ELECTRONICS MECHANIC

(Common for Technician Power Electronics System)

NSQF LEVEL - 4

1st Year

TRADE THEORY

SECTOR : ELECTRONICS & HARDWARE

(As per revised syllabus July 2022 - 1200 Hrs)

Directorate General of Training

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

NATIONAL INSTRUCTIONAL MEDIA INSTITUTE, CHENNAI

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

Sector : **Electronics & Hardware**

Duration : **2 Years**

Trade : **Electronics Mechanic - 1st Year Trade Theory- NSQF Level - 4 (Revised 2022)**

Developed & Published by

National Instructional Media Institute
Post Box No.3142
Guindy, Chennai - 600 032
INDIA
Email: chennai-nimi@nic.in
Website: www.nimi.gov.in

First Edition : July 2022 Copies : 500

Rs.390/-

FOREWORD

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

The National Instructional Media Institute (NIMI), Chennai has now come up with instructional material to suit the revised curriculum for **Electronics Mechanic 1st Year Trade Theory NSQF Level - 4 (Revised 2022) in Electronics & Hardware Sector.** 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 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

SHRI. ATUL KUMAR TIWARI., I.A.S.,
Secretary,
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 Ministry of Skill Development and Entrepreneurship) Government of India, with technical assistance from the Govt. of the Federal Republic of Germany. The prime objective of this institute is to develop and provide instructional materials for various trades as per the prescribed syllabi (NSQF LEVEL - 4) 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.

In order to perform the skills in a productive manner instructional videos are embedded in QR code of the exercise in this instructional material so as to integrate the skill learning with the procedural practical steps given in the exercise. The instructional videos will improve the quality of standard on practical training and will motivate the trainees to focus and perform the skill seamlessly.

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 organisations to bring out this Instructional Material **(Trade Theory)** for the trade of **Electronics Mechanic** (NSQF LEVEL - 4) (Revised 2022) under **Electronic & Hardware** Sector for ITIs.

MEDIA DEVELOPMENT COMMITTEE MEMBERS

Shri. C. Anand	-	Vocational Instructor, Govt. ITI for Women Puducherry.
Shri. A. Jayaraman	-	Training Officer (Rtd), Govt. of India CTI, Guindy Chennai - 32.
Shri. R.N. Krishnasamy	-	Vocational Instructor (Rtd) MDC Member, NIMI, Chennai - 32.
Smt. S, Gowri	-	J.T.O Govt. ITI Thiruvanmiyur.
Shri. E. Krishnaraj	-	J.T.O Govt. ITI Hosur.
Shri. Prakash M	-	Senior Instructor Areacode, Govt I.T.I Kerala

NIMI CO-ORDINATORS

Shri.Nirmalya Nath	-	Deputy Director, NIMI- Chennai - 32.
Shri S.Gopalakrishnan	_	Assistant Manager, NIMI, Chennai - 32.

NIMI records its appreciation for 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 NIMI staff who have contributed towards the development of this Instructional Material.

NIMI is also grateful to everyone who has directly or indirectly helped in developing this Instructional Material.

INTRODUCTION

TRADE PRACTICAL

The trade practical manual is intented to be used in workshop . It consists of a series of practical exercises to be completed by the trainees during the course of the **Electronics Mechanic** trade supplemented and supported by instructions/ informations to assist in performing the exercises. These exercises are designed to ensure that all the skills in compliance with NSQF LEVEL - 4 (Revised 2022)

The manual is divided into Fourteen modules. The Fourteen modules are given below:

Module 1 - Basic workshop safety

Module 2 - Basics of AC and Electrical cables, Single range meters

Module 3 - Cells and Batteries

Module 4 - AC & DC Measuring Instruments, Basic Workshop Practice

Module 5 - Digital Storage Oscilloscope

Module 6 - Soldering/Desoldering and various switches

Module 7 - Active and Passive components

Module 8 - Power supply circuits

Module 9 - Transistor

Module 10 - Power Electronic Components

Module 11 - Opto Electronics

Module 12 - Basic Gates,Combinational circuits, Flip Flops

Module 13 - Electronic Circuit Simulator

Module 14 - Op Amp and Timer applications

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

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

TRADE THEORY

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

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

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

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

CONTENTS

LEARNING / ASSESSABLE OUTCOME

On completion of this book you shall be able to

S.No.	Learning Outcome	Ref.Ex.No
1	Perform basic workshop operations using suitable tools for fitting, riveting, drilling etc. observing suitable care & safety following safety precautions. **(NOS: ELE/N1002)**	1.1.01 - 1.1.12
2	Select and perform electrical/ electronic measurement of single range meters and calibrate the instrument. **(NOS: N/A)**	1.2.13 - 1.1.27
3	Test &service differentbatteries used in electronic applications and record the data to estimate repair cost. **(NOS: ELE/N7001)**	1.3.28 - 1.3.34
4	Measure AC/DC using proper measuring instruments and compare the data using standard parameter. **(NOS:)**	1.4.35 - 1.4.39
5	Measure the various parameters by DSO and execute the result with standard one. **(NOS: N/A)**	1.5.40 - 1.5.43
6	Plan and execute soldering & de-soldering of various electrical components like Switches, PCB & Transformers for electronic circuits. **(NOS:ELE/N7812)**	1.6.44 - 1.5.49
7	Test various electronic components using proper measuring instruments and compare the data using standard parameter. **(NOS:ELE/N5804)**	1.7.50 - 1.7.65
8	Assemble simple electronic power supply circuit and test for functioning. **(NOS:ELE/N5804)**	1.8.66 - 1.8.79
9	Construct, test and verify the input/ output characteristics of various analog circuits. **(NOS: N/A)**	1.9.80 - 1.9.94
10	Plan and construct different power electronic circuits and analyse the circuit functioning. **(NOS: N/A)**	1.10.95-1.10.103
11	Select the appropriate opto electronics components and verify the characteristics in different circuit. **(NOS: N/A)**	1.11.104-1.11.109
12	Assemble, test and troubleshoot various digital circuits. **(NOS:ELE/N1201)**	1.12.110-1.12.123
13	Simulate and analyze the analog and digital circuits using Electronic simulator software. **(NOS:ELE/N6102)**	1.13.124-1.12.127
14	Construct and test different circuits using ICs 741operational amplifiers & ICs 555 linear integrated circuits and execute the result. **(NOS: N/A)**	1.14.128-1.14.136

SYLLABUS

Duration	Reference Learning Outcome	Professional Skills (Trade Practical) With Indicative Hours	Professional Knowledge (Trade Theory)
Professional Skill 65 Hrs; Professional knowledge 10 Hrs	Perform basic workshop operations using suitable tools for fitting, riveting, drilling etc. observing suitable care & safety following safety precautions. **NOS: ELE/N1002**	Trade and Orientation 1. Visit to various sections of the institute and identify location of various installations. (05 Hrs.) 2. Identify safety signs for danger, warning, caution & personal safety message. (03 Hrs.) 3. Use of personal protective equipment (PPE). (05 Hrs.) 4. Practice elementary first aid. (05 Hrs.) 5. Preventive measures for electrical accidents & steps to be taken in such accidents. (02 Hrs.) 6. Use of Fire extinguishers. (05 Hrs.)	Familiarization with the working of Industrial Training Institute system. Importance of safety and precautions to be taken in the industry/shop floor. Introduction to PPEs. Introduction to First Aid. Response to emergencies e.g. power failure, fire, and system failure. Importance of housekeeping & good shop floor practices. Occupational Safety & Health: Health, Safety and Environment guidelines, legislations & regulations as applicable. (05 Hrs.)
		Hand tools and their uses 7. Identify the different hand tools. (05 Hrs.) 8. Selection of proper tools for operation and precautions in operation. (05 Hrs.) 9. Care & maintenance of trade tools. (05 Hrs.) 10. Practice safety precautions while working in fitting jobs. 1. (10 Hrs.) 11. Workshop practice on filing and hacks awing. (05 Hrs.) 12. Practice simple fitting and drilling. (10 Hrs.)	Identification, specifications, uses and maintenance of commonly used hand tools. State the correct shape of files for filing different profiles. Riveting of tags and lugs, cutting and bending of sheet metals, chassis and cabinets. (05 Hrs.)
Professional Skill 45 Hrs; Professional Knowledge 15 Hrs	Select and perform electrical/ electronic measurement of single range meters and calibratethe instrument. **NOS: N/A**	**Basics of AC and Electrical Cables** 13. Identify the Phase, Neutral and Earth on power socket, use a testers to monitor AC power. (02 Hrs.) 14. Construct a test lamp and use it to check mains healthiness. (02 Hrs.) 15. Measure the voltage between phase and ground and rectify earthing. (03 Hrs.) 16. Identify and test different AC mains cables. (03 Hrs.)	Basic terms such as electric charges, Potential difference, Voltage, Current, Resistance. Basics of AC & DC. Various terms such as +ve cycle, -ve cycle, Frequency, Time period, RMS, Peak, Instantaneous value. Single phase and Three phase supply. Terms like Line and Phase voltage/ currents. Insulators, conductors and semiconductor properties. Different type of electrical cables and their Specifications.

		17.Prepare terminations, skin the electrical wires /cables using wire stripper and cutter. (03 Hrs.) 18.Measure the gauge of the wire using SWG and outside micrometer. (03 Hrs.) 19.Refer table and find current carrying capacity of wires. (01 Hr.) 20.Crimp the lugs to wire end. (03 Hrs.) 21.Measure AC and DC voltages using multi meter. (03 Hrs.)	Types of wires & cables, standard wire gauge (SWG). Classification of cables according to gauge (core size), number of conductors, material, insulation strength, flexibility etc. (08 Hrs.)
		22. Identify the type of meters by dial and scale marking/ symbols. (03 Hrs.) 23. Demonstrate various analog measuring Instruments. (03 Hrs.) 24 Find the minimum and maximum measurable range of the meter. (02 Hrs.) 25. Carryout mechanical zero setting of a meter. (04 Hrs.) 26. Check the continuity of wires, meter probes and fuse etc. (05 Hrs.) 27. Measure voltage and current using clamp meter. (05 Hrs.)	**Single range meters** Introduction to electrical and electronic measuring instruments. Basic principle and parts of simple meters. Specifications, symbols used in dial and their meaning. (07 Hrs.)
Professional Skill 25 Hrs; Professional Knowledge 06 Hrs	Test &service different batteries used in electronic applications and record the data to estimate repair cost. **NOS: ELE/N7001** Measure AC/DC using proper measuring instruments and compare the data using standard parameter.	**Cells & Batteries** 28. Identify the +ve and -ve terminals of the battery. (02 Hrs.) 29. Identify the rated output voltage and Ah capacity of given battery. (01 Hrs.) 30. Measure the voltages of the given cells/battery using analog/ digital multimeter. (03 Hrs.) 31. Charge and discharge the battery through load resistor. (05 Hrs.) 32. Maintain the secondary Battery. (05 Hrs.) 33. Measure the specific gravity of the electrolyte using hydrometer. (03 Hrs.) 34. Test a battery and verify whether the battery is ready for use or needs recharging. (06 Hrs.)	**Cells & Batteries** Construction, types of primary and secondary cells/battery. Materials used, Specification of cells and batteries. Charging process, efficiency, life of cell/battery. Selection of cells / Batteries etc. Use of Hydrometer. Types of electrolytes used in cells and batteries. Series/ parallel connection of batteries and purpose of such connections. (06 Hrs.)
Professional Skill 60 Hrs; Professional Knowledge 20 Hrs	Measure AC/DC using proper measuring instruments and compare the data using standard parameter.	**AC & DC measurements** 35.Use the multi meter to measure the various functions (AC V, DC V, DC I, AC I, R). (10 Hrs.) 36.Identify the different types of meter for measuring AC & 1. DC parameters. (10 Hrs.) 37.Identify the different controls on the CRO/DSO front panel and observe the function of each control. (14 Hrs.)	Introduction to electrical measuring instruments. Importance and classification of meters. MC and MI meters. Characteristics of meters and errors in meters. Multi meter, use of meters in different circuits. Care and maintenance of meters. Use of CRO/DSO, Function generator, LCR meter (20 Hrs.)

		38. Measure DC voltage, AC voltage, time periodusing CRO/DSO sine wave parameters. (12 Hrs.) 39. Identify the different controls on the function generator front panel and observe the function of each control. (14 Hrs.)	
Professional Skill 25 Hrs; Professional Knowledge 09 Hrs	Measure the various parameters by DSO and execute the result with standard one. **NOS: N/A**	**Digital Storage Oscilloscope** 40.Identify the different front panel control of a DSO. (05 Hrs.) 41.Measure the Amplitude, Frequency and time period of typical electronic signals using DSO. (06 Hrs.) 42.Take a print of a signal from DSO by connecting it to a printer and tally with applied signal. (07 Hrs.) 43. Construct and test function generator using IC 8038. (07 Hrs.)	Advantages and features of DSO. Block diagram of Digital storage oscilloscope (DSO)/ CRO and applications. Applications of digital CRO. Block diagram of function generator. Differentiate a CRO with DSO. (09 Hrs.)
Professional Skill 25 Hrs; Professional Knowledge 05 Hrs	Plan and execute soldering & de-soldering of various electrical components like Switches, PCB & Transformers for electronic circuits. **NOS:ELE/N7812**	**Soldering/ De-soldering and Various Switches** 44. Practice soldering on different electronic components, small transformer and lugs. (04 Hrs.) 45. Practice soldering on IC bases and PCBs. (04 Hrs.) 46. Practice de-soldering using pump and wick. (04 Hrs.) 47. Join the broken PCB track and test. (04 Hrs.) 48. Identify and use SPST, SPDT, DPST, DPDT, tumbler, push button, toggle, piano switches used in electronic industries. (04 Hrs.) 49. Make a panel board using different types of switches for a given application. (05 Hrs.)	Different types of soldering guns, related to Temperature and wattages, types of tips. Solder materials and their grading. Use of flux and other materials. Selection of soldering gun for specific requirement. Soldering and De-soldering stations and their specifications. Different switches, their specification and usage. (05 Hrs.)
Professional Skill 85 Hrs; Professional Knowledge 25 Hrs	Test various electronic components using proper measuring instruments and compare the data using standard parameter. **NOS:ELE/N5804**	**Active and Passive Components** 50. Identify the different types of active electronic components. (05 Hrs.) 51. Measure the resistor value by colour code and verify the same by measuring with multimeter. (05 Hrs.) 52.Identify resistors by their appearance and check physical defects. (05 Hrs.) 53. Identify the power rating of carbon resistors by their size. (05 Hrs.) 54. Practice on measurement of parameters in combinational electrical circuit by applying Ohm's Law for different resistor values and voltage sources. (05 Hrs.)	Ohm's law and Kirchhoff's Law. Resistors; types of resistors, their construction & specific use, color-coding, power rating. Equivalent Resistance of series parallel circuits. Distribution of V & I in series parallel circuits. Principles of induction, inductive reactance. Types of inductors, construction, specifications, applications andenergy storage concept. Self and Mutual induction. Behaviour of inductor at low and high frequencies. Series and parallel combination, Q factor.

		55. Measurement of current and voltage in electrical circuits to verify Kirchhoff's Law. (05 Hrs.) 56. Verify laws of series and parallel circuits with voltage source in different combinations. (05 Hrs.) 57. Measure the resistance, Voltage, Current through series and parallel connected networks using multi meter. (05 Hrs.) 58. Identify different inductors and measure the values using LCR meter. (05 Hrs.) 59. Identify the different capacitors and measure capacitance of various capacitors using LCR meter. (05 Hrs.) 60. Identify and test the circuit breaker and other protecting devices. (05 Hrs.) 61.Dismantle and identify the different parts of a relay. (05 Hrs.) 62.Connect a timer relay in a circuit and test for its working. (05 Hrs.) 63.Connect a contactor in a circuit and test for its working. (05 Hrs.) 64.Construct and test RC time constant circuit. (05 Hrs.) 65.Construct a RC differentiator circuit and convert triangular wave into square wave. (05 Hrs.) 66. Construct and test series and parallel resonance circuit. (05 Hrs.)	Capacitance and Capacitive Reactance, Impedance. Types of capacitors, construction, specifications and applications. Dielectric constant. Significance of Series parallel connection of capacitors. Capacitor behaviour with AC and DC. Concept of Time constant of a RC circuit. Concept of Resonance and its application in series and parallel circuit. Properties of magnets and their materials, preparation of artificial magnets, significance of electromagnetism, types of cores. Relays, types, construction and specifications etc (25 Hrs.)
Professional Skill 60 Hrs; Professional Knowledge	Assemble simple ectronic power supply circuit and test for functioning. **NOS:ELE/N5804**	**Power Supply Circuits** 67.Identify different types of diodes, diode modules and their specifications. (04 Hrs.) 68.Test the given diode using multi meter and determine forward to reverse resistance ratio. (04 Hrs.) 69.Measure the voltage and current through a diode in a circuit and verify its forward characteristic. (05 Hrs.) 70.Identify different types of transformers and test. (04 Hrs.) 71.Identify the primary and secondary transformer windings and test the polarity. (04 Hrs.) 72.Construct and test a half wave, full wave and Bridge rectifier circuit. (05 Hrs.) 73.Measure ripple voltage, ripple frequency and ripple factor of rectifiers for different load and filter capacitors. (04 Hrs.) 74.Identify and test Zener diode. (04 Hrs.)	Semiconductor materials, components, number coding for different electronic components such as Diodes Semiconductor materials, components, number coding for different electronic components such as Diodes and Zeners etc.PN Junction, Forward and Reverse biasing of diodes.Interpretation of diode specifications.Forward current and Reverse voltage.Packing styles of diodes. Different diodes, Rectifier configurations, their efficiencies, Filter components and their role in reducing ripple. Working principles of Zener diode, varactor diode, their specifications and applications. Working principle of a Transformer, construction, Specifications and types of cores used. Step-up, Step down and isolation transformers with applications. Losses in Transformers.

		75. Construct and test Zener based voltage regulator circuit. (04 Hrs.) 76. Calculate the percentage regulation of regulated power supply. (04 Hrs.)	Phase angle, phase relations, active and reactive power, power factor and its importance.(10 Hrs.)
		IC Regulators 77. Construct and test a +12V fixed voltage regulator. (05 Hrs.) 78. Identify the different types of fixed +ve and –veregulator ICs and the different current ratings (78/79 series). (04 Hrs.) 79. Observe the output 1. voltage of different IC 723 metal/ plastic type. (04 Hrs.) 80.Construct and test a 1.2V – 30V variable output regulated power supply using IC LM317T. (05 Hrs.)	Regulated Power supply using 78XX series, 79XX series. Op-amp regulator, 723 regulator, (Transistorized & IC based). Voltage regulation, error correction and amplification etc. (05 Hrs.)
Professional Skill 90 Hrs; Professional Knowledge 30 Hrs	Construct, test and verify the input/ output characteristics of various analog circuits. **NOS: N/A**	**Transistor** 81. Identify different transistors with respect to different package type, B-E-C pins, power, switching transistor, heat sinks etc. (06 Hrs.) 82.Test the condition of a given transistor using ohm-meter. (06 Hrs.) 83. Construct and test a transistor based switching circuit to control a relay (use Relays of different coil voltages and Transistors of different β) (06hrs)	Construction, working of a PNP and NPN Transistors, purpose of E, B & C Terminals. Significance of á, â and relationship of a Transistor. Need for Biasing of Transistor. VBE, VCB, VCE, IC, IB, Junction Temperature, junction capacitance, frequency of operation. Transistor applications as switch and amplifier. Transistor input and output characteristics. Transistor power ratings & packaging styles and use of different heat sinks. (09 Hrs.)
		Amplifier 84. Construct and test fixed-bias, emitter-bias and voltage devider-bias transistor amplifier. (06 Hrs.) 85. Construct and Test a common emitter amplifier with and without bypass capacitors. (06 Hrs.) 86. Construct and Test common collector/emitter follower amplifier. (06 Hrs.) 87. Construct and test a two stage RC Coupled amplifier. (06 Hrs.)	Different types of biasing, various configurations of transistor (C-B, C-E & C-C), their characteristics and applications. Transistor biasing circuits and stabilization Techniques. Classification of amplifiers according to frequency, mode of operation and methods of coupling. Voltage amplifiers - voltage gain, loading effect. Single stage CE amplifier and CC amplifier. Emitter follower circuit and its advantages. RC coupled amplifier, Distinguish between voltage and power amplifier, Alpha, beta, voltage gain, Concept of dB dBm. Feedback and its types. (09 Hrs.)

		Oscillators 88.Demonstrate Colpitts oscillator, Hartley oscillator circuits and compare the output frequency of the oscillator by CRO. (06 Hrs.) 89.Construct and test a RC phase shift oscillator circuits. (06 Hrs.) 90.Construct and test a crystal oscillator circuits. (06 Hrs.) 91.Demonstrate Astable, monostable, bistable circuits using transistors. (06 Hrs.)	Introduction to positive feedback and requisites of an oscillator. Study of Colpitts, Hartley, Crystal and RC oscillators. Types of multi vibrators and study of circuit diagrams. (06 Hrs.)
		Wave shaping circuits 92. Construct and test shunt clipper. (06 Hrs.) 93. Construct and test series and dual clipper circuit using diodes. (06 Hrs.) 94. Construct and test clamper circuit using diodes. (06 Hrs.) 95. Construct and test Zener diode as a peak clipper. (06 Hrs.)	Diode shunt clipper circuits, Clamping / limiting circuits and Zener diode as peak clipper, uses their applications. (06 Hrs.)
Professional Skill 75 Hrs; Professional Knowledge	Plan and construct different power electronic circuits and analyse the circuit functioning. **NOS: N/A**	**Power Electronic Components** 96. Identify different power electronic components, their specification and terminals. (05 Hrs) 97.Construct and test a FET Amplifier. (10 Hrs) 98.Construct a test circuit of SCR using UJT triggering. (10 Hrs) 99.Construct a simple dimmer circuit using TRIAC. (10 Hrs) 100.Construct UJT based free running oscillator and change its frequency. (10 Hrs)	Construction of FET & JFET, difference with BJT. Purpose of Gate, Drain and source terminals and voltage / current relations between them and Impedances between various terminals. Heat Sink- Uses & purpose. Suitability of FET amplifiers in measuring device applications. Working of different power electronic components such as SCR, TRIAC, DIAC and UJT. (12 Hrs.)
		MOSFET & IGBT 101.Identify various Power MOSFET by its number and test by using multimeter. (05 Hrs) 102.Construct MOSFET test circuit with a small load. (05 Hrs) 103. Identify IGBTs by their numbers and test by using multimeter. (05 Hrs) 104.Construct IGBT test circuit with a small load. (05 Hrs)	MOSFET, Power MOSFET and IGBT, their types, characteristics, switching speed, power ratings and protection. Differentiate FET with MOSFET. Differentiate Transistor with IGBT. (08 Hrs.)
	Select the appropriate opto electronics components and verify the characteristics in different circuit. **NOS: N/A**	**Opto Electronics** 105.Test LEDs with DC supply and measure voltage drop and current using multimeter. (11 Hrs.) 106.Construct a circuit to test photo voltaic cell. (12 Hrs.) 107.Construct a circuit to switch a lamp load using photo diode. (12 Hrs.) 108.Construct a circuit to switch a lamp load using photo transistor. (12 Hrs.)	Working and application of LED, IR LEDs, Photo diode, photo transistor, their characteristics and applications. Optical sensor, opto-couplers, circuits with opto isolators. Characteristics of LASER diodes. (06 Hrs.)

Professional Skill 75 Hrs; Professional Knowledge 20 Hrs	Assemble, test and troubleshoot various digital circuits. **NOS:ELE/N1201**	**Basic Gates** 109.Verify the truth tables of all Logic Gate ICs by connecting switches and LEDs. (05 Hrs.) 110.Construct and verify the truth table of all the gates using NAND and NOR gates. (05 Hrs.)	Introduction to Digital Electronics. Difference between analog and digital signals. Number systems (Decimal, binary, octal, Hexadecimal). BCD code, ASCII code and code conversions. Various Logic Gates and their truth tables. (05 Hrs.)
		111.Use digital IC tester to test the various digital ICs (TTL and CMOS). (05 Hrs.) **Combinational Circuits** 112.Construct Half Adder circuit using ICs and verify the truth table. (06 Hrs.) 113.Construct Full adder with two Half adder circuit using ICs and verify the truth table. (06 Hrs.) 114.Construct the adder cum subtractor circuit and verify the result. (06 Hrs.) 115.Construct and Test a 2 to 4 Decoder. (06 Hrs.) 116.Construct and Test a 4 to 2 Encoder. (06 Hrs.)	Combinational logic circuits such as Half Adder, Full adder, Parallel Binary adders, 2-bit and four bit full adders. Magnitude comparators. Half adder, full adder ICs and their applications for implementing arithmetic operations. Concept of encoder and decoder. Basic Binary Decoder and four bit binary decoders. Need for multiplexing of data. 1:4 line Multiplexer / De-multiplexer. (10 Hrs.)
		117.Construct and Test a 4 to 1 Multiplexer. (05 Hrs.) 118.Construct and Test a 1 to 4 De Multiplexer. (05 Hrs.) **Flip Flops** 119.Identify different Flip-Flop (ICs) by the number printed on them. (05 Hrs.) 120.Construct and test four bit latch using 7475. (05 Hrs.) 121.Construct and test R-S flip-flop using IC7400 with clock and without clock pulse. (05 Hrs.)	Introduction to Flip-Flop. S-R Latch, Gated S-R Latch, D-Latch. Flip-Flop: Basic RS Flip Flop, edge triggered D Flip Flop, JK Flip Flop, T Flip Flop. Master-Slave flip flops and Timing diagrams. Basic flip flop applications like data storage, data transfer and frequency division. (05 Hrs.)
Professional Skill 48 Hrs; Professional Knowledge 04 Hrs	Simulate and analyze the analog and digital circuits using Electronic simulator software. **NOS:ELE/N6102**	122.Verify the truth tables of Flip-Flop ICs (RS, D, T, JK, MSJK) by connecting switches and LEDs. (05 Hrs.) **Electronic circuit simulator** 123.Prepare simple digital and electronic circuits using the software. (12 Hrs.) 124.Simulate and test the prepared digital and analog circuits. (12 Hrs.) 125.Convert the prepared circuit into a layout diagram. (12 Hrs.) 126.Prepare simple, power electronic and domestic electronic circuit using simulation software. (12 Hrs.)	Study the library components available in the circuit simulation software. Various resources of the software. (04 Hrs.)

Professional Skill 75 Hrs; Professional Knowledge 20 Hrs	Construct and test different circuits using ICs 741operational amplifiers & ICs 555 linear integrated circuits and execute the result. **NOS: N/A**	**Op - Amp & Timer 555 Applications** 127.Use analog IC tester to test the various analog ICs. (07 Hrs.) 128.Construct and test various Op-Amp circuits Inverting, Non-inverting and Summing Amplifiers. (07 Hrs.) 129.Construct and test Differentiator and Integrator. (07 Hrs.) 130.Construct and test a zero crossing detector. (07 Hrs.) 131.Construct and test Instrumentation amplifier. (07 Hrs.) 132.Construct and test a Binary weighted and R-2R Ladder type Digital-to-Analog Converters. (08 Hrs.) 133.Construct and test Astable timer circuit using IC 555. (08 Hrs.) 134.Construct and test mono stable timer circuit using IC 555. (08 Hrs.) 135.Construct and test VCO (V to F Converter) using IC 555. (08 Hrs.) 136.Construct and test 555 timers as pulse width modulator. (08 Hrs.)	Block diagram and Working of Op-Amp, importance, Ideal characteristics, advantages and applications. Schematic diagram of 741, symbol. Non-inverting voltage amplifier, inverting voltage amplifier, summing amplifier, Comparator, zero cross detector, differentiator, integrator and instrumentation amplifier, other popular Op-Amps. Block diagram of 555, functional description w.r.t. different configurations of 555 such as monostable, astable and VCO operations for various application. (20 Hrs.)

Familiarization of the Industrial Training Institute

Objectives: At the end of this lesson you shall be able to
- **identify the staff structure of the institute**
- **list the available trades in the institute and their functions**
- **describe the ITI training system in India.**

Industrial Training Institutes (ITI) plays a vital role in the economic development of the country, especially in terms of providing skilled manpower requirements by training competent, quality craftsmen.

The Directorate General of Training (DGT) comes under the Ministry of Skill Development and Entrepreneurship (MSDE) offers a range of vocational training under engineering and non engineering trades affiliated with the National Council for Vocational Training (NCVT) New Delhi. NCVT is the Govt of India body responsible for framing the polices, approving the syllabus for Craftsman Training System (CTS), carrying out the All India Trade Test and issuing the National Trade Certificates (NTC) to the successful candidates.

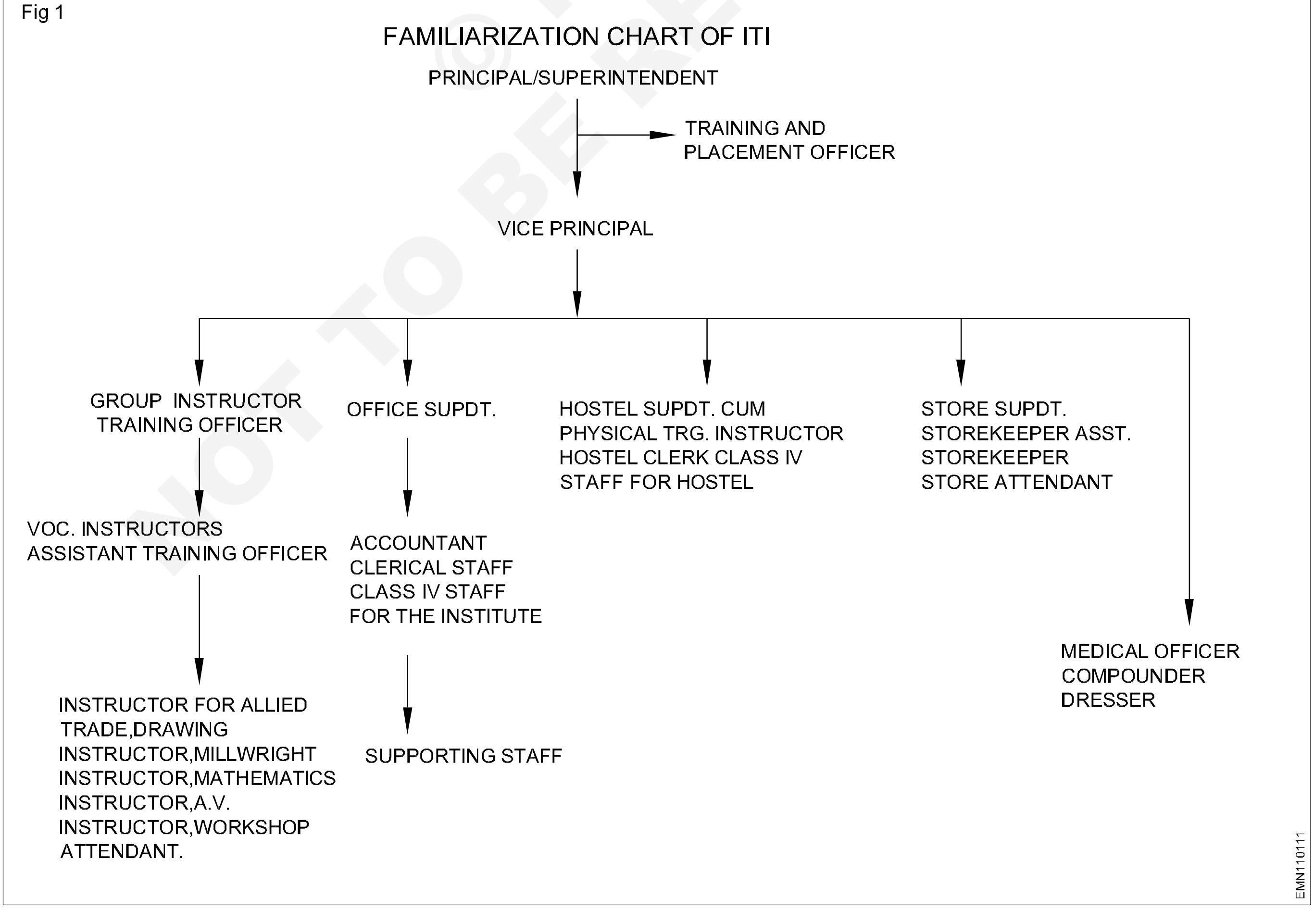
In India there are about 2293 Govt. ITIs and 10872 Private ITIs. (Based on the Govt.of India, Ministry of Labour Annual report of 2016-2017). The Govt. ITIs in each state functioning under the Directorate of Employment and Training Dept (DET) under the state Govts.

The head of the **ITI** is the Principal, under whom there is one Vice-Principal, Group Instructor/ Training officer/ A.T.O and a number of trade instructors as shown in the Organization chart of ITI.

There are133 trades selected for vocational training and 261 trades identified for Apprentice training, according to the requirement of industrial needs and the duration of the training is from 1 year to 2 years.

At present the Electronic Mechanic trade has been included under National Skill Qualification Frame work (NSQF) with level - 4 competency. The trainees are advised to make a list of other trades available in their ITI, the type of training and the scope of these trades in getting self employment or job opportunity in the rural and urban areas and also identify the location of the ITI, nearby hospital, fire station and police station etc.

Fig 1



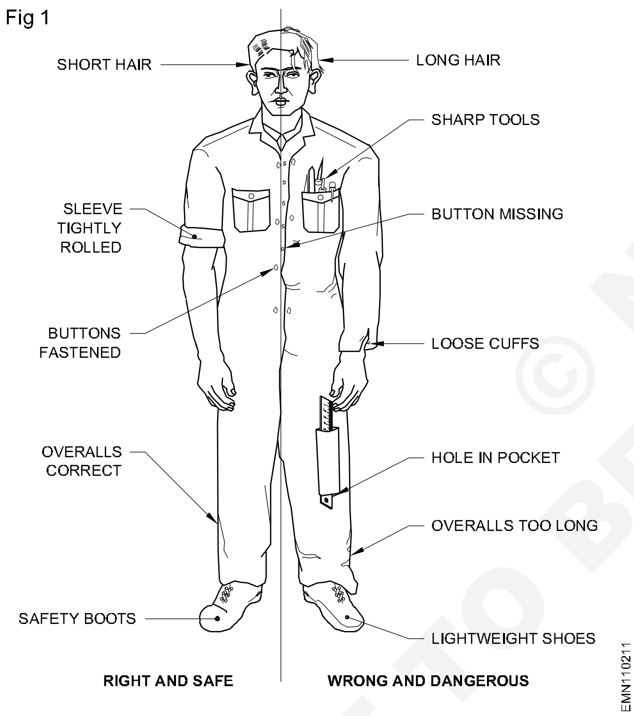
Importance of safety and precautions to be taken in the industry/ shop floor

Objectives: At the end of this lesson you shall be able to
- **state the importance of safety**
- **state the personal safety precautions to be observed**
- **list out the safety precautions to be observed while working on the machines.**

Importance of safety

Generally accidents do not happen; they are caused. Most accidents are avoidable. A Good craftsman, having a knowledge of various safety precautions, can avoid accidents to himself and to his fellow workers and protect the equipment from any damage. To achieve this, it is essential that every person should follow safety procedure. (Fig 1)

Fig 1



Safety in a workshop can be broadly classified into 3 categories.

- General safety
- Personal safety
- Machine safety

General safety

Keep the floor and gangways clean and clear.

Move with care in the workshop, do not run.

Don't leave the machine which is in motion.

Don't touch or handle any equipment/ machine unless authorized to do so.

Don't walk under suspended loads.

Don't cut practical jokes while on work.

Use the correct tools for the job.

Keep the tools at their proper place.

Wipe out split oil immediately.

Replace worn out or damaged tools immediately.

Never direct compressed air at yourself or at your co-worker.

Ensure adequate light in the workshop.

Clean the machine only when it is not in motion.

Sweep away the metal cuttings.

Know everything about the machine before you start it.

Personal safety

Wear a one piece overall or boiler suit.

Keep the overall buttons fastened.

Don't use ties and scarves.

Roll up the sleeves tightly above the elbow.

Wear safety shoes or boots or chain.

Cut the hair short.

Don't wear a ring, watch or chain.

Never lean on the machine.

Don't clean hands in the coolant fluid.

Don't remove guards when the machine is in motion.

Don't use cracked or chipped tools.

Don's start the machine until

- the work piece is securely mounted
- the feed machinery is in the neutral
- the work area is clear.

Don't adjust clamps or holding devices while the machine is in motion.

Never touch the electrical equipment with wet hands.

Don't use any faulty electrical equipment.

Ensure that electrical connections are made by an authorized electrician only.

Concentrate on your work.

Have a calm attitude.

Do things in a methodical way.

Don’t engage yourself in conversation with others while concentrating on your job.

Don’t distract the attention of others.

Don’t try to stop a running machine with hands.

Machine safety

Switch off the machine immediately if something goes wrong.

Keep the machine clean.

Replace any worn out or damaged accessories, holding devices, nuts, bolts, etc., as soon as possible.

Do not attempt operating the machine until you know how to operate it properly.

Do not adjust tool or the workpiece unless the power is off.

Stop the machine before changing the speed.

Disengage the automatic feeds before switching off.

Check the oil level before starting the machine.

Never start a machine unless all the safety guards are in position.

Take measurements only after stopping the machine.

Use wooden planks over the bed while loading and unloading heavy jobs.

Safety is a concept, understand it.

Safety is a habit, cultivate it.

Safety Sign Boards

Signboards are a common sight in almost all places such as roadways, railways, hospitals, offices, institution, industrial units and so on.

Signboards are visual indicators. The signs on the signboards may be just a symbol, a small text, a figure or a combination of these.

Signboards carry a single clear message. These messages are to ensure safety.

Signboards can be classified into four basic categories.

a) Prohibition signs

Indicating a behaviour which is prohibited (not allowed) in that situation or environment. Refer to chart 1 for examples.

b) Mandatory signs

Indicating a behaviour which is a must, which when not obeyed may cause accidents. Refer to chart 1 for examples.

c) Warning signs

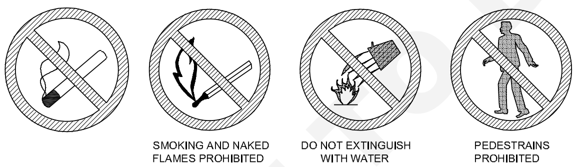
Indicating a warning such that suitable precaution is taken. Refer to chart 1 for examples.

d) Information signs

Giving information which is very useful and reduces waste of time. Refer to chart 1 for examples.

Chart 1

a) Prohibition signs



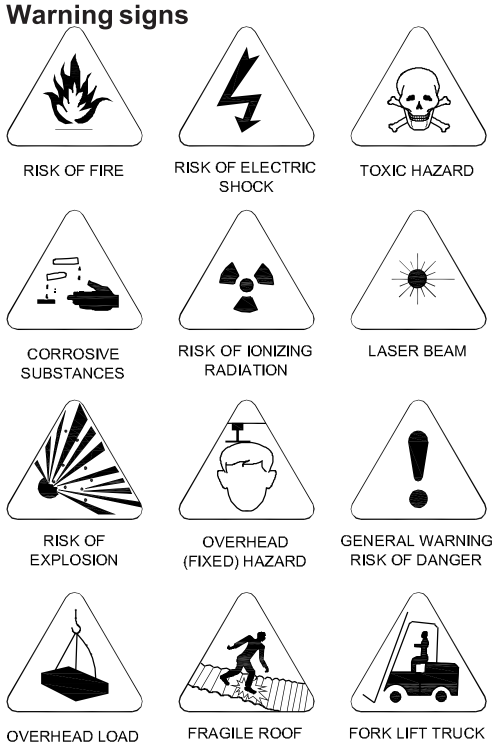
Shape	Circular.
Colour	Red border and crossbar. Black symbol on white background.
Meaning	Shows what must not be done.
Example	No smoking and naked flames

b) Mandatory signs

Shape	Circular.
Colour	White symbol on blue background.
Meaning	Shows what must be done.

Example Wear hand protection.

c) Warning signs



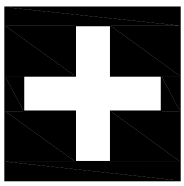
Shape Triangular.

Colour Yellow background with black border and symbols.

Meaning Warns of hazard or danger.

Example Caution, risk of electric shock.

d) Information signs



FIRST AID POINT

Shape Square or oblong

Colour White symbols on green background.

Meaning Indicates or gives information of safety provision/First aid

Example Caution, risk of electric shock.

Personal Protective Equipment (PPE)

Objectives: At the end of this lesson you shall be able to
- **state the personal protective equipment and its purpose**
- **list the most common type of personal protective equipment**
- **list the conditions for selection of personal protective equipment.**

Personal protective equipment (PPE)

Devices, equipments, or clothing used or worn by the employees, as a last resort, to protect against hazards in the workplace. The primary approach in any safety effort is that the hazard to the workmen should be eliminated or controlled by engineering methods rather than protecting the workmen through the use of personal protective equipment (PPE). Engineering methods could include design change, substitution, ventilation, mechanical handling, automation, etc. In situations where it is not possible to introduce any effective engineering methods for controlling hazards, the workman shall use appropriate types of PPE.

As changing times have modernized the workplace, government and advocacy groups have brought more safety standards to all sorts of work environments. The Factories Act, 1948 and several other labour legislations 1996 have provisions for effective use of appropriate types of PPE. Use of PPE is an important.

Ways to ensure workplace safety and use personal protective equipment (PPE) effectively.

- Workers to get up-to-date safety information from the regulatory agencies that oversees workplace safety in their specific area.
- To use all available text resources that may be in work area and for applicable safety information on how to use PPE best.
- When it comes to the most common types of personal protective equipment, like goggles, gloves or bodysuits, these items are much less effective if they are not worn at all times, or whenever a specific danger exists in a work process. Using PPE consistently will help to avoid some common kinds of industrial accidents.
- Personal protective gear is not always enough to protect workers against workplace dangers. Knowing more about the overall context of your work activity can help to fully protect from anything that might threaten health and safety on the job.
- Inspection of gear thoroughly to make sure that it has the standard of quality and adequately protect the user should be continuously carried out.

Categories of PPEs

Depending upon the nature of hazard, the PPE is broadly divided into the following two categories:

1 **Non-respiratory:** Those used for protection against injury from outside the body, i.e. for protecting the head, eye, face, hand, arm, foot, leg and other body parts

2 **Respiratory:** Those used for protection from harm due to inhalation of contaminated air.

They are to meet the applicable BIS (Bureau of Indian Standards) standards for different types of PPE.

The guidelines on 'Personal Protective Equipment' is issued to facilitate the plant management in maintaining an effective programme with respect to protection of persons against hazards, which cannot be eliminated or controlled by engineering methods listed in table1.

Table1

No.	Title
PPE1	Helmet
PPE2	Safety footwear
PPE3	Respiratory protective equipment
PPE4	Arms and hands protection
PPE5	Eyes and face protection
PPE6	Protective clothing and cover all
PPE7	Ears protection
PPE8	Safety belt and harnesses

Personal protective equipments and their uses and hazards are as follows

Types of protection	Hazards	PPE to be used
Head Protection (Fig 1)	1. Falling objects 2. Striking against objects 3. Spatter	Helmets

Foot protection (Fig 2)	1. Hot spatter 2. Falling objects 3. Working wet area	Leather leg guards Safety shoes Gum boots
Nose (Fig 3)	1. Dust particles 2. Fumes/ gases/ vapours	Nose mask
Hand protection (Fig 4)	1. Heat burn due to direct contact 2. Blows sparks moderate heat 3. Electric shock	Hand gloves
Eye protection (Fig 5, Fig 6)	1. Flying dust particles 2. UV rays, IR rays heat and High amount of visible radiation	Goggles Face shield Hand shield Head shield
Face Protection (Fig 6, Fig 7)	1. Spark generated during Welding, grinding 2. Welding spatter striking 3. Face protection from UV rays	Face shield Head shield with or without ear muff Helmets with welders screen for welders
Ear protection (Fig 7)	1. High noise level	Ear plug Ear muff
Body protection (Fig 8, Fig 9)	1. Hot particles	Leather aprons

Fig 1

Fig 2

Fig 3

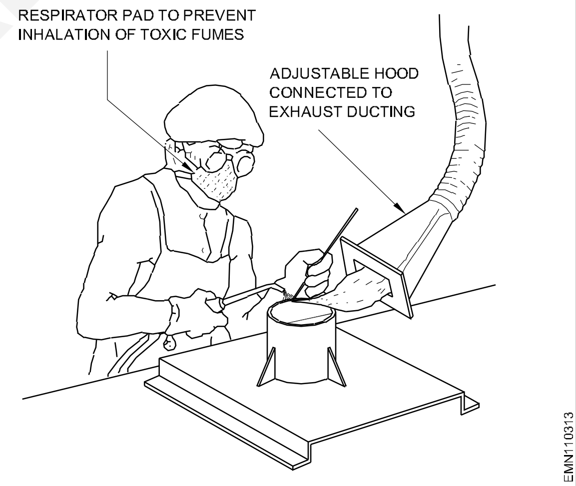


Fig 6

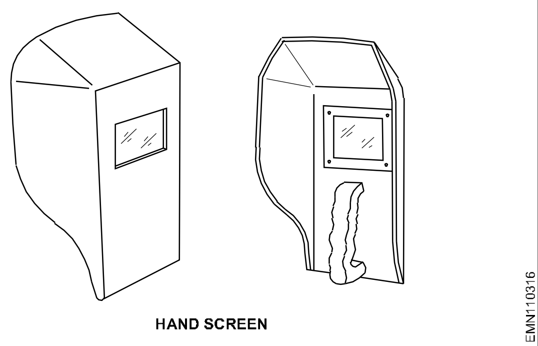
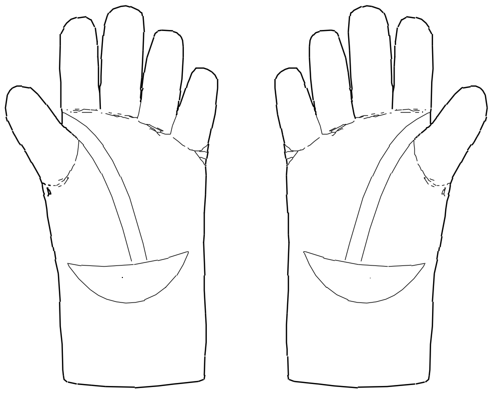


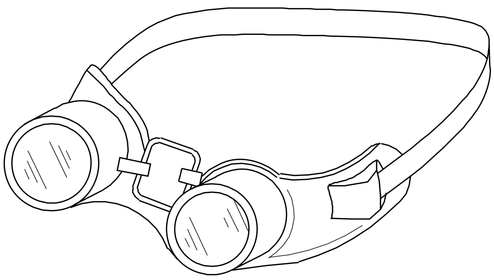
Fig 4



GLOVES

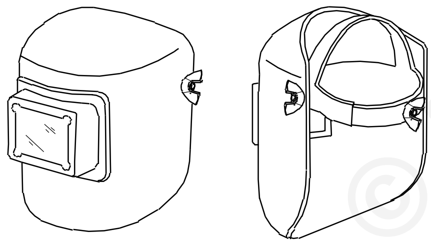
EMN110314

Fig 5



EMN110315

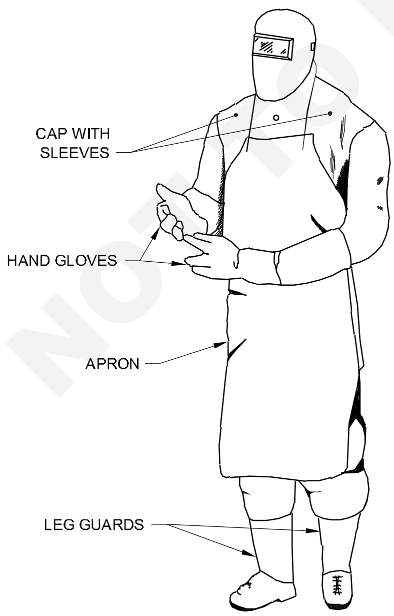
Fig 7



WELDING HELMET

EMN110317

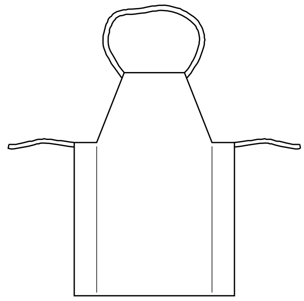
Fig 9



LEG GUARDS

EMN110319

Fig 8



APRON

EMN110318

Quality of PPE's

PPE must meet the following criteria with regard to its quality-provide absolute and full protection against possible hazard and PPE's be so designed and manufactured out of materials that it can withstand the hazards against which it is intended to be used.

Selection of PPE's requires certain conditions

- Nature and severity of the hazard
- Type of contaminant, its concentration and location of contaminated area with respect to the source of respirable air
- Expected activity of workman and duration of work, comfort of workman when using PPE
- Operating characteristics and limitations of PPE
- Ease of maintenance and cleaning.
- Conformity to Indian/ International standards and availability of test certificate.

Proper use of PPEs

Having selected the proper type of PPE, it is essential that the workman wears it. Often the workman avoids using PPE. The following factors influence the solution to this problem.

- The extent to which the workman understands the necessity of using PPE
- The ease and comfort with which PPE can be worn with least interference in normal work procedures
- The available economic, social and disciplinary sanctions which can be used to influence the attitude of the workman
- The best solution to this problem is to make 'wearing of PPE' mandatory for every employee.
- In other places, education and supervision need to be intensified. When a group of workmen are issued PPE for the first time.

First Aid

Objectives: At the end of this lesson you shall be able to
- **state the first aid**
- **explain the ABC of the first aid**
- **explain the first-aid treatment for a victim**
- **state the importance of house keeping**
- **explain environment, health and safety**
- **state the importance of safety and safety signs.**

First aid is defined as the immediate care and support given to an acutely injured or ill person, primarily to save life, prevent further deterioration or injury, plan to shift the victim to safer place, provide best possible comfort and finally help them to reach the medical centre/ hospital through all available means. It is an immediate life-saving procedure using all resources available within reach.

Imparting knowledge and skill through institutional teaching at younger age group in schools, colleges, entry point at industry level is now given much importance. Inculcating such habits at early age, helps to build good healthcare habits among people.

First aid procedure often consists of simple and basic life saving techniques that an individual performs with proper training and knowledge.

The key aims of first aid can be summarized in three key points:

- **Preserve life:** If the patient was breathing, a first aider would normally then place them in the recovery position, with the patient leant over on their side, which also has the effect of clearing the tongue from the pharynx. It also avoids a common cause of death in unconscious patients, which is choking on regurgitated stomach contents. The airway can also become blocked through a foreign object becoming lodged in the pharynx or larynx, commonly called choking. The first aider will be taught to deal with this through a combination of 'back slaps' and 'abdominal thrusts'. Once the airway has been opened, the first aider would assess to see if the patient is breathing.
- **Prevent further harm:** Also sometimes called prevent the condition from worsening, or danger of further injury, this covers both external factors, such as moving a patient away from any cause of harm, and applying first aid techniques to prevent worsening of the condition, such as applying pressure to stop a bleed becoming dangerous.
- **Promote recovery:** First aid also involves trying to start the recovery process from the illness or injury, and in some cases might involve completing a treatment, such as in the case of applying a plaster to a small wound.

Training

Basic principles, such as knowing to use an adhesive bandage or applying direct pressure on a bleed, are often acquired passively through life experiences. However, to provide effective, life-saving first aid interventions requires instruction and practical training. This is especially true where it relates to potentially fatal illnesses and injuries, such as those that require cardiopulmonary resuscitation (CPR); these procedures may be invasive, and carry a risk of further injury to the patient and the provider. As with any training, it is more useful if it occurs before an actual emergency, and in many countries, emergency ambulance dispatchers may give basic first aid instructions over the phone while the ambulance is on the way. Training is generally provided by attending a course, typically leading to certification. Due to regular changes in procedures and protocols, based on updated clinical knowledge, and to maintain skill, attendance at regular refresher courses or re-certification is often necessary. First aid training is often available through community organization such as the Red cross and St. John ambulance.

ABC of first aid

ABC stands for airway, breathing and circulation.

- **Airway:** Attention must first be brought to the airway to ensure it is clear. Obstruction (choking) is a life-threatening emergency.
- **Breathing:** Breathing if stops, the victim may die soon. Hence means of providing support for breathing is an important next steps. There are several methods practiced in first aid.
- **Circulation:** Blood circulation is vital to keep person alive. The first aiders now trained to go straight to chest compressions through CPR methods.

When providing first aid one needs to follow some rule. There are certain basic norms in teaching and training students in the approach and administration of first aid to sick and injured.

Not to get panic

Panic is one emotion that can make the situation more worse. People often make mistake because they get panic. Panic clouds thinking may cause mistakes. First aider need calm and collective approach. If the first aider himself is in a state of fear and panic gross mistakes may result. It's far easier to help the suffering, when they know what they are doing, even if unprepared to encounter a situation. Emotional approach and response always lead to wrong doing and may lead one to do wrong procedures. Hence be calm and focus on the given institution. Quick and confident approach can lessen the effect of injury.

Call medical emergencies

If the situation demands, quickly call for medical assistance. Prompt approach may save the life.

Surroundings play vital role

Different surroundings require different approach. Hence first aider should study the surrounding carefully. In other words, one need to make sure that they are safe and are not in any danger as it would be of no help that the first aider himself get injured.

Do no harm

Most often over enthusiastically practiced first aid viz. administering water when the victim is unconscious, wiping clotted blood (which acts as plug to reduce bleeding), correcting fractures, mishandling injured parts etc., would leads to more complication. Patients often die due to wrong FIRST AID methods, who may otherwise easily survive. Do not move the injured person unless the situation demands. It is best to make him lie wherever he is because if the patient has back, head or neck injury, moving him would causes more harm.

This does not mean do nothing. It means to make sure that to do something the care gives feel confident through training would make matters safe. If the first aider is not confident of correct handling it is better not to intervene of doing it. Hence moving a trauma victim, especially an unconscious one, needs very careful assessment. Removal of an embedded objects (Like a knife, nail) from the wound may precipitate more harm (e.g. increased bleeding). Always it is better to call for help.

Reassurance

Reassure the victim by speaking encouragingly with him.

Stop the bleeding

If the victim is bleeding, try to stop the bleeding by applying pressure over the injured part.

Golden hours

India have best of technology made available in hospitals to treat devastating medical problem viz. head injury, multiple trauma, heart attack, strokes etc, but patients often do poorly because they don't gain access to that technology in time. The risk of dying from these conditions, is greatest in the first 30 minutes, often instantly. This period is referred to as Golden period. By the time the patient reach the hospital, they would have passed that critical period. First aid care come handy to save lives. It helps to get to the nearest emergency room as quickly as possible through safe handling and transportation. The shorter that time, the more likely the best treatment applied.

Maintain the hygiene

Most important, the first aider need to wash hands and dry before giving any first aid treatment to the patient or wear gloves in order to prevent infection.

Cleaning and dressing

Always clean the wound thoroughly before applying the bandage gently wash the wound with clean water.

Not to use local medications on cuts or open wounds

They are more irritating to tissue than it is helpful. Simple dry cleaning or with water and some kind of bandage are best.

CPR (Cardio-Pulmonary Resuscitation) can be life-sustaining

CPR can be life sustaining. If one is trained in PR and the person is suffering from choking or finds difficulty in breathing, immediately begin CPR. However, if one is not trained in CPR, do not attempt as you can cause further injury. But some people do it wrong. This is a difficult procedure to do in a crowded area. Also there are many studies to suggest that no survival advantage when bystanders deliver breaths to victims compared to when they only do chest compressions. Second, it is very difficult to carry right maneuver in wrong places. But CPR, if carefully done by highly skilled first aiders is a bridge that keeps vital organs oxygenated until medical team arrives.

Declaring death

It is not correct to declare the victim's death at the accident site. It has to be done by qualified medical doctors.

How to report an emergency?

Reporting an emergency is one of those things that seems simple enough, until actually when put to use in emergency situations. A sense of shock prevail at the accident sites. Large crowd gather around only with inquisitive nature, but not to extend helping hands to the victims. This is common in road side injuries. No passer-by would like to get involved to assist the victims. Hence first aid management is often very difficult to attend to the injured persons. The first aiders need to adapt multi-task strategy to control the crowd around, communicate

to the rescue team, call ambulance etc., all to be done simultaneously. The mobile phones helps to a greater extent for such emergencies. Few guidelines are given below to approach the problems.

Assess the urgency of the situation. Before you report an emergency, make sure the situation is genuinely urgent. Call for emergency services if you believe that a situation is life-threatening or otherwise extremely critical.

- A crime, especially one that is currently in progress. If you're reporting a crime, give a physical description of the person committing the crime.
- A fire - If you're reporting a fire, describe how the fire started and where exactly it is located. If someone has already been injured or is missing, report that as well.

- A life-threatening medical emergency, explain how the incident occurred and what symptoms the person currently displays.
- A car crash - Location, serious nature of injures, vehicle's details and registration, number of people involved etc.

Call emergency number

The emergency number varies - 100 for Police & Fire, 108 for Ambulance.

Report your location

The first thing the emergency dispatcher will ask is where you are located, so the emergency services can get there as quickly as possible. Give the exact street address, if you're not sure of the exact address, give approximate information.

Give the dispatcher your phone number

This information is also imperative for the dispatcher to have, so that he or she is able to call back if necessary.

Describe the nature of the emergency

Speak in a calm, clear voice and tell the dispatcher why you are calling. Give the most important details first, then answer the dispatcher's follow-up question as best as you can.

Do not hang up the phone until you are instructed to do so. Then follow the instructions you were given.

How to do 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. Basic first aid allows one to quickly determine a person's physical condition and the correct course of treatment.

Important guideline for first aiders

Evaluate the situation

Are there things that might put the first aider at risk. When faced with accidents like fire, toxic smoke, gasses, an unstable building, live electrical wires or other dangerous scenario, the first aider should be very careful not to rush into a situation, which may prove to be fatal.

Remember A-B-Cs

The ABCs of first aid refer to the three critical things the first aiders need to look for.

- 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)

Avoid moving the victim

Avoid moving the victim unless they are immediate danger. Moving a victim will often make injuries worse, especially in the case of spinal cord injuries.

Call emergency services

Call for help or tell someone else to call for help as soon as possible. If alone at the accident scene, try to establish breathing before calling for help, and do not leave the victim alone unattended.

Determine responsiveness

If a person is unconscious, try to rouse them by gently shaking and speaking to them.

If the person remains unresponsive, carefully roll them on the side (recovery position) and open his airway.

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

Look, listen and feel for signs of breathing

Look for the victim's chest to raise and fall, listen for sounds of breathing.

If the victim is not breathing, see the section below

- If the victim is breathing, but unconscious, roll them onto their side, keeping the head and neck aligned with the body. This will help drain the mouth and prevent the tongue or vomit from blocking the airway.

Check the victim's circulation

Look at the victim's colour and check their pulse (the carotid artery is a good option; it is located on either side of the neck, below the jaw bone). If the victim does not have a pulse, start CPR.

Treat bleeding, shock and other problems as needed

After establishing that the victim is breathing and has a pulse, next priority should be to control any bleeding. Particularly in the case of trauma, preventing shock is the priority.

- **Stop bleeding:** Control of bleeding is one of the most important things to save a trauma victim. Use direct pressure on a wound before trying any other method of managing bleeding.
- **Treat shock:** Shock may causes loss of blood flow from the body, frequently follows physical and occasionally psychological trauma. A person in shock will frequently have ice cold skin, be agitated or have an altered mental status, and have pale colour 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 minutes.
- **Treat a burn:** Treat first and second degree burns by immersing or flushing with cool water. 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 jewellery 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 are: loss of consciousness following the injury, disorientation or memory impairment, vertigo, nausea, and lethargy.
- **Treat a spinal injury victim:** If a spinal injury is suspected, it is especially critical, not move the victim's head, neck or back unless they are in immediate danger.

Stay with the victim until help arrives

Try to be a calming presence for the victim until assistance can arrive.

Unconsciousness (COMA)

Unconscious also referred as Coma, is a serious life threatening condition, when a person lie totally senseless and do not respond to calls, external stimulus. But the basic heart, breathing, blood circulation may be still intact, or they may also be failing. If unattended it may lead to death.

The condition arises due to interruption of normal brain activity. The causes are too many.

The following symptoms may occur after a person has been unconscious:

- Confusion
- Drowsiness
- Headache
- Inability to speak or move parts of his or her body (see stroke symptoms)
- Light headedness
- Loss of bowel or bladder control (incontinence)
- Rapid heartbeat (palpitation)
- Stupor

First aid

- Call EMERGENCY number.
- Check the person's airway, breathing, and pulse frequently. If necessary, begin rescue breathing and CPR.
- If the person is breathing and lying on the back and after ruling out spinal injury, carefully roll the person onto the side, preferably left side. Bend the top leg so both hip and knee are at right angles. Gently tilt the head back to keep the airway open. If breathing or pulse stops at any time, roll the person on to his back and begin CPR.
- If there is a spinal injury, the victims position may have to be carefully assessed. If the person vomits, roll the entire body at one time to the side. Support the neck and back to keep the head and body in the same position while you roll.
- Keep the person warm until medical help arrives.
- If you see a person fainting, try to prevent a fall. Lay the person flat on the floor and raise the level of feet above and support.
- If fainting is likely due to low blood sugar, give the person something sweet to eat or drink when they become conscious.

Do not

- Do not give any food or drink of an unconscious person
- Do not leave the person alone.
- Do not place a pillow under the head of an unconscious person.
- Do not slap an unconscious person's face or splash water on the face and try to revive him.

Loss of consciousness may threaten life if the person is on his back and the tongue has dropped to the back of the throat, blocking the airway. Make certain that the person is breathing before looking for the cause of unconsciousness. If the injuries permit, place the casualty in the recovery position (Fig 2) with the neck extended. Never give any thing by mouth to an unconscious casualty.

How to diagnose an unconscious injured person

- Consider alcohol: look for signs of drinking, like empty bottles or the smell of alcohol.
- Consider epilepsy: are there signs of a violent seizure, such as saliva around the mouth or a generally dishevelled scene?
- Think insulin: might the person be suffering from insulin shock (see 'How to diagnose and treat insulin shock")?
- Think about drugs: was there an overdose? Or might the person have under dosed - that is not taken enough of a prescribed medication?
- Consider trauma: is the person physically injured?
- Look for signs of infection: redness and/ or red streaks around a wound.
- Look around for signs of Poison: an empty bottle of pills or a snakebite wound.
- Consider the possibility of psychological trauma: might the person have a psychological disorder of some sort?
- Consider stroke, particularly for elderly people.
- Treat according to what you diagnose.

Shock

A severe loss of body fluid will lead to a drop in blood pressure. Eventually the blood's circulation will deteriorate and the remaining blood flow will be directed to the vital organs such as the brain. Blood will therefore be directed away from the outer area of the body, so the victim will appear pale and the skin will feel ice cold.

As blood flow slows, so does the amount of oxygen reaching the brain. The victim may appear to be confused, weak, and dizzy and may eventually deteriorate into unconsciousness. Try to compensate for this lack of oxygen, the heart and breathing rates both speed up, gradually becoming weaker, and may eventually cease.

Potential causes of shock include: sever internal or external bleeding; burns; severe vomiting and diarrhoea, especially in children and the elderly; problems with the heart.

Power Failure

Minor electric shock, fire, or product failure may occasionally occur. Do not disassemble, modify, or repair the product or touch the interior of the product.

Minor injury due to electric shock may occasionally occur. Do not touch the terminals while power is being supplied.

Minor burns may occasionally occur. Do not touch the product while power is being supplied or immediately after power is turned OFF.

Fire may occasionally occur. Tighten the terminal screws with the specified torque.

Minor electric shock, fire, or product failure may occasionally occur. Do not allow any pieces of metal or conductors or any clippings or cuttings resulting from installation work to enter the product.

Precautions for Safe Use

Input Voltage

Use a commercial power supply for the power supply voltage input to models with AC inputs.

Inverters with an output frequency of 50/60 Hz are available, but the rise in the internal temperature of the power supply may result in ignition or burning. Do not use an inverter output for the power supply of the product.

Grounding

Electric shock occur if the ground is not connected completely.

Operating Environment

Use each product within the rated range for ambient operating temperature, ambient operating humidity, and storage temperature specified for that product.

Use the power supply within the ranges specified for vibration and shock resistance.

Do not use the power supply in locations subjects to excessive amount of dust or where liquids, foreign matter, or corrosive gases may enter the interior of the product.

Install the power supply well away from devices that produce strong, high-frequency noise and surge.

Do not use the power supply in locations subject to direct sunlight.

Mounting

The installation screws can be tightened into the power supply only to a limited depth. Make sure that the lengths of the screws protruding into the power supply are within the specified dimensions.

Wiring

Use caution when connecting the input cable to the power supply.

The power supply unit may be destroyed if the input cable is connected to the wrong terminals. Use caution when using a model with a DC input. The power supply unit may be destroyed if the polarity is reversed.

Do not apply more than 75-N force to the terminal block when tightening the terminals.

Wiring materials

Use a wire size that suits the rated output current of the power supply to be used in order to prevent smoking or ignition caused by abnormal loads.

Caution is particularly required if the output current from one power supply is distributed to multiple loads. If thin wiring is used to branch wiring, the power supply's overload protection circuit may fail to operate depending on factors such as the impedance of the load wiring even the load is short-circuited.

Therefore insertion of a fuse in the line or other protective measures must be considered.

Precautions against ingress of metal fragments (Fillings)

Drilling on the upper section of an installed power supply may cause drilling fragments to fall onto the PCB, thereby short-circuiting and destroying the internal circuits. Whether the power supply cover is attached or not, cover the power supply with a sheet to prevent ingress of fragments when performing work on the upper sector of the power supply.

Be sure to remove the sheet covering the power supply for machining before power-ON so that it does not interface with heat dissipation.

Load

Internal parts may possibly deteriorate or be damaged if a short-circuited or over current state continues during operation.

Charging a battery

When connection a battery at the load, connect an overcurrent limiting circuit and overvoltage protection circuit.

Output and Ground connections

The power supply output is a floating output (i.e., the primary side and secondary side are separated). so the output line (i.e., +V or -V) can be connected externally directly to a ground. Though the ground, however, the insulation between the primary side and secondary side will be lost. Confirm that no loops are created in which the power supply output is short-circuited through the internal circuits of the load.

Example: When the +V side of the power supply is connected directly to a ground and a load is used for which the internal 0-V line uses the same ground.

Fire safety

Prepare before a fire:

Always familiarize yourself to "where you are" and be sure to know how to reach the two nearest exits.

Remember that in a fire situation, smoke is blinding and will bank down in the rooms and hallways. This condition may force you to crouch or crawl to escape to safety. By always being aware of your surroundings, your knowledge of the nearest exits and having a plan will greatly increase your ability to deal with sudden

If you are notified of, or discover a fire:

- Move quickly to the nearest accessible exit.
- Notify, and assist others to evacuate along the way.
- If the building fire alarm is not yet sounding, manually activate the alarm pull station located near the exit.
- Exit the building and proceed to the " Area of gathering"

Evacuation procedures for persons with mobility issues:

In the event of an actual emergency incident, persons with mobility issues or who are unable to safely self-evacuate should follow this procedure:

- Relocate to an entry to an evacuation stairwell, marked by a red exit sign.
- Wait near the enclosed exit stairwell if there is no smoke or other threats to your safety. Most fire alarm activations are brief, allowing occupants to return within a few minutes.

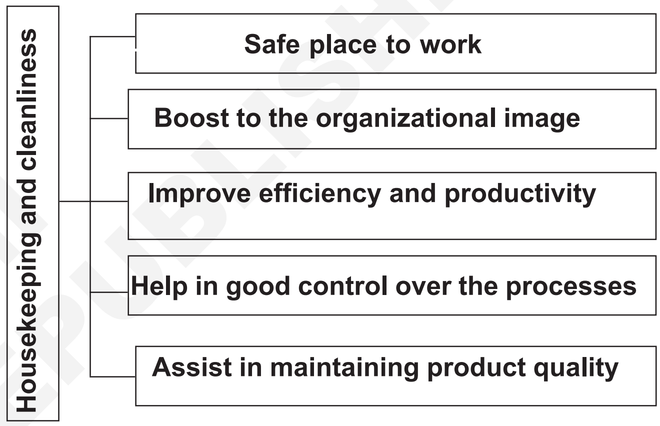
If smoke, fire, or other threat is imminent, move into the stairwell:

- After the stairwell crowd has passed below your floor level, enter the stairwell with assistant(s) and wait on the stair landing. Make sure that the door is securely closed.

Housekeeping and cleanliness at workplace

Housekeeping and cleanliness at the workplace are closely linked to the industrial safety. the degree, to which these activities are effectively managed, is an indicator of the safety culture of the organization. House keeping and cleanliness not only make the organization a safer place to work in but also provide a big boost to the image of the organization. These activities also (i) improve efficiency and productivity, (ii) helps in maintaining good control over the processes, and (iii) assist in maintaining the quality of the product. These important aspects of housekeeping and cleanliness are furnished below.

There are several signs which reflect poor housekeeping and cleanliness at the workplace in the organization. Some of these signs are (i) cluttered and poorly arranged work areas, (ii) untidy or dangerous storage of materials (such as materials stuffed in corners and overcrowded shelves etc.), (iii) dusty and dirty floors and work surfaces, (iv) items lying on the shop floor which are in excess or no longer needed, (v) blocked or cluttered aisles and exits, (vi) tools and equipment left in work areas instead of being returned to proper storage places, (vii) broken containers and damaged materials, (viii) overflowing waste bins and containers, and (ix) spills and leaks etc.



Housekeeping and cleanliness is crucial to a safe workplace. It can help prevent injuries and improve productivity and morale, as well as make a good imprint on the people visiting the workplace.

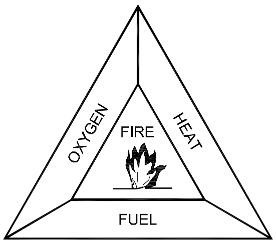
Fire extinguishers

Objectives: At the end of this lesson you shall be able to
- **state the effects of a fire break out**
- **state the conditions required for combustion relevant to fire prevention**
- **state the general precautionary measures to be taken for fire prevention**
- **determine the correct type of fire extinguisher required for a particular function**
- **state environment, health and safety.**

Fire

Fire is nothing but burning of a combustible material. For combustion the three main requirements are shown in Fig 1.

Fig 1



Fuel

Fuel can be any combustible substance in the form of a solid, liquid or gas. Examples; wood, paper, petrol, kerosene, LPG etc., The fuel will catch fire and burn provided a high enough temperature(heat) is brought about and a continuous supply of oxygen is given. It is important to note that without fuel, combustion cannot take place.

Heat

Fuels will begin to burn at a certain temperature. Different types of fuels need different temperatures to catch fire and burn. For example, wood needs a higher temperature to catch fire and burn than paper. Petrol needs much lesser temperature to catch fire and burn than paper. Generally liquid fuels give off vapour when heated. It is this vapour which ignites. Some liquids such as petrol do not have to be heated as they give off vapour at room temperature (15°C - 25°C) itself. It is important to note that without heat, fuel cannot get ignited(catch fire) and hence combustion cannot take place.

Oxygen

Oxygen exists in air. The amount of oxygen in air is sufficient to continue the combustion once it occurs. Hence to keep a fire burning, oxygen is a must. It is important to note that without oxygen, combustion cannot continue to take place.

Controlled and uncontrolled fire

Fire is a boon to mankind. Without fire, there would not be cooked food or hot water for bath as and when we want it. At the same time if the fire does not get constrained to a place of requirement, fire can become a bane(curse) to mankind. An uncontrolled fire can cause such a disaster which not only leads to destruction of material but also endanger the life of persons. Hence, the lesson one must never forget is, keep the fire under control. Every effort must be made to prevent uncontrolled fire. When there is a fire outbreak, it must be controlled and extinguished immediately without any delay.

Preventing fire

The majority of fires begin with small outbreaks. If this is not noticed, fire goes out of control and will be on its way of destruction. Hence, most fires could be prevented if suitable care is taken by following some simple common sense rules as given below.

– Do not accumulate combustible refuse such as cotton waste, waste or cloth soaked with oil, scrap wood, paper, etc. in odd corners. These refuse should be in their collection bins or points.

– Do not misuse or neglect electrical equipments or electrical wiring as this may cause electrical fire. Loose connections, low rated fuses, overloaded circuits causes over heating which may in turn lead to fire. Damaged insulation between conductors in cables cause electrical short circuit and cause fire.

– Keep away clothing and other materials which might catch fire from heating appliances. Make sure the soldering iron is disconnected from power supply and is kept safe in its stand at the end of the working day.

– Store highly flammable liquids and petroleum mixtures such as thinner, adhesive solutions, solvents, kerosene, spirit, LPG gas etc. in the storage area exclusively meant for storage of flammable materials.

– Turn off blowlamps and torches when they are not in use.

Controlling and Extinguishing fire

Isolating or removing any of three factors illustrated in Fig1, will control and extinguish fire. There are three basic ways of achieving this.

1 **Starving the fire of fuel**

To remove the fuel which is burning or cut further supply of fuel to the fire.

2 **Smothering**

To stop the supply of oxygen to the fire by blanketing the fire with foam, sand etc.

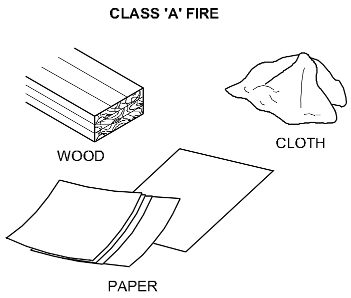
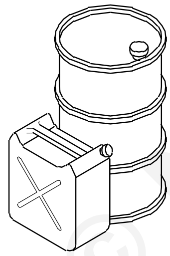
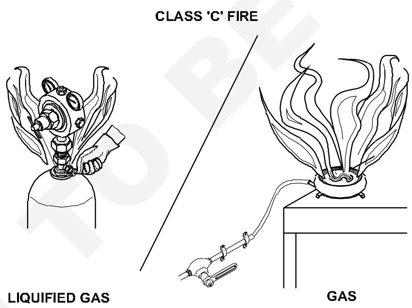
3 **Cooling**

To reduce the temperature of the fire by spraying water and thus cooling the fire.

By any one of the above three methods, fire can be first controlled and then extinguished.

For the purpose of determining the best method of extinguishing different types of fires, fires are classified under four main classes based on the type of fuel as given in Table 1.

TABLE 1

Classification of Fire	Fuel involved	Precautions and extinguishing
Class A Fire	Wood, paper cloth etc. Solid materials 	Most effective method is cooling with water. Jets of water should be sprayed on the base
Class B Fire	Flammable liquids & liquefiable solids 	Should be smothered. The aim is to cover the entire surface of the burning liquid. This has the effect of cutting off the supply of oxygen to the fire. Water should never be used on burning liquids. Foam, dry powder or CO_2 may be used on this type of fire.
Class C Fire	Gas and liquefied gas 	Extreme caution is necessary in dealing with liquefied gases. There is a risk of explosion and sudden outbreak of fire in the entire vicinity. If an appliance fed from a cylinder catches fire -shut off the supply of gas. The safest course is to raise an alarm and leave the fire to be dealt with by trained personnel. Dry powdered extinguishers are used on this type of fire.
Class D Fire	Involving metals 	The standard range of fire extinguishing agents is inadequate or dangerous when dealing with metal fires. **Fire in electrical equipment**: Carbon -di-oxide, dry powder, and vaporizing liquid(CTC) extinguishers can be used to deal with fires in electrical equipment. Foam or liquid (eg. water) extinguishers must not be used on electrical equipment at all.

Fire extinguishers

Different fire extinguishing agents should be used for different types of fires as listed in Table 1. Using a wrong type of extinguishing agent can make things worse.

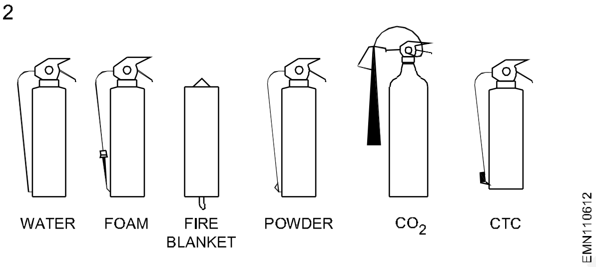
A fire extinguishing agent is the material or substance used to put out the fire. These extinguishing materials are usually (but not always) contained in a container called the 'fire extinguisher' with a mechanism for spraying into the fire when needed.

There is no classification for **electrical fires** as these are only fires in materials where electricity is present. To control electrical fire in a building the electrical supply should be cut off first.

Types of fire extinguishers

Many types of fire extinguishers are available with different extinguishing *agents* to deal with different classes of fires as shown in Fig 2. Always check the operating instructions on the extinguisher before use.

Fig 2



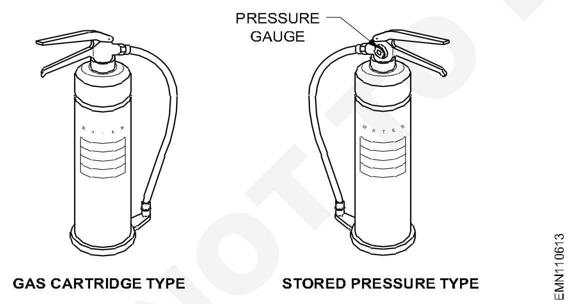
(i) Water-filled extinguishers

In water-filled extinguishers, as shown in Fig 3, there are two types based on the method of operating the extinguisher.

a Cartridge type

b Stored pressure type

Fig 3



In both the methods of operation, the discharge can be interrupted as required. This is to conserve the contact area and to prevent unnecessary damage to the material due to water.

(ii) Foam extinguishers

These may be stored pressure or gas cartridge types as shown in Fig 4.

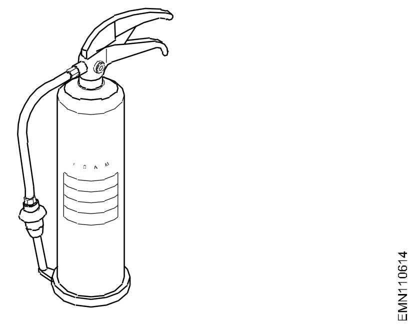
Most suitable for:

– flammable liquid fires

– running liquid fires.

Not to be used in fires where electrical equipment is involved.

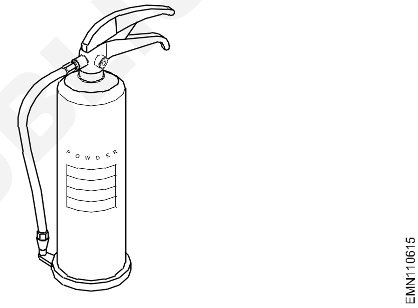
Fig 4



(iii) Dry powder extinguishers

Extinguishers fitted with dry powder may be of the gas cartridge or stored pressure type as shown in Fig 5. Appearance and the method of operation is the same as that of water-filled one. The main distinguishing feature is the fork-shaped nozzle. Powders have been specially developed to deal with Class D fires.

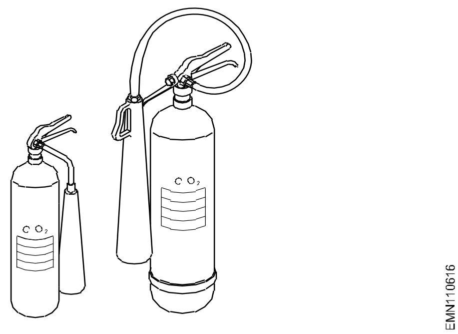
Fig 5



iv) Carbon-di-oxide (CO_2)

This type is easily distinguished by the distinctively shaped discharge horn as shown in Fig 6. These extinguishers are suitable for fires on flammable liquids and liquefiable solids. Best suited where contamination by deposits must be avoided. Not generally effective in the open air.

Fig 6

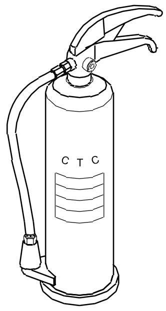


v) Halon Extinguishers (Fig 7)

Carbontetrachloride(CTC) and Bromochlorodifluoro methane (BCF). They may be either gas cartridge or non-conductive.

> **The fumes given off by these extinguishers are dangerous especially in confined space.**

Fig 7



EMN110617

General procedure to be adopted in the event of a fire

1 Raise a loud alarm by using any of the following.

Adopt any one method of giving an alarm signal for fire breaking in your institute/ workshop.

- Raising your voice and shouting Fire! Fire!Fire! .... to call the attention of others.
- Running towards the fire shouting Fire! Fire! and actuate fire alarm/bell/siren. This alarm/bell/siren to be actuated only in case of fire.
- Any other means by which the attention of others can be called and are made to understand there is a fire break out.

2 On receipt of the fire alarm signal, do the following:

- stop the normal work you are doing
- turn OFF the power for all machinery and equipments
- switch OFF fans/air circulators/exhaust fans
- switch OFF the mains if accessible.

3 If you are not involved in fire fighting team, then,

- evacuate the working premises
- close the doors and windows, but do not lock or bolt
- assemble at a safe open place along with the others
- if you are in the room/place where the fire has broken out, leave the place calmly through the emergency exit.

4 If you are involved in the fire fighting team,

- take instructions/give instructions for an organized way of fighting the fire.

If you are taking instructions,

- follow the instructions systematically. Do not be panic. Do not get trapped in fire or smoke in a hurry.

If you are giving instructions,

- assess the class of fire(class A,B,C or D)
- send for sufficient assistance and fire brigade
- judge the magnitude of the fire. Locate locally available suitable means to put-out the fire.
- ensure emergency exit paths are clear of obstructions. Attempt to evacuate the people and explosive materials, substances that can serve as further fuel for fire within the vicinity of the fire break.
- Allot clear activity to persons involved in firefighting by name to avoid confusion.
- Control and extinguish the fire using the right type of fire extinguisher and making use of the available assistance effectively.

5 After fully extinguishing the fire, make a report of the fire accident and the measures taken to put out the fire, to the authorities concerned.

Reporting all fires however small they are, helps in the investigation of the cause of the fire. It helps in preventing the same kind of accident occurring again.

Environment, health and safety (EHS) : is a discipline and specialty that studies and implements practical aspects of environmental protection and safety at work. In simple terms it is what organizations must do to make sure that their activities do not cause harm to anyone.

Regulatory requirements play an important role in EHS discipline and EHS managers must identify and understand relevant EHS regulations, the implications of which must be communicated to executive management so the company can implement suitable measures. Organizations based in the United states are subject to EHS regulations in the code of federal regulations particularly CFR 29,40, and 49. Still, EHS management is not limited to legal compliance and companies should be encouraged to do more than is required by law, if appropriate.

From a health and safety standpoint, it involves creating organized efforts and procedures for identifying workplace hazards and reducing accidents and exposure to harmful situations and substances. It also includes training of personnel in accident prevention, accident response, emergency preparedness, and use of protective clothing and equipment.

From an environmental standpoint, it involves creating a systematic approach to complying with environmental regulations, such as managing waste or air emissions all the way to helping site's reduce the company's carbon footprint.

Successful HSE programs also include measures to address ergonomics, air quality, and other aspects of workplace safety that could affect the health and well-being of employees and the overall community.

Basic hand tools

Objectives : At the end of this lesson you shall be able to
- **state the types of screwdrivers**
- **explain the parts of a combination plier and their uses**
- **state the uses of diagonal cutters**
- **state the uses of nose pliers and their types**
- **state the uses of tweezers and their types.**

Basic Hand tools

There are innumerable types of hand tools used for different types of work. Some of the basic tools which are a must for a mechanic electronics are dealing in are :

– screwdrivers

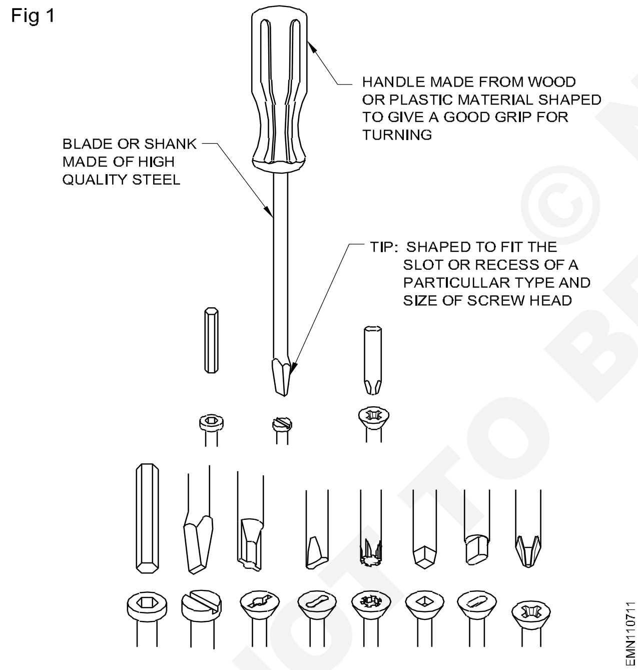
– pliers, and

– tweezers.

Screwdrivers

A screwdriver is a tool used to tighten or loosen screws. A simple screwdriver and its parts are shown in Fig 1.

Fig 1



When a screwdriver is used to tighten or loosen screws. The blade axis of a screwdriver must be linked up with that of the screw axis If this is not taken care of, the screwdriver tip/screw head/threads in the hole will get damaged.

It is important that the width and thickness of a flat screwdriver tip correspond to the dimensions of the slot it is used with. Its width should be slightly less than the length of the slot and its thickness should be almost equal to the width of the slot.

A flat tip which is too wide might cause damage to the workpiece.

Screwdrivers with flat tips are specified in size by the length of their blade and by the width of their tip. These dimensions are given in millimetres (mm).

Screwdrivers are available in many sizes, ranging from blade lengths from 25 mm to 300 mm and widths of tips ranging from 0,5 mm to 18 mm.

Using a screwdriver

The general procedure for using a screwdriver is given below.

– Select a suitable screwdriver having the required blade length, width of tip and thickness of tip.

– Check that the tip of the screwdriver is flat and square.

Pliers

Pliers are tools which are used for:

– holding, gripping, pulling and turning small parts and components,

– shaping and bending light sheet metal parts,

– forming, bending, twisting and cutting small diameter wires.

Pliers consist basically of a pair of legs which are joined by a pivot. Each leg consists of a long handle and a short jaw.

If the legs of the pliers are crossed at the pivot, the jaws will close when pressure is applied to the handles. In some pliers the jaws will close when pressure is applied to the handles.

Pliers have serrated or plain jaws. Surrogated jaws offer a better grip on the workpiece. Serrated jaws might, however, damage the surface of the workpiece. In this case protection sleeves or pliers with non-serrated jaws should be used.

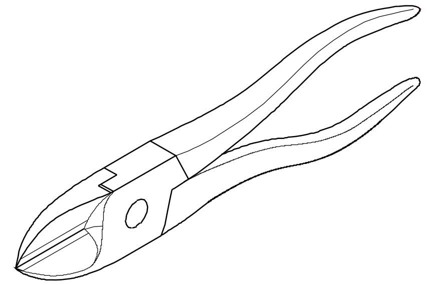
Pliers are made from high quality steel. In many cases pliers are chromium plated to protect them against rust. In climates with a high degree of humidity it is advisable to use such pliers as they will last longer and need less maintenance.

To keep pliers in good working condition, they should be kept clean, the metal parts should be wiped with an oily piece of cloth and, from time to time, a drop of oil should be applied to the pivots and joints.

Diagonal cutter plier

Fig 2 shows diagonal cutting pliers or side cutting pliers.

Fig 2



DIAGONAL CUTTING PLIERS

They are used for cutting small diameter wires and cables, especially when they are close to terminals.

They are also used to remove the sheath and insulation from cables and cords.

They can also be used for other operations such as splitting and removing cotter pins.

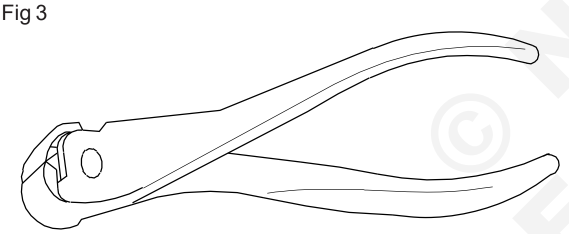
Diagonal cutting pliers are made in the following overall lengths:

100, 125, 140, 160, 180 and 200 mm.

End cutting plier

Fig 3 shows end - cutting pliers or end nippers and their applications.

Fig 3



END CUTTING PLIERS

They are used to cut small diameter wires, pins, nails and to remove nails from wood.

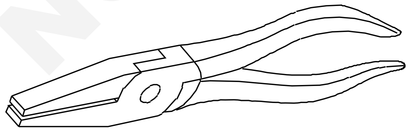
End cutting pliers are made in the following overall lengths:

130, 160, 180, 200, 210 and 240 mm.

Flat nose pliers

Fig 4 shows a flat nose pliers and its applications.

Fig 4



FLAT NOSE PLIERS

They are used to form and shape wires and small pieces of metal.

They are also used for other operations such as removing the metal sheath from cables, or gripping and holding small parts.

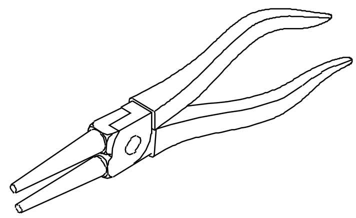
Flat nose pliers are made in the following overall lengths:

100, 120, 140, 160, 180 and 200 mm.

Round nose pliers

Fig 5 shows round nose pliers and its applications.

Fig 5



ROUND NOSE PLIERS

They are used to form curves in wires and light metal strips. The conical shape of the jaws makes it possible to form curves and circles of various dimensions.

They are also used to form eyelets in wires to fit terminal screws, and to hold small parts.

Round nose pliers are made to the following overall lengths:

100, 120, 140, 160, 180 and 200 mm.

Long nose pliers

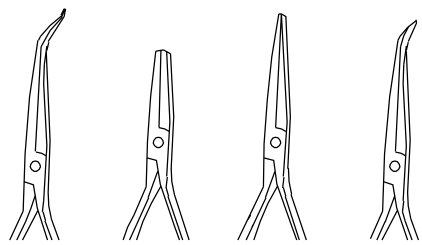
Long nose pliers and its applications. These pliers are made with straight and curved jaws.

They are used to hold small parts, especially in confined areas.

They are also used to adjust fine wires, contacts and other parts.

Long nose pliers are made with many differently shaped jaws as shown in Fig 6. Long nose pliers are available in the following overall lengths:160, 180, 200 and 220 mm.

Fig 6



Combination pliers

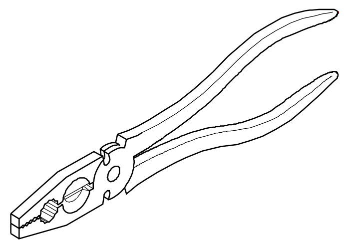
Fig 7 shows a COMBINATION PLIERS and its application. A number of operations can be performed with these pliers.

The FLAT GRIP can be used to grip and hold parts and components and to twist wires.

Many combination pliers also have a PIPE GRIP which is used to grip and hold cylindrical objects.

They also have a pair of SIDE CUTTERS which are used to cut small diameter wires and cables.

Fig 7



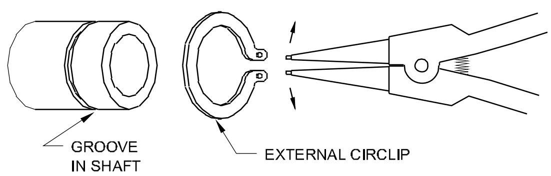
A pair of JOINT CUTTERS are provided for shearing off steel wires.

Combination pliers are available in the following overall lengths: 140, 160, 190, 210 and 250 mm.

Circlip pliers for external circlip

Fig 8 shows a CIRCLIP PLIER for EXTERNAL CIRCLIPS. The prongs of the jaws are inserted into the holes of the circlip. By applying pressure to the handles of the pliers, the jaws will expand the circlip which can then be removed or moved onto the workpiece.

Fig 8



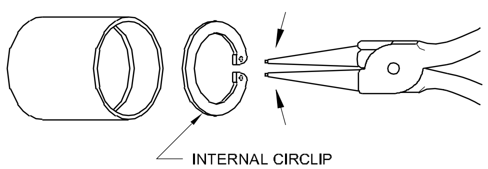
These pliers are available with straight and curved jaws in the following dimensions.

Size	Overall length	Used with circlips shaft diameter of
0	130 mm	3 - 10 mm
1	130 mm	8 - 25 mm
2	170 mm	19 - 60 mm
3	230 mm	40 - 100 mm
4	320 mm	85 - 165 mm

Circlip pliers for internal circlips

Fig 9 shows CIRCLIP PLIERS for INTERNAL CIRCLIPS. By applying pressure to the handles of the pliers, the jaws will compress the circlip which can then be removed from the workpiece.

Fig 9



These pliers are also available with straight and curved jaws in the following dimensions.

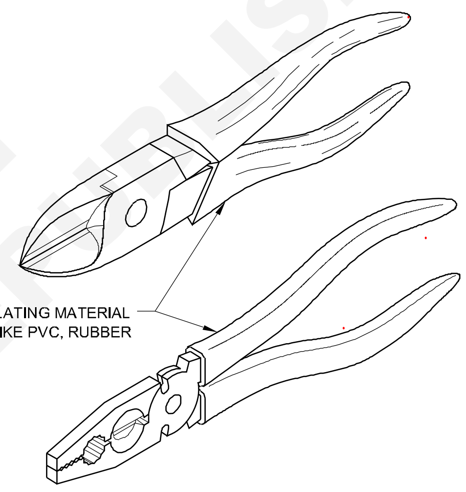
Size	Overall length	Used with circlips shaft diameter of
0	130 mm	3 - 10 mm
0	130 mm	3 - 10 mm
1	130 mm	8 - 25 mm
2	170 mm	19 - 60 mm
3	230 mm	40 - 100 mm
4	320 mm	85 - 165 mm

Pliers used by electrician

A number of pliers, especially diagonal cutting pliers, combination pliers, flat nose pliers, round nose pliers and long nose pliers, are frequently used by electricians.

As an additional safeguard against electric shock, these pliers are available with insulated handles made of high quality rubber or plastic as shown in Fig 10.

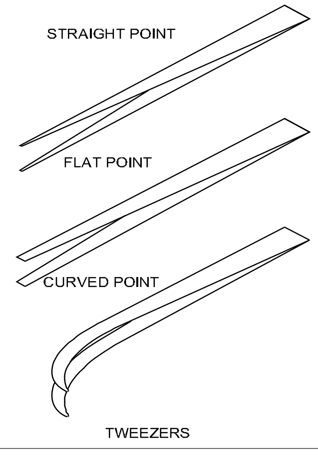
Fig 10



Tweezers

Tweezers are used to hold light weight and very small components and very thin wires/strands. Tweezers are classified according to the shape of the tip and are specified by their length and shape. Fig 11 shows different types of tweezers.

Fig 11

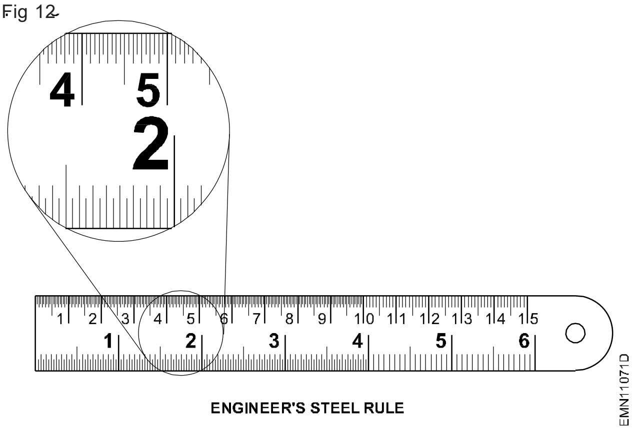


The thin structure of the tweezers permits easy access to places where fingers cannot reach. Tweezers are very useful during soldering of wires, components and placing of small screws in interior places.

Engineer's steel rule

An engineer's steel rule is the basic and most commonly used measuring tool for measuring and drawing the length of straight lines. A typical engineer's steel rule is shown in Fig 12.

Fig 12



ENGINEER'S STEEL RULE

Steel rules are made of spring steel or stainless steel. The edges are accurately ground to form a straight line.The surfaces of steel rules are satin-chrome finished to reduce glaring effect while reading, and also to prevent rusting.

Graduation on engineer's steel rule

The engineer's steel rules are generally graduated both in centimetres and inches as can be seen in Fig 12. In centimetre graduations, the smallest graduations are at intervals of 0.5 mm. In inch graduations the smallest graduation is of 1/16 of an inch. Thus the maximum reading accuracy of a steel rule is either 0.5 mm or 1/16 of an inch.

Standard sizes

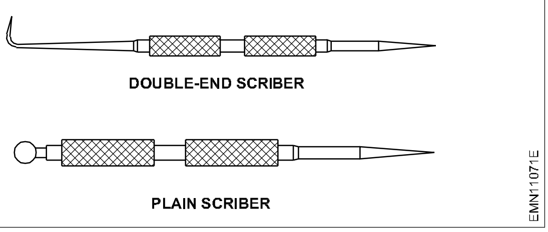
Steel rules are available in different lengths. The common sizes are 150 mm/6inches, 300 mm/12 inches and 600 mm/24 inches.

Scriber

A scriber is a pointed, sharp tool made of steel or carbon steel as shown in Fig 13. There are two types of scribers, namely,

- Plain scribers
- Double end scribers

Fig 13



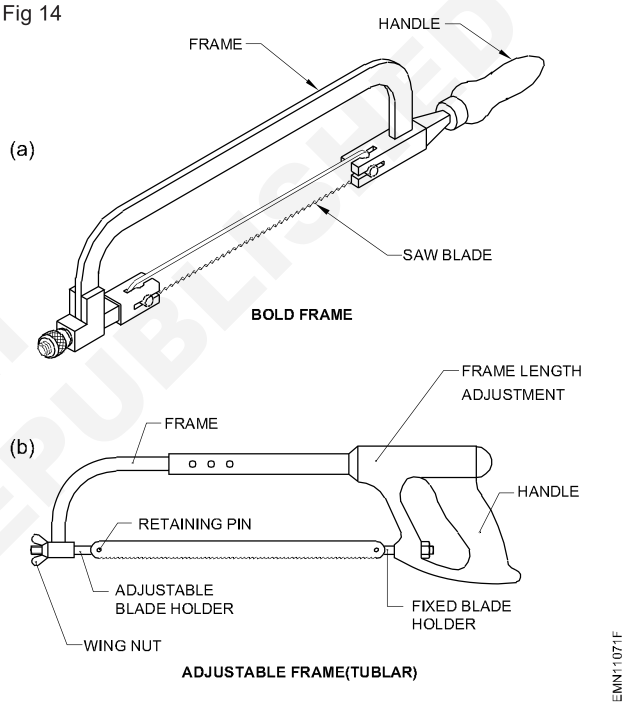
Uses of scribers

Scribers are used for scribing(marking) lines on surfaces prior to cutting. Scribers are generally used for marking on such surfaces on which pencil marking cannot be made or pencil marking is not clearly visible or pencil marking gets erased while handling or pencil marking is too thick. For example pencil marking is not suitable on Hylam or Bakelite sheets. Hence, line markings are done on these boards using scribers.

Hacksaw frame and blade

Fig 14 shows a typical hacksaw frame fitted with a blade. A hacksaw is used to cut metallic sheets or sections. It is also used to cut slots and contours.

Fig 14



Types of hacksaw frames

Bold frame: In this, the frame width is fixed and cannot be altered. Because of this only a particular standard length of hacksaw blade can be fitted with these frames.

Adjustable frame (Flat): In this, the frame is made of flat metal with provision for adjusting the width of the frame. Hence, different standard lengths of blades can be fitted with this frame.

Adjustable frame tubular type: In this, the frame is made of tubular metal with provision for adjusting the width of the frame. Hence, different standard lengths of blades can be fitted with this frame. This is the most commonly used type of hacksaw frame because this frame gives better grip and control while sawing.

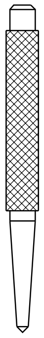
Hacksaw blades

A hacksaw blade is a thin, narrow, steel band with teeth and two pin holes at the ends. These blades are made of either low alloy steel (la) or high speed steel (hs). Hacksaw blades are available in standard lengths of 250 mm and 300 mm.

Punch

A punch is a tool used to make punch marks or light depressions at locations to be drilled or to position dividers or for making permanent dimensional features. A typical punch is shown in Fig 15. Punches are made of hardened steel with a narrow tip on one side.

Fig 15



CENTRE PUNCH

EMN11071G

Centre punch: These punches have an angle of 90^0 at the punch point. The punch mark made by this angle will be wide but not very deep. These punch marks give a good seating for the drill bit at the start of drilling. If one tries to drill at a point without a punch mark, the drill bit will slip away from the point to be drilled and may drill a hole at unwanted points, making the job a waste.

Prick punch: The angle of the prick punch is 30^0 or 60^0. The 30^0 point prick punch is used for marking light punch marks needed to position dividers. The divider leg will get proper seating in this punch mark. The 60^0 punch is used for witness marks.

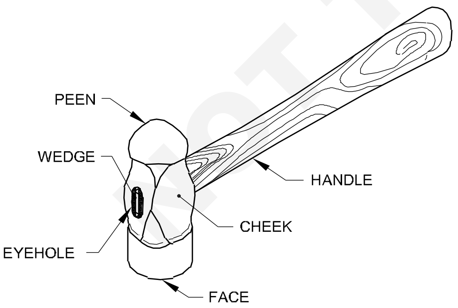
Hammer

An engineer's hammer is a hand tool used for striking purposes like punching, bending, straightening, chipping, forging, riveting etc.,

Parts of a hammer

Fig 16 shows a typical hammer with the parts labelled.

Fig 16



HAMMER

EMN11071H

The head is made of drop-forged carbon steel. The handle is generally made of such materials which can absorb the shock while striking. Wood is most popularly used as the material for the handle.

Face: The face of the hammer is that which strikes the objects. Hence, this portion is hardened. Slight convexity is given to the face to avoid digging of the face edges.

Pein: The pein is the other end of the head. It is used for shaping and forming work like riveting and bending. The pein can be of different shapes like ball pein, cross pein and straight pein. The pein of a hammer is also hardened is the face.

Cheek: The cheek is the middle portion of the hammer-head. The weight of the hammer is stamped here. This portion of the hammer head will be soft.

Eyehole: The eyehole is meant for fixing the handle. It is shaped to fit the handle rigidly. Wedges are used to fix the handle in the eyehole.

Using hammers

Before using a hammer,

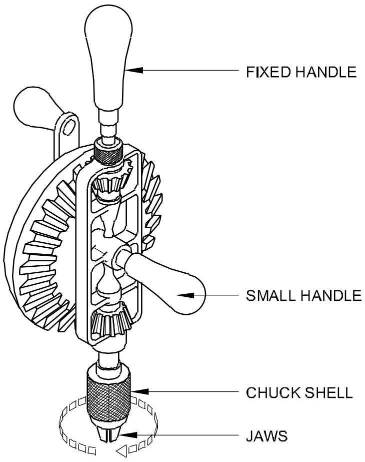
– select a hammer with the correct weight suitable for the job
– make sure the handle is properly fitted
– check the head and handle for any cracks
– ensure that the face of the hammer is free from oil or grease.

Drilling and drilling machines

Drilling is a process of making straight holes in materials. To drill holes, a machine tool known as drilling machine is used. Drilling machines are used with twist drill bits.

These drill bits rotate and penetrate into the material making holes. The drilling machines can be manually driven or electrically driven. A drilling machine can be portable/hand held or mounted on a stand. A typical manually driven, hand held drilling machine most commonly used in small electronics work is shown in Figs 17 & 19 illustrates a portable power drilling machine.

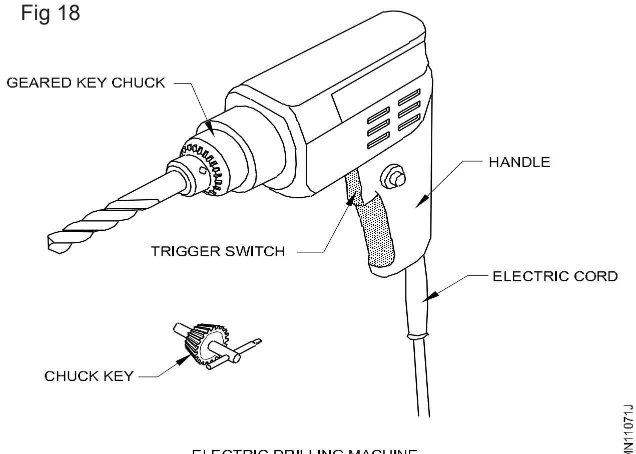
Fig 17



HAND DRILLING MACHINE

EMN11071I

Fig 18



ELECTRIC DRILLING MACHINE

The hand drill is used for drilling holes up to 6.5 mm diameter.

Electric drilling machines are used where higher drilling speed and fairly constant speed is required. Holes can be drilled faster and with higher accuracy using electric drilling machines. Portable electric drilling machines are available in 6 mm and 12 mm capacity. These drilling machines generally operate on 230 V, 50 Hz AC mains supply.

Twist drill/drill bit

Twist drills are used in drilling processes to form round holes in solid materials. When a drill is rotated and the rotating drill is pressed against the material, the drill penetrates and cuts away the material. The rate at which the drill is pressed through the material is called the 'feed'.

Speeds of drills

The outer corner of a drill bit is the most hard-worked part of the cutting lip. For example, in one revolution the outer corner cuts through twice as much metal as the mid-point of the cutting lip.

The cutting speed for a particular material is expressed in feet per minute or in metres per minute.

The recommended speed for a drill is the ideal cutting speed for the outer corners of its lips. Select the revolutions per minute of the drilling machine that will give this cutting speed at the circumference of the drill.

Files

A file is a cutting tool with multiple cutting edges used for filing different materials. Filing in one of the processes used to cut/remove small quantities of materials.

Parts of a file

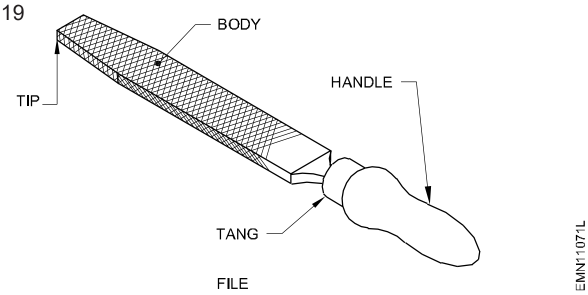
Fig 19 illustrates the main parts of a typical file.

File specification

Files are specified according to their:

- length
- grade
- cut
- shape.

Fig 19



FILE

Length is the distance from the tip to the heel. It varies form 100mm to 300mm.

Grade: Different grades of files are Rough, bastard, second cut, smooth and dead smooth.

Rough file is used for removing more quantity of metal quickly.

Bastard file is used for ordinary filing purposes.

Second cut file is used for good finishing purposes.

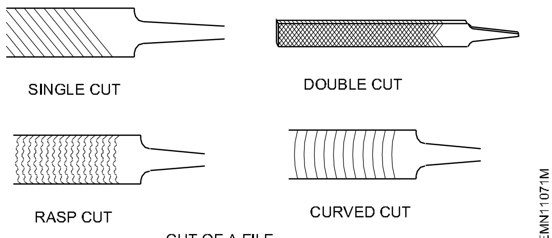
Smooth file is used for removing less metal and for giving good surface finish.

Dead smooth file is used for high degree finishing.

Cut of file

The rows of teeth on the file surface indicate the cut of a file. For example, if there is single row of teeth on the file surface as shown in Fig 20, it is called 'single cut file.'

Fig 20



CUT OF A FILE

Types of cut

The different types of cut of files are:-

- Single cut,
- Double cut,
- Rasp cut, and
- Curved cut.

Single cut: A single cut file has a single row of teeth in one direction on the face of the file at an angle of 60°. These files are used for filing soft materials such as lead, tin, aluminium etc.

Double cut: A double cut file has rows of teeth in two directions across each other at an angle of 50° to 60°, another row at 75°. These files are used to file hard materials such as steel, brass, bronze, etc.

Fitting and sheet metal work

Objectives : At the end of this lesson you shall be able to
- **state the types of sheets**
- **state the names of cutting tools**
- **define riveting and name the types of rivets.**

Cutting and bending of sheet metal

Almost all sheet metal industries use large quantities of steel rolled into sheets of various thicknesses. These sheets are sometimes coated with zinc, tin or other metals for various applications. Other than steel sheets, industries also use sheets made out of zinc, copper, aluminum, stainless steel etc.

The term **sheet metal** generally applies to metals and alloys rolled into sheets of various thicknesses of less than 5 mm. Sheets of thickness over 5 mm are called plates.

Earlier, sheets were specified by standard wire gauge(SWG) numbers. Each gauge is designated with a definite thickness.The larger the gauge number, the lesser is the thickness of the sheet. Nowadays, the sheet thickness is directly specified in millimetres(mm), such as 0.40 mm, 0.50 mm, 0.63 mm, 0.80 mm, 0.90 mm, 1.00 mm, 1.12 mm, 1.25 mm etc.

Types of sheets

Steel sheet: This is an uncoated sheet of mild steel having bluish-black appearance. The use of this metal is limited to articles that are to be painted or enamelled.

Galvanized iron sheet: The zinc-coated iron sheets are known as galvanized iron sheets, popularly known as GI sheets. The zinc coating resists rust. These are most commonly used in making water pipes. Articles like pans, buckets, furnaces, cabinets are also made using GI sheet.

Copper sheets: Copper sheets are available either as cold-rolled or hot-rolled sheets. Cold-rolled sheets are worked easily and are used in sheet metal shops. Gutters, roof flashing and hoods are common examples where copper sheet is used.

Aluminium sheets: Aluminium sheets are highly resistive to corrosion, whitish in colour and light in weight. Since aluminium is a ductile material, it can be bent to any shape easily. Aluminium sheets are widely used in manufacturing of a number of articles such as household utensils, light fixtures, windows etc.

Tin sheets: Tin sheet is a sheet of iron coated with tin to protect the iron sheet against rust. The size and thickness of the tin sheets are denoted by special marks, not by gauge numbers.

Tinned sheets are used for food containers, dairy equipment, furnace fitting etc.

Brass sheet: Brass is an alloy of copper and zinc in various proportions. It will not corrode and is extensively used in craft.

Snips - Sheet metal cutting tools

A snip is a cutting tool used for cutting thin sheets of metal. A typical snip looks as shown in Fig 1 and 3.

There are three types of snips.

1 Straight snips

2 Bent snips/curved snips

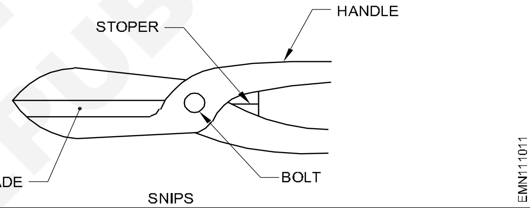
3 Universal snips

Straight snip

A typical straight snip and its parts are shown in Fig 1.

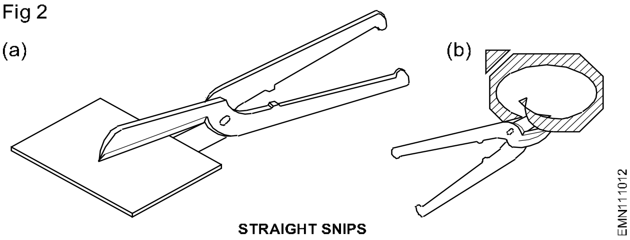
1 Handle 2 Blade 3 Stopper

Fig 1



Straight snips have straight blades for cutting thin sheets along a straight line as shown in Fig 2a. It can also be used for external curved cuts as shown in Fig 2b.

Fig 2



Bent snips/curved snips: Bent snips have curved blades as shown in Fig 3a. These snips are used for cutting internal curves and for trimming a cylinder on the outside of the cut as shown in Fig 3b.

Fig 4 shows a universal snips. Universal snips are used for most general purpose works. The best size of snip for general use is a pair of 300 mm long.

FOLDING TOOLS

Tools commonly used in the folding of sheet metal are:

– angle steel

– folding bar

– C clamp

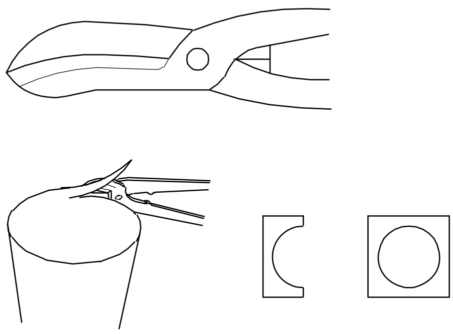
– stakes

– mallet.

Fig 3

(a)

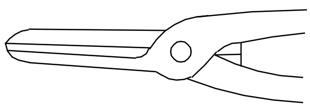
(b)



CURVED SNIPS

EMN111013

Fig 4



UNIVERSAL SNIPS

EMN111014

Angle steel: Two pieces of angles are used for folding sheet metal to an angle of 90°. These angles are fitted on a vice with the sheet metal to be bent sandwiched between the angles. For longer sheets, lengthy angles will be used along with a clamp or hand vice.

Folding bars: The sheet metal to be bent is clamped in the folding bars. The sheet metal is bent to the required shape using a mallet (wooden hammer).

C-clamp: A typical C-clamp is used as a holding device. This clamp is used when two pieces has to be securely held or fixed to one another. It is available in different sizes according to the opening width of the jaws.

Stakes: Stakes are tools used for bending, seaming and forming of sheet metal that cannot be done on any regular machine. For the above purposes, different shapes of stakes as listed below. Stakes are made of soft or cast steel.

– Hatchet stake

– Square stake

– Blow-horn square stake

– Bevel-edge square stake

Hatchet stake: It is used for making sharp bends, for bending edges and for folding sheet metal.

Square stake: It is used for general purpose bending works.

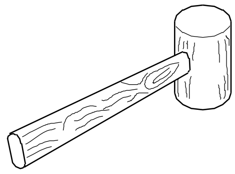
Blow-horn stake: It is used in forming, riveting or seaming tapered, cone-shaped articles, such as funnels etc.

Bevel-edged square stake: It is used to form corners and edges.

Mallet

Fig 5 shows a mallet. A mallet is used for striking while bending sheet metals. Mallets are made of wood, rubber, copper etc. Since these are soft materials, they will not damage the sheet surface while working.

Fig 5



MALLET

EMN111015

NOTCHES

Notches are angular spaces in which the sheet metal is removed. The purpose of making notches is to allow the work to be formed to the required size and shape. Notches prevent excess material from overlapping and causing a bulge at the seam and edges.

Riveting: Riveting is one of the satisfactory methods of making permanent joints of two pieces - metal snips.

It is customary to use rivets of the same metal as that of the parts that are being joined.

Uses: Rivets are used for joining metal sheets and plates in fabrication work, such as bridges, ships, cranes, structural steel work, boilers, aircraft and in various other works.

Material: In riveting, the rivets are secured by deforming the shank to form the head. These are made of ductile materials like low carbon steel, brass, copper and aluminium.

Types of rivets

The four most common types of rivets are:

- tinmen's rivet
- flat head rivet
- round head rivet
- countersunk head rivet.

Method of riveting: Riveting may be done by hand or by machine.

While riveting by hand, it can be done with a hammer and a rivet set.

Rivet set: The shallow, cup-shaped hole is used to draw the sheet and the rivet together. The outlet on the side allows the slug to drop out.

Electrical terms

Objectives: At the end of this lesson you shall be able to
- **describe electrical charge, potential difference, voltage, current, resistance**
- **explain DC and AC circuit**
- **explain single phase and 3 phase A.C. system.**

Electric charge

Charge is the basic property of elementary particles of matter. Charge is taken as the basic electrical quantity to define other electrical quantities such as voltage, current etc.

According to modern atomic theory, the nucleus of an atom has positive charge because of protons. Generally, when the word charge is used in electricity, it means excess or deficiency of electrons.

Charges may be stationary or in motion. Stationary charges are called static charge. The analysis of static charges and their forces is called electrostatics.

Example: If a hard rubber pen or a comb is rubbed on a sheet of paper, the rubber will attract paper pieces. The work of rubbing, resulted in separating electrons and protons to produce a charge of excess electrons on the surface of the rubber and a charge of excess protons on the paper. The paper and rubber give evidence of a static electric charge having electrons or protons in a static state i.e. not in motion or stationary charges.

The motion of charged particles in any medium is called current. The net transfer of charge per unit time is called current measured in ampere.

The symbol for electric charge is Q or q. A charge of 6.25 x 10^{18} electrons is stated as Q = 1 Coulomb = 1C. This unit is named after Charles A. Coulomb (1736-1806), a French physicist, who measured the force between charges.

Negative and positive polarities

Negative polarity has been assigned to the static charge produced on rubber, amber, and resinous materials in general. Positive polarity refers to the static charge produced on glass and other vitreous materials. On this basis, the electrons in all atoms are the basic particles of negative charge because their polarity is the same as the charge on rubber. Protons have positive charge because the polarity is the same as the charge on glass.

Positive charge is denoted by +Q (deficiency of electrons) and Negative charge is denoted by -Q (excess of electrons). A neutral condition is considered zero charge.

Opposite polarity/charges attract each other

If two small charged bodies of light weight are mounted so that they are free to move easily and are placed close to each other, they get attracted to each other when the two charges have opposite polarity. In terms of electrons and protons, they tend to be attracted to each other by the force of attraction between opposite charges. Furthermore, the weight of an electron is only about 1/1840 of the weight of a proton. As a result, the force of attraction tends to make electrons move towards protons.

Same polarity/charges repel each other

When the two bodies have an equal amount of charge with the same polarity, they repel each other. The two negative charges repel, while two positive charges of the same value also repel each other.

Neutralising a charge

After glass and silk are rubbed together, they become charged with electricity. But, if the glass rod and silk are brought together again, the attraction of the positive charges in the rod pulls the electrons back out of the silk until both materials become electrically neutral.

A wire can also be connected between the charged bodies for discharging. If the charges on both materials are strong enough, they could discharge through an arc, like the lightning.

Electrostatic fields

The attracting and repelling forces on charged materials occur because of the electrostatic lines of force that exist around the charged materials.

In a negatively charged object, the lines of force of the excess electrons add to produce an electrostatic field that has lines of force coming into the object from all directions.

In a positively charged object, the lack of electrons causes the lines of force on the excess protons to add to produce an electrostatic field that has lines of force going out of the object in all directions.

These electrostatic fields either aid or oppose each other.

The strength of attraction or repulsion force depends on two factors,

1) the amount of charge on each object, and
2) the distance between the objects.

The greater the amount electric charges on the objects, the greater will be the electrostatic force. The closer the charged objects are to each other, the greater the electrostatic force.

Static electric charge cannot usually perform any useful function. In order to use electrical charges to do some kind of work, say, to light up an electric bulb, the charges must be set in motion. Thus electric current is said to flow when negative charges/free electrons are moved in the same direction in a medium, for example a copper wire.

Electron movement

In order to produce an electric current, the free electrons in a copper wire must be made to move in the same direction. This can be done by putting electrical charges at the ends of the copper wire more precisely, a negative charge at one end and a positive charge at the other end of a copper wire.

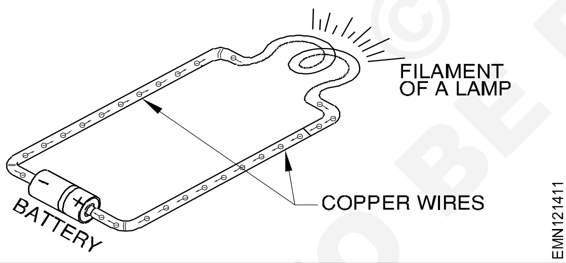
Since the free electrons in copper are negatively charged, they are repelled by the negative charge put at one end of the wire. At the same time these free electrons are attracted by the positive charge, put at the other end of the wire. Hence the free electrons in copper drift towards the positive charge, causing a flow of electric current.

A complete or closed circuit

In order to have continuous electric current, the free electrons must continue to flow. For this to happen, an electrical energy source must be used, to keep applying opposite charges at the ends of the wire. Then, the negative charge would repel the electrons through the wire. At the positive side, electrons would be attracted into the source; but for each electron attracted into the source, an electron would be supplied by the negative side into the wire. Current would, therefore, continue to flow through the wire as long as the energy source continues to apply its electrical charges. This is called a **closed circuit**. Battery is a typical source of electrical charges.

A complete or closed circuit as shown in Fig 1 is needed for current to flow.

Fig 1



Electrical Units of Measurements

Electromotive force (voltage)

The electromotive force (EMF) is a measure of the strength of a source of electrical energy. EMF is not a force in the usual mechanical sense,but it is a convenient term used for the energy which drives current through an electrical circuit.

When two charges have a difference in potential, the electric force that exists between them can be called the electromotive force (EMF). The unit of measure used to indicate the strength of emf is **volt (V)**.

Definition of Volt

When a difference of potential causes 1 coulomb of charge to do 1 joule of work, the emf is 1 volt.

The terms **potential, electromotive force (emf)**, and **voltage** are often interchangeably used.

Quantity of current

The quantity of current flowing through a wire or a circuit is determined by the number of electrons that pass a given point in one second. The unit of measure for the amount of current flowing through a wire or a circuit is **ampere** (A).

Definition of ampere

If 1 coulomb of charge passes a point in 1 second, then a current of 1 ampere is said to be flowing.

NOTE: One coulomb is 6.28×10^{18} electrons.

The term ampere came from the name of a scientist A. M. Ampere(18^{th} century). A quantity of current smaller than one ampere is measured in milliampere and micro-ampere.

1 Milliampere = $\frac{1}{1000}$ of an ampere.

1 Microampere = $\frac{1}{1000000}$ of an ampere.

Types of electricity

Irrespective of how the electricity is generated or produced, electricity can be classified into two types,

1 Alternating current supply, generally known as **AC supply**

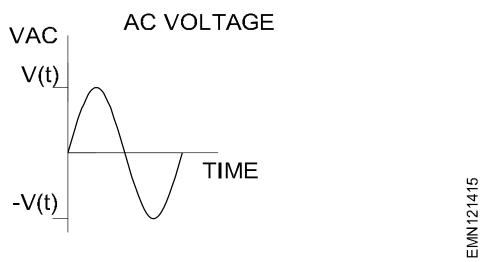
2 Direct current supply, generally known as **DC supply**.

AC supply

The term alternating current supply is given to a supply source that makes current to flow through a circuit which reverses or alternates its direction periodically. The number of times that the current alternates in a period of one second is called the **frequency** of alternation. The unit of frequency is **Hertz** denoted as Hz. In India the frequency is standardised as 50 Hz.

In India the electricity generated in hydro/thermal/nuclear power stations is AC. Fig 2 shows AC supply.

Fig 2



DC supply

The term direct current supply is given to a supply source that makes current to flow through a circuit in one direction only.

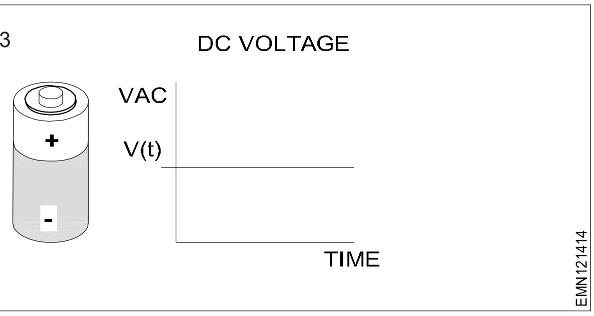
Batteries give DC supply of constant voltage.

Electric potential difference: The electrical potential difference is defined as the amount of work done to carrying a unit charge from one point to another in an electric field of the two charged bodies. In otherwords, the potential difference is defined as the difference in the electric potential.

Unit : The unit of potential difference is **volt.**

Resistance : The opposition by a substance to the flow electric current through it is called resistance. Fig 3 shows DC supply.

Fig 3



A.C. Circuits

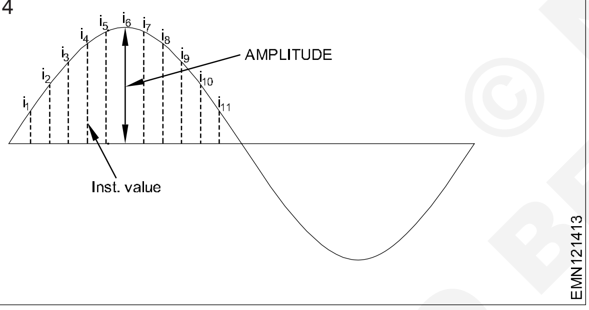
Cycle: A complete change in value and direction of alternating quantity is called cycle.

Period: Time taken to complete one cycle is called period.

Amplitude: It is the highest value attained by the current of voltage in a half cycle.

Instantaneous value: Value at any instant is called instantaneous value. Fig 4 shows this value by i_1, i_2....

Fig 4



Frequency: It is defined as the number of cycles per second. In India 50 c/s frequency is common.

Frequency = $\frac{NF}{120}$ where N is the speed in r.p.m and P is no.of poles of a machine.

R.M.S. Value: Root mean square value of an alternating current is given by that steady d.c. current which produces the same heat as that produced by the alternating current in a given time and given resistance. It is also called the virtual or effective value of A.C.

$$I_{r.m.s.} = 0.707\, I_{max}$$

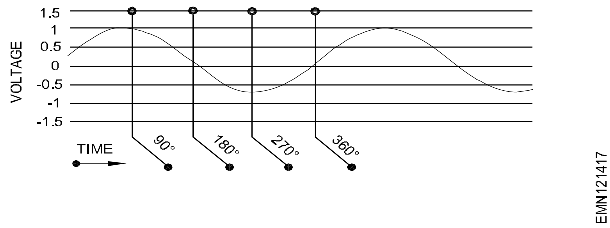
$$V_{r.m.s} = 0.707\, V_{max}$$

All A.C. voltmeters and ampere meters read r.m.s. value of voltage and current.

Peak value: The maximum of the values of quantity during a given interval.

In a single phase AC power system the voltage peaks at 90° and 270° with a complete cycle at 360°. (Fig 5)

Fig 5



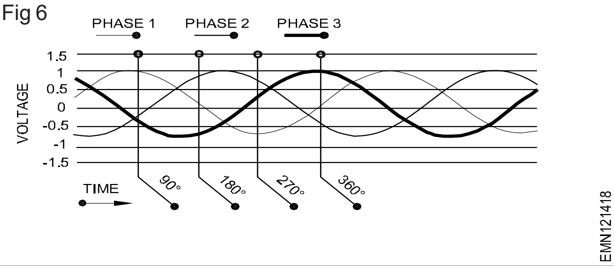
Benefits and uses of a single phase AC power supply

Single phase power supply units have a broad array of applications. Units that have a limited power need up to 1000 watts typically make the most efficient use of a single phase AC power supply. Generally, benefits of selecting a single phase system include:

- Broad array of application uses
- Most efficient AC power supply for up to 1000 watts
- Fewer design costs
- Less complex design

In a 3 phase system there are three power wires, each 120° out of phase with each other. Delta and wye are the two types of circuits use to maintain equal load across a three phase system, each resulting in different wire configurations. In the delta configuration, no neutral wire is used. The wye configuration uses both a neutral and a ground wire. (Note: In high voltage system, the neutral wire is not usually present for a three phase system.) All three phases of power have entered the cycle by 120°. By the time a complete cycle of 360° has completed, three phases of power each peaked in voltage twice as shown in Fig 6. With a three phase power supply, a steady stream of power is delivered at a constant rate, making it possible to carry more load.

Fig 6



Benefits and uses of a three phase AC power supply

Three phase power supplies offer a superior carrying capacity for higher load systems. Some of the benefits include:

Reduction of copper consumption

Fewer safety risks for workers

Lower labour handling costs

Greater conductor efficiency

Ability to run higher power loads

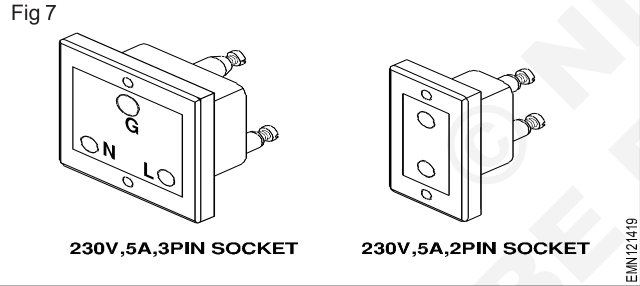
Additionally, three phase systems in delta configuration with a 208 volt load requires less circuit breaker pole positions than that of a wye configuration. In these cases, a three phases system yields further savings in installation, maintenance, and cost of production materials due to the reduction of required wires. However, in most cases, the wye configuration is preferable. When is more flexible so that it can power devices that require 3 phase, 2 phase, or 1 phase power. For example, a data centre's warehouse of servers may only require three phase power, however the technician monitory the series will likely need single phase power to operate his/her computer, tools and lights.

Line voltage and phase voltage: Line voltage is the voltage measured between any two lines in a three-phase circuit. Phase voltage is the voltage measured across a single component in a three-phase source or load.

Line current and Phase current: Line current is the current through any one line between a three- phase source and load. Phase current is the current through any one component comprising a three phase source or load. In balanced "Y" circuits, line voltage is equal to phase voltage times the square root of 3, while line current is equal to phase current.

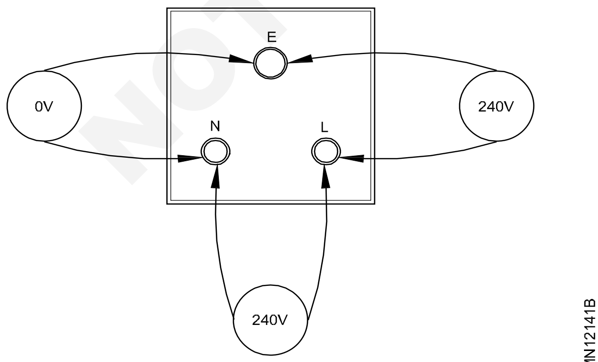
This 230 volts is used to light up the lamps, fans etc., in homes. To connect electrical appliances at home, 230 V AC is available in either two-pin or three-pin sockets as shown in Fig 7.

Fig 7



All the 3 pin outlets are generally connected through a single pole ON/OFF switch-as shown in Fig 8. While wiring a 3 pin socket, the following two important points are to be noted,

Fig 8



1 Phase should always be to the RIGHT side of the socket

2 Phase should always be wired through the ON/OFF switch.

Any defect either in mains supply or in the wiring of the socket or in the equipment connected to any other 3 pin sockets in the same building may result in different voltages.

Testing a 3 pin socker outlet: On wiring of a new 15 pin socket or if the equipment connected to an existing 3 pin socket is not working or giving a shock, it is necessary to test the socket for voltage across the phase, neutral and ground.

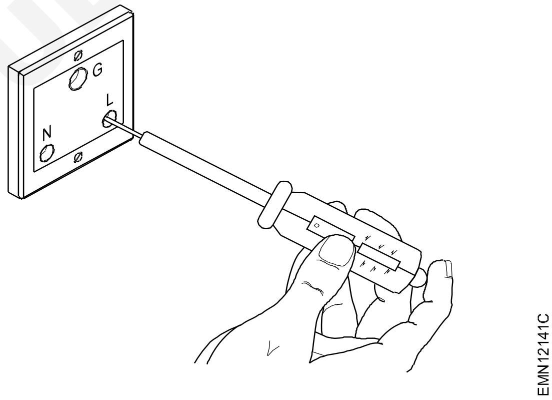
Testing a mains outlet can be done using any one or more of the following test instruments;

1 Neon tester

A neon tester or neon test lamp is an inexpensive device usually in the form of insulated shank screw driver used to indicate presence of voltage.

When a neon tester is placed at the phase point of a 3 pin socket and the other end of the tester is touched by the finger as shown in Fig 9, if voltage exists at the phase point of the socket, the neon lamp inside the tester glows indicating presence of voltage.

Fig 12



In a correct outlet the lamp should not glow when the neutral and ground points are tested.

2 Test lamp

It is an inexpensive test circuit consisting of an incandescent lamp with two lengthy wires connected across the terminals of the lamp. When the two free ends of the lamp are connected across phase-neutral points of a socket, if voltage exists across the points the lamp glows indicating presence of voltage.

3 AC voltmeter/multimeter

Using a voltmeter or a multimeter put to AC 300V range, the voltage across all the 3 terminals of the socket as in Fig 11 is measured to confirm existence of voltage and their correct levels across the outlet points.

Conditions for certifying a 3 pin socket as GOOD or SAFE

1 Voltage across phase-neutral should be equal to mains supply of 230/240 volts. Due to voltage fluctuations, phase-neutral voltage can sometimes be as low as 210 and as high as 250 V these voltage levels can also be accepted as "tolerable".

2 Voltage across phase - ground should be equal to mains supply of 230/240 V. This indicates that the ground wire to the socket and the local grounding is proper.

3 Voltage across NEUTRAL-GROUND should be zero volts or in the worst case less than 10V. This indicates that the neutral line is safe and there is no excessive leakage in the equipment(s) connected to other 3 pin sockets in the same building.

If the voltage across neutral-ground is higher than 10 volts or very high (of the order of hundreds of volts) the socket is not safe for use, especially when you want to power ON sensitive and delicate equipments/instruments like computers, CRO etc.

Conductor and Insulator

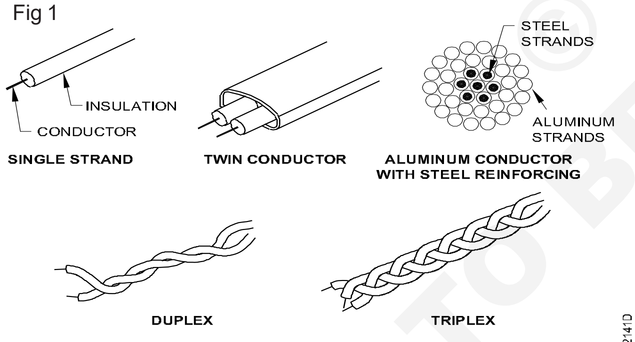
Objectives: At the end of this lesson you shall be able to
- **define conductor and insulator**
- **explain electrical cables**
- **explain the properties of insulating materials.**

Conductors: Materials that contain many free electrons and are capable of carrying an electric current are known as conductors.

Silver, copper, aluminium and most other metals are good conductors.

Wires and cables are the most common forms of conductors. They carry electric current through all kinds of circuits and systems. Wires and cables are made in a wide variety of forms suited to many different applications. (Fig 1)

Fig 1



VARIOUS FORMS OF CONDUCTOR

Conductors form an unbroken line carrying electricity from the generating plant to the point where it is used. Conductors are usually made of copper and aluminium.

A conductor is a wire or cable or other form of metal, suitable for carrying current.

All wires are conductors, but all conductors are not wires. For example copper bus bar are conductors but not wires. They are rigid rectangular bars.

Current passing through a conductor generates heat. The amount of heat depends on the value of current and the potential difference between its ends.

The rate of heat production in the conductor equals the amount of power lost by the electricity in passing through the conductor.

The cross-sectional area of the conductor must have a large enough area to give it a low resistance. But the cross-sectional area must also be small enough to keep the cost and weight as low as possible.

The best cross-sectional area depends on how much current the conductor must carry.

The rate of heat production in a conductor increases with the square of the current. As heat is produced the conductor gets hotter and the temperature rises until the rate at which the conductor releases heat to the surroundings equals the rate at which the heat is produced. The temperature of the conductor then remains steady. This steady temperature is called equilibrium temperature.

There is a limit to the temperature each kind of insulation can safely withstand. There is also a limit to the temperature the surroundings can withstand.

I.E. regulations specify the maximum current considered safe for conductors of different sizes, having different insulation and installed in different surroundings.

Size of conductors: The size is specified by the diameter or the cross-sectional area. Typical sizes are 1.5 sq mm, 2.5 sq mm, 6 sq mm etc.

A common measure of wire diameter is the standard wire gauge (SWG), commonly used in our country. The resistance of a material increases as the length of the conductor increases, and the resistance decreases as the cross-sectional area of the conductor increases. We can compare one material with another by measuring the resistance of samples.

Classification of Conductors: Wires and cables can be classified by the type of covering they have.

Bare conductors: They have no covering. The most common use of bare conductor is in overhead electrical transmission and distribution lines.

Insulated conductors: They have a coating of insulation over the metals. The insulation separates the conductor electrically from other conductors and from the surroundings. It allows conductors to be grouped without danger. Additional covering over the insulation adds mechanical strength and protection against weather, moisture and abrasion.

Stranded conductors: They consist of many strands of fine wires. The wires in stranded conductors are usually twisted together. Stranded conductors are more flexible and have better mechanical strength.

Cable: A length of insulated conductor. It may also be of two or more conductors inside a single covering. The conductors in a cable may either be insulated or bare. Cables are available in different types. There are single core, twin core, three core, four core and multi-core cables.

Properties of insulation materials: Two fundamental properties of insulation materials are insulation resistance and dielectric strength. They are entirely different from each other and measured in different ways.

Insulation resistance

It is the electrical resistance of the insulation against the flow of current. Mega-ohmmeter(Megger) is the instrument used to measure insulation resistance. It measures high resistance values in mega ohms without causing damage to the insulation. The measurement serves as a guide to evaluate the condition of the insulation.

Dielectric strength: It is the measure of how much potential difference the insulation layer can withstand without breaking down. The potential difference that causes breakdown is called the breakdown voltage of the insulation.

Every electrical device is protected by some kind of insulation. The desirable characteristics of insulation are:

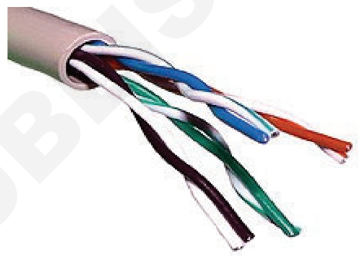
– high dielectric strength
– resistance to temperature
– flexibility
– mechanical strength
– Non hydroscopic.

No single material has all the characteristics required for every application. Therefore, many kinds of insulating materials have been developed.

Semiconductors: A semiconductor is a material that has some of the characteristics of both the conductor and an insulator. Semiconductors have valence shells containing four electrons.

Common examples of pure semiconductor materials are silicon and germanium. Specially treated semiconductors are used to produce modern electronic components such as diodes, transistors and integrated circuit chips.

Fig 2



Twisted pair cable

A comparison of the most commonly used metals as conductors in wires is given below:

PROPERTIES	TYPES OF METALS USED AS CONDUCTORS			
	Silver	**Copper**	**Gold**	**Aluminium**
Ability to be drawn into thin wires	Very good	Very good	Very good	Not goo
Flexibility (ability to bend without breaking).	Very good	Good	Very good	Not good
Conductivity (100%)	Very good (94%)	Very good (67%)	Good (56%)	Good
Resistivity in W m at 20°C	$1.6x10^{-8}$	$1.7x10^{-8}$	$2.4x10^{-8}$	$2.85x10^{-8}$
Ability to withstand	Good	Good	Very good	
Cost	Expensive	Cheap expensive	Very cheap	Very

Conductors used in common types of wires are always drawn to thin circular forms (bare wires). A few reasons why the wires are drawn in circular form are given below.

1 Drawing a conductor in the circular shape is cheaper and easier than drawing in any other form.

2 Round shape of the conductor ensures uniform current flow through the conductor.

3 Uniform diameter of wire can be maintained.

4 Insulation can be uniformly covered.

Conductor(s) of wires are covered with insulating material or an insulating coating(enamel). Some of the reasons for covering the conductor of wires with an insulator are given below:

TYPES OF INSULATORS

PROPERTIES	Polyvinyl chloride (PVC)	Vulcanised insulated rubber(VIR)	Teflon
Ability to withstand physical strain	Good (Hard & rough)	Good (Hard & rough)	Good (Hard & rough)
Ability to withstand action of acids	Good	Good	Good
Ability to withstand atmospheric variations	Good	Good	Good
Flexibility	Very good	Not good	Bad
Ease of skinning	Easy	Difficult	Difficult
Ability to withstand high temperature (heat)	Not good	Good	Very good
Cost	Cheap	Expensive	Very expensive

CURRENT CARRYING CAPACITY OF WIRES

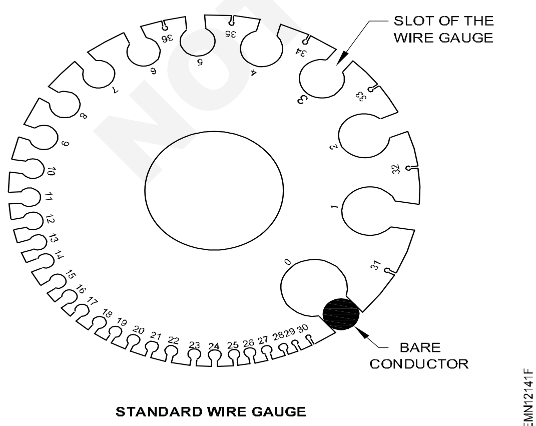
A wire is used to carry electric current. The amount of current that can flow through a wire depends on, how good is the conductivity of the conductor used (silver,copper,aluminium etc) physical dimension (diameter) of the conductor(s).

Larger the diameter of the conductor, higher is the current that can flow through it.

The maximum current that flows through a wire of a particular diameter without heating up the wire is called the maximum current carrying capacity or generally the **current carrying capacity** of a wire. Hence the current carrying capacity of a wire is directly proportional to the conductor's diameter.

STANDARD WIRE GAUGE: Size of a wire means the diameter of the conductor used in that wire. To measure the size of a wire, an instrument called **standard wire gauge (SWG)** is used as shown in Fig 3.

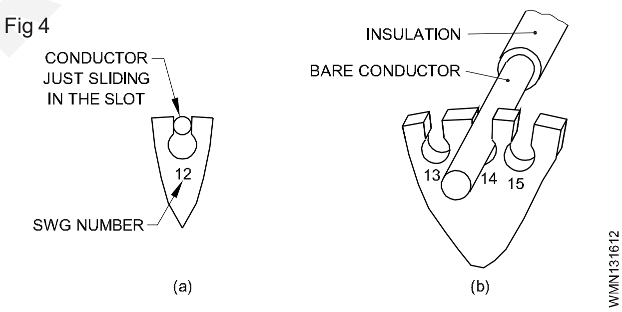
Fig 3



Standard wire gauge is a circular metal disk with varying slot sizes on its circumference. Each slot size corresponds to a gauge number which is written just below the hole. The gauge numbers specify the size of a round wire in terms of its diameter and cross-sectional area. The following points are to be noted while using/reading Standard Wire Gauge:

- As the gauge numbers increase from 0 to 36, the diameter and circular area decrease. Higher gauge numbers indicate thinner wire sizes.
- The circular area doubles for every three gauge sizes.

Fig 4



For example, No. 10 SWG has approximately twice the area of No. 13 SWG. (Fig 4)

Measurement of wire size by Outside micrometers

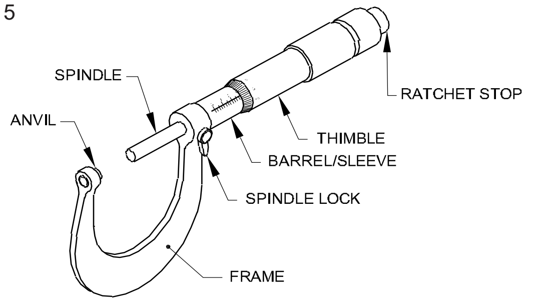
A micrometer is a precision instrument used to measure a job, generally within an accuracy of 0.01 mm.

Micrometers used to take the outside measurements are known as outside micrometers. (Fig 5)

Principle of the micrometer

The micrometer works on the principle of screw and nut. The longitudinal movement of the spindle during one rotation is equal to the pitch of the screw. The movement of the spindle to the distance of the pitch or its fractions can be accurately measured on the barrel and thimble.

Fig 5



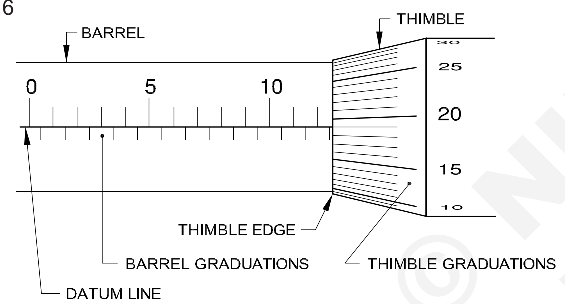
Graduations

In metric micrometers the pitch of the spindle thread is 0.5mm.

Thereby, in one rotation of the thimble, the spindle advances by 0.5 mm.

In a 0-25 mm outside micrometer, on the barrel a 25 mm long datum line is marked. (Fig 6) This line is further graduated in millimetres and half millimetres (ie. 1 mm & 0.5 mm). The graduations are numbered as 0, 5, 10, 15, 20 & 25 mm on the barrel.

Fig 6



The circumference of the bevel edge of the thimble is graduated into 50 divisions and marked 0-5-10-15... 45-50 in a clockwise direction.

The distance moved by the spindle during one rotation of the thimble is 0.5 mm.

Movement of one division of the thimble

= 0.5 x 1/50 = 0.01 mm.

This value is called the least count of the micrometer.

The accuracy or least count of a metric outside micrometer is 0.01 mm.

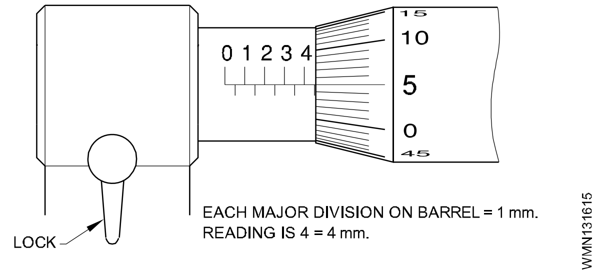
Outside micrometers are available in ranges of 0 to 25 mm, 25 to 50 mm, and so on. For electrician, to read the size of the wire 0 to 25 mm is only suitable.

Reading micrometer measurements

How to read a measurement with an outside micrometer?

a Read on the barrel scale, the number of whole millimetres that are completely visible from the bevel edge of the thimble. It reads 4 mm. (Fig 7)

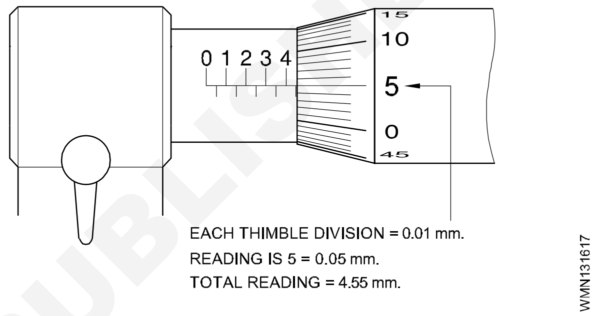
Fig 7



b Add to this any half millimetre that is completely visible from the bevel edge of the thimble and away from the whole millimetre reading.

The figure reads one division (Fig 8) mm after the 4 mm mark. Hence 0.5 mm to be added to the previous reading.

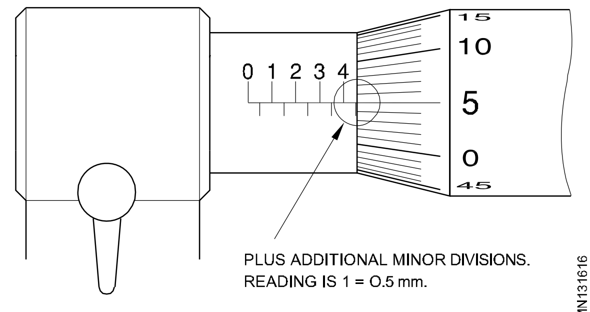
Fig 8



c Add the thimble reading to the two earlier readings.

The figure shows the 5th division of the thimble is coinciding with the datum line of the barrel. Therefore, the reading of the thimble is 5 x 0.01 mm = 0.05 mm. (Fig 9)

Fig 9



The total reading of the micrometer.

a 4.00 mm

b 0.50 mm

c 0.05 mm.

Total reading = 4.55 mm (Fig 9)

Measuring Instrument Meters

Objectives: At the end of this lesson you shall be able to
- **state the use of meters**
- **list the basic parts of a simple meter**
- **list the minimum specifications of any meter**
- **list the symbols used on meter dial and interpret their meaning.**

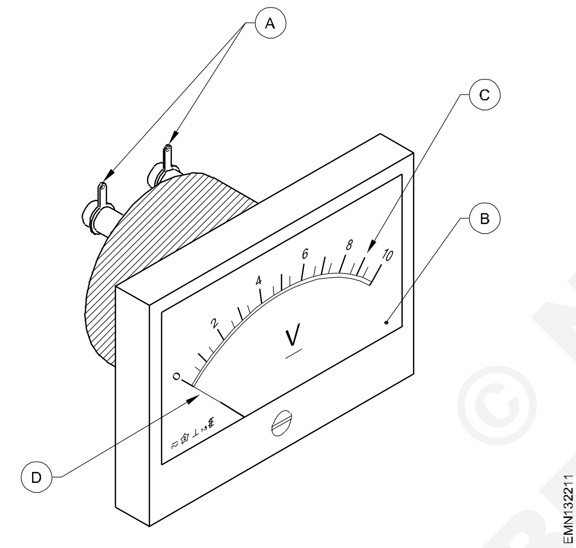
Meters

Meters are instruments used to measure electrical quantities like voltage, current, resistance etc.,

Measurement of electrical quantities is necessary while installing, operating, testing & repairing electrical & electronic equipments and circuits.

A simple meter is shown in Fig 1.

Fig 1



The electrical quantity to be measured is given to the input terminals (A) of the meter. The internal meter movement or mechanism moves the pointer(D) over the graduated scale(C) marked on a plate called the dial plate(B). The pointer stops at a point on the scale which corresponds to the magnitude of the input given at the input terminals(A).

Any simple meter must have the following minimum specifications.

[1] The electrical parameter it can measure.

Example: DC voltage, AC voltage, DC current, AC current, resistance and so on.

[2] The maximum quantity that it can measure.

Example: 10 volts, 100 volts, 1 ampere and so on.

The simple meter shown in Fig 1 can measure DC voltage. This can be found out from the symbol V̲ marked on dial plate of the meter. All meters will have such symbols by which the user can identify the electrical parameter that the meter can measure. The different symbols used and their meanings are shown in Charts 1 at the end of this lesson.

Example 1: *A symbol V on a meter dial indicates,*

V for measuring voltage

~ for measuring AC.

This means, a meter with V symbol is for measuring AC voltage.

Example 2: *A symbol V on the meter dial indicates,*

V for measuring voltage

~ for measuring AC

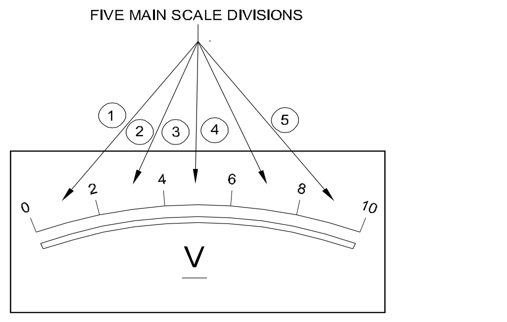
_ for measuring DC.

This means, a meter with V symbol is for measuring AC and DC voltages.

The meter scale as shown in Fig 2, is graduated/marked from 0 to 10. This means that this meter can measure up to a maximum of 10 volts. This is referred to as the maximum measurable value in that meter.

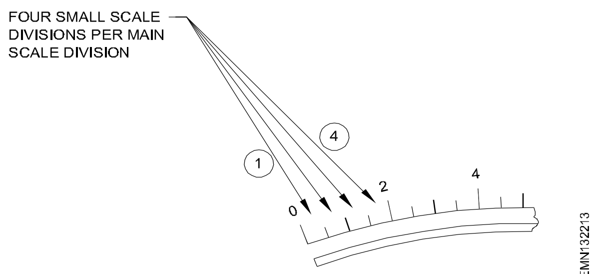
The meter scale of 0 to 10 is divided to 5 parts in steps of 2 volts as shown in Fig 2. Each division is called the Main Scale Division (MSD) of the meter scale.

Fig 2



Each main scale division in Fig 3 corresponds to 2 volts. Further each main scale division (say 0 to 2) is further divided into 4 more divisions as shown in Fig 3. These divisions are called Small Scale Divisions (SSD).

Fig 3



Main scale division

- Each Main Scale Division (MSD) is equal to,

$$\frac{\text{Full Scale Deflection}}{\text{Number of Main Scale Division}} = \frac{10}{5} \quad 2 \text{ Volts}$$

- Each main scale division corresponds to 2 volts. Further each main scale division (say 0 to 2) is further divided into 4 more divisions. These divisions are called Small Scale Divisions (SSD).
- Each Small Scale Division (SSD) therefore corresponds to,

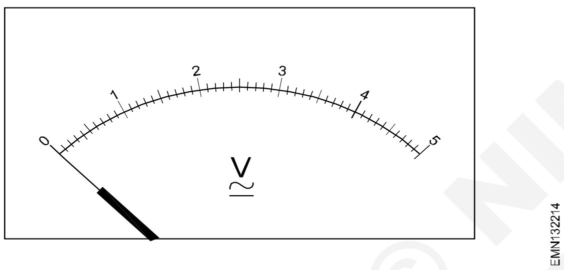
Each small scale division therefore corresponds to,

$$\frac{\text{Value of one Main Scale Division}}{\text{Number of Small Scale Division per Main Scale Division}} =$$

Hence the smallest voltage that can be accurately measured using this meter is 0.5 volts. This is nothing but the value of one small scale division of the meter.

Example: To find the maximum and minimum values that can be measured using a meter having a graduated scale as shown in Fig 4.

Fig 4



Maximum quantity the meter shown in Fig 4 can measure is equal to the full scale deflection value or the highest numeric on the right edge of the of scale = 5 volts.

Minimum quantity the meter can measure is equal to value of one small scale division

$$= \frac{\text{value of one main scale}}{\text{No. of small scale div/main div}}$$

$$\frac{1 \text{ Volt}}{10 \text{ div}} = 0.1 \text{ volts.}$$

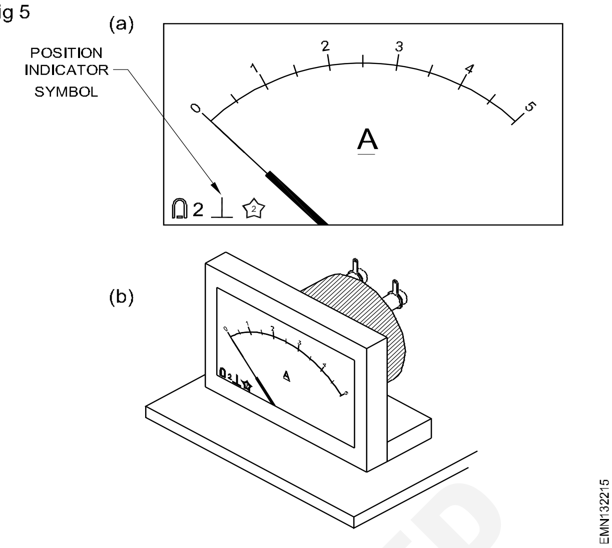
The minimum values that can be measured using the meter in Fig 4 is 0.1 volts and the maximum values that can be measured is 5 volts.

On the dial scale of any meter, in addition to the symbols indicating the electrical parameter (voltage, current etc) it can measure and the type of parameter (AC, DC, AC/DC), there are several other symbols. One of the important symbols to be identified before using the meter is the position symbol.

Fig 5(a) indicates a typical position symbol on the dial plate of a meter.

'⊥' symbol on the dial plate indicates that, the meter has to be positioned vertically (at right angle to the Table) as shown in Fig 5(b). If this meter is placed horizontally while taking measurement then, the readings shown by the meter will not be accurate.

Fig 5



Other symbols indicating the position in which a meter is to be kept while taking readings is given in the Chart 1 of this lesson.

[H.I Use Chart 1 and elaborate the meaning of the symbols in the classroom.]

One of the most common errors in meters is the Mechanical Zero error. This error is caused due to the mechanical movements involved in the meters. This error in meters is correctable. The steps involved to correct this error is called Mechanical zero setting of meters.

All meters will have a screw on it as shown in Fig 5. Keeping the terminals of the meter open, the screw is turned slowly to bring the pointer exactly to 0 position on the meter scale. This means, with no voltage applied, the meter is made to show exactly zero volts.

Care has to be taken while turning this screw as this screw is directly connected with the sensitive and delicate meter movement. Turning the screw in large amounts or in jerks may damage the meter movement permanently making the meter unusable.

Before using a meter for measurements, it is necessary to check if the meter needle is moving freely over the graduated scale. There are possibilities that the meter movement may be sticky due to dust collection on the meter movement or due to the bent pointer needle.

A simple way to check sticky pointer/meter movement is to hold the meter in hand and tilt the meter back and forth gently, checking for the free movement of the pointer. If the pointer is not moving freely, it is advised not to use that meter for making measurements.

Types of measuring Instruments

- Following are the most commonly used electronic instruments.

  i Ammeter

  ii Voltmeter

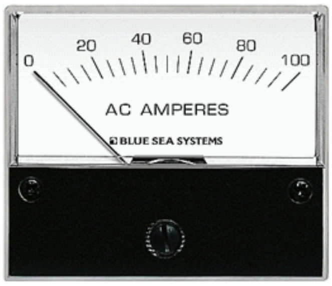
  iii Ohmmeter

  iv Multi-meter

  v Clamp Meter

i Ammeter

- Ammeter is an electronic instruments device used to determine the electric current flowing through a circuit. Ammeters measuring current in milli-ampere range is known as milli-ammeters.
- Ammeters are connected in series to the circuit whose current is to be measured. Hence this electronic instruments are designed to have as Very Low resistance/ loading as possible.



- There are two types of ammeters: DC ammeter, and AC ammeter.
- DC ammeter measures the DC current that flows through any two points of an electric circuit. Whereas, AC ammeter measures the AC current that flows through any two points of an electric circuit.

ii Voltmeter

- Voltmeter is an electronic instruments used in an electric circuit to determine the potential difference or voltage between two different points.
- Voltmeters are usually connected in parallel (shunt) to the circuit. Hence they are designed to have High resistance as possible to reduce the loading effect.
- There are two types of voltmeters: DC voltmeter, and AC voltmeter i.e RMS value of Voltage.

- DC voltmeter measures the DC voltage across any two points of an electric circuit, whereas AC voltmeter measures the AC voltage across any two points of an electric circuit.

iii Ohmmeter

- Ohmmeter is used to measure the value of Resistance between any two points of an electric circuit. It can also be used for finding the value of an unknown resistor.
- There are two types of ohmmeters: series ohmmeter, and shunt ohmmeter.
- In series type ohmmeter, the resistor whose value is unknown and to be measured should be connected inseries with the ohmmeter. It is useful for measuring high values of resistances.
- In shunt type ohmmeter, the resistor whose value is unknown and to be measured should be connected in parallel (shunt) with the ohmmeter. It is useful for measuring low values of resistances.

iv Multimeter

- Multi-meter is an electronic instrument used to measure the quantities such as voltage, current & resistance one at a time.
- This Multi-meter is also Known as Volt-Ohm-Milliammeter (VOM).
- It can be used to measure DC & AC voltages, DC & AC currents and resistances of several ranges.
- A practical multi-meter is shown in the figure, which can be used to measure various high resistances, low resistances, DC voltages, AC voltages, DC currents, & AC currents. Different scales and range of values for each of these quantities are marked in the figure.

v Clamp meter

- A clamp meter is an electrical test tool that combines a basic digital multi-meter with a current sensor. It is also called a Tong Tester.
- Clamps measure current. Probes measure voltage. Having a hinged jaw integrated into an electrical meter allows technicians to clamp the jaws around a wire,

cable or other conductor at any point in an electrical system, then measure current in that circuit without disconnecting/de-energizing it.

- Beneath their plastic mouldings, hard jaws consist of ferrite iron and are engineered to detect, concentrate and measure the magnetic field being generated by current as it flows through a conductor.

Indicating the reading of AC/DC

Symbol	Meaning of the symbol	Symbol	Meaning of the symbol
⎓	DC voltage or Current	∿	AC voltage or current
—	DC voltage or Current	$\overline{\sim}$	AC/DC voltage or current

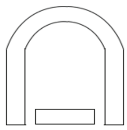
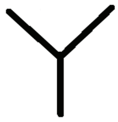
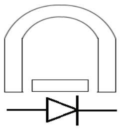
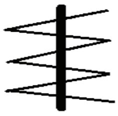
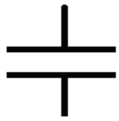
- The following symbols indicate type of meter:

Indicates type of meter

Symbol	Meaning of the symbol	Symbol	Meaning of the symbol
V	Voltmeter	A	Ammeter
mV	Milli - Voltmeter	mA	Milli - Ammeter
µV	Micro - Voltmeter	µA	Micro - Ammeter
Ω	Ohmmeter	OHMS	Ohmmeter

- The following symbols indicate the type of mechanism/ Principle of the meter pointer movement associated with the meter:

Type of mechanism/principle of the meter pointer movement

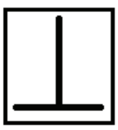
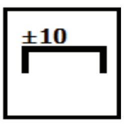
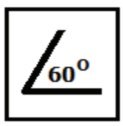
Symbol	Meaning of the symbol	Symbol	Meaning of the symbol
	Moving coil with permanent magnet		Hot wire
	Moving coil with rectifier		Bimetallic
	Moving iron		Electro static

- The following symbols indicate percentage error in the indicated meter reading:

Percentage of Error

Symbol	Meaning of the symbol	Symbol	Meaning of the symbol
	± 1% Error expressed as a percentage of the end value of measuring range		±1.5 % Error expressed as a percentage of the end value of measuring range
	±2.5% Error expressed as a percentage of the end value of measuring range		± 1.5 % Error expressed as a percentage of the true value

- The following symbols indicate the placement position of the meter:

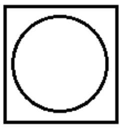
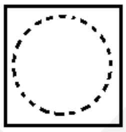
	Placement position of the meter		
	Vertical position		Horizontal position
	Horizontal position with ± 10 error permissible		Inclind position

Indicates special instructions that go with the meter

Symbol	Meaning of the symbol	Symbol	Meaning of the symbol
	No test voltage		Test voltage 1 Kilo volts
	Test voltage 2Kilo volts		Test voltage 500 volts

- The following symbols indicate special instructions that go with the meter:

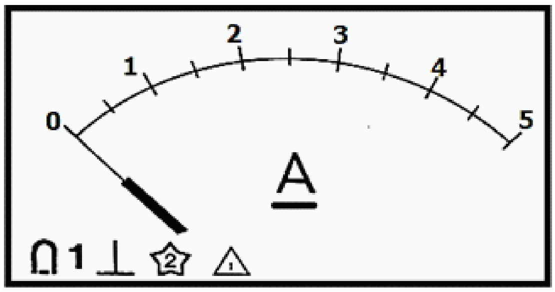
Indicates special instructions that go with meter

Symbol	Meaning of the symbol	Symbol	Meaning of the symbol
	Magnetic shield		Electrostatic shield
	Attention read instructions before use		

- The following symbols indicate special instructions that go with the meter:

Simple Example:

For a meter with dial plate markings as shown in figure, the following specifications can be identified:



- The nature and type of electrical parameter it can measure - DC Current, 0 - 5 Ampere.
- The position in which the meter is to be kept while using - Vertical Position.
- The type of mechanism used for the pointer movement - Moving Coil with Permanent Magnet.
- The percentage of error indicated in the meter reading - ±1% Error Expressed as a Percentage of the End Value of Measuring Range.
- The maximum test voltage that can be applied - Test Voltage 2 Kilovolts.
- The special instructions of the meter -Attention read instructions before use.
- The minimum and maximum quantity the meter can accurately measure - Minimum Quantity (SSD) - 0.5 A, Maximum Quantity (FSD) - 5 A.

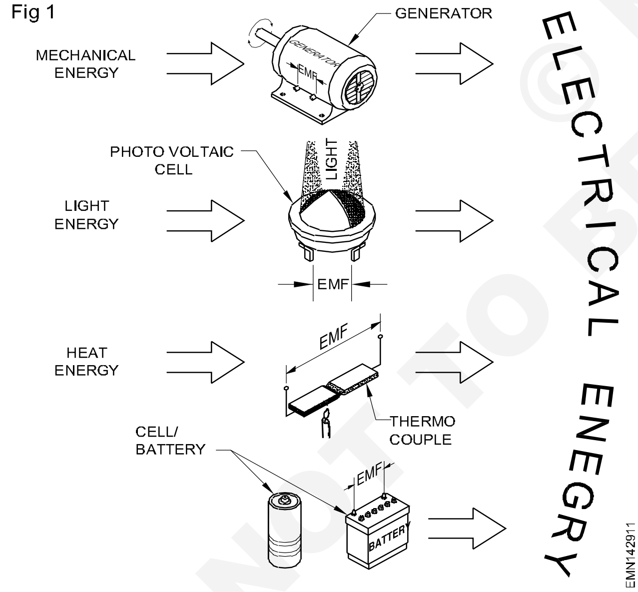
Cells and Batteries

Objectives : At the end of this lesson you shall be able to
- **state the power sources**
- **list the two main classifications of batteries**
- **state the dry and wet cells**
- **state the primary and secondary cells.**

POWER SOURCES

Devices that produce electricity are generally termed as Power sources. These power sources produce electricity by converting some form of energy into electrical energy. As shown in Fig 1, all power sources must first be supplied with external energy such as heat, light or mechanical energy before they can produce electricity with an exception in the case of cell/battery. Batteries are different from the other types of power sources because, energy is provided by chemical reaction in batteries. Therefore, no energy need be supplied from outside for the battery to produce electricity. Hence batteries are one of the most important power sources. In a battery, electrical energy is produced by the chemicals contained within the battery. Cells are the basic units of a battery. Several cells forms to make a battery. Batteries are classified mainly under two categories.

Fig 1



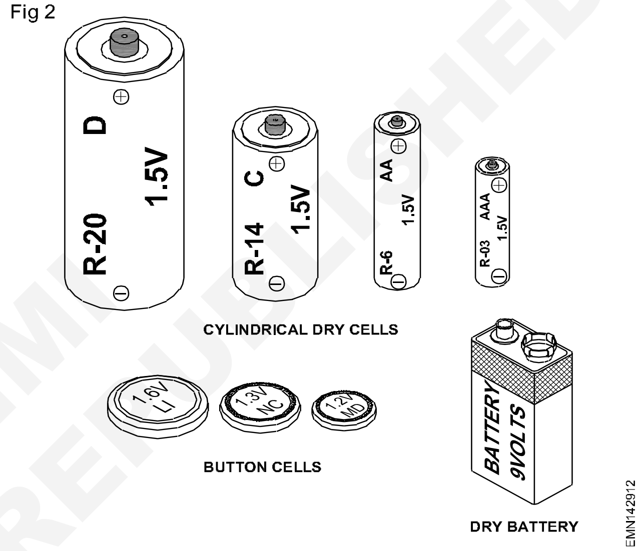
(a) Primary batteries

(b) Secondary batteries

Primary Batteries - Converts chemical energy into electrical energy. This uses the chemicals within it to start the action of energy conversion. The most common types of primary cells and batteries are shown in Fig 2.

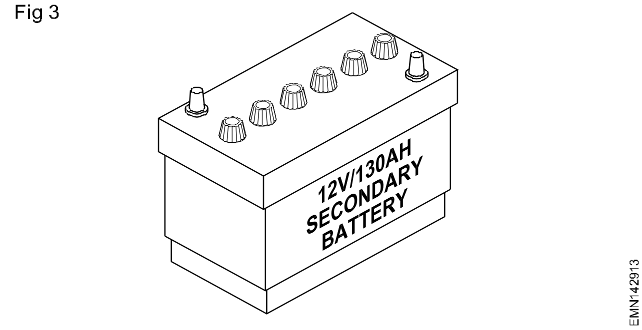
Secondary batteries - These batteries must be first charged with electrical energy. Once the battery is fully charged,it will then convert chemical energy to electrical energy. Secondary batteries first stores electrical energy supplied to it and then supply electrical energy as and when required. Hence secondary batteries are commonly called storage batteries.

Fig 2



A typical secondary storage battery is shown in Fig 3.

Fig 3



A battery may consist of two or more number of cells. The battery shown in Fig 3 has six cells of 2V each. These cells are connected in series to give 12V at battery terminals.

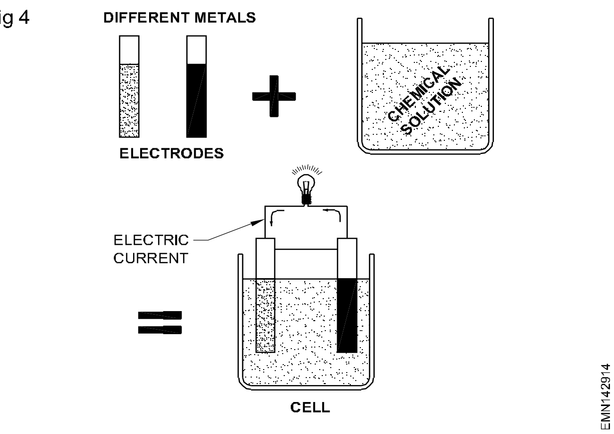
THE CELL

A cell consists of a pair of metal strips called **electrodes** and dipped in a chemical solution called **electrolyte** as shown in Fig 4.

Primary and Secondary cells

Primary cells are those which once fully used has to be thrown-out or destroyed. This is because the electrodes and electrolyte used in this type of cells cannot be reused. Hence, primary cells are non-rechargeable cells. Generally, the electrolyte used in primary cells is of paste form.

Fig 4



Secondary cells are those which once used can be reused by charging them. Hence, secondary cells are rechargeable cells. Generally, the electrolyte used in secondary cells is in liquid form. However, there are rechargeable cells with paste form electrolyte also.

In this lesson the commercial aspects of primary cells are discussed. Secondary cells are discussed in further lessons.

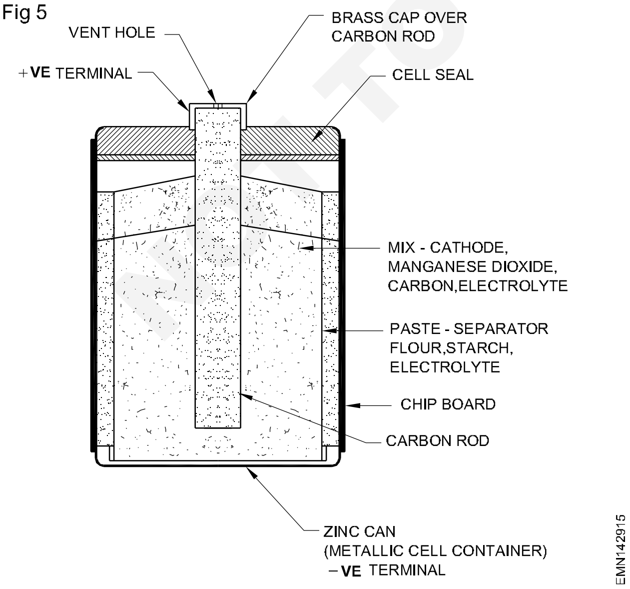
Dry and Wet cells

The electrolyte can be in liquid form or a paste form. Cells with paste form electrolyte are known as DRY cells. Cells with liquid form of electrolyte are called WET cells.

Dry cells and batteries

As the electrolyte used in dry cells is in paste form, it does not spill or leak. Hence, dry cells are used extensively in portable electrical and electronic gadgets. Typical constructional details of a zinc-carbon during cell is shown in Fig 5.

Fig 5



The two electrodes of dry cells are brought out and are available as +ve and -ve terminals of the cell. Usually the metallic cell container serves as the -ve of the cell as shown in Fig 5. The voltage that appears across the terminals depends upon the electrodes and the chemicals used in the cell. The voltage of a cell is so made as to suit the commercial requirement. Generally the voltage across the terminals of a dry cell range between 1.2 to 1.5 volts.

Dry cells and batteries are available in several shapes and sizes to suit commercial requirements. Some popular shapes of dry cells were shown in Fig 2.

Technically, any particular type of cell is defined by the materials used as electrodes and electrolytes in that cell. A dry cell with **zinc** as the -ve electrode, **carbon** as the +ve electrode with **zinc chloride** as the electrolyte is referred to as **zinc-carbon** cell or **zinc chloride** cell.

Similarly a dry cell which uses an alkaline solution as electrolyte is called an **Alkaline cells**.

A Chart on Types of cells/batteries given at the end of this lesson lists some popular dry cells along with the names of the materials used for the +ve, -ve electrodes, the electrolyte used, the available sizes, the rated output voltage and their applications.

The use of different materials for their electrodes and electrolytes results in different voltage, current rating discharge characteristics and the shelf life (life of the battery if kept unused).

NOTE: Not all types of cells are suitable for all applications. This is because some appliances draw high initial current or current in pulses which may not suit the discharge characteristics of the cell.

Weak, dead cell

Dry cells are used in various gadgets like flash lights, tape recorders etc, the cells convert the chemical energy built into them into electrical energy. In doing so, the dry cell slowly gets consumed. This means, the voltage across the cell terminals decreases and the current it can supply to the connected load becomes less and less. A stage will reach when the dry cell is no more capable of supplying sufficient voltage/current through the connected load . Then the cell is said to have become **weak** or **dead**.

As a thumb rule, dry cell can be declared unfit for use if, the voltage across its terminals is less than 75% of its rated output voltage.

Example: A used zinc chloride dry cell with a rated voltage of 1.5 volts has 1.1 volts across its terminals. Find whether the cell is usable or not.

Rated o/p voltage of the cell is 1.5V.

Measured output of the cell is 1.1V.

% Measured output with respect to rated output is

TYPES OF CELLS AND THEIR APPLICATIONS

Usual Name/Types	Classification	Negative Electrode (Anode)	Positive Electrode (Cathode)	Electrolyte	Rated output voltage	Available sizes	Applications
Carbon-Zinc (usually called Leclanche cell)	Primary	Zinc	MnO_2/C	Mixture of NH_4Cl and $ZnCl_2$	1.5V	D, C, B, A, AA, AAA	Flash lights, radio, tape batteries and for general purpose.
Carbon-Zinc (Zinc chloride cell)	Primary	Zinc	MnO_2/C	Zinc chloride	1.5V	D,C, B, A, AA, AAA	Electric shaver, electric knives transmitters, cordless drills, tools etc.
Alkaline-Manganese dioxide cell	Primary & rechargeable	Zinc	Manganese dioxide	Aqueous solution of potassium hydroxide	1.5V	D, C, AA	Camera cranking, radio controlled toys, radios & tape recorders.
Mercuric oxide cell	Primary	Zinc	Mercuric oxide	Aqueous solution of potassium hydroxide or sodium hydroxide	1.35V	C, B, AA and button cells	Cameras, watches, hearing aids, calculators etc.
Silver oxide cell	Primary	Zinc	Ag_2O	Aqueous solution of potassium hydroxide or sodium hydroxide	1.5V	Button cells	Hearing aids, digital wrist watch, micro-lamps, lights, meters etc.
Nickle-Cadmium	Rechargeable (Secondary)	Cadmium	Nickel hydroxide	Aqueous solution of potassium hydroxide	1.2V	All sizes of cyclin-drical, rectangular and button cells	Portable equipments like radio, tapes etc., rechargeable flash lights, emergency light etc.
Lithium Manganese	Primary	Lithium	Iodine/metallic oxides, sulphides button cells	Organic, inorganic water	3V to 6 V	Medium to large	Electronic watches, cal-culators, heart pacemaker life support equipments & communication equipments.

Secondary batteries - types of charge, discharge and maintenance

Objectives : At the end of this lesson you shall be able to
- **state the applications of lead-acid batteries**
- **describe the construction of lead acid batteries**
- **explain types of secondary cells, their nominal cell voltage, capacity and applications**
- **explain the effect of temperature on AH capacity**
- **state the care and maintenance of lead acid batteries**
- **describe the hydrometer**
- **connect the cells in series, parallel and series-parallel.**

Secondary batteries

Secondary batteries are made of small units known as cells. The main difference between a primary and a secondary cell is that a secondary cell can be recharged. This is because the type of chemicals used in a secondary cell is such, the chemical reaction is reversible.

When a secondary cell is supplying current to a load, the cell is said to be *discharging*. This discharging current gradually neutralizes the separated positive and negative charges at the electrodes (Anode and Cathode).

On the other hand, when current is supplied to a cell, the charges get re-formed on the electrodes due to reverse chemical reaction. This action is known as *charging* the cell. For charging a cell, the charging current is supplied by an external DC voltage source, with the cell behaving as a load.

The process of discharging and recharging is called *cycling* of the cell. As long as the cell is in good condition the discharge and charge cycles can be repeated several hundred times.

Since a secondary cell can be recharged, in other words the charges restored, these cells are called *storage cells*.

The most common type of secondary cell is the *Lead-acid cell*. A battery consisting of a combination of such cells is called *Lead-acid battery*. Lead-acid batteries are commonly used in automobiles such as cars, buses and lorries etc.,

Lead-acid, wet type cells

Lead-acid secondary batteries made of lead-acid are used in almost every automobile, for starting the engine. These batteries supply load current of 100 to 400A to the starter motor of automobiles.

The nominal voltage of a lead-acid cell is 2.2 V. By connecting three or six cells in series, batteries of 6V or 12V is obtained.

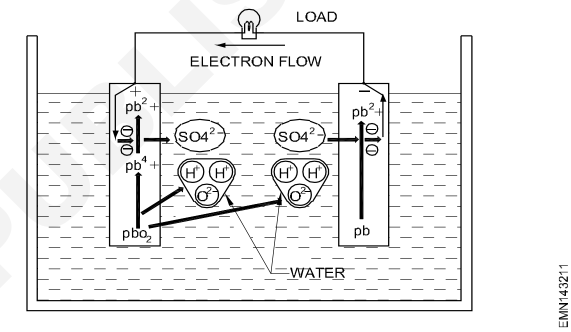
Principle of chemical action

A fully charged lead-acid cell has a lead peroxide (PbO_2) positive electrode, which will be reddish brown in colour and a gray spongy lead (Pb) as the negative electrode. These two electrodes are immersed in an electrolyte which is a diluted solution of sulphuric acid (27% sulphuric acid) having a specific gravity of 1.3. Such a cell produces an output of 2.2 V.

Discharging of lead-acid cells

The chemical action that takes place during the discharging of a lead-acid cell is shown in Fig 1.

Fig 1



During discharge, the lead (Pb) in both the electrodes react with sulphuric acid (H_2So_4) to displace hydrogen and form lead sulphate ($PbSo_4$). This lead sulphate, a whitish material, is somewhat insoluble and hence gets partially coated on both positive and negative plates. Since both plates approach the same material ($PbSo_4$) chemically, the potential difference between these plates begins to decrease. At the same time, the combining of oxygen in the lead peroxide (PbO_2) with the hydrogen atoms of the electrolyte forms water (H_2O) as shown in the equation given below,

$$Pb + PbO_2 + 2H_2So_4 \xrightarrow{\text{Discharge}} 2PbSo_4 + 2H_2O$$

It can be seen from the discharging equation that as the battery discharges (delivers energy to a load), the sulphuric acid solution becomes weaker (more and more diluted) with its specific gravity approaching 1.0.

The coating of whitish lead sulphate on the electrodes and the decrease in specific gravity of the electrolyte makes the voltage of the cell to drop off. Also, the internal resistance of the cell rises due to the sulphate coating on the plates.

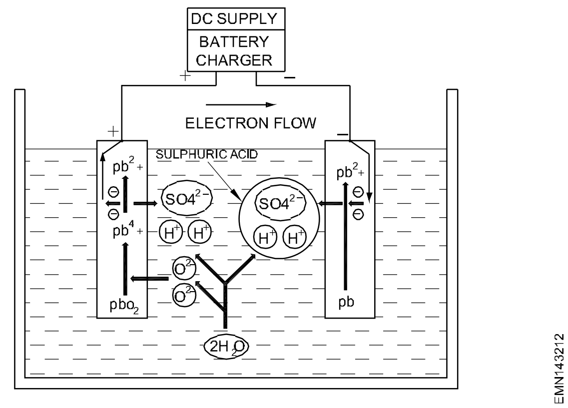
Charging of lead-acid cells

The chemical reaction that takes place during charging of a lead-acid cell is shown in Fig 2.

When a battery charger, having an output voltage (2.5V) which is slightly higher than the nominal voltage of the cell

(2.2V), is connected as shown in Fig 2, the direction of ionic flow gets reversed (refer to Fig 1 for the discharging direction). The electrical energy supplied by the charger causes the recombination of lead sulphate ($PbSo_4$) with hydrogen ions in the electrolyte. Therefore, the excess

Fig 2



water is removed from the electrolyte solution. As the electrolyte returns to its normal strength of sulphuric acid (27%) and the plates return to their original form of lead peroxide and spongy lead, the voltage across the electrodes returns to its nominal value of 2.2 V. The chemical action involved during charging can be represented by the following equation;

At the negative pole:

$PbSO_4$ + 2 electrons $\longrightarrow$ Pb + SO_4

At the positive pole:

$PbSO_4$ - 2 electrons + $2H_2O$ $\longrightarrow$ PbO_2 + So_4^{2-} - $4H^+$

As the above reactions take place simultaneously, the equation can be written as,

$2PbSO_4$ + $2H_2O$ + Electrical energy $\longrightarrow$ $2H_2So_4$ + Pb + PbO_2.

It should be noted that, to charge a lead-acid battery of 12 V (2.2 V x 6 cells), the output voltage of the battery charger used for charging should be between 14.1 V to 15 V, and, its current rating not larger than 30 A. Charging batteries at excessively higher currents can cause boiling of the electrolyte. This reduces the liquid level in the battery and causes buckling and crumbling of the electrodes, thus reducing the life of the cells and hence the battery.

The lead sulphate ($PbSO_4$) which gets coated on the +ve and -ve plates tends to harden into an insoluble salt over a period of time. Hence, it is recommended to fully recharge a battery even if it is not used for quite some time.

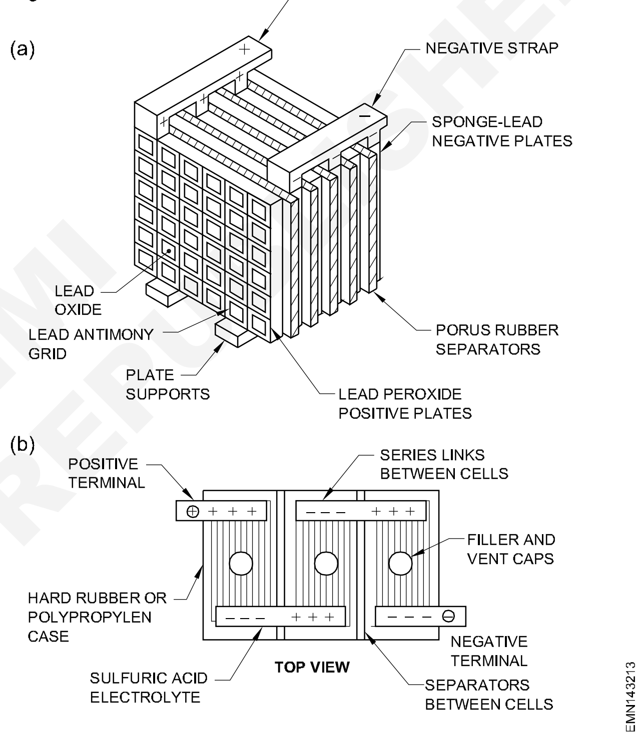
Construction of lead-acid batteries

Fig 3 shows the principle behind the construction of commercial lead acid batteries.

Although in Figs 1 and 2, the lead-acid cell electrodes were shown as single plates, in a practical cell, it will not be the case. To increase the surface area and current capacity, a number of positive and negative plates are interleaved and separated by porous rubber sheets as shown in Fig 3a. All the positive plates are electrically connected, and all the negative plates are electrically connected. These parallel connections yield a higher current capacity of the cell with an overall cell output voltage of 2.2V. Several such cells can be connected in series to obtain the required battery voltage. For example, Fig 3b shows three such cells connected in series to produce a 6 volts Lead acid battery.

In lead-acid batteries, since hydrogen gas is produced during recharging, vents (holes) are provided on the battery compartment to let hydrogen and water vapour escape into free air. The vents also help in adding distilled water to the

Fig 3



cells to compensate the water evaporated from the electrolyte.

Current rating of Lead acid batteries

The current rating of a lead acid battery is usually given in ampere-hour (AH) units, based on an 8 hour discharge period. In other words, batteries are rated in terms of how much discharge current they can supply for a specified period of time (often 8 hours). During this time, the cell's output voltage must not drop below 1.7 volts. Typical Ah values of automobile batteries range from 60 Ah to 300 Ah.

For example, A 60-AH battery, used in smaller automobiles, can supply a load current of 60/8 or 7.5 amperes for 8 hours without the cell voltages dropping below 1.7 volts. However this battery can supply less current for longer time (5 amps for 12 hours) or more current for a shorter time (60 amps for 1 hour).

Effect of temperature on AH capacity of Lead-acid batteries

As in the case of primary cells, the capacity of a lead-acid cells also decreases significantly with temperature. These cells lose approximately 0.75% of its rated ampere-hour (Ah) capacity for every 1°F decrease is temperature. At 0°F (–18°C), its capacity is only 60% of the value at 60°F (15.6°C). In cold weather, therefore, it is very important to have an automobile battery always fully charged. In addition, at very cold temperature, the electrolyte freezes more easily as it is diluted by water in the discharged condition.

> **Keep the batteries always fully charged especially in cold weather conditions.**

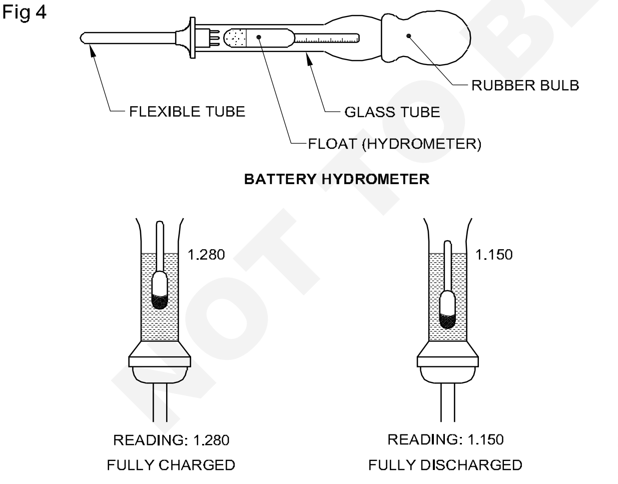
Specific gravity of electrolyte

Specific gravity is a ratio comparing the weight of a substance with the weight of water. The specific gravity of water is taken as 1 as a reference. For instance, specific gravity of concentrated sulphuric acid is 1.835. This means, sulphuric acid is 1.835 times heavier than water for the same volume.

In a fully charged lead-acid cell, the specific gravity of the electrolyte, which is a mixture of sulphuric acid and water should be 1.28 at room temperature of 70 to 80°F. As the cell discharges, more and more water gets released into the electrolyte, lowering the specific gravity. When the specific gravity of the electrolyte falls down to about 1.150, the cell can be taken as fully discharged. Hence, the state of discharge of a lead-acid cell can be found out by measuring the specific gravity of its electrolyte.

The specific gravity of electrolyte is measured using a instrument known as *Battery hydrometer* as shown in Fig 4 below.

Fig 4



Hydrometer

This meter is used to test the specific gravity of the liquid. It consists of a glass-made tube with bulb. The glass tube is filled with small lead pieces and is fitted with scale on which specific gravity is written as well as the indication of charged to discharged condition of a cell is also written. This hydrometer is kept in another glass-made tube. On one side of this tube a rubber ball is fitted and on the other side, nozzle is fitted. When the ball of this meter is pressed and released while keeping this meter in the electrolyte of the cell, the electrolyte comes in the outer glass tube in which hydrometer bulb floats and gives reading with dilute H_2SO_4. The bulb will sink in the electrolyte while with strong H_2SO_4 the bulb will come up Hence, it gives reading. The electrolyte is so filled that the Hydrometer should not stick on the upper head or the bottom of the outer tube.

Reading on the Hydrometer	1280
Full charge	1260
Half charge	1200
Full discharge	1200
or Dead	1180

The importance of specific gravity can be seen from the fact that the open circuit voltage(V) of lead-acid battery is approximately given by,

$$V = \text{Specific gravity} + 0.84.$$

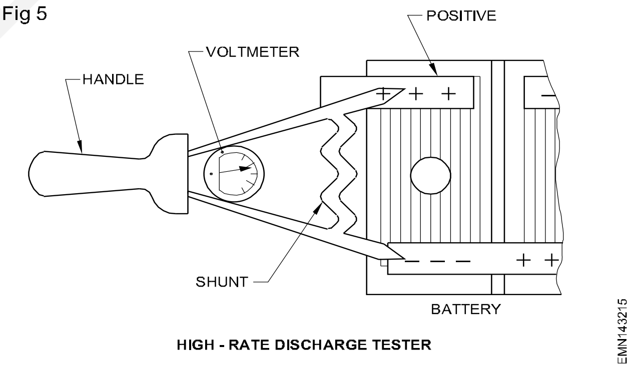
For instance, if the specific gravity is 1.280 then,

$$V=1.280 + 0.84 = 2.12V$$

Instrument for testing condition of cells - High rate discharge tester

The internal condition of a lead-acid battery cell is determined by this test. A low range (0-3V) voltmeter is shunted by a low resistance as shown in Fig 5.

Fig 5



The two terminal prods are pressed on to the terminals of a cell for testing. For fully charged cell the meter pointer points in the range of *full charge* on the meter scale. A sulphated old cell will show the discharge reading. The meter is having three colours red, yellow and green; red for fully discharged, yellow for half charged and green for fully charged condition of the cell respectively.

Topping up of lead-acid battery cells

In normal working condition of a lead-acid battery, the level of the electrolyte solution should be such that all the plates of the cells are fully immersed. If the level of the electrolyte is found to be less, then distilled water should be added to the indicated level of the cell through the vent plugs. This process of maintaining the level of electrolyte in lead-acid battery cell is called topping up.

Do not add tap water or well water for topping up. This will reduce cell life.

When a lead acid battery is being charged, the vent plugs are to be kept open for the gas produced to escape freely into air.

In case of lead-acid batteries used as back-up DC supply in un-interrupted power supplies (UPS), since charging and discharging of batteries is a continuous process, the vent plugs of the batteries will have several holes made on it for the gases produced during charging.

Care and routine maintenance of lead-acid batteries

- DO NOT use battery if it is discharged beyond the minimum value of 1.7V per cell.
- DO NOT leave a discharged battery in that condition for a long time. Even if not in use, keep the battery always fully charged.
- Always maintain the level of the electrolyte 10 to 15 mm above the top of the plates by adding suitable quantity of distilled water (NOT tap water).
- DO NOT add sulphuric acid to maintain specific gravity.
- Keep the vent openings in the filling plug always open to prevent build-up of high pressure due to the gases formed. At least the vent plug should have holes made in it.
- Wash off the acid and corrosion on the battery top using moist cloth, baking soda and water.
- Clean the battery terminals and metal supports up to the bare metal and apply vaseline or petroleum jelly over its surface.
- DO NOT test a discharged battery using a 'High rate discharge tester'.

Some applications of lead-acid batteries

Lead-acid storage battery is the most common type found in commercial market. Lead-acid batteries find a great variety and range of applications. Some common applications are listed below;

- In petrol run motor vehicles like scooters, cars etc.
- In small domestic and industrial private generating plants and in mines.
- Battery run locomotives.
- In emergency lamps for small capacity lighting.
- In uninterrupted power supplies (UPS) for providing reserve supply in the event of mains failure.

Although wet electrolyte lead-acid secondary cells are the most common type, there are other types of secondary cells which find application in certain fields due to their special features. A brief on other types of secondary batteries is given below;

Maintenance free lead-acid batteries

Recent advances in lead-acid cells have resulted in low maintenance and maintenance free batteries. In normal lead-acid batteries, the battery plates contain antimony (4%), as the plates are made of lead antimony. It has been found that the amount of *gassing* i.e. production of hydrogen while charging a cell can be reduced by lowering the amount of antimony in the lead plates. By reducing the antimony in plates to 2%, low maintenance cells can be made. These cells require very little addition of water because very little water is *boiled-off* during charging. Totally maintenance free cells use antimony-free plates allowing complete sealing of battery, since no vents are necessary because gas does not build-up at all. Once sealed, no electrolyte can evaporate from the cell. However in some batteries, a small vent is provided to relieve the pressure arising from altitude changes.

One such maintenance free lead-acid cell is the *Gelled-Electrolyte Lead-acid Cell*. This cell enjoys all the advantages of a wet lead-acid cell but avoids the problems due to liquid electrolyte as it uses a gelled electrolyte. These cells use lead-calcium grids. These cells are completely sealed and can be mounted in any position. A one-way relief valve is provided to release excess pressure if the cell's internal pressure rises too high during charging, and it automatically recloses.

Gelled-electrolyte lead acid batteries are available from 2 V to 12 V with capacities ranging from 0.9 to 20Ah, based on a 20 hour discharge rate. The maximum current for these batteries ranges from 40 to 200 A. These batteries are used in domestic emergency lamps, portable television sets, portable tools and a variety of industrial applications.

- **Nickel-cadmium (NiCd) cell**

Next to lead-acid, these cells are popular because of their ability to deliver high current and can get recycled many times. Also, the cell can be stored for a long time, even when discharged, without any damage. The NiCd cell is available in both sealed and non-sealed designs, but the sealed construction is more common. Nominal output voltage of a nickle-cadmium cell is 1.25 V per cell.

The chemical equation for the NiCd cell can be written as

$$2Ni(OH)_3 + Cd \underset{\text{discharge}}{\overset{\leftarrow \text{ charge}}{\rule{2cm}{0.4pt}}} \rightarrow 2Ni(OH)_2 + Cd(OH)_2.$$

The electrolyte is potassium hydroxide (KOH), but it does not appear in the chemical equation. The reason is that the function of this electrolyte is just to act as a conductor for the transfer of hydroxyl (OH) ions. Therefore, unlike the lead-acid cell, the specific gravity of the electrolyte in the NiCd cell does not change with the state of charge.

The NiCd cell is a true storage cell with a reversible chemical reaction of recharging that can be cycled up to 1000 times. Maximum charging current is equal to the 10-h discharge rate. It should be noted that a new NiCd battery may need charging before use.

Applications include portable power tools, alarm systems, and portable radio or television equipment.

Nickel-iron or Edison cell

This cell was once used extensively in industrial truck and railway applications. However, it has been replaced almost entirely by the lead-acid battery. New methods of construction for less weight, though making this cell a possible alternative in some applications.

The Edison cell has a positive plate of nickel oxide, a negative plate of iron, and an electrolyte of potassium hydroxide in water with a small amount of lithium hydroxide added. The chemical reaction is reversible for recharging. The nominal output is 1.2 V per cell.

Nickel-zinc cell

This type has been used in limited railway applications. There has been renewed interest in it for use in electric cars, because of its high energy density. However, one drawback is its limited cycle life for recharging. The nominal output is 1.6 V per cell.

Alkaline - manganese secondary cells

Alkaline - manganese secondary batteries are maintenance free, hermetically sealed, and will operate in any position. Individual cells use electrodes of zinc and manganese dioxide with an alkaline electrolyte of potassium hydroxide. Each cell has a nominal voltage of 1.5 V. Alkaline-manganese batteries are available in rated Ah capacity of 1 to 4 Ah. The internal resistance of these batteries is appreciably higher than NiCd batteries. Therefore, alkaline manganese batteries are not suitable for large current supplies.

Alkaline manganese batteries have been designed for electronic and electrical appliances where initial cost and low operating cost are of paramount interest. The total number of times the alkaline manganese secondary batteries can be recharged is much less than that of NiCd batteries, but the initial cost is lower.

Charging alkaline manganese batteries is different from that of NiCd batteries. According to the manufacturer's data, the charging should be done at constant current but at a constant voltage. Another difference, when compared with other secondary batteries is that, the alkaline manganese batteries must not be discharged too much; otherwise, the chemical process can be no longer reversed which means they cannot be recharged. It is recommended by the manufacturer not to discharge the cells below 1 volt.

Zinc-chlorine (hydrate) cell

This cell has been under development for use in electric vehicles. It is sometimes considered as a zinc-chloride cell. This type has high energy density with a good cycle life. Nominal output is 2.1 V per cell.

Lithium-iron sulphide cell

This cell is under development for commercial energy applications. Nominal output is 1.6 V per cell. The normal operating temperature is 800 to 900°F which is high compared with the normal operating temperature of the more popular types of cells.

Sodium-sulphur Cell

This is another type of cell being developed for electric vehicle applications. It has the potential of long life at low cost with high efficiency. The cell is designed to operate at temperatures between 550 and 650°F. Its most interesting feature is the use of a ceramic electrolyte.

Lead-acid secondary batteries made of lead-acid are used in almost every automobile, for starting the engine. These batteries supply load current of 100 to 400A to the starter motor of automobiles.

The nominal voltage of a lead-acid cell is 2.2 V. By connecting three or six cells in series, batteries of 6V or 12V is obtained.

Plastic Cells

A recent development in battery technology is the rechargeable plastic cell made from a conductive polymer, which is a combination of organic chemical compounds. These cells could have ten times the power of the lead-acid type with one-tenth the weight and the one-third the volume. In addition, the plastic cell does not require maintenance. One significant application could be for electric vehicles.

A plastic cell consists of an electrolyte between two polymer electrodes. The operation is similar to that of a capacitor. During charge, electrons are transferred from the positive electrode to the negative electrode by a dc source. On discharge, the stored electrons are driven through the external circuit to provide current in the load.

Application of maintenance free Gelled Electrolyte Lead-acid batteries

Since Gelled electrolyte lead-acid batteries are maintenance free and can be placed in any position, these batteries are extensively used in almost all types of portable equipments. The most common application of Gel-batteries can be found in *emergency lamps*. Emergency lamps are nothing but stand-by light sources, used in the event of main's failure. The type of lamp used could be a miniature tube light or a simple filament lamp. Emergency lamps which use miniature tube lights need a special circuit known as *inverter*. The function of the inverter circuit is to convert a low DC voltage into a high AC voltage.

Recharging lead-acid batteries

Recall that lead-acid batteries are rechargeable. Once the cell voltages of a lead-acid battery falls below 1.8 V, the battery needs recharging. This discharged state of battery can be found by measuring the specific gravity of the electrolyte (1.150) or by measuring the voltage across the cells of the battery.

To charge a lead-acid battery, an equipment known as Battery charger is used. A battery charger is nothing but a DC voltage source which can supply the necessary voltage and charging current to the battery.

There are two main methods of charging batteries. They are;

1 Constant current battery charging

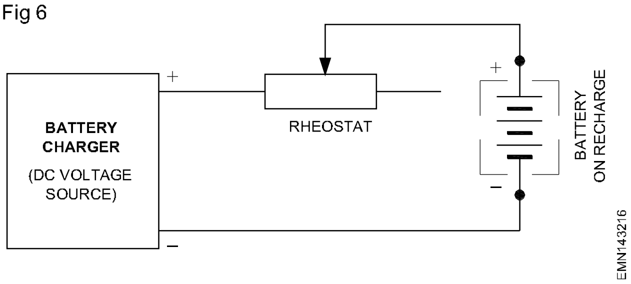
2 Constant voltage battery charging.

1) Constant current battery charging

In this method of charging batteries, the charging current supplied to the battery is kept at a prescribed (by the battery manufacturer) constant value. The amount of this constant current varies depending upon the Ah capacity of the battery. The value of constant charging current should not be excessive as this would cause excessive gassing. Excessive value current rises the cell temperature above the safe limit (generally 40°C) which will reduce the life of the battery.

Fig 6 shows a very simple method of constant current charging system.

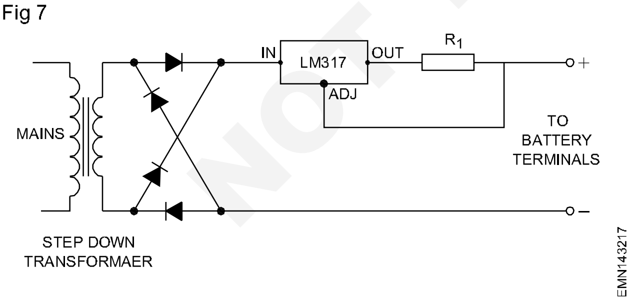
Fig 6



In constant current charging, the output DC voltage of the charger will be generally twice the nominal voltage of the battery to be charged. But, the charging current is controlled by varying the rheostat connected in series with the battery. For example, to charge a 12 V battery, the DC voltage source can be 24 V, but the charging current will be kept controlled say, 1 ampere with the help of the rheostat.

With the introduction of voltage regulator integrated circuits like LM317, it has become very simple and less expensive to make constant current battery chargers. Fig 7 shows a simple constant current battery charger using LM317. This charger can be used for any type of battery charging as long as the charging current is less than 1.5 Amperes.

Fig 7



Current can be set at any value between 10 mA and 1.5 A in the circuit at Fig 7. To have higher currents, suitable external power transistors can be used. In Fig 7, the input voltage to the regulator IC (LM317) should be 1.5 times the battery voltage (to be charged) plus 3 V. LM317 used in Fig 7 is immune to output shorts or reverse battery connections. Hence, the charger will always be safe.

The disadvantage of constant current battery charging is that it takes comparatively long time to fully charge the battery. But, the charge efficiency, which is defined as, is high compared to constant voltage battery charging.

$$\text{Charge efficiency} = \frac{\text{Charge stored by the battery}}{\text{Charge supplied to the battery}}$$

2) Constant voltage battery charging

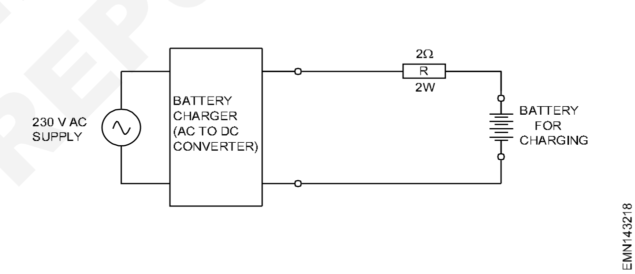
In this method, the voltage applied across the battery terminals is kept constant, but no control is imposed on the charging current. Therefore, the battery draws large charging current in the beginning and as the cells gets charged, the charging current decreases to a small value.

In this method, the time required for charging is reduced to half compared to the constant current charging. But, the charge efficiency gets reduced by approximately 10%.

In constant voltage charging, the voltage applied to the cells for charging should be fixed at about 2.3 to 2.5 volt per cell and not more. For instance, for a 12 volts car battery, the DC voltage output of the charger should be between 14 V to 15 V.

Simple constant voltage battery charging shown in Fig 8. Generally for converting AC into DC. Rectifier circuits are used. For precision operation, Thyristor based rectifiers also used.

Fig 8



Resistor R is used to limit the initial charging surge current from becoming excessively high. This is because excessive current may damage the diode and transformer of the battery charger unit.

TRICKLE Charging: Whenever a storage battery is used as an emergency reserve, as in the case of un-interrupted power supply (UPS), it is necessary to keep the batteries fully charged and ready for use at any time if the mains supply fails.

A fully charged battery, which is not connected to any load is expected to maintain its terminal voltage. But, due to internal leakage in the battery and other open circuit losses, the battery voltage slowly falls even in idle or open circuit condition. Therefore, to keep it in fully charged condition, the battery should be supplied with a charging current which is small and just sufficient to compensate the idle condition or open circuit losses. This small current charging is known as Trickle charging. Trickle charging keeps the battery always fully charged and in ready to use condition, so that, the battery can be fully made use of in emergency conditions.

Types of measuring instruments, equipments, uses and features

Objectives : At the end of this lesson you shall be able to
- **explain the principle of operation of a PMMC type movement**
- **explain D'Arsonval moving coil meter movement**
- **explain the calibration of instruments**
- **explain the parts and functions of multimeter.**

To work with electricity and to service electrical appliances, requires accurate measurements. To make electrical measurement the most popular instruments used are called Meters. Meter is a tool used to measure the basic electrical quantities such as current,potential difference(volt) and resistance. Right selection and proper use of meters can only give accurate readings.

All meters have one thing in common. They contain an internal standard to which all measured values are compared. In this respect, an electrical meter is much like a mechanical balance that compares an unknown mass to a standard mass.

Meters discussed in this lesson make use of electric current/voltage to produce a magnetic force , it then compares this force to a counter force exerted by a spring.The resultant of these forces drives a pointer which indicates the value of the electric voltage/current applied to the meter on a graduated scale found on the dial of the meter.

The D'Arsonval Movement

All meters will have some form of indicating device. Those that have a Pointer or needle that moves across a fixed scale are based on a mechanism called D' Arsonval movement.This is named after its invention by D'Arsonval Deprez. The principle of D' Arsonval movement is similar to a motor, it makes use of the force of a magnetic field exerted in a current carrying conductor. The principle of this movement is similar to that of a permanent magnet type electric motor.

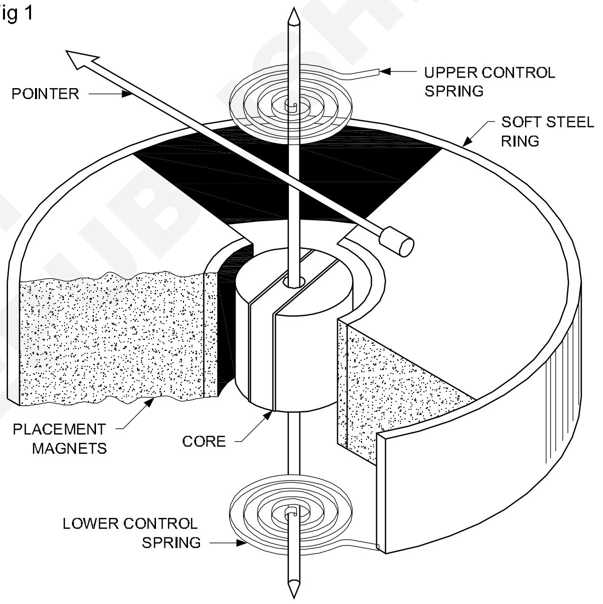
All D'Arsonval meter movements require current and a magnetic field to cause movement of the indicator. Some meters have permanent magnets that work with current to move the pointer. Such type are referred to as permanent magnet moving coil type(PMMC) meters. The other type have no permanent magnets;instead they have current carrying coils to produce the magnetic fields. These are referred to as Moving Iron type (MI) meters.

D'Arsonval meter movements consists of a permanent magnet and a moving coil, also called permenant magnet moving coil galvano meter abbreviated PMMC. The term galvanometer refers to a sensitive current-detecting device.

Fig 1 shows the essential parts of such a galvonometer.

In Fig 1, the coil is mounted on a shaft which rotates between the jewel bearings(not shown in Fig). The Soft steel core reduces the total air gap between the magnetic poles of a permanent magnet. The coil is positioned to turn against precisely made upper and lower control springs. The springs also serve as conductor to carry current to and from the coil. A light weight pointer/indicator attached to the coil indicates how far the coil has rotated. The position of the indicator on the scale tells the amount of current flowing through the coil.

Fig 1



BASIC PARTS OF A D'ARSONAVAL MOVEMENT

EMN153611

Principle of operation of a PMMC type meter movement

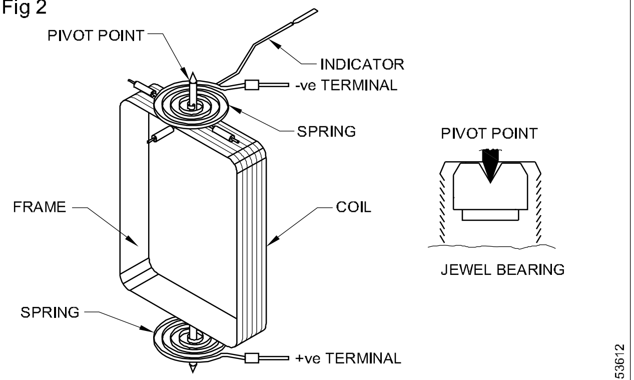
When no current flows through the coil, the control spring's tension hold the coil in a position between the pole faces. This position is defined as "Zero position".

When the coil carries current (whose value is to be measured), the force from the magnetic field due to permanent magnet exerts torque on the current carrying coil and make it rotate(like the motor principle). The indicator moves clock-wise in the direction and the springs controls/resist this motion. The magnetic field exerts a torque on the moveable coil making it to rotate.The indicator then comes to a rest at a non Zero value on the scale where the torque produced by the current and the opposition force of the spring becomes equal.

Because of the permanent magnet, the strength of the magnetic field around the coil is constant. Therefore, the deflecting force is directly proportional to the current through the moveable coil. These conditions makes it possible to calibrate the scale of the instrument to read the measurement value directly.

To allow the moving coil to deflect with bare minimum friction, the shaft of the moving coil is tapered to a point at both ends. The sharp ends rest in a highly polished jewel bearing as shown in Fig 2. The tapered ends hold the shaft precisely in position to maintain the instrument's accuracy. The bearing (usually Sapphire) reduces wear. In addition, the small area of contact keeps the torque caused by friction very low, so that the meter responds rapidly to any changes in current.

Fig 2



BEARING OF A D'ARSONVAL MOVEMENT

Damping in Moving coil type meters

Damping means to control the swing of the coil so that the pointer comes to rest quickly at its final position. Without damping, the pointer attached to the coil swings back and forth before coming to rest. In such case, it is necessary to wait till the swinging stops to take the accurate meter reading.

In permanent magnet moving coil meters, the movable coil is wound on an aluminium frame as shown in Fig 3. This frame, in addition to supporting the coil winding, the bobbin also performs the important function of damping the instrument.

Calibration of Instruments

While the tolerance figures are generally specified, this will not be true if the instrument is in use for a reasonably long time. The main reason for this could be the aging of the instrument. Therfore, to have complete confidence in the instrument used for measurement, it is necessary to "Calibrate" the instrument regularly. If an instrument is left uncalibrated, the same reading taken sometime back will be different not because of the any fault in the manufacturer's specification, but because its calibration might not have been checked within the recommended period.

Calibration is a routine procedure at stated intervals and is performed against preserved and trustworthy standards. The intervals for calibration depends on several factors such as the type of instrument, place of use, accuracy and so on. Hence, most instrument manufacturers specify the interval for calibration and suggest the procedure.

Calibration of Voltmeters and Ammeters

Among the several methods of calibration for volt meters and current meters, the two simple and popular methods are;

– Calibration by potentiometer method

– Calibration by comparison method.

Potentiometer method is the fundamental method of calibration and is necessarily used for the basic standard instrument. But this method is too slow for the general run of calibration and is more precise than needed. Hence the usual portable instruments are calibrated by comparison with a high grade standard instrument of suitable range. At present senario high precision digital instruments can be used as standard instrument while calibrating analog volt/current/ohm meters.

Advantages : The P.M.M.C. instrument

- Consumes less power
- has uniform scale and can cover an arc up to 270°
- has high torque/weight ratio.
- can be modified as voltmeter or ammeter with suitable resistors
- has efficient damping.
- is not affected by stray magnetic fields, and has no loss due to hysteresis.

Disadvantages : The P.M.M.C. instrument

- can be used only in DC
- is very delicate
- is costly when compared to a moving iron instrument
- may show errors due to loss of magnetism of the permanent magnet.

Moving iron instruments

This instrument derives its name from the fact that a piece of soft iron which is attached to the spindle and needle moves in a magnetic field produced by the current or by a current proportional to the quantity of electricity being measured.

There are two types of this instrument which are used either as voltmeter or ammeter.

They are:

– attraction type

– repulsion type.

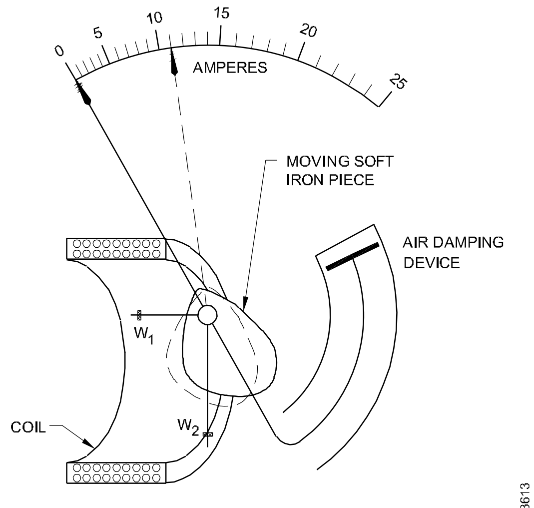
Principle of operation

The attraction type instrument works on the principle of magnetic attraction, and the repulsion type instrument works on the principle of magnetic repulsion between two adjacent pieces of soft iron, magnetised by the same magnetic field.

Construction and working of attraction type moving iron instrument

This instrument consists of an electromagnetic coil having an air core as shown in Fig 3. Just in front of the air core, an oval shaped soft iron piece eccentrically pivoted in a spindle is kept as shown in Fig 3. The spindle is free to move with the help of the jewelled bearings, and the pointer, which is attached to the spindle, could move over the graduated scale. When the electromagnetic coil is not connected to the circuit, the soft iron piece hangs vertically down due to gravitational force and the pointer shows zero reading.

Fig 3



MOVING IRON INSTRUMENT - ATTRACTION TYPE

When the electromagnetic coil is connected to the supply, the magnetic field created in the coil attracts the soft iron piece. (Fig 3) Due to the eccentricity of pivoting of the iron piece, the enlarged portion of the iron piece is pulled towards the coil. This, in turn, moves the spindle and makes the pointer to deflect. The amount of deflection of the pointer will be greater when the current producing the magnetic field is greater. Further, the attraction of the soft iron piece is independent of the current direction in the coil. This characteristic enables the instrument to be used both in DC and AC.

Construction and working of repulsion type moving iron instrument

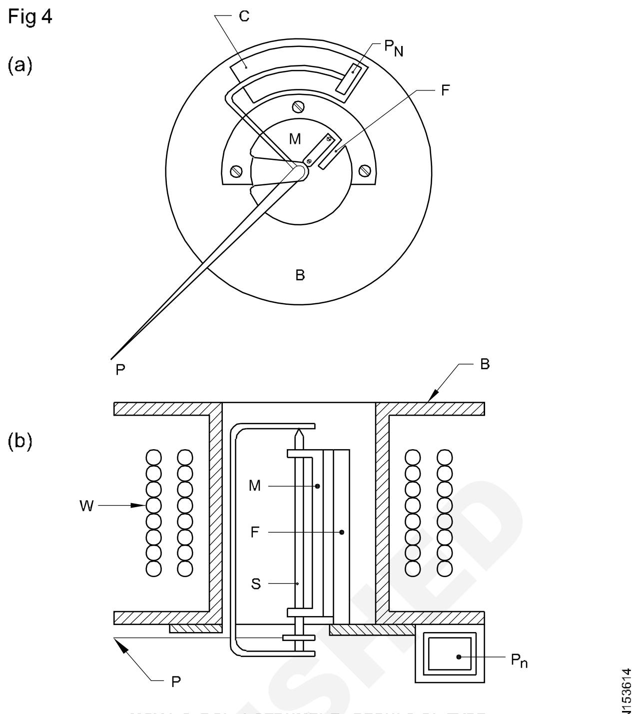
This instrument consists of a coil W wound on a brass bobbin B, inside which two strips of soft iron M and F are set axially as shown in Figs 4a & 4b. Strip F is fixed whereas the iron strip M is attached to the spindle S, which also carries the pointer P.

Spring control is used and the instrument is designed such that when no current is flowing through W, the pointer is at zero position and the soft iron strips M and F are almost touching. (Figs 4a & 4b)

When the instrument is connected to the supply, the coil W carries current which, in turn, produces a magnetic field. This field makes the fixed and moving iron F and M

respectively to produce similar poles in the ends. Therefore, the two strips repel each other. The torque set up produces a deflection of the moving system and therefore. brings into play a controlling torque due to torsion. The moving system comes to rest in such a position that the deflecting and controlling torques are equal.

Fig 4



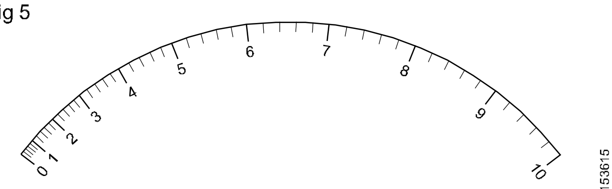
MOVING IRON INSTRUMENT - REPULSION TYPE

In this type of instrument air damping is used commonly which is provided by the movement of piston P_N in a cylindrical air chamber C as shown in Fig 4a.

Deflecting torque and graduation of scale

However, in the moving iron instruments the deflecting torque is proportional to the square of the magnetic force which, in turn, is proportional to the square of the current passing through the coil. As such the scale of this instrument will be uneven. That is, cramped at the beginning and open at the end as shown in Fig 5.

Fig 5



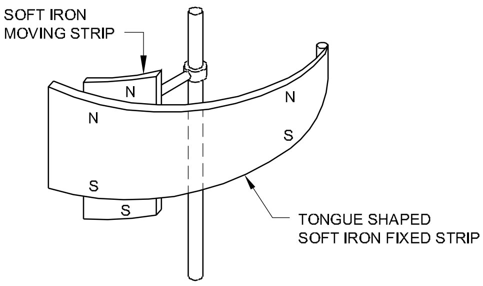
SCALE OF THE MOVING IRON INSTRUMENT (UNEVEN)

In order to achieve uniformity of scale, some manufacturers have designed tongue shaped strips as moving and fixed soft irons as shown in Fig 6a.

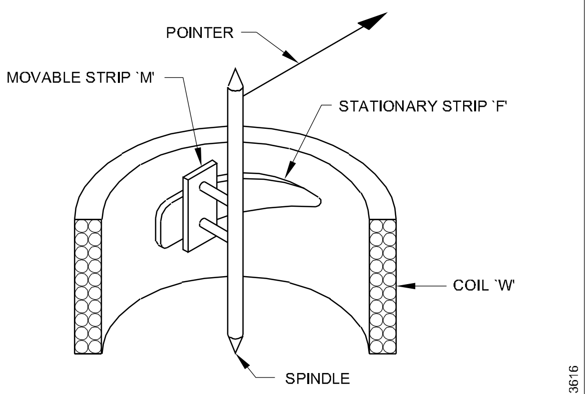
The fixed iron consists of a tongue-shaped soft iron sheet bent into a cylindrical form, while the moving iron is also made of another soft iron sheet and is so mounted as to move parallel to the fixed iron and towards its narrower end as shown in Fig 6b. The torque which is proportional to the square of the magnetic force/current is proportionally reduced by the narrow portion of the fixed iron resulting in more or less even torque, and, thereby, getting uniform scale.

Fig 6

(a)



(b)



DESIGN OF THE FIXED IRON PIECE

These instruments are either gravity or spring controlled and the damping is achieved by the air friction method as shown in Fig 6a.

USES, ADVANTAGES AND DISADVANTAGES

Uses

They are used as voltmeters and ammeters.

They can be used on both AC and DC and, hence, are called unpolarized instruments.

Advantages

They have a small value of friction errors as the torque/ weight ratio is high.

They are less costly when compared to the moving coil instruments.

They are robust owing to their simple construction.

They have satisfactory accuracy levels within the limits of both precision and industrial grades.

They have scales covering 240°.

Disadvantages

They have errors due to hysteresis, frequency changes, wave-form and stray magnetic fields.

They have non-uniform scale usually. However, special manufacturing designs are utilized to get more or less uniform scales.

Moving iron Instrument as an ammeter

It may be constructed for full scale deflection of 1 to 30A without the use of shunts or current transformers. To obtain full scale deflection with currents less than 0.1A, it requires a coil with a large number of fine wire turns, which results in an ammeter with a high impedance.

The range of the instrument, when used as an ammeter, can be extended by using a suitable shunt across its terminals. No problem arises during operation with DC but the division of current between instrument and shunt changes with the change in applied frequency while using AC.

Multimeter

The three most commonly measured electrical quantities are current, voltage and resistance. Current is measured by an ammeter, voltage by a voltmeter and resistance by an ohmmeter.

A single instrument used for measuring all the above three quantities is known as a multimeter. It is a portable, multi range instrument.

It has a full scale deflection accuracy of ±1.5 %. The lowest sensitivity of multimeters for AC voltage range is 5 kΩ/ volts and for the DC voltage range it is 20 kΩ/ volts. The lowest range of DC is more sensitive than the other ranges.

Fig 7

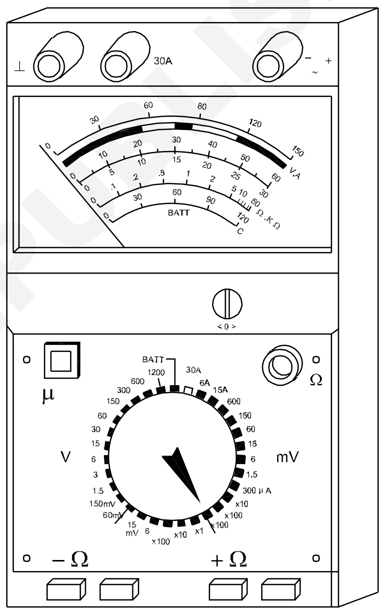


Fig 7 show typical multimeters.

Construction of a multimeter

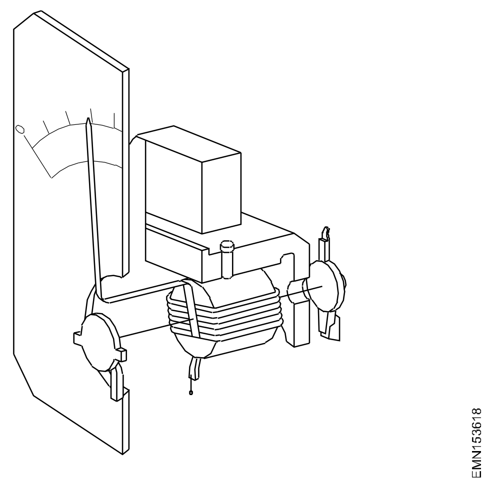
A multimeter uses a single meter movement with a scale calibrated in volts, ohms and milliamperes. The necessary multiplier resistors and shunt resistors are all contained within the case. Front panel selector switches are provided to select a particular meter function and a particular range for that function.

On some multimeters, two switches are used, one to select a function, and the other the range. Some multimeters do not have switches for this purpose; instead they have separate jacks for each function and range.

Batteries/cells fixed inside the meter case provide the power supply for the resistance measurement.

The meter movement is that of the moving coil system as used in DC ammeters and voltmeters. (Fig 8)

Fig 8



Rectifiers are provided inside the meter to convert AC to DC in the AC measurement circuit.

Parts of a multimeter

A standard multimeter consists of the main parts and controls, as shown in Fig 9.

Controls

The meter is set to measure the current, voltage (AC and DC) or resistance by means of the FUNCTION switch.

The meter is set to the required current, voltage or resistance range - by means of the RANGE switch.

The example in Fig 10 shows the switch set to 25V DC of a meter having the function and the range selected by a single switch.

Fig 9

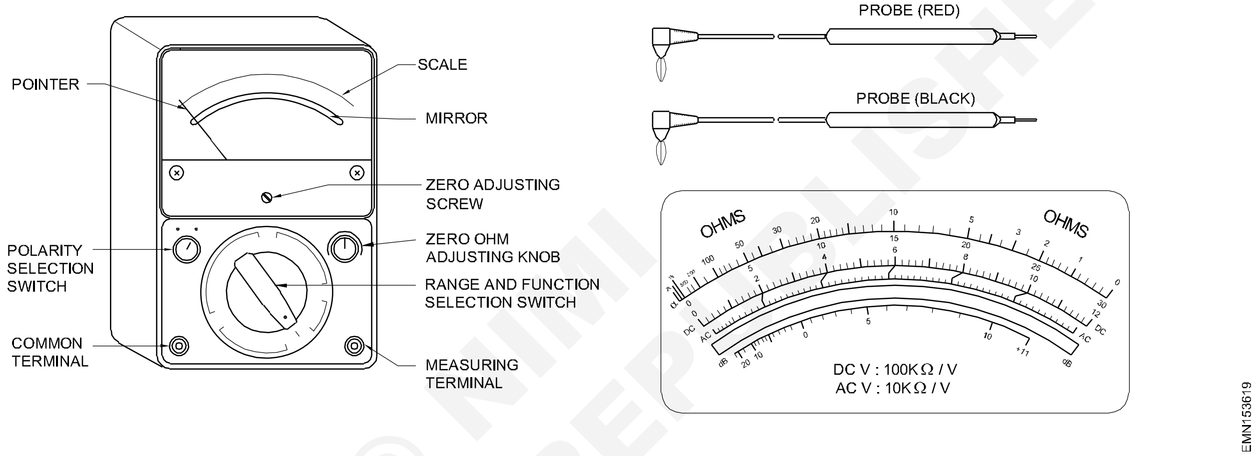


Fig 10

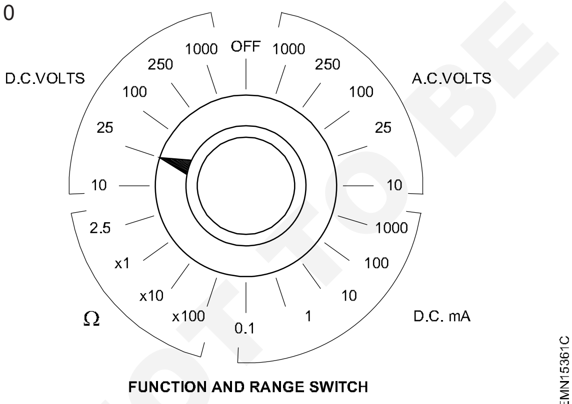
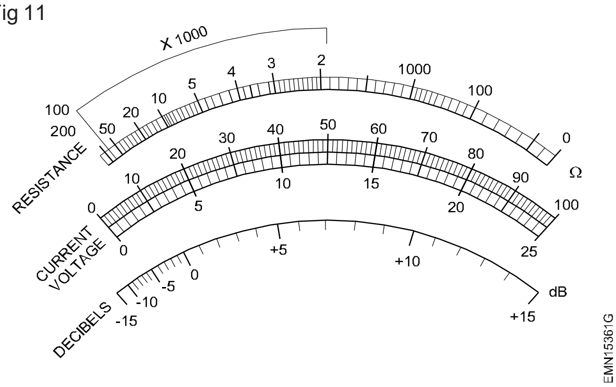


Fig 11



The scale is usually 'backward', with zero at the right.

Principle of working

A circuitry when working as an ammeter is shown in Fig 12.

Shunt resistors across the meter movement bypass current in excess of 0.05 mA at FSD. A suitable value of shunt resistor is selected through the range switch for the required range of current measurement.

A circuitry when working as a voltmeter is shown in Fig 13.

Scale of multimeter

Separate scales are provided for:

- resistance
- voltage and current.(Fig 11)

The scale of current and voltage is uniformly graduated.

The scale of the ohmmeter is non-linear. That is, the divisions between zero and infinity (∞) are not equally spaced. As you move from zero to the left across the scale, the divisions become closer together.

Fig 12

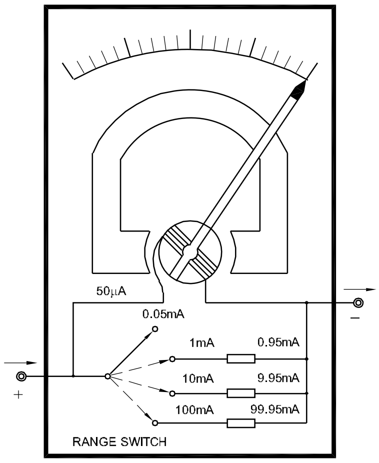
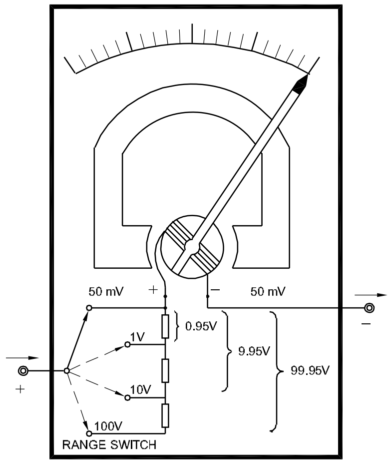


Fig 13



The voltage drop across the meter coil is dependent on the current and the coil resistance. To indicate voltages greater than 50 mV at FSD as per the circuit, multiplier resistances of different values are connected in series with the meter movement through the range switch for the required range of measurement.

A circuitry when working as an ohmmeter is shown in Fig 14.

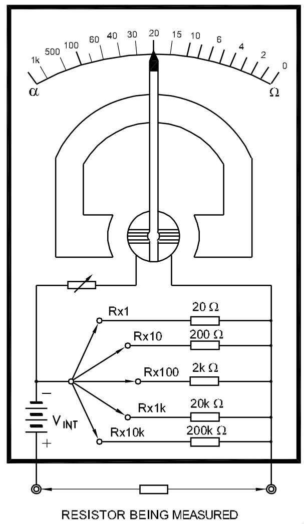
To measure resistance, the leads are connected across the external resistor to be measured as shown in Fig 14. This connection completes the circuit, allowing the internal battery to produce current through the meter coil, causing deflection of the pointer, proportional to the value of the external resistance being measured.

Zero adjustment

When the ohmmeter leads are open, the pointer is at full left scale, indicating infinite ¥ resistance (open circuit). When the leads are shorted, the pointer is at full right scale, indicating zero resistance.

The purpose of the variable resistor is to adjust the current so that the pointer is at exactly zero when the leads are shorted. It is used to compensate for changes in the internal battery voltage due to aging.

Fig 14



Multiple range

Shunt (parallel) resistors are used to provide multiple ranges so that the meter can measure resistance values from very small to very large ones. For each range, a different value of shunt resistance is switched on. The shunt resistance increases for the higher ohm ranges and is always equal to the centre scale reading on any range.

Digital Multimeter

Digital multimeters are high input impedance and better accuracy and resolution. It converts an input analog signal into its digital equivalent and displays it. the analog input signal might be digital voltage, an a.c. voltage, a resistance or an a.c/d.c current.

Measurement of resistance using multimeter

A moving coil meter can be used to measure unknown resistance by using a circuit configuration. With the test probes short circuited, the ohms adjust control is turned so that the current through the total circuit resistance deflects the meter to the full scale. Now by connecting the test probes across the unknown resistance, the current is decreased, and the deflection on the scale gives you the resistance value. Ohms law states the output current is proportional to the applied voltage. Unit of resistance is ohms.

Measurement of voltage

The moving coil meter has constant resistance so that the current through the meter is proportional to the voltage across it. so the current meter can be used to measure voltage. To extent, the voltage range of the meter, it is necessary to add resistance in series with the meter circuit. In order to measure a.c. voltage, rectification is required. The principle of generating a.c. is by electromagnetic induction is higher. While measuring unknowing voltage levels with multimeter, always range switch should be set to the highest available range and work down from there Unit of voltage is volts.

Measurement of current:

The moving coil meter is sensitive to the current and is therefore an ammeter. For d.c. measurement, the meter is placed in series with the circuit. So the circuit must be broken to connect the ammeter and it becomes the part of the circuit. For A.C. measurement, rectifier type meters are used which will respond to the average value of the rectified alternating current. Unit of current is amperes.

Electrical instruments may be classified based on the following.

– Manufacturing standards
– Function
– Effects of electric current on the instruments.

Manufacturing standards: The electrical instruments may, in a broad sense, be classified according to the manufacturing standards into absolute instruments and secondary instruments.

Absolute instruments: These instruments give the value of quantity to be measured in terms of deflection and instrument constants. A good example of an absolute instrument is the tangent galvanometer. In this instrument the value of current could be calculated from the tangent of the deflection produced by the current, the radius and number of turns of wire used and the horizontal component of the earth's magnetic field. No previous calibration or comparison is necessary in this type of instruments. These instruments are used only in standard laboratories.

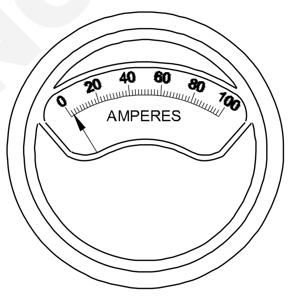
Secondary instruments: In these instruments the value of electrical quantity (voltage, current, power, etc.) to be measured can be determined from the deflection of the instruments on the calibrated dial. These instruments should be calibrated in comparison with either an absolute instrument or with one which has already been caliberated. All the instruments used commercially are secondary instruments.

Functions

Secondary instruments are further classified according to their functions, that is, whether the instrument indicates, or records the quantity to be measured. Accordingly, we have indicating, integrating and recording instruments.

Indicating instruments: These instruments, as shown in Fig 15, indicate the value of voltage, current power etc. directly on a graduated dial. Ammeters, voltmeters and wattmeters belong to this class.

Fig 15

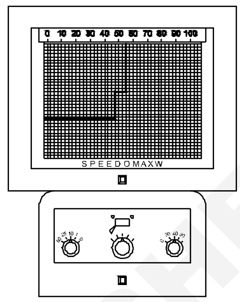


EMN15361L

Integrating instruments: These instruments measure the total amount, either the quantity of electricity or the electrical energy, supplied to a circuit over a period of time. Ampere hour meters and energy meters belong to this class.

Recording instruments: These instruments register the quantity to be measured in a given time, and are provided with a pen which moves over a graph paper. With this instrument, the quantity can be checked for any particular date and time. Recording voltmeters, ammeters and power factor meters belong to this class. Fig 16 shows such a recording instrument.

Fig 16



EMN15361M

Effects of electric current used on electrical instruments: Secondary instruments may also be classified according to the various effects of electricity upon which their operation depends. The effects utilised are as follows.

– Magnetic effect
– Heating effect
– Chemical effect
– Electrostatic effect
– Electromagnetic induction effect

Essential forces required for an indicating instrument:

The following three forces are essential requirements of an indicating instrument for its satisfactory operation. They are

– deflecting force
– controlling force
– damping force.

Deflecting force or operating force: This causes the moving system of the instrument to move from its `zero' position, when the instrument is connected to the supply. To obtain this force in an instrument, different effects of electric current, such as magnetic effect, heating effect, chemical effect etc. are employed.

Controlling force: This force is essential to control the movement of the moving system and to ensure that the magnitude of the deflection of the pointer is always the same for a given value of the quantity to be measured. As such, the controlling force always acts opposite to the deflecting force, and also brings the pointer to zero position when the instrument is disconnected from the supply.

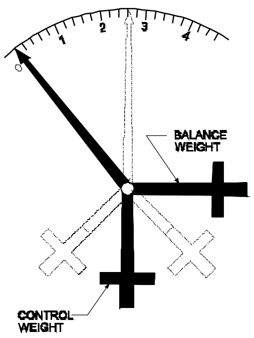
The controlling force could be produced by any one of the following ways.

- Gravity control
- Spring control

Gravity control: In this method, small adjustable weights are attached to the opposite extension of the pointer as shown in Fig 17. These weights are attracted by the earth's gravitational pull, and thereby, produce the required controlling force(torque). The instruments with gravity control are to be used in the vertical position only.

When the instrument is not connected to the supply, the control weight and the balance weight attached to the opposite end of the pointer make the pointer to be at zero position as shown in Fig 17. When the instrument is connected to the supply, the pointer moves in a clockwise direction, thereby displacing the weights as shown in dotted lines in the figure. Due to the gravitational pull, the weights will try to come to their original vertical position, thereby exerting a controlling force on the movement of the moving system.

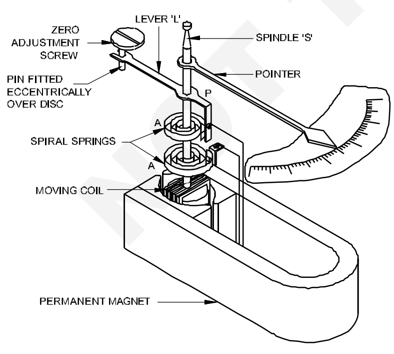
Fig 17



EMN15361N

Spring control: The most common arrangement of spring control utilises two phosphor-bronze or beryllium-copper spiral hair-springs A and B, the inner ends of which are attached to the spindle S as shown in Fig 18. The outer end of the spring B is fixed, whereas that of A is attached to the end of a lever `L' pivoted at P, thereby enabling the zero adjustment to be easily effected when needed.

Fig 18



SPRING CONTROL MOVING COIL INSTRUMENT

EMN15361O

The two springs A and B are wound in opposite directions so that when the moving system is deflected, one spring winds up while the other unwinds, and the controlling force is due to the combined torsions of the springs.

These springs are made from such alloys that they have:

- high resistance to fatigue (can be wound or unwound several times without loosing the tension)
- non-magnetic properties (should not get affected by external magnetism)
- low temperature cofficient (do not elongate due to temperature)
- low specific resistance (can be used for leading current `in' and `out' of the moving system).

Spring controlled instruments have the following advantages over the gravity controlled instruments.

Ohm meter

Resistances could be broadly classified according to their values as low, medium and high resistances.

Low resistance: All resistances of the order of 1 ohm and below, may be classified as low resistances.

Example: Armature and series field resistances of large D.C. machines, ammeter shunts, cable resistance, contact resistance, etc.

Medium resistances: Resistances above 1 ohm and upto 100,000 ohms are classified as medium resistances.

Example*:* Heater resistance, shunt field resistance, relay coil resistance etc.

High resistances: Resistances above 100000 ohms are classified as high resistances.

Example: Insulation resistance of equipment, cables etc.

Medium resistances could be measured by instruments like Kelvin's bridge, Wheatstone bridge, Slide wire bridge, Post Office box and ohmmeter. Also special designs of the above instruments allow measurement of low resistances accurately.

However for measuring high resistances, instruments like megohmmeter or Megger is used.

Ohmmeter: The ohmmeter is an instrument that measures resistance. There are two types of ohmmeters, the series ohmmeter, used for measuring medium resistances, and the shunt type ohmmeter, used for measuring low resistances. The ohmmeter, in it basic form, consists of an internal dry cell, a P.M.M.C. meter movement and a current limiting resistance.

Before using an ohmmeter in a circuit for resistance measurement, the current in the circuit must be turned off and also any electrolyte capacitor in the circuit should be discharged, as the ohmmeter has its own source of supply.

Series type ohmmeter

Construction: A series type ohmmeter consists essentially of a P.M.M.C. (`D' Arsonval) movement 'M', a limiting resistance R_1 and a battery 'E' and a pair of terminals of A and B to which the unknown resistance 'R_x' is to be connected and shunt resistance R_2 is connected in parallel to meter 'M' which is used for adjusting the zero position of the pointer.

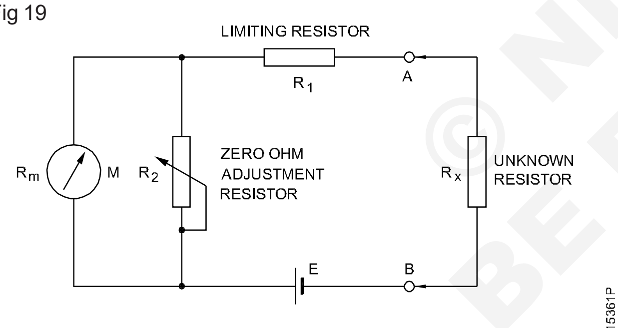
Working: When the terminals A and B are shorted (unknown resistor R_X= zero), maximum current flows in the circuit. Meter is made to read full scale current (I_{fsd})by adjusting the shunt resistance R_2. The full scale current position of the pointer is marked zero(0) ohm on the scale. When the ohmmeter leads (A & B terminals) are open, no current flows through the meter movement. Thereby the meter does not deflect and the pointer remains on the left hand side of the dial. Therefore the left side of the dial is marked infinity (∞) which means that there is infinite resistance (open circuit) between the test leads.

Intermediate marking may be placed in the dial (scale) by connecting different known values of R_x, to the instrument terminals A and B.

The accuracy of the ohmmeter greatly depends upon the condition of the battery. Voltage of the internal battery may decrease gradually due to usage or storage time. As such the full scale current drops, and the meter does not read zero when the terminals A and B are shorted. The variable shunt resistor R_2 in Fig 19 provides an adjustment to counteract the effect of reduced battery voltage within certain limits. If the battery voltage falls beyond a certain value, adjusting the zero adjusting resistance R_2 may not bring the pointer to zero position, and, hence, the battery should be replaced with a good one.

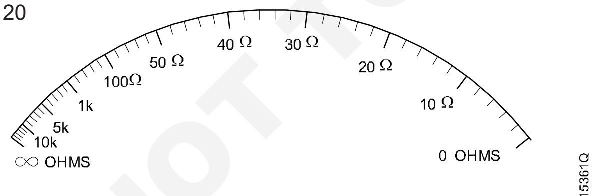
As shown in Fig 20, the meter scale will be marked zero ohms at the right end and infinite ohms at the left end.

Fig 19



SERIES TYPE OHMMETER

Fig 20



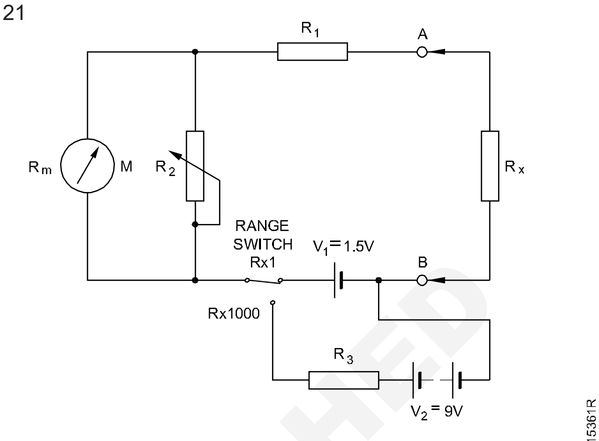
SERIES TYPE OHMMETER SCALE

This ohmmeter has a non-linear scale because of the inverse relationship between the resistance and current. This results in an expanded scale near the zero end and a crowded scale at the infinity end.

Multiple ohmmeter range: Most of the ohmmeters have a range switch to facilitate measurement of a wide range of resistors, say from 1 ohm up to 100000 ohms. The range switch acts as the multiplying factor for the ohms scale. To get the actual value of measurement,the scale reading needs to be multiplied by the R_x factor of the range switch.

The range switch arrangement is provided either through a network of resistances powered through a cell of 1.5V or through a battery of 9 or 22.5 volts. The latter arrangement is shown in Fig 21. The resistance value of R_3 is so chosen that the full scale current is passed through the meter at the enhanced source voltage.

Fig 21

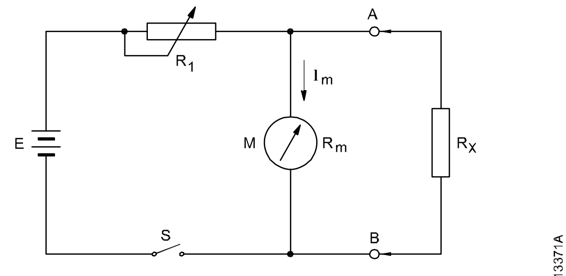


MULTI-RANGE SERIES TYPE OHMMETER

Use: This type of ohmmeter is used for measuring medium resistances only, and the accuracy will be poor in the case of very low and very high resistance measurements.

Shunt type ohmmeter: Fig 22 shows the circuit diagram of a shunt type ohmmeter. In this meter the battery 'E' is in series with the adjustable zero ohm adjust resistor R_1 and the PMMC meter movement. The unknown resistance R_X, which is connected across the terminals A and B, forms a parallel circuit with the meter. To avoid draining of the battery during storage, the switch S is of spring-loaded push button type.

Fig22

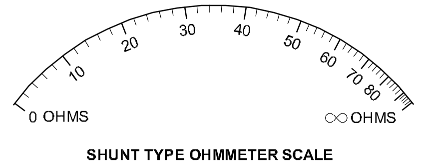


SHUNT TYPE OHMMETER

Working: When the terminals A and B are shorted (the unknown resistance R_X= zero ohm), the meter current is zero. On the other hand, if the unknown resistance R_X = μ (A and B open) the current flows only through the meter, and by a proper selection of the value R_1, the pointer can be made to read its full scale.

The shunt type ohmmeter, therefore, has the zero mark at the left hand side of the scale (no current) and the infinite mark at the right hand side of the scale (full scale deflection current) as shown in Fig 23. When measuring resistance of intermediate values, the current flow divides in a ratio inversely proportional to the meter resistance and the unknown resistance. Accordingly the pointer takes up an intermediate position.

Fig 23



Energy meter

Necessity of energy meter: The electrical energy supplied by the electricity board should be billed based on the actual amount of energy consumed. We need a device to measure the energy supplied to a consumer. Electrical energy is measured in kilowatt hours in practice. The meter used for this is an energy meter.

In AC, an induction type of energy meter is universally used for measurement of energy in domestic and industrial circuits.

Principle of a single induction type energy meter:

The opeartion of this meter depends on the induction principle. Two alternating magnetic fields produced by two coils in induce current in a disc and produce a torque to rotate it (disc). One coil (potential coil) carries current proportional to the voltage of the supply and the other (current coil) carries the load current. Torque is porportional to the power as in wattmeter. The watt-hour meter must take both power and time in to consideration. The instantaneous speed is proportional to the power passing through it. The total number of revolutions in a given time is proportional to the total energy that passes through the meter during that period of time.

Iron core: It is specially shaped to direct the magnetic flux in the desired path. It directs the magnetic lines of force, reduces leakage flux and also reduces magnetic reluctance.

Potential coil (voltage coil): The potential coil is connected across the load and is wound with many turns of fine wire. It induces eddy current in the aluminium disc.

Current coil: The current coils, connected in series with load, are wound with a few turns of thick wire, since they must carry the full load current.

Disc: The disc is the rotating element in the meter, and is mounted on a vertical spindle which has a worm gear at one end. The disc is made of aluminium and is positioned in the air gap between the potential and current coil magnets.

Spindle: The spindle ends have hardened steel pivots. The pivot is supported by a jewel bearing. There is a worm gear at one end of the spindle. As the gear turns the dials, they indicate the amount of energy passing through the meter.

Permanent magnet/brake magnet: The permanent magnet restrains the aluminium disc from racing at a high speed. It produces an opposing torque that acts against the turning torque of the aluminium disc.

Functioning of energy meters: The rotation of the aluminium disc in is accomplished by an electromagnet, which consists of a potential coil and current coils. The Law, the voltage drop (E) will be proportional to the current flowing through the coil of resistance R (E = IR). For example, you have a 0-1 milliampere meter movement with a coil resistance of 1000 ohms. When 1 milliampere is flowing through the meter coil and is causing F.S.D. the voltage developed across the coil resistance will be:

$E = I_M R_M = 0.001 \times 1000 = 1$ volt.

If only half that current (0.5 milliampere) was flowing through the coil, then the voltage across the coil would be:

$E = I_M R_M = 0.0005 \times 1000 = 0.5$ volt.

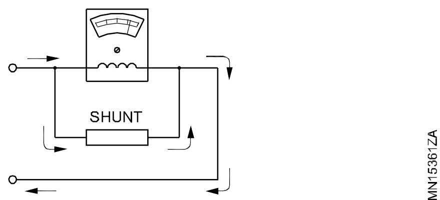
It can be seen that the voltage developed across the coil is proportional to the current flowing through the coil. Also, the current that flows through the coil is proportional to the voltage applied to the coil. Therefore, by calibrating the meter scale in units of voltage instead of in units of current, the voltage in various parts of a circuit can be measured.

Although a current meter movement inherently can measure voltage, its usefulness is limited because the current that the meter coil can handle, as well as its coil resistance, are very low. For example, the maximum voltage you could measure with the 1 milliampere meter movement in the above example is 1 volt. In actual practice, voltage measurements higher than 1 volt will be required.

Extension of range of MC ammeters

Shunts: Moving coils of basic meters by themselves cannot carry large currents, since they are made of fine wire. To measure a current greater than that which the moving coil can carry, a low resistance, called a SHUNT, is connected across the instrument terminals as shown in Fig 24.

Fig 24



The shunt, therefore, makes it possible to measure currents much greater than that could be measured by the basic meter alone.

To understand how a shunt can be used to extend the range of a current meter, it is important to understand the behavior of current flow through two resistors connected in parallel. It has already been made clear that current will divide between two resistors in parallel.

It was also made clear that the current through each resistor is inversely proportional to its resistance; that is, if one resistor has twice the resistance of another, the current flowing through the larger resistor will be half the current through the smaller one.

Current flow divides between two resistors parallel in a ratio inversly proportional to their resistance.

Resistor R_2 is twice as large as resistor R_1. Therefore, the current through R_2 will be one-half the current through R_1.

Every meter coil has definite DC resistance. When a shunt is connected in parallel with the coil, the current will divide between the coil and the shunt, just as it does between any two resistors in parallel. By using a shunt of proper resistance, the current through the meter coil will be limited to the value that it can safely handle, and the remainder of the current will flow through the shunt.

Care and Maintenance of meters

Always start by starting the range switch at a value higher than that which you reasonably expect to measure. If not, you could damage the instrument.

Make sure your multi-tester is set in the right mode. Trying to measure voltage with the mode set on "AMPS" could destroy the meter and possibly cause harm to the operator. Also, some meters are destroyed by trying to measure voltage if meter is set to measure resistance.

If you have a choice of finding a fault in a circuit with dangerous voltages on it by either testing voltages or measuring resistance, turn off the power and use the latter.

Keep test leads in good condition-No cracked insulation, keep probes sharp, connectors tight.

Do not place the instrument in a place where it may be pulled off and onto the floor or onto other circuitry.

If using an ammeter that requires that it be inserted in series with the measured circuit, turn OFF the power, make your connections, the turn ON the power and measure. Repeat procedure when disconnecting the meter.

Clamp-on type ammeters do no require the circuit to be opened for insertion of the meter; Safer and faster to use.

When using a HI-POT tester, keep the area clear of these who are not part of the testing.

Always start tests with output control at zero, and the switch in the "OFF" condition. Make sure all equipment grounds are tight, and that the device is connected and used accroding to manufacturer's instruction .

Controls and functions of Oscilloscope

Objectives : At the end of this lesson you shall be able to
- **explain the use of different controls**
- **explain the use of Alternate and Choped modes for two inputs**
- **explain sweep mode and relevant controls**
- **state 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 measuraed 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 200mvp-p at 1 kHz 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 ±3 percent may deteriorate to ±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 ±3 percent to ±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.

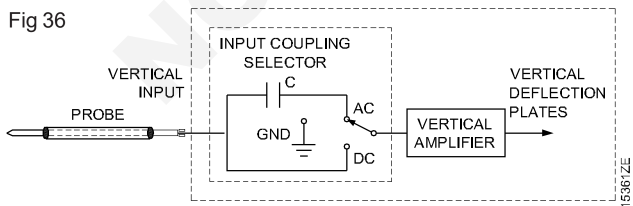
Input coupling

The coupling selector is a three-way switch, to select either DC or AC coupling and ground. In DC coupling, the input signal is fed directly into the amplifier, while AC coupling enables blocking of the DC component of the input signal and passes only the AC component of the signal to the Y amplifier. In the ground position, the input of the Y amplifier is grounded. Hence, care should be taken to ensure that the input signal is not grounded in the ground position and that only the input point of the Y amplifier in the oscilloscope is grounded.

Vertical input coupling modes

All oscilloscopes have two vertical input coupling modes, namely AC coupling and DC coupling as shown in Fig 1. In DC coupling selection, the signal to vertical input BNC receptacle is directly routed to the input of the relevant vertical amplifier as shown in Fig 36 inside the scope. As a result, what you see on the oscilloscope is what you feed into it.

Fig 36



VERTICAL INPUT COUPLING MODES

The DC coupling mode is used in majority of oscilloscope measurements whether it is measuring DC amplitudes or seeing logic low and high levels over analysing transient and repetitive AC waveforms over the specified bandwidth of the oscilloscope. However, when it comes to measuring only the amplitude of a certain DC voltage with no intention of analysing the quality of DC or looking for presence of any noise spikes, the oscilloscope in the DC coupling mode does the job.

In the AC coupling mode, the applied signal is routed to the vertical amplifier input through capacitor (Fig 1) with the result that DC, if any, in the signal gets blocked and only the AC or the time varying part is able to get through and reach the vertical amplifier input. So the displayed waveform is not what you actually feed. For instance, if you want to analyse noise spikes or ripple content riding on a DC you would have no option other than going in for the AC coupling mode.

In the DC coupling mode, the beam would go off the screen as you increase the vertical sensitivity to get an expanded display of comparatively much smaller ripple amplitude. In the AC coupling mode, you could expand the display and make the ripple portion fill the entire screen for detailed analysis.

There is a ground position (designated GND) available on the coupling selector. In this position, the input of the vertical amplifier is grounded and this position can be used to know the position of the beam for zero input.

Input impedance

This is the impedance at the Y input point and is normally specified as 1 M ohms shunted by 25 pF. It is actually the effective resistance and capacitance across the Y input. All oscilloscopes have a standard input impedance of 1M ohm paralleled approximately by 25 pF.

Maximum input voltage

It is the maximum voltage that can be safely applied to the Y input of the oscilloscope. For example, a model specifying the maximum input voltage to be 400V (DC + peak AC) means that the voltage of the signal to the input cannot exceed 400V, which includes both the DC voltage and the peak AC voltage of the signal.

Vertical operating modes and relevant controls

In a dual trace oscilloscope, if the two vertical input channels are designated CH1 and CH2, the available vertical operating modes usually are CH1, CH2, ALT (alternate), CHOP (chopped) and CH1 + CH2. CH1 mode selection implies that the beam traces the waveform applied to the channel-1 vertical input every time it sweeps across the screen.

With CH1 + CH2 mode selected, each sweep across the screen traces channel 2 vertical input waveform. When CH1 + CH2 mode (also referred to as ADD mode) is selected, what we see on the screen is sum of CH1 and CH2 signals as a function of time. Alternate (ALT) or chopped (CHOP) modes are selected when we intend to see two different signals simultaneously.

Alternate or chopped

ALT and CHOP modes are used in two different situations. In the ALT mode, CH1 and CH2 signals are traced on alternate sweeps, i.e if nth sweep traces CH1 signal then (n+1)th sweep would trace the CH2 signal, (n+2)th would trace the CH1 signal again and the process would continue. If the sweep speed is low, say slower than 10 ms/div or so, we will see a blinking display of the two sweeps. For faster sweep speeds, the two displays appear to be present at the same time. The ALT mode display of two channels thus gives an uncomfortable display when the signal frequencies are low. This mode should preferably be used for viewing high frequency signals.

In the CHOP mode, each sweep across the screen switches the beam between CH1 and CH2 at a very fast rate (the chopping frequency is typically 50 kHz to 100 kHz). In fact, we can see this chopping effect by selecting the CHOP mode and choosing a time base setting faster than the chopping frequency. CHOP mode is not suitable for viewing very high frequency signals as you are likely to miss vital signal information during the time period when the sweep is tracing the other signal. CHOP mode is, however, the right mode to select for viewing signals having frequencies of a few kilohertz or more.

In some oscilloscopes (usually the ones with lower bandwidth) we do not have a separate select button for CHOP and ALT modes. Instead, we have the dual mode in which the oscilloscope has in built circuitry to give a chopped sweep operation for lower frequency signals (or slower time base settings), and an ALT mode for viewing high frequency signals (or faster time base settings). The range of time base setting for which the scope offers a CHOP mode or an ALT mode is usually indicated on the time base selector switch.

In the front panel of a oscilloscope you would notice a light coloured semi-circular band from 0.5 s/div setting to 1 ms/ div setting indicating the CHOP mode and another dark semi-circular band from 1 ms/div indicating ALT mode.

LF Rejection

This is a method of coupling the trigger signal with the trigger circuit. The trigger signal is fed to the trigger circuit via a high-pass filter, where the low frequency component (less than 10 kHz) is eliminated. Thus, triggering is effected only by the high frequency component. When the trigger signal contains low frequency noise (particular hum) it is eliminated so that the triggering is established.

HF Rejection

In this method, the trigger signal is fed via a low-pass filter where the high frequency component (more than 30 kHz) is eliminated. Triggering is effected only by the low frequency component.

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 ($-V_e$) 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 unless. 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.

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 developed 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.

L.C.R. Meter

The LCR meter is an electronic test equipment used to measure among other parameters the impedance of a component (fig 37 and 38)

Fig 37

Usually the device under test (DUT) is subjected to an AC voltage source, then the voltage over and current through device under test are measured. The measured inpedance consists of real and complex components. The phase angle is also an important parameter.

Fig 38

L.C.R. METER

EMN15361ZG

Signal Generator: A signal generator with a multimeter and an oscilloscope forms the trio work-horse instrument of an electronic mechanic. The signal generator generate a wide variety of signal waveforms covering broad signals. Therefore, signal generators are classified in two main subdivisions based on waveforms produced and frequency ranges covered. Based on the signal waveforms produced the following main types are popular;

1 The sine-wave generator

It is most common for general-purpose testing. It is widely used in both continuous-wave (CW) and amplitude-modulated (AM) forms.

2 The square-wave generator

It is also commonly found in laboratories and is used for amplifier response testing and in performing other wave-shaping functions.

3 Pulse generator

With a facility for broad selection of pulse duration and repetition rates, these are employed for example for timing and testing electronic circuits both analog and digital.

Square-wave generators

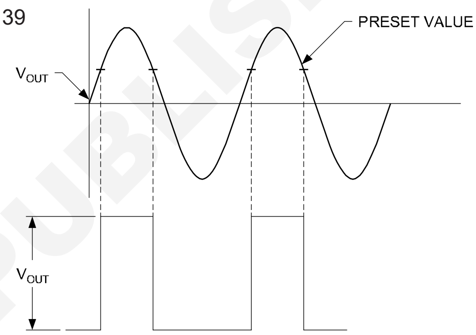
Generators for producing this type of waveform fall into two main groups: the combination sine and square-wave generators and the square-wave generators.

The first group offers a choice of either waveform but does not give the precision of square-wave output of the second group. The square wave generators provides only square waves with high precision. In relatively inexpensive combination generators, a pseudo square wave is often produced by simply clipping the original sine wave either by diode clipping or overdriven amplifier action. As a result, the products of such action retain the rise and fall portions of the sine wave. In such cases, only an approximate square wave is produced, suitable only for limited wave-shaping observations.

Combination generator

A typical laboratory combination generator generates true square waves as shown in Fig 39 with a Schmitt-trigger circuit. It generally provides frequency ranges of 10 hertz to 100 kilohertz for the square wave section. The rise time of the square wave at full-scale deflection will be generally less than 750 nanoseconds and the tilt is approximately 5 percent at 20 hertz. The peak-to-peak square-wave output will be generally 6 volts, with provision for attenuation in steps of 10 decibels each. Direct output upto 73 volts (p-p) is also provided by-passing the attenuator section.

Fig 39



EMN15361ZH

Square wave generator

A typical laboratory square-wave generator, produces square waves with flat horizontal portions, free of any noticeable overshoot and ringing. The square waves will generally have a rise time of less than 0.02 microsecond (20 nanoseconds) over the frequency range of 25 hertz to 1 megahertz. The frequency, obtained by the setting of a step switch and a continuously variable fine-frequency control can be read directly from the meter provided on the equipment.

Signal generators based on its frequency coverage

The frequency range in a signal generator can affect its operational characteristics markedly. Ranges vary from audio frequency (AF from 20 to 20,000 hertz) to radio frequency. The R-F ranges in telecommunication alone extend well into the gigahertz region, covering ranges where the higher frequencies are millions of times greater than the lower R-F frequencies as given in the Table below.

Table : Regions of the frequency spectrum

Region	Frequency band	ITU Band* No.
(VLF) Very low frequencies	3×10^3 to 3×10^4 (30 kHz)	4
(LF)Low frequencies	3×10^4 to 3×10^5 (300 kHz)	5

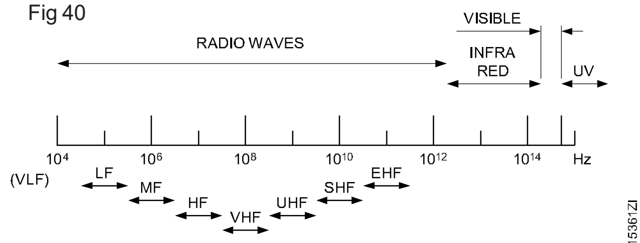
(MF) Medium frequencies	3×10^5 to 3×10^6 (3 MHz)	6
(HF) High frequencies	3×10^6 to 3×10^7 (30 MHz)	7
(VHF) Very high frequencies	3×10^7 to 3×10^8 (300 MHz)	8
(UHF) Ultrahigh frequencies	3×10^8 to 3×10^9 (3 GHz)	9
(SHF) Super high frequencies	3×10^9 to 3×10^{10} (30 GHz)	10 (or 1cm)
(EHF) Extremely high frequencies	3×10^{10} to 3×10^{11} (300 GHz)	11 (or 1cm)

***International Telecommunication Band Number**

The more common name microwave frequencies is generally used to span the regions of SHF and EHF. Radar bands in these regions have distinctive names, such as the X-Band at around 10 gigahertz.

Useful frequency regions are being explored at both the lower and upper edges of the electromagnetic spectrum shown graphically in Fig 40.

Fig 40



GRAPHIC VIEW OF ELECTROMAGNETIC SPECTRUM

Audio frequency generators

Signal generation is based on the oscillator. in addition to the common regenerative feed-back amplifier with LC resonant circuit various RC combinations can be used for the oscillating circuit of a signal generator. The one almost universally employed in practical AF generators is the Wien-bridge circuit.

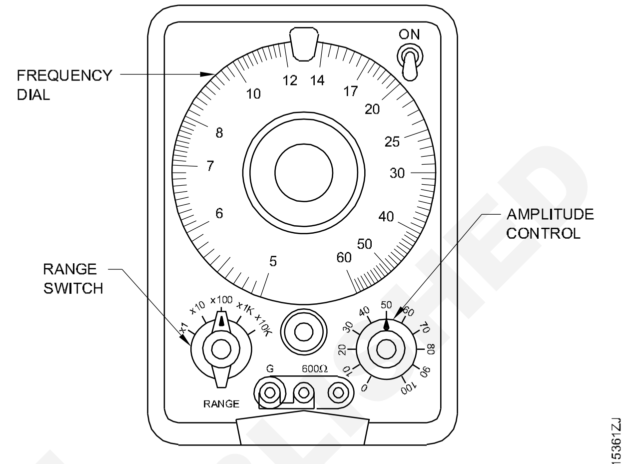
An LC circuit would require bulky nonlinear inductors for changing frequency ranges at lower frequencies. The RC circuit changes range by the use of precision resistors. Moreover, the stability of the RC circuit against changes in load is much better than the stability of an LC circuit, which reacts to load changes with variations in both the frequency and amplitude of the output. Thus even though the RC circuit requires more stages of amplification that required in an LC circuit, the resulting circuit is much more suitable for laboratory purposes and for use in practical instruments.

The AF oscillator shown in Fig 40 generates practically pure sinusoidal waveforms over the range 5 hertz to 600 kilohertz. This range includes signals in the subsonic, audio and ultrasonic bands. There are five overlapping decade bands. The first covers 5 to 60 hertz and the last 50 to 600 kilohertz. At all frequencies, output can be as great as 20 volts runs on open circuit; when delivering a signal to a 600 ohm load, the voltage across the load is one-half the open-circuit voltage, or 10 volts. The power in this matched load is thus E^2/R or

10 x 10 volts/600 ohms = 1/6 watt or 167 milliwatts

Although 167 milliwatts does not look to be large value

Fig 41



AUDIO FREQUENCY GENERATOR

Frequency coverage: 5 hertz to 600 kilohertz (or 1 hertz to 100 kilohertz in alternate model)

Calibration accuracy: ±2 percent under normal conditions

Frequency response: Within ±1 decibel (of a 1000 hertz reference) over entire frequency range.

Frequency stability: Negligible shift in output frequency for ±10 percent line-voltage variations.

Distortion: Less than 1/2 percent below 500 kilohertz (less than 1 percent above 500 kilohertz) independent of load impedance.

Balanced output: May be obtained (at maximum output) with better than 1 percent balance; or may be operated single-ended (with low side grounded), at an internal impedance of 600 ohms, for any portion of output attenuator.

When desired, the output can be obtained ungrounded by using only the high and low output terminals and leaving the ground terminal unconnected. The circuit retains its desirable characteristics throughout a variety of AF and even RF testing conditions where a pure sine-wave signal of constant amplitude over a wide frequency range is required in the laboratory.

Other version of the AF signal generator using the Wien-bridge arrangement, offers some interesting additional features. One such is that it can be synchronized from an external source and extended frequency range of 2 hertz to 2 megahertz.

When an external signal of atleast 1 volt is introduced into the ext sync jack, the oscillator locks in when it is within ±3 percent of the frequency of the introduced signal. This lock-in range can be increased proportionally as the external sync signal becomes greater. If it is a 10 volt sine wave, the frequency of the oscillator may be locked within 30 percent either side of the input signal. Besides the obvious synchronizing application of locking the oscillator output to a crystal-frequency standard, other applications include service as a phase shifter in an amplitude modulation source and an automatic phase-controlled oscillator.

Radio frequency generator

A radio-frequency generator suitable for laboratory applications as a "standard signal generator" must be able to generate frequencies from, around 100 kilohertz upto about 30 megahertz. Also it must have an output signal stable both in frequency and amplitude. It is easy to get an oscillator to oscillate in this range; but difficult to keep the frequency and amplitude constant in spite of slight changes in normal operating conditions.

A ±1 percent change in a nominal output frequency of 1000 hertz (or ±10 hertz) might easily be tolerated for an AF signal; the same change in a 10 megahertz signal would shift the frequency of 100,000 hertz and might easily detune a high-Q tuned circuit. Maintaining and checking the frequency stability of high frequency circuits is greatly simplified by the use of crystal oscillator and crystal calibration circuits. The crystal oscillator is inherently very stable and can provide constant frequencies within much better than 0.01 percent (or 1 part/10,000). When used in a crystal oven it will furnish accuracies of 1 part/1,000,000 (±0.0001 percent). For most laboratory applications, direct reading of the variable-frequency dial to around 1 percent is sufficient, if this dial frequency can be checked against a crystal calibrator whenever greater precision, usually upto ±0.01 percent is desired.

Besides being able to generate a reliably known frequency the standard signal generator must also provide that the signal be accurately calibrated in microvolts of amplitude and be capable of being modulated to a known percentage. The known amplitude callibrated in microvolts is provided by a low-impedance, variable attenuator, monitored by a meter generally labeled carrier microvolts. The low impedance is necessary to maintain constant output as the generator is fed into various loads. The output of the generator is normally provided by a coaxial cable terminated in a low resistance, generally of 50 ohms. The impedance seen by the load, which is this resistor in parallel with the attenuator is usually much lower. This low output impedance is maintained at all settings of the attenuator, which can vary the output from a few microvolts up to calibrated values of 100,000 microvolts and also upto 1 or 2 volts uncalibrated.

Typical specifications of a RF generator

Frequency range: 75 kilohertz to 30 megahertz in different ranges. Each range is push-button selected, and the frequency dial set for any frequency within that range by a reversible motor, which turns the variable capacitors.

Modulation: Continuously variable from 0 to 100 percent either at 400 or 1000 hertz or from an external source.

Output: Continuously variable from 0.1 microvolt to 2.2 volts, at an output impedance of 5 ohms (upto 2 megahertz) rising to 25 ohms (at 30 megahertz). Incidental frequency modulation is less than 0.01 percent at 30 percent amplihertz (or ±10 hertz) might easily be tolerated for an AF signal; the same change in a 10 megahertz signal would shift the frequency of 100,000 hertz and might easily detune a high-Q tuned circuit. Maintaining and checking the frequency stability of high frequency circuits is greatly simplified by the use of crystal oscillator and crystal calibration circuits. The crystal oscillator is inherently very stable and can provide constant frequencies within much better than 0.01 percent (or 1 part/10,000). When used in a crystal oven it will furnish accuracies of 1 part/1,000,000 (±0.0001 percent). For most laboratory applications, direct reading of the variable-frequency dial to around 1 percent is sufficient, if this dial frequency can be checked against a crystal calibrator whenever greater precision, usually upto ±0.01 percent is desired.

Operate the front panel controls of a digital storage oscilloscope

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

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

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

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

Digital Storage Oscilloscopes (DSO)

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

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

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

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

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

1 Data acquisition

2 Storage

3 Data display.

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

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

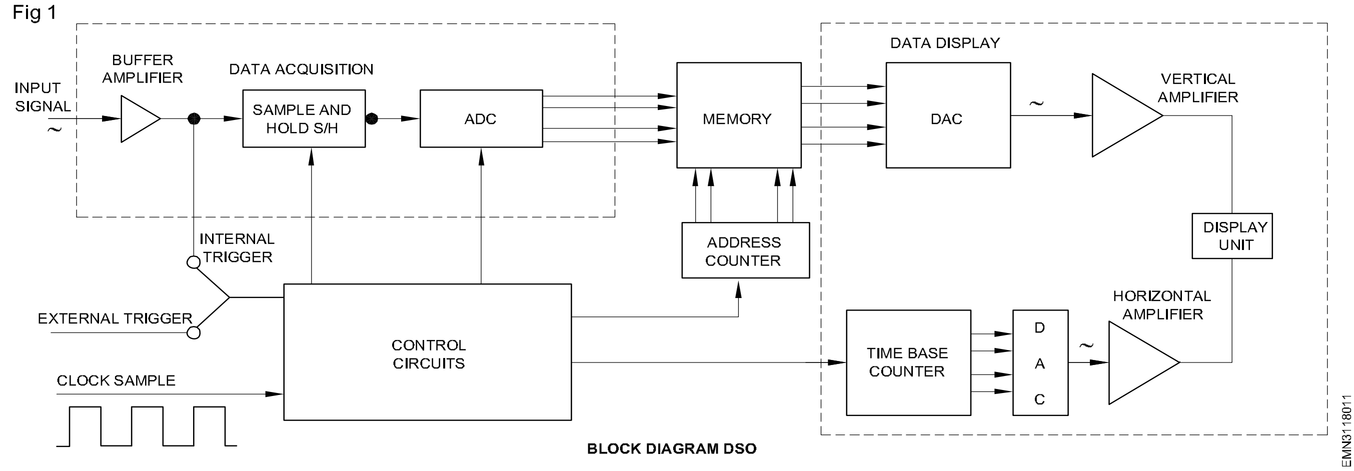
When the memory is full, the next data point from the ADC is stored in the first memory location writing over the old data. The data acquisition and the storage process is continues till the control circuit receive a trigger signal from either the input waveform or an external trigger source. When the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

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

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

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

Fig 1



BLOCK DIAGRAM DSO

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

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

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

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

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

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

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

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

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

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

- Acquires enough data to fill the portion of the waveform red frequency and displays the frequency in the lower right corner of the screen.
- Continues to acquire data while waiting for the trigger condition to occur
- Detect the trigger condition
- Continues to acquire data unti the wave form record full
- Displays the newly acquired waveform

For edge and Puse triggers, the osciloscope counts the rate at which triggedr events occur to determine trigger frequency and displays the frequency in the lower right corner of the screen.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

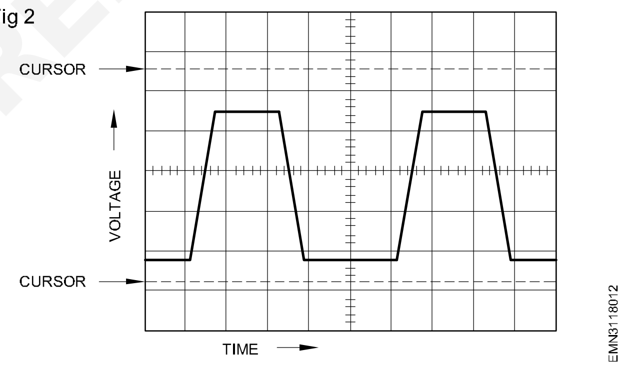
You can change the vertical scale of a waveform. The waveform display will contract or expand about the ground level.

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

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

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

Fig 2



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

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

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

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

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

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

Acquire: Push the Acquire button to set acquisition parameters

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

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

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

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

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

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

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

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

Auto set

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

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

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

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

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

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

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

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

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

For a math FFT source, measures magnitude and frequency

Utility: Push the UTILITY button to display the Utility Menu.

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

Capturing a single shot signal

Objectives : At the end of this lesson you shall be able to
- **capture a single shot signal**
- **interface the usb port to the external device**
- **understand the printer setups before printing the waveform.**

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

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

The DSO can display captured data in various ways.

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

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

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

Interface the DSO to external devices

Objectives : At the end of this lesson you shall be able to
- **interface the USB port to the external device**
- **understand the printer setups before printing the waveforms**
- **differentiate DSO with CRO**

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

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

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

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

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

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

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

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

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

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

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

You can set the print button to do the following

- Send the current image to a Pictbridge compatible printer or computer to the rear USB port
- Save the current screen image to a USB flash drive choosing among a number of formats.

- Save the current image, the waveform data points of each displayed waveform, and the current set up parameters to a USB flash drive, with a single button push

You can also set the following options before printing

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

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

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

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

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

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

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

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

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

Uses of Digital Storage Oscilloscope

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

Difference between Analog oscilloscope and digital osciloscope

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

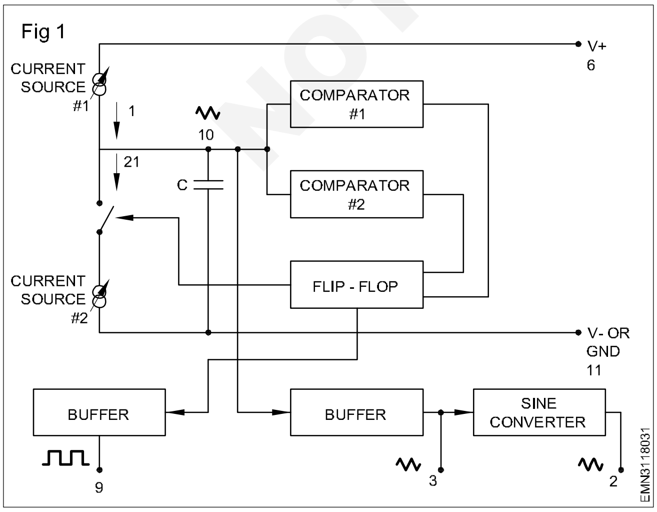
Function generator using IC 8038

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

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

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

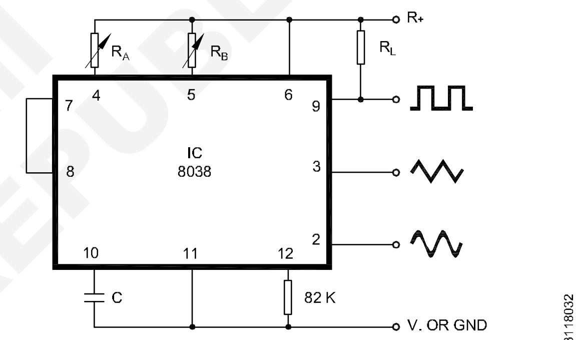
Fig 1



IC 8038 function generator (fig. 2)

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

Fig 2



IC 8038 FUNCTION GENERATOR

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

Waveform Timing

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

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

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

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

Fig 3

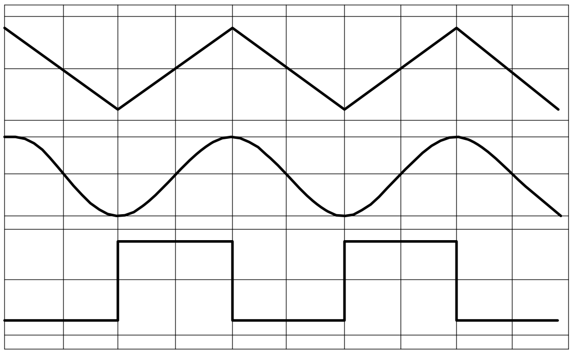
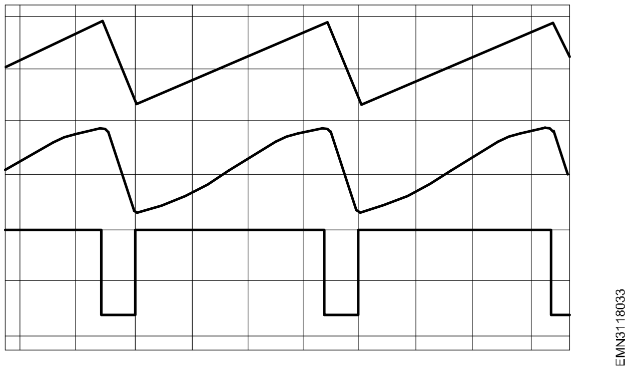


Fig 4



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

With two separate timing resistors, the frequency is given by

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

or, If $R_A = R_B = R$

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

Selecting R_A, R_B and C

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

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

R1 and R2 are shown as 11K and 39 KΩ

A similar calculation holds for R_B.

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

Soldering of wires

Objectives : At the end of this lesson you shall be able to
- **explain the purpose of solder and flux and their types**
- **describe the soldering technique**
- **describe the features of soldering iron**
- **explain desoldering and desoldering tools**
- **study the soldering and desoldering station and their specification**
- **explain the desoldering methods using pump and wick.**

Need for soldering

Requirements of an electrical joint

[1] The electrical joint must provide ideally zero resistance or at least a very low resistance path, for the flow of current.

[2] The electrical joint made should be strong enough to withstand vibrations, physical shock, bumps etc, without causing any deterioration to the quality and strength of the joint.

[3] The electrical joint should be able to withstand corrosion and oxidation due to adverse atmospheric conditions.

All the above requirements of an electrical joint can be achieved by making a solder joints.

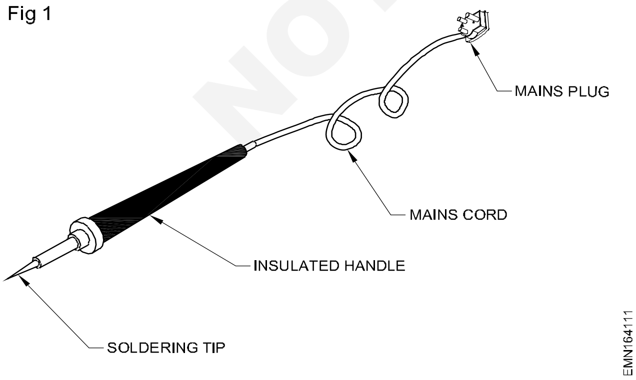
Solder

In a soldered joint, the solder is a mixture of metals, generally TIN and LEAD. It is made to melt at a certain temperature. It acts as a filler between the parts of the connection/joint to form a continuous, low resistance metallic path for conduction of electricity.

In soldering, as the metal surface is wetted (free flow of liquid solder over a surface) by the solder, a complex chemical reaction, bonds the solder to the metal surface.

The tin content of the solder diffuses with the metal surface to form a layer of a completely new alloy. The alloy so formed will have the same structure as the constituent metals and retain their metallic properties and strength.

Fig 1



Soldering and soldering irons

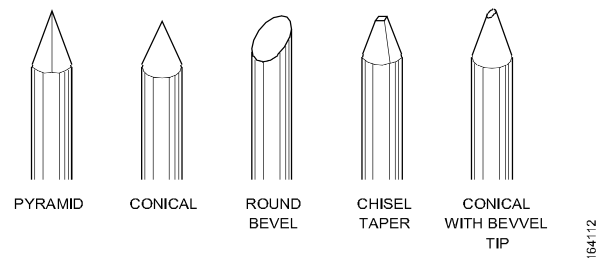
While soldering, the solder is made to melt between the metallic surfaces of the joint, using a soldering iron, as shown in Fig 1. A **soldering iron** is an instrument used to produce the required heat to carry out soldering.

Soldering irons of different wattage ratings starting from 10 watts to more than 150 watts are available commercially. Depending on the type, size and heat sensitivity of the components being soldered, the most suitable wattage soldering iron should be chosen. Most of these soldering iron work on 240V, 50Hz AC mains supply. There are special type irons which work on dc supply also. For soldering delicate components, soldering irons with temperature controlling facility are used. These are known as soldering stations.

Soldering iron tips

Soldering irons are designed to take, a variety of tip sizes and shapes as shown in Fig 2. The choice of the iron and the tip to use depends on, the nature of the joint to be soldered. A proper selection of the soldering iron and tip is important for obtaining good quality soldered joint. To solder effectively, the tip of the soldering iron must be kept clean all times.

Fig 2



COMMON SOLDERING IRON TIP SHAPES

Types of solders

Solders are available in many forms. The type to be chosen depends on, the type of soldering to be carried out. The wire type solder is the most commonly used solder for hand soldering work, using low wattage soldering iron.

Solders available in the market may have different tin-lead proportion in it. For general electronic circuit soldering work, solder with 60% tin and 40% lead is most suited. This solder is commonly called 60/40 solder. This solder has been specially developed to possess superior properties required for electronic circuit work.

Soldering FLUX

A protective oxide layer forms on the exposed surface of most metals. The rate at which the oxide layer is formed varies from metal to metal. The layer forms quickly on newly exposed metal, and over time, the layer slowly become quite thick.

This oxide layer on metals interferes with soldering. Hence, it must be removed before a soldered joint can be made.

The purpose of flux is to first dissolve the thin layer of oxide from the surface of the metals to be joined, and then form a protective blanket over them until the solder can flow over the joint surfaces to form the joint.

However, thick layers of oxide must be removed using an abrasive method as all types of flux are not capable of dissolving their oxide layers.

Types of flux

There are several types of fluxes used in different types of soldering. The type of flux used for soldering electronic components is called **rosin**. Rosin is made from a resin obtained from the sap of trees.

Rosin flux is ideal for soldering electronic components because, it become active at the soldering temperature, but revert to an inactive state when cooled again. An additional advantage is that it is non-conductive.

The rosin has activators or halides added to it. The activators used in rosins are mild acids that become very active at soldering temperatures. These acids dissolve the oxide layer on the metals to be soldered.

Organic and inorganic acid fluxes are available. These fluxes are not suitable for soldering electronic circuits.

Common forms of flux

Flux is available in a variety of forms to suit various types of application. Flux is available as a liquid, paste or a solid block. For most applications flux is often put in the solder itself during manufacture.

Not all flux types are available in all forms. For hand soldering work on electronic circuits, the best form for the flux is either as a liquid or a paste.

Rosin cored solder

Several manufacturers produce solder wire with the flux already included in one or more cores running along its length. This is known as **cored solder**.

The most popular type of cored solder for electronic hand soldering contains rosin type flux. Such solder is known as **rosin cored solder**.

When the solder is heated, the rosin flux melts before the solder. The rosin then flows out over the surface to be soldered ahead of the solder.

The amount of flux contained in the core is carefully controlled by the manufacturer and for most applications it will be sufficient. However, it is a common practice to apply additional liquid flux or flux paste to the joint, just prior to making the joint. This additional flux ensures that, sufficient flux available while the joint is being made. When the soldering has been completed, excess flux if any has to be removed.

Rosin-cored solder is available in different gauges as. It is important to choose a size suitable for the job at hand as given below;

- use 22 gauge for small joints
- use 18 gauge for medium joints
- use 16 gauge for large joints.

Soldering Technique

Soldering a joint

Selection and preparation of the soldering materials is the most time consuming phase of making a solder joint. Heating the joint and applying solder is the least time consuming but, it is the most important part of the soldering process.

Critical factors during soldering

1) Controlling the temperature of the workpiece
2) Limiting of time that a workpiece is held at soldering temperature.These factors are specially critical while soldering electronic components like resistors, capacitors, transistors, ICs etc., Failure to correctly time and coordinate the heating of the joint and add solder, will result in a poor quality joint and may even damage the components.

Stages in soldering

The soldering process can be divided into several distinct stages or phases as given below:

1 Selection and preparation of materials.

2 Heating the joint and adding solder.

3 Cooling the joint.

4 Cleaning the joint.

5 Inspecting the joint.

SELECTION AND PREPARATION OF MATERIALS

Selection of soldering iron wattage

Soldering irons are available in different wattage ratings starting from 10 watts to several 100 watts. The wattage of a soldering iron specifies the amount of heat it can produce. As a thumb rule, higher the physical dimension of the workpiece, higher should be the wattage rating of the soldering iron. Some of the suggested wattage choices are given below:

i) For soldering less temperature sensitive components such as, resistors on lug boards, tag boards, use 25 to 60W iron. For soldering on printed circuit boards, use 10 to 25 W iron.
ii) For soldering highly temperature sensitive components such as, diodes, transistors and integrated circuits, use 10 to 25 watts iron.

Selection of soldering iron tip

To ensure that the joint is heated to the required temperature ideally,

– the area of the tip face should be approximately equal to the area of the joint to be soldered

– the tip should be long enough to allow easy access to the joint.

– the tip should not be too long, as this may result in too low temperature at the tips working face.

In most soldering irons, the tip can be easily removed and replaced.

Selection of tip temperature

Good quality soldering iron tips have numbers punched on them. These numbers indicate the temperature to which the tip can be heated.

Tip No.	Temperature °C	Temperature °F
5	260	500
6	316	600
7	371	700
8	427	800

Selection of tip shape

Suggested soldering tip shapes selection table is given below;

Type of soldering work	Soldering tip shape to choose
Wires, resistors and other passive components on to lug/tag boards	CHISEL TIP
All miniature electronic components except ICs on to lug boards and printed circuit boards (PCB)	BEVEL TIP
Integrated circuits (ICs) on to printed circuit boards (PCBs)	CONICAL TIP

Selection of solder and flux

There are several sizes of the cored solders whose choice depends on the size of the joints to be soldered. Also the tin and lead percentage of the solder should be checked before using the solder. Different tin and lead combinations of solder need different temperatures for it to melt and reach the liquid state.

For electronic soldering applications, solder of tin and lead of 60/40 proportion is used. This solder proportion has a melting point of 200°C which is the required temperature for general purpose soldering irons.

While soldering to make a strong solder joint the flux should melt first, and then the solder. Therefore, while using rosin cored solder, cut off the first 5 to 10mm of the solder using a side cutter,so that any earlier melted portion of the solder blocking the rosin core is removed.

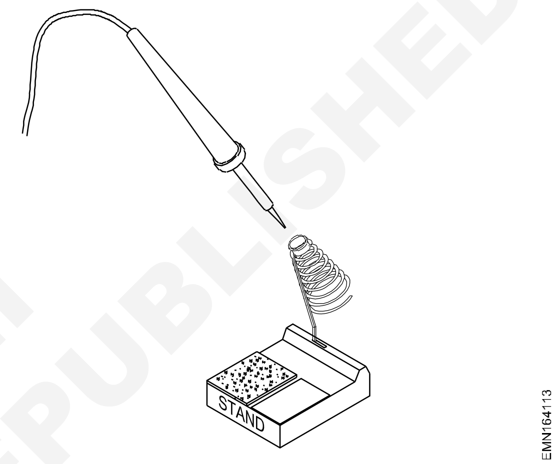
For ease of application, the flux used in addition to the cored flux in solder should be of paste form.

Flux is a chemical substance which has acidic properties. Therefore, it is advised not to touch flux by hand. Use a stick or a thin stiff brush to apply flux on workpieces. Hands should be washed after soldering work.

Soldering stand

Soldering stand plays an important role of retaining the soldering iron tip temperature around the required soldering temperature. The soldering stand should not allow the external temperature to cool the bit. At the same time the stand should not contain all the heat generated.

Fig 3



Soldering stands are specially designed as shown in Fig 3 to fulfill the above requirements. Such a design also prevents accidental burn injuries to the user of the soldering iron.

Another important requirement of a soldering stand is its mechanical stability. When the iron is taken out or placed in the stand frequently, the stand should not topple. An unstable stand is sure to cause burn injuries while carrying out serious soldering work.

Inspection of soldering iron

Most soldering irons are powered by AC mains voltage. This voltage level is high and can give shock if one is careless. Soldering irons will generally have lengthy mains cable. While using the iron, the mains cable gets twisted and will have to bear physical strain. Because of this strain, the insulation of cable may get cut. This may lead to live wires protruding out. The live wires give severe electrical shocks if it touches the user.

Hence, a thorough inspection of the soldering iron is a must before using through it.

Preparation of soldering iron for soldering

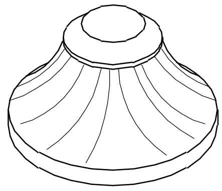
HEATING THE JOINT AND ADDING SOLDER

Tips for heating and applying solder to a joint to be soldered are given below:

– Do not apply additional flux required for a joint in one place. Apply a small amount of flux around the joint. Do not allow the flux to flow outside the area to be soldered.

- Place the iron tip at the connection such that the tip gets maximum contact with parts to be joined.
- Slowly feed the solder into the joint starting close to the soldering tip and moving towards the edge of the joint.
- Continue applying the solder to the joint until complete wetting of the joint has been achieved and the joint has a concave fillet as shown in Fig 4.

Fig 4



- After enough solder has been applied and solder removed, keep the soldering iron tip on the joint for a moment to ensure that all the flux on the joint has reached the soldering temperature. This will allow majority of the acids within the joint to break down, which otherwise will corrode the joint after a period of time.

  Generally the time taken to make a good soldered joint is between 3 to 7 seconds from applying the soldering iron.

COOLING THE JOINT

Tips for cooling a solder joint are given below:

- Allow the joint to cool without assistance. Do not blow air from your mouth or from any other source to cool the joint. Forced cooling, cools the joint much earlier than it has to, resulting in a dry or brittle solder joint which will lead to mechanical and electrical defects of the joint.
- Do not move any part of the joint while it is cooling. This disturbs the chemical bonding taking place. Movement of the joint while it is cooling results in a dry joint.

CLEANING THE JOINT

When a solder joint is made, the amount of flux applied should be just sufficient to make a good joint. But, quite often, there will be a brown waxy substance left on the joint. This is nothing but the flux residue. In its original state this residue is corrosive. Hence, the flux residue or excess flux must be removed from the joint before soldering can be considered as complete.

If the flux residue and excess flux are not properly removed, their corrosive nature of the flux will gradually destroy the component leads and the circuit board. The flux residue is also *tacky* and, if not removed, will collect dust and debris often leading to circuit failure.

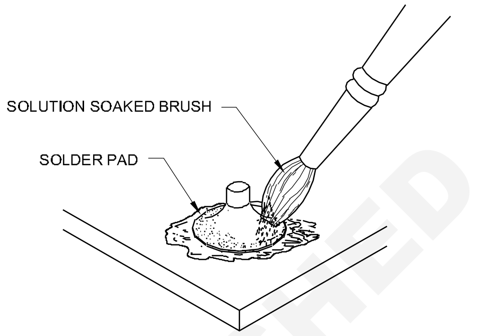
Removal of flux residue requires the use of solvents. The type of solvent depends on the flux used.

IsoPropyl Alcohol (IPA) is one of the solvents used for removing residual flux. It is available either undiluted or pre-mixed with water and can be obtained in pump sprays, aerosols, cans and drums depending on the quantity and style of use.

Cleaning using water/IPA solution

Determine the right method of application. (spray or liquid). Apply the solvent to the soldered joint. Use a clean acid brush, or some other type of stiff brush, to gently scrub the joint as shown in Fig 5, to help dissolve the residue, taking care to avoid splashing the mixture.

Fig 5



When the residue has been dissolved, dry the joint with a lint-free cloth to remove as much of the dissolved residue as possible.

Don't 's While Soldering

- **Do not use a poorly tinned soldering tip.**
- **Do not cool the tip of the iron by wiping it excessively on a damp sponge.**
- **Do not allow the solder to be carried to the joint on the tip of the soldering iron.**
- **Do not attempt to speed up the cooling of the joint by blowing on it.**
- **Do not move the soldered joint until the solder has cooled to solid state.**
- **Do not try and improve a bad solder joint by reheating. All the original solder must be removed and the joint preparation and soldering should be redone.**

Features of soldering iron

There are a number of features that the soldering irons posse need to be examined before a choice of a particular soldering iron is made. These include: size, wattage or power consumption, voltage method of temperature control, anti-static protection, type of stand available, and general maintenance and care issues.

Size: There is a wide variety of sizes of soldering iron available. Obviously those that are smaller will be more suited to fine work, and those that are larger will be more suited to the solder of items that are less delicate. The physical size will also run in parallel with the wattage or power consumption of the iron.

Wattage or power consumption: The power consumption or wattage of a soldering iron is often quoted. The wattage can vary. For basic non-temperature controlled irons, a wattage of 40 watts may be good for general work, and higher if heavy soldering is envisaged. For small PCB work, 15 or 25 watts is good value. For temperature controlled irons slightly higher wattages are common as the temperature control acts more quickly if more heat can be directed to the bit more quickly to compensate for removal of heat via the work item.

Voltage: While most soldering irons on sale in a particular will country have the correct mains voltage, 230V AC and there are also soldering irons that can run from 12 V. Some irons may be made for specialist applications where they need to run from low voltages.

Temperature control: Soldering irons use two main varieties of temperature control. The less expensive irons are regulated by the fact that when they come up to temperature, the loss of heat is the same as the heat generated. In other words they employ no form of electronic regulation. Other, more costly types have thermostatic control. This naturally regulates the temperature far better.Usually the temperature can be adjusted to the required value.These irons come into their own because when heat is drawn away by a large object being soldered,they will maintain their temperature far better. Those with no regulation may not be able to maintain their temperature sufficiently when soldering a large object,with the result that it is more difficult to melt the solder under these conditions.

Anti-static protection: With the increasing susceptibility of many electronic components,particularly the very advanced integrated circuit chips,static protection is becoming more of an issue. While most components being used by home constructors are often not damaged by static,some are. It is therefore a wise precaution to at least consider whether the soldering iron that is bought is one that has static protection.

Maintenance: When using any soldering iron it is essential that spare parts can be obtained. The soldering iron "bits" used to undertake the actual soldering have a limited life and even though the rest of the iron may work for many years,it will be necessary to change the bits at regular intervals. Additionally it is worth ensuring for the more expensive soldering irons,such as those with temperature control,that spare parts are available should they need repair.

Desoldering and desoldering tools

Desoldering

Many a time it may be necessary to disconnect/remove components and wires from a soldered or wired circuit due to the following reasons;

- Component failure(open,short etc).
- Incorrect component installation(polarity,position etc).
- Faulty or defective solder connections(dry solder etc).
- Circuit modifications(replacing,removing components etc).

Disconnecting a component or wire from any soldered circuit involves two separate actions. These are:

1 **DESOLDERING THE CONNECTION** - this action involves removal of the solder from a joint

2 **REMOVAL OF THE COMPONENT** - this action involves removing the component lead from the joint.

De-soldering the connection

De-soldering is a process of heating a soldered joint, to melt the existing solder and removing the molten solder from the joint.

De-soldering makes it easy to separate or pull-out the components,wires from the joint without unnecessary damage to the components and wires.

The heat required to melt the solder is supplied by a soldering iron. But removal of the molten solder from the joint requires the use of one of the following;

– Plunger de-soldering tool or desoldering pump

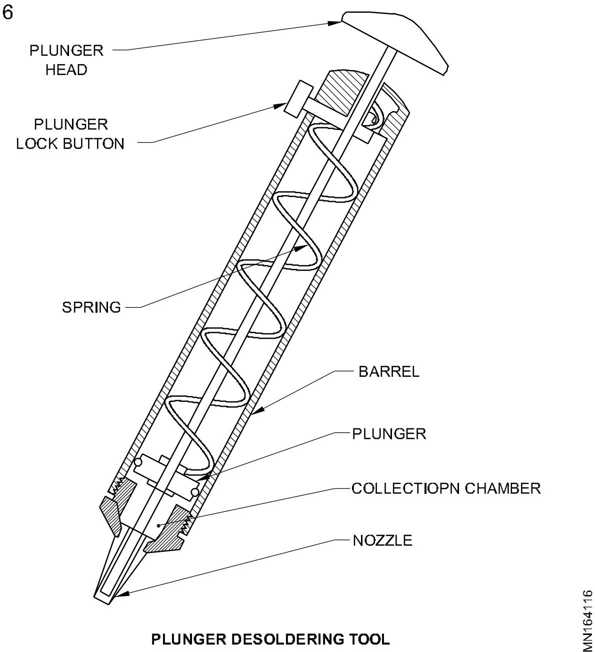
– Wicking braid

But, in many cases, desoldering is done using a nose plier and a soldering iron. First, the joint to be disconnected is heated using the soldering iron. Once the solder at the joint melts, the component lead is pulled away using a nose plier. This method of desoldering can be used for heavy components with strong leads. But this method should not be used for desoldering thin lead delicate components such as transistors, integrated circuits etc., This is because, in this method there is likelyhood of component getting overheated or the leads getting cut or leads getting detached from the body of the component.

PLUNGER DE-SOLDERING TOOL

A typical plunger de-soldering tool is shown in Fig 6.

Fig 6



PLUNGER DESOLDERING TOOL

Plunger type desoldering tool is the most commonly used desoldering tool. This tool works on the principle of air suction. When the plunger head is pushed fully inside gets locked with the help of the plunger button. This is known as cocking tool.

In this condition, the nozzle of the desoldering tool is kept almost touching the joint to be desoldered. If the joint is heated, the solder at the joint melts. If the plunger button of the desoldering pump is pressed, it releases the spring tension and moves the plunger up with a jerk. This causes the air to be sucked-in through the nozzle. Since the nozzle is now in contact with the molten solder, the molten solder is also sucked-in through the nozzle and gets collected in the collection chamber.

When the solder is removed using a plunger de-soldering tool, all the molten solder of a joint may not be sucked by the de-soldering tool at the first attempt, the joint must be reheated and the solder removed in two or three attempts.

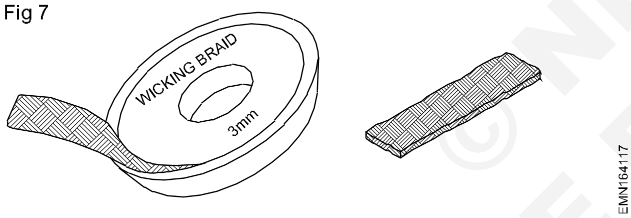
After doing one suction of molten solder, while cocking the tool for second suction, face the nozzle into a dirt collector. This is because, the solder collected at the tip of the nozzle gets pushed out every time the tool is cocked.

After several operations, the waste solder collected within the tool will begin to interfere with its operation. To prevent clogging of nozzle, this solder must be removed periodically and the tool must be cleaned and lubricated.

WICKING BRAID

Wicking braid as shown in Fig 7 is another simple de-soldering aid. This is made of copper and is soaked in flux. Wicking braid is nothing but a tape made of thin strands of copper knitted to form a mesh Fig 7.

Fig 7



A wicking braid relies on the tendency of the hot solder to flow towards the heat source. When a soldered joint is heated via a wicking tape as shown in Fig 23a, the molten solder gets drawn into the wicking braid as shown in Fig 23b. Thus the joint is now free from solder and the component can be removed easily.

The flux content of the wicking braid varies from brand to brand. Generally, the higher the level of flux in the braid, the more efficient it will be at drawing the solder from the joint.

Wicking braids are available in small, hand-held rolls and is supplied in a range of sizes from 0.8 to 6 mm wide so that the correct width of wicking braid can be selected for the joint to be de-soldered.

De-soldering using a wicking braid is commonly used for removing miniature components soldered on printed circuit boards(PCB's).

Removal of component

When solder is removed from the joint, the component can then be removed from the circuit board. If a component was soldered using clinched lead method. it is essential to remove the bridge of solder holding the lead.

To remove the solder bridge, follow the steps.

There are other special tools used for de-soldering such as De-soldering iron and multi-contact de-soldering block.

Soldering and desoldering station

Printed circuit board have changed the face of Electronics industry. Comparing the today's PCBs with the old hardwired, steel chassis devices, they lack the strength making them vulnerable to cracks and related defects. It may sometimes be possible to repair a broken PCB but it is very difficult process. Locating the cracked copper trace on the PCB is the most difficult part of the repair PCBs get damaged very easily. A little rough handing during installation or troubleshoot will invite a crack in the trace. While placing or removing PCBs from their sockets, one needs to put little extra force. This itself might cause a crack in the trace. Similarly when a component on a PCB is removed or inserted a little more heat for a little long period will make copper trace to come off the board's substrate. There may result a microscopic crack in the trace.

Soldering and Desoldering Stations

A typical competitive soldering station with ESD safe by design will comprise of hot air station soldering, LED double digital display. This kind of stations will come with PID controlled closed loop of sensor. The desolder station can give rapid heating, precise and stable temperature, suitable for soldering and de-soldering surface mounted. Such as QFPM PLCC, SOP, BGA etc package of ICs. Hot air station and intelligent cooling system, adopts imported heating wire, for a long life. There are normally light portable handle and suitable for mounting and reworking SMD component by hand for a long time.

Typical specifications of a Solder and Desolder stations :

Hot Soldering Station :		
Air Flow	:	0.16 - 1.2 Nm3/h
Pump Consumption	:	45W
Temp. Control	:	150-450°C
Heater	:	250W Metal
Rated Voltage	:	110V/220V 50/60Hz AC
Power Consumption	:	270W
Air Pump	:	Membranous
Solder Equipment	**:**	
Power Consumption	:	60W
Output Voltage	:	24V AC
Temp. Control	:	200-480
Ground Resistance	:	20 ohms

Heater : Ceramic Heating Element

A typical hot soldering station is shown in Fig 8.

Fig 8

Desoldering by using pump and wick

DESOLDERING is the process of removing soldered components from a circuit made on PCB. Desoldering pump along with the soldering iron is used for this purpose. A desoldering pump also known as solder sucker is a small mechanical device which sucks the liquid/molten solder from the joint where the components are mounted. In order to desolder a component from the PCB,we first heat up the solder joint with the soldering iron till the solder liquefies/melts. At the same moment we actuate the soldering pump by pressing the trigger lever and bring the tip over the molten metal and pull the trigger back by pressing a button. At this instant the lever is pulled back and the tip of the pump sucks the molten solder. This process is repeated until all the residue solder is sucked by the pump and the hole on the PCB is clear to solder a fresh component.

To actuate the pump the lever is pressed until there is a click sound which indicates that the lever will remain locked in the same position.

The desoldering pump's bottom head contains a hole through which the molten solder is sucked when the pump is triggered. The head is designed such that the extracted solder does not solidify and block it, consequently the sucked metal can be removed and discarded easily.

Desoldering Wick/ braid

Place the braid over a connection and heat the opposite side with an iron Sometimes adding a small amount of solder to the iron tip can actually speed up the process because that solder will help the iron transfer heat into the braid faster. Cut off and discard the dused wick. The only concern with using desoldering wick/braid is that the components and pads can easily become overheated, especially surface mount pads. As always, try to minimize the time parts are heated. This wick is 1" wide and 5 feet long, which should be satisfactory for most through-hole and many surface mount connections. Width is important because it dictates how much solder a certain length of braid can hold. Too thin, and the solder will quickly fill up the braid and stop it from absorbing. Too thick, and it will be hard not to touch neighboring joints. This particular braid is coated in pure resin - based flux that will leave a non-corrosive, non-conductive, and environmentally friendly residue the residue can be cleaned with alcohol if desired for cosmetic reason, but unless you are making military spec devices, cleaning should not be necessary. The casing is ESD safe.

Switches

Objective: At the end of this lesson you shall be able to
- **understanding varione types of switches and its application**

Switches

Electrical accessories: An electrical accessory is a basic part used in wiring either for protection and adjustment or for the control of the electrical circuits or for a combination of these functions.

Controlling accessories: The accessories which are used to control the circuits or an electrical point like switches are called `controlling accessories'. All the switches are specified in accordance with their function, place of use, type of mounting, current capacity and working voltage. For example - S.P.T. (Single pole tumbler) flush-mounted switch 6 amps 240 volts.

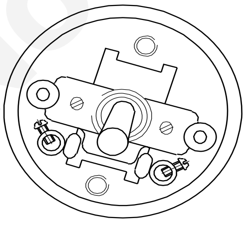
Types of switches according to their function and place of use

1 Single pole, tumbler switch
2 Single pole, two-way switch
3 Intermediate switch
4 Bell-push or push-button switch
5 Pull or ceiling switch
6 Single pole single throw switch (SPST)
7 Single pole double throw switch (SPDT)
8 Double pole single throw switch (DPST)
9 Double pole double throw switch (DPDT)

Of the above 1,2,3,4 and 6 may be either surface mounting type or flush-mounting type.

Single pole, tumbler switch: This is a two terminal device, capable of making and breaking a single circuit only. A knob is provided to make or break the circuit. It is used for controlling light or fan or 6 amps socket circuits. One - way switch is as shown in Fig 9.

Fig 9

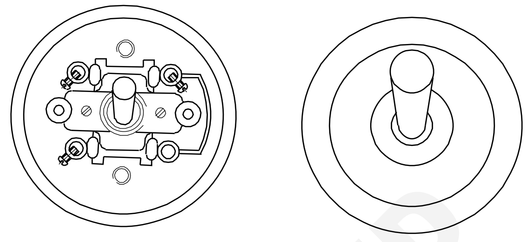


6 AMP SINGLE-WAY SURFACE MOUNTING SWITCH (COVER REMOVED)

EMN164119

Single pole, two-way switch: This is a three terminal device capable of making or breaking two connections from a single position as shown in Fig 10. These switches are used in staircase lighting where one lamp is controlled from two places. Though four terminals could be seen, two

Fig 10



(a) 6 AMP 2-WAY SURFACE MOUNTING SWITCH (COVER REMOVED)

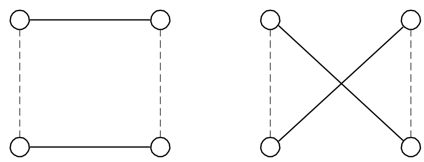
(b) A 2-WAY SWITCH WITH A METAL CAP

EMN16411A

are short circuited and only three terminals are available for connection.However, both single way and two-way switches with their cover look alike as shown in Fig 2b but can be differentiated by looking at the bottom. Single way switches will have two terminal posts whereas two-way switches will have four terminal posts.

Intermediate switch: This is a four-terminal device capable of making or breaking two connections from two positions as shown in Fig 11. This switch is used along with 2 way switches to control a lamp from three or more positions.

Fig 11



INTERMEDIATE SWITCH CONNECTIONS

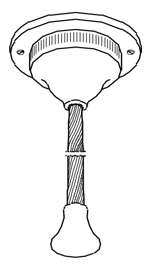
EMN16411B

Bell-push or push-button switch: This is a two-terminal device having a spring-loaded button. When pushed it `makes' the circuit temporarily and attains `break' position when released.

Pull or ceiling switch (Pendent switch): This switch shown in Fig 12 is normally a two-terminal device functioning as a one-way switch to make or break a circuit.

This switch is mounted on ceilings. As the user could operate the switch from a distance through the insulated cord, this could be used safely for operating water heaters in bathrooms or fan or lights in bedrooms.

Fig 12



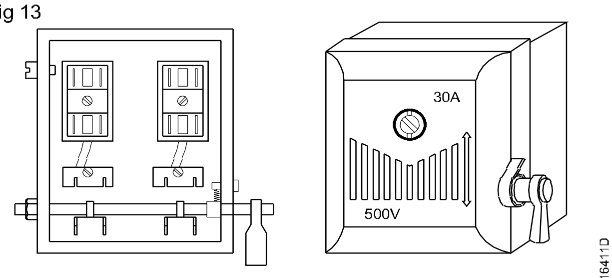
PULL SWITCH

EMN16411C

Double pole switch (D.P.switch): This is a switch with two poles, the two poles being mechanically coupled together. It is operated with a knob. It is also provided with a fuse and a neutral link. These switches are used as main switches to control main or branch circuits in domestic installation.

Double pole iron-clad main switch : This switch shown in Fig 13 is also referred to as D.P.I.C. switch and is mainly used for single phase domestic installations, to control the main supply. It controls phase and neutral of the supply simultaneously. This switch consists of two fuse-carriers. The one in the phase circuit is wired with the fuse and the other in neutral is linked with a brass plate or thick copper wire. These switches should be earthed properly to safeguard the user. The current rating of the switch varies from 16 amps to 200 amperes.

Fig 13



DPIC MAIN SWITCH

Specification of these switches should have:

– current rating

– voltage rating

– type of enclosure

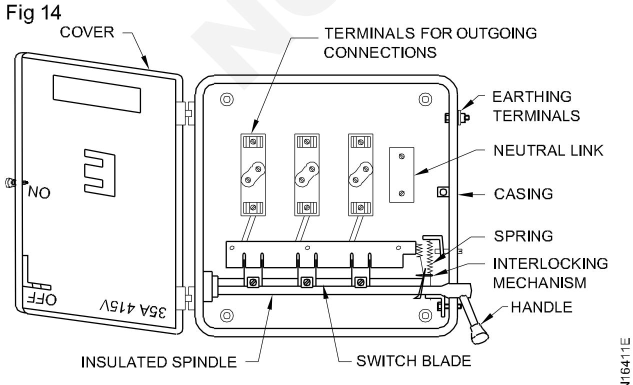
(sheet steel or cast iron).

Triple (three) pole iron-clad main switch: This is shown in Fig 14 and is also referred to as TPIC switch and is used in large domestic installation and also in 3-phase power circuits, the switch consists of 3 fuse carriers, one for each phase. Neutral connection is also possible as some switches are provided with a neutral link inside the casing.

These switches need to be earthed through an earth terminal or screw provided in the outer casing.

The current rating of the switch varies from 16 to 400 amps. Specification of these switches should have

Fig 14



FUSED ICTP `N' SWITCH

– current rating

– voltage rating

– type of enclosure (sheet steel or cast iron)

– whether with neutral link or otherwise

– rewirable type fuse carriers or HRC type fuse carriers.

Switches used in electric industry

Switching is the most fundamental function in electronics and plays a vital role in every system

Most widely used switch configurations in the industry today are:

1 Single Pole Single Throw (SPST)

2 Single Pole Double Throw (SPDT)

3 Double Pole Double Throw (DPDT)

Single Pole Single Throw (SPST) is an analog switch used in many industrial instruments and consumer devices to implement test interfaces etc. It consumes very low power with maximum current in the range of 690 nA

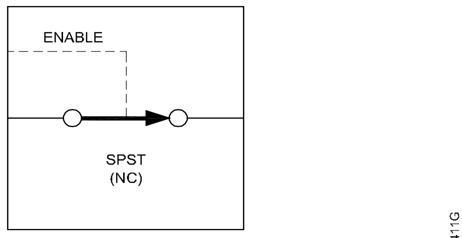
Normally open **SPST** switch can isolate multiple peripherals from source and select the required one. (Fig 15)

Fig 15

SINGLE POLE SINGLE THROW NORMALLY

Normally closed **SPST** switch can connect at all times to a peripheral and when not desired the output can be totally stopped by a press of a switch. (Fig 16)

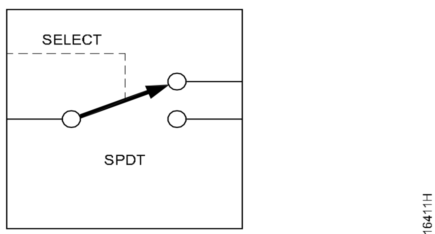
Fig 16



SINGLE POLE SINGLE THROW

Some **SPDT** switches have a select pin and other will have a enable pin. The master in the design for digital control chooses the required trigger action. (Fig 17)

Fig 17



SINGLE POLE DOUBLE THROW

Schmitt trigger action at select and enable control pins results in higher reliability.

Digital bus switches are widely used multiple peripheral and host selection functions, power and clock management, sample and hold circuits, test and debug interfaces etc.

A **dual SPDT** switch in (Fig 18) can be used

1 to route the audio signal from either base band processor to speaker

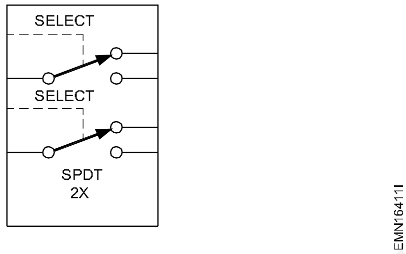
2 to wirelessly route the audio signals between cell phone and an external hands-free device.

The **dual SPDT** and dual SPST switches are available either for simultaneous selection or for simultaneous enable.

Simultaneous select is to connect one of the two signal points or peripherals

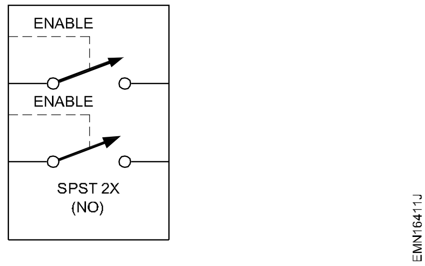
Simultaneous enable is normally open and upon control by master gets enabled remain enabled till disabled.

Fig 18



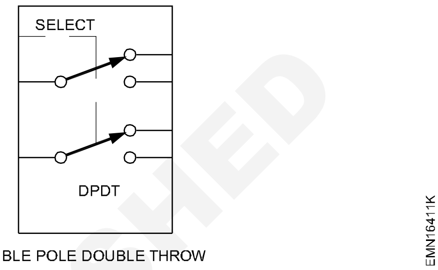
The symbol of dual SPST switch is shown in (Fig 19)

Fig 19



A DPDT switch is a dual SPDT switch into a single select pin as shown in (Fig 20)

Fig 20



Active electronic components passive and active components

Objectives: At the end of this lesson you shall be able to
- **state the passive components**
- **explain the active components.**

Passive components : Components like resistors, capacitors and inductors used in electronic circuit are called as passive components. These components by themselves are not capable of amplifying or processing an electrical signal. However these components are equally important in electronic circuit as at of active components, Without the aid of passive components, a transistor (active components) cannot be made to amplify electrical signal.

Circuits formed with passive components obey the electrical circuit laws such as Ohm's law, Kirchoff's Laws etc.,

Active components : In electronic circuits, components other than resistors, capacitors and inductors are also used. Namely transistors, diodes, vacuum tubes, SCRs, diacs, zener-diode etc. The application of electrical circuit laws (Ohm's law etc.) in the circuit containing the above components will not give correct results. i.e. these components do not obey Ohm's law, Kirchhoff's law etc. These components are called active components.

The different active components and the method of representing them by symbols are given in fig 1.

Fig 3

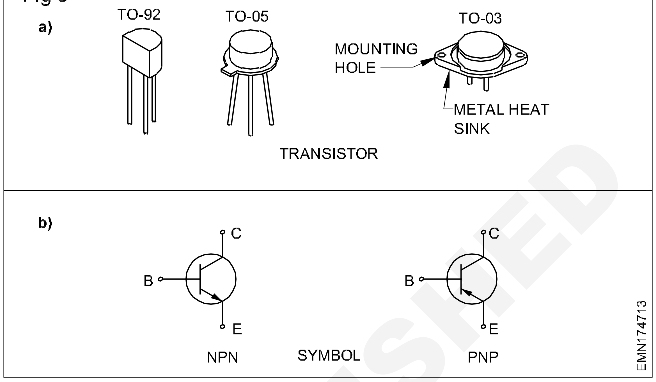
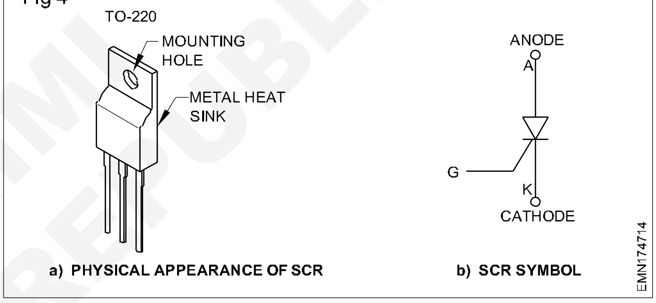


Fig 4



Passive components - Resistors

Objectives : At the end of this lesson you shall be able to
- **state the function of a resistor in a circuit**
- **explain the classifications of resistors**
- **explain the classifications of fixed value resistors.**
- **state the power rating of resistors**
- **state the tolerance in a resistor**
- **find the value of a resistor using colour code**
- **state the constructional details of fixed and variable resistors.**

Resistors

Resistors are electronic components, used to reduce, or limit, or resist the flow of current in any electrical or electronic circuit. Chart 1 at the end of this lesson shows different types of resistors.

Fig 1 shows a circuit in which the bulb glows brightly. Fig 2 shows the same circuit with a resistor, and the bulb glows dim. This is because, the current in the circuit is reduced by the 1000 ohms resistor. If the value of this resistor is increased, current in the circuit will be further reduced and the light will glow even dimmer.

Fig 1

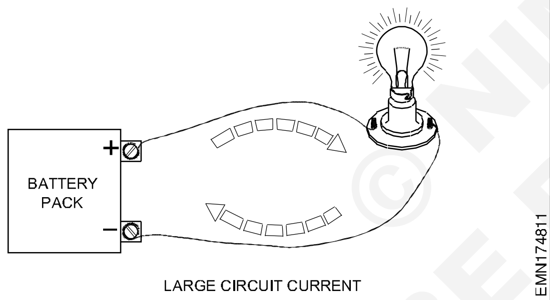
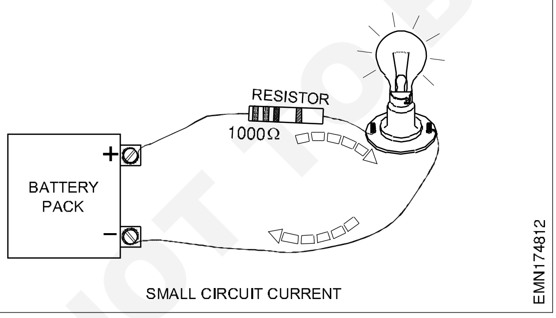


Fig 2



Resistors are made of materials whose conductivity fall in-between that of conductors and insulators. This means, the materials used for making resistors have free electrons, but not as many as in conductors. Carbon is one such material used most commonly for making resistors.

When a large number of electrons are made to flow through a resistor, there is opposition to the free flow of electrons. This opposition results in generation of heat.

Unit of resistance

The property of the resistor to limit the flow of current is known as *resistance*. The value, or quantity of *resistance* is measured in units called **ohms** denoted by the symbol Ω.

Resistors are called *passive devices* because, their resistance value does not change even when the level of applied voltage or current to it is changed. Also, the resistance value remains same when the applied voltage is AC or DC.

Resistors can be made to have very small or very large resistance. Very large values of resistances can be represented as given below;

1000 Ω	= 1 x 1000 Ω	= 1 x kiloΩ	= 1 K Ω
10,000 Ω	= 10 x 1000 Ω	= 10 x kiloΩ	= 10 K Ω
100,000 Ω	= 100 x 1000 Ω	= 100 x kilo Ω	= 100 K Ω
1000,000 Ω	= 1000 x 1000Ω	= 1000 x kiloΩ	= 1000 KΩ
		= 1Mega Ω	= 1MΩ

Classification of Resistors

Resistors are classified into two main categories.

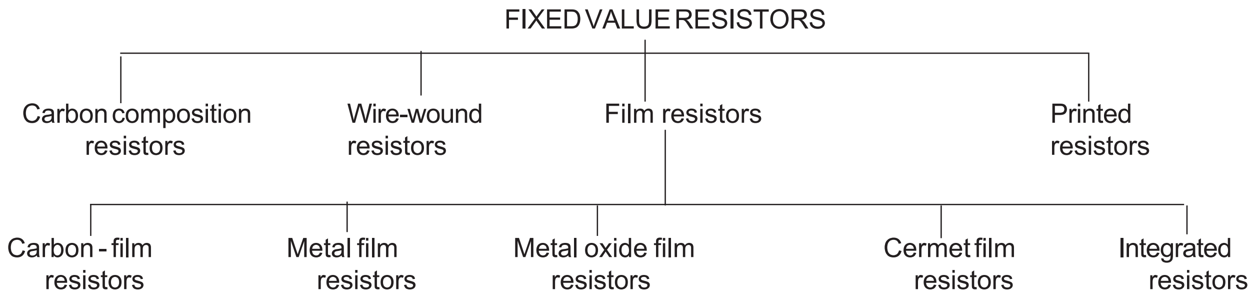
1. Fixed 2. Variable

Fixed value resistors

Its ohmic value is fixed. This value cannot be changed by the user. Resistors of standard fixed values are manufactured for use in majority of applications.

Fixed resistors are manufactured using different materials and by different methods. Based on the material used and their manufacturing method/process, resistors carry different names.

Fixed value resistors can be classified based on the type of material used and the process of making as follows.



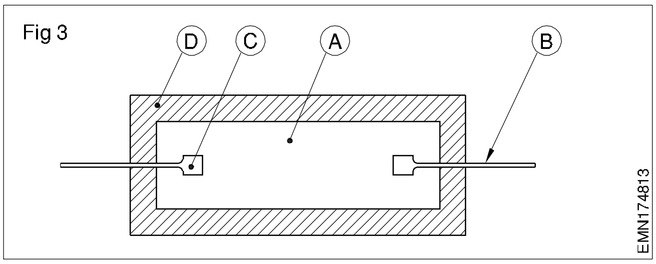
Physical appearance of some types of fixed value resistors is shown in Chart 1 at the end of this lesson.

Carbon Composition Resistors

Construction

These are the simplest and most economical of all other types. Brief constructional detail of the simplest type of carbon composition resistors commonly called *carbon resistor* is shown in Fig 3.

Fig 3



A mixture of finely powdered carbon or graphite(A), filler and binder is made into rods or extruded into desired shapes. Leads(B) made of tinned copper are then attached to the body either by soldering or embedding(C) in the body. A protective layer/tube(D) of phenolic or Bakelite is moulded around the assembly. Finally its resistance value is marked on the body.

Power rating

As already discussed, when current flows through a resistor, heat is generated. The heat generated in a resistor will be proportional to the product of applied voltage (V) across the resistor and the resultant current (I) through the resistor. This product VI is known as *power*. The unit of measurement of power is *watts*.

The physical size of a resistor should be sufficiently large to dissipate the heat generated. The higher the physical size, the higher is the heat that a resistor can dissipate. This is referred to as the power rating or wattage of resistors. Resistors are manufacturerd to withstand different power ratings. If the product of V and I exceeds the maximum wattage a resistor can dissipate, the resistor gets charred and loses all its property. For instance, if the applied voltage across a 1 watt resistor is 10 volts resulting in 0.5 Amps of current through the resistor, the power dissipated (VI) by the resistor will be 5 watts. But, the maximum power that can be dissipated by the 1 w resistor is much less. Therefore, the resistor will get overheated and gets charred due to overheat.

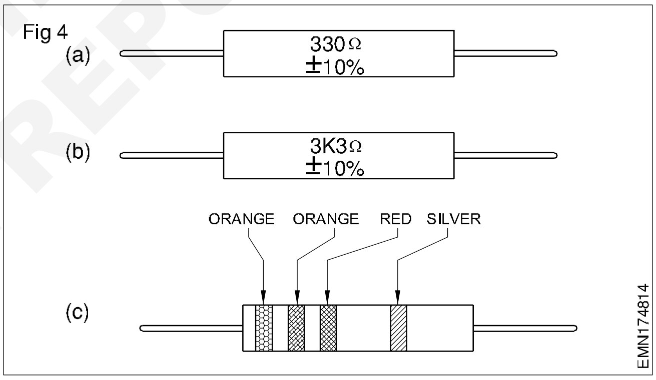
Hence, before using a resistor, in addition to its ohmic value, it is important to choose the correct wattage rating. If in doubt, choose a higher wattage resistor but never on the lower side. The power rating of resistors are generally printed on the body of the resistor.

Resistor values - coding schemes

For using resistors in circuits, depending upon the type of circuit in which it is to be used, a particular type, value and wattage of resistor is to be chosen. Hence before using a resistor in any circuit, it is absolutely necessary to identify the resistor's type, value and power rating.

Selection of a particular type of resistor is possible based on its physical appearance. Table 4 at the end of this lesson illustrates the physical appearance of most commonly used fixed value resistors. The resistance value of a resistor will generally be printed on the body of the resistor either directly in ohms as shown in Fig 4a or using a typographic code as shown in Fig 4b or using a colour code as shown in Fig 4c.

Fig 4



Colour band coding of resistors

Colour band coding as shown in Fig 6c is most commonly used for carbon composition resistors. This is because the physical size of carbon composition resistor is generally small, and hence, printing resistance values directly on the resistor body is difficult.

Tolerance

In bulk production/ manufacturing of resistors, it is difficult and expensive to manufacture resistors of particular exact values. Hence the manufacturer indicates a possible variation from the standard value for which it is manufactured. This variation will be specified in percentage tolerance. Tolerance is the range(max -to- min) within which the resistance value of the resistor will exist.

Table No.4 of pocket table book gives a list of commercially available standard preferred value of resistors.

Refer to the Pocket Table book, table nos 1, 2 and 3 for methods to read the value of resistors and their tolerance for resistors using 3 band, 4 band and 5 band colour coding schemes.

Applications

Carbon composition, fixed value resistors are the most widely used resistors in general purpose electronic circuits such as radio, tape recorder, television etc. More than 50% of the resistors used in electronic industry are carbon resistors.

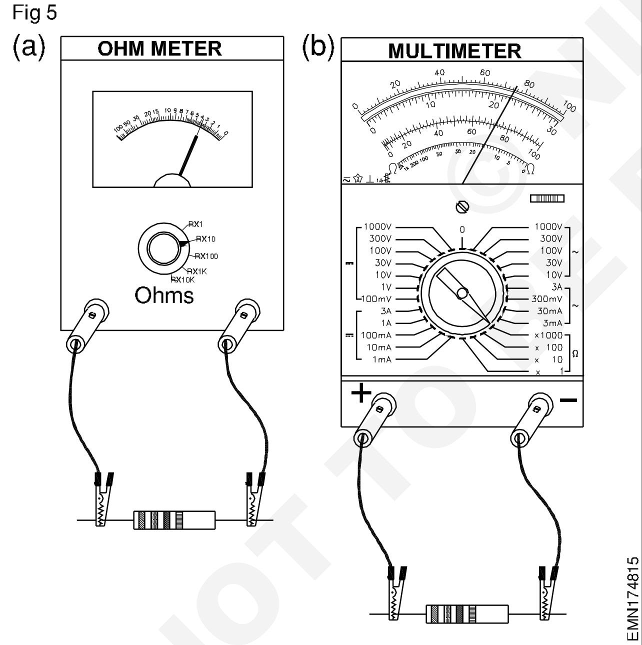
Measuring ohmic value of resistors

It is not possible to read the *exact ohmic value* of a resistor from colour/other coding schemes due to manufacturing tolerance built into the resistors. To find the exact ohmic value of resistors *ohmmeters* are used. When a resistor is placed between the test probes of an ohmmeter as shown in Fig 5a, the meter shows nearest to the exact resistance of the resistor directly on the graduated meter scale. Multimeters are also used to measure the value of resistors as shown in Fig 5b.

When a multimeter is used for resistance measurement, the resistance range switch on the meter should be put to the most suitable resistance range, depending upon the value of resistance being measured.

Table No.11 of Pocket table book suggest the meter ranges for measuring different resistor values accurately.

Fig 5



Wire-wound Resistors

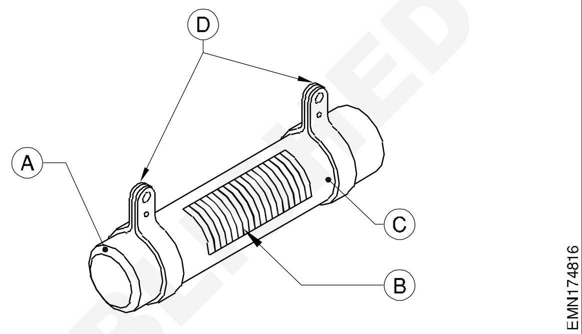
Resistors, in addition to having a required ohmic value, should also be capable of dissipating the heat produced. Carbon by its nature has a limitation in the maximum heat it can dissipate. Carbon resistors become too hot when high current flows through them. This increased heat in carbon resistors changes the ohmic value of the resistors. Sometimes the resistors may even burn open due to excessive heat. Hence carbon resistors are suited only in low power circuits safely up to 2 watts.

This limitation in carbon resistors can be overcome by using wires of resistive materials like Nichrome, Manganin etc., instead of carbon. Resistors made using wires of resistive materials are known as *wire-wound* resistors. These resistors can withstand high temperature, and still maintain the exact ohmic values. In addition, wire-wound resistors can also be made to have fractional ohmic values which is not possible in carbon composition resistors.

Construction

Typical construction of a fixed value wire-wound resistor is shown in Fig 6 . Over a porcelain former (A), resistive wire (B) such as Nichrome, Manganin or Eureka is wound. The number of turns wound depends on the resistance value required. The wire ends are attached to terminals(D).

Fig 6



The entire construction, except the terminals are coated using an insulating binder(C) such as shellac/ceramic paste to protect the wire-wound resistor from corrosion etc. In very high voltage/current application, the resistive wires are coated with vitreous enamel instead of shellac. The vitreous enamel coating protects the wire-wound resistor from extreme heat and inter-winding firing/discharge.

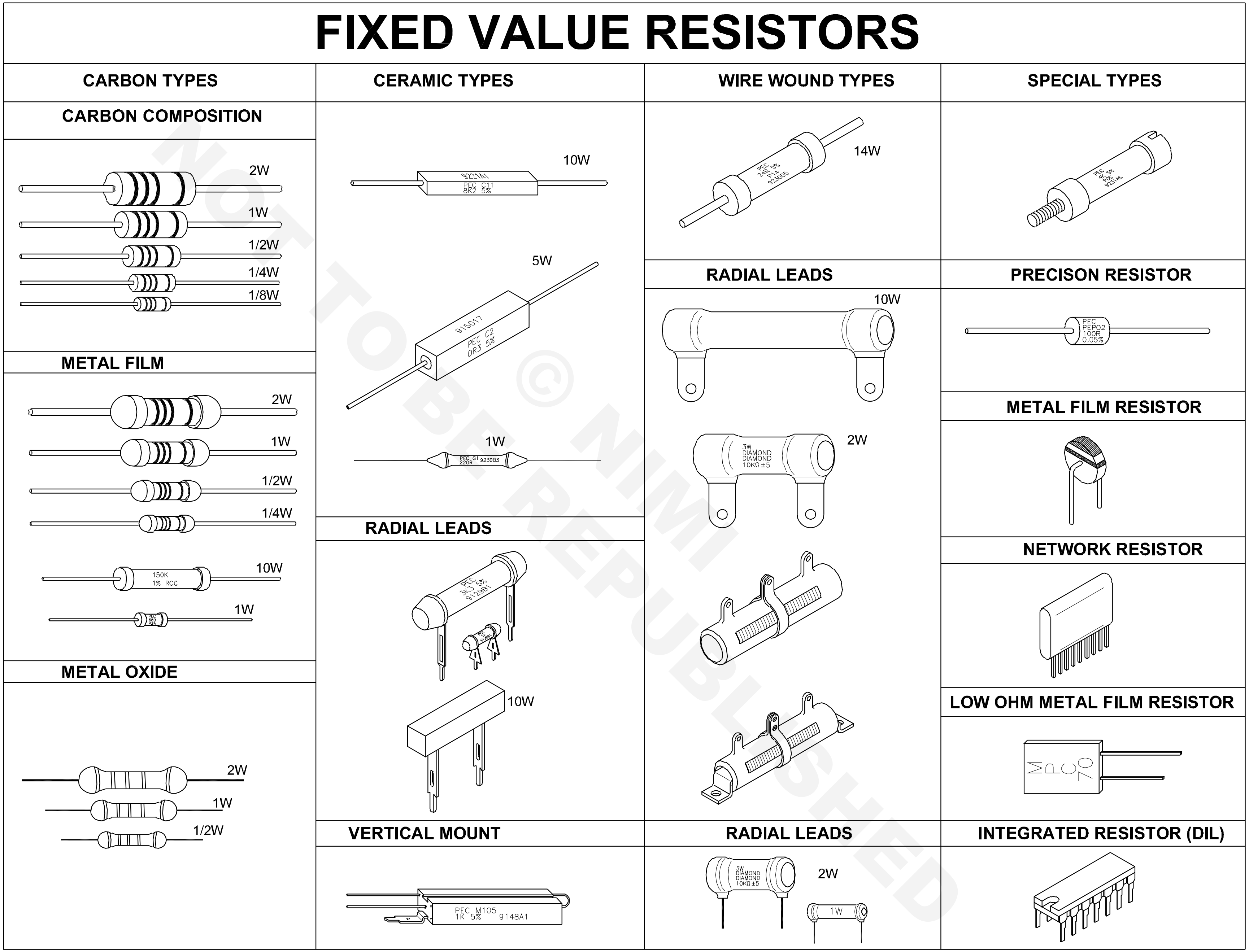
Resistor values

Wire-wound resistors are available from a fraction of an ohm to 100's of Kilo ohms, with a power ratings of 1 watt to several 100s of watts. The higher the power rating, the thicker the resistive wire used, and bigger will be the physical size of the wire-wound resistor.

Applications

Wire-wound resistors are commonly used in electronic circuits where small values, precision values, high wattage ratings are required. A few applications are : regulated power supplies, amplifiers, motor controls, servo control circuits, TV receivers etc.

Chart 1 for lesson 1.7.51 - 1.7.53



Ohm's Law

Objectives: At the end of this lesson you shall be able to
- **state Ohm's law**
- **calculate the total resistance of series resistance circuits**
- **calculate the total resistance of parallel resistance circuits**
- **power dissipation in parallel resistive circuits**

OHM'S LAW

The quantity of current flowing through a resistor depends on two factors:

1 The ohmic value of the resistor.

2 The voltage applied across the resistor.

If the voltage applied across a resistor is kept constant, higher the resistance of the resistor, lower will be the current flowing through it. In other words current (I) through a resistor is inversely proportional to resistance(R) value of the resistor.

On the otherhand, if the applied voltage (V) across a fixed value resistor is increased, the current flowing through the resistor also increases. In other words current (I) through a resistor is directly proportional to the applied voltage(V) across the resistor.

Combining the above two relationships between resistance(R), current (I) and applied voltage(V), it can be written as,

$$I = \frac{V}{R}$$

This relationship of I = V/R was found by the scientist *George Simon Ohm* and hence this is referred to as *ohm's law.*

The relationship of I = V/R can be expressed mathematically in different forms as

$$I = \frac{V}{R} \text{ or } V = I \times R \text{ or } R = \frac{V}{I}$$

These formulas are used invariably while designing or testing electrical/electronic circuits.

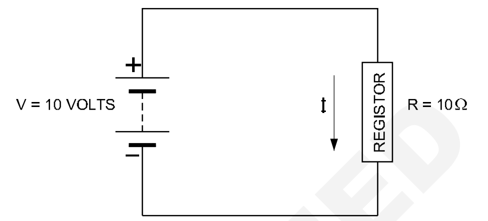
Generalising, ohm's law can be stated as follows:

Under a given constant temperature, the current flowing through a resistor is directly proportional to the voltage across the resistor and inversely proportional to the value of resistance.

This statement holds good not only for a resistor, but in common to all resistive circuits.

Example 1 : Using ohms law, find the current flowing through the resistor in Fig 1.

Fig 1



Solution :

Applied voltage across the resistor is : 10 volts

Resistance value of the resistor is given as 10 ohms.

Therefore current(I) through the resistor by Ohm's law is;

$$I = \frac{V}{R} \text{ Amps.} = \frac{10 \text{ volts}}{10 \text{ ohms}} = 1 \text{ amp.}$$

Current through the resistor is 1 ampere.

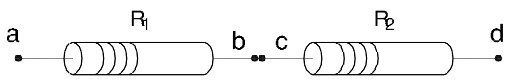
- **Resistors in series**

When resistors are connected end to end as shown in Fig 3, the resistors are said to be in series with each other.

Total resistance of resistors in series

When resistors are connected in series, the total resistance of the series connection will be equal to, the sum of individual resistance values. In Fig 2, total resistance across points a-d will be equal to $R_1 + R_2$.

Fig 2



Example : In Fig 2, if R_1 is 1 K ohms and R_2 is 2.2K ohms. The total or effective resistance between the terminals a and d will be,

(R_1 and R_2 are connected in series).

$= R_1 + R_2$

$= 1.0\ k\Omega + 2.2\ k\Omega = 3.2\ k\Omega$.

Current through a series circuit

When resistors are connected in series as shown in Fig 2, the current that flows through R_1 can only flow through R_2. This is because

– there is no other path for any other extra current to flow through R_2

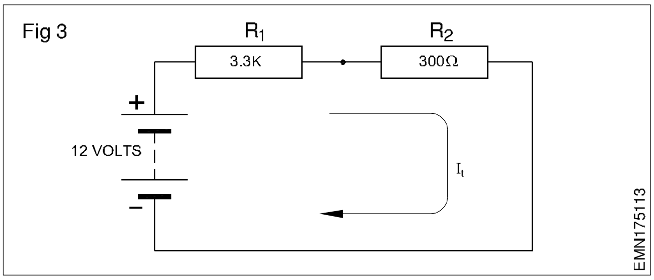
– there is no other path for the current through R_1 to escape from flowing through R_2.

Therefore *in a series circuit, the quantity of current will be the same at all the points (a,b,c,d) of the circuit*.

The quantity of current flowing through the series path is decided by both the resistors put together or the effective resistance of the circuit.

Example : Find the total circuit current(I_t) in the circuit at Fig 3.

Fig 3



Solution :

Resistors R_1 & R_2 are in series. Therefore, the effective resistance of the circuit = $R_1 + R_2$

= 3.3kΩ + 330Ω.

= 3300 + 330 = 3630 ohms.

$$\text{Circuit current } I_t = \frac{V}{R} = \frac{12\ V}{3630\ \Omega} = 0.0033 \text{ amps} = 3.3 \text{ mA.}$$

Example : Calculate the voltage drops across R_1 and R_2 for the circuit at Fig 3.

Solution :

In the circuit (Fig 3), R_1 and R_2 are in series. Hence the current through both the resistors is the same. This current is 3.3 mA as calculated in the previous example.

From Ohm's Law

Therefore the voltage drop across R_1

= I x R_1 volts

= 3.3 mA x 3.3 kΩ

= $(3.3 \times 10^{-3}) \times (3.3 \times 10^{3})$

= 3.3 x 3.3 = 10.89 volts.

Similarly the voltage drop across R_2

= (3.3×10^{-3}) x 330 ohms

= 1089 milli-volts

= 1.089 volts.

Verification of solution

Since R_1 and R_2 are in series, the sum of the voltage drops across R_1 and R_2 must be equal to the applied battery voltage of 12V. i.e, 10.89 + 1.089 = 11.979 » 12 volts = applied battery voltage.

Power dissipation in resistors

When current flows through a resistor heat is generated. This is because, the voltage driving the current through the resistor is doing some amount of work in overcoming the opposition to the flow of electrons. It is found through experiments and analysis that, the amount of work done by the voltage is directly proportional to the ohmic value(R) of the resistor and square of the current(I^2) flowing through the resistor. This work done is dissipated in the form of heat generated by the resistor. This heat dissipating capacity is known as the power or wattage of a resistor. The unit of power is *Watt*.

Power dissipated by a resistor = $I^2 \times R$ Watts.

Where,

I is the current through the resistor

and R is the resistance of the resistor.

Example : If 10 mA flow through a resistor of 10 K ohms, what is the power dissipated by the resistor ?

Power dissipated by the resistor = $I^2 \times R = (I \times I) \times R$

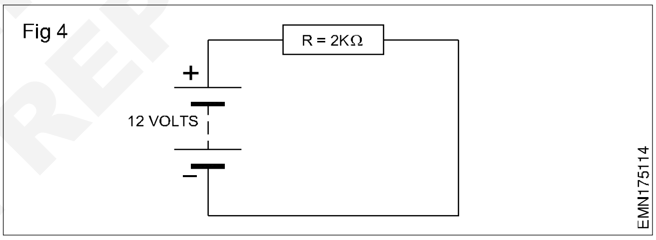
= $(10 \times 10^{-3}) \times (10 \times 10^{-3}) \times (10 \times 10^{3})$

= 1000×10^{-3} = 1000 milli-watts = 1 watt.

The power dissipated by the resistor is 1 watt.

Example : What is the total power dissipated by the circuit given at Fig 4.

Fig 4



Solution :

Current through the circuit is I_t = V/R

= 12V/ 2 kΩ = 6 mA

Power dissipated by the circuit is

= $(\text{circuit current})^2$ x circuit resistance

= $(36 \times 10^{-6}) \times (2 \times 10^{3})$

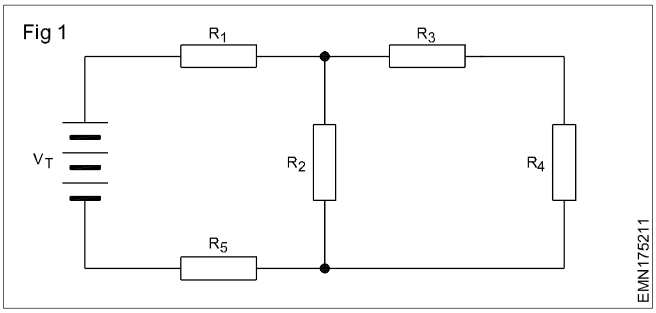
= 72×10^{-3} watts

= 72 milli-watts = 0.072 watts.

Kirchhoff's Laws

Objectives: At the end of this lesson you shall be able to
- **state Kirchhoff's current law**
- **state Kirchhoff's voltage law.**

When a circuit consists of several resistors in a complex series - parallel arrangement as in Fig 1, it is difficult to calculate the currents and voltages in the circuit using Ohm's law.

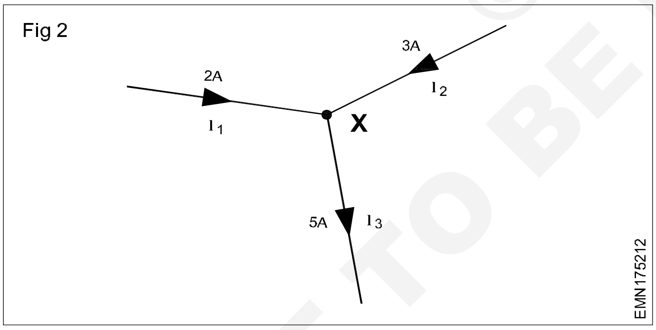


To find current and voltage drops in a complex series - parallel circuit, an easy method was found by a German physicist GUSTAV R. KIRCHHOFF. He formulated two basic laws called,

1. Kirchhoff's Current law
2. Kirchhoff's Voltage law.

1 KIRCHHOFF'S CURRENT LAW:

This law is illustrated in Fig 2.



KIRCHHOFF's Current law states that the sum of currents entering any point in a circuit is equal to the sum of currents leaving that point.

In Fig 2 currents I_1 and I_2 are entering a point X. Current I_3 is leaving the point X.

From Kirchhoff's current law, $I_1 + I_2 = I_3$ ....[1]

This equation can also be written as,

$I_1 + I_2 - I_3 = 0$ ....[2]

From equation 2, Kirchhoff's current can also be stated as The algebraic sum of currents entering and leaving any point in a circuit must be equal to zero .

To determine the algebraic sign of currents,

– consider all currents going into a point as positive and all currents going away from that point as negative.

In Fig 2 , I_1 & I_2 will have positive sign as they are going into point whereas I_3 will have negative sign as it is going out of the point X.

Hence we can also write the Kirchhoff's Current equation as,

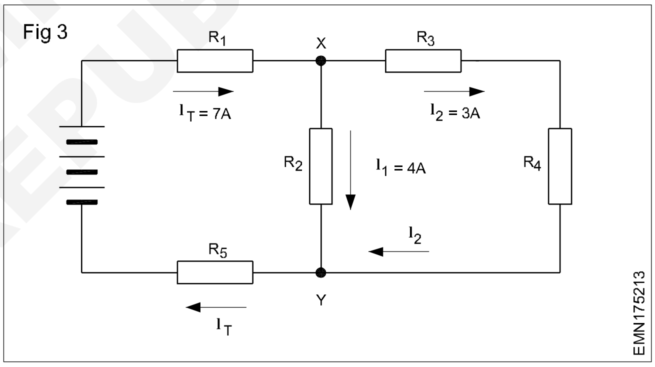
At point X,

$$(+I_1) + (+I_2) + (-I_3) = 0$$

Simplifying, $I_1 + I_2 - I_3 = 0$

Substituting current values given in Fig 2,
2Amps + 3Amps - 5Amps = 0.

For the circuit shown in Fig 3, Kirchhoff's Current equation at nodes X and Y can be written as follows:



At node X $I_T - I_1 - I_2 = 0$

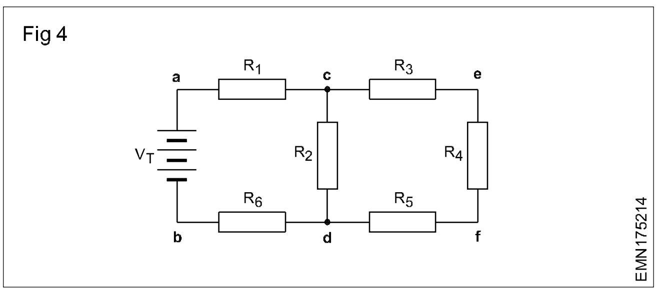
$7A - 4A - 3A = 0.$

At node Y $I_1 + I_2 - I_T = 0$

$4A + 3A - 7A = 0.$

KIRCHHOFF'S VOLTAGE LAW

In the circuit shown at Fig 4, consider the two closed paths a-c-d-b-a and a-e-f-b-a. These closed paths are called as loops. Each closed path has several resistors and there will be a voltage drop across each resistor. KIRCHHOFF's voltage law states that *The algebraic sum of voltages around any closed path is zero.*



To find the algebraic sum of voltages around a closed path,

– start from any point, go around the path and come back to the same point from where you started.

Example: *Referring to Fig 5, the method of going through a closed path is,*

– start from point **a**, go through points **c,d,b** and return to point **a**.

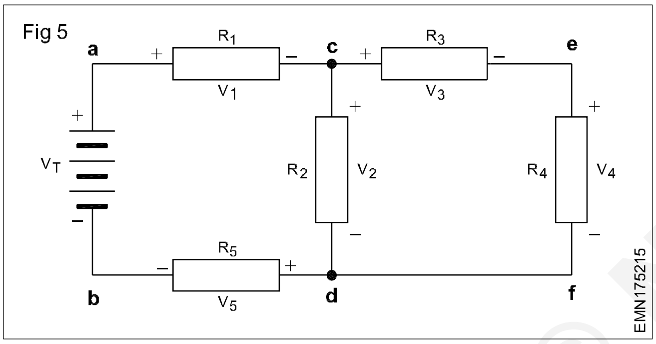
To determine the signs for voltage drop across the resistors in Fig 5,

– mark the polarity of each voltage, based on the polarity of source voltage as shown in Fig 5

– go around the path and give +ve sign for the voltage whose +ve terminal is reached first or give -ve sign for the voltage whose -ve terminal is reached first.

Write the loop equation considering the voltage sources also.

To write the loop equation for the closed path a-c-d-b-a of Fig 5, proceed as follows:



Taking clockwise direction for going through the loop, start from point a of Fig 5. Go through the chosen loop a-c-d-b-a and write down the voltage drop across the resistors including their signs and equate it to zero as given below;

$+ V_1 + V_2 + V_5 - V_T = 0$ ......[1]

Rewrite the equation as,

$+ V_1 + V_2 + V_5 = V_T$.

Similarly for the closed path a-e-f-b-a,

considering clockwise direction, start from point a of Fig 6. Go through the chosen loop a-e-f-b-a and write down the voltage drop across the resistors including their signs and equate it to zero as given below;

$+ V_1 + V_3 + V_4 + V_5 - V_T = 0$ ......[2]

Rewriting the equation,

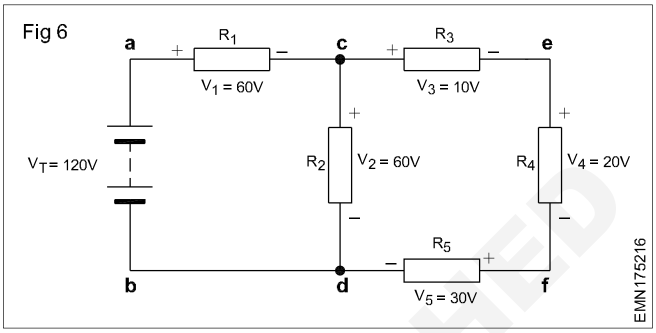
$+ V_1 + V_3 + V_4 + V_5 = V_T$.

Equations [1] & [2] above state that; In any closed loop, the sum of voltage drops across resistors is equal to the applied voltage. This can be written as:

$S V_d = V_T$,

where, $S V_d$ is the sum of voltage drops across resistors V_T is the applied voltage.

Example : Write the loop equations for the circuit given at Fig 6.



For the loop a-c-d-b-a, $+V_1 + V_2 - V_T = 0$

or $V_1 + V_2 = V_T$

Verification

60 + 60 = 120

For the loop a-e-f-b-a $+V_1 + V_3 + V_4 + V_5 - V_T = 0$

or $V_1 + V_3 + V_4 + V_5 = V_T$

Verification

60 + 10 + 20 + 30 = 120

For the loop c-e-f-d-c

$+V_3 + V_4 + V_5 - V_2 = 0$

or $V_3 + V_4 + V_5 = V_2$

Verification

10 + 20 + 30 = 60

Circuit with more than one voltage source

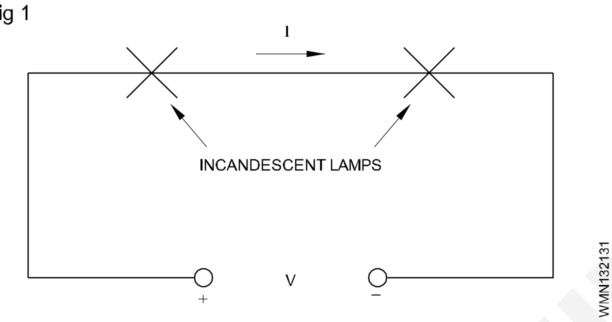
Kirchhoff's voltage law is applicable even when, there are more than one voltage source in a circuit. The method of writing loop equations remains the same.

DC series circuit

Objectives: At the end of this lesson you shall be able to
- **state the characteristics of series circuit and determine the current and voltage across each resistors**
- **state the relation between EMF potential difference and terminal voltage.**

The series circuit: If more than one resistors are connected one by one like a chain and if the current has only one path is called as series circuit. It is possible to connect two incandescent lamps in the way shown in Fig 1. This connection is called a series connection, in which the same current flows in the two lamps.

Fig 1



Current in series circuits

The current will be the same at any point of the series circuit. This can be verified by measuring the current in any two points of a given circuit as shown in Figs 2(a) and 2(b). The ammeters will show the same reading.

The current relationship in a series circuit is

$$I = I_{R1} = I_{R2} = I_{R3}.$$ (Refer Fig 4a & 4b)

We can conclude that there is only one path for the current to flow in a series circuit. Hence, the current is the same throughout the circuit.

Total resistance in series circuit

The total resistance in a series circuit is equal to the sum of the individual resistances around the series circuit. This statement can be written as

$$R = R_1 + R_2 + R_3 + ...R_n$$

where R is the total resistance

R_1, R_2 , R_3,.......R_n are the resistors connected in series.

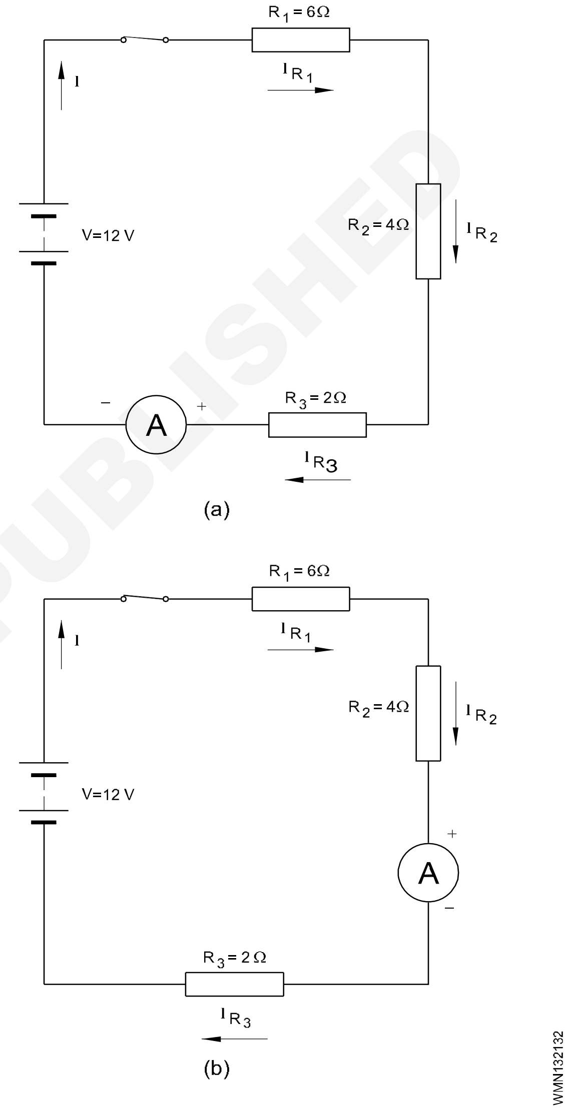
Voltage in series circuits

In DC circuit voltage divides up across the load resistors, depending upon the value of the resistor so that the sum of the individual load voltages equals the source voltage.

As the source voltage divides/drops across the series resistance depending upon the value of the resistances

$$V = V_{R1} + V_{R2} + V_{R3} + ...V_{RH}$$

Fig 2

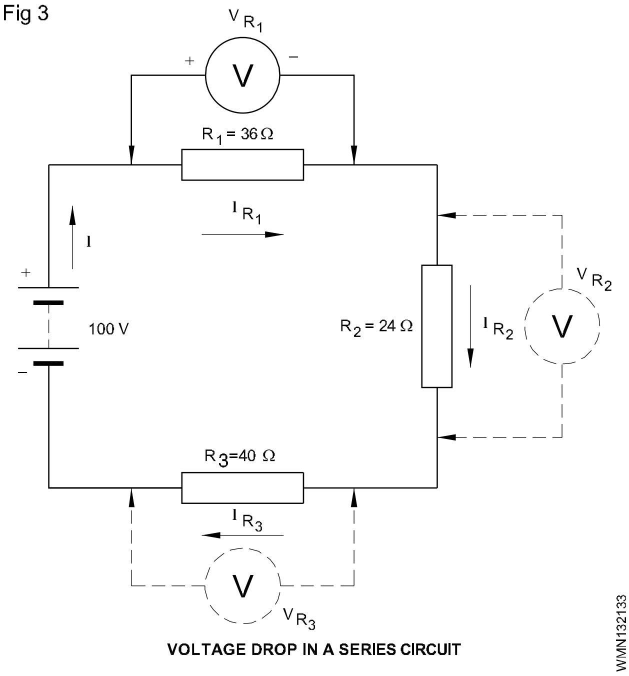


Voltages across the series resistors could be measured using one voltmeter at different positions as illustrated in Fig 3.

Voltage sources in series

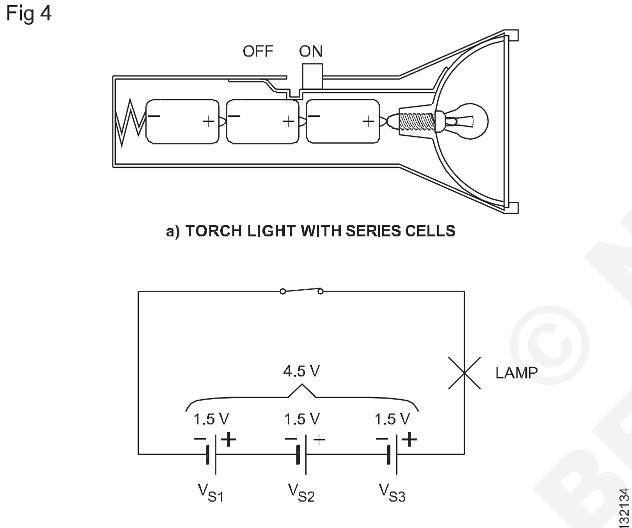
When cells are placed in a torch light, they are connected in series to produce a higher voltage as shown in Fig 4.

Fig 3



VOLTAGE DROP IN A SERIES CIRCUIT

Fig 4



a) TORCH LIGHT WITH SERIES CELLS

b) SCHEMATIC DIAGRAM OF THE TORCH LIGHT CIRCUIT

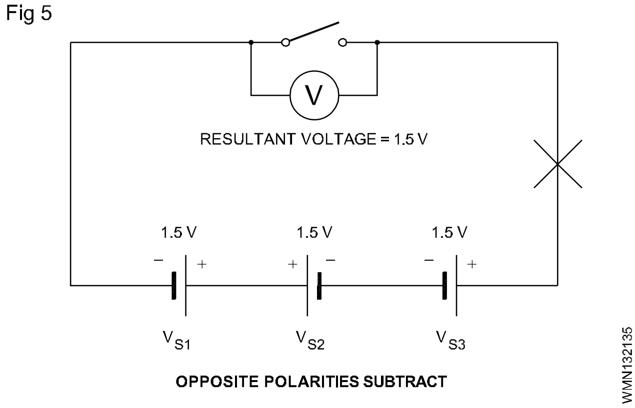
Series voltage sources are added when their polarities are in the same direction and or subtracted when their polarities are in the opposite direction. For example, if one of the ends of the cell, say V_{S2} in a torch light is wrongly placed in polarity as indicated in the schematic of Fig 5 its voltage to be subtracted as follows.

$V_{Total} = V_{S1} - V_{S2} + V_{S3}$

$= 1.5\text{ V} - 1.5\text{ V} + 1.5\text{ V}$

$= 1.5\text{ V}$

Fig 5



OPPOSITE POLARITIES SUBTRACT

Use of series connection

1 Cells in torch light, car batteries, etc.

2 Cluster of mini-lamps used for decoration purposes.

3 Fuse in circuit.

4 Overload coil in motor starters.

5 Multiplier resistance of a voltmeter.

Definitions

Electromotive force (emf)

We have seen that the electromotive force (emf) of a cell is the open circuit voltage, and the potential difference (PD) is the voltage across the cell when it delivers a current. The potential difference is always less than the emf.

Potential difference

PD = emf – voltage drop in the cell

Potential difference can also be called by another term, the terminal voltage, as explained below.

Terminal voltage

It is the voltage available at the terminal of the source of supply. Its symbol is V_T. Its unit is also the volt. It is given by the emf minus the voltage drop in the source of supply,

i.e. $V_T = \text{emf} - IR$

where I is the current and R the resistance of the source.

Voltage drop (IR drop)

The voltage lost by resistance in a circuit is called the Voltage drop or IR drop.

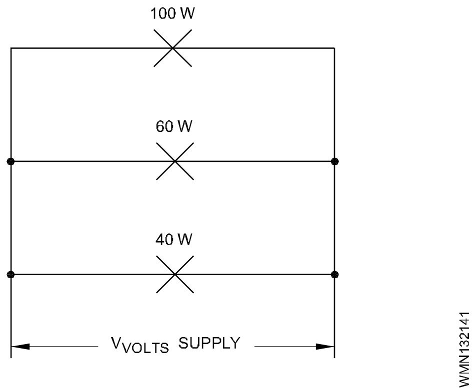
DC parallel circuit

Objectives: At the end of this lesson you shall be able to
- **determine the voltages in a parallel circuit**
- **determine the current in a parallel circuit**
- **determine the total resistances in a parallel circuit**
- **state the application of a parallel circuit.**

Voltage in parallel circuit

When 3 lamps are connected as shown (Fig 1) the voltage applied across the resistors is the same and also equal to the supply voltage.

Fig 1

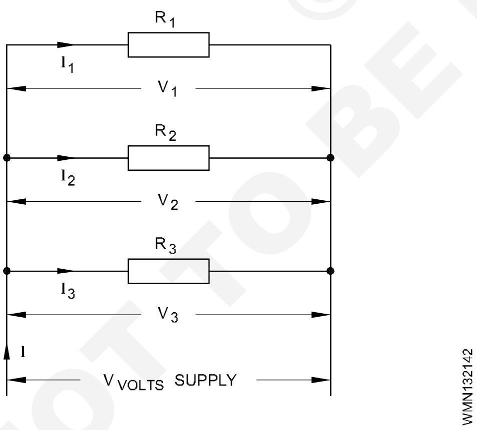


We can conclude that the voltage across the parallel circuit is the same as the supply voltage.

Mathematically it could be expressed as $V = V_1 = V_2 = V_3$.

Current in parallel circuit: Again referring to Fig 2 and applying Ohm's law, the individual branch currents in the parallel circuit could be determined.

Fig 2



$$\text{Current in resistor } R_1 = I_1 = \frac{V_1}{R_1} = \frac{V}{R_1} \quad .$$

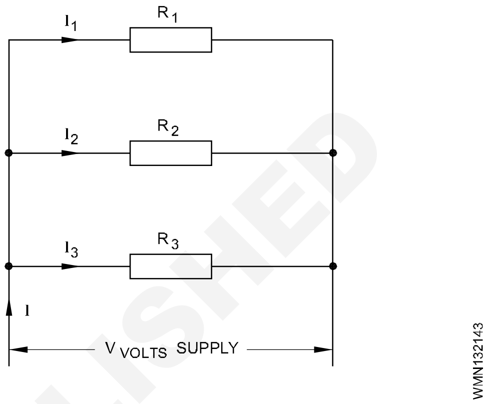
$$\text{Current in resistor } R_2 = I_2 = \frac{V_2}{R_2} = \frac{V}{R_2} \quad .$$

$$\text{Current in resistor } R_3 = I_3 = \frac{V_3}{R_3} = \frac{V}{R_3}$$

as $V_1 = V_2 = V_3$.

Refer to Fig 3 in which the branch currents I_1, I_2 and I_3 are shown to flow into resistance branches R_1, R_2 and R_3 respectively.

Fig 3



The total current I in the parallel circuit is the sum of the individual branch currents.

Mathematically it could be expressed as $I = I_1 + I_2 + I_3 + \ldots\ldots I_n$.

Resistance in parallel circuit

In a parallel circuit, individual branch resistances offer opposition to the current flow though the voltage across the branches will be same.

Let the total resistance in the parallel circuit be R ohms.

By the application of Ohm's law

we can write

$$R = \frac{V}{I} \text{ ohms or } I = \frac{V}{R} \text{ amps.}$$

where

R is the total resistance of the parallel circuit in ohms

V is the applied source voltage in volts, and

I is the total current in the parallel circuit in amperes.

We have also seen

$I = I_1 + I_2 + I_3$

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

As V is the same throughout the equation and dividing the above equation by V, we can write

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

The above equation reveals that in a parallel circuit, the reciprocal of the total resistance is equal to the sum of the reciprocals of the individual branch resistances.

Applications of parallel circuits: An electric system in which one section can fail and other sections continue to operate has parallel circuits. As previously mentioned, the electric system used in homes consists of many parallel circuits.

An automobile electric system uses parallel circuits for lights, horn, motor, radio etc. Each of these devices operates independent of the others.

Open and short circuit network

Objectives: At the end of this lesson you shall be able to
- **state about short circuit in series circuit and its effect in series circuit**
- **state the effect of an open circuit in series circuit and its causes**
- **state the effect of shorts and open in parallel circuit.**

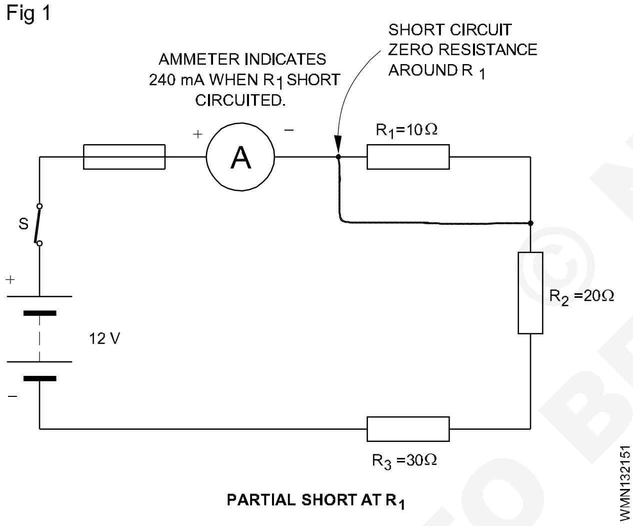
Short circuits

A short circuit is a path of zero or very low resistance compared to the normal circuit resistance.

In a series circuit, short circuits may be partial or full (dead short) as shown in Fig 1 and Fig 2 respectively.

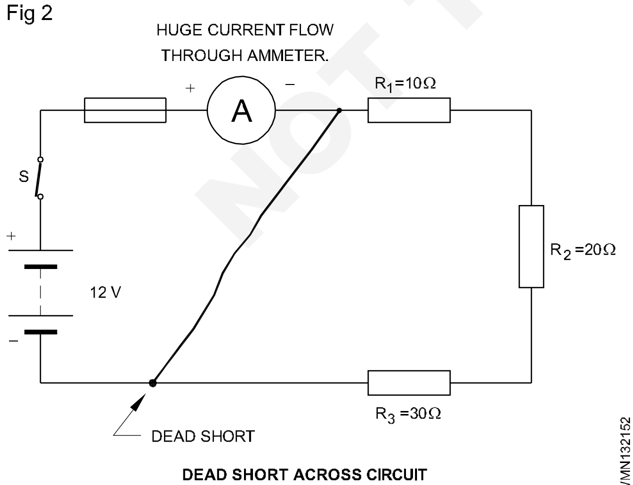
Short circuits cause an increase in current that may or damage the series circuit.

Fig 1



PARTIAL SHORT AT R_1

Fig 2



DEAD SHORT ACROSS CIRCUIT

Effects due to short circuit

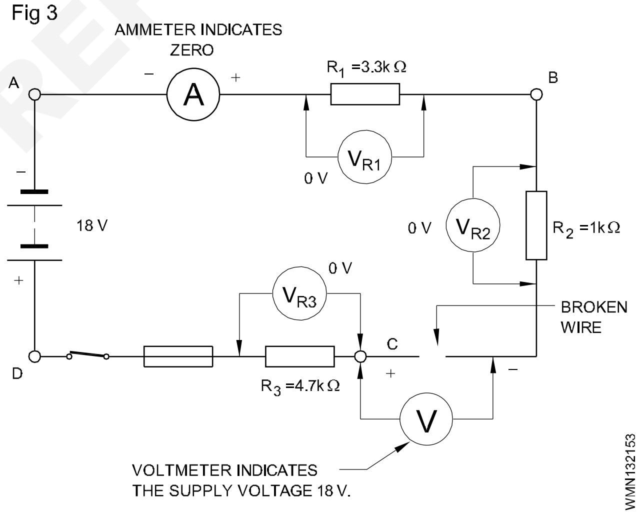
Excess current due to short circuit can damage the circuit components, power sources, or burn the insulation of connecting wires. Fire is also caused due to intense heat generated in the conductors.

Open circuit in series circuit

An open circuit results whenever a circuit is broken or is incomplete, and there is no continuity in the circuit.

In a series circuit, open circuit means that there is no path for the current, and no current flows through the circuit. Any ammeter in the circuit will indicate no current as shown in Fig 3.

Fig 3



Causes for open circuit in series circuit

Open circuits, normally, happen due to improper contacts of switches, burnt out fuses, breakage in connection wires and burnt out resistors etc.

Effect of open in series circuit

a No current flows in the circuit.

b No device in the circuit will function.

c Total supply voltage/ source voltage appear across the open.

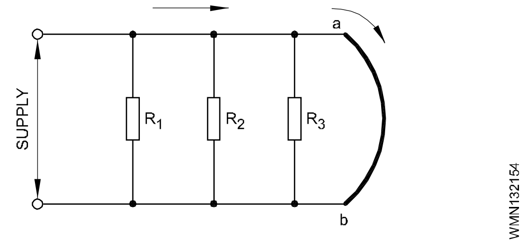
Shorts and opens in parallel circuits: The two possible defects that can occur in an electrical circuit they are;

- Short circuit
- Open circuit

Shorts in parallel circuit:

Fig 4 shows a parallel circuit with short between points ‘a’ and ‘b’.

Fig 4



This causes reduction of circuit resistance almost to zero.

Therefore, the voltage drop across ‘ab’ will be almost zero (by Ohms law).

Thus current through the resistors R_1, R_2, R_3 will be negligible and not their normal current.

The result is that a very high current in the order of hundred times of the normal current will flow through the short circuit.

A short circuit exists when current can flow from the positive terminal of the power source through connecting wires and back to the negative terminal of the power source without going through any load.

Short circuit may cause burning of the circuit elements like cables, switches etc.

Opens in parallel circuit: An open in the common line at point A as shown in Fig 5 causes no current flow in that circuit whereas an open in the branch at point B causes no current flow only in that branch. (Fig 6)

Fig 5

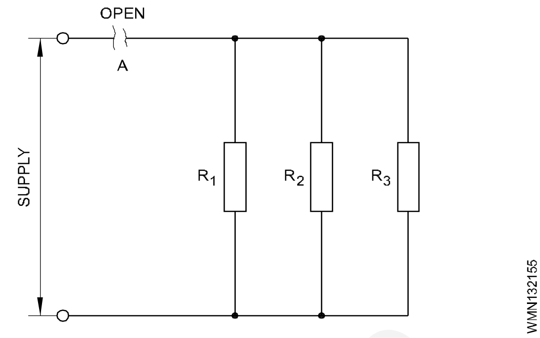
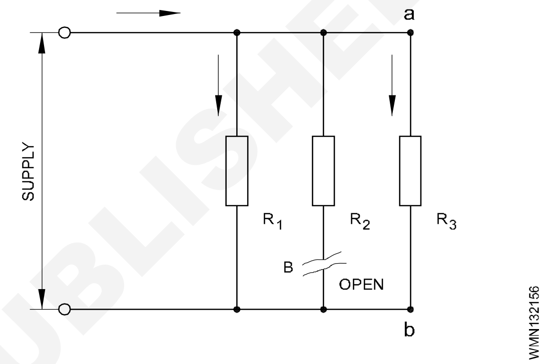


Fig 6



However, the current in branches R_1 and R_3 will continue to flow so long as they are connected to the voltage source.

Full voltage of the source will be available at open circuit terminals. It is dangerous to meddle with the terminals which are open.

Series and parallel combination circuit

Objectives: At the end of this lesson you shall be able to
- **compare the characteristics of series and parallel circuits**
- **solve series-parallel circuit problems.**

Comparison of characteristics of DC series and parallel ciruits

Sl. No.	Series circuit	Parallel circuit
1	The sum of voltage drops across the individual resistances equals the applied voltage.	The applied voltage is the same across each branch.
2	The total resistance is equal to the sum of the individual resistances that make up the circuit. $R_t = R_1+R_2+R_3+...$ etc combination.	The reciprocal of the total resistance equals the sum of the reciprocal of the resistances. The resultant resistance is less than the smallest resistance of the parallel
3	Current is the same in all parts of the circuit. resistance of each branch.	The current divides in each branch according to the resistance of each branch
4	Total power is equal to the sum of the power dissipated by the individual resistances.	(Same as series circuit) Total power is equal to the sum of the power dissipated by the individual resistances.

Passive components - Inductors

Objectives : At the end of this lesson you shall be able to
- **state inductor and inductance**
- **state self induction**
- **state the factors determining the value of an inductor**
- **explain mutual inductance**
- **explain the value of inductors in series and parallel**
- **explain Q factor.**

Inductive reactance/DC resistance of Inductance

Inductors are components consisting of coil of wire. The basic function of an inductor is to **store electric energy in the form of magnetic field**, when current flows through the inductor.

Inductance is the electrical property of inductors. Letter 'L' is used as a symbol to represent Inductance. Inductance, is the ability of a device to oppose any change in the current flowing through it. This opposition to change in current, is achieved by the energy stored by it, in the form of magnetic field.

Inductance, and thus an inductor, *chokes off* or restricts sudden changes in current through it. The change may be either increasing or decreasing. Hence inductors are also sometimes called as *Chokes*.

Principle of operation

Recall that, when current begins to flow through a conductor, magnetic flux rings start to expand around the conductor. This expanding flux induces a small voltage in the conductor called *back-emf* or *counter emf*. This induced voltage has a polarity that opposes the source voltage which creates the induced voltage.

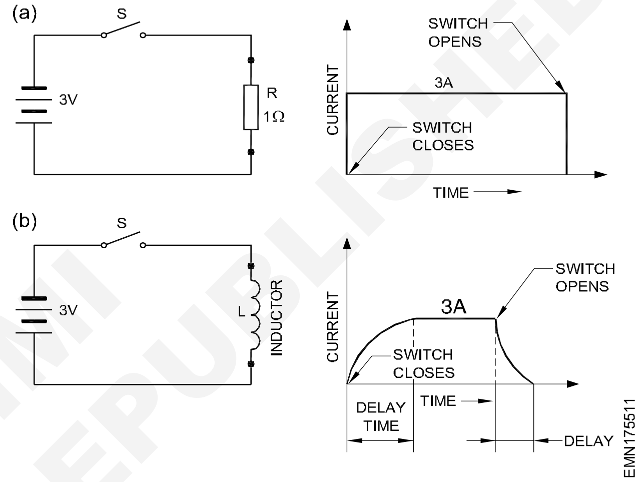
Thus, the inductance in a coil of wire, carrying current, opposes any rise or fall of current through it and tries to keep the current through it constant.

It should be noted that, the inductance cannot completely stop the increase in current because, the induced voltage is caused by the increasing flux, and the increasing flux depends on the increasing current. Therefore, an inductor can restrict only, the rate at which the current can increase or decrease through it.

Example: A Resistor of 1 Ω is connected to a DC source of 3 volts, as shown in Fig 1a. The moment switch S is ON, current will increase from 0 to its steady state value of 3Amps instantaneously, as shown in graph. When the switch is opened, the current drops back to zero just as fast as it raised.

Whereas, when the same DC voltage is applied to an Inductor having a coil resistance of 1Ω as shown in Fig 1b, the current will not increase instantaneously from 0 to its steady value because the inductor in the circuit does not allow it to happen. The current will reach the steady state value after a time delay as shown in graph. The amount of delay depends on the value of inductance and the ohmic resistance of the inductor.

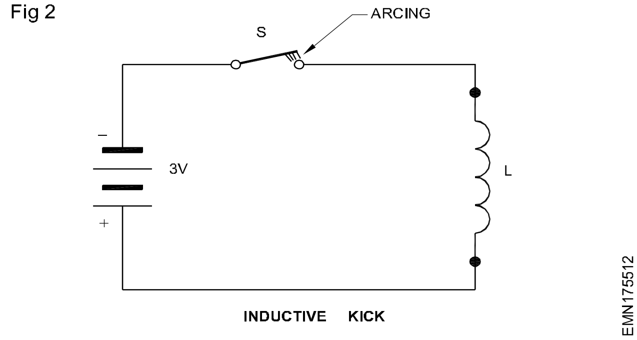
Fig 1



Once the current through the circuit in Fig 1b reaches its steady state value of 3Amps, which is decided by the ohmic value of the inductance, the magnitude of current remains constant and hence the inductive effect stops. At this point, the only opposition the inductor offers is its ohmic/DC resistance.

When the switch S of Fig 1b is opened, the back-emf(bemf) or counter emf(cemf) of the inductor becomes very high, much greater than the source voltage. This high voltage(cemf), prevents the current from instantaneously dropping to zero. It does this by ionizing the air between the switch contacts as the switch opens. This causes the switch contacts to arc and burn as shown in Fig 2. This

Fig 2



is known as inductive kick. As the energy stored in the inductors magnetic field gets used up, the switch contacts deionize and current stops.

This property of a coil to induce an emf within the coil due to a changing current through it is termed as **SELF INDUCTANCE**.

Unit of inductance - The Henry

The basic unit of measure of Inductance is Henry abbreviated as H. The unit henry is defined in terms of, the amount of cemf produced when the amplitude of current through the inductor is changing. Based on this , One Henry is that amount of Inductance which develops 1 V of cemf in the coil when the current changes at the rate of 1 Amp/sec.

From the above definition, referring Fig 3,

Inductance, $L = \dfrac{V_L}{di / dt}$

Where, V_L = Induced voltage

and $\dfrac{di}{dt}$ = rate of change of current. Refer Fig 3.

Polarity of Induced emf

The induced emf (voltage) in an inductor (cemf) has polarity that always opposes the source voltage (Lenz's law).

Fig 3

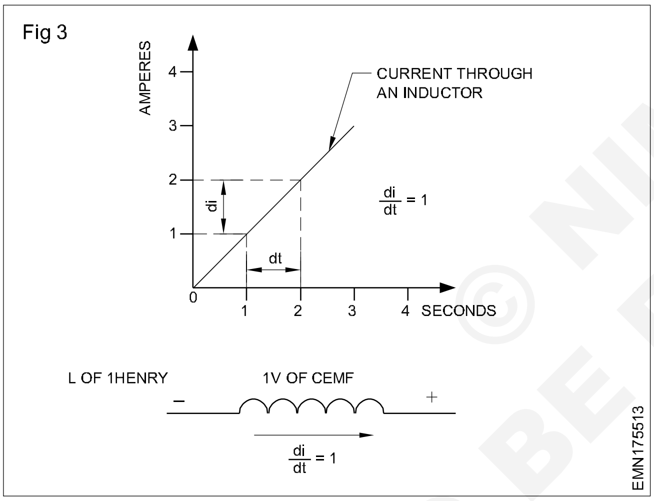


Fig 4 shows an inductor across an AC voltage source. When the applied voltage is increasing from 0 to +ve peak as shown in Fig 4a, the counter emf at end P of inductor will have +ve polarity opposing the increasing source voltage.

In Fig 4b, when the source voltage is decreasing from +ve peak to zero, the cemf at end P of the inductor will have -ve polarity opposing the decreasing source voltage.

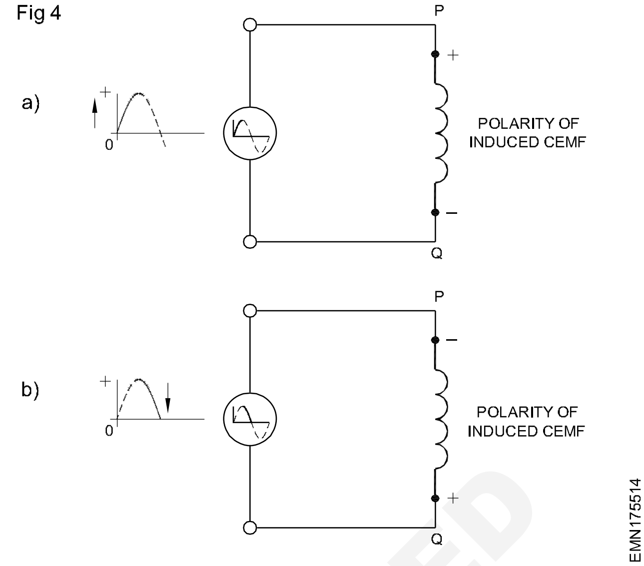
Factors determining value of Inductance

The inductance of an inductor is primarily determined by the following four factors:

1) The number of turns of wire
2) The material on which the coil is wound or the core material
3) The spacing between turns of wire and
4) The diameter of the coil

Fig 5 illustrates the effect of these factors on the inductance value.

Fig 4



Given the parameters listed above, the inductance of a coil can be calculated using the formula,

$$L = \mu \frac{N^2 A}{l} \text{ Henries}$$

where,

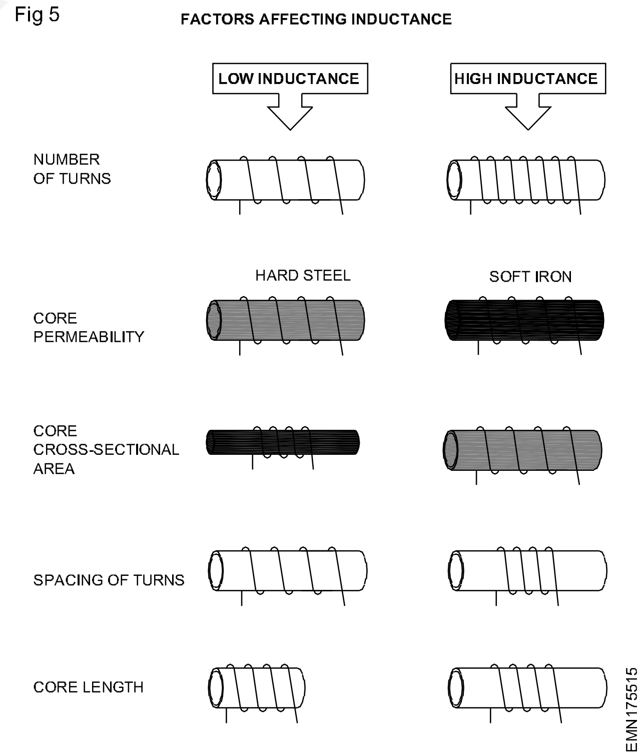
μ = Permeability of the magnetic core around which the coil is wound, in Wb/At-m ($\mu = \mu_o \mu_r$)

N = Number of turns of the coil

A = Area of cross-section of the core in square metres, m^2

l = length of the coil in meters.

Fig 5



Practical inductors and types

For practical applications, inductors are manufactured to give a specified amount of inductance. Value of practical inductors range from a few micro henries for application in high frequency communication circuits upto several henries for power supply ripple filter circuits.

Inductors can be classified under various categories as shown in Chart-1 given at the end of this lesson.

Air core coils have practically no losses from eddy currents or hysteresis. However inductor with air core have their values limited to low values in the range of micro to milli Henries. Air core inductors are used in high frequency applications.

Laminated Iron Core is formed using a group of individual laminations. Each lamination is insulated by a thin coating of iron oxide, silicon steel or varnish. This insulation increases the resistance reducing eddy current losses. These type of inductors are generally used for mains frequency of 50/60 Hz and lower audio frequency range, upto 10 kHz.

Powdered Iron Core is used to reduce the eddy currents in the core when used at radio frequencies. It consists of individual insulated granules pressed into one solid form called *slug*.

Ferrite Core is made from synthetic ceramic material which are ferromagnetic. They provide high value of flux density like iron, but have the advantage of being insulators, thus reducing the eddy current losses to bare minimum. Because of this advantage, inductors with ferrite core are used for high to very high frequency application.

Variable Inductors unlike fixed Inductors, variable inductors have the facility to vary its inductance value either in steps or continuously.

Shielded/Screened inductors will have a metal cover over the inductor. The shield is usually made of copper or aluminum. The reason for shielding is to isolate the coil from external varying magnetic field and to minimize the effect of the coils RF current on external circuits.

While making a shield/screen for an inductor the following points are to be noted;

i) metal used as cover should be a good conductor

ii) clearance between the sides of the coil and the metal should be equal to or greater than the coil radius. If the clearance is less, the shield reduces the inductance value drastically.

Moulded inductors, looks like resistors with their values colour coded. The coding scheme is same as in resistor, except that the value of L are given in microhenry (μH). For example, a coil with yellow, red and black stripes or dots as shown in Fig 10, has inductance value of 42 μH.

Laboratory type variable inductor are available in the form of a **decade box**. In this decade-inductance box precision inductors are switched in-to or out-of circuit by means of rotary switches. Decade variable inductor is used to carryout experiments and in Inductance (L) meters.

Special types of Inductors

Certain electronic circuits use a special type of Inductor called **Thin-film inductors**. These inductors are thin metal films deposited in the form of a spiral on a ceramic or epoxy base. These are tiny sized and have very low value of inductance.

Copper tube Inductors: At high frequencies, current has a tendency to flow in the skin of the conductor, this is known as **skin effect**. Therefore at high frequency & high power applications hollow copper tube coil is used as inductor instead of solid copper wire.

Variometers: If different radio frequencies are to be received using a single antenna, the electrical length of the antenna will have to be varied, to respond to different wave lengths. Variable inductors used to achieve this are called variometers.

Energy storage in inductors

Energy storage: An inductor stores energy in the magnetic field created by the current. The energy stored is expressed as follows.

where I is in amperes,

L is in henries and

W is energy in joules or watt-second

What should we do when correct values of inductors are not available?

To obtain the desired value of inductors, some series and parallel combination of inductors can be used.

Statically induced emf: When the induced emf is produced in a stationery conductor due to changing magnetic field, obeying Faraday's laws of electro magnetism, the induced emf is called as statically induced emf.

There are two types of statically induced emf as stated below:-

$$W = \frac{1}{2} L r^2$$

1 **Self induced emf** produced with in the same coil

2 **mutually induced emf** produced in the neighbouring coil

Self-induction: When an alternating current flows in a conductor and the current periodically changes the direction, the magnetic field it produces also reverses the direction. At any instant, the direction of the magnetic field is determined by the direction of the current flow.

With one complete cycle, the magnetic field around the conductor builds up and then collapses. It then builds up in the opposite direction, and collapses again. When the magnetic field begins building up from zero, the lines of force or flux lines expand from the centre of the conductor outward. As they expand outward, they can be thought of as cutting through the conductor.

According to Faraday's Laws, an emf is induced in the conductor. Similarly, when the magnetic field collapses, the flux lines cut through the conductor again, and an emf is induced once again. This is called self-inductance. (Fig 6)

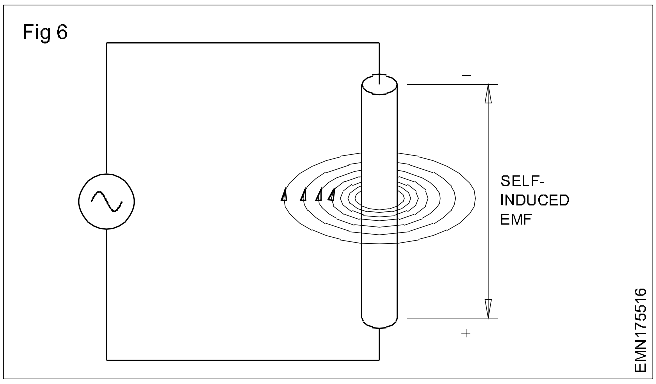


Fig 6

Inductance:Inductance (L) is the electrical property of an electrical circuit or device to oppose any change in the magnitude of current flow in a circuit.

Devices which are used to provide inductance in a circuit are called inductors. Inductors are also known as chokes, coils, and reactors. Inductors are usually coils of wire.

Factors determining inductance: The inductance of an inductor is primarily determined by four factors.

– Type of core permeability of the core m_r

– Number of turns of wire in the coil 'N'

– Spacing between turns of wire (Spacing factor)

– Cross-sectional area (diameter of the coil core) 'a' or 'd'.

The amount of inductance in a coil of wire is affected by the physical make up of the coil.

Core: If soft iron is used as a core material instead of hardened steel, the coil will have more inductance.

If all the factors are equal, an iron core inductor has more inductance than an air core inductor. This is because iron has a higher permeability, that is, it is able to carry more flux. With this higher permeability there is more flux change, and thus more counter induced emf (cemf), for a given change in current.

Number of turns: Adding more turns to an inductor increases its inductance because each turn adds more magnetic field strength to the inductor. Increasing the magnetic field strength results in more flux to cut the conductors (turns) of the inductor.

Spacing between turns of wire: When the distance between the turns of wire in a coil is increased, the inductance of the coil decreases. With widely spaced turns, many of the flux lines from adjacent turns does not link to gather. Those lines that do not link together produce no voltage in other turns. As the turns come closer together only a fewer lines of flux fail to link up.

Cross sectional area: For a given material having same number of turns, the inductance will be high with large cross-sectional area and will be low for smaller cross-sectional area.

Symbol and unit of Self-inductance: The property of a coil or conductor to self-induce an emf, when the current though it is changing, is called the coil's (conductor's) self-inductance of simply inductance. The letter symbol for inductance is L; its basic unit is henry, H.

Henry: A conductor or coil has an inductance of one henry if a current that changes at the rate of one ampere per second produces a induced voltage (cemf) of 1 volt.

The inductance of straight conductors is usually very low, and for our proposes can be considered zero. The inductance of coiled conductors will be high, and it plays an important role in the analysis of AC circuits.

Mutual Inductance (M)

When two inductors L_1 and L_2 are placed side by side close to each other shown in Fig 7a or Fig 7b, although the two coils are not electrically connected, the two coils are said to be magnetically inter-coupled.

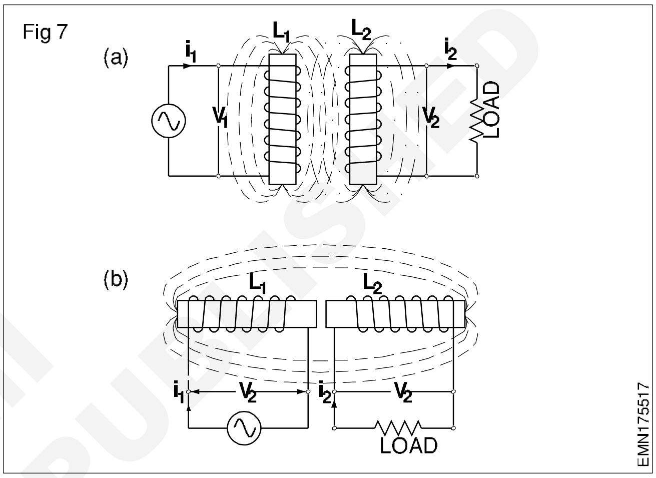


Fig 7

The changing current i_1 in coil L_1 not only self induces an emf (V_1) in L_1, but also causes a voltage (V_2) to be induced in L_2. The voltage V_2 induced in L_2 causes a current i_2 that sets-up its own changing flux around L_2. This in turn, not only self induces a voltage in L_2, but also induces an additional voltage in L_1. That is, a changing current in one coil will induce an emf in other nearby coil. This effect is known as **mutual induction**.

The two coils L_1 and L_2 of Fig 7, are said to have a mutual inductance (M), in addition to their own self-inductances (L).

Mutual inductance, like self-inductance, is also measured in units of Henrys. The definition is given below;

Two coils are said to have a mutual inductance of 1 Henry, when a current changing at the rate of 1 Amp/sec in one coil induces an emf of 1V in the other coil.

Coefficient of coupling

The amount of mutual inductance (M) between two coils depend upon, the self inductance of each coil and the amount of mutual flux between the two coils.

The amount of mutual flux, that links both coils is dependent on the physical placement of the two coils. This is indicated by the term **Coefficient of coupling, k**.

Coefficient of coupling k, between the two coils is given by,

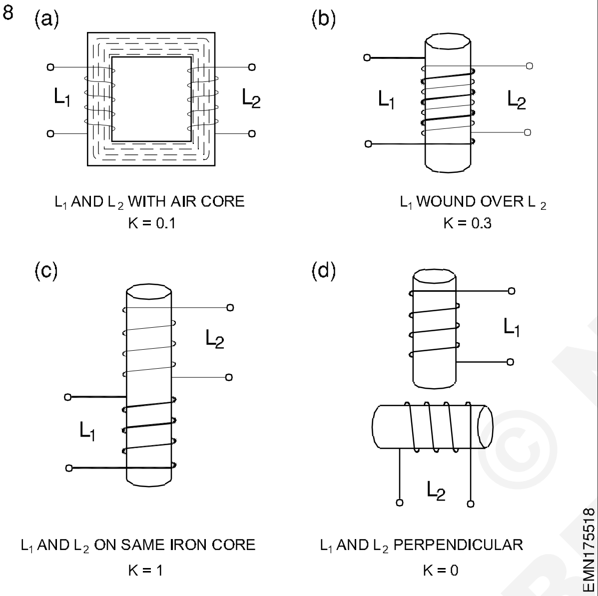
$$k = \frac{\text{Mutual flux between two coils } \phi_m \text{, in Webers}}{\text{Total flux setup by one coil, in Webers}}$$

Maximum value of **k** can be 1. This occurs when all the flux (ø) set-up by one coil is linking with the other coil. For example; when both the coils are wound as shown in Fig 15a, almost all the flux set-up in one coil is interacting with the other coil. In other words there is very little or zero leakage of flux. In such cases k is practically equal to 1. This condition of k=1 is also known as **tight coupling**.

In Fig 8b, if only 30% of the flux set-up by coil 1, links with coil 2, the coefficient of coupling is only 0.3.

In Fig 8c and Fig 15d where the coils are placed far apart or when the two coils are placed perpendicular to one another, the coupling is minimum and will be close to zero.

Fig 8



It can be shown that mutual inductance (M) between the given two coils L_1 and L_2 can be found out using the formula,

$$M = k\sqrt{L_1 . L_2} \text{ Henrys.}$$

Where,

k is the coefficient of coupling which has no units

L_1 and L_2 are inductance values, in henrys

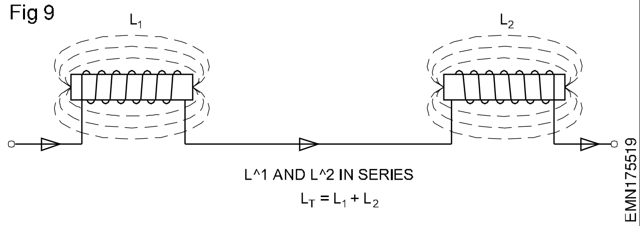
M is the mutual inductance, in henrys

INDUCTORS IN SERIES

In order to obtain a desired value of inductance, inductors can be connected either in series or in parallel.

Fig 9 shows two inductances connected in series. The spacing between the inductors are large enough so that there exists no mutual inductance between the two coils. Hence in Fig 16 k=0. In Fig 9, since the direction of current is same through both coils, the self-induced voltages are additive. Therefore the total inductance of such series connection is given by,

Fig 9



Series coils with mutual inductance

Unlike in Fig 9, when two inductors L_1 and L_2 are connected in series close to each other, the total inductance (L_T) will be larger than just the sum of L_1 and L_2. How much larger will this be depends on the mutual inductance M.

$L_T = L_1 + L_2 + L_3 + ...+ L_n$ Henrys (H)

where, L_T is the total inductance across end terminals.

$L_1, L_2 ....L_n$ are individual inductance values.

In general, the total inductance of two series-connected coils, with mutual inductance M is given by;

$L_T = L_1 + L_2 \pm 2M$

Dot notation

Whether two coils are connected series-aiding or series-opposing, it is often indicated by using *dot notation* as shown in Fig 10. When current enters both dots or leave both dots as shown in Fig 10a the mutual inductance is additive.

When the current enters one dot and leaves the other dot, as shown in Fig 10b, the mutual inductance is subtractive. In other words the dots indicate the in-phase ends of each other.

Fig 10

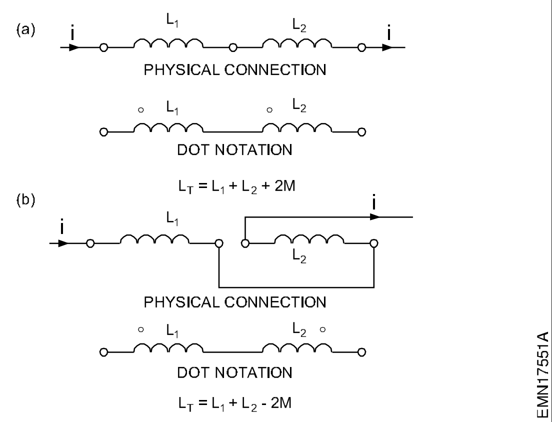


CHART - 1 **PHYSICAL APPEARANCE OF DIFFERENT TYPES OF INDUCTORS**

Fig 1 **IRON-CORE INDUCTOR OR CHOKE**

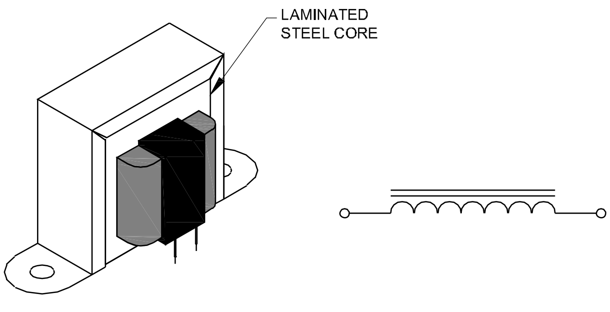


Fig 2 **AIR-CORE INDUCTORs**

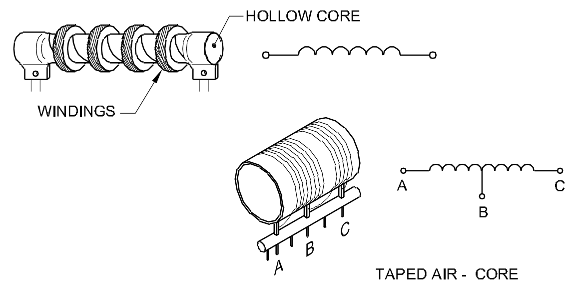


Fig 3 **FERRITE-CORE INDUCTORS**

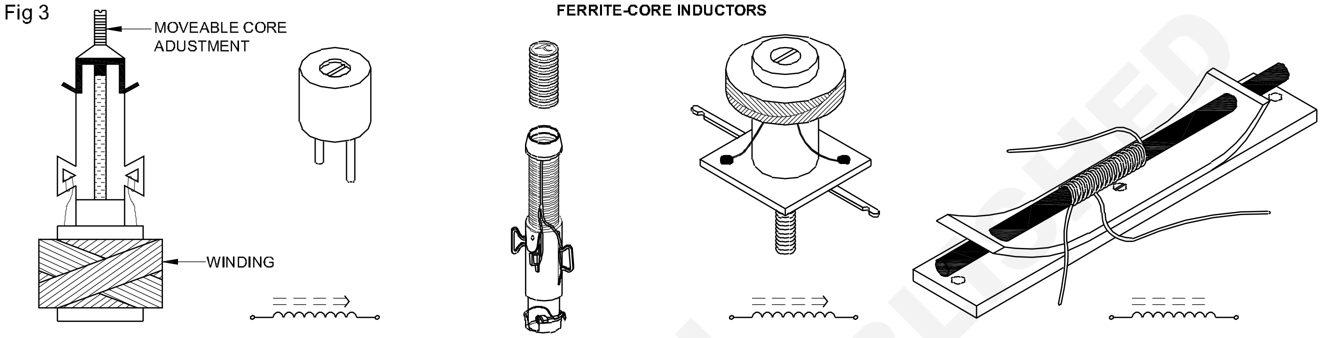


Fig 4 **SHIELDED INDUCTORS**

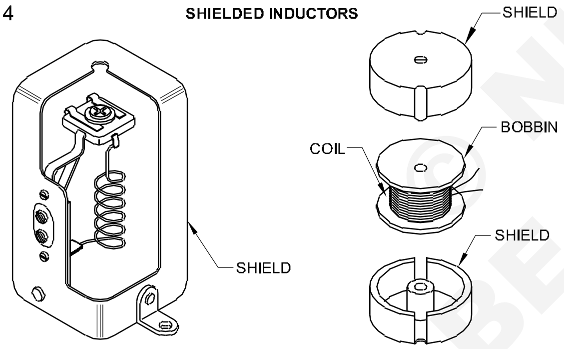


Fig 5 **HIGH FREQUENCY INDUCTORS**

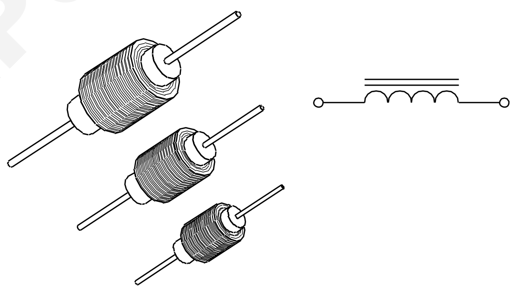


Fig 6 **MOULDED INDUCTORS**

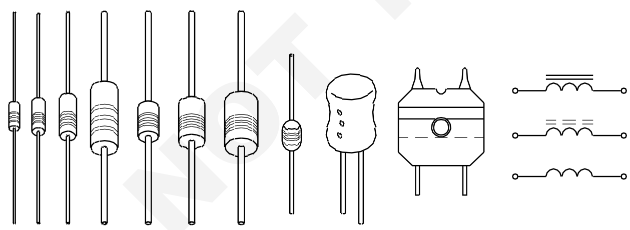
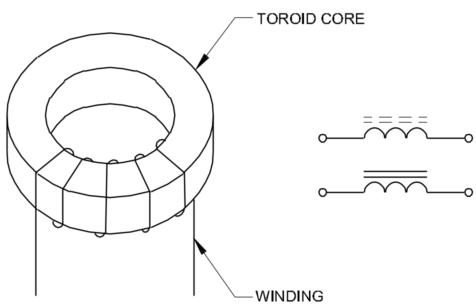


Fig 7 **TOROID FERRITE CORE INDUCTOR**



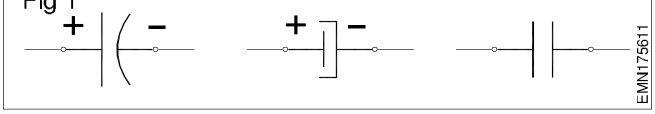
Passive components - Capacitors

Objectives : At the end of this lesson you shall be able to
- **state the function of capacitor.**
- **describe energy storing in capacitor**
- **state the factors that determine capacitance value**
- **state the functions of dielectric in a capacitor**
- **explain the types of fixed value capacitors**
- **explain the constructional details of capacitors**
- **connect the capacitors in series, parallel and series and parallel.**

Capacitors and Capacitance

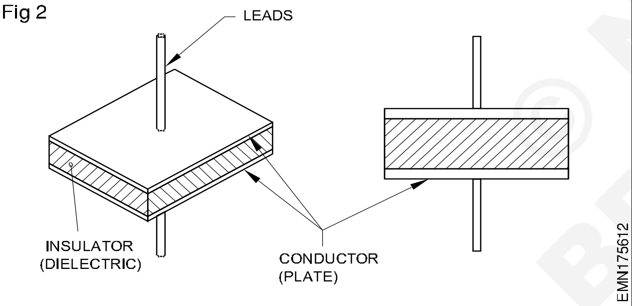
Capacitors are electronic components which can store electric energy in the form of electric charge. The charge storage ability of a capacitor is called the **Capacitance** of a capacitor. Symbols used to represent capacitors are shown in Fig 1. Alphabet 'C' is used to represent the capacitance of a capacitor.

Fig 1



A simple capacitor consists of two pieces of conductors separated by an insulator as shown in Fig 2.

Fig 2



In capacitors the conductors shown in Fig 2 are called **plates** and the insulator is called **dielectric**.

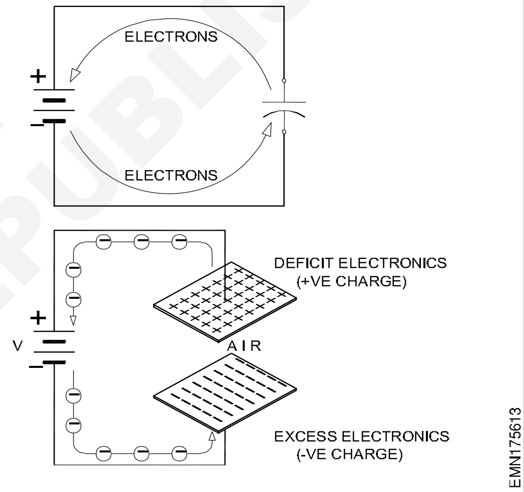
The plates of a capacitor can be of any size and shape and the dielectric may be any one of several insulator materials. Depending on the type of insulator/dielectric used capacitors are called as paper, mica, ceramic, glass, polyester, air electrolyte capacitors etc.,

Capacitor action of storing charge

When electric charge is forced on to the plates of a capacitor by some energy source, such as a battery, the capacitor stores these charges.

When a capacitor is connected to a battery as shown in Fig 3, electrons from the negative terminal of battery move through the connecting leads and pile up on one of the plates of the capacitor. At the same time free electrons from the other plate of the capacitor (remember that plates of a capacitor are conductors having free electrons) move through the connecting lead to the positive terminal of the battery. This process is known as 'charging of capacitor'. As the process of charging continues, the net result is that, one plate of the capacitor ends up with excess of electrons (Negative charge) and the other plate with deficiency of electrons (Positive charge). These charges on the plates of the capacitor represent a voltage source similar to that of the charges on the terminals of a battery/cell. The process of charging stops once the energy stored on the capacitor develops a voltage equal to that of the battery.

Fig 3



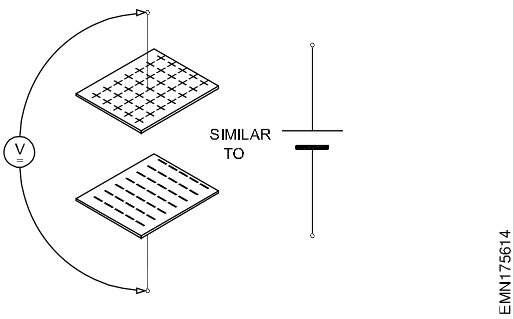
It is important to note that during the process of charging, although electrons were moving from and to the capacitor plates causing current flow in the circuit (you can connect an ammeter to measure it), no electrons moved nor did current flow from one plate through the dielectric to the other plate of the capacitor. The charging current through the circuit stops when the voltage across the capacitor becomes equal to, and in opposition to, the battery voltage. This charged capacitor can be disconnected from the circuit and used as a new energy source as shown in Fig 4.

If a voltmeter is connected across this disconnected charged capacitor, the voltmeter reads the voltage equal to that of the battery which charged it.

If a lamp is connected across this charged capacitor, the bulb glows for a moment indicating current flow through it.

The charge stored in the capacitor is sufficient to supply current through the bulb only for a short duration after which the charge filed up on the capacitor plates gets exhausted. A capacitor has limited use as a primary storage device of energy for two reasons:

Fig 4



1 For its weight and size, the amount of energy it can store is very small when compared with that of a battery.

2 The voltage available from the capacitor diminishes rapidly as energy is removed from the capacitor.

Unit of capacitance

The ability of capacitor to store electrical energy in the form of electrostatic field is known *capacitance*. The unit used to measure capacitance is **Farad** abbreviated as **F**.

A capacitor is said to have a capacitance(C) of 1 Farad, if it stores a charge(Q) of 1 coulomb when a voltage(V) of 1V is applied across its plates.

Therefore, capacitance can be mathematically expressed as,

$$\text{Capacitance} = \frac{\text{Charge}}{\text{Voltage}}$$

$$C = \frac{Q}{V} \text{Farads}$$

Farad(F) is a very large quantity of capacitance. As most circuits use capacitance values much lower than one farad (F), smaller quantities of capacitance given below are generally used:

1 Microfarad or 1μF	= 1/1000000 F	or 10^{-6}	farads
1 Nanofarad or 1 nF	= $1/10^{9}$ F	or 10^{-9}	farads
1 Picofarad or 1pF	= $1/10^{12}$ F	or	farads

10^{-12}

Example: ***What is the capacitance (C) of a capacitor that requires a charge (Q) of 0.5 coloumbs to build a voltage(V) of 25 volts across its plates?***

SOLUTION

Given: Charge (Q) = 0.5 Coloumb

Voltage (V) = 25 Volts

Using the formula,

$$\text{Capacitance, C} = \frac{\text{Q Coloumbs}}{\text{V Volts}} \text{Farads}$$

$$\text{Capacitance, C} = \frac{0.5}{25} = 0.02 \text{Farads}$$

Factors that determine the value of capacitance

The capacitance of a capacitor is determined by the following three main factors;

1 Area of the plates

2 Distance between the plates

3 Type of dielectric material (dielectric constant k)

In addition to the above factors affecting the value of capacitance, the temperature of the capacitor also affects the capacitance although not very significantly. Increase or decrease in temperature affects the characteristics of dielectric material which in-turn increases or decreases the capacitance value. Some dielectrics cause an increase in capacitance as temperature increases. These are called positive temperature coefficients, abbreviated as P. Other dielectric materials have negative temperature coefficient, abbreviated as N, in which case, increase in temperature decreases the capacitance. There are dielectric materials having zero temperature coefficient abbreviated as NPO. The temperature coefficient of a capacitor is specified by the capacitor manufacturer in parts per million per degree Celsius (PPM).

The following expression gives the relation between the three factors that determine the value of capacitance of a capacitor;

$$C = \varepsilon_r \varepsilon_o \frac{A}{d} \text{ Farads}$$

The term e_o is the permittivity of free space (air) = 8.85 x 10^{-12} C^2/Nm^2 and e_r is called the relative permittivity of the dielectric material.

The expression for capacitance (C) of a capacitor can also be written as,

$$C = k\,\varepsilon_o \frac{A}{d} \text{ Farads}$$

The ratio of the capacitance with dielectric to the capacitance with air is called relative permitivity or dielectric constant, k.

Substituting the value of e_o in the above equation, value of a capacitor using any dielectric can be found using the formula;

$$C = (8.85 \times 10^{-12})\, k \frac{A}{d} \text{ Farads}$$

where,

C = Capacitance in farads

$(8.85 \times 10^{-12}) = \varepsilon_o$ (permitivity of air)

k = dielectric constant of the insulator used between the plates

A = area of one side of the plate in square meters, m^2

d = distance between the plates in meters, m

Example: Two metal plates, each 5 x 6 cms are separated from each other by 1mm. Calculate the capacitance if the dielectric material used between the plates was,

1) air

2) glass

SOLUTION:

$k_{air} = 1$

$C = (8.85 \times 10^{-12})\, k \, \frac{A}{d}$

$= (8.85 \times 10^{-12}) \times 1 \times (5 \times 10^{-2}\,m \times 6 \times 10^{-2}\,m)/(1 \times 10^{-3}\,m)$

$= 26.55 \times 10^{-12}$ Farads

= 26.55 pico farads

C = 26.55 pF

2 From PTB table no.18

$k_{Glass} = 5$

$C = (8.85 \times 10^{-12}) \times 5 \times (5 \times 10^{-2}\,m \times 6 \times 10^{-2}\,m)/(1 \times 10^{-3}\,m)$

= 5 x 26.55pF

C = 132.75 pF

Working voltage or voltage rating of capacitor

The dielectric strength of the insulating material used between the plates of a capacitor gives the capacitor the ability to withstand a potential difference between the plates without causing arcing. Therefore, a specific capacitor using a specific type of dielectric can withstand only up to a specific voltage across it. If the voltage is further increased, the dielectric breaks down or gets punctured. This causes a burn out or a hole in the dielectric material permanently damaging the capacitor.

This maximum voltage that a capacitor can withstand is listed as one of the specifications of capacitors as *direct current working voltage*, DCWV. As an example: if a capacitor has a DCWV of 100 volts, it can be operated at 100 volts for long periods of time without any deterioration in the working of the capacitor. If the capacitor is subjected to 125V or 150V DC, the dielectric may not break down immediately but the life of the capacitor gets greatly reduced and may become permanently defective any time.

Function of a dielectric in a capacitor

1 Solves the mechanical problem of keeping two metal plates separated by a very small distance.

2 Increases the maximum voltage that can be applied before causing a breakdown, compared with air as dielectric.

3 Increases the amount of capacitance, compared with air, for a given dimension of plates and the distance between them.

Types of capacitors: Capacitors can be classified under two main categories:

1 Fixed value capacitors

The capacitance value of these capacitors is fixed at the time of manufacture. This value cannot be varied/altered by the user.

2 Variable capacitors

The capacitance of such capacitors can be varied between the specified minimum to the specified maximum values by the user.

Amongst fixed value capacitors, many different types of capacitors are manufactured to satisfy the needs of the electronic industry. These different types of capacitors are named according to the

1 Type of dielectric material used in capacitor

Example:

a If paper is used as dielectric, the capacitors are called *paper capacitors.*

b If ceramic is used as dielectric, the capacitors are called *Ceramic capacitors.*

2 Type of construction of the capacitor

Example:

a If the foils of the conductor and dielectric are rolled to form a capacitor, such capacitors are called as *Rolled foil capacitors*.

b If the plates and dielectric are in the form of Discs, such capacitors are called as *Disc capacitors*.

Different types of fixed value capacitors, their sub types, available values, rated voltage and a few applications are given in Chart 1 at the end of this lesson. Also refer to Chart 3 for illustration of some of the popular fixed value capacitors.

Specifications of capacitors

While ordering capacitors, one has to indicate the specifications needed to ensure that the desired capacitor is received. The minimum specifications to be indicated while purchasing/ordering capacitors for general use are;

1 **Type of capacitor**

For example: Ceramic, disc, styroflex, electrolytic and so...on.

2 **Capacitance value**

For example: 100µF, 0.01µF, 10pf and so....on.

3 **DC working voltage rating (DCWV)**

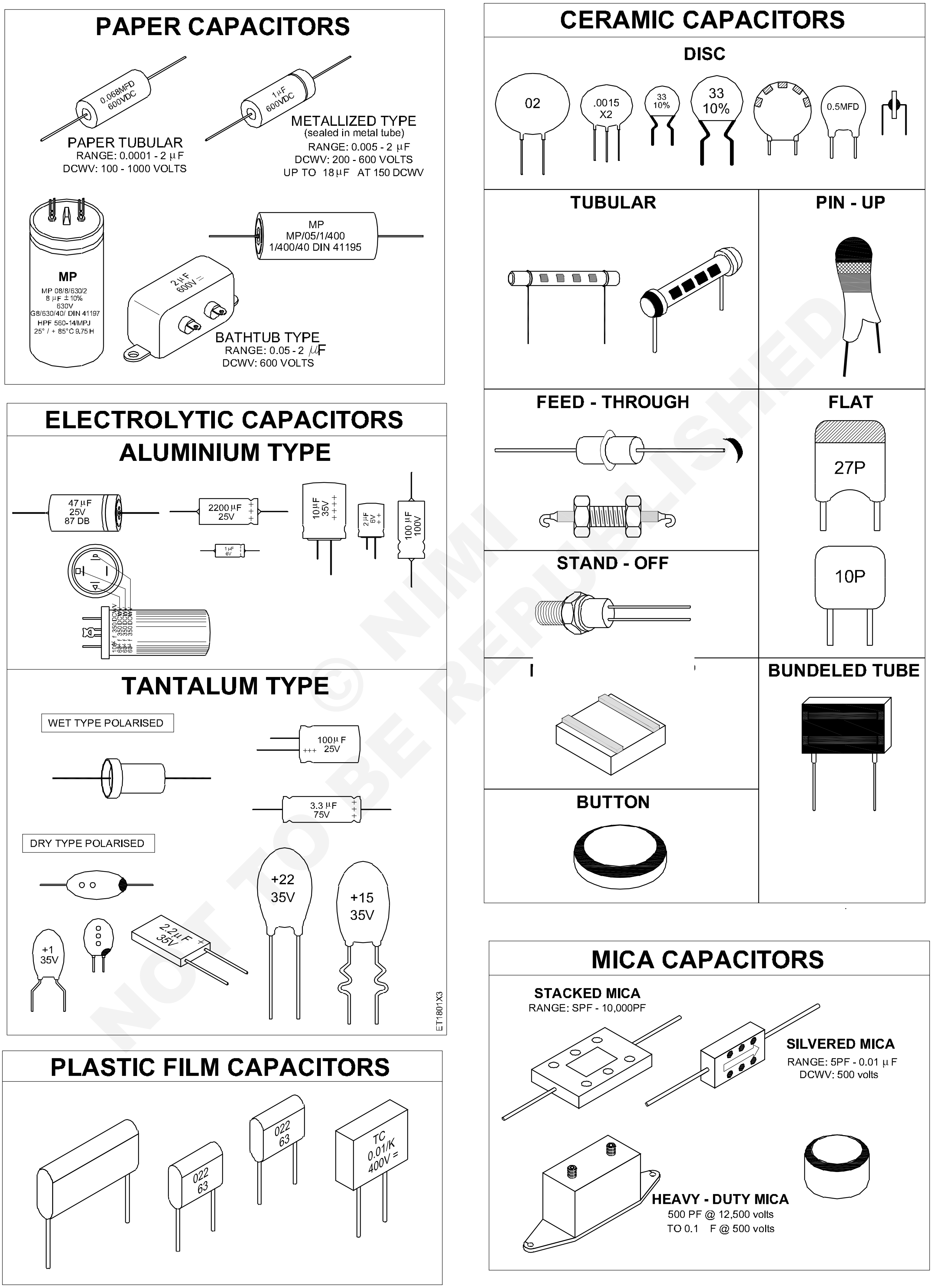
For example: 100µF-12V, 100µF-100V, 0.01µF-400V and so...on.

4 **Tolerance**

Like resistors, capacitors also have tolerances over its rated value. Tolerance of capacitors may range from ±1% to ±20%. Some capacitors may have tolerance specified as -20%, +80%.

Checking capacitors: The two simple methods to check a capacitor is by carrying out,

CHART- 1 : Physical appearance of types of fixed value capacitors



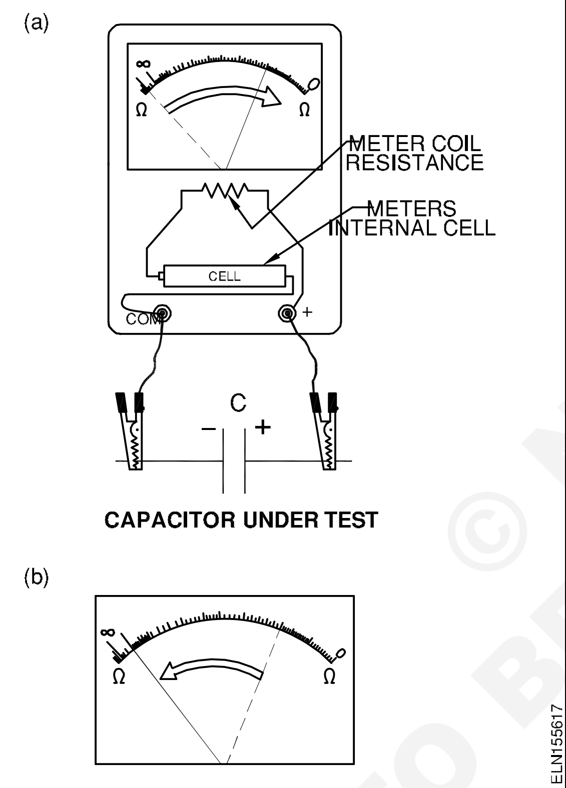
i capacitor action-normal resistance test, using a ohm-meter/multi-meter (This test is also referred as quick-test)

ii charging-holding test, using a battery and voltmeter/ multi-meter.

Capacitor action-normal resistance test

When an ohmmeter is connected across a fully discharged capacitor, initially, the battery inside the meter charges the capacitor. During this charging, at the first instance, a reasonably high charging current flows. Since more current through the ohmmeter means less resistance, the meter pointer moves quickly towards zero ohms of the meter scale as shown in Fig 5a.

Fig 5



After the initial charging, the charging current to the capacitor slowly decreases (as the voltage across the

the capacitor. During this charging, at the first instance, a reasonably high charging current flows. Since more current through the ohmmeter means less resistance, the meter pointer moves quickly towards zero ohms of the meter scale.

After the initial charging, the charging current to the capacitor slowly decreases (as the voltage across the capacitor increases towards the applied voltage). Since less and less current through the ohmmeter means high and higher resistance, the meter pointer slowly moves towards infinite resistance on the meter scale. Finally, when the capacitor is completely charged to the ohmmeter internal battery voltage, the charging current becomes almost zero and the ohmmeter reads the normal resistance of the capacitor which is a result of just the small leakage current through the dielectric. This charging effect, commonly known as Capacitor action. It indicates, whether the capacitor can store charge, or the capacitor is excessively leaky. Also the capacitor could be fully short-circuited or the capacitor is fully open-circuited.

The capacitor-action test is most suitable for high value capacitors and specially electrolyte capacitors. When small value capacitors such as ceramic disc or paper capacitors are tested for capacitor-action, due to the extremely low charging current the capacitor-action cannot be observed on the meter dial. For such small value capacitors the capacitor-charging-holding test is preferred. However if small capacitors are subjected for capacitor-action test, if the meter shows high resistance the capacitor can be taken as not shorted and hence may be taken as good.

Charging-holding test on capacitors

In this test, a given capacitor is charged to some voltage level using an external battery.

Once the capacitor is charged to the applied voltage level, the battery is disconnected and the voltage across the capacitor is monitored. The voltage is monitored for a period of time to confirm whether the capacitor is able to hold the charge atleast for a small period of time (of the order of a few seconds).

In this test, when the capacitor is tried for charging, if the capacitor does not charge at all even after connecting the battery for a considerable period of time, it can be concluded that the capacitor is either short-circuited or fully open circuited.

If the capacitor is unable to hold the charge even for a considerably small period of time, then it can be concluded that the capacitor is excessively leaky.

The following points are important and are to be noted to get correct results from this test :

1 If the capacitor to be tested is marked with + and - at its terminals (polarised-capacitor) then connect the battery with the same polarity. If a polarised capacitor is tried for charging with opposite polarity, the capacitor may get permanently damaged.

2 Use a FET input voltmeter or high ohm/volt voltmeter to monitor the holding of voltage across the charged capacitor. This is because a low ohm/volt voltmeter will draw current from the charged capacitor resulting in the early discharge of stored charges on capacitor.

The term FET stands for a type of transistor discussed in subsequent units. A FET input voltmeter is a high quality voltmeter having very high ohms/volts. This meter draws almost zero current while measuring voltage across any two terminals. Other average voltmeters draw current in the range of a few hundreds of micro-amps to a few milli-amps while measuring voltage.

Necessity of grouping of capacitors: In certain instances, we may not be able to get a required value of capacitance and a required voltage rating. In such instances, to get the required capacitances from the available capacitors and to give only the safe voltage across capacitor, the capacitors have to be grouped in different fashions. Such grouping of capacitors is very essential.

Methods of grouping: There are two methods of grouping.

- Parallel grouping
- Series grouping

Parallel grouping

Conditions for parallel grouping

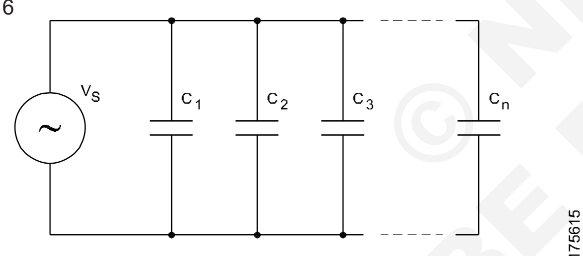
- Voltage rating of capacitors should be higher than the supply voltage Vs.
- Polarity should be maintained in the case of polarised capacitors (electrolytic capacitors).

Necessity of parallel grouping: Capacitors are connected in parallel to achieve a higher capacitance than what is available in one unit.

Connection of parallel grouping: Parallel grouping of capacitors is shown in Fig 6 and is analogous to the connection of resistance in parallel or cells in parallel.

Total capacitance: When capacitors are connected in parallel, the total capacitance is the sum of the individual capacitances, because the effective plate area increases. The calculation of total parallel capacitance is analogous to the calculation of total resistance of a series circuit.

Fig 6



CAPACITORS IN PARALLEL

By comparing Figures 6a and 6b, you can understand that connecting capacitors in parallel effectively increases the plate area.

General formula for parallel capacitance: The total capacitance of parallel capacitors is found by adding the individual capacitances.

$C_T = C_1 + C_2 + C_3 + \ldots\ldots\ldots\ldots + C_n$

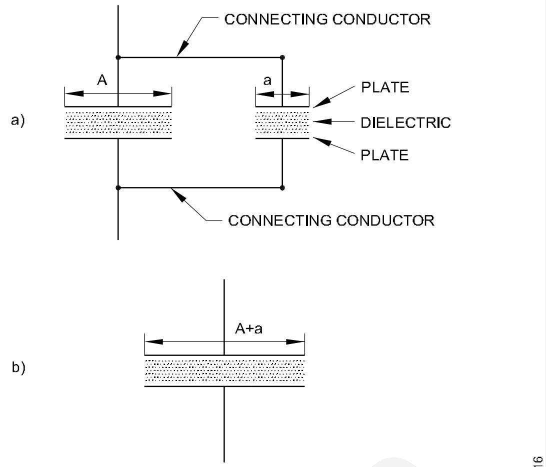
where C_T is the total capacitance,

C_1, C_2, C_3 etc. are the parallel capacitors.

The voltage applied to a parallel group must not exceed the lowest breakdown voltage for all the capacitors in the parallel group.

***Example**:* Suppose three capacitors are connected in parallel, where two have a breakdown voltage of 250 V and one has a breakdown voltage of 200 V, then the maximum voltage that can be applied to the parallel group without damaging any capacitor is 200 volts.

Fig 7



CAPACITORS IN PARALLEL. THE EQUIVALENT CAPACITANCE IN (b) IS EQUAL TO THE SUM OF THE CAPACITANCES IN (a).

The voltage across each capacitor will be equal to the applied voltage.

Charge stored in parallel grouping: Since the voltage across parallel-grouped capacitors is the same, the larger capacitor stores more charge. If the capacitors are equal in value, they store an equal amount of charge. The charge stored by the capacitors together equals the total charge that was delivered from the source.

$Q_T = Q_1 + Q_2 + Q_3 + \ldots\ldots + Q_n$

where Q_T is the total charge

Q_1, Q_2, Q_3.....etc. are the individual charges of the capacitors in parallel.

Using the equation Q = CV,

the total charge $Q_T = C_T V_S$

where V_S is the supply voltage.

Again $C_T V_S = C_1 V_S + C_2 V_S + C_3 V_S$

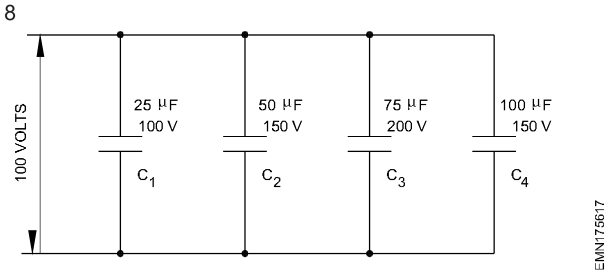
Because all the V_S terms are equal, they can be cancelled.

Therefore, $C_T = C_1 + C_2 + C_3$

Example: Calculate the total capacitance, individual charges and the total charge of the circuit given in Fig 10.

Solution

Fig 8



Total capacitance = C_T

$C_T = C_1 + C_2 + C_3 + C_4$

C_T = 250 micro farads.

Individual charge = Q = CV

$Q1 = C1V$

$= 25 \times 100 \times 10^{-6}$

$= 2500 \times 10^{-6}$

$= 2.5 \times 10^{-4}$

$= 2.5 \times 10^{-3}$ coulombs.

$Q2 = C2V$

$= 50 \times 100 \times 10^{-6}$

$= 5000 \times 10^{-6}$

$= 5 \times 10^{-3}$ coulombs.

$Q3 = C3V$

$= 75 \times 100 \times 10^{-6}$

$= 7500 \times 10^{-6}$

$= 7.5 \times 10^{-3}$ coulombs.

$Q4 = C4V$

$= 100 \times 100 \times 10^{-6}$

$= 10000 \times 10^{-6}$

$= 10 \times 10^{-3}$ coulombs.

Total charge $= Qt = Q1 + Q2 + Q3 + Q4$

$= (2.5 \times 10^{-3}) + (5 \times 10^{-3}) + (7.5 \times 10^{-3}) + (10 \times 10^{-3})$

$= (2.5+5+7.5+10) \times 10^{-3}$

$= 25 \times 10^{-3}$ coulombs.

or $QT = CTV$

$= 250 \times 10^{-6} \times 100$

$= 25 \times 10^{-3}$ coulombs.

Series grouping

Necessity of grouping of capacitors in series: The necessity of grouping capacitors in series is to reduce the total capacitance in the circuit. Another reason is that two or more capacitors in series can withstand a higher potential difference than an individual capacitor can. But, the voltage drop across each capacitor depends upon the individual capacitance. If the capacitances are unequal, you must be careful not to exceed the breakdown voltage of any capacitor.

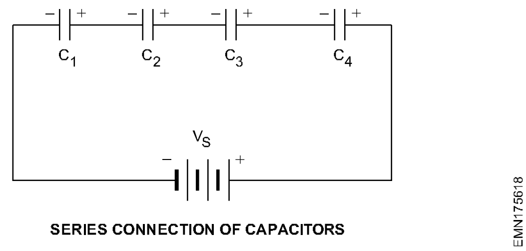
Conditions for series grouping

— If different voltage rating capacitors have to be connected in series, take care to see that the voltage drop across each capacitor is less than its voltage rating.

— Polarity should be maintained in the case of polarised capacitors.

Connection in series grouping: Series grouping of capacitors, as shown in Fig 9 is analogous to the connection of resistances in series or cells in series.

Fig 9



SERIES CONNECTION OF CAPACITORS

Total capacitance: When capacitors are connected in series, the total capacitance is less than the smallest capacitance value, because

– the effective plate separation thickness increases

– and the effective plate area is limited by the smaller plate.

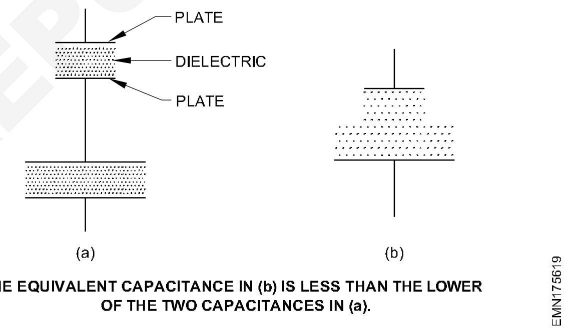
The calculation of total series capacitance is analogous to the calculation of total resistance of parallel resistors.

By comparing Figs 10 can understand that connecting capacitors in series increases the plate separation thickness, and also limits the effective area so as to equal that of the smaller plate capacitor.

General formula for series capacitance: The total capacitance of the series capacitors can be calculated by using the formula

If there are two capacitors in series

Fig 10



THE EQUIVALENT CAPACITANCE IN (b) IS LESS THAN THE LOWER OF THE TWO CAPACITANCES IN (a).

$$C_T = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + ------ + \frac{1}{C_n}}$$

or

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + ------ + \frac{1}{C_n}$$

$$C_T = \frac{C1\ C2}{C1 + C2}$$

If there are three capacitors in series

$$C_T = \frac{C_1\ C_2\ C_3}{(C_1\ C_2) + (C_2\ C_3) + (C_3\ C_1)}$$

If there are `n' equal capacitors in series

$$C_T = \frac{C}{n}$$

Maximum voltage across each capacitor: In series grouping, the division of the applied voltage among the capacitors depends on the individual capacitance value according to the formula

$$V = \frac{Q}{C}$$

The largest value capacitor will have the smallest voltage because of the reciprocal relationship.
Likewise, the smallest capacitance value will have the largest voltage.

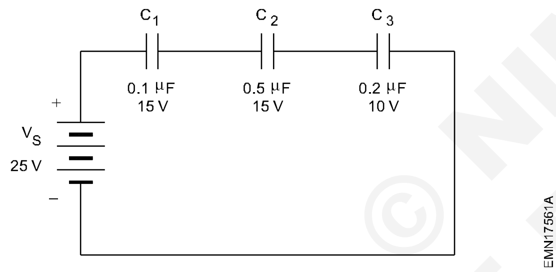
The voltage across any individual capacitor in a series connection can be determined using the following formula.

$$V_x = \frac{C_T}{C_x} \times V_s$$

where Vx - individual voltage of each capacitor
Cx - individual capacitance of each capacitor
Vs - supply voltage.

The potential difference does not divide equally if the capacitances are unequal. If the capacitances are unequal you must be careful not to exceed the breakdown voltage of any capacitor.

Fig 11



Example: Find the voltage across each capacitor in Fig 11.

Solution

Total capacitance: CT

Charge stored in series grouping: Based previous knowledge, we know that

– the current is the same at all points in a series circuit the current is defined as the rate of flow of charge.

(I = Q/t) or Q = It

The same current is flowing for the same period through the different capacitors of the series circuit. So the charge of each capacitor will be equal (same), and also equal to the total charge QT.

QT= Q1=Q2=Q3=............=Qn

But the voltage across each one depends on its capacitance value (V = Q/C)

By Kirchhoff's voltage law, which applies to capacitive as well as to resistive circuits, the sum of the capacitor voltages equals the source voltage.

V = V1+V2+V3+.........+Vn
1

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

$$\frac{1}{C_T} = \frac{1}{0.1} + \frac{1}{0.5} + \frac{1}{0.2} \text{ macro farad}$$

$$\frac{1}{C_T} = \frac{10}{1} + \frac{2}{1} + \frac{5}{1}$$

$$\frac{1}{C_T} = \frac{17}{1}, \text{ and } C_T = 0.0588 \text{ micro farad}$$

$$V_1 = \frac{C_T}{C_1} \times V_s$$

$$V_1 = \frac{0.0588}{0.1} \times 25$$

$$V_1 = 14.71 \text{ Vs}$$

$$V_2 = \frac{C_T}{C_2} \times V_s$$

$$V_2 = \frac{0.0588}{0.5} \times 25$$

$$V_2 = 2.94 \text{ volts}$$

$$V_3 = \frac{C_T}{C_3} \times V_s$$

$$V_2 = \frac{0.0588}{0.2} \times 25$$

$$V_3 = 7.35 \text{ volts}$$

Capacitive Reactance

Capacitor oppose changes in voltage with the flow of electrons onto the plates of the capacitor being directly proportional to the rate of voltage change across its plates as the capacitor charges and discharges. Unlike a resistor where the opposition to current flow is its actual resistance, the opposition to current flow in a capacitor is called reactance.

Like resistance, reactance is measured in Ohm's but is given the symbol X to distinguish it from a purely resistive R value and as the component in question is a capacitor, the reactance of a capacitor is called capacitive reactance, (X_c) which is measured in Ohms.

Since capacitors charge and dicharge in proportion to the rate of voltage change across them, the faster the voltage changes the more current will flow.

Likewise, the slower the voltage changes the less current will flow. This means the reactance of an AC capacitor is " inversely proportional " to the frequency of the supply as shown.

Capacitive reactance

Where: X_c is the capacitive reactance in Ohms, f is the frequency in Hertz and C is the AC capacitance in Farads, symbol F.S

When dealing with AC capacitance, we can also define capacitive reactance in terms of radians, where Omega, w equals 2Πf.

$$X_C = \frac{1}{2\pi f} \qquad X_C = \frac{1}{wc} \qquad W = 2\,\Pi f$$

The impedance of an AC capacitance

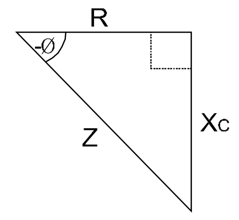
Impedance, Z which has the units of Ohms, Ω is the " Total" opposition to current flowing in an AC circuit that contains both resistance, (the real part) and reactance (the imaginary part). A purely resistive impedance will have a phase angle of 0° while a purely capacitive impedance will have a phase angle of -90°.

However when resistors and capacitors are connected together in the same circuit, the total impedance will have a phase angle some where between 0° and 90° depending upon the value of the components used. Then the impedance of our simple RC circuit can be found by using the impedance triangle.

Impedance, $Z = \frac{V}{I}$

$Z = \sqrt{R^2 + X_C^2}$

$\therefore Z^2 = R^2 + X_C^2$



The RC impedance triangle

Then: $(\text{impedance})^2 = (\text{Resistance})^2 + (\,j\ \text{Reactance})^2$ where j represents the 90° phase shift.

By using Pythogoras theorem the negative phase angle, θ between the voltage and current is calculated as.

Phase angle

$\mathbf{Z^2 = R^2 + X_c^2}$

$$\text{Cos}\varphi = \frac{R}{Z}, \text{Sin}\varphi = \frac{X_C}{Z}, \tan\varphi = \frac{X_C}{R}$$

Magnetism, Relays

Objectives : At the end of this lesson you shall be able to
- **state magnetism**
- **explain the properties of magnets**
- **state flux and flux density.**
- **state the magnetic materials**
- **state the type of magnetic field around a current carrying conductor**
- **explain relay types, construction and specification.**

Magnets and magnetism

Magnets are those which have the power to attract iron or alloys of iron (ferrous materials). Magnets available in nature are called *natural magnets* or lodestones.

The property of a material to attract pieces of ferrous materials is called **magnetism.**

Natural magnets are of very little practical use these days because it is possible to produce much better magnets by artificial means.

Magnetic and non-magnetic materials

All materials cannot be made magnets artificially. Materials which are attracted by magnets are called *magnetic materials* and only such magnetic materials can be made as artificial magnets. All other materials are called *non-magnetic materials*. A list of a few magnetic and non-magnetic materials is given below:

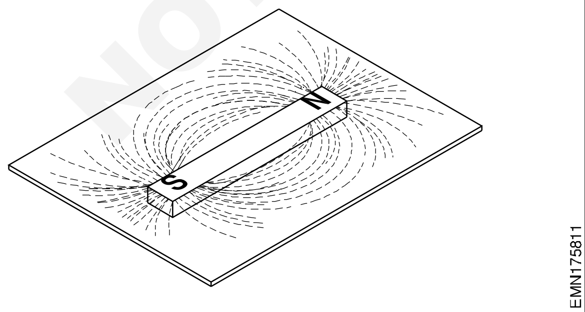
Magnetic materials	Non-magnetic materials
IRON	ALUMINIUM
STEEL	COPPER
COBALT	BRASS
NICKEL	LEAD

Poles of a magnet

The magnetic strength of a magnet is concentrated at two points on the magnet. These points are called the *poles* of a magnet.

MAGNETIC FIELD AND MAGNETIC FLUX (Ø)

Fig 1



The property of magnetism in any magnet is because of an invisible field of force between the two poles at the opposite ends of the magnet as shown in Fig 1. It can be seen that the *magnetic field is strongest at the poles*. Magnetic field exists in all directions, but decreases in strength, as you go away from the poles(decreases inversely as the square of the distance from the poles). The magnetic lines can be considered to flow outward from the north pole and enter the magnet at the south pole. The entire group of magnetic lines, which can be considered to flow outward from the north pole of a magnet, is called the *magnetic flux.* The magnetic flux is symbolically represented by the Greek letter *ø (phi)*. The more the magnetic flux ø, the stronger is the magnetic field, and hence, the magnet.

PROPERTIES OF MAGNETS

- **Unlike poles attract each other.**

When the north pole of a freely movable permanent magnet is brought near the south pole of a second permanent magnet, an invisible force causes the two poles to be attracted to each other. The two unlike poles actually stick to one another. The force of attraction between unlike poles increases as the distance between the poles decreases. Actually, the force of attraction varies inversely as the square of the distance between poles.

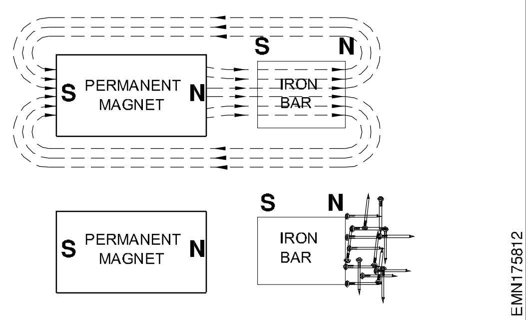
- **Like poles repel each other.**

When the north pole of a freely movable permanent magnet is brought near the north pole of a second permanent magnet, an invisible force causes the two poles to repel each other. The two unlike poles actually move away with a jerk. This force of repulsion increases as the distance between the poles decreases. Actually, the force of repulsion varies inversely as the square of the distance between poles.

- **Induces magnetic properties to magnetic materials.**

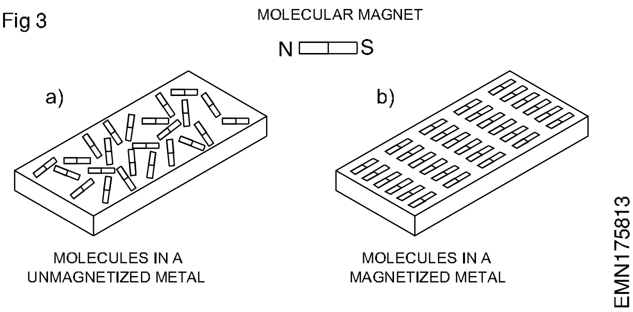
A permanent magnet can induce magnetism to an unmagnefied iron bar such that the iron bar become a magnet. To induce magnetism, it is enough if the permanent magnet comes close to the iron bar as shown in Fig 2.

Fig 2



What is happening in Fig 2 is that, the magnetic lines of force generated by the permanent magnet, make the internal molecular magnets in the iron bar line up in the same direction as shown in Fig 3b. An unmagnified iron as shown Fig 3a, the molecules will be in random directions. Note from Fig 2 that, the induced poles in the iron bar have opposite polarity from that of the poles of the permanent magnet.

Fig 3



It should be noted that inducing magnetism was possible only because the unmagnified material was a magnetic material. In Fig 3 instead of iron, a copper bar is used, the permanent magnet will not induce magnetism in copper as copper is a non-magnetic material. The magnetic field lines will be unaffected by the non-magnetic materials when placed in the magnetic field of a magnet.

TYPES OF MAGNETS

Magnets are available naturally, and can also be made artificially. When magnets are made artificially, depending on the type of material magnetism is retained for different durations. For example, if a piece of soft iron and a piece of steel are magnetized. The magnetism in steel remains for a much longer duration than in soft iron. This ability of a material to retain its magnetism is called *retentivity* of the material. Depending upon the retentivity of the material, artificial magnets can be classified as *temporary magnets* and *permanent magnets*. Temporary magnets lose their magnetic power or magnetism once the magnetizing force is removed.

The magnetism that remains in a magnetic material, once the magnetizing force is removed, is called *residual magnetism.* This term is usually only applicable to temporary magnets.

Permanent magnets retain magnetism for a long period of time.

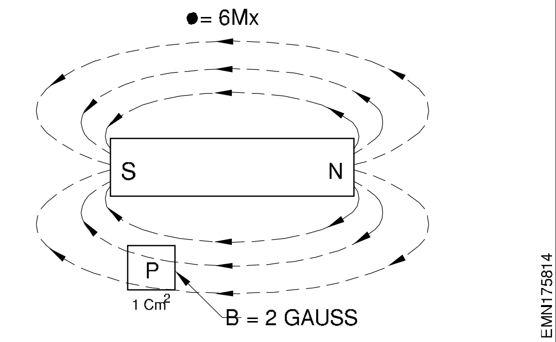
Classification of magnets, popularly used types of magnets and their applications are given in Chart 1 at the end of this lesson.

Units of magnetic flux ø

Maxwell

One *Maxwell (Mx)* unit equals one magnetic field line. In Fig 4, for example, the flux illustrated is 6 Mx because, there are six field lines flowing in or out of each pole. A one pound magnet can provide a magnetic flux ø of about 5000 Mx.

Fig 4



Maxwell is a unit of magnetic field in CGS system of units.

This is a larger unit of magnetic flux. One *weber (Wb)* equals 1×10^8 lines or maxwells. Since weber is a large unit for typical fields, microweber (µWb) unit can be used.

$1\mu Wb = 10^{-6} Wb$.

For a one lb magnet producing the magnetic flux of 5000 Mx, corresponds to 50 µWb.

Weber is a unit of magnetic field in SI system of units.

FLUX DENSITY (B)

The flux density is the number of magnetic field lines per unit area of a section perpendicular to the direction of flux as shown in Fig 4.

As a formula,

$$B = \frac{ø}{A} = \frac{\text{flux}}{\text{Area}}$$

In magnets, the flux density will be higher close to the poles because flux lines are more crowded near the poles.

Units of flux density

Gauss: One Gauss is equal to one flux line per square centimeter, or 1 Mx/cm^2.

Gauss is a unit of flux density in CGS system of units.

Since gauss is a small unit, flux density if often measured in kilogauss

1 kilogauss = 10^3 Gauss.

In SI units of measurement, the unit of flux density B, is webers per square metre (Wb/m^2). One weber per square metre is called a tesla, abbreviated as T.

Tesla is a unit of flux density in SI system of units.

CLASSIFICATION OF MAGNETIC MATERIALS

Based on the strong magnetic property of iron, other materials are classified as either magnetic or non-magnetic materials. However, a more detailed classification is given below;

1 Ferromagnetic materials

2 Paramagnetic materials

3 Diamagnetic materials

These are materials which become strongly magnetized. These materials gets magnetised in the same direction as the magnetizing field. These materials have high values of permeability in the range of 50 to 5000. Examples of ferromagnetic materials are iron, steel, nickel, cobalt, and commercial alloys such as alnico and permalloy. Permalloy has a μr of 100,000 but gets saturated at relatively low values of flux density.

Paramagnetic materials

These are materials which become weakly magnetized. These materials gets magnetised in the same direction as the magnetizing field. The permeability of paramagnetic materials is slightly more than 1. Examples of paramagnetic materials are aluminum, platinum, manganese, and chromium.

Diamagnetic materials

These are materials which become weakly magnetized. These materials gets magnetised in the opposite direction of the magnetizing field. The permeability of diamagnetic materials is less than 1. Examples of diamagnetic materials are bismuth, antimony, copper, zinc, mercury, gold and silver.

The basis of the above three classifications is the motion of orbital electrons in atoms.

There are two kinds of electron motion in the atom;

1 The electron revolving in its orbit: This motion provides a diamagnetic effect. However, this magnetic effect is weak because of the thermal agitation at normal room temperature. This results in random directions of motion that neutralizes the magnetic effect of each other.

2 The magnetic effect from the motion of each electron spinning on its own axis: The spinning electrons works as a tiny permanent magnets. Opposite spins provide opposite polarities. Two electrons spinning in opposite directions form a pair, neutralizing the magnetic fields. In the atoms of ferromagnetic materials, however, there are many unpaired electrons with spins in the same direction, resulting in a strong magnetic effect.

Iron, cobalt and nickel are said to be very good magnetic materials. Alloys of these three metals make up almost the entire range of magnetic materials used by the electrical, electronic and communication industries.

Temporary and permanent magnets

Another classification of magnetic materials based on their application are:

1 Temporary magnets

2 Permanent magnets

Soft and hard magnetic materials

Magnetic materials can be classified as:

1 Hard magnetic materials

2 Soft magnetic materials

Hard magnetic is a term is used to cover the range of materials used for making permanent magnets.

Some of the hard magnetic materials commonly used and a brief of their magnetic properties are given below;

Carbon steel

This was the only material used for permanent magnets in olden days. It has poor magnetic materials and not in much use today.

Carbon steel is now used only for applications where low cost is more important than magnetic performance.

Carbon steel is used in making compass needles, thin sheet magnets and magnets for toys.

Tungsten and chromium steels

The addition of tungsten and chromium to carbon steel gives a group of alloys having better magnetic properties than carbon steel. These materials can be rolled or forged to different shape and are machinable.

Large quantities of instrument magnets are produced from steel containing approximately 6% tungsten.

Chromium steel is cheaper to produce but slightly less effective than tungsten steel as a permanent magnet. Instrument magnets are made by punching out the shape required from steel strips containing 3% chromium.

Cobalt steel

The addition of cobalt to chromium steel considerably increases the magnetic strength of the material.

To meet all reasonable industrial requirements, a range of five cobalt steel alloys, each having a different cobalt composition are produced. These alloys can be rolled or cast and machined before hardening.

Cobalt steel alloys are used for making rotating magnets, telephone receivers, speedometer magnets, multi-pole rotors used in electric clocks and hysteresis motors.

Iron-aluminium-nickel

In 1931 an alloy of iron, aluminum and nickel was discovered. This alloy gives a better magnetic performance as a permanent magnet when compared to all the other commercially produced permanent magnetic materials.

Most permanent magnets produced today are made from Alnico and Alcomax group of alloys. These have iron-nickel and aluminium with additions of cobalt and copper.

Magnets made from these alloys can only be produced by the processes of casting and sintering. They are very brittle and cannot be machined except by grinding.

Soft magnetic is a term which covers the range of materials which are easy to magnetize and demagnetize. They are used for the cores of electromagnets or temporary magnets.

Soft magnetic materials used for making electromagnets are easy to magnetize and demagnetize. They have low hysteresis loss, higher saturation value (B), higher permeability and low coercivity values when compared with hard magnetic materials.

Soft magnetic materials are generally used for making laminated, transformer cores, motor & generator armatures and other electrical equipments which are subject to continual reversal of magnetization.

Some of the soft magnetic materials commonly used and their magnetic properties are given below;

Mild steel

It is an inexpensive material to produce, and, therefore, an ideal material to use where cost is important and the magnetic properties required not so stringent. As the carbon content in mild steel is increased, the effect is to lower the magnetic properties.

Iron-silicon alloys

A range of iron-silicon alloys, containing silicon between 0.3% to 4% is produced as sheets or strips and used for making laminations. Iron with a small amount of silicon has better magnetic properties than pure iron.

These alloys have low hysteresis loss, high saturation and are used for the magnetic circuits of electrical equipment operated at power frequencies of 50 Hz such as power transformers, alternators and electric motors of all sizes.

Due to the brittleness of the higher silicon alloys, it is not possible to make it into very thin sheets or strips.

Magnetic field around a current-carrying conductor

When current is passed through a conductor, a magnetic field is produced around it. It is important to note the following two factors about the magnetic lines of force around a current carrying conductor.

1 The magnetic lines are circular and the field is symmetrical with respect to the current carrying wire in the centre.

2 The magnetic field with circular lines of forces is in a plane perpendicular to the current in the wire.

The direction of the magnetic lines around the conductor can be determined by the right hand screw rule. The direction of magnetic lines reverses, if the direction of current through the conductor is reversed. This magnetic field around a single conductor is too weak to make the wire behave as a useful magnet.

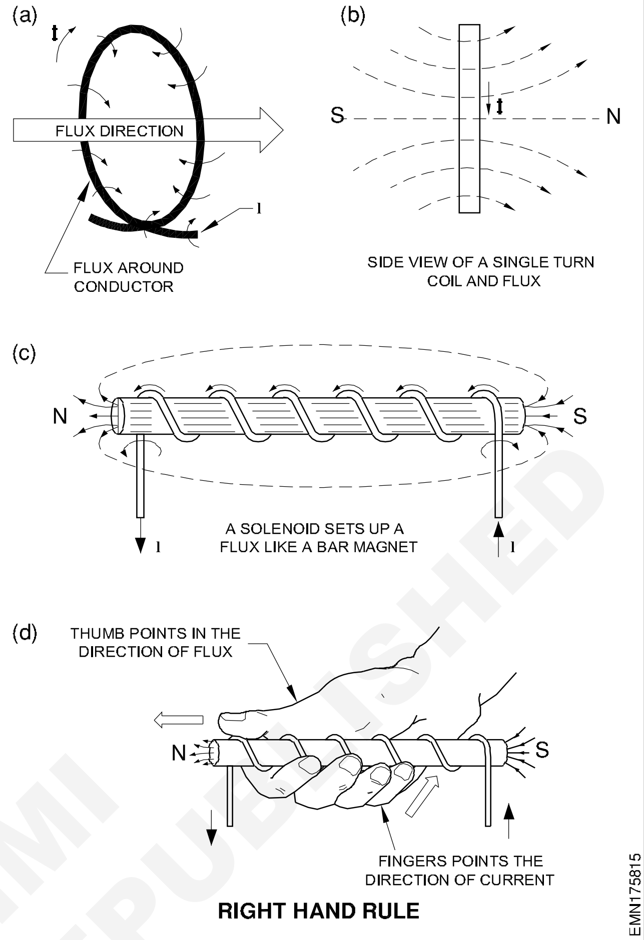
Magnetic field around a coil

Consider the effect of passing a current through a one-turn coil of wire as shown in Fig 5a.

Fig 5a and 5b shows the magnetic flux generated by the electric current passing through the centre of the coil. Therefore, a one-turn coil acts as a little magnet. It has a magnetic field with an identifiable N pole and S pole. Instead of a single turn, a coil may have many turns as shown in Fig 5c. In this case, the flux generated by each of the individual current-carrying turns, tends to link-up and pass out-of one end of the coil and back into the other end as shown in Fig 5c. This type of coil, also known as a solenoid has a magnetic field pattern very similar to that of a bar magnet.

The *right hand rule* for determining the direction of flux from a solenoid is illustrated in Fig 5d. When the solenoid is gripped with the right hand such that, the fingers are pointed in the direction of current flow in the coils, the thumb points in the direction of the flux as shown in Fig 5d. The coil now behaves like an electromagnet.

Fig 5



The solenoid acts like a bar magnet whether it has an iron core or not. Adding an iron core in a solenoid increases the flux density inside the coil. In addition, the field strength will then be uniform for the entire length of the core. It should be noted that, adding an iron core into a solenoid does not change the N and S pole positions of the solenoid.

When the direction of the current through the coil is changed, it changes the direction of magnetic lines, thereby changing the poles of the solenoid.

Applications of electromagnet

Electromagnets are used in various applications such as electrical circuit breakers, relays, door bells etc.

Faraday's law

Whenever a conductor cuts magnetic lines of force, an *emf* is induced in the conductor. This is known as Faraday's law of *Electromagnetic Induction.*

Lenz's Law

The basic principle used to determine the direction of induced voltage or current is given by *Lenz's Law*.

Lenz' law states that the direction of induced current is such that the magnetic field set-up due to the induced current opposes the action that produced the induced current.

Relays:

Introduction

In addition to solenoids, one other most popular application of electromagnets is in what are called electromagnetic relays in Fig 6.

Construction and operation of a simple relay

Electromagnetic relay is basically a switch or a combination of switches operated by magnetic force generated by a current flowing through a coil.

Essentially, a typical relay shown in Fig 7 consists of the following parts;

– an electromagnet comprising of a core and coil

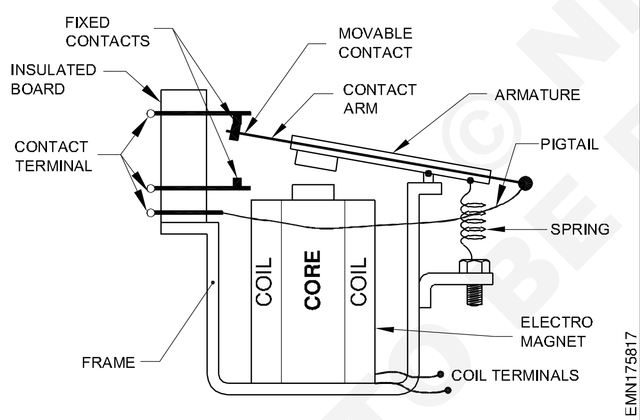
– a movable armature,pivoted and held in tension by a spring

– a set of contacts

– a frame to mount all these components.

As shown in Fig 7, a typical relay consists of a core surrounded by a coil of wire. This is mounted on a metal frame. The movable part of the relay is the armature. One end of the armature is hinged and connected to a spring. On the armature is mounted a contact arm carrying movable contacts. The fixed relay contacts and its terminals are mounted on an insulated terminal board.

Fig 7



When the relay is OFF or not energized, the contact arm touches the top contact. When the relay is energized by applying voltage to the coil terminals, the metallic armature is attracted. The armature and contact arm assembly move downward so that the contact arm mounted on the armature touches the bottom contact. Thus, the relay is doing the function of a single pole, double throw (SPDT) switch.

On removing the voltage applied to the coil, the spring attached to one end of the armature returns the armature to its original position and the contact arm touches the top contact.

Operating delay of relays

When an energizing voltage is applied to a relay coil, the relay does not work instantaneously. It takes some time, usually a few milliseconds to operate. Reasons for this delay are given below:

– Due to inductance of the relay coil, current grows slowly and takes some time to reach the required current value.

– Due to inertia, the armature takes sometime to move from one position to another.

When rated voltage is applied to terminals of a relay coil, the gradual build up of current in the coil is due to the initial opposition to the current flow by the self-inductance of the coil. After some delay, when sufficient magnetization is built up and when the force of attraction is sufficient to overcome the opposition of the tension due to return spring plus, tension of contact springs, the armature is attracted and it closes the relay contacts. The relay is then said to be energized or pulled-in or picked.

Once the relay is energised then, only a small amount of energy is required to maintain it in energized condition. The rest of the electrical energy is wasted as heat.

When the current through the coils falls below a certain value, the relay gets de-energised and the return spring pulls the armature back. This is called as relay drop-out.

From above it can be seen that, very little amount of electrical power is consumed for the switching of relay whereas most of the power is consumed while holding.

Parts of a Relay

Each part of a relay is as important as the other in the overall performance of the relay. Details of the parts of a relay and their purpose are given below:

Frame and core : One of the main function of the relay frame is to provide a base for mounting other relay parts. But, the most important function is, the frame forms a part of the complete magnetic path between the armature and core. The core, frame and armature are made of an easily magnetizable material such as iron.

Hinges : The hinges connect the armature to the frame. A good hinge must be as free from friction as possible. They must also be strong enough to support the weight of the armature and contacts. The hinges must provide low reluctance to the magnetic flux in its path from the core through the frame and the armature.

Return springs : The springs are usually very thin and cannot concentrate any large amount of flux. Spring steel, which has a lower reluctance than other materials acts to retain its magnetism and remain attracted to the core after the relay is de-energised. Springs also have a disadvantage of being stiff and are likely to break after a few operations.

Relay coil : The coil is usually wound on a former and slipped over the magnetic core in the relay frame. This permits easy replacement of damaged coils by new ones.

Coil Specifications

Generally relays are made to operate at different voltages such as, 6, 12, 18, 24, 48, 100 or 240 volts AC or DC. A coil resistance chart is usually given with relays which helps in calculating the coil current and power dissipation. Maximum wattage, maximum permissible temperature and the wattage for satisfactory operation, are specified along with relays.

Operate current – is the minimum current required to energize a relay.

Hold current – is the minimum coil current required to continue to hold the relay energized.

Release current – is the maximum current which releases the relay.

Relay coils are always insulated from the frame of the relay. The electrical resistance between the coil and the body is a measure of the isolation of energising voltage from the ground. Similarly, the electrical resistance between the coil and the contacts is a measure of the electrical isolation between the energising driving and the driven circuits. These resistances will be of the order of hundreds or thousands of megohms.

Relay contacts

The contacts on a relay are the parts that actually perform the electrical switching of the controlled circuits. Also, these contacts are the ones that cause most trouble and require frequent maintenance as compared to any other part of a relay.

Contact materials and design

The relay contacts are made of material which are very good conductors as well as corrosion-resistant.

An arc is created when the contacts open and close. This arc burns and oxidises the contacts. An oxide coating make the contacts either poor conductors or non-conductors. For this reason, contacts are made of silver, palladium and palladium-iridium alloys, gold alloys, gold plated silver, tungsten and alloys of other highly corrosion-resistant materials that do not oxidize easily.

Even with these materials, some oxidation still takes place. To get rid of the oxide, the contacts are designed to have a wiping action. As the contacts close and open, the surfaces rub together. This action rubs off any oxide or dirt which might cause poor contact.

Contacts come in many shapes and sizes, and in a variety of contact arms. These contact arms are generally called contact springs because they maintain good contact pressure.

Size of the contacts determines the current handling capability. The larger the contacts, the more current they can switch without excessive deterioration.

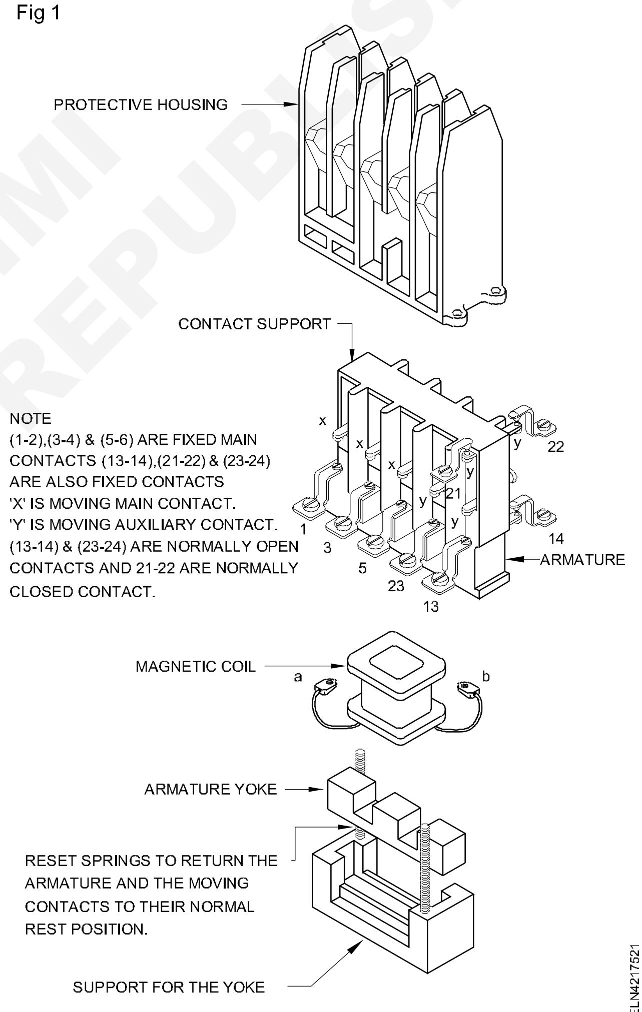
The contact arms or springs are made thick and wide enough to carry the current for which the contacts are rated. They are also made spongy enough to ensure good contact. If the springs are too soft they may vibrate when the relay opens, causing contact bounce when the contacts open and close repeatedly. This bounce can also occur on closing. The bouncing of contacts is always undesirable. Contact debouncing circuits are used to overcome the undesirable effects of contact bouncing in sensitive circuits such as digital electronic circuits.

Contactors: The contactor forms the main part in all the starters. A contactor is defined as a switching device capable of making, carrying and breaking a load circuit at a frequency of 50 cycles per second or more. It may be operated by hand (mechanical), electromagnetic, pneumatic or electro-pneumatic relays.

The contactors shown in Fig 1 consist of main contacts, auxiliary contacts and no-volt coil. As per Fig 1, there are three sets of normally open, main contacts between terminals 1 and 2, 3 and 4, 5 and 6, two sets of normally open auxiliary contacts between terminals 23 and 24, 13 and 14, and one set of normally closed auxiliary contact between terminals 21 and 22.

Auxiliary contacts carry less current than main contacts. Normally contactors will not have the push-button stations and O.L. relay as an integrated part, but will have to be used as separate accessories along with the contactor to form the starter function. The main parts of a magnetic contactor are in Fig 8

Fig 1



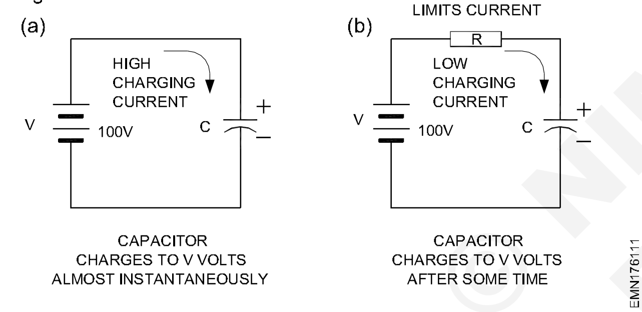
Time constant for RC circuit

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 τ 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.

Fig 1



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/τ).

This relationship between resistance, capacitance and the charging time is expressed by the equation,

$$\tau = RC$$

where t (spelled as tau) 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.

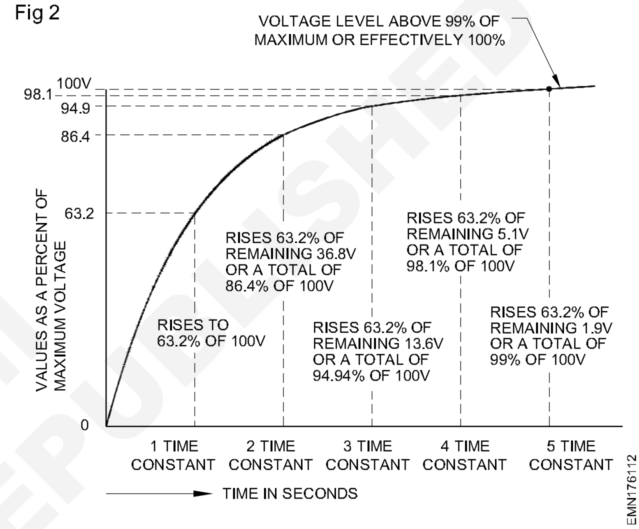
It is interesting to note that, in each succeeding time constant τ, the voltage across the capacitor increases by an additional 63.2 % of the remaining voltage. Thus, after the second time constant (2τ) the capacitor would have charged to 86.4 % of its maximum voltage,

- after 3τ, 94.9 percent, of its maximum voltage,
- after 4τ, 98.1 percent, of its maximum voltage

and – after 5τ, 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, τ.

Fig 2

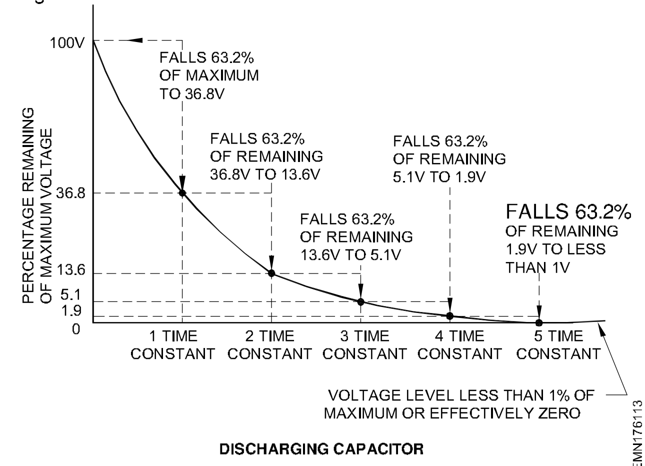


Hence, the capacitor is considered to be fully charged only after a period of more than five time constants or atleast five time constants.

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 τ, 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.

Fig 3

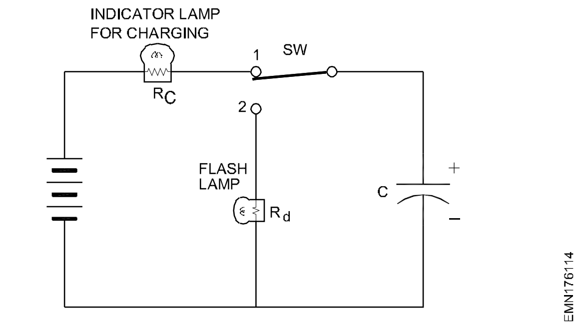


Notice the similarity between the capacitive time constant and the inductive time constant, discussed in previous lessons. The similarity is that, *the voltage across a capacitor* and *the current through an inductor* builds up/ rises and drops off/falls exactly in the same way.

Application of capacitor in camera flash units

A typical circuit of a flash unit is shown in Fig 4. A flash unit produces a short duration, high current pulse without drawing a large current from the supply.

Fig 4



When the flash unit is charging, switch SW is in position 1. The lamp resistance R_C will be large. This high resistance limits the peak charging current I_C to a low value such that the capacitor charges gradually with a large time constant $\tau_1 = R_C$ C.

When the switch is thrown to position 2, the low resistance R_d of the flash lamp allows a high discharge current through it. Hence the bulb glows very brightly for a very small duration. The duration of this current is determined by the time constant $\tau_2 = R_dC$.

All similar system of obtaining high surge current is used in applications like, electric spot welding, radar transmitter tubes etc.

Universal time-constant curves

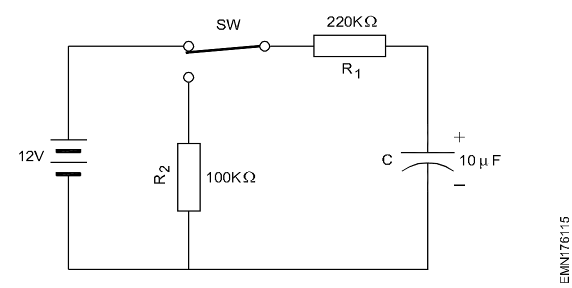
To determine the voltage and current in a capacitor at times other than 1τ, 2τ,....5τ time constants, the *universal time-constant curves* are used. Refer pocket table book, table no.14 for the universal time-constant curve.

The universal time-constant curves give the instantaneous voltage across the capacitor as a percentage of the initial or final values, with time given in time constants τ. From the graph, note that at one time constant τ, the capacitor would have charged to 63% of its final steady-state voltage. Also at this point the charging current has dropped to only 37% of its initial maximum value current. Note that, in either case, a change of 63% occurs in one time constant.

From these curves it can also be confirmed that, the *Charging or discharging of a capacitor is complete after five time constants*.

For the circuit at Fig 5, using the universal time constant curves, determine the capacitor voltage after 3.5 seconds.

Fig 5



SOLUTION

$\tau = R_1C$
$= 220 \times 10^3 W \times 10 \times 10^{-6} F$
$= 2.2$ seconds.

Allowed charge time τ = 3.5s

Equivalent number of time constants is equal to

$$= \frac{3.5s}{2.2s/\tau} = 1.59\tau \approx 1.6\tau$$

From the universal graph

where $\tau = 1.6\,\tau$, V_C is almost = 80% of V (the final value).

Therefore,

V_C = 80% of 12 volts
= 0.8 x 12 V = 9.6 volts.

While calculating the discharge time constant, the total series resistance R_1+R_2 must be considered.

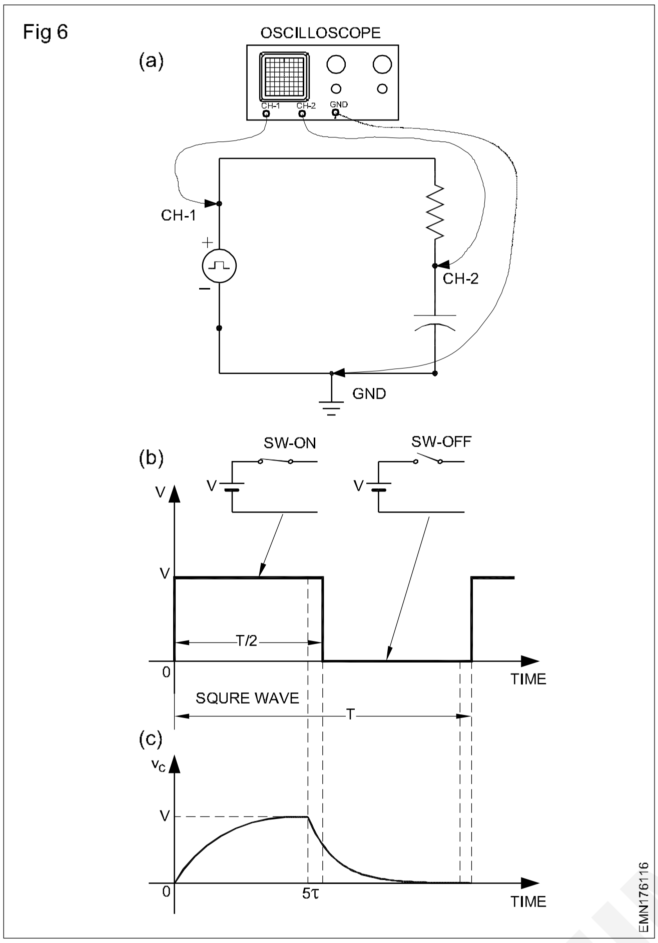
Measurement of voltage levels and capacitance using oscilloscope

A charging and discharging wave-form of a R-C circuit can be seen using an oscilloscope. However, it is difficult to view the charging and discharging of a R-C circuit having a switch similar to the one shown in Fig 5. This is because, the wave-forms appear and disappear on the screen. Hence, instead of a switch, a square wave signal as shown in Fig 6b, whose voltage level changes between 0 and V, just as a switch repeatedly switched ON and OFF, can be more conveniently used.

The advantage of using a square waveform is that, the rate of switching (ON/OFF) can be increased or decreased by increasing or decreasing the frequency of the wave-form (more optly known as pulse repetation rate, PRF).

The output of a square wave signal generator is connected to the capacitive circuit as shown in Fig 6a. The frequency of the waveform (rate of switching ON/OFF of circuit) is adjusted until the voltage wave-form across the capacitor is similar to that as in Fig 6c. Here, half-period of the square wave output (τ/2) is equal to or greater than five time constants, that is τ/2 ³ 5 RC(τ).

With the oscilloscope connected across the capacitor, as shown in Fig 6a, the time required to reach 63% of the final voltage is the time constant, τ. The voltage levels at 1τ, 2τ etc can be easily measured if the Time/Div of the CRO is



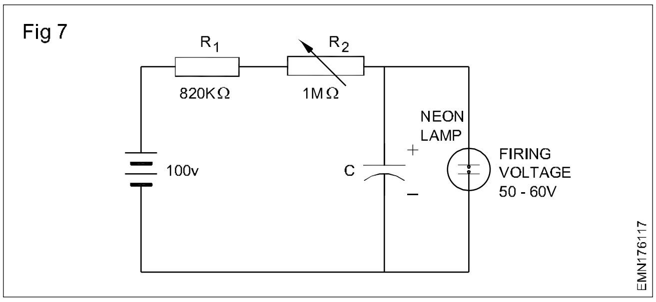
made equal to the time constant τ.

If the total resistance of the circuit is known, the capacitance of the capacitor, if unknown, can be calculated using the formula,

$$C = \frac{\tau}{R} \left(\text{Derived from the formula}, \tau = RC\right)$$

Application of R-C delay circuits

An RC circuit with a large time constant can be used to introduce delay in a circuit as shown in Fig 7.



Here, the neon lamp acts as an open circuit until a firing voltage of the lamp is reached(50-60V). When the circuit is switched ON, the voltage across the capacitor charges toward the final value of 100V, with a time constant of (R_1 + R_2)C. When the charge across the capacitor reaches a value between 50 to 60 volts, the firing voltage of the neon lamp is reached and the lamp fires. The capacitor, hence, discharges through the neon lamp, lighting it up. Because of the low resistance of the neon lamp, the capacitor voltage drops quickly and the lamp gets extinguished after being lighted for a brief period of time(flashing). The lamp once again becomes an open circuit and the capacitor starts recharging, providing a controlled delay time before the lamp one again fires. The rate of flashing can be varied by adjusting R_2.

The delay introduced by the R-C in circuit in Fig 7 can be used for several other useful purposes. For example, if it is required to delay the switching ON of a DC relay following the application of voltage to the relay coil, the circuit at Fig.7 can be used.

R.C. Differentiator

Objectives : At the end of this lesson you shall be able to
- **define R.C. differentiator**
- **connect capacitor and resistance in series**
- **explain about single pulse R.C. differentiator.**

RC Differentiator

The passive RC differentiator is a series connected RC network that produces an output signal which corresponds to the mathematical process of differentiation.

For a passive RC differentiator circuit, the input is connected to a capacitor while the output voltage is taken across a resistance being the exact opposite to the RC integrator circuit.

A passive RC differentiatior is nothing more than a capacitance in series with a resistance. It is a frequency dependant device which has reactance in series with a fixed resistance. Just like the integrator circuit, the output voltage depends on the circuits RC time constant and input frequency.

Thus at low input frequencies the reactance, XC of the capacitor is high blocking any d.c. voltage or slowly varying input signals. While at high input frequencies the capacitors reactance is low allowing rapidly varying pulses to pass directly from the input to the output.

This is because the ratio of the capacitive reactance (X_c) to resistance (R) is different for different frequencies and the lower the frequency the less output. So for a given time constant, as the frequency of the input pulses increases, the output pulses more and more resemble the input pulses in shape.

The effect of passive high pass filters and if the input signal is a wave, an **RC differentiator** will simply act as a simple high pass filter (HPF) with a cut off or corner frequency that corresponds to the RC time constant (tau, τ) of the series network.

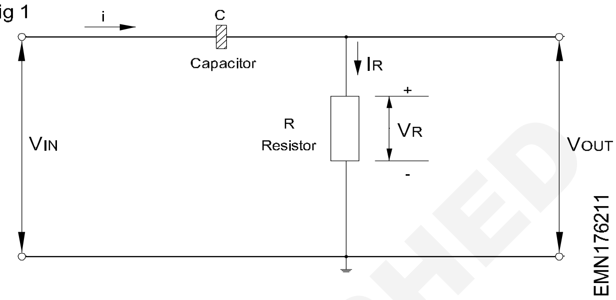
Thus when fed with a pure sine wave an RC differentiator circuit acts as a simple passive high pass filter due to the standard capacitive reactance formula of $X_C = 1/(2\Pi fc)$.

But a simple RC network can also be performed differentiation of the input signal. The rate at which the capacitor charges (or discharges) is directly proportional to the amount of resistance and capacitance giving the time constant of the circuit. Thus the time constant of a RC differentiator circuit is the time interval that equals the product of R and C. Consider the basic RC series circuit is shown in fig 1.

RC differentiator circuit

For an RC differentiator circuit, the input signal is applied to one side of the capacitor with the output taken across the resistor, then V_{out} equals V_R. As the capacitor is a frequency

Fig 1



dependent element the amount of charge it takes a time for across the plates is equal to the time integral of the current capacitor to fully charge as the capacitor can not charge instantaneously only charge exponentially.

Resistor voltage

We said previously that for the RC differentiator the output is equal to the voltage across the resistor , that is V_{out} equals VR and being a resistance, the output voltage can change instantaneous only.

However, the voltage across the capacitor cannot change instantly but depends on the value of the capacitance, C as it tries to store an electrical charge, Q across its plates. Then the current flowing into the capacitor, that is i_t depends on the rate of change of the charge across its plates. Thus the capacitor current is not proportional to the voltage but to its time variation giving: i = dQ/dt.

As V_{OUT} equals V_R where V_R according to ohms law is equal too: i_R x R. The current that flows through the capacitor must also flow through the resistance as they are both connected together in series. Thus :

$V_{OUT} = V_R = R \times i_R$

As $i_R = i_C$, therefore:

Thus the standard equation given for an RC differentiator circuit is :

RC Differentiator Formula

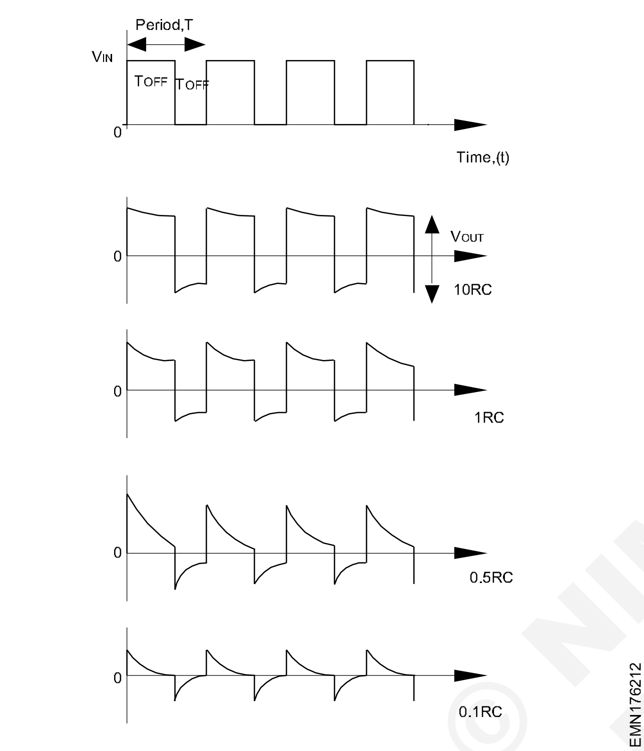
$$V_{out} = RC\frac{dV_{in}}{dt}$$

We can see that the output voltage, V_{OUT} is the derivative of the input voltage, V_{IN} which is weighted by the constant of RC. Where RC represents the time constant, T of the series circuit.

Single pulse RC differentiator

When a single step voltage pulse is first applied to the input of an RC differentiator, the capacitor " appears" initially as a short circuit to the fast changing signal. This is because the slope dv/dt of the positive-going edge of a square wave is very large (ideally infinite), thus at the instant signal appears, all the input voltage passes through to the output appearing across the resistor.

Fig 2



RC Differentiator Output Waveforms

We can see that the shape of the output wave form depends on the ratio of the pulse width to the RC time constant. When RC is much larger (Greater than 10RC) than the pulse width the output waveform resembles the square wave of the input signal.When RC is much smaller (less than 0.1 RC) than the pulse width, the output waveform takes the form of very sharp and narrow spikes as shown above

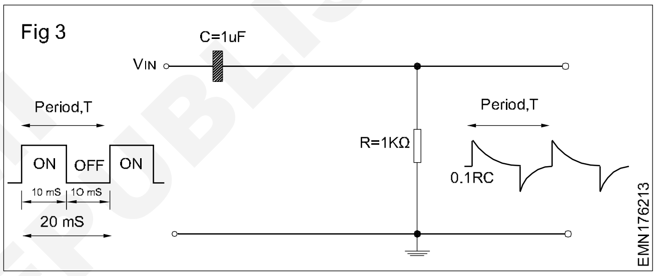
So by varying the time constant of the circuit from 10RC to 0.1 RC we can produce a range of different wave shapes. Generally a smaller time constant is always used in RC differentiator circuits to provide good sharp pulses at the output across R. Thus the differential of a square wave pulse (high dv/dt step input) is an infinitly short spike resulting in an RC differentiator circuit.

Lets assume a square wave waveform has a period, T of 20 mS giving a pulse width of 10mS (20mS divided by 2). For the spike to discharge down to 37% of its initial value, the pulse width must equal the RC time constant, that is RC = 10mS. If we choose a value for the capacitor, C of 1 uF, then R equals 10kΩ.

For the output to resemble the input, we need RC to be ten times (10RC) the value of the pulse width, so for a capacitor value of say, 1uF, this would give a resistor value of : 100kΩ. Likewise, for the output to resemble a sharpe pulse, we need RC to be one tenth (0.1 RC) of the pulse width, so for the same capacitor value of 1 uF, this would give a resistor value of: 1kΩ, and so on.

Example for RC differentiator

Fig 3



So by having an RC value of one tenth the pulse width (and in our example above this is 0.1 x 10mS = 1mS) or lower we can produce the required spikes at the output, and the lower the RC time constant for a given pulse width, the sharper the spikes. Thus the exact sharpe of the output waveform depends on the value of the RC time constant.

R.L.C. Series and parallel circuit

Objectives : At the end of this lesson you shall be able to
- **define inductive reactance**
- **define resistance and inductance in AC series circuit**
- **describe resistance and capacitance in AC series circuit**
- **explain resistance inductance and capacitance in AC series circuit**
- **describe resistance and inductance in AC parallel circuit**
- **explain resistance and capacitance in AC parallel circuit**
- **describe resistance, inductance and capacitance in AC parallel circuit**
- **explain series and parallel resonance circuit.**

Inductive reactance (X_L)

When a DC voltage is applied to an inductor, the inductor has its effect only during switching ON and switching OFF of the circuit . With steady current in circuit, inductance has no effect. Instead of DC, if a sinusoidal AC current is made to flow through an inductor, as shown in Fig 1a, since the magnitude of sinusoidal current is continuously varying, as shown in Fig 1b, the inductor continuously keep opposing these changes. This continuous opposition is entirely dependent on the induced emf in the coil and has nothing to do with opposition due to the DC resistance of the coil. The effective opposition to the flow of alternating current, due to the self induced emf. The inductive reactance can be calculated by the equation $X_L = 2\pi fL$ generated by an inductor (L) and the frequency (f) of the current.

As in a resistive circuit, where opposition to current is given by,

$$R = V_R / I_R$$

where, V_R = Voltage across the resistor

and I_R = Current through the resistor

similarly, the opposition to current by a pure inductance is given by,

$$X_L = V_L / I_L$$

where,

X_L is the inductive reactance in ohms, W

V_L is the voltage across the pure inductor in volts, V

I_L is the current through the inductor in amperes, A

Power consumed by a pure inductor

The power consumed by a pure resistor is given by;

$P = I^2R = I.V$ (V=I.R)

The power consumed by a components having both resistive and reactive component is given by $P = V.I.Cos\theta$

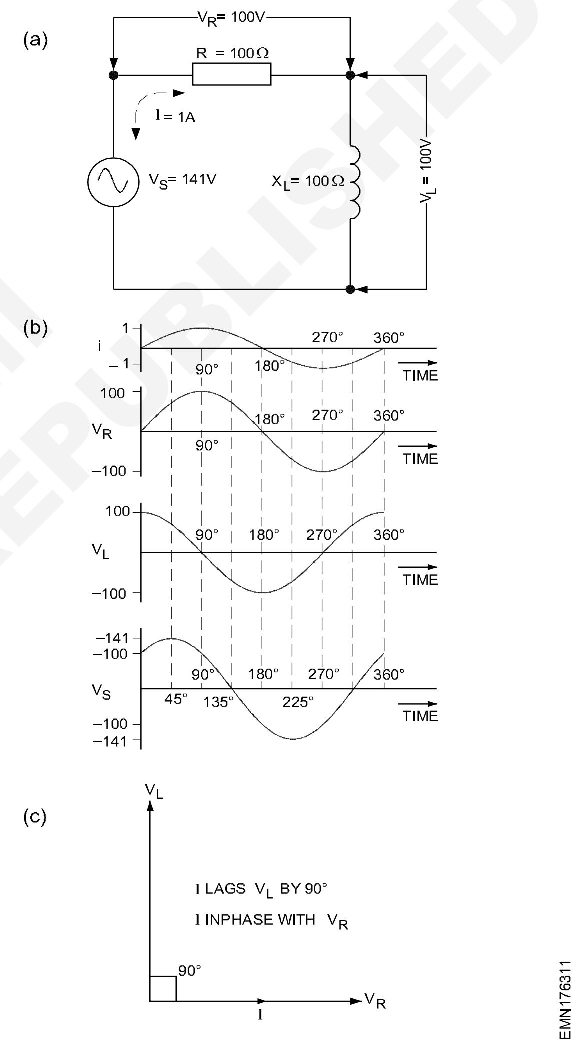
where,

V = Voltage applied across the component

I = Current through the component

and ø = Phase angle difference between V and I

Fig 1



In a pure inductor, as shown in Fig 3b, phase difference between V and I is 90°. Therefore, the power consumed by a pure inductor is $P_{inductor} = V.I.Cos90°$

Cos 90° = 0 (Refer trigonometric tables)

Therefore $P_{inductor} = V.I.0 = 0$.

R-L series circuit

Referring to Fig 1a, the circuit current(I) is limited by both the ohmic resistance R and inductive reactance X_L. Each has its own series voltage drops IR and IX_L. Here the circuit current is labeled as I, instead of I_L, because current I flows through both the series components R and L.

In this way, the total inductance (L_t) is equal to the sum of individual inductance (L_1, L_2, L_3, ...)

Graph at Fig 1b shows the instantaneous values of i, V_R, V_L and the source voltage V_S. A vector diagram of V_R, V_L and I is shown in Fig 1c. The vector diagram at Fig 1c, shows that the current I lags behind the voltage V_L by 90°. But the current I is in phase with V_R.

From the graph at Fig 1b, V_R is maximum(100V) when V_L is minimum and vice versa. This is again because of the phase difference. Because of this the series voltage drops V_R and V_L cannot be added arithmetically to get the applied source voltage V_S. The method of adding V_R and V_L is shown in Fig 2.

Fig 2a shows the vectorial addition method to get V_S knowing V_R and V_L.

Fig 2c gives the total resultant opposition to current flow due to R and X_L. This total resultant opposition due to resistance R and inductive reactance X_L is called Impedance in ohms with the symbol Z. The impedance Z, takes into account the phase relationship between R and X_L.

The impedance Z of the circuit given at Fig 2c is,

$$Z = \sqrt{R^2 + X_L{}^2} \qquad ...[4]$$

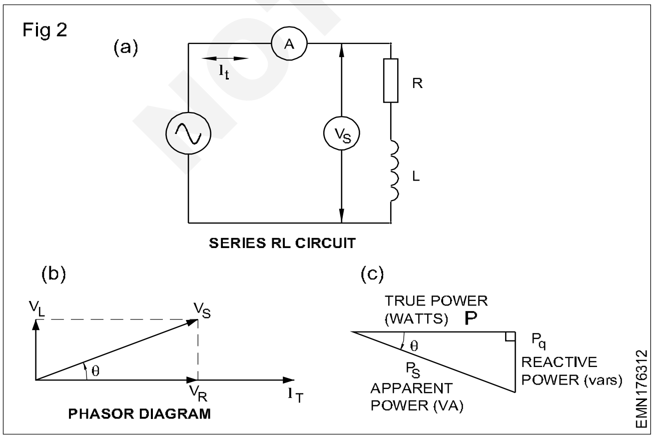
$$= \sqrt{100^2 - 100^2} = 141\Omega$$

Power consumed in a Resistance - Inductance Circuit (R-L circuit)

The total power consumed in a R-L circuit will contain the True power due to the pure resistive component and the Reactive power due to the reactive component.

The power consumed by a reactive component is referred to as reactive power.

In the series R-L circuit at Fig 2a, Apparent power P_s is the vectorial sum of True power (P) and the reactive power (P_q) as shown in Fig 2c.



Apparent power (P_s) is also given by the product of source voltage V_S and total circuit current I_t.

Apparent power = $V_s \times I_t$ in volt-ampers, VA ...[5]

To distinguish from reactive power and apparent power, the power dissipated in a resistor in the form of heat (or in any other form), the term Real power or True power is used.

True power = $V_R \times I_R$ watts, W

Quality factor - Q of coil

At high frequencies, how useful is a coil is not only judged by its inductance, but also by the ratio of its inductive reactance to its internal DC resistance of the coil. This ratio is called the Quality factor or merit or Q of the coil.

Q of a coil is given by, $Q = \frac{X_L}{R_i}$

where,

X_L is the reactance of the coil in ohms

R_i is the internal Resistance of the coil in ohms

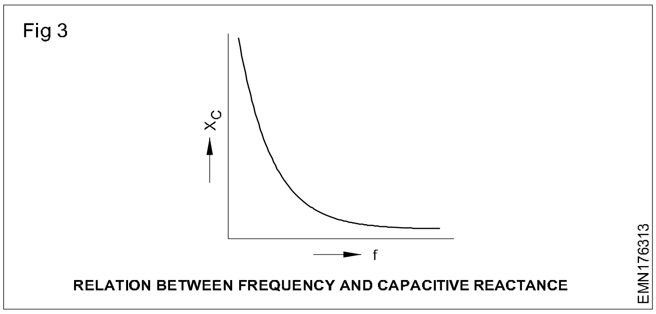
Since X_L and R_i have the same units of measure, Q has no unit.

The Q of a coil can be defined as the ability of a coil to produce self-induced voltage. The Q factor of a coil can also be defined as the capability of the coil to store energy. Hence the Q factor of a coil is also known as the storage factor.

If Q of a coil is 200, it means, that the X_L of the coil is 200 times more than it's R_i. Q of coils range from less than 10 for a low Q coil up-to 1000 for a high Q coils. R.F coils have Q in the range from 30 to 300.

R-C series circuit:

In a circuit with capacitance, the capacitive reactance (X_C) decreases when the supply frequency (f) increases as shown in Fig 3.



$$X_c \propto \frac{1}{f}$$

When the capacitive reactance X_C increases the circuit current decreases.

$$I \propto \frac{1}{X_c}$$

Therefore the increase in frequency (f) results in the increase of the circuit current in the capacitive circuit. When resistance (R), capacitance (C) and frequency f are known in a circuit, the power factor cos θ can be determined as follows.

$$X_c = \frac{1}{2\pi f c}$$

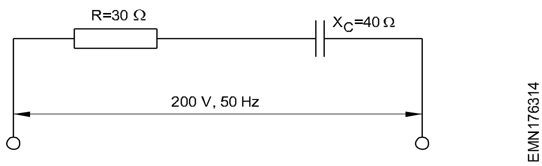
Power factor,

Power consumed in a R-C series circuit can be determined using the formula.

P= VI Cosθ where P = Power in watts, I = Current in ampere Cosθ = Power factor

Example 1: In RC series circuit shown in the diagram (Fig 4) obtain the following.

Fig 4



- Impedance in ohms
- Current in amps
- True power in watts
- Reactive power in VAR
- Apparent power in volt amp.
- Power factor

Solution

1. Impedence Z

$$= \sqrt{R^2 + X_C^2} = \sqrt{30^2 + 40^2} = \sqrt{2500} = 50\Omega.$$

2. Current $I = \frac{V}{Z} = \frac{200}{50} = 4A$

3. True power W = $I^2R = 4^2 \times 30 = 480W$

   (Power consumed by capacitor = zero)

   $V_C = IX_C = 4 \times 40 = 160$ V

4. Reactive power VAR = $V_C I = 160 \times 4 = 640$ VAR

   Apparent power $VI = 200 \times 4 = 800$ VA

PF $\cos\theta = \frac{R}{Z} = \frac{30}{50} = 0.6$

Impedance of series resonance circuit

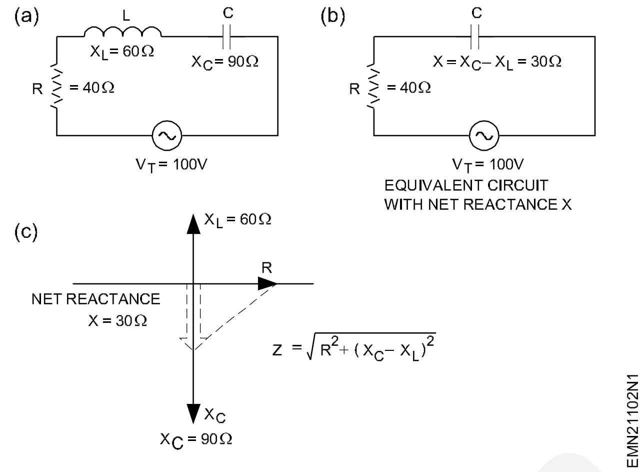
A simple series RLC circuit shown in Fig 5. In this series RLC circuit,

- resistance R is the total resistance of the series circuit(internal resistance) in ohms,
- X_L is the inductive reactance in ohms,

  and
- X_C is the total capacitive reactance in ohms.

In the circuit at Fig1, since the capacitive reactance(90W) is larger than inductive reactance(60W), the net reactance of the circuit will be capacitive. This is shown in Fig 1b.

Fig 5



If the capacitive reactance was smaller than inductive reactance the net reactance of the circuit would have been inductive.

All though the unit of measure of reactance and resistance is the same(ohms), the impedance, Z of the circuit is not given by the simple addition of R, X_L and X_C. This is because, X_L is +90° out of phase with R and X_C is -90° out of phase with R.

Hence the impedance Z of the circuit is the phasor addition of the resistive and reactive components as shown by dotted lines in Fig 1c. Therefore, Impedance Z of the circuit is given by,

$$Z = \sqrt{R^2 + (X_C - X_L)^2}$$

If X_L were greater than X_C, then the absolute value of impedance Z is will be,

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

For the circuit in Fig 3(a), total impedance Z is,

$$Z = \sqrt{R^2 + (X_C - X_L)^2}$$

$$Z = \sqrt{40^2 + 30^2}$$

Z = 50W, Capacitive *(because $X_C > X_L$)*

Current I through the circuit is given by,

$$Z = \sqrt{R^2 + (X_C - X_L)^2}$$

$$I = \frac{V}{Z} = \frac{100}{50\,\Omega} = 2 \text{ Amps}$$

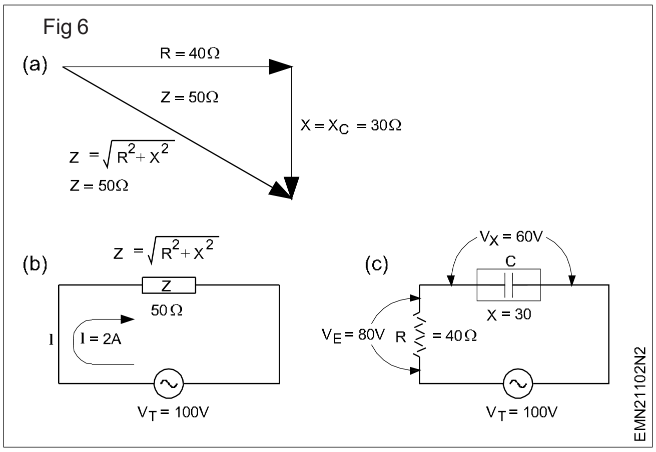
Therefore, the voltage drop across the components will be,

V_R = voltage drop across R = I.R = 2x40 = 80 volts

V_L = voltage drop across L = I.X_L = 2x60 = 120 volts

V_C = voltage drop across C = I.X_C = 2x90 = 180 volts.

Since V_L and V_C are of opposite polarity, the net reactive voltage V_X is = 180 - 120 = 60V as shown in Fig 6.



Note that the applied voltage is not equal to the sum of voltage drops across reactive component X and resistive component. This is again because the voltage drops are not in phase. But the phasor sum of V_R and V_X will be equal to the applied voltage as given below,

$$V_T = \sqrt{V_R^2 + (V_L - V_C)^2}$$

$$V_T = \sqrt{80^2 + 60^2} = 100 \text{ volts(applied voltage).}$$

Phase angle θ of the circuit is given by,

$$\theta = \tan^{-1}\frac{X_C - X_L}{R}$$

Condition at which current through the RLC Series circuit is maximum

From the formula,

$Z = \sqrt{R^2 + (X_C - X_L)^2}$ it is clear that the total impedance Z of the circuit will become purely resistive when, reactance $X_L = X_C$

In this condition, the impedance Z of the circuit will not only be purely resistive but also minimum.

Since the reactance of L and C are frequency dependent, at some particular frequency say f_r, the inductive reactance X_L becomes equal to the capacitive reactance X_C.

In such a case, since the impedance of the circuit will be purely resistive and minimum, current through the circuit will be maximum and will be equal to the applied voltage divided by the resistance R.

Series resonance

From the above discussions it is found that in a series RLC circuit,

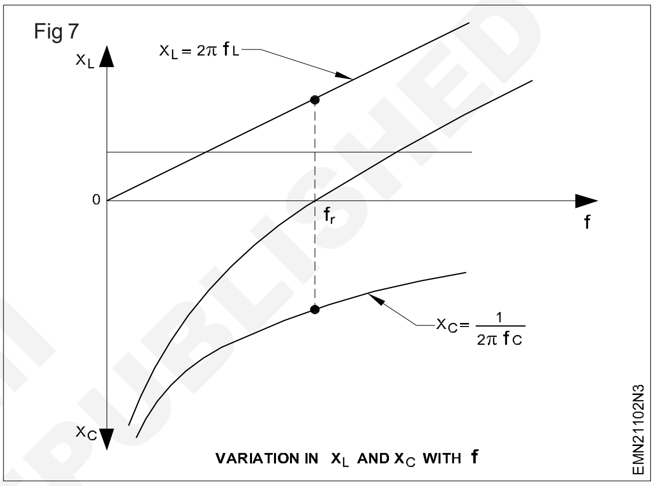
Impedance $Z = \sqrt{R^2 + (X_C - X_L)^2}$

Current $I = \frac{V}{Z}$, and

Phase angle $\theta = \tan^{-1}\frac{X_C - X_L}{R}$

If the frequency of the signal fed to such a series LC circuit(Fig 7) is increased from 0 Hz, as the frequency is increased, the inductive reactance(X_L = 2pfL) increases linearly and the capacitive reactance (X_C = 1/2pfL) decreases exponentially as shown in Fig 3.

As shown in Fig 7, at a particular frequency called the **resonance frequency, f_r**, the sum of X_L and X_C becomes zero($X_L - X_C = 0$).



From Fig 5 above, at resonant frequency f_r,

– Net reactance, X = 0 (i.e, $X_L = X_C$)
– Impedance of the circuit is minimum, purely resistive and is equal to R
– Current I through the circuit is maximum and equal to V/R
– Circuit current, I is in-phase with the applied voltage V (i.e. Phase angle θ= 0).

At this particular frequency f_r called resonance frequency, the series RLC is said to in a condition of **series resonance**.

Resonance occurs at that frequency when,

$X_L = X_C$ or 2pfL = 1/2pfC

Therefore, **Resonance frequency, f_r** is given by,

$$f_r = \frac{1}{2\pi\sqrt{LC}} \text{Hz} \quad .... (1)$$

Reactance of series RLC above and below resonance frequency f_r

Fig 8 shows the variation of net reactance of a RLC circuit with the variation in frequency.

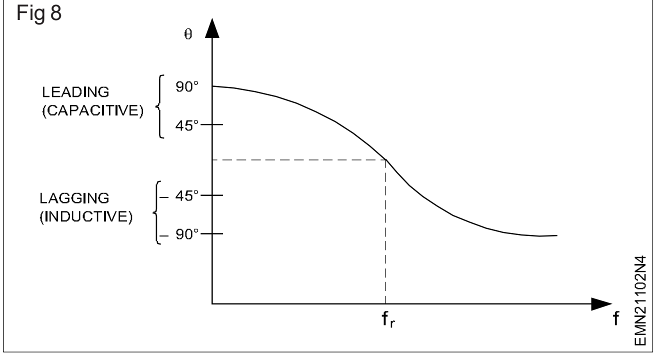
From Fig 8 above,it can be seen that the,

– net reactance is zero at resonant frequency f_r
– net reactance is capacitive below the resonant frequency

f_r

– net reactance is inductive above the resonant frequency f_r

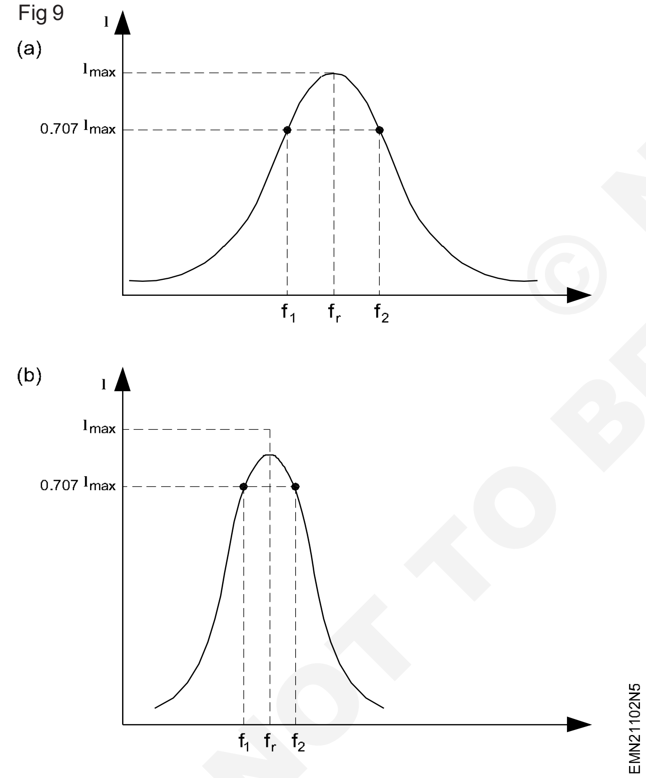
Fig 8



Selectivity or Q factor of a series RLC circuit: Figs 9a and 9b two graphs showing the current through series two different RLC circuits for frequencies above and below f_r. f_1 and f_2 are frequencies at which the circuit current is 0.707 times the maximum current, I_{max} or the -3dB points.

Fig 5 indicates that series RLC circuits select a band of frequencies around the resonant frequency, f_r. This band(f_1 to f_2 is called the **band width** f of the series RLC circuit.

Fig 9



Bandwidth $= \Delta f = f_2 - f_1$ Hz.

where, f_2 is called the upper cut off frequency and f_1 is called the lower cut off frequency of the resonant circuit.

Comparing Figs 9a and 9b, it is seen that the bandwidth of 9b is smaller than that of 9a. This is referred to as the **selectivity** or **quality factor, Q** of the resonance circuit. The RLC circuit having the response shown in Fig 5b is more selective than that of Fig 5a. The quality factor, Q of a resonance circuit is given by,

$$\text{Quality factor} = Q = \frac{f_r}{\Delta_f} = \frac{f_r}{f_2 - f_1} \qquad \text{...[2]}$$

If Q is very large, the bandwidth f will be very narrow and vice-versa. The Q factor of the series resonance circuit depends largely upon the Q factor of the coil(inductance) used in the RLC circuit.

Therefore,

$$\text{Q of coil} = \frac{X_L}{R} = \frac{2\pi f_r L}{R}$$

since,

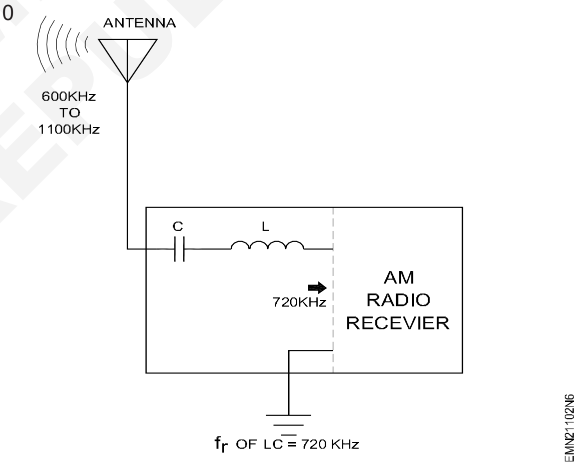
$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

Q of the series RLC circuit is given by,

$$Q = \frac{1}{R} \cdot \frac{\sqrt{L}}{\sqrt{C}} \qquad \text{...[3]}$$

Application of series resonance circuits: A series resonance circuit can be used in any application where it is required to select a desired frequency. One such application is shown in Fig 10.

Fig 10



In Fig 10, the radio receiver antenna intercepts all the frequencies available in air. The series LC circuit when tuned to 720KHz(f_r) will allow only the signal corresponding to Chennai-A radio station and rejects all other signal frequencies.

A series resonance circuit can also be used to reject an undesired frequency(used as wave trap)

A wave trap is a resonant LC circuit tuned to the frequency to be rejected. Thus the output of the tuned amplifier will not have the frequency for which the trap is tuned. This is because, at resonance the series LC of the wave trap, provides very low impedance. As the trap is connected across the collector and ground, the rejection frequency component is grounded.

Such wave traps are extensively used in very high and ultra-high frequency circuits such as television receivers, communication receivers etc.

Parallel Resonance Circuits

Objectives: At the end of this lesson you shall be able to
- **list the characteristics of LC parallel circuits at resonance**
- **explain the term Band-width in parallel LC circuits**
- **explain the storage action in parallel LC circuits**
- **explain the terms make up current and tank circuit**
- **list a few applications of parallel LC circuits**
- **compare the properties of series and parallel LC circuits at resonance, above resonance and below resonance.**

PARALLEL RESONANCE: The circuit at Fig 1, having an inductor and a capacitor connected in parallel is called parallel LC circuit or parallel resonance circuit. The resistor R, shown in dotted lines indicate the internal DC resistance of the coil L. The value of R will be so small compared to the inductive reactance, that it can be neglected.

From Fig 1a, it can be seen that the voltage across L and C is same and is equal to the input voltage V_S.

By Kirchhoff's law, at junction A,

$$I = I_L + I_C.$$

The current through the inductance I_L (neglecting resistance R), lags V_S by 90°. The current through the capacitor I_C, leads the voltage V_S by 90°. Thus, as can be seen from the phasor diagram at Fig 1b, the two currents are out of phase with each other. Depending on their magnitudes, they cancel each other either completely or partially.

If $X_C < X_L$, then $I_C > I_L$, and the circuit acts capacitively.

If $X_L < X_C$, then $I_L > I_C$, and the circuit acts inductively.

If $X_L = X_C$, then $I_L = I_C$, and hence, the circuit acts as a purely resistive.

Zero current in the circuit means that the impedance of the parallel LC is infinite. This condition at which, for a particular frequency, f_r, the value of $X_C = X_L$, the parallel LC circuit is said to be in parallel resonance.

Summarizing, for a parallel resonant circuit, at resonance,

$$X_L = X_C,$$

$$Z_p = \infty$$

$$I_L = I_C$$

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

$$I = \frac{V}{Z_p} \approx 0$$

In a parallel resonance circuit, with a pure L(no resistance) and a pure C(loss-less), at resonance the impedance will be infinite. In practical circuits, however small, the inductor will have some resistance. Because of this, at resonance, the phasor sum of the branch currents will not be zero but will have a small value I. This small current I will be in phase with the applied voltage and the impedance of the circuit will be very high although not infinite.

Summarizing, the three main characteristics of parallel resonance circuit at resonance are,

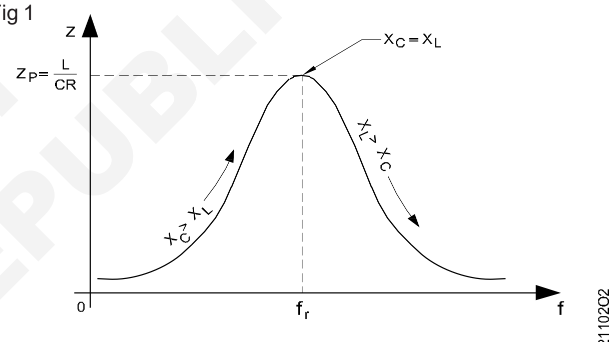
– phase difference between the circuit current and the applied voltage is zero

– maximum impedance

– minimum line current.

The variation of impedance of a parallel resonance circuit with frequency is shown in Fig 1.

Fig 1



FREQUENCY VERSES IMPEDENCE OF A PARALLEL RESONANT CIRCUIT

In Fig 1, when the input signal frequency to the parallel resonance circuit is moved away from resonant frequency f_r, the impedance of the circuit decreases. At resonance the impedance Z_p is given by,

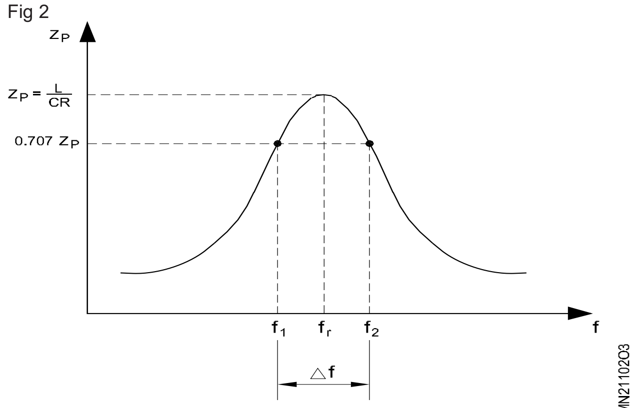
$$Z_p = \frac{L}{CR}$$

At resonance, although the circuit current is minimum, the magnitudes of I_L & I_C will be much greater than the line current. Hence, a parallel resonance circuit is also called current magnification circuit.

Bandwidth of parallel resonant circuits: As discussed in series resonance, all resonant circuits have the property of discriminating between the frequency at resonance(f_r), and those not at resonance. This discriminating property of the resonant circuit is expressed in terms of its **bandwidth (BW).** In the case of series resonant circuits the response of the circuit at resonance frequency(f_r) is in terms of the line current(which is maximum), and in a parallel resonant circuit, it is in terms of the impedance(which is maximum).

The bandwidth of a parallel resonant circuit is also defined by the two points on either side of the resonant frequency at which the value of impedance Z_p drops to 0.707 or $1/\sqrt{2}$ of its maximum value at resonance, as shown Fig 2.

Fig 2



From Fig 2, the bandwidth of the parallel resonance circuit is,

Bandwidth, BW = $\Delta f = f_2 - f_1$

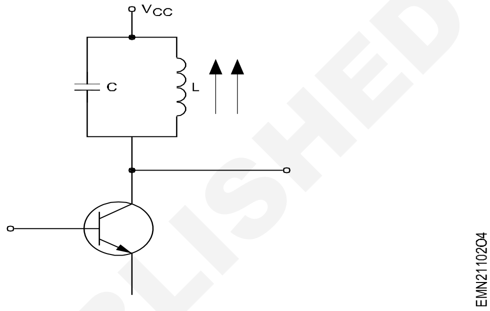
As can be seen in Fig 3, the value of Z_p is dependent on the resistance R of the coil (Z_p = L/CR). If R is less Z_p will be larger and vice versa. Since the bandwidth depends on Z_p and Z_p depends on R, we can say that the bandwidth of a resonant circuit depends upon the resistance associated with the coil. The resistance of the coil in turn decides the Q of the circuit. Thus, the Q of the coil decides the band width of the resonant circuit and is expressed as,

$$\text{Bandwidth(BW)} = \left(f_2 - f_1\right) = \frac{f_r}{Q}$$

Application of parallel resonant circuits: Parallel resonance circuits or tank circuits are commonly used in almost all high frequency circuits. Tank circuits are used as collector load in class-C amplifiers instead of a resistor load as shown in Fig 3.

Tank circuits are used in circuits known as oscillators which are designed to generate ac signals using dc supply.

Fig 3

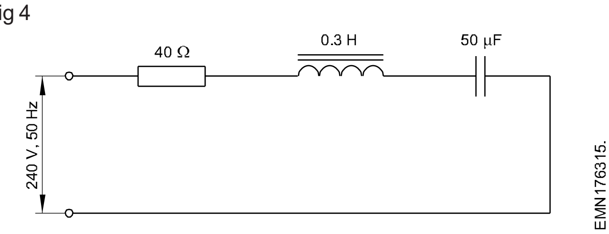


Property	Series circuit	Parallel circuit
	At resonant frequency	
Resonant frequency, f_r	$\frac{1}{2\pi\sqrt{LC}}$	$\frac{1}{2\pi\sqrt{LC}}$
Reactance	$X_L = X_C$	$X_L = X_C$
Impedance	Minimum (Z_r = R)	Maximum (Z_r = L/CR)
Current	Maximum	Minimum
Quality factor	$\frac{X_L}{R}$	$\frac{X_L}{R}$
Bandwidth	$\frac{f_r}{Q}$	$\frac{f_r}{Q}$
	Above resonant frequency	
Reactance	$X_L > X_C$	$X_C > X_L$
Impedance	Increases	Decreases
Phase difference	The current lags behind the applied voltage.	The current leads the applied voltage.
Type of reactance	Inductive	Capacitive
	Below resonant frequency	
Reactance	$X_C > X_L$	$X_L > X_C$
Impedance	Increases	Decreases
Phase difference	The current leads the applied voltage.	The current lags behind the applied voltage.
Type of reactance	Capacitive	Inductive

- **RLC Series circuit:** Assume an AC single phase circuit consisting a resistance, inductor and capacitor in series. Various parameters could be calculated as shown in the example.

Example : The value of the components shown in Fig 4 is R = 40 ohms L = 0.3 H and C = 50µ. The supply voltage is 240V 50 Hz. Calculate the inductive reactance, capacitance reactance, net reactance, impedance, current in the circuit, voltage drops across the R, L and C power factor, active power, reactive power and apparent power. Also draw the impedance triangle, voltage triangle and power triangle.

Fig 4



Calculate the resulting reactance in RLC circuit : Inductance and capacitance have directly opposite effects in an AC circuit. The voltage drop caused by the inductive reactance of the coil leads the line current by 90°. The voltage drop across the inductor coil and the capacitor are 180 degrees apart and oppose each other. To calculate the net reactance in the above example:

Inductive reactance

$X_L = 2\pi fL = 314 \times 0.3 = 94.2\ \Omega$

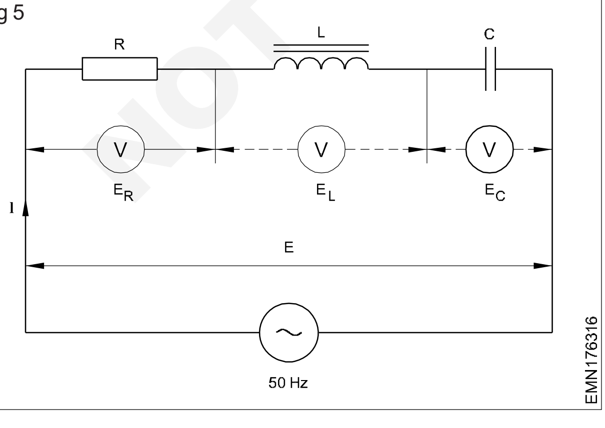
Capactive reactance

$$X_c = \frac{1}{2\pi fC} = \frac{1}{314 \times 0.00005} = \frac{1}{0.0157} = 63.69\ \Omega$$

Net reactance $= X_L - X_C = 94.2 - 63.69 = 30.51\ \Omega$

Measurement of current and voltage drop in RLC circuit. The voltage drop across R $= E_R$ across L $= E_L$ and drop across C $= E_C$ and the formula for finding their values and given below. (Fig 5)

Fig 5



$E_R = IR$

$E_L = IX_L$

$E_C = IX_C$

Current in given RLC series circuit: Current in this series circuit is $I = E/Z = 240/50.3 = 4.77$ amps.

Identifying whether the current flow is leading or lagging the voltage in a RLC series circuit: As this is a series circuit, the current is the same in all parts of the circuit, but the voltage drop across the resistor, the inductor coil and capacitor are

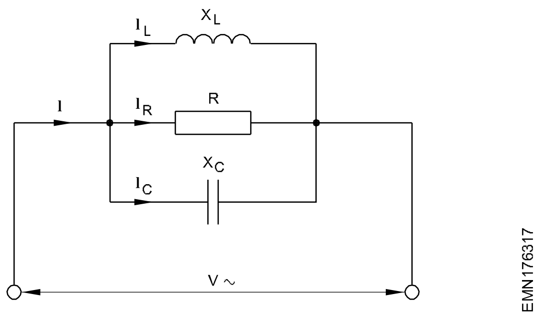
$E_R = IR = 4.77 \times 40 = 190.8$ volts

$E_L = IX_L = 4.77 \times 94.2$ W $= 449.33$ volts

$E_C = IX_C = 4.77 \times 63.69 = 303.80$ volts.

Resonance circuit: When the value of X_L and X_C are equal, the voltage drop across them will be equal and hence they cancel each other. The value of voltage drops V_L and V_C may be much higher than the applied voltage. The impedance of the circuit will be equal to the resistance value. Full value of applied voltage appears across R and the current in the circuit is limited by the value of resistance only. Such circuits are used in electronic circuits like radio/ TV turning circuits. When $X_L = X_C$ the circuit is said to be in resonance. As current will be maximum in series resonant circuits it is also called acceptor circuits. For a known value of L and C the frequency at which this occurs is called as resonant frequency. This value can be calculated as follows when $X_C = X_L$

Fig 6



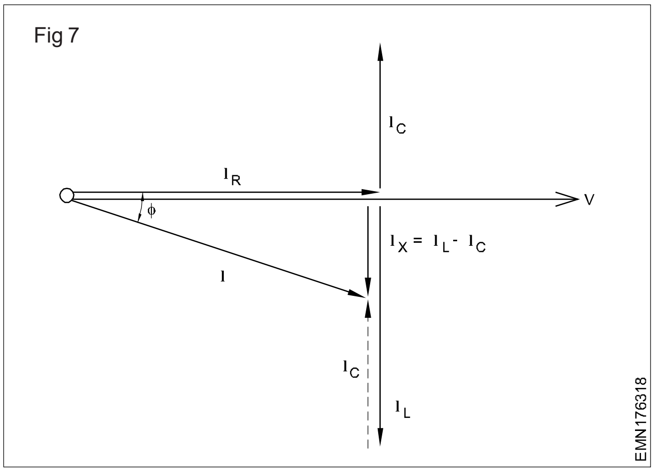
$$2\pi fL = \frac{1}{2\pi fC}$$

Hence resonant frequency $f = \frac{1}{2\pi\sqrt{LC}}$

Parallel connection of R, X_L and X_C: X_L and X_C oppose each other, that is to say, I_L and I_C are in opposition, and partly annul one another. (Fig 7)

$I_X = I_C - I_L$ or $I_L - I_C$, depending on whether the capacitive or inductive current dominates.

Fig 7



Graphic solution: when $I_L > I_C$

1 V as common value

2 I_R in phase with V

3 I_C leads by 90^o

4 I_L lags by 90^o

5 $I_X = I_L - I_C$

6 I as resultant

7 <) φ (in this case inductive, I lags)

Particular case: X_L and X_c are equally large - I_L and I_c cancel each other. Z = R; parallel resonance occurs.

Currents in the reactances may be greater than the total current.

The calculation of the resonant frequency is the same as for the series connection.

***Example**:* Calculate the value of I_T Z power factor and power for the circuit in Fig 8.

Given

$V_T = 10V$

$R = 1000\ \Omega$

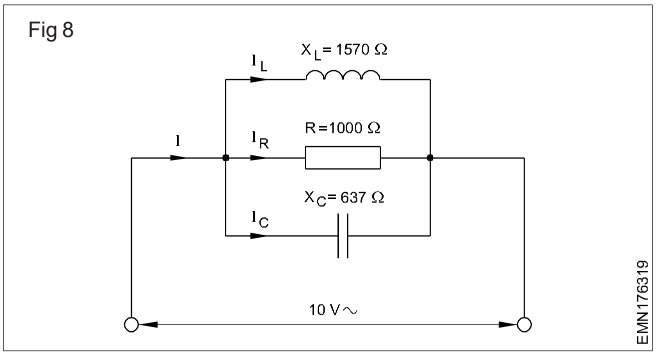
$X_L = 1570\ \Omega$

$X_C = 637\ \Omega$

Known: Ohm's Law

$$I_T = \sqrt{(I_C - I_L)^2 + I_R^2}$$

Fig 8



Solution

$$I_C = \frac{10\ V}{637\ \Omega} = 0.0157\ A = 15.7\ mA$$

$$I_L = \frac{10\ V}{1570\ \Omega} = 0.0064\ A = 6.4\ mA$$

$$I_R = \frac{10\ V}{1000\ \Omega} = 0.01 = 10\ mA$$

$$I_T = \sqrt{(0.0157 - 0.0064)^2 + 0.01^2}$$

$$= 0.0137\ A = 13.7\ mA$$

$$Z = \frac{10V}{0.0137\ A} = 730\ \Omega$$

$$P.F = \frac{Z}{R} \quad Y = \frac{1}{Z} \text{ and } g = \frac{1}{R}$$

$$= \frac{730}{1000} = 0.73$$

$$\text{PF in admittance triangle} = \frac{g}{Y} = \frac{1}{R} \times \frac{1}{1/Z} = \frac{Z}{R}$$

$$\text{Power} = V I \cos\theta$$

$$= 10 \times 0.0137 \times 0.73$$

$$= 0.1 \text{ Watt or } 100 \text{ mw.}$$

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.**

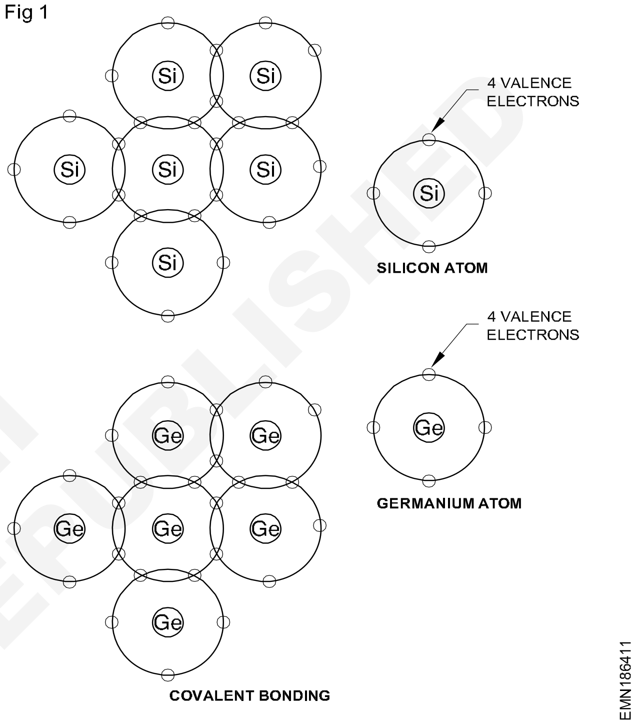
Semiconductors

Semiconductors are materials whose electrical 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.

Fig 1

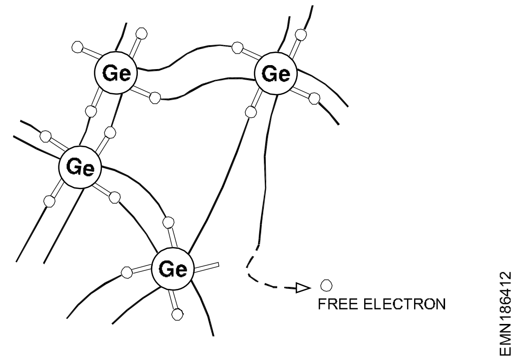


Intrinsic semiconductors

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.

Fig 2



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.

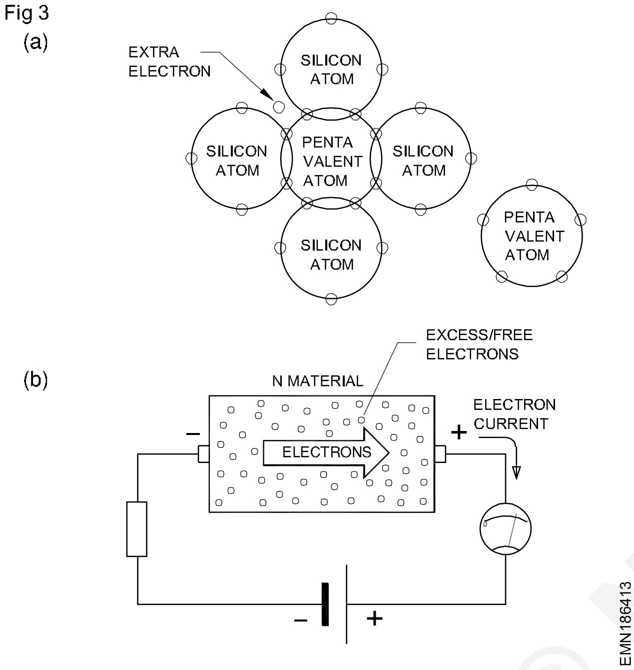
The process of adding impurity to an Intrinsic semi conductor material is known as Doping. Since the doped semiconductor materials are no longer pure, they are called impure or **extrinsic semiconductors.**

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.**

Fig 3



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.

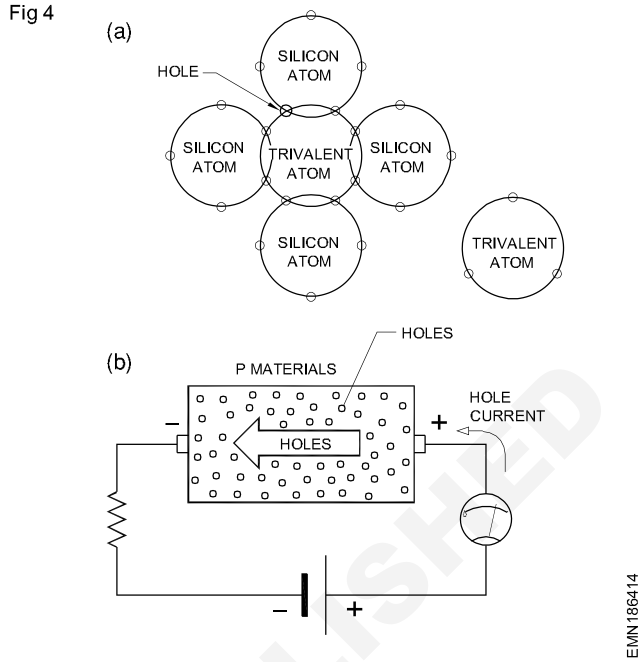
2 P-type semiconductors

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.

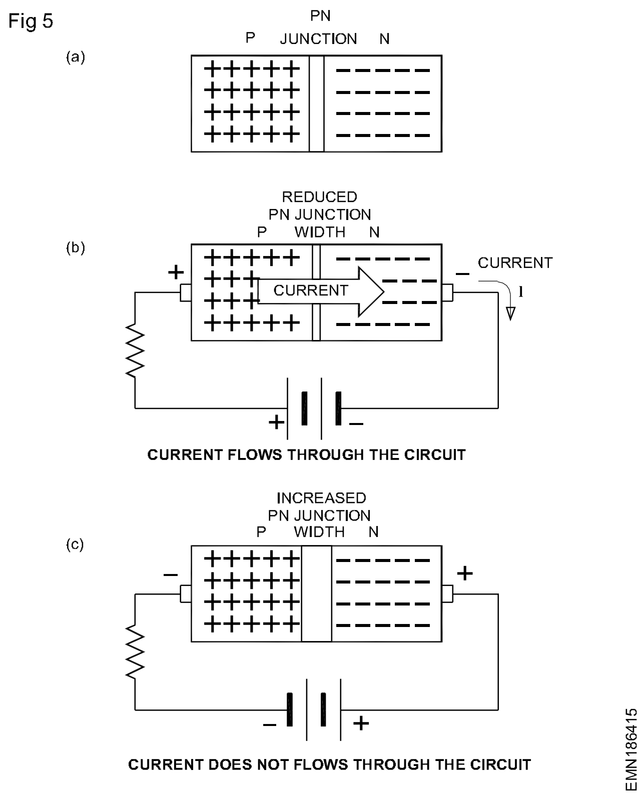
Fig 4



P-N junction

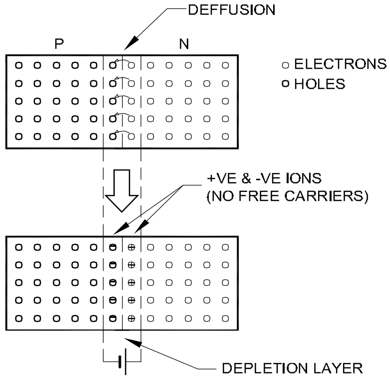
When a P-type and a N-type semiconductors are joined, a contact surface between the two materials called PN-junction is formed. This junction has a unique characteristic. This junction, has the ability to pass current in one direction and stop current flow in the other direction. To make use of this 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.**

Fig 5



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.

Fig 6



BATTERY EQUIVALENT OF JUNCTION

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.

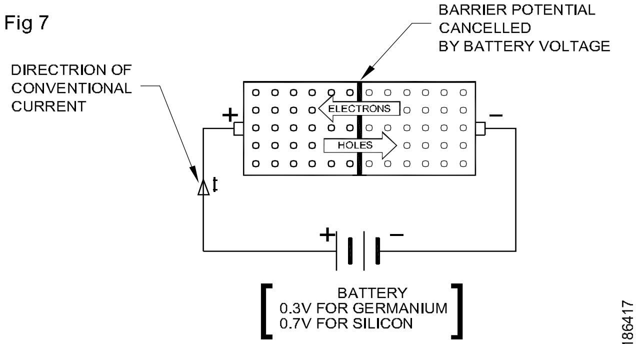
In terms of voltage applied across the terminals of the PN junction diode, a potential difference of 0.7V is required across the terminals in the case of silicon diode and 0.3V in the case of Germanium diode for the electrons, in order to cancel off the barrier potential and cross over the barrier as 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.

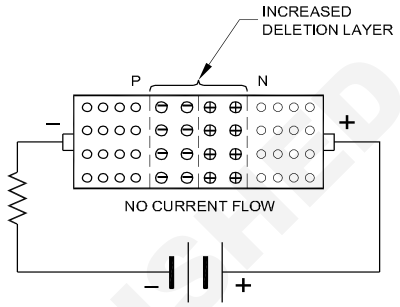
The two leads connected to the P and N terminals are known as Cathode and Anode.

Fig 7



FORWARD BIASED P N JUNCTION

Fig 8



REVERSE BIASED P N JUNCTION

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 milli watts 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

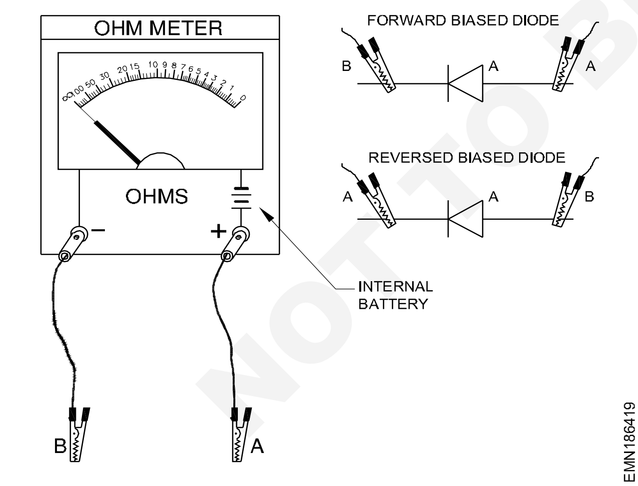
The type of packaging given to diodes is mainly based on the current carrying capacity of the diode. Low power diodes have either glass or plastic packaging. Medium power diodes have either plastic or metal packaging. High power diodes will invariably have either metal can or ceramic packaging. High 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.

Fig 9



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.

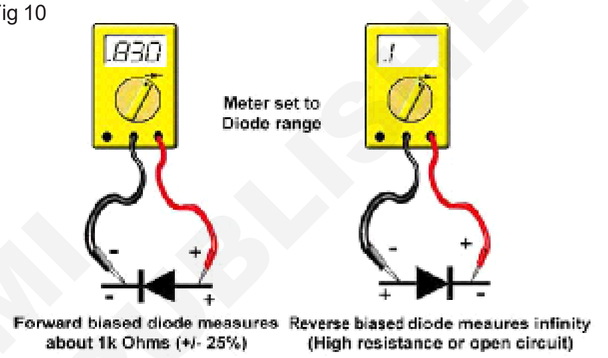
While doing the above test, if a diode shows a very low resistance in both the forward and reverse biased conditions, then, the diode under test must have got damaged or more specifically shorted. On the other hand, a diode is said to be open if the meter shows very high resistance both in the forward 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.

Fig 10



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

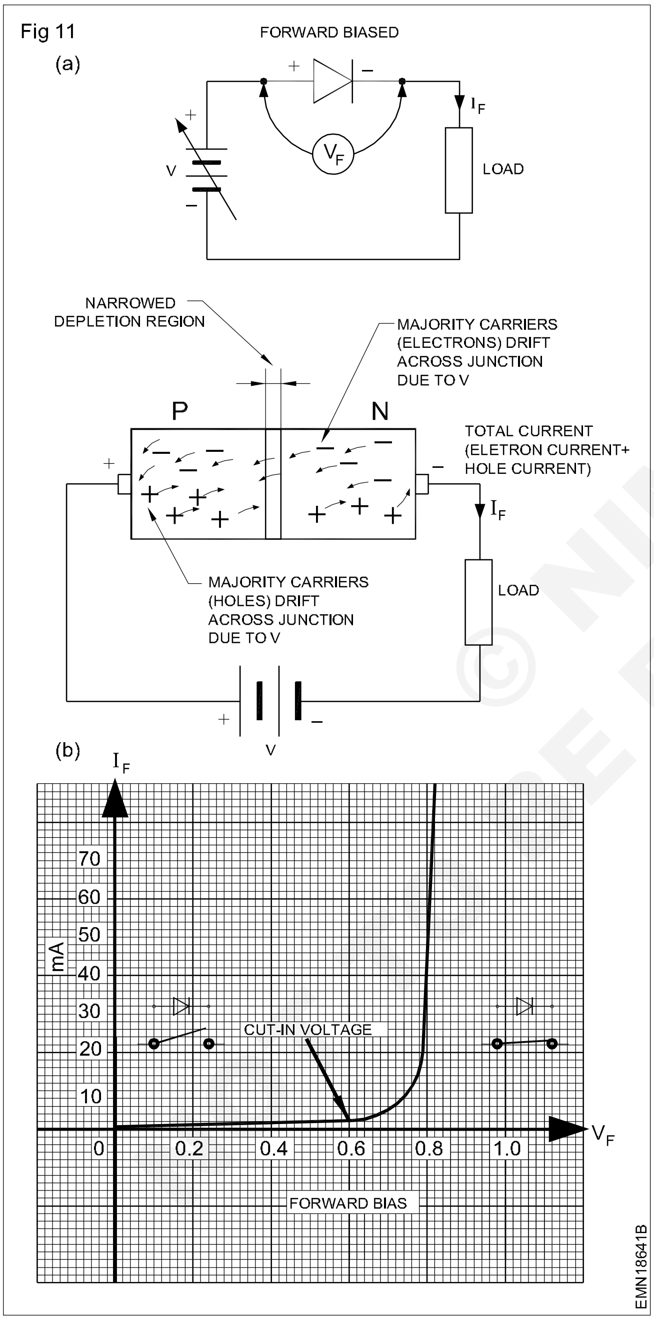
Fig 11a shows a forward biased silicon PN junction diode using a variable DC supply. When the applied voltage is slowly increased starting from 0 volts as long as the voltage across the diode V_F is less than that of the depletion barrier potential (0.7 volts for Si diodes), no current or a negligible 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.

Fig 11



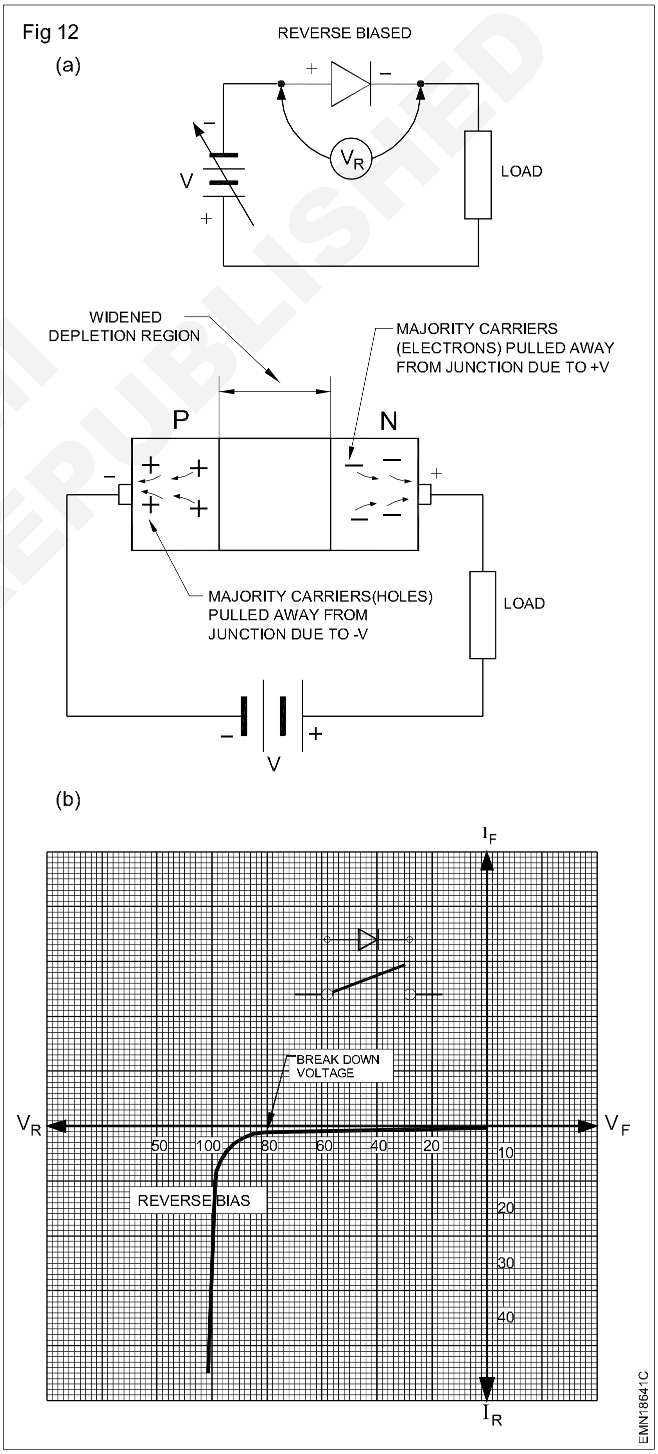
From the graph at Fig 11b, it can be seen that, once the forward voltage goes above 0.6V the diode starts conducting, resulting in considerable current through the circuit. This voltage level across the diode is referred to as *cut-in* or *knee or threshold voltage.*

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,* $I_{f max.}$

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.

Fig 12



In this condition, when the battery voltage is increased from 0 to several tens of volts, the polarity of the applied voltage instead of canceling the barrier potential, aids the barrier potential. This, instead of narrowing the depletion layer, widens the depletion layer. The widening of the depletion layer results in, not allowing the current to flow through the junction, and, hence, the load. In other words, the polarity of the applied voltage is such that the holes and electrons are pulled away from the junction resulting in a widened depletion region.

Referring to the graph shown in Fig 12b, it can be seen that there is no current even when the voltage V_R across the diode is several tens of volts.

It the applied reverse voltage is kept on increased, say to hundred volts (this depends from diode to diode), at one stage the applied voltage V_R across the junction is so large that it punctures the junction damaging the diode. This results in shorting of the diode. This short results in uncontrolled heavy current flow through the diode as shown in graph at Fig 12b. This voltage at which the diode breaks down is referred to as *reverse break-down or avalanche breakdown.*

The maximum reverse voltage that a diode can withstand varies from diode to diode. This reverse voltage withstanding capability of a diode is referred to as the *peak-inverse-voltage* or PIV of the diode. This value for diodes is given in the diode data manual. The PIV of diodes varies from a minimum of 50 volts in small signal diodes to several thousands of volts in high power diodes.

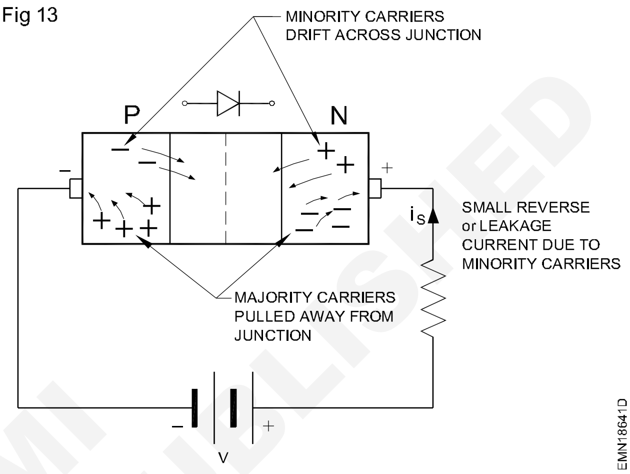
Minority current in Diodes

When a PN junction is reverse biased, due to the increased width of the depletion layer, there can be no current through the diode. But, in practice there will be a small current of the order of a few nano-amperes or a few micro-amperes through the diode as shown in Fig 13.

The reason for this small current is due to the creation of a very limited number of free electrons and holes on both sides of the junction due to thermal energy. Semiconductors are highly sensitive to temperature. Even a temperature of 25°C is sufficient to create a small number of electrons and holes resulting in a current of the order of a few nano-amperes. These current carriers created are referred to as *minority current carriers*. This current, due to minority current carriers, which flows through the diode when reverse biased, is known as reverse current or *leakage current* or *saturation current,* i_s. Based on experiments, for all silicon diodes, this reverse current doubles for each 10°C rise in temperature. For example, if it is 5nA at 25°C, it will be approximately 10nA at 35°C and so on.

Effect of temperature on barrier voltage: It is known that semiconductors are highly sensitive to temperature. Since the functioning of a diode is basically due to the unique property of its junction and its barrier voltage, the barrier voltage also depends on the junction temperature. If the temperature of the junction is increased beyond a limit (25°C), electrons are produced due to thermal agitation in the semi-conductor crystal structure. These electrons, having sufficient energy, drift across the junction. This decreases the barrier voltage. It is experimentally found that the barrier voltage decreases by 2 mV/°C increase in temperature. This reduced barrier voltage allows more current through the junction. More current heats up the junction further, reducing the barrier voltage further. If this cumulative effect continues, the junction will get damaged making the junction no more useful. Therefore, diodes should not be allowed to go above a specified temperature. This maximum limit a diode junction can withstand safely is given in the diode manual as *junction temperature,* $T_{j\,max}$.

Fig 13



Diode specification

Semiconductor diodes are used for various applications. Some of the major areas of application are listed below.

- Modulation and demodulation in communication receivers.
- Switching high speed and digital circuits.
- Low power and high power rectification.
- As surge protectors in EM relay and other circuits.
- For clipping, clamping wave-forms.

For different applications, diodes of different current carrying capacity, different PIV capacity and so on are required. Therefore, manufacturers of diodes make diodes to cater to varied applications with different specifications. Before using a diode for a particular application, it is a must to find out whether the voltage, current, and temperature characteristics of the given diode match the requirement or not.

Important specifications of a diodes

- The material the diode is made-of: This could be Silicon or Germanium or Selenium or any other semiconductor materials. This is important because the cut-in voltage depends upon the material the diode is made-of. For example, in Ge diodes the cut-in voltage is around 0.3 V, whereas in Si diodes the cut-in voltage is around 0.7V.
- Maximum safe reverse voltage denoted as V_R or V_r that

can be applied across the diode. This is also known as peak-inverse-voltage or PIV. If a higher reverse voltage 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_{vr} that flows through the diode when the Maximum reverse voltage, PIV is applied.

– Maximum forward surge current, I_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.

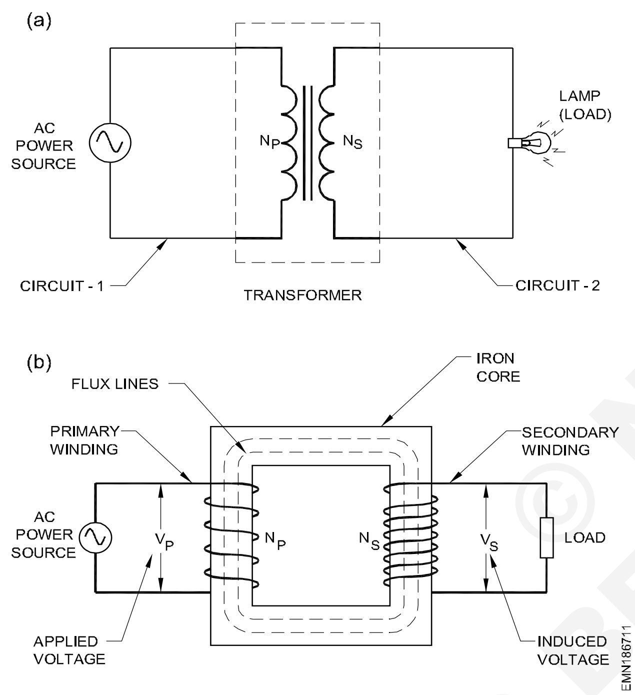
– Suggested application indicates application for which the diode is designed and produced.

Transformer

Objectives : At the end of this lesson you shall be able to
- **state the basic function of a transformer**
- **state the classifications of transformers**
- **describe the phase relationship in transformer**
- **explain losses and efficiency of transformer**
- **explain the method to determine the efficiency of transformer.**

Transformer is an electrical device used to transfer electric energy from one AC circuit to another circuit by magnetic coupling as shown in Fig 1a.

Fig 1



A transformer essentially consists of two coils of insulated conducting material, generally copper. These coils are wound on a core made of iron or ferrite as shown in Fig 1b. These coils are so arranged that magnetic flux developed in one coil will link with the other coil. Hence, mutual inductance exists between the two coils with tight-coupling (k=1). A change in current through one coil (say N_p) induces a voltage in the other coil (say N_s). The magnitude of induced voltage in the secondary winding depends on the number of turns of the coils and on how tight the magnetic coupling(k) is, between the two coils.

In a transformer, as shown in Fig 1b, the coil or the winding to which electrical energy is given from an ac power source is called the **primary winding**. In Fig 1 this coil is marked N_p. The second coil to which, energy from the primary winding is coupled magnetically is called the secondary winding (N_s in Fig 1b). If a load, say a lamp or a resistor, is connected across the secondary winding, current flows through the load although there is no direct AC power source connected to it.

Hence, transformers can be defined as devices that make use of the principle of mutual induction, in transferring electrical energy from one ac circuit to another circuit with out direct electrical connection.

> **It is important to note that transformers cannot transfer DC energy from primary winding to secondary winding, because, a DC current cannot produce changing magnetic field and hence cannot develop induced voltage.**

Important terms used with iron-core transformers are explained below;

1. Turns Ratio of a transformer

The ratio of the number of turns of coil in the primary (N_p) to the number of turns of coil in the secondary (N_s) is called the *turns ratio of the transformer*.

$$\text{Turns ratio} = \frac{N_p}{N_s}$$

> **For example, 1000 turns in the primary and 100 turns in the secondary gives a turns ratio of 1000/100, or 10:1 which is stated as ten-to-one turns ratio.**

2. Voltage Ratio of a transformer

The ratio of voltage across the primary winding(V_p) to the voltage available across the secondary winding(V_s) is called the *voltage ratio of the transformer*.

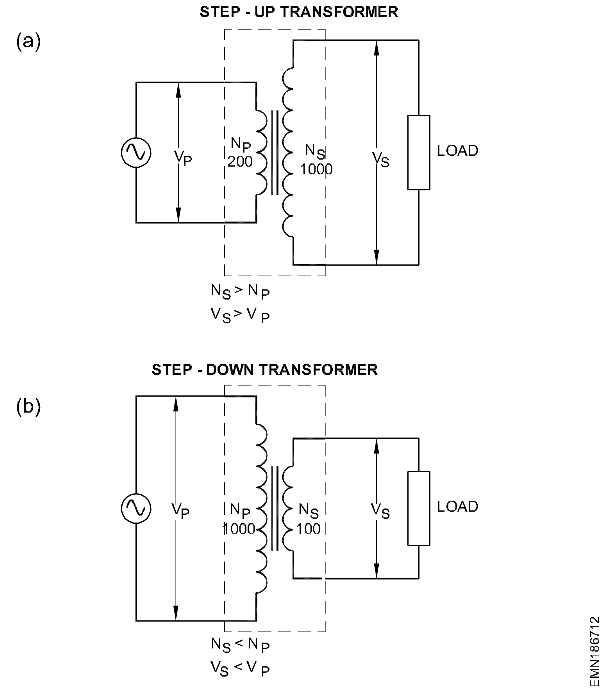
$$\text{Voltage ratio} = \frac{V_p}{V_s}$$

When coefficient of mutual coupling(k) between primary and secondary winding is 1, the voltage induced per turn of the secondary winding is the same as the self-induced voltage per turn in the primary winding. The total voltage appearing across the secondary winding depends on the number of turns of secondary winding. Therefore, the voltage ratio is in the same proportion as the turn ratio:

$$\frac{V_p}{V_s} = \frac{N_p}{N_s}$$

This means, if the secondary winding has more turns than the primary winding ($N_s > N_p$) then, the secondary voltage will be higher than the primary voltage. In other words, in such a condition the primary voltage is said to be raised or stepped-up. Such transformers are called STEP-UP transformer as shown in Fig 2a.

Fig 2



Example: As shown in Fig 2a, a transformer has 200 turns of N_p and 1000 turns of N_s, its turns ratio will be,

$$\text{Turns ratio} = \frac{N_p}{N_s} = \frac{200}{1000} = 1:5$$

For this transformer, if the applied AC primary voltage (V_p) is 110 V_{rms}, the secondary voltage will be stepped up in the same ratio as that of turns ratio. Hence, the secondary voltage will be twice the primary voltage, i.e, 5 x 110 = 550 V_{rms}.

On the other hand, when the secondary winding has less number of turns than the primary winding, the primary voltage is said to be lowered or stepped - down. Such transformers are called Step - down transformers as shown in Fig 2b.

Example: **As shown in Fig 2b a power transformer has 1000 turns of N_p and 100 turns of N_s, What is the turns ratio? How much is the secondary voltage V_s when a primary voltage is 240V?**

SOLUTION:

The turns ratio is 1000/100, or 10:1. Hence, secondary voltage will be stepped down by a factor of 1/10, making V_s equal to 240/10 or 24 Volts.

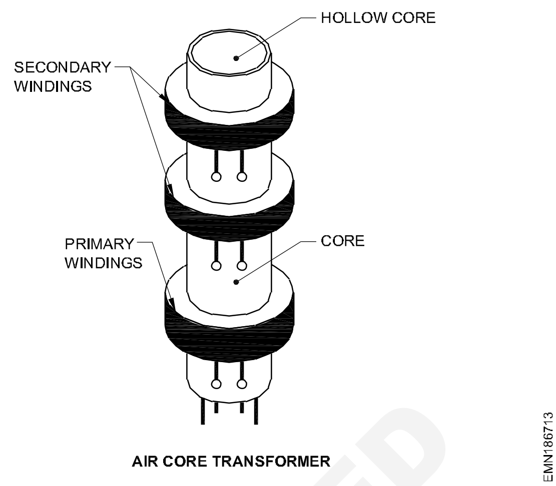
Classification of Transformers

1. Classification based on the type of Core Material used

Transformers can be classified according to the type of material used for the core as;

(a) **Air core transformers** : As shown in Fig 3, air core transformers consists of a hollow non magnetic core, made of paper or plastic over which the primary and secondary windings are wound. These transformers will have values of k less than 1. Air core transformers are generally used in high frequency applications because these will have no *iron-loss* as there is no magnetic core material.

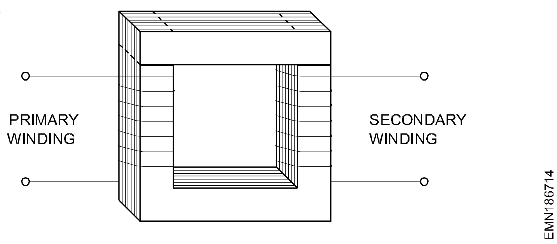
Fig 3



Iron-loss is a type of transformer loss due to core material. Transformer losses are discussed in detail in further lessons.

(b) **Iron core transformers**: Fig 4 shows a laminated iron-core transformer. These transformers have stacked laminated sheets of silicon steel over which the windings are wound. This is the most common type of transformer used with mains power supply(240V,50Hz). In these transformers, since the core is a magnetic material and due to the shape of the core, the value of k is almost equal to 1.

Fig 4



(c) **Ferrite core transformers**: These transformers have Ferrite material as its core. In most cases, the primary and secondary windings are wound on a hollow plastic core and the ferrite material is then inserted into the hollow core. These transformers are used in high frequency to very high frequency applications as they have the advantage of introducing minimum losses. In these transformer, the position of core can be changed, thus changing the value of M.

2 Classification based on the shape of core and relative position of primary and secondary windings:

(a) **Core type transformers**: In Core type of transformer, the primary and secondary windings are on two separate sections/limb of core. Core type transformers are less frequently used as their efficiency is low because the magnetic flux spreads out reducing the number of useful flux lines.

(b) **Shell type transformers**: In this type, both the primary and the secondary windings are wound on the same section/limb of the core. As the portion of the core surrounds the two windings, almost all the flux is confined to the core of the transformer. Shell type transformers have a higher efficiency as compared to core type transformers. These are widely used as voltage and power transformers.

(c) **Ring type transformers**: In this, the core is made up of circular or semicircular laminations. These are stacked and clamped together to form a ring. The primary and secondary windings are then wound on the ring. The disadvantage of this type of construction is the difficulty involved in winding the primary and secondary coils. Ring type transformers are generally used as instrument transformers for measurement of high voltage and current.

3 Classification based on the Transformation ratio:

a **Step-up Transformers**: Transformers in which, the induced secondary voltage is higher than the source voltage given at primary are called *step-up transformers*.

b **Step-down Transformers**: Transformers in which, the induced secondary voltage is lower than the source voltage given at primary are called *step-down transformers*.

c **Isolation transformers**: Transformers in which, the induced secondary voltage is same as that of the source voltage given at primary are called *one-to-one* or *isolation transformers*. In these transformers the number of turns in the secondary will be equal to the number of turns in the primary making the turns ratio equal to 1.

4 Classification based on the operating frequency:

a **Audio frequency (AF) transformers**: These AF transformers look similar to a mains voltage transformer but they are very small in size comparatively. Most AF transformers are of PCB mounting type. These transformers are designed to operate over the audio frequency range of 20 Hz to 20 kHz. Audio transformers are used in,

– coupling the output of one stage of audio amplifier to the input of the next stage (interstage coupling)

– the amplified audio signal from an amplifier to the speaker of a sound system.

These transformers are said to have *flat frequency response* over the entire audio range. This means that the transformer behaves equally well over the entire range of audio frequencies.

The transformation ratio of audio transformers will be generally less than unity.

These transformers also use a colour coding scheme to identify those used as driver transformers (for inter-stage coupling) or out-put transformers (for amplifier to speaker).

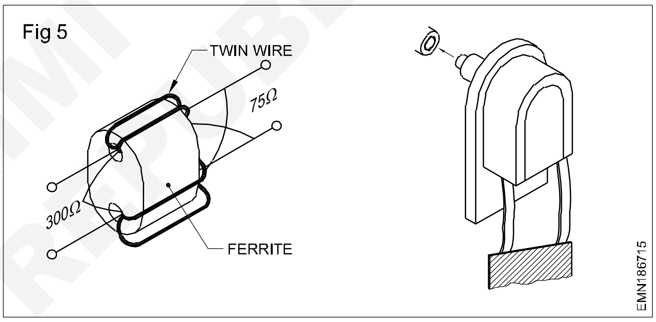
(b) High frequency transformers: The core of high frequency transformers are made of powdered iron or ferrite or brass or air core(hollow core). These transformers are called Radio frequency transformers (RFTs) and Intermediate frequency transformers (IFTs). These transformers are used for coupling any two stages of high frequency circuits such as radio receivers. The upper frequency limit of these transformers is 30 MHz.

Another speciality of these transformers is that the position of the core can be altered, which results in varied coupling and energy transfer. These transformers also have another electronic component called capacitor connected across the windings in parallel. This results in a different behavior of the transformer at different frequencies. Hence these transformer types are also called Tuned transformers.

These transformers are smaller than even audio frequency (AF) transformers. These transformers will generally be shielded/screened using a good conductor(recall lesson on inductors for need of screening).

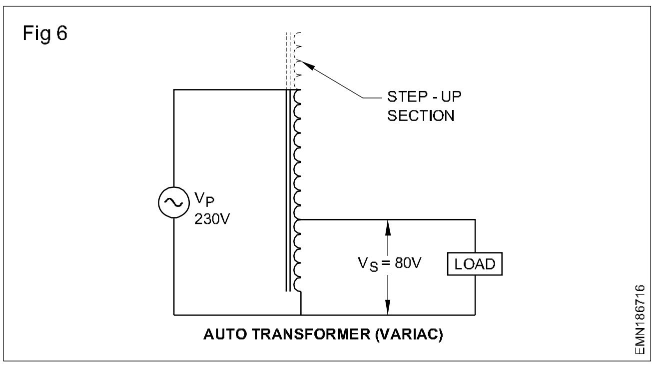
RFTs and IFTs also have a colour coding scheme to identify their different places of application.

(c) **Very high frequency transformers**: These transformers also have air or ferrite or brass as core material. These transformers are constructed specially to minimize energy losses at very high frequencies. Very high frequency transformers are available in several shapes and designs. Some of these find wide application in Television receivers. Fig 5 illustrates a high frequency transformers used in TV receivers.



5 Auto-transformers:

Auto-transformer as shown in Fig 6 is a special variety of transformers which have only a single winding. Because of single winding, there is no isolation between primary and secondary side. Auto-transformers are used when isolation between input and output is not important. Auto-transformers can be used for variable voltage operation by using a sliding contact like a potentiometer. But, it is important to note that an auto-transformer does not function as a simple voltage divider.



Auto-transformers are smaller in size and uses less iron than a conventional two winding transformer of the same rating.

Auto-transformers used for variable voltage operation are referred to the trade name of VARIAC.

As shown in Fig 6, auto-transformers has a step-up section (shown in dotted lines) which enables the transformer to develop a variable voltage output from 0 to 270V from a 240V input AC supply.

Auto-transformers are mostly used in laboratories for conducting experiments.

6 Single phase and three phase transformers:

Transformers are designed for use with single phase AC mains supply. Hence these transformers will have a single primary winding. Such transformers are known as single phase transformers. Transformers are also available for 3 phase AC mains supply. These are known as poly-phase transformers. In a 3-phase transformer, there will be three primary windings. Three phase transformers are used in electrical distribution and for industrial applications.

7. Classification based on application:

Transformers can also be classified depending upon their application for a specialized work. Since there are innumerable number of applications, the types are also innumerable. However a few of these are listed below:

Current Transformers - used in clip - on current meters, overload trip circuits etc.,

Constant voltage transformers - used to obtain stabilized voltage supply for sensitive equipments

Ignition transformers - used in automobiles

Welding transformers - used in welding equipments

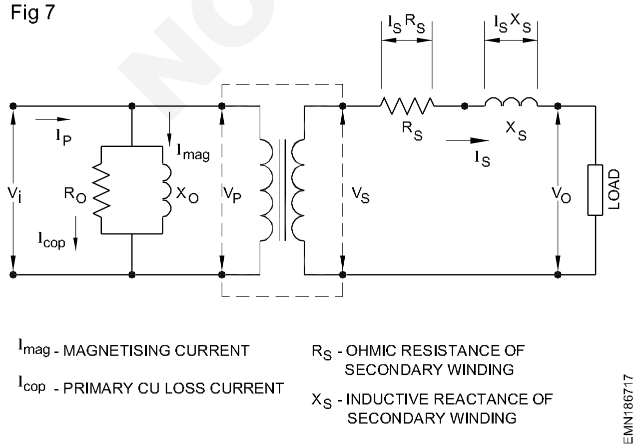
Pulse transformers - used in electronic circuits

Voltage Regulation

For simplicity in understanding, in all the previous lessons on transformers, the resistive and inductive effect of the primary and secondary windings were neglected. Also, the effect of load current on the magnitude of secondary voltage was neglected. In a practical situation, the secondary voltage of a transformer decreases as the load/ load-current is increased.

Consider the equivalent circuit of a transformer shown in Fig 7.

Fig 7



From the circuit in Fig 8, the secondary current I_s produces voltage drops I_sR_s and I_sX_s across the resistive and reactive components of the secondary winding. Consequently, the output voltage V_o is less than V_s.

When load is not connected at the output terminals of the transformer, no secondary current flows, and hence, no voltage drops occur across R_s and X_s. Hence, V_o equals V_s. Thus, the transformer secondary voltage is greatest on no-load.

Under loaded condition, the voltage drops across the resistive and reactive components of the secondary winding, reducing V_o. The larger the load current, larger will be the drop across the resistive and reactive components of the secondary and hence, smaller will be the value of V_o.

The percentage change in output voltage V_o, from no-load to full load is termed the voltage regulation of the transformer.

% Voltage regulation =

$$\frac{V_o\,(\text{No - load}) - V_o\,(\text{Full - load})}{V_o\,(\text{Full - load})} \times 100\%$$

Ideally, there should be no change in V_o from no-load to full-load, (i.e., regulation = 0%). For best possible performance, the transformer should have the lowest possible percentage regulation.

In some text books, the regulation discussed above is termed as "% Regulation-Up" some books also use, the term "% Regulation-Down" given by,

$$\text{\% voltage regulation down} = \frac{V_{o\,(NL)} - V_{o\,(FL)}}{V_{o\,(NL)}}$$

For example, if a transformer has an output of 13 V when on no-load and has an output of 11.8 V when on its rated resistive load, the regulation of the transformer is,

$$\text{\% Voltage regulation} = \frac{V_{o(NL)} - V_{o(FL)}}{V_{o(FL)}} \times 100\%$$

$$= \frac{13 - 11.8}{11.8} \times 100\% = 10\%$$

Finding regulation from OC and SC test results

$$\text{Voltage regulation} = \frac{V_{o(NL)} - V_{o(FL)}}{V_{o(FL)}} \times 100\ \%$$

$V_{o(NL)}$ is the secondary voltage in test obtained from OC test.

$V_{o(FL)}$ is the secondary voltage under rated full load.

$V_{o(FL)}$ can be calculated knowing turns ratios and the data obtained in SC test as follows;

$$V_{o(FL)} = V_{o(FL)} \times \frac{N_s}{N_p}$$

where, $V_{p(FL)} = V_{p(NL)} - V_{i(SC)}$

where, $V_{i(SC)}$ is the voltage applied to primary at full load in SC test.

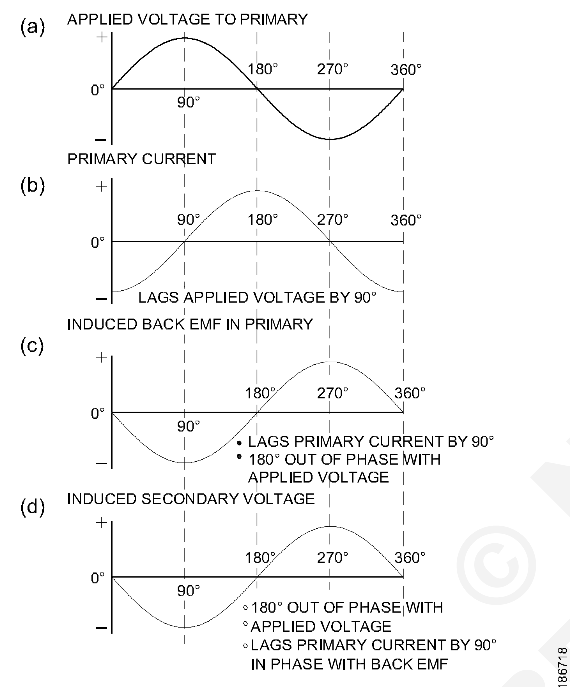
Phase relationship between primary and secondary

With Open secondary winding

For ease of understanding the phase relation ship between voltages and currents in primary and secondary of a transformer, consider a transformer having an open secondary. Referring to Fig 8, with open secondary, the primary winding works similar to that of an inductor.

This means that,

Fig 8



PHASE RELATIONSHIPS IN TRANSFORMER WITH OPEN SECONDARY

– **the primary current lags behind the applied voltage V_i by 90°** as shown in Fig 8b.

– From Lenzs' law the back-emf produced in the primary, which opposes the cause, therefore lags behind the primary current by 90° as shown in Fig 8c.

The voltage induced in secondary is maximum when the primary back-emf is maximum. That means,

– the secondary voltage lags behind the primary current by 90 degrees and hence **the secondary voltage(V_s) is 180° out of phase with the primary voltage.**

Fig 9 shows a combined illustration of the phase relationship between primary and secondary.

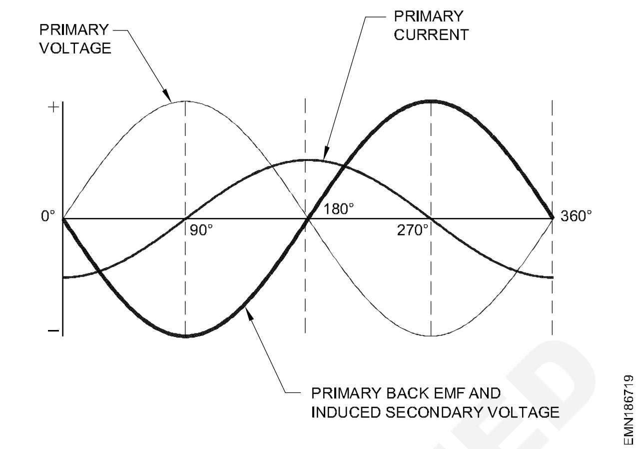
With loaded secondary

When a load is connected to the secondary of a transformer, current flows in the secondary. As in any inductance,

– **the current through the secondary winding lags behind the secondary voltage** that produces it **by 90 degrees**.

Since the secondary voltage lags behind the primary current by 90°, and since the secondary current lags behind the secondary voltage by 90°,

Fig 9



– **the secondary current is 180° out of phase with primary current**.

As the secondary current changes, it generates its own magnetic field, whose flux lines oppose those of the magnetic field created by the primary current. This reduces the strength of the primary magnetic field. As a result, less back-emf is generated in the primary. With less back-emf to oppose the applied voltage, the primary current increases. The amount of increase in primary current is directly proportional to the amount of increase in secondary current. Thus, **when secondary current in a transformer increases, the primary current automatically also increases.** And when secondary current decreases, the primary current also decreases.

Applying rated primary voltage, if the secondary of a transformer is shorted, excessive current will flow in the primary as well as in the secondary. This excessive current will not only burn out the transformer, but there is a possibility that the source supplying power to the primary would also be damaged.

The power in a DC circuit can be calculated by using the formula.

- P = E x I watts

- P = E^2/R watts.

The use of the above formulae in AC circuits will give true power only if the circuit contains pure resistance. Note that the effect of reactance is present in AC circuits.

Power in AC circuit: There are three types of power in AC circuits.

- Active power (True power)

- Reactive power

- Apparent power

Active power (true power): The calculation of active power in an AC circuit differs from that in a direct current circuit. The active power to be measured is the product of V x I x Cos θ where Cosθ is the power factor (cosine of the phase angle between current and voltage). This indicates that with a load which is not purely resistive and where the current and voltage are not in phase, only that part of the current which is in phase with the voltage will produce power. This can be measured with a wattmeter.

Reactive power: With the reactive power (wattless power)

$P_q = V \times I \times \sin\theta$

only that part of the current which is 90° out of phase (90° phase shift) with the voltage is used in this case. Capacitors and inductors, on the other hand, alternatively store energy and return it to the source. Such transferred power is called reactive power measured in volt/ampere reactive or vars. Unlike true power, reactive power can do no useful work.

Apparent power: The apparent power, $P_a = V \times I$.

The measurement can be made in the same way as for direct current with a voltmeter and ammeter.

It is simply the product of the total applied voltage and the total circuit current and until it is volt-ampere (VA).

The power triangle: A power triangle identifies three different types of power in AC circuits.

- True power in watts (P)

- Reactive power in vars (P_q)

- Apparent power VA (P_a)

The relationship among the three types of power can be obtained by referring to the power triangle. (Fig 12)

Therefore

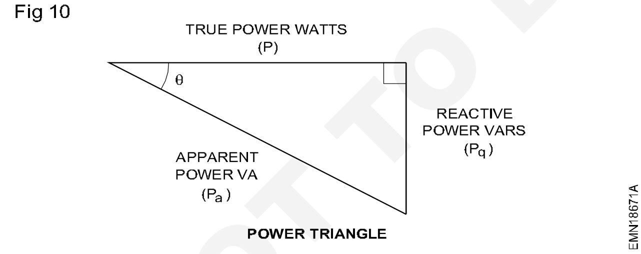
$P_a^2 = P^2 + P_q^2$ Volt- amperes (VA)

where 'P_a' is the apparent power in volt-ampere (VA)

'P' is the true power in watts (W)

P_q is the reative power in volt-amperes reactive. (VAR)

Fig 10



POWER TRIANGLE

Power factor : The ratio of the true power delivered to an AC circuit compared to the apparent power that the source must supply is called the power factor of the load. If we examine any power triangle (Fig 10), the ratio of the true power to the apparent power is the cosine of the angle q.

$$\text{Power Factor} = V \times \frac{P}{Pa} = \cos\theta$$

From the equation, you can observe that the three powers are related and can be represented in a right angled power triangle, from which the power factor can be obtained as the ratio of true power to apparent power. For inductive loads, the power factor is called lagging to distinguish it from the leading power factor in a capactive load.

sA circuit's power factor determines how much current is necessary from the source to deliver a given true power.

A circuit with a low power factor require a magnet current than a unity power factor circuit.

Efficiency of transformers

In practice, ideal transformers cannot be made. This is because some amount of power is always wasted in transferring the power from primary to secondary. Hence, the power consumed in primary will always be higher than that available in secondary. This difference in the power between primary and secondary is lost or wasted as a result of transformer losses.

Transformers can be designed and made so that the transformer losses are minimum. *The degree to which any transformer approaches the ideal condition is called the efficiency of the transformer.* Efficiency of a transformer is generally expressed in percentage as,

$$\text{Efficiency } \eta \text{ (in \%)} = \frac{\text{Output power}}{\text{Input power}} \times 100$$

LOSSES IN TRANSFORMERS

The losses in the transformer convert some of the electrical energy into heat energy. As a thumb rule, if a transformer is heating-up while in operation, the losses in the transformer is high.

Most common types of transformer losses which always exist with almost all iron-core transformers are explained below;

1. Copper losses

Transformer windings are made of many turns of copper wire. Copper wire although a very good conductor, still has some resistance. The value of this resistance depends upon the type of material and the length of wire. As the number of turns in windings increase, the longer is the length of wire, and greater will be the resistance. When primary and secondary currents flow through the windings, due to the ohmic resistance of the windings, power(I^2R) is dissipated in the form of heat.

These I^2R losses are called *Copper losses*. Copper losses increase if the currents through primary and secondary increases. Total copper loss in a transformer is equal to;

Copper loss = $I_p^2.r_p + I_s^2r_s$

Copper losses can be minimised by using a thicker gauge copper wire, but this increases the size, weight and cost of the transformer.

2 Core losses or Iron losses

Core/Iron losses in transformer are due to two different types of losses namely;

i Hysteresis loss

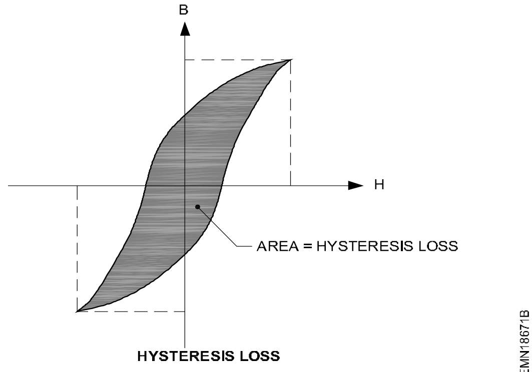
ii Eddy current loss

i Hysteresis loss

The magnetic field in the iron-core of a transformer undergoes a complete reversal 50 times each second for a mains-supply frequency of 50Hz. Every time the polarity of the supply reverses, the molecules of iron with its N-S poles change its direction, such that the direction of magnetic field reverses.

Energy has to be supplied to the molecules of the iron core to make them catch-up with the new direction of magnetic field. This turning around of molecules, or reversing the magnetism of iron core, consumes energy in the form of heat. This loss of energy, appearing in the form of heat, is proportional to the area of the B-H curve or Hysteresis loop of the core material as shown in Fig 11.

Fig 11



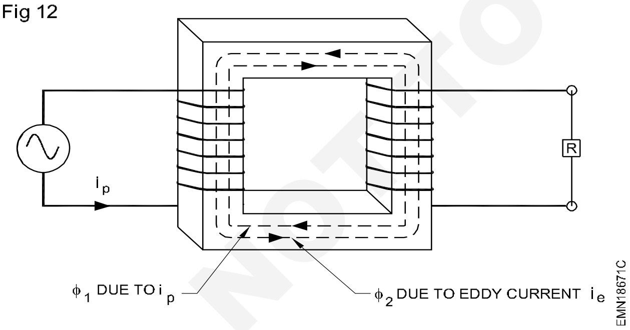
This loss of energy in the primary of the transformer in reversing the magnetism of the iron core is called *hysteresis loss* of the transformer.

It should be noted that air core transformer will not have hysteresis loss as air core transformers do not use magnetic core material.

ii) Eddy current loss

In iron-core transformers, the core material is a conducting material. So, the changing magnetic field of transformer induces a voltage in the core. This induced voltage in the core cause small current to circulate within the core. This current is called *eddy current*.

Fig 12



The induced eddy current is large if the resistance of the core material is small. Due to this circulating eddy currents and the resistance of the core material, power loss occurs in the form of heat as shown in Fig 12.

In addition, the induced eddy currents set-up an opposing flux ($ø_2$) in the core as shown in Fig 12. This results in more primary current trying to maintain the magnetic field in the core. This further increases the eddy current and hence the losses due to it.

This loss of power in a transformer due to eddy current in the transformer core is referred to as *eddy current loss*.

Eddy current loss in a transformer core can be reduced by making the core, into thin flat sections. These thin flat sections are called *laminations*.

Since these laminations have very small cross-sectional areas, the resistance offered to the setting up eddy current is greatly increased and hence the loss due to it is also reduced.

Such laminations, are stacked together.These laminations are insulated from each other by means of an insulation coating, generally shellac. Due to the insulation between laminations, the eddy currents can only flow in individual laminations. Hence the overall eddy current loss of the transformer is greatly reduced.

The power loss due to eddy currents is directly proportional to,

a the frequency of current.

b the magnitude of current.

If iron-core transformers are used at high frequencies, the eddy current losses become high. Hence iron-core transformers are not preferred in high frequency applications.

It should be noted that air core transformer will not have any eddy current loss as they do not have core material in which the eddy current can flow.

Other losses in transformers

In addition to *copper losses* and *iron losses*, transformers have two more types of losses. They are:

1 Loss due to flux leakage

2 Core saturation loss

Loss due to flux leakage

All the flux lines produced by the primary and secondary windings does not travel through the iron core. Some of the magnetic lines leak from the windings and go out into space. These leaked magnetic lines cannot do useful work. This leakage of the flux lines represents wasted energy, reducing the efficiency of the transformer.

Loss due to core saturation

When the current in the primary winding of an iron-core transformer increases, the flux lines generated follow a path through the core to the secondary winding, and back through the core to the primary winding, As the primary current first begins to increase, the number of flux lines in the core increases rapidly. Additional increases in primary current will produce only a few additional flux lines less than what it should have produced. The core is then said to be saturated. Any further increase in primary current after core saturation, results in wasted power.

Summing the different types of losses in a transformer, the total loss is given by,

Total transformer loss = Copper losses(primary + secondary) + Iron losses

(Hysteresis + eddy current) +

Flux leakage loss + Core saturation loss.

Compared with the other two losses, the flux leakage loss and the core saturation loss are negligible. Also these two losses can be greatly reduced by good transformer design and safe current level operation. Hence, the total losses that occur in a transformer can be found after knowing its copper losses and iron losses.

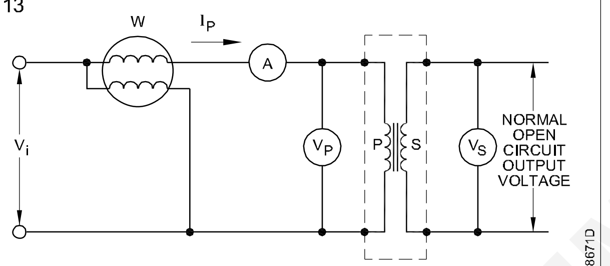
Measuring transformer losses

To determine losses in a transformer, its turns ratio and efficiency, two simple tests are conducted. These tests are, the *no-load test* and the *full-load test*.

No-load test or open circuit test (O-C test)

Fig 13 shows the circuit arrangement for O-C test on a transformer.

Fig 13



OPEN - CIRCUIT TEST ON A TRANSFORMER

The AC input voltage (V_i) is set at a rated primary voltage. The input power (P_i) is measured by the wattmeter (W). The input current (I_p) is measured by ammeter.

The open-circuit secondary voltage (V_s) is measured by voltmeter.

Since the secondary is open there is no current in secondary.

As the transformer secondary is open-circuited(I_s=0), the primary current (I_p) is very small. Since I_p is very small, the voltage drops across the ammeter and wattmeter can be neglected. So the input voltage (V_i) can be taken as primary voltage (V_p). Therefore, the ratio of the two voltmeter readings gives turns ratio of the transformer.

$$\text{Turns ratio of transformer} = \frac{N_p}{N_s} = \frac{V_p}{V_s}.$$

The input power (P_i) measured by the wattmeter (W) gives the total transformer *core losses* because with very small primary current and zero secondary current the copper losses in the windings are negligible and hence can be taken as zero.

Total losses in a transformer = Copper loss + Iron loss

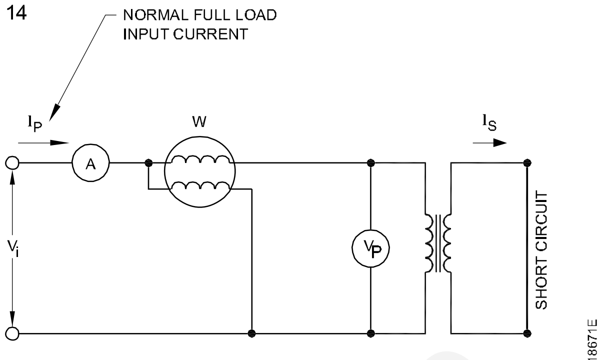
= 0 + Iron loss

With copper loss being zero, the input power measured on the wattmeter(W) is the total transformer Core loss or Iron loss (W_i).

Full load test or short circuit test (S-C test)

Fig 14 shows the circuit arrangement for S-C test on a given transformer.

Fig 14



SHORT - CIRCUIT TEST ON A TRANSFORMER

With the secondary terminals shorted, the input voltage (V_i) is increased slowly from zero till the ammeter in the primary circuit indicates rated full-load primary current, I_p. When this occurs, the rated full load secondary current I_s will be circulating in the secondary winding.

Because the secondary terminals are shorted, the voltage required at primary, V_p to produce full-load primary and secondary current is just around 3% of the rated input voltage (V_i).

In this condition, the wattmeter measuring input power (P_i) indicates the full-load copper losses for the reasons given below;

- With a low level of input voltage (3% of rated), core flux is minimum. Hence the core losses are so small that they can be neglected and taken as zero.
- Since the winding, both primary and secondary are carrying rated full-load currents, the input is supplying the rated full-load copper losses only.

Total losses = Copper loss + Iron loss

Total losses = Copper loss + 0 + Iron loss

With Iron loss being zero, the input power measured(W_c) on the wattmeter is the total transformer copper loss at rated full-load current.

Using the results of the SC test, the phase angle difference (ø) between the current and the voltage can be determined as given below;

$$\text{Power factor}, \cos\theta = \frac{\text{True power}}{\text{Apparent power}}$$

Rectifiiers

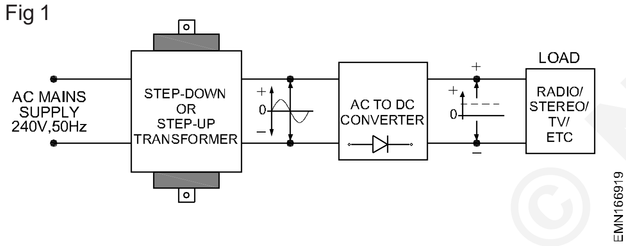
Objectives : At the end of this lesson you shall be able to
- **describe working of half wave, full wave & bridge rectifier**
- **describe ripple frequency, R.C filter, inductor fitter and L.C fitters.**

Rectifier

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.

Fig 1

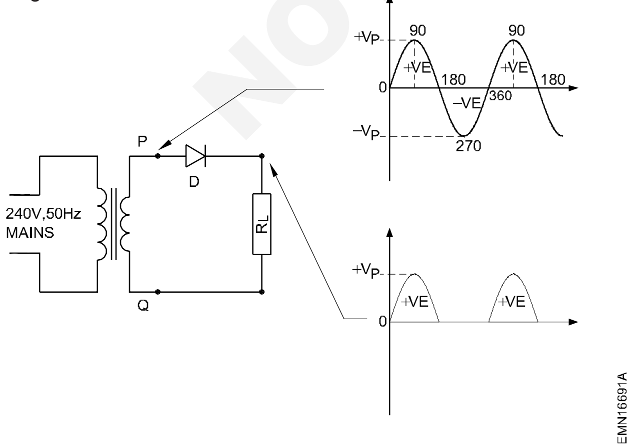


The transformer will step-down or step-up the mains AC to the required level. The stepped-up or stepped-down AC from the output of the transformer is then converted to DC using diodes making use of their unique unidirectional property.

Half wave rectifier

The simplest form of AC to DC converter is obtained by using one diode. such an AC to DC converter is known as half-wave rectifier as shown in Fig 2.

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 10, 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,

$V_{rms} = 0.707\ V_{peak}$ ....[1]

conversely,

$$V_{peak} = \frac{V_{rms}}{0.707} = \sqrt{2}\ V_{rms}$$

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 a 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.

2 Hence current flows from anode to cathode, through load R_L to secondary of transformer as shown in Fig 11b. The IR_L drop across load resistor R_L is the DC voltage V_{dc} with the polarity as shown in Fig 3b.

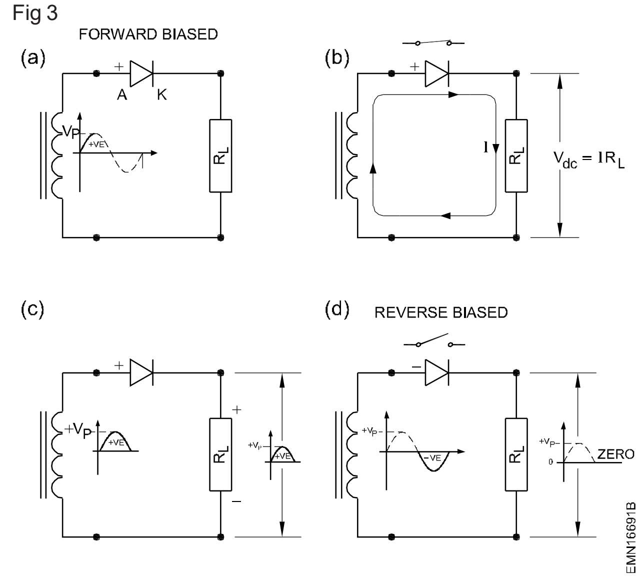
3 When the +ve half cycle of the input sinusoidal is completed, the voltage across the R_L will be a positive half sine wave as shown in Fig 3c. The peak of rectified voltage is also equal to the peak of the input AC voltage.

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



As can be seen from Fig 2, the output of the half-wave rectifier is always a +ve voltage (DC) although it is pulsating. In other words, the output is either positive (during +ve half cycle of the AC input) or zero (during -ve half cycle of AC input) but never negative. Hence, the output of a rectifier is a pulsating +ve DC voltage.

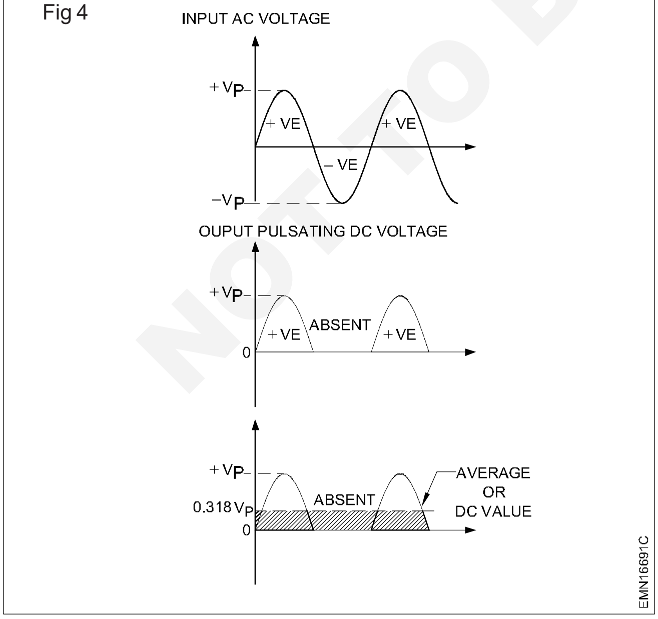
The circuit at Fig 2 is known as a half-wave rectifier as the rectification is done by the circuit only during one half cycle of the input AC signal.

Calculating output DC level in half-wave rectifiers

Two 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 whose peak voltage is equal to the peak value of the +ve half cycle of the AC input as shown in Fig 4. This can be checked using an oscilloscope.

Fig 4



The small forward voltage drop of the diode (0.7 for Si) when forward biased is ignored for simplicity in understanding.

– the pulsating signal level is zero when the input AC is in the –ve half cycle as shown in Fig 12.

Hence, when a DC voltmeter is connected across the load resistor R_L, the meter reads 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,

$V_{average}$ or $V_{dc} = 0.318\ V_P$ ....[2]

Example: If the total secondary voltage of the transformer (V_S) in Fig 2 is 24 V_{rms} (measured by AC meter), the output V_{dc} will be,

From ...1, $V_p = \sqrt{2}\ V_{rms}$

From ...2, $V_{dc} = (0.318)\ V_p = 0.45\ V_{S(rms)}$

Therefore, for a half-wave rectifier the level of output DC is given by,

$V_{dc} = 0.45\ V_{S(rms)}$ .....[3]

Where $V_{S(rms)}$ is the input rms AC voltage.

In the example considered above, the output DC voltage at Fig 10 will be,

$V_{dc} = 0.45 \times V_{S(rms)} = 0.45 \times 24 = 10.8$ volts.

Ripple frequency

From Fig 4 it is evident that the frequency of the rectified pulsating DC is same as the frequency of the input AC signal. This is true for all half-wave rectifiers.

Peak inverse voltage

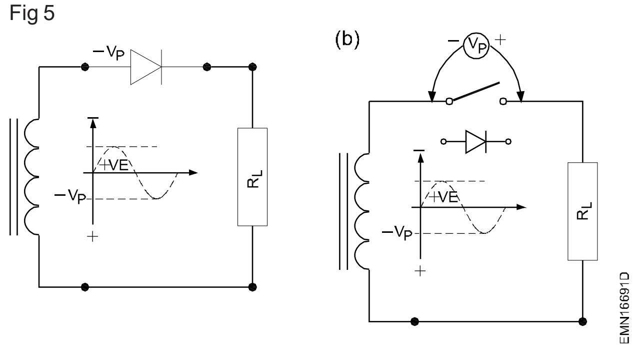
Fig 5a shows the half-wave rectifier at the instant the secondary voltage is at its maximum negative peak.

In this condition, since the diode is reverse biased, it behaves as an open switch as shown in Fig 5b. Since the diode is reverse biased, 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 $V_{S(peak)}$. Since, the -ve peak voltage and +ve peak voltage in a sinusoidal wave is same in magnitude, the peak inverse voltage (PIV) across the diode in a half wave rectifier can be taken as a $V_{S(peak)}$.

In the example considered earlier, the PIV across the diode will be,

$$V_{s(peak)} = \frac{V_{s(rms)}}{0.707} = \frac{24}{0.707} = 33.9 \approx 34 \text{ volts.}$$

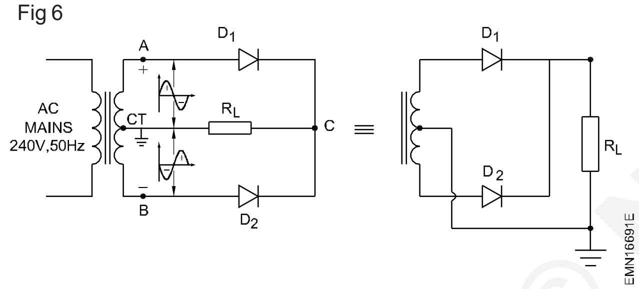
Fig 5



To avoid break down of the diode used, the PIV appearing across the diode of the designed HW rectifier must be less than the PIV rating of the diode. For instance, in the above example to avoid break down of the diode, the PIV rating of the diode should be greater than 34 volts.

Two diode full wave 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 $V_{S(peak)}$). 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) → D_1 → R_L → 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) → D_2 → R_L → 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 7

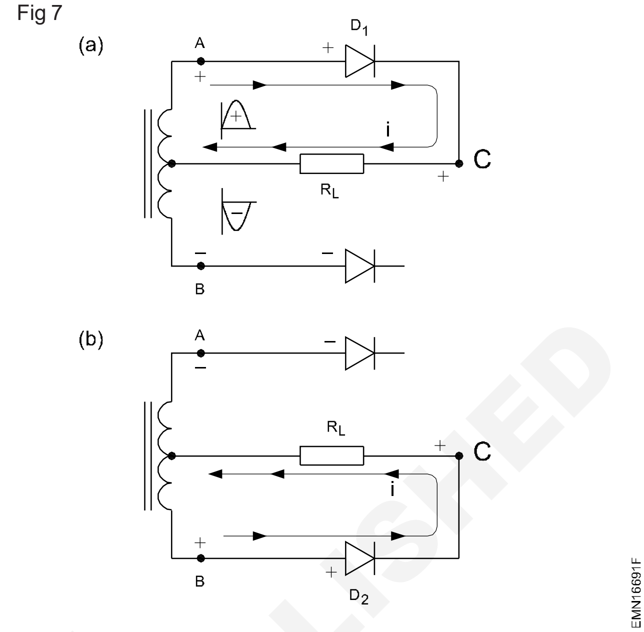
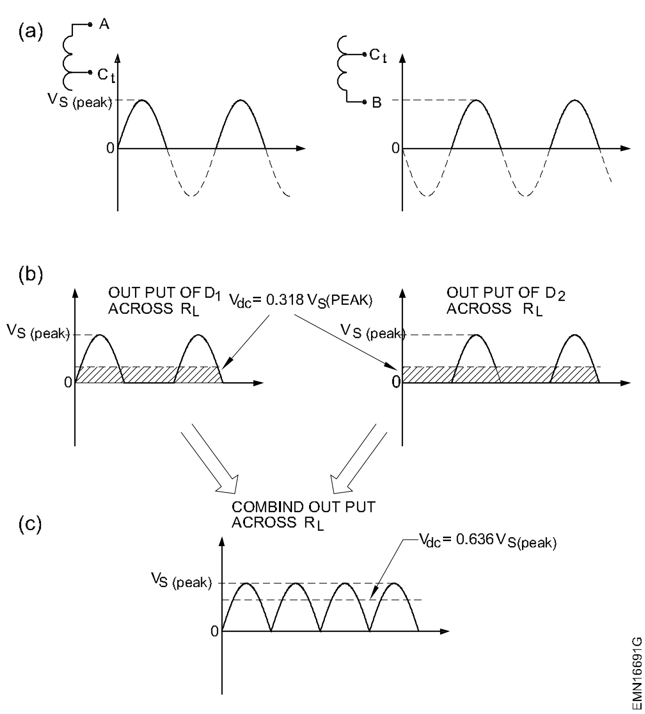


Fig 8 shows the input and output wave-forms of a fullwave rectifier. As can be seen from Fig 8, the rectifier works both in the positive and negative half cycles of the AC input to produce a DC output across the load resistor R_L. Although only one diode conducts at a time, the outputs are combined in R_L. Hence, fullwave rectifier provides double the DC current to the load compared to that of a half-wave rectifier.

Fig 8



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

Since a full wave rectifier is nothing but a combination of two half-wave rectifiers, the average or DC value of a fullwave rectifier is naturally twice the output of a half-wave rectifier driven by the same secondary voltage.

From Fig 8 it is evident that the average or DC value of a fullwave rectified output is

$V_{dc} = 0.318\ V_{S(peak)} + 0.318\ V_{S(peak)}$

$V_{dc} = 0.636\ V_{S(peak)}$

where, $V_{S(peak)}$ is the equal peak voltage between the centre-tap and any one end A or B of the transformer secondary.

In terms of $V_{S(rms)}$, V_{dc} of a fullwave rectifier is given by,

$$V_{S(rms)} = 0.707\ V_{S(peak)}$$

Therefore, $$V_{dc} = 0.636 \cdot \frac{V_{s(rms)}}{0.707}$$

$$= 0.9\ V_{S(rms)}$$

Example: Suppose the secondary voltage of the transformer is $24\text{-}0\text{-}24_{V(rms)}$, the DC output voltage of a full wave rectifier using this transformer will be,

For a two diode fullwave rectifier

$V_{dc} = 0.9\ V_{S(rms)}$

Therefore, in the given example,

$V_{dc} = 0.9 \times V_{S(rms)} = 0.9 \times 24 = 21.6$ volts.

Ripple frequency in a full wave rectifier: From Fig 16c it can be seen that two cycles of output occur for each input cycle of AC voltage. This is because, the full input voltage. As a result, the output of a full wave rectifier has a frequency double the input AC frequency. If mains AC is used as input to a fullwave rectifier, since mains frequency is 50 Hz, the output frequency of the pulsating DC will be 100 Hz.

Peak inverse voltage: Fig 9 shows the fullwave rectifier at the instant the secondary voltage reaches its maximum positive value.

Applying Kirchhoff's law around the outside loop, we get,

$2V_{s(peak)}$ – Reverse voltage (PIV) across D_2 + Forward voltage across D_1 = 0

Neglecting the small forward voltage across D_1 we have,

$2V_{s(peak)}$ – PIV across $D_2 + 0 = 0$

or PIV across $D_2 = 2V_{s(peak)}$

From the above it can be seen that each diode in a fullwave rectifier must have a PIV rating greater than the peak value of the full secondary voltage. ($2V_{s(peak)}$)

In the example considered earlier, the PIV of diodes should be greater than 34V.

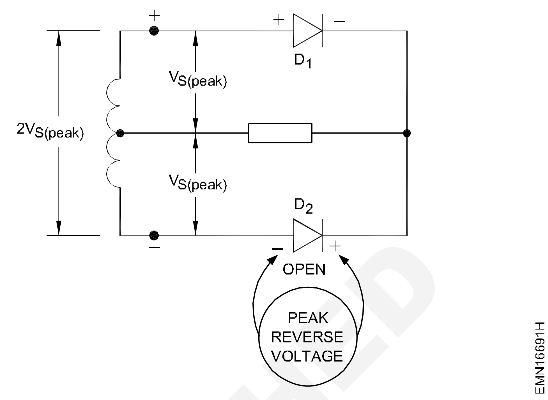
Current rating of diodes in a fullwave rectifier

If the load, R_L connected in the fullwave rectifier is, say 10Ω, the DC current through it will be,

$$I_{dc} = \frac{V_{dc}}{10\Omega}.$$

In the example considered above, V_{dc} = 21.6 volts.

Fig 9



Therefore,

$$I_{dc} = \frac{21.6}{10} = 2.16 \text{ amps.}$$

It is interesting to note this current I dc is shared by the two diodes D_1 and D_2. This is because each diode conducts only for one half cycle. Therefore, the DC current through each diode is half the total DC load current I_{dc}. Hence, the maximum current through each diode with 10Ω load will be 2.16/2 = 1.08 amps. From this it follows that the current rating ($I_{f(max)}$) of each diode need only be half the maximum/ rated load current.

In a halfwave rectifier since there is only one diode, the current rating of the diode used should be the maximum current through the load unlike in the case of a fullwave rectifier in which the current rating of the diodes used is only half the maximum current through the load.

Example: In a two diode fullwave rectifier, with a load current requirement of 1.8 amps, what should be the current ratings of the diodes used?

Since it is a two diode fullwave rectifier, the current rating of each diode should be 1/2 the total load current.

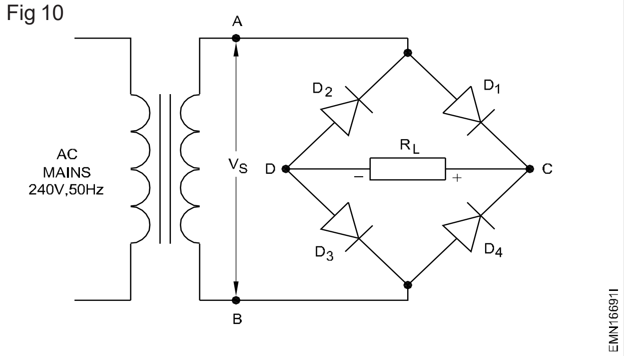
Therefore, $I_{f(max)}$ of diodes should be 1.8 amps/2 = 0.9 amps.

It is fine if a diode of 1 amp current rating is used for this rectifier circuit.

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 10. In Fig 10, 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 10, the bridge rectifier does not need a centre-tapped transformer. Also, all the secondary voltage is used for rectification at any given time.

Fig 10

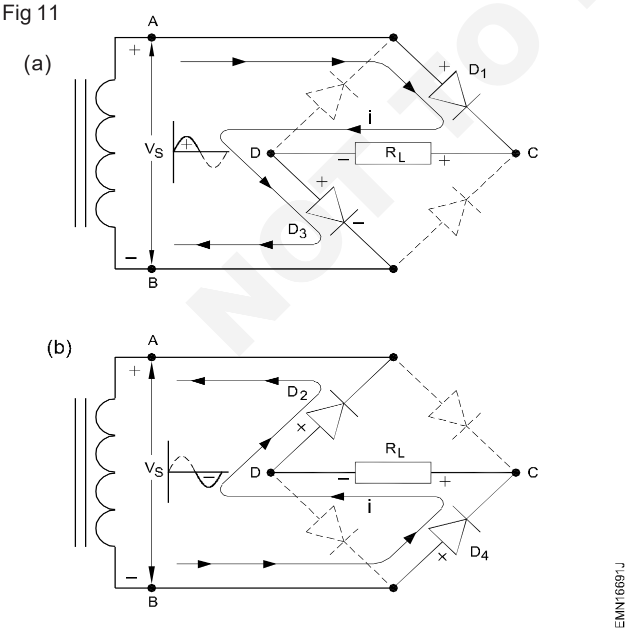


The operation of a bridge rectifier can be summarized in the following steps;

- When end A of the transformer secondary is +ve, as shown in Fig 11a, 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 19b. 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: The 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.

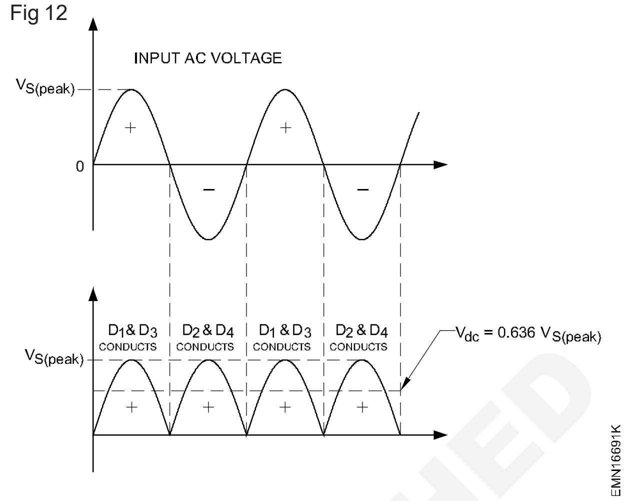
Fig 11



Output DC level in a bridge rectifier

Fig 12 shows the input AC and the output pulsating DC wave-form of a bridge rectifier.

Fig 12



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.

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.

Example: In Fig 11, if the transformer secondary voltage $V_{S(rms)}$ is 24 volts, the rectified DC voltage V_{dc} across the load R_L will be,

From equation ....2, V_{dc} for a bridge rectifier is given by,

$$V_{dc} = 0.9\ V_{S(rms)}$$

In the given example, $V_{S(rms)}$ = 24 volts

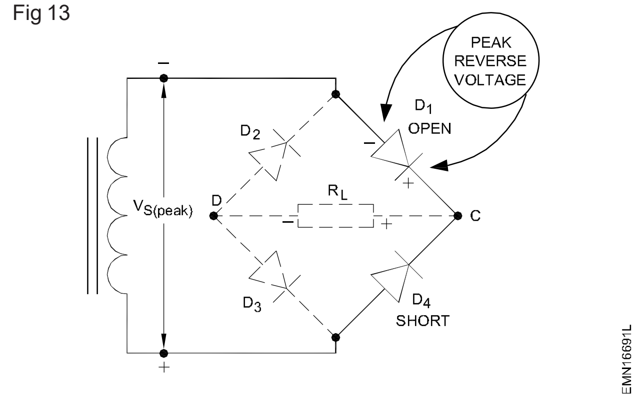
Therefore, $V_{dc} = 0.9 \times 24 = 21.6$ volts

NOTE: Using the same transformer, a two-diode fullwave rectifier would have given only 10.8 volts which is half of that of a bridge rectifier output.

Ripple frequency - Bridge rectifier: The pulsating DC output of a bridge is similar to the two diode fullwave. Hence, as in a two diode fullwave rectifier, the output ripple frequency of the bridge rectifier is also twice the input AC frequency.

Peak inverse voltage - Bridge rectifier: Fig 13 shows a bridge rectifier at the instant the secondary voltage has reached its maximum value.

Fig 13



Diode D4 is ideally short (as it is conducting) and D_1 is ideally open. Summing the voltages around the outside loop and applying Kirchhoff's law,

$V_{S(peak)}$ – PIV across D_1 + 0 = 0

or PIV across D_1 = $V_{S(peak)}$

Therefore, the peak inverse voltage across D_4 is equal to the peak secondary voltage $V_{S(peak)}$.

In a similar way, the peak inverse voltage across each diode will be equal to the peak secondary voltage $V_{S(peak)}$ of the transformer secondary. Hence the PIV ratings of the diodes used should be greater than $V_{S(peak)}$.

Example: In Fig 13, if the transformer secondary voltage $V_{S(rms)}$ is 24 volts, find the minimum PIV of diodes used.

In a bridge rectifier PIV across the diodes is same and is equal to $V_{S(peak)}$.

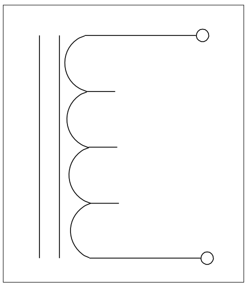
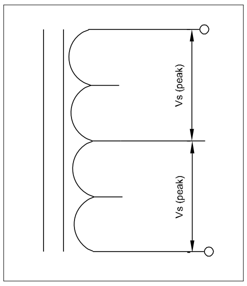
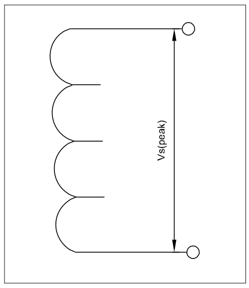
Therefore, in the given example,

$$PIV = V_{S(peak)} = \frac{V_{S(rms)}}{0.707} = \frac{24}{0.707} = 34 \text{ volts.}$$

Current rating of diodes in bridge rectifiers: As in the case of a two diode fullwave rectifier even in a bridge rectifier shown in Fig 11, diode pairs D_1, D_3 and D_2, D_4 carry half the total load current I. This is because each diode pair is conducting only during one half of the AC input cycle.

The only disadvantage of bridge rectifiers, if it is treated as a disadvantage, is that, this circuit uses four diodes for fullwave rectification instead of two as in two-diode fullwave rectifier. But this disadvantage is compensated by the simple transformer requirement of the bridge rectifier and higher DC output level. Hence, bridge rectifiers are the most popular AC to DC rectifiers for most applications.

A 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}	$2f_{input}$	$2f_{input}$

Efficiency of the Rectifier

Rectifier efficiency is defined as the ratio of DC power to the applied input AC power.

Rectifier efficiency, η = DC output power/input AC power

$I_{dc}=I_m/\pi$

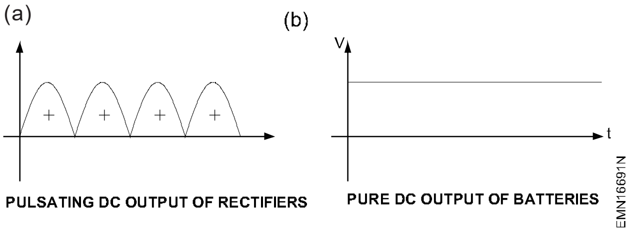
The DC output is given by : $P_{dc}= I^2_{dc} \times R_L = (I_m/\pi)^2 \times R_L$

The AC input power is given by: $P_{ac} = I^2_{rms} \times (r_f + R_L)$, where r_f is diode resistance.

Ripple filters

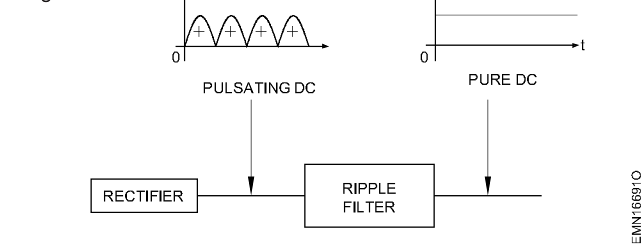
The output of rectifiers is a pulsating DC voltage as in Fig 15 a and not a pure DC voltage like the output of cells or a battery as shown in Fig 15b.

Fig 15



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 23b. 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 16.

Fig 16



Capacitor input filters: The most important component used in any ripple filter circuit is the capacitor. Recall capacitors store electrical energy and release it when required. This property of a capacitor is made use of in smoothing the pulsating output of rectifiers.

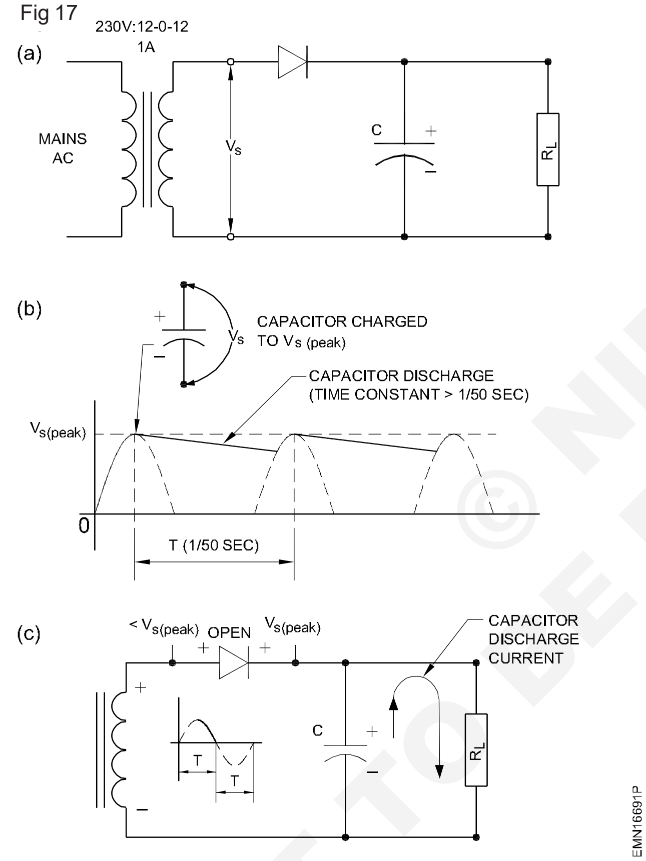
Filtering output of Half-wave rectifiers

Fig 17a 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 $V_{S(peak)}$ as shown in Fig 17b.

As shown in Fig 17b, when the input V_S just passes the positive peak, the diode stops conducting. This is because, the capacitor has $V_{S(peak)}$ volts across it with the polarity shown in Fig 17c. When V_S passes its +ve peak, the voltage at the anode of diode is slightly less than $V_{S(peak)}$. Hence, the diode is reverse biased and behaves like a open switch.

Fig 17



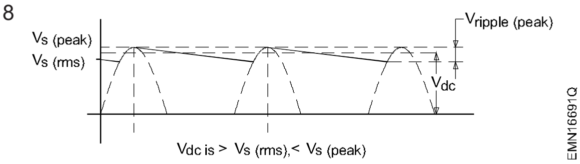
With the diode open, the capacitor discharges through the load resistance R_L. By deliberate design, the discharging time constant (product of R_L and C) is made much greater than the period T of the input signal. Because of this, the capacitor will discharge only a small portion of its stored charge during the OFF time of the diode, as shown in Fig 25b.

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 $V_{S(peak)}$. 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 25b.

From Fig 25b, 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 $V_{S(peak)}$ and discharges only a small portion of it, the DC output of the half-wave rectifier, instead of 0.45 $V_{S(rms)}$ is only slightly less than $V_{S(peak)}$ as shown in Fig 18.

Fig 18



From Fig 18, the exact value of DC voltage and ripple voltage can be calculated as given below;

$$V_{dc(HW)} = V_{S(peak)} - \frac{V_{rip\,(p-p)}}{2} \qquad .....[1]$$

Example 1: If $V_{S(peak)}$ = 34 V and $V_{rip(p-p)}$ = 3.4 V,

then, $V_{dc} = 34V - \frac{3.4}{2} = 32.3$ Volts

Refer example given in half wave rectifier lesson. Without the capacitor the same halfwave rectifier gave only 10.8V DC. Adding just one capacitor the output has increased 3 fold for the same halfwave rectifier.

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 1

Knowing the required load current I_L, for a given value of frequency f and capacitance C, the peak-to-peak ripple voltage can be found using the formula,

$$V_{rip(p-p)} = \frac{I_L}{f_r C} \qquad .....[2]$$

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.

Method 2

Another method of expressing the ripple in the output DC is by ripple factor r, defined as,

$$\text{Ripple factor, r} = \frac{V_{r(rms)}}{V_{dc}}$$

where,

r = ripple factor(dimensionless)

$V_{r(rms)}$ = rms value of ripple voltage

$$= \frac{V_{rip(p-p)}}{2\sqrt{3}}$$

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,

$$r = \frac{1}{2\sqrt{3}\ f R_L C} \quad \text{(for halfwave)}$$

.....[3]

where,

r = the theoretical ripple factor for a half-wave

C = capacitance in μF

R_L = load resistor in ohms

f = mains supply frequency in hertz.

From equation 3 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.

These formulae are used many times while troubleshooting, analyzing, or designing a capacitor-input filter. Hence, it is worthwhile memorizing these key formulae.

Filtering output of Full wave and Bridge rectifiers: From equation 2, it is clear that another way to reduce the ripple is to increase the ripple frequency f_r. In a fullwave rectifier or bridge rectifier, the ripple frequency is double the supply frequency as shown in Fig 19. As a result of higher ripple frequency, when compared with halfwave rectifier (Fig 18), the capacitor gets charged twice as often and has only half the discharge time as shown in Fig 11. 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.

Example: In a bridge rectifier with a capacitance input filter, suppose the DC load current drawn is approximately 10 mA and the filter capacitor is 470 μF, for a line frequency of 50 Hz, the peak-to-peak ripple in the output will be,

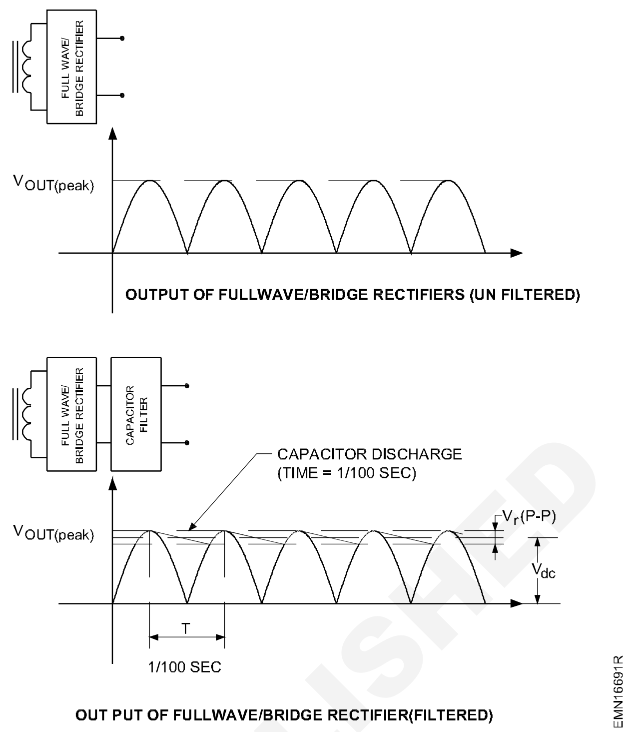
from equation (2), $V_{rip(p-p)} = \frac{I_L}{f_r C}$

Therefore,

$$V_{rip(p-p)} = \frac{10\text{mA}}{100\text{Hz} \times 470\ \mu\text{F}}$$

$$= 0.213 \text{ V}$$

Fig 19



For the same conditions in a half-wave rectifier, the ripple will be 0.426 V, which is twice as much because the ripple frequency is only 50 Hz (same as AC input frequency).

Examples If the peak voltage $V_{S(peak)}$ is 34 V, then, select a capacitor that makes the peak-to-peak ripple 10% of $V_{S(peak)}$. This means $V_{r(p-p)}$ should be around 3.4V. (Refer Example 1).

For a bridge rectifier, for a DC load current of 10mA, the value of C using 10% rule should be,

$$V_{r(p-p)} = \frac{I_L}{f_r C}$$

$$\text{or}\quad C = \frac{I_L}{f_r V_{r(p-p)}} = \frac{10\text{mA}}{100(3.4)}$$

$$= 29.4\ \mu\text{F minimum.}$$

As a standard value, use 100 μF. Recalculating $V_{r(p-p)}$,

$$V_{r(p-p)} = \frac{I_L}{f_r C} = \frac{10\text{mA}}{100 \times 100\ \mu\text{F}} = 1 \text{ Volt.}$$

With the 10 percent design rule, the DC voltage is more than 95 percent of the peak voltage which is reasonably a good design.

Assignment: Calculate value of C if the required load current is 1 Amps.

PIV rating of diodes with capacitance-input filters

Recall that the PIV across the diode in a half-wave rectifier without a filter capacitor is equal to $V_{S(peak)}$. This PIV rating changes when a filter capacitor is connected across the output of the half-wave rectifier.

Fig 20a shows a half-wave rectifier driving a capacitor-input filter. At the negative peak of the secondary voltage, the diode is reverse-biased and a peak inverse voltage appears across it. Summing up the voltages around the loop gives,

PIV across diode – $V_{S(peak}$– $V_{S(peak)}$ across C = 0

or,

PIV across diode = $2V_{S(peak)}$

From this it can be seen that, with capacitance-input filter across the diode, the PIV rating of the diode in a half-wave rectifier must be two times the peak secondary voltage $V_{S(peak)}$ or higher.

In the case of a fullwave rectifier with filter shown in Fig 20b, summing voltages around the left loop gives,

PIV – 2 $V_{S(peak)}$+ 0 = 0

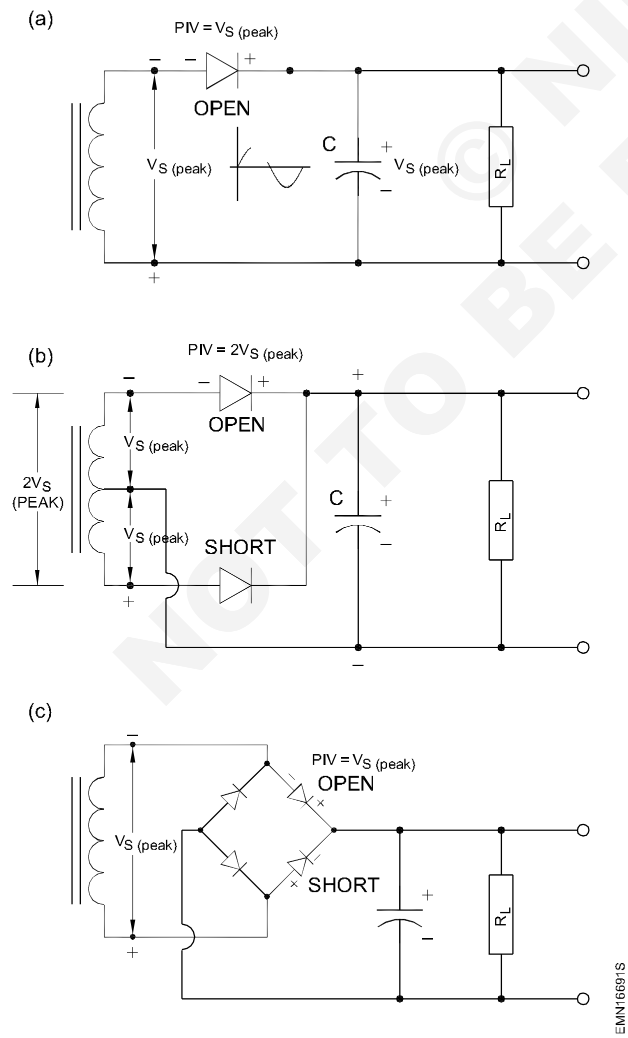
or,

PIV = 2 $V_{S(peak)}$

This means that the PIV rating of the diodes must be greater than the peak total secondary voltage($V_{S(peak)}$ + $V_{S(peak)}$). Note that this is same as in the fullwave rectifier without a filter capacitor.

In the case of a bridge rectifier circuit shown in Fig 20c, summing voltages of the outside loop gives,

Fig 20



PIV + 0 – $V_{S(peak)}$= 0

or,

PIV = $V_{S(peak)}$

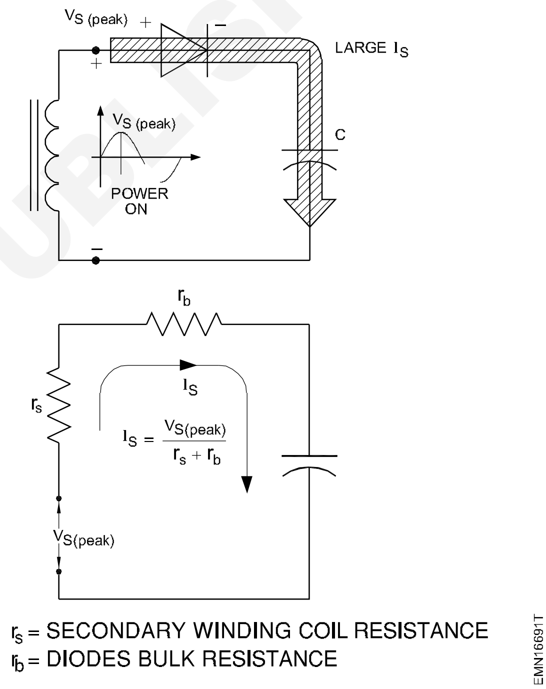
So the PIV rating of each diode in the bridge must be greater than the peak secondary voltage $V_{S(peak)}$. This is same as in a bridge rectifier without a filter capacitor.

Surge current in rectifiers with filter capacitors

In rectifiers with filter capacitors, before the input power is switched ON, the filter capacitor is uncharged. The instant the circuit is switched ON, the capacitor behaves as a short circuit. This results in a large initial charging current through the diode. This initial, sudden rush of current is called the **surge current.**

The worst case of a surge current flowing is when, the circuit is switched ON, at the very instant the secondary voltage is $V_{S(peak)}$, as shown in Fig 21. The only resistance to this rushing surge current are,

Fig 21



1 The transformer secondary winding resistance, r_s

2 The bulk resistance r_b of the diode(s).

Generally, the secondary winding resistance will be less than 1 W. The bulk resistances of diodes are given in data sheets. In general purpose diodes, r_b will be of the order of 0.2 W.

For example, if $V_{S(peak)}$ is 34 V AC and the sum of the secondary winding resistance and the diode bulk resistance is 1W + 0.2 W, then the surge current I_s would be,

$$I_s = \frac{V_{S(peak)}}{1\,\Omega + 0.2\,\Omega} = \frac{34}{1.2\,\Omega} = 28.3 \text{ amps.}$$

It is important to note that this large current is not a continuous current. This current decreases exponentially as the capacitor gets charged. However, if the capacitor is of an extremely large value, the surge current will remain at a high level for quite some time, and, hence, may damage the diode.

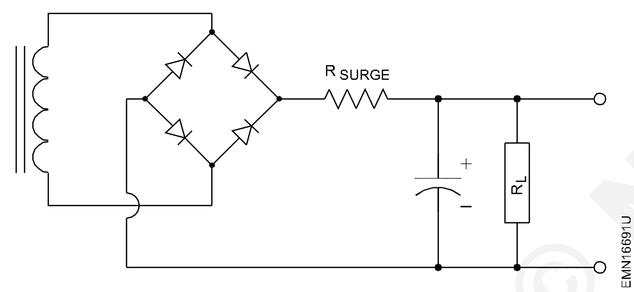
From the above, two important points are to be noted,

- The diode used must have the capability to withstand a large surge current of a short duration, generally one time period(T) of input cycle. This data is given in the diode data books.
- The value of the filter capacitor should not be excessively large as this will increase the value and duration of surge current.

Use of surge limiting resistor

In case the diode selected for a rectifier has a surge current rating less than the estimated surge current, a small resistor is included in the surge current path as shown in Fig 22. This resistor is known as surge limiting resistor or simply surge resistor.

Fig 22



This surge resistor limits the surge current because, this resistance gets added to the winding and diode bulk resistances. Using a surge resistor of a suitable value, the surge current can be restricted to any desired value.

As an example, in Fig 22, if $V_{S(peak)}$ is 34V and if a surge resistor of 4W is selected, then the surge current will be,

$$\frac{V_{S(peak)}}{\text{winding resistance} + \text{diode bulk resistance} + \text{surge resistor}}$$

$$= \frac{34}{1\Omega + 0.2\Omega + 4\Omega} = 6.5 \text{ Amps}$$

Note that the surge current has reduced from 28.3 amps to 6.5 amps by the use of a surge resistor.

When a surge resistor is used for calculating I_s, you may neglect the winding and bulk resistances, as their values are comparatively smaller.

One disadvantage in using a surge resistor is that, since it comes in series with the output, the DC voltage across the load decreases by an amount equal to the I_R drop across the surge resistor. Hence, surge resistors should not be used indiscriminately.

Filter capacitors of values less than 1000 µF usually do not produce a surge current for a long period to damage the diodes. Hence, for values of C less than 1000 µF use of surge resistors are not essential.

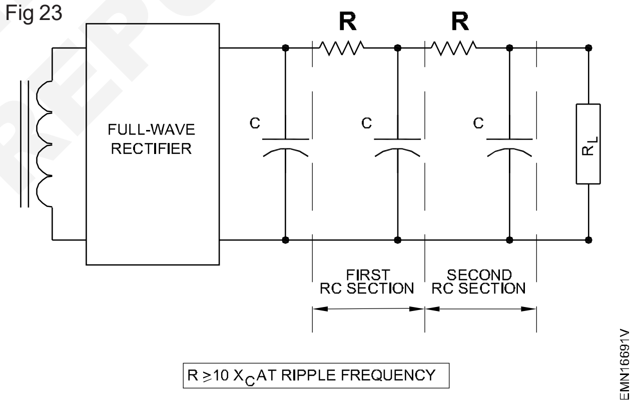
Table No.25 of the pocket table books summarizes the key information discussed so far. This table is useful for designing and troubleshooting power supplies.

RC filters

Recall that 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 31 may be connected between the filter capacitor and the load. These are known as RC 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 23, 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.

Fig 23



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.

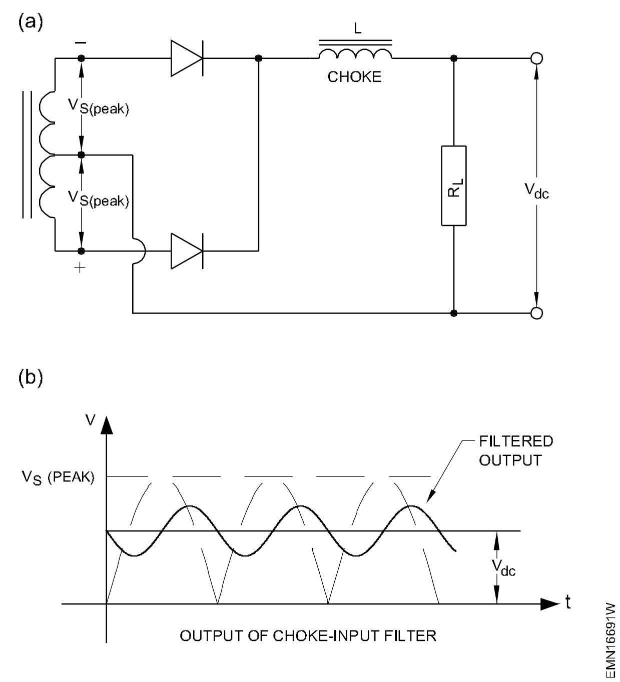
Inductor input filters

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 24a. 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 24b. Here the inductors are called Chokes as they choke the ripple.

If the coil resistance of the inductor is neglected (being very small), inductor is neglected (being very small), the DC output will be,

V_{dc} = 0.636 $V_{S(peak)}$ as in the case of capacitance filter.

Fig 24



If the resistance of the coil is considered, the DC output will be slightly less due to the I_R drop across the coil.

The ripple factor r in a full wave rectifier with inductor filter is given by,

$$r = \frac{R_L}{1618L} \quad .....[4]$$

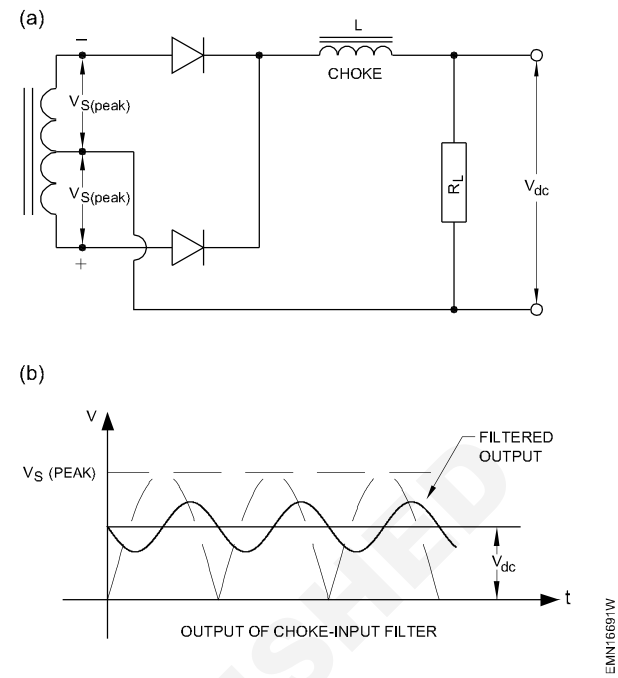
LC filters

For large load current requirements, instead of RC filters, LC filters as shown in Fig 25 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 25, 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,

Fig 25



$V_{dc} = 0.636\ V_{S(peak)}$ as in the case of a capacitor input filter.

The ripple factor, r is given by,

$$r = \frac{0.7}{LC} \quad ....[5]$$

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.

These days, LC filters are becoming obsolete because of the size and cost of the inductors. LC filters are being replaced by integrated circuit(IC) voltage regulators, active filter circuits which reduce the ripple and keep the DC voltage constant. IC regulators and active filters are discussed in detail in further lessons.

Working principle of zener diodes

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.

$$\text{\% Load regulation} = \frac{12 - 11}{12} \times 100 = 8.33\%$$

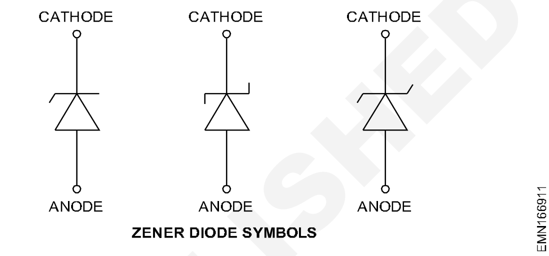
In practice the load regulation of a good power supply should be less than 0.1 %.

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.

Fig 1



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 break-down 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.

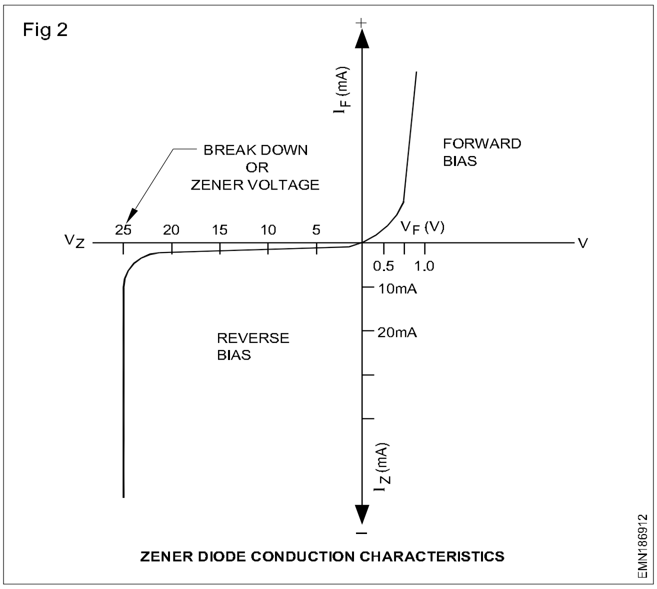
– The anode and cathode marking technique on the body is same for both zener and rectifier diodes.

– 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.

Fig 2



ZENER DIODE CONDUCTION CHARACTERISTICS

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 breakdown 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.

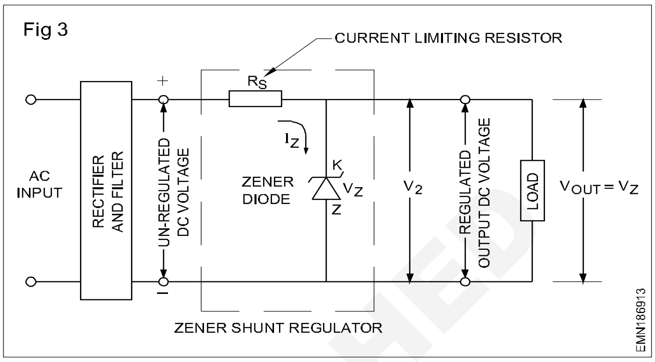
Unlike in a rectifier diode, the reverse current through the zener is not destructive. If the current is kept within the specified limits depending upon the wattage rating of the zener, using a suitable series resistance, no harm is done to the zener diode.

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.

Fig 3



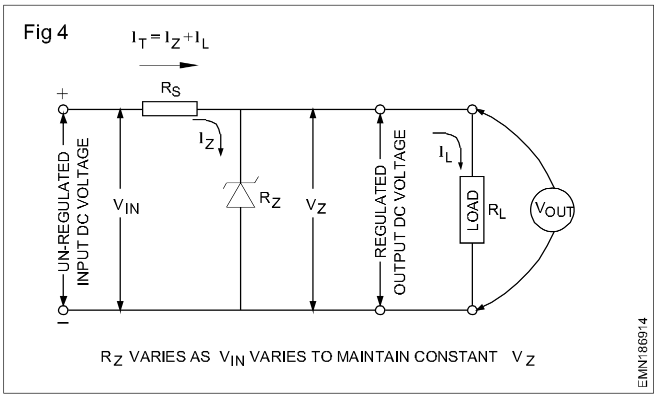
ZENER SHUNT REGULATOR

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,

Fig 4



R_Z VARIES AS V_{IN} VARIES TO MAINTAIN CONSTANT V_Z

$$I_T = I_Z + I_L$$

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 V ± 5 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.

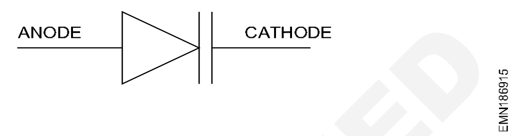
1Z 12

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.

Varactor diode or varicap diode: Varactor diode is a one kind of semiconductor microwave solid-state device and the applications of this diode mainly involve in where variable capacitance is preferred which can be accomplished by controlling voltage. These diodes are also named as varicap diodes. Even though the outcome of the variable capacitance can be showed by the normal P-N junction diodes, but these diodes are chosen for giving the desired capacitance changes as they are special types of diodes (Fig 5). Varactor diodes are specifically fabricated and optimized such that they permits a high range of changes in capacitance.

Fig 5

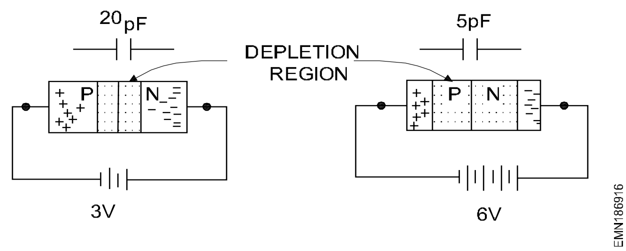


The different types of varactor diodes are available in the market such as hyperabrupt, abrupt and gallium - arsenide varactor diodes. The symbol of the varactor diode is shown in the above figure that includes a capacitor symbol at one end of the diode that signifies the characteristics of the variable capacitor of the varactor diodes.

The symbol of the varactor diodes looks like a common PN-junction diode that includes two terminals namely the cathode and the anode. And at one end this diode is inbuilt with two lines that specifies the capacitor symbol.

Working of a Varactor diode: To know the varactor diode working principle, we must know the function of capacitor and capacitance. Let us consider the capacitor that comprises of two plates aliented by an insulator as shown in the figure 6.

Fig 6



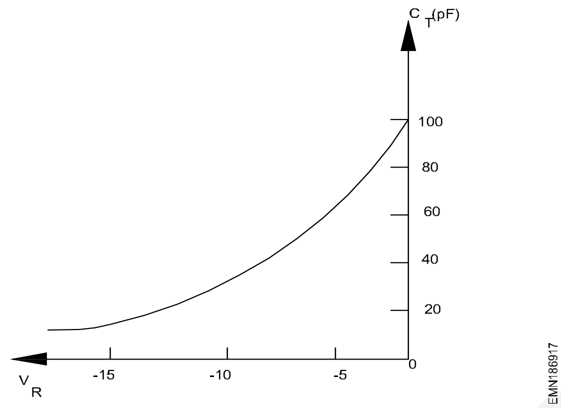
We know that, the capacitance of a capacitor is directly proportional to the region of the terminals, as the region of the terminals increases the capacitance of the capacitor increases. When the diode is in the revers biased mode, where the two regions of P-type and N-type are able to conduct and thus can be treated as two terminals. The depletion area between the P-type & N-type regions can be considered as insulating dielectric. Therefore, it is similar to the capacitor shown above.

The volume of the depletion region of the diode varies with change in reverse bias. If the reverse voltage of the diode is increased, then the size of the depletion region increases. Likewise, if the reverse voltage of the Varactor diode is decreased, then the size of the depletion region decreases.

Characteristics of varactor diode: The characteristic of varactor diode have the following:

- These diodes significantly generate less noise com pare to other diodes.
- The cost of these diodes is available at lower and more reliable also.
- These diodes are very small in size and very light weight.
- There is no useful when it is operated in forward bias.
- In reverse bias mode, varactor diode enhances the capacitance as shown in the Fig 7.

Fig 7



Applications of varactor diode: The applications of varactor diode mainly involve within the RF design area however, in this article, we are discussing about the couple of applications of varactor diodes, to illustrate how these diodes can be used in practical. The capacitor in a practical circuit can be changed with the varactor diode, but it is necessary to make sure the tune voltage necessary to set the diode capacitance. And to ensure that this diode is not influenced by the bias voltage in the circuit. By using voltage control technique in the diode ciruit, changing capacitanc can be offered.

Voltage contolled oscillators: Consider the circuit of VCO designed by using varactor diode 'D_1' as symbolized in the figure (8). The oscillator can be allowed by changing the 'D_1' diode. The capacitor C_1 is used to stop the reverse bias for the varactor diode, also neglects the diode getting short circuited through the indicator. The diode can be adjusted by applying bias through an R_1 resistor (isolating series resistor).

RF filters: The varactor diodes can be used in th RF filters to tune. In the receive front to follow the frequency of the incoming received signal which can be restricted using a control voltage. Usually, the is offered by microprcessor control through the DAC. A few of the main applications of varactor diodes can be listed below:

- These diodes can be used as frequency modulators and RF phase shifters.
- These diodes can be used as frequency multipliers in microwave receive.
- These diodes are used to change the capacitance in tank LC circuits.

Specifications of varactor diode: When choosing a varactor diode, the varactor specifications need to be carefully determined to asses whether it will meet the circuit requirements.

While there will be many varactor diode specifications that are the same as those applied to other types of diode, including signal diode, etc, there are many other varactor specifications that are crucial to the perforrnance of the varactor in any variable capacitance role.

Many of the difference varactor parameters will be detailed in the varactor specification sheet that may be accessed in the manufactures literature.

Reverse breakdown: The reverse breakdown voltage of a varactor diode is importance. The capacitance decrease with increasing reverse bias, although as voltages becomes higher the decreases in capacitance becomes smaller. However the minimum capacitance level will be determined by the maximum voltage that the device can withstand. It is also wise to choose a varactor diode that has a margin between the maximum voltage it is likely to expect, i.e. the rail voltage of the driver circuit, and the reverse breakdown voltage of the diode. By ensuring there is sufficient margin, the circuit is less likely to fail.

It is also necessary to ensure that the minimum capacitance required is achieved within the rail voltage of the driver circuit, again with a good margin as there is always some variation between devices.

Diodes typically operate with reverse bias ranging from around a couple of volts up to 20 volts or possibly higher. Some may even operate up to as much as 60 volts, although at the top end of the range comparatively little change in capacitance is seen. Also as the voltage on the diode increases. It is likely that specific supplies for the circuits driving the varactor diodes will be required.

Maximum frequency of operation

There are a number of items that limit the frequency of operation of any varactor diode. The minimum capacitance of the diode is obviously one limiting factor. If large levels of capacitance are used in a resonant circuit, this will reduce the Q.A further factor is any parasitic responses, as well as stray capacitance and inductance that may be exhibited by the device package. This means that device with low capacitance levels that may be more suitable for high frequencies will be placed in microwave type package. These and other considerations need to be taken into account when choosing a varactor diode for a new design.

As a particular varactor diode type may be available in a number of packages, it is necessary to choose the variant with the package that is most suitable for the application in view

Regulated power supply

Objectives: At the end of this lesson you shall be able to
- **explain the regulated and unregulated power supply.**

DC regulated power supply : The main purpose of a DC regulated power supply is to get a constant DC supply for electrical and electronic circuits for conducting experiments in laboratories and also to provide testing voltage for equipments like radio, TV, tape recorders, computers etc.

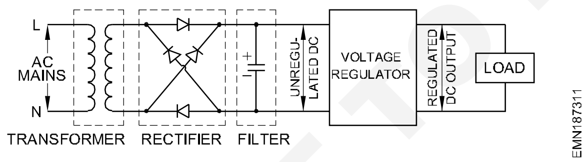
DC unregulated power supply : The most common method of obtaining DC from AC supply is to use a transformer for stepping down/up of the AC voltage and to use a rectifier circuit for converting AC supply into DC. Often capacitors/inductors are used to filter the DC output. In this type of circuits the DC output voltage changes with a change in load and is generally used in a circuit where load current is constant eg. battery charging, electroplating, communication system etc.

Types of regulated power supply : There are two basic ways of deriving a stable DC supply from an AC supply. They are the conventional way and a system using switch mode technique.

Most of the electronic equipment uses the conventional type of power supply. In this type, voltage and current regulation are used combinely.

Voltage regulated power supply: The voltage regulated power supply consists of a step down transformer, rectifier and a storage capacitor to generate an unregulated DC supply that is electrically isolated from the AC mains supply. Then this DC output voltage which is not regulated is passed through voltage regulator circuitory to get the regulated DC voltage. (Fig 1).

Fig 1



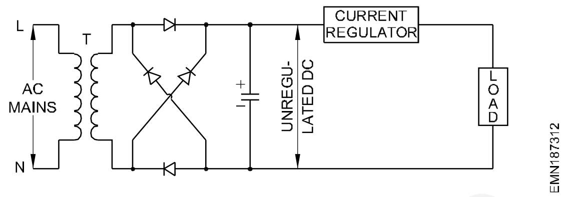
The regulator circuit parameter may consist of zener diodes, transistors or integrated circuits as discussed in Ex. 812 of 2nd year. A transistor version of a fixed voltage regulator is shown in Fig 1 of Ex.812 and a transistor version of a variable voltage regulator is shown in Fig 2 of Ex.812 of 2nd year. Please refer to them.

Current-regulated power supply : A current regulated power supply consist of an unregulated power supply similar to voltage-regulated power supply and a current limiting circuit. (Fig 2)

By suitably designing the current regulator circuit it is possible to get current regulation for a single range or a multi-range of currents.

Voltage and current regulation combined : Commercially available DC regulated power suppliers

Fig 2



provide both voltage and current regulation combined in the supply unit. (Figs 3 and Fig 4)

Fig 3

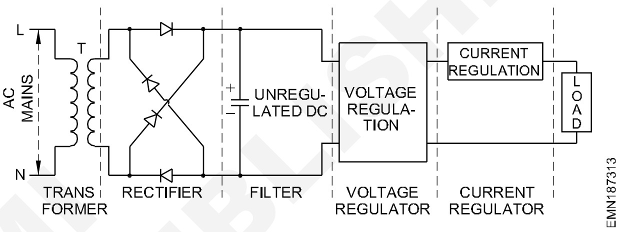
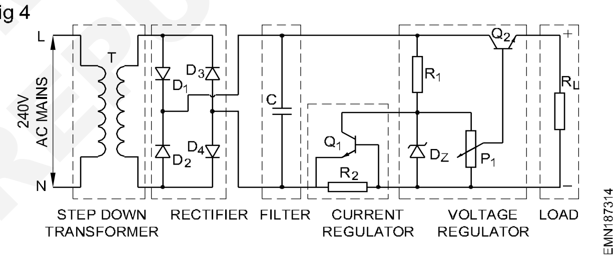


Fig 4



Circuit description : Fig 4 shows a circuit diagram of a simple voltage and current regulated power supply. The functions of circuit elements are as follows. Transformer 'T' is used for stepping down AC voltage to the required AC voltage. Full wave bridge rectifier 'D_1 to D_4' is used to rectify AC to DC voltage. A capacitor 'C' is used for filtering. The voltage across zener diode 'D_z' is used as a reference voltage source which is constant. The potentiometer 'P_1' is used for controlling the DC output voltage. Transistor Q_2 works as a voltage regulator. For a set voltage by potentiometer 'P_1' that is when there is no load, transistor Q_2 conducts less and voltage drop across collector and emitter is maximum. When the load current increases transistor 'Q_2' conducts more and the voltage drop across collector and the emitter decreases almost compensating the drop in unregulated DC output, thereby keeping the regulated output voltage constant. Transistor 'Q_2' also works as a current regulator. The conduction of transistor 'Q_1' depends upon the voltage drop across resistor 'R_2'. In turn the voltage drop across 'R_2' depends upon the resistance value of R_2 and load current ($I_L \times R_2$). When the load current increases the voltage drop across 'R_2' also increases and for a set current transistor 'Q_1' conducts resulting the base of transistor 'Q_2' to almost at negative potential reducing the output voltage. The ultimate result is the current will not increase above the set value of current but the voltage goes on decreasing for any reduction of load resistance "R_L".

TERMS USED IN SPECIFYING REGULATED POWER SUPPLIES

The regulation requirement of a regulated power supply is often associated with its application. Hence the following terms are considered while selecting a regulated power supply.

Line regulation (Source regulation) : The line regulation is also called a source regulation specifying the change in DC output voltage due to the variation in the line voltage.

$$\% \text{ Source regulation } = \frac{\begin{array}{l}\% \text{ of variation of DC output} \\ \text{voltage for a given constant load}\end{array}}{\begin{array}{l}\% \text{ of variation of ACinput} \\ \text{line voltage}\end{array}} \times 100$$

Load regulation : The load regulation is also called load effect which is defined as the change in the regulated output voltage when the load current changes from minimum to maximum.

Load regulation = No load voltage E_{NL} – Full load voltage E_{FL}

Load regulation = $E_{NL} - E_{FL}$

Load regulation is often expressed as a percentage by dividing the change in the load voltage by the no load voltage.

$$\% \text{ Load regulation } = \frac{E_{NL} - E_{FL}}{E_{NL}} \times 100$$

Ripple : The term ripple implies that the residue of AC delivered to the load as a result of imperfect rectification and filtering.

The ripple may be mentioned as AC voltage available for a given or nominal DC output voltage. In general the 'Ripple factor' is defined as the percentage ratio of the AC voltage available in the DC output.

$$\% \text{ Ripple factor } = \frac{\text{AC voltage available in DC output}}{\text{Normal DC voltage at the output}} \times 100$$

The size of the power supply unit depends upon the maximum DC output power required ie. DC voltage and DC amperes. The circuit of the regulated power supply becomes more and more sophisticated depending upon the high precision in regulation and a number of protection circuits incorporated in the equipment. The circuit may use a number of ICs transistors, controls and other components depending on the accuracy required.

Integrated circuit voltage regulators

Objectives : At the end of this lesson you shall be able to
- **state the classification of integrated circuits**
- **state the specification of I.C**
- **state the types of IC voltage regulators.**

Introduction

Electronic circuits invariably consist of a number of discrete components connected to each other in a specific way. For instance, the series regulator circuit discussed in earlier lessons, consisted of transistors, zener diodes, resistors and so on, connected in a defined way for it to function as a regulator. If all these components instead of building on a board, if they are built on a single wafer of a semiconductor crystal, then, the physical size of the circuit becomes very very small. Although small, this will do the same job as that of the circuit wired using discrete components. Such miniaturised electronic circuits produced within and upon a single crystal, usually silicon, are known as **integrated circuits** or **IC**s. Integrated circuits (ICs) can consist of thousands of active components like transistor, diodes and passive components like resistors and capacitors in some specific order such that they function in a defined way, say as voltage regulators or amplifiers or oscillators and so on.

Classification of integrated circuits

Integrated circuits may be classified in several ways. However the most popular classifications is as follows:

1 Based on its type of circuitry

(a) Analog ICs - Example: amplifier ICs, voltage regulator ICs etc.

(b) Digital ICs - Example: Digital gates, flip-flops, adders etc.

2 Based on the number of transistors built into IC

(a) Small scale integration (SSI) - consists of 1 to 10 transistors.

(b) Medium scale integration (MSI) - consists of 10 to 100 transistors.

(c) Large scale integration (LSI) - 100 to 1000 transistors.

(d) Very large scale integration (VLSI) - 1000 and above.

3 Based on the type of transistors used

(a) Bipolar - carries both electron and hole current.

(b) Metal oxide semiconductor (MOS) - electron or hole current.

(c) Complementary metal oxide semiconductor (CMOS) - electron or hole current.

Integrated circuit (IC) voltage regulators

The series voltage regulators discussed in earlier lessons are available in the form of integrated circuits (ICs). They are known as voltage regulator ICs.

There are two types of voltage regulator ICs. They are,

1 Fixed output voltage regulator ICs

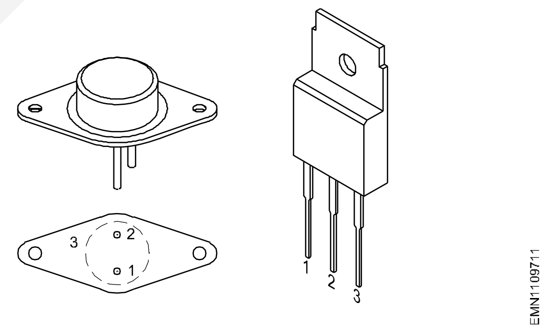
2 Adjustable output voltage regulator ICs.

Fixed output voltage regulator ICs

The latest generation of fixed output voltage regulator ICs have only three pins as shown in Fig 1. They are designed to provide either positive or negative regulated DC output voltage.

These ICs consists of all those components and even more in the small packages shown in Fig 1. These ICs, when used as voltage regulators, do not need extra components other than two small value capacitors as shown in Fig 2.

Fig 1

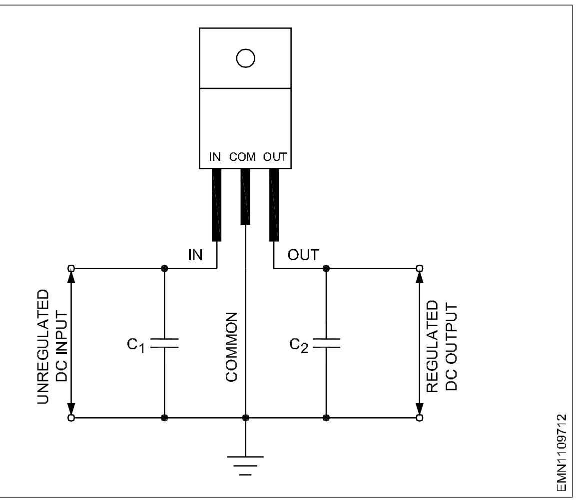


The reason behind using capacitor C_1 is, when the voltage regulator IC is more than a few inches from the filter capacitors of the unregulated power supply, the lead inductance may produce oscillations within the IC. Capacitor C_1 prevents setting up of such oscillations. Typical value of bypass capacitor C_1 range from 0.220µF to 1µF. It is important to note that C_1 should be connected as close to the IC as possible.

The capacitor C_2 is used to improve the transient response of the regulated output voltage. C_2 bypasses these transients produced during the ON/OFF time. Typical values of C_2 range from 0.1µF to 10 µF.

Fixed voltage three terminal regulators are available from different IC manufacturers for different output voltages (such as 5V, 9V, 12V, 24V) with maximum load current rating ranging from 100mA to more than three amps.

Fig 2



The most popular three terminal IC regulators are,

1 LMXXX-X series

Example: LM320-5, LM320-24 etc.

2 78XX and 79XX series

Example: 7805, 7812, 7912 etc.

A list of popular three terminal regulators is given in Pocket Table Book, Table No.30.

Specifications of three terminal IC regulators

For simplicity in understanding, let us consider the specification of a three terminal IC μA7812. The table given below lists the specifications of μA7812.

Parameter	Min.	Typ.	Max.	Units
Output voltage	11.5	12	12.5	V
Output regulation		4	120	mV
Short-circuit output current		350		mA
Drop out voltage		2.0		V
Ripple rejection	55	71		dB
Peak output current		2.2		A

– **Output voltage:**

This specification indicates the regulated DC output voltage that can be obtained from the IC. As can be seen from the sample specification table given above, the manufacturer specifies minimum, typical and maximum output voltages. While using this IC take the typical value as this value corresponds to the output voltage at IC under normal input and load conditions.

– **Output regulation**

This indicates the amount by which the output voltage may vary at rated maximum load condition. For example, in μA7812 IC, the output voltage may vary by 4 mV from its rated 12 V DC when the rated typical load current is 2.2A.

– **Short circuit output current**

This indicates the shorted current I_{SC} if the output gets shorted. In μA 7812 the output current is limited to 350mA when the output terminals are shorted.

– **Drop out voltage**

For instance, in μA7812 in which the output voltage is +12 V, the input unregulated DC voltage to the regulator must be higher than the output voltage. The specification drop out voltage indicates, the minimum positive difference between the input and output voltages for the IC to operate as a regulator. For example, in, μA7812 the unregulated input voltage should be atleast 2 volts more than the regulated DC output of 12V. This means for μA7812 the input must be atleast 14V.

The difference between the voltage across the input and output of the IC should also not to be very high as this causes unwanted dissipation. As a thumb rule, the input voltage to the regulator shall be restricted to a maximum of twice the output voltage of the regulator. For example, for μA7812, the unregulated input voltage should be more than 14V, but less than 24V.

– **Ripple rejection**

This indicates the ratio of ripple rejection between the output to input, expressed in decibels.

– **Peak output current**

This indicates the highest output or load current that can be drawn. Above this rated maximum current the safety of the IC is not guaranteed.

Identification of output voltage and rated maximum load current from IC type number

– 78XX and 79XX series are **3 Terminal voltage regulators.**

– All 78XX series are **positive output voltage regulators.**

– All 79XX series are **negative output voltage regulators.**

The term XX indicates the rated output regulated voltage.

Example:

7805

Indicates Positive output regulator ← → Indicates Output voltage is +5 V

79 12

Indicates Negative output regulator ← → Indicates Output voltage is -12 V

It is important to note that, different manufacturers of 78XX/79XX series such as Fair Child (µA/µpc), Motorola, Signetics (SS) adopt slightly different coding schemes to indicate the rated maximum current of the three pin regulated ICs. One such scheme is given below.

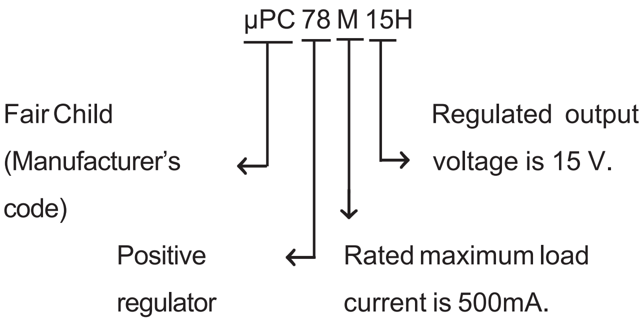
78LXX - L indicates rated maximum load current as 100mA.

78MXX- M indicates rated maximum load current as 500mA

78XX - Absence of an alphabet between 78 and XX indicates that the rated maximum load current is 1A.

78SXX - S indicates rated maximum load current is 2 amps.

Example:



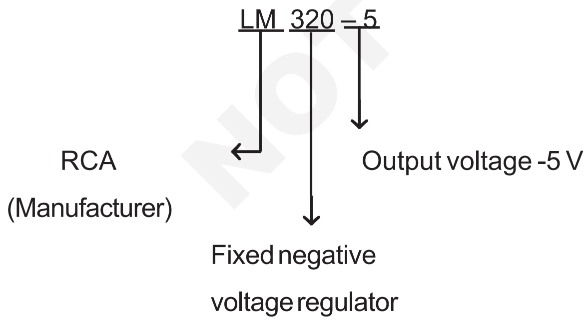
LM 3XX series of 3 terminal voltage regulators

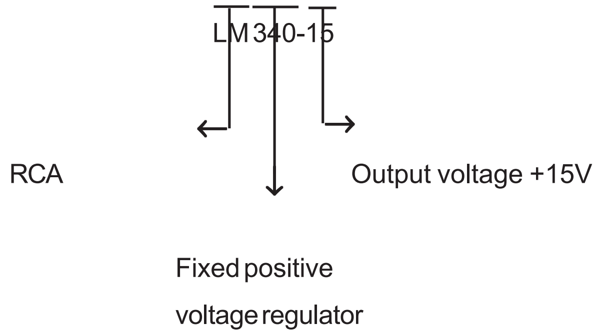
In LM series of three terminal regulators, to find the specifications, it is suggested to refer to its data manual. However, the following tips will help in identifying whether the IC is a fixed positive or fixed negative regulator.

LM320-X and LM320-XX ⟶ Fixed -ve voltage regulators.

LM340-X or LM340-XX Fixed +ve voltage regulators.

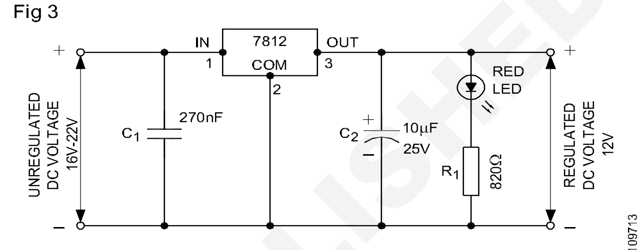
Examples:





Practical 78XX and 79XX voltage regulator circuits: Fig 3 shows the circuit connections of a 12 V, 1 A regulated power supply using 7812.

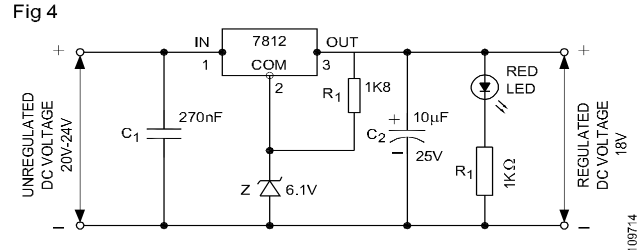
Fig 3



+12V FIXED OUTPUT VOLTAGE REGULATOR CIRCUIT

The output voltage of a 3-terminal regulator IC is with reference to the IC's common terminal (COM). When the COM terminal is grounded, the output voltage of the regulator will be the specified output voltage of the IC as shown in Fig 3. But the output voltage of the IC can be increased above the specified value by raising the voltage at the COM terminal as shown in Fig 4. Because of 6.1V zener, the output voltage will be 6.1V + 12V = 18.1V or approximately 18V as shown in Fig 4.

Fig 4

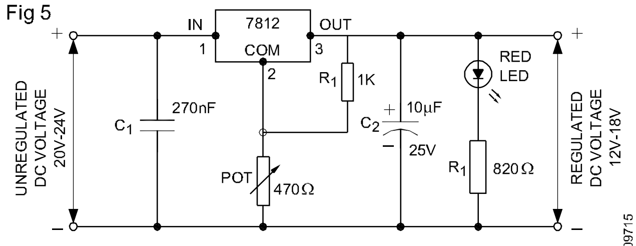


+18V FIXED OUTPUT VOLTAGE REGULATOR CIRCUIT

When the COM terminal of the IC is grounded as shown in Fig 3, the quiescent current flowing from the COM terminal to ground in 78 series is around 8 µA. This current decreases as the load current increases. When a zener is connected at COM terminal as shown in Fig 4, to ensure that the zener is always in the reverse ON condition, resistor R_1 is used. If R_1 = 1.8K, I_Z will be 7mA which is sufficient to keep the zener ON always.

Fig 5 shows a variable output voltage regulator using a fixed voltage regulator. The variable reference voltage at COM terminal is obtained using a POT.

Fig 5

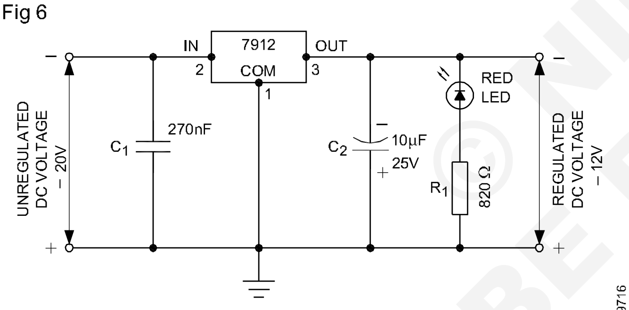


VARIABLE OUTPUT VOLTAGE REGULATOR CIRCUIT

Since the quiescent current through the pot is very low (around 8µA) and it decreases with load resistor R_1 is used to compensate the changes in the quiescent current due to loading. Therefore, the bias voltage is determined by the sum of the quiescent current I_Q and the bias current set by R_1. In Fig 5, when the resistance of the POT is set to 0, COM is grounded and hence output will be 12V. As the set value of pot increases the output voltage also increases.

Fig 6 shows a negative voltage regulator using 7912. The working of this circuit is similar to that of Fig 7 except that it is a negative voltage regulator and hence the voltage at pin no.3 of the IC will be -12volts.

Fig 6



– 12V FIXED OUTPUT VOLTAGE REGULATOR CIRCUIT

NOTE: PIN NUMBERS ARE DIFFERENT FROM 7812

Fig 7 shows a +15 volts regulator using LM340. This circuit connection is very much similar to that of the 78XX series regulator.

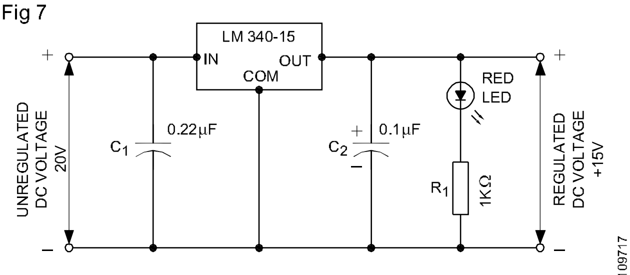
Multiple voltage using three-terminal fixed voltage regulator

Fig 8 shows how a three-terminal IC can be used to obtain multiple voltages. Such economical and elegant circuits are very useful for electronic circuits and for service technicians.

Recall, than the value input unregulated DC to a regulator should always be less than twice the output of the regulator. As shown in the third regulator (7805) of Fig 8, when it is necessary to operate with a large input voltage, a series resistance R_S can be added in series to drop required voltage.

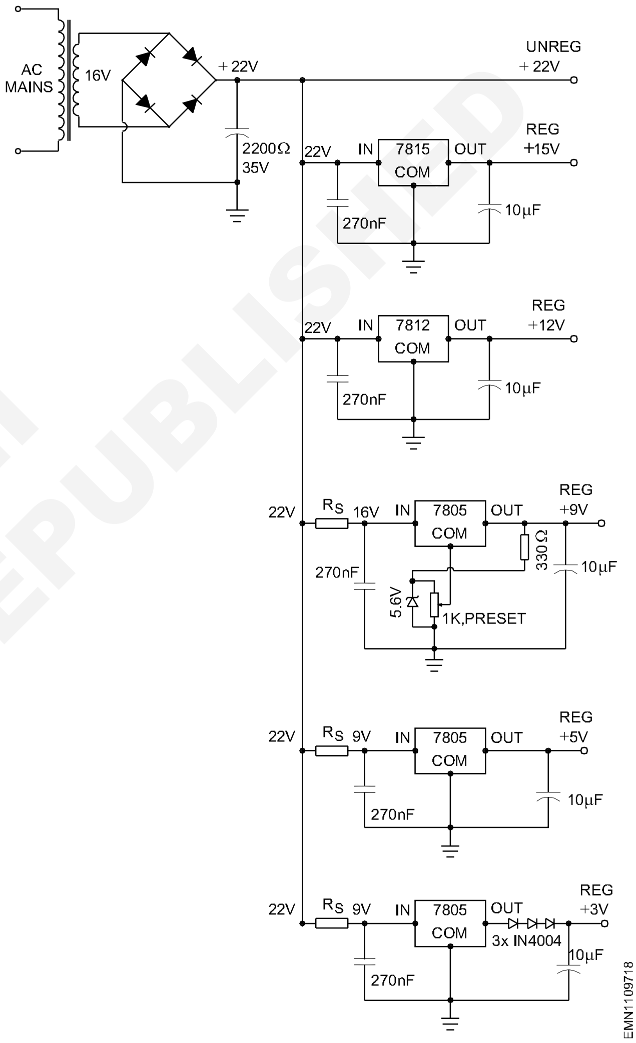
The scheme shown in Fig 8 is one of the several schemes that can be adopted to get multiple voltage output.

Fig 7



+12V FIXED OUTPUT VOLTAGE REGULATOR CIRCUIT

Fig 8

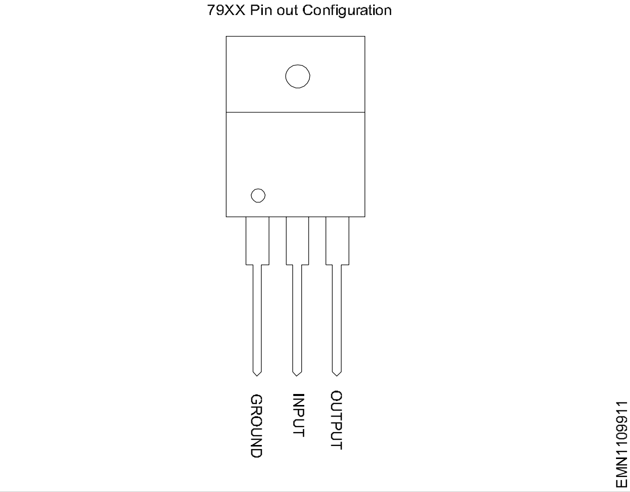


IC 79XX voltage regulator

79XX voltage regulators are very commonly used in electronic circuits. The main purpose of this IC is to supply required regulated negative voltage to the circuits. IC 79XX can supply a constant negative voltage output. In spite of any voltage fluctuations in its input voltage. It can be mainly found in the circuits in which integrated circuits that require +Vcc and -Vcc are used.

IC79xx is a three pin negative voltage controller IC as shown in Fig 9. It is a small integrated circuit used in a circuit to supply a constant negative input voltage. The number 79 indicates that it is a negative voltage regulator and xx indicates the output voltage of the IC. 'xx' can be replaced by the controlled output voltage provided by the regulator, for example, if it is 7905, then the output voltage of the IC is -5 V. Similarly if it is 7912, then output voltage of the IC is -12 volts and so on. The name of the IC may vary based on the manufacturer as LM79xx, L79xx, MC79xx etc.

Fig 9



Heat sink

IC 79xx requires heat sink for its safe operation. Heat sink boosts heat dissipation therefore the life of the device can be extended

79xx ICs and output voltages

IC Number	Output Voltage
7905	-05 Volts
7912	-12 Volts
7915	-15 Volts
7918	- 18 Volts

The pin 1 acts as the ground terminal (0V). The pin 2 acts as the input terminal (5V to 24 V). The pin 3 acts as the output terminal (constant regulated 5V).

Pin out configuration of IC 79xx.

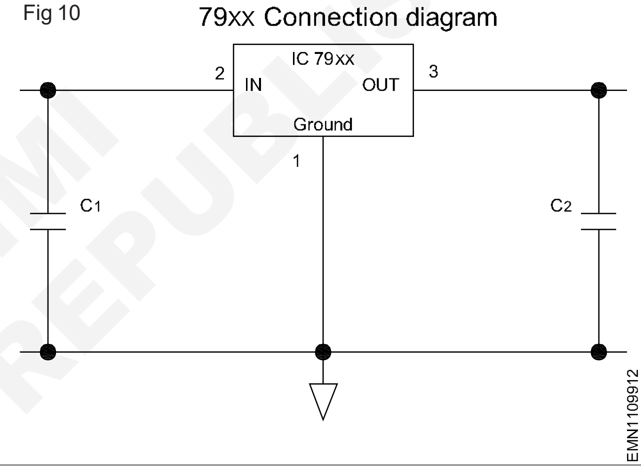
The pin out configuration of IC 79xx is shown in the diagram below

- The pin 1 acts as the ground terminal (0V).
- The pin 2 acts as the input terminal (5V to 24V)
- The pin 3 acts as the output terminal (constant regulated 5V)

Connection diagram

IC 78xx is used in circuit as shown in the Fig 10. In order to improve stability two capacitors C_1 and C_2 are used. The capacitor C_1 is used only if the regulator is seperated from filter capacitor by more than 3". It must be a 2.2µF solid tantalum capacitor or 25µF aluminium electrolytic capacitor. The capacitor C_2 is required for stability. Usually 1µF solid tantalum capacitor is used. One can also use 25µF aluminium electrolytic capacitor. Values given may be increased without limit.

Fig 10



IC 78xx

Similar to IC 79xx, IC 78xx is a three pin IC that gives a constant output voltage of +5V irrespective of the varying input voltages. The maximum value of input voltage that the IC can withstand is 24 volts.

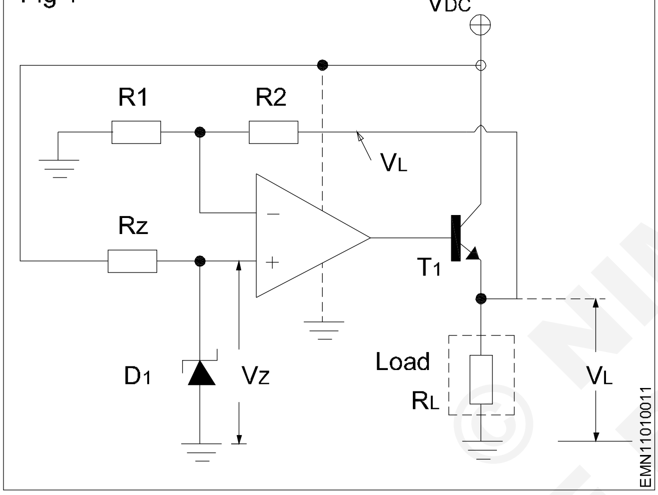
OP-AMP Voltage regulator

Objectives : At the end of this lesson you shall be able to
- **explain the concept of using an operational amplifier**
- **explain the circuit diagram of a IC723 voltage regulator..**

Concept of Op-amp voltage regulator

Here, we explain the general concept of using an operational amplifier for voltage regulation. By utilizing an op-amp and few other external components, we can easily build a linear voltage regulator. Apart for being a regulator, the same circuit is also a voltage stabilizer, able to stabilize voltage at a grade better than 0.01%. The circuit as shown in Fig 1 from a non-stabilized DC-power source, and uses a transistor (T1) inside a feedback loop. The transistor is used to supply the load with much more current than the op-amp itself could possibly supply. The D1 diode is a Zener-type diode and it is used for voltage reference.

Fig 1



D1 is biased through Rz. When correctly reverse biased, the zener diode keeps the voltage across its leads close to the zener breakdown voltage. The op-amp is used as a linear voltage amplifier. Due to the high open loop voltage gain of the op-amp, and as far as the op-amp remains in its linear region, the voltage difference between its inverting (V_-) and non-inverting input (V_+) is almost equal to zero. In other words, the voltage at its non-inverting input, in respect to the ground, equals the voltage at its inverting input:

$V_- = V_+$ (1)

Equation (1) holds true for any op-amp working at its linear region (as an amplifier).

R1 and R2 form a voltage divider, and the voltage (V_-) at their connection point is also given by the well known voltage-divider formula:

$V_- = V_L \cdot R1/(R1+R2)$ (2)

However, V+ is also equal to the zener breakdown voltage (Vz), because the non-inverting input of the op-amp is directly connected to the cathode of the zener diode

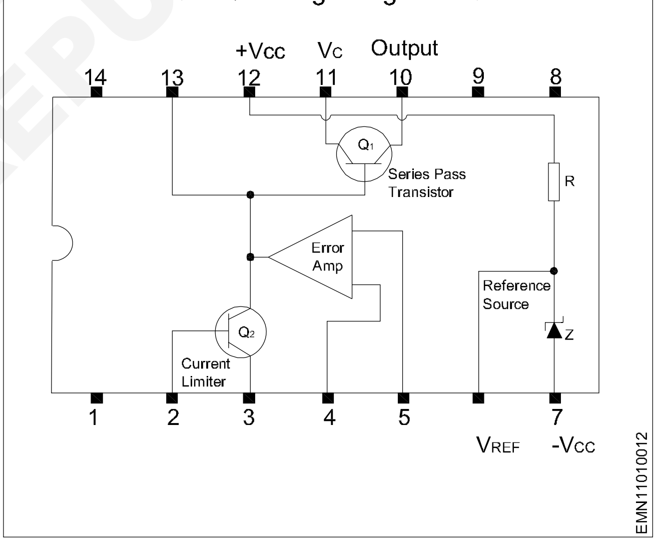
$V_+ = V_Z$ (3)

After solving (1),(2) and (3), we get: $V_L = V_Z \cdot (1+R_2/R_1)$ (4)

From equation (4), we conclude that V_L voltage (which is the voltage applied to the load) is directly proportional to the Zener voltage. As far as the Zener voltage remains stable, V_L also remains stable. Additionally, the voltage applied to the load, can be easily adjusted by adjusting R1, R2 or both of them. For continues voltage adjustment, R1 and R2 should be replaced by a potentiometer, having its wiper at the non-inverting input of the op-amp, and its other leads at the ground and the V_L line, respectively. VL_Z is not possible to exceed V_{DC}. It can be almost as much high as V_{DC} when T_1 saturates, but no more than this. V_L (the voltage at the load) could not also be lower than V_Z. That's why $V_Z<V_L<V_{DC}$.

As in any linear regulator, heat losses on T1 increase when the output voltage decreases. In fact, the power loss due to heating is the current times the voltage dropped across T1. Besides heating losses, a linear regulator is often preferred over a switching one because it does not require any inductors which can be relatively expensive or bulky.

Fig 2

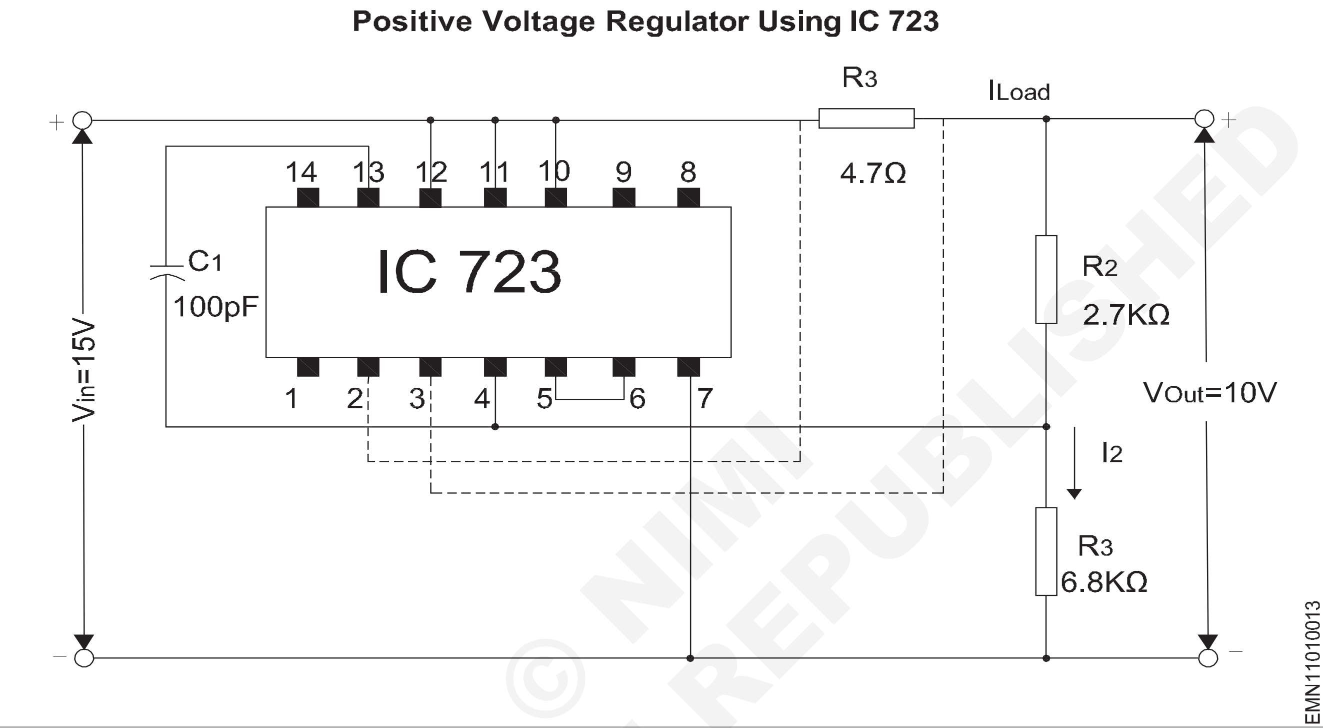


We have already explained in detail about the basics of voltage regulators and IC voltage regulators. Let us take a look at one of the most popular IC voltage regulators, the 723 voltage regulator IC. The functional diagram of the voltage regulator is shown in fig 2. It consists of a voltage reference source (pin 6), an error amplifier with its inverting input on pin 4 and non-inverting input on pin 5, a series pass transistor (pin 10 and 11) and a current limiting transistor on as pins 2 and 3. The device can be set to work as both positive and negative voltage regulations with an output voltage ranging from 2V to 37V, and output current levels up to 150m A. The maximum supply voltage is 40V, and the line and load regulations are each specified as 0.01%.

The figure shown in Fig 3 is a positive voltage regulator with an IC 723. The output voltage can be set to any desired positive voltage between (7-37) volts. 7 volts is the reference starting voltage. All these variations are brought with the change of values in resistors R1 and R2 with the help of a potentiometer. A darlington connection is made by the transistor to Q1 to handle large load current. The broken lines in the image indicate the internal connections for current limiting. Even fold back current limiting is possible in this IC. A regulator output voltage less than the 7V reference level can be obtained by using a voltage divider across the reference source. The potentially divided reference voltage is then connected to terminal 5.

Another important point to note about this IC is that the supply voltage at the lowest point on the ripple waveform, should be at least 3 V greater than the output of the regulator and greater than Vref. If it is not so a high-amplitude output ripple is possible to occur.

Fig 3



IC voltage regulators - variable output

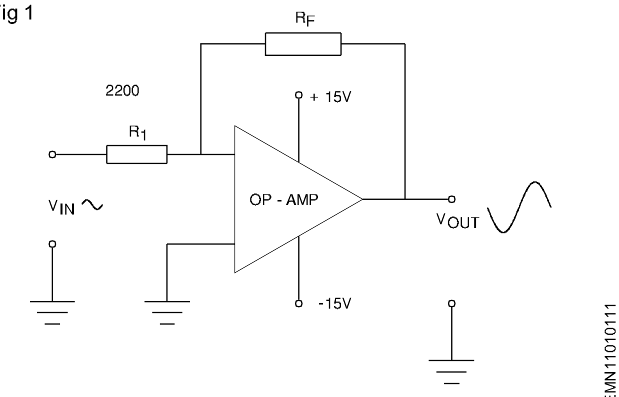
Objectives: At the end of this lesson you shall be able to
- **explain the dual power supply**
- **list a few variable regulator 3-pin ICs**
- **explain feedback and error amplification.**

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 -V_e 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.

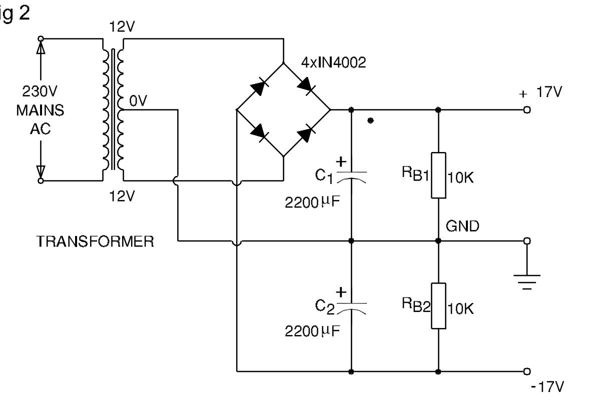
Therefore, for circuits which require both +ve and -ve DC supplies, a single power supply which can deliver both ± DC is required to be designed. Power supplies which can deliver both ± DC are generally referred to as Dual Power Supply.

Fig 1



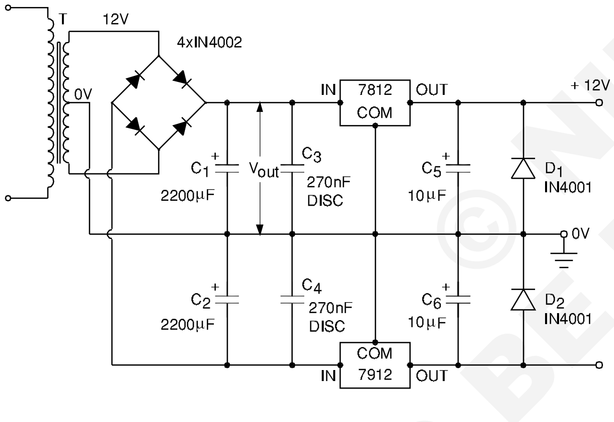
To design a ± or dual regulated power supply, as a first step it is required to design a ± unregulated DC supply. Fig 2 shows a simple method of obtaining ± unregulated DC supply.

Fig 2



Once, a ± 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 ± regulated DC supply. One such ± regulated DC supply using 7812 (+ve regulator) and 7912 (-ve regulator) is shown in Fig 3.

Fig 3



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.

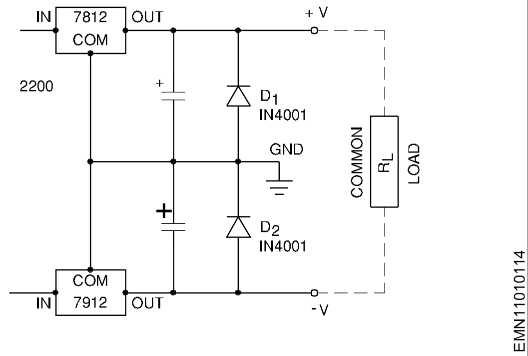
Variable/adjustable output voltage regulators

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

Fig 4



3-Terminal variable output regulators ICs

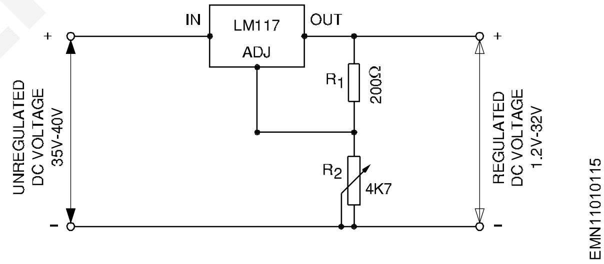
These ICs look like 3-terminal fixed output voltage regulators as shown in Fig 3. A few examples of 3-terminal adjusted output voltage regulator ICs are,

- 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.

Fig 5



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

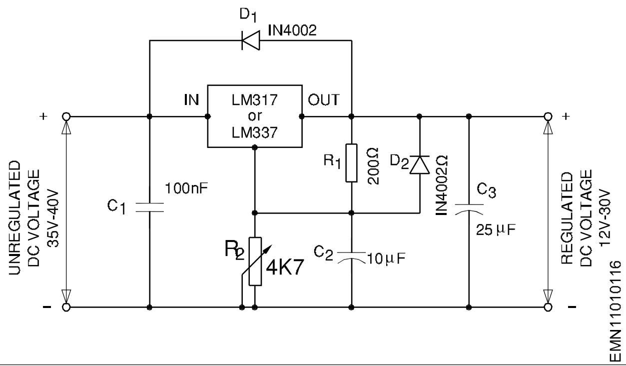
$$V_{out} = 1.2 \text{ V} \times (1 + (R_2 / R_1)) \qquad ....\{1\}$$

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.

Fig 6



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, µA723, CA3085 and so on.

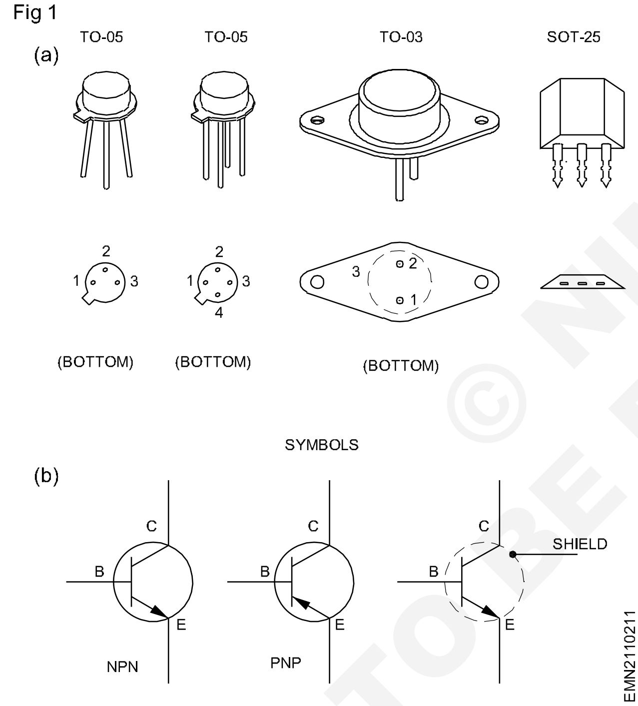
Transistors and Classification

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

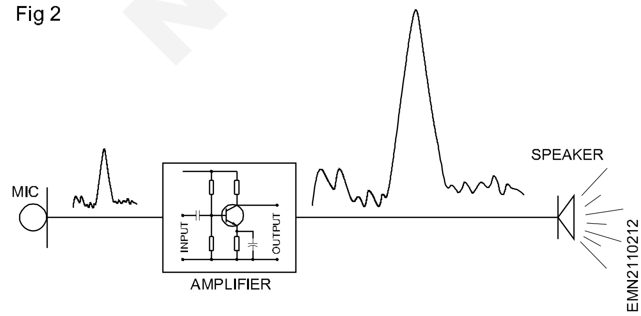
Transistors are the semiconductor devices having three or four leads/terminals. Fig 1a shows some typical transistors. Fig 1b shows the symbols used for different types of transistors.

Fig 1



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.

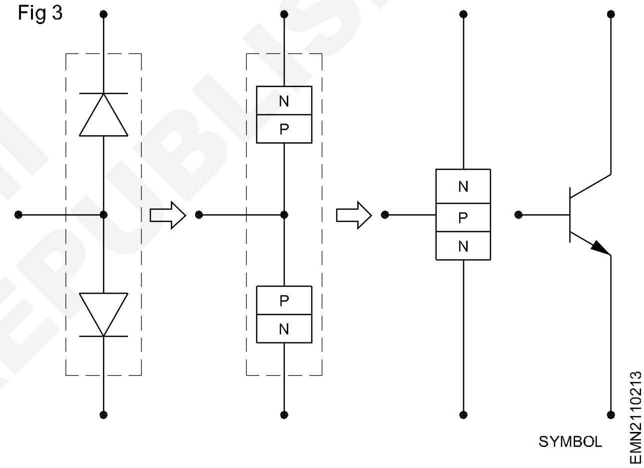
Fig 2



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.

Fig 3



- 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.

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.

2 Based on the way the P and N junctions are organized as shown in Fig 5.

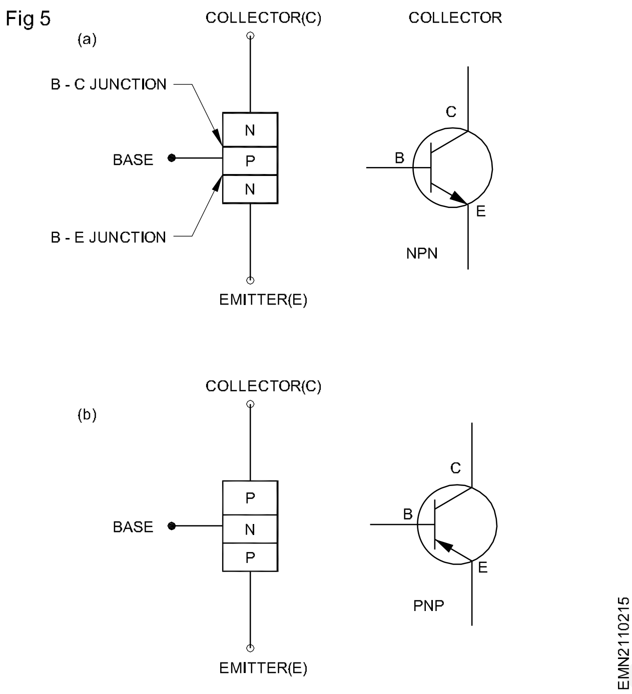
- NPN transistors

– 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.

3 Based on the power handling capacity of transistors as shown in Table below (Fig 6).

Fig 5



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.,

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.

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)

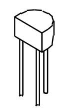
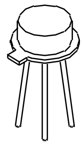
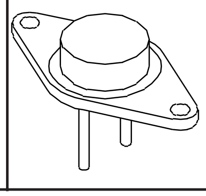
Amplification required for signals of low or audio range of frequencies in Tape recorders, PA systems etc., make use of A/F transistors. Amplifications required for signals of high and very high frequencies as, in radio receivers, television receivers etc., use R/F transistors.

5 Based on the type of final packaging

– Metal

– Plastic

– Ceramic

Low power transistors (less than 2 watts)	**Medium power transistors** (2 to 10 watts)	**High power transistors** (more than 10 watts)
Fig 6 TO-92 	TO-05 	TO-03 

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-25 and so on.

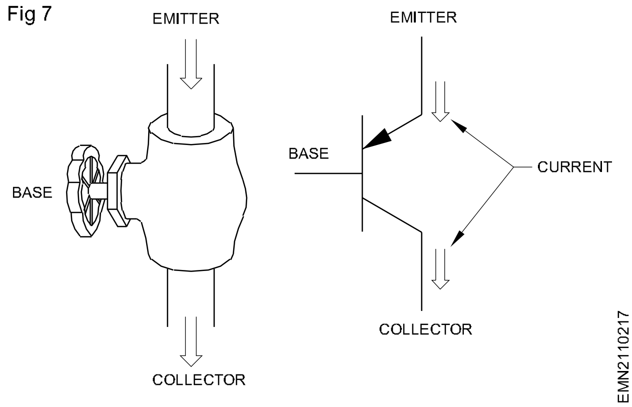
Inside a transistor

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. As shown in Fig 5, the three leads/pins/pin 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)

Fig 7



Collector - collects current carriers

Base - controls flow of current carriers from emitter to collector.

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.

Fig 8

Heat sink

In any electrical/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 9

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.

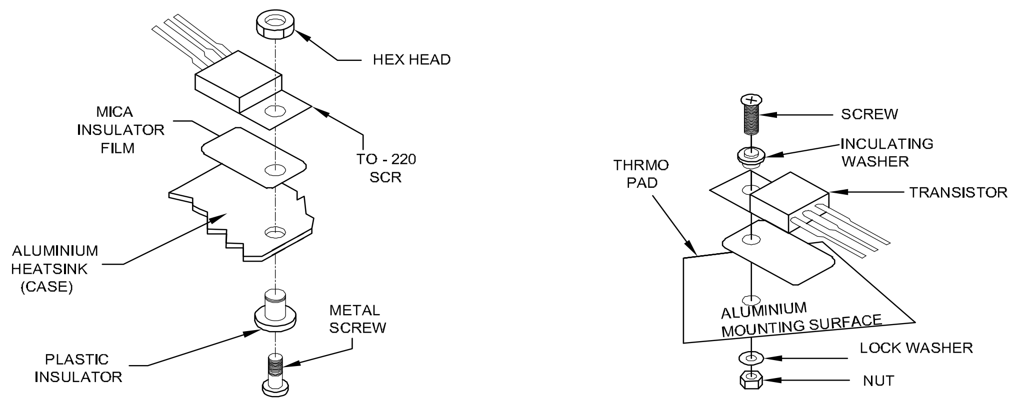
Testing transistors using ohmmeter

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 11a shows a NPN transistor and Fig 11b 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.

Fig 10



MOUNTING METHOD OF TRANSISTOR ON HEATSINK

Fig 11

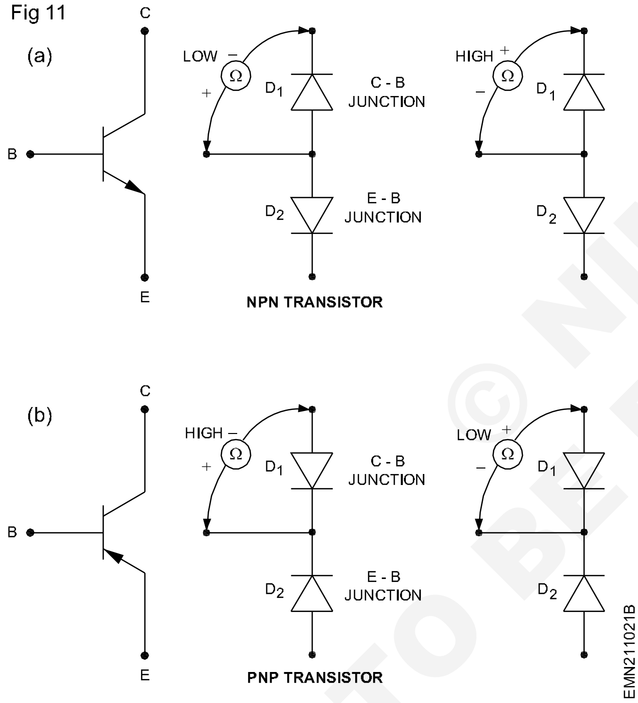
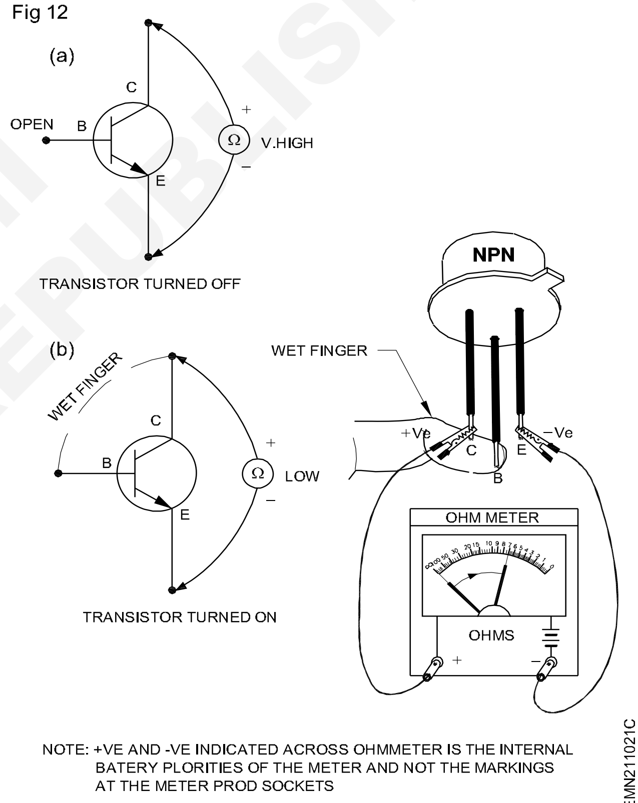


Fig 12



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 prod sockets.**

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.

The above two tests on a given transistor, using a simple ohmmeter revels the condition of the transistor. These tests are essential before using a transistor in a circuit.

Testing transistor using DMM

Electronics repair technicians often uses a digital multimeter (DMM) to test whether a transistor is working in fig 13. properly or not (servicecable or unservice cable). 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.

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.

Fig 13

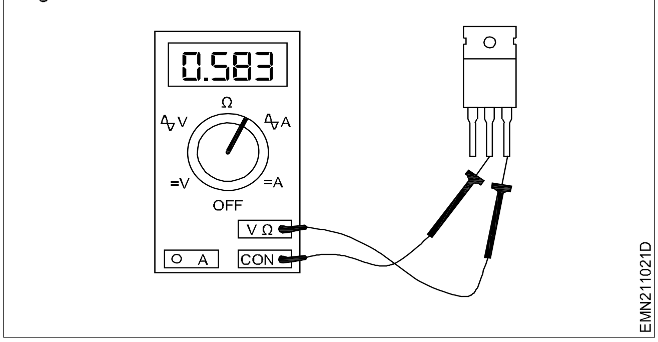
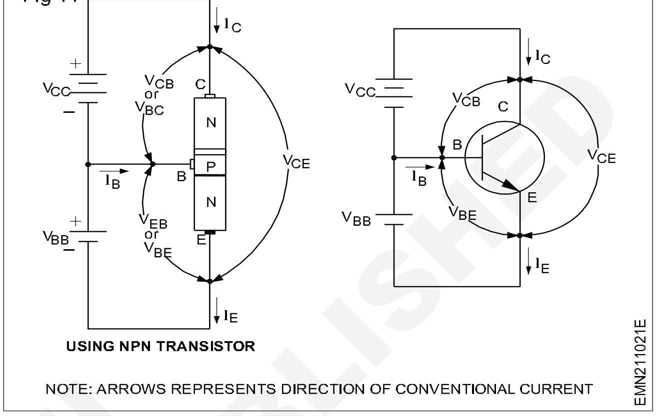


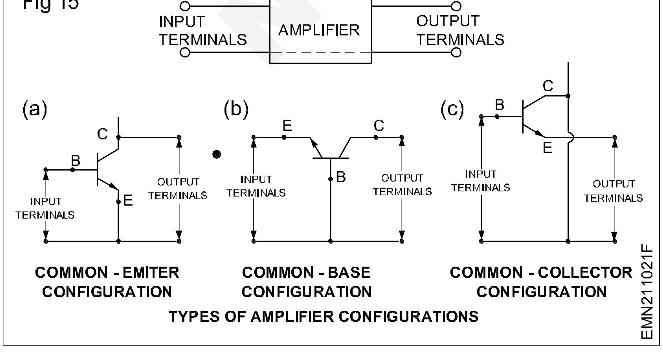
Fig 14



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'	

Types of Transistor configuration: 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 β (spell it as Beta). All data books give the current gain of transistors in β. This is because, once β 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.

Fig 15



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 β_{dc} in data books. β_{dc} of transistors is also referred to as H_{FE} in some data books.

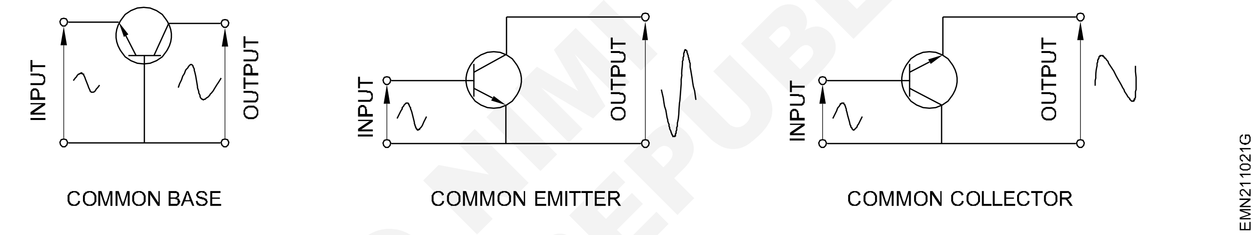
Fig 15b shows a **common-base amplifier**, where the base lead of the transistor is common to both the input and output terminals. The current gain in common-base configuration is indicated by the symbol α (spell it as alpha). The current gain α, of a common-base amplifier will always be less than 1. 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 β of a transistor is given in data books as β Minimum(MN) or β Typical(TP). This is because the value of β varies due to variations in the level of the base current. Details of variation in β is discussed in detail in further lessons. While designing a circuit, it is suggested to use the typical value of β of the transistor. If the data book gives only the minimum value of β, the typical value can be taken as twice the minimum value.

Characteristics	Common base	Common emmiter	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



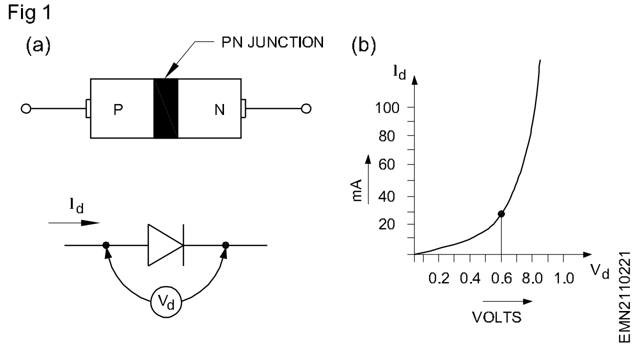
Transistors Input and Output Characteristics of Transistors

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.**

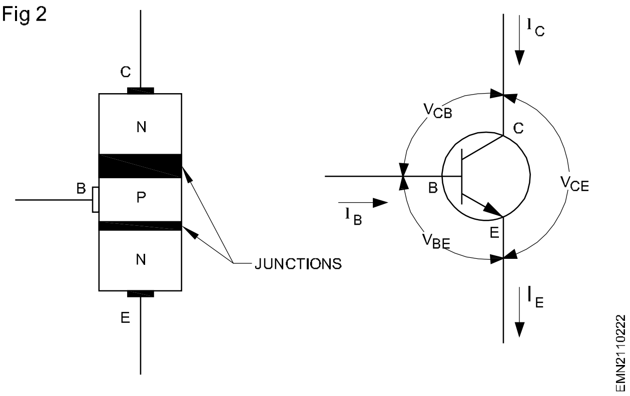
A semiconductor diode, as shown in Fig 1, has only one PN junction. When the voltage across the PN junction is increased or decreased, the current through the diode increases or decreases. There is only one voltage parameter(V_d) and one current parameter(I_d). Therefore, the relationship between these two parameters is easy to understand through the diode characteristic graph of V_d versus I_d as shown in Fig 1b.

Fig 1



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.

Fig 2



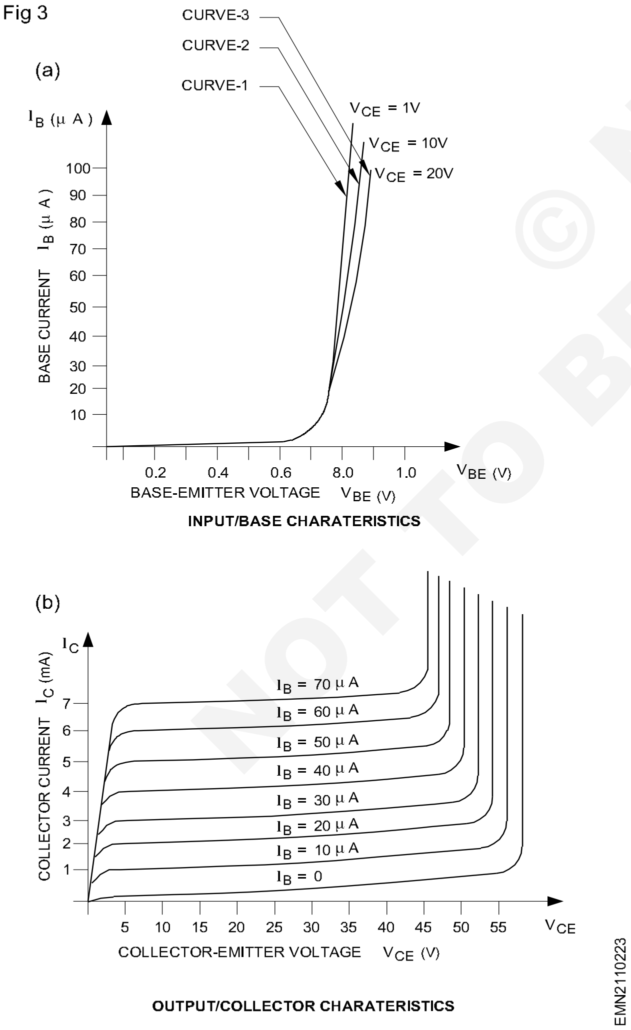
Any change in any one parameter causes changes in all the other parameters. Hence it is not very easy to correlate the effect of one parameter with the others. To have a clear understanding of their relationship a minimum of two characteristics graphs should be plotted for any transistor. They are,

– Input characteristics

– Output characteristics.

For simplicity in understanding, consider a common-emitter amplifier. The two characteristics graphs are shown in Fig 3.

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

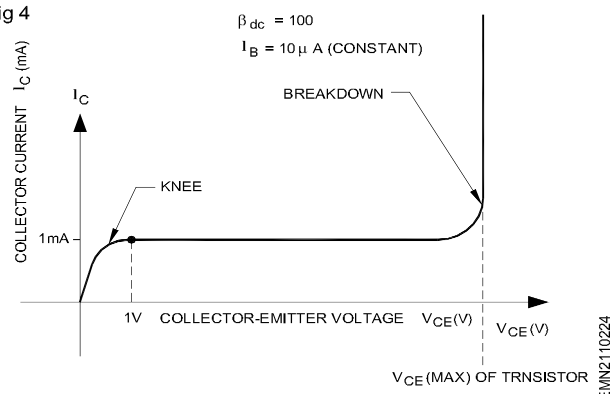


Fig 4 shows the collector characteristics for a constant I_B of 10µA. Behavior of I_C for different values of V_{CE} is explained below;

- 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 β_{dc} of approximately 100, the collector current is approximately 100 times the base current as shown in Fig 4 (1mA is 100 times 10 µA).
- 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 break-down 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 β_{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.

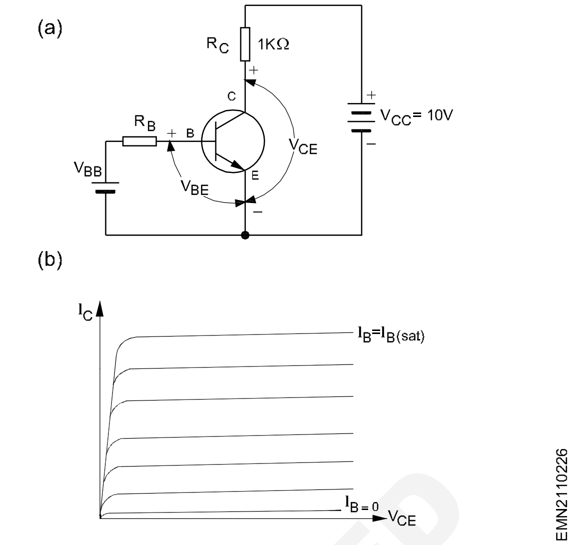
In Fig 3b, also note that the break down voltages become lower at higher currents. This means that the base-emitter voltage from *knee* point till the *break down*, known as the voltage compliance of a transistor, decreases for larger collector currents. Hence, it is necessary to avoid very high collector current such that the transistor operates in a wider active region.

DC LOAD LINES of transistors

To have a further insight into how a transistor works and in what region of the collector characteristics does it work better can be found using DC load lines.

Consider a forward biased transistor as shown in Fig 6a. Fig 6b shows the collector characteristics of the transistor used.

Fig 6



In the circuit at 6a, consider the following two situations,

- Maximum collector current, $I_{C(max)}$
- Minimum collector current, I_C

For situation (1), assume that V_{CE} is zero or collector-emitter is a short. In that case, the collector current is limited only by the collector resistor R_C. Therefore,

$$I_C = \frac{V_{CC}}{R_C} \text{ at } I_{CE} = 0$$

Under such a condition, for the circuit at Fig 6a, I_C will be equal to 10V/1KΩ = 10mA.

Mark this I_C = 10mA point along V_{CE} = 0 on the collector characteristics of the transistor as shown in Fig 7a.

For situation (2), assume that V_{CE} is maximum or collector-emitter is open. In that case, the collector current is zero.

Therefore,

$V_{CE} = V_{CC}$ In the circuit at 6a, $V_{CE} = V_{CC}$ = 10V

Mark this point of I_C = 0 and V_{CE} = 10V on the collector characteristics of the transistor as shown in Fig 7b.

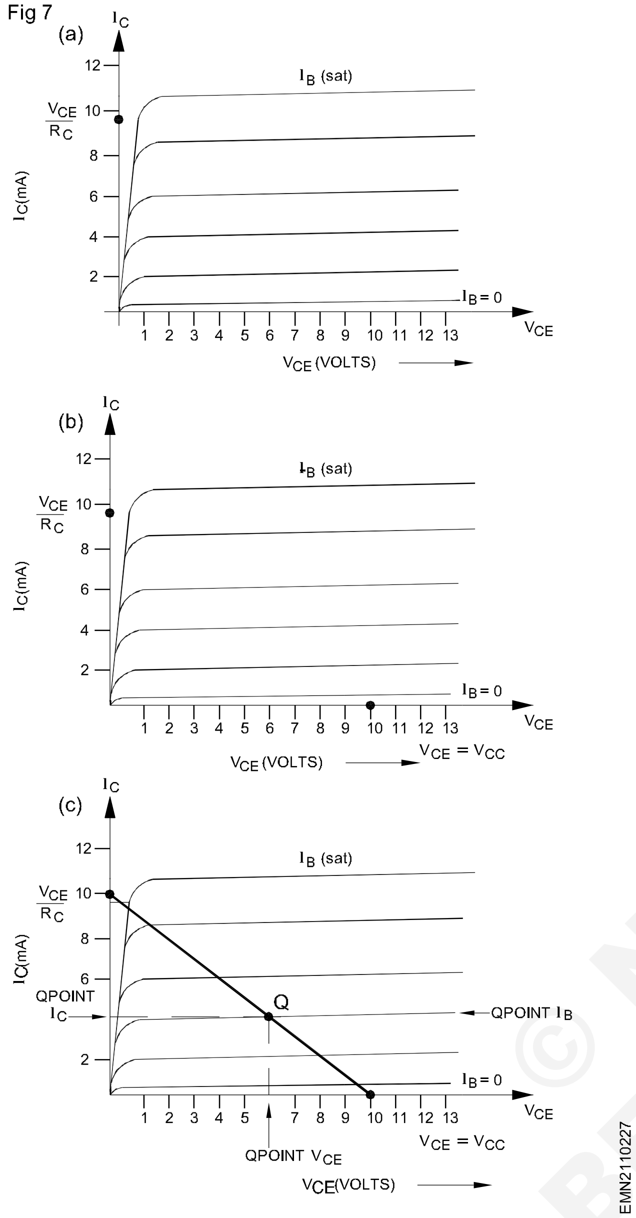
Connect the two marked points through a straight line as shown in Fig 7c. This line is called the load line.

The point at which the load line intersects the I_B = 0 is known as the cut off point. At cut off, I_B = 0; hence, emitter diode is out of forward bias and the transistor action is lost.

The point at which the load line intersects $I_B = I_{B(sat)}$ is called the saturation point. At this point the base current is maximum and the collector current is also maximum. At saturation, the collector diode comes out of the reverse bias, and hence, the normal transistor action is lost.

For a transistor to work in a normal way, i.e. as a controlled current source, it must not be made to work either in the cut off or in saturation. Therefore the ideal point would be

Fig 7



somewhere in the middle of these extreme points on the load line. This middle point is known as *Quiescent point or* Q-point as shown in Fig 7c.

Knowing the Q point, you can fix-up the value of resistors R_C and R_B of the circuit.

The DC load line shows at a glance the active V_{CE} voltage range of the transistor. In other words, it indicates that the transistor acts like a current source anywhere along the DC load line, excluding the saturation or cut off, where the current-source action of the transistor is lost.

Fixing Q point from the data available in data sheets

The Q point can be fairly accurately fixed from the data of a transistor given in transistor data books. This reduces the time consuming work of plotting the collector characteristics and the load line. To do so, the following points are very important to remember;

1 The chosen V_{CC} must be less than $V_{CE(max)}$ given in the data book

TIP : Preferably restrict value of V_{CC} to 3/4 of $V_{CE(max)}$

2 Fix the Q point I_C at 1/2 of $I_{C(max)}$ given in the data book.

3 At the Q point assume 1/2 of V_{CC} will be across V_{CE}.

4 From points (2)&(3) calculate the value of R_C.

5 From the H_{FE} value given in data book, fix the approximate value of the base current at the Q point as given below.

I_B at Q point =

$$\frac{\text{Chosen value of } I_C \text{ at the Q} - \text{point(tipno.2)}}{\text{Typical value of } H_{FE} \text{ from data book}}$$

6 From the value of I_B at the Q point and allowing a 0.7 volts drop across the base-emitter, calculate the value of R_B.

Application of a Transistor as Switch

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

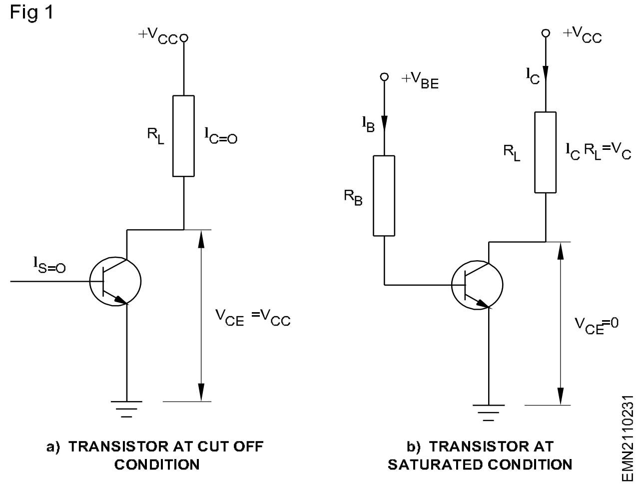
Consider the circuit in Fig 1

$V_{ce}=V_{cc}-(I_c*R_l)$……………..(1)

Since I_b=0 and I_c= 0$V_{ce}=V_{cc}$

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.

Fig 1



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.

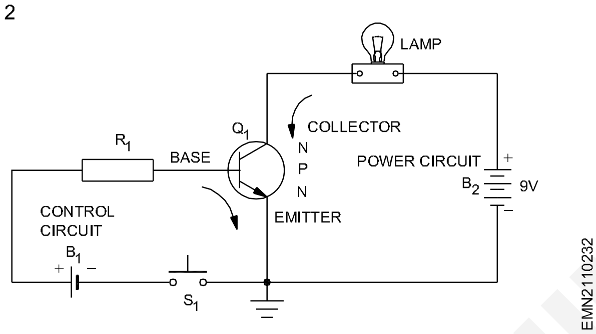
In fig 1b if the value of R_b and R_l are such that V_{ce} tends to zero, then the transistor is said to be saturates. Putting V_{ce}=0 in the eqn (1) we get

$V_{ce}=0=V_{cc}-I_cR_l$ or $I_c=V_{cc}-R_l$

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

Fig 2



In fig 2 the control circuit of the input determines the base current determines the amount of output 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 forwards 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.

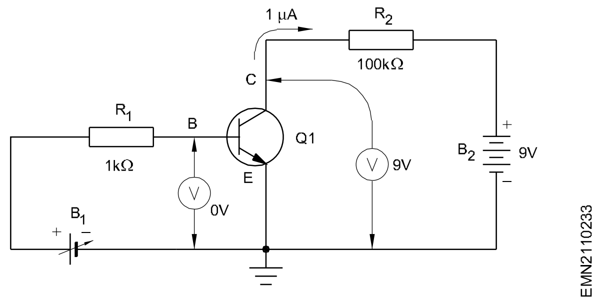
Next assume that switch that S_1 is closed this cause a small change in current flow in the control circuit .R is the current limiting resistor for the base current. Therefore the resistance from the emitter from the collector for the transistor drops. Consequently a large current flow in the power circuit causing the lamp to glow.

Operation of transistor switching circuit: The schematic circuit in the fig 3 shows the measured voltage and collector current Ic in the 'transistor OFF' condition. Note that only a tiny leakage current of 1micro amp flow from the emitter to collector. The resistance from E to C is calculated as

R=V/I=9V/0.000001A=9 M Ω

The transistor has a resistance of 9 mega ohms, which is like the open or off condition of a switch

Fig 3



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 B1,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

Fig 4

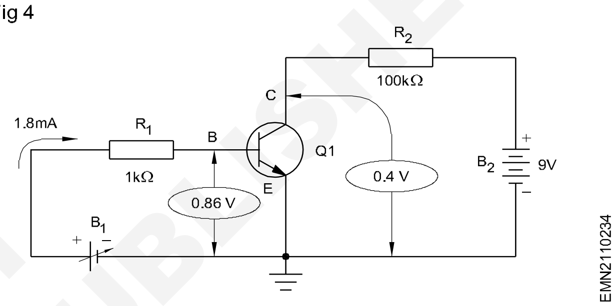
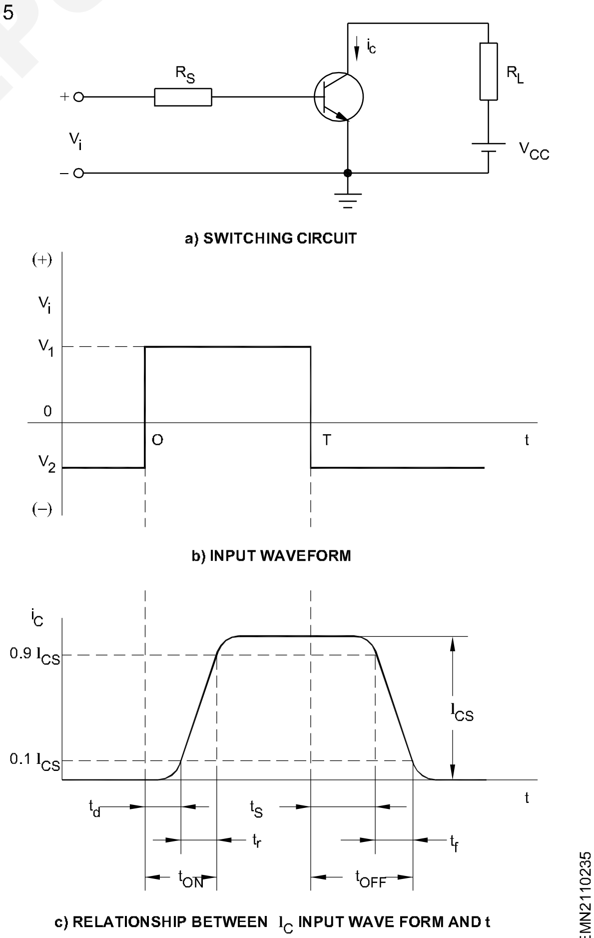


Fig 5



R=V/I=0.4V/0.085A=4.7 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 machanical relay the transistor has no moving mechanical parts.

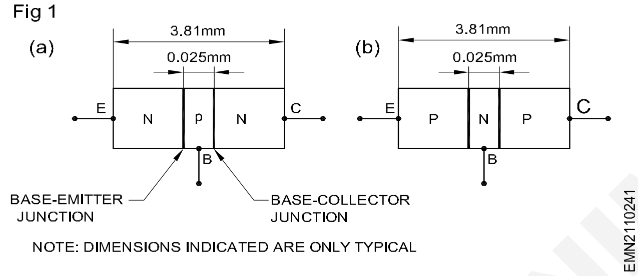
Biasing of Transistors

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 semiconductor 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.

Fig 1



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.

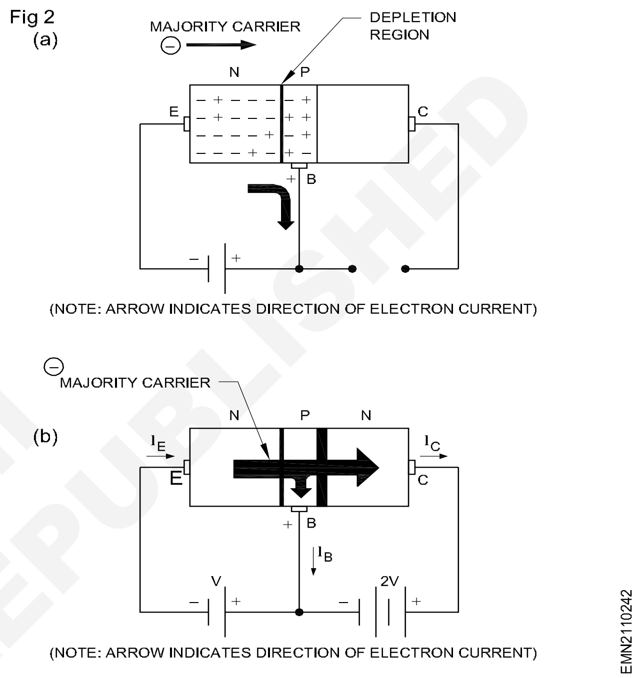
Transistor operation: As transistors have three layers, there are two junctions as shown in Fig 1. The base-emitter junction behaves as one diode junction. The base-collector junction behaves as the other diode junction.

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.

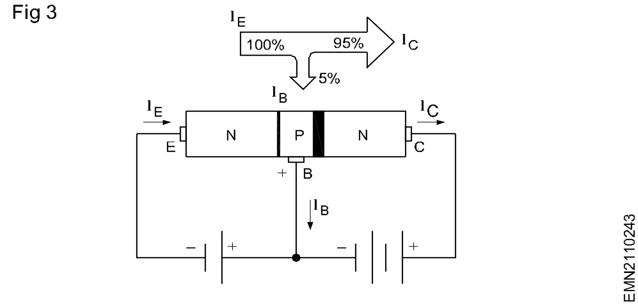
Fig 2



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.

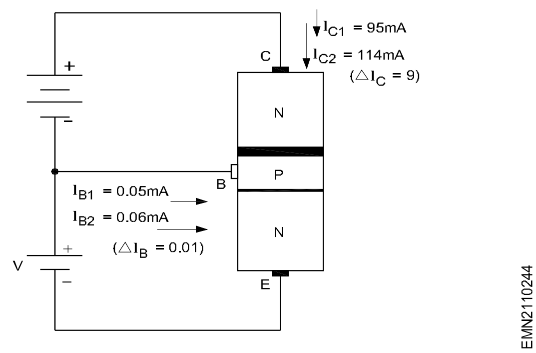
It can be seen from Fig 3, that the,

Fig 3



- current carriers come from the emitter
- base current is small(5% of emitter current)
- and, the collector current is high (95% of emitter current).

Fig 4



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 ΔI_C due to the change in the input current ΔI_B. Therefore the current gain introduced by the transistor is,

Current gain

$$= \frac{\text{Output current change } \Delta\Delta_C}{\text{Input current change } \Delta\Delta_B} = \frac{9\text{mA}}{0.01\text{mA}} = 900$$

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,

$$I_E = I_B + I_C \qquad .....[1]$$

or $I_C = I_E - I_B$

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,

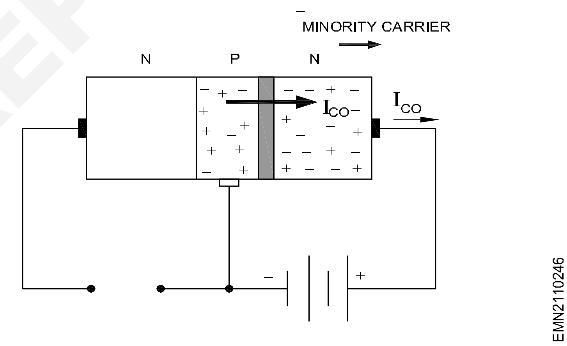
– There is no current in the base-emitter path as no bias voltage exists.

– 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 nano amperes 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.

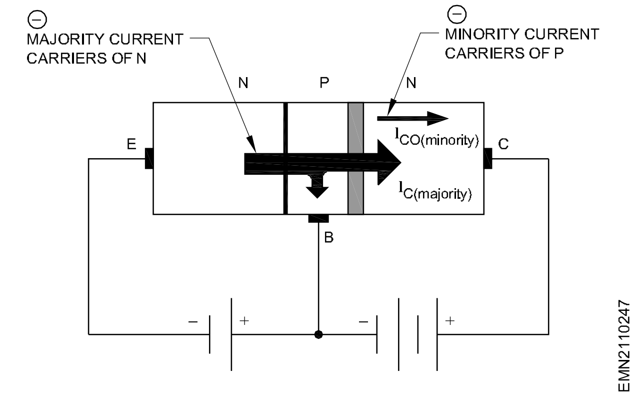
Fig 6



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,

Fig 7



$I_C = I_{C(majority)} + I_{CO(minority)}$ ....[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 milliamps

– value of I_{CO} will be in nanoamps to microamps

– value of I_B will be in microamps.

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

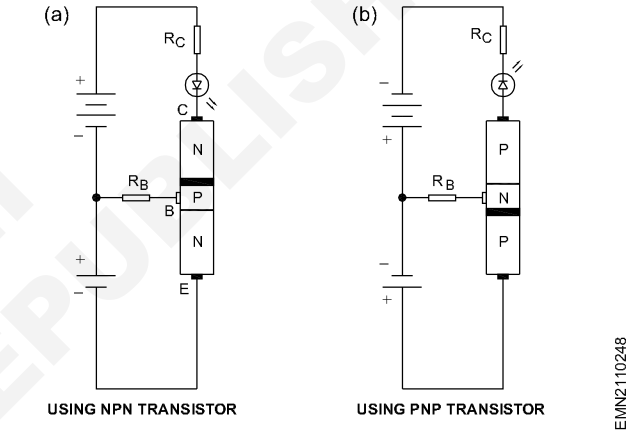
– The minority current I_{CO}, is due to electrons in the N-type base material instead of holes.

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 milliamps. 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 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.

Fig 8



Types of Transistor Biasing

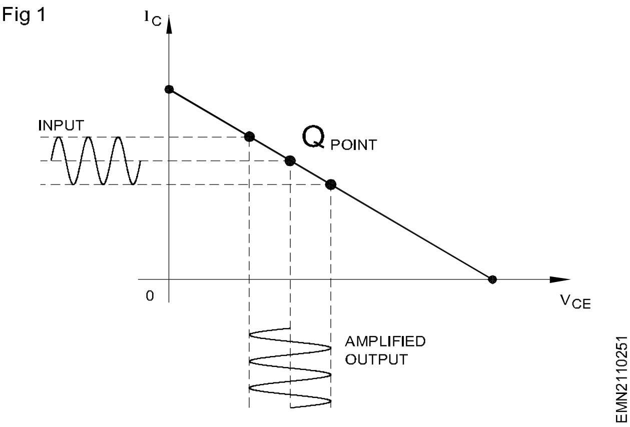
Objectives: At the end of this lesson you shall be able to
- **state the need for biasing of transistors**
- **state the reason for shifting of Q due to temperature and β_{dc} changes**
- **name the three main types of transistor biasing**
- **state the definition of amplifier**
- **list the classification of amplifier.**

Before any one rides a motor cycle or drives a car, he has to start the engine and keep the engine running. In simple terms biasing transistors is similar to keeping the transistor started before making the real use of it. Once the transistor is started, like the engine of a car, it can be made to amplify, like covering the distance by riding the car.

Before an AC signal is fed to a transistor, it is necessary to set up an operating point or the quiescent(Q) point of operation. Generally this Q point is set at the middle of the DC load line. Once the Q point is set, then the incoming ac signals can produce fluctuations above and below this Q point as shown in Fig 1.

The need for biasing of a transistor can also be explained as follows;

Fig 1



resion of transistor charatestics is obtained. It is neccessary that once oberatip boint in selected it should remain stable the maintenance of a point stable is called stabilisation.

For a transistor to remain operating in the linear region, the emitter diode must remain forward biased and the collector diode must remain reverse biased as long as the amplifier is amplifying. In other words, the amplitude variations in current and voltage of the input signal must not drive the transistor either into saturation or cut off.

Transistor stabilization with proper biasing a required quicent operating point of transistor amblifier in the active region, of transistor charatestic is obtained. It is necessary that maintenance of point stable is called stabilisation.

Stable Q point

A set Q point of a transistor amplifier may shift due to increased temperature and transistor b value changes. Therefore, the objective of good biasing is to limit this shifting of the Q point or to achieve a stable Q point.

Recall that, the Q point is nothing but a point in the output characteristic of the transistor. This point corresponds to a particular value of I_B, I_C and V_{CE}. Also recall that, the collector current I_C depends both on I_B and b of the transistor. If I_B changes, I_C changes, and hence, the Q point changes. If b changes, again I_C changes, and hence, the Q point gets shifted.

Shifting of Q due to temperature

Remember that a transistor is a temperature sensitive device. Any increase in the junction temperature results in leakage current. This increased leakage current in turn increases the temperature and the effect is cumulative. This chain reaction is called thermal run away. If this thermal run away is not stopped, it may result in the complete destruction of the transistor due to excessive heat. In transistors, due to this increased leakage current, the base current increases, and hence, the Q point gets shifted. This change in the set Q point affects the performance of the amplifier resulting in distortion.

Shifting of Q due to β_{dc} changes

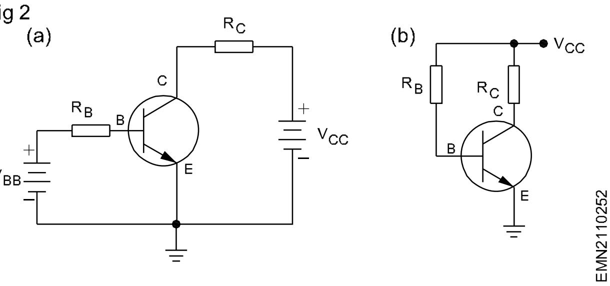
Recall that two transistors of the same type number may have different values of b. This is due to the manufacturing process of transistors. Hence, when a transistor is replaced or changed, due to different b of the replaced transistor, the Q point again gets shifted.

Therefore, a stable biasing is one which does not shift the Q-point even if temperature varies and/or the b of the transistor changes.

Types of transistor biasing: There are several ways to bias a transistor for linear operation. This means, there are several ways of setting up a Q point near the middle of the dc load line. Important biasing arrangements used with transistors are explained below:

Fig.2 Shows one type of biasing of transistor known as base-bias. As shown in Fig 2b, usually, the collector voltage supply itself is used for the base voltage instead of a separate supply.

Fig 2



The value of the base resistor R_B is fixed such that it allows the necessary Q point base current I_B. The value of R_B ensures that the base-emitter diode is always forward biased by allowing 0.7V(for silicon) across V_{EB}.

This type of biasing is the simplest of all. However, this is the worst possible way to bias a transistor because the DC Q point changes when,

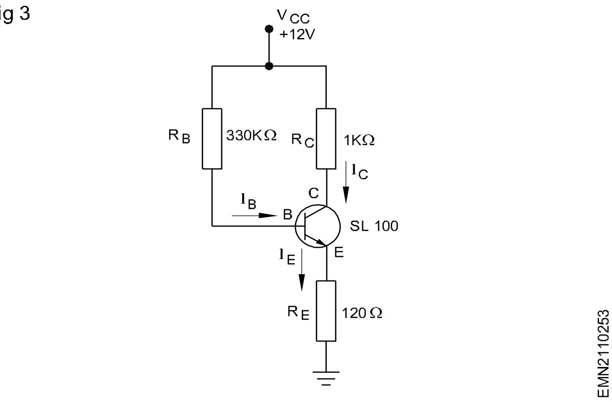
– temperature increases and

– β of the transistor is changed.

Hence, in a base-biased transistor, it is impossible to set up a stable Q point. Therefore, base biasing of transistors is not generally done in linear amplifier circuits. However, base biasing is commonly used in digital circuits (discussed in further lessons) where transistors are used as a switch and not as a linear amplifier.

2 **EMITTER BIAS or emitter feedback bias**: Fig.3 shows a emitter-biased transistor. This type of biasing compensates for the variations in β_{dc} and keeps the Q point fairly stable.

Fig 3



In Fig 3, if β_{dc} increases, the collector current increases. This in turn increases the voltage at the emitter. This increased emitter voltage decreases the voltage across the base-emitter junction and therefore, the base current reduces. This reduced base current results in less collector current, which partially offsets the increase in I_c due to increased β_{dc}.

Emitter bias is also referred to as emitter feedback bias. This is because an output quantity, i.e., the collector current, produces a change in an input quantity i.e., the base current. The term feedback means a portion of the output is given back to the input. In emitter bias, the emitter resistor is the feedback element because it is common to both the output and input circuits.

In Fig 3, if we add the voltages around the collector loop, we get,

$$I_C R_C + V_{CE} + I_E R_E - V_{CC} = 0 \quad .....\{1\}$$

Since I_E approximately equals I_C, (as I_B is comparatively very small), equation..(1) can be arranged as,

$$I_C = \frac{V_{CC} - V_{CC}}{R_C + R_E} ....\{2\} \quad .....\{2\}$$

If we add voltages around the base loop, we get,

$$I_B R_B + V_{BE} + I_E R_E - V_{CC} = 0. \quad .....\{3\}$$

Since $I_E \approx I_C$ and $I_B = I_C/b_{dc}$, we can rewrite the equation as,

$$I_C = \frac{V_{CC} - V_{BE}}{R_E + R_B/\beta_{dc}} ....(4) \quad .....\{4\}$$

From equation ...(4), the presence of term b indicates that I_C is dependent on b. The intention of emitter-feedback bias to swamp out the effect b_{dc}. This is possible when R_E is made much larger than R_B/b_{dc}. However, in practical circuits R_E cannot be made very large because, large value of R_E takes the transistor out of the linear operating region. Due to this problem, the emitter-feedback bias is almost as sensitive to changes in b_{dc} as is the base-bias. Therefore, emitter-feedback bias is also not a preferred form of transistor bias and should be avoided.

In emitter-bias, the saturation current will be,

$$I_{C(sat)} = \frac{V_{CC} - V_{CE(set)}}{R_E + R_C} ....[1]$$

When the transistor is saturated, the value of V_{CE} will be between 0.2 to 0.3V. Hence can be neglected for all practical purposes.

In Fig 3, the saturation current is,

$$Ic(set) = \frac{12\text{ V}}{1000\ \Omega + 120\ \Omega} = 10.71\text{ mA}.$$

Note: $V_{CE(sat)}$ of 0.2 volts is neglected.

When b_{dc} = 100, equation ...(4) gives,

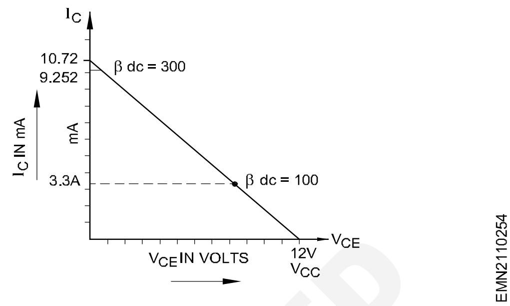
$$I_C = \frac{12\text{ V} - 0.7\text{ V}}{120\ \Omega + 330\text{ K}\Omega / 100} = 3.3\text{ mA}.$$

When b_{dc} = 300, the same equation...(4) gives,

$$I_C = \frac{12\text{ V} - 0.7\text{ V}}{120\Omega + 330\text{ K}\Omega / 300} = 9.262\text{ mA}$$

Fig 4 summarizes the calculations by showing the DC load line and the two Q points. As can be seen, a 3:1 change in b_{dc} produces almost a 3:1 change in the collector current. This change is unacceptable as a stable-biased state.

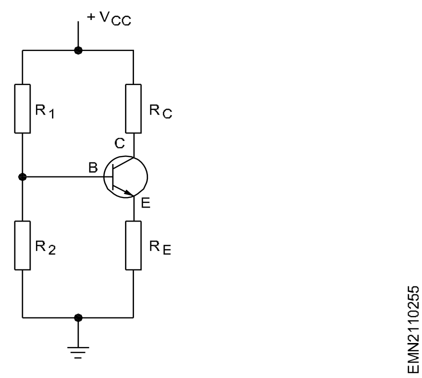
Fig 4



TIP: For linear operation of the transistor, the base resistor R_B should be greater than bR_C. A base resistance of less than $b_{dc}R_C$ produces saturation in an emitter-feedback-biased circuit.

3 Voltage - Divider bias: Fig 5 shows a typical voltage-divider bias. This type of biasing is also called the universal bias because, this is the most widely used type of biasing in linear circuits.

Fig 5



This type of biasing is known as voltage divider bias because of the voltage divider formed by resistors R_1 and R_2. The voltage drop across R_2 should be such that it forward biases the emitter diode.

Emitter current in voltage divider bias

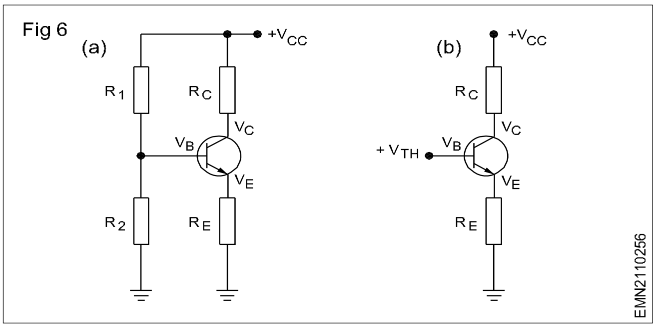
Assume that the base lead is open as shown in Fig 6b.

Looking back at the unloaded voltage divider,

$$V_{TH} = \frac{R_2}{R_1 + R_2} V_{CC} .$$

V_{TH} is known as the Thevinin's voltage. Refer reference books for Thevinin's theorem.

Now assume that, the base lead is connected back to the voltage divider as in Fig 6a. Then, voltage V_{TH} drives the base of the transistor. In other words, the circuit simplifies to Fig 6a and the transistor acts like the controlled current source.



Because the emitter is boot-strapped to the base,

$$I_E = \frac{V_{TH} - V_{BE}}{R_E}.$$

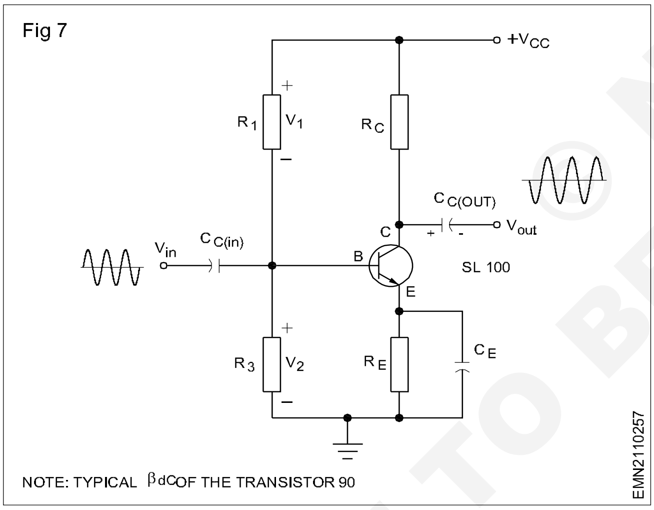
The collector current I_C will be approximately equal to I_E.

Notice that b_{dc} does not appear in the formula for emitter current. This means that the circuit is not dependent on variations in b_{dc}. This means that the divider-biased transistor has a stable Q point.

Because of the stable Q point, voltage-divider bias is the most preferred form of bias in linear transistor circuits. Hence, divider bias is used almost universally.

Simple voltage divider bias design guidelines

Fig 7 shows an amplifier using voltage-divider bias.



The capacitors C_C couple the ac signal into and out of the amplifier. The capacitor C_E is used to by-pass AC signals. A small AC input voltage drives the base, and an amplified AC output voltage appears at the collector.

In Fig 7, as far as the dc voltages and current is concerned, the capacitors appear like open circuits. Hence they can be neglected while designing the circuit for a stable Q point.

Design Step 1

Choose V_E equal to one-tenth of the chosen V_{CC}.

In Fig 7,

$V_E = 0.1V_{CC}$

$= 0.1 \times 12\ V = 1.2\ V.$

Design Step 2

Fix the required value of I_C almost equal to I_E. Ensure that the worst case chosen I_C is less than $I_{C(max)}$ of the transistor given in the data book.

For Fig 7, fix $I_E \approx I_C = 10$ mA.

$$\text{Therefore, } R_E = \frac{V_E}{I_E} = \frac{1.2\ V}{10mA} = 120\ \Omega$$

Design Step 3

To locate the Q point at approximately the middle of the DC load line, fix $V_{CE} = 0.5\ V_{CC}$.

Therefore, $V_{CE} = 0.5\ V_{CC} = 0.5 \times 12\ V = 6\ V$.

Hence, $V_{RC} = V_{CC} - V_{CE} - V_E = 12 - 6 - 1.2 = 4.8$ V.

$$\text{Therefor, } R_E = \frac{V_{RC}}{I_C} = \frac{4.8V}{10mA} 480\ \Omega$$

Choose the nearest 470W as R_C.

TIP : With the above design rule, without calculation, you can simply choose the value of R_C as,

$R_C = 4 \times R_E = 4 \times 120 = 480W$ which is the same as calculated in step 3.

Design Step 4

To make a stiff voltage divider, apply the 10:1 rule,

i.e., $R_2 \leq 0.1\ \beta_{dc}\ R_E$.

NOTE: Take the typical value of $\boldsymbol{\beta}_{dc}$ from data book.

In Fig 7, with $\beta_{dc} = 90$

$R_2 \leq 0.1 \times 90 \times 120$ W = 1080 W.

Therefore, choose $R_2 = 1000$ W = 1 KW

Design Step 5

Find the voltage divider voltages V_1 & V_2.

$V_2 = V_{BE} + V_E$

In Fig 7, $V_2 = 0.7\ V + 1.2\ V = 1.9\ V$

Therefore, $V_1 = V_{CC} - V_2$.

In Fig 7, $V_1 = V_{CC} - V_2 = 12\ V - 1.9\ V = 10.1\ V$.

Calculate R_1 using the formula,

$$R_1 = \frac{V_1}{V_2} R_2.$$

In Fig 7,

$$R_1 = \frac{10.1V}{1.9V} 1000\Omega = 5.3K\Omega \approx 5.6K\Omega$$

This completes the design of the voltage-divider bias for the transistor amplifier at Fig 7.

Fig 8a shows the transistor amplifier with the designed values of components.

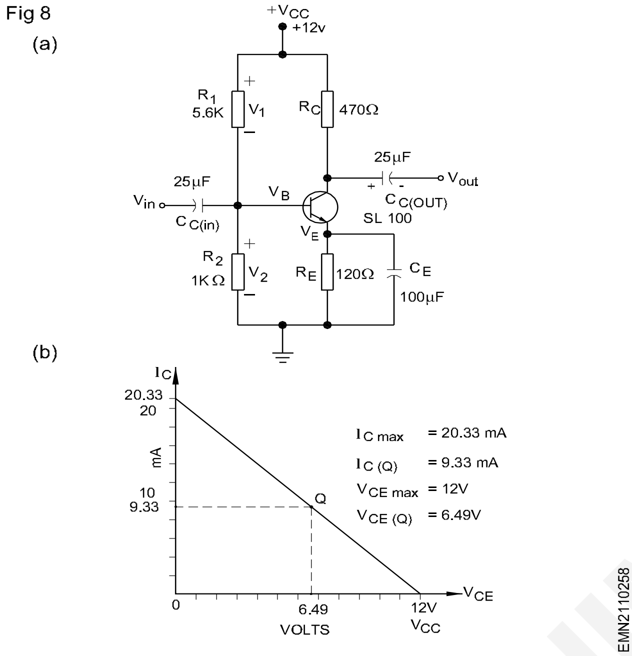
Fig ~~8b sho~~ws the DC load line and the Q point. As can be seen in Fig 8b, the Q point is near the middle of the dc load line. Hence, the designed circuit works in the linear portion of the transistor characteristic curve.

To cross check the above design we can calculate values of voltages and currents using the formulas given below;

$$V_B = \frac{R_2}{R_1 + R_2}.V_{CC}$$

Let us call the parallel combination of R_1 and R_2 as R_{BB}.

Fig 8



$$I_B = \frac{V_B - V_{BE}}{R_{BB} + (\beta + 1) R_E}$$ (See note given below)

$I_C = \beta I_B$

$V_{CE} = V_{CC} - I_C (R_C + R_E)$

NOTE: The formula given for I_B is,

$$I_B = \frac{V_B - V_{BE}}{R_{BB} + (\beta + 1)R_E}$$

This formula is arrived as given below;

$I_E = I_C + I_B$

$I_E = \beta I_B + I_B$

$I_E = (\beta+1)\, I_B$

In a divider bias, the effective resistance of $R_1 \| R_2$, denoted as R_{BB} is given by,

$$R_{BB} = \frac{R_1 . R_2}{R_1 + R_2}$$

The effective bias voltage is represented as VB is given by,

$$V_B = \frac{R_2}{R_1 + R_2}.V_{CC}$$

Writing the Kirchhoff's voltage equation for the base emitter loop at Fig 8,

$V_{CC} - I_B.R_{BB} - V_{BE} - I_E R_E = 0$ .....(1)

Note that R_{BB} is the effective resistance of parallel combination of R_1 and R_2.

Since $I_E = (\beta+1)\, I_B$

Rewriting equation...(1)

$V_{CC} - V_{BE} - I_B.R_{BB} - (\beta+1)\, I_B\, R_E = 0$

Solving the equation, we get, $I_B = \dfrac{V_{CC} - V_{BE}}{R_{BB} = (\beta + 1)R_E}$

Bias stabilisation transistor to be developed

Transistor bias stability: Through proper biasing, a desired quiescent operating point of the transistor amplifier in the active region (linear region) of the characteristics is obtained. It is desired that once selected the operating point should remain stable. The maintenance of operating point stable is called bias stabilisation.

Bias stabilization:

While designing the biasing circuit, care should be taken so that the operating point will not shift into an undesirable region (i.e, into cut - off or saturation region) Factors to be considered while designing the basing circuit:

Temperature dependent factors,

Transistor current gain the flow of current in the circuit produces heat at the junctions. This heat increases the temperature at the junctions.

Since the minority carriers are temperature dependent (gets doubled for energy 10C raise in temperature), they increase with the temperature.

2.5mv°/c depends on since = increase in Increase This in turn changes the operation point.

STABLIZATION TECHNIQUE:

This refers to the use of resistive biasing circuits which allow to vary the bias so as to keep Relatively constant with variations.

COMPENSATION TECHIQUE:

This refers to the use of temperature sensitive devices as diodes, transistors, thermistors, etc, which provide compensating voltages and current to maintain the operating point stable.

STABILITY FACTORS:

The stability factor is a measure of stability provided by the biasing circuit.

Stability factor indicates the degree of change in operating point due to variation in temperature.

Since there are 3 temperature dependent variable, there are 3 stability factors.

Idealy, stability factor should be perfectly zero to keep the operating point stable.

Practically stability factor should have the value as minimum as possible.

The purpose of an amplifier: An amplifier is an electronics device which is used to amplify or increase the e level of week input signal into very high output signal. Transistors are used as amplifier in most of circuit. In addition resistor capacitor and biasing battery are required to form complete amplifier circuit.

Almost all the electronics system works with amplifier. we are able to hear the news or other program on radio. Simply because the amplifier amplifies the weak signal received by the antenna.

Classification of Amplifiers: Various of amplifiers description are based on the following factors.

1. Based on the transistor configuration
   a. Common emitter (CE) amplifier.
   b. Common collector (CC) amplifier
   c. Common base(CB) amplifier
2. Based on the output
   a. Voltage amplifier
   b. Current amplifier
   c. Power amplifier
3. Based on the input
   a. Small signal amplifier
   b. Large signal amplifier
4. Based on coupling
   a. RC coupled amplifier
   b. Transformer coupled amplifier
   c. Impedance coupled amplifier
   d. Direct coupled amplifier
5. Based on frequency response
   a. audio frequency (AF) amplifier
   b. intermediate frequency amplifier
   c. radio frequency (RF) amplifier
   d. VHF and UHF amplifier
6. Based on the feedback
   a. current series feedback amplifier
   b. Current parallel feedback amplifier
   c. Voltage series feedback amplifier
   d. Voltage parallel feedback amplifier
7. Based on biasing condition
   a. class A power amplifier
   b. class B power amplifier
   c. class AB power amplifier
   d. class C power amplifier

Of the above mentioned serial number one and two are explained at this state. Some of the amplifier deals in this book for detailed study can refer to any standard book for the remaining portions depending on their special interest.

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.

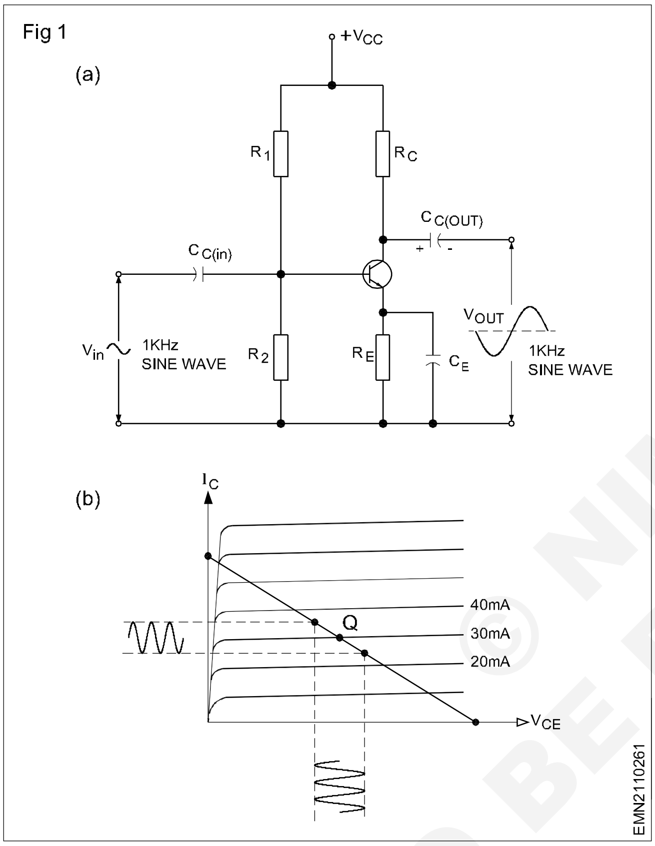
Fig 1b, shows the DC load line, the Q point and AC input and output signals. This is generally referred to as the *AC* load line. As can be seen from Fig 1b, the AC input voltage produces variations in the base current. This results in sinusoidal variations about the Q point. Variations in Q point are 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 ±10% of the collector current at Q point to keep the distortion in the amplified output with in 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 b_{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 b_{dc} of the transistor is 100, then the current gain A_i of the amplifier can be taken as 100.

Voltage gain, A 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 m $V_{(p-p)}$ and the corresponding output voltage v_{out} is 7.2 $V_{(p-p)}$, then the voltage gain A_V is given by,

$$\text{Voltage gain, } A_V = \frac{7.2_{(p-p)}}{80\text{m } V_{(p-p)}} = 90$$

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.

$$Z_{in} = \frac{v_{in}}{i_{in}}$$

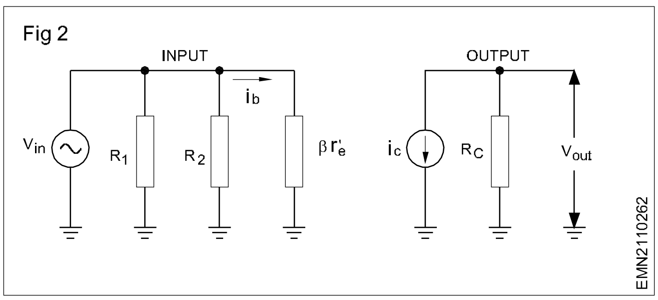
where, V_{in} and i_{in} are rms or peak or peak-to-peak values.

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,

$$Z_{in} \approx R_1 \parallel R_2 \parallel \beta r'_e \qquad .....[1]$$

where,



R_1 and R_2 are the voltage divider resistors,

b 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 b is 100, the input impedance Z_{in} will be,

br'_e = 100(25 W) = 2.5 KΩ

$Z_{in} = R_1 \parallel R_2 \parallel b\,r'_e$

= 18 KW ∥ 8.2 KW ∥ 2.5 KΩ

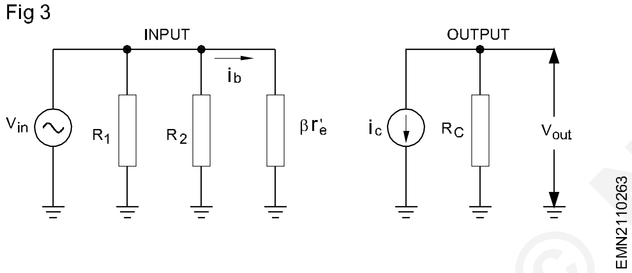
= 1.73 KΩ

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.

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.

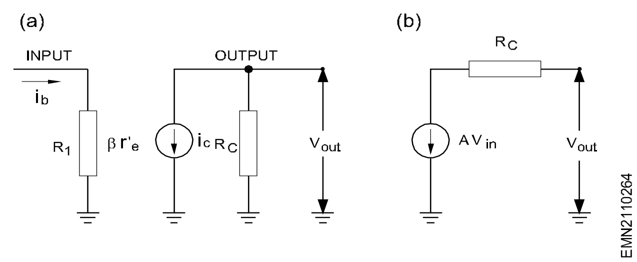
Output impedance, Z_{out}

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.

Fig 4



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 Thevinin's voltage appearing at the output is the voltage gain(A) times the input v_{in}.

Therefore, $V_{out} = A.v_{in}$

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 = 1000W, the output impedance of the amplifier is equal to the value of R_C, that is 1000 W.

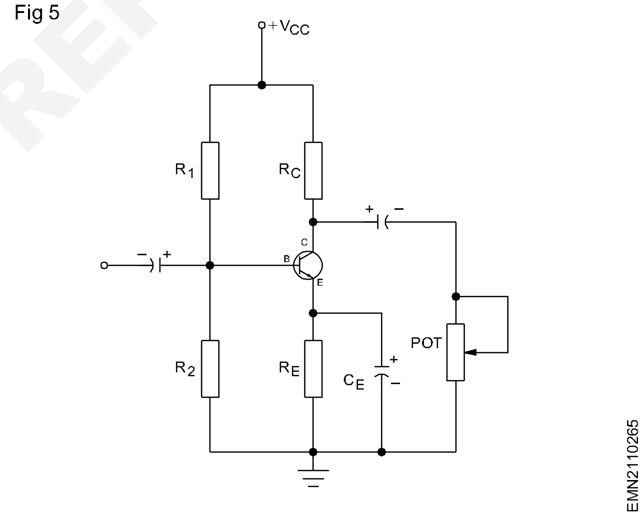
Practical way of finding Z_{out}

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.

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,

$P_{in} = v_{in}.i_b$

and the output power is given by,

$P_{out} = - v_{in}.i_b$

The negative sign associated with output power. This is because, in a CE amplifier, the output is 180° 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,

$A_p = – A_v . A_i$

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 b of the transistor is 100, then the power gain A_p of the amplifier is given by,

$A_p = - A_v.A_i = 90 \times 100 = 9000.$

This means that if an AC input power of 1 µW is given to the amplifier, the output power will be 9mwatts.

Practical way of finding A_p

Since the formula for power is, $P = I^2 \times R = I \times I \times R$

Since,

$$I = \frac{V}{R} \text{ (substituting this in above equation, we get)}$$

$$P = \frac{V^2}{R}$$

Therefore, by Ohm's law, power gain is easy to calculate when signal voltages and impedances are known as given below;

$$P_{out} = \frac{V_{out}{}^2}{Z_{out}} \quad \text{and} \quad Pin = \frac{V_{in}{}^2}{Z_{in}}$$

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° 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 µA. The corresponding collector current is 1 mA. When the AC signal is applied to the input, the base bias varies from 20 to 40 µA, as shown in Fig 1b. Since the type of transistor used is NPN, as base bias is increased to 40 µA, 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 µA, 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° out of phase with the input.

Effect of bypass Capacitor in CE Amplifiers

Objectives: At the end of this lesson you shall be able to
- **state the effect of emitter resistor bypass capacitor on,**
  - **the gain of the amplifier**
  - **input impedance of the amplifier**
  - **quality of the amplified output.**

Figs 1a and 1b show common-emitter amplifiers. The difference between the two circuits is that in Fig 1a, there is a capacitor C_E connected across the emitter resistor R_E. This capacitor is known as a bypass capacitor.

The function of the bypass capacitor are;

– to provide a low resistance path for the AC signals

– to behave as open circuit for DC signals.

The effect of the bypass capacitor are;

– increased gain of the amplifier

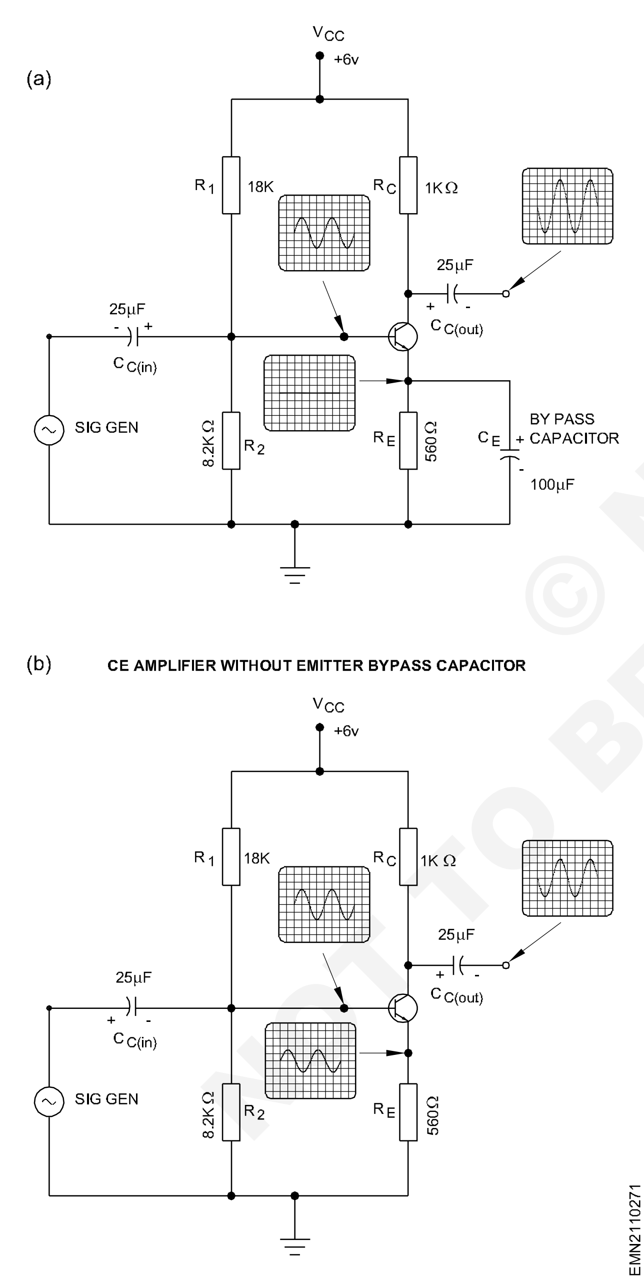
– decreased input impedance of the amplifier.

Effect of C_E on amplifier gain

To understand the effect of the bypass capacitor on the gain of the amplifier, observe the phase relationship of the waveforms at base, emitter and collector shown in Figs 1a and 1b.

As can be seen in Fig 1b, the AC signal at the emitter is in phase with the input signal. Recall that both input and output currents flow through the emitter resistor R_E.

Fig 1 CE AMPLIFIER WITH EMITTER BYPASS CAPACITOR



If R_E is not bypassed as in Fig 1b, then,

– as the input signal increases, the collector current increases, and hence, the voltage drop across R_E increases. This result in increased voltage at the emitter terminal.

– the increased voltage at the emitter results in a reduced base-emitter voltage

– this reduced V_{BE} results in less forward bias of the transistor, and hence, the collector current decreases.

Therefore, the overall effect of an un-biassed emitter resistor is that, the collector current is not allowed to freely increase for increase in the base current. Hence, the gain of the amplifier is held at almost a constant value.

If R_E is bypassed as in Fig 1a, then,

– as the input signal increases, the collector current increases. Since the emitter resistor is bypassed, the biass capacitor provides a very low resistance path for the AC current, and hence, voltage at the emitter does not increase

– since the emitter voltage does not increase, the emitter-base junction remains at increased forward bias and the increased collector current continues to flow

Therefore, the overall effect of a bypassed emitter resistor is that the collector current is allowed to freely increase for increase in the base current. Hence, the gain of the amplifier increases.

Summarizing the above effect, in a CE amplifier with the emitter resistor bypassed, the gain of the amplifier is higher when compared to that of an un-bypassed emitter amplifier.

The input impedance of a emitter resistor bypassed CE amplifier is given by,

$$Z_{in} = R_1 \parallel R_2 \parallel \beta r'_e.$$

For the emitter bypassed amplifier shown in Fig 1a, the input impedance will be,

$$Z_{in} = 18\ K \parallel 8.2\ K \parallel 100(25).$$

$$= 1.73\ KW$$

Now if the emitter resistor is not bypassed by a capacitor as shown in Fig 1b, then, the input impedance is given by,

$$Z_{in} = R_1 \parallel R_2 \parallel \beta\,(r'_e+R_E).$$

The resistor R_E is now in series with r'_e.

For the un-bypassed amplifier shown in Fig 1b, the input impedance will be,

$$Z_{in} = 18\ K \parallel 8.2\ K \parallel 100(25 + 560)$$

$$= 5.14\ K\Omega.$$

The above comparison of Z_{in} for bypassed and un-bypassed emitter CE amplifier indicates that the input impedance of the amplifier decreases drastically when the emitter resistor of the CE amplifier is bypassed with a capacitor.

Summarizing, in a CE amplifier if the emitter

resistor by passed the input-impedance of the amplifier reduces drastically when compared to the input-impedance of a CE amplifier with un-bypassed emitter resistor.

Disadvantage of bypassing emitter resistor

Although bypassing the emitter capacitor increases the gain of the amplifier, it has the following disadvantages which are very important to be considered;

– The reduced input impedance due to bypassed R_E has the loading effect on the source of the AC signal feeding the amplifier. This is very important especially when the source feeding the input is a weak signal such as the output of a R/P head of a tape recorder, crystal pick-up of a gramophone etc.,

– In a bypassed R_E amplifier, the voltage gain changes throughout the input cycle. This changing voltage gain may results in a distorted output signal.

As a compromise between an unbypassed emitter resistor and a bypassed emitter resistor, some amplifier circuits use partially bypassed emitter resistor as shown in Fig 2.

The effect of partially bypassed emitter resistor on the gain and input impedance is given below;

$$V_{out} = i_C R_C$$

(The -ve sign indicates that output is 180 out of phase with the input)

The AC voltage across $r_E + r'_e$ is,

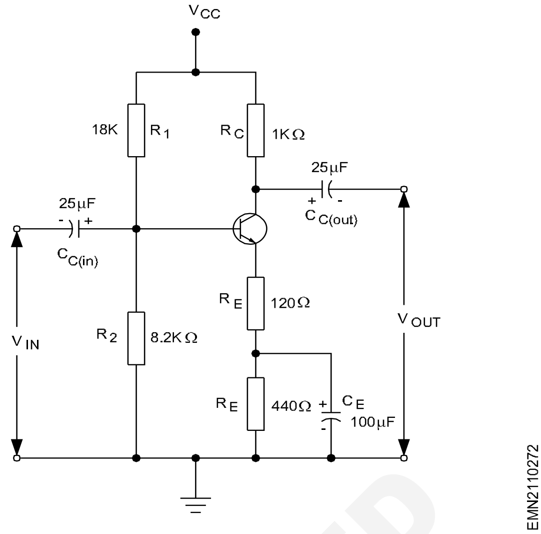
$$V_{in} = i_e (r_E + r'_e)$$

Therefore, voltage gain A_v is,

$$A_v = \frac{V_{out}}{V_{in}} = \frac{-i_c R_c}{i_e (r_E + r'_e)}$$

$$\text{Since, } I_e \ I_c, A_v = \frac{-Rc}{r_E + r'_e}$$

Fig 2



In a fully bypassed emitter resistor, the value of Av was given by

$$A_v = \frac{-R_c}{r'_e}$$

The input impedance Z_{in} of the partially by passed emitter resistor is given by,

$$Z_{in} = R_1 \parallel R_2 \parallel \beta(r_E + r'_e)$$

For the values of R_E and r_E shown in Fig 2, the input impedance Z_{in} is,

$$Z_{in} = 18K \parallel 8.2K \parallel 100(120+25)$$

$$\approx 4.06 \text{ K}\Omega$$

Note that this value of Z_{in} is in between those of fully bypassed and unbypassed emitter resistor.

Frequency Response of Common Emitter Amplifier

Objectives: At the end of this lesson you shall be able to
- **state the meaning of frequency response of an amplifier**
- **state the effect of capacitors on the frequency response of a CE amplifier**
- **find the theoretical lower cut off frequencies of an amplifier, given the values of coupling and bypass capacitors.**

Recall, when a 1kHz sine wave is fed at the input of an amplifier, the output will be an enlarged 1 kHz sine wave. The amount, by which the output voltage is enlarged, depends on the voltage gain of the amplifier.

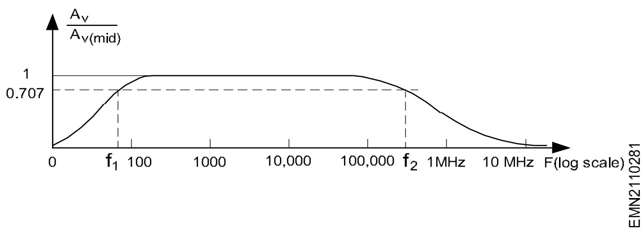
In the same amplifier, instead of a constant frequency 1kHz signal, if the frequency of the input signal is varied, from say 0 Hz (DC) to several tens of kilo Hertz, then the extent to which the input level is enlarged at the output will be different at different frequencies. In other words, the gain of the amplifier will not be the same for all frequencies.

The reason for the gain to be different at different frequencies is mainly due to the capacitors used in the amplifier circuit. In addition to these capacitors, the transistor itself is a reason for the gains to be different at different frequencies. But the effect of the transistor is negligible at low and medium frequencies.

Fig 1 shows a typical plot of gain of an amplifier at different frequencies. Note that in Fig 1, the Y axis represents the gain of the amplifier at different frequencies as a measure of the gain at mid frequency $A_{v(mid)}$.

From Fig 1, it is clear that in a capacitor coupled amplifier as in Fig 2a, the gain falls sharply towards *0* frequency and also at high frequencies. The fall in gain in the lower frequency range is mainly due to the effect of coupling capacitor C_C and bypass capacitor C_E of the amplifier.

Fig 1



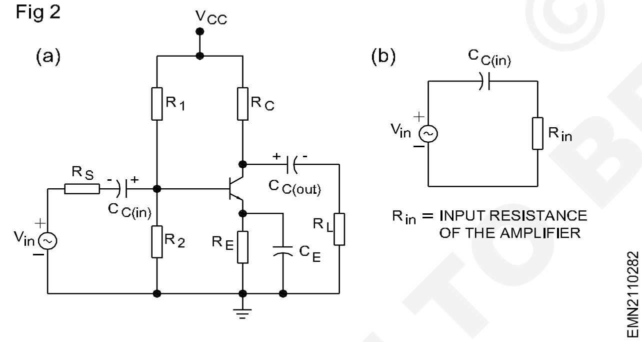
Effect of input coupling capacitor $C_{C(in)}$ on frequency response of CE amplifiers

Fig 2a shows the typical common emitter amplifier using coupling and bypassing capacitor. To understand the effect of $C_{C(in)}$, assume that the values of C_E and $C_{C(out)}$ are very large and have no effect on the frequency response of the amplifier.

The input section of the amplifier in Fig 2a can be simplified as shown in Fig 2b. In Fig 2b, R_{in} represents the input Resistance/Impedance of the amplifier.

Considering the effect of the coupling capacitor C_{Cin} for AC signals, the coupling capacitor has,

Fig 2



– very high resistance(impedance) X_C at very low frequencies and is almost infinity or open at zero frequency (DC).

$$\left(\text{Recall } X_c = \frac{1}{2\pi fC} \right)$$

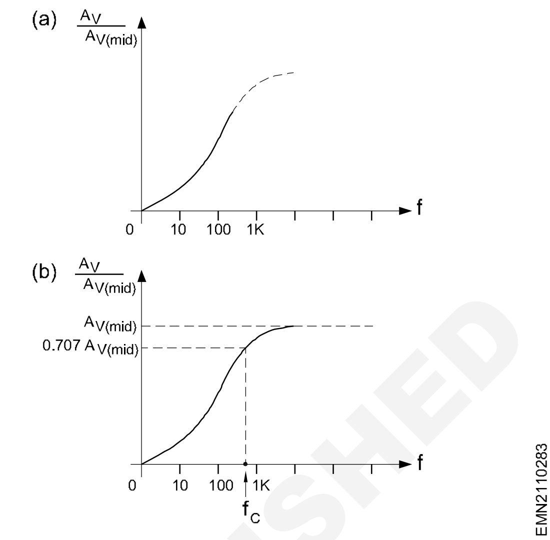
– no effect, or it behaves as a short at the mid-band frequencies, say greater than 1 kHZ and less than few hundred kHZ.

The above listed effects of the coupling capacitor $C_{C(in)}$ is because, the capacitive reactance X_C is inversely proportional to frequency f as given below;

$$X_c = \frac{1}{2\pi fc}$$

When f= 0 Hz, X_C = Infinity. Hence, the voltage across R_{in} will be zero. Therefore, at zero input frequency the output of the amplifier is 0. But as the frequency increases the voltage across R_{in} increases (as X_C decreases) and hence, the output increases. This is shown in Fig 3a.

Fig 3



As the input frequency is further increased, X_C decreases and approaches zero. Therefore, all the applied input voltage V_{in} appears across the input of the transistor. Hence, the gain of the amplifier will be high as shown in Fig 3b.

Referring to the amplifier response at low frequencies shown in Fig 3b, at a particular frequency known as the cut-off frequency $f_{C(in)}$, the reactance X_C will become equal to R_{in}. At this frequency $f_{C(in)}$, the input section of the amplifier behaves as a AC voltage divider. Hence the output voltage of the input RC network shown in Fig 2a (also known as lag network) is given by,

$$V_{out} = \frac{R_{in}}{\sqrt{R_{in}^2 + X_c^2}} V_{in} \quad \text{......[1]}$$

$$\frac{V_{out}}{V_{in}} = \frac{R_{in}}{\sqrt{R_{in}^2 + X_c^2}}$$

At cut-off frequency $f_{C(in)}$,

since, $X_C = R_{in}$,

$$R_{in} = \frac{1}{2\pi\pi_{c(in)} C_{c(in)}}$$

Therefore the critical frequency $f_{C(in)}$ is given by,

$$f_{c(in)} = \frac{1}{2\pi R_{in} C_{c(in)}} \text{.......[2]}$$

The source feeding the amplifier will have some amount of resistance coming in series as shown in Fig 4.

If this series resistance or the source resistance R_S is also considered in the input section of the amplifier, then the lower cut off frequency f_C is given by,

$$f_{c(in)} = \frac{1}{2\pi (R_s + R_{in}) C_{c(in)}} \quad [3]$$

In the CE amplifier shown in Fig 2a, R_{in} is 1.73KΩ and source resistance R_S is 1 KΩ. If the value of input coupling capacitor $C_{C(in)}$ is increased from 0.047μF to 10μF, the lower cut off frequency $f_{C(in)}$ for different values of $C_{C(in)}$ will be,

using the formula at equation ...{2},

for

$C_{C(in)}$ = 0.047μF = $f_{C(in)}$ = 1240 Hz

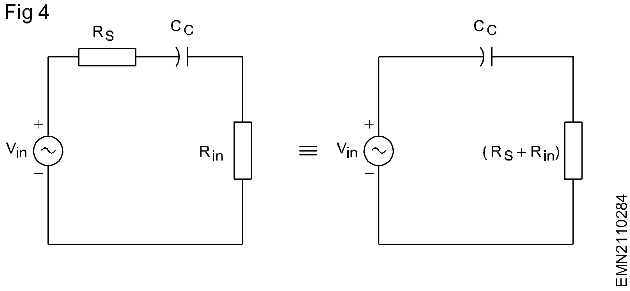
$C_{C(in)}$ = 0.47μF = $f_{C(in)}$ = 124 Hz

$C_{C(in)}$ = 4.7μF = $f_{C(in)}$ = 12.4 Hz

$C_{C(in)}$ = 10μF = $f_{C(in)}$ = 5.83 Hz.

From the above calculated values, it is clear that for the amplifier to work as an audio-amplifier(20Hz to 20 KHz), the value of the input coupling capacitor to be chosen should be 4.7μF or more.

Fig 4



Half-power point

At the lower cut-off frequency $f_{C(in)}$, the reactance of the input coupling capacitor X_C = R_{in}. If we substitute this into equation ..(1), we get

$$\frac{V_{out}}{V_{in}} = 0.707$$

This means, the voltage gain at the cut-off frequency will be 0.707 times the gain at mid frequency $A_{v(min)}$. Hence, the cutoff point $f_{C(in)}$ is sometimes called the *half-power point* because at this point, the available output power is half of its maximum value.

Feedback in Amplifiers

Objectives: At the end of this lesson you shall be able to
- **state the meaning of the term feedback**
- **state the meaning and effect of degenerative feedback**
- **state the meaning and effect of regenerative feedback**
- **list the advantages of negative feedback in amplifiers**
- **state the equation for gain of the amplifier with a feedback**
- **calculate the feedback factor k from the circuit component values in a CE amplifier.**

Meaning and effect of feedback

The term feedback means, the output signal of a circuit is given back (fed back) to the input of the same circuit.

In feeding back the output signal to input, if the fed back signal is *180° out-of phase* with the input signal, then such a feedback is referred to as Negative feedback or degenerative feedback. This type of feedback is known as degenerative because, the feedback signal opposes the input signal lowering is magnitude. Hence, the gain of the amplifier decreases.

On the other hand, if the feedback signal is in-phase with the input signal, then such a feedback is referred to as positive feedback or regenerative feedback. In a circuit with positive feedback, the fedback signal being in-phase with the input, increases the magnitude of the input signal resulting in high to very high gain of the amplifier. Positive feedback in amplifiers result in what is known as oscillations.

Although negative feedback results in reduced output of an amplifier, this type of feedback is extensively used in most of the electronic circuits because of the following advantages, negative feedback in amplifiers results in,

– stabilized voltage gain

– reduction in distortion of the amplifier output

– widening of the amplifier frequency band width

– increased input impedance

– reduced output impedance

– reduced noise in amplifier.

All radios, tape recorders and televisions invariably use negative feedback in circuits for a function called Automatic volume control or Automatic gain control (AGC).

Positive feedback is used to generate AC signal using dc supply voltage in what are known as oscillators. Signal generators which generates sinusoidal signals invariably use positive feedback in their circuits.

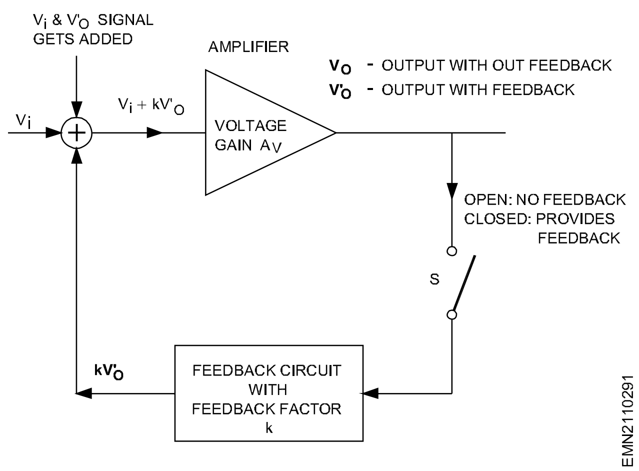
Principle of negative feedback

The principle of feedback involving feeding a signal (voltage or current) back from the output of an amplifier or a system to the input of the amplifier is shown in Fig 1.

In Fig 1 above, if the feedback switch is open then there will be no feedback. The amplifier gain will then be,

$$A_V = \frac{V_0}{V_i}$$

Fig 1



If the feedback switch is closed, then a portion of the output gets added to the input and the new output of the amplifier would be V'_O.

If the feedback switch remains ON, then portion of the new output = kV'_O is added to the input V_i. Hence, the new input to the amplifier will be $V_i + kV'_O$.

If the phase of kV'_O is 180° out-of-phase with V_i then,

$V_i + kV'_O$ will be less than V_i. This is the condition of negative feedback.

If kV'_O happened to be in-phase with V_i, then, $V_i + kV'_O$ will be greater than V_i. This is the condition of positive feedback.

It can be shown that, the overall gain of the amplifier with the feedback being either positive or negative is given by,

$$A_{Vf} = \frac{V'_0}{V_i} = \frac{A_v}{1 - kA_v} \qquad .... [1]$$

where,

A_{Vf} = voltage gain with feedback

A_v = voltage gain without feedback

k = feedback factor, usually between 0 and 1.

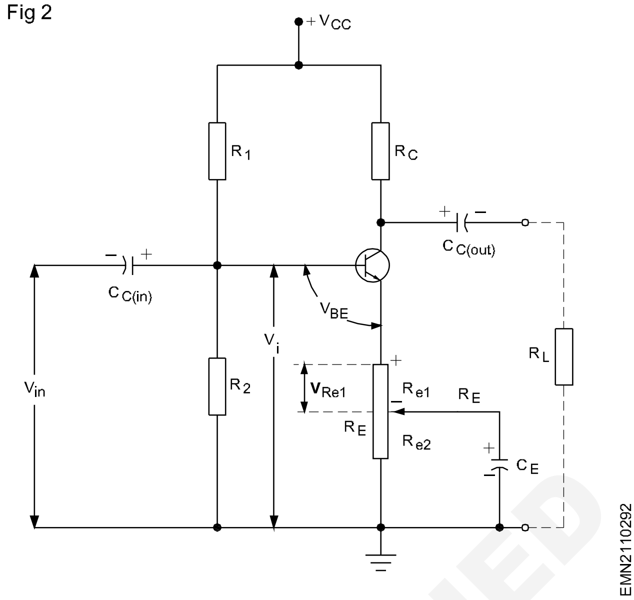
In the above equation, the term kA_v is known as the loop gain of the circuit. In negative feedback, kA_v is negative. Hence the denominator increases and, therefore, A_{Vf} decreases.

In regenerative or positive feedback kA_V, is positive; hence the denominator of equation [1] decreases, therefore A_{Vf} increases. This increase in A_{Vf} causes oscillations in the amplifier, and hence, converts the amplifier to an oscillator.

Negative feedback in common emitter amplifiers

Fig 2 shows one method of providing negative feedback in a common emitter amplifier.

Fig 2



In the amplifier at Fig 2, by not-bypassing the emitter resistor, an ac negative feedback occurs in the amplifier. The unshunted portion or the un-bypassed portion of the emitter resistor R_{e1}, has a voltage drop of V_{Re1}. This voltage V_{Re1} directly subtracts from the input voltage V_i, reducing the base emitter voltage of the transistor. That is, $V_{BE} = V_i – V_{Re1}$.

It can be shown that the amount of voltage feedback or feedback factor k is given by,

$$k = \frac{R_{e1}}{R_{out}}$$

where,

k is the feedback factor (dimension less)

R_{e1} is the un-bypassed emitted resistor in ohms.

R_{out} is the total ac load resistance = R_C / R_L in ohms.

This type of negative feedback obtained in CE amplifiers, due to un-bypassed emitter resistor is known as *current series feedback*. In this type of feedback the output current ($I_C \simeq I_E$) is sampled and a proportional voltage (across unbypassed R_E) is made to come in series with the input. This type of feedback is also known as non-inverting current feedback because current at the input (Base) is in phase with the current at output (emitter) circuit.

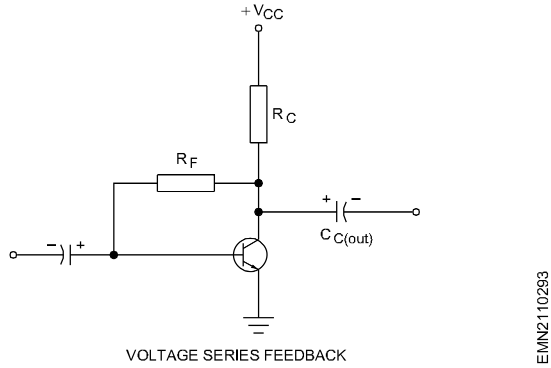
Fig 3 shows another type of negative feedback in a common emitter amplifier. This type of feedback is known as voltage series feedback.

The type of feedback shown in Fig 3, is also known as inverting voltage feedback. This method of connecting a resistor between the collector and base of a transistor resulting in a feedback is one of the methods of dc biasing of a transistor, and is also known as collector feedback configuration.

Other methods of negative feedback

In addition to the above discussed current series feedback and voltage series feedback, there are several other methods of providing negative feedback in amplifiers. Some of them are, voltage shunt feedback and current shunt feedback.

Fig 3



VOLTAGE SERIES FEEDBACK

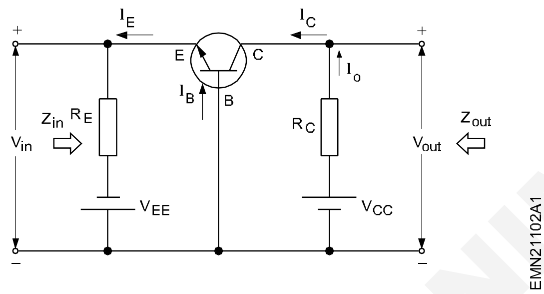
Common Base Amplifier

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.**

Fig 1 shows the typical circuit schematic of a **common base amplifier** (CB-amplifier).

Fig 1



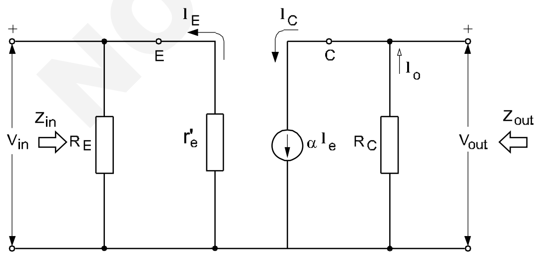
Common base amplifiers have a current gain of less than 1. Recall, the emitter current and the collector current of a transistor are almost equal. In a common base amplifier since the input current is I_E and the output current is I_C, the current gain, symbolically represented as a (alpha), is given by,

$$\text{Current gain } (\alpha) = \frac{\text{Output current}}{\text{Input current}} = \frac{I_C}{I_E}.$$

Since $I_E > I_C$, a will always be less than 1.

Fig 2 shows the ac equivalent of a common base amplifier, shown in Fig 1.

Fig 2



AC EQUIVALENT OF CB AMLIFIER

From Fig 2, the input impedance Z_{in} of CB amplifier is given by,

$$Z_{in} = R_E \parallel r'_e \qquad .....\{1\}.$$

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 25Ω).

Referring to the AC equivalent network of the CB amplifier, the output impedance Z_{out} of CB amplifier is given by,

$$Z_{out} = R_C \qquad ......\{2\}.$$

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

$$V_{out} = I_o R_C = I_c.R_C$$

Since $\alpha = \frac{I_C}{I_E}$, $I_C = \alpha.I_E$

Therefore, $V_{out} = I_C R_C = a.I_E.R_C$ ....{3}.

Since, $I_E = \frac{V_{in}}{r'e}$ equation 3 can be written as,

The voltage gain A_V of CB amplifier is given by,

$$A_V = \frac{V_{out}}{V_{in}} = \alpha \frac{V_{in}}{r'_e} R_C \frac{1}{V_{in}} = \alpha \frac{R_C}{r'_e} \qquad ......\{4\}$$

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,

$$A_P = A_i.A_V$$

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

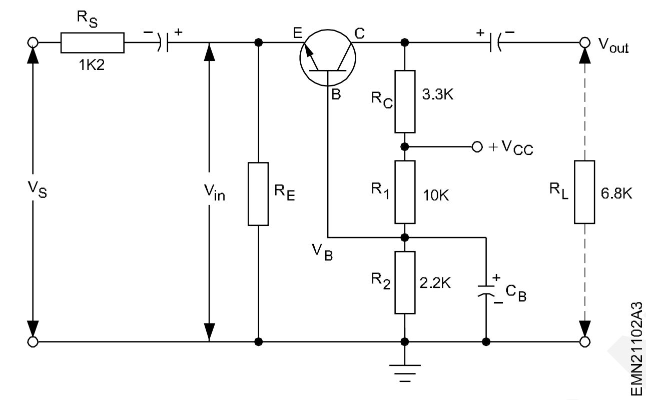
The input and output of a common base amplifier are in phase with each other. This can be found experimentally.

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,

Fig 3



$$V_B = \frac{R_2}{R_1 + R_2} V_{cc}$$

$$= \frac{2.2K}{10K + 2.2K}.12V$$

$$= 2.16 Volts$$

The emitter current I_E is given by,

$$I_E = \frac{V_B - V_{EE}}{RE}$$

$$= \frac{2.16 - 0.7}{1.2K\Omega}$$

$$= 1.22mA$$

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,

$$Zin \approx r'_e = 20.5\Omega$$

The voltage gain A_v is given by,

$$A_v = \frac{R_c}{r'_e} = \frac{3.3K}{20.5} = 160.97 = 161\ \Omega$$

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 bypas 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,

$V_{out(no\,load)} = A_v.V_{in}$

=161 x 10mV

=1610mV=1.61 volts

The output voltage of the amplifier with load R_L is given by,

$$V_{out\,(load)} = \frac{R_L}{R_C + R_L} x V_{out\,(noload)}$$

$$= \frac{6.8K}{3.3K + 6.8K} x1.61V = 1.08V$$

Class Room Assignment: Calculate the output voltage of the CB amplifier (as done in step above) if load resistor R_L was,

(i) R_L=3.3K

(ii) R_L=10K and,

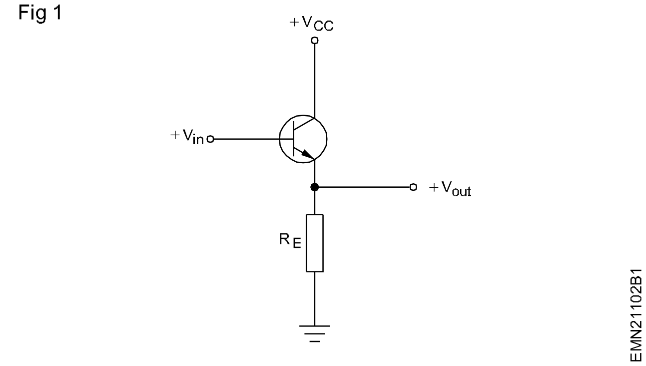
(iii) R_L=100K

Emitter Follower

Objectives: At the end of this lesson you shall be able to
- **state the need for impedance matching**
- **calculate the voltage gain, current gain, input impedance and output impedance of a transistor amplifier using circuit component values.**

Fig 1 shows another important transistor amplifier configuration. In this configuration, unlike in a common emitter amplifier where the output is taken from the collector, the output is taken from the emitter terminal of the transistor as shown in Fig 1.

Fig 1



Emitter follower can be used, to match a high impedance source to a low impedance output load. Hence, the emitter follower configuration is frequently used as an impedance matching circuit than as an amplifier.

Need for impedance matching

When a high impedance source is connected to a low impedance load, then most of the ac signal of the source gets dropped across the internal impedance of the source itself resulting in a very small portion of the signal appearing across the required load as shown in Fig 2a. One way to overcome this problem, i.e. to have almost all the signal from the source to be developed across the load, is to use an impedance matching device or a circuit between the high impedance source and the low impedance load as shown in Fig 2b.

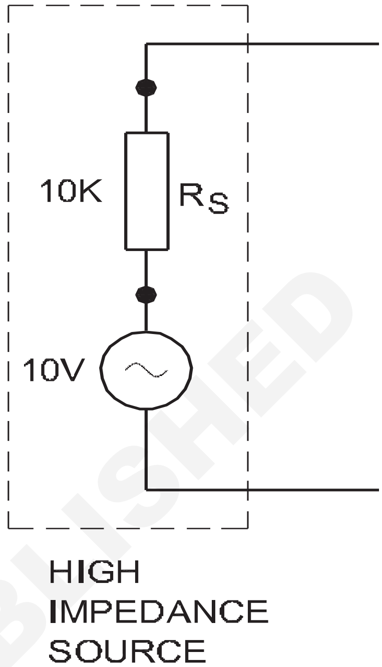
The circuit used for impedance matching in Fig 2b, is an emitter follower transistor amplifier. This is because, the emitter follower has a very high input impedance and a very low output impedance. This can be compared to that of a matching transformer where a load is matched to the source impedance for maximum power transfer.

An emitter follower circuit is also called a common collector *amplifier* because, the collector behaves as the common terminal for ac signal between the input and the output.

Voltage gain of an emitter follower

As can be seen in Fig 3, the DC output voltage of the emitter follower is $V_{out} = V_{in} - V_{BE}$

Since, V_{BE} is almost a constant value (0.7 for silicon, 0.3 for germanium) the emitter voltage follows the base voltage. It is because the emitter voltage follows the base voltage, this circuit is called **emitter follower.**



In Fig 3, if V_{in} is 3V, then V_{out} = 2.3V. If V_{in} is made 4\| then V_{out} increases to 3.3V. This means that changes in V_{out} is in phase widê changes in V_{in}. Therefore in an emitter follower the input and output signals are in phase as shown in Fig 3b. (recall, in a CE amplifier the input and output are 180° out of phase.)

Fig.3c shows the ac equivalent circuit of the emitter-follower shown in Fig 3a. The AC output voltage V_{out} is given by,

$$V_{out} = i_e R_E$$

Since the AC input voltage V_{in} is given by, $V_{in} = i_e (R_E + r'_e)$ the voltage gain A_V of the emitter follower is,

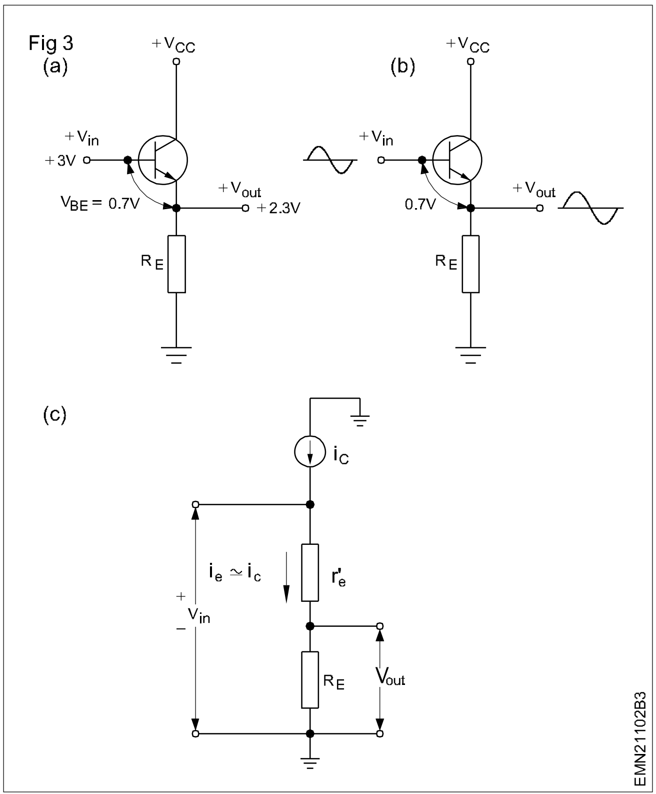
$$A_V = \frac{V_{out}}{V_{in}} = \frac{i_e R_e}{i_e (R_e + r'_e)} = \frac{R_E}{R_E + r'_e} \quad \text{........ (1)}$$

than the numerator, the value of voltage gain A_V will always be less than 1.

But since the value of r'_e is very small compared to R_E, the value of A_V approaches unity. We can therefore say that the voltage gain of the emitter follower is unity.

In Fig 3a, if R_E = 4.7KΩ and r'_e = 25W then,

$$A_V = \frac{R_E}{R_E + r'_e} = \frac{4700}{4700 + 25} = 0.995 \approx 1$$



Input impedance of emitter follower

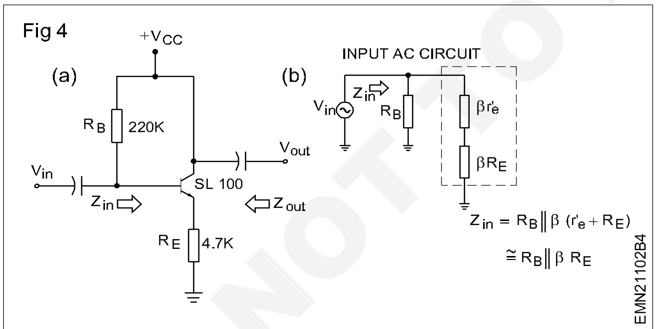
The input impedance of the emitter follower shown in Fig 3 is given by,

$Z_{in} = \beta(R_E + r'_e)$ ...... {2}

Since r'_e will be generally very small compared to R_E, equation ...{2} can be simplified as,

$Z_{in} = \beta\, R_E$

Fig 4a shows a practical emitter follower circuit using fixed biasing. The total input impedance including the biasing resistor R_B in parallel with the input impedance can be found as follows;



Writing the AC equivalent of the input of the emitter follower shown in Fig 4b, the input impedance Z_{in} is given by,

$Z_{in} = R_B \,\|\, \beta(r'_e + R_E)$ ....{3}

If r'_e is neglected,then, $Z_{in} = R_B \,\|\, \beta R_E$

Equation 3 indicates that the input impedance of a typical emitter follower is decided by the DC biasing resistance R_B. Hence, while designing an emitter follower to match a high source impedance, the values of R_B should be suitably chosen.

Example: In the emitter follower at Fig 4, if β of transistor is 100, R_B = 220 k and R_E = 4.7k the input impedance will be,

$Z_{in} = R_{in} = R_B \,\|\, \beta\, R_E$

$= 220\ K \,\|\, \beta\, R_E$

$= 220\ K \,\|\, (100 \times 4.7K)$

$= 149.85\ K\ \Omega\ 150\ K\Omega$

Output impedance of emitter follower

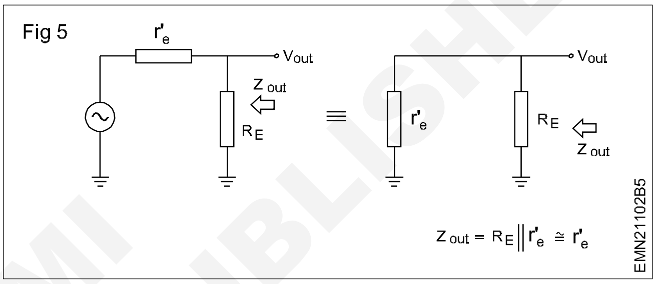


Fig 5 shows an AC equivalent or AC model of the output section of an emitter follower shown in Fig 4a.

Analiysing Fig 5, the output impedance Z_{out} is given by,

$Z_{out} = R_E \,\|\, r'_e$ ......{4}

Since R_E is usually a large resistance compared to r'_e, R_E in equation (4) can be neglected. Therefore, the output impedance of an emitter follower is approximately,

$Z_{out} = r'_e$

Example 1: Find the output impedance of the emitter follower shown in Fig 4 assuming $r'_e = 33\Omega$,

$Z_{out} = r'_e \,\|\, R_E \quad r'_e = 33\Omega.$

Current gain in emitter follower

Although the voltage gain A_V of emitter follower is approximately unity, the current gain of an emitter follower is high and is given by the equation;

$$A_i = \frac{\beta R_B}{(R_B + \beta R_E)} \quad .....\{5\}$$

Example 2*:* In the emitter follower shown in Fig 4, if β of the transistor is 100, then the current gain of the emitter follower is given by,

$$A_i = \frac{\beta R_B}{(R_B + \beta R_E)}$$

$$= \frac{(100)(220K)}{(220K) + (100)(4.7K)} = 31.88.$$

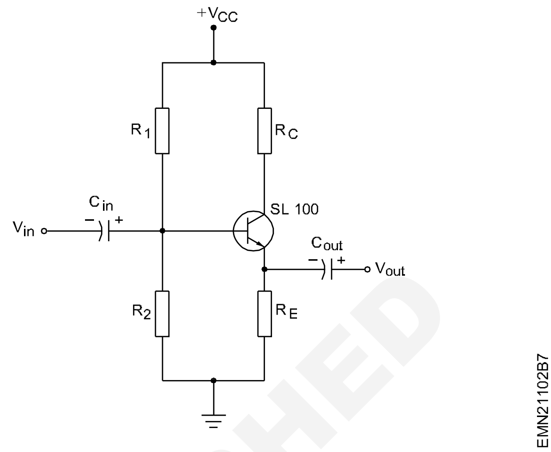
The current gain of the emitter follower can also be found as follows;

$$A_i = A_V \frac{Z_{in}}{R_E} = (0.995)\frac{150K}{4.7K} = 31.72.$$

Fixed bias was used in the emitter follower shown in Fig 4. Any other DC biasing could also be employed such as voltage divider bias as shown in Fig 6.

When voltage divider bias is used in an emitter follower, the equations for finding A_V, Z_{in}, Z_{out} and A_i remain the same, except for, that the fixed biased resistor R_B replaced by $R_1 \| R_2$.

Fig 7



Types of Cascaded Audio Amplifiers

Objectives: At the end of this lesson you shall be able to
- **state the need for cascading amplifiers**
- **state the need for coupling between the stages of amplifiers**
- **list the applications, advantages and disadvantages of direct-coupled amplifiers.**

Cascaded audio frequency (A.F.) amplifiers

Amplifiers specially designed to amplify audio frequency signals (20Hz to 20kHz) are called to as audio frequency amplifiers or A.F. amplifiers.

Single transistor amplifiers discussed in unit 09 do not provide enough gain to be used with output transducers such as speakers. Therefore, several amplifiers are usually connected in series (cascaded) as shown in Fig.2 to obtain sufficient gain to drive a speaker.

In Fig 2, the output of one amplifier, serves as the input for the next amplifier, and so on, till the required gain is obtained. Although the individual amplifiers can be of any configuration, the most commonly used is the common-emitter configuration especially in A.F amplifiers. This is because of the fact that, the voltage, current and power gain of CE amplifier is high.

Fig 1

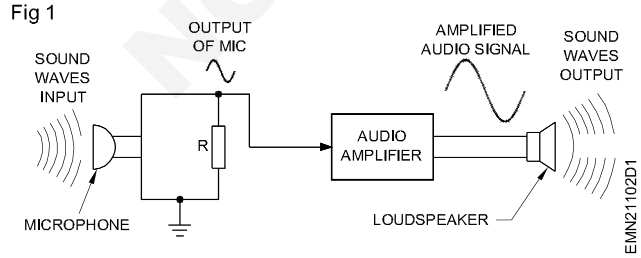
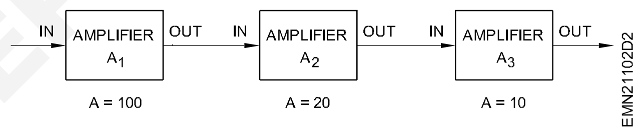


Fig 2



In Fig 2, if the gain of stage A_1 is 100, A_2 is 20 and A_3 is 10, then the overall gain or the total gain of the cascaded amplifier will be,

= Gain of A_1 x Gain of A_2 x Gain of A_3 ..[2]

Total gain = 100 x 20 x 10 = 20,000

For instance, if stage A_1 is given an input signal of strength 1mv, the output signal level will be 20 V. Such cascaded amplifiers are also referred to as *multi-stage amplifiers*.

Such cascaded or multi-stage amplifiers are common in almost all A.F amplifiers used in tape recorders, public address amplifiers and so on.

Methods of coupling

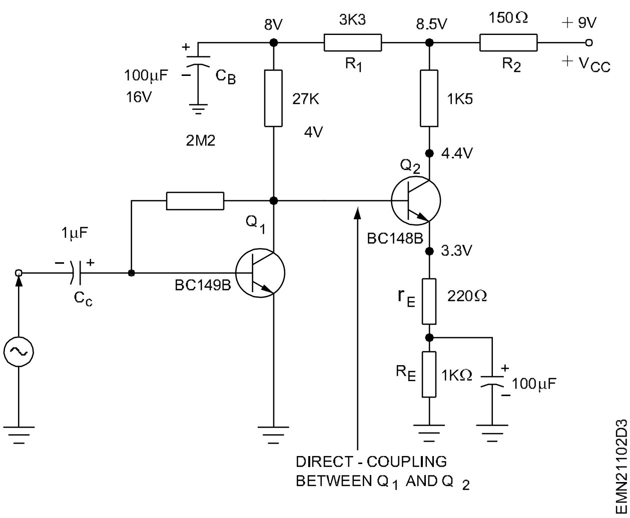
As shown in Fig. 2, in cascaded amplifiers the output of one amplifier stage has to be fed to the input of the next amplifier stage. While doing so, it is important to match the impedance between the two stages. It is even more important to have good impedance matching in low-level signal stages (initial amplifier stages) so that very little signal is lost in the process of feeding. This technique of connecting the output of one amplifier stage to the input of the next amplifier stage, such that, the impedance of the stages are matched enabling maximum transfer of signal from one to other is known as *coupling*.

There are several methods of coupling. A few of the most common methods of coupling are discussed in subsequent paragraphs:

Direct coupling

A typical direct coupled amplifier is shown in Fig 3.

Fig 3



In Fig 3, the collector of the first transistor, (first amplifier stage output) is connected directly to the base of the second transistor (second amplifier stage input). Since no components such as capacitors, transformers are used between the output of one stage and the input of another, this method of coupling is known as *direct coupling*. As there are no components involved in coupling, both the DC component of the signal and the AC component of the signal are passed to the input (base) of the 2nd amplifier. Also, since there are no frequency restricting components in the path of coupling, there is no frequency restriction in the coupled path.

In Fig 3, transistor Q_1 is self-biased. If β_{dc} of Q_1 = 100, then, the quiescent collector current I_C is given by,

$$I_C = \frac{V_{CC} - V_{BE}}{R_C + R_B \beta_{dc}} = \frac{8V - 0.7V}{27K + (2M2/100)} = 0.15mA$$

The advantage of using self-bias (feed-back bias) is that the transistor can never reach saturation, and hence, the distortion is minimum.

I_C of 0.15mA produces a drop of approximately 4 V across 27 K. Therefore, collector of Q_1 will be at 4V with respect to ground. Allowing 0.7 V for the emitter diode of Q_2, 3.3 V will be across 1 kΩ. Hence I_C of Q_2 is approximately 2.75 mA.

The voltage gain of the first stage (Q_1) is,

$$A_1 = \frac{R_C}{r'_{e_1}}$$

$$r'_{e_1} = \frac{25mV}{I_{E1}} = \frac{25mV}{0.15mA} = 166.7\ \Omega$$

Therefore,

27KW

A1 = ≈ 162

166.7W

The voltage gain of the second state (Q_2) is,

$$A_2 = \frac{R_C}{r_E + r'_{e2}}$$

$$= r'_{e2} = \frac{25mV}{I_{E2}} = \frac{25mV}{2.75mA} = 9.09\,\Omega$$

$$A_2 = \frac{1K5\,\Omega}{220\,\Omega + 9.09\,\Omega} = 6.55$$

The overall gain of the two stages is,

$A_{12} = A_1 \times A_2 = 162 \times 6.55 = 1061.1$

Although the theoretical gain is very high, due to resistance tolerance variations and impedance mis-matching, in practice A_{12} will be slightly lower.

DC potentials

In Fig 3, it is very important to note, that there is no separate DC biasing provided to the transistor Q_2. This is because, the base of the transistor Q_2 is at the same DC potential as the collector of Q_1 (4V).

Resistors R_1(3K3) and R_2(150Ω) are provided to obtain suitable DC voltages for the different stages of the amplifier using a common V_{CC} supply of +9Volts.

Applications of direct-coupled amplifiers

- For amplification of DC control voltages in industrial electronic applications (DC amplifiers).
- At the input stages of audio-amplifiers for good low frequency response down to 0Hz.
- In some applications, direct coupling is used just for economy, as this method eliminates the need of coupling capacitors.
- Direct coupling is used in circuits known as complemetnary-symmetry which use PNP and NPN transistors.

Complementry symmetry configuration is discussed in further lessons.

Disadvantages of Direct coupling

– Each successive stage of amplifiers needs progressively higher supply voltages. (V_{CC} of Q_1 and Q_2 in Fig 3.)

– Transistor characteristics like V_{BE} vary with temperature. This causes collector currents and voltages to change.

RC, LC Transformer Coupling

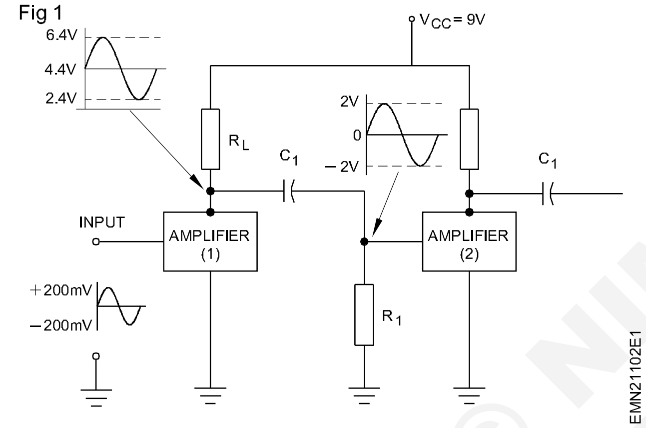
Objectives: At the end of this lesson you shall be able to
- **explain the effect of coupling capacitor on the frequency response of the amplifier**
- **explain LC coupling, its advantages, disadvantages and applications**
- **explain transformer coupling.**

Very popular method of coupling is known as Resistance-Capacitance (RC) coupling. Amplifiers using this type of coupling are called RC coupled amplifiers.

Resistance - capacitance (RC) coupling

Fig 1 shows the method of RC coupling between amplifier stages.

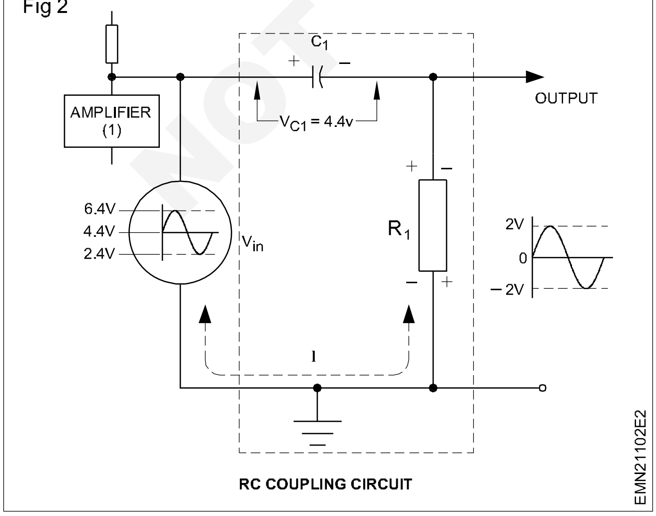
Fig 1



The output of amplifier-1 is fed through, the C_1R_1 coupling circuit, to the input of amplifier-2. The R_1C_1 coupling is shown separately in Fig 2 for analiysing how the DC component is blocked and only the AC signal variations is passed on to the next amplifier.

In Fig 2, V_{in} is the output of the amplifier (at output of A_1) and is also the input to the coupling circuit formed by C_1R_1. In Fig 2, the values of V_{in} are:

Fig 2



RC COUPLING CIRCUIT

Average DC voltage level = +4.4 V

AC variations around 4.4 V = ±2 V

Maximum instantaneous value = +6.4 V

Minimum instantaneous value = –2.4 V

With no input AC signal, the capacitor is charged to DC level of 4.4 V as shown in Fig 2. Since all the voltage is across C_1, the voltage across R_1 with respect to ground is zero. This is shown as the x axis reference at the output terminals.

When V_{in} rises to 6.4V, C_1 charges above 4.4 V and up to the maximum instantaneous value of +6.4V. The charging current through R_1 produces a positive voltage drop across R_1. All the changes of V_{in} between 4.4V to 6.4V provide a +ve half cycle of 2 volts across R_1 as shown in Fig 2.

When V_{in} falls below 4.4 V, C_1 discharges. The discharge current through R_1 produces negative voltage across R_1. All changes of V_{in} between 4.4 V and 2.4 V provide a negative half cycle across R_1 as shown in Fig 2.

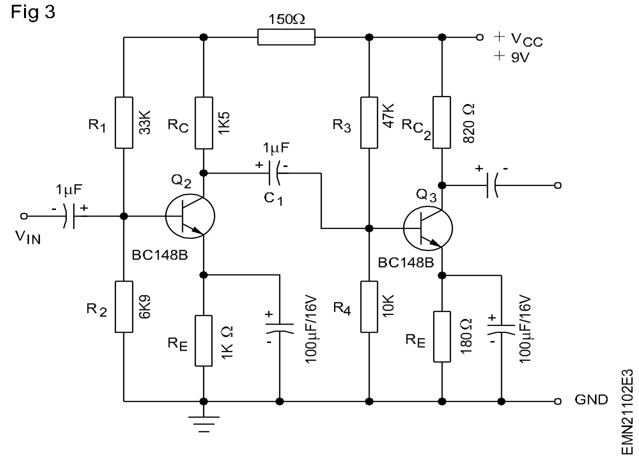
Therefore, from Fig 2, it can be seen that the voltage across R_1 is equal to only the magnitude of changes that occurred on the DC value of 4.4V at the input of the R_1C_1 network. The DC 4.4V is blocked across capacitor C_1 of the R_1C_1 network. Hence, the available output of R_1C_1 network or input to the next stage amplifier, (Amplifier 2 in Fig 1) is only the ± variations of the AC signal at the collector of amplifier 1.

It is important to note that the frequency of input signal is such that the capacitive reactance of X_{C1} is very small compared to R_1. Alternatively, the value of C_1 should be high enough such that X_{C1} is negligible compared to R_1 for the input signal frequency range. Otherwise a major portion of the AC signal gets dropped across X_{C1} and not across R_1. If so the input to the next amplifier stage (A2) will be much less than the output of the previous stage (A1).

RC coupling is a very popular method of coupling in almost all A.F amplifiers. Fig 3 shows a two stage RC coupled amplifier.

In RC coupling since DC voltage at collector Q_2 is blocked by capacitor C_1, transistor Q_3 is given separate DC bias voltage using resistors R_3 and R_4. R_3 and R_4 provide a DC bias voltage of 1.5 V at the base of Q_2 in Fig 3.

Fig 3

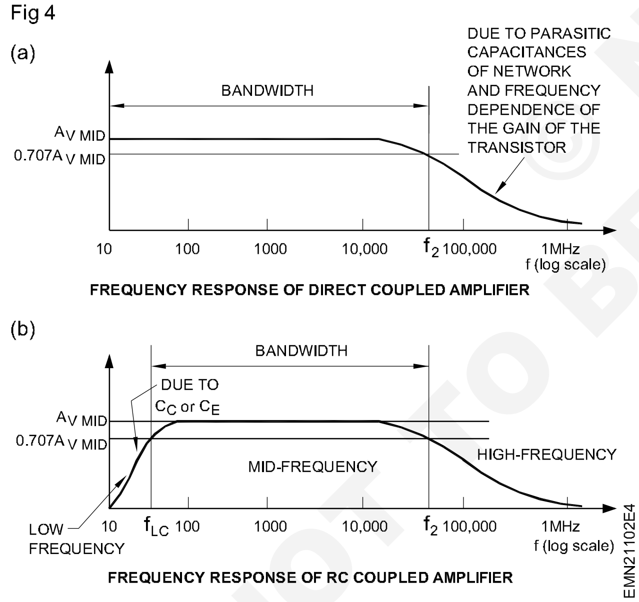


Frequency-response of RC-amplifiers

Fig 4 shows the frequency-gain responses of a typical direct coupled and RC coupled amplifiers.

In the frequency response curve of a direct-coupled amplifier shown in Fig 4a, the response is a flat from almost 0Hz up to the upper cut-off frequency. Indirect coupled amplifiers the upper cut-off frequency is determined by, either the parasitic capacitance of the circuit or the dependence of the gain of the active device (transistor) used. There is no lower cut-off frequency as there are no coupling capacitor to cause drop in gain at low frequencies.

Fig 4



In the frequency-response curve of an RC-coupled amplifier shown in Fig 4b, there is drop in gain at low frequencies. This is due to, the increased reactance of coupling capacitor C_1. The upper frequency limit in RC-coupled amplifiers is again determined by the parasitic capacitance of the circuit and the frequency dependence of the gain of the active device (transistor).

In the RC coupled amplifier circuit at Fig 3, the 3db low frequency cut-off f_{LC}, of the amplifier due to the RC coupling between transistors Q_2 and Q_3 is given by,

$$f_{LC} = \frac{1}{2\pi(R_c + R_{in})C_c}$$

where,

R_C is the collector resistor of Q_2

R_{in} is the input impedance of Q_3

C_C is the value coupling capacitor C_1 used between Q_2 and Q_3.

$$Z_{in} \text{ or } R_{in} \text{ of } Q_3 = R_3 \parallel R_4 \parallel \beta_{Q3} r'_{e(Q3)} \approx \beta_{Q3}\, r'_{e(Q3)}$$

$$r'_{e2} = \frac{25mV}{I_{E(Q3)}} = \frac{25mV}{5mA} = 5\Omega$$

If β_{dc} of Q_3 = 100

then,

$\beta_{Q3}.\, r'_{e(Q3)} = 500\Omega$

Therefore,

$$FLC = \frac{1}{2\pi(1K5+500\Omega)x10^{-6}} \approx 80 \text{ Hertz.}$$

Refer previous unit on transistors where the effect of coupling and bypass capacitors on frequency response are discussed.

The low gain at low frequencies, imposed by the coupling capacitor is the major disadvantage of RC coupled amplifiers. However, RC coupling of amplifier stages overcome the disadvantages associated with the DC coupled amplifiers such as, need of progressively higher supply voltages and the changes in DC supply resulting in undesirable changes in amplifier output.

LC coupling or Impedance coupling

Fig 5 shows a Inductance-Capacitance (LC) coupled amplifier, in which, an inductance is used as the collector load of the amplifier instead of a resistor. However, C_C is still required to block the DC voltage.

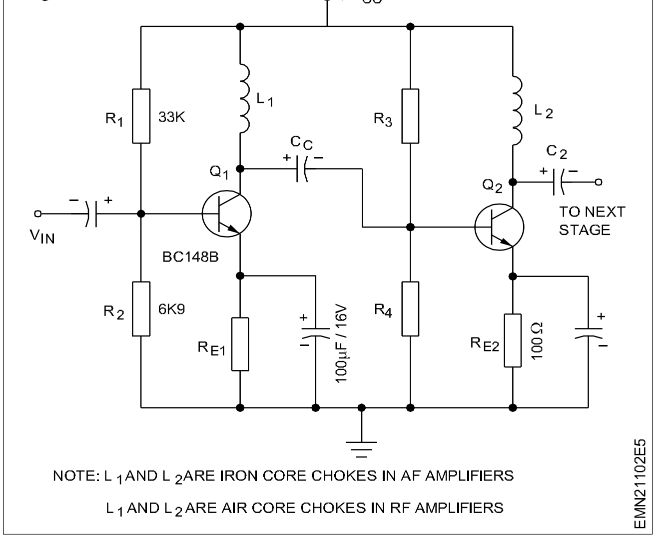
Iron core chokes L_1 and L_2 are used in A.F amplifiers, whereas air-core chokes are used in high frequency (HF) amplifiers.

The advantage of using a choke in the collector is its low DC resistance but high AC impedance. Low dc resistance results in small I_R drop, which allows most of V_{CC} to be available at the collector of the transistor amplifier. The high ac impedance for the signal results in high gain.

The disadvantages of LC coupling are,

– For A.F amplifiers, the physical size of suitable inductance value chokes will be bulky and occupies large space.

Fig 5



- Since the impedance of an inductor varies with frequency ($X_L = 2pfL$), LC amplifiers do not have uniform frequency response.
- LC coupling is expensive compared to RC coupling.

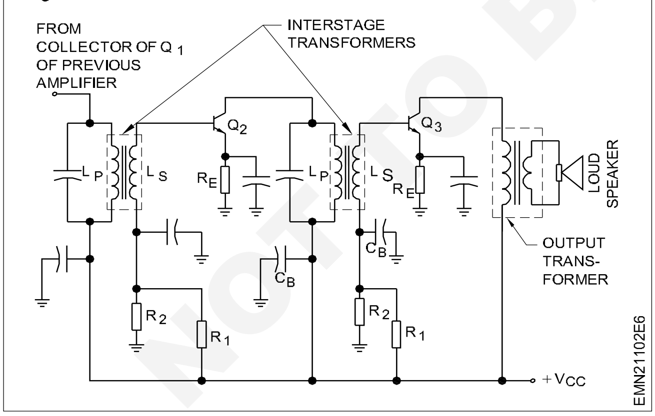
  Although LC coupling is rarely used in AF amplifiers, LC coupling is extensively and invariably used in radio frequency amplifiers (RF) in which frequencies much above a few hundred KHz is used. At such high frequencies the physical size of L will be very small.

Transformer coupling

Fig 6 shows a transformer-coupled amplifier.

The primary winding L_P of the transformer provides the necessary load impedance for the amplifier as in LC or impedance coupling. The AC signal current in L_P induces signal voltage in L_S by transformer action. Since L_S is an isolated winding, the DC component of the primary voltage and current is not transferred to L_S and hence to the next amplifier stage.

Fig 6



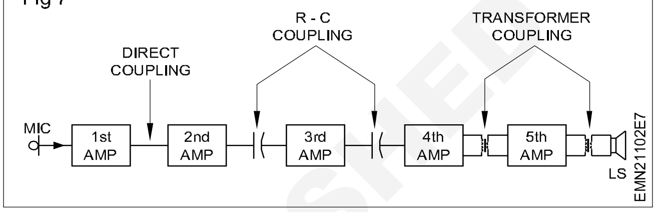
Resistors R_1 and R_2 provide the necessary DC bias for the transistors. The bypass capacitors C_B at the bottom of each primary and secondary winding provide AC ground. Hence AC signals get transferred from one stage to the subsequent stage only through transformer action.

In audio amplifiers, transformer coupling may be used between two amplifier stages or at the last stage to drive a loud speaker as shown in Fig 6. Audio output transformers are generally voltage step-down to match low impedance values of the speaker (4 to 16W).

Recall lesson on transformers-impedance matching properly.

Transformer-coupled audio amplifiers were widely used once upon a time. Due to their bulkiness and high cost they are less frequently used in present day audio amplifiers. However, transformer coupling is still used extensively in radio frequency amplifiers such as radio receivers, TV receivers etc. At these higher frequencies the size and the cost of transformers will be smaller and less expensive.

Fig 7



Coupling using more than one method

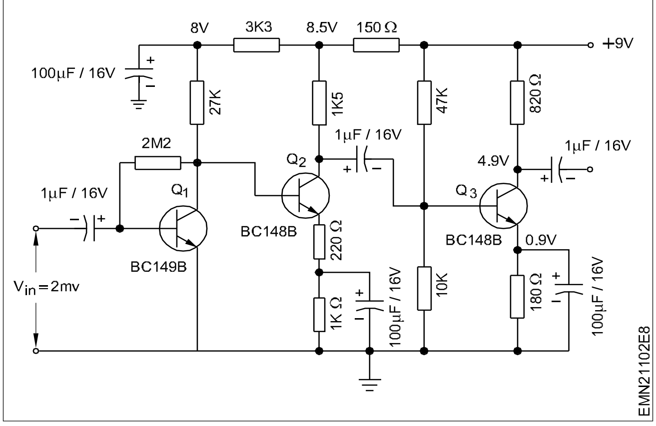
When several amplifier stages are cascaded to obtain large gains, one or more methods of coupling may be combined as shown in Fig 7 to get the best of each method.

A practical 3-stage amplifier using direct coupling between the first two stages and RC coupling between the 2nd and the 3rd stage is shown in Fig 8. This amplifier can be used to amplify the weak signals coming from transduces like, microphones.

Points for discussion in the class room

1. Voltage gain of each stage and overall gain of the cascaded amplifier (assume β_{dc} of each transistor as 100).
2. Low frequency 3db cut off (f_{LC}) due to RC coupling.
3. Advantage of direct coupling in the first amplifier stage.
4. Advantage of self-biasing in the first amplifier stage.
5. Absence of divider-biasing for Q_2.
6. V_{CC} levels at the top end of collector resistors of Q_1, Q_2 and Q_3.

Fig 8



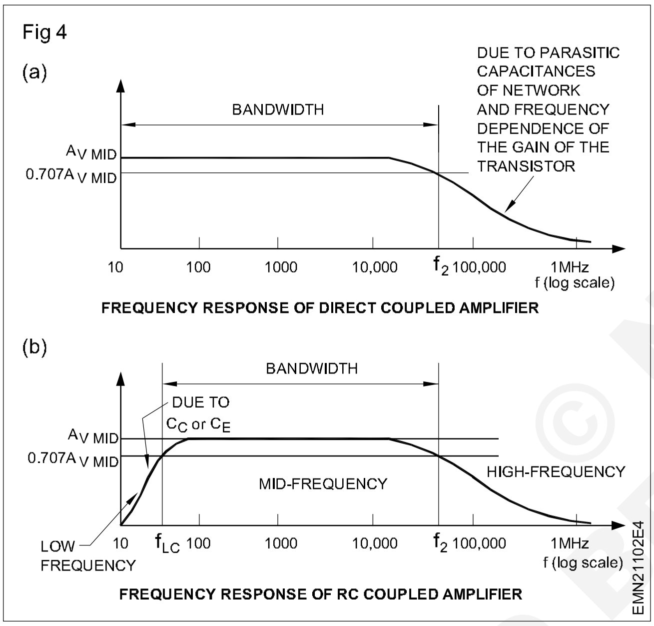
RC coupling is a very popular method of coupling in almost all A.F amplifiers. Fig 3 shows a two stage RC coupled amplifier.

In RC coupling since DC voltage at collector Q_2 is blocked by capacitor C_1, transistor Q_3 is given separate DC bias voltage using resistors R_3 and R_4. R_3 and R_4 provide a DC bias voltage of 1.5 V at the base of Q_2 in Fig 3.

Frequency-response of RC-amplifiers

Fig 4 shows the frequency-gain responses of a typical direct coupled and RC coupled amplifiers.

In the frequency response curve of a direct-coupled amplifier shown in Fig 4a, the response is a flat from almost 0Hz up to the upper cut-off frequency. Indirect coupled amplifiers the upper cut-off frequency is determined by, either the parasitic capacitance of the circuit or the dependence of the gain of the active device (transistor) used. There is no lower cut-off frequency as there are no coupling capacitor to cause drop in gain at low frequencies.



In the frequency-response curve of an RC-coupled amplifier shown in Fig 4b, there is drop in gain at low frequencies. This is due to, the increased reactance of coupling capacitor C_1. The upper frequency limit in RC-coupled amplifiers is again determined by the parasitic capacitance of the circuit and the frequency dependence of the gain of the active device (transistor).

In the RC coupled amplifier circuit at Fig 3, the 3db low frequency cut-off f_{LC}, of the amplifier due to the RC coupling between transistors Q_2 and Q_3 is given by,

$$f_{LC} = \frac{1}{2\pi(R_c + R_{in})C_c}$$

where,

R_C is the collector resistor of Q_2

R_{in} is the input impedance of Q_3

C_C is the value coupling capacitor C_1 used between Q_2 and Q_3.

Z_{in} or R_{in} of $Q_3 = R_3 \parallel R_4 \parallel \beta_{Q3} r'_{e(Q3)} \approx \beta_{Q3}\, r'_{e(Q3)}$

$$r'_{e2} = \frac{25mV}{I_{E(Q3)}} = \frac{25mV}{5mA} = 5\Omega$$

If β_{dc} of $Q_3 = 100$

then,

$\beta_{Q3} \cdot r'_{e(Q3)} = 500\Omega$

Therefore,

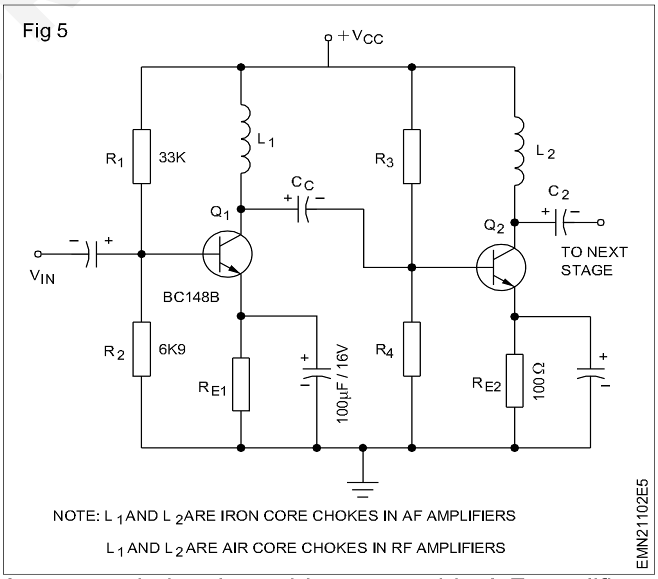
$$FLC = \frac{1}{2\pi(1K5 + 500\Omega)x10^{-6}} \approx 80 \text{ Hertz.}$$

Refer previous unit on transistors where the effect of coupling and bypass capacitors on frequency response are discussed.

The low gain at low frequencies, imposed by the coupling capacitor is the major disadvantage of RC coupled amplifiers. However, RC coupling of amplifier stages overcome the disadvantages associated with the DC coupled amplifiers such as, need of progressively higher supply voltages and the changes in DC supply resulting in undesirable changes in amplifier output.

LC coupling or Impedance coupling

Fig 5 shows a Inductance-Capacitance (LC) coupled amplifier, in which, an inductance is used as the collector load of the amplifier instead of a resistor. However, C_C is still required to block the DC voltage.



Iron core chokes L_1 and L_2 are used in A.F amplifiers, whereas air-core chokes are used in high frequency (HF) amplifiers.

The advantage of using a choke in the collector is its low DC resistance but high AC impedance. Low dc resistance results in small I_R drop, which allows most of V_{CC} to be available at the collector of the transistor amplifier. The high ac impedance for the signal results in high gain.

The disadvantages of LC coupling are,

– For A.F amplifiers, the physical size of suitable inductance value chokes will be bulky and occupies large space.

– Since the impedance of an inductor varies with frequency (X_L = 2pfL), LC amplifiers do not have uniform frequency response.

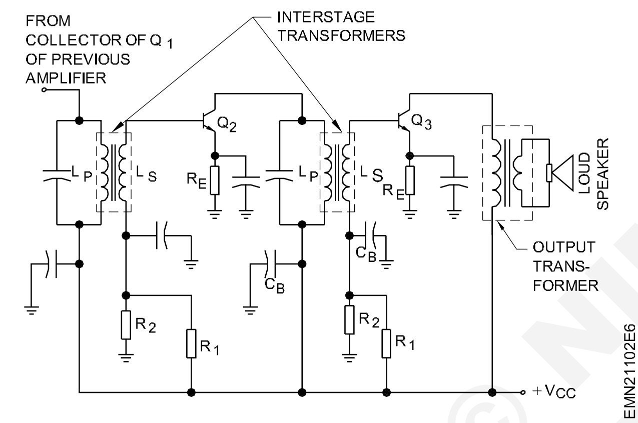
– LC coupling is expensive compared to RC coupling.

Although LC coupling is rarely used in AF amplifiers, LC coupling is extensively and invariably used in radio frequency amplifiers (RF) in which frequencies much above a few hundred KHz is used. At such high frequencies the physical size of L will be very small.

Transformer coupling

Fig 6 shows a transformer-coupled amplifier.

Fig 6



The primary winding L_P of the transformer provides the necessary load impedance for the amplifier as in LC or impedance coupling. The AC signal current in L_P induces signal voltage in L_S by transformer action. Since L_S is an isolated winding, the DC component of the primary voltage and current is not transferred to L_S and hence to the next amplifier stage.

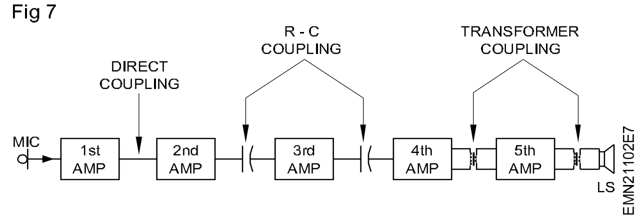
Resistors R_1 and R_2 provide the necessary DC bias for the transistors. The bypass capacitors C_B at the bottom of each primary and secondary winding provide AC ground. Hence AC signals get transferred from one stage to the subsequent stage only through transformer action.

In audio amplifiers, transformer coupling may be used between two amplifier stages or at the last stage to drive a loud speaker as shown in Fig 6. Audio output transformers are generally voltage step-down to match low impedance values of the speaker (4 to 16W).

Recall lesson on transformers-impedance matching properly.

Transformer-coupled audio amplifiers were widely used once upon a time. Due to their bulkiness and high cost they are less frequently used in present day audio amplifiers. However, transformer coupling is still used extensively in radio frequency amplifiers such as radio receivers, TV receivers etc. At these higher frequencies the size and the cost of transformers will be smaller and less expensive.

Fig 7



Coupling using more than one method

When several amplifier stages are cascaded to obtain large gains, one or more methods of coupling may be combined as shown in Fig 7 to get the best of each method.

A practical 3-stage amplifier using direct coupling between the first two stages and RC coupling between the 2nd and the 3rd stage is shown in Fig 8. This amplifier can be used to amplify the weak signals coming from transduces like, microphones.

Points for discussion in the class room

1 Voltage gain of each stage and overall gain of the cascaded amplifier (assume β_{dc} of each transistor as 100).

2 Low frequency 3db cut off (f_{LC}) due to RC coupling.

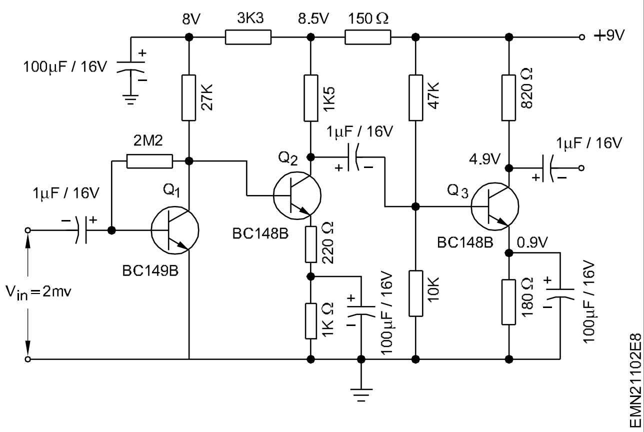
3 Advantage of direct coupling in the first amplifier stage.

4 Advantage of self-biasing in the first amplifier stage.

5 Absence of divider-biasing for Q_2.

6 V_{CC} levels at the top end of collector resistors of Q_1, Q_2 and Q_3.

Fig 8



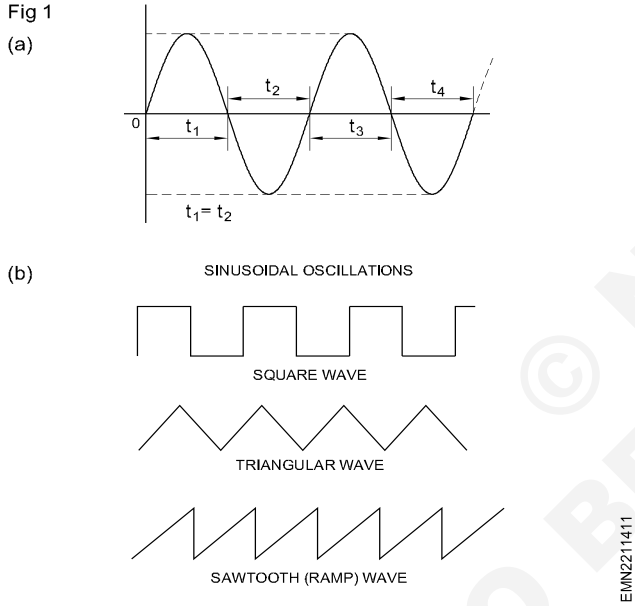
Oscillators

Objectives: At 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**
- **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.

Fig 1



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 saw-tooth waveform as shown in Fig 1b. Such oscillators are known as non-**sinusoidal oscillators** or **relaxation oscillators**.

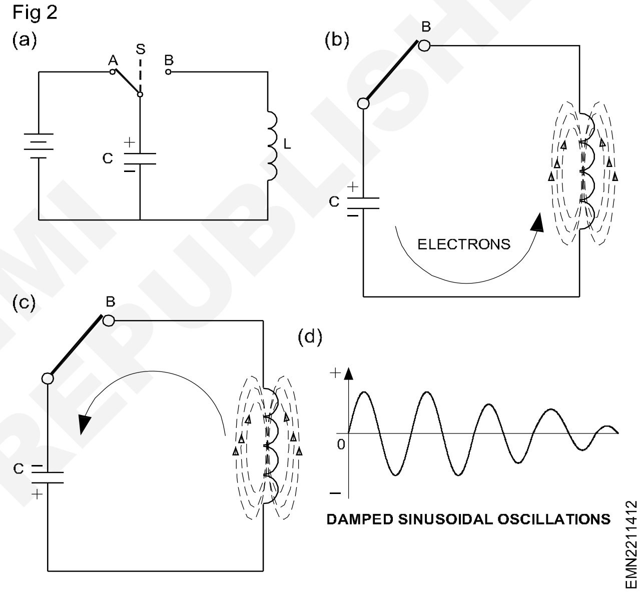
Principle of sinusoidal or harmonic oscillations

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.

Fig 2



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,

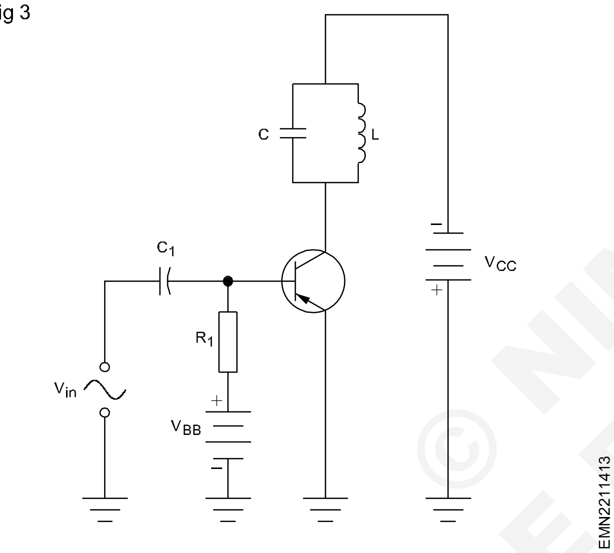
$$f = \frac{1}{2\pi\sqrt{LC}}$$

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

Fig 3



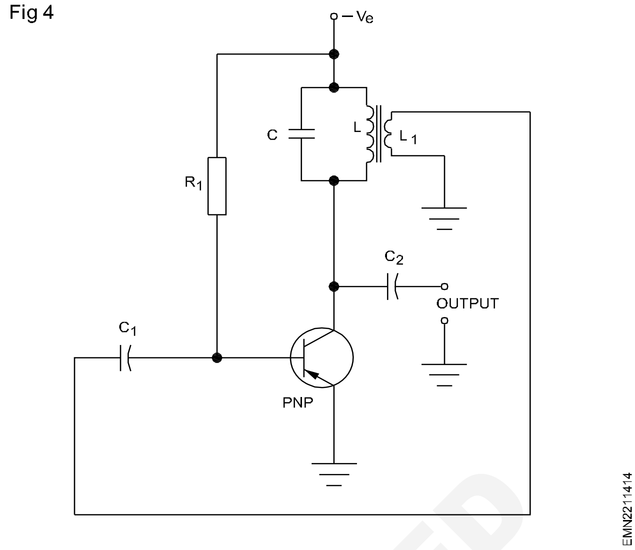
it will cause undamped oscillations without requiring any external signal. Such a circuit is known as an oscillator.

The oscillator circuit at Fig 4 is known as **tickler-coil** oscillator. Here L1 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 L1 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 L1 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

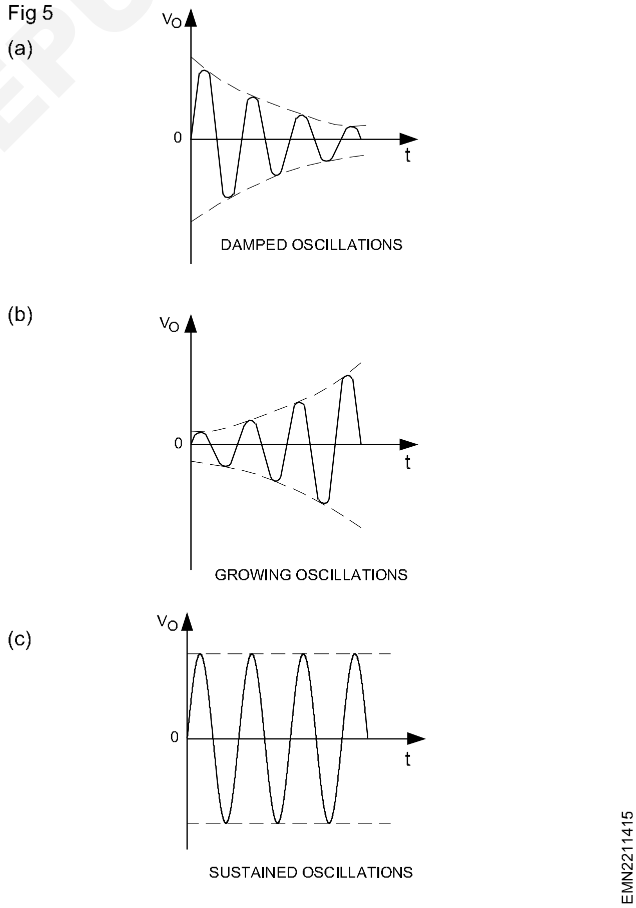
Fig 4



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 β. 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.

Fig 5



– 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=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 ticker-coil oscillator shown in Fig 4, but the tickler circuit coil L1 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.

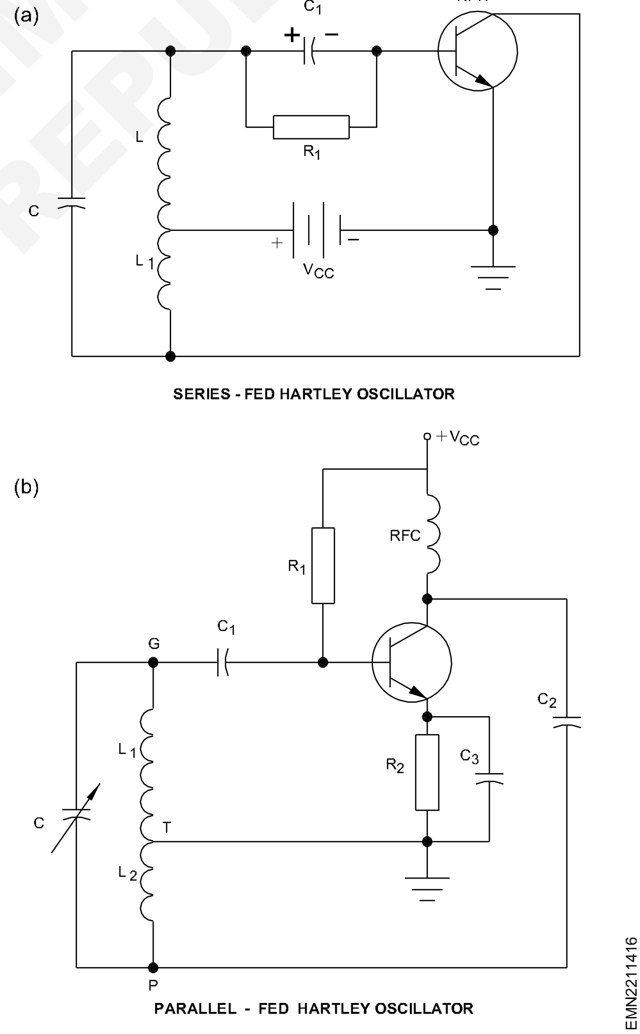
The circuit at Fig 6b is actually an amplifier with positive (regenerative) feedback to have sustained oscillations. The capacitor C_2 and inductor L_2 form the path for RF current in the collector to ground circuit.

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

Fig 6



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.

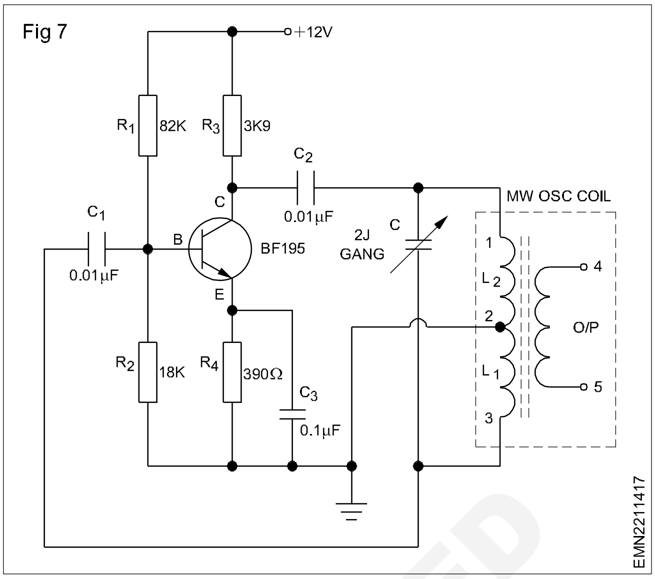
– Using an oscilloscope with a calibrated time base to measure the period of the wave-form. From the measured period, t frequency is calculated using the formula

$$f = \frac{1}{t}$$

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.

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 ß), 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 Aß to 1. If the feedback is too large, it may result in loss of some of the output voltage because of the stray power loses.

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
- **describe the working of colpits and crystal oscillator.**

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,

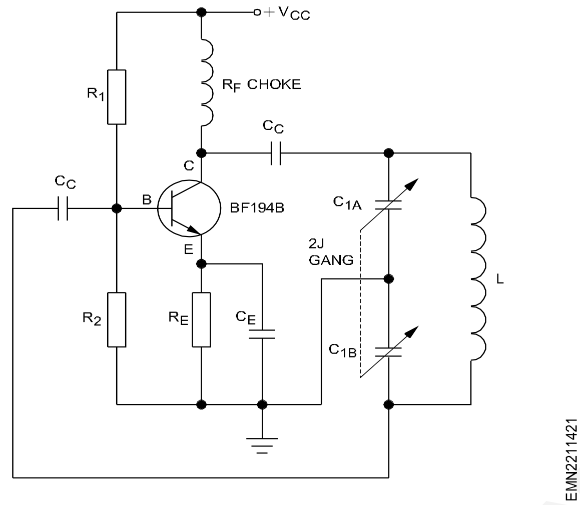
L is the inductance of the coil in henry

C is the total capacitance in farads given by,

$$C = \frac{C_{1A} . C_{1B}}{C_{1A} + C_{1B}}$$

The frequency of oscillations can be changed by using a miniature ganged capacitor for C_{1A} & C_{1B}.

Fig 1

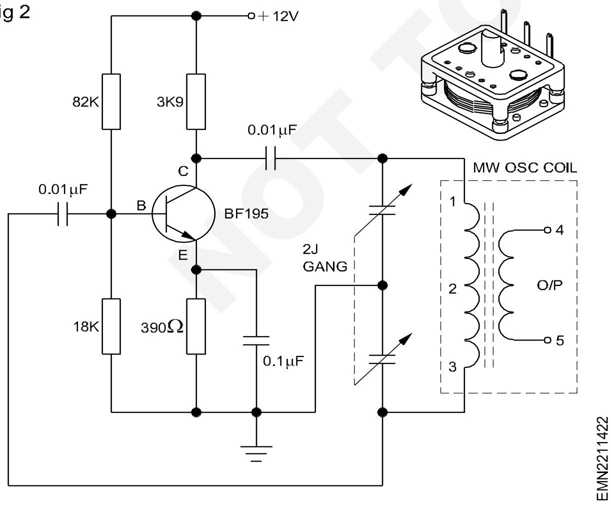


By varying the shaft of the ganged capacitor, both the capacitances C_{1A} and C_{1B} get varied, and hence, the frequency of oscillations of the oscillator varies.

Colpitts oscillators are generally used for generating frequencies above 1 MHz.

A practical colpitts 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.

Fig 2



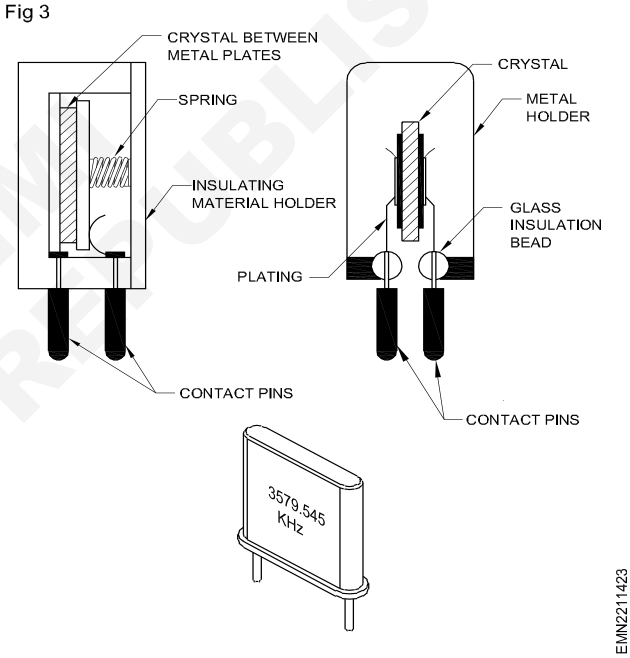
Crystal Oscillators: The LC oscillator circuits such as Hartley and Colpitts have the problem of frequency instability. The most important reason for the frequency drift in LC oscillators is, the change in value of capacitance and inductance of the tank circuit that occurs when temperature changes. As 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.

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 electrical 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 gramaphone plate. This vibrating force gives rise to corresponding voltages representing the recorded sound at the pick-up terminals.

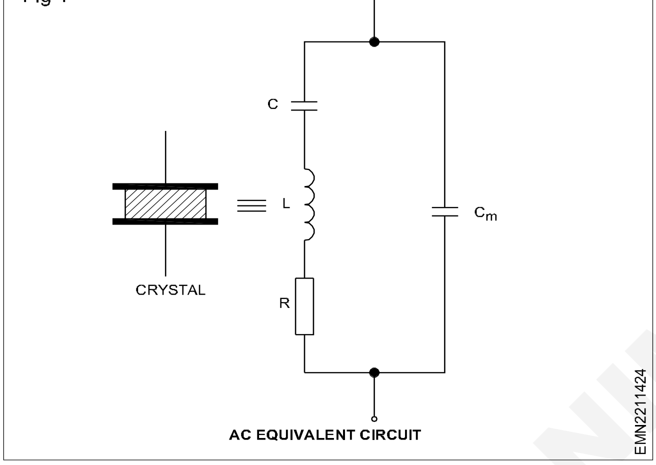
In addition to the above property of the crystal, when an emf is applied across the two plates of the crystal, the crystal will distort from its normal shape. If an opposite polarity emf is applied, the crystal will reverse its physical distorted shape. In this way, these crystals also convert electrical 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 electrical properties are concerned, a quartz crystal is equivalent to the LC resonant circuit shown in Fig 4.

Fig 4

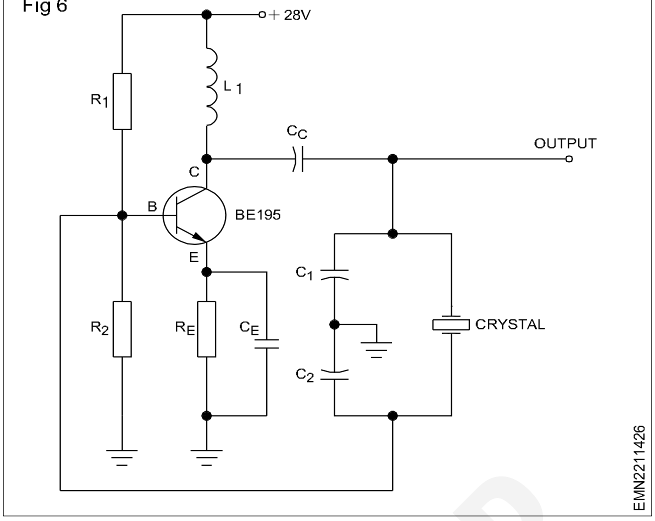


The values of L, R, C and C_m depend upon the physical size of the crystal and how the crystal is cut from the original mass. Capacitance C_m represents the mounting capacitance. For using the crystal in electronic circuits, two conducting electrodes are placed on to its two faces. Connecting leads are 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.

The resonant frequency of a crystal is usually between 0.5 and 30 MHz.

Fig 6



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_1R_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 Phase Shift Oscillator

Objectives: At the end of this lesson you shall be able to
- **state why LC oscillators are not suitable for frequencies less than 50 kHz**
- **name the two important types of RC oscillators**
- **state the schematic of a transistor RC phase-shift oscillator**
- **state the equation for frequency of oscillations in a transistor phase-shift oscillator,**

RC Oscillators: LC oscillators are not suitable for generating frequencies less than 1 MHz. To make audio frequency oscillators (<20 kHz) if LC oscillators are used, the LC values required will be too large. Hence, LC tuned circuit is not used in audio frequency oscillators.

For generating audio frequencies, resistors and capacitors(RC) can be used to provide the necessary phase shift for positive feedback. Then, the frequency of oscillations depends on the RC values. Two important types of RC oscillator are;

– the RC phase-shift oscillator

– the Wien-bridge oscillator.

An oscillator will have no input AC signal at all, but it still generates AC signal. An oscillator will have only a DC supply. The oscillator circuit, makes use of the noise generated in resistors at the switching on time of DC supply and sustains the oscillations.

To build an oscillator, the following are essential;

1) An amplifier

2) A circuit which provides positive feedback from output to input.

The gain of an amplifier with feedback is given by,

$$A_{vf} = \frac{A_v}{1 - kA_v}$$

kA_v is known as the loop gain of the amplifier.

If the loop gain kA_v is made equal to 1, and, if the sign of kA_v is made positive, i.e. by feeding back signal which is in-phase with the input signal, then there will be an output signal even though there is no external input signal. In other words, an amplifier is modified to be an oscillator by positive feedback such that it supplies its own input signal.

Example: An amplifier has a voltage gain of 40 without feedback. Determine the voltage gains when positive feedback of the following amounts is applied.

(i) k = 0.01 (ii) k = 0.02 (iii) k = 0.025

SOLUTION

(i) $$A_{Vf} = \frac{A_V}{1 - kA_V} = \frac{40}{1 - 0.01 \times 40} = \frac{40}{0.6} = 66.7$$

(ii) $$A_{Vf} = \frac{A_V}{1 - kA_V} = \frac{40}{1 - 0.02 \times 40} = \frac{40}{0.2} = 200$$

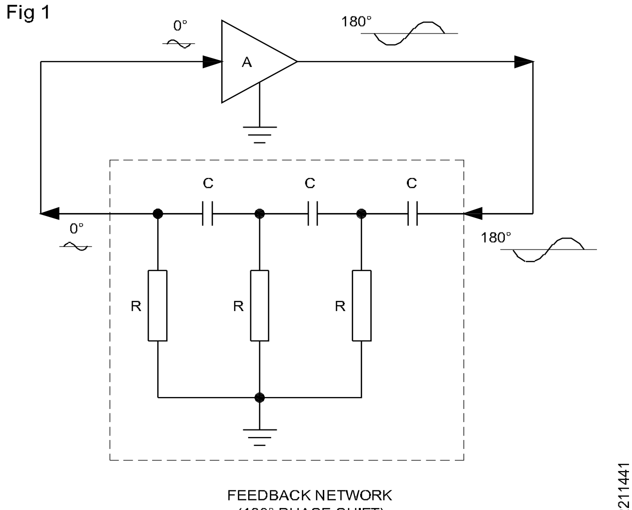
(iii) $$A_{Vf} = \frac{A_V}{1 - kA_V} = \frac{40}{1 - 0.025 \times 40} = \frac{40}{0} = \alpha$$

In (iii) the gain of the amplifier become infinite when the loop gain kA_v = +1. This is known as the critical value of the loop gain kA_v. It is important to note that the output voltage cannot be infinite. Instead the amplifier will start working as an oscillator without the need of any separate input. If the feedback path contains a frequency selective network, the requirement of kA_v = 1 can be met at only one particular frequency, such that, the output of the oscillator will be a sinusoidal signal of a particular frequency. Such oscillators are known as sine wave oscillators.

One of the simplest form of sine wave oscillators is the phase shift oscillator. Fig 1 shows the principle behind an R.C phase shift oscillator.

The feedback network shown in Fig 1 consists of resistors and capacitors which provide the required phase shift of 180° at a particular frequency f given by,

Fig 1



RC PHASE SHIFT OSCILLATOR

$$f = \frac{1}{2\pi \ C\sqrt{6}} \quad .....[1]$$

The other condition to be satisfied for oscillations to occur is that, the loop gain kA_v should be equal to unity. To satisfy this condition, using classical network analysis, it can be found that, the value of k should be, $k = \frac{1}{29}$

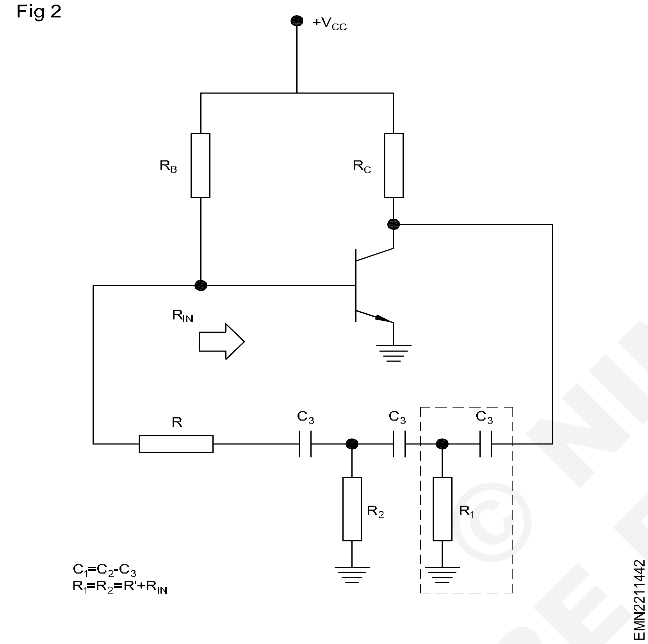
Therefore, the voltage gain of the amplifier A_v stage must be greater than 1/k or greater than 29 so that kA_v becomes equal to 1.

Transistor RC phase shift oscillator

Fig 2 shows a single transistor phase shift oscillator using resistors and capacitors in a feedback network.

There are three sections of R and C in the feedback network. Each RC section provides a 60° phase shift at a specific frequency, resulting in a 180° phase shift as required for positive feedback. This satisfies one of the two required conditions for oscillations.

Fig 2



In Fig 2, the feedback signal is coupled through a feedback resistor R' in series with the amplifier stage input resistance R_{in}. Resistor R' can be made variable for adjusting the oscillator frequency. For each of the three sections of R_C phase shift network to produce 60° phase shift, it is necessary that $C_1 = C_2 = C_3$ and $R_1 = R_2 = R' + R_{in}$.

The other required condition for oscillation, i.e. loop gain kA_v to be unity is satisfied by the circuit at Fig 2, when b of the transistor used in the circuit is,

$$h_{fe} \approx \beta = 23 + 29\frac{R}{R_c} + 4\frac{R_c}{R} \quad .....[2]$$

where, $R_1 = R_2 = R$

When β is atleast the value given by equation [2] or greater than, the circuit at Fig 2 it will oscillate.

Practical transistor RC phase shift oscillator

Fig 3 shows a practical transistor RC phase shift oscillator which is similar to that shown in Fig 2.

In Fig 3 note that resistor R_3 (in Fig 2 it is denoted as R') used for frequency adjustments is connected in series with one of the resistors of the RC section. Resistor R_4 provides the necessary bias stabilisation for the transistor operation. Note that a small value capacitor C_4 is connected in shunt with the input. The purpose of C_4 is to bypass the unwanted high frequency oscillations to ground. The value of R_3 can be varied to adjust the frequency of oscillations. However, the variation that can be obtained by R_3 is limited.

For the circuit at Fig 3, the frequency of oscillation is given by,

$$f = \frac{1}{2\pi\sqrt{6R_1^2 + 4R_1R_c}} \quad .....[3]$$

where, $C = C_1 = C_2 = C_3$

The minimum value of h_{fe} or b of the transistor used in the circuit at Fig 3 should be,

$$h_{fe} \approx \beta = 23 + 29\frac{R_1}{R_c} + 4\frac{R_c}{R_1}$$

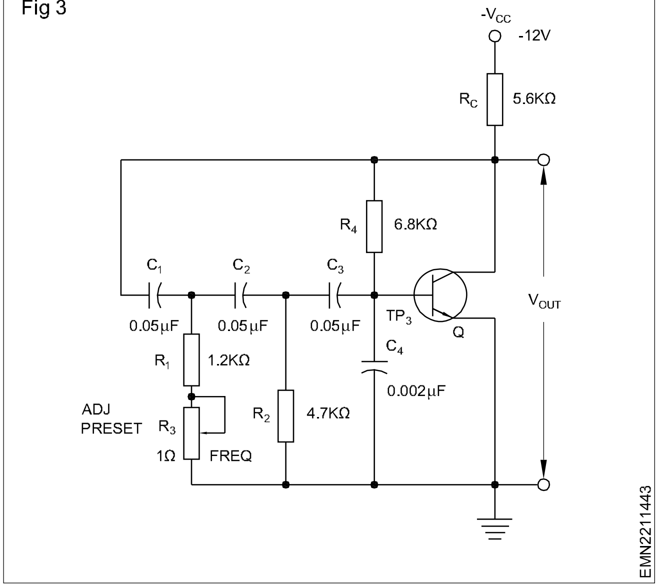
Using the component values at Fig 3, the b of the transistor used should be a minimum of,

$$\beta = 23 + 29\frac{1.2K}{5.6K} + 4\frac{5.6K}{1.2K} = 47.89$$

The frequency of oscillations can be increased by decreasing the value of R or by decreasing the value of C.

In the practical circuit at Fig 3, collector feedback bias is employed to ensure that the transistor will never go to saturation. Other biasing techniques such as voltage divider bias can also be used for dc biasing of the transistor. Since the frequency of oscillations is decided only by the feedback phase shift network, biasing resistors will not have any effect on the frequency of oscillations. The important point to be noted is that the b of the transistor should be higher than the minimum b given in equation 2 to have sustained oscillations.

Fig 3



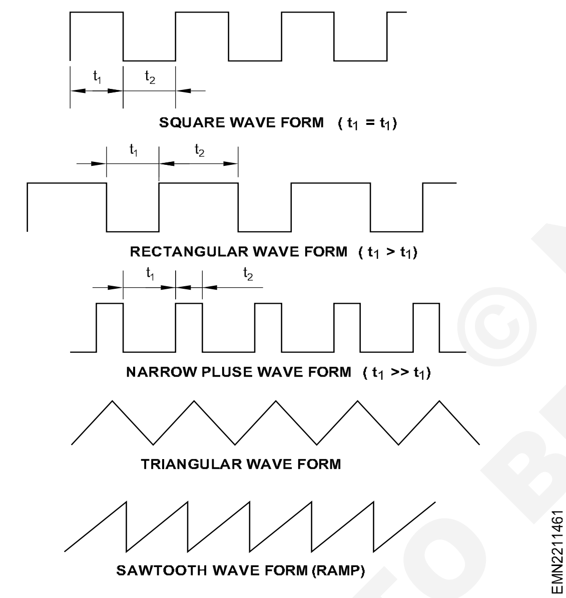
Multivibrators and Study of Circuit Diagrams

Objectives: At the end of this lesson you shall be able to
- **state the function of relaxation oscillators**
- **state the meaning of clock in the digital system**
- **explain the circuit of an astable multi-vibrator**
- **calculate the ON-time, OFF-time and PRF of astable multi-vibrators given values of R and C**
- **list a few applications of an astable multi-vibrator**
- **explain the difference among a astable multi-vibrator monostable multi-vibrator and bistable multivibrator**
- **draw the circuit of mono-shot and calculate the ON-time of the output pulse**
- **explain bistable multi-vibrator as Rs flip flop.**

NON SINUSOIDAL OSCILLATORS

A relaxation oscillator is a circuit for generating non-sinusoidal oscillations. These circuits can be used to give different types of repetitive wave-forms other than sine waves. A few types of non sinusoidal wave forms generated using relaxation oscillators are shown in Fig 1.

Fig 1



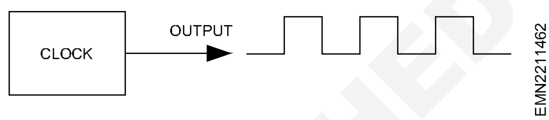
Amongst the different types of wave forms shown in Fig.1, the rectangular wave form is most frequently used for several applications. A few such applications are:

– Digital clocks, Digital computers and Digital equipments.

All digital systems need a reference frequency referred to as clock frequency to time the operation of the various sections of the system. This clock frequency is generated using a clock generator. A clock generator is nothing but a relaxation oscillator circuit which produces repetitive wave-forms, generally square wave as shown in Fig 2.

The output of this relaxation oscillator(clock generator) will be continuous pulses having two distinct states HIGH and LOW. A High state corresponds to a constant voltage (say 5V) and the low state corresponds to a different constant voltage(say 0V). These high and low states are repeated at definite intervals.

Fig 2



The clock generator or the relaxation oscillator used for generating pulse wave-forms as shown in Fig 2 is commonly known as a Multivibrator. A few applications are;

Electronic Keyboards or Pianos: In entertainment electronics, relaxation oscillators generating square wave-forms are essential for the production of electronic music. This is because, square waves are rich in harmonics.

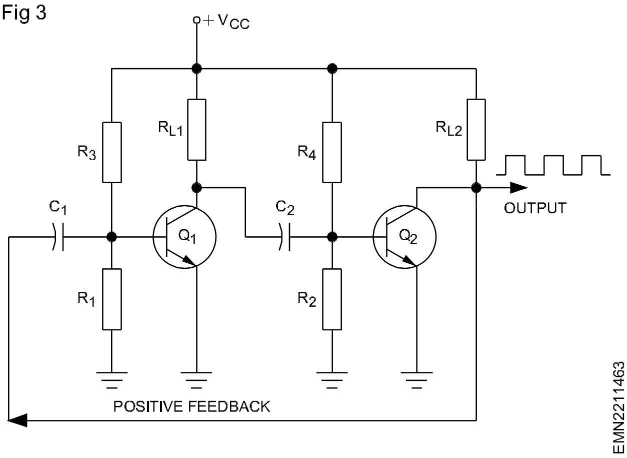
Test and Measuring Instruments: The rectangular, square and sawtooth wave-forms generators are extensively used in Oscilloscopes(CRO's), Function generators and so on.

Timers and Industrial controls: Rectangular, square wave generators are extensively used to control the delay time in switching-on and duration of on-period and several such industrial control requirement applications.

ASTABLE MULTI-VIBRATORS

A basic multi-vibrator circuit for generating square-wave is shown in Fig 3.

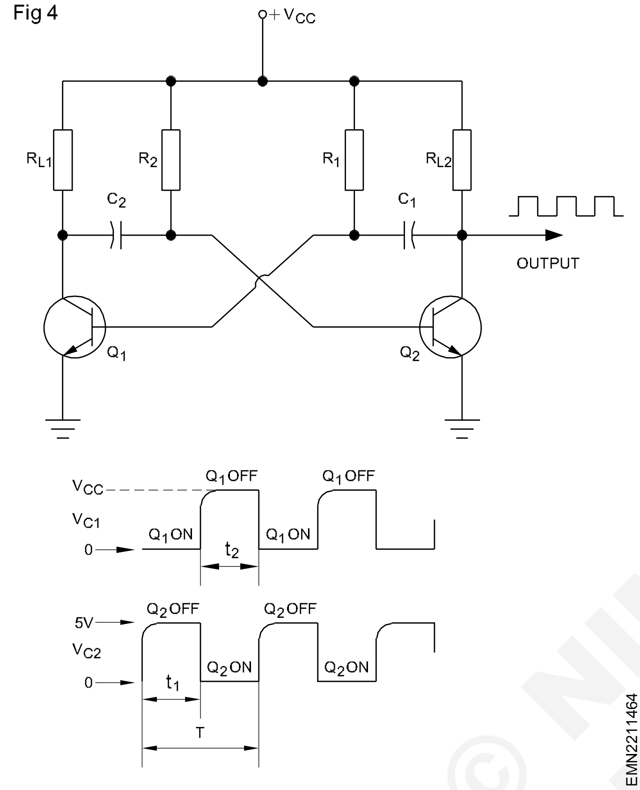
Fig 3



As can be seen, the multivibrator has two amplifier stages with feedback. The output of Q_1 drives the input of Q_2, and the output of Q_2 is fed back to Q_1. Since each CE amplifier stage introduces a phase shift of 180 degrees to its input signal, the signal fed at the input of Q_1a under goes a total phase shift of 180+180 degrees at the output. A 360 degrees phase shift between the input and output means, they are in phase. Hence, if the output signal is fed-back to input, it results in positive feed-back, which results in oscillations.

Fig 4 is a redrawn circuit of the multivibrator circuit at Fig 3. The circuit is redrawn for the sake of easier understanding of the working and waveforms.

Fig 4



In Fig 4, the oscillations are produced by switching ON-OFF of transistors. When one amplifier (stage) conducts, it cuts-off the other amplifier. When the stage which was OFF, starts to conduct, this action cuts-off the stage which was ON. This circuit is referred to as a relaxation oscillator because, at any instant of time, one amplifier stage is will be resting while the other is working.

The rate at which Q_1 and Q_2 are switched ON and OFF determines the oscillator frequency. As can be seen from the output wave form of the oscillator at Fig 4, the duration for which Q_1 is OFF is called the ON time of the pulse and the duration for which Q_1 is ON is called the OFF time of the pulse. The sum of one ON time plus one OFF time is called the time-period, T, of the wave form.

$T = t_1 + t_2$

If $R_1 = R_2$, $R_{L1} = R_{L2}$, $C_1 = C_2$ and Q_1 & Q_2 are identical, then, the ON time and OFF time due to both Q_1 and Q_2 will be same.

For instance, if each stage is ON or OFF for 0.5 ms, then the time period T is simply given 2 x 0.5 ms = 1 ms. Then the frequency of the multi-vibrator is 1/T = 1000 Hz.

Referring Fig 4, the period for which transistor Q_1 and Q_2 stays OFF is determined by the RC time constants of R_1 & C_1 and R_2 & C_2. It takes about 0.69 time constants(τ = RC) for the RC network to reach the base turn-on voltage. This gives the way to estimate the time that each transistor will be held in the off state.

t = 0.69RC.

If $R_1 = R_2$ and $C_1 = C_2$,

then,

$t_1 = t_2$ and T will be 2(0.69RC).

Example: If R_1=R_2= 47KW and C_1=C_2= 0.05μF, then the off-time of transistor will be,

$t = 0.69 \times 47 \times 10^3 \times 0.05 \times 10^{-6}$

= 1.62 m Sec.

Since R_1= R_2 and C_1 = C_2, $t_1 = t_2$ = 2 t

T= 2 x t = 2 x 1.62 m Sec.

= 3.24 m Sec.

Hence, the multivibrator produces a frequency, f, or more aptly known as *Pulse Repetition Frequency (PRF)* of square wave (because $t_1 = t_2$) given by,

$$\text{PRF or f} = \frac{1}{T} = \frac{1}{3.24 \times 10^{-3}} = 309 \text{ Hz}$$

When the values of R_1, R_2 and C_1, C_2 are not equal, the off-time of the two transistors will be different. Hence the output wave-form will be non-symmetrical or will not be a square wave form.

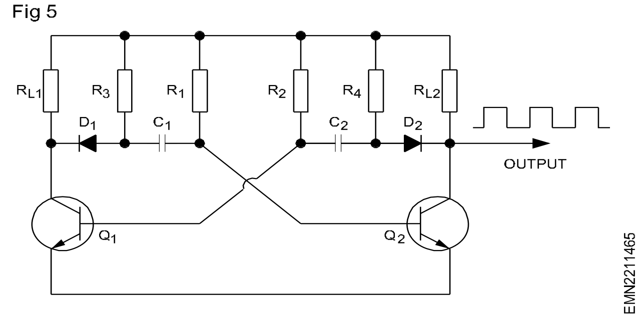
The multivibrator circuit shown in Fig 4 is known as a **free running** multi-vibrator. This mean, the multi-vibrator oscillates by itself without the need for any external signal to change the states. This free running multi-vibrator is also known as **Astable multi-vibrator**, because the amplifiers used in the circuit is not stable in either state(ON or OFF).

As can be seen in Fig 4, the square wave output of the astable multi-vibrator is having rounded edges. Such round edges are not suitable in certain critical digital applications.These rounded edges can be eliminated(made vertical) by adding two diodes and two resistors as shown in Fig 5.

The astable multi-vibrators shown in Fig 4 and Fig 5 are referred to as the collector-coupled multi-vibrators.

In addition to astable multi-vibrators which gives repetitive pulse wave form output, there are other types of multi-vibrators which are classified depending upon the manner in which the two stages of the multi-vibrator interchange their ON and OFF states. They are:

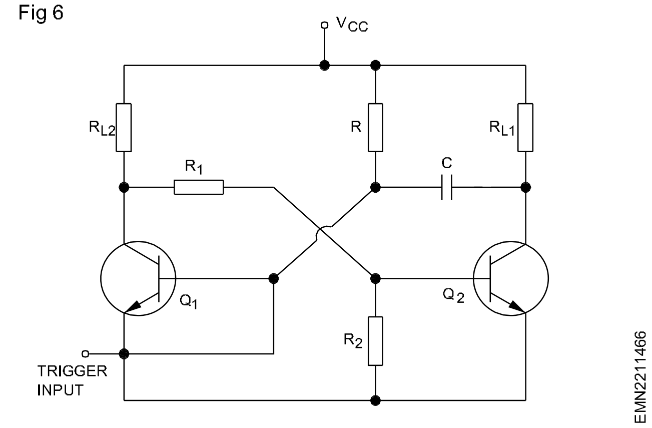
Fig 5



– Mono-stable multivibrator - having one stable state.

– Bistable multivibrator - having two stable states.

Fig 6



MONO-STABLE Multivibrators

Fig 6 shows a typical mono-stable multi-vibrator also known as **mono-shot** or **one-shot**.

A mono-shot has one stable state with one transistor conducting and the other off. This state can be changed only temporarily by giving an input pulse generally known as **trigger** pulse to the transistor which is off. But this changed state returns back to its original stable state after a period decided by the values of R and C.

Fig 7 shows a practical mono-stable multi-vibrator with trigger input. Fig 7 also shows the wave-forms at different points of the circuit.

The period t for which Q_2 is kept off temporarily is given by,

$$t = 0.69\ RC.$$

Mono-stable multi-vibrators are extensively used as timers in electronic timing control circuits.

BISTABLE Multivibrators

An astable multi-vibrator automatically switches from one state to other (ON-to-OFF or OFF-to-ON...). Whereas, a bistable multi-vibrator will change the state(ON to OFF or OFF to ON) when triggered and remain in the new state (ON or OFF). This means, a bistable multi-vibrator has two stable states. Fig 9 shows a typical bistable multi-vibrator circuit.

The circuit at Fig 9 is completely symmetrical. The potential dividers R_1, R_2 and R_3, R_4 form identical bias network at the base of transistors. Each transistor is biased from the collector of the other transistor. Due to the slightest difference in parameters of the transistor, when the circuit is switched ON, any one of the two transistors will turn-ON, and the other remain in OFF condition.

In the circuit at Fig 9, the two identical CE amplifier stages are so connected that the output of one is fed to the input of the other, through resistors R_1, R_3 and shunted by capacitors C_1, C_2. The purpose of the capacitor is nothing but to speed up the switching characteristic of the circuit to get distortion-less output wave-form. Capacitors C_1 & C_2 are also known as **commutating capacitors**.

Fig 7

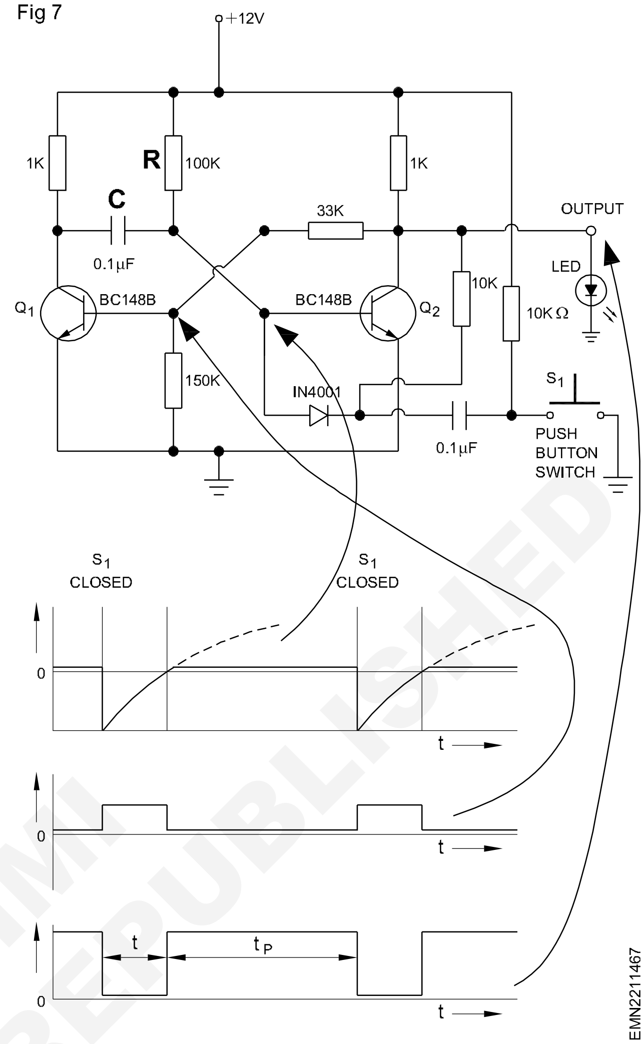
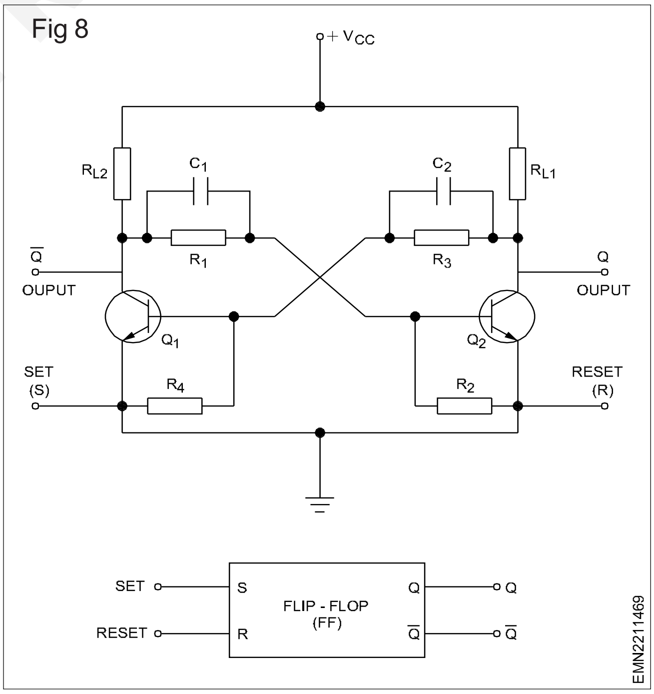


Fig 8



A bistable multi-vibrator is also known as a **flip-flop**. The output terminals are generally identified as Q & Q(Q-bar) as shown in Fig 10.

When Q is in high state (also known as **Logic-1** state in digital electronics), Q (Q-bar) will be in low state (also known as **Logic-0** state), and vice versa. This circuit is known as a flip-flop circuit because, if one output flips(high/logic-1) the other output automatically flops(low/logic-0). A flip-flop can be switched from one state to the other by applying a suitable triggering input. Flip-flops are used as a basic **memory cell** in digital computers for storing information. Flip-flops are used in various forms in almost all digital system as counters, frequency dividers and so on.

Clipper Circuit

Objectives : At the end of this lesson you shall be able to
- **define clipper circuit**
- **list the types of clippers**
- **state the functions of positive clipper with circuit**
- **state the functions of negative clipper with circuit.**

Wave shapping circuit:

A wave shapping circuit is used to change the shape of the wave form from alternating current or direct current. A clipper circuit is used to prevent the wave form voltage from exceeding the predetermined voltage without affecting the remaining part of the wave form.

Clipping circuit is a wave-shaping circuit and is used to either remove or clip a portion of the applied wave in order to control the shape of the output waveform. The portion of the voltage or the cutoff voltage may be above or below or both specified level. One of the most basic clipping circuits is the half-wave rectifier. A half-wave rectifier clips either the negative half cycle or the positive half cycle of an alternating waveform and allows to pass only one half cycle.

Classifications of clippers

According to biasing, the clippers may be classified as

- Unbiased clippers and
- Biased clippers

According to configuration used the clippers may be

- Series diode clippers
- Parallel or shunt diode clippers
- A series combination of diode, resistor and reference supply.

According to level of clipping the clippers may be

- Positive clippers
- Negative clippers
- Biased clippers
- Combination clippers

The basic components required for a clipping circuit are- an ideal diode and a resistor. In order to fix the clipping level to the desired amount, a DC battery may also be included. When the diode is forward biased, it acts as a closed switch, and when it is reverse biased, it acts as an open switch. Different levels of clipping can be obtained by varying the amount of voltage of the battery and also interchanging the positions of the diode and resistor.

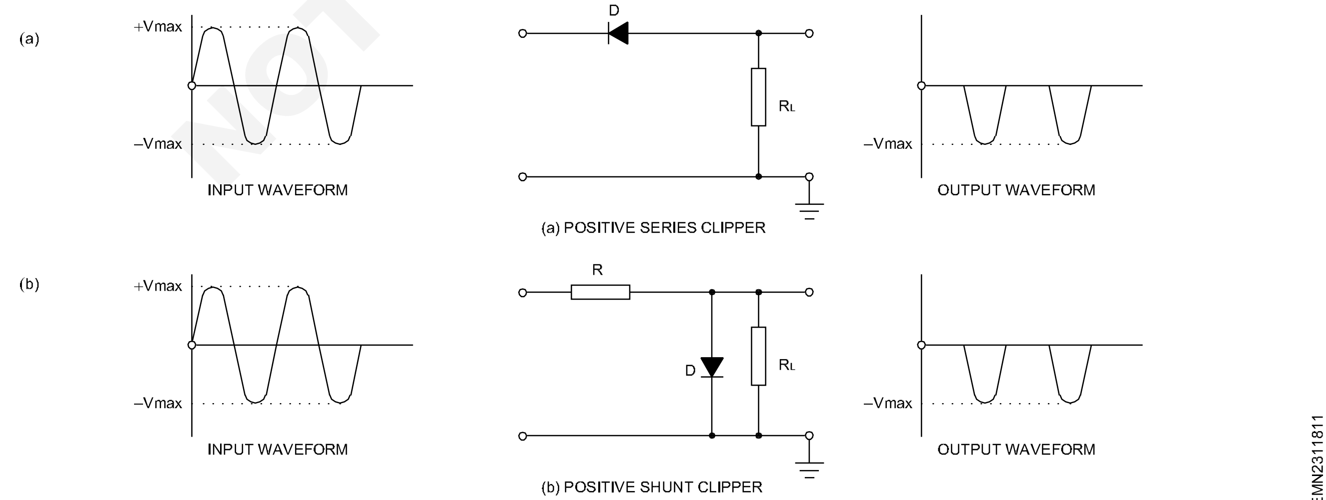
Depending on the features of the diode, the positive or negative region of the input signal is 'clipped' off and accordingly the diode clippers may be positive or negative clippers.

There are two general categories of clippers; series and parallel (or shunt). The series configuration is defined as one where diode is in series with the load, while the shunt clipper has the diode in a branch parallel to the load.

Positive Diode Clipper

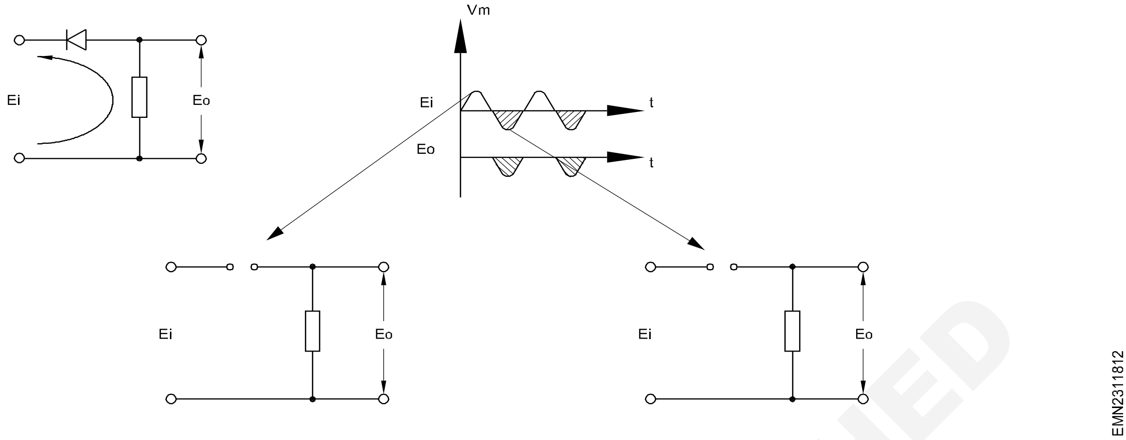
In a positive clipper, the positive half cycles of the input voltage will be removed. The circuit arrangements for a positive clipper are illustrated in the Fig. 1a and Fig. 1b given below.

Fig 1



As shown in fig. 1a, the diode is kept in series with the load. During the positive half cycle of the input waveform, the diode "D" is reverse biased, which maintains the output voltage at 0 volts. Thus causes the positive half cycle to be clipped off. During the negative half cycle of the input, the diode is forward biased and so the negative half cycle appears across the output. The above explanation will be self defined in the Fig. 2.

Fig 2



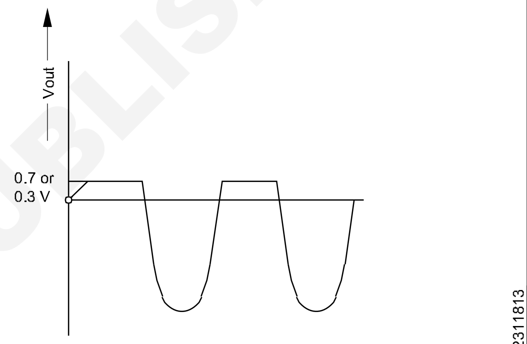
In Fig. 1(b) the diode is kept in parallel with the load. This is the diagram of a positive shunt clipper circuit. During the positive half cycle, the diode 'D' is forward biased and the diode acts as a closed switch. This causes the diode to conduct heavily. This causes the voltage drop across the diode or across the load resistance R_L to be zero. Thus output voltage during the positive half cycles in zero, as shown in the output waveform. During the negative half cycles of the input signal voltage, the diode D is reverse biased and behaves as an open switch. Consequently the entire input voltage appears across the diode or across the load resistance R_L if R is much smaller than R_L.

Actually the circuit behaves as a voltage divider with an output voltage of

$[R_L/R+R_L]\ V_{max}=-V_{max}$ when $R_L>>R$

In the above discussions, the diode is considered to be ideal one. In a practical diode, the breakdown voltage will exist (0.7V for silicon and 0.3V for Germanium). When this is taken into account, the output wave forms for positive clipper will be of the shape shown in the Fig3 below.

Fig 3

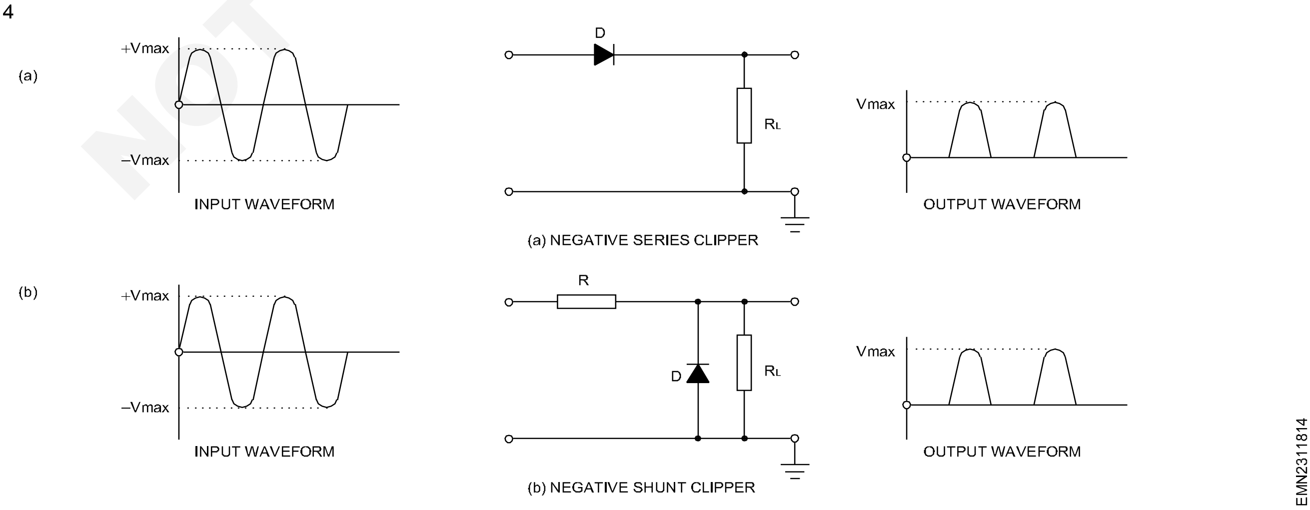


OUTPUT WAVEFORM FOR POSITIVE CLIPPER

Negative diode clipper

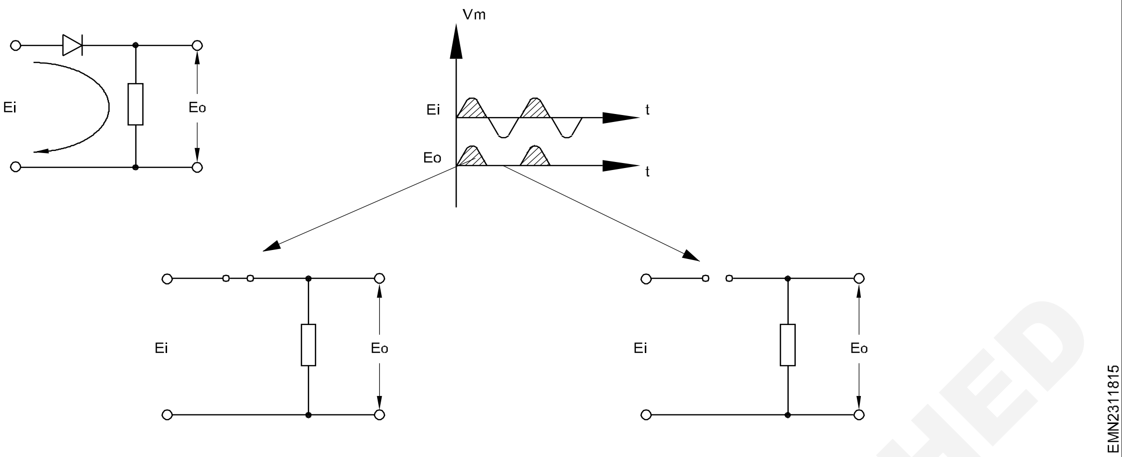
The negative clipping circuit is almost same as the positive clipping circuit, with only one difference. If the diode in figures 1(a) and (b) is reconnected with reversed polarity, the circuits will become for a negative series and shunt clippers are shown in figures 4(a) and (b) as given below.

Fig 4



As shown in the figure 4a, the diode is kept in series with the load. During the negative half cycle of the input waveform, the diode 'D' is reverse biased, which maintains the output voltage at 0 volts. Thus causes the negative half cycle to be clipped off. During the positive half cycle of the input, the diode is forward biased and so the positive half cycle appears across the output. The above explanation will be self defined in the Fig5.

Fig 5



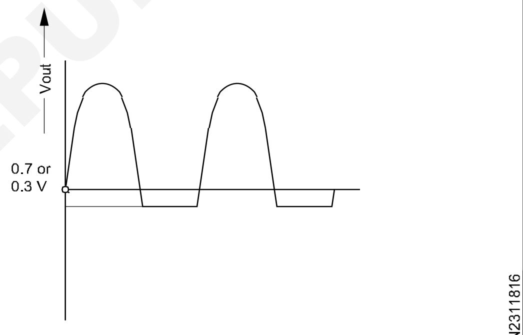
In Fig. 4(b) the diode is kept in parallel with the load. This is the diagram of a negative shunt clipper circuit. During the negative half cycle, the diode 'D' is forward biased and the diode acts as a closed switch. This causes the diode to conduct heavily. This causes the voltage drop across the diode or across the load resistance R_L to be zero. Thus output voltage during the negative half cycles is zero, as shown in the output waveform. During the positive half cycles of the input signal voltage, the diode D is reverse biased and behaves as an open switch. Consequently the entire input voltage appears across the diode or across the load resistance R_L if R is much smaller than R_L.

Actually the circuit behaves as a voltage divider with an output voltage of

$[R_L/R+R_L]\ V_{max}=V_{max}$ when $R_L>>R$

In the above discussions, the diode is considered to be ideal one. In a practical diode, the breakdown voltage will exist (0.7 for silicon and 0.3 V for Germanium). When this is taken into account, the output waveforms for negative clipper will be of the shape shown in the fig. 6 below.

Fig 6



OUTPUT WAVEFORM FOR NEGATIVE CLIPPER

Biased positive clipper and biased negative clipper

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

- **define biased negative and biased positive clippers**
- **state the functions of biased negative clipper with the circuit diagrams and waveforms**
- **state the functions of biased positive clipper with the circuit diagrams and waveforms.**

Biased negative clipper

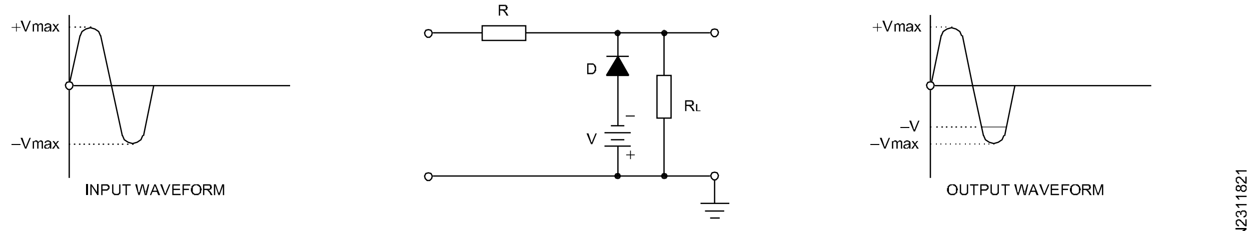
A biased clipper comes in handy when a small portion of positive or negative half cycles of the signal voltage is to be removed. When a small portion of the negative half cycle is to be removed, it is called a biased negative clipper. The circuit diagram and waveform is shown in the figure 1.

In a biased negative clipper, when the input signal voltage is positive, the diode 'D' is reverse biased. This causes it to act as an open - switch. Thus the entire positive half cycle appears across the load, as illustrated by output waveform. When the input signal voltage is negative but does not exceed the battery voltage 'V', the diode 'D' remains reverse-biased and most of the input voltage appears across the output. When negative signal voltage becomes more than the battery voltage V the diode D is forward biased and conducts heavily. The output voltage is equal to '-V' and stays at '-V' as long as the magnitude of the input signal voltage is greater than the magnitude of the battery voltage, 'V'. Thus a biased negative clipper removes input voltage when the input signal voltage becomes greater than the battery voltage.

Biased positive clipper

In a biased positive clipper, when the input signal voltage

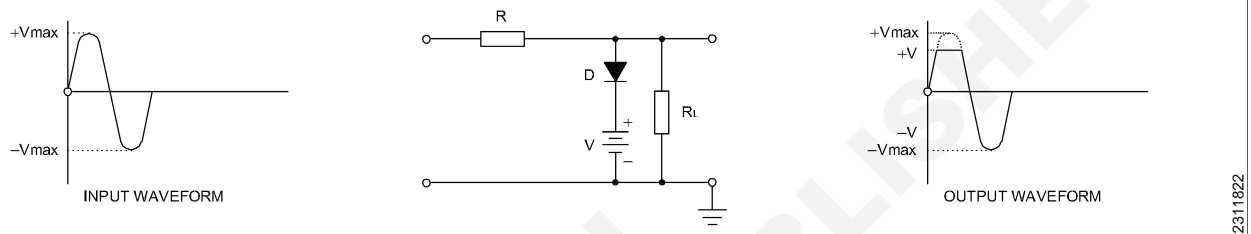
Fig 1



BIASED NEGATIVE CLIPPER

is negative, the diode 'D' is reverse biased. This causes it to act as an open - switch. Thus the entire negative half cycle appears across the load, as illustrated by output waveform . When the input signal voltage is positive but does not exceed the battery voltage 'V', the diode 'D' remains reverse-biased and most of the input voltage appears across the output. When positive signal voltage becomes more than the battery voltage V the diode D is forward biased and conducts heavily. The output voltage is equal to '-V' and stays at '-V' as long as the magnitude of the input signal voltage is greater than the magnitude of the battery voltage, 'V'. Thus a biased positive clipper removes input voltage when the input signal voltage becomes greater than the battery voltage.

Fig 2



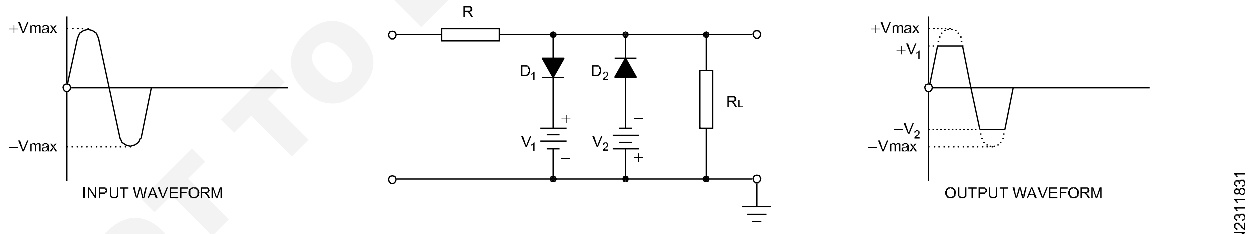
BIASED POSITIVE CLIPPER

Combination clipper

Objectives : At the end of this lesson you shall be able to
- **define combination / dual clipper**
- **state the functions of combination clipper**
- **list the applications of clipper circuits.**

When a portion of both positive and negative of each half cycle of the input voltage is to be clipped (or removed), combination clipper is employed. The circuit for such a clipper is given in the Figure1.

Fig 1



COMBINATION CLIPPER

The action of the circuit is summarized below. For positive input voltage signal when input voltage exceeds battery voltage '+V_1' diode D_1 conducts heavily while diode 'D_2' is reversed biased and so voltage '+V_1'. On the other hand for the negative input voltage signal, the diode 'D_1' remains reverse biased and diode 'D_2' conducts heavily only when input voltage exceeds battery voltage 'V_2' in magnitude. Thus during the negative half cycle the output stays at '-V_2' so long as the input signal voltage is greater than '-V_2'.

Applications

Clippers circuit has great applications in radars, digital computers and other electronic systems for removing unwanted portions of the input signal voltages above or below a specified level. Another application is in radio-receivers for communication circuits where noise pulses that rise well above the signal amplitude are clipped down to the desired level. Clipping circuits are also referred to as voltage limiters, amplitude selectors, or slicers.

Clamper circuits

Objectives : At the end of this lesson you shall be able to
- **define clamper circuit**
- **define positive clamper**
- **define negative clamper**
- **explain the working principle of positive clamper**
- **explain the working principle of negative clamper**
- **explain working of zener diode as peak clipper.**

A clamping circuit is used to place either the positive or negative peak of a signal at a desired level. The dc component is simply added or subtracted to/from the input signal. The clamper is also referred to as an DC restorer and ac signal level shifter.

A clamper circuit adds the positive or negative dc component to the input signal so as to push it either on the positive side, as illustrated in figure 1 or on the negative side, as illustrated in figure 2.

Fig 1

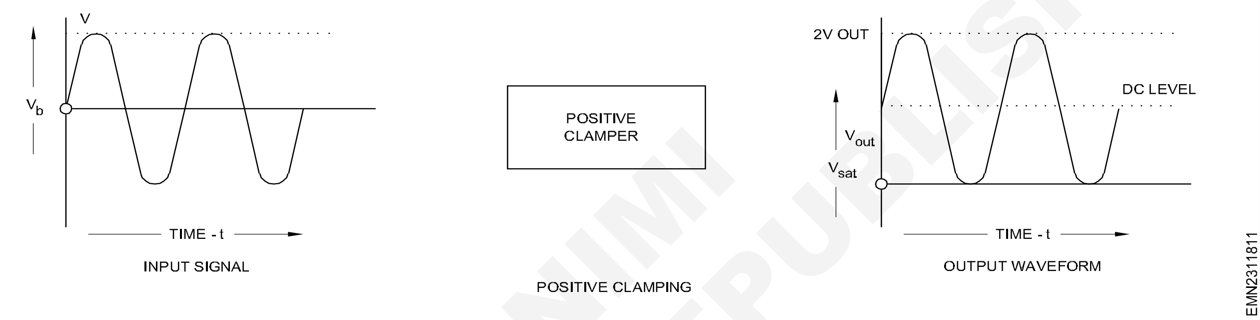
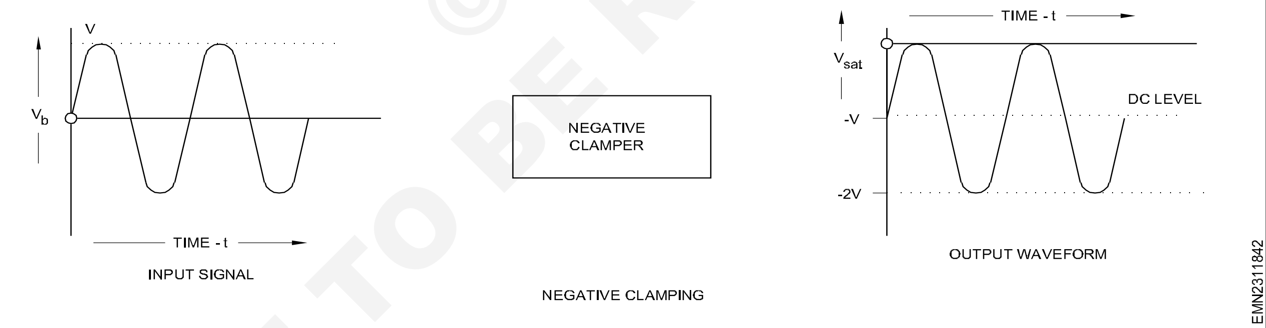


Fig 2



The circuit will be called a positive clamper , when the signal is pushed upward by the circuit. When the signal moves upward, as shown in figure (1), the negative peak of the signal coincides with the zero level.

The circuit will be called a negative clamper, when the signal is pushed downward by the circuit. When the signal is pushed on the negative side, as shown in figure (2), the positive peak of the input signal coincides with the zero level.

Application: In some cases, like a TV receiver, when the signal passes through the capacitive coupling network, it loses its dc component. This when the clamper circuit is used so as to re-establish the dc component into the signal input. Though the dc component that is lost in transmission is not the same as that introduced through a clamping circuit, the necessity to establish the extremity of the positive or negative signal excursion at some reference level is important. They also find applications in storage counters, analog frequency meter, capacitance meter, divider and stair-case waveform generator.

For a clamping circuit at least three components - a diode, a capacitor and a resistor are required. Sometimes an independent dc supply is also required to cause an additional shift. The important points regarding clamping circuits are:

- The shape of the waveform will be the same, but its level is shifted either upward or downward,
- There will be no change in the peak-to-peak or rms value of the waveform due to the clamping circuit. Thus, the

input waveform and output waveform will have the same peak-to-peak value that is, $2V_{max}$. This is shown in the figure above. It must also be noted that same readings will be obtained in the ac voltmeter for the input voltage and the clamped output voltage.

- There will be a change in the peak and average values of the waveform. In the figure shown above, the input waveform has a peak value of V_{max} and average value over a complete cycle is zero. The clamped output varies from 2 V_{max} and 0 (or 0 and $-2V_{max}$). Thus peak value of the clamped output is 2Vmax and average value is V_{max}.
- The values of the resistor R and capacitor C affect the waveform.
- The values for the resistor R and capacitor C should be determined from the time constant equation of the circuit, t = RC. The values must be large enough to make sure that the voltage across the capacitor C does not change significantly during the time interval the diode is non-conducting. In a good clamper circuit, the circuit time constant t = RC should be at least ten times the time period of the input signal voltage.

Negative clamper: Consider a negative clamping circuit, a circuit that shifts the original signal in a vertical downward direction, as shown in the figure 3. The diode D will be forward biased and the capacitor C is charged with the polarity shown in Fig. 3, the output voltage will be equal to 0V. The capcitor is charged to V. During the negatice half cycle, the diode becomes reverse - biased and acts as an open - circuit. Thus, there will be no effect on the capacitor voltage. The resistance R, being of very high value, cannot discharge C a lot during the negative portion of the input voltage and the capacitor voltage and is equal to -V -V or -2V). The value of the peak-to-peak output will be the difference of the negative and positive peak voltage levels is equal to 2V.

Positive clamper: The fig 4 shown can be modified into a positive clamping circuit by reconnecting the diode with reversed polarity. The positive clamping circuit moves the original signal in a vertical upward direction. A positive clamping circuit is shown in the Fig 4 below.

Fig 3

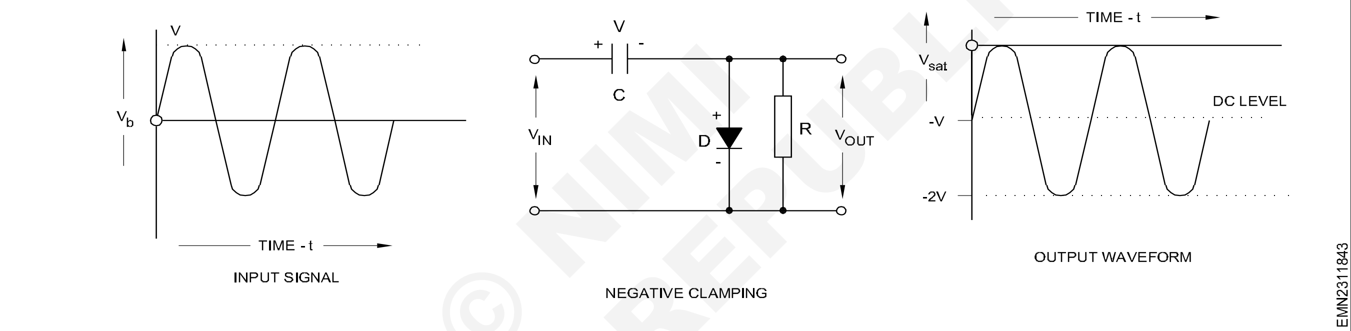
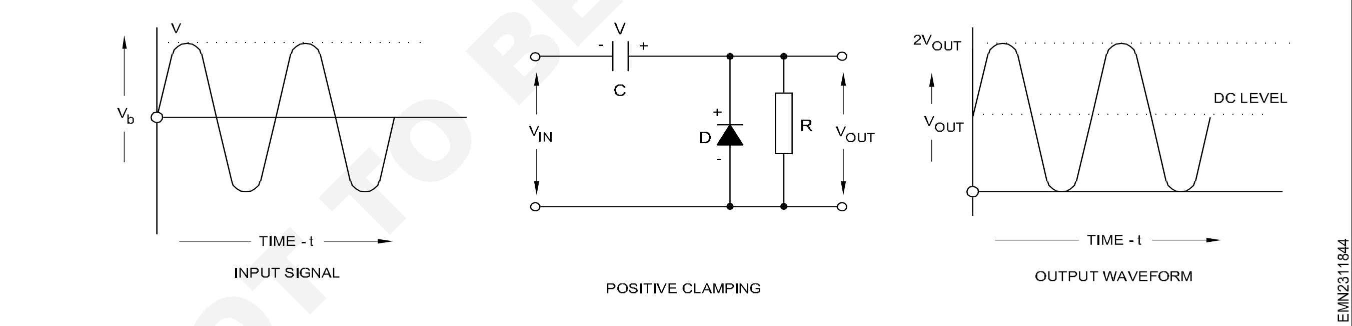


Fig 4



It contains a diode D and a capacitor C as are contained in a negative clamper. The only difference in the circuit is that the polarity of the diode is reversed. The remaining explanation regarding the working of the circuit is the same as it is explained for the negative clamper.

Consider a positive clamping circuit, a circuit that shifts the original signal in a vertical upward direction, as shown in the Fig 4. During the negative half cycle of input the diode D will be forward biased and the capacitor C is charged with the polarity shown in Fig.4, the output voltage will be equal to 0V. The capacitor is charged to V. During the positive half cycle, the diode becomes reverse-biased and acts as an open-circuit. Thus, there will be no effect on the capcitor voltage. The resistance R, being of very high value, cannot discharge C a lot during the positive portion of the input waveform. Thus during positive input, the output voltage will be the sum of the input voltage and the capacitor voltage and is equal to V+V or (2V). The value of the peak-peak output will be the difference of the negative and positive peak this portion add with diode clipper levels is equal to 2V.

Zener diode clipping circuits: The use of a bias voltage means that the amount of the voltage waveform that is clipped off can be accurately controlled. But one of the main disadvantages of using voltage biased diode clipping circuits, is that they need an additional emf battery source which may not be a problem.

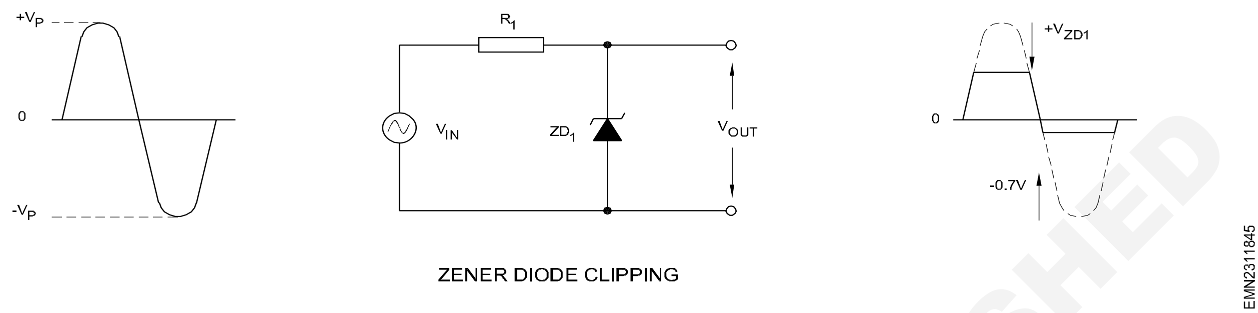
One easy way of creating biased diode clipping circuits without the need for an additional emf supply is to use Zener Diodes.

As we know, the zener diode is a another type of diode that has been breakdown region and as such as can be used voltage regulations or zener diode clipping applications. In the forward region, the zener acts just like an ordinary silicon diode with a forward voltage drop of 0.7V (700mV). When conducting, the same as above.

However, in the reverse bias region, the voltage is blocked until the zener diodes breakdown voltage is reached. At this point, the reverse current through the zener increases sharply but the zener voltage, V_z across the device remains constant even if the zener current, I_z varies.

Then we can put this zener action to good effect by using them for clipping a waveform as shown in fig 5.

Fig 5

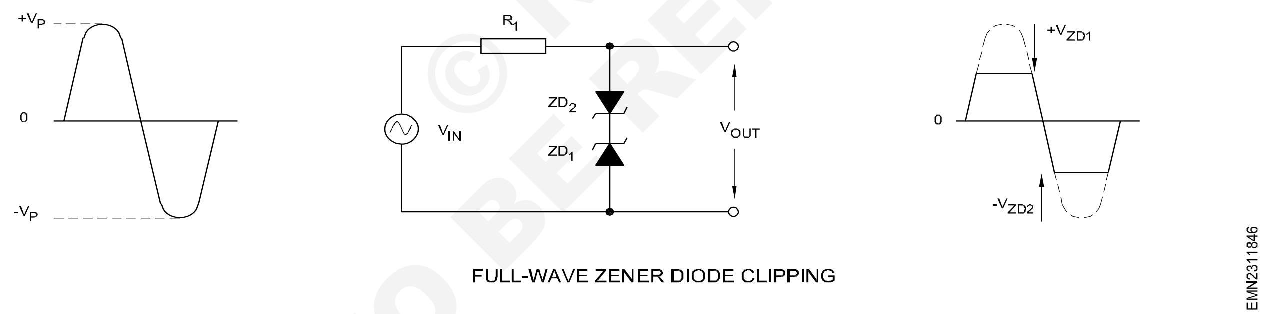


ZENER DIODE CLIPPING

Zener Diode Clipping : The zener diode is acting like a biased diode clipping circuit with the bias voltage being equal to the zener breakdown voltage. In this circuit during the positive half of the waveform the zener diode is reverse biased so the wave from is clipped at the zener voltage, $V_{ZD1.}$ During the negative half cycle the zener acts like a normal diode with its usual 0.7V junction value.

We can develop this idea further by using the zener diodes reverse voltage characteristics to clip both halves of a wave from using series connected back to back zener diodes in Fig 6.

Fig 6



FULL-WAVE ZENER DIODE CLIPPING

The output waveform from fulll zener diode clipping circuits resembles that of the previous voltage biased diode clipping circuit. the output waveform will be clipped at the zener voltage plus the 0.7V forward volt drop of the other diode. So for example, the positive half cycle will be clipped at the sum of zener diode, ZD_1 plus 0.7 ZD_2 and vice vers a for the negative half cycle.

Zener diodes are manufactured with wide range of voltages and can be use to give different voltage references on each half cycle, the same as above. Zener diode are available with zener breakdown voltages, Vz ranging from 2.4 to 33 volts, with a typical tolerance of 1 or 5%.Note that once conducting in the reverse breakdown region, full current will flow through the zener diode so a suitable current limiting resistor, R1 must be chosen.

Applications: As well as being used as rectifiers, diodes can also be used to clip the top, or bottom, or both of a waveform at a particular dc level and pass it to the output without distortion. In or examples above we have assumed that the waveform is sinusoidal but in the theory any shaped input waveform can be used.

Diode clipping circuits are used to eliminate amplitude noise or voltage spikes, voltage regulation or to produce new waveforms from an existing signal such as squaring off the peaks of a sinusoidal waveform to obtain a rectangular waveform as seen above.

The most common application of as diode clipping is as a fly wheel or free wheeling diode connected in parallel across an inductive load to protect the switching transistor form revers voltage transients.

Field Effect Transistors

Objectives: At the end of this lesson you shall be able to
- **construction of FET & JFET**
- **difference between JFET & BJT**
- **FET amplifiers in measuring device applications.**

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.

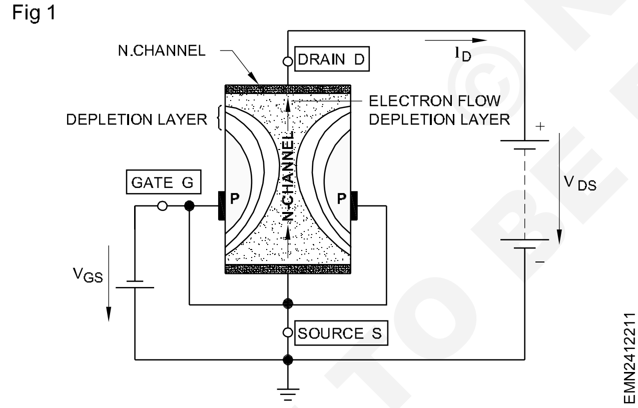
In simple terms, This means that the main current in a bipolar transistor (collector current) is controlled by the base current.

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 Fig1.

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.

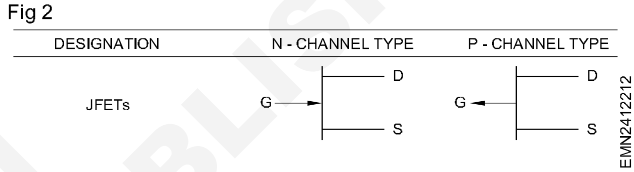
There are a wide variety of FETs. One of the fundamentals types called as junction field effect transistor (JFET) is discussed.

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.

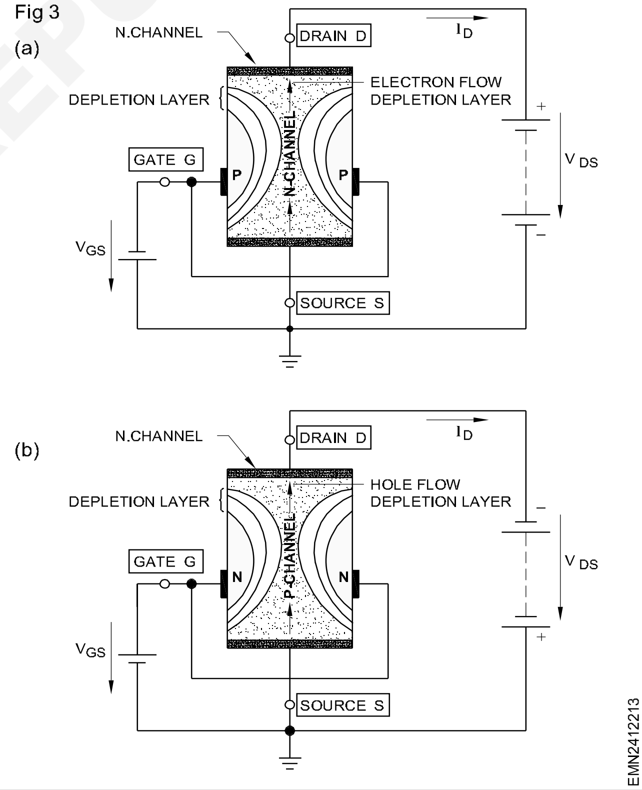
The internal diagram of a N-channel FET is shown in Fig.3.

Fig 2



Construction

Fig 3



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 electrical 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 Biploar transistors, the working point of adjustment and stabilization are also required for FETs.

Biasing 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 posive 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 $-V_{GS}$=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.

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.

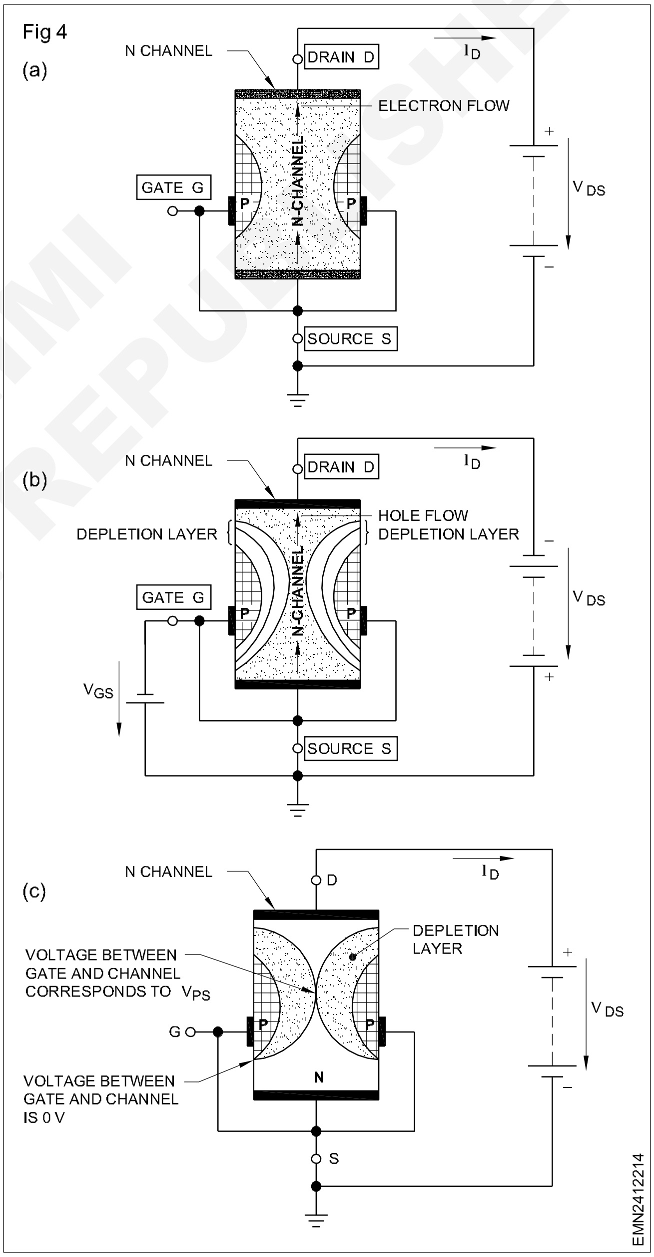
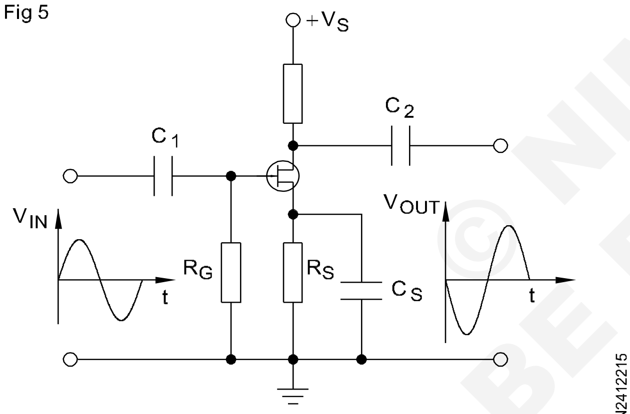


Fig 4

Important specifications of typical JFETs

Specification	BF245B	BFW10
Polarity of the device (N-type/P-type)	NN	NN
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 (Refer 6605 data manual)	fig W141e	fig W158b

Fig 5



COMMON - SOURCE CONFIGURATION

Typical applications of JFET

One very important characteristic of JFET is its very high input impedence 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

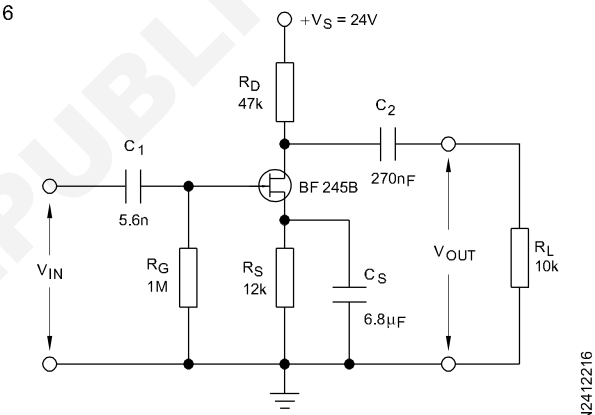
– Integrated circuits of both analog and especially in Digital technology.

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.

Fig 6



CIRCUIT DIAGRAM OF THE CALCULATED A.C VOLTAGE AMPLIFIER

Difference between JFET and BJT

JFET	BJT
1 In a JFET there is only one type of carrier ie., holes in p type channel and electrons in n-type channel. For this reason it is called unipolar transistor.	1 In BJT both electrons and holes play role in conduction. It is called as bipolar transistors.
2 As the input circuit of a JFET is reverse biase and therefore it as a input independence.	2 The input circuit of a BJT is forward based and hence has low input independence.
3 No current enters the gate & JFET.	3 In typical BJT base current might be a few A.
4 JFET uses voltage on the gate terminal to the control current between drain and source. No junction in JFET so noise level is very small	4 BJT uses the current into its base to control a large current between collector and emitter.

FET Amplifiers in measuring device applications.

- Field effects transistors (FETs) are used in mixer circuits to control low inter modulations distortions.
- FETs are used in low frequency amplifiers due to its small coupling capacitors.
- It is a voltage controlled device due to this it is used in operational amplifier 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 receiver.
- It is used in large scale integration (LSI) and computer memories because of its small size.

Working principle, specifications and testing of SCR

Objectives: At the end of this lesson you shall be able to
- **explain the construction and working principle of SCR**
- **explain VI characteristics of SCRs**
- **list the specifications of SCRs**
- **explain the method of checking SCRs using JIG.**

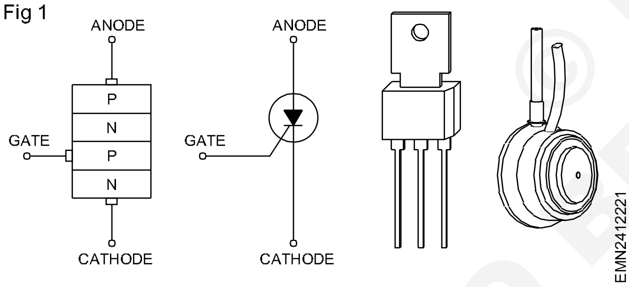
Silicon Controlled Rectifier(SCR)

Silicon Controlled Rectifier (SCR) is the first device of the thruster family. The term thruster is coined from the expression Thyratron-transistor. SCR is a semiconductor device. SCR does the function of controlled rectification. Unlike a rectifier diode, SCR has an additional terminal called the gate which controls the rectification(gated silicon rectifier).

The basic principle application of SCRs is to control the amount of power delivered to a load(motor, lamp, etc.,).

A rectifier diode will have one PN junction. SCRs on the other hand will have two PN junctions (P-N-P-N layers). Fig.1 shows the electrical symbol, basic construction and a typical SCR packages.

Fig 1



Basic operation of SCR

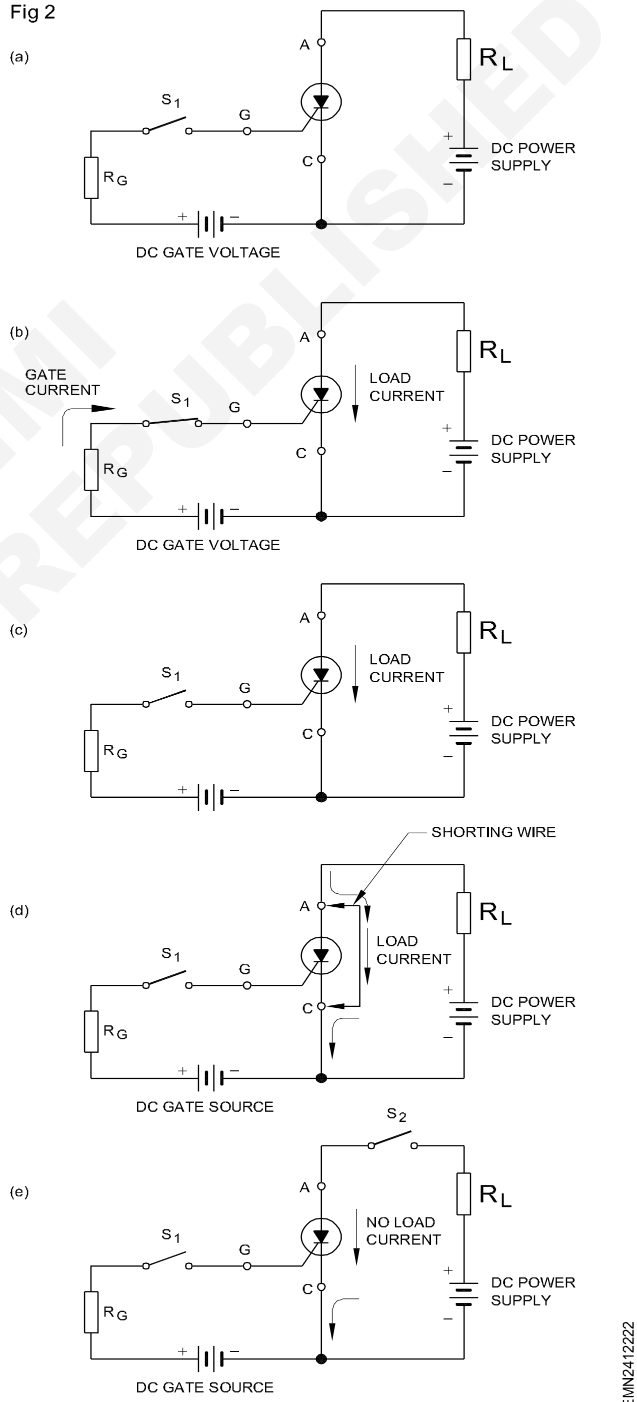
When a gate current is applied to the gate terminal, forward current conduction commences in the SCR(latched into conduction). When the gate current is removed, the forward current through the SCR **does not cut-off**. This means, once the SCR is latched into conduction, the gate loses control over the conduction. The current through the SCR can be turned off only by reducing the current through it(load current) below a critical value called the **Holding current.**

Fig 2 shows how an SCR can be gated into conduction or turned off.

In Fig 2a, with switched S1 open the SCR is in OFF state and no current is flowing through the load.

In Fig 2b, when S_1 is closed, a small gate current(around 1/1000 or less compared to load current) turns-ON (fires) the SCR. A heavy load current starts flowing through the SCR and load R_L.

Fig 2



In Fig 2c, when S_1 is opened, gate current becomes zero. This will have no effect on the current through the SCR and the heavy load current continues to flow through the SCR.

In Fig 2d, if a shorting wire is placed across the anode and the cathode terminals, the current though the SCR gets by-passed and all the current starts flowing through the shorted wire instead through the SCR. This means the current through the SCR is reduced below the rated holding current(minimum current required through SCR to keep it latched). This turns-OFF the SCR. Even when the shorting wire is removed the SCR remains to be in OFF state.

Fig 2e shows an alternative method of turning-OFF the SCR. In this instead of shorting the anode and cathode terminals of the SCR, the load current is cut-off by opening the Switch S_2. This reduced current through the SCR below the holding current and thus turns- OFF the SCR. Once the SCR is turned_OFF, the SCR does not turn-ON even if the switch S_2 is closed. To make the SCR fire again, with the switch S_2 closed, the gate current should be made to flow by closing the switch S_1.

Since the SCR does not conduct in the reverse direction, the anode of the SCR should always be positive with respect to cathode for conduction.

Important features of SCR,

- A very small gate current will control the switching of a large load current.

Example: In 2N1597 SCR, a gate current of about 10mA will switch a load current of 1.6A(1:160).

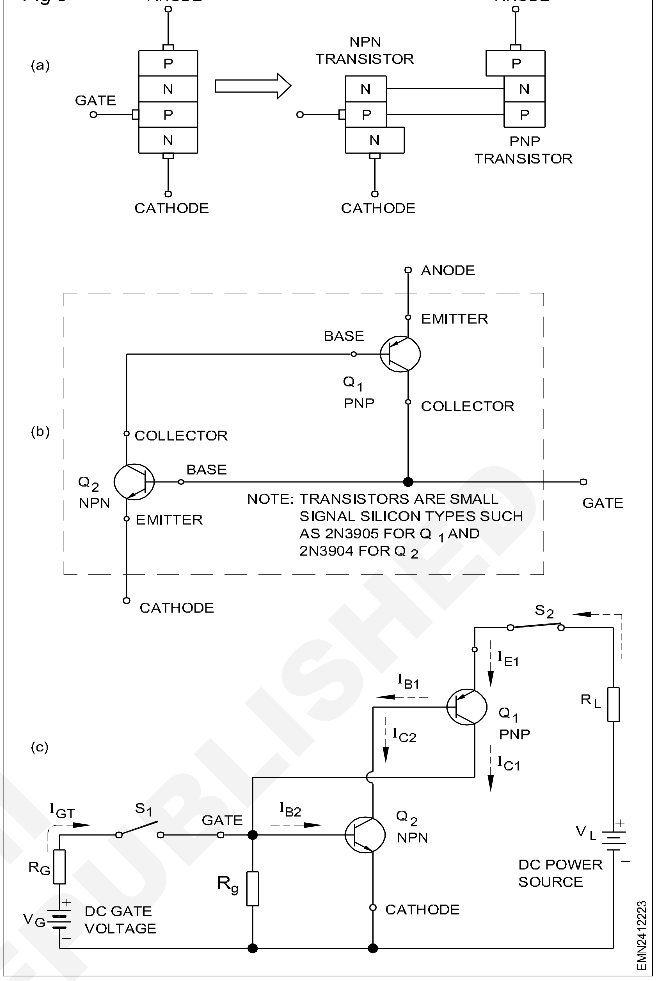
- A gate current pulse of short duration(typically 100 m sec) is sufficient to turn on the forward load current of SCR.

Understanding SCR as two interconnected transistors: For a clear understanding of how a SCR works, the four layer PNPN construction of SCR can be visualized as two independent transistors interconnected as shown in Fig 3a and 3b.

In Fig 3c, in the initial state with S_1 open, both Q_1 and Q_2 are in cutoff and hence there is no current through the load R_L.

When S_1 is closed, the gate supply V_G causes a small base current(I_{B2}) to flow from the base of Q_2. This small base current turns on Q_2 and fairly a large collector current I_{C2} flows. At the same time, the emitter-base junction of Q_1 is forward biased and turns on Q_1. Since Q_1 collector current flows through the base of Q_2, this causes I_{C2} to increase. This increase in the base and collector currents of Q_1 and Q_2 becomes regenerative and thus takes Q_1 and Q_2 to saturation. At this time even if the base externally applied gate trigger pulse is removed, since the collector current of each transistor supplies the required base current to each other transistor, both the transistors remain to be in saturation. In this condition, the SCR acts almost like a short circuit/closed switch with a resistance as small as 0.1 ohms or less.

Fig 3



To bring the SCR to OFF state, since the externally applied gate has no further control of the SCR, the only way to turn-off is to reduce the collector currents of Q_1 and Q_2 to such a level that they will not sustain the regenerative action. This can be done by breaking the load current by switching off S_2 or by placing a short across the anode and cathode of the SCR. By shorting or by opening S_2, the current through the SCR(collector currents of the interconnect transistors) is reduced below the rated **holding current.**

Holding current is that minimum value of current required to sustain the regenerative action in the interconnected transistors in the absence of the gate trigger.

The resistor Rg connected across the base and emitter of Q_2 is to provide immunity from false gate triggering signals such as noise spikes etc. Recall that such a connection at the input circuit of a transistor reduces the input(gate) impedance of the transistor.

Typical VI Characteristics of SCR

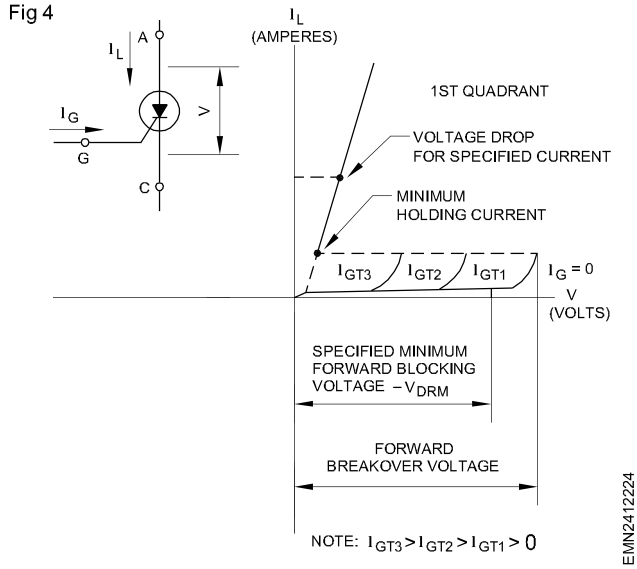
SCR operation in first quadrant with DC supply

Typical Voltage-Current (VI) characteristics of a SCR is illustrated in Fig 4.

Considering that the SCR is operated with DC supply and the device is always forward biased(+ve to anode and -ve to cathode). The V-I characteristics of a typical SCR will be as shown in Fig 4. This is called as the first quadrant operation of the SCR.

When SCR is used with AC supply, then the VI characteristics in the third quadrant will also be discussed.

Fig 4



SCR Specifications

For maximum performance, reliability and safety, each SCR should be operated within the ratings specified by the manufacturer. When you are designing a new circuit or replacing an SCR of an existing circuit, it is very essential to check the data of the SCR before using.

A typical SCR data sheet list many specifications. A few of these specifications considered as most important from the point of view of a technician are listed below;

V_{DRM}: This is referred to as the anode-cathode forward Break down voltage with no input gate current. Beyond this value, the SCR will break down into forward conduction. For typical SCRs, V_{DRM} ranges from about 30 Volts to 800 Volts.

V_{RRM}: This is referred to as the maximum anode-cathode reverse breakdown voltage. Beyond this value the SCR will break into reverse conduction. For typical SCRs, V_{RRM} also ranges from about 30 Volts to 800 Volts.

V_{GT}: This is the minimum positive gate voltage required to turn on the SCR. At temperature of 25°C typical values of V_{GT} is 0.7 to 0.8 volts. For higher temperatures of about 100 to 125°C, V_{GT} drops to approximately 0.2 volts.

I_{GT}: This is the minimum forward gate current required to turn on the SCR. Typically, low power SCRs require an I_{GT} of about 100 to 300 μA for turn-on. Medium and high power SCR needs about 5 to 150 mA for turn-on.

I_H: This is the minimum load current required to be maintained in the SCR to keep the SCR in on-state. Typical values of I_H ranges from about 6 mA for low power SCRs to 80 mA for high power SCRs.

I_T: This is the maximum allowable anode current that the SCR can withstand. This is defined by manufacturers in terms of rms forward current(I_{rms}) or average forward current (I_{avg}) for 180° of conduction. Typical values of I_{rms} for low and medium power SCRs range from about 1 to 30 Amperes.

V_{TM}: It is the maximum on state anode-cathode voltage drop across the SCR when it is conducting. Some manufacturers refer to this specification as V_F or V_{FM}. For most SCRs , V_{TM} is of the order of 1.6V.

t_{gt}: It is the time required for a specified gate current to turn on the SCR. Typical values lie in the range of 1 to 2 μSec.

t_q: It is the time required for a specified SCR to turn-off when the load circuit is made open. Typical values lie in the range of 15 to 35 μSec.

In addition to the above specifications, there are a few more specifications of SCR, some are of general nature to be considered while designing circuits using SCR and some are specific to certain SCR types. For further details refer specification sheets of SCR supplied by the manufacturers.

Specifications of a few SCRs

2N 5060

V_{RRM}	30V
V_{GT}	1.2V
I_{GT}	0.35A t_{gt}
I_H	t_q
I_T	0.8A
Package type:	TO 92

MCR 218-5

V_{DRM}	300V
V_{TM}	1.5(typ) to 1.8V(max)
V_{GT}	0.2V(min) - 2.5V(max)
I_{GT}	10mA(typ) to 25mA(max)
I_H	16mA(typ_ to 30mA(max)
$I_{T(rms)}$	8 Amps.
Package type :	TO 220

QUICK Check of SCRs

Quick check on SCRs can be carried out using a ohmmeter/ multimeter. Since SCRs are made of PNPN junction, resistance between junctions can be measured to conclude good working condition of the SCR. A good SCR shows following resistances between its terminal leads;

CHECK - 1

Between Anode - Cathode - Infinite resistance

[Irrespective of polarity]

Between Gate - Cathode

(i) Forward biased - Very low resistance (30 to 500 ohms)

(ii) Reverse biased - High resistance

Between Gate - Anode - Infinite resistance

[Irrespective of polarity]

CHECK - 2

– Set multimeter to low resistance range.

– Connect positive lead of multimeter to the anode and the negative lead to the cathode. Meter should show infinite resistance.

– Now, for moment, short anode and gate of SCR by a piece of wire. The meter should show low resistance and will continue to show low resistance even after the short between anode and gate is been removed.

It is difficult to check leaky SCRs using only a ohmmeter/multimeter.

Checking SCRs using a SCR checking JIG

A simple "SCR checking jig" is shown in Fig 5. In Fig 5, the SCR shown in dotted lines is the SCR to be checked. This could be any SCR that you want to check.

In Fig 7, the stepped down 12V AC is rectified by diode D_1 and filtered by capacitor C_1 when switch S_2 is at position A. The rectified and filtered DC is applied to the anode of SCR through lamp L_1 via a limiting resistor R_4. Resistor R_2, R_3 in series with a push button switch S_3 form a potential divider across DC. Voltage across R_3 is applied to the gate of SCR. This voltage is sufficient to turn on the SCR. Another push button Switch S_4 is connected directly across the Anode and Cathode of the SCR to be checked.

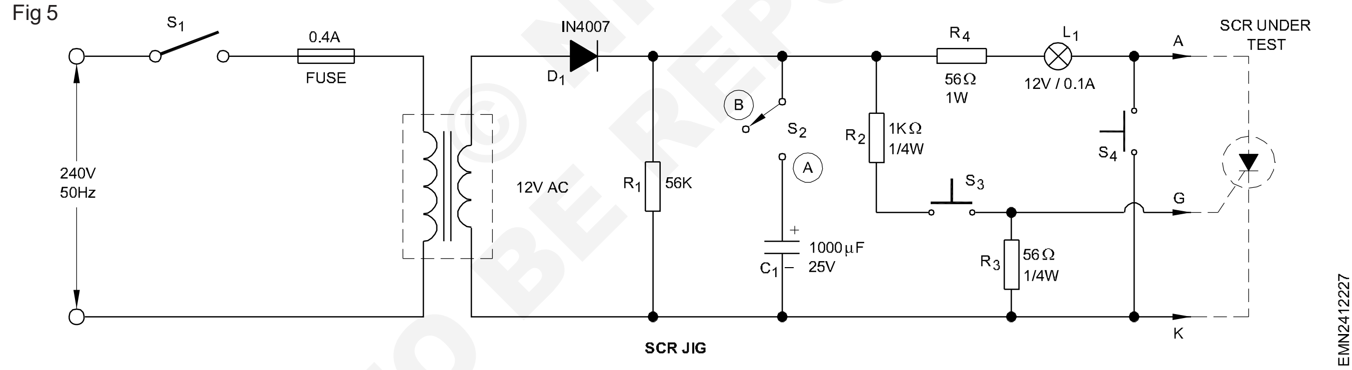
When a good SCR is placed in the test jig(in place of the SCR shown dotted) the circuit should function as given below;

1 When mains supply is on, and S_2 is at DC position, the lamp will start glowing as soon as the switch S_3 is pressed. Even on releasing S_3, the lamp should keep on glowing. Under this condition, if switch S_4 is pressed once and released the SCR stops conducting and hence the lamp stops glowing.

2 If switch S_2 is put to AC position ie., to position B, lamp should glow only as long as switch S_3 is pressed. Switch position B corresponds to feeding AC from secondary side of transformer.

Instructor to discuss reasons for 1 & 2 above as an interactive discussion. Instructor should also discuss the outcome of above steps when a open or a shorted SCR is checked.

Fig 5



Solid State Relay

Objectives : At the end of this lesson you shall be able to
- **explain construction and working of solid state relay**
- **explain advantage and disadvantages over mechanical relay.**

Solid - state relay

A **solid-state relay (SSR)** is an electronic switching device that switches conduction states when a small external voltage is applied along its n-type and p-type junctions. SSRs consist of a sensor which responds to an appropriate input (control signal), a solid-state electronic switching device which switches power to the load circuitry, and a coupling mechanism to enable the control signal to activate this switch without mechanical parts. The relay may be used to switch either AC or DC to the load. It serves the same function as an electromechanical relay, but has no moving parts.

Solid-state relays are composed of semiconductor materials, including thyristors and transistors, and have current ratings that extend from a few microamps for low-power packages up to around a hundred amps for high-power packages. They have extremely fast switching speeds usually ranging between 1 to 100 nanoseconds and are not easily affected by contact wear. Solid-state relays have several shortcomings:

1. It gets easily damaged in comparison to electromechanical relays.

2. Limited switching arrangements (SPST switching); a need for finer tuning due to high "on" resistances.

Coupling

The control signal must be coupled to the controlled circuit in a way which provides galvanic isolation between the two circuits.

Many SSRs use optical coupling. The control voltage energizes an internal LED which illuminates and switches on a photo-sensitive diode (photo-voltaic); the diode current turns on a back-to-back thyristor, SCR, or MOSFET to switch the load. The optical coupling allows the control circuit to be electrically isolated from the load.

Operation

A SSR based on a single MOSFET, or multiple MOSFETs in a paralleled array, can work well for DC loads.

MOSFETs have a built-in substrate diode that conducts in the reverse direction, so a single MOSFET cannot block current in both directions. For AC (bi-directional) operation two MOSFETs are arranged back-to-back with their source pins tied together. Their drain pins are connected to either side of the output. The substrate diodes are alternately reverse biased to block current when the relay is off. When the relay is on, the common source is always riding on the instantaneous signal level and both gates are biased positive relative to the source by the photo-diode.

It is common to provide access to the common source so that multiple MOSFETs can be wired in parallel if switching a DC load. Usually a network is provided to speed the turn-off of the MOSFET when the control input is removed.

One significant advantage of a solid-state SCR or TRIAC relay over an electromechanical device is its natural tendency to open the AC circuit only at a point of zero load current. Because SCR's and TRIAC's are thyristors, their inherent hysteresis maintains circuit continuity after the LED is de-energized until the AC current falls below a threshold value (the holding current). In practical terms what this means is the circuit will never be interrupted in the middle of a sine wave peak. Such untimely interruptions in a circuit containing substantial inductance would normally produce large voltage spikes due to the sudden magnetic field collapse around the inductance. This will not happen in a circuit broken by an SCR or TRIAC. This feature is called zero-crossover switching.

SSRs are characterised by a number of parameters including the required activating input voltage, current, output voltage and current, whether it is AC or DC, voltage drop or resistance affecting output current, thermal resistance, and thermal and electrical parameters for safe operating area (e.g., derating according to thermal resistance when repeatedly switching large currents).

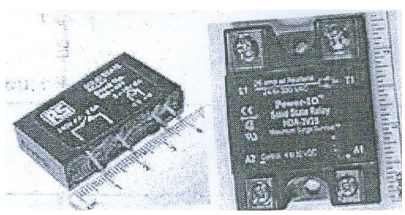
Advantages over mechanical relays

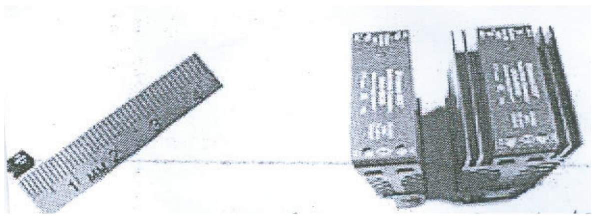
Most of the relative advantages of solid state and electromechanical relays are common to all solid-state as against electromechanical devices.

- Slimmer profile, allowing tighter packing.
- Totally silent operation
- SSRs are faster than electromechanical relays; their switching time is dependent on the time needed to power the LED on and off, of the order of microseconds to milliseconds
- Increased lifetime, even if it is activated many times, as there are no moving parts to wear and no contacts to pit or build up carbon
- Output resistance remains constant regardless of amount of use
- Clean, bounceless operation
- No sparking, allows it to be used in explosive environments, where it is critical that no spark is generated during switching
- Inherently smaller than a mechanical relay of similar specification (if desired may have the same "casing" form factor for interchangeability).
- Much less sensitive to storage and operating environment factors such as mechanical shock, vibration, humidity, and external magnetic fields.

Disadvantages

- Voltage/current characteristic of semiconductor rather than mechanical contacts:
- When closed, higher resistance (generating heat), and increased electrical noise
- When open, lower resistance, and reverse leakage current (typically µA range)
- Voltage/current characteristic is not linear (not purely resistive), distorting switched waveforms to some extent. An electromechanical relay has the low ohmic (linear) resistance of the associated mechanical switch when activated, and the exceedingly high resistance of the air gap and insulating materials when open.
- Some types have polarity-sensitive output circuits. Electromechanical relays are not affected by polarity.
- Possibility of spurious switching due to voltage transients (due to much faster switching than mechanical relay)
- Isolated bias supply required for gate charge circuit
- Higher transient reverse recovery time (Trr) due to the presence of the body diode
- Tendency to fail "shorted" on their outputs, while electromechanical relay contacts tend to fail "open".





The switching device inside a modern solid state relay starts as a multi-layer structure of P and N layers grown on a silicon wafer. These become the thyristor dies that are used inside a Power-io solid state relay. The dies are available in different sizes in order to accommodate different amperage capabilities. For example, a die that is approximately 0.25 x 0.25 inches may be the size for a 50 amp application and 0.5 x 0.4 inches might be 125 amps. All solid state relays develop heat as a result of a forward voltage drop through the junction of the die at a rate of approximately 1.2°C per amp that is being switched. Beyond a point, heat will require a lowering (or derating) of the load current that can be handled by the solid state relay.

Heatsinks are used to create a method of removing heat away from the current carrying device, thus allowing higher current operation. Adequate heat sinks, including consideration of air temperature and air flow, are essential to the proper operation of a (SSR, SCR, thyristor or IGBT package). It is necessary that the user provide an effective means of removing heat from the package. The importance of using a proper heat sink cannot be overstressed, since it directly affects the maximum usable load current and/or maximum allowable ambient temperature. Lack of attention to this detail can result in improper switching (lockup) or even total destruction of the solid state relay. Up to 90% of the problems with solid state relays are directly related to heat. There are several customer-specitic heat sink designs where overall size, fin geometry, fin angle / spacing, and draw-down geometry were optimized.

Fig 5

EM230511

With loads of less than 2-4 amperes, cooling by free flowing convection or forced air currents around the unit is usually sufficient. Loads greater than 4 Amps will require heat sinks. SSR units are to be mounted to some heat sinking metal surface, material heat conductivity should be kept in mind. Heat sinks are approximately equivalent, in heat dissipation, to a sheet of aluminium 1/8" thick by the dimensions shown below:

12" X 12" = 288 square inches of exposed surface area = approximately 2.1°C per watt thermal rise (2.1 C/W)

15" X 15" = 450 square inches = approximately 1.5 degrees C per watt thermal rise (1.5 C/W)

18" X 18" = 648 square inches = approximately 1.0 degree C per watt thermal rise (1.0 C/W)

12" X 12" = 288 square inches of exposed surface area = approximately 2.1°C per watt thermal rise (2.1 C/W)

15" X 15" = 450 square inches = approximately 1.5 degrees C per watt thermal rise (1.5 C/W)

18" X 18" = 648 square inches = approximately 1.0 degree C per watt thermal rise (1.0 C/W)

The lower the C/W rating, the better the heat sink is at dissipating the heat, given proper ventilation and ambient temperature. For example: if a solid state relay generates 45 watts of heat, on a 2.1 C/W heat sink, that relay's internal dies will increase 94.5°C above the ambient temperature. If the ambient is 40°C, the internal die temperature may be 134.5°C.

The maximum permitted temperature for the thyristor die is typically 125°C but 115°C is often used as an additional margin of safety. If air flow is restricted to near by products, or if the ambient air in the enclosure is warmer, of if the solid state relay is not firmly attached to the heat sink, then additional amperage de-rating will be required.

Heat Sink Material

The best materials for a heat sink are: gold, silver, copper, or aluminum. For industrial applications, aluminium is the most cost effective material. Typically a black anodized finish which provides additional radiant heating dissipation is used. In comparison to aluminium, twice the amount of steel and four times the amount of stainless steel would be needed to achieve the same effect. Solid state relays should never be mounted in an enclosed area without proper air flow. Units should also never be mounted to a plastic base or to painted surfaces. The heat sink should be positioned with the fins in a vertical position with an unimpeded air flow, up and through the finned heat sink. The interface between the solid state relay and the heat sink must be a flat, clean, bare (non-painted) surface that is free of oxidation.

Precautions

Care must be taken when mounting multiple SSRs in a confined area. SSRs should be mounted on individual heatsinks whenever possible. Panel mount SSRs should never be operated without proper heat sinking or in free air as they will THERMALLY SELF DESTRUCT UNDER LOAD. A simple rule-of-thumb for monitoring temperature is to slip a thermocouple under a mounting screw. If the base temperature does not exceed 45 °C under normal operating conditions, the SSR is operating in an optimal thermal environment. If this temperature is exceeded the relay's current handling ability must either be thermally improved by the use of a heatsink, or greater air flow must be provided over the device through the use of a fan. ANY moving air in an installation, greatly improves the thermal transfer from the heatsink to the air. If the actual internal SSR device ever achieves an internal temperature of 115 to 125°C, it will be permanently destroyed. Therefore, the desired engineering requirement is to provide a slow heat-rise internal SSR, and then to provide a heat sinking capability that draws the internal heat rise away at a fast rate to ensure that the internal dies do not exceed these temperatures. Thermal problems are cumulative, irreversible, and destructive.

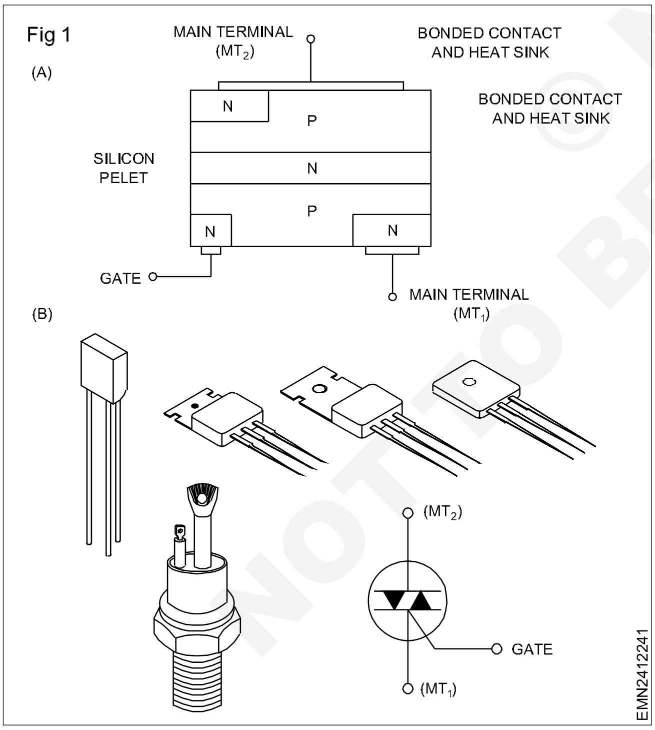
TRIAC, DIAC and their characteristics

Objectives: At the end of this lesson you shall be able to
- **explain the difference between a SCR and a TRIAC**
- **list different ways of triggering a TRIAC**
- **explain the use of TRIAC for full wave control of AC**
- **choose a Triac for a given requirement**
- **explain the method of quick testing a TRIAC**
- **explain the working, use and quick testing of DIAC**

TRIAC

TRIAC is a three terminal gated semiconductor device for controlling AC in either direction. The term TRIAC stands for TRIode AC semiconductor. TRIAC is very similar to that of two SCR connected in reverse parallel. A Triac is able to conduct a large current in both directions, being trigged ON in one direction or the other by a gate pulse of the appropriate polarity.

Basic construction of a TRIAC, its symbol and a typical TRIAC is shown in Fig 1a,1b and 1c.



As can be noticed in Fig 1, the terminals of a TRIAC are labeled as,

Main terminal-1(MT1)

Main terminal-2(MT2)

and Gate(G).

This device operated in both directions, hence the terms anode and cathode does not apply.

TRIAC triggering

TRIAC can be triggered/turned-ON by,

1) applying a gate current,
2) exceeding the avalanche breakdown voltage V_{BO}.
3) allowing the MT1 - MT2 applied voltage to increase at a rate in excess of the maximum dv/dt.

Methods 2 and 3 mentioned above are not employed in normal TRIAC operation but they may be considered as limiting factors in circuit design. Hence all further discussion is restricted to triggering the TRIAC via the gate. Since Triac is a bi-directional device, it can be triggered into conduction by a negative or a positive gate signal. TRIACs potentials are all considered with respect to main terminal-1(MT1). This gives the following possible *operating* situations or *modes*;

– MT2 +ve with respect to MT1 —Gate signal +ve (1st quadrant+)
– MT2 +ve with respect to MT1 —Gate signal -ve (1st quadrant-)
– MT2 -ve with respect to MT1 —Gate signal +ve (3rd quadrant+)
– MT2 -ve with respect to MT1 —Gate signal -ve (3rd quadrant-)

Unfortunately, TRIAC is not equally sensitive in all the above said modes. It is least sensitive in 3rd quadrant mode(MT2 negative with respect of MT1 and trigger by a +ve gate signal) so this mode is very rarely used in practice.

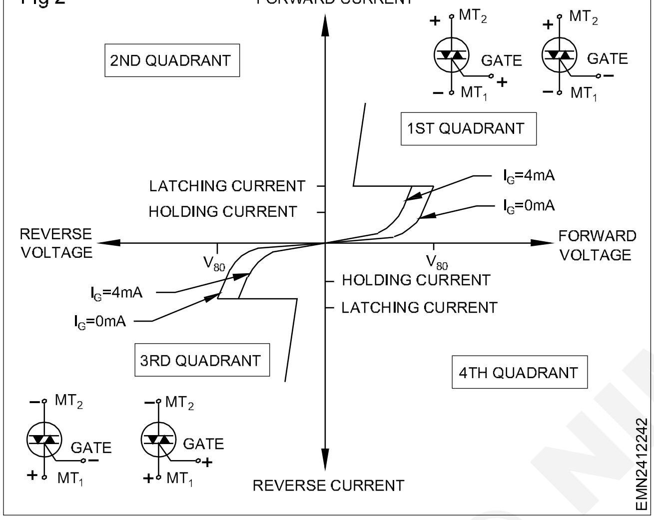
When a TRIAC is ON the current flowing between MT1 and MT2 is known as **Principal current**.

The TRIAC will remain ON as long as the current flowing through it is larger than the holding current as shown in the static characteristics of a Triac in Fig 2.

From the TRIAC static characteristics. When MT2 is positive with respect to MT1, the TRIAC operates in the first quadrant of its static characteristics, if it is not triggered, the small forward current increases slowly with increase in voltage until the breakdown voltage V_{BO} is reached and then the current increases rapidly. The device can be, and usually is, turned 'ON' at a smaller forward current by injecting a suitable gate current and the characteristics shows the effect of increasing the gate current from zero to 4 mA. The gate current must be maintained until the main current is at least equal to the latching current.

When terminal MT1 is positive with respect to MT2 the Triac operates in the third quadrant and the current flows in the opposite direction.

Fig 2



FULL WAVE control using a TRIAC

Fig 3 shows a TRIAC used for controlling the current flowing in an AC circuit. Fig shows the wave forms with different settings of POT V_{R1}.

On observing the waveforms at Fig 3, it can be seen that control is achieved by firing the TRIAC at the same point in both the positive and negative half cycle.Once triggered the device remains ON until the supply is switched OFF.

Choosing a TRIAC

Like all other components, TRIACs have maximum specified values of current and voltage that must not be exceeded. Important specifications of a TRIAC with an example is given below;

TRIAC Type code	:	BT 136	TIC 201D
I_T (rms)	:	4 Amps.	2 Amps.
V_{GT}	:	1.5 Volts.	2.5 Volts.

The value of gate current

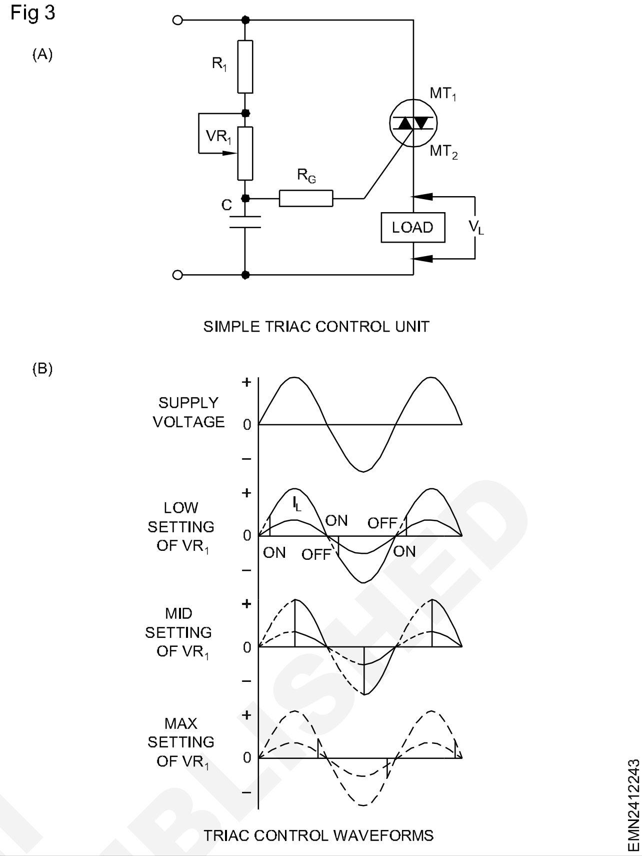
required to achieve switch on.

V_{DRM}	:	400 Volts.	400 Volts.

The maximum permitted peak

voltage.

Fig 3



In TRIACs the terms forward and reverse do not arise since it is bidirectional.

QUICK TESTING TRIACs

A quick test can be carried out on TRIAC using an ohmmeter. If the readings taken are comparable to the one shown in table below, the TRIAC can be considered as satisfactory and can be used in circuit;

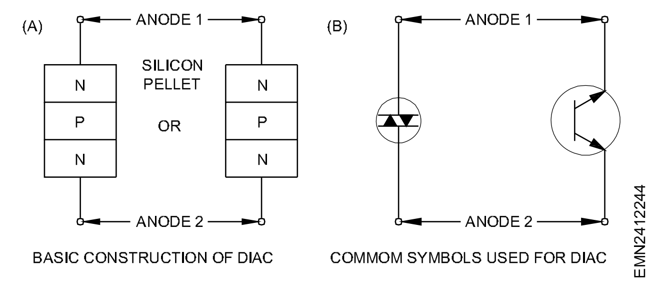
Meter polarities		Resistance
+	-	
MT2	MT1	>1M
MT1	MT2	>1M
MT2	G	>1M
G	MT2	>1M
MT1	G	~300Ω
G	MT1	~300Ω

THE DIAC

Like UJTs, DIAC is a semiconductor device used extensively as a trigger device for thyristors gate circuit. In its most elementary form, DIAC is a three layer device as shown in Fig 4.

As can be seen from Fig 4, DIAC is a three layer, two terminal semiconductor device capable of conducting current in both directions.

Fig 4



A DIAC acts in a similar manner to two diodes that are connected in reverse parallel and it therefore is able to rectify AC voltage during both half cycles. The symbol used for DIAC is shown in Fig 4b.

DIAC also resembles an NPN or PNP bipolar transistor with no base connection. Unlike bipolar transistor, the DIAC possesses uniform construction. This means, N-type and P-type doping is essentially the same at both junctions. As shown in Fig 4, disc may be constructed as either an NPN or PNP structure.

Fig 5a shows the experimental set up for testing the DIAC. The isolation transformer is used to isolate the circuit from the supply mains. The variable transformer or variac is used to apply the variable voltage to DIAC under test. The characteristic curve a typical DIAC is shown in Fig 5b.

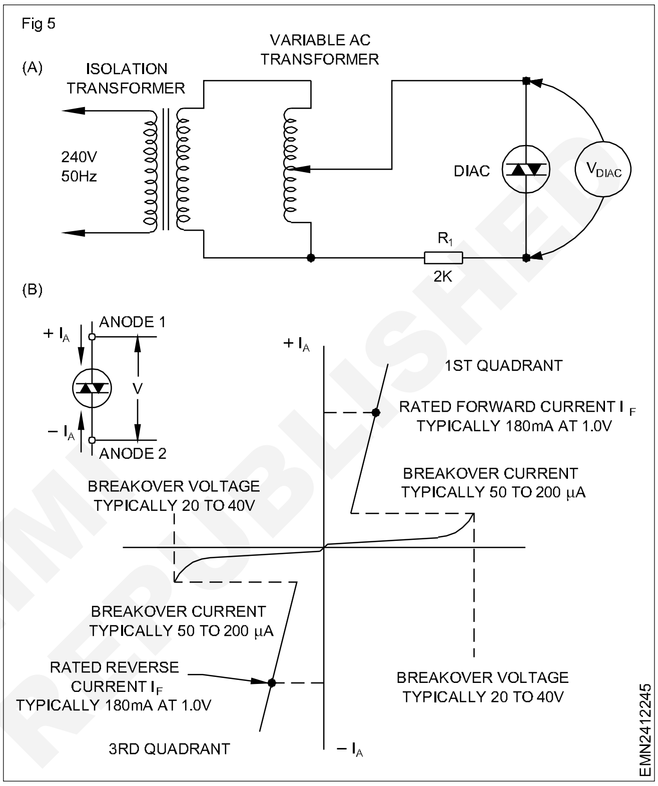
As shown in the experimental set-up at Fig 5a, when a small voltage of either polarity is applied across a DIAC, the current flows is very small as can be seen from its characteristics in the first and the third quadrants. If the applied voltage is steadily increased, the current will remain at a low value until the applied voltage reaches a value known as the Break over voltage of the DIAC as shown in Fig 12b. Once this point is reached the DIAC current increases rapidly and the DIAC voltage falls to a low value. At this point, the diac exhibits negative resistance characteristics(current conduction increases while the voltage across the device decreases). The DIAC will continue to conduct current as long as the current is greater than the Holding current of the device.

Choosing DIACs

Quick Testing DIACs

Since DIACs are similar to two diodes connected back to back and break down in either direction once the applied voltage reaches the breakdown voltage of the diode, while testing a DIAC using a ohmmeter, it should show high resistance (infinite resistance) when checked in either direction. This quick test only confirms that the DIAC is not shorted; however this quick test is worth carrying out before using the DIAC in a circuit.

Fig 5



Lamp dimmer/fan motor speed regulator using TRIAC and DIAC

Objectives: At the end of this lesson you shall be able to
- **explain the advantage of use of TRIAC for speed control of AC motors**
- **explain the need of soft-start light dimmers**
- **draw the circuit of a simple light dimmer using a DIAC and a TRIAC**
- **explain the need and working of snubber circuit in a light dimmer circuit.**

LAMP DIMMERS

Lamp dimmer is a circuit which controls AC power supplied to an incandescent lamp thereby controlling the intensity of light emitted by the lamp from almost zero to full brilliance.

Conventional and soft-start dimming of incandescent lights

Old technology light dimmers used high wattage rheostats, adjustable auto-transformers, or saturable reactors, which were large, expensive,and generated considerable heat. Present day semiconductor light dimmers have over come these deficiencies and have therefore become very popular for many applications.

Modern thyristor dimmers are inexpensive, reliable, small, generate little heat, and are easy to control remotely. These properties have not only permitted semiconductor dimmers to supersede older types in theaters and auditoriums with excellent results, but have made dimmers practical for built-in home lighting, table and floor lamps, projection equipment and other uses.

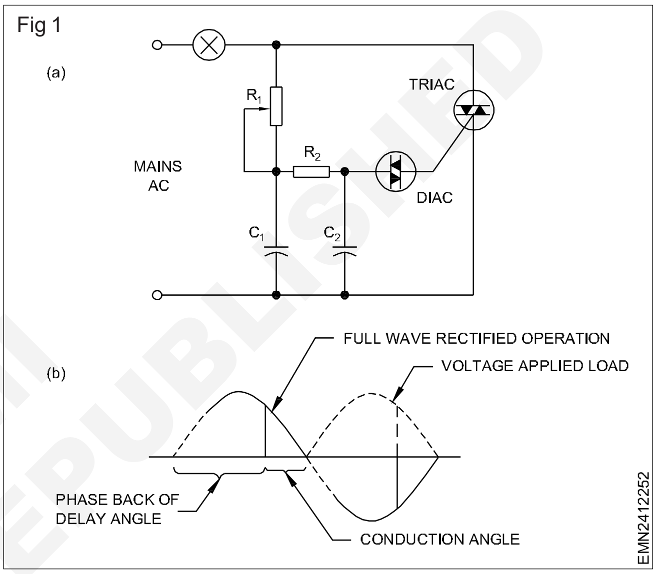
Two light dimmers for incandescent light bulbs are discussed below. Both these dimmer circuits control light intensity by adjusting the angle of conduction of a Triac connected in series with the bulb. The first dimmer uses a very simple circuit that is ideal for highly compact applications requiring minimum cost. The second dimmer features soft starting for low inrush current and consequent long lamp life. Soft start lamp dimmers are especially useful with expensive lights with short lives, such as projection lamps and photo-graphic bulbs.

Simple light dimmer

The circuit shown in Fig 1 is a wide range light dimmer using very few parts. The circuit can be operated using any mains supply source(240V, 50 Hz) by choosing apppropriate value of circuit components. The circuit can control up to 1000 watts of power to incandescent bulbs.

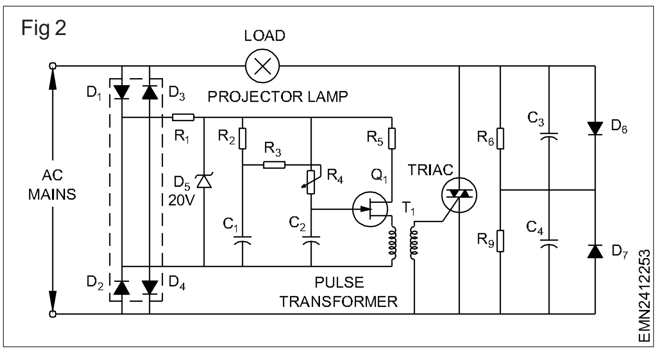
The power to the bulbs is varied by controlling the conduction angle of TRIAC. Many circuits can be used for phase control, but the single Triac circuit used is the simplest and is therefore chosen for this particular application.

The control circuit for this TRIAC must function as shown Fig 1b. The control circuit must create a delay between the time voltage is applied to the circuit and the time it is applied to the load. The TRIAC is triggered after this delay and conducts current through the load for the remaining part of each alternation. This circuit can control the conduction angle from 0˚ to about 170° and provides better than 97% of full-power control.



Light Dimmer with soft-start option

The circuit at Fig 2 is a light dimmer with soft start option. Soft starting is desirable because of the very low resistance of a cold lamp filament compared to its hot resistance. At the time of initial switching on, the low resistance of the lamp causes very high inrush currents which leads to short filament/lamp life. Lamp failures caused by high inrush currents is eliminated by the soft start feature, which applies current to the bulb slowly enough to elliminate high surges.



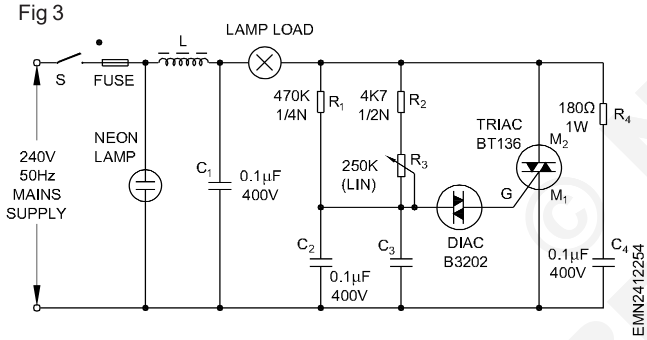
Operation of the circuit at Fig 3 begins when voltage is applied to the diode bridge consisting of D_1 through D_4. The bridge rectifies the input and applies a dc voltage to resistor R_1 and zener diode D_1. The zener provides a constant voltage of 20 volts to unijunction transistor Q_1, except at the end of each alternation when the line voltage drops to zero.

Initially the voltage across capacitor C_1 is zero and capacitor C_2 cannot charge to trigger Q_1. C_1 will begin to charge, but because the voltage is low, C_2 will have adequate voltage to trigger C_1 only near the end of the half cycle. Although the lamp resistance is low at this time, the voltage applied to the lamp is low and the in rush current is small. Then the voltage on C_1 rises, allowing C_2 to trigger Q_1 earlier in the cycle. At the same time the lamp is being heated by the slowly increasing applied voltage and by the time the peak voltage applied to the lamp has reached its maximum value, the bulb has been heated sufficiently so that the peak inrush current is kept to a reasonable value. Resistor R_4 controls the charging rate of C_2 and provides the means to dim the lamp. Power to the load can be adjusted manually by varying the resistance of R_4. T_1 is a pulse transformer. In addition to supplying the trigger to Triac, this transformer isolates the high current load circuit form the low power triggering circuit (gate isolation methods for TRIAC in discussed in further paragraphs).

A simple Lamp dimmer cum Universal motor speed controller

In the lamp dimmer cum universal speed controller circuit shown in Fig 3, a TRIAC is used as control device. Phase control technique is used to control conduction angle of the TRIAC which in turn control the power fed to the lamp.

Fig 3

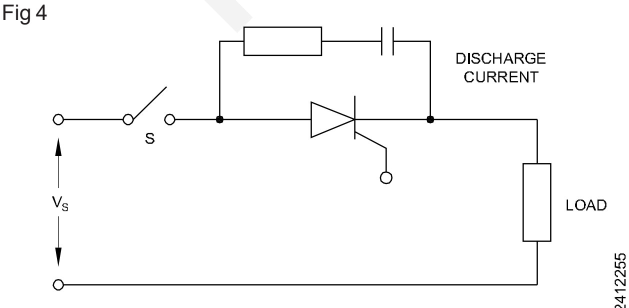


A lamp L is connected in series with AC mains supply to the TRIAC. The trigger pulses to TRIAC gate is given through DIAC. The DIAC is triggered at the same break over voltage level (30 V) during both positive and negative half cycles.

Potentiometer R_4 provides the facility for varying the intensity of light or speed of a universal motor.

Snubbers: Snubber is a small network of resister and capacitor connected across the switching circuit in power electronics as shown in Fig 4.

Fig 4

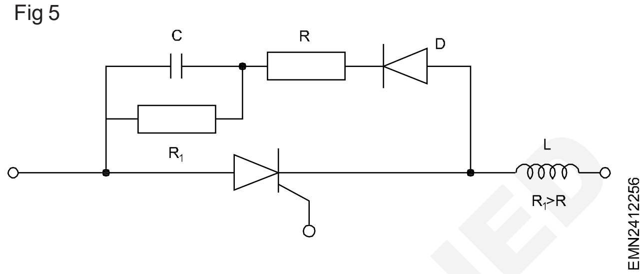


SNUBBER CIRCUIT ACROSS SCR

The function of snubber is to control the circuit reactance by absorbing the voltage spikes caused by the switching action. The purpose of snubber is to eliminate the voltage transient and ringing that occurs when the SCR opens. The snubber provides an alternate path for the current flowing through the RC circuit

Snubber circuits enhance the performance of the switch circuits by using additional components like diode D also shown in Fig 5 .The diode 'D' acts as a free wheeling diode to protect the SCR.

Fig 5



This also consists of an inductance L in series with the SCR to prevent the high di/dt that leads to damage the SCR And hence, a small value of resistance is placed in series with the capacitor to limit the high discharge current .

Snubber circuits are used to minimise switching losses in converters and associated high dv/dt and di/dt stress across power semi conductor devices. snubber circuits are of turn-ON and turn - OFF type and placed in series and parallel respectively.

Snubber Circuit: One problem with the TRIAC control is the sudden application of reverse voltage across the TRIAC immediately after it has stopped conduction. This is a serious problem when the load is a highly inductive as in motors. This reapplied voltage denoted by dv/dt can trigger-on (unwanted or false triggering) the device losing the phase control.

To avoid this false triggering, an R and C series network is placed across the circuit(R_4 and C_4 as shown in Fig 4). This RC network slows down the rate of rise of voltage applied across the TRIAC. This RC circuit connected across the TRIAC circuit is called Snubber circuit.

The inductance L and capacitor C_1 forms a low pass filter to substantially reduce the radio frequency interference (RFI) generated by the rapid turn-on and turn-off the TRIAC.

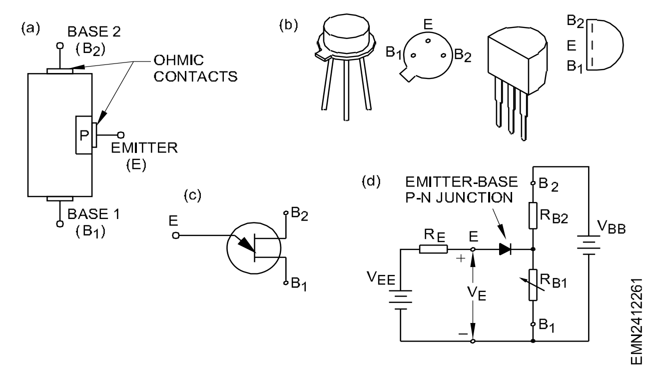
The lamp dimmer circuit at Fig 4 can be used equally well as a fan speed regulator. The only change to be made is to connect a fan in place of the lamp shown in the circuit at Fig 4. The speed can be varied from almost zero to full speed by just rotating POT R_3.

Unijunction transistor (UJT) and its applications

Objectives: At the end of this lesson you shall be able to
- **explain the construction and working principle of UJT**
- **make a quick test of UJT**
- **list the important specification of UJT**
- **list and explain the application of UJTs**

Unijunction transistor(UJT) is a three terminal semiconductor device as shown in fig 1a. In its appearance it looks like a transistor as shown in Fig 1b. As shown in Fig 1a, it consists of two layers(a P-layer and a N-layer) and therefore it has only one junction(hence its name, uni-junction).

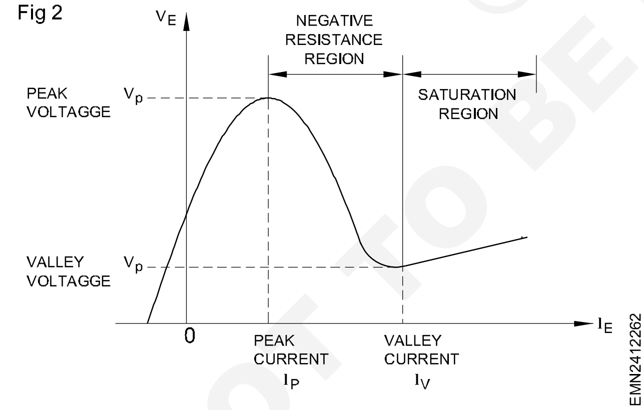
Fig 1



The symbol of UJT and its electrical equivalent circuit is shown in Fig 1c and 1d.

UJT is a special semiconductor device because it exhibits negative resistance characteristics as shown in Fig 2. The details of the characteristics are discussed in subsequent paragraphs.

Fig 2



Construction of UJT

2646 and 2N 2647 UJT's are available in the modified TO-18 case style as shown in Fig 1b.

Equivalent circuit of UJT

The electrical equivalent circuit of UJT is shown in fig 1d. The resistance between the B_1 and B_2 terminals is called the inter-base resistance R_{BB}. The N-type silicon bar serves as a resistance divided into two parts R_{B1} and R_{B2} by the PN junction. The total of the internal R_{B1} and R_{B2} is the interbase resistance R_{BB}. Value of R_{BB} is typically in the range of 4 to 10 Kohms. Also r_{B1} usually a little greater than r_{B2} because the emitter is a little closer to B_2.

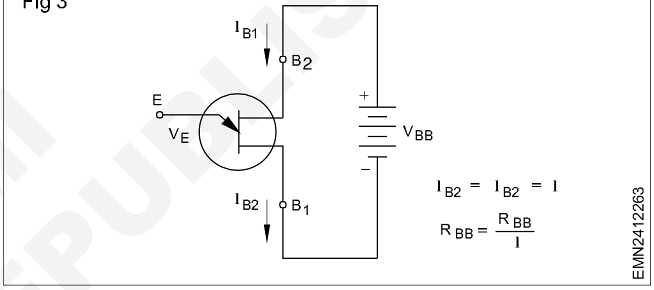
The interbase resistance R_{BB} is measured with the emitter open.

$R_{BB} = R_{B1} + R_{B2}$ at I_E=0.

Operation of UJT

The DC supply polarities for a UJT to function is shown in Fig 3. As can be seen from fig 3, B_2 is connected to +ve and B_1 to ground. As a result current(conventional) flows from B_2 to B_1. This conduction results in a voltage gradient along the N-type silicon bar. Therefore there is a voltage in the region of the emitter junction(V_E) which is positive with respect to ground. The magnitude of this voltage is given by the simple voltage divider action between R_{B1} and R_{B2}.

Fig 3



$$V_E \text{ or } (V_{RB!}) = \frac{R_{B1}}{R_{B1}+R_{B2}} V_{BB} = \eta V_{BB} \qquad ....[1]$$

The Greek letter η (eta) is called the intrinsic stand-off ratio. This is an important data of any UJT and is invariably mentioned in all UJT data sheets. From the above equation, intrinsic stand-off ration η (eta) is given by,

$$\eta = \frac{R_{B1}}{R_{B1}+R_{B2}} \qquad ....[2]$$

Typical values of h Vary form about 0.5 to 0.8 for most UJTs.

The value of h is important because, knowing h and the applied voltage across the base terminals V_{BB}, voltage across R_{B1} can be calculated using equation [1].

For example, if η = 0.65 and V_{BB} = 12 Volts,

then, $V_{RB1} = \eta_{\ VBB}$ = 0.65 x 12 V = 7.8 volts.

Voltage V_{RB1} represents the reverse bias voltage at diode D. In order for an emitter current I_E to flow, the emitter voltage V_{EB1} should be above V_{RB1} by about 0.7volts(internal barrier potential for a silicon diode). This emitter voltage V_{EB1} that will cause the diode to be forward biased and conduct emitter current is usually designated as V_P.

The value of V_P can be calculated using the formula,

$V_P = \eta\ V_{BB}$ + 0.7 volts

In the example considered above, V_P = 7.8 V + 0.7V = 8.5 Volts.

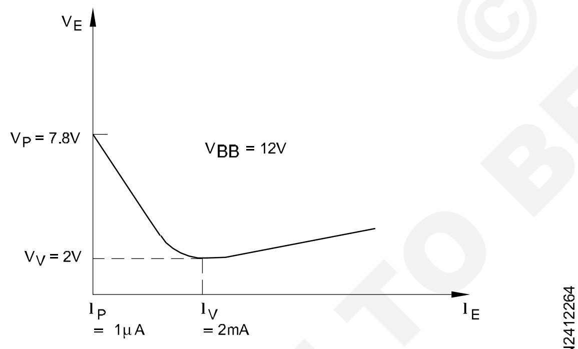
When V_P is raised to 8.5 volts, diode D conducts. This means I_E flows through the R_E,diode D, R_{B1} to ground. This sudden rush of current through the highly doped N-type R_{B1} reduces the resistance of R_{B1}(remember R_{B1} is not a fixed value resistor, it is the resistance of the N-type semiconductor). Because of the reduced R_{B1}(from a few thousand ohms to a value as low as 40 to 50 ohms) results in a small voltage drop across R_{B1}. Hence emitter voltage V_{EB1} drastically decreases to around 1 volt(from 8.5V before the diode conduction to around 1V when the diode starts conducting). This drop in the value of V_{EB1} is shown in Fig.3. This point is sometimes referred to as the on-state condition.

Since an increase in the emitter current results in decrease in emitter voltage(V_{EB1}), this region of the UJT characteristics is referred to as the negative resistance region.

After a certain point referred to as the 'valley point', any further increase in the emitter biasing voltage V_{EE}/emitter current I_E will start increasing and the voltage drop across the emitter and base-1. This region is called as the UJTs saturation region. This will occur when the rate of hole injection is so great as to build up a positive space charge in the region. It should be noted that after the valley point, the emitter current should not be increase beyond the rated maximum forward emitter current value(typically around 50mA) beyond which the diode D may break down.

A comparison of the UJT theoritical characteristics(as in Fig 2) and actual characteristics which can be plotted is shown in Fig 4.

Fig 4



PLOTTED UJT CHARACTERISTIC

Some of the important terms associated with UJT characteristics are given below;

Peak Point Current(I_P) - minimum amount of emitter current to place the UJT in negative resistance region.

Valley Current (I_V) - maximum allowable emitter current within the negative resistance region.

Valley voltage (V_V) - minimum voltage that can maintain the UJT in its negative resistance region.

Quick test of UJT using Ohm meter: From the construction of a UJT it can be seen that, Emitter and Base-1 with Base-2 open, behaves as a PN diode. Therefore, when tested using a ohm meter this should show low resistance when forward biased and high resistance when reverse biased.

Similarly Emitter and Base-2 with Base-1 open behaves as a PN diode and hence the same forward and reverse bias test using a ohm meter can be carried out to confirm its good condition.

To carry out a quick test of a given UJT, check forward and reverse bias conditions of the two diodes of UJT as given in above two paragraphs.

Typical UJT Specifications

UJT specification as can be seen in any data manual is given below. 2N 2646 UJT is taken only as a sample for understanding the specifications. Specifications for other UJT will almost be in the same format. However the manufacturers data sheets given more details than what is listed below;

Type	Device	I_P	I_V	R_{BBO}	Eta(η)
2N 2646	UJT-P	5μA	4mA	15Kohms	0.60

Application of UJTs

UJTs are employed in a wide variety of circuits involving electronic switching and voltage or current sensing applications. These include,

– Triggers for thyristers

– As oscillators

– As pulse and Saw tooth generators

– Timing circuits

– Regulated Power supplies

– Bistable circuits

and so..on.

The most common and popular application of UJT is the Relaxation oscillator. Fig 5a shows a practical relaxation oscillator using 2N 2646 UJT.

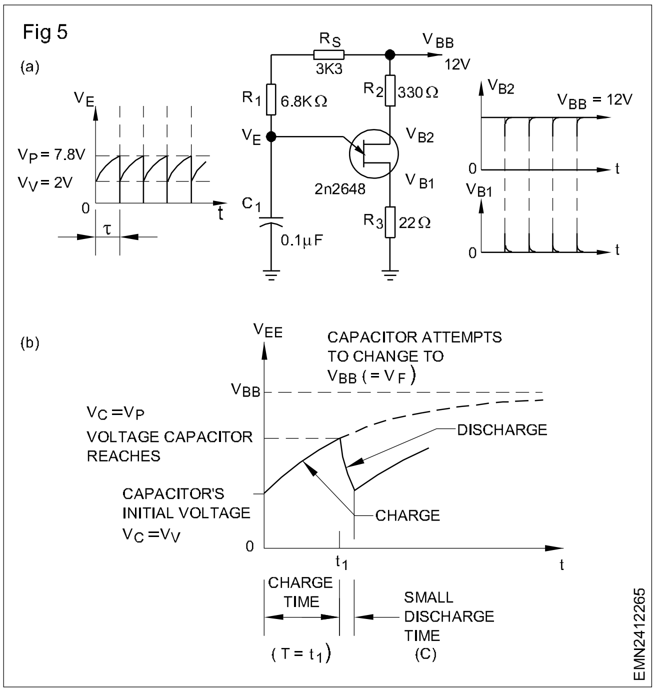
As the voltage V_{BB} is supplied, capacitor C is charged via Resistors R_s and R_1. If the voltage V_C across the capacitor cross the peak point voltage(V_P) of UJT, the UJT goes into conduction.

The sooner UJT goes into conduction, the charged capacitor C discharges rapidly as shown in Fig 5b via the low inner base resistance R_{B1} and R_3. This conduction of UJT and the discharge of C through the emitter-Base1 of UJT results in a sudden rush of current through R_3 and hence the voltage across R_3 increases sharply as shown in Fig 5.

By discharging the voltage across it, the voltage across the capacitor becomes smaller than the valley point voltage V_V. Because of this, UJT cuts-off once again. Because the UJT is cut-off, there is no current through R_3 and hence the voltage across it (output voltage) becomes zero as shown in Fig 5.

Once the UJT is cut-off, capacitor C starts charging again through R_S and R_1. When the charged voltage again crosses the value of V_P, UJT turns-on again and the cycle repeats resulting in continuous pulse wave form at the output(across R_3).

Fig 5



The frequency of oscillation of the UJT oscillator depends on,

[1] Time constant tau(τ) given by tau(τ) = R_E x C

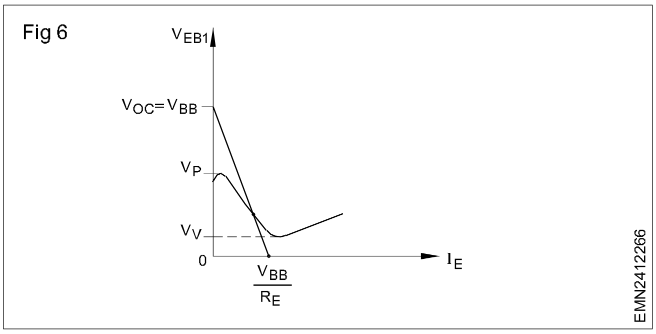
and [2] Value of intrinsic standoff ratio eta(η) of the UJT.

The frequency of oscillation(f_o) of the UJT relaxation oscillator is given by the formula,

$$f_o = \frac{1}{T} \approx \frac{1}{R_E C \ln\left[\frac{1}{(1-\eta)}\right]}$$

For a UJT to function properly in an oscillator, its DC load line must cross the negative resistance region of its emitter characteristics as shown in Fig 6.

Fig 6



An important thumb rule while designing an relaxation oscillator using UJT is given below;

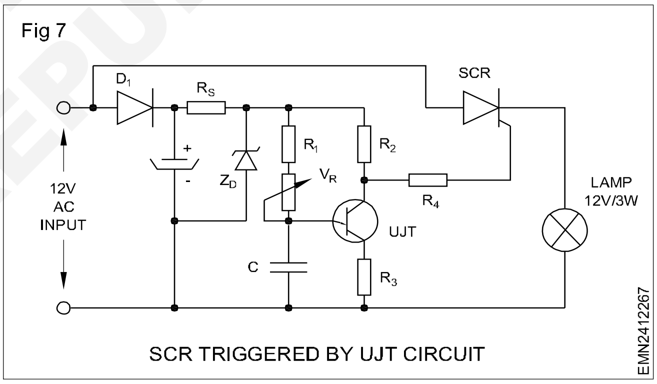
Minimum and Maximum values of R_E to ensure oscillations,

$$R_{E(max)} = \frac{V_{BB} - V_P}{I_P}$$

UJT Triggered SCR circuit is one of the application of UJT in the UJT relaxation oscillator, that is used to trigger the SCR to control its load current as shown in Fig7.

In this circuit, the gate triggerring pulses are shaped by the values of variable resistor V_R and decides the timing of trigger pulse produced by the UJT. This in turn controls the brightness of the lamp load current supplied by the SCR's triggering pattern.

Fig 7



SCR TRIGGERED BY UJT CIRCUIT

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.

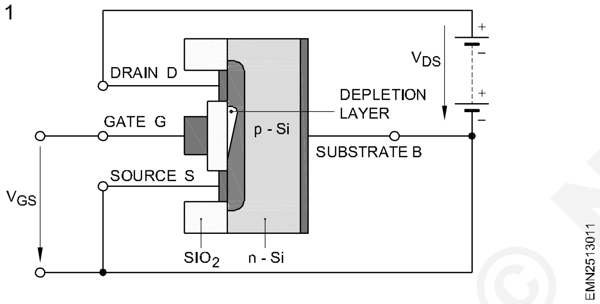
Types of MOSFETs

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 electrical connection between the source and drain without an external field-action. This channel is covered by an insulting layer of silicon dioxide (SiO_2), to which a metal electrode is applied as the gate connection.

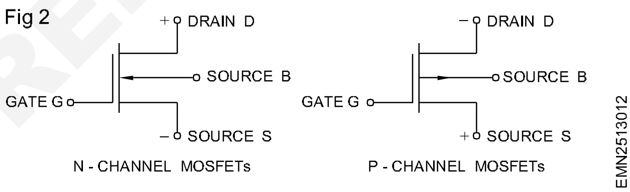
If a voltage U_{DS} is applied between source and drain, at U_{GS} = 0V an electron current flows from the source electrode via the n-channel to the drain electrode. If, however, a negative voltage is applied to control electrode G, the electrons present in the n-channel are forced out of the vicinity 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.

Fig 2



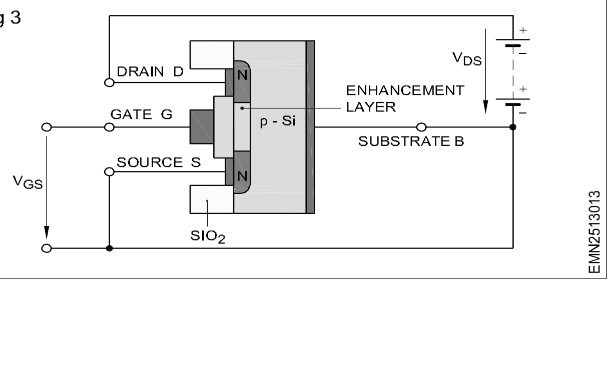
N-channel MOSFETs are operated with a positive drain-source voltage. They have a considerably greater practical significance than p-channel MOSFETs, which require a negative drain-source voltage for their operation.

Enhancement-type MOSFETs

Construction and mode of operation

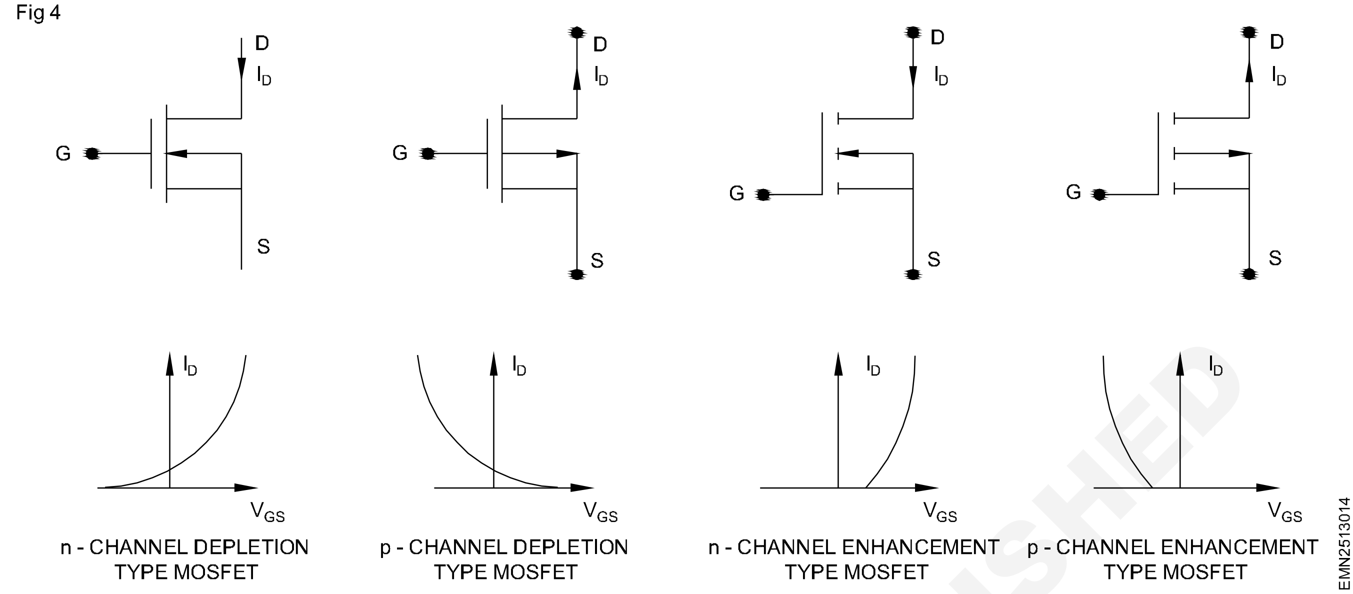
Enhancement-type MOSFETs have a similar technological construction to the depletion types. Without the external action of a field, however, no conducting channel exists between the drain connection and the source connection, so that at U_{GS} = 0V, no drain current can flow. Fig. 3 shows the construction of an enhancement-type n-channel MOSFET.

Fig 3



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



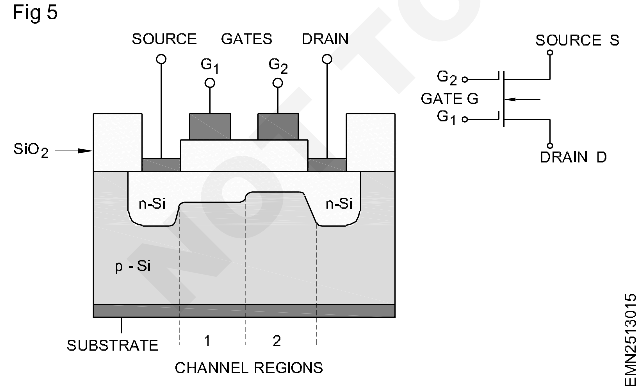
Enhancement-type MOSFETs are only rarely produced as individual transistors. Their construction and working principle are, however, widely used in integrated MOS switching circuits.

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”.

Fig 5

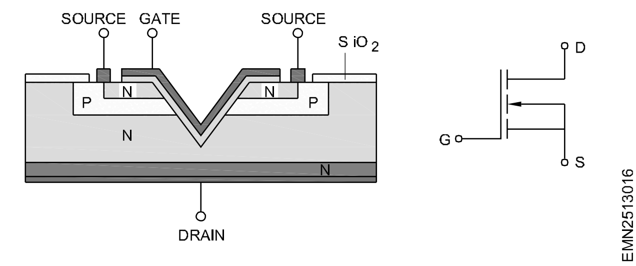


VMOSFET

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 μm with a forward resistance of approximately 1kΩ to 10kΩ. 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.

Fig 6

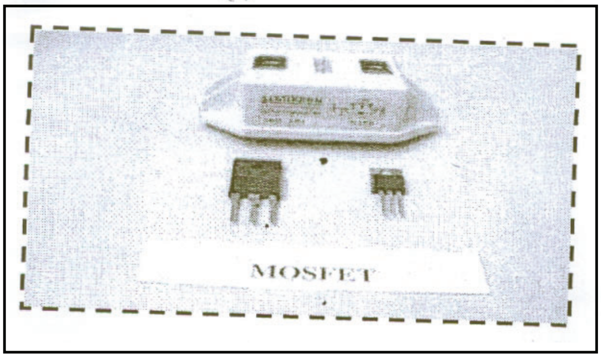


The depletion type MOSFETs are normally ON type switches i.e, with the gate terminal open a nonzero drain current can flow in these devices. This is not convenient in many power electronic applications. Therefore, the enhancement type MOSFETs (particularly of the n-channel variety) is more popular for power electronics applications. This is the type of MOSFET which will be discussed in this lesson. Fig 7 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.

Fig 7



The gate region of a MOSFET which is composed of the gate metallization, the get (silicon) oxide layer and the p-body silicon forms a high quality capacitor. When a small voltage is application 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 SiO_2 and the silicon as shown in the fig. 8(a)

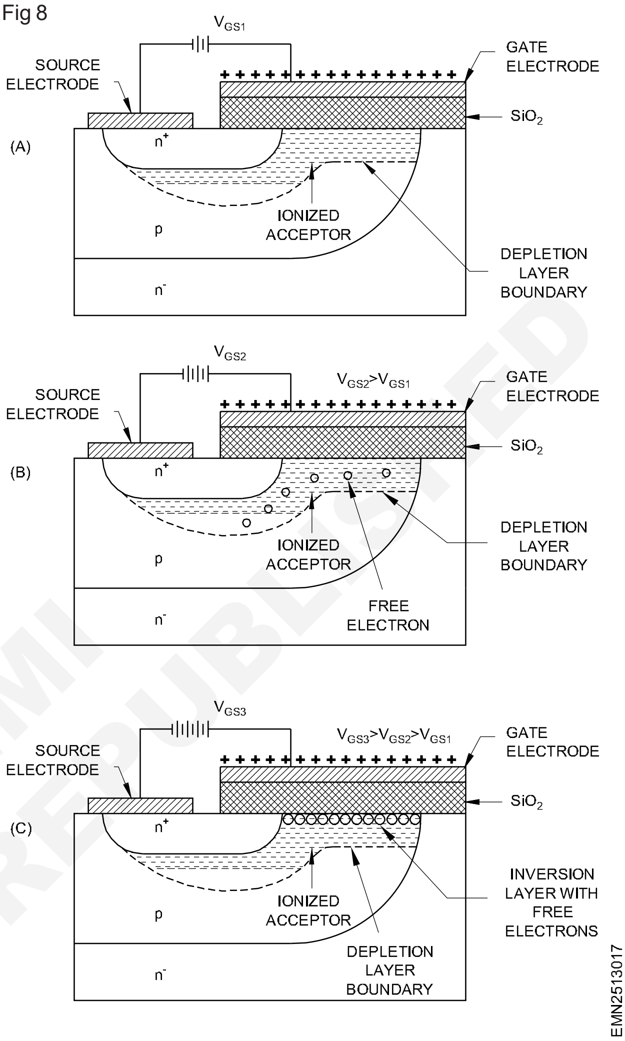
The positive charge induced on the gate metallization repels the majority hole carriers from the interface region between the gate oxide and the P type body. This exposes the negatively charged acceptors and a depletion region is created.

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.

Fig 8



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 di oxide is used as an insulating layer between the gate and the substrate of the transistor.

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 as researchers try to find other types of transistors that can be a suitable replacement for it.

Advantages of MOSFET

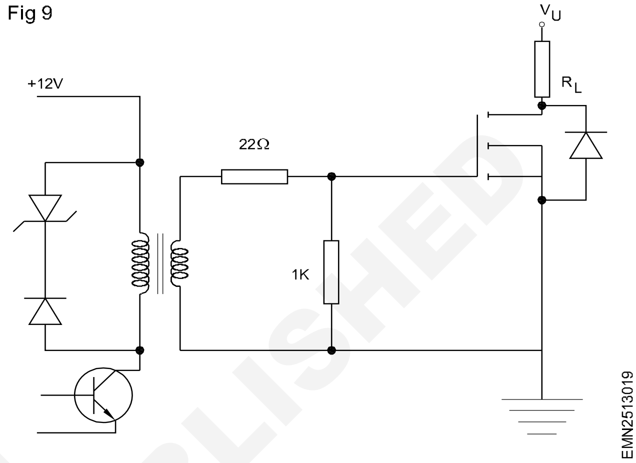
1. Low gate signal power requirement.
2. Fast switching speed. No storage time effect as in transistors.
3. Power MOSFETs are not subjected to forward or reverse bias secondary breakdowns.

Drive circuit for MOSFETs

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.

A common method of coupling the drive circuitry is to use a pulse transformer. PTs are used to isolate logic circuitary from MOSFETs operating at high voltages.

Fig 9



Insulated Gate Bipolar Transistor (IGBT)

Objectives : At the end of this lesson you shall be able to
- **explain the characteristics of IGBT**
- **differentiate the FET and MOSFET**
- **list the advantages and disadvantages of IGBT**
- **differentiate between BJT and IGBT.**

Introduction to IGBT

The insulated gate bipolar transistor or IGBT is a three-terminal power semiconductor device, noted for high efficiency and fast switching.

It has high input impedance and large bipolar current - carrying capability.

It switches electric power in many modern appliances: electric cars, variable speed refrigerators, air-conditioners, and even stereo systems with switching amplifiers. Since it is designed to rapidly turn on and off, amplifiers that use it often synthesize complex waveforms with pulse width modulation and low-pass filters. The IGBT combines the simple gate-drive characteristics of the MOSFETs with the high-current and low-saturation-voltage capability of bipolar transistors by combining an isolated gate FET for the control input, and a bipolar power transistor as a switch, in single device. The IGBT is used in medium - to high-power applications such as switched mode power supply, traction motor control and induction heating. Large IGBT modules typically consist of many devices in parallel and can have very high current handling capabilities in the order of hundreds of amperes with blocking voltages of 6,000V.

The IGBT is suitable for many applications in power electronics, especially in Pulse Width Modulated (PWM) servo and three-phase drives requiring high dynamic range control and low noise. It also can be used in Uninterruptible Power Supplies (UPS), Switched-Mode Power Supplies (SMPS), and other power circuits requiring high switch repetition rates. IGBT improves dynamic performance and efficiency and reduced the level of audible noise. It is equally suitable in resonant-mode converter circuits.

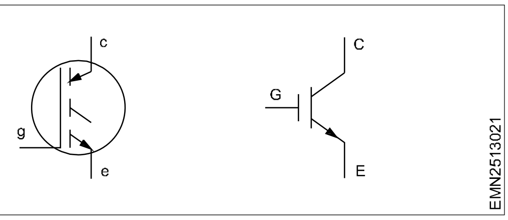
The main advantages of IGBT over a Power MOSFET and a BJT are:

1 It has a very low on-state voltage drop due to conductivity modulation and has superior on-state current density. So smaller chip size is possible and the cost can be reduced.

2 Low driving power and a simple drive circuit due to the input MOS gate structure. It can be easily controlled as compared to current controlled devices (thyristor, BJT) in high voltage and high current applications.

3 It has superior current conduction capability compared with the bipolar transistor. It also has excellent forward and reverse blocking capabilities.

Fig 1



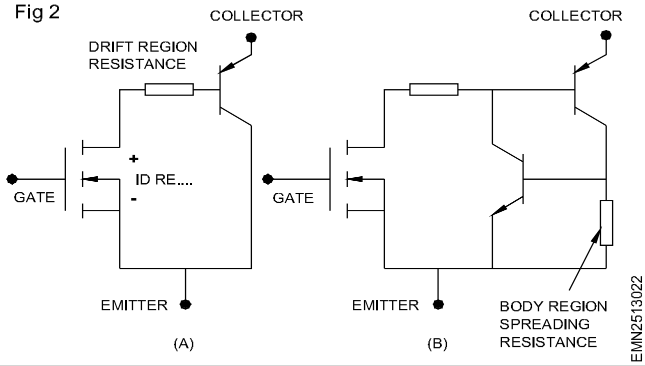
The main drawbacks are:

1 Switching speed is inferior to that of a Power MOSFET and superior to that of a BJT. The collector current tailing due to the minority carrier causes the turnoff speed to be slow.

2 There is a possibility of latch up due to the internal PNPN thyristor structure.

The IGBT is a semiconductor device with four alternating layers (P-N-P-N) that are controlled by a metal-oxide semiconductor (MOS) gate structure without regenerative action.

Fig 2



Difference betweeen BJT and IGBT

1 BJT is a current driven device, whereas IGBT is driven by the gate voltage.

2 Terminals of IGBT are known as emitter, collector and gate, whereas BJT is made of emitter, collector and base.

Light Emitting Diodes (LEDs)

Objectives: At the end of this lesson you shall be able to
- **describe LED and its working**
- **list popular types of LEDs**
- **calculate the resistor value to be used with LED for a given application**
- **state how to protect LEDs from high reverse voltage**
- **explain the working principle of LDR, photoresistor and Laser diode**
- **optical sensor and its types and application**
- **opto coupler and its types and applications**
- **opto-Isolator and its types and application.**

Light Emitting Diodes

In recent years, the use of filament lamps/bulbs which consume quite an amount of power, has less life and delicate to handle are becoming obsolete as output indicators of electric systems. With the advancement in the field of optical electronics several devices have been developed as a substitute for filament lamps. One of the most common and popular of these new devices is the **Light Emitting Diode** abbreviated as **LED**. These LEDs are now used as indicators in almost all electrical and electronic circuits and equipments.

The advantages of LEDs over incandescent bulbs are listed below;

1 LEDs have no filaments to heat and so require less current to glow.

2 LEDs require lower voltage level (typically 1.2 to 2.5 V) than the conventional bulbs.

3 LEDs last much longer - upto several years.

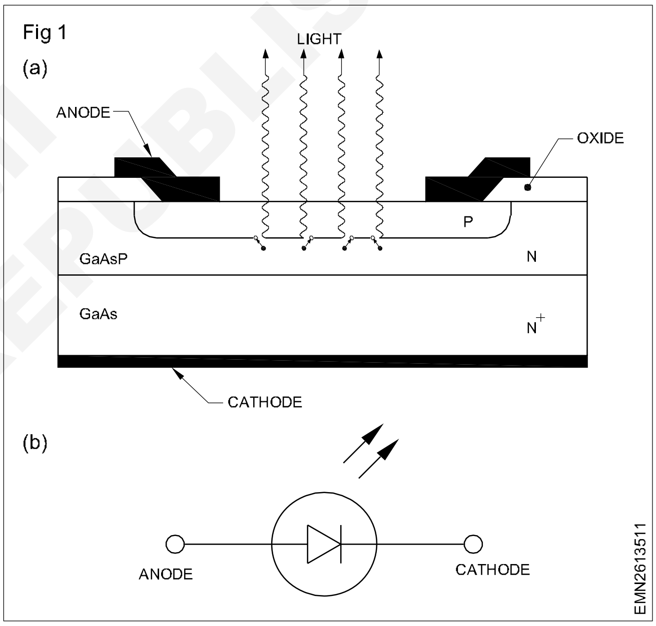
4 Because there is no filament to heat up, LEDs are always cool.

5 LEDs can be switched ON and OFF at a much faster rate compared with conventional lamps.

Principle of working of LEDs

LED is nothing but a type of diode. LEDs also posses the unique unidirectional property like general purpose diodes. But, the materials used in making LEDs are different; hence, their characteristics are different too. Therefore, it is very important to note that although LED is also a type of diode, it cannot and should not be used for the purpose of rectifying AC to DC.

Recall that a general purpose diode or a rectifier diode conducts when energy is supplied to the electrons (Si=0.7V, Ge=0.3V) to cross the barrier junction. Each electron, after acquiring the supplied extra energy, crosses the junction and falls into the hole on the P side of the junction while the electron recombines with a hole, the electron gives up the extra energy by it. This extra energy is dissipated in the form of heat and light. In general purpose diodes because the silicon material is not transparent(opaque), the light produced by the electrons does not escape to the outer environment. Hence, it is not visible. But LEDs are made using semi-transparent materials instead of silicon. Because the material used in making LEDs is semi-transparent, some of the light produced by the electrons escapes to the surface of the diode, and, hence, is visible as shown in Fig 1a.



LEDs are typically doped with gallium arsenic, gallium phosphate or gallium arseno-phosphate. Different dopes cause the LED to emit light of different colours(wavelengths) such as red, yellow, green, amber, or even invisible infrared light.

The schematic symbol of LED is shown in Fig 1b. The arrows are used to indicate that light is radiated from the device.

Types of LEDs

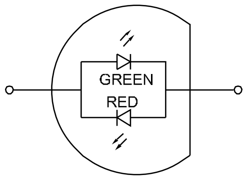
Single colour LEDs: Most of the commercially available and commonly used LEDs are single colour LEDs. These LEDs radiate one of the colours such as red, green, yellow or orange. Different coloured LEDs will have different forward voltages as given in the table below:

Colour of LED	Red	Orange	Yellow	Green
Typical Forward voltage drop	1.8V	2V	2.1V	2.2V

These typical forward voltage drops are at a typical LED forward current I_f = 20 mA

Two colour LEDs: These LEDs can give two colours. Actually, these are two LEDs put in a single package and connected as shown in Fig 2.

Fig 2

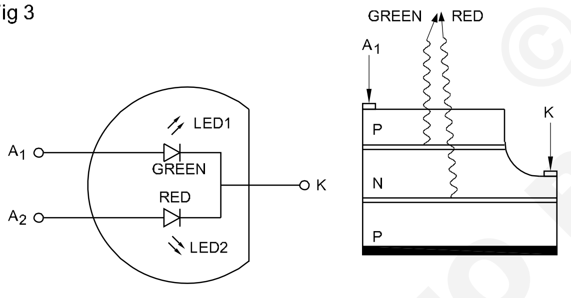


EMN2613512

In a two-colour LED, two LEDs are connected in inverse parallel, so that one of the colour is emitted when the LED is biased in one direction and the other colour is emitted when the LED is biased in the other direction. These LEDs are more expensive than the single colour LEDs. These LEDs are useful to indicate +ve, –ve polarities, GO-NOGO indication, null detection etc.

Multicolour LEDs: These are special types of LEDs which can emit more than two colours. These LEDs comprises of a green and a red LED mounted in a three-pin common cathode package as shown in Fig 3.

Fig 3



EMN2613513

This LED will emit green or red colour by turning ON only one LED at a time. This LED will emit orange or yellow by turning on the two LEDs with different current ratios as shown in the table given below:

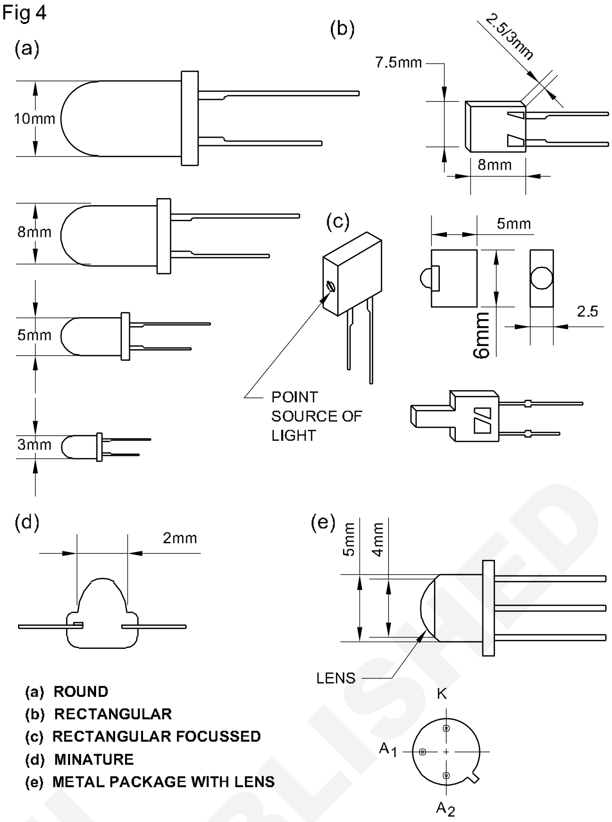
Output colour	Red	Orange	Yellow	Green
LED-1 current	0	5mA	10mA	15mA
LED-2 current	15mA	3mA	2mA	0

Sizes and shapes of LEDs

LEDs are available commercially in different shapes and sizes to suit varied commercial applications. Fig 4 shows some of the most popular shapes and sizes of LEDs.

The light output of LED may be guided as point-source or diffused. The point-source LED provides a small point of light while the diffused type has a lens which diffuses the light into a wide angle viewing area.

Fig 4

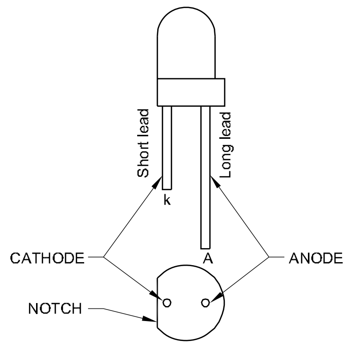


EMN2613514

Terminals of LEDs

Since LEDs are basically diodes, they have anode and cathode terminals/leads as in any general purpose diode. Fig 5 shows the methods to identify the terminals of a LED.

Fig 5



EMN2613515

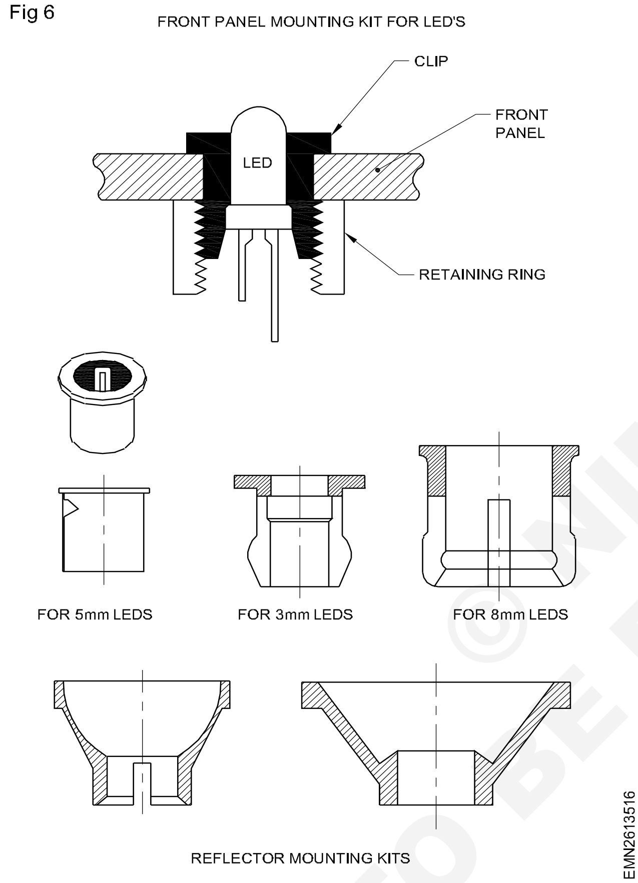
Mounting kits for LEDs

Special mounting kits, as shown in Fig 6, are available for fixing the LEDs on to the printed circuit boards and monitoring panels. These kits not only extend the life of the LED by way of protecting it from mechanical stress but also make the output of the LED clearly visible.

Testing LEDs using Ohmmeter

The anode and cathode terminals of a general purpose diode can be checked easily using an ohmmeter. But, in the case of LEDs, unlike general purpose diodes, the forward voltage of LED ranges from 1.5 to 3 volts (in some cases it is higher than 3 V), and a typical forward current ranges from 10 mA to more than 50mA. Because of this large forward voltage and current requirement of the LEDs, it is not always possible to test the LEDs using an ohmmeter. The reason is, most of the portable type ohmmeters/multimeters use internal battery of not more than 3V for the operation of the meter. This voltage would have got reduced with constant use of the meter. Hence, when an LED is tested using an ohmmeter, the glow of the LED may be very dim or the LED may not glow at all depending on the condition of the battery inside the meter. Hence, the condition of an LED cannot be confidently confirmed using a meter. However, since meter testing is the quickest, this can be used while purchasing an LED from the vendor where other equipments may not be available for testing.

Fig 6



Specifications of LEDs

Specifications sheet of a typical LED is given in the table below;

A Typical LED-specification sheet

(For: FairChild, FLV117 Red LED)

Characteristics	Min.	Typical	Max.
Forward current, I_f		20 mA	50 mA
Forward voltage, V_f		1.7V	3V
Reverse voltage, V_R		8V	
Axial luminous intensity	0.8 mcd	2 mcd	
Angle of half intensity		±20°	
Peak wave-length		665 nm	

From the specifications of a typical LED given above, the following important points are to be noted;

– The forward voltage drop of the LED is much higher (1.7V to 3V) than that of general purpose diodes.

– The reverse voltage that can be applied to the LED is much lower than in general purpose diodes.

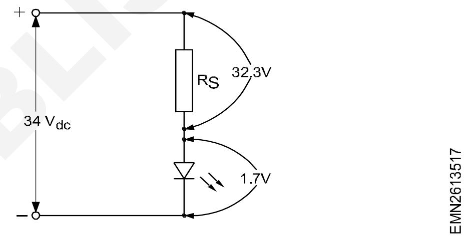
The above two important points confirm that, LEDs do not have the same characteristics as general purpose diodes.

In the typical LED specification, for instance, if 8 V or more is applied across the LED in the reverse biased polarity, the LED will be destroyed.

Example: What value of R_S is required, if a red colour LED is to be used in a circuit with a source of 34V dc.

Using the specifications of the red LED given in the table, it is clear beyond doubt that the LED cannot be connected across 34 volts supply directly (maximum Vf = 3V). Hence, as shown in Fig 7, a resistor is to be used in series with the LED which must drop to 32.3 volts if the voltage across LED should be 1.7 V.

Fig 7

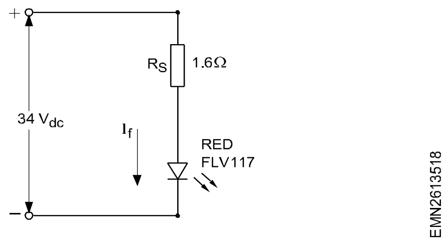


For the LED to give reasonably good light, the current through the LED has to be 20 mA, as indicated in the specifications sheet. So, the value of R_S must be,

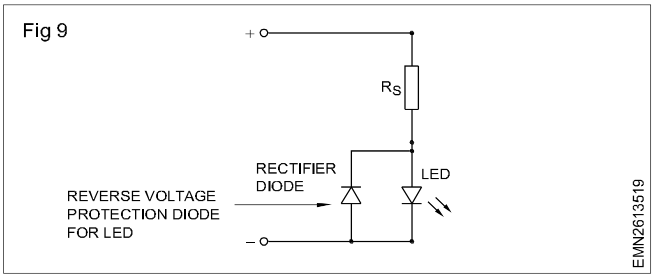
$$R_S = \frac{V}{I} = \frac{32.3\ V}{0.02\ A} = 1615\ \Omega$$

Since the maximum permissible current through the LED is given as 50 mA, it is possible to use a standard 1.6KΩ resistor. This will make a current of 20.2 mA to flow through the LED which is well within the permitted maximum current rating. The LED can now be safely connected across a source voltage of 34 V as shown in Fig 8.

Fig 8



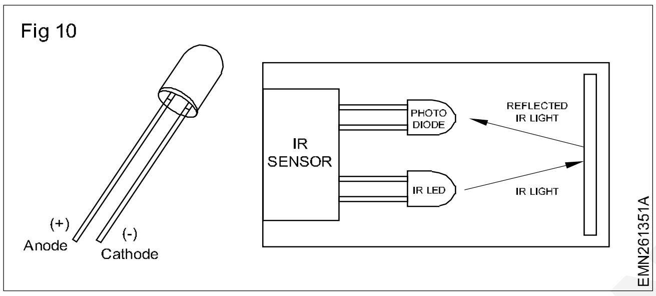
Note that, the maximum reverse voltage that can be applied for the chosen LED is only 8 volts. If accidentally a reverse voltage greater than 8 volts is applied, the LED will get damaged permanently. One way to protect the LED is by connecting a rectifier diode in parallel to the LED as shown in Fig 9.



In Fig 9, when a reverse voltage across the LED becomes more than 0.7 V, the rectifier diode conducts with a forward voltage of 0.7 V. Thus the reverse voltage across the LED is restricted to 0.7 V which is much less than the maximum reverse voltage of 8 V of the LED, and hence the LED is safe.

IR LED

An infrared light-emitting diode (IRLED) is a special-purpose LED is shown in fig 10 that emits infrared signals. Specifically, it is a semiconductor device that releases infrared rays when exposed to electrical current.



Unlike LEDs that project parts of the visible light spectrum, IRLEDs are not used to provide lighting. They are, instead, most commonly used in various signal transfer systems, such as in remote controls for televisions, night-vision cameras and other devices. An IRLED beams light with data signals to control the device. IRLEDs are also used in security installations, cameras and other kinds of technologies. They are useful because of their low energy consumption and low heat generation.

Infrared Sensor. An Infrared light emitting diode (**IR LED**) is a special purpose LED emitting **infrared** rays ranging 700 nm to 1 mm wavelength.

Different IR LEDs may produce infrared light of differing wavelengths, just like different LEDs produce light of different colors. IR LEDs are usually made of gallium arsenide or aluminum gallium arsenide. In complement with IR receivers, these are commonly used as sensors.

The appearance of IR LED is same as a common LED. Since the human eye cannot see the infrared radiations, it is not possible for a person to identify if an IR LED is working. A camera on a cell phone camera solves this problem. The IR rays from the IR LED in the circuit are shown in the camera.

Pin Diagram of IR LED

An IR LED is a type of diode or simple semiconductor. Electric current is allowed to flow in only one direction in diodes. As the current flows, electrons fall from one part of the diode into holes on another part. In order to fall into these holes, the electrons must shed energy in the form of photons, which produce light. It is necessary to modulate the emission from IR diode to use it in electronic application to prevent spurious triggering. Modulation makes the signal from IR LED stand out above the noise. Infrared diodes have a package that is opaque to visible light but transparent to infrared.

IR sensor An IR sensor is a device that detects IR radiation falling on it. Proximity sensors (used in touch screen phones and edge avoiding robots), contrast sensors (used in line following robots) and obstruction counters/sensors (used for counting goods and in burglar alarms) are some applications involving IR sensors.

IR Sensor Principle of Working: An IR sensor consists of two parts, the emitter circuit and the receiver circuit. This is collectively known as a photo-coupler or an optocoupler.

The emitter is an IR LED and the detector is an IR photodiode. The IR photodiode is sensitive to the IR light emitted by an IR LED. The photo-diode's resistance and output voltage change in proportion to the IR light received. This is the underlying working principle of the IR sensor.

The type of incidence can be direct incidence or indirect incidence. In direct incidence, the IR LED is placed in front of a photodiode with no obstacle in between. In indirect incidence, both the diodes are placed side by side with an opaque object in front of the sensor. The light from the IR LED hits the opaque surface and reflects back to the photodiode.

Proximity Sensors Proximity sensors employ reflective indirect incidence principle. The photo diode receives the radiation emitted by the IR LED once reflected back by the object. Closer the object, higher will be the intensity of the incident radiation on the photodiode. This intensity is converted to voltage to determine the distance. Proximity sensors find use in touchscreen phones, among other devices. The display is disabled during calls, so that even if the cheek makes contact with the touchscreen, there is no effect.

Burglar Alarm Direct incidence of radiation on the photodiode is applicable in burglar alarm circuit. The IR LED is fit on one side of the door frame and the photodiode on the other. The IR radiation emitted by the IR LED falls on the photodiode directly under normal circumstances. As soon as a person obstructs the IR path, the alarm goes off. This mechanism is used extensively in security systems and is replicated on a smaller scale for smaller objects, such as exhibits in an exhibition.

Laser diode

Like LEDs laser diodes are typical PN junction devices used under a forward-bias. The word LASER is an acronym for light amplification by stimulated emission of radiation. The use of laser is (becoming increasing common) in medical equipment used in surgery and in consumer products like compact disk (CD) players, laser printers, hologram scanners etc.

(a) Construction

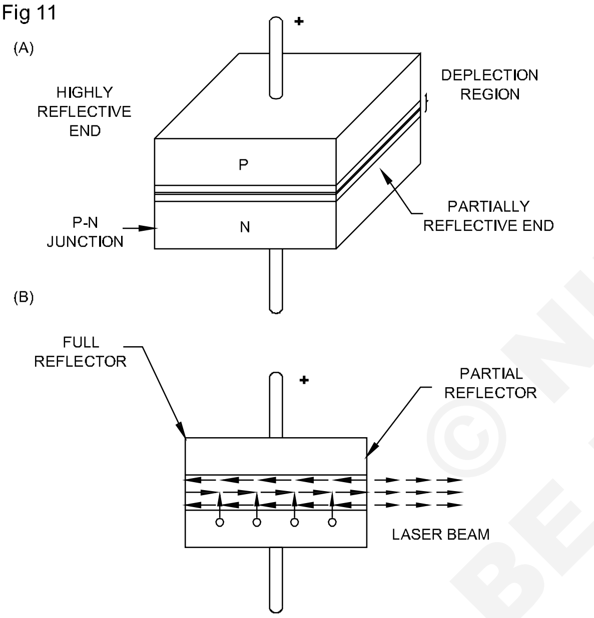
Broadly speaking, the laser diode structure can be divided into two categories:

1 **Surface-emitting laser diodes:** These laser diodes emit light in a direction perpendicular to the PN junction plane.

2 **Edge-emitting laser diodes:** These laser diodes emit light in a direction parallel to the PN junction plane.

Fig.11a shows the structure of an edge-emitting laser diode. This type of structure is called Fabry-Perot type laser. As seen from the figure, a P-N junction is formed by two layers of doped gallium arsenide (GaAs). The length of the PN junction bears a precise relationship with the wave length of the light to be emitted. As seen, there is a highly reflective surface at one end of the junction and a partially reflective surface at the other end. External leads provide the anode and cathode connections.

Fig 11



(b) Theory

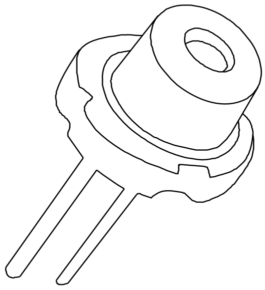
When the PN junction is forward biased by an external voltage source, electrons move across the junction and usual recombination occurs in the depletion region which results in the production of photons. As forward current is increased, more photons are produced which drift at random in the depletion region. Some of these photons strike the reflective surface perpendicularly. These reflected photons enter the depletion region, strike other atoms and release more photons. All these photons move back and forth between the two reflective surfaces. Fig.11. The photon activity becomes so intense that at some point, a strong beam of laser light comes out of the partially reflective surface of the diode.

(c) Unique characteristics of laser light

The beam of laser light produced by the diode has the following unique characteristics

1 It is coherent i.e there is no path difference between the waves comprising the beam;

Fig 12

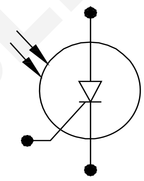


2 It is monochromatic i.e. it consists of one wavelength and hence one colour only.

3 It is collimated i.e emitted light waves travel parallel to each other.

Laser diodes have a threshold level of current above which the laser action occurs but below which the laser diode behaves like a LED emitting incoherent light. The schematic symbol of a laser diode is similar to that of LED. Incidentally, a filter or lens is necessary to view the laser beam.

Fig 13



d) Applications

Laser diodes are used in variety of applications ranging from medical equipment used in surgery to consumer products like optical disk equipment, laser printers, hologram scanners etc. Laser diodes emitting visible light are used as pointers. Those emitting visible and infrared light are used to measure range (or distance). The laser diodes are also widely used in parallel processing of information and in parallel interconnections between computers. Some of these applications are discussed in the following articles.

Printers using laser diodes

There are two types of optical sources usually used in printers; (1) laser diodes and (2) LED arrays. The printers using laser diodes are called laser beam printers (or simply laser printers). These are one of the most attractive type of equipment in office automation in today's world. Words and figures can be printed rapidly and clearly more easily by a laser printer than by other types of printers.

Hologram scanners

An infrared light -emitting diode (LED) is a type of electronic device that emits infrared light not visible to the marked eye. An infrared (IR) LED operates like a regular LED, but may use different materials to produce infrared light. This infrared light may be used for a remote control, to transfer data between devices, to provide illumination for night vision equipment, or for a variety of other purposes.

An infrared LED is like all LEDs a type of diode, or simple semiconductor. Diodes are designed so that electric current can only flow in one direction. As the current flows, electrons fall from one part of the diode into holes on another part. In order to fall into these holes, the electrons must shed energy in the form of photons, which produce light.

Infrared emitting diode infrared light working principle and characteristics

TV monitoring systems engineering in the past rarely used infrared light, but because of today's society not only increase the crime rate, infrared light surveillance in a more prominent role, not only the treasury, oil depots, armories, books library, the cultural relics department, prison and other important departments, but also in the general monitoring system have been adopted. Even residential area television monitoring project has also applied the IR IP camera. This shows that people on television monitoring system engineering requirements increasingly standardized, higher and higher. On the important places are increasingly demanding to do 24 hours of continuous monitoring.

Infrared light into its mechanism of semiconductor infrared radiation emitting solid (infrared emitting diode) infrared light and infrared light two kinds of thermal radiation, most of the infrared infrared IP camera are used as a light-emitting diode LED IR infrared security surveillance camera's main material.

Infrared emitting diode infrared light, the principle and characteristics are as follows: the matrix of infrared light - emitting diode light. Infrared emission diode by the infrared radiation efficiency of the material commonly gallium arsenide GaAs) made of a PN junction, applied to the PN junction forward bias injection current excitation infrared light. Spectral power distribution center wavelength 830~950nm, half-peak bandwidth of about 40nm or so, it is the narrow distribution as ordinary CCD monochrome camera can be a range of feelings. Its biggest advantage is that you can completely red storm, (using 940~950nm wavelength infrared tube) or only weak red storm (red storm is a visible red light) and long life.

Infrared light - emitting diodes transmit power with irradiance $\mu W/m^2$ representation. In general, the infrared radiation power and forward current is proportional to but near the maximum forward current rating, the temperature of the device due to the current heat consumption rises, the light emission power down. Infrared diode current is too small, it will affect the radiation power of the play, but the work current is too general affect their life and even the infrared diode burned. Industry's popular in video surveillance camera inside the built-in cooling system that allows the camera steady work longer.

Light Dependant Resistor (LDR)

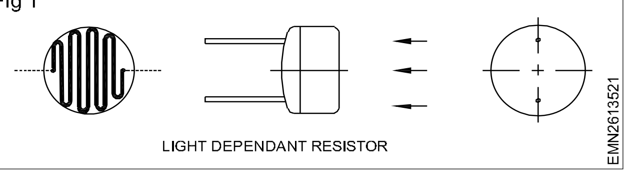
Objectives : At the end of this lesson you shall be able to
- **explain the working principle of LDR.**

Light Dependant Resistor

The name itself tells us what the component does. "photo" is for light "resistor" is to resist the flow of current.

Photoresistors, also known as light dependent resistor (LDR), Cadmium Sulfide cells (CDS cells), photoconductor and sometimes simply photocells are a type of transducer which converts energy from one form to another where one of the known forms is electrical energy. To keep things simple, we will refer to it as photoresistor. Resistance in a photoresistor inversely varies with the amount of light it is exposed to. Bright light=Less resistance and low light=more resistance. These sensors are used to make light sensitive devices and are more often found in street lights, cheap toys, outdoor clocks etc., if you have ever wondered how a street light turns on in the night and switches off in the day, you will be surprised to find a cheap photoresistor circuitry inside it.

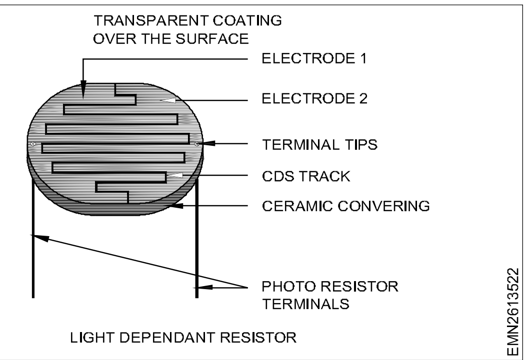
Fig 1



Phototransistors/photodiodes/photovoltaic cells are altogether different and do not confuse that with these photoresistors.

Cadmium sulfide is often used to make these components due to its low cost. Other materials such as Lead sulfide, Indium antimonide and Lead Selenide are also used for high end requirements.

Fig 2



How do they work?

Working principle of a photoresistor is relatively simple. If you have already read electricity basics, you know that electricity is nothing but movement of electrons within a material. Conductors have low resistance and insulators have high resistance. The third category is the semiconductors which stand between a conductor and an insulator. Photoresistor is made of one such semiconductor with very high resistance with only a few free electrons. When light falls on this material, photons from light is absorbed by these materials and energy is transferred to electrons which break up resulting in lower resistance and higher conductivity. The resistance in low light to bright light it results in only a few hundred ohms. When exposed to low light, the resistance in a photoresistor can be several mega-ohms (5-20M** dependent on the type & size) and in bright light it results in only a few hundred ohms. Also photoresistors are non-polarized, meaning it can be connected either way in a circuit.

You can easily connect the leads with a multimeter on resistance mode and check resistance of your photoresistor. Face it towards bright light and check the resistance. Now place your hand or cover it up with a black tape and check the resistance again. You see that the resistance drastically increases once you cover the photoresistor.

Advantages

1 Cheap and will not make a hole in your pocket if you spoil few

2 Commonly found in most robot hobby shops

3 Available in different sizes with different specification

4 Easy to design and implement them in a circuitry.

Drawbacks

1 Highly inaccurate. Each one behaves differently than the other. If the first one has a resistance of 150Ω in bright light, second one can have 500Ω of resistance in the same light.

2 They cannot be used to determine precise light levels.

3 Very slow for sensitive applications. If you put a LDR in a speeding robot and tell it to stop at an obstacle, you end up seeing your robot crash.

Photoresistor applications

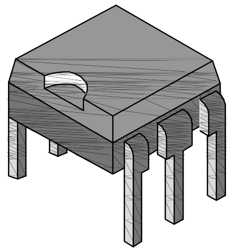
The photoresistor or light dependent resistor is attractive in many electronic circuit designs because of its low cost, simple structure and rugged features. While it may not have some of the features of the photo -resistor is widely used in circuits such as photographic meters, flame or smoke detectors, burglar, card readers, controls for street lighting and many others.

The properties of photoresistors can vary quite widely dependent upon the type of material used. Some have very long time constants, for example it is therefore necessary to carefully choose the type of photoresistor for any given circuit or application.

Generally transformers not only provide higher or lower voltage differences between their primary and secondary windings, but they also provide "electrical isolation" between the higher voltages on the primary side and the lower voltage on the secondary side.

Thus transformers isolate the primary input voltage from the secondary output voltage using electromagnetic coupling by means of a magnetic flux, circulating within the iron laminated core. But we can also provide electrical isolation between an input source and an output load using just light by using a very common and valuable electronic component called an Optocoupler.

Fig 3



EMN2613523

An Optocoupler, also known as an Opto-isolator or Photo-coupler, is an electronic components that interconnects two separate electrical circuits by means of a light sensitive optical interface.

The basic design of an Optocoupler consists of an LED that produces infra-red light and a semiconductor photo-sensitive device that is used to detect the emitted infra-red beam. Both the LED and photo sensitive device are enclosed in a light - tight body or package with metal legs for the electrical connections as shown.

An optocoupler or opto-isolator consists of a light emitter, the LED and a light sensitive receiver which can be a single photo-diode, photo-transistor, photo-resistor, photo-SCR or a photo TRIAC and the basic operation of an optocoupler is very simple to understand.

Assume a photo-transistor device as shown. Current from the source signal passes through the input LED which emits an infra-red light whose intensity is proportional to the electrical signal.

This emitted light falls upon the base of the photo-transistor, causing it to switch-ON and conduct in a similar way to a normal bipolar transistor.

Fig 4

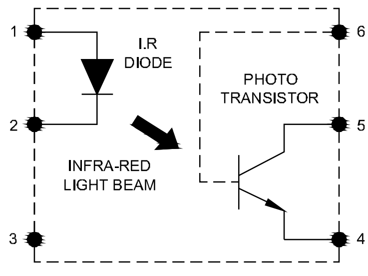


PHOTO TRANSISTOR OPTOCOUPLER

EMN2613524

The base connection of the photo-transistor can be left open for maximum sensitivity or connected to ground via a suitable external resistor to control the switching sensitivity making it more stable.

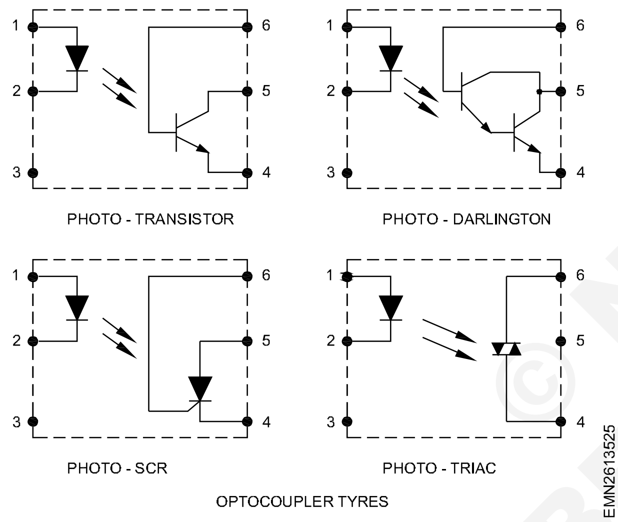
When the current flowing through the LED is interrupted, the infra-red emitted light is cut-off causing the photo transistor to cases conducting. The photo-transistor can be used to switch current in the output circuit. The spectral response of the LED and the photo-sensitive device are closely matched being separated by a transparent medium such as glass, plastic or air. Since there is no direct electrical connection between the input and output of an optocoupler, electrical isolation upto 10kV is achieved.

Optocouplers are available in four general types, each one having an infra-red LED source but with different photo-sensitive devices. The four optocouplers are classed the photo transistor, photo-darlington, photo-SCr and photot-Triac as shown in below.

Optocoupler types

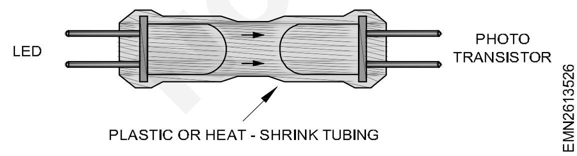
The photo-transistor and photo-darlington devices are mainly for use in DC circuits while the photo-SCR and photo-Triac allow AC powered circuits to be controlled. There are many other kinds of source - sensor combinations, such as LED - photodiode, LED-LASER, lamp photoresistor pairs, reflective and slotted optocouplers.

Fig 5



Simple homemade optocouplers can be constructed by using individual components. An LED and a photo-transistor are inserted into a rigid plastic tube or encased in heat-shrinkable tubing as shown. The advantage of this home-made optocoupler is that tubing can be cut to any length you want and even bent around corners. Obviously, tubing with a reflective inner would be more efficient than dark black tubing.

Fig 6



Home-made optocoupler

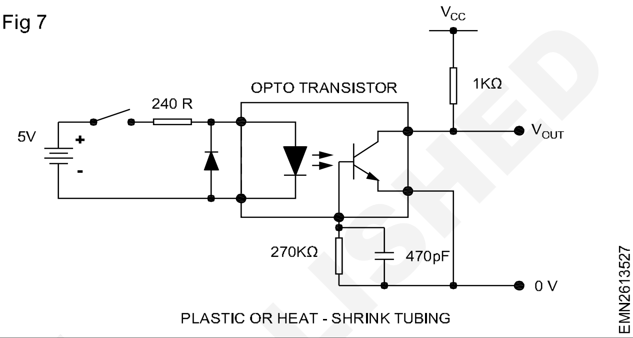
Optocoupler applications

Optocouplers and opto-isolators can be used on their own, or to switch a range of other larger electronic devices such as transistors and TRIACs providing the required electrical isolation between a lower voltage control signal and the higher voltage or current output signal. Common applications for optocouplers include microprocessor input/output switching, DC and AC power control, PC communications, signal isolation and power supply regulation which suffer from current ground loops, etc. The electrical signal being transmitted can be either analogue (linear) or digital (pulses).

In this application, the optocoupler is used to detect the operation of the switch or another type of digital input signal. This is useful if the switch or signal being detected is within an electrically noisy environment. The output can be used to operate an external circuit, light or as an input to a PC or microprocessor.

An optotransistor DC Switch

Fig 7



As well as detecting DC signals and data, Opto-Triac isolators are also available which allow AC powered equipment and mains lamps to be controlled. Opto - coupled Triacs such as the MOC 3020, have voltage ratings of about 400 volts making them ideal for direct mains connection and a maximum current of about 100mA. For higher powered loads, the opto-Triac may be used to provide the gate pulse to another larger triac via a current limiting resistor as shown.

Triac optocoupler application: This type of optocoupler configuration forms the basis of a very simple solid state relay application which can be used to control any AC mains powered load such as lamps and motors. Also unlike a thyristor (SCR), a Triac is capable of conducting in both halves of the mains AC cycle with zero-crossing detection.

Optocouplers and Opto-isolators are great electronic devices that allow devices such as power transistors and Triacs to be controlled from a PCs output port, switch or low voltage data signal. Their main advantages is the high electrical isolation between the input and output allowing relatively small signals to control much large voltages and currents.

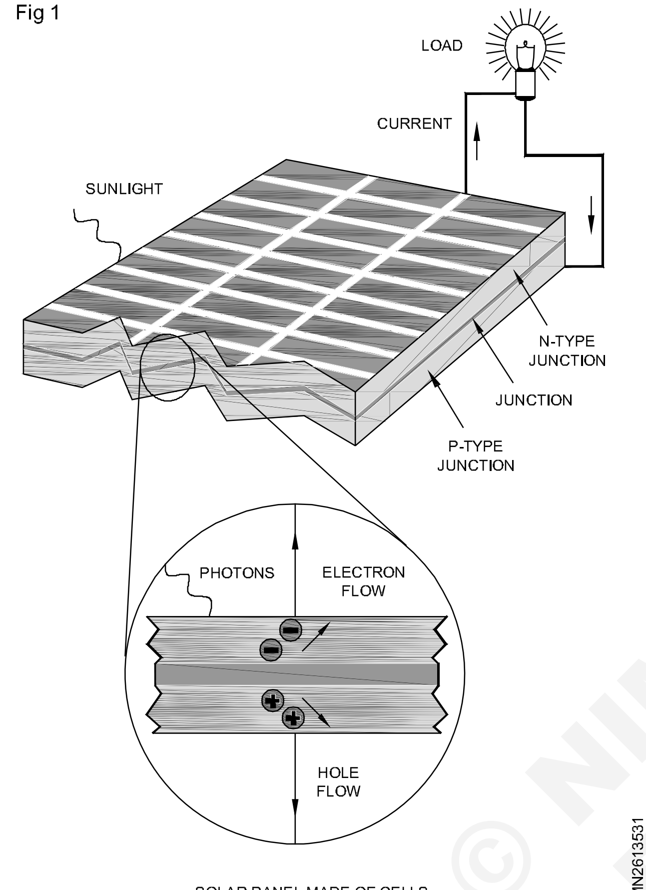
An optocoupler can be used with both DC and AC signals with optocouplers utilizing a SCR (thyristor) or Triac as the photo-detecting device are primarily designed for AC power control applications. The main advantage of photo-SCRs and photo-Triacs is the complete isolation from any noise or voltage spikes present on the AC power supply line as well as zero crossing detection of the sinusoidal waveform which reduces switching and inrush currents protecting any power semiconductors used from thermal stress and shock.

Photovoltaic Cell

Objectives : At the end of this lesson you shall be able to
- **explain the working principle of solar cells / photovoltaic cell.**

How a solar cell makes electricity?

Fig 1



SOLAR PANEL MADE OF CELLS

A **solar cell** is also called as **photovoltaic cell:** Under the sun, a **solar cell** or **p**hoto **v**oltaic cell (PV cell) acts as a photosensitive diode that instantaneously converts light - but not heat - into electricity. Some PV cells can also convert infrared (IR) or ultraviolet (UV) radiation into DC electricity.

Cell Layers

A top, phosphorus - diffused silicon layer carries free electrons with negative charges. A thicker, boron doped bottom layer contains holes, or absences of electrons, that also can move freely.

Sun Activation

1 Photons bombard and penetrate the cell

2 They activate electrons, knocking them loose in both silicon layers.

3 Some electrons in the bottom layer sling -shot to the top of the cell.

4 These electrons flow into metal contacts as electricity, moving into a circuit throughout a 60cell module.

5 Electrons flow back into the cell via a solid contact layer at the bottom creating a closed loop or circuit and the bulb glows.

Powering homes and businesses with solar

Current leaving a module, or array of modules, passes through a wire conduit leading to an inverter. This device, about the shape of a waffle iron, inverts direct current, which flows with a fixed current and voltage, into alternating current, which flows with oscillating current and voltage. Appliances worldwide operate on AC. From the inverter, the solar generated power feeds into circuitry of a household, business or power plant and onto the region's electrical grid. A remote, or independent, power system also can form a self-contained circuit without connecting to the grid. The off-grid system, however, requires batteries to store power for times, such as night, when modules do not capture enough light energy from the sun.

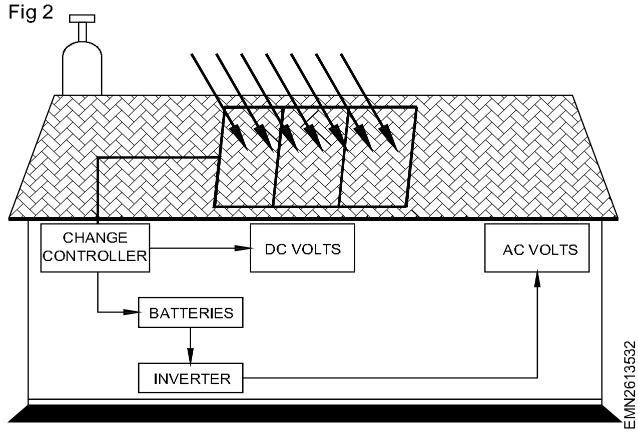
Large sets of PV cells can be connected together to form solar modules, arrays, or panels.

A solar panel turns the sun's light into electricity! We see electricity at work every day. For instance, when you turn on a lamp, electrons move through the cord and light up the bulb. That flow of electrons is called electricity.

One solar panel is made up of many small cells. Each of these cells uses light to make electrons move. The cell is made up of two different layers that are attached together. The first layer is loaded with electrons, so the electrons are ready to jump from this layer to the second layer. That second layer has had some electrons taken away, so it is ready to take in more electrons.

When the light hits an electron in the first layer, the electron jumps to the second layer. That electron makes another electron move, which makes another electron move, and so on. It was the sunlight that started the flow of electrons, or electricity.

Fig 2



Photodiodes and Phototransistors

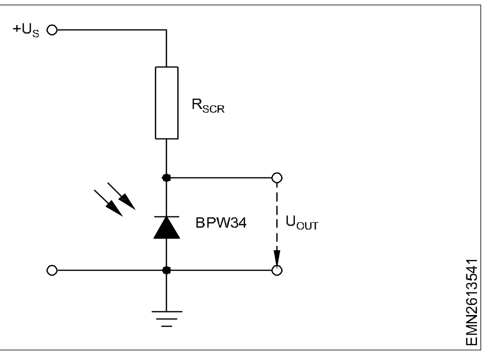
Objectives: At the end of this lesson you shall be able to
- **explain working of photodiode**
- **explain the advantages of PIN photodiode**
- **list the application of photodiodes**
- **explain working of photodiode**
- **explain the working of a light controlled switch using photo transistor.**

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

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.

Fig 2

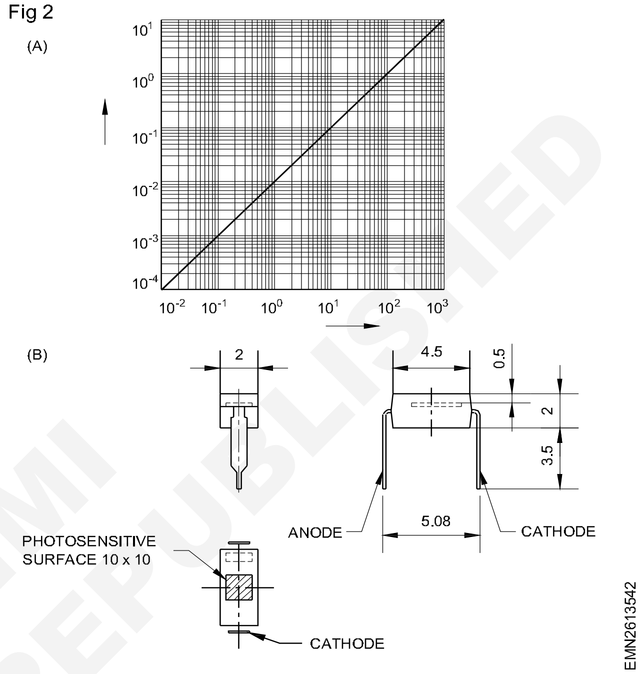
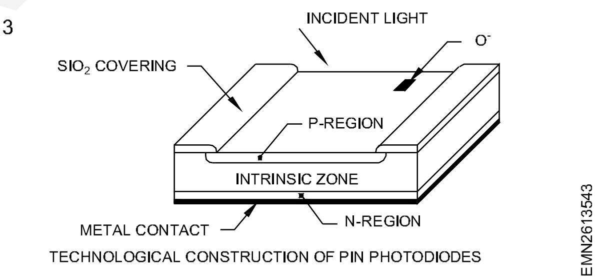


Fig 3



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.

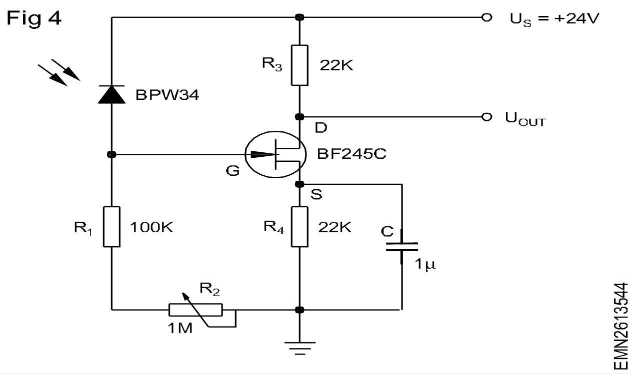
Typical application of Photodiodes

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.

Fig 4

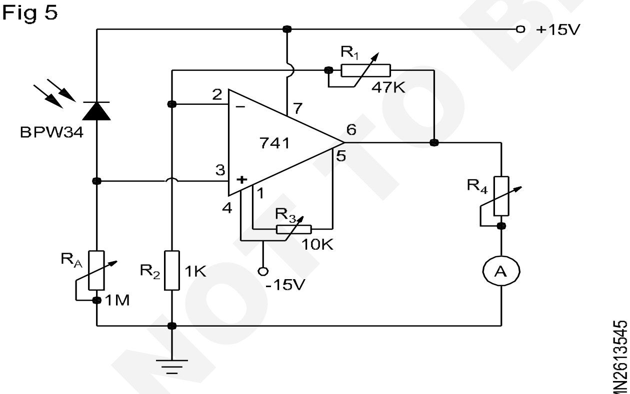


The working point of the FET can be adjusted with trimmer R_2. As the illumination on the photo diode increases, the negative gate is reduced and therefore V_{out} reduces. The same value of R_3 and R_4 are chosen to ensure linear relationship between I_{photo} and V_{out} over a wide range. Thus this photoamplifer 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 5μA/lx. The sensor has the type designation TFA 1001W and is intended for use in video cameras and optical instruments.

Fig 5

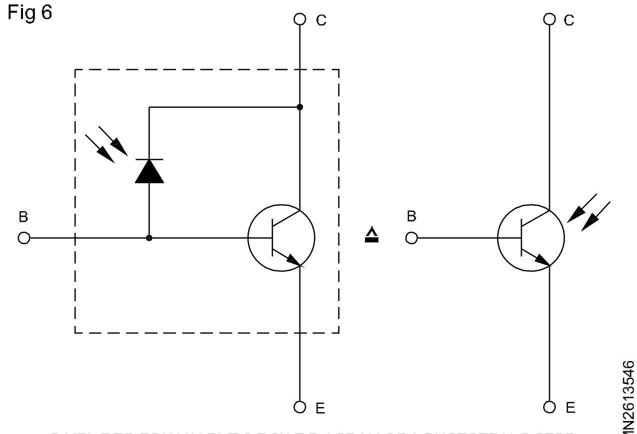


ILLUMINATION PHOTOMETER WITH OP-AMP

PHOTOTRANSISTOR

Both in the construction and in their mode of operation, phototransistor's can be thought of as a combination of a photodiode and a normal bipolar transistor. The simplified equivalent circuit diagram of a phototransistor is shown in Fig 6.

Fig 6



SIMPLIFIED EQUIVALENT CIRCUIT DIAGRAM OF A PHOTOTRANSISTOR

Without illumination, only a very small dark current I_{Ro} flows through the photodiode. This dark current, at the same time is the base current of the transistor. The following is then obtained for the dark current I_{Co} of the transistor,

$I_{Co} = B \times (I_{CBo} + I_{Ro})$,

Where,

I_{CBo}, is the reverse current of the collector/base diode and B is the current gain of the transistor.

When the photodiode is illuminated, a photocurrent I_{photo} flows, which is amplified by the current gain B and is superimposed on the dark current.

Therefore, the collector current of the phototransistor is,

$I_C = I_{Co} + B \times I_{photo}$

Since the dark current I_{Co} is much less than B x I_{photo}, I_{Co} can generally be neglected, so in practice,

I_C approximately = $B \times I_{photo}$

Advantage of Phototransistors over Photodiodes

Advantages of phototransistors over photodiodes are,

- their considerably greater sensitivity and
- the illuminance-dependent collector current IC, which is increased by a factor B.

Type and availability

Phototransistors are produced with and without external base terminals. If no base terminal exists, the collector current is exclusively controlled by the change in the illuminance. It is then no longer possible to specify a working point. Such phototransistors are therefore usually used only as light-sensitive switches.

Example of phototransistors without an external base terminal;

Type number BPX81

Limiting data for BPX81:

U_{CEmax} = 32V i_{Cmax} = 50 mA

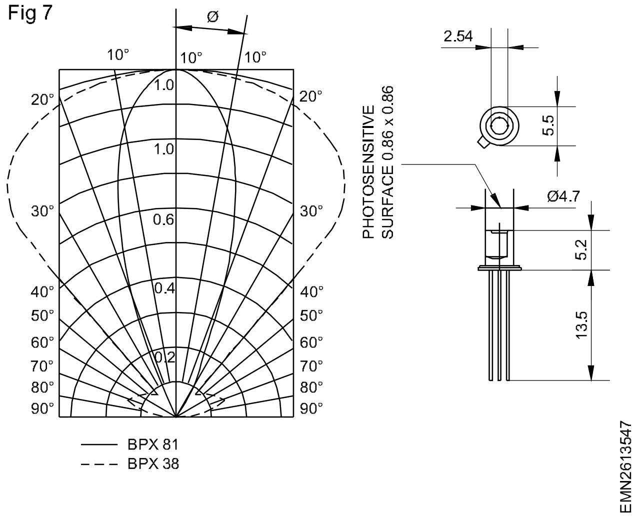
V_{Jmax} = 90°C P_{tot} = 100mW

R_{thJA} = 750 K/W

BPX 81 is used both for visible and infrared light because of its wide spectral sensitivity. Fig 7 shows the BPX81 phototransistor with component dimensions.

BPX 38 phototransistor belongs to the group of phototransistors with external base terminal. The aperture angle of BPX 38 is larger than BPX 81. Therefore BPX 81 has better directional characteristics compared to BPC 38. Fig 7 shows the typical construction of BPX 38 phototransistor.

Fig 7



BPX 38 is available in four sensitivity groups. The data is given in the table below;

Group	II	III	IV	V
Photocurrent	0.2 to	0.32 to	0.5 to	0.8 to
I_{photo} at	0.4 mA	0.63mA	1.0mA	1.6mA
E_e=0.5mW/cm^2				
B	150	240	350	-

Typical applications

Of the numerous possible applications of light-sensitive phototransistors, two very simple circuits applications are given below;

Light controlled amplifier with phototransistor

Together with the phototransistor, resistor R1 again forms a light-sensitive voltage divider. The phototransistor is thus operated like a photodiode with a greater sensitivity and heavier photocurrent. It is therefore possible to drive a low-power transistor, such as BC140 directly by the collector of the phototransistor as shown in Fig 8.

Illumination Photometer

Fig 9 shows a circuit with a roughly linear characteristic $I_e = f(E_e)$ as an illumination photometer for measuring illuminance. It works with a Darlington circuit, consisting of an npn phototransistor BPX81 and a pnp transistor BC307.

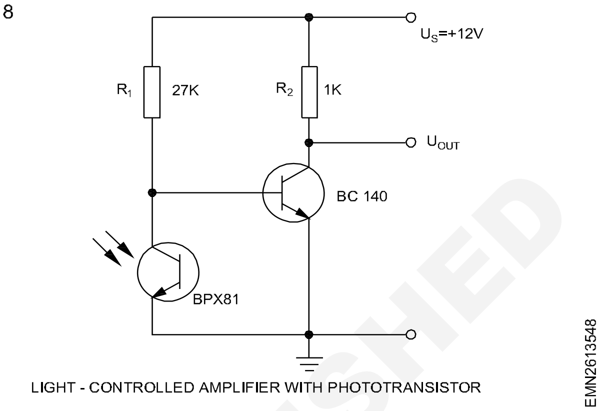
Light controlled switch using phototransistor

Fig 10 shows a circuit which evaluates the states;

"Phototransistor illuminated" or "Phototransistor not illuminated"

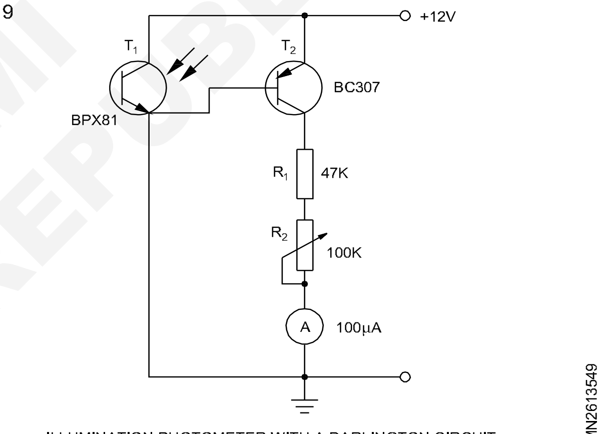
The Opam in the circuit works as a comparator. It is used as a signal comparator cum signal amplifier. When the phototransistor gets illuminated, the voltage at the -ve input of the opamp is higher than that at the +ve input and the output V_{out} is at 0 volts because of the operation with only one supply voltage. When the phototransistor is not illuminated, the conditions at the inputs of the opamp are reversed and the output voltage V_{out} is approximately 24 volts.

Fig 8



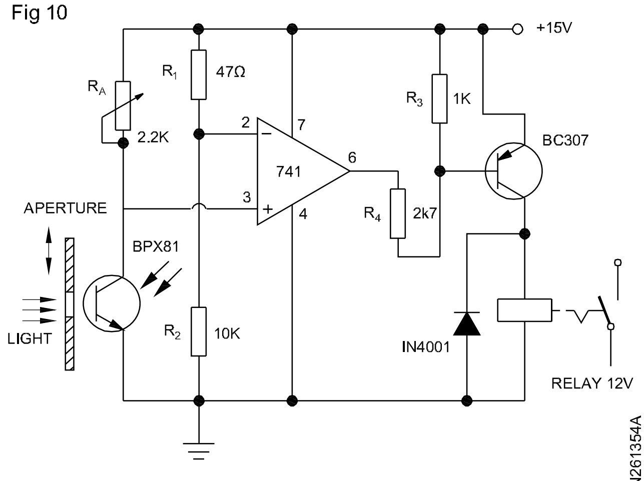
LIGHT - CONTROLLED AMPLIFIER WITH PHOTOTRANSISTOR

Fig 9



ILLUMINATION PHOTOMETER WITH A DARLINGTON CIRCUIT

Fig 10



LIGHT-CONTROLLED SWITCHING AMPLIFIER

Application of opto electronic devices

Objectives : At the end of this lesson you shall be able to
- **explain the meaning and application of optoelectronics**
- **explain the working of a basic optical receiver**
- **explain the working of a optocoupler**
- **explain the principle of Optical fibres**
- **explain the working principles of opto- isolator.**

Optoelectronics is the integration of electronics, optics and light to more effectively and economically control an electromechanical operation, transfer information or make measurements.

The term light means both visible and invisible. Visible light is seen by the human eye whereas, infrared light is below the range of human perception. Optoelectronic devices include light emitters, photodetectors or sensors, optic fibers, visual displays and a variety of fittings to link computers, telephones and televisions.

Optoelectronic components have proved superior to mechanical sensing and switching as they cost less, they are smaller, light in weight, they are faster and have longer life.

Optocomponents

Optocomponents fall into two general categories-light emitters and light sensors. Light emitters and sensors can be further divided into devices that operate in the visible light range and those that operate in the infrared region.

A further differentiation in the various devices involves their physical structure. Different-sized holders have been designed for different devices.

Light sensors are divided according to their speed of operation, frequency of operation and ability to provide amplification. A further division relates to whether the light emitter and sensor are an integral part of one holder such as in the optocoupler or optoisolator.

The specific application will determine whether a photodiode, phototransistor, photo-Darlington or Schmitt trigger device is necessary. In digital applications, for example high-speed devices are generally required.

Optoisolators and optocouplers are finding wide application in power control devices, where they are used in place of relays.

Photoresistor

The photoresistor is the basic light sensing component. It is generally made of either cadmium Sulfide (CdS) or cadmium selenide (CdSe). The devices are made by the deposition of a layer of the semiconductor material on a substrate of ceramic or silicon. A clear coating of glass or plastic, to form a lens can be used to focus the light. The semiconductor material in a dark state has few free electrons however when light (photons) irradiates the cell's surface, the electron flow increases and resistivity decreases. A dark cell may have a resistance of 30 to 50 $M\Omega$, where as an illuminated cell's resistance may drop to under 5 $k\Omega$. Dark-to-light resistance ratios of 10,000/1 are quite common. Accompanying the resistance change is also a change in response time. Photoresistors does not respond instantaneously to the influx of light.

Photoresistors are sensitive to different wave lenghts. The CdS photoresistor peaks in the region of 0.60μm (6000 A). CdSe photoresistors peaks in the region of 0.7 to 0.75 μm. Both peaks above the visible light response.

Photoresistors are also manufactured from selenium, germanium and silicon. The material that is used determines the sentivity and response time of the sensor.

Geometric patterns in the semiconductor layer can also affect the sensitivity of photoresistors. Zigzag or interleaved patterns provide greater surface areas but a lower operating voltage. The photoresistor can be used as a potentiometer for the biasing of oscillators or amplifiers.

Photovoltaic cell

It is PN junction diode. The P material is often made of selenium or silicon and the N material is cadmium or silicon.

Light irradiating the solar cell (junction area) reduces its energy band and causes electrons to move toward the N-type material while the holes move toward the P material. Externally, a dc potential can be measured that is in the range of 0.6 to 0.7V, with the P-material terminal being positive and the N material being negative.

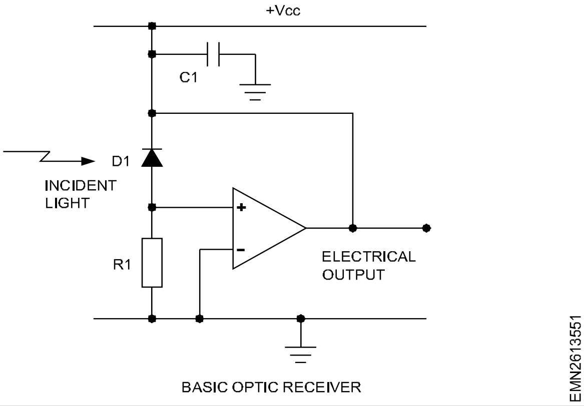
The surface area determines the current supply capability. Cells can be connected in series to increase the total voltage or in parallel to increase the total current.

The photovoltaic cell has its peak response in the range of 0.5 μm. Cells made from indium antimonide operate in the near-infrared region. Most solar cells are very active in the visible light spectrum.

Optical receivers

An optical receiver shown in Fig 1 consists of a photo-diode, pin or avalanche which converts the incident light into photo-current and a low-noise amplifier which amplifies the photo-current. The performance, i.e. bandwidth, dynamic range and noise figure of the receiver is mainly determined by the low-noise amplifier. The amplifier may employ silicon bipolar or field-effect transistors. A number of optical receiver packages are produced by various manufacturers, one such is the National Semiconductors LH0082.

Fig 1



Optocouplers

The optocoupler also called an optoisolator, is a completely sealed IRED exciter and a photodetector. The exciter and detector are two completely isolated circuits; yet signals can be readily transferred between them. A low-voltage source can be made to control a high-voltage output circuit with complete isolation and without the high potential danger often encountered.

The optocoupler may contain an IRED emitter with a photodiode, phototransistor, Darlington or laser sensor. To use these devices effectively, their characteristics must be known. Although many of their characteristics are similar to those for circuits using discrete components, there is a difference in the degree of isolation between the input and output circuits. The isolation features can be divided into three types: isolation resistance, isolation capacitance and dielectric breakdown ability. The isolation resistance is in the order of $1 \times 10^{11}\Omega$. The circuit resistance, external to the coupler, may be much lower in value. The capacitive isolation ranges from less than 1 pF to less than 3 pF and is the capacitance of the dielectric materials. Again, the circuit board layout may have a higher capacity than the coupler. Both the resistance and capacitive values are affected by the distance and medium between the source and detector. A piece of glass which is often used, affects the isolation characteristics.

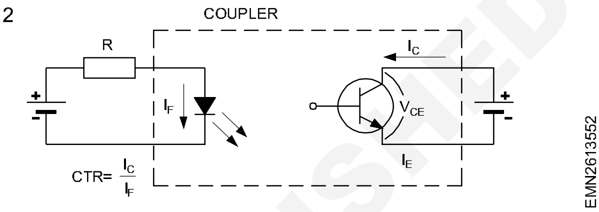
The dielectric resistance breakdown, rated in volts, defines the maximum voltage that can be applied. Other factors such as waveshape, temperature and altitude also affect the dielectric breakdown rating. Although a coupler may withstand 1000 V DC. It may only withstand 500 V AC. Couplers that have been previously subjected to high-surge voltages may exhibit a higher leakage resistance and/or short circuits between elements.

Input-output characteristics of an optocoupler, are similar to those for circuits that use discrete components. The input of the coupler is usually an IRED and the output is one of several type of sensors. In some couplers, additional reflective surfaces may be added, or components such as an R or C may be needed in order to meet specific applications. The choice of IRED emitter with a photodiode, phototransistor or Darlington will depend on the specific application.

An important consideration in the use of the optocoupler or optoisolator is the current-transfer ratio. This parameter measures how much current is transferred from the IRED to the sensor in the presence of complete electrical isolation. The CTR used with any LED-sensor combination, describes the current gain (or loss) from input to output. Essentially, the CTR is similar to comparing the I_C to I_B in a transistor circuit. Fig 2 shows the emitter-sensor circuits of a coupler.

The CTR in a coupler is defined as the ratio of I_C to I_F and from the practical point of view, the combined circuit acts as a CE amplifier except for the fact that there is no common tie between the input-output circuits. Depending on the type of sensor, the CTR can range from a loss to a gain of more than 1000.

Fig 2



Optical fibres

Principle: The suggestion that information could be carried on light and sent over long distances in thin fibres of very pure (optical) glass was first made in 1966. Eleven years later, the world's first fibre optic telephone link was made to work in Britain. It is expected that eventually all cables at homes and offices will change over from copper to glass cables.

Light, like radio waves is electromagnetic radiation but because of its much higher frequency (typically 10^{14} Hz = 10^5 GHz), it has a considerably greater information-carrying capacity because of its wide bandwidth. When light is modulated and guided by glass fibre cables installed in cable ducts, it escapes the severe attenuation it would suffer from rain and fog if sent through the air. It is also free from 'noise' due to electrical interference and hence distances of atleast 30 km can be used without regenerators/ repeaters.

Compared with copper cables, optical fibre cables are lighter, smaller and easier to handle.

Lasers

The 'light' used in optical fibres is infrared radiation in the region just beyond the red end of the visible spectrum. Optical fibres employ 1300 or 1500 nm waves since, the longer the wavelength, the less is the atenuation of the radiation by the glass. This is why infrared is preferred to 'visible' light in optical fibres.

The infrared is generated by a tiny semiconductor laser made from gallium, aluminium and arsenic. A laser (standing for light amplification by the stimulated emission of radiation) produces a very narrow coherent beam of electromagnetic radiation of one particular frequency. Coherent light, in contrast to light from other sources (e.g a lamp) consists of waves vibrating in phase with each other, rather like the radiation, at much lower frequencies, from a radio transmitter. The detector at the receiving end is a photodiode which converts the optical signal into an electrical one.

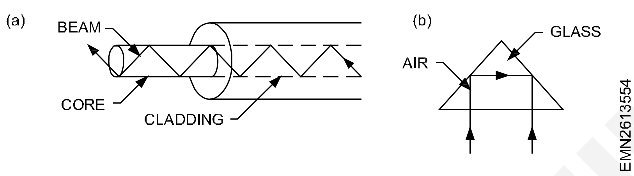
Modulation

The infrared is pulse code modulated by the speech or other data to be transmitted. Digital signals are sent in the form of pulses of radiation, being on for a '1' and off for a '0'.

Optics

The optical fibres, which are about 0.1mm in diameter have a glass core of higher refractive index than the glass cladding around it. As a result, the infrared beam is trapped in the core by total internal reflection at the core-cladding boundary as shown in Fig 3a. This is just as light is in the prisms as shown in Fig 3b of binoculars when it strikes the back surface of the prism where the refractive index is high in the glass but low in the air. The glass in optical fibres is so pure that a 2 km length absorbs less 'light' than a sheet of window glass.

Fig 3



Capacity

The information carrying capacity of an optical fibre system is about the same as the best coaxial cables. It is typically around 140M bit/sec. A 140M bit/s system can carry about 2000 telephone channels or 250 music channels or 2 colour TV channels or a mixture of these. 140 M bit/s is a very high rate of information transfer being equivalent to delivering 8 average length books every second!

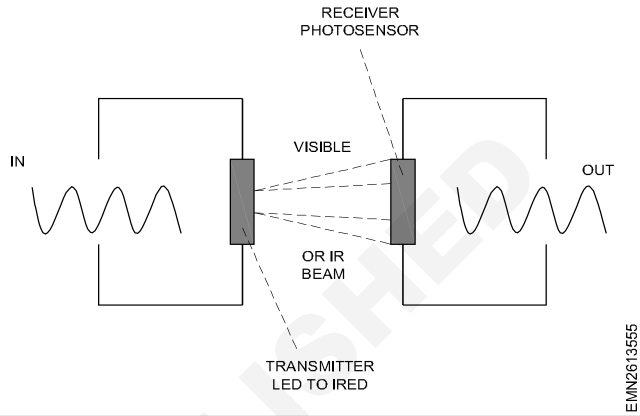
Optoisolator (optical coupler or optocoupler)

An optoisolator (also known as optical coupler, optocoupler and opto-isolator) is a semiconductor device that uses a short optical transmission path to transfer an electrical signal between circuits or elements of a circuit, while keeping them electrically isolated from each other. These components are used in a wide variety of communications, control and monitoring systems that use light to prevent electrical high voltage from affecting a lower power system receiving a signal.

In its simplest form, an optoisolator consists of a light-emitting diode (LED), IRED (infrared-emitting diode) or laser diode for signal transmission and a photosensor (or phototransistor) for signal reception. Using an optocoupler, when an electrical current is applied to the LED, infrared light is produced and passes through the material inside the optoisolator. The beam travels across a transparent gap and is picked up by the receiver, which converts the modulated light or IR back into an electrical signal. In the absence of light, the input and output circuits are electrically isolated from each other.

Electronic equipment, as well as signal and power transmission lines, are subject to voltage surges from radio frequency transmissions, lightning strikes and spikes in the power supply. To avoid disruptions, optoisolators offer a safe interface between high-voltage components and low-voltage devices.

Fig 4



The optoisolator is enclosed in a single device, and has the appearance of an integrated circuit (IC) or a transistor with extra leads. Optocouplers can be used to isolate low-power circuits from higher power circuits and to remove electrical noise from signals.

Optoisolators are most suited to digital signals but can also be used to transfer analog signals. The isolation of any data rate of more than 1 Mb/sec is considered high speed. The most common speed available for digital and analogoptoisolators is 1 Mb/sec, although 10 Mb/sec and 15 Mb/sec digital speeds are also available.

Optoisolators are considered too slow for many modern digital uses, but researchers have created alternatives since the 1990s.In communications, high-speed optoisolators are used in power supplies for servers and telecom applications -- Power over Ethernet (PoE) technology for wired Ethernet LANs, for example.

Optoisolator components can also protect Ethernet and fiber optic cables from electrical surges. In VoIP phones, electrical signals can be isolated using a transistor output optocoupler.Although no longer common, where modems are used to connect to telephone lines, the use of optoisolators allow a computer to be connected to a telephone line without risk of damage from electrical surges or spikes. In this case, two optoisolators are employed in the analog section of the device: one for upstream signals and the other for downstream signals. If a surge occurs on the telephone line, the computer will be unaffected because the optical gap does not conduct electric current.

Digital IC families and their operational characteristics

Objectives : At the end of this lesson you shalll be able to
- **define the basic terms related to digital IC gates**
- **recognize the different types of packages of ICs used in the digital IC**
- **list different levels of integration used in fabrication of digital IC**
- **differentiate logic families and their characteristics**
- **explain safety precaution to be adopted while handling CMOS ICs**
- **compare the TTL and CMOS families**
- **explain digital IC numbering system.**

Introduction

A digital system is a combination of devices designed to Process information that are represented in digital form. Example of a few most popular digital systems are,

- Digital computers
- Calculators,
- Digital audio and video equipments
- Telephone system ..... etc.,

Digital Telephony is probably the world's largest digital system.

In electronic circuits, signals are represented in voltage or current. In these circuits, the signal representation will have a number of voltage or current levels.

In such analog signals, the transition from one level to another is usually smooth rather than sudden diffence between and the transition between them is also smooth rather than sudden.

Digital signals on the other hand can have only two discrete states. These states can be called as,

- **ON state**: A state at which a predefined voltage is present. For example, the level could be, +5 Volts, +10Volts and it is also represented as high, one, etc.
- **OFF state**: A state at which a predefined voltage is other than the ON state voltage is present. For example, the level could be, 0 Volts, -5 Volts and it is also represented as low, zero etc.,

The discrete levels in digital signals are technically referred to as logic levels. Generally, the ON state described above is referred as the LOGIC 1 state and the OFF state as the LOGIC 0 state. It is very essential to note that, in digital signal representation, no state exists in between the logic-0 and logic-1 state.

For example,if we say Logic-0 corresponds to 0 volts and Logic-1 corresponds to 1 volt. In such a digital system, voltage levels of 2V,3V,4V etc., have no meaning (further details are discussed in lessons that follows).

Because the transition time between ON to OFF state or vice versa is abrupt in digital signals, analysis of digital systems varies from that of pure analog systems such as amplifiers etc.,

Compared to analog circuits, digital circuits contains less number of discrete components such as resistors, capacitors etc., This is mainly for the reason that the Integrated circuit(IC) technology has advanced so much, millions of components can be prefabricated in a single IC. Most digital circuits are made of such VLSI (very large scale Integration) IC as its main circuit component with a few decoupling capacitor for supplying clean DC voltage.

It is important to note that any analog signal can be converted to a digital signal (in the form 1s or 0s). Example given below gives a clue about how analog signals can be represented as digital signals,

ANALOG VOLTAGE	DIGITAL VALUE
0 volt	0 0 0 0
1 volt	0 0 0 1
2 volt	0 0 1 0
3 volt	0 0 1 1
4 volt	0 1 0 0
5 volt	0 1 0 1
6 volt	0 1 1 0
7 volt	0 1 1 1
8 volt	1 0 0 0
9 volt	1 0 0 1
10 volt	1 0 1 0

Details of how this conversion is done is discussed in further lessons.

Digital systems offer the following advantages over analog systems

- Easier to design
- Information storage is easy
- Accuracy and precision are greater
- Programmable
- Circuitry can be fabricated on IC chips more easily
- High speed functions

The operations carried out using digital signals are called Logic operations. Example of Logic operation are given below;

Assuming there are two inputs and if the Inputs are,

– the circuit output should be Logic-1 if atleast any one of the two inputs is Logic-1.

  A circuit that performs such a logical operation is called as a **OR** gate.

– the circuit output should be Logic-1 only when both the inputs are Logic 1's.

  A circuit that performs such a logical operation is called as a **AND** gate.

– the circuit output should be inverse of the input. If the input is Logic-1, then the output should be Logic-0 and vice-versa.

A circuit that performs such a logical operation is called as a **NOT** gate.

Every logic operation, even the most extensive and the most complicated - can be reduced to combinations of the above said three basic logic functions. By combining these three operations, several other functions such NAND, NOR and so on (discussed in further paragraphs).

These basic functional circuits are called Gates, such as OR gate, AND gate and NOT gate. The practical implementation of logic operations is effected by logic circuits. In the meantime, a large number of circuit families have been produced in integrated circuit technology. The starting point of standard development was the TTL (Transistor-Transistor-Logic) family(earlier to it was the RTL and DTL families), from which several other families with improved properties have been derived. The TTL family of gates have defined voltage levels and permissable tolerances. Some of the important terminologies associated with digital ICs are given below;

Types of IC package

The ICs come in a wide variety of package types. The factors which determine the type of package are

– amount of circuitry contained in the IC

– number of external connections that need to be made to it.

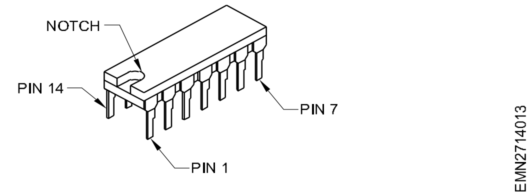
– humidity of the environment, ambient temperature at which the IC is to operate

– method of mounting on the PCB.

DIP [Dual in line package]

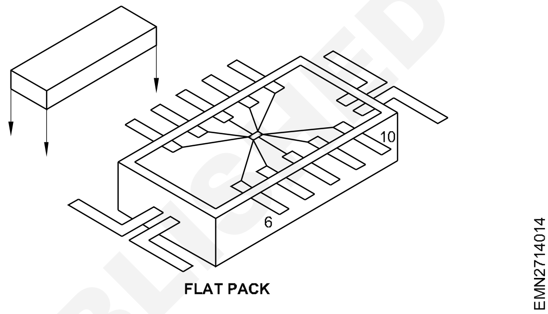
The external connecting pins are in parallel rows along the two long edges of the package as shown in Fig 3. In DIP ICs, number of pins varies from 4 to 64 depending on the internal circuitry. For low temperature and low humidity, epoxy plastic packages are used. For high temperature or for devices that dissipate large amount of power, ceramic packages are used.

Fig 3



Ceramic flat package: This type of IC packages are hermetically sealed as shown in Fig 4, which means that they are totally immune to the effects of humidity. These packages are often used in military equipments that they must be able to withstand harsh environments. Pins are counted around the package from notch or dot. These packages are usually mounted in high quality sockets on the circuit board.

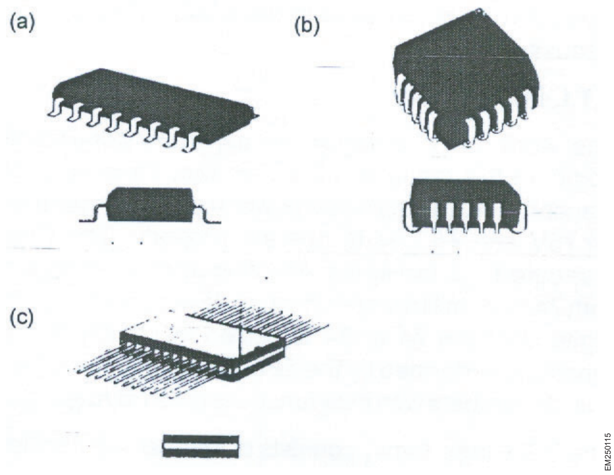
Fig 4



Surface mount package

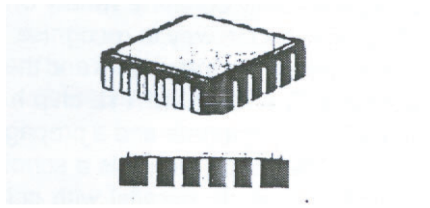
This popular package is similar to the standard DIP except that it is smaller and, as the name implies, its pins are constructed so that it can be soldered directly to metal pads on the PCB. One type of SMT package called small out line IC is shown in Fig 5a. Since surface mount packages are soldered on one surface of the circuit board, holes don't have to be drilled on the PCB. Surface mount devices have further advantages, that they are more easily handled by equipment, which automatically mounts components in the correct position on circuit boards during manufacturing. The PLCC (Plastic Leaded chip carrier) type package is shown in Fig 5b. Another variety of SMT package is known as Flat pack is shown in Fig 5c.

Fig 5



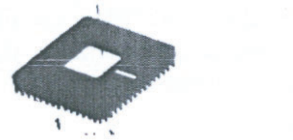
Ceramic chip carrier package: These chips are intended to be clamped into a socket as shown in Fig 6 so that the pads press against contacts which are connected to P.C.B signal lines pin 100 this package is to the right of the notched corner.

Fig 6



Pin grid array package: These ICs are used for VLSI digital circuits such microprocessor. The number of pins in the array depends on the complexity of the internal circuit. The four corner pin positions are usually left without pins. Common array sizes are 10 x 10, 13 x 13 and 14 x 14, large ICs such as these are put in sockets so they can easily be replaced if the device fails.

Fig 7



S.No.	Complexity	Number of Gates	Application
1	Small-Scale Integration (SSI)	Fewer than 12	Basic gates
2	Medium-Scale Integration (MSI)	12 to 99	Flip-flops, regiater etc.
3	Large-Scale Integration (LSI)	100 to 9999	Memories, microprocessor
4	Very large-Scale Integration (VLSI)	10,000 to 99,999	-do-
5	Ultra large-Scale Integration (ULSI)	100,000 or more	-do-

Logic family

Digital ICs are classified not only by their complexity, logical operation, speed of operation but also by the specific circuit technology to which they belong. The circuit technology is referred to as a digital logic family. Each logic family has its own basic electronic circuit upon which more complex digital circuit and components are developed. The basic circuit in each technology is NAND, NOR or an inverter gate. The electronic components, and material used in the construction of the basic circuit are usually used as the name of the technology. The various logic families of ICs used in electronic circuit are briefly discussed below.

TTL Logic family

The word TTL is expanded as Transistor-Transistor Logic. In this family ICs are built with transistors. Most standard TTL ICs require a power supply voltage between +4.75V and +5.25V to operate properly. The ICs of standard TTL family are identified by numbers that start with 74 or for military specification devices 54, two or three digits after the 74 or 54 are used to identify the logic functions performed by the device. Some of the 74 series TTL IC numbers with their functions given at Appendix 'D'.

The TTL logic family consists of several sub families as shown in logic family tree. The difference between the various TTL series are in their electrical characteristics, such as power dissipation, propagation delay and switching speed. They do not differ in the pin assignment or logic operation performed by the internal circuits.

The most popular 7400 series is a line of standard TTL chips. This bipolar family contains variety of compatible SSI and MSI devices. One way to recognise TTL design is the multiple emitter input transistors and the totem pole output transistors. The standard TTL chip has a power dissipation of about 10mw/gate and a propagation delay of around 10ns. The series 74S00 is a schottky version having a schottky diode in parallel with collector-base terminals. In this, transistors are prevented from saturating thereby propagation delay is reduced typically to 3ns. By increasing internal resistances and including schottky diodes, low power schottky diodes numbered from 74LS00 are manufactured limiting the power dissipation to 2mw per gate low power schottky TTL is the most widely used of the TTL types. In this family of devices, a floating input is equivalent to a high input. In electrically noise environment, floating inputs may pick up enough noise voltage to produce unwanted changes in the output stages and hence inputs should not kept be floating in TTL family. A modified TTL design namely three state TTL allows us to connect outputs directly. Earlier computers used open-collector devices with their bases but the passive pull-up limited the operating speed. These newer devices are much faster and have a control input that can turn off the devices. When this happens the output floats and presents a high impedance to whether it is connected to and hence are widely used for connecting to bases.

E.C.L

Emitter-coupled logic circuits provide the highest speed with propagation delay typically of 5ns. The most common ECL ICs are designated as the 10000 series. E.C.L is used in systems such as super computers and signal processors where high speed is essential. The ECL family IC use is restricted to few applications because of the following reasons.

- The gates in ICs dissipate relatively large amounts of power.
- Needs extra circuitry for gates to operate.
- The -ve power supply voltage and logic levels make ECL gates difficult to interface with other logic family members.

MOS

The Metal Oxide Semiconductor is a unipolar transistor that depends upon the flow of only one type of carrier, which may be either electrons or holes. A p-channel MOS is referred to as PMOS and an N-channel as NMOS. NMOS is the one that is commonly used in circuits with only one type of MOS transistor. MOS technology allows a very large number of circuits to be built in a single IC. It is this technology which has made possible the microprocessors, memories and other LSI devices which are used to build microcomputers.

CMOS

PMOS circuitry or NMOS circuitry can't be used alone for making simple logic gate devices such as done in T.T.L devices, for various reasons. However by building the circuits on the IC by using one PMOS and NMOS transistors connected in complementary fashion, it is possible to produce logic gate devices which have the desired characteristics. That is why these ICs are called complementary metal oxide semiconductors or just CMOS.

CMOS ICs are designated in 4000 series. The family includes logic functions such as those available in T.T.L family. CMOS sub families operate properly with a power supply voltage of +3V to +15V.

By the time the 4000 series of CMOS was developed, most logic designers has become very familiar with the logic functions, part numbers and pin connections of the devices in the standard T.T.L sub family. So as to make CMOS ICs more compatible with T.T.L standards, the CMOS, TTL compatible ICs are made available in 74C00 series. 74HC00 series (high speed) 74HCT00 series, refer Table Performance comparison of CMOS and TTL logic families is given in the Table below:

Technology	CMOS		TTL				
	Silicon Gate	Metal-Gate	Std.	Low-Power Schottky	Schottky	Advanced Low-Power Schottky	Advanced Schottky
Device series	74HC	4000	74	74LS	74S	74ALS	74AS
Power dissipation (mW/gate)							
Static	0.0000025	0.001	10	2	19	1	8.5
AT 100 kH_z	0.17	0.1	10	2	19	1	8.5
Propagation delay time (ns)							
(CL = 15 pF)	8	50	10	10	3	4	1.5
Maximum clock frequency (MHz)							
(CL = 15 pF)	40	12	35	40	125	70	200
Speed/Power product (pJ)							
(at 100 kHz)	1.4	11	100	20	57	4	13
Minimum output drive IOL (mA)							
(VO = 0,.4V)	4	1.6	16	8	20	8	20
Fan-out;							
LS loads	10	4	40	20	50	20	50
Same-series	*	*	10	20	20	20	40
Maximum input current, IIL (mA)							
(VI = 0.4V)	±0.001	-0.001	-1.6	-0.4	-2.0	-0.1	-0.5

*Fan-out is frequency dependent

COMPARISON OF TYPICAL NOISE MARGINS:

Noise Margin	HCMOS (V)	Std TTL (V)	LS TTL (V)	S TTL (V)	AS TTL (V)
V_{NH}	1.4	0.4	0.7	0.7	0.7
V_{NL}	0.9	0.4	0.4	0.4	0.4

Digital I.C numbering system

Number and letters on IC packages identify the logic family and the logic function of a device. In addition to these numbers and letters, an IC may have numbers and letter which indicate manufacturers name, the factory where the device was manufactured, the year and month the device manufactured, the package type and a code which indicates how thoroughly the device was tested.

Ex: 74HCTOON

74 HCT OO N

XXX XXX X

Letter codes for common package type

N = Plastic dip

J = Ceramic dip

D = Glass/metal dip

W = Flat pack

Manufacturer code

Code	Manufacturer
AM	Advanced micro device
CD	GE/RCA
DM	National semiconductor
F	Fair child
GD	Gold star
H	Harris
HD	Hitachi
IM	Intersil
KS	Samsung
LR	Sharp
M	SGS
MC	Motorola
MM	Monolithic memories
MN	Panasonic
N	Signetics
P	Intel
SN	Texas instruments
SP	SPI
US	Sprague
TC	Toshiba

Number systems

Objectives : At the end of this lesson you shalll 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**
- **understanding of Boolean algebra and De-Margans theorem.**

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

10^3	10^2	10^1	10^0	
				$1 \times 10^3 = 1000$
				$9 \times 10^2 = 900$
				$6 \times 10^1 = 60$
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, $[34]_{10} = [100010]_2$

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.

```
       0
16 |   1    1       MSB
16 |  27   11 or B
16 | 432    0       LSB
```

$[432]_{10} = [1B0]_{16}$

Hexadecimal to Decimal

This conversion can be done by putting it into the positional notation.

Ex: $223A_{16} = 2 \times 16^3 + 2 \times 16^2 + 3 \times 16^1 + A \times 16^0$

$= 2 \times 4096 + 2 \times 256 + 3 \times 16 + 10 \times 1$

$= 8192 + 512 + 48 + 10$

$= 8762_{10}$

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 compared of digit symbols such as right 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:

Ex: $(15)_8$ ˜ $(13)_{10}$

Octal Decimal

Octal to Decimal conversion

```
     0
8 |  1   1    MSB
8 |  13  5    LSB
```

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

Octal number 2 3 7 4

$(2374)_8$ = $(2 \times 8^3)+(3 \times 8^2)+(7 \times 8^1)+(4 \times 8^0)$

= (2 x 512)+(3 x 64)+(7 x 8)+(4 x 1)

= 1024 + 192 + 56 + 4

$(2374)_8 = (1276)_{10}$

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 $(25)_8 = (\ )_2$

2 5

010 101

$(25)_8 = (010101)_2$

2 $(7526)_8 = (\ )_2$

7 5 2 6

111 101 010 110

$(7526)_8 = (111101010110)_2$

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

$(110101)_2$ = $(\ )_8$

110 101

6 5 = $(65)_8$

$(11010000100)_2$ = ( )

011 010 000 100 = $(3204)_8$

3 2 0 4

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.

8421 code: The 8421 code is a type of binary coded decimal (BCD), binary coded decimal means that each decimal digit, 0 through 9 is represented by a binary code of four bits. The designation 8421 indicates the binary weights of the four bits (2^3, 2^2, 2^1, 2^0). The ease of conversion between 8421 code numbers and the familiar decimal numbers in the main advantage of this code. All you have to remember are the ten binary combinations that represents the ten decimal digits as shown in Table.

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 $(35)_{10}$ = (?) 8421 code

3 5

0011 0101 = 00110101

2 $(2458)_{10}$ = (?) 8421 code

2 4 5 8

0010 0100 0101 1000 = 0010010001011000

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.

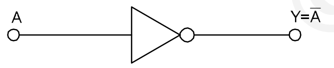
The commonly used codes other than BCD codes are

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.

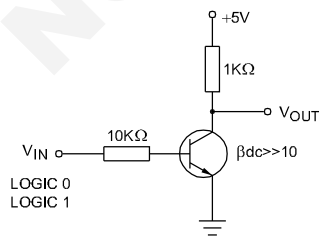
Fig 1



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.

Fig 2



TRANSISTOR INVERTER

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 = A.

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 , 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 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.

Ex: A+B, 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.

Ex: AB, B, A ,

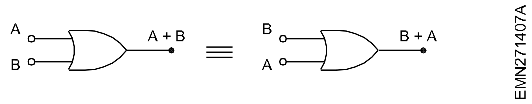
A product term is equal to 1 if and only if each of the literals in the term is one(1). A product term is equal to 0 when one or more of the literal are 0.

Laws of Boolean algebra

Commutative law

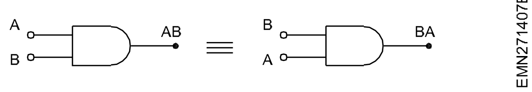
The commutative law for addition for two variables is written algebraically A + B = B + A as shown in Fig 3.

Fig 3



The commutative law for two variable multiplication is AB= BA as shown in Fig 4.

Fig 4

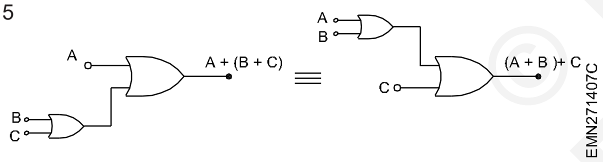


This law states that the order in which the variables are ORed/ANDed make no difference.

Associative law

The associative law of addition is written algebraically as follows for three variables as shown in Fig 5.

Fig 5



A+(B+C) = (A+B)+C

The associative law of multiplication is written as follows for three variables.

A(BC) = (AB)C

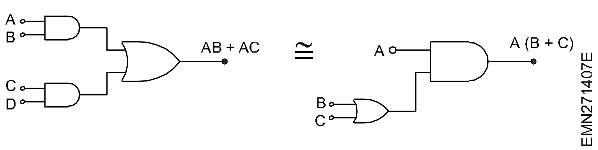
This law states that it makes no difference in what order the variables are grouped when ORing/ANDing more than two variables.

Distributive law

The distributive law is written for three variables as follows.

A(B+C) = AB + AC

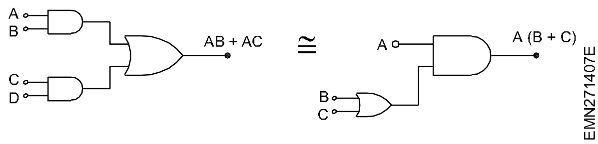
Fig 6



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 7.

The distributive law also express the process of factoring in which the common variable 'A' is factored out of the product terms.

Fig 7



Ex: AB + AC = A(B+C)

Boolean Algebra Rules

1 $A + 0 = A$

2 $A + 1 = 1$

3 $A + A = A$

4 $A + \overline{A} = 1$

5 $A + AB = A$

6 $A + \overline{A}B = A + B$

7 $A \cdot 0 = 0$

8 $A \cdot 1 = A$

9 $\overline{\overline{A}} = A$

10 $A \cdot A = A$

11 $A \cdot \overline{A} = 0$

12 $(A + B)\,(A + C) = A + BC$

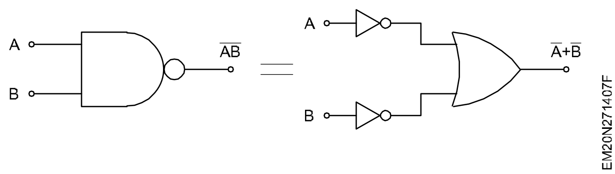
De-Morgans theorem

Theorem I

The complement of a product of variables is equal to the sum of the complements of the variables.

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 8.

Fig 8

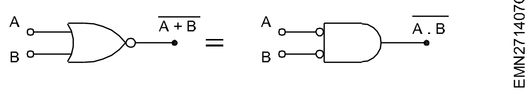


Theorem II

The complement of a sum of variables is equal to the product of the complements of the variables.

The complement of two ore more variables ORed is equivalent to the AND of the complements of the individual variables as shown in Fig 9.

Fig 9



Simplify the equation using De-Morgan's theorem

1 $\overline{(A+B+C)D} = \overline{A+B+C}\ \overline{D}$ $\quad(\overline{AB} = \overline{A}+\overline{B})$

$= \overline{A}.\overline{B}.\overline{C}.\overline{D}$ $\quad(\overline{A+B} = \overline{A}.\overline{B})$

2 $\overline{ABC+DEF} = \overline{ABC}.\overline{DEF}$ $(\overline{A+B} = \overline{A}.\overline{B})$

$= (\overline{A}+\overline{B}+\overline{C}).(\overline{D}+\overline{E}+\overline{F})$

Simplification of Boolean equations

Prove that $A+\overline{A}B = A+B$

LHS

$= A+\overline{A}B$

$= (A+AB)+\overline{A}B$

$= AA+AB+\overline{A}\cdot B$

$= AA+AB+\overline{A}B+0$

$= AA+AB+\overline{A}B+A\overline{A}$

$= A(A+B)+\overline{A}(B+A)$

$= (A+\overline{A})(A+B)$

$= 1.(A+B)$

$= A+B$

Prove that (A+B) (A+C) = A + BC

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

Since
$A = A.A;$
$A = 0$
$A+\overline{A} = 1$

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 (Distributive law)

AB + AC + B + BC   Since BB=B

AB + B + AC   (A+ A = A, A.A =A)

B(A + 1) + AC   (1+A=1)

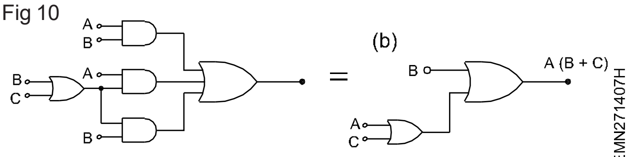
B + AC

II step write logic diagram for the equations

AB + A(B+C) + B(B+C) = B + AC

Circuit before simplification is shown in Fig 10a. Circuit after simplification is shown in Fig 10b.

Fig 10



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.

$\overline{A}BC + A\overline{B}\overline{C} + \overline{A}\overline{B}\overline{C} + A\overline{B}C + ABC$

$\overline{A}BC + \overline{B}\overline{C}(A+\overline{A}) + AC(\overline{B}+B)$

$\overline{A}BC + \overline{B}\overline{C} + AC$

$\overline{A}BC + AC + \overline{B}\overline{C}$

$C(A+\overline{A}B) + \overline{B}\overline{C}$

$C(A+B) + \overline{B}\overline{C}$

$AC + BC + \overline{B}\overline{C}$

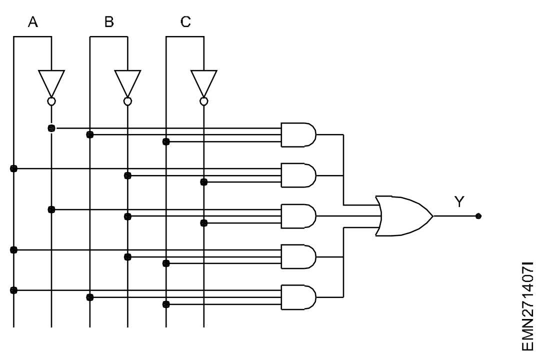
$\overline{A}BC + A\overline{B}\overline{C} + \overline{A}\overline{B}\overline{C} + A\overline{B}C = ABC = Y$

$AC + BC + \overline{B}C = Y$

$\overline{A}BC + A\overline{B}\overline{C} + \overline{A}\overline{B}\overline{C} + A\overline{B}C + ABC = Y$

Logic diagram for the given equation is shown in Fig 11.

Fig 11



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.**

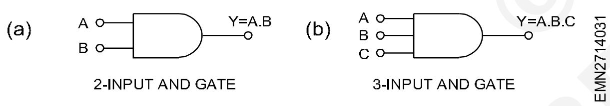
Introduction: Lagic gates are electcronic circuits used in digital circuits for the purpose of decisions. Logic circuits are basically of two types namely decision making circuits and memory circuits. Their functioning depends on the binary inputs they receive and produce binary output which are a function 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.

Fig 1



Truth table

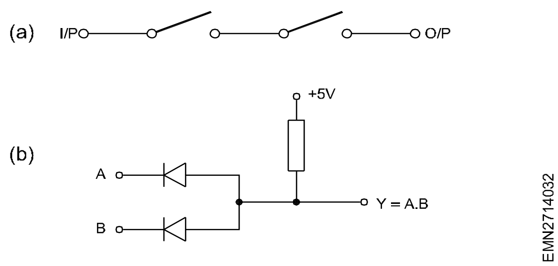
Two input AND gate

A	B	Y=A.B
0	0	0
0	1	0
1	0	0
1	1	1

Electrical equivalent circuit of an AND gate

The electrical equivalent of AND gate and AND gate using diodes are shown in Fig 2a and 2b.

Fig 2

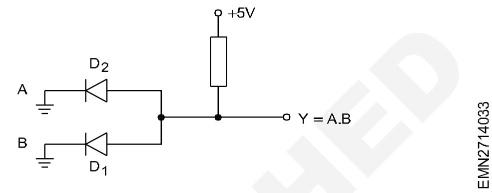


Two input AND gate using diode

Condition-1

A=0, B=0, Y=0 as shown in Fig 3.

Fig 3



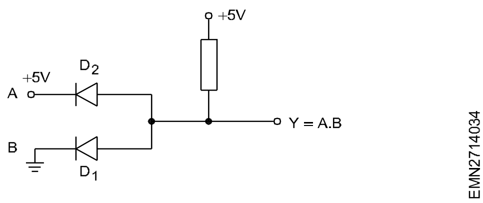
During the above condition inputs A and B are connected to ground to make logic low inputs. During this condition, both the diodes conduct, and pulls the output Y to logic0.

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_1 is conducting.

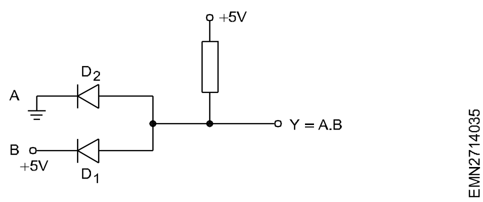
Fig 4



Condition- 3

A=1, B=0, Y=0 as shown in Fig 5.

Fig 5



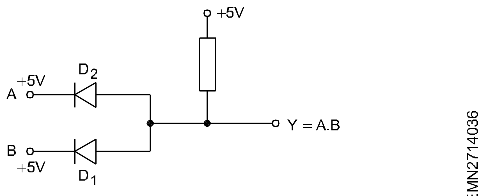
The condition-3 is similar to the condition-2. D_2 is forward biased. D_1 is reverse biased. Hence, output Y is pulled to logic-0.

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.

Fig 6



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.

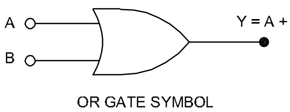
AND gates are available in the form of IC.IC7408 is a TTL type AND gate IC having 4 numbers of AND gates in side it.

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

Fig 7



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

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 descrete 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 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.

Fig 9

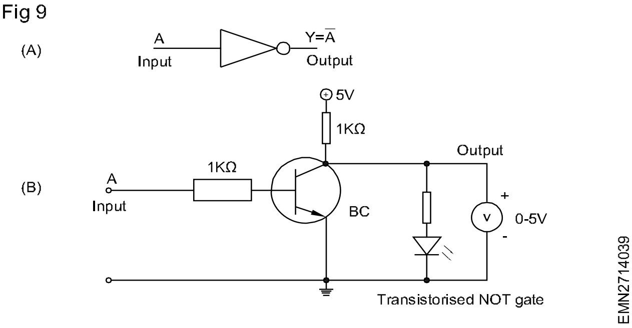
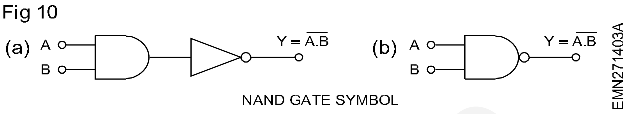


Fig 10



Truth table

A	B	Y=A.B
0	0	1
0	1	1
1	0	1
1	1	0

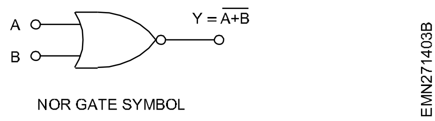
The truth table cleary shows that the NAND gate operation is the complement of the AND gate.

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 opertation 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.

Fig 11



Truth table

Input		Output
A	B	Y=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 logic1. 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

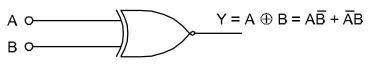
Exclusive-OR gate

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.

Fig 12



EX-OR GATE SYMBOL

The truth table of EX-OR gate is given below.

Truth Table

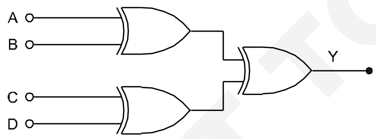
A	B	Q=A⊕B
0	0	0
0	1	1
1	0	1
1	1	0

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

Fig 13



FOUR INPUT EX-OR GATE

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 summarizes 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 contain 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

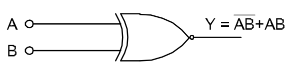
input to an Exclusive-OR gate produces a low output, while an odd parity input produce a high output.

Exclusive-NOR gate

Inputs		**Output**
A	B	Q= A + B
0	0	1
0	1	0
1	0	0
1	1	1

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.

Fig 14



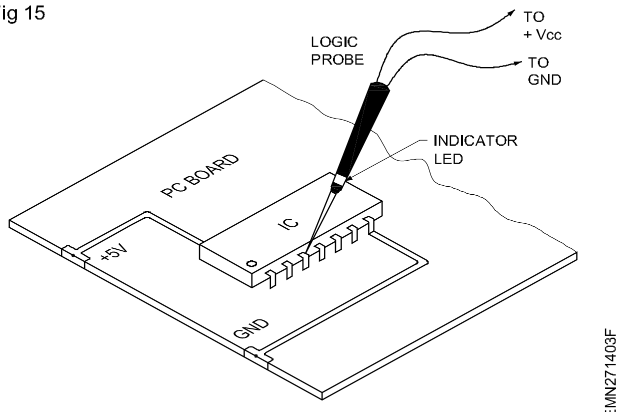
EX-NOR GATE SYMBOL

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



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).

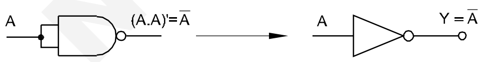
NAND gate as a universal gate: To prove that any Boolean function can be implemented using only NAND gates,we will show that the AND,OR, and NOT operations can be performed using only these gates.

NAND gate implemented as NOT gate.

In the following circuit NAND gate is used as **an inverter (NOT gate).**

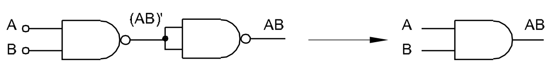
All input pins of NAND gates are connected to the input signal A gives an output A as shown in Fig 18.

Fig 18



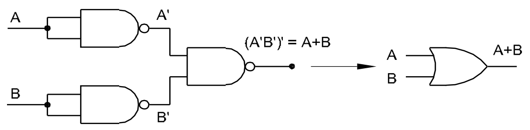
NAND gate implemented as AND gate. An AND gate can be implemented by NAND gate as shown in figure19. (The AND is replaced by a NAND gate with its output complemented by a NAND gate inverter).

Fig 19



NAND gates implemented as OR gate. An OR gate can be implemented by NAND gates as shown in figure20. (The OR gate is replaced by a NAND gate with all its inputs complemented by NAND gate inverters).

Fig 20



Thus it is proved that the NAND gate is a universal gate since it can implement the AND, OR and NOT logic functions.

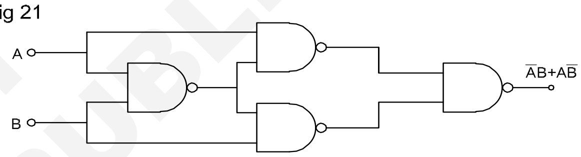
NOR gate as a universal gate. In the following paragraphs the NOR gate is used to prove that any Boolean function can be implemented only with NOR gates.NOR to replace the AND,OR and NOT operations .

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 is connected to the input signal

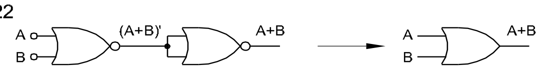
A gives an output $\overline{A}$ as shown in Fig 21.

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)

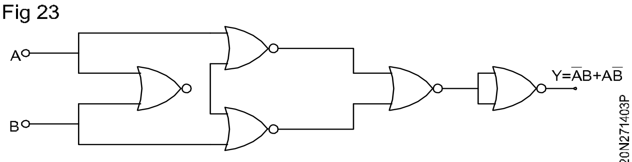
Fig 22



NOR gate implemented as AND gate

An AND gate can be implemented by NOR gates as shown in the figure 23.(The AND gate is replaced by a NOR gate with all its inputs complemented by NOR gate inverters)

Fig 23



Thus it is proved that the NOR gate is a universal gate since

Binary arithmetic

Objectives : At the end of this lesson you shalll be able to
- **define binary arithmetic**
- **perform binary addition**
- **perform binary subtraction using 1's compliment and 2's compliment**
- **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 forth 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.

$A_7A_6A_5A_4A_3A_2A_1A_0$

$B_7B_6B_5B_4B_3B_2B_1B_0$

?

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, A7 is the MSB and A0 is the LSB, similarly for the 2nd number B7 and B0 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×-2^7 (128)	= -128
1×2^6 (64)	= +64
1×2^5 (32)	= +32
1×2^3 (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 compliment is = - 23.

2's compliment 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 compliment of a binary number is found by adding ONE(1) to the LSB of the 1's compliment.

2's Compliment = (1's compliment) + 1

Example:

Find the 2's compliment of 1011011

Solution

1011011	-	Binary number
0100100	-	1's compliment
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 compliment

Example:

Express the decimal -39 as an 8 bit number in sign-magnitude using 2's compliment system.

Solution

In the 2's compliment system, -39 is produced by taking the 2's compliment of +39 (00100111) as follows.

+39	=	00100111	Binary number
		11011000	1's compliment
	+	1	
		11011001	2's compliment
-39	=	11011001	

Verification =

-2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
-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, 2^7 should be taken as -ve sign.

-128+64+16+8+1 = -128+89

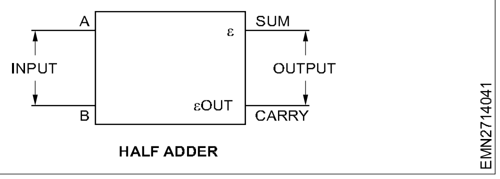
= -39

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 earlier.

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.

Fig 1



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 S=A + B	Carry C_{out} = 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_{out}) can be expressed as the AND of the input variables.

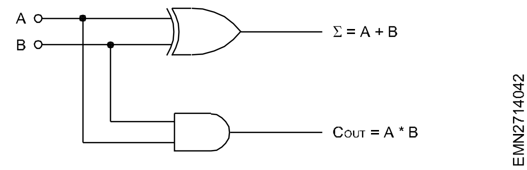
C_{out} = A.B ——> 1

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.

Sum(S) = A + B ——> 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.

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.

Fig 3

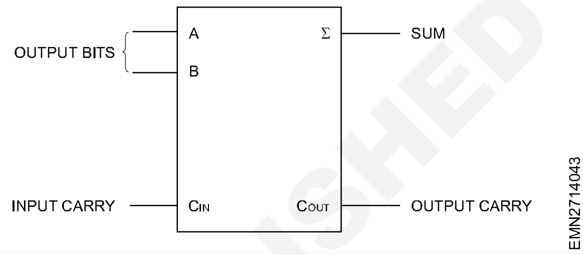


Table 2

A	B	C_{in}	Cout	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

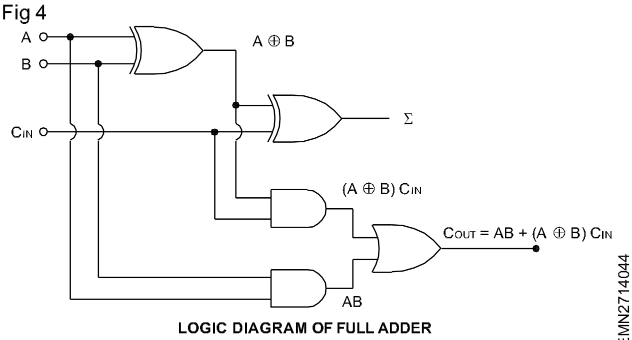
The full-adder must add the two input bits along with the input carry. From the truth-table of the half-adder we know that the sum of the input bits A and B is A + B. To get the sum output of the full adder the input carry (C_{in}) must be exclusive-ORed with A + B. Then the sum

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.

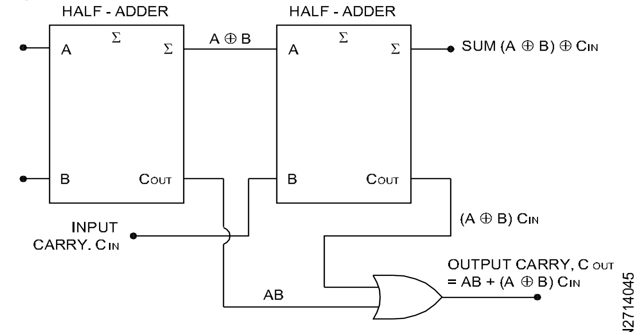
The output carry of the full-adder is therefore produced by the inputs A, ANDed with B and A + B ANDed with C_{in}. These two terms are ORed, and expressed in equation shown below and this function is implemented and combined with the sum logic to form a complete full-adder circuits, as shown in Fig 4.

Fig 4



LOGIC DIAGRAM OF FULL ADDER

Fig 5



FULL - ADDER IMPLEMENTED WITH HALF - ADDERS

2 Bit parallel adder (para)

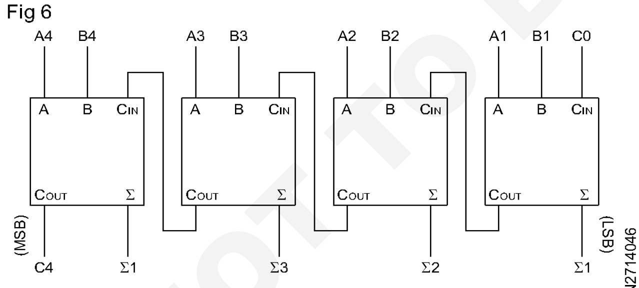
C_{out} = AB + (A + B) C_{in}

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.

Fig 6



BLOCK DIAGRAM OF 4 BIT PARALLEL ADDER

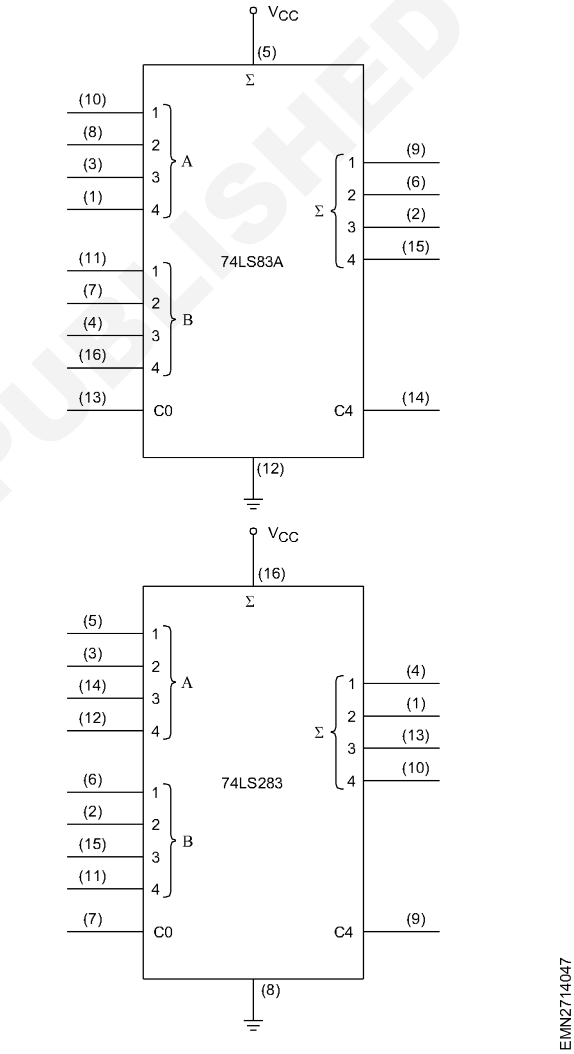
Block diagram of 4 bit parallel adder: The LSB, (A1 and B1) in each number being added into the right most full-adder; the higher order bits are applied as shown to the successively higher order adders, with MSBs (A4 and B4) in each number being applied to the left most full adder. The carry output of 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.

Fig 7



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 compliment.

Example:

The result of 2's compliment of the positive number 0110(+6) is 1's compliment of the number + 1

i.e   1001 + 1 = 1010

1010 is 2's compliment of 0110(+6), which is equal to -6 in decimal system, as shown below.

1   0   1   0

-8 + 0 + 2 + 0 = -6

Example:

Subtract 6 from 9 in 2's compliment method

9-6 = 3   normal method

9+(-6) = 3   2's compliment method

Binary form

9 = 1001 (minuend)   1001 - 0110 = 0011

6 = 0110 (subtrahend)

2's compliment method

I step: 2's compliment of subtrahend 0110 is

1's compliment of subtrahend + 1

i.e 1001 + 1 = 1010 (equal to -6 in decimal system)

II step: Add minuend with 2's compliment of subtrahend

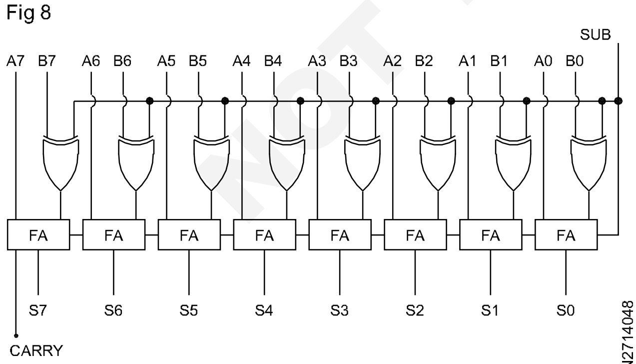
i.e 1001 + 1010 = 10011

Discard the carry 1, then the result is 0011.

Adder-Subtracter

Full adder can be used for to add or subtract binary numbers. The Fig 8 shows the how adder circuit can be used as subtractor.

Fig 8



BINARY ADDER - SUBTRACTOR

The carry out from each full adder is the carry into the next-higher full adder. The numbers being proposed are A_7....A_0 and B_7.......B_0 while the output sum is S_7......S_0. With 8 bit arthimetic, the final carry is ignored. With 16-bit arthimetic, the final carry is the carry into the addition of the upper byte.

Addition

  A_7.........A_0

+ B_7.........B_0

  S_7.........S_0

During an addition, the SUB signal is deliberately kept in the low state, therefore the binary number B_7..........B_0 passes through the controlled inverter (through Ex-OR gate) with no change. The full-adders then produce the correct output SUM.

For instance, suppose that the numbers being added are +125 and -67, then $A_{7.........A0}$ = 01111101 and B_7..........B_0 = 10111101.

Since SUB=0 during an addition, the CARRY IN to the LSB column is 0.

0   <—— Sub input

01111101   <—— Input 'A'

+ 10111101   <—— Input 'B'

100111010

During 8 bit arithmetic operation 'last carry' is ignored, therefore the answer is S_7..........S_0 = 00111010.

Subtraction

A_7..............A_0 (minuend)

(-) B_7..............B_0 (subtrahend)

S_7..............S_0

During the subtraction, the SUB signal is deliberately put into high state. Therefore the controlled inverter (Ex-OR gates) produces the 1's compliment of 'B' inputs, because the SUB is the carry IN, to the first full-adder (tied to logic-1) circuit processes the data as given.

1 <—SUB

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

S_7 S_6 S_5 S_4 S_3 S_2 S_1 S_0

When A_7...........A_0 is applied with all zeros the circuit produces the 2's compliment of B_7............B_0 because 1 is being added to the 1's compliment B_7............B_0, when

A_7...........A_0 doesn't equal zero the effect is equivalent to adding A_7..........A_0 and the 2's compliment of B_7............B_0.

Example:

(A - B)

82 - 17

A B S

= 01010010 - 00010001 = ?

The controlled inverter produces the 1's compliment of B, which is 11101110, since SUB=1 during a subtraction, the circuit performs the following condition.

1 <—— SUB

01010010 <—— A input

11101110 <—— B input

____

101000001 <—— S output

____

For 8-bit arithmetic, the final carry is ignored, therefore the answer is S_7..........S_0 = 01000001.

This answer is equivalent to decimal +65 which is the algebraic difference between the number +82 and +17.

Subtraction circuit based on 2's compliment method using Adder IC

In this circuit the Minuend is applied to the A inputs of IC 7483 and Subtrahend is fed to the B inputs, through EX-OR gates and output is taken at S outputs, as shown in Fig9.

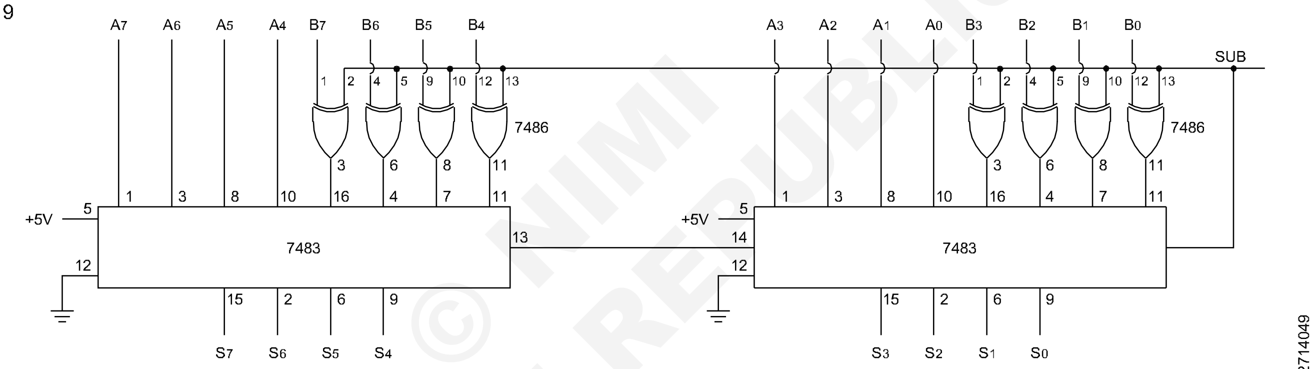
The IC 7486 is on Exclusive-OR gate used for 1's complimenting the SUBTRAHEND.

Carry input and one input from each Ex-or-gate is tied to some logic status. For addition SUB input should be logic-0, for subtraction sub input should be at logic-1 state.

Digital comparator [Magnitude comparators]

Another common and very useful combinational logic circuit is that of the **Digital Comparator** circuit.

Fig 9



TWO 7483s CAN ADD OR SUBTRACT BYTES

Digital or Binary compartors are made up from standard AND,NOR and NOT gates that compare the digital signals present at their input terminals and produce an output depending upon the condition of those inputs.

The digital comparator accomplishes this using several logic gates that operate on the principles of Boolean Algebra. There are two main types of Digital Comparator available and these are.

1. Identity comparator - an identity comparator is a digital comparator with only one output terminal for when A =B, either A=B, either A= B = 1 (HIGH) or A =B= 0 (LOW)

2.Magnitude comparator - a Magnitude comparator is a digital comparator which has three output terminals, one each for equality, A = B greater than, A > B and less than A<B

The purpose of a Digital Comparator is to compare a set of variables or unknown numbers, for example A (A1,A2,A3,.....An, etc) against that of a constant or unknown value such as B (B1,B2,B3,.....Bn, etc) and produce.

1 - bit Digital comparator circuit

The operation of a 1- bit digital comparator is shown in the the below truth table.

Digital Comparator Truth Table

Inputs		Outputs		
B	A	A>B	A=B	A<B
0	0	0	1	0
0	1	1	0	0
1	0	0	0	1
1	1	0	1	0

In the circuit does not distinguish between either two "0" or two "1" 's as an output A=B is produced when they are both equal, either A = B= "0" or A = B= "1". the output condition for A=B resembles that of a commonly available logic gate, the Exclusive -NOR or Ex - NOR function (equivalence) on each of the n-bits giving : Q =A + B

Digital comparators actually use Exclusive - NOR gates within their design for comparing their respective pairs of bits. When we are comparing two binary or BCD values or variables against each other, we are comparing the "Magnitude" of these values, a logic "0" against a logic "1" which is where the term Magnitude Comparator comes from.

As well as comparing individual bits, we can design larger bit comparators by cascading together of these and produce a n - bit comparator just as we did for the n-bit adder in the previous tutorial. Multi - bit comparators can be constructed to compare whole binary or BCD words to produce an output if one word is larger, equal to or less than the other.

A very good example of this is the 4- bit Magnitude Comparator. Here, two 4 - bit words ("nibbles") are compared to each other to produce the relevant output with one word connected to inputs A and the other to be compared.

4 - bit Magnitude comparator

Some commercially available digital comparators such as the TTL 74LS85 or CMOS 4063 4 - bit magnitude comparator have additional input terminals that allow more individual comparators to be "cascaded" together to compare words larger than 4 - bits with magnitude comparators of "n" - bits being produced. These cascading inputs are connected directly to the corresponding outputs of the previous comparator as shown to compare 8,16 or even 32-bit words.

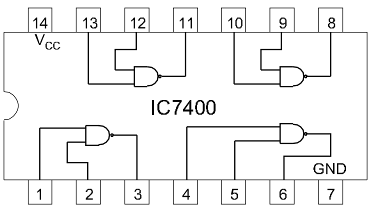
8 - bit word comparator

When comparing large binary or BCD numbers like the example above, to save time the comparator starts by comparing the highest - order bit (MSB) first. If equality exists, A = B then it compares the next lowest bit and so on until it reaches the lowest - order bit, (LSB).If equality still exists then the two numbers are defines as being equal.

If inequality is found, either A> B or A<B the relationship between the two numbers is determined and the comparison between any additional lower order bits stops. Digital Comparator are used widely in Anlogue - to - Digital converters, (ADC) and Arithmetic Logic Units, (ALU) to perform a variety of arithmetic operations.

PIN DIAGRAM OF LOGIC ICs

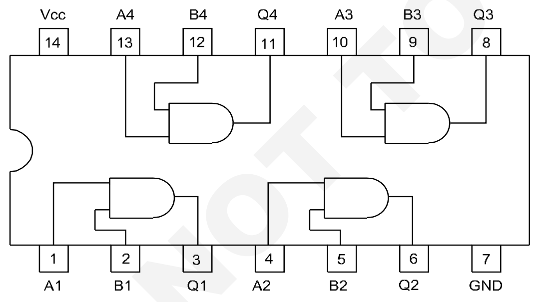
Fig 10



PINOUT DIAGRAM OF IC7400

EMN271404A

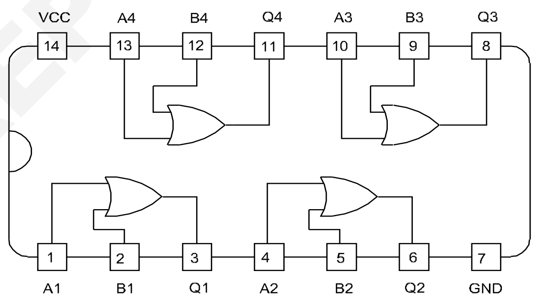
Fig 11



AND GATE IC 7408

EMN271404B

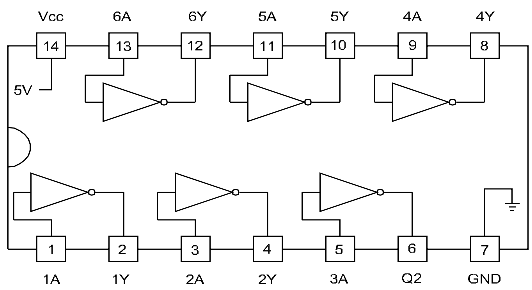
Fig 12



OR GATE IC 7432

EMN271404C

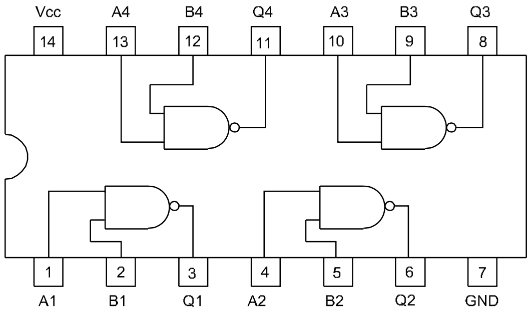
Fig 13



NOT GATE IC 7404

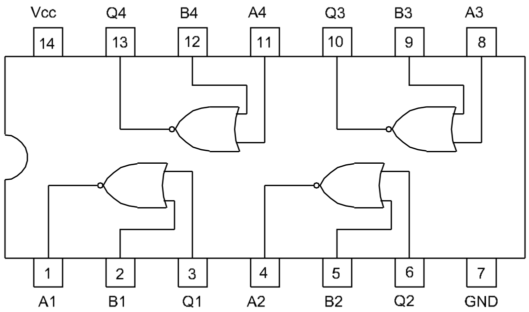
EMN271404D

Fig 14



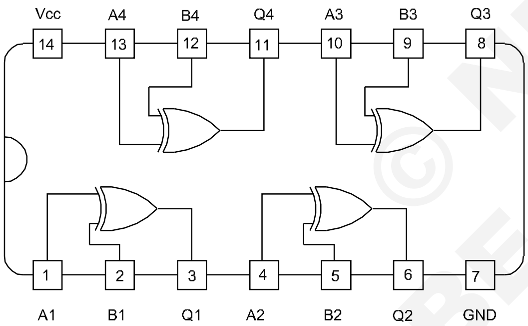
NAND GATE IC 7400

Fig 15



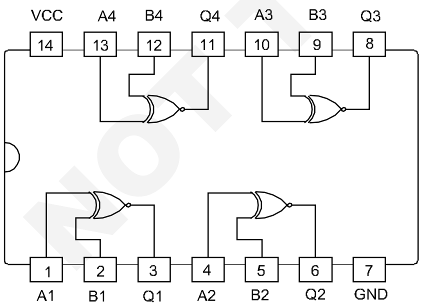
NOR GATE IC 7402

Fig 16



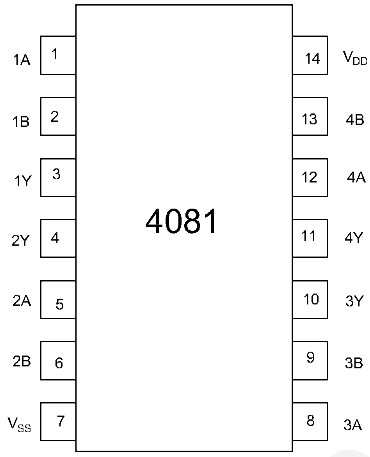
EX-OR GATE IC 7486

Fig 17



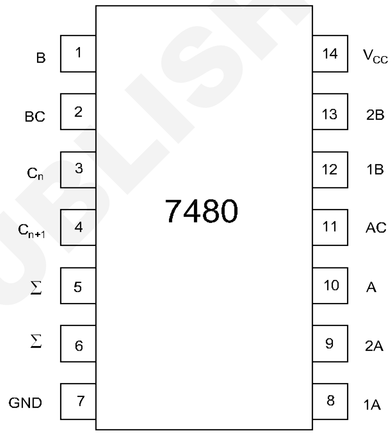
EX-NOR GATE IC 74266

Fig 18



HALF ADDER IC 4081

Fig 19



FULL ADDER IC7480

Concept of encoder and decoder

Objectives : At the end of this lesson you shall be able to
- **concept of encoder and decoder**
- **explain 2 to 4 binary decoder its working**
- **explain 4 to 2 binary encoder and its working.**

Concept of encoder and decoder

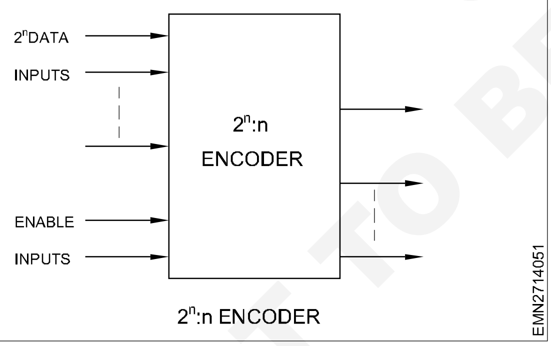
The encoders and decoders play an essential role in digital electronics.

- Encoders & decoders are used to convert data from one from to another form.
- These are frequently used in communication system such as telecommunication, networking, etc... to transfer data from one end to the other end.
- Similarly, in the digital domain, for easy transmission of data, it is often encrypted or placed within codes, and then transmitted. At the receiver, the coded data is decrypted or gathered from the code and is processed in order to be displayed or given to the load accordingly.

Binary Encoder

A binary encoder is shown in Fig 1. It has 2^n input lines and n output lines, hence it encodes the information from 2^n inputs into an n- bit code. From all the input lines, only one of an input line is activated at a time, and depending on the input line, it produces the n bit output code.

Fig 1



2^n:n ENCODER

The figure below shows the block diagram of binary encoder which consists of 2^n input lines and n output lines. It translates decimal number to binary number.

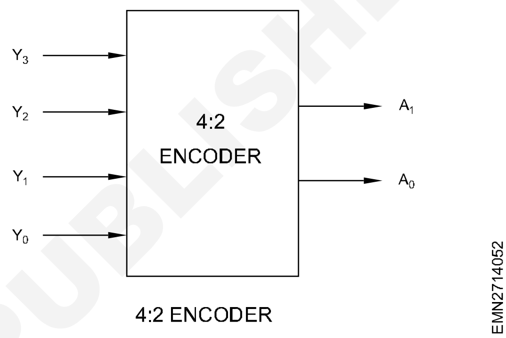
The output lines of an encoder correspond to either true binary equivalent or in BCD coded form of the binary for the input value. Some of these binary encoders include decimal to binary encoders, decimal to octal, to binary encoders, decimal to BCD encoders, ect.

Depending on the number of input lines, digital or binary encoders produce the output codes in the form of 2 or 3 or 4 bit codes.

4 - to - 2 Bit Binary Encoder

The block diagram and truth table of a 4 input encoder is shown in Fig 2. The truth table consists of four rows, since, it is assumed that only one input is the value of 1 then the corresponding binary code associated with that enabled input is displayed at the outputs.

Fig 2



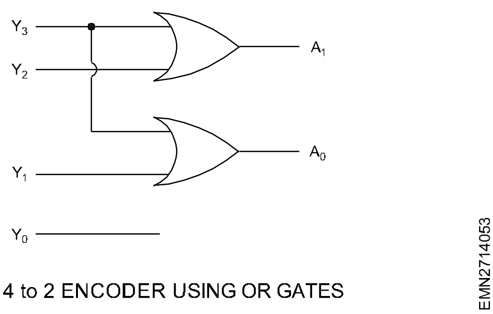
4:2 ENCODER

The output Y_0 is 1 when either input Y_1 or Y_3 is 1, also the output Y_1 is set to 1 when either input Y_2 or Y_3 is 1.

Y_3	Y_2	Y_1	Y_0	A_1	A_0
0	0	0	1	0	0
0	0	1	0	0	1
0	1	0	0	1	0
1	0	0	0	1	1

The output from 4-to-2 encoder is generated by the logic circuit implemented by a set of OR gates as shown in Fig 3. In the figure a, the output of the encoder is same if input activated is the Io input (Io =1) or if no input is activated i.e. all the inputs are zero.

Fig 3



4 to 2 ENCODER USING OR GATES

This causes ambiguity in the encoding output. To avoid this ambiguity, a valid encode output can be added as an additional output assumes a value 1 when Io is equal to 1.

Decimal to BCD Encoder

This type of encoder usually consists of ten input lines and 4 output lines, Each input line corresponds to the each decimal digit and 4 outputs correspond to the BCD code.

This encoder accepts the decoded decimal data as an input and encodes it to the BCD output which is available on the output lines.

The figure below shows the basic logic symbol of decimal to BCD encoder along with its truth table. The truth table represents the BCD code for each decimal digit.

From this we can formulate the relationship between the BCD bit and decimal digit. It is important to note that there is no explicit input line for decimal zero. When this condition occurs, i.e. decimal inputs 1 to 9 all are zero. than the BCD output is 0000.

Binary Decoder

The **Binary Decoder** is another combinational logic circuit constructed from individual logic gates and is the exact opposite to that of an Encoder

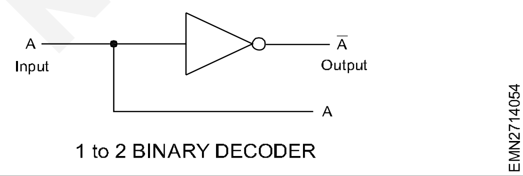
The name "Decoder" means to translate or decode coded information from one format into another, so a digital decoder transforms a set of digital input signals into an equivalent decimal code at its output.

Binary Decoders are another type of digital logic device tha t has inputs of 2 - bit or 3- bit or 4-bit codes depending upon the number of data input lines, so a decoder that has a set of two or more bits will be defined as having an n - bit code, and therefore it will be possible to represent 2^n possible values. Thus, decoder generally decodes a binary value into a non - binary one by setting exactly one of its n outputs to logic "1".

If a binary decoder receives n inputs (usually grouped as a single Binary or boolean number) it activates one and only of its 2^n outputs based on that input with all other outputs deactivated.

So for example, an inverter (NOT - gate) can be classed as a 1- to -2 binary decoder as 1 - input and 2- output (2^1) is possible because with an input A it can produce two outputs A and (not - A) as shown in Fig 4.

Fig 4



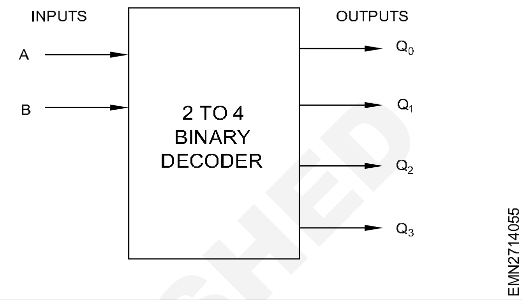
1 to 2 BINARY DECODER

Then we can say that a standard combinational logic decoder is an **n- to - m** decoder, when $m \le 2^n$, and whose output , Q is dependent only on its current inputs, determines which binary code or binary number is corresponds to that binary input.

A Binary Decoder converts coded inputs into coded outputs, where the input and output codes are different and decoders are available to "decode" either a binary or BCD (8421 code) input pattern to typically a decimal output code. Commonly available BCD - to - Decimal decoders include the TTL 7442 or the CMOS 4028. generally a decoders output decoder" circuits include, 2- to- 4, 3- to - 8 and 4- to -16 line configurations.

An example of a 2- to -4 line decorder along with its truth table is shown in Fig 5a and 5b.

Fig 5



A2-to-4 Binary Decoder

(b) A	B	Q_0	Q_1	Q_2	Q_3
0	0	**1**	0	0	0
0	1	0	**1**	0	1
1	0	0	0	**1**	0
1	1	0	0	0	**1**

This simple example above of a 2- to-4 line binary decoder consists of an array of four AND gates. The 2 binary inputs labelled A and b are decoded into one of 4 outputs, hence the description of 2- to -4 binary decoder.

This simple example above of a 2- to-4 line binary decoder consists of an array of four AND gates. The 2 binary inputs labelled A and b are decoded into one of 4 outputs, hence the description of 2- to -4 binary decoder. Each output represents one of the miniterms of the miniterms of the 2 input variables, (each output = a miniterm).

The binary inputs A and B determine which output line from Q0 to Q3 is "HIGH" at logic level "1" while the remaining outputs are held "LOW" at logic "0" so only one output can be active (HIGH) at one time. Therefore, whichever output line is "HIGH" identifies the binary code present at the input, in other words it "de - codes" the binary input.

Some binary decoders have an additional input pin labelled "Enable" that controls the outputs from the device. This extra allows the decoders outputs to be turned "ON" or " "OFF" as required. These types of binary decoders are commonly used as "memory address decoders" in microprocessor memory applications.

The binary decoder is a de multiplexer with an additional data line that is used to enable the decoder. An alternative way of looking at the decoder circuit is to regard inputs A,B and C as address signals. Each combination of A,B or C defines a unique memory address.

A 2-to-4 line binary decoder (TTL 74155)can be used for decoding any 2-bit binary code to provide four outputs, one for each possible input combination. However, sometimes it is required to have a Binary Decoder with a number of outputs greater than is available, so by adding more inputs, the decoder can potenially provide 2^n more outputs as show in Fig 6.

So for example, a decoder with 3 binary inputs (n=3), would produce a 3-to- 8 line decoder (TTL 74138) and 4 inputs (n = 4) would produce a 4-to-16 line decoder (TTL 74154) and so on. But a decoder can also have less than 2^n outputs such as the BCD to seven segment decoder (TTL 7447) which has 4 inputs and only 7 active outputs to drive a display rather than the full 16 (2^n) outputs as you would expect.

Here a much larger 4 (3 data plus 1 enable) to 16 line binary decoder has been implemented using two smaller 3-to-8 decoders.

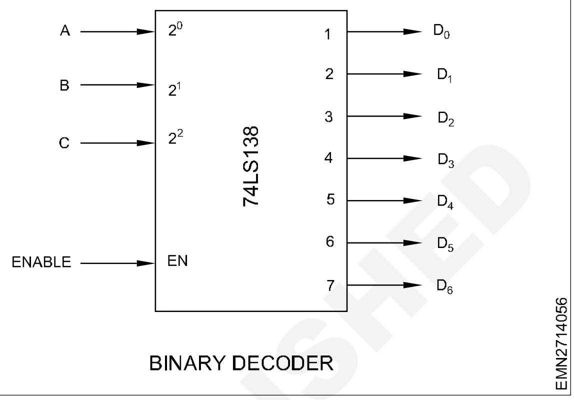
An encoder is device which converts familiar numbers or characters or symbols into a coded format. it accepts the alphabetic characters and decimal numbers as inputs and produces the outputs as a coded representation of the inputs.

It encodes the given information into a more compact form. In other words,it is a combinational circuit that performs the opposite function of a decoder.

These are mainly used to reduce the number of bits needed to represent given information. In digital systems, encoders are used for transmitting the information. Thus the transmission link uses fewer lines to transmit the encoded information.

In addition, these encoders are used for encoding the data which is to stored for later use as it facilitates fewer bits storing over the available space.

Fig 6



BINARY DECODER

Multiplexers & Demultiplexers

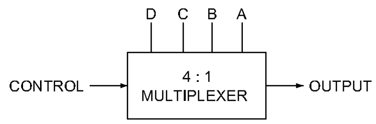
Objectives : At the end of this lesson you shalll be able to
- **state the need of multiplexers and demultiplexers in digital circuits**
- **explain the application of a multiplexer & demultiplexer in data transmission.**

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.

Fig 1



EMN2714061

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.

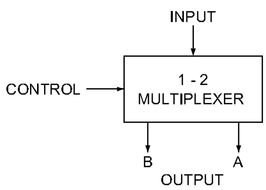
Truth Table

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 demultilexer at Fig 2 is given in Table 2.

Fig 2



EMN2714062

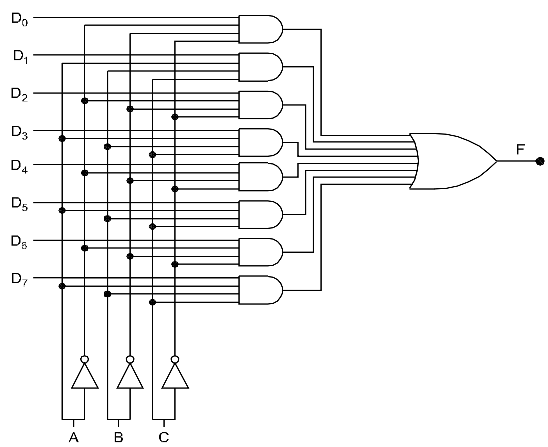
Table 2

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.

Fig 3



AN EIGHT DIGIT MULTIPLEXER CIRCUIT

EMN2714063

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.

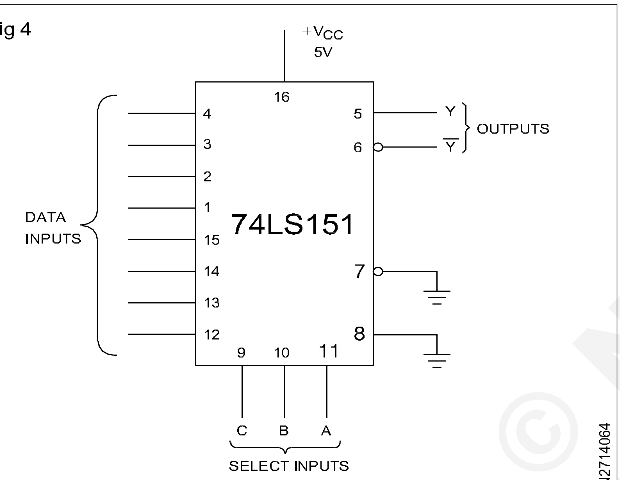
Demultiplexer: The inverse of a multiplexer is a demultiplexer. A demultiplexer routes its single input signal to one of 2n outputs, depending on the values of the n control lines. For instance, if the binary value on the control signal is all zeros, the 0th output line is selected and if the binary 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.

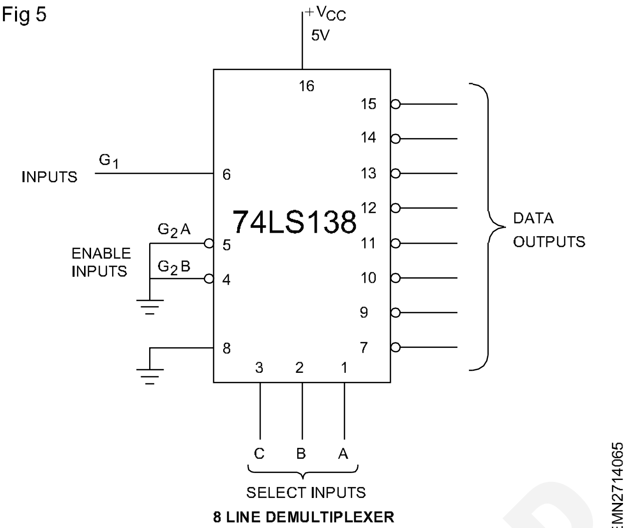
In Fig 6, the eight inputs could be eight signals coming from different transducers measuring eight different type of data (say, temperature, pressure,...) in a industrial environment. At the other end the output of the demultiplexer may be fed to eight different measuring instruments meant for measuring the individual parameters.

Fig 4



8 LINE MULTIPLEXER

Fig 5

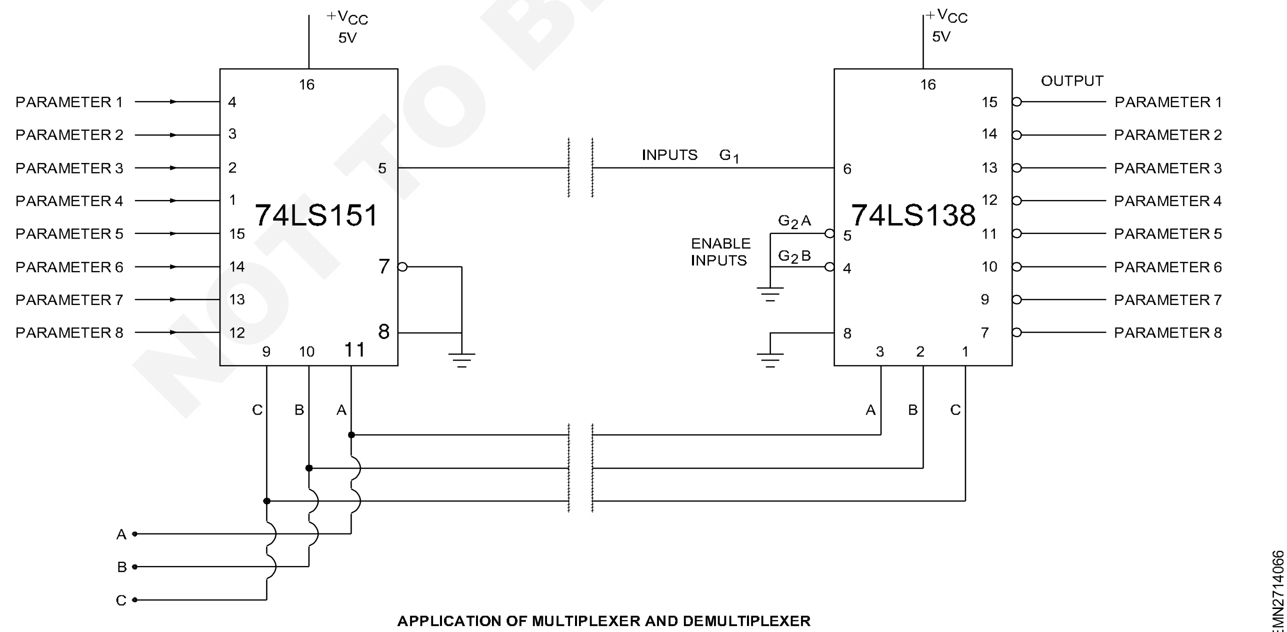


8 LINE DEMULTIPLEXER

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 demultiplxer 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.

Fig 6



APPLICATION OF MULTIPLEXER AND DEMULTIPLEXER

Latch circuits and applications

Objectives: At the end of this lesson you shall be able to
- **explain NOR latch and NAND latch using discrete gates**
- **state the concepts of clocked flip flops**
- **discuss the effect of bouncing and debounce circuits**
- **explain D flip-flop and its truth table**
- **explain clocked D flip-flop and its truth table**
- **discuss the difference between edge triggering and level triggering and types of edge trigger**
- **write logic diagram for the given Boolean equations**
- **simplify the logic diagram using Boolean algebra.**

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 $\overline{Q}$. 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.

Fig 1

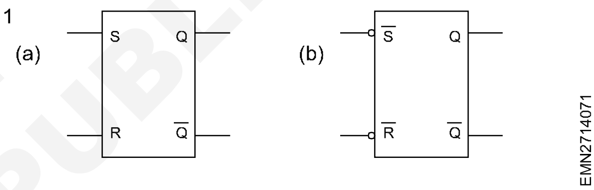


Fig 2

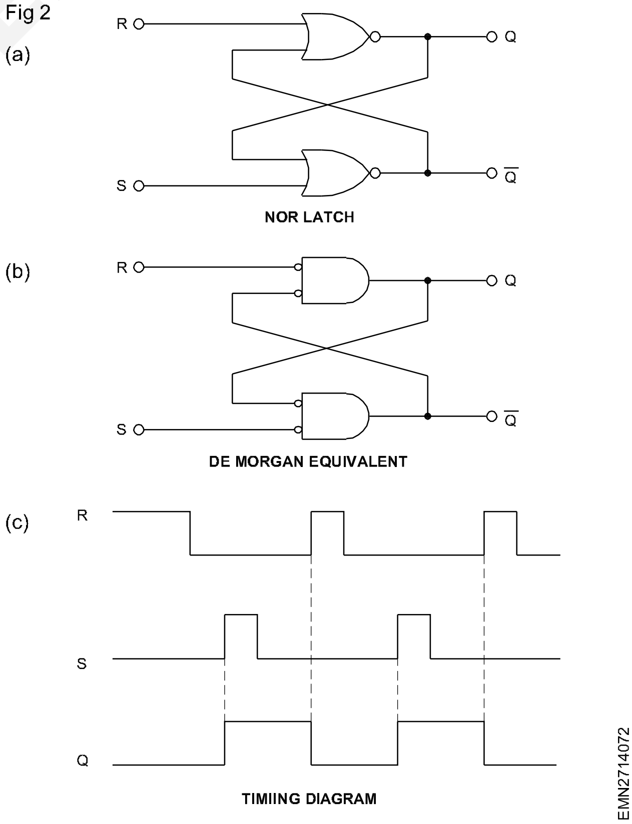
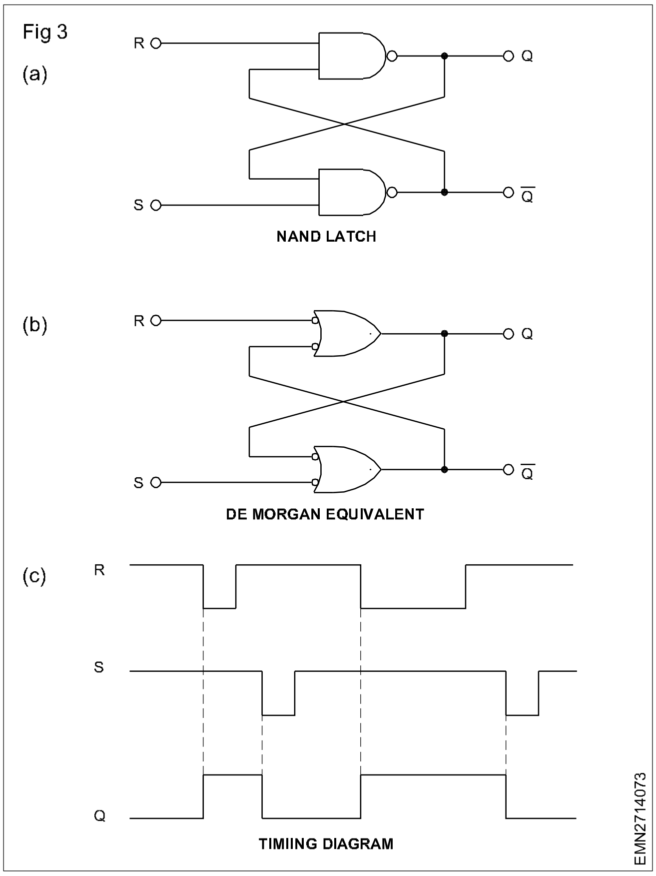


Fig 3



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 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.

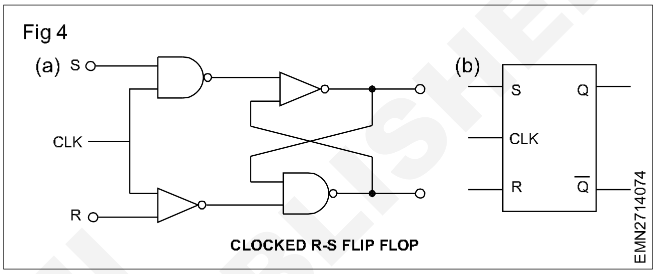
Condition 4

R=1, S=1. This condition is the normal resting state and it has no effect on the output state. The Q and 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.

Fig 4



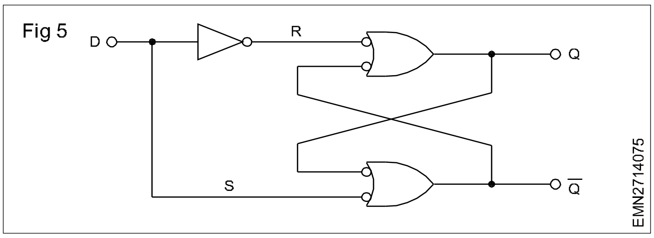
Truth Table

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	race condition

For the flip-flop to operate properly there must be a transition form 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

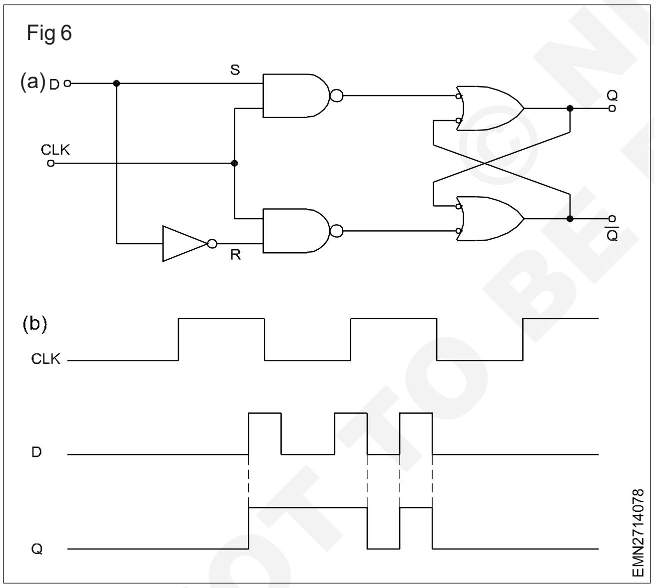
D	Q
0	0
1	1

Clock D latch

CLK	D	Q
0	X	NC
1	0	0
1	1	1

Clocked D-flip-flop

The Fig 6a 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.



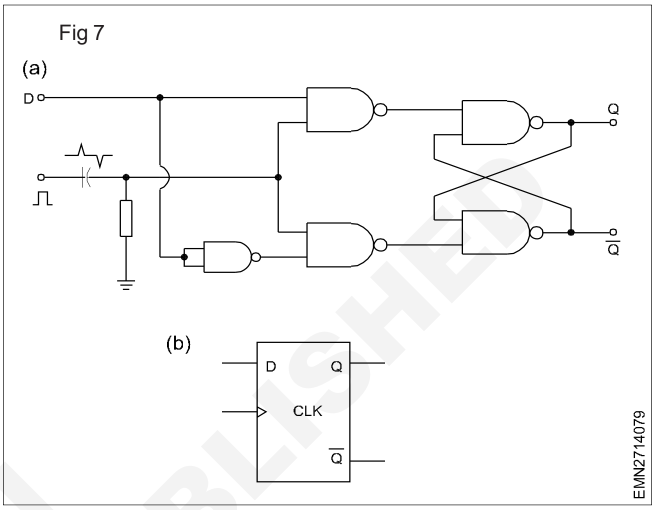
Truth table for level clocked D flip flop

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 7b.



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

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.**

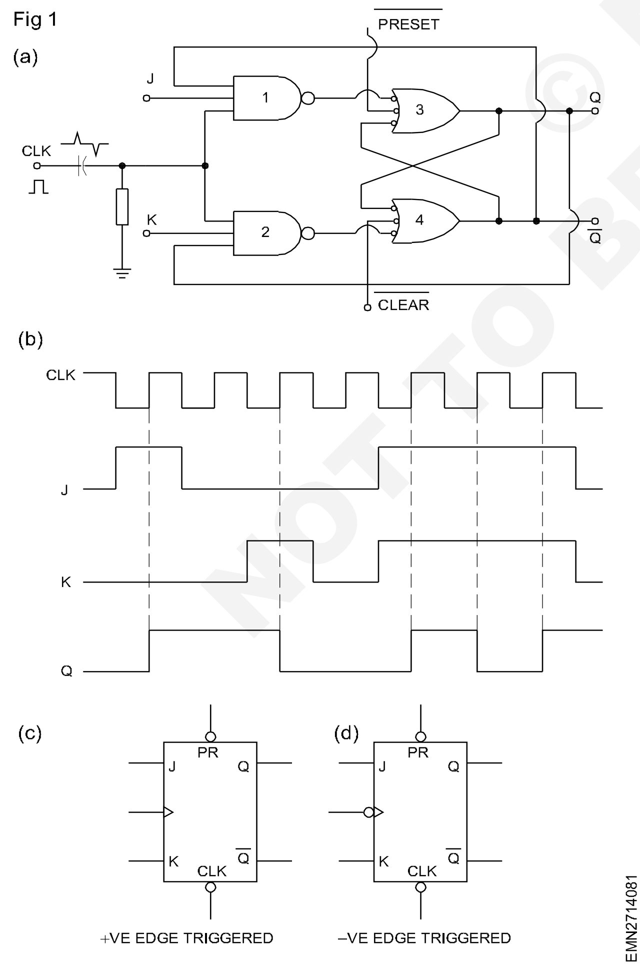
Truth table

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.

Operation of J-K flip flop

Fig 1



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 Operation of J-K 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

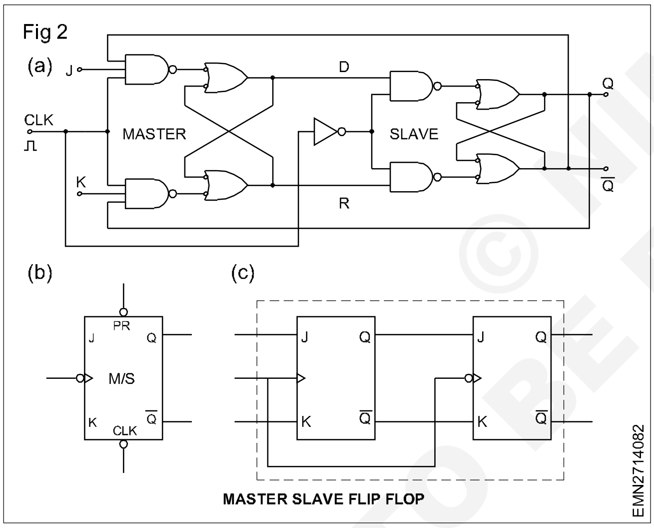
When power is first applied, flip-flops come up in random states. To get some computers started, an operator has to push a master reset button, this sends a clear (reset) signal to all flip-flops, normally clear signal will be active low, (i.e) logic zero should be applied for clear the output. When clear is applied to gate-4 as shown in Fig 1a then the Q will be forced to Logic-0, then automatically 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 LOWCLR 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

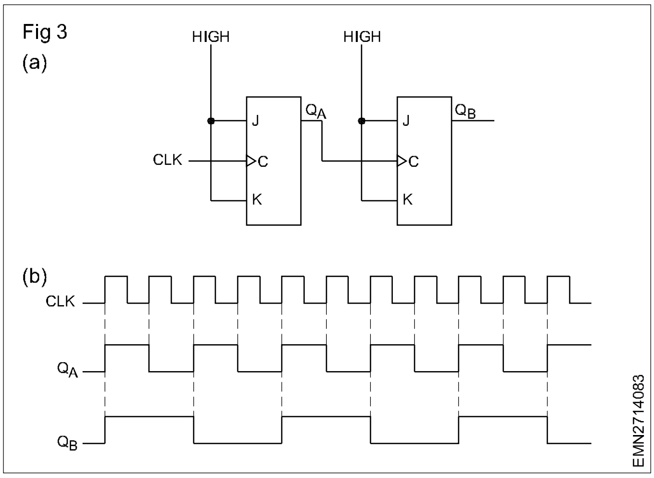
Low J & Low K produces an inactive state regardless of the what the clock is doing. If K goes high by itself, the next clock pulse resets the flip-flop. If J goes high by itself, the next clock pulse sets the flip-flop when J & K are both high, each clock pulse toggle the state of flip flop.

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.



Electronic Simulation Software

Objectives : At the end of this lesson you shall be able to
- **define electronic simulation software**
- **build a circuit with simulation software**
- **virtual instrumentation testing.**

Electronic Simulation Software

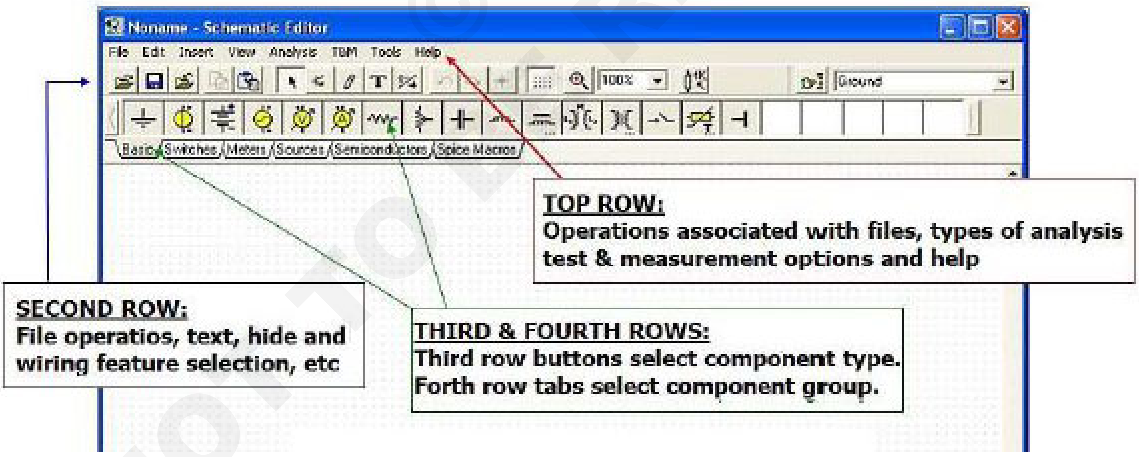
Introduction :

- Electronic Circuit simulation is a preparatory software tool designed to create, test and analyse various analog and digital circuits.
- Simulation software allows for modelling of simple to complex circuit operation and is an invaluable analysis tool.
- Electronics simulation software engages the user by integrating them into the learning experience.
- A great collection of most of the electronic components such as passive to active devices are used for circuit drawing, circuit design and analysis.
- There are several free version of electronic circuit simulation softwares available in internet. Also tutorial video guides the user to make use of the application of these simulation softwares.

Free and open source circuit simulation software:

- The list of well - structured free circuit simulation software's window based simulator are given below:
  - NgSpice
  - MultiSim
  - QUCS
  - MacSpice
  - Xspice
  - LTSpice
  - PECS
  - TINA-TI
  - Circuit Logix ,etc.
- In the following paragraphs how one of the free version of electronic circuit simulation software can be installed into the computer system after downloaded from the internet and made use of this application software tool for creating, testing virtually using electronic testing & measuring instruments are explained in a step by step manner.
- TINA - TI is a powerful circuit design and simulation tool. IT is ideal for designing,testing,and troubleshooting a broad variety of basic and advanced electronic circuits.
- The tool is ideal for helping designers and engineers to develop and test circuit ideas.
- It is a software program developed by both **Texas Instruments** and **DesignSoft,Inc.**

Fig 1



The schematic editor window

Requirement of PC Configuration:

- The minimum hardware and software requirements for the currently released TINA-TI version are :

i IBM PC - compatible computer running Microsoft windows 98/ME/NT/2000/XP

ii Pentium or equivalent processor

iii 64MB of RAM

iv Hard disk drive with at least 100MB free space

v Mouse

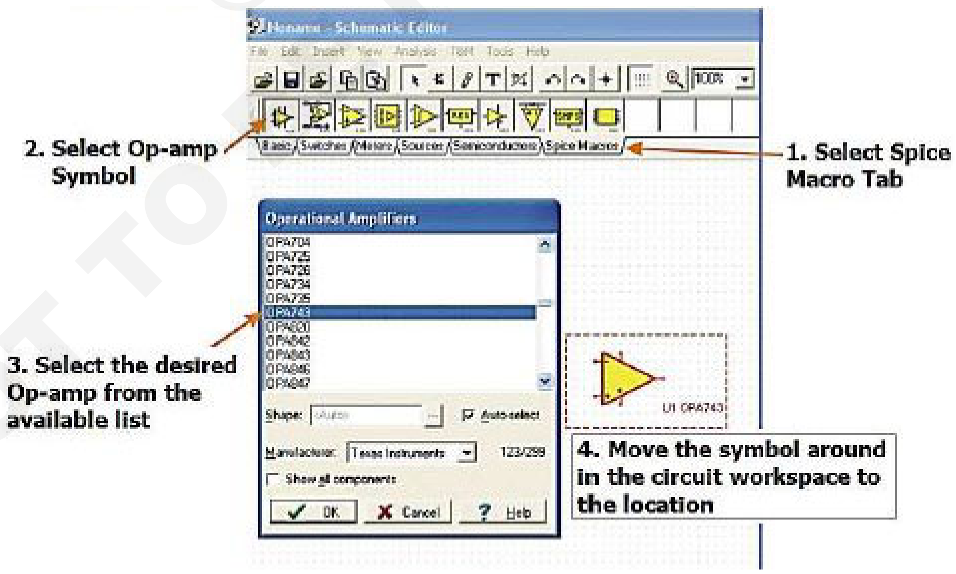
vi VGA adapter card and monitor

- Once the free version of software is downloaded to the system, we can select the program through the windows start menu or by clicking the simulation software Icon on the desktop that was created during the installation.
- The first screen appears as shown in figure 1 is the schematic editor layout.
- The empty workspace on the sheet is the design window where the test circuit is to be created.
- Below the schematic Editor title bar is an operational menu row with selections such as file operations, analytical operations, test and measurement equipment selection, etc.
- Located just below the menu row is a row of icons associated with different file and TINA tasks.
- The final row of icons allows selecting a specific component group. These component groups contain basic passive components, semiconductors, and even sophisticated device macro models. These groups are accessed to build the circuit schematic.

Building a circuit using the electronic circuit simulator:

- For building a circuit using simulator, select the required active and passive components and arrange the components and wire the components as per the circuit diagram.
- A search through a circuit application handbook provides a number of op- amp based designs. A texas instruments 'OPA743 12V CMOS Op- amp is selected for the circuit application.
- This amplifier is well - suited for this design, and provides very good DC and AC performance.
- It operates with supplies of 3.5V to 12V; our example requires 5V (10V).
- The step- by- step procedure is as follows:
- Select the spice macros tab and then the op-amp symbol to access the OPA743 macro model. When the Op-amp model list appears, scroll down and click on the OPA743
- Then click OK. The op-amp symbol appears in the circuit workspace. With the mouse clicked drag the symbol into position on the workspace as shown in Fig 2.
- It is locked into position on the circuit workspace by clicking the left mouse button.

Fig 2



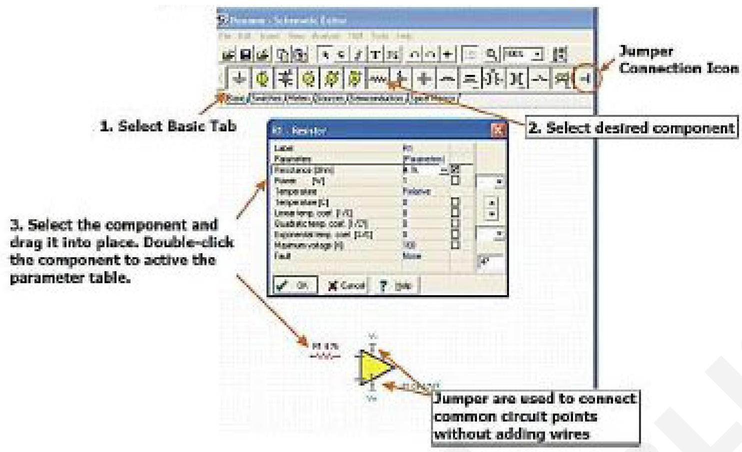
Building a circuit with Op-Amp IC

Adding passive and Active Components:

- Component selection is easily accomplished by clicking on a component group from the lower row of tabs: Basic, switches, Meters, etc.
- These tabs provide a wide variety of passive components, sources, meters, relays, semiconductors, and the previously-mentioned circuit macros.

- Click on the scematic symbol for a particular component and drag it into position in the circuit workspace.A left mouse button click lock it into place.
- In our example ,select a resistor from the basic group, and then position it next to the Op-amp symbol.
- The resistor value and other component characteristics may be altered by selecting the individual parameter boxes and changing the respective values.Select the component parameter box and highlight the value you wish to change.Use the key board,enter a new value by typing over the value that is shown in Fig 3.
- Similar parametric tables are available for passive devices, sources,semiconductors,and other component types.

Fig 3

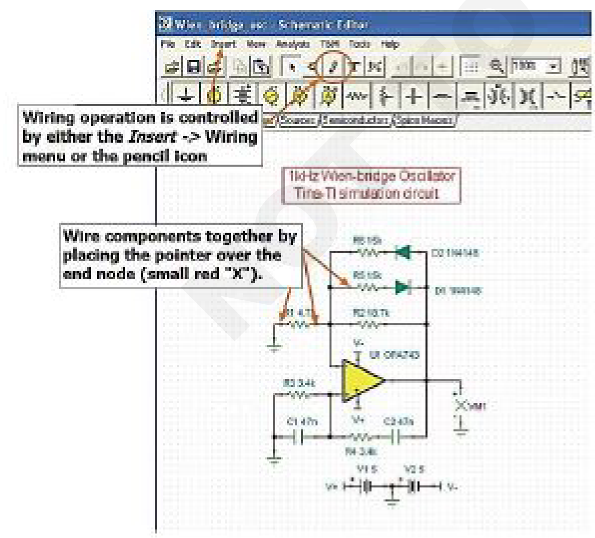


Active and passive component selection

Arranging and wiring components:

- Once all components are selected and properly positioned,they can be wired together.Each component has nodes where circuit connections are needed.
- These nodes with a small red x.(The x looks more like two small lines at the wiring node than the alpha character.)
- Wiring components to each other is easily done as shown in Fig 4 by placing the mouse pointer over a node connection and holding the left mouse button down.
- A wire is drawn as the mouse is moved along the circuit space grid.Release the mouse button when the wire reaches the intended end connection point.
- The wiring function also may be accessed from the insert menu,or the icon that looks like a small pencil.

Fig 4



Wiring components together

Analysis Capabilities:

- When the circuit schematic entry is complete, the circuit is nearly ready for simulation.The analysis process begins by selecting the Analysis menu.
- A list of different types of analysis-such as AC,DC, Transient, or Noise-appears.
- The first option under the Analysis menu is an **Error Rules Check (ERC)**.Selecting this feature runs this check on the circuit ; a pop -up window then lists any circuit errors.
- If an error is lited in the window,clicking on that error line highlights the error point in the schematic.The error window also lists types of circuit errors that are found during the analysis.
- Even if the ERC is not selected, the software automatically performs a check at the start of a simulation.
- Upon selecting one type of analysis to perform,

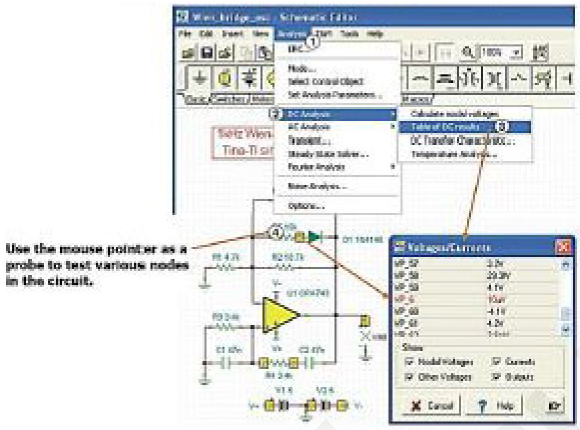
another window appears that displays different setting selections that are associated with that particular analysis.

- Nominal settings are initially provided; these parameters may be set as needed for the desired output.

DC Analysis:

- Follow these steps -(illustrated in Figure - 5) to perform a DC analysis.
  - Click on the Analysis menu.
  - Select DC Analysis.
  - Click on Table of DC Results. The Voltages/Currents table appears.
  - Use the mouse pointer as a probe to test the circuit nodes.
- The probed node and measured value are displayed in red in the Voltages/Currents table, as shown in Figure -5.

Fig 5

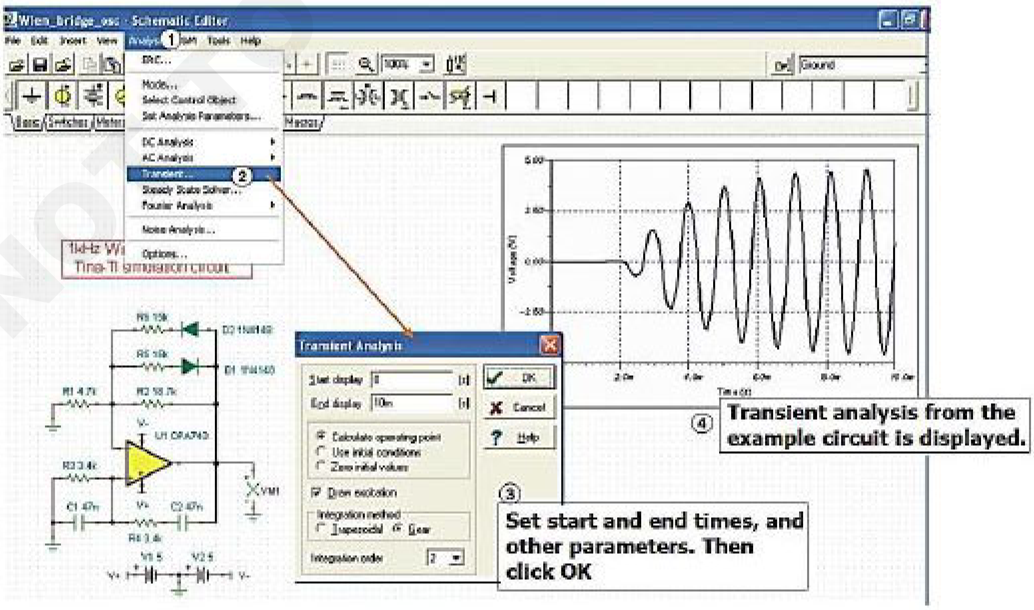


DC Analysis with Voltages/current table

Transient Analysis:

- The transient analysis performed on the example Wien-bridge oscillator circuit is shown in Fig 6.
- It illustrates the Wien-bridge oscillator strat-up and steady-state performance.
- The display in the actual window may be edited with axis labelling, scales, background grid colour, and act, all set as desired by the individual user.
- Follow these steps (marked in Figure 6) to perform a transient analysis.
- Click on the analysis menu.
- Select Transient.
- The Transient Analysis dialog box appears.Enter start and end times, and other parameters as desired.
- Click OK to run the analysis.

Fig 6

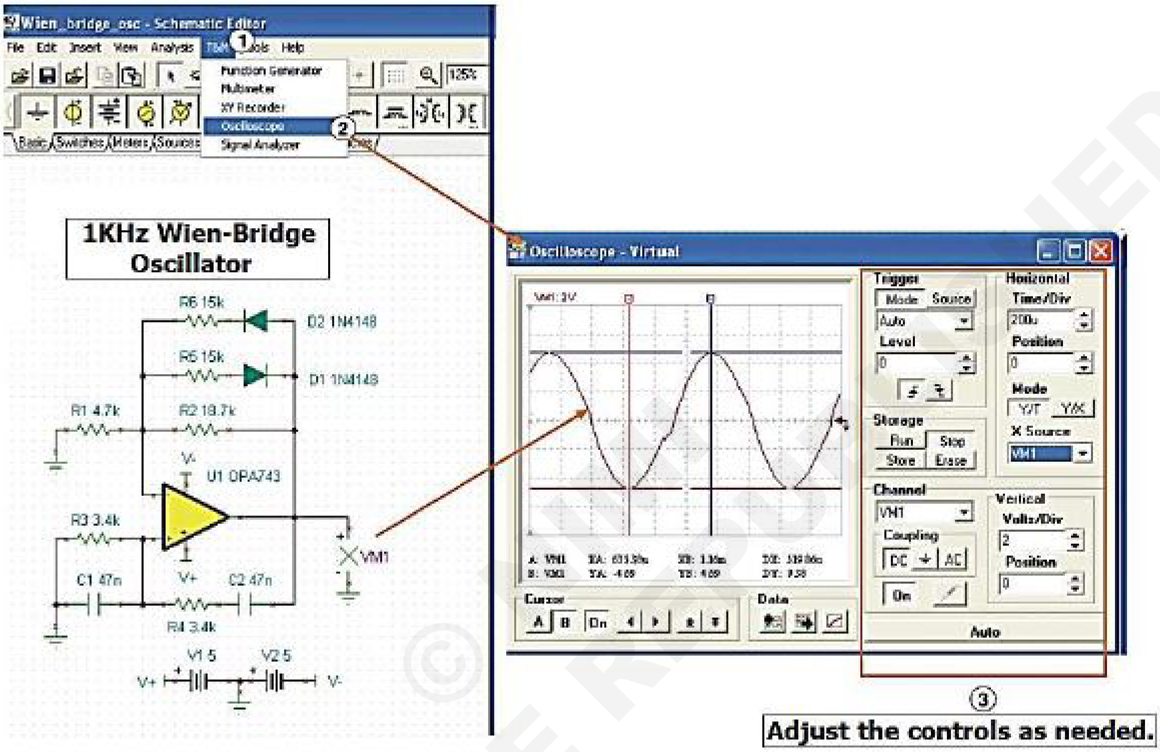


Transient analysis on wein-bridge oscillator

Test and Measurement:

- The Simulation software generates post-simulation result in tables and plots,depending on the type of analysis performed.
- A virtual oscilloscope as shown in Fig 7 is used to observe the steady - state output of the Wien-bridge oscillator circuit. In the same way, a virtual signal analyzer can also be used together with an amplifier circuit so that the harmonic performance of a simulation can be observed.
- To access the virtual oscillosocope, select T&M (step 1 in Figure), and then osilloscope (step 2).Place the cursor at the output of the simulated circuit, and adjust the controls in the virtual oscilloscope dialog box as needed.
- The T&M selection options also include a virtual AC/DC multi-meter, function generator, and an X-Y recorder.
- The function generator may be adjusted in combination with a virtual oscilloscope or analyser.

Fig 7



Virtual instrumentation testing

Thus , the electronic simulation software can be effectively utilized to design,construct,test and analyse various operational parameters using the required electronic components from simple resistor to sophisticated integrated circuits available in the library of resources.After completion of constructing the circuit,required DC power supply, signal generators,digital multimeter even the oscillosope like instruments are simply clicked and connected virtually to make measurements of voltage, current or waveform observation with the ease of clicking the mouse and keyboard.

Operational amplifiers and their applications

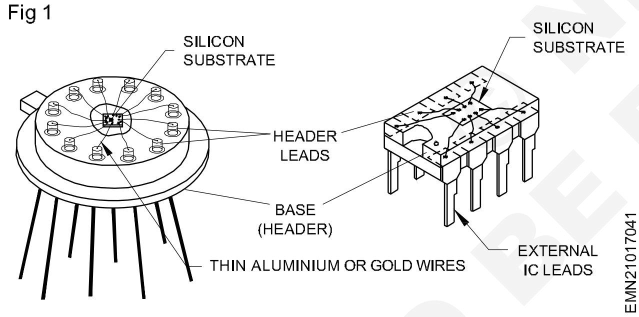
Objectives : At the end of this lesson you shall be able to
- **state the base material used in making ICs**
- **state the most important considerations in designing ICs**
- **state the meaning of operational amplifier**
- **state the two basic modes of operation of Op- Amps**
- **list ideal and typical 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.

Fig 1



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 μ 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.

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.

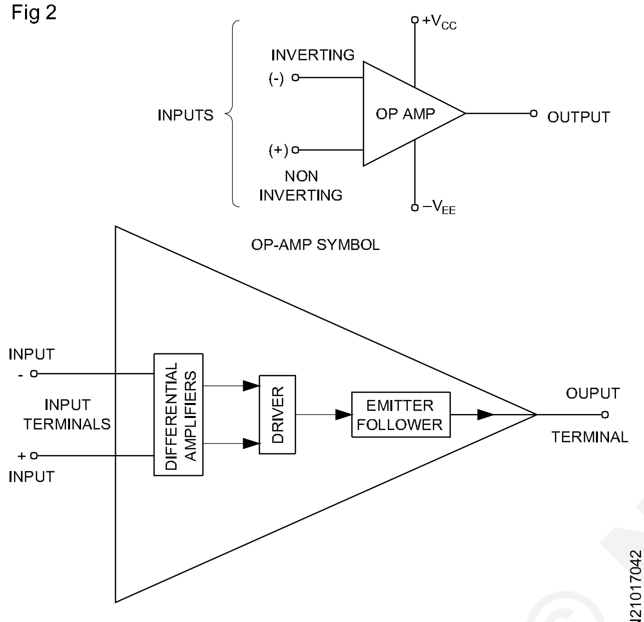
Basic linear integrated circuit-'Operational Amplifiers' (Op-Amps)

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.

Fig 2



BLOCK DIAGRAM OF CIRCUITS IN AN OPERATIONAL AMPLIFIERS

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.

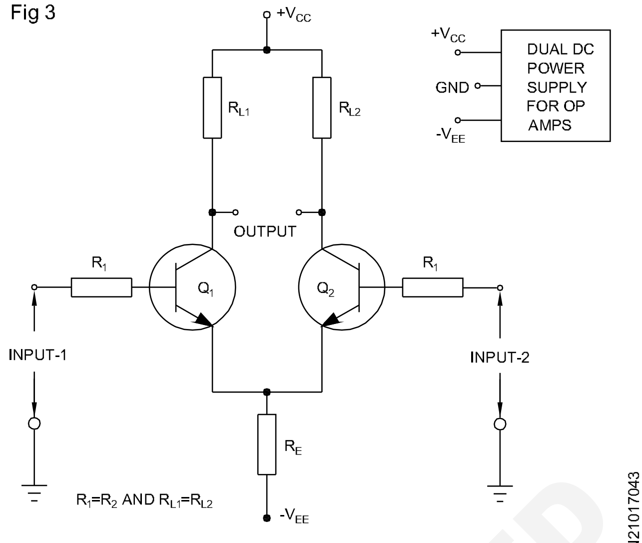
A typical differential amplifier stage is shown in Fig 3. A differential amplifier stage consists of two transistors with an input to each transistor. The output is taken between the collectors of the transistors as shown in Fig. The most important point to note is, both the transistors have identical 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.

Fig 3



DIFFERENTIAL AMPLIFIER

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,

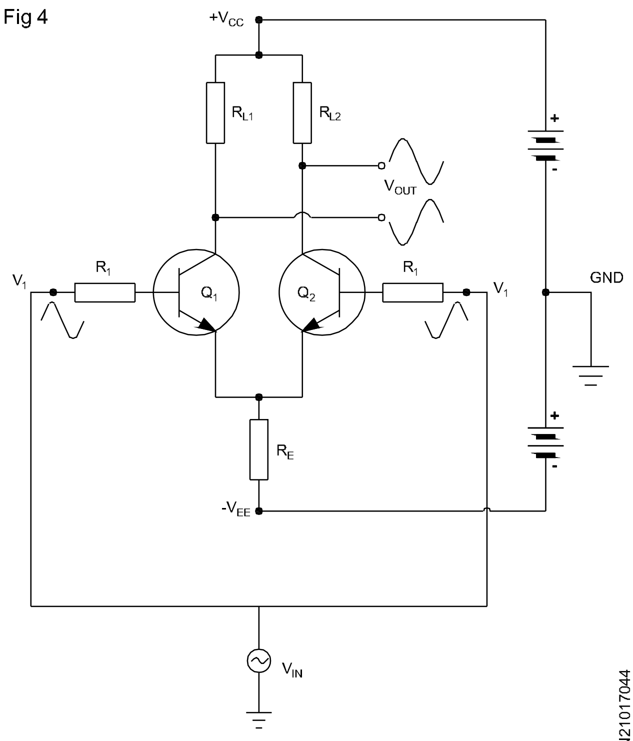
$V_{out\ (com)} = A(V_1\ V_2)$

Where,

A is the grain of each transistor

V_1 and V_2 are the base input voltages measured to ground.

Fig 4



COMMON MODE OF OPERATION

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,

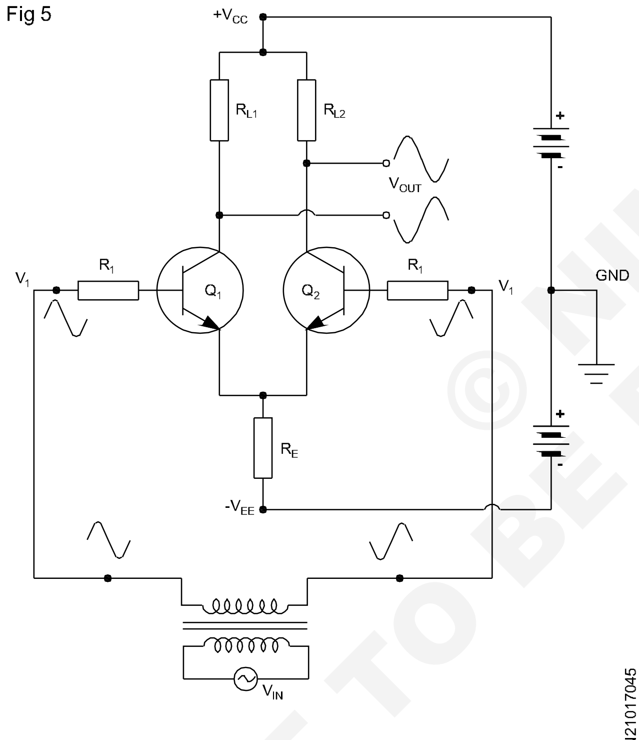
$V_{out} = A(V_1\ V_2) = A\ (V_1 - V_1) = A\ (0)$

Differential-mode operation

Fig 5 shows the differential-mode operation. When the two input signals are out of phase by 180°, the amplifier amplifies the difference of the input signals. Since the input signals are of equal in amplitude, but out of phase by 1 80° 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,

$V_{out\ (Dif)} = A\ [\ V_1 - (\ -V_2\ )] = A\ [\ (2V_1)] = ..2A\ (V_1)$

Fig 5



DIFFERENTIAL-MODE OF OPERATION

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.

The CMRR is defined as the ratio of the powers of the differential gain over the common-mode gain, measured in positive decibels

where

$$CMMR = 20\ \log_{10}\left(\frac{Ad}{Ac}\right)$$

Ad - differential gain

Ac - Common mode gain

Methods of giving input and taking output in differential amplifiers

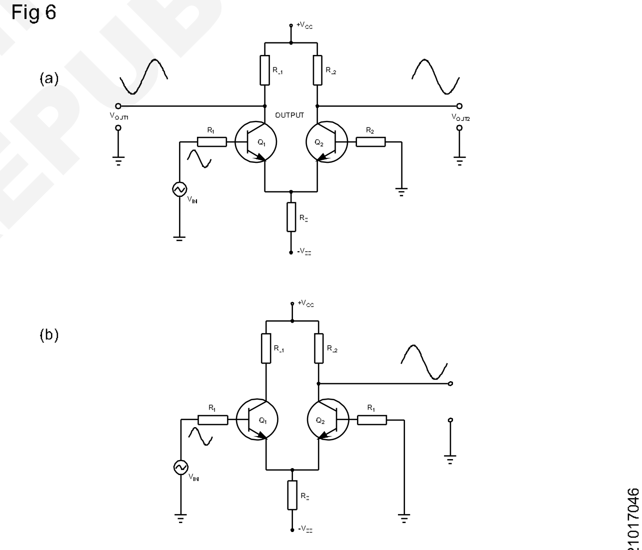
A differential amplifier is normally used with a double ended input and double ended output. But this is not a compulsion. A differential amplifier can also be used as single ended input and with single ended output.

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.

Fig 6



DIFFERENTIAL AMPLIFIER

Recall that the two transistors of a push-pull amplifiers need signal of some amplitude but out-of-phase by 180°.

Differential input:

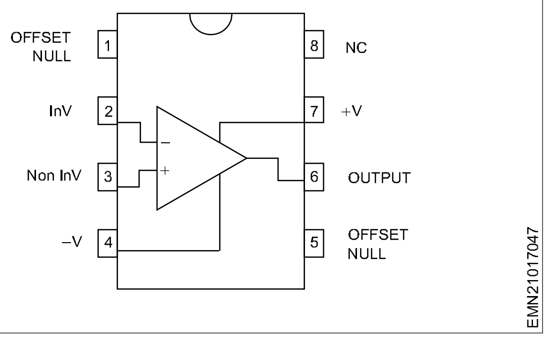
The two inputs given are signals having opposite polarity(180° out of phase). The input is similar to input to a push-pull amplifier.

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° 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.

Fig 7

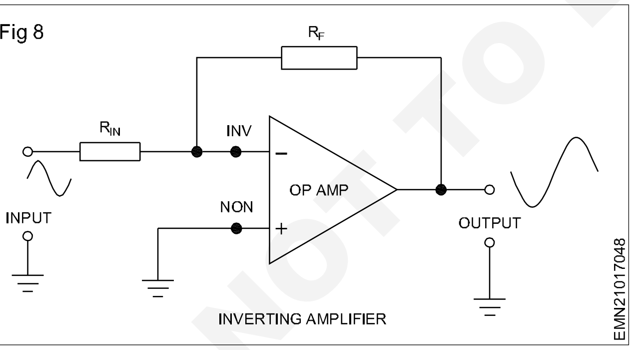


Gain of Op-Amps

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.

Fig 8



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}.

$$\text{Inverting Amplifier Gian } \left(A_{inv}\right) = -\frac{R_F}{R_1}$$

Negative sign indicates inverting of output signal generally, amplifier gain can also be written as

$$A = \frac{Vo}{V_{in}}$$

As an example, let us calculate the closed-loop voltage gain, for the inverting amplifier at Fig 8. Assume values of R_F = 470 KΩ and R_{in} = 47 KΩ. 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 out put voltage of the non – inverting amplifier is given by,

$V_{out(inv)} = A_{(inv)} \cdot V_{in}$

in the given example,

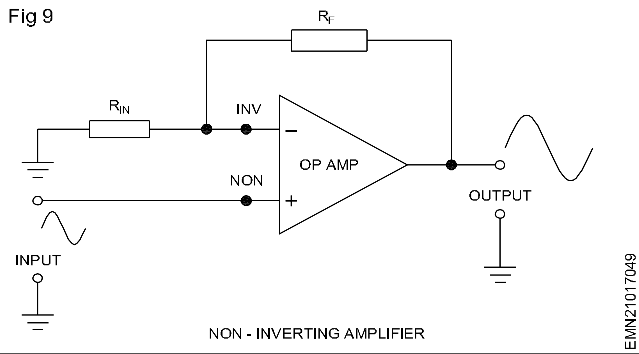
$V_{OUT\ (NON)}$ = 10x0.5 v

= 5.0 Volts

QP-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}.

Fig 9



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,

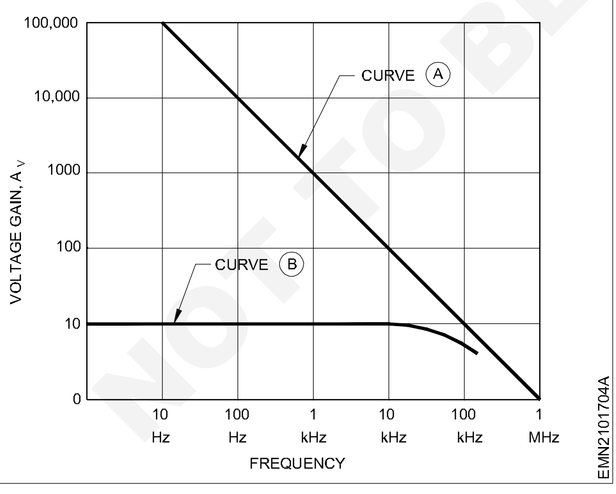
$$\text{Gain at1kHz} = \frac{\text{GEP}}{1\text{kHz}} = \frac{1\text{MHz}}{1\text{kHz}} = 1000$$

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 $A_{(CIOSED)}$ of the Op-Amp is set at say 10, then the frequency response of the Op-Amp becomes almost flat upto 100kMz. This is one of the major advantages of negative feed back in Op-Amps.

Fig 10



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 = ∞

Input resistance $R_{in} = \infty$

Output resistance $R_0 = 0$.

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 ≈ 1 MHz (unity gain)

Input resistance, R_{in} 2 MΩ

Output resistance $R_0 \leq 50\ \Omega$

Typical Op-Amp applications

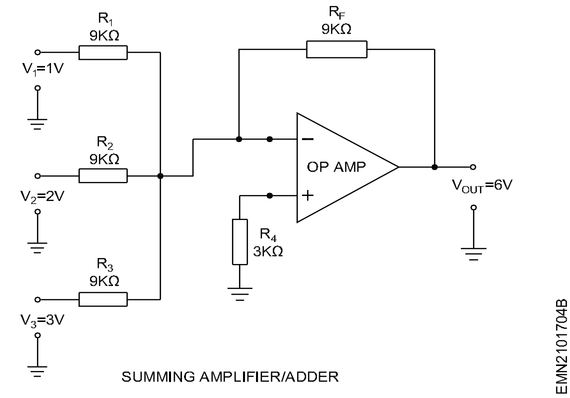
Application of Op-Amps are innumerable. This is because, of the flexibility that is built into the internal circuit of the Op-Amp. In addition to its basic function of amplification, Op-Amp are used as comparators, adders, subtracters, differentiator, integrators and so on.

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,

$$V_{out} = \left[\left(\frac{R_f}{R_1} xV_1\right)\right] + \left(\frac{R_f}{R_1} xV_2\right) + \left(\frac{R_f}{R_1} xV_3\right)$$

Fig 11



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}=(1x1V)+(1x2V)+(1x3V)

V_{out}=1V+2V+3V=6Volts

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/μS) means, the amplitude of output voltage can change by a maximum of 1 V in 1μS. 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 (+ Ve, com,-Ve) DC supply. Typical values of DC supply voltages are ± 9 V ± 15 V and ± 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.11.

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)

Single supply operation of Op-Amps

Most Op-Amp circuits are designed to work using dual (±) DC power supply. Due to some inconvenience of dual 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.

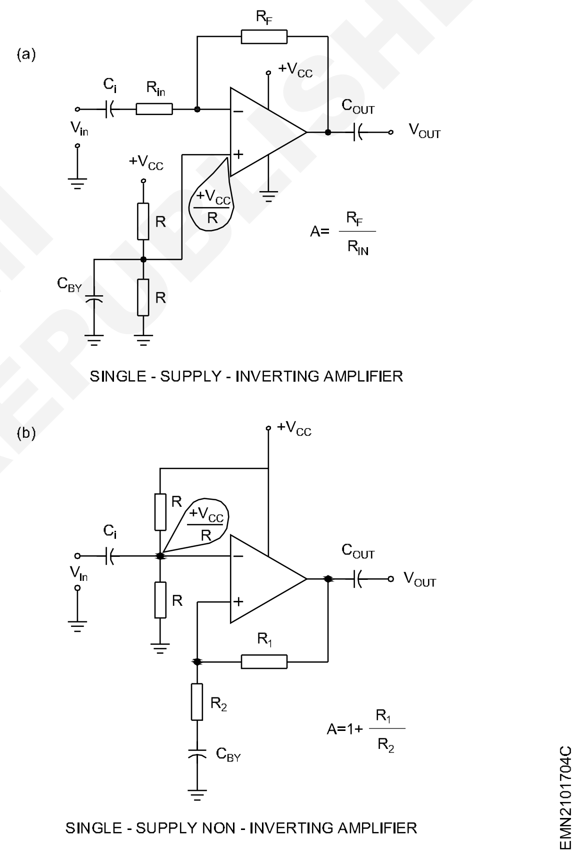
Noise in operational amplifiers: Undesired electrical signals present in the output of an amplifier is referred to as *noise.* Noise in the output of a circuit may be due to the noise generated in the circuit (internal) or noise getting into the circuit from external sources. External noise can be minimised 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 uF 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.

Fig 12



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.

(i) It is used in non linear analog systems- the non linear applications are comparator, rectifier, clipper, clamper, log and antilog amplifier, multiplier etc.

(ii) 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.

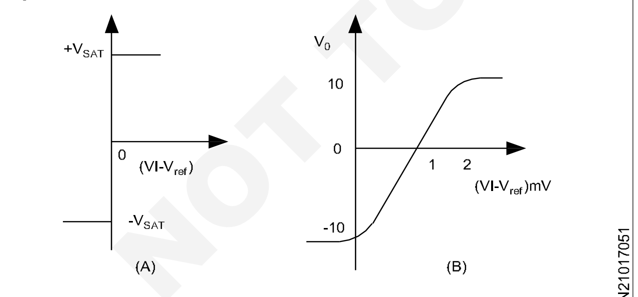
A comparator is a circuit which compares a signal voltage at one input of an op-amp with the known reference voltage at the other input. There are two types of comparator

(i) non - inverting comparator

(ii) inverting comparator

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 Fig1.

Fig 1



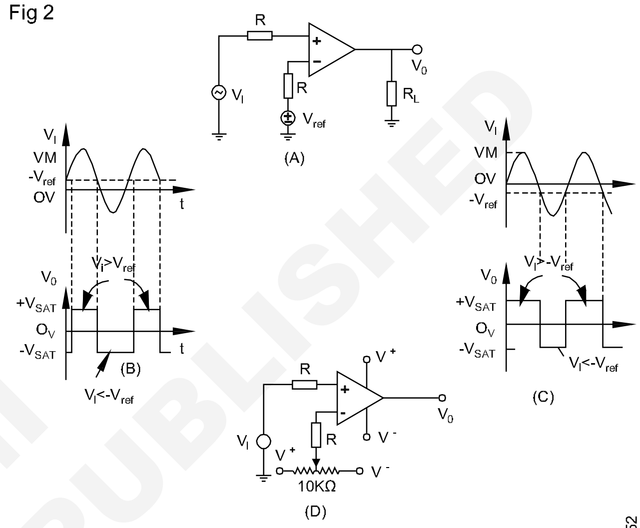
THE SYMBOL OF OP-AMP

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.

Fig 2



A. NON INVERTING COMPARATOR INPUT AND OUTPUT WAVEFORM FOR
B. VREF POSITIVE
C. VERF NEGATIVE
D. PRACTICAL NON INVERTING COMPARATOR

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 :

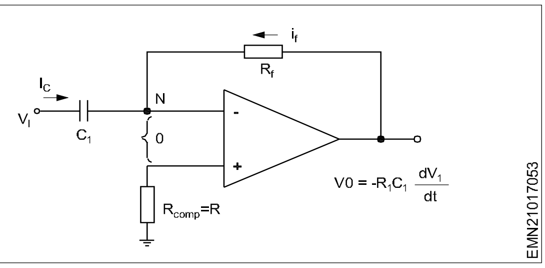
The node N is at virtual ground potential (i.e) V_N=0. The current through the feedback resistor is V_0/R_f and there is no current through the op-amp. Therefore the nodal equation at node N is

$C_1 dV_1/dt + Vo/R_f = 0$ (or) $Vo = -R_f C\ dVi/dt$.

Thus the output voltage V_o is a constant ($-R_f C_1$) times the derivative of the input voltage V_1 and circuit is known as differentiator which is shown in Fig 3. The minus sign indicates a 180 phase shift of the output waveform Vo with respect to the input signal. The output is the time derivative of the input signal, if V_i = sin wt.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'.

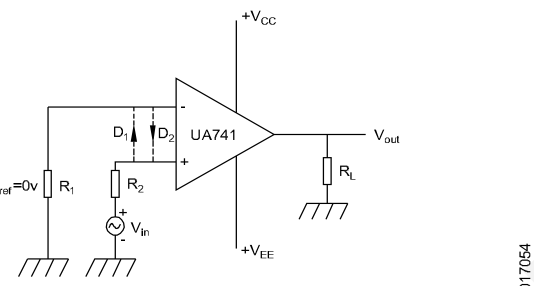
Adding the input resistor R_{in} inseries to the capacitor will increase the gain by R_F/R_{in} and it will act as a differenctiator at low frequencies.

Fig 3



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. Anyone 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 (Vref = 0V). An input sine wave is given as Vin. These are shown in the circuit diagram and input and output waveforms of an inverting comparator with a 0V reference voltage.

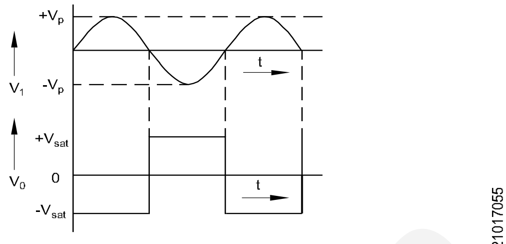
Fig 4



Zero Crossing Detector Using UA 741 op-amp IC

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 Vout 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 D1 and D2 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.

Fig 5



Zero Crossing Detector Using 741IC Waveform

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 or V = Q/C .... (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

V/T = Q/T
C

Since the charging is constant, we can write

V/T = I/C

or V = IT/C .... (2)

Where V = capacitor voltage

I = charging current, Vin / R

T = charging time

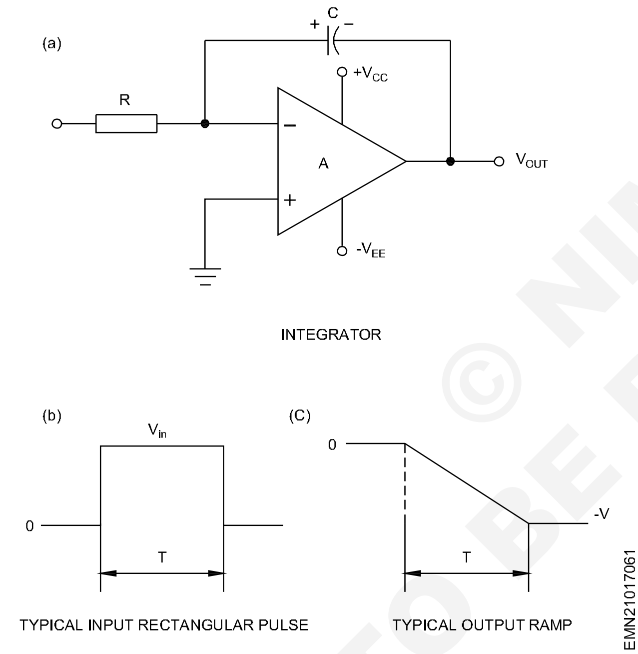
C = capacitance.

This is the voltage across the capacitors. Because of the phase reversal, V_{out} = - V.

For Example: If I = 4mA, T = 2msec and C = 1 F, then the capacitor voltage at the end of the charging period is (4mA) (2ms)/1uF = 8V because of the phase reversal, the output voltage is -2V after 2ms.

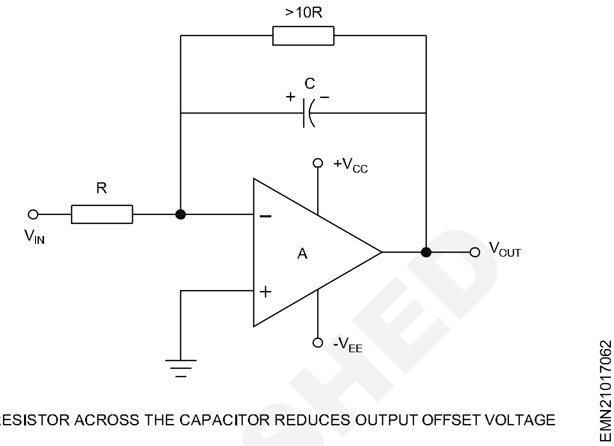
In Fig 1, since the capacitor acts like an open to DC signals, the closed-loop voltage gain equals to the open-loop voltage gain at zero frequency. This will produce too much output offset voltage without negative feed back at zero frequency, the circuit will treat the input offsets as a valid input signal. The input offsets will eventually charge the capacitor and drive the output into positive or negative saturation.

Fig 1



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.

Fig 2



RESISTOR ACROSS THE CAPACITOR REDUCES OUTPUT OFFSET VOLTAGE

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**
- **describe the operation of DAC.**

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.

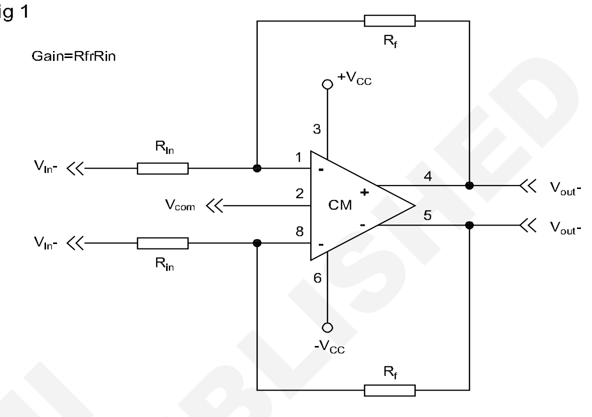
The V_{COM} pin can be connected to a data converter reference voltage pin to achieve tight tracking between the op-amp common mode voltage and the data converter common mode voltage. In this application, the data converter also provides a free dc level conversion for single supply circuits. The common 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 Rf /Rin a familier 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.

Fig 1

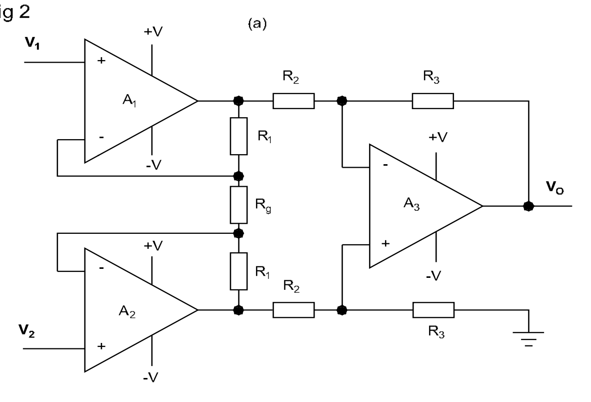


The output stage may use devices such as meters, oscilloscopes and display circuits. The signal source of instrumentation amplifier is the output of the transducer. To amplify the low level output signal of the transducer, instrumentation amplifier is used in the middle.

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.

Fig 2

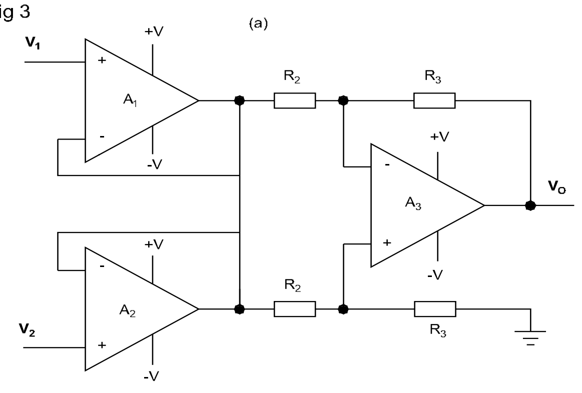


INSTRUMENTATION AMPLIFIER USING OP-AMP

A circuit providing an output based on the difference between two inputs is given in the above circuit. In the circuit diagram, op-amps labelled A1 and A2 are the input buffers. The gain of these buffer stages are not unity because of the presence of R1 and Rg. Op amp labelled A3 is wired as a standard differential amplifier. R3 connected from the output 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 (Av)= Vo/(V2-V1) = (1 + 2R1/Rg) x R3/R2. For varying the gain, replace Rg with a suitable potentiometer. A simplified instrumentation amplifier design is shown in Fig 3.

Fig 3



SIMPLIFIED INSTRUMENTATION AMPLIFIER

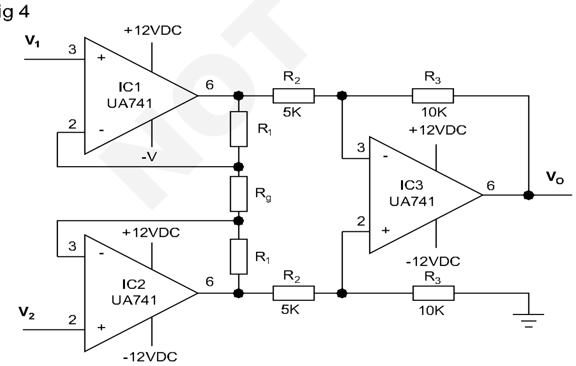
EMN21017073

Here the resistances labelled R1 are shorted and Rg is removed. This results in a full series negative feedback path and the gain of A1 and A2 will be unity. The removal of R1 and Rg simplifies the equation to Av = R3/R2.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 A1 and A2.

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 +/-12V DC and has a gain 10. If you need a variable gain, then replace Rg with a 5K POT. Instead of using uA741 you can use any op-amp but the power supply

Fig 4



PRACTICAL INSTRUMENTATION AMPLIFIER USING OP-AMP

EMN21017074

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 +/-15V DC.

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 V1, as shown in figure 3 and ground the other input terminal (V2).

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

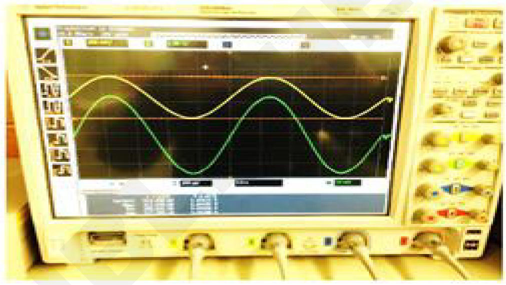


Fig 5 displays the input and the output on the same time scale, but different voltage scales. To ensure the gain is about 10, take the output voltage and divide it by the input voltage. This example has Vout/Vin = 5.046 V/513.66 mV = 9.82.

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.

Digital-to-analog converter: Digital to analog converter is an important section in any digital system as indicated in the above two examples. OP-AMP is the most common element used in the D to A converter.

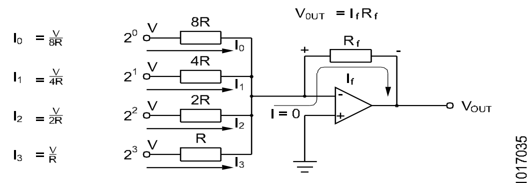
The basic problem in converting a digital signal into an equivalent analog signal is to change the 'n' digital voltage levels into one equivalent analog voltage. This can be most easily accomplished by designing a resistive network as shown in Fig 6, that will change each digital level into an equivalent binary weighted voltage or current.

The values of the input resistors network is chosen to be inversely proportional to the binary weights of the corresponding input bits, the lowest-value resistor(R) corresponds to the highest binary weighted input (2^n). The other resistors are multiples of R(2R, 4R and 8R) and correspond to the binary weights, 2^{n-1}, 2^{n-2}, 2^{n-3}...........2^{n-n} respectively.

The I/P currents are also proportional to the binary weights, thus the o/p voltage is proportional to the sum of the binary weights because the sum of the input current is through R_f.

The Fig 6 shows a 4 bit DAC, each of the input resistors will either have current or have no current, depending on the input voltage level. If the input voltage is zero (binary 0), the current is also zero. If the input voltage is HIGH (binary 1), the amount of current depends on the input resistor value and is different for each input resistor.

Fig 6



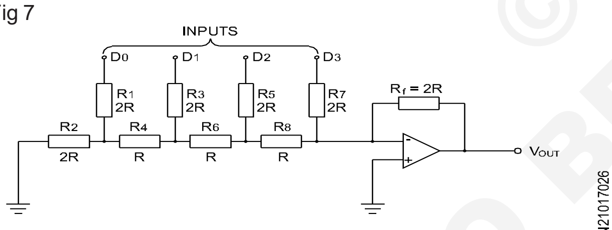
FOUR BIT DIGITAL-TO-ANALOG CONVERTOR

Since there is practically no current into the op-amp inverting input, all of the input currents SUM together and go through R_f, since the inverting input is at 0V (Virtual ground), the drop across R_f is equal to the o/p voltage, so $V_{out}=I_fR_f$.

The main disadvantage of this type of DAC is the number of different resistor values. For example, An 8 bit converter requires eight resistors, ranging from some value of R to 128R in binary-weighted steps. This range of resistors requires tolerances of one part in 255 (less than 0.5%) to accurately convert the input, making this type of DAC very difficult to mass-produce.

R/2R ladder digital-to-analog converter: The Fig 7 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.

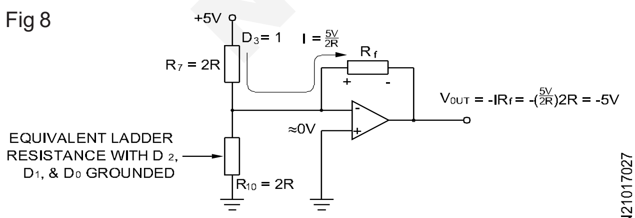
Fig 7



R/R2 LADDER DIGITAL-TO-ANALOG CONVERTER

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 8. Essentially no current goes through the 2R equivalent resistance because the inverting input is at virtual ground.

Fig 8



DIGITAL TO ANALOG (D/A) CONVERSION

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 (˜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. Thevanize the R2/2R 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 thevanizing 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 -1.25 volts.

When the input is 0001: When D_0 input is at +5V and the others are at ground, this condition represents 0001, again thevanizing 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

$$V_{out} = \frac{D_0 2^0 + D_1 2^1 + D_2 2^2 + D_3 2^3 + ...D_{n-1} 2^{n-1}}{2^n}$$

where D_0, D_1, D_2, D_3........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)x 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 ±0.1%, then the maximum error for any output voltage is (10V) (0.001)=10mV, ideally, the accuracy should be, at most ±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 ±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 ±1/2 LSB of its final value when a change occurs in the input code.

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.**

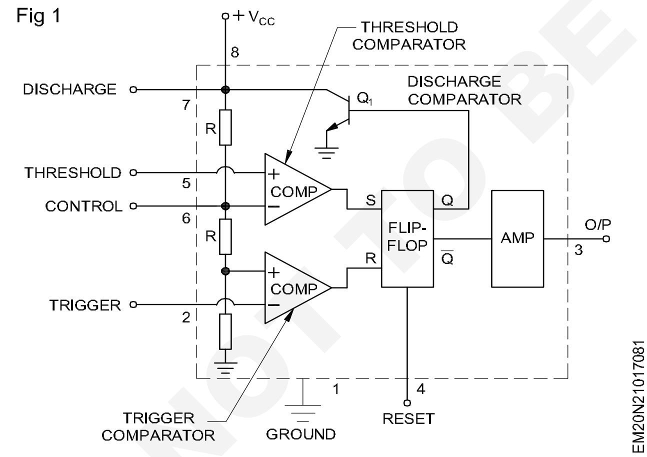
Timer

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.

Fig 1



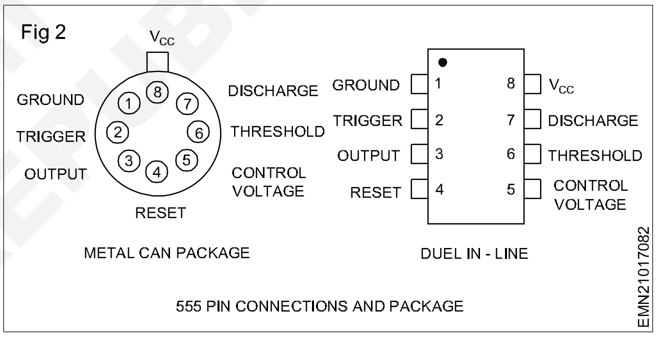
As can be seen from Fig 1, the 555 IC contains two comparators, one transistor, three equal value resistors, a flip-flop, and an output stage. Timer find application in precision timing, pulse generator, sequential timing, time delay circuits, pulse width modulation, pulse position modulation and linear 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.

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

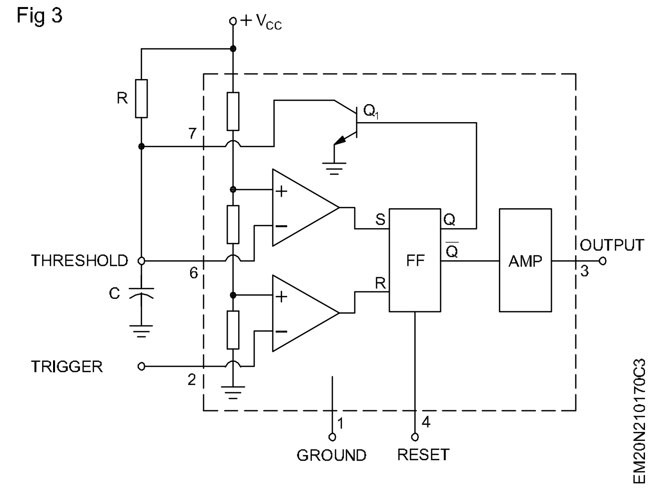
– as a mono-stable (one-shot) multi-vibrator.

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.

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,

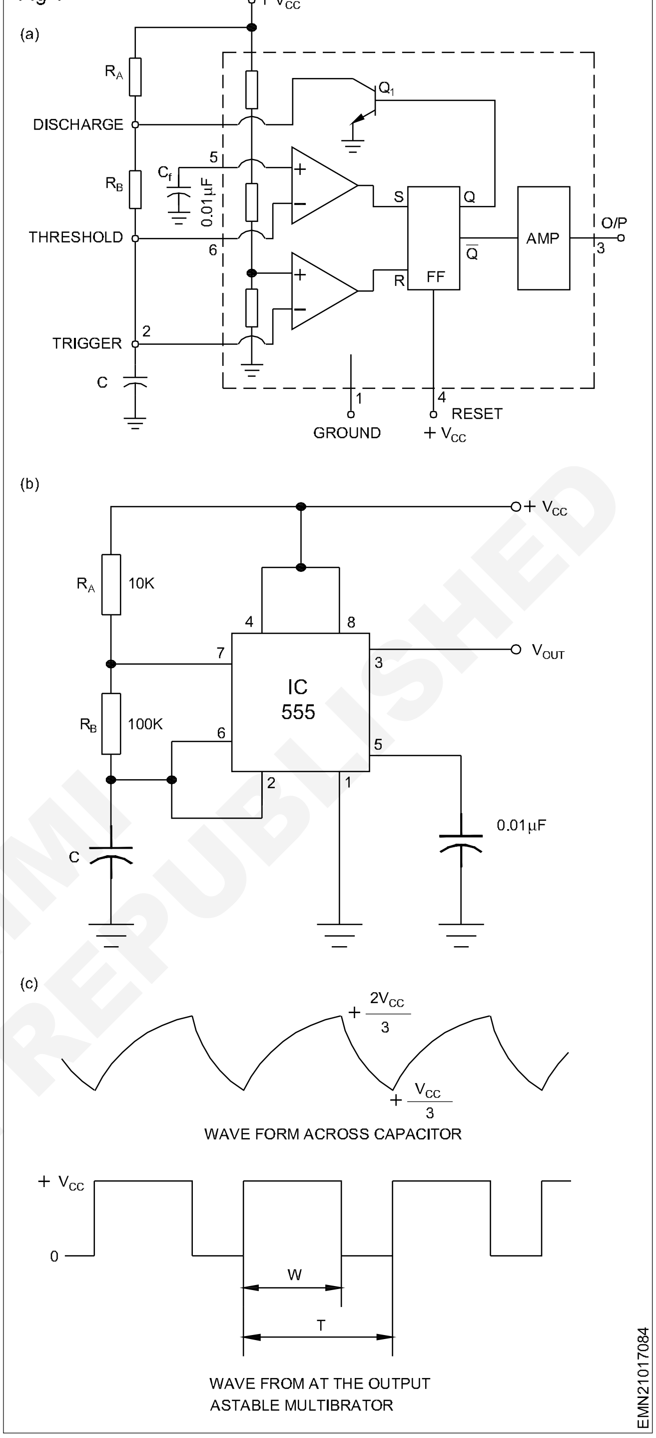
  $$t = (R_A + R_B)C$$

- 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,

  $$t = R_BC$$

- 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 2/3V_{cc}. Wave-forms at the capacitor(trigger input) and at the output 555 are shown in Fig 4c.

Fig 4



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, $T = t_{ON} + t_{OFF}$

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.

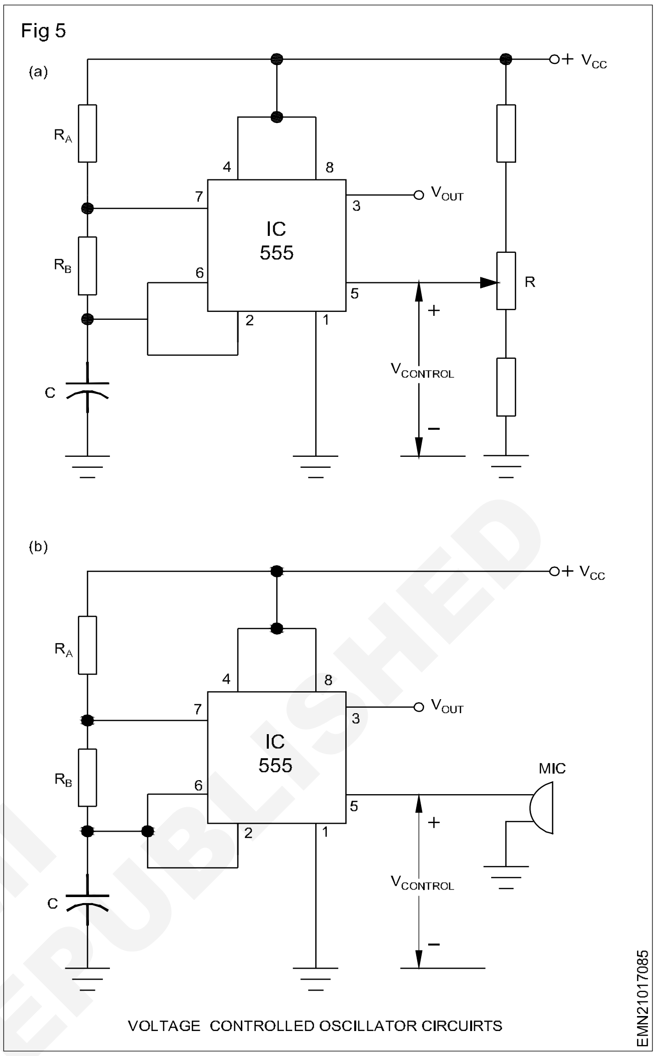
– Flashing light : if lamps or LEDs are connected at the output of the astable, the lamp/LED flashes at the rate set by the values of RC.

– 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 $2/3V_{cc}$ owing to the internal resistive voltage divider. However, by connecting an external component or voltage source as shown in Fig 5a, 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 $1/3V_{CC}$ 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.



Voltage Controlled Oscillator (VCO)

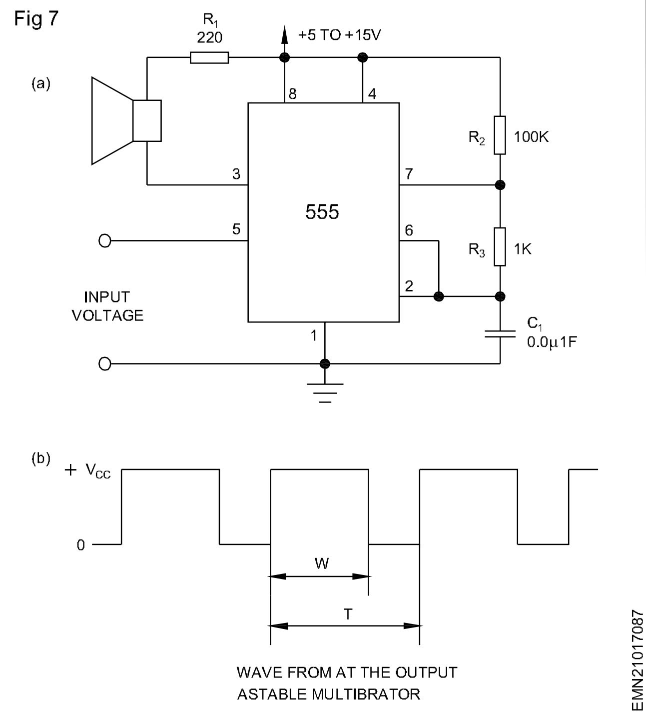
Voltage-Controlled Oscillator (VCO) circuit using the 555 timer IC as the main component as shown in Fig 7(a). As expected, the 555 timer is configured as an astable multi vibrator to be able to serve as an oscillator. An astable multi vibrator is just a timing circuit whose output oscillates between '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.

Fig 7



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**
- **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 monosatable 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 Q1 is turned ON and C is discharged. The timer stays in this stable state, and nothing happens tills 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 Ror C is, the wider the output pulse. The formula for pulse width is given by,

Pulse width (W) = 1.1RC

For exmple, 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 alos 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.

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 2.

In this circuit,the output frequency of PWM signal is controlled by selecting resistor RV1 and capacitor C1. A variable resistor is used in place of fixed resistor for changing duty cycle of the output signal. Capacitor Charging through D1 diode and Discharge through D2 diode generates PWM signal at 555 timer's output pin. The frequency of PWM signal is calculated using the formula:

$$F = 0.693*RV1*C1$$

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 3.
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).

Different duty cycle of PWM waveforms are shown in Fig 4.

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.

Fig 1

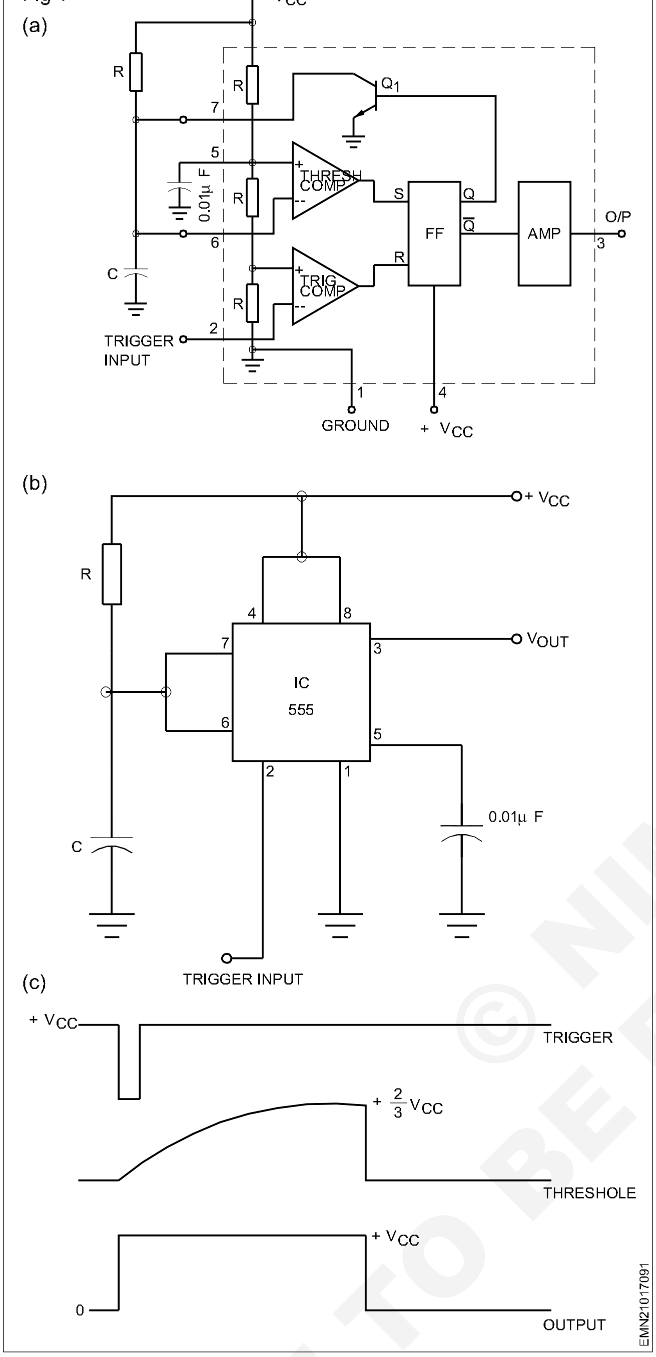


Fig 4

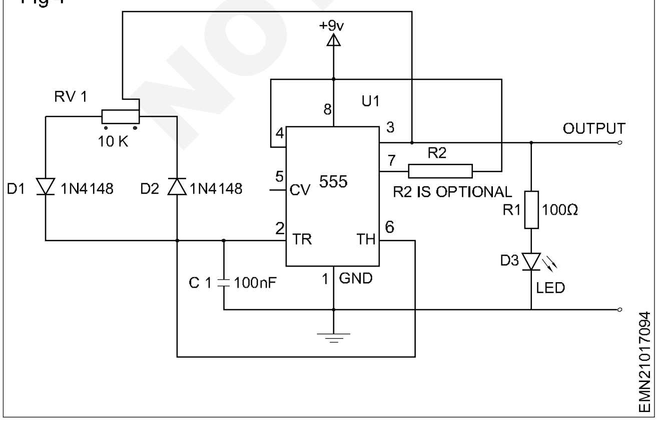


Fig 3

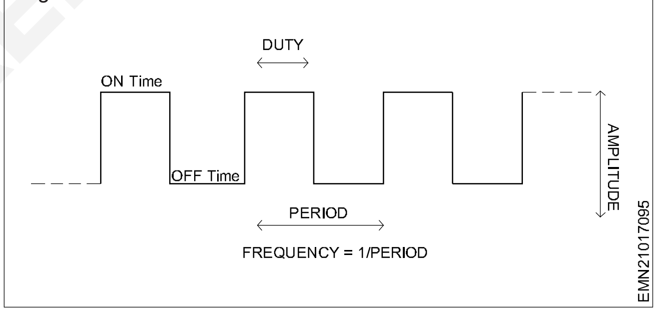


Fig 4