3

SOLDERING STATION

## Soldering tweezers

For soldering and desoldering small surface-mount components with two terminals, such as some links, resistors, capacitors, and diodes, soldering tweezers can be used; they can be either free-standing or controlled from a soldering station. The tweezers (fig. 4) have two heated tips mounted on arms whose separation can be manually varied by squeezing gently against spring force, like simple tweezers; the tips are applied to the two ends of the component. The main purpose of the soldering tweezers is to melt solder in the correct place; components are usually moved by simple tweezers or vacuum pickup.

Fig 4

Soldering tweezers

## Selection of soldering guns

Most soldering "guns" are vastly overpowered for electronics soldering and can easily overheat components or expose them to harmful voltages. However, some people cleverly use them to solder multiple leads on surface mount devices. Soldering "guns" are for plumbing and much heavier duty applications, and are usually over 100 Watts. The "guns" work by passing high currents through the tips, and these currents can generate voltages that damage electronic components. Also, magnetic fields from guns with transformers can damage some electronics. By forming the heating element in the shape of the chip, a soldering gun can be used to heat many leads simultaneously.

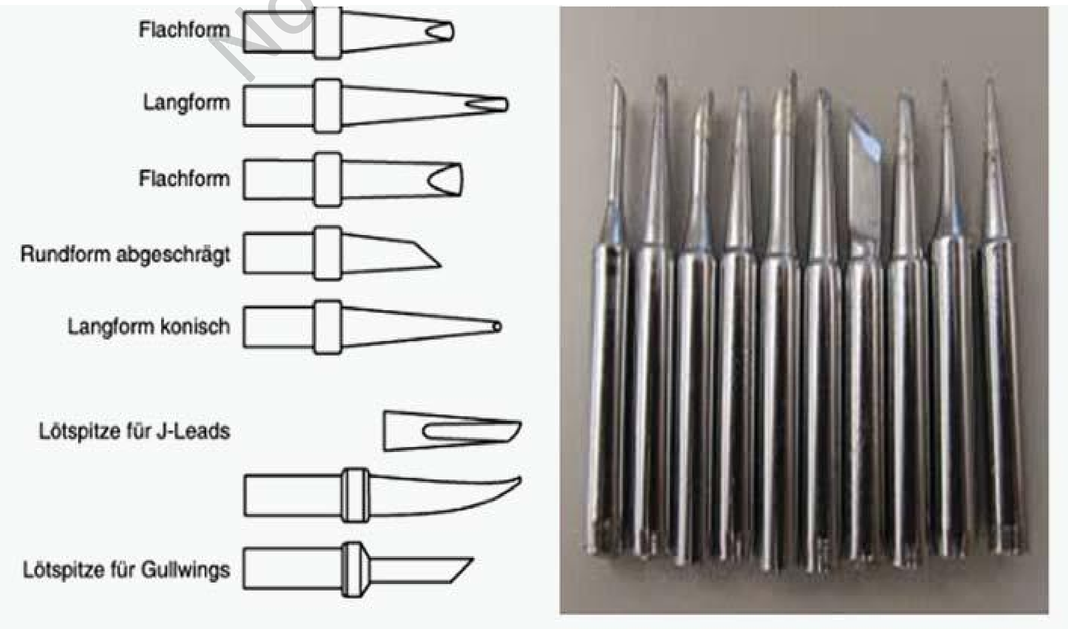
## Tips and types

Most soldering irons for electronics have interchangeable tips, also known as bits that vary in size and shape for different types of work. Pyramid tips with a triangular flat face and chisel tips with a wide flat face are useful for soldering sheet metal. Fine conical or tapered chisel tips are typically used for electronics work. Tips may be straight or have a bend. Concave or wicking tips with a chisel face with a concave well in the flat face to hold a small amount of solder are available. Tip selection depends upon the type of work and access to the joint; soldering of 0.5mm pitch surface-mount ICs, for example, is quite different from soldering a through-hole connection to a large area. A concave tip well is said to help prevent bridging of closely spaced leads; different shapes are recommended to correct bridging that has occurred. Due to patent restrictions not all manufacturers offer concave tips everywhere; in particular there are restrictions in the USA.

Older and very cheap irons typically use a bare copper tip, which is shaped with a file or sandpaper. This dissolves gradually into the solder, suffering pitting and erosion of the shape. Copper tips are sometimes filed when worn down. Iron-plated copper tips have become increasingly popular since the 1980s. Because iron is not readily dissolved by molten solder, the plated tip is more durable than a bare copper one, though it will eventually wear out and need replacing. This is especially important when working at the higher temperatures needed for modern lead-free solders. Solid iron and steel tips are seldom used because they store less heat, and rusting can break the heating element. (Fig.5)



Fig 5



## Identification of Pin 1 marking in various SMD IC packages

**Objectives :** At the end of this lesson you shall be able to

- **to identify the pin 1 marking of various SMD IC packages which is indicated in different methods**
- **how to differentiate the orientation of IC package pin details in order to avoid wrong soldering and to avoid economic loss without damaging costly IC package like motherboard ICs.**

### Pin 1 marking in a DIP SMD IC

Fig 1

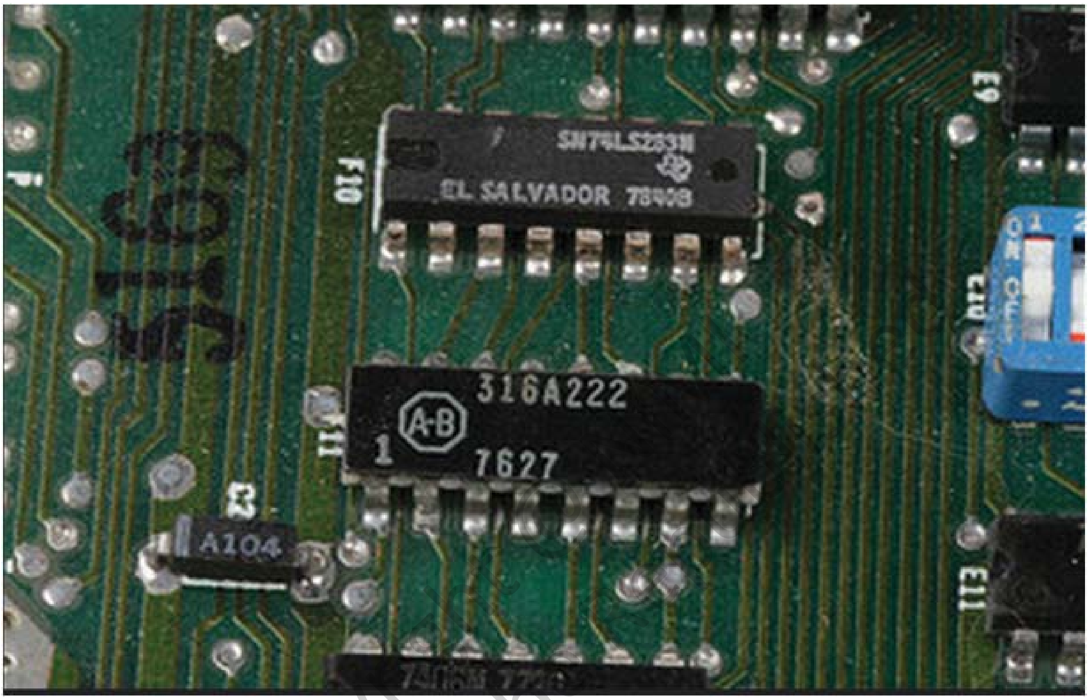
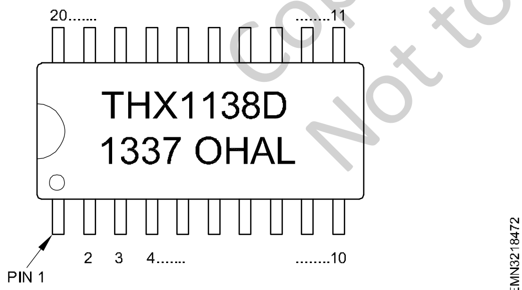



Fig 2




Here is a basic rule that applies for most integrated circuits. There is a polarity mark somewhere. From that polarity mark, move counterclockwise around the chip, and number the pins starting at 1. as shown in fig. 1

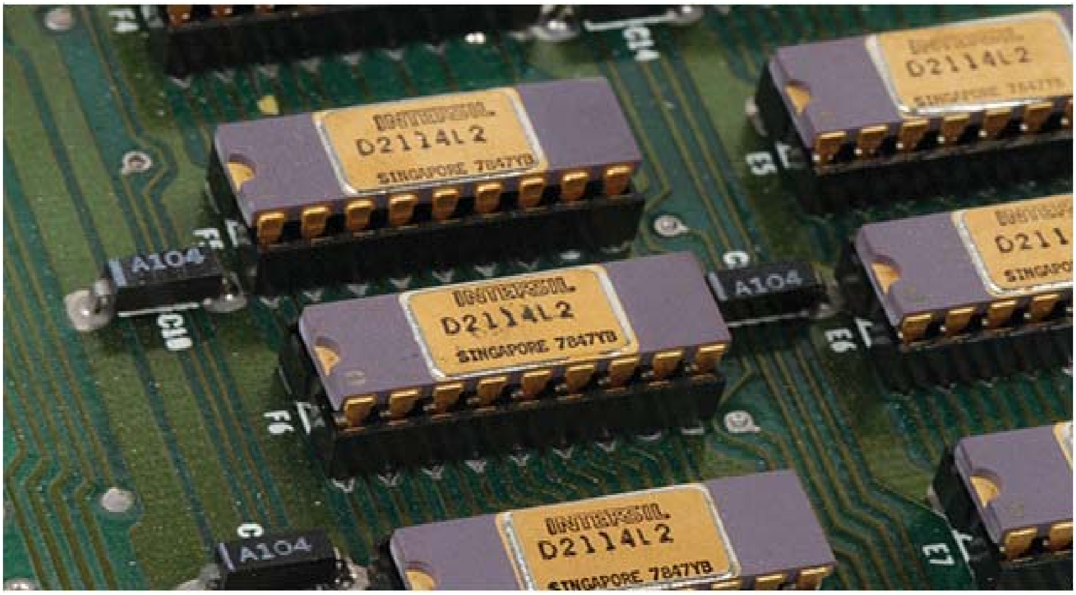
A common polarity marker is a half - moon shape at one end of the chip. Another is a small dot by pin 1, or sometimes a small triangle or tab instead. Sometimes several of these marks can appear. as shown in fig. 2

Often pin 1 is in a corner of the chip, and its only that corner - not the pin itself - that is marked by the small circle or triangle.

In the above IC part number "THX1138D," manufactured in week 37 of 2013, and it has a mysterious lot or internal code "OHAI" that may or may not be explained in the datasheet. The polarity marks are a half - moon indentation on the left hand side as well as a dot by pin 1. This device has 20 pins, numbered counterclockwise along the two edges from 1 to 20.

As well see, there are plenty of examples of this, or close variations on it. But there are also cases where there are "no" direct marks, but you can instead rely on the orientation of the text to understand the numbering. The text orientation is consistant, and for chips of this shpae (with pins on two opposite sides), you can reliably assume that the polarity mark goes to the left of the text.

Fig 3




Here are some classic and beautiful examples of chips with well - marked polarity. These are “ceramic DIP” integrated circuit packages.

Fig 4

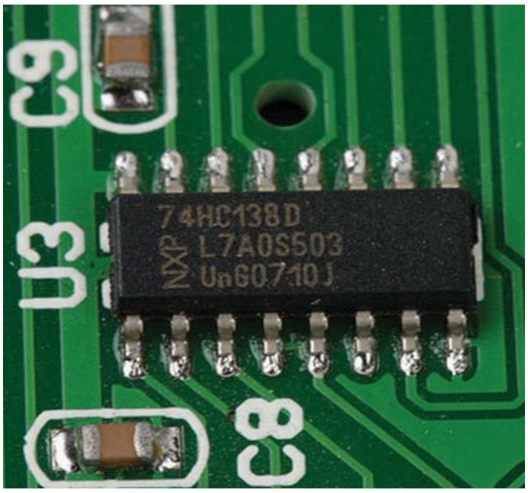

Each has a molded half - moon shape as well as a more subtile dot by pin 1. as shown in fig. 3

This is a modern higher - density variation on the same design. It is a wide, low - profile plastic package called a 66-pin TSSOP ( and a 128 M bit DDR SDRAM, if you are curious). The orientation is given by the half - moon shape on the left hand side and by the dot in the lower left corner. Now, that dot actually looks like it’s closer to pin 2 than to pin 1 - Again, the makrer oten lables the corner where pin 1 lives, not the individual pin. as shown in fig. 4 & 5.

Fig 5

This 74 HC245D " as shown in fig. 6 octal bus transceiver" chip from NXP has the half - moon shape on theleft hand side, plus a slightly more unusual polarity marking feature. The entire front edge of the chip - the edge containing pin 1 - is slightly beveled.

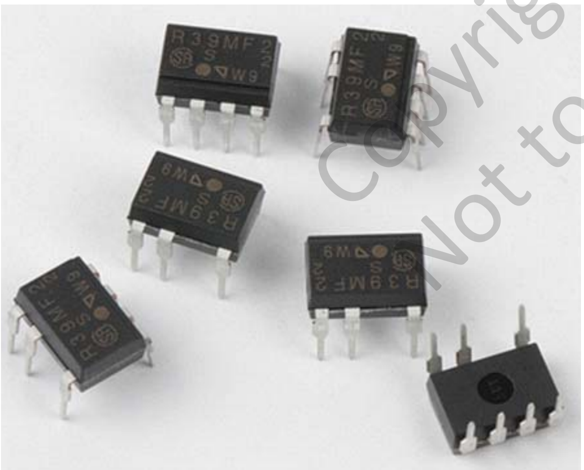
Fig 6




And now here is a chip that has less of a "direct" indication of its orientations - no dot or half moon shape. As we discussed earlier, you can realy on the orientation of the text in cases like this, and imagine an effective polarity mark on theleft hand side of the chip. Pin 1 is on the power left hand side.

If you look very closely, as shown in fig. 7 you will see that there is one additional polarity marking feature, in that this chip also has a very slightly beveled front edge.

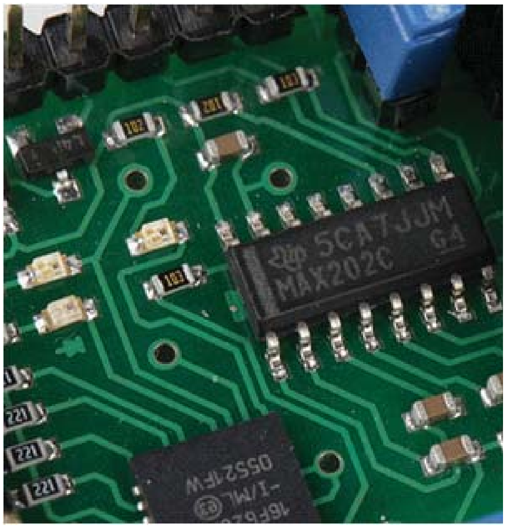
Fig 7



His is a some whatunusual seven - yes- seven pin DIP chip. It is a neat little solid - state relay capable of switching small loads on AC line voltage (0.9 A at up to 240 VAC) from a low - voltage digital input. Presumably, it has seven pins so that you can not put in backwards. This chip also relies on a combination of text orientation and level at the side with pin 1. as shown in fig. 8

Care ful : That apparent "dot' is not a polarity indicator ; pin 1 is still at the corner of the chip. as shown in fig. 9

Fig 8




Here is one more variation. There is printed bar on the left hand side of this chip to act as a polarity indicator, taking the place of the half - moon shape.

Fig 9


Some times you will come across very different looking chips with very obvious polarity markers. This chip from agilent has a gold stripe on the upper left hand corner. as shown in fig. 10

Fig 10

**Pin 1 identification**

Sometimes a chip has a notched corner to indicate where pin 1 lives as shown in fig. 11. The white silkscreen on the circuit board shows an exaggerated picture of this notching, by the lower - left corner.

Fig 11


The 486 is agood example of a chip with a notched corner, while the 68030 has a gold stripe to indicate pin 1

This broadcom chip has a dot by the corner with pin 1, as shown in fig. 12 but that is a pretty suitable mark . If you chip already mounted to a board, that can provide some better information to verify the orientation. For example, pin 1 of this chip is also marked by a white do on the circuit board, and the other three corners have a mark, as though those corners were un-noticed.

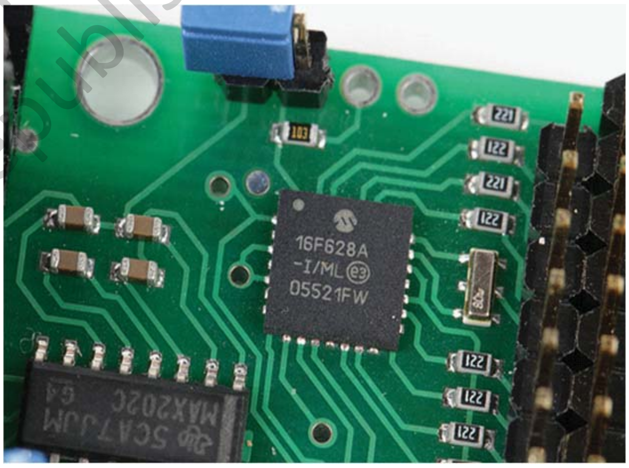
Fig 12


Here is another chip that is some what ambiguous. Pin 1 is clearly marked with an arrow on the circuit board. If the chip were loose it would be a little less clear because not only is there a dot by pin 1, as shown in fig. 13 & 14 but there is also apparently a dot by the opposite corner. It may be just a coincidental mold mark, but it's still potentially confusing.

Fig 13


This is far from an exhaustive list, but is meant to show off some of the common ways that chip orientation is differentiated.

Fig 14




## Ball grid array and pin grid array components

**Objectives :** At the end of this lesson you shall be able to
- **to study the structural details of ball grid array SMD ICs**
- **to study the advantages and disadvantages of BGA package**
- **to study the structrual details of pin grid array package.**

A ball grid array (BGA) is a type of surface mount packaging (a chip carrier ) used for integrated circuits. BGA packages are used to permanently mount devices such as microprocessors. A BGA can provide more interconnection pins than can be put on a dual in-line or flat package. The whole bottom surface of the device can be used, instead of just the perimeter. The leads are also on average shorter than with a perimeter - only type, leading to better performance at high speeds. as shown in fig. 1

Fig 1

Soldering of BGA devices requires precise control and is usually done by automated processes. BGA devices are not suitable for socket mounting.

With the increasing component density of today's electronics printed circuit boards and the very high track densities that result, connectivity on many boards has become a problem. Even migrating to greater numbers of layers for the PCB cannot overcome many of the problems. To assist in resolving this problem an integrated circuit package known as the ball grid array, BGA was introduced. The BGA components provide a far better solution for many boards, but care is required when soldering BGA components to ensure that the BGA solder process is correct and that the reliability is at least maintained or preferably improved.

The ball grid array of BGA, is a very different package to those using pins, such as the quad flat pack. The pins of the BGA package are arranged in a grid pattern and this gives rise to the name. In addition to this, rather than having the more traditional wire pins for the connections, pads with balls of solder are used instead. On the printed circuit board, PCB, on to wich the BGA components are to be fitted there is a matching set of copper pads to provide the required connectivity.

BGA packages offer many advantages over their quad flat pack rivals and as a result they are being used increasingly for the manufacture of electronic circuits.

**Advantages of BGA**

**High density**

The BGA is a solution to the problem of producing a miniature package for an integrated circuit with many hundreds of pins. Pin grid arrays and dual-in-line surface mount (SOIC) packages were being produced with more and more pins, and with decreasing spacing between the pins, but this was casuing difficulties for the soldering process. As package pins got close together, the danger of accidentally bridging adjacent pins with solder grew. BGAs do not have this problem if the solder is factory - applied to the package.

**Heat conduction**

A further advantage of BGA packages over packages with discrete leads (i.e packages with legs) is the lower thermal resistance between the packge and the PCB. This allows heat generated by the integrated circuit inside the package to flow more easily to the PCB, preventing the chip from overheating.

**Low - inductance leads**

The shorter an electrical conductor, the lower its unwanted inductance, a propertty which causes unwanted distortionof signals in high - speed electronic circuits. BGAs with their very short distance between the package and the PCB, have low lead inductances, giving them superior electrical performance to pinned device.

**Improved PCB design as a result of lower track density :** Track densities around many packages such as the quad flat pack become very high because of the very close proximity of the pins. A BGA spreads the contacts out over the full are of the package greatly reducing the problem.

**The BGA package is robust :**

Packages such as the quad flat pack have very fine pins, and these are easily damaged by even the most careful handling. It is almost impossible to repair them once the pins are bent wing to their very fine pitch. BGAs do not suffer from this as the connections are provided by pads with the BGA solder balls on them which are very difficult to damage.

**Lower thermal resistance :** BGAs offer a lower thermal resistance between the silicon chip itself then quad flat pack devices. This allows heat generated by the integrated circuit inside the package to be conducted out of the device onto the PCB faster and more effectively.

**Improved high speed performance :** As the conductors are on the underside of the chip carrier. This means that the leads within the chip are shorter. Accordingly unwanted lead inductance levels are lower, and in this way, Ball grid array devices are able to offer a higher level of performacne than their QFP counterparts.

**BGA solder process**

One of the initial fears over the use of BGA components was their solderability and whether traditional forms of connection. As the pads are under the device and not visible it is necessary to ensure the correct process is used and it is fully optimised. Inspection and rework were also concerns.

Fortunately BGA solder techniques have proved to be very reliable, and once the process is set up correctly BGA solder reliability is normally higher than that for quad flat pack. This means that any BGA assembly tends to be more reliable. Its use is therefore now widespread in both mass production PCB assembly and also prototype PCB assembly where circuits are being developed.

**For the BGA solder process, reflow techniques are used. The reason for this is that the whole assembly needs to be brought up to a temperature whereby the solder will melt underneath the BGA componets themselves. This can only be achieved using reflow techniques.**

For BGA soldering, the solder balls on the package have a very carefully controlled amount of solder, and when heated in the soldering process, the solder metls. Surface tension causes the molten solder to hold the package in the correct alignment with the circuit board, while the solder cools and solidifies. The composition of the solder alloy and the soldering temperature are carefully chosen so that the solder does not completely melt, but stays semi-liquid, allowing each ball to stay separate from its neighbours.

### BGA solder joint inspection

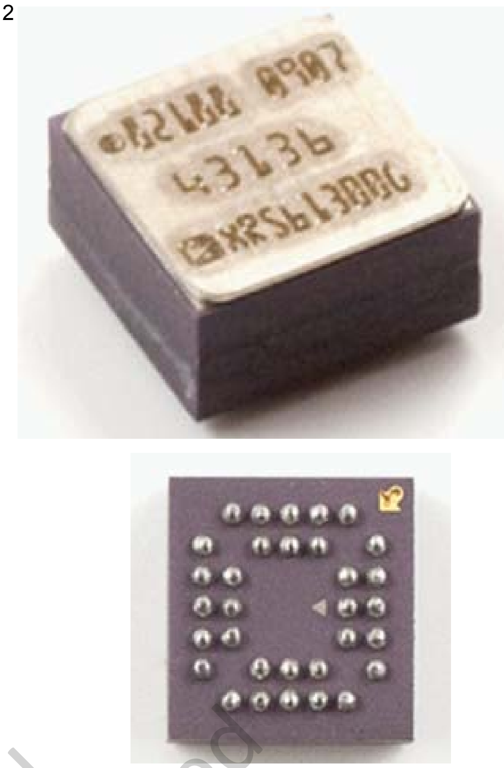
BGA inspection is one are of the manufacturing process that has raised a considerable amount of interest since the introduction of the first BGA components. BGA inspection cannot be achieved in the normal way using straight foreard optical techniques because, quite, obviously the solder joints are underneath the BGA components and they are not visible. This creates problems for BGA inspection. It also created a considerable degree of unease about the technology when it was first introduced and many manufactures undertook tests to ensure that they were able to solder the BGA components satisfactorily satisfactorily. The main problem with soldering BGA components is that sufficient heat must be applied to ensure that all the balls in the grid melt sufficiently for every BGA solder joint to be satisfactorily made.

The solder joints cannot be fully tested by checking the electrical performance. While this form of test of the BGA solder process will reveal conductvity at that time, it does not give a full picture of how the BGA solder process has succeeded. It is possible that the joint may not be adequately made and that over time if will fall. For this the only satisfactory means of test is a form of BGA inspection using x-rays. This form of BGA inspection is able to look through the device at the soldered joint beneath. Fortunately,it is found that once the heat profile for the solder machine is set up correctly, the BGA components solder very well and few problems are encountered with the BGA solder process.

### BGA rework

As might be anticipated, it is not easy to rework BGA assemblies unless the correct equipment available. If a BGA componets is suspected as being faulty, then it is possible to remove the device. This is achieved by locally heating the BGA component to metl the solder undermeath it. as shown in fig. 2

Fig 2



In the BGA rework process, the heating is often achieved in a specialized rework station. This comprises a jig fitted with infrared heater, a thermocouple to monitor the temperature and a vacuum device for lifting the package. Great care is needed to ensure that only the BGA is heated and removed. Other devices nearby need to be affected as little as possible otherwise they maybe damaged.

BGA technology in general and in particular the BGA soldering process have proved themselves to be very successful since they were first introdcued. They are now an integral part of the PCB assembly process used in most companies for mass production and for prototype PCB assembly.

### Pin grid array package

A pin grid array, often abbreviated PGA, is a type of integrated circuit packaging. In a PGA the package is square or rectangular, and the pins are arranged in a regualr array on the underside of the package. The pins are commonly spaced 2.54 mm (0.1”) apart, and may to may not cover the entire underside of the package. as shown in fig. 3 & 4.

Fig 3

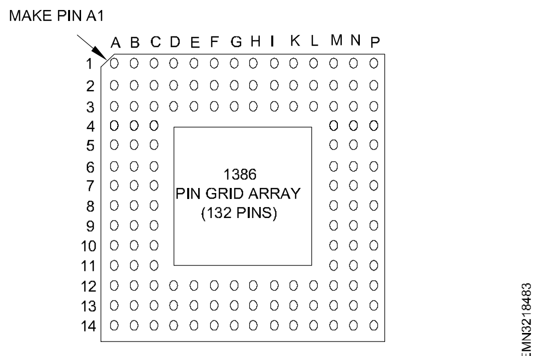
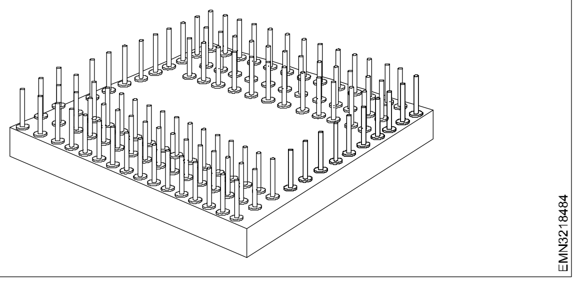


Fig 4




PGAs are often mounted on printed circuit boards using the through hole method of inserted into a socket. PGAs allow for more pins per integrated circuit than older packages such as dual in line package (DIP)

The familiar dual in line (DIL) package can have up to 68 leads with a spacing between pins of 2.54 mm. The chip carrier family has a pin count that ranges from 20 to 84, with pin spacing of 1.274 mm; although pin counts above 84 can be produced, the problems of handling become severe above 84 pins ( the 84 pin chip carrier is approximately 30 x 30 mm). The PGA (Pin grid array) package allows up to 144 pins (spacing 2.54 mm). It has an high power dissipation capability and it is now being extended to a low cost plastic version. However the route interconnection on the PC board is difficult and the connections are difficult to inspect. Surface mounting technique also offers a large number of pins. The placement of the IC must be automatic and the soldering technique not conventional. However, the quad flat pack has from 36 to 128 pins with spacing from 1 mm to 0.65 mm. It has potentially a low cost but the number of suppliers is very limited.

**Pin grid array and variations (PGA/SPGA/CPGA/ PPGA)**

Pin grid array or PGA packaging is the standard used for most fifth generation processors, starting with the intel 80286 over a decade ago. PGA packages are square or rectangular and have two or more rows of pins going around their perimeter. They are inserted into a special socket on the mother board or daughtercard. PGA packaging was invented because newer processors with wider data and address buses required a large number of interface pins to the motherboard, and DIP packaging just was not up to the task.

PGA comes in two different main material types. The standard PGA used on most processors until recetnly is made from a ceramic material, and is also called CPGA for that reason. Some newer processors use a plastic package, called PPGA. The plastic package is both less expensive and thermally superior to the CPGA. It has a raised metal square area on is surface for heat transfer to the heat sink that works better than the CPGA.

Eventually, as the number of connections for Pentium and later processsors exceeded 200 and approahced 300, intel needed to be able to pack even more pins into the same amountof space. To do this, intel staggered the pin layout so that they could be compressed more tightly. (The idea is similar to how a wine rack stacks bottles.) This is sometimes called SPGA. Pentium and later chips are made with this design.

Finally, the Pentium pro processor uses a pseical from of PGA called a “dual patttern PGA”. This is of course becasue the pentium pro has a dual - chip package containing both the chip itself and its miniaturized, integrated secondary cache.



## Re-flow soldering

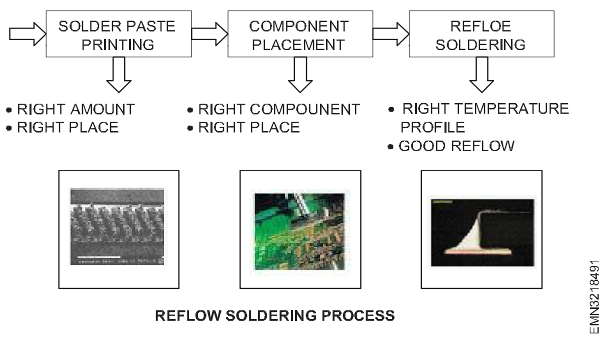
**Objective :** At the end of this lesson you shall be able to
- **explain the Reflow soldering and working principle.**

**Reflow soldering and working principle**

Reflow soldering is a process in which a solder paste (a sticky mixture of powdered solder and flux) is used to temporarily attach one or several electrical components to their contact pads, after which the entire assembly is subjected to controlled heat, which melts the solder, permanently connecting the joint. Heating may be accomplished by passing the assembly through a reflow oven or under an infrared lamp or by soldering individual joints with a hot air pencil as shown in fig. 1 reflow soldering process.

Reflow soldering is the most common method of attaching surface mount components to a circuit board, although it can also be used for through-hole components by filling the holes with solder paste and inserting the component leads through the paste. Because wave soldering can be simpler and cheaper, reflow is not generally used on pure through-hole boards. When used on boards containing a mix of SMT and THT components, through-hole reflow allows the wave soldering step to be eliminated from the assembly process, potentially reducing assembly costs.

Fig 1




REFLOW SOLDERING PROCESS

The goal of the reflow process is to melt the solder and heat the adjoining surfaces, without overheating and damaging the electrical components. In the conventional reflow soldering process, there are usually four stages, called "zones", each having a distinct thermal profile:

preheat, thermal soak (often shortened to just soak), reflow, and cooling.

### Preheat zone

Maximum slope is a temperature/time relationship that measures how fast the temperature on the printed circuit board changes. The preheat zone is often the lengthiest of the zones and often establishes the ramp-rate. The ramp-up rate is usually somewhere between 1.0 °C and 3.0 °C per second, often falling between 2.0 °C and 3.0 °C (4 °F to 5 °F) per second. If the rate exceeds the maximum slope, damage to components from thermal shock or cracking can occur. Solder paste can also have a spattering effect. The preheat section is where the solvent in the paste begins to evaporate, and if the rise rate (or temperature level) is too low, evaporation of flux volatiles is incomplete.

### Thermal soak zone

The second section, thermal soak, is typically a 60 to 120 second exposure for removal of solder paste volatiles and activation of the fluxes (see flux), where the flux components begin oxide reduction on component leads and pads. Too high a temperature can lead to solder spattering or balling as well as oxidation of the paste, the attachment pads and the component terminations. Similarly, fluxes may not fully activate if the temperature is too low. At the end of the soak zone a thermal equilibrium of the entire assembly is desired just before the reflow zone. A soak profile is suggested to decrease any delta T between components of varying sizes or if the PCB assembly is very large. A soak profile is also recommended to diminish voiding in area array type packages.

### Reflow zone

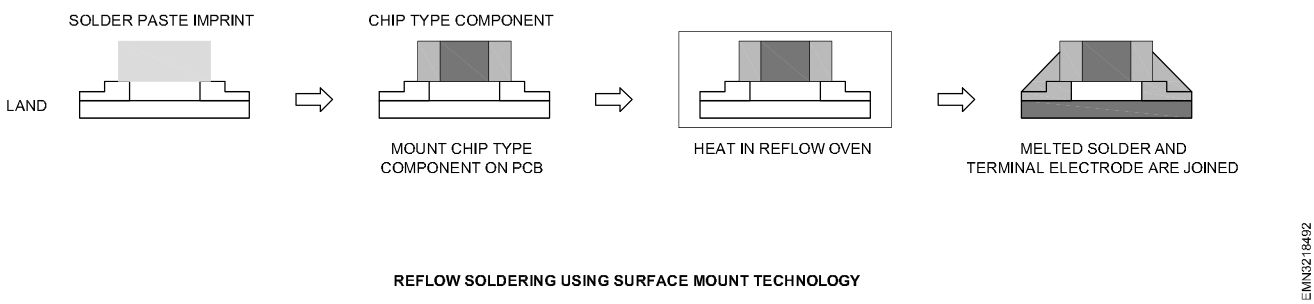
The third section, the reflow zone, is also referred to as the "time above reflow" or "time above liquidus" (TAL), and is the part of the process where the maximum temperature is reached. An important consideration is peak temperature, which is the maximum allowable temperature of the entire process. A common peak temperature is 20-40 °C above liquidus. This limit is determined by the component on the assembly with the lowest tolerance for high temperatures (the component most susceptible to thermal damage). A standard guideline is to subtract 5 °C from the maximum temperature that the most valueable component can sustain to arrive at the maximum temperature for process. It is important to monitor the process temperature to keep it from exceeding this limit. Additionally, high temperatures (beyond 260 °C) may cause damage to the internal dies of SMT components as well as foster intermetallic growth. Conversely, a temperature that isn't hot enough may prevent the paste from reflowing adequately.

Time above liquidus (TAL), or time above reflow, measures how long the solder is a liquid. The flux reduces surface tension at the junction of the metals to accomplish metallurgical bonding, allowing the individual solder powder spheres to combine. If the profile time exceeds the manufacturer's specification, the result may be premature flux activation or consumption, effectively "drying" the paste before formation of the solder joint. An insufficient time/temperature relationship causes a decrease in the flux's cleaning action, resulting in poor wetting, inadequate removal of the solvent and flux, and possibly defective solder joints. Experts usually recommend the shortest TAL possible; however, most pastes specify a minimum TAL of 30 seconds, although there appears to be no clear reason for that specific time. One possibility is that there are places on the PCB as shown in fig. 2 that are not measured during profiling, and therefore, setting the minimum allowable time to 30 seconds reduces the chances of an unmeasured area not reflowing. A high minimum reflow time also provides a margin of safety against oven temperature changes. The wetting time ideally stays below 60 seconds above liquidus. Additional time above liquidus may cause excessive intermetallic growth, which can lead to joint brittleness. The board and components may also be damaged at extended times over liquidus, and most components have a well-defined time limit for how long they may be exposed to temperatures over a given maximum. Too little time above liquidus may trap solvents and flux and create the potential for cold or dull joints as well as solder voids.



Fig 2

SOLDERING USING SURFACE MOUNT TECHNOLOGY AND REFLOW METHOD

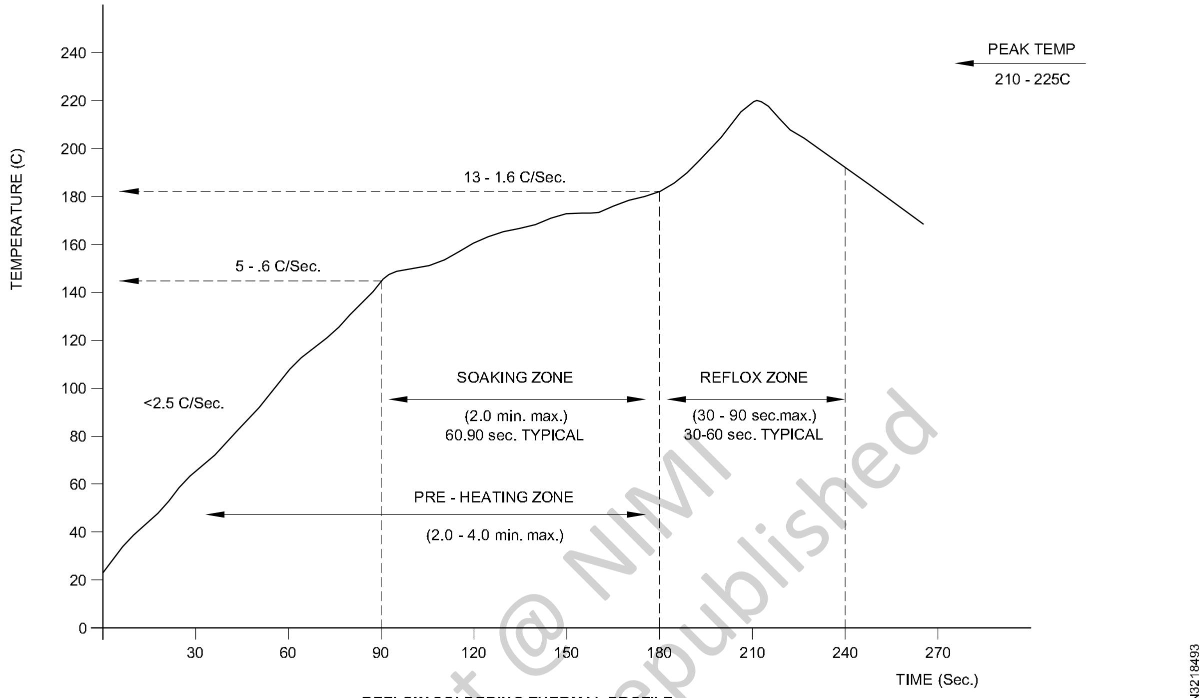



REFLOW SOLDERING USING SURFACE MOUNT TECHNOLOGY

**Cooling zone**

The last zone is a cooling zone to gradually cool the processed board and solidify the solder joints. Proper cooling inhibits excess intermetallic formation or thermal shock to the components. Typical temperatures in the cooling zone range from 30-100 °C (86-212 °F). A fast cooling rate is chosen to create a fine grain structure that is most mechanically sound. Unlike the maximum ramp-up rate, the ramp-down rate is often ignored. It may be that the ramp rate is less critical above certain temperatures; however, the maximum allowable slope for any component should apply whether the component is heating up or cooling down. A cooling rate of 4°C/s is commonly suggested. It is a parameter to consider when analyzing process results. Reflow solding thermal profile as shown in fig. 3.

Fig 3




REFLOW SOLDERING THERMAL PROFILE

## Introduction to non-soldering interconnection and printed circuit boards

**Objectives :** At the end of this lesson you shall be able to
- **define crimping, wire wrapping, conductive adhesives, chip on board and tape automated bonding**
- **define printed circuit board and its types.**

### Crimping

A crimping tool is a device used to join two pieces of metal by deforming one or both of them in a way that causes them to hold each other. The result of the tool's work is called a crimp. A good example of crimping is the process of FRC connector to the end of a cable as shown in the fig.1.

Fig 1

FRC CRIMPING TOOLS

### Wire wrapping

Wire wrap is a method to construct electronic circuit board as shown in fig 2. Electronic components mounted on an insulating board are interconnected by lengths of insulated wire run between their terminals, with the connections made by wrapping several turns around a component lead or a socket pin. Wires can be wrapped by hand or by machine, and can be hand-modified afterwards. It was popular for large-scale manufacturing in the 60s and early 70s, and continues to be used for short runs and prototypes. The method eliminates the design and fabrication of a printed circuit board. Wire wrapping is unusual among other prototyping technologies since it allows for complex assemblies to be produced by automated equipment, but than easily repaired or modified by hand.

Fig 2

WIRE WRAPPING AND TOOL

### Conductive adhesives

An electrically conductive adhesive is glue that is primarily used for electronics as shown in fig.3. The electric conductivity is caused by a component that makes 80% of the total mass of an electrically conductive adhesive. This conductive component is suspended in a sticky component that holds the electrically conductive adhesive together. The particles of the conductive component are in contact to each other and in this way make electric current possible.

Fig 3


CONDUCTIVE ADHESIVES

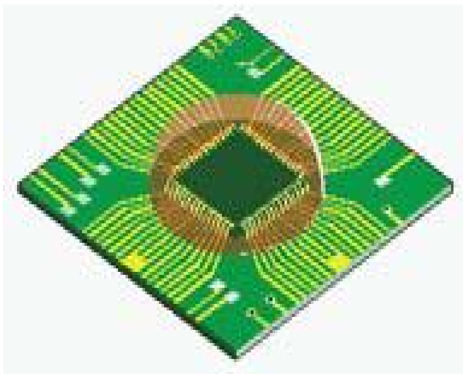
### Chip on Board

### Chipboard may refer to

A type of paperboard generally made from reclaimed paper stock; as shown in the fig. 4

- White lined chipboard, a grade of paperboard
- Particle board, a type of engineered wood known as "chipboard" in some countries

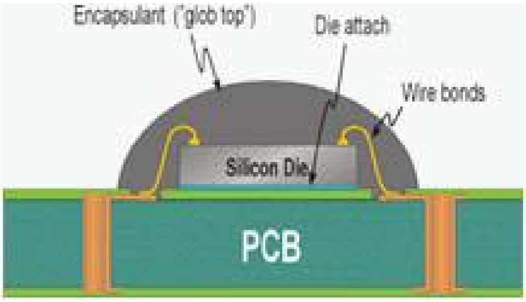
Fig 4



CHIP ON BOARD

The bare chip is adhered and wire bonded to the board, and an epoxy is poured over it to insulate and protect it. For illustrative purposes only, this picture shows a clear epoxy. This side view shows how the wires connect the chip to the printed circuit board (PCB) as shown in fig.5.

Fig 5



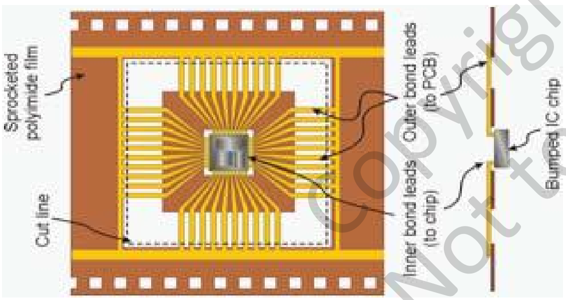

CHIP ON BOARD SIDE VIEW OF PCB

### Tape automated bounding

Tape-automated bonding (TAB) is a process that places bare integrated circuits onto a printed circuit board (PCB) by attaching them to fine conductors in a polyamide or polyimide film, thus providing a to directly connect to external circuits as shown in fig.6.

Process that places bare chips onto a printed circuit board (PCB) by first attaching them to a polyimide film, the film is moved to the target location, and the leads are cut and soldered to the board. This is also called a "tape carrier package" (TCP), the bare chip is then encapsulated ("glob topped") with epoxy or plastic.

Fig 6




TAPE AUTOMATED BONDING

### Printed Circuit Board

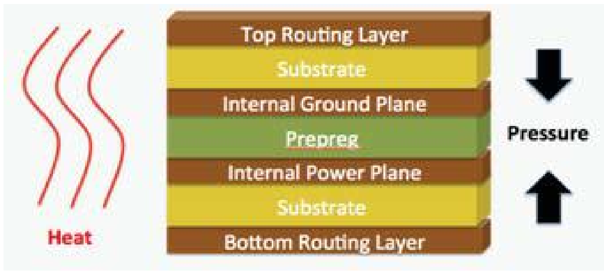
A printed circuit board (PCB) mechanically supports and electrically connects electronic components using conductive tracks, pads and other features etched from copper sheets laminated onto a non-conductive substrate. PCBs can be single sided (one copper layer), double sided (two copper layers) or multi-layer (outer and inner layers). Multi-layer PCBs allow much higher component density. Conductors on different layers are connected with plated-through holes called vias. Advanced PCBs may contain components - capacitors, resistors or active devices - embedded in the substrate.

The PCBs are manufactured with "1 oz copper" (~35µm thick or 1.4 mils) on the outer layers. If there are inner layers, they are almost always manufactured with "1/2 ounce copper"(~17.5µm thick or 0.7 mils)

The thickness of the copper layer on the PCB measured in ounces per square foot or ounces. It can also be given in micrometers, inches or mils.

FR-4 glass epoxy is the primary insulating substrate upon which the vast majority of rigid PCBs are produced. A thin layer of copper foil is laminated to one or both sides of an FR-4 panel. Circuitry interconnections are etched into copper layers to produce printed circuit boards. Complex circuits are produced in multiple layers as shown in fig. 7.

Fig 7




CONSTRUCTION OF MULTI LAYER PCB

Printed circuit boards are used in all electronic products. Alternatives to PCBs include wire wrap and point-to-point construction. PCBs require the additional design effort to lay out the circuit, but manufacturing and assembly can be automated. Manufacturing circuits with PCBs is cheaper and faster than with other wiring methods as components are mounted and wired with one single part. Furthermore, operator wiring errors are eliminated.



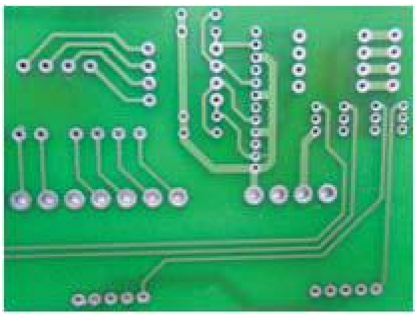
### Types of PCBs

- Single side PCB
- Double side PCB
- Multi layer PCB

### Single side PCB

Single-sided printed circuit boards are easily designed and quickly manufactured as shown in fig.8. Single sided boards are available with surface finishes including Organic surface protectant (OSP), Immersion Silver, Tin, and Gold plating along with both leaded and lead-free Hot Air Solder Level (HASL).

Fig 8



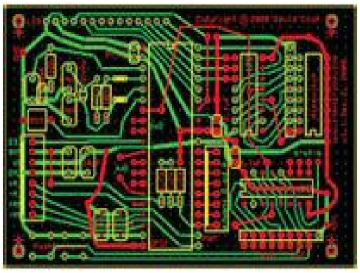
SINGLE SIDE PCB

**Ex:** Power supplies, Relays (automotive and industrial), Timing circuits, Sensor products

### Double Side PCB

Double Sided PCBs (also known as Double-Sided Plated Thru or DSPT) as shown in fig. 9 circuits are the gateway to higher technology applications. DSPT the advantage of the plated through-hole is quickly adapted and allowed electronic designs to expand in capability and shrink in physical size. Today the double sided printed circuit board technology remains the workhorse of the assembly industry. There are limitless applications for old and new designs.

Fig 9



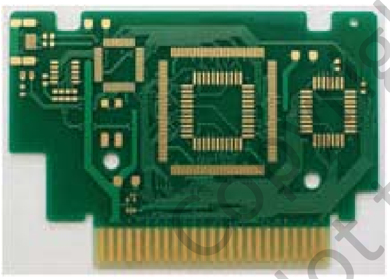
DOUBLE SIDE PCD BOARD

**Ex:** Industrial controls, Power supplies, Converters, Control relays

### Multi- layer PCB

Multilayer printed circuit boards (PCBs) representes the next major evolution in fabrication technology as shown in fig. 10. From the base platform of double sided plated thru came a very sophisticated and complex methodology that would again allow circuit board designers a dynamic range of interconnects and applications.

Fig 10



MULTI LAYER PCB

Multilayer circuit boards were essential in the advancement of modern computing. The multilayer PCB basic construction and fabrication are similar to micro chip fabrication on a macro size. The range of material combinations is extensive from basic epoxy glass to exotic ceramic fills. Multilayer can be built on ceramic, copper, and aluminum. Blind and buried vias are commonly produced, along with pad on via technology.

**EX:** Computers, File servers, Cell phone

### Test of PCB

In this blog some basic procedures for finding faults with PCBs and fixing those faults. Though there are many circuit testing programs and probes available in the market for skilled technicians and test engineers there are no general guidelines. If you face some problems like when you end up removing an entire track (connection from one component to another) on the PCB you can use a simple piece of wire to imitate the connection. Solder the two ends of the wire where you think the connection should be present on the PCB as shown in fig. 11.

Fig 11


TESTING OF PCB

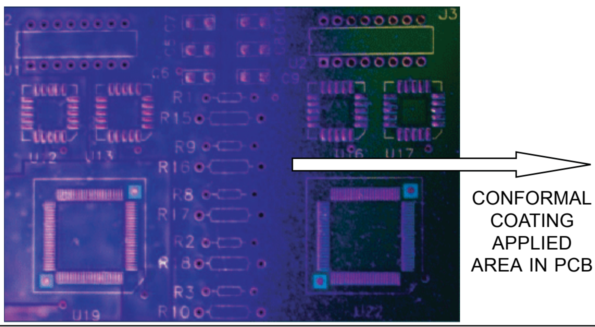


## Types of conformal coating and its removal methods

**Objectives :** At the end of this lesson you shall be able to
- **define conformal coating & its types**
- **explain how to coat the conformal coating**
- **describe various method of removal of conformal coating.**

Conformal coating is a protective chemical coating or polymer film 25-75µm thickness that is applied onto the printed circuit board .It is used to protect PCB from damages due to contamination, salt spray, moisture, fungus, dust and corrosion and also a physical barrier. When coated, it is clearly visible as a clear and shiny material as shown in Fig. 1.

Fig 1



CONFORMAL COATING APPLIED AREA IN PCB

### Types of Conformal Coating

Conformal coatings can be classified in to five main categories by their chemical composition.

1 Silicone Resin (SR)

2 Epoxy Resin (ER)

3 Acrylic Resin (AR)

4 Poly para xylylene (XY).

5 Polyurethane(Urethene) Resin (UR)

### Silicone

Fig 2 shows the silicon conformal coating pack

Fig 2


Silicone conformal coatings provide excellent protection in high temperature environments. It has good moisture ,humidity, chemical résistance and salt-spray resistance. It's typical temperature range is -65 °C to 200 °C. It is very flexible. Removal of this coating requires specialized solvents and long soak time.

### Epoxy

Epoxy coatings are available as a two part thermosetting mixture. These conformal coatings are very hard and good humidity resistance, chemical resistance and high abrasion. Epoxy coating is quite easy to apply but impossible to remove without damaging the components.

Fig.3a shows SMD IC on PCB

Fig 3a

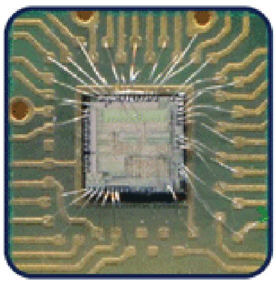


Fig.3b shows how to apply epoxy coating on SMD IC's

Fig 3b

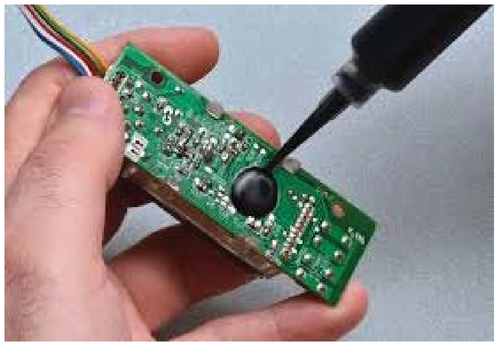
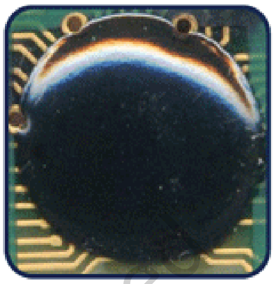


Fig. 4 Shows the epoxy applied COB (chip on board)

Fig 4



### Acrylic

Acrylic coatings are solvent based. It provides Fair elasticity and general protection.

They are low cost, easy to apply and remove. It exhibits low moisture absorption and have short drying times.

These types of coating have high di-electric strength, abrasion resistance. It typical dielectric withstand is greater than 1500 volts and has a temperature range of -59 °C to 132 °C.

Fig. 5 Shows the acrylic type conformal coating.

Fig 5


### Para - Xylylene

Paraxylene coatings are applied by chemical vapour deposition (CVD). These coatings provide excellent di-electric strength and resistance to solvents.

### Poly Urethene

Urethene coatings are hard and durable which has excellent resistance to solvents. It has similar moisture resistance to acrylic and silicon. It is difficult to apply and hard to be removed. Temperature range is quite similar to acrylic.

Fig. 6 Shows as urethane containers.

Fig 6


## Coating process

The coating material can be applied by various methods, from brushing, spraying and dipping.

Before coating a printed circuit board must be cleaned and de-moisturized.

**The following steps are used for coating.**

1 Board is cleaned.

2 Protected areas like terminal pins, connectors are masked off or removed.

3 Coating is applied using a spray process on both sides of the PCB and its edges.

4 Coating isto be cured according to the coating type. ( air dry, oven dry or UV light cure.)

5 Masking is removed and any removed parts are reassembled.

**Characteristics Conformal Coating Type**

| Characteristics | Conformal Coating Type | | | | |
|---|---|---|---|---|---|
| | Epoxy | Acrylic | Polyurethane | Silicone | Paraxylylene |
| Hard | ✓ | | ✓ | | ✓ |
| Medium Hard | | ✓ | ✓ | | |
| Soft | | | ✓ | ✓ | |
| Heat Reaction | ✓ | ✓ | ✓ | | |
| Surface Bond, Very Strong | ✓ | | | ✓ | ✓ |
| Surface Bond, Strong | | ✓ | | ✓ | |
| Surface Bond, Meduim | | | ✓ | ✓ | |
| Surface Bond, Light | | | | ✓ | |
| Solvent Reaction | | ✓ | | | |
| Smooth Surface | ✓ | ✓ | ✓ | ✓ | ✓ |
| Nonporous Surface | ✓ | ✓ | ✓ | | ✓ |
| Glossy Surface | ✓ | ✓ | ✓ | | |
| Semi glossy Surface | | | | ✓ | |
| Dull Surface | | | | | ✓ |
| Rubbery Surface | | | | ✓ | |
| Brittle | ✓ | ✓ | | | |

### Conformal Coating Removal Methods

On occasion it is necessary to remove a conformal coating from the circuit board to replace damaged components. The methods and materials used to remove coatings are determined by the coating resins as well as the size of the area. The basic methods are as follows.

- Solvent
- Peeling
- Thermal/Burn - through
- Micro Blasting
- Grinding /Scraping

**Solvent Removal :** Most conformal coating are suscepitble to solvent removal, however it must be determined if the solvent will damage parts or components on the circuit board. Acrylics are the most sensitive to solvents hence their easy removal; epoxies,urethanes and silicones are the least sensitive. Parlylene cannot be removal with solvent.

**Peeling :** Some conformal coating can be peeled from the circuit board. Silicone conformal coating and some flexible conformal coatings can be removed by peeling method.

**Thermal/Burn - through :** A common technique of coating removal is to simply burn through the coating with a soldering iron as the board is reworked. The process can be used to remove small areas of conformal coating.

**Micro blasting :**Micro blasting removes the conformal coating by using a concentrated mix of soft abrasive and compressed air to abrade the coating. The process can be used to remove small areas of conformal coating. It is most commonly used when removing Parylene and epoxy coatings.

**Grinding/Scraping :** In this method the conformal coating is removed by abrading the circuit board. This method is more effective with harder conformal coatings, sucha as parylene, epoxy and polyurethane. This method is only used as a method of last resort, as serious damage can be incurred.

**Thermal :** The thermal removal technique (including using a soldering iron to burn through the conformal coating) is the least recommended technique of coating removal. Most conformal coatings require a very high temperature and /or long exposure times. Thermal removal can cause the lifting of surface mount pads from boards also, temperature - sensitive components may be damaged. Extreme caution must be taken when burning through conformal coating because some coatings emit very toxic vapors that are hazardous to the people doing the stripping and those around them.

**Mechanical**

Mechanical removal techniques include cutting, picking, sanding or scraping the area of coating to be removed. However, most of the conformal coating are very tough and abrasion- resistant, making the probability of damage to the board very high.

**Chemical :** Chemical removal techniques were the most popular techniques for the removal of conformal coatings without affectingthe board or its components. But there is no one perfect solvent for all applications, and in some cases no solvent will be suitable at all.

## Introduction to rework and repair concepts

**Objective :** At the end of this lesson you shall be able to
- **explain the solder mask, solder joints, tracks, pads and plated through hole.**

### Solder mask

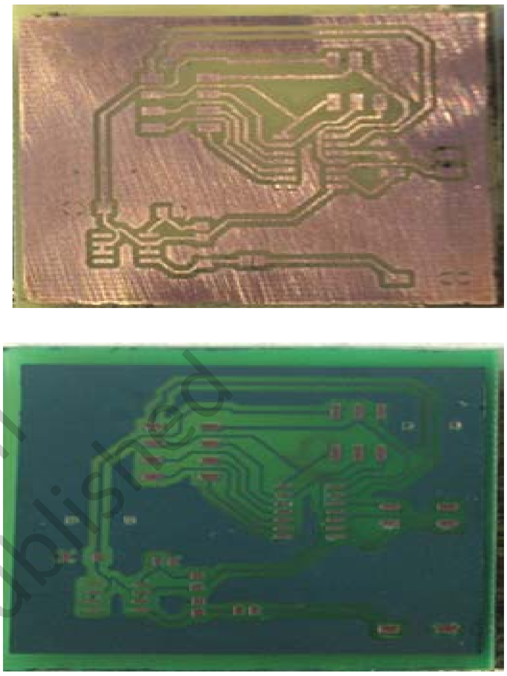
Solder mask or solder stop mask or solder resist is a thin layer of polymer applied to the copper traces of a printed circuit board (PCB) for protection against oxidation short circuits, corrosion, and other problems. Solder mask is a thin layer of polymer and to prevent solder bridges from closely spaced solder pads. A solder bridge is an unintended electrical connection between two conductors by means of a small blob of solder. Once applied, openings must be made in the solder mask wherever components to be soldered. This is done by photolithography. Solder mask is mostly green in color, but is now available in many colors.

- Green
- Matte Green
- Red
- Blue
- Yellow
- White
- Black
- Matte Black

Mostly Green colours used as solder mask as shown in Fig.1a & 1b.

Fig 1a

Fig 1b





Solder mask as shown in fig. 2a & 2b comes in different media depending upon the demands of the application.

Fig 2a

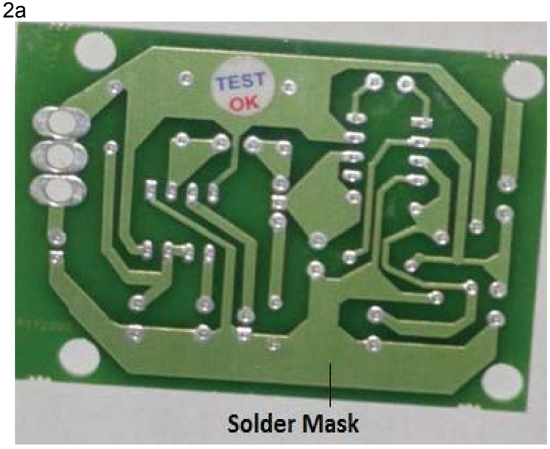
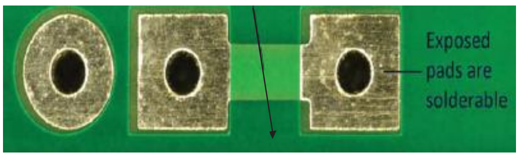



Fig 2b




SOLDER MASK COVERS UP THE SIGNAL TRACES BUT LEAVES THE PADS TO SOLDER.

The lowest-cost solder mask is epoxy liquid that is silkscreened through the pattern onto the PCB. Other types are,

Liquid photoimageable solder mask (LPSM) inks.

Dry film photoimageable solder mask (DFSM).

LPSM are silkscreened and sprayed on the PCB, exposed to the pattern and developed to provide openings in the pattern for parts to be soldered to the copper pads.

DFSM is vacuum laminated on the PCB then exposed and developed.

All three processes go through a thermal cure after the pattern is defined.

**Solder joints**

The solder joints are very much important in construction of PCB as shown in Fig.3a & 3b.

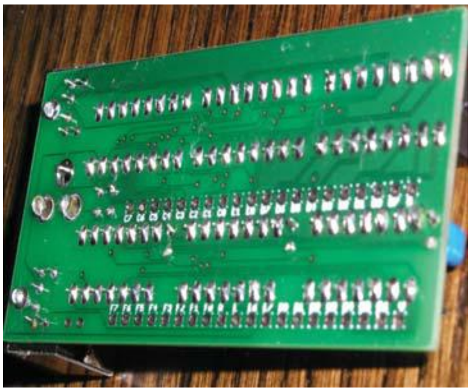


Fig 3a

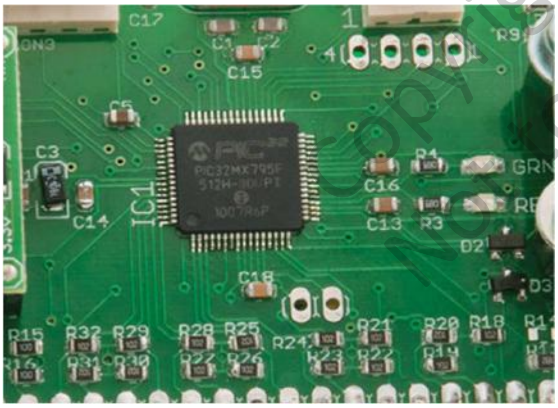


Fig 3b

- If the solder joints are poor
- It will cause the equipment to not to work.
- There is a possibility that the solder joint could fail intermittently.
- It will introduce noise into the circuit.

Fig.4 Shows the method of solder joints on PCB

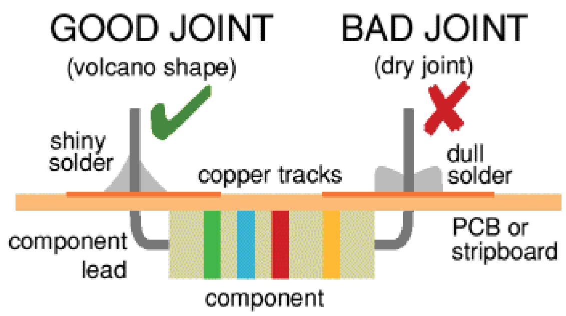


Fig 4

**Good solder joint**

Most solder joints are good and do not cause any problems. A good solder joint will have a shiny finish to it, and it should not have too much solder as shown in fig.5.

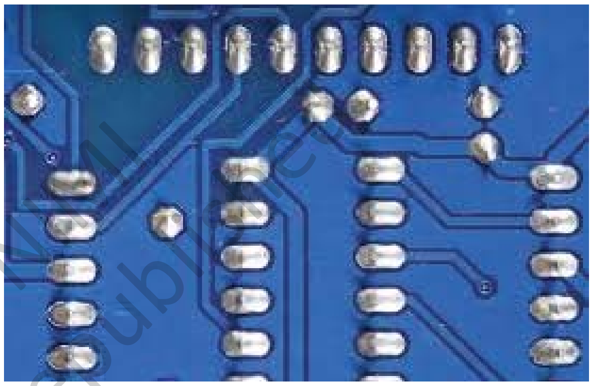


Fig 5

The contour of the solder around the joint should be slightly concave.

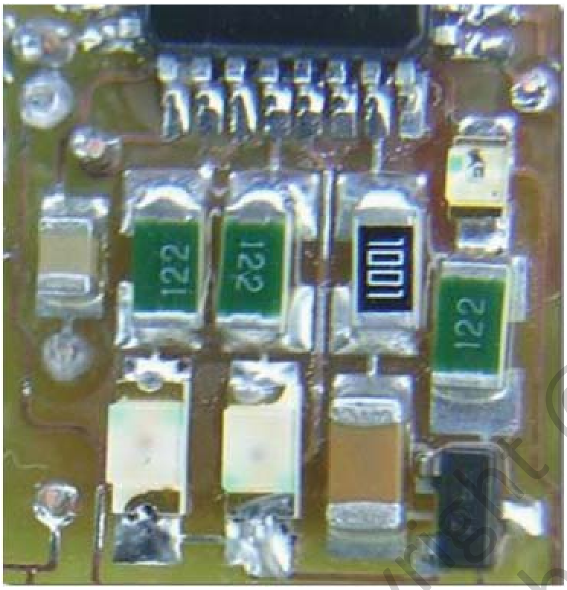
**Poor solder joints**

Too much solder on a joint may lead to poor joints as shown in fig. 6a, 6b, 6c


Fig 6a

Fig 6b

Fig 6c




## Excess solder on joints

On printed circuit boards if too much solder is used then it could spill over onto another track, causing a short circuit as shown in fig.7a & 7b.

Fig 7a

Fig 7b

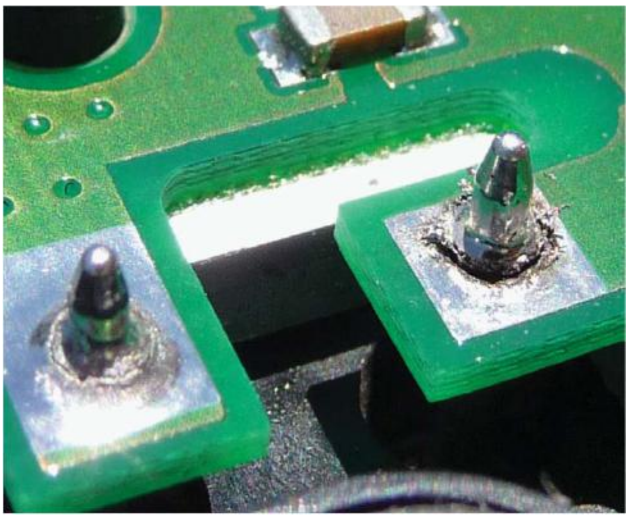
## Dry joints

Dry joints are the main problem of solder joint. These solder joints may be completely open circuit, or they may be intermittent, high resistance or noisy. Therefore it is essential that no dry solder joints are present in any electronics equipment.

It is easy to identify dry joints as shown in fig.8a & 8b. Good solder joints are shiny, where as dry joints have a dull or matt finish.

Fig 8a

Fig 8b



When a dry joint is found, the solder on the joint should be removed and care to be taken when re-soldering it, to ensure that a good joint is made.

**Tracks**

Commonly there is no recommended standard for track sizes. Size of track will depend upon the requirements of the design, the routing space and clearance. Every design will have a different set of electrical requirements which can vary between tracks on the board. As a general rule bigger the track width is better. Bigger tracks have lower DC resistance, lower inductance, can be easier and cheaper for the manufacturer to etch, and also easier to inpsect and rework. The lower limit of track width will depend upon the "track/space" resolution. For example, a manufacturer may quote a 10/8 track /space. This means that tracks can not be less than 10 thou wide, and the spacing between tracks, or pads, or any part of tracks are the copper, can not be less than 8 thou. Always quoted in thou's, with track width first and then spacing. IPC standard recommands 4 thou as being a lower limit.

A "thou" is 1/1000th of an inch = 1 thou (0.001 inch)

Fig.9 shows the tracks on the PCB.

Fig 9

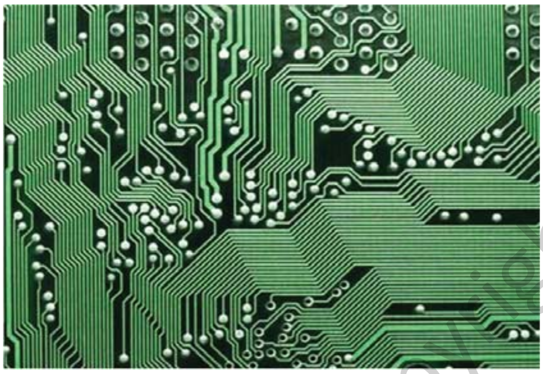
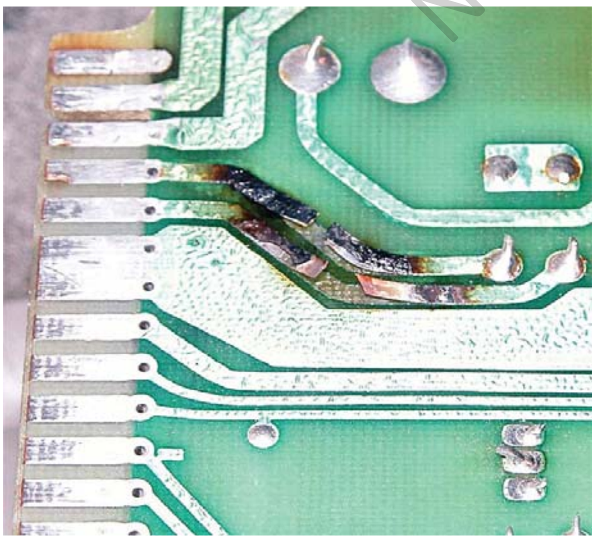


Fig. 10 shows the damaged track on PCB which is to be repaired.

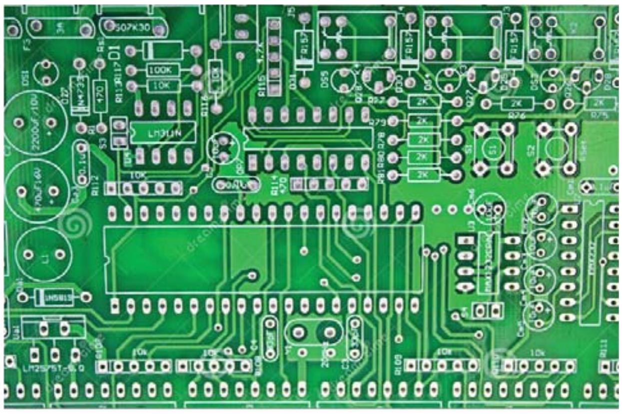
Fig 10



**Pads**

Fig. 11 shows the pads of PCB

Fig 11

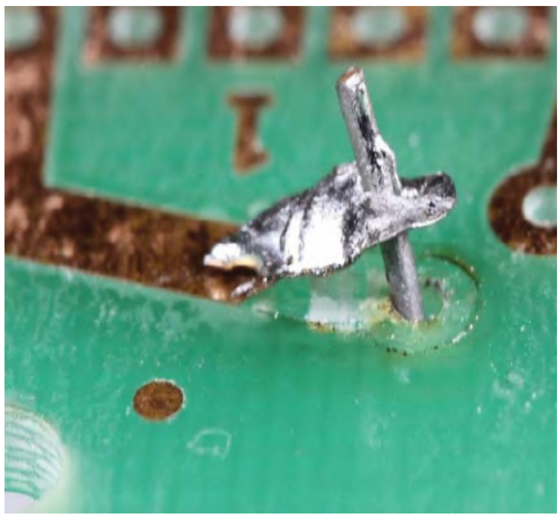


Pad sizes, shapes and dimensions will depend upon the component used to assemble the board. There is an important parameter known as the pad/hole ratio. This is the ratio of the pad size to the hole size. The pad should be at least 1.8 times the diameter of the hole, or at least 0.5 mm larger. This is to allow for alignment tolerances on the drill and the artwork on top and bottom layers. This ratio gets more important the smaller the pad and hole become, and particularly relevant to vias. Pads for components like resistors, capacitors and diodes should be round, with around 70 thou. diameter being common. Dual in line (DIL) components like IC's are oval shaped pads.

Pin.1 of the chip should be rectangular shape and other pins are circular or oval.

Fig.12 shows the damaged pad which is to be reworked.

Fig 12



## Plated-Through Hole

"Through-hole technology", refers the mounting system used for electronic components inserted into holes in PCBs and soldered to pads on the opposite side either by manual assembly or automated insertion mount machines. PCBs are initially had tracks printed on one side only. Later two sides are used, and then multi-layer boards are using now a days. Similarly, through holes became plated-through holes (PTH), Fig.13. is a Plated-Through Hole in a ten layer board.

Fig 13

Plated-through holes are used to make the components contact with required conductive layers and making interconnections between the layers called vias.

In PTH electrolysis deposition are done after the holes are drilled, then copper is electroplated to build up the thickness, Finally the boards are screened, and plated with metal.The amount of plating used in the hole depends on the number of layers in the printed circuit board, however only the least amount of metal is used for this process. Holes through a PCB are typically drilled with small-diameter, drill bits are made up of solid coated tungsten carbide. Fig.14 shows the eyelets, which can be used to repair if PTH or vias are damaged.

Fig 14

## Desoldering & soldering of individual SMDs

**Objectives :** At the end of this lesson you shall be able to
- **state methods of removing individuals SMDs**
- **state methods of soldering individuals SMDs**
- **list the surface Mount device assembly process (SMT)**
- **state the advantages & disadvantages of SMT over through - hole technique.**

**Desoldering of SMD components**

SMDs can be removed using special soldering stations employing custom desoldering tips or hot air jets. If these are not available. Remove components using desoldering braid and flux.

To remove an SMD that is already mounted to a circuit board, you will need a roll of fresh desoldering braid and RMA (rosin, mildly activated) flux (liquid or paste). Desoldering braid oxidizes over time, so if it looks dull, replace it.

In filtrate about one inch of the desoldering braid with flux (if it didn't come that way). Lay the braid over the solder joint and gently press down with the tip of a soldering pencil. The solder will wick into the braid. Each area of braid can only be used once, so trim it after each try. Repeat several times for each solder joint until all solder (except a very thin film) has been removed.

Grip the component with tweezers and gently twist to release the component(don't pull or you may lift the pads). If the component does not release from the pads, go back and try to remove more solder.

This technique takes practice, so try removing several components from a surplus board before attempting it on an important project.

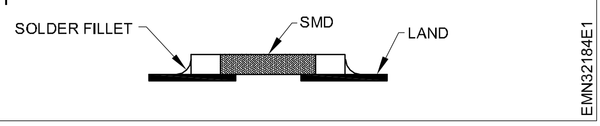
**Soldering of SMDs components**

There are several ways to successfully solder SMD components to a circuit board. Some are easier to learn than other, and some require the use of special materials (like solder paste, which is a mixture of powdered solder and flux) or special equipment (like SMD solder stations).

One of the simplest ways to solder SMDs is to first glue the components in position on a PC board, then solder the connections. The procedure is:

- Clean the copper side of the board with a nonconductive abrasive pad until it is shinny. Wipe off any residue with a tissue and denatured alcohol.
- Glue the components into position using Duco cement. Apply the cement to the end of a toothpick, then use the toothpick to apply a drop of cement to the circuit board. Do not get any glue on the pads or any place where you want the solder to flow.
- Using self-locking tweezers, position the components on the board. Let the adhesive dry.
- Gently nudge the components sideways with a toothpick. If the component moves, try gluing it again.
- Apply RMA type paste flux to the component terminals and pads using a toothpick. Apply the flux where you want solder to flow. The function of the flux is to conduct heat from the soldering tip uniformly to the pad and component. The flux also removes surface oxides, which can prevent solder wetting.
- Touch the soldering tip (set to about 600$^{o}$F) to the PAD. Never apply heat directly to the component (it may crack).
- Apply small diameter 63/37 solder (0.020" works well) to the pad adjacent to the component terminal. The solder will flow to the component and will form a fillet between the component and pad.
- Let the solder cool and remove the flux with denatured alcohol. Inspect with a 4x watchmakers loupe or magnifying glass. The solder joint should be a concave fillet, bright and mirror smooth with no pits as shown in Figure 1.

Fig 1




**A good solder joint will have smooth, concave fillets as shown in this side view**

**Conclusion**

Working with SMDs can be challenging, and mastering this technology takes a little patience and practice. Like the transition from point-to-point wiring to printed circuit boards, it is similar to traditional through-hole technology but requires some new skills.

**Surface - Mount Assembly process**

The MICRO FOOT products surface - mount assembly operations include solder paste printing, component placement, and solder reflow. This is shown in the process flow chart in figure.

**SMT Assembly process flow chart**

Incoming tape and reel inspection

⇩

Solder paste printing

⇩

Component pick and placement

⇩

Reflow

⇩

Flux cleaning (optional)

⇩

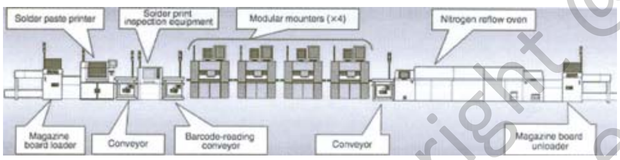
Solder joint inspection

⇩

Board Test

**Surface - Mount Assembly Process Flow**

Fig 2



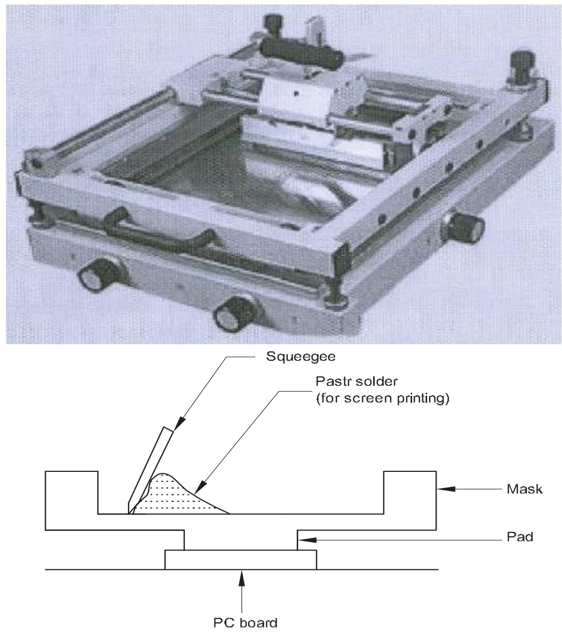

**Stencil design:** Stencil design is the key to ensuring maximum solder paste deposition without compromising the assembly yield from solder joint defects (such as bridging and extraneous solder spheres). The stencil aperture is dependent on the copper pad size, the solder mask opening, and the quantity of solder paste.

The optimum stencil thickness is 0.125mm (5 mils) for MICRO FOOT 0.80mm pitch products, 0.1mm (4 mils) for MICRO FOOT 0.5mm pitch MOSFETs, analog switches, UCSP analog switches, and 0.4mm pitch MOSFET products.

### Solder Paste Printing

The solder paste printing process involves transferring solder paste through pre-defined apertures via the application of pressure. The solder paste recommended is eutectic 63Sn/37Pb non clean solder paste or lead (Pb)-free 95.5Sn3.8Ag0.7Cu non clean solder paste. Stencil alignment accuracy should be ± 50µm. It is recommended to use type 3 (25 µm to 45 µm particle size range) or fine solder paste for printing. Solder paste printing parameters should be optimized using standard procedures for specific printing machines to ensure repeatable deposits for all the pads on the entire board.

Fig 4



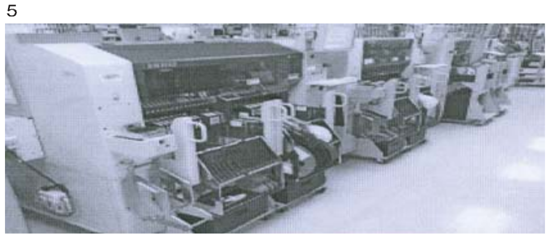

It is very important to clean the stencil frequently during printing operations, preferably after every application or every other application. Dry clean the stencils as often as possible; wet cleaning should be avoided if possible. This will help to minimize printing defects, especially from the paste or residue at the bottom of the stencil.

### Chip Pick and Placement

MICRO FOOT parts can be picked up from pocketed carrier tape reels and placed directly onto PCBs with standard pick-and-process equipment. A non-metallic pickup tool (nozzle) should be used to avoid scratching the top surface of the device, which could result in nucleation sites for microcracking. The side-lighting option on the pick-and-place machine's vision system should be used when attempting to use an individual bump recognition approach to ensure greater clarity in bump recognition. Feeders should be well maintained to eliminate any sources of vibration since feed vibration can cause misalignment or complete dislocation of the devices within the pocket after the cover tape has been peeled back.

Extreme care should be used when any tool comes into contact with the devices. The silicon chip is made of glass, and can easily be subject to damage. To prevent die cracking during pickup and placement, the pick-and-place force should be less than 150 g during pickup. No force needs to be exerted during placement. It is recommended that bumps be dipped into solder paste on the PCB to greater than 20 % of the paste block height. Though the part will self-center during solder reflow, the maximum placement offset is 0.02 mm.

Fig 5



### Reflow Process

MICRO FOOT products are compatible with all industry solder reflow processes for both Eutectic and Pb-free processes. Nitrogen purge is recommended during reflow operation to ensure optimum solderability. It is comprised of four stages:

- **Preheat:** From ambient through the first thermal excursion
- **Preflow:** This portion determines the ramp-up time from the preheat temperature to the reflow temperature
- **Reflow (wetting):** This portion determines the time of the actual reflow. The minimum peak temperature (TP) needs to exceed the melting point of the alloy
- **Cooldown:** After the peak temperatures are attained, the PCB passes out of the heated portion of the reflow oven. The cooling rates should not exceed - 4 °C/s.

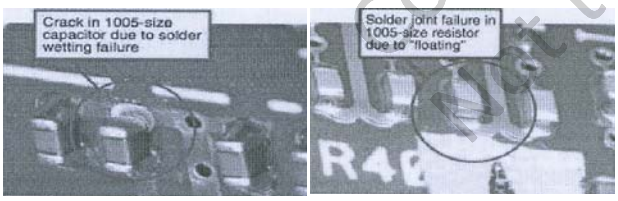
### Flux Cleaning

MICRO FOOT products are compatible with all standard post-solder cleaning processes, including heated water, saponifiers, and solvents. No special cleaning techniques are required due to the small area and large standoff of these devices.

### Solder Joint Inspection

Visual inspection or microscope checks can confirm the ball alignment and tilting. X-ray inspection may be used to detect non-visible solder joints defects such as voiding, ball bridging, and missing balls. Die shear testing may be used to verify the solder joint quality. Table 7 shows the die shear specifications for MICRO FOOT products.

Fig 6

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### Rework

To replace MICRO FOOT products on the PCB, the rework procedure is much like the rework process for a standard BGA or CSP, as long as the rework process duplicates the original reflow profile. The key steps are as follows:

1. Remove the MICRO FOOT device using a convection nozzle to create localized heating similar to the original reflow profile. Preheat from the bottom.
2. Once the nozzle temperature is + 190 °C, use tweezers to remove the part to be replaced.
3. Resurface the pads using a temperature-controlled soldering iron.
4. Apply gel flux to the pad.
5. Use a vacuum needle pick-up tip to pick up the replacement part, and use a placement jig to place it accurately.
6. Reflow the part using the same convection nozzle and preheat from the bottom, matching the original reflow profile.

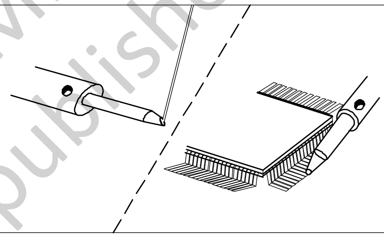
### Advantage and disadvantage of SMT over older through - hole technique

Semiconductor packaging has evolved with the increased demand for greater functionality, smaller size, and added utility. In modern PCBA design there are two main methods of mounting components onto a PCB: Through Hole Mounting and Surface Mounting.

### Through Hole Mounting (THM):

In through hole mounting the components' leads are placed into holes drilled through the bare PCB board. THM was the original technology to produce printed circuit board assemblies, but this has been almost completely replaced by surface mount except in special circumstances.

Fig 7



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**Advantages:** THM provides stronger mechanical bonds versus SMT techniques, making through hole ideal for components that might undergo mechanical stress - for example, connectors or heavy components such as transformers. In a modern assembly facility, through hole is considered a secondary operation, not part of the primary assembly process.

**Disadvantages:** On the bare PCB side, THM requires the drilling the holes, which makes it more time-consuming and expensive to produce. THM also limits the available routing area on any multilayer boards, because the drilled holes must pass through all the PCB's layers. On the assembly side, component placement rates for THM are a fraction of surface mount placement rates, making THM prohibitively expensive. Further, THM requires the use of wave, selective, or hand-soldering techniques, which are much less reliable and repeatable than reflow ovens used for surface mount.

**Surface Mount Technology (SMT):** SMT is a technique that involves mounting the components directly onto the surface of the PCB.

**Advantages:** SMT allows for smaller PCB size, higher component density, and more real estate to work with. Because there are fewer drilling holes required, SMT allows for lower cost and faster production time. During assembly, SMT components can be place at rates of thousands, even tens of thousands, of placements per hour, versus less than a thousand for THM. Solder joint formation is much more reliable and repeatable using programmed reflow ovens versus through techniques. SMT has been shown to be more stable and perform better in shake and vibration conditions.

**Disadvantages:** SMT can be unreliable when used as the sole attachment method for components subject to mechanical stress (i.e. external devices that are frequently attached or detached).

Overall, surface mounting will almost always prove more efficient and cost-effective over through hole mounting. It is used in over 90 percent of PCBAs today. However, special mechanical, electrical, and thermal considerations will continue to require THM, keeping it relevant well into the future.

**Reflow Solder Process Description**

The basic reflow solder process consists of: Application of a solder paste to the desired pads on a printed circuit board (PCB) Placement of the parts in the paste. Applying heat to the assembly which causes the solder in the paste to melt (reflow), Wet to the PCB and the part termination resulting in the desired solder fillet connection.

A) Solder paste the solder paste mixes are improving as the demands of reflow soldering of SMT increase. Selection and specification of the optimum paste id a key item in the reflow solder process.

B) Placement of the parts in the paste is not difficult if the pad design considers all the applicable tolerances. (see KEMET Application Bulletin “Surface Mount- Mounting Pad Dimensions and Considerations”). Care should be taken during the transporation of the PCB’s not to smear the solder paste or move parts. Inspection of palcement accuracies and subsequent manul movement of parts in wet paste has been shown to increase repair rates after soldering.

C) Application of heat to result in the eventual solder joint must consists of the following discreate items: Preheat cycle is intened to drive off most of the volaties solvents contained in the paste before the flux begains to work. This assists in initiating fluxing action on the solder powder and the metal surface to be joined. Additional preheat time to elevate the temperature of the PCB, solder paste, and terminations to a temperature near the melting point of the solder. Additional heat transfer to elevate the temperature over the liquids points of the solder Temperatures to be achieved are the liquids melting point of solder. Liquidous points for-60 Sn/36 Pb/2 Ag solder is 179 C Additional heat should be limited to minimize the time some parts are above critical temperature Assited temperature, cool down to the solidification temperature near cleaning temperature.

Equipment unique to surface mounting includes inspection and repair/ rework equipment. Inspection equipment for surface mounting in electronics has not matured yet. There are two main types of automated inspection equipmnet on the market x-ray and laser. However, most electronic companies depends on visual inspection at 2 to 10X, using either microscope of magnifying lamp.

**Solder Paste and Its Application in SMT**

Solder paste or solder cream is simply a suspension of fine solder particles in a flux vehicle. In electronics indutry, solder paste is used in surface mount technology (SMT) to solder SMDs on to the printed circuit board. The composition of the particles can be tailored to produce a paste of the desired melting range. Additional metals can be added to change paste compositions for specialized applications. Praticle size and shape, metal content and flux type can be varied to produce pastes to varying viscosity. Availability of solder paste

Solder paste is available in both leaded (with lead) and lead-free ( with no lead) forms. It can be no-clear or water soluble. with no-clean solder paste, there is not need to clean the board after soldering, Water soluble solder paste is easily soluble in water with no harm.

How to get the best solder joints from solder paste application

1 In order to achieve good solder paste printing results, a combination of the right solder paste material, the right tools and the right process are necessary. Kester is a trusted brand in manufacturing solder paste and other soldering material including solder wire, solder bar, solder flux etc. Although the supplier is essentially responsible for providing the desired solder paste and screens or stencils and the squeegee blades, the user must control process and equiment variables to achieve good print quality. Even the best solder paste, equipment, and application methods are not sufficient by themselves to ensure acceptable results.

**Using Solder Paste:**

Start by applying flux to the circuit boards pads. The apply solder paste on the all the pads of the components you want tosolder.

Using tweezers, place the component in its correct position and hold it three. Place the tip of the soldering iron onto each of the pads so that the solder melts and makes good connections between the component and the board.

**Flood with solder:**

This methods is for soldering chips.

As usual start by applying flux to the pads on the circuit board. Fasten one of the corner pins of the chip to its pad by using a bit of solder. Make sure the chip is properly aligned on the pads.

Hold the chip in place while touching the corner pad with the tip of the soldering iron so that the solder melts the pin and the pad together.

Check the aligment of the chip. If it is not in its place, use your soldering iron to loosen the pin chip and align the chip properly. Continues soldering on the opposite corner by putting a bit of solder on the soldering iron tip then touching the circuit board pad and pins at the same time.

Do this for all the pins of the chip one by one.

After all the pins have been soldered you should inspect the solder joints carefully with a microscope or loupe to check for bad joints or solder bridges.

**Baking and Preheating**

This proedure covers baking and preheating of printed circuit boards and PCB assemblies to prepare the product for the subseqequent operations.

1 Baking

Baking is used to eleminate the absorbed moisture. When ever possible printed circuit boards and PCB assemblies should be baked proir to soldering. Desoldring and coating operation to prevent blistering, measling or other laminate degradation.

2 Preheating

Preheating is used to promote the adhesion of subsequent materials to the board surface and to raise the temperature of the circuit board to allow soldering and desoldering operations to be completed more quickly.

3 Auxiliary Heating

Auxiliary heating is the addition of a second source of heat. This can be from a hot air tool, or from a second soldering station. A common application is to provide additional heat when removing through hole components that my have connections to internal power or ground planes.

4 Thermal Profiles

Ball grid array, chip scale packages, and flip chi[ packages may require the development of “Time Temperature Profiles” to remove or install these devices.

Cation

Baking and preheating procedures must be carefully selected to ensure that temperature and time cycles used do not degrade the product. Enviroment conditions must also be carefully considered to ensure that vapors, gases, etc.., generated during the heating process do not contaminate the product’s surfaces.

**Selection of Haedware Tools:**

Introducing to Pick and Place Equipment Selection:

For most purpose, selecting pick and place machine can be broken down into three simple steps:

1 Understanding how equipment is specified by manufactures.

2 Calculating your product requirements:

- Speed/capacity
- Maximum and minimum component sizes
- Precision and accuracy
- Board or panel size
- Number and types of component feeders

3 Benchmarking machines from various manufactures against your requirements.

Fig 1

EMN32184F1

**SMD Reflow Oven**

The reflow oven is a machine used primarily for reflow soldering of surface mount electronic components to printed circuit boards (PCB)

The reflow oven process principle and introduction

The reflow oven is the most important welding technology in surface mount technology. It has been widely used in many industries including mobile phones, computer, automotive electronics, control circuits, communications, LED lighting and many other industries. More and more electronic devices are converted from through hole to surface mount, and reflow oven replaces wave soldering is a obvious trend in welding industry.

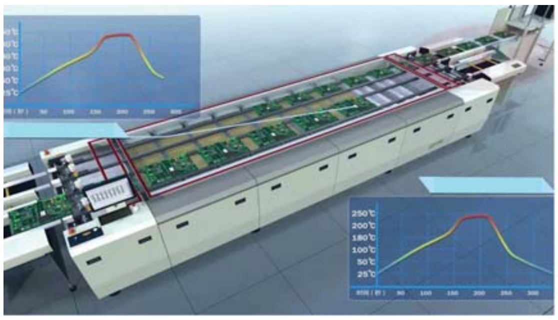
The whole SMT surface mounting line consists of three parts, such as steel mesh solder paste printing machine, SMT machine and reflow oven furnace. For the machine, and compared with lead free, and no new demands on the equipment itself: for screen printing machine, and a lead-free solder paste in the physical properties there are some diffrences, so put forword some improvement on the devices itself, but there is no qualitative change. the key of lead-free is in reflow oven.

The lead paste (Sn63Pb37) melting points of 183 dgrees, if you want to form a good weld must have the thickness of 0.5-3. 5um intermetallic compounds in welding, intermetallic compound formation temperature is above the melting point of 10-15, the lead welding is 195-200.

The maximum withstand temperature of the electronic devices on the circuit board is generally 240 degrees. Therefore, for lead welding, the ideal welding process window is 195-240 degrees

Because of the change of melting point of lead-free solder paste, lead-free welding has brought great changes for welding process. At present, the lead-free solder paste is Sn96Ag0.5Cu3.5 and the melting points is 217-221 degrees. Good lead-free solder must also be formed 0.5-3.5um thickness intermetallic compounds, intermetllic compound formation temperature is also above the melting point of 10-15 degrees, for lead-free welding, that is, 230-235 degrees. Since the highest temperature of lead-free solder electronic devices will not change, therefore, for lead free soldering, ideal welding process window is 230-245 degrees. The substantial reduction of process window brings great challanges to ensure welding quality, and also brings higher requirements to stability and reliability of lead-free wave soldering equipment. Becuase the equipment itself is coupled with the electronic device transverse temperature diffrence, due to diffrences in size of heat capacity will produce temperature diffrences in the heating process, so in the process control of lead-free reflow oven can be adjusted in the process of welding temperature window becomes very small, this is the real lead-free reflow to the difficulty.

Fig 1



## Fuses-terminology-types-uses

**Objectives :** At the end of this lesson you shall be able to
- **explain the purpose of the fuse in a circuit**
- **explain the types of fuse bases**
- **classify the different types of fuses and their uses.**

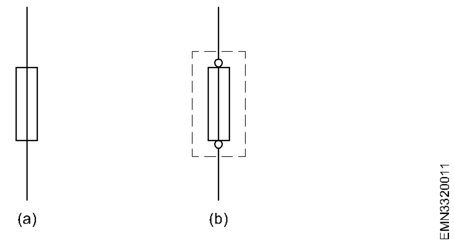
**Purpose of fuses :** A fuse is a safety device used for the purpose of protecting a circuit against excess current. In the event of excessive current, the fuse element melts and opens up the circuit thereby protecting it from damage.

Symbols : These are the graphical symbols used to illustrate an electrical fuse in electro - technical diagrams.

General symbols of a fuse (Fig. 1a)

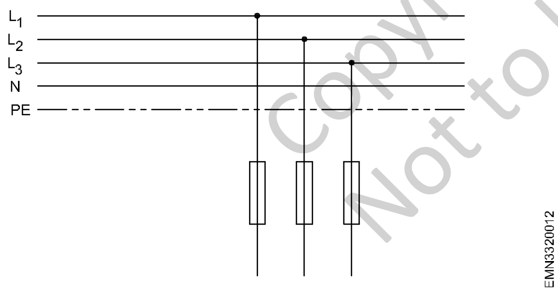
Fuse with terminals and protective housing (Fig. 1b)

Fig 1




**Placement of fuses :** In electrical installations, the fuses are always connected into the live wires ($L_1$, $L_2$ and $L_3$ as shown in fig. 2) and never into the neutral N or the protective earth line (PE).

Fig 2




### Terminology

**Fuse element :** The part of the fuse which is designed to melt and open up a circuit.

**Fuse - carrier :** The removable portion for carrying the fuse element.

**Fuse base :** The fixed part of the fuse provided with terminals for connection to the circuit which is suitable for the receptacle of the fuse - carrier.

**Current rating :** Safe maximum current that can pass continuously without overheating.

**Fusing current :** The current at which the fuse element melts

**Cut - off factor :** Time (period ) taken for a fuse to interrupt the circuit in the event of a fault.

**Fusing factor :** Ratio between minimum fusing current and current rating.

$$\text{Fusing factor} = \frac{\text{Minimum fusing current}}{\text{Rated current}}$$

The fusing factor for a re-wireable fuse varies between 1.4 to 1.7 and may go up to 2.0, but for a HRC fuse it is 1.1

However, a fuse selected for over - current protection should not have a fusing factor of more than 1.4.

The fusing factor for a re-wirable fuse varies between 1.4 to 1.7 and may go up to 2.0, but for a HRC fuse it is 1.1

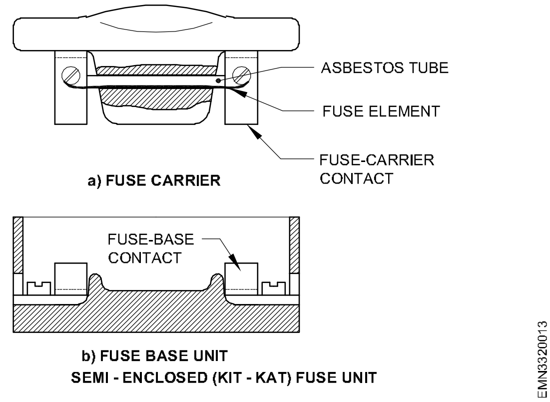
However, a fuse selected for over-current protection should not have a fusing factor of more than 1.4.

**Types of fuses used in domestic wiring:**

- Re-wirable type (up to 200A)
- Cartridge type (up to 1250A)

**Rewirable type fuse (Fig. 3):** The fuse element in this type of fuse consists of a wire which may be replaced when necessary. These fuses are simple in construction and the initial cost as well as the renewal cost is very low.

Fig 3




The fuse elements used in this type are tinned copper wire, lead and tin alloy. Approximate sizes of fuse elements of tinned copper wire or aluminium wire for use in semi-enclosed fuses are shown in Table 1.

The fuse element will melt after approximately 2 minutes when carrying a current equal to twice the current rating. However, the cut-off time factor varies in rewirable fuses due to:

- the construction of the carrier (design of fuse-carrier/ base)
- the manner in which the fuse wire has been fitted
- the length of time the fuse was in service
- ambient temperature
- the amount of current etc.

Small fuse wires in parallel in a carrier to carry a large current should be avoided, as far as possible. The actual rating becomes less than the sum of the ratings of the individual strands. A paralleling factor of 0.7 to 0.8 is used to multiply the sum of the rating of individual strands to get the actual current rating.

Example: 35 SWG - copper wire has a fuse rating of 5 amps, and 3 strands in parallel together will a have current rating equal to 5x3x0.8=12 amps when 0.8 is taken as the paralleling factor.

**Disadvantages of rewirable type fuse:**

- Deterioration of the fuse element by oxidation due to heating.
- Lack of discrimination.

Table 1

| Current rating for | Approximate fusing current Amp. | Tinned copper wire | | Aluminium wire dia. in mm |
|---|---|---|---|---|
| | | S.W.G. | Diameter in mm | |
| 1.5 | 3 | 40 | .12192 | -- |
| 2.5 | 4 | 39 | .13208 | – |
| 3.0 | 5 | 38 | .1524 | .195 |
| 4.0 | 6 | 37 | .17272 | – |
| 5.0 | 8 | 35 | .21336 | – |
| 5.5 | 9 | 34 | .23368 | – |
| 6.0 | 10 | 33 | .254 | .307 |
| 7.0 | 11 | 32 | .27432 | – |
| 8.0 | 12 | 31 | .29464 | – |
| 8.5 | 13 | 30 | .31496 | – |
| 9.5 | 15 | – | ---- | .400 |
| 10.0 | 16 | 29 | .34544 | – |
| 12.0 | 18 | 28 | .37592 | – |
| 13.0 | 20 | – | ---- | .475 |
| 13.5 | 25 | – | ---- | .560 |
| 14.0 | 28 | 26 | .4572 | – |
| 15.0 | 30 | 25 | .508 | .630 |
| 17.0 | 33 | 24 | .5588 | – |
| 18.0 | 35 | – | ---- | .710 |
| 20.0 | 38 | 23 | .6096 | – |
| 21.0 | 40 | – | ---- | – |
| 22.0 | 45 | – | ---- | .750 |
| 24.0 | 48 | 22 | .7112 | .850 |
| 25.0 | 50 | – | ---- | .90 |
| 29.0 | 58 | 21 | .8128 | – |
| 30.0 | 60 | – | ---- | 1.00 |
| 34.0 | 70 | 20 | .9144 | 1.22 |
| 37.5 | 80 | – | ---- | 1.25 |
| 38.0 | 81 | 19 | 1.016 | -- |
| 40.0 | 90 | – | ---- | 1.32 |
| 43.0 | 98 | – | 1.1176 | – |
| 43.5 | 100 | – | ---- | 1.40 |
| 45.0 | 106 | 18 | 1.2192 | – |
| 55.0 | 120 | – | ---- | 1.60 |
| 62.0 | 130 | – | ---- | 1.70 |
| 65.0 | 135 | 17 | 1.4224 | – |
| 66.0 | 140 | – | ---- | 1.80 |
| 69.0 | 150 | – | ---- | 1.85 |
| 73.0 | 166 | 16 | 1.6256 | – |
| 75.0 | 175 | – | --- | 2.06 |
| 78.0 | 197 | 15 | 1.8288 | – |
| 80.0 | 200 | – | ---- | 2.24 |
| 102.0 | 230 | 14 | 2.032 | – |
| 130.0 | 295 | 13 | 2.3368 | – |



- Effected by the fluctuation of the ambient temperature.
- Premature failure due to deterioration under normal load.
- Low speed operation (poor cut-off factor)
- External flash or arc on blowing.
- Poor rupturing capacity (under short-circuit condition).
- Wrong rating possible by human error.

Rewirable-type fuses up to 16A rated current should not be used in locations where short circuit level exceeds 2 KA, and those of higher ratings in locations where the S.C. level exceeds 4 KA. (I.S. 2086-963)

Cartridge fuses: Cartridge fuses are developed to overcome the disadvantages of the rewirable fuses. Due to high temperature, prolonged use and oxidation, rewirable fuses deteriorate and interrupt the supply even when carrying normal current. As cartridge fuse elements are enclosed in an air tight chamber, deterioration does not take place. Further the rating of a cartridge fuse could be accurately determined from its marking. However, the cost of replacement of cartridge fuses is more than that of rewirable fuses.

**Cartridge fuses can be grouped as those with a:**

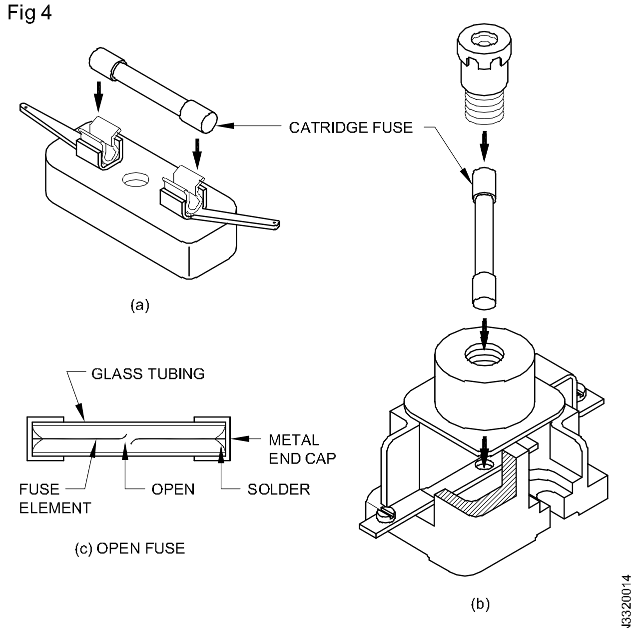
- low rupturing capacity (Say rupturing capacity up to 50 KA.)
- high rupturing capacity. (Say rupturing capacity above 80 KA.)

Rupturing capacity is the ability of a fuse to open the faulty circuit without much arcing or damage to itself. For domestic installations, low rupturing capacity fuses are used whereas for high power factory installations, and for installations connected from high power sources, high rupturing capacity (HRC) fuses are used.

**Low rupturing capacity cartridge fuses can be further divided into:**

- Ferrule-contact cartridge fuses.(Fig. 4)

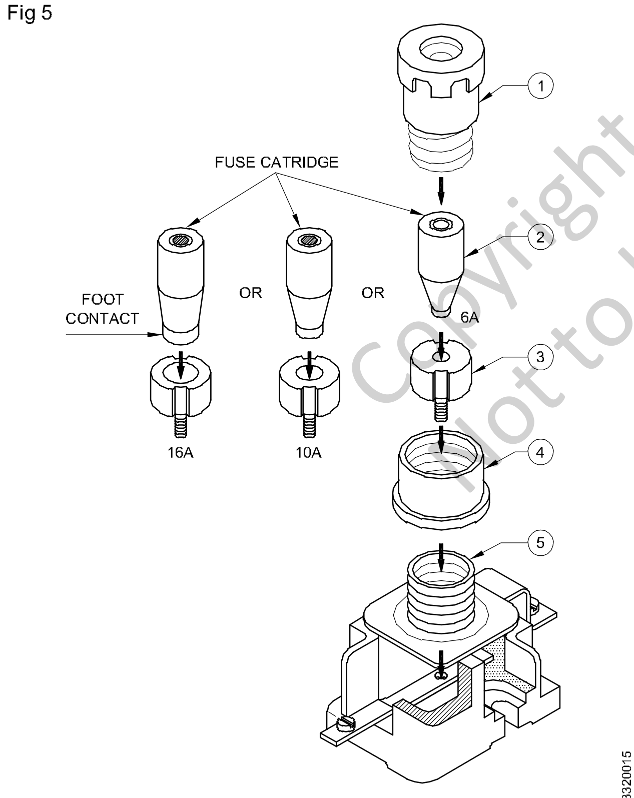
Fig 4




FERRULE - CONTACT CATRIDGE FUSE UNIT

- diazed screw-type cartridge fuses.(Fig. 5)

Fig 5




DIAZED SCREW TYPE CATRIDGE FUSE UNIT

Ferrule-contact cartridge fuses: This type, shown in Fig. 4, is used for protecting electrical and electronic circuits. These are available in 25, 50, 100, 200, 250, 500 milliamperes, and also in 1,2,5,6,10,16 & 32 amperes capacity. Normally the current rating is written on one side of the cap, and while replacing, the same capacity fuse should be used. Its body is made of glass and the fuse wire is connected between two metallic caps.

This fuse can be plugged into the fuse socket as shown in Fig 4a or it can be fitted into a fuse base with a screw, in a fuse- holder of the type shown in Fig. 4b.

Diazed screw-type cartridge fuses: This is shown in Fig. 5. It is also not of a rewirable type. This type of fuse is commonly used in domestic and industrial electrical installations in many countries. It consists of the following parts as shown in Fig. 5.

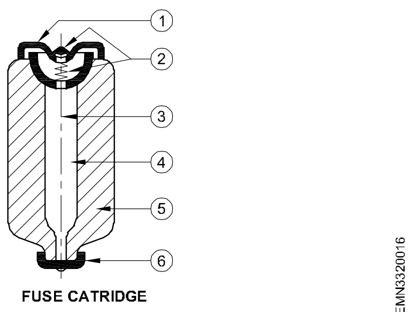
- Screw cap or fuse cartridge-holder (1)
- Fuse cartridge (2)
- Fitting screw or contact screw (3)
- Protective plastic or ceramic ring (4)
- Fuse base or fuse socket (5)

Fuse cartridges are available for rated electric currents of: 2, 4, 6, 10, 16, 20, 25, 35, 50 and 63 amperes. To prevent the insertion of a fuse cartridge having a larger current rating than intended, the foot contacts of the fuse cartridges have different diameters for each rated current(the smaller the current the smaller the diameter of the foot contact). As there is also a separate fitting screw for each type of cartridge, it is not possible to insert, let's say, a 35 amp. fuse cartridge into the fitting screw of a 25 amp fuse cartridge.



Fig. 6 shows the inside of one of the afore-mentioned fuse cartridges. It shows the ceramic body of the cartridge with its foot and head contacts. The two contacts are linked by a fuse wire which is embedded in sand. Each cartridge has a break indicator which will be ejected from the cartridge if the fuse wire is burnt out. The parts of this cartridge, shown in Fig. 6, are:

Fig 6

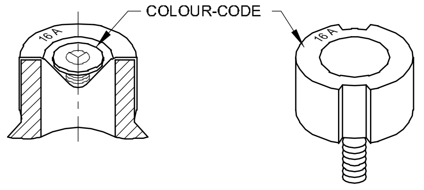



FUSE CATRIDGE

- head contact(1)
- break indicator(2)
- fuse wire(3)
- sand filling(4)
- ceramic fuse body(5)
- foot contact. (6)

For easy identification of the fuse cartridges and the corresponding fitting screws, they are marked with various colours at the places shown in Fig. 7. For each current rating, a different colour is used.

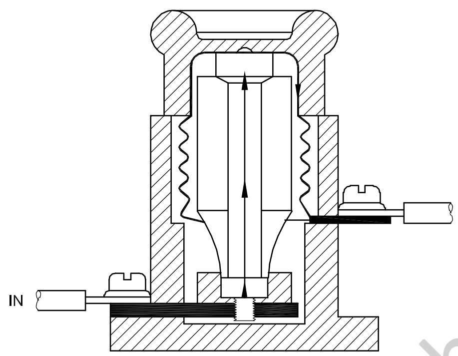
Fig 7




| | | | |
|---|---|---|---|
| Pink | - 2 amperes | Blue | - 20 amperes |
| Brown | - 4 amperes | Yellow | - 25 amperes |
| Green | - 6 amperes | Black | - 35 amperes |
| Red | - 10 amperes | White | - 50 amperes |
| Grey | - 16 amperes | Copper | - 63 amperes |

Fig 8 shows the flow of the electric current through the fuse base and the fuse. In order to prevent the accidental touching of a live line, the electrical supply must be connected to the terminal which is connected to the fixing screw at the bottom of the base.

Fig 8

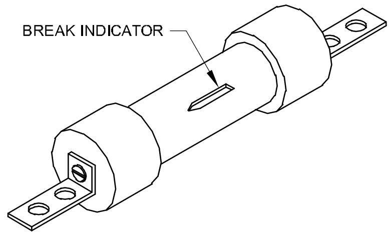



Diazed type fuses are available in two categories,

a)quick-response type and b) delayed-action type. The quick-response type is used for heating circuits and normal loads whereas the delayed- action type is used for motor circuits and highly inductive circuits.

High rupturing capacity fuses (Fig. 9): They are cylindrical in shape and are made of a ceramic body filled in with a chemically treated filling powder or silica to quench the arcing quickly without any fire hazard.

Fig 9




Normally a silver alloy is used as the fusing element and when it melts due to the excessive current, it combines with the surrounded sand/powder, and forms small globules without making an arc, spark or gas. HRC fuses can open a short-circuited circuit within 0.013 second. It has an indicator to show the fuse has blown. The rupturing capacity of the fuse could be calculated from the following formula.

$$\text{Rupturing capacityin MVA} = \frac{\text{Fault current in amperes} \times \text{Circuit voltage}}{10^6}$$

As HRC fuses are capable of opening circuits having very high faulty currents, these are preferred in high power circuits even though the replacement cost is high.

**Comparison between H.R.C. & Rewirable fuses**

| **Rewirable** | | **HRC fuse** |
|---|---|---|
| Rupturing capacity | Not recommended for currents exceeding 200 A or for more than 600V or where there is a possibility of S.C. fault of more than 5 MVA. | Normal types cater to fault loads up to 2500 KVA. For certain applications, fuses up to 50 MVA are obtainable. |
| Rupturing speed(Cut-off factor) | Rating and cut-off are not absolutely reliable. | Very rapid. Usually AC supply current is cut off within the first half cycle. |
| Discrimination | Poor. | Accurate. |
| Safety in operation | Risk of flash-over under heavy fault condition. | No external flame. |
| Deterioration | Oxidation and consequent scaling causes reduction in the cross-sectional area, thus increasing resistance, and leading to over-heating and premature rupturing. | No oxidation is the element is completely sealed. |
| Fusing factor | Copper wire upto 20A 1.7 over 20A 2.0. | As low as 1.1. |

## Miniature circuit breaker (MCB)- types- construction- working- specification

**Objectives**: At the end of this lesson you shall be able to
- **explain the types, working principle and parts of a miniature circuit breaker.**
- **state the advantages and disadvantages of MCB**
- **explain the working of combination circuit breaker (ELCB + MCB)**
- **state the categories of MCB's**
- **state the applications of MCBs.**

### Circuit Breaker

A circuit breaker is a mechanical switching device capable of making, and breaking currents under normal circuit condition and also making, carrying current under normal condition and breaking currents under abnormal circuit conditions like a short circuit.

### Miniature circuit breaker (MCB)

A miniature circuit breaker is a compact mechanical device for making and breaking a circuit both in normal condition and in abnormal conditions such as those of over current and short circuit.

### Types of MCB's

MCBs are manufactured with three different principles of operation namely

a Thermal Magnetic

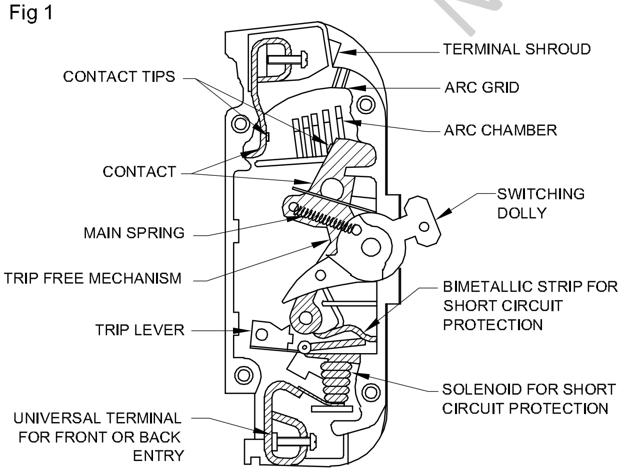
b Magnetic hydraulic and

c Assisted bimetallic

### Thermal magnetic MCB

As shown in Fig. 1, the switching mechanism is housed in a moulded housing with phenolic moulded high mechanically strong switching dolly. This type of MCB is also provided with bimetallic over load release.

Fig 1




NOTE: THE HATCHED PORTION SHOWS THE PATH OF CURRENT FROM TOP TERMINAL TO BOTTOM

**THERMAL MAGNETIC TYPE MCB**

EMN3320021

The electric current gets through two contact tips one each on moving and fixed contact of silver graphite.

An arcing chamber incorporating de-ionising arc chutes for control and quick suppression of the arc is provided in the gap between two contacts. It has a ribbed opening closed by metal grid which allows ventilation and escape of gases.

For protection against over-load and short circuit, MCB's have thermal magnetic release unit. The overload is taken care of by bimetallic strip, short circuit currents and over loads of more than 100% are taken care by solenoid.

### Working

The bimetallic strip when flexing due to temperature rise caused by increasing normal rated current beyond 130% rotates a trip lever carrying an armature to which it is to brought into field of a solenoid. The solenoid is designed to attract the armature to full position at about 700% overload or instantaneous short circuit current.

For initial portion of current wise (130% to 400%) tripping of circuit breaker is due to thermal action, between 400 to 700% tripping is due to combined thermal and magnetic action and beyond 700% due to fully magnetic action.

### Magnetic hydraulic MCB

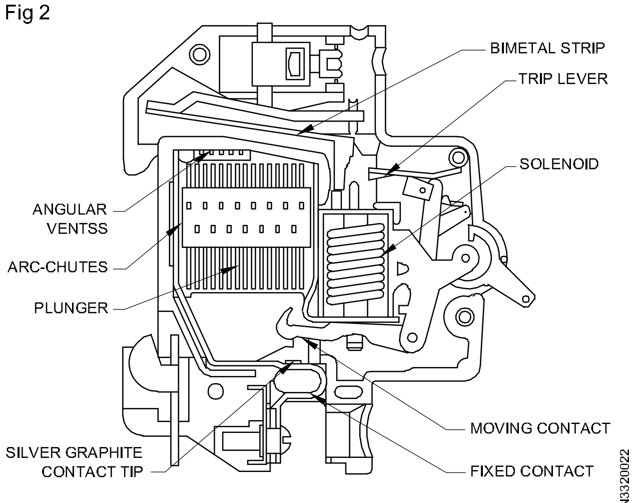
Magnetic hydraulic circuit breaker operates on the principle of a solenoid and hydraulically damped plunger.

### Construction and working

A movable ferrous plunger is held against a non-ferrous tube containing polysiloxane liquid which have flat temperature viscosity characteristic in temperature range of 20 to 60°C. The solenoid is a series coil in the circuit of MCB. As the plunger moves towards a pole piece, the reluctance of magnetic path.

Containing the armature is cumulatively reduced leading to some magneto motive force producing a progressively increasing flux. The armature is then attracted causing the mechanism to trip and open the controls on overload or short circuit. Instantaneous tripping occurs on very large currents 7 to 8 times the full load current. The construction of magnetic hydraulic tripping mechanism is as shown in Fig. 2.

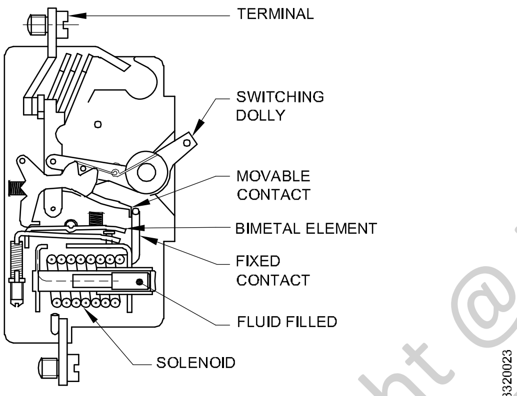
Fig 2




MAGNETIC HYDRAULIC MCB

### Assisted Bimetal Tripping MCB (Fig. 3)

Fig 3

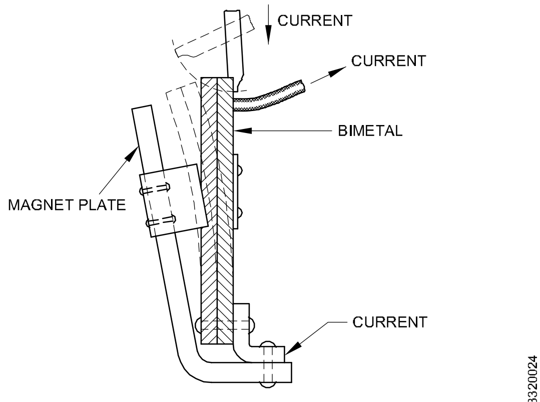



ASSISTED BIMETAL TRIPPING MCB

In the assisted bimetal form of construction, the time delay characteristic is provided by a thermally operated bimetal element which may be either directly or indirectly heated. Instantaneous tripping in short circuit condition is achieved by arranging a powerful magnetic pull to deflect the bimetal as shown in Fig. 4.

This method utilises the magnetic field which is produced when a current flows through the conductor. By locating the bimetal near to a substantial section of ferrous material,

Fig 4




ASSISTED BIMETAL TRIPPING

the magnetic field associated with current flowing in the bimetal will cause a sideways pull to be applied to the bimetal element, attracting the bimetal towards the ferrous material. This sideways pull is arranged to coincide in direction with the normal direction of movement of the bimetal, which is powerful enough to deflect the bimetal (in heavy over load or short circuit condition) sufficiently to trip the breaker.

### Design and rating of MCBs

MCBs are normally rated for 25°C ambient temperature and are available in the following various combination of poles and current ratings. (Fig. 5)

| Sl.No. | No. of poles | Current |
|---|---|---|
| 1 | Single pole MCB | 0.5 to 60A |
| 2 | Double pole MCB (ie. 2 MCBs with common trip bar) | 5 to 60A |
| 3 | Triple pole MCB | 5 to 60A |
| 4 | Four pole MCB | 5 to 60A |

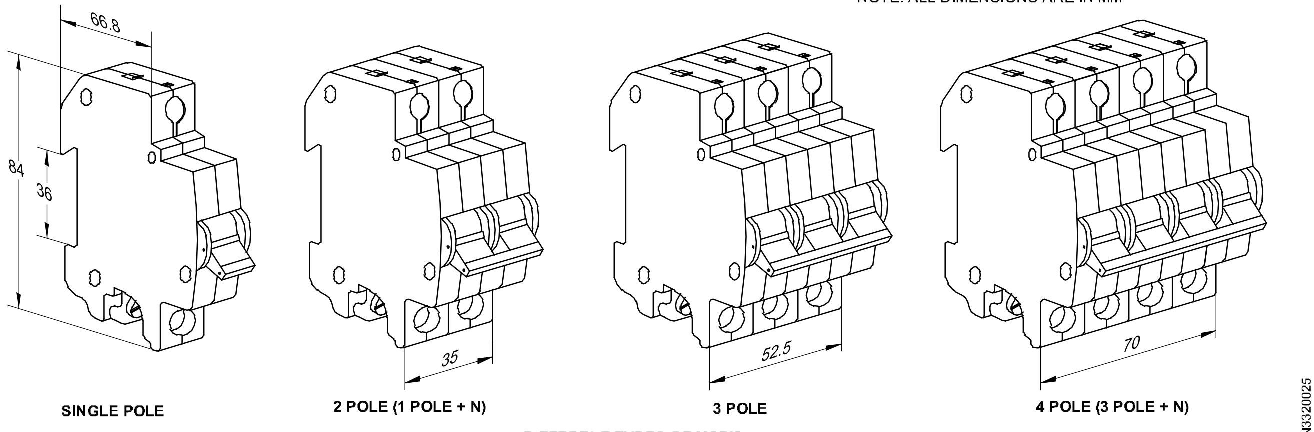
### Isolators

An isolator is a switch only. These cannot be used for automatic tripping. Isolators are not meant for either closing or breaking the circuit on load or short circuit. Isolators have the same physical dimensions of MCBs



Fig 5

NOTE: ALL DIMENSIONS ARE IN MM




DIFFERENT TYPES OF MCB'S

and are available in the following configurations and ratings.

| No. of poles | Current rating |
|---|---|
| Single pole | 30, 60, and 100A |
| Single pole and Neutral | 30, 60, and 100A |
| Double pole | 60, and 100A |
| Triple pole | 60, and 100A |
| Four pole | 60 and 100A |

**Breakers with neutral**

Breakers are available with switched neutral for applications where the neutral is to be disconnected when the mains are switched off. They are available in current ratings from 5 to 60 amp and in the following configurations.

1 Single pole and neutral

2 Double pole and neutral

3 Triple pole and neutral

**ELCB + MCB combination circuit breaker**

Now a days some manufacturers have introduced an ELCB + MCB combination circuit breaker which can be used instead of using separate MCB and ELCB (earth leakage circuit breaker). This combination not only allows reduction in costs, but also ensures extremely efficient protection from all low voltage and medium voltage electrical hazard of shock and fire caused by

1 over current

2 short circuit

3 earth leakage

4 earth fault.

**Earth leakage circuit breakers are now generally called Residual Current (RC) circuit breakers.**

**Working**

The RC + MCB combination employs a modular concept for efficient operation. The MCB module consists of a thermal trip (bimetallic) for overload protection and a hammer trip (magnetic) for short circuit.

**Operating system**

The thermostatic bimetal has close calibration to provide reliable protection without nuisance tripping.

The hammer trip active current limiting system provides high rupturing capacity during short circuits. The typical trip time for clearing short circuits is only 2 to 3 millisecond. Specially designed arc chutes, arc runner and silver graphite contact system ensures high reliability and a long maintenance free operating life.

The residual current module works on the core balance transformer principle. It includes high permeability magnetic core and temperature resistant insulated copper wire wound with high degree of symmetry to eliminate nuisance tripping. The residual current signal from the core balance transformer is fed to a super sensitive permanent relay. This relay is calibrated to operate at about 100 micro volt Amp directly on the residual current energy. The relay operates when the leakage power threshold is crossed and activates the MCB tripping mechanism internally. All tripping mechanisms are truly current operated. They do not require any auxiliary power source other than the fault leakage current energy itself.

The rated load currents of the RC + MCB combination are 6A, 10A, 16A, 20A, 25A, 32A and 35A. The bimetal trip is so adjusted that no tripping will occur upto 1.3 times the rated current.

**Categories of MCBs**

Certain manufacturers like Indo Kopp manufacture MCBs in three different categories namely 'L' series, 'G' series, and 'DC' series.

**'L' series MCBs**

'L' series MCBs are designed to protect circuits with resistive loads. The tripping factor for current ratings upto 10 A is 1.6 $I_n$ and for current ratings above 10 A is 1.35 $I_n$. They are ideal for protection of equipment like Geysers, ovens and general lighting systems.

**'G' series MCBs**

'G' series MCBs are designed to protect circuits with inductive loads. The over load tripping factor for all current ratings is above 1.1 $I_n$. The magnetic tripping commences above 7 times the rated current. G series MCBs are suitable for protection of motors, air conditioners, hand tools, halogen lamps etc.,

**'DC' series MCBs**

'DC' series MCBs are suitable for voltage upto 220V DC and have a breaking capacity up to 6kA.

The tripping characteristics are similar to 'L' an 'G' series. They find extensive application in DC controls, locomotives, diesel generator sets etc.,

**Advantages of MCB**

1 Tripping characteristic setting can be done during manufacture and it cannot be altered.

2 They will trip for a sustained overload but not for transient overload.

3 Faulty circuit is easily identified

4 Supply can be quickly restored

5 Tamper proof

6 Multiple units are available.

**Disadvantages**

1 Expensive

2 More mechanically moving parts

3 They require regular testing to ensure satisfactory operation.

4 Their characteristics are affected by the ambient temperature.

**Moulded case circuit breakers (MCCB)**

Moulded case circuit breakers are similar to thermo magnetic type MCBs except that these are available in higher ratings of 100 to 800amp at 500V 3-phase.

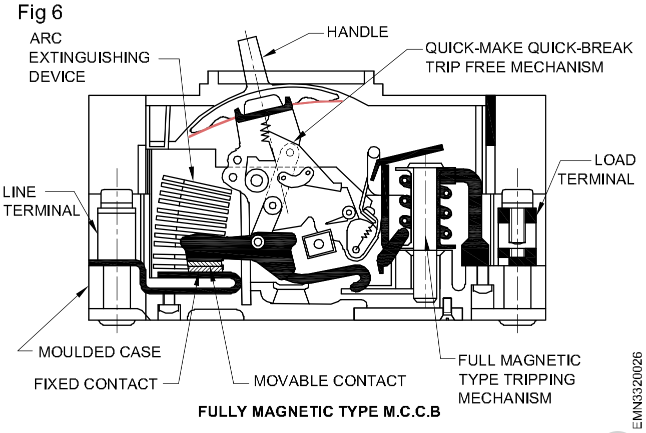
In MCCB, thermal and magnetic releases are adjustable. A shunt release is also incorporated for remote tripping and interlocking at MCCB. MCCBs are provided with under voltages release. There are two types of MCCB.

1 Thermal magnetic type

2 Fully magnetic type

The constructional feature of a fully magnetic MCCB design is shown in Fig. 6.

Fig 6




FULLY MAGNETIC TYPE M.C.C.B

**Advantages of MCCB**

1 MCCBs occupy much less space in comparison to fuse switch units or switch fuse units.

2 MCCBs provide equal amount of protection against high faults as switch gears having HRC fuses.

**Disadvantages**

1 MCCBs are much costlier.

**Application of (RC + MCB) combination circuit breakers**

1 All residential premises can have incoming protection after energy meter instead of fixing fuse and main switch.

2 All domestic equipments like water heaters, washing machines, electric iron, pump sets etc.,

3 All construction and outdoor electrical equipments such as lifts, hosts, vibrators, polishing machines etc.,

4 All industrial distribution and equipments

5 All agriculture pump sets.

6 Operation theaters and electrically operated medical equipment such as X-ray machines.

7 All neon sign installations

8 All low and medium voltage electrical distributions.

**Technical specification of MCBs**

| | |
|---|---|
| Related voltage | 240/ 415V AC 50Hz |
| | Up to 220V DC |
| Current rating | 0.5, 1, 1.6, 2, 2.5, 3, 4, 5, 6, 7.5, |
| | 10, 16, 20, 25, 32, 35, 40 and 63A. |
| No. of poles | 1,2,3 |
| Types | 'L' 'G' and 'DC' series |
| Breaking capacity | Upto to 9kA |
| Mechanical life | 1,00, 000 operations |
| Electrical life | 50,000 operations |
| Overload capacity | 15% over load |
| Housing | Glass fiber reinforced polyester |
| Fixing | Snap fixing on 35 mm DIN channel |
| Types of terminals | $25mm^2$ box type terminal at the |
| | incoming and outgoing. |

**Definition of Breaking capacity of MCB**

The short circuit breaking capacity of the circuit breaker is the current more than the prospective fault current at the point of installation of circuit breaker. Prospective fault current is the maximum fault current which may have to be interrupted by the circuit breaker.

# ELCB-types-working principle-specification

**Objectives** : At the end of this exercise you shall be able to
- **explain the working principle, different types and construction of an Earth Leakage Circuit Breaker (ELCB)**
- **explain the technical specifications of ELCB's.**

### Earth Leakage Circuit Breakers

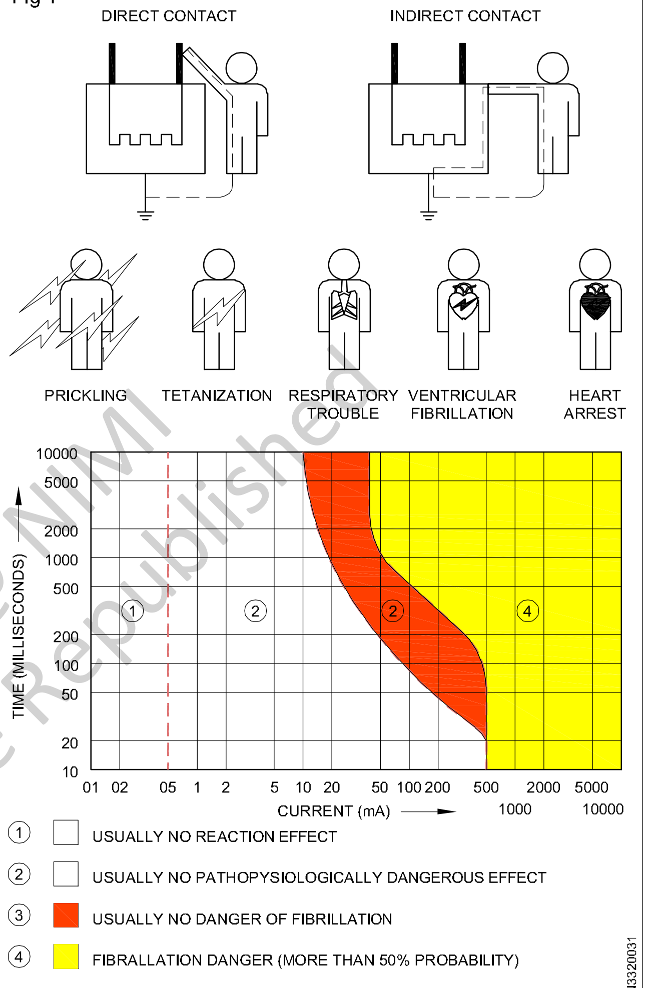
The sensation of electric shock is caused by the flow of electric current through the human body to earth. When a person comes in contact with electrically live objects like water heaters, washing machines electric iron etc., the extent of damages caused by this current depends on its magnitude and duration.

This kind of current is called the leakage current which comes in milli-amps. These leakage current being very small in magnitude go undetected by the fuses/MCBs are the major cause for the fires due to electricity.

The leakage current to earth also results in the wastage of energy and excessive billing for electricity not actually used.

Residual current operated circuit breakers are internationally accepted means of providing maximum protection from electric shocks and fires caused due to earth leakage current and also prevents the waste of electrical energy. These residual current circuit breakers (RCCB) are popularly called as Earth leakage circuit breakers (ELCB). Fig 1 shows the effect of electric current on human body in various levels represented in graph.

Fig 1



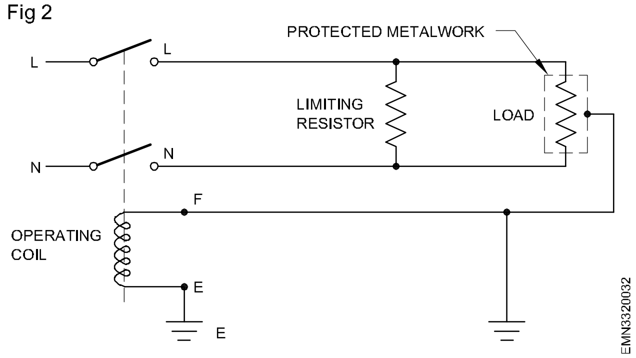

EFFECT OF ELECTRIC CURRENT ON HUMAN BODY

Basically ELCBs are of two types namely voltage operated ELCBs and the current operated ELCBs.

### Voltage operated ELCB (Fig. 2)

This device is used for making and breaking a circuit. It automatically trips or breaks the circuit when the potential difference between the protected metal work of the installation and the general mass of earth exceeds 24V. This voltage signal will cause the relay to operate. Voltage operated ELCBs are meant to be used where it is not practicable to meet the requirements of IEE wiring regulation by direct earthing or where additional protection is desirable. (Fig. 2)

Fig 2




The above circuit shows the principle of operation of a voltage operated ELCB.

### Current operated ELCB

This device is used for making and breaking a circuit and for breaking a circuit automatically when the vector sum of current in all conductors feeding the circuit controlled by the circuit breaker differs from zero by a predetermined amount. Current operated ELCBs are much more reliable in operation, easier to install and maintain.

### Construction of ELCB

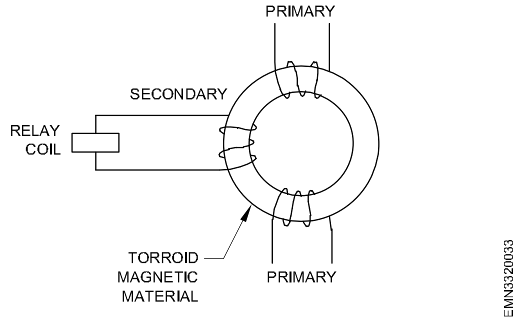
It consists of a Torroid ring made of high permeability magnetic material. It has two primary windings each carrying the current flowing through phase and neutral of the installation. The secondary winding is connected to a highly sensitive electron magnetic trip relay which operates the trip mechanism.

## Working principle of ELCB (RCD breaker)

The residual current device is a circuit breaker which continuously compares the current in the phase with that in the neutral. The difference between the two is called as the residual current which is flowing to earth.

The purpose of the residual current device is to monitor the residual current and to switch off the circuit if it rises from a preset level. The arrangement of RCD is shown in Fig. 3.

Fig 3




The main contacts are closed against the pressure of a spring which, provides the energy to open them when the device trips. Phase and neutral current pass through identical coils wound in opposing direction on a magnetic circuit, so that each coil will provide equal but opposing numbers of ampere turns when there is no residual current. The opposing ampere turns will cancel and no magnetic flux will be set up in the magnetic circuit.

In a healthy circuit the sum of the current in phases is equal to the current in the neutral and vector sum of all the current is equal to zero. If there is any insulation fault in the circuit then leakage current flows to earth. This residual current passes to the circuit through the phase coil but returns through the earth path and avoids the neutral coil, which will therefore carry less current. So the phase ampere turns exceeds neutral ampere turns and an alternating magnetic flux results in the core. The flux links with the secondary coil wound on the same magnetic circuit inducing an emf into it. The value of this emf depends on the residual current, so it drives a current to the tripping system which depends on the difference between them and neutral current.

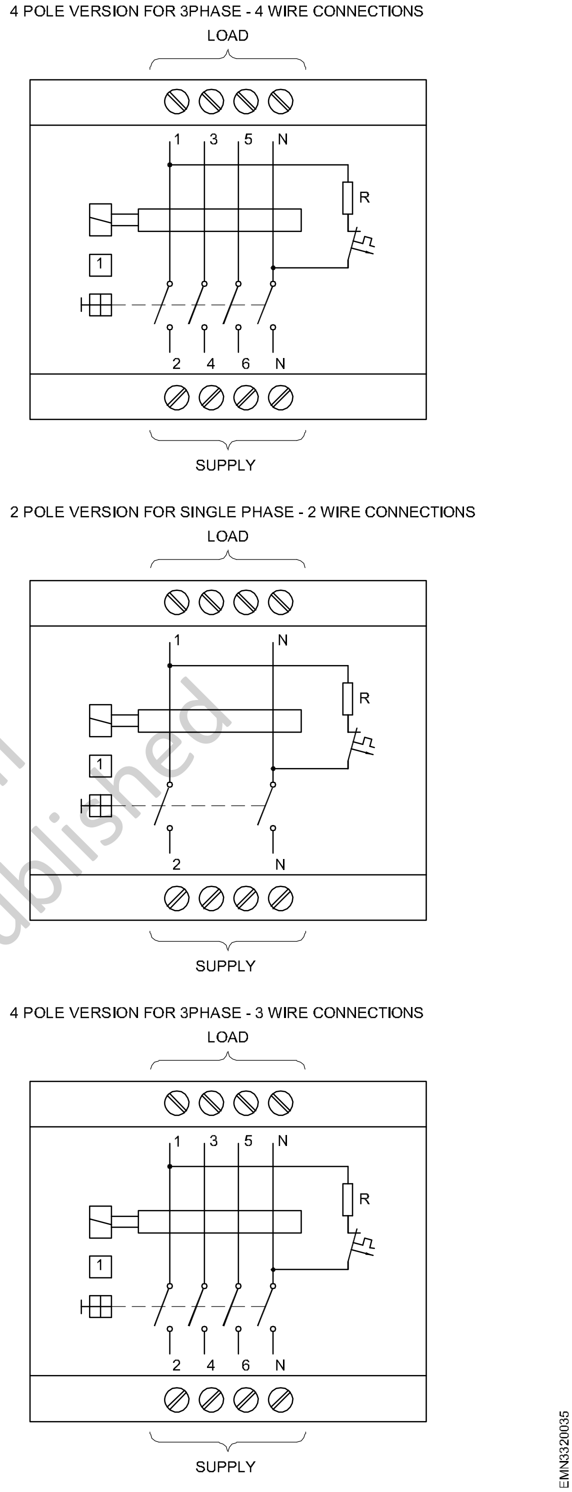
When tripping current reaches a predetermined level the circuit breaker trips and open the main contacts and thus interrupts the circuit.

Fig 4 shows a 4 pole Residual current circuit breaker being connected in a 3-phase 4 wire system load circuit.

### Test Switch

As shown in Fig 5 test switch is a requirement of BS842. It is used to test the functioning of ELCB. When the test button is pressed it circulates additional current through neutral coil which is determined by the value of current limiting resistor R. As a result there exists a difference in current flowing through phase and neutral coils and hence the ELCB trips off.

Fig 5




### Technical specification

The current ratings of ELCB are 25A, 40A and 63A.

No. of poles - 2 and 4

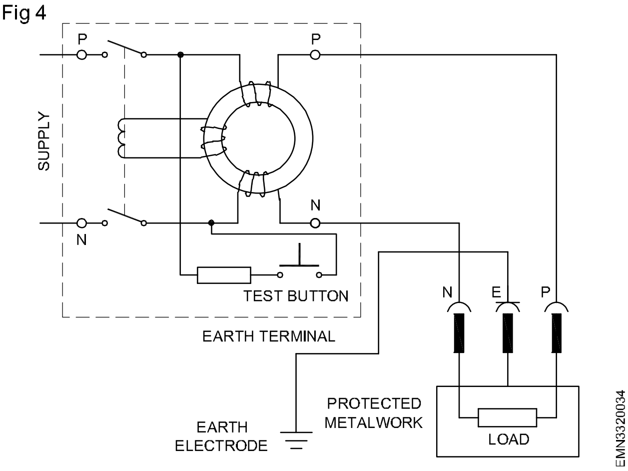
Nominal voltage - 240/415V 50Hz.

Sensitivities: ELCBs are designed to trip at leakage currents of 30mA, 100mA, and 300mA.

Electrical life: More then 10,000 operations.

Mechanical life: 20000 to 100000 operations.

Fig 4




Tripping time - < 30ms.

**Time delayed RCCB**

There are cases, where more than one RCCB is used in an installation, for example a complete installation may be protected by an RCCB rated at 100mA, while a socket intended for equipment may be protected by 30mA device. Discrimination of the two devices then becomes important. For example an earth fault occurs in the equipment giving an earth fault current of 250mA. Since the fault current is higher, than the operating current of both devices both will trip. It does not follow, that the device with smaller operating current will trip first. This is a lack of discrimination between the two devices. To ensure proper discrimination, the device with a larger operating current, has a deliberate time delay built into its operation. It is called time-delayed RCCB.

**Calculation of Earth fault loop impedance**

Earth wire from an equipment to the earth electrode is called earth loop. Its impedance should not be more than 50 earth fault loop impedance in ohm, multiplied by the rated tripping current of the R.C.C.B.(ELCB) in ampere should not exceed 50 (i.e) $Z_E \times I_t < 50$.

Where Z = Earth wire loop impedance

$I_t$ = Rated tripping current in Ampere

**Example**

An ELCB with a rated tripping current of 30mA, the maximum possible Earth fault loop impedance will be

$$Z_E\,(max) = 50/I_t = \frac{50}{0.03} = 1666 \text{ ohm}$$

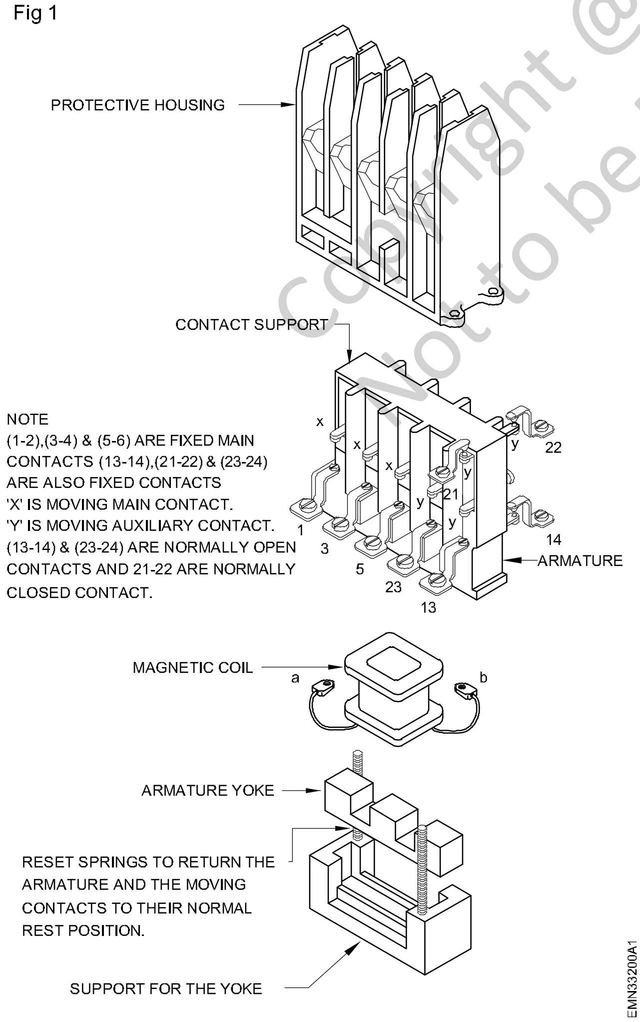
## Contactors-parts-functions-troubleshooting-symbols

**Objectives:** At the end of this lesson you shall be able to
- **explain the basic contactor circuit with a single push-button station for start and stop**
- **state the function of a no-volt coil, its rated voltage, position of operation, its common troubles, their causes and remedies.**

**i) Contactors:** The contactor forms the main part in all the starters. A contactor is defined as a switching device capable of making, carrying and breaking a load circuit at a frequency of 60 cycles per hour or more. It may be operated by hand (mechanical), electromagnetic, pneumatic or electro-pneumatic relays.

The contactors shown in Fig. 1 consist of main contacts, auxiliary contacts and no-volt coil. As per Fig 1, there are three sets of normally open, main contacts between terminals 1 and 2, 3 and 4, 5 and 6, two sets of normally open auxiliary contacts between terminals 23 and 24, 13 and 14, and one set of normally closed auxiliary contact between terminals 21 and 22. Auxiliary contacts carry less current than main contacts. Normally contactors will not have the push-button stations and O.L. relay as an integrated part, but will have to be used as separate accessories along with the contactor to form the starter function.

Fig 1

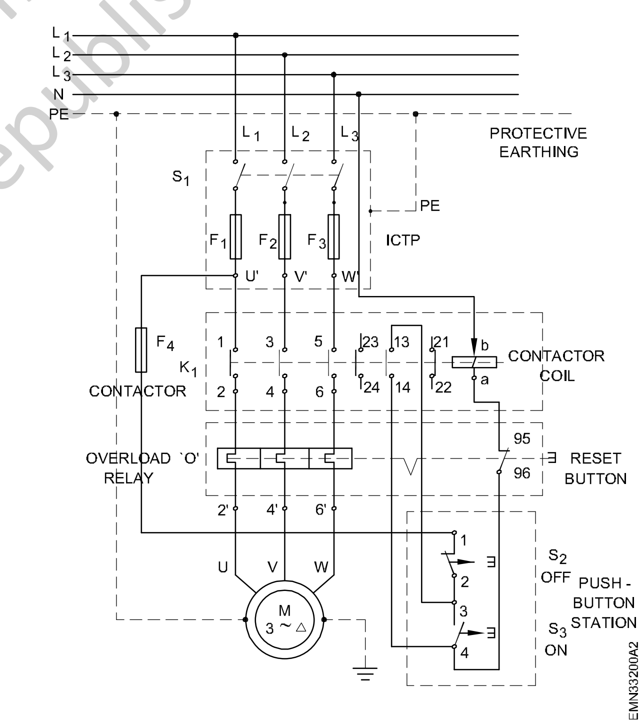



The main parts of a magnetic contactor are shown in Fig. 1, and Fig. 2 shows the schematic diagram of the contactor when used along with fused switches (ICTP), push-button stations and OL relay for connecting a squirrel cage motor for starting directly from the main supply. In the same way the direct on-line starter consists of a contactor, OL relay and push-button station in an enclosure.

### Functional description

Power circuit: As shown in Fig.2, when the main ICTP switch is closed and the contactor $K_1$ is operated, all the three windings U V & W of the motor are connected to the supply terminals R Y B via the ICTP switch, contactor and OL relay.

Fig 2

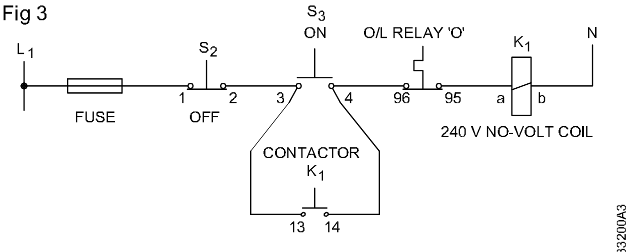



The overload current relay (bimetallic relay) protects the motor from overload (`motor protection'), while the fuses F1/F2/F3 protect the motor circuit in the event of phase-to-phase or phase-to-frame short circuits.

### Control circuits

**Push-button actuation from one operating location:** As shown in the complete circuit Fig. 3, and the control circuit Fig. 3, when the `ON' push-button $S_3$ is pressed, the control circuit closes, the contactor coil is energised and the contactor $K_1$ closes. An auxiliary, a normally open contact 13,14 is also actuated together with the main contacts of $K_1$. If this normally open contact is connected in parallel with $S_3$, it is called a self-holding auxiliary contact.

Fig 3




CONTROL CIRCUIT

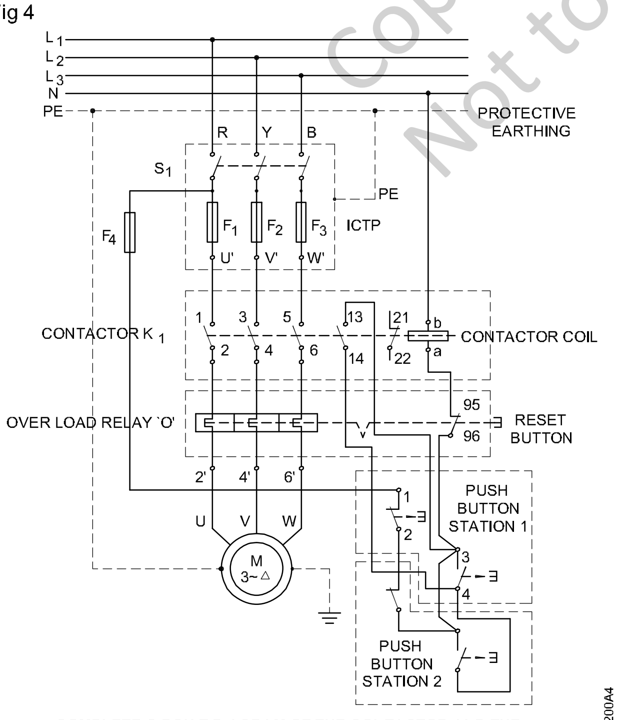
After $S_3$ is released, the current flows via this self-holding contact 13,14, and the contactor remains closed. In order to open the contactor, $S_2$ must be actuated. If $S_3$ and $S_2$ are actuated simultaneously, the contactor is unaffected.

In the event of overloads in the power circuit, the normally closed contact 95 and 96 of overload relay `O' opens, and switches off the control circuit. Thereby $K_1$ switches `OFF' the motor circuit.

Once the contact between 95 and 96, is opened due to the activation of the overload relay `O', the contacts stay open and the motor cannot be started again by pushing the `ON' button $S_3$. It has to be reset to normally closed position by pushing the reset button. In certain starters, the reset could be done by pushing the `OFF' button which is in line with the overload relay `O'.

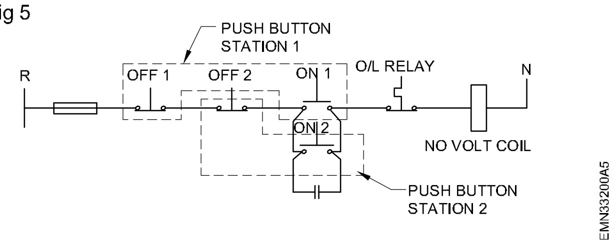
**Push-button actuation from two operating locations:** If it is desired to switch a contactor off and on from either of the two locations, the corresponding OFF push-buttons should be connected in series, and the ON push-buttons in parallel, as shown in the complete diagram Fig 4 and the control diagram Fig. 5.

Fig 4




COMPLETE CIRCUIT DIAGRAM OF THE CONTACTOR AND THE 3 PHASE SQUIRREL CAGE INDUCTION MOTOR

Fig 5




If either of the two ON push-buttons is actuated, $K_1$ is energised and holds itself closed with the help of normally-open contact 13 & 14 which is closed by contactor $K_1$. If either of the two OFF push -buttons is actuated, the contactor opens.

Purpose of overload relays: The overload relays protect the motor against repeated, excessive momentary surges or normal overloads existing for long periods, or high currents caused in two phases by the single-phasing effect. These relays have characteristics which help the relay to open the contactor in 10 seconds if the motor current is 500 percent of the full load current, or in 4 minutes if the current is 150 percent of the full load current.

**Tripping of starters:** A starter may trip due to the following reasons.

– Low voltage or failure of power supply

– Persistent overload on the motor

In the first instance, the tripping occurs through the coil which opens the contacts when the voltage falls below a certain level. The starter can be restarted as soon as the supply is back to normal.

The relay trips the starter when there is an overload. It can be restarted only after the relay is reset and the load becomes normal.

**No-volt coil:** A no-volt coil consists of generally more number of turns of thin gauge of wire.

**Coil voltages:** Selection of coils depends on the actual supply voltage available. A wide variety of coil voltages like 24V, 40V, 110V, 220 V 230/250 V, 380V 400/440V AC or DC are available as standard for contactors and starters.

**Troubleshooting in contactor:** Table 1 gives the common symptoms their causes and remedies.

Table 1

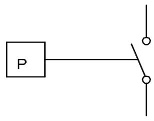
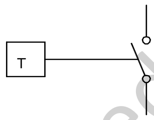
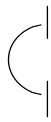
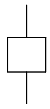
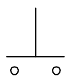
| Symptoms | Causes | Remedies |
|---|---|---|
| Motor does not start when the 'start' button is pressed. However on pressing the armature of the contactor manually, motor starts and runs. | Open in no-volt coil circuit. | Check the main voltage for lower than acceptable value. Rectify the main voltage. Check the control circuit wiring for loose connection. Check the resistance of the no-volt coil winding. If found incorrect replace the coil. |
| Motor starts when `ON' button is pressed. It however stops immediately when `ON' button is released. | Auxiliary contact in parallel with the start-button is not closing. | Check the parallel connection from `ON' button terminals to the auxiliary contact of the contactor.<br>Rectify the defect.<br>Check the auxiliary contact points of the contactor for erosion and pittings. Replace, if found defective. |
| Motor does start when the start-button is pressed. However, a humming or chattering noise comes from the starter. | Movable armature and fixed limb of electromagnet are not stably attracted. | Dust or dirt or grit between the mating surfaces of the electromagnetic core. Clean them.<br>Low voltage supply. Find the cause and rectify the defect.<br>Break in the shading ring in the case of AC magnet. |
| Failure of contactor due to too much heating of the `No' volt coil. | Higher incoming supply rating. No-volt coil rating is not high. | Higher supply voltage than normal. Reduce the incoming voltage.<br>Voltage rating of the no-volt coil is less. Replace with standard rating, according to the main supply. |
| Motor does not restart immediately after tripping of OL relay even though OL relay was reset. | It takes a little time for the thermal bimetal to cool and reset. | Wait for 2 to 4 minutes before re-starting. |
| Coil does not get energised even though supply voltage is found across the no-volt coil terminals. | Open-circuited NVC.<br>NVC burnt out. | Check the nylon strip on relay.<br>Check the nylon button below the start button<br>Replace, if necessary. |
| Relay coil has been changed. However motor does not start when the start-button is pressed. | Control circuit of relay open. | Check the control circuit for open.<br>Clean the control station contacts.<br>Overload relay not reset. |
| Humming or chattering noise. | Low voltage.<br>Magnetic face between yoke and armature is not clean.<br>Shading ring on iron core missing. | Feed the rated voltage.<br>Clean the surfaces of yoke and armature.<br>Provide shading ring in the iron core |

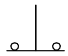
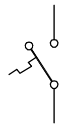
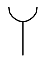
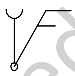
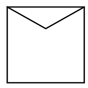
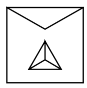
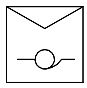
## ii) B.I.S. symbols pertaining to contactor and machines

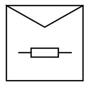
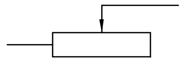
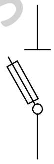
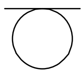
Identify and draw B.I.S. symbols pertaining to rotating machines and transformers (BIS 2032 Part IV), contactors, switch, gear and mechanical controls (BIS 2032 Part VII, 2032 Part XXV and XXVII).

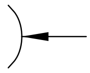
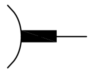
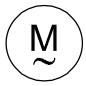
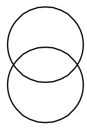
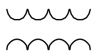
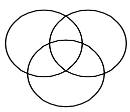
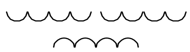
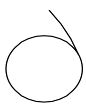
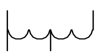
**The table given below contains most of the important symbols used by an electrician. However, you are advised to refer to the quoted B.I.S. standards for further additional information.**

Table

| S.No. | BIS Code No. | Description | Symbol | Remarks |
|---|---|---|---|---|
| | BIS 2032 (Part XXV)-1980 | | | |
| 1 | 9.3 | Pressure switch |  | |
| 2 | 9.4 | Thermostat |  | |
| 3 | 9.5 | Circuit-breaker |  | |
| 4 | 9.5.1 | Alternate symbol of circuit-breaker.<br>**Note : The rectangle of symbol 9.5 should contain some indication that a circuit-breaker is concerned.** |  | |
| 5 | 9.5.2 | Alternate symbol for circuit breaker. |  | |
| 6 | 9.9 | Contactor, normally open. |  | |
| 7 | 9.9.1 | Contactor, normally closed. |  | |
| 8 | 9.10 | Push-button with normally open contact. |  | |

| S.No. | BIS Code No. | Description | Symbol | Remarks |
|---|---|---|---|---|
| 9 | 9.10.1 | Push-button with normally closed contact. |  | |
| 10 | 9.11 | Isolator. |  | |
| 11 | 9.16 | Thermal overload contact. |  | |
| 12 | 9.17 | Socket(female). |  | |
| 13 | 9.17.2 | Socket with switch. |  | |
| 14 | 9.18 | Plug (male). |  | |
| 15 | 9.19 | Plug and socket (male and female). |  | |
| 16 | 9.20 | Starter, general symbol. |  | |
| 17 | 9.22 | Star- delta starter. |  | |
| 18 | 9.23 | Auto-transformer starter. |  | |
| 19 | 9.24 | Pole-changing starter (Example, 8/4 poles). |   | |

| | | | |
|---|---|---|---|
| 20 | 9.25 | Rheostatic starter. |  |
| 21 | 9.26 | Direct on-line starter. |  |
| 22 | 9.27.1 | Resistor with moving contact, general symbol. |  |
| 23 | 9.29 | Fuse. |  |
| 24 | 9.29.1 | Alternate symbol for fuse. |  |
| 25 | 9.31 | Isolating fuse-switch. |  |
| | BIS 2032 Part(XXV11) 1932 | **Contactors** | |
| | 3.2 | **Qualifying symbols** | |
| 26 | 3.2.2 | Circuit-breaker function. |  |
| 27 | 3.2.4 | Switch-disconnector (isolator switch) function. |  |
| 28 | 3.14 | Winding<br>Note: The number of half circles is not fixed, but if desired a distinction might be made for the different windings of a machine as specified in 3.2,3.3 and 3.4. |  |
| 29 | 3.24 | Commutating or compensating winding. |  |

| | | | | |
|---|---|---|---|---|
| 30 | 3.34 | Series winding. |  | |
| 31 | 3.44 | Shunt winding or separate winding. |  | |
| 32 | 3.54 | Brush or slip-ring. |  | |
| 33 | 3.64 | Brush on commutator. |  | |
| 34 | 4.2.1 | Direct current generator, general symbol. |   | |
| 35 | 4.2.2 | Direct current motor, general symbol. |   | |
| 36 | 4.3.1 | AC generator, general symbol. |   | |
| 37 | 4.3.2 | AC motor, general symbol |   | |
| | 5.1 | General Symbols | | |
| 38 | 5.1.1 | Transformer with two separate windings. |  |  |
| | | | **Simplified multiline representation** | **Complete multiline representation** |
| 39 | 5.1.2 | Transformer with three separate windings. |  |  |
| 40 | 5.1.3 | Auto-transformers |  |  |

## Relays-types-operations-specification-symbols

**Objectives:** At the end of this lesson you shall be able to
- **define a realy**
- **classify relays according to the operating force and function**
- **state the common codes used for specifying contacts and poles**
- **specify a relay**
- **explain the function of the shading coil in an AC relay**
- **state the causes of the failure of the relay**
- **identify the symbols used in relay as per I.S.2032 (Part XXVII).**

**Relay:** A relay is a device which opens or closes an auxiliary circuit under predetermined conditions in the main circuit.

Relays are extensively used in electronics, electrical engineering and many other fields.

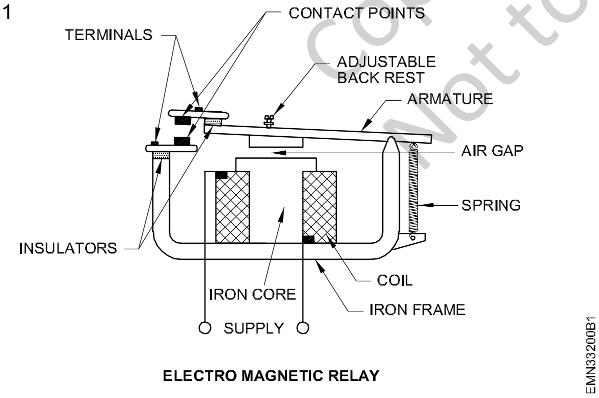
There are relays that are sensitive to conditions of voltage, current, temperature, frequency or some combination of these conditions.

Relays are also classified according to their main operating force as stated under.

- Electromagnetic relays
- Thermal relays

**Electromagnetic relay:** A relay switch assembly is a combination of movable and fixed low-resistance contacts that open or close a circuit. The fixed contacts are mounted on springs or brackets, which have some flexibility. The movable contacts are mounted on a spring or a hinged arm that is moved by the electromagnet in the relay as shown in Fig. 1.

Fig 1




ELECTRO MAGNETIC RELAY

The other types of relays coming under this group are as follows.

**Current sensing relay:** A current sensing relay functions whenever the current in the coil reaches an upper limit. The difference between the current specified for pick up (must operate) and non-pick up (must not operate) is usually closely controlled. The difference in current may also be closely controlled for drop out (must release) and non-drop out (must not release).

**Under-current relay:** Under-current relay is an alarm or protective relay. It is specifically designed to operate when the current falls below a predetermined value.

**Voltage sensing relay:** A voltage sensing relay is used where a condition of under-voltage or over-voltage may cause a damage to the equipment. For example, these types of relays are used in voltage stabilizers. Either a proportional AC voltage derived from a transformer or a proportional DC derived from a transformer and rectifier is used for this purpose.

**Latching relays**

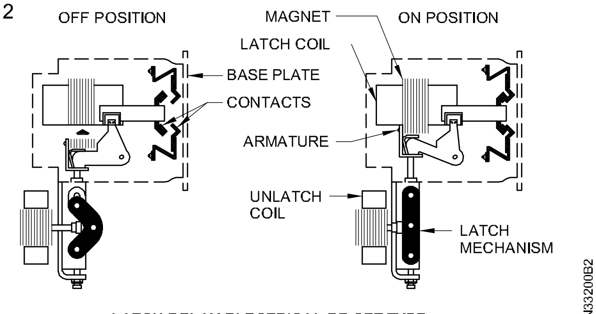
Latching relays are capable of maintaining their contacts in the last assumed position without the maintained current in the coil. These relays hold their contacts in position after power is cut off.

There are two basic kinds of latching relays called mechanical reset and electrical reset.

**Mechanical re-set relays:** Mechanical re-set relays have a coil, an armature mechanism, and a mechanical latching device that locks the armature in the operated position after the coil has been de-energised. Manual tripping of the locking mechanism, re-sets the relay.

**Electrical reset relays:** An electrical re-set relay shown in Fig. 2 has the same operating mechanism, but it includes a second coil and armature to trip the latching mechanism. This system allows remote re-setting of the relays to their original position.

Fig 2




LATCH RELAY ELECTRICAL RE-SET TYPE

**Reed relays**

Reed relays physically look different than other kinds of relays. They consist of essentially magnetically actuated reed switches, with actuating solenoids or coils.

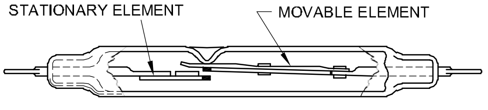
In the reed relay, freedom from contamination and the limited number of moving parts, avoid many disadvantages of the conventional electromechanical relays. In addition to the above, the contact resistance is kept to minimum due to the fact the contact points are made either with gold or rhodium. Further, these relays need very low power to operate and can handle a 250 watt solenoid load on their contacts.

There are three types of reed relays namely

- dry-reed relay
- ferreed relay
- mercury wetted contact relay

**Dry reed relay:** Fig.3 shows this type of relay. Two opposing reeds are sealed in to a narrow glass tube. The reeds overlap at their free ends. At the contact area, they are usually plated with gold or rhodium to produce a low contact resistance. They may have multipole multicontact designs.

Fig 3

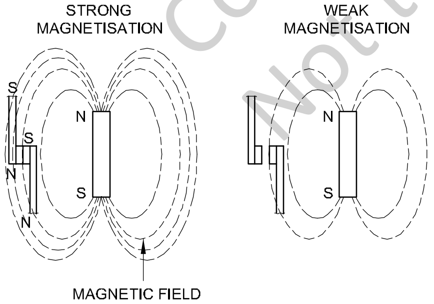



DRY REED RELAY

**Ferreed relay:** The word ferreed denotes a reed relay in which the dry-reed switch is contained with one or more magnetic members. The magnetisation can be changed by current pulses in associated coils.

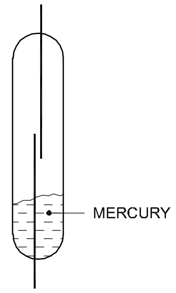
As shown in Fig. 4 in the magnetised state the magnetic members supply a field strong enough to close the contacts. In the other magnetised state, the field is too weak to hold the contacts closed. An operating pulse through the coil produces the first state. A release pulse produces the second state. The contacts can break or make within 5 micro-seconds duration.

Fig 4




**Mercury wetted contact relay:** As shown in Fig. 5 this relay consists of a glass enclosed reed with its base immersed in a pool of mercury. When the coil surrounding the capsule is activated, mercury makes the contact between fixed and movable contacts.

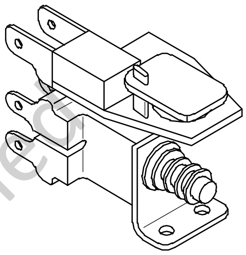
Fig 5




MERCURY-WETTED REED RELAY

**Impulse relay:** The impulse relay shown in Fig. 6 is a special single-coil relay. It has an armature-driven mechanism that alternatively assumes one of two positions as the coil is pulsed. This mechanism moves the contact from one position to the other and back again as electrical pulses are received. The relay can operate on AC or DC power.

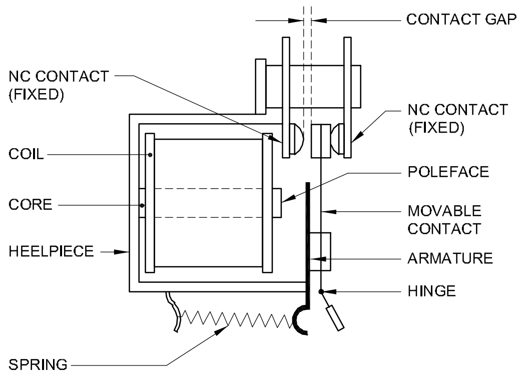
Fig 6




IMPULSE RELAY

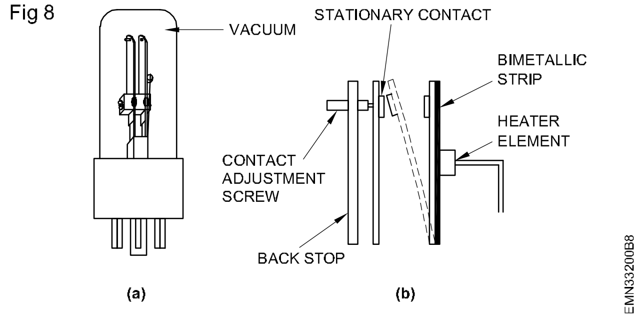
**Clapper-type armature relay:** The simplest contact arrangement used in armature relays is the break-make or transfer-contact combination. A clapper-type armature, shown in Fig. 7 opens or closes the contacts. A movable contact is attached directly to the armature by means of a flexible strip of metal. When the electromagnet operates, the armature moves this contact, opening and closing the two sets of contacts.

Fig 7




**Thermal relay:** A thermal relay shown in Fig. 8 is one that operates by changes in temperature. Most of the bimetallic relays where the bimetallic element changes its shape, in response to changes in temperature comes under this group. It takes time for the heating element to reach the necessary temperature and more time to raise the temperature of the bimetallic element. Therefore, thermal relays are often used as time-delay relays.

Fig 8




**Poles and contacts:** Relays may operate single or as multi-poles and may open or close specified contacts. In writing specifications certain abbreviations as stated below are commonly used.

SP - Single pole

SB - Single break

ST - Single throw

DB - Double break

DP - Double pole

DM - Double make

DT - Double throw

NO - Normally open

3P - Three pole

NC - Normally closed

4P - Four pole

For example a 4PDT has a four-pole, double throw contact arrangement.

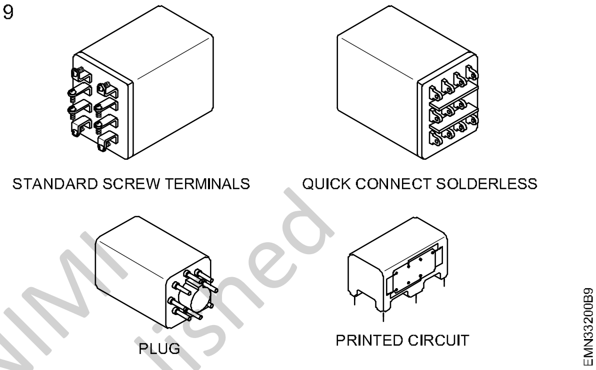
NO indicates the contacts are open in the unoperated position of the relay and they are called as normally open (NO) contacts.

NC indicates the contacts are closed in the unoperated position of the relay and they are called normally closed (NC) contacts.

Table 1 given below lists some of the relay contact combinations.

**Enclosures and mounts:** Relays are normally enclosed in plastic or metal caps to protect the operating parts against dust and environment. Relays can be mounted to the circuit direct by plug-in system, PCB mounting or may be wired separately using screws terminals. These types are shown in Fig. 9.

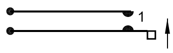
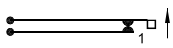
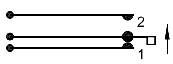
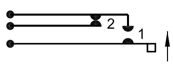
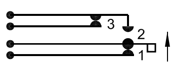
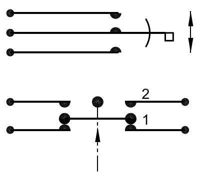
Fig 9

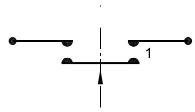
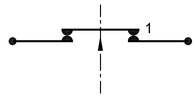
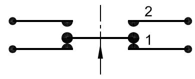



**AC relay:** In an AC relay magnet, the magnetic field continually changes direction. With a 50 Hz supply the magnetic field passes through zero 100 times per second. At the time of zero field, the armature starts to release. Although the field quickly builds up in the reverse direction, a noisy chatter can result.



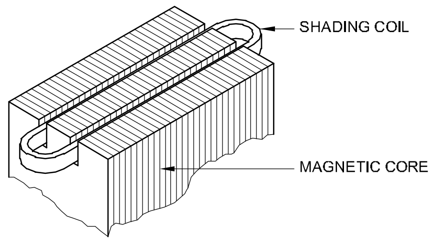
Table 1

| Design | Sequence | Symbol |
|---|---|---|
| 1 SPST-NO | Make 1 |  |
| 2 SPST-NC<br>SPDT | Break 1<br>Break1 before make 2 |  |
| 3 SPDT | Make 1 before break 2 |  |
| 4 SPDT<br>(B-M-B) | Break 1 before make 2 before break 3 |  |
| 5 SPDT-NO | Center OFF |  |
| 6 SPDT-NC-NO<br>(DB-DM) | Double break 1<br>double make 2 |  |

| Design | Sequence | Symbol |
|---|---|---|
| 7 SPST-NO (DM) | Double make 1 |  |
| 8 SPST-NC (DB) | Double break 1 |  |
| 9 SPDT-NC (DB-DM) | Double break 1<br>double make 2 |  |

To eliminate chatter, a shading coil as shown in Fig. 10 is placed near the tip of the magnet pole face. This shading coil establishes a magnetic field that lags the main magnetic field slightly and aids in keeping the magnet sealed when the main field passes through zero.

Fig 10




**An AC relay should not be used in DC supply.**

**The AC relay when connected to DC supply, will draw more current in the absence of inductive reactance and result in burning out the coil.**

Causes of relay failures: Relay failures are usually caused by the gradual deterioration of the parts. This deterioration can be electrical, mechanical or chemical in nature.

The environmental shirks that contribute to physical breakdown include large temperature changes, shock, vibration and voltage or current changes. Therefore, it is important that these factors are taken into consideration to ensure reliable performance of relays.

In general, when a relay fails, look for the following.

1 Improper control voltage.

2 Dirt, grease or gum on contacts or moving parts.

3 Excessive heating of parts: discolouration or charred insulation on coil or base.

4 Bending of moving parts.

5 Corrosion or deposits on metal parts.

6 Excessive wear on moving parts.

7 Loose connections.

8 Improper spring tension.

9 Improper control pressure.

10 Improper functioning of the time delay device.

While specifying relays the following particulars are necessary.

Type of operating voltage

AC or DC

Sequence of operation ____________________

Operating voltage ____________________ volts

Current rating ____________________ amps

Coil resistance ____________________ ohms

Number of contacts ________ NO ________ NC

Number of poles ____________________

Type of mount ____________________

Type of enclosure ____________________

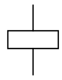
Symbols used in relay circuit: Following are the I.S. symbols connected with the relays as per I.S.2032(Part XXVII). These may be used along with the contact symbols for illustrating the function of the relay.

## Elements of electro-mechanical relays

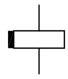
(Except measuring and protective relays)

**Relay coils**

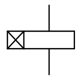
1 Relay coil (General symbol)



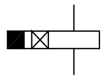
2 Relay coil of a slow-releasing relay



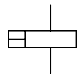
3 Relay coil of a slow operating relay



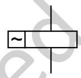
4 Relay coil of a slow-operating and slow-releasing relay



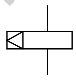
5 Relay coil of a high speed relay (fast-operating and fast-releasing)
**Note: This symbol should be used only if it is desirable to emphasize that a certain relay is essentially more rapid than other relays and that use is made thereof.**



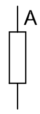
6 Relay coil of an AC relay



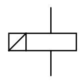

7 Relay coil of a mechanically latched relay



8 Note: The two windings of the relay coil are to be marked by the same sign, for example, the letter A.




9 Actuating device for a thermal relay



**Windings**

10 Winding of a slow releasing relay

11 Winding of a slow operating relay

12 Winding of a polarised relay


13 Winding of a permanent relay

14 Energy flow from the bus-bars

15 Energy flow towards the bus-bars

**Purpose of overload relays:** The overload relays protect the motor against repeated, excessive momentary surges or normal overloads existing for long periods, or high currents caused in two phases by the single-phasing effect. These relays have characteristics which help the relay to open the contactor in 10 seconds if the motor current is 500 percent of the full load current or in 4 minute

### Types of overload relay

There are two types of overload relays. They are :

- magnetic overload relay
- thermal (bimetallic) overload relay.

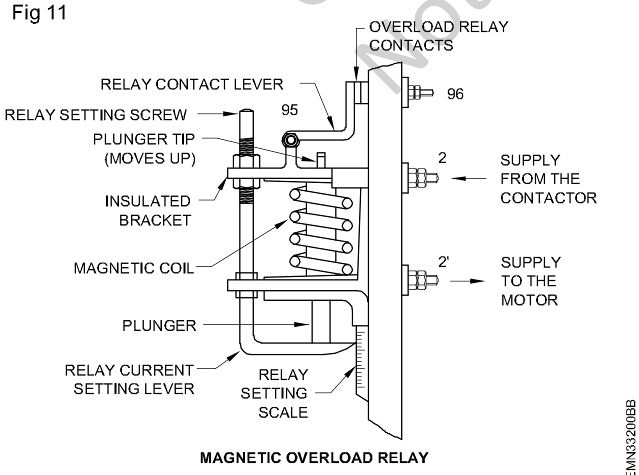
Normally there are 3 coils in a magnetic relay and 3 sets of heater coils in a bimetallic relay so that two coils will operate in case of single phasing which help in avoiding the burning out of the motor.

**Magnetic overload relay:** The magnetic overload relay coil is connected in series with the motor circuits. The coil of the magnetic relay must be wound with a wire, large enough in size to pass the motor current. As these overload relays operate by current intensity and not by heat, they are faster than bimetal relays.

As shown in Fig. 11, the magnetic coil carries the motor current through terminals 2 and 2' which is in series with the power circuit. The relay contacts, 95 and 96, are in series with the control circuit. When a current more than a certain stipulated value, as set by the relay set scale, passes through the power circuit, the magnetic flux produced by the coil will lift the plunger in an upward direction. This upward movement makes the plunger tip to push the relay contact lever, and the contact between terminals 95 and 96 opens. This breaks the no volt coil circuit and the contactor opens the power circuit to the motor. The relay contacts between terminals 95 and 96 stay open till the rest-button (not shown in the figure) is pressed.



Fig 11



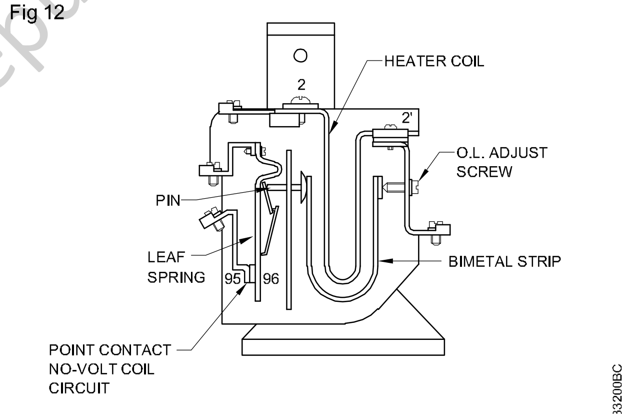

MAGNETIC OVERLOAD RELAY

**Bimetallic overload relays:** Most bimetallic relays can be adjusted to trip within a range of 85 to 115 per cent of the nominal trip rating of the heater unit. This feature is useful when the recommended heater size may result in unnecessary tripping, while the next larger size will not give adequate protection. Ambient temperatures affect thermally-operated overload relays.

The tripping of the control circuit in the bimetallic relay results from the difference of expansion of two dissimilar metals fused together. Movement occurs if one of the metal expands more than the other when subjected to heat. A U-shaped bimetallic strip is used in the relay as shown in Fig. 12. The U-shaped strip and a heater element inserted in the centre of the U compartments for avoiding possible uneven heating due to variations in the mounting location of the heater element.

As shown in Fig 12, under normal conditions, the bimetallic strip pushes the pin against the leaf-spring tension, and the point contacts 95 and 96 are in a closed position, and hence the no-volt coil circuit is completed while the motor is running. When a higher current passes through the heater coil connected to terminals 2 and 2', the heat generated in the coil heats up the bimetal strip which bends inward. Hence the pin retracts in the right hand direction and the leaf-spring opens the contact between 95 and 96 to open the contactor. The relay cannot be reset immediately as the heat in the bimetallic strips require some time for cooling.

Fig 12




BIMETALLIC OVERLOAD RELAY

**Relay setting:** The overload relay unit is the protection centre of the motor starter. Relays come in a number of ranges. Selection of a relay for a starter depends upon the motor type, rating and duty.

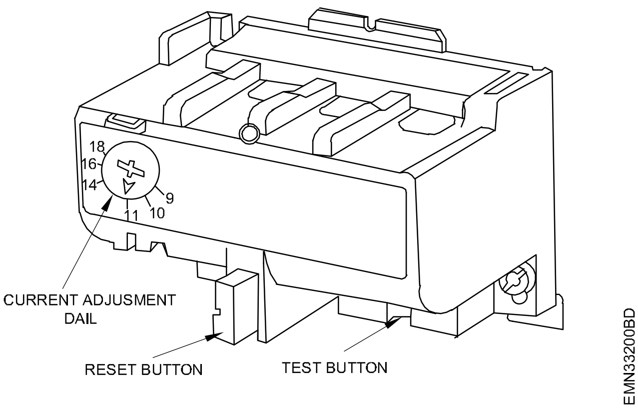
For all direct on-line starters, relays should be set to the actual load current of the motor. This value should be equal to or lower than the full load current indicated on the name-plate of the motor. Described here is a simple procedure for setting the relay to the actual load current.

Set the relay to about 80% of the full load current. If it trips, increase the setting to 85% or more till the relay holds. The relay should never be set at more than the actual current drawn by the motor. (The actual current drawn by a motor will be less than the full load current in most cases, as motors may not be loaded to capacity.)

Thermal overload is used for motor protection basically thermal overload relay overload relay is an overcurrent protection of the simplest type. The working principle of thermal overload relay is very simple thermal overload relay is shown in Fig .13. An adjustment dial located on the unit allows the ampere trip setting. A manual test button is provided to test the operation of the relay control contacts

It is known that diffrent material have diffrent coefficient of thermal expansion. So if two diffrent metals joined together are heated, then the metal having the greater value of

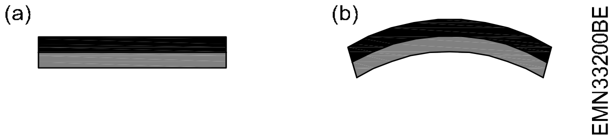
Fig 13




coefficient of thermal expansion will expand more as compared to the other and this will cause a bend in the bimetallic strip as shown in Fig 14 a and 14 b. This phenomenon is used in thermal overload relay.

Thermal overload relays: most bimetallic relays can be adjusted to trip within a range of 85 to 115 per cent of the normal trip rating of the heater unit. This feature is useful

Fig 14




when the recommended heater unit. This feature is useful when the recommended heater size may result in unnecessary tripping, while the next larger size will not give adequate protection. Ambient temperatures effect thermally-operated overload relays.

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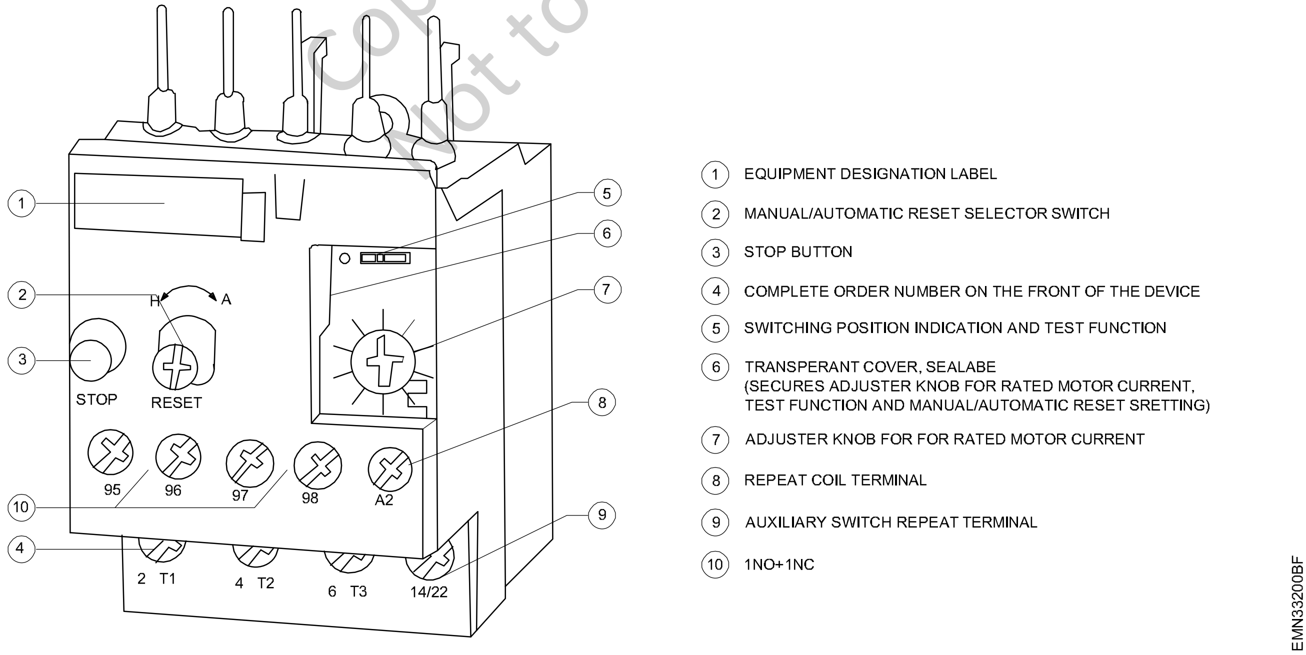
Fig 15



Relay setting: The overload relay unit is the protection centre of the motor starter. Relays come in a number of ranges. Selection of a relay for a starter depends upon the motor type, rating and duty.

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The thermal overload relay shown in Fig-15 is designed for current-depending protection of loads upto 100A with normal starting (see Functions) against excessive temperature rises due to overload or phase failure.

An overload or phase failure results in an increase of the motor current beyond the set motor rated cuurent via heating elements inside the device this current rise heats up the bimetallic which then bend and as a result trigger the auxiliary contacts by means of a tripping mechanism. The auxiliary contacts then switch off the load by means of the contactor.

The break time depends on the ratio between the tripping current and operating current the “tripped” status is signalloo

ed by means of a switch position indicator. The contactor is either reset manually or automatically after the recovery time has elapsed they comply with important worldwide standrads and approvals.

# Single phase induction motors-types- resistance start-induction run motor, centrifugal switch-capacitor start, induction run motor-capacitor start, capacitor run motor

**Objectives:** At the end of this lesson you shall be able to
- **explain briefly the types of AC single phase motors**
- **explain the necessity and methods of split-phasing the single phase to obtain a rotating magnetic field**
- **explain the principle, construction, operation characteristic and application of single phase resistance / induction-start / induction-run motors.**

**i) Single phase induction motors**

Single phase motors perform a great variety of useful services at home, office, farm, factory, and in business establishments. These motors are generally referred to as fractional horsepower motors with a rating of less than 1 H.P. Most single phase motors fall into this category. Single phase motors are also manufactured in 1.5,2,3 and up to 10 H.P. as a special requirement.

Single phase motors may be broadly classified as split-phase induction motors and commutator motors according to their construction and method of starting.

Split-phase induction motors can be further classified as:

- resistance-start, induction-run motors
- induction-start, induction-run motors
- permanent capacitor motors
- capacitor-start, induction-run motors
- capacitor-start, capacitor-run motors
- shaded pole motors.

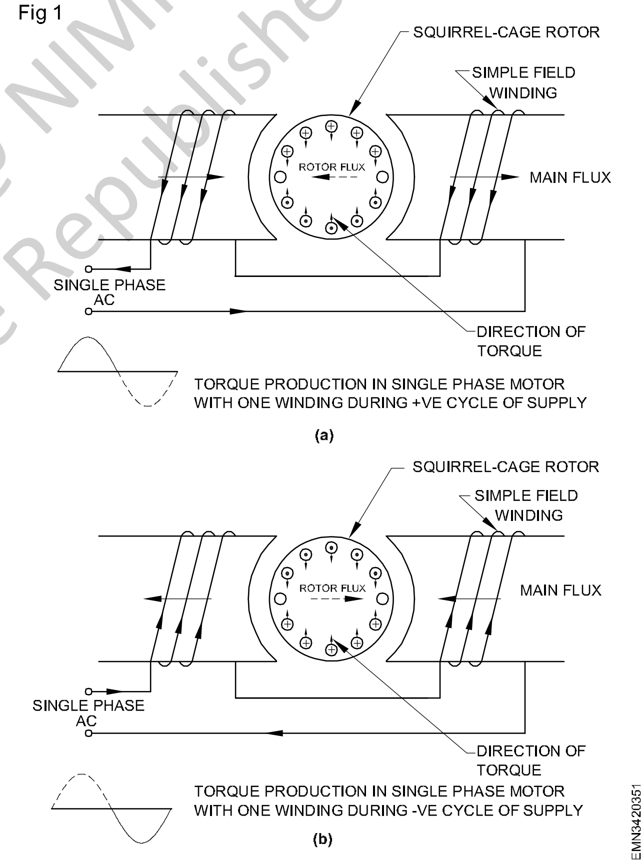
Commutator motors can be classified as:

- repulsion motors
- series motors.

The basic principle of operation of a split-phase induction motor is similar to that of a polyphase induction motor. The main difference is that the single phase motor does not produce a rotating magnetic field but produces only a pulsating field. Hence to produce the rotating magnetic field, phase-spliting is to be done to make the motor to work as a two-phase motor for starting.

First, let us examine the behaviour of the magnetic field as set up by an AC current in a sinlge-phase field winding. With reference to Fig 1, at a particular instant, the current flowing in the field winding produces the magnetic field as shown in Fig 1a. Since the produced magnetic field is varying, it will induce currents in the rotor bars which in turn will create a rotor flux. This stator-induced flux, according to Lenz's law, opposes that of the main field. By applying this principle, the current direction in the rotor bars can be determined as shown in Fig 1a, as well as the torque created between the field and rotor currents. It is apparent that the downward torque produced by the upper rotor conductors is counteracted by the upward torque produced by the lower rotor conductors; hence no rotation results. In the next instant, as shown in Fig 1b, the voltage in the input supply changes its polarity, creating a main field with a change in direction. This main field produces a torque, downward in upper conductors, and upwards in bottom conductors resulting in the cancellation of torque with no movement of the rotor, in this case also. Since the field is pulsating, the torque is pulsating although no net torque is produced over a full cycle.

Fig 1



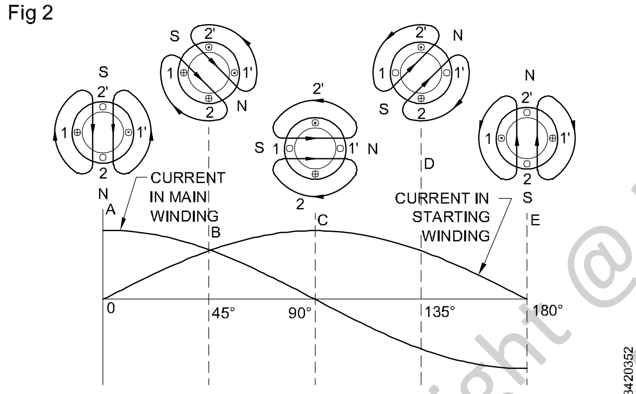

If the rotor is given a small jerk in any direction in the above mentioned cases, it will go on revolving, and will develop a torque in that particular direction due to interaction between the rotor and stator fluxes. Because of this effect, the split-phase motor, once started, needs only one winding to be connected to the supply for running. It is clear that a single phase induction motor, when having only one winding, is not self-starting. If the main field is made revolving instead of pulsating, a rotational torque could be produced in the rotor.

**Producing a rotating field from two 90° out-of-phase fields:** One of the methods of producing a rotating magnetic field is by split-phasing. This could be done by providing a second set of winding in the stator called the starting winding. This winding should be kept physically at 90 electrical degrees from the main winding, and should carry a current out of phase from the main winding. This, out of phase current, could be achieved by making the reactance of the starting winding being different from that of the main winding. In case both the windings have similar reactance and impedance, the resulting field, created by the main and starting windings, will alternate but will not revolve and the motor will not start.

By split-phasing, the two (main and starting) fields would combine to produce a rotating magnetic field as stated below.

Fig 2 shows that the main (1,1') and starting (2,2') windings are kept in the stator at 90° to each other. For consideration, only, one half cycle is shown with the effects at $45^0$ increments.

Fig 2




PRODUCING ROTATING FIELD FROM TWO 90° OUT-OF-PHASE FIELDS



At position `A', only the main winding is producing flux, and the net flux will be in a vertical direction, as shown in the stator diagram. At instant `B', 45° later, both windings are producing flux, and the net flux direction will also have rotated 45°. At position `C', the maximum flux is now in a horizontal direction because only the starting winding is producing flux. At instant `D', the current from the main winding is building up again, but in a new direction, while that from starting winding is now decreasing. Therefore, the net flux at this instant will be as shown in position D. At position `E', the maximum flux is just the opposite of what it was at instant `A'. It should now be evident that the two out-of-phase fields are combining to produce a net rotating field effect.

**Working of split-phase motor:** At the time of starting, both the main and starting windings should be connected across the supply to produce the rotating magnetic field. The rotor is of a squirrel cage type, and the revolving magnetic field sweeps past the stationary rotor, inducing an emf in the rotor. As the rotor bars are short-circuited, a current flows through them producing a magnetic field. This magnetic field opposes the revolving magnetic field and will combine with the main field to produce a revolving field. By this action, the rotor starts revolving in the same direction of the rotating magnetic field as in the case of a squirrel cage induction motor, which was explained earlier.

Hence, once the rotor starts rotating, the starting winding can be disconnected from the supply by some mechanical means as the rotor and stator fields form a revolving magnetic field.

**Resistance-start, induction-run motor:** As the starting torque of this type of motor is relatively small and its starting current is high, these motors are most commonly used for rating up to 0.5 HP where the load could be started easily.

The essential parts are as shown in Fig 3a.

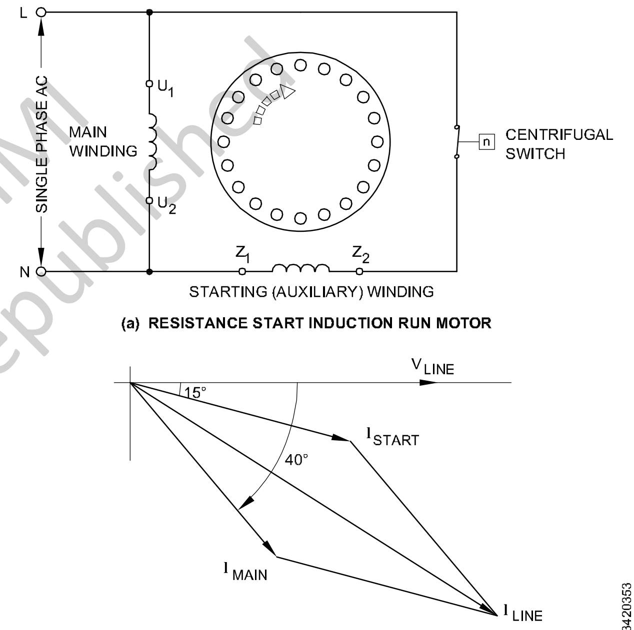
– Main winding or running winding

– Auxiliary winding or starting winding

– Squirrel cage type rotor

– Centrifugal switch

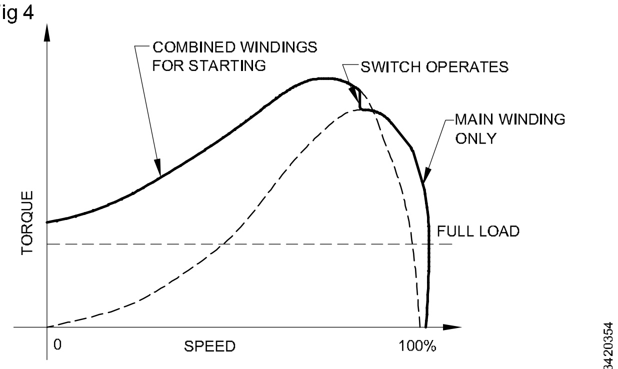
Fig 3




The starting winding is designed to have a higher resistance and lower reactance than the main winding. This is achieved by using smaller conductors in the auxiliary winding than in the main winding. The main winding will have higher inductance when surrounded by more iron, which could be made possible by placing it deeper into the stator slots. It is obvious that the current would split as shown in Fig 3b. The starting current `I start' will lag the main supply voltage `V' line' by 15° and the main winding current. `I main' lags the main voltage by about 40°. Therefore, these currents will differ in time phase and their magnetic fields will combine to produce a rotating magnetic field.

When the motor has come up to about 75 to 80% of synchronous speed, the starting winding is opened by a centrifugal switch, and the motor will continue to operate as a single phase motor. At the point where the starting winding is disconnected, the motor develops nearly as much torque with the main winding alone as with both windings connected. This can be onserved from the typical torque-speed characteristics of this motor, as shown in Fig 4.

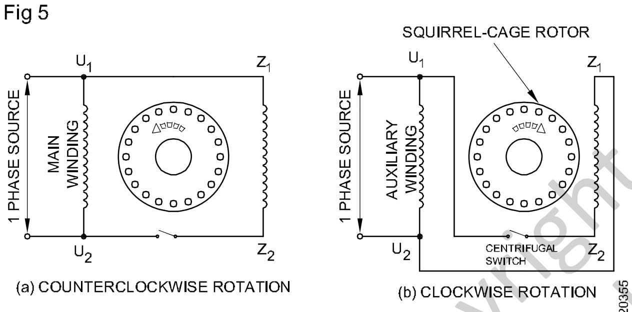
Fig 4




TORQUE SPEED CHARACTERISTIC OF SPLIT PHASE MOTOR

The direction of rotation of a split-phase motor is determined by the way the main and auxiliary windings are connected. Hence, either by changing the main winding terminals or by changing the starting winding terminals, the reversal of direction of rotation could be obtained. Rotation will be, say counter-clockwise, if $Z_1$ is joined to $U_1$ and $Z_2$ is joined to $U_2$ as per Fig 5a. If $Z_1$ is joined to $U_2$ and $Z_2$ is joined to $U_1$, then the rotation will be clockwise, as shown in Fig 5b.

Fig 5




METHOD OF CHANGING THE DIRECTION OF ROTATION OF RESISTANCE START INDUCTION RUN MOTOR

Application of resistance-start, induction-run motor: As the starting torque of this type of motors is relatively small and its starting current is high, these are manufactured for a rating up to 0.5 HP where the starting load is light. These motors are used for driving fans, grinders, washing machines and wood working tools.

Induction-start, induction-run motor: Instead of resistance start, inductance can be used to start the motor through a highly inductive starting winding. In such a case, the starting winding will have more number of turns, and will be imbedded in the inner areas of the stator slots so as to have high inductance due to more number of turns, and the area will be surrounded by more iron. As the starting and main windings in most of the cases are made from the same gauge winding wire, resistance measurement has to be done to identify the windings. This motor will have a low starting torque, higher starting current and lower power factor.

**ii) Centrifugal switch**

**The centrifugal switch:** The centrifugal switch is located inside the motor and is connected in series with the starting winding in the case of capacitor-start, induction-run motors, and for disconnecting the starting capacitor in the case of a two value, capacitor-start, capacitor-run motor. Its function is to disconnect the starting winding after the rotor has reached 75 to 80% of the rated speed. The usual type consists of two main parts. Namely, a stationary part as shown in Fig 1, and a rotating part as shown in Fig 2. The stationary part is usually located on the front-end plate of the motor and has two contacts, so that it is similar in action to a single-pole, single-throw switch. When the rotating part is fitted in the rotor, it rotates along with it. When the rotor is stationary, the insulator ring of the rotating part is in an inward position due to spring tension. This inward movement of the insulator ring allows the stationary switch contacts to be closed which is due to the movable lever pressure against the leaf-spring tension in the switch.

Fig 1

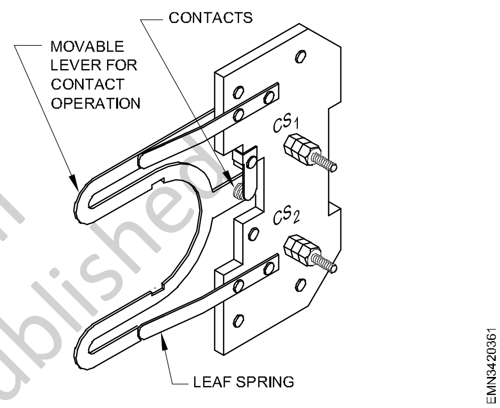
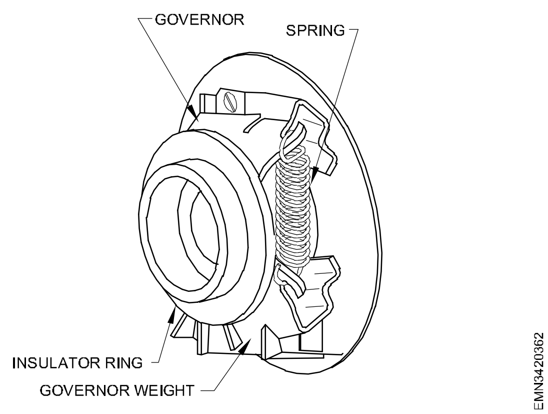


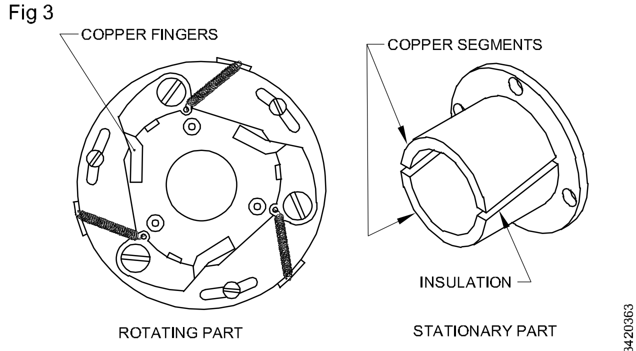

Fig 2




When the rotor attains about 75% of the rated speed, due to centrifugal force, the governor weights fly out, and this makes the insulator ring to come outward. Due to this forward movement of the insulated ring, it presses the movable lever, and the contacts connected through terminals $CS_1$ and $CS_2$ open the starting winding.

In older types of centrifugal switches, the stationary part consists of two copper, semicircular segments. These are insulated from each other and mounted inside the front-end plate. The centrifugal switch connections are given to these segments. The rotating part is composed of three copper fingers that ride around the stationary segments, while the motor is at rest or running at lower than 75% of the rated speed. These parts are illustrated in Fig 3.

Fig 3



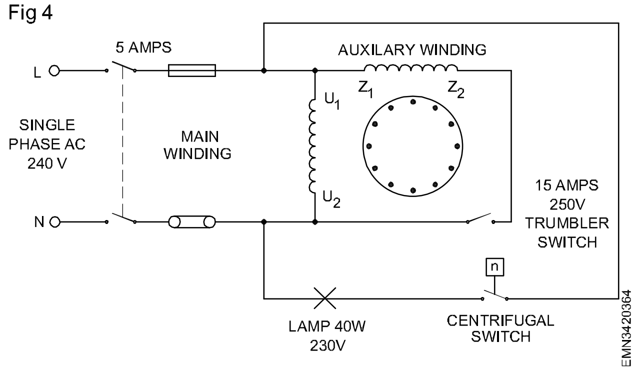

CENTRIFUGAL SWITCH

At the time of starting, the segments are shorted by the copper fingers, thus causing the starting winding to be included in the motor circuit. At approximately 75 percent of the full speed, the centrifugal force causes the fingers to be lifted from the segments, thereby disconnecting the starting winding from the circuit.

**Maintenance of centrifugal switch:** Access to the centrifugal switch could be had by removing the inspection plate, located in the end covers of the motor. In very many cases, the switch is accessible only when the end plate is removed. These switches need to be checked atleast once in six months to ensure their proper operation. Look for broken or weak springs, for improper movement, for dirt or corrosion or pittings in the contact points. Make sure all parts work freely without binding. Replace the switch, if found defective.

**Testing the operation of a centrifugal switch:** Though the centrifugal switch could be tested in a static condition, it will be very difficult to assess its operation at dynamic condition. As most of these switches cannot be checked without opening the end plate, the procedure becomes lengthy and cumbersome. To check the dynamic operation of the switch the following method is suggested. Disconnect the interconnecting terminals of the centrifugal switch from the supply and the starting winding. Connect the starting (auxiliary) winding through a 15 amps, single-pole, tumbler switch to the rated supply as shown in Fig 4, and keep the trumbler switch in the `ON' position.

Fig 4




Connect the terminals of the centrifugal switch, through a lamp as shown in Fig 4. Switch `ON' the motor. When the centrifugal switch is in the closed position, the lamp will light. As the motor picks up speed, say in about 20 seconds, open the tumbler switch to disconnect the starting winding. When the speed of the motor attains about 75% of the rated value, the centrifugal switch, if it operates correctly, will open its contacts which could be observed from the lamp going `off'. Soon after switching `on' the main supply, if the lamp is not lighted, or if it lights up but does not go out after 30-40 seconds (75 % of the rated speed) then the centrifugal switch is deemed to be not working, and should be repaired or replaced.

**Manual D.O.L. starter:** A starter is necessary for starting and stopping the motor, and for providing overload protection.

A manual starter, as it appears, is shown in Fig 5, an open view of the starter is shown in Fig 6, and the internal parts are shown in Fig 7, as a schematic diagram. A manual starter is a motor controller with a contact mechanism operated by hand. A push-button operates the mechanism through a mechanical linkage. As shown in Figs 6 & 7, the starter may have both a thermal overload relay and a magnetic overload relay for overload protection and short circuit protection respectively. Both the relays are made to operate independently, in case of overload or short circuit, to release the start-button for disconnecting the motor from supply. Most of the present day, manual starters have either of the two relays only. Basically, a manual starter is an ON-OFF switch with overload relay only.

Fig 5

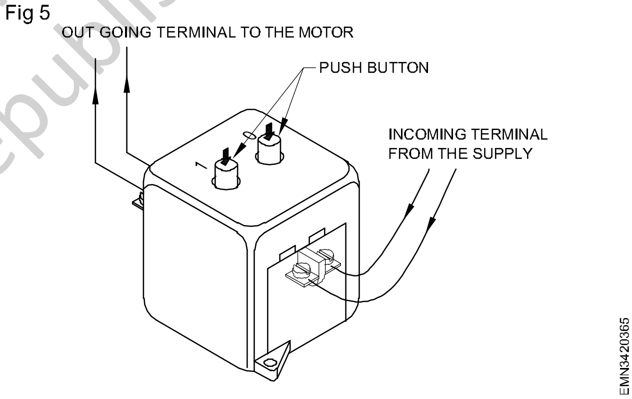
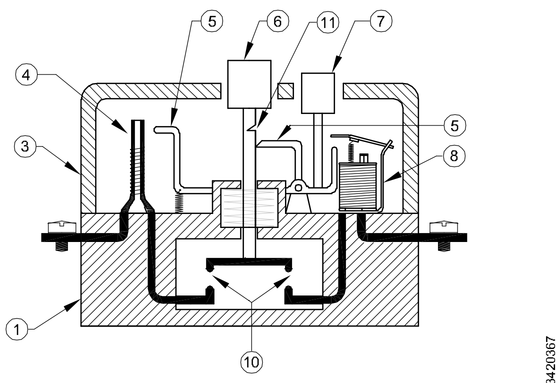
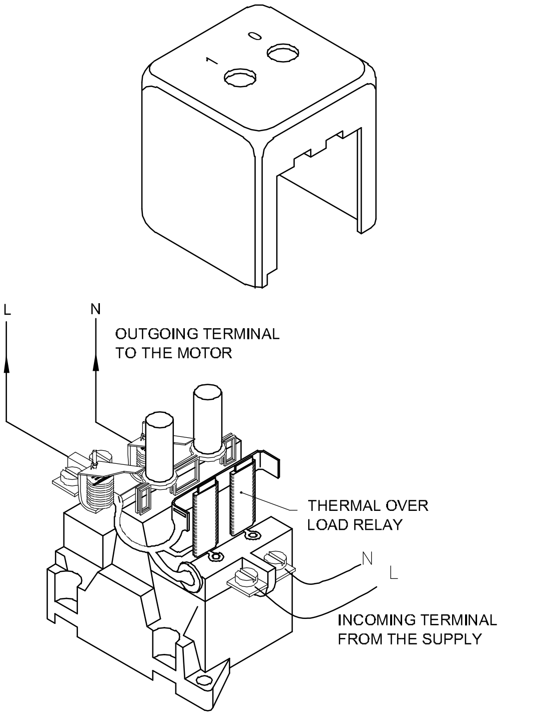



Fig 7




SCHEMATIC DIAGRAM OF A MANUAL D.O.L STARTER

Fig 6




OPEN VIEW OF MANUAL D.O.L STARTER

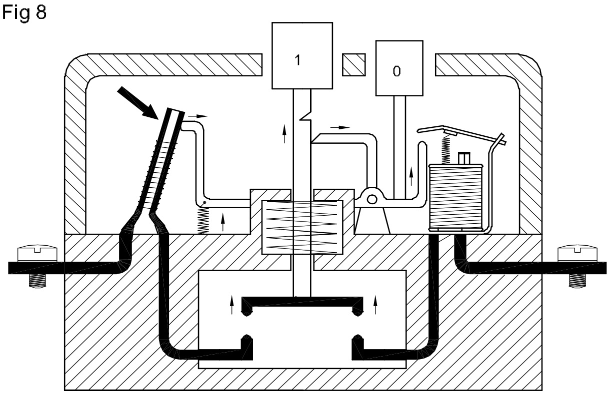
Manual starters are simple and they provide quiet operation.

**Operation:** Pushing the `ON' button closes the contacts. The contacts remain closed until the STOP button is pushed or the overload relay or the short circuit relay trips the starter.

As shown in Fig 7, when the `ON' push-button (6) is pressed, the switching contact (10) gets closed, and remains in a closed position, as the mechanical lever system (5) holds the stem of the `ON' button by the cavity (11) against the spring tension. By operating the stop button (7), the mechanical lever system (5) gets disengaged from the stem cavity, making the stem of the `ON' button to spring back, thereby opening the switching contacts (10).

**Operation of overload relay:** In the case of sustained overloads, the heavy currents passing through the heating element of the thermal overload relay heats up the bimetallic strip, making it to bend as shown by the arrow in Fig 8, thereby activating the mechanical lever system to open the switching contacts.

Fig 8




OPERATION OF O/L RELAY IN A MANUAL D.O.L. STARTER

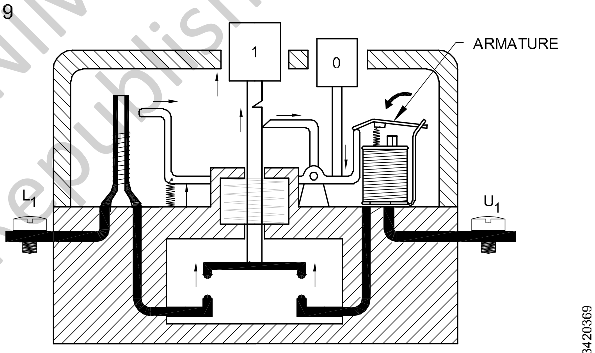
The current setting of the thermal overload relay can be changed by adjusting the setting screw, provided for this purpose (not shown in the figure.)

**Operation of short-circuit relay:** In the case of a short circuit in the motor circuit, the short circuit current will be very high in value. Though the thermal overload relay is also in series with such a short circuit current, it is sluggish in operation and takes considerable time to operate. On the other hand, the short circuit current within such time of delayed operation, will sufficiently damage the motor winding, power cables or the connected supply line.

The magnetic relay will operate faster than the thermal overload relay in such cases.

During normal load current the magnetic field produced by the coil will not have sufficient pull to attract the armature. But in case of short circuit, the current will be very high and the coil produces sufficient magnetism to attract the armature. Downward movement of the armature activates the mechacnical lever mechanism as shown by the arrow in Fig 9 and the switching contact opens. These contacts cannot be reclosed until the starter mechanism has been reset by pressing the Stop button.

Fig 9

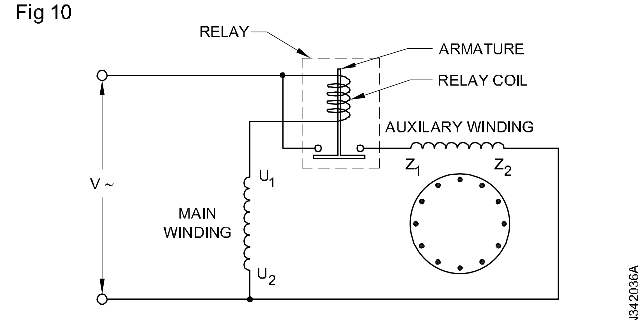



OPERATING OF MAGNETIC RELAY DURING SHORT CIRCUIT

Manual starters are used for fractional horsepower motors. They usually provide across-the-line starting. Manual starters cannot provide low-voltage protection or no-volt release. If power fails, the contacts remain closed, and the motor will restart when the power returns. This may be an advantage for pumps, fans, compressors, and oil burners. But in the case of machinery it can be dangerous to people operating the equipment, and hence, such manual starters are not recommended to be used in these places.

**Electromagnetic relay:** Single phase induction motors, like poly phase induction motors takes heavy current from the time during starting when started direct on line Advantage of this high starting current is taken to operate electromagnetic type relay which performs the same function as the centrifugal device. Connection diagram for such a relay is shown in Fig 10.

Fig 10




WIRING DIAGRAM FOR AN ELECTROMAGNETIC RELAY

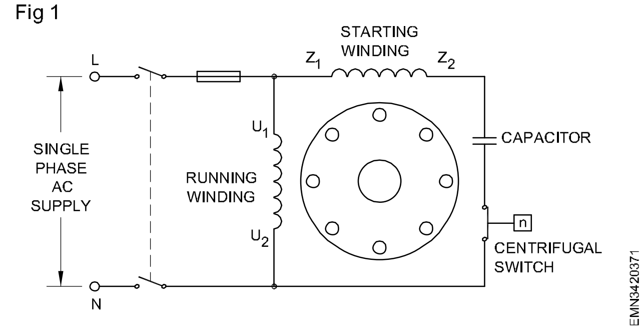
The relay has a coil which is connected in series with the main winding. The auxiliary winding is connected across the supply through a normally open contact of the relay. Since split-phase motors are usually started direct on line, the initial current inrush may be as high a five to six times the rated current. During the starting period, when the main winding current is high, the armature of the relay will be drawn upwards, thereby closing the relay contacts. The auxiliary winding will, therefore, get connected across the supply, thus helping the motor to start rotating. As the rotor starts rotating, the line current gradually goes on decreasing. After the motor reaches proper speed, the main winding current drops to a low value and causes the armature of the relay to fall downwards and open the contacts, thereby cutting out the auxiliary winding from the supply. Such relays are located outside the motor so that they can be easily serviced or replaced. As centrifugal switches are mounted internally, their servicing or replacement is not as simple as an externally mounted over-current relay.

**iii) Capacitor-start, induction-run motor**

A drive which requires a higher starting torque may be fitted with a capacitor-start, induction-run motor as it has excellent starting torque as compared to the resistance-start, induction-run motor.

**Construction and working:** Fig 1 shows the schematic diagram of a capacitor-start, induction-run motor. As shown, the main winding is connected across the main supply, whereas the starting winding is connected across the main supply through a capacitor and a centrifugal switch. Both these windings are placed in a stator slot at 90° electrical degrees apart, and a squirrel cage type rotor is used.

Fig 1

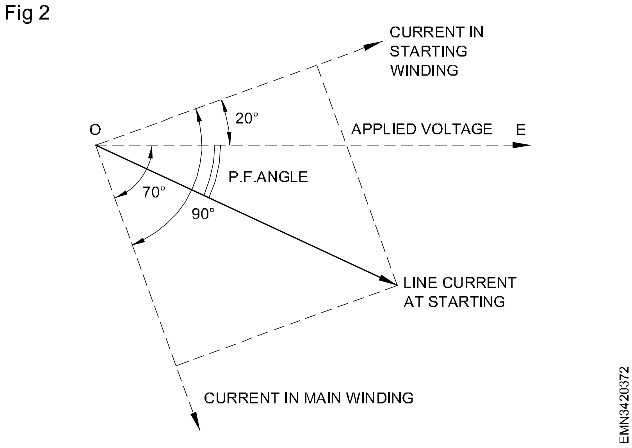



As shown in Fig 2, at the time of starting, the current in the main winding lags the supply voltages by about 70° degrees, depending upon its inductance and resistance.

On the other hand, the current in the starting winding due to its capacitor will lead the applied voltage, by say 20° degrees.

Hence, the phase difference between the main and starting winding becomes near to 90 degrees. This in turn makes

Fig 2




the line current to be more or less in phase with its applied voltage, making the power factor to be high, thereby creating an excellent starting torque.

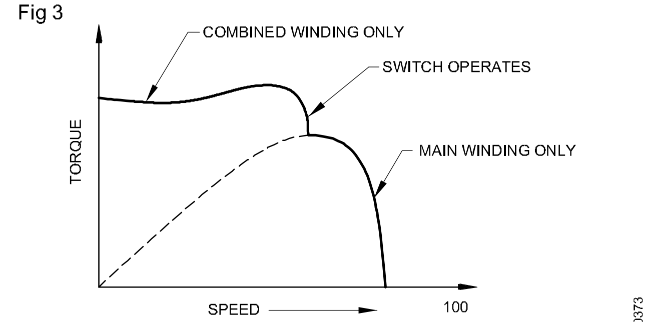
However, after attaining 75% of the rated speed, the centrifugal switch operates opening the starting winding, and the motor then operates as an induction motor, with only the main winding connected to the supply.

**Reversing the direction of rotation:** In order to reverse the direction of rotation of the capacitor start, induction-run motor, either the starting or the main winding terminals should be changed. This is due to the fact that the direction of rotation depends upon the instantaneous polarities of the main field flux and the flux produced by the starting winding. Therefore, reversing the polarity of any one of the fields will reverse the torque.

**Characteristic:** As shown in Fig 2, the displacement of current in the main and starting winding is about 80/90 degrees, and the power factor angle between the applied voltage and line current is very small. This results in producing a higher power factor and an excellent starting torque, several times higher than the normal running torque, as shown in Fig 3. The running torque adjusts itself with load by varying inversely with respect to speed as shown in the characteristic curve in Fig 3.

Application: Due to the excellent starting torque and easy direction-reversal characteristic, these machines are used

Fig 3




TORQUE-SPEED CHARACTERISTIC OF CAPACITOR START INDUCTION RUN MOTOR in belted fans, blowers, dryers, washing machines, pumps and compressors.

**iv) Capacitors used in single phase capacitor motors**

A capacitor is a device which can store electrical energy in the form of electrostatic charge. However the main purpose of the capacitor in the single phase motors is to split the phase for producing the rotating magnetic field. In addition, they also draw the leading current, thereby improving the power factor.

**Precautions to be followed while using a capacitor in a single phase capacitor motor:** Paper or electrolytic capacitors of non-polarized types are used for starting AC capacitor type motors. These capacitors have special marking for use in AC circuits, and will not have polarity marking. Paper or electrolytic capacitors for use in DC circuits have polarity markings. They must not be used in AC circuits as the reversal of AC voltage will heat up the capacitor, producing enormous gas inside the can, thereby blowing it into pieces.

The AC voltage rating inscribed on the capacitor will have two ratings. One for working voltage and another for the maximum value of voltage. Working voltage refers to the normal R.M.S. rating of the supply mains while the maximum rating will be AC peak voltage which will be $\sqrt{2}$ times the rated R.M.S. voltage. Hence, while replacing a capacitor, a careful scrutiny of voltage rating is essential, as otherwise the capacitor may fail and may also explode.

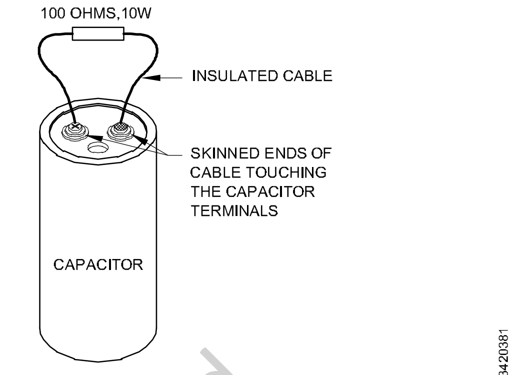
The duty cycle is another important point to be checked. In most of the capacitors, the marking will indicate whether it is for intermittant (short duty) or continuous (long duty) rating. Though continuous rated capacitors can be used for intermittant rating, never an intermittant (short duty) rating capacitor should be used for continuous rating. This has some relation with the centrifugal switch operation, frequency of starting and stopping and load. When the load is heavy or the centrifugal switch is not proper, there will be a chance for the starting winding, along with the capacitor, to be in the main circuit for a long time. In such cases the capacitor, which is intermittant rated, will fail due to overheating. This should be checked when the capacitor fails often in a specified capacitor-start motor.

The capacity of the capacitor, which is given in microfarads, should be the same as is specifed by the manufacturer of the motor. A lower value will result in poorer starting torque and high starting currents, whereas a higher rating may not allow the speed to reach the rated value resulting in the starting winding to be in main line for a long time there by ending in poor operation and efficiency. In capacitor-start, capacitor-run motors, there will be two capacitors. As the starting capacitor will be 5 to 15 times of the rating of the running capacitor, and will also be of intermittant-rated electrolytic type, when compared to the running capacitor, which will be of continuous-rated, oil-filled type. Due care should be taken while connecting these capacitors in the motor, avoiding wrong selection and connection.

While handling a capacitor, due care should be taken to avoid shocks. A good capacitor can hold its charge for several days, and when touched, may give a severe shock. Hence, before touching any terminal of the capacitor, which is in use, the electrical charge should be discharged through a test lamp or through a 100 ohms 10 watts resistor as shown in Fig 1. Direct shorting of the capacitor terminals for discharging should be avoided as far as possible as this results in creating an enormous strain to the inner parts of the capacitor and it may fail.

**Method of testing capacitors:** Before removing a capacitor from the motor connection for testing, it should be discharged

Fig 1




METHOD OD DISCHARGING A CAPACITOR

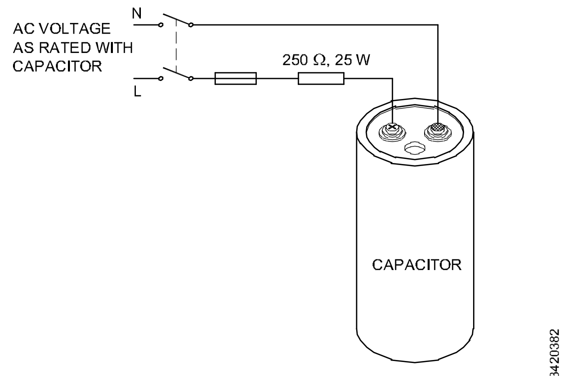
to avoid fatal shocks. The following methods are recommended for testing the large value paper, electrolytic or oil-filled capacitors.



**Charge-discharge test:** check the working voltage indicated on the capacitor. If the value is equal or more than that of the usual, single phase voltge, say 230V AC 50 Hz, we can connect it to the supply through a 100 ohms, 25 watts resistor as shown in Fig 2. Preferably, keep the capacitor, while testing on line voltage, inside a covered cardboard box or in a wooden box. Sometimes, if the capacitor is defective, it may explode and cause injury to you. Switch on the circuit for about 3-4 seconds. Then switch `OFF' the supply, and remove the supply terminals carefully with the help of an insulated pliers, without touching the capacitor terminals. Then, short the capacitor terminals with the help of a screwdriver. A bright spark is an indication that the capacitor is working. A dull spark or no spark indicates the capacitor is weak or open. On the other hand, no sparks while touching with the supply terminals indicate that the capacitor is opened. In the case of low capacity capacitors, the spark will be very feeble even if the capacitor is in good condition. Further, this check or the ohmmeter test described in the next para, does not indicate the de-rated value of the capacitor. Hence a capacity check is necessary as will be explained later.

Ohmmeter test: Before using the ohmmeter, the capacitor should be thoroughly discharged to avoid damage to the ohmmeter. Set the range of the ohmmeter to resistance and adjust to zero ohms. Touch the terminals of the capacitor and watch the deflection of the meter. If the needle deflects towards zero and then moves towards infinity, the capacitor is working. Reverse the test leads and test it again, the needle will do the same thing again in a good capacitor. If the capacitor is open, the needle will

Fig 2

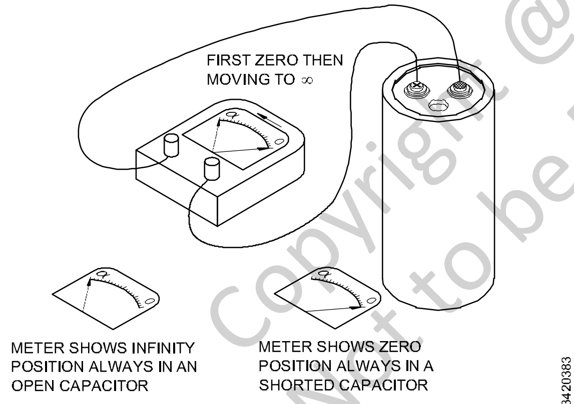



CHARGE TEST ON CAPACITOR

not go to zero position but will remain in infinity side. On the other hand, in a shorted capacitor, the needle will be in zero position but will not go to infinity side at all. These results are illustrated in Fig 3.

**Capacity test:** Connection should be as shown in Fig 4. Keep the resistance value maximum at the time of switching `on' to protect the ammeter. Keep the capacitor inside a cardboard or wooden box to avoid injury in case of explosion. The ammeter (I) and voltmeter (V) readings are to be taken when the resistor is completely cut out from the circuit. From the meter readings, the capacity rating of the capacitor in microfarads can be calculated.

Fig 3




TESTING A CAPACITOR WITH A MULTIMETER

Capacity of capacitor in $C_F$ Farad $= \frac{I}{2\pi FV}$

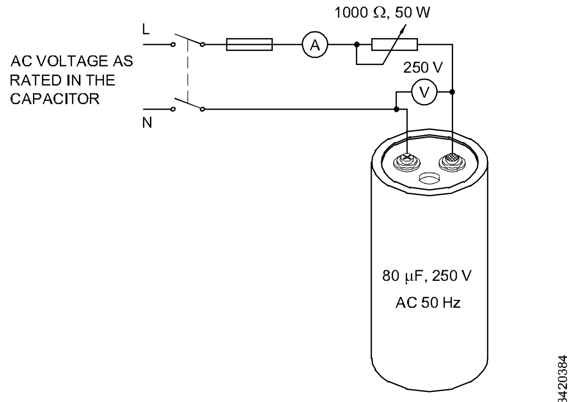
Capacity in microfarad $C_{mf} = \frac{I \times 10^6}{2\pi FV}$

$$= \frac{3182 \times I}{V} \text{ microfarad}$$

If the capacity is 20 percent more or less than the notified value, replace it.

**Insulation test on capacitors:** According to BIS 1709-1984 recommendations, the insulation test conducted between the shorted capacitor terminals and the metal can, when measured by a 500V megger/insulation tester, should not be less than 100 megohms. If the can is of insulating material, the measurement could be made between the capacitor terminals and the metal strap holding the can.

Fig 4




CAPACITY TEST ON CAPACITOR

**v) Capacitor-start, capacitor-run motor**

Capacitor-start, capacitor-run motors are of two types as stated below.

– Permanent capacitor motor (Single value capacitor motor)

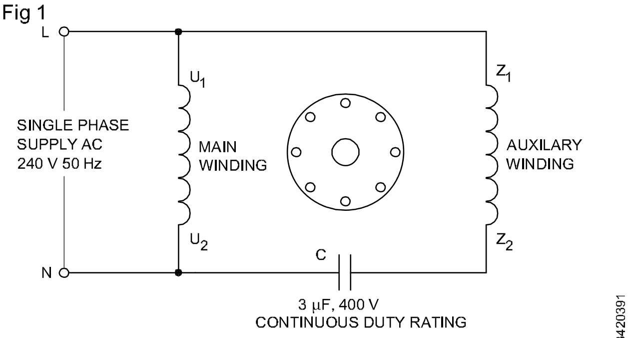
– Capacitor-start, capacitor-run motor (Two-value capacitor motor)

**Permanent capacitor motor:** This type of motor is shown in Fig 1 which is most commonly used in fans. This motor is preferred in drives where the starting torque is not required to be high, while at the same time elimination of the centrifugal switch in the motor is necessary for easy maintenance. The capacitor is connected in series with the auxiliary winding, and remains so throughout the operation. These capacitors should be of oil-type construction and have continuous duty rating.

To avoid low efficiency, the capacity of the condensers is kept low, which, in turn, brings down the starting torque to about 50 to 80% of the full-load torque.

The torque-speed characteristic of the motor is shown in Fig 2. This motor works on the same principle as the capacitor-start, induction-run motor with low starting torque

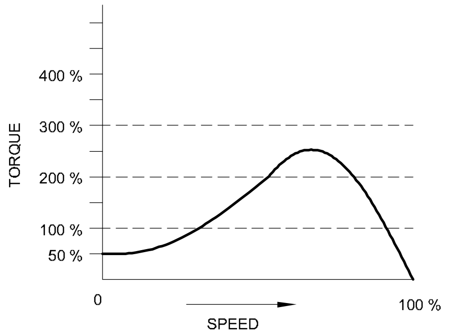
Fig 1




CIRCUIT DIAGRAM OF PERMANENT CAPACITOR MOTOR

but with higher power factor, during starting as well as in running.

Fig 2




TORQUE-SPEED CHARACTERISTIC OF PERMANENT CAPACITOR MOTOR

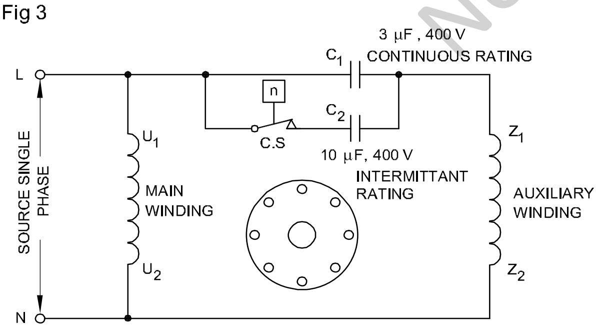
This motor is most suitable for drives, which require a lower torque during start, easy changes in the direction of rotation, stable load operation and higher power factor during operation. *Examples* - fans, variable rheostats, induction regulators, furnace control and arc welding controls. This motor is cheaper than the capacitor-start, induction-run motor of the same rating.

**Capacitor-start, capacitor-run motors:** As discussed earlier capacitor-start, induction-run motors have excellent starting torque, say about 300% of the full load torque, and their power factor during starting is high. However, their running torque is not good, and their power factor, while running, is low. They also have lesser efficiency and cannot take overloads.

These problems are eliminated by the use of a two-value capacitor motor in which one larger capacitor of electrolytic (short duty) type is used for starting, whereas a smaller capacitor of oil-filled (continuous duty) type is used for running, by connecting them with the starting winding as shown in Fig 3. A general view of such a two-value capacitor motor is shown in Fig 4. This motor also works in the same way as a capacitor-start induction-run motor, with the exception, that the capacitor C1 is always in the circuit, altering the running performance to a great extent.

The starting capacitor which is of short-duty rating will be

Fig 3



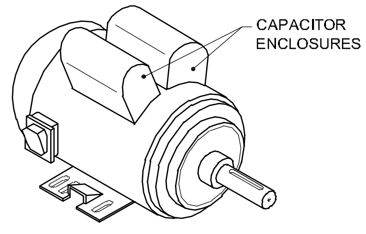

SCHEMATIC DIAGRAM OF A CAPACITOR-START CAPACITOR-RUN MOTOR

disconnected from the starting winding with the help of a centrifugal switch, when the starting speed attains about 75% of the rated speed.

**Characteristic**

The torque-speed characteristic of this motor is shown in

Fig 4

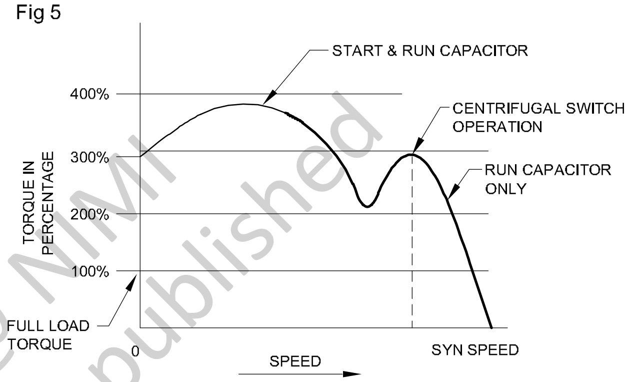



CAPACITOR-START CAPACITOR-RUN MOTOR

Fig 5. This motor has the following advantages.

- The starting torque is 300% of the full load torque.
- The starting current is low, say 2 to 3 times of the running current.
- Starting and running P.F. are good.
- Highly efficient running.

Fig 5




TORQUE-SPEED CHARACTERSTIC OF CAPACITOR-START CAPACITOR-RUN MOTOR

- Extremely noiseless operation.
- Can be loaded up to 125% of the full-load capacity.

**Application**

These motors are used for compressors, refrigerators, air-conditioners etc. where the duty demands a higher starting torque, higher efficiency, higher power factor and overloading. These motors are costlier than the capacitor-start, induction- run motors of the same capacity.

**vi) Maintain, service and troubleshoot the single phase (Split phase) motors**

General maintenance and sesrvicing of single phase(split phase) motor incorporates checking the following area.

- Incoming cables
- Main switch I.C.D.P.
- Starter
- Motor.

Checking the incoming cables should be started from the main distribution board. A visual check of the colour of cables would indicate whether the cables are underrated and need replacement. While discolouring of cables, throughout the circuit indicate under rating of the cables, the discolouring at ends near the terminal connections indicate loose connections.

A thorough check up of the tightness of termination screws is necessary at the distribution board, main switch of the motor, starter and the motor.

**Checking the main switch:** Normally visual inspection of the inner parts of the main switch will indicate loose connections, improper capacity fuses and badly positioned baffles of contact. Rectify the defects after proper shut down.

**Checking the starter:** Before opening the starter switch off the power supply. Starter contacts should be checked for perfect closing with proper tension. Most of the present days starter contacts could be checked by placing a small thin card board in between the movable and fixed contacts and closing the contactor manually. Holding the contactor movable mechanism by hand try to pull the paper board. Sufficient grip of the paper board will indicate proper contact. Move the paper board to other contacts and check similarly.

Check the contact points for perfect smooth surface. According to the manufacturer's instructions the contact points could be either cleaned with cloth or with the help of a smooth sandpaper. Badly pitted or welded contacts need replacement.

Check the overload mechanism whether the setting is tallying with the motor current rating. If necessary set them correctly.

Check the no-volt coil mechanism for smooth functioning. No volt coil resistance could be measured and compared with the earlier measurement. Variation in resistance value or discolouring of the coil indicate the coil needs to be replaced with a similar one.

**Checking the motor:** First the motor should be visually inspected for broken parts. Observe the noise while running. The resistance values of winding and insulation value between the winding and frame should be taken before dismantling. These values, when compared with the earlier values found in the maintenance history cards, will give sufficient idea to the technician regarding the expected trouble area.

Make it a point to draw the connection diagram of the terminal plate before disconnecting any lead for testing. While checking the motor continuity (open circuit) checks must be done for both main and starting winding and also in the centrifugal switch. Open circuits in split phase motors are often caused by loose or dirty connections or broken wires.

Once the open winding is detected, dismantle the motor and check the end leads and winding interconnection leads. Most of the faults could be rectified at this stage. In case the open is detected inside the coils of the winding. It is better to rewind the motor.

While checking the motor winding for shorts, use of an internal growler is a most handy equipment. Proceed as follows:- Dismantle the motor and remove the rotor. Place the growler on the core of the stator, place a metal blade in the core and move it around. Rapid vibration of the metal blade held at the other side of the coil will indicate shorted coil.

The procedure may be followed by moving the internal growler slot to slot and at the same time moving the blade inside the core. Alternatively shorted winding could be checked by the use of low voltage DC supply. Connect the suspected winding to a low voltage DC supply. Measure the voltage drop across each coil. Shorted coil will register low voltage drop.

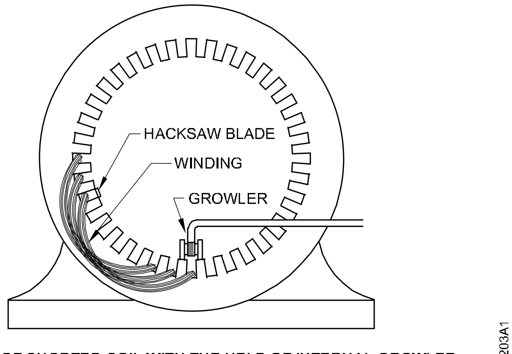
Shorted winding may blow the fuse or in some cases it will result in smoke in the winding without blowing the fuse. In either case dismantle the motor and visually inspect the winding. A burnt winding is easy to recognize by its smell and appearance.

If a short circuit exists between the main and starting winding it may result ultimately in a burnt out motor. To locate the short circuited section, connect one lead of main winding to the supply line through the test lamp. Connect the next lead of supply to one lead of starting winding. Glowing of the test lamp indicates short between the windings.

To detect the place of short, push the starting or main winding away from each other using a fibre wedge at various places of the winding. If the lamp goes out at a particular stage, the short is indicated at that place. Inserting a leatheroid paper between the windings will solve the problem.

If the centrifugal switch appears to be in good condition, but the contacts are found open, it is necessary to position the switch properly in the shaft or adjust and dress the contact points. Construction and operation of one type of centrifugal switch is shown in Fig 1.

Fig 1




DETECTION OF SHORTED COIL WITH THE HELP OF INTERNAL GROWLER
(FULL WINDING IS NOT SHOWN TO HAVE BETTER CLARITY)

## Three phase induction motors-principle-construction-characteristics - insulation test-types

**Objectives** : At the end of this sexercise you shall be able to
- **state the principle of a 3-phase induction motor**
- **explain briefly the method of producing a rotating field.**

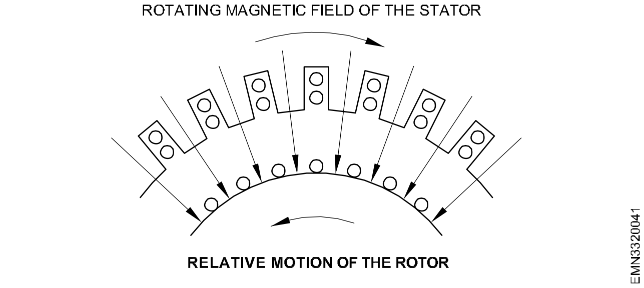
The three-phase induction motor is used more extensively than any other form of electrical motor, due to its simple construction, trouble-free operation, lower cost and a fairly good torque speed characteristic.

**i) Principle of 3-phase induction motor:** It works on the same principle as a DC motor, that is, the current-carrying conductors kept in a magnetic field will tend to create a force. However, the induction motor differs from the DC motor in fact that the rotor of the induction motor is not electrically connected to the stator, but induces a voltage/ current in the rotor by the transformer action, as the stator magnetic field sweeps across the rotor. The induction motor derives its name from the fact that the current in the rotor is not drawn directly from the supply, but is induced by the relative motion of the rotor conductors and the magnetic field produced by the stator currents.

The stator of the 3-phase induction motor is similar to that of a 3-phase alternator, of revolving field type. The three-phase winding in the stator produces a rotating magnetic field in the stator core as it will be explained later. The rotor of the induction motor may have either shorted rotor conductors in the form of a squirrel cage or in the form of a 3-phase winding to facilitate the circulation of current through a closed circuit.

Let us assume that the stator field of the induction motor is rotating in a clockwise direction as shown in Fig. 1. This makes for the relative motion of the rotor in an anticlockwise direction as shown in Fig. 1. Applying Fleming's right hand rule, the direction of emf induced in the rotor will be towards the observer as shown in Fig. 2. As the rotor conductors have a closed electric path, due to their shorting, a current will flow through them as in a short-circuited secondary of a transformer.

Fig 1




The magnetic field produced by the rotor currents will be in a counter-clockwise direction as shown in Fig 2 according to Maxwell's Corkscrew rule. The interaction between the stator magnetic field and the rotor magnetic field results in a force to move the rotor in the same direction as that of the rotating magnetic field of the stator, as shown in Fig. 3. As such the rotor follows the stator field in the same direction by rotating at a speed lesser than the synchronous speed of the stator rotating magneticfield.

Fig 2

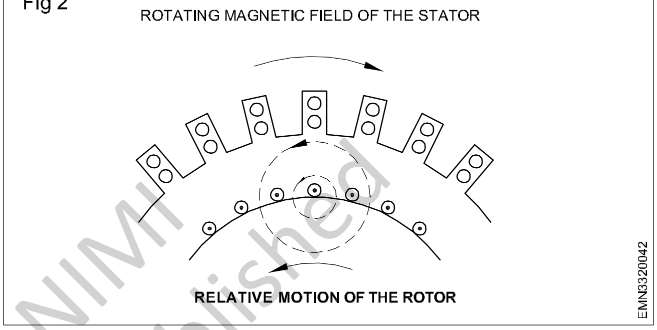
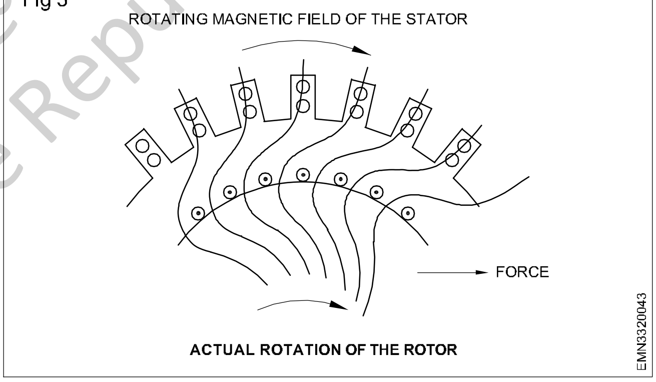



Fig 3



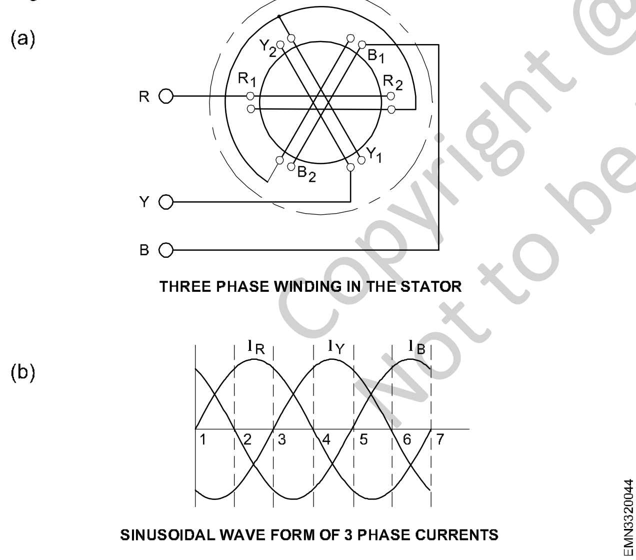

At higher speeds of the rotor nearing to synchronous speeds, the relative speed between the rotor and the rotating magnetic field of the stator reduces and results in a smaller induced emf in the rotor. Theoretically, if we assume that the rotor attains a speed equal to the synchronous speed of the rotating magnetic field of the stator, there will be no relative motion between the stator field and the rotor, and thereby no induced emf or current will be there in the rotor. Consequently there will not be any torque in the rotor. Hence the rotor of the induction motor cannot run at a synchronous speed at all. As the motor is loaded, the rotor speed has to fall to cope up with the mechanical force; thereby the relative speed increases, and the induced emf and current increase in the rotor resulting in an increased torque.

**To reverse the direction of rotation of a rotor:** The direction of rotation of the stator magnetic field depends upon the phase sequence of the supply. To reverse the direction of rotation of the stator as well as the rotor, the phase sequence of the supply is to be changed by changing any two leads connected to the stator.

**Rotating magnetic field from a three-phase stator:** The operation of the induction motor is dependent on the presence of a rotating magnetic field in the stator. The stator of the induction motor contains three-phase windings placed at 120 electrical degrees apart from each other. These windings are placed on the stator core to form non-salient stator field poles. When the stator is energized from a three-phase voltage supply, in each phase winding will set up a pulsating field. However, by virtue of the spacing between the windings, and the phase difference, the magnetic fields combine to produce a field rotating at a constant speed around the inside surface of the stator core. This resultant movement of the flux is called the `rotating magnetic field', and its speed is called the `synchronous speed'.

The manner, in which the rotating field is set up, may be described by considering the direction of the phase currents at successive instants during a cycle. Fig. 4a shows a simplified star-connected, three-phase stator winding. The winding shown is for a two-pole induction motor. Fig .4b shows the phase currents for the three-phase windings. The phase currents will be 120 electrical degrees apart as shown in Fig. 4b. The resultant magnetic field produced by the combined effect of the three currents is shown at increments of 60° for one cycle of the current.

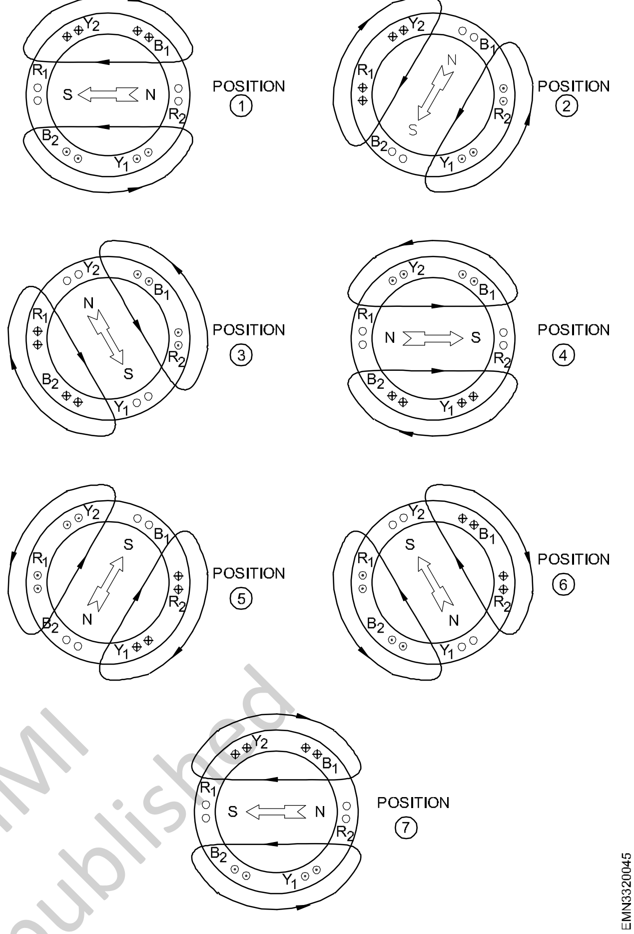
Fig 4




At position (1) in Fig 4b, the phase current $I_R$ is zero, and hence coil R will be producing zero flux. However, the phase current $I_B$ is positive and $I_y$ is negative.

Considering the instantaneous current directions of these three phase windings, as shown in Fig 4b at position 1, we can indicate the current direction in Fig. 5(1).

Fig 5




For convenience the +ve current is shown as +ve sign, and the -ve current is shown as dot (•) sign. Accordingly $Y_2$ and $B_1$ are shown as positive and $Y_1$ and $B_2$ are shown as negative. Using Maxwell's corkscrew rule, the resulting flux by these currents will produce a flux as shown in Fig 5(1). The arrow shows the direction of the magnetic field and the magnetic poles in the stator core.

At position 2, as shown by Fig. 5(2), 60 electrical degrees later, the phase current $I_B$ is zero, the current $I_R$ is positive and the current $I_Y$ is negative. In Fig 5a the current is now observed to be flowing into the conductors at the coil ends $R_1$ and $Y_2$, and out of the conductors at coil $R_2$ and $Y_1$. Therefore, as shown in Fig. 5c(2), the resultant magnetic poles are now at a new position in the stator core. In fact the poles in position 2 have also rotated 60° from position (1).

Using the same reasoning as above for the current wave positions 3, 4, 5, 6 and 7, it will be seen that for each successive increment of 60 electrical degrees, the resultant stator field will rotate a further 60° as shown in Fig. 5. Note that from the resultant flux from position (1) to position (7), it is obvious that for each cycle of applied voltage the field of the two-pole stator will also rotate one revolution around its core.

From what is stated above it will be clear that the rotating magnetic field could be produced by a set of 3-phase stationary windings, placed at 120° electrical degrees apart, and supplied with a 3-phase voltage.

The speed at which the field rotates is called synchronous speed, and, it depends upon the frequency of supply and the number of poles for which the stator is wound.

Hence

$N_s$ = Synchronous speed in r.p.m.

$$= \frac{120F}{P}$$

where `P' is the number of poles in the stator, and `F' is the frequency of the supply.

**ii) Construction of a 3-phase squirrel cage induction motor - relation between slip, speed, rotor frequency, copper loss and torque**

Three-phase induction motors are classified according to their rotor construction. Accordingly, we have two major types.

– Squirrel cage induction motors

– Slip ring induction motors.

Squirrel cage motors have a rotor with short-circuited bars whereas slip ring motors have wound rotors having three windings, either connected in star or delta. The terminals of the rotor windings of the slip ring motors are brought out through slip-rings which are in contact with stationary brushes.

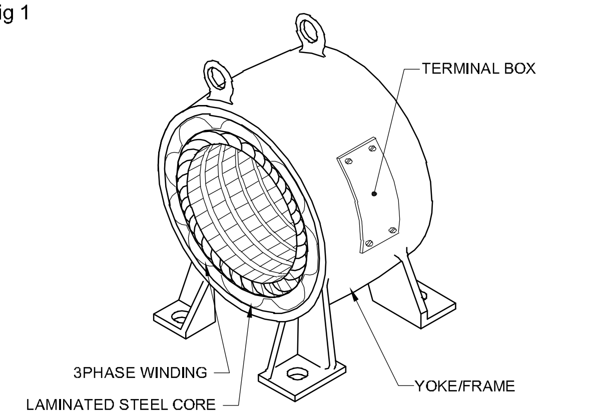
Development of these two types of induction motors is due to the fact that the torque of the induction motor depends upon the rotor resistance. Higher rotor resistance offers higher starting torque but the running torque will be low with increased losses and poor efficiency. For certain applications of loads where high starting torque and sufficient running torque are the only requirements, the rotor resistance should be high at the time of starting, and low while the motor is running. If the motor circuit is left with high resistance, the rotor copper loss will be more, resulting in low speed and poor efficiency. Hence it is advisable to have low resistance in the rotor while in operation.

Both these requirements are possible in slip-ring motors by adding external resistance at the start and cutting it off while the motor runs. As this is not possible in squirrel cage motors, the above requirements are met by developing a rotor called double squirrel cage rotor where there will be two sets of short circuited bars in the rotor.

**Stator of an induction motor:** There is no difference between squirrel cage and slip-ring motor stators.

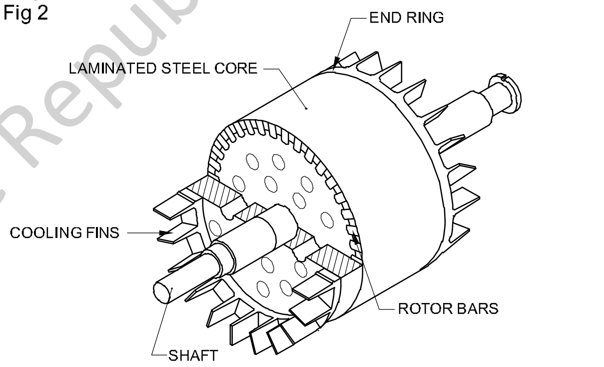
The induction motor stator resembles the stator of a revolving field, three-phase alternator. The stator or the stationary part consists of three-phase winding held in place in the slots of a laminated steel core which is enclosed and supported by a cast iron or a steel frame as shown in Fig.1. The phase windings are placed 120 electrical degrees apart, and may be connected in either star or delta externally, for which six leads are brought out to a terminal box mounted on the frame of the motor. When the stator is energised from a three-phase voltage it will produce a rotating magnetic field in the stator core.

Fig 1




**Rotor of a squirrel cage induction motor:** The rotor of the squirrel cage induction motor shown in Fig. 2 contains no windings. Instead it is a cylindrical core constructed of steel laminations with conductor bars mounted parallel to the shaft and embedded near the surface of the rotor core. These conductor bars are short circuited by an end-ring at either end of the rotor core. On large machines, these conductor bars and the end-rings are made up of copper with the bars brazed or welded to the end rings as shown in Fig.3. On small machines the conductor bars and end-rings are sometimes made of aluminium with the bars and rings cast in as part of the rotor core.

Fig 2

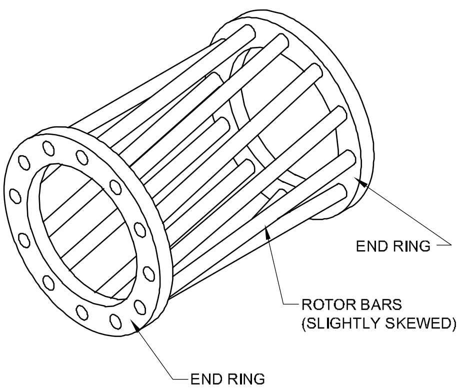



CAGE-TYPE ROTOR IN PART SECTION SHOWING CAST ALUMINIUM BARS AND END RINGS

The rotor or rotating part is not connected electrically to the power supply but has voltage induced in it by transformer action from the stator. For this reason, the stator is sometimes called the primary, and the rotor is referred to as the secondary of the motor. Since the motor operates on the principle of induction; and as the construction of the rotor, with the bars and end-rings resembles a squirrel cage, the name squirrel cage induction motor is used. (Fig. 3)

The rotor bars are not insulated from the rotor core because they are made of metals having less resistance than the core. The induced current will flow mainly in them. Also, the bars are usually not quite parallel to the rotor shaft but are mounted in a slightly skewed position. This feature tends to produce a more uniform rotor field and torque; also it helps to reduce some of the internal magnetic noise when the motor is running.

Fig 3



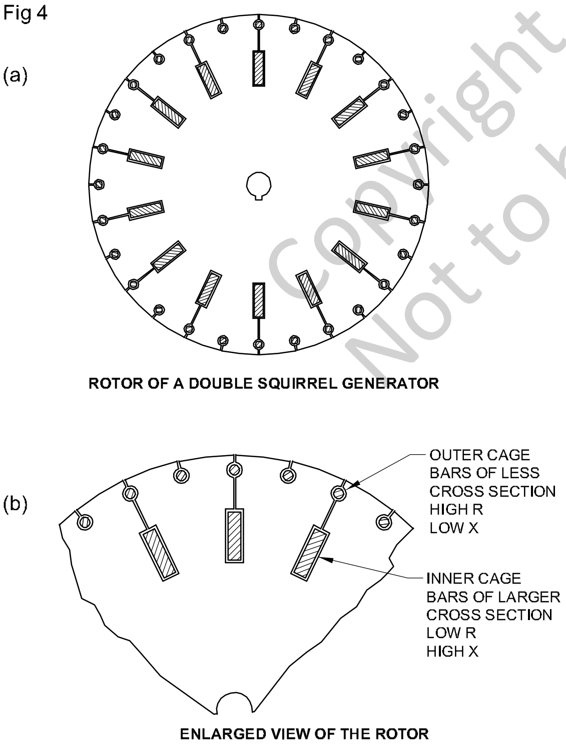

DETATCHED VIEW OF THE SQUIRREL CAGE MOTOR ROTOR BARS

**End shields:** The function of the two end shields which are to support the rotor shaft. They are fitted with bearings and attached to the stator frame with the help of studs or bolts.

**Double squirrel cage induction motor**

**Rotor construction and its working:** This consists of two sets of conductor bars called outer and inner cages as shown in Fig. 4. The outer cage consists of bars of high resistance metals like brass, and is short-circuited by the end-rings. The inner cage consists of low resistance metal bars like copper, and is short-circuited by the end-rings. The outer cage has high resistance and low reactance, whereas the inner cage has low resistance but being situated deep in the rotor core, has a large ratio of reactance to resistance.

Fig 4




ENLARGED VIEW OF THE ROTOR

At the time of starting, the rotor frequency is the same as the stator frequency. Hence the inner cage which has higher inductive reactance offers more resistance to the current flow. As such very little current flows through the inner cage at the time of starting.

The major part of the rotor current at the time of starting could flow through the outer ring which has high resistance. This high resistance enables to produce a high starting torque.

As the speed increases, the rotor frequency is reduced. At low frequency, the total resistance offered for the current flow in the inner cage reduces due to reduction of reactance ($X_L = 2\pi f_r L$), and the major part of the rotor current will be in the inner cage rather than in the highly resistant outer cage.

As such, the low resistance of the inner cage becomes responsible for producing a torque just sufficient to maintain the speed.

**Slip and rotor speed:** We have already found that the rotor of an induction motor must rotate in the same direction as the rotating magnetic field, but it cannot rotate at the same speed as that of the magnetic field. Only when the rotor runs at a lesser speed than the stator magnetic field, the rotor conductors could cut the stator magnetic field for an emf to be induced. The rotor current could then flow and the rotor magnetic field will set up to produce a torque.

The speed at which the rotor rotates is called the rotor speed or speed of the motor. The difference between the synchronous speed and the actual rotor speed is called the `slip speed'. Slip speed is the number of revolutions per minute by which the rotor continues to fall behind the revolving magnetic field.

When the slip speed is expressed as a fraction of the synchronous speed, it is called a fractional slip.

Therefore, fractional slip S

$$= \frac{N_s - N_r}{N_s}$$

Then percentage slip (% slip)

$$= \frac{N_s - N_r}{N_s} \times 100$$

where $N_s$ = synchronous speed of the stator magnetic field

$N_r$ = Actual rotating speed of the rotor in r.p.m.

Most squirrel cage induction motors will have a percentage slip of 2 to 5 percent of the rated load.

**Example**

Calculate the percentage slip of an induction motor having 6 poles fed with 50 cycles supply rotating with an actual speed of 960 r.p.m.

Given:

Poles = 6

$N_r$ = Rotor speed = 960 r.p.m.

F = frequency of supply = 50 Hz

$N_s$ = Synchronous speed

$= 120\frac{f}{P}$

$= \frac{120 \times 50}{6} = 1000$ r.p.m.

$\% \text{ slip} = \frac{N_s - N_r}{N_s} \times 100$

$= \frac{1000 - 960}{1000} \times 100 = 4\%$

**Generated voltage in the rotor and its frequency:** As the rotor cuts the stator flux, it induces voltage in rotor conductors and it is called the rotor voltage. The frequency of this rotor voltage is equal to the product of the slip and stator (supply) frequency.

Frequency of the rotor voltage

$f_r$ = Fractional slip x stator frequency

$= \frac{N_s - N_r}{N_s} \times f$ or sf

From the above, we find that, at the time of starting, the rotor is at rest, and the slip will be equal to one and the rotor frequency will be the same as the stator frequency. When the motor is running at high speed, the slip will be low and the frequency of the rotor will also be low.

**Example 1**

A 3-phase induction motor is wound for 4 poles, and is supplied from a 50 Hz supply. Calculate a) the synchronous speed, b) the speed of the rotor when the slip is 4 percent, and c) the rotor frequency.

a Synchronous speed $= N_s = \frac{120f}{P}$

$= \frac{120 \times 50}{4} = 1500$ r.p.m.

b Actual speed of the rotor $= N_r$

Percentage slip $= \frac{N_s - N_r}{N_s} \times 100$

$N_s - N_r = \frac{N_s \times \text{Percentage slip}}{100}$

$N_r = N_s - \frac{N_s \times \%\text{slip}}{100}$

$= 1500 - \frac{1500 \times 4}{100}$

= 1440 r.p.m.

c Rotor frequency $f_r$ = Slip x Stator frequency

$= \frac{N_s - N_r}{N_s} \times f$

$= \frac{1500 - 1440 \times 50}{1500}$

$= \frac{60 \times 50}{1500} = 2$ Hz.

**Example 2**

A 12-pole, 3-phase alternator driven at a speed of 500 r.p.m. supplies power to a 8-pole, 3-phase induction motor. If the slip of the motor at full load is 3%, calculate the full load speed of the motor.

Let $N_r$ = actual speed of motor

Supply frequency = frequency of alternator

$= \frac{12 \times 500}{120} = 50$ Hz.

Synchronous speed $N_s$ of the induction motor

$= \frac{120 \times 50}{8} = 750$ r.p.m.

$\% \text{ slip } S = \frac{N_s - N_r}{N_s} \times 100 = 3$

$= \frac{750 - N_r}{750} \times 100 = 3$

$750 - N_r = \frac{3 \times 750}{100} = 22.5$

$N_r$ = 727.5 r.p.m.

**Example 3**

A 400V, 3-phase, eight-pole 50 Hz squirrel cage motor has a rated full load speed of 720 r.p.m. Determine

a the synchronous speed

b the rotor slip at rated load

b the percentage slip at rated load

d the percentage slip at the instant of start up

e the rotor frequency at the rated load

f the rotor frequency at the instant of start up.

**Solution**

a Synchronous speed $N_s = \frac{120 \times f}{p}$

$= \frac{120 \times 50}{8} = 750$ r.p.m.

b Slip at rated load = 750 - 720 = 30 r.p.m.

c Percent slip at rated load = $\frac{30 \times 100}{750} = 4\%$

d At the instant of start up the rotor speed is zero, and hence the percentage slip will be 100 percent.

e Rotor frequency at rated load $f_r$

$$= \frac{(f \times \text{percentage slip})}{100}$$

$$= \frac{50 \times 4}{100} = 2 \text{ Hz.}$$

f At the instant of starting the slip is 100 percent. Therefore, at this instant the rotor frequency will be equal to the stator frequency $f_r$ (at starting) = f = 50 Hz.

**Rotor copper loss:** Rotor copper loss is the loss of power taking place in the rotor due to its resistance and the rotor current. Though the resistance of the rotor for a squirrel cage motor remains constant, the current in the rotor depends upon the slip, transformation ratio between the stator and rotor voltages and the inductive reactance of the rotor circuit.

Let T = torque developed by the motor

$P_R$ = power developed in the rotor

$P_m$ = power converted in the rotor as mechanical power

$n_S$ = the synchronous speed in r.p.m.

$n_r$ = the rotor speed in r.p.m.

Then $P_R = 2\pi n_s T$ watts

$P_m = 2\pi n_r T$ watts.

The difference between $P_R$ - $P_m$ is the rotor copper loss.

$P_R - P_m$ = Rotor copper loss

Rotor copper loss= $2\pi T(n_s - n_r)$

$$\frac{\text{Rotor copper loss}}{2\pi T} = (n_s - n_r)$$

$$\frac{\text{Rotor copper loss}}{2\pi n_S T} = \frac{(n_S - n_r)}{n_S}$$

= Fractional slip

Rotor copper loss = Fractional slip x Input power to the rotor

$= S \times 2\pi n_s T.$

Torque: The torque production in an induction motor is more or less the same as in the DC motor. In the DC motor the torque is proportional to the product of the flux per pole and the armature current. Similarly in the induction motor the torque is proportional to the flux per stator pole, the rotor current and also the rotor power factor.

Thus we have,

Torque is proportionally = Stator flux x rotor current x rotor power factor.

Let $E_1$ be the applied voltage

Ø be the stator flux which is proportional to $E_1$

S be the fractional slip

$R_2$ be the rotor resistance

$X_2$ be the rotor inductive reactance at standstill

$SX_2$ be the rotor inductive reactance at fractional slip S

K be the transformation ratio between stator and rotor voltages

$E_2$ be the rotor induced emf and equal to $SKE_1$

$I_2$ be the rotor current,

Cosθ be the rotor power factor.

$Z_2$ be the rotor impendence.

We can conclude mathematically the following final results.

$$T \ \alpha \ \text{Ø} \ I_2 \ \text{Cos}\theta 2$$

This can be deduced in to a formula

$$T \ \alpha \ \frac{SKE_1^2 R_2}{R_2^2 + S^2 X_2^2}$$

$$T \ \alpha \ \frac{\text{Rotor copper loss}}{\text{Fractional slip}}$$

Starting torque $\alpha \ \frac{R_2}{R_2^2 + X_2^2}$ as fractional slip S = 1

Maximum torque $\alpha \ \frac{1}{X_2}$

where $X_2$ in inductive reactance of the rotor at standstill and is constant.

**Motor torque calculation:** Since the stator flux and induced rotor current for an induction motor are not easily measured, the torque equation T = K $Ø_s \ I_R$ Cos $\theta_R$ is not the most practical equation to be used for determining a motor torque. Instead the Prony Brake torque equation described earlier may be used, provided the motor's output power and Rev/min are known.

$$\text{Output power in watts} = \frac{2\pi \times \text{torque} \times \text{Rev/min}}{60}$$

$$\text{Torque (newton metres)} = \frac{(60 \times \text{output watts})}{(2\pi \times \text{Rev/min})}$$

$$= \frac{(9.55 \times \text{output watts})}{(\text{Rev/min})}$$

A motor's power may also be stated in British horsepower (hp). In this case the output power in watts will be equal to the output horsepower multiplied by 746 (1 hp = 746w).

In case the motor power is given in metric horsepower, the output power in watts will be equal to the metric horsepower, multiplied by 735.6 (1 metric horsepower = 735.6 watts).

**Example**

Determine the torque in newton metres produced by a 5 hp squirrel cage motors rotating at 1440 r.p.m.

Assuming it is British horsepower, output power in watts

$$= \text{hp} \times 746$$

$$= 5 \times 746 = 3730 \text{ watts.}$$

$$\text{Torque (newton metres)} = \frac{(60 \times \text{output watts})}{(2\pi \times \text{Rev/min})}$$

$$= \frac{(60 \times 3730)}{(2 \times 3.14 \times 1440)}$$

$$= 24.75 \text{ newton metres.}$$

**iii) Insulation test on induction motors**

It is often said that electricity is a good servant but a bad master. This is because electricity is so useful but can cause accidents, and even death if one is careless. A large number of accidents, which occur in electrical motors, is due to leakage of current from the conducting part of the motor to the non-conducting part. The main reason is the weak insulation caused by the damaged insulation materials of the motor.

Insulation materials used on winding wires or in between winding wires and the slots of the laminated core, or the insulated sleeves of lead cables may get damaged due to the following reasons.

- Moisture content in the atmosphere (Ex. Electrical motors in harbours)
- Chemicals and their fumes in the surroundings (Ex. Electrical machines in chemical plants)
- High temperature of the surrounding (Ex. Electrical machines in steel rolling mill)
- High temperature emanating from the machine itself while working. (Ex. Electrical machines at hill tops where the cooling ability of the thin air is poor.)
- Dust, dirt, oil particles deposited on the windings and cables. (Ex. Electrical machines in cement plants, oil mills, chemical plants etc.)
- Aging of the machine.

When the insulation deteriorates, the insulation resistance value is reduced, and the current may leak to the frame of the electrical machine. If the machine is not properly earthed, the leakage currents may develop a dangerous potential on the frame. If somebody comes in contact with the frame, he may get even fatal shocks. These leakage currents also produce erroneous readings in the measuring equipment, and also affect the working of the other electrical equipments. As such the National Electrical Code has stipulated certain minimum standards for the insulation resistance value.

**Method of testing insulation resistance of the electrical motor and the recommended value of the resistance as per National Electrical Code:** Before putting into operation, the electrical motor must be tested for its insulation resistance. This is to make sure that there is no leakage between the current carrying parts of the motor and the non-current carrying metal parts of the motor. As insulation resistance may fail during the course of operation due to the reasons mentioned above, it is most necessary to check the insulation resistance at intervals, say once in a month, for any motor which is in operation, as a preventive maintenance check. These values of insulation resistance must be recorded in the maintenance card and whenever the value goes below the accepted value, the motor winding has to be dried and varnished to improve the conditions.

**Condition and acceptable test results:** According to NE code, the insulation resistance of each phase winding against the frame and between the windings shall be measured. A megohm-meter of 500V or 1000V rating shall be used. Star points should be disconnected while testing.

To avoid accidents due to weak insulations, first the insulation resistance value between any conducting part of the machine and the frame of the machine should be tested, and the measured value should not be lesser than one megohm as a thumb rule, or more precisely should not be less than a value based on the voltage and rated power of the motor as given in the National Electrical Code.

$$\text{Insulation resistance } R_i = \frac{20 \times E}{1000 + 2P}$$

where

$R_1$ is the insulation resistance in megohms at 25°C

$E_n$ related phase-to-phase voltage and

P rated power in KW.

If the resistance is measured at a temperature different from 25°C, the value shall be corrected to 25°C.

**General instruction for the measurement of insulation resistance:** Insulation resistance of an electric motor may be in the range of 10 to 100 megohms but as it varies greatly in accordance with the temperature and humidity of the electric motor, it would be difficult to give a definite value. When the temperature of such a motor is raised, the insulation resistance will initially drop considerably, even below the acceptable minimum. If any suspicion exists on this score, the motor winding shall be dried out. The equation given above is used to calculate the insulation resistance as a standard value. However it should not be less than 1 megohm as an acceptable value.

Secondly, in the case of accidental leakage of currents from any current carrying part to non-current carrying metal part, there should be a ground system which should provide a minimum impedence path for the faulty (leakage) current to flow. Thereby protective devices like fuses or circuit-breakers or earth leakage circuit-breakers or earth fault relays would function and disconnect the supply to the defective motor circuit.

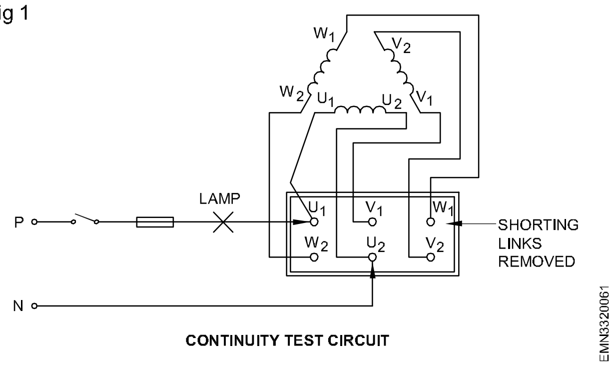
However, this will not be possible unless and until the ground (earth) system has minimum impedance. This could be achieved by the following means.

- Using low resistance earth continuity conductors between the frame of the motor and the earth electrode.
- Providing rust-proof metal parts like bolts, nuts and lugs for connecting the earth continuity conductor (ECC) with the frame as well as the main electrodes. (Galvanised nuts and bolts are to be used.)
- Keeping the earth electrode resistance value as low as possible such that in case of leakage, any one unit of the protective system will operate to isolate the motor from the supply.

**Necessity of continuity test before insulation test:** While testing the insulation resistance between the winding and the frame, it is the usual practice to connect one prod of the Megger to the frame and the other prod to any one of the terminals of the winding. Likewise, when testing insulation resistance between windings, it is the usual practice to connect the two prods of the Megger to any two ends of a different winding. In all the cases it is assumed that the windings are in sound condition and the two ends of the same winding will be having continuity. However, it is possible the winding may have a break, and part of the winding may have a higher insulation resistance and the other part might have been grounded. Hence, to increase the reliability of the insulation resistance test, it is recommended that continuity test may be conducted in the motor before the insulation test, to be sure, that the winding is sound and the insulation resistance includes the entire winding.

**Continuity test:** The continuity of the winding is checked by using a test lamp in the following method as shown in Fig.1. First the links between the terminals should be removed.

Fig 1

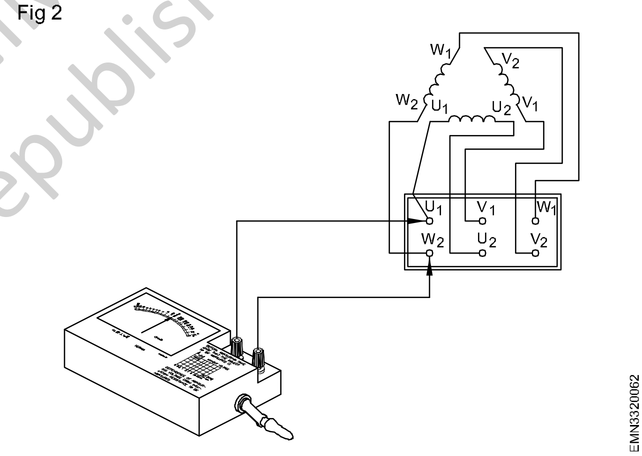



The test lamp is connected in series with a fuse and a switch to the phase wire and the other end is connected to one of the terminals (say $U_1$ in Fig. 1). The neutral of the supply wire is touched to the other terminals one by one. The terminal in which the lamp lights is the other end of the winding connected to the phase wire (say $U_2$ in Fig. 1). The pairs are to be found in a similar manner. Lighting of the lamp between two terminals shows continuity of the winding. Lighting of the lamp between more than two terminals shows short between the windings.

**Limitations of lamp continuity test:** However, this test only shows the continuity but will not indicate any short between the turns of the same winding. A better test would be to use an ohmmeter having an accurate low resistance range to measure the resistance of the individual windings. In a 3-phase induction motor, the resistance of the three windings should be the same, or more or less equal. If the reading is less in one winding, it shows that the winding is shorted.

**Insulation test between windings:** As shown in Fig. 2, one of the Megger terminals is connected to one terminal of any one winding (say $U_1$ in Fig. 2) and the other terminal of the Megger is connected to one terminal of the other windings (say $W_2$ in Fig. 2).

Fig 2



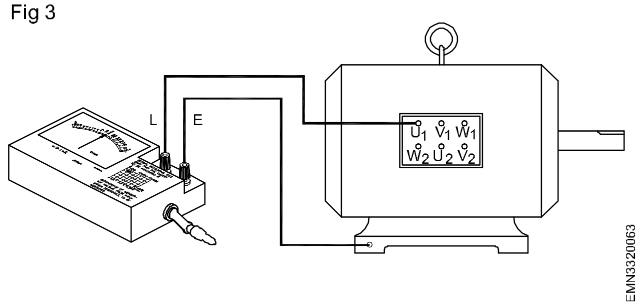

When the Megger handle is rotated at its rated speed, the reading should be more than one megohm. A lower reading than one megohm shows weak insulation between the windings, and needs to be improved. Likewise the insulation resistance between the other windings is tested and the values are recorded in Table 1.

Table 1

| S.No. | Between windings | Insulation resistance values in megohms | Remarks |
|---|---|---|---|
| 1 | U and W | | |
| 2 | U and V | | |
| 3 | V and W | | |

**Insulation resistance between winding and frame:** As shown in Fig. 3, one terminal of the Megger is connected to one of the phase windings, and the other terminal of the Megger is connected to the earthing terminal of the frame. When the Megger handle is rotated at the rated speed, the reading obtained should be more than one megohm. A lower reading than one megohm indicates poor insulation between the winding and the frame and needs to be improved by drying and varnishing the windings.

Fig 3




Likewise the other windings are tested and the readings are tabulated as shown in Table 2.

Table 2

| S.No. | Between windings | Insulation resistance values in megohms | Remarks |
|---|---|---|---|
| 1 | U and frame | | |
| 2 | U and frame | | |
| 3 | V and frame | | |

Necessity of frame earthing: The frame of the electrical equipment/machine needs to be earthed because :

– the earthing system provides safety for persons and apparatus against earth faults.

– the object of an earthing frame is to provide as nearly as possible a surface under and around the motor which shall be of uniform potential, and as near zero or absolute earth potential, as possible.

According to I.E.rules, for reasons of safety, the frame of the motor has to be connected by two distinct earth connections to two earth electrodes with the help of properly sized earth continuity conductors. Further the earth system resistance (earth electrode 5 ohms and earth continuity conductor one ohm, if not specified) should be sufficiently low such that the protective devices in the motor circuit will operate and isolate the circuit in case of earth faults.

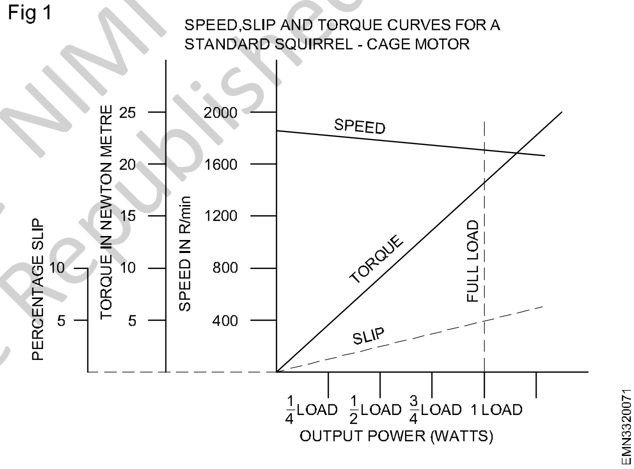
**iv) Characteristics of squirrel cage induction motor**

The most important characteristic of the induction motor is the speed torque characteristic which is also called the mechanical characteristic. A study of this characteristic will give an idea about the behaviour of the motor in load conditions. As the torque of the motor is also dependent on the slip, it will be interesting to study the characteristic of the squirrel cage induction motor to find the relationship between load, speed, torque and slip.

**Speed, torque and slip characteristics :** It has already been made clear that the rotor speed of a squirrel cage motor will always lag behind the synchronous speed of the stator field. The rotor slip is necessary in order to induce the rotor currents required for the motor torque. At no load, only a small torque is required to overcome the motor's mechanical losses, and the rotor slip will be very small, say about two percent. As the mechanical load is increased, however, the rotor speed will decrease, and hence, the slip will increase. This increase in slip inturn increases the induced rotor currents, and the increased rotor current in turn, will produce a higher torque to meet the increased load.

Fig. 1 shows the typical speed torque and slip characteristic curves for a standard squirrel cage motor. The speed curve shows that a standard squirrel cage motor will operate at a relatively constant speed from no load to full load.

Fig 1




Since the squirrel cage rotor is constructed basically of heavy copper/aluminium bars, shorted by two end rings, the rotor impedance will be relatively, low and hence, a small increase in the rotor induced voltage will produce a relatively large increase in the rotor current. Therefore, as the squirrel cage motor is loaded, from no-load to full load, a small decrease in speed is required to cause a relative increase in the rotor current. For this reason, regulation of a squirrel cage motor is very good. But the motor is often classified as a constant speed device.

The slip curve shows that the percentage slip is less than 5% load, and is a straight line.

Since the torque will increase in almost direct proportion to the rotor slip, the torque graph is similar to the slip graph which also has a straight line characteristic as shown in Fig. 1.

**Relationship between torque, slip rotor resistance and rotor inductive reactance :** It was stated earlier that torque is produced in an induction motor by the interaction of the stator and the rotor fluxes. The amount of torque produced is dependent on the strength of these two fields and the phase relation between them. This may be expressed mathematically as

$T = K \phi_s I_R \cos\phi$

where T = torque in Newton metre

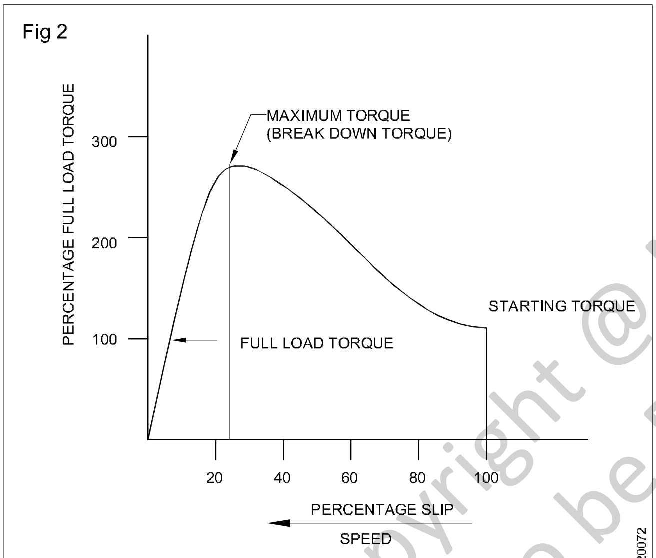
K = a constant

$\phi_s$ = stator flux in weber

$I_R$ = rotor current in ampere

$\cos\phi$ = rotor power factor

From no load to full load, the torque constant (K), the stator flux ($\phi_s$) and the rotor power factor ($\cos\phi$) for a squirrel cage motor will be practically constant. Hence the motor's torque will vary almost directly with the induced rotor current ($I_R$) since the rotor current inturn will vary almost directly with its slip. Variation of the torque of a squirrel cage motor is often plotted against its rotor slip as shown in Fig. 2.



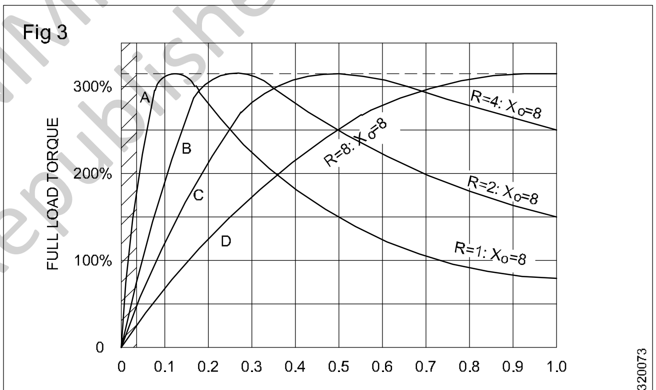

TORQUE VARIATION VERSUS SLIP FOR A STANDARD SQUIRREL - CAGE MOTOR

The increase in the rotor current, and hence, the increase in the rotor torque for a given increase in the rotor slip is dependent on the rotor power factor. The rotor resistance for a squirrel cage motor will be constant. However, an increase in slip will increase the rotor frequency, and the resulting inductive reactance of the rotor from no load to full load and even upto 125 percent of rated load, the amount of rotor slip for a standard squirrel cage motor is relatively small and the rotor frequency will seldom exceed 2 to 5 Hz. Therefore, for the above range of load the effect of frequency change on impedance will be negligible, and as shown in Fig. 2, the rotor torque will increase in almost a straight relationship with the slip.

Inbetween 10 to 25 percent slip the squirrel cage motor will attain its maximum possible torque. This torque is referred to as the maximum breakdown torque, and it may reach between 200 and 300 percent of the rated torque as shown in Fig. 2. At the maximum torque, the rotor's inductive reactance will be equal to its resistance.

However, when the load and the resulting slip are increased much beyond the rated full load values, the increase in rotor frequency, and hence, the increase in rotor reactance and impedance become appreciable. This increase in rotor inductive reactance and the resulting decrease in rotor power factor will have two effects; first, the increase in impedance will cause a decrease in the rate at which the rotor current increases with an increase in slip, and second, the lagging rotor power factor will increase; that means, the rotor flux will reach its maximum sometime after the stator peak flux has been swept by it. The out-of-phase relationship between these two fields will reduce their interaction and their resulting torque. Hence, if the motor load is increased beyond the breakdown torque value, the torque falls rapidly due to the above two effects and the motor operation becomes unstable, and the motor will stall.

**Effect of rotor resistance upon the torque/slip relationship:** Fig. 3 shows the relationship between torque and slip when the rotor resistance is changed. The shaded portion of the curve shows the actual operating area. Curve A for an induction motor with low rotor resistance, say 1 ohm, Curve B is for 2 ohm, Curve C is for 4 ohm and Curve D for 8 ohm.




FRACTIONAL SLIPS TORQUE/SLIP CURVES FOR AN INDUCTION MOTOR

**Breakdown torque :** In all these cases the standstill inductive reactance of the rotor is the same, say 8 ohm. From the curves it is clear that the maximum (breakdown) torque is the same for the four values of R. Further it is also clear that the maximum torque occurs at greater slip for higher resistance.

**Starting torque :** At the time of starting, the fractional slip is 1, and the starting torque is about 300% of the full load torque for the rotor having maximum resistance as shown by curve D of Fig. 3, and at the same time the rotor having low resistance will produce a starting torque of 75% of the full load torque only, as shown by curve A of Fig. 3. Hence, we can say that an induction motor having high rotor resistance will develop a high torque at the time of starting.

**Running torque :** While looking at the normal operating region in the shaded portion of the graph, it will be found the torque at running is appreciably high for low resistance rotor motors and will be conspicuously less for high resistance rotor motors.

As squirrel cage induction motors will have less rotor resistance, their starting torque is low but running torque is quite satisfactory. This is partly compensated by the double squirrel cage motors which produce high starting and normal running torque. On the other hand, the slip ring induction motor, due to its wound rotor, has the possibility of inclusion of resistance at the time of starting and reducing the same while running.

**Application of squirrel cage induction motor :** Single squirrel cage motors are used widely in industries and in irrigation pump sets where fairly constant speed is required. This motor has fairly high efficiency, costs less and is found to be robust in construction.

Double squirrel cage induction motors are used in textile mills and metal cutting tool operations where high starting torque is essential.

**v) Efficiency of induction motor**

When the three-phase induction motor is running at no-load, the slip has a value very close to zero. The torque developed in the rotor is to overcome the rotational losses consisting of friction and windage. The input power to the motor is to overcome stator iron loss and stator copper loss. The stator iron loss (consisting of eddy current and hysteresis) depends on the supply frequency and the flux density in the iron core. It is practically constant. The iron loss of the rotor is, however, negligible because the frequency of the rotor currents under normal condition is always small.

If a mechanical load is then applied to the motor shaft, the initial reaction is for the shaft load to drop the motor speed slightly, thereby increasing the slip. The increased slip subsequently causes $I_2$ to increase to that value which, when inserted into the equation for torque calculation (i.e $T = K\phi_s\ I_2 \cos\phi_s$), yields sufficient torque to provide a balance of power to the load. Thus an equilibrium is established and the operation proceeds at a particular value of slip. In fact, for each value of load horsepower requirement, there is a unique value of slip. Once slip is specified then the power input, the rotor current, the developed torque, the power output and the efficiency are all determined. The power flow diagram in a statement form is shown in Fig. 1. Note that the loss quantities are placed on the left side of the flow point. Figure. 2 is the same power flow diagram but now expressed in terms of all the appropriate relationships needed to compute the performance.

Fig 1

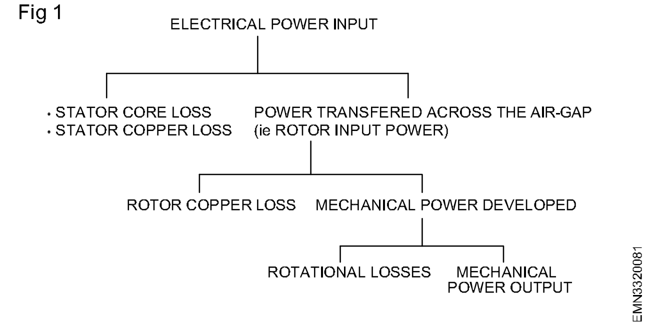
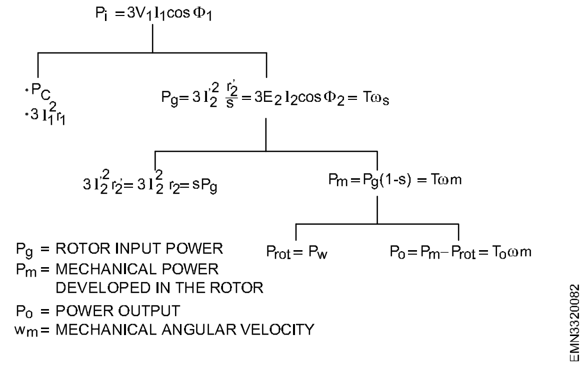



Fig 2




Torque, Mechanical power and Rotor output : Stator input $P_i$ = stator output + stator losses.

The stator output is transferred fully inductively to the rotor circuit.

Obviously, rotor input $P_g$ = stator output.

Rotor gross output, $P_m$ = rotor input $P_g$ = rotor cu. losses.

This rotor output is converted into mechanical energy and gives rise to the gross torque T. Out of this gross torque developed, some is lost due to windage and friction losses in the rotor, and the rest appear are useful torque $T_o$.

Let n r.p.s be the actual speed of the rotor and if it is in Nm, then

$T \times 2\pi n$ = rotor gross output in watts, $P_m$.

$$\text{Therefore, } T = \frac{\text{rotor gross output in watts, } P_m}{2\pi\ n}\ \text{N.m}$$

The value of gross torque in kg.m is given by

$$T = \frac{\text{rotor gross output in watts}}{9.81 \times 2\pi\ n}\ \text{Kg m}$$

$$= \frac{P_m}{9.81 \times 2\pi\ n}\ \text{Kg m}$$

If there were no copper losses in the rotor, the rotor output will equal the rotor input and the rotor will run at synchronous speed.

$$\text{Therefore, } T = \frac{\text{rotor input } P_g}{2\ \pi\ n_s}$$

From the above two equation we get,

Rotor gross output = $P_m = T\omega = T \times 2\pi n$

Rotor input = $P_g = T\omega_s = T \times 2\pi n_s$

The difference between the two equals the rotor copper loss.

Therefore, rotor copper loss = s x rotor input

= s x power across air gap

= $sP_g$.

$$\text{Also rotor input, } P_g = \frac{\text{rotor copper loss}}{s}$$

Rotor gross output $P_m$ = Input $P_g$ - rotor cu.loss

= $(1 - s) P_g$

or $\frac{\text{rotor gross output, } p_m}{\text{rotor input, } p_g} = 1 - s$

rotor gross output. $Pm = (1 - s)P_g$

Therefore rotor efficiency $= \frac{n}{n_s}$

### Example

The power input to a 4-pole, 3-phase, 50 Hz. induction motor is 50kW, the slip is 5%. The stator losses are 1.2 kW and the winding and friction losses are 1.8 kW. Find (i) the rotor speed, (ii) the rotor copper loss, (iii) the efficiency.

Data given

| | |
|---|---|
| No. of poles | P = 4 |
| Frequency | f = 50 Hz |
| Phases | = 3 |
| Input kW | = 50 |
| Slip | s = 5% |
| Stator losses | = 1.2 kW |
| Friction & Windage losses | = 1.8 kW |

Find:

| | |
|---|---|
| rotor speed | = N |
| rotor copper loss | = s x input power to rotor |
| efficiency | = $\eta$ |

### Solution

$$\text{Synchronous speed} = N_s = \frac{120f}{p} = \frac{6000}{4} = 1500 \text{ rpm}$$

$$\text{Fractional slip} = s = \frac{N_s - N_r}{N_s}$$

$$\frac{5}{100} = \frac{1500 - N_r}{1500}$$

$$75 = 1500 - N_r$$

Therefore, rotor speed, Nr = 1500 - 75 = 1425 rpm.

Input power to rotor = (50 - 1.2)kW

Rotor copper loss = s x input power to rotor

= 0.05 x 48.8

= 2.44 kW.

Rotor output windage = Rotor input - (Friction and loss + rotor cu.loss) = 48.8 - (1.8 + 2.44)

= 44.56 kW

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}} = \frac{44.56 \times 100}{50} = 89.12\%.$$

### vi) Types of squirrel cage motors

The three-phase squirrel cage motors have been standardised according to their electric characteristics into six types designated as design A, B, C, D, E and F. Standard squirrel cage induction motors which were of shallow, slot types are designated as class A. For this reason class A motors are used as a reference and are referred to as 'normal starting-torque', normal starting current, normal slip motors.

**Classes of squirrel-cage motors**

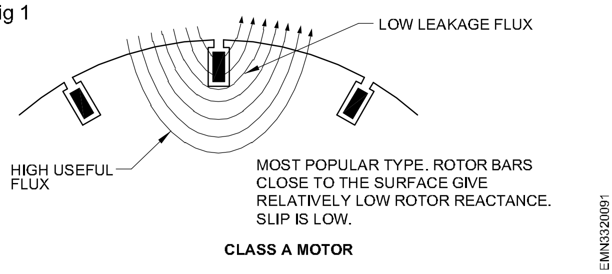
(According to starting characteristics)

| Class | Starting torque | Starting | Current Slip |
|---|---|---|---|
| A | Normal | Normal | Normal |
| B | Normal | Low | Normal |
| C | High | Low | Normal |
| D | High | Low | High |
| E | Low | Normal | Low |
| F | Low | Low | Normal |

Out of these six, four specific designs A through D are common squirrel cage motors. These four classes, however, cover nearly all practical applications of induction machines.

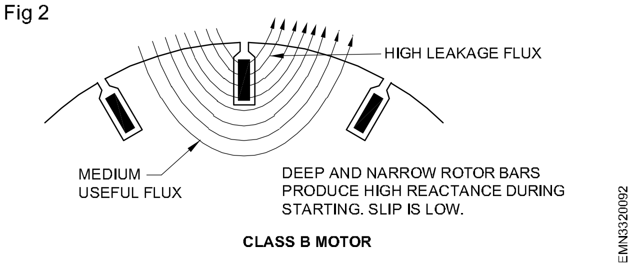
Class A motors: These motors are characterised by having a low rotor-circuit resistance and reactance. Its locked rotor current with full voltage is generally more than 6 times the full load current. Because of their low resistance, starting currents are very high. They operate at very small slips (s < 0.01) under full load. Machines in this class are suitable only in situations where very small starting torques are required. The rotor bar construction of such motor is shown in Fig. 1.

Fig 1




**Class B motors:** These are general purpose motors of normal starting torque and starting current. The speed regulation at full load is low (usually under 5%) and the starting torque is in the order of 15% of the rated speed being lower for the lower speed and larger motors. It should be realised that although the starting current is low, it generally is 600% of full load value. (Fig .2)

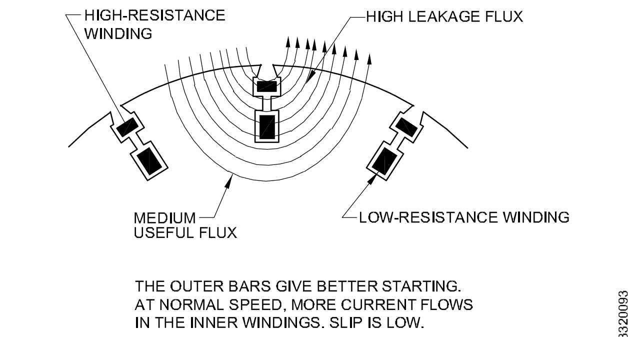
Fig 2




CLASS B MOTOR

**Class C motors:** Compared to class B motors, class C motors have higher starting torque, normal starting current and run at slips of less than 0.05 at full load. The starting torque is about 200% of the rated speed and the motors are generally designed to start at full-load. Typical application of this class motor is driving conveyors, reciprocating pumps, and compressors. (Fig. 3)

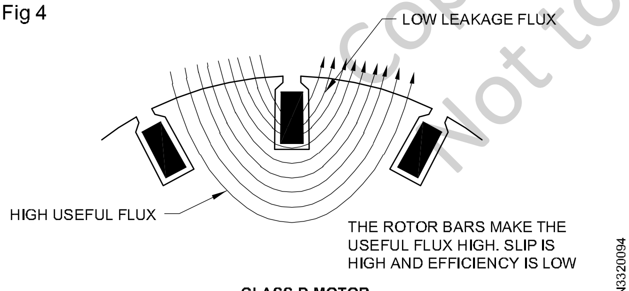
Fig 3




CLASS C MOTOR

**Class D motors:** These are high slip motors with high starting torque and relatively low starting current. As a result of the high full load slip, their efficiency is generally lower than that of the other motor classes. The peak of the torque speed curve, resulting in a starting torque of about 300%, is identical to the starting torque. (Fig.4)

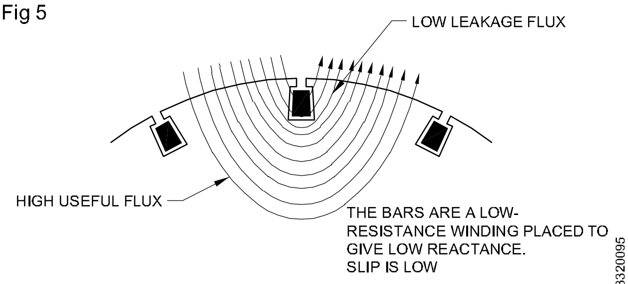
Fig 4




CLASS D MOTOR

Class E motors as shown in the fig.5

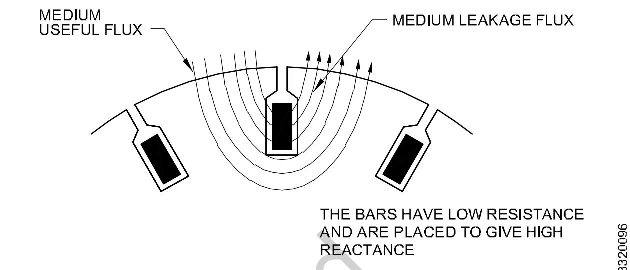
Fig 5




CLASS E MOTOR

Class F motors as shown in the fig.6

Fig 6




CLASS F MOTOR

Now when the motor is stationary, the frequency of the rotor current is the same as the supply frequency. But when the rotor starts revolving, then the frequency depends upon the relative speed or on slip speed. Let at any slip speed, the frequency of the rotor current be $f_r$ then

$$N_s - N = \frac{120f_r}{p}$$

$$\text{also, } N_s = \frac{120f}{p}$$

Dividing one by the other, we get

$$\frac{f_r}{f} = \frac{N_s - N}{N_s} = s$$

$$f_r = sf$$

## Starters for induction motors-D.O.L, manual star-delta starter, semi automatic star-delta starter and automatic star/delta starter

**Objectives:** At the end of this lesson you shall be able to
- **state the necessity of starters and types**
- **state the specification of a D.O.L. starter, explain its operation and application**
- **explain the necessity of a back-up fuse and its rating according to the motor rating.**

**i) Necessity of starter:** A squirrel cage induction motor just before starting is similar to a polyphase transformer with a short-circuited secondary. If normal voltage is applied to the stationary motor, then, as in the case of a transformer, a very large initial current, to the tune of 5 to 6 times the normal current, will be drawn by the motor from the mains. This initial excessive current is objectionable, because it will produce large line voltage drop, which in turn will affect the operation of other electrical equipment and lights connected to the same line.

The initial rush of current is controlled by applying a reduced voltage to the stator winding during the starting period, and then the full normal voltage is applied when the motor has run up to speed. For small capacity motors, say up to 3 Hp, full normal voltage can be applied at the start. However, to start and stop the motor, and to protect the motor from overload currents and low voltages, a starter is required in the motor circuit. In addition to this, the starter may also reduce the applied voltage to the motor at the time of starting.

**Types of starters:** Following are the different types of starters used for starting squirrel cage induction motors.

- Direct on-line starter
- Star-delta starter
- Step-down transformer starter
- Auto-transformer starter

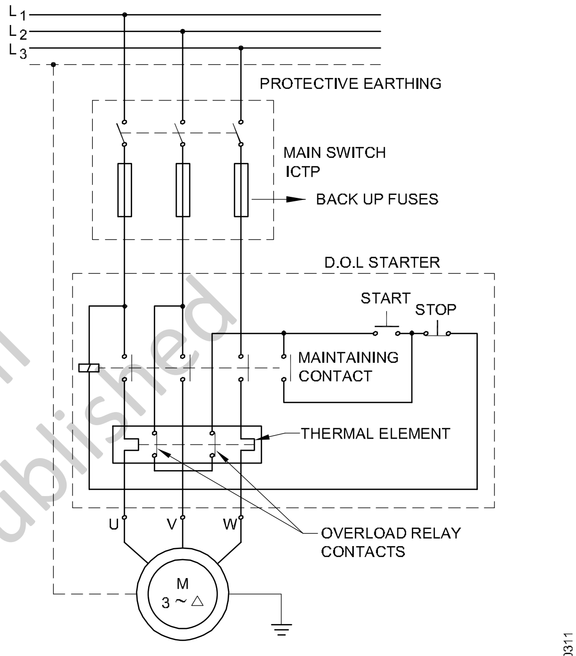
In the above starters, except for the direct on-line starter, reduced voltage is applied to the stator winding of the squirrel cage induction motor at the time of starting, and regular voltage is applied once the motor picks up the speed.

**Selection of starter:** Many factors must be considered when selecting starting equipment. These factors include starting current, the full load current, voltage rating of motor, voltage (line) drop, cycle of operation, type of load, motor protection and safety of the operator.

A D.O.L. starter is one in which a contactor with no-volt relay, ON and OFF buttons, and overload relay are incorporated in an enclosure.

**Construction and operation:** A push-button type, direct on-line starter, which is in common use, is shown in Fig. 1. It is a simple starter which is inexpensive and easy to install and maintain.

Fig 1




WIRING DIAGRAM OF A DIRECT ON-LINE STARTER WITH PROTECTIVE DEVICES

There is no difference between the complete contactor circuit explained in Exercise 12 and the D.O.L.starter, except that the D.O.L. starter is enclosed in a metal or PVC case, and in most cases, the no-volt coil is rated for 415V and is to be connected across two phases as shown in Fig 1. Further the overload relay can be situated between ICTP switch and contactor,or between the contactor and motor as shown in Fig. 1, depending upon the starter design. Trainees are advised to write the working of the D.O.L. starter on their own by going through the explanation given in Exercise 12 which is for a complete contactor circuit.

**Specification of D.O.L. starters:** While giving specification, the following data are to be given.

D.O.L. STARTER

Phases - single or three.

Voltage 230 or 415V.

Current rating 10, 16, 32, 40, 63, 125 or 300 amps.

No-volt coil voltage rating AC or DC 12, 24, 36, 48, 110, 230/250, 360, 380 or 400/440 volts.

Number of main contacts 2, 3 or 4 which are normally open.

Number of auxiliary contacts 2 or 3. 1 NC + 1 NO or 2 NC + 1 NO respectively.

Push-button - one `ON' and one `OFF' buttons.

Overload from setting – amp-to-amp. Enclosure - metal sheet or PVC.

**Applications:** In an induction motor with a D.O.L. starter, the starting current will be about 6 to 7 times the full load current. As such, D.O.L. starters are recommended to be used only up to 3 HP squirrel cage induction motors, and up to 1.5 kW double cage rotor motors.

**Necessity of back-up fuses:** Motor starters must never be used without back-up fuses. The sensitive thermal relay mechanism is designed and calibrated to provide effective protection against overloads only. When sudden short circuits take place in a motor circuit, the overload relays, due to their inherent operating mechanism, take a longer time to operate and open the circuit. Such delays will be sufficient to damage the starter motor and connected circuits due to heavy in-rush of short circuit currents. This could be avoided by using quick-action, high-rupturing capacity fuses which, when used in the motor circuit, operate at a faster rate and open the circuit. Hence H.R.C. diazed (DZ) type fuses are recommended for protecting the installation as well as the thermal overload relay of the motor starter against short circuits. In case of short circuits, the back-up fuses melt and open the circuit quickly. A reference table indicating fuse ratings for different motor ratings is given.

It is recommended that the use of semi-enclosed, rewirable, tinned copper fuses may be avoided as for as possible.

**The given full load currents apply in the case of single phase, capactor-start type motors, and in the case of 3-phase, squirrel cage type induction motors at full load having average power factor and efficiency. The motors should have speeds not less than 750 r.p.m.**

**Fuses upto and including 63 A are DZ type fuses. Fuses from 100 A and above are IS type fuses (type HM).**

Table of relay ranges and back up fuses for motor protection

| Sl. No. | Motor ratings 240V 1-phase | | | Motor ratings 415V 3-phase | | | Relay range A | Nominal back-up fuse recommended |
|---|---|---|---|---|---|---|---|---|
| | hp | kW | Full load current | hp | kW | Full load current | a | c |
| 1 | | | | 0.05 | 0.04 | 0.175 | 0.15 - 0.5 | 1A |
| 2 | 0.05 | 0.04 | | 0.1 | 0.075 | 0.28 | 0.25 - 0.4 | 2A |
| 3 | | | | 0.25 | 0.19 | 0.70 | 0.6 - 1.0 | 6A |
| 4 | 0.125 | 0.11 | | 0.50 | 0.37 | 1.2 | 1.0 - 1.6 | 6A |
| 5 | 0.5 | 0.18 | 2.0 | 1.0 | 0.75 | 1.8 | 1.5 - 2.5 | 6A |
| 6 | 0.5 | 0.4 | 3.6 | 1.5 | 1.1 | 2.6 | 2.5 - 4.0 | 10A |
| 7 | | | | 2.0 | 1.5 | 3.5 | 2.5 - 4.0 | 15A |
| 8 | 0.75 | 0.55 | | 2.5 | 1.8 | 4.8 | 4.0 - 6.5 | 15A |
| 9 | | | | 3.0 | 2.2 | 5.0 | 4.0 - 6.5 | 15A |
| 10 | 1.0 | 0.75 | 7.5 | 5.0 | 3.7 | 7.5 | 6.0 - 10 | 20A |
| 11 | 2.0 | 1.5 | 9.5 | 7.5 | 5.5 | 11.0 | 9.0 - 14.0 | 25A |
| 12 | 3.0 | 2.25 | 14 | 10.0 | 7.5 | 14 | 10.0 - 16.0 | 35A |



**Manual star-delta switch/starter**

**Necessity of star-delta starter for 3-phase squirrel cage motor:** If a 3-phase squirrel cage motor is started directly, it takes about 5-6 times the full load current for a few seconds, and then the current reduces to normal value once the speed accelerates to its rated value. As the motor is of rugged construction and the starting current remains for a few seconds, the squirrel cage induction motor will not get damaged by this high starting current.

However with large capacity motors, the starting current will cause too much voltage fluctuations in the power lines and disturb the other loads. On the other hand, if all the squirrel cage motors connected to the power lines are started at the same time, they may momentarily overload the power lines, transformers and even the alternators.

Because of these reasons, the applied voltage to the squirrel cage motor needs to be reduced during the starting periods, and regular supply could be given when the motor picks up its speed.

Following are the methods of reducing the applied voltage to the squirrel cage motor at the start.

– Star-delta switch or starter

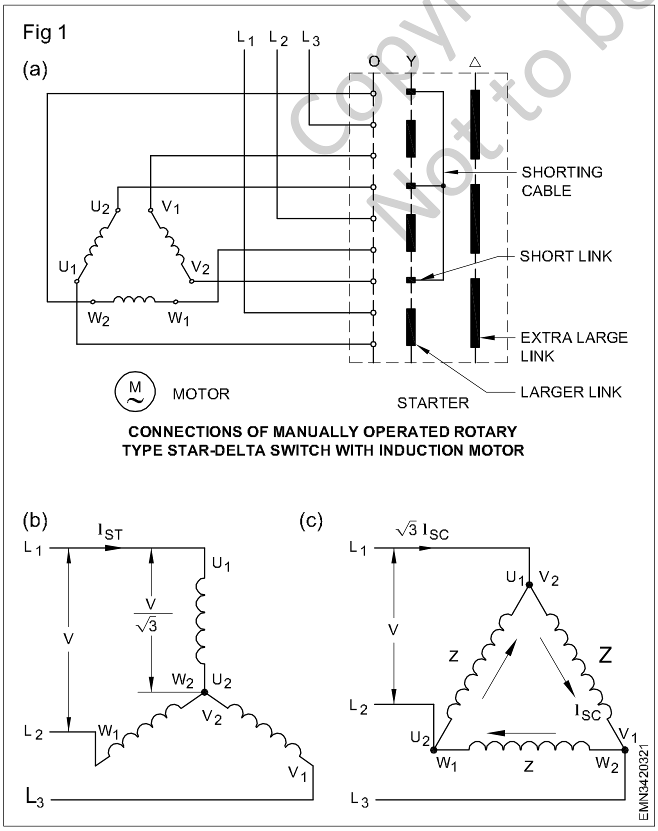
– Auto-transformer starter

– Step-down transformer starter

**Star-delta starter:** A star-delta switch is a simple arrangement of a cam switch which does not have any additional protective devices like overload or under-voltage relay except fuse protection through circuit fuses, whereas the star-delta starter may have overload relay and under voltage protection in addition to fuse protection. In a star-delta switch/starter, at the time of starting, the squirrel cage motor is connected in star so that the phase voltage is reduced to $1/\sqrt{3}$ times the line voltage, and then when the motor picks up its speed, the windings are connected in delta so that the phase voltage is the same as the line voltage. To connect a star-delta switch/starter to a 3-phase squirrel cage motor, all the six terminals of the three-phase winding must be available.

As shown in Fig 1a, the star-delta switch connection enables the 3 windings of the squirrel cage motor to be connected in star, and then in delta. In star position, the line supply $L_1$, $L_2$ and $L_3$ are connected to the beginning of windings $U_1$, $W_1$ and $V_1$ respectively by the larger links, whereas the short links, which connect $V_2$ $U_2$ and $W_2$, are shorted by the shorting cable to form the star point. This connection is shown as a schematic diagram. (Fig.1b)

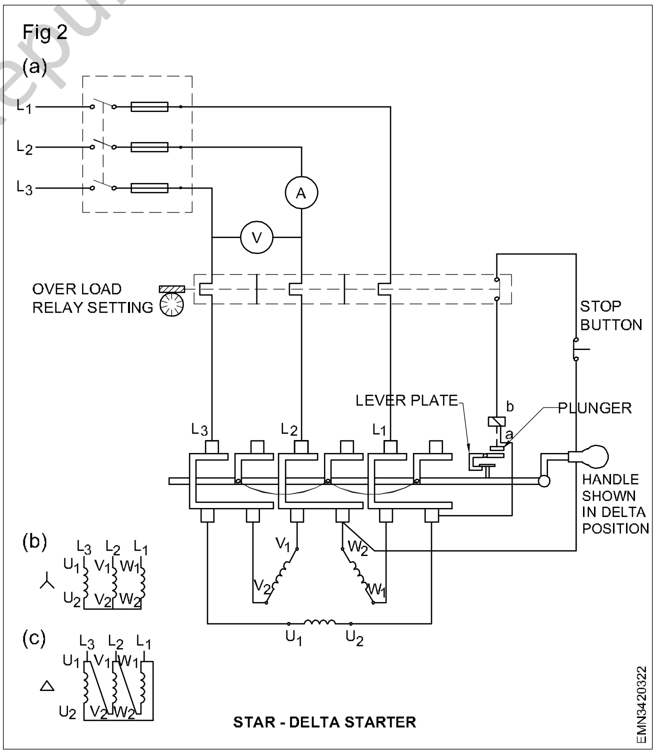
When the switch handle is changed over to delta position, the line supply $L_1$, $L_2$ and $L_3$ are connected to terminals $U_1$ $V_2$, $W_1$ $U_2$ and $V_1$ $W_2$ respectively by the extra large links to form a delta connection. (Fig. 1c)




**Manual star-delta starter:** Fig. 2 shows the conventional manual star-delta starter. As the insulated handle is spring-loaded, it will come back to OFF position from any position unless and until the no-volt (hold-on ) coil is energised. When the hold-on coil circuit is closed through the supply taken from $U_2$ and $W_2$, the coil is energised and it holds the plunger, and thereby the handle is held in delta position against the spring tension by the lever plate mechanism. When the hold-on coil is de-energised the plunger falls and operates the lever plate mechanism so as to make the handle to be thrown to the off position due to spring tension. The handle also has a mechanism (not shown in Fig) which makes it impossible for the operator to put the handle in delta position in the first moment. It is only when the handle is brought to star position first, and then when the motor picks up speed, the handle is pushed to delta position.

The handle has a set of baffles insulated from each other and also from the handle. When the handle is thrown to star position, the baffles connect the supply lines $L_1$, $L_2$ and $L_3$ to beginning of the 3-phase winding $W_1$, $V_1$ and U1 respectively. At the same time the small baffles connect $V_2$, $W_2$ and $U_2$ through the shorting cable to form the star point. (Fig 2b)

When the handle is thrown to delta position, the larger end of the baffles connect the main supply line $L_1$, $L_2$ and $L_3$ to the winding terminals $W_1U_2$, $V_1W_2$ and $U_1V_2$ respectively to form the delta connection. (Fig. 2c)




The overload relay current setting could be adjusted by the worm gear mechanism of the insulated rod. When the load current exceeds a stipulated value, the heat developed in the relay heater element pushes the rod to open the hold-on coil circuit, and thereby the coil is de-energised, and the handle returns to the off position due to the spring tension.

The motor also could be stopped by operating the stop button which in turn de-energises the hold-on coil.

**Back-up fuse protection:** Fuse protection is necessary in the star-delta started motor circuit against short circuits. In general, as a thumb rule for 415V, 3-phase squirrel cage motors, the full load current can be taken as 1.5 times the H.P. rating. For example, a 10 HP 3-phase 415V motor will have approximately 15 amps as its full load current.

To avoid frequent blowing of the fuse and at the same time for proper protection, the fuse wire rating should be 1.5 times the full load current rating of the motor. Hence for 10 HP, 15 amps motor, the fuse rating will be 23 amps, or say 25 amps.

**Comparison of impact of star and delta connections on starting current and torque of the induction motor:** When the three-phase windings of the squirrel cage motor are connected in star by the starter, the phase voltage across each winding is reduced by a factor of $1/\sqrt{3}$ of the applied line voltage (58%), and hence the starting current reduces to 1/3 of that current which would have been drawn if the motor were directly started in delta. This reduction in starting current also reduces the starting torque to 1/3 of the starting torque which would have been produced in the motor, if it were started directly in delta.

The above statement could be explained through the following example.

**Example**

Three similar coils of a 3-phase winding of a squirrel cage induction motor, each having a resistance of 20 ohms and inductive reactance of 15 ohms, are connected in (a) star (b) delta through a star-delta starter to a 3-phase 400V 50 Hz supply mains.

Calculate the line current and total power absorbed in each case. Compare the torque developed in each case.

**Solution**

Impedence per phase

$$Z_{ph} = \sqrt{R^2 + X^2}$$

$$= \sqrt{20^2 + 15^2}$$

Star connection

$$E_{Ph} = \frac{E_L}{\sqrt{3}} = \frac{400}{\sqrt{3}} = 231 \text{ volts}$$

$$I_{Ph} = \frac{E_{ph}}{Z_{ph}} = \frac{231}{25} = 9.24 \text{amps}$$

$$I_L = I_{sh} = 9.24 \text{amps.}$$

$$\text{Power absorbed} = \sqrt{3}\, E_L\, I_L \cos\theta$$

$$= \sqrt{3} \times 400 \times 9.24 \times 1$$

Assuming PF = 1, we have = 6401 watts.

Delta connection

$$E_{ph} = E_L = 400V$$

$$I_{Ph} = \frac{E_{ph}}{Z_{ph}} = \frac{400}{25} = 16A$$

$$I_L = \sqrt{3}\, I_{ph} = 1.732 \times 16 = 27.7 \text{ A}$$

$$\text{Power absorbed} = \sqrt{3}\, E_L I_L \cos\theta$$

(assume PF = 1)

$$= \sqrt{3} \times 400 \times 27.7 \times 1$$

$$= 19190 \text{ W.}$$

The torque developed is proportional to the square of the voltage across the winding.

In the case of star, the voltage across the winding $E_{ph}$

$$E_{ph} = \frac{E_L}{\sqrt{3}}$$

$$= \frac{E^2_L}{\sqrt{3}} K \text{ in star}$$

In the case of delta, the voltage across the $E_{ph}$ winding

$$E_{ph} = E_L.$$

Hence torque

$$(E_L)^2 K = E^2_L K.$$

By comparison the torque developed in star connection at the time of starting is 1/3 of the torque developed in a delta connection (running).

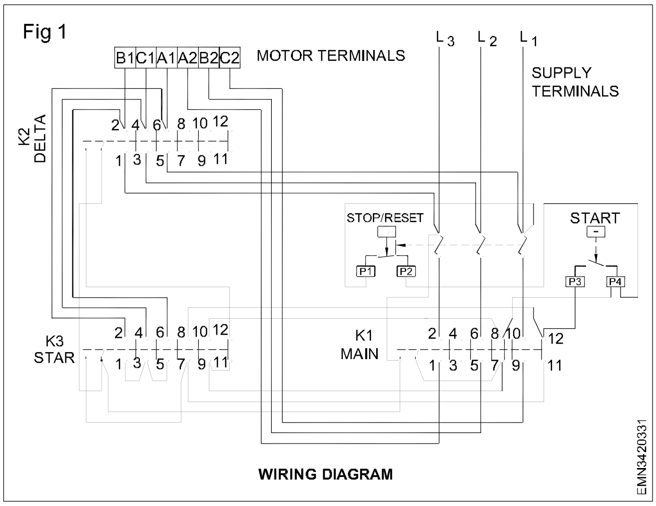
As the torque is 3 times less in starting due to the star connection, whenever a motor has to be started with heavy loads, the star-delta starter is not used. Instead an auto-transformer or step-down transformer starter could be used as the voltage tapping can be changed to more than 58% of the line voltage to suit the torque requirement.

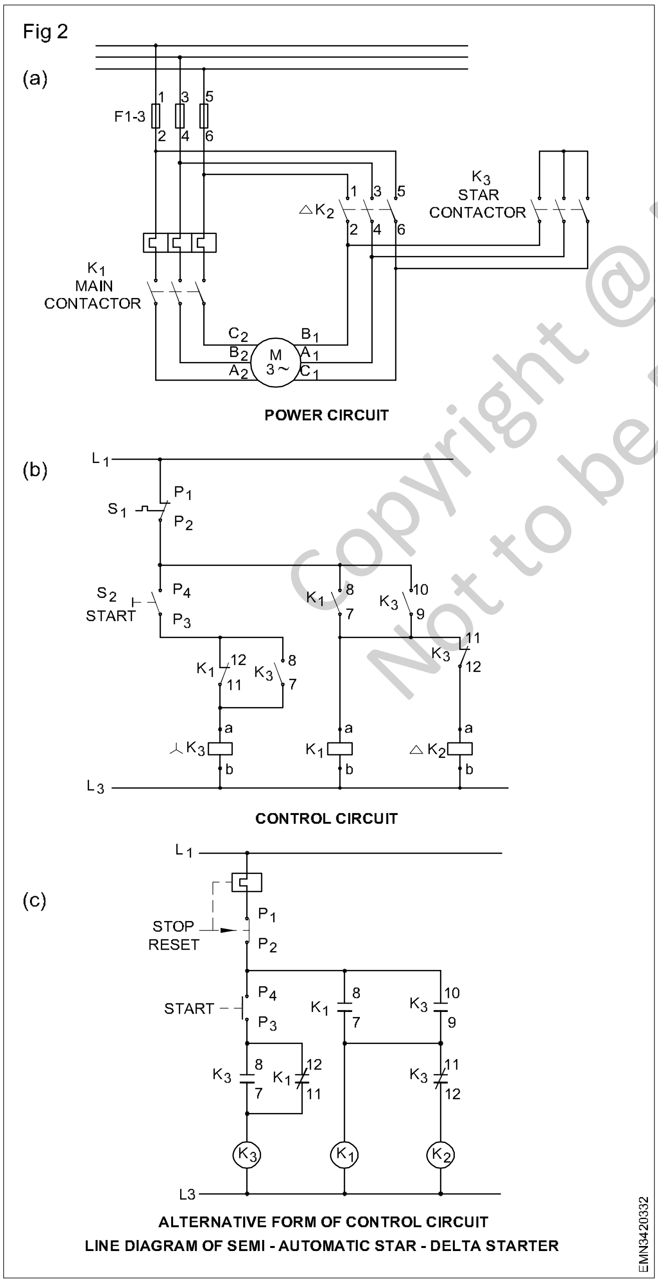
**ii) Semi-automatic star-delta starter**

The standard squirrel cage induction motors with both ends of each of the three windings brought out (six terminals) are known as star-delta motors. If the starter used has the required number of properly wired contactors, the motor can be started in star and run in delta.

The proper use of manual star-delta starter demands a special skill in handling the starter. The sluggish operation of the manual lever often causes damage to the moving and fixed contacts in a manual star-delta starter.

The contactors are employed for making and breaking the main line connections. Figure .1 shows the wiring diagram and Fig. 2 shows the line diagram of power circuit and the control circuit.




**Operation:** Refer to the control circuit and power circuit diagrams shown in Fig. 2. When the start button $S_2$ is pressed the contactor coil $K_3$ energises through $P_4$, $P_3$ and $K_1$ normally closed contact 12 and 11. When $K_3$ closes, it opens the normally closed contact $K_3$ between 11 and 12 and makes contact between 10 and 9 of $K_3$. The mains contactor $K_1$ energies through $P_4$, 10 and 9 of $K_3$. Once $K_1$ energises the NO contact of $K_1$ point 8 and 7 establishes a parallel path to $K_3$ terminals 10 and 9.

The star contactor $K_3$ remains energised so long as the start button is kept pressed. Once the start button is released, the $K_3$ coil gets de-energised. The $K_3$ contact cannot be operated because of the electrical interlock of $K_1$ and normally closed contacts between terminals 12 and 11.

When the $K_3$ contactor get de-energised the normally closed contact of $K_3$ between terminals 11 and 12 establishes contact in the contactor $K_2$ - coil circuit. The delta contactor $K_2$ closes.

The operator has to observe the motor starting and reaching 70% of the synchronous speed for satisfactory starting and running of the induction motor.

Figure. 2(c) shows the alternative form of drawing control circuit.



### iii) Automatic star-delta starter

**Applications :** The primary application of star-delta motors is for driving centrifugal chillers of large central air-conditioning units for loads such as fans, blowers, pumps or centrifuges, and for situations where a reduced starting torque is necessary. A star-delta motor is also used where a reduced starting current is required.

In star-delta motors all the winding is used and there are no limiting devices such as resistors or auto-transformers. Star-delta motors are widely used on loads having high inertia and a long acceleration period.

**Overload relay settings :** Three overload relays are provided on star-delta starters. These relays are used so that they carry the motor winding current. This means that the relay units must be selected on the basis of the winding current, and not the delta connected full load current. The motor name-plate indicates only the delta connected full load current, divide this value by 1.73 to obtain the winding current. Use this winding current as the basis for selecting and setting the motor winding protection relay.

**Operation :** Figure 1 shows the line diagram of the power circuit and the control circuit of the automatic star-delta starter. Pressing the start button S-energises the star contactor $K_3$. (Current flows through $K_4$T NC terminals 15 & 16 and $K_2$ NC terminals 11 & 12). Once $K_3$ energises the $K_3$ NO contact closes (terminals 23 & 24) and provide path for the current to close the contactor $K_1$. The closing of contactor $K_1$ establishes a parallel path to start button via $K_1$ NO terminals 23 & 24.

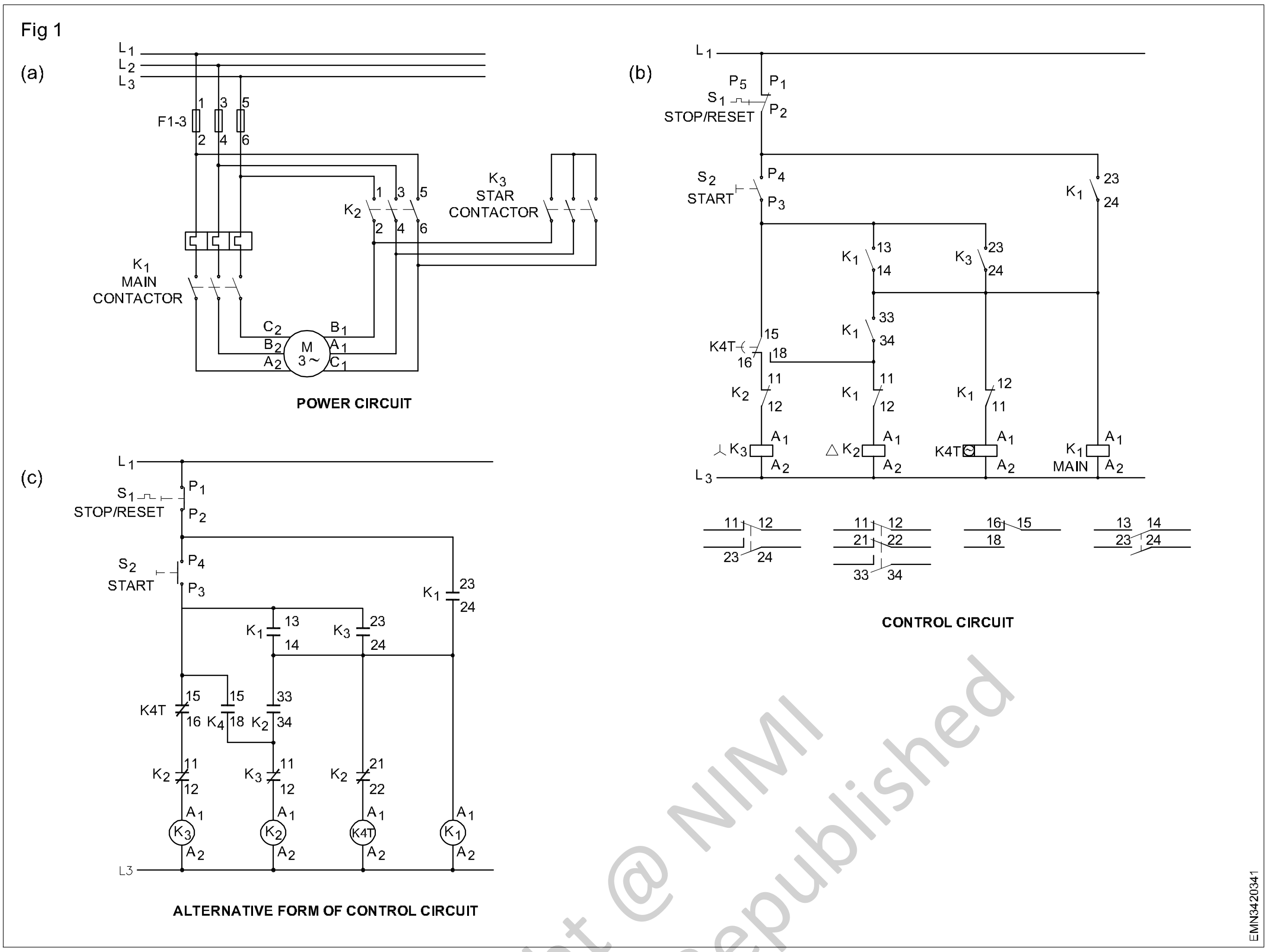
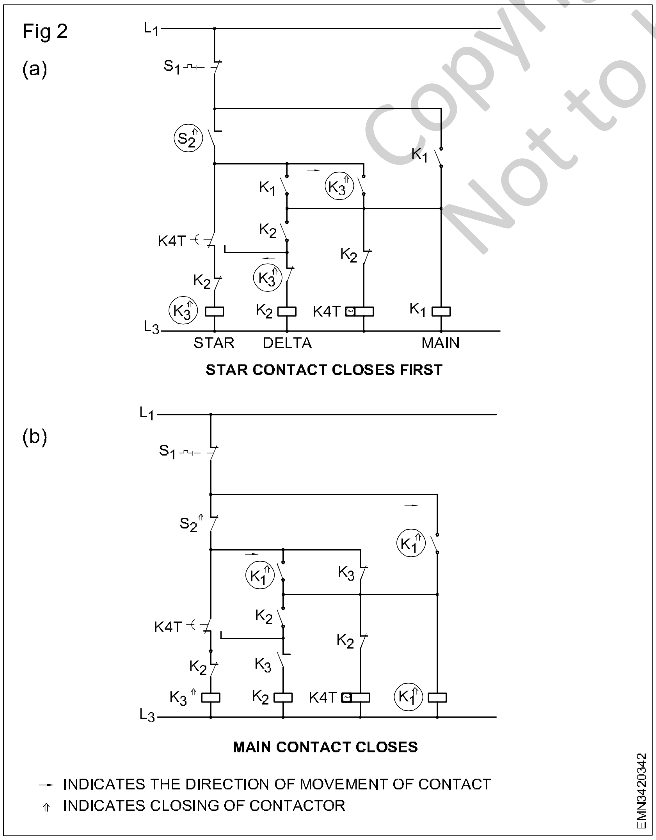
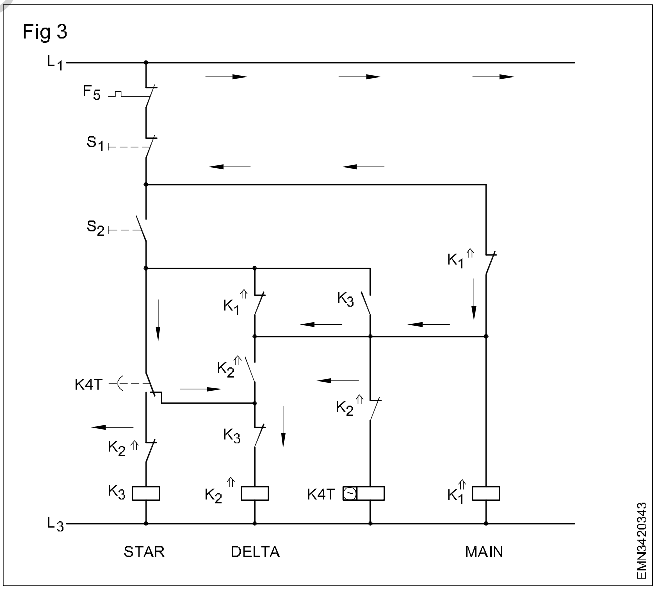



Figure. 2 shows the current direction and closing of contacts as explained above.

Similarly Figure. 3 shows the action taking place after the timer relay operating the contact K4T.



## Types of audio and video connectors

**Objectives:** At the end of this lesson you shall be able to
- **list the different types of Audio and Video connectors**
- **explain the construction of Audio and Video connectors**
- **explain the applications of connectors.**

**Introduction:** The various types of equipments used in the field of communications and broadcasting are in the form of cabinets closed on all sides by metal plates. The input-output connections, Auxiliary inputs and outputs and other connections to the equipment are brought out in the form of connectors mounted normally on the rear side of the equipment. So connections to the equipments by cables cannot be done with open ended cables. The cable ends should also have suitable mating connectors for giving input or taking the output from the equipments.

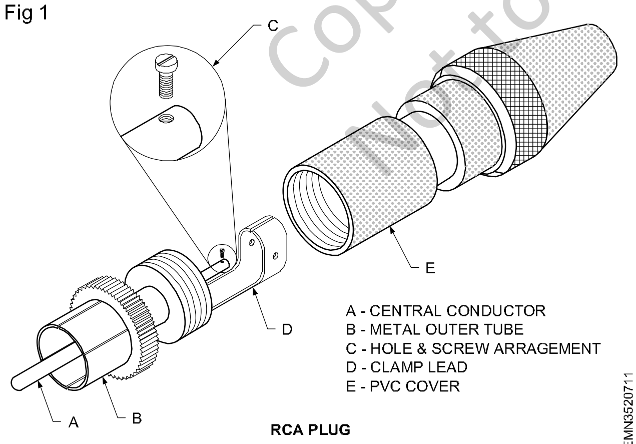
The use of such connectors makes it easy to remove equipment or replace the equipment whenever necessary. The cable connections can easily be changed to other equipments when cables and equipments are provided with connectors. Also the use of such connectors are helpful in making firm and reliable connections. In addition, in many cases the usage of connectors helps for fool proof operation avoiding errors due to wrong connections.

**Audio Connectors**

The details of some of the Audio connectors which are mostly in use are as follows.

**RCA plug and sockets:** The exploded view of the RCA connector plug is given in Fig.1.

Fig 1




The RCA plugs and sockets are invariably used in commercial equipments like audio consoles, recorders, TV receivers, video cassette recorders/players and some commercial amplifiers. These connectors can be used only with unbalanced audio cables. They are normally used for connecting high impedance inputs and outputs.

The exploded view of RCA plug is shown in fig.1. The RCA plug consists of metal outer tube (B) and an inner central conductor (A) insulated from one another by foam or styroflex spacer. The cable side of the inner conductor is in the form of a small cylindrical rod with a hole and screw arrangement (C) for connecting the centre conductor of the unbalanced cable. There is also a clamp like lead (D) fixed to the outer tube to which the shield of the unbalanced cable is to be connected using a crimp tool or a nose plier.

The entire rear portion of the connector (cable end) is protected by a strong PVC cover (E) which is screwed to the metal connector. A sleeving of suitable diameter may be used at the cable connection to prevent the strands of the shield touching the inner conductor.

The RCA plugs can also be used with video cables (RG58/59) to connect video inputs and outputs in commercial equipments.

RCA sockets (female) are available in different styles; The construction of these sockets is more or less similar as PCB mount type and panel mount type as shown in fig. 2A & 2B. The central conductor is the inner tube separated from the outer tube by a plastic or foam spacer. The dimensions of the inner tube and outer tube are such that the male plug tightly sits making firm contact.

Fig 2a

PCB MOUNT TYPE

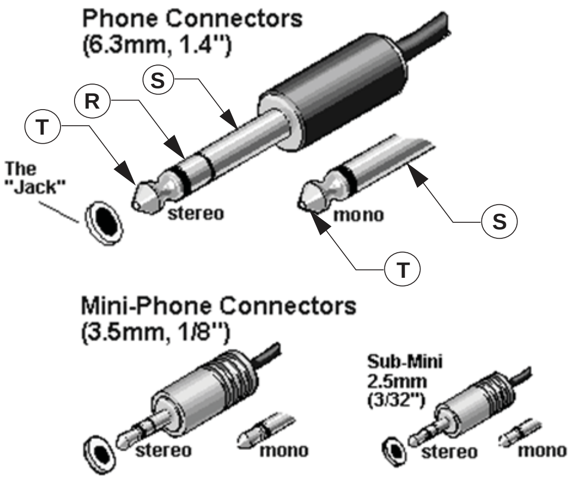
Fig 2b

PANEL MOUNT TYPE

**Phono Jack (Unbalanced):** Phono jacks are generally used wherever more flexibility in operation is required. For example in patch panels where the inputs and outputs of various equipments are available these phono jacks are useful as patch chords for connecting the equipments.

This audio jack is commonly seen on stereo headphones for audio devices ,cell phones, although there is a wide range of uses including audio input as well as output. It is also called as TRS phono plug connector with 3 contact places on the jack separated by two insulation layers as shown in fig.3

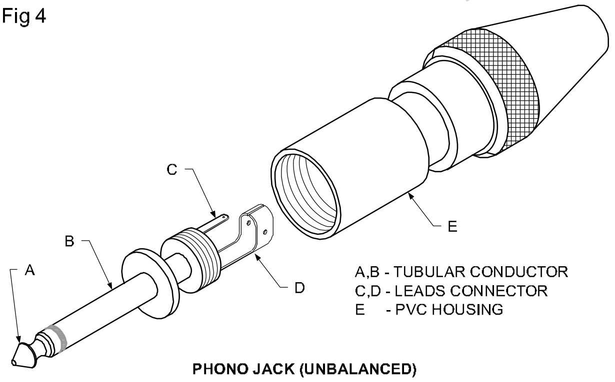
Fig 3




TRS is an acronym representing Tip + Ring + Sleeve. The 2 contact (Tip + Sleeve or TS) version is typically for mono audio and the three contact version (TRS) is typically for stereo audio. There are also other variants such as a four contact version which is often designed for camcorders, the extra ring for the video signal, or for modern cell phones and mobile devices facilitating earphone and microphone combination headsets.

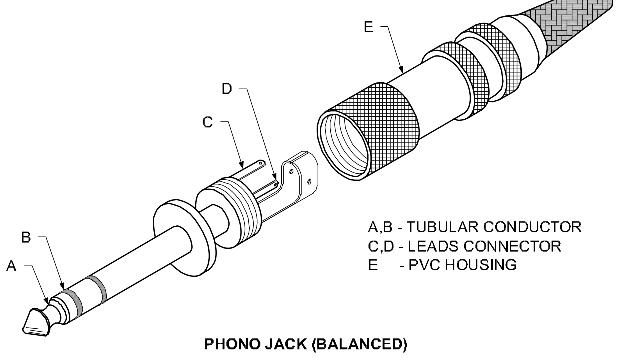
The exploded view of construction of the phono jack is given in Fig. 4. This type of phono jack is used with unbalanced circuits. It has two concentric tubular conductors (A&B) are gold plated and insulated from one another. The inner conductor A is having a conical edge and a locking wedge. The leads from these conductors are brought out on the cable side (C & D). The inner conductor of the cable is soldered to the inner lead and the shield of the cable is crimped to the outer lead with a crimping tool or nose plier. The entire rear portion is covered and protected by a PVC housing (E) which is screwed to the metal frame. The gold plating given to the jack is to provide very good electrical contact. The unbalanced phono jacks are used mostly in commercial equipments like audio consoles, tape recorders, patch panels and audio amplifiers.

Fig 4




**Phone Jack (Balanced):** The phono jacks are also available for balanced circuits. The construction of balanced phono jack is more or less similar to the above except that there are three concentric tubular conductors instead of 2 as in the case of unbalanced jack. The construction is shown in Fig. 5.

Fig 5

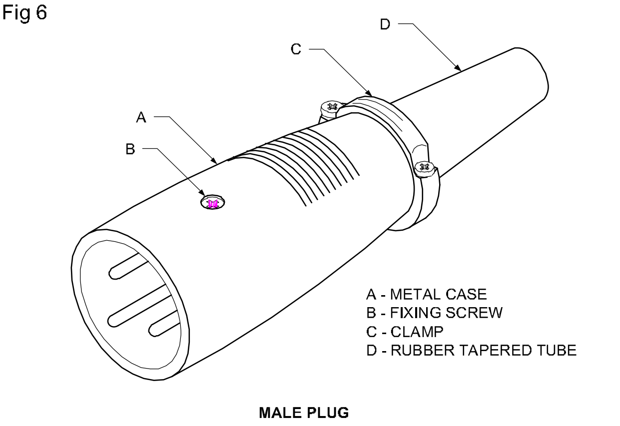



The leads (C & D) from the concentric tubular conductors (A & B) are brought out on the cable side. The two live leads of the balanced cable are connected to the central two conductors while the screen (shield) is crimped to the lead from the outermost tubular conductor. The entire rear portion of the jack is covered and protected by a PVC housing (E) which is screwed to the metal jack.

The balanced phono jacks are used for patch chords in patch panels for connecting to audio equipments having balanced inputs and outputs. Most professional equipments like Hi-Fi audio equipments have balanced inputs and outputs.

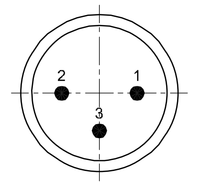
**XLR Male plug (cable type):** It consists of a metal case with an insulator disc inside holding the three pins in precise position. The cable ends of the pins have curved edges to enable easy soldering. The clamp provided at the cable end of the connector helps to hold the audio cable tightly so that movement or shaking of the cable will not affect the soldering connection at the pins. A thick rubber tapered tube is provided for leading the cable inside and helps to give right flexibility at the connector. A typical XLR male plug shown in Fig. 6.

Fig 6




The arrangement of pins in a XLR male plug is shown in Fig. 7. The three leads of the Audio cable namely two live leads and shield can be connected to any pin in any sequence. But a standard sequence should be followed to avoid wrong inter-connections between various equipments. The international standard is to connect the screen (ground) to pin 1 and the live leads of the cable to pin 2 & pin 3. This standard should be followed in connecting any XLR connector.

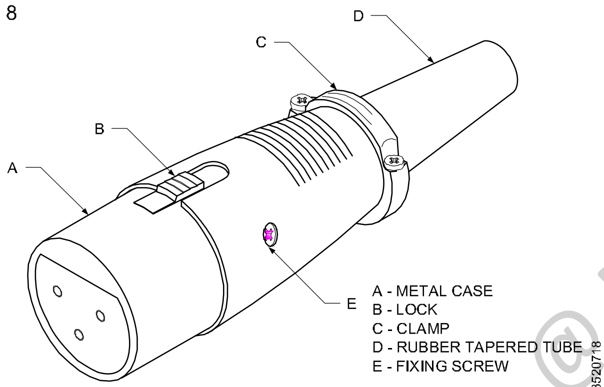
Fig 7




PIN ARRANGEMENT

**XLR Female plug (cable type) :** XLR Female plug (cable) is shown in Fig .8. The XLR female plug consists of a metal case with three sockets held in position by fibre spacer. The metal case is provided with a locking arrangement which helps to hold the connector in locked position. While removing the plug, the lockpin should be pressed slightly while pulling out the plug. The cable end of the connector is similar to that of the male connector described above.

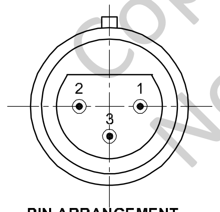
Fig 8




FEMALE PLUG

The standards used for connecting audio cable to XLR connectors should be followed here also. The screen (ground) should be connected to Pin No.1 and the live leads to pins 2 & 3. The pin configuration is shown in Fig. 9.

Fig 9

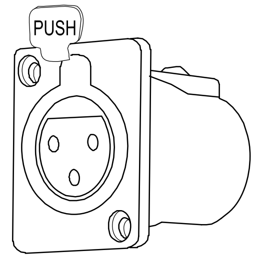



PIN ARRANGEMENT

XLR female plugs (cable) should be used for feeding the input to the equipment by inserting it to the male panel mounted connector fixed in the equipment.

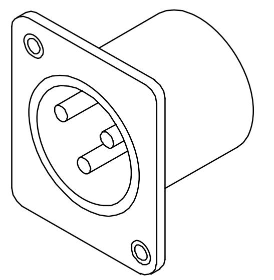
**XLR panel mount Male and Female receptacles:** The panel mount receptacles shown in Fig. 10 & 11 are fixed in the equipments for feeding input into and taking the output from the equipments. The mating cable connectors are inserted into these connectors and are locked by the pins. The lock is provided in the female panel mount connector for locking the male cable connector and in the female cable connector for locking into the male receptacle fixed in the equipment. The input/output connections cannot go wrong since a male cable connector can go only into the female panel mount and vice versa.

Fig 10




FEMALE PANEL MOUNT XLR

Fig 11




MALE PANEL MOUNT XLR

The numbering is similar to what was described earlier and the same standard should be used.

The male panel mount receptacle is the input to the equipment and the female panel mount receptacle is the output of the equipment.

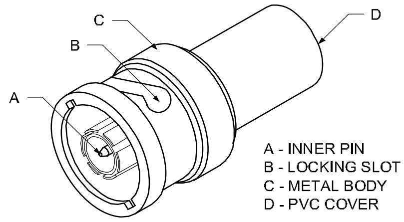
All XLR connectors described above are used only for connecting balanced input and output using two core screened Audio cables.

**Video Connectors**

The details of some of the common video connectors are as follows.

**BNC (Male plugs) :** The BNC male plugs are very common in video systems and equipments. It consists of an inner conductor in the form of a pin and outer metal housing as shown in fig.12. The inner pin is gold plated normally for providing good electrical contact. The inner pin is kept insulated from the outer housing by a styroflex or foam spacer. The outer housing has a turnable locking arrangement. The plug is pushed into the female receptacle and when turned clockwise the connector gets locked. While removing, the housing is gently turned anti-clockwise and pulled.

Fig 12




BNC MALE PLUG

The cable side of the connector is in the form of a tube through which the inner conductor of the cable is connected to the central pin. The outer shield of the cable is expanded and spread over the knurled portion of the tube.

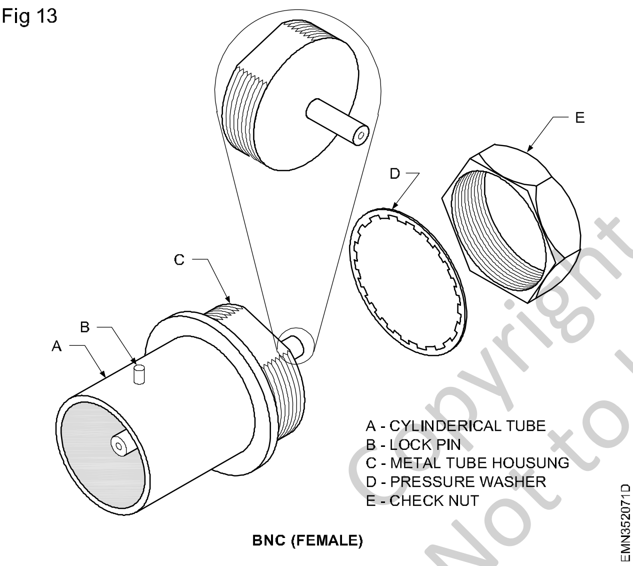
Another cylindrical tube is run over this bed and crimped. Now the inner pin and the outer metal housing act as two leads of the video cable. A protective PVC cover is provided at the rear of the connector to reduce strain at the cable connection.

The BNC plugs are used alongwith the following types of co-axial cables in video circuits.

| | | |
|---|---|---|
| RG58<br>RG174A<br>RG8A/U<br>RG142B/U<br>RG213/U<br>RG179B/U | RG59<br>RG223/U<br>RG55B/U<br>RG188A/U<br>RG400/U<br>RG214/U | BNC connectors are used both for 50 and 75 ohms cables. |

**BNC (Female) connectors:** BNC female connectors can be either of cable type or panel mount type. Mostly they are of panel mount type fixed as input and output ports of various video equipments. Fig.13 illustrates the panel mount BNC connector. It consists of an inner thin cylindrical tube fixed centrally inside a larger outer metal tube housing. Styroflux or foam is used as the spacer between the two. The outer housing has two short pins used for locking the male plug.

Fig 13




In the rear portion of the connector the leads from the inner conductor is brought out to which the centre lead of the cable is soldered. The shield of the cable is connected to the chassis (ground) at a point nearest to the connector. Since the outer frame of connector is fixed to the panel, it gets grounded.

In the cable type BNC female connector, the rear portion (cable side) is similar to that of the male plug and the procedure for giving cable connection is also same.

### HDMI connector

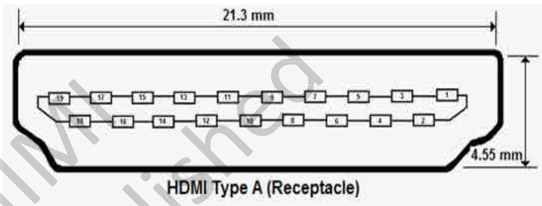
**HDMI (High-Definition Multimedia Interface)** is a proprietary audio/video interface for transferring uncompressed video data and compressed or uncompressed digital audio data from an HDMI-compliant source device, such as a display controller, to a compatible computer monitor, video projector, digital television, or digital audio device. HDMI is a digital replacement for analog video standards.

No signal conversion is necessary, nor is there a loss of video quality when a DVI-to-HDMI adapter is used. The CEC (Consumer Electronics Control) capability allows HDMI devices to control each other when necessary and allows the user to operate multiple devices with one remote control handset.

Several versions of HDMI have been developed and deployed since initial release of the technology but all use the same cable and connector. Other than improved audio and video capacity, performance, resolution and color spaces, newer versions have optional advanced features such as 3D, Ethernet data connection, and CEC (Consumer Electronics Control)extensions.

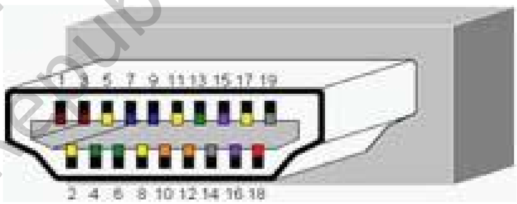
The HDMI specification defines 5 connector types. The normal full-size single-link Type A is shown in fig.14a & 14b.

Fig 14a




HDMI SOCKET

Fig 14b




HDMI PLUG CONNECTOR



### S/PDIF connector

S/PDIF (Sony/Philips Digital Interface Format) connector plug is shown in fig.15a & 15b is a type of digital audio interconnect used in consumer audio equipment to output audio over reasonably short distances. The signal is transmitted over a fiber optic cable with TOSLINK connector. S/PDIF interconnects components in home theatres and other digital high fidelity systems.

Fig 15a

S/PDIF CONNECTOR PLUG

Fig 15b

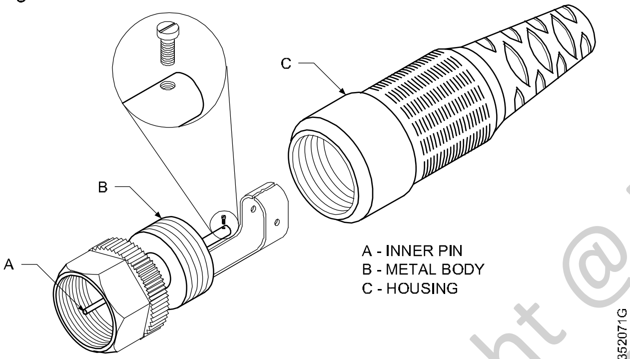
S/PDIF SOCKET

S/PDIF is based on the professional AES3 interconnect standard. S/PDIF can carry two channels of uncompressed PCM audio or compressed 5.1 or 7.1 surround sound (such as DTS audio codec) it cannot support lossless formats (such as Dolby TrueHD and DTS-HD Master Audio) which require greater bandwidth like that available with HDMI .

This mode is used to connect the output of a DVD player or computer, via optical to a home-theatre amplifying receiver that supports Dolby Digital or DTS. Another common use is to carry two channels of uncompressed digital audio from a CD player to an amplifying receiver.

**'F' connectors:** The general view of the F connector is given in Fig.16. It consists of an inner pin and outer housing separated and insulated from one another. The housing (outer) is hexagonal in the outside and cylindrical and threaded inside. The threading is used for tightening the connector after pushing it to the female receptable. The leads on the cable side are similar as in the case of RCA plug where the inner and outer leads of the cable are connected.

Fig 16




'F' CONNECTOR

'F' connectors are invariably used in cable TV circuits and equipments with cables of 75 ohm impedance.

'F' type connectors also come in a different forms where the centre lead of the cable (single strand) is directly used as the central conductor of the connector. The shield of the cable is just clamped and crimped to the outer conductor of the connector.

In addition to the common connectors described above, you will come across some other type also used in equipments. Barrel power connector is one of them used specifically to provide power connection to devices as shown in fig. 17 below.

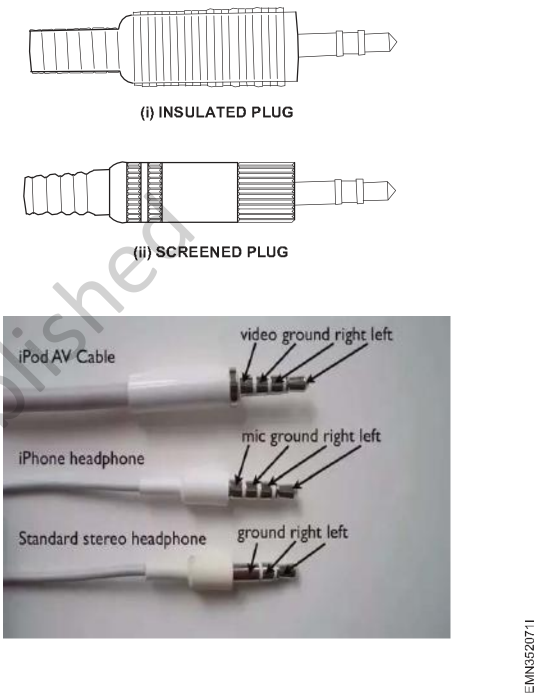
Fig 17


Barrel power connector is also called as coaxial power connector.-It is used specifically to provide power connection to devices. The female barrel connector or 'jack' is available as PCB mount, cable mount or panel mount types. The male barrel connector or 'plug' is usually found in a wire termination by soldering / crimping. The two connectors are 'tip' and 'sleeve' as shown in fig.17. The outer diameter of the sleeve is most commonly either 5.5mm or 3.5mm and will be mating with 2.5mm or 2.1mm pin; 3.5mm sleeve will mate with 1.3mm pin. Polarity of sleeve and tip is shown by a small diagram on the device.

**Jack connectors**

**Stereo 3.5 mm Plugs:** These are shown in Fig.18. Available in two versions, insulated plug or screened plug. The insulated type has a moulded body with a cable strain relief sleeve and the screened type has a metal body with a moulded cable strain relief sleeve. Miniature 2.5 mm plugs also are in use.

Fig 17




**Chassis Mounting PCB Socket:** This is shown in Fig. 19. Enclosed chassis socket with silver plated normally closed contacts (Double circuit). Plated mounting bush. Earth contact connected to bush.(Stereo socket)

Fig 19

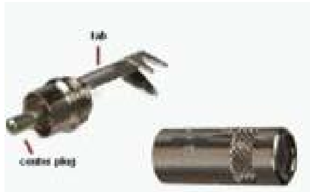
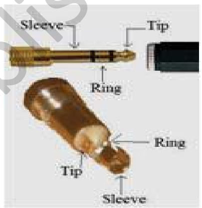
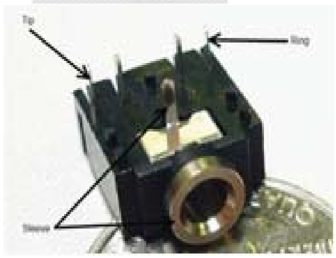
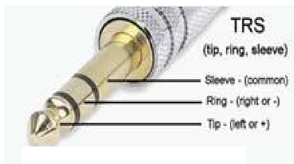
CHASSIS MOUNTING PCB SOCKET

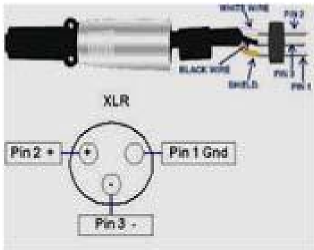
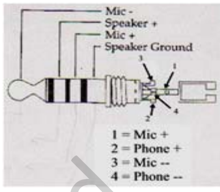
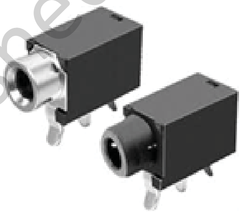
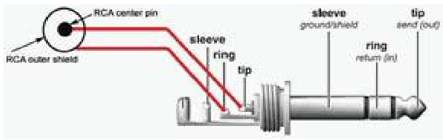
**Chassis Socket:** This is shown in Fig. 20. Enclosed chassis socket with silver-plated closed circuit contacts (single circuit). Plated mounting bush. Earth contact connected to bush.

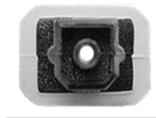
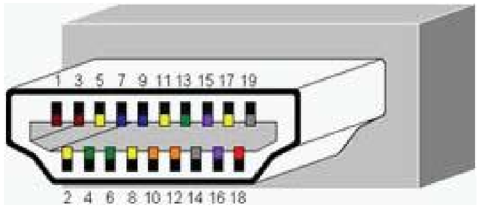
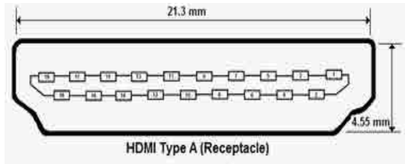
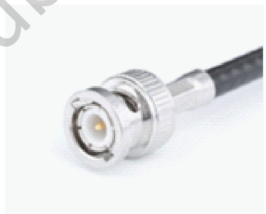
Fig 20

CHASSIS MOUNT SOCKET

**Chart showing various types of sockets/jacks and plugs used for Audio/Video and DC power connectors**

| Sl.No. | Socket / connector Name | Socket / connector Image |
|---|---|---|
| 1 | RCA socket -Female |  |
| 2 | RCA plug- Male |   |
| 3 | TRS-Jack- Female (6.35mm) |  |
| 4 | TRS plug - Male(6.35mm) |   |
| 5 | TRS Jack- Female (6.35mm) |  |
| 6 | TRS plug - Male (6.35mm) |   |
| 7 | XLR connector- female |  |

| Sl.No. | Socket / connector Name | Socket / connector Image |
|---|---|---|
| 8 | XLR connector- Male |  |
| 9 | TRRS jack- Female |  |
| 10 | TRRS plug- male |  |
| 11 | Headphone Jack- Female |  |
| 12 | Headphone plug- Male |  |
| 13 | TOS Link -optical Jack -female |  |
| 14 | TOS link - optical plug- male |  |
| 15 | S/PDIF connector- male |  |

| Sl.No. | Socket / connector Name | Socket / connector Image |
|---|---|---|
| 16 | S/PDIF connector female |  |
| 17 | HDMI Female Connector |   |
| 18 | HDMI male connector |   |
| 19 | BNC Female connector |  |
| 20 | BNC Male Connector |  |
| 21 | F - Connector |  Male  Female |
| 22 | Barrel DC connector- plug |  |
| 23 | Barrel DC connector -jack |  |

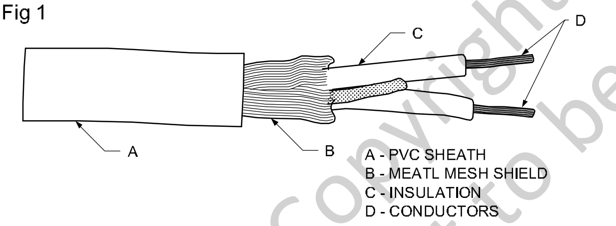
## Audio and Video/RF Cables

**Objectives:** At the end of this lesson you shall be able to
- **list different types of audio cables**
- **describe construction of audio cables**
- **list the application of audio cables**
- **list different types of video/RF cables**
- **describe the construction of video cable and RF cables**
- **list the application of video and RF cables.**

**Audio Cables:** Audio frequencies range from 20 Hz to 20kHz. In other words frequencies from 20Hz to 20kHz are audible by human ear. Any information conveyed at these frequencies are wanted signals. Any other disturbances like noise cross talk and hum are unwanted signals. The audio equipments are designed and assembled to handle only wanted signals and reject unwanted signals. Similarly the audio cables used inside the audio equipments and also cables used for connecting two or more equipments and devices should also be such that they reject unwanted signals. For this purpose the audio cables are provided with a shield which is grounded at both ends of the cable. This shield acts as a screen and prevents induction of noise. This shield surrounding the live leads runs throughout the length of the cable in the form of a metal (copper) mesh.

The general construction of an audio cable is shown in the fig. 1.

Fig 1




AUDIO CABLE

The two conductors (D,D) are made up of either single strand or multi-stranded with polythene insulation (C) around each conductor. The shield (B) made up of metal in the form of a mesh is fixed around the two leads and run throughout the length of the cable. Normally a cotton braid is also provided in between the leads and the shield to give flexibility to the cable. A PVC sheath (A) is provided over the metal shield to give protection to the cable from weather and also to provide mechanical strength.

There are different types of audio cables depending upon their applications and usage. Wherever unbalanced circuits are connected single core screened cables are used and wherever balanced circuits are connected two core screened cables are used. Some of the commercial microphones gives the unbalanced output for which single core audio cables (Flexible) are used.

The number of strands in each conductor and the gauge (thickness) of each strand depend upon the application. When the signal level is low, we must avoid loss in the line or cable. For example, the signal output from a normal microphone is very low. This low level signal should reach the amplifier at the other end of the cable with minimum loss. For this we must use a cable with more number of strands. The gauge of each strand can be thin to provide flexibility to the cable.

In the case where an amplifier output (line output) of moderate level getting connected to another equipment, line loss is not very important. But the cable has to be slightly more sturdy. Here we can use a cable having less number of strands each strand being a slightly thicker gauge.

In the case where the output of a high power amplifier is to be connected to another location we have to choose a cable having more number of strands and thicker gauge to avoid line loss and to reduce heating of the cable.

The choice of cable depends on the signal level, length for the cable and durability. Of course cost is also a factor.

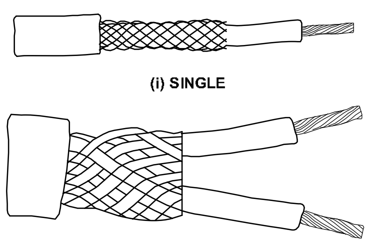
The details of various types of commonly used Audio cables are as follows.

**Standard Round:** Fig. 2 shows standard type braided screen cables. They offer low noise for use in low-level signal circuits.

16/0.2mm tinned copper stranded conductors, PVC insulated, braided screen and grey PVC sheath.

**Cores:** red (single), blue and red (twin).

Fig 2




STANDARD ROUND

**Capacitance:** 360 pF/m (single); core to screen 288 pF/m and core to core 171 pF/m (twin). Twin type has twisted cores for hum reduction.

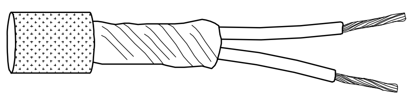
Given below is a list of common audio cables, their types, specifications and applications.

**Types of Audio cables**

| Sl.No. | Type | Specification | Application |
|---|---|---|---|
| 1 | Microphone cable 10 x 0.2mm | Low noise single core Amplifiers (Unbalanced) | Microphones, Pre-Amplifiers Programme shielded |
| 2 | Microphone cable | Low noise Two core 26 x 0.1mm Flexible, Shielded | Microphones, Pre-Amplifiers Programme Amplifiers (Balanced) |
| 3 | Standard Audio cable | Two core 14 x 0.2mm cotton braided shielded | Line Amplifiers, Audio consoles, Tape recorders, Programme Amplifiers |
| 4 | General purpose Audio cable | Two core 26 x 0.1mm cotton braided shielded | For any indoor and outdoor applications |
| 5 | Heavy duty Audio cables | Two core individually screened 7 x 0.2mm | Data Transmission |
| 6 | Heavy duty Audio cable | Four core Individually screened 7 x 0.2mm | Data Transmission |

**Microphone Cables:** Fig. 3 shows a 2-core standard type Microphone cable. This is a low noise screened cable. Construction ensures good transmission properties desirable in many professional audio & low level programme circuits. Two 55/0.1 mm plain copper stranded conductors PVC insulated and twisted together.

Fig 3



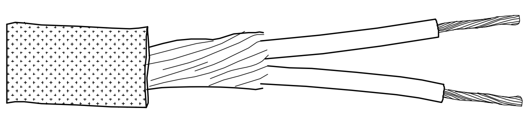
MICROPHONE CABLE

EMN3520723

Fig. 4 shows a 2 core flexible type Microphone cable. This cable is designed to fulfill the conflicting requirements of flexibility and good screening properties, thus making it suitable for hand-held or free-standing microphone applications. Two 28/0.1mm plain annealed copper stranded conductors, PVC insulated with a single lap screen constructed from plain annealed copper with a grey PVC outer sheath.

Capacitance 273pF/m Dia.5.4mm

Fig 4

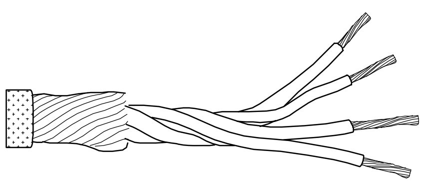


MICROPHONE CABLE

EMN3520724

Fig. 5 shows a 4-core standard type Microphone cable.

Fig 5



4 CORE CABLE

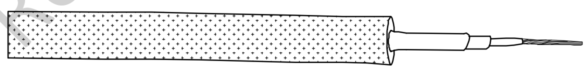
EMN3520725

This cable comes with four 14/0.12 mm tinned copper stranded conductors, PVC insulated and wrapped with polythene tape. Capacitance 125 PF / m.

This is also a High-grade, low-noise, screened cables and the construction ensures good transmission properties desirable in many professional audio and low noise level.

**Patch/instrument Cable:** It is shown in the Fig. 6.

Fig 6



PATCH/INSTRUMENT CABLE

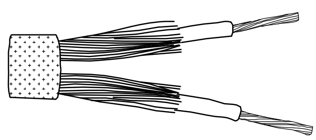
EMN3520726

An instrument/patch cable which has been developed with the emphasis on mechanical stability and consistent electrical performance. This black 6mm cable is ideal for stage use where mechanical strength is the prime consideration.

**Specifications :** Strand / conductor : 7 x 0.202 mm shield : Double shield of lapped copper screen, Capacitance 110 PF/m, resistance : 78.2 Ω / km.

**Heavy Duty Twin:** Fig.7 shows 2 core Heavy duty twin with individually lapped screen.

Fig 7



HEAVY DUTY TWIN

EMN3520727

**Speaker cable :** Speaker wire is used to make the electrical connection between loudspeakers and audio amplifiers. Modern speaker wire consists of two electrical conductors individually insulated by plastic (such as PVC, PE or Teflon) or, less commonly, rubber. The two wires are electrically identical, but are marked to identify the correct audio signal polarity. Most commonly, speaker wire comes in the form of zip cord as shown in fig. 8.

Fig 8

Zip-cord is a type of electrical cable with two conductors held together by an insulating jacket that can be easily separated simply by pulling apart. The design of zip-cord makes it easy to keep conductors that carry related electrical signals together and helps avoid tangling of cables. Conductors may be identified by a color tracer on the insulation, or by a ridge molded into the insulation of one wire, or by a colored tracer thread inside the insulation. Zip cords are intended for use on loudspeakers.

Thicker wires reduce resistance. As speaker impedance drops, lower gauge (heavier) wire is needed to prevent degradation to damping factor - a measure of the amplifier's control over the position of the voice coil. High-power in-car audio systems using 2-ohm speaker circuits require thicker wire than 4 to 8-ohm home audio applications. Most consumer applications use two conductor wires. A common rule of thumb is that the resistance of the speaker wire should not exceed 5% of the rated impedance of the system.

Two individually screened 7/0.2 mm tinned copper stranded conductors laid side by side in a flat 'figure 8' grey PVC outer sheath. Capacitance of core to screen -320 pF/m.

**Video Cables/RF Cables:** All video and RF circuits and equipments uses only unbalanced inputs and outputs. The term unbalanced means that the signal is carried only by the live lead whose potential is always referred with respect to ground which is common. Hence the video/RF connectors and video/RF cables both associated with these circuits and equipments are also unbalanced. We have seen in the case of Video/RF connectors there is only the central pin live. The housing or the outer of the connector is grounded. Similarly the RF/Video cables also have only one live limb which is kept insulated from the shield (ground) by a suitable solid material. The construction of a Video/RF cable is similar and standard in all cases. The types of cables vary depending upon the application.

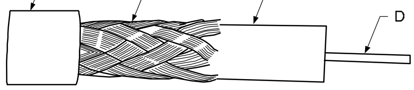
The general construction of a Video/RF cable is shown in the Fig. 9.

The specification of the cable are as follows:

1/0.6mm copper plated steel conductor, solid polyethylene insulation, plain copper braid and sheathed in either black or white PVC.

Video/RF cables are invariably co-axial cables.

Fig 9




The co-axial cable consists of a central conductor which may be single or multiple stranded copper material or copper coated steel material. This conductor is placed inside a polyethylene (Dielectric) insulation (C). This is surrounded by the shield which is in the form of a mesh made of copper (B). The entire above assembly is protected by a PVC sheath (A) which protects the cable from heat and other weather conditions and also provides strength.

There are different types of RF co-axial cables depending upon the application and usage. Thin cables like RG58 or RG59 are used in low power applications whereas cables like RG8 which are thicker are used for higher power handling. The length of the transmission line also decides the type of cable to be used. Co-axial cables are available generally in two main types distinguished by their characteristic impedances. The characteristic impedance of a cable is defined as the impedance that will be offered at the measuring end for a total length equal to infinity. Co-axial cables are of two types (a) 50 ohms co-axial cable and (b) 75 ohms co-axial cable. All RF equipments are of 50 ohms and video base band equipments are standardised for 75 ohms.

So the choice of RF cable depends on the characteristic impedance, signal power level, length of the cable and durability.

A list of common type of RF cables, their specification and applications are given in the table next page.

### Types of RF cables

| | | Specifications | | | |
|---|---|---|---|---|---|
| | | Characteristic impedance in Ohms | Attenuation for 10m at 100 MHZ | Thickness | |
| 1 | RG58C/U | 50 | 3 db | 5mm | Short length RF cabling |
| 2 | RG214/U | 50 | 0.76 db | 10.8mm | RF Transmission line |
| 3 | RG223/U | 50 | 1.41 db | 5.5mm | Short length RF cabling |
| 4 | RG213/U | 50 | 0.62 db | 10.3mm | RF Transmission line |
| 5 | RG18A/U | 50 | 0.3 db | 24mm | Long length RF Transmission line |
| 6 | RG174/U | 50 | 2 db | 2.5mm | For wiring inside RF equipments |
| | RG59B/U | 75 | 1.9 db | 6.15mm | General purpose video cabling |
| | RG179B/U | 75 | 3.2 db | 2.5mm | Short length video cabling |
| | CT167 | 75 | 3.7 db | 10.1mm | Cable TV |
| | CT100 | 75 | 3.9 db | 6.65mm | |
| | CT125 | 75 | 4.9 db | 78mm | |
| | RG6U | 75 | | 6.96 | Cable TV - long lines |
| | RG11U | 75 | 0.6 db | 10.29mm | Closed circuit TV (video) cabling |

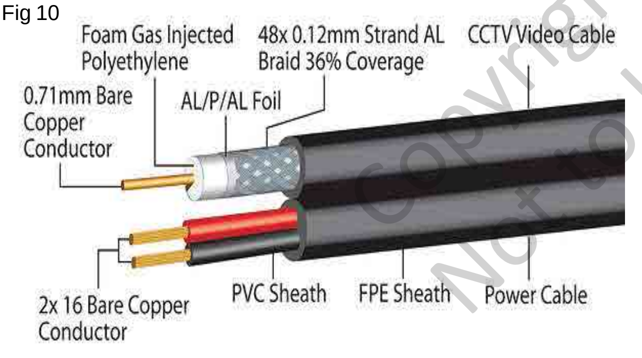


Other types of video cables come with power supply line along the coaxial cable are given below.

**RG59 Coaxial Cable + 2 Core Power CCTV cable**

RG59+2 composite cable is shown in fig.10.

Fig 10




This cable is also called as shotgun cable, is more economical in saving your installation time and money fitting 1 cable instead of 2. It allows you to send power in the two cores and a video signal in Coaxial cable down just the one cable. The two cables run in shotgun style can easily be separated to allow the power cores to be taken to a power source leaving the RG59 to be crimped for connection to a Digital Video Recorder (DVR), Video camera, or monitor.

**PTZ combo cable-** The PTZ combo cable is shown in fig.11

Fig 11

This heavy duty Pan Tilt Zoom- (PTZ) cable is an ideal choice for applications with pan, tilt and zoom security cameras. PTZ Combo cable is a 3 in 1 cable which supports the data, power and video signal. The power cores are 0.15 x 30 stranded to prevent interruptions and are colour coded red 12V and black 0V to avoid any errors in connection. These power cores can also be used to run 24V AC, ideal for most PTZ installations.

## Termination of cable ends of crimping and soldering

**Objectives:** At the end of this lesson you shall be able to
- **state the application of BNC plug**
- **state the application of 'N' male connectors**
- **state the application of 'F' connectors**
- **describe the crimping process used in co-axial cables and connectors**
- **describe the stripping process using a cable stripper**
- **state the advantage and disadvantages of crimping.**

The structure and description of various types of video and RF connectors and co-axial cables were discussed in Ex.1 Related Theory.

The co-axial cables cannot be used directly without putting the proper connectors at their ends. The impedances faced by RF circuits will be perfect only if connected by correct type of cables and proper connectors. In other words RF circuits will get matched to their loads only when properly connected. If co-axial cables with bare ends are used there will be mismatch causing reflections and may cause damage to the devices in the RF circuits. Hence the usage of co-axial cables of proper character impedance (Zo) with suitable connectors is a must in RF circuits. Even RF connectors are designed for 50 and 75 ohms depending upon the application.

**Selection of cable with BNC connector:** A BNC connector of 75 ohms characteristic impedance (Zo) connected to a RG59 cable (whose Zo is also 75 ohms) is suitable for wiring in video circuits. All video circuits invariably use 75 ohms as the standard in their design. BNC connectors of Zo 50 ohms should not be used with co-axial cable of Zo 75 ohms. This will cause mismatch, reflections and heating of components.

**Selection of co-axiable with N type connectors:** Similarly in the case of 'N' connectors, the characteristic impedance of 'N' connectors is 50 ohms only. They should be used only with co-axial cables having Zo as 50 ohms. The impedance of the connector must match the impedance of the cable used. Also the impedance of the cable connector assembly must match the impedances of the equipments where they are used for inter-connectivity.

Table 1 gives the types of cables suitable for BNC connectors of both types.

Table - 1

| Cables with 75 ohms BNC connectors | Application |
|---|---|
| RG59B/U<br>RG179B/U<br>RG6 | Video circuits and cabling<br>Closed circuit<br>TV |

| Cables with 50 ohms BNC connectors | Application |
|---|---|
| RG58C/U<br>RG174A/U<br>RG8A/U<br>RG213/U<br>RG214/U<br>RG188/U<br>RG223/U | Low power<br>RF circuits<br>and interconnecting<br>low power RF<br>equipments |

Some of the types of co-axial cables having Zo as 50 ohms to be used alongwith 'N' connectors are given in table 2. The outer diameter of these cables are such that they fit into the connector. These co-axial cables are also meant for more power handling capacity.

Table - 2

| Co-axial cable type | Overall outer diameter (inch) | Characteristic impedance | Application |
|---|---|---|---|
| RG8A/U | 0.285 | 50 | Short and medium length |
| RG9 | 0.280 | 50 | transmission lines and |
| RG9A | 0.280 | 50 | inter-connecting cables. |
| RG55B | 0.116 | 50 | Used in medium power |
| RG400 | 0.116 | 50 | RF equipments (upto 100W) |
| RG213 | 0.285 | 50 | |
| RG214 | 0.285 | 50 | |

**Selection of co-axial cable with F connectors :** In the case of F connectors, the impedance of these connectors is 75 ohms. Hence they should be used only with co-axial cables having characteristic impedance of 75 ohms.

The co-axial cables commonly used with 'F' connectors are given in table 3.

Table-3

| Type of cable | Overall outer dia | Zo Nominal impedance in ohms | Applications |
|---|---|---|---|
| RG6 | 0.185 | 75 | Short length out-door and cabling in cable TV field. |
| RG59 | 0.146 | 75 | Example: LNBC to satellite receiver, modulator - amplifier |
| CT100 | 0.25 | 75 | connections, Roof top to TV receivers tap off connections etc. |

While making co-axial cable-connector assemblies there is a possibility of some thin strands of the shield of the cable touching the inner at the connector end. This should be carefully avoided. Also while checking the continuity during testing shake the connector ends of the cable while holding multimeter prods. The centre pin and the outer of the connector should not show continuity even while shaking the cable.

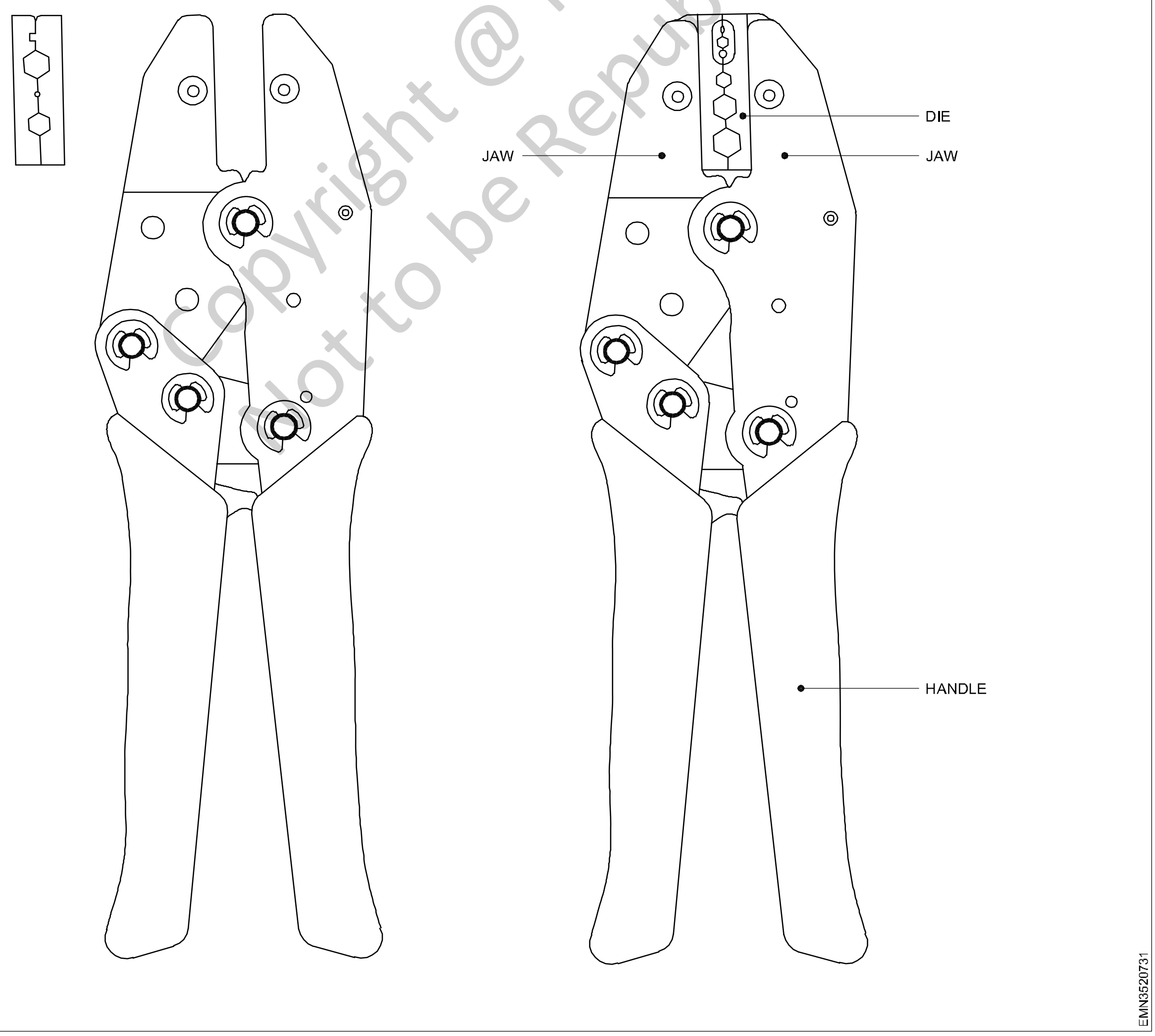
**The Crimping tool :** We have come across crimping tools used with power cables where the cable ends are connected to lugs and crimped for firm contact. Similarly we have crimping tools used for co-axial cable connections. Crimping ensures very good contact and also avoids breaking of the cable leads which is normal in soldered connections.

The crimping tool type HT 301C is used for crimping common types of video and RF connectors. HT 301C is useful for crimping BNC connectors while making co-axial cable connector assembly.

Figure 1 shows the crimping tool. It is 8.7" professional Hexagon/Oval type Ratchet and useful for F, BNC, TNC, N, Fiberoptic thinnet - PVC & Thinnet Teflon connectors.



Fig 1



It consists of a pair of jaws with a set of DIE in between the jaws. The DIE set consists of three or four hexagonal holes.

The jaws can be opened and closed by the two handles. The frame is made up of carbon steel and hardened so that it can withstand heavy pressure.

The handles are sufficiently long to give good leverage. The handles get locked automatically when the jaws are fully closed. Slight pressure on the handles releases the lock and causes the jaws to open. As detailed in the figure, the die can be replaced depending upon the requirement.

The specification are given in table 4. It explains clearly the dimensions of various dies in the tool and also gives the types of cables that can be used for crimping. For example HT 301C has four dies 8.1mm, 6.5mm, 5.41mm and 1.72mm.

Table - 4

**A specification of all dimension and RG size**

| HT | ⬡ | ⬡ | ⬡ | ⬡ | PIN ⬡ | SQ PIN ■ | FOR CRIMPING RG TYPE CABLE |
|---|---|---|---|---|---|---|---|
| 301A | | .256"<br>6.5 mm | .213"<br>5.41 mm | | .698"<br>1.72 mm | | 59, 62, 140, 210, BELDEN 8279<br>55,58,141,142,223,303,400, Fiber Optic |
| 301B | .319"<br>8.1mm | | .213"<br>5.41mm | | .187"<br>4.75mm | | 6, 55, 58, 141, 142, 223, 303, 400<br>174, Fiber Optic |
| 301C | .319"<br>8.1mm | .256"<br>6.5mm | .213"<br>5.41mm | | .068"<br>1.72mm | | 6, 59, 62, 140, 210, BELDEN 8279<br>55, 58, 141, 142, 223, 303, 400, Fiber Optic |
| 301D | .324"<br>8.3mm | .256"<br>6.5mm | .213"<br>5.41mm | | .068"<br>1.72mm | | 5, 6, 58, 59, 62, 140, 141, 142, 212, 222, 303<br>Fiber Optic BELDEDN 8281, 8279, 9231, 9141 |

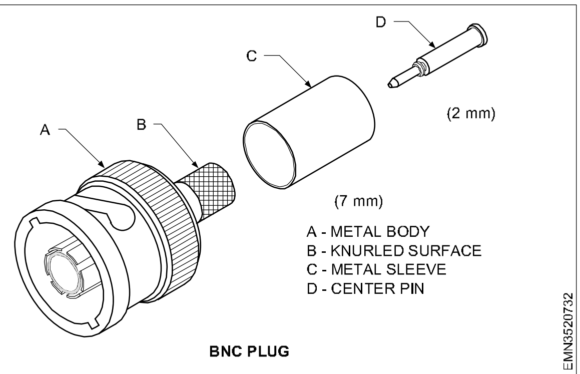


The RG 59B/U co-axial cable has an outer diameter of 6.15mm (including the PVC sheath) and the diameter of the inner conductor is 0.6mm whereas in the BNC (crimp type) connector the Outer Diameter of the centre pin is 2mm and that of the metal sleeve is 7mm. For crimping these two we must use the dies 1.72mm for the inner conductor and 5.41mm for the shield.

After stripping the PVC sheath and dressing the lead insert the inner conductor into the center pin (D) and crimp it using the 1.72 mm die.

The dimensions of the BNC plug are shown in Fig. 2. Next, after inserting the metal sleeve (C) over the screen spread over the knurled surface (B), use 5.41mm die to crimp the metal sleeve.

Fig 2




BNC PLUG

**The advantages of using crimping are**

a) Crimping ensures firm mechanical and electrical contact.

b) It avoids breaking of leads which we normally experience in soldered connection.

c) The crimping saves a lot of time. The process is very quick.

The only disadvantages in crimping is, the connector once used for crimping, cannot be re-used. It should be thrown out only. This is the reason why precaution should be taken to cut the cable end to correct dimensions and positioned properly before crimping.

**Cable stripper :** Many people are in the habit of using shaving blades for removing the PVC sheath of the cable. This is first of all hazardous as there is a possibility of injuring the fingers. Secondly while cutting the sheath the blade may cut the strands of the inner conductor. In the case of a co-axial cable, while cutting the PVC sheath, the strands of the screen also may get cut thereby rendering it weak while connecting.

Cable strippers are available in the market for various applications to overcome the above difficulty.

The cable stripper is simple in construction. It consists of a pair of jaws made of hard bakelite frame. The jaws are spring loaded and can be opened by a short lever operated by the thumb. There is a hole in the jaw through which the cable to be stripped is inserted after opening the jaws. A sharp piece of blade kept moulded inside this hole is used for cutting the sheath. The blade is kept in a position to cut precisely the PVC sheath only.

After inserting the cable into the jaw, it has to be positioned carefully for cutting only the required length of the sheath.

Turning the stripper enables the blade to cut along the perimeter of the cable sheath. You have to make two or three rounds to allow the blade to cut fully and uniformly all around the PVC sheath.

Now slight pulling the stripper and the cable apart will release the length of PVC sheath along from the cable.

Use of the cable stripper is simple and fast and saves time. It does not cut the screen mesh of the co-axial cable. Also the instrument is safe for handling.

Fig 3 shows the clear pictorial views to carry out the following instructions.

Instructions

1 Insert coax cable at the end of the stripper by pressing your thumb on the other end opening the jaws. Once the coax cable is on position, release the thumb to close jaws.

2 Insert index finger on through the hollow end and turn the stripper, while holding the coax cable with your other hand, about 3-5 times clockwise.

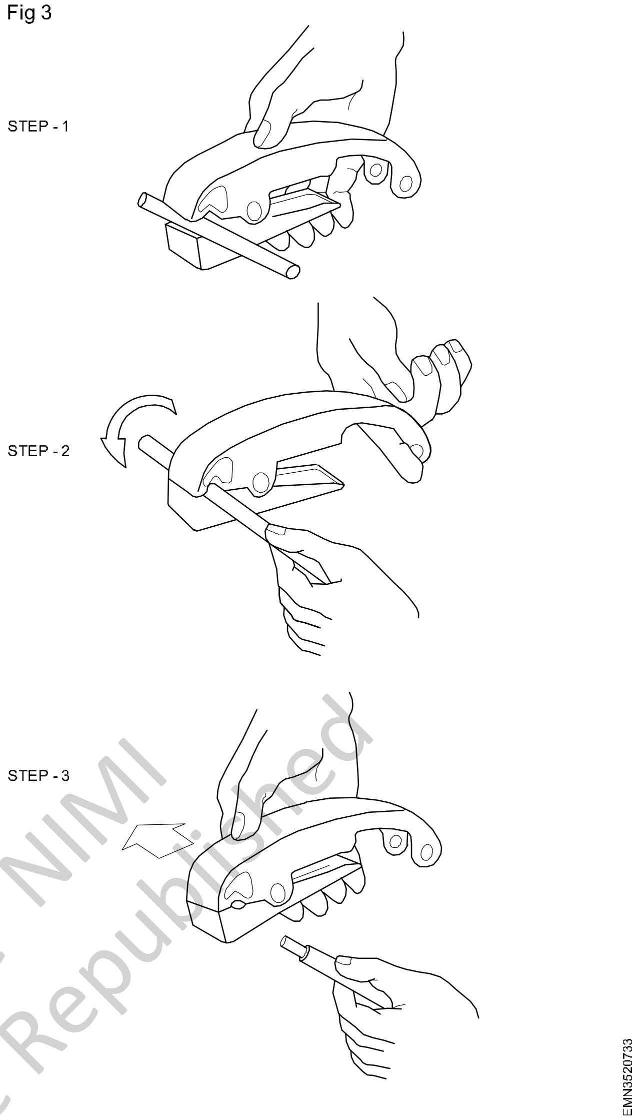
3 After turning, hold the stripper with the hand that you used to turn the stripper, and pull sideways, while maintaining your hold of the other hand on the coax cable, which should complete the strip of the cable. Lastly, open the jaws to release the scraps out of the stripper.

**Universal crimping tools:** Today Universal crimping tools are available in different shapes and sizes. Compression Tool is available in market for crimping connectors on to the coaxial cable ends. Two types of Universal crimping and compression Tools used for crimping the 'F'-connector, BNC- Connector and RCA- Connector is shown in fig.4a, 4b & 4c below.

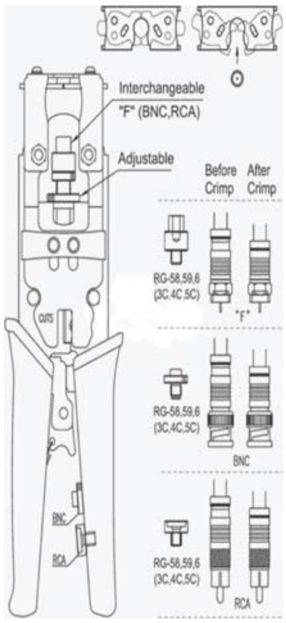
4a

4b

Fig 3




4c




These tools can be used to crimp 'F', BNC, and RCA connectors onto RG6, and RG59 coaxial cables. This compression tool kit is a compact solution for technicians with the highest performing on coaxial cable crimping.

# Different types of cable and connectors used in LAN

**Objectives:** At the end of this lesson you shall be able to
- **list different types of cables used in networking**
- **explain the construction of a twisted pair cable**
- **explain the construction of a coaxial cable.**

### Cables or Transmission media

Network computers must have a pathway to contact other computers. The physical path through which the electrical signals travel is called transmission media or cables.

Cable media are wires that conduct electricity/signal. The following types of cables are used in LAN.

1 Twisted pair cable

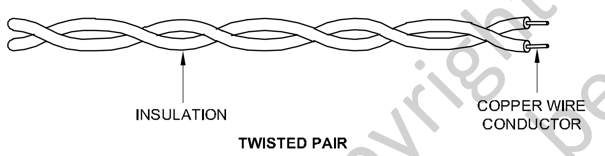
2 Co-axial cable

### 1. Twisted pair cable

Twisted pair is a common scheme for using copper wire as telecommunication cable because copper is a good conductor of electrons. Twisted copper wires reduces cross talk and signal emissions.

Twisted pairs are formed by two insulated 22 to 26 gauge copper wires that are twisted about each other as in Fig. 1. These twisted cables are available in two types.

Fig 1






The two types of cables are:

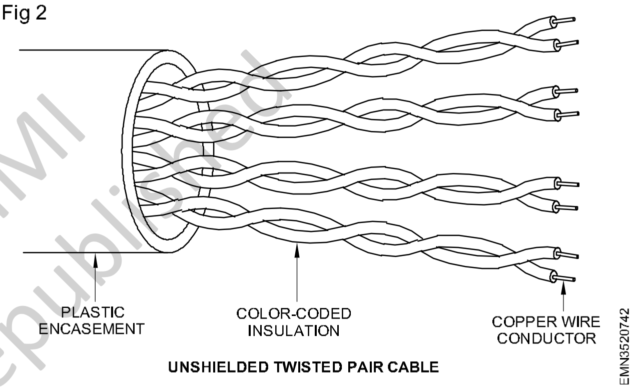
– Unshielded twisted pair cable.

– Shielded twisted pair cable.

### Unshielded twisted pair cable (UTP)

Unshielded twisted pair cable is composed of a set of twisted pairs with a simple plastic encasement as in Fig. 2.

Fig 2




It is commonly used in telephone systems and has been largely standardized.

Twisted pair network cables are rated in terms of their capability to carry network traffic. They are referred as category 3, 4 5e and cat 6.

| | | | | | |
|---|---|---|---|---|---|
| Category 3/Cat 3 | - | 10 Mbps | - | used for voice grade telephone or 10 mbps ethernet |
| Category 4/Cat 4 | - | 16 Mbps | - | Token ring network |
| Category 5/Cat 5 | - | 100 Mbps | - | For 100 Mbps Ethernet |
| /ECat 5 | - | 100/1000 Mbps | | |

### CAT 6 cable

**Cat 6** is a "twisted pair" network cable used for carrying data signals at speeds of up to 550MHz of Bandwidth. This cable is preferred for more advanced networking installations where a higher bandwidth than normal is required.

With Gigabit Ethernet, Broadband, Audio/Video and Security capabilities, Cat6 is ideal for any critical network installation. Whether it's for wiring a home, office or entire campus, we have the solution that's right for the installation.

Cat6 is backward compatible with the CAT 3, 5, 5e cable standards. As with Cat5 and Cat5e cabling, Cat6 cables consists of 4 unshielded twisted pairs(UTP) of copper wires with a soft supporting member in the center of the cable as shown in fig. 3.

Fig 3

Cat6 standard also includes more stringent specifications for cross talk and system noise.

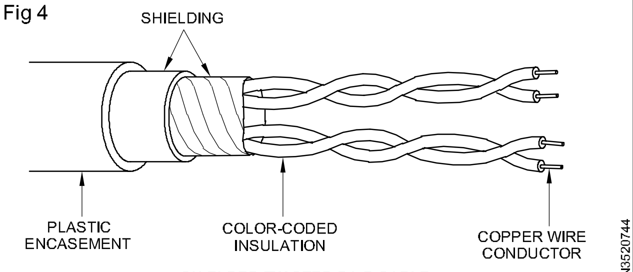
ECategory 5 and category 5 UTP are commonly used in computer networking.

UTP cables are limited to a length of 100 meters (328 feet) for each node to Hub connection.

**Shielded twisted pair cable**

Today, the mostly used cable is UTP. But some forms of shielded twisted pair (STP) still exist. The below Fig. 4 shows the STP cable. It is used in places where electromagnetic interference caused by electric motors, power lines and other sources.

Fig 4



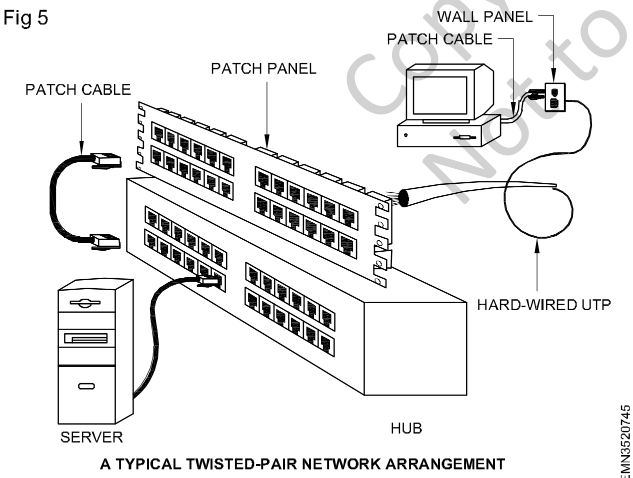

SHIELDED TWISTED PAIR CABLE

The STP is insulated cable which includes bundled pair wrapped in a foil shielding.

**UTP**

UTP is a popular choice for structured cabling systems used widely in office network environments. Structured cabling system is a network cabling pattern which follows strict engineering design rules. It allows voice, data and video to be transmitted/received on the same cabling system. It allows shifting, adding and replacing the nodes easily. The arrangement is as shown in Fig. 5.

Fig 5




A TYPICAL TWISTED-PAIR NETWORK ARRANGEMENT

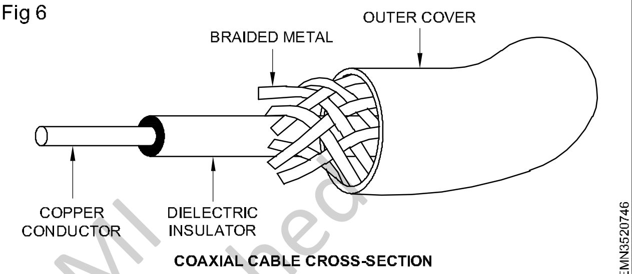
The cabling starts from the Hub or switch which is placed in a Rack centrally. A patch cable (usually 6-10 feet long) connects a port on the hub to a patch panel which is also in the Rack using RJ-45 connectors on each end. On the back side of the patch panel, the UTP cable is hard-wired or crimped to the panel connector. From the patch panel, theUTP cable runs continuously to a wall jack or information outlet (I/O). The information outlet contains a RJ-45 jack called I/O jack in it.

The UTP cable is crimped to the information outlet. Another patch cable connects to the RJ-45 jack in the information outlet and the other end gets connected to the NIC of the computer. Note that the distance from the connector on the hub to the connector on the computer's NIC cannot exceed 100 metres of cable length.

**2. Co-axial cable**

Co-axial cable commonly called ("Coax") is made of two conductors that share a common axis, hence the name ("co", "axis"). typically, the centre of the cable is relatively stiff solid copper wire or stranded wire surrounded by an insulating plastic foam. The foam is surrounded by the second conductor, a wire mesh tube as in Fig. 6.

Fig 6




COAXIAL CABLE CROSS-SECTION



Several co-axial cable standards are in comon use for computer networking. The most common types meet one of the following ohm and size stanards.

– 50 ohm RG-8 and RG-11 (used in thick Ethernet specifications.)

– 50 ohm RG-58 (used in thin Ethernet specifications).

- 75 ohm RG-59 (used for low power video and RF

– 75 ohm RG-62 (used for ARC net specifications)

The co-axial cable can handle a speed of only 10 Mbps maximum and the distance it can drive is only 185 m maximum.

**Types of Co-axial cable**

There are two types of co-axial cable

– Thin (Thinnet)

– Thick (Thicknet)

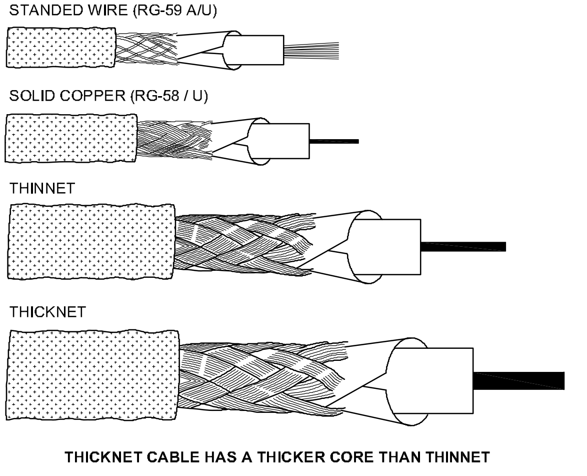
Thinnet: Thinnet is a flexible coaxial cable about 0 .25 inch thickness. Because this type of coaxial is flexible and easy to work with, it can be used in almost any type of network installation. as shown in fig.7

Thicknet : Thicknet is relatively rigid co-axial cable about 0.405 inches in diameter. The copper core is thicker than a thinnet.

**RJ45 Cable Wiring:**

RJ stands for Registered Jacks. These are used in telephone and data jack wiring.RJ-45 is a 8-position, 8-conductor jack used in 10BaseT and 100BaseT Ethernet wiring.

Fig 7




RJ-45 conductor data cable contains 4 pairs of wires each consists of a solid colored wire and a strip of the same color. There are two wiring standards for RJ-45 wiring: T-568A and T-568B. Although there are 4 pairs of wires, 10BaseT/100BaseT Ethernet uses only 2 pairs: Orange and Green.

The other two colors (blue and brown) may be used for a second Ethernet line or for phone connections. The two wiring standards are used to create a cross-over cable (T-568A on one end, and T-568B on the other end), or a straight-through cable. as shown in fig. 8 & 9.

Fig 8

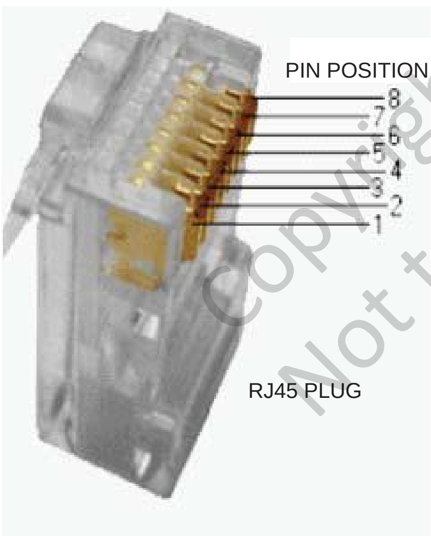
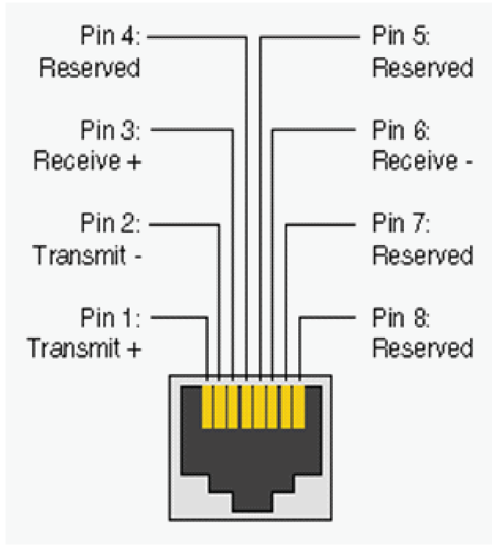



Fig.10. Colours of wires & pin numbers for T568A cable end

Fig.11. Colours of wires & pin numbers for T568B cable end

Fig 9




RJ45 socket

Fig 10

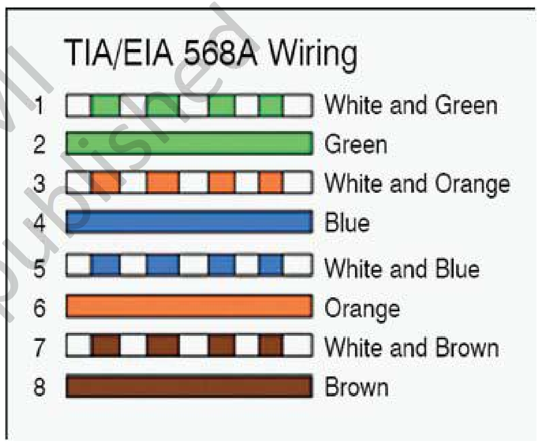
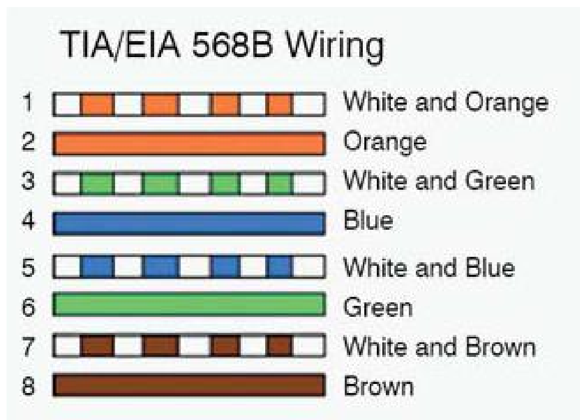


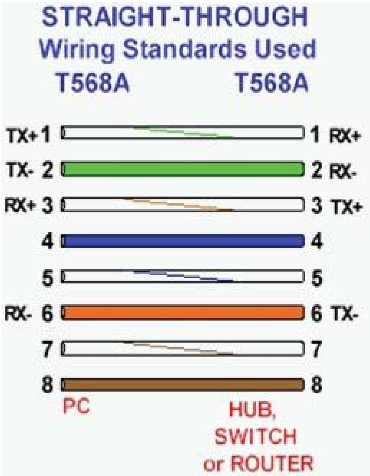

Fig 11



The straight-through cables are used when connecting Data Terminating Equipment (DTE) to Data Communications Equipment (DCE), such as computers and routers to modems (gateways) or hubs (Ethernet Switches).

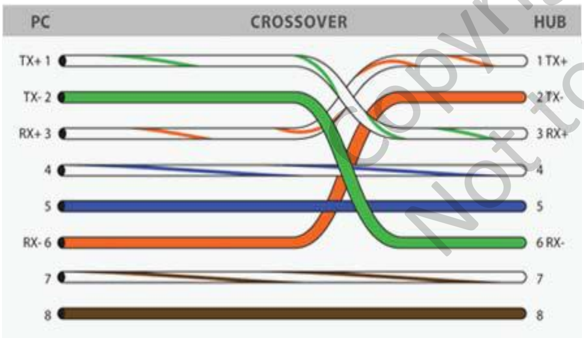
To create a straight-through cable, you'll have to use either T-568A or T-568B on both ends of the cable. As shown n figure- Fig.12.

Fig 12




The cross-over cables are used when connecting DTE to DTE, or DCE to DCE equipment; such as computer to computer, computer to router; or gateway to hub connections.To create a cross-over cable, you'll have to use T-568A at one end and T-568B at another end of the cable as shown in fig.13.

Fig 13




**RJ45 Input / Output box** (I/O Box) is a preparatory cable with both ends terminated by RJ45 keystone jacks for LAN network; it is also called as wall jack. The keystone jack is shown in fig.14(a). Keystone jack has color code running down A and B standards on both sides of the jack to be followed with the colours of wires. Using a punch down tool the wires are punched down into the blades designed to work with solid conductors into the keystone jack as shown in fig. 14 b. It is prepared as a straight through cable terminated at both ends with RJ45 sockets. It is used to connect the router to personal computer and printer etc in the networking. It consists of one or more number of RJ45 keystone sockets fitted onto a face plate and it is wired internally by punching down the wires of the CAT cable into respective terminals as shown in fig.14 c

Fig 14a

Fig 14b


Fig 14c

It is prepared as a straight through cable terminated at both ends with RJ45 sockets. This I/O Box is used for extending the network connectivity for a maximum allowable distance of 100meters.

## Cables and Connectors of a PC system

**Objectives:** At the end of this lesson you shall be able to
- **establish the need for cables and connectors in a PC system**
- **list the types of cables/connectors used to interconnect PC peripherals**
- **list the types of cables/connectors used to interconnect mother board with devices.**

**Basic Computer**

A personal computer consists of a mother board, RAM - add on cards, Hard disk drive (HDD), Floppy disk drives FDD, Power supply, cabinet, monitor, key board and a mouse. These parts are available as separate modules. It is possible to integrate all these devices into one complete unit with minimum interconnections. In practice these modules are interconnected using cables, connectors, and edge connectors. Such an arrangement gives the flexibility of changing subsystem and ease of trouble shooting.

**Cables and connectors**

Different types of cables used in the computer are multicored round shielded cable, unshielded cables and multicored flat cable as per the international standards. Chart -1 shows various types of connectors used in PC. Mouse, key board and monitor comes with a cable, terminated with connectors at one end .Hard disk, FDD, CD-ROM and other such devices are terminated with a 40 pin/50pin/34 pin FRC connectors. Power supply to HDD, FDD and CD-ROM units also fed through the hard plastic connectors.

HDD, is connected to the Mother Board with a flat cable (40 pin) for data transmission and 4 pin hard plastic connector for the Power. These cables are made in such away that we can connect two devices at a time (one master and the other slave). In a typical system the connection may be any of the following type

i) M/B to HDD and CD drive

ii) M/B to two HDDs

ii) M/B to two CD drive

FDD is connected to the MB with a 34 pin flat cable for data transfer and 4 pin hard plastic Molex connector for power. We can connect two floppy disks at a time using the cable. They can be either two "5 1/4 "or two "3 1/2" or combination of both. But nowadays only "3 1/2 " i.e. 1.44MB drives are used and the "5 1/2" are out dated

The rear panel connectors are identified by their standard types such as D type, DIN type, mini DIN type or PS/2 type, RJ type, BNC, RCA and USB. All these types have male and female connectors. Chart 1 at the end of this lesson provides details on various connectors and cables.

DB-9 is a D-type subminiature connector or D- sub type of connector. It has items for male connector and I holes for female connector. Today DB 9 has mostly been replaced by USB, PS-2, fire wire and others. Still many devices are using DB9 interface for serial communication D type 25 pin male connectors are located on the rear side of the cabinet usually denoted as COM-1 & COM -2 are used for serial communication. These are connected to mother board using two 10 core cables. A D type 25 pin ( female ) parallel port is located on the rear side of the cabinet is used for parallel communication. This is also called as printer port or asynchronous port which is connected to the mother board using a 25 core flat cable. Printers are connected to the parallel port. A general mouse comes with a 9 pin D type female connector which is connected to the serial port.

Universal Serial Bus (USB) is also a communication port similar to serial port used to connect modem, scanners and Web-cameras etc. USB ports are used to connect the peripherals having the USB connectors. Two 5 core or 4 core cables are connected between the Mother Board and the USB terminations on the rear side of the PC.

Mini jack connectors are used to connect Audio IN and OUT of external audio sources. Computers with sound card are provided with female mini jack connectors at the rear side. Allows to attach microphone or external sound source, speakers . The PCs CD-ROM drive audio is connected to the sound card internally.

RCA connectors are used for video IN and OUT to external video sources. Computers with TV tuner card/ video digitizer card are provided with female type RCA connectors at the rear side.

Game port is a 15 pin D type (normal) connector provided at the rear side of the computer to connect JOY stick which is a popular multi directional pointing device used for playing computer games.

Monitors come with a cable terminated with a 15 pin D type male connector. It is connected to the CPU through a 15 pin D type female video connector located at the rear side of the cabinet. This connector is a high density connector, packed in a 9 pin D type shell construction.

Registered Jack (RJ) connectors are available as two wire, 4 wire and 8 wire terminations. They are denoted as RJ 11( 4 pin) and RJ 45 ( 8 pins) etc. RJ-female connectors are located at the rear side of a computer if the computer is fitted with a modem or network card. RJ 11 is used to interface telephone connection (for modem). RJ 45 for network interface connection - (for net work). BNC - "Baynet Naur Connector" is used for coaxial cable termination.

The BNC connectors are also used in networking computers using coaxial cable.

Normal Key boards are terminated with a DIN type male connector. A DIN type female connector is provided at the rear side of the PC through which the key board is connected to the PC. A miniature DIN connector is also provided on the PC for connecting keyboards terminated with PS/2 connector or mouse terminated with PS/2.

**Connector /converters**

Usually connectors are matched properly between cabinet and devices. Sometimes the connectors may not match. Convertors are available to match these devices. For example - a PS/2 (mini DIN) mouse can be converted to match 9 pin serial connector, if the mother board does not have PS/2 connector (mini DIN). In this way we can use the device with unmatched connector saving cost of a new device. Converters are available for Modem, Keyboard, mouse.

**HDMI** (High-Definition Multimedia Interface) is a proprietary audio/video interface for transferring uncompressed video data and compressed or uncompressed digital audio data from an HDMI-compliant source device, such as a display controller, to a compatible computer monitor, video projector, digital television, or digital audio device. HDMI is a digital replacement for analog video standards.

**FireWire** The IEEE 1394 High Performance Serial Bus (HPSB), FireWire is a high-speed interface mostly developed and promoted by Apple for video transmission. Introduced in 2000, FireWire was added to camcorders and a variety of A/V equipment. Even early iPods could connect via FireWire. Still included on Mac laptop and desktop computers, modern camcorders have replaced FireWire with USB, HDMI and other video outputs. There are two types as FireWire 400 and 800.

USB 3.0 is the third major version of the Universal Serial Bus (USB) standard for interfacing computers and electronic devices. Among other improvements, USB 3.0 adds the new transfer mode SuperSpeed (SS) that can transfer data at up to 5 Gbit/s (625 MB/s), which is about ten times faster than the USB 2.0 standard.

**eSATA & USB Hybrid Port**

A combo port that connects to external SATA (eSATA) drives and USB devices with cables up to two meters long. The eSATA USB Hybrid Port (EUHP) also eliminates the external power cable by supplying 5 or 12 volts to eSATAp (eSATA powered) drives.

Both of these ports connect to regular external eSATA drives. However, the Hybrid Port also supplies power to eSATAp drives as well as connects USB devices. If the port is blue, it supports USB 3.0, otherwise only USB 2.0. **S/PDIF (Sony/Philips Digital Interface Format)** is a type of digital audio interconnect used in consumer audio equipment to output audio over reasonably short distances. The signal is transmitted over a fiber optic cable with TOSLINK connectors. S/PDIF interconnects components in home theatres and other digital high fidelity systems.

S/PDIF is based on the professional AES3 interconnect standard. S/PDIF can carry two channels of uncompressed PCM audio or compressed 5.1/7.1 surround sound (such as DTS audio codec).

**Digital Visual Interface (DVI)** is a video display interface developed by the Digital Display Working Group (DDWG). The digital interface is used to connect a video source, such as a display controller to a display device, such as a computer monitor. It was developed with the intention of creating an industry standard for the transfer of digital video content.

The interface is designed to transmit uncompressed digital video and can be configured to support multiple modes such as DVI-D (digital only), DVI-A (analog only), or DVI-I (digital and analog). Featuring support for analog connections, the DVI specification is compatible with the VGA interface.

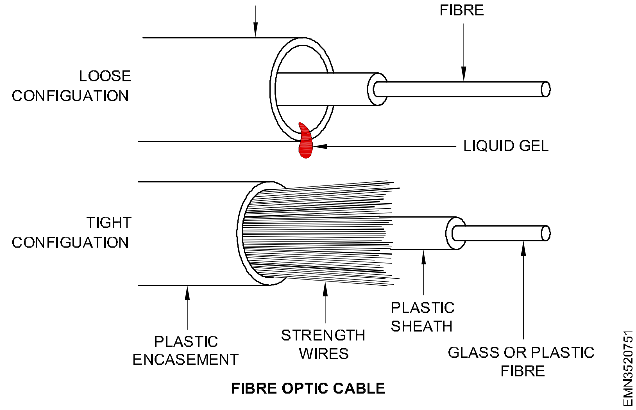
**S/PDIF (Sony/Philips Digital Interface Format)** is a type of digital audio interconnect used in consumer audio equipment to output audio over reasonably short distances. The signal is transmitted over a fiber optic cable with TOSLINK connectors. S/PDIF interconnects components in home theatres and other digital high fidelity systems.

S/PDIF is based on the professional AES3 interconnect standard. S/PDIF can carry two channels of uncompressed PCM audio or compressed 5.1/7.1 surround sound (such as DTS audio codec).; it cannot support lossless formats (such as Dolby TrueHD and DTS-HD Master Audio) which require greater bandwidth like that available with HDMI or Display Port.

**Fiber optic cable**

Fiber optic cable is made of light- coducting glass or plastic core surrounder by more glass and a tough outer sheath as in Fig 1 The center core provide the light path or wave guide while the galss or cladding is composed of varying layers of reflective glass. The glass or cladding is composed of varying layers of reflective glass. The glass cladding is designed to refract ligh back into the core. Each core and cladding strand is surronded by a tight or loose sheath in tight configurations, the strand is completely surrounded by the outer plastic sheath. Loose configuration use a liquid gel or other material between the strand and the protective sheath.

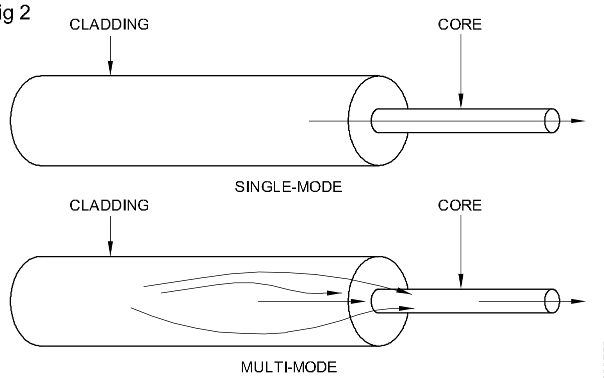
Fig 1



FIBRE OPTIC CABLE

The Optical fibers may be multimode or single mode in nature. single mode fiber has been optimized to allow only one light path while multimode fiber allows various paths. The following figure explains single mode and multimode fibers. Fig 2

Fig 2




FIBRE OPTIC CABLE

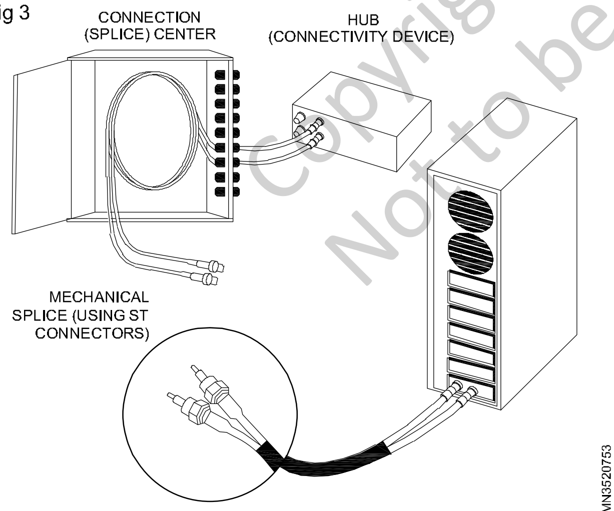
Single mode fiber cable can be used for distance upto 10kms. and multimode cable foe upto 2.5km. The typical speeds are 100/1000 Mbpz. The types of optic cable are diffrentiated by mode, composition ( glass or plastic) and core/cladding size.

Common types of fiber optical cables:

- 8.3 micron core/125 micron cladding single mode
- 62.5 micron core/125 micron cladding multimode
- 50 micron core/125 micron cladding multimode
-100 micron core/140 micron cladding multimode

The common fiber optic cables installation is given in the following Fig 3

Fig 3

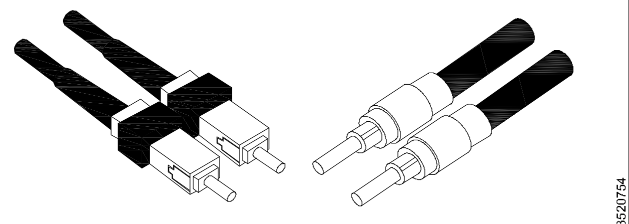



The single carried by a single mode cable is generated by a laser source and that of a multimode by light emitting diode (LED). Together, these qualities allow single mode cable to operate at higher bandwiths than multimode and traverse distance upto 50 times longer. single mode cable is cheaper than multimoda and has a relatively high bend radius, which makes it mode diffcult to work with. MMF is most commonly used.

**Fiber optic connectors**

The connector used fiber optic cables is called an ST (straight tip) connection shown Fig 4

Fig 4

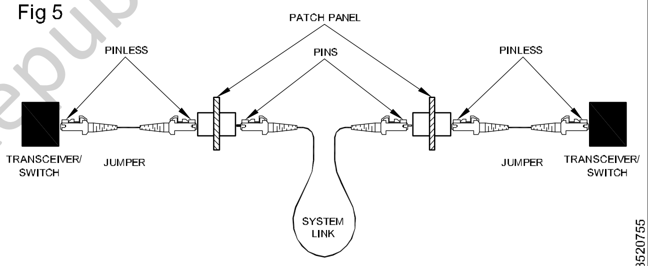



FIBRE-OPTIC SC (LEFT) AND ST (RIGHT) CONNECTORS

One more connector type is SC (subscribe connector) is coming up popularly. It has a square body and locks by simply pushing into the socket.

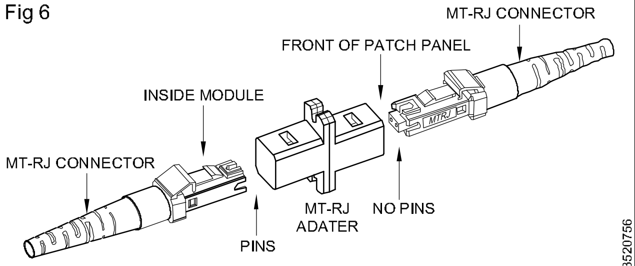
The MTRJ is a new fiber optic connecotr being used widely. it can operate at Gigbit ethernet speeds ( 1000 Mbps) easily. The MT-RJ has a lacthing mechanism similar to the RJ-45 UTP connector. A standard MT-RJ connection consists of 3 components: a male connector (with pins), a female MT-RJ (with guide holes) and as MTRJ adapater. it is easily to install and maintain and should be considedred for any new installation. The figure 5 and 6 show the MTRJ connectors and connections in use.

Fig 5




TYPICAL PATCH PANEL TO PATCH PANEL SYSTEM WITH MT-RJ CONNECTORS

Fig 6




MATING OF A PINNED MT-RJ CONNECTOR TO PINLESS MT-RJ CONNECTOR

Fiber-Optic connectors can attach to the cable in several ways, using either a crimped compresion fitting or an epoxy giue.

Fiber cables are mainy used for backbone connectivity across the floors or when the distance cannot be covered by UTP cable limitation or when the network path to be connected is exposed to sky.

Fiber cables come in three varieties depending on the place of usage.

1 Indoor cables-for in -house usage within buildings.
2 outdoor cables/Armoured cable-to be used in areas which are exposed to sky. Has an additional hard shield to prevent any occassional damage.
3 Indoor/outdoor cable can be used inside and outside buildings. Does not carry heavy shield as in outdoor cable, but better than indoor cable.

**Diffrent types of network connectivity hardware**

In s network number of hardware devices are used to connect each computer to a media segment. These devices are:

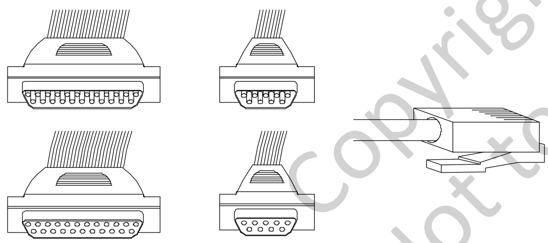
1 Transmission media connectors
2 Network interface boards
3 Modems

We can also connect multiple seprate segments of transmission media to form one large network. For this purpose we use the following nerworkng devices.

1 Repeaters
2 Hubs
3 Bridges
4 Multiplexers
5 Transceiver
6 Routers

1 Transmission media connectors:
Every medium has one or more physical connecotors to which you can attach various devices (Fig 7)

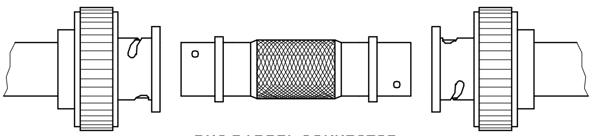
Fig 7




**BNC (Bayonet nut connector)**

It is a connecotor for co-axial cable that locks when one connector is insrted into another and is roated 90 degree as in Fig 8

Fig 8




Speakon connector
The Speakon is an electrical connecotr used in professional audio systems for connecting loudspeakers to amplifiers. Speakon connectors are rated for 40 A RMS continuous current, higher than 1/4-inch TS phone connectors, two-pole twist lock, and XLR connecotr for loudspeakers

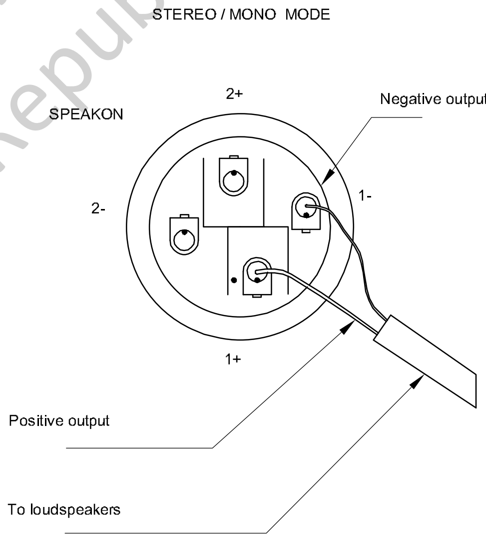
The speaker connecotr connector (male) shown in Fig 9

Fig 9


A Speakon connecotr is designed with a locking system that may be designed for soldering or screw-type connections. Line connecotrs (female) mate with (male) panel connectors at both ends, Recently the manufacture has introduced new series called STX which include also male line connectors and female panel Speakon connecotrs are designed for use in speaker cables. With 1/4' speaker jacks and XLR connections. It is possible for users to erroneously use low-current shielded microphone or instrument cables are intended solely for use in high current audio applications,

The connection diagram of speakon female socket is shown in Fig 10

Fig 10




Connector arrange their contacts in two concentric rings with the inner contacts named +1,+2, etc. and the outer contacts connectors (in the four-pole and eight-pole version only). named -1, -2, etc. [5] The phase conventions is that positive voltage on the + contact causes air to be pushed away form the speakers.

Speakon connectors are made in two, four and eight-pole configurations. The two-pole line connector will mate with the four -pole panel connector, connecting to +1 and -1: but the reverse combination will not work. The eight-pole connector is physically larger to accommodate the extra poles. The four-pole connector is the most common at least from the availability of ready-made leads, as it allows for things like bi-amping(two of the four connections for the higher-frequency signal, With the other two for the lower-frequency signal) without two separate cables.

**Cables & Connectors**

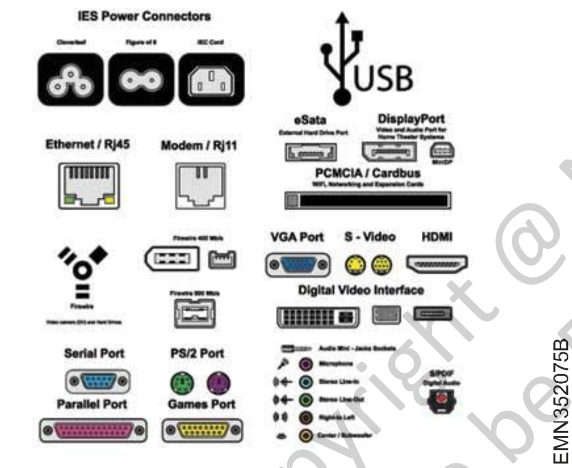
A port is a physical docking point using which an ex termal devices can be connected to the computer. It can also be progrommatic docking point through which information flows from a program to the computer or over the internet. Diffrent types ports used in computer is Shown in Fig 11.

Characteristics of ports

A port has the following characteristics-

- External devices are connected to a computer using cables and ports.
- Ports are slots on the motherboard into which a cable of external devices is pligged in.
- Examples of external devices attached via ports are the mouse, keyboard, monitor, microphone, speakers, etc.

Fig 11




**Important Types Of Ports**

**Serial port**

- Used for external modems and older computer mouse
- Two versions: 9 pin, 25 pin model
- Data travels at 115 kilobits per second

Parallel port

- Used for scanners and printers
- Also called printer port
- 25 pin model
- IEEE 1284-complaint Centronics port

PS/2 Port

- Used for old computer keybord and mouse
- Also called mouse port
- Most of the old computers provide two PS/2 port, each for the mouse and keybord
- IEEE 1284-complaint Centronics port

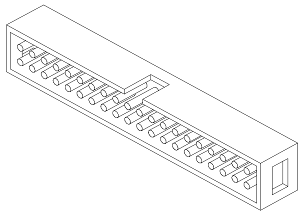
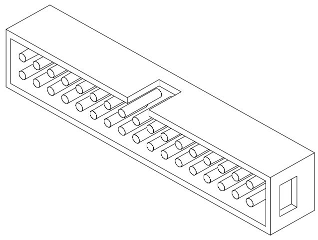
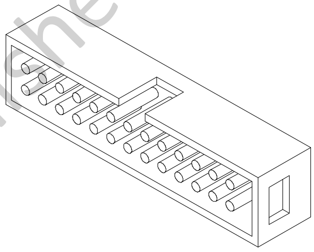
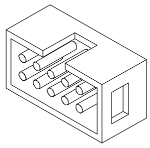
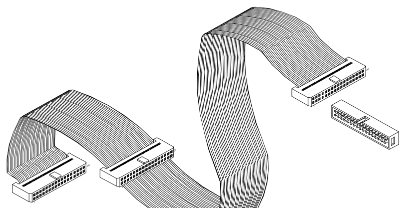
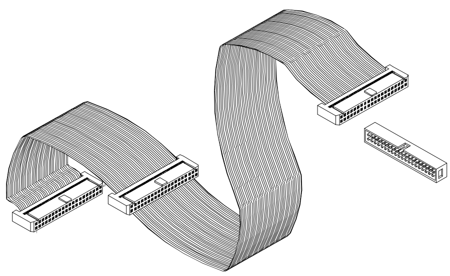
Universal Serial Bus (or USB) Port

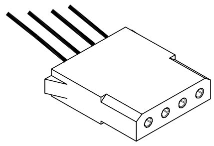
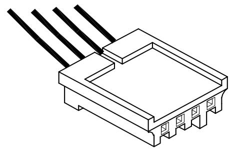
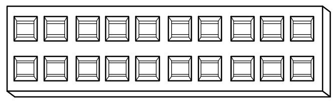
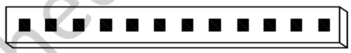
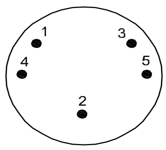
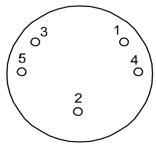
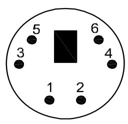
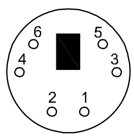
- It can connect all kinds of external USB ports as minimum.
- It was intorduced in 1997.
- Most of the computers provide two USB port.

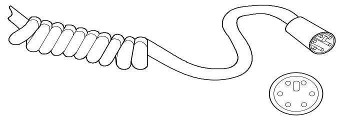
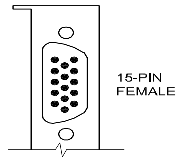
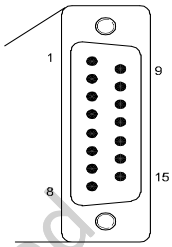
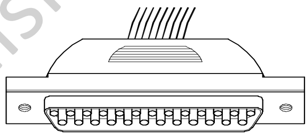
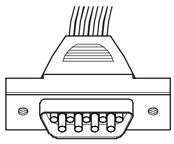
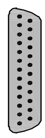
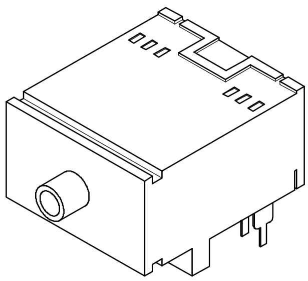
VGA Port

- Connects monitor to a computer's video card.
- It has 15 holes.
- Similar to the serial port connector. However, serial port connector has Pins, VGA port has holes.

**Chart 1**

| Description | Application | Cable/connector |
|---|---|---|
| 40 pin FRC male connector located on M/B | To connect MB with HDD |  40 PIN FRC CONNECTOR |
| 34 pin FRC male connector located on M/B | To connect MB with FDD |  34 PIN FRC CONNECTOR |
| 25 pin FRC male connector located on M/B | To connect MB with Parallel port provided on the rear side of the PC |  26 PIN FRC CONNECTOR |
| 10 pin FRC male connector located on M/B | To connect MB with serial port "D" connector provided on the rear side of the PC |  10 PIN FRC CONNECTOR |
| FDD cable (data) located inside the PC | To connect MB with FDD |  FLOPPY DISK CABLE |
| HDD cable (data) located inside the PC | To connect MB with HDD |  HARD DISK CABLE |

| Description | Application | Cable/connector |
|---|---|---|
| 4 pin Molex connector from SMPS unit | SMPS to HDD,FDD,DVD- ROM |  MOLEX CONNECTOR |
| 4 pin Berg connector from SMPS unit | SMPS to FDD (3 1/2'') |  BERG CONNECTOR |
| 20 pin Berg connector from SMPS unit | SMPS (ATX) to MB | ATX  20 PIN BERG CONNECTOR |
| 12 pin Berg connector | SMPS (AT) to MB | AT  12 PIN BERG CONNECTOR |
| 5 pin DIN plug on key board cable | Key board to MB |   5-PIN DIN PLUG |
| 5 pin DIN socket provided on the rear side of the PC | MB to key board |   5-PIN DIN SOCKET |
| 5 pin Miniature DIN plug on keyboard cable | Key board to MB |   5-PIN MINI-DIN PLUG |
| 5 pin Miniature DIN socket provided on the rear side of the PC | MB to key board |   5-PIN MINI-DIN SOCKET |

| Description | Application | Cable/connector |
|---|---|---|
| PS/2 Key board connectors | Mouse to MB |  NEW STYLE PS/2 MINI DIN KEYBOARD CONNECTOR WITH SIX PINS |
| 15 pin High density VGA connector on the rear side of PC | MB to Monitor |   HIGH DENSITY CONNECTOR |
| 15 pin D type connector | To connect Joy stick |   15-PIN D-SHELL CONNECTOR |
| D-25 pin male connector on the rear side of the PC | Serial port (Com-port) |  25 PIN MALE CONNECTOR |
| D-9 pin male connector on the rear side of the PC | Serial port (Com-port) |  9 PIN MALE CONNECTOR |
| D-25 pin female connector on the rear side of the PC | Parallel port (Printer port) |  25-PIN FEMALE CONNECTOR |
| Mini Jack socket on the rear side of the PC | Audio IN /MIC |  MINI JACK SOCKET |

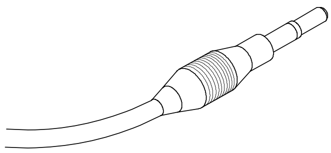
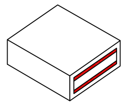
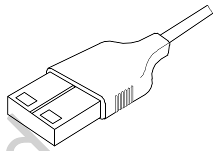
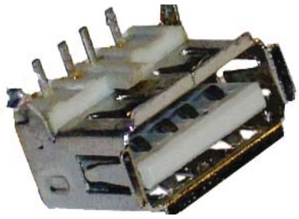
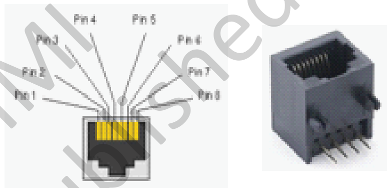
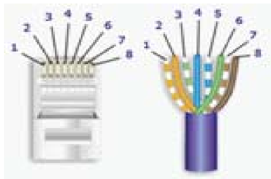
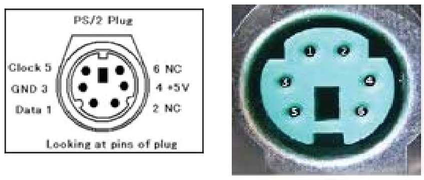
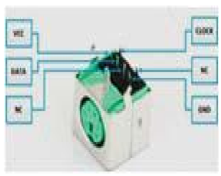
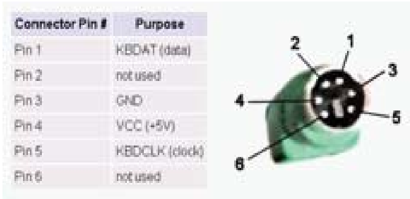
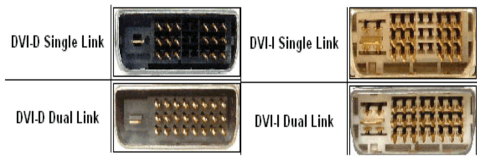
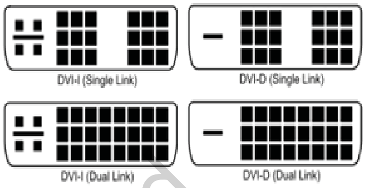
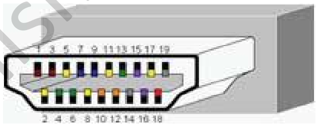
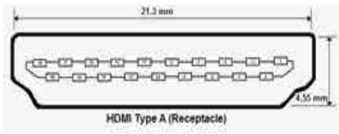
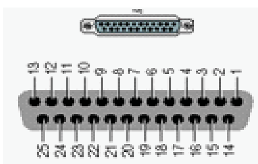
| Description | Application | Cable/connector |
|---|---|---|
| Mini Jack from external audio device | External Audio Devices to Sound card |  MINI JACK |
| USB female connector provided on the rear side of the PC | MB to USB peripherals |  FEMALE USB CONNECTOR |
| USB male connector from the USB device | USB peripherals to MB |  MALE USB CONNECTOR |

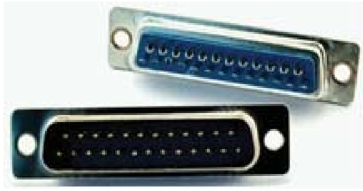
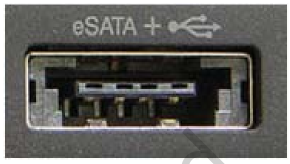
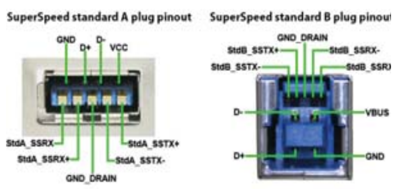
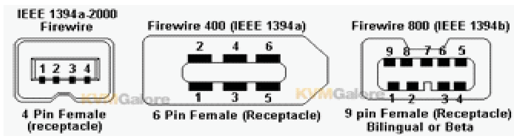


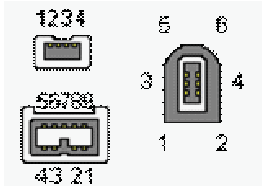
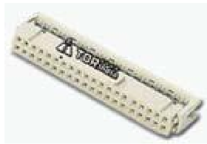
**Chart showing various types of sockets /ports and plugs used for Computer Rear Panel & Mother board**

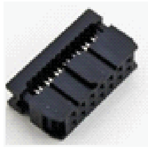
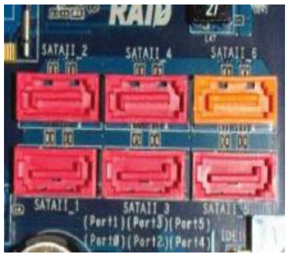
| Sl.No | Port/Socket &plug Name | Port/Socket &plug Image |
|---|---|---|
| 1 | Mains Power supply Connector and plug |   |
| 2 | Mains Power supply adaptor and plug |   |
| 3 | Audio jack (3.5mm) |  |

| Sl.No | Port/Socket &plug Name | Port/Socket &plug Image |
|---|---|---|
| 4 | Audio plug (3.5mm) |  |
| 5 | USB -2.0- female |  |
| 6 | USB-2.0- male |  |
| 7 | RJ-45jack- Female |  |
| 8 | RJ-45 plug-Male |  |
| 9 | PS-2 mouse port |  |
| 10 | PS-2 mouse plug |  |
| 11 | PS-2 keyboard port |  |

| Sl.No | Port/Socket &plug Name | Port/Socket &plug Image |
|---|---|---|
| 12 | PS-2 keyboard plug |   |
| 13 | DVI male connector |   |
| 14 | DVI port |   |
| 15 | HDMI plug |  |
| 16 | HDMI Port |   |
| 17 | DP9-Serial female plug |  |
| 18 | DP9-Serial male port |  |
| 19 | DP-25 Parallel plug |  |

| Sl.No | Port/Socket &plug Name | Port/Socket &plug Image |
|---|---|---|
| 20 | DP-25 Parallel port |  |
| 21 | eSATA -female |  |
| 22 | eSATA - Port |  |
| 23 | VGA port (DP-15) |  |
| 24 | VGA male plug (DP-15) |  |
| 25 | USB -3.0 port -male |  |
| 26 | USB-3.0 port - female |  |
| 27 | IEEE 1394( fire wire)- Female |  |

| Sl.No | Port/Socket &plug Name | Port/Socket &plug Image |
|---|---|---|
| 28 | IEEE 1394 ( fire wire)- male |  |
| 29 | 40 Pin FRC Female connector |  |
| 30 | 40 pin FRC Male connector |  |
| 31 | 34 pin FRC male connector |  |
| 32 | 34 Pin FRC female connector |  |
| 33 | 26 Pin FRC Female Connector |  |
| 34 | 26 pin FRC Male Connector |  |

| Sl.No | Port/Socket &plug Name | Port/Socket &plug Image |
|---|---|---|
| 35 | 10 pin FRC Male Connector |  |
| 36 | 10Pin FRC female Connector |  |
| 37 | S/PDIF connector- male |  |
| 38 | S/PDIF connector- female |  |
| 39 | SATA cable |  |
| 40 | SATA port |   |

## Radio wave propagation - principles, fading etc

**Objectives :** At the end of this lesson you shall be able to
- **explain the fundamentals of radio wave propagation**
- **explain the phenomena of fading & propagation characteristics through different media.**

**Radio wave propagation**

Radio wave propagation. A radio wave is form of radiant energy (electromagnetic radiation) that propagates at the speed of light (186,000 miles or 300, 000,000 meters per second). Radio propagation is the behavior of radio waves when they are transmitted, or propagated from one point on the earth to another, or into various parts of the atmosphere. As a form of electromagnetic radiation, like light waves, radio waves are affected bythe phenomena of reflection, refraction, diffraction, absorption, polarization and scattering.

Radio wave propagation is affected by the daily changes of water vapor in the troposphere and ionization in the upper atmosphere, due to the sun. Understanding the effects of varying conditions on radio propagation has many practical applications, from choosing frequencies for international shortwave broadcastors to design reliable mobile telephone systems, radio navigation and operation of radar systems.

Radio propagation is also affected by several other factors determined by its path from point to point. This path can be a direct line of sight path or an over the horizon path aided by refraction in the ionosphere, which is a region between 60 and 600 km approximately. Factors influencing ionospheric radio signal propagation can include sporadic -E, solar flares, geomagnetic storms, ionospheric layers tilts and solar porton events.



**Table 1 : Radio frequencies and their primary mode of propagation**

| | Band | Frequency | Wave length | Propagation via |
|---|---|---|---|---|
| ELF | Extremely Frequency | 3-30 Hz | 100, 000 km 10,000 km | |
| SLF | Super low Frequency | 30-300 Hz | 10,000 1,000 km | |
| ULF | Ultra low Frequency | 0.3-3 kHz | 1000- 100 km | |
| VLF | Very low Frequency | 3-30 kHz | 100 km-10 km | Guided between the earth and the ionosphere |
| LF | Low frequency | 30-300 kHz | 10 km-1 km | Guided between the earth and the D layer of the ionosphere and<br>Surface waves |
| MF | Medium frequency | 300-3000 kHz | 1000-100m | E, F layer ionospheric refraction at night, when D layer absorption weakens |
| HF | High frequency (Short wave) | 3-30 MHz | 100-10m | E Layer ionospheric refraction<br>F1, F2 layer ionospheric refraction |
| VHF | Very high frequency | 30-3000 MHz | 10-1 m | Infrequent E ionospheric ($E_s$) refraction uncommonly F2 layer ionospheric refraction during high sunspot activity up to 50 MHz and rarely to 80 MHz. Generally direct wave. Sometimes tropospheric ducting |
| UHF | Ultra high frequency | 300-300 MHz | 100-10 cm | Direct wave. Sometimes tropospheric ducting |
| SHF | Super high frequency | 3-30 GHz | 10-1 cm | Direct wave |
| EHF | Extremely high Frequency | 30-300 GHz | 10-1 mm | Direct wave limited by absorption |
| THF | Tremendously high frequency | 0.3 - 3 THz | 1-0.1 mm | |

#### Surface modes ( ground wave)

Surface wave

Lower frequencies (between 30 and 3, 000 KHz) have the property of following the curvature of the earth via ground wave propagation in the majority of occurrences.

Early commerical and professional radio services relied exclusively on long wave, low frequencies and ground - wave propagation. To prevent interference with these services, amateur and experimental transmitters wire restricted to the higher (HF) frequencies, felt to be useless since their ground - wave range was limited. Upon discovery of the other propagation modes possible at medium wave and short wave frequencies, the advantages of HF for commercial and military purposes became apparent. Amateur experimentation was then confined only to authorized frequency segments in that range.

#### Direct modes (line-of-sight)

Line of sight is the direct propagation of radio waves between antennas that are visible to each other. This is probably the most common of the radio propagation modes at VHF and higher frequencies. Because radio signals can travel through many non - metallic objects, radio can be picked up through walls. This is still line - of sight propagation. Examples would include propagation between a satellite and a ground antenna or receptionof television signals from a local TV transmitter.

#### Ionospheric modes (sky wave)

#### Sky wave

Sky wave propagation, also referred to as skip, is one of the modes that rely on refraction of radio waves in the ionosphere, which is made up of one or more ionized layers in the upper atmosphere. F2 - layer is the most important ionospheric layer for long - distance, multiple - hop HF propagation, through F1, E and D - layers also play significant roles. The D- layer, when present during sunlight periods, causes significant amount of signal loss, as does the E - layer whose maximum usable frequency can rise to 4 MHz and above, thus block higher frequency signals from reaching the F2 - layer. The layers, or more appropriately “regions”, are directly affected by the sun on a daily diurnal cycle, a seasonal cycle and the 11-year sunspot cycle and determine the utility of these modes. During solar maxima, or sunspot highs and peaks, the whole HF range up to 30 MHz can be used usually around the clock and F2 propagation up to 50 MHz is observed frequently depending upon daily solar flux 10.7 cm radiation values. During solar minima, or minimum sunspot counts down to zero, propagation of frequencies above 15 MHz is generally unavailable.

#### Multipath fading basics

Multipath fading is a feaure that needs to be taken into account when designing or developing a radio communications system. In any terrestrial radio communications system, the signal will reach the receiver not only via the direct path, but also as a result of reflections from objects such as buildings, hills, ground, water, etc, that are adjacent to the main path.

The overall signal at the radio receiver is a summation of the variety of signals being received. As they all have different path lengths, the signals will add and subtract from the total dependent upon their relative phases.

At times there will be changes in the relative path lengths. This could result from either the radio transmitter or receiver moving, or any of the objects that provides a reflective surface moving. This will result in the phases of the signals arriving at the receiver changing, and in turn this will result in the signal strength varying as a result of the different way in which the signals will sum together. It is this that causes the fading that is present on many signals.

## Need for modulation & types of modulation

**Objectives :** At the end of this lesson you shall be able to
- **explain the need for modulation**
- **explain various types modulation & demodulation techniques.**

**Need for modulation**

The velocity of electromagnetic waves is 3 x $10^8$ $ms^{-1}$. On the other hand, the velocity of sound waves cannot be used to transmit intelligence to far off place. Only electromagnetic waves can be made to do this.

Modulation is extremely necessary in communication systems due to the following reasons.

**Sub topics**

1 Practical antenna length (L)

2 Wireless communication

3 Operating range

**Practical antenna length (L)**

When free space is the communication channel, antennas operate effective only when their dimensions are of the order of the magnitude of wave length of the signal being transmitted.

Now, $L = \lambda = \frac{u}{v} = \frac{3 \times 10^8}{v} Hz$

$\lambda$ = Wave length

u = Velocity of electro magnetic wave

v = Frequency to be radiated in Hz

The aduio frequencies range from 20 Hz to 20 kHz. Suppose a frequency of 20 kHz is to be radiated directly into space. For this,

Length of antenna = $\frac{3 \times 10^8}{20 \times 10^3} m = 15000 m = 15$ km

this is too long antenna to be constructed practically. So, it is impracticable to radiate audio signal directly into space.

Let us now calculate the length of the antenna if a carrier wave of say, 1000 kHz is used to carry the signal.

Length of antenna = $\frac{3 \times 10^8}{10^6} m = 300$ m

An antenna of 300 m length can be easily construct.

**Wireless communication**

One desirable feature of radio transmission is that it should be carried wihtout wires (i.e) radiated into space. At audio frequencies, radiation is not practicable because the efficiency of radiation is poor. However, efficient radiation of electrical energy is possible at high frequencies (>20kHz). For this reason, modulation is always done in communication systems.

**Operating range**

The energy of a wave depends upon its frequency. The greater the frequency of the wave, the greater is the energy possessed by it. As the audio signal frequencies are small, these cannot be transmitted over large distance if radiated directly into space. The only pracitcal solution is to modulate a high frequency carrier wave with audio signal and permit the transmission to occur at this high frequency (carrier frequency) .

**What is modulation?**

The best way to define modulation is

The process of impressing low -frequency information to be transmitted on to a high -frequency wave, called the carrier wave, by changing the characteristics of either its amplitude, frequency , or phase angle is called modulation.

Another definition for modulation is.

The process of altering the characteristics of the amplitude, frequency, or phase and of the high - frequency signal in accordance with the instantaneous value of the modulating wave is called modulation.

**Types of modulation**

The sinusoidal carrier wave can be given by the equation.

Vc = Vc Sin (Wct+$\theta$) = Vc Sin $2\pi f_c t+\theta$)

Vc = Maximum value

fc = Frequency

$\theta$ = Phase relation

Wc = Angular velocity

t = time

Since the three variables are the amplitude, frequency, and phase angle, the modulation can be done by varying any one of them. Thus there are three modulation types namely.

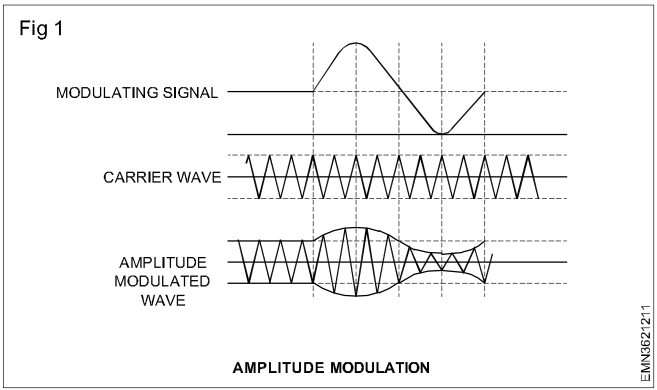
- Amplitude modulation ( AM)
- Frequency modulation (FM)
- Phase modulation (PM)

In India, radio broadcasting is done through amplitude modulation. Television broadcasting is done with amplitude modulation for video signals and frequency modulation for audio signals.

## Amplitude modulation (AM)

### Definition

The method of varying amplitude of a high frequency carrier wave in accordance with the information to be transmitted, keeping the frequency and phase of the carrier wave unchanged is called amplitude modulation. The information considered as the modulating signal and it is superimposed on the carrier wave by applying both of them to the modualtor. The detailed diagram showing the amplitude modulation process is given below. (Fig.1)




As shown above, the carrier wave has positive and negative half cycles. Both these cycles are varied according to the information to be sent. The carrier then consists of sine waves whose amplitudes follow the amplitude variations of the modulating wave. The carrier is kept in an envelope formed by the modulating wave. From the figure, you can also see that the amplitude variaiton of the high frequency carrier is at the signal frequency and the frequency of the carrier wave is the same as the frequency of the resulting wave.

### Analysis of amplitude modulation carrier wave

Let $v_c = V_c \text{ Sin } \omega_c t$

$V_m = v_m \text{ Sin } \omega_m t$

$V_c$ - Instantaneous value of the carrier

$V_c$- Peak value of the carrier

$\omega_c$- Angular velocity of the carrier

$v_m$-Instantaneous value of the modulating signal

$V_m$- Maximum value of the modulating signal

$\omega_m$- Angular velocity of the modulating signal

$f_m$- Modulating signal frequency

It must be noted that the phase angle remains constant in this process. Thus it can be ignored. The amplitude of the carrier wave varies at $f_m$.

The amplitude modulated wave is given by the equation.

$A= v_c+v_m=v_c+v_m \text{ Sin } \omega_m t=v_c[1+(v_m/v_c \text{ Sin } \omega_m t)]$

m - Modualtion index. The ratio of $v_m/v_c$

Instantaneous value of amplitude modualted wave is given by the equation.

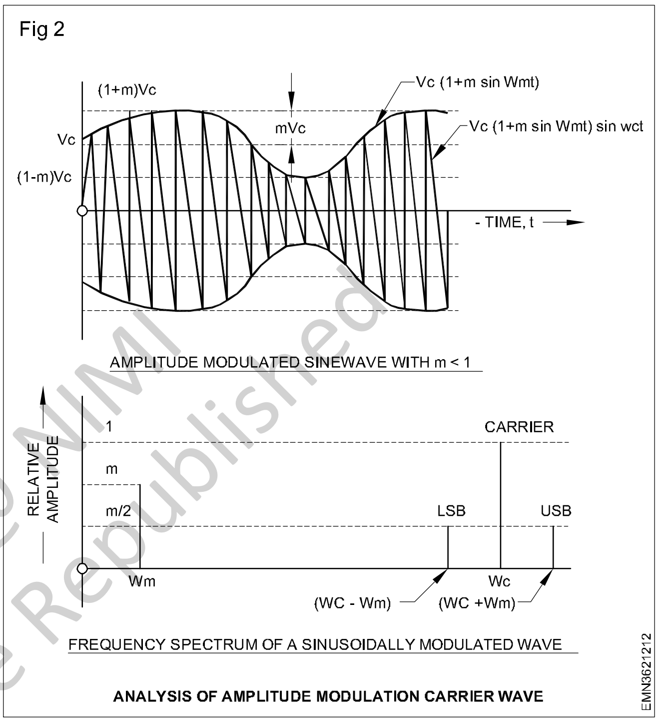
$v=A \text{ Sin } \omega_c t = v_c (1+m \text{ Sin } \omega_m t) \text{ Sin } \omega_c t$

$= v_c \text{ Sin } \omega_c t +mv_c (\text{Sin } \omega_m t \text{ Sin } \omega_c t)$

$v=V_c \text{ Sin } \omega_c t + [mv_c/2 \text{ Cos } (\omega_c - \omega_m) t - mv_c/2 \text{ Cos } (\omega_c+\omega_m)t]$

The above equation represents the sum of three sin waves. One with amplitude of $V_c$ and a frequency of $(\omega_c - \omega_m)2$ and the third one with an amplitude of $mv_c/2$ and a frequency of $(\omega_c + \omega_m)$ 2.

In practice the angular velocity of the carrier is knwon to be greater thanthe angular velocity of the modulating signal $(\omega_c >> \omega_m)$. Thus, the second and third cosine equations are more close of the carrier frequency. The equation is represented graphically as shown below. (Fig.2)




### Amplitude modulation frequency spectrum

Frequency spectrum of AM wave

Lower side frequency - $(\omega_c - \omega_m)$ 2

Upper side frequency - $(\omega_c + \omega_m)$ 2

The frequency components present in the AM wave are represented by vertical lines approximately located along the frequency axis. The height of each vertical line is drawn in proportion to its amplitude. Since the angular velocity of the carrier is greater than the angular velocity of the modulating signal, the amplitude of side band frequencies can never exceed half of the carrier amplitude.

Thus there will not be any change in the original frequency, but the side band frequencies $(\omega_c - \omega_m)2$ and $(\omega_c + \omega_m)2$ will be changed. The former is called the upper side band (USB) frequency and the later is known as lower side and band (LSB) frequency.

Since the signal frequency $\omega_m/2$ is present in the side bands, it is clear that the carreir voltage two side banded frequencies will be produced when a carrier is amplitude modulated by a signal frequency. That is, an AM wave has a band width from $(\omega_c - \omega_m)/2$ to $(\omega_c + \omega_m)/2$, that is $2\omega_m/2$ or twice the signal frequency is produced. When a modulating signal has more than one frequency, two side band frequencies are produced by every frequency. Similarly for two frequencies of the modualting signal 2 LSB's and 2 USB's frequencies will be prodcued.

The side bands of frequencies present above the carrier frequency is known to be the upper side band and all those below the carrier frequency belong to the lower side band. The USB frequencies represent the some of the individual modulating frequencies and the LSB frequencies represent the difference between the modulating frequency and the carrier frequency. The total bandwidth is represented in terms of the higher modulating frequency and is equal to twice this frequency.

**Modulation index (m)**

The ratio between the amplitude change of modulated carrier wave to the amplitude of the normal carrier wave is called modulation index. It is represented by the letter 'm'.

It can also be defined as the range is which the amplitude of the carrier wave is varied by the modulating signal.

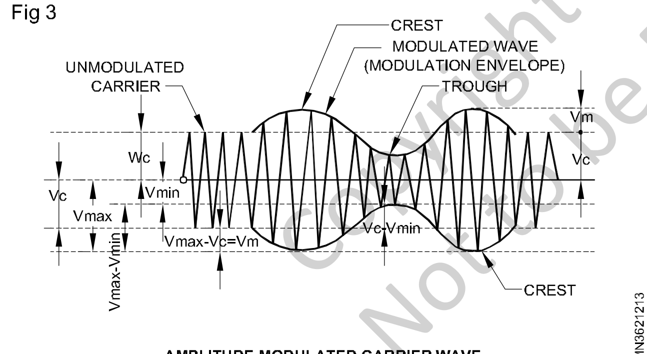
$m=V_m/V_c$

Percentage modulation, $\%m=m*100 = V_m/V_c * 100$

The percentage modulation lies between 0 and 80%

Another way of expressing the modulation index is in terms of the maximum and minimum values of the amplitude of the modulated carrier wave. This is shown in the figure below. (Fig.3)

Fig 3




AMPLITUDE MODULATED CARRIER WAVE

**Amplitude modualted carrier wave**

Amplitude modulated carrier wave

From the figure we know that

$2V_{in}=V_{max}- V_{min}$

$V_{in} = (V_{max}-V_{min})/2$

$V_c=V_{max} -V_{in}$

$=V_{max} - (V_{max}-V_{min})/2$

$=(V_{max} +V_{min})/2$

Substituting the values of $V_{in}= V_m$ and Vc in the equation m =Vm/Vc, we get

$M= V_{max}-V_{min}/V_{max} + V_{min}$

As told earlier, the value of 'm' lies between 0 and 0.8. The value of m determines the strength and the quality of the transmitted signal. In an AM wave, the signal is contained in the variations of the carrier amplitude. The audio signal transmitted will be weak of the carrier wave is only modulated to a very small degree. But if the value of m exceeds unity, the transmitter output produces erroneous distortion.

**Power relations in an AM wave**

A modualted wave has more power than had by the carrier wave before modulating. The total power components in amplitude modulation can be written as;

$P_{total}=P_{carrier}+P_{LSB}+ P_{USB}$

Considering additional resistance like antenna resistance R.

$P_{carrier} = [(V_c/\sqrt{2})/R]^2=V^2_c/2R$

Each side band has a value of m/w $V_c$ and r.ms value of $mV_c/2\sqrt{2}$. Hence power in LSB and USB can be written as

$P_{LSB} = P_{USB} = (mV_c/2\sqrt{2})^2/R=m^2/4*V^2C/2R=m_2/4P_{carrier}$

$P_{total} =V^2C/2R+[m^2/4*V^2C/2R]+[m^2/4*V^2C/2R] = V^2{}_C/2R(1+m^2/2)=P_{carrier}(1+m^2/2)$

In some applications, the carrier is simulataneously modulated by several sinusoidal modulating signals. In such a cause, the total modulation index is given as.

$Mt=\sqrt{(m1^2+m2^2+m3^2+m4^2+...)}$

If $I_c$ and it are the r.m.s values of unmodualted current and total modulated current and Ris the resistance through which these current flow,then,

$P_{total}/P_{carrier}=(It.R/Ic.R)^2 = (It/Ic)^2$

$P_{total}/P_{carrier}=(1+m^2/2)$

$(I_t/I_c)^2 = 1+m^2/2$

**Limitations of amplitude modulation**

1 Low efficiency- since the useful power that lies in the small bands is quite small, so the efficiency of AM system is low.

2 Limited operating range - The range of operation is small due to low efficiency. Thus, transmission of signals is difficult.

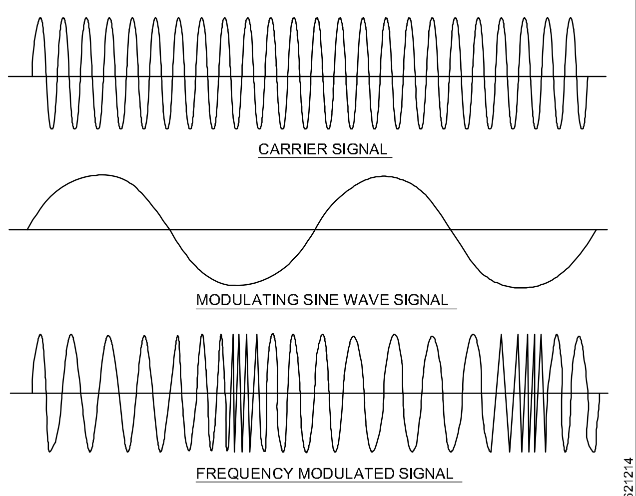
3 Noise in reception- As the radio receiver finds it difficult to distinguish between the amplitude variations that represent noise and those with signals, heavy noise is prone to occur in its reception.

4 Poor audio quality - To obtain high fidelity reception, all audio frequencies till 15 kilo Hertz must be reprodcued and this necessitates the band width of 10 Kilo Hertz to minimize the interference from the adjacent broadcasting stations. Therefore in AM broadcasting stations audio quality is known to be poor.

## Frequency modulation

The carrier frequency is varied according to the instantaneous amplitude of message signal or modualting signal by keeping the amplitude of carrier signal constant is called frequency. (Fig.4)

Fig 4




SIGNALS

### Advantages of frequency modualtion

- Frequency modulation has more noise resistivity when compared to other modulation techniques. That is why they are mainly used in broadcasting and radio communications. And we are all well aware that radio communication use mainly frequency modulation for transmission. We know that noise will occur mainly to the amplitude of the signal. In frequency modulation, amplitude is made constant and only frequency is varied, so we can easily find out the noise in the amplitude by using a limiter.
- The frequency modulation is having greater resistance to rapid signal strength variation, which we will use in FM radios even while we are travelling and frequency modulation is also mainly used in mobile communication purposes.
- For transmitting messages in frequency modulation, it does not require special equipments like linear amplifiers or repeaters and transmission levels or higher when compared to other modulation techniques. It does not require any class C or B amplifiers for increasing the efficiency.
- Transmission rate is good of frequency modulation when compared to other modulation that is frequency modulation can transmit around1200 to 2400 bits per second.
- Frequency modulation has a special effect called capture effect in which high frequency signal will capture the channel and discard the low frequency or weak signals from interference.

### Disadvantages of frequency modulation

In the transmission section, we do not need any special equipment but in the reception, we need more complicated demodulations for demodulating the carreir signal from message or modualting signal.

Frequency modulation cannot be used to find out the speed and velocity of a moving object. Static interferences are more than compared to phase modulation. Outside interference is one of the biggest disadvantages in the frequency modulation. There may be mixing becasue of nearby radio stations, pagers, construction walkie-talkies etc.

To limit the band width in the frequency modulation, we use some filter which will again introduce some distortions in the signal.

Transmittes and receiver should be in same channel and one free channel must be there between the systems.

### Application of frequency modulation (FM)

- Frequency modulation is used in radio' which is very common in our daily life.
- Frequency modulation is used in audio frequencies to synthesize sound.
- Used in applications of magnetic tape storage.

## Phase modulation

PM, is used in many applications to carry both analog and digital signals. Keeping the amplitude of the carrier signal constant, the phase is varied according to the instantaneous amplitude of information signals.

### Advantages and disadvantages of phase modulation

- The main advantages of phase modulation is that it has less interfernce from static, which is why we use this type of modulation in finding, out the speed or velocity of a moving object. In frequency modulation, we cannot find out the velocity of moving object.
- The main disadvantage is phase ambiguity comes if we increase the phase modualtion index, and data loss is more and we need special equipment like frequency mulitiplier for increasing the phase modulation index.

### Applications of phase modulation

- Phase modulation application is not different from frequency modulation. Phase modulation is also used in communication systems.
- It may be used in binary phase shift keying

# Fundamentals of antenna, various parameters, types & applications

**Objectives :** At the end of this lesson you shall be able to
- **explain the fundamentals of antenna**
- **explain various types & parameters of antennas**
- **explain the applications of various antennas.**

## Antenna fundamentals

An antenna is a device for converting electromagnetic radiation in space into electrical currents in conductors or vice - versa, depending on whether it is being used for receiving or for transmitting, respectively. Passive radio telescopes are receiving antennas. It is usually easier to calculate the properties of transmitting antennas. Fortunately, most characteristics of a transmitting antenna (e.g its radiation pattern) are unchanged when the antenna is used for receiving, so we often use the analysis of a transmitting antenna to understand a receiving antenna used in radio astronomy.

An antenna is an electrical device designated to radiate or capture electromagnetic (EM) waves. In order to properly appreciate this definition, and the physical operation of antennas as a whole, we will have to familiarize the reader with some basic electromagnetic concepts.

The physical laws governing all classical electromagnetic phenomena are maxwell's equations. First introduced by the scottish scientish james clark maxwell, in his famous article. "A dynamical theory of the electromagnetic field', in 1864.

An antenna gives the wireless system three fundamental properties gain, direction and polarization. Gain is a measure of increase in power. Direction is the shape of the transmission pattern. A good analog for an antenna is the reflector in a flashlight. The reflector concentrates and intensifies the light beam in a particular direction similar to what a parabolic dish antenna would do to a RF source in a radio system.

## Antenna gain

Antenna gain is measured in decibels, which is a ratio between two values. The gain of a specific antenna is compared to the gain of an isotropic antenna. An isotropic antenna is a theoretical antenna with a uniform three - dimensional radiation pattern (similar to a light bulb with no reflector). dBi is used to compare the power level of a given antenna to the theoretical isotropic antenna. The U.S FCC uses dBi in its calculations. An isotropic antenna is said to have a power rating of 0 dB, meaning that it has zero gain /loss when compared to itself.

Unlike isotropic antennas, dipole antennas are real antennas. Dipole antennas have a different radiation pattern compared to isotropic antennas. The dipole radiation pattern is 360 degrees in the horizontal plane and 75 degress in the vertical plane (assuming the dipole antenna is standing vertically) and resembles a donut in shape. Because the beam is slightly concentrated, dipole antennas have a gain over isotropic antennas of 2.14 dB in the horizontal plane. Dipole antennas are said to have a gain of 2.14 dBi (in comparison to an isotropic antenna).

Some antennas are rated in comparison to dipole antennas, which is denoted by the suffix dBd. Hence dipole antennas have a gain of 0 dBd (=2.14 dBi)

Note: Mjaority of documentaiton refers to dipole antennas as having a gain of 2.2 dBi. The actual figure is 2.14 dBi, but is often rounded up.

You can also use the dB abbreviation to describe the power level rating of antennas.

dBi - For use with isotropic antennas

dBd- With reference to dipole antennas

The power rating difference between dBd and dBi is approximately 2.2 that is, 0 dBd = 2.2 dBi.

## Antenna types

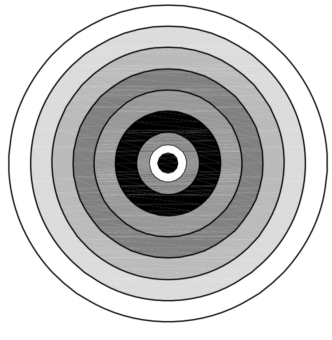
Each type of antenna offers different coverage capabilities. As the gain of an antenna increases, there is some tradeoff to its coverage area. Usually high- gain antennas offer longer coverage distances, but only in a certain direction. The radiation patterns below help to show the coverage areas of the styles of antennas that are Omnidirectional, Yagi and Patch antennas.

### Omnidirectional antenna

An omnidirectional antenna (Fig. 1) is designed to provide a 360 degree radiation pattern. This type of antenna is used when coverage in all directions from the antenna is required. The standard 2.14 dBi "Rubber duck" is one style of omnidirectional antenna.

Figure. Omnidirectional antennas

Fig 1




OMNIDIRECTIONAL ANTENNAS

## Directional Antennas

Directional antennas come in many different styles and shapes. an antenna does not offer any added power to the signal; it simply redirects the energy it receives from the transmitter. By redirecting this energy, it has the effect of providing more energy in one direction and less energy in all other directions. As the gain of a directional antenna increases, the angle of radiation usually decreases, providing a greater coverage distance, but with a reduced coverage angle. Directional antennas include patch antennas (Figure 2) Yagi antennas (Figure 3) and parabolic, dishes. Parabolic dishes have a very narrow RF energy path and the installer must be accurate in aiming these types of antennas these at each other.

Figure 2 : Directional Antenna

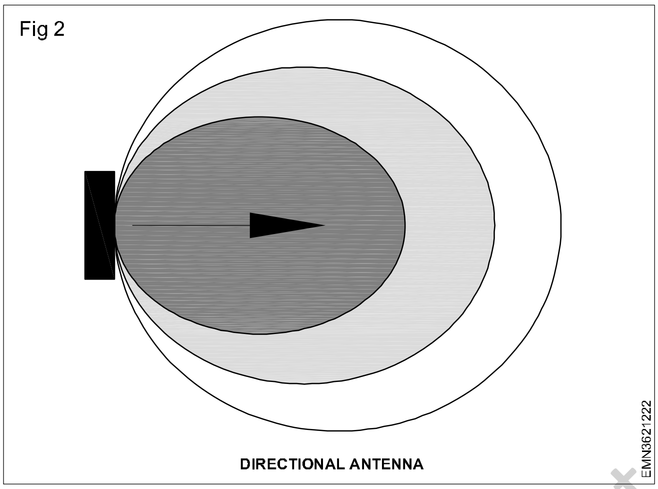
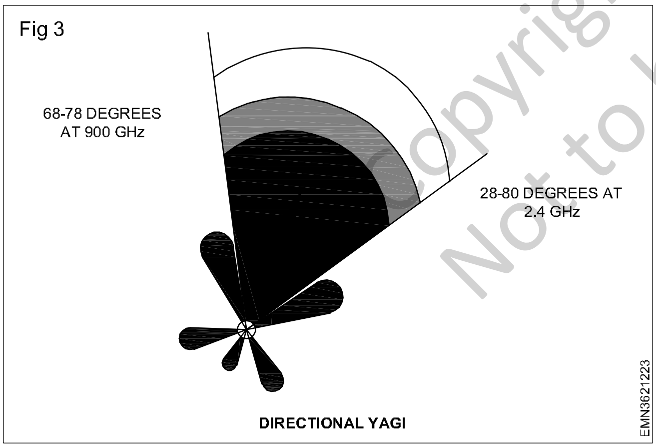



Figure 3 : Yagi antenna




## Yagi antenna / Yagi /Uda antenna

The yagi antenna sometimes called the yagi - Uda RF antenna is widely used where gain and directivity are required from an RF antenna design. (Fig.4)

**In this section**

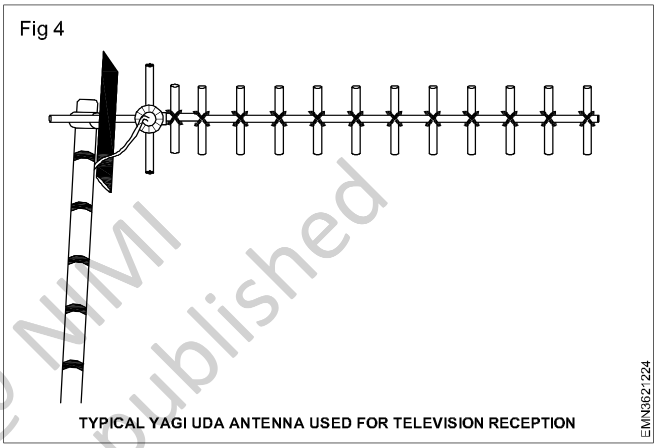
- Yagi antenna
- Yagi antenna theory
- Yagi antenna gain
- Yagi impedance & matching

The Yagi antenna or Yagi - Uda antenna / aerial is one of the most successful RF antenna designs for directive antenna applications.

The Yagi or Yagi - Uda antenna is used in a wide variety of applications where an RF antenna design with gain and directivity is required.

The Yagi has become particularly popular for television reception, but it is also used in very many other domestic and commercial applications where an RF antenna is needed that has gain and directivity.

Not only is the gain of the Yagi antenna important as it enables better levels of signals to noise ratio to be achieved, but also the directivity can be used to reduce interference levels by focussing the transmitted power to areas where it is needed, or receiving signals best from where it emanate.



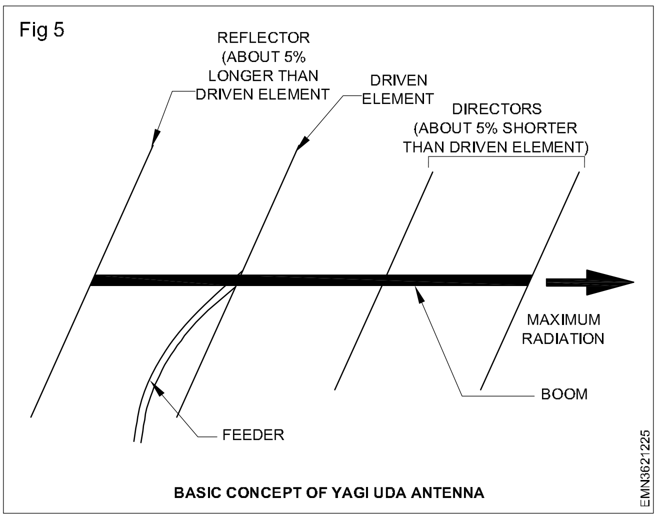

**Typical Yagi Uda antenna used for television reception**



## Yagi antenna history

The full name for the antenna is the Yagi - Uda antenna. The Yagi antenna derives its name from its two Japanese inventors Hidetsugu Yagi and Shintaro Uda. The RF antenna design concept was first outlined in a paper that Yagi presented in 1928.

## Yagi antenna - the basics (Fig.5)



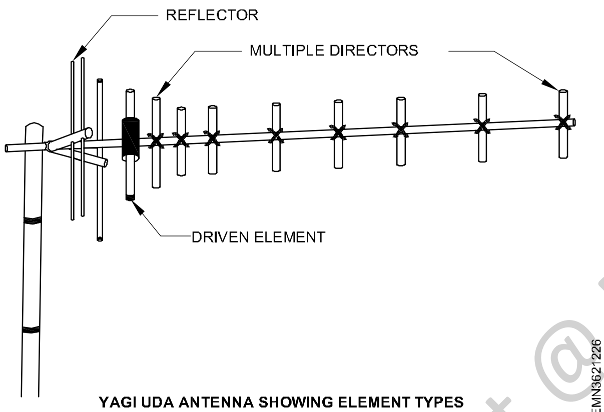

**Basic concept of Yagi Uda antenna**

The Yagi antenna design has a dipole as the main radiating or driven element. Further 'parasitic' elements are added which are not directly connected to the driven element.

These parasitic elements within the Yagi antenna pick up power from the dipole and re- radiate it. The phase is in such a manner that it affects the properties of the RF antenna as a whole, causing power to be focussed one particular direction and removed from others.

The parasitic elements of the Yagi antenna operate by re-radiating their signals in a slightly different phase to that of the driven element. In this way the signal is reinforced in some directions and cancelled out in others. It is found that the amplitude and phase of the current that is induced in the parasitic elements in dependent upon their length and the spacing between them and the dipole or driven element. (Fig.6)

Fig 6




YAGI UDA ANTENNA SHOWING ELEMENT TYPES

**Yagi Uda antenna showing element types**

There are three types of element within a Yagi antenna.

- Driven element : The driven element is the Yagi antenna element to which power is applied. It is normally a half wave dipole or often a folded dipole.
- Refelctor : The Yagi antenna will generally only have one reflector. This is behind the main driven element, i.e the side away from the direction of maximum sensitivity.

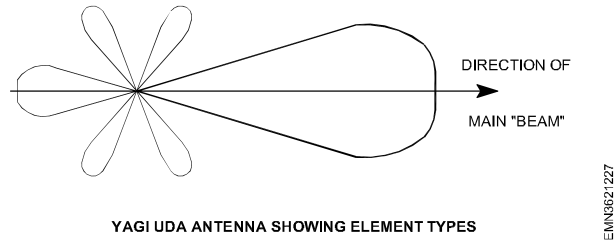
Further reflectors behind the first one add little to the performance. However many designs use reflectors consisting of a reflecting plate, or a series of parallel rods simulating reflecting plate. This gives a slight improvement in performance, reducing the level of radiation or pick - up from behind the antenna, i.e in the backwards direction.

Typically a reflector will add around 4 to 5 dB of gain in the forward drection.

Director : There many be none, one or more reflectors in the Yagi antenna. The director or directors are placed in front of the driven element, i.e in the direction of maximum sensitivity.

The antenna exhibits a directional pattern consisting of a main forward lobe and a number of spurious side lobes. The main one of these is the reverse lobe caused by radiation in the direction of the reflector. The antenna can be optimized to either reduce this or produce the maximum level of forward gain. Unfortunately the two do not coincide exactly and a compromise on the performance has to be made depending upon the application. (Fig.)

Fig 7




YAGI UDA ANTENNA SHOWING ELEMENT TYPES

**Yagi antenna radiation pattern**

**Parabolic antenna (Fig.8)**

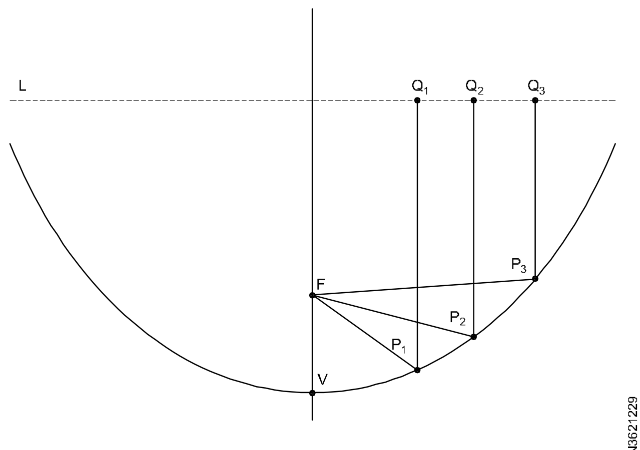
Fig 8

A parabolic antenna is an antenna that uses a parabolic reflector, a curved surface with the cross - sectional shape of a parabola, to direct the radio waves. The most common form is shaped like a dish and is popularly called a dish antenna or parabolic dish. The main advantage of a parabolic antenna is that it has high directivity. It functions similarly to a search light or flash light reflector to direct the radio waves in a narrow beam, or receive radio waves from one particular direction only. Parabolic antennas have some of the highest gains, that is, they can produce the narrowest beam widths, of any antenna type. In order to acheive narrow beam widths, the parabolic reflector must be much larger than the wave length of the radio waves used, so parabolic antennas are used in the high frequency part of the radio spectrum, at UHF and microwave (SHF) frequencies, at which the wave lengths are small enough that conveniently - size reflectors can be used.

Parabolic antennas are used as high - gain antennas for point -to point communications, in applications such as microwave relay links that cary telephone and television signals between nearby cities, wireless WAN/LAN links for data communications, satellite communications and spacecraft communication antenna. They are also used in radio telescopes.

The other large use of parabolic antennas is for radar antennas, in which there is a need to transmit a narrow beam of radio waves to locate objects like ships, airplanes, and guided missiles. With the advent of home satellite television receivers, parabolic antennas have become a common feature of the landscapes of modern countries.

Fig 9




PARABOLIC ANTENNA

Parabolic antennas are based on the geometrical property of the paraboloid that the paths $FP_1Q_1$, $FP_2Q_2$, $FP_3Q_3$ are all the same length. so a spherical wave front emitted by a feed antenna at the dish's focus F will be reflected into an outgoing plane wave L travelling parallel to the dish's axis VF. (Fig.9)

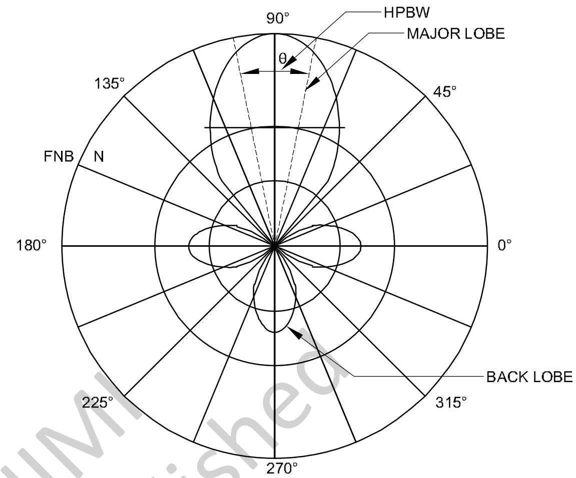
**Basic antenna parameters**

An antenna does not radiate uniformly in all directions. For the sake of reference, we consider a hypothetical antenna called an isotropic radiator having equal radiation in all directions. A directional antenna is one which can radiate or receive electromagnetic waves more effectively in some directions than in others. The relative distribution of radiated power as a function of direction in space (i.e., as function of θ and ϕ) is called the radiation pattern of the antenna. Instead of 3D surface, it is common practice to show planar cross action radiation pattern. E- plane and H- plane patterns give two most important views. The E-plane pattern is a view obtained from a section containing maximum value of the radiated field and electric field lies in the plane of the section. Similarly when such a section is taken such that the plane of the section contains H field and the direction of maximum radiation.

A typical radiation pattern plot is shown in fig.10 below.

**Typical radiation pattern in polar coordinates**

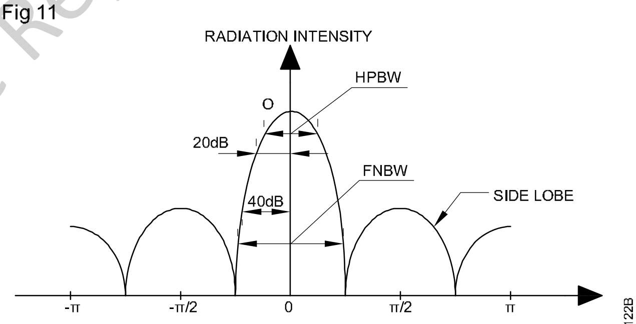
Fig 10




TYPICAL RADIATION PATTERN IN POLAR COORDINATES

**Typical radiationpattern in rectangular coordinates (Fig.11)**

Fig 11




PARABOLIC ANTENNA

# Introduction to AM, FM & PM, SSB-SC, DSB - SC modulation & demodulation techniques

**Objectives :** At the end of this lesson you shall be able to
- **explain the AM modulation & demodulation techniques**
- **expalin the modulation techniques of SSB-SC, DSB - SC in AM**
- **explain the FM modulation & demodulation techniques**
- **expalin the PM modulation & demodulation techniques.**

### Amplitude modulation index & depth

Amplitude modulation index and modulation depth are key parameters for any AM transmission as it is necessary to keep the index or depth within limits to reduce distortion and interference.

It is often necessary to define the level of modualtion that is applied to a signal.

In order to have a standard method of achieving this a factor or index known as the modulation index is widely used for this. A complementary figure known as the amplitude modulation depth is also seen on many occasions.

As an indicator of the level of modulation on an amplitude modualted signal, the modulation index is important - too low level of modulation and the modulation does not utilzie the carrier efficiently - too high and the carrier can become over modualted causing sidebands to extend out beyond the allowed bandwidth causing interference to other users.

### AM modulation index basics

Modualtion indices are described for various forms of modulation. The amplitude modulation, AM, modualtion index can be defined as the measure of extent of amplitude variation about an un - modulated carrier.

As with other modulation indices,the modulation index for amplitude modulation (AM) indicates that amount by which the modulated carrier varies around its static un - modulated level.

When expressed as a percentage it is the same as the depth of modulation. In other words it can be expressed as.

Modulation index $m = \frac{M}{A}$

A = carrier amplitude

M = modulation amplitude

Where :

A is the carrier amplitude . M is the modualtion amplitude and is the peak change in the RF amplitude from its unmodualted value.

From this it can be seen that for an AM modulation index of 0.5, the modulation causes the signal to increase by a factor of 0.5 and decrease to 0.5 of its original level.



### Amplitude modulation depth

A complementary figure to modulation index is also used for amplitude modulation signals. Known as the modulation depth, it is typically the modulation index expressed as a percentage.

Thus a modulation index of 0.5 would be expressed as a modulation depth of 50%.

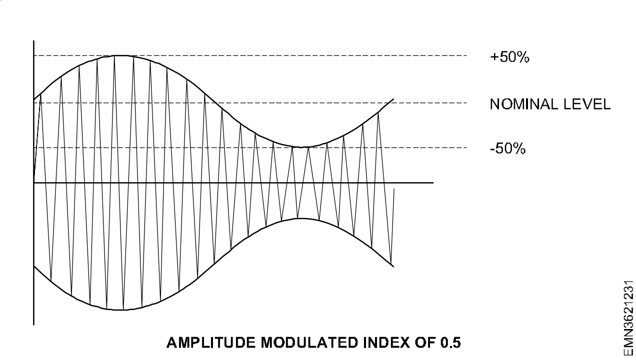
However often the two terms and figures are used interchangeably and figures for a modulation index of 50% are often seen where the index is 0.5

Modulation index / modulation depth examples

Typically the modulation index of a signal will vary as the modulating signal intensity varies. However some static values enable the various levels to visualized more easily.

### Amplitude modulated index of 0.5 (Fig.1)

Fig 1

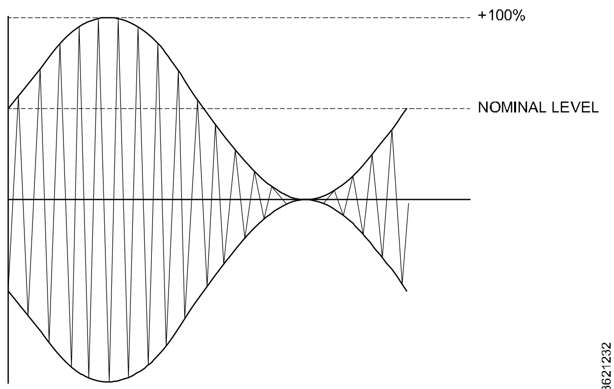



When the modulation index reaches 1.0, i.e a modulation depth of 100% the carrier level falls the zero and rise to twice its non - modualted level.

### Amplitude modualted index of 1.0 (Fig. 2)

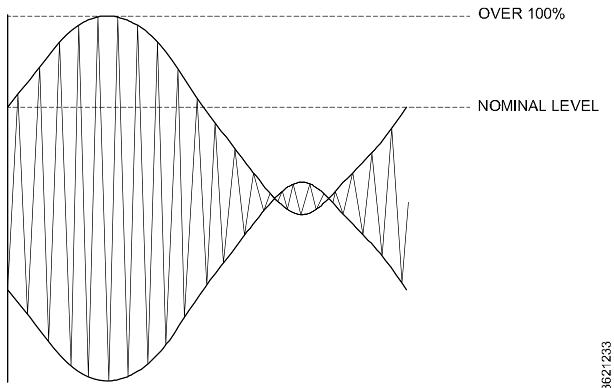
Any increase of the modulation index above 1.0, i.e 100% modulation depth causes over modulation. The carrier experiences 180° phase reversals where the carrier level would try to go below the zero point. These phase reversals give rise to additional side bands resulting from the phase reversals (phase modualtion) that extend out, in theory to infinity. This can cause serious interference to other users if not filtered.

Fig 2




AMPLITUDE MODULATED INDEX OF 1.0

Fig 3




AMPLITUDE MODULATED INDEX OF MORE THAN 1.0

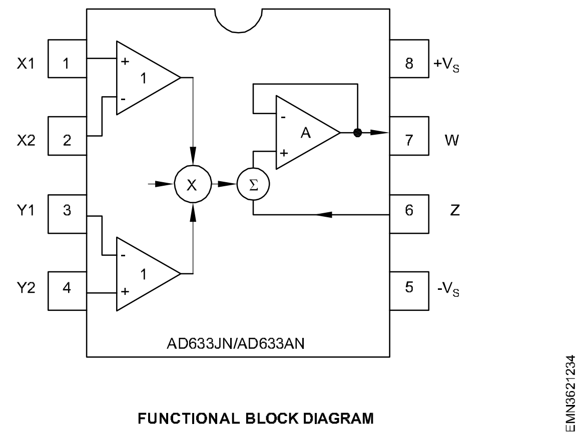
### Amplitude modulated index of more than 1.0 i.e over - modulated (Fig. 3)

Broadcast stations in particular take measures to ensure that the carrier of their transmissions never become over modulated. The transmitters incorporate limiters to prevent more than 100% modulation. However they also normally incorporate automatic audio gain controls to keep the audio levels such that near 100% modulation levels are achieved for most of the time.

### AM - Modulator & demodulator

In this section we describe the circuits used for generation and demodulation of amplitude modulated signals. An analog multiplier IC AD633( Analog devices) has been used to generate the AM signal. The AD 633 is a functionally complete, four quadrant, analog multiplier. It includes high impedance, differential X and Y inputs, and a high impedance summing input (Z). The low impedance output voltage is a nominal 10V full scale provided by a buried zener. The functional diagram of the AD633 is shown in figure 4.

Fig 4




FUNCTIONAL BLOCK DIAGRAM

Functional block diagram from figure 4, we find that

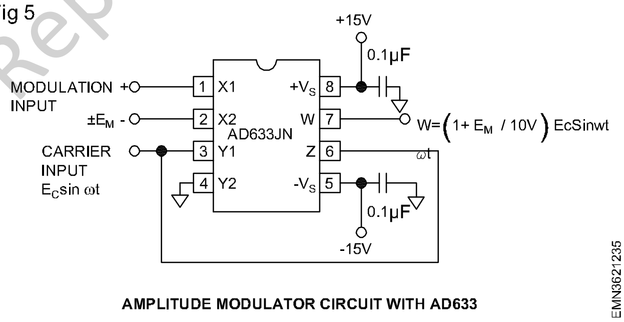
$$W = \frac{(X1-X2)(Y1-Y2)}{10V} + Z$$

Details of AD633 is available in the data sheet.

### Amplitude modulator circuit with AD633

The AD633 can be used as a linear amplitude modulator with no external components. Figure 5 shows the circuit. The carrier and modulation inputs to the AD633 are multiplied to produce a double sideband signal. The carrier signal is fed forward to the Z input of the AD633 where it is summed with the double sideband signal to produce a double side band with the carrier output.

Fig 5




AMPLITUDE MODULATOR CIRCUIT WITH AD633

For single tone modulation, $E_m A_m \sin(\varpi_m t)$ is used. The index of modulation can be varied by changing Am.

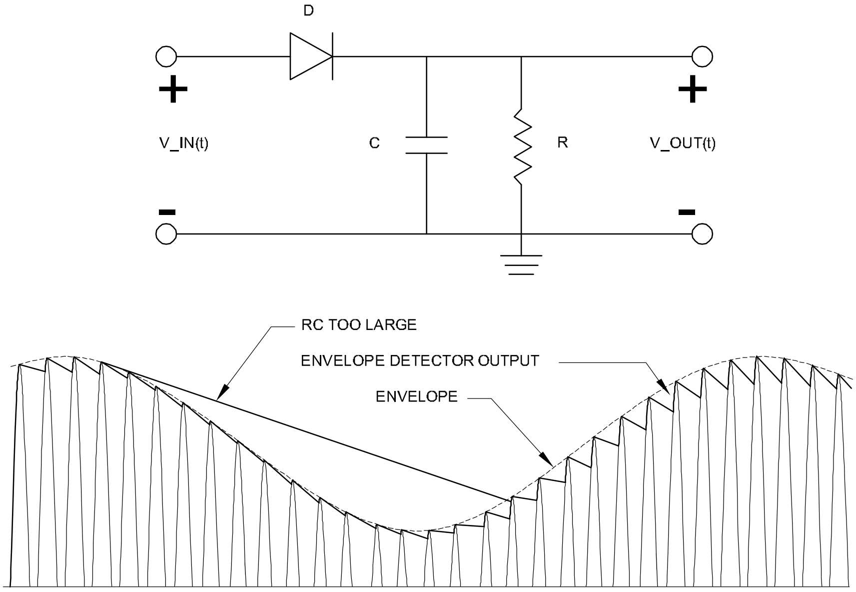
### Demodulation of AM signal

As stated earlier, an envelope detector has been used here for demodulation. An envelope detector (Fig 6) is an electronic circuit that takes a high frequency modualated signal as input and provides an output which is the "envelope" of the original signal. The capacitor in the circuit stores charge on the rising edge and release it slowly through the resistor when the signal falls. The diode in series rectifies the incoming signal, allowing current flow only when the positive input terminal is at a higher potential than the negative input terminal (Fig 6).

### Envelope detection process

For a sinusoidally modualted signal, if the time constant of the detector is chosen such that

Fig 6




AMPLITUDE MODULATOR CIRCUIT WITH AD633

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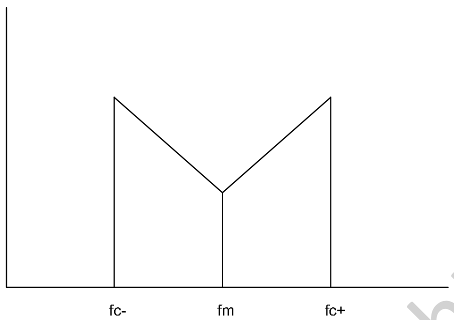
Fig 7




SPECTRUM PLOT OF AN DSB-SC SIGNAL

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$RC \leq \frac{1}{2\pi f_m}\left(\frac{\sqrt{1-m^2}}{m}\right)$, the detector can always follow the message envelope.

**Double - side band suppressed carrier transmission (DSB-SC)**

It transmission in which frequencies produced by amplitude modulation (AM) are symmetrically spaced above and below the carrier frequency and the carrier level is reduced to the lowest practical level, ideally being completely suppressed.

In the DSB - SC modulation,unlike in AM, the wave carrier is not transmitted; thus, much of the power is distributed between the side bands, which implies an increase of the cover in DSB-SC, compared to AM, for the same power used.

DSB-SC transmission is a special case of double - side band reduced carrier transmission. It is used for radio data systems.

**Spectrum**

DSB- SC is basically an amplitude modulation wave without the carrier, therefore reducing power waste, giving it a 50% efficiency. This is an increase compared to normal AM transmission (DSB), which has a maximum efficiency of 33.333%, since 2/3 of the power is in the carrier which carriers no intelligence, and each side band carriers the same information. Single side band (SSB) suppressed carrier is 100% efficient.

Spectrum plot of an DSB- SC signal (Fig.7)

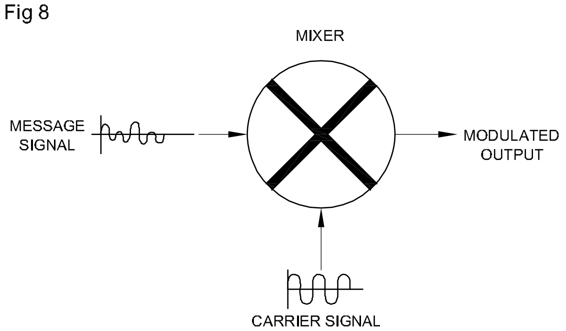
**Generation**

DSB- SC is generated by a mixer. This consists of a message signal multiplied by a carrier signal. The mathematical representation of this process is shown below, where the product-to-sum trigonometic identify is used. (Fig.8)

$$\underset{\text{Message}}{V_m \cos(\omega_c t)} \times \underset{\text{Carrier}}{V_c \cos(\omega_c t)} =$$

$$\underset{\text{2 Modulated signal}}{\frac{V_m V_c}{}}[\cos(\omega_m + \omega_c)t) + \cos((\omega_m - \omega_c)t)]$$

Fig 8




TITLE

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**Demodulation**

Demodulation is done by multiplying the DSB - SC signal with the carrier signal just like the modulation process. This resultant signal is then passed through a low pass filter to produce a scaled version of original signal. DSB-SC cab be demodulated by a simple envelope detector, like AM, if the modulation index is less than unity. Full depth modulation requires carrier re-insertion.

Modulated signal

$$\underset{\text{Message}}{V_m \cos(\omega_m t)} \times \underset{\text{Carrier}}{V_c \cos(\omega_c t)} =$$

$$\frac{V_m V_c}{2 \text{ Modulated signal}}[\cos(\omega_m + \omega_c)t) + \cos((\omega_m - \omega_c)t)]$$

$$= \left(\frac{1}{2} V_c V_c^{'}\right)\frac{V_m \operatorname{Cos}(\omega_m t)}{\text{Original message}} +$$

$$\frac{1}{2} V_c V_c V_m [\operatorname{Cos}((\omega_m - 2\omega_c)t)]$$

The equation above shows that by multiplying the modulated signal by the carrier signal, the result is a scaled version of the original message signal plus a second term. Since $\omega_c \gg \omega_m$ this second term is much higher in frequency than the original message. Once this signal passes through a low pass filter, the higher frequency component is removed, leaving just the original message.

**Distortion and attenuation (Fig. 9)**

For demodulation, the demodulation oscillator's frequency and phase must be exactly the same as modulation oscillator's otherwise, distortion and / or attenuation will occur.

To see this effect, take the following conditions.

Message signal to be transmitted : f(t)

Modulation (carrier) signal : $V_c \cos(\omega_c t)$

Demodulation signal (with small frequency and phase deviations from the modulation signal )

$V_c^{'} \cos[(\omega_c + \Delta\omega)t + \theta]$

The resultant signal can then be given by

$$f(t) \times V_c \cos(\omega_c t) \times V_c^{'} \cos[(\omega_c + \Delta\omega)t + \theta]$$

$$= \frac{1}{2} V_c V_c^{'} f(t) \cos(\Delta\omega t + \theta) + \frac{1}{2} V_c V_c^{'} f(t) \cos$$

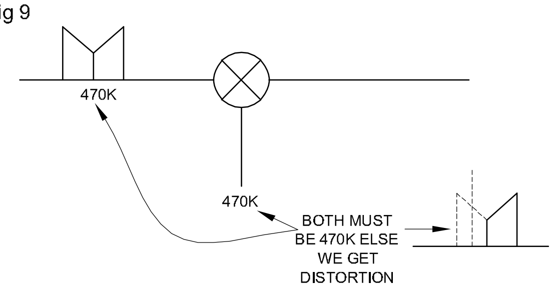
$$[(2\omega_c + \Delta\omega)t + \theta]$$

After low pass filter

$$= \frac{1}{2} V_c V_c^{'} f(t) \cos(\Delta\omega t + \theta)$$

The cos $(\Delta\omega t + \theta)$ terms results in distortion and attenuation of the original message signal. In particular, if the frequencies are correct, but the phase is wrong, contribution from θ is a constant attenuaton factor, also $\Delta\omega.t$ represents a cyclic inversion of the recovered signal, which is a serious form of distortion.

Fig 9

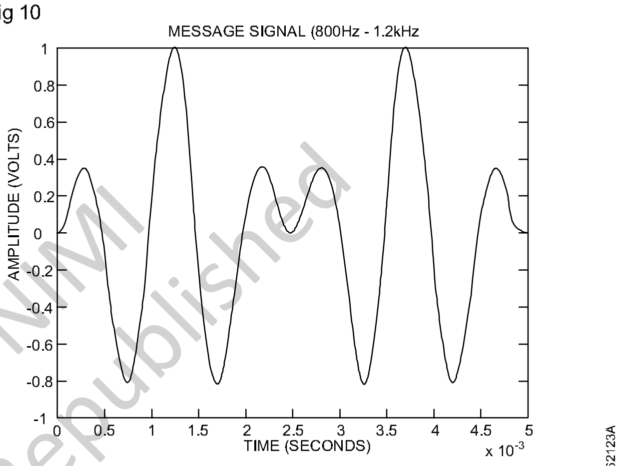



DISTORTION AND ATTENUATION

**How it works (Fig.10)**

This is best shown graphically. Below is a message signal that one may wish to modulate into a carrier, consisting of a couple of sinusoidal components.

Fig 10




DISTORTION AND ATTENUATION

The equation for this message signal in (fig 10) is

$$s(t) = \frac{1}{2}\cos(2\pi 800t) - \frac{1}{2}\cos(2\pi 1200t)$$

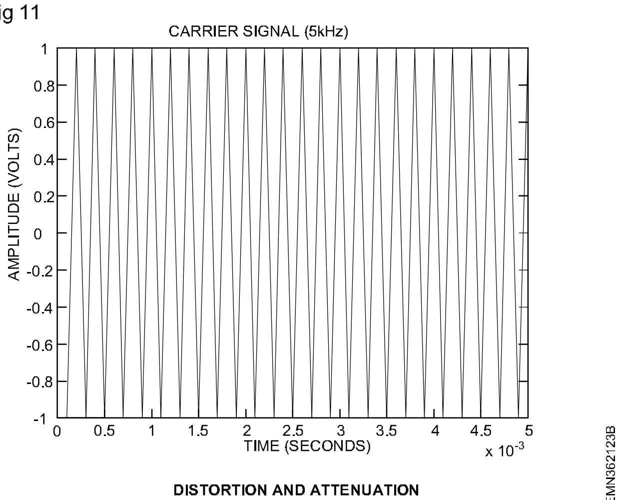
The carrier, in this case, is a plain is a plain 5 kHz

$$c(t) = \cos(2\pi 5000t)$$

The modulation is performed by multiplication in the time domain, which yields a 5 KHz carrier signal, whose amplitude varies in the same manner as the message signal.

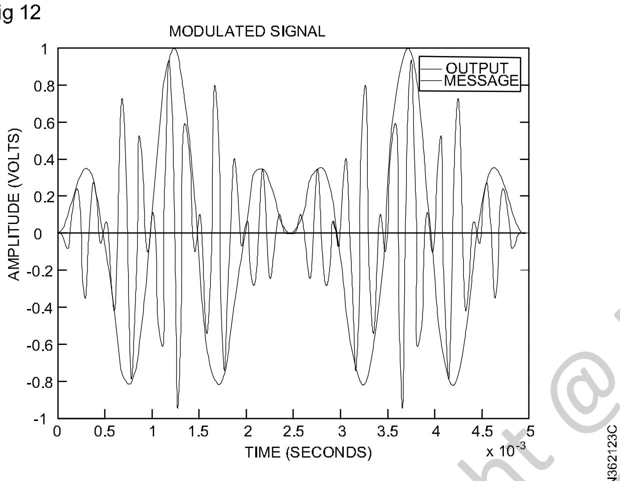
$$x(t) \underset{\text{Carrier}}{\cos(2\pi 5000t)} \times \underset{\text{Message signal}}{\left[\frac{1}{2}\cos(2\pi 800t) - \frac{1}{2}\cos(2\pi 1200t)\right]}$$

Fig 11




DISTORTION AND ATTENUATION

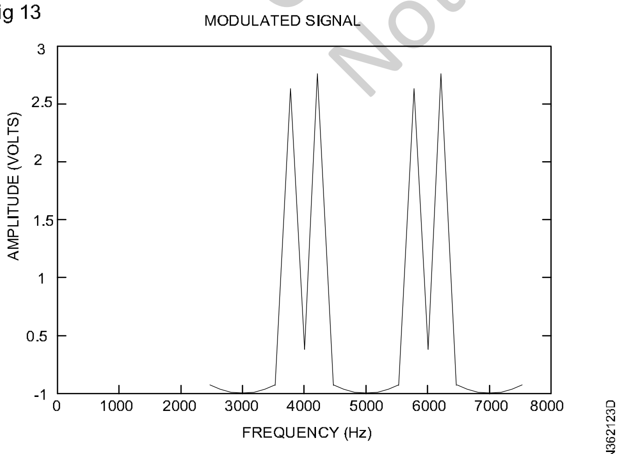
Fig 12




DISTORTION AND ATTENUATION

The name "suppressed carrier" comes about because the carrier signal component is suppressed -it does not appear in the output signal. This is apparent when the spectrum, of the output signal is viewed. (Fig.11, 12 & 13)

Fig 13

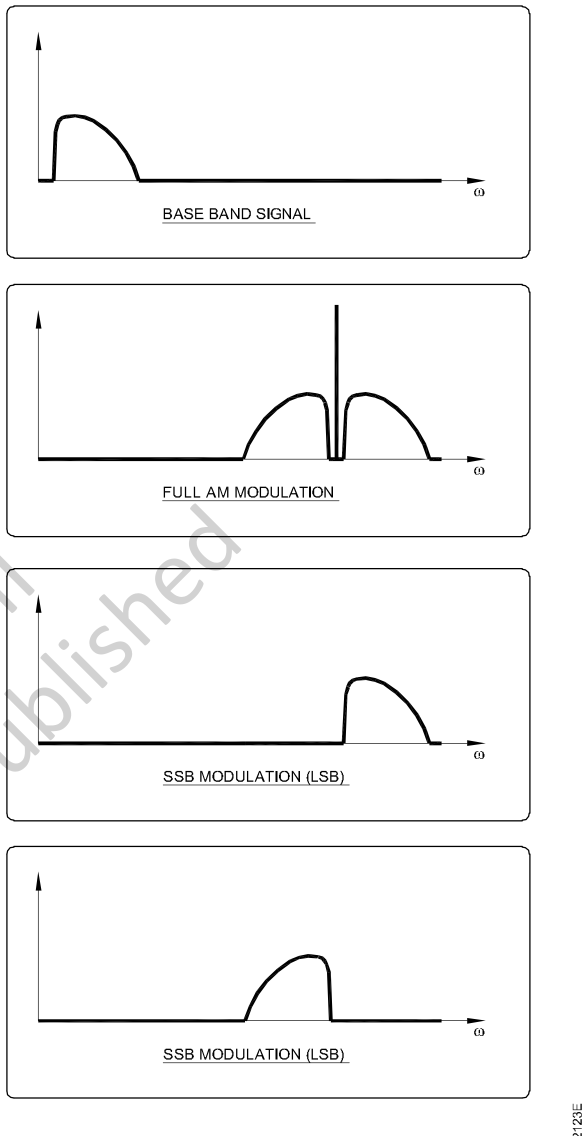



DISTORTION AND ATTENUATION

## Single - side band modulation

In radio communications, single - side band modulation (SSB) or single - side band suppressed - carrier (SSB-SC) is a refinement of amplitude modulation which uses transmitter power and band width more efficiently. Amplitude modulation produces an output signal that has twice the bandwidth of the original base band signal. Single - side band modulation avoids this band width doubling, and the power wasted on a carrier, at the cost of increased device complexity and more difficult tuning at the receiver.

Fig 14




SINGLE-SIDE BAND MODULATION

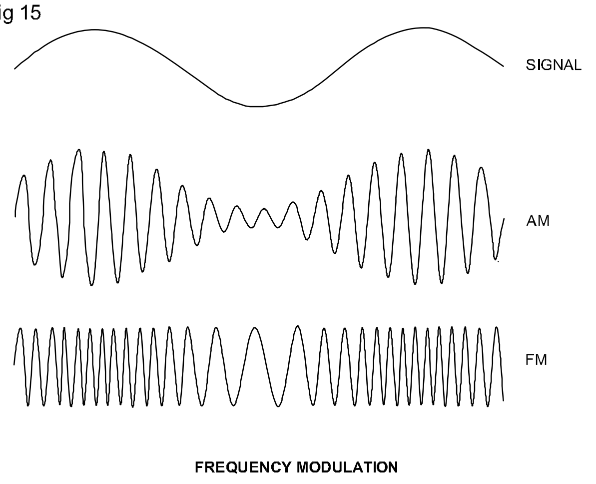
Illustration of the spectrum of AM and SSB signals is shown in fig14. The lower side band (LSB) spectrum is inverted compared to the baseband. As an example, a 2 KHz audio base band signal modualted onto a 5 MHz carrier will produce a frequency of 5.002 MHz if upper side band (USB) is used or 4.998 MHz is LSB is used.

## Frequency modulation

A signal may be carried by an AM or FM radio wave.

In telecommunications and signal processing, frequency modulation (FM) is the encoding of information in a carrier wave by varying the instantaneous frequency of the wave. (Compare with amplitude modulation, in which the amplitude of the carrier wave varies, while the frequency remains constant) fig.15.

Fig 15




In analog signal applications, the difference between the instantaneous and the base frequency of the carrier is directly proportional to the instantaneous value of the input - signal amplitude.

Digital data can be encoded and transmitted via a carrier wave by shifting the carrier's frequency among a predefined set of frequencies - a technique known as frequency - shift keying (FSK). FSK is widely used in modems and fax modems, and can also be used to send morse code. Radio teletype also uses FSK.

Frequency modulation is used in radio, telemetry, radar, seismic prospecting, and monitoring newborns for seizures via EEG. FM is widely used for broadcasting music and speech, two - way radio systems, magnetic tape- recording systems and some video- transmission systems. In radio systems frequency modulation with sufficient bandwidth provides an advantage in cancelling naturally - occuring noise.

Frequency modulation is known as phase modulation when the carrier phase modulation is the time integral of the FM signal.

**Modulation index**

As in other modulation systems, the value of the modulation index indicates by how much the modulated variable varies around its unmodulated level. It relates to variations in the carrier frequency.

$$h = \frac{\Delta f}{fm} = \frac{f\Delta |x_m(t)|}{f_m}$$

where fm is the highest frequency component present in the modulating signal xm(t), and is the peak frequency - deviation -i.e the maximum deviation of the instantaneous frequency from the carrier frequency. For a sine wave modulation, the modulation index is seen to be the ratio of the amplitude of the modulating sine wave to the amplitude of the carrier wave (here unity)

If h< 1, the modulation is called narrowband FM, and its bandwidth is approximately 2fm. Sometimes modulation index h<0.3 rad is considered as narrowband FM otherwise wideband FM.

**Noise reduction**

A major advantage of FM in a communications circuit, compared for example with AM, is the possibility of improved signal to noise ratio (SNR). Compared with an optimum AM scheme, FM typically has poorer SNR below a certain signal level called the noise threshold, but above a higher level - the full improvement or full quieting threshold - the SNR is much improved over AM. The improvement depends on modulation level and deviation. For typical voice communications channels, improvements are typically 5-15 dB. FM broadcasting using wider deviation can achieve even greater improvements. Additional techniques, such as pre - emphasis of higher audio frequencies with corresponding de-emphasis in the receiver, are generally used to improve overall SNR in FM circuits. Since FM signals have constant amplitude, FM receivers normally have limiters that remove AM noise, further improving SNR.

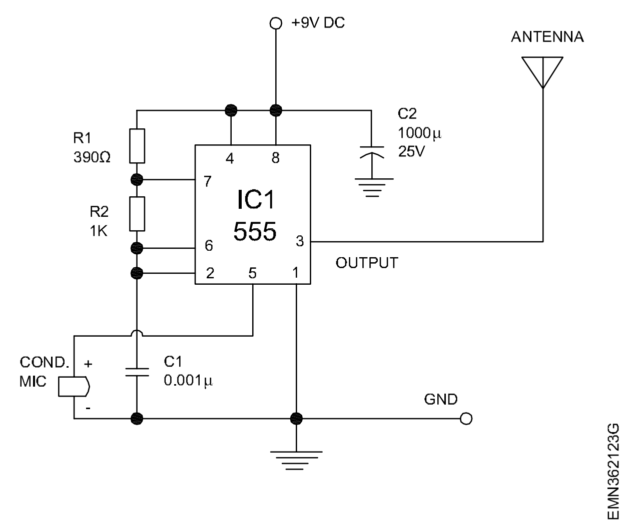
**IC based AM transmitter circuit**

IC 555 (IC1) is used as a free running multivibrator designed for a frequency of around 600 kHz. The frequency of the multivibrator can be calcuated as follows: f =1.443(R1+2R2) C1 where R1 and R2 in ohms, capacitor C1 in microfarads, and frequency f in hertz. This frequency can be changed by simply replacing R2 with a variable resistor or C1 with gang capacitors. A condenser microphone is used for audio signal input.

The IC 555 multivibrator is used as a voltage-to-frequency converter. The output of the condenser microphone is given to pin 5 of ICI, which converts the input voltage or voice signal into appropriate frequency at output pin 3. This frequency produces an electromagnetic wave, which can be detected by a near by AM radio receiver, and you can hear your own voice in that radio. (Note that if there is no noise in receiver, tune it to 600 kHz.)

The circuit operates with a 9V regulated power supply or a 9V battery. For antenna, connect 2-3m long wire at pin 3.

Fig 16



# Block diagram of AM & FM transmitter, FM generation & detection

**Objectives :** At the end of this lesson you shall be able to
- **explain the working of AM transmitters**
- **explain the working of FM transmitters**
- **list the types of FM detection**
- **sketch the different types of FM detector circuits.**

### AM transmitters

Transmitters that transmit AM signals are known as AM transmitters. These transmitters are used in medium wave (MW) and short wave (SW) frequency bands for AM broadcast. The MW band has frequencies between 530 KHz and 1650 KHz, and the SW band has frequencies ranging from 3 MHz to 30 MHz. The two types of AM transmitters that are used based on their transmitting powers are.

High level AM transmitters

Low level AM transmitters

High level transmitters are high level modulation, and low level transmitters use low level modulation.

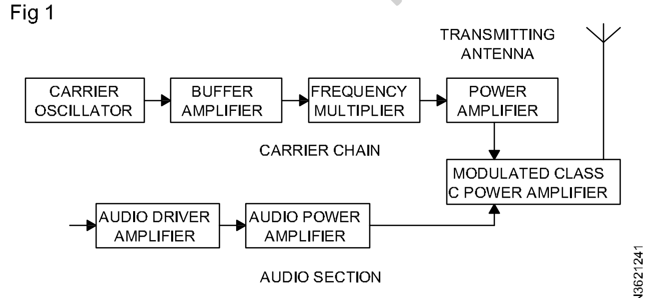
The choice between the two modulation schemes depends on the transmitting power of the AM transmitter. In broadcast transmitters, were the transmitting power may be of the order of kilowatts, high level modulation is employed. In low power transmitters, where only a few watts of transmitting power are required, low level modulation is used.

### High level and low level transmitters

Below figure 1 show the block diagram of high level and low level transmitters. The basic difference between the two transmitters is the power amplification of the carrier and modulating signals.

### High level AM transmitter

Fig 1




BLOCK DIAGRAM OF HIGH LEVEL AM TRANSMITTER

Figure (1) is drawn for audio transmission. In high level transmission, the powers of the carrier and modulating signals are amplified before applying them to the modulator stage, as shown in figure (1). In low level modulation, the powers of the two input signals of the modulator stage are not amplified.

**The various sections of the figure(1) are:**

- Carrier oscillator
- Buffer amplifier
- Frequency multiplier
- Power amplifier
- Audio section
- Modulated class C power amplifier

### Carrier oscillator

The carrier oscillator generates the carrier signals, which lies in the RF range. The frequency of the carrier is always very high. Because it is very difficult to generate high frequencies with good frequency stability, the carrier oscillator generates a sub multiple with the required carrier frequency. This sub multiple frequency is multiplied by the frequency multiplier stage to get the required carrier frequency. Further, a crystal oscillator can be used in this stage to generate a low frequency carrier with the best frequency stability. The frequency multiplier stage then increases the frequency of the carrier to its required value.

### Buffer amplifier

The purpose of the buffer amplifier is to first matches the output impedance of the carrier oscillator with the input impedance of the frequency multiplier, the next stage of the carrier oscillator. It then isolates the carrier oscillator and frequency multiplier.

This is required so that the multiplier does not draw a large current from the carrier oscillator. If this occurs, the frequency of the carrier oscillator will not remain stable.

### Frequency multiplier

The submultiples frequency of the carrier signal, generated by the carrier oscillator, is now applied to the frequency multiplier through the buffer amplifier. This stage is also known as harmonic generator.

The frequency multiplier generates higher harmonics of carrier oscillator frequency. The frequency multiplier is a tuned circuit that can be tuned to the requisite carrier frequency that is to be transmitted. Power amplifier

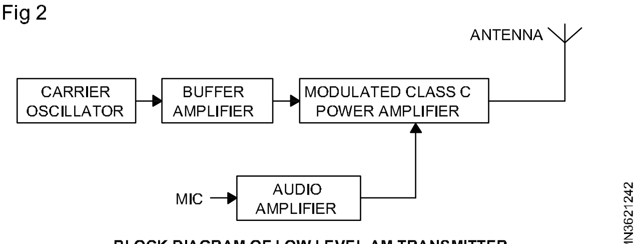
The power of the carrier signals is then amplified in the power amplifier stage. This is the basic requirement of a high level transmitter. A class C power amplifier gives high power current pulses of the carrier signal at its output.

## Audio section

The audio signal to be transmitted is obtained from the microphone, as shown in figure (1). The audio driver amplifiers the voltage of this signal. The amplification is necessary to drive the audio power amplifier. Next, a class A or a class B power amplifier amplifies the power of the audio signal.

## Low level AM transmitter

Fig 2




BLOCK DIAGRAM OF LOW LEVEL AM TRANSMITTER

The low level AM transmitter shown in the figure (2) is similar to a high level transmitter, except that the powers of the carrier and audio signals are not amplified. These two signals are directly applied to the modulated class C power amplifier.

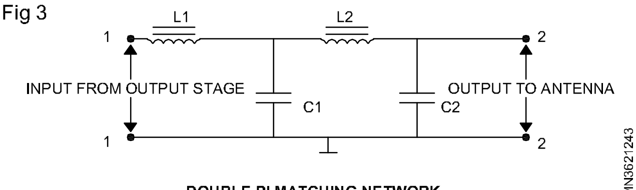
Modulation takes place at the stage, and the power of the modulated signal is amplified to the required transmitting power level. The transmitting antenna then transmits the signal.

## Coupling of output stage and antenna

The output stage of the modulated class C power amplifier feeds the signal to the transmitting antenna. To transfer maximum power from the output stage to the antenna it is necessary that the impedance of the two sections match. For this, a matching network is required. The matching between the two should be perfect at all transmitting frequencies. As the matching is required at different frequencies, inductors and capacitors offering different impedance at different frequencies are used in the matching networks.

The matching network must be constructed using these passive components. This is shown in figure (3)

Fig 3




DOUBLE PI MATCHING NETWORK

The matching network used for coupling the output stage of the transmitter and the antenna is called double TT network. This network I consists of two inductors. L1 and L2 and two capacitors, C1 and C2. The values of these components are chosen such that the input impedance of the network between 1 and 1. Shown in figure (3) is matched with the output impedance of the output stage of the transmitter. Further, the output impedance of the network is matched with the impedance of the antenna.

The double TT matching network also filters unwanted frequency components appearing at the output of the last stage of the transmitter. The output of the modulated class C power amplifier may contain higher harmonics, such as second and third harmonics, that are highly undesirable. The frequency response of the matching network is set such that these unwanted higher harmonics are totally suppressed, and only the desired signal is coupled to the antenna.

## FM transmitter (Fig. 4)

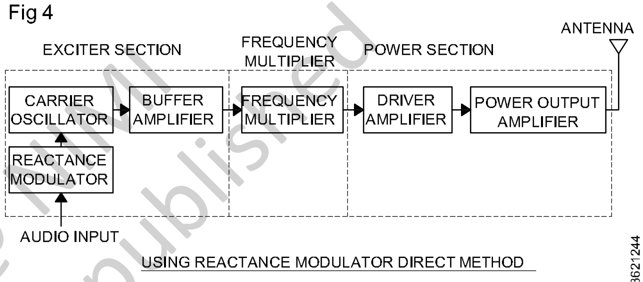
The FM transmitter has three basic sections

1 The exciter section contains the carrier oscillator, reactance modulator and the buffer amplifier

2 The frequency multiplier section, which features several frequency multipliers.

3 The power output section, which includes a low level power amplifier, the final power amplifier, and the impedance matching network to properly load the power section with the antenna impedance.

Fig 4




FM TRANSMITTER



The essential function of each circuit in the FM transmitter may be described as follows.

## The exciter

1 The function of the carrier oscillator is to generate a stable sine wave signal at the rest frequency, when no modulation is applied. It must be able to linearly change frequency when fully modulated, with no measurable change in amplitude.

2 The buffer amplifier acts as a constant high impedance load on the oscillator to help stabilize the oscillator frequency. The buffer amplifier may have a small gain.

3 The modulator acts change the carrier oscillator frequency by application of the message signal. The positive peak of the message signal generally lowers the oscillator's frequency to a point below the rest frequency, and the negative message peak raises the oscillator frequency to a value above the rest frequency. The greater the peak to peak message signal, the larger the oscillator deviation.

## Frequency multiplier

Frequency multipliers are tuned input, tuned output RF amplifiers in which the output resonant circuit is tuned to a multiple of the input frequency. Common frequency multipliers are 2x, 3x and 4x multiplication. A 5x frequency multiplier is sometimes seen, but its extreme low efficiency forbids widespread usage. Note that multiplication is by whole numbers only.

**Power output section**

The final power section develops the carrier power, to be transmitted and often has a low power amplifier driven the final power amplifier.

The impedance matching network is the same as for the AM transmitter and matches the antenna impedance to the correct load on the final over amplifier.

**Frequency Multiplier**

A special form of class C amplifier is the frequency multiplier. Any class C amplifier is capable of performing frequency multiplication.

For example a frequency doubler can be constructed by simply connecting a parallel tuned circuit in the collector of a class C amplifier that resonates at twice the input frequency when the collector current pulse occurs, it excites or rings the tuned circuit at twice the input frequency.

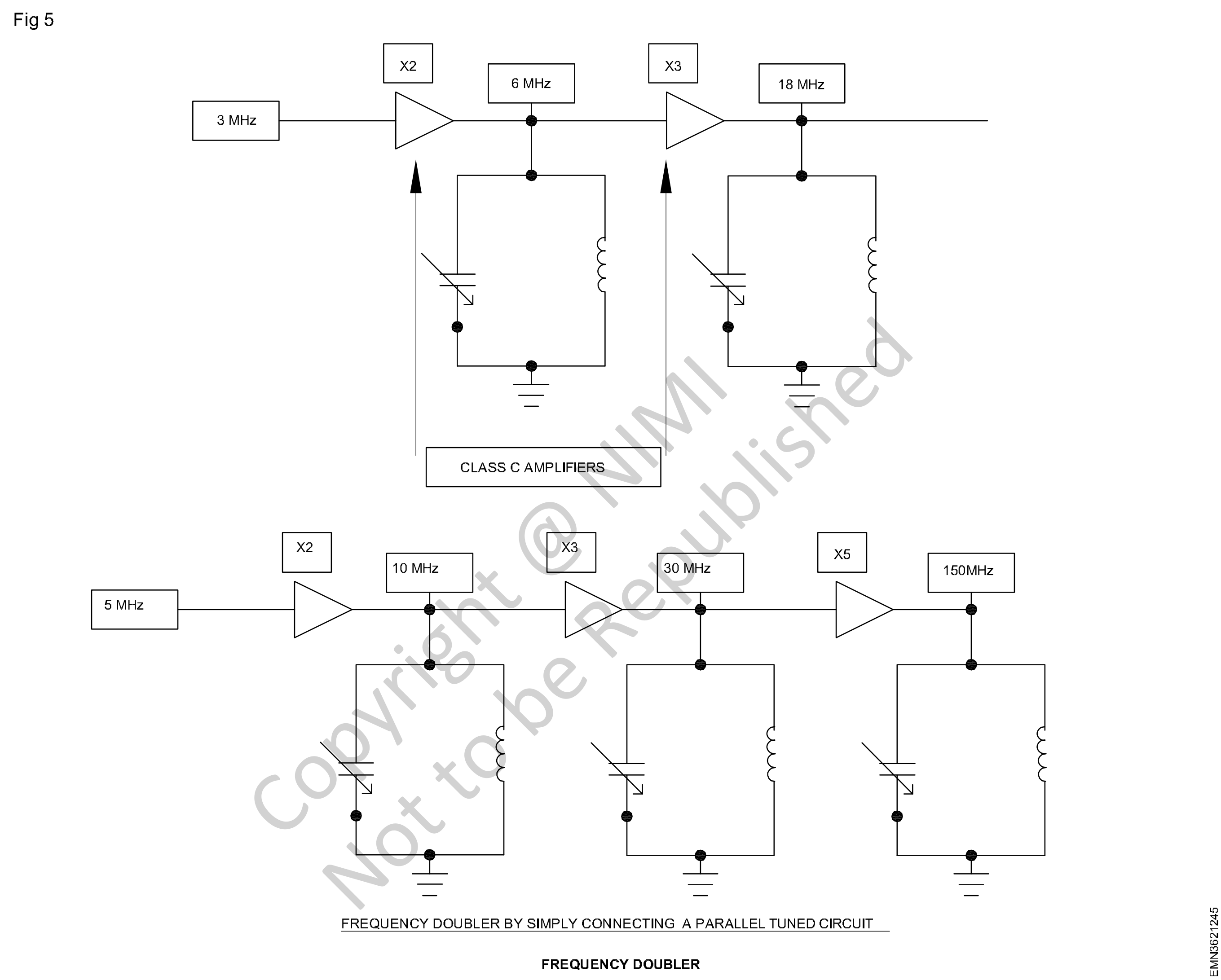





**Fig 5: Frequency doubler by simply connecting a parallel tuned circuit**

A current pulse flows for every other cycle of the input. A tripler circuit is constructed in the same way except that the tuned circuit resonates at 3 times the input frequency. In this way, the tuned circuit receives one input pulse for every three cycles of oscillation it produces multipliers can be constructed to increase the input frequency by any integer factor up to approximately 10. As the multiplication factor gets higher, the power output of the multiplier decreases . For most practical applications, the best result is obtained with multipliers of 2 and 3. Another way to look the operation of class C multipliers is to remember that the no sinusoidal current pulse is rich in harmonics. Each time the pulse occurs, the second, third, fourth, fifth, and higher harmonics are generated. The purpose of the tuned circuit in the collector is to act as a filter to select the desired harmonics.

In many applications a multiplication factor greater than that achievable with a signal multiplier stage is required. In such cases two or more multipliers are cascaded to produce an overall multiplication of 6. In the second examples, three multipliers provide an overall multiplication 30. The total multiplication factor is simply the product of individual stage multiplication factors.

## Reactance modulator

The reactance modulator takes its name from the fact that the impedance of the circuit acts as a reactance (capacitive or inductive) that is connected in parallel with the resonant circuit of the oscillator. The varicap can only appear as a capacitance that becomes part of the frequency determining branch of the oscillator circuit. However, other discrete devices can appear as a capacitor or as an inductor to the oscillator, depending on how the circuit is arranged . A colpitts oscillator uses a capacitive voltage divider as the phase reversing feedback path and would most likely tapped coil as the phase reversing element in the feedback loop and most commonly uses a modulator that appears inductive.

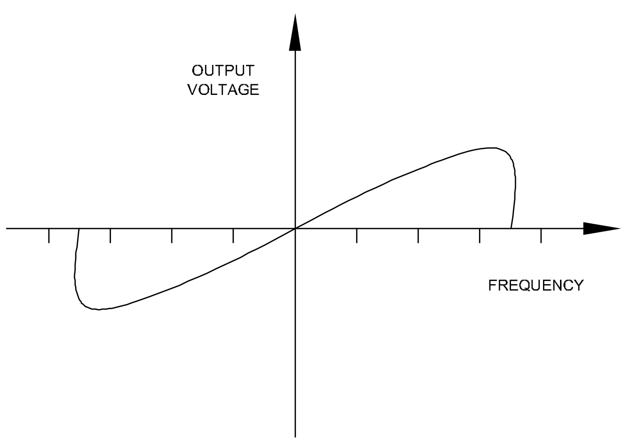
## FM generation & Detection

In order to be able to receive FM signal, a receiver must be sensitive to the frequency variations of the incoming signals. As already mentioned these may be wide or narrow band. However the set is made insensitive to the amplitude variations. This is achieved by having a high gain IF amplifier. Here the signals are amplified to such a degree that the amplifier runs into limiting. In this way any amplitude variations are removed.

In order to be able to convert the frequency variations into voltage variations, the demodualtor must be frequency dependent. The idea response is perfectly linear voltage to frequency characteristics. Here it can be seen that the centre frequency is in the middle of the response curve and this is where the un-modulated carrier would be located when the receiver is correctly tuned into the signal. In other words there would be no offset DC voltage present. (Fig.6)

The ideal response is not achievable because all systems have a finite bandwidth and as a result a response curve known as an "S" curve is obtained. Outside the bandwidth of the system, the response falls, as would be expected. It can be seen that the frequency variations of the signal are converted into voltage variations which can be amplified by an audio amplifier before being passed into headphones, loudspeaker, or passed into other electronic circuitry for the appropriate processing.

Fig 6




CHARACTERISTIC "S" CURVE OF AN FM DEMODULATOR

To enable the best detection to take place the signal should be centred about the middle of the curve. If it moves off too far then the characteristic becomes less linear and higher levels of distortion result. Often the linear region is designed to extend well beyond the bandwidth of a signal so that this does not occur. In this way the optimum linearity is achieved. Typically the bandwidth of a circuit for receiving VHF FM broadcasts may be about 1MHz whereas the signals is only 200 KHz wide.

There are a number of circuits that can be used to demodulate FM. Each type has its own advantages and disadvantages, some being used when receivers used discrete components, and others now that ICs are widely used.

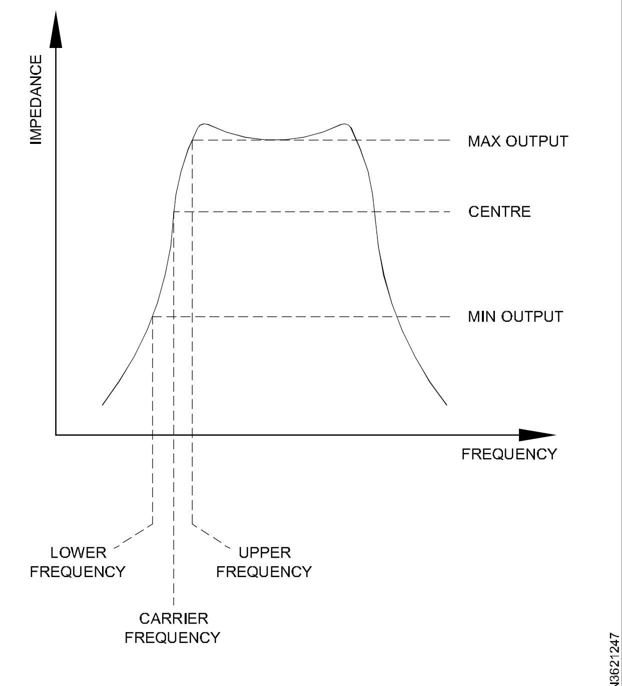
Below is a list of some of the main types of FM demodulator of FM discriminator / detector . In view of the widespread use of FM, even with the competition from digital modes that are widely used today, FM demodulators are needed in many new designs of electronics equipment.

## Slope FM detector (Fig.7)

The very simplest from of FM demodulation is known as slope detection or demodulation. It consists of a tuned circuit that is tuned to a frequency slightly offset from the carrier of the signal.

As the frequency of the signals varies up and down in frequency according to its modulation, so the signal moves up and down the slope of the tuned circuit. This causes the amplitude of the signal to vary in t line with the frequency variations. In fact at this point the signal has both frequency and amplitude variations.

Fig 7




FM SLOPE DETECTION CONCEPT

It can be seen from the diagram that changes in the slope of the filter, reflect into the linearity of the demodulation process. The linearity is very dependent not only on the filter slope as it falls away, but also the tuning of the receiver - it is necessary to tune the receiver off frequency and to a point where the filter characteristic is relatively linear.

The final stage in the process is to demodulate the amplitude modulation and this can be achieved using a simple diode circuit. One of the most obvious disadvantages of this simple approach is the fact that both amplitude and frequency variations in the incoming signal appear at the output. However the amplitude variations can be removed by placing a limiter before the detector.

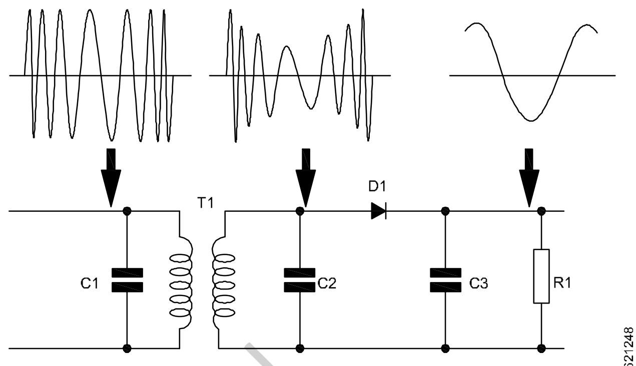
A variety of FM slope detector circuits may be used, but the one below shows one possible circuit with the applicable wave forms. The input signal is a frequency modulated signal. It is applied to the tuned transformer (T1, C1, C2 combination) which is offset from the centre carrier frequency. This converts the incoming signal from just FM to one that has amplitude modulation superimposed upon the signal.

This amplitude signal is applied to a simple diode detector circuit. D1, Here the diode provides the rectification, while C3 removes any unwanted high frequency components, and R1 provides a load

**FM slope detection advantages & disadvantages**

FM slope detection is not widely used, and yet it has some limited applications. Knowing the advantages and disadvantages enables the technique to be used where applicable. (Fig.8)

Fig 8




FM SLOPE DETECTOR CIRCUIT SHOWING WAVEFORMS

| Advantages | Disadvantages |
|---|---|
| Simple - can be used to provide of FM demodulation when only an AM detector is present | Not linear as the output is dependent upon the curve a filter |
| Enable FM to be detected without any additional circuitry | Not particularly effective as it relies on centring the signal part of the way down the filter curve where signal strengths are less. |
| | Both frequency and amplitude variations are accepted and therefore much higher levels of noise and interference are experienced |

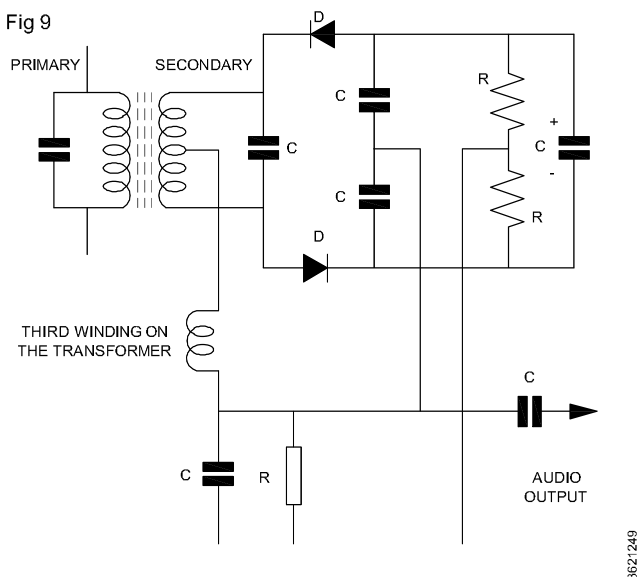


**Ratio detector**

When circuits employing discrete components were more widely used, the Ratio and Foster - seeley detectors were widely used. Of these the ratio detector was the most popular as it offers a better level of amplitude modulation rejection of amplitude modulation. This enables it to provide a greater level of noise immunity as most is amplitude noise, and it also enables the circuit to operate satisfactorily with lower levels of limiting in the preceding IF stages of the receiver. (Fig.9)

The operation of the ratio detector cenres around a frequency sensitive phase shift network with a transformer and the diodes that are effectively in series with one another. When a steady carrier is applied to the circuit the diodes act to produce a steady voltage across the resistors R1 and R2, and the capacitor C3 charges up as a result.

Fig 9




RATIO DETECTOR CIRCUIT

The transformer enables the circuit to detect changes in the frequency of the incoming signal. It has three windings. The primary and secondary act in the normal way to produce a signal at the output. The third winding is un-tuned and the coupling between the primary and the third winding is very tight, and this means that the phasing between signals in these two windings is the same.

The primary and secondary windings are tuned and lightly coupled. This means that there is a phase difference of 90 degrees between the signals in these windings at the centre frequency. If the signal moves away from the centre frequency the phase difference will change. In turn the phase difference between the secondary and third windings also varies. When this occurs the voltage will subtract from one side of the secondary and add to the other causing an imbalance across the resistors R1 and R2. As a result this causes a current to flow in the third winding and the modulation to appear at the output.

The capacitors C1 and C2 filter any remaining RF signal which may appear across the resistors. The capacitor C4 and R3 also act as filters ensuring no RF reaches the audio section of the receiver.

**Ratio detector advantages & disadvantages**

As with any circuit there are a number of advantages and disadvantages to be considered when choosing between several options.

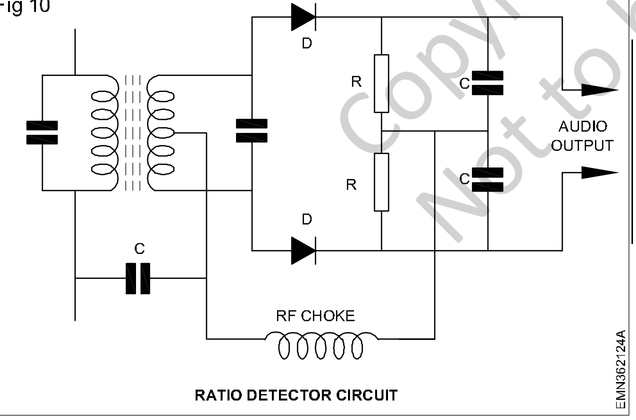
| Advantages | Disadvantages |
|---|---|
| Simple to construct using discrete components<br>Offers good level of performance and | High cost of transformer<br>Typically lends itself to use in only circuits using discrete components and not integrated within an IC |

As a result of its advantages and disadvantages the ratio detector is not widely used these days. Techniques that do not require the. Use of a transformer with its associated costs and those than can be more easily incorporated within an IC tend to be used.

**Foster -Seeley FM detector**

The foster seeley detector or as it is sometimes described the foster seeley discriminator has many similarities to the ratio detector. The circuit topology looks very similary, having a transformer and a pair of diodes, but there is no third winding and instead a choke is used. (Fig.10)

Fig 10




RATIO DETECTOR CIRCUIT

Like the ratio detector, the foster - seeley circuit operate using a phase difference between signals. To obtain the different phased signals a connection is made to the primary side of the transformer using a capacitor, and this is taken to the centre tap of the transformer. This gives a signals that is 90 degrees out of phase.

When an un-modulated carrier is applied at the centre frequency, both diodes conduct, to produce equal and opposite voltage across their respective load resistors. These voltages cancel each one another out at the output so that no voltage is present. As the carrier moves off to one side of the centre frequency the balance condition is destroyed, and one diode conducts more than the other. This results in the voltage across one of the resistors being larger than the other, and a resulting voltage at the output corresponding to the modulation on the incoming signal.

The choke is required in the circuit to ensure that no RF signals appear at the output. The capacitors C1 and C2 provide a similar filtering function.

Both the ratio and foster - seeley detector are expensive to manufacture. Wound components like coils are not easy to produce to the required specification and therefore they are comparatively costly. Accordingly these circuits are rarely used in modern equipment.

**Foster - Seeley detector advantages & disadvantages**

As with any circuit there are a number of advantages and disadvantages to be considered when choosing between the various techniques available for FM demodulation.

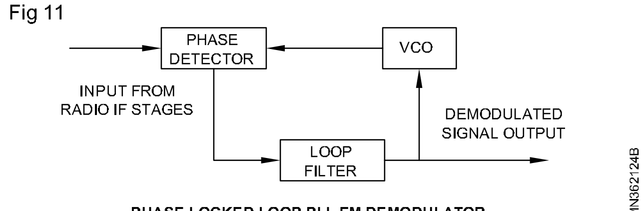
| Advantages | Disadvantages |
|---|---|
| Offers good level of performance and reasonable linearity<br>Simple to construct using discrete components | Does not easily lend itself to being incorporated within an integrated circuit<br>High cost of transformer |

As a result of its advantages and disadvantages the foster seeley detector or discriminator is not widely used these days. Its main use was within radios constructed using discrete componetns.

**PLL, Phase locked loop FM demodulator (Fig.11)**

The way in which a phase locked loop, PLL FM demodulator works is relatively straightforward. It required no changes to the basic locked loop, itself, utilizing the basic operation of the loop to provide the required output.

Fig 11




PHASE LOCKED LOOP PLL FM DEMODULATOR

When used as an FM demodulator, the basic phase locked loop can be used without any changes. With no modulation applied and the carrier in the centre position of the pass - band the voltage on the tune line to the VCO is set to the mid position. However if the carrier deviates in frequency, the loop will try to keep the loop in lock. For this to happen the VCO frequency must follow the incoming signal, and in turn for this to occur the tune line voltage must vary. Monitoring the tune line shows that the variations in voltage correspond to the modulation applied to the signal. By amplifying the variations in voltage on the tune line it is possible to generate the demodulated signal.

The PLL FM demodulator is normally considered a relatively high performance form of FM demodulator or detector. Accordingly they are used in many FM receiver applications.

**Linearity :** The linearity of the PLL FM demodulator is governed by the voltage to frequency characteristic of the VCO within the PLL. As the frequency deviation of the incoming signal normally only swings over a small portion of the PLL bandwidth, and the characteristic of the VCO can be made relatively linear, the distortion levels from phase locked loop demodulations are normally very low. Distortion levels are typically a tenth of a percent.

**Manufacturing costs :** The PLL FM demodulator lends itself to integrated circuit technology. Only a few external components are required, and in some instances it may not be necessary to use an inductor as part of the resonant circuit for the VCO. These facts make the PLL FM demodulator particularly attractive for modern applications.

**PLL FM demodulator design considerations**

When designing a PLL system for use as an FM demodulator, one of the key considerations is the loop filter. This must be chosen to be sufficiently wide that it is able to follow the anticipated variations of the frequency modulated signal. Accordingly the loop response time should be short when compared to the anticipated shortest time scale of the variations of the signal being demodulated.

A further design consideration is the linearity of the VCO. This should be designed for the voltage to frequency curve to be as linear as possible over the signal range that will be encountered, i.e the centre frequency plus and minus the maximum deviation anticipated

In general the PLL VCO linearity is not a major problem for average systems, but some attention may be required to ensure the linearity is sufficiently good for hi- fi systems.

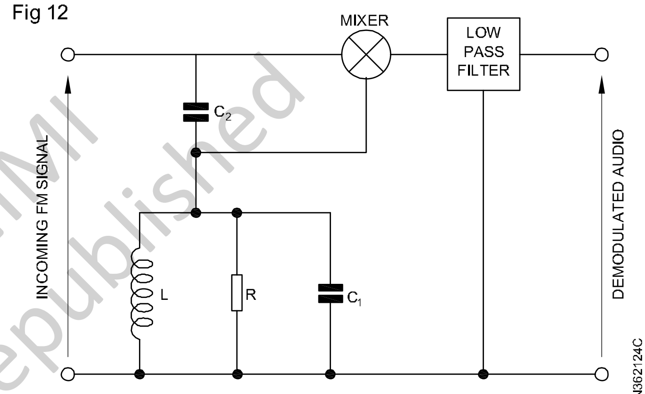
**Quadrature FM demodulator (Fig.12)**

The basic format of the quadrature detector is shown below

It can be seen that the signal is split into two components. One of these passes through a network that provides a basic 90° phase shift, plus an element of phase shift dependent upon the deviation.

The original signal and the phase shifted signal are then passed into a multiplier or mixer.

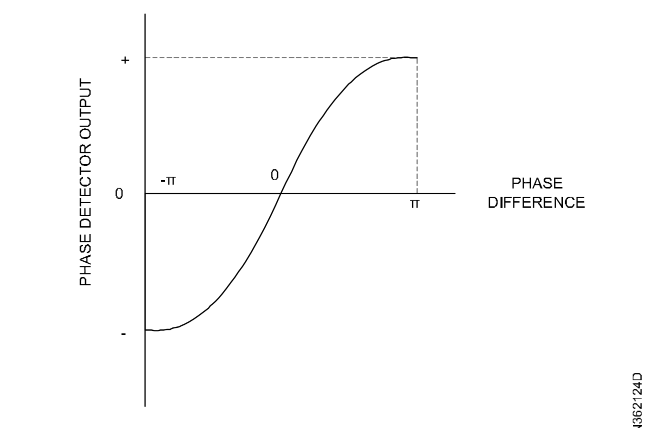
Fig 12




QUADRATURE FM DEMODULATOR CIRCUIT

The mixer output is dependent upon the phase difference between the two signals, i.e it acts as a phase detector and produces a voltage output that is proportional to the phase difference and hence to the level of deviation on the signal. (Fig.13)

Fig 13




MIXER PHASE RESPONSE FOR QUADRATURE FM DETECTOR

It the operation of the system is designed to ensure that the deviation remains well away from the 90° points, then the linearity remains very good.

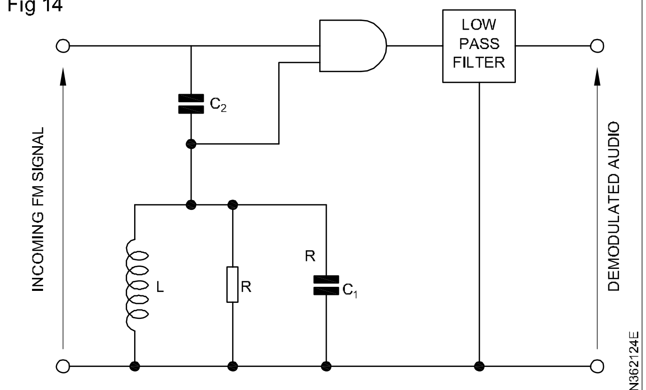
In terms of performance, the quadrature detector is able to operate with relatively low input levels, typically down to levels of around 100 microvolts and it is very easy to set up requiring only the phase shift network to be tuned to the centre frequency of the expected signal. It also provides good linearity and this results in low levels of distortion.

**Coincidence FM demodulator**

This form of demodulator has many similarities to the quadrature detector. It uses digital technology and replaces a mixer with a logic NAND gate. Often the analogue multiplier is replaced by a logic AND gate and the input signal is hard limited to produce a variable frequency waveform. (Fig.14)

The operation of the circuit is fundamentally the same, but it is known as a coincidence detector. Also the output of the AND gate has an integrator to 'average' the output waveform to provide the required audio output, otherwise it would consist of a series of square wave pulses

Fig 14




FM COINCIDENCE DEMODULATOR USING AN AND GATE

**Quadrature detector advantages & disadvantages**

The quadrature detector offers significant advantages for many circuits, but as with any decision, a number of different advantages and disadvantages have to be considered when selecting a given circuit for FM demodulation.

| Advantages | Disadvantages |
|---|---|
| Offers good level of performance and including linearity | Requires the use of a coil |
| Can be incorporated into an integrated circuit | Some designs may require setting during manufacture |

Despite the disadvantages, the quadrature FM detector is the circuit of choice for many radio receivers.

# Type of radio receivers, superhetrodyne receiver, block diagram, principles, characteristics, advantages and disadvantages

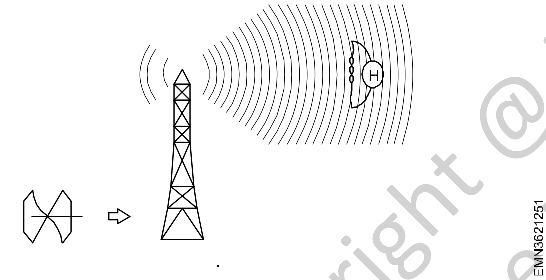
**Objectives :** At the end of this lesson you shall be able to
- **explain the basic principles and characteristics of radio reception.**
- **list the different types of radio receivers.**
- **explain the advantages and disadvantages of different types of radio receiver.**
- **sketch the blocks of Superhetrodyne radio receiver.**

## Principle of radio receivers

The modulated wave emitted from a transmitting antenna in the form of electromagnetic waves(energy) travels in free space at the speed of light ($3x10^8$ metres/sec). The distance of electromagnetic waves travel depends upon the chosen type of transmitting antenna and the transmitted power.

As shown in Fig.1, if a wire is suspended above the ground in the region where the electromagnetic waves are traveling. The passing electromagnetic waves induces a small voltage in the wire.

Fig 1



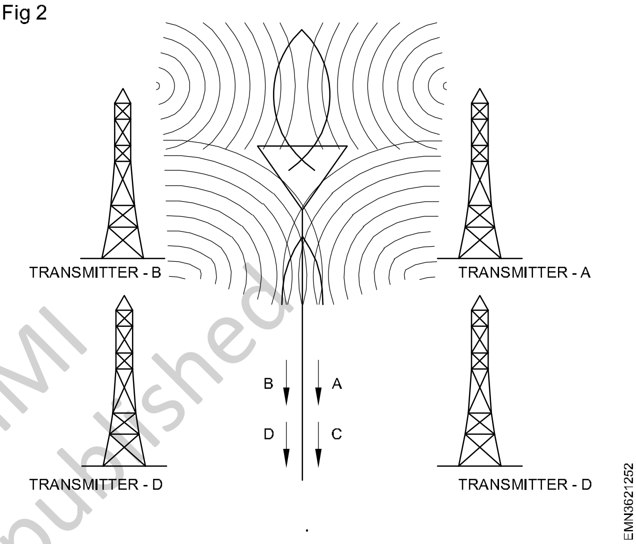

Although the induced voltage in the suspended wire is very small, of the order of microvolts, the wave-form of the induced voltage is an exact replica of the signal transmitted by the transmitting antenna. Thus the suspended wire acts as a receiving antenna.

If the received weak signal, at the receiving antenna is processed, the information (voice and music etc.) which modulates the carrier at the transmitter can be reproduced.

### Selecting required electromagnetic waves (signal)

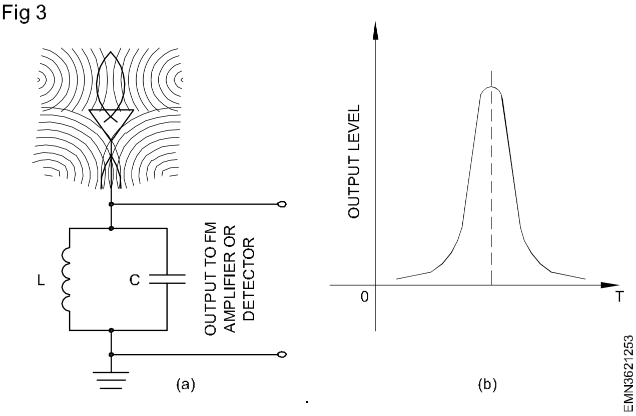
Since several transmitting antennas of several stations transmit information(voice and music etc.) simultaneously into air, the electromagnetic waves of several stations simultaneously exist in free space. All these electromagnetic waves corresponding to several stations intercept(cut) the receiving antenna at the same time. Each of these simultaneously induces voltages in the receiving antenna as shown in Fig. 2. Hence, the receiving antenna or the aerial will have signal voltages corresponding to several transmitting stations as shown in Fig 2.

Fig 2




The first job of a radio receiver is to select a particular station signal in which we are interested and reject the rest of signals. This can be done easily using a tuned circuit as shown in Fig 3a.

Fig 3




As already discussed in previous units, the frequency response of the parallel tuned circuit in Fig 3a will be as shown in Fig. 3b. How good is this parallel tuned circuit, in selecting a particular frequency signal is termed as the selectivity of the circuit.This selectivity of the tuned circuit in a receiver decides whether or not the receiver suffers from interference of unwanted stations.

### AM receiver and frequency bands

AM broadcasting is restricted to the following frequency bands;

Medium wave (MW) band 530KHz to 1650KHz

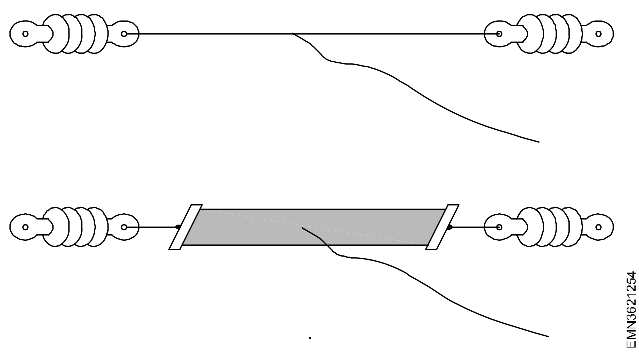
Short wave(SW)band 3MHz to 26 MHz

Broadcasting stations, transmitting amplitude modulated(AM) MW band signals rely on ground waves for propogation. The SW band AM transmitters on the other hand rely both on ground waves and sky waves for propogation. hence, the distance covered by MW stations is much less than that of SW stations.

### The receiving antenna of AM receivers

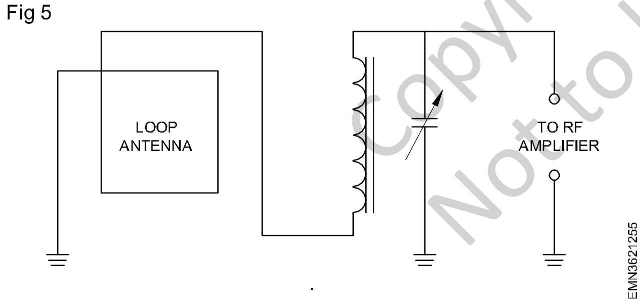
In earlier days a lengthy copper wire or a lengthy copper tape made of a thin copper wire mesh as shown in Fig 4 were used as receiving antennas.

Fig 4




Due to the large space occupied by these antennas, a loop antenna couple to an antenna transformer as shown in Fig 5 is used.

Fig 5

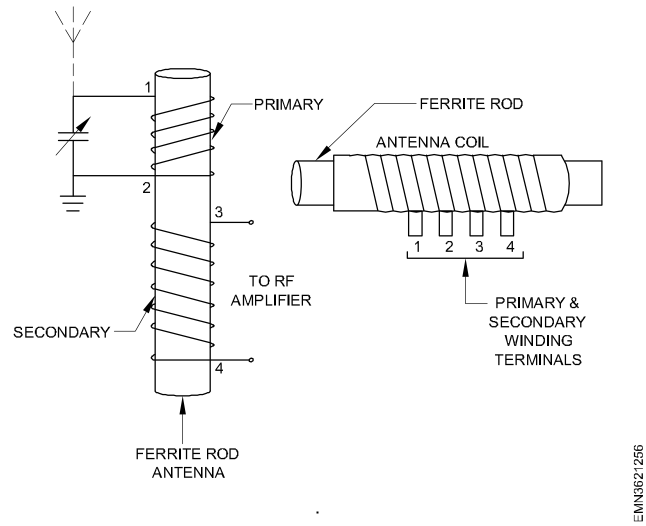



The ferrite rod antenna is shown in fig 6. This antenna with ferrite, having an extremely high permeability has excellent pick-up/receiving characteristics.

The antenna transformer used to couple the selected signal to the next stage is often referred to as antenna coil rather than antenna transformer. The primary winding of the antenna coil (antenna transformer)isolates the antenna side from the tuned circuit and provides proper impedance matching to the antenna.

Generally ferrite core antenna coil is wound on insulating material such as paper or plastic. The gauge of wire used and the number of turns used for the antenna coils designed to receive MW band station and the SW band station differ.

Fig 6




### Types of radio receivers

There are mainly 4 types of radio receivers .they are listed as follows

1 Basic crystal Radio Receiver.

2 T.R.F.RadioReceiver.

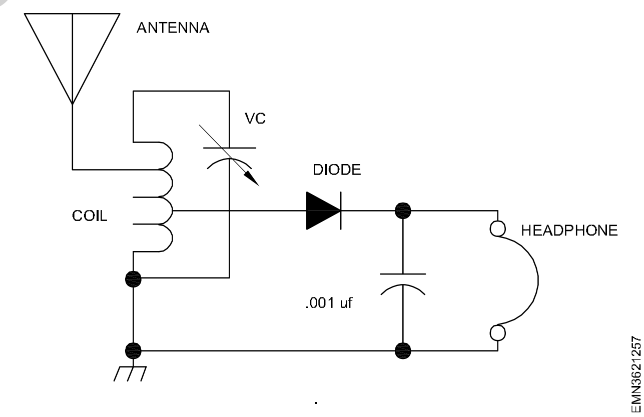
3 Reflex radio Receiver

4 Superhetrodyne Radio Receiver.

### 1 Basic crystal Radio Receiver

Here is the schematic diagram for a very basic crystal radio set fig.7. This basic radio uses no power other than that provided by the transmitting antenna from the radio station.

Fig 7




This circuit consists of an inductor (also called a coil), a variable capacitor (used to be called a variable condenser), a germanium diode (formerly called a crystal), a filtering capacitor and finally very high impedance headphones.

The inductor has taps on it one to connect the antenna and other to connect the detector diode.

The variable capacitor is usually connected across the whole of the inductor to form a tuned circuit for our crystal radio set.

### Earth connection for crystal radio set

For the crystal radio set circuit to perform at all well you need a very good earth connection.

The symbol connected to the top of the inductor or coil and variable capacitor denotes an antenna. The higher and longer (50' or 17 metres) this antenna is, the better the likely reception.

Radio signals (waves) such as we encounter in the AM radio band have two halves. One half travels across the surface of the earth at the speed of light through people, buildings and other objects. The other half, a mirror image, travels beneath the surface of the earth. This radio wave has a definite length. Its length is the speed of light divided by the frequency. These radio waves we want to detect with our crystal radio set.

**Variable Capacitor:** .A capacitor which tuned about 15 pF to 365 pF.

**Inductor or Coil:** Here an air core inductor wound on some suitable non metallic form.

**Diode:** In lieu of the old crystal detector we use a germanium diode of the 1N34 or OA90 type.

**Fixed Capacitor:** This is for filtering and may be 0.001 μF, 1 nF or 1000 pF type (all those values are the same - just expressed in different units).

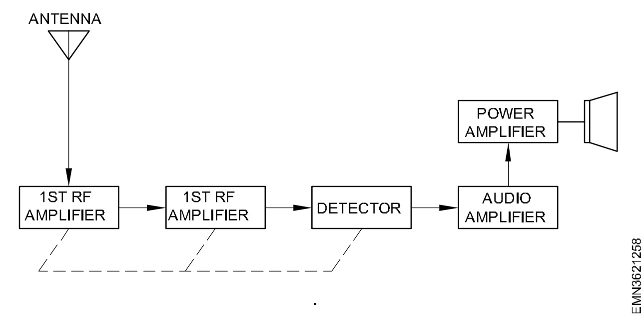
**Headphones:** This is by far the hardest part to obtain. The type used for hi-fi will notwork here. Ideally you need high impedance 2,000 ohm types, but these are nearly impossible to find. You can sometimes buy 1,000 ohm crystal earpieces. The headphone is a high impedance load for the crystal set and as we are working on free power from the air we can't load it down. The power is not available. Remember we're using free power from the sky.

**Frequency range:** The frequency range of a set like this is mainly determined by the square root of the ratio of Maximum Capacitance to Minimum Capacitance of the variable capacitor.

**A.M. Radio band:** This would cover about 530 KHz to about 1650 KHz. This is slightly more than a 3:1 ratio.

### 2. T.R.F. Receiver

Fig 8




A tuned radio frequency receiver (or TRF receiver) is a type of radio receiver that is composed of one or more tuned radio frequency (RF) amplifier stages followed by a detector (demodulator) circuit to extract the audio signal and usually an audio frequency amplifier. This type of receiver was popular in the 1920s. Early examples could be tedious to operate because when tuning in a station each stage had to be individually adjusted to the station's frequency, but later models had ganged tuning, the tuning mechanisms of all stages being linked together, and operated by just one control knob as shown in the block diagram (fig 8).

By the mid 1930s it was replaced by the superheterodyne receiver .

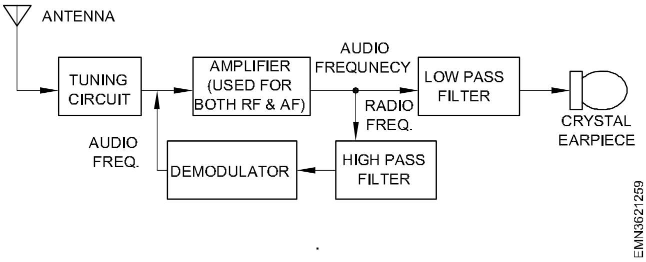
Limitations in the crystal receiver can be largely overcome by what are known as TRF receivers. This type of receiver essentially consists of a chain of radio frequency amplifiers which improves the selectivity and test sensitivity of the radio receiver.

- The selectivity is improved over that of simple crystal receiver .The selectivity is improved because we have introduced a stage of RF amplification before the detector circuit.
- Although theoretically it is possible to further improve the sensitivity of the receiver by adding additional RF amplifier stages.In practice several problems and difficulties arise if the number of RF amplifier stages are more. Some of these difficulties are listed below;
- Because of the instability problem, the number of RF stages that can be used is limited. It is practically impossible to build a very high gain RF amplifier merely by connecting several stages together. Each stage is obviously operating at the same frequency and it is very easy to have positive feedback from the latter stages to the input. Even though the voltage feedback may very small, because of a high gain of the amplifier stages, conditions for self-oscillation are almost always present. Therefore the amplifier may turn around and work as an oscillator.
- The other problem is to do with tracking. Every stage has its own tuned circuit and it is necessary to vary resonant frequency of each tuned circuit in such a way that all tuned circuit have the same resonant frequency. Apart from the practical difficulty of obtaining ganged capacitor with many sections, the inevitable stray capacitance in the various parts of the circuit upset the matching of each stage.
- The next problem has to do with the fidelity of the final audio output. Although additional tune circuits improve the selectivity and results in excellent sensitivity, the overall response becomes very sharp. It is as though a single tuned circuit with an extremely high Q value is being used. In order to receive the transmitted program information, a receiver which can respond not only to the carrier but also to the side bands is required. As the receiver becomes more and more selective, the side bands get eliminated increasingly. Therefore, the audio frequency response becomes restricted.
- Although the above drawbacks severely limit the use of TRF-receivers these receivers are used in some applications in which the radio receiver is expected to receive only a few station and is used sparingly.

## 3 Reflectional receiver

A reflectional radio receiver (Fig 9) (also called a reflex radio) is a radio receiver in which the same amplifier is used for both the high-frequency radio (RF) and low-frequency sound (AF) signals. The radio signal from the output of the amplifier passes detection and then re-enters the input of the amplifier. During the second pass, the sound frequency is amplified then passed to the earphone. The German company Telefunken applied the German patent 293300 in the year 1913 for the reflex receiver.

Fig 9




Reflectional radio receivers were used because fewer amplifier devices are needed. They also consume less electricity than a receiver designed with two separate amplifiers.

However, this design is less stable, with the possibility of breaking into unwanted oscillation. A greater level of skill and experience is needed to debug the assembled device before it starts working. For a reflex circuit to work properly, bypassing and filtering are major considerations also.

It is important to ensure that the signal is at all time entirely operating within the linear range of the amplifier, or else inter-modulation (IM) will occur. It is difficult to judge when minor amounts of non-linearity occur in an amplifier. A reflex circuit will immediately produce severe distortion and possible oscillation as soon as the signal exceeds the linear range of the active component's curves. As this is the circumstance where the active device begins to work as a detector, which means it is mixing signal with the AF being fed back to amplify. This adds considerable difficulty to the making of a circuit which is dependably free of problems for all signals available.

## 4. Superheterodyne Receiver (Fig.10)

Edwin Armstrong the US Engineer invented the superhet or superheterodyne receiver as we know it today with a fixed frequency, intermediate frequency, filter and a variable local oscillator. His idea was developed in 1918.

The superheterodyne receiver revolves around the process of mixing. Here RF mixers are used. (This is not the same as mixers used in audio desks where the signals are added together).

When two signals are beating together it is found that the output contains signals at frequencies other than the two input frequencies. New signals are seen at frequencies that are the sum and difference of the two input signals, i.e. if the two input frequencies are f1 and f2, then new signals are seen at frequencies of (f1+f2) and (f1-f2).

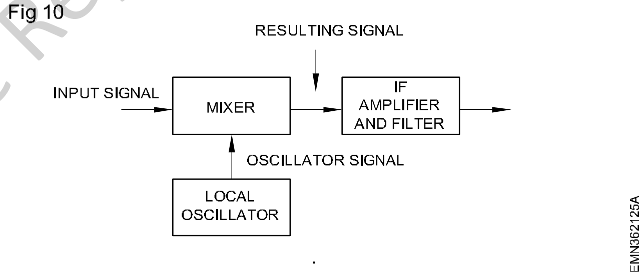
To take an example, if two signals, one at a frequency of 600 KHz and another at a frequency of 1055KHz are mixed together then new signals at frequencies of 455KHzand1655KHz are generated.

### Design and principle of operation

In the superhet radio, the received signal enters one inputs of the mixer. A locally generated signal (local oscillator signal) is fed into the other. The result is that new signals are generated. These are applied to a fixed frequency intermediate frequency (IF) amplifier and filter. Any signals that are converted down and then fall within the pass-band of the IF amplifier will be amplified and passed on to the next stages. Those that fall outside the pass-band of the IF are rejected. Tuning is accomplished very simply by varying the frequency of the local oscillator.

The advantage of this process is that very selective fixed frequency filters can be used. They are normally at a lower frequency than the incoming signal. This enables their performance to be better and less costly.

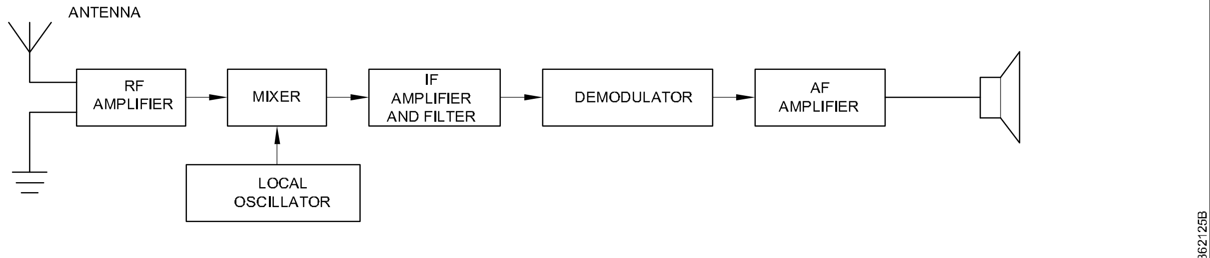
Fig 10




### Basic superheterodyne block diagram and functionality

The basic block diagram of a basic superhet receiver is shown below in fig.11. This details the most basic form of the receiver and serves to illustrate the basic blocks and their function.

Fig 11




BLOCK DIAGRAM OF SUPERHETERODYNE RADIO RECEIVER

- The way in which the receiver works can be seen by following the signal as it passes through the receiver.
- Front end amplifier and tuning block: Signals enter the front end circuitry from the antenna.

**This block performs two main functions:**

- **Tuning:** The tuning is applied to the RF stage. The purpose of this is to reject the signals on the image frequency and accept those on the wanted frequency. It must also be able to track the local oscillator so that as the receiver is tuned, so the RF tuning remains on the required frequency. Typically the selectivity provided at this stage is not high. Its main purpose is to reject signals on the image frequency which is at a frequency equal to RF + 2IF. As the tuning within this block provides all the rejection for the image response, it must be at a sufficiently sharp to reduce the image to an acceptable level. However the RF tuning may also help in preventing strong off-channel signals from entering the receiver and overloading elements of the receiver.
- **Amplification:** In terms of amplification, the level is carefully chosen so that it does not overload the mixer when strong signals are present, but enables the signals to be amplified sufficiently to ensure a good signal to noise ratio is achieved. The amplifier must also be a low noise design. Any noise introduced in this block will be amplified later in the receiver.
- **Mixer / frequency translator block:** The tuned and amplified signal then enters one port of the mixer. The local oscillator signal enters the other port. The performance of the mixer is crucial to many elements of the overall receiver performance. It should be as linear as possible. If not, then spurious signals will be generated and these may appear as 'phantom' (ghostly appearing) received signals.
- **Local oscillator:** The local oscillator may consist of a variable frequency oscillator that can be tuned by altering the setting on a variable capacitor. Alternatively it may be a frequency synthesizer that will enable greater levels of stability and setting accuracy.
- **Intermediate frequency amplifier, IF block:** Once the signals leave the mixer they enter the IF stages. These stages contain most of the amplification in the receiver as well as the filtering that enables signals on one frequency to be separated from those on the next. Filters may consist simply of LC tuned transformers providing inter-stage coupling, or they may be much higher performance ceramic or even crystal filters, dependent upon what is required.The criterion for choosing a suitable intermediate frequency is, the IF value should not coincide with the frequency of any powerful radio station (or its harmonics). With the above in mind the following IF values have been standardized by the Electronic industries association(EIA) for different types of receivers which are used throughout the world;

**Types of receiver Broadcast band IF value**

AM receivers 530 KHz to 25 MHz

FM receivers 88 KHz to 108 MHz

- Detector / demodulator stage: Once the signals have passed through the IF stages of the superheterodyne receiver, they need to be demodulated. Different demodulators are required for different types of transmission, and as a result some receivers may have a variety of demodulators that can be switched in to accommodate the different types of transmission that are to be encountered. Different demodulators used may include:
- AM diode detector, Synchronous AM detector (in AM receivers),Basic FM detector,PLL FM detectorOR Quadrature FM detector(in FM receiver)
- Audio amplifier: The output from the demodulator is the recovered audio. This is passed into the audio stages where they are amplified and presented to the headphones or loudspeaker.

**Image frequency interference**

Assume two broadcasting stations are transmitting at two different frequencies say, 800 KHz and 1710 KHz respectively. suppose a receiver is tuned to station broadcasting at 800 KHz, then the local oscillator produces a frequency of 1255 KHz (800 KHz + 455 KHz =1255 KHz ) for an IF of 455 KHz . suppose, an undesired station transmitting at 1710 KHz happens to reach the mixer input, then the local oscillator frequency of 1255 KHz, also can mix with this undesired signal of 1710 KHz and produces IF of 455 KHz (1710 KHz -1255KHz = 455 KHz). This results in two signals of 455 KHz reaching the IF stage for amplification.

Since the IF amplifiers amplify all signals in the frequency range of 455 KHz, both the station signals get amplified and are available for detection. When the signal are detected and further amplified by the audio amplifiers, the audio signal so produced will be a mix of the information broadcasted from the two stations. This causes confusion and unintelligible information. This phenomenon is called Image Frequency Interference. The unwanted frequency of 1710 KHz is called the image frequency. The effect of image frequency interference is shown in Fig.12

- Image frequency interference is one major disadvantage of superheterodyne receiver operation.
- The problem of image frequency interference, possibilities of minimizing it and its consequences are listed below;
- Image frequencies can be prevented by using highly selective RF amplifier circuits.
- However, inclusion of RF stage in commercial radio receivers will be quite expensive. Also high selectivity may result in chopping-off of a portion of the received side bands.

Fig 12

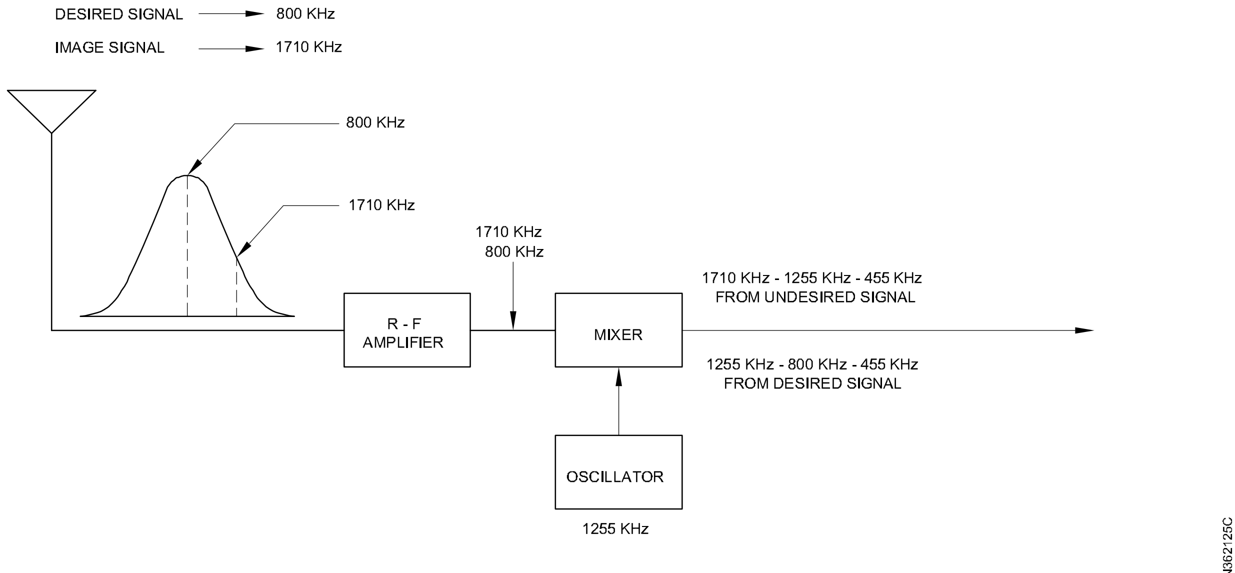


IMAGE FREQUENCY INTERFERENCE

- By making the intermediate frequency (IF) value as high as possible such that the image frequencies are outside the RF band of the receiver.
- However, if the value of IF is very high than the selectivity will be such that, unwanted RF signal from an adjacent station will also be picked up resulting in an another type of interference . This is called adjacent channel interference. In addition, a high value of IF result in tracking difficulties. Hence the IF cannot be very high also.
- NOTE: Tracking is the ability of tuning the local oscillator frequency exactly 455 KHz above the RF carrier frequency.
- The following are the major factor influencing the choice of the intermediate frequency in any particular system;
- If the intermediate frequency is too high, poor selectivity and poor adjacent channel rejection results unless sharp cut off (e.g. crystal) filters are used in the IF stages.
- A high value of intermediate frequency increases tracking difficulties.
- As the intermediate frequency is lowered, image-frequency rejection becomes poorer. This is because, rejection is improved as the ratio of image frequency to signal frequency is increased, and this, naturally, requires a high IF.
- A very low intermediate frequency can make the selectivity too sharp, cutting off the side-bands. This problem arises because, Q must be low when IF is low, and hence the gain per stage is low. Thus a designer is more likely to raise the Q than to increase the number of amplifiers.
- If the IF is very low, the frequency stability of local oscillator must be made correspondingly higher because any frequency drift is now a larger proportion of the low IF than of a high IF.
- The intermediate frequency must not fall within the tuning range of the receiver, or else instability will occur and heterodyne whistles will be heard, making it impossible to tune to the frequency band.



## Characteristics of receiver

### Selectivity

One of the problems in a receiver is its inability to sharply select the required station. This station selection performance of a radio receiver depends on the characteristics of the tuned LC circuit which has to accept only the desired frequency, while rejecting the rest. This characteristic is termed as selectivity of the receiver.

Selectivity is the ability of a receiver to tune-in or receive a desired channel frequency while rejecting other undesired channel frequencies.

Selectivity of a receiver is determined by the bandwidth of the tuned circuit in the receiver. This in turn depends upon the Q of the tuned circuit. Hence, if the required selectivity cannot be obtained by a single tuned circuit, (due to the limitation in the value of achievable Q) the required selectivity can be obtained by increasing the number of tuned circuits used in a receiver .

### Sensitivity

Sensitivity of a receiver is measured in terms of the voltage that must be induced in the antenna by electromagnetic signals to develop a standard audiooutput from the amplifier. This standard output is arbitrarily chosen as 50 mWatts.

Sensitivity of a receiver is the ability of the receiver to respond satisfactorily to weak signal voltages. In other words , sensitivity is the minimum signal input voltage required to produce a specified output.

The sensitivity of broadcast receivers is not more than 100 microvolts. Under most favourable conditions, specially designed communication receivers have the highest sensitivity of the order of 1 microvolt.

The lower the numerical figure indicated for sensitivity, the better is the receiver. For example, if receiver-A is said to have a sensitivity of 100 microvolts, it means a minimum of 100 microvolt is necessary for this receiver to function satisfactorily. If another receiver-B is said to have a sensitivity itself is sufficient for this receiver to function satisfactorily. Hence, receiver-B is more sensitive compared to receiver-A.

**Fidelity**

Fidelity of a receiver is the ability of a receiver to truly re-produce theaudio signals transmitted.

Fidelity is the term used to indicate the accuracy of reproduction at the output of the radio receiver.

Usually it is found that the sound produced by one radio is differentfrom another radio. This is because the radio receiver may not be in a position to reproduce all the audio frequency transmitted by the transmitters.

The fidelity of the receiver depends on various factors such as , carrier frequency alignment of the receiver, frequency response of the A.F. amplifier and the loudspeaker.

**Signal to noise ratio**

Another important parameter associated with radio receiver,that define the quality of the radio receiver ,is the Signal to noise ratio.

Signal to noise ratio is the ratio of signal power at the output to the noise power at the given R.F. frequency. Usually the ratio is found out at various frequencies .The ratio is always expected to be very high. In other words the higher the signal-to-noise ratio, the better is the radio receiver.

**Advantages and drawbacks of the superheterodyne design**

An important advantage of superheterodyne receivers is that the intermediate-frequency amplifier does not need to be tuned, Regardless of the frequency of the incoming signal. For this reason, superheterodyne receivers are easy to tune. Only the input circuit, radio-frequency amplifier, and local oscillator needed to be tuned. Such tuning is usually carried out by means of a single control knob. Since the intermediate-frequency amplifier is not tunable, multicircuit electric filters can be readily used in it to provide high selectivity, and the required signal amplification can be easily obtained. Automatic frequency control and automatic gain control can also be incorporated without difficulty.

A disadvantage of superheterodyne receivers is the possibility of spurious responses due to frequency conversion. The image frequency and the frequency of the desired signal exhibit a mirror-like symmetry .Another example of a spurious response is the noise-produced signal distortions that appear as whistles. Methods of minimizing spurious responses include increasing the radio-frequency selectivity of the receiverand choosing an intermediate frequency that is outside the frequency range of the desired incoming signals.

**Further developments for superheterodynereceiver**

**Basic Doublesuperheterodyne receiver concept**

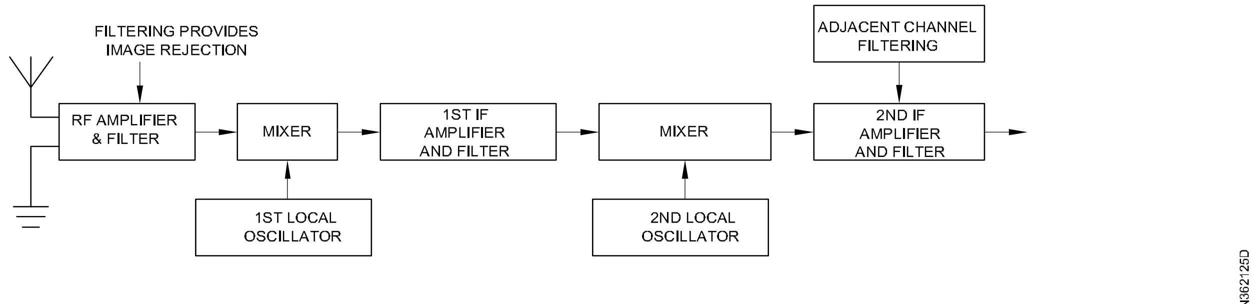
The basic concept behind the double superheterodyne radio receiver is the use of a high intermediate frequency to achieve the high levels of image rejection that are required, and a further low intermediate frequency to provide the levels of performance required for the adjacent channel selectivity.

Typically the receiver will convert the incoming signal down to a relatively high first intermediate frequency (IF) stage. This enables the high levels of image rejection to be achieved ,as the image frequency lies at a frequency twice that of the IF away from the main or wanted signal.

**Block diagram of a basic double superheterodyne radio receiver.**

The diagram in fig 13 shows a very basic version of the double superheterodyne receiver. Many sets these days are far more complicated. Some superhet radios have more than one frequency conversion, and other areas of additional circuitry to provide the required levels of performance. However the basic superheterodyne concept remains the same, using the idea of mixing the incoming signal with a locally generated oscillation to convert the signals to a new frequency.

Fig 13




BLOCK DIAGRAM OF A BASIC DOUBLE SUPERHETERODYNE RADIO RECEIVER

## Block diagram of FM Receivers, AM/FM-RF Alignment

**Objectives :** At the end of this lesson you shall be able to
- **sketch the block of FM receiver**
- **explain the function of limiter circuit in FM receiver**
- **explain how detection of FM is different from AM**
- **explain the working of discriminator circuit**
- **explain the advantage of radio detector over discriminator**
- **explain the with circuit detector the working of radio detector**
- **state the advantage of FM over AM**
- **state the necessity of alignment in radio receiver**
- **name the two main type of alignment required in a receiver**
- **explain the IF alignment and RF alignment in receiver.**

### FM Receiver

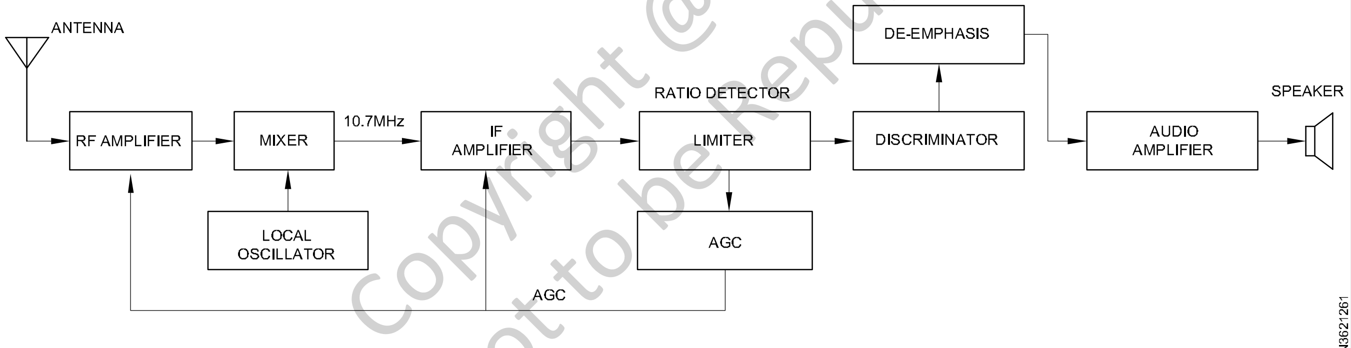
The block diagram of an FM superheterodyne receiver is shown in Fig.1

A typical FM receiver block diagram shown in fig.1 is quite similar to that of AM receiver. The RF amplifier amplifies the received signal intercepted by the antenna. The amplified signal is then applied to the mixerstage. The second input of the mixer comes from the local oscillator. The two input frequencies of the mixer generate an IF signal of 10.7 MHz. This signal is then amplified by the IF amplifier. The output of the IF amplifier is applied to the limiter circuit. The limiter removes the noise in the received signal and gives a constant amplitude signal.

This circuit is required when a phase discriminator is used to demodulate an FM signal.

The output of the limiter is now applied to the FM discriminator or detector, which recovers the modulating signal.

Fig 1




FM SUPERHETERODYNE RECEIVER



However, this signal is still not the original modulating signal. Before applying it to the audio amplifier stages, it is deemphasized. De-emphasizing attenuates the higher frequencies to bring them back to their original amplitudes as these are boosted or emphasized before transmission.

The output of the deemphasized stage is the audio signal, which is then applied to the audio stages and finally to the speaker.

It should be noted that a limiter circuit is required with the FM discriminators. If the demodulator stage uses a ratio detector instead of the discriminator, then a limiter is not required. This is because the ratio detector limits the amplitude of the received signal.

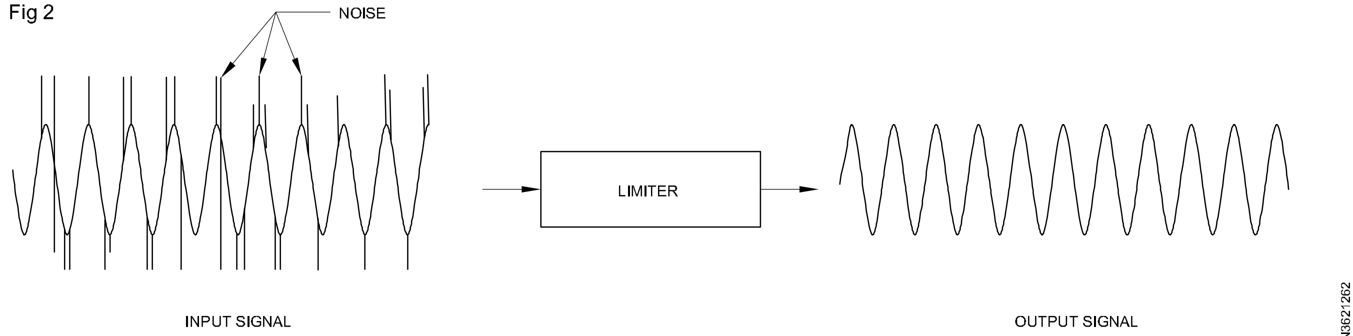
In FM receivers, generally, AGC is not required because the amplitude of the carrier is kept constant by the limiter circuit. Therefore, the input to the audio stages controls amplitudes and there are no erratic changes in the volume level. However, AGC may be provided using an AGC detector. This generates a dc voltage to control the gains of the RF and IF amplifier.

However, notice that a limiter stage appears between the IF stage and the detector stage. This is one way an FM receiver can reject noise. Fig.2 shows what happens in a limiter stage.

In the limiter shown in Fig.2 the input signal is very noisy. The output signal is noise -free. By limiting or by amplitude clipping, all the noise spikes have been eliminated. Some FM receivers uses two stages of limiting to eliminate most noise interference.

Limiting cannot be used in a AM receiver because the amplitude variations carry the information to the detector. In FM reception, the frequency variations contain the information. Amplitude clipping in a FM receiver will remove just the noise but does not remove the information.

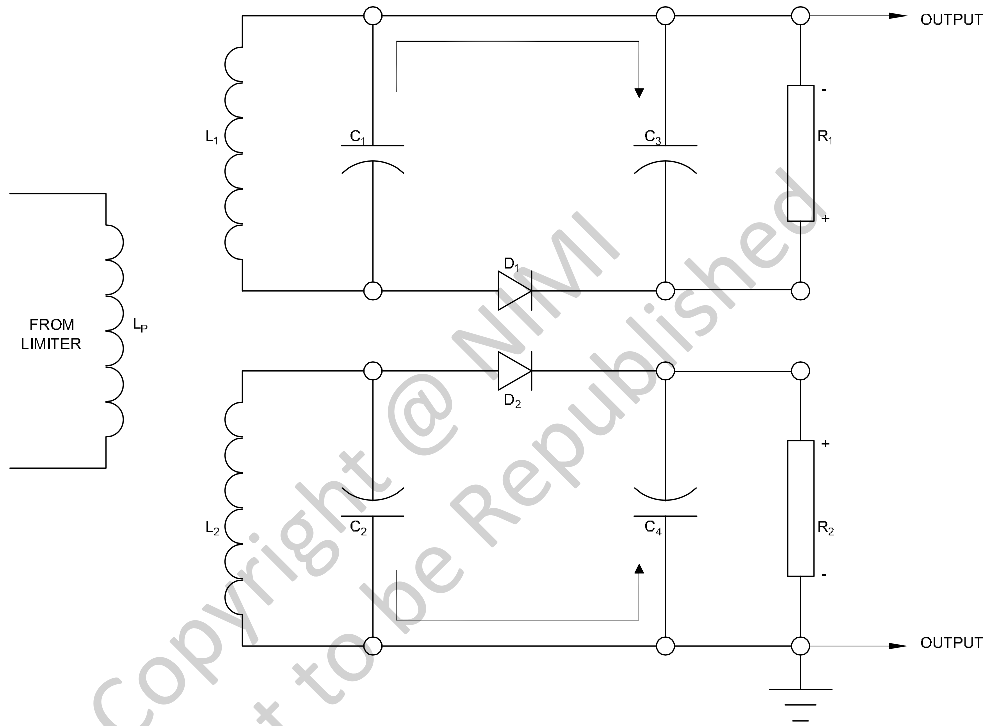
Fig 2




**OPERATION OF A LIMITER**

Detection in FM is more complicated than in AM. Since FM contains several side bands above and below the carrier, a signal nonlinear detector (such as a diode) will not demodulate the signal. To detect a FM signal needs a double tuned discriminator circuit shown in Fig.3.

Fig 3



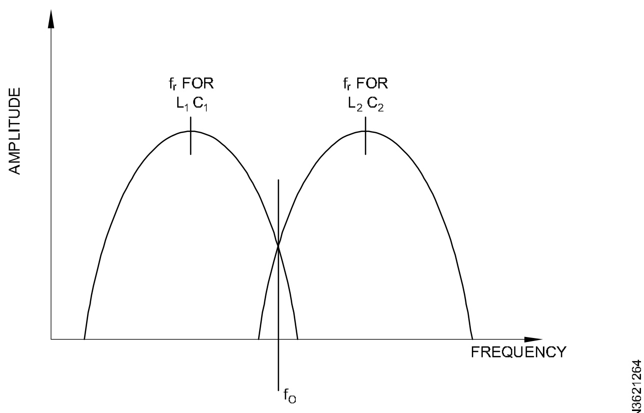

**DISCRIMINATOR**



The discriminator circuit shown in Fig.3 can serve as an FM detector. The discriminator works by having two resonant points. One is above the carrier frequency, and one is below the carrier frequency.

In the discriminator circuit shown in Fig.3, when the carrier is unmodulated, D1 and D2 will conduct an equal amount. This is because the circuit is operating where the frequency response curves cross . The amplitude is equal for both tuned circuits at this point. The current through R1 will be equal to the current through R2. If R1 are equal in resistance, the voltage drops will also be equal. Since the two voltages are series-opposing, the output voltage will be zero. This means , carrier is at rest(no modulation), the discriminator output is zero. The frequency response curves of this discriminator is shown in Fig.4.

Fig 4




**DISCRIMINATOR RESPONSE CURVES**

In the frequency response curves for the discriminator circuit, $f_o$ represents the correct point on the curves for the carrier. In a FM receiver, the station's carrier frequency will be heterodyned to $f_o$. This represents a frequency of 10.7 MHz for broadcast FM receivers. The heterodyning process allows one discriminator circuit to demodulate any signal over the entire commercial FM band.

Suppose the carrier shifts higher in frequency because of modulation, this will increase the amplitude of the signal in $L_2C_2$ and decrease the amplitude in $L_1C_1$. Hence there will be more voltage across $R_2$, and less across $R_1$. Thus the output of the discriminator goes positive.

On the other hand when the carrier shifts below $f_o$, the signal is closer to the resonant point of $L_1C_1$. More voltage will drop across $R_1$, and less across $R_2$. Hence, the output goes negative.

**The output from the discriminator circuit will be,**

- zero when the carrier is at rest,
- positive when the carrier moves higher in frequency, and
- negative when the carrier moves lower in frequency.

Thus the output of the discriminator is a function of the carrier frequency.

**Automatic frequency control**

The output of the discriminator can also be used to correct any drift in the receiver oscillator frequency. FM detector feeds a signal to the audio amplifier and to a stage marked AFC. AFC stand for automatic frequency control. If the oscillator output frequency happens to change for some reason, then, $f_o$ will not exactly be 10.7 MHz. There will be a steady DC output voltage from the discriminator. This DC voltage can be used as a control voltage to change the oscillator frequency automatically and set it back to 10.7 MHz.

The discriminator circuit discussed above work fairly well; but they are sensitive to amplitude changes. This is why one or two limiters are needed for noise free reception. An improved method of FM detection is by using the ratio detector instead of the discriminator. Ratio detectors are not very sensitive to the amplitude of the signal. This makes it possible to build receivers without limiters and still provide good noise rejection. FM detector circuits used in FM receivers are generally used in conjunction with integrated circuits(IC's).They usually have the advantage of requiring no alignment or only one adjustment whereas alignment for discriminators and ratio detectors is more time-consuming.

**Introduction to receiver alignment**

**What is Alignment?**

Alignment is the process of adjusting the IF and RF circuits for best reception (sensitivity, selectivity and absence of whistles) and accurate indication of the frequency/wavelength on the tuning scale. The set will have been properly aligned when it was manufactured but could require realignment either due to component ageing and drift or because somebody ("The Phantom") has been fiddling with the adjustments previously.

Since a radio receiver has several tuned circuits, all these must be tuned to their correct frequencies for the receiver to work satisfactorily for all stations in the desired band. This process of tuning the circuits to their correct frequencies is referred to as receiver alignment.

There are two main alignments to be carried out in a superhet radio receiver. They are,

- IF alignment
- RF alignment.

IF alignment is carried out such that all the IF transformers of the receiver are tuned to the correct standard intermediate frequency.

The main requirement for RF alignment is setting the local oscillator to tune in the station frequencies on the dial. RF alignment has two parts, one at the lower end of the band and the other at the higher end of the band. At the lower end, either the oscillator coil or the padder capacitor is adjusted. At the higher end frequencies, the trimmer capacitor is used to do the adjustment.



**Test set up for receiver alignment for AM**

Although a simple radio receiver can be aligned without the need of any specialized test equipment, to carry out alignment accurately and in a professional way, certain minimum test equipment's are very much necessary .They are;

- RF signal generator with facility for modulated output
- An AC voltmeter
- A DC voltmeter
- A dummy antenna
- A non-metallic screwdriver.

**IF alignment procedures**

Aligning the IF amplifiers means tuning the IF transformers to obtain the maximum output signal at the IF center frequency of 455 kHZ. There are several accepted method for IF alignment. Generally the manufactures of the receivers specify the method to be followed for alignment, in the form of table. Generalizing these methods, the two main methods of IF alignment is;

[1] IF alignment using a RF signals, set at IF center frequency and without any modulation of the IF signal

The procedure is employed by manufactures of high end communication sets. As this procedure is generally not employed in the training environment.

[2] IF alignment using a RF signal set at IF center frequency and modulated using a 400 HZ signal with 30% modulation.

This procedure makes use of an IF carrier, modulated with 30% modulation using a 400 HZ sine wave. This procedure is most commonly employed for IF alignment for most commercial radio receivers. A brief procedure of this method of IF alignment is given below.

**Step 1:**

Short the gang condenser portion of the MW antenna tuned circuit. Set the gang its half way(half open). Set cores of all IFTs towards the top of the can.

Setting the gang half open corresponds to pointer position of 1000 kHZ on the dial scale.

**Step 2:**

Connect a 0-2 V AC voltmeter across the detector load.

**Step 3:**

Set the output level of the RF signal generator modulated 455 kHZ to low.

**Step 4:**

Feed 455 kHZ modulated RF signal through a 0.22 μF coupling capacitor to the base of the mixer amplifier .Turn the receiver power ON. Set the modulated RF output amplitude just high enough for the AC voltmeter at the detector load to read about 0.5 to 1.0 Volt AC.

**Step 5:**

Using a non-metallic screwdriver, starting from the detector side, tune the last IFT core (IFT-3) for maximum signal output on the AC meter. Then, tune the preceding IFT (IFT-2) and go ahead till you reach the first IFT(IFT-1) such that the AC voltage reading is maximum.

NOTE: If you have not disconnected the audio stage, you will listen to the 400 Hz tone at the speaker. The tone level heard becomes maximum when all the IFTs are correctly tuned.

After carrying out the above procedure of IF alignment, remove the modulated RF signal fed at the base of the transistor of the converted stage.

**RF alignment procedures**

Recall that RF alignment is nothing but setting the frequency of the local oscillator to tune -in to correct station frequencies on the dial.

**RF alignment has two parts;**

1) RF alignment at the low end of the band (say around 1500 kHz in MW band) for setting the oscillator frequency and antenna.

2) RF alignment at the high end of the band (say around 1500 kHz in MW band) for setting the oscillator frequency and antenna.

As in IF alignment, RF alignment can be carried out using modulated carrier as given below;

RF alignment-using modulated RF signal:

This consists of two parts;

1] Oscillator frequency setting

2] MW antenna setting.

**1] Oscillator frequency setting- to adjust tracking**

(a) Setting oscillator frequency for low end of the band

**Step 1:**

Using a frequency counter set the signal generator to 530 kHz modulated (standard). To radiate the signal from the signal generator, connect the signal generator lead to a standard radiation loop or use a 0.01 μF capacitor across the generator leads. Keep this setup close to the receiver.

**Step 2:**

Position the dial pointer at 520 kHz position on the dial (lowest frequency marking).

Keep the volume control in the maximum volume position.

**Step 3:**

Turn the MW oscillator coil core very gently in clockwise direction using an insulated screwdriver, till you receive the radiated signal clearly

Do not turn the coil core (slug) more than one third at a time; else the core may get broken.

(b) Setting oscillator frequency for high end of the band

**Step 4:**

Now set the signal generator to 1630 kHz modulated.

**Step 5:**

Position the dial pointer at 1630 kHz position on the dial. Keep the volume control in the maximum volume position.

**Step 6:**

Adjust the MW oscillator trimmer gently, till you receiver the radiated signal clearly.

Repeat the above two procedures twice, as adjustment of the oscillator trimmer affects the oscillator coil adjustment. The idea is to obtain the best tracking of the oscillator and RF circuits.

**2] MW antenna setting**

(a) Adjusting MW antenna coil position for better sensitivity at the Low-end of the band

**Step 1:**

Set the signal generator to 640 kHz modulated (standard).bring the radiating loop connected to receiver.

**Step 2:**

Position the dial pointer at 640 kHz position on the dial. Keep the volume control in the maximum volume position.

**Step 3:**

Slide the MW antenna coil over the ferrite rod along the length of ferrite rod.The 400Hz modulating signal tone output from receiver increases. Position the coil where the output is maximum. Put a wedge to lock the antenna coil in that place temporarily.

(b) Adjusting antenna coil trimmer for better sensitivity for the high end of the band

**Step : 1**

Without changing the position of the dummy antenna, set the signal generator to 1630 kHz modulated (standard).

**Step 2:**

Position the dial pointer at 1630 kHz position on the dial. Keep the volume control in the maximum volume position.

**Step 3:**

Adjust the MW antenna trimmer gently, till you receive the 400 Hz radiated tone loudly and clearly.

Repeat the above two procedures of antenna setting twice, as adjustment of the antenna trimmer affects the antenna coil adjustment.

(c) Adjusting both MW antenna coil and trimmer for good reception of station in mid-band

**Step 1:**

Set the signal generator to 1000 kHz (modulated)

**Step 2:**

Position the dial pointer at 1000 kHz position on the dial. Keep the volume control at the maximum volume position.

**Step 3:**

Switch ON receiver and check if the 400 kHz modulating tone is loudly and clearly heard at the receiver speaker.

**Step 4:**

Without changing the position of the dummy antenna, decrease the output amplitude of the signal generator such that the radiated signal strength is very low and the output on speaker is very feeble i.e., just audible.

Reducing the radiated signal strength the generator is just to simulate weak station.

**Step 5:**

Remove the wedge fixed to the antenna. Gently shift the position of the antenna coil on the ferrite rod little by little on either side of its previous position to get maximum possible 400 Hz tone sound output from the speaker. Put the wedge and/or apply wax to permanently lock the antenna coil at that position.

**Step 6:**

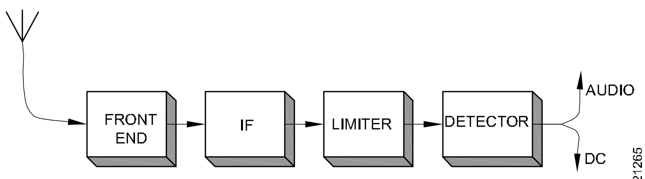
Adjust the MW antenna trimmer carefully till you receive the radiated signal as above.

**General procedure for aligning an FM receiver**

The procedure below is a general list of steps involved in the RF section of an FM broadcast receiver alignment. it should not be done unless you have the minimum equipment &have experience in RF alignment techniques.

There are a few things you must be aware of to get the order of alignment right; fig.5 helps in understanding the signal path a bit.

Fig 5




GENERAL PROCEDURE FOR ALIGNING AN FM RECEIVER

**The main sections from antenna to detector output are;**

First of all the one single most important contributor to the overall alignment is the detector. If the detector and IF are not setup properly then overall performance will suffer; FM stereo separation will be poor if the response of the basic receiver is poor. The detector must be resonant at the IF frequency and centered before going on to the other stages.

Except for models that have adjustable IF's (10/ B,18,19,20/B), this is the only IF section alignment adjustment that you should consider. The early classic models mentioned above are beyond the scope of this document and should not be attempted unless you have access to the proper equipment and have complex IF filter experience, however the detector and RF front end adjustments are applicable.

The equipment you will need are:

1 FM generator

2 Frequency counter

3 Distortion analyzer

4 DC coupled scope or DVM

**Detector alignment**

1 Ground the scope input at 10mv/division, and center the line on 0, or set the DVM to a low DC volts scale.

2 Disconnect the antenna.

3 Connect the scope or DVM to the DC output of the detector.

4 Connect the Distortion analyzer to audio output.

5 Find a very quiet area of the band that has no stations, this is usually at the lower band edge. By rocking the tuning back and forth there should be no DC change at the detector output or center tune meter movement. Sometimes placing a little shorting wire across the antenna input will help to find a quiet spot. You are setting the detector to the center of the noise generated by the IF/Limiter.

6 Using a non-metallic tuning tool, tune the secondary of the detector (usually the top slug) transformer to achieve 0VDC.

7 Connect a signal generator set for this unused frequency with an output level of 1 KμV, +/- 75 KHz (100%) modulation and adjust it's frequency for 0 VDC then adjust the primary slug for minimum distortion. The center tune meter should show centered.

8 Repeat steps 5 and 6 until there is minimum distortion with a signal and 0 VDC output at the detector with no signal present.

**Front end alignment**

The FM Circuit with tuning any station from 88-108 Mhz range and converting any selected station to exactly a 10.7 MHz signal to feed the I.F. (Intermediate Frequency) amplifier stages. This requires that all the stages of the R.F section track together, each stage is tuned by one of the gangs in the big variable capacitor that the tuning knob turns.

The front end contains several adjustments usually in pairs, one for the low end and one for the high end of the tuning range. There is usually an inductor for the low end and capacitor for the high end. Check and repair any dial string and pulley problems before proceeding, do not use any kind of lubricant on the dial string or pulleys, as this will cause slipping on the Gyrotouch(tm) shaft. A tuner properly working should with one good strong spin action should glide all the way by itself from one end of the band to the other, or at least most of the way. If it doesn't there is a binding or friction problem that should be fixed before alignment.

Using a frequency counter set the generator to 88 MHz and set the local oscillator inductor for 0 VDC at the detector; (center tune on meter if the unit has one)

Set the generator to 108 MHz and set the local oscillator trim capacitor for 0 VDC at the detector

Repeat 1 -2 until there is no change, they may take 3 or 4 times until both ends are correct.

If you just want to set the local oscillator and don't have access to a frequency counter you can use a couple of known stations near both band edges.

Check the center accuracy at 98 MHz, it should be pretty close. since you have adjusted just the band edges above. You are expecting that the center will fall in place. Repeat the local oscillator adjustments a little closer off the edges say at 90 and 106 MHz. usually this is not necessary but should be noted.

Just like the local oscillator there is also one or more pairs of capacitors for the RF path for both band edges.

1 Set the generator for 88 MHz or nearby open channel, set the generator for 3 - 5 μV and adjust for maximum audio or minimum distortion. These are sensitivity adjustments, so you may have to fiddle with the generator output to be at a level below significant limiter action.

2 Set the generator for 108 MHz or nearby open channel; adjust for maximum output or minimum distortion.

3 Repeat steps 1 - 2 until there is no noticeable improvement.

Depending on the model there may be a neutralization adjustment. This is circuit used to prevent the first stage from oscillating and to give a low noise figure. While it's rare that it needs adjustment, in cases where the RF stage is oscillating, adjust in small increments until the stage becomes stable. You will notice that the stage is oscillating if there are extraneous noises or carriers and that the overall sensitivity is low. If you end up adjusting the neutralization trimmer, you will have to repeat steps 1 - 3 above as they are interactive, but only on the first stage.

It sounds complicated, but just remember detector alignment first, then oscillator adjustments, then RF stages. Inductors are for the low end and caps are for the high end.

If there is a post mixer transformer it can be set just like the sensitivity adjustments (weak signal) at any frequency. if you want to take the time, if this transformer is present, repeat the detector adjustment.

If there is a signal strength meter adjustment, set the generator for 100 μV and set for 90% deflection.

# Digital modulation and demodulation techniques, sampling, quantization, encoding

**Objectives :** At the end of this lesson you shall be able to
- **explain the principle of digital communication**
- **list the fundamental techniques of digital modulation and demodulation**
- **explain the term of sampling**
- **explain the meaning of quantization**
- **describe the terms of encoding.**

Digital communication is the physical transfer of data in terms of a digital bit stream or a digitized analog signal over a point-to-point or point-to-multipoint communication channel. (Fig.1)

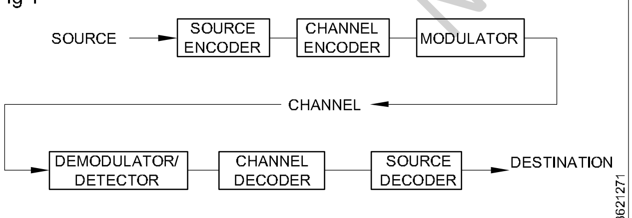
The messages are either represented by a sequence of pulses by means of a line code (baseband transmission), or by a limited set of continuously varying wave forms (pass-band transmission), using a digital modulation method.

The pass-band modulation and corresponding demodulation (also known as detection) is carried out by modem equipment. (Fig.2)

According to the most common definition of digital signal, both baseband and pass-band signals representing bit-streams are considered as digital transmission,while an alternative definition only considers the baseband signal as digital, and pass-band transmission of digital data as a form of digital-to-analog conversion

In case of digital transmission, the message signal is transmitted in the form of 0's and 1's. If the signal is digital, it is transmitted directly through the physical wires and if the signal is analog, it is first converted to digital form using PCM and then transmitted through physical wires like coaxial cable or optical fibers.

Fig 1

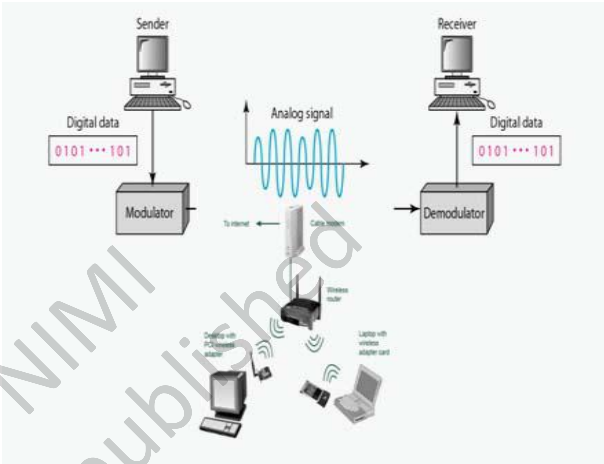



DIGITAL COMMUNICATION MODEL

In digital modulation, an analog carrier signal is modulated by a discrete signal.

Digital modulation methods can be considered as digital-to-analog conversion, and the corresponding demodulation as analog-to-digital conversion.

Fig 2



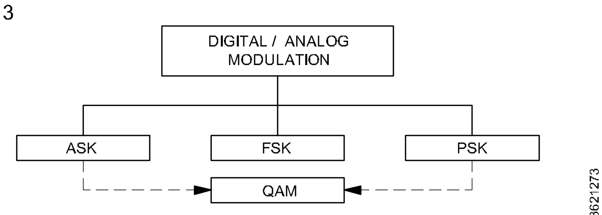



## Fundamental Techniques

The most fundamental digital modulation techniques are based on keying: (Fig.3)

- ASK (Amplitude-Shift Keying): A finite number of amplitudes are used.
- FSK (Frequency-Shift Keying): A finite number of frequencies are used.
- PSK (Phase-Shift Keying): A finite number of phases are used
- QAM (Quadrature Amplitude Modulation): A finite number of at least two phases and at least two amplitudes are used.

Fig 3

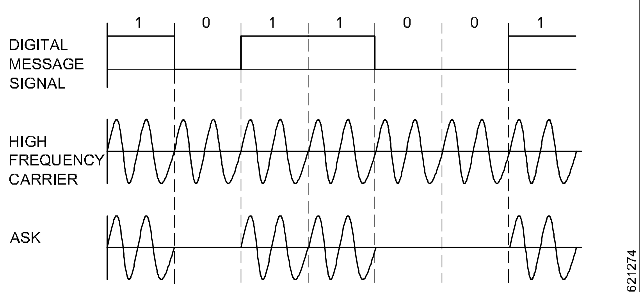



FUNDAMENTAL TECHNIQUES

## Amplitude Shift Keying - ASK

Amplitude shift keying (ASK) is a digital modulation process, in which digital message signal is modulated with the high frequency carrier. The amplitude of the carrier is changed according to the message signal. It is similar to AM When input = high i.e. at logic 1, output's amplitude is same as high frequency carrier's amplitude. When input = low i.e. at logic 0, output is 0. Hence the information of the message signal is contained in the amplitude of the carrier signal i.e. if input is 1, carrier is on and if input is 0. carrier is off. Therefore, it is also known as On Off keying. (Fig.4)

Fig 4




AMPLITUDE SHIFT KEYING - ASK

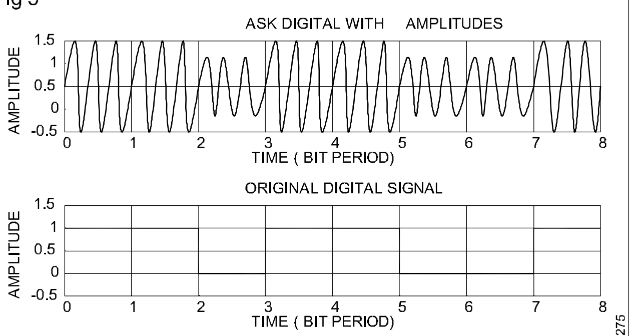
## ASK demodulation

Demodulation is the process of recovering the original message signal from the modulated signal .i.e., the reverse process of modulation. It is also known as Detection. An Ideal demodulator should produce an output as same as the original message signal before modulation.

But practically it is not possible, due the presence of noise (like Gaussian noise, white noise, short noise, etc...), hence, deviations occur after demodulation, this is known as Distortion.

The ASK demodulator, which is designed specifically for the symbol-set used by the modulator, the presence or absence of a sinusoid in a given time interval needs to be determined the amplitude of the received signal and maps it back to the symbol it represents, thus recovering the original data. Frequency and phase of the carrier are kept constant. (Fig.5)

Fig 5




WAVE FORM

## Advantages of Amplitude-shift keying (ASK)

The main advantage of ASK modulation is generation of ASK is very much easy. Both ASK modulation and demodulation processes are relatively inexpensive. The ASK technique is also commonly used to transmit digital data over optical fiber. There are many other advantages of ASK, Such as Amplitude-shift keying transmitters are very simple and transmitter current is low.

## Disadvantages of Amplitude-shift keying (ASK)

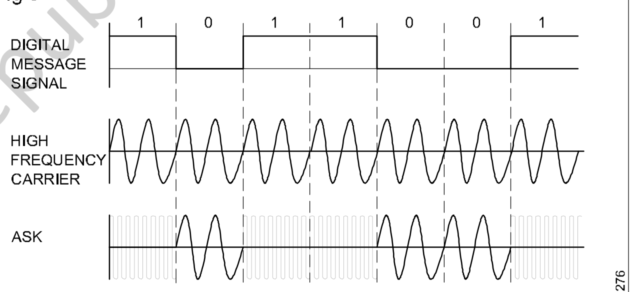
ASK is linear and sensitive to atmospheric noise, distortion and propagation condition on different routes in PSTN (Public switched telephone network).It requires excessive bandwidth and is therefore a waste of power.

## Frequency Shift Keying - FSK (Fig.6)

Frequency shift keying (FSK) is the most common form of digital modulation in the high-frequency radio spectrum, and has important applications in telephone circuits.

The digital message signal is modulated with the high frequency carrier. The frequency of the carrier is changed according to the message signal. It is similar to FM When input = high i.e. at logic 1, carrier frequency is shifted up i.e. frequency increases. When input = low i.e. at logic 0, carrier frequency is shifted down i.e. frequency decreases. Hence the information of the message signal is contained in the frequency of the carrier signal.

Fig 6

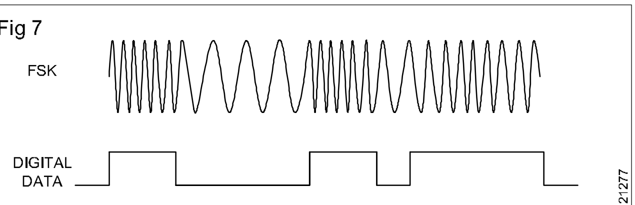



FREQUENCY SHIFT KEYING - FSK

## FSK demodulation

The FSK demodulation methods for FSK can be makes all positive voltages into binary 1's and all negative voltages into binary 0's.This type of demodulator was very popular due to its relative simplicity and its noncritical tuning. Phase-locked-loop (PLL) demodulators are a more recent technique, but they have very similar performances to that of FM detector demodulators.(Fig.7)

Fig 7




FSK DEMODULATION

**Advantages of FSK**

- Low Noise, Since Amplitude Is Constant
- Power Requirement Is Constant
- Operates In Virtually Any Wireless communication Available
- High Data Rate
- Used In Long Distance Communication
- Easy To Decode
- Good Sensitivity

**Disadvantages of FSK**

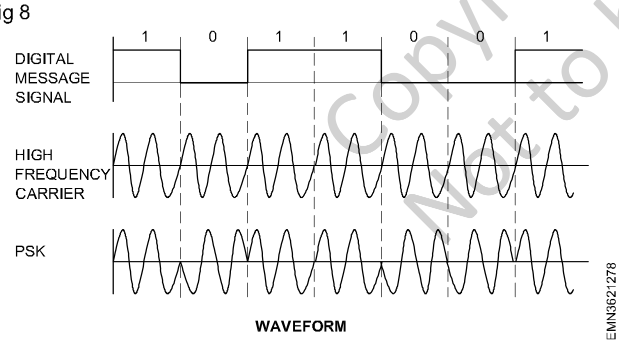
- Complex Circuits.
- Coherent FSK is not often used in practice due it the difficulty and cost in generating two reference frequencies close together at the receiver.
- It requires more bandwidth.
- The FSK is not preferred for the high speed modems because with increase in speed, the bit rate increases.

**Phase Shift Keying - PSK:**

Phase-shift keying (PSK) is a digital modulation scheme that conveys data by changing, or modulating the phase of a reference signal (the carrier wave).

The digital message signal is modulated with the high frequency carrier. The phase of the carrier is changed according to the message signal. It When input = low i.e. at logic 0, output wave is 180 degrees out of phase with the carrier is similar to PM When input = high i.e. at logic 1, output wave is in phase with the carrier. i.e. 0 degrees phase. (Fig.8)

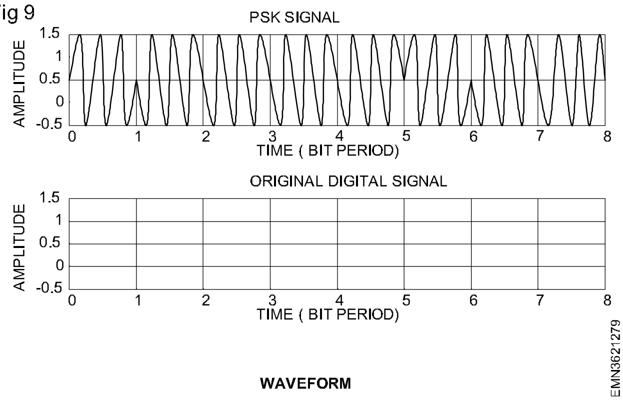
Fig 8




Any digital modulation scheme uses a finite number of distinct signals to represent digital data. PSK uses a finite number of phases, each assigned a unique pattern of binary digits.

The demodulator, which is designed specifically for the symbol-set used by the modulator, determines the phase of the received signal and maps it back to the symbol it represents, thus recovering the original data. This requires the receiver to be able to compare the phase of the received signal to a reference signal. (Fig.9)

Fig 9




**Advantages of PSK**

- PSK is less susceptible to errors than ASK, while it requires/occupies the same bandwidth as ASK
- More efficient use of bandwidth (higher data-rate) are possible, compared to FSK.
- High power efficiency
- It is used in low data rate wireless communication.

**Disadvantages of PSK**

- More complex signal detection / recovery process, than in ASK and FSK.
- Low bandwidth efficiency.

**Quadrature Amplitude Modulation - QAM**

Quadrature Amplitude Modulation (QAM) is both an analog and a digital modulation scheme. It conveys two analog message signals, or two digital bit streams, by changing (modulating) the amplitudes of two carrier waves, using the amplitude-shift keying (ASK) digital modulation scheme or amplitude modulation (AM) analog modulation scheme.

The two carrier waves, usually sinusoids, are out of phase with each other by 90° and are thus called quadrature carriers or quadrature components - hence the name of the scheme. The modulated waves are summed, and the final waveform is a combination of both phase-shift keying (PSK) and amplitude-shift keying(ASK).

In the digital QAM case, a finite number of at least two phases and at least two amplitudes are used and it also used extensively as a modulation scheme for digital telecommunication systems.

The QAM modulator and QAM demodulator are key elements within any quadrature amplitude modulation system.

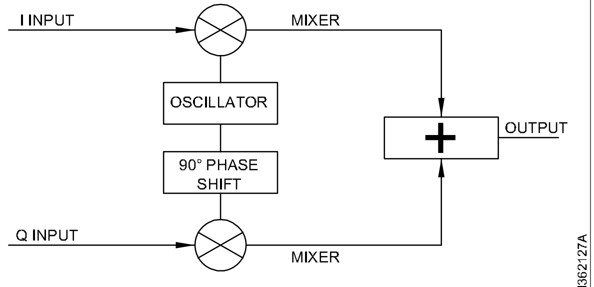
The modulator and demodulator are used to encode the signal, often data into the radio frequency carrier that is to be transmitted. Then the demodulator is used at the remote end to extract the signal from the RF carrier so that it can used at the remote end.

As quadrature amplitude modulation is a complex signal, specialised QAM modulators and demodulators are required.

## QAM modulator basics

The QAM modulator essentially follows the idea that can be seen from the basic QAM theory where there are two carrier signals with a phase shift of 90° between them. These are then amplitude modulated with the two data streams known as the I or In-phase and the Q or quadrature data streams. These are generated in the baseband processing area. (Fig.10)

Fig 10

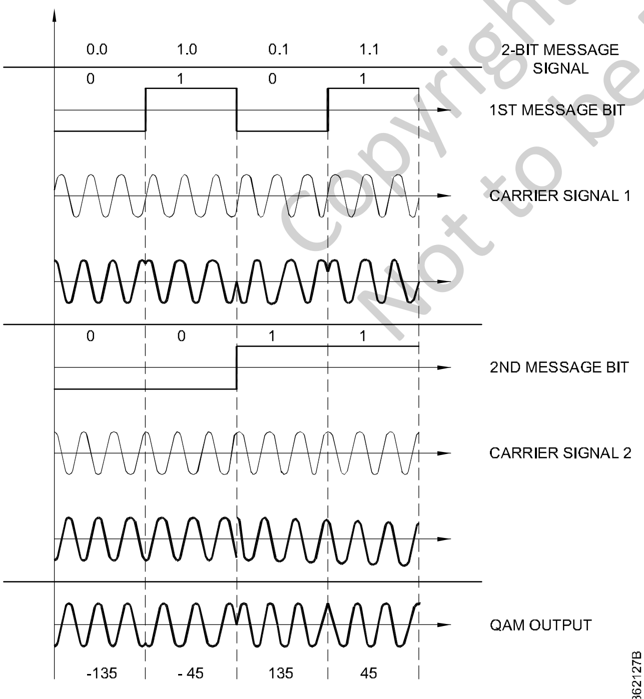



QAM MODULATOR BASICS

The two resultant signals are summed and then processed as required in the RF signal chain, typically converting them in frequency to the required final frequency and amplifying them as required.

It is worth noting that as the amplitude of the signal varies any RF amplifiers must be linear to preserve the integrity of the signal. Any non-line varieties will alter the relative levels of the signals and alter the phase difference, thereby distorting the signal and introducing the possibility of data errors. (Fig.11)

Fig 11

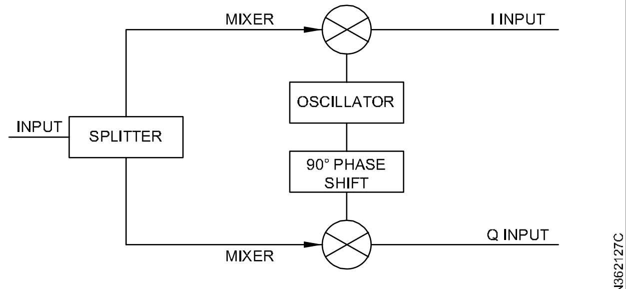



WAVEFORM

The QAM demodulator is very much the reverse of the QAM modulator.

The signals enter the system, they are split and each side is applied to a mixer. One half has the in-phase local oscillator applied and the other half has the quadrature oscillator signal applied. (Fig.12)

Fig 12




BASIC QAM DEMODULATOR DIAGRAM

The basic modulator assumes that the two quadrature signals remain exactly in quadrature.

A further requirement is to derive a local oscillator signal for the demodulation that is exactly on the required frequency for the signal. Any frequency offset will be a change in the phase of the local oscillator signal with respect to the two double sideband suppressed carrier constituents of the overall signal.

Systems include circuitry for carrier recovery that often utilises a phase locked loop - some even have an inner and outer loop. Recovering the phase of the carrier is important otherwise the bit error rate for the data will be compromised.

### Advantages of QAM

- QAM appears to increase the efficiency of transmission for radio communications systems by utilizing both amplitude and phase variations.
- The advantage of using QAM is that it is a higher order form of modulation and as a result it is able to carry more bits of information per symbol.
- By selecting a higher order format of QAM, the data rate of a link can be increased.
- Baud Rate (Baud Rate - No. of symbols per second) is high.

### Disadvantages of QAM

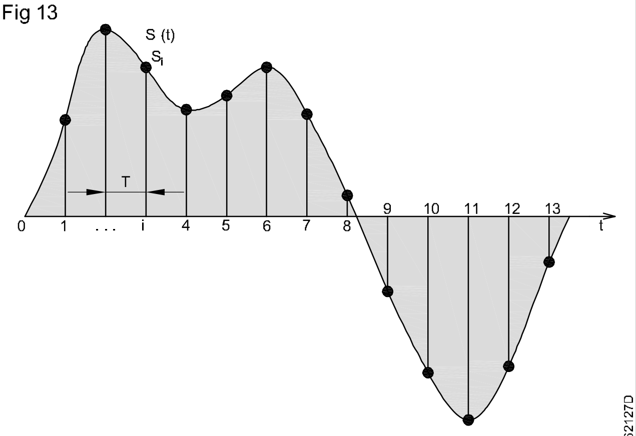
- First it is more susceptible to noise. Receivers for use with phase or frequency modulation are both able to use limiting amplifiers that are able to remove any amplitude noise and thereby improve the noise reliance.
- The second limitation is also associated with the amplitude component of the signal. When a phase or frequency modulated signal is amplified in a radio transmitter, there is no need to use linear amplifiers, whereas when using QAM that contains an amplitude component, linearity must be maintained.

- Almost always requires a highly stable local oscillator
- In the optical domain this is very expensive.

**Sampling**

In signal processing, sampling is the reduction of a continuous signal to a discrete signal. A common example is the conversion of a sound wave (a continuous signal) to a sequence of samples ( discrete-time signal). (Fig.13)

Fig 13




SAMPLING OF A RANDOM WAVE

A sample is a value or set of values at a point in time or space. A theoretical ideal sampler produces samples equivalent to the instantaneous value of the continuous signal at the desired points.After sampling, the process of converting a continuous-valued discrete-time signal to a digital (discrete-valued discrete-time) signal is known as analog-to-digital conversion

Sampling is usually done by using PAM (Pulse Amplitude Modulation). In this the analog signal is sampled at a given pulsing frequency.

**Criteria for Sampling:**

The criteria for sampling is given by Nyquist, known as Nyquist sampling theorem. The Nyquist sampling theorem provides a prescription for the nominal sampling interval required to avoid aliasing. It may be stated simply as follows:

"The sampling frequency should be at least twice the highest frequency contained in the signal."

**Types of Sampling**

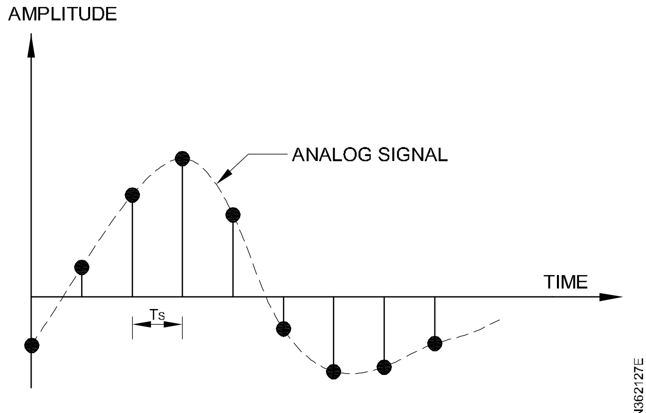
There are three basic types of sampling used in the process of sampling process.

They can be differentiated by their output waveform that they produce and the process involved in producing them.

**1) Ideal Sampling (Fig.14)**

- In this the samples are the instants of that time
- It is obtained by Pulse Modulation with
- Pulse of low duty cycle ideally, not possible but is used for theoritical purpose.

Fig 14

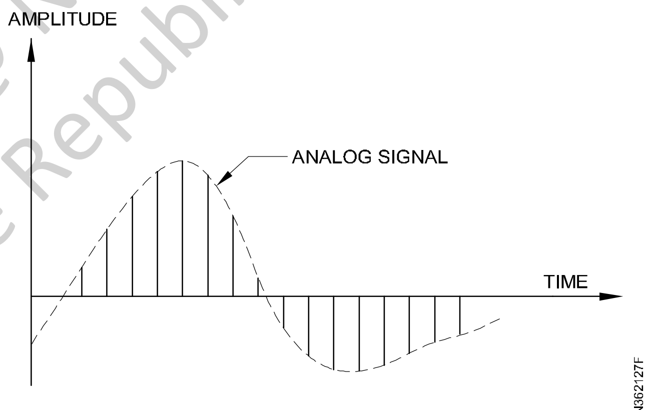



IDEAL SAMPLING

**2) Natural Sampling (Fig.15)**

- In this the samples are not the instant but of a small period of time
- It is obtained by PAM.
- This is usually used for the comparison of sampled output at various time intervals of various signals
- It has low SNR (Signal to Noise Ratio - The amount of original signal present to that of the noise in given signal).

Fig 15

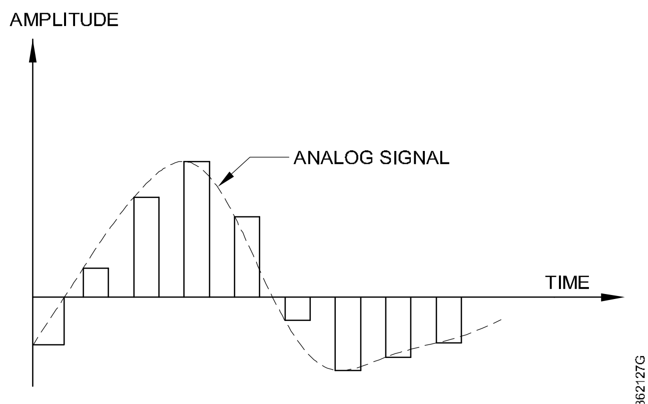



NATURAL SAMPLING

**3) Flat- top Sampling (Fig.16)**

- This is similar to Natural Sampling

Fig 16




FLAT-TOP SAMPLING

- In this the top is made flat irrespective of the signal form
- This is usually used for Quantization as it gives higher SNR values when compared to natural sampling.

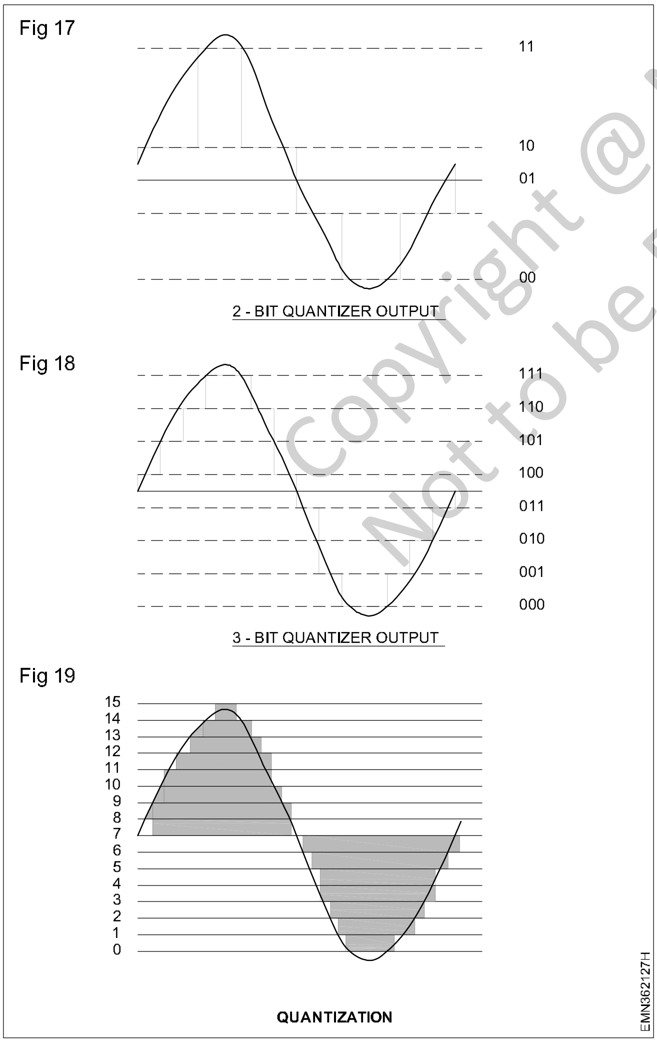
**Quantization**

Quantization in digital signal processing, is the process of mapping a large set of input values to a (countable) smaller set - such as rounding values to some unit of precision.

A device or algorithmic function that performs quantization is called a quantizer.

The round-off error introduced by quantization is referred to as quantization error.

In analog-to-digital conversion, the difference between the actual analog value and quantized digital value is called quantization error or quantization distortion. This error is either due to rounding.. The error signal is sometimes modeled as an additional random signal called quantization noise because of its stochastic behavior.Quantization is involved to some degree in nearly all digital signal processing, as the process of representing a signal in digital form ordinarily involves rounding. (Fig.17, 18 & 19)




The output of the quantization depends on the resolution of the quantizer, i.e., if a sinusoidal wave to be quantized is given to a 2-bit quantizer then the output has 4 levels in its output,

If it is a 3-bit quantizer then the output has 8 levels, thus the number of levels can be given based on the resolution of the quantizer, i.e., the number of output bits of the quantizer.

**Quantization Error**

- When a signal is quantized, we introduce an error - the coded signal is an approximation of the actual amplitude value.
- The difference between actual and coded value (midpoint) is referred to as the quantization error.

**Encoding**

An encoder is a device, circuit, transducer, software program, algorithm that converts information from one format (code) to another for the purpose of standardization, speed and security.

In telecommunication it is a device used to change a signal such as bit stream into a code.

The encoding is used to follow up standards so that type conversion from one to another doesn't affect the overall process. E.g.: NRZ-S is used in USB communication irrespective of the type of hardware, thus they ensure a standard.The usually used coding technique is line-coding technique. It is the coding technique followed to coding only single bit at a time.

Line coding consists of representing the digital signal to be transported by an amplitude- and time-discrete signal that is optimally tuned for the specific properties of the physical channel (and of the receiving equipment). The waveform pattern of voltage or current used to represent the 1's and 0's of a digital data on a transmission link is called line encoding.

**The common types of line encoding are**

**a. Unipolar encoding.**

- Return to Zero (RZ).

**b. Polar encoding.**

- Non-Return to Zero Level (NRZ-L).
- Non-Return to Zero Space (NRZ-S).
- Non-Return to Zero Inverted (NRZ-I).
- Non-Return to Zero Mark (NRZ-M).

**c. Bipolar encoding.**

- Alternate Mark Inversion(AMI)

**d. Manchester encoding.**

### Unipolar Encoding

Unipolar encoding or Return to Zero is a line code. A positive voltage represents a binary 1, and zero volts indicates a binary 0. It is the simplest line code, directly encoding the bit stream, and is analogous to on-off keying in modulation. (Fig.20)

In unipolar NRZ the duration of the MARK pulse ($\Gamma$) is equal to the duration (To) of the symbol slot. (Fig.21)

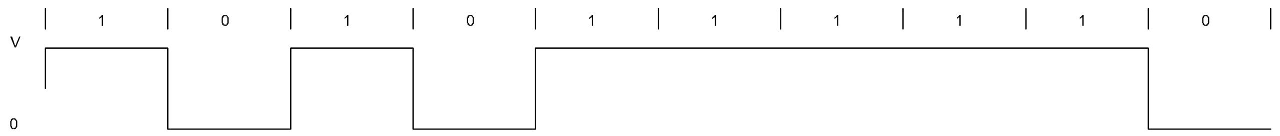
### Advantages

- Simplicity in implementation.
- Doesn't require a lot of bandwidth for transmission.

### Disadvantages

- Presence of DC level (indicated by spectral line at 0 Hz).
- Contains low frequency components. Causes "Signal Droop" (explained later).
- Does not have any error correction capability.
- Does not possess any clocking component for ease of synchronisation.
- Is not transparent. Long string of zeros causes loss of synchronisation.

Fig 20



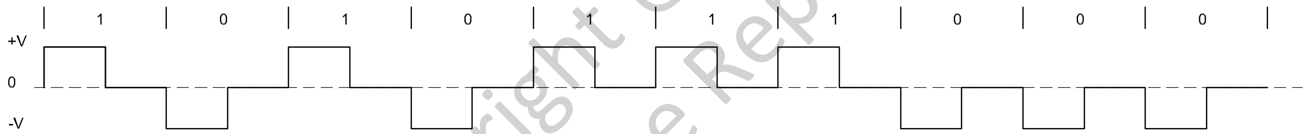

RETURN TO ZERO WAVEFORM

EMN362127I

### Polar encoding (Fig.22)

In polar signalling a binary 1 is represented by a pulse g1(t) and a binary 0 by the opposite (or antipodal) pulse g0(t) = -g1(t). Polar signalling also has NRZ and RZ forms.

Fig 21




NON - RETURN TO ZERO WAVEFORM

EMN362127J



### Advantages

- Simplicity in implementation.
- No DC component.

### Disadvantage

- Continuous part is non-zero at 0 Hz. Causes "Signal Droop".
- Does not have any error correction capability.
- Does not posses any clocking component for ease of synchronisation.
- Is not transparent.

### Types

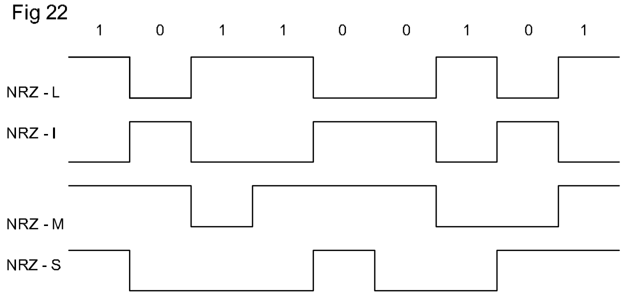
1 NRZ-L

2 NRZ-I

3 NRZ-M

4 NRZ-S

Fig 22




TYPES OF POLAR ENCODING

EMN362127K

### Bipolar encoding (Fig.23)

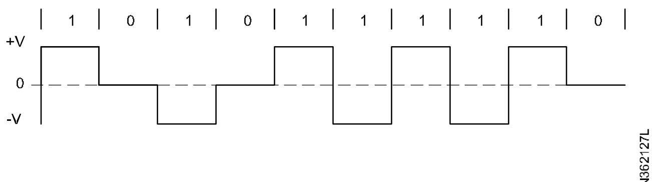
Bipolar Signalling is also called "alternate mark inversion" (AMI) uses three voltage levels (+V, 0, -V) to represent two binary symbols. Zeros, as in unipolar, are represented by the absence of a pulse and ones (or marks) are represented by alternating voltage levels of +V and -V.

Alternating the mark level voltage ensures that the bipolar spectrum has a null at DC and that signal droop on AC coupled lines is avoided.

The alternating mark voltage also gives bipolar signalling a single error detection capability.

Like the Unipolar and Polar cases, Bipolar also has NRZ and RZ variations.

Fig 23




BIPOLAR (AMI) WAVEFORM

### Advantages

- No DC component.
- Occupies less bandwidth than unipolar and polar NRZ schemes.
- Does not suffer from signal droop (suitable for transmission over AC coupled lines).
- Possesses single error detection capability.

### Disadvantages

- Does not possess any clocking component for ease of synchronisation.
- Is not transparent.

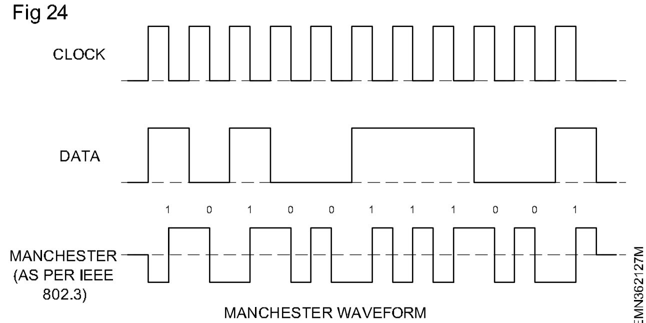
### Manchester encoding (Fig.24)

In Manchester encoding, the duration of the bit is divided into two halves. The voltage remains at one level during the first half and moves to the other level during the second half.

Manchester encoding follows XOR operation.

| Clock | Data | Manchester Encoding |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 0 |

Fig 24




MANCHESTER WAVEFORM

The transition at the centre of every bit interval is used for synchronization at the receiver. Manchester encoding is called self-synchronizing. Synchronization at the receiving end can be achieved by locking on to the transitions, which indicate the middle of the bits.

### Advantages

- No DC component.
- Does not suffer from signal droop Easy to synchronise with.
- Is Transparent.

### Disadvantages

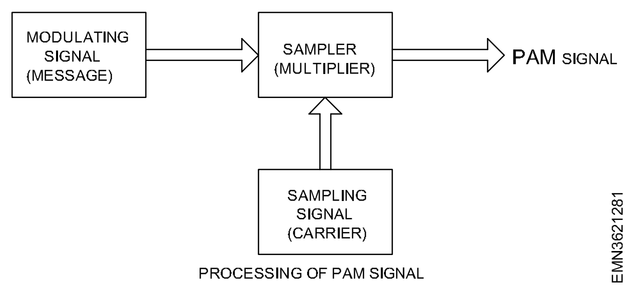
- Because of the greater number of transitions it occupies a significantly large bandwidth.
- Does not have error detection capability.

**Modulation and Demodulation of analog signal using PAM,PPM,PWM**

Pulse amptitude modulation (PAM) is the basic from of pulse modulation in which the signal is samped at regular intervals and each sample is made proportation to the amplitude of the modulating signal at the sampling instant.

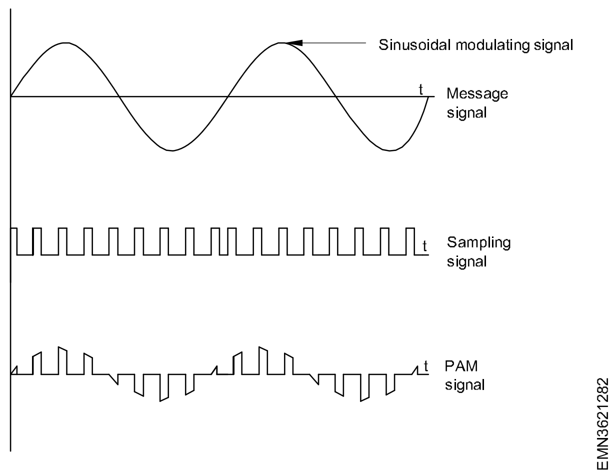
The processing of PAM signal is shown in Fig 1. The two signals i.e, modulating signal and sampling signal or carrier signal are sent to the sampler (Multiplier) stage where the amplitude of the signal proportational to the modulating signal through which information is carried. This is PAM signal

Fig 1




The PAM signal along with the message signal and the sampling signal, that is the carrier train of pulses waveform plotted in time domain are shown in Fig 2

Fig 2

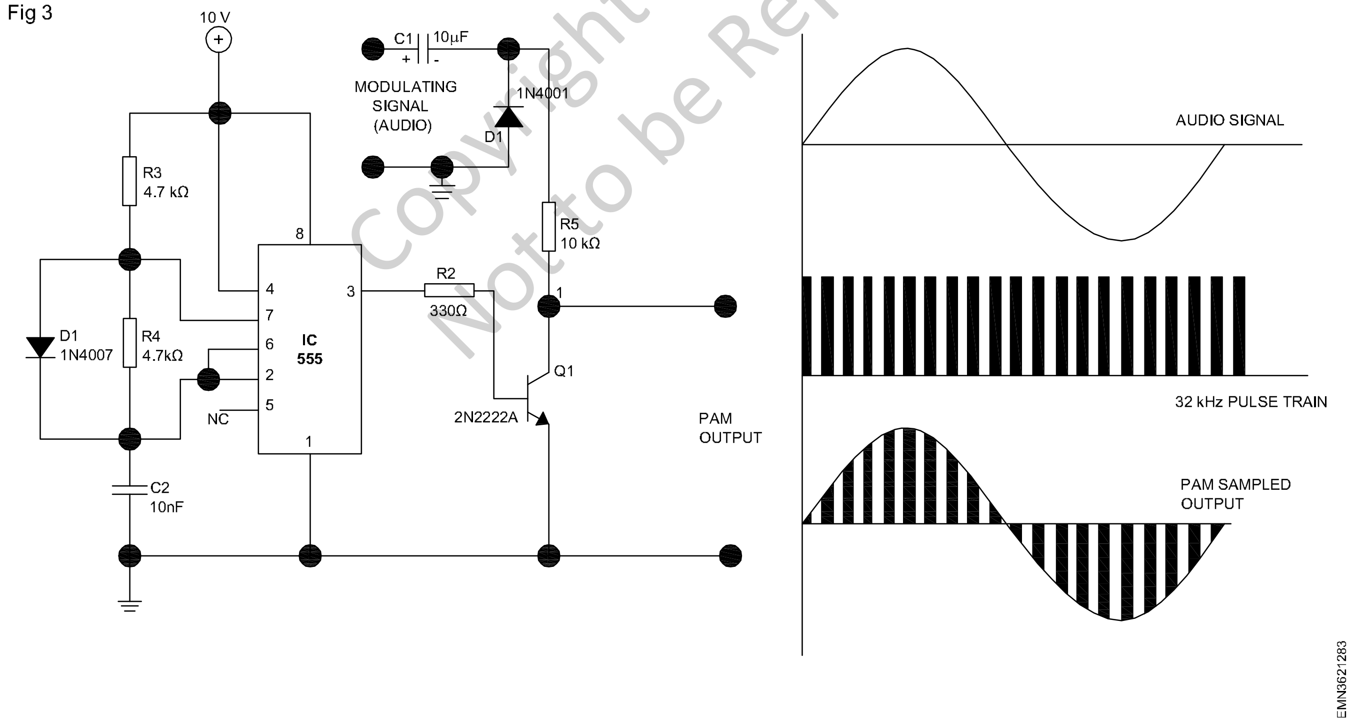



PAM circuit using IC555 and NPN transistor is shown in Fig 3. The timer chip is wired in astable multivibrator configuration with the NPN transistor base at terminal output pin. Its pulse frequency is designed at least twice that of audio signal. The collector of transistor is coupled with low frequency audio signal through positive clamper using capacitor C1 and diode D1.

The positive clamping will shift the level of audio signal above 'O' volt. The output at the collector of transistor is PAM wave as shown in Fig 3. The amplitude of pulse generated by the IC555 varies in accordence with the instantaneous amplitude of information signal.



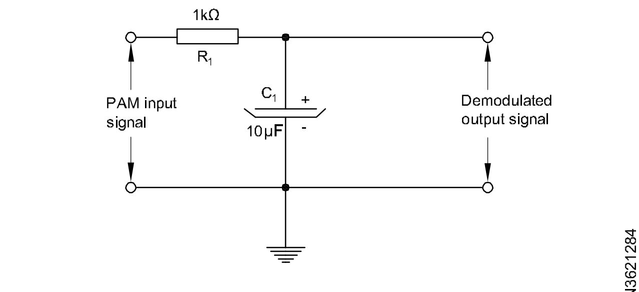
Fig 3



## Demodulation of PAM

PAM siganl is demodulated by the low pass filter circuit shown in Fig 4. The RC network eliminates high frequency ripples and generates the demodulated signal proportional to the PAM input signal.

Fig 4



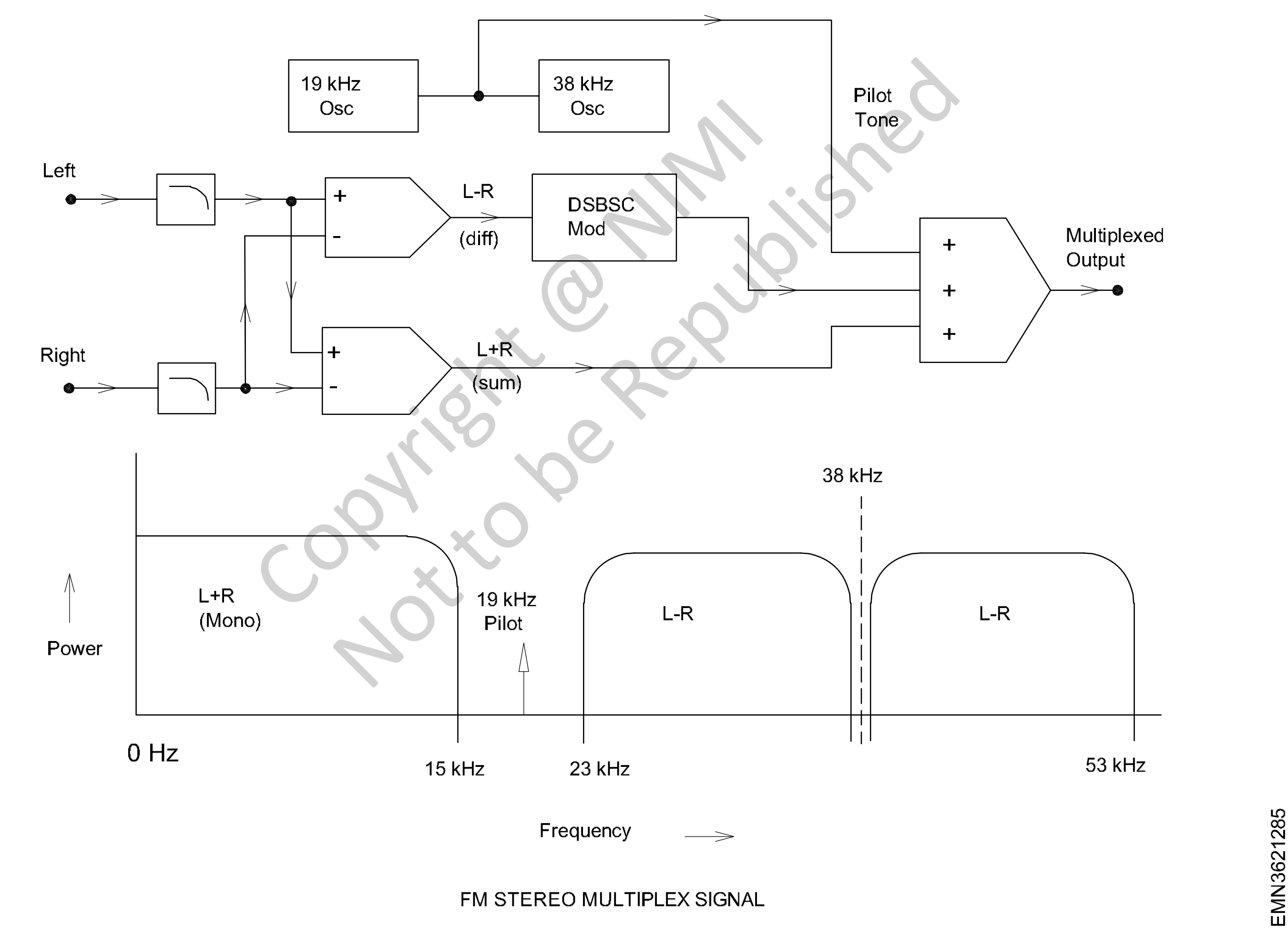

PAM DEMODULATOR CIRCUIT

## Stereo FM Radio

As most radio listeners are aware, One of the main advantages of FM radio broadcasting over AM/Medium Wave is the avaliability of stereo sound. This involves transmitting and receiving image. In principle, we can use two complete transmitter/receiver systems to send stereo sound. In practice, however, it makes more sense to use multiplexing.

When introducting an improved service-stereo for FM, or colour for TV-broadcasters are often stuck with the 'old grannie problem'. This is the fact that there will be thousands/millions of listeners/viewers who can't afford (or don't want the new improved service). They want to be able to go on receiving mono/black & white just as if nothing had changed. For this reason one of the main engineering requriements when introducing stereo to FM radio was to do it in a way which went unnoticed by anyone using cheap old mono radios. This menas that the system chosen is more comples than otherwise it would need to be.

Fig 5




FM STEREO MULTIPLEX SIGNAL



The standard FM stereo system which has been adopted by broadcasters around the world is illustrated in figure the system uses frequency division multiplexing to combine the two signals destined for the left and right hand loudspeakers. The signals are first passed through filters which only allow through frequencies up to 15KHz. The L and R signals are then added to produce a sum signal and subtracted one from the other to procedure a diffrent signal. The sum is essentially a monophonic signal which is what we would send for playing through a single loudspeakers. The diffrence signal is used to DSBSC modulated a 38 kHz sinewave.

The DSBSC output is added to the sum (mono) signal and the combination is sent on the transmitter's FM modulator. A monophonic receiver can now ignore the stero information simply by using a filter after its FM demodulator to block everything above 15kHz. A stereo receiver has to have, an addition circuit after the FM demodulator which can detect and demodulate which can detect and demodulate the DSBSC wave. Once it has done this it has recovered the diffrence information and can recreate the left and right signals by adding/ subracting.

Demodulating a DSBSC signal can be diffrent due to the adsence of the carrier whose frequency & phase need to perform demodulation. In the stereo system this problem is dealt with by including in the broadcast signal a 19kHz pilot tone. This comes from a 19 kHz master oscillator at the tranmitter to which the 38 kHz subcarrier oscillator is phase locked.The 19kHz master oscillator at the transmitter to which the 38 kHz subcarrier oscillator is phase locked. The 19 kHz master oscillator at the transmitter to which the 38 kHz subcarrier oscillator is phase locked. The 19 kHz pilot tone falls in a spectral region above the mono sum signal and below the DSBSC diffrence signal information.(The DSBSC signal extends =15kHz around 38 kHz since the input modulating signals are band limited to 15kHz.)

The stereo receiver looks at incoming FM demodulated signals. It knows that the 15-23 kHz range should be vacant unless a stereo signal is being transmitted. If a 19kHz pilot tone is present it can be recognised and used to control the frequency and phase of a 38 kHz oscillator in the receiver's stereo decoder. This can then demodulated the diffrence information and combine it with the mono (sum) signal to recover the stereo sound. The presence of the 19 kHz tone is also often used to make the receiver presence of the 19 kHz tone is also often used to make the receiver light up an indicator with flags that a stereo multiplexed signal is being received (This doesn't of course, guarantee the sound is in stereo. Broadcasters often leave the sstem on when transmitting mono material! Then L always equals R and the diffrence DSBSC signal is always zero.)

From erailer section on FM we know that the noise power spectral density of a demodulated FM signal tends to increase with the square of the modulation frequency. This means that there will be more noise in the 23 - 53 kHz band used for the diffrence signal than for the 0 - 15 kHz band used for the sum signal. As a result we require a significantly higher input signal level to receive a stereo transmission with the same output S/N as a mono signal. A careful analysis shows that we need around a tenflod increase in the received signal level to obtain the same S/N for stereo as mono. This is why many radios & FM tuners sound noisier in stereo than in mono. A similar argument applies to interference. Stereo reception is significantly more susceptible to interference. Stereo recception is significantly more susceptible to interference than mono.

**Multiplexing of AM signal**

Analog signals are easily multiplexed by using frequency division multiplexing (FDM) technique for multiplexing AM signals for transmission. FDM is a networking technique in which multiple data signals are combined for simulataneous transmission via a shared comminication medium. FDM uses a carrier signal at a descrete frequency for each data stream and then combines many modulated signals into one in such a manner that each individual signal can be retrieved at the destination.

The following Fig 1 shows the process of FDM of three voice signals with diffrent carrier frequencies are modulated and sent together over a cable by using FDM technique

In FDM a guard band frequency of 9 khz is provided between different AM channels to keep signals from intefering with each other. This process of multiplexing of AM signal is adopted at Transmitter and then goes to media at different slots of frequency.

Since the PAM, PPM and PNM are analog signals, the multiplexing of these signals are required with FDM technique.



Fig 1

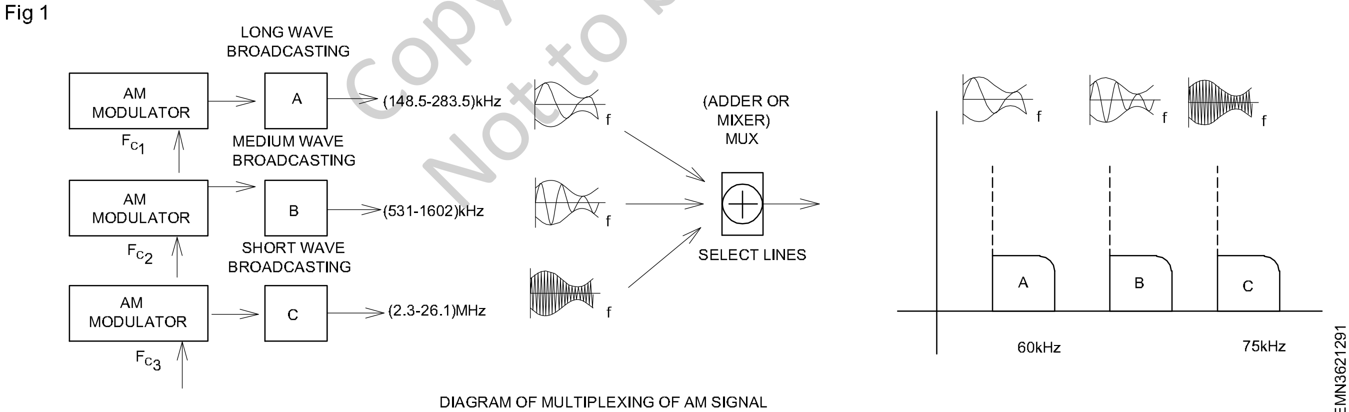



DIAGRAM OF MULTIPLEXING OF AM SIGNAL

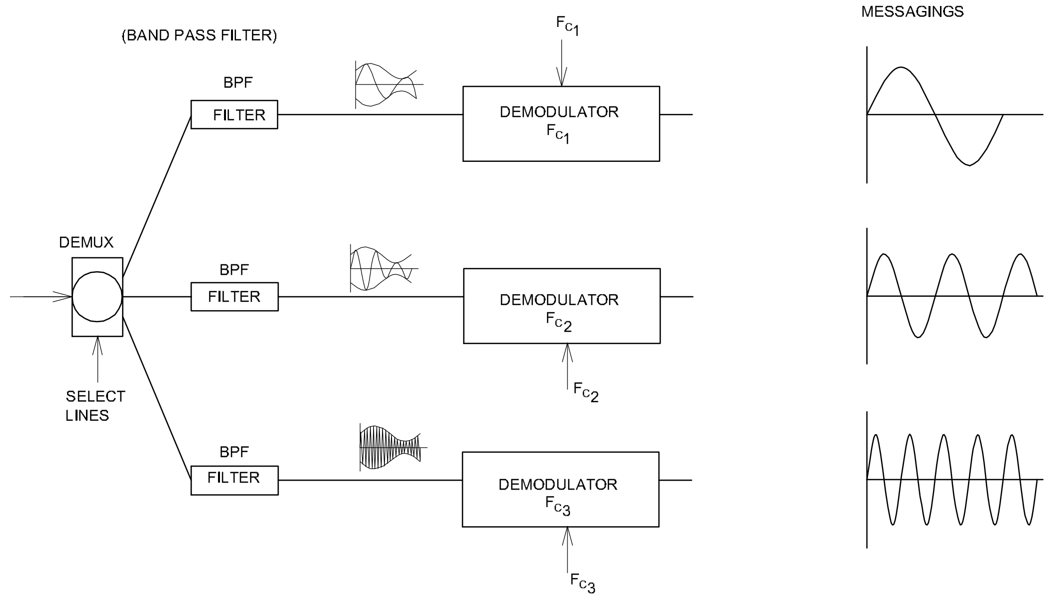
**Demultiplexing of AM signal**

Demultiplexing is the reverse process of the multiplexing action the demultiplexer is also known as 'DEMUX'

A demux circuit seperates multiple analog or digital seprates form one signal received over a single shared medium such as a single conductor of copper wire or fiber optical cable

At receiving end the DEMUX receive the signal from the multiplexer and it converts back to orginal form the following diagram shown in Fig 2 explain the

Fig 2



DEMULTIPLEXING OF AM SIGNAL

demultiplexing of three AM signls from a multiplexed signal.

The composite signal of diffrent carrier are seperated by the 'DEMUX' using select lines (data selector) Then each signal passes through band pass filter (BPF) where all the carrier are seperated.

Now, each modulated signal is applied at demodulators to detect all the three orginal message signals at receiving end.

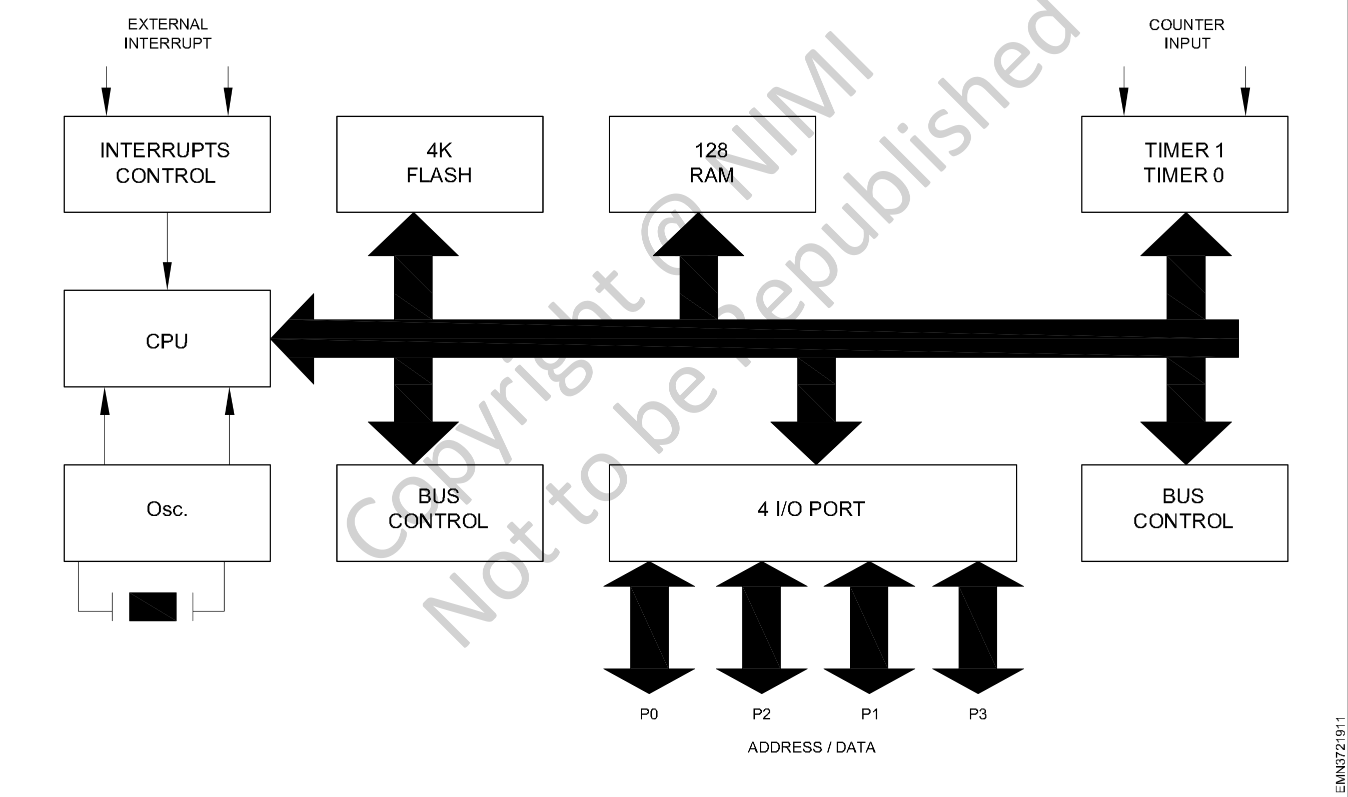
## Architecture of 8051

**Objectives :** At the end of this lesson you shall be able to
- **understand the architecture of 8051 microcontroller**
- **differetiate between microprocessor and microcontroller**
- **observe advantages of microcontroller.**

### Microcontroller

The main reason for the development of microcontroller is to overcome the drawback of the microprocessor. Even though microprocessors are powerful devices, they require external chips like RAM, ROM input/output ports and other components in order to design a complete working system. This made it economically difficult to develop computerized consumer applicances on a large scale as the system cost is very high. Microcontrollers are the devices that actually fit the profile "Computer - on - a chip" as it consists of a main processing unit or processor along with some other components that are necessary to make it a complete computer. The components that are present on a typical microcontroller IC are CPU, memory, input / ouput ports and timers. The block diagram of a microcontroller is shown below in fig.1.

Fig 1






Microcontrollers are basically used in embedded systems. Microcontrollers can be classified based on bus width, memory structure and instruction set. Bus width indicates a the size of the data bus.

Microcontrollers can be classified as 8-bit, 16- bit or 32-bit based on the bus width. Higher bus widths often result in better performance. Microcontrollers can be divided into two types based on their memory structures ; Embedded memory and external memory. In case of embedded memory microcontrollers, the required data and program memory is embedded into the IC. Whereas external memory microcontrollers do not have program memory embedded on them and require an external chip for the same. Now a day, all microcontrollers are embedded memory microcontrollers. The classification based on instruction set is similar to that of a microprocessor. They can be either CISC (complex instruction set computer) or RISC (Reduced instruction set computer. Majority of microcontrollers follow CISC architecture with over 80 instructions. Microcontrollers can also be divided based on their computer architecture into von neumann and harvard.

**Functions of different ICs used in the microcontroller kit**

**1 EPROM : 27256 ( 32k x 8 EPROM)**

The micro-51 EB LCD has a standard EPROM configuration of 32KB. The address for the monitor EPROM is 0000-3FFF. EPROM expansion is C000-FFFF.

**2 RAM : 61256 ( 256K x 16 BIT SRAM)**

The micro - 51 EB LCD has 32 KB of read /write program / data memory using one 61256 whose addres is from 4000 to BFFFF. The micro - 51 EB LCD has one more 32KB of read/write data memory using one 61256 whose address is 0000-3FFF and C000-FEFF.

**3 Parallel I/O interface : 8255 PPI (Programmable pheripheral interface)**

Intel 8255 programmble pheripheral interface 24 programmbable I/O lines configured as three 8 bit ports direct bit set / reset capability. Three modes of operation namely basic I/O, strobed I/O and bidirectional bus.

**4 RS485 Drivers and RS232 drivers : ICL 232 (RS232) and 74LBC184D (RS485)**

8051 is used for serial communication with associated diver for interface immunity and overcoming attenuation.

**5 Address Latch : (74LS273)**

It is used to latch the address (A0-A7) from AD lines (AD0-AD7). The latch stores the number output by the 8051 from the databus. So that the LED can be lit with any 8 bit binary number.

**6 Data bus buffer : (72LS244)**

It connect 8 bit of input data to I/O pheripheral devices.

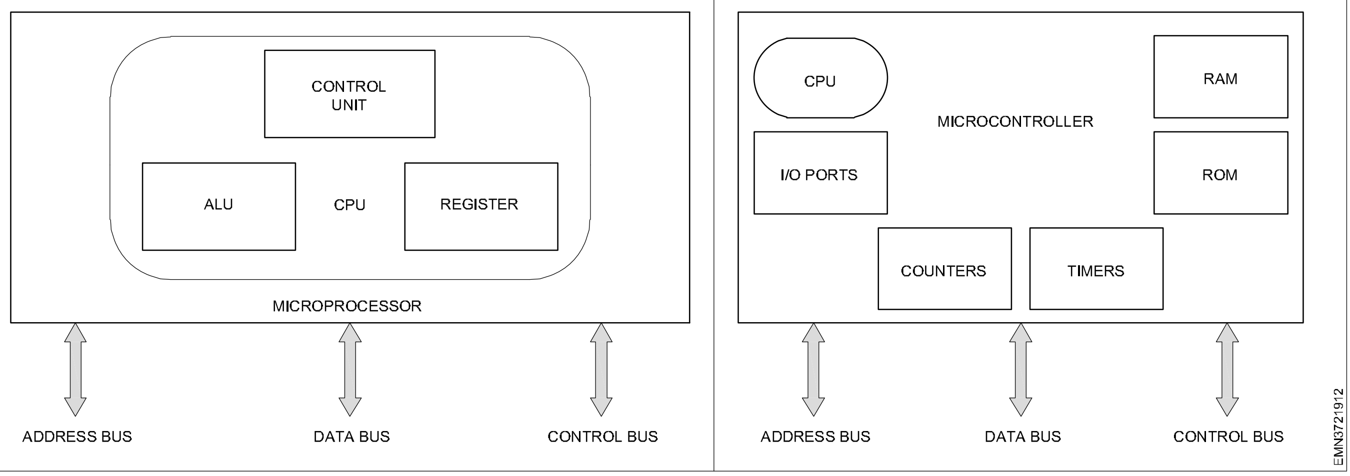
**7 LCD interface and LCD module : ( IC74174)**

The LCD is diaplay is driven by both address latch and data bus buffer.

The following table shows some of the difference between microprocessors and microcontrollers.

| Micropocessor | Microcontroller |
|---|---|
| Microprocessor assimilates the function of a central processing unit (CPU) on to a single integrated circuit (IC) | Microcontroller can be considered as a small computer which has a processor and some other components order to make it a micro computer chip. |
| Microprocessors are mainly used in designing general purpose systems from small to large and complex systems like super computers | Microcontrollers are used in automatically controlled devices |
| Microprocessors are basic components of personal computers | Microcontrollers are generally used in embedded system . |
| A microprocessor based system can perform numerous tasks | A microcontroller based system can perform single of very few tasks . |
| The main task of microprocessor is to perform the instruction cycle repeatedly. This includes fetch, decode and execute. | In addition to performing the tasks of fetch, decode and execute, a microcontroller also controls its environment based on the output of the instruction cycle. |
| In order to build or design a system (Computer, a microprocessor has to be connected externally to some other components like memory (RAM and ROM) and input output ports | The IC of a microcontroller has memory (both RAM, ROM) integrated on it along with some other components like I/O devices and timers |
| The overall cost of a sytem built using a microprocessor is high. This is because of the requirement of external components. | Cost of a system built using a microcontroller is less, all the components are readily available. |
| Generally power consumption and dissipation is high because of the external devices. Hence it requires external cooling system. | Power consumption is less |
| The clock frequency is very high usually in the order of Giga Hertz. | Clock frequency is less usually in the order of Mega Hertz. |

Fig 2




Advantages of microcontroller : As the microcontroller is having on - chip I/O ports, timer/counters, code and data memory (limited) which reduces the program exeuction time. (Fig.2)

**Comparative study of 8051 and 8052.**

Although the 8051 microcontroller was introduced first with 8 bit capacity the enhanced version of 8051 been developed later which is called 8052 micro controller. The 8052 microcontroller is technically designed with certain additional features. The common features of these microcontrollers are given in Table - 1 and the diffrences are given in Table - 2 below:

**Table - 2**

**Diffrences between 8051 and 8052**

| PARAMETERS | 8051 | 8052 |
|---|---|---|
| Internal RAM (DATA Memory) | 128byte | 256 Bye |
| Internal ROM (Code Memory) | 4Kb | 8Kb |
| Timer/Counter | 2 | 3 |
| No.of interrupt | 5 | 6 |

**Table - 1**

**Commom features of 8051 and 8052**

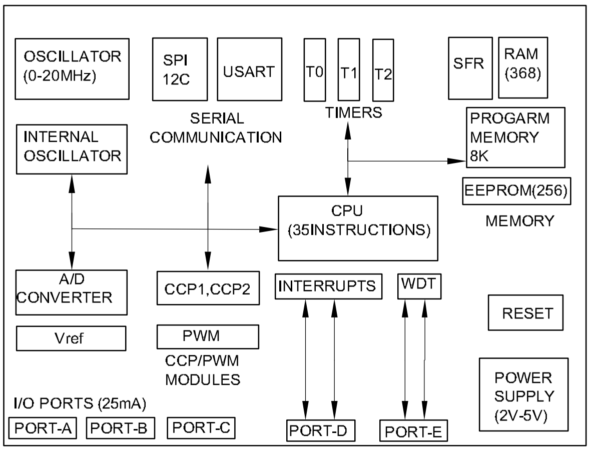
| Sl.No. | Parameter | 8051 | 8052 |
|---|---|---|---|
| 1. | Clocks instruction cycle | 12 | 12 |
| 2. | UARTs/serial ports | 1 | 1 |
| 3. | Maximum program size without external logic | 64K | 64K |
| 4. | Maximum PIO port pins | 32 | 32 |
| 5. | Size | 8Bit | 8Bit |

**Peripheral Interface Controller**

Peripheral Interface Controller (PIC) is the world's smallest and very fast microcontroller that can be programmed to execute a vast range of tasks compare with other controllers. These programming and the simulated process of this microcontroller can be done by a circuit-wizard software. PIC microcontroller is an IC and its architecture comprises of CPU, RAM, ROM, timers, counters and protocols like SPI, UART, CAN which are used for interfacing with other peripherals. Microcontrollers are used for industrial purpose also the advantages of using this microcontroller includes low power consumption, high performance, supports hardware and software tools such as simulators, compilers, and debuggers.

The block diagram of PIC microcontroller architecture is shown in (Fig-1) comprises of central processing unit (CPU), I/O ports, A/D converter, memory organization, timers/counters, serial communication, interrupts, oscillator and CCP module that are discussed in given below:

Fig 1




ARCHITECTURE OF PIC MICROCONTROLLER

EMN3721921

## Architecture of PIC Microcontroller

### Central Processing Unit (CPU)

PIC microcontroller's CPU is not different like other microcontroller CPU, which includes the ALU, controller unit, the memory unit, and accumulator. ALU is mainly used for arithmetic and logical operations. The memory unit is used to store the commands after processing. The control unit is used to control the internal & external peripherals, and the accumulator is used to store the final results and further processes.

### Memory Organization

The memory module of the PIC microcontroller architecture consists of Random Access Memory (RAM) Read Only Memory (ROM) and STACK.

## Memory Organization

### Random Access Memory (RAM)

(RAM) The Random access memory is used to store the information temporarily in its registers. It is categorized into two banks, each bank has so many registers. The RAM registers are categorized into two types, namely Special Function Registers (SFR) General Purpose Registers (GPR).

### General Purpose Registers (GPR)

As the name implies, These registers are used for general purpose only. For instance, if we want to multiply any two numbers by using this microcontroller. Usually, registers are used for multiplying and storing in other registers. So, GPR registers don't have any superior function,- CPU can simply access the data in the registers.

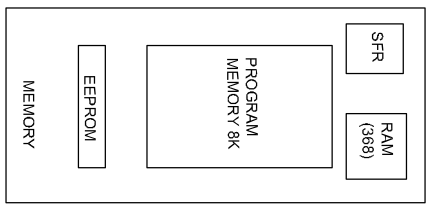
### Special Function Registers (SFR)

As the name implies, SFRs are used only for special purposes. These registers work based on the function assigned to them, and these registers cannot work as a normal register. For instance, if you cannot use the STATUS register for storing the information, SFRs are used for viewing the status of the program. So, the user cannot change the SFR's function; the function is given by the manufacturer at the time of built-up.

### Memory Organization

The memory organization of Peripheral Interface Controller (PIC) is shown in Fig 2 which includes the following:

Fig 2




EMN3721922

- Read Only Memory (ROM)
- Electrically Erasable Programmable Read Only Memory (EEPROM)
- Flash Memory
- Stack

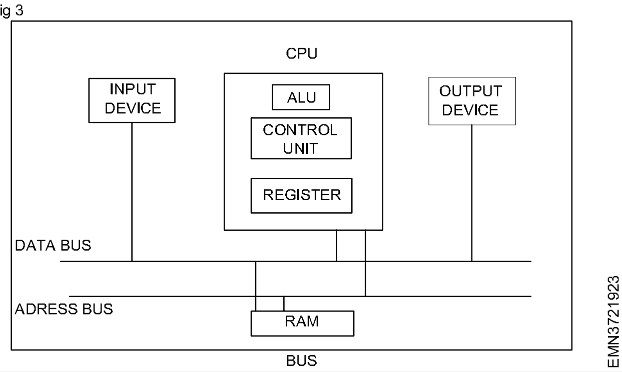
## Input Output (I/O) Ports

The PIC microcontroller consists of 5-ports, namely Port-A, Port-B, Port-C, Port-D and Port-E.

## BUS

BUS is used to transfer and receive the data from one peripheral to another as shown in Fig 3. It is categorized into two types as data bus and address bus.The Data Bus is used to transfer or receive the data.

Fig 3



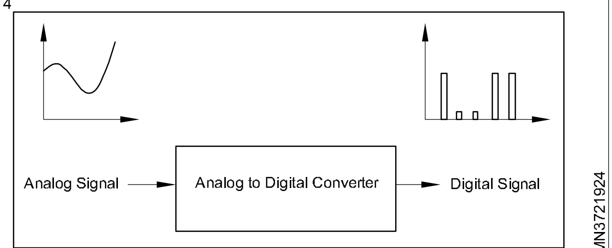
BUS

The address bus is used to transfer the memory address from the peripherals to the Central Processing Unit(CPU).Input /Output pins are used to interface the exterior peripherals; both the UART and USART are serial communication protocols, used to interface with serial devices such as GPS, GSM, IR, Bluetooth, etc.

## Analog to Digital (A/D) Converter

A/D converter is shown in Fig 4 . It is used to convert analog voltage values to digital voltage values. An A/D module in PIC Microcontroller Controller comprises of 5-inputs for 28-pin devices and 8-inputs for 40-pin devices. The operation of the A/D converter is controlled by special registers like ADCON0 & ADCON1. The upper and lower bits of the converter are stored in registers like ADRESH and ADRESL. In this process, it needs 5V of an analog reference voltage.

Fig 4



Analog to Digital Converter

## Timer/Counters

PIC microcontroller has four-timer/counters wherein the one 8-bit timer and the remaining timers have the choice to select 8 or 16-bit mode. Timers are used for generating accuracy actions, for example, creating specific time delays between two operations.

## Interrupts

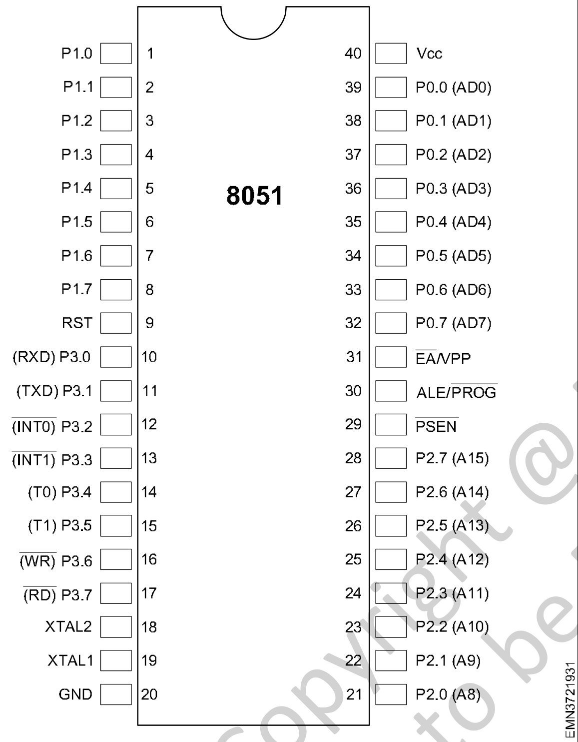
PIC microcontroller consists of 20 internal and 3-external interrupt sources which are allied with different peripherals like USART, ADC, Timers, and so on.

# Pin details of 8051, Internal data memory, SFR and on-chip features

**Objectives :** At the end of this lesson you shall be able to
- **pin diagram of 8051**
- **data memory and special function registers**
- **utilization of on - chip resources such as ADC.**

**The pin diagram of 8051: 8051 is a 40 pin microcontroller with I/O ports (Ref.Fig.1)**

Fig 1






There are 4 ports in 8051 IC (Port 0, Port 1, Port 2 and Port 3) 32 pins are function as I/O port lines and 24 of these lines are dual purpose (P0, P1, P3). Each can operate as I/O, or as a control line or part of the address or data bus. Eight lines in each port can be used in interfacing to parallel devices like printers, DAC etc., or each line the port can be used in interfacing to single bit devices like LED's, switches, transistors, solenoid, motors and loudspeakers.

**PORT 0 (32-39 Pins )**

It is a dual purpose port ( P0.0-P0.7). For simple design it is used as I/O ports. For larger design with external memory, it is used as multiplexed address and data bus (AD0-AD7)

**PORT 1(1-8 Pins )**

It is a dedicated I/O port ( P1.0-P1.7). It is used only to inferface with the external devices.

**PORT 2 (21-28 Pins )**

It is a dual purpose port (P2.0-P2.7). It is used as I/O port or higher byte of address bus (A8-A15).

**PORT 3 (10-17 Pins )**

It is a dual purpose port (P3.0- P3.7) It is used as I/O port, or used to special features of 8051 (Table 1)

Table 1

| BIT | Name | BIT Address | Alternate function |
|---|---|---|---|
| P 3.0 | RXD | B0H | Receive data for serial port |
| P 3.1 | TXD | B1H | Transmit data for serial port |
| P 3.2 | INT0 | B2H | External interrupt 0 |
| P 3.3 | INT1 | B3H | External interrupt 1 |
| P 3.4 | T0 | B4H | Timer /counter 0 external input |
| P 3.5 | T1 | B5H | Timer/counter 1 external input |
| P 3.6 | WR | B6H | External data memory write stroke |
| P 3.7 | RD | B7H | External data memory read stroke |
| P 1.0 | T2 | 90H | Timer/ Counter 2 external input |
| P 1.1 | T2EX | 91 H | Timer /Counter 2 capacture / reload |

**RST (9 Pin No )**

It is a master reset input pin. It should be kept high to start - up 8051.

**On- chip oscillator (18-19 Pins)**

It is a crystal oscillator with stabilizing capacitor connected to pin number 18 and 19. The normal crystal frequency is 12 MHz.

**Power connection (20,40 Pins)**

The 8051 operates at +5V DC. Pin No. 40 is Vcc. Pin No. 20 is Vss (GND)

**PSEN (Program store enable ) (29 Pin No)**

PSEN is an output and control signal to enable the external memory.

**ALE (Address Latch Enable) (30 Pin No)**

ALE is an ouput signal to control demultiplexing the address and data bus. ALE signal oscillates at 2 MHz.

**EA (External access) (31 Pin No)**

It is an input signal is generally kept high ( +5VDC) or low (GND). If EA is high 8051 executes program from internal ROM. If EA is low it executes program from external memory.

**Internal data memory**

128 Bytes of internal data memory is divided in to two parts, Part I is RAM (00- 7FH) Part II is special function registers (SFR) (80-FFH) Fig. 2

**RAM**

i) Register Bank (00H-1FH) 4 banks (Bank 0,1,2,3 ) Each bank consisting of 8 register (R0-R7)

ii) Bit addressable RAM (20 H-2FH)

iii) General purpose RAM (30 H-7FH)

**i. Register banks**

The bottom 32 locations of internal memory contain the register banks. The 8051 instruction set supports of 8 registers R0 through R7, and by default these registers are addresses 00H-07H.

**ii. Bit addressable RAM**

There are 128 general - purpose bit addressable locations at byte addresses 20 H through 2FH (8 bits /byte X 16 bytes = 128 bits ). These addresses are accessed as bytes or as bits, depending on the instruction.

For example, to set bit 67H, the following instruction could be used.

Set B 67H

Note that "Bit address 67H" is the most significant bit at "byte address 2CH".

**iii. General purpose RAM**

General purpose RAM consisting of address location(30H-7FH) which is byte addressable available to programmer to store data /programs.



Fig 2

RAM

Summary of the 8051 on-chip data memory (RAM)

| Byte address | Bit address | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 27 | 3F | 3E | 3D | 3C | 3B | 3A | 39 | 38 |
| 26 | 37 | 36 | 35 | 34 | 33 | 32 | 31 | 30 |
| 25 | 2F | 2E | 2D | 2C | 2B | 2A | 29 | 28 |
| 24 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 |
| 23 | IF | IE | ID | IC | IB | IA | 19 | 18 |
| 22 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 |
| 21 | 0F | 0E | 0D | 0C | 0B | 0A | 09 | 08 |
| 20 | 07 | 06 | 05 | 04 | 03 | 02 | 01 | 00 |
| 1F – 18 | Bank 3 | | | | | | | |
| 17 – 10 | Bank 2 | | | | | | | |
| 0F – 08 | Bank 1 | | | | | | | |
| 07 – 00 | Default register bank for R0-R7 | | | | | | | |

Bit – addressable locations (20 – 27)

| Byte address | Bit address | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 7F – 30 | General Purpose RAM | | | | | | | |
| 2F | 7F | 7E | 7D | 7C | 7B | 7A | 79 | 78 |
| 2E | 77 | 76 | 75 | 74 | 73 | 72 | 71 | 70 |
| 2D | 6F | 6E | 6D | 6C | 6B | 6A | 69 | 68 |
| 2C | 67 | 66 | 65 | 64 | 63 | 62 | 61 | 60 |
| 2B | 5F | 5E | 5D | 5C | 5B | 5A | 59 | 58 |
| 2A | 57 | 56 | 55 | 54 | 53 | 52 | 51 | 50 |
| 29 | 4F | 4E | 4D | 4C | 4B | 4A | 49 | 48 |
| 28 | 47 | 46 | 45 | 44 | 43 | 42 | 41 | 40 |

Bit-addressable locations (28 – 2F)

**21 SFRs are available, out of 21, 11 are bit addressable and 10 are byte addressable**

| | |
|---|---|
| P0 (80 H) | : Port 0, bit addressable |
| SP (81 H) | : Stack pointer |
| DPL (82 H) | : Data pointer low byte |
| DPH (83 H) | : Data pointer high byte |
| PCON (87H) | : Power control register |
| TCON (88H) | : Timer control register, bit addressable |
| TMOD (89H) | : Timer mode register |
| TL0 (8AH) | : Timer 0 low byte |
| TL1 (8BH) | : Timer 1 low byte |
| TH0 (8CH) | : Timer 0 high byte |
| TH1 (8DH) | : Timer 1 high byte |
| P1 (90H) | : Port 1, bit addressable |
| SCON (98H) | : Serial port control register, bit addressable |
| SBUF (99H) | : Serial data buffer, byte addressable |
| P2 (A0H) | : Port 2, bit addressable |
| IE (A8H) | : Interrupt enable, bit addressable |
| P3 (B0H) | :Port 3, bit addressable |
| IP (B8H) | : Interrupt priority, bit addressable |
| PSW (D0H) | : Program status word, bit addressable |
| ACC (E0H) | : Accumulator, bit addressable |

**On-chip features of 8051 philips microcontroller**

The derivative of 8051 philips microcontroller is most powerful 8 bit microcontroller. It has got an 8 bit CPU optimized for control application. 64 K program memory space, 64K data memory space, 4K bytes of on - chip program memory. 128 bytes of on - chip data memory, 32 bi-directional and individually addressable I/O lines, two 16 bit timer / counters, one full duplex serial port and 6 source /5- vector interruput with two priority level on - chip.

**Utilization of on - chip resources such as ADC**

The PCF 8591 is a single - chip, single - supply low - power 8 bit CMOS data acquisition, device with four analog inputs, one analog output and a serial I2C - bus interface. The functions of the device include analog input multiplexing, on- chip track and hold function, 8 bit analog-to-digital conversion and an 8- bit digital - to analog conversion. The maximum conversion rate is given by the maximum speed of the I2C- bus.

**Features and benefits**

- Single power supply
- Operating supply voltage 2.5V to 6.0V
- Low standby current
- Serial input and output via I2C- bus
- I2C address selection by 3 hardware address pins
- Max sampling ratte given by I2C- bus speed
- 4 Analog inputs configurable as single ended or differential inputs
- Auto- incremented channel selection
- Analog voltage range from VSS to VDD
- On - chip track and hold circuit
- 8-bit successive approximation A/D conversion
- Multiplying DAC with one analog output.

**Applications**

Supply monitoring

Reference setting

# Instruction set of 8051, arithmatic and logical function

**Objectives :** At the end of this lesson you shall be able to
- **write program for adding, subtracting, multiplying and dividing two 8 bit numbers**
- **write program for logical and, or function for two 8 bit numbers.**

**Assembly software for 8051**

Here some simple assembly language programs for 8051 microcontroller are given to understand the operation of different instructions and to understand the logic behind particular program.

MOVC A, @ A+DPTR ; A ← ext_code_mem (A+DPTR)

MOVC A, @ A+PC ; A ← ext_code_mem (A+PC)

**8051 Instruction set**

The 8051, 8-bit microcontroller family instruction set includes 111 instructions, 49 of which are single - byte, 45 two - byte and 17 three - byte instruction. The instruction opcode format consists of a function mnemonic followed by a destination & source operand field. The instruction set is divided into four functional groups.

- Data transfer
- Arithmetic
- Logic
- Control transfer

**i. Data transfer instructions**

Data transfer operations are divided into three classes:

- General - purpose
- Accumulator - specific
- Address - object

None of these operations affects the PSW flag settings except a POP or MOV directly to the PSW.

**Examples**

MOV A, # 45 - Immediate addressing mode

MOV A, R1 - Register addressing mode

MOV 45h, A - Direct addressing mode

MOV @ R1, 32 h - Indirect addressing mode

**ii. Arithmetic instructions**

The MCS - 51 family microcontrollers have four basic mathematical operations. Only 8- bit operations using unsigned arithmetic are supported directly. The overflow flag, however, permits the addition and subtraction operation to serve for both unsigned and signed binary integers. Arithmetic can also be performed directly on packed BCD representations.

**Examples**

ADD A, #84 - Immediate addressing mode

SUBB A, R2 - Register addressing mode

ADD 73h, a - Direct addressing mode

ADDC @R1, 25h - Indirect addressing mode

**iii. Logic instructions**

The MCS - 51 family microncontrollers perform basic logic operations on both bit and byte operands.

**Bit level (single operand) operations**

In 8051 internal RAM and SFRs can be addressed by the address of each bit within a byte. This bit addressing is very convenient when we wish to alter a single bit of a byte. The ability to operate on individual bits creates the need for the area of RAM that contains data addresses that hold a single bit. The bit addresses are numbered from 00H to 7FH to represent the 128d bit addresses that exist from byte addresses 20H to 2FH.

CLR sets a or any directly addressable bit to zero (0)

SETB sets and directly bit - addressable bit to one (1).

CPL is used to complement the contents of the A register without affecting any flag, or any directly addressable bit location.

RL, RLC, RR, RRC, SWAP are the five operations that can be performed on A. RL, rotate left, RR, rotate right, RLC, rotate left through carry, RRC, rotate right through carry and SWAP, rotate left four. Four RLC and RRC and CY flag become equal to the last bit rotated out. SWAP rotates A left four places to exchange bits 3 through 0 with bits 7 through 4.

**Byte level (two operand) operations**

ANL performs bits wise logical AND of two operands (for both bit and byte operands) and returns the result to the location of the first operand.

ORL performs bit wise logical OR of two source operands (for both bit and byte operand) and returns the result to the location of the first operand.

XRL performs logical exclusive OR two source operands (byte operands) and returns the result to the location of the first operand.

**Example**

ANL A, #45h - Immediate addressing mode

ORL A, R2 - Register addressing mode

XRL 52h, A - Direct addressing mode

ANL @R3, 65h - Indirect addressing mode

**iv. Control transfer instructions**

There are three classes of control transfer operations: unconditonal calls, returns, jumps, conditional jumps, and interrupts. All control transfer operations, some upon a specific condition, cause the program execution to continue a non - sequential location in program memory.

**Example**

**CJNE A, #22H, loop** - Immediate addressing mode

**DJNZ R1, loop** - Register addressing mode

**DJNZ 30H, loop** - direct addressing mode

**JMP @A + DPTR** - Indirect addressing mode

**Notes on data addressing modes**

**Rn-** Working register R0-R7

**Direct -** 128 Internal RAM locations, any I/O port, control or status register

**@Ri -** Indirect internal or external RAM location addressed by register R0 or R1

**#data -** 8-bit constant included in instruction

**#data 16-** 16- bit constant included as bytes 2 and 3 of instruction.

**bit -** 128 software flags, any bit - addressable I/O pin, control or status bit

**A** - accumulator

**Notes on program addressing modes**

**addr16-** Destination address for LCALL and LJMP may be anywhere within the 64-kbyte program memory address space.

**addr11-** Destination address for ACALL and AJMP will be within the same 2- kbyte page of program memory as the first byte of the following instruction.

**rel** - SJMP and all conditional jumps include an 8-bit offset byte. Range is +127/- 128 byts relative to the first byte of the following instruction.



**Instruction set summary**

| **Mnemonic** **Arithmetic operations** | | **Description** | **Byte** | **Cycle** |
|---|---|---|---|---|
| ADD | A, Rn | Add register to accumulator | 1 | 1 |
| ADD | A, direct | Add direct byte to accumulator | 2 | 1 |
| ADD | A @Ri | Add indirect RAM to accumulator | 1 | 1 |
| ADD | A, # data | Add immediate data to accumulator | 2 | 1 |
| ADDC | A, Rn | Add register to accumulator with carry flag | 1 | 1 |
| ADDC | A, direct | Add direct byte to A with carry flag | 2 | 1 |
| ADDC | A, @ Ri | Add indirect RAM to A with carry flag | 1 | 1 |
| ADDC | A, # data | Add immediate data to A with carry flag | 2 | 1 |
| SUBB | A, Rn | Subtract register from A with borrow | 1 | 1 |
| SUBB | A, direct | Subtract direct byte from A with borrow | 2 | 1 |
| SUBB | A, @Ri | Subtract indirect RAM from A with borrow | 1 | 1 |
| SUBB | A, #data | Subtract immediate data from A with borrow | 2 | 1 |
| INC | A | Increment accumulator | 1 | 1 |
| INC | Rn | Increment register | 1 | 1 |
| INC | direct | Increment direct byte | 2 | 1 |
| DEC | @Ri | Increment indirect RAM | 1 | 1 |
| DEC | A | Decrement accumulator | 1 | 1 |
| DEC | Rn | Decrement register | 1 | 1 |
| DEC | direct | Decrement direct byte | 2 | 1 |

| | | | | |
|---|---|---|---|---|
| DEC | @Ri | Decrement indirect RAM | 1 | 1 |
| INC | DPTR | Increment data pointer | 1 | 2 |
| MUL | AB | Multiply A and B | 1 | 4 |
| DIV | AB | Divide A by B | 1 | 4 |
| DA | A | Decimal adjust accumulator | 1 | 1 |

| **Logic Operations** | | **Description** | **Byte** | **Cycle** |
|---|---|---|---|---|
| ANL | A, Rn | AND register to accumulator | 1 | 1 |
| ANL | A, direct | AND direct by the to accumulator | 2 | 1 |
| ANL | A, @Ri | AND indirect RAM to accumulator | 1 | 1 |
| ANL | A, @data | AND immediate data to accumulator | 2 | 1 |
| ANL | direct, A | AND accumulator to direct byte | 2 | 1 |
| ANL | direct, #data | AND immediate data to direct byte | 3 | 2 |
| ORL | A, Rn | OR register to accumulator | 1 | 1 |
| ORL | A, direct | OR direct byte to accumulator | 2 | 1 |
| ORL | A, @Ri | OR indirect RAM to accumulator | 1 | 1 |
| ORL | A, #data | OR immediate data to accumulator | 2 | 1 |
| ORL | direct, A | OR accumulator to direct byte | 2 | 1 |
| ORL | direct, #data | OR immediate data to direct byte | 3 | 2 |
| XRL | A, Rn | Exclusive OR register to accumulator | 1 | 1 |
| XRL | A, direct | Exclusive OR direct byte to accumulator | 2 | 1 |
| XRL | A, @Ri | Exclusive OR indirect RAM to accumulator | 1 | 1 |
| XRL | A, #data | Exclusive OR immediate data to accumulator | 2 | 1 |
| XRL | direct, A | Exclusive OR accumulator to direct byte | 2 | 1 |
| XRL | direct, #data | Exclusive OR immediate data to direct byte | 3 | 2 |
| CLR | A | Clear accumulator | 1 | 1 |
| CPL | A | Complement accumulator | 1 | 1 |
| RL | A | Rotate accumulator left | 1 | 1 |
| RLC | A | Rotate accumulator left through carry | 1 | 1 |
| RR | A | Rotate accumulator right | 1 | 1 |
| RRC | A | Rotate accumulator right through carry | 1 | 1 |
| SWAP | A | Swap nibbles within the accumulator | 1 | 1 |

| Data transfer | | Description | Byte | Cycle |
|---|---|---|---|---|
| MOV | A, Rn | Move register to accumulator | 1 | 1 |
| MOV | A, direct | Move direct byte to accumulator | 2 | 1 |
| MOV | A, @Ri | Move indirect RAM to accumulator | 1 | 1 |
| MOV | A, #data | Move immediate data to accumulator | 2 | 1 |
| MOV | Rn, A | Move accumulator to register | 1 | 1 |
| MOV | Rn, direct | Move direct byte to register | 2 | 2 |
| MOV | Rn, #data | Move immediate data to register | 2 | 1 |
| MOV | direct, A | Move accumulator to direct byte | 2 | 1 |
| MOV | direct, Rn | Move register to direct byte | 2 | 2 |
| MOV | direct, direct | Move direct byte to direct byte | 3 | 2 |
| MOV | direct, @Ri | Move indirect RAM to direct byte | 2 | 2 |
| MOV | direct, #data | Move immediate data to direct byte | 3 | 2 |
| MOV | @Ri, A | Move accumulator to indirect RAM | 1 | 1 |
| MOV | @Ri, direct | Move direct byte to indirect RAM | 2 | 2 |
| MOV | @Ri, #data | Move immediate data to indirect RAM | 2 | 1 |
| MOV | DPTR, #data 16 | Load data pointer with a 16 - bit constant | 3 | 2 |
| MOV | A, @A+DPTR | Move code byte relative to DPTR to accumulator | 1 | 2 |
| MOVC | A, @A, +PC | Move code byte relative to PC to accumulator | 1 | 2 |
| MOVX | A, @Ri | Move external RAM ( 8-bit addr.) to A | 1 | 2 |
| MOVX | A, @DPTR, A | Move A to external RAM (16-bit addr.) | 1 | 2 |
| PUSH | direct | Push direct byte onto stack | 2 | 2 |
| XCH | A, Rn | Exchange register with accumulator | 1 | 1 |
| XCH | A, direct | Exchange direct byte with accumulator | 2 | 1 |
| XCH | a, @Ri | Exchange indirect RAM with accumulator | 1 | 1 |
| XCHD | A, @Ri | Exchange low- order nibble indir. RAM with A | 1 | 1 |



**Boolean variable manipulation**

| Mnemonic | | Description | Byte | Cycle |
|---|---|---|---|---|
| CLR | C | Clear carry flag | 1 | 1 |
| CLR | bit | Clear direct bit | 2 | 1 |
| SETB | C | Set carry flag | 1 | 1 |
| SETB | bit | Set direct bit | 2 | 1 |
| CPL | C | Complement carry flag | 1 | 1 |
| CPL | bit | Complement direct bit | 2 | 1 |

| Mnemonic | | Description | Byte | Cycle |
|---|---|---|---|---|
| ANL | C, bit | AND direct bit to carry flag | 2 | 2 |
| ANL | C, /bit | AND complement of direct bit to carry | 2 | 2 |
| ORL | C, bit | OR direct bit to carry flag | 2 | 2 |
| ORL | C, /bit | OR complement of direct bit to carry | 2 | 2 |
| MOV | c, bit | Move direct bit to carry flag | 2 | 1 |
| MOV | bit, C | Move cary flag to direct bit | 2 | 2 |

**Program and Machine control**

| Mnemonic | | Description | Byte | Cycle |
|---|---|---|---|---|
| ACALL | addr16 | Absolute subroutine call | 3 | 2 |
| LCALL | addr16 | Long subroutine call | 3 | 2 |
| RET | - | Return from subroutine | 1 | 2 |
| RETI | - | Return from interrupt | 1 | 2 |
| AJMP | addr16 | Absolute jump | 3 | 2 |
| LJMP | addr16 | Long jump | 3 | 2 |
| SJMP | rel | Short jump (relative addr.) | 3 | 2 |
| JMP | @A + DPTR | Jump inidrect relative to the DPTR | 1 | 2 |
| JZ | rel | Jump if accumulator is zero | 2 | 2 |
| JNZ | rel | Jump if carry flag is not zero | 2 | 2 |
| JC | rel | Jump if carry flag is set | 2 | 2 |
| JNC | rel | Jump if carry flag is not set | 2 | 2 |
| JB | bit, rel | Jump if direct bit is set | 3 | 2 |
| JNB | bit, rel | Jump if direct bit is set | 3 | 2 |
| JBC | bit, rel | Jump if direct bit is set and clear bit | 3 | 2 |
| CJNE | A, direct, rel | Compare direct byte to A and jump if not equal | 3 | 2 |
| CJNE | A, #data, rel | Compare immediate to A and jump if not equal | 3 | 2 |
| CJNE | Rn, #data, rel | Compare immed. to reg. and jump if not equal | 3 | 2 |
| CJNE | @Ri, #data, rel | Compare immed. to ind. and jump if not equal | 3 | 2 |
| DJNZ | Rn, rel | Decrement register and jump if not zero | 2 | 2 |
| DJNZ | direct, rel | Decrement direct byte and jump if not zero | 3 | 2 |
| NOP | | No operation | 1 | 1 |



**Program 1: 16 - bit addition**

**Objective**

To perform 16-bit additoin of the two 16-bit data using immediate addressing and store the result in memory.

**Theory :**

As there is only one 16- bit register in 8051, 16-bit addition is performed by using ADDC instruction twice, i.e adding LSD first and MSD next.

## Example

The program is to add the 16-bit data 1234 with the data 5678 and store the result at the locations 4150 and 4151 using immediate addressing.

Result : (4150) = AC (LSB); (4151) = 68 (MSB)

DATAL1 = 34; DATAL2 = 78

DATAM1 = 12; DATAM2 = 56

DATAM1 - MSD OF DATA1,

DATAM2 - MSD OF DATA2,

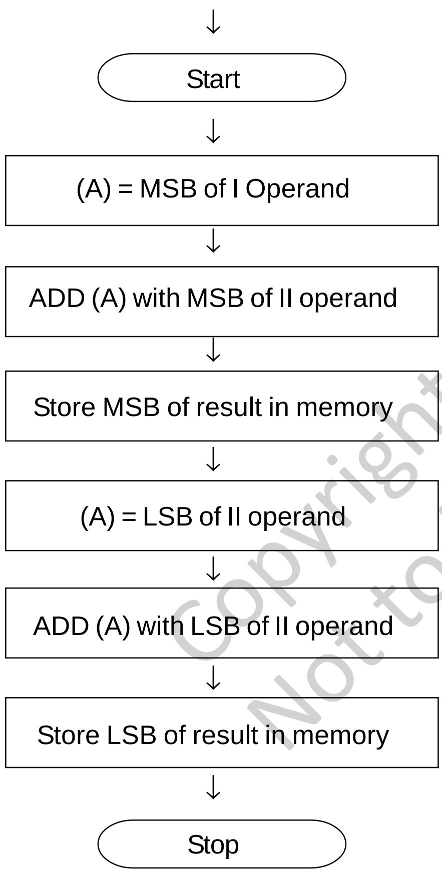
DATA1 - LSD OF DATA1,

DATA2 - LSD OF DATA 2,

**Flowchart:**

Program for 16 bit addition (refer manual)

16- Bit Addition




**Program :**

```
CLR         C
MOV         A, #DATAL1
ADDC        A, #DATAL2
MOV         DPTR, # 4150
MOVX        @DPTR, A
INC         DPTR
MOV         A, #DATAM1
ADDC        A, #DATAM2
MOVX        @DPTR, A
HLT : SJMP  HLT
```

**Object codes**

| Memory addreses | Object codes | Mnemonics |
|---|---|---|
| 4100 | C3 | CLR C |
| 4101 | 74 | MOV A,#DATAL1 |
| 4102 | 34 | |
| 4103 | 34 | ADDC. A, #DATAL2 |
| 4104 | 78 | |
| 4105 | 90 | MOV DPTR, #4150 |
| 4106 | 41 | |
| 4107 | 50 | |
| 4108 | F0 | MOVX @DPTR, A |
| 4109 | A3 | INC DPTR |
| 410A | 74 | MOV A, #DATAM1 |
| 410B | 12 | |
| 410C | 34 | ADDC A, #DATAM1 |
| 410D | 56 | |
| 410E | F0 | MOVX @DPTR,A |
| 410F | 80 | |
| 4110 | FE | HERE, SJMP HERE |



**Program 2 - 8 bit subtraction**

**Objective**

To perform subtraction of two 8-bit data using immediate addressing and store the result in memory.

**Theory**

Using the accumulator, subtraction is performed and the result is stored. Immediate addressing is employed. The SUBB instruction writes the result in the accumulator.

**Example**

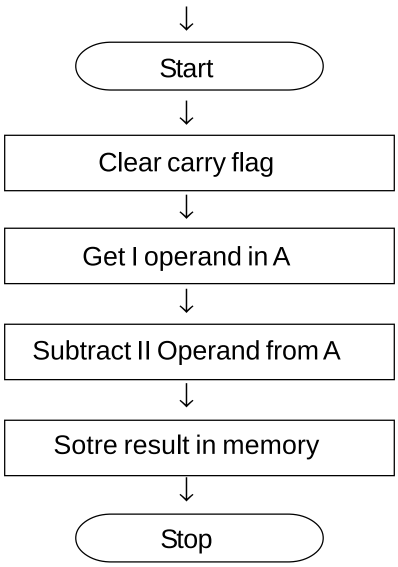
Sample data : DATA1 = 20

DATA 2 = 10

Result : (4500) = 10

**Flow chart**

**8 - bit subtraction**




| | |
|---|---|
| CLR | C |
| MOV | A, #DATA1 |
| SUBB | A, #DATA2 |
| MOV | DPTR, #4500 |
| MOVX | @DPTR, A |
| Here : SJMP | Here |

**Object codes**

| Memory addreses | Object codes | Mnemonics |
|---|---|---|
| 4100 | C3 | CLR C |
| 4101 | 74 | MOV A,#DATAL1 |
| 4102 | 20 | |
| 4103 | 94 | SUBB A, #DATAL2 |
| 4104 | 10 | |
| 4105 | 90 | MOV DPTR, #4500 |
| 4106 | 45 | |
| 4107 | 00 | |
| 4108 | F0 | MOVX @DPTR, A |
| 4109 | 80 | Here: SJMP here |
| 410A | FE | |

**Procedure**

i Enter the op codes and data in the trainer

ii Execute the program and verify for results

iii Change data and see that correct results are obtained.

**Exercises**

i. Subtract the contents of location 4500 from the contents of location 4501 and store the result at location 4600.

Sample data : (4500) = 56

(4501) = 6A

Result : (4600) = 14

ii. Perform the same subtraction using two's complement addition.

**Program 3 - 8 bit multiplication**

**Objective**

To obtain the product of two 8-bit data using immediate addressing and store the result in memory.

**Theory**

The 8051 has a "MUL" instruction unlike many other 8-bit processors. MUL instruction multiplies the unsigned eight - bit integers in A and B. The low - order byte of the product is left in A and the high- order byte in B. If the product is > 255, the overflow flag is set. Otherwise it is cleared. The carry flag is always cleared.

**Example**

Let us multiply the contents of registers A and B and store the 16-bit result at locations 4500 and 4501.

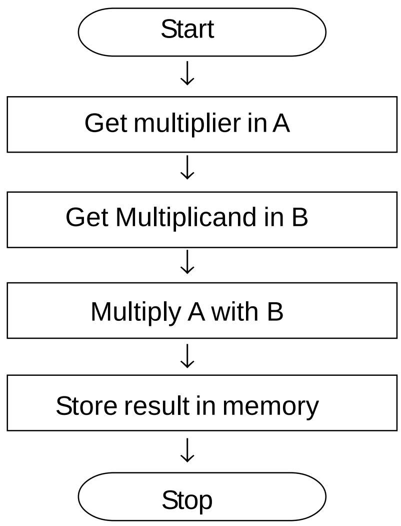
Sample data : DATA 1= 0A

DATA2 = 88

(4500) = 50 (LSB)

(4501) = 05 (MSB)

**8-bit Multiplication**




**Program**

| | |
|---|---|
| MOV | A, #DATA1 |
| MOV | B, #DATA2 |
| MUL | AB |
| MOV | DPTR, #4500 |
| MOVX | @DPTR, A |

| | |
|---|---|
| INC | DPTR |
| MOV | A, B |
| MOVX | @DPTR, A |
| Here : SJMP | Here |

**Object codes**

| Memory address | Object codes | Mnemonics |
|---|---|---|
| 4100 | 74 | MOV A,#DATAL1 |
| 4101 | 0A | |
| 4102 | 75 | MOV A,#DATAL2 |
| 4103 | F0 | |
| 4104 | 88 | |
| 4105 | A4 | MUL AB |
| 4106 | 90 | MOV DPTR, # 4500 |
| 4107 | 45 | |
| 4108 | 00 | |
| 4109 | F0 | MOVX @DPTR, A |
| 410A | A3 | INC DPTR |
| 410B | E5 | MOV A, B |
| 410C | F0 | |
| 410D | F0 | MOVX, @DPTR, A |
| 410E | 80 | Here : SJMP here |
| 410F | FE | |

**Procedure**

i. Enter the above opcode from 4100

ii. Execute the program; see that the result is stored correctly.

iii. Change data and check if the results are correct each time.

**Exercises**

i. Obtain the square of a number stored in memory

Sample : (4500) = 0A

Result : (4600) = 64

ii. Obtain the fourth power of 08 using MUL instruction and store the result in memory.

Result : (4500) = 10 (MSB)

(4501) = 00 (LSB)

iii. Do a decimal multi - byte addition in 32-bit and store the result in memory.

Data : (4500) = 04 - Count

(4551) = 99 - First number

(4552) = 99

(4553) = 99

(4554) = 99

(4561) = 99 - Second number

(4562) = 99

(4563) = 99

(4564) = 99

Result : (4570) = 98

(4571) = 99

(4572) = 99

(4573) = 99

(4574) = 01

**Program 4 - 8 bit division**

**Objective**

To divide an 8-bit number by another 8-bit number and store the quotient and remainder in memory.

**Theory**

The 8051 has a "DIV" instruction unlike many other 8-bit processors. DIV instruction divides the unsigned eight - bit integer in A by unsigned 8-bit integer in register B. The accumulator receives the integer part of the quotient and register B receives the integer remainder. The carry and flags will be cleared.

**Example**

Let the divisor and dividend be in registers B and A respectively.

Data : DATA 1 = 65 - Dividend

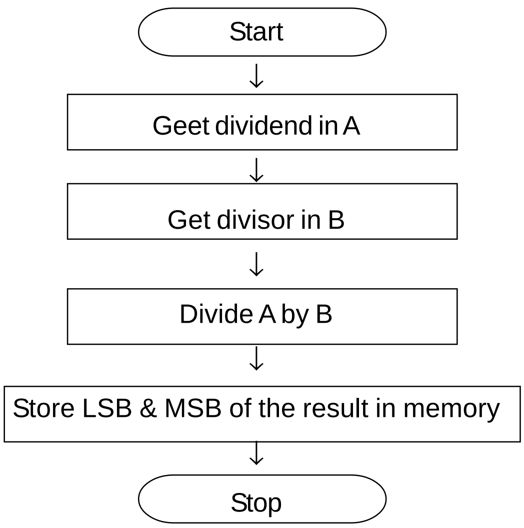
DATA2 = 08 - Divisor

Result : (4500) = 0C - Quotient

(4501) = 05= Remainder

**Flow Chart**

**8 bit by 8- bit division**



**Program**

MOV A, #DATA1 ; Load Acc. with dividend
MOV B # DATA2 ; Load Reg. B with divisor
DIV AB
MOV DPTR, # 4500
MOVX @DPTR, A ; Store quotient at 4500
INC DPTR
MOV A, B ; Store remainder at 4501
MOVX @DPTR, A
HLT : SJMP HLT

**Object codes**

| Memory address | Object codes | Mnemonics |
|---|---|---|
| 4100 | 74 | MOV A,#DATAL1 |
| 4101 | 65 | |
| 4102 | 75 | MOV B,#DATAL2 |
| 4103 | F0 | |
| 4104 | 08 | |
| 4105 | 84 | DIV AB |
| 4106 | 90 | MOV DPTR, # 4500 |
| 4107 | 45 | |
| 4108 | 00 | |
| 4109 | F0 | MOVX @DPTR, A |
| 410A | A3 | INC DPTR |
| 410B | E5 | MOV A, B |
| 410C | F0 | |
| 410D | F0 | MOVX, @DPTR, A |
| 410E | 80 | Here : SJMP here |
| 410F | 0E | |
| 4110 | 41 | |

**Procedure**

i. Enter the opcodes and the data in the trainer

ii. Execute the program and check for results

iii. Change data and check for the corresponding results.

**Discussion**

One's complement is nothing but the logical operation 'NOT' In this example, the CPL instruction has been employed . Since the two's complement of a number is its one's complement +1, by INC instruction has been employed. It can also be performed by adding 1 to one's complement number by using ADD instruction.

**Exercise**

i) Obtain the one's and two's complement of the data 77 and store it in memory.

Result : One's complement (4500) = 88

Two's complement (4501) = 89

**Program 5**

**Objective**

Perform OR function of an 8 bit number

**Theory**

Setting bits can be done by ORing that particular bit by1. The following program explains how to set a particualr bit in an 8-bit number by using the ORL instruction of 8051

**Example**

In the following program, the contents of the accumulator is ORed with an immediate data accordingly to set the required bits.

Sample data : DATA1 = 2F

DATA2 = 45

Result : (4500) = 6F

**Program**

MOV A, # DATA 1
ORL A, # DATA 2
MOV DPTR, # 4500
MOVX @DPTR, A
Here : SJMP Here

**Object codes**

| Memory address | Object codes | Mnemonics |
|---|---|---|
| 4100 | 74 | MOV A,#DATA1 |
| 4101 | 2F | |
| 4102 | 44 | ORL A,#DATA 2 |
| 4103 | 45 | |
| 4104 | 90 | MOV DPTR, #4500 |
| 4105 | 45 | |
| 4106 | 00 | |
| 4107 | F0 | MOVX @DPTR, A |
| 4108 | 80 | Here; SJMP here |

**Procedure**

i. Enter the opcodes and execute the program

ii. Check whether the corresponding bits are set accordingly.

## Discussion

The ORL instruction can be used to set a particular bit in the command or control registers of peripherals interfaced with the processor and can also be used to determine if the status read from peripherals is as expected.

## Exercises

i. Set alternate bits in an 8-bit number, starting from bit 0 and store the result at location 4200 in memory.

ii. Store successive powers of 2 from 0 to 7 in consecutive memory locations starting from 4300.

Result : (4300) = 01

(4301) = 02

(4302) = 04

(4303) = 08

(4304) = 10

(4305) = 20

(4306) = 40

(4307) = 80

## Program 6

## Objective

To perform AND function of an 8 bit number.

## Theory

The ANL instruction of 8051 can be used to reset bits. AND ing with zero prodcues a cleared bit. ANDing with one does not change the status of the bit.

## Example

To mask bits 0 and 7, the 8- bit data has to be ANDed with 7E, which is 01111110 in binary.

Sample data : DATA 1 = 87

DATA 2 = 7E

Result : (4500) = 06

## Program

```
MOV           A, #DATA 1
ANL           A, # DATA 2
MOV           DPTR, # 4500
MOVX          @DPTR, A
Here : SJMP   Here
```

## Object codes

| Memory address | Object codes | Mnemnics |
|---|---|---|
| 4100 | 74 | MOV A,#DATA1 |
| 4101 | 87 | |
| 4102 | 54 | ANL A, #DATA 2 |
| 4103 | 7E | |
| 4104 | 90 | MOV DPTR, #4500 |
| 4105 | 45 | |
| 4106 | 00 | |
| 4107 | F0 | MOVX @DPTR, A |
| 4108 | 80 | Here; SJMP here |
| 4109 | 08 | |
| 410A | 41 | |

## Procedure

i. Enter the opcodes from 4100 and execute the program.

ii. Check whether the result is 06 at 4500

## Discussion

The ANL instruction can be used to check whether a particular status is reached in the peripheral device just like the ORL instruction. The other logical instruction available in the instruction set of 8051 is the XRL (Exclusive -OR). The CLR (clear operand) instruction is also a logical instruction which can be used to initialize registers in counter operations.

## Timer on the microcontroller kit

**Objectives :** At the end of this lesson you shall be able to
- **Explain the function of timer is 8051**
- **design a delay program using timer in microcontroller kit.**

The 8051 microcontroller has two independent 16 bit up counting timers named timer 0 and timer 1 and this article is about generating time delays using the 8051 timers. Generating delay using pure software loops have been already discussed here but such delays are poor in accuracy and cannot be used in sensitive applications. Delay usng timer is the most accurate and surely the best method.

A timer can be generalized as a multi - bit counter which increments / decrements itself on receiving a clock signal and produces an interrupt signal up on roll over. When the counter is running on the processor's clock, it is called a "Timer", which counts a predefiend number of processor clock pulses and generates a programmable delay. When the counter is running on an external clock source (may be periodic or aperiodic external signal) it is called a "counter" itself and it can be used for counting external events.

In 8051, the oscillator output is divided by 12 using a divide by 12 network and then fed to the timer as the clock signal. That means for an 8051 running at 12 MHz, the timer clock input will be 1 MHz. That means the timer advances once in every 1μS and the maximum time delay possible using a single 8051 timer is ($2^{16}$) x (1μS) = 65536μS. Delays longer than this can be implemented by writing up a basic delay program using timer and then looping it for a required number of time. We will see all these in detail in next following sections.

**Designing a delay program using 8051 timers**

While designing delay programs in 8051, calculating the initial value that has to be loaded in to TH and TL registers forms a very important thing. Let us see how it is done.

Assume the processor is clocked by a 12MHz crystal.

That means, the timer clock input will be 12MHz/12=1MHz

That means, the time taken for the timer to make one increment = 1/1MHz= 1μs.

For a time delay of "X" μS the timer has to make "X" increments.

$2^{16}$= 65536 is the maximim number of counts possible for a 16 bit timers.

Let TH be the value that has to be loaded to TH registed and TL be the value that has to be loaded to TL register.

Then, THTL = Hexadecimal equivalent of (65536-X) where (65536-X) is considered in decimal.

**Example**

Let the required delay be 1000 μS =(ie; 1mS)

That means X = 1000

65536- X = 65536 - 1000 = 64536

645536 is considered in decimal and converting it to hexadecimal gives FC18

That menas THTL = FC18

Therefore TH=FC and TL = 18

**Program for generating 1mS delay using 8051 timer**

The program shown below can be used for generating 1mS delay and it is written as a subroutine so that you can call it anywhere in the program. Also you can put this in a loop for creating longer time delays (multiples of 1ms). Here timer 0 of 8051 is used and it is operating in MODE1 (16 bit timer).

Delay : MOV TMOD< #0000001B/ Sets timer 0 to MODE1 (16 bit timer). Timer 1 is not used

MOV TH0, #0FCH // TH0 register with FCH

MOV TL0, #018H // Loads TL0 register with 18H

SETB TR0 // Starts the timer 0

Here : JNB TF0, Here// Loops here until TF is set (ie ; until rool over)

CLR TR0 // Stops timer 0

CLR TF0 // Clear TF0 flag

RET

The above delay routine can be looped twice in order to get a 2mS delay and it is shown in the program below.

Main : MOV R6, #2D

LOOP : ACALL DELAY

DJNZ R6, LOOP

SJMP Main

Delay : MOV TMOD, #00000001B

MOV TH0, #0FCH

MOV TL0, #018H

SETB TR0

Here : JNB TF0, here

CLR TR0

CLR TF0

RET

**Few points to remember while using timers**

- Once timer flag (TF) is set,the programmer must clear it before it can be set agian
- The timer does not stop after the timer flag is set. The programmer must clear the TR bit in order to stop the timer.
- Once the timer overflows, the programmer must reload the initial start values to the TH and TL registers to begin counting up from.
- We can configure the desired timer to create an interrupt when the TF flag is set.
- IF interrupt is not used, then we have to check the timer flag (TF) is set using some conditional branching instruction.
- Maximum delay possible using a single 8051 timer is 65536µS and minimum is 1 µS provided that you are using a 12MHz crystal for clocking the microcontroller.

# Application of 8051 (motor, traffic control)

**Objectives :** At the end of this lesson you shall be able to
- **explain the application of 8051 microcontroller**
- **design the circuit to control of DC motor using 8051.**

### Application of 8051 microcontroller

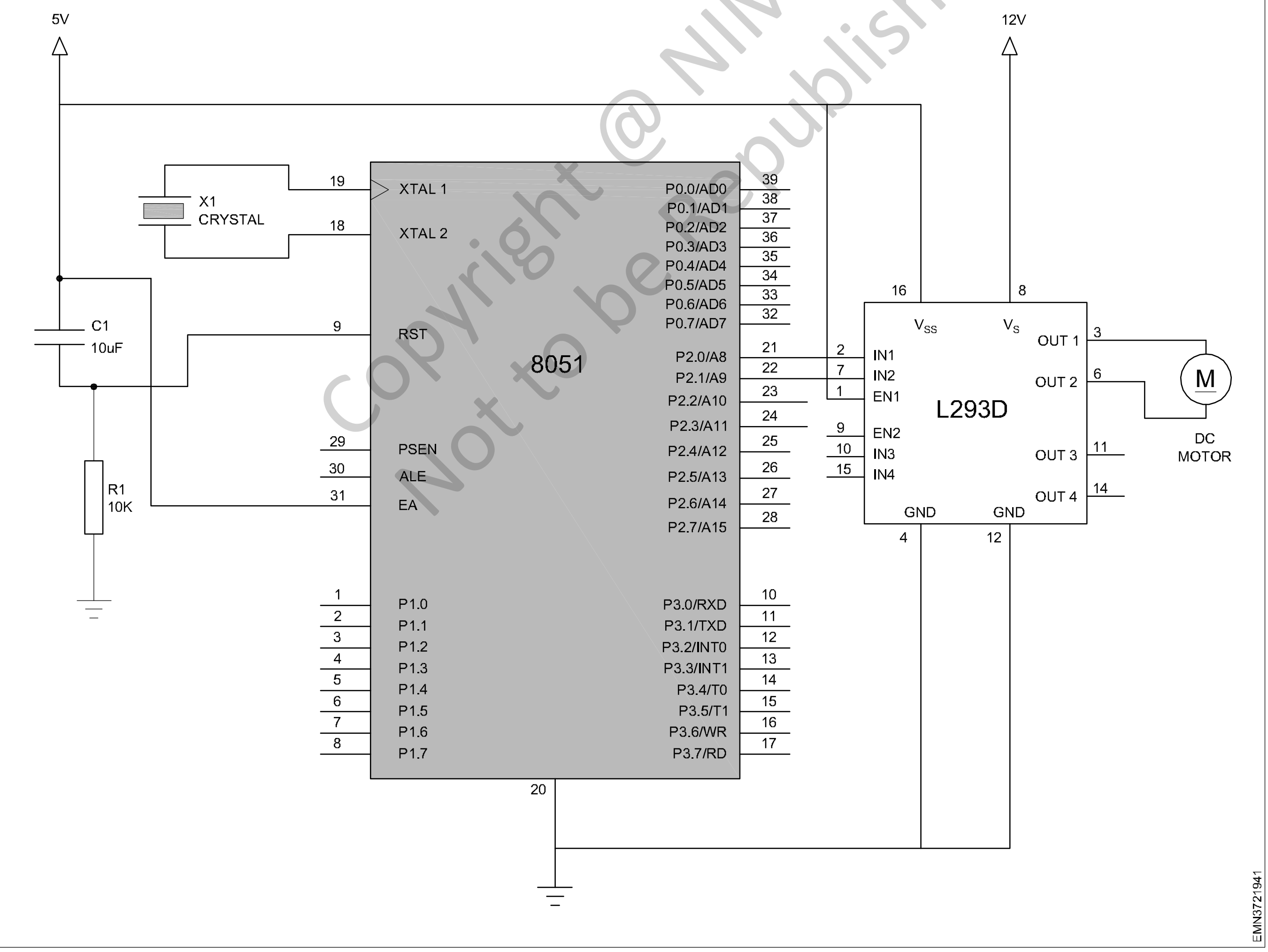
A microcontroller is a versatile chip which can be used in various fields starting from simple consumer electronics to high end medical, automobile and defence application also. So now a day the microcontrollers are found in every walk of life.

### Interfacing DC motor to 8051 using L293D

A DC motor runs in response to the applied DC current. It prodcues torque by using both electric and magnetic field.

The DC motor has rotor, stator, field magnet brushes, shaft, commutator etc., The DC motor required large currents of the order of 400 mA for its rotation. But this much amount of current cannot be generated by the ports of the microcontroller. So if it is direclty connect the DC motor to the ports of the conroller it may draw high current for its operation from the port and hence the microcontroller may be damaged. So we use a driving circuit along with opto isolator provides an additional protection to the microcontroller from large currents. (fig )1

Fig 1



**Assembly lanuage program to control DC motor using 8051**

| ORG | 0000H | | Remarks |
|---|---|---|---|
| Main | Set B | P1.2 | |
| | MOV | P1, # 00000001B | Motor runs in clockwise |
| | ACALL | Delay | |
| | MOV | P1, #00000010B | Motor runs in anticlockwise |
| | ACALL | Delay | |
| | SJMP | Main | Motor rotates continuously in clockwise for some time and anticlockwise for some time |
| Delay | MOV | R4, # FFH | Load R4 register with FF |
| | MOV | R3, #FFH | Load R3 register with FF |
| LOOP1 | DJNZ | R3, LOOP1 | Decrement R3 until it is zero |
| LOOP2 | DJNZ | R4, LOOP2 | Decrement R4 until it is zero |
| | RET | | Return to the main program |

**Traffic light control**

Traffic lights, which may also be known as stop lights, traffic lamps, traffic signals, signal lights, robots or semaphore, are signaling devices positioned at road intersections, pedestrian crossings and other locations to control competing flows of traffic.

**Interfacing traffic light with 8051**

The traffic light controller section consists of 12 Nos. point LEDS are arranged by 4 lanes in PS/8051 trainer kit. Each lane has go (green), listen (yellow) and stop (red) LED is being placed (Refer fig.2).

**About the colors of traffic light control**

Traffic lights alternate the right of way of road users by displaying lgihts of a standard color (red, yellow/amber, and green), using a universal color code ( and a precise sequence to enable comprehension by those who are color blind). In the typical sequence of colored lights.

Illumination of the green light allows traffic to proceed in the direction denoted.

Illumination of the yellow/ amber light denoting, if safe to do so, prepare to stop short of the intersection, and

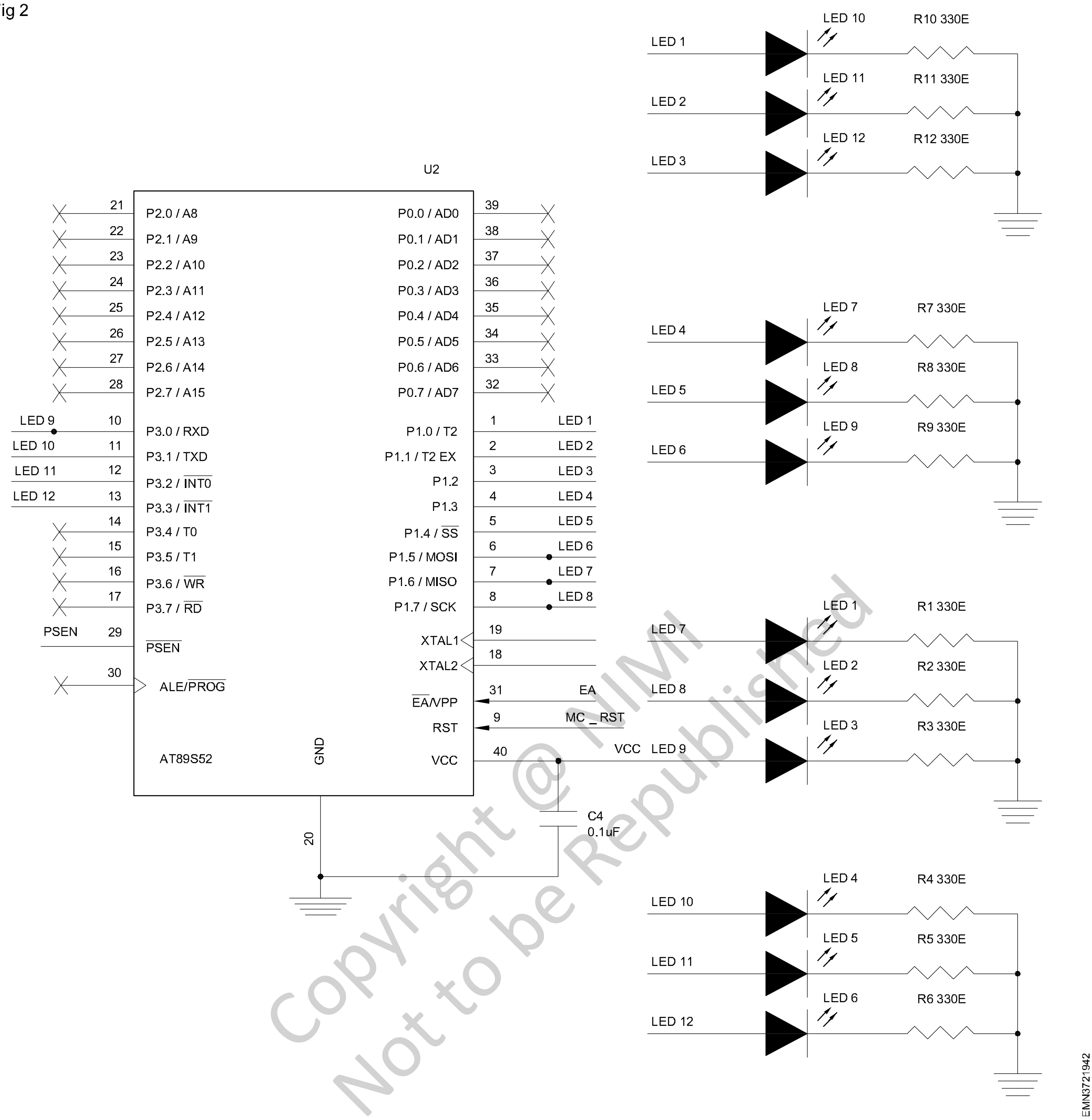
Illumination of the red signal prohibits any traffic from proceeding.

Usually, the red light contains some orange in its hue, and the green light contains some blue, for the benefit of people with red - green color blindness, and "green" lights in many areas are in fact blue lenses on a yellow light ( which together appear green)

**PIN assignment with 8051**

| LAN direction | 8051 lines | Modules |
|---|---|---|
| South | P1.0<br>P1.1<br>P1.2 | Go<br>Listen<br>Stop |
| East | P1.3<br>P1.4<br>P1.5 | Go<br>Listen<br>Stop |
| North | P1.6<br>P1.7<br>P3.0 | Go<br>Listen<br>Stop |
| West | P3.1<br>P3.2<br>P3.3 | Go<br>Listen<br>Stop |
| PWR | 13-16<br>17,19<br>18, 20 | NC<br>Vcc<br>GND |

Fig 2






**Assembly program to interface traffic light**

**Opcode** **Mnemonics**

Title :

Program to inferface

Traffic light with 8051

CNTL PORT : 4003

PORT A : 4000

PORT B : 4001

| Memory Address | Opcode | Mnemonics |
|---|---|---|
| 8500 | 90 85 45 | Start : MOV DPTR, # TRE |
| 8503 | 7A 0C | MOV R2, #0C |
| 8505 | E0 | MOVX @DPTR, A |
| 8506 | C0 83 | PUSH DPH |
| 8508 | C0 83 | PUSH DPL |
| 850A | 90 40 03 | MOV DPTR, #CNTL PORT |
| 850D | F0 | MOVX @DPTR, A |
| 850E | D0 82 | POP DPL |
| 8510 | D0 82 | POP DPL |
| 8512 | A3 | INC DPTR |
| 8513 | E0 | LOOP 1: MOVX @DPTR, A |
| 8514 | C0 83 | PUSH DPH |
| 8516 | C0 82 | PUSH DPL |
| 8518 | 90 40 00 | MOV DPTR, # PORTA |
| 851B | F0 | MOVX @ DPTR, A |
| 851C | D0 82 | POP DPL |
| 851E | D0 83 | POP DPH |
| 8520 | A3 | INC DPTR |
| 8521 | E0 | MOVX @DPTR, A |
| 8522 | C0 83 | PUSH DPH |
| 8524 | C0 82 | PUSH DPL |

| Memory Address | Opcode | Mnemonics |
|---|---|---|
| 8526 | 90 40 01 | MOV DPTR, #PORT B |
| 8529 | F0 | MOVX @DPTR, A |
| 852A | 12 85 36 | LCALL DELAY |
| 852D | D0 82 | POP DPL |
| 852F | D083 | POP DPH |
| 8531 | A3 | INC DPTR |
| 8532 | DA DF | DJNZ R2, LOOP 1 |
| 8534 | 80 CA | SJMP START |
| 8536 | 7F 10 | DELAY: MOV R7, # 10H |
| 8538 | 7D FF | LOOP P3, MOV R6, # 0FFH |
| 853C | 00 | LOOP2 : NOP |
| 853D | 00 | NOP |
| 853E | DE FC | DJNZ R6, LOOP2 |
| 8540 | DD F8 | DJNZ R5, LOOP3 |
| 8542 | DF F4 | DJNZ R7, LOOP4 |
| 8544 | 22 | RET |

TRE : 8545

| | |
|---|---|
| 8545 | 21H, 09H, 10H, 00H (South way) |
| 8549 | 0CH, 09H, 80J, 00H (East way) |
| 854D | 64H, 08H, 00H, 04H (North way) |
| 8551 | 24H, 03H, 02H, 00H (West way) |
| 8555 | End |

Note : The schematics sections given is, traffic light connected to port 1 and port 3 the sample program is given based on 8255

# Different types of Level Sensors and their workings

**Objectives :** At the end of this lesson you shall be able to
- **define the transducers, sensors and basics of passive & active transducers**
- **explain thermistor, its types and construction details**
- **describe the working principle, features, applications, advantage & disadvantages.**

**Transducers and sensors**

**Transducer**

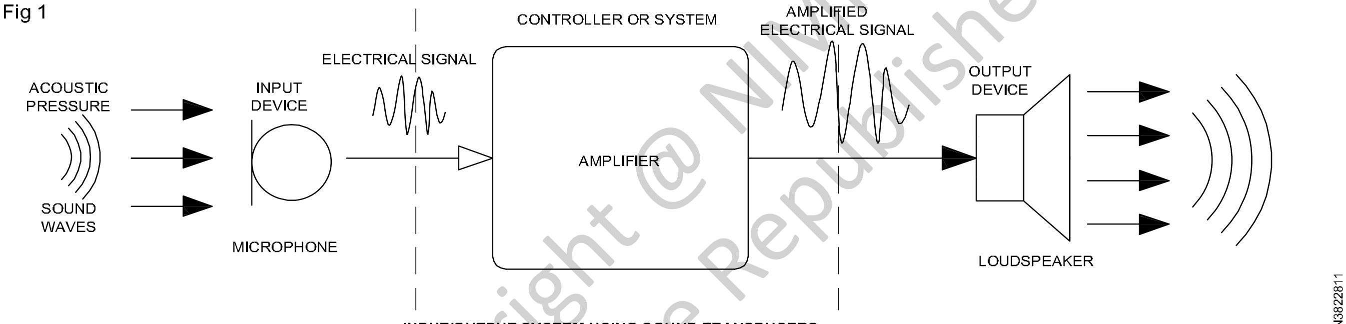
A transducer is a device that is used to convert a physical quantity into its corresponding electrical signal or vice versa. In most of the electrical systems, the input signal will not be an electrical signal, but a non-electrical signal. This will have to be converted into its corresponding electrical signal if its value is to be measured using electrical methods.

**Sensor:** Devices which perform an "Input" function are commonly called Sensors because they "sense" a physical change in some characteristic that changes in response to some excitation, for example heat or force is converted into an electrical signal.

There are different types of Sensors and Transducers, both analogue & digital and input & output available to choose from. The type of input or output transducer being used, really depends upon the type of signal or process being "Sensed" or "Controlled" but we can define a sensor and transducers as devices that converts one physical quantity into another.

**Simple Input/Output System using Sound Transducers as shown in fig. 1**

Fig 1




INPUT/OUTPUT SYSTEM USING SOUND TRANSDUCERS



There are different types of sensors and transducers available in the market, and the choice of which one to use really depends upon the quantity being measured or controlled. The more common types given in the table 1.

Table 1

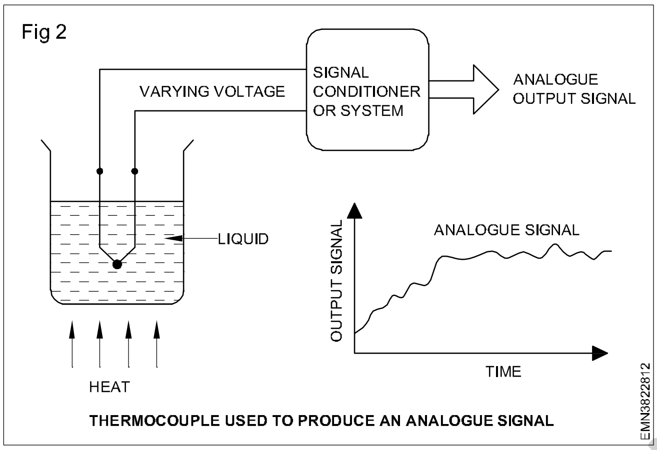
| Physical quantity being measured by the sensor | Input Device (Sensor) | Output Device (Actuator) |
|---|---|---|
| Light Level | Light Dependant Resistor (LDR)<br>Photodiode, Photo-transistor<br>Solar Cell | Lights & Lamps<br>LED's & Displays<br>Fibre Optics |
| Temperature | Thermocouple, Thermistor,<br>Thermostat, Resistive Temperature Detectors | Heater, Fan |
| Force/Pressure | Strain Gauge, Pressure Switch<br>Load Cells | Lifts & Jacks<br>Electromagnet, Vibration |
| Position | Potentiometer, Encoders<br>Reflective/Slotted Opto-switch<br>LVDT | Motor, Solenoid<br>Panel Meters |
| Speed | Tacho-generator, Reflective/Slotted Opto-coupler, Doppler Effect Sensors | AC and DC Motors<br>Stepper Motor, Brake |
| Sound | Carbon Microphone, Piezo-electric Crystal | Bell<br>Buzzer, Loudspeaker |

## Analogue and Digital Sensors

### Analogue Sensors

Analogue Sensors produce a continuous output signal or voltage which is generally proportional to the quantity being measured. Physical quantities such as Temperature, Speed, Pressure, Displacement, Strain etc are all analogue quantities as they tend to be continuous in nature. For example, the temperature of a liquid can be measured using a thermometer or thermocouple which continuously responds to temperature changes as the liquid is heated up or cooled down. as shown in fig. 2

**Thermocouple used to produce an Analogue Signal**



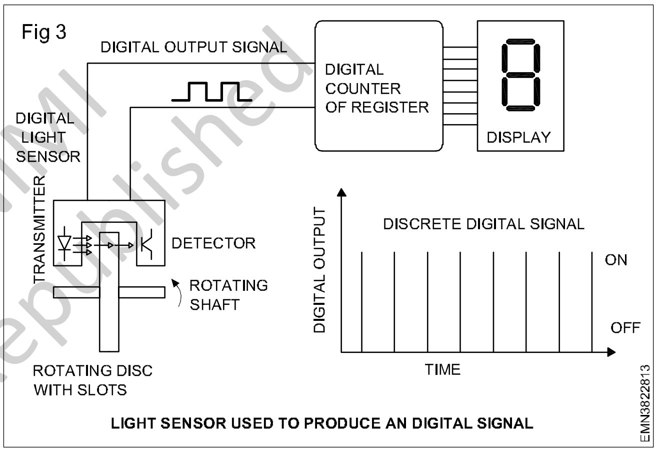

Analogue sensors tend to produce output signals that are changing smoothly and continuously over time. These signals tend to be very small in value from a few mico-volts (uV) to several milli-volts (mV), so some form of amplification is required. Then circuits which measure analogue signals usually have a slow response and/or low accuracy. Also analogue signals can be easily converted into digital type signals for use in micro-controller systems by the use of analogue-to-digital converters (ADCs).

### Digital Sensors

As its name implies, **Digital Sensors** produce a discrete digital output signals or voltages that are a digital representation of the quantity being measured. Digital sensors produce a **Binary** output signal in the form of a logic "1" or a logic "0", ("ON" or "OFF"). This means then that a digital signal only produces discrete (non-continuous) values which may be outputted as a single "bit", (serial transmission) or by combining the bits to produce a single "byte" output (parallel transmission).

**Light Sensor used to produce an Digital Signal**

In our simple example as shown fig.3 the speed of the rotating shaft is measured by using a digital LED/Opto-detector sensor. The disc which is fixed to a rotating shaft (for example, from a motor or robot wheels), has a number of transparent slots within its design, As the disc rotates with the speed of the shaft, each slot passes by the sensor in turn producing an output pulse representing a logic "1" or logic "0" level.





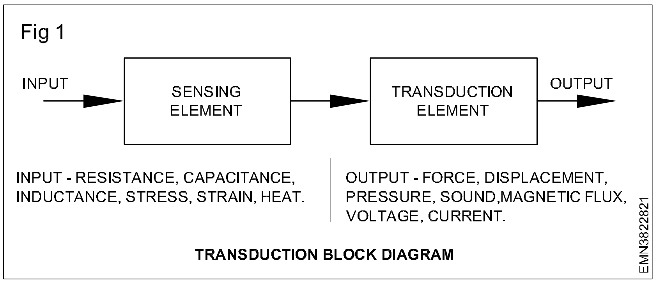

# Basics of passive and active transducers

**Objectives :** At the end of this lesson you shall be able to
- **define the classification of the transducers**
- **explain the various type of passive and active transducers**
- **describe the procedure for selection of transducers.**

A transducer is a device that is used to convert a physical quantity into its corresponding electrical signal. In most of the electrical systems, the input signal will not be an electrical signal, but a non-electrical signal. This will have to be converted into its corresponding electrical signal if its value is to be measured using electrical methods.

A transducer will have basically two main components. They are as shown in fig. 1

**Sensing Element :** The physical quantity or its rate of change is sensed and responded to by this part of the transistor.




**Transduction Element :** The output of the sensing element is passed on to the transduction element. This element is responsible for converting the non-electrical signal into its proportional electrical signal.

There may be cases when the transduction element performs the action of both transduction and sensing.

**Diffrent Types of Level Sensors and their Workings**

A level sensor is one kind of device used to determine the liquid level that flows in an open system or closed system The level measurements can be available in two types namely continous measurements and point level measurements. The continuous level sensor is used to measure the levels to a precise limit whereas point level sensors used to determine the level of liquid wheather that is high or low.

Fig 4

LEVEL SENSORS

EMN3822814

Generally these sensors are connected to an output unit for sending out the results to a monitoring system The present technologies use wireless transmission of information to the monitoring system, which is very useful in imprtant and hazardous locations that cannot be simply accessed by common workers.

**Classification of Level sensors**

**Ultrasonic Level sensors**

Level sensors are classified according to their working principle and their applications.

Ultrasonic level sensors are used to detect the levels of sticky liquid substances and bulkiness materials as well. They are worked by producing audio waves at the range of frequency from 20 to 200 kHz. These waves are then replicated back to a transducer The ultrasonic level sensors are used to control the liquid level, fine-grained solids within mining and powders, food and beverage industries and chemical processing

**Capacitance Level Sensors**

These sensors are used to detect the liquid levels like slurries and aqueous liquids They are operated by using a probe for checking level changes. These level changes are transformed into analong signals. The probes are generally made of conducting wire by PTFE insulation But stainless steel probes are extermely responce and hence they are appropriate for measuring non-conductive subsance granular or materials with low dielectric constant. These types of sensors are very simple to use and clean as they do not have any moving components.

They are commonly used in applications like Tank level monitoring in chemical, water treatment, food, battery industries and involving high pressure and temperature

**Optical Level Sensors**

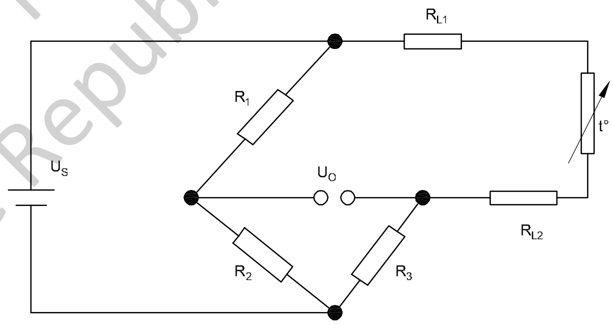
Optical level sensors are used to detect liquid including poised materials, interface between two immiscible liquids and the occurrence of sediments. They are working based on the changes of transmission in infrared light emitted from an IR LED. The interference from the produced light can be reduced by using a high energy IR diode and pulse modulation methods.

Continuous optical level sensors, on the other hand, use the highly internse laser light that can infuse dusty enviroments and notice liquid substances. They are commonly used in applications like leak detection and tank level measurement

**RTD Configuration**

An RTD can be connected in a two, three or four-wire configuration. The two-wire configuration is the simplest and also the most error prone. In this setup, the RTD is connected by two wires to a Wheatstone bridge circuit and the two output voltage is measured. The disadvntage of this circuit is that the two connecting lead wire

Fig 5

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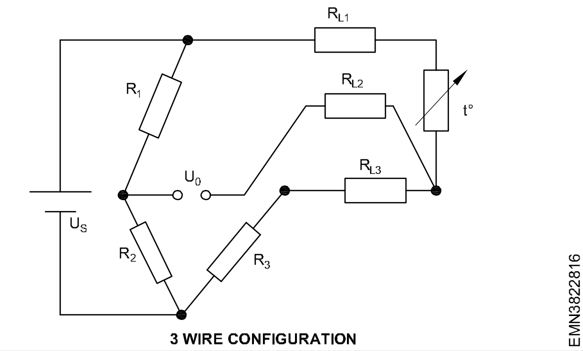
resistances add directly two RTD's resistance and error is incurred.

**2-Wire Configuration**

The four-wire configuration consists of two current leads and two potential leads that measure the voltage drop across the RTD. The two potential leads are high resistance to negate the effect of the voltage drop due to current flowing during the measurement.

This configuration is ideal for canceling the lead wire resistance in the circuit as well as eliminating the effects of different lead resistance, Which was possible problem with the three-wire configuration. The four-wire configuration is commonly used when a highly accurate measurement is requried for the application

Fig 6




3 WIRE CONFIGURATION

## Float Switch

Liquid Level sensors or float switches are used to monitor liquid levels in tanks or other vessels and are designed to react according to react according to predefined high or low levels. They are connected to the pump motor in series with the supply.

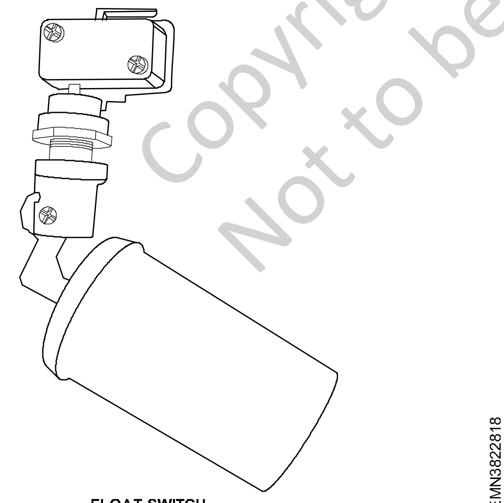
The folat switch is shown in Fig 8. It consists of a micro switch attached to a assembly with a hollow cylinderical sealed float hinged to move up and down

**The micro switch is N/C type and connects power supply to motor for pumping water into tank.**

When the water raises the float raises and the attached, lever pushes the knob of micro switch open/disconnect the electrical circuit. Thus the pump motor is switched OFF.

Whenever the water level decreases the float comes down, there by the micro switch is automatically connect power

Fig 8



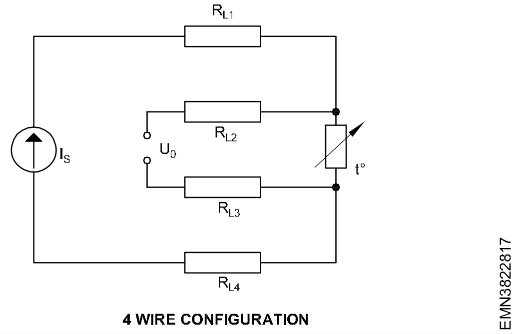

FLOAT SWITCH

to the motor.

## Float Value

A float valve is used to shut off the flow of liquids, normally water, at a predetermined level. when adjusted and working properly a float value is very accurate and extremely reliable. Float values are found in nearly every over head water tank at home as well as in many industrial applications. The concepts of the float value is very simple,

Fig 7

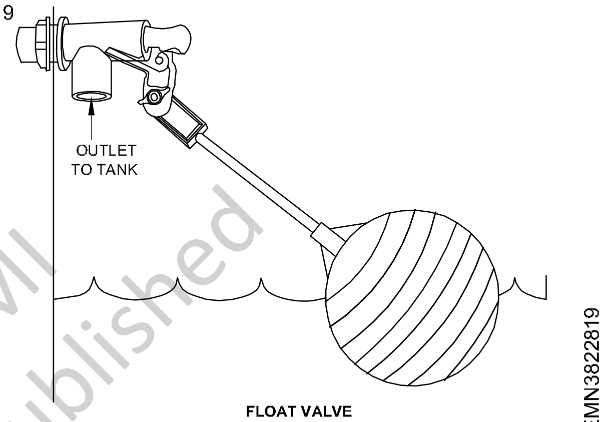



4 WIRE CONFIGURATION

Which accounts for its reliability and wide spread use.The float value is shown in Fig 9

It consists of a value connected to a hollowball sealed float rises with it: once it rises to a pre-set level, the

Fig 9




FLOAT VALVE

mechanism forces the lever to close the valve and shut off the water flow.



**Classification of transducers (Passive & Active)**

**Passive transducers**

Passive transducer require an external power supply to operate, called an excitation signal which is used by the sensor to produce the output signal.

**Active transducers**

Active transducers are self-generating devices because their own properties change in response to an external effect.

**1. Passive Type Transducers**

**a) Resistance Variation Type**

**Resistance Strain Gauge -** The change in value of resistance of metal semi-conductor due to elongation or compression is known by the measurement of torque, displacement or force.

**Resistance Thermometer / Resistance Temperature Detector (RTD) -** The change in resistance of metal wire due to the change in temperature known by the measurement of temperature

**Resistance Hygrometer -** The change in the resistance of conductive strip due to the change of moisture content is known by the value of its corresponding humidity.

**Hot Wire Meter -** The change in resistance of a heating element due to convection cooling of a flow of gas is known by its corresponding gas flow or pressure.

**Photoconductive Cell -** The change in resistance of a cell due to a corresponding change in light flux is known by its corresponding light intensity.

**Thermistor -** The change in resistance of a semi-conductor that has a negative co-efficient of resistance is known by its corresponding measure of temperature.

**Potentiometer Type -** The change in resistance of a potentiometer reading due to the movement of the slider as a part of an external force applied is known by its corresponding pressure or displacement.

**b) Capacitance Variation Type**

**Variable Capacitance Pressure Gauge -** The change in capacitance due to the change of distance between two parallel plates caused by an external force is known by its corresponding displacement or pressure.

**Dielectric Gauge -** The change in capacitance due to a change in the dielectric is known by its corresponding liquid level or thickness.

**Capacitor Microphone -** The change in capacitance due to the variation in sound pressure on a movable diaphragm is known by its corresponding sound.

**c) Inductance Variation Type**

**Eddy Current Transducer -** The change in inductance of a coil due to the proximity of an eddy current plate is known by its corresponding displacement or thickness.

**Variable Reluctance Type -** The variation in reluctance of a magnetic circuit that occurs due to the change in position of the iron core or coil is known by its corresponding displacement or pressure.

**Proximity Inductance Type -** The inductance change of an alternating current excited coil due to the change in the magnetic circuit is known by its corresponding pressure or displacement.

**Differential Transformer -** The change in differential voltage of 2 secondary windings of a transformer because of the change in position of the magnetic core is known by its corresponding force, pressure or displacement.

**Magnetostrictive Transducer -** The change in magnetic properties due to change in pressure and stress is known by its corresponding sound value, pressure or force.

**d) Voltage and Current Type**

**Photo-emissive Cell -** Electron emission due to light incidence on photo-emissive surface is known by its corresponding light flux value.

**Hall Effect -** The voltage generated due to magnetic flux across a semi-conductor plate with a movement of current through it is known by its corresponding value of magnetic flux or current.

**Ionisation Chamber -** The electron flow variation due to the ionisation of gas caused by radio-active radiation is known by its corresponding radiation value.

**2. Active Type**

**Photo-voltaic Cell -** The voltage change that occurs across the p-n junction due to light radiation is known by its corresponding solar cell value or light intensity.

**Thermocouple -** The voltage change developed across a junction of two dissimilar metals is known by its corresponding value of temperature, heat or flow.

**Piezoelectric Type -** When an external force is applied on to a quartz crystal, there will be a change in the voltage generated across the surface. This change is measured by its corresponding value of sound or vibration.

**Moving Coil Type -** The change in voltage generated in a magnetic field can be measured using its corresponding value of vibration or velocity.

**Selection of Transducer**

Selection of a transducer is one of the most important factors which help in obtaining accurate results. Some of the main parameters are given below.

- Selection depends on the physical quantity to be measured.
- Depends on the best transducer principle for the given physical input
- Depends on the order of accuracy to be obtained
- Based on whether the transducer is active or passive.

**Characteristic of transducer**

All transducers, irrespective of their measurement requirements, exhibit the same characteristics such as range, span, etc.

# Thermistors

**Objectives :** At the end of this lesson you shall be able to
- **define thermistor and its types**
- **define construction and working principle, salient features of the thermistor**
- **describe the application, advantages & disadvantages.**

**Thermistor:**

A thermistor is a resistance thermometer, or a resistor whose resistance is dependent on temperature. The term is a combination of "thermal" and "resistor". It is made of metallic oxides, pressed into a bead, disk, or cylindrical shape and then encapsulated with an impermeable material such as epoxy or glass.

A thermistor is a temperature sensor constructed of semiconductor material that exhibits a large modification in resistance in proportion to a tiny low modification in temperature. Thermistor is inexpensive, rugged, and reliable and responds quickly. Because of these qualities thermistors are used to measure simple temperature measurements, but not for high temperatures. Thermistor is easy to use, cheap, and durable and responds predictably to a change in temperature. Thermistors are mostly used in digital thermometers and home appliances such as refrigerator, ovens, and so on. Stability, sensitivity and time constant are the final properties of thermistor that create these thermistors sturdy, portable, cost-efficient, sensitive and best to measure single-point temperature. Thermistors are available in different shapes like rod, disc, bead, washer, etc. This article gives an overview of thermistor working principle and applications.

**Types of thermistor:**

There are a number of ways in which thermistors can be categorised into the different thermistor types. The first is dependent upon the way they react to heat. Some increase their resistance with increasing temperature, while others exhibit a fall in resistance.

It is possible to use a very simplified equation for the curve of a thermistor to expand this idea:

$$\Delta R = k \times \Delta T$$

**Where**

$\Delta R$ = change in resistance.

$\Delta T$ = change in temperature.

k = first-order temperature coefficient of resistance.

In most cases the relationship between temperature and resistance is non-linear, but over small changes a linear relationship can be assumed.

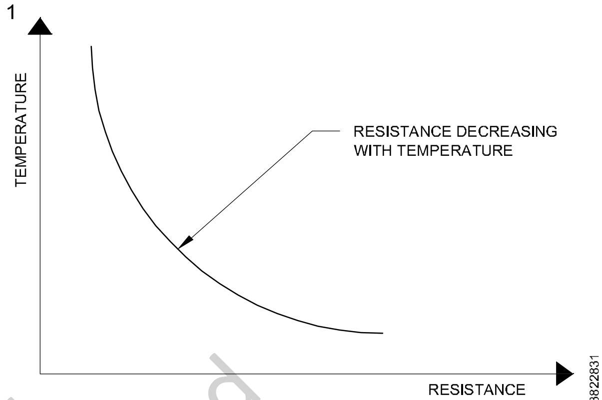
There are two types of thermistor

1 Negative Temperature Coefficient (NTC)

2 Positive Temperature Coefficient (PTC)

**Negative Temperature Coefficient (NTC):**

Fig 1

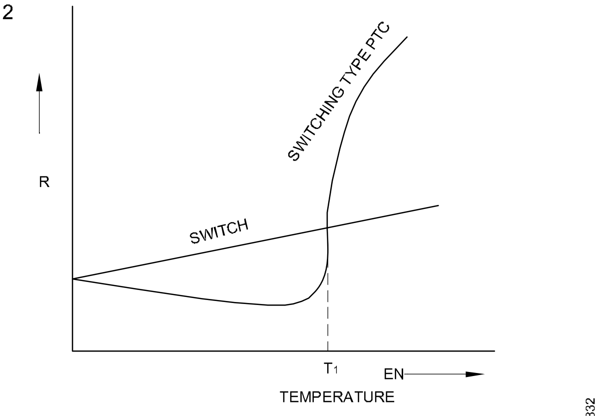



NTC TEMPERATURE VS RESISTANCE CURVE

Negative Temperature Coefficient (NTC) thermistor, when the temperature increases, resistance decreases. Conversely, when temperature decreases, resistance increases as shown in the fig 1. This type of thermistor is used the most.

**Positive Temperature coefficient (PTC):**

Fig 2

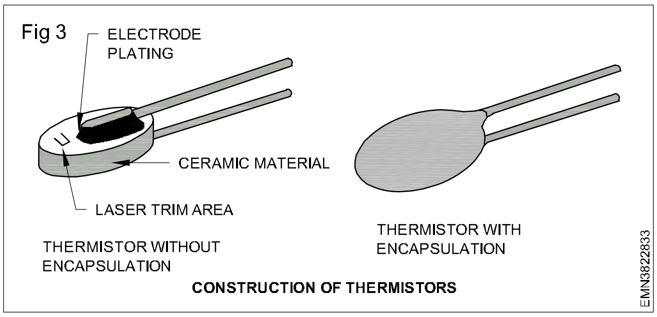



PTC TEMPERATURE VS RESISTANCE

A PTC thermistor works a little differently. When temperature increases, the resistance increases, and when temperature decreases, resistance decreases as shown in the fig 2.This type of thermistor is generally used as a fuse.

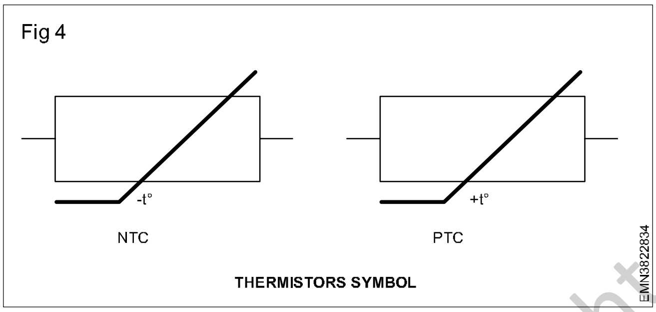
**Construction**

The device is manufactured from materials like sintered mixtures of oxides of metals such as manganese, nickel, cobalt, and iron. Their resistances range from 0.4 ohms to 75 mega-ohms and they may be fabricated in wide variety of shapes and sizes. Smaller thermistors are in the form of beads of diameter from 0.15 millimeters to 1.5 millimeters. Such a bead may be sealed in the tip of solid glass rod to form probe which is easier to mount




than bead. Alternatively thermistor may be in the form of disks and washers made by pressing thermistor material under high pressure into flat cylindrical shapes with diameter from 3 millimeters to 25 millimeters. Washers may be stacked and placed in series or parallel to increase power disciplining capability. As shown in fig. 3.

**Working Principle**




A thermistor is an inexpensive and easily obtainable temperature sensitive resistor, thermistor working principle is, its resistance is depending upon temperature. When temperature changes, the resistance of the thermistor changes in a predictable way, the benefits of using a thermistor are accuracy and stability, There are two types of termistors available as NTC and PTC, their symbols are shown in Fig 4.

**Salient features of thermistor**

1 Thermistors are compact, rugged and inexpensive.

2 It exhibit high stability.

3 The response time of thermistor can vary from a fraction of second to minutes, depending on the characteristics and contraction of the thermistor.

4 The response time varies inversely with the dissipation factor.

5 The dissipation factor varies with the degree of thermal isolation of the thermistor.

6 The upper temperature limits is depending on physical changes in the material and the contact materials

7 A low current must be allowed through the thermistor to avoid self heating.

**Application**

1 Temperature control of air conditioner and refrigerator.

2 Room temperature monitoring

3 Surge Suppression in power lines in SMPS.

4 This device is used to measure the temperature of incubators.

5 NTC thermistors are used to measure and monitor batteries while they are kept for charging.

6 They are used to know the temperature of oil and coolant used inside automotive engines.

**Advantages of Thermistor**

1 When the resistors are connected in the electrical circuit, heat is dissipated in the circuit due to flow of current. This heat tends to increase the temperature of the resistor due to which their resistance changes. For the thermistor the definite value of the resistance is reached at the given ambient conditions due to which the effect of this heat is reduced.

2 In certain cases even the ambient conditions keep on changing, this is compensated by the negative temperature characteristics of the thermistor. This is quite convenient against the materials that have positive resistance characteristics for the temperature.

3 The thermistors are used not only for the measurement of temperature for the measurement of power etc.

4 They are also used as the controls, overload protectors, giving warnings etc.

5 The size of the thermistors is very small and they are very low in cost. However, since their size is small they have to be operated at lower current levels.

**Disadvantages**

1 The high resistivity of thermistors is a significant advantage, since it leads to very small errors, which could be even hundred time smaller compared to measurement errors of RTDs.

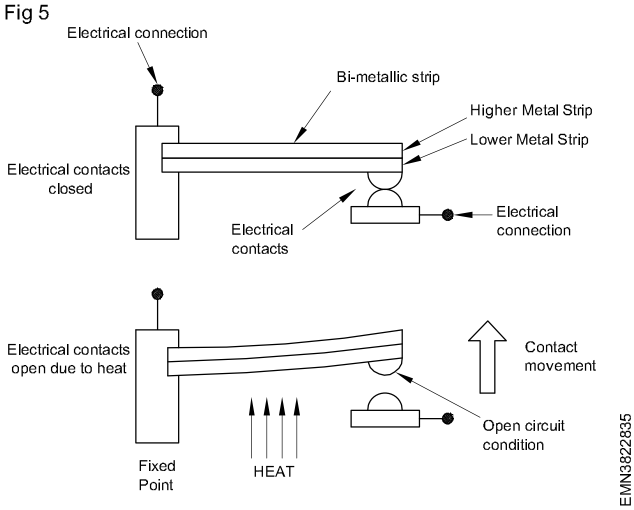
2 In general, thermistors are more fragile than RTDs and thermocouples and therefore require delicate handling and mounting. Another drawback of them is that because they consist of semiconductors, they are more prone to permanent de-calibration (drifting out of their specified tolerance). Contrary to applicability of RTDs and thermocouples, use of thermistors is generally limited to a temperature range of few hundred degrees Celsius.

3 Small mass of thermistors also makes them susceptible to self-heating errors.

**The Theromostat**

The thermostat is a contant type electro-mechanical temperature sensor or switch, that basically consists of two diffrent metals such as nickel, copper, tungsten or aluminium etc, that are bonded together to form a Bi-metalllic strip. The different linear expansion rates of the two dissimilar metals produces a mechanical bending movement when the strip is subjected to heat.

Fig 5




The bi-metallic strip can be used itself as an electrical switch or as a mechanical way of operating an electrical switch in thermostatic controls and are used extensively to control hot water heating elements in boilers, furnaces, hot water storage tanks as well as in vehicle radiator cooling systems. The Bi-metallic Thermostat in shown in Fig 5

The thermostat consists of two thermally different metals stuck together back to back. When it is at normal temperature closed and current passes through the thermostat. When it has heated up, one metal expands more than the other and the bonded bi-metallic strip bends up (or down) opening the contacts preventing the current from flowing.

**On/Off thermostat**

There are two main types of bi-metallic strips based mainly upon their movement when subjected to temperature changes. There are the 'snap-action' types that produce an instantaneous "ON/OFF" or "OFF/ON" type action on the electrical contacts at a set temperature point, and the slower 'creep-action' types that gradually change their position as the temperature changes.

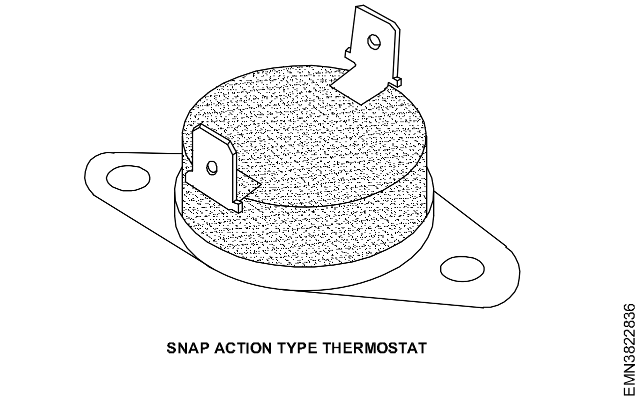
Snap-action type thermostat is shown in Fig 6 It is commonly used in our homes for controlling the temperature set point of ovens, irons, immersion hot water tanks and they can also be found on walls to control the domestic heating system.

Creeper types generally consist of a bi-metallic coil or sprial that slowly unwinds or coils-up as the temperature changes. Generally, creeper type bi-metallic strips are more sensitive to temperature changes than the temperature gauges and dials etc.

Although snap-action type thermostats are very cheap and are available over a wide opeating range, one main disadvantage of the standard snap-action type thermostat is when used as a temperature sensor, they have a large hysteresis range from when electrical contacts open until when they close again for example it may be set 20°C but may not open until 22°C or close again until 18°C

Commercially available bi-metallic thermostats for home use do have temperature adjustment screws that allow for a more precise desired temperature set-point and hysteresis level to be pre-set.

Fig 6




SNAP ACTION TYPE THERMOSTAT

**Temperature sensor ICs**

A silicon temperature sensor is an integrated circuit, include extensive signal processing circuitry within the same package as the sensor. There is n need to add compensation circuit for temperature sensor ICs. Some of these are analogue circuits with either voltage or current output. Other combine analogue sensing circuits with voltage comparators to provide alerts functions. Some other sensor ICs combine analogue-sensing circuitry with digital input/output and control registers, making them an ideal solution for microprocessor-based systems.

There are a wide variety of temperature sensor ICs that are available to simplify the broadest possible range of temperature monitoring

Tempeature sensor ICs are classified into different types like voltage output, current ouput, digital output, resistance

Fig 7(a)

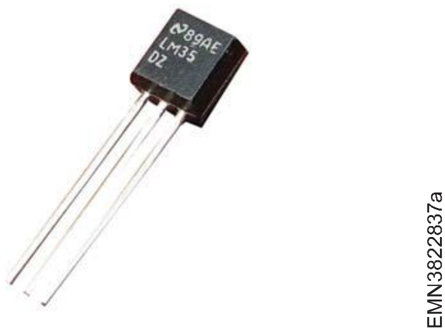
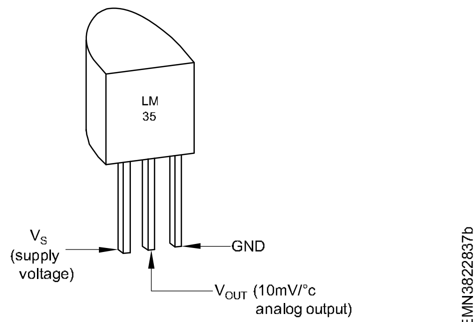



Fig 7(b)



output silicon and Diode temperature sensors. Modern semiconductor temperature sensors offer high accuracy and high linearity over an operating range of about 55°C to +150°C. Internal amplifiers can scale the output to convient values, such as 10mV/°C. As an example the LM 35 temperature sensor outline diagram is shown in the Fig 7 a and b

**Feature of LM35 Temperature Sensor:**

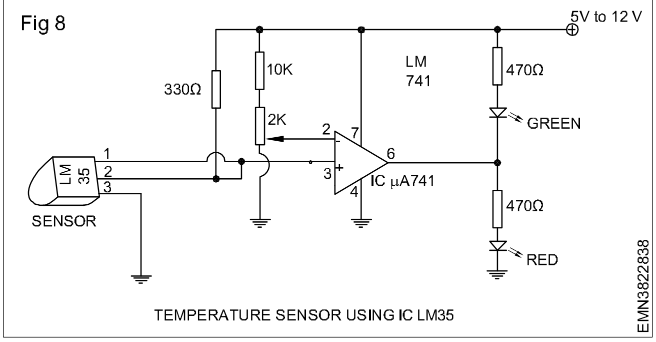
- Calibrated directly in Celsius.
- Rated for full -55°C to +150°C range
- Suitable for remote applications
- Low cost due to wafer-level trimming
- Operated from 4 to 30 volts
- Low self-heating
- **±**1/4°C of typical nonlinearity

The Above temperature sensor has three terminals. This of sensor consists of a material that performs the operation according to temperature to vary the resistance. This change of resistance is sensed by the circuit and it calculate temperature. When the voltage increases then temperature also rises.

Temperature sensors directly connected to microprocessor input and thus capable of direct and reliable communication with microprocessors. The sensor unit can communicate effectively with low-cost processors without the need of A/D converters.

A practical circuit using temperatue sensor IC LM 35 is shown in Fig 8, in which the sensor output is connected to the non-investing input of the Op-Amp IC 741. On reaching the predetermined temperature the circuit produces the output changes the status of LED indicator.

Fig 8




TEMPERATURE SENSOR USING IC LM35

# Resistance Temperature Detectors (RTD)

**Objectives :** At the end of this lesson you shall be able to
- **explain about RTD and its types.**
- **define construction and working principle of the RTD (PT100).**
- **describe the application, limitation, advantages & disadvantages.**

### Resistance Temperature Detectors

Resistance Temperature Detectors (RTD), as the name implies, are sensors used to measure temperature by correlating the resistance of the RTD element with temperature.

RTDs are relatively immune to electrical noise and therefore well suited for temperature measurement in industrial environments, especially around motors, generators and other high voltage equipment.

A **Resistance Thermometer or Resistance Temperature Detector** is a device which is used to determine the temperature by measuring the **resistance** of pure electrical wire. This wire is referred to as a temperature sensor. If we want to measure temperature with high accuracy, RTD is the only one solution in industries. It has good linear characteristics over a wide range of temperatures. The physical appearances of different RTDs are shown in fig 1a & 1b.

Fig 1a

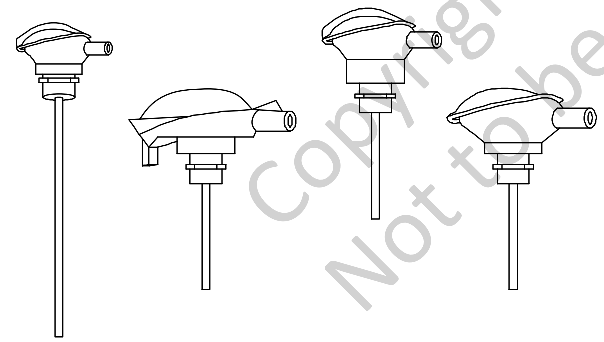
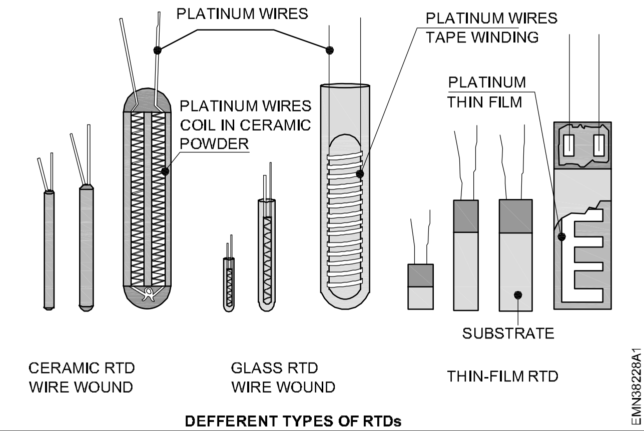


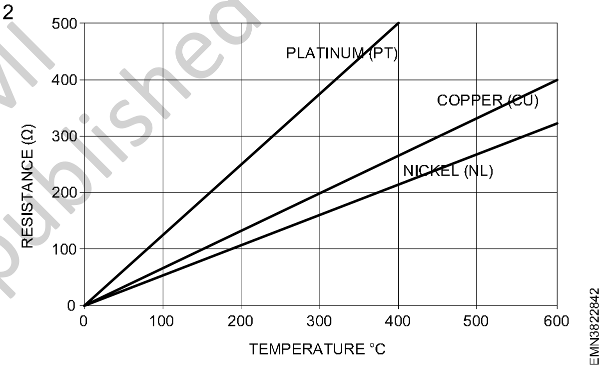
Fig 1b




DEFFERENT TYPES OF RTDs

In **RTD** devices Copper, Nickel and Platinum are widely used metals. These three metals are having different resistance variations with respect to the temperature variations. That is called resistance-temperature characteristics as shown in fig.2. Platinum has the temperature range of 650°C, and then the Copper and Nickel have 120°C and 300°C respectively. The figure-2 shows the resistance-temperature characteristics curve of the three different metals. For Platinum, its resistance changes by approximately 0.4 ohms per degree Celsius of temperature.

Fig 2




The purity of the platinum is checked by measuring R100 / R0. Because, whatever the materials actually we are using for making the RTD that should be pure. If it is not pure, it will deviate from the conventional resistance-temperature graph. So $\alpha$ and $\beta$ values will change depending upon the metals.

### Types of RTDs based on wires color code : (Fig 3)

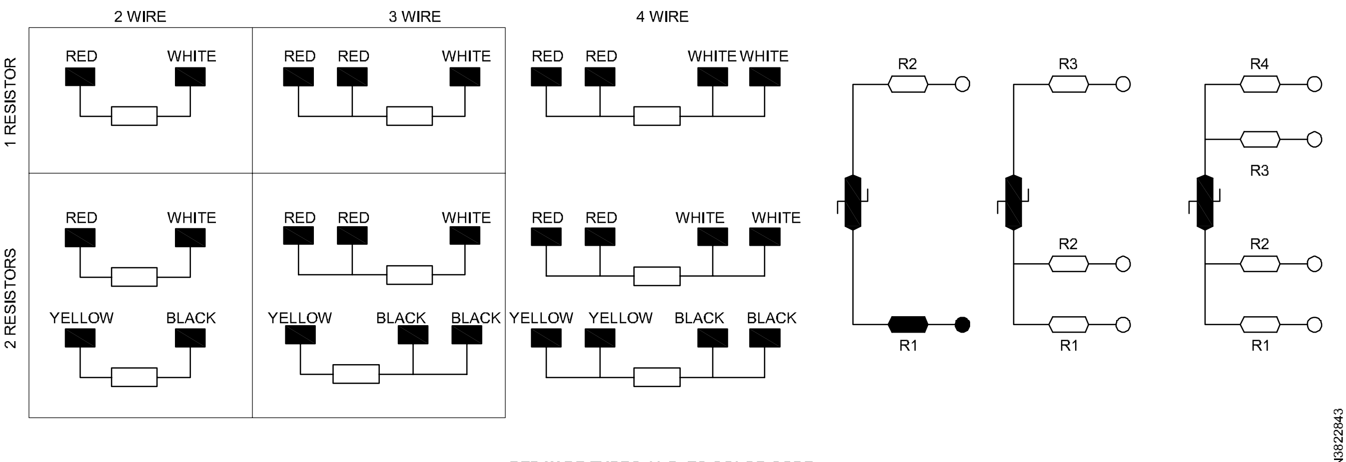
Main trend for industrial resistance temperature detector is platinum RTD due to physical stability and high applicable temperature.

There are the other RTDs such as Nickel, Platinum-cobalt, and so on.

### RTD Configuration

An RTD can be connected in a two, three, or four-wire configuration. The two-wire configuration is the simplest and also the most error prone. In this setup, the RTD is connected by two wire to a wheatstone bridge circuit and the output voltage is measured. The disadvantage of this circuit is that the resistance of two connecting lead wires are added directly to the RTDs resistance and an error is incurred.

Fig 3




RTD WIRE TYPES AND ITS COLOR CODE

## 2- Wire Configuration

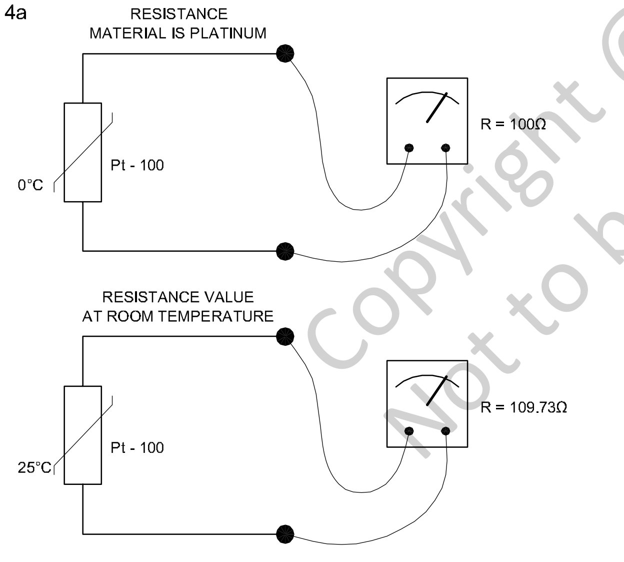
The four-wire configuration consists of two current leads and two potential leads that measure the voltage drop across the RTD. The two potential leads are high resistance to negate the effect of the voltage drop due to curent flowing during the measurement.

This configuration is ideal for cancelling the lead wire resistances in the circuit as well as eliminating the effects of different lead resistances, which was a possible problem with the three-wire configuration is commonly used when a highly accurate measurement is requried for the application.

**Note: Refer to the RTD user manual/datasheet for type of RTD based on lead colour**

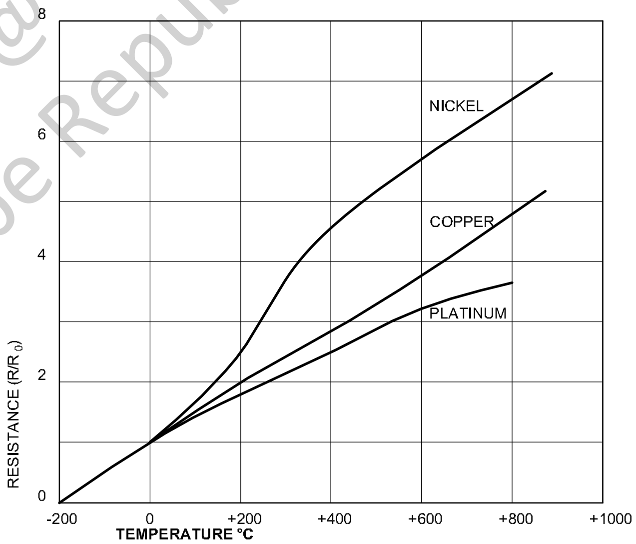


Fig 4a




Pt - 100 CONNECTION WIRING DIAGRAM

4b




RESISTANCE VS TEMPERATURE CURVE

## Pt-100 working principle

A platinum resistance temperature detector (RTD) Pt100 is a device with a typical resistance of 100 Ω at 0°C (it is called Pt100). It changes resistance value as its temperature changes following a positive slope (resistance increases when temperature is increasing).as show in fig 4a & 4b.

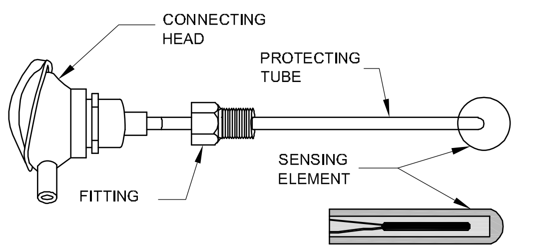
They have been used for many years to measure temperature in laboratory and industrial processes, and have developed a reputation for accuracy, repeatability, and stability. A RTD can typically measure temperatures up to 850 °C.

## Pt100 types

There are basically three styles of Pt100 sensing elements. Each style has unique characteristics and advantages.

**Wire wound Element:** The wire wound sensor is the simplest sensor design. The sensing wire is wrapped around an insulating mandrel or core. The winding core can be round or flat, but must be an electrical insulator. The coil diameter provides a compromise between mechanical stability and allowing expansion of the wire to minimize strain and consequential drift. as shown in fig. 5

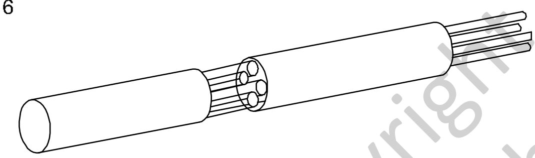
Fig 5




Pt-100 WIRE WOUND TUBE

**Coiled Element:** The coiled sensor shown in fig. 6 is a method to produce a "strain free" design. A strain free design allows the sensing wire to expand and contract free of influences from other materials in the assembly. Techniques similar to those used in this design are used in Standard Platinum Resistance Thermometers (SPRT), which are used as laboratory standards.

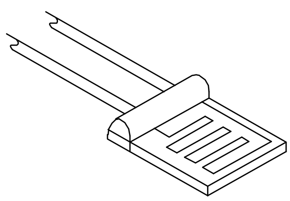
Fig 6




Pt - 100 COILED ELEMENT

**Thin Film Element:** The thin film sensing element is manufactured by depositing a very thin layer of platinum on a ceramic substrate. This layer is usually just a 10 to 100 angstroms (1e-8 centimeters) thick. The platinum film is coated with epoxy or glass. This coating helps protect deposited platinum film and acts as a strain relief for the external lead wires as shown in fig. 7. The advantage of the thin film Platinum RTD is low cost and low thermal mass. The low thermal mass makes them respond faster and they are easier to assemble into small packages. Disadvantages are that they are not as stable as wire wound RTDs.

Fig 7




Pt - 100 THIN FILM ELEMENT

### Limitations of RTD

In the RTD resistance, there will be I2R power dissipation by the device itself that causes a slight heating effect. This is called as self-heating in RTD. This may also cause an erroneous reading. Thus, the electric current through the RTD resistance must be kept sufficiently low and constant to avoid self-heating. Because of this the RTD is used only up to maximum 600°C

### Applications of RTDs include

- Air conditioning and refrigeration servicing
- Food Processing
- Stoves and grills
- Textile production
- Plastics processing
- Petrochemical processing
- Micro electronics
- Air, gas and liquid temperature measurement
- Exhaust gas temperature measurement

### RTD's should be used

- When accuracy and stability are a requirement of the customer's specification
- When accuracy must extend over a wide temperature range
- When area, rather than point sensing improves control
- When a high degree of standardization is desirable

### Advantages of Resistance Temperature Detectors

- The advantages of using RTDs include:
- Linear over wide operating range
- Wide temperature operating range
- High temperature operating range
- Interchangeability over wide range
- Good stability at high temperature

### Disadvantages of Resistance Temperature Detectors

The disadvantages of using RTD's include:

- Low sensitivity
- Higher cost than thermocouples
- No point sensing
- Affected by shock and vibration requires three or four-wire operation

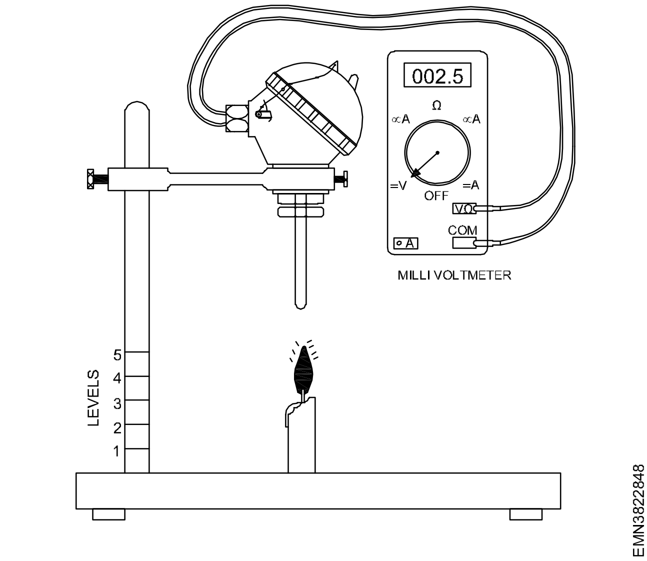
> **Note: Refer the RTD user manual for leads colors and temperature vs resistances graph**

**Testing of thermocouple sensor under laboratory setup**

The thermocouple sensor can be tested in the laboratory by fixing the thermowell bulb on a stand under a lit fire of a candle, as shown in Fig 8. The height of the candle has to be increased form the base as per the graducated scale mashing on the stand. The output voltage produced bt the sensor is measured using a DC millivoltmeter for each level and reading for corresponding temperatures are recorded and compared to confirm the correct working of thermocouple sensor.

In the same method of experiment, the RTD can also be fixed on the stand under the lit fire flame of the candle as shown in Fig 9. For diffrent height of the flame, corresponding resistance variations of each temperature across the output terminals of the RTD is measured using ohm meter and its working can be ascer tained.

Fig 8



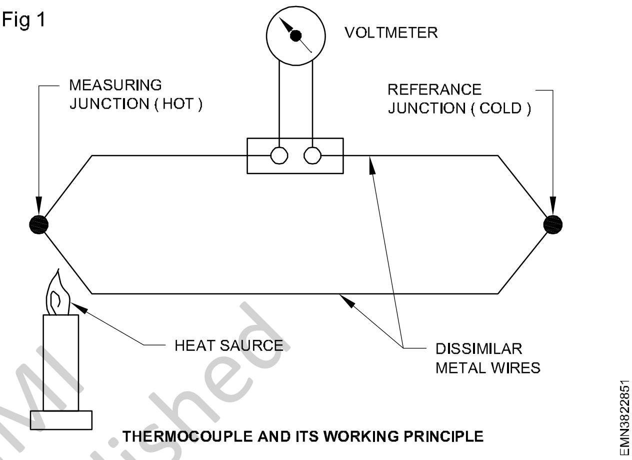
## Thermocouple

**Objectives :** At the end of this lesson you shall be able to
- **define thermocouple and its working principle**
- **explain the various type of thermocouple .**
- **describe the application, advantages & disadvantages**
- **explain the characteristics curve graph of mV Vs temperature measured.**

### Thermocouple and its working principle

Thermocouple is a device consisting of two dissimilar conductors or semiconductors that contact each other at one or more points as shown in fig.1. A thermocouple produces a voltage when the temperature of one of the contact points differs from the temperature of another, in a process known as the thermoelectric effect. Thermocouples are a widely used type of temperature sensor for measurement and control and can also convert a temperature gradient into electricity.

Fig 1




THERMOCOUPLE AND ITS WORKING PRINCIPLE

### Type of thermocouples

Characteristic functions for thermocouples that reach intermediate temperatures, as covered by nickel alloy thermocouple types E,J,K,M,N,T. Also shown are the noble metal alloy type P, and the pure noble metal combinations gold-platinum and platinum-palladium.

The table - 1 showing the different type to thermocouple and its range.

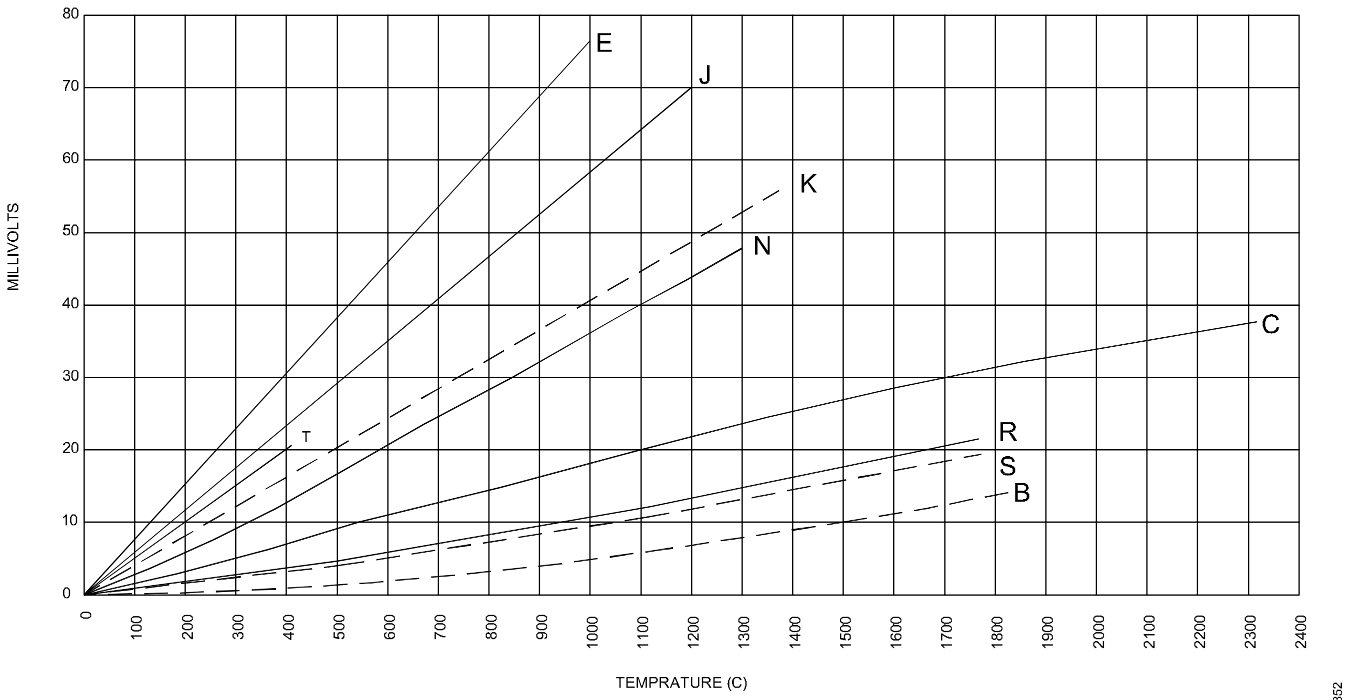
**Thermocouple Characteristics table - 1**

| ANSI/ ASTM | Symbol Single | Generic Names | Color Coding | | Magnetic Yes/No | Environment (Bare Wire) |
|---|---|---|---|---|---|---|
| | | | Individual Conductor | Overall jacket extension grade wire | | |
| T | TP<br>TN | Copper Constantan, Nominal Composition: 55% Cu, 45% Ni | Blue<br>Red | Blue | X<br>X | Mild Oxidizing, Reducing, Vacuum or Inert, Good where moisture is present |
| J | JP JN | Iron Constantan, Nominal Composition : 55% Cu, 45% Ni | White<br>Red | Black | X<br>X | Reducing Vacuum, Inert, Limited use in oxidizing at High Temperatures, Not recommended for low temps. |
| E | EP<br>EN | Chromel &, Nominal Composition: 90% Ni, 10% Cr Constantan, Nominal Composition : 55% Cu, 45% Ni | Purple<br>Red | Purple | X | Oxidizing or Inert, Limited use in Vacuum or Reducing |

| ANSI/ ASTM | Symbol Single | Generic Names | Color Coding | | Magnetic Yes/No | Environment (Bare Wire) |
|---|---|---|---|---|---|---|
| | | | Individual Conductor | Overall jacket extension grade wire | | |
| K | KP<br>KN | Chromel, Nominal Composition: 90% Ni, 10% Cr Alumel*, Nominal Composition: 95% Ni, 2% Mn, 2% Al | Yellow<br>Red | Yellow | X<br>X | Clean Oxidizing and Inert, Limited use in Vacuum or Reducing |
| N | NP<br>NN | Nicrosil*, Nominal Compositions : 84, 6% Ni, 14.2%, Cr, 1.4% Si Nisil*, Nominal Composition: 95.5%, Ni, 4.4% Si, 1% Mg | Orange<br>Red | Orange | X<br>X | Clean Oxidizing and inert. Limited use in Vacuum or Reducing |
| S | SP<br>SN | Platinum 10% Rhodium Pure Platinum | Black<br>Red | Green | X<br>X | Oxidizing or Inert Atmospheres, Do not Insert in metal tubes. Beware of contamination. |
| R | RP<br>RN | Platinum 13% Rhodium Pure Platinum | Black<br>Red | Green | X<br>X | Oxidizing in Inert Atmospheres. Do not insert in metal tubes. Beware of contamination |
| B | BP<br>BN | Platinum 30% Rhodium Platinum 6% Rhodium | Gray<br>Red | Gray | X<br>X | Oxidizing or Inert Atmospheres. Do not insert in metal tubes. Beware of contamination. ` |
| C | P<br>N | Tungsten 5% Rhenium Tungsten 26% Rhenium | Green<br>Red | Red | X<br>X | Vacuum, Inert, Hydrogen Atmospheres, Beware of Embrittlement. |

**Temperature Vs mV graph for various type of Thermocouples: (fig 2)**

Fig 2




TEMPERATURE Vs mV GRAPH FOR VARIOUS TYPE OF THERMOCOUPLES

## Applications

1 Temperature measurement for kilns, gas turbine exhaust, diesel engines.

2 Temperature measurement of industrial processes and fog machines.

3 For process temperature measurement of Steel, Cement , Petro chemical etc.,

## Advantage:

1 Thermocouples are suitable for measuring over a large temperature range, from - 270 up to 3000 °C (for a short time, in inert atmosphere).

2 They are less suitable for applications where smaller temperature differences need to be measured with high accuracy, for example the range 0-100 °C with 0.1 °C accuracy

## Disadvantage :

1 Thermocouples measure their own temperature.

2 Thermocouples can error in reading their own temperature, especially after being used for a while, or if the insulation between the wires loses its resistance due to moisture or thermal conditions

3 Beware of electrical hazards using thermocouples, they are electrical conductors. RTD's are less sensitive to electrical noise.

4 Thermocouples DO NOT MEASURE AT THE JUNCTIONS! They can't, it is physically impossible to have a temperature gradient at a point.

5 The distance between thermocouple and heater element will generate a thermal lag which can be compensated by the temperature controller.

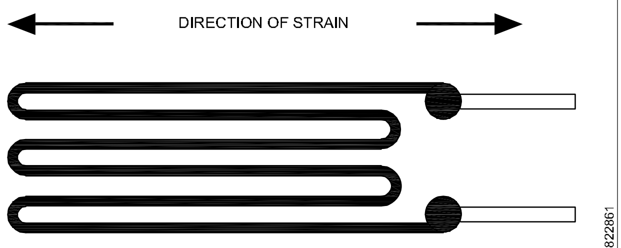
## Strain gauges and load cell

**Objectives :** At the end of this lesson you shall be able to
- **explain the strain gauges and its types**
- **define construction and working principle & gauge factor**
- **explain the load cell and strain gauge load cell**
- **describe the application, advantages and disadvantages.**

### Strain Gauges

A strain gauge (or strain gage) is a device used to measure strain on an object. The most common type of strain gauge consists of an insulating flexible backing which supports a metallic foil pattern. The gauge is attached to the object by a suitable adhesive, such as cyanoacrylate. As the object is deformed, the foil is deformed, causing its electrical resistance to change. This resistance change, usually measured using a Wheatstone bridge, is related to the strain by the quantity known as the gauge factor. as shown in fig 1.

Fig 1




STRAIN GAUGE

### Types of strain gauges

There are four main types of strain gauges: mechanical, hydraulic, electrical resistance, and piezoelectric.

1 Mechanical

2 Hydraulic

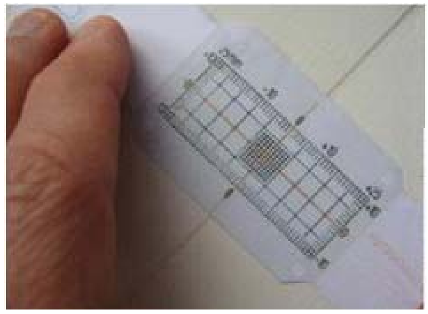
3 Electrical Resistance

4 Piezoelectric

### Mechanical strain Gauge

Suppose you have a crack forming in a wall of your home because of subsidence and you want to know if it's getting any worse. Call in the building inspectors and they'll probably glue a piece of tough, plexiglass plastic, ruled with lines and a scale, directly over the crack. Sometimes known as a crack monitor, you'll find it's actually made up of two separate plastic layers. The bottom layer has a ruled scale on it and the top layer has a red arrow or pointer. You glue one layer to one side of the crack and one layer to the other so, as the crack opens, the layers slide very slowly past one another and you can see the pointer moving over the scale. Mechanical strain gauges as shown in fig 2.

Fig 2



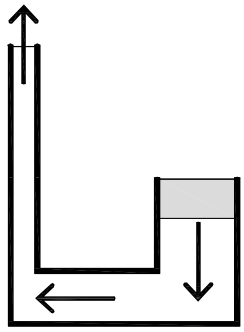
MECHANICAL STRAIN GAUGE

### Hydraulic strain Gauge

One of the problems with strain gauges is detecting very small strains. You can imagine, for example, a situation where your house is slowly subsiding but the amount of movement is so small that it won't show up-perhaps until the damage is done. With a simple crack detector such as the ones described above, it takes 1mm of building movement to produce 1mm of movement on the surface of the crack detector. But what if we want to detect movements smaller than this that doesn't show up on a scale? In this case, what we really need is a strain gauge with leverage that amplifies the strain, so even a tiny movement of the detecting element produces a very large and easily measurable movement of a pointer over a scale.

Hydraulic detectors offer a solution and work much like simple syringes. Syringes are essentially hydraulic pistons where a small movement of fluid in a large piston (the part you press with your finger) produces a much larger movement of fluid in a small piston attached to it (the needle where the fluid comes out). It's easy to see how this can be used in a strain gauge: you simply connect your large piston to whatever it is that's producing the strain and use a smaller piston in a smaller tube, marked with a scale, to indicate how much movement has occurred. The relative size of the pistons determines how much the movement you're trying to detect is scaled up. Typically, hydraulic strain gauges like this multiply movement by a factor of 10 or so and are commonly used in geology and Earth science. As shown in fig 3.

Fig 3



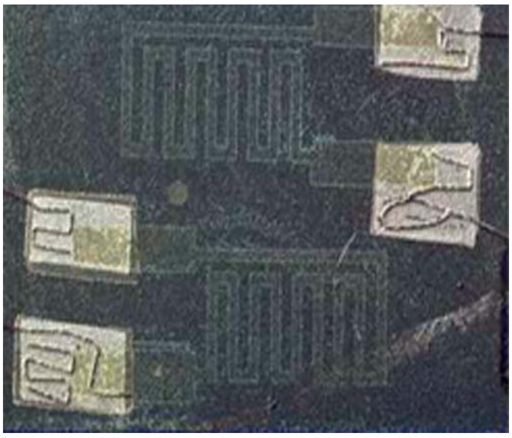
HYDRAULIC STRAIN GAUGE

### Electrical Resistance strain gauge

If you're designing something like an airplane wing, typically you need to make far more sophisticated measurements (and many more of them) than a simple mechanical strain gauge will allow. You might want to measure the strain during takeoff, for example, when the engines are producing maximum thrust. You can't go sticking little plastic strain gauges onto the wing and walk out to measure them during a flight! But you can use electrical strain gauges to do much the same thing from a flight recorder in the cockpit.

The most common electrical strain gauges are thin, rectangular-shaped strips of foil with maze-like wiring patterns on them leading to a couple of electrical cables. You stick the foil onto the material you want to measure and wire the cables up to your computer or monitoring circuit. When the material you're studying is strained, the foil strip is very slightly bent out of shape and the maze-like wires are either pulled apart (so their wires are stretched slightly thinner) or pushed together (so the wires are pushed together and become slightly thicker). Changing the width of a metal wire changes its electrical resistance, because it's harder for electrons to carry electric currents down narrower wires. So all you have to do is measure the resistance and, with a bit of calculation, you can calculate the strain. If the forces involved are small, the deformation is elastic and the strain gauge eventually returns to its original shape-so you can keep making measurements over a period of time, such as during the test flight of a prototype plane as shown in fig 4.

Fig 4



ELECTRICAL RESISTANCE STRAIN GAUGE

### Piezoelectric Strain Gauge

Some types of materials, including quartz crystals and various types of ceramics, are effectively "natural" strain gauges. If you push and pull them, they generate tiny electrical voltages between their opposite faces. This phenomenon is called piezoelectricity (pronounced pee-ay-zo electricity) and it's probably best known as a way of generating the timekeeping signal in quartz watches. Measure the voltage from a piezoelectric sensor and you can calculate the strain very simply. Piezoelectric strain gauges are among the most sensitive and reliable and can withstand years of repeated use as shown in fig 5.

Fig 5

PIEZOELECTRIC STRAIN GAUGE

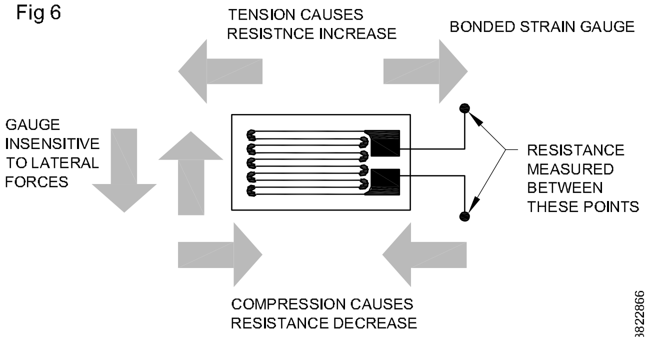
### Principle of Working - Strain Gauges

When force is applied to any metallic wire its length increases due to the strain. The more is the applied force, more is the strain and more is the increase in length of the wire. If L1 is the initial length of the wire and L2 is the final length after application of the force, the strain is given as:

$\in = (L_2 - L_1)/L_1$

Further, as the length of the stretched wire increases, its diameter decreases. Now, we know that resistance of the conductor is the inverse function of the length. As the length of the conductor increases its resistance decreases. This change in resistance of the conductor can be measured easily and calibrated against the applied force. Thus strain gauges can be used to measure force and related parameters like displacement and stress. The input and output relationship of the strain gauges can be expressed by the term gauge factor or gauge gradient, which is defined as the change in resistance R for the given value of applied strain $\in$. As shown in fig 6 working principle of strain gauge.

Fig 6




STRAIN GAUGES WORKING PRINCIPLE

**Gauge factor**

The gauge factor GF is defined as:

Where

is the change in resistance caused by strain,

is the resistance of the unreformed gauge, and

is strain.

For metallic foil gauges, the gauge factor is usually a little over 2. For a single active gauge and three dummy resistors in a Wheatstone bridge configuration, the output from the bridge is:

$$GF = \frac{\Delta R / R_G}{\varepsilon}$$

where

$\Delta R$ is the change in resistance caused by strain,

$R_G$ is the resistance of the unreformed gauge, and

$\varepsilon$ is strain.

For metallic foil gauges, the gauge factor is usually a little over 2. For a single active gauge and three dummy resistors in a Wheatstone bridge configuration, the output $\nu$ from the bridge is:

$$\nu = \frac{BV.GF.\varepsilon}{4}$$

where

*BV* is the bridge excitation voltage.

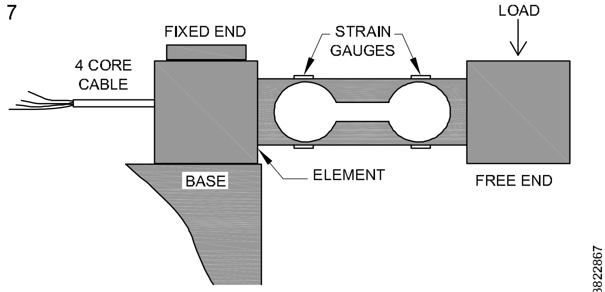
Foil gauges typically have active areas of about 2-10 $mm^2$ in size. With careful installation, the correct gauge, and the correct adhesive, strains up to at least 10% can be measured. Gauge factor(G.F)=1+2$\mu$ where$\mu$=poisson's ratio.

**Load cell:**

A load cell is a device that is used to convert a force into electrical signal. Strain gauge load cells are the most common types of load cells. There are other types of load cells such as hydraulic (or hydrostatic), Pneumatic Load Cells, Piezoelectric load cells, Capacitive load cells, Piezoresistive load cells.etc.

Load cells are used for quick and precise measurements. Compared with other sensors, load cells are relatively more affordable and have a longer life span as shown in fig 7.

Fig 7




LOAD CELL

**Uses of Load Cells**

Load cells are used in several types of measuring instruments such as laboratory balances, industrial scales, platform scales and universal testing machines. Installed load cells in glass fiber nests to weigh albatross chicks. Load Cells are used in a wide variety of items such as the seven-post shaker which is often used to setup race cars.

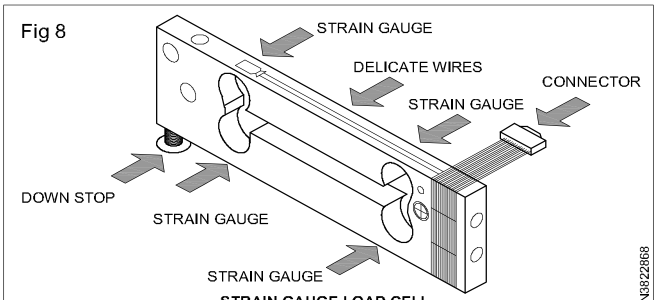
**Strain gauge load cell**

Through a mechanical construction, the force being sensed deforms a strain gauge as shown in the fig 8. The strain gauge measures the deformation (strain) as a change in electrical resistance, which is a measure of the strain and hence the applied forces. A load cell usually consists of four strain gauges in a Wheatstone bridge configuration. Load cells of one strain gauge (Quarter Bridge) or two strain gauges (half bridge) are also available. The electrical signal output is typically in the order of a few millivolts and requires amplification by an instrumentation amplifier before it can be used. The output of the transducer can be scaled to calculate the force applied to the transducer.

Strain gauge load cells are the most common in industry. These load cells are particularly stiff, have very good resonance values, and tend to have long life cycles in application. Strain gauge load cells work on the principle that the strain gauge (a planar resistor) deforms/stretches/ contracts when the material of the load cells deforms appropriately. These values are extremely small and are relational to the stress and/or strain that the material load cell is undergoing at the time. The change in resistance of the strain gauge provides an electrical value change that is calibrated to the load placed on the load cell.

Strain gauge load cells convert the load acting on them into electrical signals. The gauges themselves are bonded onto a beam or structural member that deforms when weight is applied. In most cases, four strain gauges are used to obtain maximum sensitivity and temperature compensation. Two of the gauges are usually in tension, and two in compression, and are wired with compensation adjustments. The strain gauge load cell is fundamentally a spring optimized for strain measurement. Gauges are mounted in areas that exhibit strain in compression or tension. The gauges are mounted in a differential bridge to enhance measurement accuracy. When weight is applied, the strain changes the electrical resistance of the gauges in proportion to the load. Other load cells are fading into obscurity, as strain gauge load cells continue to increase their accuracy and lower their unit costs.

Fig 8




STRAIN GAUGE LOAD CELL

**Advantages of strain Gauge**

1 There is no moving part.

2 It is small and inexpensive.

**Disadvantages of strain Gauge**

1 It is non-linear.

2 It needs to be calibrated.

**Application of Strain gauge**

1 Residual stress

2 Vibration measurement

3 Torque measurement

4 Bending and deflection measurement

5 Compression and tension measurement

6 Strain measurement

**Advantages of load cells**

1 Rugged and compact construction

2 No moving parts

3 Can be used for static and dynamic loading

4 Highly Accurate

5 Wide range of measurement

6 Can be used for static and dynamic loading

**Disadvantages of load cells**

1 Calibration is a tedious procedure

# Proximity sensors

**Objectives :** At the end of this lesson you shall be able to
- **define proximity switches**
- **explain the different types of proximity switches**
- **describe the selection, advantages and disadvantages.**

### Proximity sensors

Proximity sensors detect the presence of objects without physical contact.It detects the presence or absence of objects using electromagnetic fields, light, and sound. There are many types, each suited to specific applications and environments.

### Types of proximity

1 Capacitive

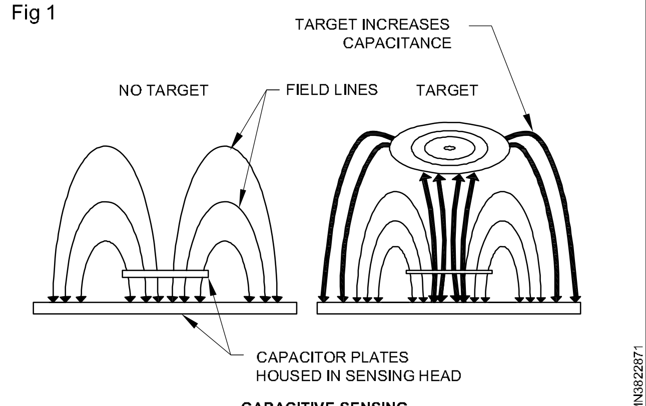
2 Inductive

3 Photo electric

### Capacitive Transducers

It is important to know the basics of a parallel plate capacitor. Being the simplest form of a capacitor, it has two parallel conducting plates that are separated to each other by a dielectric or insulator with a permittivity of E (for air). Other than paper, vacuum, and semi-conductor depletion region, the most commonly used dielectric is air. as shown in fig 1.

Fig 1



CAPACITIVE SENSING

Due to a potential difference across the conductors, an electric field develops across the insulator. This causes the positive charges to accumulate on one plate and the negative charges to accumulate on the other. The capacitor value is usually denoted by its capacitance, which is measured in Farads. It can be defined as the ratio of the electric charge on each conductor to the voltage difference between them.

The capacitance is denoted by C. In a parallel plate capacitor, $C = [A*\epsilon_r*9.85*10^{12}\ F/M]/d$

A - Area of each plate (m)

d - Distance between both the plates (m)

$\epsilon_r$ - Relative Dielectric Constant

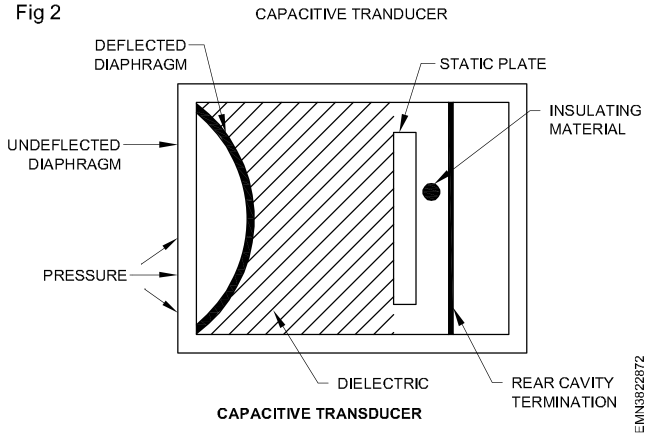
The value $9.85*10^{12}$ F/M is a constant denoted by $\epsilon_0$ and is called the dielectric constant of free space.

From the equation it is clear that the value of capacitance C and the distance between the parallel plates,d are inversely proportional to each other. An increase of distance between the parallel plates will decrease the capacitance value correspondingly. The same theory is used in a capacitive transducer. This transducer is used to convert the value of displacement or change in pressure in terms of frequency.

### Parts of Capacitance Transducer (fig 2)

As shown in the figure 2, a capacitive transducer has a static plate and a deflected flexible diaphragm with a dielectric in between. When a force is exerted to the outer side of the diaphragm the distance between the diaphragm and the static plate changes. This produces a capacitance which is measured using an alternating current bridge or a tank circuit.

Fig 2



CAPACITIVE TRANSDUCER

A tank circuit is more preferred because it produces a change in frequency according to the change in capacitance. This value of frequency will be corresponding to the displacement or force given to the input.

### Advantages

- It produces an accurate frequency response to both static and dynamic measurements.

### Disadvantages

- An increase or decrease in temperature to a high level will change the accuracy of the device.

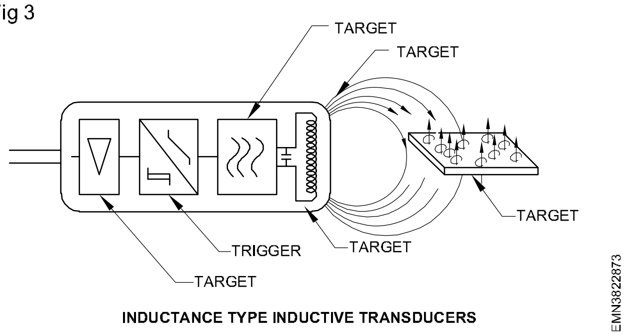
- As the lead is lengthy it can cause errors or distortion in signals.

**Inductance Type Inductive Transducers**

The inductance type of the inductive transducers simple single coil is used as the transducer. When the mechanical element whose displacement is to be measured is moved, it changes the permeance of the flux path generated by the circuit, which changes the inductance of the circuit and the corresponding output. The output from the circuit is calibrated directly against the value of the input, thus it directly gives the valve of the parameter to be measured.

The figure 3 shows the single coil inductive circuit. Here the magnetic material is connected to the electric circuit and it is excited by the alternating current. At the bottom there is another magnetic material that acts as the armature. As the armature is moved, the air gap between the two magnetic material changes and the permeance of the flux generated by the circuit changes that changes the inductance of the circuit and its output. The output meter directly gives the valve of the input mechanical quantity.

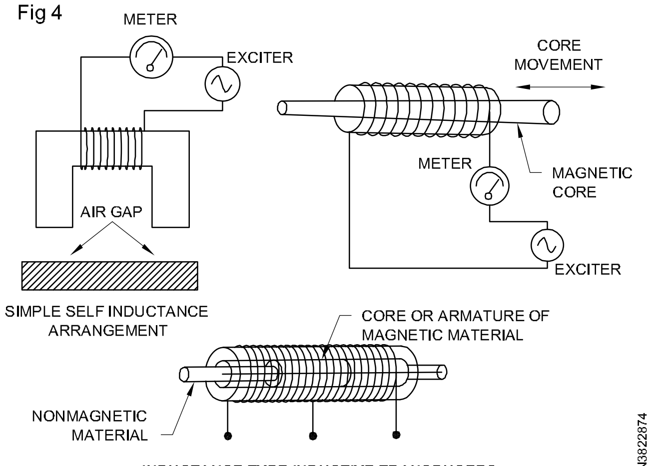
Fig 3




INDUCTANCE TYPE INDUCTIVE TRANSDUCERS

In the figure 4, coil is wound around the round hollow magnetic material and there is magnetic core that moves inside hollow magnetic material. In the above circuits the change in the air gap or the change in the amount of the magnetic material in the circuit can be used to produce the output proportional to the input.

Fig 4




INDUCTANCE TYPE INDUCTIVE TRANSDUCERS

Another arrangement of the coils is shown in figure 3, where two coils are used. In this circuit the movement of the core changes the relative inductance of the two coils and over all inductance of the circuit. This system is used in the devices along with the inductive bridge circuit. In this circuit the change in the induction ratio of the two coils provides the output proportional to the mechanical input.

In the above arrangements the supply of the current and the output is obtained from the same coil or circuit.

**Advantages**

1 Non contact type

2 Maintenance free

3 pnp or npn type

4 360°-viewable output indicators for easy operation and maintenance

5 Electrical protections against short circuits, overload, transient noise, false pulses and reverse polarity (DC models) to help reduce downtime and maintenance costs

**Disadvantages**

Virtually nil but following may be noted

1 Cannot be repaired

2 Must be free from oil and dust

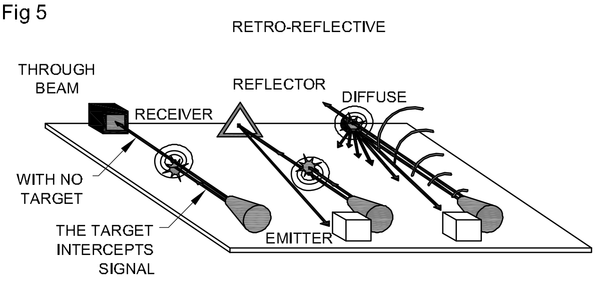
3 Cable connections to be checked regularly

**Photoelectric sensors**

Photoelectric sensors are so versatile that they solve the bulk of problems put to industrial sensing. Because photoelectric technology has so rapidly advanced, they now commonly detect targets less than 1 mm in diameter, or from 60 m away. Classified by the method in which light is emitted and delivered to the receiver, many photoelectric configurations are available. However, all photoelectric sensors consist of a few of basic components: each has an emitter light source (Light Emitting Diode, laser diode), a photodiode or phototransistor receiver to detect emitted light, and supporting electronics designed to amplify the receiver signal. The emitter, sometimes called the sender, transmits a beam of either visible or infrared light to the detecting receiver.

All photoelectric sensors operate under similar principles as shown in fig. 5 Identifying their output is thus made easy; dark-on and light-on classifications refer to light reception and sensor output activity. If output is produced when no light is received, the sensor is dark-on. Output from light received, and it's light-on. Either way, deciding on light-on or dark-on prior to purchasing is required unless the sensor is user adjustable. (In that case, output style can be specified during installation by flipping a switch or wiring the sensor accordingly.)

Fig 5




LASERS OF SOUND WAVES SERVE AS THE SIGNAL IN THREE SETUPS. IN THROUGH BEAM AND RETRO-REFLECTIVE, THE SIGNAL SHOOTS FROM THE EMITTER TO RECEIVER UNTIL THE TARGET CUTS IT OFF. IN DIFFUSE SENSING, THE SIGNAL DIVERGES UNTIL A TARGET MOVES IN AND REFLECTS SOME BACK TO THE RECEIVER.

PHOTOELECTRIC / ULTRASONIC SENSING SETUPS

EMN3822875

**Through-beam**

The most reliable photoelectric sensing is with through-beam sensors. Separated from the receiver by a separate housing, the emitter provides a constant beam of light; detection occurs when an object passing between the two breaks the beam. Despite its reliability, through-beam is the least popular photoelectric setup. The purchase, installation, and alignment of the emitter and receiver in two opposing locations, which may be quite a distance apart, are costly and laborious. With newly developed designs, through-beam photoelectric sensors typically offer the longest sensing distance of photoelectric sensors - 25 m and over is now commonplace. New laser diode emitter models can transmit a well-collimated beam 60 m for increased accuracy and detection. At these distances, some through-beam laser sensors are capable of detecting an object the size of a fly; at close range, that becomes 0.01 mm. But while these laser sensors increase precision, response speed is the same as with non-laser sensors - typically around 500 Hz.

One ability unique to through-beam photoelectric sensors is effective sensing in the presence of thick airborne contaminants. If pollutants build up directly on the emitter or receiver, there is a higher probability of false triggering. However, some manufacturers now incorporate alarm outputs into the sensor's circuitry that monitor the amount of light hitting the receiver. If detected light decreases to a specified level without a target in place, the sensor sends a warning by means of a builtin LED or output wire.

Through-beam photoelectric sensors have commercial and industrial applications. At home, for example, they detect obstructions in the path of garage doors; the sensors have saved many a bicycle and car from being smashed. Objects on industrial conveyors, on the other hand, can be detected anywhere between the emitter and receiver, as long as there are gaps between the monitored objects, and sensor light does not "burn through" them. (Burn-through might happen with thin or lightly colored objects that allow emitted light to pass through to the receiver.)

**Application and selection of proximity sensor:**

**Proximity Sensor comparison table -1**

| Technology | Sensing Range | Applications | Target Materials |
|---|---|---|---|
| Inductive  | <4-40 mm | Any close - range detection of ferrous material | Iron Steel Aluminum Copper etc.  |
| Capacitive  | <3-60 mm | Close - range detection of non - ferrous material | Liquids Wood Granulates Plastic Glass etc.  |
| Photoelectric  | <1mm - 60 mm | Long - range small or large target detection | Silicon Plastic Paper Metal etc.  |

| Technology | Sensing Range | Applications | Target Materials |
|---|---|---|---|
| Ultrasonic<br> | <30 mm - 3 mm | Long - range detection of targets with difficult surface properties. Color/ reflectivity insensitive. | Cellophane Foam Glass liquid Powder etc<br> |

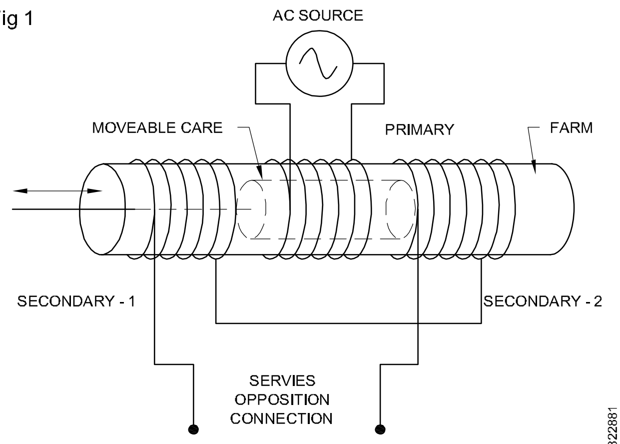
# Displacement measurement using LVDT

**Objectives :** At the end of this lesson you shall be able to
- **define LVDT**
- **explain the working principle and operation of LVDT**
- **state the advantages, disadvantages and application of LVDT.**

### Details of LVDT and its construction

Linear variable differential transformers (LVDT) are used to measure displacement. LVDTs operate on the principle of a transformer. As shown in Figure 1, an LVDT consists of a coil assembly and a core. The coil assembly is typically mounted to a stationary form, while the core is secured to the object whose position is being measured. The coil assembly consists of three coils of wire wound on the hollow form. A core of permeable material can slide freely through the center of the form. The inner coil is the primary, which is excited by an AC source as shown. Magnetic flux produced by the primary is coupled to the two secondary coils, inducing an AC voltage in each coil.

Fig 1




GENERAL LVDT ASSEMBLY

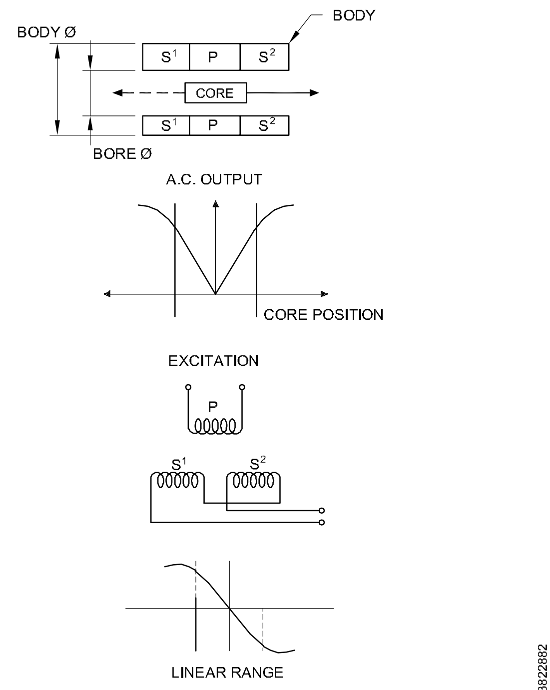
### LVDTs Working principle

The LVDT or Linear Variable Differential Transformer is a well established transducer design which has been used throughout many decades for the accurate measurement of displacement and within closed loops for the control of positioning. So, how does an LVDT work? In its simplest form, the design consists of a cylindrical array of a primary and secondary windings with a separate cylindrical core which passes through the centre. (Fig 2a).

The primary windings (P) are energized with a constant amplitude A.C. supply at a frequency of 1 to 10 kHz. This produces an alternating magnetic field in the centre of the transducer which induces a signal into the secondary windings (S &S ) depending on the position of the core.

Movement of the core within this area causes the secondary signal to change (Fig 2b). As the two secondary windings are positioned and connected in a set arrangement (push-pull mode), when the core is positioned at the centre, a zero signal is derived.

Fig 2




LVDTs WORKING PRINCIPLE

Movement of the core from this point in either direction causes the signal to increase (Fig 2c). As the windings are wound in a particular precise manner, the signal output has a linear relationship with the actual mechanical movement of the core.

The secondary output signal is then processed by a phase-sensitive demodulator which is switched at the same frequency as the primary energising supply. This results in a final output which, after rectification and filtering, gives D.C. or 4-20mA output proportional to the core movement and also indicates its direction, positive or negative from the central zero point (Fig 2d).

### Advantage:

The distinct advantage of using an LVDT displacement transducer is that the moving core does not make contact with other electrical components of the assembly, as with resistive types, as so offers high reliability and long life. Further, the core can be so aligned that an air gap exists around it, ideal for applications where minimum mechanical friction is required.

The LVDT design lends itself for easy modification to fulfill a whole range of different applications in both research and industry.

**Disadvantages of LVDT**

- Very high displacement is required for generating high voltages.
- Shielding is required since it is sensitive to magnetic field.
- The performance of the transducer gets affected by vibrations
- Its is greatly affected by temperature changes.
- Internally non contact but externally has to be connected where the measurement has to be made
- Not feasible for very long range measurements

**Applications of LVDT**

LVDT is used to measure displacement ranging from fraction millimeter to centimeter.

Acting as a secondary transducer, LVDT can be used as a device to measure force, weight and pressure, etc..

## Different types of charts

## Chart showing the details of SMD components ( EX NO 184)

**Chart-1**

**Shape and makings of some common SMDs**

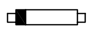
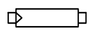
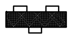
| Component | Shape | Markings |
|---|---|---|
| Chip resistor |  | Labelled with value ( See table 3) |
| Chip capacitor |  | Not marked |
| Polarized capacitor |  | Plus end marked with notch or band |
| Diode |  | Cathode end marked with notch or band |
| SOT ( small outline Integrated circuit) |  | May be marked, unmarked, or house numbered, pin one marked with beveled side, dot, band. or notch. |

**Chart - 2**

**Common SMD case sizes**

| Case Size | Components Length(Inches) | Components Width(Intches) |
|---|---|---|
| 0603 | 0.063 | 0.030 |
| 0805 | 0.080 | 0.050 |
| 1206* | 0.126 | 0.063 |
| 2010 | 0.200 | 0.100 |
| 2512 | 0.250 | 0.125 |

This is the most common size for SMD resistors and chip capacitors

**Chart-3**

**Typical resistor markings and corresponding values**

| Inprint | Resistance value |
|---|---|
| 101 | 100 |
| 471 | 470 |
| 102 | 1k |
| 122 | 1.2k |
| 103 | 10k |
| 123 | 12k |
| 104 | 100k |
| 124 | 120k |
| 474 | 470k |
| 100R | 100 |
| 634 | 634 |
| 909 | 909 |
| 1001 | 1 k |

| Inprint | Resistance value |
|---|---|
| 4701 | 4.7 k |
| 1002 | 10 k |
| 1502 | 15 k |
| 5493 | 549 k |
| 1004 | 1 M |

**Chart-4**

**Coding with alphanumerical characters**

Capacitance code (2nd digit from left)

| Capacitance pF | 1 | 1.5 | 2.2 | 3.3 | 4.7 | 6.8 |
|---|---|---|---|---|---|---|
| Code | A | E | J | N | S | W |
| Mulplicator | 10 | 10 | 10 | 10 | 10 | 10 |
| Code | 5 | 6 | 4 | 3 | 2 | 1 |

**Nominal Voltage Code(first digit from left)**

| **Volt** | 4 | 6.3 | 10 | 16 | 20 | 25 | 35 |
|---|---|---|---|---|---|---|---|
| Code | G | J | A | C | D | E | V |

Example 1

1. 0pF, 16V...CA
2. 2pF, 6.3V....JJ

**Various connectors used in SMD soldering work stations**

Chart showing the pannel controls and accessories of SMD soldering work station

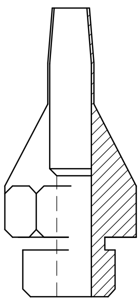
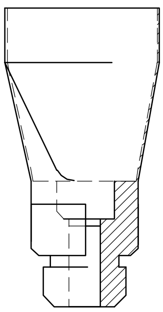
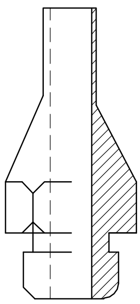
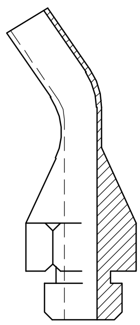
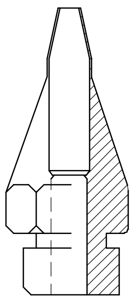
Fig 1

Fig 2

## Chart Showing all types of special tool/ crimping tools used for SMD soldering / Desoldering work.

Fig 1

Fig 2

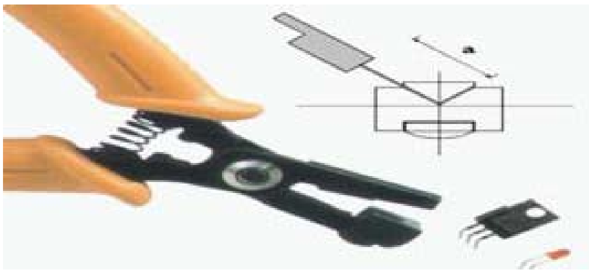
| POPULAR OVAL | FAN | ROUND | ANGLED | FINE/JET |
|---|---|---|---|---|
| Fig 3  |  |  |  |  |

EMN3219013

Fig 4

Heated Tweezers

Fig 5



90° Forming tool

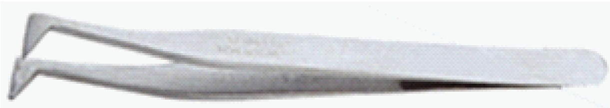
Fig 6

Anti - Static Desoldring Pump/
Solder Sucket

Fig 7

Tool Cut Kink forming

Fig 8



90° SMD tweezer

Fig 9

Curved tweezer

Fig 10

PGA extractor

Fig 11

Reverse action tweezer

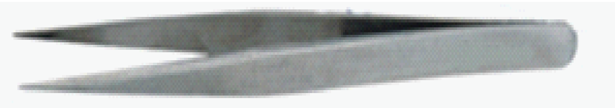
Fig 12

PLCC socket extraction tool

Fig 13

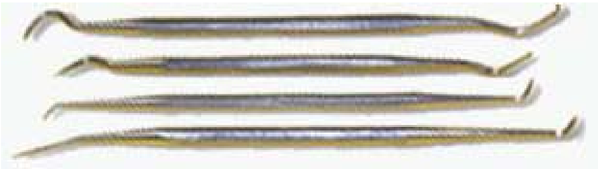
Parallel paddle tweezer

Fig 14



Rounded points tweezer

Fig 15



SMD probers & spudgers

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## Chart showing special tools used for SMD components, SMD IC soldering / desoldering

Fig 1

**Anti - Static Desolderin Pump**

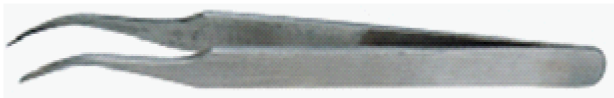
Fig 2

**Heated Tweezers**

Fig 3

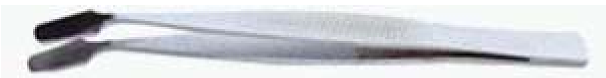
**90° Forming tool**

Fig 4



**Curved tweezer**

Fig 5



**Parallel paddle twezeer**

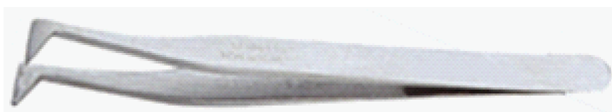
Fig 6

**PGA extractors**

Fig 7

**PLCC socket extraction tool**

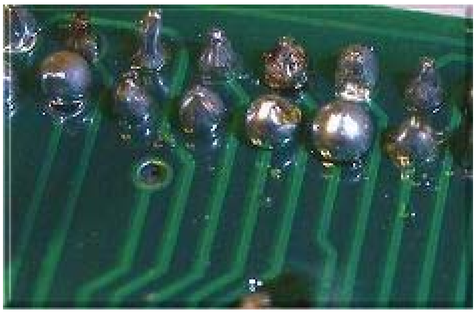
Fig 8



**90° SMD tweezer**

## Chart showing various types of soldering joint defects

Fig 1



Poor solder joints

Fig 2

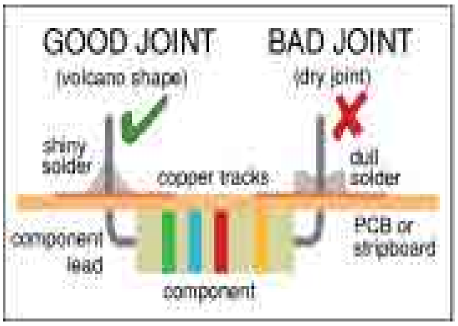
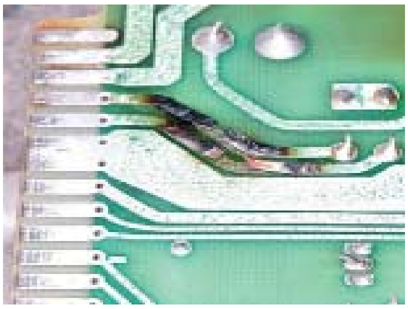



Fig 3



Shows the damage track on PCB

Fig 4

Damage Pad

Fig 5

Fig 6

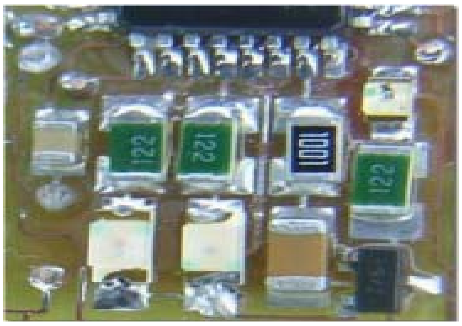


Fig 7

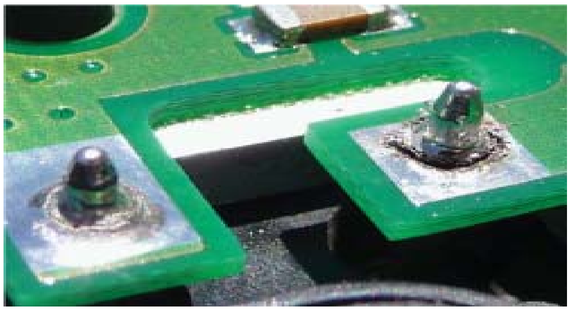
Excess solder on joints

Fig 8

Fig 9

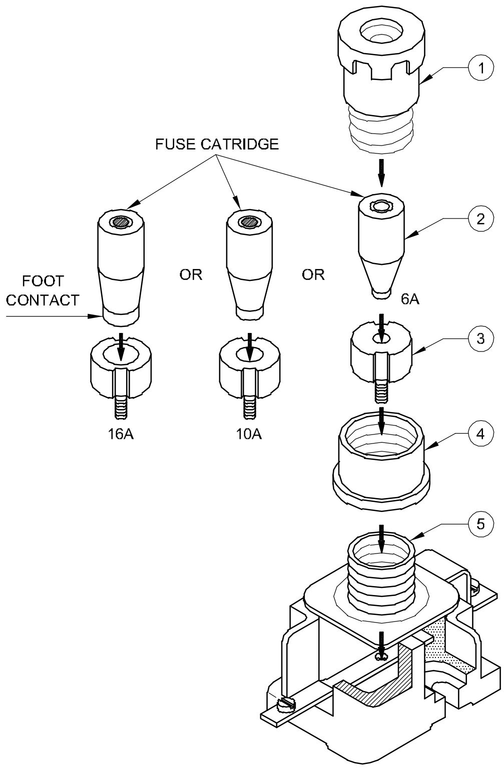
Dry Joints

Fig 10



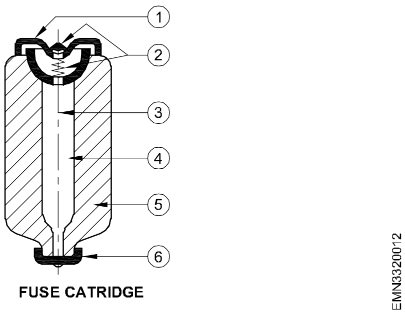
## Chart Showing all types of fuses and fuse holders

Fig 1



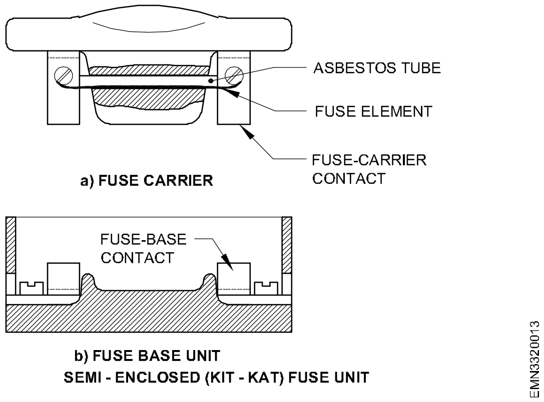

DIAZED SCREW TYPE CATRIDGE FUSE UNIT

Fig 2



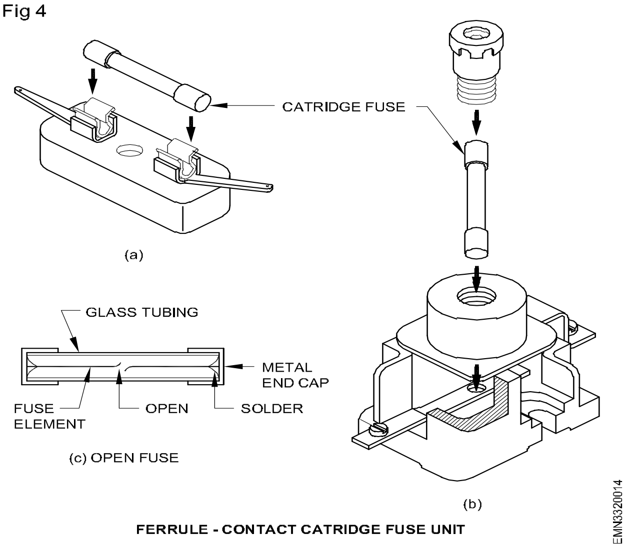

FUSE CATRIDGE

Fig 3




SEMI - ENCLOSED (KIT - KAT) FUSE UNIT

Fig 4




FERRULE - CONTACT CATRIDGE FUSE UNIT

Fig 7

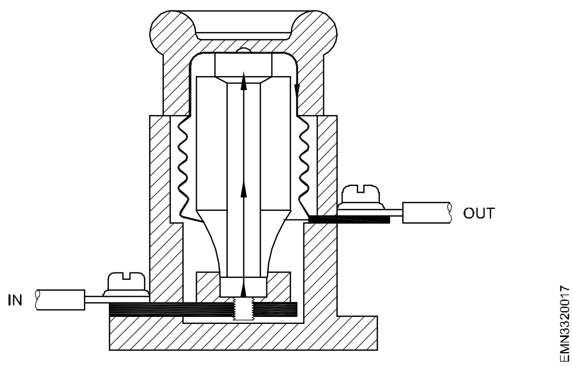


Fig 5

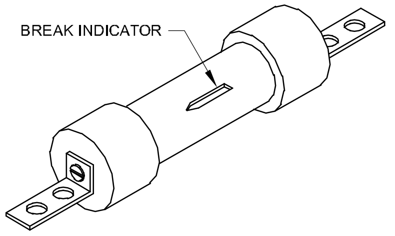



Fig 8

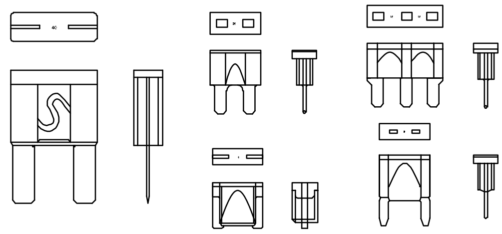
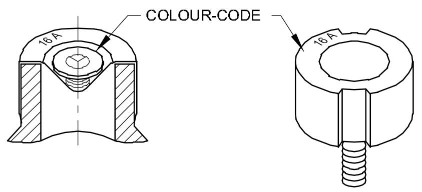



Fig 6

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## Chart showing all types of connectors/socket/plugs used for Audio, Video and RF Applications

Fig 1

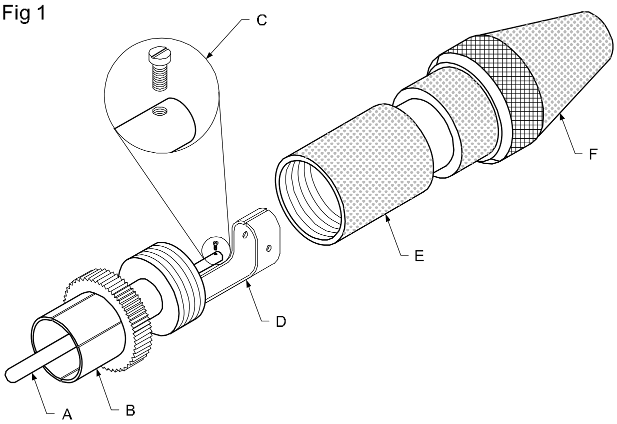



Fig 3

Fig 2

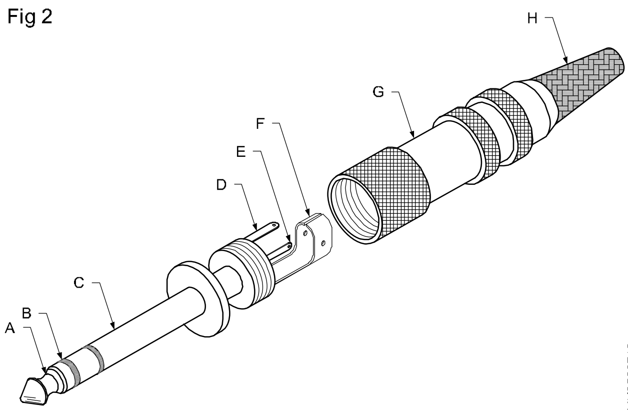
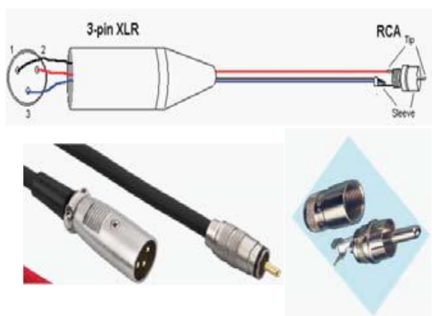
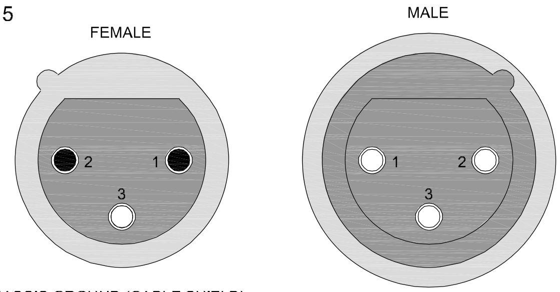



Fig 4




F- CONNECTOR

Fig 5

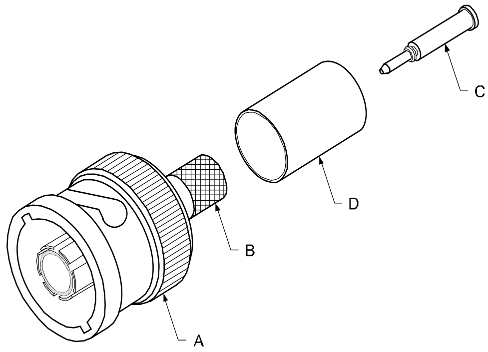



1. CHASSIS GROUND (CABLE SHIELD)
2. POSITIVE POLARITY TERMINAL FOR BALANCED AUDIO CIRCUITS (AKA "HOT")
3. NEGATIVE POLARITY TERMINAL FOR BALANCED CIRCUITS (AKA "COLD")

**PIN AND FUNCTIONS**

EMN3520715

Fig 6




EMN3520716

Fig 7

**RJ45 PLUG**

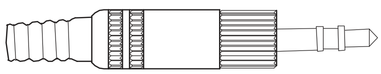
Fig 8

**RJ45 SOCKET**

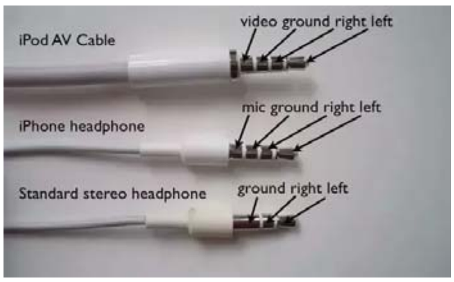
Fig 9

**RJ11**

Fig 9(a)



**(ii) SCREENED PLUG**




EMN3520719a

Fig 10

**RJ11 SOCKET**

Fig 11

**CHASSIS MOUNT SOCKET 3.5mm**

Fig 12

CHASSIC MOUNTING PCB SOCKET 3.5mm

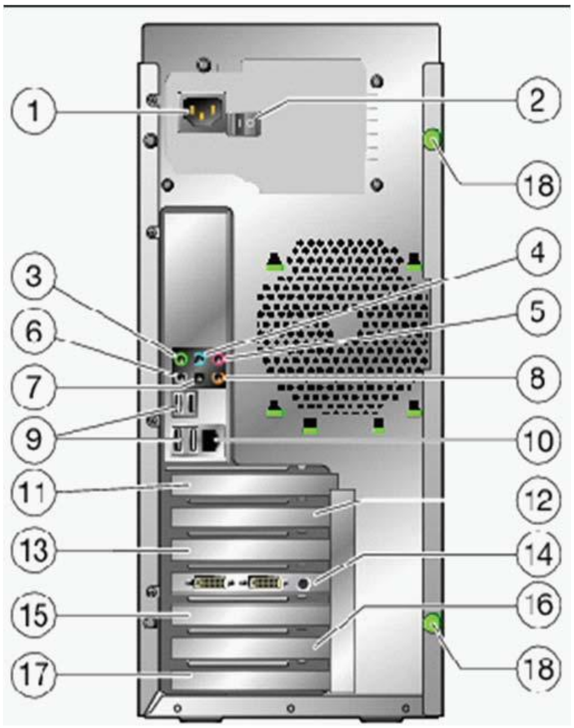
Fig 13


Barrel Connector

— — — — — — — — — —

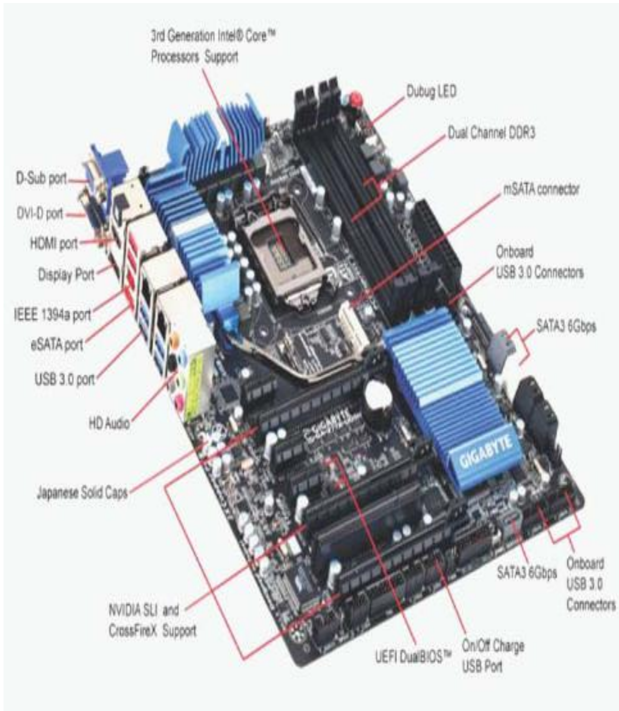
## Chart - 1 Showing rear panel of multimedia computer

Fig 1




## Chart - 2 : Showing internal ports and slots of mother board of multimedia computer

Fig 2



## Chart showing the Pinout Diagram/Data sheet of the IC TEA5591A and the layout Of AM/FM Radio receivers

Fig 1

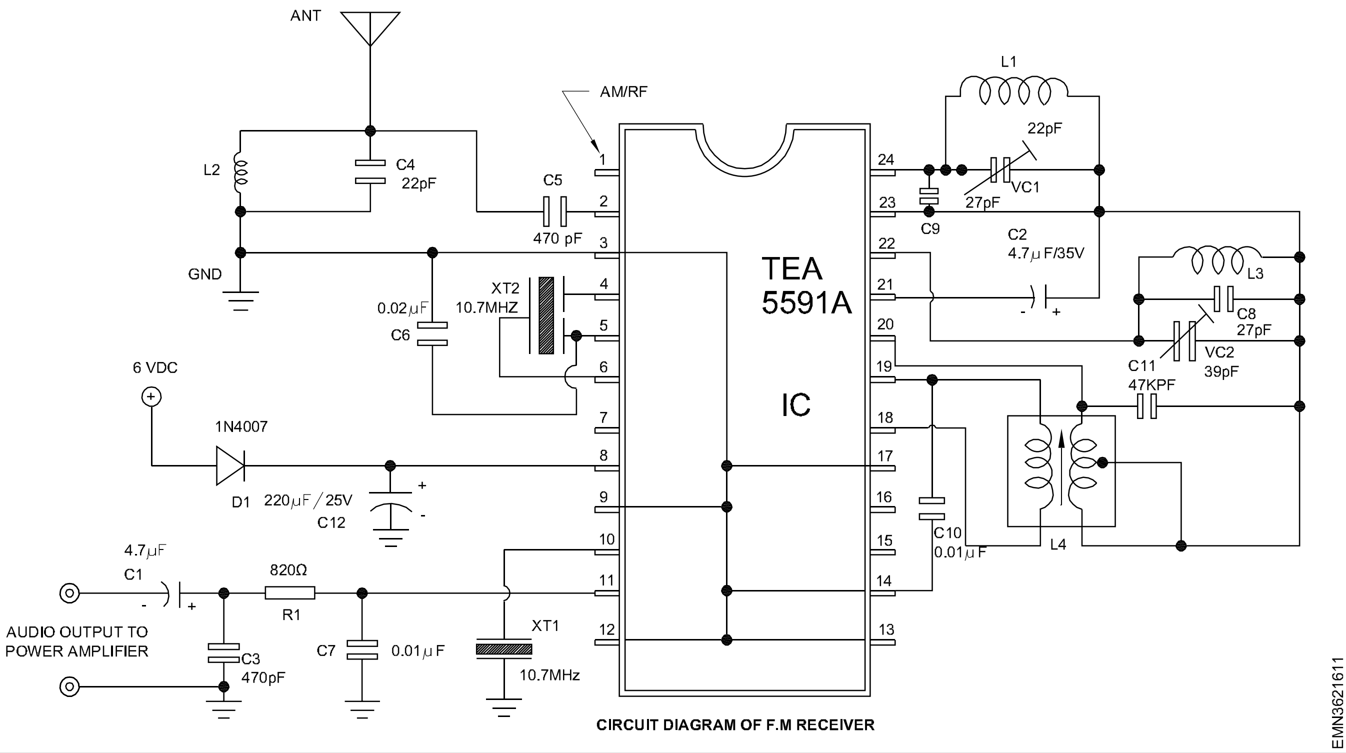
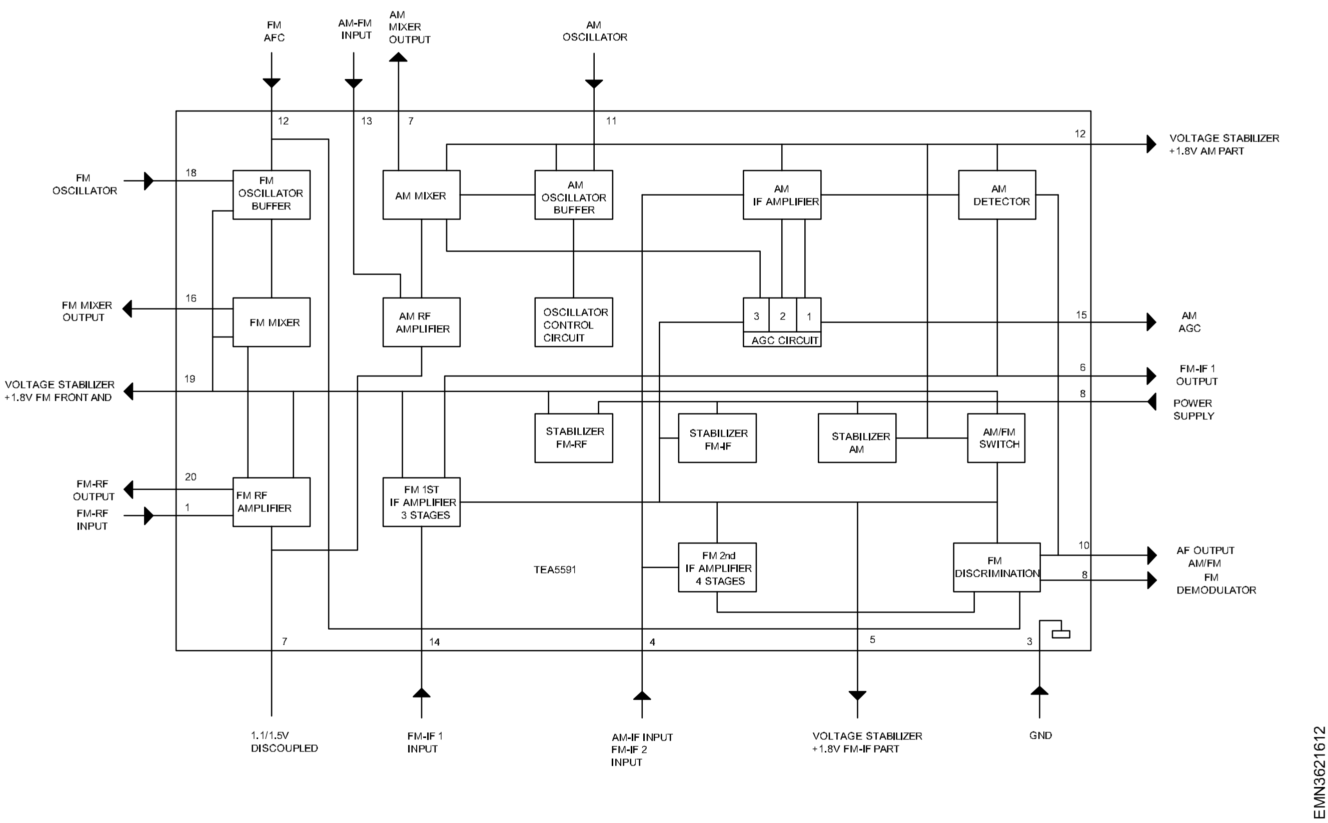



Fig 2

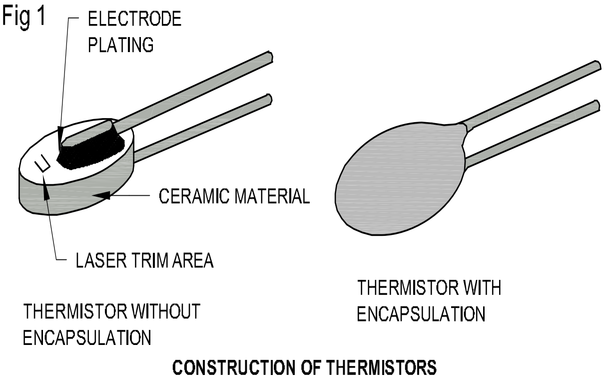


| S.No | Description | Pin Number |
|---|---|---|
| 1 | FM ocillator | 17,18 |
| 2 | Mixer | 16 |
| 3 | RF Input - Pin | 1 |
| 4 | Output | 20 |
| 5 | 1st IF Ampl | 14 |
| 6 | 2nd IF Ampl | 4 |
| 7 | FM Demodulation | |
| 8 | AM/FM - Output | 10 |
| 9 | Power supply | 8 |
| 10 | AGC (AM) | 15 |
| 11 | AM oscilletor | 11 |
| 12 | AM RF input | 13 |
| 13 | AM mixer put | 7 |
| 14 | AM AFC | 17 |

| **Stage - 1** | **Pin Number** |
|---|---|
| RF amp input | 2 |
| **Stage - 2** | |
| FM Osc | 22 |
| **Stage - 3** | |
| Mixed output | 20 |
| **Stage - 4** | |
| IF amp 1st input | 18 |
| **Stage - 5** | |
| IF amp 2nd output | 4 |
| **Stage - 6** | |
| FM Demodulation | 10 |
| **Stage - 7** | |
| AF output | 11 |
| **Supply** | |
| Positive+ Vcc | 8 |
| Common ground | 3 |

## Chart showing all types of Sensors, with colour codes and other details (EX.No.3.8.228 to 232)

Fig 1




CONSTRUCTION OF THERMISTORS

Fig 1a

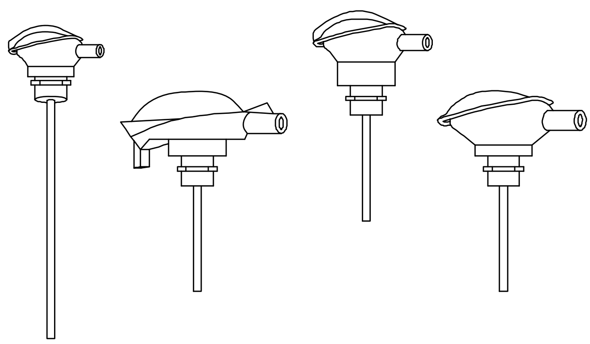
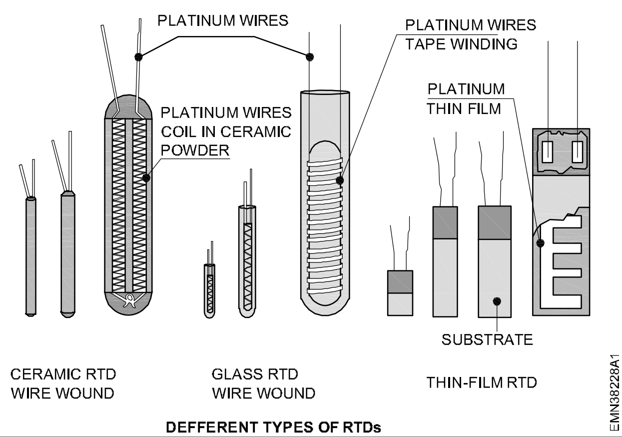


Fig 1b

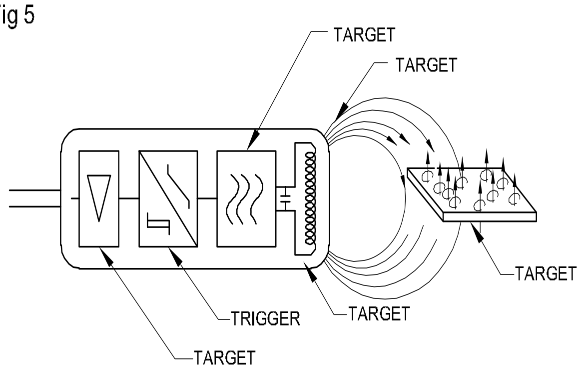



DEFFERENT TYPES OF RTDs

Fig 4

PIEZOELECTRIC STRAIN GAUGE

Fig 5

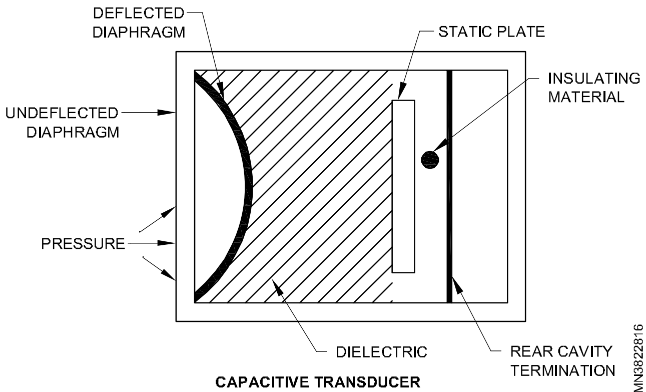



INDUCTANCE TYPE INDUCTIVE TRANSDUCERS

EMN3822815

Fig 6

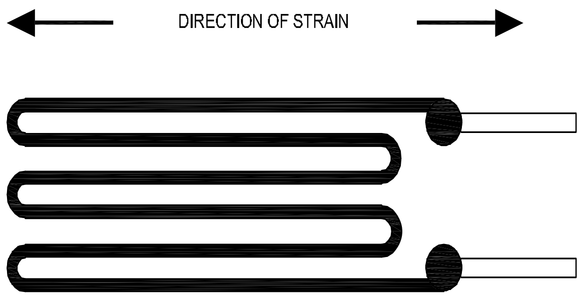
CAPACITIVE TRANDUCER




CAPACITIVE TRANSDUCER

EMN3822816

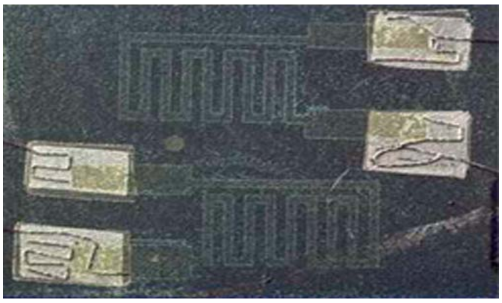
Fig 8




STRAIN GAUGE

EMN3822818

Fig 7

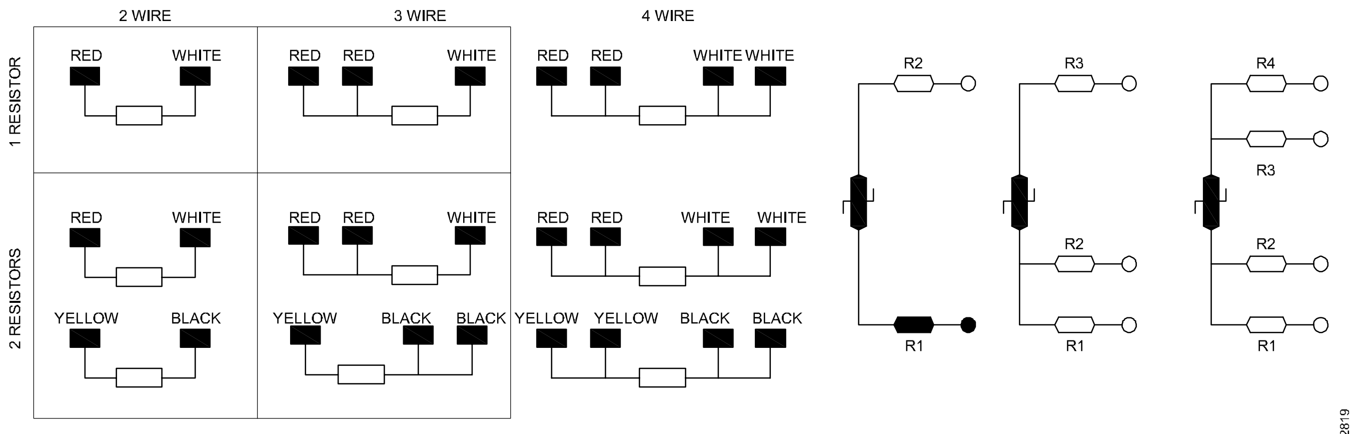


**Electrical Resistance Strain Gauge**

## Proximity Sensor Comparison

| Tecnology | Sensing Range | Applications | Target Materials |
|---|---|---|---|
| Live  | <4-40 mm | Any close - range detection of ferrous material | Iron Steel Aluminium Copper etc.  |
| Capcititive  | <3-60 mm | Close - range detection of non- ferrous material | Liquid Wood Granulates Plastic etc.  |
| Photoelectric  | <1mm - 60 mm | Long - range small or large target detection | Silicon Plastic Paper Metal etc.  |
| Ultrasonic  | <30 mm - 3 mm | Long - range detection of targets with difficult surface properties. Color/ reflectivity insensitive. | Cellophane Foam Glass liquid Powder etc.  |

Fig 9



RTD WIRE TYPES AND ITS COLOR CODE

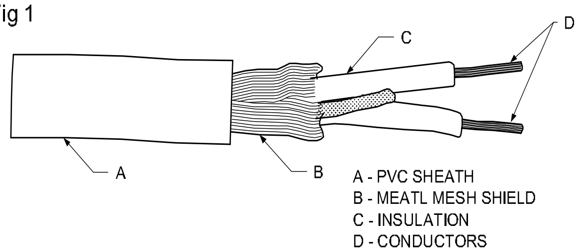
**Thermocouple Characteristics**

| ANSI/ ASTM | Symbol Single | Generic Names | Color Coding Individual Conductor | Color Coding Overall jacket extension grade wire | Magnetic Yes/No | Environment (Bare Wire) |
|---|---|---|---|---|---|---|
| T | TP<br>TN | Copper Constantan, Nominal Composition: 55% Cu, 45% Ni | Blue<br>Red | Blue | X<br>X | Mild Oxidizing, Reducing, Vacuum or Inert, Good where moisture is present |
| J | JP JN | Iron Constantan, Nominal Composition : 55% Cu, 45% Ni | White<br>Red | Black | X<br>X | Reducing Vacuum, Inert, Limited use in oxidizing at High Temperatures, Not recommended for low temps. |
| E | EP<br>EN | Chromel &, Nominal Composition: 90% Ni, 10% Cr Constantan, Nominal Composition : 55% Cu, 45% Ni | Purple<br>Red | Purple | X | Oxidizing or Inert, Limited use in Vacuum or Reducing |

| ANSI/ ASTM | Symbol Single | Generic Names | Color Coding | | Magnetic Yes/No | Environment (Bare Wire) |
|---|---|---|---|---|---|---|
| | | | Individual Conductor | Overall jacket extension grade wire | | |
| K | KP<br>KN | Chromel, Nominal Composition: 90% Ni, 10% Cr Alumel*, Nominal Composition: 95% Ni, 2% Mn, 2% Al | Yellow<br>Red | Yellow | X<br>X | Clean Oxidizing and Inert, Limited use in Vacuum or Reducing |
| N | NP<br>NN | Nicrosil*, Nominal Compositions : 84, 6% Ni, 14.2%, Cr, 1.4% Si Nisil*, Nominal Composition: 95.5%, Ni, 4.4% Si, 1% Mg | Orange<br>Red | Orange | X<br>X | Clean Oxidizing and inert. Limited use in Vacuum or Reducing |
| S | SP<br>SN | Platinum 10% Rhodium Pure Platinum | Black<br>Red | Green | X<br>X | Oxidizing or Inert Atmospheres, Do not Insert in metal tubes. Beware of contamination. |
| R | RP<br>RN | Platinum 13% Rhodium Pure Platinum | Black<br>Red | Green | X<br>X | Oxidizing in Inert Atmospheres. Do not insert in metal tubes. Beware of contamination |
| B | BP<br>BN | Platinum 30% Rhodium Platinum 6% Rhodium | Gray<br>Red | Gray | X<br>X | Oxidizing or Inert Atmospheres. Do not insert in metal tubes. Beware of contamination. ` |
| C | P<br>N | Tungsten 5% Rhenium Tungsten 26% Rhenium | Green<br>Red | Red | X<br>X | Vacuum, Inert, Hydrogen Atmospheres, Beware of Embrittlement. |

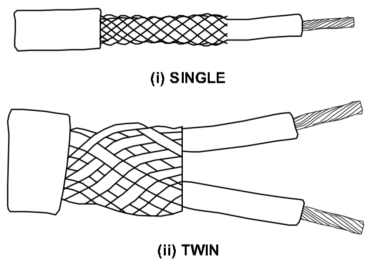
# Chart Showing all types of cables used for Audio, Video, and RF signal Applications.

Fig 1




AUDIO CABLE

Fig 2




STANDARD ROUND

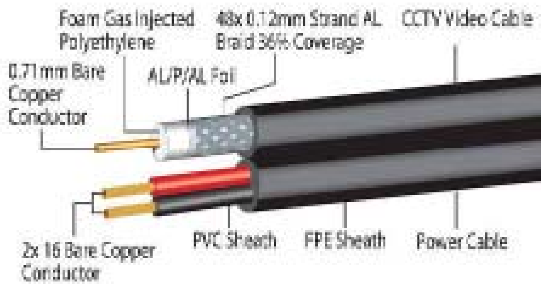
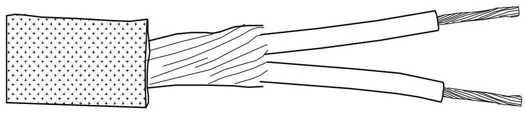
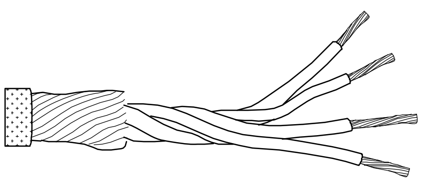



Fig 3



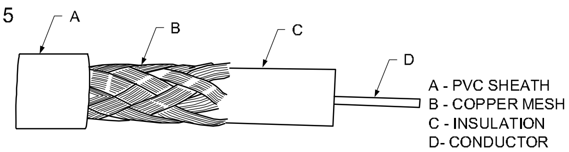

MICROPHONE CABLE

Fig 4




4 CORE CABLE

Fig 5




VIDEO/RF CABLE