

# INSTRUMENT MECHANIC

NSQF LEVEL - 4

1<sup>st</sup> Year

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## TRADE THEORY

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SECTOR : ELECTRONICS & HARDWARE

(As per revised syllabus July 2022 - 1200 of hrs)



Directorate General of Training

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



**NATIONAL INSTRUCTIONAL  
MEDIA INSTITUTE, CHENNAI**

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

**Sector : Electronics & Hardware**

**Duration : 2 Years**

**Trades : Instrument Mechanic - 1<sup>st</sup> year -Trade Theory - NSQF Level - 4 (Revised 2022)**

**Developed & Published by**



**National Instructional Media Institute**

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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 2022 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 Media Development Committee members of various stakeholders viz. Industries, Entrepreneurs, Academicians and representatives from ITIs.

The National Instructional Media Institute (NIMI), Chennai, an autonomous body under 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 **Instrument Mechanic - 1st Year - Trade Theory - NSQF Level - 4 (Revised 2022) in Electronics & Hardware Sector under** Annual pattern. The NSQF Level - 4 (Revised 2022) Trade Practical 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 - 4 (Revised 2022) trainees will also get the opportunities to promote life long learning and skill development. I have no doubt that with NSQF Level - 4 (Revised 2022) the trainers and trainees of ITIs, and all stakeholders will derive maximum benefits from these Instructional Media Packages 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

Addl. Secretary / Director General (Training)  
Ministry of Skill Development & Entrepreneurship,  
Government of India.

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 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.

**Chennai - 600 032**

**EXECUTIVE DIRECTOR**



## 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 **Instrument Mechanic - 1st Year - NSQF Level - 4** (Revised 2022) under the **Electronics & Hardware** Sector for ITIs.

### MEDIA DEVELOPMENT COMMITTEE MEMBERS

|                 |   |                                                                      |
|-----------------|---|----------------------------------------------------------------------|
| Smt. D. Chitra  | - | Training Officer,<br>Govt. I.T.I Ambattur Chennai - 50.              |
| Smt. S. Gomathy | - | Training Officer,<br>Govt. I.T.I Guindy Chennai - 32.                |
| Smt. S. Vijaya  | - | Assistant Training Officer,<br>Govt. I.T.I Women Salem.              |
| Smt. Hemalatha  | - | Assistant Director (Retd),<br>Govt. R.I centre, Guindy, Chennai - 32 |

### NIMI - COORDINATORS

|                         |   |                                          |
|-------------------------|---|------------------------------------------|
| Shri. Nirmalya Nath     | - | Deputy Director,<br>NIMI, Chennai - 32.  |
| Shri. S. Gopalakrishnan | - | Assistant Manager<br>NIMI, Chennai - 32. |

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 PRACTICAL

The trade practical manual is intended to be used in practical workshop. It consists of a series of practical exercises to be completed by the trainees during the course. These exercises are designed to ensure that all the skills in compliance with NSQF LEVEL - 4 (Revised 2022) syllabus are covered.

The manual is divided into Fifteen modules.

- Module 1 Basic Safety
- Module 2 Basic Fitting
- Module 3 Tube Joint and Fitting
- Module 4 Basic Electricity & Passive Components
- Module 5 Electrical Machine
- Module 6 Transformer
- Module 7 Electrical Measuring Instruments
- Module 8 Semi Conductor, Transistors and Power Supply Circuit
- Module 9 Oscillators
- Module 10 Operational Amplifiers
- Module 11 Logic Circuits
- Module 12 A/D and D/A Converters
- Module 13 Digital Meters and CRO
- Module 14 Computers
- Module 15 Microprocessor 8085

The skill training in the shop floor is planned through a series of practical exercises centered 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.

## TRADE THEORY

The manual of trade theory consists of theoretical information for the Course of the **Instrument Mechanic** Trade Practical NSQF Level - 4 (Revised 2022) in **E & H**. The contents are sequenced according to the practical exercise contained in NSQF LEVEL - 4 (Revised 2022) syllabus on Trade Theory attempt has been made to relate the theoretical aspects with the skill covered in each exercise to the extent possible. This correlation is maintained to help the trainees to develop the perceptual 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 indications about the corresponding practical exercises are given in every sheet of this manual.

It will be preferable to teach/learn trade theory connected to each exercise at least 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 for the purpose of self-learning and should be considered as supplementary to class room instruction.

## CONTENTS

| Lesson No.     | Title of the Exercise                                                                                     | Learning Outcome | Page No. |
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|                | <b>Module 1 : Basic Safety</b>                                                                            |                  |          |
| 1.1.01 - 09    | Familiar with industrial Training Institute (ITI)                                                         | 1                | 1        |
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| 1.2.10 - 19    | Basic hand tools                                                                                          | 1                | 20       |
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| 1.3.20 - 23    | Copper tube cutting, bending, swaging and flaring                                                         | 2                | 33       |
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## LEARNING / ASSESSABLE OUTCOME

On completion of this book you shall be able to

| Sl. No. | Learning Outcome                                                                                                                                                                                                                                                                                                                                             | Ref.Ex.No          |
|---------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------|
| 1       | Plan and organize the work to make job as per specification applying different types of basic fitting operation and Check dimensional accuracy using precision instruments following safety precaution. [Basic fitting operation – marking, Hacksawing, Chiseling, Filing, Drilling, Taping and Grinding etc. Accuracy: $\pm 0.5\text{mm}$ ] CSC/N0304       | 1.1.01<br>1.2.09   |
| 2       | Apply a range of skills to execute tube joints, dismantle and assemble tubes and fittings of PI arc & ferrule and test for leakage. [range of skills- cutting, threading, flaring, bending and joining] ELE/N9410                                                                                                                                            | 1.3.20<br>1.3.23   |
| 3       | Identify, test the cable and measure the electrical parameters. ELE/N9411                                                                                                                                                                                                                                                                                    | 1.4.24<br>1.4.30   |
| 4       | Test various electrical passive and active components using proper measuring instruments and compare the data using standard parameter. ELE/N9412                                                                                                                                                                                                            | 1.4.31<br>1.4.39   |
| 5       | Identify, test and use of various types of switches, E.M. relays, Circuit breaker and construct electrical circuits. ELE/N9413                                                                                                                                                                                                                               | 1.4.40<br>1.4.44   |
| 6       | Estimate, Assemble, install and test wiring system. PSS/N6001                                                                                                                                                                                                                                                                                                | 1.4.45-48          |
| 7       | Test various electrical passive and active components using proper measuring instruments and compare the data using standard parameter. ELE/N9412                                                                                                                                                                                                            | 1.4.49-50          |
| 8       | Verify characteristics of resonance circuits. ELE/N9413                                                                                                                                                                                                                                                                                                      | 1.4.51-54          |
| 9       | Plan, execute commissioning, testing and evaluate performance of AC & DC motors and generators. ELE/N9402                                                                                                                                                                                                                                                    | 1.5.55-61          |
| 10      | Execute testing, evaluate performance and maintenance of transformer. PSS/N2406, PSS/N2407                                                                                                                                                                                                                                                                   | 1.6.62-65          |
| 11      | Plan, select, and carry out measurement, extension of range, overhauling, testing and calibration of 'D' Arsonval meter, PMMC meter. ELE/N9414                                                                                                                                                                                                               | 1.7.66-70          |
| 12      | Select, perform electrical/electronic measurement, earthing installation service and calibrate MI instruments, electro dynamometer instruments, Induction type and Special instruments- voltage tester, continuity tester, rotation tester, phase sequence indicator, synchronising, synchronous cope, frequency meter, thermocouple type ammeter. ELE/N9415 | 1.7.71-83          |
| 13      | Identify, Test various analog and power electronics components, Construct, test and analyze the circuit functioning. ELE/N9404                                                                                                                                                                                                                               | 1.7.84-98          |
| 14      | Detect the faults and troubleshoot SMPS, UPS, inverter, converter and Thyristor family. ELE/N7202                                                                                                                                                                                                                                                            | 1.8.99-<br>1.8.105 |

|    |                                                                                                                                                                                                                                |                      |
|----|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------|
| 15 | Identify, place, solder and desolder and test different SMD, discrete components with due care and following safety norms using proper tools /setup. ELE/N5102                                                                 | 1.8.106<br>1.8.111   |
| 16 | Identify, Test various analog and power electronics components, Construct, test and analyze the circuit functioning. ELE/N9407                                                                                                 | 1.9.112<br>1.9.113   |
| 17 | Construct and test different circuits using operational amplifiers circuits and execute the result. ELE/N9407                                                                                                                  | 1.9.114<br>1.10.121  |
| 18 | Identify, test and Verify all digital ICs. Assemble, test and troubleshoot various digital circuits and digital instruments. ELE/N9405                                                                                         | 1.10.122<br>1.13.143 |
| 19 | Measure the various parameters by CRO and execute the result with standard one. ELE/N9416                                                                                                                                      | 1.13.144<br>1.13.145 |
| 20 | Install and setup operating system and related software in a computer & Practice with MS office and application software related to instruments. ELE/N9417                                                                     | 1.13.146<br>1.14.155 |
| 21 | Identify various functional blocks of a microprocessor system, identify various I/O Ports, write and executive simple program and Interface a model application with the microprocessor kit and run the application. ELE/N9418 | 1.15.156<br>1.15.160 |

# SYLLABUS

| Duration                                                     | Reference Learning outcome                                                                                                                                                                                                                                                                                                                             | Professional Skills (Trade Practical) With Indicative Hours                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | Professional Knowledge (Trade Theory)                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|--------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Professional Skill 90 Hrs.<br>Professional Knowledge 16 Hrs. | Plan and organize the work to make job as per specification applying different types of basic fitting operation and Check dimensional accuracy using precision instruments following safety precaution. [Basic fitting operation – marking, Hacksawing, Chiseling, Filing, Drilling, Taping and Grinding etc. Accuracy: $\pm 0.5\text{mm}$ ] CSC/N0304 | <ol style="list-style-type: none"> <li>1. Importance of trade training, List of tools &amp; Machinery used in the trade. (01 Hrs.)</li> <li>2. Safety attitude development of the trainee by educating them to use Personal Protective Equipment (PPE).(05 Hrs.)</li> <li>3. First Aid Method and basic training. (03 Hrs.)</li> <li>4. Safe disposal of waste materials like cotton waste, metal chips/ burrs etc. (03 Hrs.)</li> <li>5. Safety signs for Danger, Warning, caution &amp; personal safety message. (03 Hrs.)</li> <li>6. Preventive measures for electrical accidents &amp; steps to be taken isuch accidents (04Hrs.)</li> <li>7. Use of Fire extinguishers.(03Hrs.)</li> <li>8. Practice and understan precautions to be followed while working in fitting jobs. (05 Hrs.)</li> <li>9. Safe use of tools and equipmentsused in the trade (05 Hrs.)</li> </ol> | Organization of the Institute, Departments various trades & functions. Types of work, responsibility to be undertaken, incentives and future planning of profession. Safely precautions to be observed in the trade both during 'theoretical Periods' and 'Practical hours/workshop hours' Elementary First Aid. Safety and hazards. Sign boards and types. Hazardous and non-hazardous. Environmental pollution related to the trade- caused, consequences, mitigation and control. (06 Hrs.) |
|                                                              |                                                                                                                                                                                                                                                                                                                                                        | <ol style="list-style-type: none"> <li>10. Demonstration and uses of hand tools- screwdrivers,pliers, spanners, tweezers, tester, wire stripper, electrician knife, steel rule, scribe, punches, hammer. (06 Hrs.)</li> <li>11. Visual inspection of raw material for rusting, scaling, corrosion etc. (05 Hrs.)</li> <li>12.Filing- flat &amp; square (Rough finish). (05 Hrs.)</li> <li>13. Filing practice, surface filing, side and checking 900 by try square. (05 Hrs.)</li> <li>14. Marking out lines, filling and saving use of vice to given dimensions. (05 Hrs.)</li> <li>15. Filing- Flat, square and Parallel to an accuracy of 0.5mm. (05 Hrs.)</li> </ol>                                                                                                                                                                                                        | <p>Basic hand tools, types, classification use &amp; metal cutting fundamentals.</p> <p>Filing- Flat, square and Parallel to an accuracy of 0.5mm.</p> <p>Measurement &amp; measuring instruments, Marking tools, Fasteners &amp; Fastening devices. (05 Hrs.)</p>                                                                                                                                                                                                                             |

|                                                              |                                                                                                                                                                                                                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                                                                                                                                                                                                                                                                   |
|--------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                              |                                                                                                                                                                                                                    | 16. Measurement of Length, Height & Diameter by Vernier callipers and Micrometers. (05 Hrs.)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                                                                                   |
|                                                              |                                                                                                                                                                                                                    | 17. Select drill bits, reamers and tapes. (02 Hrs.)<br>18. Drill through holes and blind holes. (10 Hrs.)<br>19. Form external thread with dies to standard size. (10 Hrs.)                                                                                                                                                                                                                                                                                                                                                                                                                        | Precision Measuring Instruments, gauge blocks, sine bar, dial indicators, vernier calipers, micrometers, bevel protractor, thickness gauges.<br><br>Element & types of screw threads used in instruments, Calculation of drill size for tapping. (05 Hrs.)                                        |
| Professional Skill 25 Hrs.<br>Professional Knowledge 04 Hrs. | Apply a range of skills to execute tube joints, dismantle and assemble tubes and fittings of PI arc & ferrule and test for leakage. [range of skills- cutting, threading, flaring, bending and joining] ELE/ N9410 | 20. Flaring of tube and tube joints. (06Hrs.)<br>21. Cutting and threading of tube length. (06 Hrs.)<br>22. Fitting of tube and per sketch observing conditions used for tube work. (06 Hrs.)<br>23. Fit and assemble tubes, PI arc and ferrule fittings. (07 Hrs.)                                                                                                                                                                                                                                                                                                                                | Types of tubes used for instrumentation. Tube cutter, Flaring tools, swedging tools, equipment's & fixture required for pipe bending, straightening, thread cutting, method of installation. (04 Hrs.)                                                                                            |
| Professional Skill 20 Hrs.<br>Professional Knowledge 05 Hrs. | Identify, test the cable and measure the electrical parameters. ELE/N9411                                                                                                                                          | 24. Construct a test lamp and use it to check mains healthiness. (02Hrs.)<br>25. Measure the voltage between phase and ground and rectify earthing. (03 Hrs.)<br>26. Prepare terminations, skin the electrical wires /cables using wire stripper and cutter. (03 Hrs.)<br>27. Measure the gauge of the wire using SWG and outside micrometre. (03 Hrs.)<br>28. Refer table and find current carrying capacity of wires. (03Hrs.)<br>29. Measure AC and DC voltages using multi meter. (03 Hrs.)<br>30. Use the multi meter to measure the various functions (AC V, DC V, DC I, AC I, R). (03 Hrs.) | Electrical components-conductor, semiconductor & insulators. Standard wire gauge (SWG). Introduction of electricity- static electricity. Current, voltage, P.D, E.M.F, resistance. Electrical circuit - D.C & A.C circuit differences. Importance of grounding. (05 Hrs.)                         |
| Professional Skill 20 Hrs.<br>Professional Knowledge 05 Hrs. | Test various electrical passive and active components using proper measuring instruments and compare the data using standard parameter. ELE/ N9412                                                                 | 31. Measure the resistor value by colour code and verify the same by measuring with multi-meter. (02 Hrs.)<br>32. Practice soldering on IC bases and PCBs. (03 Hrs.)<br>33. Practice de-soldering using pump and wick. (02 Hrs.)<br>34. Join the broken PCB track and test. (02 Hrs.)                                                                                                                                                                                                                                                                                                              | Uses of multimeter. Resistor, Resistivity and colour code, Types of resistors used in instrumentation. Definition and purpose of soldering and desoldering. Soft soldering.<br><br>Types of soldering irons. Solder & flux. Care & precaution of soldering. De-soldering tools and method of use. |



|                                                                         |                                                                                                                                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                                                                                                                                                                                                                                                                                                                  |
|-------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                         |                                                                                                                                                           | <p>35. Practice on measurement of parameters in combinational electrical circuit by applying Ohm's Law for different resistor values and voltage sources. (03Hrs.)</p> <p>36. Measurement of current and voltage in electrical circuits to verify Kirchhoff's Law. (02 Hrs.)</p> <p>37. Verify laws of series and parallel circuits with voltage source in different combinations. (02 Hrs.)</p> <p>38. Measure the resistance, Voltage, Current through series and parallel connected networks using multi meter. (02 Hrs.)</p> <p>39. Measure and test the voltages of the given cells/battery using analog/digital multi-meter. (02Hrs.)</p> | <p>Ohm's law &amp; Kirchhoff s laws. Series &amp; parallel circuits. Primary &amp; secondary cells and batteries. (Liquid &amp; dry). Maintenance free batteries construction-charging, efficiency-use, advantage.(05 Hrs.)</p>                                                                                                  |
| <p>Professional Skill 20 Hrs.</p> <p>Professional Knowledge 04 Hrs.</p> | <p>Identify, test and use of various types of switches, E.M. relays, Circuit breaker and construct electrical circuits. ELE/N9413</p>                     | <p>40. Dismantle and identify the different parts of a relay. (04 Hrs.)</p> <p>41. Connect a timer relay in a circuit and test for its working. (04 Hrs.)</p> <p>42. Connect a contactor in a circuit and test for its working. (04 Hrs.)</p> <p>43. Construct and test series and parallel resonance circuit. (04Hrs)</p> <p>44. Make a panel board using different types of switches for a given application. (04 Hrs.)</p>                                                                                                                                                                                                                   | <p>Switches and types. Magnet and magnetism, magnetic properties. Magnetic campus and its uses. Explanation of Electro-magnetism, Advantages, disadvantages-application-types E.M. relays. (04 Hrs.)</p>                                                                                                                         |
| <p>Professional Skill 20 Hrs.</p> <p>Professional Knowledge 04 Hrs.</p> | <p>Estimate, Assemble, install and test wiring system. PSS/N6001</p>                                                                                      | <p>45. Practice cutting, threading of different sizes &amp; laying Installations. (05 Hrs.)</p> <p>46. Draw layouts and practice in PVC Casing-capping, Conduit wiring with minimum to a greater number of points of minimum 15 mtrs. (05 Hrs.) length. (05 Hrs.)</p> <p>47. Wire up PVC conduit wiring to control one lamp from two different places. (05 Hrs.)</p> <p>48. Draw layouts and practice Wiring for instrument panel. (05Hrs.)</p>                                                                                                                                                                                                 | <p>Principles of alternating current, A.C &amp; DC electricity, types of wave forms, time period and frequency, peak to peak values, RMS values, Average values. (04 Hrs.)</p>                                                                                                                                                   |
| <p>Professional Skill 20 Hrs.</p> <p>Professional Knowledge 04 Hrs.</p> | <p>Test various electrical passive and active components using proper measuring instruments and compare the data using standard parameter. ELE/ N9412</p> | <p>49. Measure the inductor value by written/colour code and verify the same by measuring with LCR meter. (10 Hrs.)</p> <p>50. Measure charge, energy store of capacitor in series and parallel circuits with voltage source in different combination. (10 Hrs.)</p>                                                                                                                                                                                                                                                                                                                                                                            | <p>Inductor and Inductance, types of inductors, Factors affecting the value of inductance, self-inductance (L), Capacitance, types of capacitor, unit of capacitance, factors affecting the value of capacitors, charge, energy stored in capacitors. Capacitors in series and parallel. Capacitors in DC circuit. (04 Hrs.)</p> |



|                                                              |                                                                                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|--------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Professional Skill 20 Hrs.<br>Professional Knowledge 05 Hrs. | Verify characteristics of resonance circuits. ELE/N9413                                                   | <p>51. Measure capacitive and inductive reactance with increase/decrease the input frequency of the circuit. (05 Hrs.)</p> <p>52. Measure current &amp; voltage and determine the characteristics of RL, RC and RLC in AC series circuits. (05 Hrs.)</p> <p>53. Measure the resonance frequency in AC series circuit and determine its effect on the circuit. (05 Hrs.)</p> <p>54. Measure current &amp; voltage and determine the characteristics of RL, RC and RLC in AC series circuits. (05 Hrs.)</p>                                                                                                                                                                                | A.C.-impedance, Inductive reactance, capacitive reactance. AC current through - R, L, C circuits. Resonance in RLC circuit. Importance - of series and parallel resonance. (05 Hrs.)                                                                                                                                                                                                                                                       |
| Professional Skill 46 Hrs.<br>Professional Knowledge 10 Hrs. | Plan, execute commissioning, testing and evaluate performance of AC & DC motors and generators. ELE/N9402 | <p>55. Start, run and reverse the direction of rotation of single-phase AC motors. (07Hrs.)</p> <p>56. Practice on speed control of single-phase AC motors. (06Hrs.)</p> <p>57. Install, connect and determine performance of single-phase DC motors. (07 Hrs.)</p> <p>58. Start, run and reverse the direction of rotation of single-phase DC motors. (06Hrs.)</p> <p>59. Install an alternator, identify parts and terminals of alternator. (07Hrs.)</p> <p>60. Perform speed control of DC motors - field and armature control method. (06 Hrs.)</p> <p>61. Connect, start and run three phase induction motors by using DOL, star-delta and auto-transformer starters. (07 Hrs.)</p> | <p>Introduction of AC and DC generators working principles, construction.</p> <p>Operation, field magnets, armature windings, commutator and brushes, EMF equation. Faraday's Law, Lenz's Law, Fleming's left Hand and right-hand rules. DC motors working principles, construction, operation, types. Different speed controlling techniques of DC motors. AC motors, induction motors, three phase motors, stepper motors. (10 Hrs.)</p> |
| Professional Skill 20 Hrs.<br>Professional Knowledge 05 Hrs. | Execute testing, evaluate performance and maintenance of transformer. PSS/N2406, PSS/N2407                | <p>62. Perform OC and SC test to determine and efficiency of single-phase transformer. (05Hrs.)</p> <p>63. Determine voltage regulation of single-phase transformer at different loads and power factors. (05 Hrs.)</p> <p>64. Verify and measure voltage regulation of auto transformer at different loads. (05 Hrs.)</p> <p>65. Perform series and parallel operation of two single phase transformers. (05 Hrs.)</p>                                                                                                                                                                                                                                                                  | Transformer, types, transformation ratio. Open circuit test and short circuit test, regulation Auto transformer. Current measurement. Instrument transformer. Potential transformer and current transformer. (05 Hrs.)                                                                                                                                                                                                                     |

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| Professional Skill 40 Hrs.<br>Professional Knowledge 06 Hrs. | Select, perform electrical/ electronic measurement, earthing installation service and calibrate MI instruments, electro dynamometer instruments, Induction type and Special instruments-voltage tester, continuity tester, rotation tester, phase sequence indicator, synchronising, synchroscope, frequency meter, thermocouple type ammeter. ELE/N9415 | 66. Overhaul, check, fault find, repair, test of voltmeter and ammeter. (07 Hrs.)<br>67. Study the construction circuit operation and adjustment for correct functioning of zero errors on voltmeter and ammeter. (06Hrs.)<br>68. Find the minimum and maximum measurable range of the meter. (07Hrs.)<br>69. Test the shunt and series resistance of various range of ammeter. (07 Hrs.)<br>70. Practice multipliers for different range extension of voltmeter and ammeter. (07 Hrs.)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | <b>Basics of electrical measuring instruments-</b><br>Types - absolute and secondary instruments. Types of secondary instruments, DC instruments - 'D1 Arsonval meter, PMMC meter-working principle, method of working, moving coil operation. (FSD) full scale deflection reading, measurement value, meter sensitivity, accuracy. Meter resistance, maximum power, capability etc.<br><b>Meter range extension-</b><br>Converting galvanometer into ammeter, voltmeter. Range extension of voltmeter, ammeter.<br>Shunt resistance and series resistance value calculation. Meter resistance, meter FSD identification techniques. (06 Hrs.)                                                                                                                                                                                                                                                                                                                                      |
| Professional Skill 60 Hrs<br>Professional Knowledge 10 Hrs.  | Select, perform electrical/ electronic measurement, earthing installation service and calibrate MI instruments, electro dynamometer instruments, Induction type and Special instruments-voltage tester, continuity tester, rotation tester, phase sequence indicator, synchronising, synchroscope, frequency meter, thermocouple type ammeter. ELE/N9415 | 71. Prepare plate earthing and measure earth resistance by earth tester / megger. (05 Hrs.)<br>72. Test earth leakage by ELCB and relay. (05 Hrs.)<br>73. Measure the power using wattmeter. (05 Hrs.)<br>74. Test and calibrate wattmeter. (05Hrs.)<br>75. Familiar with the construction of energy meter and ampere hour meter. (03 Hrs.)<br>76. Overhaul, check and fault find of ampere hour meter. (05 Hrs.)<br>77. Test and calibrate ampere hour meter. (05 Hrs.)<br>78. Measure power in single and three phase circuit using voltmeter & ammeter. (05 Hrs.)<br>79. Overhaul and maintenance of KWH meter and energy meter. (05 Hrs.)<br>80. Test and calibrate KWH meter and energy meter. (05 Hrs.)<br>81. Measure power factor in three phase circuit by using power factor meter and verify the same with voltmeter, ammeter and wattmeter readings. (05 Hrs.)<br>82. Practice of use voltage tester to Test electrical power in circuit, to test for proper grounding, to | Ohm meters- measuring electrical resistance. Basic construction of Ohm meter, working method of ohmmeter. Types of Ohm meter - series and shunt type of ohm meters. Megger/insulation tester, earth tester - construction working advantages and disadvantages of various types of ohm meter.<br>AC instruments - types of AC measuring instruments - MI, electro dynamometer type, Working principle, construction, advantages and disadvantages of MI instruments and electro dynamometer instruments. Various applications.<br>Induction type meters -working principle construction and operation of induction type instruments. Construction and Applications - single phase and three phase energy meter, watt meter. Watt hour meter, Ampere Hour meter, power factor meter etc.<br>Special instruments: voltage tester, continuity tester, rotation test, phase sequence indicator, synchronizing, the synchroscope, frequency meter. Thermocouple type ammeters. (10 hrs.) |

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|                                                                         |                                                                                                                                        | <p>determine whether adequate voltage is present in a wire. (05Hrs.)</p> <p>83. Determines the phase sequence of the three-phase supply system using Phase sequence indicator. (02 Hrs.)</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| <p>Professional Skill 80 Hrs.</p> <p>Professional Knowledge 16 Hrs.</p> | <p>Identify, Test various analog and power electronics components, Construct, test and analyze the circuit functioning. ELE/ N9404</p> | <p>84. Test the power diode, Zener diode, tunnel diode, photo diode using multi meter and determine forward to reverse resistance ratio. (05 Hrs.)</p> <p>85. Determine V-I characteristics of semiconductor diode. (05 Hrs.)</p> <p>86. Measure the voltage and current through a diode in a circuit and verify its forward characteristic. (05 Hrs.)</p> <p>87. Measure the voltage and current through a Zener diode in a circuit and verify its forward and reverse characteristic. (05 Hrs.)</p> <p>88. Construct and test fixed-bias, emitter-bias and voltage divider-bias transistor amplifier. (05Hrs.)</p> <p>89. Construct and Test a common emitter amplifier with and without bypass capacitors</p> <p>90. Construct a single stage amplifier and measure current gain, voltage gain &amp; power gain. (05 Hrs.)</p> <p>91. Construct and test a FET Amplifier. (04 Hrs.)</p> <p>92. Construct and test a half wave, full wave and Bridge rectifier circuit. (05 Hrs.)</p> <p>93. Construct and test different filter circuit used in rectifier and measure output voltage with load. (05 Hrs.)</p> <p>94. Construct and test Zener based voltage regulator circuit. (03Hrs.)</p> <p>95. Construct and test Zener and transistor-based series regulator. (03 Hrs.)</p> <p>96 Construct and test a +12V fixed voltage regulator. (05 Hrs.)</p> <p>97 Construct and test a fixed +15ve and -15ve voltage regulator using ICs. (05 Hrs.)</p> <p>98 Construct and test a 1. (05Hrs.)2V 30V variable output regulated power supply using IC LM317T and its characteristics. (05 Hrs.)</p> | <p>Semiconductor, Covalent bond, Doping, Intrinsic and extrinsic semiconductor. PN junction diode, Forward and Reverse characteristics. Specification of diodes (data sheets). Applications of diode. Special semiconductor diode-Zener diode, tunnel diode, Photo diode.</p> <p>Transistors. Defining transistors, NPN&amp; PNP transistor, Symbol, operation, Biasing of Transistor &amp; mode of Application. Transistor CB, CC, CE Amplification, current gain, voltage gain, and power gain. Introduction to FET, MOSFET.</p> <p>Rectifiers: half wave rectifier, full wave (bridge &amp; center tapped) rectifier. Voltage multipliers. Filters: Introduction, purpose and use of ripple filter. Types of filters. Capacitance filter, inductance filters, RC filters, LC filters, voltage dividers and bypass filters.</p> <p>Voltage regulators.</p> <p>Introduction &amp; purpose Zener regulators, shunt regulators, series regulators, IC regulators, variable regulators. (16 hrs.)</p> |
| <p>Professional Skill 20 Hrs.</p>                                       | <p>Detect the faults and troubleshoot SMPS,</p>                                                                                        | <p>99 List the defect and symptom in the faulty SMPS. (02 Hrs.)</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |

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| Professional Knowledge<br>04 Hrs.                            | UPS, inverter, converter and Thyristor family. ELE/N7202                                                                                                      | <p>100 Measure / Monitor major test points of computer SMPS. (02Hrs.)</p> <p>101. Troubleshoot the fault in the given SMPS unit. Rectify the defect and verify the output with load. Record your procedure followed for trouble shooting the defects. (05Hrs.)</p> <p>102. Open top cover of a UPS; identify its isolator transformers, the UPS transformer and various circuit boards in UPS. (03 Hrs.)</p> <p>103. Perform load test to measure backup time. (03 Hrs.)</p> <p>104. Install and test an inverter. (02Hrs.)</p> <p>105. Troubleshoot the fault in the given inverter unit. Rectify the defects and verify the output with load. (03Hrs.)</p> | <p><b>Power Supply units.</b></p> <p>Introduction, purpose &amp; use. UPS and SMPS, inverters and converters and their applications. (04 Hrs.)</p>                                                                                                                                                     |
| Professional Skill 20 Hrs.<br>Professional Knowledge 04 Hrs. | Identify, place, solder and desolder and test different SMD, discrete components with due care and following safety norms using proper tools/setup. ELE/N5102 | <p>106. Measure and plot input and output characteristics of a CE amplifier. (05 Hrs.)</p> <p>107. Check for cold continuity of PCB. (03 Hrs.)</p> <p>108. Solder the SMD components from the given PCB. (04 Hrs.)</p> <p>109. De-solder the SMD components in the same PCB. (04 Hrs.)</p> <p>110. Repair solder mask and damage pad. (04 Hrs.)</p>                                                                                                                                                                                                                                                                                                          | <p>General characteristics of an amplifier, Concept of amplification.</p> <p>PCB basic construction, applications. Lay outting circuit on PCB. (04 Hrs.)</p>                                                                                                                                           |
| Professional Skill 20 Hrs.<br>Professional Knowledge 05 Hrs. | Identify, Test various analog and power electronics components, Construct, test and analyze the circuit functioning. ELE/N9407                                | <p><b>Oscillators</b></p> <p>111. Demonstrate Colpitts oscillator, Hartley oscillator circuits and compare the output frequency of the oscillator by CRO. (08Hrs.)</p> <p>112. Construct and test a RC phase shift oscillator circuits. (06 Hrs.)</p> <p>113. Construct and test a crystal controlled oscillator circuit. (06Hrs.)</p>                                                                                                                                                                                                                                                                                                                       | <p>Oscillator's oscillations, oscillation frequency, basic working principle and working of Tank circuit, Crystal controlled oscillators, Phase shift oscillators, RC phase shift oscillators, Colpitt, Clapp, Hartley. (05 Hrs.)</p>                                                                  |
| Professional Skill 44 Hrs.<br>Professional Knowledge 10 Hrs. | Construct and test different circuits using operational amplifiers circuits and execute the result. ELE/N9407                                                 | <p>114. Use analog IC tester to test the various analog ICs. (07Hrs.)</p> <p>115. Construct and test various Op Amp circuits Inverting, Non inverting and Summing Amplifiers. (05 Hrs.)</p> <p>116. Construct and test Differentiator and Integrator circuits. (05 Hrs.)</p>                                                                                                                                                                                                                                                                                                                                                                                 | <p><b>Operational Amplifier.</b></p> <p>Differential amplifier, ideal op-amp.</p> <p>Op-amp with feedback, advantages of feedback. Inverting and Non inverting and inverting amplifier, Op-amp as summer, differential amplifier. V to I converter and I to V converter, Instrumentation amplifier</p> |

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|                                                                          |                                                                                                                                               | <p>117. Construct and test a voltage to current and current to voltage converter circuit using Op-amp. (05 Hrs.)</p> <p>118. Construct and test Instrumentation amplifier (04 Hrs.)</p> <p>119. Construct and test Astable timer circuit using IC 555. (06 Hrs.)</p> <p>120. Construct and test mono stable timer circuit using IC 555. (06Hrs.)</p> <p>121. Construct and test 555 timers as pulse width modulator. (06Hrs.)</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | <p>Basics of op- amp applications - integrator, differentiator,</p> <p>Introduction of timers (555) and its applications. (10 Hrs.)</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| <p>Professional Skill 125 Hrs.</p> <p>Professional Knowledge 20 Hrs.</p> | <p>Identify, test and Verify all digital ICs. Assemble, test and troubleshoot various digital circuits and digital instruments. ELE/N9405</p> | <p>122. Verify the truth tables of all Logic Gate ICs by connecting switches and LEDs. (05 Hrs.)</p> <p>123. Construct and verify the truth table of all the gates using NAND and NOR gates. (05 Hrs.)</p> <p>124. Use digital IC tester to test the various digital ICs (TTL and CMOS). (05 Hrs.)</p> <p>125. Construct and verify the truth table of all the gates using DTL circuit. (05 Hrs.)</p> <p>126. Construct Half Adder circuit using ICs and verify the truth table. (05 Hrs.)</p> <p>127. Construct Full adder with two Half adder circuit using ICs and verify the truth table. (05 Hrs.)</p> <p>128. Construct Half subtractor and full subtractor circuit using ICs and verify the truth table. (05 Hrs.)</p> <p>129. Construct the adder cum subtractor circuit and verify the result. (05 Hrs.)</p> <p>130. Construct and test R-S flip-flop using IC7400 with clock and without clock pulse. (06 Hrs.)</p> <p>131. Verify the truth tables of JK Flip-Flop using ICs by connecting switches and LEDs. (06 Hrs.)</p> <p>132. Construct and test 7493 as a modulus-12 counter. (06 Hrs.)</p> <p>133. Construct and test seven segment LED display decoder with IC 7447. (06 Hrs.)</p> <p>134. Measure current flowing through a resistor and display it on LED Module. (06 Hrs.)</p> | <p><b>Number systems;</b> binary, octal, decimal and hexadecimal number system. Conversion of number systems. Boolean algebra, binary addition, subtraction, multiplication and division. 1's and 2's compliment, BCD code, ASCII code, gray code. Logic Circuits. Basic gates-AND, OR and NOT gates. De-Morgan's Theorem.</p> <p>Universal gates - NAND and NOR gates.</p> <p>Special gates - Ex-OR, Ex-NOR gates and Buffer and its applications. Basic digital ICs, function, digital application, logic symbols.</p> <p>Adders - Half adder, full adder Subtractor - Half subtractor, full subtractor.</p> <p>Flip flops - RS flip flop, clocked RS flip flop, JK flip flop,</p> <p>Basics of Counters and registers. Multiplexer and de-multiplexer.</p> <p>Digital meters: displays: LED, 7 segment display, LCD, CRT, electro-luminescent displays, electro-phoretic image display, liquid vapor display, dot matrix display.(10 Hrs.)</p> |



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|                                                              |                                                                                                                                                            | <p>135. Construct and test Digital to Analog (D/A) Binary Weighted resistor converter by using op-amps. (06 Hrs.)</p> <p>136. Construct and test Digital to Analog (D/A) converter using R-2R ladder network circuit. (06 Hrs.)</p> <p>137. Perform the interfacing of IEEE 488.2 standard with a single controller can control up to 15 different instrument connected star topology. (06 Hrs.)</p> <p>138. Perform the interfacing of RS232 to the PC. (06 Hrs.)</p> <p>139. Convert RS-485 signals to RS-232 signals using RS-485 to RS-232 converter. (06 Hrs.)</p> | <p><b>A/D and D/A converters,</b></p> <p>Introduction, weighted register D / A converter, binary(R-2R) ladder D / A converter, specification for D / A converter, Ramp or counter type A/D converter, GPIB (general purpose interface bus) IEEE - 488, RS 232. (06 Hrs.)</p> |
|                                                              |                                                                                                                                                            | <p>140. Display a word on a two-line LED. (05 Hrs.)</p> <p>141. Measure current flowing through a sensor and display it on a LED module (DPM). (05 Hrs.)</p> <p>142. Practice on measuring instruments in single and three phase circuits e.g. (05 Hrs.) Phase sequence meter and Frequency meter etc. (05 Hrs.)</p> <p>143. Practice on time measuring instrument to measure the time in different electrical control circuit. (05 Hrs.)</p>                                                                                                                           | <p>Digital meters: frequency meter, phase measuring meter, and time measuring instruments. Digital capacitance meter. (04 Hrs.)</p>                                                                                                                                          |
| Professional Skill 20 Hrs.<br>Professional Knowledge 05 Hrs. | Measure the various parameters by CRO and execute the result with standard one. ELE/N9416                                                                  | <p>144. Measure the Amplitude, Frequency and time period of typical electronic signals using CRO. (10 Hrs.)</p> <p>145. Take a print of a signal from DSO by connecting it to a printer and tally with applied signal. (10 Hrs.)</p>                                                                                                                                                                                                                                                                                                                                    | <p>CRO: introduction and applications of CRO, functional block diagram of CRO, CRT power supply. Various types of probes. Applications of various types of CROs like dual beam CRO, Dual trace CRO, storage oscilloscope. (05 Hrs.)</p>                                      |
| Professional Skill 70 Hrs.<br>Professional Knowledge 10 Hrs. | Install and setup operating system and related software in a computer & Practice with MS office and application software related to instruments. ELE/N9417 | <p>146. Practice on windows interface and navigating windows. (07 Hrs.)</p> <p>147. Customize the desktop settings and manage user accounts. (07 Hrs.)</p> <p>148. View system properties and control panel details. (07 Hrs.)</p> <p>149. Install necessary application software for windows i.e. office package and media player. (07 Hrs.)</p> <p>150. Burn data, video and audio files on CD/DVD using application software. (07 Hrs.)</p>                                                                                                                          | <p>Introduction to Computer, Block diagram of PC, software familiarization of Multimedia System consisting of CD ROMS, DVD ROMS, Sound Cards. (05 Hrs.)</p>                                                                                                                  |

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|                                                             |                                                                                                                                                                                                                              | <p>151. Dismantle and assemble the desktop computer system. (07 Hrs.)</p> <p>152. Replace RAM and ROM from CPU. (07 Hrs.)</p> <p>153. Identify different parts, its function and operation of modem. (07 Hrs.)</p> <p>154. Install a modem to the computer to send and receive data over a telephone line or a cable or satellite connection. (07 Hrs.)</p> <p>155. Construct and test DAC and ADC using computer network circuit. (07 Hrs.)</p> | Computer Hardware, Computer systems, computer hardware, CPU, CPU operations, ROMs and RAMs, I/P and O/P and peripheral equipments, terminals, printers, MODEMS, Data interface, ADC and DAC. (05 Hrs.)                                                                                                                                                                                                                    |
| Professional Skill 40 Hrs<br>Professional Knowledge 10 Hrs. | Identify various functional blocks of a microprocessor system, identify various I/O Ports, write and execute simple program and Interface a model application with the microprocessor kit and run the application. ELE/N9418 | <p>156. Measure the crystal frequency, connect it to the processor. (10 Hrs.)</p> <p>158. Use 8085 microprocessor, connect 8 LED to the port, blink the LED with a switch. (10 Hrs.)</p> <p>159. Perform addition and subtraction of two 8-bit numbers using 8085 microprocessors. (10 Hrs.)</p> <p>160 Demonstrate entering of simple programs, execute &amp; monitor the results. (10 Hrs.)</p>                                                | <p>Introduction to microprocessor microcomputers, Memories Intel 8085. Architecture</p> <p>Instruction set of 8085, Microprocessor.</p> <p>1. Data transfer group.</p> <p>2. Arithmetic group.</p> <p>3. Logic group. (05 Hrs.)</p> <p>Basic Programming of 8085 such as adding, subtraction of two 8-bit numbers, etc. Block diagram and pin' diagram 8255 and its operation. Microprocessor applications. (05 Hrs.)</p> |





## **Familiar with industrial Training Institute (ITI)**

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

- **explain the industrial training institute which comes under Ministry of Skill Development and Entrepreneurship (MSDE) in association with Director general of training (DGT)**
- **explain the work structure in ITI using organization chart**
- **define working methods in a store of an ITI.**

**Introduction :** Directorate General of training: To give employment opportunity for the youths by imparting industrial training at various institutes. This also includes training for women in separate institutes. The various skills developed by these student will be of great help in securing jobs in the competitive market.

The Directorate General of Training (DGT) under the aegis of Ministry of Skill Development and Entrepreneurship (MSDE), is the apex organization for development and co-ordination of the long-term vocational training across the country.

In job market the requirements in different fields with expertise working knowledge is required. The skill development for various people (of low income group, SC/ST and physically challenged) were given in the training institute. There are suitable courses for candidates who passed out school final like tenth standard and plus two.

### **Training institute under DGT**

- 13350 Industrial Training institute in India

- 31 Central institute
- 10 Advanced training institute (ATI)
- 2 Electronic process instrumentation (EPI) under ATI
- 2 Foremen training institute (FTI)
- Central industrial training institute (CTI)
- 1 National Vocational and Technical Institute FOR WOMEN (NVTI)
- 15 Regional vocational training institute for women (RVTI)
- 2 Institute of Training of Trainers (IToTs)
- 2 State government's ItoTs
- Central Staff Training and Research Institute (CSTAR)
- National Instructional Media Institute (NIMI)

## **Familiarise with the working of Industrial Training Institute including store procedure**

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

- **explain working of Industrial Training Institute**
- **explain familiar with the training instructors of the institute**
- **define familiar with the courses offered in the institute**
- **define familiar with institute store and its function.**

In all Industrial Training Institute in India same syllabus has been followed.

There are total 13350 industrial training institute in India which includes government ITI, Private ITI approved by state government and national vocational training institute which imparts training to around 19 lakhs youth in 126 trades. This is as per data 2016-2017. Under each state, the industrial training institute function under state

government's Employment and training ministry. Head of the ITI is the Principal. The Vice Principal and Training placement officer will report to the principal. Below this hierarchy officers of different trades, office superintendent, hostel warden/ PT instructor, store in charge and medical officer deploy their duties. The organizational chart is as given below.

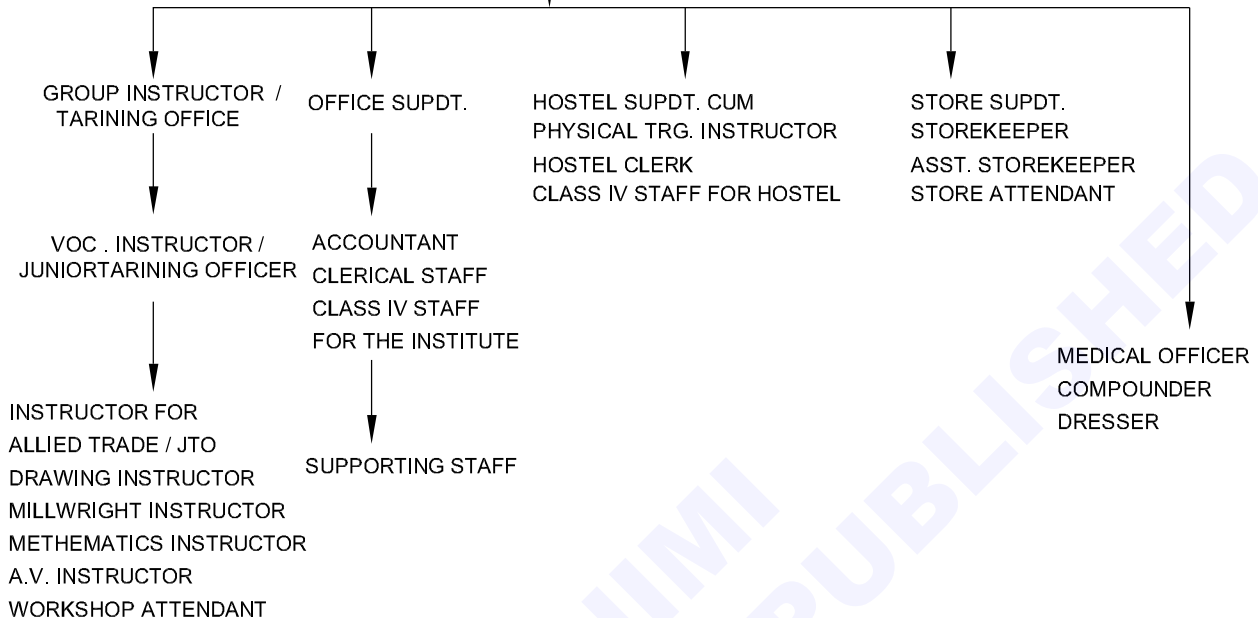
Fig 1

## ORGANISATIONAL CHART OF ITI

PRINCIPAL/SUPERINTENDENT

↓  
TRAINING AND  
PLACEMENT OFFICER

↓  
VICE PRINCIPAL



IM20N110111

## Importance of safety and general precaution observed in the industry / shop floor

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

- explain importance of safety
- explain list down the safety precaution in a machine shop
- define list down the personal safety precautions
- define list out the safety precaution while working in a machine.

In general accidents won't happen on its own but accidents are caused on different reasons. Most of the accidents can be avoided. A good workman should know all the safety precautions so that he will along with his coworkers were in an accident-free zone. To achieve this each and everybody should follow the safety precaution as shown in figure 1 below.

In workshops safety is divided into three broad categories.

- General safety
- Personnel safety and
- Machine safety.

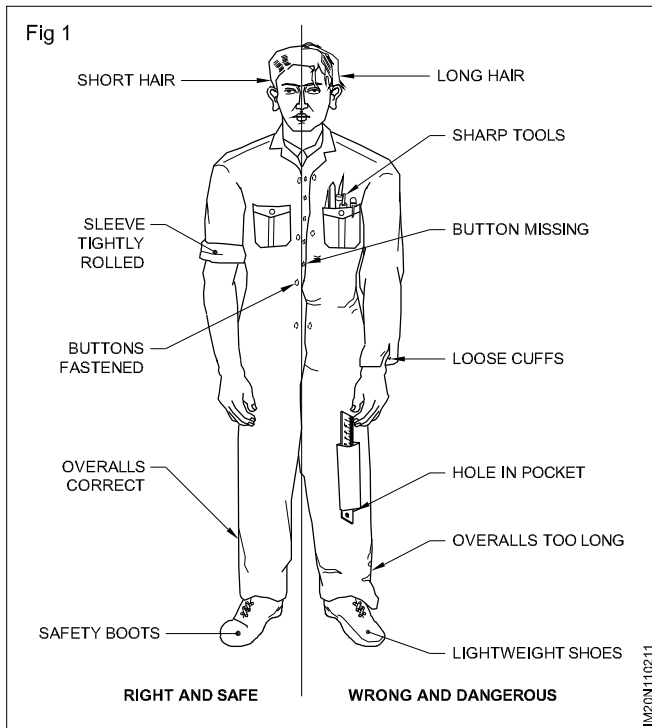
### General safety

- Floor and foot paths should be kept clean. There should not be obstacles in the path
- Be attentive while walking and don't run.
- While the machine is running don't go elsewhere
- Don't touch or handle a machine unless you are authorized to do.

- Don't walk under a hanging load.
- Don't play while you are working on a machine.
- Choose appropriate tools for the job.
- Place the tools after work in it's place.
- Clean the oil drop immediately.
- Change the tool immediately when it is damaged or worn out.
- Don't direct the compressed air towards you or anyone.
- Ensure there is sufficient light in the workshop.
- Clean the machine while it is not running.
- Remove metal burrs and turnings.
- Before running a machine understand all aspect of handling the machine.

### Personnel safety

- As far as possible wear a single apron or a boiler suit.
- Insert all buttons of the apron.
- Don't use neck tie and scarves.



- Roll up the sleeve above the ankles tightly.
- Wear safety shoes.
- Haircut should be done closely
- Don't wear hand watch, rings and neck chains.
- Don't lean on the machine
- Don't wash hand on cold liquids.
- When the machine is running don't remove the safety apparatus.
- Don't use cracked or chipped tools
- Don't start the machine unless a) The working object is firmly held and b) The feed machinery should be in neutral.
- Don't adjust the clamps or hand held parts while the machine is running
- Don't touch the Electronics equipment with wet hands
- Don't operate faulty Electronics equipment
- Ensure that the Electronics wiring has been done by an approved electrician
- Concentrate on your work. Always be cool and calm
- Work as per the operating procedure methodically.
- Don't speak with others while working on machine.
- Don't distract other's concentration of work

## Personal Protective equipment (PPE)

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

- explain about personal protective equipment, and the purpose of using
- explain about occupational hazards
- explain about occupational health safety and cleanliness
- explain listing out the high usage personal protective gears

In Personal Protective Equipment (PPE) is clothing or equipment designed to reduce employee exposure to chemical, biological, and physical hazards when on a

- Don't stop the running machine by hand.

### Machine safety

- Stop the machine immediately if something wrong happens.
- Keep the machine clean.
- The auxiliary tools such as spanner, fixing nuts and bolts should be changed if they are damaged or worn out.
- Learn thoroughly how to operate a machine before attempting to start.
- Don't adjust the tools while the Electronics machine is running. Do the adjustment after stopping machine.
- If you want to change the speed of the machine, stop the machine first.
- Before switching off the machine ensure to switch off the automatic feeds.
- Before starting the machine check the oil level.
- Ensure all the safety guards were in its places and then start the machine.
- Take measurement of the job after switching off the machine.
- While lifting or moving down heavy objects place this on a bed spread with wooden planks.

**Safety is a philosophy and understand this**

**Safety is custom and tradition. Always follow this habit.**

### Job opportunity in India and abroad at various Industries

An ITI certificate holder after completion of the course will have Job opportunity in manufacturing industries and workshops of Government / Private companies. They get plenty of opportunities in abroad as skilled workers.

### Self-employment

One can become the owner of a factory or an auxiliary unit to design and manufacture engineering products.

### Further learning scopes change can be implemented

- On the particular engineering branch one can do Apprentice training.
- One can enhance his qualification by doing craft instructor certificate course.
- One can join Engineering Diploma course

risks to acceptable levels. PPE is recommended to be the last level of defense to prevent occupational injuries

One can do reverse engineering methods instead of using PPE. A design change can be implemented. Alternate safety procedures can be adopted. A good illuminated and ventilated work shop can increase safety. PPE should be adopted for the last resort. As times are changing Government and its opinion committee prescribe new safety standards according to the work place and nature of jobs.

As per factory law 1948 and building and other construction workers law 1996 stipulate use of PPE to a greater extend.

#### **Ways to ensure works place safety and use personal protective equipment effectively**

- Information about daily safety bulletin from regulated bodies should be shared with the workers by the concern authorities.
- Shop floor peoples should read all safety information books and know how to use PPE effectively.
- In general, the most used PPE like goggles, hand gloves and aprons should be used while in machine working, other wise there is no use in using them. Using PPE equipment quite often will fetch good results in work shop and will be accident free.
- The PPE alone won't safe us fully from danger. Through understanding and intricacies of the work should be known. Then only it will safe us from fear of being unhealthy and accidents from work.
- The PPE should be inspected for it's quality to ensure the safety continuously.

**Categories of PPE :** We can classify the PPE in to two category as per the nature of the accidents

- **Non respiratory:** This will protect us from injuries to our body externally. This will protect us in head, eyes, face, hand, feet and rest of body parts.
- **Respiratory:** These are due to breathing the contaminated atmosphere. The contamination may be due to fumes, toxic chemical evaporation and deadly infectious viruses.

**Table for Personal Protective Equipment**

| SI.No | PPE                              |
|-------|----------------------------------|
| PPE 1 | Helmet                           |
| PPE 2 | Safety footwear                  |
| PPE 3 | Respiratory protective equipment |
| PPE 4 | Arms and hand protection         |
| PPE 5 | Eyes and face protection         |
| PPE 6 | Protective clothing and overall  |
| PPE 7 | Ear protection                   |
| PPE 8 | Safety belts and harnesses       |

Maintenance of PPE should be under the control of Management. The above schedule is for the non-effective method by standard engineering procedures.

**Quality of PPE:** In order for PPE to work effectively, strict technical performance specifications and standards need to be met so that it can protect the person. Refer the table below.

Choose the PPE according to the safety from hazards for which it should be protected.

#### **Selection of PPE requires certain conditions**

- Nature of the accident and its severity
- The density of dust particles in the atmosphere.
- When using the PPE calculate the time taken to finish the job, the easiness of doing the job and the comfort level of wearing the PPE.
- Estimate to which extend the PPE will withstand
- Easy for maintaining and cleaning.
- Should confirm to International and Indian standards.

#### **Proper use of PPE**

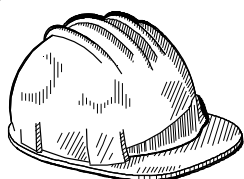
Well chosen PPE should be used by the workers.

Normally workers avoid using PPE. To over come this problem, refer the below points

- Give time for the workers to understand how important to use PPE.
- Give some relief from the operating rules and insist workers to use PPE
- The present status of economics, social activities and laws of discipline can be used to stream line the natural habits of the workmen.
- Make mandatory to use PPE at all times by the workers.
- When giving PPE to a group of workmen, always ensure the workmen knows the importance of using PPE and supervise whether they are using it or not.

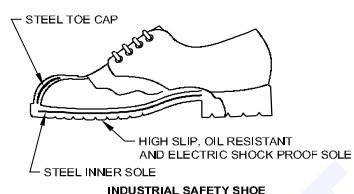
| Types of safety | Hazards type                                                                                                                                                                                       | Figure                                                          |
|-----------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------|
| Head Protection | <ul style="list-style-type: none"> <li>While falling down</li> <li>While striking on hard surface</li> <li>Spatter</li> </ul>                                                                      | Helmet (Fig 1)                                                  |
| Feet protection | <ul style="list-style-type: none"> <li>Hot spatter</li> </ul>                                                                                                                                      | Steel toe cap safety shoes of industrial standard (Fig 2)       |
| Nose Protection | <ul style="list-style-type: none"> <li>Falling objects</li> <li>Working on wet surface</li> </ul>                                                                                                  | Respiratory pads (Fig 3)                                        |
| Hand protection | <ul style="list-style-type: none"> <li>Dust particles</li> <li>Fumes, gases and vapors</li> <li>Burns due to direct contact of fire</li> <li>Heat due to sparks</li> <li>Electric shock</li> </ul> | Gloves (Fig 4)                                                  |
| Eye protection  | <ul style="list-style-type: none"> <li>Floating dust particles</li> <li>Radiation of infra-red and ultra violet rays</li> </ul>                                                                    | Googles and welding helmet (Fig 5)                              |
| Face protection | <ul style="list-style-type: none"> <li>Sparkles while welding &amp; grinding</li> <li>Welding spatter striking</li> <li>Safety from UV rays</li> </ul>                                             | Face shield (Figs 6 & 7)                                        |
| Ear protection  | <ul style="list-style-type: none"> <li>High decibel noise (more sounds)</li> </ul>                                                                                                                 | Ear muffs and ear plugs (Fig 8)                                 |
| Body protection | <ul style="list-style-type: none"> <li>Heat particles</li> </ul>                                                                                                                                   | Apron, cap with sleeve, hand gloves and leg guard (Figs 9 & 10) |

Fig 1



HELMET

Fig 2



INDUSTRIAL SAFETY SHOE

STOUT LEATHER PREVENTS INJURY TO THE ANCHILIES TENDON



INDUSTRIAL SAFETY BOOT

Fig 5

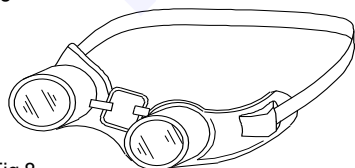
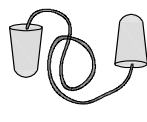


Fig 8



EAR MUFFS



EAR PLUG

Fig 3

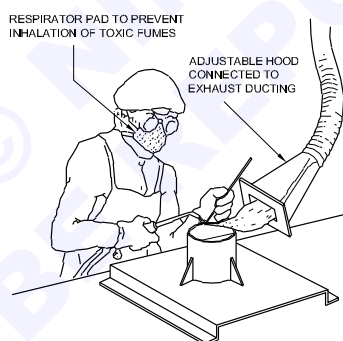
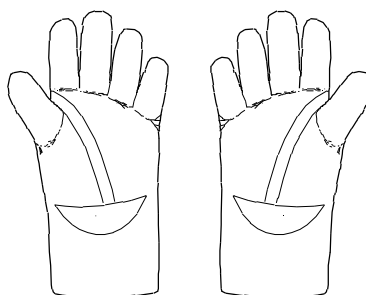


Fig 4



GLOVES

Fig 9

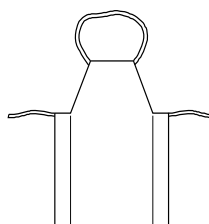
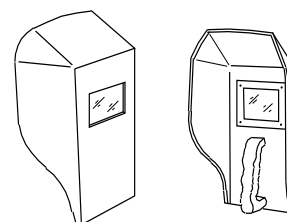
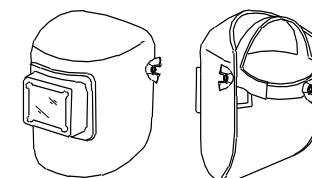


Fig 6



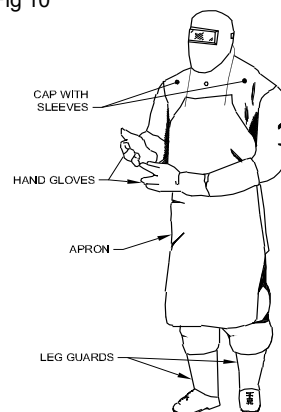
HAND SCREEN

Fig 7



WELDING HELMET

Fig 10



LEG GUARDS



# First Aid

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

- explain about first aid
- list out the main objectives of the first aid
- explain ABC of first aid
- explain how to give first aid to the injured person.

First aid is (abbreviated - means) as ABC – airway, breathing and circulation

The five main aims of first aid are to:

- Preserve life.
- Prevent the escalation of illness or injury.
- Promote recovery.
- Provide pain relief.
- Protect the unconscious

**Preserve the life :** The first and foremost objective is to preserve the life. Check if the patient is breathing. Place the patient leaned in one direction. This will ensure to clean the tongue from the throat. This will ensure any objects like food particles will go inside the stomach. If not this object will cause choking which leads to death. The blocked object generally cause breathing trouble. The first aid person should squeeze the stomach and beat the back side of the patient. After this check if the patient is breathing normally.

**Prevent the escalation of illness or injury :** As a part of first aid training, you'll learn how to treat wounds and attend to injuries to prevent further spread or damage. For example, if the patient is bleeding with huge blood loss, the first aider's goal is to stop the bleeding until professional medical representative arrives.

**Promote recovery :** Promotion of recovery includes using a first aid kit to help the person in need. This can involve washing, disinfecting, and bandaging a wound. In some cases, an antibiotic ointment can be used to promote healing

**Training :** Offering pain relief tablet if it doesn't cause risk to the patient. If the person is bleeding, some pain relief medicine is not advisable. It's better to ask a medical expert first before offering any sort of medicine.

Protecting an unconscious person includes safely removing them from a dangerous environment like a fire or busy road to safer conditions nearby. In a first aid course, participants learn how to position an unconscious person so that airways, breathing and circulation (ABC) aren't obstructed. The goal of protecting an unconscious person is to ensure their safety before medical help arrives.

Along with the above five objectives, first aid also provides reassurance to the patient and confidence in the first aider to respond appropriately. It's a necessary and critical stage for preventing serious harm and is an indispensable skill to have.

## The five key principles of first aid

- Don't panic

- Take swift action
- Neutralize the situation
- Call for medical assistance
- Administer necessary treatment

## ABC of First Aid

The ABC is A: Airway, B: Breathing and C: Circulation.

**Airway:** First ensure free passage of air is available around the patient. Crowd around the patient will cause suffocation and leading to death.

**Breathing:** If breathing stops then it may lead to death of the patient. Loosen any tight clothing. Continue to monitor the person's breathing and pulse until medical help arrives. Give breathing support by certain techniques.

**Circulation:** The blood circulation is most important for patient's survival. Nowadays the first aid persons were given training in CPR (cardiopulmonary resuscitation)

There are certain norms to be followed by the First aid person.

**Not to panic:** Panic will lead to further damage of the situation. Judgmental error happens when you are in panic. The first aid person should be calm and composed. Decision taken while on emotion will lead the patient to danger. Hence be calm and attentive to the surrounding. Quick and hopeful approach will be supportive to the patient.

**Call medical emergencies:** If circumstances permit call medical emergencies and ambulance immediately. This correct approach will save the life.

**Surroundings play a vital role:** For each and every different situation we have to adopt different approach. For example the first aid person should ensure no accident will happen to him and there will be nobody in the surrounding and take suitable action to the patient.

**Do not harm:** In most of the time the first aid given in enthusiastic manner will lead to further complications. For example, giving water to the patient in dizzy condition, cleaning the frozen blood and moving the limbs which has been fractured. With wrong first aid some time the patient dies. They may survive if wrong first aid has not been given. Don't move the patient if the situation does not warrant. If the patient is suffering from injury at the back, neck or head, don't move the patient here and there unnecessarily. Hence at times keep the patient as where he is lying.

This does not mean that you should not do anything. Trained first aid worker should give first aid safely and confidently. Hence when a person is unconscious handle with utmost care. When a person is suffering injury due to

sharp objects, never try to remove the sharp object. This will lead to hemorrhage (severe blood loss). Find some help under these circumstances.

**Reassurance:** Console the patient to the possible extent. This will give confidence to the patient.

**Stop the bleeding:** When there is blood injury, apply direct pressure on the cut or wound with a clean cloth or tissue until bleeding stops.

**Golden hours:** Head injuries, multiple trauma, heart attack and stroke will be treated in good multi-specialty hospitals in India. The vital thing is to take the patient to these hospital in time. The first thirty minutes is more important and this is called the golden hours. Most patients survived after getting treatment before these golden hours. Giving the required first aid immediately and getting an ambulance and admitting the patient within 30 minutes is the duty of the first aid worker.

**Maintaining the hygiene:** Keep your hand clean with a good sanitizer. If required use sterile gloves to safe guard from viruses and bacteria.

**Cleaning and dressing:** After washing your hand follow these steps

**Apply Gentle Pressure:** This step applies only if the wound is bleeding.

- Rinse with Water.
- Use an Antibiotic Cream or Ointment.
- Bandage the Wound – Sometimes if required.

Not to use local medications on cuts or open wounds: Local medications instead of giving relief will give irritation to the tissues. Wash gently the wound with clean water and apply certain bandage.

**CPR (Cardio - Pulmonary resuscitation) method for heart and lungs:** Often CPR will save the life. The three steps of CPR in order.

- Call 911 or ask someone else to.
- Lay the person on their back and open their airway.
- Check for breathing. If they are not breathing, start CPR.
- Perform 30 chest compressions.
- Perform two rescue breaths.
- Repeat until an ambulance or automated external defibrillator (AED) arrives.

**Declaring the death:** You should not declare the death of a person on the spot. A well-qualified doctor should declare the death, by death certificate.

**How to report a medical emergency:** It may seem simple to report a medical emergency but in practice it is difficult. There is a tensed atmosphere at the accident place. There will be large crowd of onlookers who won't lend an arm for support. On road side accidents this is common. Hence it is very difficult to give first aid to the victim. The first aid person should do many things at the same time. Mobile phones were very useful at these times.

Evaluate the urgency of the situation. Assure the situation requires emergency reporting. If the situation leads to death or causing severe damage then only report emergency.

**A crime scene:** If you are witnessing a crime, give identification and description of the criminal.

**A fire accident:** If you are going to report a fire accident then get details and the correct location of the accident. Give details of someone missing or having burn injuries.

**A life:** Medical emergency for life in danger. Describe how the incidence happened and the present status of the victim or patient.

**A car crash:** Describe correctly where the accident occurs, dangerous wound of the victims, vehicles registration number and how many persons affected in the accidents.

**Call emergency service:** Emergency number differs for each service.

Police 100, Fire control 101, Ambulance of fire service 102, Traffic police 103, Accident help line 108 and so on....

**Report your location:** The emergency team will arrive at spot very quickly. This depends on your report of how precise the location to the dispatcher. Nowadays there are various methods using advanced techniques in mobile phone. Through GPS enabled navigators you can pinpoint the location.

**Give your phone number to the emergency dispatcher :** It is important to give your phone number to the emergency dispatcher for the possible details from your end.

Describe the nature of the emergency: Speak with clarity to the emergency dispatcher. First tell him the important details. Then answer the question of the dispatcher to the possible extent of the known facts.

**Do not hang up the phone:** Don't hang up your phone till the dispatcher finishes giving the instructions to you.

**Basic first aid:** Basic first aid refers to the initial process of assessing and addressing the needs of someone who has been injured or is in physiological distress due to choking, a heart attack, allergic reactions, drugs, or other medical emergencies.

#### Important guide lines for first aider (Fig 1)

- **Evaluate the situation:** Are there things that might put you at risk of harm? Are you or the victim threatened by fire, toxic smoke, gasses, an unstable building, live Electronics wires, or another dangerous scenario? Do not rush into a situation where you could end up as a victim yourself.

**Remember ABC:** The ABCs of CPR refers to the three critical things you need to look

**Airway:** Does the person have an unobstructed airway?

**Breathing:** Is the person breathing?

**Circulation:** Does the person show a pulse at major pulse points (wrist, carotid artery, groin)?



Fig 1

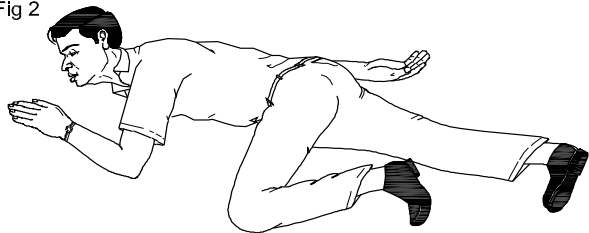


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**Avoid moving the victims:** Moving an injured person can cause additional injury and pain, and may complicate the victim's recovery. Generally, you shouldn't move an injured person while treating them. If at all possible, wait for trained first responders so you don't cause the victim more harm.

**Call emergency service:** Call emergency service as early as possible by yourselves or through someone else. If you are alone in the accident spot, make arrangement for easy breathing to the victim. As far as possible never leave the victim alone. (Fig 2)

Fig 2



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**Determine responsiveness:** Before you start any rescue efforts, you must remember to check the victim for responsiveness. If you suspect that the victim has sustained spinal or neck injury, do not move or shake him. Otherwise, awake the victim gently by speaking continuously till you have to see response by victim.

If the person remains unresponsive and has no pulse, prep are for CPR. Unless you suspect a spinal injury, carefully roll them onto their back and open their airway. If you suspect a spinal injury, leave the person where they are, provided they are breathing.

- Keep the head and neck aligned.
- Carefully roll them onto their back while holding their head.
- Open the airway by lifting the chin.

#### **Look, listen and feel for sign of breathing:**

- Make sure the patient's chest heaves up and down and listen to his breathing.
- If the accident victim does breathe and unconscious then roll him over a side with head aligned with the body. This will drain the saliva and stop the tongue from protruding. Also this will ensure to open the wind pipe so to enable vomiting

**Check the victim's circulation:** Look closely for change in color of the victim. Check his pulse rating at carotid artery which is on two sided of the neck. If there is no pulse then do the CPR.

In the center of the chest, just below an imaginary line running between the nipples, put your two hands together and compress the chest down approximately 2 inches (5.1 cm) at a rate of 100 compressions per minute. After 30 compressions, give two rescue breaths, done by opening the airways, closing the nose, and fully covering the mouth hole. Then check vitals. If the breaths are blocked, reposition the airway. Make sure the head is tilted slightly back and the tongue is not obstructing it. Continue this cycle of 30 chest compressions and two rescue breaths until someone else relieves you.

#### **Treat bleeding, shock and other problems if needed:**

After ensuring victim's normal breath and pulse normal, the next foremost step is to stop bleeding especially on head. Also give preference to victims affected by Electronics shock.

**Stop bleeding:** Control of bleeding is one of the most important things you can do to save a trauma victim. Use direct pressure on a wound before trying any other method of managing to bleed.

**Treat shock :** Shock, often caused by a loss of blood flow to the body, frequently follows physical and occasionally psychological trauma. A person in shock will frequently have cool, clammy skin, be agitated or have an altered mental status, and have pale color to the skin around the face and lips. Untreated, shock can be fatal. Anyone who has suffered a severe injury or life-threatening situation is at risk for shock.

**Choking victim:** Choking can cause death or permanent brain damage within minute. This is performed by straddling the victim from behind and bear-hugging them with your hands interlocked above their belly button but beneath their breastbone. Thrust upward to expel air from the lungs and repeat until you are successful in clearing the object from the windpipe.

**Treat a burn:** Treat first- and second-degree burns by immersing or flushing with cool water for at least 10 minutes (no ice). Don't use creams, butter, or other ointments, and do not pop blisters. Third-degree burns should be covered with a damp cloth. Remove clothing and jewelry from the burn, but do not try to remove charred clothing that is stuck to burns.

**Treat a concussion:** If the victim has suffered a blow to the head, look for signs of concussion. Common symptoms include:

- Loss of consciousness following the injury
- Disorientation or memory impairment
- Vertigo
- Nausea (vomiting)
- Lethargy.
- loss of memory of recent events (short terms memories)

**Treatment to spinal injury:** If you suspect a spinal injury, it is especially critical that you not move the victim's head, neck, or back unless they are in immediate danger. You also need to take special care when performing rescue

breathing or CPR. Stay with the victim until help arrives.

**Unconsciousness (COMA):** A coma is a prolonged state of unconsciousness. During coma, a person is unresponsive to the environment. The person is alive and looks like they are sleeping. However, unlike in a deep sleep, the person cannot be awakened by any stimulation, including pain. If nobody attends to this patient then he may die.

When normal function of the brain stops then coma may occur. There are many reasons for brain to stop.

- Lack of oxygen for a few minutes to the brain causes cell death of brain tissues.
- Bleeding in the layers of the brain may cause coma due to swelling and compression on the injured side of the brain.
- When there is no blood flow to a major part of the brain stem or loss of blood accompanied with swelling, coma can occur.
- Infections of the central nervous system, can also cause coma.
- In people with diabetes, coma can occur when blood sugar levels stay very high or too low, can also lead to a coma. This type of coma is usually reversible once the blood sugar is corrected. However, prolonged high sugar level can lead to permanent brain damage and persistent coma.
- Coma may cause due to epileptic fits.
- Due to the spread of poison like inhaling poison gases or snake bites may lead to coma.
- When you become severe addict to drugs and consumption of limitless alcohol may result coma.
- Low or high blood pressure may be one of the reasons for coma.
- Excessive body temperature both hot and cold

Followings were the symptoms when a patient is unconscious

- Confused mindset
- Drowsiness
- Head ache
- Speechless and possible stroke
- Light headedness
- Un control bowel and bladder
- Heart palpitation
- Stupor

#### How to diagnose an unconscious injured person

- From alcohol smell in the patient's body or near by bottles one can conclude the reason for unconsciousness.

- Persons suffering from epileptic fits: Drooling of frothing saliva from the mouth is one of the symptoms. The dresses were not proper in order is a general symptom.
- We can see the diabetic person who is suffering from lack of insulin intake.
- We can think about the excessive intake of Psychotropic Substances like heroin, lsd etc. If it is a prescribed drug, check whether less intake of medicine by the patient.
- Check whether the patient is mentally or physically depressed.
- Check the red coloring around the wound due to blood or red tissues due to infection.
- Check the wound is due to snake bite.
- Mentally depressed person may become lunatic. Keep this also in consideration.
- Strokes will often attack elderly persons. Keep this in mind while attending senior citizen.

Please keep in mind of the above factors and decide the nature of disease.

**Electric shock :** Loss of fluid from the body is too dangerous. This may lead to blood pressure. At the same time the blood flow is not uniform. Blood is circulated to the other parts through the outer surface. Hence the skin of the patient becomes white and body turns cold. The oxygen to the brain is low as low blood flows to the brain. (Fig 3)

Fig 3



# Disposal of waste materials

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

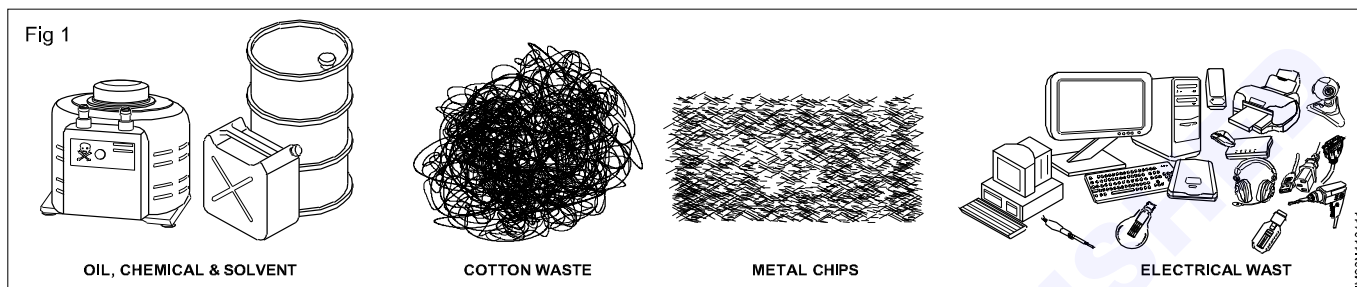
- explain the waste materials
- explain many types of waste and how and where it is generated
- list out the wastage in a workshop
- explain the ways of disposing the waste
- sort out the wastes and keep it in bins with color identification.

**Waste materials :** Industrial waste generated by Industries, Mines, Mills etc were called as waste materials.

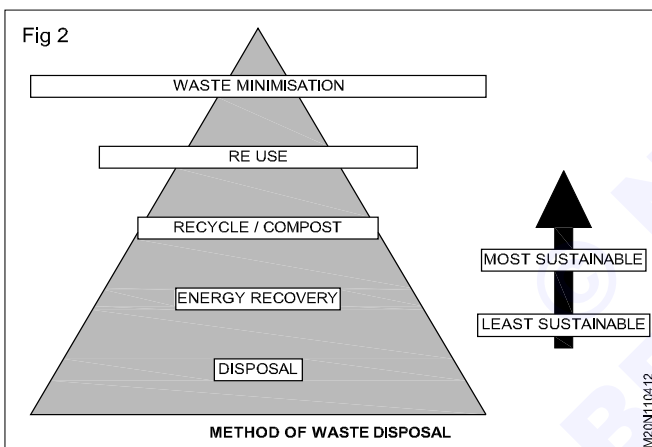
## List of waste materials (Fig 1)

- Cotton wastes

- Different metal wastes
- Lubricating oil, coolant oil, solvent etc
- E- Waste, Electronics and electronic wastes.
- Glass wastes



## Method of waste disposal (Fig 2)



**Recycling:** In waste disposal management, recycling the waste is important and cost-effective method. The cost of recycling is less and easy to implement. If you do recycling, we can save the production and energy cost and reduce environmental pollution.

**Composting:** Composting is the natural process of recycling organic matter, such as leaves and food scraps, into a valuable fertilizer that can enrich soil and plants.

**Landfills:** This is the general term of filling the different wastes in an open dumping yard. The land require for the dumping is large and controlled by waste management organizations.

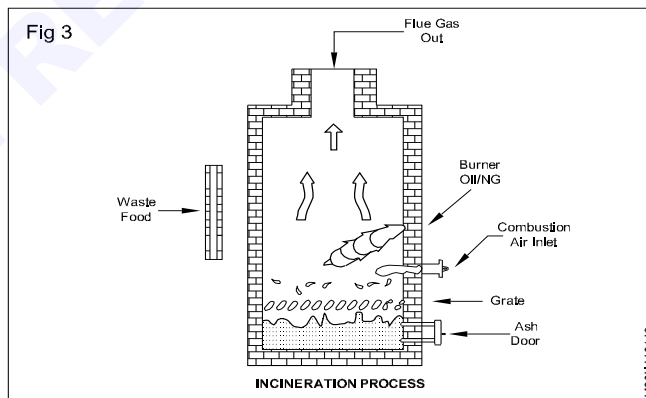
**Burning the waste materials:** If you can't able to recycle the waste or to find proper place to store, then you can burn the waste by fire. This burning should be a controlled combustion and the technology which employs destroying organic materials in the waste.

## Advantage of waste disposal

- To ensure the work place is clean.
- Un hygienic environment is removed.
- Enhance the economy.

- Reduce environmental pollution
- Saves the earth and conserve energy.

**Incineration (Fig 3):** By this method the waste is burned in a controlled manner and the ash, gas and heat were produced. New techniques are developed for this burning process, used as energy-generating methods. The burned out remains were treated and released to the environment. 90% of the waste is minimized.



**Waste compaction:** Plastic materials such as plastic bottles, plastic cans were compressed and sent for recycling. For this more space is required. Hence to transport from one place to another it becomes a tough job.

## Color codes for bins for waste segregation

| Sl.No. | Waste material | Colour code |
|--------|----------------|-------------|
| 1      | Paper          | Blue        |
| 2      | Plastic        | Yellow      |
| 3      | Metal          | Red         |
| 4      | Glass          | Green       |
| 5      | Food           | Black       |
| 6      | Others         | Sky blue    |

# Occupational health hazards and safety

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

- explain the workshop safety
- explain about health condition related to work and safety
- explain the purpose of health condition related to work and safety
- define work related hygiene
- define work related dangers
- define work related disease.

**Safety:** Safety will free us from danger, accident, damage and grief. It acts as a corrective measure that is reviewed and approved by safety experts periodically to ensure a safe workplace and sustainable business operations

## Occupational health and safety

- It is commonly known as OSH or Occupational Safety Health. It deals with healthy condition of work people and the safety to be followed while doing work in workshop.
- The prime concern is to protect the working environment free from accidents.
- This will not only protect directly the workmen but also the all stakeholders such as the employers, customers, family of the workmen and people living in the surrounding.
- The factory related division such as hospital, industrial hygiene and safety department, general hygiene and industrial safety engineering division were interlinked to each other.

**Need of occupational health safety :** For a factory to run smoothly and peacefully, the workmen in the factory should be hale and healthy and work in a safety atmosphere.

This is a decisive factor for the performance of the factory in a coordinated manner to achieve great victories. It shines in top as an accident-free factory.

To increase efficiency in manufacture, the workmen should be strong and free from diseases. This should be watched by the employer.

This will enhance the unity among workers and their morale.

Absenteeism will be reduced.

Increase the production efficiency.

Decrease the work-related accidents. Increase the quality and standard of the product.

## Occupational (industry) hygiene

- Occupational hygiene deals with the accidents in workplace, environmental reasons and depressed status of workmen. The employer should anticipate, estimate, approve and mitigate these problems.
- These will happen either inside the factory or outside the factory.
- These will cause deterioration of the workmen's health, his strength and his well being

**Anticipation (identification) :** The accidents that may happen and danger it may pose to the workmen should be known from previous accidents. Employer should chart a method to escape from this accident.

**Recognition (Acceptance):** Accept the disastrous effect of the accident.

**Evaluation (Measurement and assessment):** An accident rate is calculated by multiplying the number of recorded incidents by 200,000, and then dividing that number by the number of work hours in the organization.

Compare this result after every accident and evaluate a method to minimize

**Control of workplace hazard:** Six steps to control the hazard

**Step 1:** Design or re-organize to eliminate hazards.

**Step 2:** Substitute the hazard with something safer.

**Step 3:** Isolate the hazard from people. ...

**Step 4:** Use engineering controls. ...

**Step 5:** Use administrative controls. ...

**Step 6:** Use Personal Protective Equipment (PPE)

**Occupational Hazards:** The following are the type of occupational hazards

- Physical hazards due to noise, heat and cold stress, vibration, radiation of both ionized and non-ionized and illumination.
- Chemical hazards due to burning inflammable substance, explosion, toxic, corrosive and radioactive.
- Biological hazards due to bacteria, virus, fungi, plant pest and infection
- Physiological hazard due to old age, sex, ill health, sickness and fatigue.
- Psychological hazards due to wrong attitude, smoking, alcoholism and un skilled. Poor discipline, absenteeism, disobedience, aggressive behavior, accident proneness, violent behavior, bullying and sexual harassment.
- Mechanical hazards due to unsafe machinery, joblessness, no protective gears and no accessories for control.
- Electronics hazards due to no earthing, short circuit, break in wire and no fuse or switch to break the circuit.



- Ergonomics hazards due to in experienced people handling technical matters, machineries stationed at wrong places, wrong design, non-maintenance of equipment, worst condition and using wrong tools.

### Golden words of safety

**The one who violate safety is the one doing accident**

## Safety practice

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

- explain the responsibilities of the employer and the employee
- define safety procedures and four basic safety signs.

**Safety:** Safety is the state of being safe; freedom from the occurrence or risk of injury, danger, or loss of live.

**Responsible person in the event of an accident :** Accident doesn't happen on its own but caused by careless peoples. The law says both the employer and the employee were responsible for the accident.

### Employer's responsibility

- Providing a workplace that is free from hazards that may cause injury or diseases
- Providing free annual health examinations to employees in notified establishments,
- Issuing appointment letters to employees, and
- Informing relevant authorities in case an accident at the workplace leads to death or serious bodily injury of an employee.
- Additional duties are prescribed for employers in factories, mines, docks, plantations, and building and construction work, including provision of a risk-free work environment, and instructing employees on safety protocols.

### Employee's Responsibility

- While at work a worker must: take reasonable care for their own health and safety.
- Take reasonable care for the health and safety of others.
- Comply with any reasonable instructions, policies and procedure given by their employer, business or controller of the workplace.

**Rules and procedures at workplace :** The employee should follow the rules and regulations issued by the employer. These may be written rules, otherwise you can follow the trend prevailing from the coworkers. They are how to use and preserve certain tools, how to complain if machineries break down, emergency discipline, not to move objects to restricted place and other activities. Adhering to these will improve the safety.

**Safety signs:** You should be able to know and interpret the various signs placed in a workplace. Some of these may be very familiar to you. For example, "NO SMOKING". But for others it will be new. You should encourage them to learn these signs. The signs may be warning you about the possible accidents. So don't ignore them.

Safety signs can be divided into four categories. These signs can be understood by their shape and color. Some signs are words only and other with words and figures. For example a lift for maximum capacity and height.

The four basic categories of safety signs

### Prohibitory sign (Fig 1)



### Mandatory signs (Fig 2)



## Warning signs (Fig 3)

## Information sign (Fig 4)



| Sign        | Shape              | Colour                                                              | Object                                | Example                     |
|-------------|--------------------|---------------------------------------------------------------------|---------------------------------------|-----------------------------|
| Prohibition | Circle             | Red circumferences with white/ red diagonal strip and black objects | Denoted what should not to be done    | No smoking                  |
| Mandatory   | Circle             | On blue background with white objects                               | Denote what should be done            | Hand gloves                 |
| Warning     | Triangle           | Yellow background, black border and object                          | Denote dangerous and accidental zones | Warning about electrocution |
| Informative | Square or triangle | Green background with white sign                                    | Information about safety              | First aid centre            |

### Questionnaires about your safety

- Do you know the general safety law about your workshop?
- Are you familiar with your work-related safety laws?
- Do you know how to work without danger to yourselves, to your co-workers and to the general public?
- Do you ensure the apparatus, tools and machines are really safe?
- Do you wear safety equipment?
- Do you know how to use the apparatus, tools and machines safely?
- Are you provided with safety gadgets and its safety instructions?
- Have you been given the required training and advice to execute your work safely?
- Do you know who is responsible for safety in your department?
- Do you know who is the safety representative?

## Operation Electronics mains/ circuit breakers and Electronics safety

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

- explain about operate Electronics mains and circuit breaker
- explain about Electronics safety and its important.

**Electronics safety : Electronics shock :** An electric shock occurs when a person comes into contact with an

Electronics energy source. Electronics energy flows through a portion of the body causing a shock. Exposure



to Electronics energy may result in no injury at all or may result in devastating damage or death. When electricity passes through a man for a few seconds of 10 million amps, he may die surprisingly.

The severity of the Electronics shock depends on the amount of electricity passed and the duration of the Electronics shock. Ensure these before moving to emergency medication. Ensure the age of the person, environmental atmospheric conditions, dry or wet surface on which the person is lying, the measurement of voltage and check his footwear.

**Effect of electric shock :** Electronics shocks due to 40 volt supply will give a tingling sensation which won't be fatal but makes a person to jolt and out of balance. If the Electronics shock is due to higher voltage, then he may be thrown to some distance. He may face severe injuries. The muscles in his body may contract and he can't able to remove the live wire. In these circumstances he may become unconscious and his heat muscles will operate inconsistently. Due to this death might occur. Some wound will appear where the live wire is in contact with person.

#### Action to be taken in case of an electric shock

- First and foremost, isolate the person from the live wire. Turn off the source of electricity, if possible. If not, use a dry, nonconducting object made of cardboard, plastic or wood to move the source away from you and the injured person.
- Begin CPR if the person shows no signs of circulation, such as breathing, coughing or movement.
- Try to prevent the injured person from becoming chilled.
- Apply a bandage. Cover any burned areas with a sterile gauze bandage, if available, or a clean cloth. Don't use a blanket or towel, because loose fibers can stick to the burns.

**Treatment to be given for the victim of electric shock:** The injuries due to Electronics shock on a victim need not be revealing. If you notice injury then clean it with antibiotic ointment and sterile dressings. Contact the first aid center or the hospital as soon as possible to give medical aid for the victim.

If the victim is conscious give the following treatment.

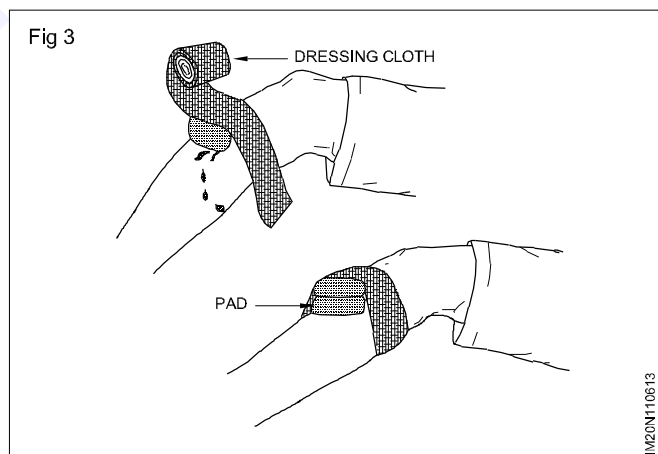
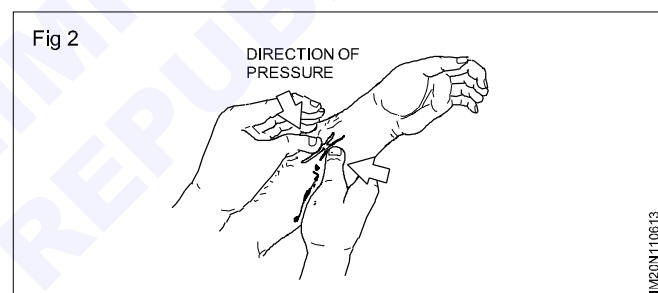
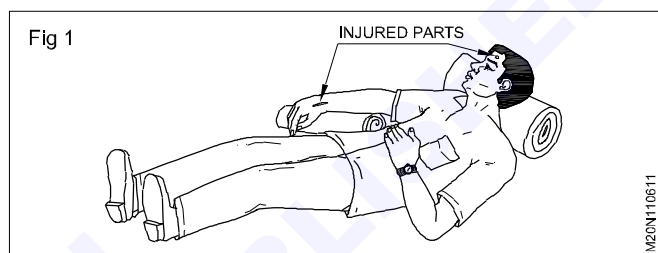
- Loosen the clothe around neck, chest and hip.
- Check the pulse and breathing.
- If the situation turns worst then do the CPR if you are well versed with procedure. Otherwise call the ambulance immediately.

**Don't give any thing orally to the unconscious victim. Don't move away from the victim. A man suffering from Electronics shock as well as burn due to fire. Don't waste time and give first aid to the burn injuries. Check his pulse and breathing. With out calling external help make the victim to breath and have normal pulse. This you can do if you are a trained CPR professional.**

**Treatment to be given in case of burns and severe bleeding :** Due to Electronics shock injuries may happen which lead to bleeding and unbearable pain. If the body totally burnt, then clean the body with clean water or clean paper or cloth. Be careful about the blisters and bubbles on the skin. This will reduce some pain on the victim. For the next stage medication move the victim to the hospital.

Check the bleeding on wrist, hand or fingers. If possible to stop the bleeding do it yourself. Then call the doctor. Do the following for the first aid.

Manage the victim to lie down and take rest. As shown in figure 1 place the injured portion of the body facing upward with out any obstruction. As shown in fig 2 keep pressure around the wound until bleeding stops. As shown in figure 3 use a sterile pad on the wound and close it with a gauge bandage.



#### General procedure to be adopted for treating a person from electric shock

- First find the source of Electronics shock and isolate the person by switching off the source. If it is not possible to locate the Electronics switch, then pull the person by wearing gloves in your hand. If gloves were not available, force the person to move away by any strong wooden object or any insulating materials.
- Move the person slowly to an airy place.

- Check the consciousness and pulse rate of the shock victim. Check any wounds found on the body of the victim. If require arrange for CPR.
- Call the doctor. Till such time give the required help to the victim.
- Keep along with the victim until he is fine.
- If the shock victim able to drink then you can give him hot beverages.

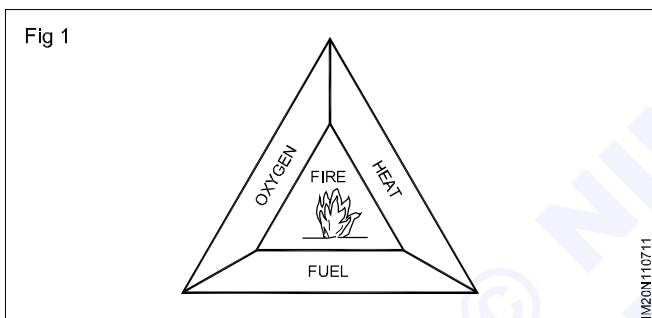
## Safety practice - Fire extinguishers

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

- explain the consequences of fire accident
- explain the reasons in workshop fire accidents
- explain the fire extinguisher's role in firefighting
- explain the general precautions to be followed to avoid fire accidents.

Fire hazards happen due to the inflammable objects stored in a fire prone zone. The uncontrollable fire in unwanted place and time will create damage. This on some time will cause serious injuries to mankind or at some time leads to death. Hence we should control the spreading of fire and extinguish with in no time.

Is it possible to prevent fire? Yes we can do this by removing the three factors for fire accidents. Refer fig 1 given. The reason for continuous fire is



- **A source of ignition:** On certain temperature each substance will burn. During heat, the liquids and solid substances begins to evaporate. This vapor is always having the tendency to burn continuously unless controlled. For example, petrol on room temperature of 15-degree c will evaporate.
- **A source of fuel:** If oxygen and high temperature were given to any solid or liquid substance, then it will burn.
- **A source of oxygen:** The oxygen is found in abundance in the atmosphere. This will aid the continuous burning.

**Extinguishing the fire:** Basics principles on which fire extinguishers works:

**Smoldering:** It involves removal of oxygen or decreasing presence of oxygen.

**Cooling:** It involves the process of reducing heat or removal of heat.

**Starvation:** It involves the removal of fuel from the scene of fire.

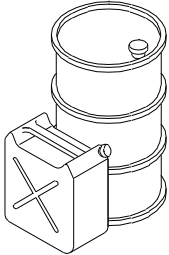
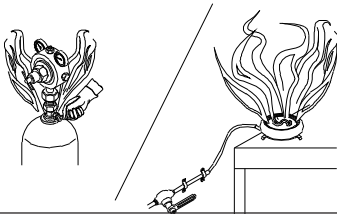
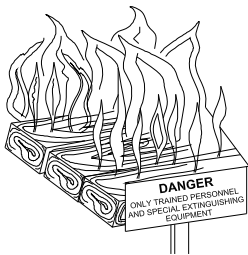
**Preventing Fire:** Many of the fire accident resulting from a small spark to an uncontrollable fire. This can be avoided with a little care and common sense to extinguish in the beginning. Flammable objects like cotton waste and wood wastes were heaped together carelessly is one of the reasons for fire accident. Dispose these wastes to the appropriate bins. Electronics fire is caused by faulty equipment and short circuits. The short circuit across the terminal can be avoided by tightening the connection. Correct rating of the fuse is most important. If the rating of the fuse is not correct, it won't melt and keep on feeding the faulty current to trigger the fire accident. Check also the insulation of the conductor and use only certified conductors.

Clothes which are easily prone to fire should be away from heat source. After the work completion shut off the heaters.

Thinner, adhesive solution, solvent, kerosine, sprit and LPG Gas were inflammable materials. These should be preserved in separate room away from heat and fire. When not in use switch off the blow lamps and torches.

**Classification of fire:** Fire is divided into four categories as per the type of fuel. For different type of fire different method of fire extinguishing method were done. (refer fig 2 to 5).

| Fuel                                                            | Method of extinguishing                                                                                                                      |
|-----------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|
| <p>Class 'A' Fire<br/>Wood, paper, cloth of solid materials</p> | <p>Good practice is to cool them with jet of water. The jet should be aimed at the bottom of the fire and gradually towards upward fire.</p> |

|                                                                                                                                                                    |                                                                                                                                                                                                                                                                                       |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p><b>Class 'B' Fire</b><br/>Flammable liquids and<br/>and liquidable solids</p>  | <p>Objects should be smothered. The total area of the burning liquid should be covered. This will ensure to stop oxygen. Don't pour water over the burning liquid. Use foam, dry powder or CO<sub>2</sub> in cylinder.</p>                                                            |
| <p><b>Class 'C' Fire</b><br/>Gas and liquefied natural gas</p>                    | <p>When using liquefied gas great care should be taken. This will explode and the entire area will be in flame. Under this circumstances fire alarm should be initiated and the fire should be extinguished by experts. Use dry powder extinguisher for this fire hazard</p>          |
| <p><b>Class 'D' Fire</b><br/>Involving Metals</p>                                | <p>To quench the fire in metals the conventional/standard procedure is not suitable to follow. On Electronics appliances the fire is quenched by spraying dry powder carbon- di- oxide and dry powder carbon tetra chloride. Don't pour water or foam on the burning machineries.</p> |

## Health and environmental guidelines

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

- explaining safety, hygiene, and environmental guidance
- explain hygiene and work and 1948 factories act.

### The laws listed below should be observed

- |                                                                               |                                                                   |
|-------------------------------------------------------------------------------|-------------------------------------------------------------------|
| 1 Enviromental safety as per act 1986                                         | 10 2000 law of guidance to stop substance liquefying              |
| 2 Environmental safety as per law 1986                                        | 11 1987 revised act of 1982 of air pollution and control          |
| 3 Effect of environment on 1994 plan of expansion estimation                  | 12 1982 act of air pollution and control.                         |
| 4 Pollution and control as per 1999 law.                                      | 13 1982 law of air pollution and control.                         |
| 5 1989 law of importance to chemical hazards and storing of chemicals         | 14 1983 Tamil Nadu laws of air pollution and control              |
| 6 2000 revised law of importance to chemical hazards and storing of chemicals | 15 2000 law of the sound pollution board control and enforcement. |
| 7 1989 law of unnecessary hazards management and handling.                    | 16 1978 and 1988 revised act of 1974 pollution and water control. |
| 8 1998 law of unwanted biology medicine management and handling               | 17 1983 Tamil Nadu law for pollution and water control.           |
| 9 2000 law of management and handling                                         | 18 1997 counter act for 1991 water pollution and water control.   |
|                                                                               | 19 1978 law for water pollution and water control.                |
|                                                                               | 20 1948 factory law                                               |

- 21 1950 law for Tamil Nadu factories
- 22 1981 law for Gas cylinders
- 23 1910 act for Indian electricity
- 24 1956 law for Indian electricity
- 25 1934 act for Petroleum.
- 26 1976 law for petroleum.
- 27 1991 act for people's insurance.
- 28 1991 law for people's insurance
- 29 2000 law for dangerous unwanted management and handling.

Worst working environment will spoil the health and safety of an employee. This not only in factory but can also prevail elsewhere. The factory employee face numerous health issues and non-safety in the surroundings. The occupational hazards not only affect the employee but also his family and the peoples around him.

The followings are the revised act Of 1987(20). Occupational safety and health.

- Fencing should be done around a machine.
- Care while operating a machine
- Engage young employees in dangerous machines.
- Run machinery with power for cutting, bending and shearing operation.
- Automated machines
- Cover the new machines.
- Prohibit children where women employee are at work in cotton extraction

- For lifting and hoisting
- Lifting machines with chain and rope.
- Rotating machines
- Pressure plant
- Evaluated floors and stair case.
- Persons with obesity
- Safety for eyes
- Warning against dangerous sparks and gases.
- Warnings for the usage of the portable electric lights
- Inflammable and explosive particles and gases.
- Warning against the occurrence of such accidents
- Safety of machine and building
- Maintenance of building
- Cleanliness
- Disposal of unwanted wastes.
- Air flow and temperature.
- Dust and smoke
- Artificial moisturization
- Excessive crowd.
- Light
- Drinking water
- Toilet and urinal facility.
- Bin for spitting.

## Basic understanding on hot work, confined space work and material handling equipment

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

- explain about hot work and need to do hot work
- describing stopped interval
- describing metal handling equipment and its use.

**Hot work :** For construction and maintenance works we need to do brazing, soldering, welding, gas cutting of metals and heating the metal and forming it requires high heat. Works under such hot condition are termed as hot works. These hot works are dangerous and expoldable. Workers still do all types of hot works. It is inevitable. But can be preventable to some extend.

| Instead of                  | Use                     |
|-----------------------------|-------------------------|
| Saw or torch cutting        | Manual hydraulic shears |
| Welding                     | Mechanical bolting      |
| Sweat soldering             | Screwed or flanged pipe |
| Torch of radial saw cutting | Mechanical pipe cutter  |

**Stopped interval of space :** Employees at times need to work on a confined space with out any room to move freely. Such restricted movement of work with in a low area is tedious to work. But work needs to be done. Working in a confined space is dangerous because of the risks from noxious fumes, reduced oxygen levels, or a risk of fire. If a confined space has noxious fumes, you should consider how these can be ventilated or removed if there is a risk of liquids or gases flooding in, you should establish whether the valves can be locked shut if someone is going into a confined space and there is not enough oxygen to breathe properly, you must provide breathing apparatus or ventilate the space to increase oxygen levels before entering.

Confined working spaces were done in water tanks, small vessels, silos, storage bins, hoppers, vaults, pits, man-hole, tunnels, duct work, pipe line etc.

## Material handling equipment

Material handling is “the loading, unloading, and movement of goods, as within a factory or warehouse, especially by the aid of mechanical devices. Thus, material handling equipment means devices that help a warehouse function by moving and storing goods.

### Different types of material handling equipment

**Type 1:** Storage and Handling Equipment: These are shelves and racks where you store your material in between receiving it and shipping it. They are often designed to utilize vertical space so the warehouse can hold more items. Bins, drawers, stacking frames, flow racks, cantilever racks, and mezzanines are also included in this category.

**Type 2:** Bulk Material Handling Equipment: If there's a lot of material altogether, you're probably using bulk material handling equipment. An example would be a silo, a large

cylinder that can hold stuff like grain. Other examples include hoppers which are large funnel shaped metal container, bucket elevators, conveyor belts...etc.

**Type 3:** Industrial Trucks: These are vehicles or equipment that move materials. Sometimes workers run them, and sometimes they are automatic. Automated Guided Vehicles (AGVs) fall under both engineered systems and industrial trucks. Example: Fork lift, platform truck, order picker, pallet trucks and hand trucks.

**Type 4:** Engineered Systems: These are vehicles or equipment that move materials. Sometimes workers run them, and sometimes they are automatic. Automated Guided Vehicles (AGVs) fall under both engineered systems and industrial trucks. Examples: Robotic delivery system, automated storage and retrieval system. Basically anything that moves materials around the warehouse so workers don't have to.

## Lifting and handling of loads

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

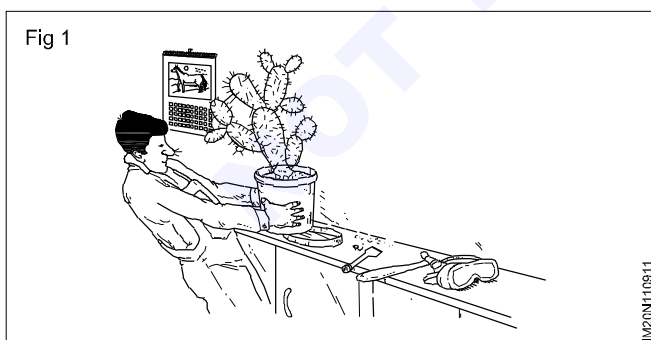
- explain non procedural weight lifting and its consequences
- explain six points of weight lifting.

Most of the accidents happen while lifting the load or moving the load from one point to other. A situation may arise for a worker to fix a heavy machine in a cramped area. Lifting heavy weight in a confined area may result an injury to the worker. At the same time weight need not be a factor for accidents.

Lifting weights by non-procedural method will cause pain on muscles, knees and particularly on spinal cord. The pain due to these are very severe. We may collide with other objects while moving with heavy loads.

### Types of injury and how to avoid them

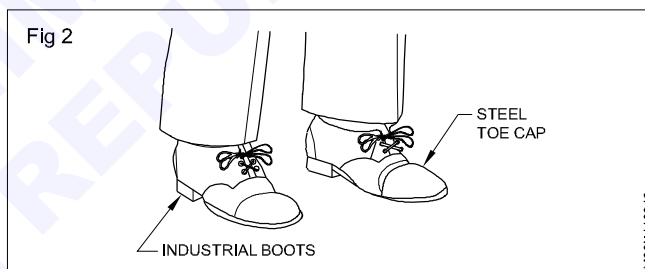
**Cuts and abrasions (Fig 1):** Cuts and abrasion results due to rough surface and uneven sharp objects. Generally, hand gloves of leather is good for protection. But at the same time other body parts may injure due to heavy weight. So, review the weight to be handled.



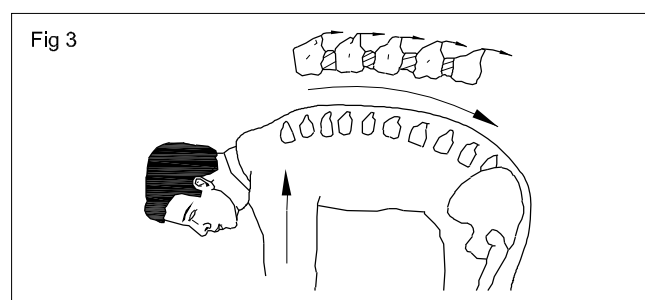
**Crushing of feet or hand (Fig 2):** The load should be placed with out harming hand and foot. When lifting heavy load to height use some equipment.

**Strain to muscles and joints:** These are due to excessive weight lifting and improper way of lifting. When lifting heavy weights, improper movements will cause strain to muscles

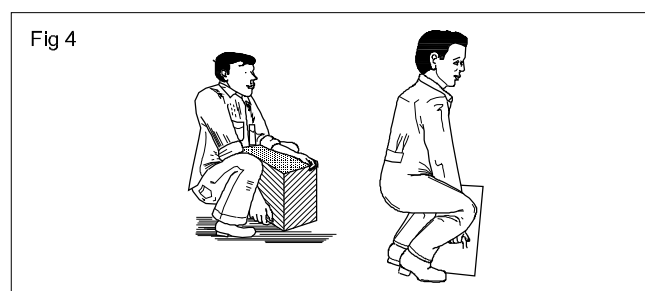
and joints. Don't take heavy weight on back. Your back is not a weight lifting machine.



As per figure 3 the bend spinal cord will take six time the load when compared to straight position. Fig 3 refers to the bend spinal cord position.



**Preparing to lift:** Prepare your selves before lifting heavy weight. (Fig 4)





Which to move?

From where to which place?

Need any help?

Is there any resistance on the way between the loading points?

Person should be able to see the direction where he is going with load?

Carry the load in ascending order of weight.

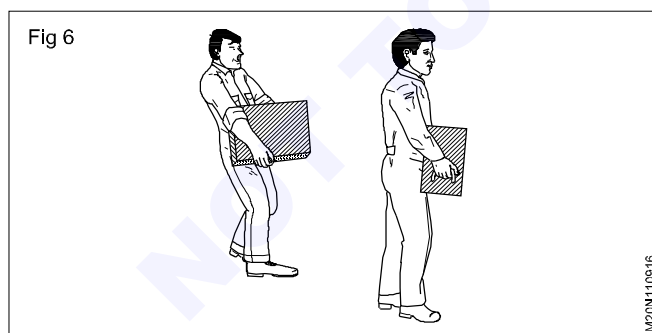
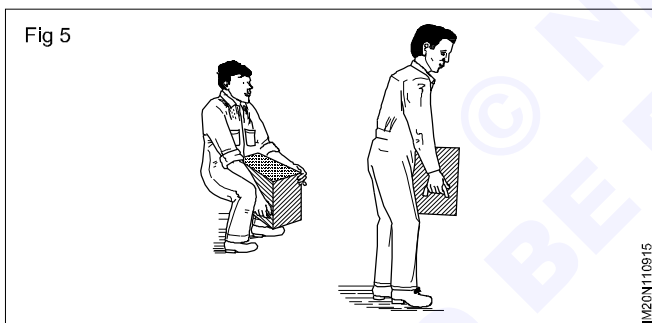
The following are the factors for a person able to carry weight

- Age
- Body structure
- Factors apart from body structure.
- Experience of the person in lifting load.

### Difficulties of lifting heavy loads

- The weight is not only the factor
- The shape of the object may be tough to handle
- When compact loads were lifted, the pressure on the arm muscles with extended hands will cause pain on back and stomach.
- Without handles it is tough to move or lift the weight.

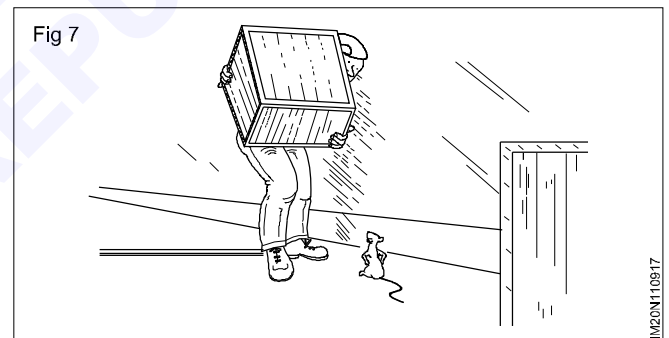
### Correct manual lifting procedures (Figs 5&6)



- Face to the direction in which the load to be moved and lift the load and proceed
- The person should sit on his fore toe and lift the weight hugging to his body. Check whether the handle is safe.
- Before lifting the load, the spine of the loader should be straight.
- Keep the legs straight and lift the load. With the help of strong thigh muscles and bones the load can be easily lifted. Lift the load with ease and without any jerk looking straight and keep the back straight.
- Until the lifting operation to the desired height keep your spine in an upright position. When the desired height is arrived then bend your hips slightly backward and come to a balance position with the load.
- The weight should be hugged to your body. While on turning move your whole body with weight. Keep the load towards your body until you reach your destination. Don't move your hip and wrist alone while turning, move your whole body with the load.

### Lowering the load (Fig 7)

Ensure the unloading point free from any obstacles. When unloading the knees should be bent half way and the spine and head straight. Don't bend your head towards the load. Even at this point the hands should be aligned with the load.



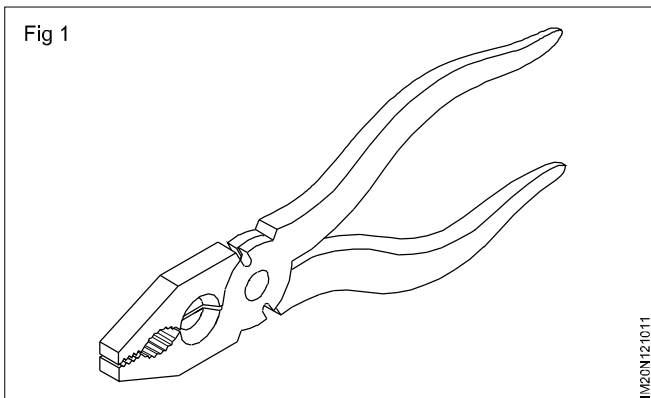


## Basic hand tools

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

- explain the types of hand tools
- describe the various marking tools and methods of marking
- explain various types of accessories.

### Combination plier (Fig 1)

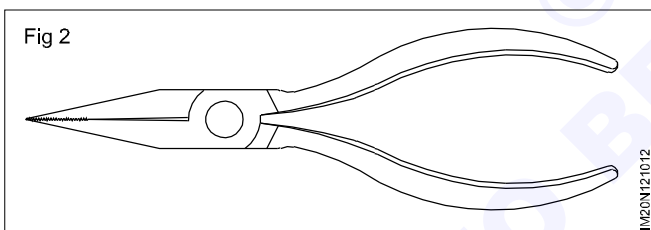


Combination plier is made of forged steel and specified by its length

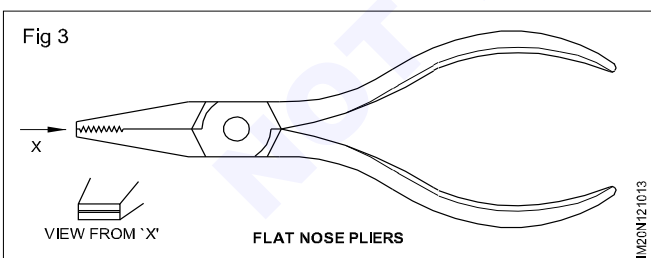
It is used to hold small pipes for cutting cables and used as insulated plier in Electronics work.

**Long nose plier (Fig 2):** This plier is made of steel and specified by its length. Used to hold nuts in.

Small holes and in narrow space.



**Flat nose plier (Fig 3):** This plier is to hold thin flat objects

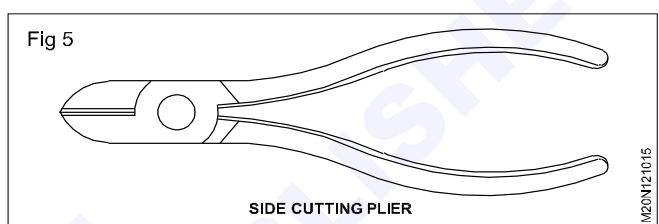
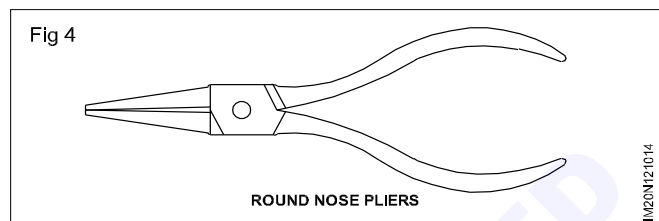


**Round nose plier (Fig 4):** Round nose plier is used to form small hook and loop in wires.

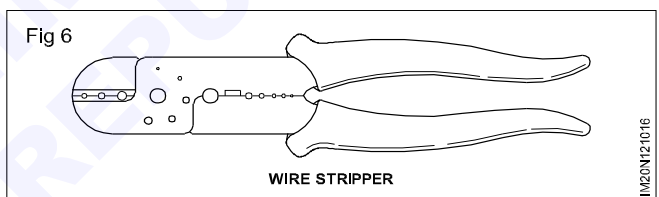
**Side cutting plier (Fig 5):** Side cutting plier is made of steel and specified by its length.

Used to cut wires very closer

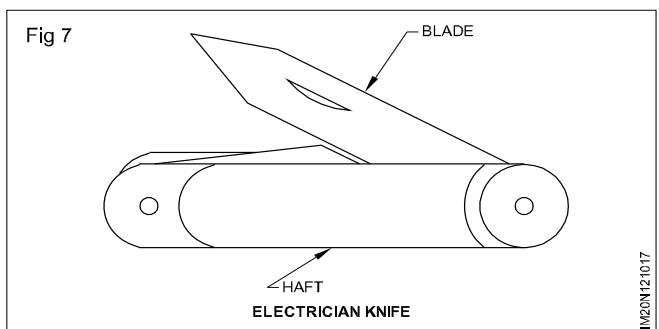
**NOTE:** Pliers should not be used as hammers.



**Wire stripper (Fig 6):** This tool used to remove insulation from wire without damaging.



**Electronics knife (Fig 7):** This tool is made of steel and contains two blades which can be folded in a holder.



It is used to remove insulation and clean the surfaces of the wire.

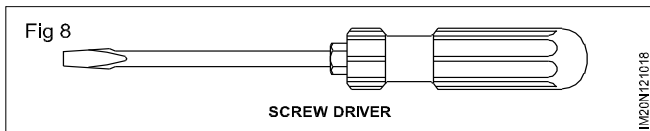
This tool should not be used for cutting the wires.

**Screw driver (Fig 8):** Screw driver is used to fix and remove screw.

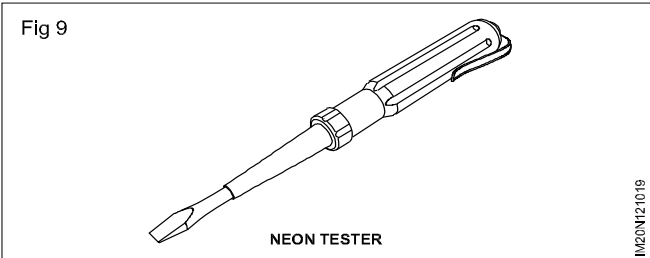
Use appropriate screw drivers for the slots in screw head

Use insulated screw driver for Electronics appliances (Electronics works)

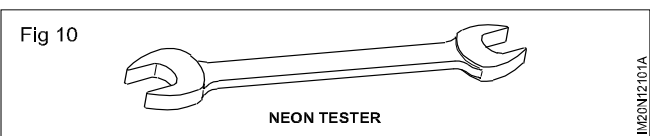
**Connectors:** A small screw driver of length 75mm which is used to remove and fix small screws



**Neon tester (Fig 9) :** Neon tester is used to check the supply. It contains a small glass tube filled with Neon gas and a neon lamp. A varistor is connected in series to neon lamp.



**Double ended spanner (Fig 10) :** This is made of cast steel and its size is stamped on the flat portion.

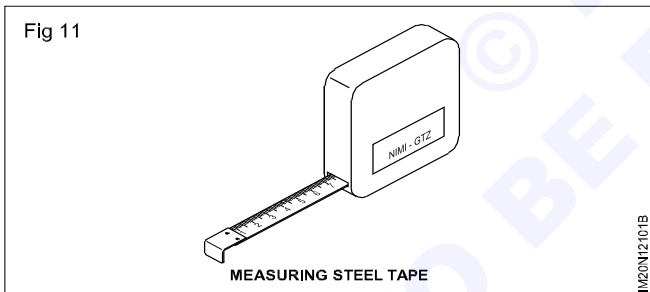


It is used to tighten and loosen the bolt and nut.

A single ended spanner also available.

**Measuring steel tape (Fig 11):** Measuring steel tape is a thin steel strip.

It has measurements of both metric and non-metric measurements printed.

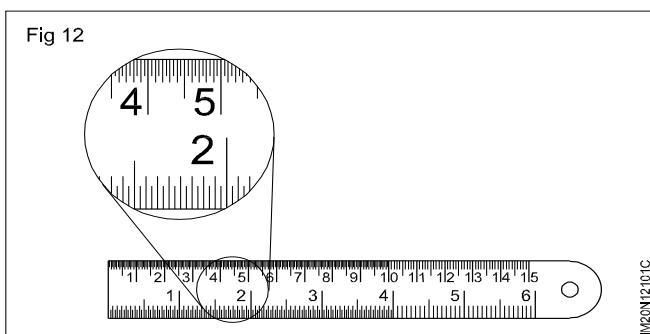


It is used to measure the length, breadth and height of the objects.

The tape is available in various length in sizes for specified usage.

**Steel rule (Fig 12) :** A steel ruler is manufactured from either spring or stainless steel.

It has marking either in metric, non-metric or both markings along its length



It is used to measure and check dimensions of objects in meter or in feet

Available in 150 mm, 300 mm and 600 mm sizes

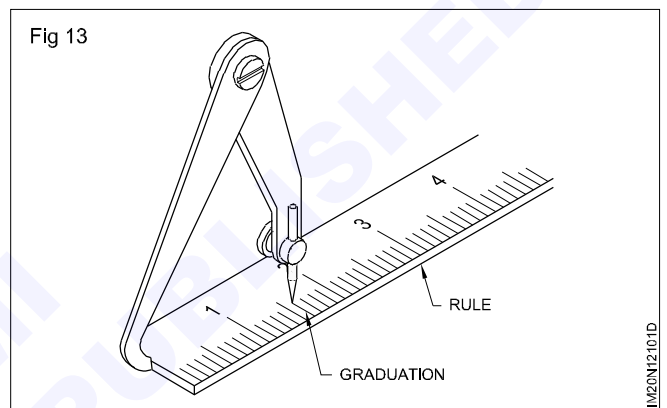
**Graduation :** Normally graduation is made on upper side for metric and lower side for British

**Accuracy :** The measurement accuracy in metric is 0.5 mm and in British it is 1/64 inch

**Materials :** Steel scale is made of spring steel, stainless steel, alloy steels and

High carbon steels hardened and tempered (Heat treated)

**Jenny caliper (or) Odd leg caliper (Fig 13) :** This is a marking tool having one leg bend inwards used to scribe or measure other leg is straight pointer portion is attached with locknut in order to move up and down.



Other name of Jenny Caliper

- 1 Hermaphrodite caliper
- 2 Odd leg caliper
- 3 Leg to pointer caliper

Types

- 1 Fixed point Jenney caliper
- 2 Adjustable Jenney caliper

**Try square (Figs 14, 15 & 16) :** Try square is used to draw (mark) and check right angle in a work piece.

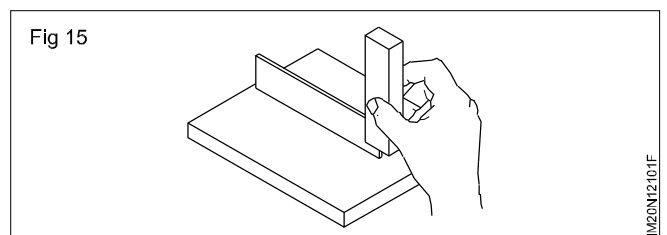
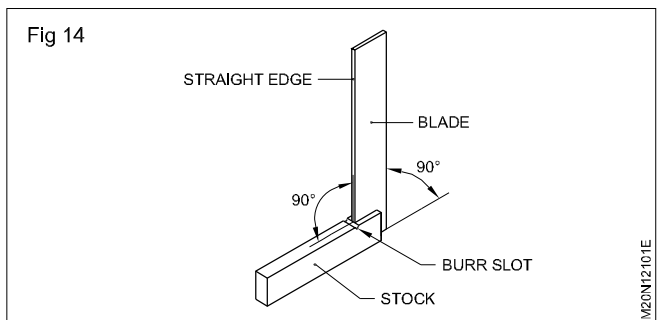
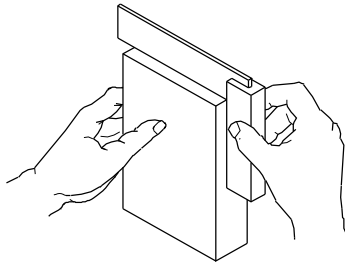


Fig 16



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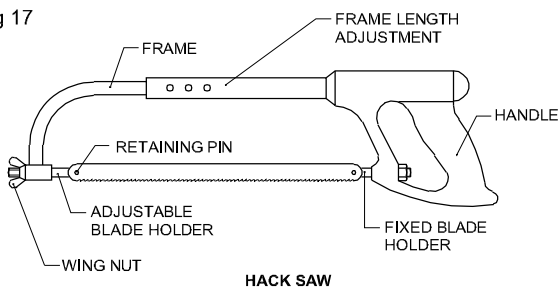
The stock of try square is made of cast iron and blade is made of carbon steel

Try square is specified by its length of blade (100, 150 and 200mm) and type.

**Types:** Solid, Adjustable and master try squares

**Hacksaw (Fig 17):** Hack saws blade and frame are important prime tools used to cut metals by fitters

Fig 17



IM20N12101H

**Hack saw frame :** It is a frame on which hack saw is fixed and it is made of mild steel

Tension piece is made of high carbon steel. Wing nut is made of cast iron.

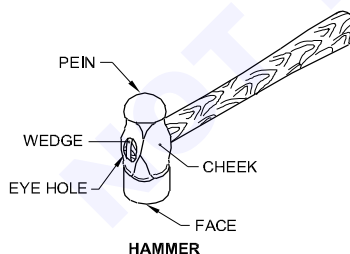
Handle is made of wood

**Types of Hack saw**

- 1 Fixed hack saw frame
- 2 Adjustable Hack saw frames
- 3 Deep cut Hack saw frames

**Hammer (Fig 18) :** Hammer is of the important tool in engineering field.

Fig 18



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Hammer is used to striking, cutting, chipping, forging, bending, punching and

Straightening sheets. It also used for riveting works.

Hammer is available from 125 grams and varies in size depending on work to be done

**Material :** The face and pein portion of hammer is made of drop forged carbon steel hardened

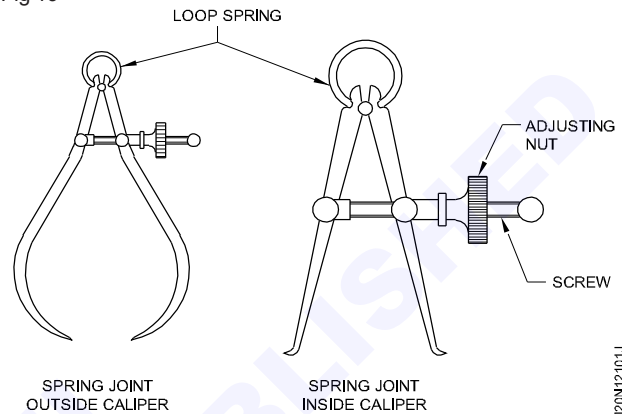
And tempered with the wooden handle.

**Types of hammer**

- 1 Hard head hammer: Used for hard works
- 2 Ball pein hammer
- 3 Straight pein hammer
- 4 Cross pein hammer
- 5 Double face hammer
- 6 Sledge hammer and
- 7 Claw hammer

**Caliper (Fig 19) :** Caliper is an indirect measuring tool used to measure inside and outside dimensions with the help of steel rules

Fig 19



IM20N12101J

**Material :** Caliper is made of high carbon steel or medium carbon steel.

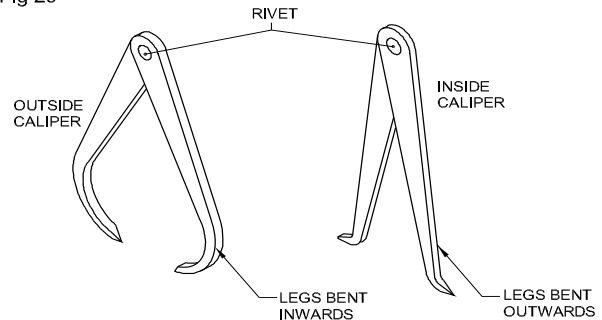
The measuring face is normally hardened and tempered.

It is also made of mild steel case hardened.

**Type of joint caliper**

- 1 Firm Joint caliper (Fig 20)

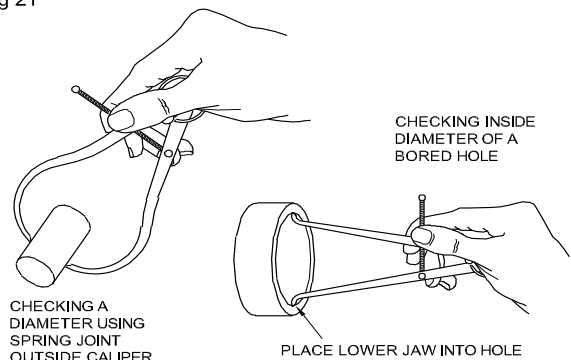
Fig 20



IM20N12101K

- 2 Spring joint caliper (Fig 21)

Fig 21

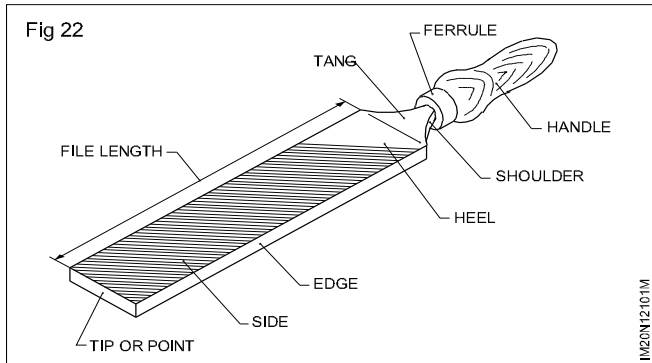


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**Types of legs :** Depends upon the shape of legs calipers are classified into

- 1 Outside calipers and
- 2 Inside calipers

**Files (Fig 22) :** File is a multi-point cutting tool used to remove unwanted metal portions from a job in order to bring to the required shape



#### Parts

- 1 Tip or point ,
- 2 Edge,
- 3 Face or side,
- 4 Heal,
- 5 Shoulder ,
- 6 Tang,
- 7 Ferrule
8. Handle

#### Uses

- 1 To remove unwanted metals so that the required shape of the job is met
- 2 Used to file the portion to be fitted and
- 3 To give good appearance to the job

File is specified by its length, grade, cut and shapes.

| SI.No              | Grade number of teeth |
|--------------------|-----------------------|
| 1 Rough file       | 8 teeth per cm        |
| 2 Bastard file     | 12 teeth per cm       |
| 3 Second cut file  | 16 teeth per cm       |
| 4 Smooth file      | 20 to 24 teeth per cm |
| 5 Dead smooth file | 40 teeth per cm       |

#### Types of files

- 1 Flat file
- 2 Square file
- 3 Three square or triangular file
- 4 Round file
- 5 Half round file
- 6 Safe edge file
- 7 Hand file
- 8 Knife file

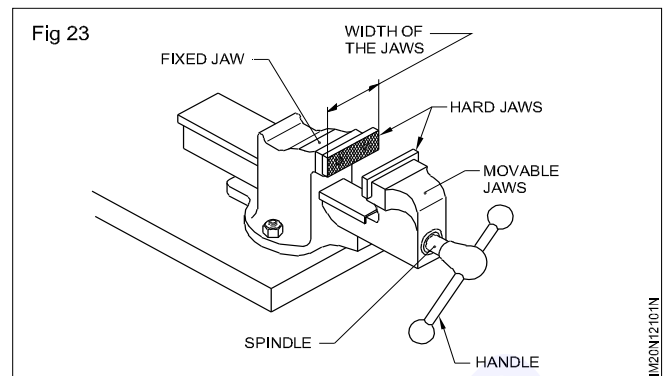
**Vice (Fig 23) :** Vice is used to hold job firmly while doing filing, chipping, hand sawing, drilling, planning, happing and dieing operation.

Different types of vices available depends upon the jobs.

#### Types

- 1 Bench vice
- 2 Machine vice
- 3 Universal vice
- 4 Swivel base vice

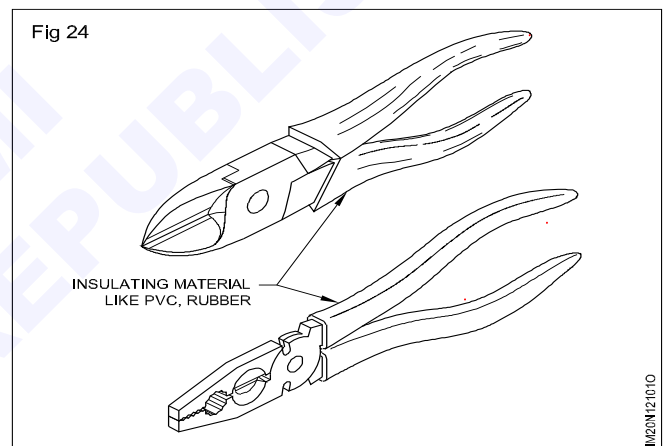
- 5 Pipe vice
- 6 Hand vice
- 7 Leg vice
- 8 Tool makers vice
- 9 Pin vice and
- 10 Quick release vice



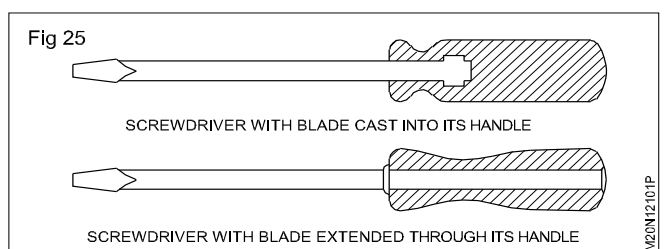
**Pliers (Fig 24) :** Plier is made of steel and specified by its length. It is used to hold, cut, and twist wires Also to hold small pipes.

Insulated plier is used for Electronics works

Size of the plier available in 150mm , 200mm length



**Screw driver (Fig 25) :** This tool has a handle made of wood or plastic and a blade made of steel. Working edge is hardened. It is specified by the blades length. It is used to tighten and loosen the screws. Suitable tip of the screw driver is used to fit in the slot of screws. Insulated screw drivers are used for electric works. Size of screw drivers: 100 mm 150 mm 200 mm 250 mm and 300 mm available.

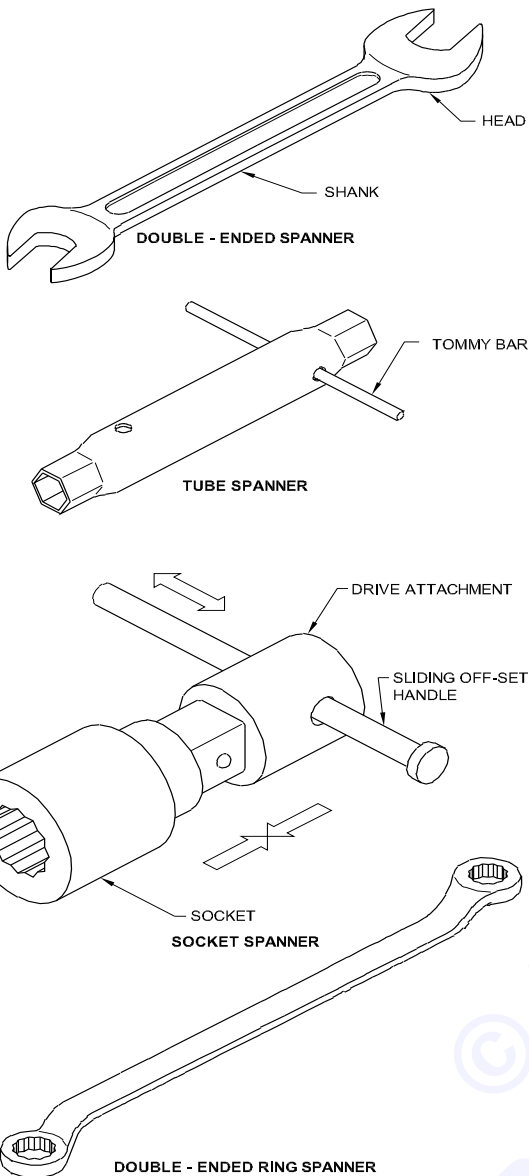


**Spanner (Fig 26) :** This tool is made of forged steel. It is specified by the space of flat portion of nut.

**Types :** Single end spanner , double end spanner and adjustable spanner.

In adjustable spanner jaws can be moved so that various size of bolt and nut can be tightened or loosened. In narrow and deep places ring and box spanners are used.

Fig 26

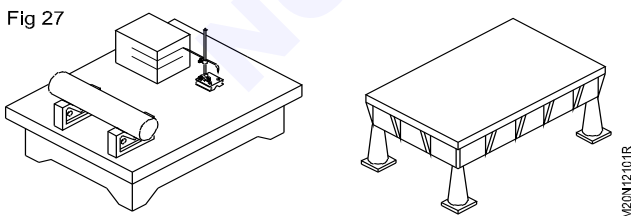


### Marking tools

**Surface plates (Fig 27)** : It is made of cast iron which is stress relieved to prevent distortion. The work surface is machined and scrapped. The underside is heavily ribbed to provide rigidity.

Available in grade 1,2&3. Grade 1 surface plate is acceptable for most work. Surface plates are specified by their length, breadth, grade and Indian standards number.

Fig 27

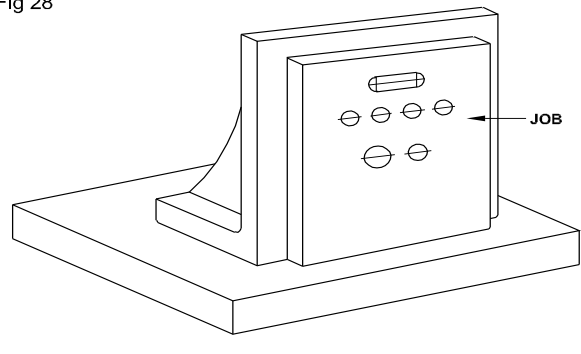


**Angle plates (Fig 28)** : This is used to support jobs and to provide a vertical or angular plane for marking. Angle plate is made of cast iron or cast steel machined accurately to an angle 90°.

### Types

- 1 Plain solid angle plate

Fig 28

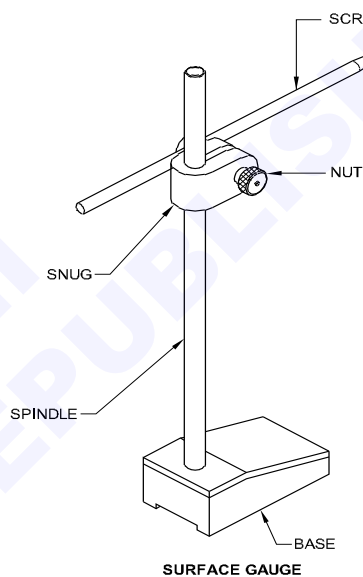


- 2 Slotted angle plate

- 3 Swivel type angle plate

**Surface gauge (Fig 29)** : It is also called scribing block and used to mark parallel lines to datum surface.

Fig 29



The two types of surface gauges are

- 1 Fixed type and
- 2 Universal type

Parts as shown in Fig 29

- 1 Base
- 2 Rocker arm
- 3 Pillar

**V Block (Fig 30 & 31)** : V Block is used to hold job while marking and setting. Since it has V shaped Groove it is called V block. It is made of closed grain cast steel.

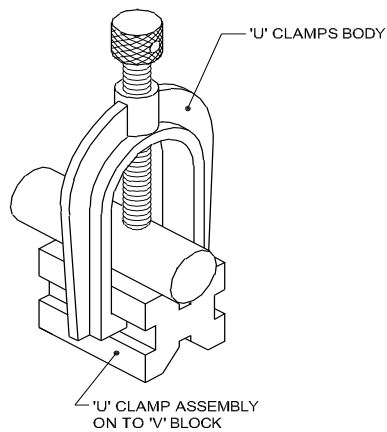
V Block is available either in square or rectangular shape.

### Types of V Blocks

- 1 Single level single groove V Block
- 2 Single level double groove V Block
- 3 Double level single groove V Block
- 4 Match fair V Block

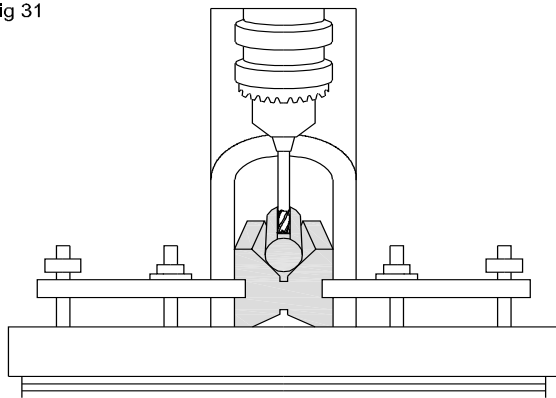
**Punch (Fig 32)** : In order to make the scribed line visible till the completion of work dots are punched over the line by the punch. Punch has a cylindrical body knurled at the middle portion. The end portion is sharpened to the required angle according to the job to be done. Head portion is chamfered.

Fig 30



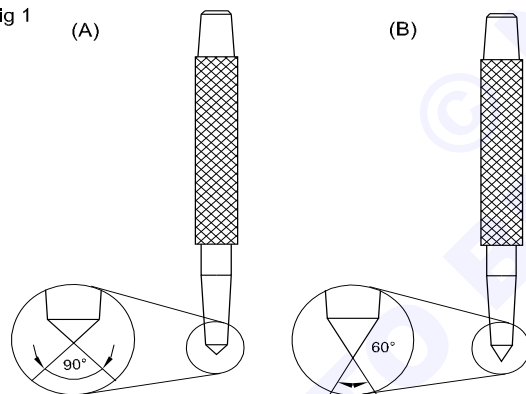
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Fig 31



IM20N12101V

Fig 1



IM20N12101W

**Material:** Punch is made of tool steel or high carbon steel hardened and tempered

### Types

1 Center punch, 2 Prick punch, 3 Dot punch, 4 Pin punch, 5 Hollow punch

6 Bell center punch and 7 Letter and number punch

**Accessories nuts (Fig 33) :** In fitting works nuts are used along with bolts for mating two parts.

Threads were being cut inwards in the nuts and the edges are chamfered for safety.

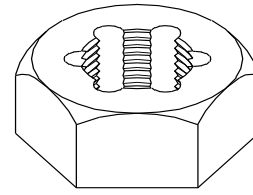
**Types of Nuts :** 1 Hexagonal nut, 2 Square nut, 3 Lock nut, 4 Slotted nut, 5 Castle nut, 6 Symmonds lock nut, 7 T Nut, 8 Wiring nut and 9 knurled nut .

**Screws (Fig 34) :** Screws are used as fasteners along with nut like bolts. Available in various sizes.

**Types:** 1 Heavy duty machine screws, 2 Light duty

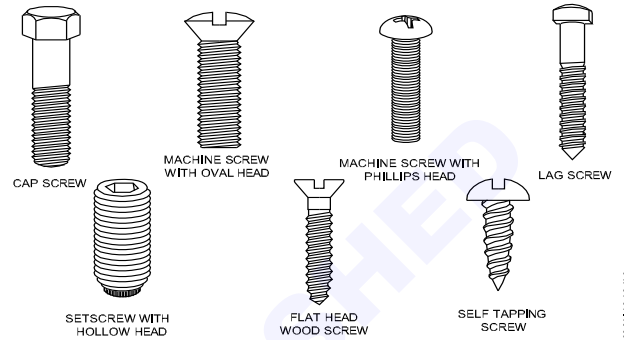
machine screws, 3 Set screws, 4 Group screws, 5 Thump screw and 6 Self tapping screw

Fig 33



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Fig 34



IM20N12101Y

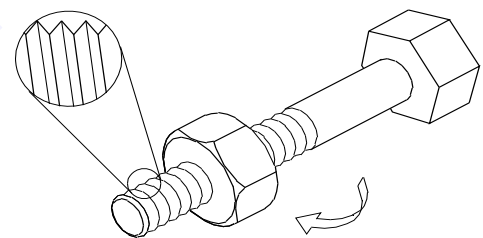
**Bolts (Fig 35) :** Bolts are used to join as well as dismantle the machine parts.

It has a head portion and a threaded body portion.

Spanner is used to hold the head portion of the bolt while tightening and loosening.

Fig 35

ENLARGED VIEW



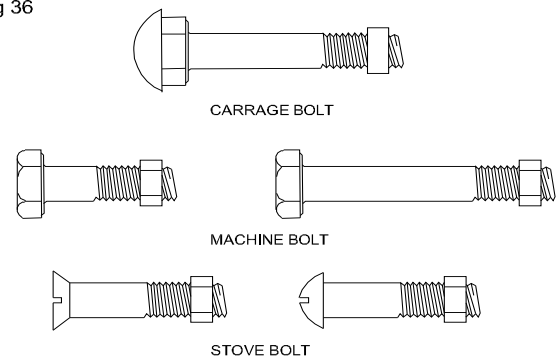
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**Specification :** Bolts are specified by its head shape, type of thread cut on the body, diameter,

**Length and ISI number :** For an example Hexagonal bolt metric 10x60-4.8.I.S.1963

**Types of bolts :** Bolts types depends upon head shape and places where it is used.

Fig 36



IM20N12101Z1



## Scribers

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

- explain the features of scribers
- explain uses of scribers.

Scribers is a hand tool used to mark lines on job materials which are to be filed or machined. These are made of hardened high carbon steel.

The tip of the scriber should be sharp enough to draw thin lines.

The tip of the scriber should be sharpened if found blunt.

Scribers are available in different sizes and shapes. Normally plain scriber is used for marking.

## Precision Instruments

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

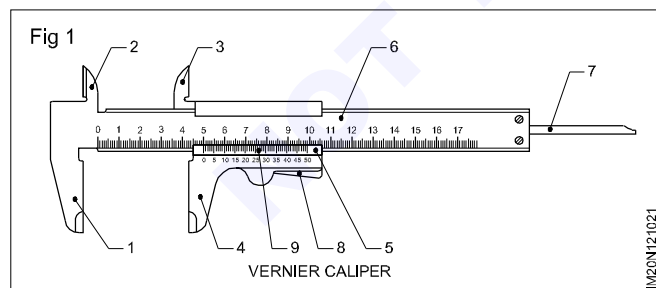
- explain the types of precision instruments, types and method of working and use.

**Introduction :** Precision instruments are used to measure the jobs very accurately during the progression and finished stages. By these instruments measurements can be checked to the accuracy of 0.01 mm. so that high quality is maintained.

### Types

- |                           |                        |
|---------------------------|------------------------|
| 1 Vernier caliper         | 2 Outside micrometer   |
| 3 Inside micrometer       | 4 Depth micrometer     |
| 5 Dial test indicator     | 6 Vernier height gauge |
| 7 Vernier depth gauge and |                        |
| 8 Sine Bar                |                        |

**Vernier caliper (Fig 1) :** The distance between two edges of a job is difficult to determine by the eyes while using normal measuring instruments. Hence a French scientist Piere Vernier in the Year 1830 discovered Vernier Caliper. The instrument based on the principal of sliding Movements. When two lines coincide with each other so the measurement will be accurate. The instruments are called by its name Vernier Caliper, Vernier height gauge



### Vernier bevel protractor

**Uses:** Inside, outside and depth dimensions can be measured by vernier caliper.

**Material:** Vernier caliper is made of Invar steel, nickel steel or stainless steel

**Parts:** 1 Beam 2 Fixed jaw 3 Movable jaw 4 Fine adjusting screws 5 Locking screws

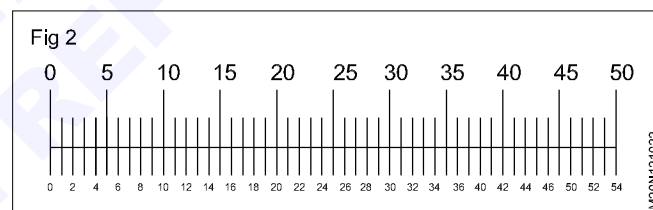
While marking lines on the object the scribers should be hold like pencils so that, Lines drawn are parallel to the edge of the object. Don't place the scribers inside the pockets since its edge is very sharp.

Use cork to cover the sharp edge of the scribe so that injury and accidents can be avoided.

### 6 Depth bar and 7 Thumb lever

The beam is graduated in inches at the upper side and in mm at lower side called main scale. Similarly in movable jaw graduation are marked in inches and milli meter. In a single vernier caliper separate calipers are available for British and metric measurements

**Least count of a vernier caliper (Fig 2) :** The smallest or least measurement measured by the caliper is called least count



When the fixed and movable jaws are closed that is when zeroes of main and

Vernier scales coincides, 49th division of the main scale and 50th division of Vernier Scale are coinciding.

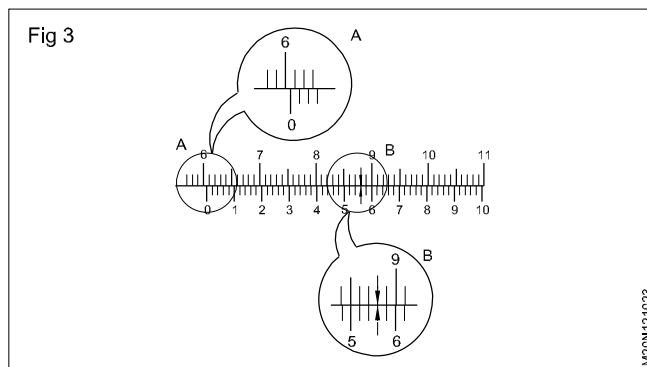
So the least count is calculated as below

$$1 \text{ MSD} = 1 \text{ mm} \quad 49 \text{ MSD} = 49 \text{ mm}$$

49 mm is divided into 50 divisions

Therefore in vernier scale 1 division =  $(1 - 49/50) = 0.02 \text{ mm}$ .

Example of reading Vernier Caliper (Fig 3)



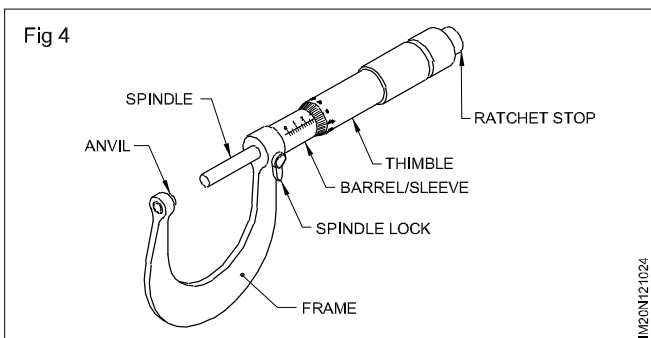
Main scale reading + 60mm

Vernier division coinciding with main scale = 28mm

Hence value =  $28 \times 0.02 = 0.56\text{mm}$ . Therefore the reading is  $60 + 0.56 = 60.56\text{mm}$

### Inside and outside depth micrometer

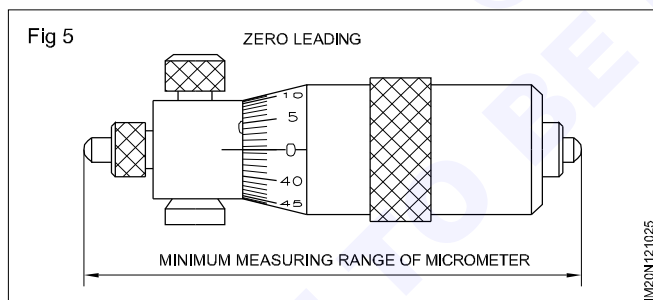
**Outside depth micrometer (Fig 4) :** Outside micro meter is used to measure outside dimensions to an accuracy of 0.01mm. It works on bolt and nut principle. Job is placed in between the anvil and spindle for measurement. In metric, English method of measurement the Marking is done in inches and mm and available in different ranges Metric vernier micrometer has more accuracy of 0 to 25mm and for British 0 to 1 inch.



**Material:** Frame is made of malleable cast iron. Anvil, spindle and sleeve are made of steel alloy

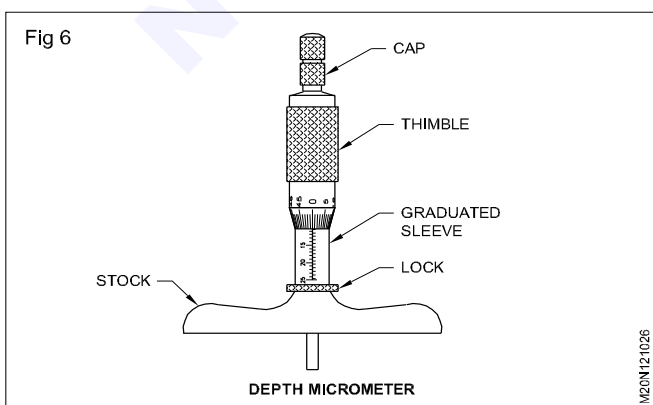
**Parts :** 1 Frame 2 Anvil 3 Spindle 4 Sleeve / Barrel 5 Thimble 6 Ratchet stop 7 Lock nut (spindle lock)

**Inside micrometer (Fig 5):** It is used to measure the inside dimensions to an accuracy of 0.01mm and 0.01 inch

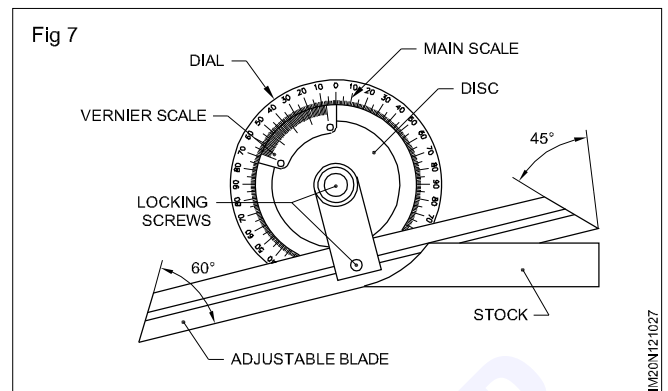


**Parts:** 1 Spindle 2 Base 3 Barrel/Sleeve 4 Thimble 5 ratchet stop and 6 lock nut.

### Depth micrometer (Fig 6)



**Vernier bevel protractor (Fig 7) :** It is used to measure angle with an accuracy of 5 minutes. Angular dimensions can be drawn and measured. The blade edges are made to angle of  $60^\circ$  &  $30^\circ$ .

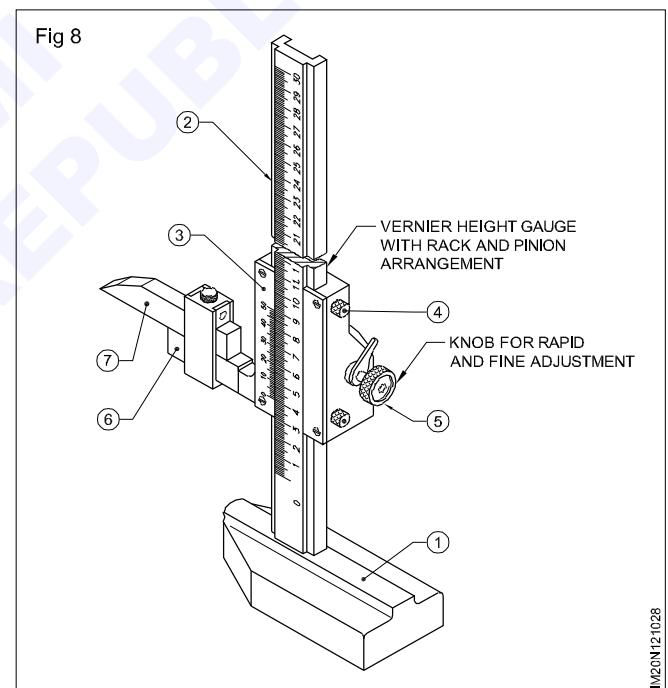


Least count = 2 msp – 1 vsd

= 120 min – 115 min (120 inch – 115 inch)

= 5 min (5 inch)

**Vernier height gauge (Fig 8) :** It is used to measure the height of a job and marking off set scriber is used to mark below the base



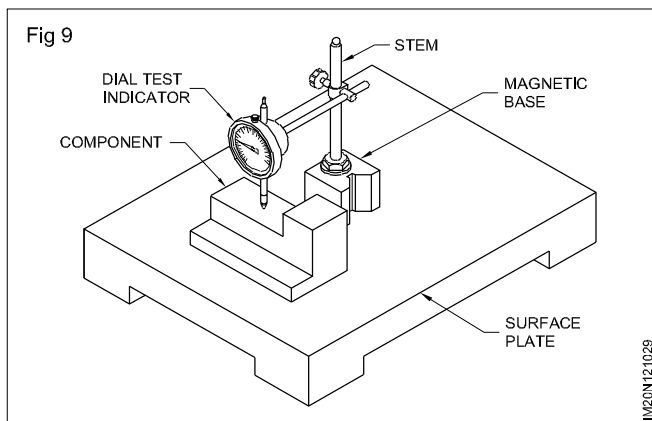
**Parts:** 1 Base 2 Beam 3 Vernier scale 4 Lock nut 5 Fine adjusting screw 6 screw jaw and 7 Offset scriber

**Dial test indicator (Fig 9):** Dial test indicators are high precision instruments used for comparing and determining the variations in the size of a component to fix in a stand.

### Uses

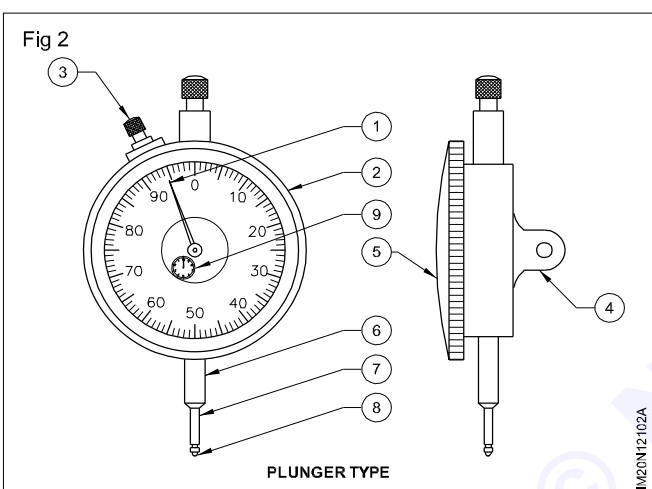
- 1 Used to identify the ups and downs on a surface of the job
- 2 To check the accurate surface of a machine
- 3 To measure the slope along with sine bar
- 4 To set jobs in lathe very accurately

## 5 To check big size shaft mating



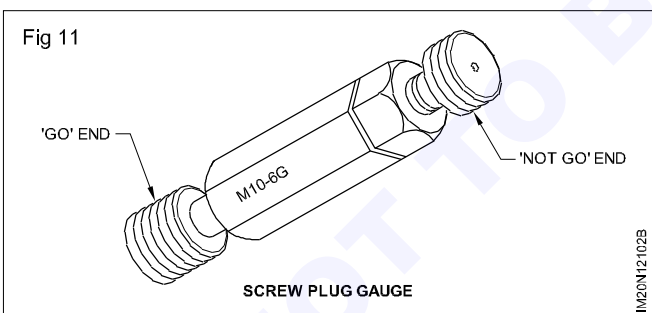
### Types

1 Plunger type (Fig 10) and 2 Level type



**Parts:** 1 plunger 2 Anvil 3 Stem 4 Disc or dial 5 Rotatable bezel 6. Bezel clamp 7 Pointer and 8 Revolution counter

### Gauges (Fig 11,12,13&14)



**Introduction:** Gauges are important measuring device in engineering fields it is used to provide certain dimensional information according to a specified standard and to check the measurement very quickly gauges are mainly used for checking the dimensions of the job in different shapes and sizes. They are made of steels. Inexperienced persons can use the gauge very easily. The production time can be reduced and number of jobs can be increased.

### Classification of Gauges

1 Standard Gauge 2 Limit Gauge and 3 Adjustable Gauge

Fig 12

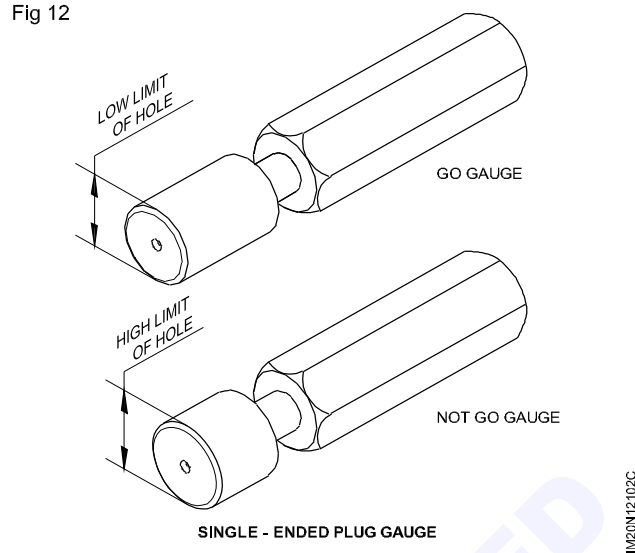


Fig 13

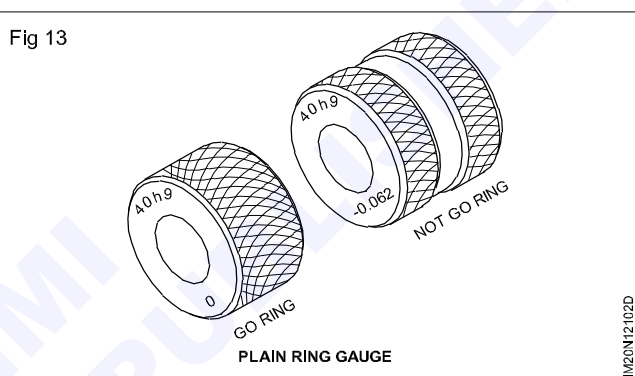
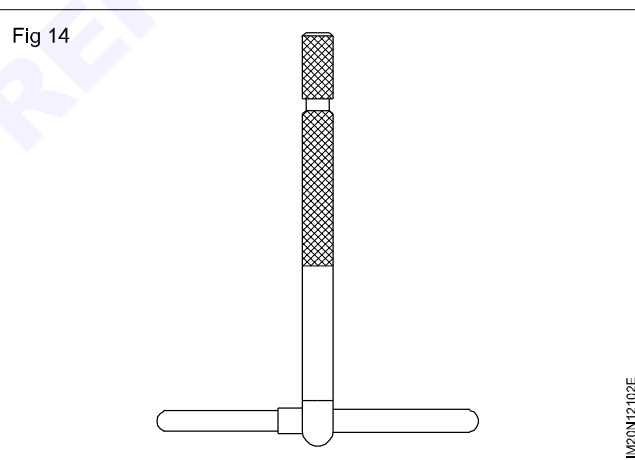


Fig 14



### Types of Gauges

- |                    |                     |
|--------------------|---------------------|
| 1 Plug Gauge       | 2 Snap Gauge        |
| 3 Ring Gauge       | 4. Telescopic Gauge |
| 5 Feeder Gauge and | 6 Radius Gauge.     |

**Sine bar :** Sine bar is a device used to measure the angle and slopes of a job to An accuracy one minute of the degree.

### Uses

- 1 To measure angles in job
- 2 Used to measure slope angle along with slip gauge blocks

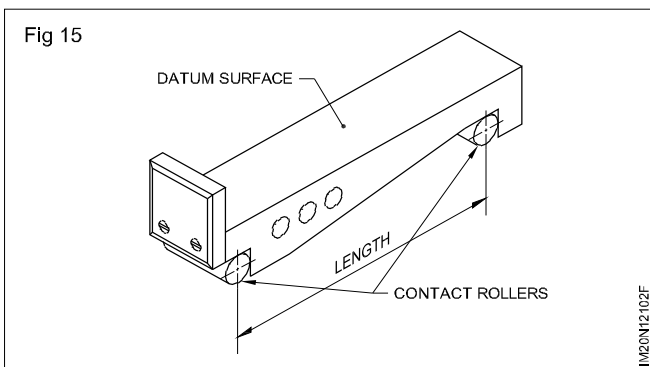
3 Used to measure angles for milling, grinding and inspection applications.

**Principle :** It works on the principle of Trigonometry.

$\sin \theta = \text{Opposite side} / \text{Hypotenuse}$

In a right angled triangle the ratio between opposite side to the hypotenuse is the value of Sine Slip gauge and surface plates were used along with sine bar. The surface plate will be at the base, slip gauge will be on opposite side and sine bar will be on the hypotenuse so as to form a right angled triangle.

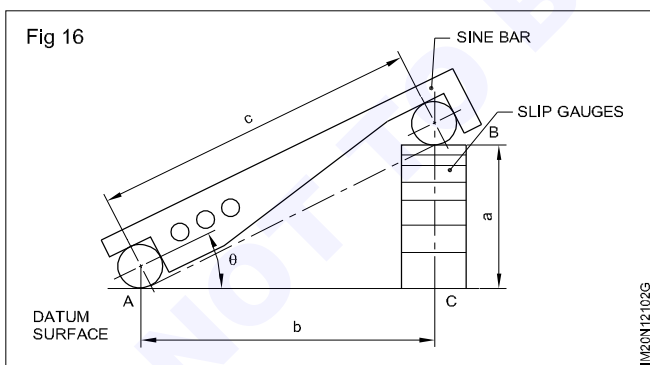
**Material (Fig 15):** Made of high chromium corrosion resistant steel. It is hardened, precision ground and stabilized.



#### Construction

- 1 Sine bar is rectangular in shape. It has holes across the surface. This holes will reduce its weight and can be able to fix with the slotted angle on its body.
2. Two control rollers of equal size were fixed on edges of the sine bar. The distance between the two rollers is the size of the sine bar. Normally the size of sine bar used will be 100mm, 250mm and 500mm.

#### Working method (Fig 16)



- 1 First stack the slip gauges as per the angle of the job to be measured
- 2 Now place the sine bar roller of one end on the slip gauge and the other roller on the surface plate.
- 3 The job to be measured will be placed on the sine bar as shown in fig 16.
- 4 Set a dial test indicator on a vernier height gauge or on a suitable support the plunger part should touch on the job so that the pointer is on zero

- 5 Now slowly move the dial test indicator to the other end of the job. If any variation. Found on the indicator then the angular measurement wont be correct. For this we have to either increase or decrease the height of slip gauge. The indicator should always be in zero while moving along the job. Then only it will be considered as a good job set.

#### Calculation 1

- 1 The height of the slip gauge block is 17.36mm.
- 2 Length of the sine bar is 100mm

**Now what is the angle of the job?**

#### Formula

$\sin \theta = \text{Opposite side} / \text{hypotenuse}$

In fig 16 AB is the slip gauge height = 17.36mm (opposite side)

AC is the length of sine bar = 100mm (hypotenuse)

$$\text{Therefore } \sin \theta = 17.36 / 100 \\ = 0.1736$$

$$\theta = \sin^{-1}(0.1736)$$

$$\theta = 10^\circ$$

#### Calculation 2

Length of sine bar is 100mm. What is the height of the slip Gauge to to set an angle  $30^\circ$

#### Formula

$\sin \theta = \text{Opposite side} / \text{hypotenuse}$

AB is the height of slip gauge H

AC is the sine bar length=100mm

The angle for which the setting to be done  $\theta = 30^\circ$

$$\sin 30^\circ = H / 100$$

$$\text{Therefore } H = 100 \times \sin 30^\circ \\ = 100 \times 0.5 \\ = 50\text{mm}$$

**Slip gauge (Fig 17) :** Slip gauge is rectangular or square in shape. It is made of high grade steel, grinded to high precession and lapped surface finished. Slip gauge is available in sizes separately on various sets. This is called cage blocks

**Slip Gauge set :** Slip Gauge sets are available in metric and British sizes separately. In these metric size blocks of 86 numbers were widely used.

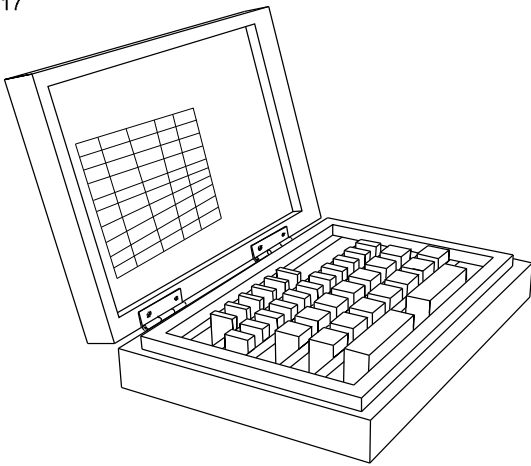
#### Grade

Quality of the Gauge blocks are divided into four category

- 1 **Grade 00 :** This grade gauge blocks are used to determine the

Grades of other gauge blocks manufactured. This is the first grade of the four grades available

Fig 17

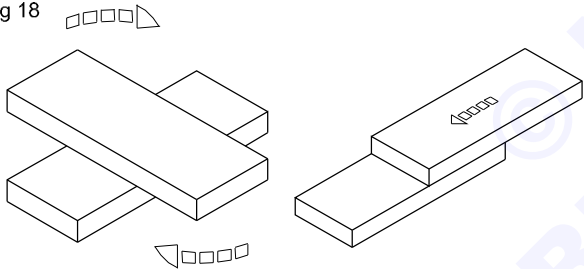


- 2 **Grade 0** : This is used for the inspection of more accurate parts
- 3 **Grade 1** : This is used to find the accuracy of jobs in workshops
- 4 **Grade 2** : This is used for ordinary jobs.

Gauge blocks are certified under three category by B.I.S. They are grade 0, grade 1 and grade 2

**Warning : Rigging :** By placing two gauge blocks on one above the other forming the sign + as in fig 18 and turning the top gauge into a straight line.

Fig 18



## Screw threads

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

- list out the parts and type of thread
- explain the drill size required for tapping.

**Introduction :** In engineering field machine parts are assembled either by brazing, riveting or by welding. In these process it is very difficult to separate the parts without damage. Hence bolts, nuts, studs and screws were used. Parts can be dismantle easily since threads has been made. Threading principle has been discovered by an English man Sir Joseph whitworth on 1814. A screw thread is defined as a ridge of uniform section in the form of a helix on either internal or external surface of a cylinder.

**Terminology of the Thread (Parts as in Fig 1)**

- 1 **Axis of the screw rod** : It is the linear center straight line of the rod
- 2 **Major diameter:** It is the largest diameter of the top of the thread. This diameter is the size of the screw.

This has been done in order to avoid air being passed between gauges. After the job is done the slip gauge should be dismantle as assembled

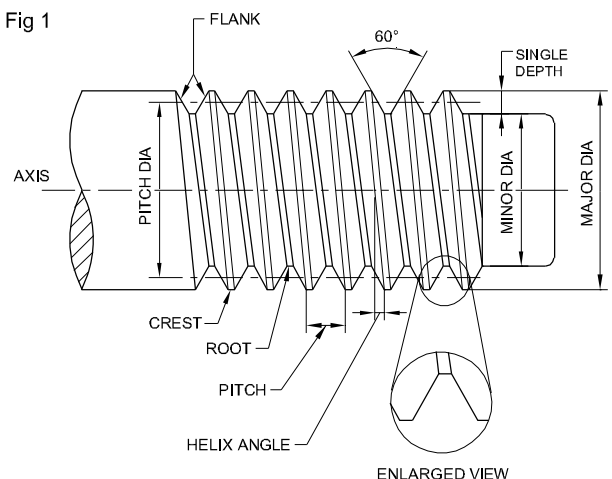
Points to be remembered for the selection of blocks while performing rigging

- 1 As far as possible use small number of blocks
- 2 For the given measurement place from right to left on decimal points

### Care and maintenance

- 1 After the job has been done the blocks should be washed in tetra chloride solution and a layer of petroleum jelly should be applied on blocks
- 2 When used again the blocks should be cleaned in tetra chloride.
- 3 Use large blocks first for rigging and setting the gauge blocks.
- 4 As far as possible avoid touching the lapped surface area
- 5 Always wipe the cage blocks with animal skin
- 6 After the job is done place the blocks in their boxes and store them in a well humidified room.

Fig 1





- 3 **Minor diameter:** For external thread the minor diameter is the smallest diameter after cutting the full thread. In case of internal thread, it is the diameter of the hole drilled for forming the thread
- 4 **Pitch Diameter :** The distance between the centers of opposite threads
- 5 **Root :** The bottom surface joining the two sides of adjacent threads
- 6 **Crest:** The top surfaces joining two sides of adjacent threads
- 7 **Flank or side :** The surface joining the crest and root
- 8 **Depth:** The perpendicular distance between the root and crest of a thread.
- 9 **Thread angle :** It is the included angle between the flanks of adjacent threads
- 10 **Helix angle :** The angle of inclination of the thread to the imaginary perpendicular line
- 11 **Pitch :** The distance between two adjacent thread measured parallel to the axis
- 12 **Lead :** The distance a threaded component moves along the matching component during one complete revolution. In a single start thread lead equal to pitch

**Uses:** Screw threads are used as fasteners to hold together and dismantle when required. For lifting loads by screw jacks threads were used. Used to adjust die tool

**Used to make accurate measurements in micrometer**

**Standardization of threads:** Machineries and machine parts manufactured in various countries can be used globally in any country. Accordingly the threads and angle of threads were determined as unique values and these values were standard values.

**Necessity of standardization :** While a Japanese machine is used in Tamil nadu the parts such as bolts and nuts were damaged due to wear and tear they can be produced locally instead of importing. This is the advantage of standardization.

**Types of threads :** Threads are classified by the angle being cut & TPI (thread per inch)

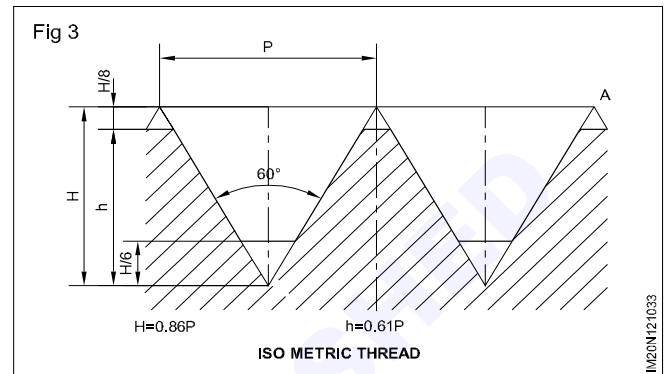
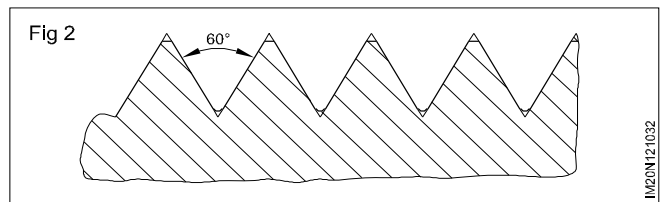
**TPI basis :** Number of threads being cut per inch. If more number of cuts per inch then it is called fine thread and less number of threads per inch called course threads.

- 1 **V Threads:** A) ISO Metric thread B) ISO Inch thread (united threads) C) British whitworth thread, D) British standard fine thread and E) BA Threads
- 2 Square thread and knuckle thread ,
- 3 Trapezoidal thread, Acme thread
- 4 Saw toothed thread and Buttruss thread

1 **V Threads (Fig 2) :** Threads are being cut in V shapes. Example : Bolt , Nut spindles

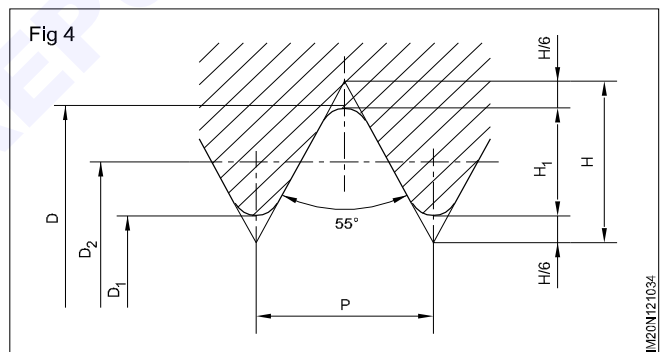
- i **ISO Metric threads (Fig 3) :** The angle of thread is 60 degrees. It is authorized by BIS. For external

threads the root portion is circular and crest portion is flat construction. For internal threads root is formed by  $1/8$  th part of pitch which is round and crest is flat.



- ii **ISO Inch thread (Fig 4) Unified thread :** The angle of thread is 55 degrees and V shape thread is used for all type of works.

- iii **BSW (British Standard Whitworth) (Fig 4) Thread:** This is used for all type of work. The angle thread is  $55^\circ$  and has 'V' shape.



- iv **BSF Thread (Fig 4) British standard fine thread:** This is similar to BSW thread and number of TPI is more. It is used where vibration and shocks encounters.

- v **British Association Thread BS Threads :** Angle of  $47.5^\circ$  is cut in this type of small bolt and screws. BA tap set has size OBA to 22BA. Only 2 nos of taps were available in each sizes.

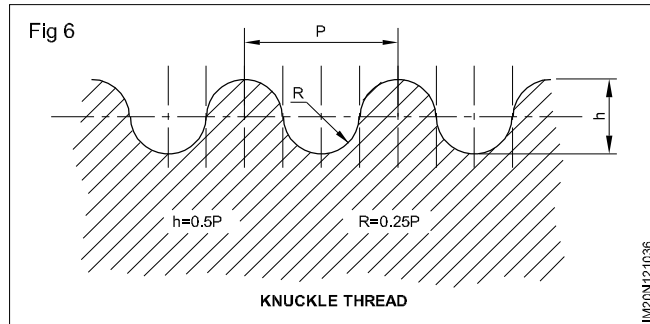
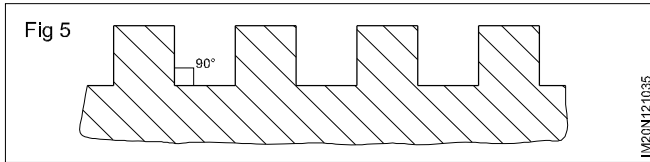
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- i **Square Thread (Fig 5) :** This type of thread is being cut in screw jacks, vice spindle and fly press. The angle of thread is  $90^\circ$ . These threads were used in mechanical power transmission and for lifting weights.

- ii **Knuckle Thread (Fig 6) :** This thread is used in casting works, wooden works and railway wagon coupling.

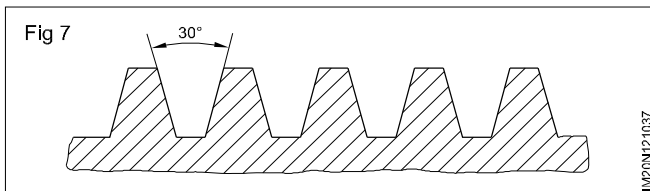
The crest and roots are semicircular in shape.



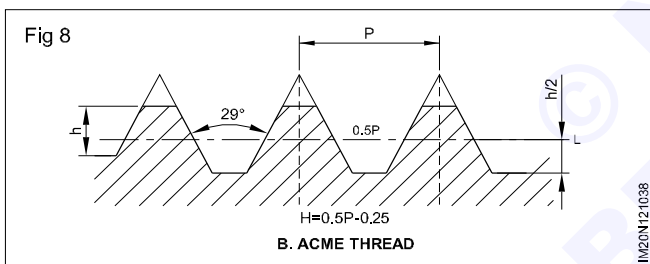


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- i **Trapezoidal Threads (Fig 7)** : The angle between the flanks were  $30^\circ$ . For joining and releasing the parts of the machine while in operations these threads were used.

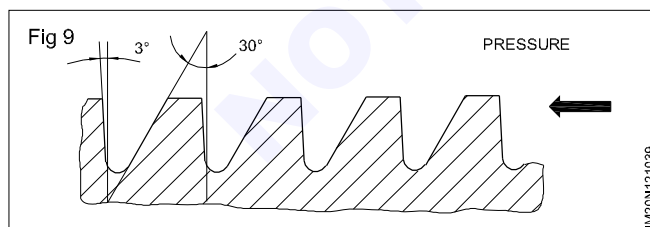


- ii **ACME Threads (Fig 8)** : The angle of threads is  $29^\circ$ . It is used in lead screws and automobile lathes



4

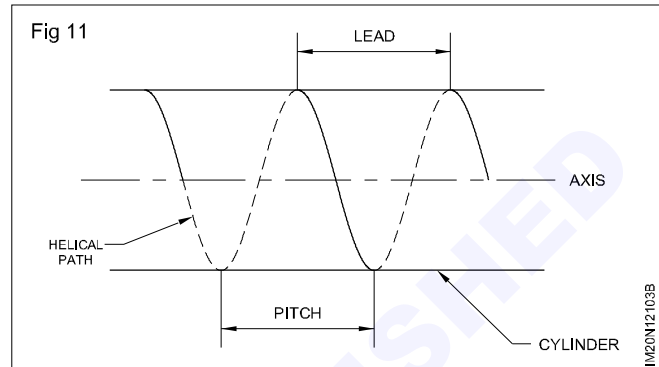
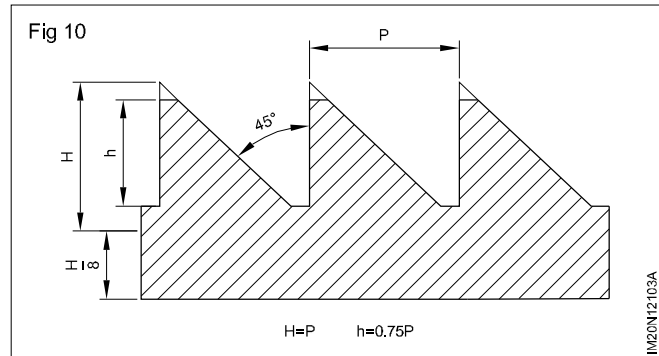
- i **SAW Tooth threads (Fig 9)**: The thread is having a slope of  $3^\circ$  on one side and  $30^\circ$  at other side. It is used in place where pressure has to be given on one direction like in carpenter's vice spindle and quick release press.)



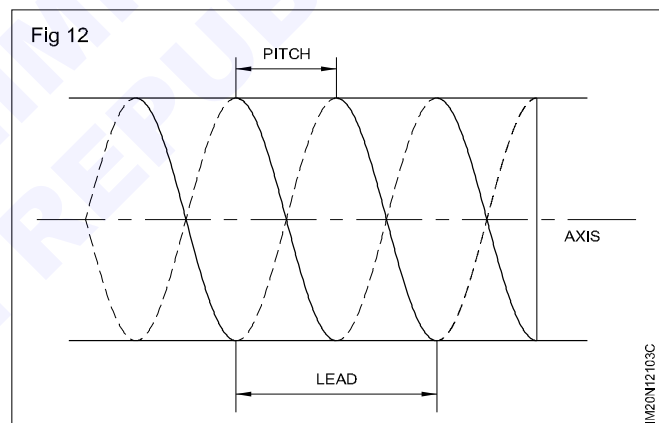
- ii **Buttress Thread (Fig 10)** : The thread has  $90^\circ$  on one side and  $45^\circ$  at the other side. It is widely used in hand press and quick release vice.

### Starts of thread

**Single start thread ( Fig 11)** : Thread being cut starting from one place is called single start thread. In this type pitch and lead are equal.



**Double start thread (Fig 12)** : Thread which start from two points (opposite to each other) are cut and known as double start thread. In this lead is double the pitch size.



**Multi start thread** : Threads starts from more than two points are called Multi start thread. Here lead of the thread is greater than the pitch and depends upon the number of starts in thread formation.

**Tap and tap drill size** : Tap is a cutting tool to form internal threads in engineering works. Before doing tapping, drill hole to be made according to the tap to be used.

Formula for metric size Tap.

Drill size = Tap size (  $2 \times 0.6134 \times \text{pitch}$  ). For M10 Tap the drill size is calculated as shown Drill size =  $10 - (2 \times 0.6134 \times 1.5)$

$$= 10 - (1.226 \times 1.5) , = 10 - 1.839 , = 8.161$$

or 8.2mm

### Explanation

Minor diameter = Major diameter – 2 x depth and depth =  $0.6134 \times \text{pitch}$

2 depth of thread =  $2 \times 0.6134 \times \text{pitch}$

$$= 1.226 \times 1.5 , = 1.839 \text{mm or } 1.84 \text{mm}$$

Minor diameter =  $10 - 1.839 , 8.161 \text{ or } 8.2 \text{mm}$

## Copper tube cutting, bending, swaging and flaring

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

- explain type of copper tube study about copper cutting, bending, swaging of the diameter of the tube and flaring the edges of the tube.

### Types of copper tube

**Soft copper tubes:** These are used in refrigeration and air conditioner appliances

**Hard copper tubes:** These are used in commercial type of refrigeration appliances. The tubes cannot be bend. But if need arises. It can be bend by using "L" bend, elbows, coupling, reducers, "T" joints and by brazing the tubes.

Soft copper tubes are available in the following sizes

50 feet length rolled in coil shape

3/16 inch (4.5mm), 1/4 inch (6mm), 5/16 inch (7.5mm), 3/8 inch (9mm), 7/16 inch (10.5mm), 1/2 inch (12 mm), 9/16 inch (13.5 mm), 5/8 inch (15mm) and 3/4 inch (18.5mm) of outer dia.

**Hard copper tubes:** Hard copper tubes are available in the following sizes

1/4 inch (6mm), 3/8 inch (9mm), 1/2 inch (12 mm), 5/8 inch (15mm), 3/4 inch (18.5mm), 7/8 inch (21mm), 1 inch (25.4mm), 1 and 1/8 inch (32mm), 1 and 3/8 inch (35mm) and 1 and 5/8 inch (41mm) of outer diameters.

**Steel tubes** used in refrigerator has thin wall thickness

**Stainless steel tubes:** These are used in machineries for dairy and ice cream production.

**Plastic tubes:** These are used in drain water pipe line, in water cooling condenser and for circulating the acids in descaling operation.

**Flexible copper tube:** These are used in automobiles and air conditioner for the flow of refrigerant by suction. Copper tubes of dimension 3/16" to 7/8" are to be cut by using tube cutter. Hacksaw blade with frame are used for cutting copper tubes of size more than 1 and 1/8".

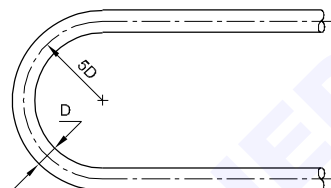
**Tube bending (Figs 1 - 5) :** Tube bending is done to bend the tubes without reducing the cross sectional area or should not be pinched. The diameter of the bend should be greater than the diameter of the copper tube by 5 to 10 times. Spring bender will always hold tight with the copper tube. While removing, the bender should be rotated slightly to ease the copper tube.

**Swaging of copper tubes (Fig 6):** In order to join two copper tubes of same size by brazing, we have to first do swaging operation. Brazing will be easy and sturdy than flare connection. Length of swaging should be equal to the diameter of the copper tube.

While using punch type swaging tool, the copper tube must be inserted correctly into the hole of the flaring block.

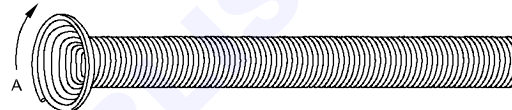
Then fix the copper tube on the punch and hammer it. While using lever type place the tube in the expander and pull the lever.

Fig 1



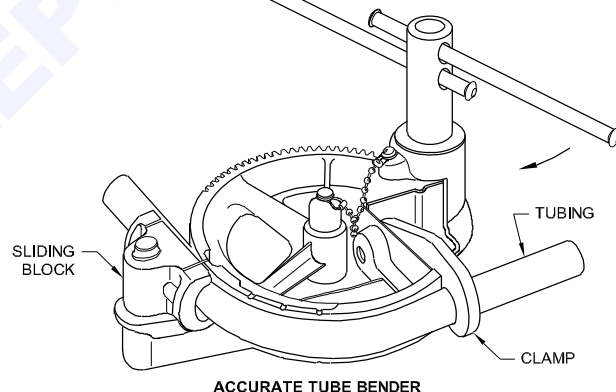
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Fig 2



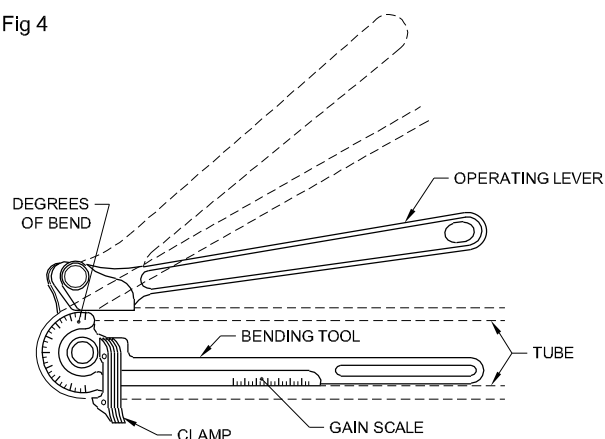
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Fig 3



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Fig 4

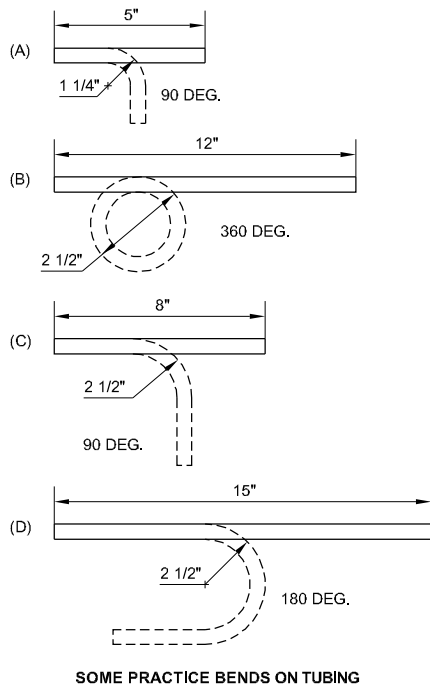


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### Flaring, flare fitting and testing the joints

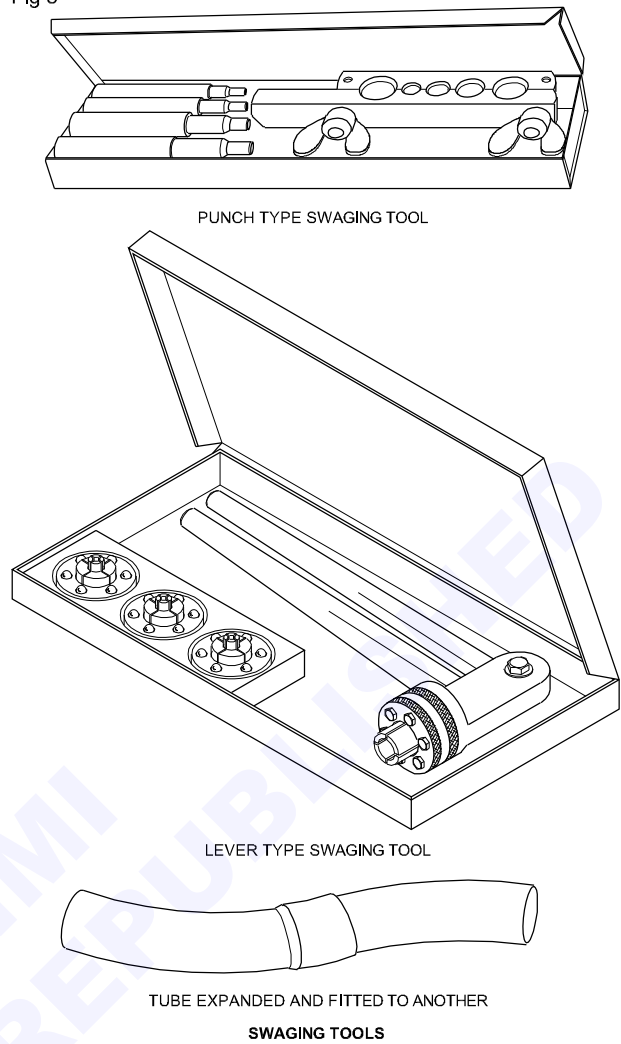
**Necessity of flaring :** In order to avoid gas leakage and to ensure vapor tight seal, flaring need to be done.

Fig 5



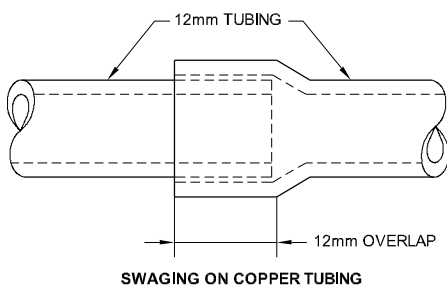
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Fig 8



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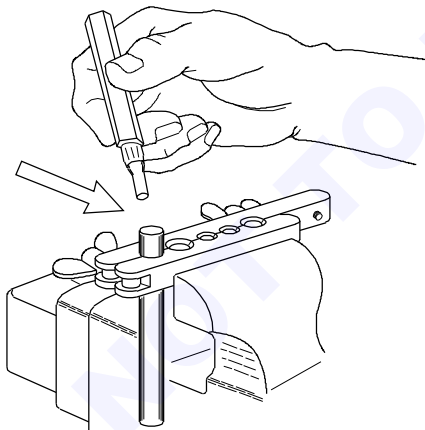
Fig 6



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This is the process of expanding the mouth of the copper tube so as to fix effectively on the appliances. (Figs 7 & 8)

Fig 7



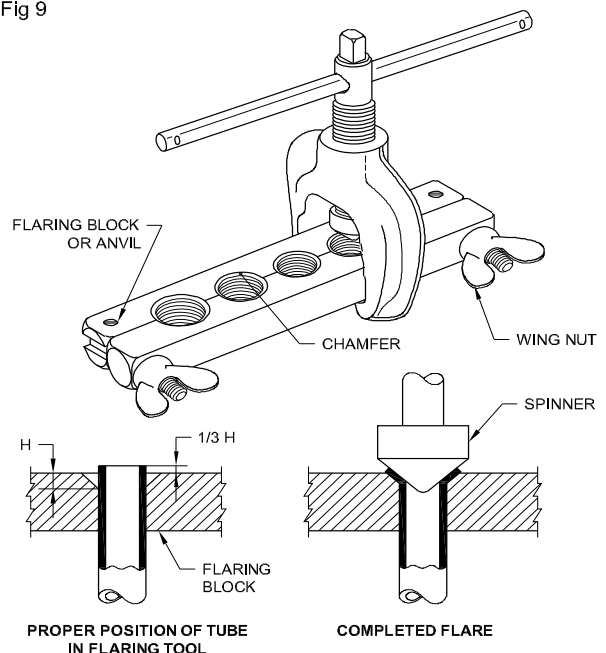
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**Types of flaring :** 1 Single thickness flare and 2 Double thickness flare

**Single thickness flare (Fig 9)** is used for small diameter copper tubes.

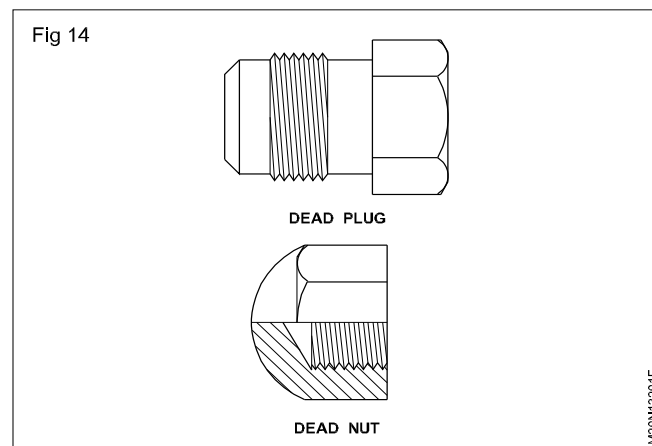
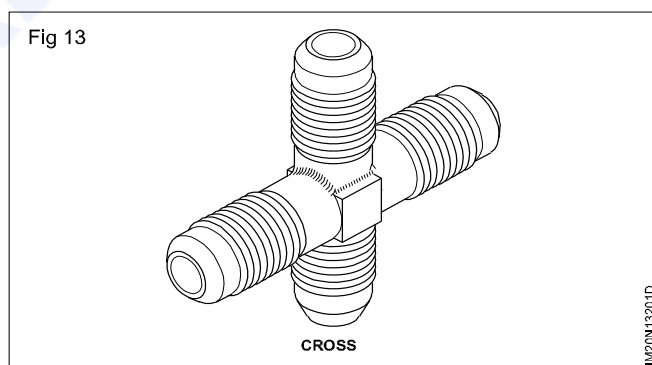
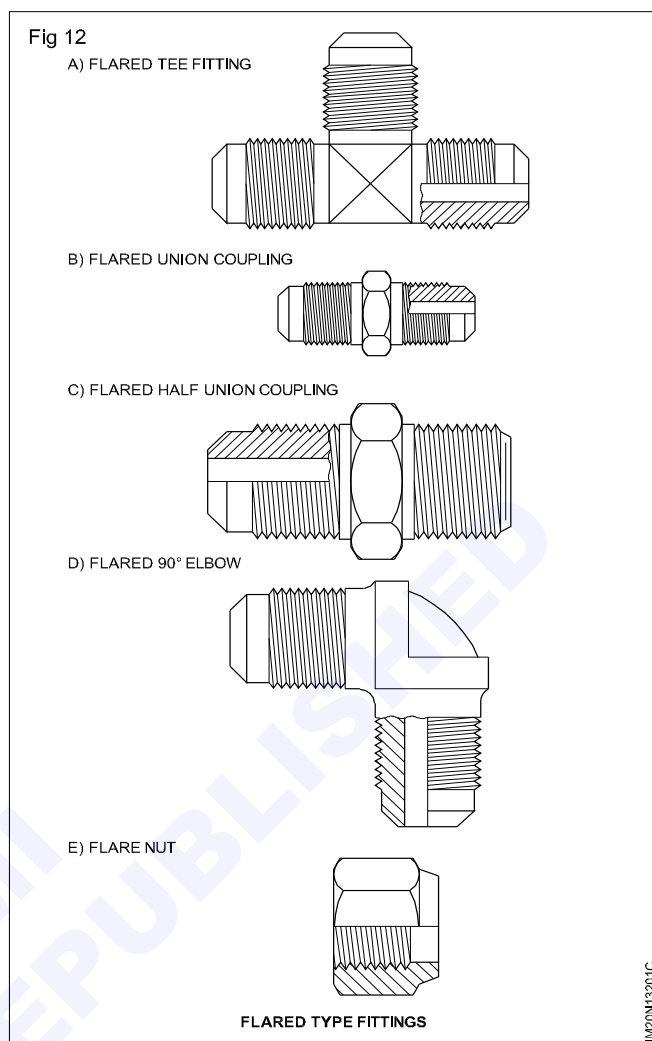
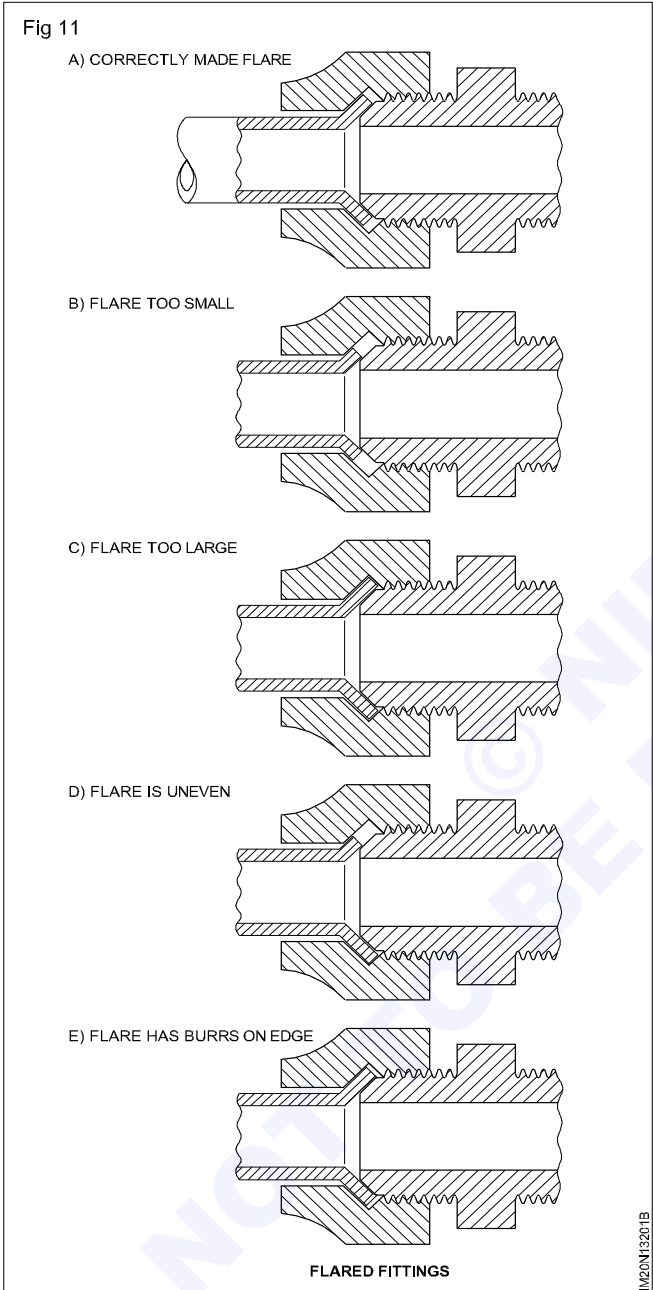
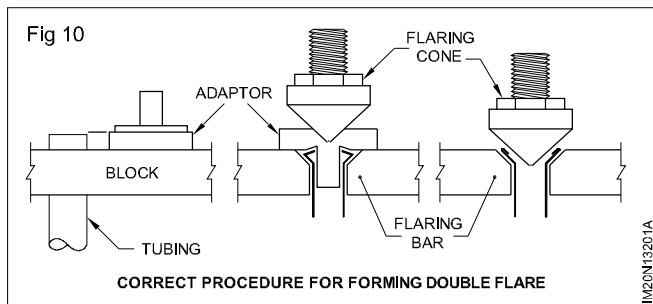
**Double thickness flare (Fig 10):** It is used for large diameter of more than 98mm copper tubes. Expansion of mouth is only possible for large diameter copper tubes. Double thickness flare are more rigid than single thickness flare.

Fig 9



IM20N132019

In Fig11 shows the proper and improper flares. This shows how the expansion of the mouth does not match with the apparatus. The flares are uneven, too small, too big or have burrs.



**Flaring tube fittings (Figs 12,13 & 14) :** Figure shows how flaring tube fitting done on copper tubes.

Pressuring the joint on tube : If tubes are joined by flaring or by brazing then the strength of the tube is to be checked before connecting with the apparatus. For this checking dry nitrogen gas of 150 psig or 10kg/cm<sup>2</sup> is used. Soap solution is to be used to check the leakage in the tube.

For pressure testing in system the tube joint is subjected to high pressure than ideal pressure of system.

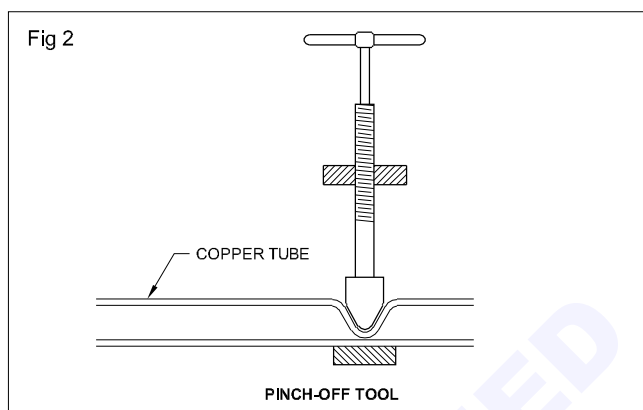
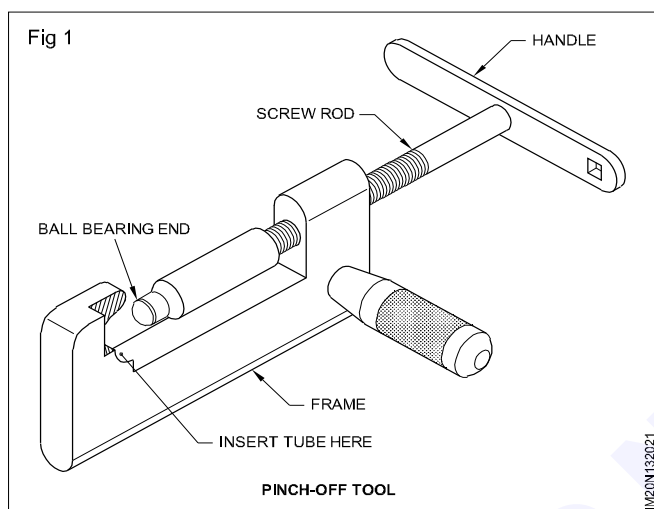
## Pinching and leak test

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

- state about the pinching tools , its principle of operation and uses
- draw the diagram and mention its parts
- understand brazing method, leak test after pinching.

**Application description :** Pinching process is done when copper tube is pressed and applied pressure from one end so that it can't be released to the other end

Fig 1 & 2 shows one type of pinching tool. Here a screw type rod with a handle at one end a ball bearing at the other end. The screw type spindle rod is attached to a main frame. After placing the copper tube in it's place the handle is rotated clockwise. Now the copper tube is being pinched so that brazing work can be done on the pinched end.



**Test for leak:** After pinching the copper tube will be removed from the pinching tool. Now the refrigerant from the system will be injected to the copper tube. Test with soap solution has to be done on copper tube surface to test leakage.

## Tubes and pipes

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

- define the use of tubes and pipes
- determine the pipe bending, threading and cutting devices
- list out the type of pipe joints.

### Introduction

Pipes are used to carry water and deliver to the sewage system. Also used to transfer fluids in chemical laboratories and industries. Pipe joints are used to avoid leakages. Plumbers will carry out the work of pipe installation and pipe joints.

**Pipes:** Pipe is a hollow cylindrical circular shaped object. Depending upon the type of work light duty and heavy duty pipes are available.

**Tubes:** Tubes are available in different shapes such as square , rectangle and circular of smaller size of less than 12mm diameter.

### Purpose of Tubes and Pipes

- 1 Cold and hot water can be transferred from one place to other place.
- 2 Dirty water can be transferred to a sewerage plant.
- 3 Transporting fluids such as hydraulic oil, lubricating oil and inflammable oil.

- 4 Transmission of high pressure steam , special liquids, and gases from one place to other.

**Pipe materials :** Pipes are classified according to materials used for manufacturing.

Metal tubes are

- |                       |                         |
|-----------------------|-------------------------|
| 1 Mild steel pipes    | 2 Cast iron pipes       |
| 3 Cast iron soil pipe | 4 Galvanized iron pipes |
| 5 Copper pipes        | 6 Aluminum pipes        |
| 7 Brass pipes and     | 8 Lead pipes.           |

Non-Metal tubes are

- |                  |            |
|------------------|------------|
| 1 Rubber         | 2 PVC      |
| 3 Stone ware and | 4 Plastic. |

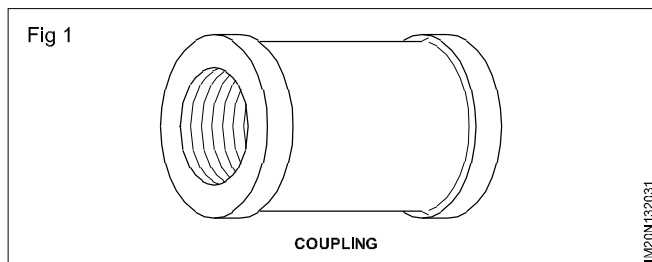
These are all used in Electronics works.

**Pipe fittings :** These are the devices joining one or more pipes of the same or different sizes. Fitting is also used to

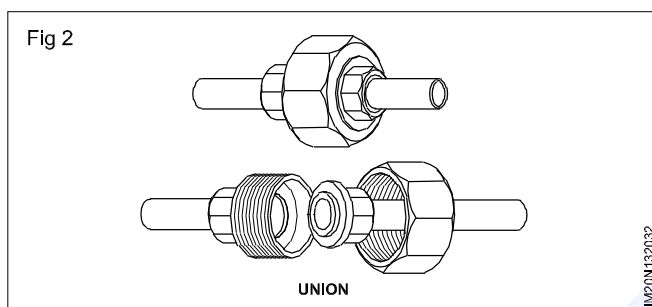
change the direction of flow of the materials. Also for terminating the flow of material in last end of the pipe.

### Types of Pipe fittings

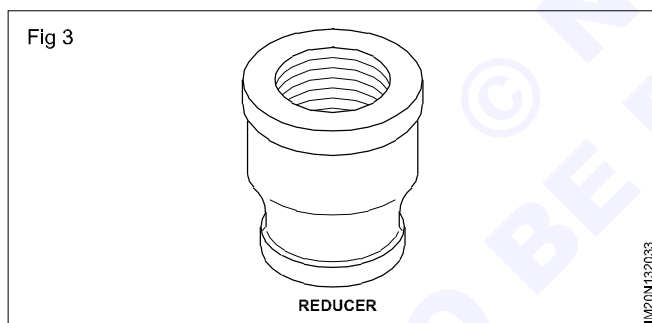
- 1 Coupling joints are used to join same diameter of pipes. Inner threaded portion of coupling is joined with outer threaded portion of the pipe. (Fig 1)



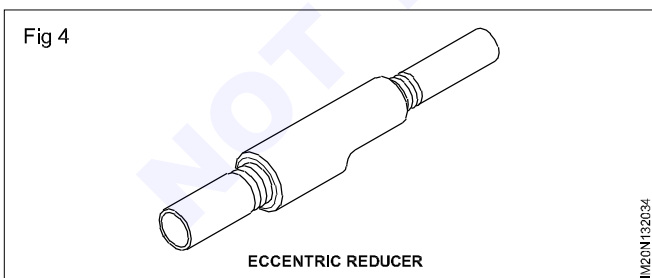
- 2 Union fittings can be inserted into the pipe line and can be tightened or loosened (Fig 2)



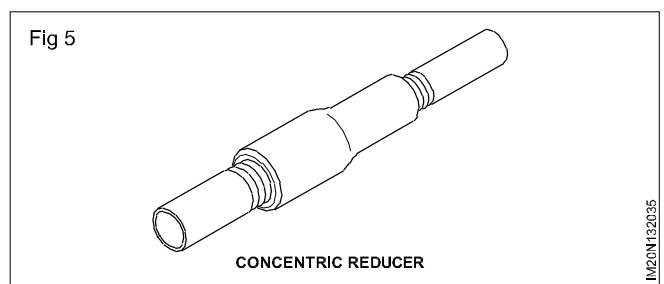
- 3 Reducer pipe fittings are used to join different size of pipes. (Fig 3)



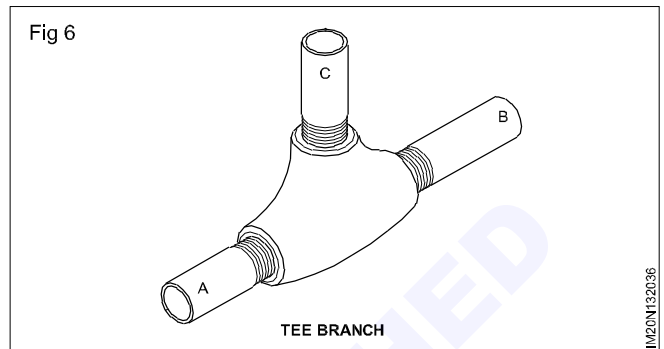
- 4 Eccentric reducer fitting are used to join different size of pipes on different axis. (Fig 4)



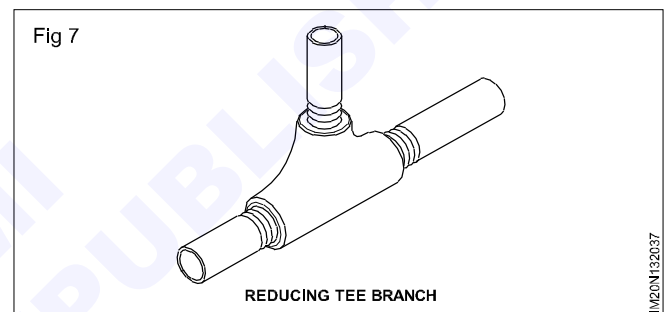
- 5 Concentric reducer fitting are used to join different size of pipes on same axis. (Fig 5)



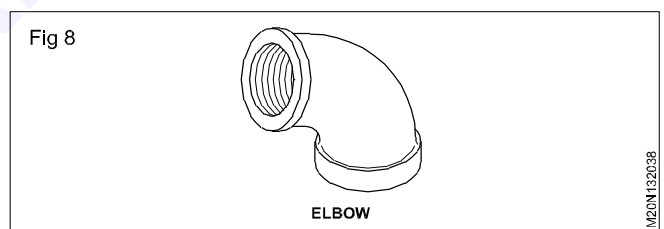
- 6 Tee branch types of fittings are used as shown in figure. Joint is done from main pipe to small pipe of same or different sizes. (Fig 6)



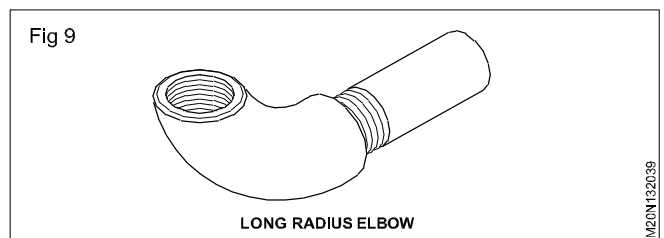
- 7 Reducing Tee branch is used to join small tubes from the main bigger size tube. (Fig 7)



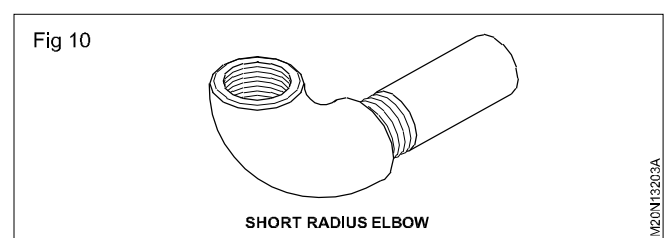
- 8 Elbow joints are used to change the direction of pipes to an angle of 45° or 90° (Fig 8)



- 9 Long radius elbow joints are having radius more than 1.5 times of the bore size of the pipe. (Fig 9)

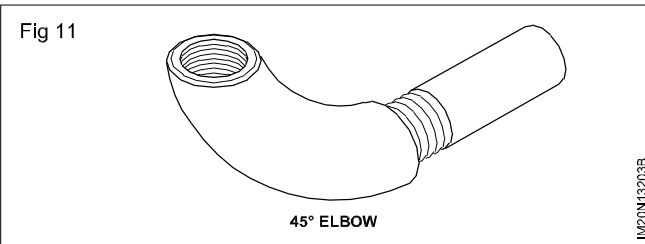


- 10 Short radius elbow joints are having radius same as the bore size of the pipe. (Fig 10)



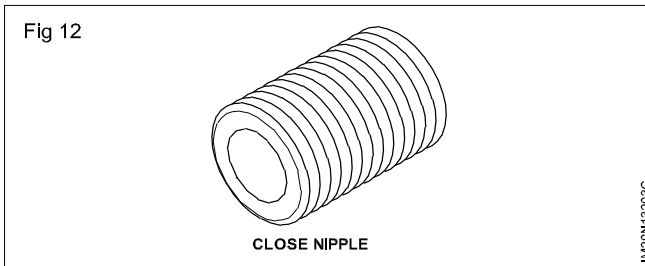


- 11 45 degree elbow joints are used to change the direction of pipe to 45 degree (Fig 11)

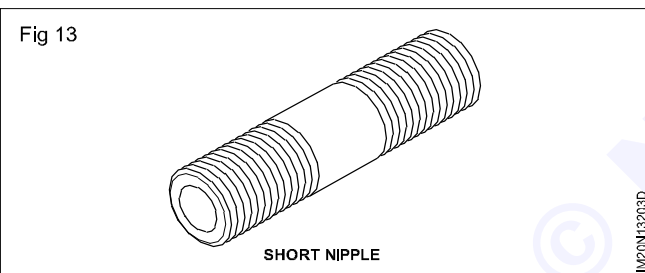


- 12 Pipe nipple fittings are used to join internal threaded pipes such as

- A Closed nipple fitting has thread to its full length and in small length (Fig 12)



- B Short nipple fitting has threads on its two ends and middle portion is plain (Fig 13)



**Cutting tools :** For cutting the pipes to the required length various tools are used. They are

- 1 Wheel pipe cutter and
- 2 Multi wheel chain pipe cutter.

**Wheel pipe cutter (Fig 14)** is used to press the walls of the pipe and cut the pipe to the desired length.



**Parts:** Wheel cutter, Guide roller and adjusting screws.

**Uses:** In air-condition works and to cut copper and brass pipes without any burr.

#### Method of using pipe cutter

- 1 Mark the portion to be cut on the pipe and hold it tightly on the pipe vice

- 2 Insert the pipe cutter at the marked portion. Now the cutter wheel should be aligned with the pipe marking. While keep on doing this the "V" shaped cutter wheel portion will make depth on pipe and the pipe will be cut in to two.

- 3 Excess metals while cutting will be left on the pipe and this can be removed by pipe reamer or by files.

#### Multi wheel chain pipe cutter (Fig 15)



**Use:** For large diameter pipe cutting it is used. Depending upon the diameter of the pipe more number of wheels and wings are utilized for cutting.

**Pipe bending :** Without using fittings the pipes can be bent to the desired direction and used. While bending the tubes care should be taken so that no scratch or dent is formed on tube. This can be achieved by two methods.

- 1 Pipe bending by hand and
- 2 Pipe bending by fixtures or machines.

#### Pipe bending by hand

Sand is filled in the pipe and heated to moderate temperature. Template can be drawn on the floor or on a wooden plank. Now wooden pieces were filled on one end of the pipe. Pipe is fixed in the vice rigidly. Heat the portion to be bent with a welding torch. Apply force on the other end of the tube to bend for the required shape in template

#### Pipe bending by Machine

##### Types:

#### 1 Portable hand operated pipe bender (Fig 16)

**Parts :** Tripod stand, pipe stop lever, handle or lever and inside former.



This type of pipe bender has three legs. Semicircular inside former is fixed according to the outer diameter of the pipe.

#### 2 Bench type hand operated pipe bender (Fig 17)

**Parts:** Inner former, Lever or handle, Adjusting screws and Pipe guide.

Fig 17



**Use:** Used to bend pipes easily to the required shape without damaging the pipes. This pipe bender is used to bend GI Pipes.

### Hydraulic pipe bending machine

For bending the pipe without filling sand hydraulic pipe bending is used.

Pipes having diameter of 75mm can be bend by this machine.

By using inner formers pipes can be bend to our desired shapes.

**Pipe threading (Fig 18) :** Pipes are threaded to join with the fittings. Generally BSP type threads are used. Threading can be done by using die stock in lathe machine for external threads. For checking the thread formed thread plug gauge is used (Figs 19, 20 & 21)

Fig 18

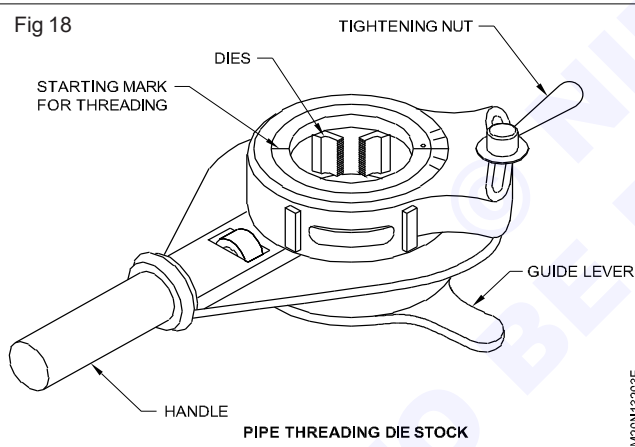
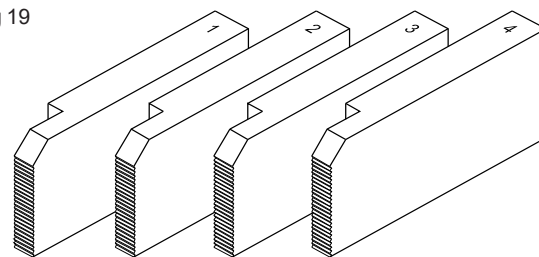


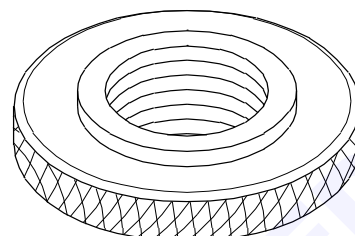
Fig 19



PIPE THREADING DIE SET

IM20N13203F

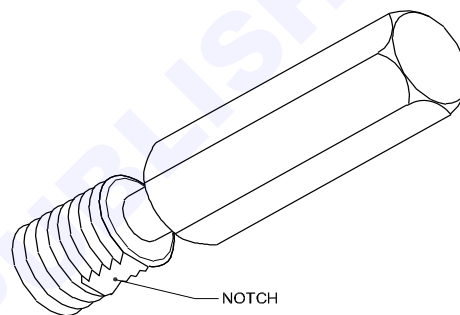
Fig 20



PIPE THREAD GAUGE

IM20N13203G

Fig 21



PLUG THREAD GAUGE

IM20N13203H

## Electricity and fundamental laws

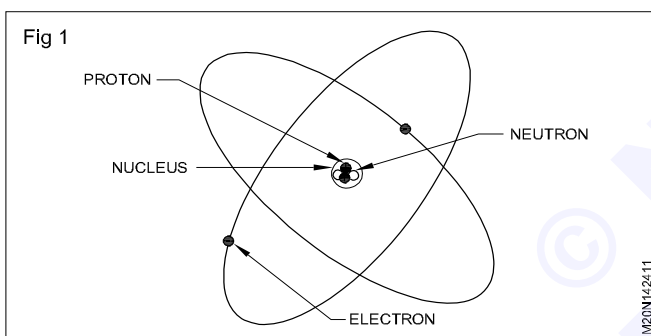
**Objectives:** At the end of this lesson you shall be able to

- explain electricity and its fundamental laws
- describe about conductors, semiconductors and insulators
- draw Electronics symbols
- differentiate AC and DC circuits.

Electricity is a form of energy. Without electricity, any machines or Electronics equipment cannot function. As per electronic theory, matter has weight and occupies some space. The three states of matter are solid, liquid and gaseous and are formed by molecules. The molecules were divided into sub particles called as atom.

The atom can be further divided into Neutrons, Electrons and Protons. The center nuclear portion of the atom consist of positively charged particles called Protons and Neutrons. Neutrons have no charge. Around the nucleus negatively charged particles revolve in fixed orbits known as electrons.

This structure is called as Atomic structure. Number of protons and electrons are equal. Refer Fig 1.



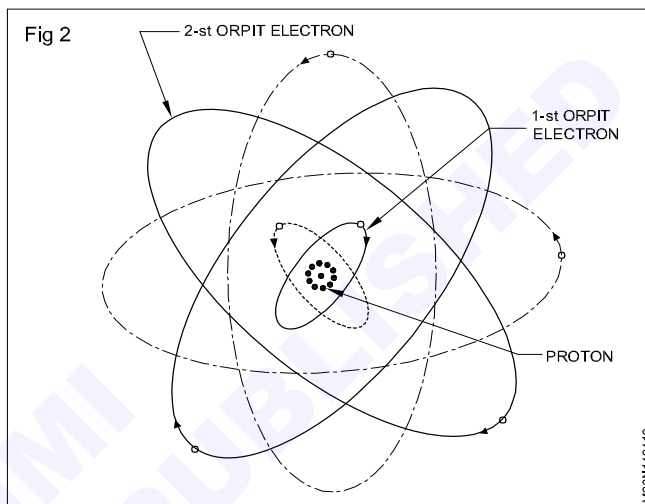
**Atomic structure (Fig 2):** Electrons the negatively charged particles revolves around the nucleus at fixed orbits called as shells. These are denoted by K, L, M, N, O and P letters. The number of electrons in each shell can be found out by simple formula  $2n^2$  where "n" is the number of shell. Thus in first shell it will be  $2 \times 1^2 = 2$ . In the second shell,  $2 \times 2^2 = 8$  and so on, The negative charged electrons have attractive force with positive charged protons so as to revolve around the nucleus. The electrons revolving in its final shell or orbit will have less attractive force with the nucleus. These electrons in the final orbits were called free or valance electrons.

By giving sufficient force on this free electrons this can be dislodged from its orbit and fly away to the next atoms final orbit. This chain action of movement of electron is called as electric current.

**Conductor :** In a material where the conduction of free electrons in outer orbit happens freely then that material is called as conductor. In metals where the number of free electrons in the outer shell is one, two or three then it is a good conductor. For example the good conductors are copper, aluminum, silver, gold, zinc, lead etc.

**Insulators :** In the atomic structure of elements where the number of electrons in the outer orbits have 5, 6, or 7 then

that elements are called insulator. For example insulators are glass, rubber, mica, plastic, PVC etc.



**Semi conductors :** Semiconductor elements will have four free electrons in its outer shell. Semiconductors will have the properties of both conductor and insulator. Example silicon and germanium.

**Current :** The movement of electrons in an Electronics circuit is known as current.

Symbol of current: I

Unit of current: A (Ampere)

Measuring device: Ammeter

Connecting method of Ammeter in a circuit; In series

**Ampere :** The electron movement in one minute through a conductor or the quantity of current passes through a conductor of one ohm resistance and one volt EMF is called ampere.

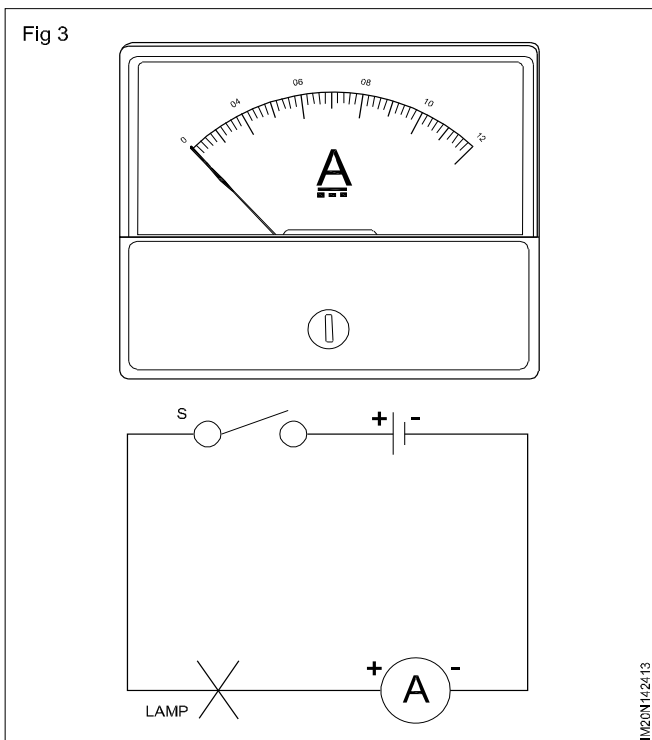
**Ammetre (Fig 3) :** An instrument to measure the current in a circuit is called an Ammeter. This has to be connected in series of a an Electronics circuit.

$1 \text{ KA} = 1000 \text{ Amps} = 1 \times 10^3 \text{ A}$ .

$1 \text{ milli Ampere} = 1 \text{ mA} = 1/1000 = 1 \times 10^{-3} \text{ A}$

**Electro Motive Force (EMF) :** The force required to move electrons from one end to other end in a circuit is called Electro motive force. It is deonted by the symbol ' E ' and the unit ' V ' (Volt). EMF can't be measured directly but can be calculated by the formula  $\text{EMF} = V_t + IR$ .

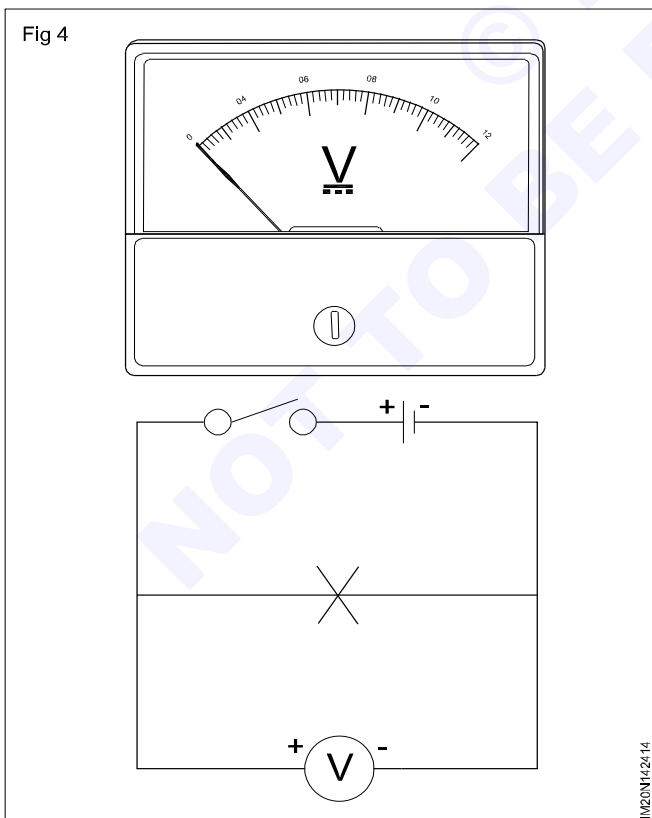
**Potential difference :** The difference of Electronics pressure between two points in an Electronics circuit is



known as potential difference. This value is less than electro motive force. The symbol is 'V' unit of measurement is in Volts. The measuring instrument is voltmeter which should be always connected in parallel to the circuit.

**Voltmeter (Fig 4) :** The connection of voltmeter is shown in the figure.

$$1KV = 1000V = 1 \times 10^3 V$$



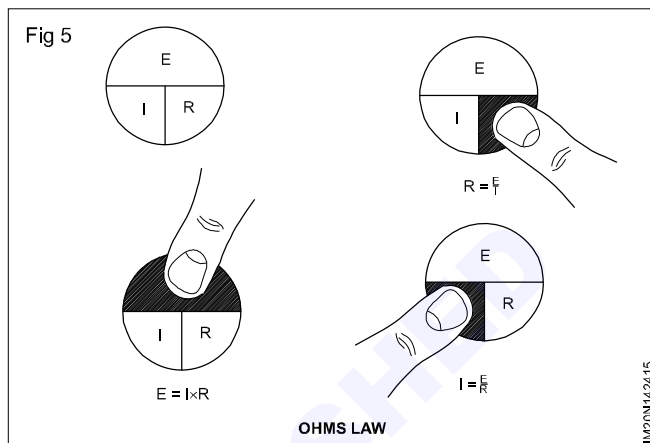
$$1 \text{ milli volt} = 1 / 1000 = 1 \times 10^{-3}$$

$$1 \text{ micro volt} = 1 / 1000000 = 1 \times 10^{-6}.$$

**Resistance :** In an Electronics circuit the resistance required to for one ampere of current with one volt potential difference is one resistance of unit ohm.

**OHMS Law :** In a closed DC circuit of constant temperature the current is directly proportional to the voltage and inversely proportional to the resistance. (Fig 5)

$$I = E / R, E = I \times R \text{ and } R = E / I.$$



### Work, power, force and energy

**Work :** Is the force required to move an object in its direction and said work being done.

$$\text{Work} = \text{Force} \times \text{Distance moved}, W = F \times S$$

Work is measured in unit of Joules or Newton meter.

**Joule :** If one Newton force is acted on an object to move a distance of one meter then the work done is one joule

$$1 \text{ joule} = 1 \text{ NM} = 10^7 \text{ ergs. } 9.8 \text{ joules} = 1 \text{ M Kg}$$

Newton is the scientist who discovered gravitational force.

**SUM :** Calculate the work to be done if 50 Newton force is applies to move an object to a distance of 500 millimeter. p

$W = F \times S$  where F is the force S is the distance moved and W is the work done

So  $W = 50 \times 500 = 25000 \text{ Newton millimeter. } 1000 \text{ Newton milli meter} = 1 \text{ Newton M which is } 25000 / 1000 = 25 \text{ N M or } 25 \text{ joules.}$

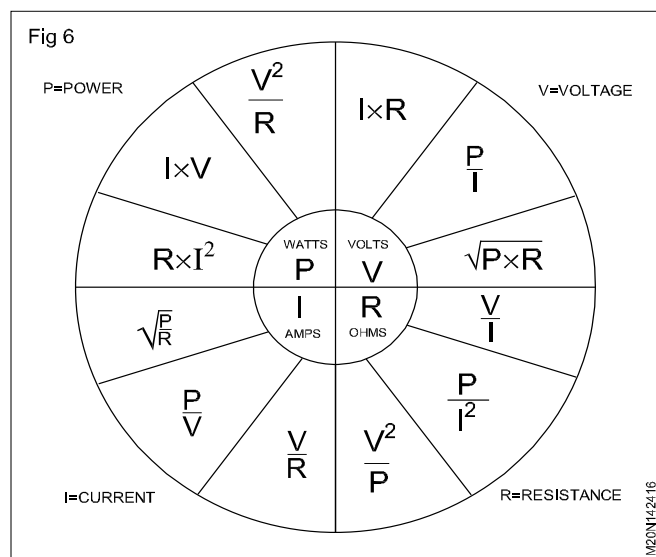
**Power (Fig 6) :** Power is the quantity of work done in one minute.

$P = W / T$  where P is the power, W is the work done and T is the time taken. Hence one Joule work done in one minute is denoted by letter P. In an Electronics circuit if one amp is applied between two points of 1 volt potential difference then the power consumed in the circuit is 1 watt. Power (P) = Voltage(V) X Current (I) or in short  $P = V \times I$ .

**Horse power :** The power consumed by any Electronics machinery is specified in unit horse power or HP Thus 1 HP = 746 Watts or 0.746 KW.

**Efficiency :** The ratio between the output power to the

input power is called efficiency. Percentage efficiency can be expressed as (output power / input power) x 100.



**Energy :** Energy is defined as the power consumed in a load in one hour. Energy is measured in the unit of Kilo watt hour KWH. ENERGY = POWER X TIME.  $E = P \times T$ .

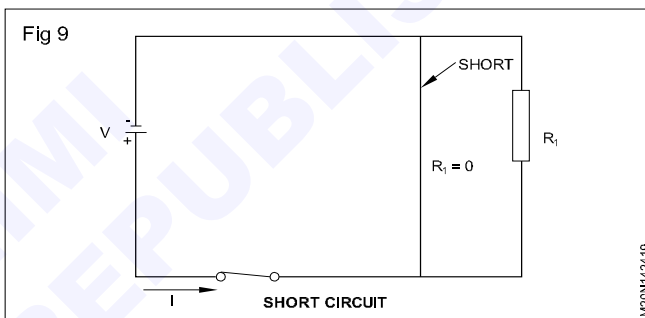
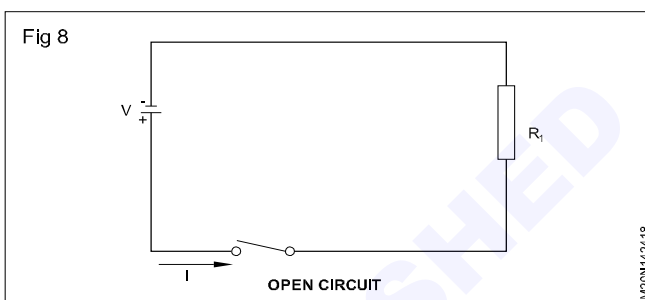
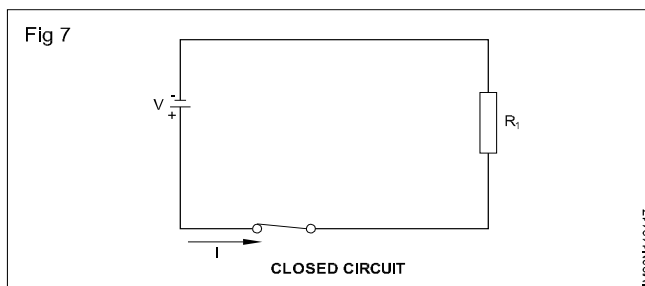
**Electronics circuit :** It is the path for circulating Electronics current. An Electronics circuit includes a source for power such as battery or generator, resistors, inductors, capacitors, diodes and switching transistors.

**Closed circuit (Fig 7) :** As shown in the figure a closed circuit is a one where the current flow completes without interruption.

**Open circuit (Fig 8) :** As in figure if the switch is in OFF position or the load is disconnected or there is discontinuity in the conductor then the circuit is in open condition.

**Short circuit (Fig 9):** It is a connection established in an Electronics circuit so that the current flows in an unplanned

or accidental path. Example a storm damaging a power line and cutting off electricity. Short circuit usually takes place when live wire touches ground.



As shown in figure the two ends of supply is connected before the load and short circuit occurs.

| Sl. No | Alternative current (AC)                                 | Direct current (DC)                                                   |
|--------|----------------------------------------------------------|-----------------------------------------------------------------------|
| 1      | AC Circuit has no polarity. Frequency is 50 or 60Hz      | DC circuit has polarity of +ve and -ve. The frequency is always zero. |
| 2      | Voltage can be stepped up or down by using transformers. | Voltage cannot be varied.                                             |
| 3      | Transmission cost is less.                               | Transmission cost is high.                                            |
| 4      | Maintenance expense is less.                             | Maintenance expense is high.                                          |
| 5      | Power factor ranging from zero to unity.                 | Power factor is always unity.                                         |
| 6      | AC supply has been generated by generators               | DC supply has been generated by batteries.                            |

**Conductors :** Materials having low resistance to current flow is called conductors. Example: Silver, copper, aluminum etc.

Character of a good conductor.

- 1 Less specific resistance
- 2 Capacity to have good conductivity
- 3 Should not be affected by heat for conductivity
- 4 Should have good strength

- 5 Capable of having the property to join or solder.
- 6 Should have good ductility to draw wires of long length

#### Types of conductors and their properties

- 1 **Silver :** Silver has less specific resistance and good conductivity of 98%. Since the cost of the metal is high it is mainly used in Electronics instrument starters and the contact tip of relays.



- 2 **Copper:** Copper has a good conductivity of electricity. Long wires can be drawn and flattened to a sheet. Simple connection can be made. It is rust free having a long life. Used in armature, field winding, instrument coils.
- 3 **Aluminum:** Aluminum has less weight and can be drawn into lengthy wires and can be flattened into

sheets. Having conductivity of 60%. Care should be taken while using aluminum wires. Widely used in underground cables, overhead lines and industrial motor connection.

#### Comparison of copper and aluminium

| Sl.No. | Property      | Copper                    | Aluminium                 |
|--------|---------------|---------------------------|---------------------------|
| 1      | Density       | 8.93 Kg / cm <sup>3</sup> | 2.75 Kg / cm <sup>3</sup> |
| 2      | Colour        | Reddish brown             | White                     |
| 3      | Stress        | 220 Nm /mm <sup>2</sup>   | 70 Nm /mm <sup>2</sup>    |
| 4      | Conductivity  | 50 ohms /m                | 5 ohms / meter            |
| 5      | Melting point | 1083°C                    | 66°C                      |

#### Types of conductors

- 1 Bare conductor
- 2 Insulated conductor
- 3 Solid conductor and
- 4 Standard conductor

**Bare conductor:** It has no insulation over the surface. Mainly used in earthing, overhead transmission lines.

**Insulated conductor:** As the names implies there is insulating material over the surface. Nonconductive material resistant to the electric current surround the cable inside forms protection against weather and short circuits,

**Solid conductors:** Solid conductor consist of solid center heavier core metal. It is used for outdoor use where more durability and higher current carrying capacity is required.

**Stranded conductors:** These are thin, bundled wires are compressed and insulated with bon conductive outer layer. Stranded wire is more flexible. Making it ideal for connecting electronic components on a board.

**Insulator :** An electric insulator is a material in which electric current does not flow. The atoms of the insulator having electrons tightly bound which cannot move easily. It has two main properties of die-electric strength and insulation property.

**Die electric strength :** The die-electric strength of an insulating material is its Electronics strength. Under the strong electric field the insulating properties of an insulator breakdown allowing flow of charge. Its unit is KW /mm. Die-electric voltage is the voltage under which the insulator breaks down its insulating property.

**Insulation resistance :** The alternating current resistance between two Electronics conductors or two system of conductors separated by an insulating medium. The insulation resistance is measured by Megger, Ohm meter and Insulation tester.

#### Properties of insulator

- 1 Specific resistance is more.
- 2 Easily flexible in nature
- 3 More die-electric strength
- 4 Easily melting quality
- 5 More mechanical strength
- 6 Withstand heat
- 7 Water resistance and
- 8 Not affected by ambient temperature.

#### Types of insulators and its uses

**Mica:** Mica has more die-electric strength and specific resistance. Resist high temperature and normally used in electric iron box, and commutator as insulator. **Asbestos:** Asbestos are resistant to heat, fire, chemical and biological degradation. Asbestos has more die-electric strength. It is available in the form of sleeve, tape, rope, and circular shape. Asbestos were used in circuit breakers and Electronics iron box.

**Poly vinyl chloride (PVC):** PVC is less rigid, high impact strength, can easily extruded and moulded and has lower temperature resistance. Used as insulating sheath around wires and cables.

**Glass:** It is transparent and resist high temperature. Used in electric bulbs, tube lights and mercury arc rectifier.

**Rubber:** Pure rubber is soft in nature. It is water resilient and resistant to alkalis and acids. Hard rubber can be manufactured by mixing sulphur, zinc oxide and red lead. Used as an insulator in Electronics supply.

**Wires :** Solid conductors which has uniform diameter and circular cross section and withstand pulling force are called Electronics wire.

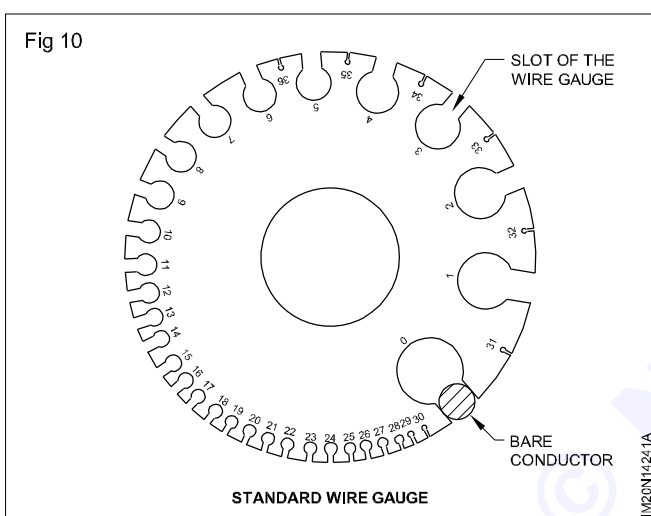
**Cable :** It is an assembly of one or more Electronics conductor held together with an overall insulating sheath.



## Standard wire gauge

**Measurement of cable:** Cables are denoted by their gauge numbers. Diameter of the cable is measured by micrometer. The cross sectional area is calculated by diameter of the wire.

Standard wire gauge is used to measure the thickness of electric wire. The gauge is made of steel. A circular steel plate having slots on its circumference. Each hole slot corresponds to a gauge number which is written below the slot. The gauge number specifies the diameter and cross sectional area of the wire. The slot size around the gauge varies from 0.0076" to 0.324" (0.19mm to 8.23mm). The largest slot will have the number zero inscribed below it. The number below the slot goes from zero to 36. For example if we want to know the gauge of the wire, it is inserted into the slot correctly fitted and the numerical value below the slot denotes the gauge of the wire. (Fig 1)



7/2.24 gauge means it is a seven strand wire and each strand's diameter equal to 2.24mm and cross sectional area is 4mm<sup>2</sup>. Total cross sectional area of seven strands are 25mm<sup>2</sup>.

The table below shows the gauge number for which the size in inch and cross sectional area in mm<sup>2</sup> is mentioned. In the other table the multi strand wire cross sectional area of copper and aluminum wire for which the current carrying capacity is denoted.

| SWG No. | mm   | inch  |    |      |       |
|---------|------|-------|----|------|-------|
| 0       | 8.23 | 0.324 | 10 | 3.25 | 0.128 |
| 1       | 7.62 | 0.300 | 11 | 2.95 | 0.116 |
| 2       | 7.01 | 0.276 | 12 | 2.64 | 0.104 |
| 3       | 6.40 | 0.252 | 13 | 2.34 | 0.092 |
| 4       | 5.89 | 0.234 | 14 | 2.03 | 0.080 |
| 5       | 5.38 | 0.212 | 15 | 1.83 | 0.072 |
| 6       | 4.88 | 0.192 | 16 | 1.63 | 0.064 |
| 7       | 4.47 | 0.176 | 17 | 1.42 | 0.056 |
| 8       | 4.06 | 0.160 | 18 | 1.22 | 0.048 |
| 9       | 3.66 | 0.144 | 19 | 1.02 | 0.040 |
|         |      |       | 20 | 0.91 | 0.036 |

|    |      |        |    |      |        |
|----|------|--------|----|------|--------|
| 21 | 0.81 | 0.032  | 31 | 0.29 | 0.0116 |
| 22 | 0.71 | 0.028  | 32 | 0.27 | 0.0108 |
| 23 | 0.61 | 0.024  | 33 | 0.25 | 0.0100 |
| 24 | 0.56 | 0.022  | 34 | 0.23 | 0.0092 |
| 25 | 0.51 | 0.020  | 35 | 0.21 | 0.0084 |
| 26 | 0.46 | 0.018  | 36 | 0.19 | 0.0076 |
| 27 | 0.42 | 0.0164 | 37 | 0.17 | 0.0068 |
| 28 | 0.38 | 0.0148 | 38 | 0.15 | 0.0060 |
| 29 | 0.34 | 0.0136 | 39 | 0.13 | 0.0052 |
| 30 | 0.31 | 0.0124 | 40 | 0.12 | 0.0048 |

**Earthing :** In Electronics wiring work safety from electrocution should be important. For this Earthing plays an important role. An electrode is buried under the earth to a depth of 2.5 meters. An attached conductor from the electrode is taken which is having zero volt.

### Purpose of earthing

- 1 When leakage of current from machinery and Electronics apparatus happens, it is dangerous to touch them by human and other living things. Earthing protect this.
- 2 When thunder and lightning struck during rainy seasons, large amount of Electronics discharge pass through tall buildings and transmission line earthing wire conduct this discharge to the ground.
- 3 To maintain a stabilized line voltage earthing should be done.

The metal parts of the Electronics appliances should be properly earthed. This will ensure the leakage current to pass through low resistance earth wire to the ground. Further the protective fuse in the supply will melt and isolate the circuit from main power source. When earthing is done properly in a machine and if the leakage current passes through the human body it reaches the earth. The amount of leakage current a human body can withstand is 5 mA only and above this level it will be fatal.

### Type of earthing

- 1 **System earthing :** In order to safe guard the Electronics system, a good earthing is provided to ensure the potential of each conductor restrict to its desired value for insulation. System earthing should be done in Generating station and Sub stations.
- 2 **Equipment earthing :** As the name suggest the metal portion of the equipment should be connected to earth a conductor. This will safe guard the equipment and persons working on it.

#### Note:

- 1 The earthing wire should of large diameter, less resistance and at zero volt.
- 2 Greenish yellow insulation sleeve over the earthing conductor is used. The earthing tube should be painted in orange color.

**Good earthing :** The conductor which has less resistance and conduct large leakage current should be used in a good earthing system. The value of the earth resistance is 3 ohms, on a rocky place it should be 8 ohms. In a good earthing the conductor resistance should be one ohm.

### Terminology

- 1 Earth:** The earth electrode is connected with the earth is called earthing and if any objects connected to the earth electrode then these objects are termed as earthed.
- 2 Earth electrode:** The metal plates and pipes connected to the mass of the earth is called earth electrode.
- 3 Earth continuity conductor:** The conductor which join the earth electrode and the metal parts of the appliances is termed as earth continuity conductor.

| Size of the earthing conductor (ECC) |                                                                |
|--------------------------------------|----------------------------------------------------------------|
| Smallest value                       | For copper 1.5mm <sup>2</sup> and aluminium 2.5mm <sup>2</sup> |
| Largest value                        | For copper 70mm <sup>2</sup> and aluminium 120mm <sup>2</sup>  |

In an Electronics circuit if the value of the current equals to 15,20,30 and 60 Amps then the ECC copper conductor should have 14,12,10 and 8 SWG.

- 4 Earth current:** The value of the earth leakage current is known as earth current.
- 5 Earth fault:** When an Electronics conductor by accident get in touch with the ground then the fault occurs in the system is termed as Earth fault.
- 6 Earth terminal:** In Electronics appliances terminal will be provided to join the earth wire.
- 7 Fault current:** Due to defective insulation in conductors current will pass adjacent to the conductors or from conductor to earth is termed as Fault current .
- 8 Leakage:** Due to low insulation of the conductor the current will flow to other places
- 9 Leakage current:** Due to low insulation or short circuit low fault current flow is called leakage current.
- 10 Live:** Between an object and earth if potential difference exist then current will flow .

### Electronics symbols

|   |                          |                                                                                     |
|---|--------------------------|-------------------------------------------------------------------------------------|
| 1 | AC (Alternating current) |  |
| 2 | DC (Direct current)      |  |
| 3 | Positive                 |  |
| 4 | Negative                 |  |

**11 Functional insulation:** The insulation required for function of the Electronics appliances and basic safety against shock is known as functional insulation.

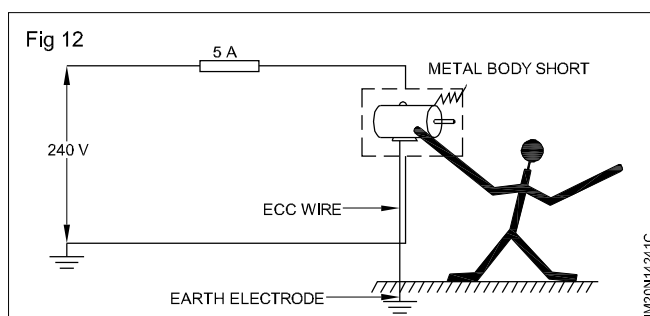
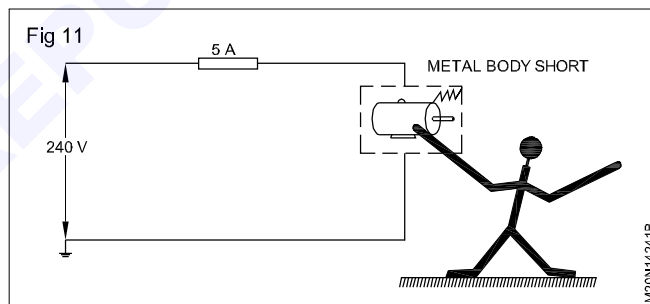
**12 Reinforced insulation:** Like functional insulation, reinforced insulation will have more doubled insulation and safety.

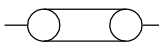
On touching the metal portion of an appliance which is not earthed. (Fig 7)

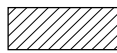
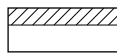
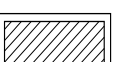
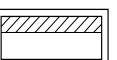
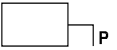
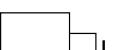
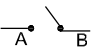
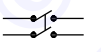
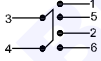
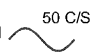
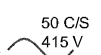
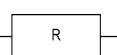
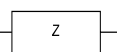
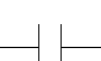
As shown in figure when the insulation of the wire in an appliance breakdown, the live wire will get in touch with the metal body. When 240V supply exist and the metal part having 800 ohms resistive value and when one touches it he will get 240milliamp or 0.3Amp resulting electrocution. It should be noted that the rating of fuse is 5A which is not sufficient to blow by 300milli amp current.

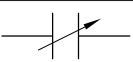
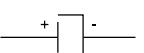
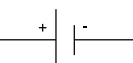
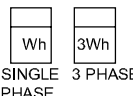
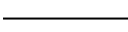
On touching the metal portion of an appliance which is earthed. (Fig 8)

As shown in the figure the metal portion of the appliance get in touch with the live wire, then large amount of leakage current will flow to earth. For example the total resistance in series of metal portion of appliance, main cable, ECC wire and earth mass will be 8 ohms. The applied voltage is 240V and the leakage current will be 30Amps. With 5Amp fuse installed this 30Amp current will be six time higher and will blow the fuse. For this reason the person will be safe from shock in an earthed system.



|   |                           |                                                                                       |
|---|---------------------------|---------------------------------------------------------------------------------------|
| 5 | Neutral                   | <b>N</b>                                                                              |
| 6 | Phase                     | <b>L</b>                                                                              |
| 7 | Neutral link              |  |
| 8 | Main board without switch |  |

|    |                                        |                                                                                     |
|----|----------------------------------------|-------------------------------------------------------------------------------------|
| 9  | Main board with switch                 |    |
| 10 | Distribution board without switch      |    |
| 11 | Distribution board with switch         |    |
| 12 | Main fuse board without switch         |    |
| 13 | Main fuse board with switch            |    |
| 14 | Distribution fuse board without switch |    |
| 15 | Distribution fuse board with switch    |    |
| 16 | Main switch (Power)                    |    |
| 17 | Main switch (lighting)                 |    |
| 18 | Single pole single throw switch (SPST) |  |
| 19 | Single pole double throw switch (SPDT) |  |
| 20 | Double pole single throw switch (DPST) |  |
| 21 | Double pole double throw switch (DPDT) |  |
| 22 | Two way switch                         |  |
| 23 | Single phase 50HZ alternating current  |  |
| 24 | Three phase 50HZ alternating current   |  |
| 25 | Resistor                               |  |
| 26 | Impedence                              |  |
| 27 | Inductor                               |  |
| 28 | Capacitor                              |  |

|    |                                       |                                                                                       |
|----|---------------------------------------|---------------------------------------------------------------------------------------|
| 29 | Variable capacitor                    |    |
| 30 | Electrolytic capacitor                |    |
| 31 | Cell                                  |    |
| 32 | Battery                               |    |
| 33 | Ammeter AC,DC,AC/DC                   |    |
| 34 | Voltmeter AC,DC,AC/DC                 |    |
| 35 | Watt meter                            |    |
| 36 | Ohm meter                             |    |
| 37 | Multi meter                           |    |
| 38 | Phase indicator meter                 |   |
| 39 | Power factor meter                    |  |
| 40 | Frequency meter                       |  |
| 41 | Galvano meter                         |  |
| 42 | Energy meter                          |  |
| 43 | Generator, DC generator, AC generator |  |
| 44 | Ceiling fan                           |  |
| 45 | Fuse                                  |  |
| 46 | Fuse with supply side indication      |  |
| 47 | Wiring                                |  |

|    |                          |  |
|----|--------------------------|--|
| 48 | Surface wiring           |  |
| 49 | Under surface wiring     |  |
| 50 | Surface conduit wiring   |  |
| 51 | Conduit concealed wiring |  |
| 52 | Earth                    |  |

|    |                  |  |
|----|------------------|--|
| 53 | Earth flare      |  |
| 54 | Earth test point |  |
| 55 | Main transformer |  |
| 56 | Auto transformer |  |

## Multi meter, resistor, soldering and desoldering

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

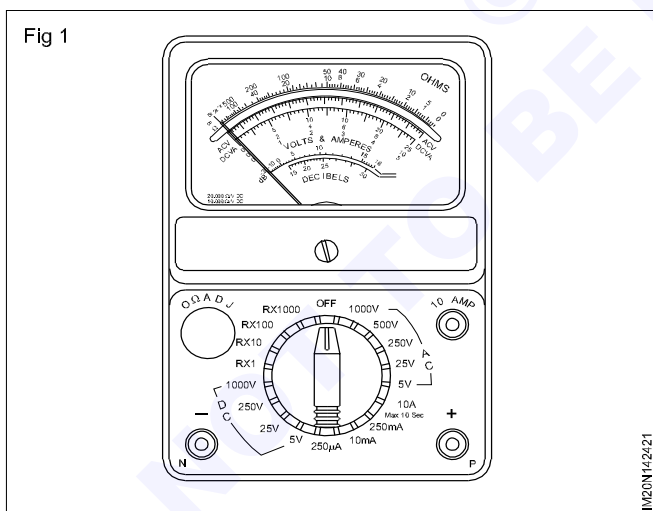
- explain the method of using multi meter
- explain to calculate resistance value by color code
- describe the method soldering and de-soldering and type of soldering iron.

### Multi meter

Multi meter is used to measure AC/DC current, voltage and value of resistors. This instrument is also called as VOM meter (Volt, ohm and milli ammeter).

### Types of multi meter

#### 1 Analogue Multi meter (Fig 1)



- These are old ordinary type of multi meter.
- Two types of meter as selector type and multi plug type available.
- This meter has a moving arrangement and a pointer moves over a graduated scale of parameters like voltage, amps and ohmic value.
- While using in DC circuit polarity has to be checked.
- When measuring 1000V DC using separate jack the selector switch should be in 500V position. Use

separate jack for the measurement up to DC 10Amp with +10 and -10 jack.

- For measuring resistors the mode should be on DC.
- For the measurement of AC parameter, a rectified AC is given to the moving system. By using the rectifier the sensitivity in AC mode will be 5000 ohms / V
- Initially select the high range of measurement if we don't know the range.
- Step by step change the selector range to measure the exact parameter.
- The tolerance in reading will be 3% if the pointer is in extreme position, 6% when the pointer is at middle portion and 12% when the pointer is at 1/4 portion of scale. So it is very important to select the range.
- For all DC measurements give supply after connecting the leads. Similarly leads should be taken out after the supply is disconnected.
- For measuring electrolytic capacitor discharge the capacitor before measuring.
- Zero adjustment should be done by shorting the leads.

### Use of Multi meter

- To check the continuity of circuit and the apparatus connected.
- To check the supply availability at the source and its value.
- To check the continuity of measuring instruments, its resistance & voltage.
- To measure the value of current

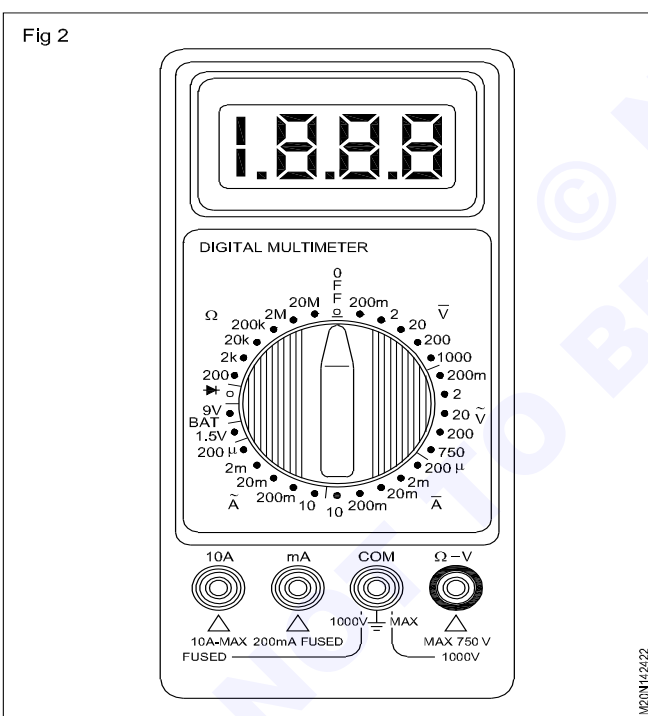
- 5 Checking the Electronics appliances resistive power.
- 6 To check the capacitors, resistors, diodes and Transistors.

#### Precaution to be taken while using Multi meter

- 1 While on supply never use resistors for measurement.
- 2 While measuring the current never use the test lead in parallel to supply.
- 3 Don't use more than the selected range.
- 4 If the test leads were damaged in insulation then use new leads.
- 5 After the testing is over remove the red lead first and then the black lead.

**2 Electronic Multi meter (Digital type):** Active and passive components are there in the circuit. Available in the range of a) Selector switch type b) Auto ranging type and c) LCD

**Digital multimeter (Fig 2) :** The display used in this meter is either LCD (Liquid crystal display) or LED (Light emitting diode). Display is by four digit with a decimal point. When measuring DC polarity symbol is there on left side of the digit. Seven segment display feature is made in both LCD and LED. Last three digit will be from 0 to 9 and first digit 1 only.



| Digit | Segment | Digit | Segment |
|-------|---------|-------|---------|
| 1     | BC      | 6     | FGCD    |
| 2     | ABGED   | 7     | ABC     |
| 3     | ABGCD   | 8     | ABCDEFG |
| 4     | FGBC    | 9     | ABGFC   |
| 5     | AFGCD   | 0     | ABCDEF  |

0.999 will be shown as .999. For 0.001 increase will show as 1.000. Similarly from 1.999 an increase of 0.001 will

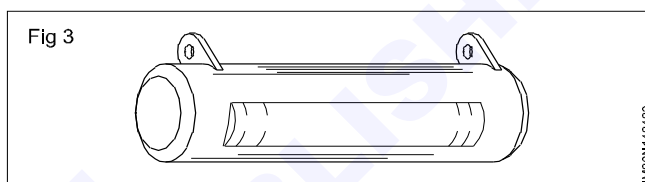
show as 2.00 of 3 digit only. All the seven segments will be connected to a supply.

**Resistors :** These are passive components in a circuit. Manufactured in specific values. Used to limit the current and to have voltage drop in the circuit. These are from 0.1 watts to hundreds of watts power resistors in use.

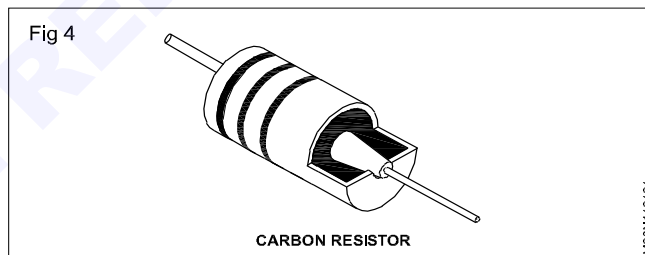
#### Type of resistors

- a Wire wound resistors    b Carbon resistors
- c Metal film resistors    d Carbon film resistors

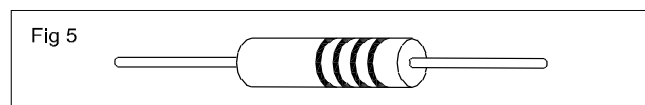
**1 Wire wound Resistor (Fig 3):** In wire wound resistor compressed insulating paper of ceramic, porcelain or Bakelite will be used. Nicrome wires were wound on the ceramic former. Normally these are from 1 watt to more than 100 watts. The resistive value will be from 1 ohm to several thousand ohms. In this type of resistors when more than the specified current passes then the wire will break down resulting open circuit.



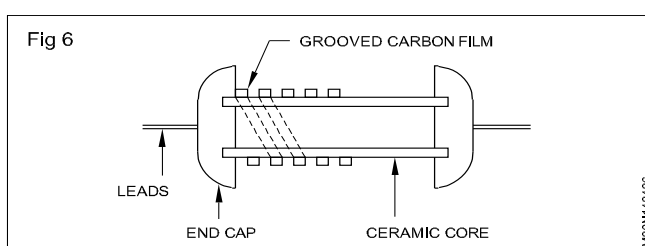
**2 Carbon resistor (Fig 4) :** These carbon resistors were made of pure carbon or mixture of carbon. These resistors will have leads on both ends as shown in fig. These type of resistors are having 1 ohm to 22 mega ohms and power capacity as 0.1 to 2 watts.



**3 Metal film resistor (Fig 5):** These resistors are manufactured by slim to fat films. From 1 ohm to 10 mega ohm capacity is available. Power is only 1 watt. Temperature ranging 120°C to 175 °C will withstand in this type. PTC and NTC resistors were used for switching purpose on specified temperature.



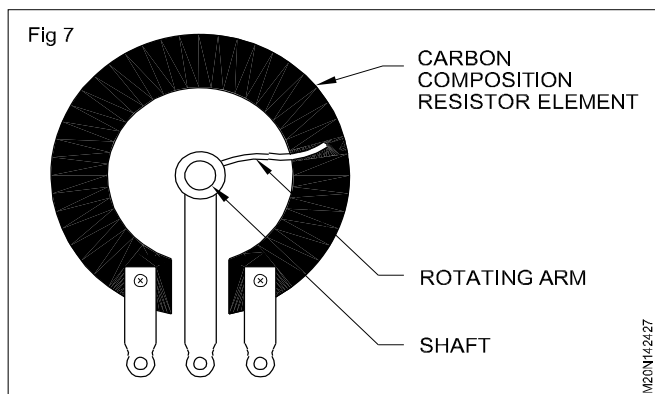
**4 Carbon film resistor (Fig 6):** On a ceramic tube thin layer of carbon is deposited. It will withstand 85 to 155 °C. Available from 1 ohm to 1 mega ohm range. Power dissipation is only 1 watt.





## Classification of resistor with their function

- Fixed resistors** : The value of resistance is fixed.
- Variable resistors (Fig 7)**: The value of the resistance can be varied. The sliding contact will determine the value of the resistor and can be varied. Another rotary type is also available to vary the resistance value.



**Resistor color coding (Fig 8)** : Since the resistor is small in size we can't print the value on the surface. For this color coding is employed. There are 4/5/6 color band rings over the surface. Each color represent a particular value (as given in the chart). Through this we can find the value of the resistor.

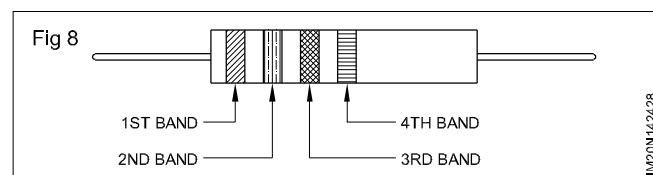


Figure shows four color bands. First two color bands represent the first two digit of the value. Third digit is its multiplier. That is the first two digits should be multiplied with the third band multiplier. Fourth band is for the tolerance to the value. For example in Fig 8 the color bands are red, green, orange and gold and the value is determined as below.

|          | 4 band         | 5 band         | 6 band                  |
|----------|----------------|----------------|-------------------------|
| 1st band | 1st digit      | 1st digit      | 1st digit               |
| 2nd band | 2nd digit      | 2nd digit      | 2nd digit               |
| 3rd band | multiplier     | 3rd digit      | 3rd digit               |
| 4th band | tolerance      | multiplier     | multiplier              |
| 5th band | Not applicable | tolerance      | tolerance               |
| 6th band | Not applicable | Not applicable | Temperature coefficient |

|             |                    |                    |                |
|-------------|--------------------|--------------------|----------------|
| First color | Second color green | Third color Orange | Fourth Gold    |
| Red 2       | Green 5            | Orange 1000        | Gold $\pm 5\%$ |

The value of resistor is  $2 \times 5 \times 1000 = 25000$  ohms. Tolerance is  $\pm 5\%$  then the value is in between 23750 ohms to 26250 ohms. For large value of resistance Kilo or Mega were prefixed. Some resistors will have shortened print as below

1K=1000 ohms, 1K6=1600 ohms, 0.1K=100 ohms, 0.1M=10000 Ohms and 1M5 is 1500000 ohms. For tolerance J  $\pm 5\%$ , K  $\pm 10\%$  and L  $\pm 20\%$  .

**Color chart table (For four band resistor)**

| Color  | 1st band/dot<br>1st digit | 2nd band/dot<br>2nd digit | 3rd band/dot<br>Multiplier | 4th band/dot<br>Tolerance |
|--------|---------------------------|---------------------------|----------------------------|---------------------------|
| Black  | -----                     | 0                         | 1                          | -----                     |
| Brown  | 1                         | 1                         | $10^1$                     | $\pm 1\%$                 |
| Red    | 2                         | 2                         | $10^2$                     | $\pm 2\%$                 |
| Orange | 3                         | 3                         | $10^3$                     | $\pm 3\%$                 |
| Yellow | 4                         | 4                         | 10 to power 4              | $\pm 4\%$                 |
| Green  | 5                         | 5                         | 10 to power 5              | $\pm 5\%$                 |
| Blue   | 6                         | 6                         | 10 to power 6              | -----                     |
| Violet | 7                         | 7                         | 10 to power 7              | -----                     |
| Grey   | 8                         | 8                         | 10 to power 8              | -----                     |
| White  | 9                         | 9                         | 10 to power 9              | -----                     |
| Gold   | -----                     | -----                     | 10 to power-1              | $\pm 5\%$                 |
| Silver | -----                     | -----                     | 10 to power-2              | $\pm 10\%$                |
| None   | -----                     | -----                     | -----                      | $\pm 20\%$                |



# Soldering

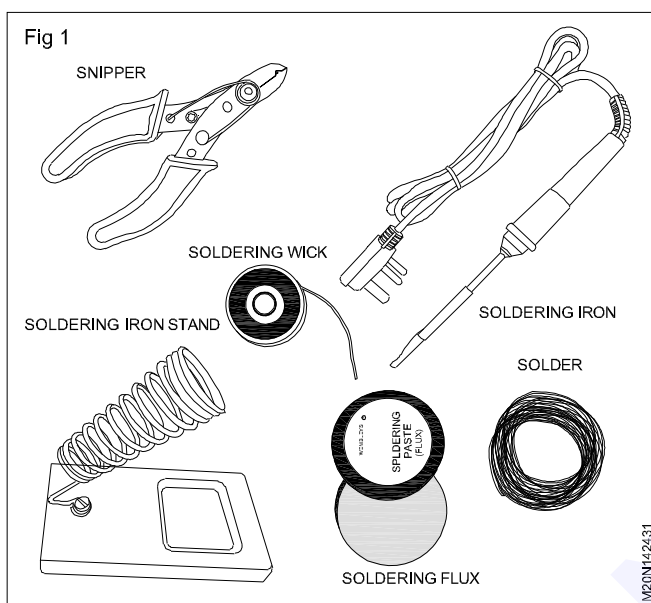
**Objectives:** At the end of this lesson you shall be able to

- explain about soldering .

**Soldering :** Soldering is a process used for joining metal parts to form a mechanical or Electronics bond. It uses a low melting point metal alloy which is melted and applied to the metal parts.

**Solder :** Tin and lead were used in different ratio to form an alloy.

## Soldering kit (Fig 1)



## Soldering procedure

- 1 Remove the insulation from the cable to be joined. Brush and clean the tip of the cables and prepare for the joint.
- 2 Brush a small amount of flux on the tip of the cables.
- 3 The surface of the cable should be brushed with flux till it is shining. Remove excess flux and wipe the surface with clean cloth.
- 4 Insert the tinned tip of the conductor to the lug and solder it.
- 5 Clean the lug surface with clean cloth.

## Safety and precaution while doing soldering

- 1 The element of the soldering iron should be carefully cleaned.
- 2 Before heating the solder flux should be applied.
- 3 Don't touch the element of the soldering iron while in use.
- 4 Turn the unit off after soldering or not in use.
- 5 Always put the soldering iron on its stand and never put this on work bench.
- 6 Avoid breathing fluoride fumes while soldering.

## Types of soldering

| Types               | Mix of metals       | Temperature       | Type of flux  | Metal to join                             |
|---------------------|---------------------|-------------------|---------------|-------------------------------------------|
| Tin Man             | Tin 50%<br>Lead 50% | 392°F or<br>200°C | Zinc chloride | Bronze, Copper,<br>iron and steel         |
| Electricians solder | Tin 60%<br>Lead 40% | 365°F or<br>185°C | Resin         | Tinning, soldering,<br>Electronics joints |
| Fine                | Tin 90%<br>Lead 10% | 426°F or<br>219°C | Tallow        | Tinning, Electronics<br>joints            |

**Necessity of Flux:** When the metals to be soldered heated in the surrounding air, a thin layer of oxides forms. To remove this oxides and to make the surface clean flux is used. The melting point of flux is lesser than solder. For different types of metal soldering different flux is available.

**Type of flux:** For copper and its alloy metals Resin flux is used. For aluminum metals aluminum flux or Eyre No 7 flux is used. For E-Mild steel zinc chloride flux is used. Diluted hydro chloride flux is used for G.I sheets.

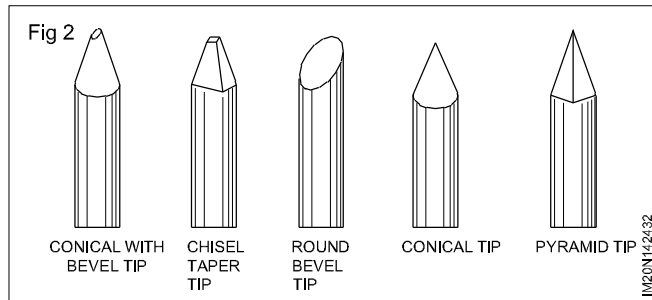
**Types of soldering iron :** We differential soldering iron for Electronics works and non-Electronics works. For non-Electronics iron soldering tip used for soldering. For soldering cable, pipe and automobile metal parts were heated with blow lamps and then soldered. In an Electronics iron the soldering bit heated by an element. This is classified as per voltage for light duty soldering iron (6, 12, 24, 50 and 110V) and 230V soldering iron.

Also classified under wattage use as light duty (5W to 20W) and medium duty soldering iron (200W to 2400W). High temperature sensitive components like diode, transistor and IC should be used for soldering by 5 to 25W soldering iron. Similarly for low temperature sensitive components like wire, resistor, inductor and capacitor can be soldered with 25 to 60 watts soldering iron. The bit portion of the soldering iron will be either screw or block type. These bits are made of either with copper or copper plated with iron. These bits are available in different shapes as shown in figure 2.

- 1 Round,
- 2 Round bevel,
- 3 Pyramid,
- 4 Conical with bevel tip
- 5 Chisel.

Component like resistor, inductor and capacitors were used with chisel tip iron. It is good to have the same width of component surface to the bit. If the length of the bit is

longer it is easy for soldering. Short tip will have low temperature on tip of bit. Long usage of the bit will undergo wear and tear. We have to file the tip of the bit. To avoid wear and tear of the tip should be cleaned with wire brush and placed on sponge pad.



**Tinning :** The technique of making a thin layer of solder over the surface or dipping method is known as tinning.

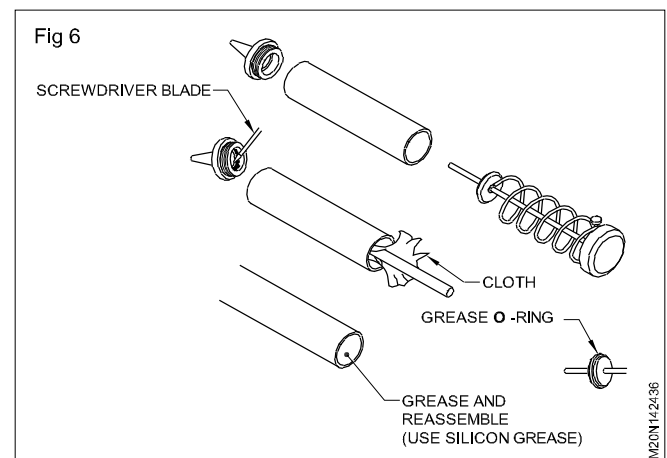
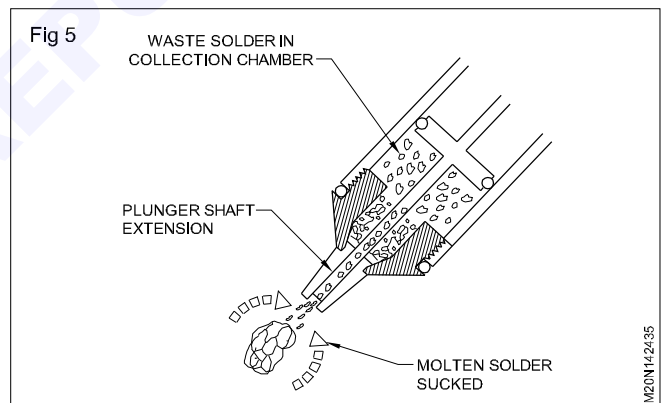
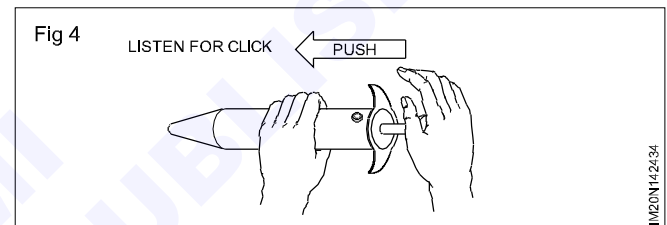
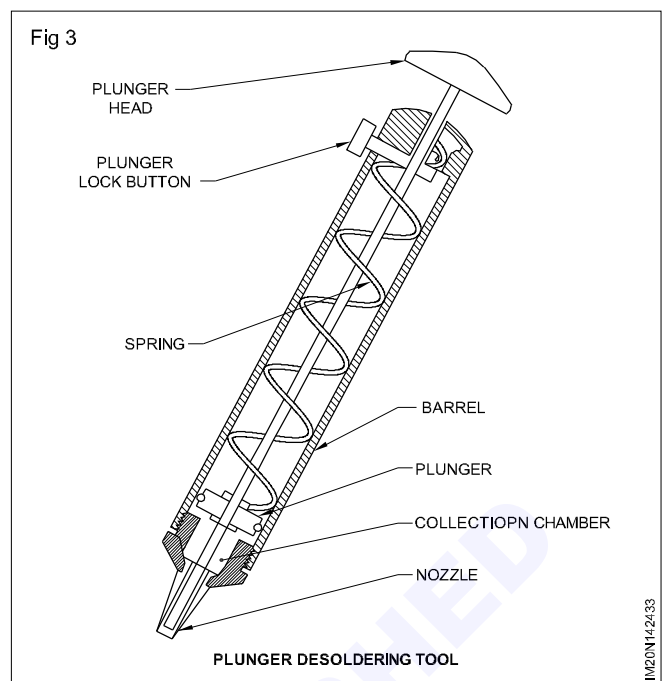
### Soldering stages

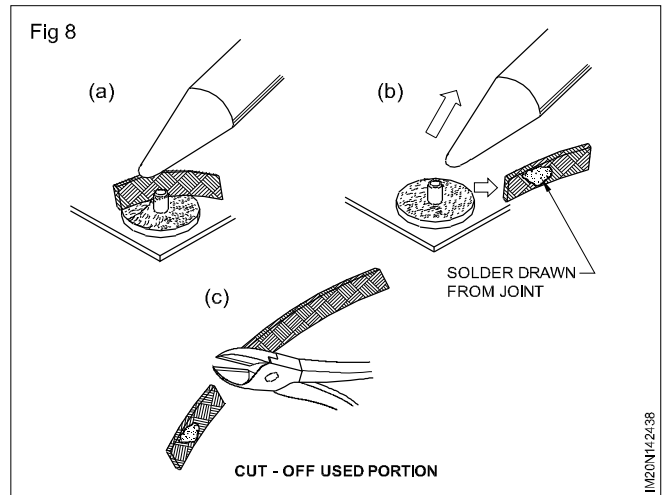
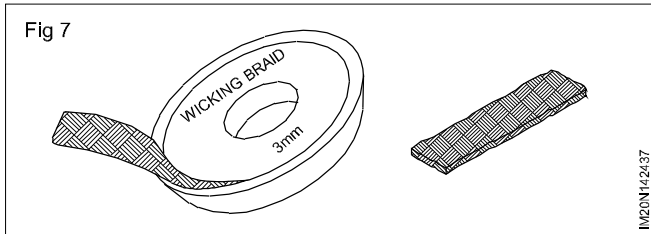
- 1 Before soldering take the required amount of solder and flux
- 2 **Heating the joints:** After applying enough solder keep the tip for 3 to 65 seconds. Doing this the flux will attain the temperature of the solder and unwanted vapor will go away resulting good soldered joint.
- 3 **Cooling the joints:** While doing soldering the joining position should not undergo any change until the solder solidified. Otherwise the joint will be weak and called as cold or dry joint.
- 4 **Cleaning the joints:** After soldering the excess flux around the joints should be removed. Otherwise the corrosive nature of the flux will damage the component and the board. Moreover dust will settle on this joints and make the circuit inoperative. To remove the excess flux we used many solvent. One of the solvent is ISO Propyl alcohol. Apply this dilutes solvent where the flux has to be removed. Then remove the dissolved flux by ordinary strip brush.

**Desoldering :** Sometime we have to remove a component from the circuitry. This is done by heating the soldered joint and removing the component. This process is called De- soldering. This is the simplest process of removing wires and components from the soldered area. For de- soldering we use de-soldering pump or plunger and wicking tool. (Fig 3&4). Refer fig 3 this tool has been used widely. This works on the suction principle. In fig 4 the plunger has to be inserted fully till the button locks. This tool is known as cocking tool.

Heat the place where de-soldering to be done. Place the nozzle and press the button. Now pull the plunger and the molten solder will be collected as shown in fig 5. We have to repeat this process some more time until all the solder were collected. As shown in fig 6 the solder on the nozzle should be cleaned for the next time use.

**Wicking Braid:** Another de-soldering tool as shown in fig 7&8.





## Ohm's law and Kirchoff's law, cells and batteries

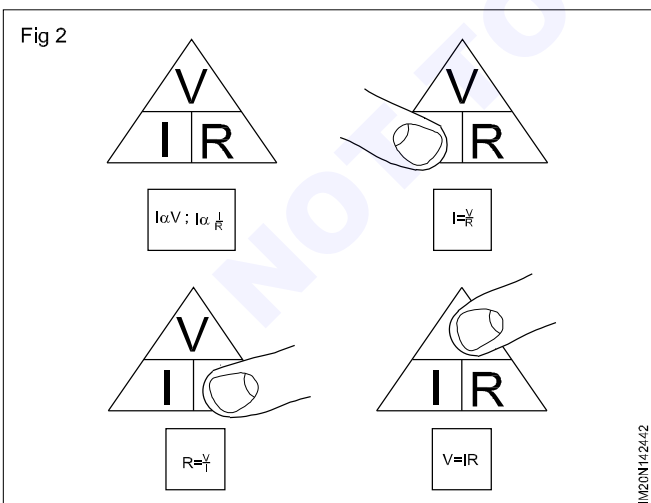
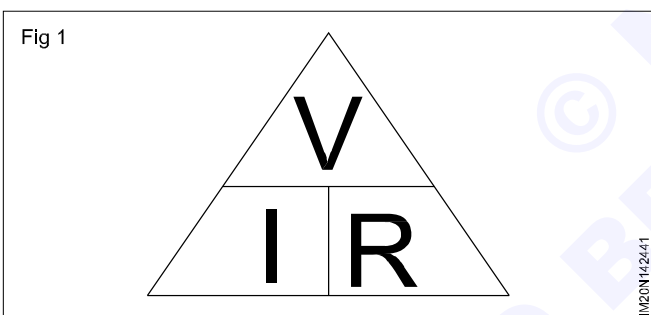
**Objectives:** At the end of this lesson you shall be able to

- explain Ohm's and Kirchoff's law
- explain series and parallel connections
- explain types of primary cells, its usage and how it works
- explain secondary cells maintenance and how it works.

**Ohm's Law :** Ohm's law states 'For constant temperature in a closed Electronics circuit, the voltage between any two points is directly proportional to the current passing through it and inversely proportional to the resistance of the circuit.  $I = V/R$ . (Figs 1 & 2)

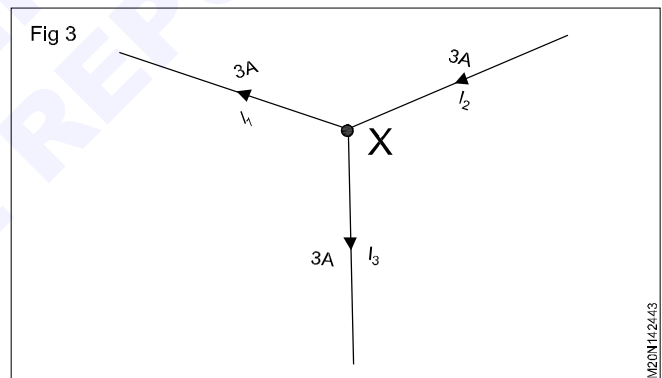
no loss in current. The current towards the point is marked as + and leaving the point is marked as -. Now  $I_1 + I_2 - I_3 = 0$ .

$$\Sigma \text{ in} = \Sigma \text{ out}$$

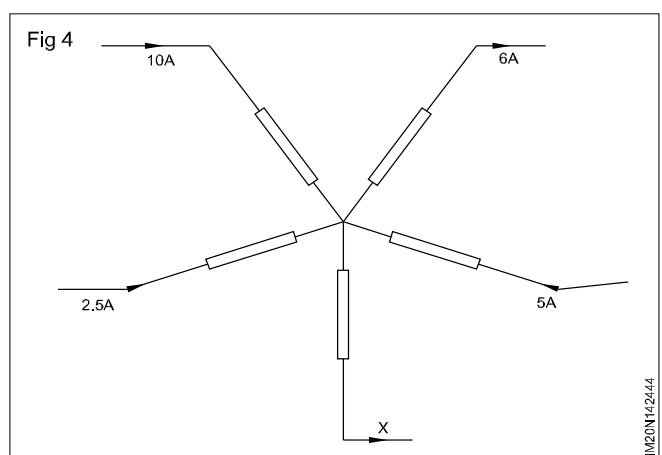


### 1 Kirchoff's first Law (or) current law (or) point law (refer Fig 3)

The law says the total current entering a point or node in a circuit equals to the total current leaving the point provided



For example as in Fig 4 the current towards the junction equals to current away from.



$$I_1 + I_3 + I_4 - I_2 - I_5 = 0$$

$$I_1 + I_3 + I_4 = I_2 - I_5$$

$$\Sigma \text{ in} = \Sigma \text{ out}$$

$$10\text{A} + 2.5\text{A} + 5\text{A} = 6\text{A} + X$$

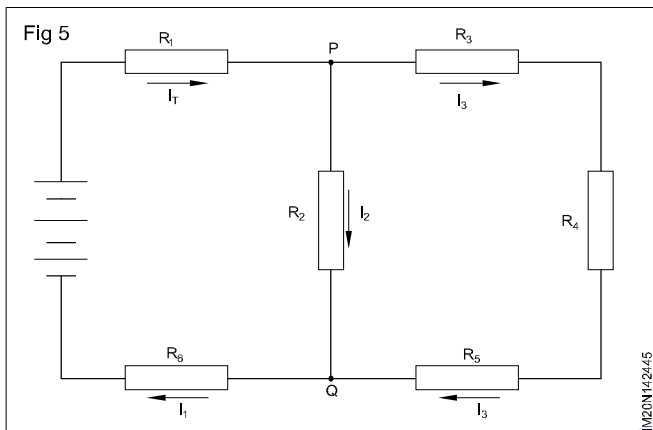
$$7.5\text{A} = 6\text{A} + X$$

$$6\text{A} + X = 17.5\text{A}$$

$$X = 17.5 - 6\text{A}$$

$$X = 11.5\text{A}$$

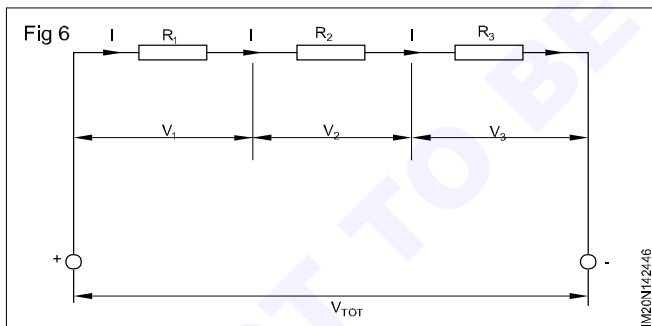
## 2 Kirchhoff's second law (or) voltage law (or) mesh law (Fig 5)



The voltage around a loop circuit equals to the sum of the every voltage drop in the same loop will always be zero. Thus  $V = IR_1 + IR_2 + IR_3 = \Sigma V = 0$

**Types of circuit :** Type of the circuit is by the way the resistance is included in the circuit.

### 1 DC series circuit (Fig 6)

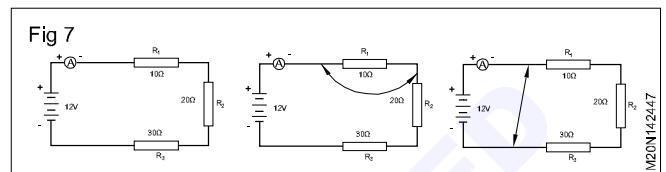


More than one resistor were joined in series. In this one end portion join with the second beginning portion. Now supply will be given to the first begin end of the resistor to the last end of the final resistor.

- 1 Total resistance value is  $R_1 + R_2 + R_3$
- 2 Voltage drop across each resistors with constant current is  $V_1 = IR_1$ ,  $V_2 = IR_2$  and  $V_3 = IR_3$ .
- 3 The total of  $V_1 + V_2 + V_3$  will be equal to the source supply.
- 4 The current will be same since all the resistors are connected in series.
- 5 If any break occurs in the circuit then no current will flow.

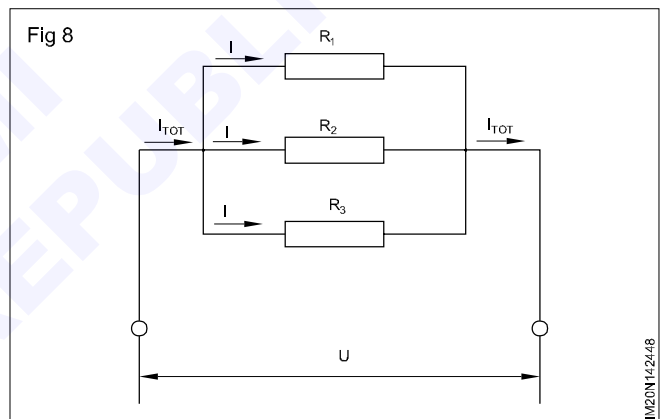
**Application:** Used for serial light set, connecting cells in a car battery, and batteries in a torch cell.

**Open in a series circuit:** In a circuit as shown in Fig 7, when a voltage is applied and if an ammeter connected in series shows zero reading then we can ensure it is in open circuit. In open circuit nothing will work. There won't be any voltage drop across the resistor. But if you connect a volt meter between the open point and one end of source supply then the voltmeter will show the supply voltage. Like that if we disconnect the source supply and connect an ammeter in series then the reading of the ammeter is infinite.



**Reason for open circuit:** There is no contact with source terminal, breakage in wire, burned out resistance and blown fuse.

### DC parallel circuit (Fig 8)



All the resistors will be connected in parallel. That is each beginning point of resistors were connected in series and connected to one end of source. Similarly the second end of all resistors were connected in series and connected to the other end of the source. Supply is given between the two end of source.

In this circuit supply is given on both ends of each resistors and value is same.

Current in each resistor is inversely depends on its value.  $I_1 = V/R_1$ ,  $I_2 = V/R_2$  and  $I_3 = V/R_3$ . The total current passing through the circuit is equal to the sum of all current passing through the resistor.  $I_T = I_1 + I_2 + I_3$ .

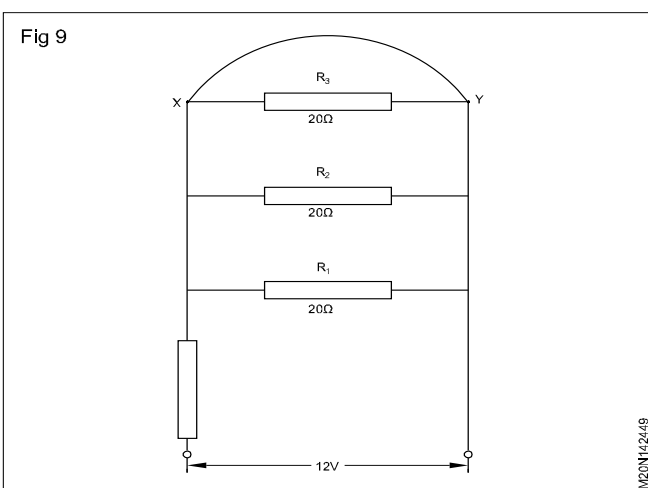
To calculate the total resistance of the circuit  $1/R_T = 1/R_1 + 1/R_2 + 1/R_3$ .

If the parallel connected resistors were of equal value then the total resistance will be equal to  $1/3R$ .

The total resistance in a parallel circuit will be lesser than the least resistance connected.

**Short in a parallel circuit:** As in Fig 9 if a short occurs between the points X&Y, then the total resistance of the circuit is zero and the circulating current will be high. To

avoid this, a fuse or a circuit breaker (MCB) should be connected. If  $R_3$  alone shorted then it should be understood  $R_1$  &  $R_2$  too shorted. If in any one of the branch is shorted then it should be presumed all branches are shorted.



### Application

- 1 The load in each branch of the parallel circuit can be controlled.
- 2 From a single supply source lot of loads can be connected.
- 3 DC series parallel circuit

### Cell and batteries

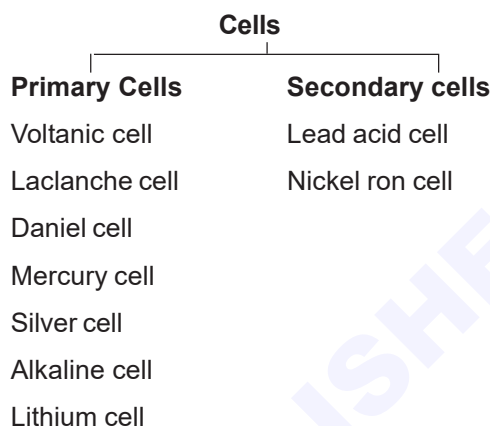
**Introduction :** When an Electronics current passes through an electrolyte, chemical reaction happens. This process is known as electrolysis and used for electro plating, block making, battery charging and for the separation of metals.

**EMF generation due to chemical reaction :** If two electrodes for example carbon and zinc were placed in a jar containing a solution of water and sulphuric acid. If

this two electrodes were connected to an external load, a chemical reaction takes place. Due to this Electronics current will pass through the load. This system of two electrodes in an electrolytic substance is called a cell. Group of cells connected in series formation is known as battery.

### Types of cells

- 1 Primary cells and
- 2 Secondary cells.



**Primary cells:** A primary cell is a cell that is designed to be used once and discarded, and not recharged with electricity and reused like a secondary cell. In general, the electrochemical reaction occurring in the cell is not reversible, and so these cells cannot be recharged. For example. Dry cells used in radio, wall clock and calculators.

**Secondary cells:** A secondary cell or battery is one that can be Electronicsly recharged after use to their original pre-discharge condition, by passing current through the circuit in the opposite direction to the current during discharge Example lead acid cell, Nical cadmium cell, and Nical iron cell.

| Primary cells                                                                                                                                                                                                                                                                                                                                                  | Secondary cells                                                                                                                                                                                                                                                                                                                                            |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>The chemicals used in this cell will produce chemical reaction on its own and when load is connected current flows</p> <p>After discharge this cell can't be used.</p> <p>This cell has low AH capacity</p> <p>No maintenance required</p> <p>Less weight</p> <p>Very low internal resistance</p> <p>Short life</p> <p>Average terminal voltage is 1.5V</p> | <p>The chemicals used in these cell will produce chemical reaction and the current produced will be stored</p> <p>After discharge this cell can recharged and can be used.</p> <p>AH capacity is large.</p> <p>Lot of maintenance is required</p> <p>More weight</p> <p>Low internal resistance</p> <p>Long life</p> <p>Average terminal voltage is 2V</p> |

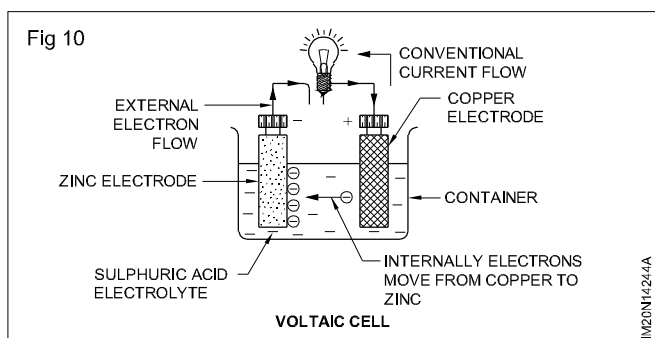
### Describe Voltaic cell and explain its action (Fig 10)

As shown in figure 10 a copper and a zinc plate were placed inside a glass jar without touching each other. The jar is filled with an electrolyte of diluted sulphuric acid. If we connect a voltmeter in between the plates, voltage indicates an EMF has been generated. If we connect a bulb as shown in Fig 10, a chemical reaction

will happen inside the jar and this will produce a current and glow the bulb. First  $\text{SO}_4$  will reach in zinc electrode and turns to zinc sulphate  $\text{ZnSO}_4$ . Hydrogen  $\text{H}_2$  will reach the copper electrode and becomes neutral. Hydrogen gas has emanated and rest of Hydrogen forms on the copper plate.  $\text{Zn} + \text{H}_2\text{SO}_4$  reacts to  $\text{ZnSO}_4 + \text{H}_2$ . Inside the cell the current passes through copper plate and then to bulb.



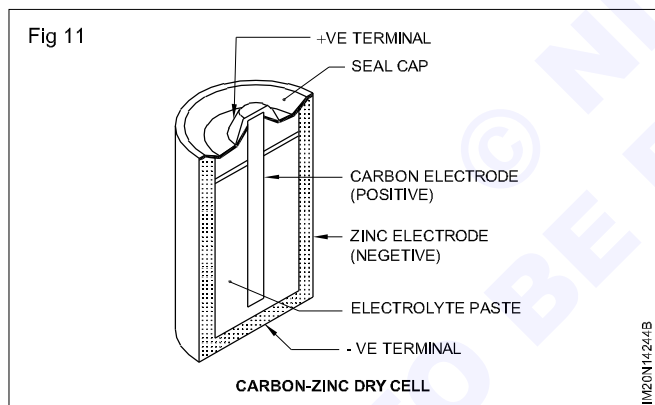
The copper plate acts as cathode and zinc plate as anode. The EMF is 1.1V.



### Describe Daniel cell and explain its action

A Daniel cell is a best example of galvanic cell. It consists of two electrodes of copper and mercury layered zinc. Each electrode is immersed in its own electrolyte of copper sulphate and zinc sulphate respectively in a porous vessel. The zinc rod acts as negative electrode and copper as positive electrode. When we join the two electrodes with wire to a bulb then current will flow. The hydrogen flow from the porous vessel to copper plate will oxidized.  $\text{Zn} + \text{H}_2\text{SO}_4 \rightarrow \text{ZnSO}_4 + \text{H}_2$  and  $\text{H}_2 + \text{CuSO}_4 \rightarrow \text{H}_2\text{SO}_4 + \text{Cu}$ . Due to this polarization is restricted. The EMF generated is 1.1V. The internal resistance is 2 ohms. This cell is used in laboratories to have stabilized current.

### Dry cell (Fig 11)



As in Fig 11 the outer shell is made of zinc sheets which acts as negative electrode. In center the carbon rod is placed which acts as positive electrode. Around the carbon rod ammonium chloride in paste form is placed. This acts as electrolyte. The paste should be wet then only chemical reaction takes place and that's why zinc chloride is used. The top of the cell is sealed with tar. On top there is metal cap which is positive and the bottom is negative terminal. The EMF of dry cell is 1.5V, internal resistance is 0.4 to 0.5 ohm. Three sizes of dry battery were available in market as AA, C and D. (AA Pen type, C medium size and D large economy size).

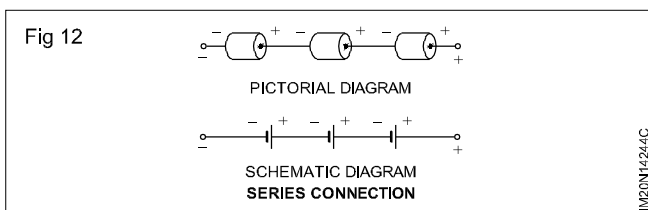
### Alkaline cell

The construction and working principle is same as that of dry cell. The outer portion is made of zinc sheet which act as negative electrode. A cylindrical portion in the center which contains potassium chloride acts as Positive electrode. The manufacturing cost is higher than the dry

cell. This cell is more advantageous over dry cell. For example a D type alkaline cell 1.5V capacity has 8 Ah than dry cell of 2Ah of same capacity. The life of the alkaline cell is 2 to 3 years and dry cell is 1.5 .

### Grouping of cells

#### Cells in series (Fig 12)

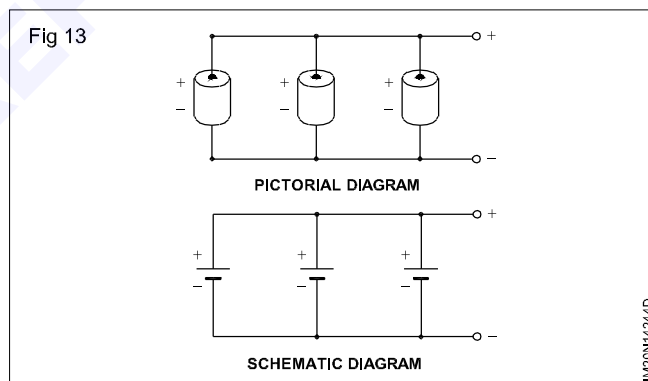


When the cells are connected in series then the total voltage  $E$  is the sum of the individual voltages as  $E = E_1 + E_2 + E_3 + \dots$ . Internal resistance given by the sum of their individual internal resistance as given by  $r = r_1 + r_2 + r_3 + \dots$ . For  $n$  number of same voltage cell total cell voltage  $= n \times V$  volts and total internal resistor  $= n \times r$  ohms. If this cell is connected to an external load of resistance  $R$  then total resistance  $= R + nr$  ohms.

$I = \text{Total EMF} / \text{Total Resistance} = NE / R + nr$  amps. For maximum current total internal resistance should be small than the external resistance.

#### Cells in parallel (Fig 13)

As shown in figure when 'm' of similar cells of EMF ' $E$ ' and internal resistance of ' $r$ ' are connected in parallel



Total internal resistance  $= r / m$  ohms

Total external resistance  $= R$  ohms and Total EMF  $= E$  Volts.

Hence total resistance of the circuit  $= R + r/m$  ohms

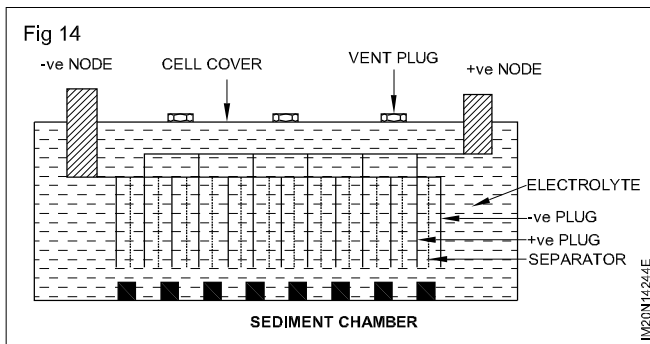
Total current in the circuit is  $E / (R + r/m)$ . For maximum current the external resistor should be small than the internal resistance.

Example: 1) 5 cells of 1.5V each having 0.3 ohms resistance is connected in series and connected to an external resistor of 2 ohms. What will be the current in the circuit.

$$I = NE / (R + Nr) = (5 \times 1.5) / (5 \times 0.3) + 2 = 7.5 / 3.5 = 2.14 \text{ A}$$



## Construction of lead acid battery (Fig 14)



As shown figure the positive plate has two type.

- 1 Plante plate and
- 2 Faure plate

**Plante plate:** For charging and discharging All lead pure electrode is used. It will take time form this plates and also costly. Hence these are rarely used.

**Faure plate:** The lead plate is rectangular grid in shape having the paste of lead peroxide on it.

**Negative plate:** The lead plate is rectangular grid in shape having the paste of spongy lead which act as active material .There will be one additional negative plate than the positive plate. On each side of the positive side a negative plate is available. This will increase the strength of the positive plate both sides are used effectively.

**Separators:** In between the positive and negative plates, a thin porous rubber material is placed. This rubber separator will pass the electrolyte and act as good insulation.

**Container:** The container is made of hard rubber. Electrodes are placed inside the container along with the separator. The container is filled with electrolyte. The bottom portion of the container is having ribs to hold the plates. This bottom portion is known as sediment chamber. When the chemical reaction takes place continuously, the active materials will fall in the sediment chamber. Each cell have wall so that electrolyte doesn't pass to the other cell. Each cell has vent plug and cover.

**Plate connector:** This is made of pure lead. All positive plates are connected together and forms a group. Likewise negative plates are also formed as a group.

**Post connector:** This is made of lead and connected to plate connector and brought out outside to the cell cover.

### Terminal marking of cell connector

| Terminal | Marking | Color       | Thickness | Shape    |
|----------|---------|-------------|-----------|----------|
| Positive | +       | Red         | Small     | Circle/V |
| Negative | -       | Black/ blue | Large     | Flat     |

These are made of lead & will be connected either in series or in parallel to the cell end.

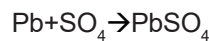
**Electrolyte:** The electrolytes were made by the mixture of water and sulphuric acid to the ratio of 1:3 and the specific gravity of 1.24 to 1.28

## Charging and discharging of lead acid battery

- 1 During discharge positive ion will go to the positive plate and negative ion to the negative plate.
- 2 During charging positive ion will go negative plate and negative ion will go to positive plate.

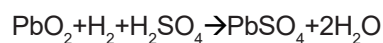
### During the beginning of discharge

Positive plate---- lead peroxide ( $PbO_2$ )----dark brown color.  
 Negative plate-----Sponge lead ( $Pb$ )----slate grey color.  
 Electrolyte----Diluted sulphuric acid (specific gravity 1.28)  
 When connected to a load  $H_2SO_4$  will be separated to  $H_2$  and  $SO_4$  and comes to negative plate.



Lead + sulphate  $\rightarrow$  lead sulphate.

When  $H_2$  comes to the positive plate it turns to lead sulphate and water is formed.

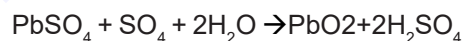


### During the end of discharge

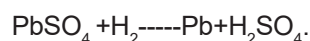
- 1 Positive and negative plate turns into lead sulphate which is white in color.
- 2 Since water is produced the specific gravity of electrolyte will be 1.1
- 3 The voltage of the cell will drop from 2.2V to 1.8V.
- 4 The chemical energy turns into Electronics energy which has been spend.

### During the beginning of charging

When DC supply is given to the terminals of the cell,  $H_2SO_4$  will separate as  $H_2$  and  $SO_4$ . The  $SO_4$  will comes to the positive plate and chemical reaction takes place.



Positive electrode turns into lead peroxide and electrolyte  $H_2SO_4$  forms. When  $H_2$  comes to the negative plate, chemical reaction takes place as



Negative plate turns as sponge lead and electrolyte  $H_2SO_4$  forms.

### During the end of charging

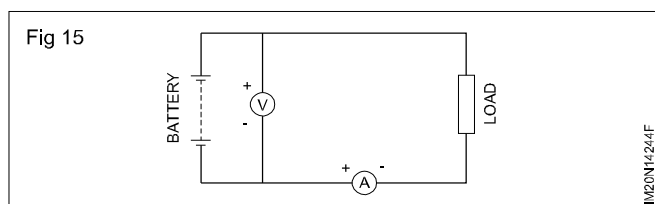
- 1 Positive plate changed to lead peroxide and negative plate changed into spongy lead.
- 2 The specific gravity of the electrolyte raised to 1.28
- 3 The voltage of the cell increased from 1.8V to 2.2V.
- 4 Electronics energy changed into chemical energy and stored.

| Charge | +ve plate     | electrolyte    | -ve plate     |
|--------|---------------|----------------|---------------|
| ↑      | Lead peroxide | Sulphuric acid | Sponge lead   |
| ↓      | Lead sulphate | Water          | Lead sulphate |

### Indication of fully charged battery

- 1 **Color of the plates:** On full charged battery positive plate will be dark brown and negative plate will be slate grey.
- 2 **Specific gravity:** The specific gravity will be 1.6
- 3 **Emanation of gases:** Hydrogen and Oxygen gases were produced and emanated as water bubbles.
- 4 **Voltage of the cell:** On full charge it will be 2.6 V while on full discharge 1.8 to 1.6V.

By referring to fig 15 circuit, we can find the voltage with load and voltage without load. By the switch in closed position we can see on load voltage and in open position we can see off load voltage shown in voltmeter.



### The internal resistance of the cell

While the load is applied to the electrodes the current not only passes through the load but also passes through the electrolyte and completes the circuit. The resistance offered to the current flow inside the cell is known as internal resistance of the cell. Internal resistance depends on electrolyte, the distance between the plates and the surface area of the electrodes. The voltage drop occurs inside the cell depends on the current generated.

### Precautions to be observed in the maintenance of batteries

For long life and good operation of the battery the following warnings to be considered.

- 1 Don't keep the batteries on discharge for long time
- 2 The acid level should be maintained above the electrodes.
- 3 Add distilled water when the level of electrolyte is below the electrodes.
- 4 The speed of charge and discharge should be maintained.
- 5 While on charging gas will be released and proper vents should be provided.
- 6 When preparing electrolytes water should not added to the acid instead drop by drop acid should be added to the water.
- 7 The batteries should be clamped rigidly in automobiles.
- 8 Frequently check the specific gravity of the electrolyte.
- 9 Don't bring flame near the charging station.
- 10 Smear Vaseline instead grease on to the terminal.

### Precaution while charging

- 1 The temperature of the battery should not exceed 45°.
- 2 Don't use any tools in the charging circuit without switch off position.
- 3 Don't disturb the connections while on charging.
- 4 Care should be taken not to spill acid on clothes. Ammonium solution should be used for the spill in clothes.
- 5 Use only DC source for charging.
- 6 Check the polarity of the both DC source and battery terminal for correct connection.
- 7 The DC source voltage should be greater than the battery voltage.
- 8 The battery should be placed in a well ventilated place.

## Type of switches and magnetism

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

- explaining switch and switch types
- explain magnetism
- explaining magnetic compass.

**Switch and its types :** Switch is used in an Electronics circuit to break the current flow or to make the current flow. There are basically four type of switches.

- 1 Single pole single throw (SPST)
- 2 Single pole double throw (SPDT)
- 3 Double pole single throw (DPST) and
- 4 Double pole double throw (DPDT).

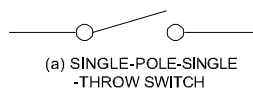
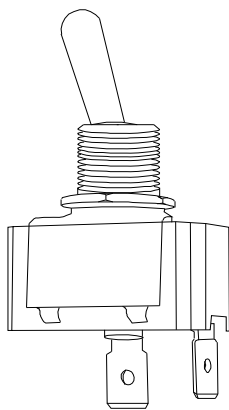
**Single pole single throw (SPST) (Fig 1) :** This switch has two terminals and used in industries widely. Low effort is required to operate this switch. The rating of 6A, 16A of 250V were available.

**Single pole double throw (SPDT) (Fig 2) :** This switch has three terminals. This switch is used in the circuit to control flow in two different paths.

**Double pole single throw (DPST) (Fig 3) :** This switch has four different terminals and is often used to connect two source terminals to their respective output terminals (but never to each other). A DPST switch can be used in an "ON/OFF" configuration, where its terminal pairs are either connected ("ON") or not connected ("OFF")

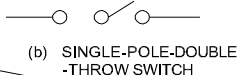
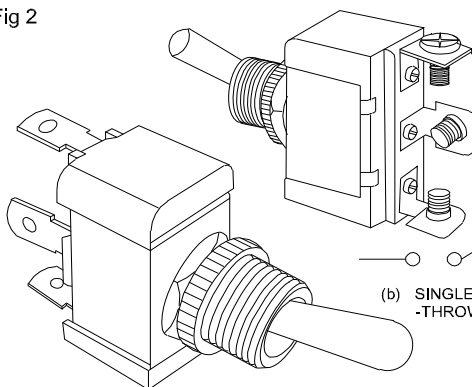
**Double pole double throw (DPDT). (Fig 4) :** This switch is a switch that has 2 inputs and 4 outputs; each input has 2 corresponding outputs that it can connect to. Each of the terminals of a double pole double switch can either be in 1 of 2 positions. This makes the double pole double throw switch a very versatile switch. This switch is the combination of two SDPT switch and used to control the motor rotation in two direction.

Fig 1



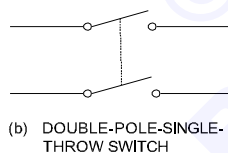
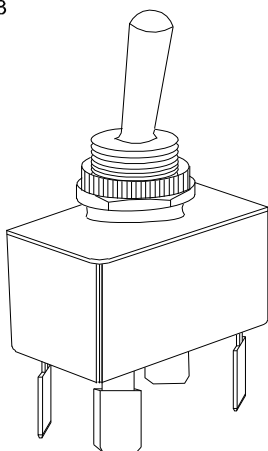
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Fig 2



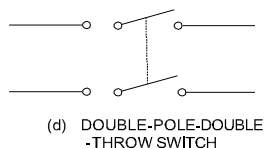
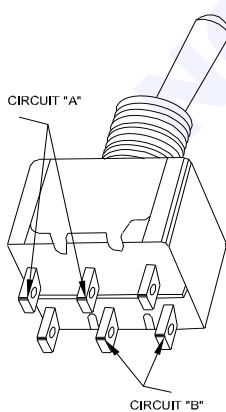
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Fig 3



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Fig 4



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## Magnetism and electro magnetism

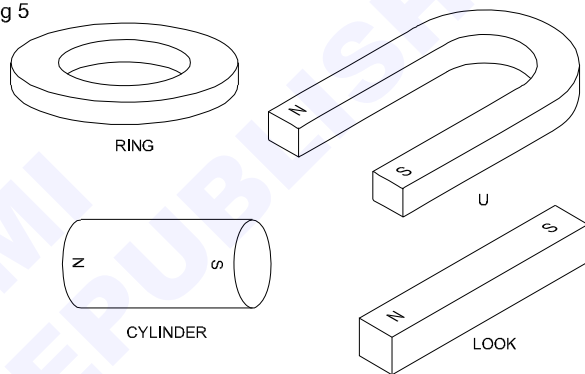
Magnetite is an iron ore available in nature. It has the capacity to attract certain other metals.

### Classification of Magnets

- 1 Natural magnets:** The magnetite mineral Lodestone available in nature has got special magnetizing property than other magnetite materials. It will show the North and South poles.
- 2 Artificial Magnets:** Metals having Iron or Iron alloys display magnetic properties by induction of electric current. These are called artificial magnets. There are two types of artificial magnets in use.

- i Permanent magnet:** Iron, nickel, alnico, tungsten steel and cobalt steel can be used for the production of permanent magnet. As shown in fig 5 the shape of these magnet varies as horse shoe, ring, bar and cylinder.

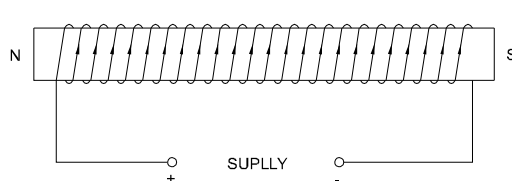
Fig 5



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- ii Electro magnet: (Fig 6)** Metals such as soft steel, silicon steel are used. Over this copper coils are formed. When an electric current passes through this setup, the metal acts as magnet.

Fig 6



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### Advantages of electro magnetism

- 1 By passing electric current can change to magnetism
- 2 By reversing the direction of current flow the polarity of the magnet can be changed.
- 3 By controlling the current flow we can control the magnetic force.
- 4 Magnet can be made to the desired shape.
- 5 We can retain the magnetic force (without any change) as long as we desire.

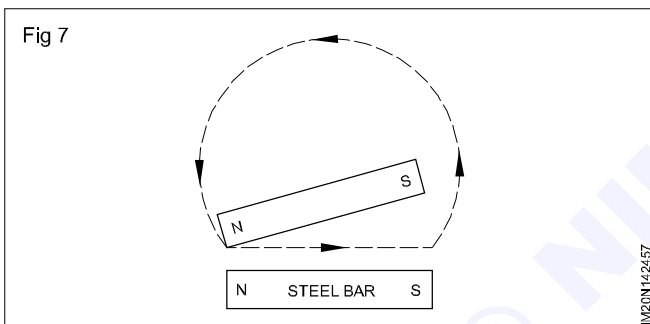
## Differences between Electro magnet and permanent magnet

| Sl.No | Electro magnet                                                                        | Permanent magnet                        |
|-------|---------------------------------------------------------------------------------------|-----------------------------------------|
| 1     | Easy polarity change                                                                  | No polarity change                      |
| 2     | Magnetic pole strength can be changed                                                 | Magnetic pole strength can't be changed |
| 3     | Used in small and big motors and generators.                                          | Used in very small motors.              |
| 4     | Heavy weight can be lifted and can be hold                                            | No lifting of weights                   |
| 5     | Used in generators, measuring instruments, protective relays, lifts, bell and buzzers | Used in cycles dynamo and small toys.   |
| 6     | High cost                                                                             | Low cost                                |
| 7     | Can't be used for direction in compass                                                | Is used in compass to find direction    |

### Methods of Magnetization

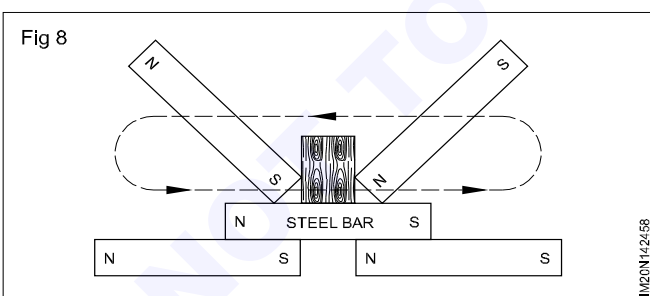
- 1 Touch method
- 2 By means of electric current
- 3 By induction method.

#### Touch method (Fig 7)



The steel bar which has to be magnetized is placed on a work bench. Now take a bar magnet and rub on the steel bar from one end to the other end. Repeat the same process again and again. The steel bar will become a magnet.

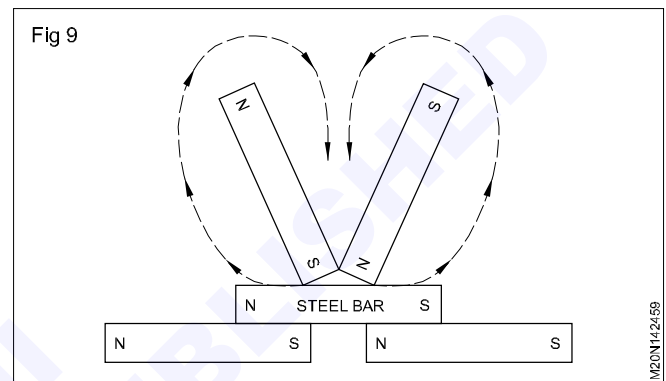
#### Double Touch method (Fig 8)



Place the steel bar to be magnetized on top of the two bar magnets as shown. Place a wooden piece on center of the steel bar. Now move a bar magnet from one center to the end as shown. This should be done again and again till the steel bar turns magnet.

#### Divided touch method (Fig 9)

Place the steel bar to be magnetized on top of the two bar magnets as shown. In this no wooden piece is required. Now two magnet bar should be rubbed from center of the steel bar to the edge and again from center to the edge as shown till the steel bar turns magnet.



**By means of electric current :** Wind a copper conductor on iron core and when a DC current passes through the coil, the iron core turns into electromagnet. Now place the steel bar which is to be magnetized near the iron core. Due to induction the steel bar now magnetized.

### Type of Magnetic materials

- 1 Ferro magnetic materials
- 2 Paramagnetic materials and
- 3 Diamagnetic materials.

**Ferro magnetic materials :** Iron and alloys of iron which are easily attracted by magnets were called Ferro magnetic materials. The magnetic permeability of this metals are high. Example of iron, nickel, and cobalt steel are can be given.

**Paramagnetic materials :** These are the metals which are weakly attracted by magnets. Example of aluminum, gold and copper can be given. The permeability is slightly greater than 1.

**Diamagnetic materials :** Materials that are freely magnetized when placed in the magnetic field. However, the magnetization is in the direction opposite to that of the magnetic field. The magnetism that is shown by these materials is known as diamagnetism. For example bismuth, glass and water can be given. The permeability is slightly less than 1.

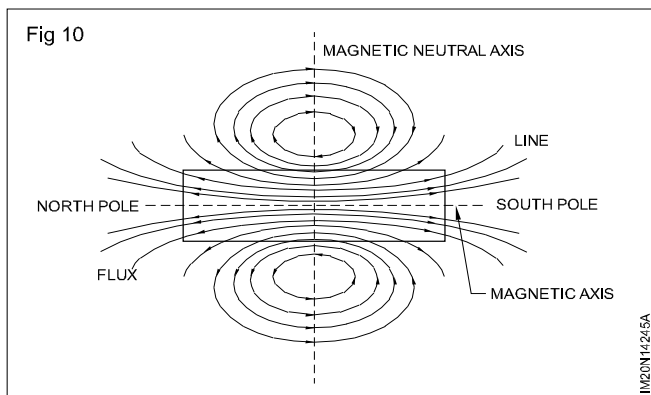
### Fundamental magnetic terms

**Magnetic poles :** In a bar magnet where the magnetic lines goes-in and comes-out ends are called magnetic poles. At the ends of the magnetic bar the field strength



will be high. North pole of a magnet will have the magnetic lines comes out and in south poles the magnetic lines were goes-in.

**Magnetic Lines of force (Fig 10) :** These are imaginary lines drawn by a magnetic needle from North Pole of a magnet. Lines will be very close near the ends of the magnet



**Magnetic circuit :** In a bar magnet the imaginary magnetic lines from north to south poles externally and south to North Pole internally in completion is called Magnetic circuit.

**Magnetic flux :** Magnetic flux is a measurement of the total magnetic field which passes through a given area.. Its unit is in weber (Wb) and symbol  $\Phi$ . One weber = 10 to power 8 maxwell.

**Magnetic field :** The magnetic field is the area around a magnet in which the effect of magnetism is felt.

**Magnetic axis :** The straight line joining the two poles of a magnet is called the magnetic axis

**Magnetic saturation :** The material which is to be magnetized will have the magnetic property to some extend and even if we give more force the magnetic strength will not increase. This called the saturation point of magnetism.

**Magnetic screening :** There is no insulation for the magnetic lines. Hence if we want to protect ourselves from the magnetic lines .some type of shield or screening should be done. For example, when a soft iron ring is placed in a magnetic field, most of the lines are found to pass through the ring and no lines pass through the space inside the ring.

**Residual magnetism :** When a DC current passes through a coil it is magnetized. If the current is stopped the coil is no longer magnetized but it will have some amount of magnetism. This is called residual magnetism.

**Magneto Motive Force (MMF):** The force required to produce magnetic lines in a magnetic circuit is called MMF. This is like the EMF, the force required to drive the electrons in a Electronics circuit. The unit is in Ampere turns. This depends on the current, number of turns in the coil, magnetic material and the cross sectional area.

**Ampere turns :** The number of turns in a coil and the amount of current passing through it determines ampere turn. Thus 1 MMF equals to one ampere current passing through a one turn coil in a vacuum.

**Reluctance :** In a magnet the resistive force which opposes the formation of magnetic line magnetic reluctance. Reluctance= MMF/FLUX. & denoted by letter S and the unit is ampere turns/weber

**Permeability :** Magnetic permeability is defined as the ratio of the magnetic induction to the magnetic intensity. The symbol is  $\mu$ .(mue). It is the ratio between the flux density and the magnetizing force. The permeability of air is 1

**Magnetic field strength or Field intensity or magnetic intensity**

Magnetic field strength refers to the ratio of the MMF which is required to create a certain Flux Density within a certain material per unit length of that material. This denoted by letter H. Its unit is in Ampere turns per meter.

**Flux density :** The number of magnetic lines on a unit surface is called flux density. It is denoted by letter B Its unit is weber per meter square called as Tesla T . Hence flux density = Total flux / core area.

**Coil :** The number of turns of wire wound around a core (as of iron) to create a magnetic field for an electromagnet or an induction coil.

**Helix and solenoid :** In a coil if the length is greater than the diameter of the coil, then it is called solenoid. If the diameter is greater than the length then it is called Helix. The solenoid is a coil of wire, and the plunger is made of soft iron. The magnetic field is formed around the coil when an electric current passes through it and draws the plunger in. We can say that the solenoid is responsible for converting Electronics energy into mechanical work.

**Toroid :** If the solenoid is made in ring form then it is called toroid.

### Properties of a Magnet

- 1 It will attract iron and metals of iron alloys.
- 2 If you hang the magnet on a thread, North pole will looks towards north and south pole to south direction.
- 3 By the principal of induction a magnetic material placed near magnet will turns into a magnet.
- 4 Like poles will always repel and unlike poles will attract each other.
- 5 If you break a magnet in to pieces then each piece will act as individual magnet.
- 6 It will lose its magnetic properties if it is heated or struck down by a hammer.
- 7 Each poles are having same magnetic strength.
- 8 We can't increase the magnetic strength beyond its saturation point.

### Properties of magnetic lines

- 1 Magnetic lines will travel from North pole to south pole externally and south pole to North pole internally.
- 2 Each and every magnetic lines will be a closed one.



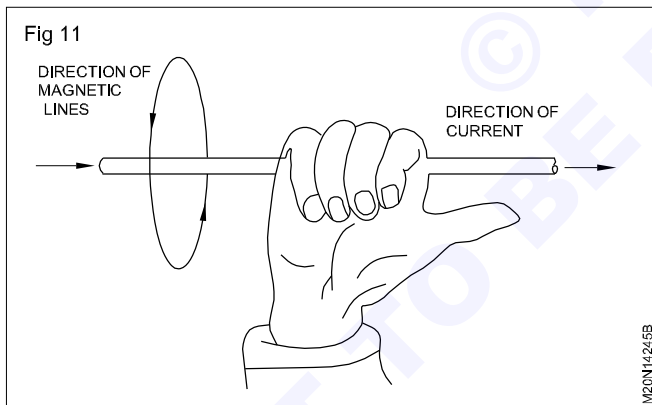
- 3 Magnetic lines won't intersect with each other.
- 4 Magnetic lines of same pole will leave from each other.
- 5 These lines pass easily through magnetic materials.
- 6 When these magnetic lines pass through a magnetic material, they turn the material into a magnet.
- 7 Magnetic lines can be visualized as a rubber ring.

#### Care and maintenance of permanent magnet

- 1 Don't strike the magnet with a hammer, apply heat on the magnet or throw it on a hard surface. The magnet will lose its properties either in part or in full.
- 2 Store your magnets with a keeper - A keeper is a small piece of iron that is generally added temporarily between the north and south poles of a magnet.
- 3 Keep magnets in pairs to avoid both north and south sides from touching.
- 4 When storing multiple magnets, keep them in a non-ferromagnetic container.
- 5 Keep away from dampness. While due to wetness and rust formation, it will lose its property.

#### Determine the direction of magnetic field around a current carrying conductor

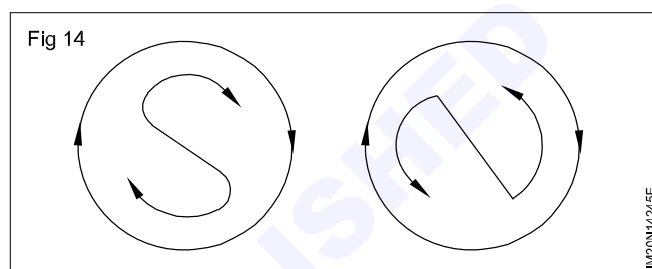
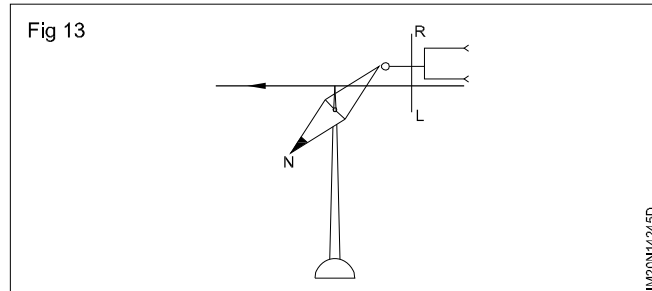
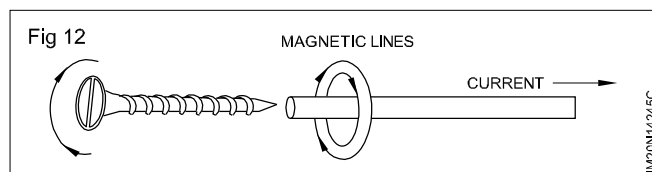
- 1 **By right hand grip rule (Fig 11):** Consider holding a current carrying conductor on your right hand. The direction of the index finger leads to the direction of current and the rest of the folded fingers direction indicate the magnetic line direction.



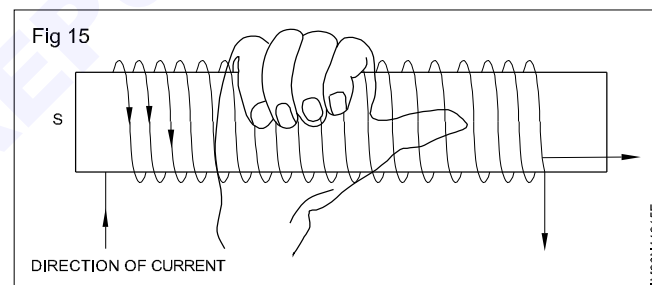
- 2 **By cork screw rule (Fig 12):** Consider screwing a right handed thread screw in a wooden board. Direction of the screw indicates the direction of current and the rotational direction of the screw driver indicates the direction of magnetic lines.
- 3 **By Ampere rule (Fig 13):** Consider the current is passing from feet to head and if we find by a magnetic needle, the north pole of the magnetic needle will turn to your left.

#### Determination of pole direction in an electro magnet

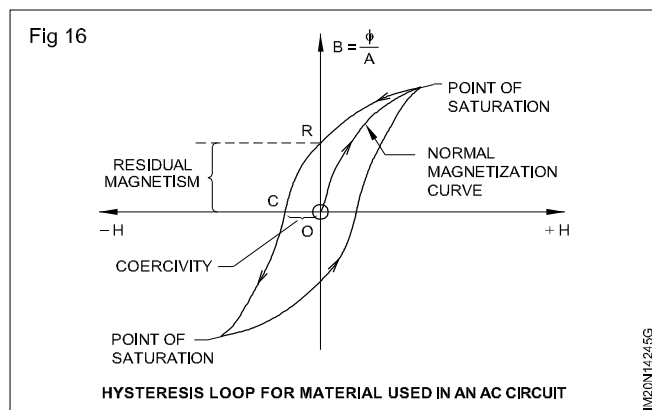
- 1 **End rule (Fig 14):** If you look one end of the coil and assuming current passing in clockwise direction then that end is south pole and the other end is North pole.



- 2 **Helix or right hand rule (Fig 15):** Imagine holding a current carrying coil in your right hand. Consider the folded fingers represent the direction of current. Now the index finger points the North pole and the other end denotes south pole.



**Hysteresis loop (Fig 16) :** Consider a coil wound on an iron core. When a DC current passes through the coil controlled by a variable resistor. By this when we increase the current the magnetizing force is  $H$ , Flux density is  $B$ , will increase. If we plot this on a graph paper  $H$  in  $x$  axis and  $B$  in  $y$  axis. The line joining the plotted points will look like a closed loop and called as Hysteresis loop.



In the beginning the value of  $H$  and  $B$  are zero. When the current is increased gradually value of  $H$  increases in direct

proportion to B. After a particular point if value of H increases the value of B won't increase. This is the point of saturation. This denoted as OA in the Fig 16. When we decrease current the value of H and B reduces. We can notice the rate of increase in value of B is not same as rate of decrease in value. When H becomes zero B won't come to zero but remain in value ob. This is the value of residual magnetism.

When we increase the value of H in the opposite direction up to the point c then the value of B comes to zero. The force required to remove the magnetizing force in opposite (oc) is called the magnetic coercive force. When H increases still further B too increases in opposite and attains magnetic property.(od). When H is reduced retentive magnetism of value oe is attained. When H is increased in positive direction the magnetic deflection force "of" takes place. Lastly magnet is saturated and comes to point (a). If we join the points a, b, c, d,e,f and back to a, we get a loop. The area of the loop determine the electromagnetic property of the metal. The force required to remove the residual magnetic field which is magnetic coercive force will dissipated as heat. So in large magnetic coercive force materials large power loss happen. This loss is known as Hysteresis loss.

While using the core of the electro magnet its area of hysteresis loop should be small. For example the area of the hysteresis loop of silicon steel is small. Hence in most cases silican steel is used as a core metal in making of electro magnet.

### Hysteresis loss

$$= \eta \beta m^{1.6} f v \frac{W}{m^3}$$

| Sl. No. | Material         | Hysteresis co-efficient |
|---------|------------------|-------------------------|
| 1       | Silicon Steel    | 0.001                   |
| 2       | Mild steel sheet | 0.003                   |
| 3       | Pure iron        | 0.004                   |
| 4       | Cast steel       | 0.012                   |
| 5       | Cast iron        | 0.016                   |

Pure iron is used as the core in electro magnets. For large size electromagnet silicon steel core is used. Iron and nickel mixed alloy of Permalloy core is used where less magnetic field is required as in Telephone. The mu metal which is an alloy of nickel, copper, chromium, and iron is used as core for less permeability and resistance. This will reduce the eddy current loss. This is used as magnetic screener in instrument transformer.

### Comparison of electric and magnetic circuit

#### Type of EMF:

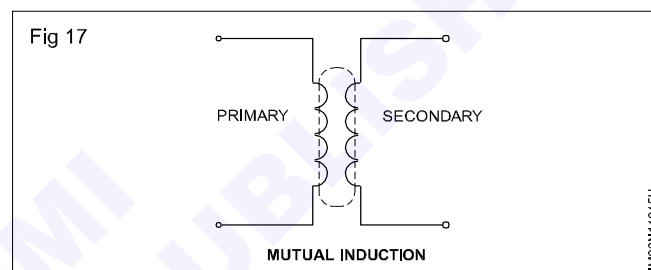
- 1 Dynamically induced EMF and
- 2 Statically induced EMF.

**Dynamically induced EMF:** In order to generate a dynamically induced EMF (electromotive force), the

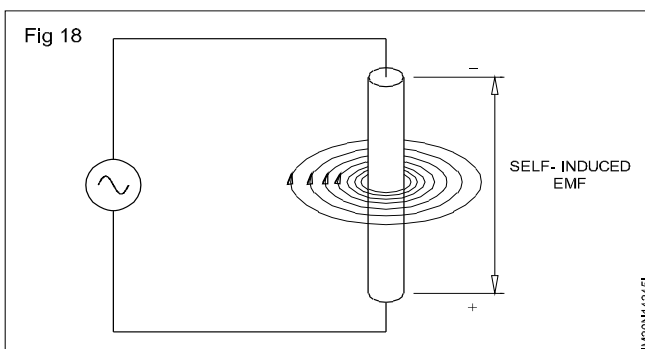
magnetic field system must be kept stationary while the conductor is moving. Alternately, the magnetic field system can be kept moving while the conductor is kept stationary. For example Generator. Induced EMF = BLV SINØ Volts, where B is the flux density, L is the length of the conductor, V is the relative velocity between the field conductors and Ø is the angle by which the conductor cuts the magnetic field.

**Statically induced EMF:** This type of EMF is generated by keeping the coil and the magnetic field system, stationary at the same time; that means the change in flux linking with the coil takes place without either moving the conductor (coil) or the field system.

**Mutual induction (Fig 17):** As shown two coils were placed nearby. When one coil is supplied with current the varying magnetic field is formed. This magnetic field will induce an EMF in the nearby coil. This is known as mutual induction. This used in transformers, induction furnace and ignition coil.



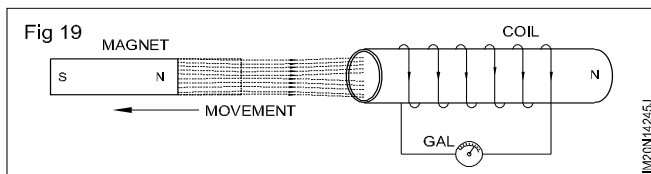
**Self-induction (Fig 18):** When an AC current passes through a coil the magnetic field around the coil varies. This varying magnetic field will induce an EMF on the stationary coil. This EMF is called self-induced EMF. This EMF will act in opposition to the AC voltage applied. Used in auto transformer, lightning arrestor, fluorescent lamp choke, choke used in welding filament and in arc rectifiers to sustain the arc.



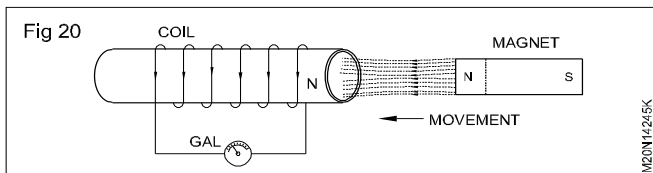
### Factors depends on induction

- 1 Number of turns in the coil.
- 2 Length of the coil.
- 3 Cross sectional area of the coil
- 4 Permeability of the core.

**Lenz's Law (Fig19) :** Lenz's law of electromagnetic induction states that the direction of the current induced in a conductor by a changing magnetic field is such that the magnetic field created by the induced current opposes the initial changing magnetic field which produced it.

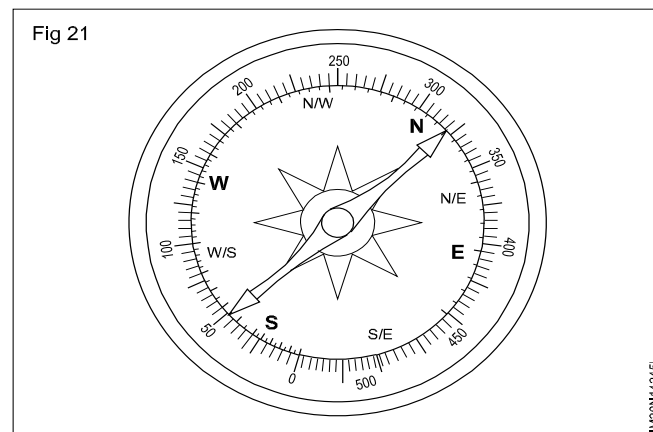


As shown in figure 20 if we move the north pole of a bar magnet inside the coil then a current will produce in ant clock direction. Hence the coil is subjected to North pole where the magnet is inserted. This north pole of coil end will oppose the north pole of the bar magnet as shown in figure.



Now if we remove the bar magnet from the coil the movement of current is clock wise. The polarity of coil now become south where the bar magnet has been removed. Now this south polarity of coil end will attract the north polarity of the bar magnet. The EMF induced by this will oppose the one which created this EMF.

## Magnetic Compass (Fig 21)



The magnetic compass, in navigation or surveying, an instrument for determining direction on the surface of Earth by means of a magnetic pointer that aligns itself with Earth's magnetic field. The dial of the compass is graduated in degrees of 360. North is 0 degree, East is 90 degree, South is 180 degree and west is 270 degree.

| S.No. | Electronics circuit                            | Magnetic circuit                              |
|-------|------------------------------------------------|-----------------------------------------------|
| 1     | Current $\frac{\text{EMF}}{\text{Resistance}}$ | Flux $\frac{\text{MMF}}{\text{Reluctance}}$   |
| 2     | Current (I) - (ampere)                         | Flux ( $\Phi$ ) - (Weber)                     |
| 3     | EMF (Volt)                                     | MMF (Ampere turn)                             |
| 4     | Resistance $R = \frac{\rho L}{A}$              | Reluctance $S = \frac{L}{\mu A}$              |
| 5     | conductivity $= \frac{1}{\text{Restivity}}$    | Permeability $= \frac{1}{\text{Reluctivity}}$ |
| 6     | Current density (A/m <sup>2</sup> )            | Flux density B (wb/m <sup>2</sup> )           |
| 7     | conductance $= \frac{1}{\text{Reistance}}$     | Perminance $= \frac{1}{\text{Reluctance}}$    |
| 8     | Resistivity                                    | Reluctivity $\mu_o \mu_r A$                   |

**Circuit breaker :** Circuit breaker is a controlling device. This can be used to make on and off the circuit under any load condition. When over load, short circuit or earth fault happens in a circuit, large amount of current will flow in the circuit. The circuit breaker can be used to break the circuit either manually or automatically during such faults. The circuit breaker works safely under fault condition drawing more power. The circuit breaker can with stand the fault to its rupturing capacity measured by MVA (mega volt ampere)

**Working principle of a Circuit breaker :** In circuit breaker there is fixed and a moving contact called as electrodes. On normal working condition the contacts will

be closed. When required the contacts can be opened either manually or automatically by the initiation of external devices. Due to some Electronics fault the circuit breaker is opened by the actuation of trip coil. The moving contacts were separated by the fixed contacts during fault condition. This separation causes an arc in between the contacts resulting interruption of current and production of heat. To lower this heat the arc much be quenched by oil, vacuum, air or sulfur hexafluoride gas (SF<sub>6</sub>).

### Types of circuit breaker

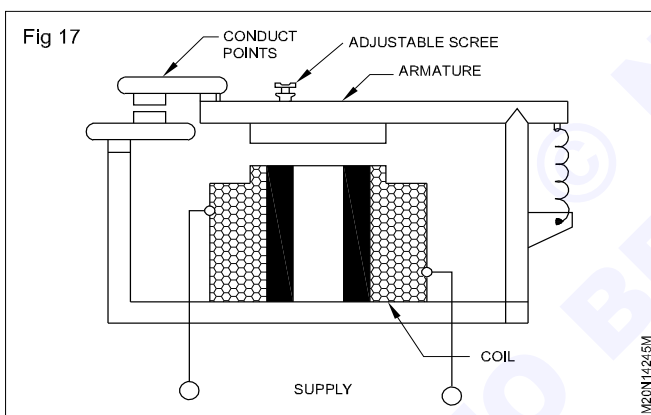
- 1 Oil circuit breaker (OCB)

- 2 Air circuit breaker(ACB)
- 3 Air blast circuit breaker(ABCB)
- 4 Miniature circuit breaker(MCB)
- 5 Molded case circuit breaker(MCCB)
- 6 Earth leakage circuit breaker(ELCB)
- 7 Vacuum circuit breaker(VCB) and
- 8 Sulfur hexafluoride circuit breaker(SF6CB).

**Relays :** A relay is the device that opens or closes the contacts to cause the operation of the other electric control. Relays control one Electronics circuit by opening and closing contacts in another circuit.

These relays are very much used Electronics, electronics and power system generation and distribution. The relay operates on sensing the parameters of current, voltage, frequency, heat and gas. We can see two types of basic relays.

- 1 **Electro mechanical relays (Fig 22) :** The relay consist of a pair of contacts, one moving and the other fixed. An electromagnetic coil is mounted on a frame. Under normal condition when supply is not given to the coil, the contact is open (NO). When the coil is energized by a voltage on some condition then it will attract the moving contact so that it make contact with the fixed contact and now the contacts closed (NC).



When the current decreases from a pre-determined value an Undercurrent relay is used. When the voltage increases or decreases from a pre-determined value is to be prevented then we use Voltage sensing relay.

**Current sensing relay:** This relays are used in circuits where the current exceed or decreased from a predetermined value.

**Under current relay:** The relay will operate when the current decreases from the determined value.

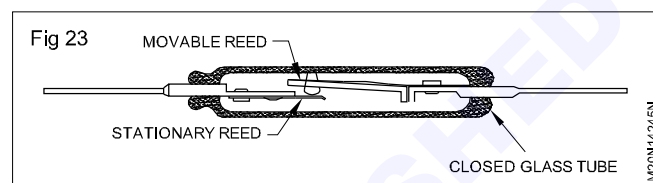
**Voltage sensing relay:** These relays operate when the voltage level increase or decrease from a predetermined value.

**Latching relay:** The contacts which maintains its position (open or close) even after the coil is de-energized is known as latching relay. To reset the contacts manually a spring hand reset mechanism is used. (HR) . The contacts can be reset Electronicsly through a coil is known as Electronics reset contacts(ER).

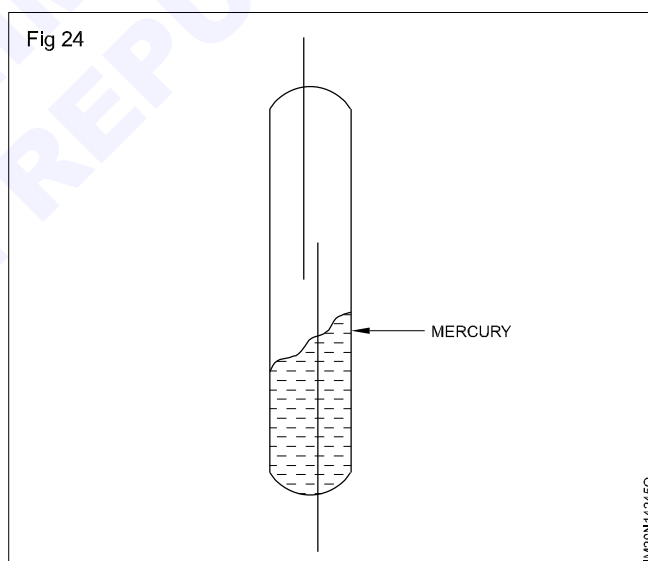
**Reed Relay:** Apart from normal relays, the reed relay employs a solenoid which induces movement on reed switch. Less power is required for the operation of reed relays. The tips of the contacts were made from gold or radium. The resistive tendency to current at the tips were low.

### Types of reed relays

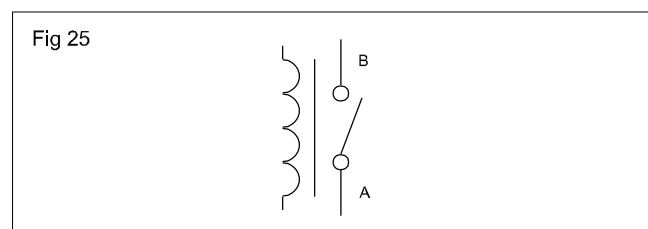
- 1 **Dry reed relay (Fig 23):** This relay consist of two reed contacts one fixed and the other moving. This arrangement is fitted inside a narrow glass tube. To prevent oxidation the tube is filled with an inert gas. A coil is wound around the tube and when it gets energized, the open contact of the reed relay is closed. When the coil is de-energized the reed contact tip opened.



- 2 **Mercury wetted contact relay (Fig 24):** On a vertically mounted closed glass tube, two reeds are mounted inside. A little mercury is filled at the bottom of the tube. When the coil around the tube is energized a magnetic field causes the reed contacts touch each other.



- 3 **Ferreed relay (Fig 25):** A switch is placed near an electromagnet. Due to the strong magnetic field present in the electromagnet the switch is pulled and closed. This is due to the pulse received by electromagnet. With absence of pulse the electromagnet de-energized and the switch open.





**Clapper type armature relay :** A moving contact fixed to an armature is placed on either side of two fixed contacts. On normal condition the right hand side fixed contact will be in touch with the moving contact. When the armature is energized the moving contact will move to its left side making contact with the left fixed contact and breaking contact from right fixed contact. With this we can make a closed contact open and opened contact closed.

**Impulse relay :** This is a special type of relay capable of operating in AC and DC circuits. When the coil get pulse, the mechanism in the armature moves contacts from one position to other position. When another release pulse applied to the coil the contacts returns to its original position.

**Thermal relay :** Thermal relay operates on variation in temperature. A bimetallic flexible moving contact bends and make contact with a fixed contact when the temperature varies from a predetermined value. There is some time delay for the bimetal strip to sense the temperature. This has been used as a time delay function in relays.

**AC Relay :** The magnetic field in an AC relay changes 100 times in a 50Hz system. Due to this there will be chattering on the contacts. To avoid this chattering there is a groove on the pole face in which a shading ring is placed. This shading ring will produce a magnetic field which will be lagging the main magnetic field. Hence when main magnetic field become zero there will be a little magnetic field in the shading ring. This will prevent chattering.

**Note :** Don't give DC supply to an AC relay. If a DC supply by accident given, large current will pass (due to absence of inductive reactance) and burn the coil. But if we change the polarity in a DC relay no harm is done and the relay will operate.

**Use of Solenoid:** Normally solenoid were used as electro magnets. Apart from this it can be used for

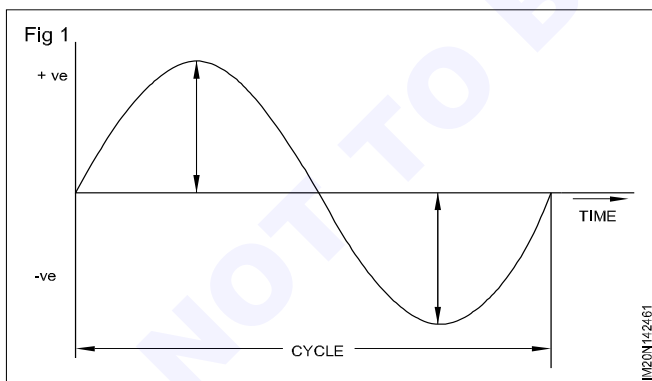
- 1 Used as inductance or impedance,
- 2 Miniature receiving antenna.

## AC Circuits

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

- explain the principles of AC Current
- explain difference between AC and DC
- explain laws governing AC current.

**Alternating current (Fig 1):** The current produced in AC generator or Alternator is called Alternating current. This along a particular time the value will vary in both directions. The voltage or current will be zero at first and in one direction it will increase and attain maximum value and then decreases to zero. Again it will increase in the opposite direction to maximum and then decrease to zero.



AC supply is used everywhere in house, offices, factories, shops etc. This is the cheapest generation of power and can be transmitted over long distance with less transmission loss. Large power with many times of voltage with low current can be transmitted. The AC generation is 6.6KV, 11KV, 33KV and with the help of step up transformer higher voltage of 66KV, 110KV, 220KV and 400KV can be transmitted. These will be ultimately reduced by step down transformers to 415V (3Ø) and used. The 1 Ø supply is 240V between the one phase and neutral is used for many single phase domestic and industrial appliances.

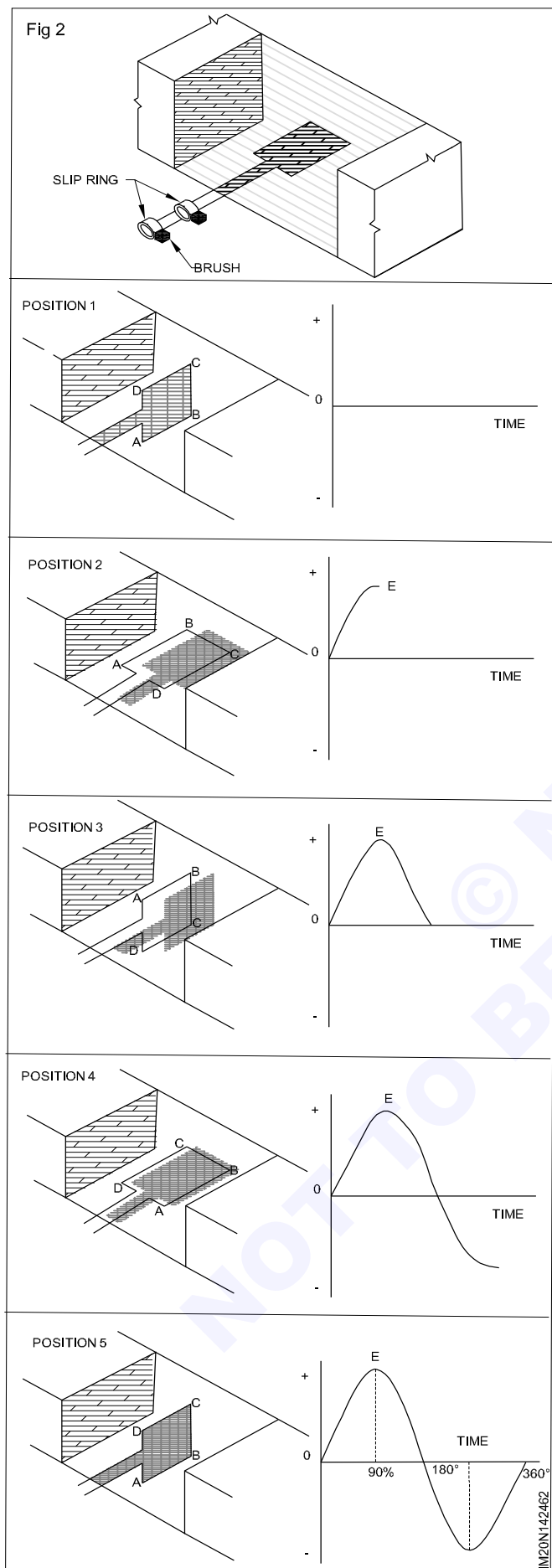
### Difference between AC and DC

| S.No | AC                                                          | DC                                          |
|------|-------------------------------------------------------------|---------------------------------------------|
| 1    | 6.6KV, 11KV, 33KV generation                                | 6600V and less value in generation          |
| 2    | Voltage can be stepped up or down by transformer            | Transformation can't be done                |
| 3    | Less transmission charges                                   | Transmission cost is costly                 |
| 4    | Less maintenance cost                                       | High maintenance cost                       |
| 5    | High power alternator of range 500000KW can be manufactured | Up to 10000KW generator can be manufactured |
| 6    | Speed control is not easy                                   | Speed control is easy                       |

**AC Generator :** AC generation takes place as per Faraday's Law. When a conductor revolves in a magnetic field an EMF is induced in the conductor which is proportional to the rate of change of flux linkage. The wave form produced by the AC generating current is of Sine form.

**EMF generated in AC generator (Fig 2) :** Inside a cylindrical magnet of south pole a conductor of AB,CD rotate clock wise and an EMF is induced as shown in the figure 2.



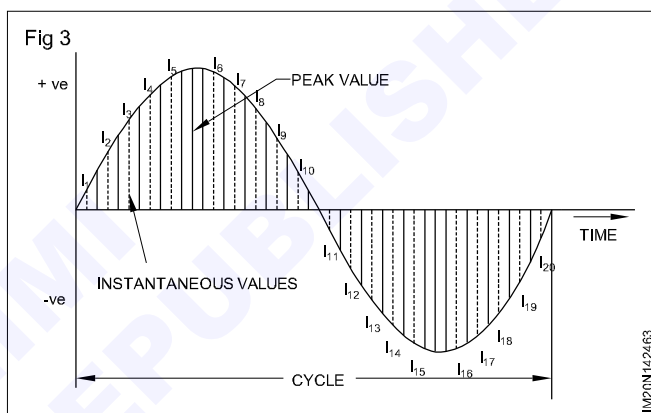


| Position of the conductor | Induced EMF                       |
|---------------------------|-----------------------------------|
| 0°                        | ZERO V                            |
| 0 - 90°                   | ZERO TO MAXIMUM IN Positive value |
| 90 - 180°                 | Positive maximum EMF to ZERO      |
| 180 - 270°                | Zero to negative maximum EMF      |
| 270 - 360°                | Negative maximum to zero V        |

When the conductor revolves a full circle of 360 degree in the magnetic field an alternating current is produced.

### AC fundamental terms and definitions

**Cycle (Fig 3):** The alternating current or voltage undergoes changes one time in its magnitude and direction and comes to its original position, has termed as one cycle.



**Period:** The time taken to complete one cycle is called the period.  $T = 1 / F$  second.

**Frequency:** The number of cycles performed in one second is called frequency. In India 50 cycles per second AC current is generated. The unit of frequency is in Hertz.  $F = PN / 120$  where P is the number of poles and N is the revolution per minutes.

**Instantaneous Value:** The instantaneous value is "the value of an alternating quantity (it may ac voltage or ac current or ac power) at a particular instant of time.

**Peak or maximum value:** In an A.C source, peak value of A.C is the maximum value of current in either direction of the cycle.

**Average value:** The average value of alternating current or voltage is defined as the average of all values of current or voltage over a positive half-cycle or negative half-cycle.  $I_{av} = I_1 + I_2 + I_3 + \dots + I_n$ .  $I_{rms} = I_{max} \times 0.707$  and  $V_{rms} = V_{max} \times 0.707$ .

**RMS value:** All the square root of the instantaneous values in an half cycle is termed as Root Mean Square value RMS All AC meters shows the RMS value and also called as effective value.

**Form factor:** The ratio of the value of RMS to the average value is the form factor.. Hence Form factor = RMS Value / Average value =  $0.707 \times I_{max} / 0.637 I_{max} = 1.1$

**Crest factor:** Crest factor is defined as the ratio of peak value to RMS value which is  $I_{\max} / I_{\text{RMS}} \times 0.707 = 1.414$

**Scalar quantity:** It is a measurable quantity that is fully described by a magnitude or amount. In scalar quantity the addition and subtraction is algebraically.

**Vector quantity:** A vector quantity is defined as the physical quantity that has both directions as well as magnitude. The addition and subtraction cannot be done as in scalar quantity and should be done vector addition and subtraction.

**Phasor:** A phasor is a scaled line whose length represents an AC quantity that has both magnitude (peak amplitude) and direction (phase) which is frozen at some point in time.

**Phase:** The current and voltage in an AC circuit do not peak at the same time. The angular phase difference between the maximum possible values of the two alternating quantities having the same frequency is called the phase difference.

**In phase:** If two sine waves attain same higher and lower magnitude in same time, then the two waves are said to be "in phase". There is no phase angle difference between these two waves.

**Out of phase:** If two sine waves attain same higher and lower magnitude in different time, then they are called "out of phase" waves.

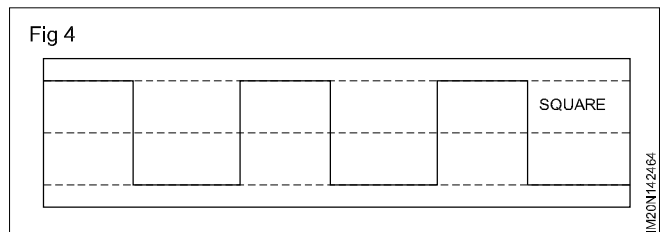
**Phase angle:** The difference in angle between two out of phase sine wave is termed as the phase angle.

**Leading quantity:** When in two sine waves, the first sine wave which attain its maximum value is called the leading quantity.

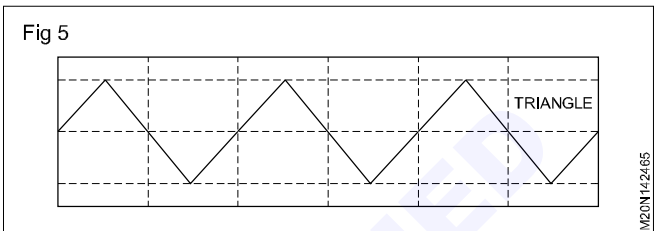
**Lagging quantity:** When in two sine waves, the second sine wave which attain its maximum value is called the lagging quantity.

### Types of wave forms

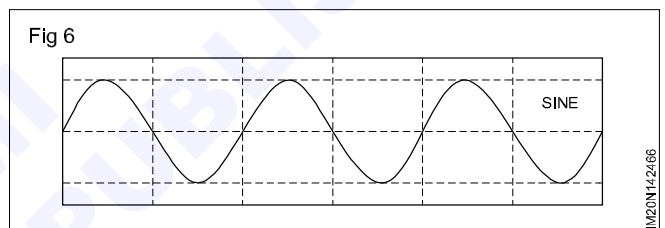
- 1 **Square wave form (Fig 4):** Square wave is a non-sinusoidal wave. The amplitude alternates at a steady frequency between fixed minimum and maximum values, with the same duration at minimum and maximum. In an ideal square wave, the transitions between minimum and maximum are instantaneous. The waves has odd harmonics.



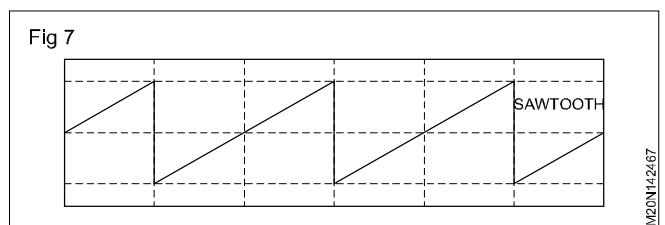
- 2 **Triangular wave (Fig 5):** It is a non-sinusoidal waveform named for its triangular shape. It is a periodic, piecewise linear, continuous real function. The waves has odd harmonics.



- 3 **Sine wave (Fig 6):** This is a sinusoidal uniform wave. In every points in the waves the angular displacement is proportional to the trigonometric sine function.



- 4 **Saw tooth wave (Fig 7):** The saw tooth wave (or saw wave) is a kind of non-sinusoidal waveform. It is so named based on its resemblance to the teeth of a saw. The convention is that a saw tooth wave goes upward and then sharply drops.



## Inductor and inductance

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

- describe inductor and inductance
- explain types of inductors
- explain inductors in series and in parallel
- explain self-induction and mutual induction and the
- explain Q factor of the coil.

**Inductance :** Inductance is the tendency of an Electronics conductor to oppose a change in the electric current flowing through it .The flow of electric current in a coil creates a magnetic field around the conductor. The field strength depends on the magnitude of the current. The coil is called

inductor. The unit of inductor is in Henry(H) denoted by symbol L.

### Types of inductors

- 1 Air core inductor

- 2 Iron core inductor
- 3 Ferite core inductor
- 4 Laminated core inductor.
- 5 Variable inductor
- 6 Film inductor
- 7 Coupled inductor
- 8 Toroidal inductor and
- 9 Multi-layered inductor

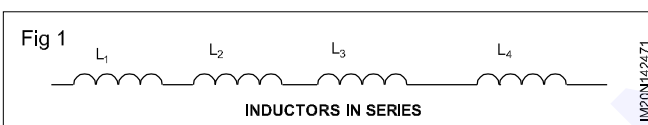
#### Factors determining the inductance

- 1 Core material
- 2 Number of turns
- 3 Distance between each turns and
- 4 The cross sectional area or diameter of the coil.

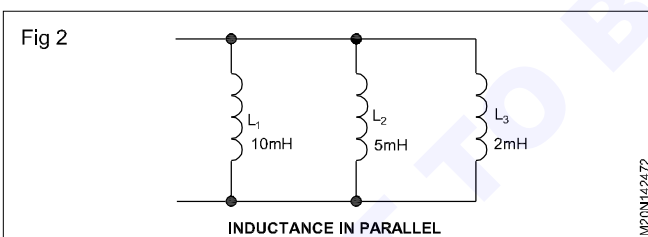
**Energy stored:** Due to the inductance, the current produce the magnetic field and store the energy.

$$W = \frac{1}{2} L \times I^2$$

**Inductors in series (Fig 1) :** As shown when inductors connected in series the total value of inductance is equal to the sum of all inductance in series.  
 $L = L_1 + L_2 + L_3 + \dots + L_n$



**Inductors in parallel (Fig 2):** If the inductors were connected in parallel then the total value of the inductance is given by  $1/L = 1/L_1 + 1/L_2 + 1/L_3 + \dots + 1/L_n$ . The value of total inductance will be less than the smallest value of inductor connected in series.



**Fixed and variable inductors:** Fixed inductors as name implies have fixed value of inductance. Example: Bulb ballast, antenna filter circuit and voltage controlled oscillator. The value of the variable inductance is achieved by moving

## Capacitors

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

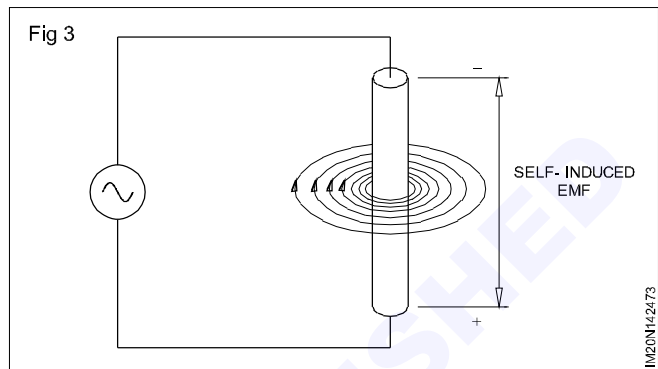
- describe capacitor and capacitance
- explain the principal of capacitor and explain how the energy is stored
- explain types of capacitors
- explain how to check capacitors.

**Introduction :** Capacitor is a device which stores energy. In between two parallel Electronics conductor an insulating material called di-electric material is placed.

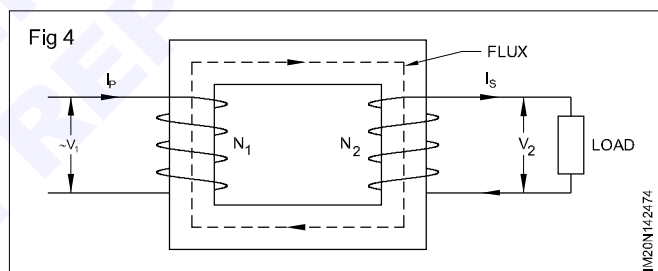
the core either inside or outside of the coil. It is used in radio and other equipment that require specific fine tuning of inductance.

**Henry:** In a circuit in one second if 1 ampere flows and induce an EMF of 1 volt then the inductance of the coil is 1L (Henry)

**Self-induction (Fig 3) :** As shown in figure an AC supply is given to the coil. The magnetic field around the coil varies and produce an EMF with the non-moving coil. EMF produced is by self-induction.



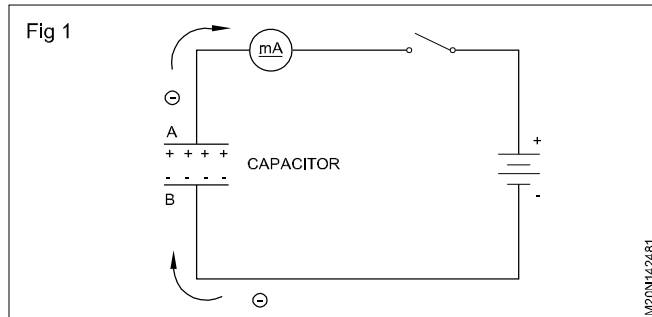
**Mutual induction (Fig 4) :** As shown in figure two coils are placed nearby on a core. Supply is given to one coil and the magnetic field produced by it will interact with the nearby coil. The magnetic field is a fluctuating one it produces an EMF on the second coil. This is due to mutual inductance.



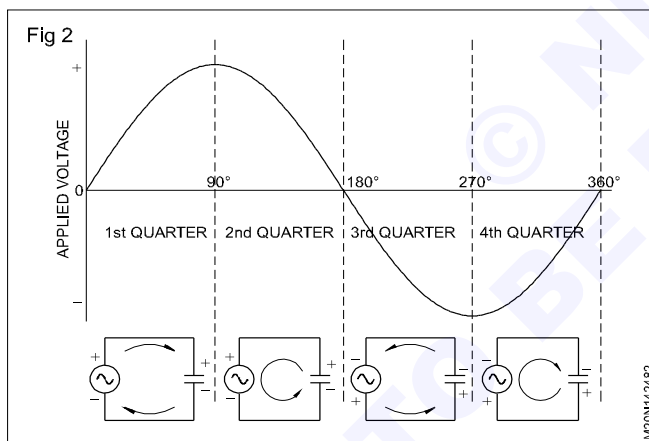
**Q Factor :** This factor is used to determine the quality of an inductor. It is the ratio of the inductive reactance to its resistance at a constant frequency. Large Q factor inductors are used in tuning circuit of radio receiver.

$$Q = \frac{XL}{R} = \frac{2\pi f l}{R}$$

the switch is "on" we can see through the milli ammeter a DC current is flowing. Within seconds the voltage between the capacitor plates will be same of the DC source supply, no electron movement takes place. This will be indicated as zero in milli ammeter. In this stage we know the capacitor stores the energy. Now if we connect a load across the electrodes of the capacitor then the energy stored will be dissipated.



As shown in figure 2 when a capacitor is connected to an AC supply, the first quarter (0 to 90°) will charge the capacitor and in the second quarter (90 to 180°) the capacitor discharges. Like that in opposite direction of 180 to 270° and 270 to 360° charge and discharge happens. Since this is happening continuously there will be AC current flowing with out stop. On contrary to this in DC circuit the charge only happens and discharge doesn't happens automatically. Hence we can conclude the capacitor in a DC circuit resist the current flow.



**Capacitance:** Capacitance is the property to store electric charge. The unit of capacitance is in Farad and denoted by symbol "C". Capacitance  $C = \text{Charge } Q / \text{Voltage } V$ ,  $C = Q/V$  farads.

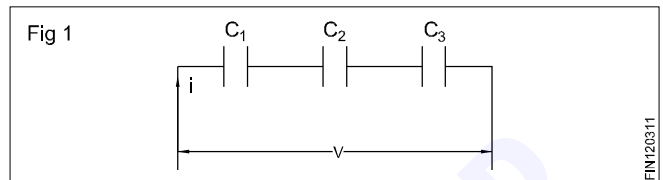
**Farad:** If the applied voltage across the capacitor is 1 volt to produce 1 coulomb charge then the capacitance value is 1 farad.. 1 farad = 1 coulomb / 1 volt. Farad is a large unit, hence it is called in micro farad. 1 micro farad = 10 to the power minus 6 farad. 1 Nano farad = 10 to the power minus 9 farad, 1 pica farad = 10 to the power of minus 12 farad.

**Energy stored in a capacitor:** The energy stored in a capacitor depends on its capacitance and charged voltage.  $E = (1/2) \times C V^2$ . Where E is the energy, C the capacitance and V voltage.

**Factors determining the capacitance :** The value of the capacitance of a capacitor depends

- 1 Directly proportional to the surface area of the metal sheets
- 2 Indirectly proportional to the distance in between the electrode
- 3 Depends on the di-electric strength of the insulator and
- 4 Depends on the temperature.

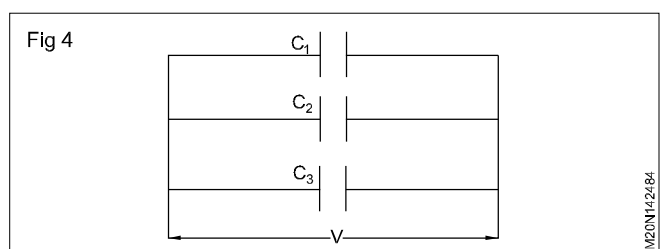
**Capacitors connected in series (Fig 3) :** More than one capacitors are connected in series and the voltage applied as shown.



- 1 Total value of the capacitance =  $1 / C_1 + 1 / C_2 + 1 / C_3 + \dots + 1 / C_n$ .
- 2 Charge in all capacitors is same  $C_1 = C_2 = C_3 \dots = C_n$
- 3 The voltage drop in each capacitor depends on its capacitance.
- 4 The sum of the voltage drop of all the capacitors equal the source supply voltage.
- 5 The voltage drop on each capacitor will be small than its rated voltage.

To determine the voltage drop in a capacitor,  $V_x = (C_t \times V_s) / C_x$  where  $V_x$  is the total voltage drop,  $C_t$  is the total value of capacitance,  $V_s$  is the supply voltage.

**Capacitors connected in parallel (Fig 4):** More than one capacitor is connected in parallel. Supply is given across the capacitors.



- 1 Total value of the capacitance  $C_t = C_1 + C_2 + C_3 + \dots + C_n$ .
- 2 Voltage drop across each capacitor is the same.
- 3 The charge in each capacitor depend on its capacitance.
- 4 The total value of the charge  $Q_t$  will be the sum total of individual charges =  $Q_1 + Q_2 + Q_3 + \dots + Q_n$
- 5 The supply voltage should be greater than the break down voltage of the capacitor in parallel.

**Note:** The total capacitance of the circuit is always greater than the least value capacitor.

**Types of capacitors:** The types depends on the di-electric insulator used in it.

- 1 Mica capacitor
- 2 Ceramic capacitor.

- 3 Electrolytic capacitor
- 4 Paper capacitor
- 5 Variable capacitor.

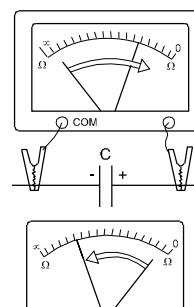
#### Use of capacitors

- 1 In tube lights:** When connected in parallel to the tube, the power factor increases. When two tube lights connected in parallel, a capacitor in series to a tube light will remove the stroboscopic effect is removed. By connecting the capacitor in parallel to the starter of the tube, the radio interference is reduced. Also the spark produced at the contact point in starter while opening will be arrested.
- 2 In gas discharge lamps:** Choke or high reactance transformer is used and this will reduce the power factor. To compensate this a capacitor is used in parallel to the starter.
- 3 In Motor:** In a single phase motor a capacitor is connected in series with the starting winding. By doing so the single phase works like a two phase and good starting happens.
- 4 In Supplies:** To short come the power factor loss due to the inductive load, a capacitor is connected in parallel to the supply.

**Checking of the capacitor (Fig 5) :** A fully discharged capacitor is connected to a high range ohm meter as shown in the figure. Through the meters battery voltage negative, the capacitor begins to charge.

To check the capacitor connect meter leads to the leads of the capacitor. Due to the low resistance between both terminals of the meter and capacitor a large amount of current will flow.

Fig 5



Due to this the pointer of the meter moves rapidly to infinity. When the capacitor is charged, the potential difference between the meter and capacitor terminal drops down. Due to the low current the needle of the meter moves to zero. By this Quick test we can check the capacitor. This testing is not suitable for low value capacitance of ceramic and paper capacitor. The charging current will be very low for movement of the meter pointer. Quick test is suitable for high value and electrolytic capacitors.

**Time constant :** The time taken for a fully discharged capacitor to attain 63% of charge in seconds is known as the time constant. The symbol is  $\tau$  (tau in Greek alphabet).  $\tau = RC$  where  $R$  is resistance and  $C$  is the capacitance. In each time constant the capacitor takes 63% of time for charge and 37% time for discharge. For example  $1\mu\text{F}$  capacitor with  $2\text{M}\Omega$  resistor of  $50\text{V}$  supply will have the time constant  $\tau = CR = 2 \times 10^6 \times 1 \times 10^{-6} = 2$  seconds. Hence in 5 time constant of  $(5 \times 2 = 10 \text{ seconds})$  capacitor will reach  $50\text{V}$ .

| Time constant                 | Charging voltage                             | Charging current                            |
|-------------------------------|----------------------------------------------|---------------------------------------------|
| 1 <sup>st</sup> time constant | 31.6V (63% OF 50V)                           | $0.37 \times 25 = 9.35 \mu\text{A}$         |
| 2 <sup>nd</sup> time constant | $31.6 + 11.6 = 43.2\text{V}$ (for 18.4V 63%) | $0.37 \times 9.25 = 3.4 \mu\text{A}$        |
| 3 <sup>rd</sup> time constant | $43.2 + 4.3 = 47.5\text{V}$ (for 6.8V 63%)   | $0.37 \times 3.4 = 1.26 \mu\text{A}$        |
| 4 <sup>th</sup> time constant | $47.5 + 1.6 = 49.15\text{V}$ (for 2.5V 63%)  | $0.37 \times 1.26 = 0.47 \mu\text{A}$       |
| 5 <sup>th</sup> time constant | $49.15 + 0.57 = 49.7\text{V}$ (for 0.9V 63%) | $0.37 \times 0.47 = 0.1 \mu\text{A}$ near 0 |

#### Types, ratings and application of capacitors

| Types                 | Capacity         | DC Volt range | Use                                 |
|-----------------------|------------------|---------------|-------------------------------------|
| Ceramic disc          | 1PF TO 1MF       | 50-500        | RF and general                      |
| Ceramic tube          | 1PF TO 100PF     | 500-5K        | General usage and VHF               |
| Paper                 | 0.001 TO 1PF     | 200-1600      | Motor and power supply power factor |
| Polyester             | 0.001MF          | 100-600       | Small electronic circuit            |
| Electrolytic Aluminum | 1 TO 500000MF    | 50-100        | Power supply and filter circuit     |
| Mica                  | 330PF TO 0.05MF  | 50-100        | High frequency                      |
| Ceramic-variable      | 1.5 TO 16.1PF    | 200           | High frequency                      |
| Film variable         | 0.85 TO 1.2-30PF | 50            | Oscillator antenna RF circuit       |
| Air variable          | 10 TO 365PF      | 50            | Broadcast receiver                  |
| Teflon variable       | 0.25 TO 1.5PF    | 2000          | VHF & UHF                           |



# Impedance

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

- explain Impedance, Reactance, Admittance and Q Factor
- explain Electronics resistance, Inductor and Capacitor in series and in parallel.

**Impedance :** In a circuit having resistance, inductance, capacitance together or any of the two together forms resistance to the electric current flow is known as impedance. Denoted by the letter Z. Unit is in ohms.

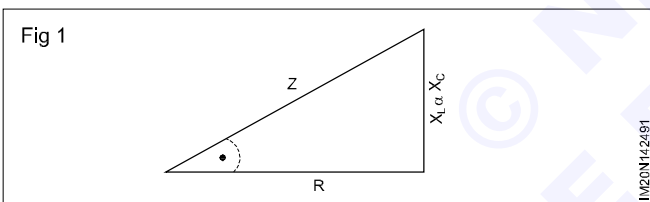
$$Z = \sqrt{R^2 + (X_L \approx X_C)^2}$$

**Inductive reactance:** In a coil the resistance to the inducement of EMF is called inductive reactance. The symbol is  $X_L$  and the unit is ohm.  $X_L = 2\pi fL$  Where f is the frequency and L is the inductance.

**Capacitive reactance:** The resistive force offered to the charging of capacitor is called capacitive reactance. This is denoted by symbol  $X_C$ . And the unit in ohm.

$$X_C = \frac{1}{2\pi fC} \quad C \text{ is the capacitance.}$$

**Impedance triangle:** In an impedance triangle, the resistance (r) is always on the bottom of the triangle, the reactance (x) always goes on the side and the hypotenuse is always the impedance (z). (Fig 1)



$$Z = \sqrt{R^2 + X^2}$$

$$X_L \text{ or } X_C = \sqrt{Z^2 - R^2}$$

$$R = \sqrt{Z^2 - X^2}$$

$$\cos \theta = \frac{R}{Z}$$

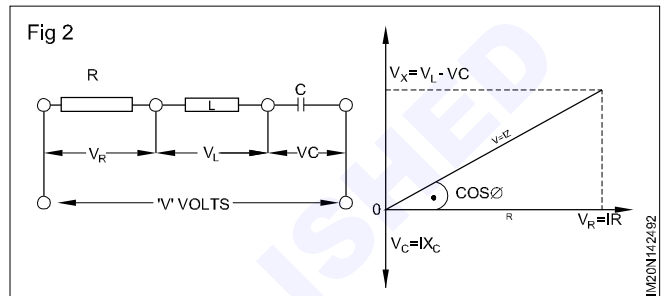
$$\sin \theta = \frac{X_L \text{ or } X_C}{Z}$$

**Resistor, inductor and capacitor in series:** In Fig 2 R, L, C were connected in series to a AC supply source. V. The voltage drop in each element is  $V_R$ ,  $V_C$  and  $V_L$ . The current in the resistor will be in phase with voltage, in inductance it is  $90^\circ$  lagging and in capacitor it is  $90^\circ$  degree leading.  $V_L$  and  $V_C$  will depend on the value of  $X_L$  and  $X_C$ . Power factor depends on these values. Like in this RLC circuit frequency f is in direct proportion to inductive reactance and inversely proportional capacitive reactance. So with change in frequency at one stage  $X_L$

and  $X_C$  will be same and only resistance exist in the circuit. The frequency at which  $X_L$  and  $X_C$  becomes same is called the resonance frequency and which is given by the formula

$$\frac{1}{2\pi\sqrt{LC}}$$

The power factor at the resonance frequency is unit PF. When  $V_L$  and  $V_C$  are same then it is called voltage resonance.



**AC Parallel circuit:** In AC parallel circuit the voltage will be same in all the branch and the current depends on branch impedance. The total current in the circuit is addition of phasor value of the branch current. To know the total current we can find in two ways

- 1 Vector or phasor method and
- 2 Admittance method.

AC Parallel circuit admittance method to find current (Fig 3) Branch current  $I = E/Z$  and  $I = E \times I/Z$  where  $I/Z$  is the admittance and is the inverse value of the impedance. It is denoted by Y and equals to  $I/E$ . Hence total admittance  $Y_t = \text{Total current} / \text{applied voltage} = \text{addition of phasor current divided by the applied voltage}$ . Admittance can be determined by two components.

- 1 The component in phase to the applied voltage is called the conductance and denoted by letter "g".
- 2 The component which is in perpendicular (quadrature) to the applied voltage is called susceptance and denoted by letter "b"

$$\begin{aligned} \text{Conductance } g &= \text{Admittance} * \cos \theta, \\ &= Y * \cos \theta, \\ &= I/Z * R/Z \quad (Y = 1/Z \cos \theta = R/Z) = R/Z^2 \end{aligned}$$

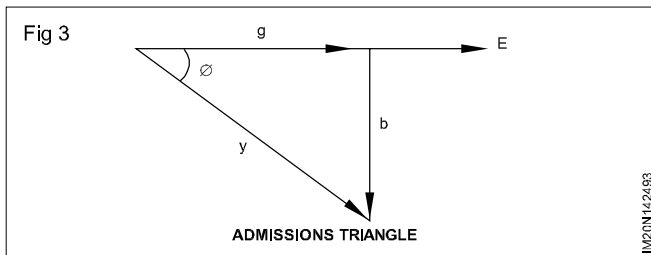
$$\text{Conductance } g = R / R^2 + X^2.$$

$$\begin{aligned} \text{Susceptance } b &= \text{Admittance} * \sin \theta, \\ &= Y * \sin \theta, \\ &= I/Z * R/Z, X/Z^2 \end{aligned}$$

Susceptance  $b = X / R^2 + X^2$ . The units of admittance, conductance and Susceptance is mho with symbol  $\mathfrak{U}$

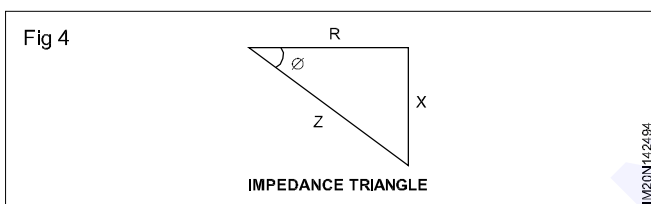
## Admittance

**RLC Parallel circuit (Fig 3):** In the circuit the resistor, inductor and the capacitors were connected in parallel.



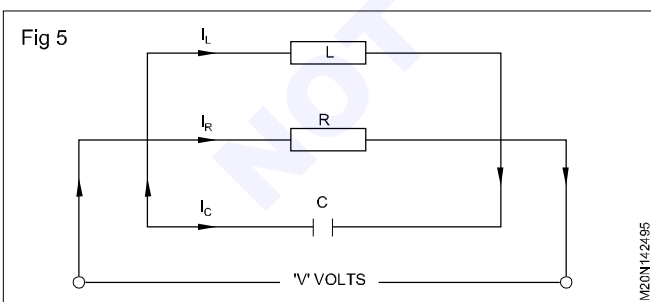
- 1 In this circuit the voltage across the resistor and capacitor will be the supply voltage.
- 2 The current in the resistor will be in phase with the supply voltage. The current in inductor will be  $90^\circ$  lagging to the supply voltage and by leading  $90^\circ$  to the capacitor.
- 3 Adding the currents in the three elements vectorially we get  $I_x = I_L - I_C$ . Hence the line current will be (Fig 4)

$$I = \sqrt{I_R^2 + (I_L - I_C)^2}$$



**Resonance in AC circuit :** Electronics resonance occurs in an AC circuit when the effects of the two reactances, which are opposite and equal, cancel each other out as  $X_L = X_C$ . The point on the above graph at which this happens is where the two reactance curves cross each other.

**Series resonance (Fig 5) :** Consider a RLC circuit in which resistor, inductor and capacitor are connected in series across a voltage supply. This series RLC circuit has a distinguishing property of resonating at a specific frequency called resonant frequency.

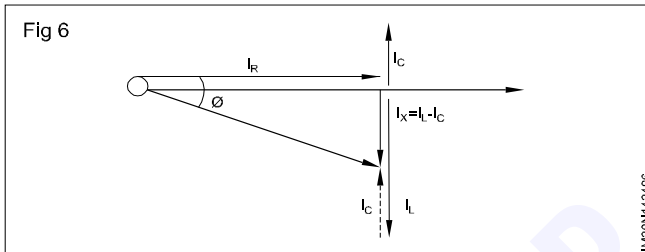


In this circuit containing inductor and capacitor, the energy is stored in two different ways

When a current flows in an inductor, energy gets stored in magnetic field.

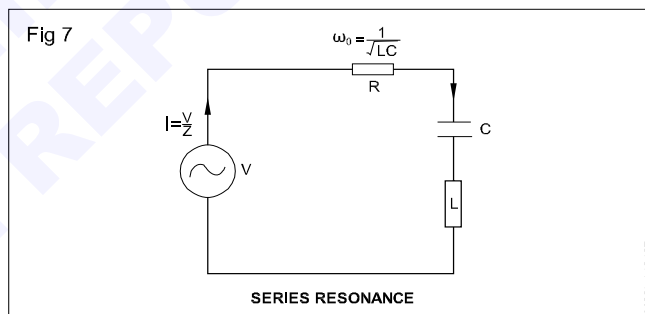
When a capacitor is charged, energy gets stored in static electric field.

**Parallel resonance circuit (Fig 6) :** A parallel circuit containing a resistance, R, an inductance, L and a capacitance, C will produce a parallel resonance (also called anti-resonance) circuit when the resultant current through the parallel combination is in phase with the supply voltage. At resonance there will be a large circulating current between the inductor and the capacitor due to the energy of the oscillations, then parallel circuits produce current resonance.

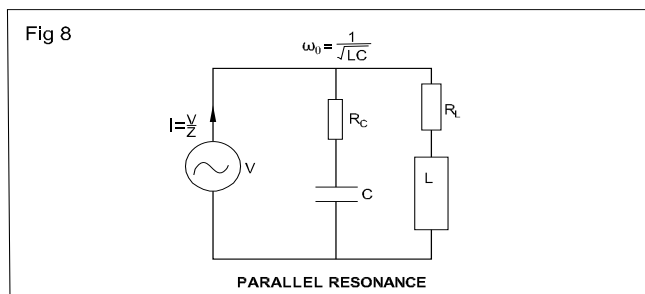


**Resonance in RLC circuit:** In series RLC circuit the resonance depends on the magnitude of the inductive and capacitive reactance to be equal.

**Converting Galvano meter to Ammeter (Fig 7):** As shown in the figure ammeter should be connected in series in the circuit. By adjusting the shunt resistor more current will be passing in the circuit. By this way Galvano meter has been working as an ammeter. The shunt should be connected in parallel to the meter. Now the total current in the circuit is  $I = I_g + I_s$ . Where  $I_g$  is galvano meter current and  $I_s$  current through shunt.



**Converting Galvano meter to Volt meter (Fig 8):** As shown in the figure voltmeter should be always connected in parallel. Galvano meter is a sensitive meter hence can't be used to measure high voltage. A series high resistor is connected with galvano meter to read the voltage.



**Q Factor:** Q factor (also known as Quality Factor or Q-factor) is defined as a dimensionless parameter that describes the underdamped condition of an oscillator or resonator. The quality factor measures the performance of a coil, a capacitor, or an inductor in terms of its losses and resonator bandwidth.

## AC Generator and DC generators and its working principles

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

- explain the principle of AC/DC Generators and its working
- explain Faraday's law, Lenz's law and Fleming left hand rule.

**Introduction :** These are called Alternator or AC Generator. This will produce constant frequency and rotate in a constant speed and hence also called as Synchronous Alternator or Synchronous Generator. These machines convert mechanical energy to Electronics energy. As per Faraday's laws of electromagnetic induction AC voltage is induced.

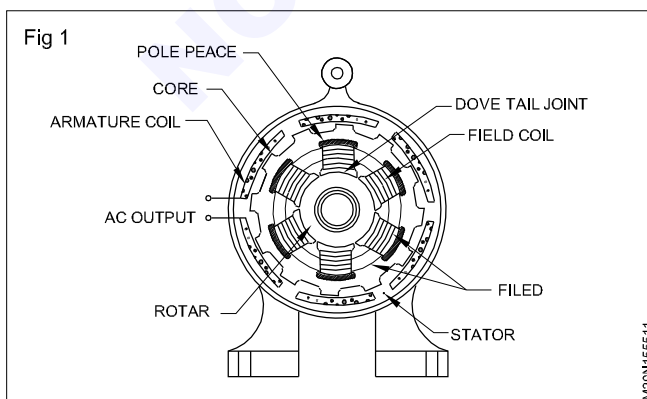
**Working principal of Alternator :** At the center of the main magnetic field a current carrying rotating conductor cut the magnetic field and an EMF is induced in the conductor. This is the principal of DC Generator and AC generator too work on the same principal. The value of the induced EMF depends on the flux and the speed of the conductor.

The AC voltage induced in the armature is collected by the slip rings. In DC Generator the field is stationary and the armature rotates. In Alternator the armature is stationary and field rotates OR the field is stationary and armature rotates.

### Advantage of Armature stationary and rotating type

- 1 The weight of the field is less and can be rotated in high speed. Due to this more voltage can be produced.
- 2 In the stationary armature the windings are more and the conductor is thick. Due to this the induced voltage can be increased with increase in output power.
- 3 With stationary armature the insulation of the winding can be done easily.
- 4 With the stationary armature the induced voltage can be collected by stationary terminals. There is no need for carbon brushes and thereby avoiding sparks.
- 5 To give supply to the field two slip rings and brushes of low capacity required.

### Parts of an Alternator (Fig 1)



The main three parts are

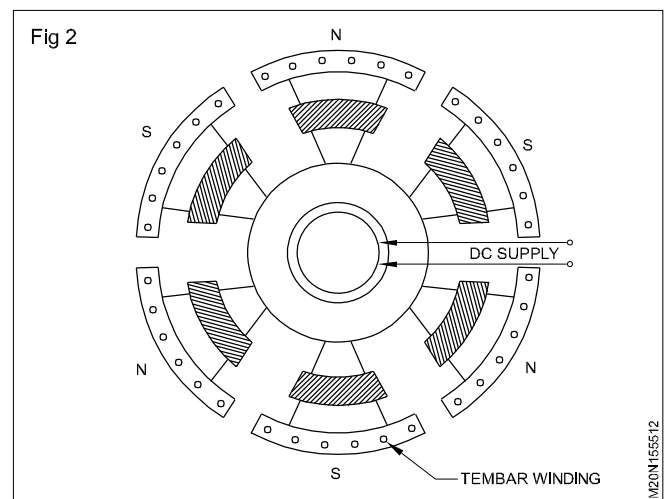
- 1 Stator,
- 2 Rotar and
- 3 Excitor.

**1 Stator:** The frame is made of cast iron. Slotted silican steels core is fixed inside the stator frame. Inside the slot the windings are placed. The inner silicon stell core is laminated so that the eddy current loass due to the armature core is lowered. The armataure winding on the stator get heated and for cooling ventilating ducts were available.

**2 Rotor:** Therte are two types of rotors.

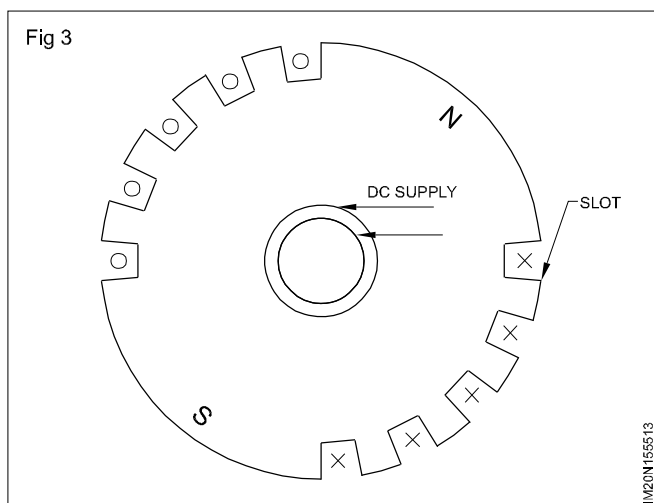
- A Salient pole rotor and
- B Smooth cylindrical rotor.

**A Salient pole rotor (Fig 2) :** As shown in the figure thin laminated silican stamping were joined together by rivet or bolts. This forms as poles. This poles are projected towards the stationary armature. The top area of this poles are curved. This type of rotors are small in length and large in diameter. There is space enough to place the field coils. The conduction of heat in the field coil is done easily. The cost of rotor is low. During operation machine produce much sound. To prvent hunting the face of the poles are provided with damper windings. The field coils are connected in series so that north and south poles were created. The two ends of the field coil is connected to the slip ring. This rotors are used in slow and medium speed alternator. The poles formed is from 6 to 40. The maximum speed is 1000 RPM. To start the rotor a disel engine is used as the prime mover.



**2 Smooth cylindrical rotor(Fig 3):** As shown in figure the cylindrical rotor of long length with less diameter is

used. Rotor is made of steel with slots over its surface. Field windings were placed inside the slots. 2 or 4 poles can be formed in the rotor. These rotors are used in high speed alternator. The maximum speed is from 1500 to 3000RPM. Since the rotor speed is high, it is made of solid steel by forging. This is used with steam turbine. This alternator has got high machine strength.



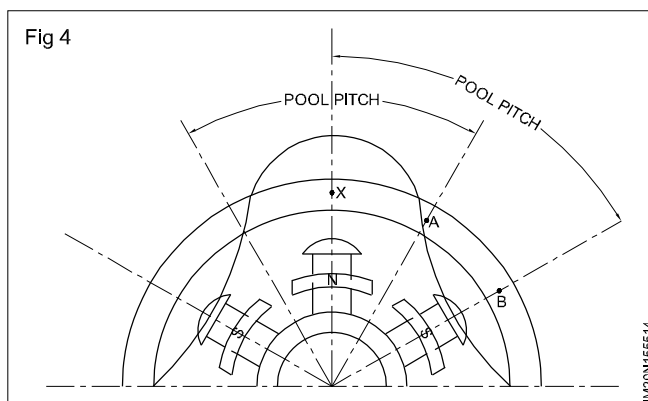
**3 Exciter:** A small DC shunt or a compound generator is connected to the alternator shaft. The exciter produces 110 to 250V DC. This voltage is fed to the field of the rotor through slip rings.

**4 Damper winding:** Damper windings are used to prevent hunting and to attain the synchronous speed of the alternator. On the top side of the salient pole shoe, holes are there to hold copper bars. The ends of the copper bars are shorted. This is called damper winding or squirrel cage winding. When the alternator rotates on normal synchronous speed no current passes through the damper winding. When the rotor deviates from synchronous speed there will be current in the damper winding. This current produces a torque on the shaft which adjusts the speed to synchronous speed. Moreover, these damper windings on unbalanced load conditions will balance the 3 phase supply. No damper winding is provided on turbo alternators since the field poles are solid and strong.

**5 Relation between speed and frequency of alternator (Fig 4):** Rotor speed of the alternator  $N$ , Frequency of the induced EMF ( $f$ ), and number of poles  $P$  has a relation between each other. As shown in Fig 4, the conductor  $X$  rotates from the mid of the pole in a clockwise direction. When the conductor passes the mid of the north pole, the flux density is higher and the EMF induced is also high. When the conductor is in between the two poles, less EMF is induced, and when it comes at the center of the south pole, again high EMF is induced. The direction of the EMF induced is opposite to each other under North and South poles. Hence, when the conductor passes through a pair of poles, a full cycle EMF is induced.

$P$  = Total number of poles.

$N$  = Speed of rotor in RPM



$F$  = Frequency of the induced EMF in Hertz.

The number of cycles produced is the number of pairs of poles per revolution. The number of frequency on one revolution is  $= P / 2$

Conductor revolves per second  $= N / 60$

Hence frequency per second  $f = (P/2) * (N/60) = PN / 120$  Hz.

### EMF Equation of an Alternator :

$Z$  = Total number of conductors per phase

$\Phi$  = Flux per pole

$P$  = Number of poles

$K_d$  = Distribution factor

$f$  = Frequency

$K_c$  = Coil span factor

$K_f$  = Form factor

One conductor in one cycle cuts the flux  $= 2\Phi$  weber

One conductor in one second cuts the flux  $= 2\Phi f$  weber

One conductor in one second cuts 1 weber flux, the voltage induced is ONE VOLT.

In conductor in one second the EMF induced is  $= 2\Phi f$  Volts

$Z$  conductors induced EMF  $= 2\Phi f Z$

Average EMF induced in one phase  $= K_d K_c 2\Phi f Z$  Volts

RMS value of EMF induced in one phase  $= K_d K_c K_f 2\Phi f Z$  Volts

Form factor of sinusoidal wave  $= 1.1 = 1.11 * 2\Phi f Z K_d K_c$  Volts

Therefore  $E = 2.2 * \Phi f Z K_d K_c$  Volts

**Impulse relay :** This works on both AC and DC supplies. This consists of a coil which is energized by an impulse. An armature connected to a mechanism will move a contact from open to close or close to open position. On removal of the pulse, the contact goes back to its original position.

**Thermal Relay:** This relay will operate depending upon the temperature. The bimetallic strip on heat sensing will bend and touch a contact or break a contact. It will take time for sensing heat by the bimetallic strip. Hence, this relay is used for time delay function.



**AC Relay:** The magnetic field of this relay changes 100 times in a 50 Hz supply. Hence this reaches zero and change the direction. Due to this chattering takes place. To avoid chattering, a groove on the pole phase with a shading ring is places. This shading will create a magnetic field which is lagging the main magnetic field. So when the main magnetic field becomes zero there is some amount of magnetic field in the shading ring. This will eliminate chattering.

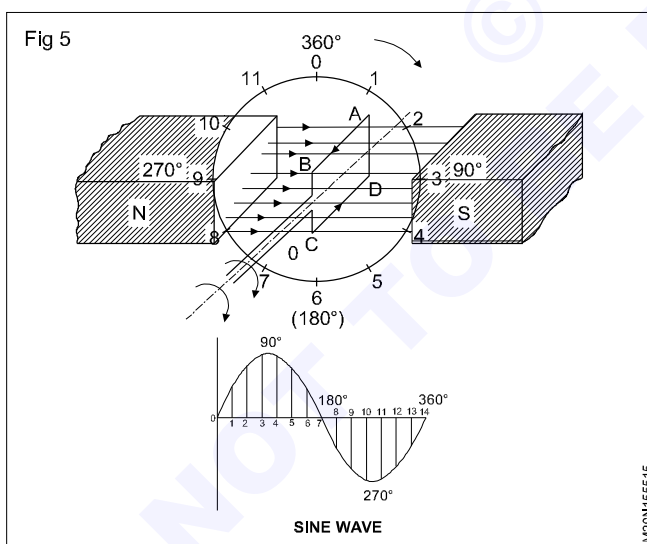
**Note: Don't give DC supply to an AC relay. If given to a DC supply, on absence of inductive reactance excessive current will flow which burns the coil. Likewise in a DC relay with AC input the positive/negative polarity changes resulting the coil burned out.**

### Principle of DC Generator

As per Faradays law of electromagnetism an Electronics force is produced in the Generator.

- 1 In between a magnetic field if a conductor rotates then an EMF is induced in the conductor.
- 2 This induced EMF value directly in proportion to the change in flux and the speed at which the conductor cuts the flux. Reasons for dynamically induced EMF are
  - A Magnetic field,
  - B Conductor and
  - C the force required to rotate the conductor.

### EMF Generated in DC Generator (Fig 5)



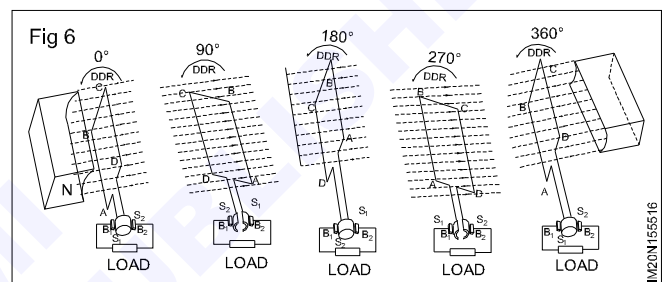
Assume a conductor AB,CD revolves in between the magnetic field of North and South pole in clock wise direction. This will create an alternating Electronics force on the conductor.

The full revolution of the conductor 0 to 360° is shown below.

| Position of the conductor | Induced Electronics force                       |
|---------------------------|-------------------------------------------------|
| 0°                        | zero                                            |
| 0 to 90°                  | On positive side from zero to maximum EMF value |
| 90 to 180°                | On positive side from maximum EMF to zero value |
| 180 to 270°               | On negative side from zero to maximum EMF value |
| 270 to 360°               | On negative side from maximum EMF to zero value |

On completion of one revolution of the conductor, an alternating current of one cycle is induced. This AC current will be converted to DC current by commutator.

### AC to DC conversion in a commutator (Fig 6)



In the figure 6 AB and CD conductor of end S1 and S2 is connected to two slip rings. Two brushes B1 & B2 is placed on the slip ring. The brushes are connected to the load. The conductor and the slip ring rotates together. Brush is stationary. In this the conductor moves from 0 to 180° anti clock wise with AB conductor in South Pole, the current will flow inwards from A to B. The conductor CD is in the North pole and the current will flow outwards from C -D.

So  $S2 \rightarrow B1 \rightarrow \text{LOAD} \rightarrow B2 \rightarrow S1 \rightarrow AB \rightarrow CD \rightarrow S2$  completes the circuit flow of current.

When conductor moves from 180° to 360°, AB will be under North Pole the flow inwards  $B \rightarrow A$ . The conductor CD will be in South Pole and the current flows outwards  $D \rightarrow C$ . The slip ring S1 will be with brush B1 and S2 with B2 connected the circuit closes as

$S1 \rightarrow B1 \rightarrow \text{LOAD} \rightarrow B2 \rightarrow S2 \rightarrow DC \rightarrow BA \rightarrow S1$ . Even though current flow will be changing its direction in conductor, the current in the load will be in one direction only.  $B1 \rightarrow \text{LOAD} \rightarrow B2$ . The alternating AC is converted to DC by the slip ring. This DC is pulsating and by using many segments of commutator pure DC will be generated.

### Faraday's Law of induction

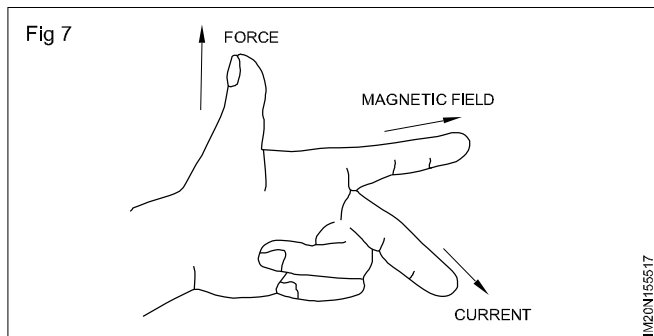
**First Law:** When a conductor rotates in a magnetic field it cuts the magnetic field and an EMF is induced in the conductor.

**Second Law :** The amount of EMF induced in the conductor is directly proportional to the flux.

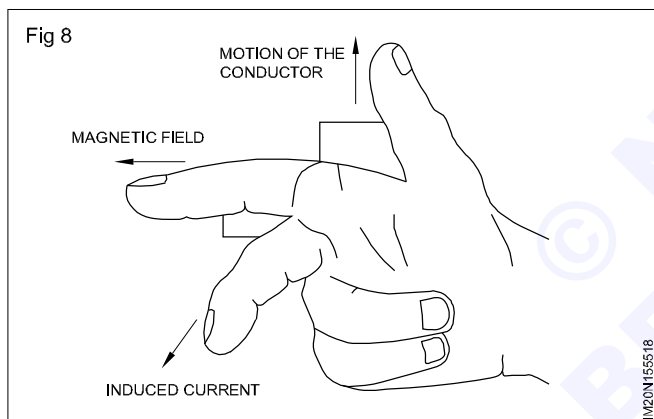
**Lenz Law :** Lenz law states that an induced electric current flows in a direction such that the current opposes the change that induced it.



**Fleming's left hand rule (Fig 7):** Fleming's Left Hand Rule states that if we arrange our thumb, forefinger and middle finger of the left-hand perpendicular to each other, then the thumb points towards the direction of the force experienced by the conductor, the forefinger points towards the direction of the magnetic field and the middle finger points the direction of the current



**Fleming's left hand rule (Fig 8) :** Fleming's Right Hand Rule states that if we arrange our thumb, forefinger and middle finger of the right-hand perpendicular to each other, then the thumb points towards the direction of the conductor, the forefinger points towards the direction of the magnetic field and the middle finger points towards the direction of the induced EMF in the conductor.

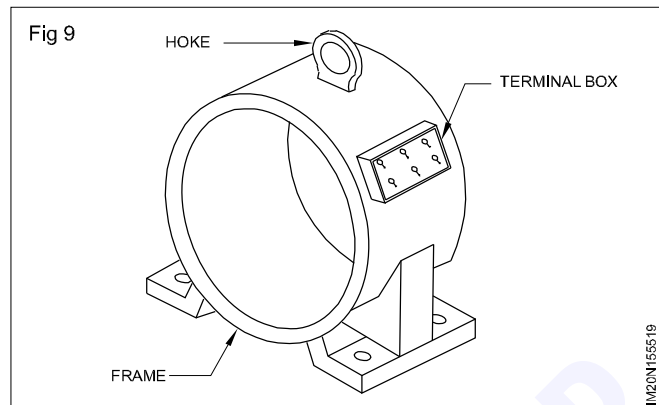


### Parts of DC Generators and their function

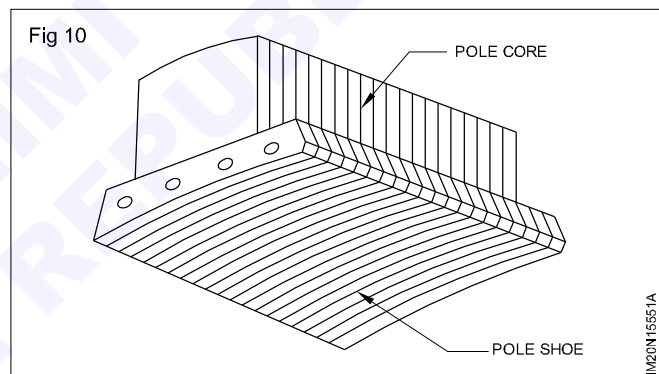
- 1 Frame or Yoke
- 2 Pole core and pole winding
- 3 Field coil or field winding
- 4 Armature core
- 5 Armature winding
- 6 Commutator
- 7 Brush and brush holder
- 8 Brush rocker
- 9 Bearing
- 10 Front and rear end cover.
- 11 Terminal box.

**1 Frame or yoke (Fig 9):** This is the machine outer part and called as frame or yoke. This give support to the field poles and is a total enclosure to protect the machine. This is used to conduct the magnetic flux in

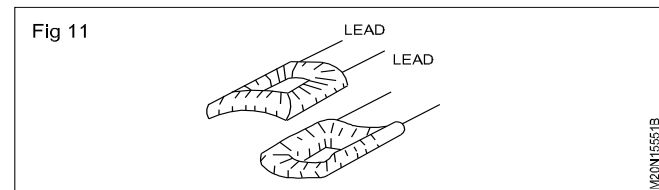
field poles. Fir small generator yoke is made of cast iron and cost is low. For bigger machine it is made of cast steel or rolled steel. The base and terminal box were fitted to the yoke.



**2 Pole core and pole shoe (Fig 10):** The field magnet comprise the pole core and pole shoes. Pole core and shoes were made up of thin stamping of silicon steel of thickness 0.25mm to 1mm. This is pressed in a hydraulic press and riveted or bolted together. Pole shoe forms a less air gap between armature and poles so that the flux will be uniform. It also support the field coil.

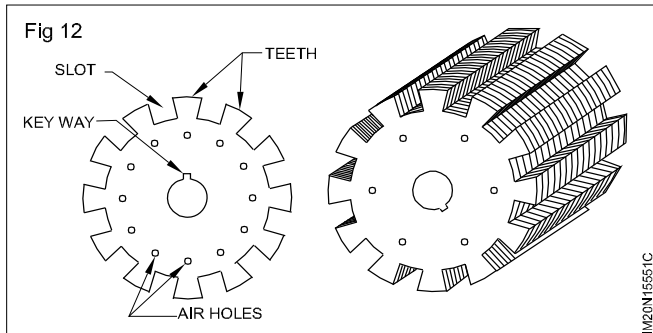


**3 Field coil or field windings (Fig 11):** Field coil or pole coil are made of copper wire or copper rectangular strips having the required turns. It is well insulated. This pole coil is placed on the pole core between yoke and pole shoe. When current is passed through the coil, a magnetic pole set on the pole shoe. The magnetic flux from north to South Pole is bisected by the rotating armature conductor. This will induce an EMF. Series winding will have less field resistance when compared to short field winding which has large resistance.



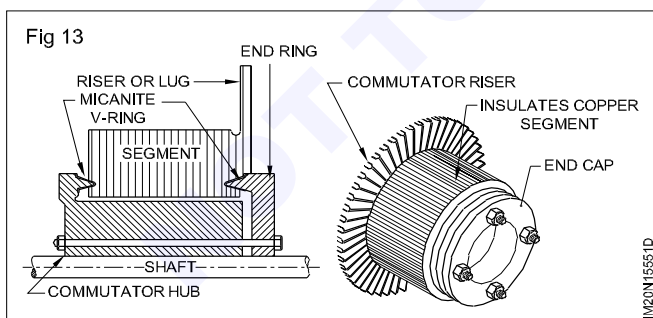
**4 Armature core (Fig 12):** The armature is made up of 0.5mm circular laminated silicon steel plates either cylindrical or in the form of drum. The stampings are riveted together. On the circumference of the armature slots were cut either by die cut or by punching device. A keyway is made inside diameter of the armature. To

cool the armature duct holes were drilled along the cylinder. The armature winding is placed on the slots. In order to arrest the winding on the slots, wedge made of wood, bamboo or fiber is used. The armature core gives less resistance to the magnetic field and also serves to complete the magnetic circuit. On the mild steel shaft the armature core, commutator, and bearings were placed.



**5 Armature windings:** The winding is done on a former. First it is done on rectangular shape then by using coil puller the desired shape is achieved. This coil is placed inside the insulated slots. The resistance of the armature wing is 1 ohm or less than 1 ohm.

**6 Commutator (Fig13):** The commutator is used to get the current from armature winding. The alternating current produced by the armature will be converted to DC current by the commutator and supply it to the load. Hard copper in the shape of wedge is placed to form a cylindrical structure. Each of this is called the segments. Between two segments mica insulation is provided. The number of coils in the armature and the number of segments in commutator is same. One side of the copper strip is raised and having slot on it. This portion is called the raiser or copper lug. The tip of the armature winding were soldered to the lug of the riser. Due to the centrifugal force the segments will disintegrate. To avoid this a V shaped groove has been cut on the segment. This has been filled with V shaped micanite ring and end rings. This structure is placed on the shaft.

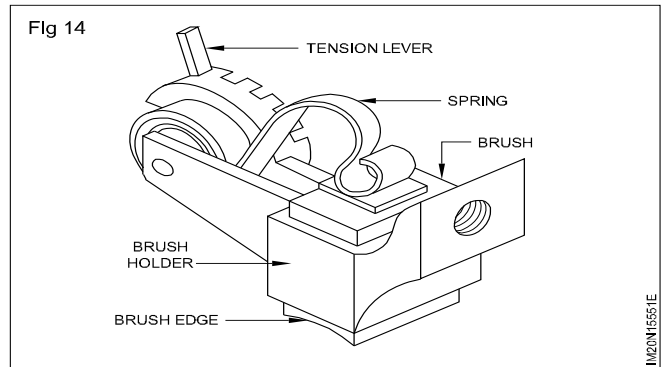


**7 Brush and brush holder (Fig 14):** Brushes are used to collect the DC current from the rotating commutator. This is made up of copper or carbon mixed alloy. By adjusting the spring in the brush holder the pressure to the brush can be adjusted.

**8 Brush rocker:** The ring shaped insulating material which hold the brush holder is called as the brush rocker arm. This is used to align the brush position to the neutral axis. Brush rocker is fixed to the bearing

cover or to the bracket support on the yoke.

**9 Bearings:** Normally ball bearings are used. For heavy



duty roller bearings are used. These bearings are filled with high density oil so as to reduce the sound while running. To reduce wear and tear sleeve bearing is used.

**10 Front and rear cover:** This is made of cast iron in circular shape. End plates are fitted with screws on yoke. In the center of the cover there is provision to hold bearings on which the armature shaft rests. To give air circulation long radial slots were made. The front and end cover were denoted by the rotating sign on commutator side and pulley on motor side.

**11 Terminal box:** This is made up of hylam or Bakelite insulating plate. With the help of bolt and nut armature and field coil ends were fixed. Also used to connect the load.

**Eddy current.** If the armature core is made of solid metal then its Electronics resistance is low. If this solid metal revolve in pole magnetic field an EMF is induced in the armature core. Current due to this EMF is called eddy current.

Since the Electronics resistance of the solid core is less, huge current will flow and heat the armature core. This will affect the insulation of the armature coil. Also flux loss will happen. To avoid all this short come the core of the armature is made up of 0.5mm thick silicon steel and coated with varnish on both sides. These are pressed and riveted together. Thus the eddy current loss is reduced.

### Types of armature winding

- 1 Lap winding,
- 2 Wave winding.

### Difference between lap winding and wave winding

| Lap winding                                                                   | Wave winding                                                                  |
|-------------------------------------------------------------------------------|-------------------------------------------------------------------------------|
| The number current path is equal to the number of Poles ( $a=p$ )             | Whatever be the number of poles, only two way path for the current. ( $a=2$ ) |
| Brushes are placed as per the number of poles                                 | Whatever be the number of poles, only two brushes were placed.                |
| The total current generated is equal to the sum of the parallel path current. | Total current is available in two path.                                       |
| Low voltage and high current application is used.                             | High voltage and low current application is used.                             |

## EMF Equation of DC generator

A single conductor intersect one weber flux in one second will induce one EMF Volt.

Number of poles = P

Speed of flux produced by poles = Weber ( $10^8$  maxwell)

Rotating speed = N RPM

Number of total conductors in armature = Z

Paths in armature = a

EMF induced in the generator = E

A single conductor intersecting flux

in one revolution =  $\Phi P$  weber

Rotation of armature in a second =  $N/60$

In a conductor number of flux intersected per second =  $\Phi P * N/60$

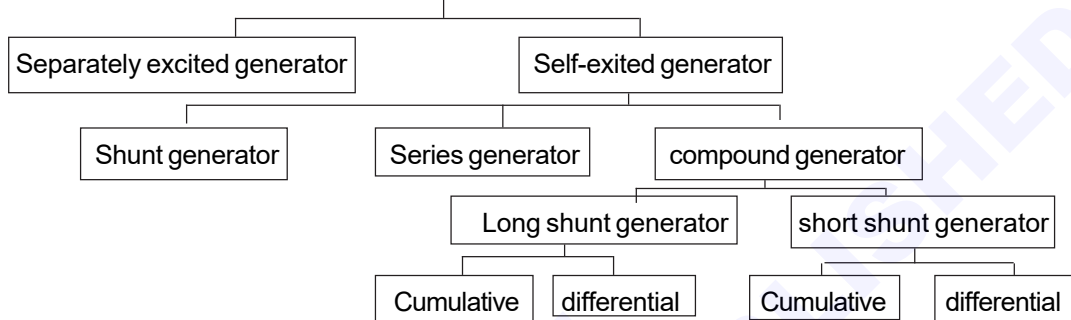
CONDUCTOR IN A SINGLE parallel PATH =  $Z / a$

Voltage in a single parallel path E =  $(\Phi Z N / 60) * (Z / a)$  volts

EMF Produced in the generator =  $(\Phi Z N / 60) * (P / a)$  volts

P, Z, a are constant. Hence the induced EMF is directly proportional to the flux and the speed of conductor.

## Types of DC Generators



## DC Motor

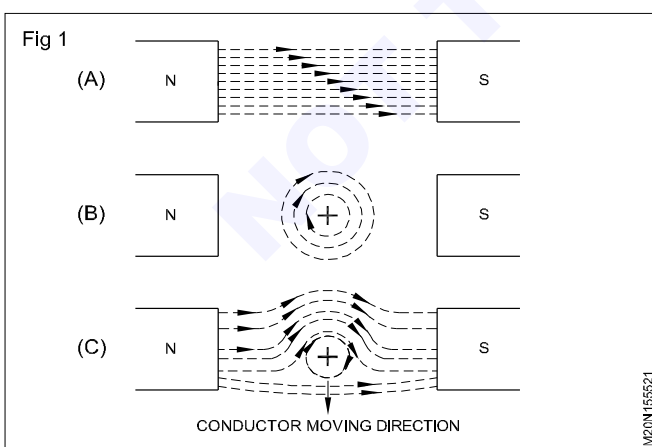
**Objectives:** At the end of this lesson you shall be able to

- explain principle and operation of DC motors
- explain types of DC motors
- explain speed controls of DC motors.

**Introduction :** The machine which convert the Electronics energy to mechanical energy is called a motor. A DC machine can be used as a motor or generator.

**Principle of DC motor :** A current carrying conductor placed in a magnetic field will experience a torque. This is the principle under which the motor operate.

### Operation of a DC motor (Fig 1)



It is shown figure 1 the flux between the poles are uniform. In figure2 the magnetic field shown around a current carrying conductor (right hand grip)

In figure 3 the flux produced by the poles and the current carrying conductor is shown. In this the flux on top side of the conductor is in the direction of the pole flux, and increased. Due to this the top portion of the conductor is closely surrounded by the pole flux and opposes the bottom portion of the pole flux. The flux at the bottom portion of the conductor is low. The bend flux at top portion will try to straighten and due to this a force has been created which push the conductor down. Thus a torque has been produced in the conductor. The closed conductor which is placed in the magnetic field of the poles will undergo cyclic polarity change the pole flux will push the conductor downwards and upwards, the conductor rotate in a single direction. With many such conductors wound on the armature it rotates continuously.

**Back or counter EMF :** As per Faraday's electromagnetic induction when the armature rotates it will cut the magnetic field of the poles which are stationary and an EMF is induced in the armature. This EMF is called the counter or back EMF. The direction of the EMF is as per Fleming's right hand rule. Value of EMI  $E_b = \Phi Z N P / 60 a$  Volts. The induced back EMF in the rotor will be in opposite to the applied voltage. Back EMF is less than the applied voltage.  $E_b = V - I_a * R_a$ .

**Torque produced in DC motor :** A Turning force along the axis of an object is called the torque. Torque = Force

x the radius and the unit is Newton meter.  
 $T = F \times r = F \times \text{distance moved by the force}$ .  
 $W = F \times 2\pi r$  which is  $2\pi r$ . The work to be done in a second is  $W = 2\pi r \times N/60$  joules or watt and N is the revolution per minute RPM.

**Armature torque :** The torque produced in all the conductors is the total torque of the armature. Work to be done =  $2\pi T_a N / 60$  watt.  $E_b = V - I_a R_a$   
 $V = E_b + I_a R_a$   $V I_a = E_b I_a + I_a^2 R_a$ , which is the given Electronics energy force.  $E_b I_a$  is the Electronics energy transformed to the work done.

$I_a^2 R_a$  is the armature copper loss.

The Electronics energy transformed = The work done.  
 $E_b I_a = 2\pi T_a N / 60$  and  $T_a = E_b I_a \times 60 / 2\pi N = 9.55 E_b I_a / N$  Newton meter.

**Shaft torque or output torque :** The total torque in the armature is used for the work done in the shaft. This torque is known as shaft or output torque  $T_{sh}$ . The loss occurs in motor ( $T_a - T_{sh}$ ). Torque in shaft will be less than the torque in armature. Shaft torque. When BHP is measured, the engine torque is determined by applying a brake to the flywheel "as opposed to using a torque".  
 $BHP = 2\pi T_{sh} N$ . And  $T_{sh} = BHP \times 60 / 746 / 2\pi N$ .

#### Relation between Torque, armature current and flux

The torque produced in the motor is directly proportional to the current flowing in the armature and the flux produced by the poles.  $T_a = \text{proportional to armature current and flux}$ .

$$E_b I_a = \frac{2\pi T_a N}{60} \quad \left[ E_b = \frac{\phi Z N P}{60 x a} \right]$$

$$\frac{\phi Z N P I_a}{60 x a} = \frac{2\pi T_a N}{60}$$

$$2\pi T_a a = \phi Z P I_a \quad (\text{Cross multiplication})$$

$$T_a = \frac{\phi Z P I_a}{2\pi a} = T_a \propto I_a \phi$$

**Speed of the DC motor:**  $E_b = \phi Z N P / 60 a$  in which Z, P and a are constant. Therefore  $E_b = \phi N$  and  $N = E_b / \phi$

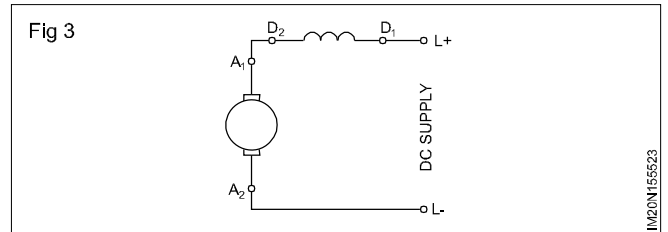
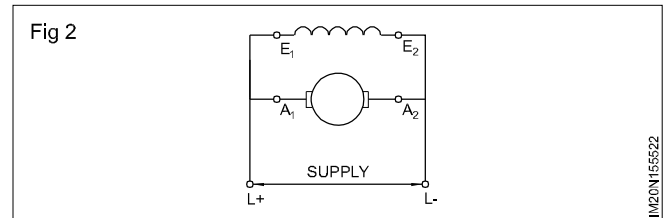
The speed of the motor is directly proportional to the back EMF and indirectly proportional to the flux.

#### Types of DC motors

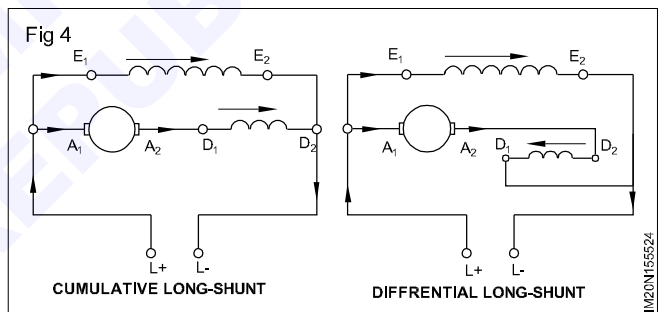
- 1 Shunt motors
- 2 Series motor and
- 3 Compound motor

**Shunt motor (Fig 2) :** The shunt is a winding of thin wires of more turns and resistance which is connected in parallel to the armature.

**Series motor. (Fig 3):** The series winding is a thick few turns winding having low resistance. This is connected in series with the armature.

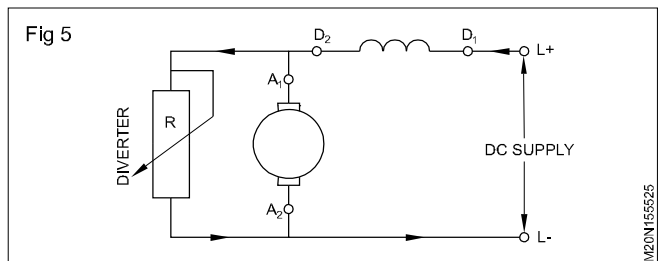


**Compound motor (Fig 4):** In this both series and shunt windings were connected. The series winding is connected in series to the armature and shunt winding in parallel to the armature. Parallel shunt winding is called short shunt. Another shunt winding which connected in series with armature is called long shunt winding. The current which passes through the series connected shunt which is in opposite direction of the parallel shunt is called differential compound motor. The current which passes through the series connected shunt which is in same direction of the parallel shunt is called cumulative compound motor.



**Speed control of DC motor :**  $N = \phi / E_b$  where  $E_b = V - I_a R_a$  therefore  $N = V - I_a R_a / \phi$ . The armature resistance of the motor, field flux and supply voltage can be changed to vary the speed and control it.

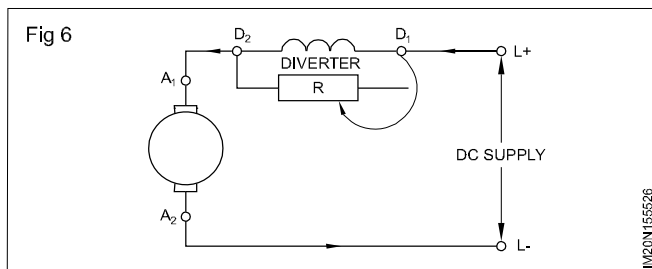
**DC Series motor speed control by armature divider (Fig 5):** A variable resistance is connected in parallel to the armature. This will reduce the overall resistance and the current flow is increased. The flux will increase since the current increases.



$E = E_b / \phi$ . So increase in flux will reduce the speed. In this control we get speed less than normal speed.

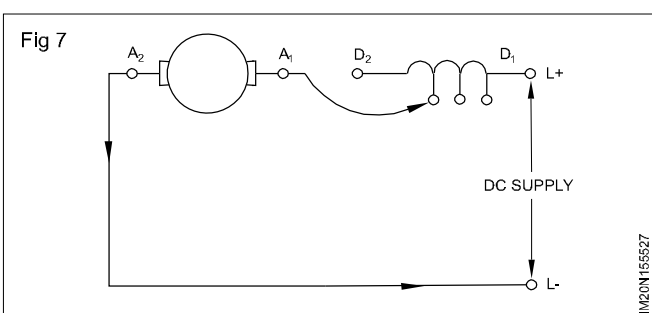
**DC Series motor speed control by field divider (Fig 6) :** A variable resistor is connected in parallel to the field as shown in figure. In this the current to the field is low and so the low flux.



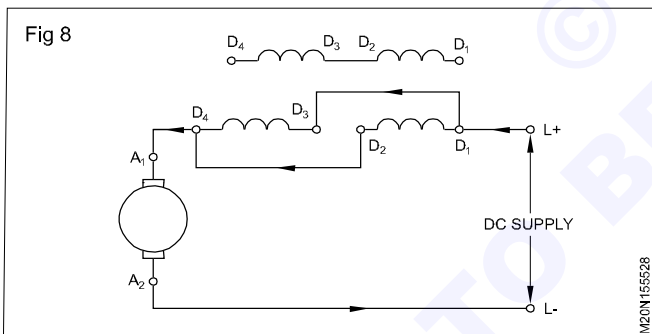


$E = E_b / \Phi$ . So decrease in flux will increase the speed. In this control we get speed greater than normal speed.

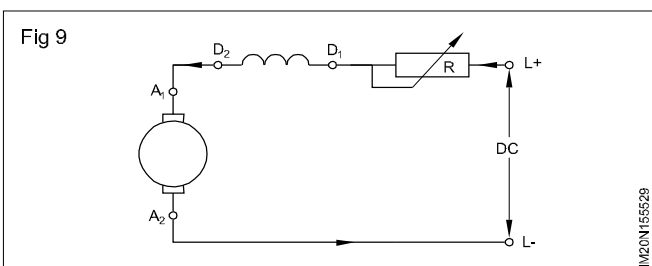
**Tapped field control (Fig 7):** In this tapping will be provided in the series winding and connected as shown in figure. At first the motor is run at its full speed and can be varied by changing tapping in series winding. With change in flux due to change in number of series winding we can achieve variable speed. This type of motor is often used in small application like fan motor and mixie motors.



**Series Parallel method (Fig 8) :** This is a very easy method to achieve two speed controls. This type of speed control is very much used in the fan motor.

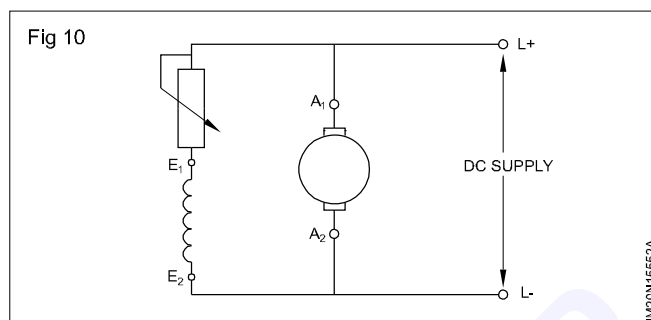


**Supply voltage control method (Fig 9):** The series field is connected in series with a variable resistor. The current to the series field can be varied. With this speed from zero to its maximum can be achieved. Fractional horse power motor employs this technique. The power loss due to the heat generated in the variable resistor can be eliminated by suitable silicon controlled rectifier(SCR)



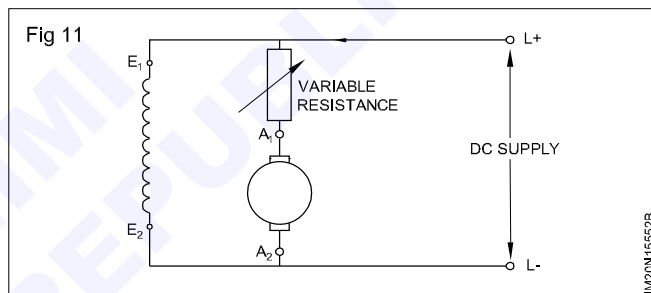
**Shunt motor speed control - By armature control (Fig 10):** In series with the armature a variable resistor is

connected. The voltage to the armature is reduced. Hence  $E_b$  reduces. So speed reduces. In this method we get low speed than the normal speed. There will be no change in the field current. It will be costlier to do with this speed control. Power loss and heat produced by resistor will be high.



**Application:** Printing machine, low power cranes and hoists.

**Shunt motor speed control - By field control (Fig 11):** A variable resistor connected in series with the field. Since the current to the field is less, the flux also reduces. Hence the speed will be high and above the normal speed.



### Advantages

- 1 Can get speed more than the normal speed.
- 2 The current to the field is low, hence low power loss and heat.
- 3 This method is simple, cost effective and more efficient.

### Disadvantage

- 1 Field strength is weak and in high speed torque is reduced.
- 2 Commutation will occur due to weak field

### Single phase induction motor

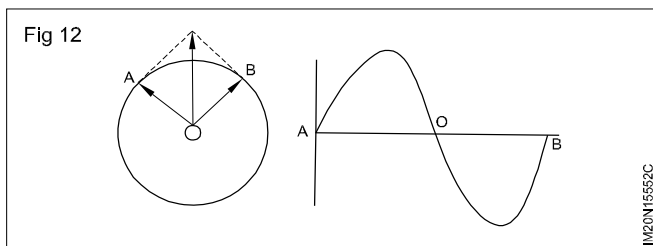
**Introduction:** By construction 1 $\Phi$  induction motor is very similar to 3 $\Phi$  induction motor. This is largely used in houses, offices and in industries. Normally it is available in 1 HP rating and in FHP. For special application the rating will be 1.5 HP to 10 HP.

### Working principal of single phase induction motor

**(Fig12):** When a single phase AC supply is given the stator field it produces a pulsating magnetic field instead of a rotating magnetic field. In the AC cycle the first positive cycle will produce a field which turns the rotor in clock wise direction. The next negative cycle produce a field which turns the rotor in anti-clock wise direction. In net effect the rotor won't rotate at all and vibrates. But if we



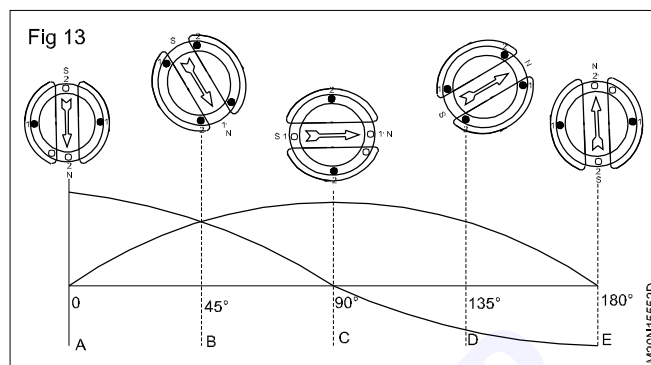
rotate the rotor in one direction with the hand it will produce a torque and rotate.



So a single winding induction motor won't self-start. To make it self-start another winding is used. This winding is called the auxiliary or self-start winding. When the motor attains 75% speed the starter winding disconnect from the circuit by a centrifugal switch. The motor will now run in the main winding.

**Producing a rotating magnetic field by two windings (Fig 13) :** By splitting the single phase supply we can create a rotating magnetic field in single phase induction motor. To achieve the phase splitting an additional start or auxiliary winding is used along with the main winding. Auxiliary winding is so placed in the main winding so as

to create a 90 degree out of phase current with the current in main winding. By changing the number of turns and thickness of the starting winding the value of the reactance changes from that of main winding. This change in reactance cause the out of phase current in both windings.



In case the reactance of the both windings are same then the field produced in not a rotating magnetic field but a varying magnetic field. Note the wave form of the current in main and auxiliary winding which is 90 degree apart and poles are formed suitably.

| Degree | Position | Main winding (1-1')                                            | Starter winding(2-2')                    | Rate of magnetic rotation                                   |
|--------|----------|----------------------------------------------------------------|------------------------------------------|-------------------------------------------------------------|
| 0°     | A        | Large amount of current and flux                               | No current and no flux                   | 0°                                                          |
| 45°    | B        | Current flows and flux produced.                               | Current flows and flux generated         | 0 to 45° rotation                                           |
| 90°    | C        | Current becomes zero and no flux production                    | Current flows and flux generated         | 45 to 90° rotation.                                         |
| 135°   | D        | Current flows in opposite direction<br>Flux produced           | Current reduces still flux produced.     | 90 to 135° rotation.                                        |
| 180°   | E        | Maximum current flows in opposite direction. Flux is produced. | Current becomes zero. Flux becomes zero. | 135 to 180° rotation.<br>That is 0° state in 180° opposite. |

In figure the magnetic field displacement for every half cycle of the AC in 45° period is shown. Like this following 180° the poles will rotate till 360° and attain the position of 0°. This is how the rotating magnetic field happens in single phase induction motor.

### Classification of single phase induction motor

- 1 Resistance start induction run motor.
- 2 Induction start induction run motor.
- 3 Capacitor type motor.
  - a Permanent capacitor start motor.
  - b Capacitor start induction run motor
  - c Capacitor start capacitor run motor.
- 4 Shaded pole motor.
- 5 Stepper motor.

**Stepper motor :** Basically the stepper motor is like a synchronous motor. There is no commutator and brush on the rotor. The motor on getting input pulse from a controller will rotate the rotor to the fixed angular step.

The number of input pulse will have equal number of step rotation on the rotor. Then speed of rotor depends on the frequency of the input pulse. The shaft of the stepper motor won't rotate continuously but will be positioned precisely with accurate speed control. The number of steps in each full rotation will be from numbers 12, 24, 72, 144, 180 and 200. Corresponding to this step angle for each step will be of angle 300, 150, 50, 20 and 18.

**Note: The special feature of the stepper motor is used in open loop control system.**

An open-loop system is a type of control system in which the output of the system depends on the input but the input or the controller is independent of the output of the system. These systems do not contain any feedback loop and thus are also known as non-feedback system.

**Step Angle :** For every command pulse from the controller the degree of turn of the shaft is the step angle  $\beta$ .

The least step angle is 0.72° and maximum 90°. Normally the step angle 1.8°, 2.5°, 7.5° and 15° were the standard. To determine the step angle we have to consider the stator

poles or the number of teeth.  $\beta = N_s - N_r \cdot 360 / N_s - N_r$ . The number of steps required for one full rotation is called Resolution. So Resolution =  $360^\circ / \beta$ .

**Note: This motor is so designed to hold the rotor for a longer period in its position even though there is stator current present in the winding. No damage is done to the rotor on this state. But on other motors with stalled rotor, back EMF collapses and high current pass through the winding causing it to burn and damage.**

### Types of Stepper motor

- 1 Variable reluctance (VR) Stepper motor
  - 2 Permanent magnet (PM) Stepper motor
  - 3 Hybrid stepper motor.
- 1 Variable reluctance (VR) Stepper motor :** This type of stepper motors are in existence for quite a long period. This consists of stator winding soft iron rotor which has teeth cut on the circumference. When the stator is given the DC voltage, the poles will produce a magnetic force which pulls the teeth of the shaft and cause rotation.
- 2 Permanent magnet (PM) Stepper motor :** This low resolution stepper motor is very cheap. Their step angles  $7.5$  to  $150^\circ$  (48-24 step per turn).. The magnetic flux density is increased with the formation of north and south poles parallel to the shaft. The torque is much more forceful than VR type stepper motor. This is also called as Tin can or Can stock.
- 3 Hybrid stepper motor :** This motor is having the best characteristic of PM and VR stepper motor. The step resolution, torque and speed were very good. The step angle is  $3.60^\circ$  to  $0.90^\circ$  (100-400 steps per turn) But the cost of this motor is higher than PM stepper motor.

### Advantages

- 1 When the motor is stationary and the windings are energized will have the full torque
- 2 The angular movement of the shaft is directly proportional to the input pulse.
- 3 We can achieve different speeds since this depends on the frequency of the input pulse.
- 4 With load we can operate on low speed.
- 5 On open loop system digital pulse is being given. The construction of the stepper motor is simple and cost of controlling is small
- 6 Starting, stopping and reversing can be done.
- 7 The accurate position of the shaft and its speed can be achieved
- 8 There is no contact brush on the rotor hence life time of the motor depends on the bearings

### Disadvantage

- 1 If proper controlling is not done then resonance will happen
- 2 It is not easy to run in high speed.

**Applications:** Printers, hard disc drive, Fax machines, Plotters, Modern office equipments, medical apparatus and in Robotics

### Three phase induction motor :

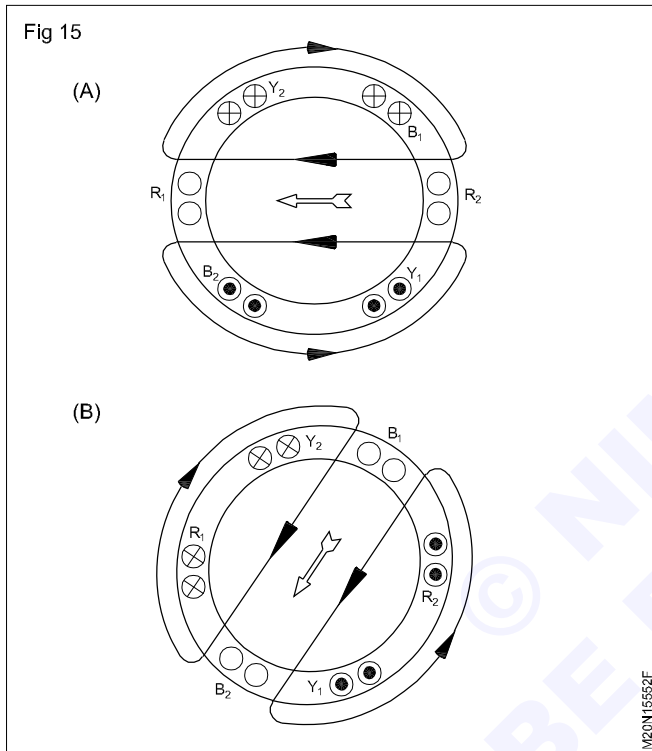
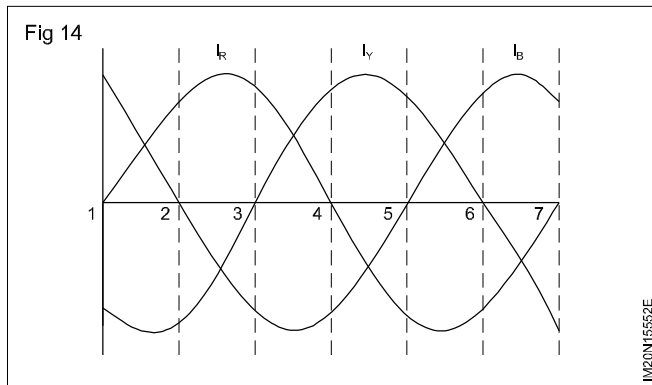
**Introduction :** The motor is a device which converts Electronics energy to mechanical energy. The three phase induction motor on three phase AC supply. The simple construction, low repair, good torque, good speed, and low cost were the prime reason for choosing them over the single phase and DC induction motors. Used in industries, home and offices. This works on the principle of magnetic induction and hence called induction motor.

**Operation of a Three phase Induction motor :** The principle of DC motor will be applicable to this motor. The current carrying conductor will experience a torque when placed in a magnetic field. There is no Electronics connection to the rotor. On the contrary Electronics current is induced in the conductor. The stator acts like the primary of a transformer. Rotor acts like the secondary of the transformer.

When the stator is given the 3 phase electric supply, rotating magnetic field is produced. This field cuts the conductors in the rotor which were shorted. An EMF is produced in the rotor which drives the current. This magnetic field which is responsible for the production by the stator magnetic field will be in opposite direction. This can be inferred by Maxwell's cork screw rule. The rotor experiences a torque due to the stator field. Due to this the rotor rotates following the same direction of the rotor field. The speed of rotor is less than the speed of the stator magnetic field. The speed at which the stator rotating field is known as the synchronous field and the trailing rotor speed is the actual speed.

**Rotating magnetic field in the stator :** The induction motor rotates due to the rotating magnetic field on the stator. The stator comprises three windings at  $120^\circ$  Electronics. These are non-salient stator poles. When a three phase supply is given to the winding, three separate pulsating fields are produced. Due to the Electronics phase difference on the three windings the fields in each winding together form a single rotating field on the stator. When a two pole induction motor is given a 3 phase supply how the rotating magnetic field is as shown in figure A. The Electronics current in the stator winding is  $120^\circ$  Electronics degree apart. The resultant current is shown on  $60^\circ$  interval. After  $60^\circ$  Electronics degree in fig A a number 2 is denoted. The phase current  $I_b$  is zero and positive and  $I_y$  is negative. Now as shown in figure C then end of the coil Y2 and R1 the current goes inwards as positive. In Y1 and R2 end the current comes out which is negative. Due to this the magnetic poles will be shifted by  $60^\circ$  and come to new position. On this basis of the current

wave position, each Electronics 60 degree addition (3,4,5,6,7) poles position keeps on changing and comes



to initial position on 360°

The speed of the rotating magnetic field is the synchronous speed. This depends on the supply frequency and number of poles .  $N_s = 120f / P$  where  $N_s$  is the synchronous speed ,  $f$  is the supply frequency and  $P$  is the number of poles.

### Slip and Rotor speed

The rotor on induction motor will rotate on the same direction of the rotating magnetic field. This is less than the synchronous speed. The difference between the synchronous and actual speed persist. Due to this the conductor will cut the field continuously and torque is produced. The difference between the synchronous speeds to the actual speed is called as slip. Fractional slip  $S = \frac{N_s - N_r}{N_s}$  , % of slip  $= (\frac{N_s - N_r}{N_s}) * 100$ . The value of the % slip in an induction motor is normally 2% to 5%

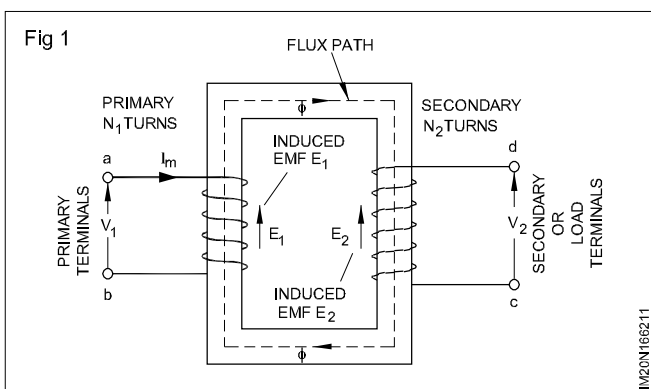
## Transformers and its working principles

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

- explain the principle of transformer
- explain the types of transformers
- experimenting the transformer by open and short circuit.

**Introduction :** Transformers works on mutual induction principle. In Electronics substation it is widely used for lower voltage to higher voltage and vice versa.

### Transformer and its principle of operation (Fig 1)



Marinating the same frequency power has been transformed from one circuit to the other circuit.

On an iron core two winding were formed by Electronicsly insulated one from the other is formed. The winding on which the supply given is known as the primary winding and the other winding is secondary from which the output is taken. When applying AC supply to the primary winding an alternating magnetic flux is produced through the axis of the iron core. This flux cut the winding and as per Faraday's laws of electromagnetic induction an electro motive force is produced.. The EMF generated in the secondary winding is due to mutual induction. EMF induced is proportional to the number of turns in the winding.

**Types of Transformers (Fig 2):** Types of transformers were shown in figure. As per the voltage to be transformer we can again sub divided into

- Step up and
- Step down transformer.

**1 Step up transformer:** The number of turns in secondary winding is more than the primary winding. Due to this EMF produced in the secondary is greater than the applied primary voltage..

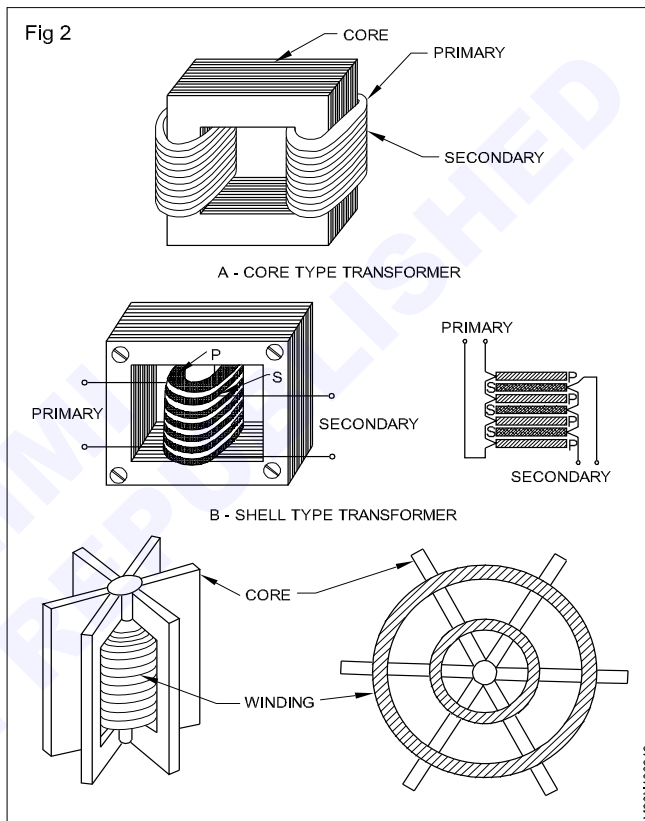
**2 Step down transformers:** The number of turns will be less than the primary winding. Hence the EMF produced in the secondary is less than the voltage applied in the primary.

**Transformer core:** As per construction

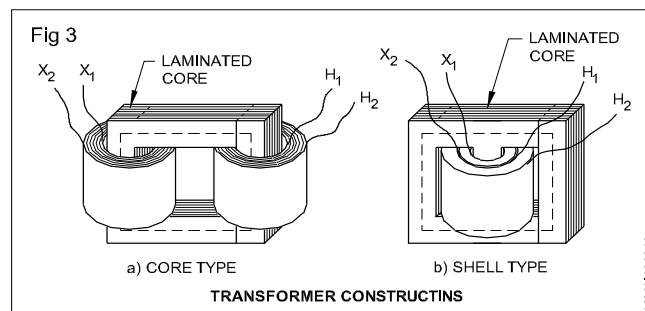
- Core type transformer

2 Shell type transformer and

3 Berry type transformer.



**Core type transformer (Fig 3a&b)**



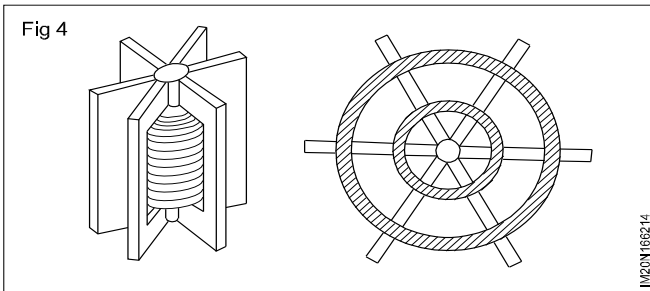
Construction as shown in fig 3a&3b. The cores will be of the rectangular sheets of I & L shapes. The coils on the core will be cylindrical. The primary and secondary coils were wound on separate limbs. Since the winding is around the core, it is called as core type transformer.

### Shell type transformer (Fig 3b)

The core of the shell type transformer is made of E&I shape sheets. There will be three limbs in this type of transformer. In the center limb the primary and secondary winding is

wound on one over other. The center limb will be larger than the outer limbs. The core is around the winding as a shell, so it is called shell type transformer.

#### Berry type transformer (Fig 4)



The berry type transformer is as shown in fig4. Then primary and secondary windings were wound on the center limb of a rectangular sheets formed as a cylindrical one. It is very difficult to wind the coil in berry type transformer. This type of transformer is very rarely used.

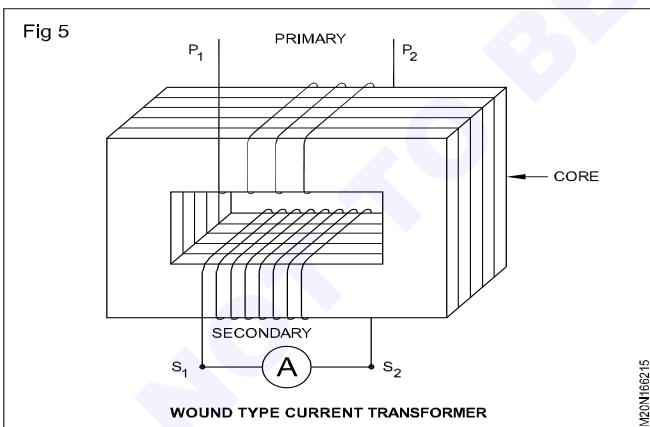
#### Type as per cooling method employed

- 1 Natural air cooling transformer
- 2 Air blast cooling transformer
- 3 Oil immersed natural air cooling transformer, and
- 4 Oil immersed forced air cooling transformer

#### Type as per the usage

- 1 Power transformer and
- 2 Distribution transformer.

**1 Power transformer (Fig 5) :** The power transformer is used in Electronics generating station. Generation of low power electricity at generating station is very cheap. To transmit this power as it is to faraway places by transmission lines will incur heavy losses. To overcome this the voltage at the generating end is stepped up and transmitted.



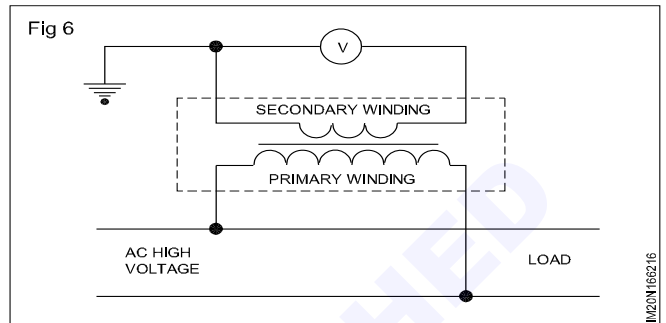
**2 Distribution transformer :** A distribution transformer or service transformer is a transformer that provides the final voltage transformation in the electric power distribution system, stepping down the voltage used in the distribution lines to the level used by the customer.

**Instrument transformer:** To measure high voltage and currents, this type of instrument is used.

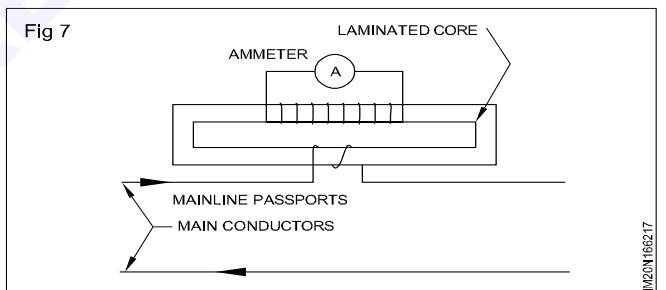
#### Types for the usage in instruments

- 1 Potential transformer and
- 2 Current transformer.

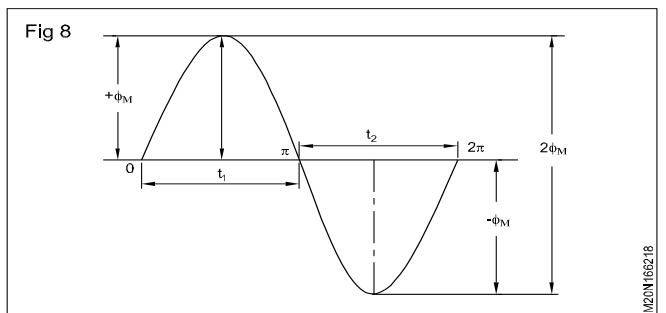
**Potential transformer PT (Fig 6):** This transformer with a voltmeter is used widely to measure high voltage. For the primary winding, thin wire of large turns of small diameter wires were used. This coil has to be connected in parallel to the HT supply to be measured. The secondary wire consist of few turns of large diameter wires. The secondary is connected to the voltmeter. One end of the secondary is connected to earth to prevent high voltage due to loose connection. The secondary voltage voltmeter (110V) is calibrated with the full capacity of the primary voltage.



**Current transformer CT (Fig 7):** Current transformer is used to measure the high current in transmission and distribution lines. The core of the transformer should have low reactance and low iron loss. To reduce secondary leakage reactance the windings were wound closely. One or more turns of the primary winding is connected in series with the line in which the current is to be measured. The large turns secondary winding is connected to the ammeter with an end of the winding earthed. The ammeter in the secondary is so calibrated to read the full heavy current of primary.



**EMF Equation of a transformer (Fig 8):** The EMF induced in a transformer depend on the flux density ( $\phi_m$ ) in the core, system frequency (F) and the number of turns in the winding(N) In a full AC cycle the flux becomes zero 4 times.



In one frequency change in flux =  $4\phi_m$  Webber. In F frequency change in flux =  $4\phi_m F$  webber. In one second one webber flux has been cut and the induced EMF is 1 volt. In a cycle the EMF induced is =  $4\phi_m F$



webber volt. If  $N$  is the number of turns in winding then the EMF induced =  $4\phi mFN$  volt. This is the average EMF induced in the winding.

Since the wave form is sinusoidal the effective EMF (RMS) is = the form factor  $\times$  average value. Form factor = RMS value / average value = 1.1. The induced EMF Value =  $1.1 \times 4\phi mFN$  volts, where  $\phi m = B_{max} \times \text{area}$ . And  $B_{max}$  equql to Maximum flux density weber/m<sup>2</sup>.

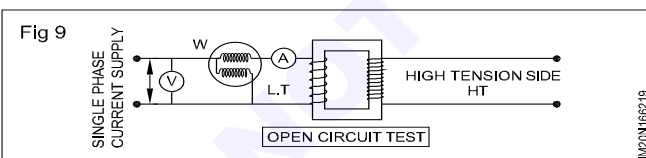
Area is in meter<sup>2</sup>.  $N_p$  turns in primary will have an induced EMF  $E_p = 4.4\phi mFN_p$  volts.  $N_s$  turns in secondary the induced EMF  $E_s = 4.4\phi mFN_s$  volts.

**Transformer ratio (K):** It is the ration between factors in primary winding to the factors in secondary wings of Primary induced voltage  $E_p$ , Primary number of turns  $N_p$ , primary current  $I_p$  to secondary induced EMF  $E_s$ , secondary number of turns  $N_s$  and secondary current  $I_s$ . RMS value of the primary induced EMF =  $4.44 \phi mFN_p$  volt. RMS value of the secondary induced EMF =  $4.44 \phi mFN_s$  volt. RMS secondary / RMS primary =  $4.44 \phi mFN_s / 4.44 \phi mFN_p = N_s / N_p = K$  also known as turns ratio AND  $E_s / E_p$  is the voltage ratio. If we consider a ideal transformer without any loss then the power input = power output. Which is  $V_p \times I_p = V_s \times I_s$  and  $I_p / I_s = V_s / V_p = K$ .

If we demote voltage current and number of turns together Transformation ratio =  $V_s / V_p = N_s / N_p = I_p / I_s$ .

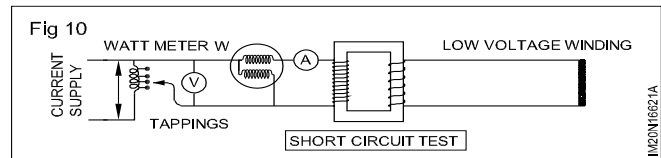
**Transformer tests:** Transformer is a static device since it has got no moving parts. So there is no frictional loss. Like in other machines there are core losses and copper losses. This can be found out as below.

**1 Open circuit test (Fig 9):** The object of this test is to find out core or iron loss. The core or iron loss depends on voltage and frequency. In this test voltage of low value and normal frequency is applied. The secondary winding (high voltage side) should kept in open. When there is no load in the secondary the primary current is called as "no load current. Normally this no load current will be small and hence a small range ammeter and watt meter has been connected as shown in the figure. The no load current in ammeter is low and the copper losses due to this is insignificant. So the core and copper losses were as red by the watt meter.

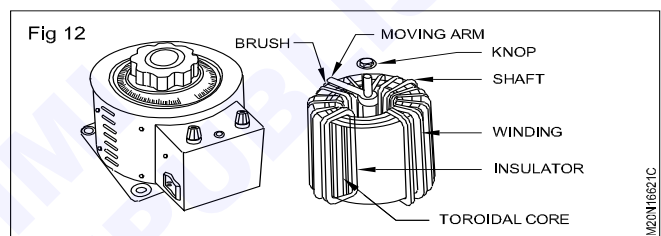
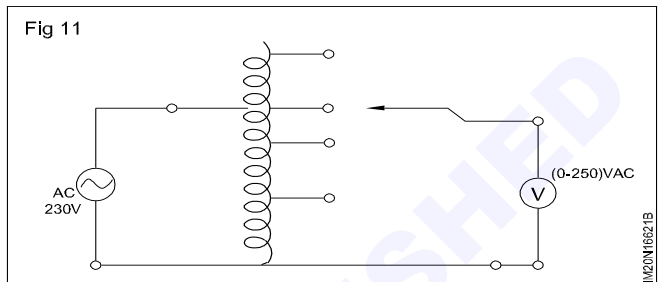


**2 Short circuit test (Fig 10):** The object of the test is to find out copper or variable loss. The copper loss in a transformer is directly proportional to the square of the current. The volt meter, ammeter and watt meter were connected as shown in the figure 9 with high voltage winding. Low voltage side winding is short circuited. With an auto transformer the primary winding is supplied with normal frequency slowly rising supply voltage. The voltage increased till the full load current passes in the primary side. Now on full load current the meter reading of watt meter is the copper or the

variable loss. % voltage regulation =  $(V_o - V_l) / V_o \times 100$ . Where  $V_o$  is the no load voltage and  $V_l$  is the full load voltage.



**Auto transformer (Fig 11):** This is a single winding transformer. The core with the single winding, input and output leads were taken as shown in Fig 11. The current pass in between the input and output terminals. Fig 12 shows the parts of a auto transformer.



### Advantages

- 1 The amount of winding material is less and so the price also low. Power loss is low.
- 2 With the tapping in winding we can get low voltage.
- 3 When comparing with the two winding transformer the voltage regulation is good.
- 4 When comparing with the two winding transformer and auto transformer of similar capacity, the efficiency of auto transformer is high.

### Application of auto transformer

- 1 The same transformer can be used as step-up and step-down transformer.
- 2 Can be used as a voltage booster.
- 3 The three phase auto transformers were used in 3 phase induction motor starter.
- 4 In transmission line 3 phase auto transformer is used for grid connection.

### Disadvantages of auto transformer

- 1 When in the winding of the auto transformer output(secondary) have any winding cut then the total load will shifted to input primary side.
- 2 The short circuit current will be more severe than the 2 winding transformer.
- 3 The load cant be taken off from the primary winding.

## Electrical measuring instruments and its working principles

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

- explain types of Electronics instruments, its torque and damping methods.

**Introduction :** When we learn about electricity we come across terms like current, voltage, resistance, frequency, power factor...etc.

Each of the parameters are having separate units and we measure them with different meters. Meters can be broadly classified into

- 1 Absolute instruments and
- 2 Secondary instruments.

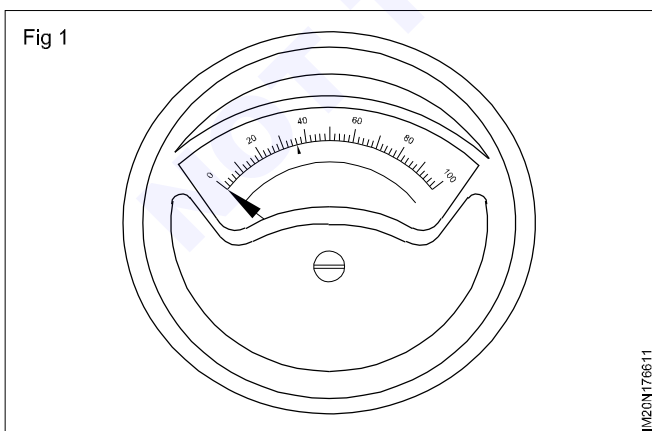
**1 Absolute instruments:** The values of the quantity to be calculated in terms of physical constants and their deflection are given by Absolute Instruments. The measurement measured by this meter need not be compared with other types of meter. Example: Tangent Galvano meter.

**2 Secondary instruments:** Secondary instruments are those, in which the value of Electronics quantity to be measured can be determined from the deflection of the instruments. These meters are calibrated with the help of absolute instruments. Most of the meters are of Secondary instruments. For example: Ammeter, voltmeter, energy meter etc.

### Classification of secondary instruments

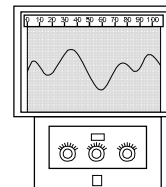
- 1 Indicating or deflecting instrument
- 2 Recording instrument and
- 3 Integrated instruments

**1 Indicating or deflecting instrument (Fig 1):** Measurements were indicated over a dial over which a pointer moves. Example: Ammeter, Voltmeter, Energy meter, Ohm meter etc.



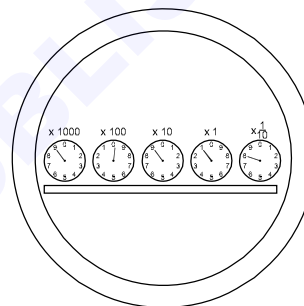
**2 Recording instrument (Fig 2):** For a particular duration the varying measurement has been drawn on a graph paper. These measuring instruments were used in Electronics generation station. Example: ECG machine and thermo scope

Fig 2



**3 Integrated instruments (Fig 3):** The Electronics energy spend during a particular time is measured by integrated instrument. For the best example is the energy meter. It cumulate the Electronics energy and shows over a time by the counters n the face of the meter.

Fig 3



### Torque or force on an indicating type instrument

For proper function of indicating instrument, three type of torque or force is required.

- 1 Deflecting or driving torque.
- 2 Controlling torque
- 3 Damping torque.

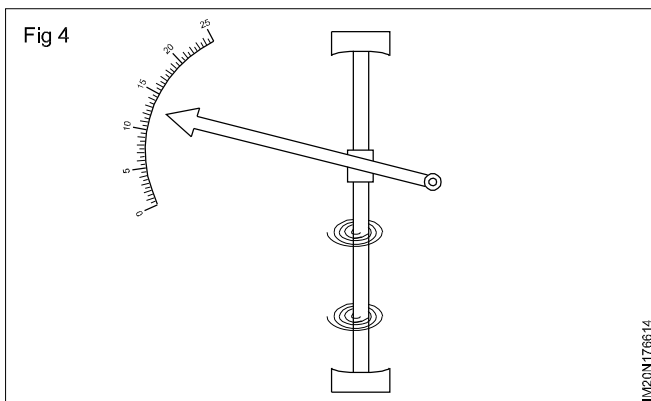
**1 Deflecting or driving torque:** This torque will move the pointer from zero position. Due to the effect of the current this torque is produced. ( Magnetic effect, heat effect, electro static effect, induction effect or by chemical effect). This torque converts Electronics energy to mechanical energy.

**2 Controlling torque:** To stop the pointer due to the deflecting torque at the desired measuring value another torque is required. This torque is known as controlling torque. The controlling torque opposed the deflecting torque. When both the torques were same, the pointer stops. When the supply is removed, the pointer returns to zero due to the controlling torque.

### Types of controlling torque

- a Spring control and
- b Gravity control.

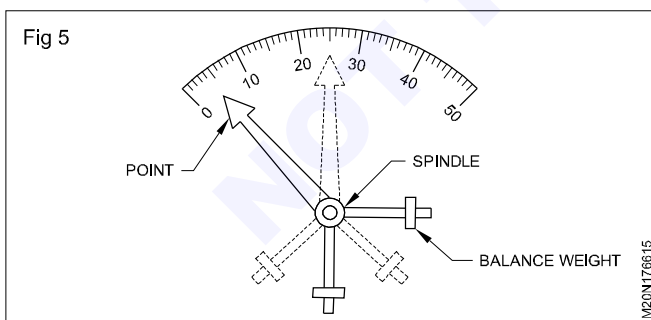
- a Spring control (Fig 4):** As shown in the figure two coiled shape phosphor bronze hair springs were mounted on a spindle up and down. The two springs were fixed so that when one spring expands, the other spring will compressed. When the spindle rotates one spring compress and other spring expands due to the deflecting and controlling torques. When the measured unit reaches both torques are same and will be shown on the dial. When the supply is disconnected the compressed spring will be released (due to control torque) and the pointer returns to zero. These springs should have the following characteristic.



- 1 Should be nonmagnetic.
- 2 Should be of least Electronics resistance
- 3 Should not elongate due to heat.
- 4 After repeated numerous operation the spring should retain its spring force.

**Advantages:** The spring is used for conducting the current to the moving coil. Can be used on any stage.

- b Gravity control (Fig 5):** In this method the controlling torque is achieved by the gravitational force. As shown in the figure two weights are positioned in perpendicular to each other. One is the control weight and the other is the balance weight. Control weight is used to bring controlling torque and to bring the pointer back to zero. Balance weight is used to stabilize the pointer over the reading.



**Advantages:** Cheaper than the control springs and the scale of the instrument is uniform

- 3 Damping torque:** The indicating needle will oscillate around the reading eventhough deflecting and controlling torque is present. This will take time for the reading. To get instantaneous reading another torque known as damping torque is required. If the needle shows the

reading without any oscillation and quickly then we can assure critical damping is used. Due to excessive damping the indicator will move slowly to its destination. Due to under damping the indicator moves very slowly and take time. There will be oscillation of the needle over the scale.

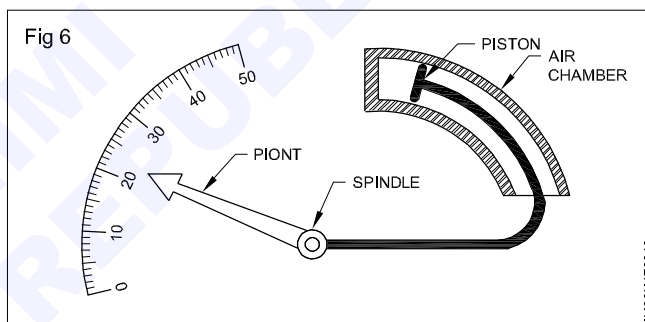
There are three types of dampings.

- A Air friction damping.
- B Fluid friction damping and
- C Eddy current damping.

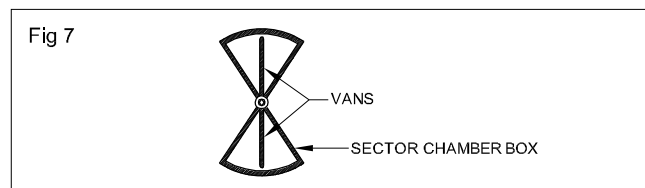
**A Air friction damping:** Damping by air friction employs

- 1 Piston type and
- 2 Box or sector type.

**Piston type (Fig 6):** A light aluminum piston is connected to the spindle of the meter. This piston will move to and fro inside a chamber which is closed on one side. When the needle moves the piston moves inside the air chamber. The air inside the chamber is pressed. Compressed air escape through the edge of the piston slowly. This create a damping torque and will establish the needle vibration free.

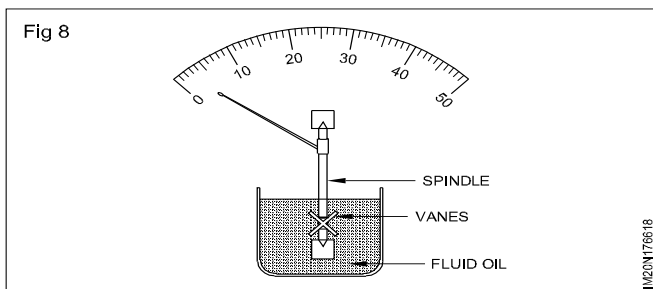


**Box or sector type (Fig 7):** Figure shows two quadral circular air chamber. A rectangular plate is fixed inside the chamber. The plate is fixed to the spindle. When the needle moves the plate will moves inside the air chamber and produce the damping torque.



**Fluid friction damping (Fig 8):** A x shaped aluminum sheet is immersed in a damping fluid. Aluminum sheet is connected to the spindle. When the pointer turns the spindle rotates and the aluminum sheet inside the damping fluid creates a damping torque. Due to this the pointer is stable. The damping fluid should have the following characteristic.

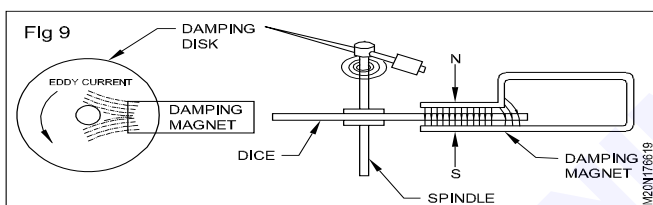
- 1 Should be nonconductive.
- 2 No change in viscosity
- 3 Should not evaporate.
- 4 It should not corrode the plate.



### Disadvantage

This type of damping force should be used in meters where placed in vertical position.

**C Eddy current damping (Fig 9):** This method of damping is superior than other damping methods. A thin copper or aluminum disc is mounted on a spindle. This disc will rotate between a U shaped permanent magnet. When the pointer moves, the spindle rotate along with disc. The magnetic field between the poles of the magnet will cut the rotating disc. An EMF is induced in the disc. This EMF produces an eddy current, which moves in opposite to the EMF. This will create a damping torque known as eddy current damping torque.



**Identification of meter terminals :** If it is a DC meter then marking will be +VE AND - VE. Red will be +VE and black will be - VE. If it is an AC meter then phase and neutral will be of same color. On multi range meter the phase will be in red color and neutral will be in black with voltage rating indicated. If the meter is provided with range selector switch or knob then proper rating selection should be done by selector or knob. If the value of the source is unknown then measure with high range first, then for the fraction measure with the desired switch range. The indicator should deflect more than 60% of range for sellection.

### Details on the instrument dial

#### 1 Measuring range and unit

|          |        |                                      |
|----------|--------|--------------------------------------|
| V        | VOLT   | $\mu$ V MV and KV                    |
| A        | AMPERE | $\mu$ A mA and KA                    |
| W        | WATT   | mW MW KW                             |
| $\Omega$ | OHM    | m $\Omega$ , K $\Omega$ , M $\Omega$ |
| HZ       | HERTZ  | KHZ MHZ                              |

#### 2 Types of supply

|       |                                |
|-------|--------------------------------|
| —     | Direct current DC              |
| ~     | Alternating current            |
| ~ ~   | Direct and alternating current |
| ~ ~ ~ | 3 phase AC                     |

### 3 Testing potential

|     |            |
|-----|------------|
| ☆   | Upto 500V  |
| ☆ 2 | 2000V      |
| ☆ 0 | No voltage |

### 4 Using position

|      |                      |
|------|----------------------|
| ⊥    | Verticle             |
| └┘   | Horizontal           |
| 60°  | Use angle 60°        |
| ±2°  | From vertical ± 2°   |
| ±10° | From horizontal ±10° |

**5 Accuracy class:** For % of full scale deflection and % of actual reading

|     |                           |
|-----|---------------------------|
| 2.5 | Measuring range end value |
| 2.8 | Length of scale           |

### 6 Indication error

|     |                        |
|-----|------------------------|
| 1   | Indicating loss ± 1%   |
| 2.5 | Indicating loss ± 2.5% |
| 3.5 | Indicating loss ± 3.5% |

### 7 Type of instrument

|    |                                            |
|----|--------------------------------------------|
| ⌋  | Moving coil meter                          |
| ⌋⌋ | Moving iron meter                          |
| ⌋⌋ | Electro magnetic quotiemt meter            |
| ⌋⌋ | Electro dynamic meter with magnetic screen |
| ⌋⌋ | Moving coil with rectfier                  |
| ⌋⌋ | Thermo couple meter                        |
| ⌋⌋ | Separate series and shunt resistance meter |
| ⌋⌋ | Induction type meter                       |
| ⌋⌋ | Vibarator type meter                       |
| ⌋⌋ | Hot wire meter                             |
| ⌋⌋ | Electro static type meter                  |

## 8 Type of scale

|  |                                                                               |
|--|-------------------------------------------------------------------------------|
|  | Course and course fine scale. Error of 1 to 2.5% applicable panel meters      |
|  | Fine scale meters. 0.1 to 0.3% error instruments with mirror in back ground   |
|  | Extended scale. Used in short time over load or starting current measurement  |
|  | Linear scale. Used in moving coil instruments. Full range of scale is uniform |
|  | Non-linear scale. Used in moving iron instruments. Scale is non uniform       |
|  | Non-linear scale coarse. Used in Megger                                       |

### Cause of errors in meter

- Device error:** These errors are due to assembly while manufacture, wrong adjustment and using in wrong position.
- Influence error:** Due to environmental moisture, heat, vibration and magnetic field
- Switching error:** Wrong connection of the meter
- Human error:** Error in reading due to parallax and wrong calculation of sub division.

Apart from these the amount of error in the meter changes as given in the table. The error were given in number will represent  $\pm$  value and expressed as %

| Error      | Useage                                       |
|------------|----------------------------------------------|
| 0.1 TO 0.3 | In laboratories where precision is important |
| 0.5        | Laboratory and portable measuring instrument |
| 1 TO 2.5   | Panel instruments used in factories          |

### Type of indicators or pointers

|   |                  |  |
|---|------------------|--|
| 1 | Standard pointer |  |
| 2 | Knife pointer    |  |
| 3 | Lance pointer    |  |

|   |                                 |  |
|---|---------------------------------|--|
| 4 | Reed or tube pointer            |  |
| 5 | Hair line pointer               |  |
| 6 | Knife pointer with mirror scale |  |

**Mirror scale:** This is used where precision is important. Parallax error will happen during reading when the pointer is leaned to some angle and not straight. We have to take reading by not seeing the image of pointer on the mirror but to see straight on the needle. By this Parallax error is avoided.

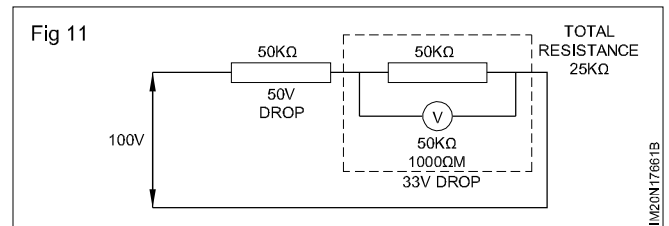
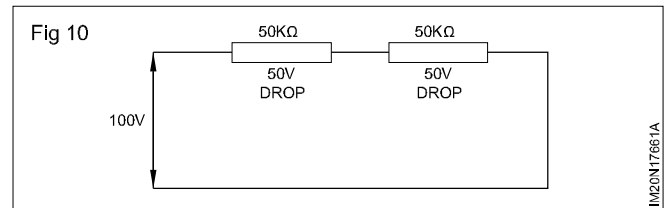
**Zero adjustment:** There is provision for the pointer doesn't go below or beyond maximum value. There are two stoppers on the dial to prevent this. By adjusting the zero adjustment screw the pointer can be brought in line with zero reading of the scale. As far as a meter is concerned when the battery voltage reduces, zero error will occur. By When the zero adjustment screw is turned, there is a provision to get the correct voltage by a variable resistor inside.

**Meter sensitivity:** The current required to turn the scale deflection of the scale is called the meter sensitivity. This



level will vary from 5 micro amp to 75 milli amps. When a moving coil meter(PMMC) is used as a Volt meter a series resistance(multiplier) of high value is connected to the coil of the meter. At this level the sensitivity of the meter is = Resistance between the meter / meter range. That is it is the inverse ratio of the full scale deflection current. This denoted by ohms per volt.  $S = 1 / I(FSD) = 1/1\text{ma} = 1/(1/1000) = 1000\text{ohms/volt}$ .

**Loading effect of voltmeter:** The sensitivity is an important factor before selecting a voltmeter for the desired voltage measurement. Loading effect of the voltmeter is the difference between actual voltage that exists in the circuit without connecting the voltmeter and the voltage that appears after connecting voltmeter. A voltmeter is placed across a resistor to measure its voltage. For example refer figure 10 & 11. For each voltage drop of 50K in the two resistors we can arrive as 50V. In the figure 8 let us assume we use to measure the voltage drop across the resistor of 50k ohm with a less sensitivity meter(1000 ohms per volt). When the meter range is at 50V its resistance is 50K $\Omega$ .



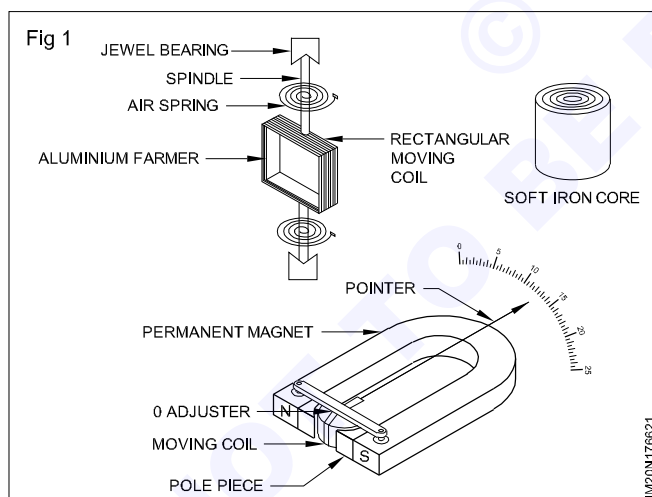
For 1 volt it is 1000 $\Omega$ . For 50 volts it is 5000 $\Omega$ . When this voltmeter is connected in parallel to the 50K $\Omega$  resistor, then the total resistance will be reduced by 25K $\Omega$ . and the voltmeter reading will be  $(25 / 70) * 100\text{V} = 33.3\text{V}$ . Hence the voltmeter shows 33.3 volts instead 50volts. This wrong meter reading is called the loading effect.

## Permanent magnet moving coil meter -PMMC

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

- explain the meter sensitivity, zero adjustment and effect of voltmeter
- explain the principle and working of PMMC .

**Permanent magnet moving coil meter (Fig 1) :** When a current carrying conductor is placed in a magnetic field then a torque will be induced in the conductor. This DC motor principle is used in PMMC.



As shown in figure 1 a U shaped permanent magnet is used. Pole shoes are fixed at the end of the poles for uniform air gap with the moving coil. Thin strand is wound over a rectangular former made of copper or aluminum. This rectangular former gives a stable shape to the coil and give eddy current damping to the meter. At the center of the former a circular soft iron cylindrical core is placed. This core reduces the reluctance in the magnetic flux and increases its value. It core also serve to distribute uniform flux in between the poles. The coil wounded on the former is attached to the spindle. On top and bottom of the spindle, hair springs made of phosphorous bronze were fixed. These springs produces the controlling torque. Provision

is made to the rotating coil to give the source supply. The pointer is attached to the spindle which moves over a graduated scale. On two end of the spindle jewel bearings were mounted.

**Operating principles:** When current passes through the moving coil which is placed in the magnetic field, a torque is induced in the coil. This rotate the spindle. The pointer will moves over the scale due to the spindle rotation. The torque is proportional to the current and hence the scale is linear and uniform.

The torque produced is  $T = BLINr$  Newton, where  $B$ =Flux density in weber/M<sup>2</sup>.,  $L$  is the effective length of the coil in meter,  $I$  is the current in Amps and  $N$  is the number of turns in the coil.

**Note:** By using this meter we can measure directly the current in micro Amps. For measuring more current we have to use shunts. For still more current to measure, Multipliers are used.

### Advantage

- 1 Consume less power.
- 2 Uniform scale and 270° deflection
- 3 More torque / weight ratio
- 4 Superior damping torque.
- 5 Safety from stray magnetic field.
- 6 There is no hysteresis loss.
- 7 Using correct resistance, meter can be used as Ammeter or Voltmeter.

## Disadvantages

- 1 Can be used only on DC supply
- 2 Only spring control can be used
- 3 Cost is high
- 4 Due to loss in magnetism of the permanent magnet there might be error in measurement.

## FORMULAS

Ammeter - Shunt

$$1 \quad I_m / I = S / (S + R_m) \text{ OR}$$

## Extending the range of meter

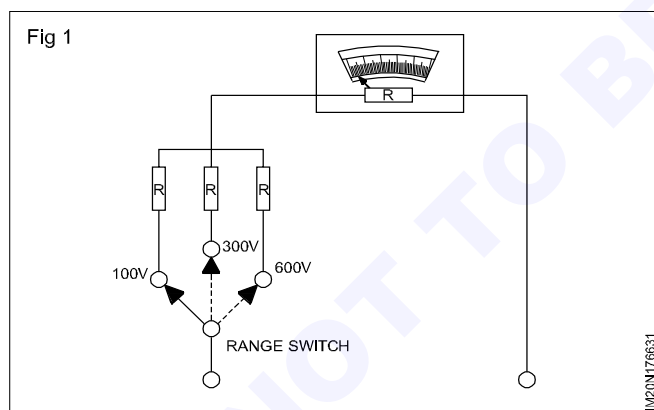
**Objectives:** At the end of this lesson you shall be able to

- explain the extending the range of voltmeter
- explain the extending the range of ammeter.

**Extending the range of Volt meter:** All meters are having constant resistance. According to the passage of current voltage drop occur.  $V = I_m R_m$ . All meters are manufactured to withstand a particular current carrying capacity. Hence to measure high voltage we have to increase the coil resistance. For this series resistance are used and called as multipliers. To calculate multiplier resistance  $MR = (V - V_m) / I_m$  or  $MR = (MF - 1) * R_m$ ,

$MF = V / V_m$ . Where  $M_R$  is the multiplier resistance,  $V$  is the voltage to be measured,  $V_m$  is the full scale deflection,  $I_m$  is the meter current and  $MF$  is the multiplying factor.

**Multi range voltmeter (Fig 1):** As shown in figure the multi range voltmeter is having multipliers or the required range. These are selected by the switch and connected to the circuit.



**Note:** Normally the resistor will change its value due to temperature change. Hence the multiplier resistor should be made of material having low temperature co-efficient. Materials such as manganese and constantan should be used. The temperature coefficient of Manganese is 0.000015 and that of constantan is 0.00001.

$S = (I_m R_m) / (I - I_m)$ , where  $I_m$  = Full scale deflection current,  $R_m$  = Meter coil resistance  $S$  = Shunt resistance,  $I_m R_m$  = Voltage drop of the meter, and  $V$  = Measuring voltage

- 2  $M = (V - V_m) / I_m$  where  $V$  is the measuring voltage,  $V_m$  is the full scale deflection,  $I_m$  meter current, and  $M$  multiplier resistance.

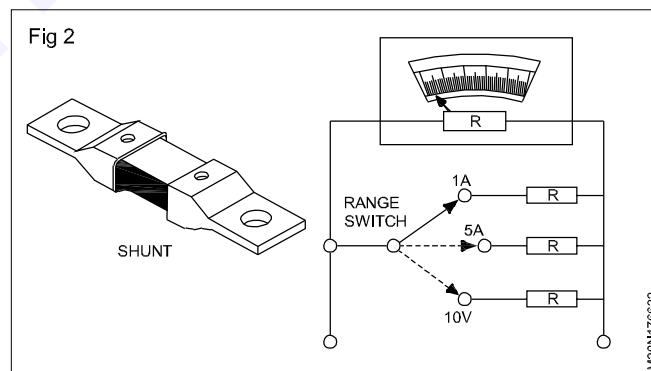
$KWH$  = revolution of disc / Meter constant.

**Extending the range of Ammeter meter:** The meter coil will withstand to certain current limit. To measure current above that limit, a resistor in parallel to the coil is used. This resistor is called as Shunt.

To calculate the value of shunt resistance  $S_R = (I_m R_m) / (I - I_m)$  where  $S_R$  is the shunt resistor,  $S_M$  is the meter resistance,  $I_m$  is the meter current and  $I$  is the current to be measured.

**Note :** The shunt resistor is made of manganese and there wont be any variation in resistance due to temperature.

**Multi range Ammeter (Fig 2) :** Shunt resistance of equal number is used for the range number. This is selected through a range selector switch.



| S.No | Moving Iron                                                                    | Moving coil                                                                                                                |
|------|--------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------|
| 1    | A piece of pig iron is attracted by the electro magnet and a torque is induced | A current carrying conductor is placed in the magnetic field of permanent magnet and a torque is induced in the conductor. |
| 2    | Spring gravity control is used                                                 | Only normal spring control is used                                                                                         |
| 3    | Air damping is used                                                            | Eddy current damping is used.                                                                                              |

|    |                                                                                                                 |                                                                                                 |
|----|-----------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|
| 4  | The deflection torque is directly proportional to the square of the current (T directly proportional to $I^2$ ) | The deflection torque is directly proportional to the current (T directly proportional to $I$ ) |
| 5  | The scale is uniform                                                                                            | The scale is not uniform                                                                        |
| 6  | This is not for precision measurement                                                                           | Precision measurement can be taken.                                                             |
| 7  | Low price                                                                                                       | High price                                                                                      |
| 8  | High power loss                                                                                                 | Low power loss                                                                                  |
| 9  | Can be used both in AC & DC supply                                                                              | Only DC supply can be given                                                                     |
| 10 | Used in AC/DC Ammeter, voltmeter                                                                                | Used in DC Ammeter, DC voltmeter, Galvano meter and Ohm meter.                                  |

## Ohm meter

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

- explain principle of ohm meter, its construction and working method
- explain megger and earth tester construction and working method.

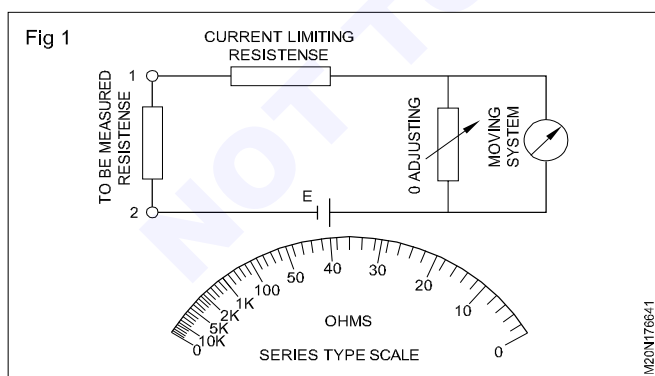
From  $1\Omega$  to  $100000\Omega$  of mid range resistors can be measured by any one of the following methods

- 1 By ohm meter
- 2 By Wheatstone bridge method
- 3 By Ammeter and Voltmeter
- 4 By comparison method
- 5 By substitution method.

### Types of Ohm meter

- 1 Series type ohm meter and
- 2 Shunt type ohm meter

**Series type ohm meter (Fig 1):** This is used to measure medium range resistors of value  $1\Omega$  to  $100000\Omega$ . In this type, the moving system, current limiting resistance  $R$  and the resistor to be measured in series as shown. Zero adjusting resistor is connected in parallel to the moving system. The left hand side of the scale is indicated with infinity mark and right hand side with zero. The left hand side of the scale is narrow and not in uniform.

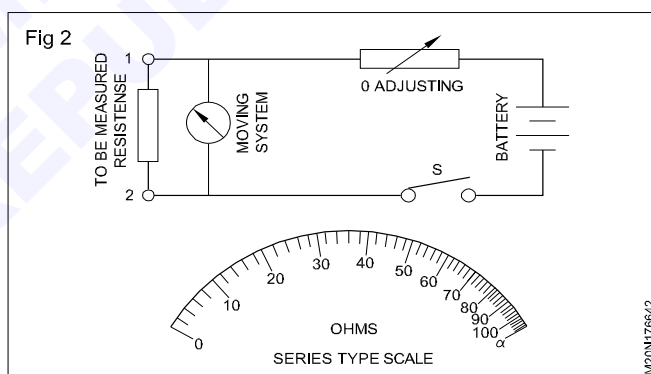


**Working principle:** When a current carrying conductor is placed in a magnetic field, the conductor will experience a torque. On this principle this meter works.

Between terminal 1&2 a resistor is connected. When the switch  $S$  is closed a current which is indirectly proportional the resistance will flow in the circuit. Due to this the indicator moves and shows the value of resistance.

**Shunt type Ohm meter (Fig 2):** This is used to measure resistance of low value. The left hand side of the scale begin with zero and the right hand side ends with infinity. In this type moving system  $M$ , zero adjusting resistor, and battery will be connected in series. In parallel to the battery the resistance to be measured is connected.

### Working method (Fig 2)

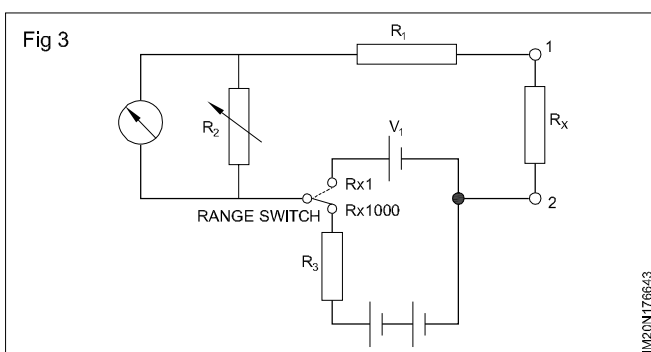


- 1 The resistance to be measured and the battery are connected in parallel. As per shunt type when 1&2 points are shorted, the full level current will not pass through the moving system. Hence there is no current in moving system and no deflection of needle and the reading is zero.
- 2 When terminal 1&2 is open, the full current will pass through the moving system and maximum torque is produced and the needle will deflect to end of right side scale showing reading infinity.
- 3 When a resistor is connected in between terminal 1&2, the current passing through the moving system is inversely proportional to the resistance to be measured and the resistance of the meter coil. This current produces a torque which moves the deflection of pointer over the scale.

**Note:** The accuracy of the meter depends on the condition of the battery. Before using the meter terminal 1&2 is shorted and zero adjustment is done by the variable resistor.

**If this is not possible then use a new battery. Before using the meter don't give supply. The electrolytic capacitors should be discharged. Since the relation between the current and the resistance is inverse the scale of the meter is not uniform. It will be narrow towards infinity.**

**Multi range ohm meter (Fig 3):** With a single meter we can measure in the range of  $1\Omega$  to  $100000\Omega$  of medium resistance. For accurate readings ranges of 0-100, 0-10000 and 0-100000 were selected through a range switch. Range switch acts as a multiplier factor in ohm meter. The actual reading should be the pointer placement multiply with the range factor. In a series ohm meter type how the range switch and battery were connected is shown in figure 3.

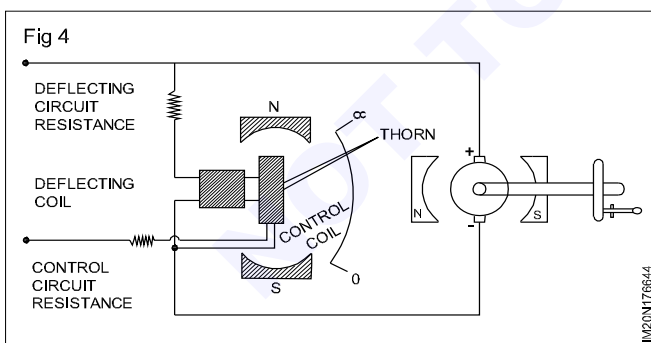


**Note: The accuracy in this meter is low when low and high resistance were measured**

**Megger or Insulation tester:** To measure insulation resistance ( meg ohm) megger is used. This is also called as meg ohm meter. There are two important parts in this meter.

- 1 Hand driven generator and
- 2 High range ohm meter.

**Construction (Fig 4):** When the handle of the megger is rotated around 160 RPM a DC voltage of 500 or 1000V is produced by the generator inside. The current range will be 5 to 10m amps.



The construction of the Megger is shown in the figure below. The Megger has one current coil and the two voltage coils V1 and V2. The voltage coil V1 is passed over the magnet connected to the generator. When the pointer of the PMMC instrument deflects towards infinity, it means that the voltage coil remains in the weak magnetic field and thus experienced the very little torque. the torque experienced by the coil increases when it moves inside the strong

magnetic field. The coil experience the maximum torque under the pole faces and the pointer set at the zero end of the resistance scale.

For improving the torque, the voltage coil V2 is used. The coil V2 is so allocated that when the pointer deflects from infinity to zero coil moves into a stronger magnetic field.

In Megger, the combined action of both the voltage coils V1 and V2 are considered. The coil comprises a spring of variable stiffness. It is stiff near the zero end of the coil and becomes very weak near the infinity end of the spring.

The spring compresses the low resistance portion and opens the high resistance of the spring, which is the great advantage of the Megger because it is used for measuring the insulation of the resistance which is usually very high.

The instrument has voltage selector switch which is used for selecting the voltage range of the instrument. The voltage range is controlled by selecting the varying resistance R connected in series with the current coil. The voltage is generated by connecting the hand driven generator.

**Working of Megger :** The testing voltage is usually 500, 1000 or 2500 V which is generated by the hand driven generator. The generator has centrifugal clutch due to which the generator supplied the constant for the insulation test. The constant voltage is used for testing the insulation having low resistance.

The Megger has three coils two pressure coils and one current coil. The pressure coil rotates the moving coil in the anticlockwise direction, whereas the current coil rotates it in the clockwise direction.

When the unknown resistance is connected in the circuit, the pointer of the moving coil becomes stable. The pressure coil and the current coil balance the pointer and set it in the middle of the scale.

The deflection of the pointer is directly proportional to the voltage applied to the external circuit. When the testing circuit is applied across the Megger, and if there is no shorting throughout the insulation then the pointer deflects towards the infinity. Which shows that the resistance has high insulation. For low resistance, the pointer moves towards zero.

**Note:** Before using the megger, its terminals should be kept open and the handle is rotated. Now the indicator shows infinity. When the terminal is short circuited the indicator will show zero. This pre-check should be done before using megger. When current flows in the live line don't use the megger. Rotate the handle in the direction indicated. Apart from insulation resistance this meter is also used for continuity test.

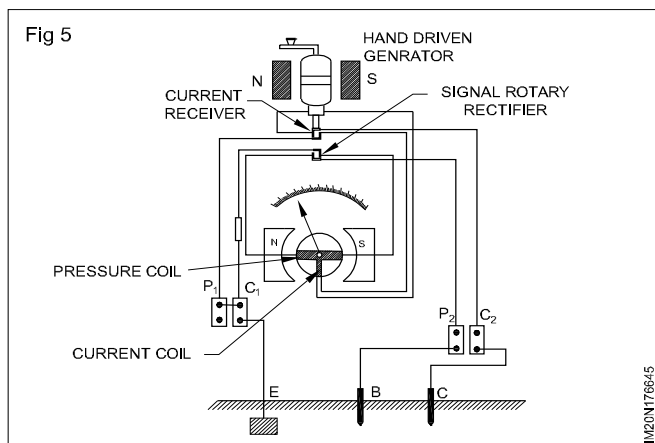
Now in the market we get domestic electronic megger with push button type selector. For industry megger operated by motor is available. The megger is classified as per its voltage generation.

When doing the insulation test between line and body, the earth terminal of the megger is connected to the body. For testing the insulation test of a machine the megger voltage should be the double the machine rated voltage.



| Megger range            | Where used                                            |
|-------------------------|-------------------------------------------------------|
| 50000M $\Omega$ / 2500V | Power transformers and high tension equipment testing |
| 2000M $\Omega$ / 1000V  | To test power circuit and motors.                     |
| 50M $\Omega$ / 500V     | To test house wiring and small motors of 250V range.  |

**Earth resistance tester (Fig 5) :** This is used to measure the earth resistance, earth continuity and soil resistivity. Fall of potential method is used for the measurement.



#### Parts

- 1 Hand driven generator,
- 2 Rotary current reverser.
- 3 Synchronous rotary rectifier and
- 4 Ohm meter.

**Construction :** Hand driven Generator: When the handle of the generator is rotated to about 160 RPM a voltage of 500V DC is produced. On its armature shaft, a rectifier and a current reversal mechanism is fixed.

**Rotary current reverser:** This is fixed on the generator shaft. The DC voltage generated into AC voltage which is

to be driven to the ground. If we use DC directly for the measurement then it will be wrong measurement due to electrolytic EMF.

**Synchronous rotary rectifier:** A voltage drop is produced when the AC voltage is injected to the earth. This AC voltage should not be given to moving coil type ohm meter. Hence with rectifier the AC is converted to DC and given to the Ohm meter.

**Ohm meter:** The Ohm meter is built in to the system to measure the earth resistance. Refer figure 5. In the middle of the poles of a permanent magnet, a current and a pressure coil is placed on the same spindle 90° apart. Current coil is connected in series and the pressure coil is connected in parallel. In between the two coils a pointer is fixed which moves over a scale. There are four terminals P1, P2, C1 and C2. Here P1 and C1 were shorted and brought to another terminal called E which is connected to the earth electrode. P2 and C2 were connected to auxiliary electrodes B and C.

**Operation:** The auxiliary electrodes B & C were to be separated from earth electrode by 12.5 and 25 meters apart. B and C terminals should be on the earth too. As shown in the figure E, B, C were connected and the handle of the generator is rotated to 160 RPM. Due to this the current in the current coil and the current in the pressure coil will have a ratio and the pointer will move as per this ratio and show a measurement. This is the measurement of earth. To measure the correct resistance, it is done in four or five places (the distance between the spikes same) and do the average measurement.

**Note:** A frequency is generated in the meter. Another equal frequency associated with the circuit will cause the pointer to vibrate. At this point the rotation through the handle should be increased or decreased so as to stop the pointer vibration

## Types of indicating instruments

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

- explain the types of indicating instruments and its operation
- explain the advantages and disadvantages of indicating instruments.

### Types of indicating instruments

- 1 Moving iron instrument (attractive and repulsive)
- 2 Permanent magnet moving coil instrument
- 3 Dynamo meter
- 4 Electro static meter.
- 5 Induction meter.

**Moving iron attraction type (Fig 1):** If a small iron is placed in a magnetic field then it will be attracted to the field. On this principle this instrument works. As shown in figure an oval shaped soft iron is placed inside a spindle which is connected to an indicator which moves over a graduated scale. The spindle rests on jewel bearing. In this

setup the iron moves inside the coil of the air core. The movement of the iron in the air core depends on square of the current directly.  $T = I^2$ . Whatever be the current direction in the coil, the iron always moves inside the core. This instrument can be used both in AC and DC circuits.

#### Advantages

- 1 Can be used in AC and DC supplies. There is no polarity marking on the terminals.
- 2 Gravity or spring control is used.
- 3 Air damping is used.
- 4 Uses high operating torque.



- 5 Cost of this instrument is low.
- 6 Low turn high diameter coils are used for ammeter and high turn low diameter coils are used in volt meter. For this reason shunt and multipliers are need not be used to measure the parameters to some extent.
- 7 Meter needle can have a deflection up to 240 degrees for better accuracy.

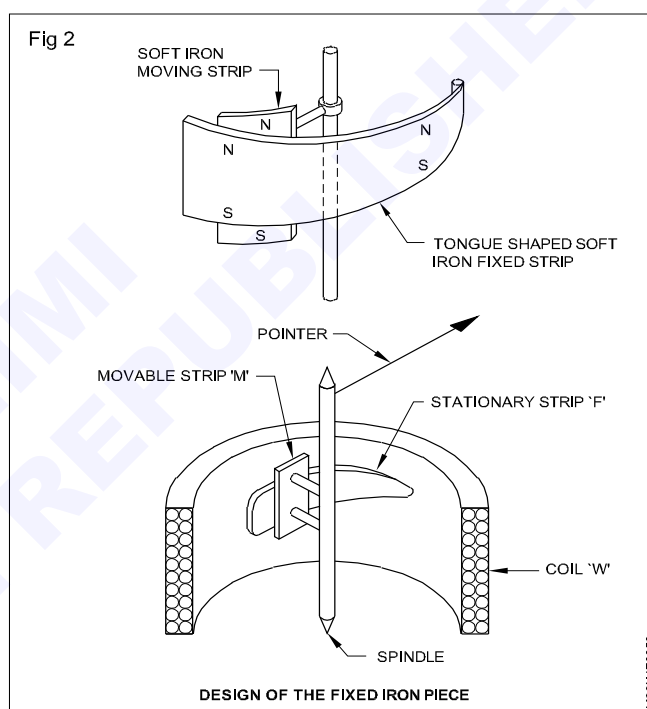
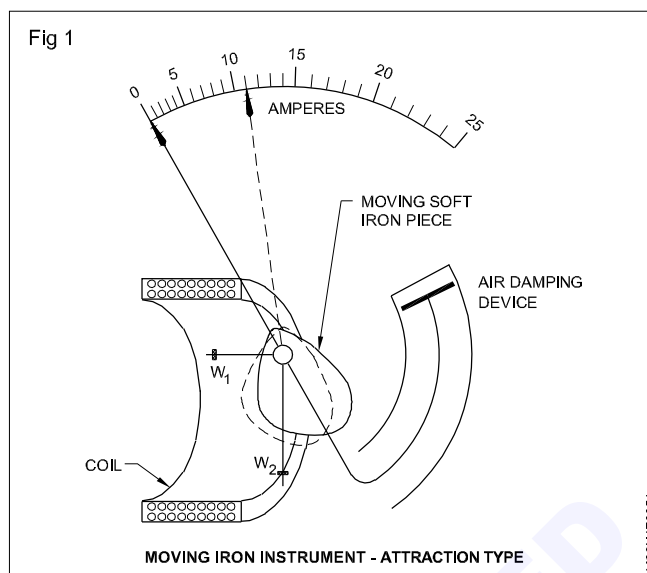
### Disadvantages

- 1 Calibration is not linear that is at the beginning it will be narrow and dispersed at the end.
- 2 Errors are due to Hysteresis, frequency and stray magnetic field.

**Repulsion type motors (Fig 2) :** The principle of operation is force due to repulsion of like poles of magnet. As shown in figure two soft iron pieces were mounted on a spindle in parallel. One soft iron is movable and the other is fixed. This is placed inside the air core of the coil. The pointer is attached to the spindle which moves over a scale. The supply is given and the coil produces a magnetic field which creates same polarity on the two soft iron strips. A repulsive force created in between the two soft iron strips and the moving strip will turn the spindle which in turn moves the pointer.

In moving iron meter the torque  $T$  is directly proportional to the square of the current, the reading at the start will be narrow then widens. To offset this and to have a more or less uniform graduation of the scale, the fixed iron will be conical of less area at the tip.

Due to deflection, the moving soft iron will move from the base of the fixed iron to the tip of the fixed iron. This deflection torque is low and the scale is more or less uniform. Air friction damping is used. The characteristics are similar to attraction type meter.



## Watt meter and energy meter

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

- explain the principle of watt meter and its working method
- explain the advantage and disadvantage of wattmeter
- explain the working of energy meter and the description of its parts.

### Wattmeter

To determine the power used in an AC circuit we use the formula  $W = VI \cos \theta$ . Hence we can find voltmeter, ammeter and power factor meter to determine the power. But to setup the three meters with connections, time consumed and the changes in load will give errors in readings. To overcome this the function of the three meters can be combined to give a single meter called wattmeter.

### Types of Wattmeter

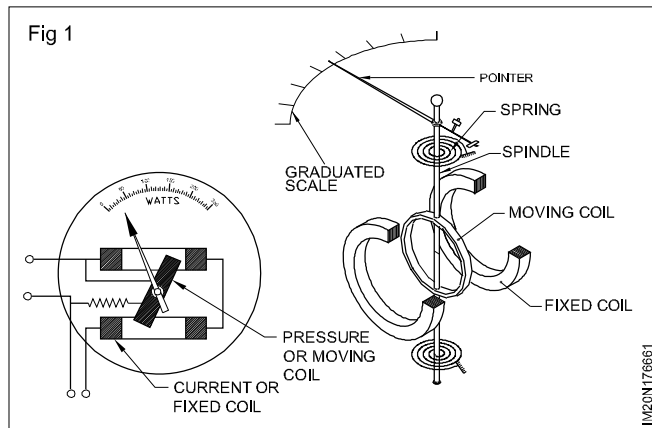
- 1 Dynamo meter type used in AC and DC.
- 2 Induction type used in AC only.

- 3 Electro static type which is used in DC only.

**Dynamo meter type Watt meter (Fig 1) :** Dynamo meter type instruments can be used in both AC and DC. This meter works on the principle of DC Motor. That is when a current carrying conductor is placed on a magnetic field then the conductor will experience a torque.

As shown in figure 1 there are two coils pressure coil (moving coil) and current coil (fixed coil). Two current coils of less resistance and thick wires of few turns were connected in series with the load. The pressure coil is of high resistance coil wound on a wound on an aluminum former. This is placed in between the two fixed coils. The former is

connected to the spindle. To have the controlling torque for the moving coil and to give supply springs were provided. The aluminum former on which the pressure coil is wound, gives eddy current damping. To avoid high voltage being fed to the pressure coil, a high resistance is connected in series. The weight of the pressure coil is less and able to rotate freely. Moreover, the series resistor will provide zero degree in between the moving coil current and the pressure coil voltage that is they are in phase.



**Working principle :** The pressure coil produces fixed magnetic field. The current coil produces magnetic field

as per the load current. Due to these magnetic forces the torque produced will be directly proportion to the product of current and voltage. When this instrument is used as Ammeter and voltmeter, the scales are uniform. While using as wattmeter the scales are uniform. Deflecting torque  $T \propto V \cdot I$  OR  $T \propto W$ . Air in-between the coil acts as a core and hence hysteresis effect will be low.

#### Advantages

- 1 Can be used both in AC and DC
- 2 Got more accuracy
- 3 When using as a watt meter the scale is uniform.
- 4 Since it is air core, losses due to hysteresis and eddy current is low.

#### Disadvantages

- 1 The cost is high when compared to PMMC.
- 2 While using as an Ammeter or Voltmeter the scale wont be uniform
- 3 It is less torque weight ratio and hence less sensitivity.
- 4 Consume more power while in operation

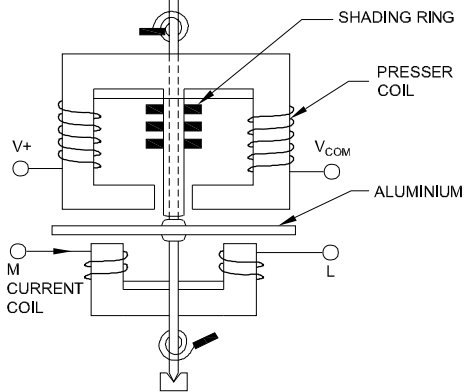
#### Using dynamo meter type meter as Ammeter and Voltmeter

|                                                                                                               |  |
|---------------------------------------------------------------------------------------------------------------|--|
| To measure less amount of current (micro or milli amps) the coils should be connected as shown in the figure. |  |
| To measure high amount of current the coils should be connected with shunt resistance as shown in the figure. |  |
| To use this meter as Voltmeter connection should be done as per in the circuit shown.                         |  |

**Induction type Wattmeter (Fig 2) :** This meter works on the principal of Electromagnetic induction. This can be used only on AC. In this a shunt magnet (pressure coil) and a series magnet (current coil) were used. Thick coil of few turns is used as current coil (M, L) and connected in series with the supply. Thin wire of more turns of pressure

coil ( $V + V_{COM}$ ) is connected in parallel to the supply. In between the two magnets a thin aluminum disc attached to a spindle is placed with bearings for easy rotation. To produce damping a U shaped permanent magnet is placed. For controlling torque spring control is used.

Fig 2

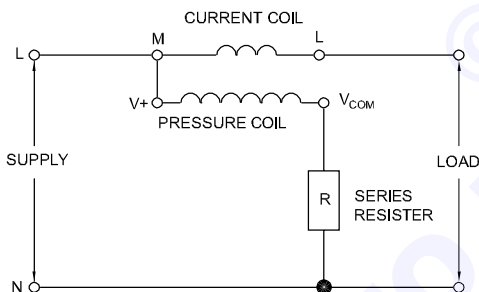


IM20N17662

**Working principle :** When current flows in the meter the shunt magnet will have constant magnetic field. In the series magnet the magnetic field is as per the current to the load. When these two fluxes cut the aluminum disc an eddy current is produced. This eddy current and the magnetic fields due the two magnets will interact with each other and produce a torque in the aluminum disc. This torque will rotate the spindle causing the deflection of pointer over the scale. The deflecting torque is directly proportional to the watt. Between the pressure coil voltage and flux 90 degree out phase should be achieved. For this in the shunt magnet copper shading rings were used. This meter is very efficient.

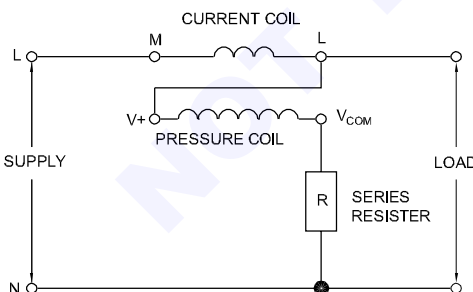
**Connect the wattmeter pressure coil as per the measurement of current (Fig 3 & 4)**

Fig 3



IM20N17663

Fig 4



IM20N17664

As shown in the figure the pressure coil is connected before the current coil on the supply side. The voltage drop due to the current coil for the load will be less than the voltage drops across the pressure coil to the load. This will create a power loss and this power is added to power and shows wrong reading.

When load current is low the voltage drop in the current coil is very less and the error will be less if the pressure coil is connected as in the figure.

As shown in figure 4 the pressure coil is connected after the current coil from supply side. Here in the current coil we will get current of the load and the current in pressure coil which will lead to error in reading. In this connection when the load current is high the current through the pressure coil is very low and the error also low.

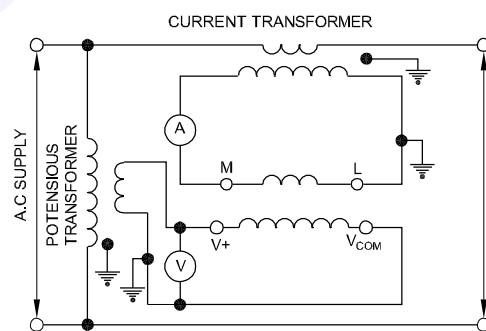
**Wattmeter rating :** The rating of the pressure coil in the wattmeter will be 110V, 220V and 500V. The current coil rating will be 1A, 5A, 10A, 20A, and 30A. If the supply is above 500V then use a potential transformer. For more than 30A use current transformer. When using these transformer wattmeter of rating 5A and 110V is generally used.

**Advantage of using current and potential transformers for high current/voltage measurements**

- 1 The length of the conductor for connection to the meter is reduced.
- 2 The insulation level of the meter can be reduced.
- 3 The high voltage / current proximity can be avoided.
- 4 To make measurements accurately.

**Method by which potential / current transformers connected to wattmeter (Fig 5) :** As shown in fig 5 when connecting a current transformer, the primary should be connected in series with the high current supply. The secondary should be connected to the current coil of wattmeter between terminal M & L along with an ammeter.

Fig 5



IM20N17665

The primary of the potential transformer is connected in parallel to the high voltage supply. The secondary of the potential transformer is connected in parallel to the pressure coil of wattmeter between the terminals V+ , VCOM. A Volt meter is connected in parallel

By these connection methods the calculation of high voltage and current can be done as

Supply voltage = Wattmeter pressure coil reading X PT Ratio

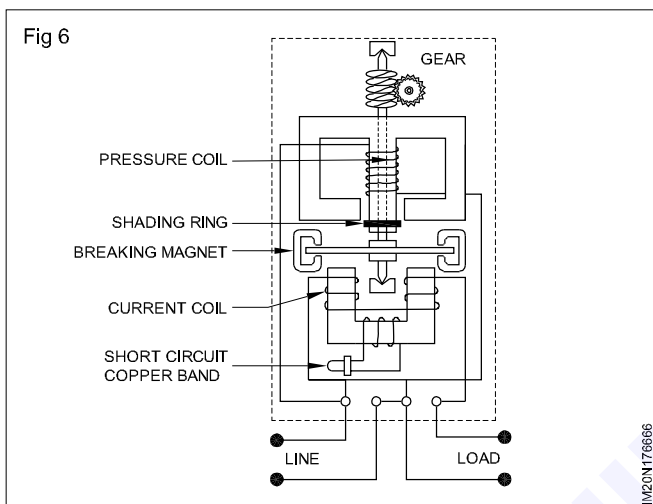
Full heavy current = Wattmeter current coil reading x CT Ratio

To calculate the power = CT Ratio x PT Ratio x wattmeter reading.

**Note : This meter will be useful in its reading when supply voltage and frequency is constant.**

**Single phase energy meter :** This is a rotating type instrument. In these instruments driving, breaking and recording devices were available. The wattage consumed by the load multiplied by the duration of consumption will give the energy consumed. To measure this energy meter is used. This works on electromagnetic induction principal.

**Construction of Energy meter (Fig 6) :** Iron core: The magnetic flux will form in a particular path in Energy meter. Hence the leakage flux and the magnetic reluctance is very low.



**Current coil:** On an iron core thick wire of few turns will be wound and connected in series to the load. The full load current will pass through this coil.

**Potential or voltage coil:** On an E shaped iron core thin wire of large turn will be wound and connected in parallel to the supply. This will produce eddy current aluminum disc.

**Disc:** The disc is formed by a thin circular aluminum disc. This placed in between two magnets. The disc is attached to a spindle which house a worm gear and counting wheels. The disc rotates at a speed directly proportional to the product of current in the current coil and voltage across the voltage coil.

**Spindle:** This is made of hardened steel rod of small diameter. Both ends of the rod are pointed. For rotation of the spindle with out any friction, the ends are placed on jewel bearings. On top of the spindle a small worm gear is fixed.

**Shading rings:** Copper shading rings will be placed on the center of the shunt magnet. This shading ring is used to create 90-degree phase angle between the flux produced by the pressure coil and its voltage. To avoid losses due to friction two more moving copper shading rings were placed.

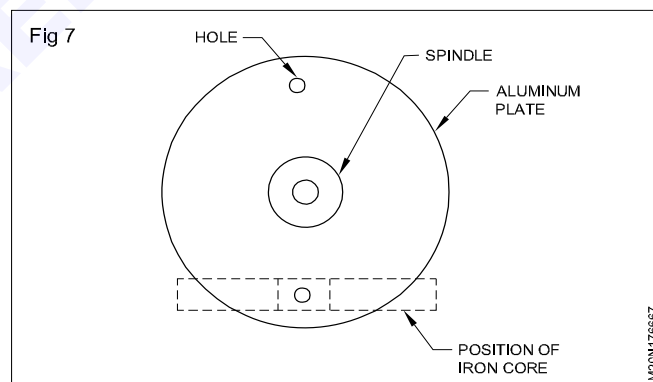
**Breaking magnet:** To give breaking, the aluminum disc is placed in between two U shaped permanent magnet. This magnet is called the breaking magnet. This magnet will produce an opposite torque to the torque produced in the aluminum disc.

**Working principal:** When supply is given to the meter, the current in the pressure coil is directly proportional to the supply voltage. A magnetic field is created in the pressure coil. At the same time the load current will pass through the current coil which also produces a magnetic field. These two magnetic fields cut the aluminum disc and produce eddy current on the disc. This eddy currents will react with the two magnetic fields and produce a torque on the aluminum disc. The spindle along with the disc rotates. The worm gear attached to the spindle moves to show the reading.

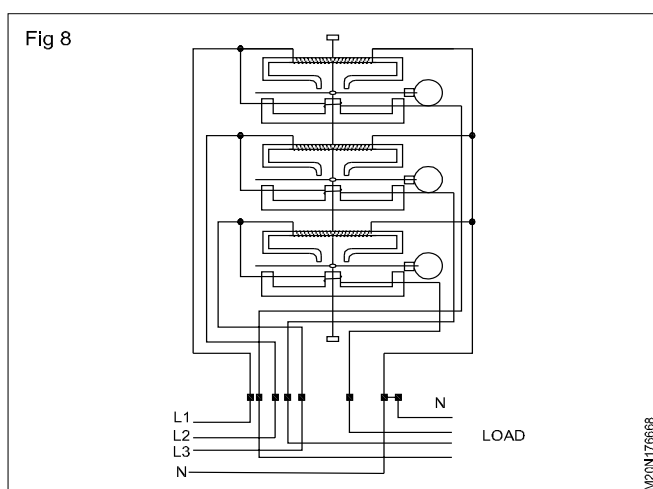
**Creeping error:** With out any load and with absence of current in the current coil, there will be some residual flux in the pressure coil. This will cause to rotate the disc at very slow speed. Due to this small amount of power will be shown as consumed on no load condition. This error is known as creeping error. This is due to

- 1 To compensate the frictional losses the torque produced might be high,
- 2 The pressure coil is being fed more voltage than required and
- 3 Due to vibration and stray magnetic fields.

**To avoid creeping error (Fig 7) :** To arrest the aluminum disc being on rotation with out any load, two opposite holes were punched on the aluminum disc. These holes when comes under the pressure coil while on rotation will give a resistive force to stop the disc. So when the current stops due to no load the disc will rotate only half a revolution.



**3 phase 4 wire energy meter (3 Phase 4 element type) (Fig 8)**

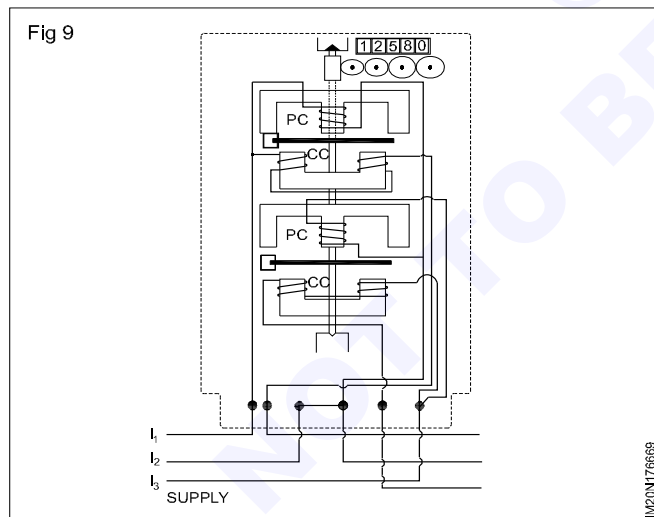


As shown in figure single phase meter of three units were placed one below another. The three-aluminum disc were mounted on a single spindle. The three-pressure coil (240V) were given 3 phase supply. Due to the torque on the aluminum discs the spindle rotate. The speed of the spindle depends on the power consumed.

The power used and the duration of usage will be calculated by the worm gears to the counting units. To adjust the power factor and to compensate losses due to friction, shading rings were used. With permanent magnets the breaking force is produced.

In certain meters the torque will be produced in a single disc from 3 single phase discs placed at 120-degree side wise. Here there will be only one break magnet. The three phase 4 wire energy meter is used with balanced load and unbalanced load. It is used where single phase as well as three phase as separate loads to be measured.

**3 phase 3 wire energy meter (Fig 9) :** In this type he principal of measurement by two-watt meter is used. This contains two current coils and two pressure coils (415V). As shown in figure the two current coils were connected in series to two separate loads. Each end of the pressure coil is connected to the line where the current coils is connected. The other two end of the pressure coil is connected to the third phase. The two-aluminum disc on common spindle will rotate in between the current and pressure coils. The disc rotates as per the flux produced by the two coils. The gear positioned on the spindle will show the consumed watt hour (KWH). On the edge of the disc, U shaped permanent magnet is positioned. This is used for breaking. On certain meters the torque will be produced on a single disc. To produce the breaking torque a single U-shaped permanent magnet is used.



3 phase 4 wire energy meter is used where balance and unbalance load condition exists.

### Reasons for error in the driving system

- 1 The change in amount of flux is due to high variation in supply frequency and resistance in shunt coil magnet.
- 2 The variation in supply frequency and resistance in shunt coil magnet will cause a shift in current and voltage wave form.

- 3 The magnetic circuit is not symmetric. (Not uniform)

### Reasons for error in the driving system

- 1 Excessive friction in the moving parts.
- 2 The strength of the permanent magnet decreases due to aging.
- 3 The self-breaking effect due to the series magnet.
- 4 The change in Electronics resistance value of the disc.

### Correcting the tolerance value

With rated voltage on potential coil and the current in current coil is at zero, the disc will rotate. To arrest the rotation of the disc two holes were punched on opposite side of the disc. When the disc passes in between the poles with rated voltage on electro magnet will stop the disc rotation. With this we can ensure the low load adjustment.

### Unity power factor when the load is connected

The rated voltage on potential coil and full load current on the current coil will rotated the disc on correct speed. We should ensure this. If the disc rotates on different speed, the position of the break magnet should be adjusted to have the desired disc speed.

### 0.5 power factor when load us connected

With rated voltage and full load current, adjust the meter low power factor and ensure correct speed of the disc.

On unity and 0.5 power factor again ensure the meter disc rotates at correct speed.

With unity and 0.5 power factor the meter should be tested for correct speed with 100% load current and 5% low load current.

To calculate the error in the energy meter

The power recorded by the meter and actual power used ,expressed in percentage is the error in the energy meter.

True power can be calculated with the reading of the volt meter, ammeter and the power factor meter.

True power =  $(EI \cos \theta t) / (1000 \times 3600) \text{ Kwh}$ . "t" is the time taken in seconds.

Recorded power is the product of the meter constant and the number of revolutions in a particular time. Meter constant is the number of revolution per KWH)

Recorded energy = ( Number of revolutions in a particular time / meter constant)

% error =  $((\text{Recorded energy} - \text{True energy}) / \text{True energy}) \times 100$

To calculate the error in the energy meter by another method.

Here meter constant is compared with the test constant.

Meter constant (watt second per second) =  $(3600 \times 1000) / (\text{number of revolution for 1 KWH})$

Test constant =  $EI \times t \text{ (in seconds)} / \text{Number of actual revolutions}$



Hence % error = (Meter constant - test constant) / (test constant) x 100

If the meter registers more power than the actual power then it is +ve error

If the meter registers less power than the actual power then it is -ve error

| Magnitude of error | Power factor | Percentage full load current |
|--------------------|--------------|------------------------------|
| ± 2.5              | 1 lagging    | 5%                           |
| ± 2.5              | 0.5          | 10%                          |
| ± 2                | one          | 10% to 200%                  |
| ± 2                | 0.5 lagging  | 20% to 200%                  |

In IS 722(PART II 1977) the energy meter rating and accuracy is given. Standard basic current IB is 2.5, 5, 10, 20 and 30A. Highest rated current is 200 x (2 times IB)

The allowable error with current and power factor

Three phase energy meter standard rating: 10, 20, 30, 50 and 100A with voltage 120/240/415 Volts.

For instrument current transformers: 1A or 5A

To calculate multiplication factor in a multi range watt meter.

Multiplication factor MF = (Pressure coil range x current coil range) / (Highest reading on dial)

To calculate power with CT and PT connected in a multi range watt meter

Power W = Watt meter reading x MF x CT Ratio x PT Ratio

### Types of power factor meter

- 1 Electro dynamic power factor meter.
- 2 Moving iron power factor meter.

### Single phase power factor meter - Dynamo meter type

#### Construction

It consists of a fixed coil FF (split into two parts) which carries the current of the circuit under test. So, the magnetic field produced by this coil is proportional to the main current

## Frequency meter

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

- explain the working principle of frequency meter
- explain the analogue and digital frequency meter
- explain phase sequence indicator, continuity tester and synroscope.

### Frequency meter

There are many types of frequency meters.

- 1 Mechanical resonance type
- 2 Electronics resonance type,
- 3 Ratio meter type.

The identical pressure coils A and B pivoted on a spindle constitutes the moving system. Pressure coil A has a non-inductive resistance R which is connected in series with it, and coil B has a highly inductive choke coil L which is connected in series with it. The two coils are connected across the voltage of circuit. The value of R and L are so adjusted that the two coils carry the same value of current at normal frequency i.e.  $R = \omega L$ .

The current through the coil A is in phase with the circuit voltage while that through the coil B lags the voltage by an angle  $\phi$  which is nearly equal to  $90^\circ$ . The angle between the planes of coils is equal to  $\phi$ . Connections to moving coils are made through thin silver or gold ligaments which are extremely flexible and this gives a minimum control effect on the moving system.

#### Note:

- 1 When the load is not connected to the meter the pointer will denote some reading since there is no control mechanism in this type of meter.
- 2 The scale graduation is like this. With center as 1 and to both left and right the readings were 0.9, 0.8, 0.7, 0.6....0
- 3 Left hand side indicates inductive(lagging) and right capacitive (leading) loads.

**AC Voltage and current measurement using PMMC Meter (Rectifier type) :** This type of meter employs a rectifier to change AC to DC and use for the measurement. As shown in the picture a rectifier is used along with a DC meter. The use of low frequency copper oxide rectifiers will give good indication up to 20KHz. In an AC circuit a DC meter with a diode is used to measure the AC voltage.

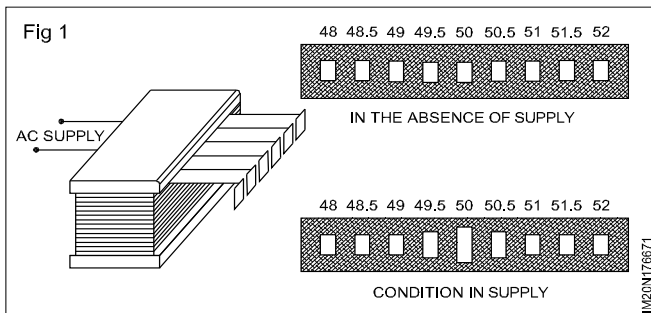
#### Advantage of Rectifier instrument

- 1 Silicone or Germanium rectifiers are used in radio frequency application
- 2 Rectifier instrument is 50% more sensitive than AC meter.
- 3 Milli ammeter and Micro ammeters were manufactured by using rectifier instruments.

Apart from this Electronic frequency counter, Frequency bridge stroboscope and oscilloscope are used to measure frequency.

**Mechanical resonance vibration Frequency meter (Fig 1) :** This instrument works on the principal of mechanical resonance. This consist of number of thin steel

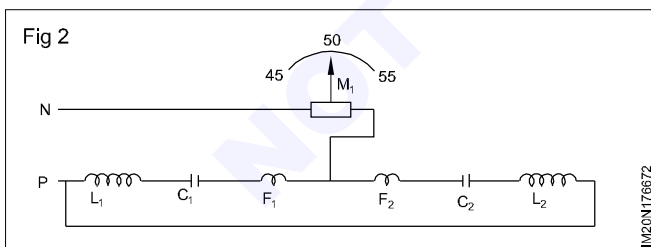
strips called "reeds". The reeds are placed in a row alongside and closed to an electromagnet. The reeds feel attractive force from the electromagnet and starts vibrating. The reeds are 4mm width and 0.5mm thick. On ascending order the reeds are placed. Each successive reeds has a difference of 0.5Hz. So for a frequency of range 47 to 53 Hz 13 reeds were required. The front of the leads were bend to 90 degrees and painted in white color. On each reed the corresponding frequency will be indicated on a scale.



**Working principle:** When the frequency meter is connected to the supply voltage for which the frequency is to be measured, the electro magnet will produce a varying magnetic field. This field change as per frequency. The vibration corresponds to the frequency will be sensed by the reed and starts vibrate. For example in a 50Hz supply the reed marked for 50Hz will vibrate speedily when compared to 49.5 and 50.5 reeds.

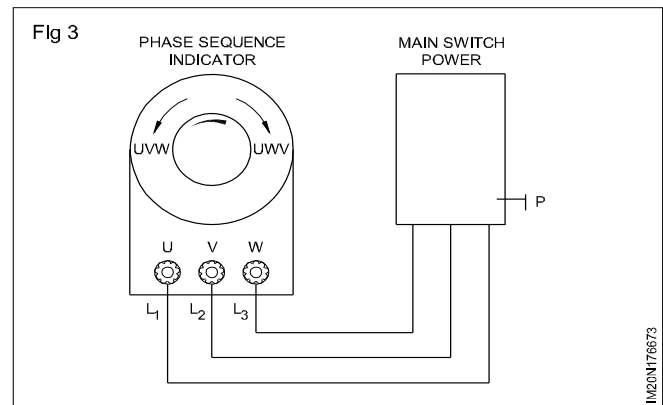
**Disadvantage:** If the supply voltage is low, the vibration in the reeds were minimum and can't be noticed. To get accurate measurement the reeds should be finely tuned. It is very tough to determine decimal frequency below 0.5Hz.

**Electronics resonance Frequency meter (Fig 2):** As shown in the figure there are two fixed coil connected with a moving coil. Fixed coil F1 will resonate on 45 Hz with L1 and C1 combination. Similarly F2 will resonate to 55 Hz with combination of L2 and C2. The current I1 and I2 passing through F1 and F2 will be the vector sum of the current passing through the moving coil M1. As shown in the figure when supply voltage is given the current through the fixed coil will be out of phase to the voltage.

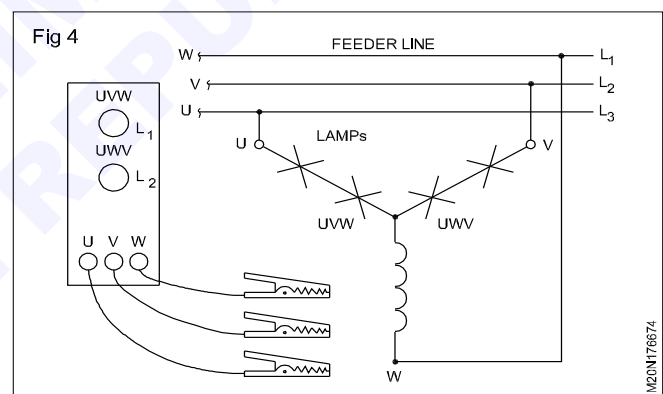


**Phase sequence indicator (Fig 3):** When phase sequence changes there won't be any suffering in light and heating load. This meter shows the phase sequence of a three phase system. On the dial in opposite direction two different sequences were marked. Three phases of a AC supply is connected to U,V and W terminals of the meter. Now the disc in the indicator will rotate. The rotation UVW of the disc ensures the correct sequence RYB phase of the supply . If we change any one phase of the supply

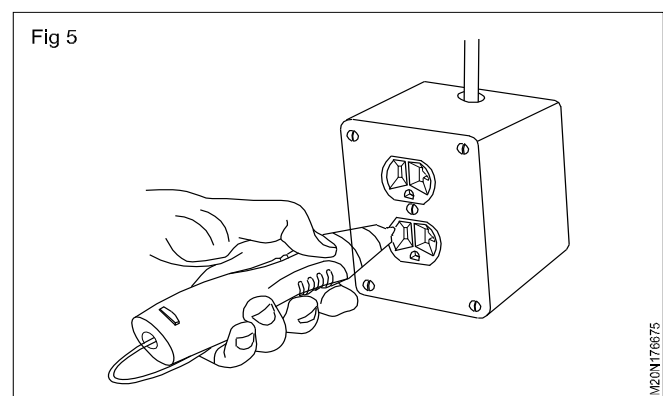
then the disc rotate on the opposite direction to the previous one.



**Phase indicator using choke and lamp (Fig 4):** In this meter two lamps were connected to two phases of the supply. The choke (inductor) is connected to the 3rd phase of the supply with other end to mid connection of series lamp. This will form as a star connection. The lamp on one phase is denoted as UVW and the other lamp denoted as UWV. This is connected to the three phase supply through rest leads as shown. When connected, the lamp which glow brighter will indicate the phase sequence of the supply. Instead of connecting a choke, a capacitance can be connected for checking the phase sequence of the supply.

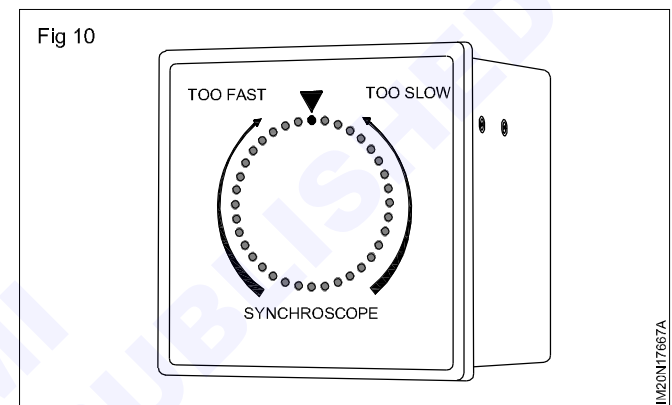
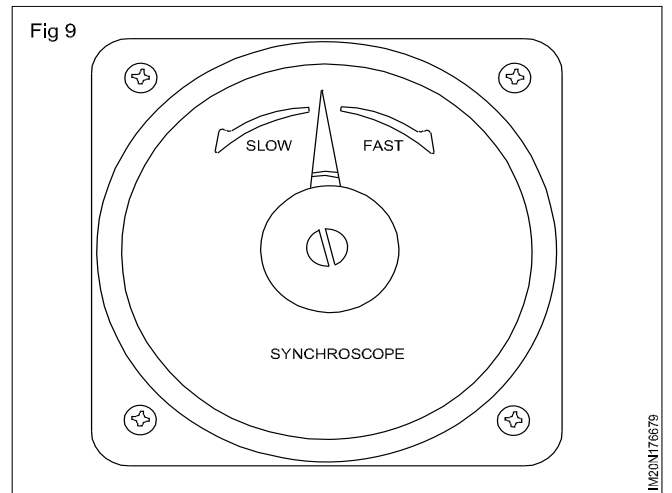
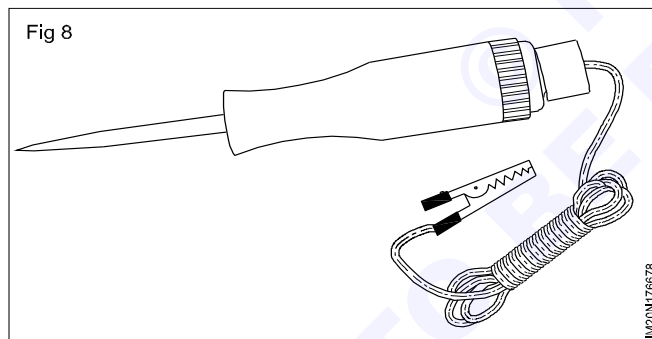
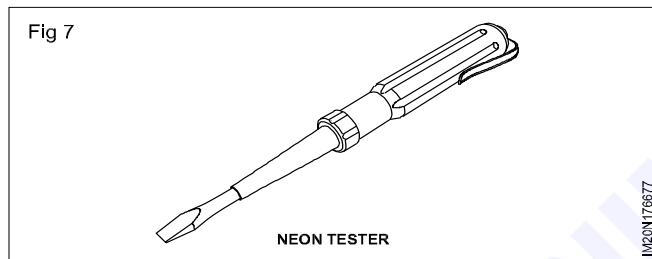
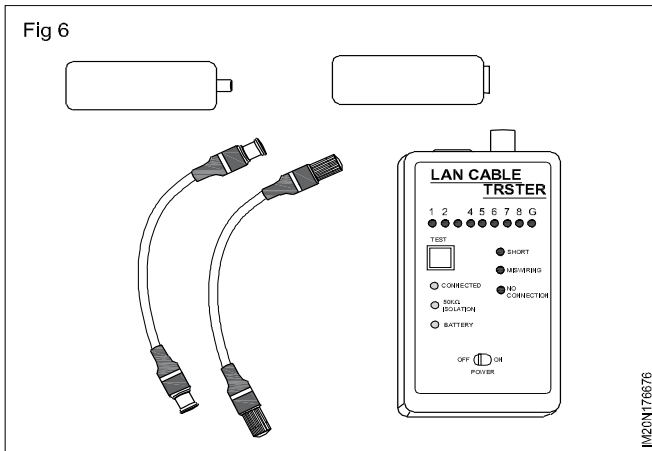


**Continuity tester (Fig 5&6):** Continuity tester is a device used to check the path of the circuit's continuity. The circuit under test should not have any supply prior to testing. On figure 7&8 the voltage tester is used to test the voltage between any two points in a circuit.



**Synchroscope (Fig 9 &10):** Synchronization is the process of connecting two different Electronics supply.

For example two generating system connected to a common network. The fundamental rule to observe 1) The magnitude of current and voltage of the system should be same, 2) Their frequencies should be same 3) The phase sequence of the two systems to be same. The instance to which the switch is closed for connecting the two supplies is done by the Synchroscope.



## Semiconductor diodes

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

- define semiconductors
- state the types of semiconductors
- state the unique property of a PN junction
- explain the classifications of diodes
- list out type numbers/code numbers of diodes.

### Semiconductors

Semiconductors are materials whose Electronics property lies between that of Conductors and Insulators. Because of this fact, these materials are termed as semiconductors. In conductors the valence electrons are always free. In an insulator the valence electrons are always bound. Whereas in a semiconductor the valence electrons are normally bound but can be set free by supplying a small amount of energy. Several electronic devices are made using semiconductor materials. One such device is known as Diode.

### Semiconductor theory

Basic semiconductor materials like other materials have crystal structure. The atoms of this structure, are bonded to each other as shown in Fig 1. This bonding is known as covalent bonding. In such a bonding, the valence electrons of the atoms are shared to form a stable structure as shown in Fig 1.

### Intrinsic semiconductors

The most important of the several semiconductor materials are Silicon (Si) and Germanium (Ge). Both these semiconductor materials have four valence electrons per atom as shown in (Fig 1). These valence electrons, unlike in conductors, are not normally free to move. Hence, semiconductors in their pure form, known as Intrinsic semiconductors, behave as insulators.

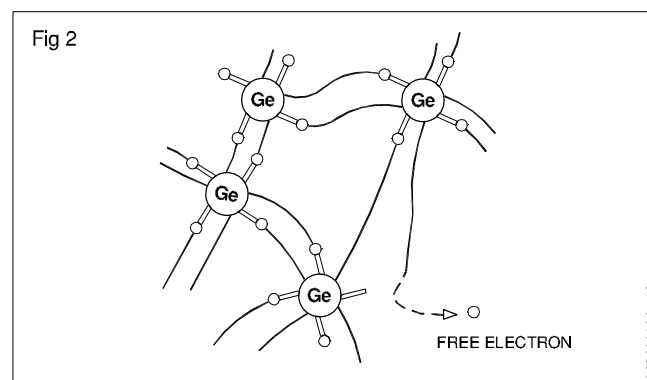
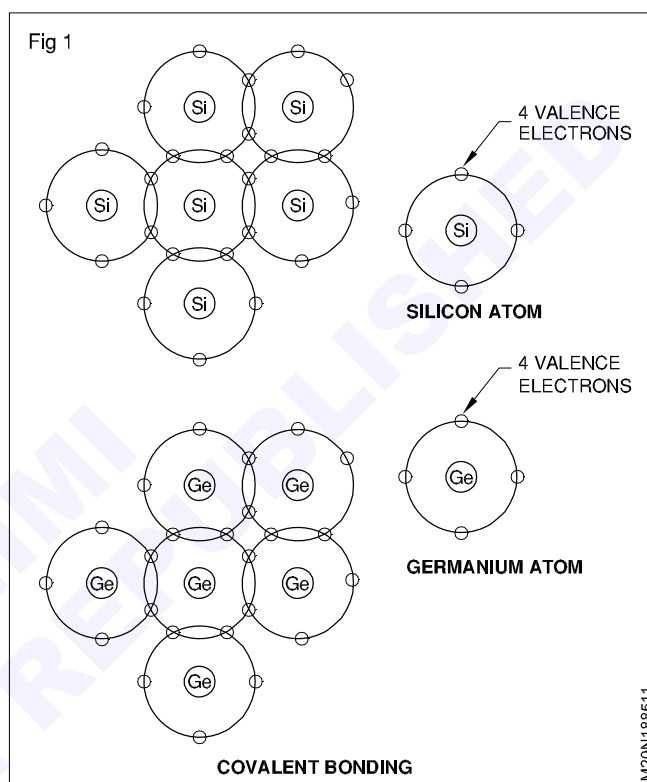
However, the valence electrons of a semiconductor can be set free by applying external energy. This energy will tear-off the bound electrons from their bond and make them available as free electrons as shown in (Fig 2). The simplest method of turning bonded valence electrons into free electrons is by heating the semiconductor.

The higher the temperature to which the semiconductor is heated, more the bound electrons becoming free and will be able to conduct electric current. This type of conduction in an intrinsic semiconductor (pure semiconductor) as a result of heating is called intrinsic conduction.

From the above said phenomena, it is important to note that semiconductors are temperature-sensitive materials.

### Extrinsic semiconductor

The number of free electrons set free by heating a pure semiconductor is comparatively small to be used for any useful purpose. It is found experimentally that, when a small quantity of some other materials such as



Arsenic, Indium, Gallium etc. is added to pure semi conductor material, more number of electrons become free in the mixed material. This enables the semiconductor to have higher conductivity.

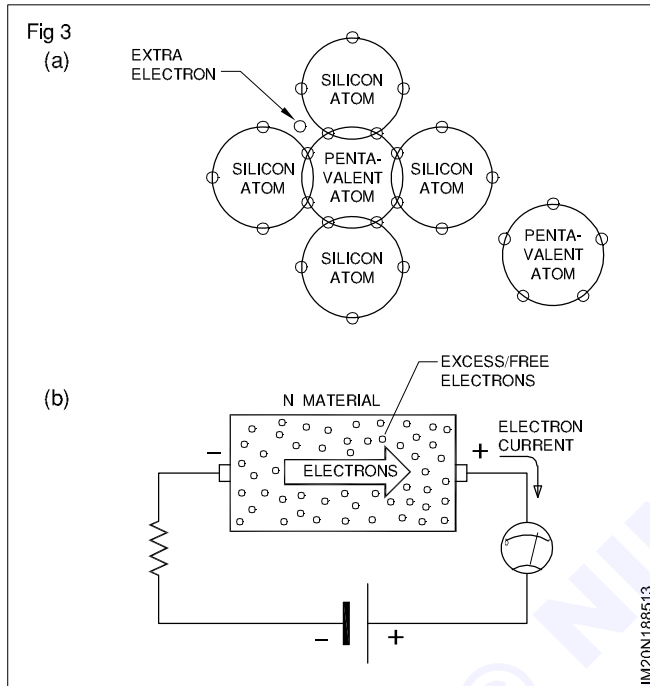
These foreign materials added to the pure semiconductor are referred to as impurity materials.

The process of adding impurity to an Intrinsic semiconductor material is known as Doping. Since the doped semiconductor materials are no longer pure, they are called impure or **extrinsic semiconductors**.

Depending upon the type of impurity used, extrinsic semiconductors can be classified into two types;

## 1 N-type semiconductors

When a pentavalent material like Arsenic (As) is added to a pure Germanium or pure Silicon crystal, one free electron results per bond as shown in (Fig 3a). As every arsenic atom donates one free electron, arsenic is called the donor impurity. Since a free electron is available and since the electron is of a Negative charge, the material so formed by mixing is known as **N type material**.



When a N-type material is connected across a battery, as shown in Fig 3b, current flows due to the availability of free electrons. As this current is due to the flow of free electrons, the current is called electron current.

In N type semi conductor the current is due to electrons, therefore the electrons are the majority charge carriers.

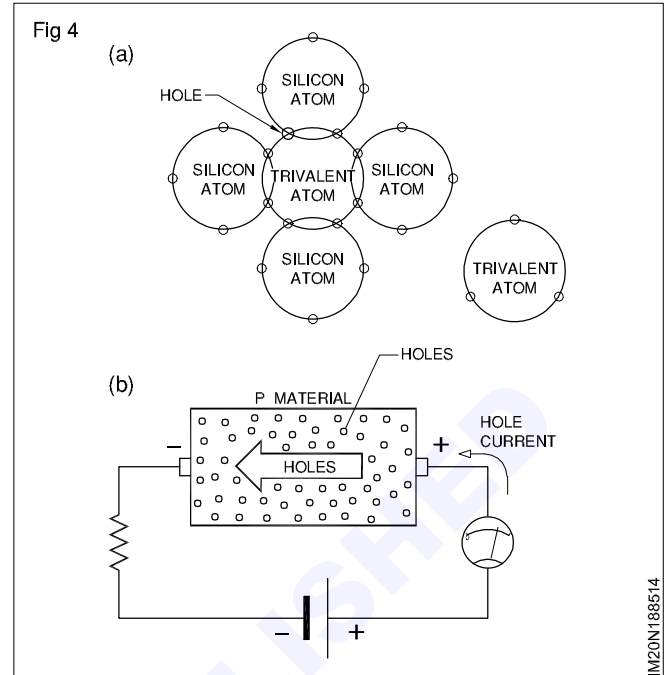
The semi conductor materials are temperature sensitive, heating causes the covalent bonds to break down by creating electron-hole pair. The holes are minority charge carriers - in N type semi-conductors.

## 2 P-type semiconductors

When a trivalent material like Gallium(Ga) is added to a pure Germanium or pure Silicon crystal, one vacancy or deficit of electron results per bond as shown in Fig 4a. As every gallium atom creates one deficit of electron or hole, the material is ready to accept electrons when supplied. Hence gallium is called acceptor impurity. Since vacancy for an electron is available, and as this vacancy is a hole which is of Positive charge, the material so formed is known as **P-type material**.

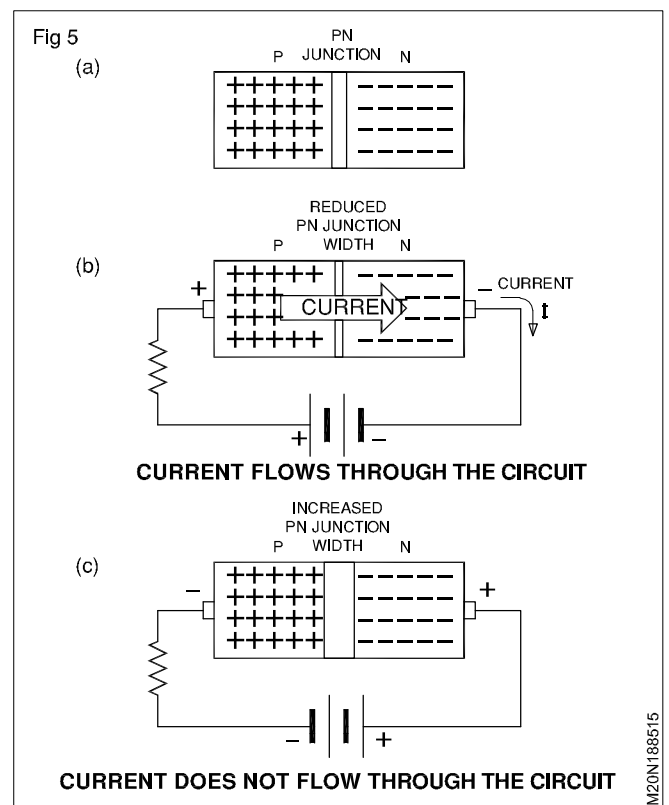
When a P-type material is connected across a battery as shown in Fig 4b, current flows due to the availability of free holes. As this current is due to flow of holes, the current is called hole current.

The holes are the majority charge carriers in P type semi conductor and the electrons are the minority charge carriers.



## P-N junction

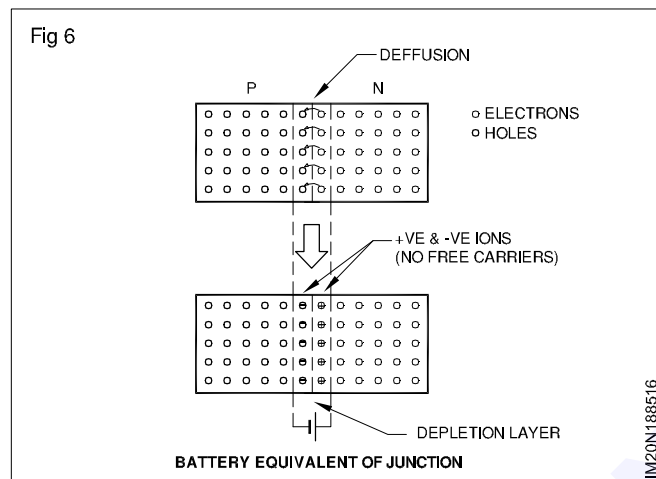
When a P-type and a N-type semiconductors are joined, a contact surface between the two materials called PN-junction is formed. This junction has a unique characteristic. This junction, has the ability to pass current in one direction and stop current flow in the other direction. To make use of this unique property of the PN junction, two terminals one on the P side and the other on the N side are attached. Such a PN junction with terminals attached is called a **Diode**.





When a P and N material is put together, at the junction of P and N materials, as shown in Fig 6, some electrons from the N-material jump across the boundary and recombine with the hole near the boundary of the P-material. This process is called diffusion. This recombination makes atoms near the junction of the P-material gaining electrons and become negative ions, and the atoms near the junction of the N-material, after losing electrons, become

positive ions. The layers of negative and positive ions so formed behave like a small battery. This layer is called the depletion layer because there are neither free electrons nor holes present (depleted of free carriers). This depletion region prevents further the movement of electrons from the N-material to the P material, and thus an equilibrium is reached.



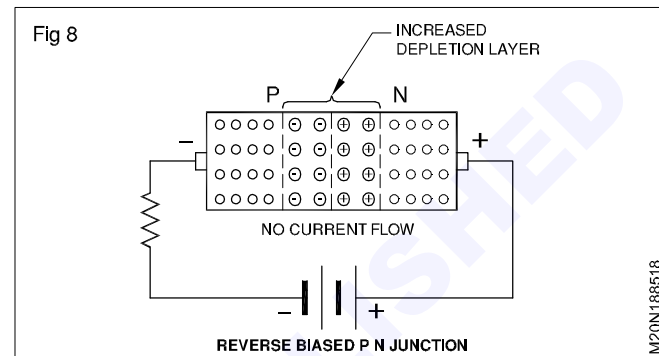
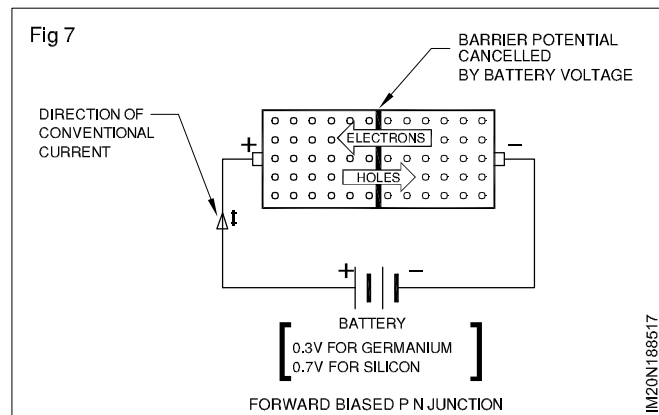
The internal voltage set up due to +ve and -ve ions at the junction is called barrier potential. If any more electrons have to go over from the N side to the P side, they have to overcome this barrier potential. This means, only when the electrons on the N side are supplied with energy to overcome the barrier potential, they can go over to the P side.

In terms of voltage applied across the terminals of the PN junction diode, a potential difference of 0.7V is required across the terminals in the case of silicon diode and 0.3V in the case of Germanium diode for the electrons, in order to cancel off the barrier potential and cross over the barrier as shown in Fig 7. Once the barrier potential gets canceled due to external voltage application, current flows through the junction freely. In this condition the diode is said to be forward biased.

When the applied external battery polarity is as shown in Fig 8, instead of canceling the barrier potential, the external battery voltage adds up to the barrier potential, and, hence, no current flows through the junction. In this condition the diode is said to be reverse biased.

Since current flows through a PN junction diode when it is forward biased and does not when reverse biased, the diode can be thought of to be a unidirectional current switch.

The two leads connected to the P and N terminals are known as Cathode and Anode.



To forward-bias a diode, the Anode should be connected to the +ve terminal of the battery and the Cathode to the -ve terminal of the battery. When a diode is in the forward biased condition, the resistance between the terminals will be of the order of a few ohms to a few tens of ohms. Hence, current flows freely when a diode is forward biased.

On the other hand, when a diode is reverse biased, the resistance between the terminals will be very high, of the order of several tens of megohms. Hence, current does not flow when a diode is reverse biased. As a rule, the ratio of resistance in forward to reverse bias should be of at the minimum order of 1:1000.

## Types of diodes

The PN junction diodes discussed so far are commonly referred to as rectifier diodes. This is because these diodes are used mostly in the application of rectifying AC to DC.

## Classification of Diodes

### 1 Based on their current carrying capacity/power handling capacity, diodes can be classified as

- **low power diodes:** can handle power of the order of several milliwatts only
- **medium power diodes:** can handle power of the order of several watts only
- **high power diodes:** can handle power of the order of several hundreds of watts.

### 2 Based on their principal application, diodes can be classified as,

- **Signal diodes:** low power diodes used in communication circuits such as radio receivers etc. for signal detection and mixing

- **Switching diodes:** low power diodes used in switching circuits such as digital electronics etc. for fast switching ON/OFF of circuits
- **Rectifier diodes:** medium to high power used in power supplies for electronic circuits for converting AC voltage to DC.

### 3 Based on the manufacturing techniques used, diodes can be classified as,

- **Point contact diodes:** a metal needle connected with pressure on to a small germanium(Ge) or silicon(Si) tip.
- **Junction diodes:** made by alloying or growing or diffusing P and N materials on a semiconductor substrate.

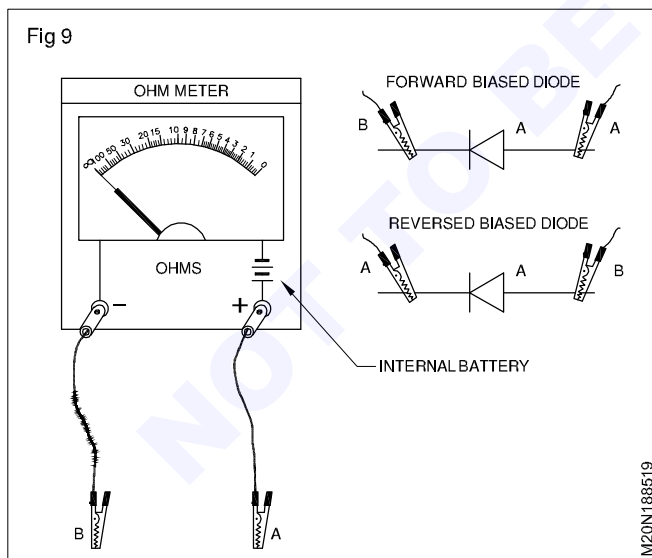
### Types of diode packaging

The type of packaging given to diodes is mainly based on the current carrying capacity of the diode. Low power diodes have either glass or plastic packaging. Medium power diodes have either plastic or metal packaging. High power diodes will invariably have either metal can or ceramic packaging. High power diodes are generally of stud-mounting type.

### Testing rectifier diodes using ohmmeter

A simple ohmmeter can be used to quickly test the condition of diodes. In this testing method, the resistance of the diode in forward and reverse bias conditions is checked to confirm its condition.

Recall that there will be a battery inside an ohmmeter or a multimeter in the resistance range. This battery voltage comes in series with the leads of the meter terminals as shown in Fig 9 and lead A is positive, lead B negative.



If the positive lead of the ohmmeter, lead A in the Fig 10, is connected to the anode of a diode, and the negative (lead B) to the cathode, the diode will be forward-biased. Current will flow, and the meter will indicate low resistance.

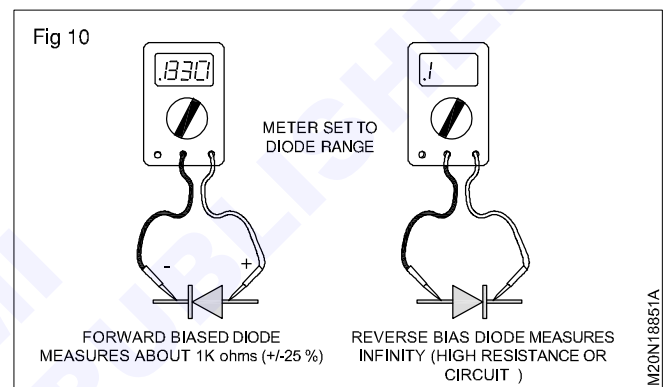
On the other hand, if the meter leads are reversed, the diode will be reverse-biased. Very little current will flow because a good diode will have very high resistance when reverse biased, and the meter will indicate a very high resistance.

While doing the above test, if a diode shows a very low resistance in both the forward and reverse biased conditions, then, the diode under test must have got damaged or more specifically shorted. On the other hand, a diode is said to be open if the meter shows very high resistance both in the forward and reverse biased conditions.

### Testing of diodes using digital Multimeter

If the digital multimeters are used for testing the diodes, first the selector switch must be kept at diode testing position. The +ve terminal of the MM (lead A as in the fig 10 must be connected to the anode of a diode and the negative terminal (lead) to the cathode, the diode is forward biased the MM will display the barrier voltage of the diode in the forward biased condition.

On the other hand, if the meter leads are reversed, the diode will be reverse biased and MM will display 1.



BYxxx, xxx- from 100 onwards, examples: BY127, BY128 etc.

DRxxx, xxx- from 25 onwards. examples: DR25, DR150 etc.,

1Nxxxx examples: 1N917 1N4001, 1N4007 etc.

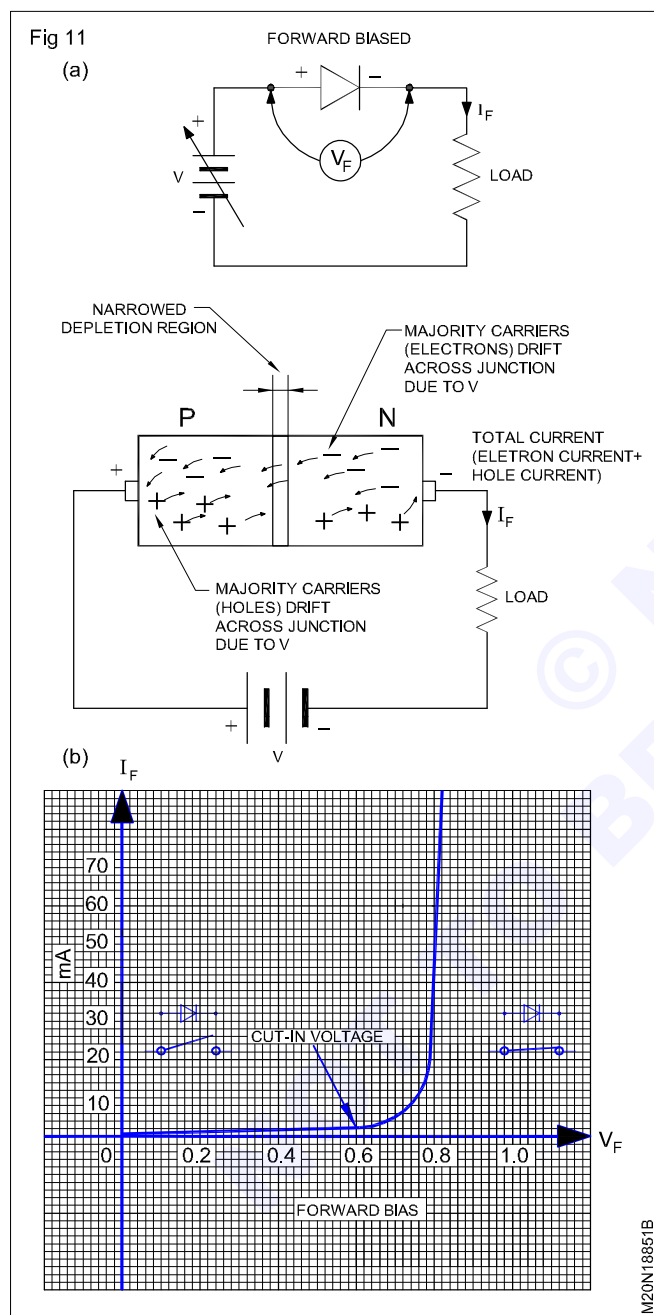
### Behaviour of diode when FORWARD BIASED

Fig 11a shows a forward biased silicon PN junction diode using a variable DC supply. When the applied voltage is slowly increased starting from 0 volts as long as the voltage across the diode  $V_F$  is less than that of the depletion barrier potential (0.7 volts for Si diodes), no current or a negligible current flows through the diode, and, hence, through the circuit. This is shown in the graph at Fig 11b.

But once the voltage  $V_F$  across the diode becomes equal to or greater than the barrier potential 0.6 to 0.7V, there will be a canceling effect of the barrier potential. Hence, the free electrons from the N region get pushed away by the -ve battery terminal (remember like charges repel) and cross over the junction, pass through the P region and get attracted by the + terminal of the battery. This results in the *electron current* passing through the diode, and, hence, through the Load.

In a similar way, the holes in the P region are pushed away by the +ve battery terminal, cross over the junction, pass through the N region and get attracted by the -ve terminal of the battery. This results in *hole current* through the diode, and, hence, through the Load.

Thus current flows through the diode when the forward bias potential is higher than the barrier potential. This current flow through the diode is because of both electrons and holes. The total current in the circuit is the sum of the hole current and the electron current. Hence, diodes are called *bipolar devices* in which both hole current and electron current flows.



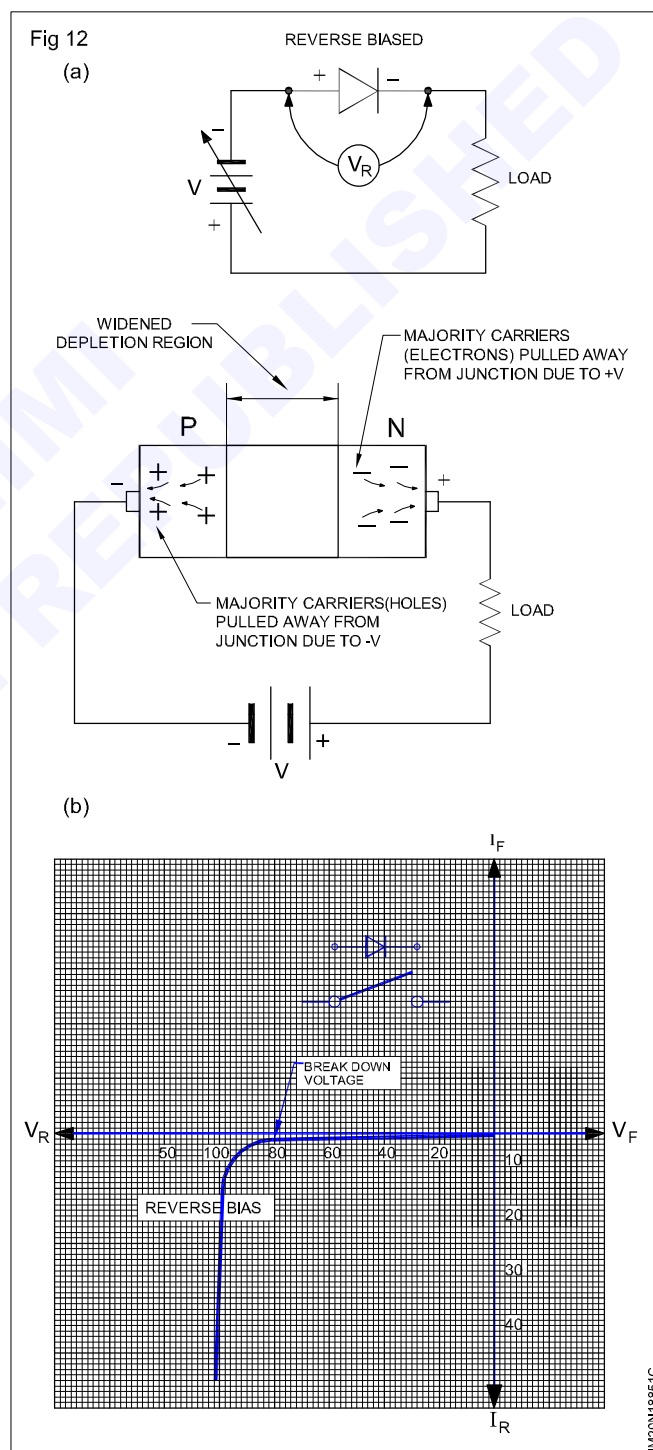
From the graph at Fig 11b, it can be seen that, once the forward voltage goes above 0.6V the diode starts conducting, resulting in considerable current through the circuit. This voltage level across the diode is referred to as *cut-in* or *knee* or *threshold voltage*.

If the applied forward voltage is further increased beyond the cut-in voltage, the depletion layer further narrows down

allowing more and more current to flow through the diode. It can be seen from the graph at Fig 11b, that beyond the cut-in voltage, the current increases sharply for very small voltage increase across the diode. In this region, above the cut-in voltage, the forward biased diode behaves almost like a closed switch. The only limiting factor for the current at this stage is the maximum current the diode can handle without getting burnt or the junction getting punctured permanently. This current limit is given in diode data books as *maximum forward current*,  $I_{Fmax}$ .

### Behaviour of diode when reverse biased

When an external DC voltage is connected across the diode with the polarity as shown in Fig 12, the diode is said to be reverse biased.



than the rated PIV is applied across the diode, it will become defective permanently.

- Maximum average forward current,  $I_F$  or  $I_f$  that a diode can allow to flow through it without getting damaged.
- Forward voltage drop,  $V_F$  or  $V_f$  that appears across the diode when the maximum average current,  $I_F$  flows through it continuously.
- Maximum reverse current,  $I_{r\text{r}}$  that flows through the diode when the Maximum reverse voltage, PIV is applied.
- Maximum forward surge current,  $I_{s\text{s}}$  that can flow through the diode for a defined short period of time.
- The maximum junction temperature in degree centigrade the diode junction can withstand without malfunctioning or getting damaged.
- Suggested application indicates application for which the diode is designed and produced.

The above listed specifications go with all rectifier diodes. As all these specifications cannot be printed on the physically small size diodes, the diodes are printed with a type number instead. When this type number is referred to in the manufacturer's manual, the detailed specifications for a particular type number of the diode can be obtained.

There are hundreds and thousands of diode manufacturers all over the world. To bring standardization for the diodes and other components manufactured by different manufacturers, the manufacturers and standards associations have set certain international standards for the benefit of users of the components. The principal industry standard numbering systems are dealt with here:

#### a The JEDEC type code

The EIA in USA maintains a register of **1N**, **2N** types familiarly known as Jedec types, which have world wide acceptance.

1N is used as a prefix for semiconductors with one junction. For example all 1N components refer to diodes because diodes have one junction. Prefix 2N is used with components having two junctions.

#### b The PRO-ELECTRON type code.

The Association International Pro-electron in Europe maintains a register of Pro-electron types which have wide acceptance in Europe.

Components in the Pro-electron system have,

- i two letter and numeral code for consumer devices (Example, BY127 and so on).

- ii three letter and numeral code for industrial devices. (Example, ACY17 and so on).

The first letter in the pro-electron type code indicates the type of semiconductor material used in making the device. Example, device numbers starting with A are made of germanium.

The second and third letter indicate the applications of the component. Example, in the type code BY127, the second letter Y indicates that it is a rectifier diode.

The numeral after the second or third letter is the code number of its detailed voltage, current and temperature specifications.

#### c The JIS type code

In Japan, the JIS, (Japanese Industrial Standards) code is used. This system of component numbering is almost universal. In this system, all component numbers start with 2S, followed by a letter and several numbers. Example. 2SB364. The letters after the S has the following significance:

A = pnp hf

B = pnp lf

C = npn hf

D = npn lf

Some components will have type numbers which does not match with any of the above said international standards. Then, these type numbers are particular to the individual manufacturers. These codes are generally referred to as manufacturer's house code. However, these type numbers may conform to one or more of the international standards. Almost all standard diode data books lists popular manufacturers house codes.

#### Diode equivalents

There are several occasions, especially while servicing electronic circuits, it may not be possible to get a replacement for a diode of a particular type number. In such cases one can obtain a diode having specification closest to the one to be replaced. Such diodes are referred to as equivalents.

**Example:** In a circuit, diode 1N 4007 is found to be defective. If 1N4007 is not available in stock, then, instead of 1N4007, BY127 can be used because BY127 is the equivalent for 1N4007.



# Photodiodes

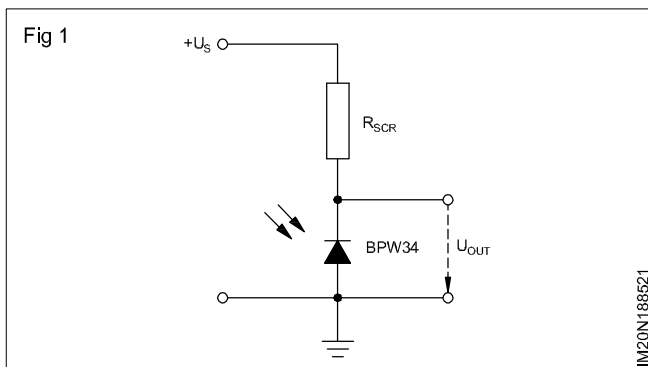
**Objectives:** At the end of this lesson you shall be able to

- explain working of photodiode
- explain the advantages of PIN photodiode
- list the application of photodiodes
- explain working of photodiode and tunnel diode.

## PHOTODIODES

### P-N Photo diodes

Photodiodes are produced by silicon techniques. Photodiodes are operated in the reverse direction. A supply voltage and a series resistor are therefore required to operate photodiodes. The basic circuit for the operation of photodiodes is shown in Fig 1.



When no light is incident on the photodiode, a reverse current flows through the p-n junction, as it does in any normal semiconductor diode, but in photodiodes it is usually referred to as the “dark current”  $I_{Ro}$ .

When light strikes the p-n junction, crystal bonds are broken as a result of the supply of energy. Mobile charge-carrier pairs are produced, which immediately migrate as a result of the electric field present. The holes travel towards the p-layer and the electrons towards the n-layer. As a result of illumination, an additional photocurrent  $I'_{photo}$  occurs, which increases linearly with the illuminance. This photocurrent is superimposed as a reverse current on the relatively small dark current, so that for the total photocurrent occurring with illumination, the following applies:

$$I_{photo} = I_{Ro} + I'_{photo}$$

Since  $I_{Ro}$  is far smaller than  $I'_{photo}$  then:

$$I_{photo} = I'_{photo}$$

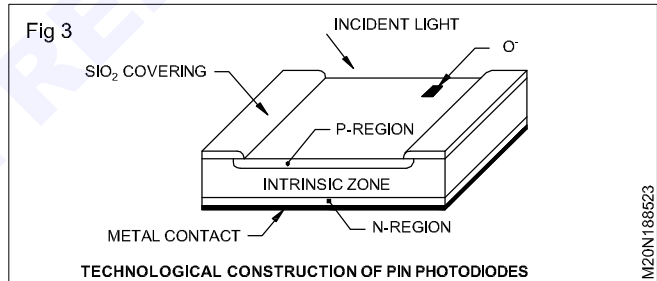
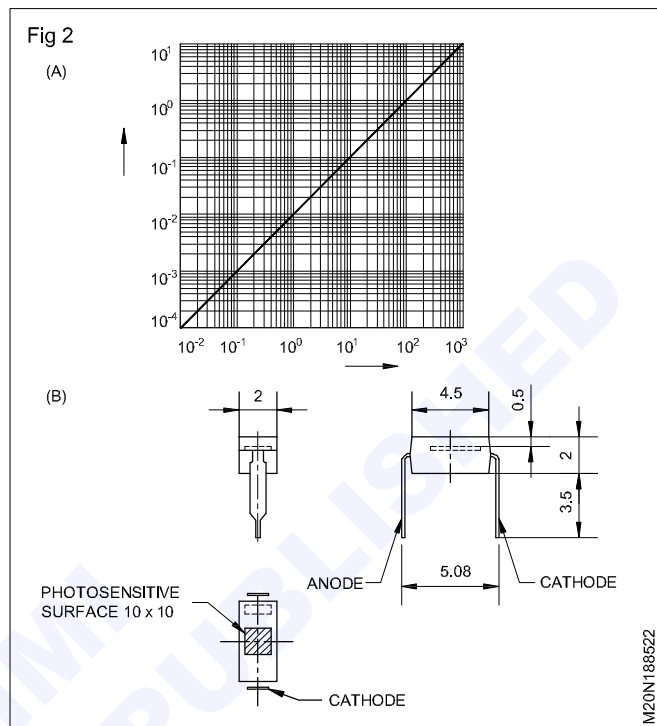
The rise in  $I_{photo}$  is almost linear. Photodiodes are therefore particularly suitable for the accurate measurement of illuminance. Physical appearance and dimensions of a typical photodiode BPW 32 is shown in Fig 2.

### PIN Photo diodes

PIN photodiodes were developed to overcome the drawbacks of p-n photodiodes. The letters PIN indicate the zone sequence as given below;

P-layer/Intrinsic-layer/N-layer

A typical internal construction of a PIN photodiode is shown in Fig 3.



The advantages of PIN photodiodes are;

- high sensitivity in the infrared range
- short switching times,

because of which, they are extensively used in remote control using modulated infrared light.

In operation they are similar to p-n photo diodes as shown in Fig 1.

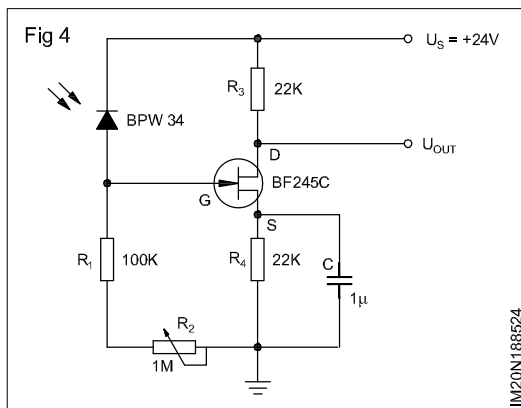
### Typical application of Photodiodes

Because of the very small photocurrent, photodiodes are generally used with an amplifier as shown in Fig 4. Amplifier stages with FET(Field Effect Transistor) are usually used with photodiodes because of the high input resistance of FET.

NOTE: Field Effect Transistors well known as FET is another type of transistor. Details of FET is discussed in lessons to follow.



Circuit diagram of a simple Light controlled amplifier is shown in Fig 5. This circuit uses a single FET for amplifying the output of the photodiode connected in series with a resistor.



The working point of the FET can be adjusted with trimmer  $R_2$ . As the illumination on the photo diode increases, the negative gate is reduced and therefore  $V_{out}$  reduces. The same value of  $R_3$  and  $R_4$  are chosen to ensure linear relationship between  $I_{photo}$  and  $V_{out}$  over a wide range. Thus this photoamplifier works satisfactorily not only for very slow changes in illumination but also with alternating light.

#### Illumination Photometer using photodiode and Opamp

An illumination Photometer with an op-amp as an amplifier is shown in Fig 5. The output of the photo sensor follows the illuminance linearly, which may be in the range between 0.05 lx and 5000 lx, with a sensitivity of  $5\mu A/lx$ . The sensor has the type designation TFA 1001W and is intended for use in video cameras and optical instruments.

#### What is a Tunnel Diode?

A tunnel diode (also known as a **Esaki diode**) is a type of semiconductor diode that has effectively “negative resistance” due to the quantum mechanical effect called tunneling. Tunnel diodes have a heavily doped pn junction that is about 10 nm wide. The heavy doping result in a broken band gap, where conduction band electron states on the N-side are more or less aligned with valence band hole states on the P - side.

The application of transistors in a very high in frequency range are hampered due to the transit time and other effects. Many devices use the negative conductance property of semiconductors for these high frequency applications. A tunnel diode is one of the most commonly used negative conductance devices. It is also known as Esaki diode after L. Esaki for his work on this effect.

The concentration of dopants in both p and n region is very high, at around  $10^{24} - 10^{25} m^{-3}$ . The pn junction is also abrupt. For this reasons, the depletion layer width is very small. In the current voltage characteristics of tunnel diode, we can find a negative slope region when a forward bias is applied is very high so at absolute zero temperature the Fermi levels lies within the bias of the semiconductors.

**Characteristics of Tunnel Diode:** When reverse bias is applied the Fermi level of the p-side becomes higher than the Fermi level of n-side. Hence, the tunneling of electrons

from the balance band of p-side to the conduction band of n-side takes place. With the interments of the reverse bias the tunnel current also increases. When forward bias is applied the Fermi level of n-side becomes higher than the Fermi level of p-side, thus the tunneling of electrons from the n-side to p-side takes place. The amount of the tunnel current is very large than the normal junction current. When the forward bias is increased, the tunnel current is increased up to certain limit.

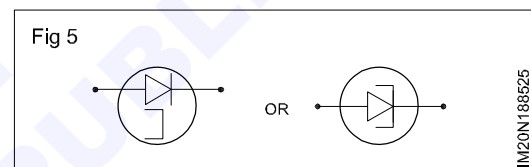
When the band edge of n-side is the same as the Fermi level in p-side, the tunnel current is maximum with the further increment in the forward bias the tunnel current decrease and we get the desired negative conduction region. When the forward bias is raised further, normal pn junction current is obtained which is exponentially proportional to the applied voltage. The V-I characteristics of the tunnel diode is given,

The negative resistance is used to achieve oscillation and often Ck+function is of very high frequency frequencies.

#### Tunnel Diode Symbol

The symbol for a tunnel diode is shown below.

#### Tunnel Diode Applications



Tunnel diode is a type of sc diode which is capable of very fast and in microwave frequency range. It was the quantum mechanical effect which is known as tunneling. It is ideal for fast oscillators and receivers for its negative slope characteristics. But it cannot be used in large integrated circuits - that's why its applications are limited.

When the voltage is first applied current starts flowing through it. The current increases with the increase of voltage. Once the voltage rises high enough suddenly the current again starts increasing and tunnel diode starts behaving like a normal diode. Because of this unusual behavior, it can be used in number of special applications started below.

#### Oscillator Circuits

Tunnel diodes can be used as high frequency oscillators as the transition between the high Electronics conductivity is very rapid. They can be used to create oscillation as high as 5Gz. Even they are capable of creativity oscillation up to 100 GHz in a appropriate digital circuits.

#### Used in Microwave circuits

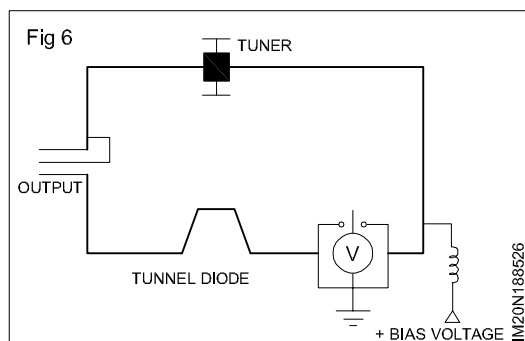
Normal diode transistors do not perform well in microwave operation. So, for microwave generators and amplifiers tunnel diode are used. In microwave waves and satellite communication equipments they were used widely, but lately their usage is decreasing rapidly, as transistors which operate in this frequency range are becoming available.

### Resistant to Nuclear Radiation:

Tunnel diodes are resistant to the effects of magnetic fields, high temperature and radioactivity. That's why these can be used in modern military equipment. These are used in nuclear magnetic resource machine also. But the most important field of its use is satellite communication equipments.

### Tunnel Diode Oscillator

Tunnel diode can make a very stable oscillator circuit when they are coupled to a tuned circuit or cavity, biased at the centre point of negative resistance region. Hewlett is an example of tunnel diode oscillatory circuit (Fig )



The tunnel diode is loosely coupled to a tunable cavity. By using a short, antenna feed probe placed in the cavity off centre loose coupling is achieved. To increase the stability of oscillation and achieve o/p power over wider bandwidth loose coupling is used. The range of the output power produced is few hundred micro - watts.

This is useful for many microwave applications. The physical position of the tuner determines the frequency of operation. If the frequency of operation is changed by this method, that is called mechanical tuning. Tunnel diode oscillators can be tuned electronically also.

Tunnel diode oscillators which are meant to be operated at microwave frequencies, generally use some form of transmission lines as tunnel circuit. These oscillators are useful in applications that require a few milliwatts of power, example - local oscillators for microwave superhetrodyne receiver.

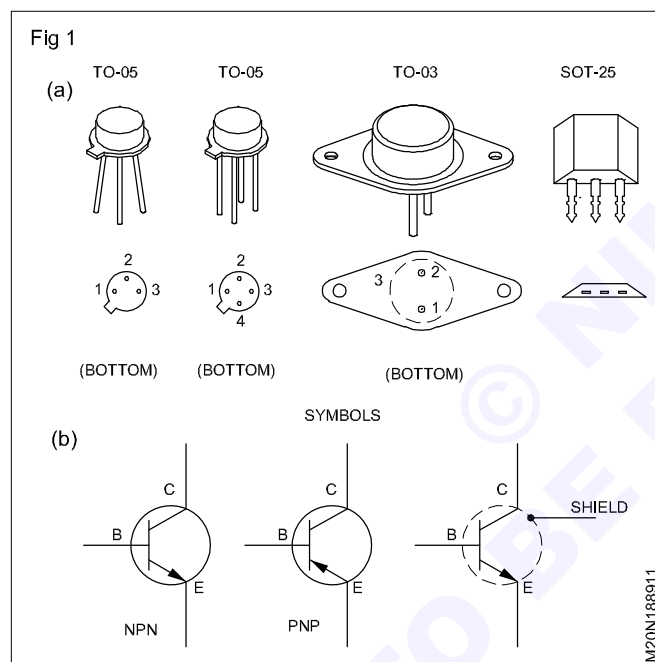
## Transistors and Classification

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

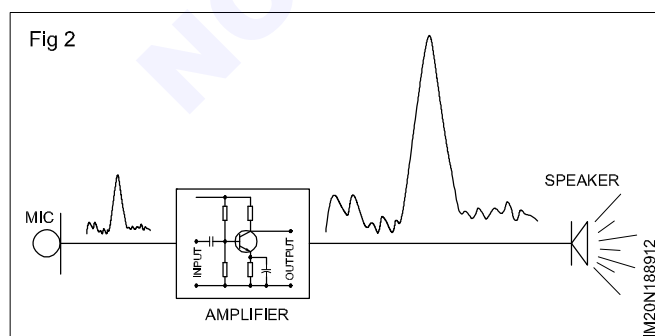
- introduction of transistors
- list the advantages of transistors over vacuum tubes
- list the important classifications of transistors
- state the name and functions of terminals of a transistor
- name of the types of transistor packages
- describe the two tests to be conducted on a transistor before using it
- working principle of transistor.

### Introduction

Transistors are the semiconductor devices having three or four leads/terminals. Fig 1a shows some typical transistors. Fig 1b shows the symbols used for different types of transistors.

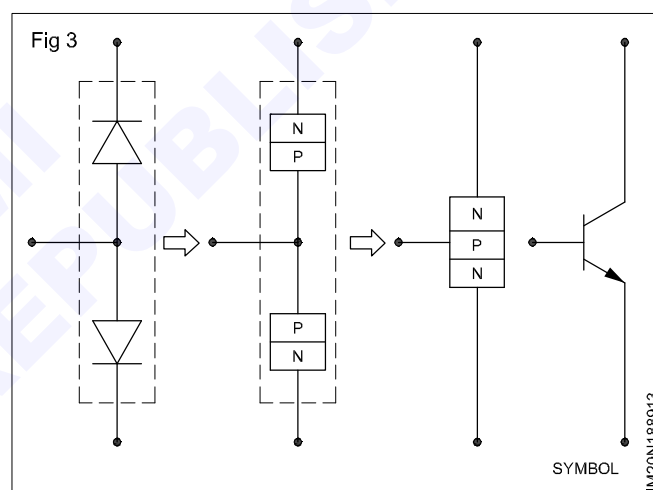


Transistors are mainly used for enlarging or amplifying small electric/electronic signals as shown in Fig 2. The circuit which uses transistors for amplifying is known as a transistor amplifier.

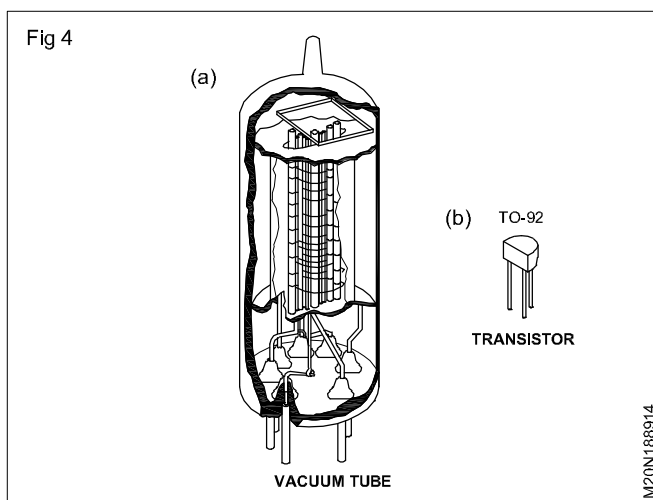


One other important application of transistors is its use as a solid state switch. A solid state switch is nothing but a switch which does not involve any physical ON/OFF contacts for switching.

Transistors can be thought of as two PN junction diodes connected back to back as shown in Fig 3.



Before the transistors were invented (1947), there was what were known as vacuum tubes which were used in amplifiers. A typical vacuum tube is shown in Fig 4a.



Compared with the present day transistors the vacuum tubes were big in size, consumed more power, generated lot of unwanted heat and were fragile. Hence vacuum tubes became obsolete as soon as transistors came to market.

Transistors were invented by Walter H. Brazil and John Barlow of Bell Telephone Laboratories on 23rd Dec. 1947. Compared to vacuum tubes (also known as valves), transistors have several advantages. Some important advantages are listed below;

- Very small in size (see Fig 4b)
- Light in weight
- Minimum or no power loss in the form of heat
- Low operating voltage
- Rugged in construction.

To satisfy the requirements of different applications, several types of transistors in different types of packaging are available. As in diodes, depending upon the characteristics, transistors are given a type number such as BC 107, 2N 6004 etc., The characteristics data corresponding to these type numbers are given in *Transistor data books*.

## CLASSIFICATION OF TRANSISTORS

### 1 Based on the semiconductor used.

- Germanium transistors
- Silicon transistors

Like in diodes, transistors can be made, using any one of the above two important semiconductors. However, most of the transistors are made using silicon. This is because, silicon transistors work better over a wide temperature range (higher thermal stability) compared to germanium transistors.

Transistor data books give information about the semiconductor used in any particular transistor.

### 2 Based on the way the P and N junctions are organized as shown in Fig 5.

- NPN transistors
- PNP transistors

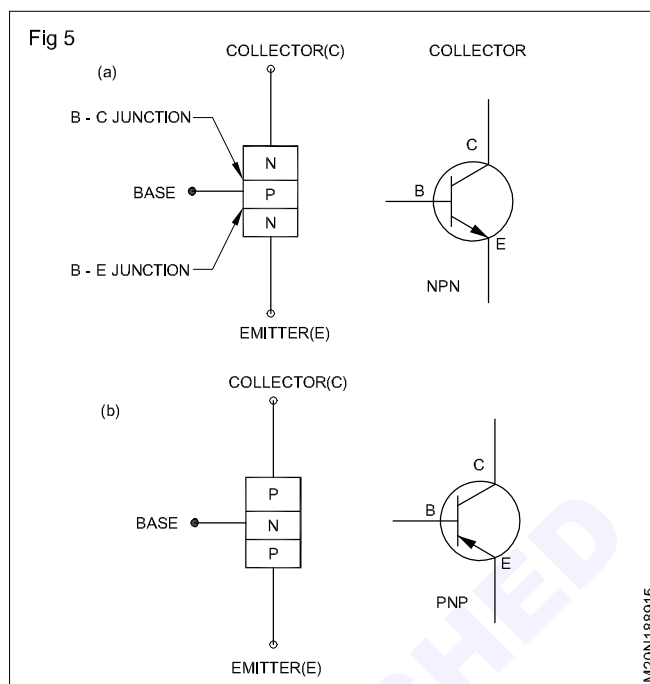
Both NPN and PNP transistors are equally useful in electronic circuits. However, NPN transistors are preferred for the reason that NPN has higher *switching speed* compared to PNP.

**Details of switching speed is discussed in further lessons.**

Whether a transistor is PNP or NPN can be found with the help of transistor data book.

### 3 Based on the power handling capacity of transistors as shown in Table below (Fig 6).

Low power transistors, also known as small signal amplifiers, are generally used at the first stage of amplification in which the strength of the signal to be amplified is low. For example, to amplify signals from a microphone, tape head, transducers etc.,



| Low power transistors<br>(less than 2 watts) | Medium power transistors<br>(2 to 10 watts) | High power transistors<br>(more than 10 watts) |
|----------------------------------------------|---------------------------------------------|------------------------------------------------|
| Fig 6<br>TO-92<br>                           | TO-05<br>                                   | TO-03<br>                                      |

Medium power and high power transistors, also known as large signal amplifiers are used for achieving medium to high power amplification. For example, signals to be given to loudspeakers etc. High power transistors are usually mounted on metal chassis or on a physically large piece of metal known as heat sink. The function of heat sink is to, take away the heat from the transistor and pass it to air.

Transistor data books give information about the power handling capacity of different transistor.

### 4 Based on the frequency of application

- Low freq. transistors (Audio frequency or A/F transistors)
- High freq. transistor (Radio frequency or R/F transistors)

Amplification required for signals of low or audio range of frequencies in Tape recorders, PA systems etc., make use of A/F transistors. Amplifications required for signals of high and very high frequencies as, in radio receivers, television receivers etc., use R/F transistors.

## 5 Based on the manufacturing method

- Grown junction
- Alloy junction
- Planar type
- Point contact
- Epitaxial
- Mesa

The aim of each manufacturing process is to yield transistors most suitable for a particular type of application.

Transistor data books generally do not give information about the adopted manufacturing process of transistor. However, the relevant details can be obtained from the transistor manufacturer.

## 6 Based on the type of final packaging

- Metal
- Plastic
- Ceramic

Metal packaged transistors are generally used in medium and high power amplifications. Plastic packaging is generally used for low power amplification. Some plastic packages come with a metal heat sink. Such transistors are used for medium power amplification. Ceramic packaging is used for special purpose very high frequency applications, for higher temperature stability etc.,

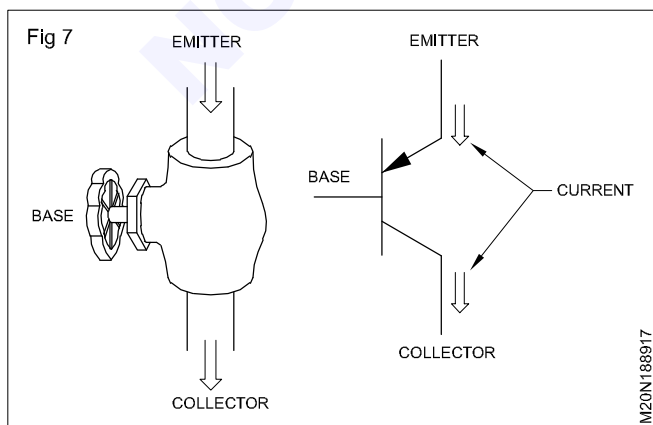
Some examples of packaging type codes used with transistors are, TO-3, TO-92, SOT-23 and so on.

Transistor data books give information about the type of packaging and its case outline.

### Inside a transistor

Inside a transistor there are two PN junctions connected to each other as shown in Fig 3 and Fig 5. Outside a transistor, one can see only three leads. These leads are known as **base**, **emitter** and **collector** as shown in Fig 5. As shown in Fig 5, the three leads/pins/pigtails called **base**, **emitter** and **collector** are taken from each of doped semiconductor material.

In simple terms, as shown in Fig 7, the function of the **base**, **emitter** and **collector** regions of a transistor are,



Emitter - emits current carriers (electrons/holes)

Collector - collects current carriers

Base - controls flow of current carriers from emitter to collector.

While connecting a transistor to a circuit, it is necessary to identify the base, the emitter and the collector pins. A Transistor data book gives information on pin identification of transistors. However, it is convenient to put sleeve wires over the transistor pins for the following reasons;

- for easy identification while wiring
- sleeves act as spacers while mounting and soldering
- they ensure the required minimum lead distance from the solder joint to the transistor body.

Following colour scheme is suggested for putting sleeves to transistor pins although, any convenient colour scheme may be adopted.

Base pin - Blue colour sleeve

Emitter pin - Red colour sleeve

Collector pin - Yellow colour sleeve

Shield pin - Black colour sleeve

### Transistor type packages:

The popular transistors with different ratings used for general purpose to special applications are manufactured in a variety of package styles. Some of the commonly used transistors with their package numbers and lead identifications are shown in Fig 8.

### Heatsink

In any Electronics/electronic circuits the high power rectifiers, SCRs, transistors, MOSFETs, even LEDs used in high bright lights consumes power generates considerable amount of heat while the circuit is functioning. Typically power handling semiconductor devices/components are inadequate to dissipate heat as their dissipation capability is significantly low.

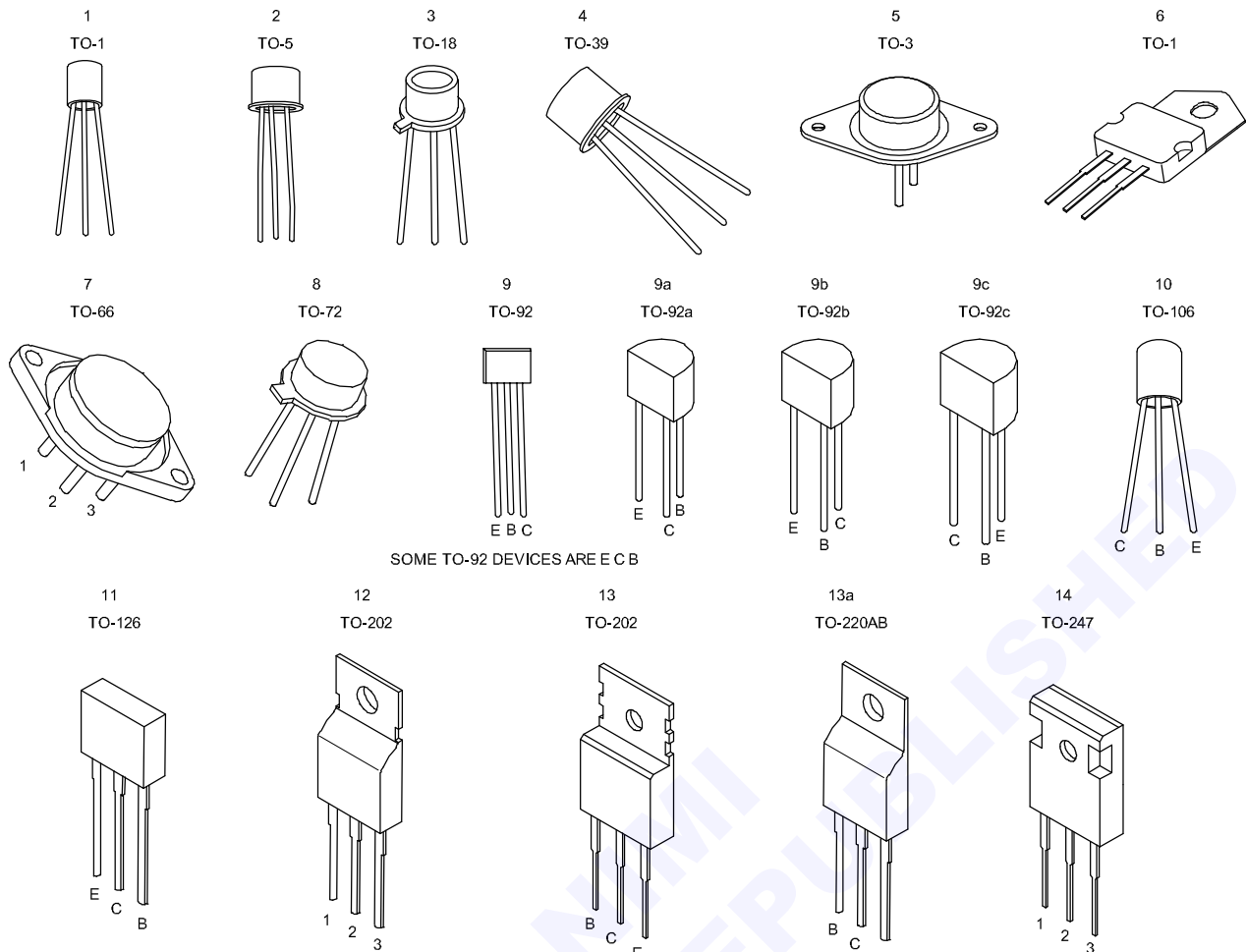
Due to this reason, heating up of components leads to malfunctioning problems and may cause failure of the entire circuit or performance of the system. Therefore, to solve these problems, heatsinks are the solution that must be provided to these semiconductor devices for cooling purpose.

Heatsink is a device made of aluminium metal attached to the electronic device, that dissipates heat into surrounding air medium and cools them for improving their performance reliability and also avoids the damage to the components. Heat sink transfers the heat or thermal energy from a high temperature component to a low temperature medium like air.

Heatsinks are classified into different categories as extruded heatsinks as they can be made as extrusions based on the heat dissipating rating shape and size etc as shown in Fig 9.



Fig 8



To select a particular heatsink various parameters are to be taken into consideration such as heat dissipation rate in watts, maximum junction temperature of device in degree celsius, air flow condition etc.

The method of mounting a transistor in To - 220 package is shown in Fig 10. A thin mica film is introduced between the transistor body and the aluminium heatsink surface. An insulating washer inserted to avoid short circuit by the screw and nut used for tightly fastening to the heatsink that radiates the heat generated of the transistor.

### Testing transistors using ohmmeter

#### 1 Junction test

Since a transistor can be regarded as two diodes connected back-to-back, a transistor's general working condition (quick-test) can be assessed by checking these two diodes as shown in Fig 11a and 11b.

Fig 8a shows a NPN transistor and Fig 8b shows a PNP transistor. The imaginary diodes 1 and 2 can be tested as testing any diode. When a diode is tested, if the ohmmeter shows high resistance in one direction and low resistance in another direction, then the diode corresponding to that diode junction can be regarded as GOOD. One important point to note in a transistor is that, both the diodes of the transistor should be GOOD to declare the transistor as GOOD.

While connecting a transistor to a circuit, it is necessary to identify the base, the emitter and the collector pins. A Transistor data book gives information on pin identification of transistors. However, it is convenient to put sleeve wires over the transistor pins for the following reasons;

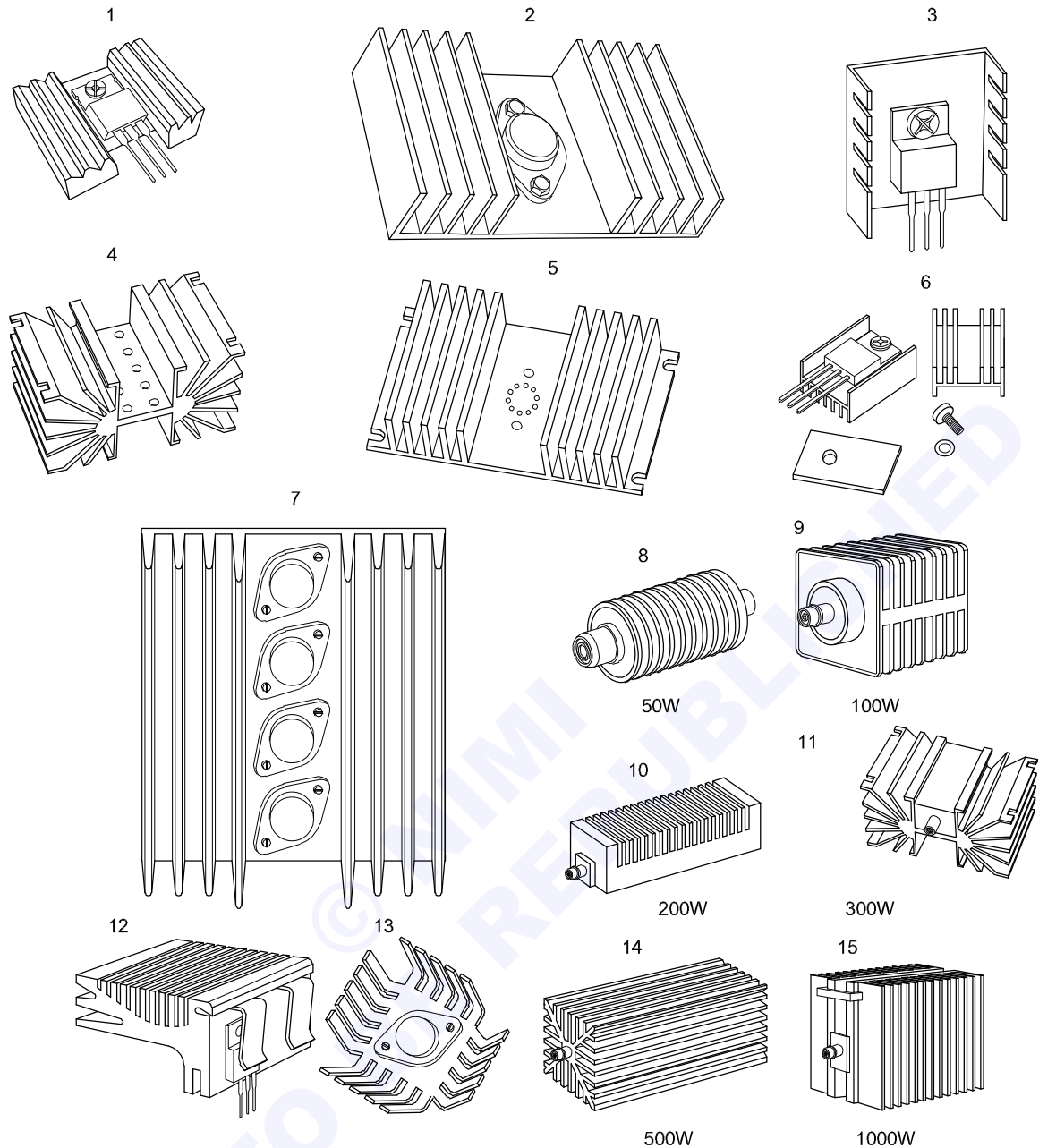
#### 2 Quick turn-on test

Recall that the base lead of the transistor controls the flow of current carriers from emitter to collector. So, if the base is open, then there can be no current flow through emitter-collector. This means, the resistance between emitter and collector will be high when the base is open as shown in Fig 12a. This can be checked using an ohmmeter with the base lead open.

**In Fig 12, the +ve and -ve indicated across ohmmeter is the internal battery polarities of the meter and not the markings at the meter prodsockets.**

When the collector and base leads of a transistor is touched with a wet finger as the base of the transistor turns ON the transistor and makes current to flow through emitter-collector. Because of the current flow, the resistance across emitter-collector will be low. From this test it is possible to make a quick test of the transistors basic operation. This test is most suitable for low power and medium power transistors.

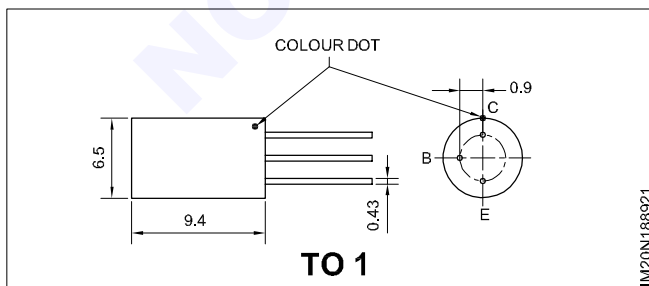
Fig 9



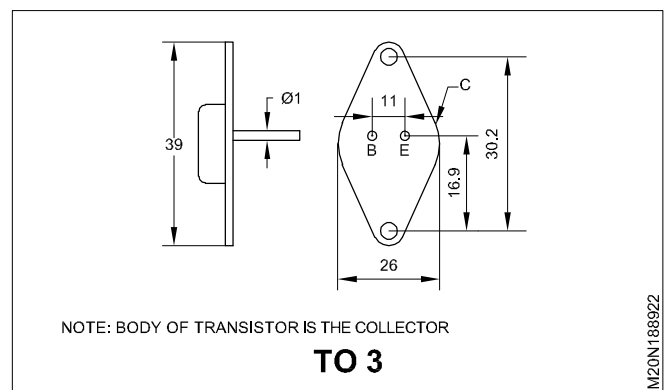
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Chart - 1

### Types of transistor packages and pin identification chart



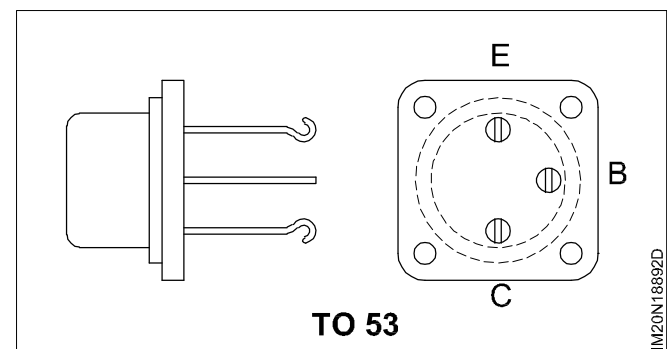
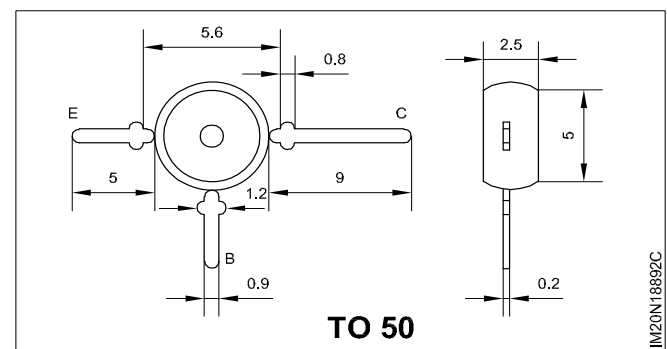
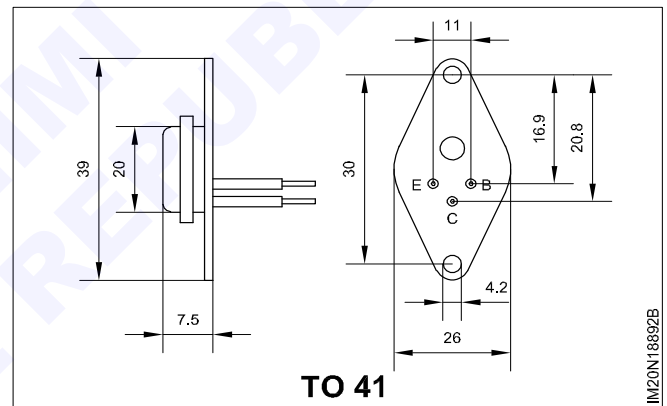
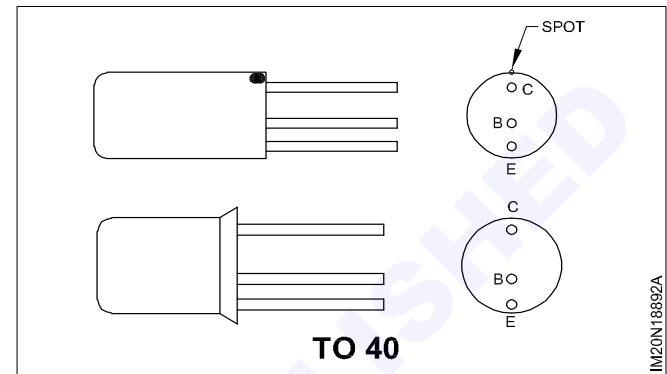
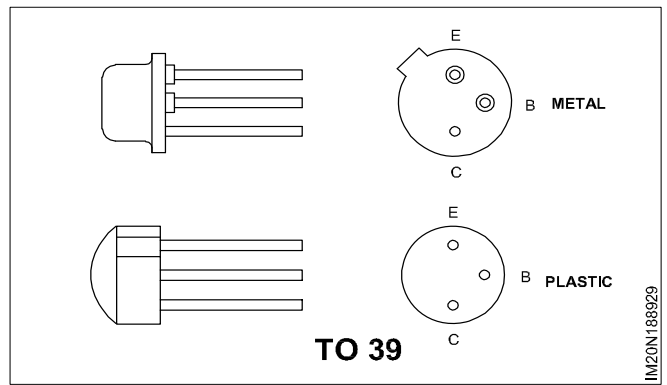
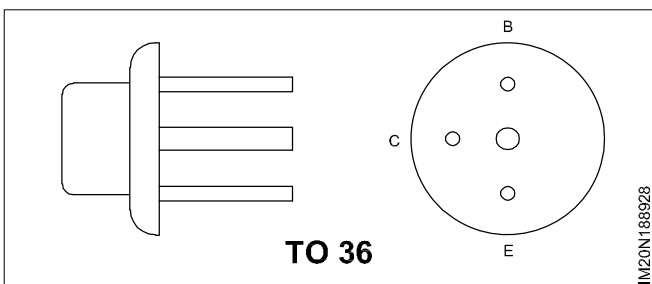
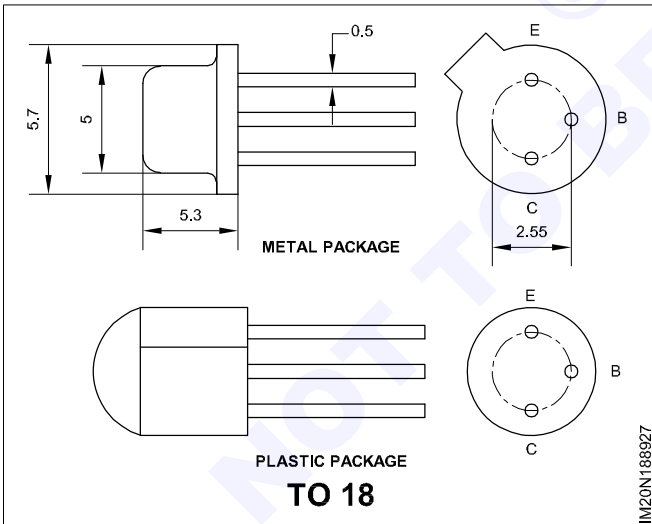
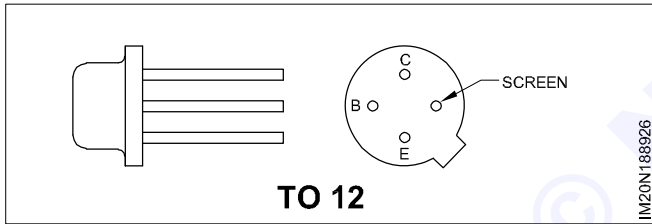
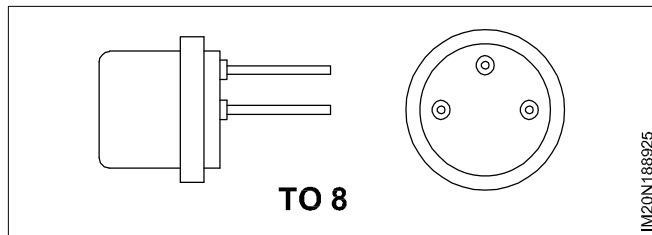
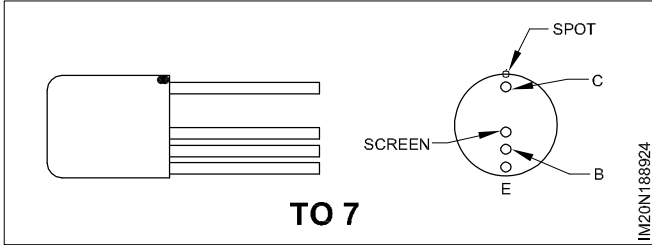
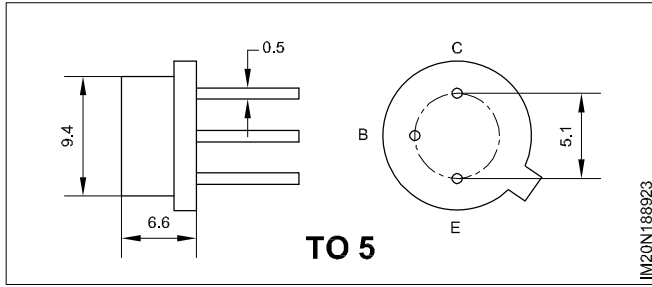
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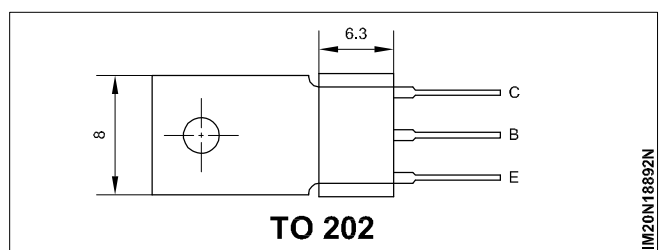
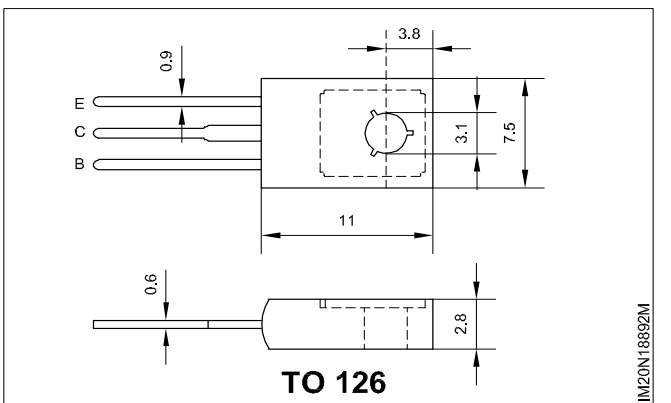
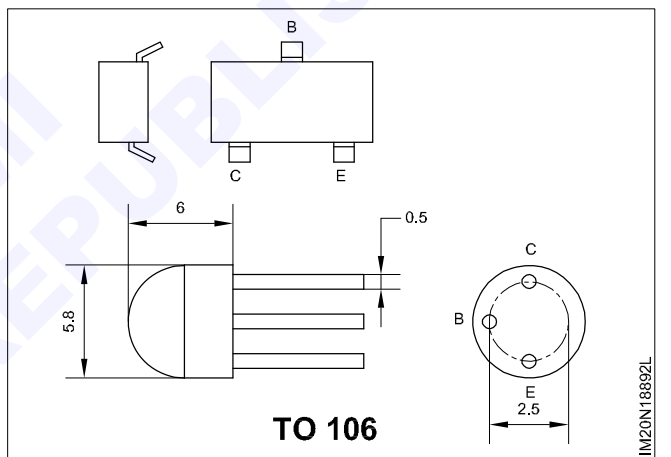
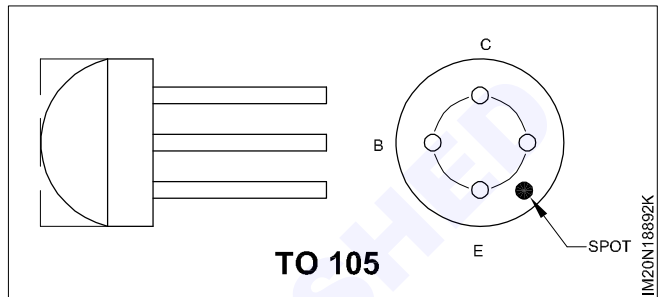
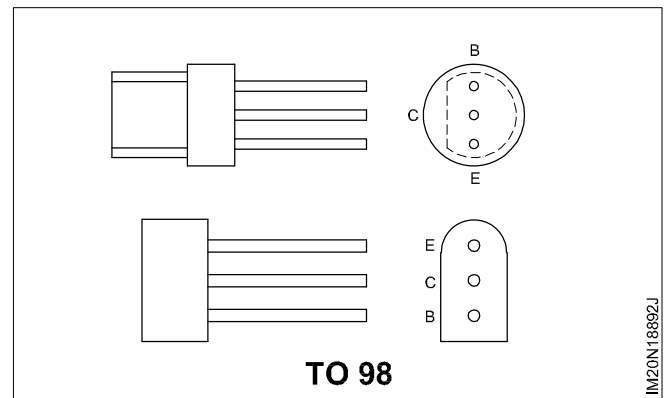
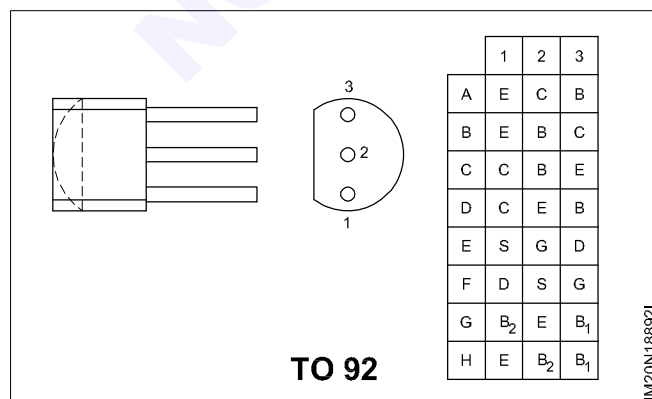
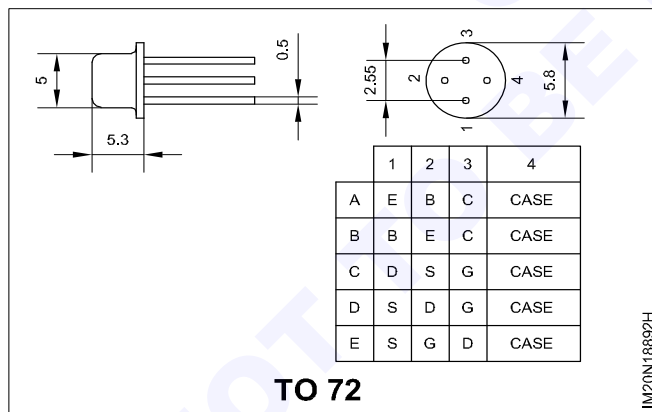
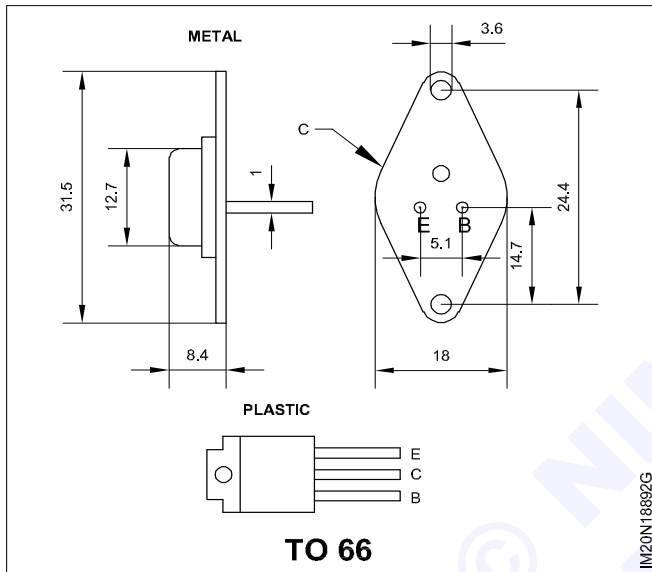
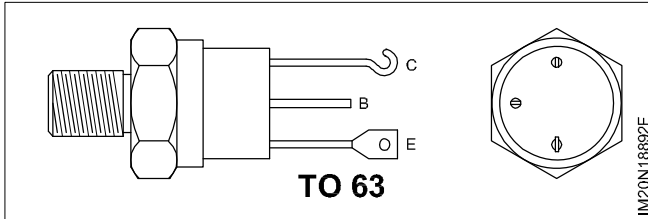
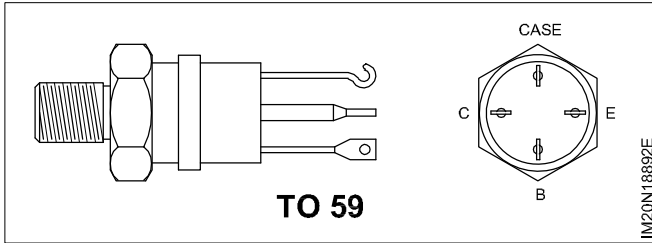


NOTE: BODY OF TRANSISTOR IS THE COLLECTOR

TO 3

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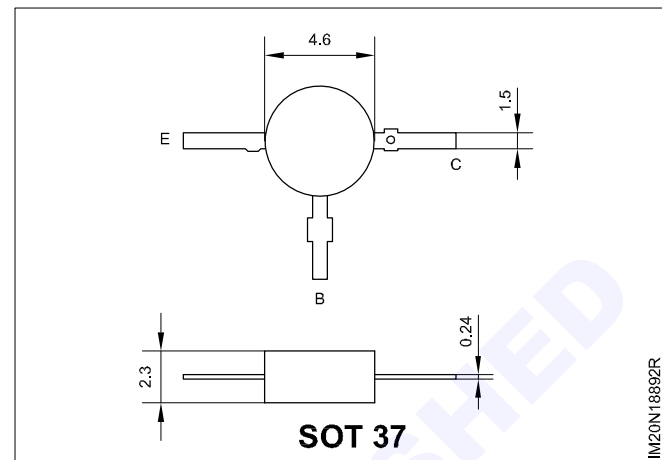
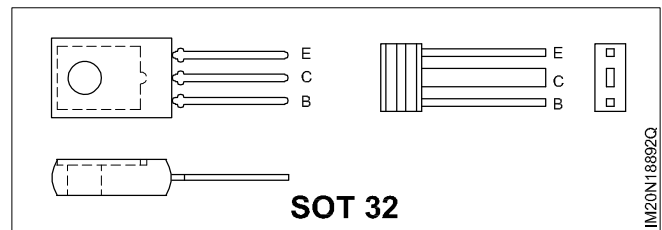
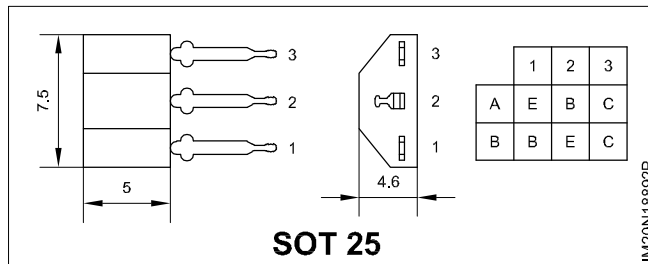
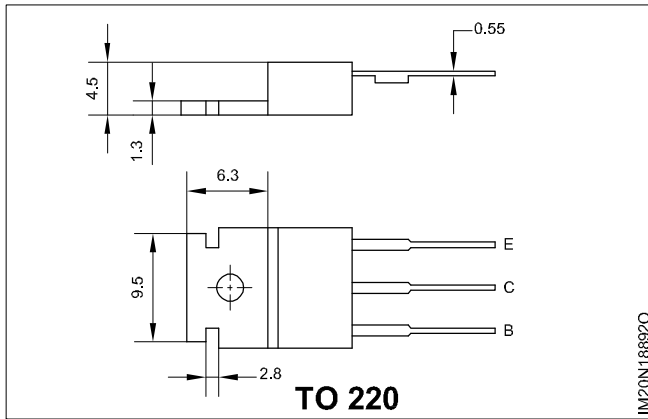
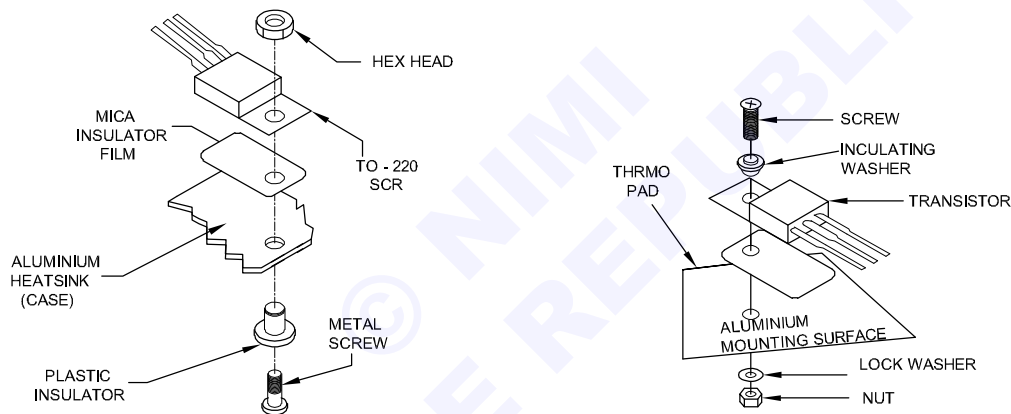


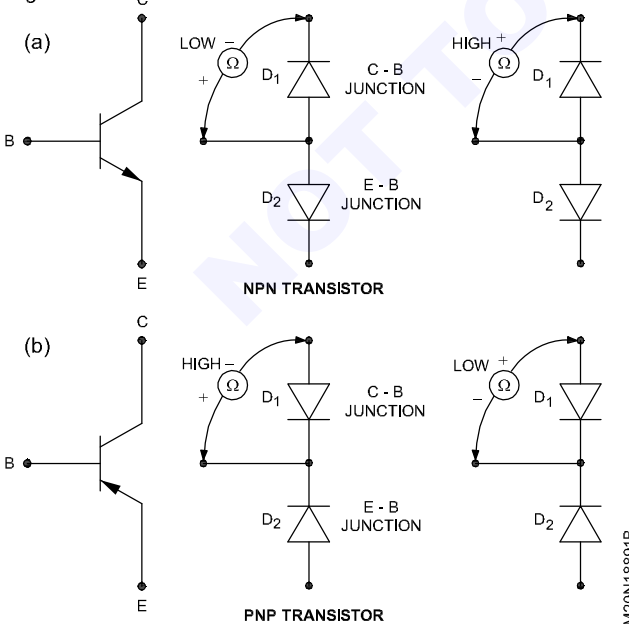
Fig 10



MOUNTING METHOD OF TRANSISTOR ON HEATSINK

IM20N18891A

Fig 11



The above two tests on a given transistor, using a simple ohmmeter reveals the condition of the transistor. These tests are essential before using a transistor in a circuit.

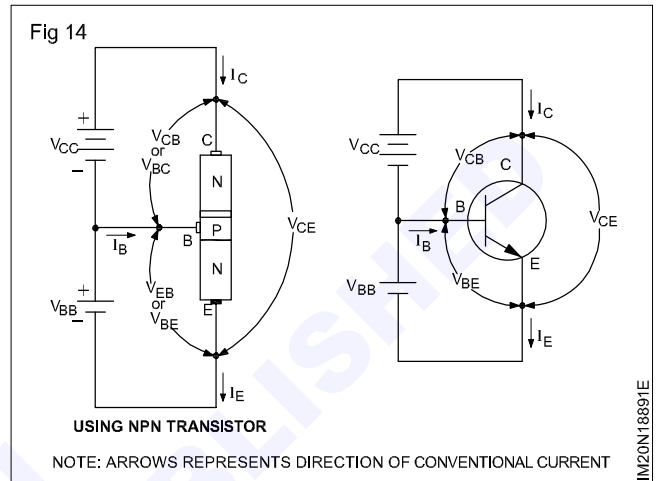
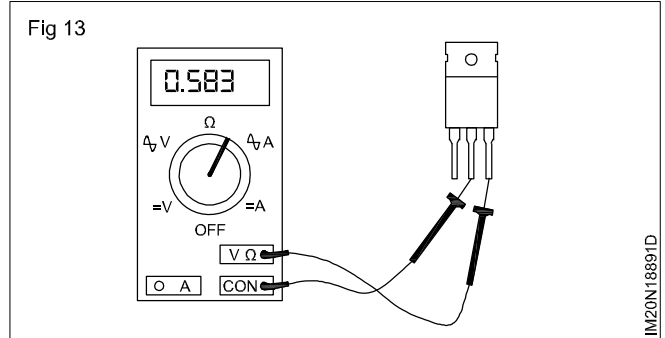
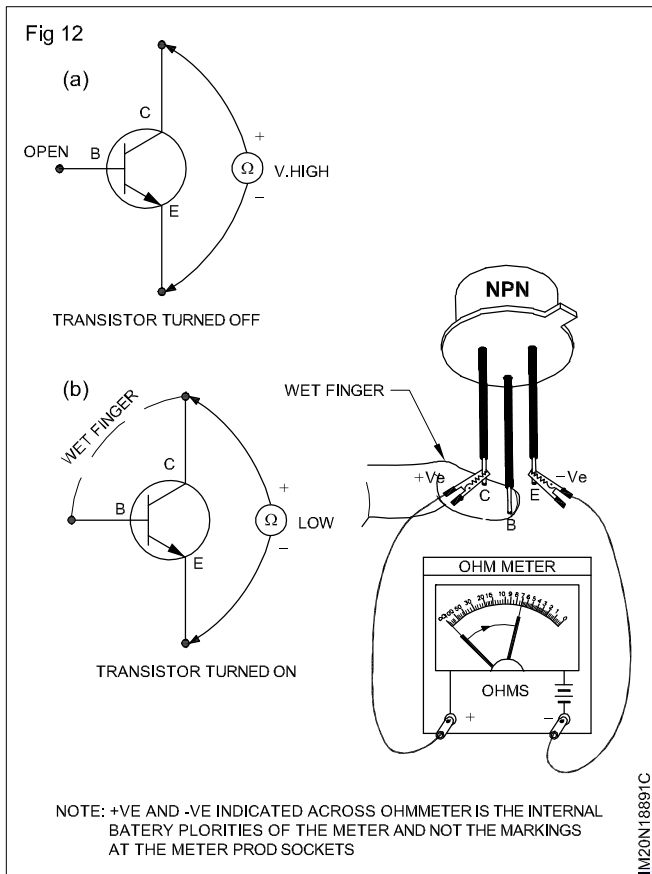
### Testing transistor using DMM

Electronics repair technicians often use a digital multimeter (DMM) to test whether a transistor is working in fig 14. properly or not (serviceable or unserviceable). The DMM is shown simple test with DMM function/ range switch set at the diode symbol (Diode test mode) is used for this purpose.

There are three set of testing across the base to Emitter, base to collector and Emitter to collector terminals both in forward and reverse directions as shown in Fig 14. are to be carried out to determine the condition of any transistor.

As the transistor is considered to be junction of two - back - to - back diodes, in this test, the DMM measures the voltage drop across the base to Emitter and base to collector in both directions. The readings of common type of small signal type normal working (Serviceable) silicon NPN transistor is given in the table below as a reference.





| Direction | Base to Emitter | Base to collector | Emitter to collector | Remarks     |
|-----------|-----------------|-------------------|----------------------|-------------|
| Forward   | 0.45v to 0.9v   | 0.45 to 0.9v      | 'OL'                 | serviceable |
| Reverse   | 'OL'            | 'OL'              | 'OL'                 |             |

Incase the bipolar transistor measures contrary to these readings it is considered to be defective. Also, with the voltage drop readings it is possible to determine the emitter lead of an unknown/unmarked transistor, as the emitter - base junction typically has a slightly higher voltage drop than the collector- base junction.

Thus, this test is used only to verify whether the transistor is serviceable or not, but it does not guarantee that the transistor is operating within its designated parameters.

## Transistor data from transistor data book

### Introduction

Voltage across the junctions and current through the base, collector and emitter in a transistor are symbolically . The direction of current arrows corresponds to the direction of conventional current.

Similar to diodes, at the contact region of each P-N junction, there are depletion regions. The depletion is at the region forward biased base-emitter junction and wide at the reverse biased base-collector junction.

### 1 Maximum permissible emitter-base voltage, $V_{EB(max)}$ or $V_{BE(max)}$

Recall from the lesson of P-N junction diodes, that the forward bias voltage required to set a PN junction into conduction is 0.7volts for silicon and 0.3 volts for germanium.

Any further increase in forward bias voltage across the PN junction increases only the current through the junction. If an excessively large forward voltage is applied across a P-N junction, the junction ruptures resulting in short circuit of the junction. Then, the P-N junction no more behaves as a PN junction. Hence, while applying forward voltage across a P-N junction, the maximum permissible voltage limit should not be crossed.

In a transistor, the forward voltage across the base-emitter PN junction is referred to as  $V_{EB}$  or  $V_{BE}$ . The maximum value of  $V_{EB}$  that can be applied across this junction is indicated as  $V_{EB(Max)}$ . If the applied voltage across E-B junction, exceeds  $V_{EB(Max)}$ , the junction will rupture and the transistor will become defective.

The value of  $V_{EB(Max)}$  is different for different transistors. This specification for any particular transistor can be obtained from transistor data books. As an example  $V_{EB(max)}$  of a few transistors are given below;

| Transistor type number | BC147 | BC148 | BC180 | BF200 |
|------------------------|-------|-------|-------|-------|
| $V_{EB(max)}$          | 6V    | 5V    | 3V    | 3V    |

The terms  $V_{EB(max)}$  and  $V_{BE(max)}$  are the same

## 2 Maximum permissible collector-base voltage, $V_{CB(max)}$ or $V_{BC(max)}$

When a P-N junction is reverse biased, the junction does not conduct. If the applied reverse voltage is increased beyond a limit, the junction ruptures and the junction starts conducting like any conductor losing its original property. This maximum permissible reverse voltage that can be applied across the collector-base is indicated by  $V_{CB(max)}$  or  $V_{BC(max)}$ . This value is different for different transistors. This value for any particular transistor can be obtained from transistor data book. As an example  $V_{CB(max)}$  for a few transistors are given below;

| Transistor type number | BC147 | BC148 | BF170 | BF200 |
|------------------------|-------|-------|-------|-------|
| $V_{CB(max)}$          | 50V   | 30V   | 160V  | 30V   |

## 3 Maximum permissible Collector-Emitter Voltage, $V_{CE(max)}$

This is the maximum voltage that can be applied across the collector-emitter junction of a transistor. Beyond this voltage both the base-emitter and the base-collector junction will get damaged.  $V_{CE(max)}$  is also different for different transistors.  $V_{CE(max)}$  for any particular transistor can be obtained from transistor data book. As an example  $V_{CE(max)}$  for a few transistors are given below

| Transistor type number | BC147 | BC148 | BF170 | BF200 |
|------------------------|-------|-------|-------|-------|
| $V_{CE(max)}$          | 45V   | 20V   | 160V  | 20V   |

## 4 Maximum permissible collector current, $I_{C(max)}$

This is the maximum current that can be forced to flow through the collector region of a transistor. If current higher than this limit is forced the collector, the transistor will get heated up excessively and eventually burn out. This specification  $I_{C(max)}$  of a transistor indicates whether the transistor is low, medium or a high power transistor.  $I_{C(max)}$  of any particular transistor can be obtained from transistor data book.  $I_{C(max)}$  for a few transistors are given below;

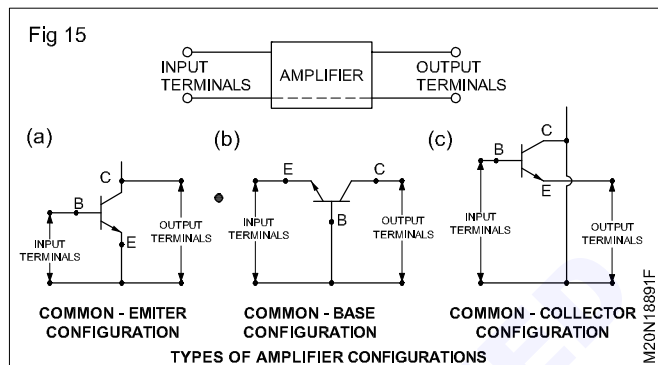
| Transistor type number | BC547 | BC548 | BF170 | BF200 |
|------------------------|-------|-------|-------|-------|
| $I_{C(max)}$           | 200mA | 200mA | 50mA  | 20mA  |

## 5 Minimum DC current gain, $\beta_{dc}$ or $H_{FE}$

The current gain of a transistor is a ratio of the output current to the input current. A transistor can be connected in three different ways as shown in Fig 15.

Fig 15a is referred to as **common-emitter configuration** or common-emitter amplifier. This is because, the emitter lead of the transistor is used as a common terminal between the input and output. Common emitter amplifiers are the most commonly used amplifier configuration in electronic circuits. This is because, in this configuration, you get the best out of a transistor. Details of common

emitter configuration are discussed in further lessons. The **current gain** in common-emitter configuration is indicated by the symbol  $\beta$  (spell it as Beta). All data books give the current gain of transistors in  $\beta$ . This is because, once  $\beta$  of a transistor is known, the current gain of the transistor when connected in other configurations as shown in Fig 15b and Fig 15c can be easily computed.



The value of  $b$  given in data books is generally the current gain calculated as a ratio of, a small change in DC base current ( $DI_B$ ) to a corresponding change in the DC collector current ( $DI_C$ ).

Hence, a suffix DC is attached to the term  $b$  and given as  $\beta_{dc}$  in data books.  $\beta_{dc}$  of transistors is also referred to as  $H_{FE}$  in some data books.

Fig 15b shows a **common-base amplifier**, where the base lead of the transistor is common to both the input and output terminals. The current gain in common-base configuration is indicated by the symbol  $\alpha$  (spell it as alpha). The current gain  $\alpha$ , of a common-base amplifier will always be less than 1. Although the current gain of this amplifier is very low, this configuration is preferred over the common emitter configuration in some special amplifiers. Details of common-base amplifiers are discussed in further lessons.

Fig 15c shows a **common-collector amplifier**, where the collector lead is common to both the input and output terminals. This common-collector configuration is also known as **emitter-follower** because, voltage at the emitter lead follows the voltage given at the base of the transistor. The current gain in a common-collector amplifier is not very much different from that of the common-emitter amplifier. Hence, no separate symbol is used to indicate the current gain of a common-collector amplifier. This configuration is as important and as popular as the common-emitter configuration because, it is used to interconnect circuits having different impedances. Details of this circuit are discussed in further lessons.

It is very important to note that the  $\beta$  of a transistor is given in data books as  $\beta_{Minimum(MN)}$  or  $\beta_{Typical(TP)}$ . This is because the value of  $\beta$  varies due to variations in the level of the base current. Details of variation in  $\beta$  is discussed in detail in further lessons. While designing a circuit, it is suggested to use the typical value of  $\beta$  of the transistor. If the data book gives only the minimum value of  $\beta$ , the typical value can be taken as twice the minimum value.

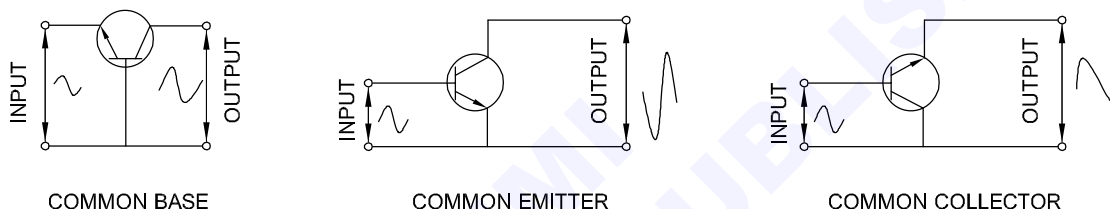
## 6 Typical application of a particular type of transistor

Transistor applications are almost infinite. However, these applications can be broadly classified as given below;

- Industrial circuit applications
- Consumer circuit applications
- Special purpose circuit applications

| Characteristics                    | Common base                          | Common emitter                    | Common collector        |
|------------------------------------|--------------------------------------|-----------------------------------|-------------------------|
| Input resistance                   | Very low (less than 100ohm)          | Low (less than 2K)                | High (above 100k ohm)   |
| Output resistance                  | Very high (more than 100k ohm)       | High (less than 50k ohm)          | Low (less than 100 ohm) |
| Current gain                       | Less than one                        | High (about 100)                  | Very high (above 100)   |
| Voltage gain                       | Medium                               | High                              | Medium                  |
| Phase relation between I/P and O/P | In phase                             | 180 phase shift (invert or phase) | In phase                |
| Applications                       | High frequency applications for more | Audio frequency application       | Impudence matching      |

Fig 16



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Under each of the above classification, there may be one or more further classifications. Transistor data books give these details as appendix to the data book. Data books generally adopt some form of symbolic coding scheme under the column *use/appln* to indicate the application of a particular transistor. Meanings of the codes will be given in the appendix of the data book.

For example, in Towers International Transistor Selector Data Book, for the transistor 2N 6004, under the column USE the codes mentioned is AMG. This means 2N6004 is,

- A - Audio frequency transistor
- M - Medium current rating
- G - General purpose applications

From this code, we can conclude that the transistor 2N6004 is used for general purpose amplifier circuits in the audio frequency range for medium current/power application.

Important specifications that go along with any transistor, can be summarised as follows;

- maximum permissible emitter-base voltage,  $V_{EB(max)}$  or  $V_{BE(max)}$
- maximum permissible collector-base voltage,  $V_{CB(max)}$  or  $V_{BC(max)}$
- maximum permissible collector-emitter voltage,  $V_{CE(max)}$
- maximum permissible collector current,  $I_{C(max)}$
- minimum or typical dc current gain,  $b_{dc}$  or  $H_{FE}$

- typical application of the transistor.

In addition to the above listed specifications, there are a few more specifications for transistors. These specifications will be introduced at the appropriate place in further lessons.

### Transistor type numbering scheme

The transistor type numbering scheme follows the same PRO-ELECTRON(European), JEDEC(American), JIS(Japan) and House codes (particular to the manufacturer) standards as used for diodes.

Transistors in Pro-electron standard are registered with,

- two letter and three numeral codes or
- three letter and two numeral codes.

A few examples of,

- Two letter and three numeral codes are, AC128, BC107, BF200 etc.
- Three letter and two numeral codes are, ACY17, BCX73 etc.

### Two letter and three numeral codes

The first letter in the type number of the device indicates, the type of semiconductor material used in making the device.

**Example:** Device numbers starting with B are made of Silicon.

The second and third letters indicate the general applications of the component.

**Example:** In transistor type code BC107, the second letter C indicates that it is a low power audio frequency transistor. Table No.28 of pocket table book gives further details of pro-electron codes for transistors.

The three digit numerals after two or three letters is the registration code number which corresponds to the detailed voltage, current and temperature specification of that transistor. This detailed specification can be obtained referring to data book.

### Three letter and two numeral code

If the transistor has a three letter and two numeral code, then the first two letters carry the same meaning as given in the above example. The third letter indicates that the device is manufactured for a specific field of application.

For example: BCY98 indicates that it is a silicon, audio/low frequency, low power, industrial transistor.

**In Jedec(USA) standard** transistor type numbering scheme, the first numeral gives the number of PN junctions in the device. For example 1 for diodes as they have only one PN junction and 2 for conventional bipolar transistors

as they have two PN junctions. This first numeral is followed by the letter N and a register number. For example a device numbered 2N6004 indicates that, it is a device with two junctions (transistor) which was the 6004th to be registered in the standards. The detailed specification for the registered number can be found referring to transistor data book.

**In JIS (Japan) standard** transistor type numbering scheme, all transistor numbers start with 2S followed by a letter and several numbers(e.g. 2SB77). The letter after S has the following significance,

**A = PNP** transistor for high frequency application

**B = PNP** transistor for low frequency application

**C = NPN** transistor for high frequency application

**D = NPN** transistor for low frequency application

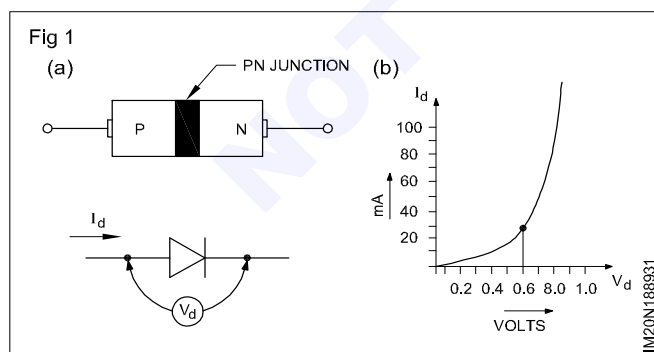
Manufacturers who cannot manufacture transistors which satisfy the full detailed specification of any of the above said standards employ their own coding scheme. Such coding schemes are known as **House codes** and they are particular to individual manufacturers. One such House code maintained by, The **Semiconductors Ltd.**, Poona, has house code such as SL100, SG100 etc.

## Transistors Input and Output Characteristics of Transistors

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

- state the necessity of characteristic curves for transistors
- list and explain the two important characteristic curves of transistors
- define voltage and break down voltage
- state the importance of DC load line curves
- state the meaning of Q-point
- state the method of fixing Q-point for a given transistor using the transistor data.

A semiconductor diode, as shown in Fig 1, has only one PN junction. When the voltage across the PN junction is increased or decreased, the current through the diode increases or decreases. There is only one voltage parameter( $V_d$ ) and one current parameter( $I_d$ ). Therefore, the relationship between these two parameters is easy to understand through the diode characteristic graph of  $V_d$  versus  $I_d$  as shown in Fig 1b.

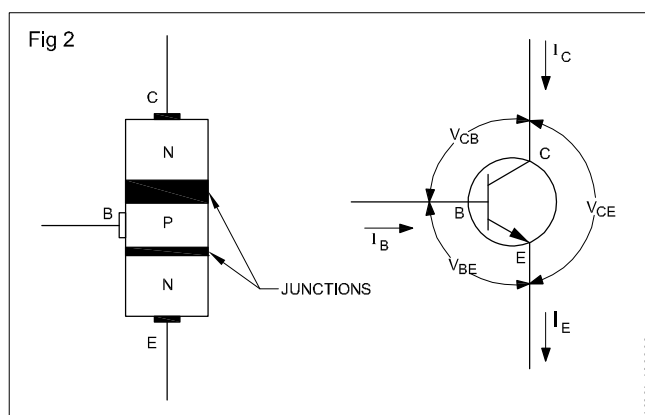


In a transistor since there are two PN junctions there are three voltage parameters  $V_{BE}$ ,  $V_{BC}$ ,  $V_{CE}$  and three current parameters  $I_B$ ,  $I_C$ ,  $I_E$ , as shown in Fig 2.

Any change in any one parameter causes changes in all the other parameters. Hence it is not very easy to correlate

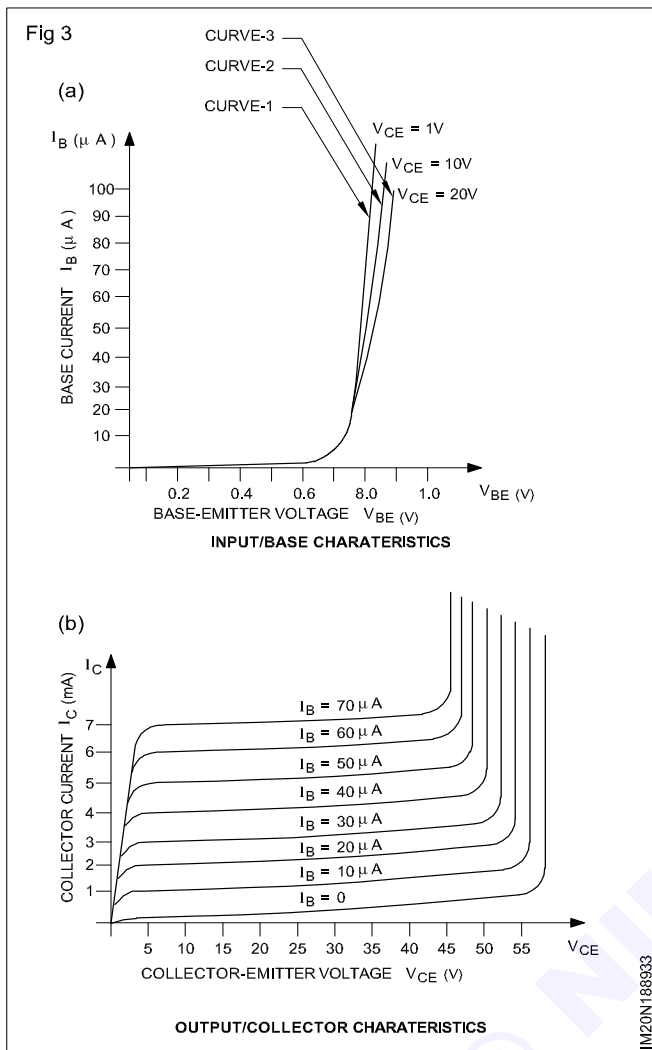
the effect of one parameter with the others. To have a clear understanding of their relationship a minimum of two characteristics graphs should be plotted for any transistor. They are,

- Input characteristics
- Output characteristics.



For simplicity in understanding, consider a common-emitter amplifier. The two characteristics graphs are shown in Fig 3.





### Input characteristics or Base characteristics

The graph at Fig 3a shows the relationship between the input voltage  $V_{BE}$  and input current  $I_B$  for different values of  $V_{CE}$ .

Since the base-emitter section of a transistor is nothing but a diode, the graph resembles a diode curve as in Fig 1b. But, it is important to note that in Fig 3a, there is a diode curve for each value of the collector-emitter voltage  $V_{CE}$ .

While plotting the diode curve 1 of Fig 3a, the value of  $V_{CE}$  was maintained constant at 1V. In curves 2 and 3, the value of  $V_{CE}$  was increased and hence the path of the curve becomes different.

Why does this happen? The answer is, because of the higher collector voltages, the collector gathers a few more electrons flowing through the base-emitter. This reduces the base current. Hence, the curve with higher  $V_{CE}$  has slightly less base current for a given  $V_{BE}$ . This phenomenon is known as Early effect.

The gap shown between the curves in Fig 3a is very small. In practice, this gap will be so small, sometimes not even noticeable.

### Plotting input/base curves of any given transistor

Necessary data for plotting the input or base characteristics can be obtained by constructing a simple test circuit as shown in Fig 3.

In this test circuit,  $V_{CE}$  is set to the required value by adjusting the voltage source  $V_{CC}$ . A resistor is introduced in the collector of the transistor to prevent excessive current in the collector which may damage the transistor.

The base-emitter voltage  $V_{BE}$  can be set by adjusting the potentiometer. An additional resistor is introduced in series with the DC supply  $V_{BB}$  and the POT only to limit the voltage across  $V_{BE}$  and hence, the base current.

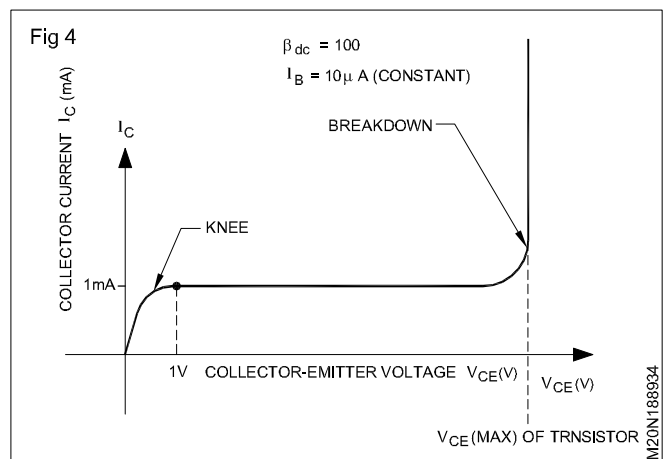
### Output characteristics or Collector characteristics

The graph at Fig 3b, shows the relationship between the output voltage  $V_{CE}$  and output current  $I_C$  for different values of  $I_B$ .

For simplicity in understanding, consider one of the curves of Fig 3b for a particular value of  $I_B$  as shown in Fig 4.

Fig 4 shows the collector characteristics for a constant  $I_B$  of  $10\mu A$ . Behavior of  $I_C$  for different values of  $V_{CE}$  is explained below;

- When  $V_{CE}$  is 0, the collector-base diode is not reverse-biased. Therefore, the collector current is negligibly small.
- For  $V_{CE}$  between 0.7V and 1V, the collector diode gets reverse-biased. Once reverse biased, the collector gathers all the electrons that reach its depletion layer. Hence the collector current rises sharply and then becomes almost constant.
- Above the knee voltage and below the break down voltage, the collector current does not rise steeply or the current is almost constant even if the value of  $V_{CE}$  is increased. Thus the transistor works like a controlled constant current source in this region.
- Assuming that the transistor has a  $\beta_{dc}$  of approximately 100, the collector current is approximately 100 times the base current as shown in Fig 4 (1mA is 100 times  $10\mu A$ ).
- If  $V_{CE}$  is further increased, beyond the break down level,  $V_{CE(max)}$ , the collector-base diode breaks down and normal transistor action is lost. The transistor no longer acts like a current source. As the collector-base gets ruptured, the junction is shorted and hence current increases rapidly above the breakdown point as shown in Fig 4.





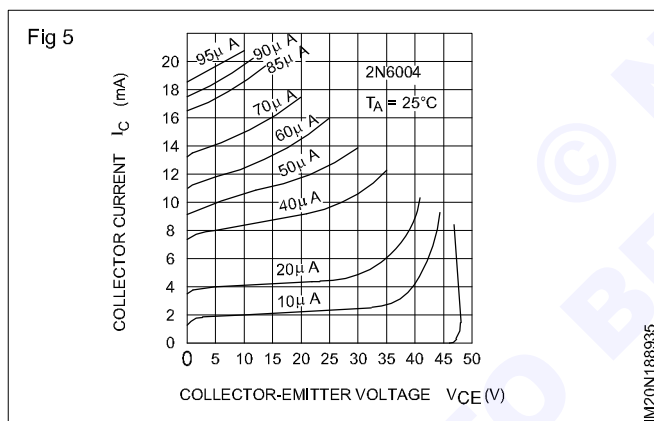
If several curves for different  $I_B$  are drawn on the same graph, the collector curves look like what is shown in Fig 3b.

Since the assumed  $\beta_{dc}$  of the transistor was approximately 100, the collector current is approximately 100 times greater than the base current at any point in the active region. These curves are sometimes called as *static* collector curves because DC currents and voltage are being plotted.

In Fig 3b, notice that at the bottom most curve, even though the base current is zero, a small collector current exists. This is because of the leakage current of the collector diode. For silicon transistors this leakage current is so small that it can be almost ignored.

In Fig 3b, also note that the break down voltages become lower at higher currents. This means that the base-emitter voltage from *knee* point till the *break down*, known as the voltage compliance of a transistor, decreases for larger collector currents. Hence, it is necessary to avoid very high collector current such that the transistor operates in a wider active region.

Generally transistor data sheets/books do not show collector curves of transistors. To see the collector curves of a particular transistor, an instrument known as *curve tracer* is used. This instrument looks similar to an oscilloscope. It displays collector curves similar to those shown in Fig 5.

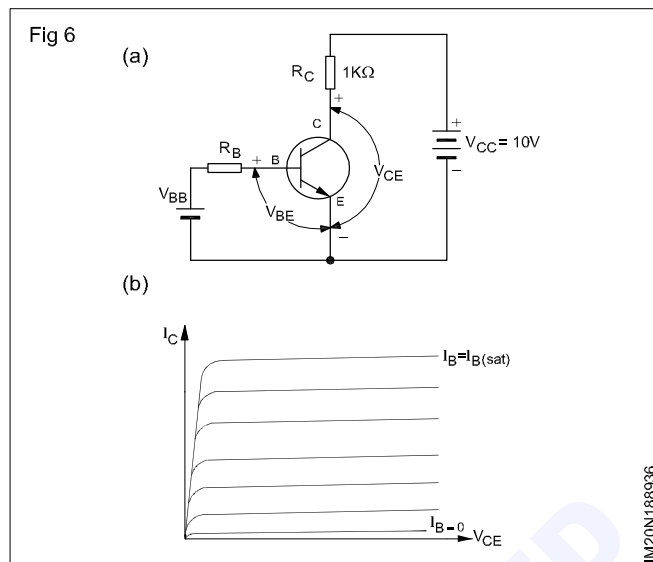


If different transistors are tried on the curve tracer, you will notice changes in knee voltage,  $\beta_{dc}$ , breakdown voltage, etc.

**TIP:** Two transistors of the same type number (e.g. 2N6004) may have a wide variation in the collector curves.

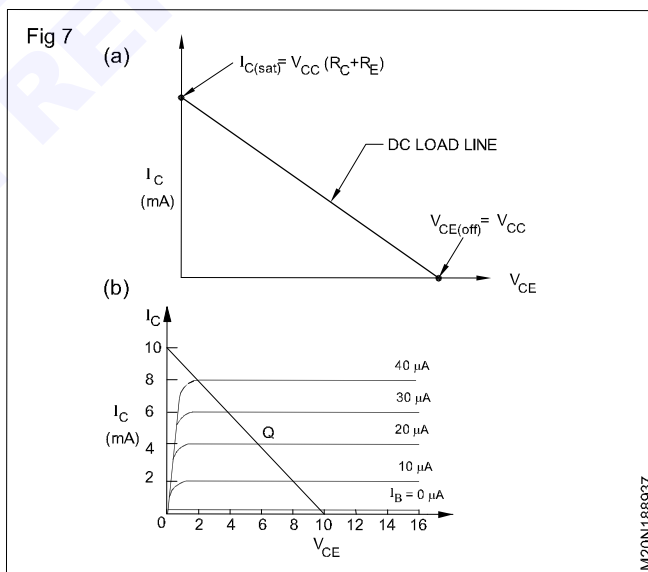
The collector curves are very important because, from these curves the following important information required while designing an amplifier circuit using a particular type of transistor can be obtained;

- DC current gain  $\beta$  of the transistor at different set DC values of  $I_B$  and  $V_{CE}$ .
- Maximum value of  $V_{CE}$  that can be applied for a set value of  $I_B$  and  $I_C$ .
- Maximum value of  $I_C$  that can be made to flow for a set value of  $I_B$ .



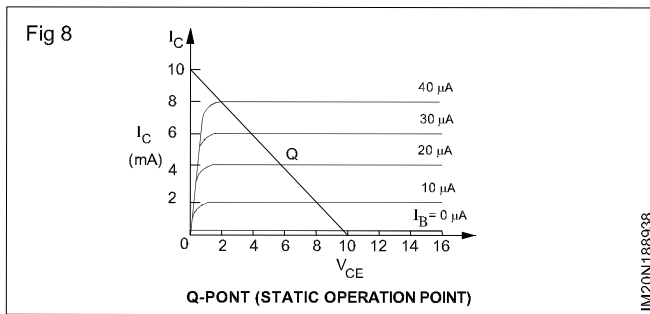
### DC Load Line

- The straight line is known as the **DC load line**
- Its significance is that regardless of the behavior of the transistor, the collector current  $I_C$  and the collector-emitter voltage  $V_{CE}$  must always lie on the load line, depends ONLY on the  $V_{CC}$ ,  $R_C$  and  $R_E$
- It must be true at the same time as the transistor characteristic. Solve two condition using simultaneous equation



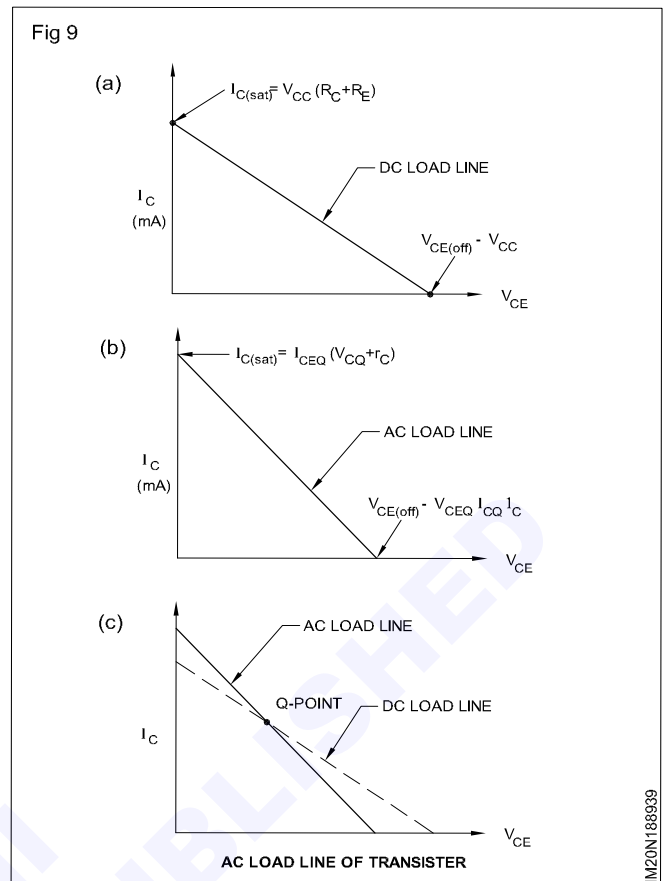
### Q-Point (Static Operation Point)

- The intersection of the dc bias value of  $I_B$  with the dc load line determines the Q-point.
- It is desirable to have the Q-point centered on the load line. Why?
- When a circuit is designed to have a centered Q-point, the amplifier is said to be midpoint biased.
- Midpoint biasing allows optimum ac operation of the amplifier.



### AC Load Line

- The ac load line of a given amplifier will not follow the plot of the dc load line.
- This is due to the dc load of an amplifier is different from the ac load.



## Application of a Transistor as Switch

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

- explain the function of the transistor
- explain the operation of a transistor as a switch
- describes the operation of a transistor switching circuit
- state the application of transistor switch.

**The function of a transistor at cut-off condition:** the transistor is operation at cut-off condition when the emitter and collector junction are both reverse biased

Consider the circuit in Fig 1

$$V_{ce} = V_{cc} - (I_c \cdot R_L) \dots \dots \dots (1)$$

$$\text{Since } I_b = 0 \text{ and } I_c = 0 \quad V_{ce} = V_{cc}$$

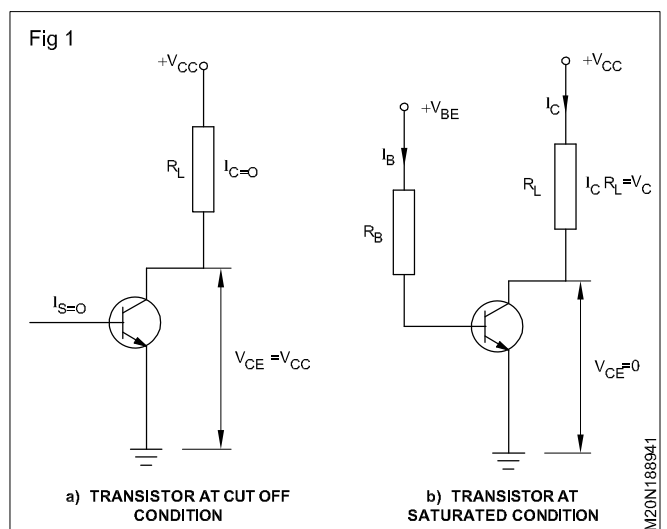
The transistor is said to be cut off for the simple reason that it does not conduct any current as in fig 1a. this corresponds to a switch in an open state, therefore a transistor at cut off is said to be open state.

**The function of a transistor at a saturation condition:** The transistor is operated at a saturated condition when both the emitter and collector are in forward bias.

In fig 1b if the value of  $R_b$  and  $R_L$  are such that  $V_{ce}$  tends to zero, then the transistor is said to be saturates. Putting  $V_{ce} = 0$  in the eqn (1) we get

$$V_{ce} = 0 = V_{cc} - I_c R_L \text{ or } I_c = \frac{V_{cc}}{R_L}$$

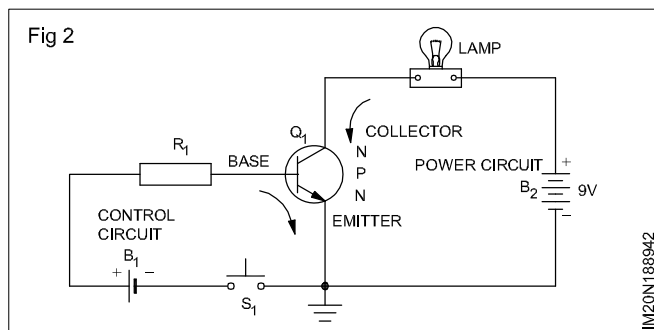
**The operation of a transistor as a switch:** The switch action for  $Q_1$  in fig. 2 illustrated how the output current can be conducted at the input .note the following importance operating characteristics.



- transistor is normally off without output current unless forward voltage is applied in the base emitter circuit
- the forward voltage controlling the base current mines the amount of output current

In fig 2 the control circuit of the input determines the base current determines the amount of output current.

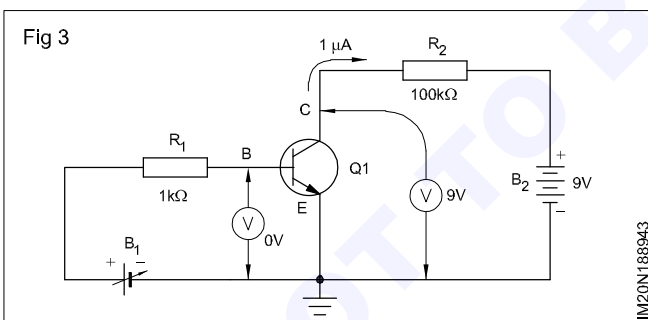
In fig 2 the control circuit of the input determines the base current. For the power circuit the output is the collector current. An NPN transistor is used for  $Q_1$ . the emitter is common to both (a) the current circuit at the input and (b) the power output circuit



The base emitter junction of  $Q$  in fig 2 can be forward biased by the battery  $B_1$ . Switch  $S_1$  must be closed apply the forward voltage. reverse polarity means that the N collector is more positive than base, with switch  $S_1$  open, no current flow in base emitter. The reason is that the forward voltage is not applied. therefore the resistance of the emitter to the collector of the transistor is very high. No current flows in the power circuit and the lamp does not glow.

Next assume that switch that  $S_1$  is closed this cause a small change in current flow in the control circuit.  $R$  is the current limiting resistor for the base current. Therefore the resistance from the emitter from the collector for the transistor drops. Consequently a large current flow in the power circuit causing the lamp to glow.

**Operation of transistor switching circuit:** The schematic circuit in the fig 3 shows the measured voltage and collector current  $I_c$  in the 'transistor OFF' condition. Note that only a tiny leakage current of 1 micro amp flow from the emitter to collector. The resistance from E to C is calculated as



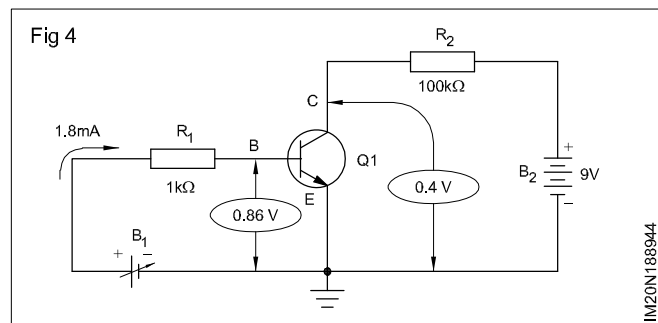
$$R = V/I = 9V/0.000001A = 9M \Omega$$

The transistor has a resistance of 9 mega ohms, which is like the open or off condition of a switch

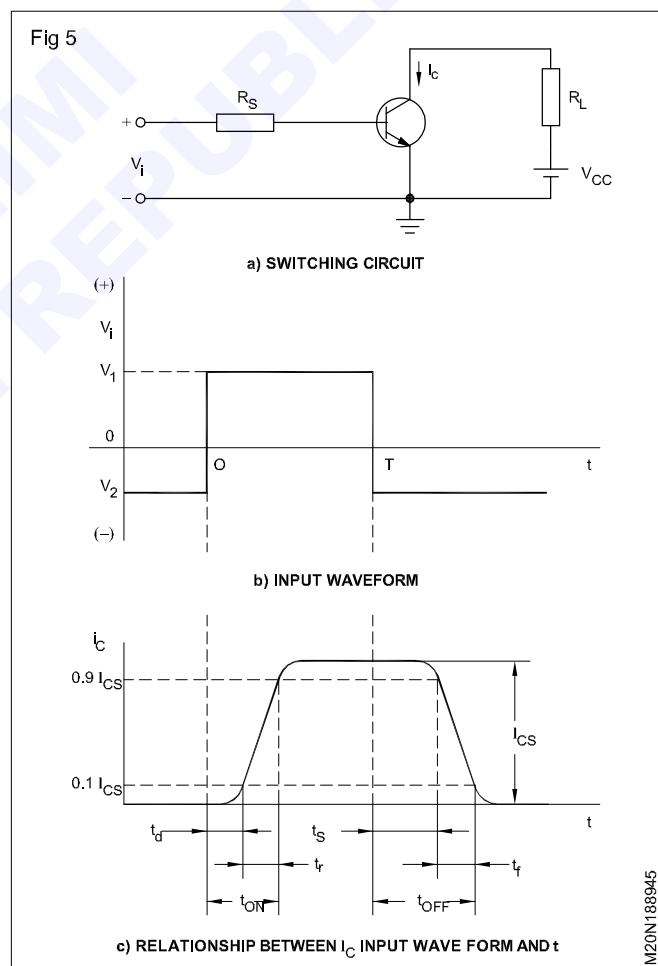
The fig 4 shows the measured voltage and current in the 'transistor ON condition. First, the voltage from the emitter to the base has been increased by adjusting  $B_1$ . The forward -biased voltage of 0.86V at the emitter-base junction of the transistor cause the resistance of the transistor from E to C drop this resistance from E to C is calculated as

$$R = V/I = 0.4V/0.085A = 4.7 \text{ ohms}$$

The transistor in fig 4 is said to be at saturation, when it has reached its maximum collector current. when used as switch, the transistor is divided into cut off and saturation by the base current varied by the emitter -base voltage.



**Transistor switching time:** now let pay attention to the behavior of the transistor as a transistor from one state to the other. consider the transistor circuit shown in fig 5b. this wave form makes transistor between the voltage level  $V_2$  and  $V_1$  at  $V_2$  the transistor is at cut off and at  $V_1$  is applied between the base and the emitter through a resistor  $R_2$  which may be included explicitly in the circuit or may represent the output impedance of the source furnishing the wave form.



In the fig the current does not immediately responds to the input signal. Instead there is a delay and the time escaped during this delay

$$t_{off} = t_d + t_r$$

When the input signal is at state  $t=T$  the current again falls to the responds. Immediately

$$t_{off} = t_s + t_f$$

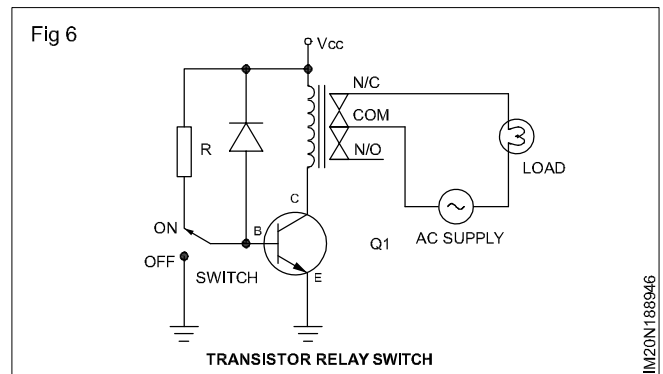
### The application of transistor as a switch:

The transistor switch is used as

- as an electronic on off switch
- in the mono stable and bi-stable multi vibrators.
- In counter and pulse generator circuit
- in clipping and clamping circuit
- as a sweep starting switch in the cathode ray oscilloscopic equipments
- as a relay, but unlike the mechanical relay the transistor has no moving mechanical parts.

**Transistor relay switch:** Transistor driven relay electronic switch circuit shown in Fig 6. This type of circuits are mostly used in electronic circuits to drive high current and voltage circuits by using a small input voltage or current.

Circuit in Fig. 5 is same as transistor switch. In this relay will be the load for transistor. Transistor will ON-OFF relay by operating base current and relay will be operated high by current or voltage load.



When is connected to small current (in Fig 6. switch connected to  $V_{cc}$  through current limiting resistor  $R_s$ ), transistor will go in saturation, so transistor will act as close switch so, current flows through relay. Due to current flowing in Relay. Relay will be magnetised and N/O contact will close. So, bulb load connected to the AC supply will ON.

When in put switch is OPEN, there is no current flowing to base of transistor. Transistor will goes in cut off, so transistor will act as OPEN switch \*\*\* current how through relay. Relay will not be energized and N/O contact remains open. So, bulb load is not getting current, it will not glow.

## Biasing of Transistors

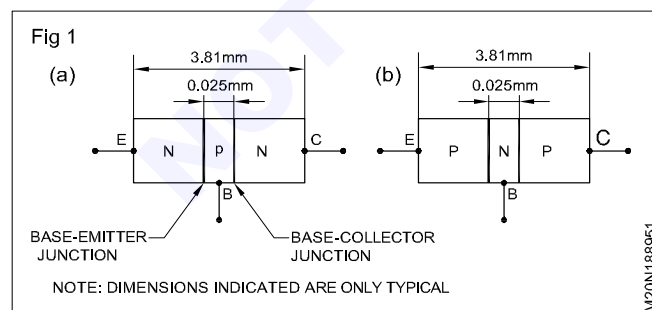
**Objectives:** At the end of this lesson you shall be able to

- describe the operation of a NPN transistor & PNP transistor
- state the typical percent of base current and collector current in a properly biased transistor
- state the relationship between  $I_E$ ,  $I_B$  and  $I_C$
- state when a transistor is said to be properly biased
- state the meaning of leakage current  $I_{co}$ .

### Biasing of transistors

Biasing a transistor means giving correct polarity and current level of voltages at the terminals of a transistor, such that, it functions as intended. (as an amplifier or as a solid state switch etc.)

Recall, transistors are three-layer semi-conductor devices consisting of either a P-type layer sandwiched between two N-type layers as shown in Fig 1a or N-type layer between two P-type layers as shown in Fig 1b.



From Fig 1, the following points are important to note;

- The widths of the outer layers, i.e. emitter and collector layers are much greater than that of the base layer.
- The emitter layer is heavily doped compared to both the base and collector layers.

- The base layer is very thin, of the order of 1/10th the width of the outer layers, and is very lightly doped.

### Transistor operation

As transistors have three layers, there are two junctions as shown in Fig 1. The **base-emitter** junction behaves as one diode junction. The **base-collector** junction behaves as the other diode junction.

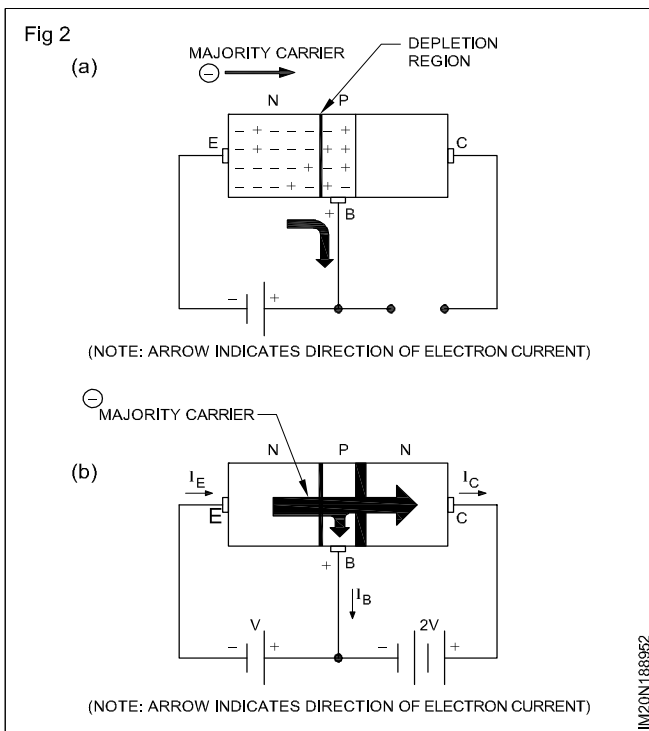
Recall that a diode junction conducts only when +ve supply is connected to the P material and -ve supply to the N material. Fig 2a shows a NPN transistor where the base-emitter junction is forward-biased. Hence, the diode conducts resulting in large flow of majority carriers (electrons) from N-type to P-type material.

Fig 2b shows the base-emitter junction forward biased and the base-collector junction is reverse-biased. Why is the base-collector reverse biased? what effect does this connection have on the transistor operation?

The answer is, in a NPN transistor, majority carriers are electrons, because, the emitter and collector are N-type materials. Free electrons are generated in the N-type emitter because of the forward-biased base-emitter junction. If the collector voltage is not there, then all the generated electrons flow to the base as shown in Fig 2a.

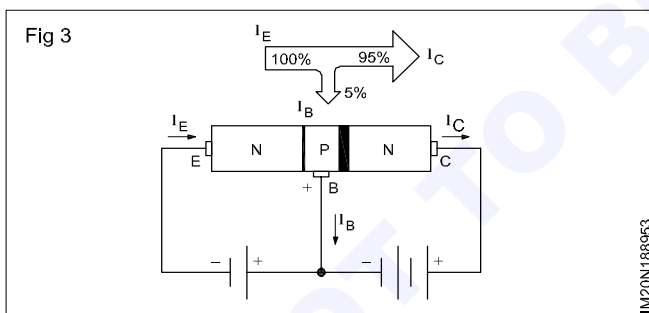
When the base-collector is reverse-biased, then, a positive voltage appears at the collector. This positive voltage at the

collector completely changes the path of the electron current flow. Because of the thin base and the low base-to-emitter voltage (0.7V for silicon), about 95 percent of the electrons pass through the thin base and are attracted to the more positive potential collector as shown in Fig 2b. Only a very small percentage of the electrons from the emitter combine with holes in the base.



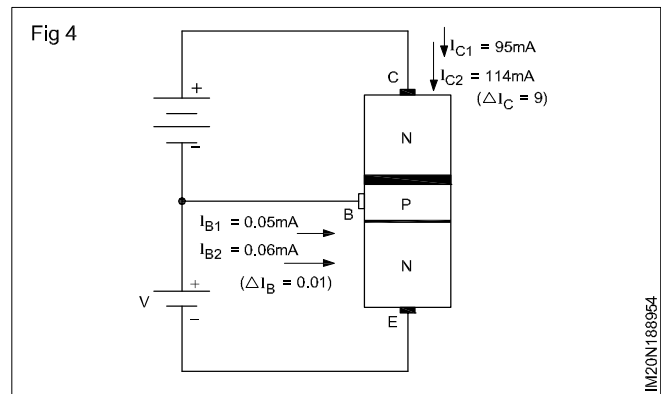
It can be seen from Fig 3, that the,

- current carriers come from the emitter
- base current is small( 5% of emitter current)
- and, the collector current is high (95% of emitter current).



Under such conditions, it can be seen that, small changes in the emitter-base current will result in large change in the collector current. For example, an increase of say one electron in base current will result in an increase of 19 electrons in the collector current. This is because the collector current is 95% of the emitter current whereas the base current is only 5% of emitter current. This means that the value of the collector current can be easily controlled by changes in the bias on the emitter-base junction.

Summarizing, small changes in the base current results in large changes in the collector current as shown in Fig 4. This is nothing but amplification which is the intended function of a transistor. This behaviour of a transistor is known as Transistor action.



The ratio of the change in output current to the change in the input current is called the **amplification** or **gain**. In Fig.4, change in output current is  $\Delta I_C$  due to the change in the input current  $\Delta I_B$ . Therefore the current gain introduced by the transistor is

Current gain

$$\text{Current gain} = \frac{\text{Output current change } \Delta I_C}{\text{Input current change } \Delta I_B} = \frac{9\text{mA}}{0.01\text{mA}} = 900$$

**Gain is a dimension-less quantity**

This condition as shown in Fig 4, in which the two junctions of the transistor are connected to such polarities of the voltage source, such that the transistor behaves as an amplifier, the transistor is then said to be properly biased or correctly biased.

**Some books use the term Forward biased instead of the term properly biased.**

Summarising a transistor is said to be properly biased or correctly biased or forward biased if,

- its base-emitter junction is forward biased
- and, its base-collector junction is reverse biased.

On the other hand, if the polarities of voltages connected to transistor junctions is as shown in Fig 5a and 5b, because the base-emitter junction is reverse biased, no electrons are available for conduction, and, hence, the transistor action does not exist. If the base-emitter is forward biased but the base-collector is not reverse biased as shown in Fig 5c, then, there is no amplification as both the junctions simply conduct as diodes.

In a properly biased transistor as shown in Fig 3 and Fig 4, the relationship between  $I_E$ ,  $I_B$  and  $I_C$  is given by,

$$I_E = I_B + I_C \quad \dots[1]$$

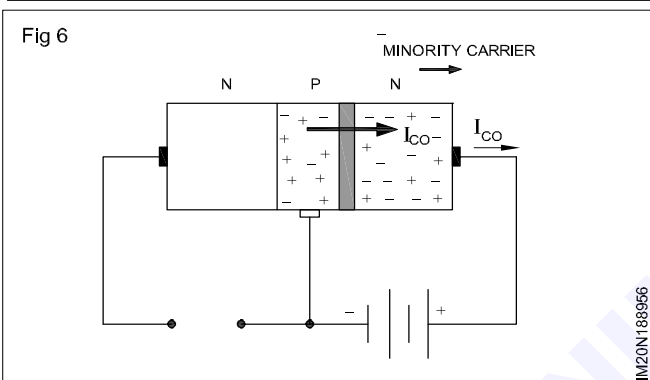
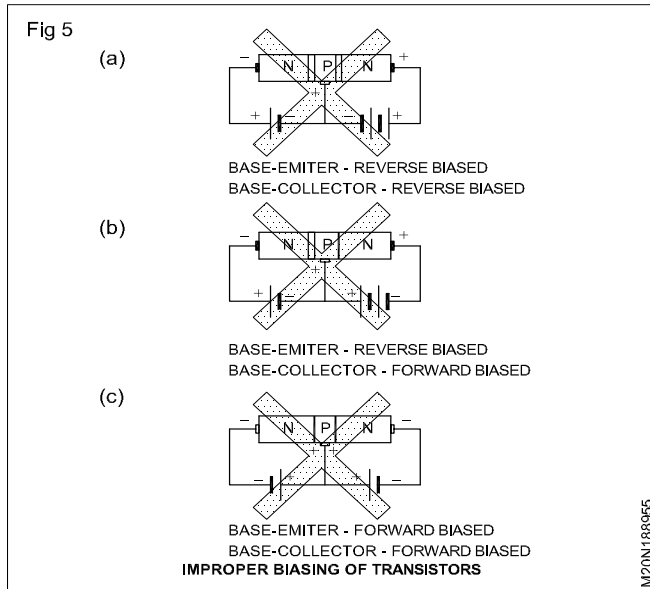
$$\text{or } I_C = I_E - I_B$$

$$\text{or } I_B = I_E - I_C$$

**Minority current in transistors**

In NPN transistor, as shown in Fig 6, if no voltage is applied across the base-emitter junction, but a reverse-bias is applied across the base-collector junction, the following things happen,





- There is no current in the base-emitter path as no bias voltage exists.
- The base-collector diode is reverse biased; hence, the forward current due to the majority current carriers (electrons) is zero.
- A small quantity current of the order of a few nanoamperes to microamperes flows in the base-collector. This small reverse current is due to minority current carriers, electrons in the **P-type** base material.
- The minority current increases if the voltage applied to the base-collector increases or the junction temperature increases. This is because current increases temperature and temperature releases current carriers from the covalent bond structure.

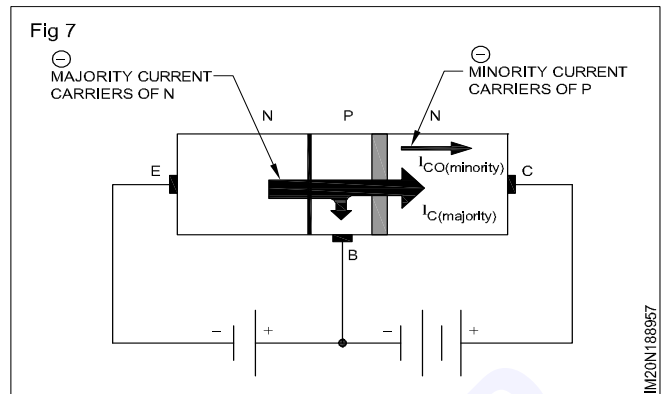
This minority current is called the leakage current and is shown by the symbol  $I_{CO}$ .  $I_{CO}$  means, collector current  $I_C$  with emitter terminal open. The value of this leakage current  $I_{CO}$  will be given in the transistor data sheets for all transistors.

As shown in Fig 7, since the forward collector current  $I_C$  due to majority carriers and the leakage current  $I_{CO}$  due to minority current carriers flow in the same direction, they are combined. Therefore, the total collector current will be equal to,

$$I_C = I_{C(\text{majority})} + I_{CO(\text{minority})} \quad \dots\dots[2]$$

Because of the minority current  $I_{CO}$ , the value of collector current  $I_C$  will be slightly more than that, given in the

equation  $I_C = I_E - I_B$ . However, this slight increase in  $I_C$  value can be neglected because, the value of  $I_{CO}$  will be very very small compared to  $I_C$  (due to  $I_E$ ) at normal working temperature.



In any typical general purpose transistor,

- value of  $I_C$  and  $I_E$  will be in milliamperes
- value of  $I_{CO}$  will be in nanoamperes to microamperes
- value of  $I_B$  will be in microamperes.

### Operation of PNP transistors

Working of a PNP transistor is exactly the same as that of NPN transistors discussed earlier, if the role played by the electrons in NPN transistors is interchanged with holes as given below;

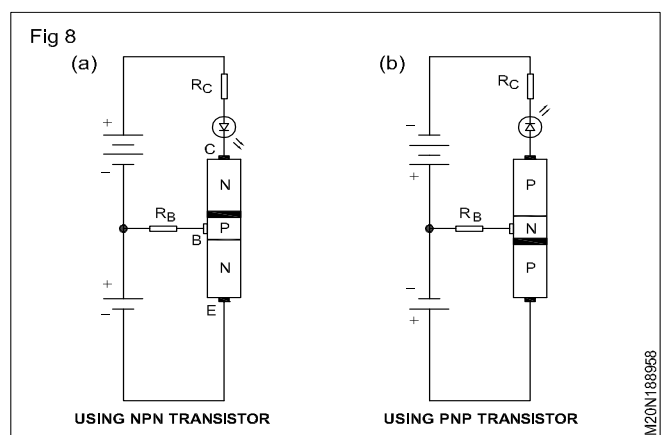
In a PNP transistor,

- The majority current carriers are holes instead of electrons
- The minority current  $I_{CO}$ , is due to electrons in the N-type base material instead of holes.

### Test circuit for testing proper transistor biasing

If a transistor is properly biased (i.e. B-E junction forward biased and C-B junction reverse biased), then, there will be collector current  $I_C$  of the order of milliamperes. To check this an LED is connected in the collector circuit of the transistors as shown in Figs 8a and 8b. The LED in the collector circuit glows only when the transistor is properly biased otherwise the LED remains OFF.

Resistor  $R_B$  and  $R_C$  are introduced in the circuit to limit the base and collector currents such that the transistor does not get damaged due to excessive current.



## Gain and impedance of common emitter amplifier

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

- state the meaning and method of finding voltage gain
- state the meaning and method of finding input impedance
- state the meaning and method of finding output impedance
- state the meaning and method of finding power gain
- state the phase relationship between input and output in a CE amplifier.

After a transistor is biased with the Q point near the middle of the DC load line, the transistor can be made to amplify AC and DC signals as shown in Fig 1a. When we use a transistor to amplify a small AC signal, the small AC signal to be amplified is coupled to the base of the transistor using a capacitor. A capacitor is used for AC coupling because as discussed in earlier lessons capacitors behave as short for AC signal and open for DC signal. The varying amplitude and frequency of the coupled AC signal produces greater value variations in the collector current of the same shape and frequency as shown in Fig 1b.

As shown in Fig 1a, if the input is a 1 kHz sine wave, the output will be an enlarged 1 kHz sine wave. The small sine wave given at the base of the transistor produces variations in the base current. Hence, the collector current is an amplified sine wave of the same frequency. The sinusoidal collector current flows through the collector resistor and produces an amplified sine wave output. Such amplifiers which retain the shape of the input signal at the output are called linear amplifiers.

Fig 1b, shows the DC load line, the Q point and AC input and output signals. This is generally referred to as the AC load line. As can be seen from Fig 1b, the AC input voltage produces variations in the base current. This results in sinusoidal variations about the Q point. Variations in Q point are nothing but the variations in the collector current resulting amplified form of the input signal.

For small input signal levels, generally referred to as small signal operation, the peak to peak swing in the collector current should be less than the  $\pm 10\%$  of the collector current at Q point to keep the distortion in the amplified output within acceptable limits.

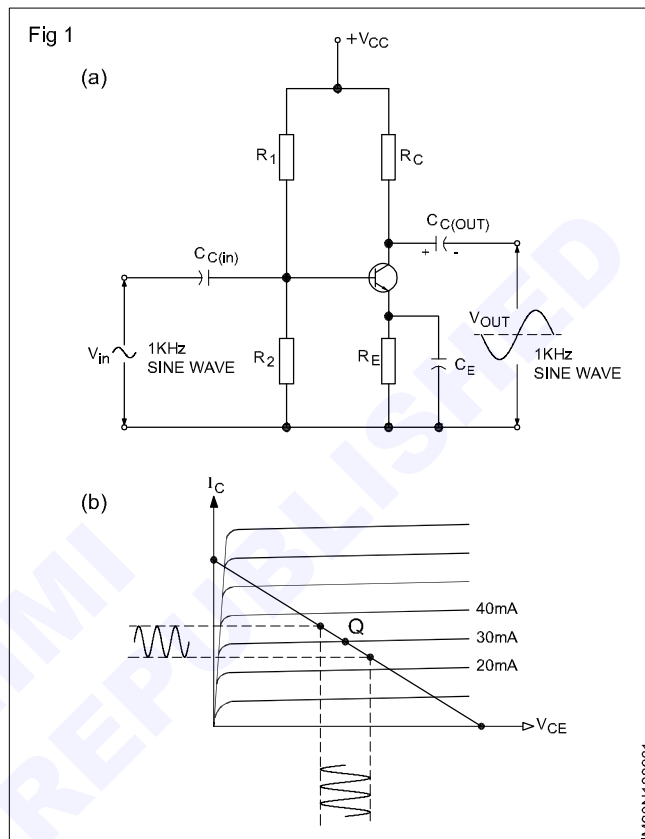
For large input signal levels, generally referred to as large-signal operation, the peak to peak swing in the collector current will be larger (more than 10%). If the swing is very large, the transistor may go into saturation and cut off. This swing into saturation and cut off will clip the positive and negative peaks of the output signal. This clipping is nothing but distortion, meaning, the output will not be an exact replicate of the input signal.

### AC CURRENT GAIN $A_i$ of a CE amplifier

The AC current gain of a CE amplifier shown in Fig 1 is the ratio of the AC component of the collector current  $i_c$  to the AC base current  $i_b$ .

$$A_i = \frac{i_c}{i_b}$$

**Small letter i is used to represent AC current whose value keeps changing with time.**



It is to be noted that in most linear CE amplifier circuits the current gain  $A_i$  is almost equal to  $\beta_{dc}$  of the transistor. Therefore the following approximation can be used for  $A_i$ .

$$A_i \approx \beta$$

In the amplifier at Fig 1, if  $\beta_{dc}$  of the transistor is 100, then the current gain  $A_i$  of the amplifier can be taken as 100.

### Voltage gain, $A_v$ or $A_v$ of CE amplifier

The voltage gain of an amplifier is the ratio of AC output voltage to the AC input voltage. This is represented as,

$$\text{Voltage gain, } A_v = \frac{V_{out}}{V_{in}}$$

**Small letter v is used for voltage because it is AC voltage whose amplitude keeps changing with time.**

For example, in Fig 1, if the input voltage  $v_{in}$  is 80 mV<sub>(p-p)</sub> and the corresponding output voltage  $v_{out}$  is 7.2 V<sub>(p-p)</sub>, then the voltage gain  $A_v$  is given by,

$$\text{Voltage gain, } A_v = \frac{7.2 \text{ (p-p)}}{80 \text{ mV (p-p)}} = 90$$

A voltage gain of 90 means that, in this amplifier, a base voltage of 1 mV produces an output voltage of 9 mV.

**The input and output voltage may be rms, peak, peak-to-peak, as long as the input and output are measured the same way consistently.**

### Input impedance, $Z_{in}$ of CE amplifier

Recall that the maximum transfer of power takes place when the impedances of the supplying and receiving circuits are matched.

If impedances are to be matched for best circuit operation, both impedances must be known. If a single device such as a microphone, speaker, relay, etc. is to be used, its impedance will be given by the manufacturer. The amplifier to be designed for such a circuit must have an input or output impedance to match the input-output devices.

The AC source driving the amplifier has to supply AC current to the amplifier. The less the current the amplifier draws from the source, the better because the supplying source does not get loaded. The input impedance of the amplifier determines how much of current the amplifier takes from the ac source or the preceding stage of the amplifier.

In the normal frequency range of an amplifier, the coupling and by pass capacitors behave as a short for ac. The AC input impedance  $Z_{in}$  sometimes referred to as input resistance  $R_{in}$  is defined as the ratio of input signal voltage to input signal current.

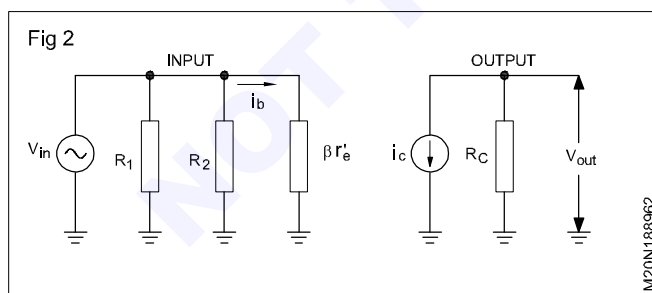
$$Z_{in} = \frac{V_{in}}{i_{in}}$$

where,  $V_{in}$  and  $i_{in}$  are rms or peak or peak-to-peak values.

Fig 2 shows the AC equivalent circuit of the CE amplifier shown in Fig 1.

From the AC equivalent circuit the input impedance  $Z_{in}$  is given by,

$$Z_{in} \blacktriangle R_1 \parallel R_2 \parallel \beta r'_e \quad \dots\dots[1]$$



where,

$R_1$  and  $R_2$  are the voltage divider resistors,

$\beta$  is the DC current gain and  $r'_e$  is the ac emitter resistance ( $V_{BE}/I_E$ ).  $r'_e$  is approximately equal to 25W when the Q point is chosen at the mid of the load line.

In the CE amplifier at Fig 1, if  $R_1 = 18KW$ ,  $R_2 = 8.2KW$  and the transistor  $\beta$  is 100, the input impedance  $Z_{in}$  will be,

$$\beta r'_e = 100(25 W) = 2.5 KW$$

$$Z_{in} = R_1 \parallel R_2 \parallel \beta r'_e$$

$$= 18 KW \parallel 8.2 KW \parallel 2.5 KW$$

$$= 1.73 KW.$$

### Practical way of finding $Z_{in}$

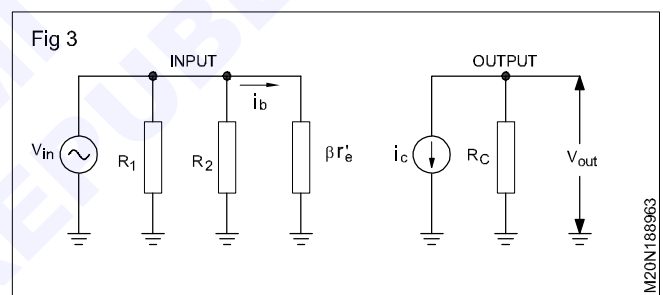
To find  $Z_{in}$  of a given CE amplifier circuit, it is merely necessary to measure the AC signal input voltage and current. Then, use these values in the formula, and calculate  $Z_{in}$ .

A simpler method to measure  $i_{in}$  is to connect a series input resistance of known value in series with the input signal, as in Fig 3.

The voltage drop across the resistor  $R_s$  is measured, and Ohm's law is used to determine  $i_{in}$ .

$$I_{in} = \frac{V_x - V_y}{R_s}$$

The value of  $V_{in}$  can be measured directly, as shown in Fig 3.



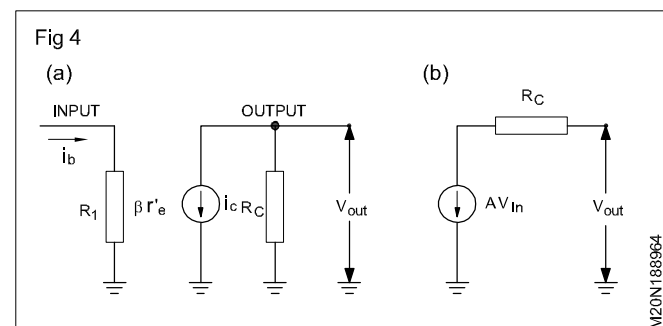
### Output impedance, $Z_{out}$

The output impedance of a CE amplifier is naturally the impedance at the output terminals.

To find the  $Z_{out}$  of the CE amplifier shown in Fig 4, consider the AC equivalent of the output as shown in Fig 4a.

Recall that a transistor operating in the linear portion of its characteristics curve is like a current source. Therefore, we can represent it as a current source  $i_c$ .

As can be seen from Fig 4a, this collector current source is in parallel with the collector resistor  $R_C$ . Assuming that the collector current source is ideal, it has infinite internal impedance. Then, the only impedance in the output is the collector resistor  $R_C$ .



The Thevenin's voltage appearing at the output is the voltage gain( $A$ ) times the input  $v_{in}$ .

Therefore,  $V_{out} = A \cdot v_{in}$

Hence, the output AC equivalent circuit of the amplifier can be simplified as shown in Fig 4b. In Fig 4b, an ideal output voltage source  $AV_{in}$  with zero internal impedance is in series with the collector resistor  $R_C$ . Therefore, the output impedance of the CE amplifier is approximately equal to the collector resistor  $R_C$ ,

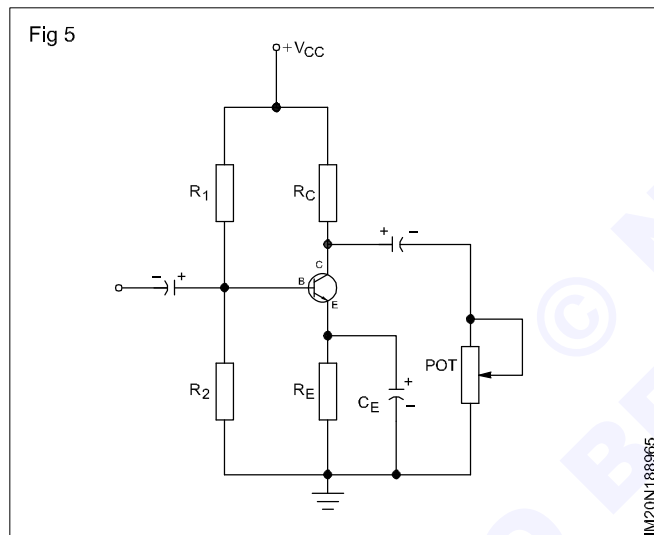
$$Z_{out} \approx R_C$$

In the CE amplifier circuit at Fig 1, if  $R_C = 1000\Omega$ , the output impedance of the amplifier is equal to the value of  $R_C$ , that is  $1000\Omega$ .

#### Practical way of finding $Z_{out}$

The easiest way of measuring the output impedance of a CE amplifier circuit is given below;

- 1 Measure the unloaded output voltage  $V_{out}$  of the CE amplifier.
- 2 Place a variable resistor across the load terminals, as shown in Fig 5.



- 3 Adjust the variable resistor until the voltage drop across it is one-half of the unloaded output voltage  $V_{out}$ .
- 4 Remove the variable resistor and measure its value. This value is equal to  $Z_{out}$ .

**$Z_{out}$  is not a fixed value; it varies with transistor voltages and the load resistance. Care must always be taken to maintain an undistorted signal when input or output impedances are measured.**

#### Power gain, $A_p$ of a CE amplifier

In the CE amplifier shown in Fig 1, the input power is given by,

$$P_{in} = v_{in} \cdot i_b$$

and the output power is given by,

$$P_{out} = -v_{out} \cdot i_c$$

**The negative sign associated with output power. This is because, in a CE amplifier, the output is  $180^\circ$  out of phase with the input signal. Details are discussed in the forthcoming paragraphs.**

In the CE amplifier at Fig 1, power gain  $A_p$  is the ratio of output signal power to input signal power. The formula is,

$$\text{Power gain} = \frac{P_{out}}{P_{in}}$$

Power gain is also given by,

$$A_p = -A_v \cdot A_i$$

where,

$A_v$  is the voltage gain ( $v_{out}/v_{in}$ )

$A_i$  is the current gain ( $i_c/i_b$ )

For the amplifier at Fig 1, if  $A_v = 90$  and the  $\beta$  of the transistor is 100, then the power gain  $A_p$  of the amplifier is given by,

$$A_p = -A_v \cdot A_i = 90 \times 100 = 9000.$$

This means that if an AC input power of  $1\mu W$  is given to the amplifier, the output power will be  $9mW$ .

#### Practical way of finding $A_p$

Since the formula for power is,  $P = I^2 \times R = |I| \times R$

Since,

$$I = \frac{V}{R} \quad (\text{substituting this in above equation, we get})$$

$$P = \frac{V^2}{R}$$

Therefore, by Ohm's law, power gain is easy to calculate when signal voltages and impedances are known as given below;

$$P_{out} = \frac{V_{out}^2}{Z_{out}} \quad \text{and} \quad P_{in} = \frac{V_{in}^2}{Z_{in}}$$

Knowing the values of  $P_{out}$  and  $P_{in}$  power gain of the circuit can be calculated.

#### Power gain, $A_p$ in decibels, dB

The power gain of amplifiers is often expressed in decibels (dB). To calculate the power gain of an amplifier in decibels, use the following formula.

$$\text{Power gain dB} = 10 \log \frac{P_{out}}{P_{in}}$$

#### Input - Output phase relationship

Recall, that while calculating the power gain it was mentioned that the output signal of a CE amplifier is  $180^\circ$  out of phase with its input signal. To find out why this happens in a CE amplifier, assume that the DC base bias current  $I_B$  at the set Q point is  $30\mu A$ . The corresponding

collector current is 1 mA. When the AC signal is applied to the input, the base bias varies from 20 to 40  $\mu\text{A}$ , as shown in Fig 1b. Since the type of transistor used is NPN, as base bias is increased to 40  $\mu\text{A}$ , collector current  $i_c$  increases. The resultant effects are,

- the increased transistor conduction causes less voltage drop across the transistor ( $V_{CE}$ )
- increased  $i_c$  causes a larger voltage drop across  $R_C$ . Hence, the voltage across the collector to ground gets reduced.

In Fig 1a, as the output signal is taken across the transistor collector and ground, an increasing signal voltage causes a decreasing output signal.

As the input signal level decreases, say to 20  $\mu\text{A}$ , the forward bias is less and transistor conduction decreases. When transistor conduction decreases, its resistance is higher and so the voltage drop across it increases. With increased voltage drop across the transistor, the output voltage  $V_{out}$  increases. This increase in  $V_{out}$  reduces the voltage drop across the collector load resistance  $R_C$ .

From this, it can be concluded that in a CE amplifier, a negative-going input signal causes a higher, or, more positive-going output signal. Therefore, in a CE amplifier the output is  $180^\circ$  out of phase with the input.

### Practical way of finding input-output phase relationships

The phase relationship between input-output can be found in two ways as given below.

**Method 1:** Using a dual trace CRO, connect one of the CRO inputs to the input of the amplifier and the other CRO input to the output of the amplifier. Make the oscilloscope to trigger on the input signal. The waveforms shown on the CRO show the phase relationship between input and output as shown in Fig 6a.

**Method 2:** If a single trace CRO is used, then instead of feeding complete sinewave to the input, feed only the positive signal pulses as shown in Fig 6b. These positive pulses can be generated using a simple half-wave rectifier as shown in Fig 6c.

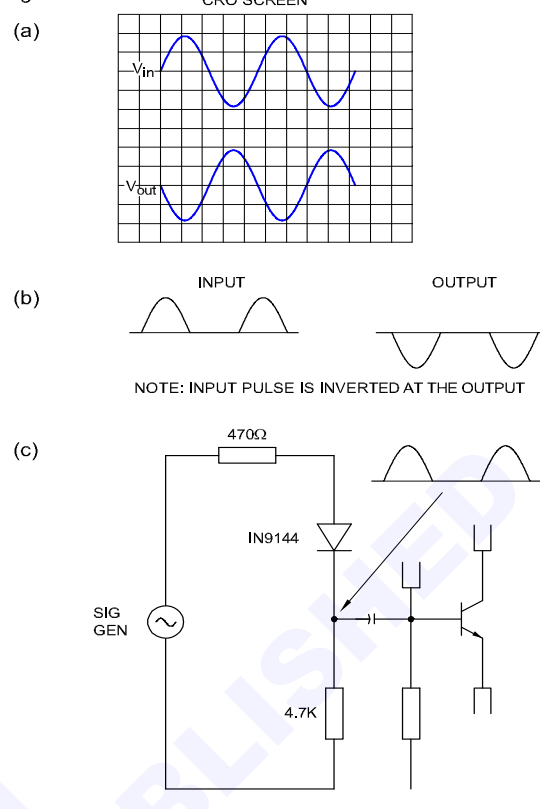
With the positive pulse fed at the input, the output of the CE amplifier will be negative pulse as shown in Fig 6b. Use the signal as an external trigger source for the CRO to view the waveform.

### dB vs dBm

When a physical quantity, such as power or intensity, is measured relative to a reference level it is expressed in decibels (dB), which is a logarithmic unit. Decibel is considered as a dimensionless unit because it is a ratio of two quantities with the same unit thus cancellation takes place. It is used for quantifying the ratio between two values. The best example of this is the signal - to -noise ratio.

Sound pressure level is typically measured in dB but the unit is not limited to that quantity alone. There are a lot of uses of this measuring unit particularly in engineering.

Fig 6



Since it is applicable in measuring signals, anything that can be expressed in waves may also be measured with dB. In the disciplines of acoustics electronics, dB is liberally utilized.

To be exact, decibel dB is expressed in this term:  $\text{dB } 10 \log (P_1/P_2)$ . Where  $P_1$  and  $P_2$  are two different values of power.

It is primarily used because it can represent an extremely huge number into a convenient scale. In radio link designs, values often differ enormously and to contrast these values decibel is used. Its logarithmic properties make calculation easier. With the implementation of dB, engineers and physicist are now able to calculate values with simple few numbers as an alternative of arduous 9 to 10-digit ones.

dBm is different but definitely related to dB. dBm stands for an absolute power level. It is in reference to another unit of power the milliwatt.

Mathematically,  $\text{dBm} = 10 \log (P/1\text{mW})$

The value of "P" is power in watts. Then, with further calculation, you can convert the absolute power unit "P" into dBm. The value of power level "P" is now referenced to 1 mW. The unit dBm is devised because in practice, 1 mW is a convenient reference point from which to measure power. dBm is considered as an absolute unit "a unit to measure power."

Additionally, based on what value the power is referred to, a particular absolute value of power can be in any kind. If dBm "which can be written in dBmW by the way - is acquired because of 1 mW reference, a value can be in a form of dBW if it is referred to 1 watt.

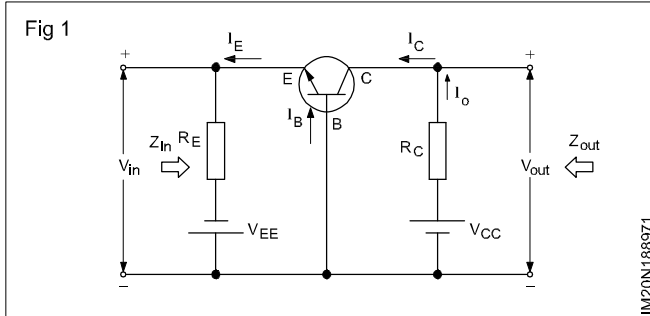


# Common Base Amplifier

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

- calculate the voltage gain, current gain, input impedance and output impedance of a common base amplifier
- list the typical applications of common base amplifiers.

Fig 1 shows the typical circuit schematic of a **common base amplifier** (CB-amplifier).

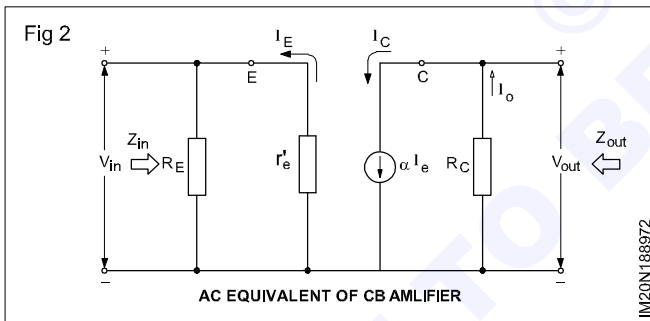


Common base amplifiers have a current gain of less than 1. Recall, the emitter current and the collector current of a transistor are almost equal. In a common base amplifier since the input current is  $I_E$  and the output current is  $I_C$ , the current gain, symbolically represented as  $\alpha$  (alpha), is given by,

$$\text{Current gain } (\alpha) = \frac{\text{Output current}}{\text{Input current}} = \frac{I_C}{I_E}$$

Since  $I_E > I_C$ ,  $\alpha$  will always be less than 1.

Fig 2 shows the ac equivalent of a common base amplifier, shown in Fig 1.



From Fig 2, the input impedance  $Z_{in}$  of CB amplifier is given by,

$$Z_{in} = R_E \parallel r'_e \quad \dots\dots\{1\}.$$

Since  $R_E$  is generally much greater than  $r'_e$ , eqn..1 can be simplified as,

$$Z_{in} = r'_e$$

The equation for  $Z_{in}$  indicates that, the input impedance of a CB amplifier is very low and almost equal to the ac resistance  $r'_e$  of the emitter diode (recall  $r'_e$  will be generally  $25\Omega$ ).

Referring to the AC equivalent network of the CB amplifier, the output impedance  $Z_{out}$  of CB amplifier is given by,

$$Z_{out} = R_C \quad \dots\dots\{2\}.$$

Equation 2 indicates that the output impedance of a CB amplifier is relatively high, of the order of kilo ohms (because you can fix the value of  $R_C$  as you wish ! ).

From Fig 2, the output voltage  $V_{out}$  is

$$V_{out} = I_o R_C = I_C R_C$$

$$\text{Since } \alpha = \frac{I_C}{I_E}, I_C = \alpha \cdot I_E$$

$$\text{Therefore, } V_{out} = I_C R_C = \alpha \cdot I_E \cdot R_C \quad \dots\dots\{3\}.$$

$$\text{Since, } I_E = \frac{V_{in}}{r'_e} \text{ equation 3 can be written as,}$$

The voltage gain  $A_v$  of CB amplifier is given by,

$$A_v = \frac{V_{out}}{V_{in}} = \alpha \frac{V_{in}}{r'_e} R_C \frac{1}{V_{in}} = \alpha \frac{R_C}{r'_e} \quad \dots\dots\{4\}$$

Since  $r'_e$  is very small compared to  $R_C$ , the voltage gain  $A_v$  of the CB amplifier is quite high.

The power gain  $A_p$  of the CB amplifier is given by,

$$A_p = A_i \cdot A_v$$

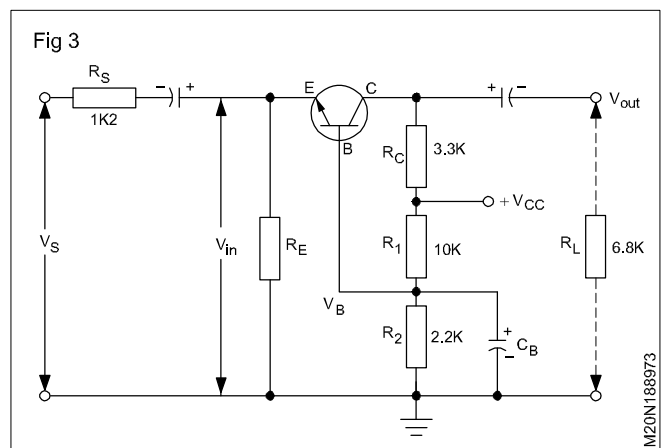
Power gain  $A_p$  will be medium because although  $A_i$  is less than or equal to 1,  $A_v$  of the CB amplifier is quite high.

## Input/Output phase relationship

The input and output of a common base amplifier are in phase with each other. This can be found experimentally.

Fig 3 shows a CB amplifier with voltage divider bias.

In Fig 3, the base of the transistor is at ac ground due to the bypass capacitor  $C_B$ . The input signal drives the emitter and the output is taken from the collector. The biasing resistors  $R_1$ ,  $R_2$  will have negligible effect on the input impedance. Therefore, the input impedance of the CB amplifier is approximately equal to  $r'_e$  itself.



The voltage at the base (at  $T_1$ ) is given by,

$$V_B = \frac{R_2}{R_1 + R_2} V_{CC}$$

$$= \frac{2.2K}{10K + 2.2K} \cdot 12V$$

$$= 2.16V$$

The emitter current  $I_E$  is given by,

$$I_E = \frac{V_B - V_{EE}}{R_E}$$

$$= \frac{2.16 - 0.7}{1.2K\Omega}$$

$$= 1.22mA$$

Therefore,  $r_e'$  is given by,

$$r_e' = \frac{25mV}{I_E}$$

$$= \frac{25mV}{1.22mA} = 20.5\Omega$$

Input impedance  $Z_{in}$  is given by,

$$Z_{in} \approx r_e' = 20.5\Omega$$

The voltage gain  $A_v$  is given by,

$$A_v = \frac{R_c}{r_e'} = \frac{3.3K}{20.5} = 160.97 = 161$$

The output impedance  $Z_{out}$  is given by,

$$Z_{out} \approx R_c = 3.3K\Omega$$

The input  $V_{in}$  to the amplifier is given by (note that  $C_B$  bypass  $R_2$  for AC signal),

$$V_{in} = \frac{r_e'}{R_s + r_e'} V_s$$

$$\frac{20.5\Omega}{1K\Omega + 20.5\Omega} 500mV = 10mV$$

Therefore the unloaded output voltage  $V_{out}$  is given by,

$$V_{out(no load)} = A_v \cdot V_{in}$$

$$= 161 \times 10mV$$

$$= 1610mV = 1.61V$$

The output voltage of the amplifier with load  $R_L$  is given by,

$$V_{out(load)} = \frac{R_L}{R_c + R_L} \times V_{out(no load)}$$

$$= \frac{6.8K}{3.3K + 6.8K} \times 1.61V = 1.08V$$

**Class Room Assignment:** Calculate the output voltage of the CB amplifier (as done in step above) if load resistor  $R_L$  was,

- $R_L = 3.3K$
- $R_L = 10K$  and,
- $R_L = 100K$

## Field Effect Transistors

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

- identify various power electronic component
- construction of FET & JFET
- difference between FET & BJT
- difference between JFET & BJT
- Heat sink and its purposes
- FET amplifiers in measuring device applications.

### Identification & different power electronic components

A thyristor is an improved diode. Besides anode (A) and cathode (K) it has another lead which is commonly described as a gate (G), as found on picture. The same way a diode does, a thyristor conducts current when the anode is positive compared to the cathode, but only if the voltage on the gate is positive and sufficient current is

flowing into the gate to turn on the device. When a thyristor starts conducting current into the gate is of importance and thyristor can only be switched off by removing the current between anode and cathode. If S1 is closed, the thyristor will not conduct, and the globe will not light. If S2 is closed for a very short time, the globe will illuminate. To turn off the globe S1 must be opened. Thyristors are marked in some circuits as SCR, which is an acronym for silicon

controlled rectifier. A triac is very similar to thyristor, with the difference that can conduct in both directions. It has three electrodes called anode 1 (A1), anode 2 (A2), and gate (G). It is used for regulation of alternating current circuits. Devices such as hand drills or globes can be controlled with a triac. Thyristor and triacs are marked alphanumerically, KT430, for example. Low power thyristors and triacs are packed in same housings as transistors, but high power devices have completely different housing. Pin-outs of some common thyristors and triacs are shown a and b. Diacs or two-way diodes as they are often referred to, are used together with thyristors and triacs. Their main property is that their resistance is very large until voltage on their ends exceeds some predefined value. When the voltage is under this value, a diac respond as a large value resistor, and when voltage rises it acts as a low value resistor.

### Field effect transistors (FET)

The main difference between a bi polar transistors and a field effect transistor is that,

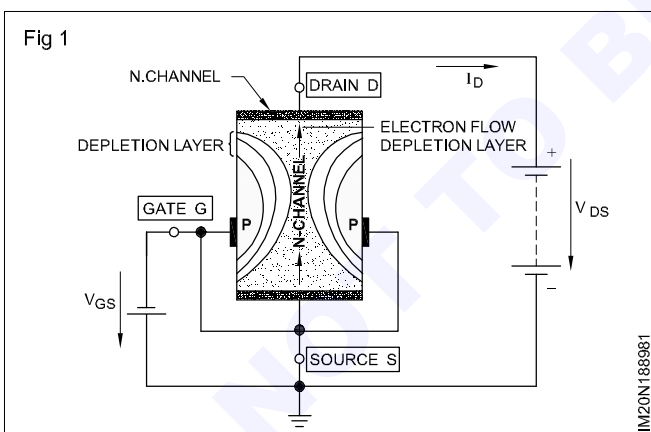
Bi - polar transistor is a current controlled device.

In simple terms, This means that the main current in a bipolar transistor (collector current) is controlled by the base current.

Filed effect transistor is a voltage controlled device.

This means that the voltage at the gate (similar to base of a bipolar transistor) controls the main current.

In a bi-polar transistor (NPN or PNP) the main current always flows through N-doped and P-doped semi conductor materials. whereas, in a field effect transistor the main current flows either only through the N-doped semiconductor or only through the p-doped semiconductor as shown in the Fig 1.



If the main current flow is only through the N-doped material, then such a FET is referred as a N-channel or N type FET. The current through the N-doped material in the n-type FET is only by electrons.

If the main current flow is only through the p-doped material, then such a FET is referred as a p-channel or p-type FET. The current through the P-doped material in the p-type FET is only by holes.

Unlike in bipolar transistors in which the main current both by electrons and holes, in contrast in FET depending on

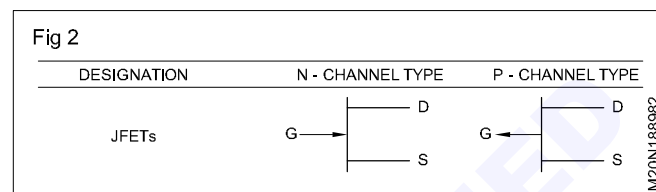
the type of (P or N type) the main current in either by electrons or by holes and never both. For this reason FET are also known as uni polar transistors or uni polar device.

There are a wide variety of FETs. One of the fundamentals types called as junction field effect transistor (JFET) is discussed.

### Junction Field effect Transistor(JFET)

It is a three terminal device and looks similar to a bi-polar transistor. The standard circuit symbols of N-channel and P-channel type FETs are shown in Fig 2.

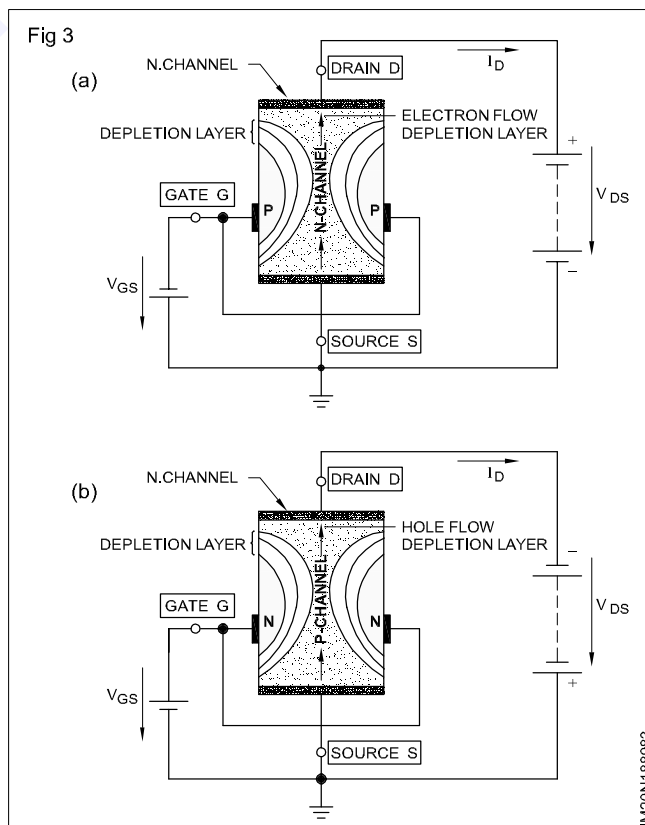
The internal diagram of a N-channel FET is shown in Fig.3.



### Construction

As shown in Fig 3a, a n-Channel JFET has a narrow bar of n-type. To this, two p-type junctions are diffused on opposite sides of its middle part Fig 3a. These diffused junctions form two P-N diodes or gates. The n-type semiconductor area between these junctions/gates is called channel. The diffused P regions on opposite sides of the channel are internally connected and a single lead is brought out which is called gate lead or terminal. Direct Electronics connections are made at the two ends of the bar. One of which is called source terminal, S and the other drain terminal, D.

A p-channel FET will be very similar to the n-channel FET in construction except that it uses P-type bar and two N type junctions as shown in Fig 3b.



FET notation listed below are essential and worth memorizing,

- 1 Source terminal: It is the terminal through which majority carriers enter the bar(N or P bar depending upon the type of FET).
- 2 Drain terminal: It is the terminal through which majority carriers come out of the bar.
- 3 Gate terminal: These are two internally connected heavily doped regions which form two P-N junctions.
- 4 Channel: It is the space between the two gates through which majority carriers pass from source to drain when FET is working(on).

### Working of FET

Similar to Bipolar transistors, the working point of adjustment and stabilization are also required for FETs.

### Biased a JFET

- Gates are always reverse biased. Therefore the gate current  $I_G$  is practically zero.
- The source terminal is always connected to the end of the supply which provides the necessary charge carriers. For instance, in an N-channel JFET source terminal S is connected to the negative of the DC power supply. And, the positive of the DC power supply is connected to the drain terminal of the JFET.

Whereas in a P channel JFET, Source is connected to the positive end of the power supply and the drain is connected to the negative end of the power supply.

Let us now consider an N channel JFET, the drain is made positive with respect to source by voltage  $V_{DS}$  as shown in Fig 4a. When gate to source voltage  $V_{GS}$  is zero, there is no control voltage and maximum electron current flows from source(S) - through the channel - to the drain(D). This electron current from source to drain is referred to as Drain current,  $I_D$ .

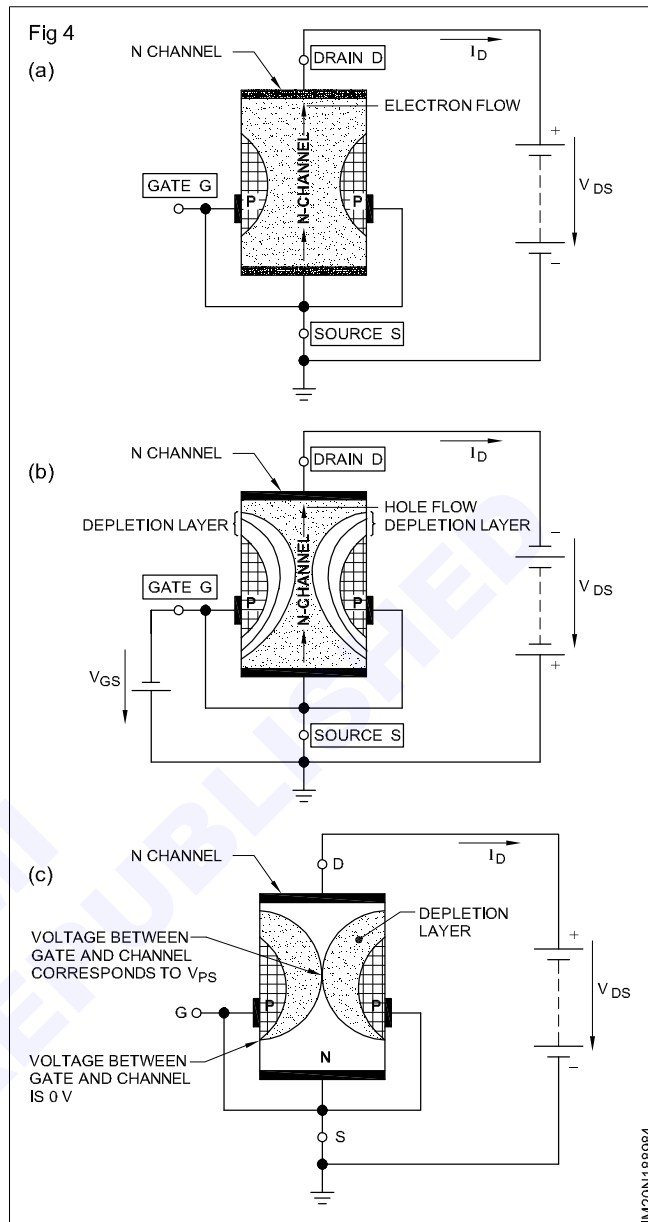
When gate is reverse biased with a negative voltage( $V_{GS}$  negative) as shown in Fig 4b, the static field established at the gate causes depletion region to occur in the channel as shown in Fig 4b.

This depletion region decreases the width of the channel causing the drain current to decrease.

If  $V_{GS}$  is made more and more negative, the channel width decreases further resulting in further decrease in drain current. When the negative gate voltage is sufficiently high, the two depletion layers meet and block the channel cutting off the flow of drain current as shown in Fig 4c. This voltage at which this effect occurs is referred to as the Pinch off voltage,  $V_P$ .

Thus, by varying the reverse bias voltage between gate and source( $-V_{GS}$ ), the drain current can be varied between maximum current (with  $-V_{GS}=0$ ) and zero current(with  $-V_{GS}=\text{pinch off voltage}$ ). So, JFET can be referred as a voltage controlled devices.

P channel JFET operates in the same way as explained above except that bias voltages are reversed and the majority carrier of channel are holes.

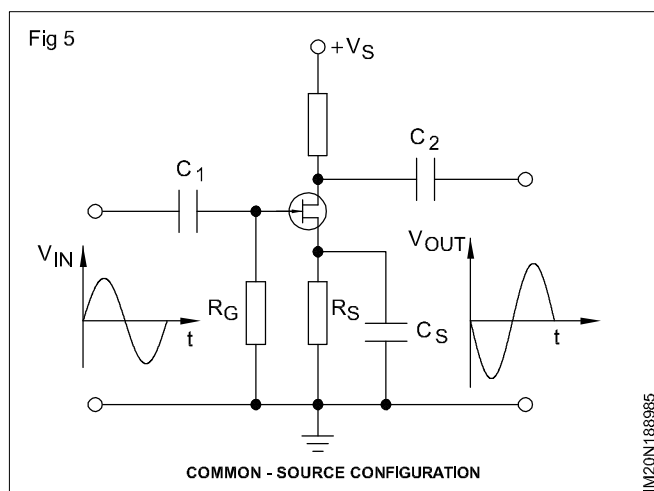


### Important specifications of typical JFETs

|                                        | BF245B    | BFW10     |
|----------------------------------------|-----------|-----------|
| Polarity of the device (N-type/P-type) | Nj        | Nj        |
| Maximum drain-source voltage, $V_{DS}$ | 30 V      | 30 V      |
| Maximum gate-source voltage, $V_{GS}$  | 30 V      | 30 V      |
| Maximum drain current, $I_D$           | 25 mA     | 20 mA     |
| Maximum forward gate current, $I_G$    | 10 mA     | 10 mA     |
| Pinch-off Voltage (at $I_D=0$ ), $V_P$ |           | 8 V       |
| Maximum power dissipation, $P_{max}$   | 300 mW    | 300mW     |
| Package type                           | TO92      | TO72      |
| Pin Diagram                            | fig W141e | fig W158b |
| (Refer 6605 data manual)               |           |           |

The term Nj in the specification indicates that it is a N-type junction FET.

As discussed earlier FETs also need a proper biasing arrangement for it to work. Like transistors, FETs can also be connected in different configuration. Fig 5 gives a simple common source amplifier configuration.



### Typical applications of JFET

One very important characteristic of JFET is its very high input impedance of the order of  $10^9$  ohms. This characteristic of FET has made it very popular at the input stage of a majority of electronic circuits.

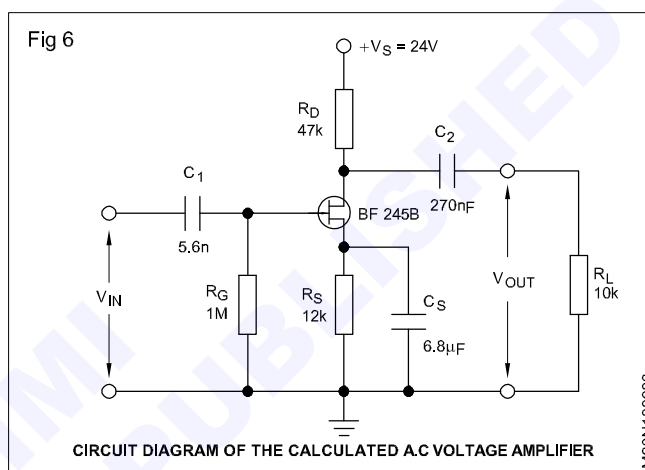
As discrete components FETS are chiefly used in,

- DC voltage amplifiers
- AC voltage amplifiers(input stage amplifiers in HF and LF ranges)
- Constant current sources
- Integrated circuits of both analog and especially in Digital technology.

One application of JFETs are illustrated below;

### 1 Fixed gain a.c voltage amplifier

In the circuit at Fig 6, the amplification is determined by the design. it can be varied within certain limits of the drain resistance and the source resistance are made variable. Potentiometers can be connected in series for this purpose.



### Difference between JFET and BJT

| JFET                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | BJT                                                                                                                                                                                                                                                                                                                                                                                                            |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ol style="list-style-type: none"> <li>1 In a JFET there is only one type of carrier i.e., holes in p type channel and electrons in n-type channel. For this reason it is called unipolar transistor.</li> <li>2 As the input circuit of a JFET is reverse biased and therefore it has a high input impedance.</li> <li>3 No current enters the gate of JFET.</li> <li>4 JFET uses voltage on the gate terminal to control the current between drain and source. No junction in JFET so noise level is very small.</li> </ol> | <ol style="list-style-type: none"> <li>1 In BJT both electrons and holes play a role in conduction. It is called a bipolar transistor.</li> <li>2 The input circuit of a BJT is forward biased and hence has low input impedance.</li> <li>3 In typical BJT base current might be a few μA.</li> <li>4 BJT uses the current into its base to control a large current between collector and emitter.</li> </ol> |

### FET Amplifiers in measuring device applications.

- Field effect transistors (FETs) are used in mixer circuits to control low intermodulation distortions.
- FETs are used in low frequency amplifiers due to their small coupling capacitors.
- It is a voltage controlled device due to this it is used in operational amplifiers as voltage variable resistors.
- It is commonly used as input amplifiers in devices i.e. voltmeters, oscilloscopes, and other measuring

devices, due to their high input impedance.

- It is also used in radio frequency amplifiers for FM devices.
- It is used for mixer operations of FM and TV receivers.
- It is used in large scale integration (LSI) and computer memories because of its small size.



# MOSFET

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

- state the principle of operation of MOSFET and its types
- list the special type of MOSFETs
- explain the features of MOSFETs.

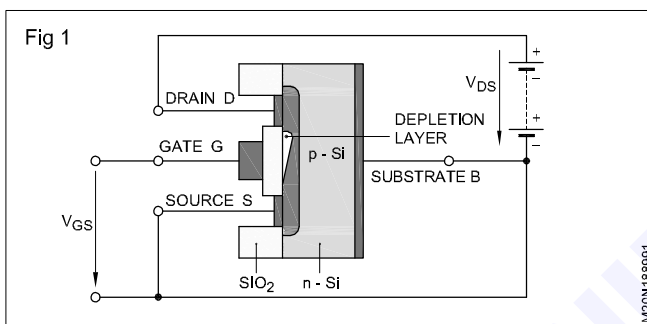
In MOSFETs, control is via an insulating layer instead of a junction (as in JFETs). This insulating layer is generally made of silicon dioxide, from which the very name MOSFET is derived (Metal Oxide Semiconductor). Some times the MOSFETs are also referred to as Insulated-gate FET, for which the abbreviation used are IFET or IGFET.

## Types of MOSFETs

### Depletion-type MOSFETs

#### Construction and mode of operation

Fig 1 shows the construction of a depletion MOSFET of the n-channel type (Fig 1).



Here, two highly doped n-zones are diffused into a p-doped silicon plate, which is referred to as the substrate, and are provided with junction-free drain and source connections. Between the two zones there is a thin weakly n-doped channel, which produces an Electronics connection between the source and drain without an external field-action. This channel is covered by an insulating layer of silicon dioxide ( $\text{SiO}_2$ ), to which a metal electrode is applied as the gate connection.

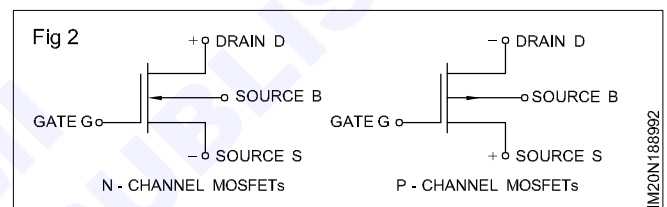
If a voltage  $U_{DS}$  is applied between source and drain, at  $U_{GS} = 0V$  an electron current flows from the source electrode via the n-channel to the drain electrode. If, however, a negative voltage is applied to control electrode G, the electrons present in the n-channel are forced out of the vicinity of the gate electrode, so that a zone depleted of charge carriers is produced there. This causes a constriction of the n-channel and consequently also a reduction of its conductivity. If the gate voltage becomes more negative, the conductivity of the channel is reduced, as is consequently also the drain current  $I_D$ . Another peculiarity of depletion-type MOSFETs is that they can also be controlled with a positive gate-voltage. Charge carriers are then drawn out of the p-doped substrate into the n-channel and its conductivity is increased even further, compared with the conductivity at  $U_{GS} = 0V$ .

#### Designations and circuit symbols

The same designations are used for the connections of MOSFETs as they are for JFETs, i.e source, drain and gate. MOSFETs, however, have another electrode, which

is referred to as the substrate connection. Together with the semiconductor material of the channel, this substrate forms a p-n junction, which can be used as a second control-electrode. It is then led out of the casing, like the other electrodes. In a number of versions, however, the substrate electrode is connected directly to the source connection in the casing, which rules out the additional control possibility.

Fig 2 shows the circuit symbols for depletion-type n-channel MOSFETs and p-channel MOSFETs. For the n-channel type, the arrow points towards the line representing the channel; in the case of the p-channel type, on the other hand, it points away from the line representing the channel. The continuous line representing the channel indicates that it is a depletion-type MOSFET.

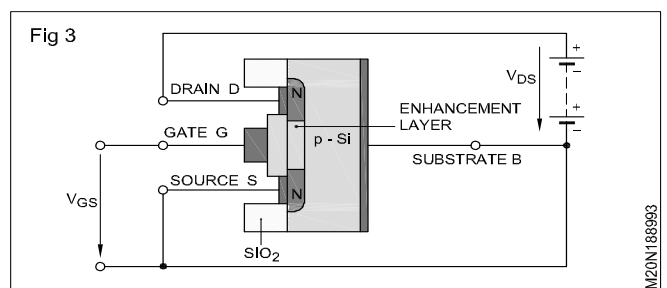


N-channel MOSFETs are operated with a positive drain-source voltage. They have a considerably greater practical significance than p-channel MOSFETs, which require a negative drain-source voltage for their operation.

### Enhancement-type MOSFETs

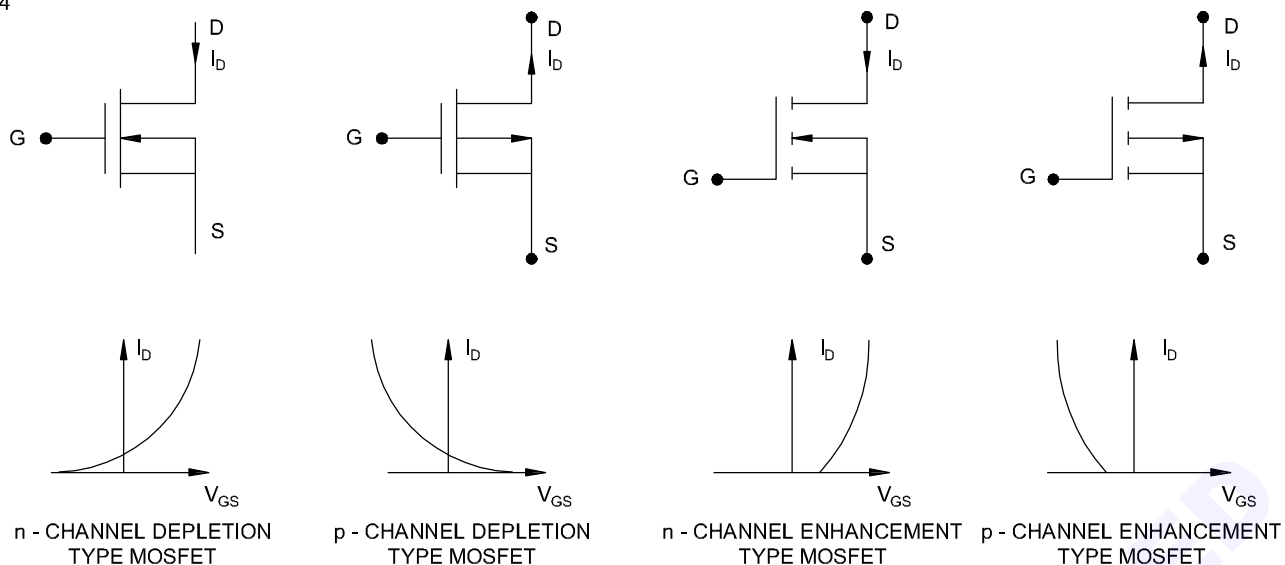
#### Construction and mode of operation

Enhancement-type MOSFETs have a similar technological construction to the depletion types. Without the external action of a field, however, no conducting channel exists between the drain connection and the source connection, so that at  $U_{GS} = 0V$ , no drain current can flow. Fig. 3 shows the construction of an enhancement-type n-channel MOSFET.



The same circuit designations are used for the four electrodes of the enhancement-type MOSFET as they are for the depletion types: drain, source, gate and substrate. The circuit symbols used are different. The line representing the channel in the circuit symbol is discontinuous for an enhancement - type MOSFET. This indicates that no drain current  $I_D$  flows at  $U_{GS} = 0V$ . The circuit symbols for the two types of enhancement MOSFET are given in Fig. 4.

Fig 4

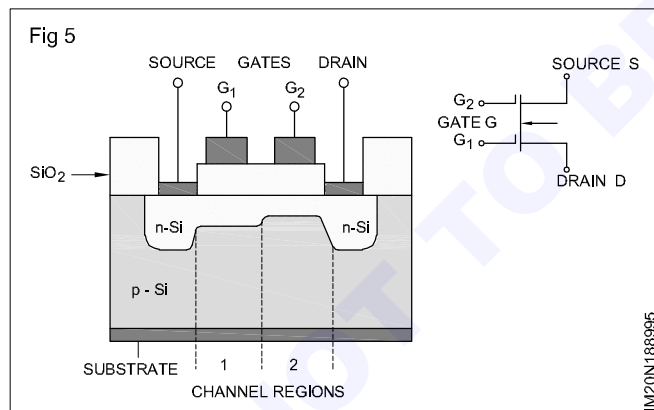


Enhancement-type MOSFETs are only rarely produced as individual transistors. Their construction and working principle are, however, widely used in integrated MOS switching circuits.

### Special types of MOSFET

#### Dual-gate MOSFET

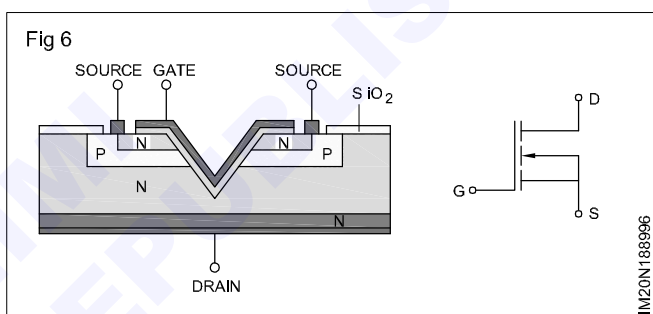
The dual-gate MOSFET is a special type of depletion MOSFET. It has two series-connected channel regions as the current path. The conductivity of each of these two channel regions can be independently controlled via its own gate. The construction and circuit symbol of a depletion-type dual-gate MOSFET of the n-channel type are reproduced in Fig.5. Because of the four connections, this special type is also referred to as a "MOSFET tetrode".



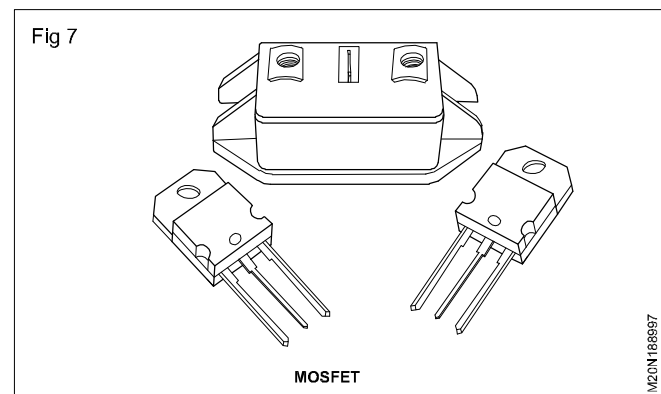
#### VMOSFET

The field-effect transistors dealt with so far, can handle only relatively small powers during amplification or switching. The reason for this is the relatively long channel of approximately 5  $\mu\text{m}$  with a forward resistance of approximately 1k $\Omega$  to 10k $\Omega$ . With present-day manufacturing techniques, it is possible to produce a vertical structure for field-effect transistors, instead of the customary horizontal sequence of layers. consequently, higher allowable currents and voltages are obtained, so that considerably greater powers can be amplified or switched.

Fig 6 shows the construction of an enhancement-type n-channel VMOSFET and the associated circuit symbol.



From above Fig 7 it can be concluded that depletion type MOSFETs are normally ON type switches i.e, with the gate terminal open a nonzero drain current can flow in these devices. This is not convenient in many power electronic applications. Therefore, the enhancement type MOSFETs (particularly of the n-channel variety) is more popular for power electronics applications. This is the type of MOSFET which will be discussed in this lesson. Fig 6(b) shows the photograph of some commercially available n-channel enhancement type power MOSFETs.



#### Operating principle of a MOSFET

At first glance it would appear that there is no path for any current to flow between the source and the drain terminals since at least one of the p n junctions (source - body and body-drain) will be reverse biased for either polarity of the

applied voltage between the source and the drain. There is no possibility of current injection from the gate terminal either since the gate oxide is a very good insulator. However, application of a positive voltage at the gate terminal with respect to the source will convert the silicon surface beneath the gate oxide into an n type layer or "channel", thus connecting the source to the drain as explained next.

The gate region of a MOSFET which is composed of the gate metallization, the gate (silicon) oxide layer and the p-body silicon forms a high quality capacitor. When a small voltage is applied to this capacitor structure with gate terminal positive with respect to the source (note that body and source are shorted) a depletion region forms at the interface between the  $\text{SiO}_2$  and the silicon as shown in the fig. 8(a)

The positive charge induced on the gate metallization repels the majority hole carriers from the interface region between the gate oxide and the P type body. This exposes the negatively charged acceptors and a depletion region is created.

Further increase in  $V_{GS}$  causes the depletion layer to grow in thickness. At the same time the electric field at the oxide-silicon interface gets larger and begins to attract free electrons as shown in fig. 8b. The immediate source of electron is electron-hole generation by thermal ionization. The holes are repelled into the semiconductor bulk ahead of the depletion region. The extra holes are neutralized by electrons from the source.

As  $V_{GS}$  increases further the density of free electrons at the interface becomes equal to the free hole density in the bulk of the body region beyond the depletion layer. The layer of free electrons at the interface is called the inversion layer and is shown in Fig. 8(c). The inversion layer has all the properties of an n type semiconductor and is a conductive path or "channel" between the drain and the source which permits flow of current between the drain and the source. Since current conduction in this device takes place through an n-type "channel" created by the electric field due to gate source voltage it is called "enhancement type n-channel MOSFET".

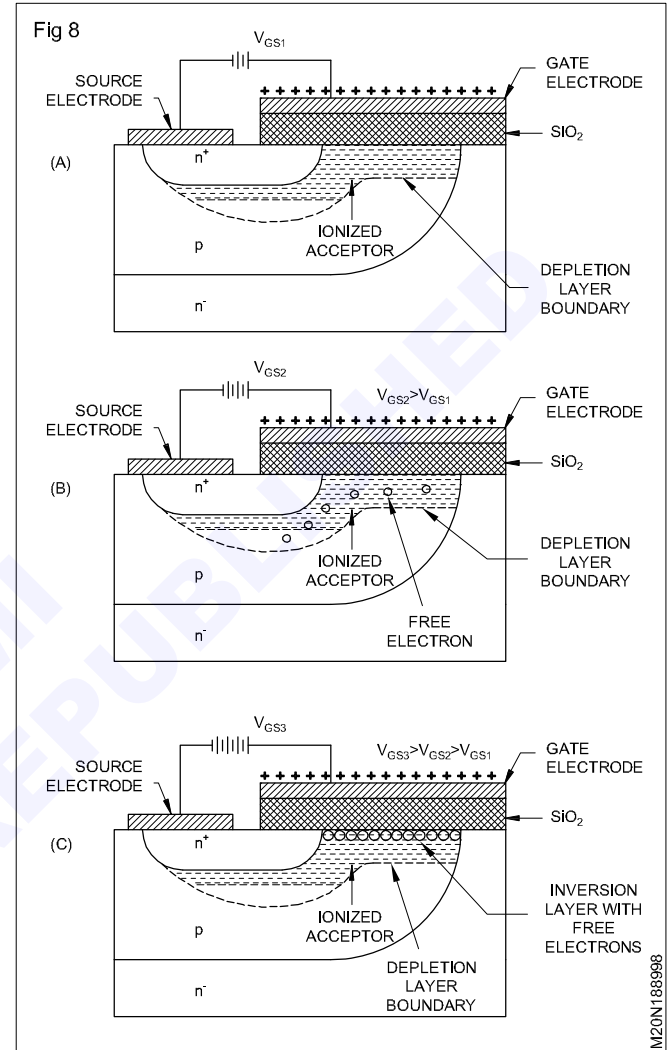
The value of  $V_{GS}$  at which the inversion layer is considered to have formed is called the "gate-source threshold voltage  $V_{GS(th)}$ ". As  $V_{GS}$  is increased beyond  $V_{GS(th)}$  the inversion layer gets somewhat thicker and more conductive, since the density of free electrons increase further with increase in  $V_{GS}$ . The inversion layer screens the depletion layer adjacent to it from increasing  $V_{GS}$ . The inversion layer screens the depletion layer adjacent to it from increasing  $V_{GS}$ . The depletion layer thickness now remains constant.

### FET Vs MOSFET

The transistor, a semiconductor device, is the device that made all our modern technology possible. It is used to control the current and even to amplify it based on an input on an input voltage or current. There are two major types of transistors, the BJT and the FET. Under each major category, there are many subtypes. This is the most significant difference between FET and MOSFET. FET stands for field effect transistor and is a family of very

different transistors that collectively rely on an electric field created by the voltage on the gate in order to control the current flow between the drain and the source. One of the many types of FET is the Metal - Oxide Semiconductor field effect transistor or MOSFET. The Metal - Oxide Semiconductor (i.e) silicon dioxide is used as an insulating layer between the gate and the substrate of the transistor.

Fig 8



The silicon dioxide is basically a capacitor is basically a capacitor that holds charge whenever voltage is applied to the gate. This charge then creates a field by pulling oppositely charged particles or repelling particles with the same charge and allows or restricts the flow of the current between the drain and source.

CMOS (complementary Metal -Oxide Semiconductor) basically uses a p-type and n-type MOSFETs in pairs to complement each other. In this configuration, MOSFETs only have significant power consumption during switching and not while it holds its state. This is very desirable, especially in modern computing equipment where power and thermal limits are pushed to the edge. Other types of FET cannot replicate this capability or are too expensive to manufacture.

Advancements in MOSFETs are constantly evolving, both in size as companies keep going into smaller architectures. But also in design like the 3D MOSFETs that show a lot of promise. MOSFETs are the transistor of choice for today

There will be switching losses. A sample drive circuit for a MOSFET is shown in the figure below.

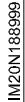
One method of coupling the drive circuitry is to use a transformer. PTs are used to isolate logic circuitry operating at high voltages.

1. Low gate signal power requirement.
2. Fast switching speed. No storage time effect as in transistors.
3. Power MOSFETs are not subjected to forward or reverse bias secondary breakdowns.

There are several circuits for turning a power MOSFET ON or OFF. The type of circuit depends on application. As a thumb rule, the higher the gate current at turn-on and turn-off, the lower will be switching losses. A sample drive circuit for a MOSFET is shown in the figure below.

There will be switching losses. A sample drive circuit for a MOSFET is shown in the figure below.

One method of coupling the drive circuitry is to use a transformer. PTs are used to isolate logic circuitry operating at high voltages.



## Half wave and full wave rectifier

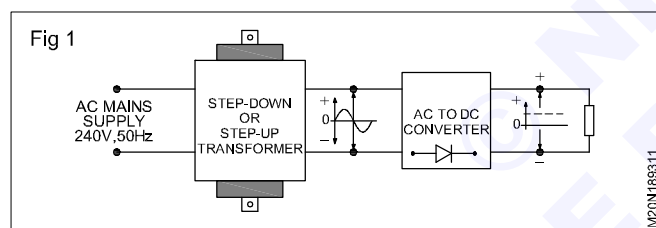
**Objectives :** On completion of this lesson you shall be able to

- state the meaning of the term rectification
- describe the working of a half wave rectifier
- state the limitations of half wave rectifier
- describe the working of a two-diode full wave rectifier
- list the disadvantages of two-diode full wave rectifier.

### RECTIFICATION

Almost all electronic circuits need DC voltage for their working. This DC voltage can be obtained by dry cells and batteries. Use of a dry cell is practicable only in portable electronic circuits such as transistor radio, tape recorders etc. But in circuits requiring large voltages and currents, like high power audio amplifiers, television sets etc. batteries will not only be very expensive but also be voluminous.

An alternative method of obtaining DC voltage is by converting the AC mains supply of 240V, 50Hz into DC voltage. This technique is not only convenient but also takes very small space compared to battery packs. **This process of converting AC to DC is known as rectification.** Fig 1 shows the principle of converting AC to DC of required voltage level.



The transformer will step-down or step-up the mains AC to the required level. The stepped-up or stepped-down AC from the output of the transformer is then converted to DC using diodes making use of their unique unidirectional property.

### HALFWAVE RECTIFIER

The simplest form of AC to DC converter is by using one diode. such an AC to DC converter is known as *half-wave rectifier* as shown in Fig 2.

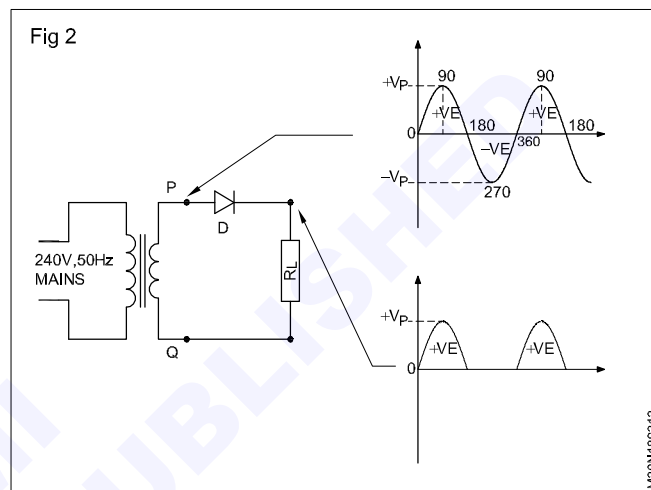
At the secondary of the transformer, across terminals P & Q, when seen on a CRO, the electric signal is a sinusoidal wave with its peak value of  $V_p$  and a frequency determined by the rate at which the alternations (+ve to -ve) are taking place. In Fig 2, the frequency is 50Hz as this voltage is taken from 50Hz AC mains supply.

If the voltage across P and Q is measured using an AC voltmeter, the voltmeter shows the rms (root mean square) value,  $V_{rms}$  of the sinusoidal wave which will be less than the peak value. The relationship between  $V_{Peak}$  and  $V_{rms}$  is given by,

$$V_{rms} = 0.707 V_{Peak} \quad \dots\dots[1]$$

conversely,

Fig 2



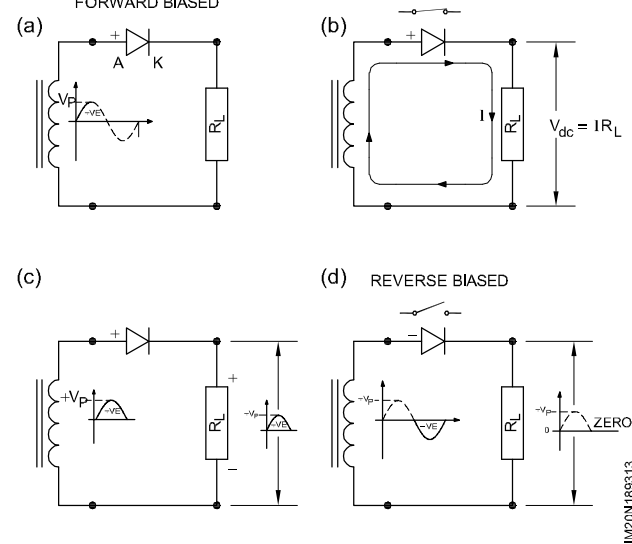
When this sinusoidal signal is applied across the diode D as shown in Fig 2, the diode conducts (behaves as a closed switch) only during the +ve half cycle of the input sinusoidal voltage and does not conduct (behaves as an open switch) during the -ve half of the input sinusoidal voltage. This process repeats again and again thus producing a pulsating +ve wave-form at the output across the load,  $R_L$  as shown in Fig 2.

The operation of a half-wave rectifier circuit can be summarised with the help of Fig 3 as follows:

- 1 During the positive half cycle of AC input, the diode is forward biased as the anode of diode is positive as shown in Fig 3a.) Hence current flows from anode to
- 2 Hence current flows anode to cathode, through load  $R_L$  to secondary of transformer as shown in Fig 3b. The  $IR_L$  drop across load resistor  $R_L$  is the DC voltage  $V_{dc}$  with the polarity as shown in Fig 3b.
- 3 When the +ve half cycle of the input sinusoidal is completed, the voltage across the  $R_L$  will be a positive half sinewave as shown in Fig 3c. The peak of rectified voltage is also equal to the peak of the input AC voltage.
- 4 During the negative half cycle of the input AC, the diode is reverse biased as the anode of diode is negative as shown in Fig 3d.
- 5 Hence, the diode behaves as an open switch and no current flows through the load and hence there is no voltage output across load  $R_L$  as shown in Fig 3d.
- 6 After completing the -ve half cycle, when the input signal goes positive again, the whole operation repeats starting from step 1.



Fig 3



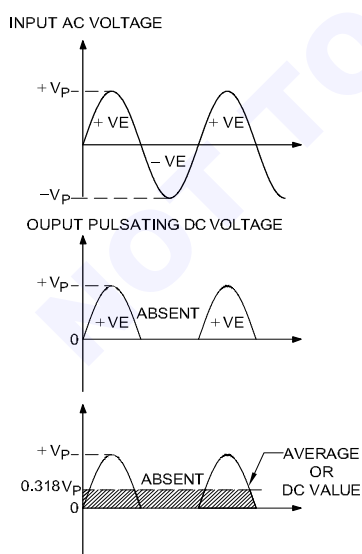
### Calculating output DC level in half-wave rectifiers

Important points to note for calculating the output DC level of a halfwave rectifier are;

- the output of a halfwave (HW) rectifier across the load resistor is a pulsating DC
- the peak voltage is equal to the peak value of the +ve half cycle of the AC input
- the pulsating signal level is zero when the input AC is in the -ve half cycle as shown in Fig 4.
- hence the output DC can be read by connecting voltmeter across the load resistor which will read the average DC value of the pulsating signal, ignoring the diode drop
- The average DC value of the pulsating output in a half wave rectifier is given by,

$$V_{\text{average}} \text{ or } V_{\text{dc}} = 0.318 V_p \quad \dots\dots[2]$$

Fig 4



### Ripple frequency

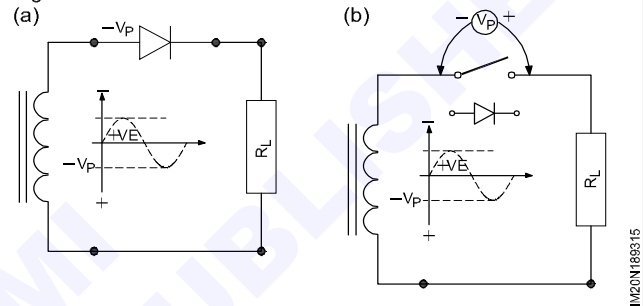
The frequency of the rectified pulsating DC is same as the frequency of the input AC signal.

### Peak inverse voltage

The half-wave rectifier at the instant the secondary voltage is at its maximum negative peak shown in Fig 5a. Since the diode is reverse biased, it behaves as an open switch there is no voltage across the load  $R_L$ . Therefore, From Kirchhoff's voltage law, all the secondary voltage appears across the diode as shown in Fig 5b. This is the maximum reverse voltage that appears across the diode in the reverse biased condition. This voltage is called the peak reverse voltage or more commonly as the **peak inverse voltage (PIV)**. Therefore, in a half-wave rectifier the peak inverse voltage across the diode is equal to the -ve peak value of the secondary voltage  $V_{s(\text{peak})}$ .

$$V_{s(\text{peak})} = \frac{V_{s(\text{rms})}}{0.707}$$

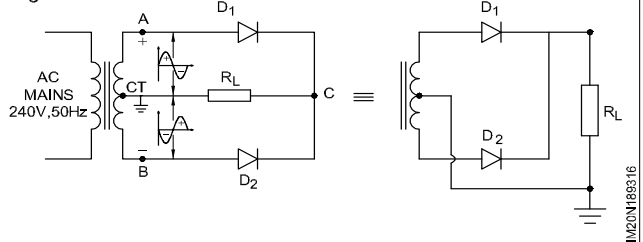
Fig 5



### TWO-DIODE FULLWAVE RECTIFIER

In a half-wave rectifier there is no rectification action during the -ve half cycle of the input AC voltage. Because of this the output DC level is low ( $0.318 V_{s(\text{peak})}$ ). This limitation of a half-wave rectifier can be overcome by using two diodes and a centre-tap-transformer as shown in Fig 6.

Fig 6

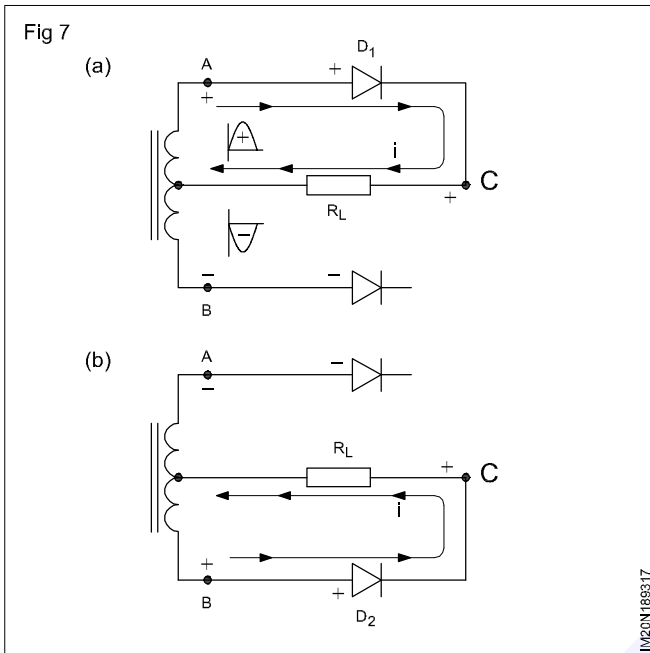


In Fig 6, each diode and the common load resistor  $R_L$  form two independent half-wave rectifiers. Because of the centre-tapped secondary winding, each diode receives only half of the total secondary voltage.

The opposite ends of the transformer secondary windings always have opposite polarities with respect to the centre tap. As shown in Fig 6, when end A of the secondary winding is positive, the bottom end B will be negative.

For the polarity shown in Fig 7a, the anode of  $D_1$  is positive and, hence, forward biased. Whereas, the anode of  $D_2$  is negative, and, hence, does not conduct. Current flows from the transformer (end A)  $\rightarrow D_1 \rightarrow R_L \rightarrow$  back to the transformer centre-tap. This direction makes point C across the load  $R_L$  as the +ve terminal of the output DC voltage.

During the next half cycle, end B of transformer is +ve and A is –ve as shown in Fig 7b. Hence the anode of  $D_2$  is +ve and this diode conducts whereas  $D_1$  does not. Current flows from the transformer(end B)  $\rightarrow D_2 \rightarrow R_L \rightarrow$  back to the transformer centre-tap. This direction of current again makes point C across the load  $R_L$  as the +ve terminal of the output DC voltage.



It is important to note the following two points;

- At any instant of time either  $D_1$  or  $D_2$  conducts but never both.
- While any of the two diodes is conducting, the rectified current  $i$ , flows through  $R_L$  in the same direction as shown in Fig 7a and Fig 7b. So the DC output voltage is positive at the common cathodes of the diodes  $D_1, D_2$ .

Fig 8 shows the input and output wave-forms of a fullwave rectifier. As can be seen from Fig 8, the rectifier works both in the positive and negative half cycles of the AC input to produce a DC output across the load resistor  $R_L$ . Although only one diode conducts at a time, the outputs are combined in  $R_L$ . Hence, fullwave rectifier provides double the DC current to the load compared to that of a half-wave rectifier.

Since both the half cycles of the input AC signal are rectified by the circuit at Fig 6, this circuit is known as a *fullwave rectifier*. Since this fullwave rectifier uses two diodes this circuit is also known as *two diode fullwave rectifier*.

#### Output DC level in a two-diode full wave rectifier

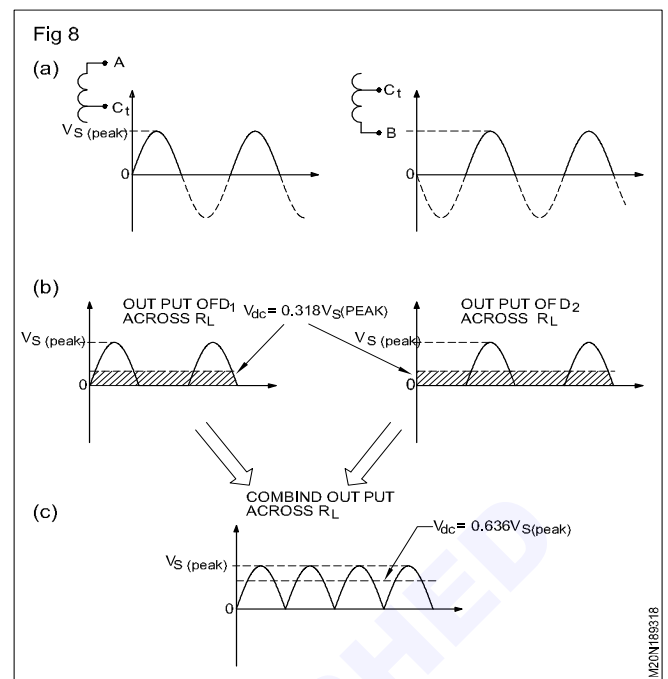
A full wave rectifier is a combination of two half-wave rectifier. The DC value of a fullwave rectifier is twice the output of a half-wave rectifier. It is evident from Fig 8 that the average or DC value of a fullwave rectified output is

$$V_{dc} = 0.636 V_{S(peak)} [0.318 V_{S(peak)} + 0.318 V_{S(peak)}]$$

where,  $V_{S(peak)}$  is the equal peak voltage between the centre-tap and one end of the transformer 'secondary' in terms of rms  $V_{dc}$  can be given by the

$$V_{S(rms)} = 0.707 V_{S(peak)}$$

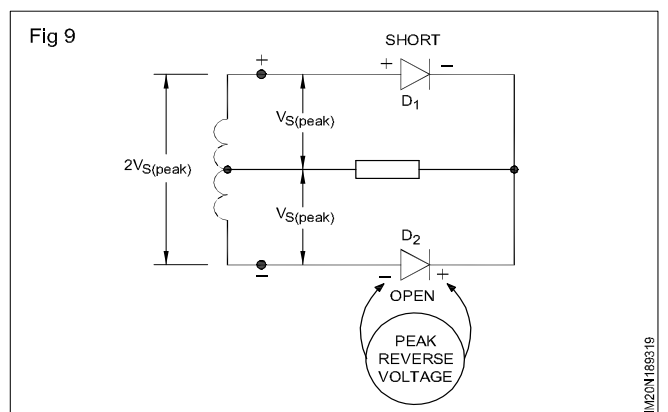
$$\text{Therefore, } V_{dc} = 0.636 \cdot \frac{V_{S(rms)}}{0.707} = 0.9 V_{S(rms)}$$



#### Ripple frequency in a full wave rectifier

From Fig 8c it is seen that two cycles of output occur for each input cycle of AC voltage. This is because, the full wave rectifier has inverted the negative half-cycle of the input voltage. As a result, the output of a full wave rectifier has a frequency double the input AC frequency. This is because the fullwave rectifier has inverted the negative half cycle of the input voltage, therefore if the main frequency is 50 Hz. the output frequency of the pulsating DC will be 100 Hz.

The fullwave rectifier at the instant the secondary voltage reaches its maximum positive value. From Fig 9, It is seen that each diode in a full wave rectifier must have PIV rating greater than the peak value of the full secondary voltage  $2V_{S(peak)}$ .



#### Disadvantages of TWO DIODE fullwave rectifier

The full wave rectifier using two diodes and centre tap transformer has the following disadvantages;

- A centre-tapped transformer that produces equal voltages on each half of the secondary winding is difficult to manufacture and, hence, expensive.
- Centre-tapped transformers are generally bulkier than ordinary transformers, and, hence, occupy larger space.
- In a two diode full wave rectifier, only half of the secondary voltage is made use of at a time although it works in both +ve and –ve half cycles.

# Bridge rectifier

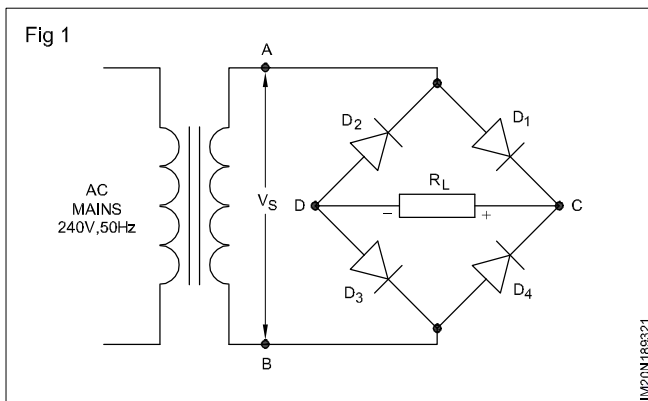
**Objectives :** On completion of this lesson you shall be able to

- describe the working of a bridge rectifier
- compare half-wave, fullwave and bridge rectifiers.

## THE BRIDGE RECTIFIER

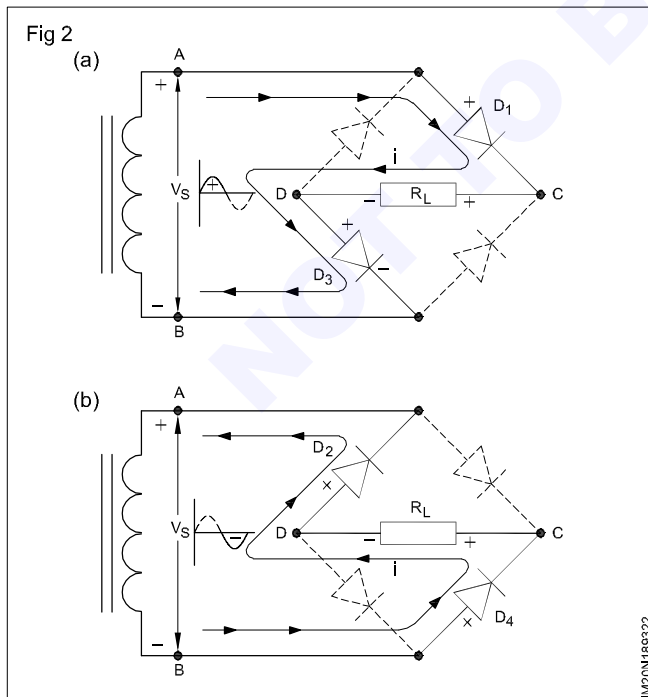
The disadvantages of a full wave rectifier using two diodes and centre-tap transformer can be overcome by a modified fullwave rectifier as shown in Fig 1. In Fig 1, since the diodes are connected in the form of a bridge, this rectifier circuit is commonly known as a *Bridge rectifier*.

As can be seen in Fig 1, the bridge rectifier does not need a centre-tapped transformer. Also, all the secondary voltage is used for rectification at any given time.



The operation of a bridge rectifier can be summarized in the following steps;

- When end A of the transformer secondary is +ve, as shown in Fig 2a, diodes  $D_1$  and  $D_3$  are forward biased whereas,  $D_2$  and  $D_4$  are reverse biased, and, hence,  $D_2$  and  $D_4$  do not come in the circuit.

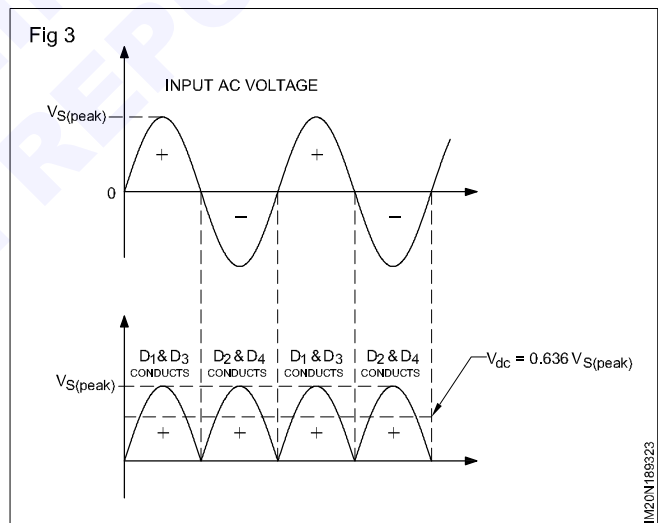


- Current flows from the transformer(end A)  $\rightarrow D_1 \rightarrow R_L \rightarrow D_3 \rightarrow$  back to the transformer(end B). From the direction of the current flow point C is the positive terminal of the DC output across  $R_L$ .
- During the other half cycle of the input (–ve half cycle), end B of the transformer becomes +ve as shown in Fig 2b. Diodes  $D_4$  and  $D_2$  are forward biased, whereas  $D_1$  and  $D_3$  are reverse biased.
- Current flows from the transformer(end B)  $\rightarrow D_4 \rightarrow R_L \rightarrow D_2 \rightarrow$  back to the transformer(end A). From the direction of the current flow, point C is again the +ve terminal of the DC output across  $R_L$ .

Note that, current  $I$  is in the same direction through  $R_L$  during both +ve and –ve half cycles of the input AC. The result is, a +ve rectified DC voltage appears at the end of  $R_L$  connected to the cathodes of  $D_1$  and  $D_4$ .

## Output DC level in a bridge rectifier

Fig 3 shows the input AC and the output pulsating DC waveform of a bridge rectifier.



This wave-form is similar to that of the full wave rectifier using a centre-tap transformer. Hence, the average DC value of the output is,

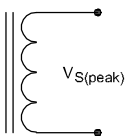
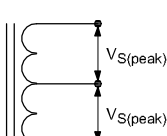
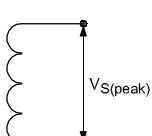
$$V_{dc} = 0.636 V_{S(peak)}$$

$$\text{or } V_{dc} = 0.9 V_{S(rms)}$$

where,  $V_{S(rms)}$  is the full secondary AC rms voltage.

**NOTE:** In a two-diode fullwave rectifier  $V_{S(rms)}$  refers to only half of the total secondary voltage whereas in a bridge rectifier  $V_{S(rms)}$  refers to full secondary voltage.

Comparison of **half-wave**, **fullwave** and **bridge rectifier** is given below in a tabular form;

|                                               | Half wave                                                                         | Full wave                                                                          | Bridge                                                                              |
|-----------------------------------------------|-----------------------------------------------------------------------------------|------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
| • Number of diodes required                   | 1                                                                                 | 2                                                                                  | 4                                                                                   |
| • Transformers Peak output voltage            |  |  |  |
| • DC output voltage in terms of $V_{S(peak)}$ | $0.318 V_{S(Peak)}$                                                               | $0.636 V_{S(Peak)}$                                                                | $0.636 V_{S(Peak)}$                                                                 |
| • DC output voltage in terms of $V_{S(rms)}$  | $0.45 V_{S(rms)}$                                                                 | $0.9 V_{S(rms)}$                                                                   | $0.9 V_{S(rms)}$                                                                    |
| • Diode current rating                        | $I_{L(max)}$                                                                      | $0.5 I_{L(max)}$                                                                   | $0.5 I_{L(max)}$                                                                    |
| • Peak inverse voltage                        | $V_{S(peak)}$                                                                     | $2V_{S(peak)}$                                                                     | $V_{S(peak)}$                                                                       |
| • Ripple frequency                            | $f_{input}$                                                                       | $2f_{input}$                                                                       | $2f_{input}$                                                                        |

## Filters

**Objectives :** On completing this lesson you shall be able to

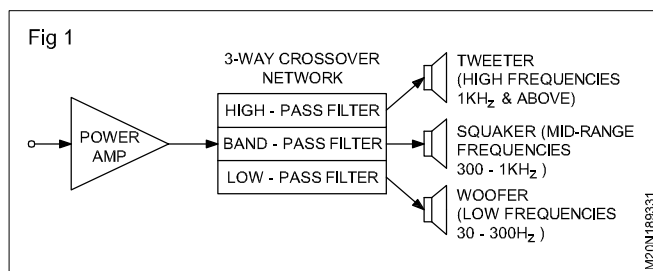
- state the meaning of frequency selective filters
- define an electronic filter
- state different types of filters
- define a low pass filter
- define cut-off frequency
- define a high pass filter
- applications of high pass filter
- define a band pass filter
- applications of band pass filter
- explain roll-off rate
- list a few applications of LPFs.

### Filters

The term **to filter**, in general, means to selectively remove. For example, water filters are used to remove dust, dirt and disease causing germs from water. This means, the water filter selectively removes or blocks dust, dirt and disease causing germs but allows or passes purified water. In a similar way, in electronics, signals may consist of more than one frequency component. Then filters which selectively remove or allow a band of frequencies are used. Such filters are called **filters**. These filters are common in electronic circuits.

Filters are electronic circuits comprising of electronic components such as resistors, capacitors, inductors, and

sometimes active devices such as transistors, IC's etc.,. These circuits are designed to allow or to block(filter) a band of frequencies as shown in Fig 1. Filters may also be designed to allow or block a particular frequency component.



Filters constructed using only passive components such as resistors, capacitors and/or inductors are called **passive filters**.

Filters constructed using active devices such as transistors or op-amps in addition to passive components are called **active filters**.

### Types of FILTERS

Referring to Fig 1, filters may be classified as,

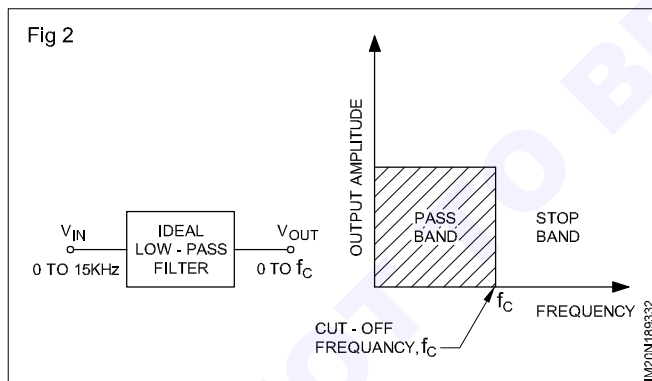
- Low pass filters** - Passes or allow low frequencies (for example: 30 to 300 Hz)
- High pass filters** - Passes or allows high frequencies (for example: 1 KHz and above)
- Band pass filters** - Passes or allows a particular band of frequencies (for example: 300 Hz to 1 KHz)

### Low Pass Filter (LPF)

An ideal low pass filter is a circuit which passes all frequency signals from 0-Hz to a particular frequency called the **cut-off frequency**. This also means that, a low pass filter stops all signals having frequency beyond the cut off frequency as shown in Fig 2.

The frequency response of an ideal low pass filter as shown in Fig 2 will be constant in the **pass band** up to the cut off frequency  $f_c$ . Beyond  $f_c$ , called as the **stop band** the output of the filter is zero.

**However, in practice it is not possible to design a LPF having ideal characteristics as in Fig 2.**

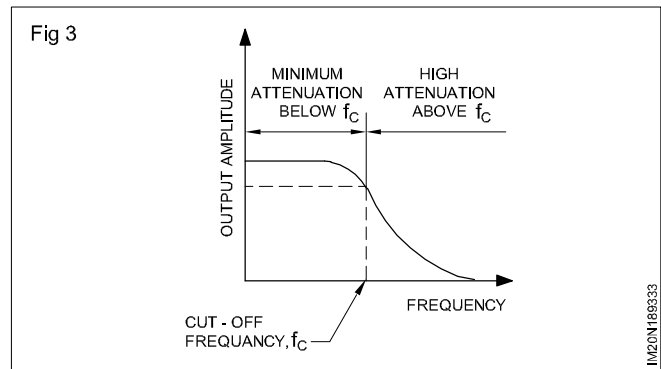


A practical low pass filter can be defined as a circuit which allows all frequencies below a particular frequency called **cut off frequency** and attenuates heavily all frequencies above the cut off frequency as shown in Fig 3.

**Attenuation means reducing the amplitude/magnitude of the signal.**

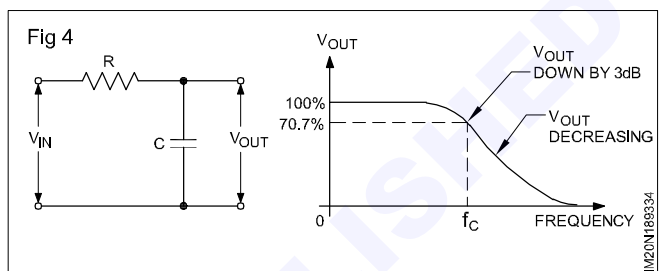
Low pass filters can be constructed using,

- Resistors and capacitors - referred to as RC-filters
- Inductors and capacitors - referred to as LC-filters.



### Passive RC-low pass filter

A typical RC low pass filter and its frequency response is shown in Fig 4.



The output of the RC low pass filter is taken across capacitor C.

When input  $V_{in}$  is DC (0 Hz), capacitor C behaves practically as open circuit. At low frequencies, reactance of C ( $X_c = 1/2\pi f_c$ ) is very high. Hence, at low frequencies capacitor behaves almost as open circuit. Therefore, at low frequencies output of filter is same as the input.

When input signal frequency increases, the capacitive reactance  $X_c$  decreases ( $X_c$  is inversely proportional to frequency).

Therefore, capacitor C gives a low resistance path for the high frequency signals to ground. Hence, as the input signal frequency increases the output of the filter  $V_{out}$  decreases. This is shown in Fig 4. At a particular high frequency, capacitor C acts as a short circuit grounding all the input. When this happens,  $V_{out} = 0$  volt.

### Definition of cut-off frequency

The **cut-off frequency**,  $f_c$  is defined as the frequency at which the power output of the filter is one half of the input power. In terms of voltage, at cut-off frequency  $f_c$ , the output amplitude will be 70.7% of the input amplitude as shown in Fig 4.

Cut off frequency  $f_c$  of a RC low pass filter can be calculated using the formula,

$$f_c = \frac{1}{2\pi RC}$$

where, R = Resistance in ohms

C = Capacitance in farad

$f_c$  = Cut off frequency in Hz.



A low pass filter constructed using one resistor and one capacitor as shown in Fig 4 is known as a single stage LPF. This is also called a single pole LPF. Since the output of a LPF lags from input, LPFs are also referred to as Lag networks.

### Measurement of gain in DECIBEL (dB)

Gain of a LPF is given by,

$$\text{Gain in dB} = 20 \log \frac{V_{\text{out}}}{V_{\text{in}}}$$

At cut-off frequency, since the output voltage will be 70.7% of the input ,

$$\begin{aligned} \text{Gain of a LPF at cut-off frequency } f_c &= 20 \log (0.707) \\ &= -3 \text{ dB} \end{aligned}$$

Hence, in a LPF,  $f_c$  is also called the **3 dB frequency** of the filter.

### ROLL-OFF

The rate at which the output level of LPF decreases depends on the number of stages in the LPF as shown in Fig 5.

The rate of decrease in output level, or rate of increase in attenuation after the cut off frequency  $f_c$  is called **roll-off**. Roll-off of a filter is expressed in decibels-per-decade(dB/decade) or decibels-per-octave(dB/octave).

The higher the number of stages in a LPF, the higher will be the roll-off rate and better will be the performance of the LPF as shown in Fig 5.

The disadvantage of cascading more number of filter stages is, the attenuation to the input signal is the pass-band increases as more number of resistors come in series between the input and output.

In general, a n-pole (n-stage) LPF will have 20 x n dB/decade roll off.

### Passive LC Low Pass Filter

Low pass filter can be constructed using an inductor (L) and a capacitor (C). A typical L-C low pass filter designed for  $f_c = 1 \text{ KHz}$  is shown in Fig 6.

The frequency response of LC low pass filter and RC low pass filter will have the same shape. The cut-off frequency in LC low pass filter is given by,

$$f_c = \frac{1}{2\pi\sqrt{LC}}$$

where, L = inductance value in henry

C = capacitance value in farad.

In audio frequency circuits, LC low pass filters are not preferred as the physical size of the inductor will be large. However, in radio frequency applications(r.f), LC filters are popular as the inductor size will be small at such high frequencies.

**Applications of Low Pass Filter :** Low pass filters are used in wide variety of applications. A few such applications are;

Fig 5

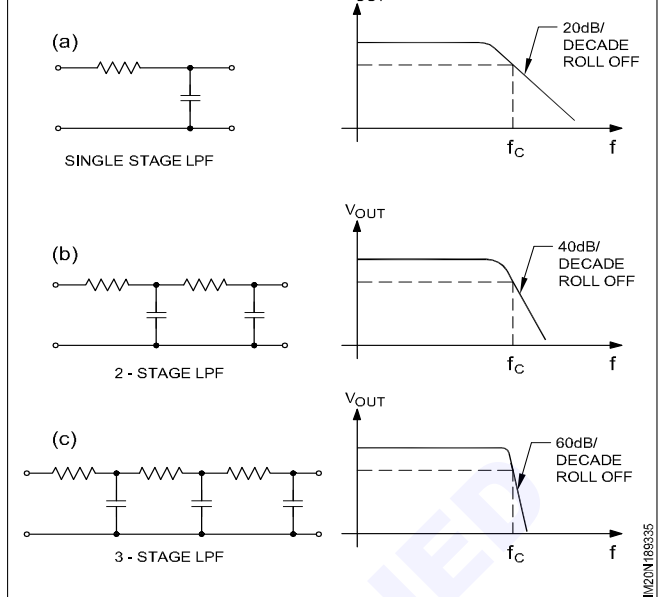
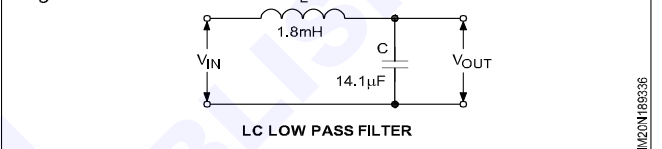


Fig 6



- 1 in DC power supplies as ripple filter to block AC ripples from reaching the output.
- 2 in **tone control circuit** of amplifiers, tape recorder amplifiers etc., to separate low frequencies (Bass signals).
- 3 in cross over networks (shown in Fig 7) in speaker boxes.

### High Pass Filters (HPF)

A **High pass filter** is a circuit that only allows signals above a particular frequency called cut-off frequency to pass through it. An ideal HPF blocks signals whose frequency is below the cut off frequency  $f_c$  as shown in Fig 7a. The frequency response of a practical HPF is shown in Fig 7b.

### Applications of High Pass Filters

High pass filters are used in wide variety of applications. A few such applications are;

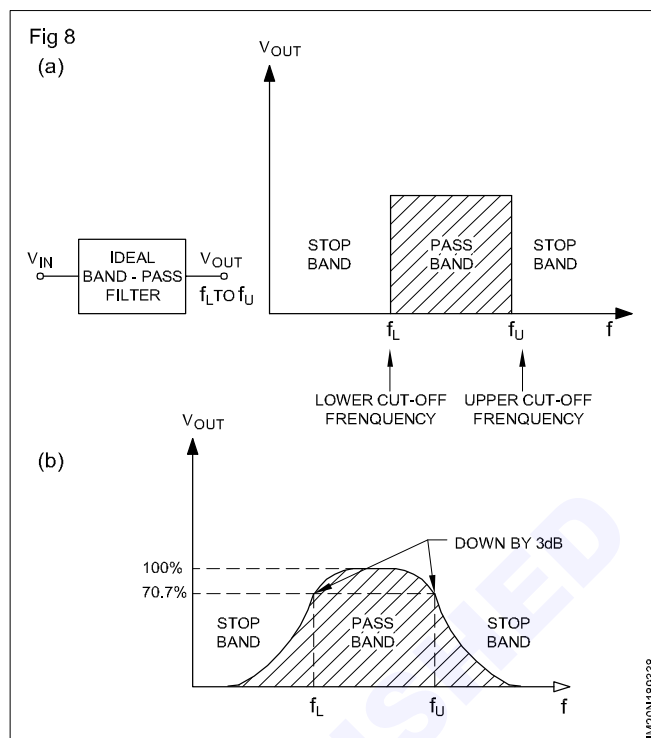
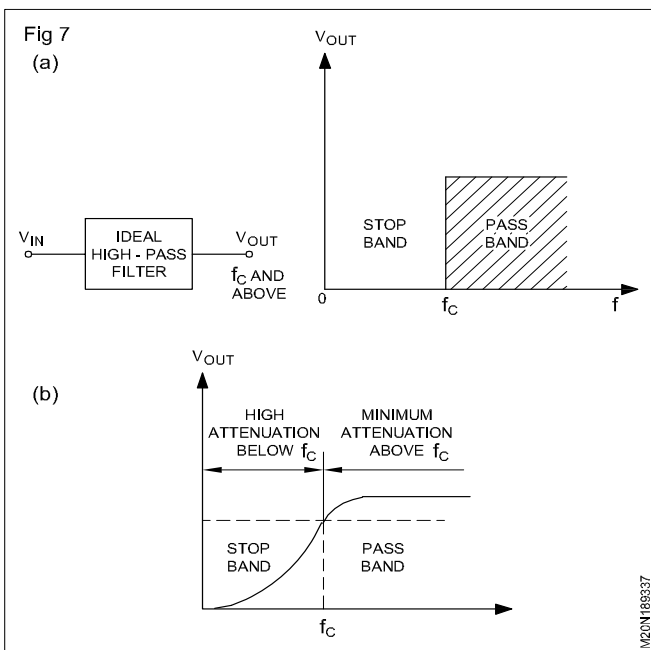
- in tape recorders and amplifier tone control network
- in loud speaker cross over network
- in scratch filters
- in communication transmitters and receivers.

### Band Pass Filters (BPF)

A **band pass filter** is a circuit that allows all the signals whose frequency is between two frequency limits called **lower cut off frequency ( $f_L$ )** and **upper cut off frequency ( $f_U$ )**. Band pass filter heavily attenuates signals whose frequency is less than the lower cut off frequency or more than the upper cut off frequency as shown in Fig 8.

**Applications of Band Pass Filters :** Band pass filters are used in wide variety of applications. A few such applications are;

- in cross over network
- as voice filters in amplifiers
- in graphic equalizer networks
- in communication transmitters and receivers.



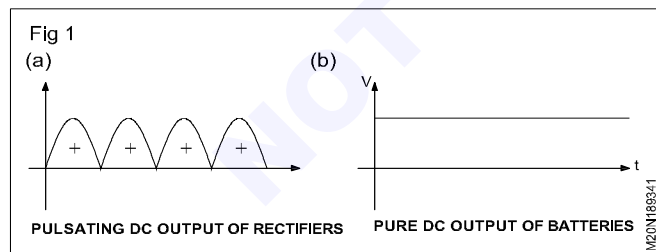
## Ripple filters for rectifiers

**Objectives :** On completion of this lesson you shall be able to

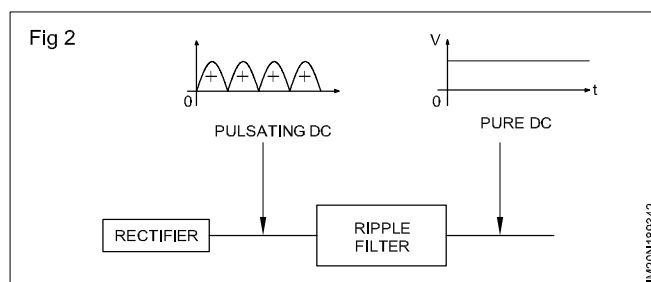
- state the need for filtering pulsating DC
- describe how a capacitor filters the pulsating DC
- state the value of ripple after filtering, using a capacitor input filter in the half wave rectifiers
- state the value of filtered DC output in terms of rms and peak value of input AC in the half wave rectifiers
- design a simple capacitor filter using 10% ripple rule for a full wave rectifier
- state the working of RC  $\pi$  filters
- state how inductors can be used to smoothen pulsating DC
- state the output level and the ripple level of a choke input filter.

### Ripple filters

The output of rectifiers is a pulsating DC voltage as in Fig 1a and not a pure DC voltage like the output of cells or a battery as shown in Fig 1b.



Pulsating DC voltages cannot be used in most of the electronic circuits like radios, tape recorders etc. These circuits require pure DC voltage similar to that of the output of a battery as shown in Fig 1b. Hence, it is required to remove or at least reduce the pulsation in the output of the rectifier circuits. The circuits used to filter off or reduce the pulsation in the DC output of rectifiers are known as smoothing circuits or more popularly as *ripple filters* as shown in Fig 2.

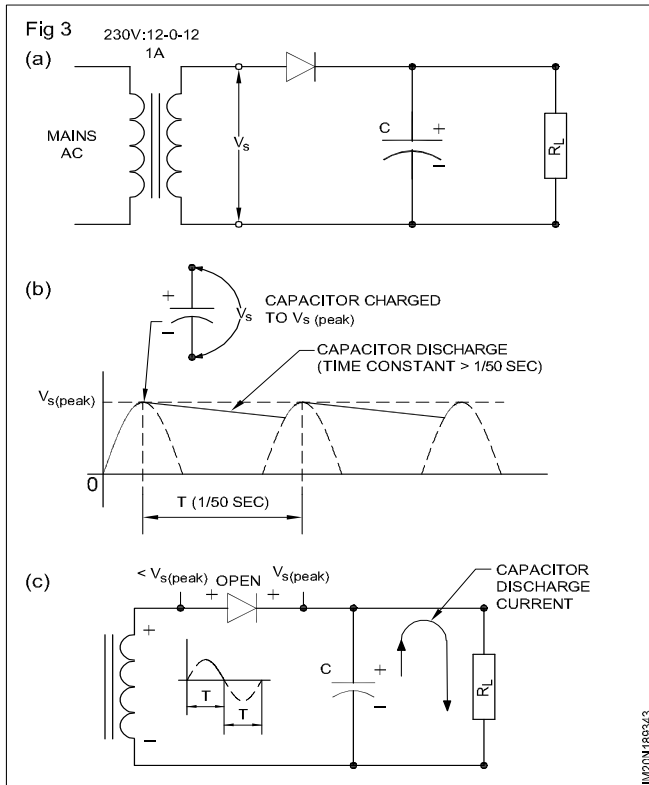


### Capacitor input filters

The most important component used in any ripple filter circuit is the capacitor. Since capacitors store Electronics energy and release it when required. This property of a capacitor is made use of in smoothing the pulsating output of rectifiers.

### Filtering output of Half-wave rectifiers

Fig 3a shows a capacitor input filter connected at the output of a half-wave rectifier.



During the first quarter cycle of source voltage  $V_s$ , the diode is forward-biased and ideally behaves like a closed switch. Since the output of diode is connected directly across the capacitor, the capacitor charges to the peak voltage  $V_{s(\text{peak})}$  as shown in Fig 3b.

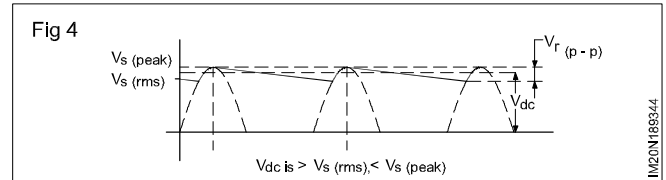
As shown in Fig 3b, when the input  $V_s$  just passes the positive peak, the diode stops conducting. This is because, the capacitor has  $V_{s(\text{peak})}$  volts across it with the polarity shown in Fig 3c. When  $V_s$  passes its +ve peak, the voltage at the anode of diode is slightly less than  $V_{s(\text{peak})}$ . Hence, the diode is reverse biased and behaves like a open switch.

With the diode open, the capacitor discharges through the load resistance  $R_L$ . By deliberate design, the discharging time constant (product of  $R_L$  and  $C$ ) is made much greater than the period  $T$  of the input signal. Because of this, the capacitor will discharge only a small portion of its stored charge during the OFF time of the diode, as shown in Fig 3b.

By the time the capacitor loses a small portion of its charge, the source voltage again reaches its peak, the diode again conducts and recharges the capacitor to the peak voltage  $V_{s(\text{peak})}$ . This process of charging during a brief period of positive peak and discharging during the falling period of the positive peak continues as shown in Fig 3b.

From Fig 3b, it can be seen that the voltage across the load resistor is almost a pure DC voltage. The only variation from the pure DC voltage is the small ripple caused by charging and discharging of the capacitor.

As the capacitor charges to the peak value of the input  $V_{s(\text{peak})}$  and discharges only a small portion of it, the DC output of the half-wave rectifier, instead of  $0.45 V_{s(\text{rms})}$  is only slightly less than  $V_{s(\text{peak})}$  as shown in Fig 4.



From Fig 4, the exact value of DC voltage and ripple voltage can be calculated as given below;

$$V_{dc(HW)} = V_{s(\text{peak})} - \frac{V_{r(p-p)}}{2} \quad \dots[1]$$

where,

$V_{r(p-p)}$  = peak-to-peak ripple voltage, in volts

$I_L$  = required DC load current, in Amps

$f_r$  = ripple frequency in Hz

$C$  = capacitance in Farads.

Fixing the permissible  $V_{r(p-p)}$  and knowing  $f$  and  $I_L$  the required value of  $C$  can also be found using this formula.

While designing a filter circuit, the following methods can be used to calculate theoretically the ripple voltage in the output of the filter circuit;

#### METHOD

The method of expressing the ripple in the output DC is by *ripple factor  $r$* , defined as,

$$\text{Ripple factor, } r = \frac{V_{r(\text{rms})}}{V_{dc}}$$

where,

$r$  = ripple factor (dimensionless)

$V_{r(\text{rms})}$  = rms value of ripple voltage

$$= \frac{V_{r(p-p)}}{2\sqrt{3}}$$

$V_{dc}$  = DC output voltage.

If the  $R_L C$  time constant is large enough such that the capacitor is recharged in a short time compared with half the period  $T$  of input AC, the theoretical value of the ripple factor can be calculated using the formula,

$$r = \frac{1}{2\sqrt{3} f R_L C} \quad (\text{for halfwave}) \quad \dots[2]$$

where,

$r$  = the theoretical ripple factor for a half-wave

$C$  = capacitance in  $\mu F$

$R_L$  = load resistor in ohms

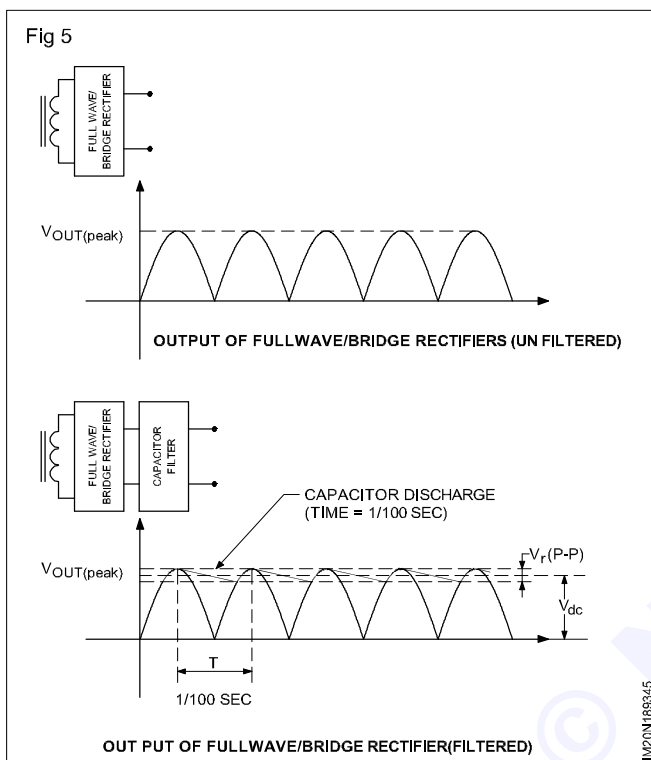
$f$  = mains supply frequency in hertz.

From equation 2 above, it is clear that one way to reduce the ripple is by increasing the discharging time constant,

$R_L C$ . In other words, increasing the value of  $C$  or  $R_L$  the time constant becomes larger, and, larger the time constant, purer is the DC output of the filter.

### Filtering output of Full wave and Bridge rectifiers

In a full wave rectifier or bridge rectifier, the ripple frequency is double the supply frequency as shown in Fig 5. As a result of higher ripple frequency, when compared with half wave rectifier (Fig 4), the capacitor gets charged twice as often and has only half the discharge time as shown in Fig 5.



Therefore, the ripple in the filtered output is smaller and the DC output voltage approaches more closely the peak voltage  $V_{S(peak)}$ .

The formulae used for calculating the ripple in the output or the ripple factor is the same as discussed for half-wave rectifiers.

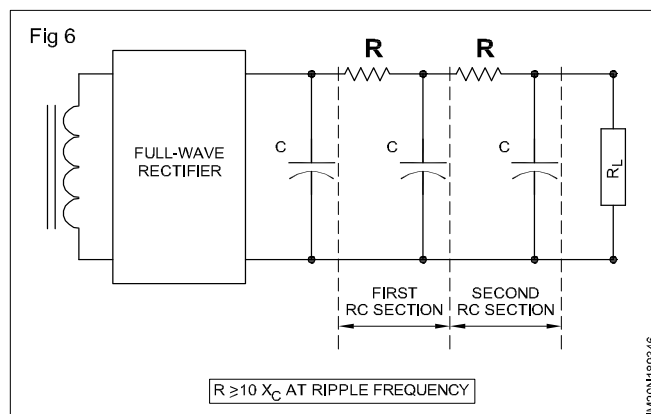
### Ripple filter design guidelines

While designing a capacitor-input filter, you need to choose a capacitor that is large enough to keep the ripple small. How small is the ripple depends on how large is the capacitor. As capacitor becomes larger, it costs more and hence, more expensive will be the filter circuit.

Most designs use the **10 percent rule**. This says, select a capacitor that will hold the peak-to-peak ripple at approximately 10 percent of the peak voltage  $V_{S(peak)}$ .

### RC filters

With the 10 % ripple rule we get a peak-to-peak ripple of around 10 percent of the DC load voltage. To further reduce the ripple at the output, filters as shown in Fig 6 may be connected between the filter capacitor and the load. These are known as RC  $\pi$  filters. These filters reduce the ripple in the output to less than 1 percent making the output a pure DC similar to the output of a battery.



In Fig 6, the two RC filter sections are connected between the input capacitor  $C$  and the load resistor  $R_L$ . While designing these filter sections, the value of  $R$  is made much greater than  $X_C$  at the ripple frequency. Therefore, a major portion of the ripple voltage gets dropped across  $R$  instead of across the load resistor  $R_L$ . Typically, the value of  $R$  must be at least 10 times greater than  $X_C$  at the ripple frequency. This results in each RC section attenuating (reducing) the ripple by a factor of 10. Thus more the number of sections of RC, less is the ripple across  $R_L$  and purer is the DC output voltage across  $R_L$ .

The main disadvantage of the RC filter sections is the loss of DC voltage across each  $R$ . Hence, RC filter circuits are suitable only for small load currents or for large load resistance.

### Inductor input filters

An alternative to using a capacitor in parallel with the load resistor, is to use an inductor in series with the load as shown in Fig 7. Since an inductor opposes any change in current through it, the inductor coil will cause a smoothing effect in the output as shown in Fig 7. Here the inductors are called *Chokes* as they choke the ripple.

If the coil resistance of the inductor is neglected (being very small), the DC output will be,

$$V_{dc} = 0.636 V_{S(peak)} \text{ as in the case of capacitance filter.}$$

If the resistance of the coil is considered, the DC output will be slightly less due to the  $I_R$  drop across the coil.

### LC filters

For large load current requirements, instead of RC filters, LC filters as shown in Fig 8 are preferred. The reason is, a large portion of the ripple voltage is dropped across the inductor with minimum DC voltage drop because inductors have only a small winding resistance.

In Fig 8,  $X_L$  is made much greater than  $X_C$  at the ripple frequency. Hence, the ripple across the load is reduced to extremely low levels.

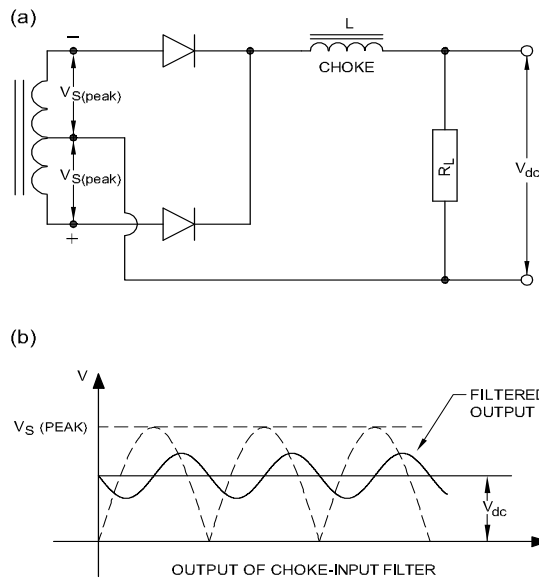
Neglecting the choke's resistance, the DC output voltage is given by,

$$V_{dc} = 0.636 V_{S(peak)} \text{ as in the case of a capacitor input filter.}$$

The ripple factor,  $r$  is given by,

$$r = \frac{0.7}{LC} \dots [3]$$

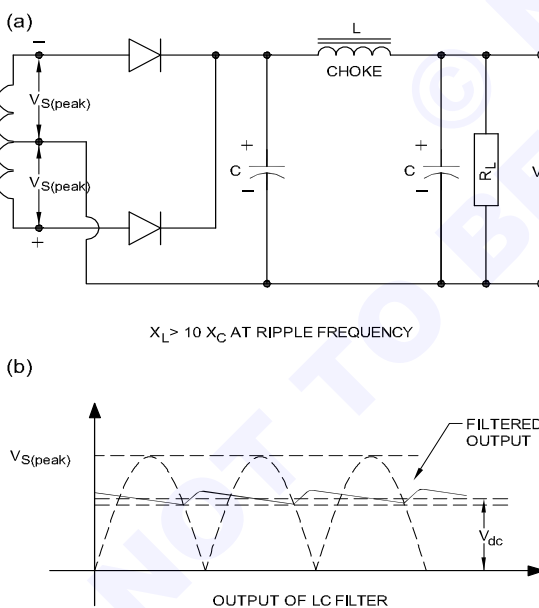
Fig 7



From the above equation for  $r$ , unlike in case of capacitor input filter, it can be seen that in a LC filter circuit the ripple factor is not determined by the value of the load resistor. Hence, with a capacitor and inductor in the filter circuit, the ripple is independent of the load current.

Now a days LC filters are being replaced by integrated circuit (IC) voltage regulators, active filter circuits which reduce the ripple and keep the DC voltage constant.

Fig 8



### Voltage multiplier

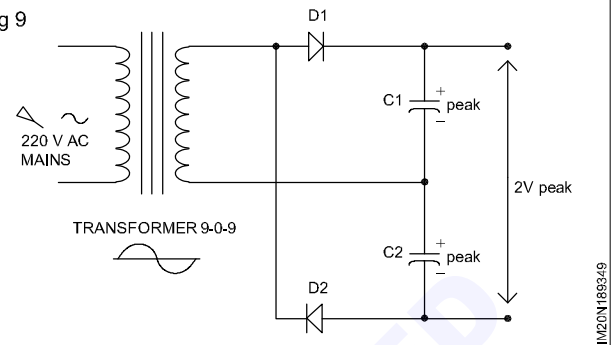
The voltage multiplier is a type of diode rectifier circuit which can produce an output voltage any time greater than the applied input voltage. Although it is usual in electronic circuit to use a voltage transformer to increase a voltage sometime a suitable step-up transformers are required for high voltage applications may not always be available. So we are using voltage multiplier circuit which increases or steps-up the voltage without use of transformer.

### Application

It is used in Electronics and electronic circuits application such as microwave oven, CRT strong electric field coils & high voltage test equipments.

### Full wave voltage doubler

Fig 9



The input voltage gets doubled through this circuit. During the positive half cycle sinusoidal wave of AC, Diode  $D_1$  get forward biased and  $D_2$  get reverse biased, so capacitor  $C_1$  charges through the  $P_1$  to the peak value of sine wave ( $V_{peak}$ ) and during the negative half cycle of sine wave,  $D_2$  is forward biased and  $D_1$  reverse biased, so capacitor  $C_2$  gets charged through the  $p_2$  to peak.

Now both the capacitors are charged to  $V_{peak}$  so we get the  $2V_{peak}$  ( $V_{peak} + V_{peak}$ ) across the  $C_1$  and  $C_2$  with no load connected.

### Voltage tripler circuit

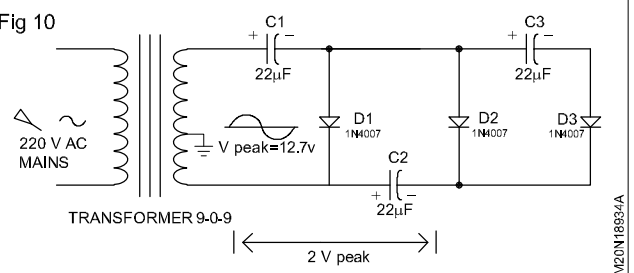
In this we need to add 1 more diode and capacitor to the half wave voltage double circuit.

In first positive half cycle capacitor  $C_1$  gets charged to  $V_{peak}$  and capacitor  $C_2$  charged to  $2V_{peak}$  in the negative half cycle.

Now, during second positive half cycle, Diode  $D_1$  and  $D_3$  conducts and  $D_2$  gets reverse biased. In this way capacitor  $C_2$  charges the capacitor  $C_3$  up to the same voltage as itself, which is  $2V_{peak}$ .

Now the capacitor  $C_1$  and  $C_3$  are in series and voltage across  $C_1$  is  $V_{peak}$  and voltage across  $C_3$  is  $2V_{peak}$  so the voltage across the series connection of  $C_1$  and  $C_3$  is  $V_{peak} + 2V_{peak} = 3V_{peak}$  and get triple the voltage of input  $V_{peak}$  Volt.

Fig 10



### Voltage divider circuit

A voltage divider circuit or a potential divider circuit is a simple electronics circuit that converts a higher input voltage to a lower output voltage just by using a couple of



resistors. It is often used in analog circuits like op-amp based circuits for example, where the required voltage may be variable.

The following images shows as a simple voltage divider circuit consisting of two resistors R1 and R2. VIN is the input voltage while VOUT is the output voltage taken across the resistor R2.

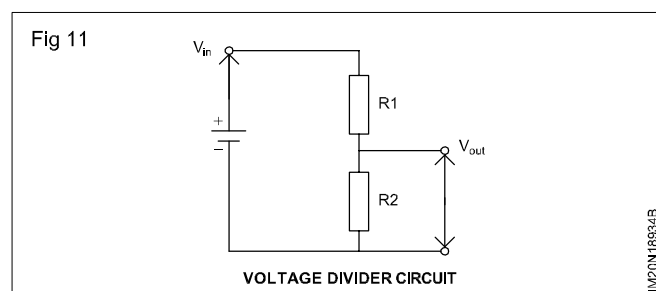
Thus, just by using two resistors R1 and R2, we can convert any input voltage VIN to any desired output voltage VOUT by appropriately choosing the values of R1 and R2.

### Voltage Divider Equation

The formula for calculating the output voltage VOUT of a voltage divider network is given below:

$$V_{OUT} = (V_{IN} * R_2) / (R_1 + R_2)$$

Where, VIN = Input Voltage



VOUT = Output Voltage

R1 and R2 values of two resistors.

From the above equation of the Voltage Divider formula, we can confirm that the scaling factor for the output voltage is determined by the ratio  $R_2 / (R_1 + R_2)$ .

### Deriving voltage divider equation

The basis for the voltage divider circuit is the Ohm's Law. In fact, we can derive the voltage divider equation simply by using the Ohm's Law. We know according to Ohm's law that current flowing in a circuit is directly proportional to the voltage to potential difference across the circuit.

In the above statement, the proportionality constant is the resistance of the circuit (or component).

Using Ohm's Law in the above circuit, we can calculate the input voltage as

$$V_{IN} = I * R_1 + I * R_2 = I * (R_1 + R_2)$$

Similarly, the output voltage is

$$V_{OUT} = I * R_2$$

If we observe the above two equations, it is clear that the current is same in both the equations and hence we can re-write the above equations as follows:

$$I = V_{IN} / (R_1 + R_2) \text{ and}$$

$$I = V_{OUT} / R_2$$

Equating the above two equations, we get

$$V_{OUT} / R_2 = V_{IN} / (R_1 + R_2)$$

$$\text{Finally, } V_{OUT} = V_{IN} * R_2 / (R_1 + R_2)$$

### Example

Let us see an example for the voltage divider equation. Let VIN be 5V and the values of R1 and R2 are 10000 Ω (10 KΩ) and 20000 Ω (20 KΩ) respectively. From the above given equation, we can calculate the value of VOUT as follows:

$$V_{OUT} = 5 * 20000 / (10000 + 20000)$$

$$V_{OUT} = 3.3V$$

This combination of R1 as 10KΩ and R2 as 20 KΩ is one of the commonly used voltage divider circuits to convert a 5V level signal to a 3.3V level signal.

### Applications

Voltage dividers are quite commonly used in analog as well as digital circuits. Some of the common applications of voltage divider circuits are mentioned below.

#### 1 Level shifters

One of the main applications of a voltage divider is to act as a level shifter. As already mentioned in the introduction, if the microcontroller and a sensor are working at different voltage levels, then a simple level shifter consisting of a couple of resistors configured in voltage divider fashion will do the job.

A typical requirement is to convert a 5V signal from a Microcontroller to a 3.3V signal for the sensor. We can do this by simply using two resistors of 10KΩ and 20 KΩ as R1 and R2.

#### 2 Potentiometers

Potentiometer or simply a POT is a variable resistor with three terminals. Using a potentiometer, you can implement a voltage divider circuit with variable output voltage. You can achieve this by connecting the input voltage across the extreme pins of the potentiometer and taking the output across the wiper terminal.

By adjusting the position of the wiper of the potentiometer, the output voltage also varies.

#### 3 Resistive sensors (LDR and Thermistor)

Two of the commonly used sensors in DIY Projects are LDR (Light Dependent Resistor) and Thermistor. Both these sensors are of resistive type. But the problem is that a Microcontroller like Arduino for example, will only read voltages at the input.

By connecting the resistive sensors (LDR or Thermistor) in a voltage divider circuit, you can obtain the voltage across the sensor and program the microcontroller to scale the value accordingly.

## Voltage regulators

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

- state the need of regulators in power supplies
- state the formula to calculate the % load regulation factor
- explain the important specifications of a zener diode
- explain working characteristic, application and specification of varactor diode.

### Voltage regulators

The DC output voltage level of power supplies such as, full-wave and bridge rectifiers, tend to decrease or increase,

- when the load current increases or decreases
- when the AC input voltage level decreases or increases.

Such variations in the output DC voltage level of power supply is not acceptable for most of the electronic circuits. Hence, it is required to regulate the DC output of power supplies so as to keep the DC output level constant, inspite of variations in the DC load current or the AC input voltage. Circuits or components used to keep the DC output voltage of a power supply constant are called voltage regulators.

### Regulation factor

The ability of a power supply to maintain a constant DC output voltage for variations in the load current is referred to as load regulation. Load regulation of a power supply is generally given as a percentage.

$$\text{Load regulation factor \%} = \frac{V_{NL} - V_{FL}}{V_{NL}} \times 100$$

where,

$V_{NL}$  = DC output at no load or open circuit

and  $V_{FL}$  = DC output at rated full load.

It should be noted that lower the percentage of load regulation factor, better is the voltage regulation.

**Example:** The DC output of a power supply is 12 volts at no-load and 11 volts at full load.

$$\% \text{ Load regulation} = \frac{12 - 11}{12} \times 100 = 8.33\%$$

In practice the load regulation of a good power supply should be less than 0.1 %.

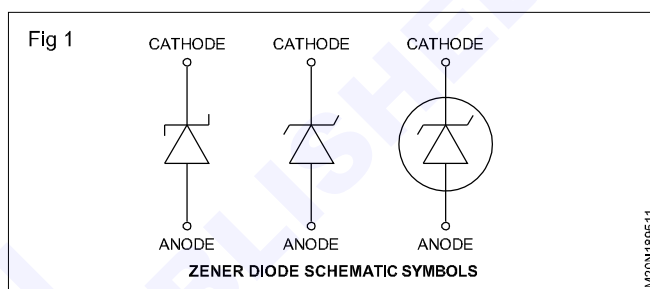
Regulating the DC output voltage for variations in the input AC level is termed as line regulation. This is discussed in further units.

### The zener diode

In a power supply one of the simplest ways of regulating the DC output voltage (keeping the output voltage constant) is by using a zener diode. With zener in reverse breakdown condition, the voltage across the zener diode remains constant for a wide range of input and load variations.

Because of this property, zener diodes are also known as voltage regulators or voltage reference diodes. Fig 1 shows the symbol used for zener diodes.

The difference between a rectifier diode and a zener diode are listed below;

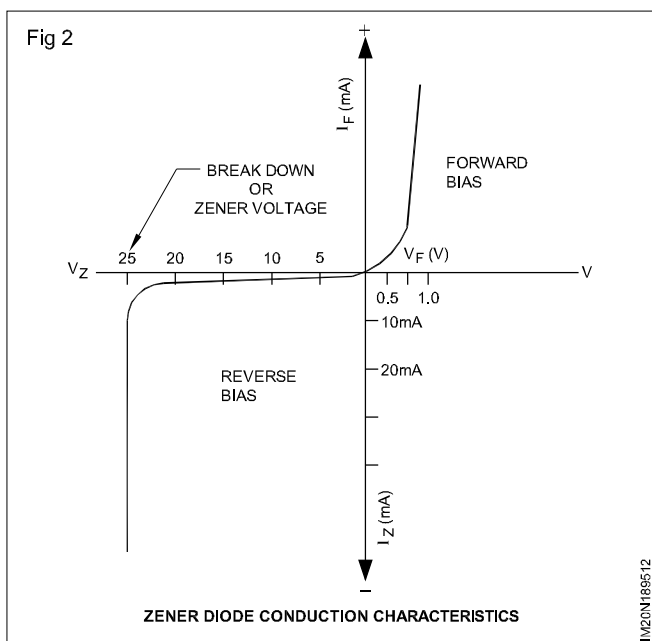


- Compared to normal rectifier diodes, zener diodes are heavily doped.
- Unlike ordinary diodes which do not work in the breakdown region, zener diodes work only in the breakdown region.
- Generally rectifier diodes are used in forward-biased condition, whereas zeners are always used in reverse-biased condition.
- The reverse breakdown voltage of zener diodes is very much less (3 to 18V) compared to rectifier diodes (minimum 50V).

The similarities of a zener diode with those of general purpose rectifier diodes are listed below;

- Zener diodes are also PN junction diodes, which are also generally made of silicon.
- Zener diodes also have two terminals (anode and cathode).
- In physical appearance, the zener diodes and ordinary diodes look alike.
- Like rectifier diodes, zener diodes are also available with glass, plastic and metal casing.
- The anode and cathode marking technique on the body is same for both zener and rectifier diodes.
- The zener can be tested with an ohmmeter in the same way as in rectifier diodes.
- Zener requires approximately the same voltage for it to be forward-biased into conduction as that of an ordinary diode.

Fig 2 shows the conduction characteristics of a typical zener diode. Because of the nature and heavy doping in a zener, its characteristics are different compared to a rectifier diode.



Note that, the zener diode acts as a rectifier diode when forward biased. It also behaves as a rectifier diode when reverse-biased, till the voltage across it reaches the break-down voltage. As can be seen from Fig 2, even the reverse or leakage current remains almost negligible and constant despite the increase in the reverse-biased voltage till the break down voltage, also called zener voltage is reached. But, Once the zener break-down voltage is reached, the diode current begins to increase rapidly and the zener suddenly begins to conduct. In the case of a normal rectifier diode, once the break down voltage is reached the diode gets punctured and starts conducting heavily whereas, in a zener diode, the diode does not get punctured even though it conducts current in the reverse biased condition.

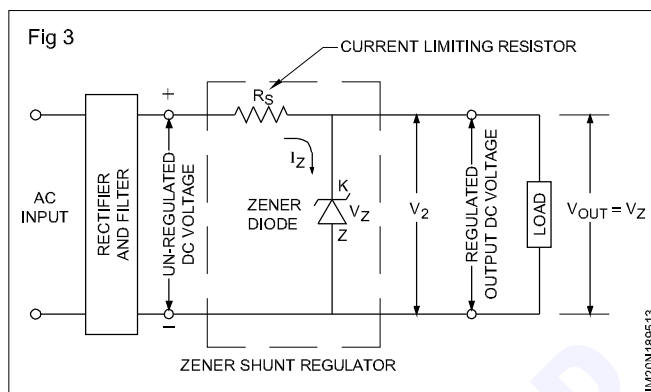
The cause for this reverse conduction is referred to as the avalanche effect. The avalanche effect cause, the electrons to be knocked loose from their bonds in the crystal structure. As more electrons are loosened, they in turn knock others and current builds quickly. This action causes the voltage drop across the zener to remain constant regardless of the zener current. As shown in Fig 2, once the zener voltage is reached, very small voltage changes create much greater current changes. It is this characteristic, which makes the zener useful as a constant voltage source or as a voltage regulator.

Unlike in a rectifier diode, the reverse current through the zener is not destructive. If the current is kept within the specified limits depending upon the wattage rating of the zener, using a suitable series resistance, no harm is done to the zener diode.

Because the zener diode is designed to operate as a breakdown device, the zener can be brought out of condition easily. A zener is brought out of its zener conduction by lowering the reverse-biased voltage below the zener voltage or by reversing the polarity of the applied voltage.

## Application of zener diodes

The most popular use of zener diodes is as voltage regulators in DC power supplies. Fig 3 illustrates a simple zener regulated power supply.

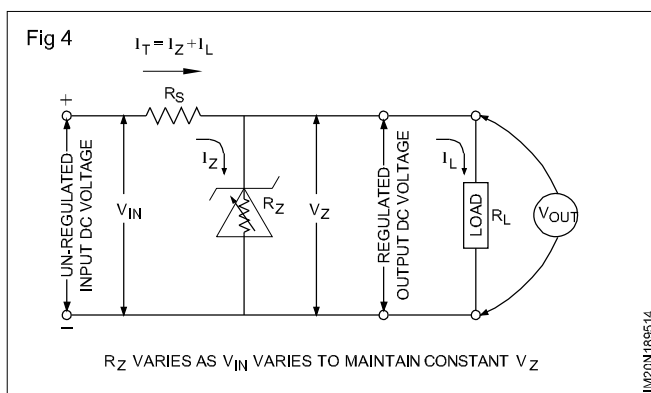


In the circuit at Fig 3, the zener diode is in parallel with the output or load of the power supply. It is very important to note that the zener is connected in the reverse-biased condition. Such a parallel circuit connection is often called a shunt. When used in this way, the zener is said to be a shunt regulator.

In Fig 3, the zener begins to conduct in the reverse-biased condition as the voltage across it reaches the zener voltage  $V_Z$ . The voltage across the zener remains constant immaterial of the input DC voltage. Since the load is in parallel with the zener, the voltage across the load  $V_{OUT}$  will be same as the voltage across the zener  $V_Z$  ( $V_{OUT} = V_Z$ ).

If the input DC voltage to the zener increases, as can be seen from its characteristics in Fig 2, the current  $I_Z$  through the zener increases but the voltage across the zener remains the same due to avalanche effect. Because the zener voltage,  $V_Z$  does not change, the output voltage  $V_{OUT}$ , does not change and so the voltage across the load is constant. Thus, the output is said to be regulated.

Referring to Fig 4, the zener can be looked at as an automatically changing resistance. Total current through the resistance  $R_S$  is given by,



$$I_T = I_Z + I_L$$

Thus the voltage across  $R_S$  is,

$$V_R = (I_Z + I_L) R_S$$

If the input DC voltage  $V_{IN}$  increases, output voltage  $V_{OUT}$  tends to increase. In the meantime, the zener conducts more heavily, causing more current (more  $I_Z$ ) to flow through  $R_S$ . Hence, more voltage drop occurs across  $R_S$ . This increase in drop across  $R_S$  offsets the increase in the output voltage  $V_{OUT}$ , thus retaining the voltage across load  $R_L$  at its original value. Likewise, if the value of  $R_L$  is decreased (increased  $I_L$ ), current through the zener  $I_Z$  decreases, retaining the value of  $I_T$  through  $R_S$ . This ensures sufficient load current through the load  $R_L$  without decrease in the level of  $V_{OUT}$ .

### Zener specifications

Like in rectifier diodes, the type-code number is marked generally on the body of the zener. From the type-code marked, detailed specifications of the zener can be found referring to any standard diode data manual.

Important zener diode specifications are listed below;

- **Nominal Zener voltage,  $V_Z$ :** This is the reverse biased voltage at which the diode begins to conduct in reverse bias.
- **Zener voltage tolerance:** Like the tolerance of a resistor, this indicates the percentage above or below  $V_Z$ . For example,  $6.3\text{ V} \pm 5\text{ percent}$ .
- **Maximum zener current,  $I_{Z,max}$ :** This is the maximum current that the zener can safely withstand while in its reverse-biased conduction (zener) mode.
- **Maximum power dissipation,  $P_Z$ :** is the maximum power the zener can dissipate without getting damaged.

- **Impedance ( $Z_Z$ ):** The impedance of the zener while conducting in zener mode.
- **Maximum operating temperature :** The highest temperature at which the device will operate reliably.

These specifications of zener diodes are given in diode data books.

The example given below enables to interpret the specifications of certain types of zener diodes without the need to refer diode data book:

**Example 1:** The type-code printed on a zener is BZ C9V1.

#### BZ C9V1

| B       | Z     | C            | 9V1  |
|---------|-------|--------------|------|
| silicon | zener | 5% tolerance | 9.1V |

**Example 2:** The type-code printed on a zener is 1Z 12.

#### 1Z 12

| 1                                          | Z     |                                        | 12  |
|--------------------------------------------|-------|----------------------------------------|-----|
| Means a semiconductor with one PN junction | zener | No tolerance code means, 10% tolerance | 12V |

Other popular zener diode type-codes are, 1N750, 1N4000, ZF27, ZP30, DZ12, BZ148, Z6, etc.

## Series regulators and shunt regulators

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

- state the disadvantages of a zener regulator
- state the working of a simple series regulator
- design a simple series regulator for a required dc output voltage
- write the blocks of a series regulator with voltage feedback and explain their functions
- design a series regulator for a given input-output specification
- design a shunt regulator and explain their functions.

### Disadvantages of a zener regulator

Voltage regulated power supply using zener diode discussed in previous Lesson is the simplest form of voltage regulator. But, zener voltage regulators have two main disadvantages:

- 1 When the load current requirement is higher, say of the order of a few amperes, the zener regulator requires a very high wattage zener diode capable of handling high current.
- 2 In a zener regulator, the load resistor sees an output impedance of approximately the zener impedance,  $R_Z$  which ranges from a few ohms to a few tens of ohms (typically  $5\Omega$  to  $25\Omega$ ). This is a considerably high output impedance because the output impedance of a ideal power supply should be zero ohms.

These two disadvantages of zener regulators are overcome in a simple series regulator shown in Fig 1a.

The simple series regulator shown in Fig 1a, redrawn in Fig 1b is nothing but a zener regulator followed by an emitter follower. A circuit like this can hold the load voltage almost constant, thus working as a voltage regulator.

The advantages of this circuit are listed below;

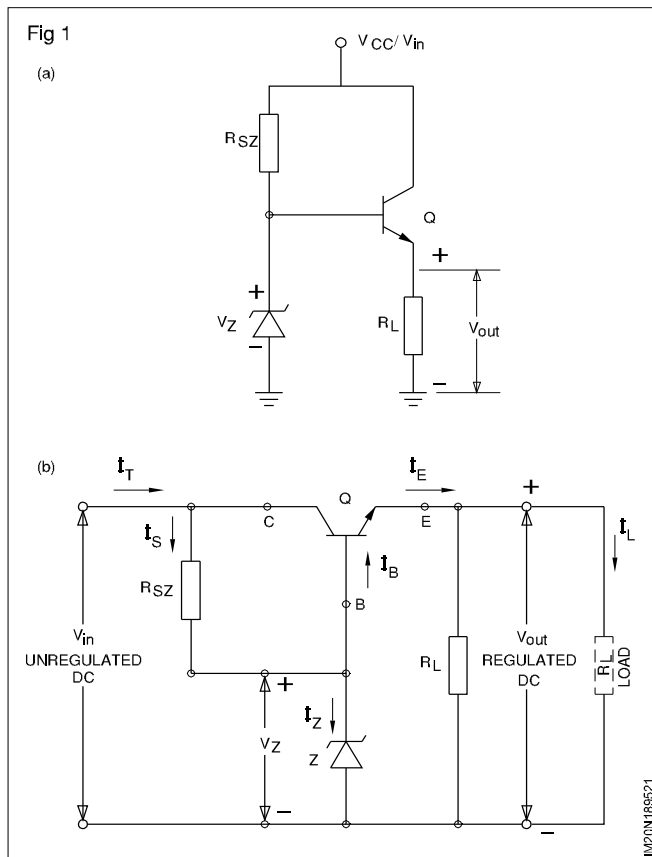
#### 1 Less load on the zener diode

In this circuit Fig 1a or 1b the base current is very much smaller than the emitter current or the load current, a very small wattage zener diode itself is sufficient.

For instance for a load of say 1 amp, if the  $\beta_{dc}$  of the transistor is 100, then the zener diode need to handle only, 20mA for a typical  $I_{Z(min)}$  of 5 to 10mA.



Fig 1



## 2 Lower output impedance

This circuit also offers a lower output impedance of 0.07W which is close to the ideal output impedance of zero required for a power supply. For further information, refer IMP of Electronic Mechanic 1st year.

### Working of a simple series regulator

In Fig 1b, the current through  $R_{SZ}$  should be atleast equal to zener breakdown current, plus, base current for the transistor Q.

The voltage across the zener,  $V_Z$  drives the base of the emitter follower. Therefore, the dc output voltage is bootstrapped to within one  $V_{BE}$  drop of the zener voltage. The regulated dc output voltage will be,

$$V_{out} = V_Z - V_{BE} \quad \dots\dots[1]$$

The collector - emitter voltage across the transistor will be the difference in the voltage between the input and output.

$$V_{CE} = V_{in} - V_{out}$$

If the input voltage  $V_{in}$  increases, the output voltage  $V_{out}$  remains constant due to the bootstrapped zener voltage. Therefore, the drop across the collector-emitter,  $V_{CE}$  of the transistor increases compensating the rise in the input voltage  $V_{in}$ .

For example, in the series regulator shown in Fig 1b, if  $V_{in}$  is 15 V and  $V_{out}$  is 12 volts, then,  $V_{CE}$  will be,

$$V_{CE} = V_{in} - V_{out} = 15 - 12 = 3 \text{ V.}$$

If  $V_{in}$  increases to say 20 V, then  $V_{CE}$  increases to 20-12=8 V, thus keeping the output voltage unaltered at 12 volts.

Since the collector and emitter of the transistor in Fig 1b is in series with the input and output terminals, and carries all the load current and this type of regulators are known as **series voltage regulators**. Hence the transistor is referred to as the pass transistor.

Because of the fact, that all the load current must flow through the pass transistor and that the value of  $V_{CE}$  increases when  $V_{in}$  increases, the wattage rating of the pass transistor should be high enough to handle the dissipation.

For instance, while supplying a load current of 300 mA, with  $V_{in}$  at 20 V and  $V_{out}$  at 12V,  $V_{CE}$  will be 8 V. Therefore, the dissipation at the transistor will be,

$$P_D = V_{CE} \times I_L = 8 \times 300 \text{ mA} = 2400 \text{ mw} = 2.4 \text{ watts}$$

To accommodate this, the wattage rating of the chosen pass transistor should be greater than 2.4 watts.

**TIP:** Allow at least 20% higher rating. For the example above, choose a transistor of rating 2.4 + 0.48 watts 3 watts.

Because there will be quite a high dissipation depending on load current requirement, medium to high power transistors are used as pass transistors.

### Temperature effect on output voltage

When temperature increases,  $V_{BE}$  decreases. Therefore,  $V_{out}$  increases by the change of current in  $V_{BE}$ .

Data sheets of transistors usually give information about how much  $V_{BE}$  changes with temperature.

For all practical purposes, an approximate of 2 mV decreases in  $V_{BE}$  for each degree rise in temperature. For instance when the temperature of the transistor rises from 25°C (room temperature) to 75°C (due to power dissipation at the transistor),  $V_{BE}$  decreases approximately 100 mV. Hence, the output will increase by 100 mV. This is relatively small, and hence, can be neglected.

Temperature also has an effect on the voltage across the zener. Any increase or decrease in the voltage across the zener is reflected at the output. Hence, while choosing the zener, it is equally important to know the temperature coefficient of the zener, specially when the power supply is connected to higher loads of the order of a few amperes.

### Zener based shut regulator

zener diode is used as a voltage regulator that provides a constant voltage from a source whose voltage varies substantially.

As the supply voltage  $V_s$  is increased, in this case, the voltage drop across  $R_L$  will be more as compared to the zener diode breakdown voltage. Thus, causing zener diode to conduct in its breakdown region.

The zener current  $I_z$  is limited by the series  $R_s$  from exceeding rated max value  $I_{zmax}$ .

$$I_s = \frac{V_s - V_z}{R_s}$$



Current through  $R_s$  is given by-

$$I_s = I_z + I_L$$

Source current gets split into  $I_z$  and  $I_L$  at the junction-

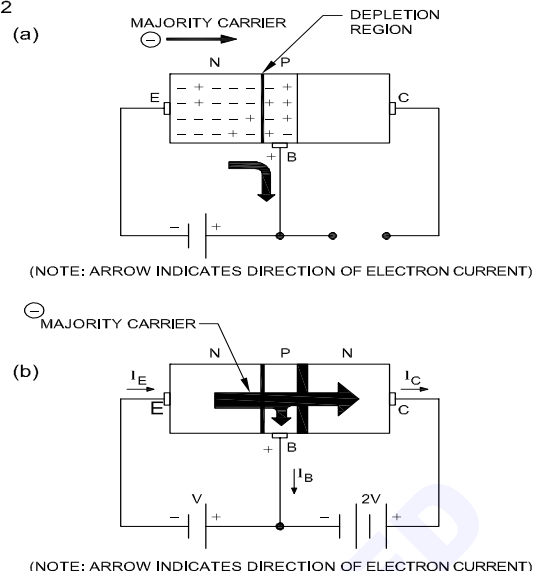
The voltage across zener diode  $V_z$  remains constant until it is operating in breakdown region through the zener current  $I_D$  may vary considerably.

If here, the input voltage is increased further, the current through the diode and load increases. As the resistance across the diode decrease this will cause more current to flow through the diode.

As a result, the voltage drop across  $R_s$  will be more thus the voltage at the output will be a value that is close to the input or supply voltage.

Hence we can say, the zener diode maintains a uniform voltage across the load unless the supply voltage is more than zener voltage.

Fig 2



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## IC voltage regulators and variable regulators

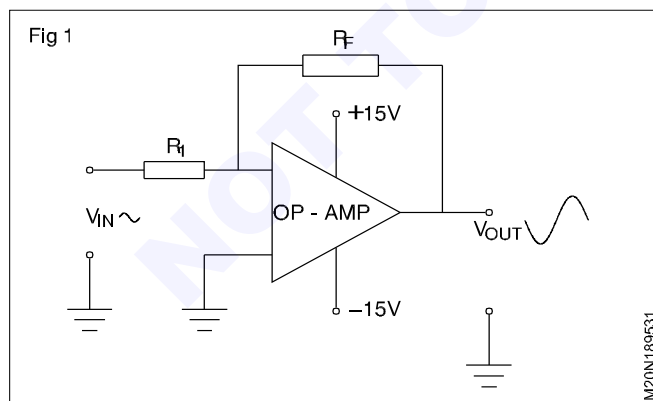
**Objectives:** At the end of this lesson you shall be able to

- explain the dual power supply
- list a few variable regulator 3-pin ICs
- explain feedback and error amplification.

### Dual power supply

Most electronic circuits generally need either a +ve DC supply or a -ve DC supply for its working. However, there are circuits which are designed to work using both +ve and -ve supplies. An example of circuits which require both +ve and -ve supply are the OP-AMPS. OP-AMPS are integrated circuit amplifiers which need, +ve supply, -ve supply and ground. A typical OP-AMP circuit is shown in Fig 1.

Therefore, for circuits which require both +ve and -ve DC supplies, a single power supply which can deliver both  $\pm$  DC is required to be designed. Power supplies which can deliver both  $\pm$  DC are generally referred to as Dual Power Supply.



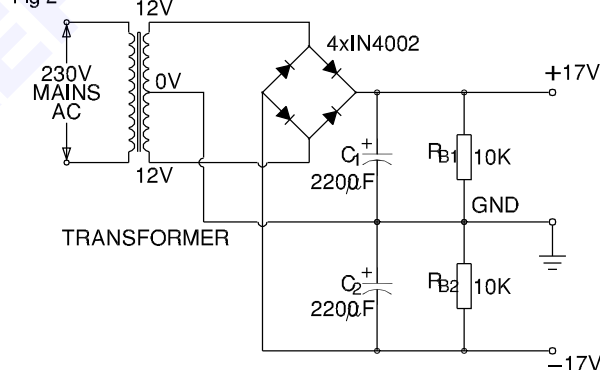
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To design a  $\pm$  or dual regulated power supply, as a first step it is required to design a  $\pm$  unregulated DC supply. Fig 2 shows a simple method of obtaining  $\pm$  unregulated DC supply.

Once, a  $\pm$  unregulated DC supply is available, one each of +ve regulator 3-terminal IC and a -ve regulator 3-terminal IC can be attached, to obtain a  $\pm$  regulated DC supply. One

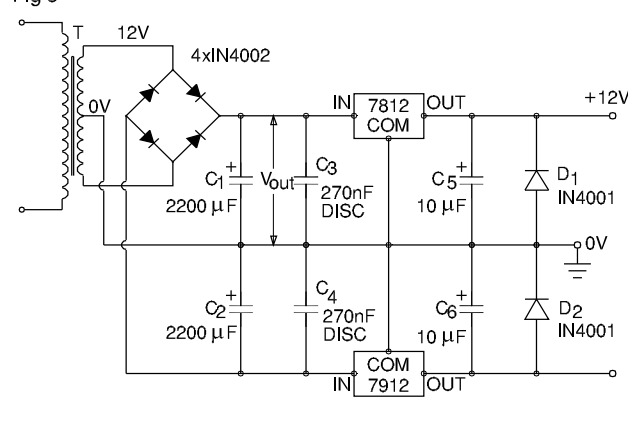
such  $\pm$  regulated DC supply using 7812 (+ve regulator) and 7912 (-ve regulator) is shown in Fig 3.

Fig 2



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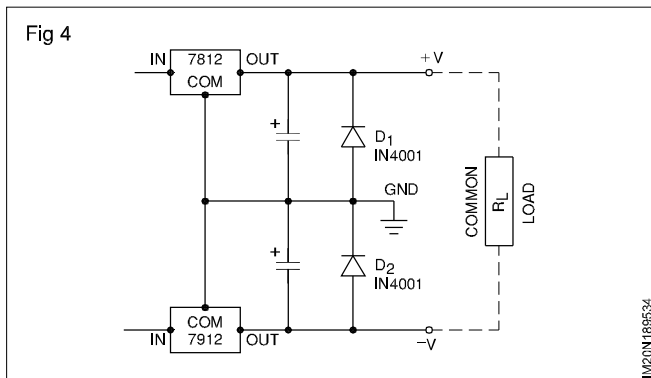
Fig 3



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The +ve and -ve regulator circuits shown in Fig 3. The function of diodes is very important. If these diodes  $D_1$  and  $D_2$  are not used, the regulator ICs may get damaged due to

common load problems. The term common load means, a load connected across the +ve and -ve outputs of the regulator as shown in Fig 4. Because of the fact that these common leads does not make use of the ground (GND) several problems occur when the supply is switch ON, in case of over loads and so on. Hence to avoid the common load problem in dual power supplies diodes  $D_1$  and  $D_2$  are very essential.



### Variable/adjustable output voltage regulators

A number of IC voltage regulators are available using which an adjustable output voltage of 1.2V to 32 volts can be obtained. Amongst these adjustable output voltage regulators, there are two types:

3-Terminal variable output voltage regulators ICs

Multi-terminal variable output voltage regulator ICs

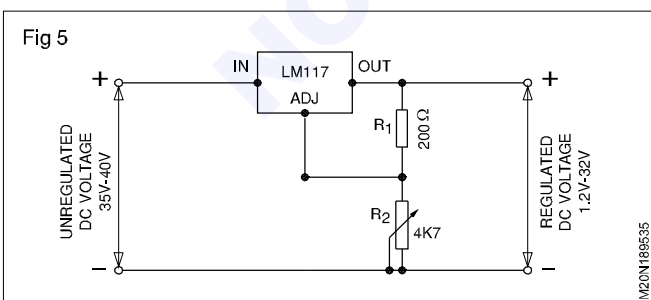
### 3-Terminal variable output regulators ICs

These ICs look like 3-terminal fixed output voltage regulators as shown in Fig 3. A few examples of 3-terminal adjusted output voltage regulator ICs are,

- LM117 Output adjustable from 1.2 V to 37 V
- LM317 Output adjustable from 1.2 V to 32 V
- LM338 Output adjustable from 1.2 V to 32 V
- LM350 Output adjustable from 1.2 V to 33 V

These variable output voltage regulator ICs are designed for adjustable output voltage, unlike the fixed output 3-pin regulators such as 7812, LM 340-5 etc which can be modified to get variable output voltage.

Fig 5 shows a basic variable output voltage regulator.



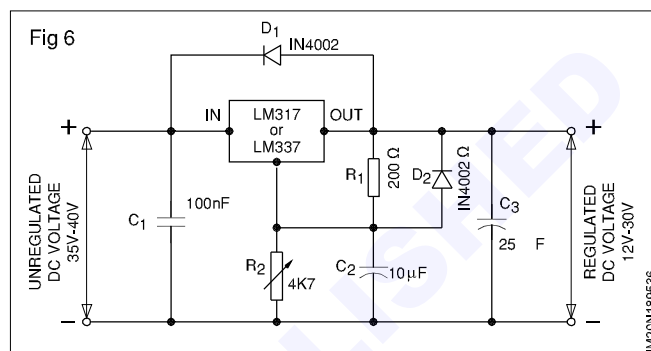
In the circuit at Fig 3, if the adjustment terminal (ADJ) is grounded, the output of the regulator will be 1.2 volts. To obtain a higher output voltage a small reference voltage is given at ADJ using a voltage divider circuit consisting of  $R_1$

and  $R_2$  as shown in Fig 5. With this the regulated output voltage is approximately given by

$$V_{out} = 1.2 \text{ V} \times (1 + (R_2 / R_1)) \quad \dots\dots\{1\}$$

A practical version of the circuit at Fig 3 is shown in Fig 6. This circuit uses a few bypass capacitors and protection diodes.

In Fig 6, capacitor  $C_1$  is used to prevent setting up of the oscillations and should be connected as close to IC as possible. Capacitor  $C_2$  is used to improve the ripple in the output voltage. Note that the value of  $C_3$  should not be very high (recall, surge current). Capacitor  $C_2$  is used to avoid excess ringing.



When external capacitors are used with any IC regulator, it is necessary to add protection diodes to prevent the capacitors from discharging through low current points into the regulator. Hence, diodes  $D_1$  and  $D_2$  are used.  $D_1$  protects the IC against shorts due to  $C_3$  and  $D_2$  protects against shorts due to  $C_2$ .

The ICs LM317 and 338 have built in fold back current limiting and thermal protection. These ICs are available in both plastic and metal packages with current ratings from 0.1A (LM317L) to 5A (LM338K).

**LM117, LM317 and LM338 are of the same family ICs, and hence, are interchangeable.**

### Multiple-pin-Variable voltage regulator ICs

Unlike 3-pin fixed output voltage regulators and 3-pin variable output voltage regulators, voltage regulator ICs having multiple pins are designed for versatility. These multiple pin IC regulators can be used as a linear regulator (all the regulators discussed so far), or as a switching regulator (to be discussed), or as a shunt regulator (to be discussed) or as a current regulator (to be discussed).

Generally in multiple pin types of regulators, dissipation limitation of the IC packages restrict the output current to a few tens of milliamps. However, external transistors can be added to obtain currents in excess of 5A.

Some of the multiple pin, versatile IC regulators are, LM100, LM105, LM205, LM305,  $\mu$ A723, CA3085 and so on.

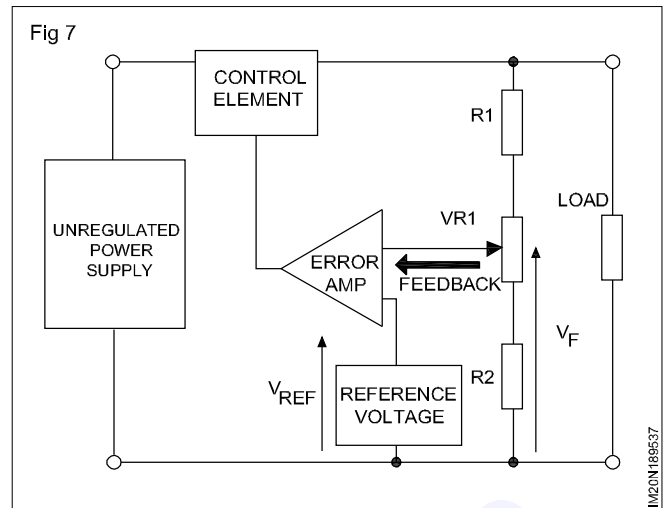
### Feedback and Error Amplification

To improve on the simple series regulator a feedback circuit and error amplifier can be added to the basic series circuit.

Fig 7 shows a block diagram of a series regulator circuit with error amplification. In this system the reference voltage  $V_Z$  is compared with a feedback voltage  $V_F$ , which is a portion of the actual output voltage. The difference between the two inputs produces an error voltage that is used to vary the conduction of the control element, correcting any error in the output voltage.

### Error-correction power amp

Error correction looks at the difference between the amp output and the amp input (taking into account of course the amp gain). Any difference is returned to the input and added to that input, in precisely the right amount to make the output identical to the input. Because the output is now identical to the input, distortion becomes ideally not just smaller, but zero. In practice, this will not happen, as the precision with which you can return the error and add it at the input is always less than perfect. Also, whatever the load, the output stays correct, so it looks as if the output impedance is really zero (or close to it). This technique does not require that the amp (open loop) gain is very, very high. It is enough if the amp has a gain close to the final required gain, and then the ec fills in the missing fraction in the signal.



## Switch Mode Power Supply

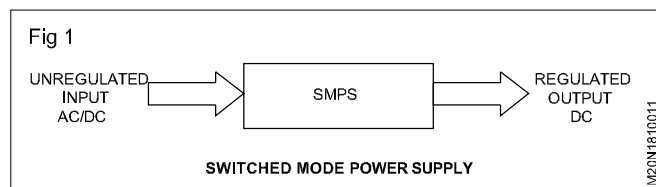
**Objectives :** At the end of this lesson you shall be able to

- state the need for SMPS
- describe the basic concept of SMPS
- compare between linear power supply and SMPS
- explain the working principles of different types of SMPS
- list out the advantages and disadvantages of SMPS
- state the applications and topologies of SMPS.

### Switched-Mode Power Supply(SMPS)

The electronic power supply integrated with the switching regulator for converting the Electronics power efficiently from one form to another form with desired characteristics is called as switched mode power supply. This is working on the principle of switching regulation.

It is used to obtain regulated DC output voltage from unregulated AC or DC input voltage.



The SMPS system is highly reliable, efficient, noiseless and compact because the switching is done at very high rate in the order of several KHz to MHz.

### Need for switch-mode power supplies

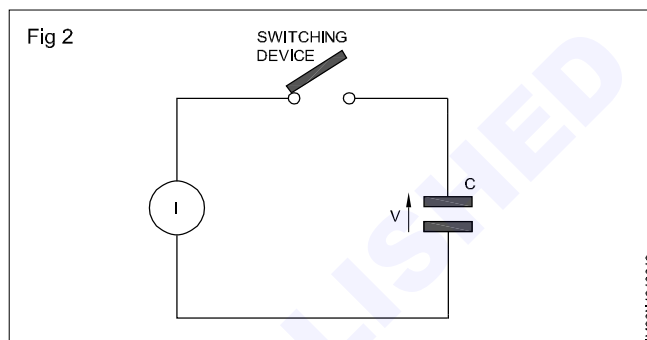
Many household Electronics devices require a supply of voltage which is both constant and well regulated, but the voltage which comes from power outlets are noisy AC voltages. The power from such outlet needs to be managed by electronic circuits which are generally referred to as power supplies, even though the power comes from the outlets.

Basically, the AC supply from the outlet has a sinusoidal wave shape, and it is rectified in order to produce a DC voltage. The noisy high voltage need to be converted to a regulated low voltage so that it can be used by low voltage electronic devices such as TV, DVD, Mobile, etc.

### Basic concept of SMPS

The basic concept of SMPS is the regulation by using a switching regulator. SMPS uses a series switching element that turns the current supply to a smoothing capacitor on and off.

The switching element is turned on is controlled by the voltage on the capacitor. If it is higher than required, the series switching element is turned off, if it is lower than required, it is turned on. In this way the voltage on the smoothing or reservoir capacitor is maintained at the required level.



### Working principles of SMPS

Fig 3 shows the block diagram of SMPS with an AC input and a regulated DC output.

### AC input section

#### Input filter

The AC input from the main supply goes to the input filter to reduce EMI.

Input filter is a protective circuit, which is used to suppress short pulses around the AC voltages. The circuit consists of inductor and high voltage capacitors. A MOV(Metal Oxide Vaistor) is connected across the AC supply to prevent any surge or spikes in the voltages and also PFC circuit is used to correct the power factor.

### Rectifier

AC input is converted to DC voltage using a rectifier diodes. The rectifier consisting of a full wave bridge diode or module and large filter capacitors to obtain a smoothed high DC voltage around 300 V DC. The current is drawn from the mains supply.

### Power section

The power section consists of high frequency ferrite core transformer and switching power transistors (MOSFETs) to switch D.C Voltage across the transformer winding. This section converts the rectified high voltage DC into AC at a frequency of 20 KHz - 100 KHz. A current sense circuit is provided to sense overload current and to protect SMPS from overloading. Since the input voltage is chopped into an AC waveform and placed into a magnetic element additional winding can be added to provide for more than one output voltage.

### Comparison between linear power supply and SMPS

|                                            | Linear power supply                                                                                                                                                                                                                                                                                           | SMPS                                                                                                                                                                                                                                                                                       |
|--------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1 Transformer size and weight              | Heatsinks for high power linear regulators add size and weight.                                                                                                                                                                                                                                               | Smaller transformer                                                                                                                                                                                                                                                                        |
| 2 Operating frequency                      | 50 Hz or 60 Hz                                                                                                                                                                                                                                                                                                | 15 KHz to 1 MHz                                                                                                                                                                                                                                                                            |
| 3 Output voltage                           | Limited voltage available. Voltage varies significantly with load.                                                                                                                                                                                                                                            | Any voltages available. Voltage varies little with load.                                                                                                                                                                                                                                   |
| 4 Efficiency, heat, and power dissipation  | If regulated: efficiency largely depends on voltage difference between input and output; output voltage is regulated by dissipating excess power as heat resulting in a typical efficiency of 30–40%. If unregulated, transformer iron and copper losses may be the only significant sources of inefficiency. | Output is regulated using duty cycle control; the transistors are switched fully on or fully off, so very little resistive losses between input and the load.<br><br>The only heat generated is in the non-ideal aspects of the components and quiescent current in the control circuitry. |
| 5 Circuit complexity                       | Usually a simpler circuit; unregulated may be simply a diode and capacitor. Regulated has a voltage-regulating circuit and a noise-filtering capacitor.                                                                                                                                                       | Consists of a controller IC, one or several power transistors and diodes as well as a pulse transformer, inductors, and filter capacitors. Some design complexities present which are not found in linear regulator circuits.                                                              |
| 6 Radio frequency interference             | Mild high-frequency interference may be generated by AC rectifier diodes under heavy current loading.                                                                                                                                                                                                         | EMI/RFI produced due to the current being switched on and off sharply. Therefore, EMI filters and RF shielding are needed to reduce the disruptive interference.                                                                                                                           |
| 7 Electronic noise at the output terminals | It can cause audible mains hum in audio equipment, brightness ripples in analog security cameras.                                                                                                                                                                                                             | Noisier due to the switching frequency of the SMPS.                                                                                                                                                                                                                                        |
| 8 Electronic noise at the SMPSs            | Causes harmonic distortion to the input AC. input terminals                                                                                                                                                                                                                                                   | Non power-factor-corrected cause harmonic distortion.                                                                                                                                                                                                                                      |
| 9 Power factor                             | Low for a regulated supply because current is drawn from the mains at the peaks of the sinusoidal voltage.                                                                                                                                                                                                    | Ranging from very low to medium since a simple SMPS without PFC draws current spikes at the peaks of the AC.                                                                                                                                                                               |

#### Output section

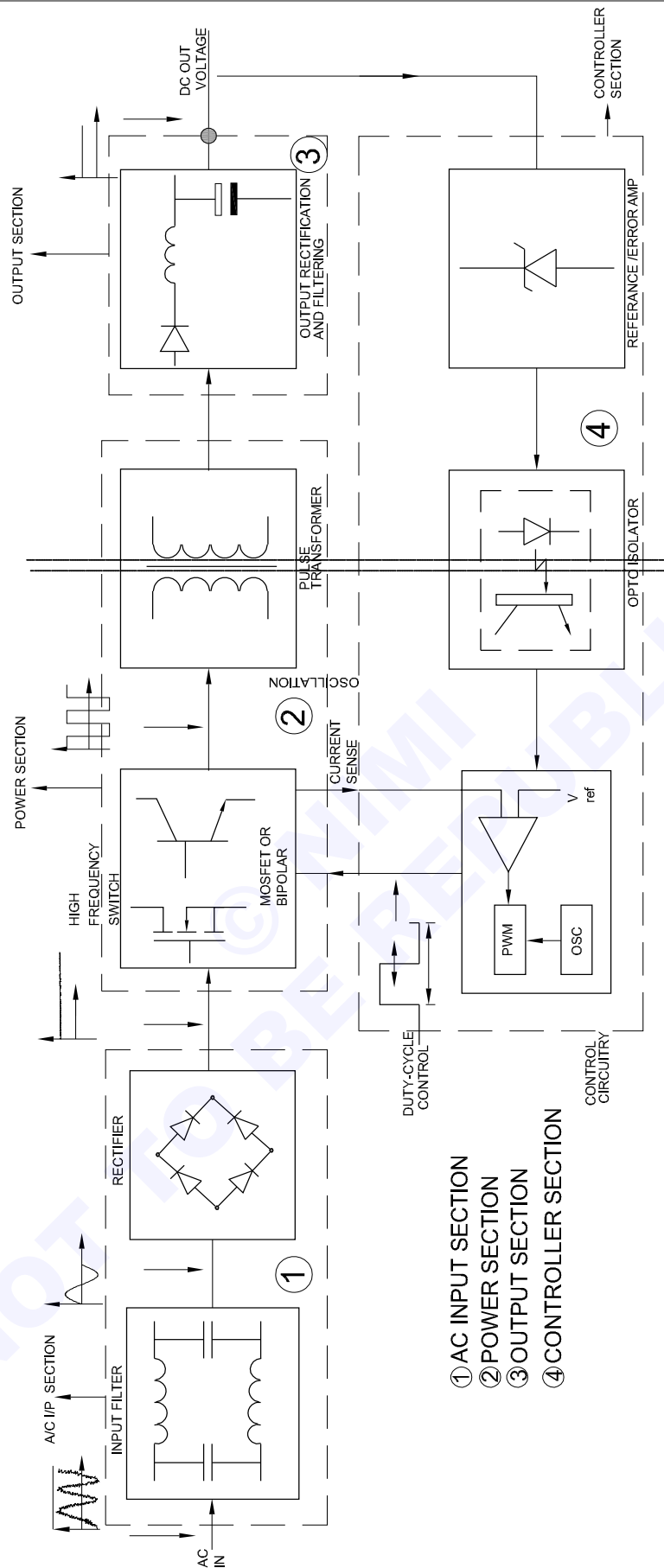
The output section consists of rectifier and filter circuits for output above the volts ordinary silicon diodes are used. Since the A/C output of the transformer at 20 KHz schottky diodes are used, because of its fast recovery than silicon diodes to get lower voltages. For even lower output voltages MOSFETs may be used as synchronous rectifiers. The filter circuit consists of an inductor and capacitor.

#### Control section

The controller consists of a feedback circuit PWM circuit and isolation mechanism (opto - coupler). A feedback circuit monitors the output ref voltage of 2.5V and compares it with a reference voltage. Any change in 5V with respect to the load creates an error voltage. This error voltage modifies the pulse width of the output pulses. The output pulses in turn drives the power switching transistor. The output pulses are not directly connected to the power switching transistor. For safety reasons, the output



Fig 3



BLOCK DIAGRAM OF SMPS

IM20N1810013

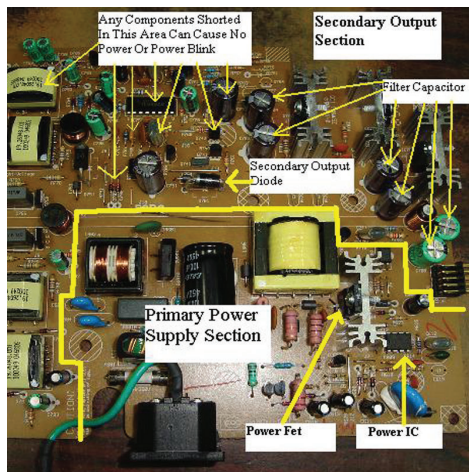
section is isolated by an opto-coupler and transformer. Over current is sensed through a current transformer. The output of current transformer is rectified and used to shut

down the power controller when an excess current is drawn.

## Different types of SMPS

### Model 1 : SMPS

Fig 4



### Model 2 : SMPS used in PC

Fig 5

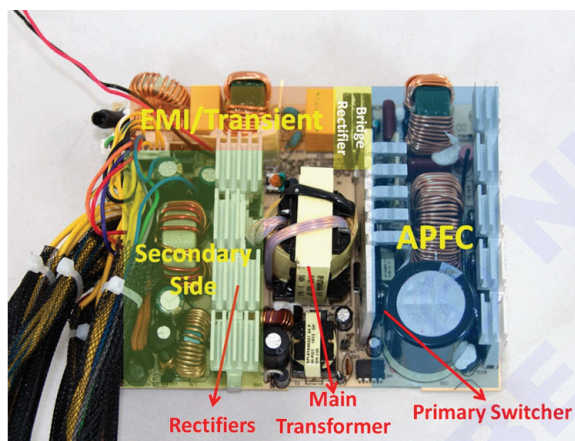
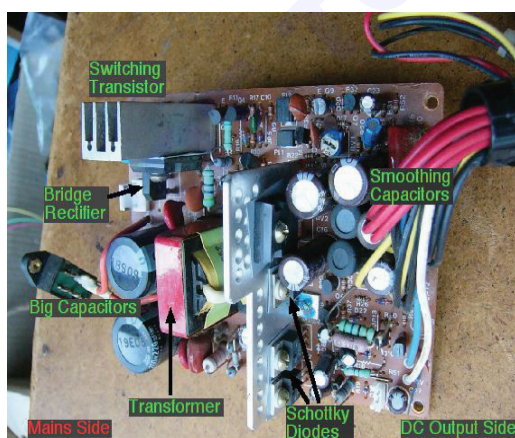
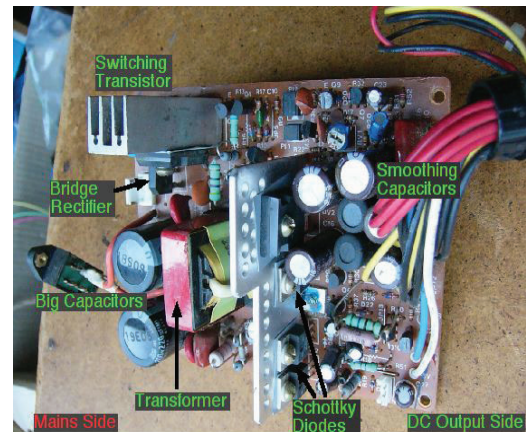


Fig 6



SMPS IN PC

Fig 6



SMPS IN PC

### ATX SMPS (Fig 7)

below A : input EMI filter and bridge rectifier;

B : input filter capacitors

Between B and C : Primary side heat sink;

C : Pulse transformer

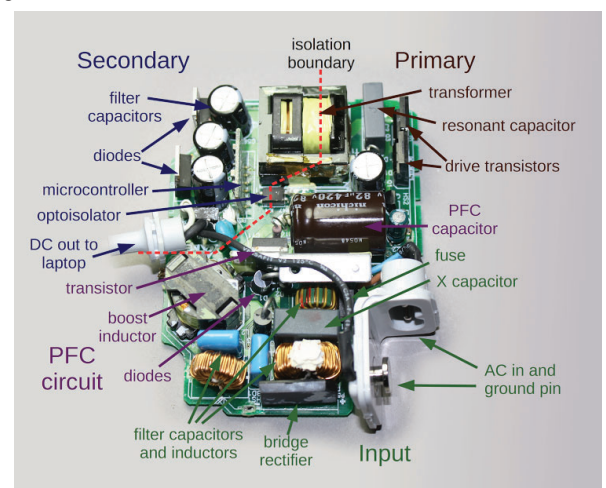
Between C and D : Secondary side heat sink;

D : Output filter coil;

E : Output filter capacitors.

The coil and large yellow capacitor below E are additional input filtering components that are mounted directly on the power input connector and are not part of the main circuit board.

Fig 8



SMPS used in Laptop

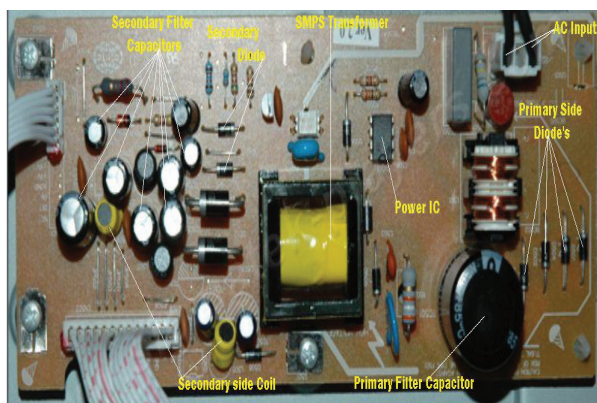
### Basic parts and their function

- 1 **EMI/Transient filter** : Suppress incoming and outgoing EMI/RFI and protects from voltage spikes.
- 2 **Bridge rectifier** : Rectifies the AC power stream to DC.



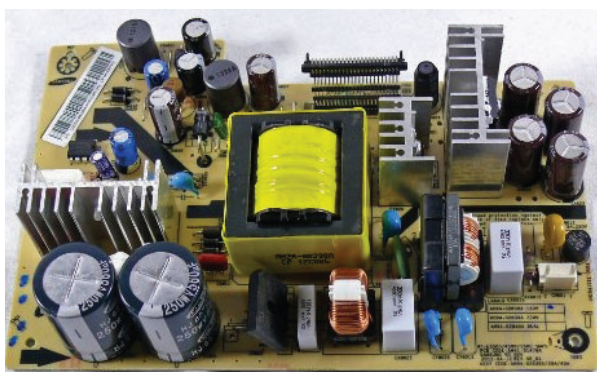
- 3 **APFC** : Controls the current supplied to the PSU so that the current waveform is proportional to the mains voltage waveform.

Fig 9



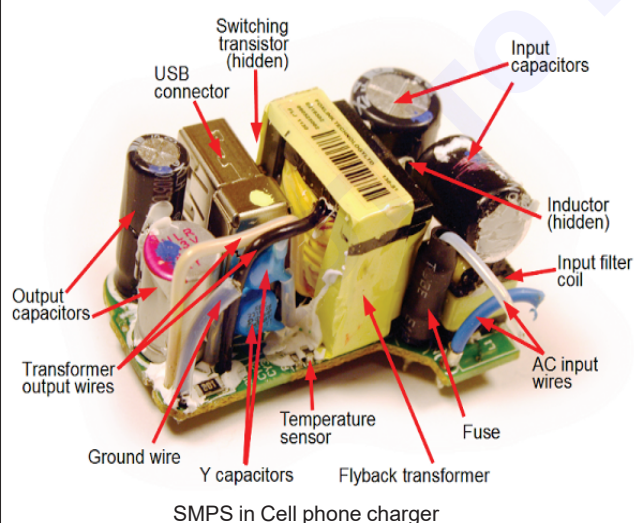
SMPS in DVD player

Fig 10



SMPS in Home theatre main board

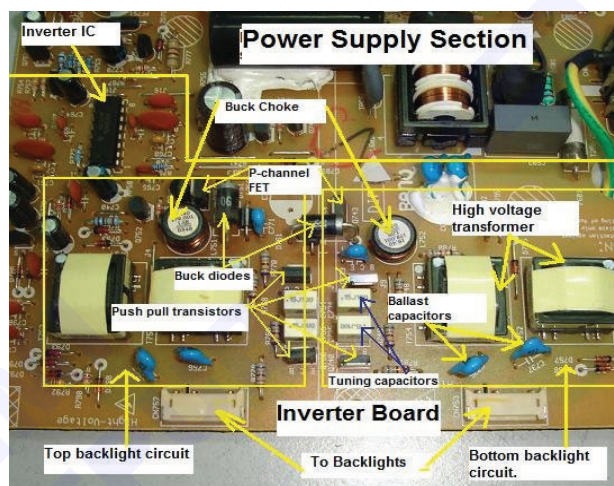
Fig 11



SMPS in Cell phone charger

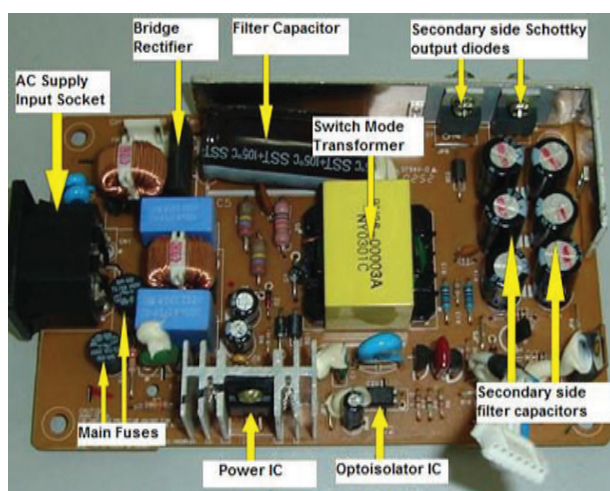
- 6 **Output rectifiers & filters** : Generate the DC outputs and filter them.
- 7 **Protection circuits** : Shut down the PSU when something goes wrong.
- 8 **PWM controller** : Adjusts the duty cycle of the main switches, in order to keep steady output voltage under all loads.
- 9 **Isolator** : Isolates the voltage feedback that comes from the DC outputs and heads to the PWM controller.
- 10 The part of the SMPS before the pulse transformer is called "primary" side and the part after it "secondary" side.

Fig 12



SMPS in LED TV

Fig 13



SMPS in LCD monitor

## Advantages & Disadvantages of SMPS

### Advantages

- 1 Higher efficiency, smaller size, lighter weight.
- 2 Heat dissipation is very low.
- 3 Wide AC input voltage range. (Ex. 90V-270V)

- 4 **Main switches**: Chop the DC signal to very small energy packets, with high frequency.
- 5 **Transformer** : Isolates primary from secondary side and converts (steps down) the voltage.

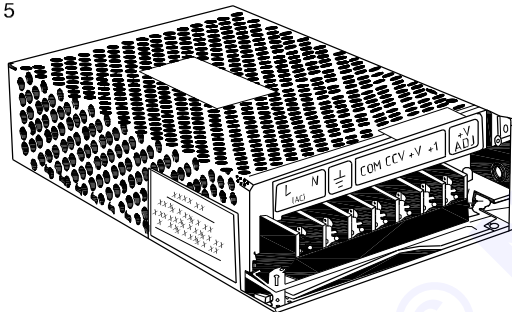
- 4 High precision voltage regulation.
- 5 Low output noise ripple.
- 6 Strong protection function. (Ex. Short circuit in output)

Fig 14



Din rail SMPS in control panel

Fig 15



SMPS IN CONTROL PANEL

### Disadvantages

- 1 Complexity of the circuit.
- 2 Line filter is necessary to avoid EMI.
- 3 Non-PFC SMPS cause harmonic distortion.
- 4 Servicing of SMPS is very difficult.

### Applications of SMPS

- 1 Personal computers
- 2 Battery chargers
- 3 Central power distribution
- 4 Vehicles (Electric bike vehicle & space vehicles)
- 5 Consumer electronics
- 6 Lighting
- 7 Space station

#### Personal computers

Personal computers have parts like Hard disk, Mother board, CPU, CD Rom, etc. In order to run these devices switch mode power supply is used efficiently.

#### Battery chargers (Mobile phone, Digital camera, Laptop computer)

Due to their high volumes, mobile phone chargers use effective ringing choke converter (RCC) SMPS topology.

### Central power distribution

Where integration of capacitors for stabilization and batteries as an energy storage or AC hum and other interference needs to be avoided in the power distribution, SMPS may be essential for efficient conversion of electric DC energy. For AC applications where frequency and voltage can't be produced by the primary source an SMPS may be essential.

### Vehicles

In automobile industry where ordinary trucks use nominal 24V DC but they need 12 V DC & SMPS. Cars use nominal 12V DC and may need to convert this to drive equipment using SMPS. Space vehicles use a lightweight switched-mode power supplies to convert voltages produced by solar panels and fuel cells to the voltages required by equipment.

### Consumer electronics

Television receivers, DVD players, Home theatres, Cordless phone, uses a switch-mode power supply. When the AC voltage reduced to as low as 90 V and as high as 260V, but the image has no alterations.

### Lighting

Powering of LED circuits is accomplished with switched-mode power supply setup as a constant current source where efficiency is important.

### Space station

The Electronics power system on the International Space Station (ISS) uses multiple switch-mode power supplies to convert between the voltage produced by the solar array and battery system, and the voltages required by the different modules. The eight solar panels generate 262 kW at 160 V DC, used to charge nickel-hydrogen batteries that provide power when the solar array is in shadow during earth eclipse. A system voltage of 160 V DC is used for the main power distribution throughout the station.

The space shuttle uses three fuel cells generating 30–36V DC. Some is converted into 400 Hz AC power and 28V DC power using SMPS.

### Topologies of Switch Mode Power Supply

There are different types of topologies for SMPS, among those, a few are as follows

- 1 DC to DC converter
- 2 AC to DC converter
- 3 Fly back converter
- 4 Forward converter

#### 1 Working principle of DC to DC converter SMPS

In a DC-to-DC converter, primarily a high-voltage DC power is directly obtained from a DC power source. This high-voltage DC power is switched at a very high switching speed usually in the range of 15 kHz to 50 kHz.

Then it is fed to a step-down transformer which is comparable to the weight and size characteristics of a transformer unit of 50Hz. The output of the step-down transformer is further fed into the rectifier. This filtered and



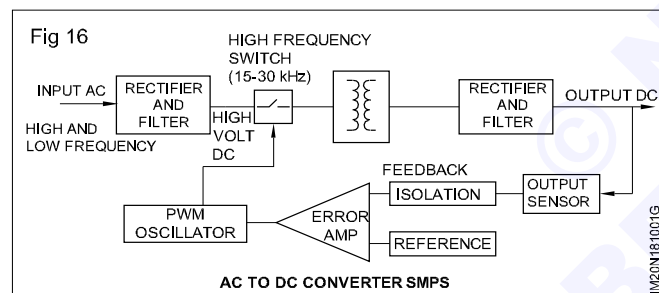
rectified output DC power is used as a source for loads, and a sample of this output power is used as a feedback for controlling the output voltage. With this feedback voltage, the ON time of the oscillator is controlled, and a closed-loop regulator is formed.

The output of the switching-power supply is regulated by using PWM (Pulse Width Modulation). As shown in the circuit above, the switch is driven by the PWM oscillator, such that the power fed to the step-down transformer is controlled indirectly, and hence, the output is controlled by the PWM, as this pulse width signal and the output voltage are inversely proportional to each other.

If the duty cycle is 50%, then the maximum amount of power is transferred through the step-down transformer, and, if duty cycle decreases, then the amount of power transferred will decrease by decreasing the power dissipation.

## 2 Working principle of AC to DC converter SMPS

The block diagram of AC to DC converter SMPS is shown in Fig 16. AC input is converted into DC by rectification process using a rectifier and filter. This unregulated DC voltage is fed to the large-filter capacitor or PFC (Power Factor Correction) circuits for correction of power factor as it is affected. This is because around voltage peaks, the rectifier draws short current pulses having significantly high-frequency energy which affects the power factor to reduce.



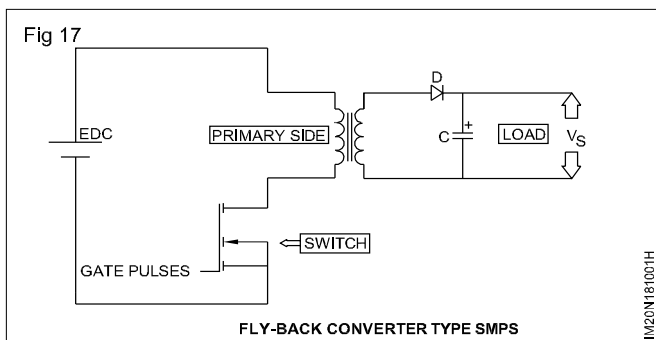
It is almost similar to the above discussed DC to DC converter, but instead of direct DC power supply, here AC input is used. So, the combination of the rectifier and filter, shown in the block diagram is used for converting the AC into DC and switching is done by using a power MOSFET amplifier with which very high gain can be achieved. The MOSFET transistor has low on-resistance and can withstand high currents. The switching frequency is chosen such that it must be kept inaudible to normal human beings (mostly above 20kHz) and switching action is controlled by a feedback utilizing the PWM oscillator.

This AC voltage is again fed to the output transformer shown in the figure to step down or step up the voltage levels. Then, the output of this transformer is rectified and smoothed by using the output rectifier and filter. A feedback circuit is used to control the output voltage by comparing it with the reference voltage.

## 3 Working principle of Fly-back converter type SMPS

The SMPS circuit with very low output power of less than 100W (watts) is usually of Fly-back converter type SMPS,

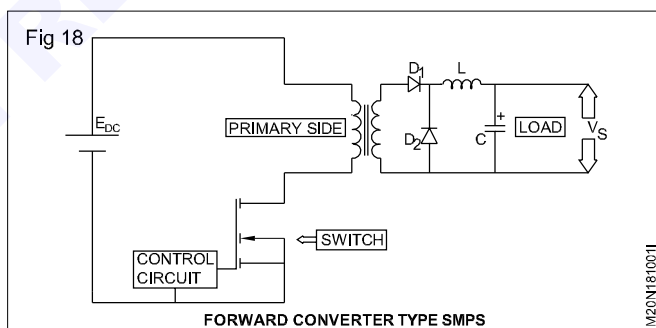
and it is very simple and low-cost circuit compared to other SMPS circuits. Hence, it is frequently used for low-power applications. The principle of operation is explained using Fig 18.



The unregulated input voltage with a constant magnitude is converted into a desired output voltage by fast switching using a MOSFET; the switching frequency is around 100 kHz. The isolation of voltage can be achieved by using a transformer. The switch operation can be controlled by using a PWM control while implementing a practical fly-back converter.

Fly-back transformer exhibits different characteristics compared to general transformer. The two windings of the fly-back transformer act as magnetically coupled inductors. The output of this transformer is passed through a diode and a capacitor for rectification and filtering. As shown in Fig 18, the voltage across this filter capacitor is taken as the output voltage of the SMPS.

## 4 Working principle of forward converter type SMPS



Forward converter type SMPS is shown in Fig 19. It is almost similar to the Fly-back converter type SMPS, but in the forward converter type, a control is connected for controlling the switch and at the output of the secondary winding of the transformer, and the rectification and filtering circuit is complicated as compared to the fly-back converter.

It can be called as a DC to DC buck converter, along with a transformer used for isolation and scaling. In addition to the diode D1 and capacitor C, a diode D2 and an inductor L are connected at the output end. If switch S gets switched ON, then the input is given to the primary winding of the transformer, and hence, a scaled voltage is generated at the secondary winding of the transformer.



Thus, the diode D1 gets forward biased and scaled voltage is passed through the low-pass filter preceding the load. If the switch S is turned off, then the currents through the primary and secondary winding reach to zero, but the current through the inductive filter and load can not change abruptly, and a path is provided to this current by the freewheeling diode D2. By using the filter inductor, the required voltage across the diode D2 and to maintain the EMF required for maintaining the continuity of the current at inductive filter.

Even though the current is diminishing against the output voltage, approximately the constant output voltage is

maintained with the presence of the large capacitive filter. It is frequently used for switching applications with a power in the range of 100 W to 200 W.

Different types of topologies are there in which SMPS can be realized such as Buck converter, Boost converter, Self Oscillating fly-back converter, Buck-boost converter, Boost-buck, Cuk, Sepic. But only a few are discussed in this article, namely DC to DC converter, AC to DC converter, Fly-back converter and Forward converter.

## SMPS used in personal computers

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

- explain SMPS and different types of SMPS used in PC
- explain different types of connectors used in personal computer SMPS
- discuss the need of ATX SMPS in PC
- explain the functions of SMPS used in PC
- explain the working of PWM IC
- differentiate between AT and ATX type SMPS.

### SMPS used in PC

Switch Mode Power Supply of a PC is housed in a metal box. It consists of an electronic circuit board, a fan, AC power sockets, power supply interface connectors for motherboard, hard disk drive and floppy disk drive. AC power switch is connected as an optional item to the power cable from the SMPS.

Fig 1



SMPS with its cables or connectors

### Basic connectors in PC SMPS

20 + 4 Pin ATX / Motherboard connector

CPU 4 + 4 Pin connector

SATA power connector

Floppy 4 pin connector

Peripheral 4 pin molex connector

PCI-e 6 pin/PCI-e 8 pin connector.

### Types of SMPS used in PC

There are 3 types of SMPS

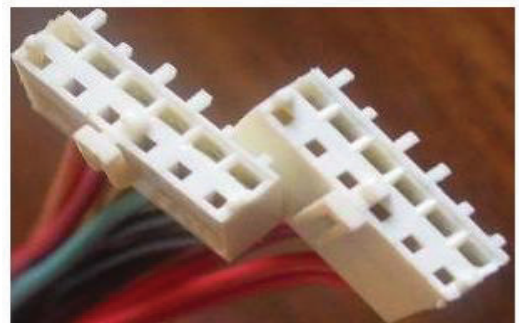
- 1 AT SMPS
- 2 ATX SMPS
- 3 BTX SMPS

These three types of SMPS have different connectors and each wire has different voltages.

### AT SMPS

AT stands for Advanced Technology. These are all old SMPSs. They had 12pin power connector, this is called as AT power connector. They were used in Pentium-I, Pentium-MMX, Pentium-II and Pentium-III CPUs as shown in Fig 2.

Fig 2



### ATX SMPS

ATX stands for Advanced Technology eXtended. They had 20pin Power connector, this is called as ATX power connector. They were used in Pentium-III, Pentium-IV and AMD CPUs as shown in Fig 3.

### BTX SMPS

BTX stands for Balanced Technology eXtended. They have 24pin Power connector, this is also called as ATX power connector. It has 15pin SATA power connectors. They are used in Dual core, core2duo, Quad core, i3, i5, i7 and latest AMD CPUs.

Fig 3

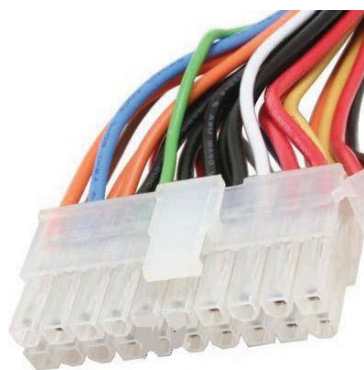


Fig 5

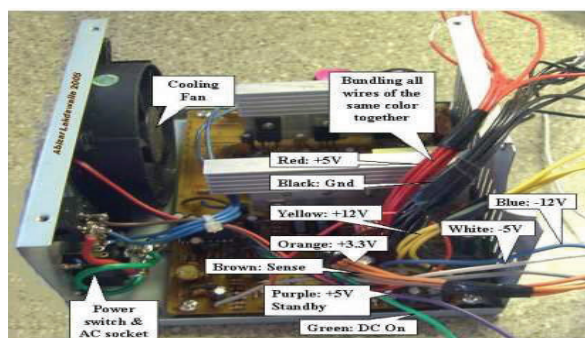


## Connectors

### 20/24 Pin ATX / Mother board connector

This is the connector that goes to the motherboard to provide it with power. The connector has 20 or 24 pins. One of the pins belongs to the PS-ON wire (it is usually green). This connector is the largest of all the connectors. In older AT power supplies, this connector was split in two: P8 and P9. A power supply with a 24-pin connector can be used on a motherboard with a 20-pin connector. In cases where the motherboard has a 24-pin connector, some power supplies come with two connectors (one with 20-pin and other with 4-pin) which can be used together to form the 24-pin connector as shown in Fig 6 and 7.

Fig 4



### Voltages of power connector

| SMPS          | AT   | ATX   | BTX   |
|---------------|------|-------|-------|
| Red           | +5V  | +5V   | +5V   |
| Yellow        | +12V | +12V  | +12V  |
| Blue          | -12V | -12V  | -12V  |
| White         | -5V  | -5V   | -5V   |
| Black         | 0V   | 0V    | 0V    |
| Orange        | +5V  | +3.3V | +3.3V |
| Green         | —    | +5V   | +5V   |
| Gray or Brown | —    | +5V   | +5V   |
| Purple        | —    | +5V   | +5V   |

- Red : It is used to provide stated voltage.
- Yellow : It is used for motor running
- White & Blue : It is used for backward compatibility
- Black : It is used for grounding purpose
- Orange : It is used to provide stated voltage
- Green : It is used for power supply ON in ATX
- Gray or Brown : It is used for power Good(Self-test OK) signal in ATX
- Purple : It is used to provide +5V whenever the PSU is powered. Even when the green wire is not connected to ground. (Stand by)

Fig 6

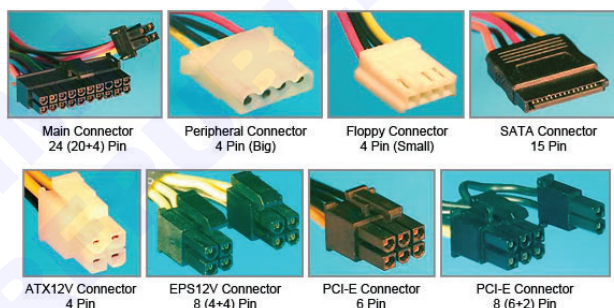


Fig 7

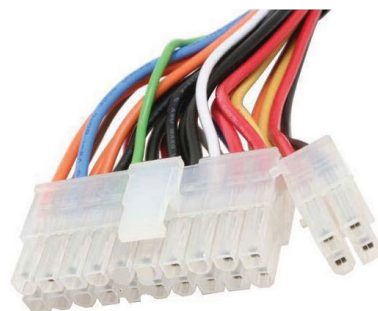


Fig 8



Connected attached (24 pins)

# Uninterruptible Power Supply

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

- state the need of UPS
- differentiate inverter and UPS
- explain the block diagram of UPS.

## Uninterruptible Power Supply (UPS)

An uninterruptible power supply (UPS) is a device that allows a computer to keep running for at least a short time when the primary power source is lost. It also provides protection from power surges.

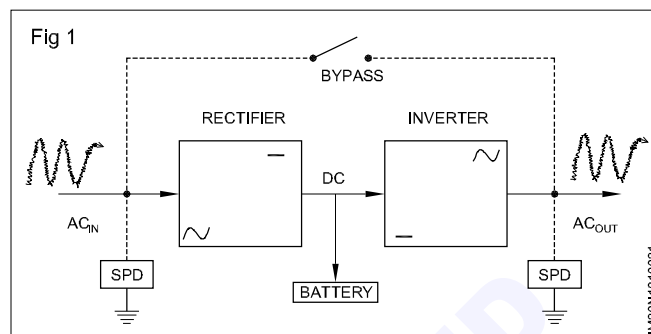
### Need of UPS

An Uninterruptible Power Supply (UPS) is used to protect critical loads from mains supply problems, including spikes, voltage drops, fluctuations and complete power failures using a dedicated battery.

A surge protector (or surge suppressor or surge diverter) is an appliance or device designed to protect Electronics devices from voltage spikes. A surge protector attempts to limit the voltage supplied to an electric device by either blocking or shorting to ground any unwanted voltages above a safe threshold.

### Difference between Inverter and UPS (TABLE 1)

The differences between inverter and UPS under certain important parameters are given in TABLE 1 below.



### Block diagram of UPS

The simplified block diagram of UPS is shown in Fig 1.

In UPS, the AC from the mains power is transformed to DC. This DC is continuously charging the battery. The DC output from the battery is fed to inverter that converts it into AC output and supplies to the equipment.

TABLE 1  
Difference between Inverter and UPS

| Sl. No. | Parameters          | Inverter                                                                                                                  | UPS                                                                                                     |
|---------|---------------------|---------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------|
| 1.      | Back-up time        | In inverter, the back up time is not rapid. So the computers may break down or data loss.                                 | In UPS, the back up time of power supply is rapid. It will not make any computer crash or loss of data. |
| 2.      | Technical variation | The power is consistently drawn from battery.                                                                             | The AC is changed into DC. This DC helps to charge the battery.                                         |
| 3.      | Time delay          | 500 ms                                                                                                                    | 3 to 8 ms                                                                                               |
| 4.      | Connection          | The inverter connected to main power supply for providing electricity to different applications such as fan, lights, etc. | UPS directly connected to different application such as computer, printers, etc.                        |
| 5.      | Price               | Low                                                                                                                       | High                                                                                                    |

### Rectifier

A rectifier is an Electronics device that converts alternating current (AC), which periodically reverses direction, to direct current (DC), which flows in only one direction. The process is known as rectification.

### Battery

Battery is a device consisting of one or more electrochemical cells with external connections provided, to power Electronics devices.

## Inverter

Inverter is an electronic circuit that converts low voltage DC into high voltage AC power. In solar-electric systems, an inverter may take the 12, 24, or 48 volts DC and convert to 230 volts AC, conventional household power.

The main power AC is supplied to the inverter, and it is transformed into DC simultaneously, which keeps charging the battery continuously. There is a sensor and relay structure that always monitors the ON or OFF status of the main supply.

As soon as there is a power failure, the relay actuator activates the inverter switch. Every other action is similar to the UPS, but because of the sensor and relay process, there is a delay while activating the switch.

## Types of UPS

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

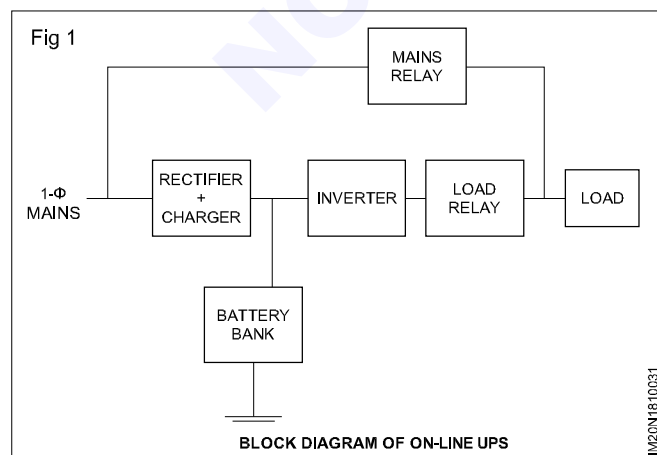
- list different types of UPS
- compare ON-line, OFF-line and line interactive types of UPS
- state specification of UPS, power factor, calculating battery back-up
- explain types of indications and protection.

### Different types of UPS

- 1 ON line UPS
- 2 OFF line UPS
- 3 Line interactive UPS

#### ON line UPS

ON line UPS are also known as double conversion UPS or True ON Line UPS. There are two stages in its operation. In the first stage the mains AC is rectified to DC. There is a DC bus. DC bus can get power from both the DC battery and DC obtained by rectifying the mains AC. In the second stage DC power available from DC bus is converted to AC by the inverter and this AC is connected to the output. In normal operation output comes from mains AC via rectifier and inverter. When mains AC fail, output comes from DC battery via inverter. The changeover is instantaneous. There is no power transfer switch and hence no time delay. When mains AC is available normal operation continues and the rectifier recharges the battery. A bypass switch connects mains AC directly to the output in case there is some problem with the UPS. (Fig 1)



## Static transfer switch

Static transfer switches (STS) are such Electronics devices which are used for very fast switching between Electronics power sources. It is used in UPS immediately switch main power supply, to its stored backup power.

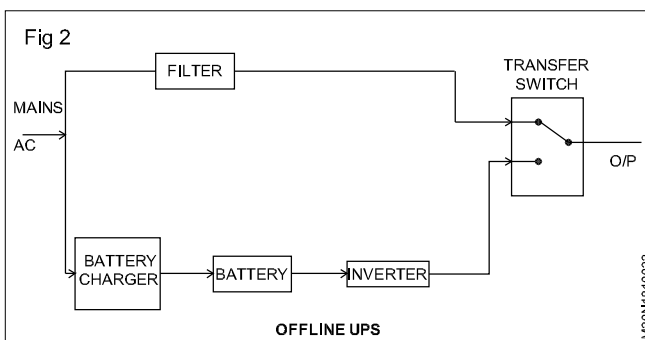
They perform instantaneous switching operations and thus supply immediate power to the load.

Metal Oxide Semiconductor Field Effect Transistor (MOSFET) power transistors, Insulated Gate Bipolar Transistor (IGBT) devices, microprocessor ICs, Operational amplifier ICs, adjustable voltage regulator ICs, Oscillator and pulse width modulator ICs, GATE ICs, timer etc. are some the important components found in on line UPS.

On line UPS offer the best power protection against all types of disturbances. The output voltage of an On Line UPS is highly stabilized with typical value of tolerance of 1 percent i.e. the output voltage is between 227 and 233 volt and frequency is between 49.95 Hz and 50.05 Hz. The output waveform is purely sinusoidal. A typical modern on line UPS is equipped with protections against short circuit, over-voltage and under-voltage etc, MCB for input, output and battery, and has digital LCD display with facility for displaying input and output voltage and frequency, battery status, output power delivered and error codes and messages.

On line UPS models generally have capacity more than 5kVA. High capacity On Line UPS can be built for all possible requirements and battery backup time can be increased to suit particular need by adding batteries. Sophisticated on Line UPS are available with many advanced features and are highly reliable but are costlier.

#### OFF line UPS

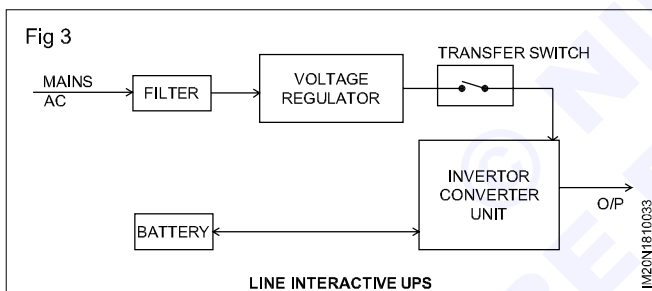




An OFF line UPS is shown in Fig 2. It is also known as stand by UPS or Backup UPS and supplies emergency power when mains AC fail. The capacity of an off line UPS is generally below 1kVA. A very common application is with PC. In the event of sudden load shedding the off line UPS supplies emergency power to the PC so that work can be continued till normal power is restored or the PC can be safely switched off.

In normal mode mains AC is directly connected to the output through a filter unit. The filter unit filters noise present in the mains AC. When mains AC fails the inverter converts DC power of battery to AC and transfer switch connects this AC to the output. This changeover happens very quickly but is not instantaneous and a time delay of few milliseconds is involved. This time delay normally does not affect ordinary load. Again when mains AC comes, the transfer switch connects mains AC to output. Thus the transfer switch keeps on changing connection of output to between mains AC and AC output of inverter. When mains AC is available, the charger unit recharges the battery. An offline UPS does not have provision for stabilizing the mains AC. Under voltage and over voltage of mains AC activates the power transfer switch and connects AC obtained from inverter to the output. Thus in case of off line UPS under voltage and over voltage of mains AC has similar impact as absence of mains AC.

#### Line interactive UPS



In a line interactive UPS mains AC is connected to the output through a filter and voltage regulating unit. The

voltage regulator usually is an auto transformer with number of tapping and stabilizes the mains input by bucking or boosting as per requirement. A single unit called Inverter converter unit performs the functions of battery charger and inverter. When mains AC is available inverter converter unit charges the battery. When mains AC fails it inverts DC to AC and supplies power to load. The transition is not instantaneous and time delay of few milliseconds is involved. Compared to Off line UPS, line interactive UPS performs better as the mains AC is regulated. Line interactive UPS are generally available with capacity between 750VA and 5KVA and are commonly used for computer network with small group of computers.

#### Comparison between OFF-line, ON-line and LINE-interactive UPS

##### OFF-Line UPS

OFF-line UPS passes the input AC to the output sockets if the AC power is available. It always monitor the voltage level in the mains, and if there is a voltage drop or mains failure, it switches ON the inverter to give AC power to the device until the mains supply returns to normal. The switch over time from AC to inverter AC is less than five milli seconds so that the functioning of the equipment is not affected.

##### ON-Line UPS

ON-Line UPS uses an inverter which always ON to give sine wave AC to the output socket. The incoming AC is first converted into DC to charge the battery as well as to give power to the inverter. The inverter converts the DC to AC continuously to power the load. If power fails, the battery backup circuit switches ON and takes the load. Online UPS is more efficient than the Offline UPS and uses a "constant duty inverter". It also has a "static bypass" system that transfers the load to the AC power if the inverter system fails. The advantage of the online UPS is that, it clean up the AC waveform by converting it into DC then reconverting this DC to fresh AC. ON-Line UPS regulate voltage within  $\pm 2-3\%$ .

#### Specification of UPS

| Sl. No. | Parameter              | Details                                                                                              |
|---------|------------------------|------------------------------------------------------------------------------------------------------|
| 1       | Type of UPS            | TRUE ONLINE                                                                                          |
| 2       | CAPACITY               | 2 KVA/5 kVA                                                                                          |
| 3       | Technology             | The UPS shall be based on IGBT, and microprocessor controlled for providing better sine wave output. |
| 4       | AC input voltage range | 175V to 275 V AC, single phase                                                                       |
| 5       | Input frequency        | 47-53 Hz, (Suitable for working with generator supply)                                               |
| 6       | UPS power factor       | 0.9 or better                                                                                        |
| 7       | AC output voltage      | 230V AC, Single phase                                                                                |
| 8       | Output frequency       | 50 Hz                                                                                                |
| 9       | Waveform               | Sinusoidal                                                                                           |



|    |                            |                                                           |
|----|----------------------------|-----------------------------------------------------------|
| 10 | Efficiency                 | 90% (at rated output voltage and frequency)               |
| 11 | Total harmonics distortion | 2% maximum                                                |
| 12 | Indications                | Standard visual indications for proper function of UPS.   |
| 13 | Protections                | Over & Under voltage cut-off, overload, and short         |
| 14 | Back up time               | 2kVA = 8 hour at 400 watt load, 5kVA = 8 hr at 1000W load |
| 15 | Type of batteries          | Sealed maintenance free (SMF)<br>Lead Acid Battery        |
| 16 | Remote monitoring          | SNMP based monitoring                                     |

### Line-interactive UPS

Line-interactive UPS system use automatic voltage regulation (AVR) to correct abnormal voltages without switching to battery. The UPS detects when voltage crosses a preset low or high threshold value and uses transformers to boost or lower the voltage by a set amount to return it to the acceptable range. Line-interactive UPS system typically regulate output within  $\pm 8\text{-}15\%$  of the nominal voltage.

### Power factor

Power factor is a quantity which has important implications when sizing a UPS system and power distribution equipment. Power is a measure of the delivery rate of energy and in DC (direct current). Electronics circuits is expressed as the mathematical product of Volts and Amps (Power = Volts x Amps). However, in AC (alternating current) power system, a complication is introduced; namely that some AC current (Amps) may flow into and back out of the load without delivering energy. This current, called reactive or harmonic current, gives rise to an "apparent" power (Volt x Amps) which is larger than the actual power consumed. This difference between the apparent power and the actual power gives rise to the power factor. The power factor is equal to the ratio of the actual power to the apparent power. The apparent power is expressed as the Volt-Amp or VA rating. Therefore, the actual power in any AC system is the VA rating multiplied by the power factor.

"Watts = volts x amps x power factor". Unfortunately, the PF is rarely stated for most equipment, but it is always a number of 1.0 or less.

A double-conversion UPS gives voltage distortion problem created by the UPS. The input of a double-conversion UPS is essentially a big rectifier. The current drawn by the UPS is non-sinusoidal. This can cause the voltage from the AC mains also to become non-sinusoidal. The voltage distortion can cause problems in all Electronics equipment connected to that power source, including the UPS itself. It will also cause more power to be lost in the wiring supplying power to the UPS due to the spikes in current flow. This level of "noise" is measured as a percentage of "total harmonic distortion of the current" (THDI). Classic UPS rectifiers have a THDI level of around 25%-30%.

There are several solutions to reduce the THDI in a double-conversion UPS:

### Passive power-factor correction

Classic solutions such as passive filters reduce THDI to 5%-10% at full load. They are reliable, but big and only work at full load.

### Active power-factor correction

An alternative solution is an active filter. Through the use of such a device, THDI can drop to 5% over the full power range. The newest technology in double-conversion UPS units is a rectifier that does not use classic rectifier components (thyristors and diodes) but uses high-frequency components instead. A double-conversion UPS with an insulated-gate bipolar transistor rectifier and inductor can have a THDI as small as 2%.

Uninterruptible power supply (UPS) systems are rated in kilowatts (kW) and others in kilo-volt-amperes (kVA).

1 kW and kVA simply mean 1,000 watts or 1,000 volt-amperes - the "kilo" prefix being used for larger numbers.

For large UPS systems have been designed based on a PF of 0.8, which means that a 100 kVA UPS will only support 80 kW of "real" power load. Most UPS systems has power factors of 0.95 - 0.98.

Neither the kW nor the kVA capacity of the UPS can be exceeded, but because of the higher PF numbers, it is usually the kW rating. There are some UPS systems on the market that are PF-corrected so that the kW and kVA ratings are the same.

### Calculating UPS/Inverter battery backup

Before calculating the Battery Backup, let us know a few factors that vary battery backup.

For UPS with 875VA we can use a maximum load of 640 watts.

677VA we can use a maximum load of 540 watts.

## UPS circuit description and working

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

- describe working of UPS circuit
- explain controller circuit
- explain the working of ON-Line UPS using PIC micro controller, charging circuit, alarm circuit and indicator circuit

### Uninterruptible power supply (UPS): Circuit description and working (Fig 1)

The circuit drawn pertains to a regular industrial UPS (Uninterruptible Power Supply), which shows how the batteries take control during an in Electronics supply variation beyond the normal limits of the voltage line, without disruption on the operation providing a steady regulated output (5V by LM7805) and an unregulated supply. (12V).

The input to the primary winding of the transformer (TR1) is 240V. The secondary winding can be 15 volts if the value is atleast 12 volts running 2 amp. The fuse(FS1) acts as a mini circuit for protection against short circuits, or a defective battery cell. The presence of electricity will cause the LED 1 to light. The circuit is designed to offer more flexible pattern wherein it can be customized by using different regulators and batteries to produce regulated and unregulated voltages. Utilizing two 12 volt batteries in series and a positive input 7815 regulator, can control a 15V supply.

### UPS are generally categorized as:

Standby - battery backup and surge protection

Line interactive - variable - voltage transformer and regulates the output AC voltage.

Online - Supplies all or atleast a part of the output power.

### Digital control of an UPS

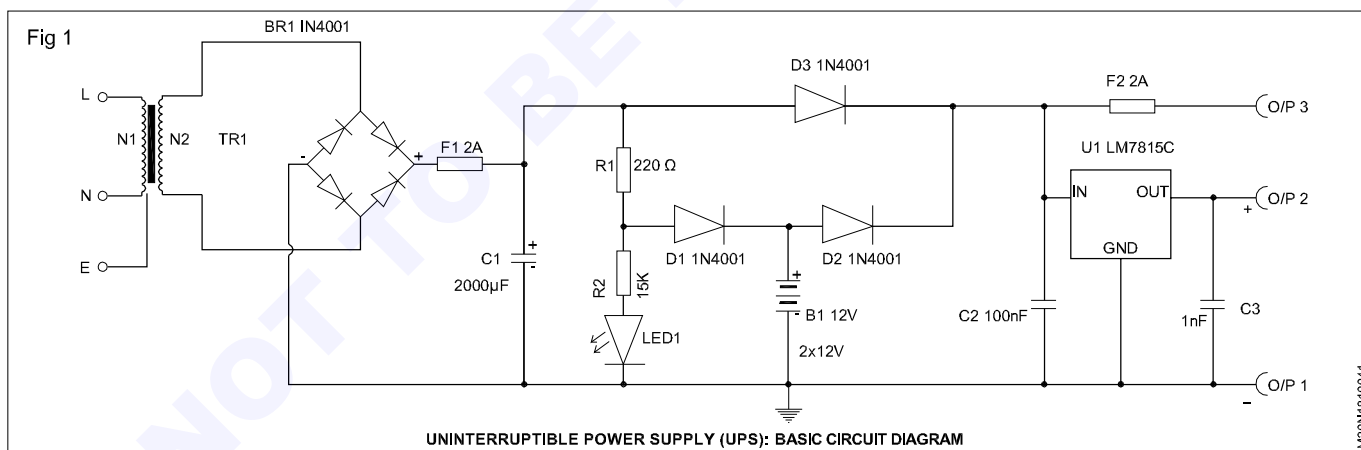
Uninterruptible power supply systems (UPS) are necessary for all applications where electronic systems have to work also in case of power failure (i.e. computer centers, hospital equipment, communication equipment etc.). Many mainframe computers are fed by UPS systems.

UPS systems conventionally consist of a synchronous generator, a fly-wheel for short-time energy storage and a battery powered motor or diesel engine.

By progress in power electronics static power converters can be realized, especially for mid-range output power (i.e. 5 - 50 kVA). In recent times there is increasing demand for UPS systems with low-distortion output voltages and sinusoidal input currents. Even at non-linear loads producing output currents with high harmonic content, sinusoidal output voltage is required. Due to this, even at unsymmetrical loads a static inverters can be better than rotary converters.

### Static UPS system hardware

Static UPS systems consist of a rectifier with a single or three-phase mains connection, a DC-link with a battery for power storage and a single- or three-phase output converter.



The bypass serves as an energy link in times of system failure or overload situations. (Fig 2)

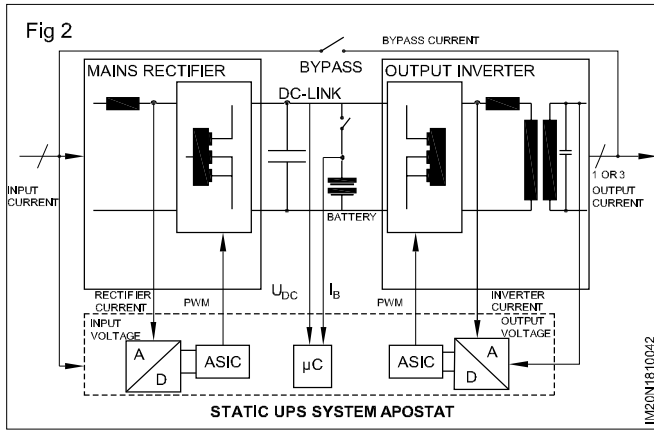
### Static UPS system hardware

Static UPS systems consist of a rectifier with a single or three-phase mains connection, a DC-link with a battery for power storage and a single- or three-phase Output converter. The bypass serves as an energy link in times of system failure or overload situations. (Fig 3)

### Output Inverter

Since output loads are not symmetrical, every output inverter is made up of four power switches building a four-quadrant converter feeding the output transformer. The stray filters the output voltage Inductance of the specially-designed transformer and the output capacitance.

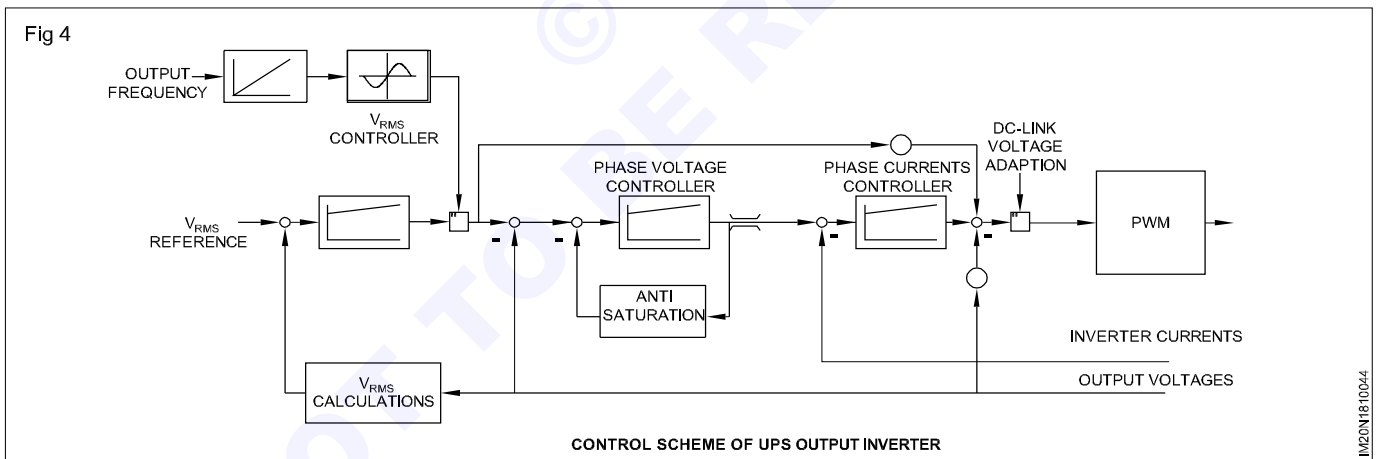
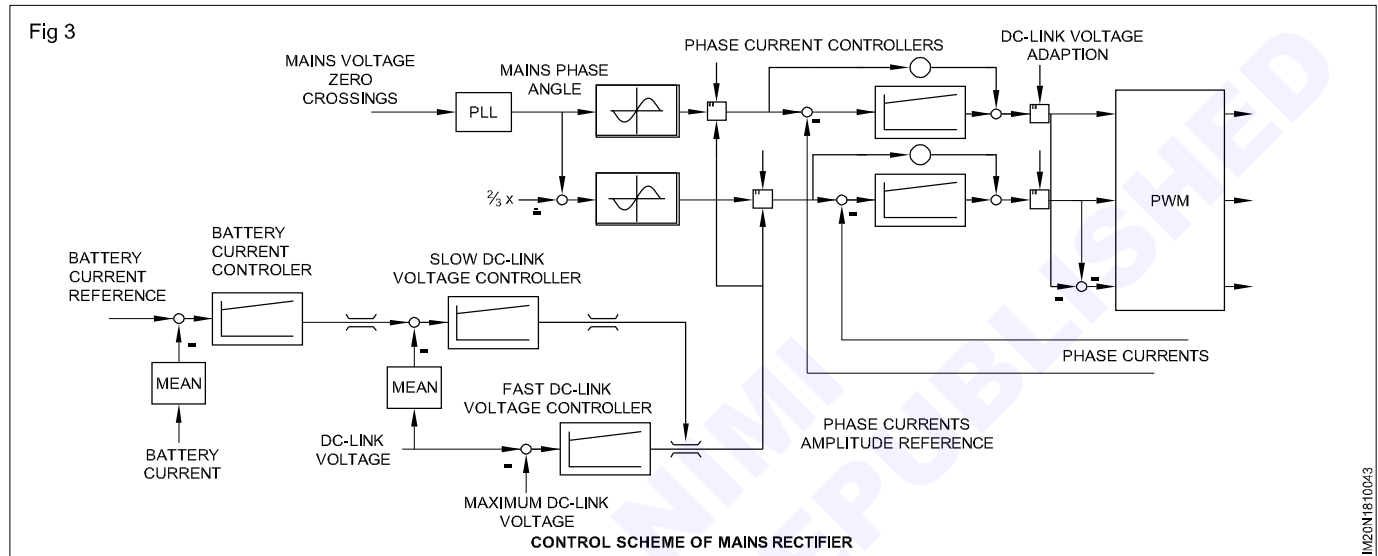
The control scheme of the output inverter is shown in Fig 4. The Controlled quantity is the output voltage. An underlying current control loop is implemented for protection of the power devices. The output value is



transformed to switching signals by pulse width modulation (PWM).

PI-controllers for AC quantities normally have phase and amplitude errors, which are not tolerable. On the other hand, PI-controllers provide predictable behavior at all operating modes. To reduce undesired effects feed-forward signals from the reference and output voltage are used. To eliminate the influence of the changing DC link voltage on the gain of the current controller the current control output is multiplied with the reciprocal value of the DC voltage.

The reference for the current controller is taken from the



voltage controller. A modified PI-controller was chosen; special algorithms are implemented to cope with the saturation problem of the output transformer. The output

## Inverter and Converter

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

- describe the basic concept of inverter
- explain principle of operation of inverter
- explain the functional blocks of inverter
- state the installation procedure of inverter
- describe the basic concept of converter
- state the applications of inverter.

### Definition

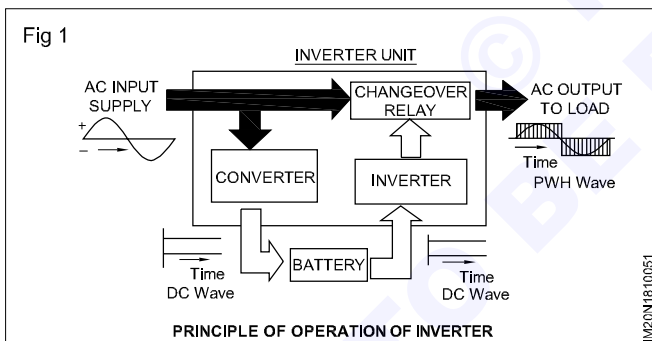
Converts DC to AC power by switching the DC input voltage (or current) in a pre-determined sequence so as to generate AC voltage (or current) output.

Circuitry that performs the opposite function of rectifier, converting DC to AC, is called an inverter.

The input voltage, output voltage, output frequency, and overall power handling depends on the design of the specific device or circuitry of inverter. The inverter does not produce any power; it only converts the DC battery power into AC power to load.

### Principle of operation

Inverter unit converts AC mains supply into DC and stores DC power in the battery. when AC mains present (Mains mode) the input AC power is directly passes to output load through changeover relay. When the absence of AC mains (inverter mode), DC power stored in the battery is converted



into AC by the use of electronic circuits, inverter transformer, etc. and is supplied to the load as shown in fig.1.

### Block diagram representation

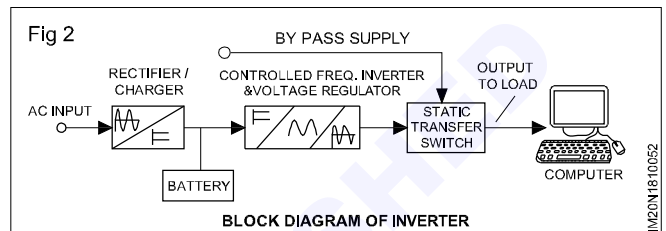
The simplified block diagram of the inverter is shown in fig.2. AC mains supply is connected to the sensing section, which senses the presence of AC input voltage and activates the battery charging section through the solid-state relay. During the presence of AC mains, AC supply directly goes to the output socket and to the connected load.

In the absence of AC mains supply, the AC mains sensing section activates the changeover type solid-state relay in milli-seconds time and connects the battery supply to the oscillator, driver and output chopper/switching sections to produce the 50Hz sine wave.

The oscillator generates trigger pulses and amplified by

the driver section, which controls the duty cycle of the semiconductor switches.

Thus, the inverter circuit produces AC supply and the battery supplies the required DC for the standby operation



to run the AC load.

### Function of an inverter

The Function block diagram of the inverter is shown in fig.3. The functioning of an inverter may be understood in the following two situations.

- a When the AC mains power supply is available.
- b When the AC mains power supply is not available.

### When the AC mains power supply is available - Main mode

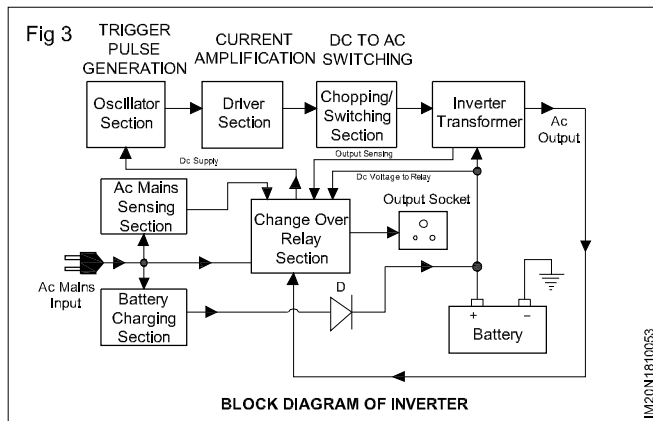
- When the AC mains supply is available, the AC mains sensing circuit senses it and the supply goes to the changeover relay, which provides,
  - i Mains supply to the battery charging section and
  - ii AC mains supply directly to the output socket/load.
- Battery charging section converts AC mains into 12/24V DC voltage, then regulated and battery is charged using it.
- There are special circuits for sensing the battery voltage and when the battery is fully charged the charging is stopped.
- In some inverters there will be a trickle charging circuit which keeps the battery constantly at full charge.

### When the AC mains power supply is not available - inverter mode

Under the absence of the AC mains power supply, an oscillator circuit inside the inverter produces a 50Hz trigger signal.

action of the MOSFETs or transistors produces 50Hz alternating signal at the primary of the inverter transformer.

- Thus a 220V AC supply is available at the secondary



of the inverter transformer.

- This secondary voltage is made available at the output socket of the inverter by a changeover solid state relay.

### Changeover period

The time required for an inverter to switch from AC mains power to battery power is known as changeover period. This is in the range of 3-8 milli-seconds.

### Annunciation and protection section

Inverter contains various circuits to automatically sense and tackle various situations that may occur when the inverter is running or in standby.

This annunciation section monitor the abnormal situations such as overload, over heat, low battery, over charge etc. and indicates by means of LED display/indicators and buzzer alarm.

The overload protection circuit is used for the protection of inverter and trips the unit and low battery cut-off circuit is used to cut-off the load from the inverter.

### Installation of an inverter

Power rating and calculation: Inverter power is rated in VA or KVA. Before purchasing the inverter, power consumption of load/appliances that is to be connected with inverter is to be calculated as follows;

Power in VA (Volt ampere) = AC volts x Total load current.

Power in KVA (Volt ampere) = (AC volts x Total load current)/1000.

Power in watts = AC voltage x Total load current x P.F. where P.F = power factor (If not given assume approximate value of 0.8. which is standard for homes)

Also power in watts = power in VA x P.F.

Example: Connected loads:

|                        |                 |                          |
|------------------------|-----------------|--------------------------|
| 3 Nos. of ceiling fans | = 2 x 75 watts  | = 150 watts              |
| 3 Nos. of cfl light    | = 3 x 23 watts  | = 69 watts               |
| 1 No. of television    | = 1 x 150 watts | = 150 watts              |
|                        |                 | <b>Total = 369 watts</b> |

Therefore the connected load in wattage is 369 W.

Considering approximate power factor of 0.8, the connected load in VA is  $369/0.8 = 461.25\text{VA}$  as the connected load capacity comes to 462 VA, the required inverter capacity to be purchased is 500 VA.

### Selection of location

The first thing is selection of suitable location for placing the inverter. While choosing the location the following points are to be considered for better operation;

- Make sure the inverter is not placed near any hazardous or flammable materials.
- It must also not be exposed to moisture or water.
- The selected location must be away from direct sunlight and is a dry area.
- It must be placed in an area near the main board of house.

### Mouting the inverter

An inverter can be mounted horizontally either on a vertical surface or on or under a horizontal surface as well. Inverter is always placed on the insulation material like wood, foam or hard board.

### Battery installation

There are two main families of batteries used in inverters

- Nickel - cadmium batteries
- Lead - acid batteries

Most commonly liquid or pasted (SMF - Sealed Maintenance Free) Lead-acid batteries are using.

Before connecting the new battery to inverter, battery is to be charged fully, otherwise its life and backup time will be reduced.

While connecting the batteries the polarity of the battery and the inverter terminals should exactly match i.e. positive and negative to negative.

During charging/discharging of batteries, oxygen and hydrogen gas produced due to chemical reactions in the batteries and hence a vent hole will be there in the top up cap.

For liquid type batteries, distilled or demineralised water is to be added periodically with the electrolyte for maintaining the specific gravity of electrolyte between 1.260-1.280 (Fully charged battery).

### Inverter wiring

The input connector of the inverter is connected with the AC mains supply and the AC output of the inverter is connected to the Electronics/electronics appliances which is called inverter load. Always the connected load should be less than the VA capacity of the inverter.

Application of Inverter inverter used in many applications like UPS, speed controllers, electric motors etc.

### Voltage converter and output rectifier

If the output is required to be isolated from the input. as is usually the case in mains power supplies, the inverted AC is used to drive the primary winding of a high-frequency transformer. This converts the voltage up or down to the required output level on its secondary winding. The output transformer in the block diagram serves this purpose.

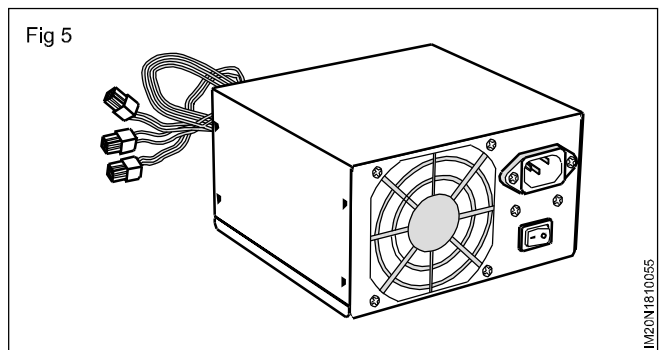
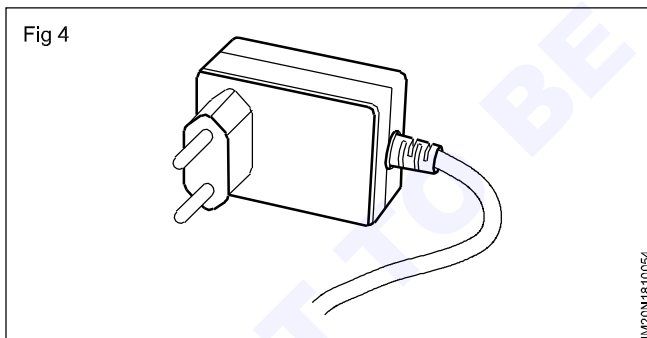
If a DC output is required, the AC output from the transformer is rectified. For output voltages above ten volts or so, ordinary silicon diodes are commonly used. For lower



voltages, schottky diodes are commonly used as the rectifier elements; they have the advantages of faster recovery times than silicon diodes(allowing low-loss operation at higher frequencies) and a lower voltage drop when conducting. For even lower output voltages, MOSFETs may be used as synchronous rectifiers; compared to schottky diodes, these have even lower conducting state voltage drops.

The rectified output is then smoothed by a filter consisting of inductors and capacitors. For higher switching frequencies, components with lower capacitance and inductance are needed.

Simpler, non-isolated power supplies contain an inductor instead of a transformer. This type includes boost converteres, buck converters and the buck-boost converters. These belong to the simplest class of single input, single output converters which use one inductor and one active switch. The buck converter reduces the input voltage in direct proportion to the ratio of conductive time to the total switching period, called the duty cycle. For example an ideal buck converter with a 10 V input operating at a 50% duty cycle will produce an average output voltage of 5 V. A feedback control loop is employed to regulate the output voltage by varying the duty cycle to compensate for variations in input voltage. The output voltage of a boost converter but can be greater than, equal to or less than the magnitude of its input voltage. There are many variations and extensions to this class of converters but these three form the basis of almost all isolated and non-isolated DC to DC converters. By adding a second inductor the Cuk and SEPIC converters can be implemented or by adding additional active switches, various bridge converters can be realized.



Other types of SMPSs use a capacitor - diode voltage multiplier instead of inductors and transformers. These are mostly used for generating high voltages at low current (cockcroft walton generator). The low voltage variant is called charge pump.

Switched-mode power supply units (PSUs) in domestic products such as personal computers often have universal inputs, meaning that they can accept power from mains supplies throughout the world, although a manual voltage range switch may be required. Switch-mode power supplies can tolerate a wide range of power frequencies and voltages.

Due to their high volumes mobile phone chargers have always been particularly cost sensitive. The first chargers were linear power supplies, but they quickly moved to the cost effective ringing choke converter (RCC) SMPS topology, when new levels of efficiency were required. Recently the demand for even lower no-load power requirements in the application has meant that flyback topology is being used more widely; primary side sensing flyback controllers are also helping to cut the bill of materials (BOM) by removing secondary-side sensing components such as optocouplers.  
(citation needed)

Switched-mode power supplies are used for DC to DC conversion as well. In automobiles where heavy vehicles use a nominal 24 V<sub>DC</sub> cranking supply, 12 V for accessories may be furnished through a DC/DC switch-mode supply. This has the advantage over tapping the battery at the 12 V position (using half the cells) that all the 12 V load is evenly divided over all cells of the 24 V battery. In industrial settings such as telecommunications racks, bulk power may be distributed at a low DC voltage (from a battery back up system, for example) and individual equipment items

will have DC/DC switched-mode converters to supply whatever voltages are needed.

A common use for switched-mode power supplies is as extra-low-voltage sources for lighting, and for this application they are often called “electronic transformers”.

## Printed Circuit Boards - etching, component side marking

**Objectives :** On completion of this lesson you shall be able to

- state the types of etchants used for etching PCBs
- state the method of preparing an etchant solution
- list the advantages of marking component positions on PCBs.

### Etching

Once the required portions on the copper foil side of the laminate is painted/masked and dried, the next step is to remove the copper present in the unmasked portions of the laminate. This process is known as etching.

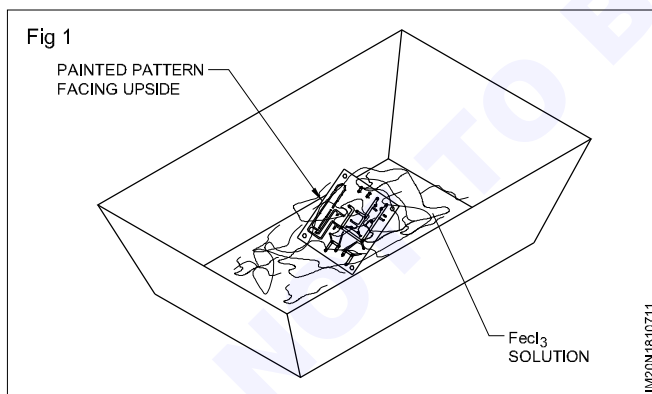
Only after etching the unwanted areas of the copper foil, the metal side of the laminate gets the actual shape of the circuit connection required.

Etching is done using any one of the following chemicals;

- Alkaline ammonia
- Sulphuric-hydrogen peroxide
- Ferric chloride
- Cupric chloride

The most popular amongst beginners and economical way of etching, is the manual etching process. This is done generally using a solution of ferric chloride. Ferric chloride is available in liquid, powder and crystal forms.

While preparing the etching solution, concentrated ferric chloride solution/powder is mixed with lukewarm water (27°F) and stirred well using a glass rod. This forms a diluted acid ( $\text{FeCl}_3$ ) solution.

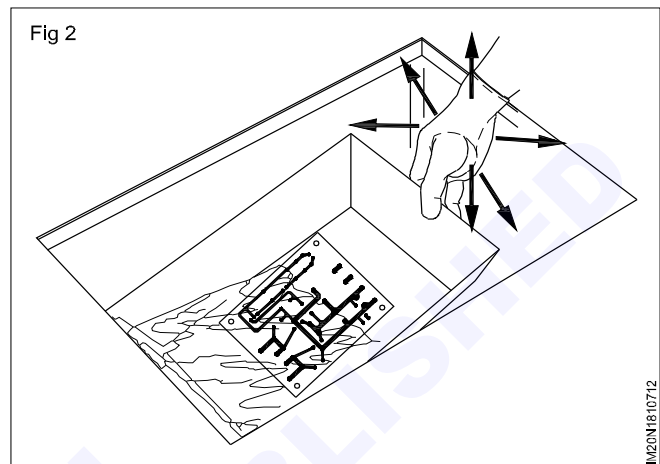


The ratio of ferric chloride and water decides the rate of etching. The typical ratio is, 100mg of concentrated ferric chloride powder/liquid for one litre of water. This  $\text{FeCl}_3$  is prepared in a plastic tray of suitable size such that the painted laminate to be etched can be fully immersed as shown in Fig 1.

Since ferric chloride is an acid solution, although diluted, it is harmful to the skin. Hence, rubber gloves are to be used while working with this solution.

The painted laminate to be etched is slid into the  $\text{FeCl}_3$

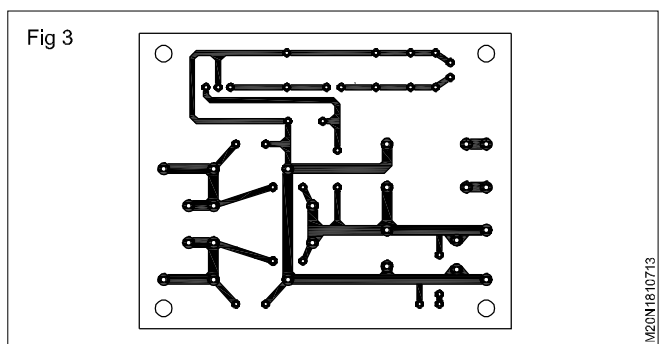
solution of required quantity, with the painted surface of the laminate facing the top as shown in Fig 1, such that, as the process of etching progresses, the extent of etching is visible.



To ensure speedy and uniform etching, the etchant solution is agitated lightly by shaking and tilting the tray as shown in Fig 2. Too much of agitation of the solution should be avoided, as this may peel off the ends of the painted tracks and remove those portions which were not intended to be etched.

As the etching progresses, the copper in the unwanted portion is gradually removed. When the etching is complete, all the copper in the unwanted portion disappears and the etched portion will have the colour of the insulator of the laminate board.

Once the unwanted portions of copper are completely etched, the board is taken out of the solution and is cleaned using fresh water to remove the remaining  $\text{FeCl}_3$  solution.



This stops any further etching process.

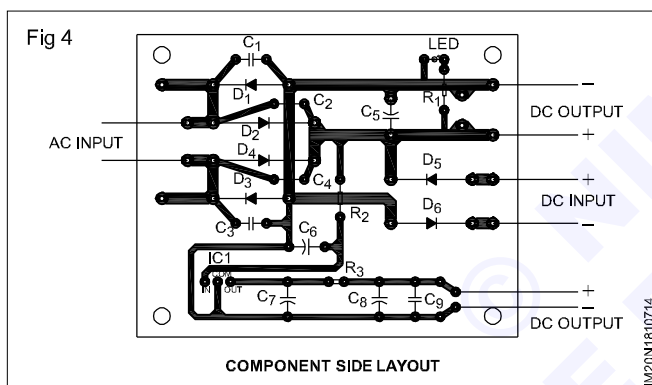
After cleaning the board using water and drying, the etch-resistant ink/paint on the lay out pattern is removed using solvents, such as, thinner or petrol. The cleaned board will then have bright copper stripes and pads, only in the required portions representing the circuit as shown in Fig 3.

### Drilling holes on PCBs

The next step after etching and removing the mask/paint is to drill holes of required diameter at the pad centers for inserting the components, input/output and  $V_{cc}$  & ground (Gnd) connections. Extra care is to be taken while drilling holes because carelessness while drilling may peel off the pad area of the copper. Some hints for drilling on PCB's are given below;

- If the point where drilling is to be made is not clear, punch the point again such that the drill bit sits at the punched point before starting the drilling.
- Use a high speed drill gun/machine.
- Use drill bits of the required size. If an exact size drill bit is not available, use a drill bit one size smaller but never one size larger.
- Fix the PCB firmly on a vice using wooden block so that the PCB does not become loose while drilling and peel of the pad area copper.
- Ensure that all the points required are drilled because, once the components are mounted, drilling holes on the PCB may damage the mounted components due to vibration.

After drilling holes, clean the PCB such that it is free from



burr and dust. Apply varnish on the layout pattern, to protect the copper pattern from corrosion.

### Preparing and marking component lay out

A typical component side of a PCB with the components marked on it is shown in Fig 4.

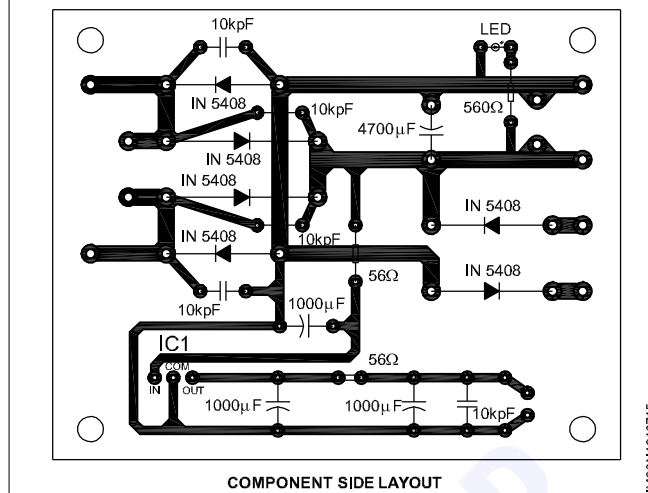
Marking the position of the components on the component side of the PCB has two main advantages,

- Increases the speed of mounting the components as the need of searching for the correct place for mounting the component is eliminated.
- Polarities of the components' terminals can be marked on the board itself such that the possibility of polarity errors committed while assembling the board is eliminated.

The standard procedure of component marking is to mark either the symbol of the component along with its code number or just the code number across the pads as shown in Fig 4.

A separate *component list sheet*, containing the component code number along with its value as shown below, is prepared for reference while collecting the components and assembling the PCB.

Fig 5



| Component  | Code     | Specification              |
|------------|----------|----------------------------|
| Resistors  | R1       | 1K Ohms, 1W, 5%            |
|            | R2, R3   | 680 Ohms, 1/4W, 10%        |
| Capacitors | C1       | 1000uF, 50V, axial         |
|            | C2 to C7 | 0.01uF, 100V, ceramic disc |
| Diodes     | D1, D2,  | 1N4007                     |
|            | D3, D4   |                            |
|            |          |                            |

For circuits using less number of components, instead of a separate component list the component values are marked directly on the printed circuit board as shown in Fig 5.

To prepare manually the *component side layout* of the PCB, the reverse of the pad positions of the PCB's *solder side lay out* is traced on to a graph sheet, and the component positions and polarities indicated using standard symbols. The components are numbered and a component list is prepared.

The component side layout is then traced on to the insulator side (component side) PC board using a carbon sheet and pencil. The traced portions on the board are redrawn/touched using a permanent marker pen or using paint and a thin brush.

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.

### Tape automated bonding

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.

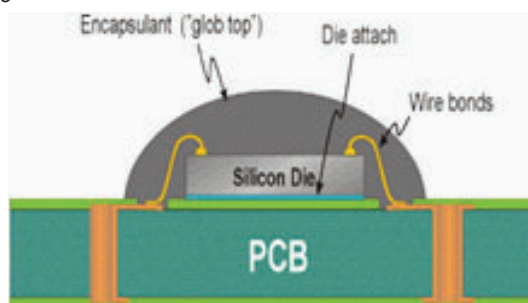
Process that places bare chips onto a printed circuit board (PCB) by first attaching them to a polyimide film, the film is moved to the target location, and the leads are cut and soldered to the board. This is also called a "tape carrier package" (TCP), the bare chip is then encapsulated ("glob topped")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



## Printed Circuit Board

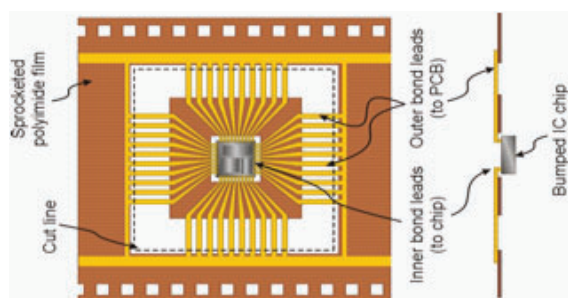
A printed circuit board (PCB) mechanically supports and electronically connects electronic components using

Fig 5



CHIP ON BOARD SIDE VIEW OF PCB

Fig 6



TAPE AUTOMATED BONDING

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.

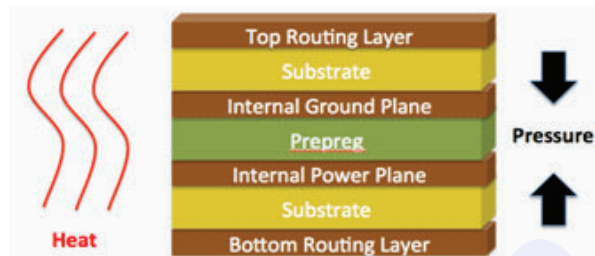
Printed circuit boards are used in all electronic products. Alternatives to PCBs include wire wrap and point-to-point construction. PCBs require the additional design effort to lay out the circuit, but manufacturing and assembly can be automated. Manufacturing circuits with PCBs is cheaper and faster 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

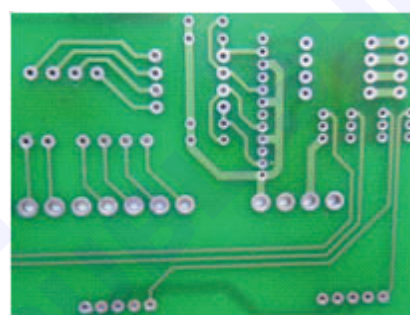
### Single side PCB

Fig 7



CONSTRUCTION OF MULTI LAYER PCB

Fig 8



SINGLE SIDE PCB

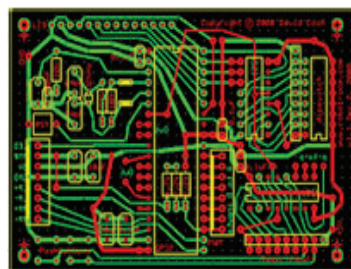
Single-sided printed circuit boards are easily designed and quickly manufactured as shown in fig.8. Single sided boards are available with surface finishes including Organic surface protectant (OSP), Immersion Silver, Tin, and Gold plating along with both leaded and lead-free Hot Air Solder Level (HASL).

**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

Fig 9

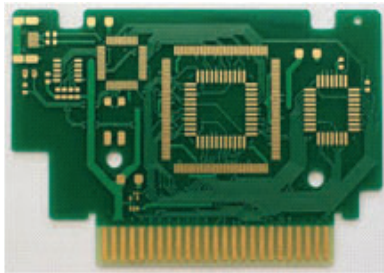


DOUBLE SIDE PCB BOARD

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 10



MULTI LAYER PCB

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

### Multi- layer PCB

Multilayer printed circuit boards (PCBs) represents 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.

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

Fig 11



TESTING 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.

### 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(Urethane) Resin (UR)

Fig 12



### Silicone

Fig 12 shows the silicon conformal coating pack

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

Fig 13a

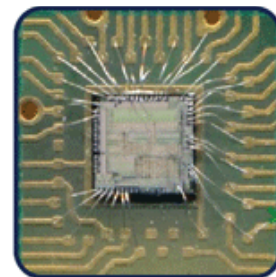
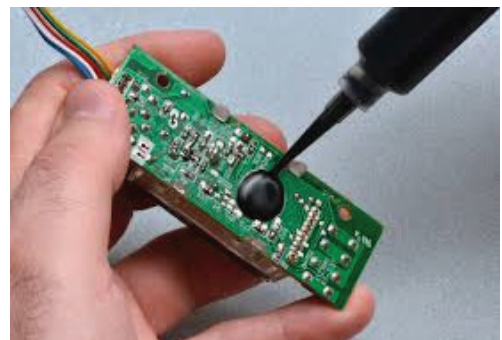


Fig 13b



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



Fig 14



impossible to remove without damaging the components.

Fig.13a shows SMD IC on PCB

Fig.13b shows how to apply epoxy coating on SMD IC's

Fig. 14 Shows the epoxy applied COB (chip on board)

### Acrylic

Acrylic coatings are solvent based. It provides Fair

Fig 15



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 15 Shows the acrylic type conformal coating.

### Para - Xylylene

Paraxylylene coatings are applied by chemical vapour

Fig 16



deposition (CVD). These coatings provide excellent di-electric strength and resistance to solvents.

### Poly Urethane

Urethane 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 16 Shows as urethane containers.

### 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 is to 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           | Characteristics Conformal Coating Type |         |              |          |               |
|---------------------------|----------------------------------------|---------|--------------|----------|---------------|
|                           | Epoxy                                  | Acrylic | Polyurethane | Silicone | Paraxyllylene |
| Hard                      | ✓                                      |         | ✓            |          | ✓             |
| Medium Hard               |                                        | ✓       | ✓            |          |               |
| Soft                      |                                        |         | ✓            | ✓        |               |
| Heat Reaction             | ✓                                      | ✓       | ✓            |          |               |
| Surface Bond, Very Strong | ✓                                      |         |              | ✓        | ✓             |
| Surface Bond, Strong      |                                        | ✓       |              | ✓        |               |
| Surface Bond, Medium      |                                        |         | ✓            | ✓        |               |
| Surface Bond, Light       |                                        |         |              | ✓        |               |
| Solvent Reaction          |                                        | ✓       |              |          |               |
| Smooth Surface            | ✓                                      | ✓       | ✓            | ✓        | ✓             |
| Nonporous Surface         | ✓                                      | ✓       | ✓            |          | ✓             |
| Glossy Surface            | ✓                                      | ✓       | ✓            |          |               |

Semi glossy Surface

✓

Dull Surface

✓

Rubbery Surface

✓

Brittle

✓

✓

## 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

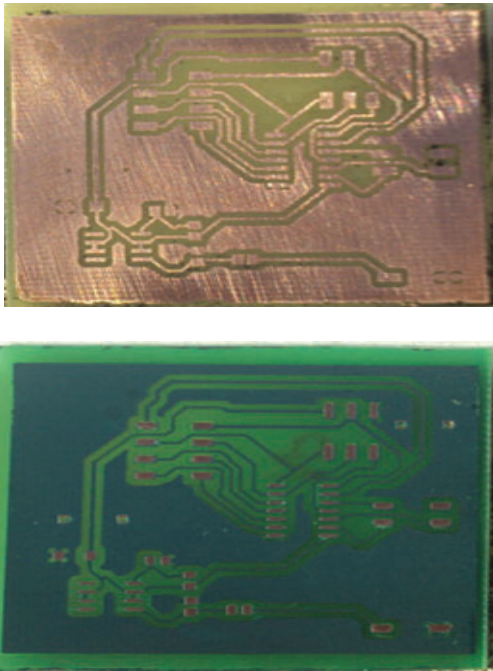
Solder mask or solder stop mask or solder resist is a thin layer of polymer applied to the copper traces of a printed circuit board (PCB) for protection against oxidation short circuits, corrosion, and other problems. Solder mask is a thin layer of polymer and to prevent solder bridges from closely spaced solder pads. A solder bridge is an unintended Electronics 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.

Fig 1a



Fig 1b



- Green

Fig 2a

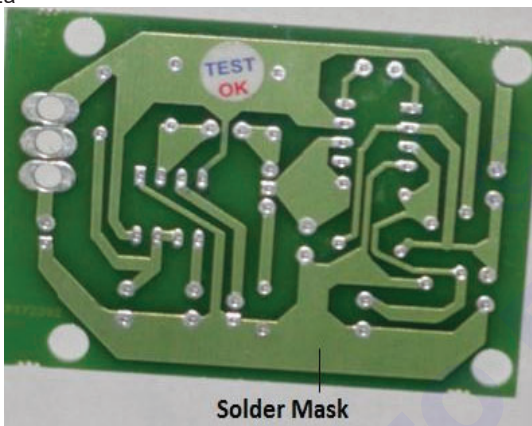
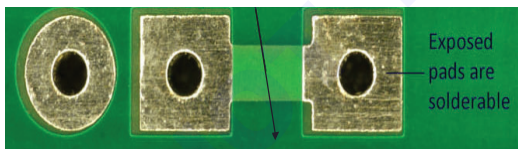


Fig 2b



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

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

Mostly Green colours used as solder mask as shown in

Fig.1a & 1b.

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

The lowest-cost solder mask is epoxy liquid that is

Fig 3a

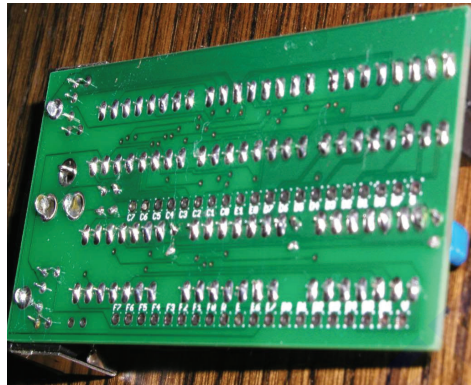
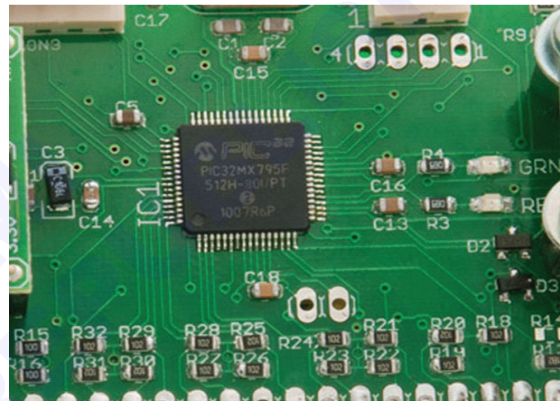


Fig 3b



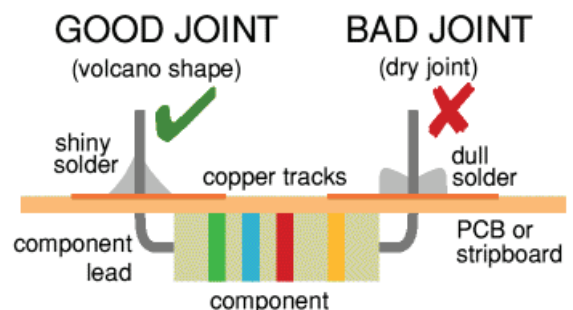
silkscreened through the pattern onto the PCB. Other types are

Liquid photoimageable solder mask (LPSM) inks.

Dry film photoimageable solder mask (DFSM).

LPSM are silkscreened and sprayed on the PCB, then exposed and developed.

Fig 4



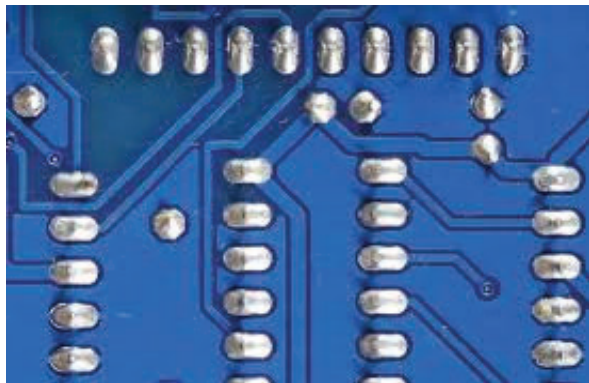
DFSM is vacuum laminated on the PCB then exposed and developed.

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

Solder joints



Fig 5



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

Fig 6a



Fig 6b



- 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.

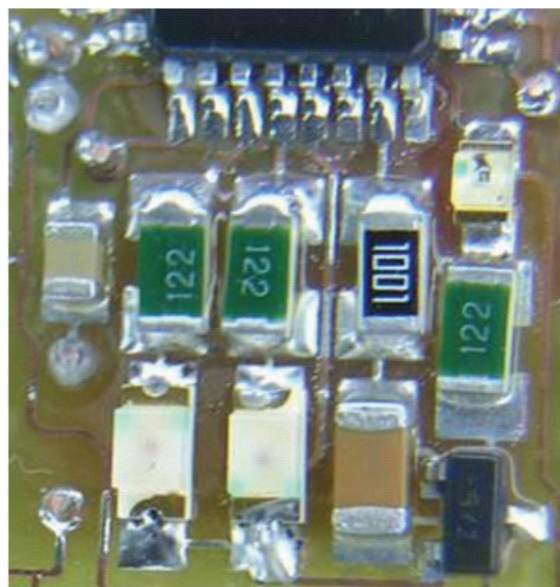
Fig.4 Shows the method of solder joints or PCB

#### 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.

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

Fig 6c



#### Poor solder joints

Too much solder on a joint may lead to poor joints as

Fig 7a



Fig 7b



shown in fig. 6a, 6b, 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.



## Dry joints

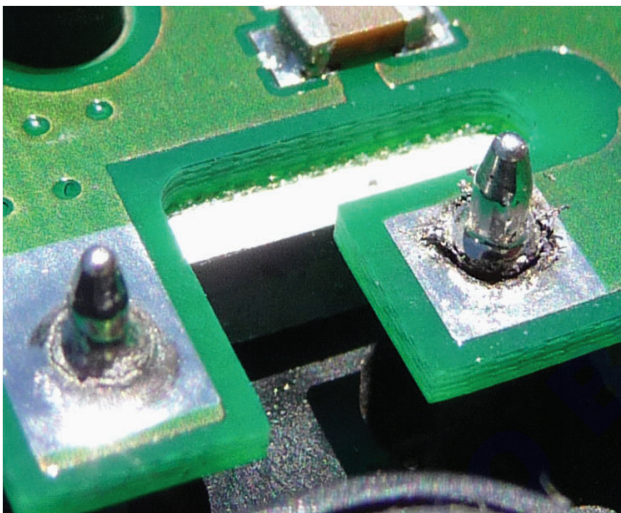
Dry joints are the main problem of solder joint. These solder joints may be completely open circuit, or they may be intermittent, high resistance or noisy. Therefore it is essential that no dry solder joints are present in any electronics equipment.

It is easy to identify dry joints as shown in fig.8a & 8b. Good solder joints are shiny, whereas 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 Electronics 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 inspect 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 recommends 4 thou as being a lower limit.

Fig 9

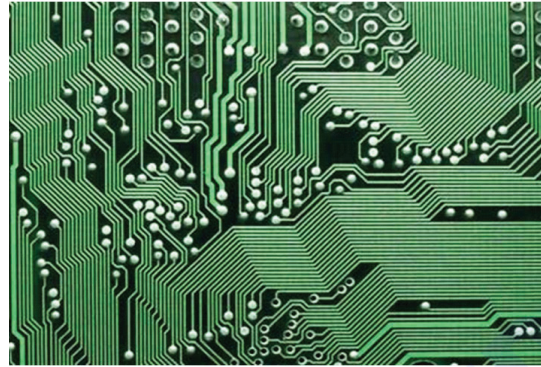


Fig 10

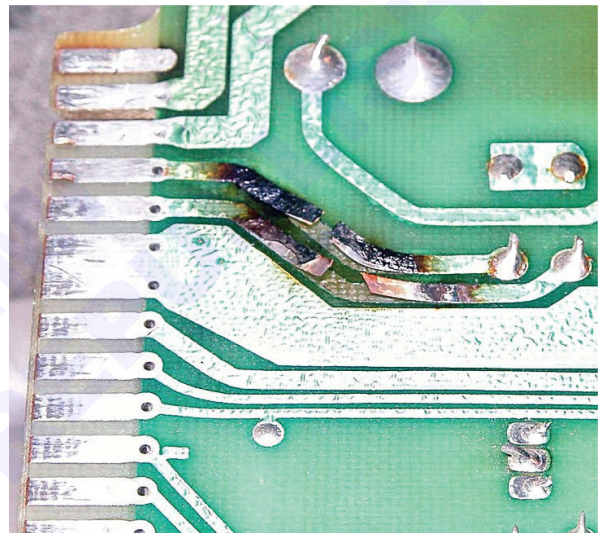
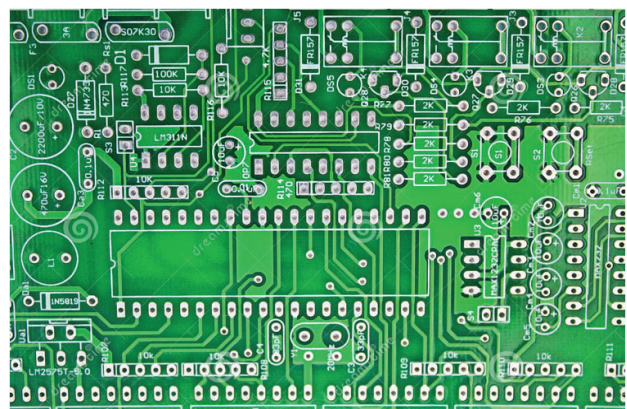


Fig 11



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

Fig.9 shows the tracks on the PCB.

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

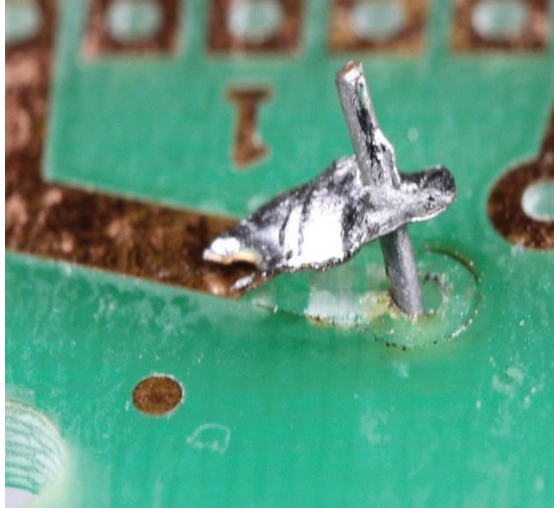
## Pads

Fig. 11 shows the pads of PCB



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.

Fig 12



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.

Fig12 shows the damaged pad which is to be reworked.

### 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



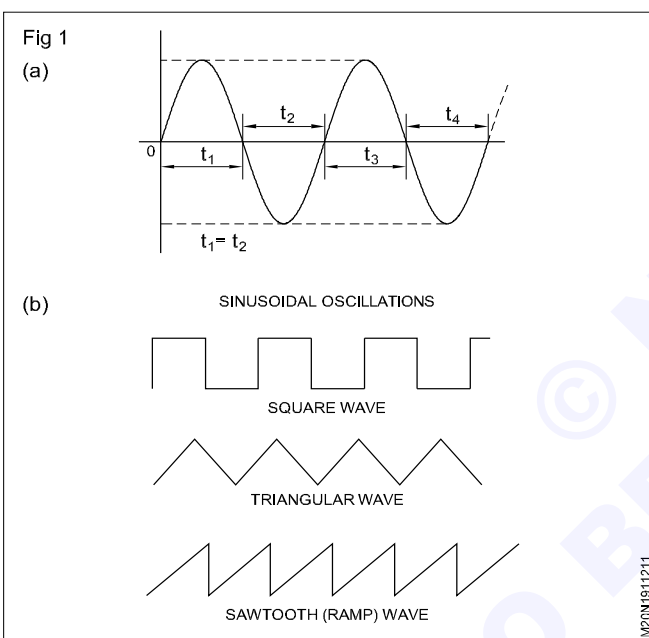
## Oscillators and its working principles

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

- state the function of an oscillator
- name the two main classifications of oscillators
- explain the principle of oscillation in a tank circuit
- state the Barkhausen criterion
- list the basic requirements for an oscillator
- list the feed back requirement for an amplifier to take-off and have sustained oscillations
- explain the working of parallel-fed Hartley oscillator with the help of a circuit
- calculate frequency of oscillations, for the given values of L & C.

### Oscillator

An oscillator is a circuit for producing voltages that vary in a regular fashion with respect to time. The output wave forms of oscillators are repeated exactly in equal successive intervals of time as shown in Fig 1a and Fig 1b.



The output wave-form of an oscillator may be sinusoidal as shown in Fig 1a. Such oscillators are known as **sine wave oscillators** or **harmonic oscillators**.

The output of oscillators may be square, triangular or sawtooth waveform as shown in Fig 1b. Such oscillators are known as **non-sinusoidal oscillators** or **relaxation oscillators**.

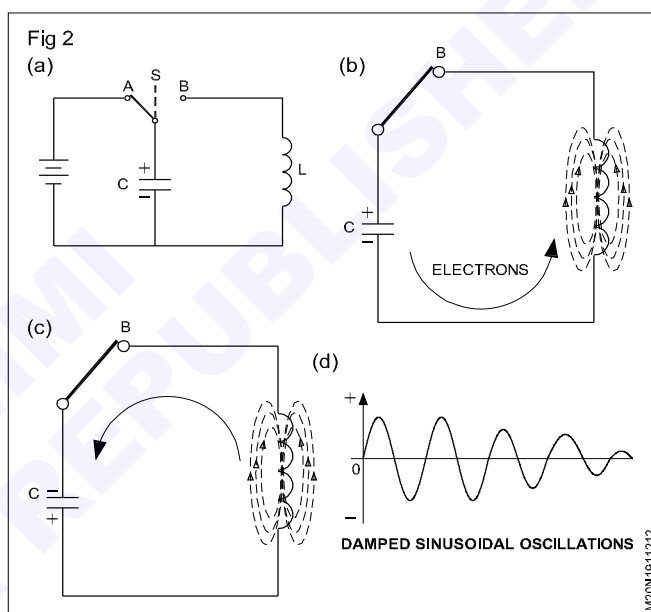
### Principle of sinusoidal or harmonic oscillations

Fig 2a shows an inductor and a capacitor connected in parallel as a parallel LC resonant circuit. A parallel LC circuit is also known as *tuned circuit* or *tank circuit*.

In Fig 2a, when switch S is put into position A, the capacitor gets charged with the bottom plate being negative and the top plate positive. This means, energy is stored in the capacitor in the form of an electric charge.

When switch S is put into position B, as in Fig 2b, the capacitor starts discharging through the inductor, creating an expanding magnetic field around L. Since the inductor

has the property of opposing any sudden change in current through it, the current builds up slowly.



Once the capacitor gets fully discharged, the magnetic field around L begins to collapse. The collapsing magnetic field, induces a voltage (back-emf) in L. This back emf tends to maintain the electron flow through L in the same direction as when C was discharging. Hence, this back emf in the inductor starts charging the capacitor with opposite polarity as shown in Fig 2c. After the magnetic field has totally collapsed, C would have got charged in the opposite direction as shown in Fig 2c.

Again capacitor C discharges through the inductor in the opposite direction. An expanding magnetic field appears around L but in the opposite direction.

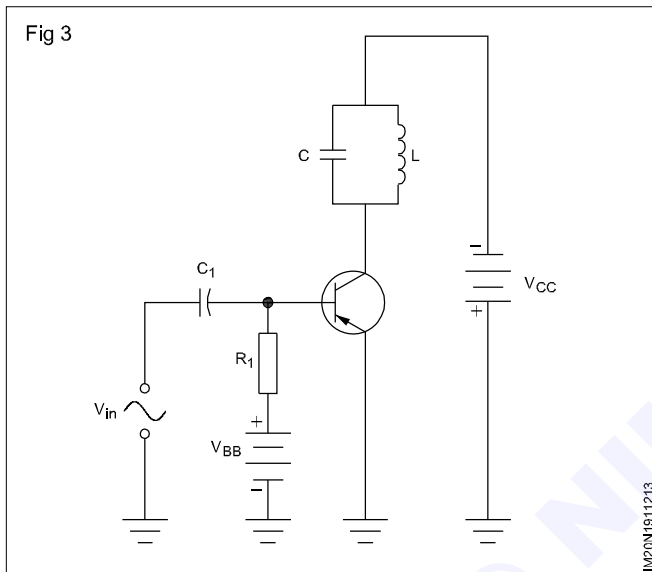
This process continues back and forth, causing the electrons to oscillate in the tuned tank circuit. If the inductor was ideal (zero resistance) and the capacitor was totally loss-free, this process would have continued indefinitely, and would have resulted in a continuous sinusoidal waveform as shown in Fig 1a. However, owing to the resistance in an practical inductor, and the losses in the capacitor due to the resulting  $I^2 R$  (heat loss), the amplitude of the oscillation decreases gradually (damped) and ultimately the oscillations die down as shown in Fig 2d.

The frequency of oscillation produced by the resonant frequency is given by,

$$f = \frac{1}{2\pi\sqrt{LC}}$$

### Overcoming losses in tank circuit for sustained oscillations

To avoid the damping of oscillations, when the energy fed into the circuit has been used up, it is necessary to supply more energy by charging the capacitor again. As shown in Fig 2a, by switching S between A and B at proper time, the oscillations can be maintained thus obtaining sinusoidal waveform of constant amplitude and frequency.



In Fig 4 a transistor amplifier connected in such a way that it will cause undamped oscillations without requiring any external signal. Such a circuit is known as an oscillator.

The oscillator circuit at Fig 4 is known as **tickler-coil** oscillator. Here  $L_1$  is inductively coupled to  $L$ . When power is first switched ON to the circuit, current flows in the transistor. As the current flows through  $L$ , it induces a voltage in  $L_1$  which is coupled to the base of the transistor and is amplified. If the phase of the feedback voltage is aiding, then there is an increase in the collector current. This action builds up a large current pulse which excites the LC tank into oscillations. The signal fed by  $L_1$  to the base of the transistor is a sine wave of the same frequency as that in the LC circuit and of proper phase to sustain the oscillations. The signal induced in the base thus eliminates the need for an external input to the oscillator and the LC tank will oscillate as long as the DC power to the circuit is ON.

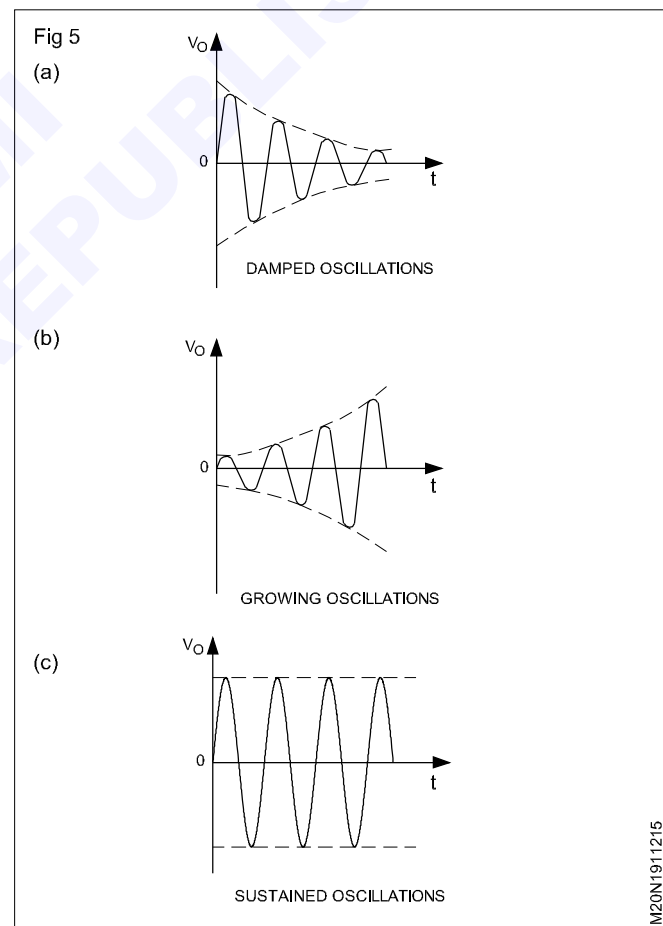
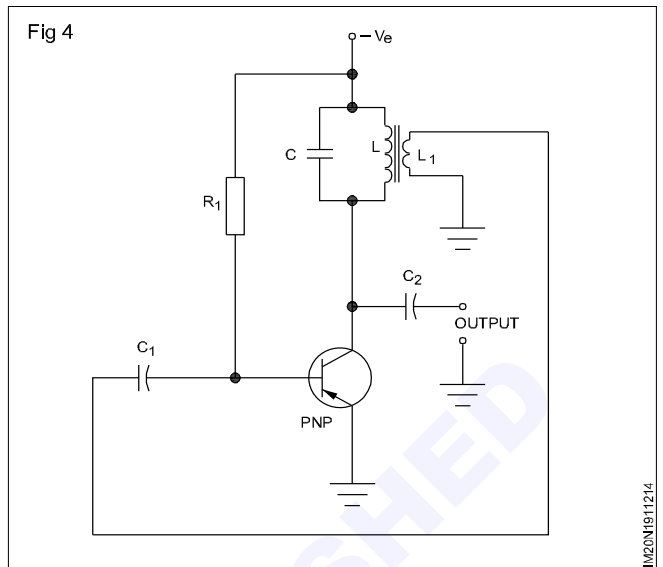
The feedback given to the amplifier in Fig 4 in the proper phase so as to sustain(keep going) oscillations is referred to as positive feedback or **regenerative feedback**.

### BARKHAUSEN CRITERION

The mathematical analysis for an amplifier to oscillate on its own is given below:

- In the amplifier shown in Fig 4, assume that the gain of the amplifier is  $A$  and the feedback factor is  $\beta$ . If

the product of  $A\beta$  is less than 1 ( $A\beta < 1$ ), then the output signal will be a damped oscillations which will die down as is shown in Fig 5a.



- if  $A\beta > 1$ , the output voltage builds up as shown in Fig 5b. Such oscillations are called growing oscillations.
- If  $A\beta = 1$ , the output amplitude of oscillations remains constant as in Fig 5c.

When the feedback is positive(regenerative), the overall gain of the amplifier with feedback( $A_f$ ) is given by,

$$A_f = \frac{A}{1 - A\beta}$$

When  $A\beta = 1$ , the denominator of the equation will be zero, and hence  $A_f = \text{Infinity}$ . The gain becoming infinity means, there is output without any input. i.e. the amplifier becomes an oscillator. This condition  $A\beta = 1$ , is known as **Barkhausen criterion for oscillations**.

Summarizing, the basic requirements for an oscillator are;

- 1 A stable DC power supply source
- 2 An amplifier
- 3 A regenerative (positive) feedback from output to input
- 4 A LC tank circuit to determine the frequency of oscillations.

### Starting signal for oscillators

As discussed above an oscillator gives alternating output voltage without an input signal once the amplifier is given a regenerative feedback. But in a practical oscillator circuit, to start off oscillations, no starting input signal is provided. However, the starting signal of an oscillator is generated by the noise voltage while switching on the oscillator circuit. Such noise voltages are produced due to the random motion of electrons in resistors used in the circuit.

Noise voltage contains almost all the sinusoidal frequencies of small amplitude. However, it gets amplified and appears at the output terminals. The amplified noise now drives the feedback network, which is a resonant tank circuit. Because of this tuned tank circuit, the feedback voltage  $A\beta$  is maximum at a particular frequency  $f_r$ , which will be the frequency of oscillations. Furthermore, the phase shift required for positive feedback is correct at this frequency  $f_r$  only. Thus although the noise voltage contains several frequency components, the output of the oscillator will contain a single sinusoidal frequency  $f_r$ , the resonant frequency of the tank circuit.

To summarize, the following are the requirements of an oscillator circuit to take-off with oscillations and have sustained oscillations;

- There must be positive feedback.
- Initially the loop gain product  $A\beta$  must be  $> 1$ .
- After the circuit starts oscillating, the loop gain product  $A\beta$  must decrease to 1 and remain at 1.

### Hartley Oscillator

One of the simplest of sinusoidal oscillators is the Hartley oscillator shown in Figs 6a and 6b.

Shown in Fig 6a is a series-fed Hartley oscillator. This circuit is similar to the tickler-coil oscillator shown in Fig 4, but the tickler circuit coil  $L_1$  is physically connected to  $L$ , and is hence a part of  $L$  (like an auto-transformer). This oscillator is called **series-fed** because, the high frequency oscillations generated and the DC paths are the same, just as they would be in a series circuit. Series-fed Hartley oscillators are not preferred due to their poor stability of

oscillations.

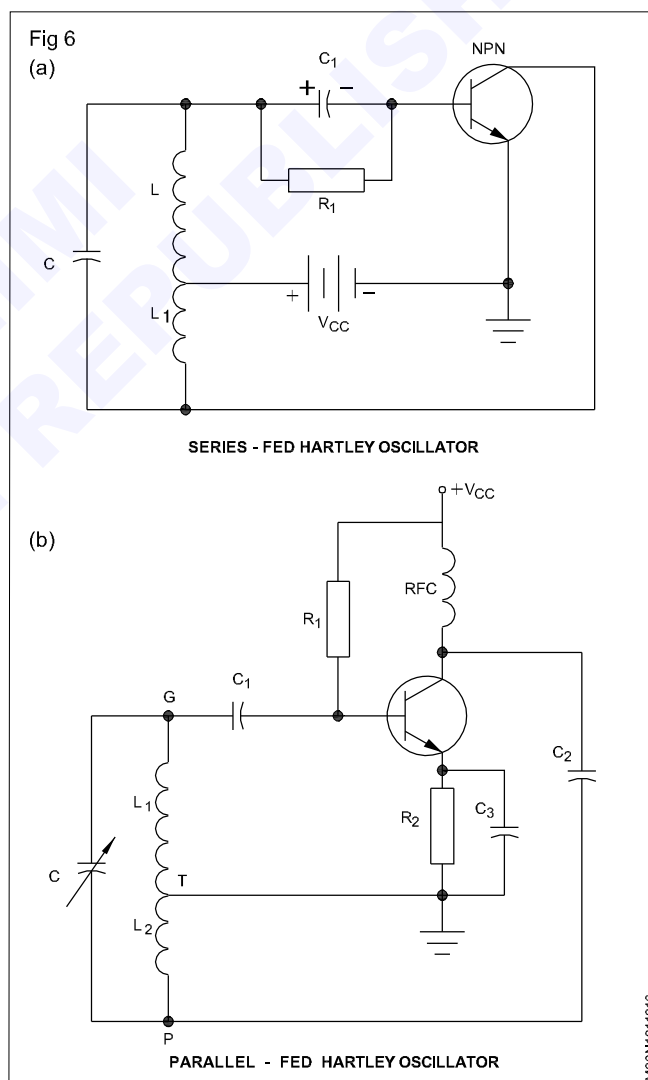
Fig 6b is parallel-fed Hartley oscillator commonly used in radio receivers. Parallel-fed Hartley oscillators are known for their high stability of oscillations.

The circuit at Fig 6b is actually an amplifier with positive (regenerative) feedback to have sustained oscillations. The capacitor  $C_2$  and inductor  $L_2$  form the path for RF current in the collector to ground circuit.

RF current through  $L_2$  induces a voltage in  $L_1$  in proper phase and amplitude to sustain oscillations.

The position of the tap at the junction of  $L_1$  and  $L_2$  determines how much signal is fed back to the base circuit.

The capacitor  $C$  and the inductors  $L_1 + L_2$  forms the resonant tank circuit of the oscillator which determines the frequency of oscillations. Capacitor  $C$  can be made as a variable capacitor for tuning the oscillator to different frequencies.  $C_1$  and  $R_1$  form the RC circuit which develops the bias voltage at the base.



The RF choke at the collector keeps the high frequency AC signal out of the  $V_{CC}$  supply. In cheaper oscillator circuits the RF choke is omitted and is replaced by a resistor.

Resistor  $R_2$  connected in the emitter provides DC stabilization.  $R_2$  is bypassed by  $C_3$  to prevent AC degeneration.



The Hartley oscillator coil has three connections. These are usually coded on the coil. If they are not, it is generally possible to identify them by a resistance check. The resistance between the taps T and P as shown in Fig 6b, is small compared with the resistance between T and G. If the coil connections are not made properly, the oscillator will not work.

### Checking Oscillator Frequency

The frequency of an oscillator can be computed if the values of L ( $L = L_1 + L_2$ ) and C are known using the formula,

$$f = \frac{1}{2\pi\sqrt{LC}}$$

where, f is in hertz, L in henrys, and C in farads.

The frequency of an oscillator may be measured in two ways,

- Using a direct read-out frequency meter also known as frequency counter which is most accurate, popular and easy to use.
- Using an oscilloscope with a calibrated time base to measure the period of the wave-form. From the measured period, t frequency is calculated using the formula

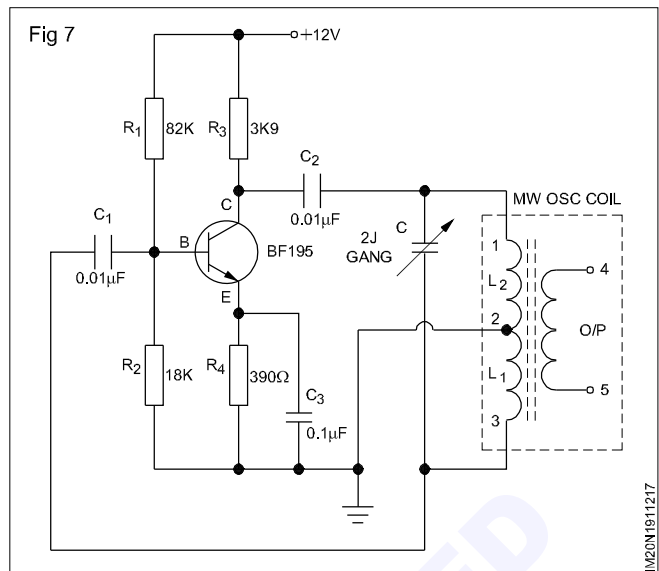
$$f = \frac{1}{t}$$

where, f is the frequency in Hz and t the time period in seconds.

A practical Hartley Oscillator circuit using medium-wave oscillator coil as L is shown in Fig 7.

The advantage of using a medium wave oscillator coil for L is that the output can be taken out of the secondary winding (4 and 5) of the coil.

The transistor used is a silicon high frequency transistor (BF series) as the oscillator frequency is in the range of 1 MHz.



The divider biasing is provided to make the DC conditions such that the amplifier works as Class A. With the heavy feedback (large β), the large feedback signal drives the base of the transistor into saturation and cut-off. This large feedback signal produces negative DC clamping at the base, changing the operation from Class A to Class C. The negative clamping automatically adjusts the value of Aβ to 1. If the feedback is too large, it may result in loss of some of the output voltage because of the stray power losses.

When you build an oscillator, you can adjust the amount of feedback to maximize the output voltage. The trick is to use enough feedback to start under all conditions (different transistors, temperature, voltage etc.), but not so much that you lose more output than necessary.

The frequency of oscillations of the oscillator circuit at Fig 7 can be varied by varying the position of the shaft of the gang of the gang capacitor ( $C_4$ ).

## Colpitt's and Crystal Oscillator

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

- state the difference in the feed back method in a Colpitt's oscillator compared to Hartley oscillator
- calculate frequency of oscillations for the given the values of L and C
- state the main disadvantage of LC oscillators and give reasons
- describe the piezo electric property of crystals
- explain the AC equivalent circuit of piezo electric crystals
- describe the circuit of a crystal oscillator and explain the function of the components.

### COLPITT'S Oscillator

Colpitts oscillator is another type of sinusoidal oscillator or harmonic oscillator which uses a tank circuit for oscillations. Colpitts oscillators are very popular and are widely used in commercial signal generators and communication receivers.

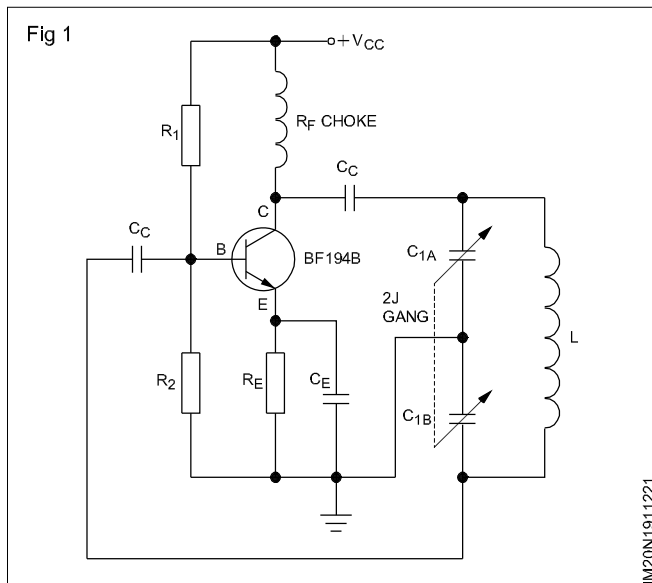
A typical Colpitt's oscillator shown in Fig 1 is similar to a Hartley oscillator. The only difference is that the Colpitts oscillator uses a split capacitor for the tank instead of a split inductor used in Hartley oscillators.

The parallel-fed or shunt-fed Colpitt's oscillator shown in Fig1, uses the common emitter configuration. The capacitors  $C_{1A}$  &  $C_{1B}$  form the voltage divider used to provide the feedback signal. The voltage drop across  $C_{1B}$  determines the feedback voltage. All other components in this circuit have the same function as in the Hartley circuit.

The frequency of oscillations of the Colpitt's oscillator is given by,

$$f = \frac{1}{2\pi\sqrt{LC}}$$





where,

$f$  is the frequency of oscillation in hertz,

$L$  is the inductance of the coil in henry

$C$  is the total capacitance in farads given by,

$$C = \frac{C_{1A} \cdot C_{1B}}{C_{1A} + C_{1B}}$$

The frequency of oscillations can be changed by using a miniature ganged capacitor for  $C_{1A}$  &  $C_{1B}$ .

By varying the shaft of the ganged capacitor, both the capacitances  $C_{1A}$  and  $C_{1B}$  get varied, and hence, the frequency of oscillations of the oscillator varies.

Colpitts oscillators are generally used for generating frequencies above 1 MHz.

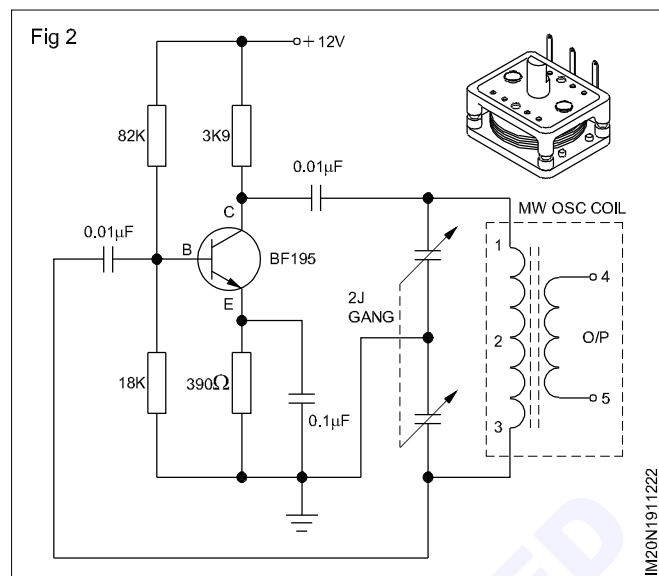
A practical Hartley Oscillator circuit using a ganged capacitor for  $C_{1A}$  and  $C_{1B}$  and a medium wave oscillator coil for  $L$  is shown in Fig 2.

### Crystal Oscillators

The LC oscillator circuits such as Hartley and Colpitts have the problem of frequency in-stability. The most important reason for the frequency drift in LC oscillators is, the change in value of capacitance and inductance of the tank circuit that occurs when temperature changes. As the temperature increases or decreases, the values of  $L$  and  $C$  deviate causing the circuit to oscillate at a frequency different from the desired resonant frequency. Other reasons for frequency deviation are, the leads of transistor, inter electrode and wiring capacitances.

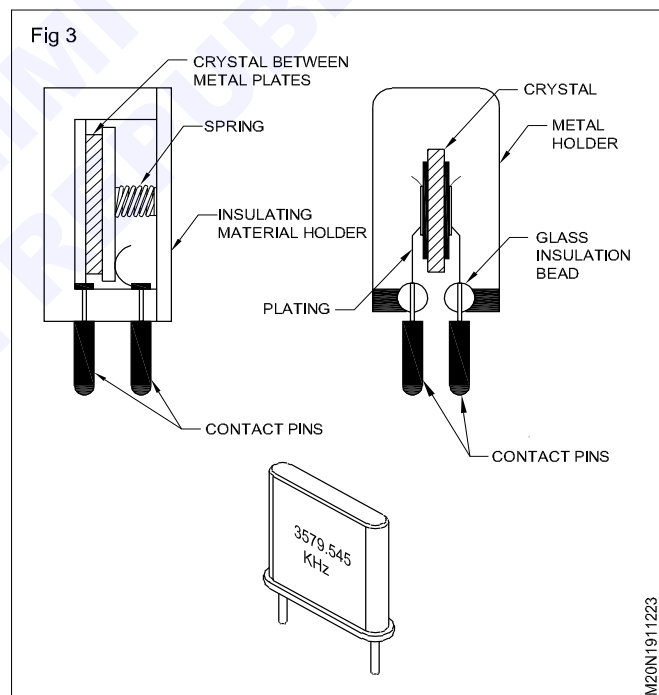
The problem of frequency drift can be largely overcome by using high  $Q$  coils and good quality capacitors. But, with ordinary inductors and capacitors,  $Q$ -values in excess of a few hundred is very difficult or impossible to achieve.

Large improvements in frequency stability can be achieved by using a **quartz crystal** in the place of the conventional tuned circuit. Such oscillator circuits are referred to as *crystal controlled oscillators*.



### Piezo Electric Effect

It was discovered that certain crystals such as **quartz** and **Rochelle**, exhibit a special property known as piezo-electric property. A quartz crystal looks like a piece of thin frosted glass usually cut into 1/4 to 1 inch squares as shown in Fig 3.



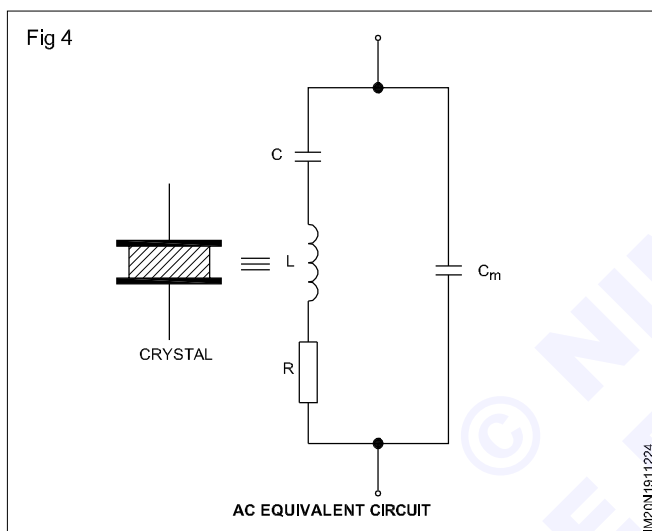
When such a crystal is held between two flat metal plates and pressed together, a small emf will be developed between the plates as if the crystal became a battery for an instant. When the plates are released, the crystal springs back to its original shape and an emf of opposite polarity is developed between the two plates. In this way, mechanical energy/force is converted to Electronics energy by the crystal. This property is made use of in the pick-ups for gramophone records. In a gramophone record, small mechanical vibrations are produced when the stylus tracks the groove on the gramophone plate. This vibrating force gives rise to corresponding voltages representing the recorded sound at the pick-up terminals.

In addition to the above property of the crystal, when an emf is applied across the two plates of the crystal, the crystal will distort from its normal shape. If an opposite polarity emf is applied, the crystal will reverse its physical distorted shape. In this way, these crystals also convert Electronics energy into mechanical energy.

The above two reciprocal actions of a crystal are known as **piezo-electric effect**. Such crystals are housed in crystal holders as shown in Fig 3.

Amongst several crystals having this piezo-electric property, the quartz crystal is most popular because, this material is almost perfectly elastic. If mechanical oscillations are started in this crystal it takes a long time for the oscillations to die away. Quartz crystals therefore, have a very high mechanical Q.

So far as the Electronics properties are concerned, a quartz crystal is equivalent to the LC resonant circuit shown in Fig.4.

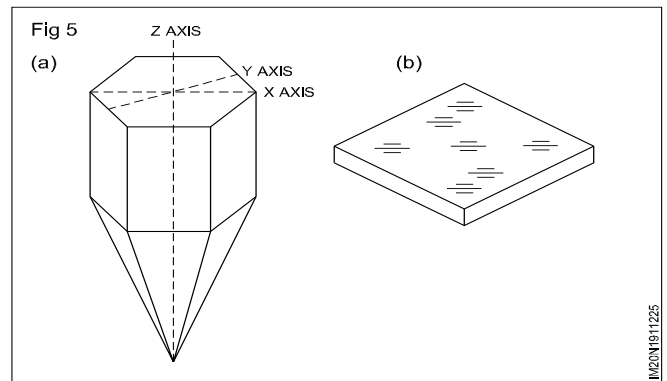


The values of  $L$ ,  $R$ ,  $C$  and  $C_m$  depend upon the physical size of the crystal and how the crystal is cut from the original mass. Capacitance  $C_m$  represents the mounting capacitance. For using the crystal in electronic circuits, two conducting electrodes are placed on to its two faces. Connecting leads are then joined to these electrodes. When the leads are connected to a source of oscillating voltage, mechanical vibrations are set up within the crystal. If the frequency of the oscillating voltage is close to a resonant frequency of the crystal, then the crystal forces the oscillating voltage to coincide with the oscillating frequency of the crystal. Hence, in an oscillator, by using the crystal in the place of an LC resonant circuit, the frequency of oscillation is determined almost entirely by the crystal. Q values in excess of 20,000 are easily obtained with readily available crystals resulting in highly stable oscillating frequency.

Hence, when accuracy and stability of the oscillation frequency are important, a quartz crystal oscillator is used instead of Hartley or Colpitts oscillators.

### Crystal cuts

The natural shape of a quartz crystal is a hexagonal prism with pyramids at the ends as shown in Fig 5a.

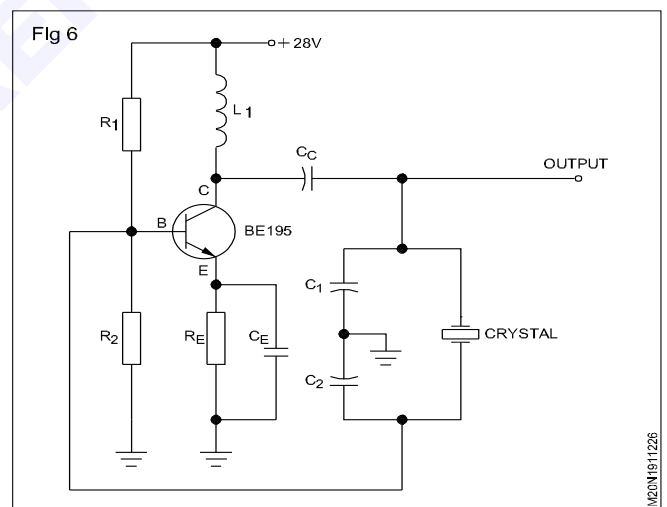


To get an usable crystal out of this, a rectangular slab is cut out of the natural crystal as shown in Fig 5b. Depending upon the angle of the cut and the thickness of the slab, the fundamental frequency of vibration of the crystal varies. The resonant frequency of a crystal is usually between 0.5 and 30 MHz.

### Pierce crystal oscillator

The pierce crystal controlled oscillator shown in Fig 6 is often used because it requires very few components and has good frequency stability.

The pierce crystal oscillator is similar to the Colpitts oscillator but for the inductance coil replaced by a crystal. Here the crystal across the collector and the base terminals of the transistor determines the oscillating frequency. As in a Colpitts oscillator, capacitors  $C_1$  and  $C_2$  form a capacitive voltage divider for feedback. The AC voltage across  $C_2$  provides the necessary positive feedback to the base.



In Fig 6, the crystal acts like an inductor that resonates with  $C_1$  and  $C_2$ . In the base circuit, the  $R_1 R_2$  divider supplies forward bias voltage from the  $V_{cc}$ . Bias stabilization is provided by the  $R_E C_E$  combination in the emitter circuit. In Fig 6, if the crystal resonant frequency is, say 3579.545 Hz, then the oscillator oscillates at the same frequency and gives a sinusoidal output of 3579.545 Hz.

Crystal oscillators are generally used in,

- mobile radio transmitters and receivers
- broadcast transmitters
- test equipments such as signal generators where exact frequency and very high frequency stability are of utmost importance. The frequency drift in crystal controlled oscillators will be less than 1 Hz per  $10^6$  Hz.

## RC time Constant

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

- explain the importance of RC time constant
- state the need of universal time constant curve
- list a few applications of RC time delay circuits
- explain the use of oscilloscope in measuring time delay.

### RC time constant $\tau$ while charging

When a capacitor is connected across a battery or a source of dc voltage as shown in Fig 1a, it charges almost instantaneously. This is because there is no resistance in the charging circuit to limit the charging current. On the other hand, if a resistor is connected in series with the capacitor, as shown in Fig 1b, the resistance limits the maximum current that can flow in the series circuit. This limiting of charging current causes delay in the time required for the capacitor to charge up to the source voltage.

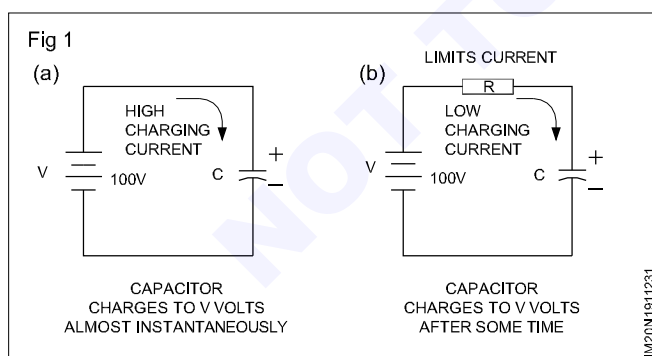
Even if a resistor were not connected in the circuit, the resistance due to connecting wires, leads internal resistance of the supply source acts as a lumped resistance to delay the charging. The exact time required for the capacitor to charge depends on both the resistance (R) in the charging circuit, and the capacitance (C) of the capacitor (recall higher capacitance value allows higher current in the circuit,  $I = CV/t$ ).

This relationship between resistance, capacitance and the charging time is expressed by the equation,

$$t = RC$$

where  $t$  (spelled as tow) is the capacitive time constant or RC time constant, representing the time required for the capacitor to charge to 63.2% of its full charge voltage.

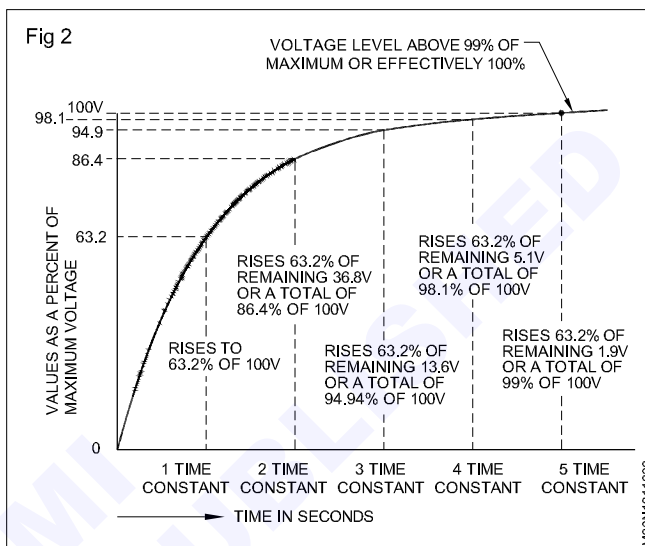
It is interesting to note that, in each succeeding time constant  $t$ , the voltage across the capacitor increases by an additional 63.2 % of the remaining voltage. Thus, after the second time constant ( $2t$ ) the capacitor would have charged to 86.4 % of its maximum voltage,



- after  $3t$ , 94.9 percent, of its maximum voltage,
  - after  $4t$ , 98.1 percent, of its maximum voltage
- and
- after  $5t$ , more than 99 percent of its maximum voltage.

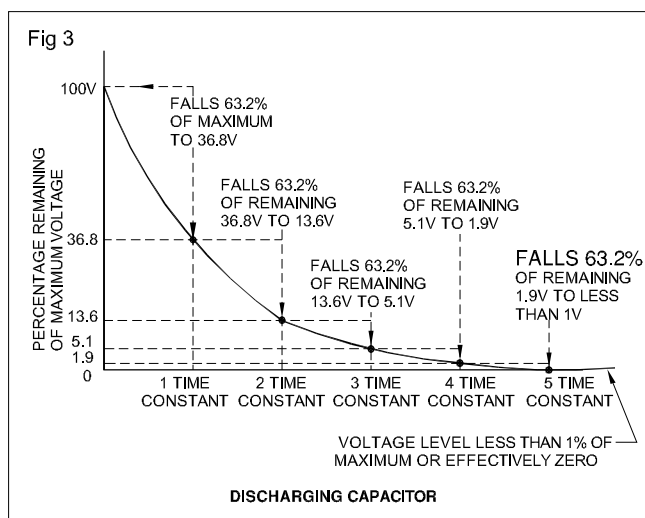
Fig 2 shows the charging curve of the resistor - capacitor (RC) circuit shown in Fig 1 and its relationship with RC time constant,  $t$ .

Hence, the capacitor is considered to be fully charged only after a period of more than five time constants or at least five time constants.



### RC time constant while discharging

As in charging, while a capacitor is discharging, there is time delay in discharging the stored charges depending upon the value of resistance and capacitance. This discharge time constant  $t$ , is also given by  $RC$ . This time constant gives the time required for the voltage across a discharging capacitor to drop to various percentages of its maximum value as shown in graph at Fig 3.



Notice the similarity between the capacitive time constant and the inductive time constant, discussed in previous lessons. The similarity is that, the voltage across a capacitor and the current through an inductor builds up/ rises and drops off/falls exactly in the same way.

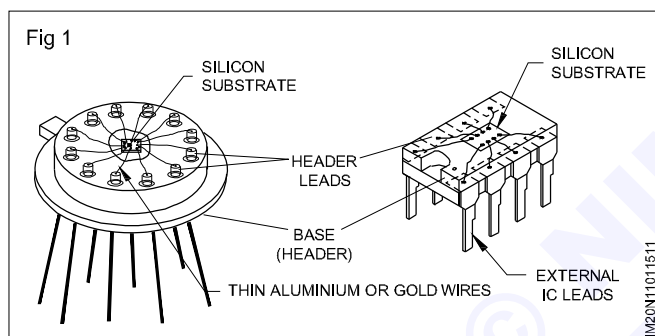
## Operational amplifiers and their applications

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

- state the base material used in making ICs
- state the most important considerations in designing ICs
- state the meaning of operational amplifier
- state the two basic modes of operation of Op- Amps
- list ideal and typical characteristics of Op-Amps
- explain a simple summing and differential amplifier
- state the meaning of slew rate and its importance.

### Integrated circuits

An integrated circuit (IC), as its name implies, is an integrated (put together) form of several components of a circuit on a single chip or wafer of a semiconductor material, generally silicon. ICs may have hundreds of active components (transistors, diodes) and passive components (resistors, capacitors etc.,).



The active and passive components are deposited or diffused on this minute sized silicon substrate. The substrate is then mounted on a ceramic or a insulated metal base called header as shown in Fig. 1. Aluminum or gold wires of about one-third thickness of a human hair are bonded between the IC contacts called pads and the header leads.

ICs are made by a complex photographic process on a very small sized surface. This process is known as micro photolithographic process

The base material of ICs is a highly refined silicon chip (also known as substrate) as shown in Fig 1. Generally the size of the silicon substrate is of the size of a pin head.

The number of pins each IC has depends on the complexity of the circuit built into the IC. However, any IC will have minimum of 3 pins as in any voltage regulator ICs, to more than 64 pins in computer ICs.

In IC, fabrication of active components such as transistors and diodes take much less space on the chip than resistors and capacitors.

Direct coupling between transistor stages are used in ICs. Also transistors are used as resistors instead of fabricating resistors themselves. Components like chokes, coils and transformers cannot be fabricated in ICs because of its physical bulkiness. Therefore, wherever inductors are necessary for a circuit leads are brought out of the ICs such

that, inductors can be connected external to the IC. Most ICs are designed to be used for more than one application by making small changes in external circuitry. For example, an IC may be used as an amplifier or as an oscillator and so on.

The commonly used OP-AMP ICs are  $\mu$ A741-single op-amp and LM 324 - having four op-amp. They come in DIP and having larger input voltage range no latch up, high gain short circuit protection, no frequency compensation required.

Input voltage range from -15v to +15v while common mode input is from -12v to +12v supply current is 1.7mA power consumption is 50 mV.

The leading IC manufactures are signetics, texas instruments, fair child and national semi conductors limited.

### Advantages of integrated circuits

- Although the circuit inside an IC is complex consisting of a large number of components, the overall physical size of the IC is extremely small resulting in miniaturization of the electronic gadgets size.
- Drastic decrease in the overall weight of the gadget due to miniaturised size of the circuit.
- Low power requirement.
- Increased reliability due to less number of solder connections.
- Greater flexibility in use of the same IC for different circuit configurations.
- Better functioning under wide range of temperatures.
- Low cost per IC due to large scale production of ICs.

### Limitation of integrated circuits

- Large value capacitors and resistors cannot be fabricated.
- Chokes, inductors and transformers cannot be fabricated.
- If any one stage inside the IC circuit becomes defective, the complete IC has to be discarded.
- Handling is very delicate.

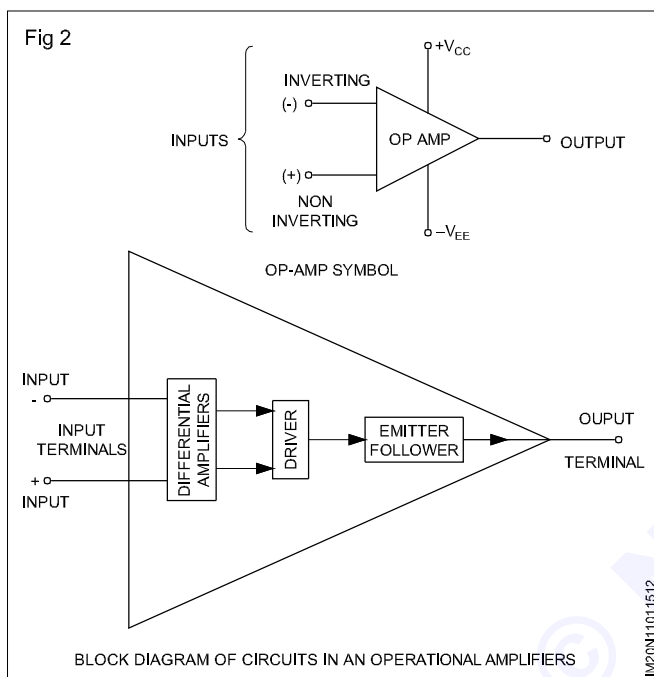


## Basic linear integrated circuit-‘Operational Amplifiers’ (Op-Amps)

An operational amplifier, often referred as op-Amp, is a high gain, direct coupled differential amplifier, designed to amplify both DC and AC signals.

The term operational is used with these amplifiers because, in early days these amplifiers were used in analog computers to perform mathematical operations such as addition, multiplication etc.,

Symbol used to represent an Op-Amp and the functional blocks inside it are shown in Fig 2.



As can be seen from Fig 3, operational amplifiers will have two inputs and one output. The reason for having two input points is that Op Amps have a special type of amplifier configuration known as Differential amplifier as its first stage.

A typical differential amplifier stage is shown in Fig 3. A differential amplifier stage consists of two transistors with an input to each transistor. The output is taken between the collectors of the transistors as shown in Fig. The most important point to note is, both the transistors have identical characteristics, load resistors, input resistors and a single emitter resistor. Dual power supply (+ve, -ve and Gnd) is required for differential amplifiers (single supply can also be used with a few extra components). If a dual supply is used and if the amplifier is properly balanced (symmetrical values), the output voltage across the collectors will be equal to the difference of the two input voltages. Hence, this amplifier is called differential amplifier.

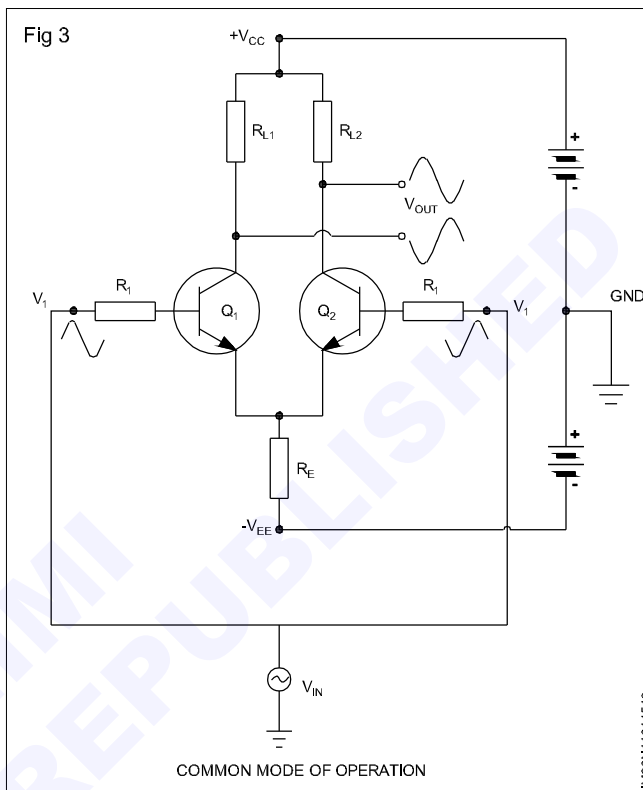
### Modes of operation of differential amplifiers

Any operational amplifier can be operated in two modes. They are,

- Common-mode operation
- Differential-mode operation.

### Common-mode operation

In Fig 4, since both sides of the differential amplifier circuit are identical, if an identical signal (same level and phase) is applied to both the inputs (transistors), the same output signal results from both collectors. If a meter is connected across the outputs the voltage difference will be zero. Thus, the output is equal to the gain times the difference between the input voltages. Mathematically, this is expressed as,



$$V_{out (com)} = A(V_1 - V_2)$$

Where,

A is the gain of each transistor

$V_1$  and  $V_2$  are the base input voltages measured to ground.

This mode of operation is called Common-mode operation.

In common-mode operation, a differential amplifier theoretically rejects the common mode signals (signal that is identical at each input) and hence the output will be zero as shown below,

If both the magnitude and phase of  $V_1$  and  $V_2$  are the same, then,

$$V_{out} = A(V_1 - V_2) = A(V_1 - V_1) = A(0)$$

In practice, since the two halves of the circuit cannot be perfectly identical, instead of zero output there will be a very small output. For example, a differential amplifier with a 0.5 V common-mode input signal may give an output of 0.025 V instead of zero. This 0.025V is because of the slight mismatch between the two half of the differential amplifier circuit.

### Differential-mode operation

Fig 5 shows the differential-mode operation. When the two input signals are out of phase by  $180^\circ$ , the amplifier



amplifies the difference of the input signals. Since the input signals are of equal in amplitude, but out of phase by  $180^\circ$  the output signal is equal to, twice the gain times the input signal. This can be mathematically written as, If magnitude of  $V_1 = V_2$  then,

$$V_{\text{out (Dif)}} = A [V_1 - (-V_2)] = A [2V_1] = 2A (V_1)$$

### Common-mode rejection ratio

The common-mode rejection ratio (CMRR) of a differential amplifier (or other device) is the rejection by the device of unwanted input signals common to both input leads, relative to the wanted difference signal. An ideal differential amplifier would have infinite CMRR; this is not achievable in practice. A high CMRR is required when a differential signal must be amplified in the presence of a possibly large common-mode input. An example is audio transmission over balanced lines.

Ideally, a differential amplifier takes the voltages,  $V_+$  and  $V_-$  on its two inputs and produces an output voltage  $V = A_d(V_+ - V_-)$  where  $A_d$  is the differential gain. However, the output of a real differential amplifier is better described as

$$V_o = A_d(V_+ - V_-) + \frac{1}{2}A_{cm}(V_+ + V_-),$$

Where is the common-mode gain, which is typically much smaller than the differential gain.

The CMRR is defined as the ratio of the powers of the differential gain over the common-mode gain, measured in positive decibels (thus using the 20 log rule):

As differential gain should exceed common-mode gain, this will be a positive number, and the higher the better. The CMRR is a very important specification, as it indicates how much of the common-mode signal will appear in your measurement. The value of the CMRR often depends on signal frequency as well, and must be specified as a function thereof.

It is often important in reducing noise on transmission lines. For example, when measuring the resistance of a thermocouple in a noisy environment, the noise from the environment appears as an offset on both input leads, making it a common-mode voltage signal. The CMRR of the measurement instrument determines the attenuation applied to the offset or noise.

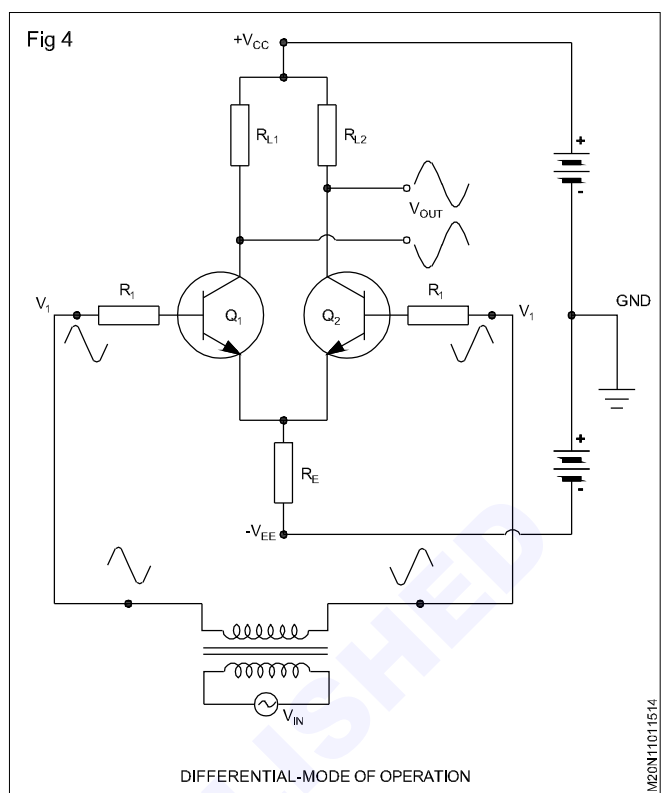
### Methods of giving input and taking output in differential amplifiers

A differential amplifier is normally used with a double ended input and double ended output. But this is not a compulsion. A differential amplifier can also be used as single ended input and with single ended output.

**Single-ended input:** The input signal is applied to only one input and the other input is grounded as shown in Fig.6a.

#### Single-ended output:

The output can be taken from the collector of Q1 to Gnd or Q2 to Gnd or from both collectors to ground as shown in Fig 6b. when the output is taken from both collectors to Gnd the two signals provide a push-pull output as shown in Fig 6b.



Recall that the two transistors of a push-pull amplifiers need signal of some amplitude but out-of-phase by  $180^\circ$ .

### Differential input:

The two inputs given are signals having opposite polarity ( $180^\circ$  out of phase). The input is similar to input to a push-pull amplifier.

**Differential output:** The output is taken across the two collectors which is nothing but the difference between the two collector voltages. The difference will be zero when the input voltages are equal and are of the same polarity. The input signals add up if they have opposite polarities.

### Practical Op-Amps and applications

Most of the commercially available Op-Amp ICs will usually have two input terminals and only one output terminal as shown in Fig 7. The two inputs of the Op-Amp are called, INVERTING(-) and NON-IN-VERTING(+) inputs. This is because, a signal applied to the inverting (-) input, produces output which will be  $180^\circ$  out of phase with the input. Whereas a signal applied, to the NON-INVERTING (+) input produces an output which will be in-phase with the input.

### Gain of Op-Amps

The gain and other characteristics of the operational amplifier depends upon the external components connected externally to the Op-Amp.

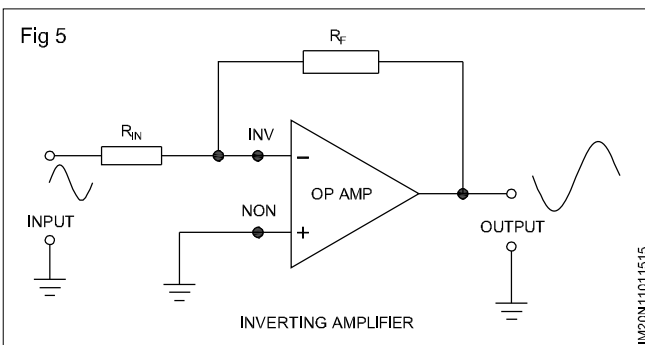
The theoretical gain of Op-Amps is very high, of the order of 100,000 or more. In practical amplifiers using Op-Amp, a resistor is used to provide an external negative feed back to the Op-Amp. The negative feedback resistor is generally connected between the output terminal to either of the input terminals as shown in Fig 8. Although the negative feed back reduces the gain of the amplifier drastically (10 to

1000), the negative feed back makes the amplifier stable, prevents it from going into oscillations and increases the frequency response range of the amplifiers.

The gain of Op-Amp without negative feedback is referred to as OPEN LOOP GAIN whereas, the gain of Op-Amp with feed back is referred to as CLOSED LOOP GAIN.

### Op - AMP as inverting amplifier

Fig 8 shows a typical inverting amplifier using an Op-AMP. In this inverting amplifier, the input signal is applied to the INVERTING (INV) terminal. The NON-INVERTING (NON) terminal which is grounded the input signal is applied at the INV terminal, the output of the amplifier will be an amplified signal of opposite polarity. The resistor  $R_F$  between the output and input provides necessary negative feedback. The amount of negative feedback provided depends on the values of resistors  $R_F$  and  $R_{in}$ .



$$\text{Inverting Amplifier Gain } (A_{inv}) = -\frac{R_F}{R_1}$$

Negative sign indicates inverting of output signal generally, amplifier gain can also be written as

$$A = \frac{V_o}{V_{in}}$$

As an example, let us calculate the closed-loop voltage gain, for the inverting amplifier at Fig 8. Assume values of  $R_F = 470 \text{ K}\Omega$  and  $R_{in} = 47 \text{ K}\Omega$ . Assume an input signal voltage of 0.5V.

The closed-loop gain of an inverting amplifier is given by,

$$A_{inv} = \frac{R_F}{R_{in}}$$

$$A_{inv} = \frac{-470K}{47K} = -10$$

Since  $R_F/R_{in} = A_{(inv)}$ , equation can also be written as,

The output voltage of the non – inverting amplifier is given by,

$$V_{out(inv)} = A_{(inv)} \cdot V_{in}$$

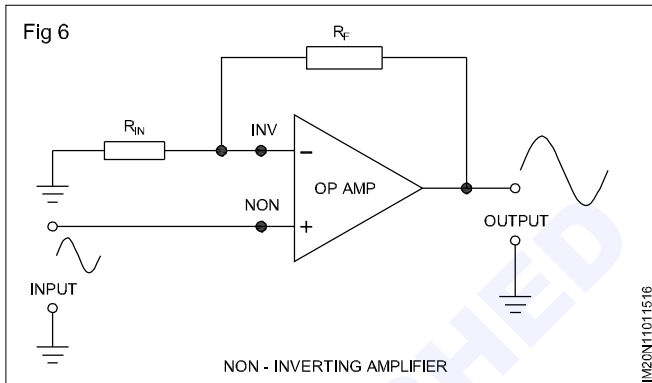
in the given example,

$$V_{OUT (NON)} = 10 \times 0.5 \text{ v}$$

$$= 5.0 \text{ Volts}$$

### OP Amp non inverting amplifier

In the Fig. 9 shows a typical amplifier using OP-Amp. In this non-inverting amplifier, the input signal is applied to the non-inverting (NON) terminal. The output signal of amplifier is same polarity (inphase) of applied input signal. The resistor  $R_F$  between output and input providing necessary feedback. The amount of feedback provided by amplifier depends on value of  $R_F$  and  $R_{in}$ .



$$\text{For gain } A_{(NON)} = \frac{V_{out}}{V_{in}} = \frac{R_{in} + R_F}{R_{in}} = 1 + \frac{R_F}{R_{in}}$$

### Gain-bandwidth product(GBP)

Typical frequency response of an Op-Amp is from direct current, or 0 Hz, to more than 1 MHz. However, because of internal shunt capacitances, the amplifier gain drops off sharply as the frequency is increased Therefore to specify the gain of an Op-Amp at different frequencies, a term called as Gain-Bandwidth-Product(GBP) is specified. For example, if the GBP of an Op-Amp is given as 1MHz, it means that the gain of the Op-Amp becomes unity at an input signal of 1 MHz. It is always useful to know the gain-bandwidth product (GBP), of the Op-Amp being used.

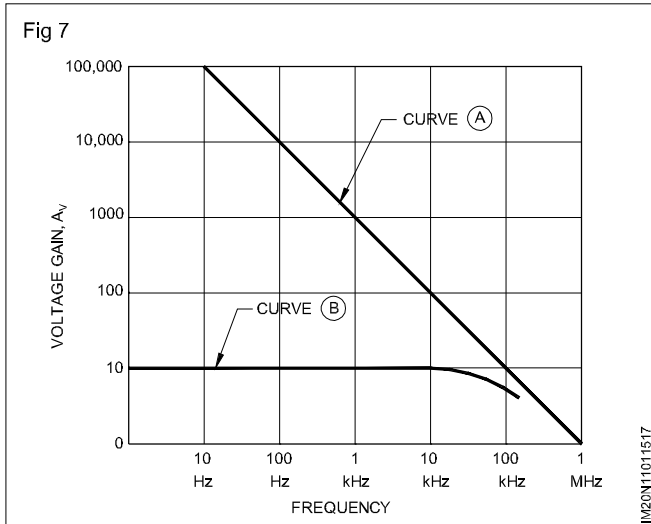
**Example:** The GBP of an Op-AMP is specified as 1 MHz. What is the maximum gain that can be obtained using this Op- Amp at 1 kHz GBP of 1 MHz means, gain = 1 at 1 MHz. Therefore, at 1 kHz more gain will be,

$$\text{Gain at 1kHz} = \frac{\text{GBP}}{1\text{kHz}} = \frac{1\text{MHz}}{1\text{kHz}} = 1000$$

This means, at 1 kHz an OpAmp with GPB of 1 MHz provides a maximum gain of 1000. This is shown in curve A of Fig 10.

Curve A of Fig 10 shows the open loop frequency response of an Op-Amp with a constant GBP of 1 MHz. As can be seen from curve A, for the same Op-Amp, the gain is 100 at 10 kHz, 10 at 100 kHz and becomes unity at 1 MHz.: This huge variation in open loop gain  $A_{(OPEN)}$ , can be made almost constant using negative feedback.

As shown in curve B of Fig 10, using suitable value of resistor  $R_F$  and  $R_{in}$ , if the closed loop gain  $A_{(CLOSED)}$  of the Op-Amp is set at say 10, then the frequency response of the Op-Amp becomes almost flat upto 100kHz. This is one of the major advantages of negative feed back in Op-Amps.



**TIP:** The lower you set the gain of the amplifier, the higher will be the bandwidth of the amplifier.

### Characteristics of Op-Amps

An ideal operational amplifier will have the following characteristics:

Voltage gain  $A_v = \infty$

Bandwidth BW =  $\infty$

Input resistance  $R_{in} = \infty$

Output resistance  $R_o = 0$ .

In practice such ideal characteristics cannot be achieved. However, in many practical situations, Op-Amps come close to these characteristics. Typical specifications of an Op-Amp is given below:

Voltage gain,  $A_v \leq 100,000$

Bandwidth, BW  $\approx 1$  MHz (unity gain)

Input resistance,  $R_{in} \geq 2$  M $\Omega$

Output resistance  $R_o \leq 50 \Omega$

### Typical Op-Amp applications

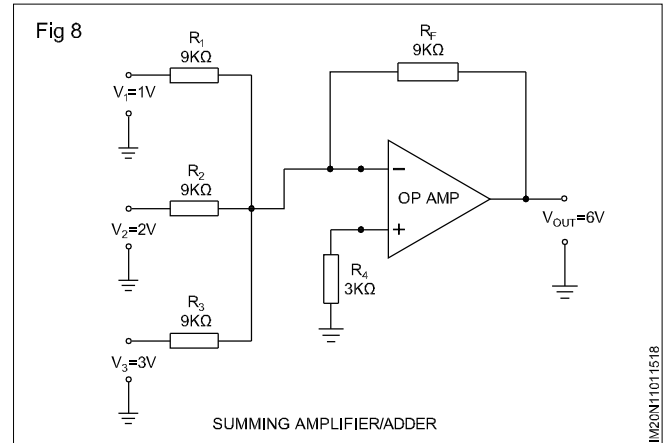
Application of Op-Amps are innumerable. This is because, of the flexibility that is built into the internal circuit of the Op-Amp. In addition to its basic function of amplification, Op-Amp are used as comparators, adders, subtractors, differentiator, integrators and so on.

### Application of Op-Amp as a summing amplifier

Fig 11 is the circuit of a Op-Amp summing amplifier or in simple terms an adder. Here, the Op-Amp is used as an inverting amplifier to do the summing operation. In Fig 11, three input signals are applied to the INV terminal of the Op-Amp through resistors  $R_1$ ,  $R_2$  and  $R_3$ . The amount of negative feedback given to the Op-Amp is dependent on the value of  $R_f$  divided by each resistor in the feedback path. As a result, the output voltage of the Op-Amp is given by,

$$V_{out} = \left[ \left( \frac{R_f}{R_1} \times V_1 \right) \right] + \left( \frac{R_f}{R_1} \times V_2 \right) + \left( \frac{R_f}{R_1} \times V_3 \right)$$

If,  $R_1 = R_2 = R_3 = R_f$ , then  $R_f/R$  becomes 1 in each signal path.



Then, the output is given by,

$$V_{out} = V_1 + V_2 + V_3$$

$$V_{out} = (1 \times 1V) + (1 \times 2V) + (1 \times 3V)$$

$$V_{out} = 1V + 2V + 3V = 6V$$

The output of 6V is equal to the sum of the three input voltages. Note that the value of resistor  $R_4$  (3K) at the NON terminal of Op-Amp is made equal to the parallel combination of three 9 K resistors at the INV terminal. This resistor is required to balance the inputs of the differential amplifier in the Op-Amp.

### Slew rate in Op-Amps

Slew rate is an important characteristic of Op-Amps. The term slew refers to the rate of change of the output voltage. As an example, a slew rate of 1 volt per microsecond (V/ $\mu$ S) means, the amplitude of output voltage can change by a maximum of 1 V in 1 $\mu$ S. Fast slew rate or high slew rate is desirable for high frequency amplifiers, especially those with non-sinusoidal input signal wave shapes.

### DC supply voltage for Op-Amps

Op-Amps generally need dual (+V<sub>e</sub>, com., -V<sub>e</sub>) DC supply. Typical values of DC supply voltages are  $\pm 9V$ ,  $\pm 15V$  and  $\pm 12V$ . Note that both positive and negative voltages of same amplitude is required for Op-Amps. The V+ is used as the collector voltage, and the V- is used as the emitter supply voltage of the first differential amplifier stage of the Op Amp as shown in Fig.4

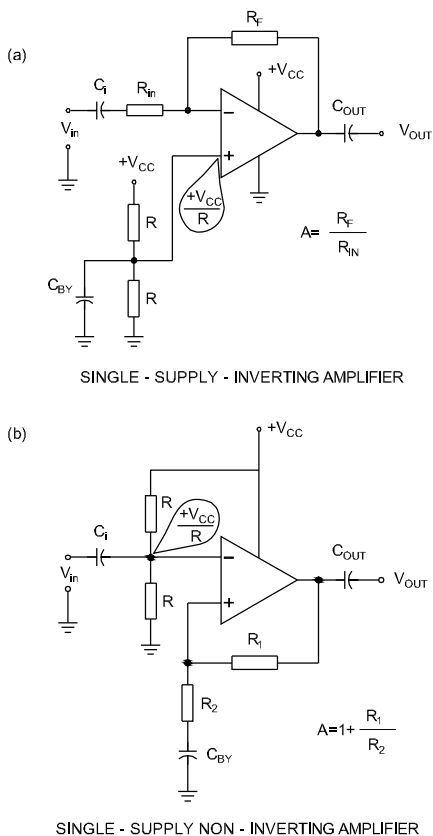
The DC load current drawn from the power supply for an Op-Amp is generally less than a few milliamps. Typical power rating of Op-Amps is around 500 mW.

### Commercial Op-Amp ICs

The earliest and most popular commercial Op-Amp is the 741 IC. This Op-Amp IC is manufactured by several manufacturers, and hence, carries along with it tags such as uA 741 (Fairchild), LM 741 (National semiconductor) and so on. Commercially several other types of Op-Amp ICs having different type numbers are available in the market. Some IC packages may consist of more than one Op-Amp built-in a single package. For instance, LM324 (National semiconductors) is a quad-operational amplifier. The term quad means it has four Op-Amp in one package.

Some of the popular Op-Amps and its specifications manufactured by National Semiconductors)

Fig 9



### Single supply operation of Op-Amps

Most Op-Amp circuits are designed to work using dual ( $\pm$ ) DC power supply. Due to some inconvenience of dual

## Op-Amp applications - comparators, differentiator

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

- explain the zero crossing detector circuit using Op Amp IC uA 741
- describe op-amp as comparator, differentiator.

### Applications of op-amp:

Op-amp is a building block of linear or analog systems. It has countless applications.

- It is used in non linear analog systems- the non linear applications are comparator, rectifier, clipper, clamper, log and antilog amplifier, multiplier etc.
- It is used in linear circuits, the output varies with input signal in a linear manner. The linear applications are adder, subtractor, voltage to current converter, current to voltage converter, differentiator, integrator, differential amplifier, instrumentation amplifier and etc.

### Comparator :

An operational amplifier in the open loop configuration operates in a non linear manner. Comparator, detector, limiters and converters work in this mode.

A comparator is a circuit which compares a signal voltage at one input of an op-amp with the known reference voltage at the other input. There are two types of comparator

- non - inverting comparator
- inverting comparator

supplies, many Op-Amp circuits are made to work using single supply. The method of making Op-Amps to work with single-supply is shown in Figs 12a and 12b.

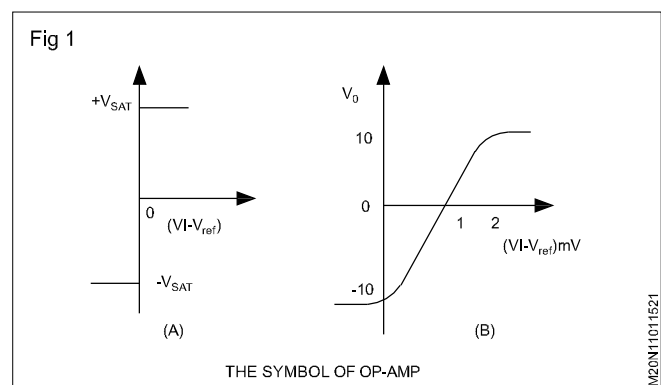
### Noise in operational amplifiers

Undesired Electronics signals present in the output of an amplifier is referred to as *noise*. Noise in the output of a circuit may be due to the noise generated in the circuit (internal) or noise getting into the circuit from external sources. External noise can be minimised by adopting proper construction techniques. A few tips to reduce external noise is listed below;

- 1 Shorten the interconnecting wire lengths. Mount components as close to the Op-Amp as possible. Keep the output circuit components away from the input components (this avoids unwanted feedback).
- 2 Bypass the Op-Amp  $+V_{CC}$  supply pins using 0.01 to 0.1  $\mu$ F disc capacitors.

Even if there is no significantly visible/audible noise at the output, there will be some noise in the output of Op-Amp due to internal noise. This internal noise can be minimised by avoiding large values of  $R_{in}$  and  $R_F$ . This internally generated noise due to resistors can be reduced to a large extent by connecting a small capacitor in the range of 3 to 56 pF across feedback resistor  $R_F$ . This will reduce internal noise, specially the high frequency noise.

The output of an op-amp is  $+V_{sat} = (+V_{cc})$  and  $-V_{sat} (-V_{cc})$  in the ideal transfer characteristics and commercial transfer characteristics is shown in Fig 1.



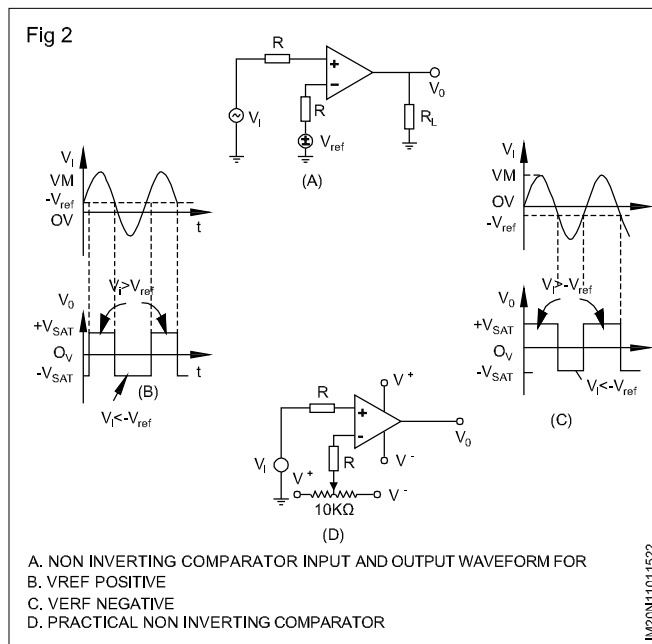
### Non -inverting comparator :

If the fixed reference voltage is applied to the (-) input, and the time varying signal voltage  $V_{in}$  is applied to the (+) input, then the arrangement is called non inverting amplifier.

The output voltage is at  $-V_{sat}$  for the applied input voltage less than the reference voltage ( $V_i < V_{ref}$ ). And goes to



$+V_{sat}$  for  $(V_i > V_{ref})$  the input voltage greater than the reference voltage. The circuit diagram, input and output waveforms are shown in Fig 2.



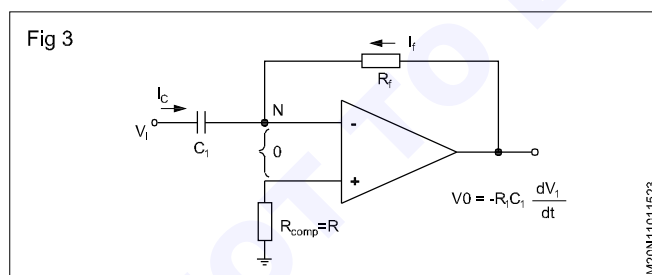
### Differentiator :

One of the simplest of the op-amp circuit that contain capacitor is the differentiator. It performs mathematical operation of differentiation, that is the output waveform is the derivative of input waveform. It produces an output signal proportional to the rate of change of its input signal.

### Analysis :

The node N is at virtual ground potential (i.e)  $V_n = 0$ . The current through the feedback resistor is  $V_o/R_f$  and there is no current through the op-amp. Therefore the nodal equation at node N is

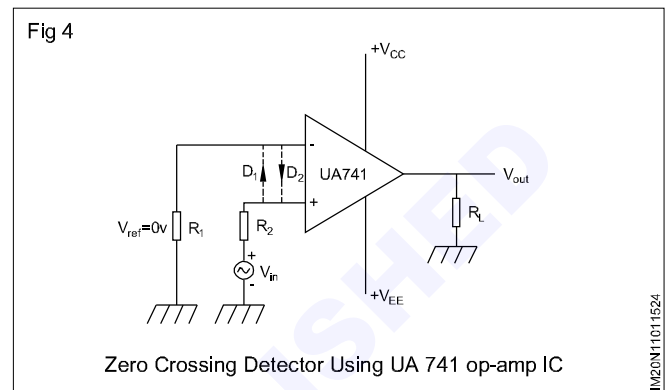
$$C_1 dV_i/dt + V_o/R_f = 0 \text{ (or) } V_o = -R_f C_1 dV_i/dt.$$



Thus the output voltage  $V_o$  is a constant  $(-R_f C_1)$  times the derivative of the input voltage  $V_i$  and circuit is known as differentiator which is shown in Fig 3. The minus sign indicates a 180 phase shift of the output waveform  $V_o$  with respect to the input signal. The output is the time derivative of the input signal, if  $V_i = \sin \omega t$ . So the output of the op-amp varies with frequency and will vary high at high frequency. Hence it is also known as "High Pass filter circuit".

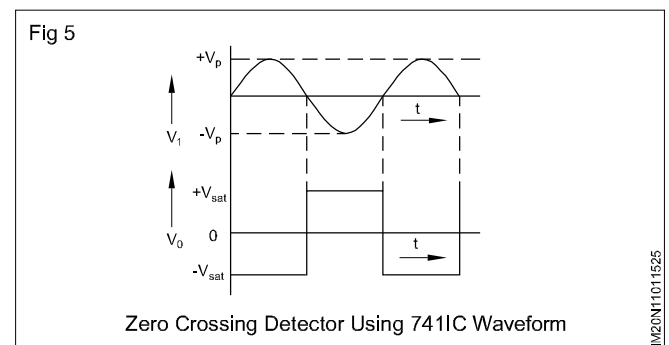
Adding the input resistor  $R_{in}$  in series to the capacitor will increase the gain by  $R_f/R_{in}$  and it will act as a differentiator at low frequencies.

**Zero Crossing Detector using 741 IC** is shown in Fig 4. The zero crossing detector circuit is an important application of the **Op-Amp comparator circuit**. It can also be called as the sine to square wave converter. Any one of the inverting or non-inverting comparators can be used as a zero-crossing detector. The only change to be brought in is the reference voltage with which the input voltage is to be compared, must be made zero ( $V_{ref} = 0V$ ). An input sine wave is given as  $V_{in}$ . These are shown in the circuit diagram and input and output waveforms of an inverting comparator with a 0V reference voltage.



### Zero-Crossing Detector Using UA741 op-amp IC

As shown in Fig 5 the waveform, for a reference voltage of 0V, when the input sine wave passes through zero and goes in positive direction, the output voltage  $V_{out}$  is driven into negative saturation. Similarly, when the input voltage passes through zero and goes in the negative direction, the output voltage is driven to positive saturation. The diodes  $D_1$  and  $D_2$  are also called clamp diodes. They are used to protect the op-amp from damage due to increase in input voltage. They clamp the differential input voltages to either +0.7V or -0.7V.



In certain applications, the input voltage may be a low frequency waveform. This means that the waveform only changes slowly. This causes a delay in time for the input voltage to cross the zero-level. This causes further delay for the output voltage to switch between the upper and lower saturation levels. At the same time, the input noises in the op-amp may cause the output voltage to switch between the saturation levels. Thus zero crossing are detected for noise voltages in addition to the input voltage. These difficulties can be removed by using a **regenerative feedback circuit with a positive feedback** that causes the output voltage to change faster thereby eliminating the possibility of any false zero crossing due to noise voltages at the op-amp input



# Integrator Using Operational Amplifier

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

- explain the performance of circuit using Op-Amp integrator
- how to reduce the output offset voltage in Op-integrator.

An integrator is a circuit that performs the mathematical operation of integration since it produces an output voltage that is proportional to the integral of the input. With an Op-amp, we can build an integrator, a circuit that produces a well defined ramp output for a rectangular constant input.

The Fig 1 shown is an Op-Amp integrator. The typical input to an integrator is a rectangular pulse. As shown in Fig 1b, the  $V_{in}$  represents a constant voltage during pulse time  $T$  and it is applied to the left end of  $R$ . Because of virtual ground, the input current is constant and equals.  $I_{in} = V_{in} / R$ . Approximately all this current goes to the capacitor. The basic capacitor law says that

$$C = Q/V \text{ or } V = Q/C \quad \dots\dots\dots (1)$$

The change  $Q$  increases linearly since a constant current is flowing into the capacitor. This means that the capacitor voltage increases linearly with the polarity. The output voltage is a negative ramp because of the phase reversal of the Op-Amp as shown in Fig 1C. At the end of the pulse period, the input voltage returns to zero, and the charging current stops. Since the capacitor hold its charge, the different voltage remains constant at a negative level.

For output voltage divide eq.(1) by  $T$

$$\frac{V}{T} = \frac{Q/T}{C}$$

Since the charging is constant, we can write

$$\begin{aligned} V/T &= I/C \\ \text{or } V &= IT/C \quad \dots\dots\dots (2) \end{aligned}$$

Where  $V$  = capacitor voltage

$I$  = charging current,  $V_{in} / R$

$T$  = charging time

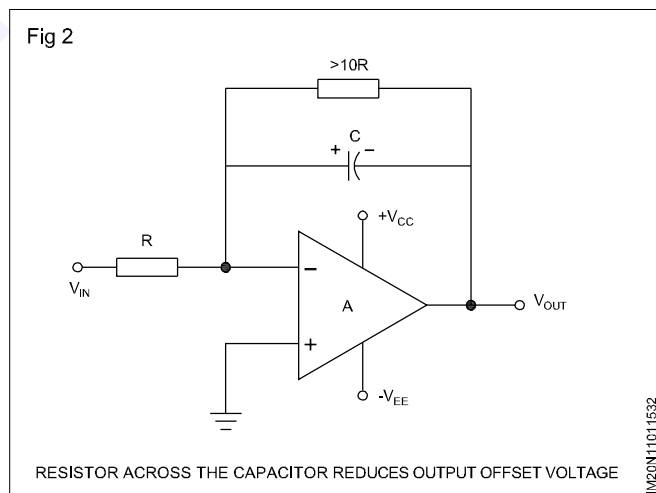
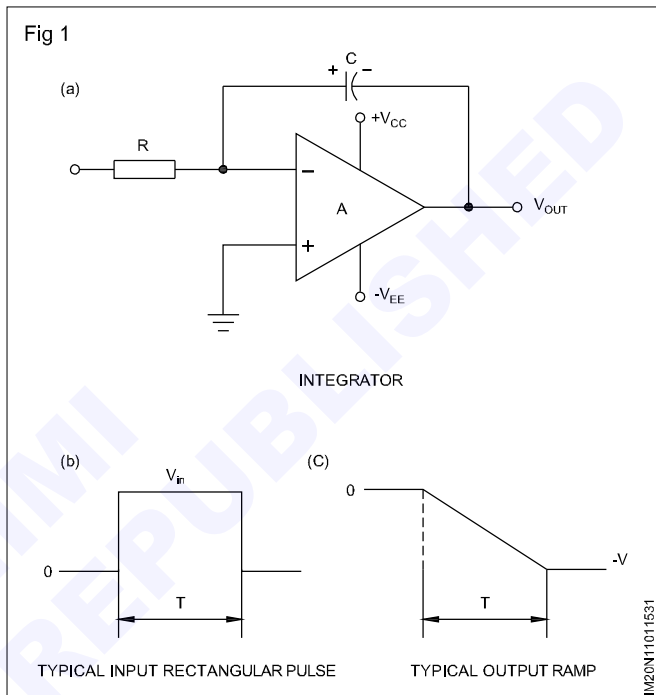
$C$  = capacitance.

This is the voltage across the capacitors. Because of the phase reversal,  $V_{out} = -V$ .

For Example: If  $I = 4\text{mA}$ ,  $T = 2\text{msec}$  and  $C = 1\text{F}$ , then the capacitor voltage at the end of the charging period is  $(4\text{mA})(2\text{ms})/1\text{uF} = 8\text{V}$  because of the phase reversal, the output voltage is  $-2\text{V}$  after  $2\text{ms}$ .

In Fig 1, since the capacitor acts like an open to DC signals, the closed-loop voltage gain equals to the open-loop voltage gain at zero frequency. This will produce too much output offset voltage without negative feed back at zero frequency, the circuit will treat the input offsets as a valid input signal. The input offsets will eventually charge the capacitor and drive the output into positive or negative saturation.

By inserting a resistor in parallel with capacitor as shown in Fig 2, we can reduce the effect of input offsets. This resistor should be atleast 10 times larger than the input resistor i.e., if the added resistance equals  $10R$ , the closed loop voltage gain is  $-10$  and the output offset voltage is greatly reduced.



# Op-Amp Applications - Differential & Instrumentation Amplifiers

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

- describe the working of differential amplifier
- describe the operation of Instrumentation amplifier.

## Differential amplifier

The easiest way to construct fully-differential circuit is to think of the inverting op-amp feedback topology. In fully-differential op-amp circuits, there are two inverting feedback paths:

- 1 Inverting input to noninverting output
- 2 Noninverting input to inverting output

Both feedback paths must be closed for the fully - differential op-amp to operate properly.

The differential amplifier has a unique feature that many circuits don't have - two inputs. This circuit amplifies the difference between its input terminals. Other circuits with one input actually have another input – the ground potential. But, in cases where a signal source (like a sensor) has both of its terminals biased at several volts above ground, you need to amplify the difference between the terminals. What about noise that adds an unwanted voltage equally to both terminals of a sensor? The differential amplifier reject the noise and rescue the signal.

### A new pin

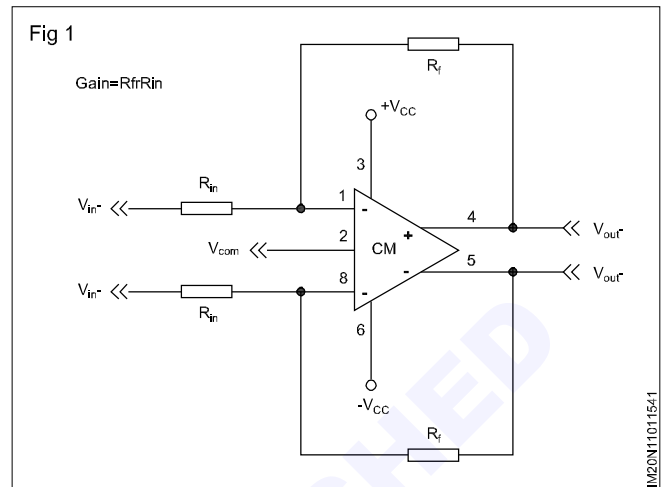
Fully-differential op-amps have an extra input pin ( $V_{COM}$ ). The purpose of this pin is to provide a place to input a potentially noisy signal that will appear simultaneously on both inputs – i.e. common mode noise. The fully-differential op-amp can then reject the common mode noise.

The  $V_{COM}$  pin can be connected to a data converter reference voltage pin to achieve tight tracking between the op-amp common mode voltage and the data converter common mode voltage. In this application, the data converter also provides a free dc level conversion for single supply circuits. The common mode voltage of the data converter is also the dc operating point of the single-supply circuit. The designer should take care, however, that the dc operating point of the circuit is within the common mode range of the op-amp + and – inputs. This can most easily be achieved by summing a dc level into the inputs equal or close to the common mode voltage.

### Gain

A gain stage is a basic op-amp circuit. Nothing has really changed from the single-ended design, except that two feedback pathways have been closed. The differential gain is still  $R_f / R_{in}$  a familiar concept to analog designers. Fig 1 shows the differential amplifier circuit.

This circuit can be converted to a single-ended input by connecting either of the signal inputs to ground. The gain equation remains unchanged, because the gain is the differential gain.



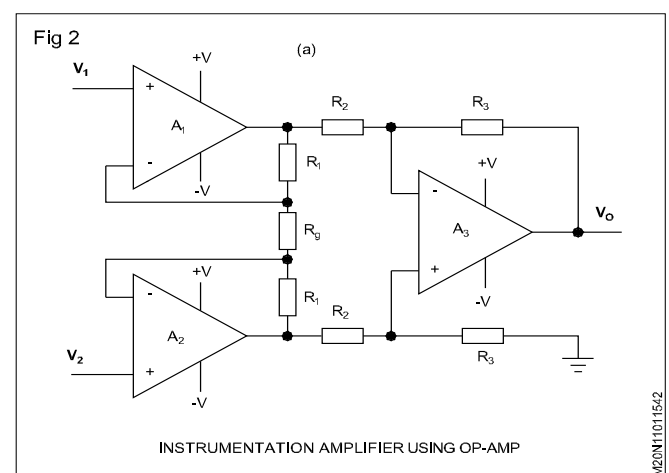
## Instrumentation amplifier

An instrumentation system is used to measure the output signal produced by a transducer. The input stage is composed of a transducer, depending on the physical quantity to be measured.

The output stage may use devices such as meters, oscilloscopes and display circuits. The signal source of instrumentation amplifier is the output of the transducer. To amplify the low level output signal of the transducer, instrumentation amplifier is used in the middle.

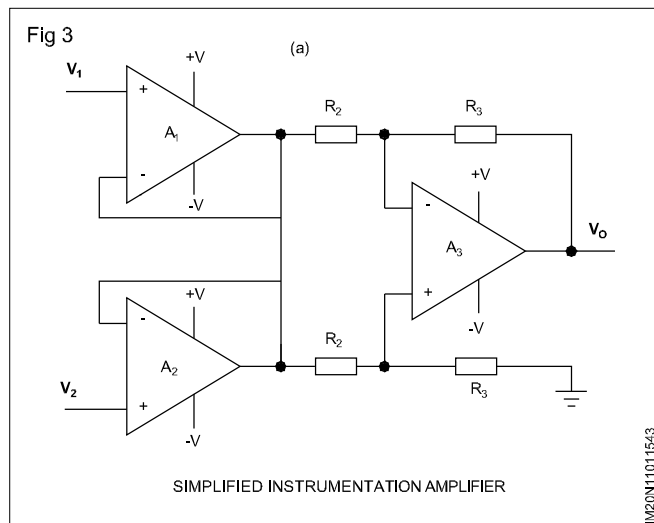
Instrumentation amplifier is a kind of differential amplifier with additional input buffer stages. The addition of input buffer stages makes it easy to match impedance with the preceding amplifier stage. Instrumentation amplifier is commonly used in industrial test and measurement applications. They are generally used in situations where high sensitivity, accuracy and stability are required. The instrumentation amplifier also has some useful features like low offset voltage, high CMRR (Common mode rejection ratio), high input resistance, high gain etc.

The circuit diagram of a typical instrumentation amplifier using three op-amps is shown in Fig 2.



ut of A3 to its non-inverting input is the feedback resistor. R2 is the input resistor.

The voltage gain of the instrumentation amplifier can be expressed by using the equation below: Voltage gain ( $A_v$ ) =  $V_o/(V_2-V_1) = (1 + 2R_1/R_g) \times R_3/R_2$ . For varying the gain, replace  $R_g$  with a suitable potentiometer. A simplified instrumentation amplifier design is shown in Fig 3.

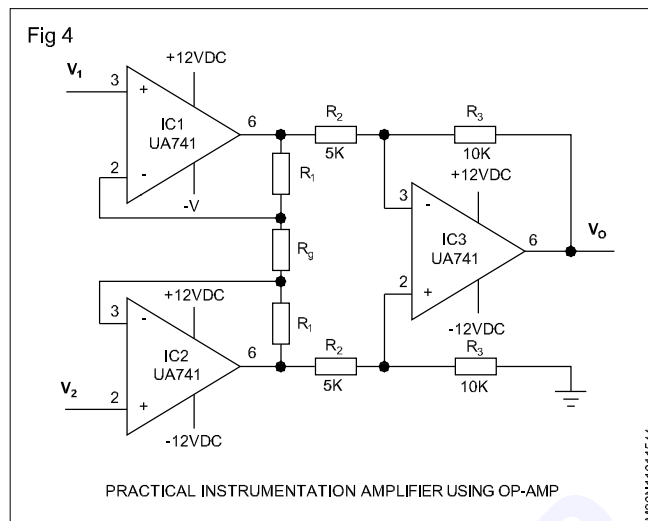


Here the resistances labelled  $R_1$  are shorted and  $R_g$  is removed. This results in a full series negative feedback path and the gain of  $A_1$  and  $A_2$  will be unity. The removal of  $R_1$  and  $R_g$  simplifies the equation to  $A_v = R_3/R_2$ . The output impedance is also low, being in the range of milliohms. The input bias current of the instrumentation amplifier is determined by the op-amps  $A_1$  and  $A_2$ .

Practical instrumentation amplifier using op-amp.

A practical instrumentation amplifier circuit designed using uA741 op amp is shown in Fig 4. The amplifier operates from  $\pm 12V$  DC and has a gain 10. If you need a variable gain, then replace  $R_g$  with a 5K POT. Instead of using uA741 you can use any op-amp but the power supply voltage must be changed according to the op amp. A single LM324 op amp IC is a good choice. Out of the four op-amps inside the LM324, three can be used for IC1, IC2, IC3 and the remaining one can be left alone. This reduces the PCB size a lot and makes the circuit compact. Supply voltage for LM324 can be up to  $\pm 15V$  DC Fig 4.

A high gain accuracy can be achieved by using precision metal film resistors for all the resistances. Because of large negative feedback employed, the amplifier has good linearity, typically about 0.01% for a gain less than 10.

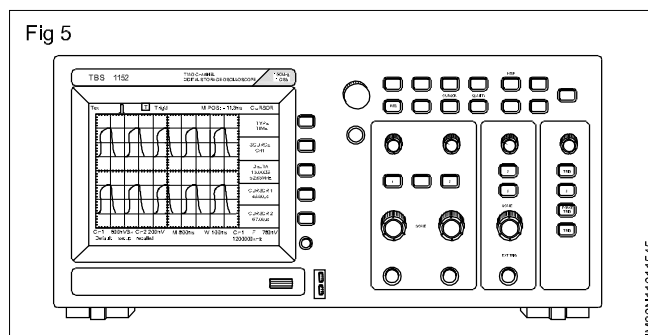


Once the circuit is built, set the function generator to a 500mVp-p Sine wave at 1 kHz and input it to  $V_1$ , as shown in figure 3 and ground the other input terminal ( $V_2$ ).

In order to test the gain of the instrumentation amplifier, place the oscilloscope probe of Channel-1 on the function generator and another probe on the output of instrumentation amplifier. With the power supplied to the circuit and a proper waveform as an input, one should see an output similar to Fig 5.

Fig 5 displays the input and the output on the same time scale, but different voltage scales. To ensure the gain is about 10, take the output voltage and divide it by the input voltage. This example has  $V_{out}/V_{in} = 5.046 V/513.66 mV = 9.82$ .

Instrumentation amplifiers are easy to design and can be used in many applications. The simplicity of the design depends on the selection of the resistor values. If chosen correctly, the gain can be calculated and changed only with one resistor value.



## Converters

**Objectives :** On completion of this lesson you shall be able to

- explain voltage-to-current converter and current-to-voltage converter.

### Voltage-to-current converter

Fig 1 shows a feedback circuit. Since the returning voltage opposes the input voltage the feedback is negative, from Fig 1.

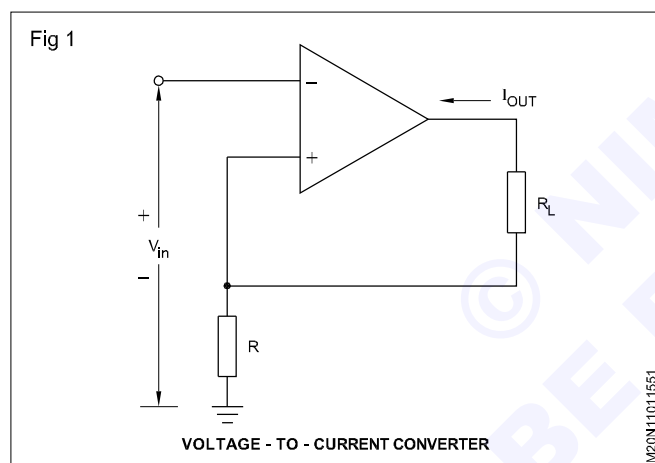
$$I_{out} = V_{in}/R \quad \dots\dots (1)$$

$$Z_{in} = \infty \quad \dots\dots (2)$$

$$Z_{out} = \infty \quad \dots\dots (3)$$

In a perfect voltage-to-current convertor, the output current depends only on the input voltage and the value of R.

The infinite input impedance means the voltage-to-current converter will not load down the circuit driving it. Also, the infinite output impedance implies the circuit acts like a current source. A voltage-to-current converter has a high input impedance and a high output impedance. One of the application of voltage-to-current converter is in building an electronic voltmeter.



### Current to voltage converter

Fig 2 shows current-to-voltage converter of negative feedback. From Fig 2.

$$V_{out} = R \times I_{in} \quad \dots\dots (1)$$

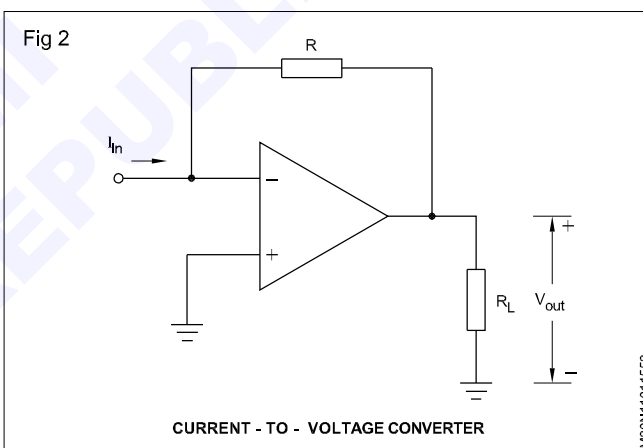
$$Z_{in} = 0 \quad \dots\dots (2)$$

$$Z_{out} = 0 \quad \dots\dots (3)$$

In a perfect current-to-voltage converter the output voltage depends only on the input current and the value of R.

The zero input impedance means the converter looks like a perfect current sink (ground). A current-to-voltage converter will not load down the circuit driving it and also its output voltage is unaffected by small load resistance.

A current-to-voltage converter has a low input impedance and a low output impedance. One of the application of the current-to-voltage converter is in building an electronic ammeter.



## Timer IC and its applications

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

- list the features that make 555 a popular integrated circuit
- name the functional blocks of a IC555
- describe the principle of operation of a IC555
- list different types of packaging of IC555
- explain the schematic of an astable multi-vibrator using IC 555
- find the ON-time and OFF-time of a given astable multi-vibrator using 555
- explain the term PRF
- list a few applications of astable multi-vibrator
- describe the working of VCO using IC 555.

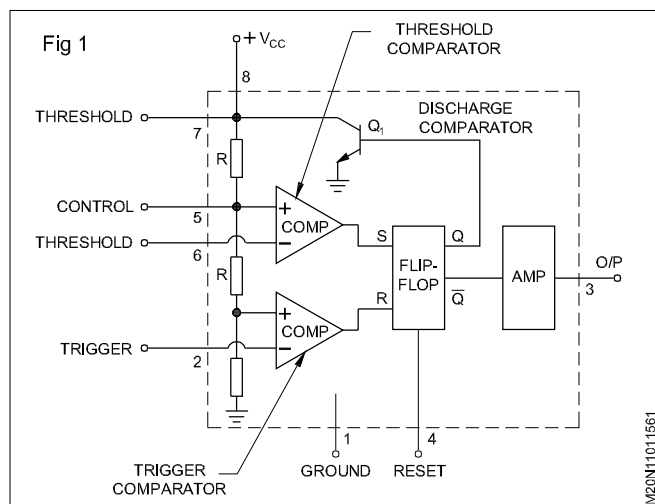
### Timer

Applications such as square wave, ramp, pulse generators, and one-shot multi-vibrators etc. require a circuit essentially capable of producing timing intervals. Due to the circuit components count and the delicacy in using transistors, integrated circuits(ICs) are preferred. One such most suitable and popular IC for producing timing

intervals is the 555. This IC is popularly known as **555 timer**. Similar to operational amplifiers, 555 IC is reliable, easy to use in a variety of applications, and at low cost. The 555 IC can operate from a wide range of supply voltages of + 5 V to +18 V. This makes 555 compatible with standard digital circuits whose voltage levels(0-state = 0V, 1-state = 5 V) are known as TTL (transistor-transistor logic) levels.

## The 555 timer

The functional blocks in 555 timer is shown in Fig 1.

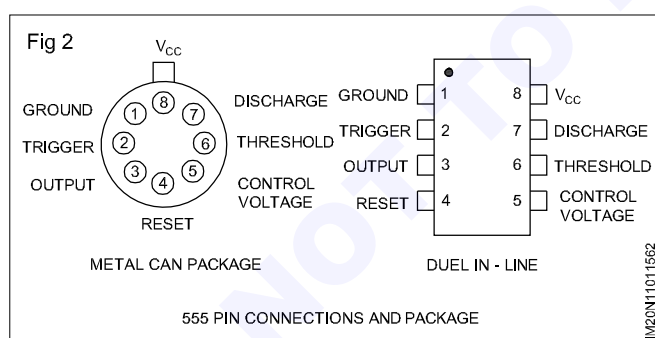


As can be seen from Fig 1, the 555 IC contains two comparators, one transistor, three equal value resistors, a flip-flop, and an output stage. Timer find application in precision timing, pulse generator, sequential timing, time delay circuits, pulse width modulation, pulse position modulation and linear ramp generator circuits, time period is adjustable from micro seconds to hours. Output source or sink current 200 mA, output and supply TTL compatible temperature stability each better than 0.005% per degree centigrate. Normally ON and normally OFF output they are available in 8 and 16 pin package.

A comparator is a circuit having two inputs and a single output. It compares the signal voltage given at one input with a reference voltage on the other input as shown in Fig 2. Comparators are essentially made using Op-Amps.

### Types of 555 timer IC packages

The 555 timer IC is available in two package styles metal can (TO) and DIP as shown in Fig 2.



### Source and Sink current capacity

The internal circuitry of 555 requires about 0.7mA per supply volt (7 mA for  $V_{CC} = +10V$ ) to set up internal bias currents. Maximum power a 555 IC can dissipate is around 600 mW.

The maximum current that can be drawn from the output terminal(pin No.3) of 555(called source current) or the maximum current that can be forced through the output terminal(called sink current) is around 40 mA.

## Modes of operation

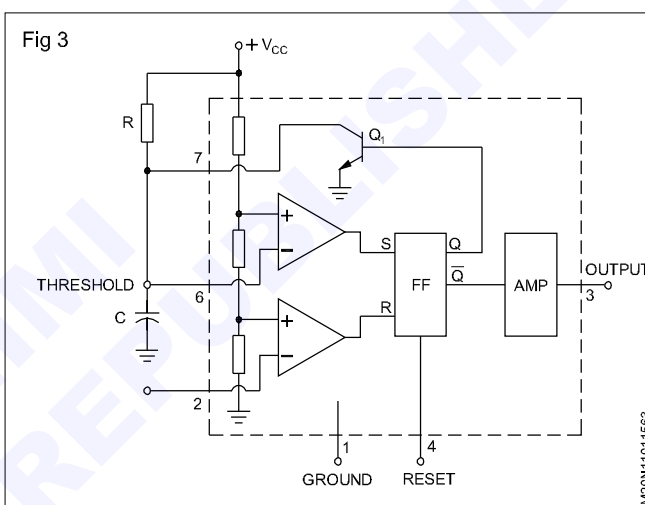
The 555 IC timer has two modes of operation:

- as an astable(free-running) multi-vibrator
- as a mono-stable (one-shot) multi-vibrator.

### Principle of 555 operation

Referring to the block diagram of IC 555 in Fig 1, at the input there are two comparators connected to an internal resistive voltage divider. Both comparators have a reference input tied to the voltage divider. The **threshold comparator** is referenced to as  $2(V_{CC}/3)$ , and the **trigger comparator** is referenced to as  $V_{CC}/3$ . Comparator outputs are connected to a **set-reset flip-flop**. If the trigger voltage input falls below  $V_{CC}/3$ , its associated comparator resets the flip-flop output low.

For using the 555 IC, certain external components are required to be connected as shown in Fig 3.



The threshold input is usually connected to an external RC timing circuit. If the capacitor charge(threshold input) exceeds the  $2/3 V_{CC}$  reference on the threshold comparator, the comparator is triggered and the flip-flop is set. When the flip-flop is set, the discharge transistor is turned-on and the capacitor discharges.

### IC 555 as an astable multi-vibrator

Fig 5 shows 555 connected for astable operation.

- The reset input is connected to  $V_{CC}$ . If it were connected to ground, 555 will get disabled.
- $C_f$  provides noise filtering for the control voltage input.
- When the discharge transistor is off, capacitor C is charging through  $R_A$  and  $R_B$ . Thus the circuit time constant is given by,

$$t = (R_A + R_B)C$$

- As capacitor C charges, the threshold input voltage will soon reach  $2V_{CC}/3$ . At this point the flip-flop changes states, causing the discharge transistor  $Q_1$  to turn on. Transistor  $Q_1$  saturates and discharges C through resistor  $R_B$  and  $Q_1$ . The discharge time constant is therefore given by,

$$t = R_B C$$



- Since the threshold and trigger inputs are tied together, as C discharges, at some point it falls to a value below  $1/3 V_{CC}$  and activates the trigger comparator. This resets the RS flip-flop, turning OFF  $Q_1$  and allowing C to start charging again. So, 555 operates as an astable multi-vibrator by causing C to continuously charge and discharge between  $1/3 V_{CC}$  and  $2/3 V_{CC}$ . Wave-forms at the capacitor(trigger input) and at the output 555 are shown in Fig 4c.

It is important to note that, because the charging path for C is through  $R_A + R_B$  and the discharge path is through only  $R_B$ , the output is not symmetrical. In other words, the ON-time and the OFF-time of the output pulses are not equal. The ratio of the ON-time of the pulse to the OFF-time of the pulse is known as **duty cycle**. The duty cycle of 555 astable circuit range from near 50% to near 100%. The duty

cycle can be calculated as follows:

$$\text{Duty cycle}(D) = \frac{R_A + R_B}{R_A + 2R_B} \times 100\%$$

From the above equation,

- if  $R_B$  is made much greater than  $R_A$ , the duty cycle will approach 50 %.
- for higher duty cycle,  $R_A$  should be made greater than  $R_B$ .

### Pulse Repetition Frequency(PRF)

The term frequency is generally used with repetitive wave-forms which are symmetrical such as sine wave form. For repetitive wave-forms which are non-symmetrical such as the output of an astable multi-vibrator, instead of the term frequency the term **Pulse Repetition Frequency(PRF)** is used. PRF can be calculated as follows:

If  $t_{ON}$  is the ON-time of the pulse

and, if  $t_{OFF}$  is the OFF-time of the pulse,

then, Time period,  $T = t_{ON} + t_{OFF}$

$$\text{Hence, PRF} = \frac{1}{T}$$

### Application of astable multi-vibrators

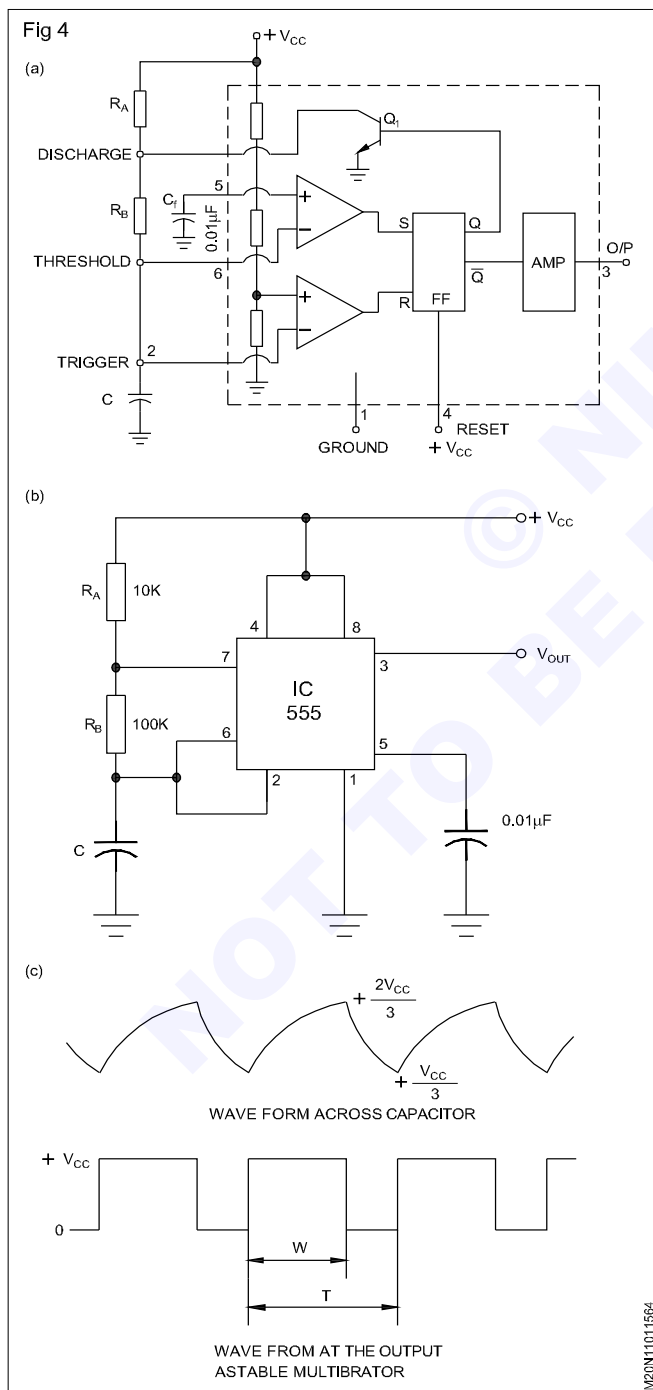
Application of astable multi-vibrators are almost innumerable: some general applications are listed below;

- **In electronic pianos** : different frequencies are generated by astable with different RC values.
- **Signal injectors** : used as a testing instrument by service technicians.
- **Flashing light** : if lamps or LEDs are connected at the output of the astable, the lamp/LED flashes at the rate set by the values of RC.
- **As Voltage Controlled Oscillator(VCO)**: The oscillator frequency is controlled by the input control voltage. A VCO circuit is shown in Fig 6.

### IC 555 Timer as VCO

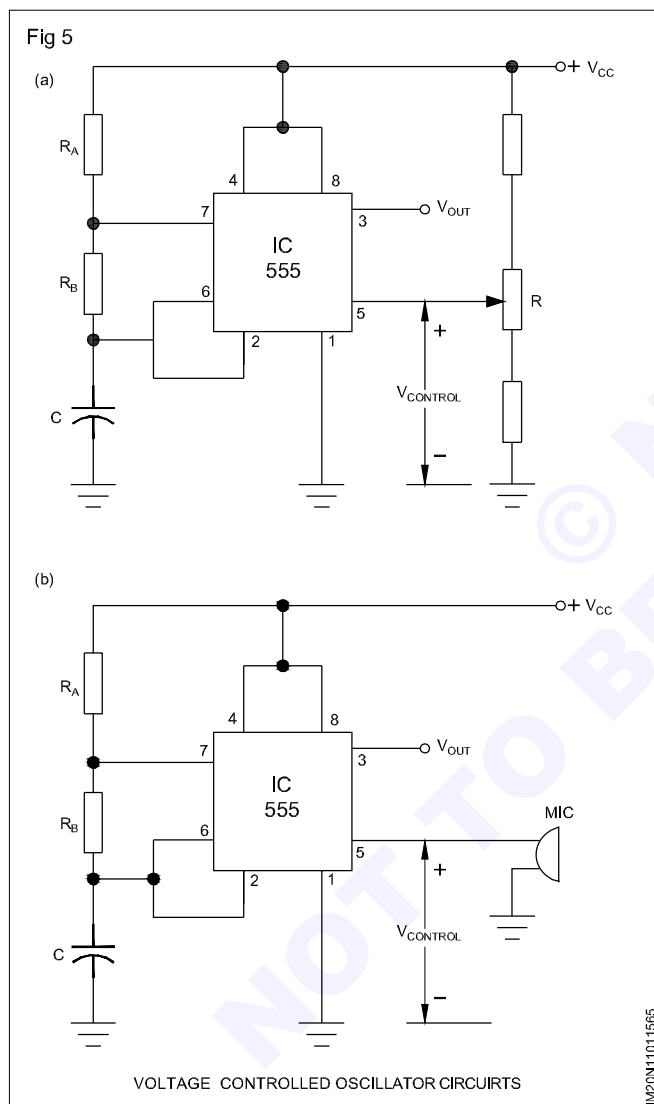
A Voltage-Controlled Oscillator (VCO) changes its output frequency in relation to the input voltage at the control input of the threshold comparator (pin No.5). The voltage at pin 5 is normally  $2/3 V_{CC}$  owing to the internal resistive voltage divider. However, by connecting an external component or voltage source as shown in Fig 6a, the voltage at pin 5 can be changed. If the voltage on pin 5 is raised, the capacitor must charge to a higher value, which decreases the output frequency. With pin 5 elevated in voltage, a greater time is required for C to discharge to  $1/3 V_{CC}$  as well.

Voltage controlled oscillator circuit can be used in digital circuits where, data are converted to tones for recording or transmission on telephone lines. Such a circuit may produce a tone of 2400 Hz when a low is applied to pin 5 and a tone of 1200 Hz when a high is applied. Fig 5b shows a typical VCO whose output frequency is in relationship to the voice input amplitude.



## Working of Monostable Multivibrator with 555 Timer Circuit

- The output of the monostable multivibrator using 555 timer remains in its stable state until it gets a trigger.
- In monostable 555 multivibrator, when both the transistor and capacitor are shorted then this state is called as a stable state.
- When the voltage goes below at the second pin of the 555 IC, the o/p becomes high. This high state is called quasi stable state. When the circuit activates then the transition from a stable to quasi stable state.
- Then the discharge transistor is cut off and capacitor starts charging to VCC. Charging of the capacitor is done via the resistor R1 with a time constant  $R1C1$



- Hence, the voltage of the capacitor increases and finally exceeds  $\frac{2}{3} V_{CC}$ , it will change the internal control flip flop, thereby turning off the 555 timer IC
- Thus the o/p goes back to its stable state from an unstable state.

Finally we can conclude that, in the monostable multivibrator using 555 timer, the output stays in a low state until it gets a trigger input. This type of operation is used in push to

operate systems. When the input is triggered, then it will go to high state and comes back to its original state.

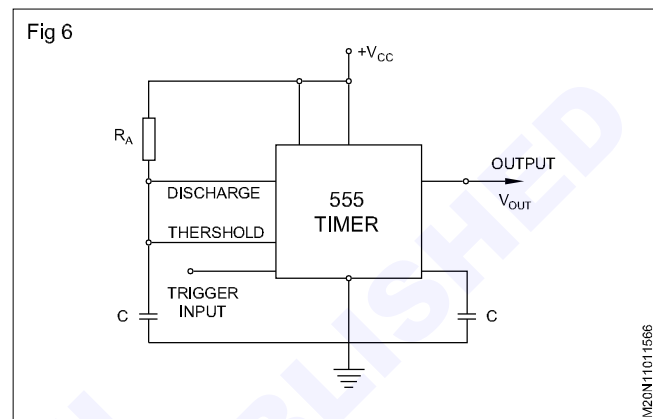
## 555 timer Example

A 555 Timer IC in a Monostable multivibrator is needed to produce a time delay in a circuit. If a 10 mF timing capacitor is used, then calculate the value of the resistor required to produce a minimum output time delay of 500ms.

$$R = \frac{t}{1.1C}$$

Where,  $t = 0.5$ ,  $C = 10\text{mF}$

Insert these values in the above formula



$$R = \frac{0.5}{1.1 \times 10 \times 10^{-6}}$$

$$= 45.5 \text{ kilo Ohms}$$

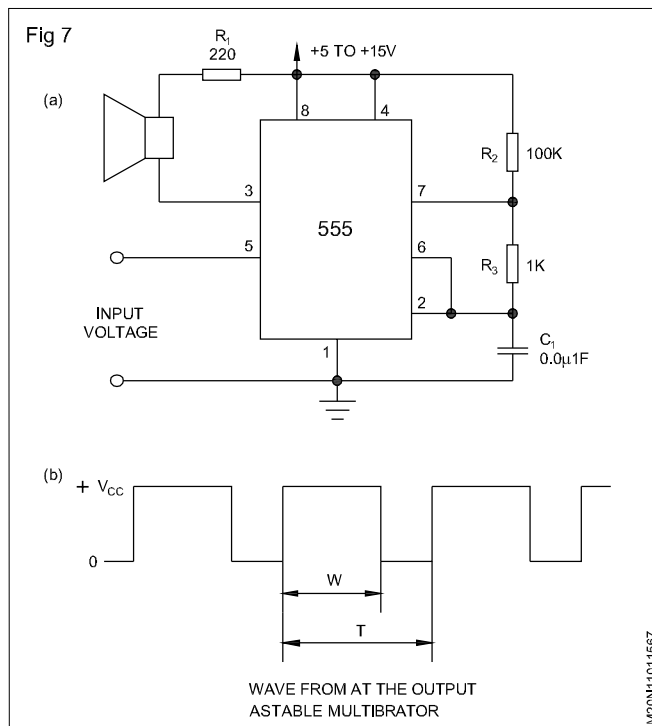
## Applications of 555 timer in Monostable Mode

The applications of the 555 timer circuits mainly involve in various 555 timer based projects in monostable mode.

## Voltage Controlled Oscillator (VCO)

Voltage-Controlled Oscillator (VCO) circuit using the 555 timer IC as the main component as shown in Fig 7(a). As expected, the 555 timer is configured as an astable multivibrator to be able to serve as an oscillator. An astable multivibrator is just a timing circuit whose output oscillates between 'low' and 'high' continuously, in effect generating a train of pulses, as shown in the Fig 7(b) of the circuit.

- 1 The difference of this circuit with the basic 555 astable circuit is that its 555's pin 5 is tied to an external voltage source.
- 2 Pin 5 is the 555's control voltage pin, which allows the user to directly adjust the threshold voltages to which the pin 2/pin 6 input voltages are compared by the 555's internal comparators. Since the outputs of these comparators control the internal flip-flop that toggles the output of the 555, adjusting the pin 5 control voltage also adjusts the frequency at which the 555 toggles its output.
- 3 Increasing the input voltage at pin 5 decreases the output oscillation frequency while decreasing the input voltage increases the output oscillation frequency.



### Application of VCO

- Phase locked loop.
- Function generator.
- Frequency synthesizers, used in communication circuits.
- Production of electronic music/different types of noise.
- Electronic jamming equipment.

## Monostable multivibrator

**Objectives :** On completion of this lesson you shall be able to

- **monostable multivibrator circuit using timer IC 555**
- **find values of R and C for a required output pulse width**
- **name the most popular application of mono-shot**
- **explain pulse width modulator using timer IC 555**

### IC 555 as a Monostable multivibrator

Fig 1, shows the circuit connections of a monostable multivibrator using 555 timer IC. It is also called as mono shot multi.

In Fig 1, unlike in an astable multi-vibrator, the trigger input is held at voltage near  $V_{CC}$ . When the monostable timer is to be made to change to its state, the trigger input must be made to fall to less than  $1/3V_{CC}$ .

When a trigger input is given i.e when the level at the trigger input is brought below  $1/3V_{CC}$ , the flip-flop is reset, therefore  $Q_1$  goes to cut-off, and C begins to charge.

When the charge on C increases to  $2/3 V_{CC}$ , the flip-flop is made to set by the threshold comparator. Thus  $Q_1$  is turned ON and C is discharged. The timer stays in this stable state, and nothing happens till the trigger input is brought to less than  $1/3V_{CC}$ .

The time during which the output stays in the high state is determined by the RC time constant. The larger R or C is, the wider the output pulse. The formula for pulse width is given by,

$$\text{Pulse width (W)} = 1.1RC$$

For example, if  $R = 10K$  and  $C = 0.01F$ , the mono-stable output pulse width will be,

$$W = 1.1 \times 10 \times 10^3 \times 0.01 \times 10^{-6} \\ = 0.11 \text{ m sec.}$$

If the value of R is increased to  $R = 100K$  and  $C = 0.01F$ , the mono-stable output pulse width will be,

$$W = 1.1 \times 100 \times 10^3 \times 0.01 \times 10^{-6} \\ = 1.1 \text{ m sec.}$$

In Fig 1, notice that pin 5 is bypassed to ground by a small-value capacitor. The value of this capacitor is typically about  $0.01F$ , and its purpose is to provide noise filtering for the control voltage. Pin 4 is also tied high ( $+V_{CC}$ ) again. Recall that, if pin 4 is tied low, the 555 will not operate and will be in the reset state.

### Applications of 555 Mono-shot

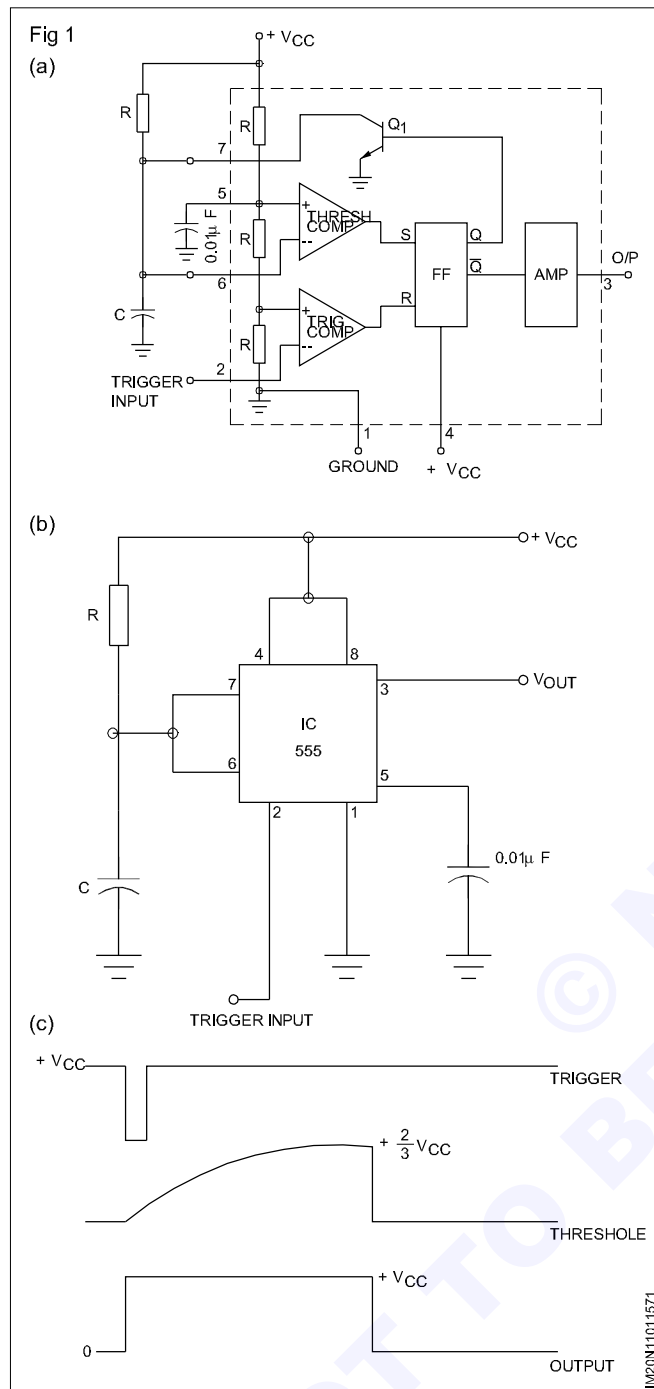
Applications of 555 timer as mono-shot are as numerous or even more than that of astable multivibrator. Amongst the applications of 555 as mono-shot, the most popular uses are in the time delay or timer circuits. Fig 2 shows a 555 used as a time-delay device.

In the circuit at Fig 2, the output changes states after a delay period once the input trigger pulse is received. The duration of delay in the output is decided by the values of the circuit components R and C.

In the circuit at Fig 2, assume that the transistor is ON and hence pin 2 of 555 is at ground. Because of this, capacitor C is unable to charge.

When negative trigger input pulse is applied to the base of transistor  $Q_1$ ,  $Q_1$  is turned off. On cut-off of  $Q_1$ , capacitor C begins to charge until it reaches  $2(V_{CC}/3)$ . Once the

charge on C goes slightly above  $2(V_{CC}/3)$ , the 555 output is made to change state.



The delay in the change of state at output is due to the RC time constant. Simple time delay circuit shown in Fig 2 is used where a short time delay is required. One application of such a delay circuit is in disk drives in computers. Computer users should not keep floppy disks in the drives when the computer is turned on. This is because, the power surge can damage the written information on the disk and make it non-readable. If the user happens to have kept the floppy disk unknowingly, then, using a time delay circuit if the disk electronics are turned on a fraction of a second after the power has been turned on, the surge would not exist, and therefore, there is no danger of the information on the disk getting corrupted (damaged).

## Security alarm circuit using Mono-shot and Astable

Fig 3 shows a security alarm circuit, which gives an audible alarm when an intruder happens to touch the trigger touch plate.

The circuit consists of a mono-shot coupled to an astable multivibrator. When the touch plate is touched by hand, the monoshot makes its output go high for some duration (set by RC). This high level is coupled to the reset pin (pin 4) of the astable. Recall that the output of the astable will be present only when the reset pin is held high. Therefore, as long as the reset pin of the astable is high, the astable gives a repetitive output pulse (PRF set by RC values) which makes the speaker give an audible alarm calling the attention of the security.

The circuit at Fig 3 can be modified to suit several other applications such as,

- water level indicator
- smoke detector
- fire detector and so on.

For further reading on 555 applications refer reference books listed at the end of this book.

## Pulse Width Modulation

PWM (Pulse Width Modulation) is one of the circuits for controlling many electronics devices. PWM is a digital signal which is most commonly used in control circuitry. PWM is widely used for motor controlling, lighting controlling etc. Sometime we do not use microcontroller in our applications and if we need to generate PWM without microcontroller then we prefer some general purpose ICs like op-amp, timers, pulse generators etc. 555 Timer IC is a very useful and general purpose IC which can be used as Pulse Width Modulator. The circuit using a 555 timer IC for generating PWM is shown in Fig 4.

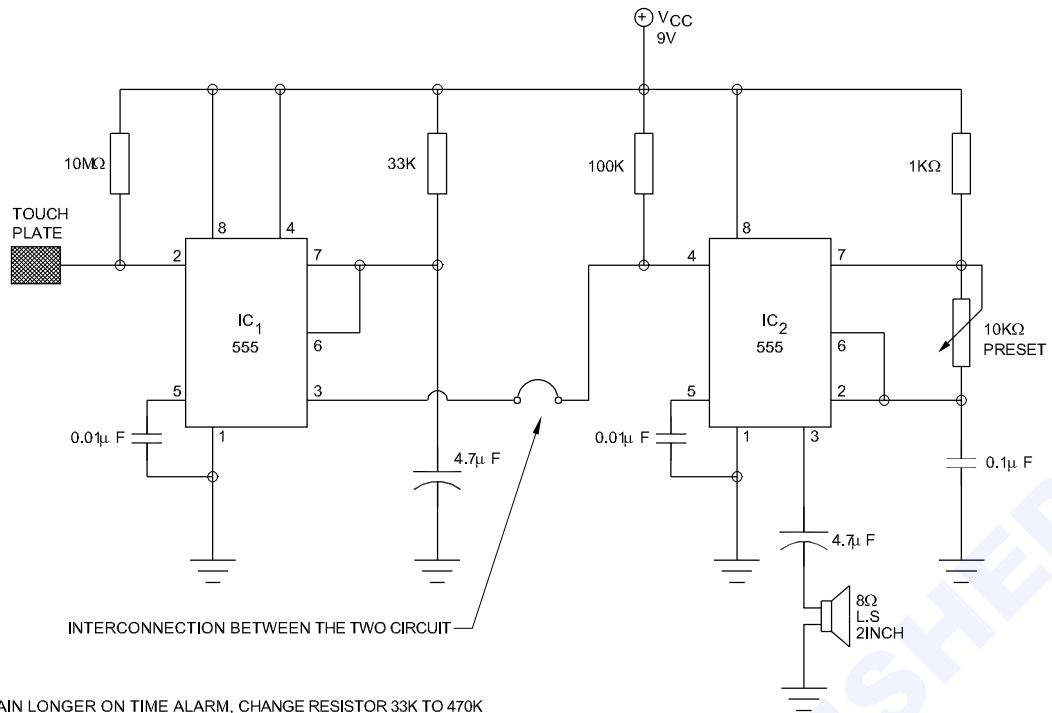
In this circuit, the output frequency of the PWM signal is controlled by selecting resistor RV1 and capacitor C1. A variable resistor is used in place of a fixed resistor for changing the duty cycle of the output signal. Capacitor charging through D1 diode and discharge through D2 diode generates a PWM signal at the 555 timer's output pin. The frequency of the PWM signal is calculated using the formula:

$$F = 0.693 \cdot RV1 \cdot C1$$

This signal is set high (5V) and low (0V) in a predefined time and speed. The time during which the signal stays high is called the "on time" and the time during which the signal stays low is called the "off time". There are two important parameters for a PWM as discussed below:

- 1 **Frequency of a PWM:** The frequency of a PWM signal determines how fast a PWM completes one period. One period is complete ON and OFF of a PWM signal as shown in Fig 5.
- 2 **Duty cycle of the PWM:** The percentage of time in which the PWM signal remains HIGH (on time) is called as duty cycle. If the signal is always ON it is in 100% duty cycle and if it is always off it is 0% duty cycle. Duty Cycle = Turn ON time / (Turn ON time + Turn OFF time).

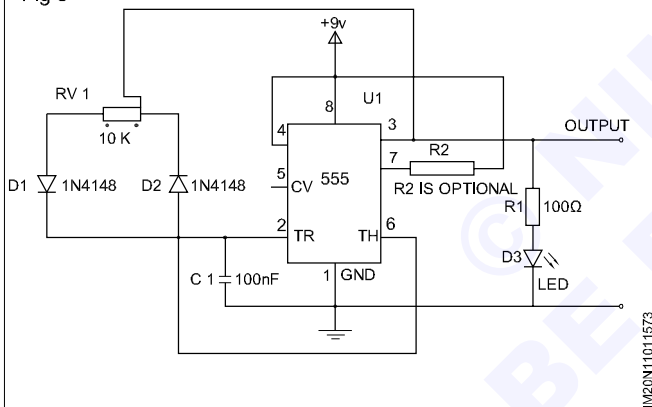
Fig 2



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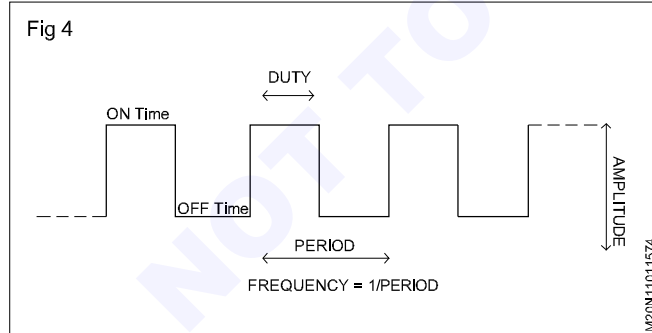
Different duty cycle of PWM waveforms are shown in Fig 6.

Fig 3



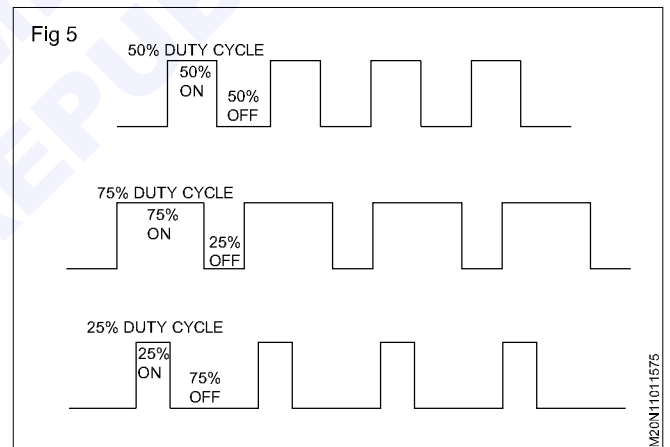
IM20N11011573

Fig 4



IM20N11011574

Fig 5



IM20N11011575

3 Pulse Width Modulation, or PWM, is a technique for getting analog results with digital means. Digital control is used to create a square wave, a signal switched between ON and OFF.



## Number systems

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

- differentiate between different number systems like decimal, octal, binary and hexadecimal and conversion between them and different types of codes
- explain NOT gate using transistor
- explain the characteristics of TTL NOT gate IC 7404, list commercially available NOT gate IC
- explain logic probe based on CMOS NOT gate IC.

### Introduction

When we hear the word 'number' immediately we recall the decimal digits 0,1,2....9 and their combinations. Modern computers do not process decimal numbers. Instead, they work with binary numbers which use the digits '0' and '1' only. The binary number system and digital codes are fundamental to digital electronics. But people do not like working with binary numbers because they are very long when representing larger decimal quantities. Therefore digital codes like octal, hexadecimal and binary coded decimal are widely used to compress long strings of binary numbers.

Binary number systems consists of 1s and 0s. Hence this number system is well suited for adopting it to the digital electronics.

The decimal number system is the most commonly used number system in the world. It uses 10 different characters to show the values of numbers. Because this number system uses 10 different characters it is called base-10 system. The base of a number system tells you how many different characters are used. The mathematical term for the base of a number system is radix.

The 10 characters used in the decimal number systems are 0,1,2,3,4,5,6,7,8,9.

### Positional notation and weightage

A decimal integer value can be expressed in units, tens, hundreds, thousands and so on. For example decimal number 1967 can be written as  $1967 = 1000 + 900 + 60 + 7$ . In powers of 10, this becomes

|        |        |        |        |                        |
|--------|--------|--------|--------|------------------------|
|        |        |        |        | $1 \times 10^3 = 1000$ |
| $10^3$ | $10^2$ | $10^1$ | $10^0$ | $9 \times 10^2 = 900$  |
|        |        |        |        | $6 \times 10^1 = 60$   |
| 1      | 9      | 6      | 7      | $7 \times 10^0 = 7$    |
|        |        |        |        | 1967                   |

i.e.  $[1967]_{10} = 1(10^3) + 9(10^2) + 6(10^1) + 7(10^0)$

This decimal number system is an example of positional notation. Each digit position has a weightage. The positional weightage for each digit varies in the sequence  $10^0$ ,  $10^1$ ,  $10^2$ ,  $10^3$  etc starting from the least significant digit.

The sum of the digits multiplied by their weightage gives the total amount being represented as shown above.

In a similar way, binary number can be written in terms of weightage.

To get the decimal equivalent, then the positional weightage should be written as follows.

$$[1010]_2 = 1(2^3) + 0(2^2) + 1(2^1) + 0(2^0) \\ = 8 + 0 + 2 + 0$$

$$[1010]_2 = [10]_{10}$$

Any binary number can be converted into decimal number by the above said positional weightage method.

### Decimal to Binary conversion

Divide the given decimal number by 2 as shown below and note down the remainder till you get the quotient - zero.

#### Example

|   |    |         |
|---|----|---------|
|   | 0  |         |
| 2 | 1  | 1 → MSB |
| 2 | 2  | 0       |
| 2 | 4  | 0       |
| 2 | 8  | 0       |
| 2 | 17 | 1       |
| 2 | 34 | 0 → LSB |

The remainder generated by each division form the binary number. The first remainder becomes the LSB and the last remainder becomes the MSB of binary number.

Therefore,  $[34]_{10} = [100010]_2$

### Counting binary number

To understand how to count with binary numbers, let us see how an odometer (Km indicator of a car) counts with decimal numbers,

The odometer of a new car starts with the reading 0000.

After traveling 1km, reading becomes 0001.

Successive km produces 0002, 0003 and so on upto 0009

At the end of 10th km, the units wheel turns back from 9 to 0, a tab on this wheel forces the tens wheel to advance by 1. That is why the number changed from 0009 to 0010. That is, the units wheel is reset to 0 and sent a carry to the tens wheel. Let us call this familiar action as reset and carry. The other wheels of odometer also reset and carry. For instance, after covering 999km, the odometer shows 0999.

After the next km, the unit wheel resets and carries, the tens wheel resets and carries, the hundreds wheel resets and carries and the thousands wheel advances by 1 to get the reading 01000.

### Binary odometer

Visualize a binary odometer, a device whose wheels have only two digits 0 and 1. When each wheel turns, it displays 0 then 1 and then back to 0 and the cycle repeats. A four digit binary odometer starts with 0000.

After 1km, it indicates - 0001.

The next km forces the units wheel to reset and sends carry. So the number changes to 0010.

The third km results in 0011.

After 4km, the units wheel resets and sends carry, the second wheel resets and sends carry and the third wheel advances by 1. Hence it indicates 0100.

Table below shows all the binary numbers from 0000 to 1111 equivalent to decimal 0 to 15.

| Decimal | Binary |
|---------|--------|
| 0       | 0000   |
| 1       | 0001   |
| 2       | 0010   |
| 3       | 0011   |
| 4       | 0100   |
| 5       | 0101   |
| 6       | 0110   |
| 7       | 0111   |
| 8       | 1000   |
| 9       | 1001   |
| 10      | 1010   |
| 11      | 1011   |
| 12      | 1100   |
| 13      | 1101   |
| 14      | 1110   |
| 15      | 1111   |

**Hexadecimal number system:** In hexadecimal system there are 16 characters. They are 0,1,2,3,4,5,6,7,8,9, A,B,C,D,E,F where A=10, B=11, C=12, D=13, E=14, F=15 in decimal. In this system, the base is 16. This system is mainly used to develop programmes for computers.

*For Example*

$$[23]_{16} = [35]_{10} ; 16^1 \times 2 + 16^0 \times 3 = 32 + 3 = 35;$$

$$[2C]_{16} = [44]_{10} ; 16^1 \times 2 + 16^0 \times 12 = 32 + 12 = 44;$$

### Decimal to hexadecimal conversions

The conversion of decimal to hexadecimal is similar to binary conversion. Only difference is that divide the decimal number successively by 16, and note down the remainder.

$$\begin{array}{r|l} 0 & \\ 16 & 1 \quad 1 \rightarrow \text{MSB} \\ 16 & 27 \quad 11 \text{ or B} \\ 16 & 432 \quad 0 \rightarrow \text{LSB} \end{array}$$

$$[432]_{10} = [1B0]_{16}$$

### Hexadecimal to Decimal

This conversion can be done by putting it into the positional notation.

$$\begin{aligned} \text{Ex: } 223A_{16} &= 2 \times 16^3 + 2 \times 16^2 + 3 \times 16^1 + A \times 16^0 \\ &= 2 \times 4096 + 2 \times 256 + 3 \times 16 + 10 \times 1 \\ &= 8192 + 512 + 48 + 10 \\ &= 8762_{10} \end{aligned}$$

### Octal number

The octal number system provides a convenient way to express binary numbers. It is used less frequently compared to hexadecimal in conjunction with computers and microprocessors to express binary quantities for input and output purposes.

The octal number system is composed of digit symbols such as eight symbols such as 0,1,2,3,4,5,6,7.

Since there are 8-symbols, radix or base is 8. Positional weightage is ..... $8^3, 8^2, 8^1, 8^0$ .

To distinguish octal numbers from other number systems subscript 8 is used as follows:

$$\text{Ex: } (15)_8 \sim (13)_{10}$$

Octal      Decimal

### Octal to Decimal conversion

$$\begin{array}{r|l} 0 & \\ 8 & 1 \quad 1 \rightarrow \text{MSB} \\ 8 & 13 \quad 5 \rightarrow \text{LSB} \end{array}$$

As in other number systems, each digit should be multiplied by its positional weightage and added to get decimal equivalent.

### Convert $(2374)_8$ into decimal number

Positional weightage :  $8^3, 8^2, 8^1, 8^0$

$$\begin{aligned} \text{Octal number} & \quad 2 \quad 3 \quad 7 \quad 4 \\ (2374)_8 &= (2 \times 8^3) + (3 \times 8^2) + (7 \times 8^1) + (4 \times 8^0) \\ &= (2 \times 512) + (3 \times 64) + (7 \times 8) + (4 \times 1) \\ &= 1024 + 192 + 56 + 4 \end{aligned}$$

$$(2374)_8 = (1276)_{10}$$

### Decimal to octal conversion

A method of converting a decimal number to an octal number is the repeated division by 8, each successive division by 8 yields a remainder that becomes a digit in the equivalent octal number. The first remainder generated is the least significant digit (LSD).

$$(359)_{10} = (547)_8$$

|   |     |         |
|---|-----|---------|
|   | 0   |         |
| 8 | 5   | 5 → MSB |
| 8 | 44  | 4 or B  |
| 8 | 359 | 7 LSB   |

### Octal to binary

Each octal digit can be represented by a 3-bit binary number, because of this it is very easy to convert from octal to binary. Each octal digit is represented by three bits as shown in the table.

| Octal digit | 0   | 1   | 2   | 3   | 4   | 5   | 6   | 7   |
|-------------|-----|-----|-----|-----|-----|-----|-----|-----|
| Binary      | 000 | 001 | 010 | 011 | 100 | 101 | 110 | 111 |

To convert each octal number to a binary, simply replace each octal digits with the corresponding binary bits.

Example

$$1 \quad (25)_8 = ( \quad )_2$$

$$\begin{array}{cc} 2 & 5 \\ 010 & 101 \end{array}$$

$$(25)_8 = (010101)_2$$

$$2 \quad (7526)_8 = ( \quad )_2$$

$$\begin{array}{cccc} 7 & 5 & 2 & 6 \\ 111 & 101 & 010 & 110 \end{array}$$

$$(7526)_8 = (111101010110)_2$$

### Binary to octal

Conversion of a binary number to an octal number is the reverse of the octal-to-binary conversion. The procedure is as follows.

- 1 Start with the right most group of three bits and moving from right to left, convert each 3-bit group to the equivalent octal digit.
- 2 If there are not three bits available for the left most group, add either one or two zero's to make complete group. These leading zero's will not affect the value of the binary number.

Example

$$(110101)_2 = ( \quad )_8$$

$$\begin{array}{cc} 110 & 101 \end{array}$$

$$\begin{array}{cc} 6 & 5 \\ (11010000100)_2 & = (65)_8 \end{array}$$

$$(11010000100)_2 = ( \quad )_8$$

$$\begin{array}{cccc} 011 & 010 & 000 & 100 \\ 3 & 2 & 0 & 4 \end{array} = (3204)_8$$

### BCD (Binary Coded Decimal)

Binary Coded Decimal (BCD) is a way to express each of the decimal digits with a binary code, since there are only ten code groups in the BCD system, it is very easy to convert between decimal and BCD. Because decimal system is used for read and write, BCD code provides an excellent interface to binary systems. Examples of such interfaces are keypad inputs and digital readouts.

| Decimal digit | 0    | 1    | 2    | 3    | 4    | 5    | 6    | 7    | 8    | 9    |
|---------------|------|------|------|------|------|------|------|------|------|------|
| BCD           | 0000 | 0001 | 0010 | 0011 | 0100 | 0101 | 0110 | 0111 | 1000 | 1001 |

The 8421 code is the pre-dominant BCD code, and when we refer to BCD, we always mean the 8421 code unless otherwise stated.

### Invalid code

You should realize that with four bits, sixteen numbers (0000 through 1111) can be represented, but in the 8421 code only ten of these are used. The six code combinations that are not used 1010, 1011, 1100, 1101, 1110 and 1111 are invalid in the 8421 BCD code.

To express any decimal number in BCD, simply replace each decimal digit with the approximate 4-bit binary code.

Example

$$1 \quad (35)_{10} = ( ? )_{8421 \text{ code}}$$

$$\begin{array}{cc} 3 & 5 \\ 0011 & 0101 = 00110101 \end{array}$$

$$2 \quad (2458)_{10} = ( ? )_{8421 \text{ code}}$$

$$\begin{array}{cccc} 2 & 4 & 5 & 8 \\ 0010 & 0100 & 0101 & 1000 = 0010010001011000 \end{array}$$

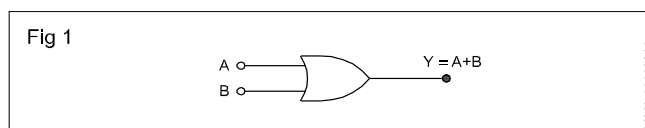
There are many specialized codes used in digital system other than BCD code. Some codes are strictly numeric, like BCD and others are alphanumeric which are used to represent numbers, letters, symbols and instructions.

The commonly used codes other than BCD codes are

- 1 Gray code
- 2 Excess 3 code
- 3 ASCII code - American, Standard code for Information interchange
- 4 Alphanumeric code

### Inverters (NOT Gate)

An inverter is a gate with only one input signal and one output signal. The output state is always the opposite of the input state. Logic symbol is shown in Fig 1.



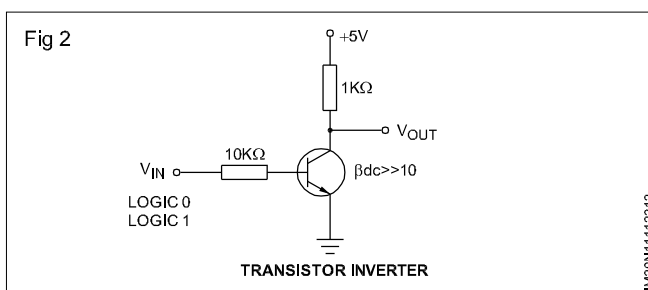
### Transistor inverter

The above circuit shows the transistor inverter circuit. The circuit is a common emitter amplifier which works in saturation or in cut off region depending upon the input voltage. When  $V_{in}$  is in low level, say less than the transistor cut in voltage 0.6V in silicon type, the transistor goes to cut off condition and the collector current is zero. Therefore,  $V_{out} = +5V$  which is taken as high logic level. On the other hand, when  $V_{in}$  is in high level, the transistor saturates and  $V_{out} = V_{sat} = 0.3V$  i.e low level.

The table summarizes the operation

| Vin     | Vout    |
|---------|---------|
| Low(0)  | High(1) |
| High(1) | Low(0)  |

The logic expression for the inverter is as follows: If the input variable is 'A' and the output variable is called Y, then the output  $Y = \bar{A}$ .



## Logic gates and logic probes

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

- explain the function of logic gates
- explain the AND gate using diode and its truth table
- explain the OR gate using diode and its truth table
- explain a NOT gate using transistor and its truth table
- explain the NAND, NOR gate and their truth table
- explain the EX-OR and EX - NOR gates and their truth table.

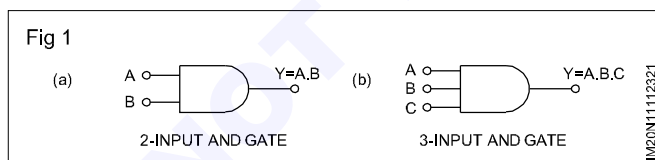
### Introduction

Logic gates are electronic circuits used in digital circuits for the purpose of decisions. Logic circuits are basically of two types namely decision making circuits and memory circuits. Their functioning depends on the binary inputs they receive and produce binary output which are a function of the input as well as the characteristics of the logic circuit they implemented. All logic gates have a single output and they may have two or more inputs. For specific decision making function there are several types of logic gates are used. Basic Logic gates are a group of the logic gates specifically called as AND, OR and NOT gates. All these gates have their own identical, logical function. By the combination of these gates we can obtain any Boolean or logical functions or any logical function.

### AND gates

The AND gate has two or more inputs but only one output. All input signals must be held high to get a high output. Even if one of the inputs is low, the output becomes low.

The schematic symbols for 2 input and 3 input AND gates are shown in Fig 1a and 1b.



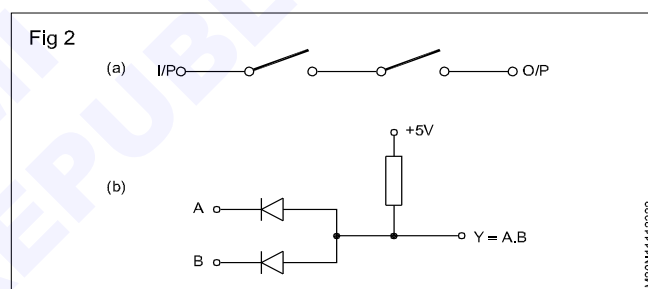
Truth table

Two input AND gate

| A | B | Y=A.B |
|---|---|-------|
| 0 | 0 | 0     |
| 0 | 1 | 0     |
| 1 | 0 | 0     |
| 1 | 1 | 1     |

### Electronics equivalent circuit of an AND gate

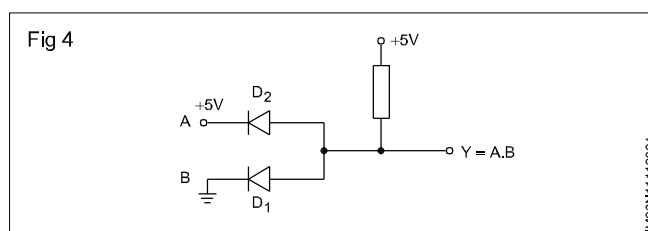
The Electronics equivalent of AND gate and AND gate using diodes are shown in Fig 2a and 2b.



### Two input AND gate using diode

#### Condition-1

A=0, B=0, Y=0 as shown in Fig 3.



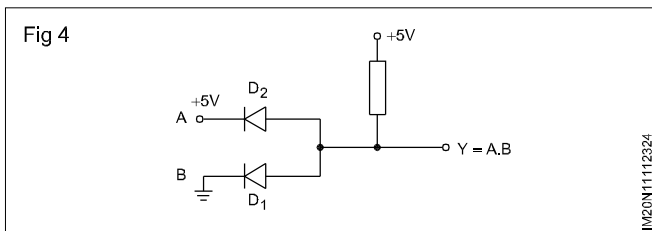
During the above condition inputs A and B are connected to ground to make logic low inputs. During this condition, both the diodes conduct, and pulls the output Y to logic 0.

#### Condition-2

A=0, B=1, Y=0 as shown in Fig 4.

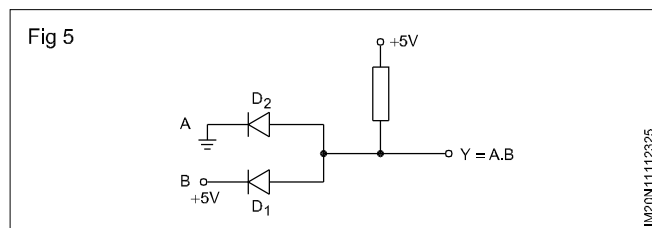
In the condition shown in Fig 4, diode  $D_1$  is connected to logic-0 input and diode  $D_2$  is connected to +5V [Logic high]. Diode  $D_1$  is in forward bias and conducts. Diode  $D_2$  is having equal potential (+5V) at anode and cathode. So potential difference between anode and cathode is 0. Hence diode

D2 does not conduct. The output Y is pulled down to logic zero, since D<sub>1</sub> is conducting.



### Condition-3

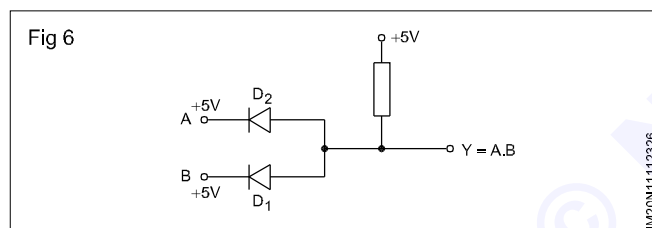
A=1, B=0, Y=0 as shown in Fig 5.



The condition-3 is similar to the condition-2. D<sub>2</sub> is forward biased. D<sub>1</sub> is reverse biased. Hence, output Y is pulled to logic-0.

### Condition-4

A=1, B=1, Y=1 as shown in Fig 6.



In this condition both the diodes are reverse biased. So both the diodes act as open circuit. Therefore, output Y is +5V i.e y is in logic1 condition.

For pin diagram refer to the data sheet of the IC.

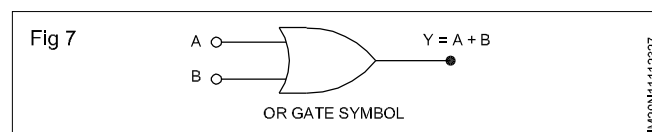
A. For example, if 1000 pulses pass through the gate in the 1 second interval of the enabled pulse, there are 1000 pulses/sec. That is, frequency is 1000Hz.

AND gates are available in the form of IC. IC7408 is a TTL type AND gate IC having 4 numbers of AND gates in side it.

## OR gate

The OR gate has two or more inputs, but only one output.

The output of an OR gate will be in 1 state if one or more of the inputs is in 1 state. Only when all the inputs are in 0-state, the output will go to 0-state. Fig 7 shows the schematic Symbol of an OR Gate



The boolean expression for OR gate is  $Y = A + B$ .

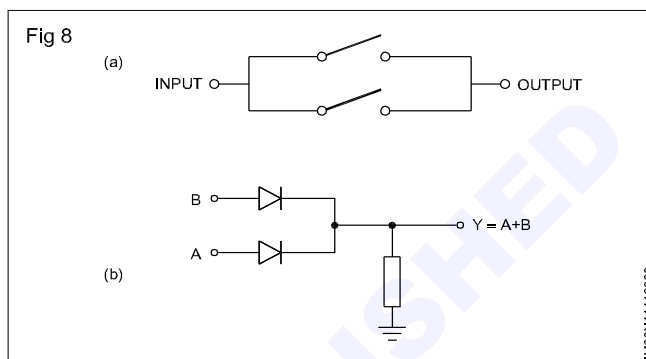
The equation is to be read as Y equals A ORed B. Two-input truth table given below is equivalent to the definition of the OR operation.

Truth table for OR gate

| A | B | $Y = A + B$ |
|---|---|-------------|
| 0 | 0 | 0           |
| 0 | 1 | 1           |
| 1 | 0 | 1           |
| 1 | 1 | 1           |

## Electronics equivalent circuit

The Fig 8a shows the Electronics equivalent circuit of an OR gate. It is evident that if any one of the switch is closed, there will be output.



## 2 in-input OR gate using diode

The Fig 8b shows one way to build a 2-input OR gate, using diodes. The inputs are labeled as A and B, while the output is Y.

Assume logic 0 = 0V (low)

logic 1 = +5V (high)

Since this is a 2 input OR gate, there are only four possible cases,

**Condition:1** A is low and B is low. With both the input voltage low, both the diodes are not conducting. Therefore the output Y is in low level.

**Condition:2** A is low and B is high, The high B input voltage (+5V) forward biases the lower diode, producing an output voltage that is ideally +5V (actually +4.3V taking the diode voltage drop 0.7V into consideration). That is, the output is in high level. During this condition, the diode connected to input A is under reverse bias or OFF condition.

**Condition:3** A is high and B is low, the condition is similar to case 2. Input A diode is ON and Input B diode is OFF and Y is in high level.

**Condition:4** A is high, B is high. With both the inputs at +5V, both diodes are forward biased, since the input voltages are in parallel, the output voltage is +5V ideally [+4.3V to a second approximation]. That is, the output Y is in high level.

OR gates are available in the IC form. IC7432 is a TTL OR gate IC having 4 OR gates inside it. For pin diagram refer to the data sheet of the IC.

## Simple application of OR gate

### Intrusion detection

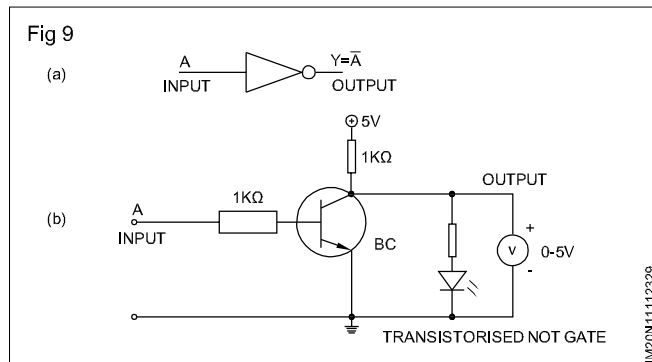
Simplified portion of an intrusion detection and alarm system is two windows and a door. The sensors are



magnetic switches that produce a high(1) output when windows and doors are opened and a low(0) output when closed. As long as the windows and the door are secured, the switches are closed and all three of the OR gate inputs are in low(0). When one of the windows or the door is opened, a high(1) output is produced on that input of the OR gate and the gate output goes high. It then activates an alarm circuit to warn of the intrusion.

### NOT gate

The NOT gate has only one input and one output as per the schematic symbol shown in Fig 9a and the circuit to construct the NOT gate using discrete components in Fig 9b.



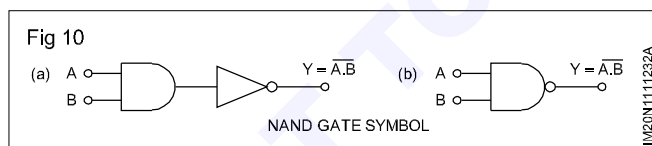
The NOT gate inverts the logic stage of a binary signal input. The small circle (bubble) at the output of the symbol is formally called a negation indicator and designates the logical complement.

### NAND gate

The **NAND** gate is the complement of the **AND** operation. Its name is an abbreviation of NOT **AND**.

The schematic symbol for the NAND gate consists of an AND symbol with a bubble on the output, denoting that a complement operation is performed on the output of the AND gate.

The schematic symbol and truth table of NAND gate is shown in Fig 10a & b.



Truth table

| A | B | Y = $\overline{A \cdot B}$ |
|---|---|----------------------------|
| 0 | 0 | 1                          |
| 0 | 1 | 0                          |
| 1 | 0 | 0                          |
| 1 | 1 | 0                          |

The truth table clearly shows that the NAND gate operation is the complement of the AND gate.

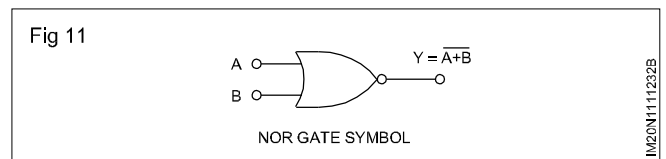
### NOR gate:

The NOR gate is the complement of the OR operation. Its name is an abbreviation of NOT OR.

The schematic symbol for the NOR gate consists of an OR symbol with a bubble on the output, denoting that a

complement operation is performed on the output of the OR gate.

The schematic symbol and the truth table of NOR gate is shown in the figure 11.



Truth table

| Input |   | Output                 |
|-------|---|------------------------|
| A     | B | Y = $\overline{A + B}$ |
| 0     | 0 | 1                      |
| 0     | 1 | 0                      |
| 1     | 0 | 0                      |
| 1     | 1 | 0                      |

The output of NOR gate is '0' even if one of the input is in logic 1. Only when both the inputs are in logic '0', the output is in logic '1'.

The IC 7402 is a TTL type NOR gate IC. It contains 4 NOR gates. For pin details of the IC refer to the data sheet of the IC.

### EX-OR gate

#### Exclusive-OR gate

Exclusive OR gate is actually formed by a combination of other gates already discussed. However, because of their fundamental importance in many applications, these gates are treated as basic logic elements with their own unique symbols.

The EX-OR gate has only two inputs unlike the other gates, it never has more than two inputs.

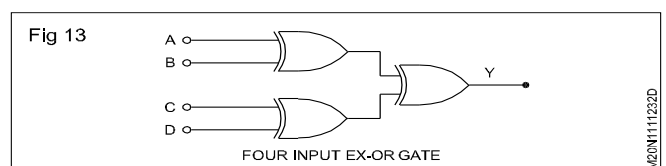
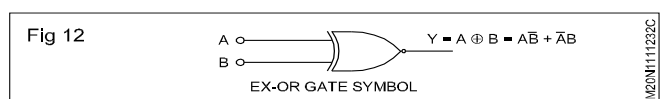
The schematic symbols of Exclusive-OR (XOR for short) is gate shown in Fig 12.

The truth table of EX-OR gate is given below.

Truth Table

| A | B | Q = $A \oplus B$ |
|---|---|------------------|
| 0 | 0 | 0                |
| 0 | 1 | 1                |
| 1 | 0 | 1                |
| 1 | 1 | 0                |

Using 2-input EX-OR gates as building blocks, an EX-OR gate with more than two inputs can be built as shown in Fig 13



## Four input EX-OR gate

$$Y = A+B+C+D$$

Truth Table

| A | B | C | D | Y | Remarks for input |
|---|---|---|---|---|-------------------|
| 0 | 0 | 0 | 0 | 0 | Even              |
| 0 | 0 | 0 | 1 | 1 | Odd               |
| 0 | 0 | 1 | 0 | 1 | Odd               |
| 0 | 0 | 1 | 1 | 0 | Even              |
| 0 | 1 | 0 | 0 | 1 | Odd               |
| 0 | 1 | 0 | 1 | 0 | Even              |
| 0 | 1 | 1 | 0 | 0 | Even              |
| 0 | 1 | 1 | 1 | 1 | Odd               |
| 1 | 0 | 0 | 0 | 1 | Odd               |
| 1 | 0 | 0 | 1 | 0 | Even              |
| 1 | 0 | 1 | 0 | 0 | Even              |
| 1 | 0 | 1 | 1 | 1 | Odd               |
| 1 | 1 | 0 | 0 | 0 | Even              |
| 1 | 1 | 0 | 1 | 1 | Odd               |
| 1 | 1 | 1 | 0 | 1 | Odd               |
| 1 | 1 | 1 | 1 | 0 | Even              |

To summarize the action by referring truth table of 4-input XOR gate, each input word with an odd number of 1's produces a logic HIGH(1) output and for words with an even number of 1's it produces logic-Low(0) output. Because of this reason the EX-OR gate is used for parity check, IC 7486 is an quad 2 input EX-OR gate which is available both in TTL and CMOS family.

### Application of EX- OR gate as a parity checker.

Parity is the term used to mention the number of 1's in a binary word. Even parity means an n-bit input has even number of 1s. For instance, 110011 has even parity because it contains four 1s. Odd parity means an n-bit input has an odd no. of 1s. For example, 110001 has odd parity because it contains three 1s.

### Parity checker

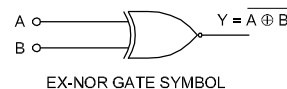
Exclusive-OR gates are ideal for checking the parity of a binary number because they produce an output 1 when the input has an odd no. of 1s. Therefore an even parity

input to an Exclusive-OR gate produces a low output, while an odd parity input produces a high output.

### Exclusive-NOR gate

| Inputs |   | Output   |
|--------|---|----------|
| A      | B | Q= A + B |
| 0      | 0 | 1        |
| 0      | 1 | 0        |
| 1      | 0 | 0        |
| 1      | 1 | 1        |

Fig 14



IM20N111232E

The schematic symbols for the EX-NOR (XNOR) gate is shown in Fig 14. Like the XOR gate, XNOR has only two inputs. The bubble on the output of the XNOR symbol indicates that its output is opposite that of the XOR gate.

In an exclusive-NOR gate operation, "Output Q is LOW" if input A is LOW and input B is HIGH or if A is HIGH and B is LOW, Q is HIGH if A and B are both HIGH or both LOW.

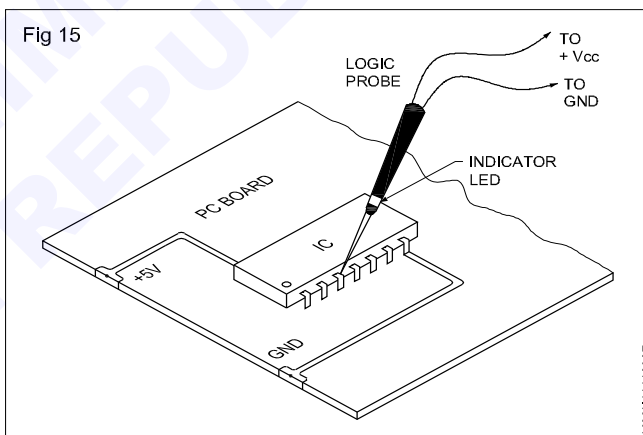
### Application

EX-OR gate can be used as a controlled inverter. One of its inputs can be used to control whether the signal at the other input will be inverted or not. This property will be useful in certain application.

### Logic probe

A logic probe is used to monitor the logic level activity at an IC pin or any other accessible point in a logic circuit. Logic probe normally has one or more indicator LEDs that indicate the various conditions of the logic signal. The indication may be related to logic HIGH, LOW, Intermediate & Pulsing states that are present at that point in the circuit which the probe tip is touching. Fig 15 shows how a logic probe is connected to an IC pin.

Fig 15



IM20N111232F

A logic probe is used as a troubleshooting tool of digital systems. The most common internal failures of digital ICs are as follows

- 1 Malfunction in the internal circuitry.
- 2 Inputs or Outputs open circuited.
- 3 Inputs or Outputs shorted to ground or Vcc.
- 4 Short between two pins (other than ground or Vcc).

### Malfunction in the internal circuitry

This is usually caused by one of the internal components failing completely or operating outside its specifications. When this happens the IC do not respond properly to the IC inputs. The behaviour of outputs cannot be predicted because it depends on what internal component has failed. This type of internal IC failure is not as common as other three.

### Inputs shorted to ground or Vcc

This type of internal failure will cause the input to be stuck in the LOW or HIGH state. This kind of faults result short

circuiting either with  $V_{CC}$  or ground depending on the state of input.

### Outputs shorted to ground or $V_{CC}$

This type of internal failure will cause the output to be stuck in the LOW or HIGH state. This type of failure has no effect on other logic signals at the inputs.

### Open circuited input or output

Sometimes very fine conducting wire that connects an IC pin to the IC's internal circuitry will break, producing an open circuit. The open gate will be in the floating state and this state will be assumed by TTL devices as a valid logic 1 and CMOS devices will respond erratically and may even become damaged from overheating.

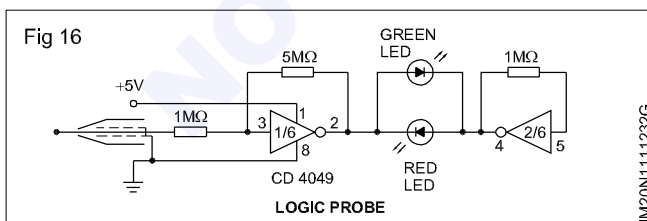
### Short between two pins

An internal short between two pins of an IC will force the logic signals at those pins always be identical. Whenever two signals that are supposed to be different show the same logic-level variations, there is a good possibility that the signals are shorted together.

In most of the cases discussed above, a logic probe acts as a good troubleshooting tool to diagnose faulty circuits. Among other things, the logic probe is useful for locating short circuits that occur in manufacturing. For example during the stuffing and soldering of printed circuit boards, an undesirable splash of solder may connect two adjacent tracks. Known as solder bridge, this kind of trouble can short-circuit a node to the ground or to the supply voltage. The node is then stuck in a low or high state. The probe helps you to find short-circuited nodes because it stays in one state, no matter how the inputs are changing.

### Logic probe circuit using inverters

A simple circuit for indicating the logic levels using NOT gates is shown in Fig 16. The circuit consists of two inverters biased in the linear region. If the logic probe is connected to a 'low' level input, the 'high' going output of NOT gates makes LED-1 to glow. On the other hand, if the input probe is connected to a high level, the low going output of NOT gate makes LED-2 to glow. The two back to back connected LEDs protect each other against excessive reverse voltage. As the input impedance is very high, a shielded wire is required to connect the probe to the input of IC.

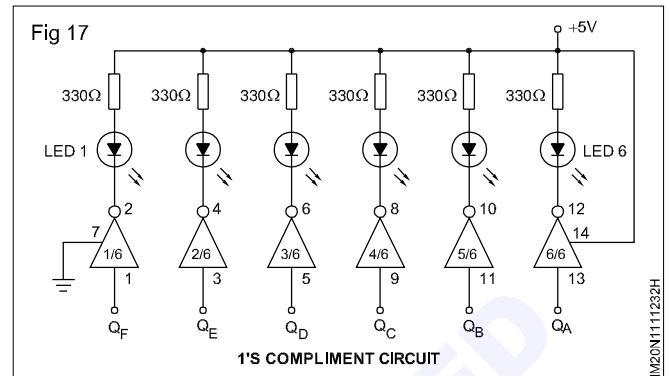


7404 is a TTL IC having six inverters inside, CD4011 is a CMOS IC having six inverters, refer table book for IC pin configuration.

### 1's complement circuit using inverter (Fig 17)

The Fig 17 shows a circuit for producing the 1's complement of an 6-bit binary number. The bits of the binary number are applied to the inverter inputs and the 1's complement of the

number appears at the o/p.s. LED1 to LED6 indicate the status of inputs  $Q_F$  to  $Q_A$ . Logic 1 on any of the inverter inputs  $Q_F$  to  $Q_A$ , will make the output low causing corresponding LED to glow. If the LED glows, input to that particular inverter gate is high. In this matter the above circuit works as logic level indicator. Logic probe



An universal gate is a that can be used to implement any Boolean function without the need to use any other type of gate.

The NAND and NOR gates are universal gates.

In actual practice, the NAND and NOR gates are used to fabricate all the basic gates required in IC digital logic families.

In practice, an AND gate is typically implemented as a NAND gate followed by an inverter not the other way around.

In the same way an OR gate is typically implemented as a NOR gate followed by a NOT gate.

Now let us discuss how to implement the NOT, AND, and OR gates using universal gate.

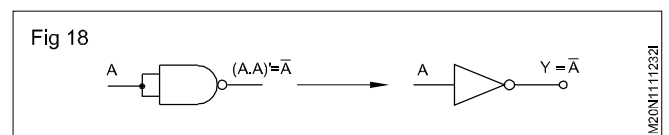
### NAND gate as a universal gate:

To prove that any Boolean function can be implemented using only NAND gates, we will show that the AND, OR, and NOT operations can be performed using only these gates.

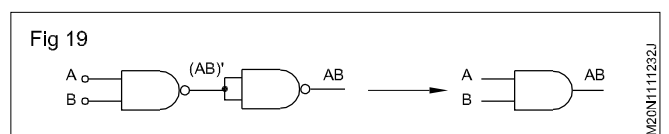
NAND gate implemented as NOT gate.

In the following circuit NAND gate is used as an inverter (NOT gate).

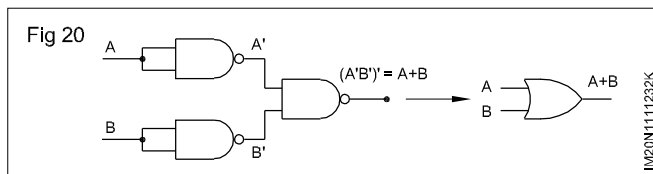
All input pins of NAND gates are connected to the input signal A gives an output A as shown in Fig 18.



NAND gate implemented as AND gate. An AND gate can be implemented by NAND gate as shown in fig 19. (The AND is replaced by a NAND gate with its output complemented by a NAND gate inverter).



**NAND gates** implemented as OR gate. An OR gate can be implemented by NAND gates as shown in figure 20. (The OR gate is replaced by a NAND gate with all its inputs complemented by NAND gate inverters).

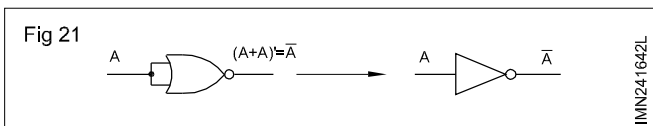


Thus it is proved that the NAND gate is a universal gate since it can implement the AND, OR and NOT logic functions.

NOR gate as a universal gate. In the following paragraphs the NOR gate is used to prove that any Boolean function can be implemented only with NOR gates. NOR to replace the AND, OR and NOT operations.

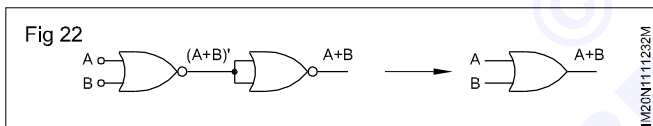
NOR gate implemented as NOT gate. In the following circuit a NOR gate is used as **an inverter (NOT gate)**.

All input pins of NOR gate are connected to the input signal A gives an output  $\bar{A}$  as shown in Fig 21.



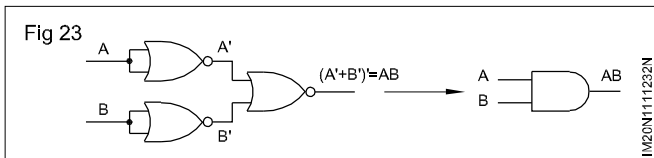
**NOR gate** implemented as AND gate.

An OR gate can be implemented by NOR gates as shown in fig 22. (The OR is replaced by a NOR gate with its output complemented by a NOR gate inverter)



NOR gate implemented as AND gate

An AND gate can be implemented by NOR gates as shown in the fig 23. (The AND gate is replaced by a NOR gate with all its inputs complemented by NOR gate inverters)



Thus it is proved that the NOR gate is a universal gate since it can implement the AND, OR and NOT logic functions.

### Heat Sink used in Electronics and electronic component

In any Electronics circuit some amount of heat while the circuit is functioning. Typically power handling semiconductor devices like power transistors and the opto electronics such as light emitting diodes, lasers generate heat in considerable amounts and these components are inadequate to dissipate heat, as their dissipation capability is significantly low.

Due to this, heating up of the components leads to malfunctioning problems and may cause failure of the entire circuit or system's performance. So, to solve these problems, heat sinks are the solution that must be provided to those semiconductor devices for cooling purpose.

Heat sink is a device made of aluminium metal attached to an electronic circuit, that dissipates heat mainly from the power transistors of a circuit into the surrounding medium and cools them for improving their performance, reliability and also avoids the damage to the components. For the cooling purpose, it incorporates a fan or cooling device.

Whenever two objects with different temperature come into contact with each other, conduction occurs causing the fast-moving molecules of the high-heat object to collide with the slow-moving molecules of the cooler objects, and thus, transfers thermal energy to the cooler object, and this is termed as thermal conductivity.

Similarly, heat sink transfers the heat or thermal energy from a high-temperature component to a low-temperature medium like air.

The heat sinks are classified into different categories based on different criteria. Let us consider the major types, namely active heat sinks and passive heat sinks.

## Binary arithmetic

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

- define binary arithmetic
- perform binary addition
- perform binary subtraction using 1's complement and 2's complement
- explain half adder circuit, full adder circuit
- explain 4 bit parallel adder circuit using IC 74LS83
- explain IC 74LS83 4 bit parallel adder can be used for subtraction.

Binary arithmetic is essential in all digital computers and in many other types of digital systems. To understand digital systems, you must know the basics of binary addition, subtraction, multiplication and division.

### Binary addition

Physical quantities are represented by numbers. Addition represents combining of physical quantities. Digital computers do not process decimal numbers, they process

binary numbers. Addition is a key process to perform subtraction, multiplication and division. The four basic cases for adding binary digits are as follows.

$0 + 0 = 0$ ; Sum is 0 with a carry of 0.

$0 + 1 = 1$ ; Sum is 1 with a carry of 0.

$1 + 0 = 1$ ; Sum is 1 with a carry of 0.

$1 + 1 = 10$ ; Sum is 0 with a carry of 1.



Notice that the first three cases result in a single bit and in the fourth case the addition of two 1's yields a binary two i.e. 10. When binary numbers are added, the last condition creates a sum of 0 in a given column and a carry of 1 over to the next column to the left, as illustrated in the following addition of 11 + 01.

|       |   |   |   |
|-------|---|---|---|
| carry | 1 | 1 |   |
|       | 0 | 1 | 1 |
| +     | 0 | 0 | 1 |
|       |   |   |   |
|       | 1 | 0 | 0 |
|       |   |   |   |

In the right most column, 1+1=0 with a carry of 1 to the next left column. In the middle column, 1+1+0=0 with a carry of 1(one) to the next left column. In the left most column, 1 remains as final carry of the 2 bit addition. Hence the result is 100.

Example:

|   |         |       |       |
|---|---------|-------|-------|
| 1 |         | carry | 1110  |
|   | 14      |       | 1110  |
|   | 10      |       | 1010  |
|   |         |       |       |
|   | 24      |       | 11000 |
|   |         |       |       |
| 2 | 10 + 12 |       |       |
|   | 10      |       | 1010  |
|   | 12      | +     | 1100  |
|   |         |       |       |
|   | 22      |       | 10110 |
|   |         |       |       |

The above process is column-by-column addition which can be applied to find the sum of two binary numbers of any length. The following example shows 8-bit arithmetic addition operation.

|       |       |       |       |       |       |       |       |
|-------|-------|-------|-------|-------|-------|-------|-------|
| $A_7$ | $A_6$ | $A_5$ | $A_4$ | $A_3$ | $A_2$ | $A_1$ | $A_0$ |
| $B_7$ | $B_6$ | $B_5$ | $B_4$ | $B_3$ | $B_2$ | $B_1$ | $B_0$ |

|   |
|---|
| ? |
|---|

The most significant bit (MSB) of each number is on the left side and least significant bit is on the right side. For the first number,  $A_7$  is the MSB and  $A_0$  is the LSB, similarly for the 2nd number  $B_7$  and  $B_0$  are the MSB and LSB respectively.

### Signed numbers

Digital systems such as the computer, must be able to handle both +ve and -ve numbers, A signed binary numbers consists of both sign and magnitude information. The sign indicates whether a number is +ve or -ve and the magnitude is the value number. There are three ways in which signed numbers can be represented in binary form: sign magnitudes, 1s compliment, and 2's compliment.

### Sign-magnitude system

The left most bit in a signed binary number is the sign bit, which tells you whether the number is +ve or -ve, A zero in the left most position represents +ve number and a ONE represents -ve number. The remaining bits are the magnitude bits. The magnitude bits are in true (uncomplimented) binary form for both +ve and -ve numbers.

Example:

+25 is expressed as an 8 bit signed binary number using the sign magnitude system as

+ 25 = 0 0 0 1 1 0 0 1

Sign bit    Magnitude bit

- 25 = 1 0 0 1 1 0 0 1

Notice that the only difference between +25 and -25 is with the sign bit because the magnitude bits are same for both +ve and -ve numbers.

"In the sign-magnitude system, a -ve number has the same magnitude bits as the corresponding +ve number but the sign bit is a 1." Although sign magnitude system is straight forward, calculators and computers do not use it, because circuit implementation is more complex than other systems.

### 1's complement system

Positive numbers in the 1's complement system are represented the same way as the positive sign magnitude numbers. In the 1's complement system, a negative number is the 1's compliment of the corresponding +ve number.

Example:

The decimal number -25 is expressed as the 1's compliment of +25 (00011001) as 11100110.

i.e 1's compliment of 00011001 (+25) = 11100110 (-25)

(The 1's compliment of a binary number is obtained by simply changing each 0 to a 1 and each 1 to a 0).

Example:

Determine the decimal value of the signed binary numbers expressed in 1's compliment.

1 1 1 0 1 0 0 0

The bits and their powers of two weights for the -ve number are as follows.

Notice that the -ve sign bit has a weight of  $-2^7$  or -128

|        |       |       |       |       |       |       |       |
|--------|-------|-------|-------|-------|-------|-------|-------|
| $-2^7$ | $2^6$ | $2^5$ | $2^4$ | $2^3$ | $2^2$ | $2^1$ | $2^0$ |
| 1      | 1     | 1     | 0     | 1     | 0     | 0     | 0     |

Summing the weights where there are 1s.

$1 \times -2^7$  (128) = -128

$1 \times 2^6$  (64) = +64

$1 \times 2^5$  (32) = +32

$1 \times 2^3$  (8) = +8

= -128+104

= -24



Adding 1 to the result, the final number is =  $-24 + 1 = -23$ .

The decimal value of the signed number 11101000 expressed in 1's complement is = -23.

### 2's complement system

Positive numbers in the 2's complement system are also represented the same way as in sign magnitude and 1's complement system. Negative numbers are 2's complement of the corresponding positive no's.

2's complement of a binary number is found by adding ONE(1) to the LSB of the 1's complement.

2's Complement = (1's complement) + 1

Example:

Find the 2's complement of 1011011

#### Solution

|         |   |                |
|---------|---|----------------|
| 1011011 | - | Binary number  |
| 0100100 | - | 1's complement |
| 1       | - | Add 1          |

---

+ 0100101

---

For example, the decimal number -25 can be expressed in binary form by writing 2's complement for +25.

|     |   |          |   |                |
|-----|---|----------|---|----------------|
| +25 | = | 00011001 | - | Binary number  |
|     |   | 11100111 | - | 2's complement |

Example:

Express the decimal -39 as an 8 bit number in sign-magnitude using 2's complement system.

#### Solution

In the 2's complement system, -39 is produced by taking the 2's complement of +39 (00100111) as follows.

|     |   |          |                |
|-----|---|----------|----------------|
| +39 | = | 00100111 | Binary number  |
|     |   | 11011000 | 1's complement |

+ 1

---

11011001

---

2's complement

-39 = 11011001

Verification

|                 |                |                |                |                |                |                |                |
|-----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| -2 <sup>7</sup> | 2 <sup>6</sup> | 2 <sup>5</sup> | 2 <sup>4</sup> | 2 <sup>3</sup> | 2 <sup>2</sup> | 2 <sup>1</sup> | 2 <sup>0</sup> |
| -128            | 64             | 32             | 16             | 8              | 4              | 2              | 1              |

---

|   |   |   |   |   |   |   |   |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 |
|---|---|---|---|---|---|---|---|

---

Since the MSB of the binary equivalent is one so, 2<sup>7</sup> should be taken as -ve sign.

-128+64+16+8+1 = -128+89  
= -39

The 2's complement system is preferred for representing signed numbers as it requires a summation weights regardless of whether the number is +ve or -ve. It is used in most computers because it makes arithmetic operations easier.

### Basic Adder

Adders are used in many types of digital systems in which numerical data are processed. Computers and calculators perform binary operations on two binary numbers at a time, where each number can have several binary digits. The logic symbol for a half adder is shown in Fig 1. There are two basic categories of adders.

- 1 Half adder
- 2 Full adder

### Half adder

The half-adder accept two binary digits on its inputs and produces two binary digits on its outputs, a sum bit and a carry bit.

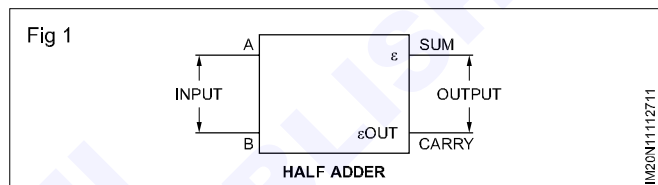


Table 1 (Truth table)

| A | B | Sum<br>S=A + B | Carry<br>C <sub>out</sub> = AB |
|---|---|----------------|--------------------------------|
| 0 | 0 | 0              | 0                              |
| 0 | 1 | 1              | 0                              |
| 1 | 0 | 1              | 0                              |
| 1 | 1 | 0              | 1                              |

From the logic operation of the half-adder as stated in the Table 1, expression can be derived for the sum and the output carry as functions of the inputs, notice that the output carry is a 1 only when both A and B are 1s. Therefore carry (C<sub>out</sub>) can be expressed as the AND of the input variables.

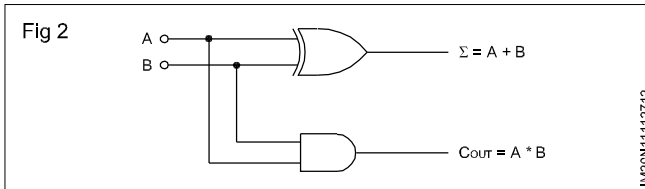
$$C_{out} = A.B \quad \longrightarrow 1$$

The sum output(S) is a 1 only if the input variables, A and B are not equal. The sum can therefore be expressed as the exclusive -OR of the input variables.

$$\text{Sum}(S) = A + B \quad \longrightarrow 2$$

From equation 1 and 2 the logic implementation required for the half-adder function can be developed. The output carry is produced with an AND gate with 'A' and 'B' on the inputs and the sum outputs is generated with an Ex-OR gate, as shown in Fig 2.

## Full adder



The full adder accepts three inputs including an input carry and generates a sum output and an output carry.

The basic difference between a full-adder and a half-adder is that the full-adder accepts an input carry. A logic symbol for a full-adder is shown in Fig 3 and the truth table in the Table 2 shows the operation of a full-adder.

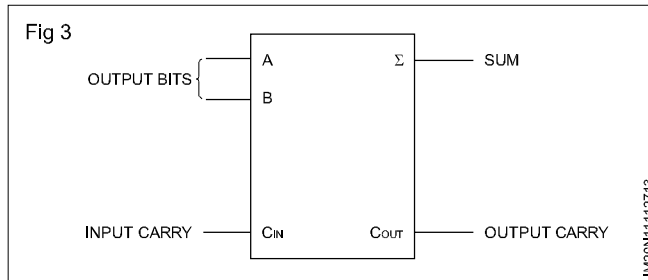


Table 2

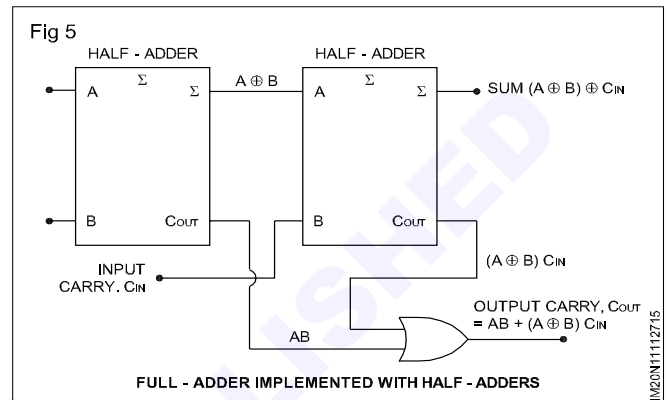
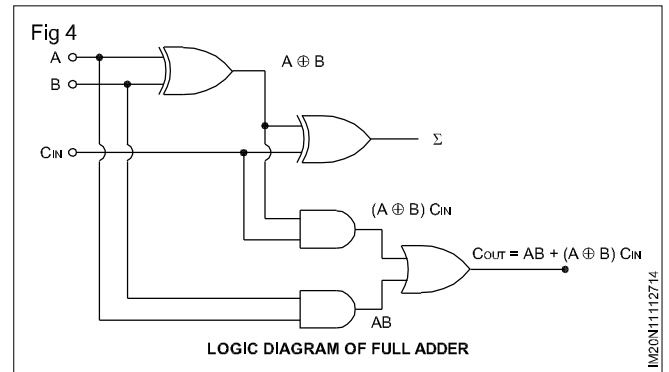
| A | B | C <sub>in</sub> | C <sub>out</sub> | S |
|---|---|-----------------|------------------|---|
| 0 | 0 | 0               | 0                | 0 |
| 0 | 0 | 1               | 0                | 1 |
| 0 | 1 | 0               | 0                | 1 |
| 0 | 1 | 1               | 1                | 0 |
| 1 | 0 | 0               | 0                | 1 |
| 1 | 0 | 1               | 1                | 0 |
| 1 | 1 | 0               | 1                | 0 |
| 1 | 1 | 1               | 1                | 1 |

The full-adder must add the two input bits along with the input carry. From the truth-table of the half-adder we know that the sum of the input bits A and B is  $A + B$ . To get the sum output of the full adder the input carry ( $C_{in}$ ) must be exclusive-ORed with  $A + B$ . Then the sum

$$S = (A + B) + C_{in}$$

This means that to implement the full-adder sum function, two exclusive-Or gates can be used. The first must generate the term  $A + B$ , and the second has the inputs from the output of the XOR gate and the input carry, as shown in Fig 4.

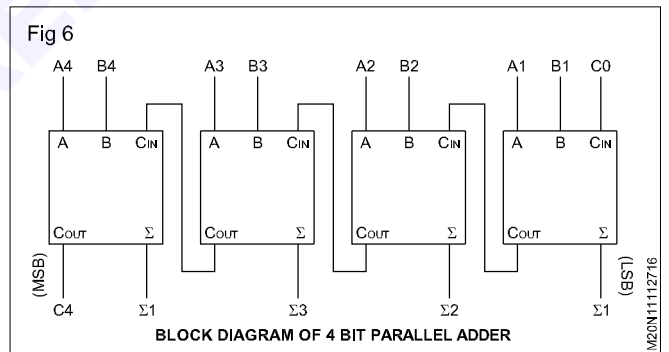
The output carry of the full-adder is therefore produced by the inputs A, ANDed with B and  $A + B$  ANDed with  $C_{in}$ . These two terms are ORed, and expressed in equation shown below and this function is implemented and combined with the sum logic to form a complete full-adder circuits, as shown in Fig 4.



## 2 Bit parallel adder (para)

$$C_{out} = AB + (A + B) C_{in}$$

The Fig 5, shows there are two half-adders, connected as shown in block diagram to form full-adder.



## Four bit parallel adder

A basic 4-bit parallel adder is implemented with four full-adders as shown in the Fig 6.

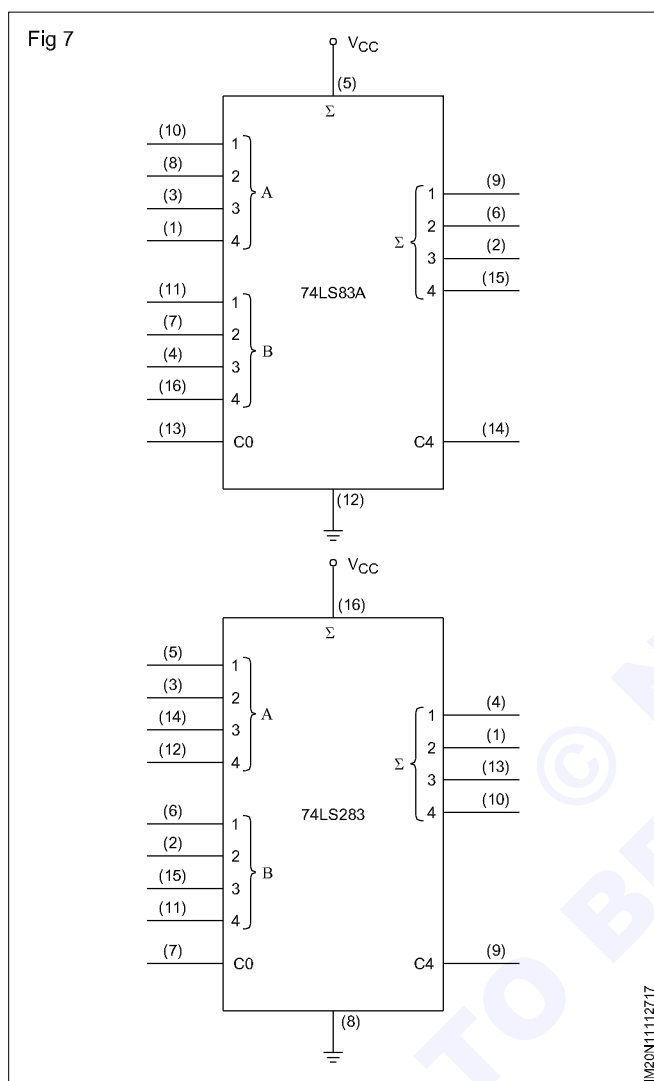
### Block diagram of 4 bit parallel adder

The LSB, (A1 and B1) in each number being added into the right most full-adder; the higher order bits are applied as shown to the successively higher order adders, with MSBs (A4 and B4) in each number being applied to the left most full adder. The carry output of each adder is connected to the carry input of the next higher order adder as indicated.

In the manufacturer's data sheets the input labeled  $C_0$  is the input carry to the least significant bit adder,  $C_4$  is the output carry of the most significant bit adder, and  $S_1$ (LSB) through  $S_4$ (MSB) are the sum outputs.

## 74LS83 4 bit parallel adder

4-bit parallel adders that are available as Medium-Scale Integrated(MSI) circuits are the 74LS83A and the 74LS283 low-power Schottky TTL devices. These devices are also available in other logic families such as standard TTL (7483A and 74283) and CMOS (74HC283). The 74LS83A and the 74LS283 are functionally identical to each other but not pin compatible, that is the pin numbers for the inputs



and outputs are different due to different power and ground pin connections. For the 74LS83A,  $V_{CC}$  is pin 5 and ground is pin 12 on the 16-pin package. For the 74LS283,  $V_{CC}$  is pin 16 and ground is pin-8, which is a more standard configuration. Logic symbols for both of these devices are shown in Fig 7 with pin numbers in parenthesis.

The 4 bit parallel adder can be expanded to handle the addition of higher bit numbers by a process called cascading. In this process, the carry output of the lower-order adder is connected to carry input of the higher-order adder being cascaded.

## Binary subtraction

Subtraction is a special case of addition. For example Subtracting +6 (the subtrahend) from +9 (the minuend) is equivalent to adding -6 to +9. Basically the subtraction operation changes the sign of the subtrahend and adds it

to the minuend. The result of a subtraction is called the difference.

$$9 - 6 = 9 + (-6)$$

The sign of a positive or negative binary number is changed by taking its 2's complement.

Example:

The result of 2's complement of the positive number 0110(+6) is 1's complement of the number + 1

$$\text{i.e } 1001 + 1 = 1010$$

1010 is 2's complement of 0110(+6), which is equal to - 6 in decimal system, as shown below.

$$\begin{array}{r} 1 \quad 0 \quad 1 \quad 0 \\ -8 + 0 + 2 + 0 = -6 \end{array}$$

Example:

Subtract 6 from 9 in 2's complement method

$$9 - 6 = 3 \quad \text{normal method}$$

$$9 + (-6) = 3 \quad \text{2's complement method}$$

## Binary form

$$9 = 1001 \text{ (minuend)} \quad 1001 - 0110 = 0011$$

$$6 = 0110 \text{ (subtrahend)}$$

## 2's complement method

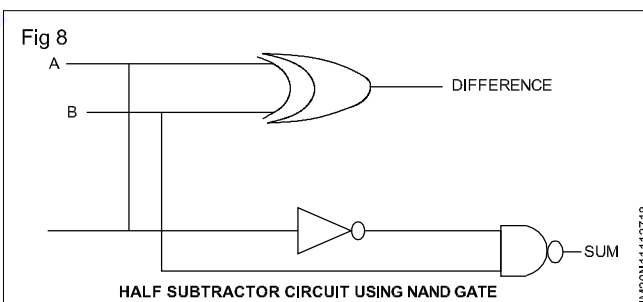
I step: 2's complement of subtrahend 0110 is

1's complement of subtrahend + 1

$$\text{i.e } 1001 + 1 = 1010 \text{ (equal to -6 in decimal system)}$$

II step: Add minuend with 2's complement of subtrahend

$$\text{i.e } 1001 + 1010 = 10011$$



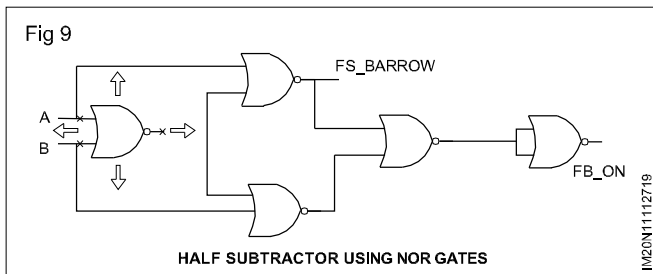
Discard the carry 1, then the result is 0011.

## Half subtractor circuit using nand gate

The designing of the subtractor can be done by using logic gates like the NAND gate & Ex-OR gate. In order to design this half subtractor circuit, we have to know the two concepts namely difference and borrow.

## Subtractor circuit using nand gate

If we monitor cautiously, it is fairly clear that the variety of operation executed by this circuit which is accurately related to the Ex-OR gate operation. Therefore, we can simply use the EX-OR gate for making difference. In the same way, the borrow produced by half added circuit can



be simply attained by using the blend of logic gates like AND - gate and NOT -gate.

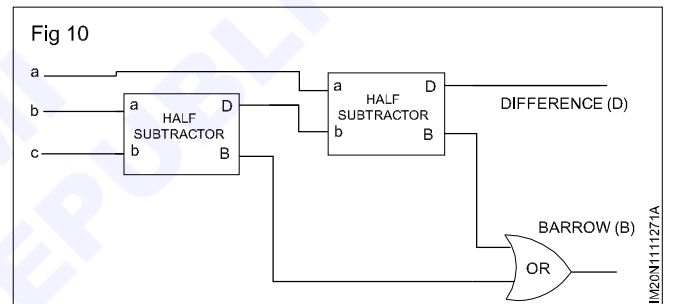
| First Bit | Second Bit | Difference | Borrow |
|-----------|------------|------------|--------|
| 0         | 0          | 0          | 0      |
| 1         | 0          | 1          | 0      |
| 0         | 1          | 1          | 1      |
| 1         | 1          | 0          | 0      |

This HS can also be designed by using NOR gates where it requires 5 NOR gates for the construction. The circuit diagram half subtractor using NOR gates is shown as:

Truthe Table

#### Full Subtractor using half subtractor

A full subtractor is a combinational device that operates the subtraction functionality by using two bits and is minuend



| Inputs |   |     | Outputs |           |
|--------|---|-----|---------|-----------|
| X      | Y | Yin | FS_Diff | FS_Borrow |
| 0      | 0 | 0   | 0       | 0         |
| 0      | 0 | 1   | 1       | 1         |
| 0      | 1 | 0   | 1       | 1         |
| 0      | 1 | 1   | 0       | 1         |
| 1      | 0 | 0   | 1       | 0         |
| 1      | 0 | 1   | 0       | 0         |
| 1      | 1 | 1   | 1       | 1         |

and subtrahend. The circuit considers the borrow the previous output and it has three inputs with two outputs. The three inputs are the minuend, subtrahend and the input received from the previous output which is borrow and the two outputs are the difference and borrow.

With the above truth table, the logical diagram and circuits diagram for the implementation of full subtractor using half subtractors is shown below:

The truth tabe for full subtractor is

## Advantages and limitations of half subtractor

The advantages of half subtractor are:

- The implementation and construction of this circuit is simple and easy
- This circuit consumes minimal power in digital signal processing
- computational functionalities can be performed at improved speed rates

The limitations of this combinational circuit are:

Even though there are extensive applications of half subtractor in many operations and functionalities, there are few limitations and those are:

- The half subtractor circuits will not accept “Borrow-in” from the previous outputs where this is the crucial drawback of this circuit
- As many real-time applications operate on the subtraction of number of bits, half subtractors devices do not hold any capability of subtracting many bits

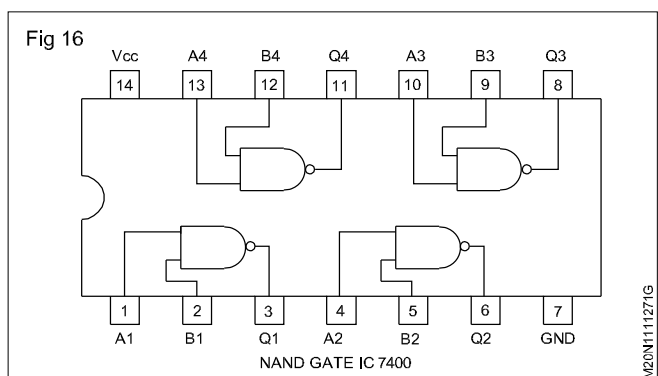
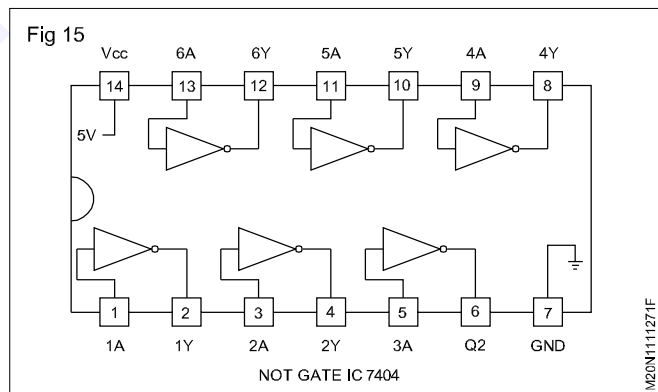
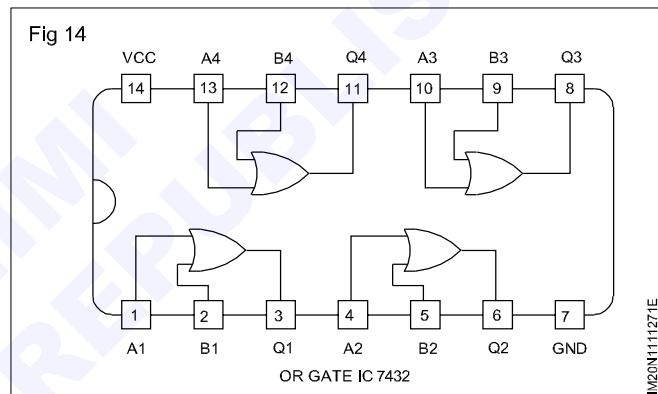
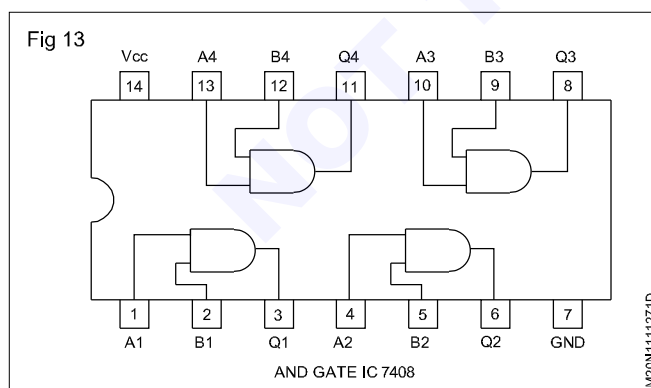
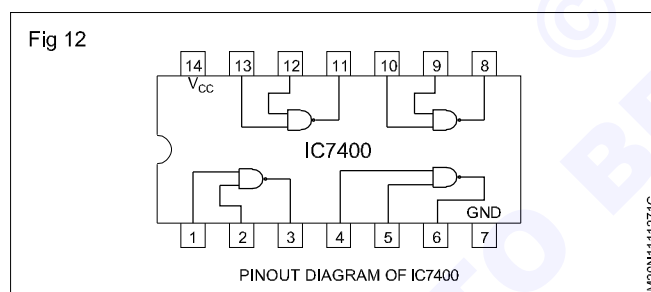
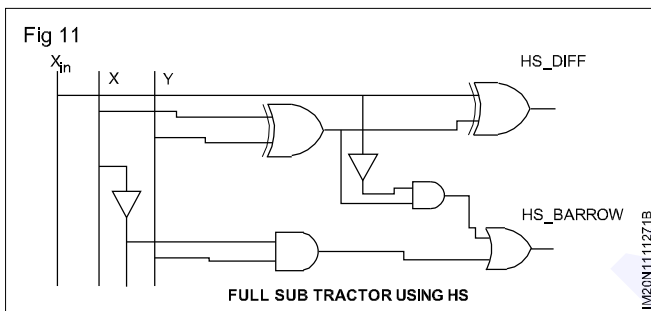
## Applications of half subtractor

The applications of half subtractor include the following.

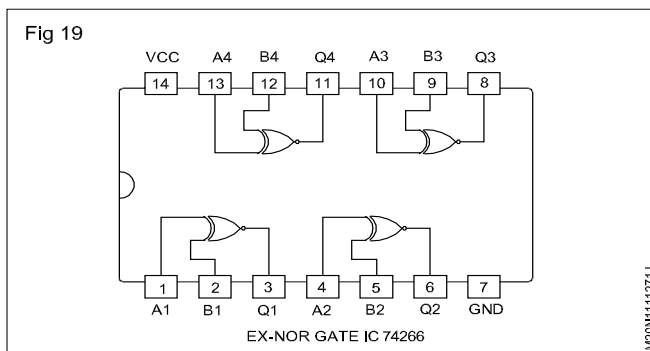
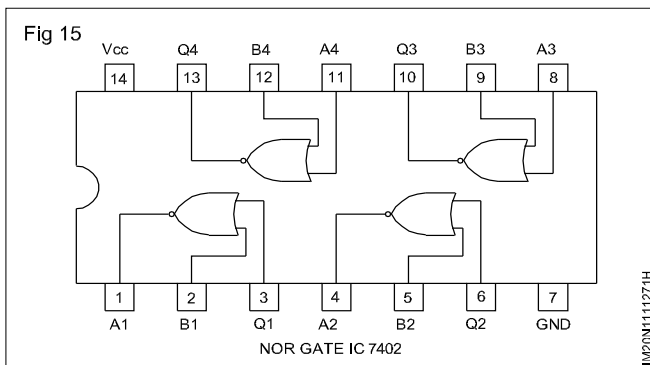
- Half subtractor is used to reduce the force of audio or radio signals
- It can be used in amplifiers to reduce the sound distortion
- Half subtractor is used in ALU of processor
- It can be used to increase and decrease operators and also calculates the addresses
- Half subtractor is used to subtract the least significant column numbers. For the subtraction of multi-digit numbers, it can be used for the LSB.

Therefore, from the above half subtractor theory, at last, we can close that by using this circuit we can subtract from one binary bit from another to provide the outputs like difference and borrow. Similarly, we can design half subtractor using nand gates circuit as well as NOR gates.

## PIN DIAGRAM OF LOGIC ICs







**Binary codes** : In the coding, when numbers, letters or words are represented by a specific group of symbols, it is said that the number, letter or word is being encoded. The group of symbols is called as a code. The digital data is represented, stored and transmitted as group of binary bits. This group is also called as binary code. The binary code is represented by the number as well as alphanumeric letter.

**Advantages of binary code** : Following is the list of advantages that binary code offers.

- Binary codes are suitable for the computer applications.

- Binary codes are suitable for the digital communications.
- Binary codes make the analysis and designing of digital circuits if we use the binary codes.
- Since only 0 & 1 are being used, implementation becomes easy.

**Classification of binary codes** : The codes are broadly categorized into following four categories.

- Weighted codes
- Non-weighted codes
- Binary coded decimal code
- Alphanumeric codes
- Error detecting codes
- Error correcting codes

**Weighted codes** : Weighted binary codes are those binary codes which obey the positional weight principle. Each position of the number represents a specific weight. Several systems of the codes are used to express the decimal digital 0 through 9. In these codes each decimal digital is represented by a group of four bits.

**Non-Weighted codes** : In this type of binary codes, the positional weights are not assigned. The examples of non-weighted codes are Excess-3 code and Gray code.

**Excess-3 code** : The Excess-3 code is also called as XS-3 code. It is non-weighted code used to express decimal numbers. The Excess-3 code words are derived from the 8421 BCD code words adding (0011)<sub>2</sub> or (3)<sub>10</sub> to each code word in 8421. The excess -3 codes are obtained as follows-

Decimal Number → 8421 BCD → Add 0011 → Excess -3

| Decimal | BCD<br>8 4 2 1 | Excess-3<br>BCD + 0011 |
|---------|----------------|------------------------|
| 0       | 0 0 0 0        | 0 0 1 1                |
| 1       | 0 0 0 1        | 0 1 0 0                |
| 2       | 0 0 1 0        | 0 1 0 1                |
| 3       | 0 0 1 1        | 0 1 1 0                |
| 4       | 0 1 0 0        | 0 1 1 1                |
| 5       | 0 1 0 1        | 1 0 0 0                |
| 6       | 0 1 1 0        | 1 0 0 1                |
| 7       | 0 1 1 1        | 1 0 1 0                |
| 8       | 1 0 0 0        | 1 0 1 1                |
| 9       | 1 0 0 1        | 1 1 0 0                |

**Gray code** : It is the non-weighted code and it is not arithmetic codes. That means there are no specific weights assigned to the bit position. It has a very special feature

that, only one bit will change each time the decimal number is incremented as shown in fig. As only one bit changes at a time, the gray code is called as a unit.

| Decimal | BCD     | Gray    |
|---------|---------|---------|
| 0       | 0 0 0 0 | 0 0 0 0 |
| 1       | 0 0 0 1 | 0 0 0 1 |
| 2       | 0 0 1 0 | 0 0 1 1 |
| 3       | 0 0 1 1 | 0 0 1 0 |
| 4       | 0 1 0 0 | 0 1 1 0 |
| 5       | 0 1 0 1 | 0 1 1 1 |
| 6       | 0 1 1 0 | 0 1 0 1 |
| 7       | 0 1 1 1 | 0 1 0 0 |
| 8       | 1 0 0 0 | 1 1 0 0 |
| 9       | 1 0 0 1 | 1 1 0 1 |

#### Application of gray code

- Gray code is popularly used in the shaft position encoders.
- A shaft position encoder produces a code word which represents the angular position of the shaft.

| Decimal | 0    | 1    | 2    | 3    | 4    | 5    | 6    | 7    | 8    | 9    |
|---------|------|------|------|------|------|------|------|------|------|------|
| BCD     | 0000 | 0001 | 0010 | 0011 | 0100 | 0101 | 0110 | 0111 | 1000 | 1001 |

#### Alphanumeric codes

A binary digit or bit can represent only two symbols as it has only two states '0' or '1'. But this is not enough for communication between two computers because there we need many more symbols for communication. These symbols are required to represent 26 alphabets with capital and small letters, number from 0 to 9, punctuation marks and other symbols.

The alphanumeric codes are the codes that represent numbers and alphabetic characters. Mostly such codes also represent other characters such as symbol and various instructions necessary for conveying information. An alphanumeric code should at least represent 10 digits and 26 letters of alphabet i.e total 36 items. The following three alphanumeric codes are very commonly used for the data representation.

**Binary Coded Decimal (BCD) code :** In this code each decimal digit is represented by a 4-bit binary number. BCD is a way to express each of the decimal digits with a binary code. In the BCD, with four bits we can represent sixteen numbers (0000 to 1111). But in BCD code only first ten of these are used (0000 to 1001). The remaining six code combinations i.e 1010 to 1111 are invalid in BCD.

#### Advantages of BCD codes

- It is very similar to decimal system.
- We need to remember binary equivalent of decimal numbers 0 to 9 only.

#### Disadvantages of BCD codes

- The addition and subtraction of BCD have different rules.
- The BCD arithmetic is little more complicated.
- BCD needs more number of bits than binary to represent the decimal number. So BCD is less efficient than binary.

- American Standard code for information Interchange (ASCII)
- Extended Binary coded decimal interchange code (EBCDIC)
- Five bit Baudot code

ASCII code is a 7-bit code whereas EBCDIC is an 8-bit code. ASCII code is more commonly used worldwide while EBCDIC is used primarily in large IBM computers.

#### Error codes

There are binary code techniques available to detect and correct data during data transmission.

| Error code                     | Description                                    |
|--------------------------------|------------------------------------------------|
| Error Detection and correction | Error detection and correction code techniques |

## Flip flop and its types

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

- explain RS flipflop and its truth table
- Explain JK flip flop and its truth table.

**Introduction :** A flip-flop is a digital circuit that has two stable states. It remains in one of these states until triggered into the other.

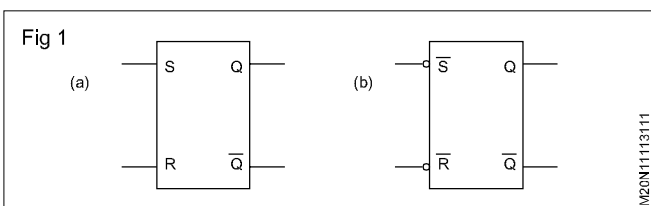
Flip-flops are used to store binary information. Digital memory circuits that can store bits of data are an essential part of any computer system.

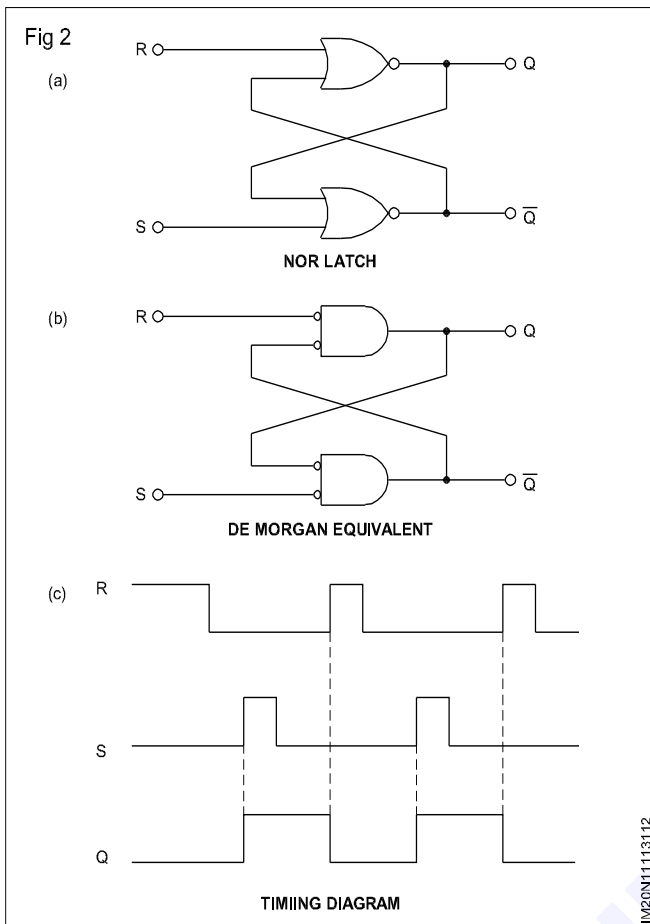
**RS flip flops :** The most basic type of flip flop is the reset/set type, hence it is known as RS flip flop.

The basic RS flip-flop can be constructed from either two NOR gates or two NAND gates. The circuit symbols is shown in Fig 1. Fig 1a shows RSF/F with active HIGH inputs. Fig 1b shows RSF/F with active LOW inputs. The

NOR gate latch and NAND gate latch both are shown in Fig 2 and Fig 3 respectively.

**NOR latch :** From Fig 2, the two NOR gates are cross-coupled so that out of one NOR gate is connected to other NOR gate input and vice versa.





Truth table for NOR latch

| R | S | Q  | Comment   |
|---|---|----|-----------|
| 0 | 0 | NC | No change |
| 0 | 1 | 1  | Set       |
| 1 | 0 | 0  | Reset     |
| 1 | 1 | *  | Race      |

Truth table for NAND latch

| R | S | Q  | Comment   |
|---|---|----|-----------|
| 0 | 0 | *  | Race      |
| 0 | 1 | 1  | Set       |
| 1 | 0 | 0  | Reset     |
| 1 | 1 | NC | No change |

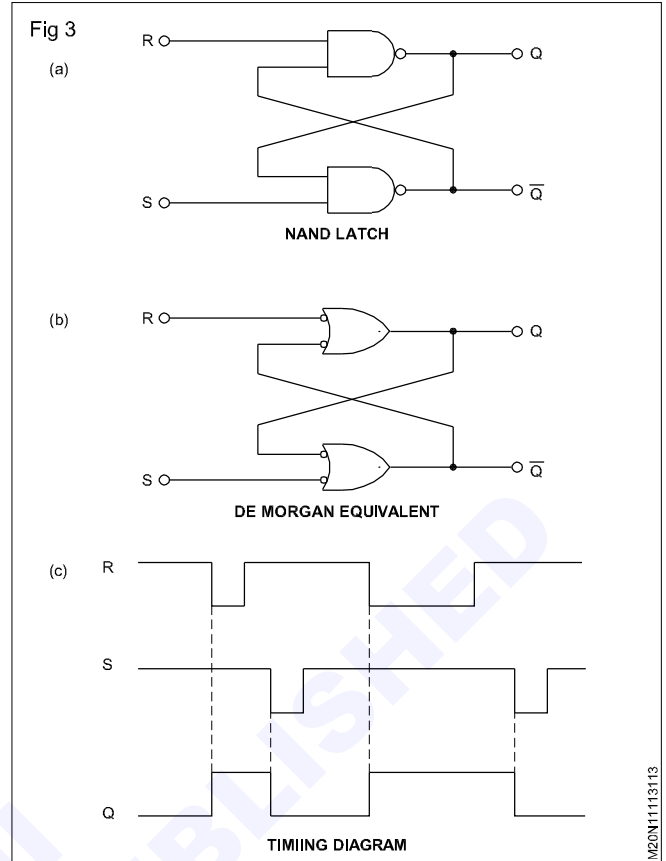
The NOR latch output are labelled as Q and  $\bar{Q}$ . The outputs will always be the inverse of each other. From the truth table of NOR latch, it can be summarised as follows.

#### Condition 1

$R=0$   $S=0$ , this condition produce the inactive state. Output 'Q' will remain with no change.

#### Condition 2

$R=0$   $S=1$ , this condition cause to go to the  $Q=1$  state where it always remain after R returns high. This is known as setting the latch.



#### Condition 3

$R=1$   $S=0$ , this condition cause to go to the  $Q=0$  state where the output remain even after S returns HIGH. This is called resetting the latch.

#### Condition 4

$R=1$   $S=1$ , this condition produce a race condition. Therefore avoid  $R=1$  and  $S=1$  condition while using a NOR latch.

#### NAND latch

From the NAND gate latch as shown in Fig 3. The two NAND gates are cross-coupled so that output of one NAND is connected to other NAND gate input and vice versa. The NAND latch outputs are labelled as Q and  $\bar{Q}$ . These outputs will always be the inverse of each other.

From the truth table, it can be summarized as follows.

#### Condition 1

$R=0$ ,  $S=0$ . This condition produce ambiguous results. It should not be used.

#### Condition 2

$R=0$ ,  $S=1$ . This condition cause the output to go the  $Q=1$  state where it will remain after R returns high. This is known as setting the latch.

#### Condition 3

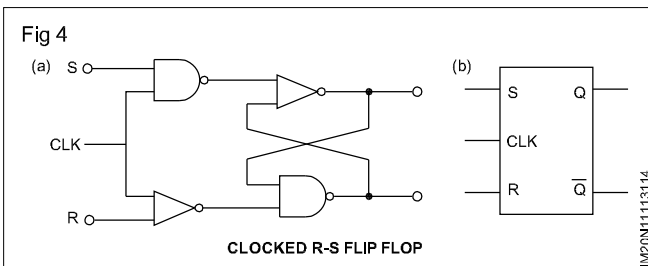
$R=1$ ,  $S=0$ . This condition cause the output to go the  $Q=0$  state, where the output will remain even after S returns HIGH. This is called clearing or resetting the latch.

#### Condition 4

$R=1, S=1$ . This condition is the normal resting state and it has no effect on the output state. The Q and  $\bar{Q}$  outputs will remain in whatever state they were prior to this input condition.

#### Clocked RS flip-flop

It is possible to strobe or clock the flip-flop in order to store information (set it or reset it) at any time, and then hold the stored information for any desired period of time. This flip-flop is called a clocked RS flip-flop and is shown in Fig 4a and the circuit symbol in 4b.



Truth Table

| Clock | R | S | Q       |
|-------|---|---|---------|
| 0     | 0 | 0 | NC      |
| 0     | 0 | 1 | NC      |
| 0     | 1 | 0 | NC      |
| 0     | 1 | 1 | NC      |
| 1     | 0 | 0 | NC      |
| 1     | 0 | 1 | 1       |
| 1     | 1 | 0 | 0       |
| 1     | 1 | 1 | Illegal |

For the flip-flop to operate properly there must be a transition from low to high on the clock input, while clock is high, the information on R and S causes the latch to set or reset. Then when clock transitions back to low, this information is retained in the latch. When this high to low transition occurred both R and S inputs were low(0) and thus there was no change of state.

#### D-flip-flop

The RS flip-flop has two data inputs, R and S. To store a high bit, you need a high S and to store a low bit, you need a high R. Generation of two signals to drive a flip-flop is a disadvantage in many applications. Further more the RS flip-flop is susceptible to a race condition. We will modify the design to eliminate the possibility of a race condition, to overcome the above disadvantage, R.S flip is slightly modified as shown in Fig 5 to have a single input called D-flip-flop.

Unclocked D latch

| D | Q |
|---|---|
| 0 | 0 |
| 1 | 1 |

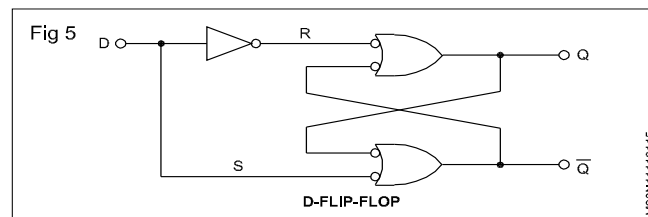
Clock D latch

| CLK | D | Q  |
|-----|---|----|
| 0   | X | NC |
| 1   | 0 | 0  |
| 1   | 1 | 1  |

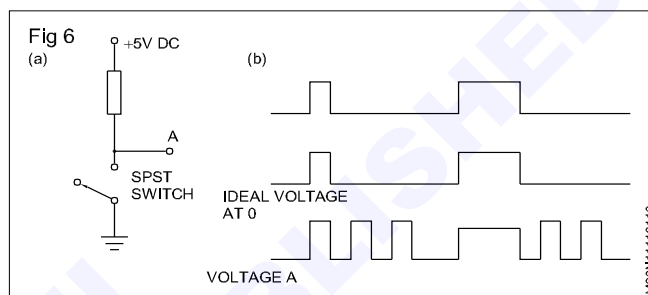
#### Contact bounce circuit

Any mechanical switching device consists of a moving contact arm restrained by some sort of spring system. As

a result when the arm is moved from one stable position to the other, the arm bounces as much as hard ball bounces when dropped on a hard surface. The number of bounces that occurs and the period of the bounce differ for each switching device.



In digital system there will be occasions to use mechanical contacts for the purpose of conveying an Electronics signal, for example the keyboard of computer. In each case the intent is to apply a high logic level usually [+5V dc] or a low logic level (0 volts DC).



As shown in the Fig 6 above, when the SPST switch is open, the voltage at point 'A' is +5V DC when the switch is closed the voltage at point 'A' is 0 volts.

Ideally the voltage waveform at 'A' should appear as shown in the waveform 6b as the switch is moved from open to closed, or vice-versa.

In actuality, the waveform at point 'A' will appear more or less as shown in waveform(C), as a result of contact bounce. Notice carefully that in this particular instance, even though actual physical contact bounce occurs each time the switch is opened or closed, contact bounce appears in the voltage level at point 'A' only when the switch is closed.

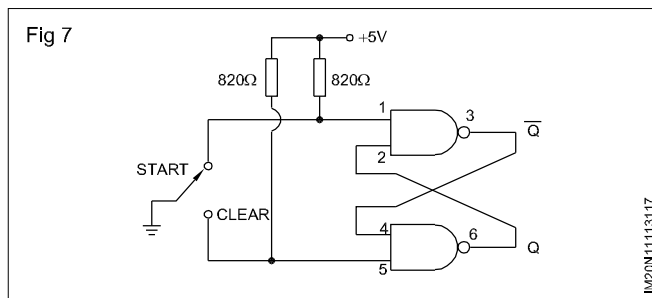
If the voltage at point 'A' is applied to the input of a T.T.L circuit, the circuit will respond properly when the switch is opened, since no contact bounce occurs. However when the switch is closed, the circuit will respond as if multiple signals were applied, rather than the single-switch closer-intended.

R.S.Latches are often used as switch debouncers. Whenever a switch is thrown from open to the closed position.

#### Bounce less switch

Floating T.T.L inputs are equivalent to high inputs. With the switch in the start position, Pin 1 is low and pin 5 is high therefore  $\bar{Q}$  (pin no.3) is high and Q (pin no.6) is low. When the switch is thrown to the clear position, pin no.1 goes high, as shown in Fig 7. Because of contact bounce, pin 5 goes alternately low and high for a few milliseconds before sets in the low state. The first time pin 5 goes low, the latch sets, Q going high and  $\bar{Q}$  going low. Subsequent bounces have no effect on Q and  $\bar{Q}$  because the latch stays set.

When the switch is thrown back to start, pin 1 bounces low and high for a while. The first time pin 1 goes low, Q goes to low and  $\bar{Q}$  going high, later bounces have no effect on Q and  $\bar{Q}$ .



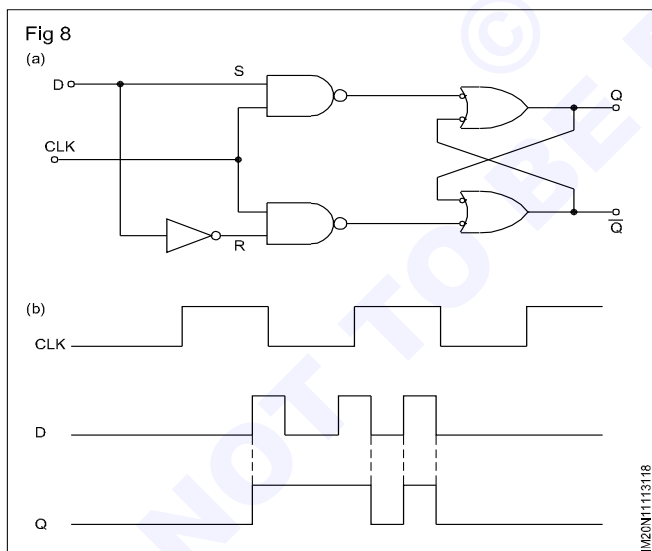
The Fig 8 shows one way to build a D latch because of the inverter databit 'D' drives the 'S' input of a NAND latch and the complement of D, drives the 'R' input. Therefore a high 'D' sets the flip-flop, low 'D' resets the flip-flop. Most important thing is no race condition.

Truth table for D-latch

| D | Q | Q |
|---|---|---|
| 1 | 1 | 0 |
| 0 | 0 | 1 |

### Clocked D-flip-flop

The Fig 8a shows the level clocked D type flip-flop. A low clock disables the input gates and prevents the latch from changing states, in other words, while clock is low, the latch is in the inactive state D controls the output, A high D sets the latch, while a low D resets it.



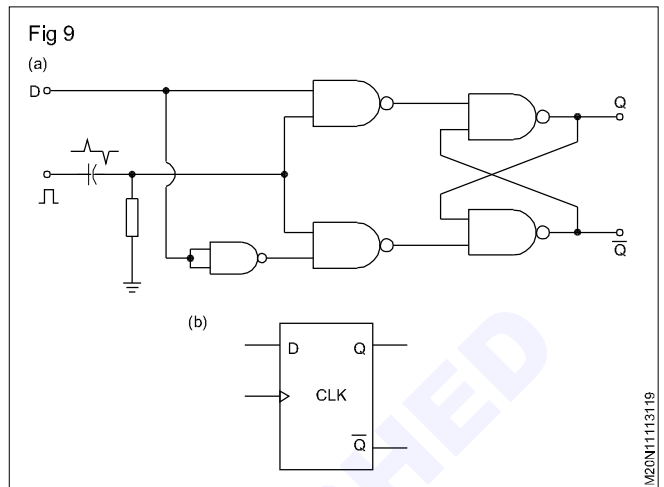
Truth table for level clocked D flip flop

| Clk | D | Q  |
|-----|---|----|
| 0   | X | NC |
| 1   | 0 | 0  |
| 1   | 1 | 1  |

The truth table summarizes the operation 'X' represents a don't care condition, it stands for either 0 or 1, while clock is low the output can't change, no matter what 'D' is, when clock is high, the output equals the input.  $Q = D$ .

### Edge triggering versus level clocking

When a circuit is edge triggered, the output can change only on the rising or falling edge of the clock. Edge triggered D - F/F using discrete gate is shown in Fig 9a and the circuit symbol is shown in Fig 9b.



When the circuit is level clocked, the output can change while the clock is high or low.

With the edge triggering, the output can change only at one instant during the clock cycle. With level clocking, the output can change during the entire period the level of the clock is maintained.

### Edge triggered D-flip-flops

Boolean algebra is convenient and systematic way of expressing and analysing the operation of logic circuits.

#### Truth table

#### Edge triggered D-Flip-flop

| CLK | D | Q  |
|-----|---|----|
| 0   | X | NC |
| 1   | X | NC |
| ↓   | X | NC |
| ↑   | 0 | 0  |
| ↑   | 1 | 1  |

#### Variable

A variable is a symbol (usually an Italic uppercase letter) used to represent a logical quantity. Any single variable can have a 1 or 0 value.

Ex: A,B,C,D or X,Y,Z etc

#### Complements

The complement is the inverse of a variable and is indicated by a bar over the variable.

Ex: The complement of A is  $\bar{A}$ , the complement of A is read as "A bar".

#### Literal

A literal is a variable or the complement of a variable.



## Boolean addition

$$0 + 0 = 0$$

$$0 + 1 = 1$$

$$1 + 0 = 1$$

$$1 + 1 = 0 \text{ with carry } 1$$

In Boolean algebra, a sum term is a sum of literals. In logic circuits, a sum term is produced by an OR operation with NAND operation involved.

$$\text{Ex: } A+B, A+\bar{B}, \bar{A}+B$$

A sum term is equal to 1 when one or more of the literals in the term are 1. A sum term is equal to 0 if and only if each of the literal is 0.

## Boolean multiplication

Boolean multiplication is equivalent to the AND operation and the basic rules are as follows.

$$0.0 = 0$$

$$1.0 = 0$$

$$0.1 = 0$$

$$1.1 = 1$$

In Boolean algebra a product term is the product of literals. In logic circuits a product term is produced by an AND operation with NO OR operations involved.

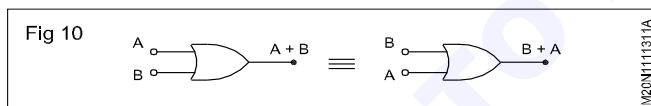
$$\text{Ex: } AB, \bar{A}B, A\bar{B}, \bar{A}\bar{B}$$

A product term is equal to 1 if and only if each of the literals in the term is one(1). A product term is equal to 0 when one or more of the literal are 0.

## Laws of Boolean algebra

### Commutative law

The commutative law for addition for two variables is written algebraically  $A + B = B + A$  as shown in Fig 10.



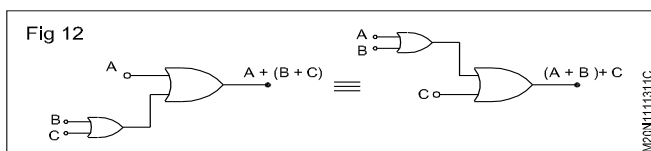
The commutative law for two variable multiplication is  $AB = BA$  as shown in Fig 11.



This law states that the order in which the variables are ORed/ANDed make no difference.

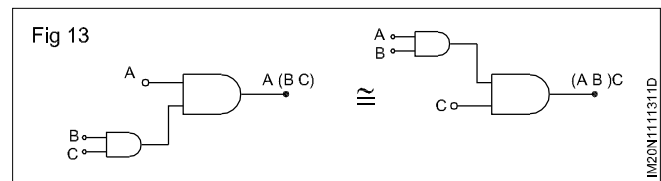
### Associative law

The associative law of addition is written algebraically as follows for three variables as shown in Fig 12.



$$A+(B+C) = (A+B)+C$$

The associative law of multiplication is written as follows for three variables Fig 13.



$$A(BC) = (AB)C$$

This law states that it makes no difference in what order the variables are grouped when ORing/ANDing more than two variables.

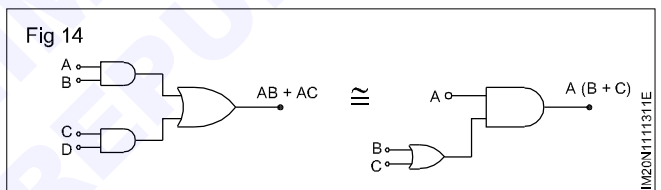
### Distributive law

The distributive law is written for three variables as follows.

$$A(B+C) = AB + AC$$

This law states that ORing two or more variables and ANDing the result with a single variable is equivalent to ANDing the single variable with each of the two or more variables and then ORing the products as shown in Fig 14. The distributive law also express the process of factoring in which the common variable 'A' is factored out of the product terms.

$$\text{Ex: } AB + AC = A(B+C)$$



## Boolean Algebra Rules

$$1 \quad A + 0 = A$$

$$2 \quad A + 1 = 1$$

$$3 \quad A + A = A$$

$$4 \quad A + \bar{A} = 1$$

$$5 \quad A + AB = A$$

$$6 \quad A + \bar{A}B = A + B$$

$$7 \quad A \cdot 0 = 0$$

$$8 \quad A \cdot 1 = A$$

$$9 \quad \bar{\bar{A}} = A$$

$$10 \quad A \cdot A = A$$

$$11 \quad A \cdot \bar{A} = 0$$

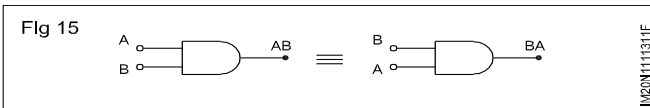
$$12 \quad (A + B)(A + C) = A + BC$$

## De-Morgans theorem

**Theorem I :** The complement of a product of variables is equal to the sum of the complements of the variables.

$$\overline{AB} = \bar{A} + \bar{B}$$

The complement of two or more variables ANDed is equivalent to the OR of the complements of the individual variables. The related figure is shown in Fig 15.

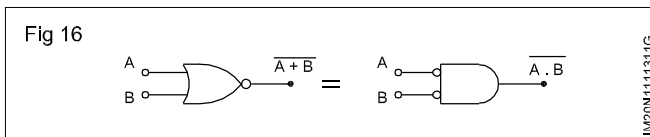


### Theorem II

The complement of a sum of variables is equal to the product of the complements of the variables.

$$\overline{A+B} = \overline{A} \cdot \overline{B}$$

The complement of two or more variables ORed is equivalent to the AND of the complements of the individual variables as shown in Fig 16.



### Simplify the equation using De-Morgan's theorem

$$1 \quad \overline{(A+B+C)D} = \overline{A+B+C} \cdot \overline{D} \quad (\overline{AB} = \overline{A} \cdot \overline{B})$$

$$= \overline{A} \cdot \overline{B} \cdot \overline{C} \cdot \overline{D} \quad (\overline{A+B} = \overline{A} \cdot \overline{B})$$

$$2 \quad \overline{ABC + DEF} = \overline{ABC} \cdot \overline{DEF} \quad (\overline{A+B} = \overline{A} \cdot \overline{B})$$

$$= (\overline{A} \cdot \overline{B} \cdot \overline{C}) \cdot (\overline{D} \cdot \overline{E} \cdot \overline{F})$$

### Simplification of Boolean equations

Prove that  $A + \overline{A}B = A + B$

LHS

$$= A + \overline{A}B$$

$$= (A + \overline{A}B) + \overline{A}B$$

$$= AA + \overline{A}B + \overline{A}B$$

$$= AA + \overline{A}B + \overline{A}B + 0$$

$$= AA + \overline{A}B + \overline{A}B + A\overline{A}$$

$$= A(A+B) + \overline{A}(B+A)$$

$$= (A + \overline{A})(A+B)$$

$$= 1 \cdot (A+B)$$

$$= A+B$$

Prove that  $(A+B)(A+C) = A + BC$

$$\text{LHS} = (A+B)(A+C)$$

$$= AA + AB + AC + BC$$

$$= A + AC + AB + BC$$

$$= A(1+C) + AB + BC$$

$$= A + AB + BC$$

$$= A(1+B) + BC$$

$$= A + BC$$

### Simplification of logic circuit using Boolean Equation

$$AB + A(B+C) + B(B+C)$$

#### I step: Simplify the Boolean equations

$$AB + AB + AC + BB + BC \quad (\text{Distributive law})$$

$$AB + AC + B + BC \quad \text{Since } BB=B$$

$$AB + B + AC \quad (A + A = A, A \cdot A = A)$$

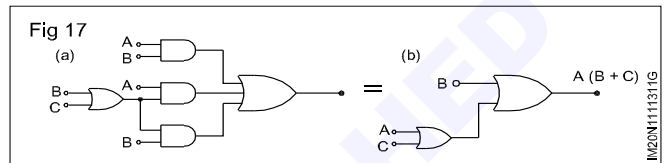
$$B(A + 1) + AC \quad (1 + A = 1)$$

$$B + AC$$

#### II step write logic diagram for the equations

$$AB + A(B+C) + B(B+C) = B + AC$$

Circuit before simplification is shown in Fig 17a. Circuit after simplification is shown in Fig 17b.



The above logic diagram and corresponding Boolean equations show how one can use Boolean Algebra for simplification of logic circuits for the desired logic output.

From the above example it is proved that how the logic circuit gates can be reduced for the same set of output result, using Boolean Algebra. The reduced logic circuit consumes less power and propagation delay time is also reduced, in other words the speed of the circuit increases.

Example

2 Simplify the Boolean expression, and write logic diagram for the given equation and for simplified equation.

$$\overline{A}BC + A\overline{B}\overline{C} + \overline{A}\overline{B}\overline{C} + A\overline{B}C + ABC$$

$$\overline{A}BC + \overline{B}\overline{C}(A + \overline{A}) + AC(\overline{B} + B)$$

$$\overline{A}BC + \overline{B}\overline{C} + AC$$

$$\overline{A}BC + AC + \overline{B}\overline{C}$$

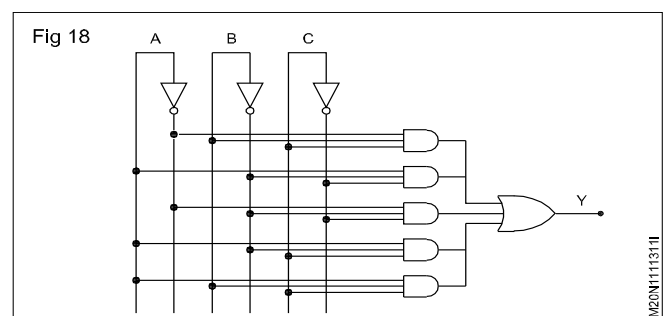
$$C(A + \overline{A}B) + \overline{B}\overline{C}$$

$$C(A+B) + \overline{B}\overline{C}$$

$$AC + BC + \overline{B}\overline{C}$$

$$\overline{A}BC + A\overline{B}\overline{C} + \overline{A}\overline{B}\overline{C} + A\overline{B}C + ABC = Y$$

Logic diagram for the given equation is shown in Fig 18.



## J K Flip-flop circuits

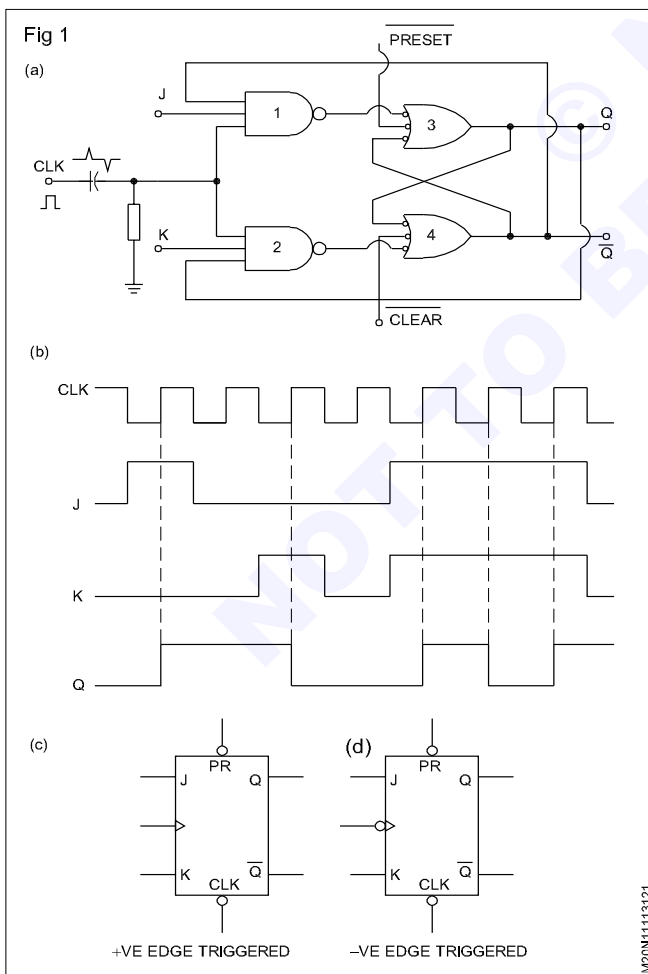
**Objectives:** At the end of this lesson you shall be able to

- explain construction of JK flip-flop using NAND gates
- state the function of Preset and clear inputs
- define the meaning active low and active high
- explain the working function of JK master slave flip-flop
- explain frequency division using flip flops.

### Operation of J-K flip flop

| Truth table |   |   |        |        |
|-------------|---|---|--------|--------|
| CLK         | J | K | Q      |        |
| 0           | x | x | NC     |        |
| ↓           | x | x | NC     |        |
| ↓           | x | x | NC     |        |
| x           | 0 | 0 | NC     |        |
| ↑           | 0 | 1 | 0      | Reset  |
| ↑           | 1 | 0 | 1      | Set    |
| ↑           | 1 | 1 | Toggle | Toggle |

The Fig 1 shows one way to build a JK flip-flop. The variables J and K are called control inputs. An R.C circuit with a short time constant, converts the rectangular clock pulse to narrow spikes. Because of the double inversion through the NAND gates, the circuit is +ve edge triggered. In other words, the input gates are enabled only on the rising edge of the clock as shown in truth table.



### Reset

When J is low and K is high the upper output gate is disabled. So there is no way to set the flip flop. The only possibility is reset. When Q is high, the lower gate passes a reset trigger as soon as the +ve clock edge arrives. This forces Q to become low. Therefore J=0 and k=1 means that a rising clock edge resets the flip-flop.

### Set

When J is high and K is low, the lower output gate is disabled. So it is impossible to reset the flip-flop. But flip-flop can be set, when Q is low, Q is high, the gate 1 passes a set trigger on the positive clock edge. This drives Q into the high state. That is J=1 and K=0 means that the next positive clock edge sets the flip flop.

### Toggle

When J and K are both high, it is possible to set or reset the flip flop depending on the current state of the output if Q is high, the lower gate passes a reset trigger on the next positive clock edge on the other hand. When Q is low the upper gate passes a set trigger on the next positive clock edge. Either way Q changes to the complement of the last state. Therefore J=1 and K=1 means that the flip-flop will toggle on the next positive clock edge.

To summarize the operation of the JK flip-flop, the circuit is inactive when the clock is low, high or on its -ve edge. Likewise the circuit is inactive when J and K are both low. Output changes occur only on the rising edge of the clock as indicated by the last three entries of the table. The o/p either resets, sets or toggles.

### Racing

Toggling more than once during a clock cycle is called Racing. Assume that the circuit is level clocked. In other words, assume that RC circuit has been removed and run the clock straight, into the gates, with a high J, high K and high clock, the output toggles. New outputs are then fed

Toggling more than once during a clock cycle is called Racing. Assume that the circuit is level clocked. In other words, assume that RC circuit has been removed and run the clock straight, into the gates, with a high J, high K and high clock, the output toggles. New outputs are then fed back to the input gates. After two propagation times (input and output gates), the output toggles again. And once more new outputs return to the input gates. In this way the output can toggle repeatedly as long as the clock is high.

To overcome this racing problem, JK master slave flip-flop has been developed.

## Clear

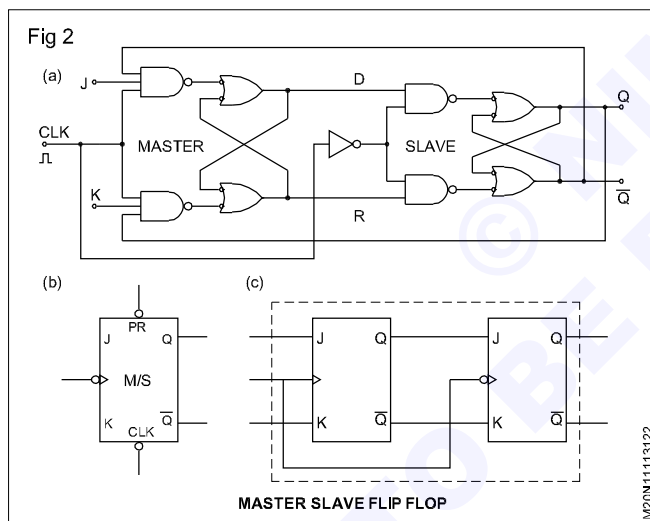
When power is first applied, flip-flops come up in random states. To get some computers started, an operator has to push a master reset button, this sends a clear (reset) signal to all flip-flops, normally clear signal will be active low, (i.e) logic zero should be applied for clear the output. When clear is applied to gate-4 as shown in Fig 1a then the Q will be forced to Logic-0, then automatically  $\bar{Q}$  will go to logic-1 condition. This signal, J and K signals have no control over output Q, when clear is set.

## Pre-set

Like clear preset is an active low input. This input also independent of CLK, J & K inputs. When preset is made logic-0, the output Q is set to logic one. It is necessary in some digital system to preset the output before the system actually runs.

## Master Slave Flip-flop

The Fig 2 shows the JK.Master Slave Flip-flop. It provides another way to avoid racing. A master slave flip-flop is a combination of two clocked flip-flops connected in cascade. Master flip-flop is positive edge triggered, slave flip-flop is negative edge-triggered flip-flop.



- While the clock is high, the master is active and the slave is inactive.
- While the clock is low, the master is inactive and the slave is active.

The J.K master slave flip-flop is used as the main counting device. The popular IC 54LS/74LS76 is a dual JK master slave flip-flop.

Look at the Summarized truth table of J.K master slave flip-flop. A low PR and LOW CLR produces a race condition therefore, PR and CLR are normally kept at a high voltage when inactive. To clear, the flip flop make clear low, to preset the F/F make preset low.

Truth table for positive edge triggered JK flip flop

| PR | CLR | CLK | J | K | Q      |
|----|-----|-----|---|---|--------|
| 0  | 0   | X   | X | X | Race   |
| 0  | 1   | X   | X | X | 1      |
| 1  | 0   | X   | X | X | 0      |
| 1  | 1   | X   | 0 | 0 | NC     |
| 1  | 1   | ↑   | 0 | 1 | 0      |
| 1  | 1   | ↑   | 1 | 0 | 1      |
| 1  | 1   | ↑   | 1 | 1 | Toggle |

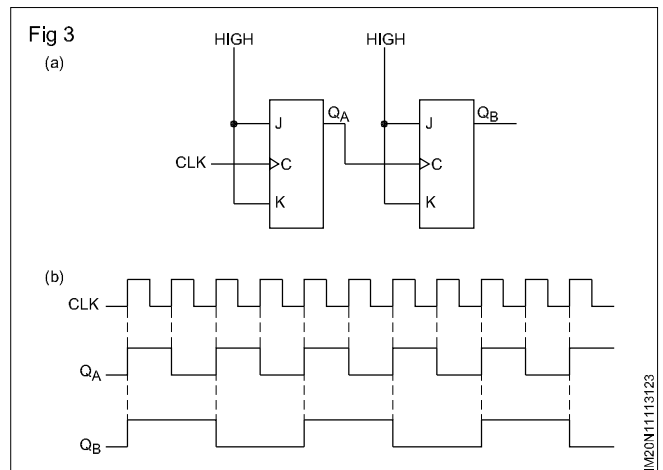
Low J & Low K produces an inactive state regardless of the what the clock is doing. If K goes high by itself, the next clock pulse resets the flip-flop. If J goes high by itself, the next clock pulse sets the flip-flop when J & K are both high, each clock pulse toggle the state of flip flop.

## Frequency division using flip flops

Flip-flops are used as frequency dividers of a periodic waveform. When a pulse waveform is applied to the clock input of a J.K flip-flop which is wired for toggle operation, provides square wave output with one half the frequency of the clock input. Thus a single flip-flop can be used for divide by -2 operation as illustrated in Fig 3. The flip-flop changes state on each triggering clock edge. This results in an output which is at half the frequency of the clock waveform.

Further division of clock frequency can be achieved by using the output of one flip-flop as the clock input to a second flip-flop as shown in Fig 3. The frequency of the QA output is divided by 2 by flip-flop B. The QB output is therefore, one fourth the frequency of the original clock input.

By connecting flip-flops in this way, a frequency division of  $2^n$  is achieved, where n is the number of flip-flops. For example, three flip-flops divide the clock frequency by  $2^3 = 8$ . Four flip-flops divide the clock frequency by  $2^4 = 16$ ; and so on.



# Counter Circuits

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

- state basic types of counters
- explain the circuit of a ripple counter
- explain a down counter using J-K Flip Flops
- explain synchronous and asynchronous decade counters
- explain module 10 and module 12 counter circuits.

## Counter

A counter is one of the most useful and versatile subsystems in a digital system. A counter driven by a clock can be used to count the number of clock cycles. Since the clock pulses occur at known intervals, the counter can be used as an instrument for measuring time and therefore period or frequency.

Basically there are two types of counters

- 1 Synchronous counter
- 2 Asynchronous counter

### Synchronous counter

In this counter every flip-flop is triggered by the clock parallelly (synchronously) and thus settling time is simply equal to the delay time of a single flip-flop. The increase in speed is usually obtained at the price of increased hardware.

### Asynchronous counter

Asynchronous counters are simple and straight forward in operation and construction and usually requires a minimum of hardware, however have a speed limitation. Each flip-flop is triggered by the previous flip-flop, [i.e., clock is applied serially] and thus the counter has a cumulative settling time. Counters such as these are also called as serial counters or ripple counters.

Serial and parallel counters are used in combination to compromise between speed of operation and hardware count. Serial, parallel or combination counters can be designed such that each clock pulse advances the contents of the counter by one, it is then operating in a count-up mode. The opposite is also possible; the counter then operates in the count-down mode. Furthermore, many counters can be either 'cleared' so that every flip-flop contains a zero, or preset such that the contents of the flip-flops represent any desired binary number.

### Ripple counter

The Fig 1a shows a counter built with JK flip-flops since the J&K inputs are tied to a high voltage, each flip-flop will toggle, when its clock input receives a negative edge.

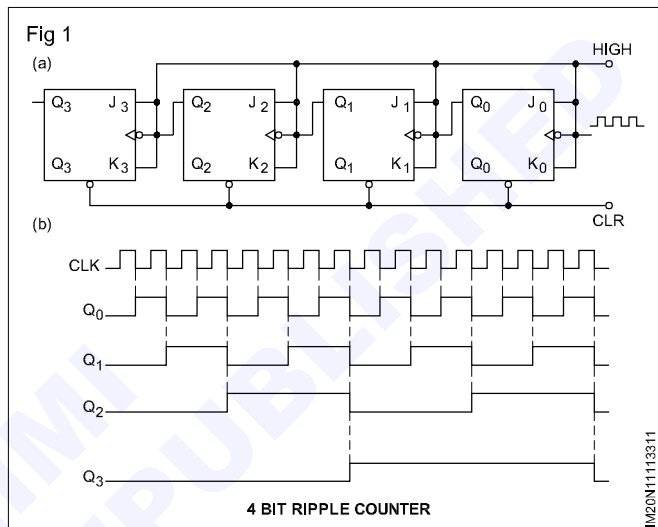
Visualize the Q outputs as a binary word.

$$Q = Q_3 Q_2 Q_1 Q_0$$

$Q_3$  is the most significant bit (MSB) and  $Q_0$  is the least significant bit (LSB). When CLR goes low, all flip-flops reset, this results in a digital word of  $Q = 0000$ .

When clear returns to high, the counter is ready to go, since the LSB flip-flop receives each clock pulse,  $Q_0$  toggles once per negative clock edge, as shown in Fig 1b.

The remaining flip-flops toggle less often because they receive their negative edges from the preceding flip-flop outputs ( $Q$ ). The triggers move through the flip-flops like a ripple in water, that is why this type of counter is called ripple counter.



### Counting sequence

When CLR goes from low to high, the Q output of all flip-flops become zeroes.

$$Q = Q_3 Q_2 Q_1 Q_0$$

$$Q = 0000$$

When the first clock pulse triggered the LSB flip-flop, its output  $Q_0$  becomes 1, so the first output word is  $Q = 0001$ .

When the second clock pulse arrives,  $Q_0$  resets to zero, and this negative falling edge sets next flip-flop output  $Q_1$  to 1 as shown in the timing diagram. Therefore, the next output word is  $Q = 0010$ .

The third clock pulse advances  $Q_0$  to 1, at this stage  $Q_0$  is having +ve rising edge, so  $Q_1$  output will not change then the counter output is  $Q = 0011$ .

The fourth clock pulse forces the  $Q_0$  flip-flop to reset and carry. In turn, the  $Q_1$  flip-flop resets and carry, in turn, the  $Q_2$  flip-flop resets and carry.

The resulting output word is  $Q = 0100$ .

The fifth clock pulse gives  $Q = 0101$ .

The sixth clock pulse gives  $Q = 0110$ .

and the seventh pulse gives  $Q = 0111$ .

ON the eighth clock pulse  $Q_0$  resets and carrier,  $Q_1$  resets and carrier,  $Q_2$  resets and carry, and  $Q_3$  advances to 1. So the output word becomes  $Q = 1000$ .



The ninth clock pulses gives  $Q = 1001$ .

The tenth gives  $Q = 1010$  and so on

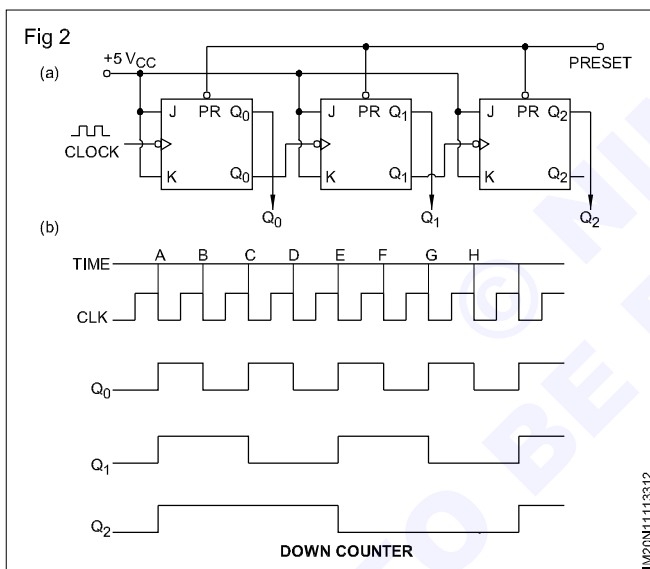
at the 15th clock pulse  $Q = 1111$

The 16th clock pulse resets all flip-flops. Therefore the counter resets to  $Q = 0000$  and the cycle repeats.

By adding more flip-flops to the left end of the counter circuit, the counter length can be extended. Eight flip-flops gives an 8 bit ripple counter, twelve flip-flops result in a 12 bit ripple counter and so on. The timing diagram is shown in Fig 1b.

### Down counter

The counter discussed above is an up counter, counts from 0 to 15 [0000 to 1111]. If a counter counts from 1111 to 0000 then it is called DOWN counter. In a down counter  $Q$  output as shown in Fig 2 is connected to the clock input of the next flip-flop. Each flip-flop toggles when its clock input goes from 1 to 0. Flip flop  $Q_0$  toggles with each negative clock transition as before. But flip flop  $Q_1$  will toggle each time  $Q_0$  goes high. Notice that each time  $Q_0$  goes high,  $Q_0$  goes low, and it is this negative transition on  $Q_0$  that triggers  $Q_1$ . The timing diagram is in Fig 2b.



A low preset signal sets all output, producing an output word of  $Q = 1111$ .

When pre goes high, the action starts.

The first clock pulse produces a negative toggle in  $Q_0$ , nothing else happens.  $Q = 1110$

The second clock pulse produces a positive toggle in  $Q_0$ , which produces a negative toggle in  $Q_1$ .  $Q = 1101$

On the third clock pulse  $Q_0$  toggles negatively and  $Q = 1100$

On the fourth clock pulse,  $Q_0$  toggles positively  $Q_1$  toggles positively and  $Q_2$  toggles negatively.  $Q = 1011$ .

Likewise counting down from 15-0 takes place, when count reaches 0, i.e.  $Q=0000$ , on the next clock pulse, all flip-flops toggles positively to get  $Q=1111$  and the cycle repeats.

## Modulo -10 Counter

### Asynchronous Decade counters

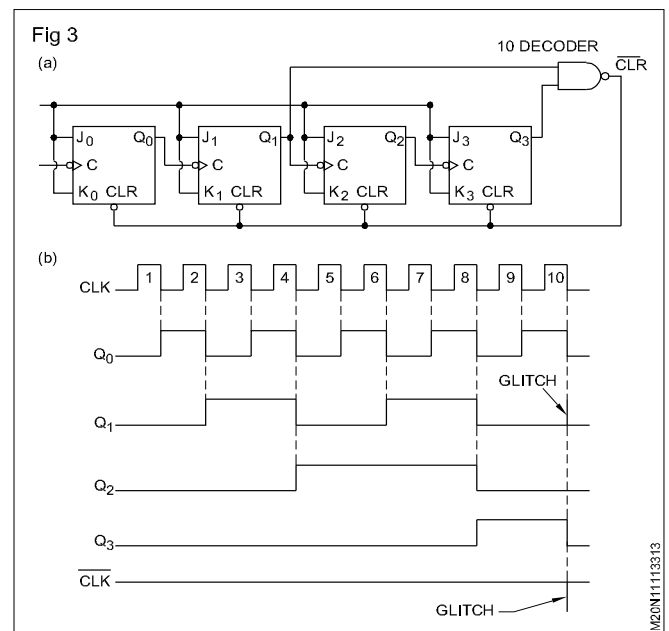
Regular binary counters have a maximum modulus, which means they progress through all of their possible states. The maximum possible number of states (maximum modulus) of a counter is  $2^n$ , where  $n$  is the number of flip-flops in the counter.

Counters can also be designed to have a number of states in their sequence that is less than the maximum of  $2^n$ . The resulting sequence is called a truncated sequence.

One common modulus for counters with truncated sequence is ten. Counters with ten states in their sequence (modulus-10) are called decade counters. A decade counter with a count sequence of zero (0000) through nine (1001) is a BCD decade counter because its ten-state sequence is the BCD code. This type of counter is useful in display applications in which BCD is required for conversion to a decimal readout.

To obtain a truncated sequence, it is necessary to force the counter to recycle before going through all of its normal states. For example, the BCD decade counter must recycle back to the 0000 state after the 1001 state. A decade counter requires four flip-flops (three flip-flops are insufficient because  $2^3 = 8$ ).

We will use a 4-bit asynchronous counter such as the one in Fig 3 and modify its sequence to illustrate the principle of truncated counters. One way to make the counter recycle after the count of nine (1001) is to decode count ten (1010) with a NAND gate and connect the output of the NAND gate to the clear ( $\overline{CLR}$ ) inputs of the flip-flops, as shown in Fig 3.

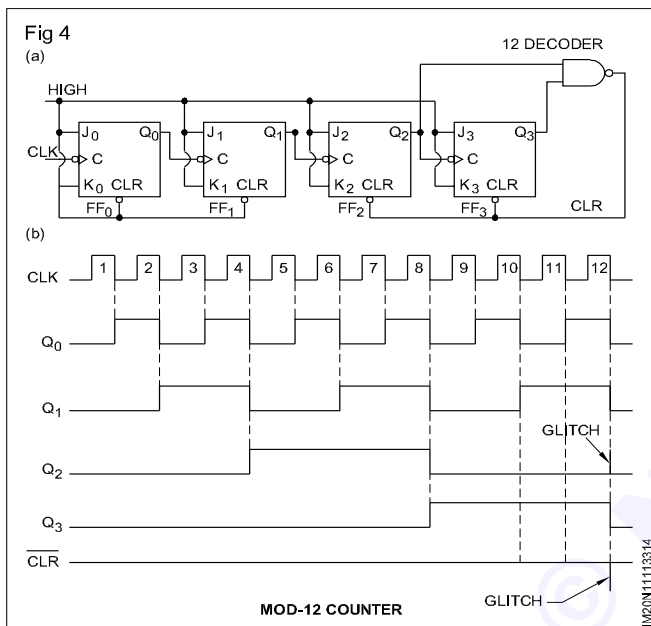


Notice in Fig 3 that only  $Q_1$  and  $Q_3$  are connected to the NAND gate inputs. This arrangement is an example of partial decoding, in which the two unique states ( $Q_1=1$  and  $Q_3=1$ ) are sufficient to decode the count of ten, because none of the other states (zero through nine) have both  $Q_1$

and  $Q_3$  HIGH at the same time. When the counter goes into count ten (1010), the decoding gate output goes LOW and asynchronously resets all the flip-flops.

The resulting timing diagram is shown in Fig 3. Notice that there is a glitch on the  $Q_1$  waveform. The reason for this glitch is that  $Q_1$  must first go HIGH before the count of ten can be decoded. Not until several nanoseconds after the counter goes to the count of ten does the output of the decoding gate go LOW (both inputs are HIGH). Thus, the counter is in the 1010 state for a short time before it is reset to 0000, thus producing the glitch on  $Q_1$  and the resulting glitch on the CLR line which resets the counter.

Other truncated sequences can be implemented in a similar way.



## Modulo-12 counter

An asynchronous counter can be implemented having a modulus of twelve with a straight binary sequence from 0000 through 1011 as shown in Fig 4a.

Since three flip-flops can produce a maximum of eight states, four flip-flops are required to produce any modulus greater than eight but less than or equal to sixteen.

When the counter gets to its last state, 1011, it must recycle back to 0000 rather than going to its normal next state of 1100, as illustrated in the following sequence chart:

| $Q_3$ | $Q_2$ | $Q_1$ | $Q_0$ |
|-------|-------|-------|-------|
| 0     | 0     | 0     | 0     |
| .     | .     | .     | .     |
| .     | .     | .     | .     |
| .     | .     | .     | .     |
| 1     | 0     | 1     | 1     |
| 1     | 1     | 0     | 0     |

Recycles

Normal next state

Observe that  $Q_0$  and  $Q_1$  both go to 0 anyway, but  $Q_2$  and  $Q_3$  must be forced to 0 on the twelfth clock pulse. Fig 4a shows the modulus-12 counter. The NAND gate partially decodes count twelve (1100) and resets flip-flop 2 and flip-flop 3. Thus, on the twelfth clock pulse, the counter is forced to recycle from count eleven to count zero, as shown in the timing diagram of Fig 4b. (It is in count twelve for only a few nanoseconds before it is reset by the glitch on CLR)

## Up/down Counters

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

- explain the basic operation of an up/down counter
- explain the 74LS190 up/down decade counter.

### UP/DOWN SYNCHRONOUS COUNTERS

An up/down counter is one that is capable of progressing in either direction through a certain sequence. An up/down counter, sometimes called a bidirectional counter, can have any specified sequence of states. A 3-bit binary counter that advances upward through its sequence (0,1,2,3,4,5,6,7) and then can be reversed so that it goes through the sequence in the opposite direction (7,6,5,4,3,2,1,0) is an illustration of up/down sequential operation.

In general, most up/down counters can be reversed at any point in their sequence. For instance, the 3-bit binary counter can be made to go through the following sequence:

|                                                      |      |
|------------------------------------------------------|------|
| UP                                                   | UP   |
| 0, 1, 2, 3, 4, 5, 4, 3, 2, 3, 4, 5, 6, 7, 6, 5, etc. | DOWN |
|                                                      | DOWN |

Table 1 shows the complete up/down sequence for a 3-bit binary counter. The arrows indicate the state-to-state

movement of the counter for both its UP and its DOWN modes of operation. An examination of  $Q_0$  of Fig 1 for both the up and down sequences shows that  $FF_0$  toggles on each clock pulse. So the  $J_0$  and  $K_0$  inputs of  $FF_0$  are

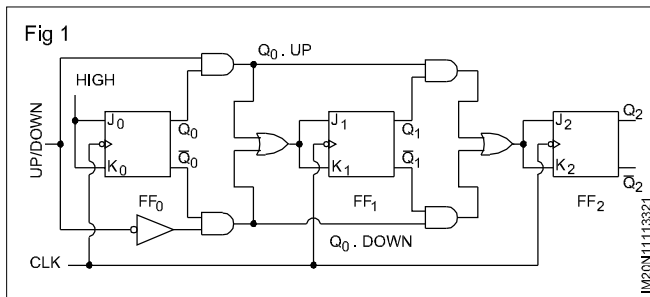
$$J_0 = K_0 = 1$$

For the up sequence,  $Q_1$  changes state on the next clock pulse when  $Q_0 = 1$ . For the down sequence,  $Q_1$  changes on the next clock pulse when  $Q_0 = 0$ . Thus, the  $J_1$  and  $K_1$  inputs of  $FF_1$  must equal 1 under the conditions expressed by the following equation:

$$J_1 = K_1 = (Q_0 \cdot \text{UP}) + (Q_0 \cdot \text{DOWN})$$

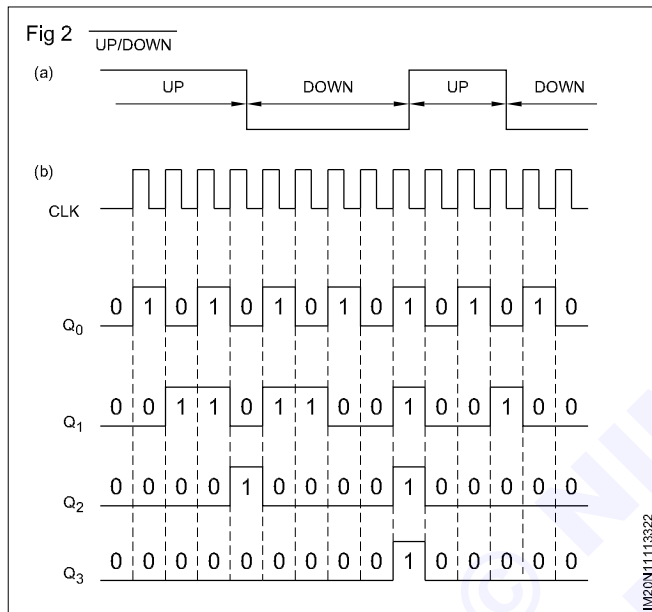
For the up sequence,  $Q_2$  changes state on the next clock pulse when  $Q_0 = Q_1 = 1$ . For the down sequence,  $Q_2$  changes on the next clock pulse when  $Q_0 = Q_1 = 0$ . Thus, the  $J_2$  and  $K_2$  inputs of  $FF_2$  must equal 1 under the conditions expressed by the following equation:

$$J_2 = K_2 = (Q_0 \cdot Q_1 \cdot \text{UP}) + (Q_0 \cdot Q_1 \cdot \text{DOWN})$$



Each of the conditions for the J and K inputs of each flip-flop produces a toggle at the appropriate point in the counter sequence.

### A synchronous 4-bit binary up/down counter



A timing diagram and the sequence of a synchronous 4-bit binary up/down counter if the clock and UP/DOWN control inputs have waveforms as shown in Fig 2. The counter starts in the all 0s state and is positive edge-triggered.

Table 1

Up/Down sequence for a 3-bit binary counter

| Clock pulse | UP | Q <sub>2</sub> | Q <sub>1</sub> | Q <sub>0</sub> | Down |
|-------------|----|----------------|----------------|----------------|------|
| 0           | →  | 0              | 0              | 0              | ↘    |
| 1           | ↘  | 0              | 0              | 1              | ↘    |
| 2           | ↘  | 0              | 1              | 0              | ↘    |
| 3           | ↘  | 0              | 1              | 1              | ↘    |
| 4           | ↘  | 1              | 0              | 0              | ↘    |
| 5           | ↘  | 1              | 0              | 1              | ↘    |
| 6           | ↘  | 1              | 1              | 0              | ↘    |
| 7           | ↘  | 1              | 1              | 1              | ↘    |

The timing diagram showing the Q outputs is shown in Fig 2b. From these waveforms, the counter sequence is as shown in Table 2.

Table 2

| Q <sub>3</sub> | Q <sub>2</sub> | Q <sub>1</sub> | Q <sub>0</sub> | Operation |
|----------------|----------------|----------------|----------------|-----------|
| 0              | 0              | 0              | 0              | UP        |
| 0              | 0              | 0              | 1              |           |
| 0              | 0              | 1              | 0              |           |
| 0              | 0              | 1              | 1              |           |
| 0              | 1              | 0              | 0              | DOWN      |
| 0              | 0              | 1              | 1              |           |
| 0              | 0              | 1              | 0              |           |
| 0              | 0              | 0              | 1              |           |
| 0              | 0              | 0              | 0              | UP        |
| 1              | 1              | 1              | 1              |           |
| 0              | 0              | 0              | 0              |           |
| 0              | 0              | 0              | 1              |           |
| 0              | 0              | 1              | 0              | DOWN      |
| 0              | 0              | 0              | 1              |           |
| 0              | 0              | 0              | 0              |           |
| 0              | 0              | 0              | 0              |           |

### The 74LS190 Up/down decade counter

Fig 3 shows a logic diagram for the 74LS190, a good example of an integrated circuit up/down counter. The direction of the count is determined by the level of the up/down input ( $D/\overline{U}$ ). When this input is HIGH, the counter counts down; when it is LOW, the counter counts up. Also, this device can be preset to any desired BCD digit as determined by the states of the data inputs when the LOAD input is LOW.

The MAX/MIN output produces a HIGH pulse when the terminal count nine (1001) is reached in the UP mode or when the terminal count zero (0000) is reached in the DOWN mode. This MAX/MIN output, along with the ripple clock output ( $\overline{RCO}$ ) and the count enable input ( $\overline{CTEN}$ ) is used when cascading counters.

Fig 4 is an example timing diagram showing the 74LS190 counter preset to seven (0111) and then going through a count-up sequence followed by a count-down sequence. The MAX/MIN output is HIGH when the counter is in either the all-0s state (MIN) or the 1001 state (MAX).

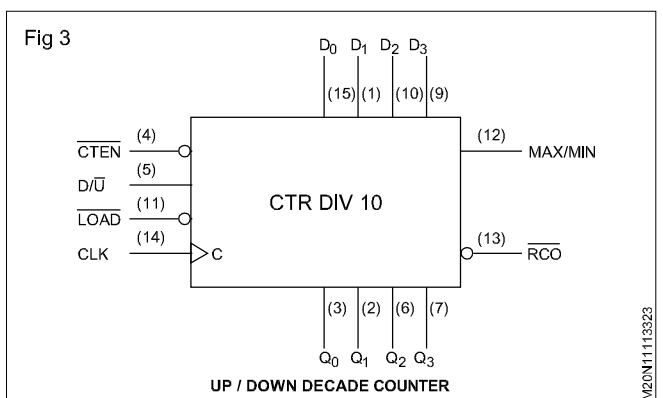
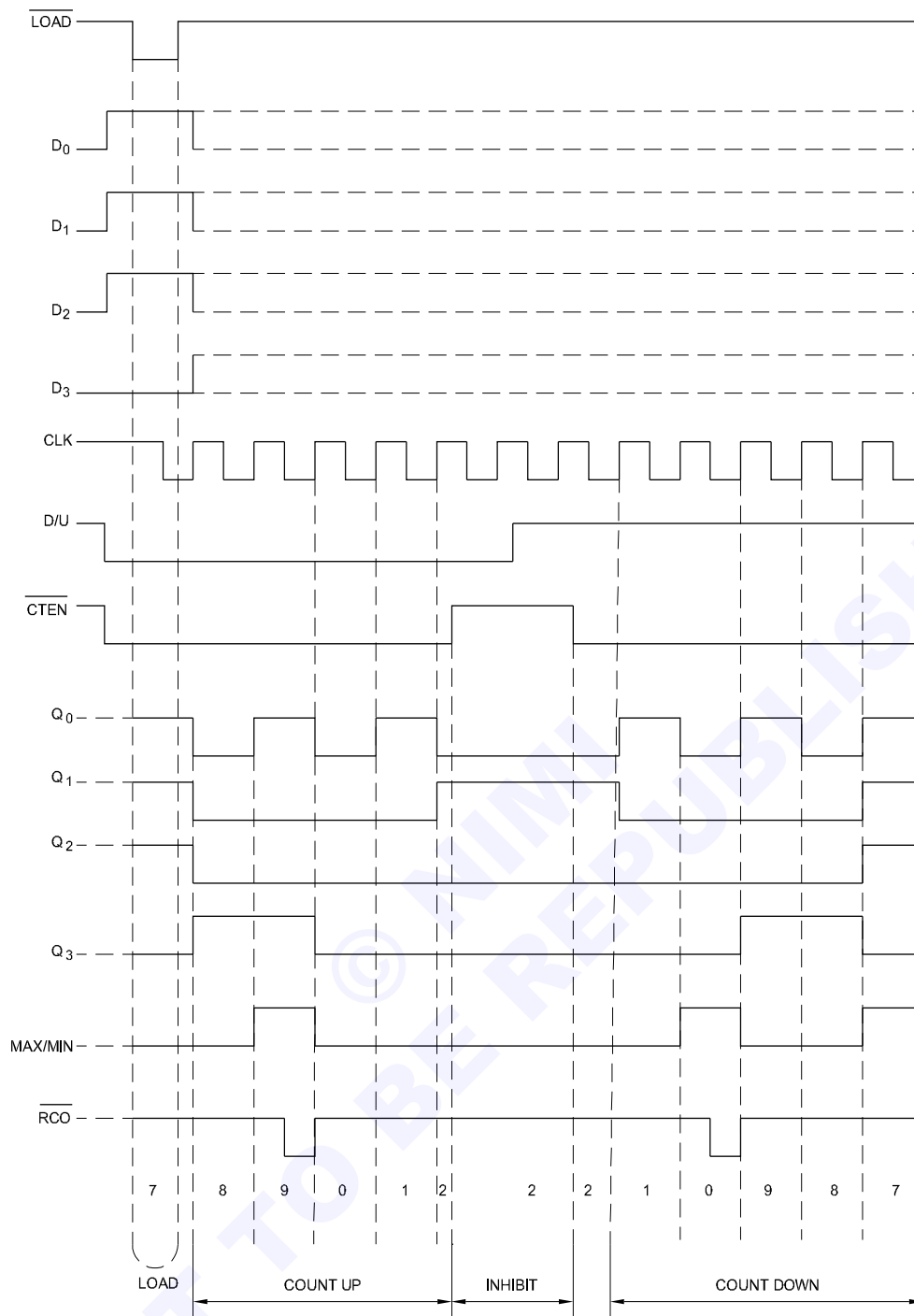


Fig 4



TIMING DIAGRAM OF 74LS190

IM20N1113324

## Shift Registers and their Applications

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

- state the basic functions of a shift register
- list and define the different configurations of shift register
- explain the function of IC7495 in different configurations.

### Introduction to shift registers

A shift register is a very important digital building block. Registers are often used to momentarily store binary information appearing at the output of an encoding matrix. A register might be used to accept input data from an

alphanumeric keyboard and then present this data at the input of a microprocessor chip. Similarly, shift registers are often used to momentarily store binary data at the output of a decoder. For instance, a register could be used to accept output data from a microprocessor chip and then

present this data to the circuitry used to drive the display on a CRT screen. Thus registers form a very important link between the main digital system and the input-output channels.

A binary register also forms the basis for some very important arithmetic operations. For example, the operations of complementation, multiplication, and division are frequently implemented by means of a register. A shift register can also be connected to form a number of different types of counters. These counters offer some very distinct advantages.

### Types of registers

A register is simply a group of flip-flops that can be used to store a binary number. There must be one flip-flop for each bit in the binary number. For instance, a register used to store an 8-bit binary number must have eight flip-flops. Naturally the flip-flops must be connected such that the binary number can be entered (shifted) into the register and possibly shifted out. A group of flip-flops connected to provide either or both of these functions is called a shift register.

The bits in a binary number (let's call them the data) can be moved from one place to another in either of two ways. The first method involves shifting the data 1 bit at a time in a serial fashion, beginning with either the MSB or the LSB. This technique is referred to as serial shifting. The second method involves shifting all the data bits simultaneously and is referred to as parallel shifting.

There are two ways to shift data into a register (serial or parallel) and similarly two ways to shift the data out of the register. This leads to the construction of four basic register types as shown in Fig 1 -serial in - serial out, serial in - parallel out, parallel in - serial out, and parallel in - parallel out. All of these configurations are commercially available as TTL MSI/LSI circuits. For instance:

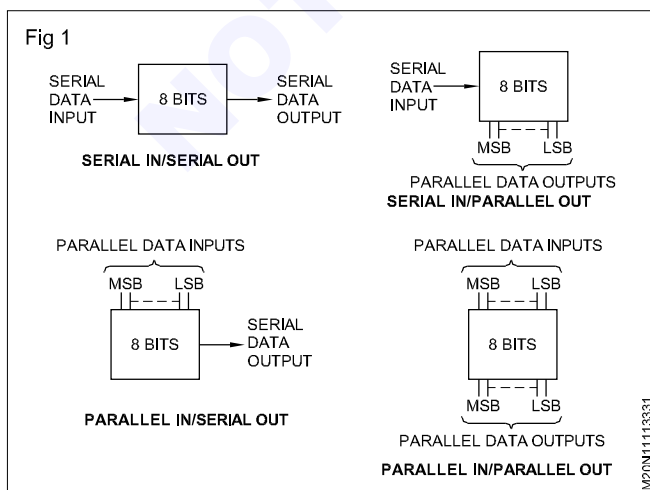
Serial in - serial out - 54/74L91, 8 bits

Serial in - parallel out - 54/74164, 8 bits

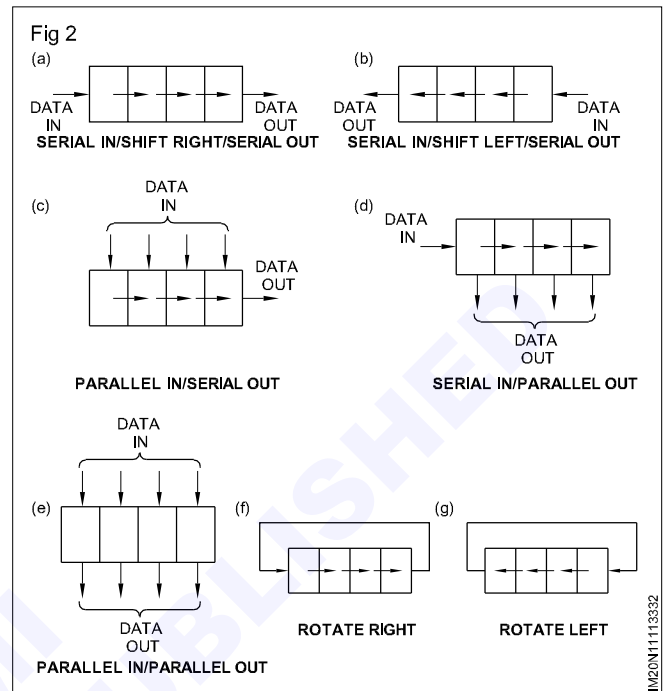
Parallel in - serial out - 54/75165, 8 bits

Parallel in - parallel out - 54/74194, 4 bits

Parallel in - parallel out - 54/74198, 8 bits



The shifting capability of a register permits the movement of data from stage to stage within the register or into or out of the register upon application of clock pulses. Fig 2a to 2g illustrate the types of data movement in shift registers. The block represents any arbitrary 4-bit register and the arrow indicate the direction of data movement.



### Serial in - serial out operation

The flip-flops used to construct registers are usually either JK or D types. So let's begin by summarizing the operation of JK flip-flop.

For a JK flip-flop, the data bit to be shifted into the flip-flop must be present at the J and K inputs when the clock transitions (low or high). Since the data bit is either a 1 or a 0, there are two cases:

- To shift a 0 into the flip-flop, J=0 and K=1.
- To shift a 1 into the flip-flop, J=1 and K=0.

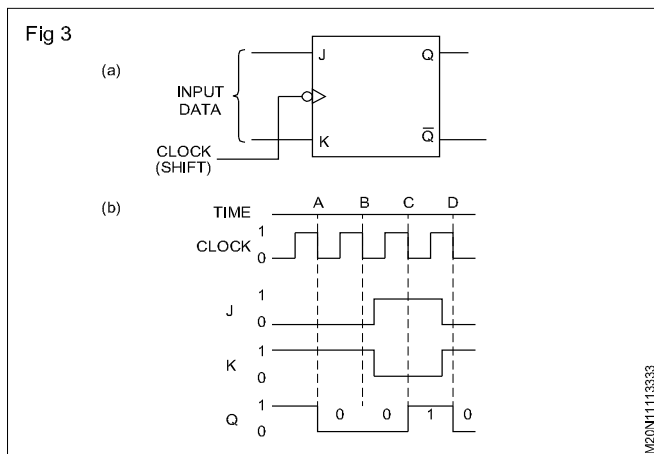
The important point to note is that the J and K inputs must be controlled to provide the correct input data. The J and K logic levels may be changing while the clock is high (or low), but they must be steady from just before until just after the clock transition (remember, setup time and hold time). For our discussion we shall use JK master-slave flip-flops having clock inputs that are sensitive to negative clock transitions. Incidentally, this negative transition of the clock is frequently referred to as a shift pulse.

The waveforms in Fig 3 illustrate these ideas. At time A, Q is reset low (a 0 is shifted into the flip-flop). At time B, Q does not change since the flip-flop had a 0 in it and another 0 is shifted in. At time C, the flip-flop is set (a 1 is shifted into it). At time D, another 0 is shifted into the flip-flop. In essence, we have shifted 4 data bits into this flip-flop in a time sequence: a 0 at time A, another 0 at time B, a 1 at time C, and a 0 at time D.

Now, consider adding three more flip-flops connected as shown in Fig 4. Let's begin with all the flip-flops reset and



then apply the exact same input signals to flip-flop Q as we did in Fig 3. Here's what happens:



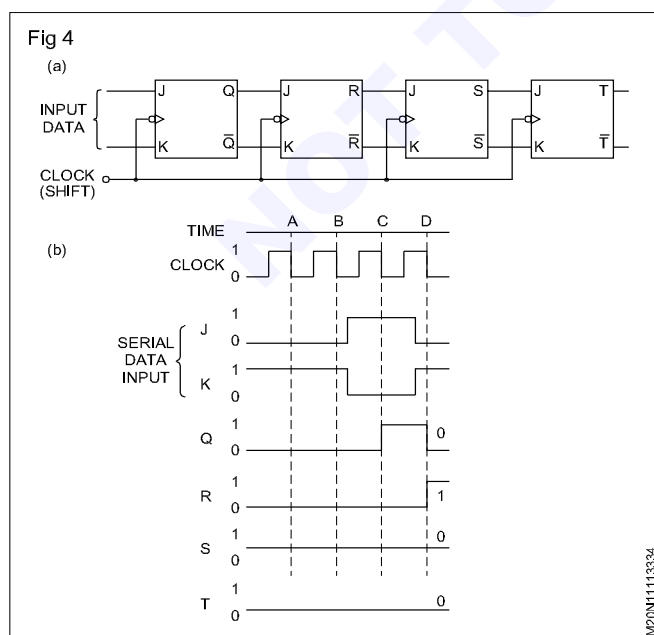
**At time A:** All the flip-flops are reset, so all J inputs are low and all K inputs are high. Then T is reset (the 0 in S is shifted into T). Similarly, the 0 in R is shifted into S, the 0 in Q is shifted into R, and the 0 at the data input is shifted into Q. The flip-flop outputs just after time A are QRST = 0000.

**At time B:** The flip-flops all contain 0s. Thus the 0 in S is shifted into T, the 0 in R shifts into S, the 0 in Q shifts into R, and the 0 at the data input shifted into Q. The flip-flop outputs are QRST = 0000.

**At time C:** The flip-flops still all contain 0s. The 0 in S shifts into T, the 0 in R shifts into S, and the 0 in Q shifts into R, but a 1 at the data input now shifts into Q. The flip-flop outputs are QRST = 1000.

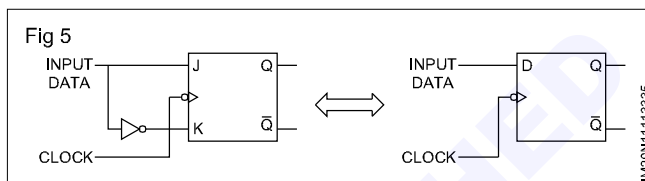
**At time D:** The 0 in S shifts into T, the 0 in R shifts into S, the 1 in Q shifts into R (the J input to R is high and the K input is low), and the 0 at the data input shifts into Q. The flip-flop outputs are QRST = 0100.

To summarize, we have shifted 4 data bits in a serial fashion into four flip-flops. These 4 data bits could represent a 4-bit binary number 0100, assuming that we began shifting with the LSB first. Notice that the LSB is in T and the MSB is in Q. These four flip-flops could be defined as a 4-bit shift register; thus this is the technique used to construct a serial-input shift register.



The serial data input for the register shown in Fig 4 requires two input signals J and K. But look carefully at the waveforms. Clearly,  $K = \bar{J}$ , or  $J = \bar{K}$ . In other words, one signal is always the complement of the other. If we were to connect an inverter between J and K on flip-flop Q with the input at J, therefore, we would need to have only one data input signal - the one required for J. But this is precisely a D-type flip-flop as shown in Fig 5. Remember the rules for a type D flip-flop; on the negative clock transition, the data present at the D input (either a 1 or a 0) will shift into the flip-flop.

Thus the 4-bit serial input shift register shown in Fig 5 can be constructed by replacing the JK flip-flops with type D flip-flops.



### Serial In Parallel Out (SIPO)

Data is entered serially into this type of register, and data bits are taken out of the register parallel from the output of each stage. Once the data bits are stored, each bit appears on its respective output line, and all bits are available simultaneously, rather than on a bit-by-bit basis as with the serial output.

The Fig 6a shows the SIPO shift register using J.K. flip-flops. All the inputs are tied to the complement of J-inputs. The clock, preset and clear inputs are -ve edge triggered. Initially all the flip-flops are cleared to logic-0 state by applying logic-0 pulse to the clear inputs.

The sequence of shifting logic information is shown in Fig 6b which gives waveform diagrams of data input, data output and clock input.

### 4-bit right-shift left-shift register IC7495

The Fig 7 shows the internal logic diagram of 4 bit shift register with parallel load capability, and with all flip-flop outputs available. This makes it possible to perform the right shift or left shift operation under control of the mode control input. For greater flexibility, the mode control selects clock-1 for the right shift mode and clock 2 for the parallel load (left shift) mode. The clock 1 and clock 2 inputs are tied together if only one clock source is required. Data transfer occurs once the -ve going edge of the clock pulse occurs.

### Parallel In Parallel Out (PIPO)

The Fig 8 shows the pins to be used for parallel in parallel out operation in IC7495. For this operation mode control should be kept at logic high. Clock 2 should be selected for applying clock pulse, data inputs are to be connected to the A,B,C & D parallel inputs, data output can be taken simultaneously from  $Q_A$ ,  $Q_B$ ,  $Q_C$  and  $Q_D$ .

When mode control is at logic high, inverter 1 output will be at logic-0. Hence AND gates 1,3,5,7 and 9 are disabled because one of the inputs of those gates will be at logic-0. Therefore clock 1 and serial inputs will be disconnected from the flip-flops. At the same time AND gates 2,4,6,8 and 10 are enabled because, both the AND gate inputs of

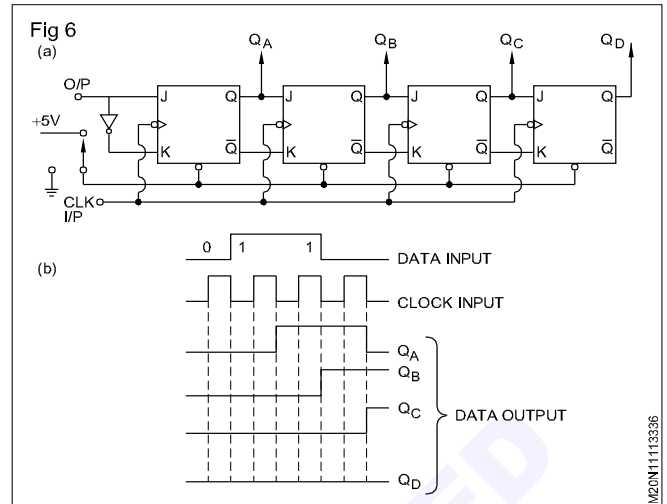
enabled gates will have high inputs simultaneously, when clock is high. Hence only clock 2 and parallel inputs are routed to the flip-flop inputs. Falling edge of the clock pulse, transmits the data information from parallel inputs to parallel outputs, simultaneously.

This type of register requires very less time (i.e one clock pulse) for transfer 1 set of parallel data information.

### Serial In Serial Out (SISO)

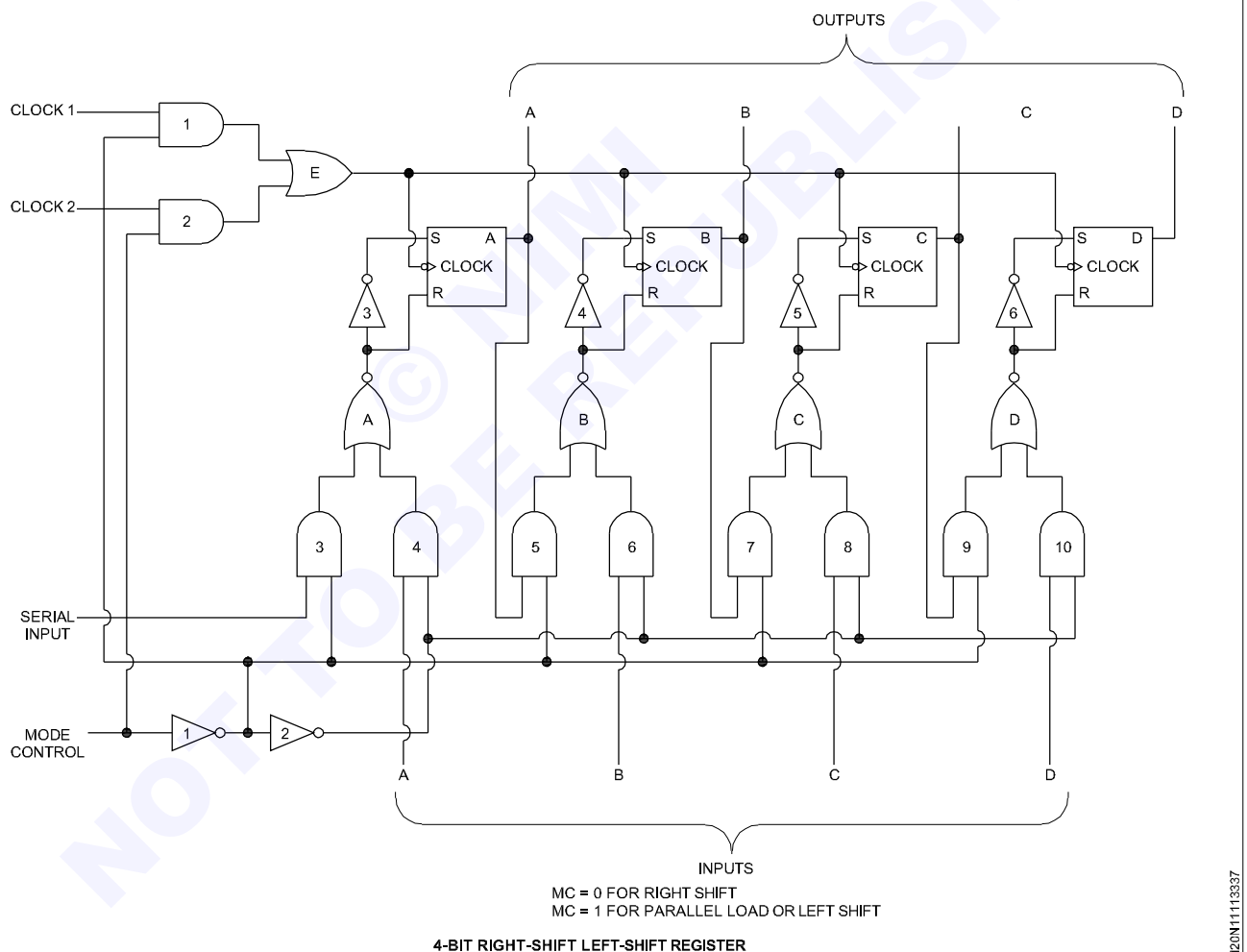
The Fig 9 shows the pins to be used for SISO operation in IC 7495. When the mode control input is at logic-0 condition inverter 1 (refer functional diagram of 7495 for inter blocks) output will be at logic-1 and that enables AND gates 3,5,7,9 and 1. AND gate-1 selects clock-1 status for triggering flip-flops through OR gate. AND gates 3,5,7,9 selects serial input data. At the same time inverter-2 output will be at logic-0 that disables AND gates 4,6,8,10 thus disconnecting all parallel inputs A,B,C and D reaching

flip-flop 4 clock pulses are required to transfer data from input to output of the shift register.



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Fig 7



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If the outputs are taken from all the outputs Q<sub>A</sub>, Q<sub>B</sub>, Q<sub>C</sub> and Q<sub>D</sub>, then this register works like serial in parallel out (shift right) register.

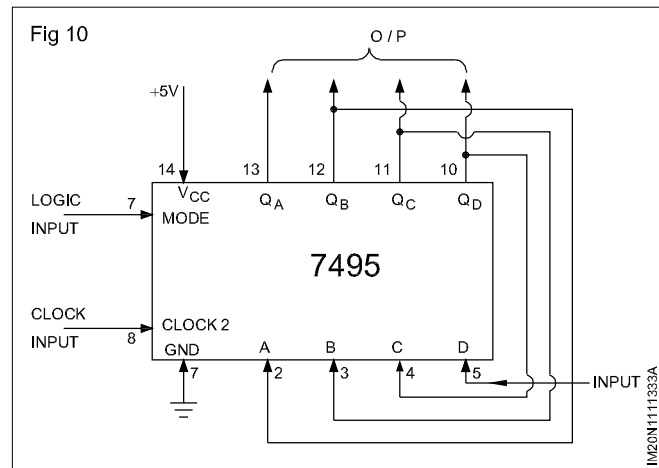
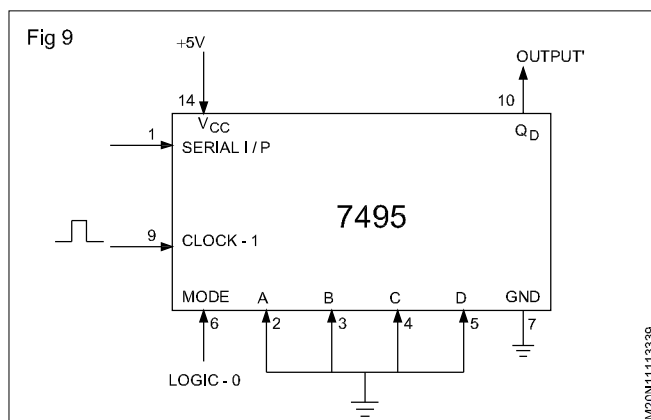
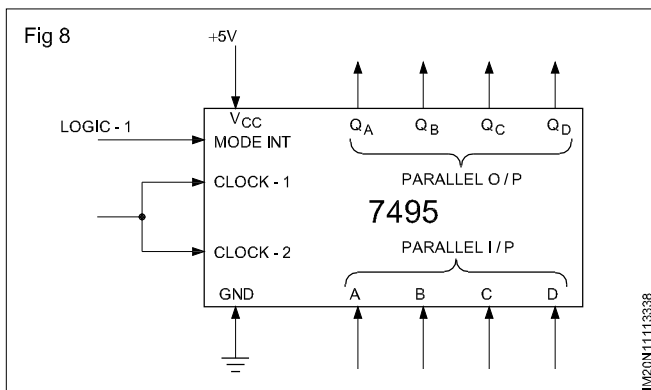
### Serial In Parallel Out (shift left)

The Fig 10 shows external wiring diagram for serial in parallel out shift left register. For shift left operation mode control signal level should be logic-1.

Data input is applied to the parallel input-D remaining parallel inputs A, B and C receives signals from the outputs Q<sub>B</sub>, Q<sub>C</sub> and Q<sub>D</sub> respectively as shown in Fig 10.

When mode control signal is at logic-1 AND gate 2 is enabled and AND gate 1 is disabled. Hence all the flip-flops get triggering pulse from clock 2. At the same time AND gates 3,5,7 and 9 are disabled and AND gates 4,6,8 and 10 are enabled, therefore parallel inputs A,B,C and D routed

to the flip-flops inputs, and serial input is disabled from the flip-flops. The data input given at the D input is shifted left as the clock pulse progress. To move data from  $Q_D$  to  $Q_A$ , 4 clock pulses are required.



## Multiplexers & Demultiplexers

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

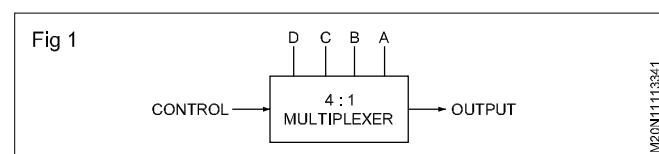
- state the need of multiplexers and demultiplexers in digital circuits
- explain the function of a multiplexer with an example
- state the relationship between number of input lines and required number of control lines
- list a few commercially available multiplexer and demultiplexer ICs
- explain the application of a multiplexer & demultiplexer in data transmission
- explain Four to One line multiplexer and its working
- explain One to Four Demultiplexer and its working.

Many applications in digital logic requires circuit with multiple input and single output, single input and multiple outputs. The output of such circuits should however be uniquely determined by a set of control signals. Such circuits find immense application in computer and data transmission. Such circuits that have one or more input lines and give one or more output which are uniquely determined by the inputs are called *Combinational circuits*. Two of the most important combinational circuits are the Multiplexers and Decoders.

### Multiplexers

A multiplexer having  $2^n$  data inputs, one data output and an  $n$ -bit control input which selects one of the input and routes it to the output is shown in Fig 1.

In Fig 1, the multiplexer has two inputs ( $2^n = 2^1=2$ , hence  $n=1$ ). It has 1-bit control signal (because,  $n=1$ ) which selects A or B as the output as given in the Truth Table 1.



Truth Table

| INPUTs |   | Control | Output           |
|--------|---|---------|------------------|
| A      | B |         |                  |
| 1      | 0 | 0       | 1 (A --> output) |
| 1      | 0 | 1       | 0 (B --> output) |

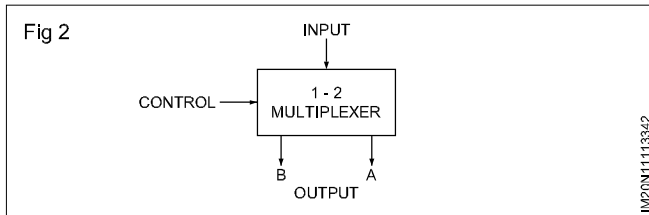
### Demultiplexer

The inverse of a Multiplexer is a Demultiplexer as shown in Fig-2. This has  $n$  input (in this case,  $n=1$ ),  $2n$  output (in this

case,  $2^n = 2^1 = 2$  outputs) and  $n$  number of control signals (in this case  $n=1$ , hence control line=1). The single input is routed to one of the  $2^n$  outputs, depending on the value of the  $n$  control lines. The truth table for the demultiplexer at Fig 2 is given in Table 2.

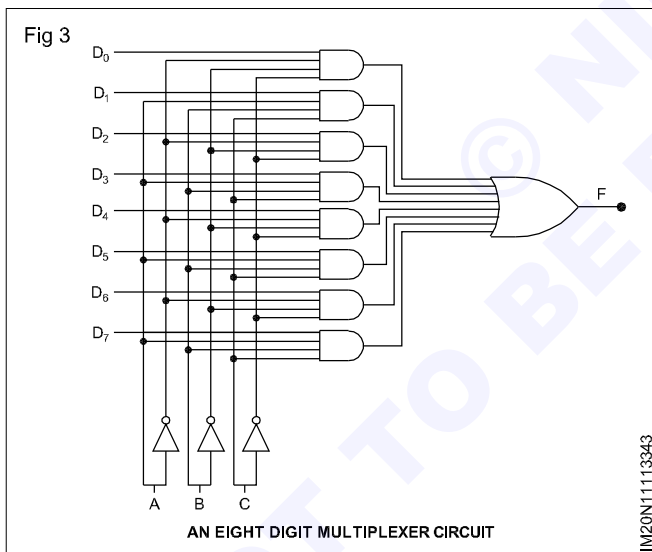
Table 2

| INPUT | Control | Output                        |
|-------|---------|-------------------------------|
| 1     | 0       | Input --> A ( Therefore, A=1) |
| 1     | 1       | Input --> B ( Therefore, B=1) |



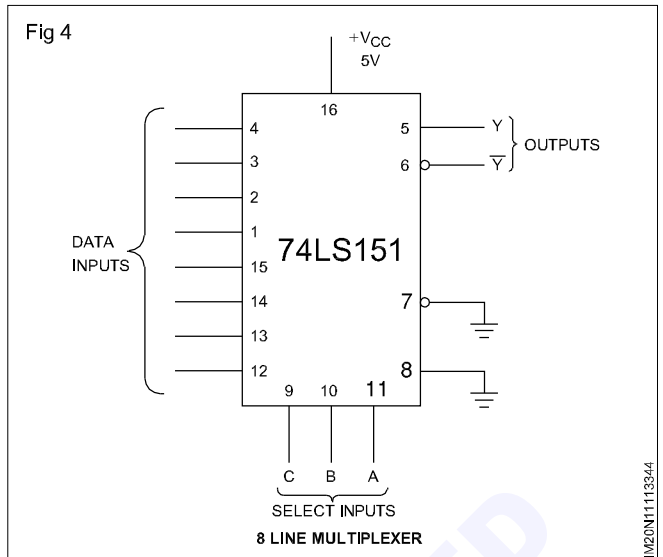
### 8-line Multiplexer

As discussed in earlier paragraphs, a multiplexer is a circuit with  $2^n$  data inputs, one data output and  $n$  control inputs. The selected data is gated or routed to the output. Fig 3 shows the schematic of an eight-input or eight-line multiplexer.



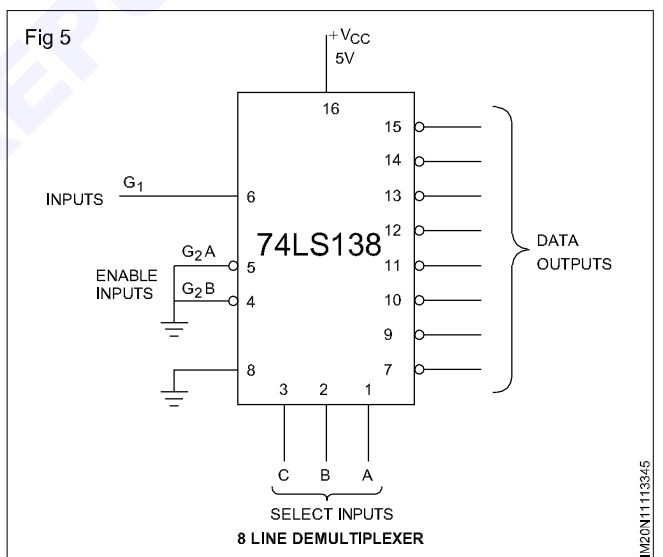
As can be seen in Fig 3, the three control lines A, B and C encode a 3-bit number that specifies which of the eight input lines is gated to the OR gate and then to the output. Immaterial of what value is on the control lines, seven of the AND gate will always output 0, the other one may output 0 or 1 depending on the value of the selected input line. Each gate is enables by a different combination of the control inputs.

Such a eight-line multiplexer is available as a MSI chip. With 8 input lines, 3 control lines, one output, may be an additional compliment output line and power supply and ground lines is implemented as a 16 pin package. One such package is the 74LS151 , 8-line multiplexer IC shown in Fig 4.



### Demultiplexer

The inverse of a multiplexer is a demultiplexer. A demultiplexer routes its single input signal to one of  $2^n$  outputs, depending on the values of the  $n$  control lines. For instance, if the binary value on the control signal is all zeros, the 0th output line is selected and if the binary value on the control lines is  $k$ , then, the  $k^{th}$  output line is selected for routing the input signal. Such demultiplexers are also available in IC package. One such IC is the 1line to 8 line demultiplexer 74LS138 as shown in Fig 5.



### Application of Multiplexers and Demultiplexers

There are almost innumerable applications of multiplexers and demultiplexers. Just to list a few are in implementing a multiplexed display, parallel to serial data converter etc.,

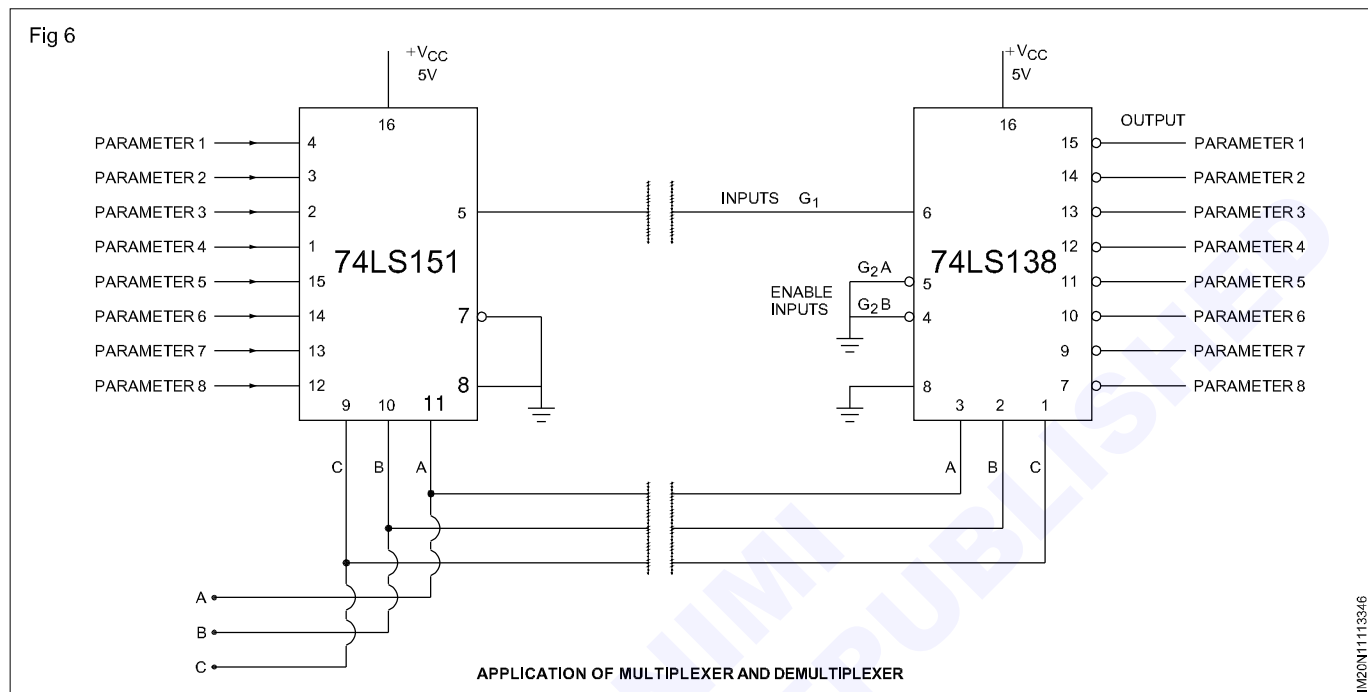
The application of multiplexer and demultiplexer can be appreciated in data transmission as shown in Fig 6.

In Fig 6, the eight inputs could be eight signals coming from different transducers measuring eight different type of data (say, temperature, pressure,...) in a industrial environment. At the other end the output of the demultiplexer may be fed to eight different measuring instruments meant for measuring the individual parameters.

If the control lines of the multiplexer and demultiplexer are simultaneously fed with binary signals sequentially from 000 to 111, then each of the parameter of the input at any given time is communicated over the line to the demultiplexer which in-turn routes it to meter which is meant for displaying the value of the value of the parameter.

Observe from Fig 6, that only one transmission line is used for communicating all the eight parameters at different

intervals of time. This is known as Time division multiplexing. Hence, multiplexers and demultiplexers are invariably used in such communication. The three control lines shown in Fig 6 could even be generated at sending and receiving station independently using one of the input line as the synchronizing input.



## Multiplexed Displays

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

- explain the constructional details and working of LED type seven segment display
- state the need and advantages of multiplexing
- explain the process of multiplexing and four digit multiplexed display .

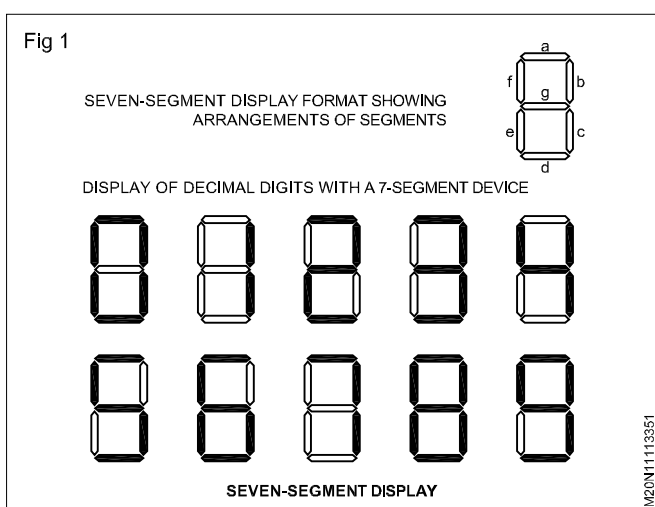
### 7-segment display

7 segment displays are used with logic circuits that decode a binary coded decimal (BCD) number and activate the appropriate digits on the display.

The Fig 1 shows a common display format composed of seven elements or segments. Energising certain combinations of these segments can cause each of the ten decimal digits to be displayed. The Fig-b shows the method of digital display for each of the ten digits by using a block segment to represent one that is energized. To produce decimal 'one' on display, segments b and c are energized, to produce 'two' segments a<sub>1</sub>, b<sub>1</sub>, g<sub>1</sub>, e<sub>1</sub> and d<sub>1</sub> are used and so on.

### LED display

One common type of 7-segment display consists of light-emitting diodes (LED) arranged as shown in Fig 2. Each segment is an LED that emits light when there is current through it.



The Fig 2 (a) is common anode arrangement requires the driving circuit to provide a low-level voltage in order to activate a given segment, when a low is applied to a

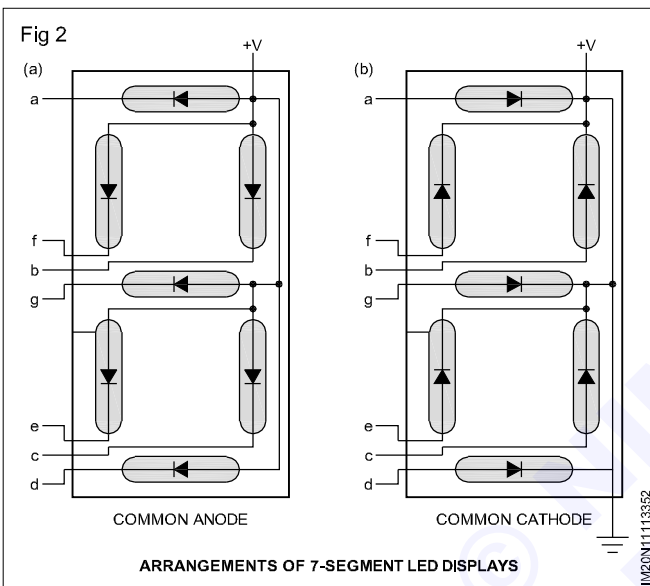


segment input, the LED is turned ON and there is current through it.

In Fig 2(b) the common cathode arrangement requires the driver to provide a high level voltage to activate a segment. When a high is applied to a segment input. The LED is turned ON and there is current through it.

## LCD display

Another common type of 7 segment display is the liquid crystal display (LCD), LCDs operate by polarizing light so that a non activated segment reflects incident light and thus appears invisible against its back ground. An activated segment does not reflect incident light and thus appears dark. LCDs consume much less power than LEDs but can't be seen in the dark, while LEDs can.



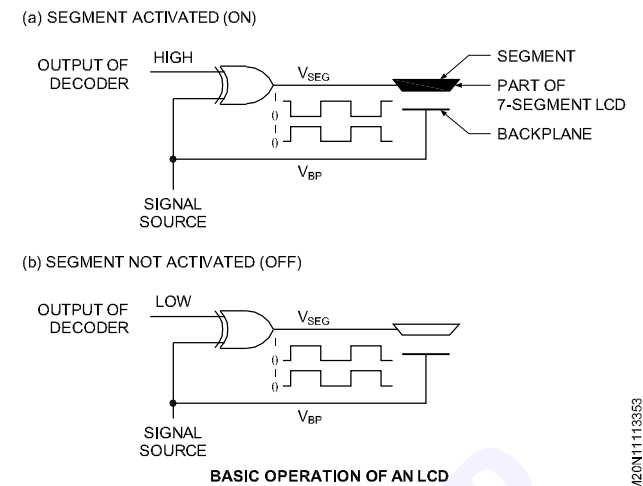
LCDs operate from a low frequency signal voltage (30 Hz to 60 Hz) applied between the segment and a common element called the back plane (bp).

The Fig 3 shows a square wave used as the source signal. Each segment in the display is driven by an Ex-OR gate with one input connected to an output of the seven segment decoder/driver and the other input connected to the signal source. When the decoder/driver output is high the Ex-OR output is a square wave that is 180° out of phase with the source signal. The resulting voltage between the LCD segment and back plane is also a square wave because when  $V_{seg} = 1, V_{bp} = 0$ , and vice-versa. The voltage difference turns the segment ON.

## Basics of LCD Displays

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

Fig 3



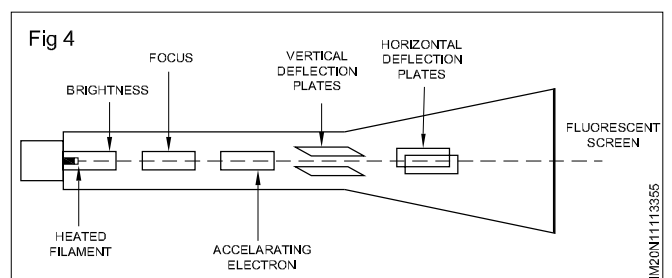
## Basic structure of an LCD

Fig 4 shows a liquid crystal cell consists of a thin layer (about 10 μm) of a liquid crystal sandwiched between two glass sheets with transparent electrodes deposited on their inside faces. With both glass sheets transparent the cell is known as transmissive type cell. When one glass is transparent and the other has a reflective coating, the cell is called reflective type. The LCD does not produce any illumination of its own. It in fact depends entirely on illumination falling on it from an external source for its visual effect.

Digital meters : Displays

Cathode ray tube

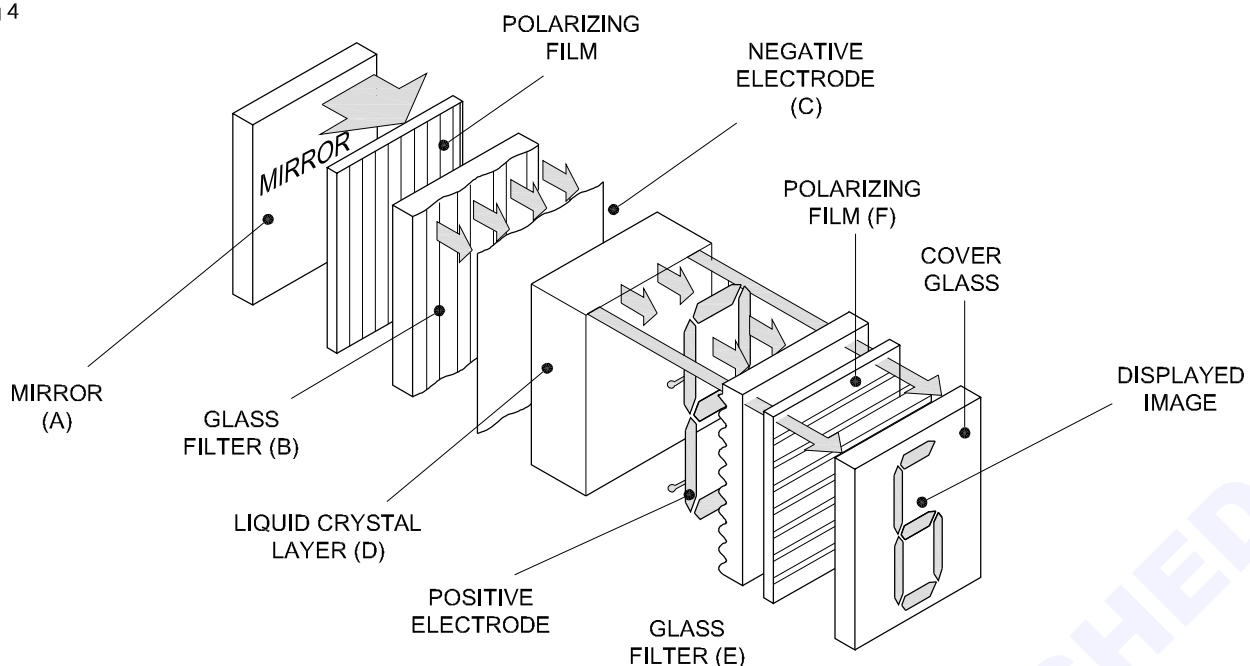
Fig 5 shows cathode ray tube is a vacuum tube containing one or more electron guns, the beams of which are manipulated to display images on a phosphorescent screen. The image may represent Electronics waveforms (oscilloscope) pictures (television set, computer monitor), radar targets or other phenomena. A CRT on a television set is commonly called a picture tube. CRT have also been used as memory devices in which case the screen is not intended to be visible to an observer.



In television and computer monitor the entire front area of the tube is scanned repeatedly and systematically in a fixed pattern called raster.

In modern CRT monitors and television the beams are bent by magnetic deflection using a deflection yoke. Electrons take deflection is commonly used in oscilloscope.

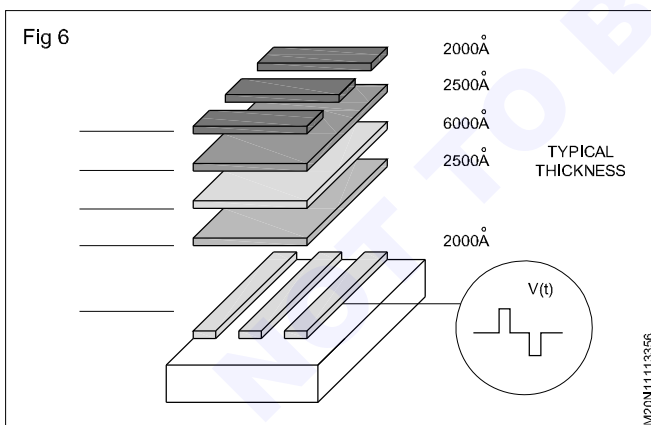
Fig 4



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### Eleuro luminescent display

The most widely used types of electro luminescent display is one, which is made by a stack of this layers of different materials. As can be seen in fig 6 the typical thicknesses of the individual layers are a few thousand angstroms and therefore such a device is named a thin film electroluminescent (TIEFL) device. The central largest is called the phosphor layer and it is sandwiched between two insulating layers on top is placed metal electrode and at the bottom electrodes made from indium, tin oxide (ITO) are placed. The two types of electrodes are placed perpendicular to each other thereby forming a matrix. At the very bottom a transparent substrate is placed. Most often glass but plastic materials have also been tried.



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The phosphor layer will emit light when a large enough electric field is applied across it. This phenomenon is known as electroluminescence, which is explained in the scientific principle section. Typically the necessary value is in the order of 1.5 MV/cm. This electric field is established by the electrodes, while the function of the two insulating layers is to prevent a large current from flowing, which could otherwise destroy the device.

The matrix formed by the electrodes makes up the different pixels of the display. The special property of the ITO

electrodes are, that they are transparent, which allows viewing of the light through the glass substrate at the bottom. The upper electrode is often made from a material, which absorbs light rather than reflecting it. This is done to insure, that the light, which propagates backwards towards this electrode, will not be reflected at some angle and then be directed out of the display through one of the other pixels, since this would lower the contrast properties of the display.

### Working principle

Electrophoretic displays use microcapsules filled with a suspension of charged pigment particles. The microcapsules are sandwiched between two parallel conducting electrode panels. At least one of these panels has to be transparent, so the microcapsules are exposed to visible light (Fig 7).

Dependent on the charge given to the panels the charged particles move to the top or bottom. This makes either the white or black particles visible. In this way, the visible light that hits the top of the microcapsule is either scattered (creating white) or absorbed (creating black).

A color display is made using a color filter. This filter divides each pixel into different colors. Either red, green and blue (RGB) or red, green blue and white (RGBW). This method is not very efficient: with RGB the filter absorbs roughly two-thirds of the light, with the RGBW roughly half of the light

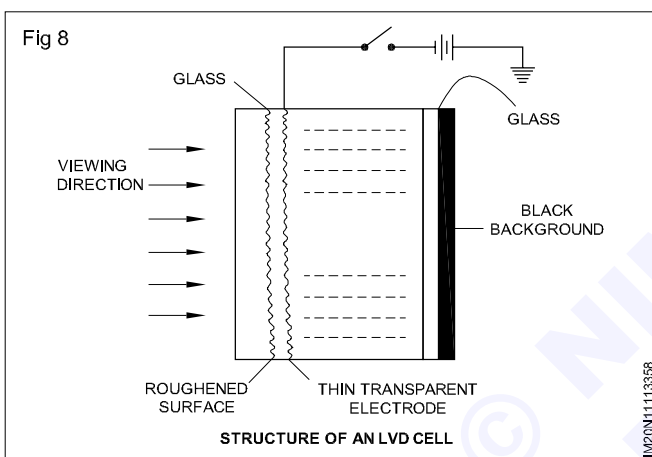
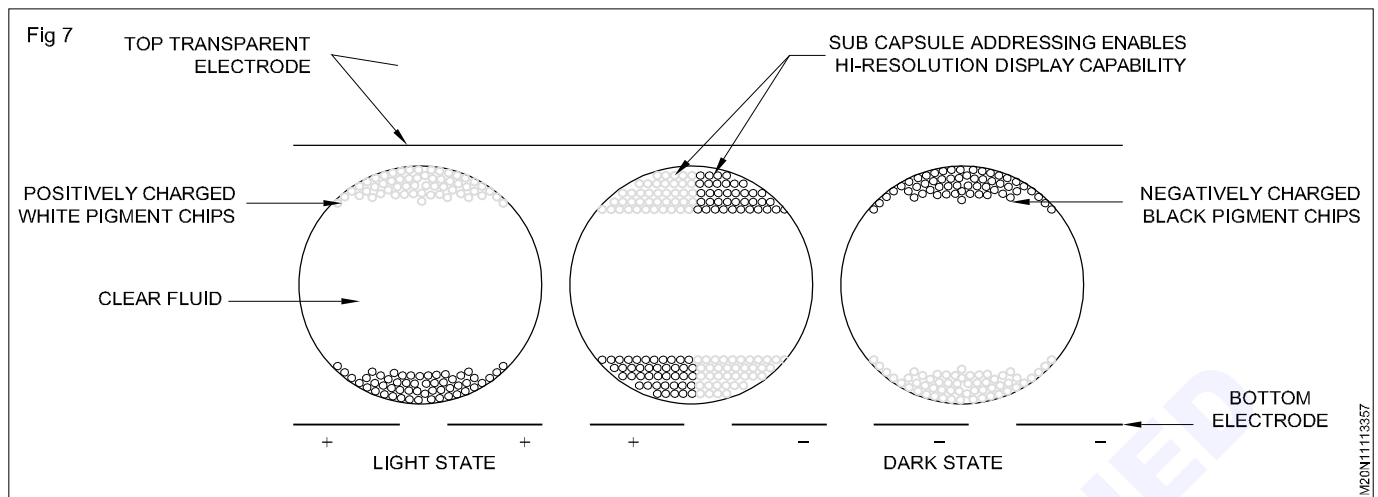
### Liquid vapour display (LVD)

Liquid vapour displays are the latest in economical display technology. They employ a new reflective passive display principle and depend on the presence of ambient lights for their operation. Fig 8 gives the structure of a typical LVD cell.

It consists of a transparent volatile liquid encased between two glass plates and spacers. The rear glass plate has a black background and the front glass surface in contact

with the liquid is roughened, so that the liquid wets it, i.e in its simplest form, an LVD consists of a roughened glass surface wetted with a transparent volatile liquid of the same

refractive index as that of the glass. The rear surface is blackened.



The transparent electrode is heated by using a voltage drive, which is the basis for the display function.

In the OFF condition of display with no voltage applied across the transparent electrode, the viewer sees the black background through the front transparent glass electrode and the liquid.

To achieve an ON condition of the display, a voltage is applied to the transparent electrode. This causes sufficient heat in the electrode, which evaporates the liquid in contact with it, and a combination of vapour film and vapour bubbles is formed around the roughened glass surface. As the

refractive index of vapour is approximately 1, there is a discontinuity established at the interface between the front glass plate and the liquid, which gives rise to light scattering. This makes it a simple display device.

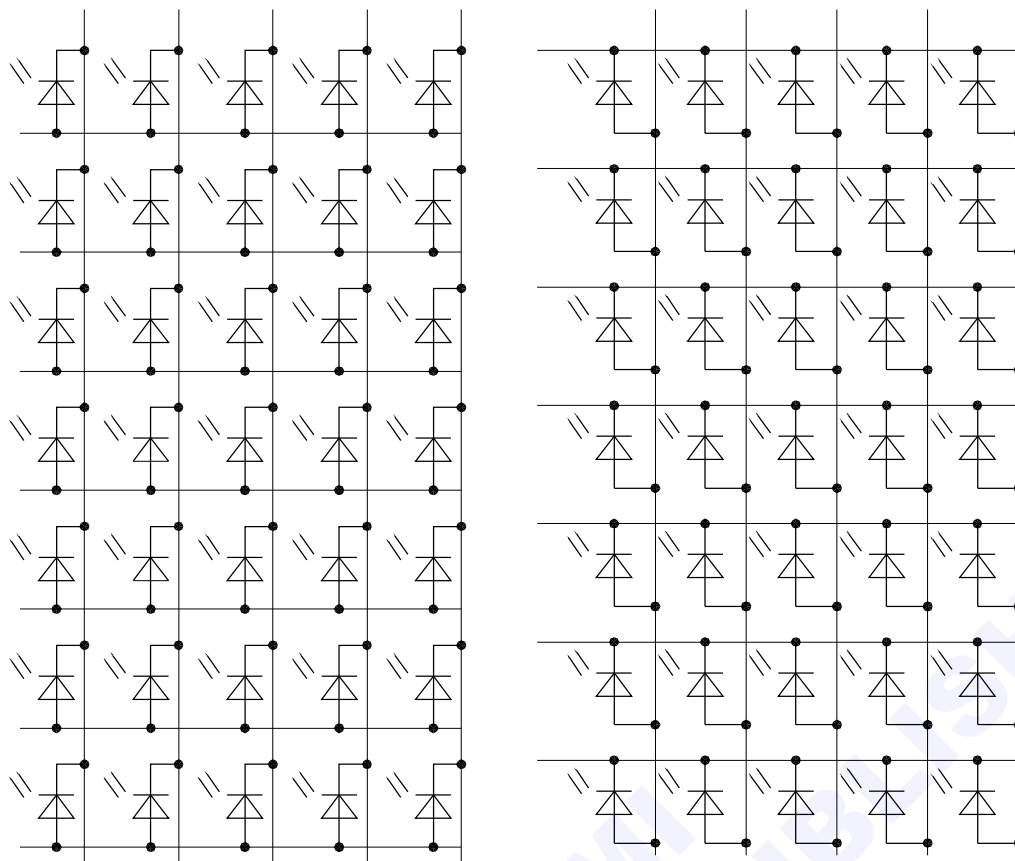
### Dot matrix display

A dot-matrix display is an electronic digital display device that displays information on machines such as clocks and watches, public transport departure indicators, and many other devices requiring a simple alphanumeric (and/or graphic) display device of limited resolution.

The display consists of a dot matrix of lights or mechanical indicators arranged in a rectangular configuration (other shapes are also possible, although not common) such that by switching on or off selected lights text or graphics can be displayed. A dot matrix controller converts instructions from a processor into signals that turn on or off indicator elements in the matrix so that the required display is produced.

structure and operation of LED dot matrix displays in a LED dot matrix display the LEDs are located at the column and row intersections of the matrix. LEDs in the same row are connected together as are LEDs in the same column. Fig 9 shows two common configurations for LED matrix displays.

Fig 9



(a) CATHODE COLUMN - ANODE ROW  
(CCAR)

(b) ANODE COLUMN - CATHODE ROW  
(ACCR)

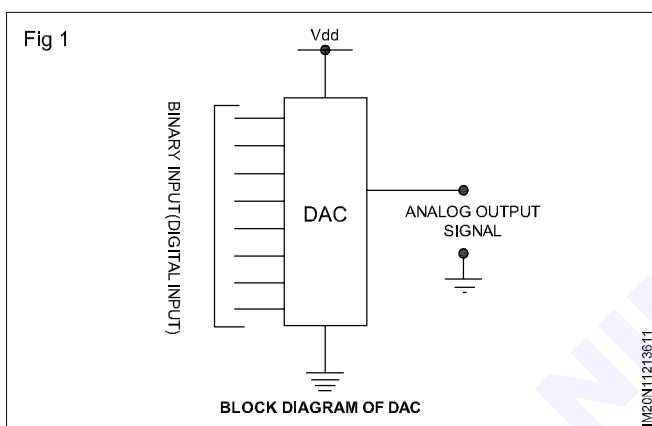
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## Digital -to- Analog converter

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

- explain the function of digital to analog converter

Digital to Analog Converter (DAC) is a device that transforms digital data into an analog signal. A DAC can reconstruct sampled data into an analog signal with precision. The digital data may be produced from a microprocessor, Application Specific Integrated Circuit (ASIC), or Field Programmable Gate Array (FPGA), but ultimately the data requires the conversion to an analog signal in order to interact with the real world. The block diagram of Basic Digital to Analog Converter is shown in Fig1.



**D/A Converter Architectures:** There are two methods commonly used for digital to analog conversion: Weighted Resistors method and the other one is using the R-2R ladder network method.

### DAC 0808 Digital to Analog converter

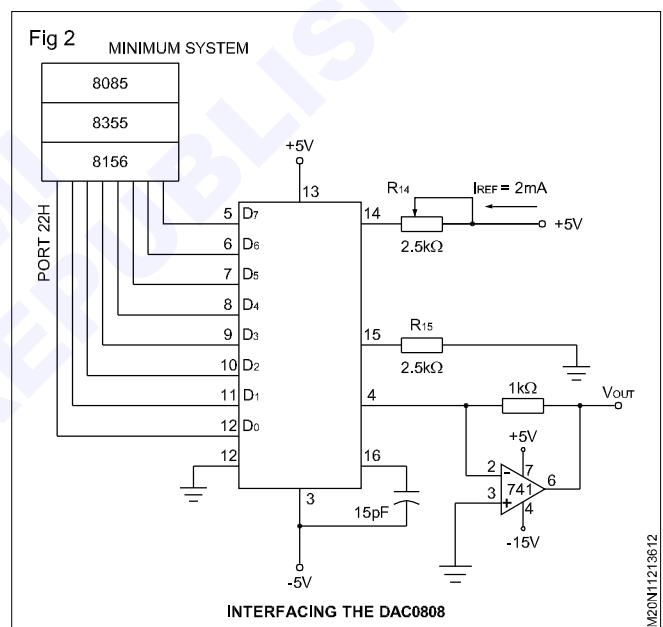
The DAC 0808 series is an 8 bit monolithic digital-to-analog converter (DAC) featuring a full scale output current setting time of 150ns while dissipating only 33mw with  $\pm 5V$  supplies. No reference current ( $I_{ref}$ ) trimming is required for most applications since the full scale output current is typically  $\pm 1$  LSB of  $255 I_{ref}/256$ . Relative accuracies of better than  $\pm 0.19\%$  assure 8-bit monotonicity and linearity, while zero level output current of less than  $4\mu A$  provides 8-bit zero accuracy for  $I_{ref} = 2mA$ , the power supply currents of the DAC 0808 series are independent of bit codes and exhibits essentially constant device characteristics over the entire supply voltage range.

The DAC 0808 will interface directly with popular TTL, DTL or CMOS logic levels, and is a direct replacement for the MC1508/MC1408.

The Fig 1 shows the data bits of a DAC0808 connected to port 22H of minimum system. Pin 2 of the DAC0808 is grounded, and a 15pF compensating capacitor is between pins 16 and 3, +5V supply sets up a reference current for the R-2R ladder, pin 14 is connected to a positive supply through a resistor (trimmer)  $R_{14}$  allows you to adjust this to

2mA and pin 15 is grounded through a resistor  $R_{15}$  is the same size as  $R_{14}$ ; this compensates for drift in the input stage of the converter. Notice that  $I_{out}$  drives the inverting input of an op-amp; therefore the final output ranges from 0 to +2V. Pin 1 is unused, pin 2 is chip ground, pin 3 ( $V_{EE}$ ) is -5V, pin 4 is the ground return for the current out of the ladder; this pin usually connects to an op-amp, pin 5 to 12 are for the 8 bits of input data, Pin 13 ( $V_{CC}$ ) is +5V. Finally a capacitor between pin 16 and pin 3 frequency-compensates the device.

### Grounding and bypassing



D/A and A/D converter IC(s) require correct grounding and capacitive bypassing in order to operate according to performance specifications. The digital signals can severely impair analog signals to contact the electromagnetic interference caused by the digital signals, the analog and digital grounds should be kept separate and should have only one common point on the circuit board. Bypass capacitors are required at the power connections to the IC, the reference signal inputs and the analog inputs to minimize noise that is induced by the digital signals. Manufacturer specifies the recommended bypass capacitor locations and values in the data sheet.

The typical DAC 0808 Digital to Analog converter is shown in Fig 2 and its working is explained below:

### Applications of Digital to Analog Converter

DACs are used in many digital signal processing applications and many more applications. Some of the important applications are discussed below.



- **Audio Amplifier** DACs are used to produce DC voltage gain with Microcontroller commands. Often, the DAC will be incorporated into an entire audio codec which includes signal processing features.
- **Video Encoder** the video encoder system will process a video signal and send digital signals to a variety of DACs to produce analog video signals of various formats, along with optimizing of output levels. As with audio codecs, these ICs may have integrated DACs.
- **Display Electronics** the graphic controller will typically use a lookup table to generate data signals sent to a video DAC for analog outputs such as Red, Green, Blue (RGB) signals to drive a display.
- **Data Acquisition Systems** data to be measured is digitized by an Analog-to-Digital Converter (ADC) and then sent to a processor. The data acquisition will also include a process control end, in which the processor sends feedback data to a DAC for converting to analog signals.
- **Calibration** the DAC provides dynamic calibration for gain and voltage offset for accuracy in test and measurement systems.
- **Motor Control** many motor controls require **voltage control signals**, and a DAC is ideal for this application which may be driven by a processor or controller.
- **Digital Potentiometer** almost all digital potentiometers are based on the string DAC architecture. With some reorganization of the resistor/switch array, and the addition of an I2C compatible interface, a fully digital potentiometer can be implemented.

### Digital to Analog converter (DAC)

Digital to analog converters is used to convert digital quantity into analog quantity. DAC converter produces an output current of voltage proportional to digital quantity (binary word) applied to its input. Today microcomputers are widely used for industrial control. The output of the microcomputer is a digital quantity. In many applications the digital output of the microcomputer has to be converted into analog quantity which is used for the control of relay, small motor, actuator e.t.c. In communication system digital transmission is faster and convenient but the digital signals have to be converted back to analog signals at the receiving terminal. DAC converters are also used as a part of the circuitry of several ADC converters.

There are several ways of making a digital to analog converter. Some of them are given as under.

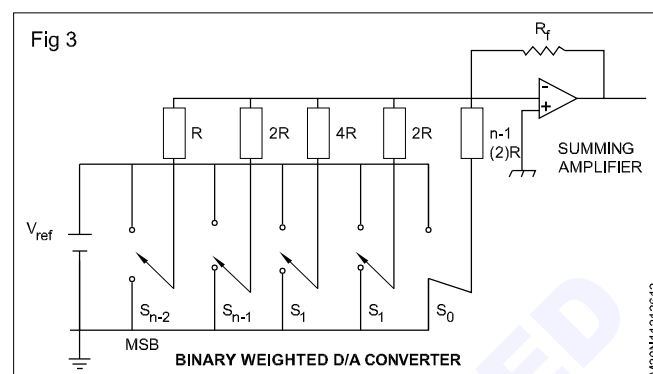
- 1 Binary weighted resistor DAC
- 2 R-2R Ladder network
- 3 Serial DAC converter
- 4 BCDDAC
- 5 Bipolar DAC

### Binary weighted resistor DAC

A binary weighted resistor ladder D/A converter is shown in fig 3

It consists of the following four major components.

- 1 switches one for each bit applied to the input



- 2 a weighted resistor ladder network. where the resistance are inversely proportional to the numerical significance of the corresponding binary digital
- 3 a reference voltage Vref and
- 4 a summing amplifier that adds the current flowing in the resistive network to develop a signal that is proportional to the digital input.

The behavior of the circuit may be analyzed easily by using "Millman's theorem". It states that "the voltage appearing at any node in a resistive network is equal to the summation of the current entering the node (assuming the node voltage is zero) divided by the summation of the conductance connected to the node

Mathematically we can write

$$V_o = \frac{\frac{V_1}{R} + \frac{V_2}{2R} + \frac{V_3}{4R} + \dots + \frac{V_n}{(2n-1)R}}{\left[ \frac{1}{R} + \frac{1}{2R} + \frac{1}{4R} + \dots + \frac{1}{(2n-1)R} \right]}$$

Assume that the resistors  $R_1, R_2, R_3, \dots, R_n$  are binary weighted resistors, thus

$$R_1 = R$$

$$R_2 = 2R$$

$$R_3 = 4R$$

$$\dots\dots\dots$$

$$\dots\dots\dots$$

$$\dots\dots\dots$$

$$R_n = (2n-1)R$$

$$V_o = \left[ \frac{\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}} \right]$$

A Resistor ladder network, can delivers a binary number say number of n bits

When  $a_i = 1$ , then bit is ON and when  $a_i = 0$  then bit is OFF

The reference voltage source  $V_R$  is considered to have zero internal impedance. The resistor that are connected to the switches have value such as to make the current flow proportion to the binary weight of the respective input. But the resistor in the MSB position has the value  $R$ , the next has the value  $2R$  etc. The resistor of the LSB have the value of  $(2^{n-1})R$ .

The current flowing in the summing amplifier is

$$I = \frac{\alpha_n - 1V_R}{R} + \frac{\alpha_n - 2V_R}{2R} + \dots \dots \frac{\alpha_1 V_R}{(2)^{n-1} R}$$

Above relation shows that output voltage of the D/A converter is proportional to a number represented by the switch that are connected to  $V_R$  i.e  $a_i = 1$

When all the bits of digital word have value of 1, then the output current of D/A converter is termed the full scale output current and is an important design parameter.

On the other hand, if all switches are open i.e all  $a_i$  coefficients are zero then the output voltage (current) is zero

The maximum output voltage  $V_0 = R_i$  depends on the feedback resistor  $R_f$ . As the operational amplifier is operated in the negative feedback mode for the purpose of summing so that it performs as an excellent current to voltage converter.

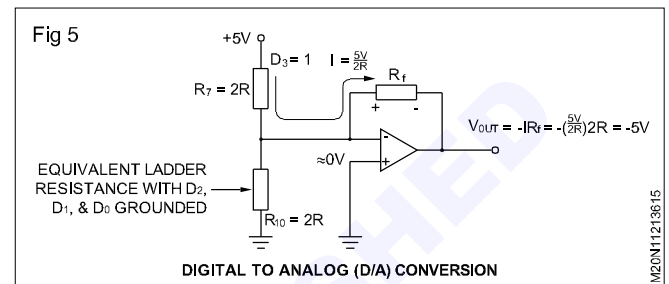
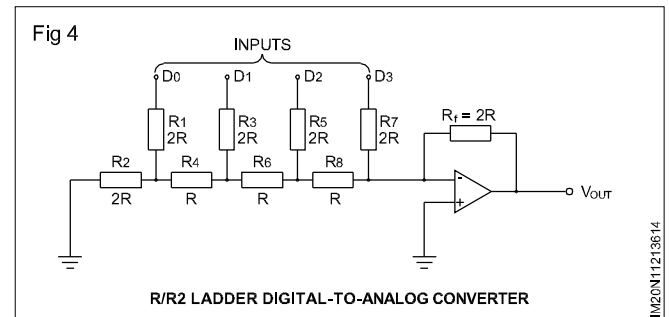
### Disadvantages / Limitations

- 1 Resistors used in the network have a wide range of values, so it is very difficult to ensure the absolute accuracy and stability of all the resistors.
- 2 It is very difficult to match the temperature coefficients of all the resistors. This factor is specially important in D/A converters operation over a wide temperature range.
- 3 When  $n$  is so large, the resistance corresponding to LSB can assume a large value, which may be comparable with the input resistance of the amplifier. This leads to erroneous results.
- 4 As the switches represent finite impedance that are connected in series with the weighted resistors and their magnitudes and variations have to be taken in to account in a D/A converter design.

**R/2R ladder digital-to-analog converter :** The Fig 4 shows another method of DA conversion using R/2R ladder resistor network, for four bits. It overcomes one of the problems in the binary-weighted input DAC. In this type DAC only two values of resistors are required  $R$  and  $2R$ .

Assuming that the  $D_3$  input is HIGH (+5V) and the others are LOW (ground 0V). This condition represents the binary 1000. A circuit analysis will show that this reduces to the equivalent form shown in Fig 5. Essentially no current goes

through the  $2R$  equivalent resistance because the inverting input is at virtual ground.



Thus all of the current ( $I = 5V/2R$ ) through  $R_7$  also goes through  $R_f$ , and the output voltage is  $-5V$ . The operational amplifier keeps the inverting (-) input near zero volts ( $\sim 0V$ ) because of -ve feedback. Therefore all current goes through  $R_f$  rather than into the inverting input.

When the  $D_2$  input is at +5V and the others are at ground. This condition represents 0100. Thevenizing the  $R_2/2R$  ladder network looking from  $R_8$ , results in a current through  $R_f$  of  $I = 2.5V/2R$ , which gives an output voltage of  $-2.5V$ . Keep in mind that there is no current into the Op-Amp inverting input and that there is no current through the equivalent resistance to ground because it has zero volts across it, due to the virtual ground.

### When the input is 0010

When  $D_1$  input is at +5V and the others are at ground, this condition represents 0010, again thevenizing the  $R_2/2R$  ladder network looking from  $R_8$ , results in a current through  $R_f$  of  $I = 1.25V/2R$ , which gives an output voltage of  $-1.25V$ .

### When the input is 0001

When  $D_0$  input is at +5V and the others are at ground, this condition represents 0001, again thevenizing the  $R/2R$  ladder network looking from  $R_8$ , results in a current through  $R_f$  of  $I = 0.625V/2R$ , which gives an output voltage of  $-0.625V$ .

Notice that each successively lower weighted input produces an o/p voltage that is halved, so that the output voltage is proportional to the binary weight of the input bits.

In equation form the o/p voltage is given by

$$V_{out} = \frac{D_0 2^0 + D_1 2^1 + D_2 2^2 + D_3 2^3 + \dots \dots D_{n-1} 2^{n-1}}{2^n}$$

where  $D_0, D_1, D_2, D_3, \dots \dots D_{n-1}$  are the digital input levels.

## Performance characteristics of digital-to-analog converter

### Resolution

The resolution of a DAC is the reciprocal of the number of discrete steps in the output. This of course, is dependent on the number of input bits.

For example: A 4-bit DAC has a resolution of one part in  $2^4 - 1$  (one part in fifteen) expressed as a percentage, this is  $(1/15) \times 100 = 6.67\%$ . The total number of discrete steps equals  $2^n - 1$ , where  $n$  is the number of bits. Resolution can also be expressed as the number of bits that are converted.

### Accuracy

Accuracy is a comparison of the actual output of a DAC with the expected output. It is expressed as a percentage of a full-scale, or maximum output voltage.

Example: If a converter has a full-scale output of 10V and the accuracy is  $\pm 0.1\%$ , then the maximum error for any

output voltage is  $(10V)(0.001) = 10mV$ , ideally, the accuracy should be, at most  $\pm 1/2$  of an LSB. For an 8-bit converter, 1 LSB is  $1/256 = 0.0039$  (0.39% of full scale), the accuracy should be approximately  $\pm 0.2\%$ .

### Linearity

A linear error is a deviation from the ideal straight-line output of a DAC. A special case is an offset error, which is the amount of output voltage when the input bits are all zeros.

**Monotonicity** : A DAC is monotonic if it doesn't take any reverse steps when it is sequenced over its entire range of input bits.

### Settling time

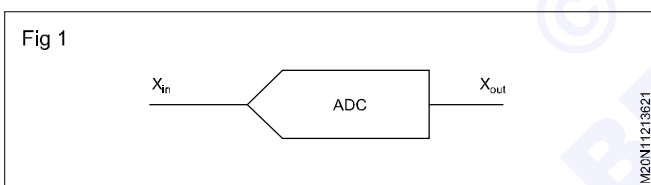
Settling time is normally defined as the time it takes a DAC to settle within  $\pm 1/2$  LSB of its final value when a change occurs in the input code.

## Analog-to-Digital Converter

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

- explain the function of A to D converter and its types
- explain successive-approximation method of A/D converter
- state the characteristic of ADC0809 IC.
- list the application of ADC

In electronics there are several circuit designed according to requirements. An analog-to-digital converter is a circuit that converts an analog signal from a microphone or a digital camera, into a digital signal. The schematic representation of ADC is shown in Fig 1.



This electronic circuit directly converts the continuous form of signal to discrete form is also expressed as A/D or A-to-D or ADC.

Analog to digital conversion is necessary when measured quantities must be in digital form for processing in a computer for display or storage. This A/D converter is a linkage between the analog (linear) world of transducers measuring parameter like temperature, pressure, vibration etc into equivalent digital signals for discrete world of processing the signal and handling the data.

The major factors that determine the quality performance of A/D converter are resolution, sampling rate, speed and linearity. The resolution is the smallest change in voltage that can be detected by the system and that can produce a change in the digital code.

The speed of a A/D converter is determined by the time it takes to perform the conversion process. Analog signal can be converted to digital codes by many methods of which successive approximation and flash A/D conversion methods are most common

### Types of Analog to Digital Converter

- **Successive Approximation ADC:** This converter compares the input signal with the output of an internal DAC at each successive step. It is the most expensive type.
- **Dual Slope ADC:** It has high accuracy but very slow in operation.
- **Pipeline ADC:** It is same as that of two step Flash ADC.
- **Delta-Sigma ADC:** It has high resolution but slow due to over sampling.
- **Flash ADC:** It is the fastest ADC but very expensive.
- Other: Staircase ramp, Voltage-to-Frequency, Switched capacitor, tracking, Charge balancing, and resolver.

### Successive-approximation A/D converter

Successive approximation is perhaps the most widely used method of A/D conversion. It has a much shorter conversion time, it also has fixed conversion time that is the same for any value of the analog input.

The Fig 2 shows basic block diagram of a 4 bit successive approximation ADC. It consists of a DAC, a successive-approximation register (SAR), and a comparator.

#### The basic operation is as follows:

The input bits of the DAC are enabled (made equal to logic-1) one at a time, starting with MSB, as each bit is enabled, the comparator produces an output that indicates

whether the analog input voltage is greater or less than the output of the DAC for the corresponding I/p. If the DAC output is greater than the analog input, the comparator's output is low, causing the bit in the register to RESET. If the DAC output is less than the analog input the '1' bit is retained in the SAR register. The system does this with the MSB first, then the next most significant bit, then the next and so on. After all the bits of the DAC have been tried, the conversion cycle is complete.

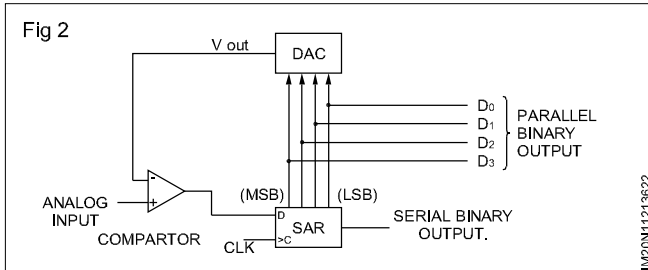


Fig 3 illustrates the step-by-step conversion of a constant analog input voltage (5V in this case). Let us assume that the DAC has the following output characteristic:  $V_{out} = 8V$  for the  $2^3$  bit (MSB),  $V_{out} = 4V$  for the  $2^2$  bit,  $V_{out} = 2V$  for the  $2^1$  bit and  $V_{out} = 1V$  for the  $2^0$  bit (LSB).

Fig 3a shows the first step in the conversion cycle with the MSB=1, the output of the DAC=8V. Since this is greater than the analog input of 5V, the output of the DAC is 8V. Since this is greater than the analog input of 5V, the output of the comparator is low, causing the MSB in the SAR to be reset to a logic-0.

Fig 3b shows the second step in the conversion cycle with the  $2^2$  bit equal to a logic-1. The output of the DAC is 4V, since this is less than the analog input of 5V, the output of the comparator switches to a HIGH, causing this bit to be retained in the SAR.

Fig 3c shows the third step in the conversion cycle with the  $2^1$  bit equal to a logic-1. The output of the DAC is 6 volts because there is a logic-1 on the  $2^2$  bit input and on the  $2^1$  bit input  $4V+2V=6V$ , since this is greater than the analog input of 5V, the output of the comparator switches to a LOW, causing this bit to be RESET to a logic-0.

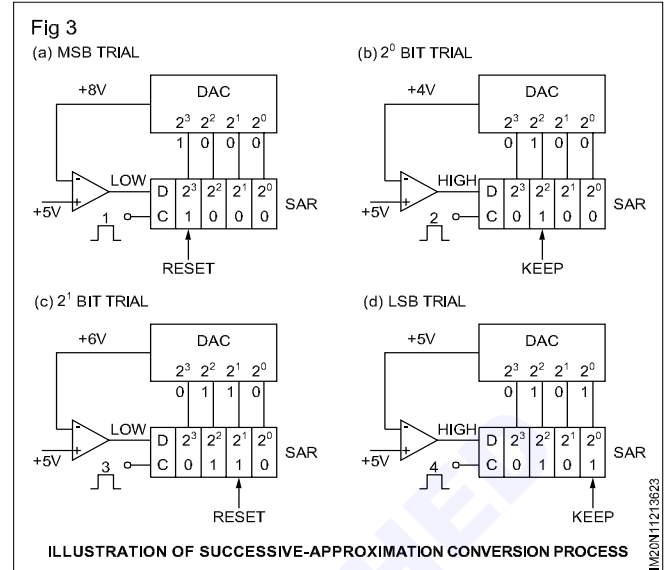
Fig 3d shows the fourth and final step in the conversion cycle with the  $2^0$  bit equal to a logic-1. The output of the DAC is 5V because there is a logic-1 on the  $2^2$  bit input and on the  $2^0$  bit input  $4V+1V=5V$ .

The four bits have all been tried, thus completing the conversion cycle. At this point the binary code in the register is 0101, which is the binary value of the analog input of 5V. Another conversion cycle now begins and the basic process is repeated. The SAR is cleared at the beginning of each cycle.

#### Analogue to digital converter ADC0808/0809 8 bit microprocessor compatible A/D converter

The ADC0808/0809 data acquisition device implement on a single chip most the elements of the standard data acquisition system. They contain an 8-bit A/D converter, 8 channel multiplexer with an address input latch and associated control logic. These device provide most of the

logic to interface to a variety of microprocessors with the addition of a minimum number of parts.



**Functional description :** The ADC0808/0809 shown in the above Fig 4 can be functionally divided into 2 basic sub circuits. These two sub circuits are an analog multiplexer and an A/D converter. The multiplexer uses 8-standard CMOS analog switches to provide for upto 8 analog inputs, the switches are selectively turned on, depending on the data latched into 3-bit multiplexer address register.

The second function block, the successive approximation A/D converter transforms the analog output of the multiplexer to an 8 bit digital word, the output of the multiplexer goes to one of two comparator inputs. The other input is derived from a 256R resistor ladder, which is tapped by a MOSFET transistor switch tree. The converter control logic controls the switch tree, funneling a particular tap voltage to the comparator, based on the result of this comparison, the control logic and the successive approximation register (SAR) will decide whether the next tap to be selected should be higher or lower than the present tap on the resistor ladder, this algorithm executed 8 times per conversion, once every 8 clock periods, yielding a total conversion time 64 clock period.

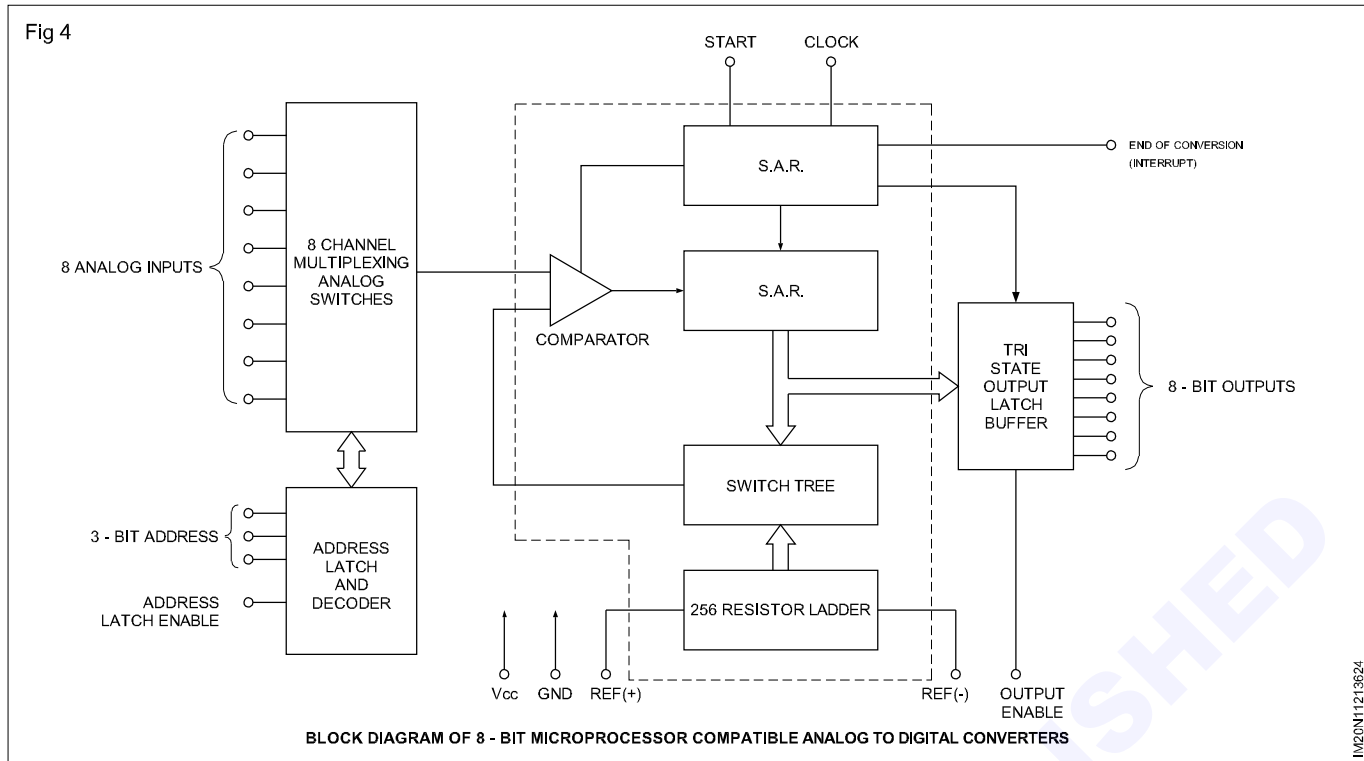
When the conversion cycle is complete the resulting data is loaded into the tristate output latch can then be read by the host system any time before the end of the next conversion. The tristate capability of the latch allows easy interface no bus oriented systems

#### Applications of ADC

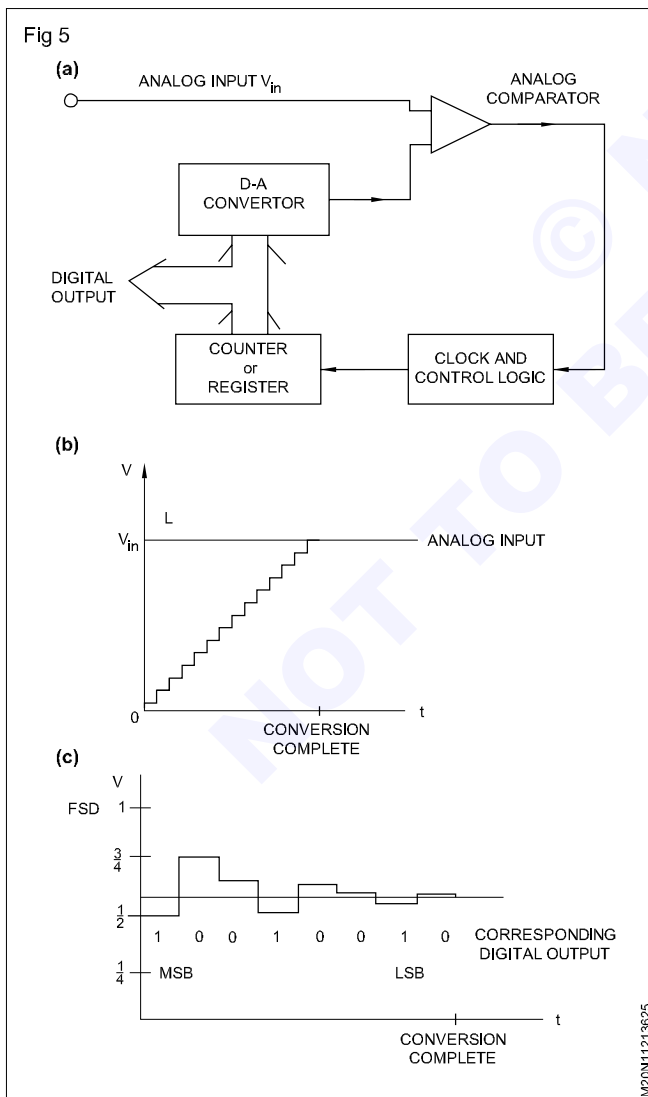
- used together with the transducer
- used is computer to convert the analog signal to digital signal
- used in cell phones
- used in micro controllers
- used in digital signal processing
- used in digital storage osilloscopes
- used in scientific instruments
- used in music reproduction technology etc.



Fig 4



The counter-ramp A-D converter (Fig 5)



The counter-ramp converter makes use of a D-A converter to perform A-D conversion. A block diagram of this converter is shown in Fig 5 (a). At the start of the conversion cycle the digital counter starts to count from zero. An analog output of the D-A converter corresponding to the digital count is compared with the analog input. When the two analog voltages are equal (within one step of the ramp) the output of the analog comparator changes its state. This stops the count and outputs a conversion complete signal indicating that the outputs of the counter now correspond to a digital code representing the analog input. The A-D conversion is thus completed and the counter is reset to start another ramp.

**The counter-ramp and successive approximation A-D converter:** (a) the block diagram of a counter-ramp and a successive approximation A-D converter (10) (b) the analog waveforms in a successive approximation A-D converter.

Counter-ramp converters are simple and stable but slow. In the worst case of an input equal to the maximum, the counter has to count through the full range for a conversion. Assuming a clock rate of 1 MHz and an 8 bit output code the rate of conversion is  $106/28 \approx 4\text{kHz}$ . This type of converter is also susceptible to noise and interference superimposed on the input signal. An erroneous conversion is made if an interference peak occurs which is big enough to trip the comparator.

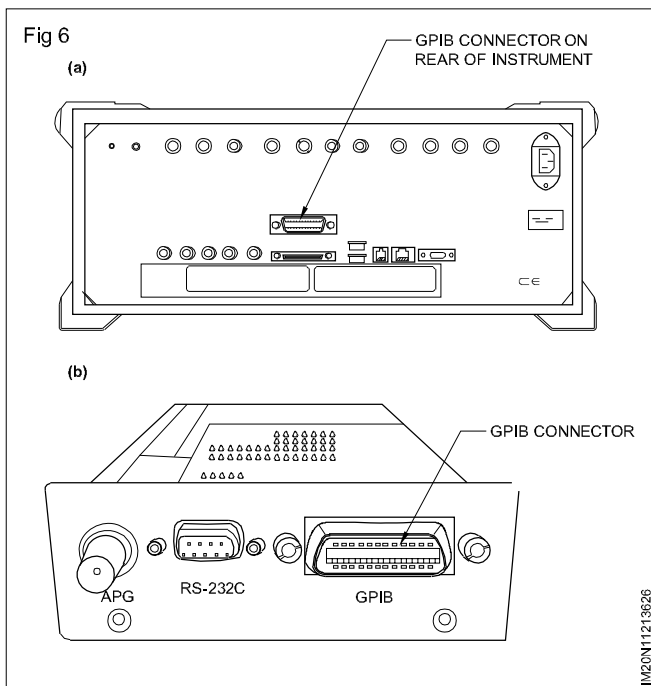
### GPIB (General purpose interface bus)

The GPIB or General purpose interface bus or IEEE 488 bus is still one of the more popular and versatile interface standards available today.

GPIB is widely used for enabling electronics test equipment to be controlled remotely. It can be used to control test equipments and any form of electronic test equipment.



Today most bench electronics test equipment has either a GPIB option or are fitted with it as standard fig 6(a) & 6 (b) shows GPIB connector on rear of the instrument.



It is one of the standard interfaces available in many stand alone, general purpose, high performance instruments for data acquisition and control employing PC.

### GPIB Standards (Fig 7)

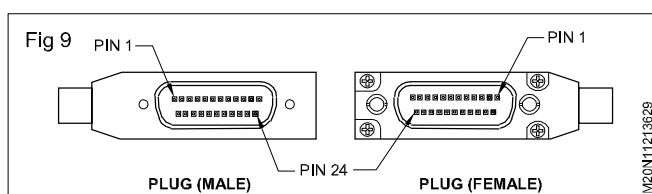
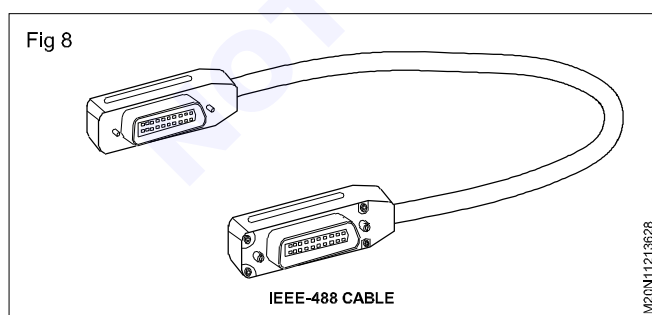
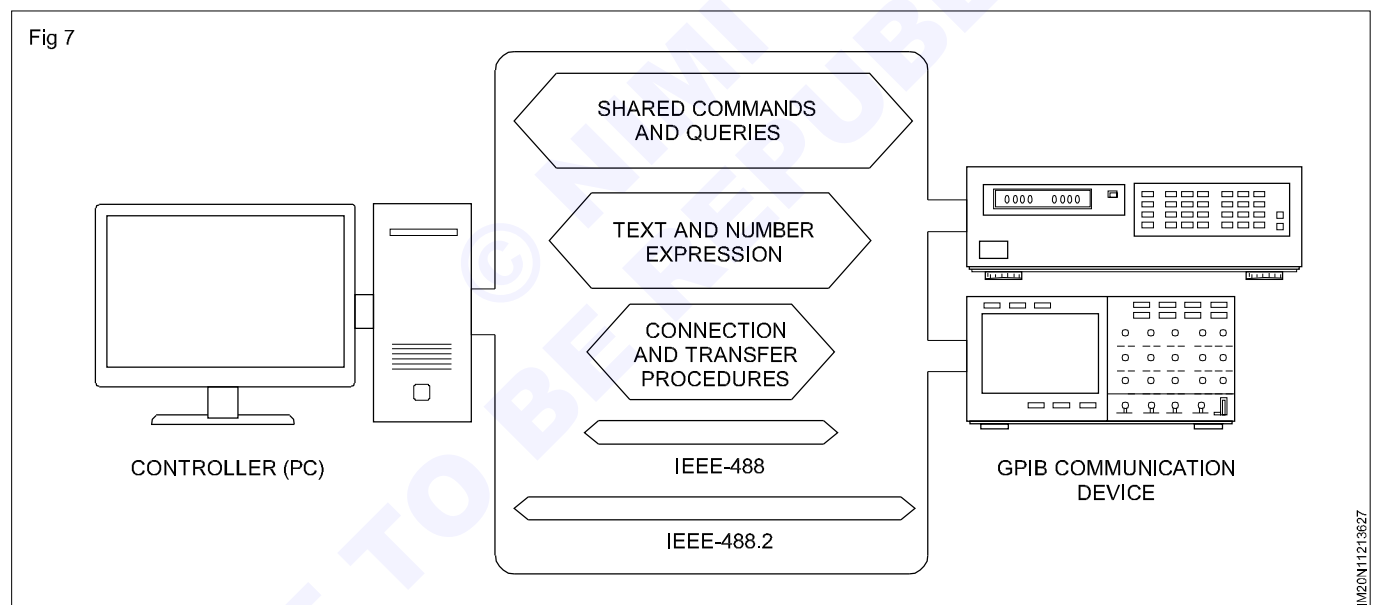
GPIB standards include IEEE - 488 and the higher level protocol IEEE - 488.2 which is currently used as mainstream. IEEE 488.2 features syntax for text data and numeric expressions, commands and queries that can be used by all instrument Fig 8 shows.

#### IEEE - 488 cable

#### IEEE - 488 cable

#### The GPIB has the following features

- The GPIB reduces the hardware for interfacing several instruments to one interface bus.
- It allows interfacing of wide variety of instruments.
- Communication between the devices is very fast and reliable.
- It is easy to setup and reconfigure. Fig 9 shows IEEE - 488 GPIB connector.



### Characteristus of GPIB

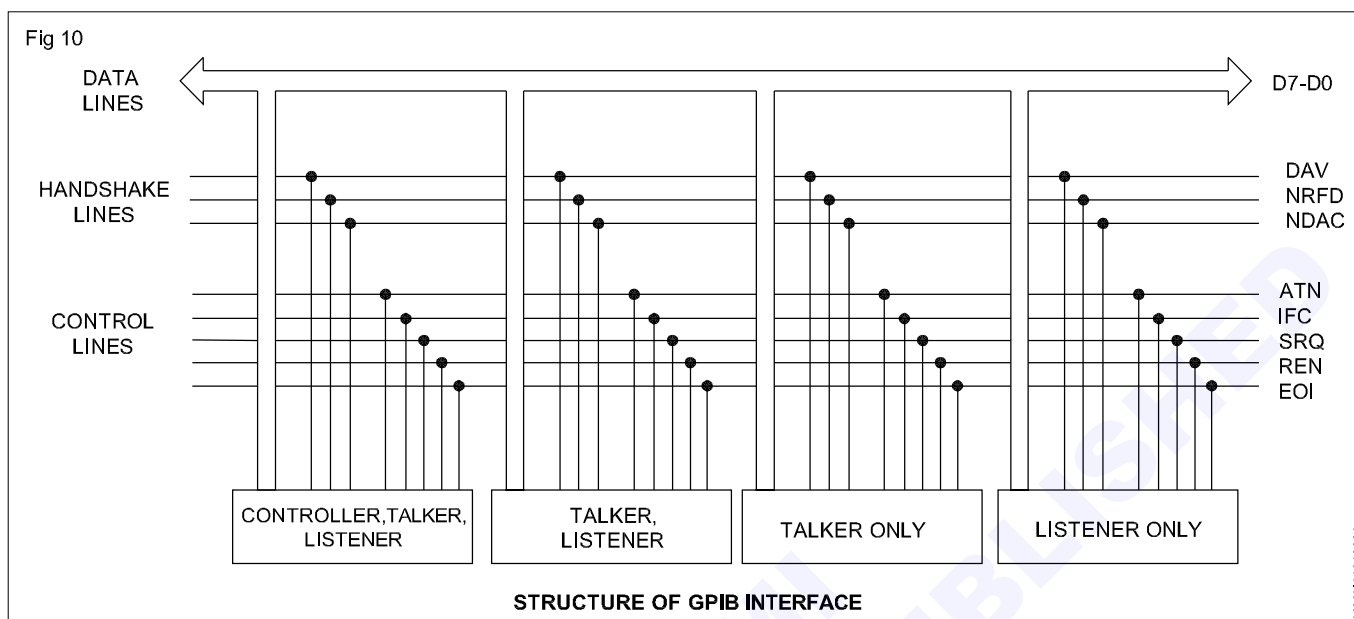
The GPIB is an ideal interface for measurement automation in laboratories. It forms an integrated measurement system by linking several laboratory instruments through the bus and by allowing a PC to control all the instruments. The GPIB has the following characteristics.

- The GPIB allows parallel and multidrop connections of up to 15 devices to the bus
- Each device on the bus is classified as talker, listener or controller.
- Each device on the bus has a unique address in the range 0-30.
- Total bus length may be up to 20 m and distance between each device may be up to 2 m.

- e GPIB transfers information as 8-bit parallel data
- f Uses hardware handshaking with special bus lines for data transfer.
- g The maximum data transfer rate on GPIB bus is 1 MB/s.

## GPIB system

Fig 10 shows the structure of the GPIB interface. Information carried by the bus is sent over 24-pin cable which connects computer to each device on the bus. GPIB allows a maximum of 15 devices to be connected to the GPIB bus. Each device connected to the GPIB serves as listener, talker or controller at any one time.



**Talker:** A device that sends data to the bus is a talker. Examples of talkers are digital voltmeter and frequency counter. A talker will be instructed to talk (send) by a controller by sending a command called talk address command. Only one device on the bus will be instructed to talk at a time.

**Listener:** A device that receives data from the bus is a listener. Examples of listeners are X-Y plotter, waveform generator and programmable power supply. Listeners will be instructed to listen (receive) by a controller by sending a command called listen address command. More than one device on the bus can be instructed to listen at a time. There can be up to 14 listeners on the bus. Devices such as, magnetic storage device and spectrum analyzer perform both talk and listen function but one function at a time.

**Controller:** A device that manages flow of information on the bus by sending command messages to all devices is a controller. The controller generates and transmits command strings to control other devices and it also receives and interprets message strings from other devices. A controller can perform talk, listen and control functions. The controller specifies other devices on the bus as talker or listener for data or command transfer. The GPIB requires at least one device on the bus to serve as the controller, and it is usually a Pc. A GPIB allows more than one controller to be on the bus. Though there can be more than one controller, only one controller can be active on the bus at any one time. A non-active controller may request control and the active control to the others.

To facilitate communication, each device on the bus is assigned a unique GPIB address, which is referred to as the primary address of the device. Though a GPIB bus can

accommodate a maximum of only 15 devices, the primary address can range from 0 to 30. The primary address for an instrument on the bus is assigned by setting the DIP switches / jumpers provided at the rear side of the instrument. Some instruments allow setting of the address from the front panel. The controller board in the PC also has an address and it is set during installation or by initializing software. The controller sends commands to all other devices on the bus. Communication between the devices on the bus is accomplished by instructing a talker to send information and instructing one or more listeners to receive the information. In a given instant, only one device is instructing one or more listeners to receive the information. In a given instant, only one device is instructing one or more listeners to receive the information. In a given instant, only one device is instructed to talk and several devices may be instructed to listen. The maximum data transfer rate on GPIB bus is 1 MB /s.

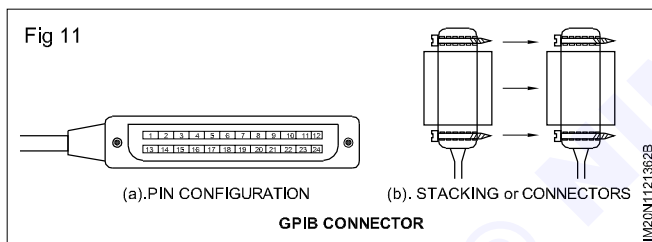
## GPIB Implementation

The GPIB is implemented with a GPIB controller adapter, associated driver software, and GPIB cables apart from PC and high performance instruments supporting GPIB interface. The GPIB controller adapters are available in various forms. Adapters that plug directly into the internal PC bus are popular and offer high performance at low cost. Adapters that connect to SCSI, serial ports, or parallel ports are easy to move from one computer to another, because they are external to the computer. The driver software provides an interface between the GPIB controller adapter hardware and the PC operating system. Implementation of GPIB takes the following steps.

- The GPIB controller hardware and driver software are installed in the PC.
- The PC and all the instruments are powered down.
- Unique address for each instrument on the bus is set.
- All the instruments and the PC are connected in a linear, star or linear / star combination configuration using standard GPIB cables.
- The PC and the instruments are powered up. It completes the GPIB hardware implementation.
- Data transfer between the constituents of the GPIB system is carried out by the software run on the controller.

The components of the GPIB system are capable of talking to each other. However, the intelligence of conversation depends on the versatility of software controlling the system.

**GPIB connector and connection configurations :** The GPIB uses a 24-pin cable to carry GPIB signals between the devices. The GPIB cable has both a male and a female connector at each end. The pin configuration of GPIB connector is shown in Fig 11 (a). The GPIB connectors can be stacked as shown in Fig 11 (b).

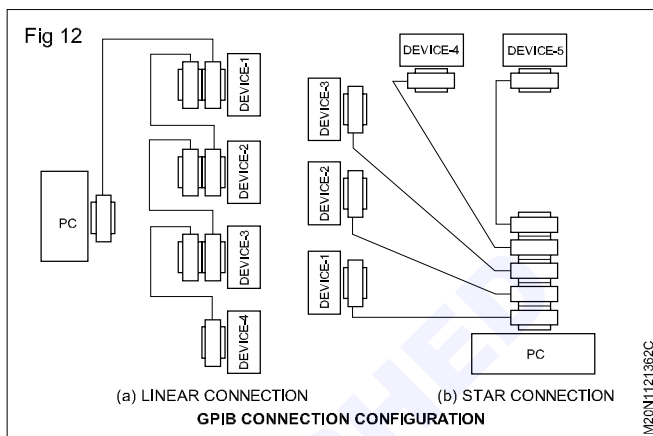


| Pin | Label  | Signal name        | Pin | Label | Signal name                   |
|-----|--------|--------------------|-----|-------|-------------------------------|
| 1   | DIO1   | Data               | 13  | DIO5  | Data                          |
| 2   | DIO2   | Data               | 14  | DIO6  | Data                          |
| 3   | DIO3   | Data               | 15  | DIO7  | Data                          |
| 4   | DIO4   | Data               | 16  | DIO8  | Data                          |
| 5   | EOI    | End or identify    | 17  | REN   | Remote enable                 |
| 6   | DAV    | Data valid         | 18  | GND   | Twisted-pair ground with DAV  |
| 7   | NRFD   | Not ready for data | 19  | GND   | Twisted pair ground with NRFD |
| 8   | NDAC   | Not data accepted  | 20  | GND   | Twisted pair ground with NDAC |
| 9   | IFC    | Interface clear    | 21  | GND   | Twisted pair ground with IFC  |
| 10  | SRQ    | Service request    | 22  | GND   | Twisted pair ground with SRQ  |
| 11  | ATN    | Attention          | 23  | GND   | Twisted pair ground with ATN  |
| 12  | Shield | Chassis ground     | 24  | GND   | Signal ground                 |

**Data lines:** The GPIB has 8-bit data bus and uses the eight data lines for sending data and command bytes from a talker or the controller to one or more listeners.

**DIO8-DIO1:** The GPIB Data input-output bus is an 8-bit, bi-directional bus operating at the TTL voltage levels. The GPIB uses the 7 LSB bits for the ASCII code. The one MSB bit is used for parity or unused.

The GPIB specifies that the length of a cable connecting the two devices on a GPIB bus cannot exceed 2 m and the total cable length in the system cannot exceed 20 m. The devices on the GPIB bus can be connected in different configurations. The devices may be connected in linear configuration as shown in Fig 12 (a) in star configuration as shown in Fig 12 (b) or in combination of both configurations.



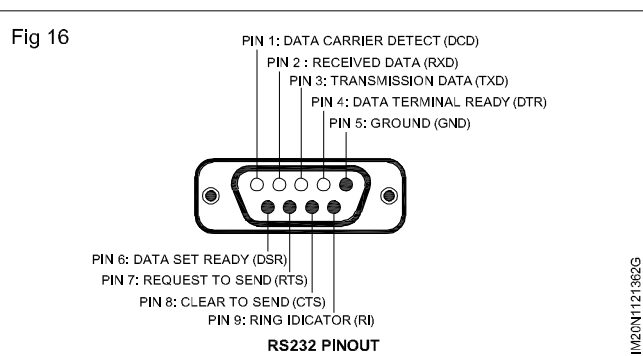
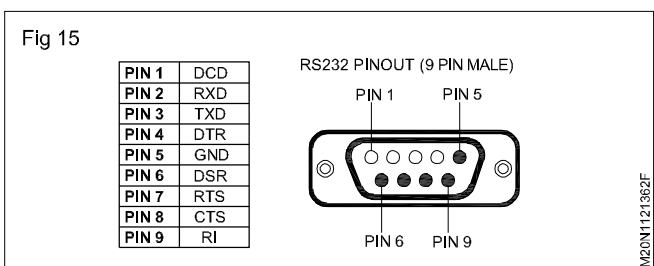
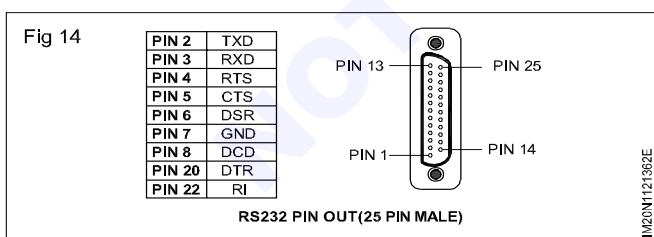
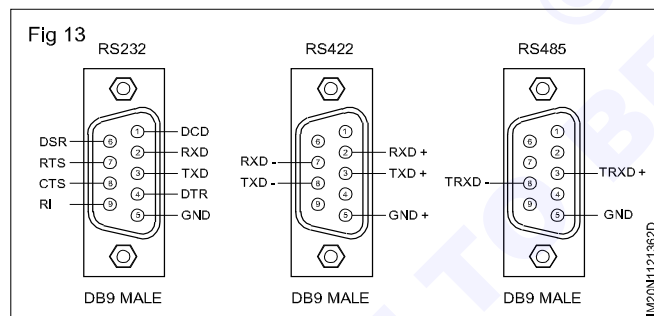
**GPIB pins and signals :** Table 1 lists the GPIB pins and signals. The GPIB uses 16 lines for its signals and eight lines for ground. The signal lines are grouped as data lines, control lines, and handshake lines. All lines on the GPIB operate at the TTL levels, but it uses negative logic. The negative logic means that voltage level less than 0.8 V corresponds to logic 1 and voltage level greater than 2.0 V corresponds to logic 0. The signal lines are driven by open-collector or tri-state drivers. The standard bus termination for the lines driven by open-collectors is a 3 k $\Omega$  resistor connected to +5 V in series with a 6.2 k $\Omega$  resistor to ground.

**Bus control lines:** The GPIB has five bus control lines. They are ATN, IFC, REN, EOI and SRQ. These lines use open collector. The functions of the bus control lines are as follows.

**RS-232 :** It telecommunications RS-232, Recommended standard 232 (1) is a standard originally introduced in 1960 (2) for serial communication transmission of data. It formally defines signals connecting between a DTE (data terminal equipment) such as a computer terminal, and a DCE (data circuit-terminating equipment or data communication equipment), such as a modem. The standard defines the Electronics characteristics and timing of signals, the meaning of signals, and the physical size and pinout of connectors. The RS-232 standard had been commonly used in computer serial ports and is still widely used in industrial communication devices.

A serial port complying with the RS-232 standard was once a standard feature of many types of computers. Personal computers used them for connections not only to modems, but also to printers, computer mice, data storage, uninterruptible power supplies, and other peripheral devices.

RS-232 when compared to later interfaces such as RS-422, RS-485 and Ethernet (Fig 13) has lower transmission speed, short maximum cable length, large voltage swing, large standard connectors, no multipoint capability and limited multidrop capability. In modern personal computer, USB has displaced RS-232 from most of its peripheral interface roles. Few computers come equipped with RS-232 ports today, so one must use either an external USB-to-RS-232 converter or an internal expansion card with one or more serial ports to connect to RS-232 peripherals. Nevertheless, thanks to their simplicity and past ubiquity, RS-232 interfaces are still used-particularly in industrial machines, networking equipment, and scientific instruments where a short range point-to-point, low-speed wired data connection is fully adequate RS-232 used to have 25 pin (Fig 14) now it is shrunk to just 9 pin (Fig 15 & 16)



## Pin Assignment

### RS232 Pin configuration

New RS232 has nine pins as mentioned earlier. These nine pins are arranged in the ports shown in RS232 connector pinout. The DCE and DTE ports are exactly similar except for the direction of data flow. These nine pins are roughly divided in to three categories and we will discuss each category below.

### RS232 features and specifications

- 1 RS232 uses asynchronous communication so no clock is shared between PC and MODEM.
- 2 Logic '1' on pin is stated by voltage of range '-15V to -3V' and Logic '0' on pin is stated by voltage of range '+3V to 15V'. The logic has wide voltage range giving convenience for user.
- 3 MAX232 IC can be installed easily to establish RS232 interface with microcontrollers.
- 4 Full duplex interface of RS232 is very convenient.
- 5 Two pin simplex RS232 interface can also be established easily if required.
- 6 A maximum data transfer speed of 19 Kbps (Kilobits per second) is possible through RS232.
- 7 A maximum current of 500 mA can be drawn from pins of RS232
- 8 The interface can be established up to a distance of 50 feet.

### Disadvantages of RS232

- 1 There is no pin dedicated for powering devices (No VCC)
- 2 More communications pins
- 3 Switching voltages between +15v and -15v is difficult at higher speeds
- 4 A maximum speed of 19 Kbps
- 5 A maximum distance of 50 feet
- 6 More pins lead to higher noise
- 7 Only a single device can be connected to RS232 connector unlike 12C
- 8 Need hardware to convert high voltage logic of RS232 to be compatible to TTL (controller and processor units)

### Where RS232 is used ?

A few examples where RS232 are suitable to use:

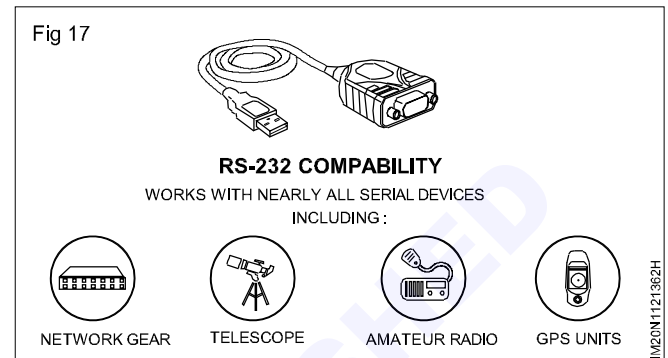
- 1 When you want a simple communication interface between two units. A two pin full duplex communication can be established easily on RS232 port.
- 2 RS232 is used in systems where clock sharing is difficult. RS232 is ASYNCHRONOUS so there will be no clock sharing between systems. All you need to do is set data bit rate for each unit. Once baud rate is set the units will sample the data according to set baud rate.
- 3 RS232 is also used to control a single unit specifically without delay or errors.
- 4 RS232 interface also delivers data with more accuracy which is a requirement in some cases.

### Applications

- 1 Personal computer
- 2 Modems

- 3 Servers
- 4 Memory devices
- 5 Motor control units
- 6 Printers and scanners
- 7 Telephone lines
- 8 Used basically where serial data transfer is required

Fig 17



| Pin name                                                                        | Pin name | Description                                                                           |
|---------------------------------------------------------------------------------|----------|---------------------------------------------------------------------------------------|
| DATA pins (Data flow takes through these pins)                                  |          |                                                                                       |
| 2                                                                               | RXD      | Receive Data (Data is received through this pin)                                      |
| 3                                                                               | TXD      | Transmit Data (Data is transmitted through this pin)                                  |
| CONTROL pins (These pins are for establishing interface and to avoid data loss) |          |                                                                                       |
| 1                                                                               | CD       | Carrier Detect (Set by MODEM when answer is received by remote MODEM)                 |
| 4                                                                               | DTR      | Data Terminal Ready (Set by PC to prepare MODEM to be connected to telephone circuit) |
| 6                                                                               | DSR      | Data set ready (set by MODEM to tell PC it is ready to receive and send data)         |
| 7                                                                               | RTS      | Request to send (set by PC to tell MODEM that MODEM can begin sending data)           |
| 8                                                                               | CTS      | Clear to send (Set by MODEM to tell PC that it is ready to receive data)              |
| 9                                                                               | RI       | Set by MODEM to tell PC a ringing condition has been detected.                        |
| Reference                                                                       |          |                                                                                       |
| 5                                                                               | GND      | Ground (Used as reference for all pin voltage pulses)                                 |



## Working of frequency meter, phase measuring meter, time measuring instrument and digital capacitive meter

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

- explain the digital instruments
- explain the working principle of frequency meter
- explain the working principle of phase measuring meter
- explain the working principle of time measuring instrument
- explain the working principle of digital capacitance meter.

### Digital Instrument

#### Definition

The instrument which represents the measurand value in the form of the digital number is known as the digital instruments. It works on the principle of quantization. The quantization is the process of converting the continuous input signal into a countable output signal.

The construction of the digital instrument is very complex, and their cost is also very high. The digital instruments consume very less power as compared to analogue instruments. The digital multimeter, digital voltmeter, digital frequency meter etc., are the examples of the digital instruments.

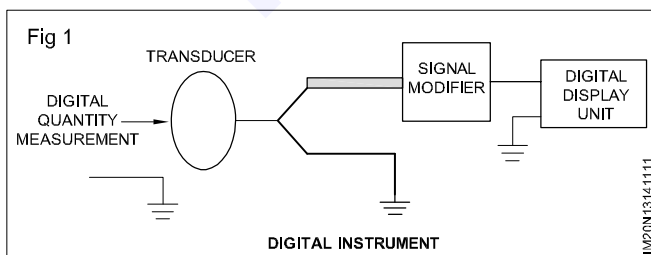
#### Important characteristic of digital instruments

The digital devices have following important features

- 1 The accuracy of the digital electronic instrument is very much high.
- 2 The digital instrument consists sensitive elements which are easily reacted with the surrounding temperature and humidity.
- 3 The input impedance of the digital instrument is very high because of which it can draw very less power.
- 4 The digital instrument is less portable.
- 5 The cost of the instrument is high.
- 6 The instrument is free from the parallax error.

In analogue instruments, the pointer is used for indicating the measuring voltage because of which the parallax error occurs. While in digital instruments the output is display on the screen. Thus, the chances of errors are less on it.

**The Construction of digital instrument is shown in the fig below (Fig 1)**



The transducer, signal modifier and the display devices are the important part of the digital instrument.

**Transducer** - The transducer is used for converting the non-Electronics or physical quantities (temperature, displacement etc.) into an Electronics quantity like voltage, current etc. which is easily measured by the meter. The transducer is not required for the Electronics input.

**Signal modifier** - It is used for modifying the input signal of very weak strength.

**Display device** - The display device is used for showing the measurand quantities in the numeric form. Mostly LED or LCD is used as digital display.

#### Advantages of digital instrument

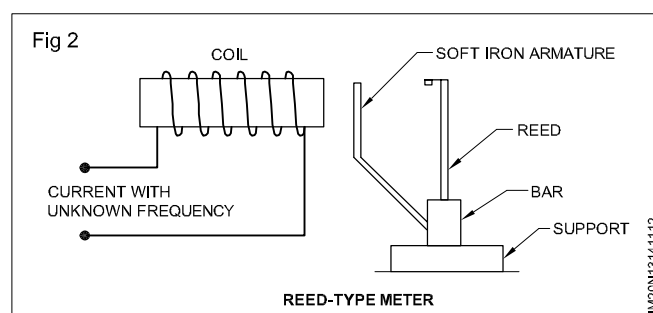
- 1 The digital instruments display the reading in the numeric form which reduces the error.
- 2 The digital output is obtained by the instrument which acts as an input for the memorable devices like floppy, recorder, printer etc.
- 3 The power consumption is less in the digital instruments.

#### Disadvantages of digital instruments

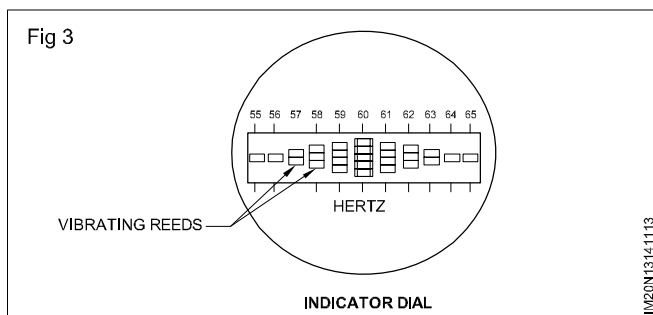
The following are the disadvantages of the digital electronics.

- 1 The overloading capacity of the instrument is low.
- 2 It is a temperature sensitive device. The digital instrument is made by the very delicate element which is easily affected by the atmospheric condition.
- 3 The effect of noise is more on digital electronics as compared to the analogue instruments.

**Digital frequency meter circuit diagram and working principle :** The frequency of periodic electric voltage or current can be determined directly by the use of a frequency meter or indirectly through a comparison with a known frequency. One of the many frequency meters that directly indicates frequency is reed-type meter of the following fig 2.

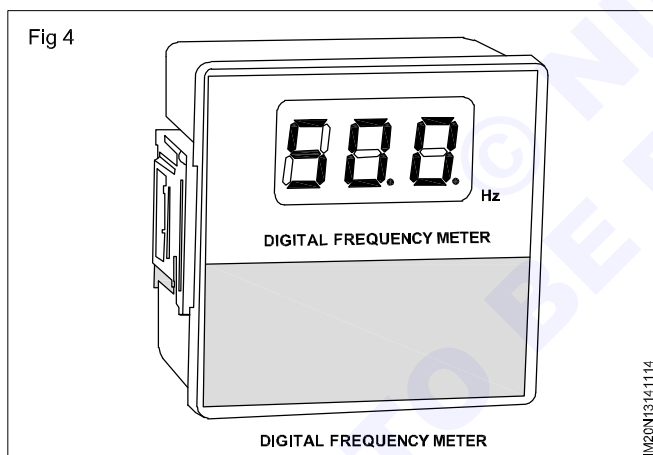


### Indicator Dial (Fig 3)



In this type of meter, many reeds are mounted on a common support, with their free ends visible on the meter face. Each reed has its own natural frequency of vibration. When an internal electromagnet is excited by the current of unknown frequency, an alternating magnetic field is produced. If the frequency of the field corresponds to the vibration frequency of the reed, that particular reeds vibrate with considerable amplitude. If two adjacent reeds vibrate with the same amplitude, the unknown frequency is halfway between those indicated by the two vibrating reeds. The reed-type meter is useful only at low frequencies and only over a limited range of frequencies.

Another type of frequency meter is the **digital frequency meter**, which measures frequency up to about 100 MHz and displays a digital readout of the measured frequency as shown in fig 4.



The digital frequency meter is commonly called a counter since it determines the frequency by electronically counting the number of cycles of an unknown signal in a standard time interval, usually 1 second. The following figure describes the basic working principle of digital frequency meter.

#### Working Principle of Digital Frequency Meter (Fig 5)

In above figure 5 pulse conversion block converts the sinusoidal signal into a discrete set of pulses. The train of discrete pulses then passes through the gate which remains open for a certain time. The electronic counter counts these pulses from gate output. The resultant value is displayed on main meter screen. In addition to its basic function of measuring frequency, the counter can count uniform or random pulses or events and displays the total.

**Digital phase meter:** The simplest technique to measure the phase difference between two signals employs two flip-

flops. The signals to be fed must be of the same frequency. First the signals must be shaped to a square waveform without any change their phase positions, by the use of a zero crossing detector. The process of measuring the phase difference can be illustrated by the schematic diagram shown in Fig 6.

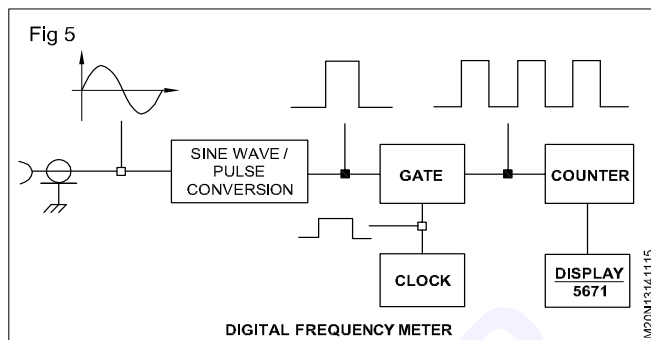


Fig 6 show the block diagram consists of two parts of preamplifier's, zero crossing detectors, J-K and a single control gate. Two signals having phases  $P_0$  and  $P_x$  respectively are applied as inputs to the preamplifier and attenuation circuit. The frequency of the two inputs is the same but their phases are different.

As the  $P_0$  input signal increase in the positive half cycle, the zero crossing detector changes its state when the input crosses zero (0) giving a high (1) level at the output. This causes the J-K/F-1 to be set (1) that is, the output (Q) of F/F-1 goes high. This high output from the F/F-1 enables the AND gate, and pulses from the clock are fed directly to the counter. The counter starts counting these pulses. Also this high output level of F/F-1 is applied to the clear input of F/F-2 which makes the output of the F/F-2 go to zero (0).

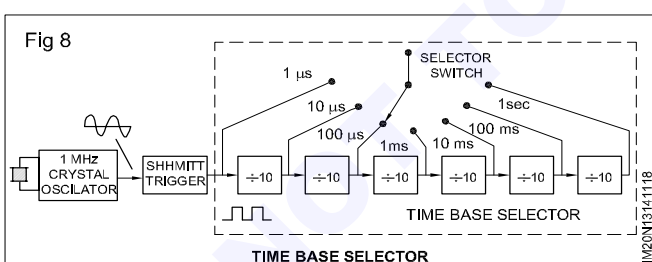
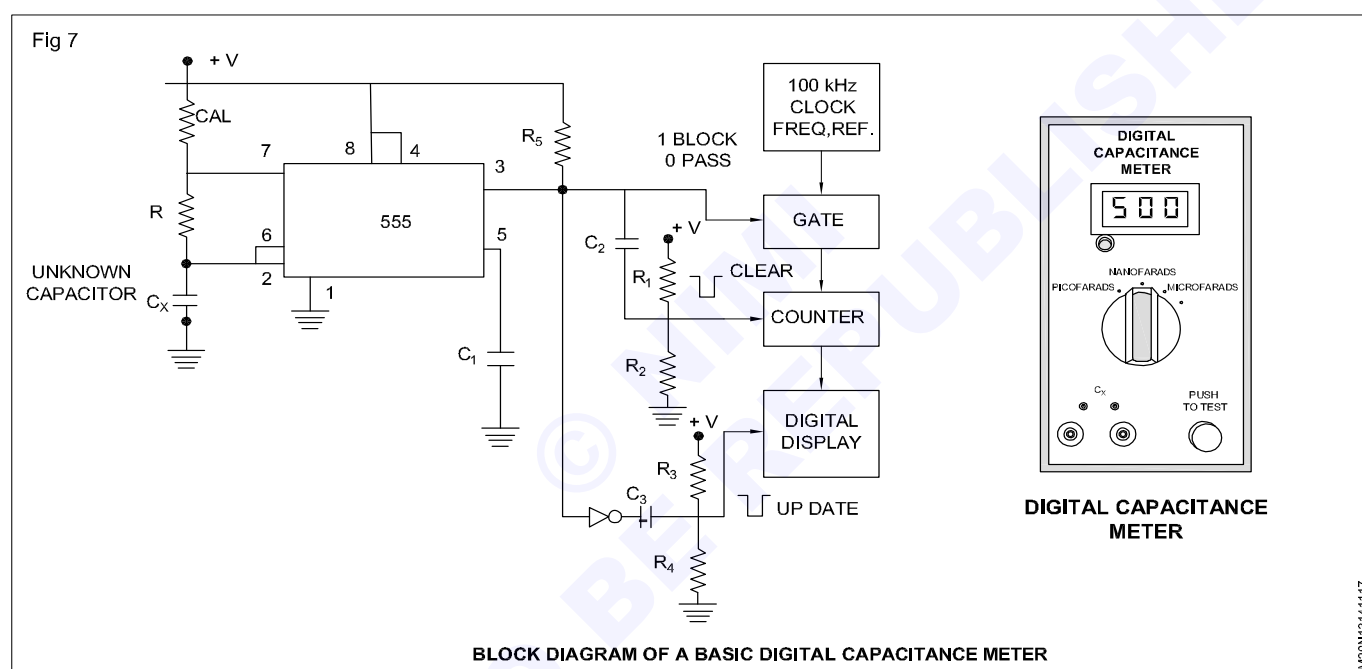
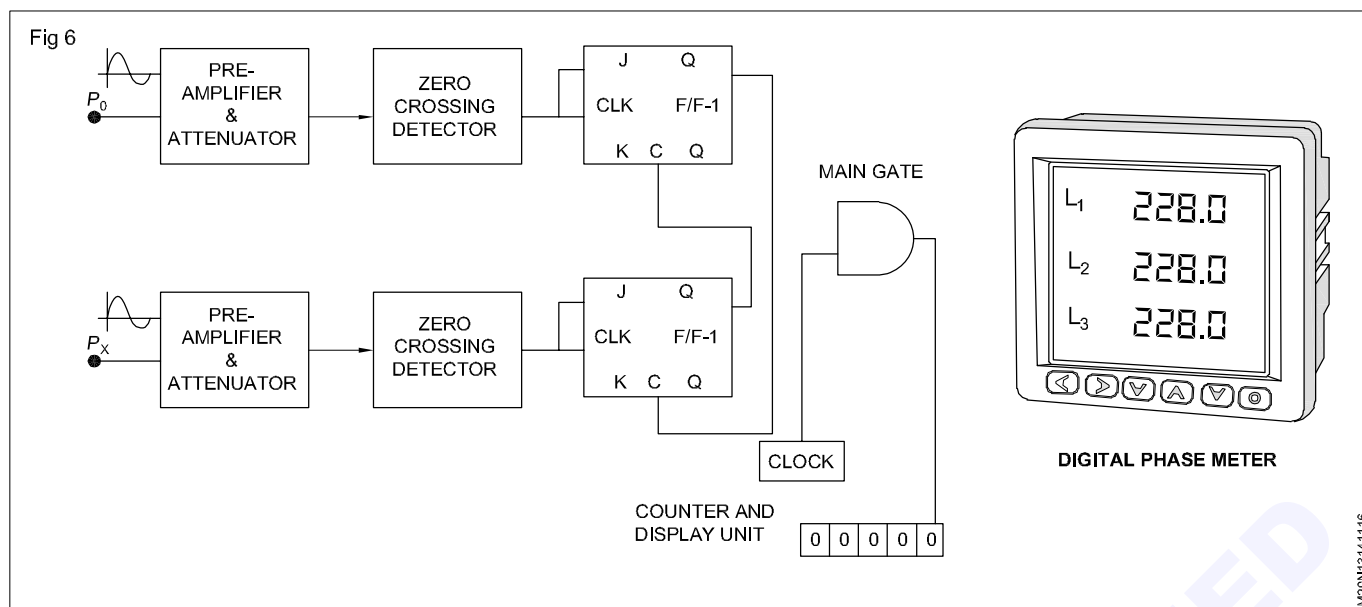
Now as the input  $P_x$ , which has a phase difference with respect to  $P_0$ , crosses zero (0) in the positive half cycle, the zero detector is activated, causing its output to go high (1). This high input in turn toggles the J-K/F-2, making its output go high. This output (Q) of F/F-2 is connected to the clear input of F/F-1 forcing the F/F-1 to reset. Hence the output of F/F-1 goes to zero (0). The AND gate is thus disabled and the counter stops counting fig 7 shows digital phase measuring meter.

#### Digital capacitance meter

Digital capacitance meter - since the capacitance is linearly proportional to the time constant, when a capacitor is charged by a constant current source and discharged through a fixed resistance, we can use a 555 timer along with some digital test equipment to measure capacitances.

The way is to measure the time period of the oscillations. By choosing the right size of charging resistance, can get a reading directly in microfarads or nanofarads. Unlike many capacitance measuring schemes, this one easily handles electrolytics up to the tens of thousands of microfarads.

A better way is to measure only the capacitor discharge time, as shown in Fig 8. With this method, any leakage in the capacitor under test will make the capacitor appear smaller in value than it actually is and is an effective indicator of how the test capacitor will behave in most timing and by pass circuits.



In this circuit, the 555 timer is used as an astable multivibrator. At the peak of the charging curve, a digital counter is reset and a clock of 100 kHz pulses is turned on and routed to the counter. When the discharge portion of the cycle is completed, the display is updated and the value of the capacitor is readout. By selecting the proper reference frequency and charging currents, one can obtain a direct digital display of the value of the capacitance.

Be sure to properly shield the leads and keep them short for low capacity measurements, since the 50 Hz hum can cause some slight instability.

## Digital measurement of time

The principle of operation of digital measurement of time is given by

The beginning of the time period is the start pulse originating from input 1, and the end of the time period is the stop pulse coming from input 2.

The oscillator runs continuously, but the oscillator pulses reach the output only during the period when the control F/F is in the 1 state. The number of output pulses counted is a measure of the time period.

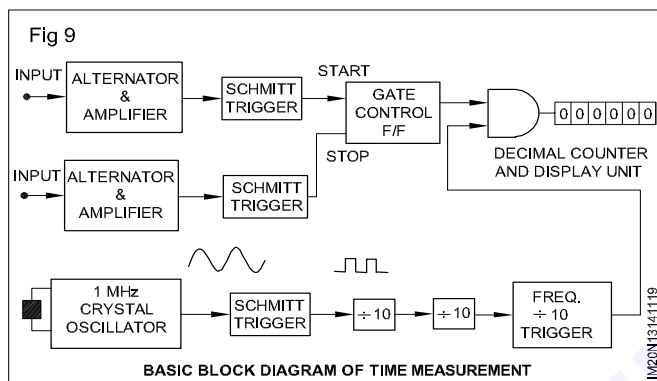
### Time base selector

It is clear that in order to know the value of frequency of the input signal, the time interval between the start and stop of the gate must be accurately known. This is called time base.

The time base consist of a fixed frequency crystal oscillator, called a clock oscillator, which has to be very accurate. In order to ensure its accuracy, the crystal is enclosed in a

constant temperature oven. The output of this constant frequency oscillator is fed to a schmitt trigger, which converts the input sine wave to an output consisting of a train of pulses at a rate equal to the frequency of the clock oscillator. The train of pulses then passes through a series of frequency divider decade assemblies connected in cascade. Each decade divider consists of a decade counter and divides the frequency by ten. Outputs are taken from each decade frequency divider by means of a selector switch; any output may be selected.

The circuit of fig 9 consists of a clock oscillator having a 1 MHz frequency. The output of the schmitt trigger is 106 pulses per second and this point corresponds to a time of 1 microsecond. Hence by using a 6 decade frequency divider, a time base with a range of 1  $\mu$ s - 10  $\mu$ s - 100  $\mu$ s - 1 ms - 10 ms - 1 s can be selected using a selector switch.



### Measurement of time (period measurement)

In some cases it is necessary to measure the time period rather than the frequency. This is especially true in the measurement of frequency in the low frequency range. To

obtain good accuracy at low frequency, we should take measurements of the period, rather than make direct frequency measurements. The circuit used for measuring frequency can be used for the measurement of time period if the counted signal and gating signal are interchanged.

The circuit for measurement of time period. The gating signal is derived from the unknown input signal, which now controls the enabling and disabling of the main gate. The number of pulses which occur during one period of the unknown signal are counted and displayed by the decade counting assemblies. The only disadvantage is that for measuring the frequency from the time by using the equation  $f = 1/T$ .

For example, when measuring the period of a 60 Hz frequency, the electronic counter might display 16.6673 ms, whence the frequency is

$$f = 1/T = \frac{1}{16.6673 \times 10^{-3}} = 59.9977 \text{ Hz}$$

the accuracy of the period measurement and hence of frequency can be greatly increased by using the multiple period average mode of operation. In this mode, the main gate is enabled for more than one period of the unknown signal. This is obtained by passing the unknown signal through one or more decade divider assemblies (DDAs) so that the period is extended by a factor of 10,000 or more.

Hence, the digital display shows more digital of information, thus increasing accuracy. However, the decimal point location and measurement units are usually changed each time an additional decade is added, so that the display is always in terms of the period of one cycle of the input signal, even though the measurements may have lasted for 10,100 or more cycles.

## Working principle of oscilloscopes

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

- list the five main functional blocks of a typical oscilloscope
- list the main parts of a CRT
- explain the need and method of post acceleration system
- explain the term Astigmatism
- explain the trigger and trigger method used in oscilloscopes
- explain how Lissajous figures can be used for frequency and Phase measurement
- explain the need of dual-beam oscilloscope and the main difference in the tube assembly used
- explain the need and principle of working of sampling oscilloscopes
- explain the working of storage tube in storage oscilloscope.

After using the Oscilloscopes in many of the previous exercises, you must be now familiar with the use of Oscilloscope. Hence, this lesson will focus on the working principle and internal details of a typical oscilloscopes used in laboratory tests.

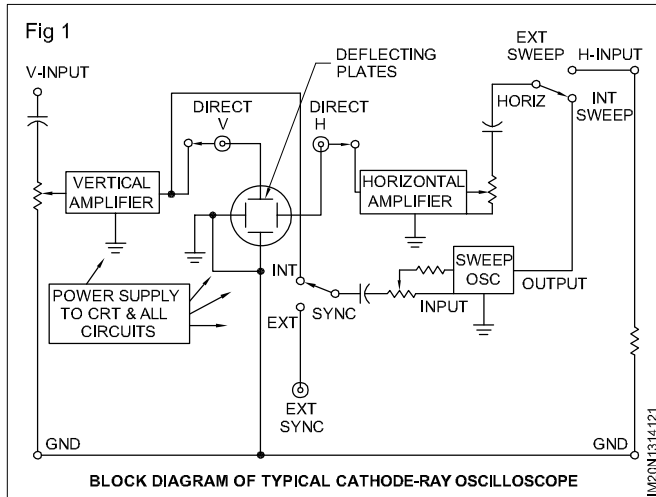
Oscilloscope is an electrostatic measurement device. The movable pointer is composed of electrons being subjected to applied electrostatic field to be measured. As electrons are the lightest charged particles, they can directly respond to very fast changes of the Electronics field strength. The heart of a Oscilloscope is the Cathode Ray Tube (CRT) which makes the signal visible by the actio of an electronic beam.

Fig 1 illustrates the simplified functional block diagram of the internal parts of an oscilloscope.

Referring to the block diagram of a general oscilloscope shown in Fig 1, observe that there are Five main functional units. These enable to display the input signal waveform.

- 1 Cathode Ray Tube (CRT).
- 2 The Vertical amplifier : This provide ample deflection of the input signal.
- 3 The Horizontal amplifier combined with the Sweep oscillator/time-base: This provide suitable time base deflection in synchronism with the input signal.

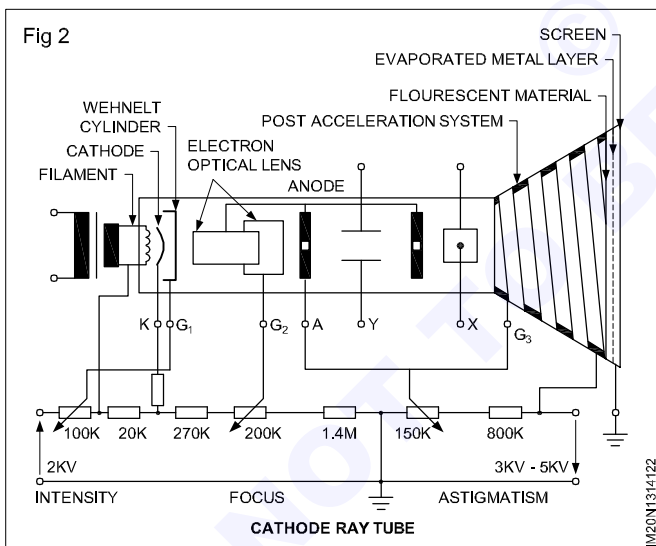




- 4 The Power supply: This is made-up of a low voltage section and a high voltage section. This supplies the required power to all the internal parts of the oscilloscope.

### The Cathode Ray Tube (CRT)

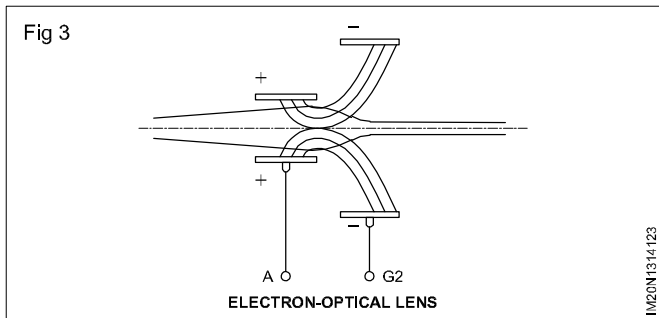
All the parts of the cathode ray tube is housed inside an evacuated glass enclosure as shown in Fig 2. CRT produces a narrow beam of electrons from an electron gun assembly. This beam is then accelerated and impinges at high speed on the phosphorescent coating (screen) of the tube face. The impact of the narrow beam of electrons on the phosphor produces a single small spot of light on the screen. It is this small round spot of light that traces out the pattern of the wave form as it is moved by the vertical and horizontal deflecting plates of the CRT.



**Cathode:** The cathode is indirectly heated. Due to a barium oxide layer on the cathode surface, a temperature of around 800°C is needed to emit sufficient number of electrons per unit of time.

**Wehnelt Cylinder:** This is designed as an orifice plate. It is connected to a negative voltage towards the cathode which controls the beam and intensity with the help of P1. This way the brightness of the screen trace can be adjusted.

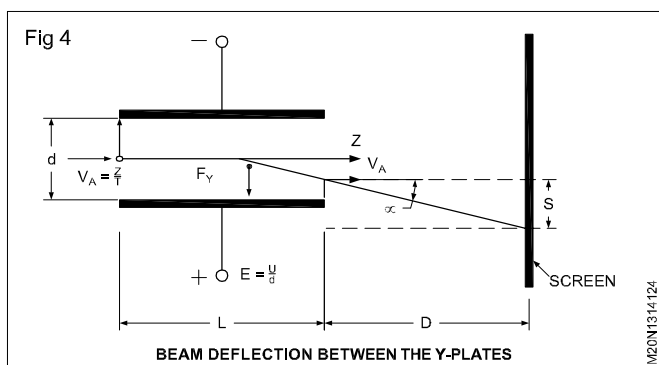
**Electron Optical lens:** This does the compression of the electron beam onto a thin line as shown in Fig 3.



The effect of the electron optical system is quite similar to the effect of a convex lens on visible light. By changing the potential of G2 towards A with the help of P2, the focal length of the lens can be set to produce a depiction which is well in focus on the screen. After having passed the electron optical lens, a parallel beam is obtained having a circular cross-section of a very small diameter.

**Anode:** It is the last electrode of the beam generating system. It is supplied by a voltage which may range between 1 and 5KV with respect to cathode. This high potential accelerates the electrons to a considerable high speed. This high speed (kinetic energy) is converted into a visual trace on the screen. The center of the anode is designed as a hole, hence the electrons are channelled through it and continue to travel with a constant velocity before hitting the phosphor material behind the face of the screen of CRT.

**Deflection Plates:** After having passed the anode opening, the electrons approach the uniform fields of the deflection plates. First they reach the Y-plates which deflect the beam in vertical direction. After that they pass the X-plates designed quite the same way as the Y-plates but turned 90 degrees towards the Y-plate. This way they deflect the beam in horizontal direction. The voltage to be measured is applied to the Y-plates, which deflects the beam by an amount (say) S as shown in Fig 4. Further details of the CRT are discussed later.



### Vertical Amplifier

The frequency response characteristics and sensitivity of the oscilloscope are determined chiefly by the vertical amplifier. Greater the sensitivity means narrower bandwidth. This is because, the product of gain times bandwidth is constant for a given amplifier.



Therefore the sensitivity of the oscilloscope is specified as so many volts/cm of vertical deflection at mid-band frequency. The 3db down response will also be specified at some specific band edge frequencies.

### Sweep Oscillator

The sweep oscillator for generating the time base in a typical general purpose oscilloscope has a frequency range from say from 10Hz to 30 KHz. It is controlled by a coarse-frequency switch and a fine-frequency variable control. The scope can thus display as many as 5 cycles of a 50Hz input and 10 cycles of 300 KHz input.

Almost in all oscilloscopes the time base is synchronized, allowing a choice between “internal” and “external” synchronization. In the internal sync position, the fine-frequency control is adjusted to set the sweep frequency as close as possible to the desired sub multiple of the input signal, then a small amount of the synchronizing voltage from the input signal locks the pattern into a stationary display. Further details about triggering is discussed in subsequent paragraphs.

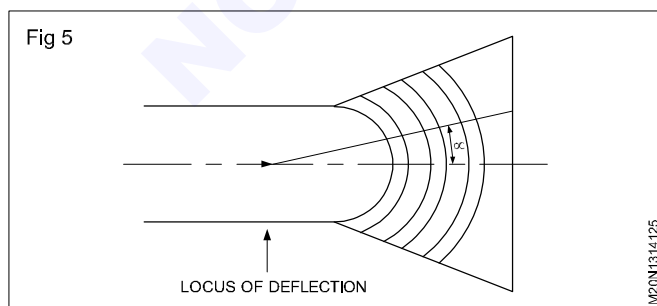
### Horizontal Amplifier

The horizontal amplifier serves two purposes. In ordinary waveform presentation, it amplifies the time-base voltage from the sweep oscillator. A control makes it possible to adjust the width of the resulting pattern. When switched out of the internal sync position, it accepts an external signal applied to the horizontal terminals and amplifies the horizontal signal to the amount required for horizontal deflection. More details about the x-deflection is discussed in further paragraphs.

### Post acceleration system

A high velocity of the electrons would certainly cause a bright appearance of the depicted spot on the screen. A high speed is obtained from a high anode voltage, which unfortunately would spoil a good deflection S. But both good deflection and a bright depiction need be coped up with.

To achieve this a post acceleration system is introduced. This system does not effect the deflection angle  $\alpha$ , but only provides additional acceleration to the electrons. For this purpose concentric rings made from graphite or a spiral are introduced into the conical part of the glass bulb as shown in Fig 5.

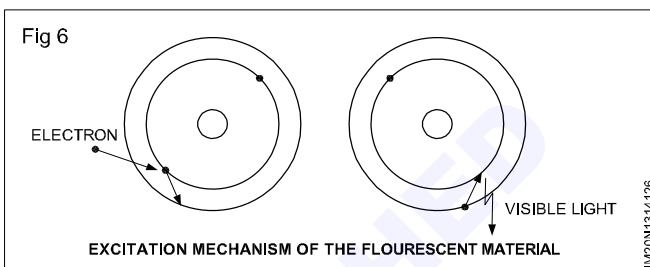


Their potential rises up to 5 kV. The rings provide areas of equal potential which are ball sections, having their centre at the locus of deflection. This design allows a post acceleration independently of the deflection angle. For any

a, the electrons have to pass the same difference of potential resulting in the same final velocity for each of them. Eventually they hit the fluorescent screen with a very high speed thus producing a bright trace.

### Fluorescent screen

The screen of an oscilloscope is covered from inside with a fluorescent substance which consists of zinc compounds. They differ from each other by different persistence and different colours. Once the electrons hit the fluorescent material they excite it for visible light radiation as shown in Fig 6.

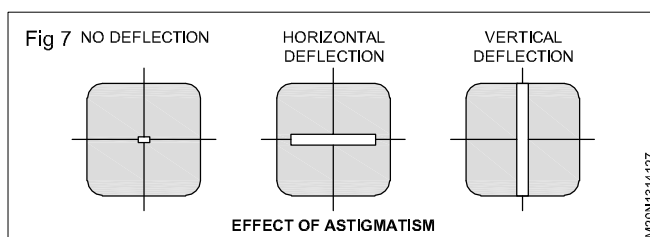


The high velocity electrons hit the atoms of the light emitting substance and they lift their electrons to orbits (around the atom core) which are of a higher energy level. They stay there for a certain short time which is typical for each substance. After that they fall back to their original orbit of lower energy level. The energy difference is emitted as a light quantum  $h \cdot \nu$  ('h' being PLANCK's natural constant and  $\nu$ , the frequency of the radiated light).

In order to avoid a negative charging of the screen trace (due to the charges of the arriving electrons) a thin metal layer of the thickness of only a few molecules is deposited on the screen from inside. It is transparent and grounded in order to draw out the incoming charge.

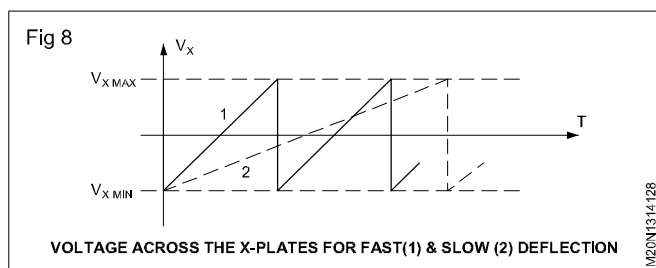
### Astigmatism

The cross section area of the beam should be a narrow circle, and so should the light spot on the screen. For this purpose the electric fields of the beam generating components need be extremely symmetrical and the deflection fields should be homogenous. Because of this condition the potentials right in the middle between the y- and the x- plates need to be the one of the anode as well as the one of the orifice plate between them which serves shielding purposes. The symmetry is set to its necessary amount with the help of potentiometer  $P_3$ . In case  $P_3$  is not properly adjusted the horizontally deflected beam may be depicted well in focus but the vertically deflected one may produce a wide screen appearance as shown in Fig 7. Modern scopes provide low tolerances for all components. So there is no need for any astigmatism potentiometer. But older types may still have it.



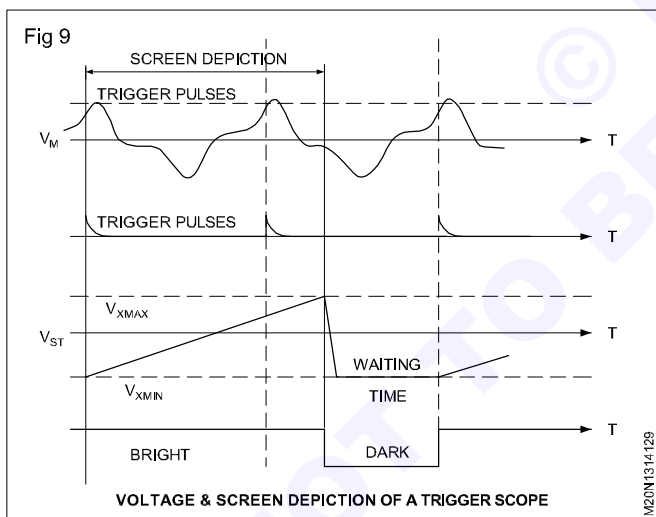
## Time base

In order to deflect the beam horizontally proportional to time a voltage  $V_x$  is needed which rises linearly with time. It is used to control the position of the light spot on the screen in x-direction. Its lowest value  $V_{x\min}$  should set the beam to the left edge of the screen and its highest one  $V_{x\max}$  to the right edge. The whole run should be provided repeatedly. The switching back from the right to the left edge should be effected as fast as possible. So, a saw tooth X-deflection voltage as shown in Fig 8 serves this purpose. For trace 2 the deflection is slower than for trace 1.



## Trigger method

The trigger instant of the saw tooth is linked to a certain instantaneous value of the measurand, the trigger level, and its slope. Once the trigger level is reached by  $V_m$  at a positive slope as shown in Fig 9, the beam starts at the left edge, for at that instant  $V_{ST} = V_{x\min}$ . The light spot travels with a certain speed in x-direction across the screen according to the slope of  $V_{ST}$  and finally reaches the right edge.



$V_{ST}$  is equal to  $V_{x\max}$  then. Immediately after  $V_{x\max}$  was reached the beam is switched back to the left edge where the trace of the measurand during the positive slope of  $V_{ST}$ . No depiction appears during the fly back time and the waiting time of the spot.

The trigger "level" may be shifted throughout the whole voltage range between peak to peak value of the measured. Doing this the depiction appears to be shifted in x-direction.

The slope of the saw tooth voltage  $V_{ST}$  can be changed in wide range from very slow to very fast allowing to depict many periods of the measurand on the screen but also only part of it.

## Power supply

Different voltages required for the oscilloscope is obtained from this unit. The exact value of voltages required for each model of the oscilloscope depends on the type of CRT used, the type of circuit components used and so..on. However essentially any CRO need a high voltage supply for the CRT and low voltage supply for the electronic circuits.

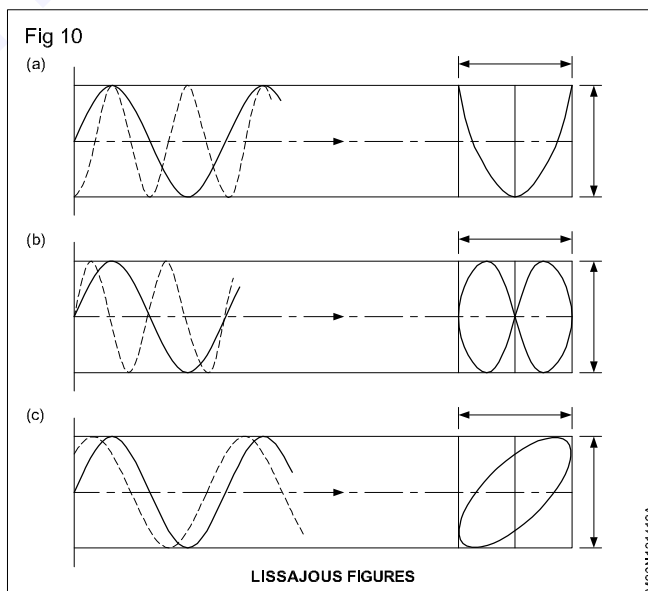
## Lissajous figures

Lissajous figures are depictions of two voltages applied to the Y- and X-plates which are periodical time functions. But the depiction on the screen is independent of the time. Whether the frequencies of  $V_x$  and  $V_y$  change fast or slow is not decisive. The trace will be the same in any case.

## Frequency measurements

Lissajous figures can be obtained from independent voltages  $V_x$  and  $V_y$ . In this case they are usually used for frequency measurements. The unknown frequency can be determined if the other one is known. Consider Fig 10a, the first graph depicts a voltage  $V_x$  of frequency  $f_x$  and a voltage  $V_y$  of the frequency  $f_y = 2f_x$ . The Lissajous figure can be sketched with the help of the voltage pairs  $V_x, V_y$  for the 9 sample points.

The same result for the frequency  $f_y$  is obtained from the second and third illustrations at Fig 10b and Fig 10c. But here the Lissajous figure appears quite different due to the phase shifted  $U_y$ . By these figures, if one frequency is known the other can be determined. But the ratio of  $f_y/f_x$  needs to be a proper fraction in order to obtain a standing screen depiction. This condition can be met with the help of a tunable frequency generator for  $f_x$ . As long as the frequency condition is not fulfilled the depiction changes its shape continuously.



Frequency measurements employing the Lissajous method have lost importance because electronic frequency counters provide easy handling possibilities and high accuracy.

## Phase measurements

If the Lissajous figure is one continuous loop as in the third depiction of Fig 10c. The frequencies  $f_x$  and  $f_y$  are equal. In

this case the figure can also be used to determine the phase angle  $\phi$  between  $V_x$  and  $V_y$ .

## ADVANCED OSCILLOSCOPES

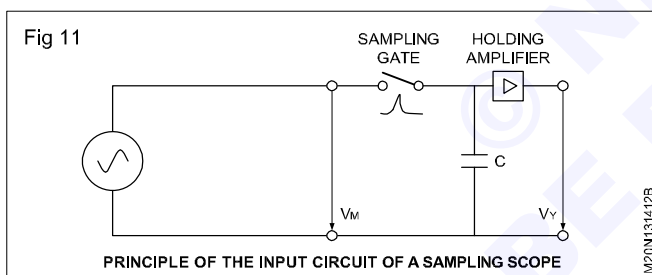
### Dual Beam Oscilloscope

In circumstance while measuring high frequency signal a dual trace may not be fast enough to display in either its "alternate mode" or "chopping mode". For such application the oscilloscope need to have two separate electron guns in one tube assembly. Such oscilloscopes are more expensive than general single beams oscilloscopes.

### Sampling oscilloscopes

To extend the range of oscilloscopes to hundreds of megahertz, a highly effective method is used called the sampling method. This method looks at the successive points with each sweep. In this way the sweep need recur only in kilohertz range to investigate and display signals in mega and gigahertz range. By this method even though the display produced may be dotted in form, it is possible to visualize waveform patterns reasonably well.

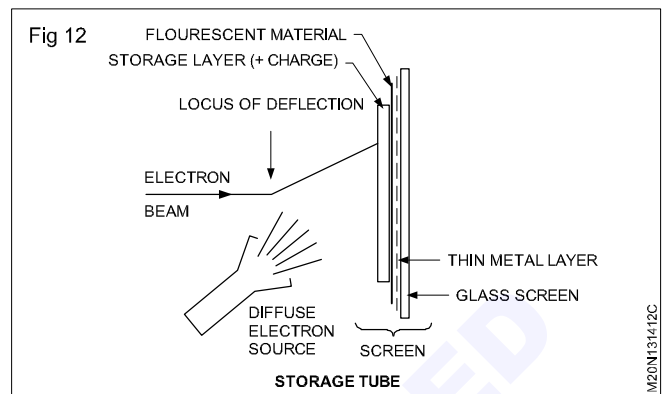
Measurands of very high frequencies ( $> 100$  MHz) cannot be directly depicted using the trigger method. But the sampling method can cope up with such signals in case they are periodical. The measured voltage  $V_m$  is continuously scanned by taking a sample, during each cycle. But the time instant of measurement is slightly shifted consecutively for each new sample. The principle of the input circuit of a sampling scope is shown in Fig 11.



The sampling gate is periodically activated for a very short sample time, scanning the voltage  $V_m$  which is provided by its source generator. During the sample time the capacitor  $C$  is charged. It takes over a voltage equal to the instantaneous value of  $V_m$  during the sample time. After the sampling gate has opened, the charge of the capacitor remains unchanged and so does its voltage. It is held constant until the gate is switched-on again and another  $V_m$  may change the capacitor voltage. This means: during the pause between two sample pulses, the capacitor voltage stays constant and an amplifier provides it at a higher (energy) level as  $V_y$ .

The rising signal  $V_m$  to be measured causes a trigger pulse periodically as shown in Fig 11. This in turn generate sampling pulses with a delay as shown in Fig 12. Each sample pulse connects the capacitor  $C$  for a very short time to the measurand and takes over its instantaneous voltage. Hence  $V_y$  changes in steps following  $V_m$ . If there are 10 sample pulses during 10 period durations of  $V_m$ , the voltage  $V_y$  has followed in steps only once. The x-plates are supplied by a step voltage arising in equal steps from  $V_x$

min to  $V_{x_{max}}$ . In this way the beam is deflected in steps from the left edge to the right edge. The step width is  $1/10$  of  $V_{x_{max}} - V_{x_{min}}$ . In this way the light emitting spot on the screen leaps from one depicted dot to the other. A dotted trace occurs. It gives quite a good imagination of the actual signal.



The number of sampling pulses needed for a full depiction of one cycle, times the period duration of the measurand, equals the time for depicting the trace once. The screen shows a time expanded appearance of  $V_m$ . It is a stroboscopic presentation of the measurand.

### Storage Oscilloscope

The ability to store a display on the oscilloscope screen has great utility for observing the transients and other phenomenon in cases where it is not practicable to relay on photographic the trace at critical moments or in a rapidly changing circumstances. The storage oscilloscopes makes it possible to store repetitive signals from very low rates up to several hundred kilohertz and also single transients. Images of high contrast can be stored for several months. Storage oscilloscopes can provide readout for computers, printers and plotters such that leisurely examination of any waveform is possible.

### CRT of Storage Oscilloscopes

**Storage tube:** Light emitting fluorescent substances are available with wide ranges of their persistence. But fluorescent materials with a very long persistence cannot cope with non-repetitive measurement voltages, which are available only once. The screen depiction may emerge too fast for proper assessment. In such cases storage tubes are of good advantage. The principle of action is shown in Fig 12.

Behind the screen there is additionally a storage layer, which is positively charged. Once the incoming electrons reach this layer, they neutralize it at the location of the trace to be depicted (due to their own negative charge). According to the function  $y(t)$  which the electron ray marks, a neutral trace is left behind amidst the positively charged area of the storage layer. This happens within the 'writing' mode of the scope which stores the information this way. For watching the trace a second source needs to be employed which emits electrons in a diffused way with comparatively low kinetic energy. These electrons (uniformly distributed) are sprayed at the storage layer. At the location of the neutral trace they may pass and can excite

the fluorescent layer for light emission. The trace becomes visible. At the other positively charged area the electrons cannot pass. Their negative charge recombines with the positive charges and this part of the field remains in dark. At first a bright trace (or spot) appears within a dark surrounding producing a beautiful contrast. But gradually, more incoming electrons discharge the positive area of the surrounding field and finally they all manage to pass over to the screen thus exciting light emission everywhere. The contrast emerges and the stored information disappears gradually, because the whole area gets neutralized eventually. This happens within the scope mode of 'view'. Usually a short time of viewing may be sufficient to assess the measurand. So one should switch over to the mode 'store' in order to sustain the information. The storage time ranges up to 60 hours for storage scopes these days, even for the switched off device. Advances in the technology of insulation materials provide this feature. In case a new trace should be stored, the whole layer needs be 'erased' first. This is effected by recharging its entire area positively.

Storage tubes are expensive. The most recent oscilloscopes store the information in digital memories. The most recent of storage oscilloscopes are the *digital storage oscilloscopes*. Refer books listed at the end for information on digital storage oscilloscopes.

## General Accessories of Oscilloscopes

### Marker Generator

The marker generator provides visual time-interval or frequency reference marks on the scope trace. Such markers can select time intervals from 1 microsecond all the way upto 5 seconds. These are particularly useful in rise-time and pulse-duration measurements.

### Electronic switch

The electronic switch displays two signals simultaneously on single-trace scopes. It is essentially a square-wave generator. The two signals which are viewed are each connected to a separate grid of a dual-section amplifier tube, operating with cutoff bias. The square wave is applied in such a fashion that is alternately unblanks each tube section, thus presenting each signal alternately to the vertical amplifier of the scope, with appropriate vertical spacing between the signals. When the switching rate is high enough, each signal appears continuous, even though it is actually being periodically interrupted. Switching rates as high as 100 kilohertz are available.

### Oscilloscope probes

The probe connects the test circuit to the testing instrument, without appreciably altering, loading, or otherwise disturbing the test circuit. Although probes may be given many different names, they fall into three principle types:

- 1 Direct probe (or test cable)
- 2 Circuit-isolation (or voltage-divider) probes
- 3 Detector (or demodulator) probe.

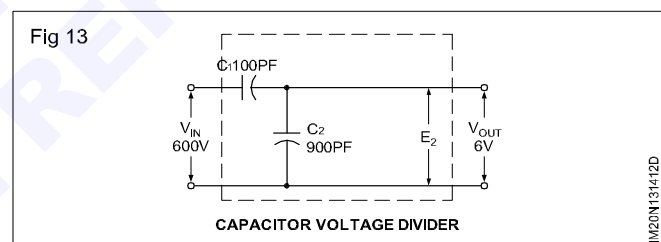
**Direct probe :** This simplest probe is a shielded coaxial cable. It avoids the stray pickup that can be troublesome

when low-level signals are being examined with correspondingly high-gain settings on the scope. It is most effective in relatively low-frequency circuits, where cable capacitance is not too important, and in such cases allows the maximum sensitivity of the scope to be used. However, the shunt capacitance of the probe and cable is added to the input impedance and capacitance of the scope, and lowers the scope's response to high impedance and high-frequency circuits being tested. Where this effect becomes important, the isolation probe is used.

### Isolation probe

To avoid the undesired circuit loading, the isolation probe is used to decrease the input capacitance and increase the input resistance of the oscilloscope. The low-capacitance probe attenuates the scope's input capacitance usually by a 10:1 ratio, necessarily attenuating the input signal by the same ratio. To equalize the time constant, resistors are commonly placed across the voltage-dividing capacitors.

Where it is desired to measure signals of high enough voltage to damage the scope's input circuitry, signal attenuation is desired, and a high-voltage probe is used. Such a probe consists of a resistive or capacitive voltage-divider circuit as shown in Fig 13. These probes allows only a small portion of the input signal to reach the scope, but preserves the waveform accurately. When isolation probes are used to measure the magnitude of test voltages, the attenuation factor by which the probe divides the input signal voltage must obviously be known, and measurements calculated accordingly.



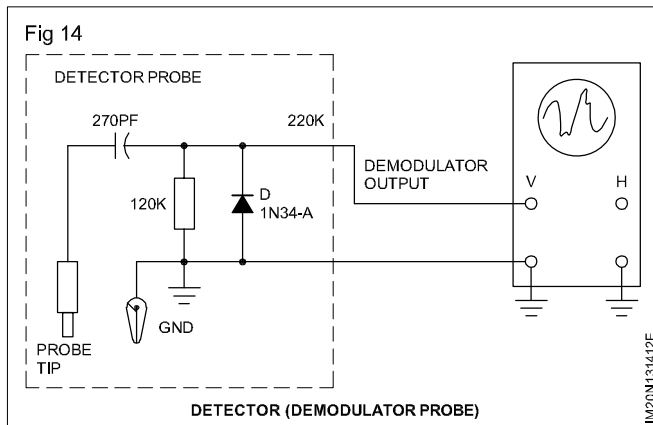
**Detector or Demodulator probe :** The detector or demodulator probe is used in analyzing response to high-frequency modulated signals used in communication, as in the R-F section of AM, FM and TV receivers. By rectifying and by-passing the radio frequency, the modulation envelope is displayed on the scope. This allows a scope capable of only audio-frequency response to trace communication signals in the range of hundreds of megahertz a range which would otherwise be far beyond the capabilities of all but highly specialised scopes. The detector probe separates the audio-frequency modulation component from the radio-frequency carrier.

The detector circuit of the probe is shown in Fig 14.

After being rectified by diode D, the audio signal corresponding to the original modulation is passed on to the output terminals. The resulting display of the audio signal can then be used to indicate the proper alignment and response of each tuned R-F circuit.

**Summary of major applications of oscilloscopes :** It would be impractical even to attempt a complete listing of all the applications of the oscilloscope. However a few major fields of application are listed below:





- 1 Measurements of instantaneous voltage and of current (indirectly)
- 2 Amplifier gain, frequency response and phase relations
- 3 Rise time and duration of pulses
- 4 Modulation percentage
- 5 Distortion
- 6 Timing comparisons of pulse trains as in ignition systems, vibration studies, telemetry and digital techniques.
- 7 Response of tuned circuits
- 8 Industrial display of non-Electronics quantities, using transducers for mechanical, thermal, optical, acoustic, chemical, biological and nuclear properties.

## Measurement using dual trace oscilloscope - 1

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

- procedure to calibrate the given CRO using internal calibration signals
- procedure to measure frequency and phase of a signal using Lissajous waveform method
- procedure to measure the propagation delay in digital signals using a divide-eight-counter.

This class room session is expected to be highly interactive and brainstorming. In this session, the instructor should take-up each of the objective listed above separately and guide the trainees to develop a procedure for carrying out the task. For example, in this classroom session, the instructor should first take-up the first objective “**procedure to calibrate the given CRO using internal calibration signals**” and brief the trainees the nature of task (calibration of CRO).

The instructor should then divide the class into 4 groups and instruct them to draft the procedure to carry out the task in hand (“to calibrate the given CRO using internal calibration signals”). To aid the trainees work, they should be provided with copies of the oscilloscope manuals, related reference books (available in the library) and advised to refer previous lessons on oscilloscope. With these reference materials in hand and the demonstration witnessed by them in the previous exercises, the trainee groups should draft the procedure for carrying out the task in hand (each group should develop one draft).

The draft developed by each group should be discussed with the entire class. During the discussion, the trainees should be motivated to point out procedural errors in the

drafts and suitable correction to it. After discussing all the drafts (4 drafts in a class of 16 trainees), the instructor should generate a procedure taking all vital points from the drafts. This shall be used as the final procedure for carrying out the task in the laboratory.

The same procedure should be repeated for all the tasks given under the objectives for this lesson.

### NOTE TO TRAINEES

- Do not waste time in drawing beautiful/colourful sketches of the test setup. Just rough pencil sketches will do.
- Refer to books and or consult your instructor when you are in doubt.
- Give opportunity for every trainee in your batch to give his idea.
- Jot down ideas given by the group members. This will help you finalize the draft more easily and in less time.

**Instructor to refer IG for more tips on conducting this brainstorming session.**



# Controls and functions in oscilloscopes

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

- explain the use of X5 and X10 magnification of in the vertical deflection factor control
  - explain the use of different coupling modes of the vertical input.
  - explain the use of CH1 and CH2 inputs of a dual trace oscilloscope effectively
  - explain the use of Alternate and Chopped modes for two inputs
  - list the use of different triggering modes such as INT, EXT, EXT/5 or EXT/10
  - list the use of different trigger source coupling modes such as LF reject, HF reject
  - list the use of different sweep display modes
  - explain the use of X-Y mode of operation
  - explain the use of Z -axis input.
- 

## Introduction

In addition to the standard front panel controls of a general purpose oscilloscopes, certain of the controls and functions which are essential while displaying the measurand clearly are discussed in this lesson. Also some tips while using the oscilloscope are also discussed in this lesson.

## Focus and Intensity

When the oscilloscope is switched on with the power on switch, the first thing to do is to get a beam trace on the oscilloscope screen. Focus and intensity controls together help to get a sharp, low intensity trace. Lower intensity not only allows to focus the display to a very fine trace, but also increases the life of the CRT of oscilloscope. The trace intensity should never be so bright that it burns a hole in the phosphor coating on the CRT screen.

The damage to the CRT with an extra bright trace is much more severe, particularly when you are working at slower sweep speeds.

## Astigmatism

Some oscilloscopes have astigmatism control that should be so adjusted that the focus control is effective on the horizontal and vertical portions of the trace. Simultaneously, astigmatism control should be adjusted with a pulsed waveform displayed on the screen.

## Trace rotation

It can be used to make the beam trace perfectly horizontal in the absence of any input signal. It is usually a trimmer whose adjustment screw can be seen on the scope's front panel or on the rear panel.

## Beam find

Often we come across a situation where we have switched the oscilloscope on, increased the intensity level, selected the auto sweep mode and tried to adjust the horizontal and vertical position controls but still have not been able to see the beam trace. Beam find control can be used to locate the beam irrespective of where it is. Pressing this button compresses the range of horizontal and vertical position controls and the result is a dot somewhere on the screen. Keeping the button pressed, adjust the two position controls to bring the dot to the centre of your scope's screen. Release the button and you will see a trace right in the middle of the screen.

## Horizontal and vertical position

Horizontal position (indicated on some scopes as <---> and vertical position (indicated on some scopes as ) are used to shift the trace horizontally and vertically respectively. There is usually a common horizontal position control in a dual trace oscilloscope. The position control shifts both the traces in the horizontal direction simultaneously. However, there are two separate vertical position controls for the two channels.

## Calibration

All oscilloscopes have a CAL output. The amplitude and the frequency of the calibration signals are indicated on the front panel by the side of the output. The calibration signal can be used to check the amplitude and the time base calibration of the oscilloscope.

Some oscilloscopes provide two calibration signals, both having the same frequency but different amplitudes. Oscilloscope may have two calibration signal outputs i.e. 2Vp-p at 1 kHz and 200m Vp-p should be checked with both the signals. Scope's calibration should be adjusted at regular intervals.

In some oscilloscopes, the output of calibration is indicated by a glowing LED. You will find an LED near the time base setting and LEDs near the vertical deflection factor selector switches of the vertical input channels. Calibration signal is also employed to adjust the probe. The conditions of an under compensated or an overcompensated probe can be easily seen with the calibration signal used as a reference.

## Bandwidth limit

Many high sensitivity, high bandwidth oscilloscopes have bandwidth limit control. Though higher bandwidth capability lets you capture high frequency signals, the unwanted high frequency noise also creeps in. It is particularly troublesome when we are viewing a very low level signal (say a few millivolts) of moderate frequency. Due to high bandwidth capability of the scope, the desired signal is often seen accompanied by a lot of hash.

## Volts/div and time/div controls

Volts/div and time/div are the controls that need frequent adjustment while viewing and analysing signals. While the former selects vertical sensitivity and is set as per the amplitude of the signal to be viewed, the latter sets sweep speed and its setting is governed by the signal frequency.

Both these controls have a selector switch setting and a fine control. The fine adjustment control in both cases should be kept in the calibrated position. The selectable positions in case of these controls are in the decades of 1-2-5.

In most oscilloscopes, there is provision for X5 magnification in the vertical deflection factor control which makes the oscilloscope more sensitive by a factor of 5. That is, 5 mV/div to 5V/div range becomes 1mV/div to 1V/div. But then we must always remember that this enhancement in vertical sensitivity is at the cost of reduced accuracy. Accuracy specification of typically  $\pm 3$  percent may deteriorate to  $\pm 5$  percent. This magnification is usually obtained by pulling the fine adjust control knob in the vertical deflection factor selector switch.

Similarly, a magnification of X10 is usually available in the time base setting, which means that sweep speed at any setting can be increased by a factor of 10 by using this feature. This enhancement is also at the expense of degradations in sweep speed accuracy. The change in accuracy may again be from  $\pm 3$  percent to  $\pm 5$  percent. X10 magnification is also achieved by pulling the fine control adjust knob in the base selector switch.

In some oscilloscopes, the time base selector has two switches and a fine adjust. One of the two switches, selectable by bigger of the two knobs, is used to select the main sweep speed. There is another switch concentrically located with a smaller knob. This is used to choose the delayed sweep speed. This second rotary switch is present only in oscilloscopes having delayed sweep facility. Also, the two switches are so internally arranged that the delayed sweep speed can never be set to be slower than the main sweep speed.

**Triggering modes and relevant controls :** All modern oscilloscopes are triggered sweep oscilloscopes, i.e. each sweep across the screen is initiated by a trigger signal either generated inside the scope or supplied externally. The source of trigger signal, the way it is coupled and the controls like 'trigger slope', 'trigger level' and 'trigger hold off' enable you to make full use of the equipment and get a stable display of many a complex waveforms or trigger on the most elusive transient events.

**Source of trigger signal :** This first relevant control is the one that selects the source of trigger signal. The available options in most of the oscilloscope are internal (INT) line, external (EXT)

When we have selected the INT source of trigger, the trigger signal is generated from the signal to be viewed. A small part of the vertical input signal is taken off, amplified, shaped and then treated as the trigger signal. In a dual channel oscilloscope, where we have two vertical inputs, a separate control decides whether it is a part of CH1 signal or CH2 signal that is to be used for generating the trigger signal. Here, if we select ALT, the trigger signal source is according to the vertical mode displayed. We should also remember that selection of CH1 signal or CH2 signal or ALT trigger arises only when trigger source selection is on INT.

When the trigger source is line, the oscilloscope picks up

50 Hz signal from its power transformer and uses this for producing trigger signal. It is suitable for getting a stable display of signals having power line frequency like ripple on a power supply.

In the EXT mode, the trigger signal is applied externally. The trigger signal amplitude requirements are specified by the manufacturer. Some scopes also have EXT/5 or EXT/10 trigger inputs. The trigger signal applied to this input is alternated by the given factor before it is applied to the trigger circuit. This mode is used when the external trigger signal level is too high.

**Trigger source coupling mode :** The coupling mode selector determines the way the trigger signal is coupled to the trigger amplifier. The available options on most of the 100 MHz oscilloscopes are DC, AC, Low Freq Rej (low frequency reject), High Freq Rej (high frequency reject) and TV. The Low Freq Rej coupling mode is usually not present in lower band-width oscilloscopes (upto 50 MHz bandwidth).

In DC coupling of trigger source, the trigger signal is directly coupled to the trigger circuitry. This mode is used when triggering is required to be effected including the DC component of the trigger signal. It is suitable for viewing DC and low frequency signals.

In AC coupling, the trigger signal is AC coupled to the trigger circuit. This is the most commonly used trigger source coupling mode as stable triggering can be achieved without being affected by the DC component of the input signal.

In the Low Freq Rej mode any frequency component below a few kilo-hertz present in the trigger signal attenuated. This mode should be used when low frequency components, 50 Hz hum for instance, is present in the trigger signal. High Freq Rej mode is used when any high frequency components present in the triggering signal are creating problems in getting a stable display. In this mode, high frequency components greater than 50 kHz present in the trigger signal are attenuated.

The TV coupling mode is used exclusively for viewing TV video signals. The signal is AC coupled to the TV sync separator circuit. The sync separator picks up the sync signal which is then used as the trigger signal. With this mode we can obtain a stable display of TV video signals.

**Trigger slope and level :** Trigger slope selection determines the slope of the trigger signal that triggers the sweep. When we select a (+) slope, the sweep is triggered anywhere on positive going or low-to-high transition of the signal. In case of (-) slope, the sweep is triggered anywhere on the negative going or high to low transition of the signal.

The trigger level decides the signal level (positive or negative) where the triggering takes place. If the signal has both positive as well as negative amplitudes, we can trigger on a positive slope and a negative level or a negative slope and a positive level as well. When we select a positive slope, the waveform can be triggered anywhere on the positive slope of this waveform, i.e. from negative peak towards positive peak. The level can be either negative or

positive. Similarly, when we select a (-) slope, the waveform can be triggered anywhere on the negative slope, i.e. from positive peak towards negative peak. The level can either be positive or negative.

**Trigger hold-off control :** This control can be used to adjust the pause between initiation of two successive sweeps and is particularly useful for viewing signals that do not repeat symmetrically. In the absence of trigger hold-off feature, it may be difficult to get a stable display of waveform of this kind. The trigger hold-off control can be used to trigger the sweep at the right time.

**Sweep modes and relevant controls :** The first selection that we have got to do is that of the sweep triggering modes. Usually, three modes are available on almost all oscilloscopes. They are auto (automatic), normal and single sweep modes.

In the auto sweep mode, the sweep generator is a free-running oscillator if there is no triggering signal, internal or external. That is, if the trigger source has been chosen to be INT, we will see a beam trace even in the absence of any vertical input. When a triggering signal is applied, the scope becomes a triggered sweep one and the trigger signal initiates the sweep as per slope and level settings. The auto mode is quite convenient when we are interested in seeing DC voltages or simple waveforms.

In the normal sweep mode, the triggering signal only initiates the sweep. In the absence of any trigger, we do not see any trace on the oscilloscope screen. In the normal mode, we have to carefully select the slope and adjust the level to get a display of the signal. This mode is suitable for viewing complex waveforms and single shot events.

In the single sweep mode, when a triggering signal is applied, the first genuine trigger initiates a sweep and after that all subsequent triggers are ignored. So there is only a single sweep. When the single sweep mode is selected, the oscilloscope gets ready to receive the trigger. This mode is very useful for viewing single-shot events.

**Sweep display modes :** The second selection that needs to be done is that of the sweep display mode. The available choices are the main sweep, delayed sweep, intensified sweep, triggered delayed sweep. These may be designated as A-sweep (mainsweep), B-delayed sweep (delayed sweep), A-intensified (intensified sweep) where the two input channels are referred to as A and B.

The main sweep is what we have been referring to so far. Its speed is set by the main time/div selector switch. It is suitable for most measurements. But what happens when we want to view a small part of a comparatively lower frequency signal on an expanded scale to look for noise glitches? If we try to expand the time base, the desired portion on the waveform is likely to go off the screen and all our efforts to bring it to the centre of the oscilloscope screen with the horizontal position control are rendered useless. One method to overcome this is to use X10 magnifier available with the main sweep. Engaging the magnifier expands the time base by a factor of 10 around the centre of the screen with the result that the desired portion stays on screen. This process is known as magnified sweep.

Magnified sweep too has its own problems. First, the intensity of the sweep diminishes quite a bit on expansion and second, this expansion may not be sufficient to permit a view of very fast glitches, for instance, a few nanoseconds wide glitch sitting somewhere on a waveform with a time period of a few milliseconds.

Delayed sweep is what comes to our rescue in such cases. As mentioned earlier, we have at our disposal two independent time base settings, one for the main sweep and the other for the delayed sweep. To make use of the delayed sweep facility, set the delayed time base at a much faster speed than the main time base. There is also a delay time multiplier (a multiturn potentiometer) control on the panel. Set that to the centre of its range. Engage the intensified sweep button. We would notice a small portion of the waveform being viewed on main sweep getting intensified. This implies that we have engaged the delayed sweep. The width of this intensified portion depends upon the time base setting of the delayed sweep.

The photograph is for a delayed sweep of 5ms/div. The width becomes narrower as we make the sweep faster. Thus, faster the delayed sweep, narrower is the intensified portion and larger is the magnification that we get. The position of this intensified portion is as per the part of the waveform we wish to expand.

After having adjusted the two things, engage the delayed sweep mode. The intensified portion fills the entire screen. In this mode, we can achieve much higher magnification without sacrificing the intensity. In some scopes, there is a provision for viewing the main sweep signal and the intensified delayed signal simultaneously. Most of the 100 MHz oscilloscopes have this facility. The availability of this feature is indicated by the ALT sweep display mode. To use this facility, depress ALT sweep display instead of main sweep.

**B Ends A mode :** Sometimes it is observed that when the delayed sweep to main sweep speed ratio is very high, the expanded display in the delayed sweep mode has somewhat reduced intensity. B Ends A mode can be used to increase the intensity of delayed sweep display by ending the main sweep at the minimum required point and increasing the display time for the delayed sweep. This happens because the slow main sweep runs for the full screen and there is very little time for the much faster delayed sweep.

Some oscilloscopes also have triggered delayed sweep facility. Operationally, it is similar to delayed sweep. In the delayed sweep mode, the delay time multiplier can be adjusted to smoothly move the intensified portion on the screen. In the triggered delayed sweep, the intensified portion jumps from one level transition to the next as the adjustment is done. After selecting the desired transition level where you want to trigger the delayed sweep and after selecting a proper slope (+) for positive going and (-) for negative going transition - the delayed sweep is engaged. This mode gives a highly reduced display jitter as the sweep is triggered by a definite trigger signal level.

**X-Y operation :** In the X-Y mode, the horizontal axis of the oscilloscope also represents a voltage rather than time as



is the case in the usual oscilloscope operation. The time base circuitry gets bypassed. The signal to be represented on the horizontal or X-axis is applied to the horizontal deflection input available on the front panel of the oscilloscope having X-Y mode feature.

CH3 input is the horizontal input. It has two selectable horizontal deflection factors of 100mV/div. and 1V/div. i.e. 100mV signal (in case of 100mV/div. selection) and 1V signal (in case of 1V/div. selection) will sweep the beam horizontally by one division. The other signal is applied to the vertical input (one of the two vertical inputs in a dual channel oscilloscope). The result is the desired X-Y display.

A major problem with this kind of X-Y mode of operation is that it offers an uncalibrated fixed sweep speed. This problem is, however, overcome in majority of modern dual channel scopes by letting one of the two vertical inputs to be used as a horizontal input in the X-Y mode. The oscilloscopes having this provision will have the letters 'X' and 'Y' written near the input connectors of the two channels to indicate X and Y inputs when we select the X-Y mode. Thus, both horizontal and vertical axes have variable calibrated deflection factors.

One can also notice that the vertical position control corresponding to vertical channel being used for X-input in X-Y mode can be used to deflect the X-Y display horizontally. X-Y operational mode has numerous applications like plotting transfer characteristics of devices and circuits, measuring phase difference between two given signals having same frequency, measuring an unknown frequency etc.

**Z-axis input :** The oscilloscope display has three components: the horizontal component (X-axis component), the vertical component (Y-axis component) and the beam intensity (Z-axis component). The intensity remains constant for a particular setting of the intensity control during normal operation. Most of the scopes have an external Z axis input located on the rear panel. A signal fed to this input can be used to modulate the intensity of the display. Use of this input in conjunction with vertical inputs has many interesting applications.

**Digital storage oscilloscope :** A digital storage oscilloscope (DSO) is an oscilloscope which stores and analyses the input signal digitally rather than using analog techniques. It is now the most common type of oscilloscope in use because of the advanced trigger, storage, display and measurement features which it typically provides.

The input analogue signal is sampled and then converted into a digital record of the amplitude of the signal at each sample time. The sampling frequency should be not less than the Nyquist rate to avoid aliasing. These digital values are then turned back into an analogue signal for display on a cathode ray tube (CRT), or transformed as needed for the various possible types of output - liquid crystal display, chart recorder, plotter or network interface.

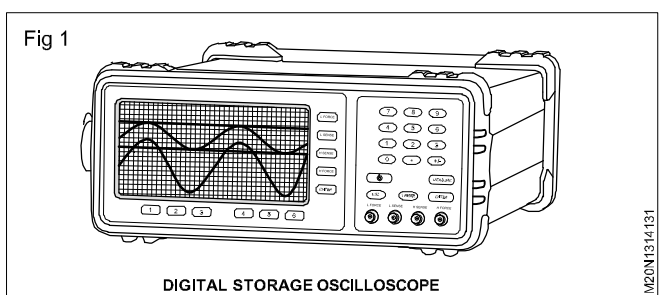
**Comparison with analog storage :** The principle advantage over analog storage is that the stored traces are as bright, as sharply defined, and quickly as non-stored traces. Traces can be stored indefinitely or written out to some external data storage device and reloaded. This allows, for example, comparison of an acquired trace from a system under test with a standard trace acquired from a known-good system. Many models can display the waveform prior to the trigger signal.

Digital oscilloscopes usually analyze waveforms and provide numerical values as well as visual displays. These values typically include averages, maxima and minima, root mean square (RMS) and frequencies. They may be used to capture transient signals when operated in a single sweep mode, without the brightness and writing speed limitations of an analog storage oscilloscope.

The displayed trace can be manipulated after acquisition; a portion of the display can be magnified to make fine detail more visible, or a long trace can be examined in a single display to identify areas of interest. Many instruments allow a stored trace to be annotated by the user.

Many digital oscilloscopes use flat panel displays similar to those made in high volumes for computers and television displays.

Digital storage oscilloscopes may include interfaces such as a parallel port, RS-232 serial port IEEE-4888 bus, USB port, or Ethernet, allowing remote or automatic control and transfer of captured waveforms to external display or storage.



## Computer, parts and their working

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

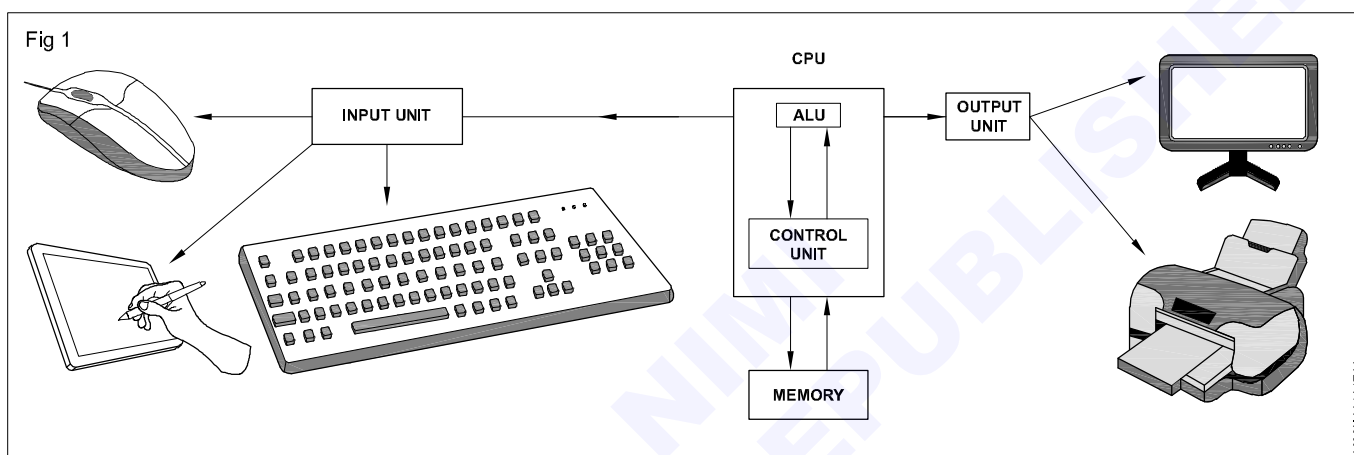
- explain the basics of computer
- identify various peripheral devices.
- identify and explain computer connection and ports
- explain the main components on the mother board
- explain the types of cables used in computer
- explain the CPU and memory.

### What is a computer?

The term computer is used to describe a device made up of electronic and electro mechanical components. The

computer itself cannot perform any task and is referred to as hardware.

A computer system consists of three elements.



- 1 Hardware
- 2 Software
- 3 People

**Hardware :** The physical components which you can see, touch and feel in the computer system are called hardware Eg monitor, keyboard, mouse etc.

**Software :** Software is used to describe the instructions that tells the computer how to perform a task. Software is categorized as

- 1 System softwares ( eg . operating systems, compilers, editors, etc)
- 2 Application softwares ( MS-word, excel, accounting packages, etc)

**People :** People who operate the computer and also create computer software instructions.

### Computer hardware

Basic components in a computer system are central processing unit (CPU), memory, the input device and output device.

**Computer systems** – Micros, Minis and Mainframes.

**Micro computer :** Micro computer is also called as personal computer or PC. It has a processor based on a single silicon chip. Personal computers come in three

different physical sizes, pocket pc's, lap pc's and desktop pc's. Pocket pc's and lap pc's belong to portable category. Microcomputer is used in small businesses.

Ex : IBM compatible or IBM clone and Apple Macintosh systems.

**Multuser microcomputers.** Until recently microcomputers were personal

computers for individual use only. But now days several microcomputers can be networked together for simultaneous use by several people.

**Mini computers:** Mini computer is simply a small mainframe computer. It is a reduced version of mainframe. Attached printers are not so fast. So it has less storage capacity less processing speed of that of mainframe computers. They are usually used by small businesses. For example research groups, engineering firms, colleges etc. use mini computers.

**Mainframe computers:** A mainframe computer is a large expensive machine whose processing speed is very high and has large amount of secondary storage and fast printers. A large mainframe computer may be used to meet the data processing requirements of the entire organization.

**Examples:** airline booking systems, Railway booking systems , weather forecast etc.



## System types

We can classify systems into the following categories :

8-bit, example : 8085 microprocessor

16-bit, example : 8086, 286, 386 processor

32-bit , example : 486

64-bit, example : Pentium - II

This gives us two basic system types or classes of hardware.

8-bit ( PC/XT) class systems

16/32/64 (AT) class systems

PC stands for personal computers, XT stands for eXTended PC, and AT stands for an advance technology PC.

The XT basically was a PC system that included a hard disk for storage in addition to the floppy drive found in the basic PC system. These systems has an 8-bit processor and an 8-bit INDUSTRY STANDARD ARCHITECTURE

(ISA) bus for system expansion. Bus is the name given to expansion slots in which additional plug in circuit board can be installed.

16-bit and greater systems are said to be AT class. 16-bit (and latter 32 and 64 bit) processors and expansion slots are included. The first AT class systems had a 16-bit version of the ISA bus which is an extension of the original 8-bit ISA bus found in the PC/XT class systems. Afterwards several expansion slots were developed for AT class systems.

## Example

16/32 bit PS/2 microchannel architecture (MCA) bus.

16-bit PC card (PCMCIA) bus

16 bit ISA bus

16/32 bit Extended ISA(EISA) bus

32/64 - bit card Peripheral Component Interconnect (PCI) bus.

The easiest way to identify a PC/XT system is by the 8-bit ISA expansion slots regardless of the processor present in the system. AT systems can be similarly identified by having 16-bit of greater slots of any type (ISA, EISA, PCI) slots.

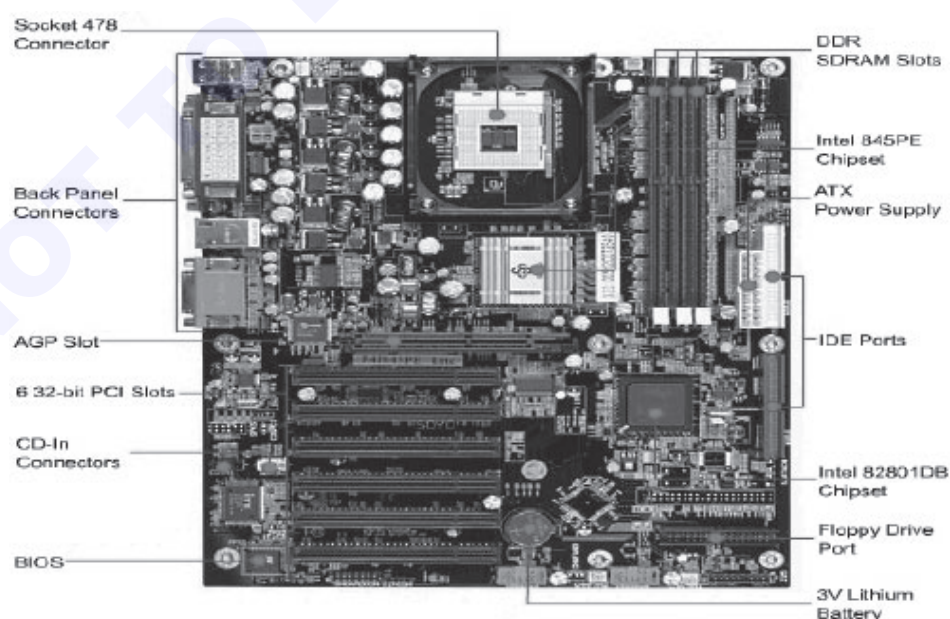
## System components

Component needed to assemble a basic modern PC system.

- Motherboard
- Processor
- Memory (Primary)
- Hard disk
- CD-ROM
- Floppy Drive
- Keyboard
- Mouse
- Monitor
- Power Supply
- Cabinet

**Motherboard :** Motherboard is the important component of the computer as everything else is connected to it. And it controls everything in the system. Motherboard are available in several different shapes. Motherboard usually contain the following individual components shown in Fig 2.

Fig 2



- 1 Processor slot
- 2 Processor voltage regulators
- 3 Motherboard chipset
- 4 Level 2 cache
- 5 Memory SIMM or DIMM sockets
- 6 Bus slots
- 7 ROM BIOS
- 8 Clock / CMOS battery
- 9 Super I/O chips

### Processor (Fig 3)

Fig 3



The processor is often thought as the engine of the computer shown in Fig 3. Then the processor reads the commands from the memory and then executes them. The processor is one of the most expensive parts of the computers and is also one of the smallest parts.

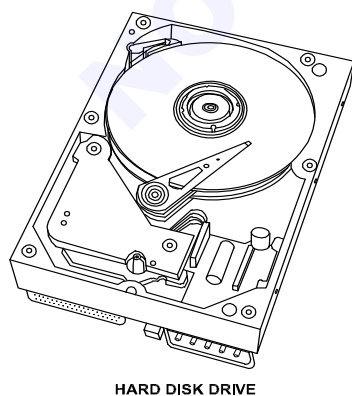
### Primary Memory

**Memory:** Is used to hold programs and data during execution.

**Primary memory** is often called as RAM (Random Access Memory). It holds all the programs and data the processor is using at a given time. RAM is volatile because its contents are erased when power is switched off. The other type of system memory is ROM (Read only Memory) which is permanent because its contents are not erased even when power is switched off. It is usually used to load an operating system.

### Hard disk drive (Fig 4)

Fig 4



A hard drive consists of spinning platters made up of aluminum or ceramic that is coated with magnetic media

shown in Fig 4. The platters come in various sizes. The hard drive with many different storage capacities can be created depending upon the density, size and number of platters. This is also called as Secondary memory. There can be several programs in the system, which cannot be stored in RAM, so we need a very huge non-volatile memory, which can be used for storing all the programs, and data when the system is not in use are called as Hard disks.

### CD-ROM drive

CD-ROM stands for compact disk read only memory. It consists of small disks similar to the gramophone records to hold digital information. As the name applies they are read only medium. With the advancement in technology writable CD's are also available.

### Floppy Disk Drive

Floppy disks are the slowest and the smallest form of secondary storage. They provide a simple way to carry information from one place to another, and backup small amount of files. In modern days floppy drive component is not as important as it was years ago. All PC's made in the last 10 years use a standard 3 1/2 inch, 1.44 MB capacity floppy drive.

### Keyboard

The keyboard is the main input device for most computers. It is used to input text or enter commands into the PC. Nowadays keyboards with additional features are available like multimedia keyboard, wireless keyboard.

### Mouse

With the invention of graphical user interface mouse is used to input information into the computer. Users simply point and click to enter information. The main advantage of mouse over keyboard is simplicity. And there are many operations that are much easier to perform with a mouse than a keyboard.

**Monitor :** The monitor is the specialized high-resolution screen similar to a television. The video card sends the contents of its video memory to the monitor at a rate of 60 or more time per second. The actual display screen is made up of red, green and blue dots that are illuminated by electron beam from behind. The video card DAC chip controls the movement of the electron beam, which then controls what dots are turned on and how bright they are. Which then determines the picture you see on the screen.

### Power supply

**SMPS (Switch Mode Power Supply):** The power supply provides power to every part in the PC. The main function of the power supply is to convert the 230 V AC into 3.3 V, 5 V and 12 V DC power that the system requires for the operations. In addition to supplying power to run the system, the power supply also ensures that the system does not run unless the power supplied is sufficient to operate the system properly. The power supply completes internal checks and tests before allowing the system to start. If the tests are successful, the power supply sends a special signal to the motherboard called **Power Good**.

If this signal is not present continuously, the computer does not run. Therefore, when the AC voltage dips and the power supply becomes stressed or overheated, the **Power Good** signal goes down and forces a system reset or complete shutdown.

**Cabinet** : The box or outer shell that houses most of the computers. The cabinet actually performs several important functions for your PC including protection to the system components, directing cooling airflow, and allowing installation access to the system components. The cabinet often includes a matching power supply and must also be designed with shape of the motherboard and other system components in mind.

**Peripheral Devices** : Any external device, which is not necessary to perform the basic operation of computer, is called as peripherals. They provide additional computing capabilities. For ex : Printers, Modems, Speakers etc.

**Modem** : Modem (Modulator and Demodulator) is typically used to send digital data over a phone line . The sending modem converts digital data into analog data, which can be transmitted over telephone lines, and the receiving modem converts the analog data back into digital form. This is used to connect to Internet.

Modems are available in different capacities.

- 300 bps - 1960s through 1983 or so
- 1200 bps - Gained popularity in 1984 and 1985
- 2400 bps
- 9600 bps - First appeared in late 1990 and early 1991
- 19.2 kilobits per second (Kbps)
- 28.8 Kbps
- 33.6 Kbps
- 56 Kbps - Became the standard in 1998
- ADSL, with theoretical maximum of up to 8 megabits per second (Mbps)

Gained popularity in 1999

**Printers** : The capability to produce a printed version often called a hard copy of a document is the primary function of a printer. Different types of printers are 1) Laser 2) Inkjet 3) Dot-Matrix.

**Network Connector** : The Network Connector, also referred to as a NIC card, is how your CPU talks to the network. A network cable is plugged into the back of the computer in this location . The other end of the network cable is plugged into a network jack in the wall. If the wall jack is "live", meaning it has been wired to talk to the network, then your computer will connect to the network

**USB Ports** : The USB ports are present on newer machines and most often require Windows 98 or higher. If you have Windows 95, the USB ports may not work. USB ports allow you to connect an external device, such as a printer, camera, scanner, or other device to your computer.

USB ports transfer information from the connected device to your computer.

**Monitor Connector** : The monitor connector is a 15 pin female connector. This is how the monitor is connected to the computer. On the back of the monitor, there is a 15 pin

male connector. The monitor cable gets plugged into the back of the computer in this location.

**Keyboard Connector** : The PS/2 Keyboard connector is where the keyboard gets connected to the computer. The keyboard cable, has a round connection with one flat side.

**Mouse Connector** : The PS/2 Mouse connector is where the mouse gets connected to the computer. Although the keyboard connector and the mouse connector look the same, they are not interchangeable. In newer PC's, the components are color coded and it is clear where the mouse and keyboard go. In older models, the keyboard connector comes first.

**Com Port 1 & 2** : Com Ports are usually have 9 pins and are male connectors. Com Port stands for communication port and is how your computer talks to external devices such as modems, scanners or digital cameras.

**Parallel Port** : The parallel port is sometimes referred to as a printer port (or LPT1) because that is the typical device that is attached to this port. The parallel port is a 25 pin female connector. If you have a direct connect printer, the male end of the printer cable (pictured later in this manual) is connected here.

**Game Stick Port** : The game stick port is where you would connect an external device like a game stick or joystick. It is a 15 pin female connector.

**Sound Card** : Sound Card – Speaker Connector

Sound Card – Audio Out Connector

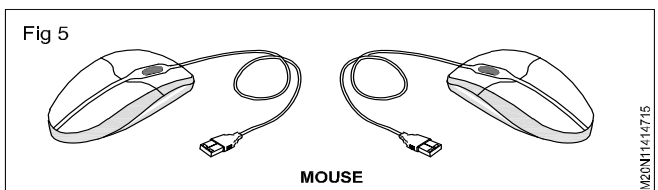
Sound Card – Microphone Connector

A sound card allows you to hear sounds from a CDROM or audio file. The connectors allow you to attach speakers microphones or headphones. If your computer does not have these connectors, you will not be able to hear sound.

**CPU Power Cord** : The CPU power cord connects the CPU to the Electronics supply.

**Keyboard** : The illustration above shows two examples of keyboard connectors – the left is the larger connector and the right is the smaller. On the larger connector, there is an arrow that should face up when you are connecting it to the CPU. On the smaller connector, there is a flat side that should face up when connecting it to the CPU.

**Mouse (Fig 5)** : The illustrations above (Fig 5) show two examples of mouse connectors. The left is a PS/2 mouse connector (circle) and the right is a serial connector that would plug into one of your com ports

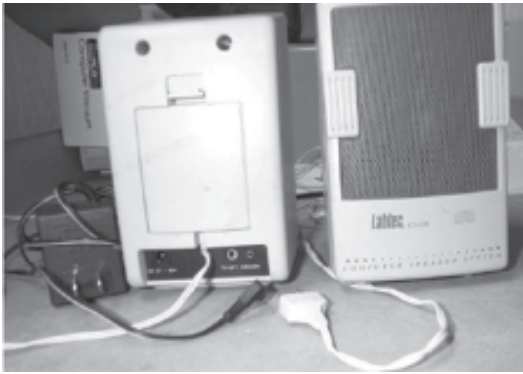


**Speakers (Fig 6)** : The following cords are connected to a set of speakers

The following cords are connected to a set of speakers shown in Fig 6



Fig 6



- Power cord – connecting one speaker to the power source
- Left to Right speaker connector – connecting one speaker to the other
- Speaker to CPU connector – connecting speakers to the CPU

**Monitor :** There are two cords attached to the back of the monitor. The first is a power cord that connects the monitor to the power source. The second is a monitor cable.

The monitor cable is a 9 pin male connector that gets connected to the monitor connector on the back of the CPU

#### Network Cable and Network Jack

The network cable can be blue, purple or off-white. One end is connected to the back of the computer (in location A) and the other end is plugged into the network jack on the wall.

#### Parallel Printer Cable

The parallel printer cable has one connector on each end. The 25 pin male connector gets connected to the back of the CPU in location G and the other end is connected to the local printer.

#### USB Printer Cable

Newer computers and printers will support the use of a USB printer cable. A USB cable will transfer information more quickly than a parallel cable. The flat end of the USB cable gets connected to the back of the CPU in location B. The square end is connected to the local printer.

The following should help you put the pieces together.

- 1 Position the CPU in the desired location
- 2 Connect one end of the **network cable** to the back of the CPU (location A) and the other to the wall jack.
- 3 Connect the **keyboard** to the back of the CPU (location D)
- 4 Connect the **mouse** to the back of the CPU (location E)
- 5 Connect the **monitor cable** to the back of the CPU (location C)
- 6 Connect the monitor power cable to the power source
- 7 If you have speakers, connect the speaker power cord to the power source, connect the left and right speaker and connect the speaker to the sound card on the back of the CPU (location J) – note, some speakers are color coded to assist in the set-up, if yours are, follow the color codes.

- 8 If you have a local printer, connect one end of the parallel printer cable or USB Printer Cable to the back of the CPU (location G or location B) and the other end to the printer
- 9 Connect one end of the power cord to the back of the CPU and the other end to the power source.

#### Mother board and CPU

- 1 **Memory:** This is the area used by the processor to store raw data and instructions
- 2 **Microprocessor:** This is the CPU, which is the main component in a computer that does all the processing work of the data fed into the computer.

It contains three units viz.,

- 1 Memory units (internal , called as registers)
- 2 Arithmetic Logic Unit (ALU)
- 3 Control Unit

**Memory Unit:** It is the nervous system of the computer. It controls arithmetic operations to be performed. These unit co-ordinates the activities of all other units in the system. It has two main functions. They are:

- 1 To control the transfer of data and information between various units
- 2 To indicate appropriate functions by the arithmetic unit
- 3 **Bus:** These are the pathways through which data and instructions pass from one area to another within the computer. The bus carries the signals to various devices that are attached to the computer. There are three buses: Address bus, Control Bus and Data bus.

**Arithmetic Logic Unit (ALU):** This unit does arithmetic calculations and logical operations involved in the program, such as addition, multiplication, comparison etc.,

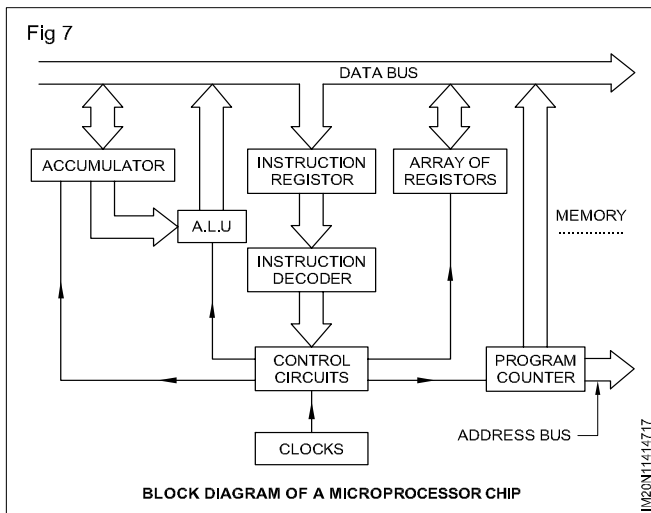
The CPU uses the address bus to select the memory address of the device in order to read and write data. The actual data is sent using the data bus. Control bus carries the control information like instructing the ALU which operation to perform. Out of these buses the address and control buses are unidirectional whereas the data bus is bidirectional.

- 4 **Storage Devices:** These are the floppy drives and hard disk drives, both of which we would discuss in detail in the lesson on secondary memory devices.
- 5 **Motherboard:** The motherboard is the primary component of the entire system. Without the support circuitry and functions that this device provides, even the CPU is unable to function. The detailed diagram of a mother – board is given below.

The various slots are provided to mount add- on cards like display cards, sound card, internal modem, hard disk controller cards etc. However, now- a – days most of these cards come in built within the motherboard itself.

Tips for removing add- on cards from the mother board

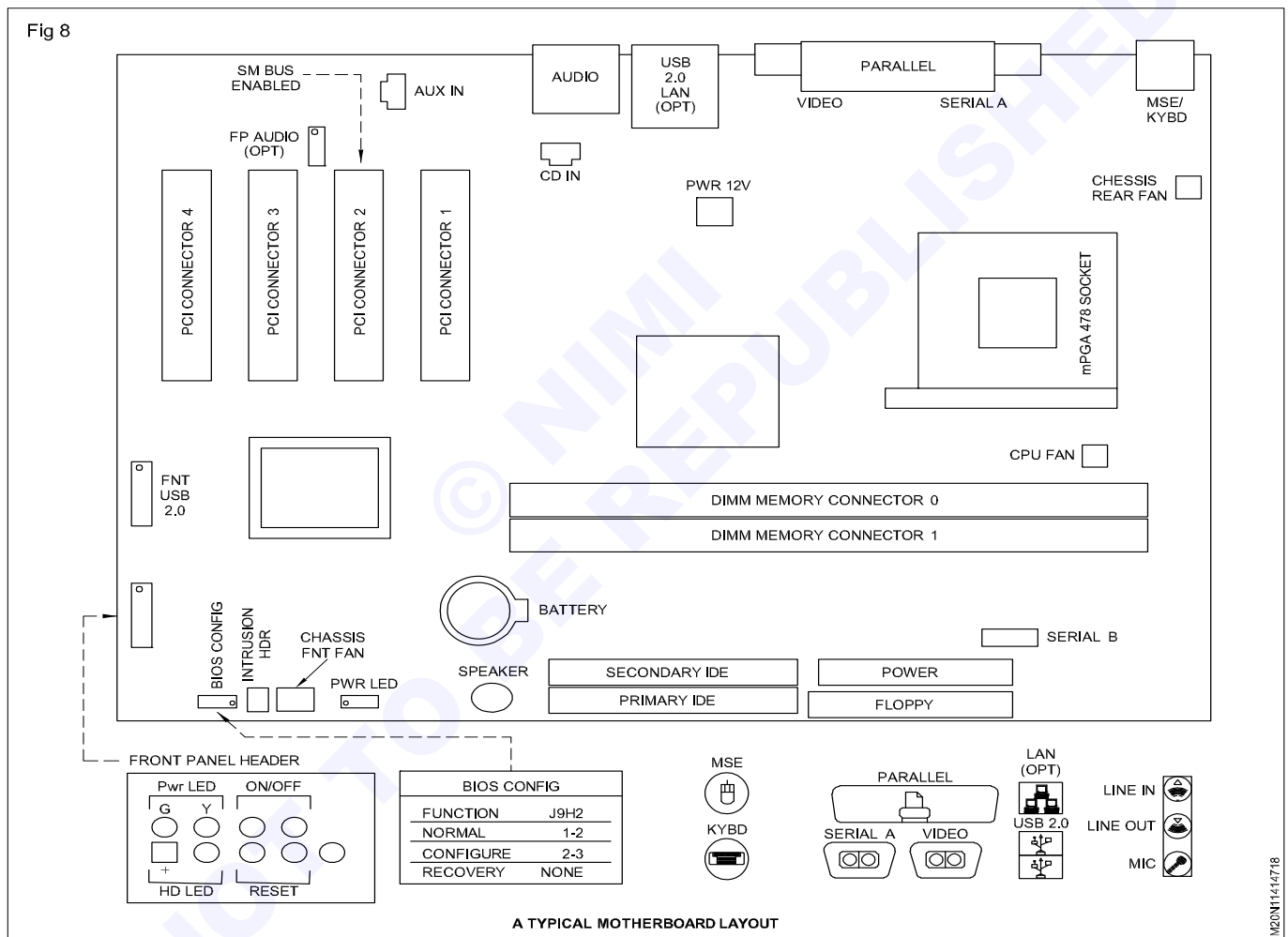
- 1 Put on anti- static wrist strap.
- 2 Ensure that all the cables from the add- on card connected on to the mother board is removed. Label the removed cable with suitable information. Before removing, record to which slot on the motherboard it was plugged.



- 3 Remove the boards mounting screw which fixes the metal mounting bracket of the add-on card.
- 4 Hold the board along its edges and rock it up gently using equal force at both holding ends and remove the card.

After removing the card, avoid touching the edge connector of the card.

- 5 Place the card preferably in an antistatic mat such that the components on the card are visible to you.
- 6 Identify and record the jumper settings on the card.
- 7 Identify and record the switch setting if any on the mother board.
- 8 Place the add-on card safely in anti-static pouch and keep it safely in the drawer of your working table or in a shelf.



### Tips for removing the Mother board from the cabinet

When all the cables and add-on board are taken out from the processor unit of PC, than it looks quite easy to work further 1

Ensure that all the cables from, the mother board is removed

- 2 Ensure that all the add-on cards connected on to the mother board is removed.
- 3 Plan/determine your most likely exit route for the mother board.
- 4 Remove the two screws holding motherboard on the chassis of the cabinet.

- 5 Locate the plastic pinch spacers holding the motherboard on to the chassis of the cabinet.
- 6 slide the motherboard until the plastic pinch spacers feel free of the motherboard using nose pliers

**Make sure that you don't accidentally remove any jumper switches with rough handling. Correct jumper settings are crucial for proper operation of the motherboard.**

Most CPU's of both types will generate have micro fan mounted right on the chip.

**RAM Modules:** These memory modules can be seen as



small PCB strips (much smaller than add-on cards) plugged into lengthy slots (DIMM-168-pin) (SIMM-72 pin) (SIMM-30 pin) perpendicularly on the motherboard as shown in Fig 8. You may see only one RAM module strip or more than one. Each RAM module strip may have capacity ranging from 4 MB to more than 128 MB.

You will generally see two small plastic card extractors on the edges of the connector.

- 7 Store the PC cabinet in a safe place.
- 8 Keep the working table clean and place the mother board for studying.
- 9 Record the jumper and switch setting on the motherboard.

### Tips for identifying the major components on the mother board

**CPU:** The Central Processing Unit or CPU, is an integrated Circuit (IC). This will be the biggest IC which you can easily identify. This IC can be of two basic types:

- 1 A super socket-7 or socket 370 types.
- 2 A socket -1 type.
- 3 **ROM BIOS Chip:** This means Read Only Memory Basic input-output System. These Chips contain permanent code that the PC uses when the PC is first turned-On.

Most ROM Bios Chips will have a glass window at its center. Sometimes this window is closed using an adhesive glossy paper slip on which it would be marked the marker of this Bios such as AWARD or AMI or PHOENIX and like. On this glossy paper slip, a few other details including the year will be printed. This is an important data to be recorded.

- 4 **Battery:** A round shining big coin like thing, held in a plastic enclosure with a '+' mark can be seen on the mother board. This is technically called as a button cell. This is actually a Lithium ion battery. This provides power supply to the CMOSRAM for maintenance of Real Time Clock (RTC) and BIOS settings.

Also shows a connector with lot of pins, generally in pairs. These provide necessary signal for the LED's and switches mounted on the front panel of the PC. Right by the sides of these connectors, markings can be seen as to which it should be connected, such as, LED, SPK, RST, etc.

- 5 **ADD-ON Cards/Expansion Card SLOTS:** There will generally be three different types of slot female edge connectors.

**ISA slots:** ISA means Industry Standard Architecture. This type of connector will be Black in color and is the longest of the three types. This slot is called as the ISA slots. These are the old versions and hence your PC mother board may have just one slot of this type or more. Note that your mother board may not have this type of slot also. If so, don't be worried as ISA is an old type and not very essential.

**PCI slots:** PCI means Peripheral Component Interconnect. These are more recent type compared to ISA and are very popular. These slots are generally white in color and smaller in size compared to ISA slots. A PC Motherboard

will definitely have one PCI slot but generally more than one.

**AGP slots:** AGP means Accelerated Graphics Port. This slot is much more recent than the PCI slot and this slot holds the add-on graphic card to enhance the graphic capabilities of your PC. This slot is generally brown in color and there will be only one such slot on the mother board. If the AGP control circuit is integrated on the mother board itself, then you may not find an AGP on the mother board.

**L2 Cache Slot:** Some mother board will have small slots for placing cache memory chip modules. These slots are generally white in color. Not all mother boards will have this slot.

**IDE/EIDE Connectors:** Most motherboards will have two such connectors, one slot marked as IDE1 or Primary and other as IDE2 or Secondary. Through these connectors IDE/EIDE devices such as HDD's and CD ROM drives are connected to the motherboard.

**Floppy Diskette Drive Connector:** This is a 34 pin male black plastic connector. On most motherboards there will be only one such connector. The cable used with connector will have facility to connect two floppy diskette drivers.

**Power supply connector on the Motherboards:** This will generally be a plastic male Molex connector will be one connector strip of 12 pins in single line. In case of ATX models, there will be two rows of 10 pin connectors.

**Keyboard port, Mouse Port, On Board Serial and Parallel Port:** Keyboard Port is one which is always on the Mother. The keyboard port can be of these types listed below.

- 1 The olden type-5 pin -DIN connector
- 2 The more recent type -6 pin P/S -2 connector.
- 3 The most modern USB port

These motherboards having only the 5-pin DIN port can also use P/S 2-keyboards using a cross adapter cable.

Those motherboards not having USB (Universal Serial Bus) circuitry on board can place a USB adapter card in one of the PCI slots. Then use the USB connector for connecting a USB keyboard.

Serial ports are generally a 9 pin male mini D shell type (DB-9) connector. Generally any motherboard will have at least two serial ports. All motherboards may not have the serial port connectors mounted right on the motherboard at its edge as shown in figure above. But there will be a 9 pin connector on the motherboard somewhere, using which, you have to run 9 wire flat cables to the ports mounted on a metal plate and fixed at one of the metal slots found at the rear of the cabinet.

Some devices need a 25 pin serial port (DB-25). However there will be only 9 pin connections at it. These DB-25 serial ports can be easily identified because, this 25 pin slot is a male connector (Whereas a DB-25 pin female is a parallel port).

Mouse is connected to any one of the DB-9 serial port or a P/S-2.6 pin mini DIN connector or a USB port. Where is

the mouse to be connected depends upon the type of connector your mouse has. However, you can use cross adapter cable to connect a mouse to a P/S-2 port or vice versa.

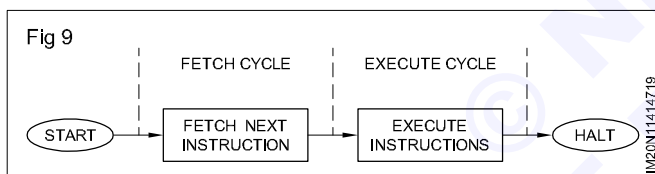
**CPU Architecture:** The basic function performed by a computer is execution of a program, which is a set of instructions stored in memory. The processor does the actual work by executing instructions specified in the program. The instruction execution takes place in the CPU registers, which are:

**Memory Address Register (MAR):** It specifies the address of memory location from which data or instruction is to be accesses (for read operation) or to which the data is to be stored (for write operation).

**Program Counter (PC):** It keeps track of the instruction which is to be executed next, after the execution of an on-going instruction.

**Instruction Register (IR):** Here the instructions are loaded before their execution.

**Instruction Execution:** The simplest model of instruction processing can be a two step process. The CPU reads (fetches) instructions (codes) from the memory one at a time, and executes or performs the operation specified by the instruction. Instruction fetches involves reading of an instruction from a memory location to the CPU register. The execution of this instruction may involve several operations depending on the nature of the instruction.



The processing needed for a single instruction (fetch and execution) is referred to as **instruction cycle**. The instruction cycle consist of the fetch cycle and the execute cycle. Program execution terminates if the electric power supply is discontinued or some sort of unrecoverable error occurs, or by a program itself.

**Fetch Cycle:** For fetch cycle, typically the program counter is used. Program counter keeps track of the instructions which is to be fetched next. The fetched instructions is in the form of binary code and is loaded into an instruction register in the CPU.

**Execute Cycle:** The CPU interprets the instructions in the instruction register and does the required action. In general, these action can be divided into the following categories.

- 1 Data may be transferred from processor to memory or from memory to processor.
- 2 Data may be transferred to or from a peripheral device and an I/O module. Following are few of the important output devices, which are used in Computer Systems

### Computer - Memory

A memory is just like a human brain. It is used to store data and instruction. Computer memory is the storage space

in computer where data to be processed and instructions required for processing are stored.

The memory is divided into large number of small parts. Each part is called cell. Each location or cell has a unique address, which varies from zero to memory size minus one.

For example, if computer has 64k words, then this memory unit has  $64 \times 1024 = 65536$  memory locations.

Memory is primarily of three types:

- 1 Cache Memory
- 2 Primary Memory/Main Memory
- 3 Secondary Memory

### Computer - RAM

A RAM constitutes the internal memory of the CPU for storing data, program result. It is read/write memory. It is called random access memory (RAM).

Since access time in RAM is independent of the address to the word that is, each storage location inside the memory is as easy to reach as other location & takes the same amount of time. We can reach into the memory at random & extremely fast but can also be quite expensive.

RAM is volatile i.e. data stored in it is lost when we switch off the computer or if there is a power failure. Hence, a backup uninterruptible power system (UPS) is often used with computers. RAM is small, both in terms of its physical size and in the amount of data it can hold.

RAM is of two types

- 1 Static RAM (SRAM)
- 2 Dynamic RAM (DRAM)

### Computer - ROM

ROM stands for Read Only Memory. The memory from which we can only read but cannot write on it. This type of memory is non-volatile. The information is stored permanently in such memories during manufacture.

A ROM stores such instructions as are required to start computer when electricity is first turned on, this operation is referred to as bootstrap. ROM chip are not only used in the computer but also in other electronic items like washing machine and microwave oven.

### Computer - Motherboard

The motherboard serves as a single platform to connect all of the parts of a computer together. A mother board connects CPU, memory, hard drives, optical drives, video card, sound card and other ports and expansion cards directly or via cables. It can be considered as the backbone of a computer

#### Features

- 1 Motherboard varies greatly in supporting various types of components
- 2 Normally, a motherboard supports a single type of CPU and few types of memories

- 3 Video Cards, Hard disks, Sound Cards have to compatible with motherboard to function properly
- 4 Mother boards, cases and power supplies must be compatible to work properly together

### Computer - Memory Units

- 1 It is the amount of data that can be stored in the storage unit.
- 2 The storage capacity are expressed in terms of Bytes

## Different types of printers

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

- state different types of print technologies and printers
- explain the impact printers/dot matrix printers
- state non-impact printers, inkjet printers & laserjet printers.

Printers are electro-mechanical devices that enable a user to print whatever is displayed by the monitor - letters, contracts, business documents, images.

### Print Technologies

A printer outputs data that is seen on the computer screen on to a paper. Most printers are used through a parallel port, but some newer ones use USB connections. The most crucial printer measurement is dots per inch rating. Printers are best chosen by actually seeing the quality of the printer output. There are many types of print technologies like Daisy wheel, Laser, Inkjet etc. Printers are normally categorized into impact and non-impact types.

Printers can be divided into two categories

- **Impact**
- **Non-Impact**

**Impact:** The impact printers incorporate a built-in mechanism to print images on paper using a series of pins or hammers which strike on an inked ribbon to create the image. For Example: Dot matrix, Daisy Wheel, etc.

**Non-Impact:** The non-impact printers include those printers that do not have any kind of contact with the paper while printing either text or image. For Example: Inkjet, Laser, Bubble Jet, etc.

These printers use different technology to print an image. For Example, a laser printer uses heat to attach microscopic particles of dry toner to specific parts of the page. An Inkjet printer has tiny nozzles through which it sprays droplets of ink on to the page.

**Impact Printers:** In this hammers or pins strike against a ribbon and paper to print the text. This mechanism is known as electro-mechanical mechanism. They are of two types.

1 Character Printer

2 Line Printer

**Character Printer:** It prints only one character at a time. It has relatively slower speed. Eg. Dot Matrix Printers

**Dot Matrix Printer:** It prints characters as combination of dots. Dot matrix printers are the most popular among serial

### Computer - Ports

- 1 A computer port is a physical docking point using which an external device can be connected to the computer
- 2 A computer port can also be programmatic docking point through which information flows from a program to computer or over the internet.

printers. These have a matrix of pins on the print head of the printer which form the character. The computer memory sends one character at a time to be printed by the printer. There is a carbon between the pins & the paper. The words get printed on the paper when the pin strikes the carbon. There are generally 24 pins.

**Non-Impact Printers:** These printers use non-Impact technology such as ink-jet or laser technology. These printers provide better quality of O/P at higher speed. These printers are of two types :

**Ink-Jet Printer:** It prints characters by spraying patterns of ink on the paper from a nozzle or jet. It prints from nozzles having very fine holes, from which a specially made ink is pumped out to create various letters and shapes. The ink comes out of the nozzle in a form of vapors. After passing through a reflecting plate, it forms the desired letter/shape at the desired place.

Laser Printer is a type of printer that utilizes a laser beam to produce an image on a drum. The light of the laser alters the Electronics charge on the drum wherever it hits. The drum is then rolled through a reservoir of toner, which is picked up by the charged portions of the drum. Finally, the toner is transferred to the paper through a combination of heat and pressure.

This is also the way copy machines work. Because an entire page is transmitted to a drum before the toner is applied, laser printers are sometimes called page printers. There are two other types of page printers that fall under the category of laser printers even though they do not use lasers at all. One uses an array of LEDs to expose the drum and the other uses LCDs. Once the drum is charged, however, they both operate like a real laser printer. One of the chief characteristics of laser printers is their resolution - how many dots per inch (dpi) they lay down.

The available resolutions range from 300 dpi at the low end to 1,200 dpi at the high end. In addition to text, laser printers are very adopt at printing graphics, so you need significant amounts of memory in the printer to print high-resolution graphics. To print a full-page graphic at 300 dpi, for example, you need at least 1 MB (megabyte) of printer RAM. For a 600 dpi graphic, you need at least 4 MB RAM.



Because laser printers are non-impact printers, they are much quieter than dot-matrix or daisy-wheel printers. They are also relatively fast, although not as fast as some dot-matrix or daisy-wheel printers. The speed of laser printers

ranges from about 4 to 20 pages of text per minute (ppm). A typical rate of 6ppm is equivalent to about 40 characters per second (cps).

## Modem

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

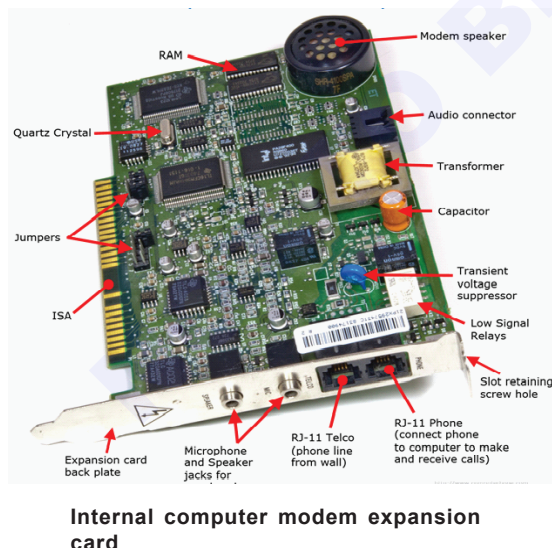
- explain different types of modems
- explain modem functionality
- explain ethernet cable and connectors RJ-45/RJ-11.

**Modem** : Short for MODulator/DEModulator, the first Modem known as the Dataphone, which was first released by AT&T in 1960. It later became more common for home users when Dennis Hayes and Dale Heatherington released the 80-103A Modem in 1977.

The Modem is a hardware device that enables a computer to send and receive information over telephone lines by converting the digital data used by your computer into an analog signal used on phone lines and then converting it back once received on the other end. The figure below, is an example of an internal expansion card modem.

The other computer's modem reconverts the analog signals (that the computer cannot understand) into digital signals (that it can). Conversion of one type of signals to another is called modulation, their reversion to the original type is called demodulation. Modern modems work at 56 thousand bits per second (Kbps) or higher data transfer speeds, perform automatic error correction, and allow voice and fax communications. Cable modems offer 2 millionbits per second (Mbps) or higher speeds, whereas advanced types of telephone services (such as ISDN) allow very high speed data transfer without any modem.

Fig 1



A type of modem that allows people to access the Internet via their cable television service.

The cable modem uses a coaxial cable television lines to provide a greater bandwidth than the dial-up computer modem. An extremely fast access to the Web is providing

by the cable modem with downstream transmission up to 38 Mbits/s and an upstream transmission up to 1 Mbits/s.

Fig 2

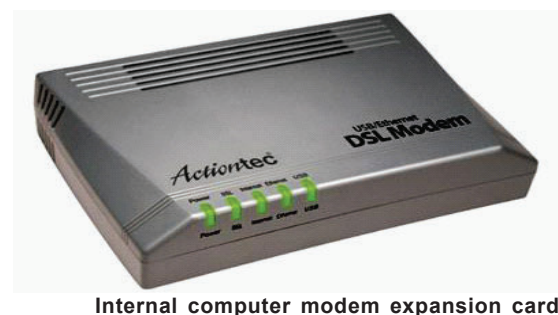


Data can be transferred over cable lines much more quickly than over traditional phone lines. Transmission rates are typically around 1.5 megabits per second. Faster transmission is actually possible, but speed is usually restricted by the cable company's (typically slower) connection to the Internet.

Unfortunately this transmission rate fluctuates with the number of users because of the shared bandwidth on which the cable technology is based.

### DSL modem

Fig 3



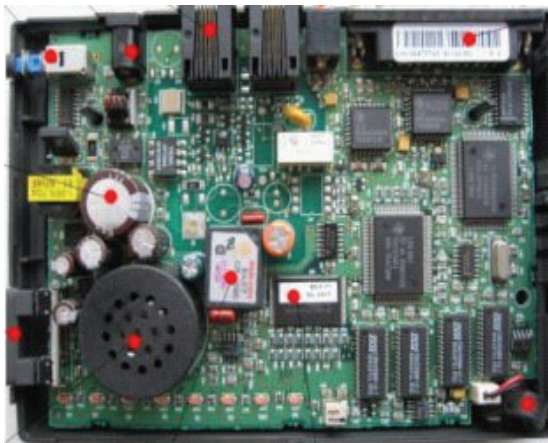
DSL (Digital Subscriber Line) modem is exclusively used for connections from a telephone switching office to the user. DSL modem is a device used to connect a single

computer or router to a DSL phone line, in order to use an ADSL service. Like other modems it is a type of transceiver. It is also called a DSL Transceiver or ATU-R. The acronym NTBBA (network termination broadband adapter, network termination broadband access) is also common in some countries. Some of the ADSL modems also manage the connection and sharing of the ADSL service with a group of machines: in this case, the unit is termed a DSL router or residential gateway.

### Parts inside a Modem

Lift the lid on a dialup modem and this is what you'll find inside:

Fig 4



- 1 On/off button:** Spring-loaded switch turns the power on and off.
- 2 Capacitors:** Have a variety of jobs to do in a modem, including smooth out current peaks.
- 3 Volume control:** Controls the loudspeaker volume.
- 4 Loudspeaker:** Relays what's happening on the phone line as your modem dials.
- 5 Modem chip:** Modulates (add digital information to the outgoing telephone signal) and demodulates (separate the digital information from the incoming signal).
- 6 Other chips:** Control modem chip and other components.
- 7 Microphone:** Allows you to send your own voice down the phone line.
- 8 Serial connection:** Connects the modem to your computer's serial (RS-232) port. Newer modems connect to the USB port instead.
- 9 Microphone socket:** Connects an external microphone so you can record messages in higher quality than if you use the built-in microphone.
- 10 Telephone sockets:** Connect your modem to a phone socket with a standard (RJ11) telephone cable. There's a second socket where you can plug a telephone handset into your modem. This lets you to use your phone through the modem when your computer's not already using the line.

**11 Power input:** Connects the modem to an external power supply unit (electricity transformer) to your modem.

### Modem functionality

Other than choosing a modem based on the type of internet connection there are a few other variables or requirements that should be looked for before purchasing.

- 1 Compatibility** - Is the modem compatible with your computer (Windows, Mac, Linux, etc)? Furthermore, is it compatible with your computer's software (7, Vista, 10.4, etc)?
- 2 Upload/download speeds** - Check the "upstream" and "downstream" speeds, as they'll differ from model to model. Often times it'll even be different from one direction (upload) to the next (download).
- 3 Security** - Does the modem support security features such as WPS (WiFi Protected Setup), WPA/WPA2 Security Protocol and WEP, TKIP and AES (64/128 bit) Encryption?
- 4 Size & mounting options** - How big/small is the modem? Will it fit well with the computer equipment? Some modems can even be attached to the wall.
- 5 Price** - Modems vary in price from as little as Rs. 1000 to as much as Rs 4000. The difference in price comes down to the type of connection and speeds

### ADSL Modem

Short for Asymmetric Digital Subscriber Line, ADSL is a type of DSL broadband communications technology used for connecting to the Internet. ADSL allows more data to be sent over existing copper telephone lines (POTS), when compared to traditional modem lines. A special filter, called a microfilter, is installed on a subscriber's telephone line to allow both ADSL and regular voice (telephone) services to be used at the same time. ADSL requires a special ADSL modem and subscribers must be in close geographical locations to the provider's central office to receive ADSL service. Typically this distance is within a radius of 2 to 2.5 miles. ADSL supports data rates of from 1.5 to 9 Mbps when receiving data (known as the downstream rate) and from 16 to 640 Kbps when sending data (known as the upstream rate).

### Ethernet cable

An Ethernet cable is one of the most popular forms of network cable used on wired networks. Ethernet cables connect devices on local area networks such as PCs, routers and switches.

### Types of Ethernet cables

Ethernet cables normally support one or more industry standards including Category 5 (CAT5) and Category 6 (CAT6).

A crossover cable is a special type of Ethernet cable specially designed for connecting two computers to each



other. By contrast, most Ethernet cables are designed to connect one computer to a router or switch.

Ethernet cables are physically manufactured in two basic forms called solid and stranded. Solid Ethernet cables:

1. offer slightly better performance plus improved protection against Electronics interference.
2. are more commonly used on business networks, wiring inside office walls or under lab floors to fixed locations.

#### **Stranded Ethernet cables**

1. are less prone to physical cracks and breaks making them more suitable for travelers and
2. are more commonly used in home networking and by travelers.

#### **Limitations of Ethernet cables**

A single Ethernet cable, like an electric power cord, can extend only limited distances due to their Electronics transmission characteristics.

Several different types of RJ-45 connectors exist. One type, designed for use with stranded cables, generally is incompatible with solid cable. Other types of RJ-45 connectors may work with both stranded and solid cables.

#### **RJ-45**



Short for Registered Jack-45, a RJ-45 is an 8-pin connection used for Ethernet network adapters. This connector resembles the RJ-11 or 6-pin connector used with telephones, but they're completely different. The picture is of a RJ-45 connector separated from the cable.

This connector is most commonly connected to the end of Cat5 cable, which is connected between a computer network card and a network device such as a network router.

**Data Acquisition systems :** The systems, used for data acquisition are known as data acquisition systems. These data acquisition systems will perform the tasks such as conversion of data, storage of data transmission of data and processing of data.

Data acquisition systems consider the following analog signals

- Analog signals, which are obtained from the direct measurement of Electronics quantities such as DC & AC voltages, DC & AC currents, resistance and etc.
- Analog signals, which are obtained from transducers such as LVDT, thermocouple & etc.

Types of data acquisition systems

Data acquisition systems can be classified into the following two types.

- Analog data acquisition systems
- Digital data acquisition systems

Now, let us discuss about these two types of data acquisition systems one by one.

#### **Analog data acquisition systems**

The data acquisition system, which can be operated with analog signals are known as analog data acquisition systems. Following are the blocks of analog data acquisition systems.

**Transducer** - It converts physical quantities into Electronics signals.

**Signal conditioner** - It performs the functions like amplification and selection of desired portion of the signal.

**Display device** - It displays the input signals for monitoring purpose.

**Graphic recording instruments** - These can be used to make the record of input data permanently.

**Magnetic tape instrumentation** - It is used for acquiring, storing & reproducing of input data.

#### **Digital data acquisition systems**

The data acquisition system, which can be operated with digital signals are known as digital data acquisition systems. So, they use digital components for storing or displaying the information.

Mainly, the following operations take place in digital data acquisition.

- Acquisition of analog signals
- Conversion of analog signals into digital signals or digital data
- Processing of digital signals or digital data

Following are the blocks of digital data acquisition systems

- **Transducer** - It converts physical quantities into Electronics signals.
- **Signal conditioner** - It performs the functions like amplification and selection of desired portion of the signal.
- **Multiplexer** - connects one of the multiple inputs to output. So, it acts as parallel to serial converter.

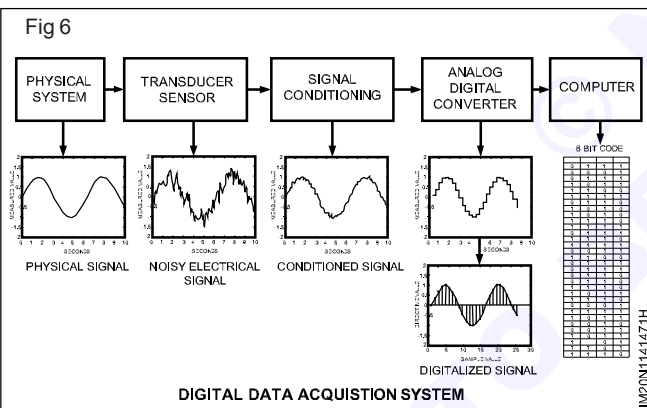
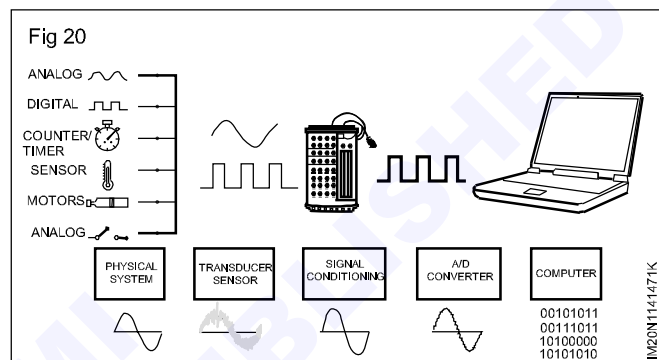
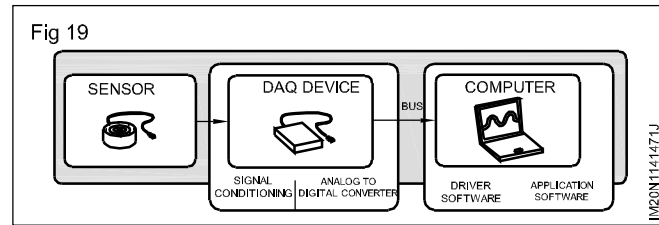
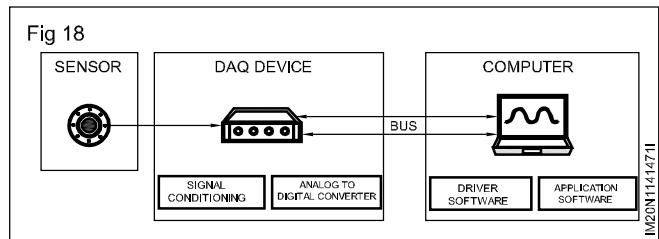
- **Analog to Digital converter** - It converts the analog input into its equivalent digital output.
- **Display device** - It displays the data in digital format.
- **Digital recorder** - It is used to record the data in digital format.

Data acquisition systems are being used in various applications such as biomedical and aerospace. So, we can choose either analog data acquisition systems or digital data acquisition systems based on the requirement.

Data acquisition applications are usually controlled by software programs developed using various general purpose programming languages such as assembly, BASIC, C, C++, C#, Fortran, Java, LabVIEW, Lisp, Pascal, etc. Stand-alone data acquisition systems are often called data loggers.

There are also open-source software packages providing all the necessary tools to acquire data from different, typically specific, hardware equipment. These tools come from the scientific community where complex experiment requires fast, flexible and adaptable software. Those packages are usually custom fit but more general DAQ packages like the maximum integrated data acquisition system can be easily tailored and is used in several physics experiments worldwide.

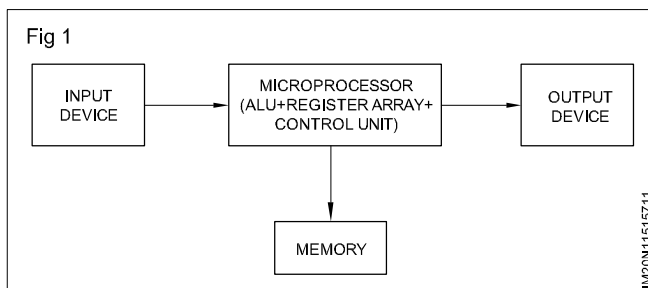
Figs 6, 7, 8 & 9 shows DAS connection in various applications



## Microprocessor - 8085 and its applications

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

- understand the architecture of 8085 microprocessor
- explain pin diagram of 8085
- write program for adding and subtracting two 8 bit numbers
- write program for ascending order and exchanging memory location
- explain instruction set of 8085
- explain pin diagram and block diagram of 8255
- explain the application of 8085.



### How does a microprocessor work?

The microprocessor follows a sequence: Fetch, decode, and execute.

Initially, the instructions are stored in the memory in a sequential order. The microprocessor fetches those instructions from the memory, then decodes it and executes those instructions till STOP instruction is reached. Later, it sends the result in binary to the output port. Between these processes, the register stores the temporarily data and ALU performs the computing functions.

### List of terms used in a microprocessor

Here is a list of some of the frequently used terms in a microprocessor

- **Instruction set** : It is the set of instructions that the microprocessor can understand.
- **Bandwidth** : It is the number of bits processed in a signal instruction.
- **Clock speed**: It determines the number of operations per second the processor can perform. It is expressed in megahertz (MHz) or gigahertz (GHz). It is also known as clock rate.
- **Word length**: It depends upon the width of internal data bus, registers, ALU, etc. An 8-bit microprocessor can process 8-bit data at time. The word length ranges from 4 bits to 64 bits depending upon the type of the microcomputer.
- **Data types** : The microprocessor has multiple data type formats like binary, BCD, ASCII, signed and unsigned numbers.

### Features of a microprocessor

Here is a list of some of the most prominent features of any microprocessor

- **Cost-effective** : The microprocessor chips are available at low prices and results its low cost.
- **Size** : The microprocessor is of small size chip, hence is portable.
- **Low power consumption** : Microprocessors are manufactured by using metal-oxide semiconductor technology, which has low power consumption.
- **Versatility** : The microprocessors are versatile as we can use the same chip in a number of application by configuring the software program.
- **Reliability** : The failure rate of an IC in microprocessors is very low, hence it is reliable.

### 3 8085 Architecture

8085 pronounced as "eighty-eighty-five" microprocessor. It is an 8-bit microprocessor designed by Intel in 1977 using NMOS technology.

It has the following configuration:

- 8-bit data bus
- 16-bit address bus, which can address upto 64KB
- A 16-bit program counter
- A 16-bit stack pointer
- Six 8-bit registers arranged in pairs: BC, DE, HL
- Requires +5V supply to operate at 3.2.MHZ single phase clock.

It is used in washing machines, microwave ovens, mobile phones, etc.

### 8085 Microprocessor - functional units

8085 consists of the following functional units

#### Accumulator

It is an 8-bit register used to perform arithmetic, logical, I/O & LOAD/STORE operations. It is connected to internal data bus & ALU.

### Arithmetic and logic unit

As the name suggest, it performs arithmetic and logical operations like addition, subtraction, and or etc. on 8-bit data.

### General purpose register

There are 6 general purpose registers in 8085 processor, i.e B, C, D, E, H & L. Each register can hold 8-bit data.

These registers can work in pair to hold 16-bit data and their pairing combination is like B-C D-E & H-L.

### Program counter

It is a 16-bit register used to store the memory address location of the next instruction to be executed. Microprocessor increments the program counter whenever an instruction is being executed, so that the program counter points to the memory address of the next instruction that is going to be executed.

### Stack pointer

It is also a 16-bit register works like stack, which is always incremented/decremented by 2 during push & pop operations.

| D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|----|----|----|----|----|----|----|----|
| S  | Z  |    | AC |    | P  |    | CY |

### Instruction register and decoder

It is an 8-bit register. When an instruction is fetched from memory then it is stored in the instruction register. Instruction decoder decodes the information present in the instruction register.

### Timing and control unit

It provides timing and control signal to the microprocessor to perform operations. Following are the timing and control signals, which control external and internal circuits:

- Control signals: READY, RD', WR', ALE
- Status signals : S0, S1, IO/M'
- DMA signals: HOLD, HLDA
- RESET signals : RESET IN, RESET OUT

### Interrupt control

As the name suggests it controls the interrupts during a process. When a microprocessor is executing a main program and whenever an interrupt occurs, the microprocessor shifts the control from the main program to process the incoming request. After the request is completed, the control goes back to the main program.

There are 5 interrupt signals in 8085 microprocessor: INTR, RST 7.5, RST 6.5, RST 5.5, TRAP.

### Serial input/output control

It controls the serial data communication by using these two instruction: SID (serial input data) and SOD (serial output data)

### Temporary register

It is an 8-bit register, which holds the temporary data of arithmetic and logical operations.

### Flag register

It is an 8-bit register having five 1-bit flip-flops, which holds either 0 or 1 depending upon the result store in the accumulator.

These are the set of 5 flip-flops:

- Sign (S)
- Zero (Z)
- Auxiliary carry (AC)
- Parity (P)
- Carry (C)

Its bit position is shown in the following diagram:

### Address buffer and address-data buffer

The content stored in the stack pointer and program counter is loaded into the address buffer and address-data buffer to communicate with the CPU. The memory and I/O chips are connected to these buses; the CPU can exchange the desired data with the memory and I/O chips.

### Address bus and data bus

Data bus carries the data to be stored. It is bidirectional, whereas address bus carries the location to where it should be stored and it is unidirectional. It is used to transfer the data & address I/O devices.

### 8085 Architecture (Fig 2)

### 8085 Pin configuration (Fig 3)

#### Address bus

A15-A8, it carries the most significant 8-bits of memory/I/O address.

#### Data bus

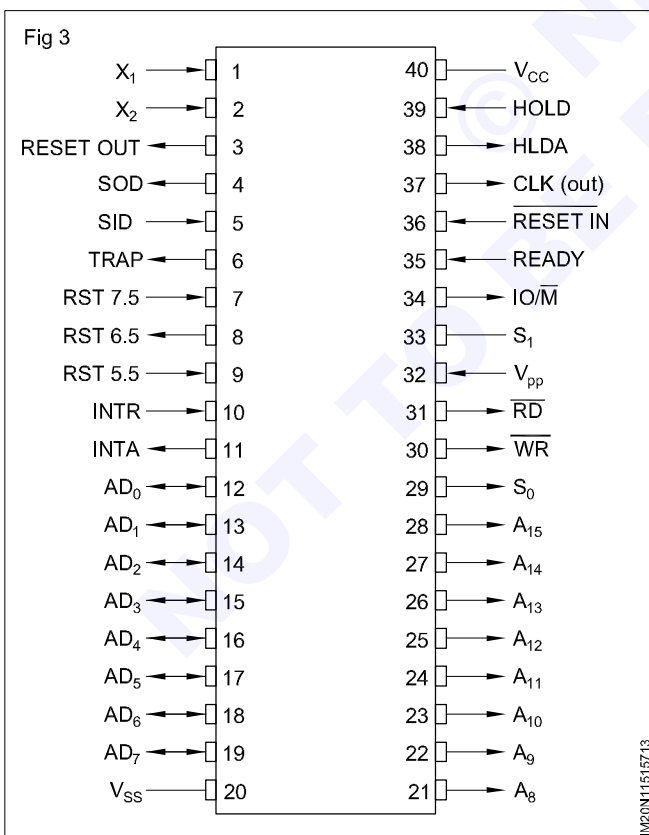
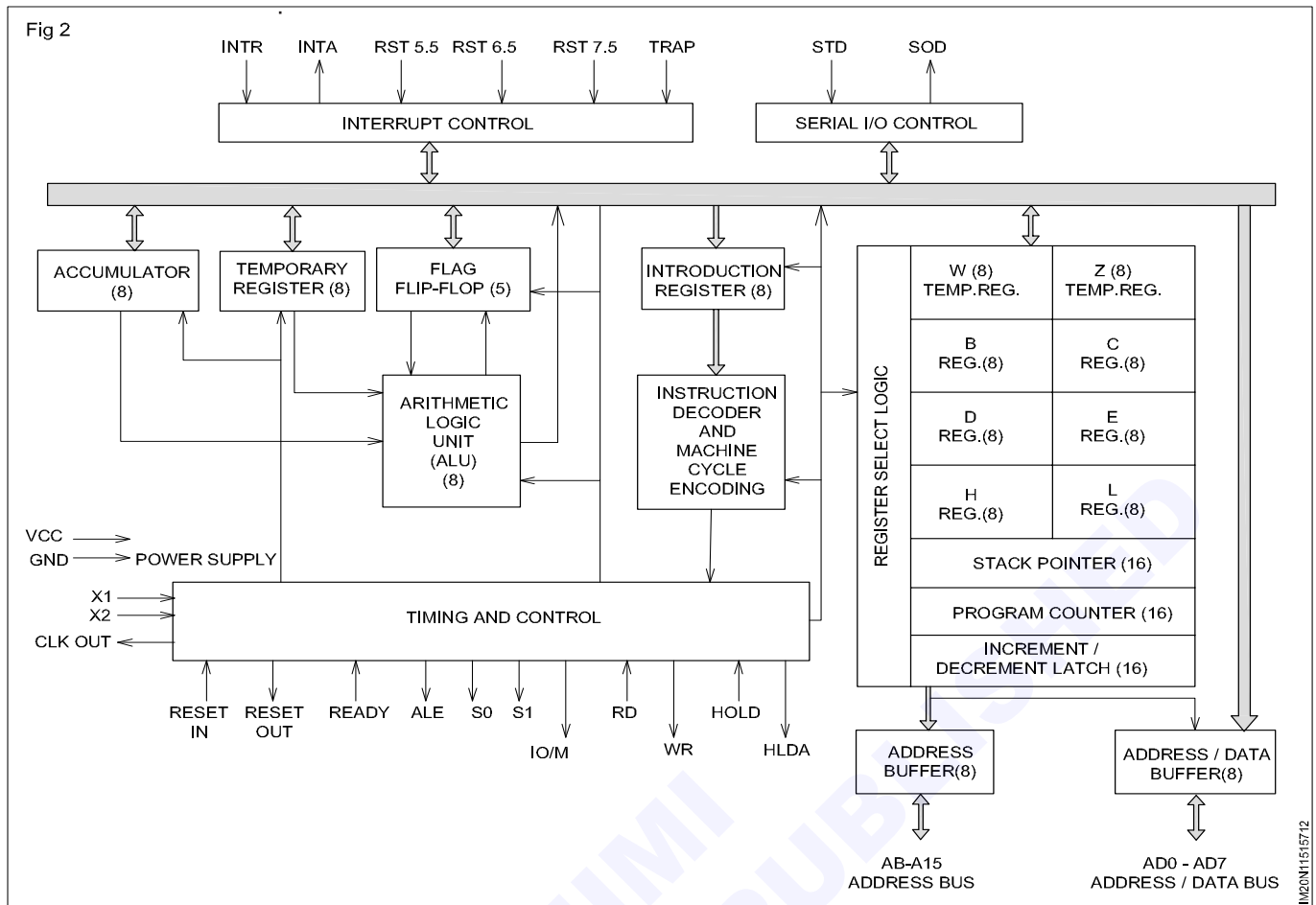
AD7-AD0, it carries the least significant 8-bit address and data bus.

### Control and status signals

These signals are used to identify the nature of operation. There are 3 control signal and 3 status signals.

Three control signals are RD, WR & ALE.

- **RD** : This signal indicates that the selected IO or memory device is to be read and is ready for accepting data available on the data bus.



- **WR:** This signal indicates that the data on the data bus is to be written into a selected memory or IO location.
- **ALE:** It is a positive going pulse generated when a new operation is started by the microprocessor. When the

pulse goes high, it indicates address. When the pulse goes down it indicates data.

Three status signals are IO/M, S0 & S1.

### IO/M

This signal is used to differentiate between IO and Memory operations, i.e. when it is high indicates IO operation and when it is low then it indicates memory operation.

### S1 & S0

These signals are used to identify the type of current operation.

### Power supply

There are 2 power supply signals: VCC & VSS. VCC indicates + 5v power supply and VSS indicates ground signal.

### Clock signals

There are 3 clock signals, i.e X1, X2, CLK OUT.

- **X1, X2:** A crystal (RC, LC N/W) is connected at these pin and is used to set frequency of the internal clock generator. This frequency is internally divided by 2.
- **CLK OUT :** This signal is used as the system clock for devices connected with the microprocessor.

### Interrupts & externally initiated signals

Interrupts are the signals generated by external devices to request the microprocessor to perform a task. There are 5 interrupt signals, i.e TRAP, RST 7.5, RST 6.5, RST 5.5



and INTR. We will discuss interrupts in detail in interrupts section.

- **INTA** : It is an interrupt acknowledgment signal
- **RESET IN** : This signal is used to reset the microprocessor by setting the program counter to zero.
- **RESET OUT** : This signal is used to reset all the connected devices when the microprocessor is reset.
- **READY** : This signal indicates that the device is ready to send or receive data. If READY is low, then the CPU has to wait for READY to go high.
- **HOLD** : This signal indicates that another master is requesting the use of the address and data buses.
- **HLDA (Hold acknowledge)**: It indicates that CPU has received the HOLD request and it will relinquish the bus in the next clock cycle. HLDA is set to low after HOLD signal is removed.

**Serial I/O signals** : There are 2 serial signals, i.e. SID and SOD and these signals are used for serial communication.

- **SOD** (Serial output data line): The output SOD is set/reset as specified by the SIM instruction.
- **SID** (Serial input data line) : The data on this line is loaded into accumulator whenever a RIM instruction is executed.

Instruction sets are instruction codes to perform some task. It is classified into five categories.

| S.No | Instruction & Description |
|------|---------------------------|
| 1    | Control Instructions      |
| 2    | Logical Instructions      |
| 3    | Branching Instructions    |
| 4    | Arithmetic Instructions   |
| 5    | Data Transfer Instruction |

### Microprocessor - 8085 control instructions

Following is the table showing the list of control instructions with their meanings.

| Opcode | Operand | Meaning                   | Explanation                                                                                                                                     |
|--------|---------|---------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------|
| NOP    | None    | No operation              | No operation is performed. i.e., the instruction is fetched and decoded                                                                         |
| HLT    | None    | Halt and enter wait state | The CPU finishes executing the current instruction and stops further execution. An interrupt or reset is necessary to exit from the halt state. |
| DI     | None    | Disable interrupts        | The interrupt enable flip-flop is reset and all the interrupts are disabled except TRAP                                                         |
| EI     | None    | Enable interrupts         | The interrupt enable flip-flop is set and all the interrupts are enabled.                                                                       |
| RIM    | None    | Read interrupt mask       | This instruction is used to read the status of interrupts 7.5, 6.5, 5.5 and serial data input bit.                                              |
| SIM    | None    | Set interrupt mask        | This instruction is used to implement the interrupts 7.5, 6.5, 5.5 and serial data output.                                                      |

### Microprocessor - 8085 logical instructions

The following table shows the list of logical instructions with their meanings

| Opcode | Operand    | Meaning                                             | Explanation                                                                                           |
|--------|------------|-----------------------------------------------------|-------------------------------------------------------------------------------------------------------|
| CMP    | R<br>M     | Compare the register or memory with the accumulator | The contents of the operand (register or memory) are M compared with the contents of the accumulator. |
| CPI    | 8-bit data | Compare immediate with the accumulator              | The second byte data is compared with the contents of the accumulator.                                |

| Opcode | Operand    | Meaning                                              | Explanation                                                                                                                                                                                                                           |
|--------|------------|------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| ANA    | R<br>M     | Logical and register or memory with the accumulator  | The contents of the accumulator are logically and with M the contents of the register or memory, and the result is placed in the accumulator.                                                                                         |
| ANI    | 8-bit data | Logical and immediate with the accumulator           | The contents of the accumulator are logically and with the 8-bit data and the result is placed in the accumulator.                                                                                                                    |
| XRA    | R<br>M     | Exclusive or register or memory with the accumulator | The contents of the accumulator are exclusive or with M the contents of the register or memory, and the result is placed in the accumulator.                                                                                          |
| XRI    | 8-bit data | Exclusive or immediate with the accumulator          | The contents of the accumulator are exclusive or with the 8-bit data and the result is placed in the accumulator.                                                                                                                     |
| ORA    | R<br>M     | Logical or register or memory with the accumulator   | The contents of the accumulators are logically or with M the contents of the register or memory and result is placed in the accumulator.                                                                                              |
| ORI    | 8-bit data | Logical or immediate with the accumulator            | The contents of the accumulator are logically or with the 8-bit data and the result is placed in the accumulator.                                                                                                                     |
| RLC    | None       | Rotate the accumulator left                          | Each binary bit of the accumulator is rotated left by one position. Bit D7 is placed in the position of D0 as well as in the carry flag. CY is modified according to bit D7.                                                          |
| RRC    | None       | Rotate the accumulator right                         | Each binary bit of the accumulator is rotated right by one position. Bit D0 is placed in the position of D7 as well as in the carry flag. CY is modified according to bit D0.                                                         |
| RAL    | None       | Rotate the accumulator left through carry            | Each binary bit of the accumulator is rotated left by one position through the carry flag. Bit D7 is placed in the carry flag, and the carry flag is placed in the least significant position D0. CY is modified according to bit D7. |
| RAR    | None       | Rotate the accumulator right through carry           | Each binary bit of the accumulator is rotated right by one position through the carry flag. Bit D0 is placed in the carry flag, and the carry flag is placed in the most significant position D7. CY is modified according to bit D0. |
| CMA    | None       | Complement accumulator                               | The contents of the accumulator are complemented. No flags are affected.                                                                                                                                                              |
| CMC    | None       | Complement carry                                     | The carry flag is complemented. No other flags are affected.                                                                                                                                                                          |
| STC    | None       | Set carry                                            | Set carry                                                                                                                                                                                                                             |

## Microprocessor - 8085 branching instructions

The following table shows the list of branching instruction with their meanings

| Opcode |                     |             | Operand        | Meaning                       | Explanation                                                                                                                                                                   |
|--------|---------------------|-------------|----------------|-------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| JMP    |                     |             | 16-bit address | Jump unconditionally          | The program sequence is transferred to the memory address given in the operand.                                                                                               |
| opcode | Description         | Flag status | 16-bit address | Jump unconditionally          | The program sequence is transferred to the memory address given in the operand based on the specified flag of the PSW.                                                        |
| JC     | Jump on Carry       | CY = 1      |                |                               |                                                                                                                                                                               |
| JNC    | Jump on no carry    | CY = 0      |                |                               |                                                                                                                                                                               |
| JP     | Jump on positive    | S = 0       |                |                               |                                                                                                                                                                               |
| JM     | Jump on minus       | S = 1       |                |                               |                                                                                                                                                                               |
| JZ     | Jump on zero        | Z = 1       |                |                               |                                                                                                                                                                               |
| JNZ    | Jump on no zero     | Z = 0       |                |                               |                                                                                                                                                                               |
| JPE    | Jump on parity even | P = 1       |                |                               |                                                                                                                                                                               |
| JPO    | Jump on parity odd  | P = 0       |                |                               |                                                                                                                                                                               |
| Opcode | Description         | Flag status | 16-bit address | Unconditional subroutine call | The program sequence is transferred to the memory address given in the operand. Before transferring, the address of the next instruction after CALL is pushed onto the stack. |
| CC     | Call on carry       | CY = 1      |                |                               |                                                                                                                                                                               |
| CNC    | Call on no carry    | CY = 0      |                |                               |                                                                                                                                                                               |
| CP     | Call on positive    | S = 0       |                |                               |                                                                                                                                                                               |
| CM     | Call on minus       | S = 1       |                |                               |                                                                                                                                                                               |
| CZ     | Call on zero        | Z = 1       |                |                               |                                                                                                                                                                               |
| CNZ    | Call on no zero     | Z = 0       |                |                               |                                                                                                                                                                               |
| CPE    | Call on parity even | P = 1       |                |                               |                                                                                                                                                                               |
| CPO    | call on parity odd  | P = 0       |                |                               |                                                                                                                                                                               |

| Opcode      |                       |             | Operand | Meaning                                   | Explanation                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |             |                 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
|-------------|-----------------------|-------------|---------|-------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|-----------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| RET         |                       |             | None    | Return form subroutine unconditionally    | The program sequence is transferred from the subroutine to the calling program.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |             |                 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| Opcode      | Description           | Flag status | None    | Return from subroutine conditionally      | The program sequence is transferred from the subroutine to the calling program based on teh specified flag of the PSW and the program execution begins at the new address                                                                                                                                                                                                                                                                                                                                                                                          |             |                 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| RC          | Return on carry       | CY = 1      |         |                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |             |                 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| RNC         | Return on no carry    | CY = 0      |         |                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |             |                 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| RP          | Return on positive    | S = 0       |         |                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |             |                 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| RM          | Return on minus       | S = 1       |         |                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |             |                 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| RZ          | Return on zero        | Z = 1       |         |                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |             |                 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| RNZ         | Return on no zero     | Z = 0       |         |                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |             |                 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| RPE         | Return on parity even | P = 1       |         |                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |             |                 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| RPO         | Return on parity odd  | P = 0       |         |                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |             |                 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| PCHL        |                       |             | None    | Load the program counter with HL contents | The contents of registers H&L are copied into the program counter. The contents of H are placed as the high-ordre byte and the contents of L as the loworder byte.                                                                                                                                                                                                                                                                                                                                                                                                 |             |                 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| RST         |                       |             | 0 -7    | Restart                                   | <div>The RST instruction is used as software instructions in a program to transfer the program execution to one of the following eight locations.</div> <table><thead><tr><th>Instruction</th><th>Restart address</th></tr></thead><tbody><tr><td>RST 0</td><td>0000H</td></tr><tr><td>RST 1</td><td>0008H</td></tr><tr><td>RST 2</td><td>0010H</td></tr><tr><td>RST 3</td><td>0018H</td></tr><tr><td>RST 4</td><td>0020H</td></tr><tr><td>RST 5</td><td>0028H</td></tr><tr><td>RST 6</td><td>0030H</td></tr><tr><td>RST 7</td><td>0038H</td></tr></tbody></table> | Instruction | Restart address | RST 0 | 0000H | RST 1 | 0008H | RST 2 | 0010H | RST 3 | 0018H | RST 4 | 0020H | RST 5 | 0028H | RST 6 | 0030H | RST 7 | 0038H |
| Instruction | Restart address       |             |         |                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |             |                 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| RST 0       | 0000H                 |             |         |                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |             |                 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| RST 1       | 0008H                 |             |         |                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |             |                 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| RST 2       | 0010H                 |             |         |                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |             |                 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| RST 3       | 0018H                 |             |         |                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |             |                 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| RST 4       | 0020H                 |             |         |                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |             |                 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| RST 5       | 0028H                 |             |         |                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |             |                 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| RST 6       | 0030H                 |             |         |                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |             |                 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| RST 7       | 0038H                 |             |         |                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |             |                 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |

| Opcode      | Operand         | Meaning | Explanation                                                                                                                                                                                                                                                                                                                                                                                                                          |             |                 |      |       |         |       |         |       |         |       |
|-------------|-----------------|---------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|-----------------|------|-------|---------|-------|---------|-------|---------|-------|
|             |                 |         | <p>The 8085 has additionally 4 interrupts, which can generate RST instructions internally and doesn't require any external hardware. Following are those instructions and their restart addresses.</p> <table><tr><th>Instruction</th><th>Restart address</th></tr><tr><td>TRAP</td><td>0024H</td></tr><tr><td>RST 5.5</td><td>002CH</td></tr><tr><td>RST 6.5</td><td>0034H</td></tr><tr><td>RST 7.5</td><td>003CH</td></tr></table> | Instruction | Restart address | TRAP | 0024H | RST 5.5 | 002CH | RST 6.5 | 0034H | RST 7.5 | 003CH |
| Instruction | Restart address |         |                                                                                                                                                                                                                                                                                                                                                                                                                                      |             |                 |      |       |         |       |         |       |         |       |
| TRAP        | 0024H           |         |                                                                                                                                                                                                                                                                                                                                                                                                                                      |             |                 |      |       |         |       |         |       |         |       |
| RST 5.5     | 002CH           |         |                                                                                                                                                                                                                                                                                                                                                                                                                                      |             |                 |      |       |         |       |         |       |         |       |
| RST 6.5     | 0034H           |         |                                                                                                                                                                                                                                                                                                                                                                                                                                      |             |                 |      |       |         |       |         |       |         |       |
| RST 7.5     | 003CH           |         |                                                                                                                                                                                                                                                                                                                                                                                                                                      |             |                 |      |       |         |       |         |       |         |       |

### 8085 Arithmetic Instructions

Following is the table showing the list of arithmetic instructions with their meanings.

| Opcode | Operand               | Meaning                                         | Explanation                                                                                                                                                                                 |
|--------|-----------------------|-------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| ADD    | R<br>M                | Add register or memory to the accumulator       | <p>The contents of the register or memory are added to the contents of the accumulator and the result is stored in the accumulator.</p> <p><b>Example</b> - ADD K.</p>                      |
| ADC    | R<br>M                | Add register to the accumulator with carry      | <p>The contents of the register or memory &amp; M the carry flag are added to the contents of the accumulator and the result is stored in the accumulator</p> <p><b>Example</b> - ADC K</p> |
| ADI    | 8-bit data            | Add the immediate to the accumulator            | <p>The 8-bit data is added to the contents of the accumulator and the result is stored in the accumulator</p> <p><b>Example</b> - ADI 55K</p>                                               |
| ACI    | 8-bit data            | Add the immediate to the accumulator with carry | <p>The 8-bit data and the carry flag are added to the contents of the accumulator and the result is stored in the accumulator</p> <p><b>Example</b> - ACI 55K</p>                           |
| LXI    | Reg.pair, 16 bit data | Load the register pair                          | <p>The instruction stores 16-bit data into the register pair designated in the operand.</p> <p><b>Example</b> - LXI K, 3025M</p>                                                            |
| DAD    | Reg. pair             | Add the register pair to H and L registers      | <p>The 16-bit data of the specified register pair are added to the contents of the HL register</p> <p><b>Example</b> - DAD K</p>                                                            |



| Opcode | Operand    | Meaning                                                  | Explanation                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|--------|------------|----------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| SUB    | R<br>M     | Subtract the register or the memory from the accumulator | The contents of the register or the memory are subtracted from the contents of the accumulator, and the result is stored in the accumulator.<br><b>Example - SUB K</b>                                                                                                                                                                                                                                                                            |
| SBB    | R<br>M     | Subtract the source and borrow from the accumulator      | The contents of the register or the memory & the borrow flag are subtracted from the contents of the accumulator, and the result is placed in the accumulator.<br><b>Example - SBB K</b>                                                                                                                                                                                                                                                          |
| SUI    | 8-bit data | Subtract the immediate from the accumulator              | The 8-bit data is subtracted from the contents of the accumulator & the result is stored in the accumulator.<br><b>Example - SUI 55K</b>                                                                                                                                                                                                                                                                                                          |
| XCHG   | None       | Exchange H and L with D and E                            | The contents of register H are exchanged with the contents of register D, and the contents of register L are exchanged with the contents of register E.<br><b>Example - XCHG</b>                                                                                                                                                                                                                                                                  |
| INR    | R<br>M     | Increment the register or the memory by 1                | The contents of the designated register or the memory are incremented by 1 and their result is stored at the same place.<br><b>Example - INR K</b>                                                                                                                                                                                                                                                                                                |
| INX    | R          | Increment register pair by 1                             | The contents of the designated register pair are incremented by 1 and their result is stored at the same place.<br><b>Example - INX K</b>                                                                                                                                                                                                                                                                                                         |
| DCR    | R<br>M     | Decrement the register or the memory by 1                | The contents of the designated register or memory are decremented by 1 and their result is stored at the same place.<br><b>Example - DCR K</b>                                                                                                                                                                                                                                                                                                    |
| DCX    | R          | Decrement the register pair by 1                         | The contents of the designated register pair are decremented by 1 and their result is stored at the same place.<br><b>Example - DCX K</b>                                                                                                                                                                                                                                                                                                         |
| DAA    | None       | Decimal adjust accumulator                               | The contents of the accumulator are changed from a binary value to two 4-bit BCD digits.<br><br>If the value of the low-order 4-bits in the accumulator is greater than 9 or if AC flag is set, the instruction adds 6 to the low-order four bits.<br><br>If the value of the high-order 4-bits in the accumulator is greater than 9 or if the carry flag is set, the instruction adds 6 to the high-order four bits.<br><br><b>Example - DAA</b> |

## 8085 Data-transfer Instructions

Following is the table showing the list of Data-transfer instructions with their meanings.

| Opcode | Operand                  | Meaning                                           | Explanation                                                                                                                                                                                                                                                      |
|--------|--------------------------|---------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| MOV    | Rd, Sc<br>M, Sc<br>Dt, M | Copy from the source (Sc) to the destination (Dt) | This instruction copies the contents of the source register into the destination register into the destination register without any alternation.<br><b>Example</b> - MOV K, L                                                                                    |
| MVI    | Rd, data<br>M, data      | Move immediate 8-bit                              | The 8-bit data is stored in the destination register or memory.<br><b>Example</b> - MVI K, 55L                                                                                                                                                                   |
| LDA    | 16-bit address           | Load the accumulator                              | The contents of a memory location, specified by a 16-bit address in the operand, are copied to the accumulator.<br><b>Example</b> - LDA 2034K                                                                                                                    |
| LDAX   | B/D Reg. pair            | Load the accumulator indirect                     | The contents of the designated register pair point to a memory location. This instruction copies the contents of that memory location into the accumulator.<br><b>Example</b> - LDAX K                                                                           |
| LXI    | Reg. pair 16-bit data    | Load the register pair immediate                  | This instruction loads 16-bit data in the register pair designated in the register or the memory.<br><b>Example</b> - LXI K, 3225L                                                                                                                               |
| LHLD   | 16-bit address           | Load H and L register direct                      | The instruction copies the contents of the memory location pointed out by the address into register L and copies the contents of the next memory location into register H.<br><b>Example</b> - LHLD 3225K                                                        |
| STA    | 16-bit address           | 16-bit address                                    | The contents of the accumulator are copied into the memory location specified by the operand.<br>This is a 3-byte instruction, the second byte specifies the low-order address and the third byte specifies the high-order address.<br><b>Example</b> - STA 325K |
| STAX   | 16-bit address           | Store the accumulator indirect                    | The contents of the accumulator are copied into the memory location specified by the contents of the operand.<br><b>Example</b> - STAX K                                                                                                                         |
| SHLD   | 16-bit address           | Store H and L registers direct                    | The contents of register L are stored in the memory location specified by the 16-bit address in the operand and the content of H register are stored into the next memory location by incrementing the operand.                                                  |

| Opcode | Operand            | Meaning                                     | Explanation                                                                                                                                                                                                                                                                                                                                                                                                                               |
|--------|--------------------|---------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|        |                    |                                             | <p>This is a 3-byte instruction, the second byte specifies the low-order address and the third byte specifies the high-order address.</p> <p><b>Example - STA 325K</b></p>                                                                                                                                                                                                                                                                |
| XCHG   | None               | Exchange H and L with D and E               | <p>The contents of register H are exchanged with the contents of register D, and the contents of register L are exchanged with the contents of register E.</p> <p><b>Example - XCHG</b></p>                                                                                                                                                                                                                                               |
| SPHL   | None               | Copy H and L registers to the stack pointer | <p>The instruction loads the contents of the H and L registers into the stack pointer register. The contents of the H register provide the high-order address and the contents of the L register provide the low-order address.</p> <p><b>Example - SPHL</b></p>                                                                                                                                                                          |
| XTHL   | None               | Exchange H and L with top of stack          | <p>The contents of the L register are exchanged with the stack location pointed out by the contents of the stack location (SP+1)</p> <p><b>Example - XTHL</b></p>                                                                                                                                                                                                                                                                         |
| PUSH   | Reg. pair          | Push the register pair onto the stack       | <p>The contents of the register pair designated in the operand are copied onto the stack in the following sequence.</p> <p>The stack pointer register is decremented and the contents of the high order register (B,D,H,A) are copied into that location.</p> <p>The stack pointer register is decremented again and the contents of the low-order register (C,E,L flags) are copied to that location.</p> <p><b>Example - PUSH K</b></p> |
| POP    | Reg. pair          | Pop off stack to the register               | <p>The stack pointer is incremented by 1 and the contents of that memory location are copied to the high-order register (B, D, H, A) of the operand.</p> <p>The stack pointer register is again incremented by 1</p> <p><b>Example - POPK</b></p>                                                                                                                                                                                         |
| OUT    | 8-bit port address | Output the data from the                    | <p>The contents of the accumulator are copied into the I/O port specified by the operand.</p> <p><b>Example - OUT K9L</b></p>                                                                                                                                                                                                                                                                                                             |
| IN     | 8-bit port address | Input data to accumulator                   | <p>The contents of the input port designated in the operand are read and loaded into the accumulator.</p> <p><b>Example - IN5KL</b></p>                                                                                                                                                                                                                                                                                                   |

## Program 4-8-bit addition

### Objective

To add two 8-bit numbers in memory and store the result in memory.

### Theory

The first data is brought to accumulator A and the second one in any one of the other registers say B. The addition is done using ADD. The result is then stored at 4152. The ADD instruction affects flags depending on result.

Example (Program)

The two data to be added are at 4150 and 4151. The result is stored at 4152.

Data : (4150) = 23

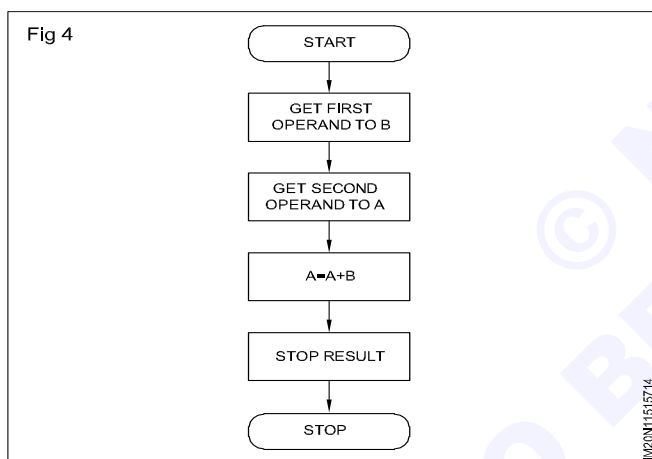
(4152) = 35

Result : (4152) = 58.

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### Flow chart

#### Flow chart for addition



### Program

LDA 4150 ; (4150)  $\Rightarrow$  (A) = 23

MOV B,A ; (A) $\Rightarrow$  (B)

LDA 4151 ; (4151) $\Rightarrow$  (A) = 35

ADD B ; (A) + (B)  $\Rightarrow$  (A)

STA 4152 (A)  $\Rightarrow$  (4152) = 58

HLT

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| Memory address | Opcodes | Mnemonics |
|----------------|---------|-----------|
| 4100           | 3A      | LDA4150   |
| 4101           | 50      |           |
| 4102           | 41      |           |

|      |    |          |
|------|----|----------|
| 4103 | 47 | MOV B, A |
| 4104 | 3A | LDA4151  |
| 4105 | 51 |          |
| 4106 | 41 |          |
| 4107 | 80 | ADD B    |
| 4108 | 32 | STA4152  |
| 4109 | 52 |          |
| 410A | 41 |          |
| 410B | 76 | HLT      |

### Object codes

#### Procedure

- 1 Key in the opcodes from the address specified.
- 2 Enter data at 4150 and 4151 as specified in the Example.
- 3 Execute the program and check for the result at 4152.
- 4 Change data at 4150 and 4151 and execute each time and check for result.

#### Discussion

In the above example, the data were loaded from memory. Note that the immediate addressing mode for load, add would greatly cut-short the program size, but using only specific data. The use of "DAA" instruction is essential for writing decimal addition programs.

### Program 5-8 bit subtraction

In this experiment, the HL register pair is first initialised to the start address of memory at which the data is stored. Then data is brought to accumulator a and the other one is subtracted from memory itself. The result from A is then stored into memory again using the HL register. The SUB instruction sets and and clear flags according to result.

#### Example : Program

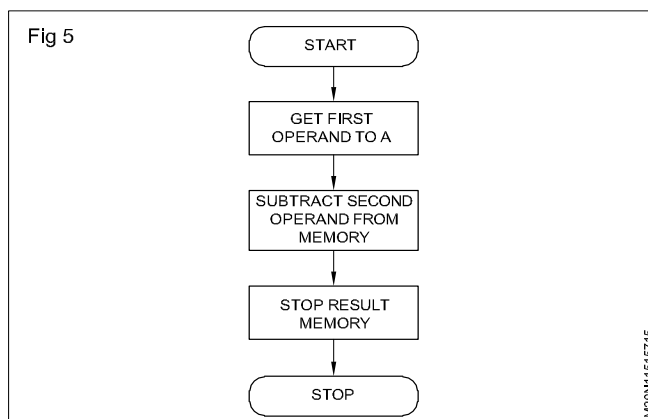
Let the data to be subtracted be 24 from 49

Data : (4150) = 49

(4152) = 24

Result : (4152) = 25.

#### Flow chart



|                |                                     |      |    |          |
|----------------|-------------------------------------|------|----|----------|
| <b>Program</b> |                                     | 4103 | 7E | MOV A, M |
| LXI H, 4150    | ; Initialise memory pointer to 4150 | 4104 | 23 | INXH     |
| MOV A, M       | ; (4150) (A) = 49                   | 4105 | 96 | SUB M    |
| INX H          | ; Point to next data.               | 4106 | 23 | INXH     |
| SUB M          | ; (4151) (A)                        | 4107 | 77 | MOV M, A |
| INX H          | ; Point to next location            | 4108 | 76 | HLT      |
| MOV M, A       | ; (A) (4152)                        |      |    |          |
| HLT            |                                     |      |    |          |

#### Object codes

| Memory address | Opcodes | Mnemonics   |
|----------------|---------|-------------|
| 4100           | 21      | LXI H, 4150 |
| 4101           | 50      |             |
| 4102           | 41      |             |

#### Procedure

- 1 Key in the opcodes from the address specified.
- 2 Enter data that is needed for execution at 4150 and 4151.
- 3 Execute the program and check for result at 4152.
- 4 Try changing data and check for result each time.

**Discussion :** The above program for subtraction can be further reduced by using immediate instruction for load and subtract.

#### Arrange numbers in an ascending order

Write a program to arrange first 10 numbers from address 3000H in an ascending order.

```

MVI B, 09      : " Initialize counter "
START          : " LXI H< 3000H : Initialize memory pointer "
MVI C, 09 H    : " Initialize counter 2 "
BACK : MOV A, M : " Get the number "
INXH           : " Increment memory pointer "
CMP M          : " Compare number with nex number "
JC SKIP        : " If less, don't interchange "
JZ SKIP        : " If equal, don't interchange "
MOV D, M
MOV M, A
DCXH
MOV M, D
INXH           : " Interchange two numbers "
SKIP:DCR C     : " Decrement counter 2 "
JNZ BACK       : " If not zero, repeat "
DCR B          : " Decrement counter 1 "
JNZ START
HLT            : " Terminate program execution "

```



## Exchanging the memory locations

Write a program to exchange the data at 5000M & 6000M memory location.

|            |                                                               |
|------------|---------------------------------------------------------------|
| LDA 5000 M | : “ Getting the contents at 5000M location into accumulator “ |
| MOV B, A   | : “ Save the contents into B register “                       |
| LDA 6000M  | : “ Getting the contents at 6000M location into accumulator “ |
| STA 5000M  | : “ Store the contents of accumulator at address 5000M “      |
| MOV A, B   | : “ Get the saved contents back into A register “             |
| STA 6000M  | : “ Store the contents of accumulator at address 6000 M”      |

Instruction sets are instruction codes to perform some task. It is classified into five categories.

| S.No | Instruction & Description |
|------|---------------------------|
| 1    | Control Instructions      |
| 2    | Logical Instructions      |
| 3    | Branching Instructions    |
| 4    | Arithmetic Instructions   |
| 5    | Data Transfer Instruction |

## Microprocessor - 8085 control instructions

Following is the table showing the list of control instructions with their meanings.

### 8255 Pin diagram (Fig 6)

Fig shows the 8255 pin diagram of microprocessor

### 8255 Block diagram

Fig shows the internal 8255 block diagram of 8255 pin diagram microprocessor. It consists of data bus buffer, control logic and Group A and Group B controls.

| Opcode | Operand | Meaning                   | Explanation                                                                                                                                     |
|--------|---------|---------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------|
| NOP    | None    | No operation              | No operation is performed, i.e., the instruction is fetched and decoded.                                                                        |
| HLT    | None    | Halt and enter wait state | The CPU finishes executing the current instruction and stops further execution. An interrupt or reset is necessary to exit from the halt state. |
| DI     | None    | Disable interrupts        | The interrupt enable flip-flop is reset and all the interrupts are disabled except TRAP.                                                        |
| EI     | None    | Enable interrupts         | The interrupt enable flip-flop is set and all the interrupts are enabled.                                                                       |
| RIM    | None    | Read interrupt mask       | This instruction is used to read status of interrupts 7.5, 6.5, 5.5 and read serial data input bit.                                             |

**Data bus buffer:** This tri-state bi-directional buffer is used to interface the internal data bus of 8255 pin diagram to the system data bus. Input or output instructions executed by the CPU either read data from or write data into the buffer. Output data from the CPU to the ports or control register, and input data to the CPU from the ports or status register are all passed through the buffer.

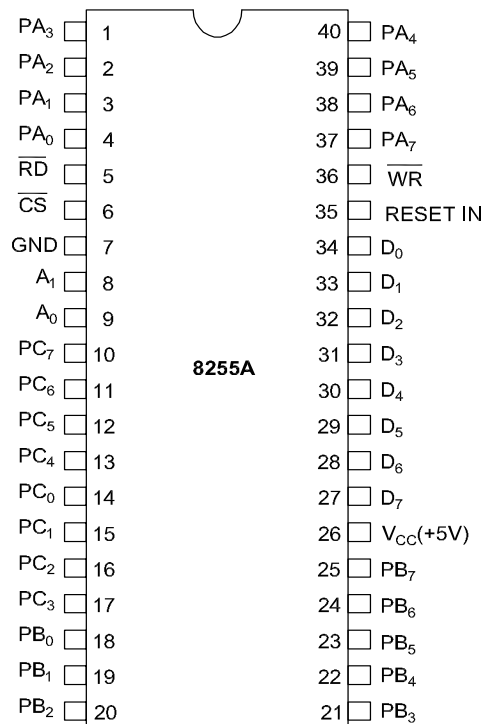
**Control logic:** The control logic block accepts control bus signals as well as inputs from the address bus and issues commands to the individual group control blocks (Group A control and Group B control). It issues appropriate enabling

signals to access the required data/control words or status word. The input pins for the control logic section are described here.

### Group A and Group B controls

Each of the group A and group B controls blocks receives control words from the CPU and issues appropriate commands to the ports associated with it. The group A controls port A and PC-PC, while the group B control block controls port B and PC-PC.

Fig 6



PIN DIAGRAM 8255A

IM20N11515716

### Port A

This has an 8-bit latched and buffered output and an 8-bit input latch. It can be programmed in three mode : mode 0, mode 1 and mode 2.

### Port B

This has an 8-bit data I/O latch/buffer and an 8-bit data input buffer. It can be programmed in mode 0 and mode 1.

### Port C

This has one 8-bit unlatched input buffer and an 8-bit output latch/buffer. Port C can be splitted into two parts and each can be used as control signals for ports A and B in the handshake mode. It can be programmed for bit set/reset operation.

### Modes of operation of 8255 microprocessor

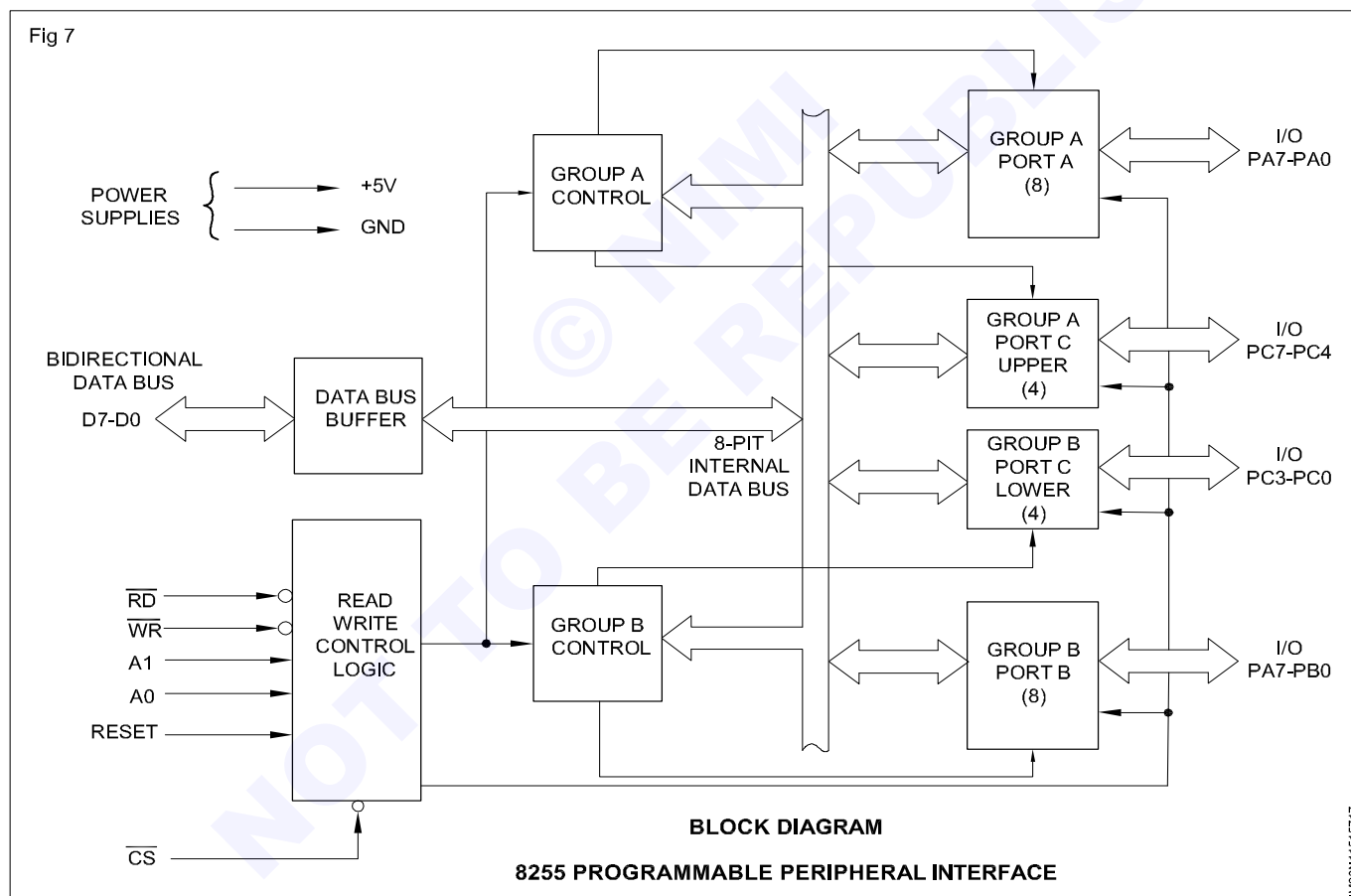
#### Bit set-reset (BSR) mode

The individual bits of port C can be set or reset by sending out a single OUT instruction to the control register. When Port C is used for control/status operation, this feature can be used to set or reset individual bits.

| Pin symbols                               | Function                                                                                                                                                                                                                                               |
|-------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| D <sub>0</sub> -D <sub>7</sub> (Data bus) | These bi-directional, tri-state data bus lines are connected to the system data bus. They are used to transfer data and control word from microprocessor (8085) to 8255 or to receive data or status word from 8255 to the 8085.                       |
| PA <sub>0</sub> -PA <sub>7</sub> (Port A) | These 8-bit bi-directional I/O pins are used to send data to output device and to receive data from input device. It functions as an 8-bit data output latch/buffer, when used in output mode and an 8-bit data input buffer, when used in input mode. |
| PB <sub>0</sub> -PB <sub>7</sub> (Port B) | These 8-bit bi-directional I/O pins are used to send data to output device and to receive data from input device. It functions as an 8-bit data output latch/buffer, when used in output mode and an 8-bit data input buffer, when used in input mode. |
| D <sub>0</sub> -D <sub>7</sub> (Data bus) | These bi-directional, tri-state data bus lines are connected to the system data bus. They are used to transfer data and control word from microprocessor (8085) to 8255 or to receive data or status word from 8255 to the 8085                        |
| PA <sub>0</sub> -PA <sub>7</sub> (Port A) | These 8-bit bi-directional I/O pins are used to send data to output device and to receive data from input device. It functions as an 8-bit data output latch/buffer, when used in output mode and an 8-bit data input buffer, when used in input mode. |
| PB <sub>0</sub> -PB <sub>7</sub> (Port B) | These 8-bit bi-directional I/O pins are used to send data to output device and to receive data from input device. It functions as an 8-bit data output latch/buffer, when used in output mode and an 8-bit data input buffer, when used in input mode. |

| A1 | A0 | $\overline{RD}$ | $\overline{WR}$ | $\overline{CS}$ | Operations                      |
|----|----|-----------------|-----------------|-----------------|---------------------------------|
|    |    |                 |                 |                 | <b>Input (Read) operations</b>  |
| 0  | 0  | 0               | 1               | 0               | Port A to data bus              |
| 0  | 0  | 0               | 1               | 0               | Port B to data bus              |
| 1  | 0  | 0               | 1               | 0               | Port C to data bus              |
|    |    |                 |                 |                 | <b>Output (Write) operation</b> |
| 0  | 0  | 1               | 0               | 0               | Data bus to Port A              |
| 0  | 1  | 1               | 0               | 0               | Data bus to Port B              |
| 1  | 0  | 1               | 0               | 0               | Data bus to Port C              |
| 1  | 1  | 1               | 0               | 0               | Data bus to control register    |
|    |    |                 |                 |                 | <b>Disable Function</b>         |
| X  | X  | X               | X               | 1               | Data bus Tri-stated             |
| 1  | 1  | 0               | 1               | 0               | Illegal condition               |
| X  | X  | 1               | 1               | 0               | Data bus Tri-stated             |

Fig 7



## I/O Modes

### Mode 0 : Simple input /output

In this mode ports A and B are used as two simple 8-bit I/O ports and Port C as two 4-bit ports. Each port (or half - port, in case of C) can be programmed to function as simply an input port or an output port. The input/output features in mode 0 are as follows:

- 1 Outputs are latched
- 2 Inputs are buffered, not latched
- 3 Ports do not have handshake or interrupt capability

### Model 1 : Input/Output with handshake

In this mode, input or output data transfer is controlled by handshaking signals. Handshaking signals are used to transfer data between devices. whose data transfer speeds

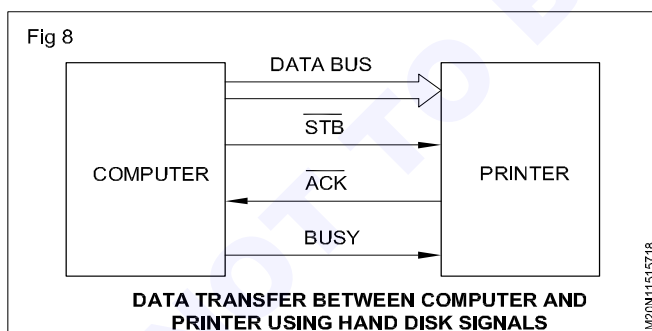
are not same. For example computer can send data to the printer with large speed but printer can't accept data and print data with this rate. So computer has to send data with the speed with which printer can accept. This type of data transfer is achieved by using handshaking signals along with data signals. Fig 14.3 shows data transfer between computer and printer using handshaking signals.

These handshaking signals are used to tell computer whether printer is ready to accept the data or not. If printer is ready to accept the data then after sending data on data bus, computer uses another handshaking signal (STB) to tell printer that valid data is available on the data bus.

The 8255 pin diagram mode 1 which supports handshaking has following features.

- 1 Two ports (A and B) function as 8-bit I/O ports. They, can be configured either as input or output ports..
- 2 Each port uses three lines from port C as handshake signals. The remaining two lines of port C can be used for simple I/O functions.
- 3 Input and output data are latched.
- 4 Interrupt logic is supported.
- 5 Mode 2 Bi-directional I/O data transfer

This mode allows bi-directional data transfer (transmission and reception) over a single 8-bit data bus using handshaking purpose. In this mode, both inputs and outputs are latched. Due to use of a single 8-bit data bus for bi-directional data transfer, the data sent out by the CPU through Port A appears on the bus connecting it to the peripheral, only when the peripheral requests it. The remaining lines of port C i.e PC0 - PC2 can be used for simple I/O functions. The Port B can be programmed in mode 0 or in mode 1. When port B is programmed in mode 1, PC0-PC2 lines of Port C are used as handshaking signals.

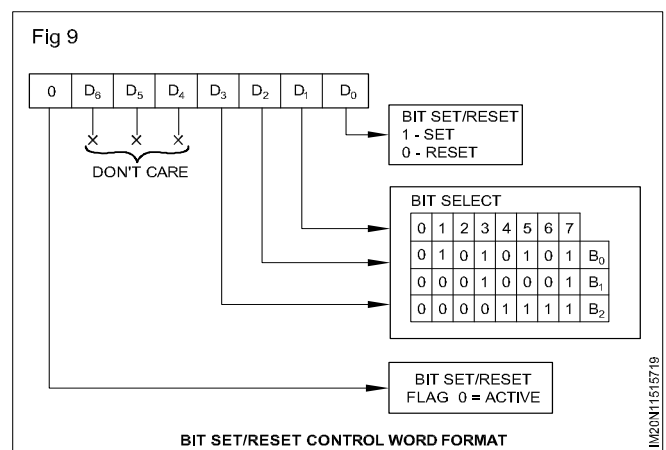


### Control word formats

A high on the RESET pin cause all 24 lines of the three 8-bit ports to be in the input mode. All flip-flops are cleared and the interrupts are reset. This condition is maintained even after the RESET goes low. The ports of the 8255 pin diagram can then be programmed for any other mode by writing a single control word into the control register, when required.

### For bit set/reset mode

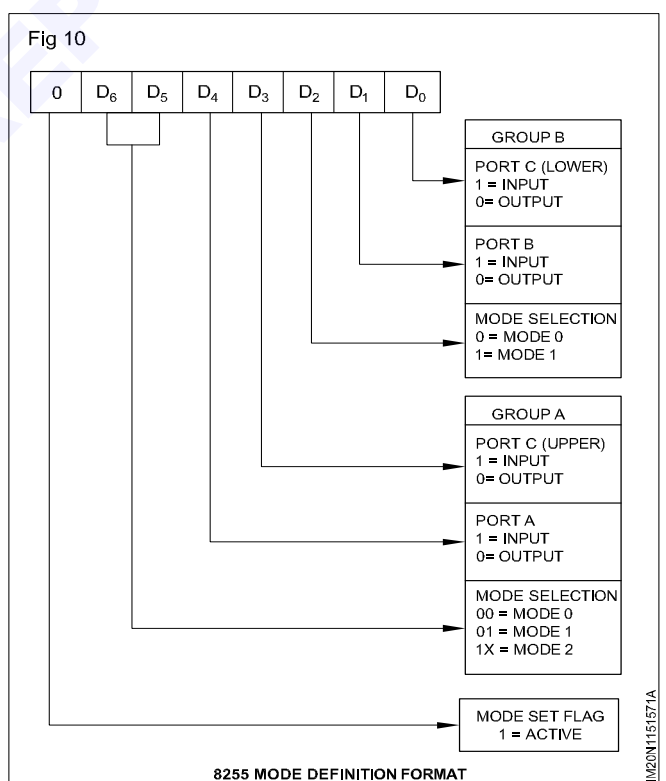
Fig shows bit set/reset control word format



The eight possible combinations of the states of bits D<sub>3</sub> - D<sub>1</sub> (B<sub>2</sub> B<sub>1</sub> B<sub>0</sub>) in the bit set-reset format (RSR) determine particular bit in PC<sub>0</sub> - PC<sub>7</sub> being set or reset as per the status of bit D<sub>0</sub>. A BSR word is to be written for each bit that is to be set or reset. For example, if bit PC<sub>3</sub> is not to be set and bit PC<sub>4</sub> is to be reset, the appropriate BSR words that will have to be loaded into the control register will be, 0XXXX0111 and 0XXX1000, respectively, where x is don't care.

The BSR word can also be used for enabling or disabling interrupt signals generated by Port C when the 8255 pin diagram is programmed for Mode 1 or 2 operation. This is done by setting or resetting the associated bit of the interrupts.

### For I/O mode



The mode definition format I/O mode is shown in Fig. The control words for both. mode definition and Bit set -reset loaded into the same control register, with bit D<sub>7</sub> used for specifying whether the word loaded into the control register is a mode definition word or bit set-reset word. If D<sub>7</sub> is high, the word is taken as a mode definition words, and if it is

low, it is taken as a bit set-rest word. The appropriate bits are set or reset depending on the type of operation desired, and loaded into the control register.

### **Microprocessor applications**

A microprocessor makes daily life easier because of its low cost, low power, small weight, and vast application in every field. There are several applications of microprocessors. Some of the important applications are:

#### **Household devices**

- The programmable thermostat allows the control of temperature at homes. In this system, a microprocessor works with the temperature sensor to determine and adjust the temperature accordingly.
- High-end coffee makers, washing machines and radio clocks contain microprocessor technology.
- Some other home items that contain microprocessor are microwaves, toaster, television technology. DVD players, ovens, stoves, clothes washers, stereo systems, home computers, alarm clocks, hand-held game devices, thermostats, video game system, bread machines, dishwashers, home lighting systems and even some refrigerators with digital temperature control.

#### **Industrial applications of microprocessor**

- Some industrial items which use microprocessor technology include cars, boats, planes, trucks, heavy machinery, elevators, gasoline pumps, credit-card processing units, traffic control devices, computer servers, most high tech medical devices, surveillance systems, security systems and even some doors with automatic entry.

#### **Transportation industry**

- Automobiles, trains and planes also use microprocessor technology.
- Consumer vehicle-buses, cars, trucks-integrate microprocessors to communicate important information throughout the vehicle. E.g. navigation systems provide information using microprocessors and global positioning systems (GPS) technology.

#### **Computers and electronics**

- Microprocessor-driven technology is the brain of the computer. They are used in all types of computers ranging from microcomputers to supercomputers.
- A cell phone or mobile device executes game instructions by way of the microprocessor.

- VCRs, television and gaming platforms also contain microprocessor for executing complex instructions and tasks.

#### **In Medicals**

- Many medical devices, like an insulin pump, are typically controlled by a microprocessor. The microprocessors perform various functions, such as processing data from bio-sensors, storing measurement, and analyzing results.

#### **Instrumentation**

- Microprocessor is also very useful in the field of instrumentation. Function generators, frequency counter, frequency synthesizers, spectrum analysers and many other instruments are available, when microprocessor are used as controller.

#### **Entertainment**

- The use of microprocessor in entertainment equipment, toys and home entertaining applications is making them more useful and full of features.

#### **Embedded systems at home**

- A number of modern devices in the home are microprocessor based i.e. camera; washing machines; calculators; hi-fi systems; telephones; microwave ovens; burglar alarms etc. The input are usually simple numeric keyboards, sensors, buttons or while the output include lights, simple LCD screens displays, motors and relays, LEDs, buzzers etc.

#### **Office automation and publication**

- Microprocessor based system with software packages has changed the office environment. Microprocessor based systems are being used for spread sheet operations, word processing, storage etc.
- The publication technology has revolutionized by the microprocessor.

#### **Communication**

- In communication the telephone industry is most important. In this industry, microprocessors are used in digital telephone sets, telephone exchanges and modem etc.
- The use of microprocessor in satellite communication, television has made teleconferencing possible.
- Railway reservation and airline reservation system also uses microprocessor technology. WAN (wide area network) and LAN (local area network) for communication of vertical information through computer network.