Government of Karnataka
Department of Pre University Education

ELECTRONICS

Prescribed Textbook for I PUC

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Director's Message

Dear Students,

We at the Department of Pre-university Education, Karnataka strive to empower each student to dream big and equip them with the tools that enable them to reach new heights and successfully deal with the challenges of life. As Swami Vivekananda said, "**Real education is that which enables one to stand on one's own legs**".

The course contents in this book are designed with the objective of equipping you well for the next level of study.

We wish you well on your journey and look forward to you becoming a responsible citizen of the nation and give back to the betterment of the society.

With best wishes,

Sd/-
C. Shikha, IAS
Director
Department of Pre University Education
Bengaluru

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PREFACE

ELECTRONICS has been introduced for pre-university students of KARNATAKA in the year 1986-87. In PUC, as a part of Science stream, PCME combination was introduced as an option.

Fundamental foundation must be made available for the present generation, as they are being brought up in an environment of modern technology.

The present world stands on the strong foundation of science creating awareness in students towards technological advancements. We must impart education based on their needs to create interest towards electronics.

This system of education demands for the syllabus to be framed in par with the CBSC/ICSE/ISC, as these streams mainly deals with basics of science, technology and research. Keeping all these in view we have framed the theory syllabus to 120 hours.

This book is the result of renewed efforts of the present Textbook Development Committee with the hope that the students will appreciate the beauty and logic of electronics.

For students pursuing electronics as the subject in their further studies the matter developed in this book will certainly provide sound base.

For students, to grab and understand concepts book is written in a simple but systematic way. Chapter name, text material, questions based on understanding, knowledge, skill, applications and exercises has been introduced in an organized manner.

Among the nine chapters, the first seven chapters are categorized under analog electronics, chapter 8 under digital electronics and chapter 9 introduces practical electronic components utilized in circuits. Chapter 1 gives an interesting insight on the everlasting electronics in various fields. Chapter 2 focuses on various concepts of charge, laws and theorems to analyse the electrical networks. Also gives a brief idea of AC principles. Chapter 3 provides awareness of using measuring instruments related to electrical, electronics and medical fields. Chapter 4 gives in-depth knowledge about passive electronic components and transducers. Chapter 5 provides the knowledge of using AC and DC to the passive components. Chapter 6 gives the clear concepts related to semiconductor devices and its application towards regulated power supply and also about display units. Chapter 7 introduces a brief idea on working and configurations of a current controlled device BJT. Chapter 8 enlightens on number systems, Boolean law's, human logical ideas implemented as gates and applications of timer. Chapter 9 gives a clear idea on electronic components to design and develop the practical electronic circuits.

In writing this book our greatest inspiration is OUR STUDENTS in KARNATAKA STATE, INDIA. Our humble and heartfelt gratitude to all our friends of Karnataka state who have inspired and assisted our team in this venture.

The final supreme judges are our READERS.

Readers are welcome to share their esteemed thoughts and valuable suggestions in improving the Textbook.

Send your feedback to pucelectronicssyllabus@gmail.com

SHOBHA DEVI

CHAIR PERSON

I PUC THEORY SYLLABUS IN ELECTRONICS - Comprehensive version ELECTRONICS–I Electricity, Electronics (analog & digital) and Electronic Components (Only S.I units to be followed)	
1. INTRODUCTION TO ELECTRONICS	4 Hours
Electronics and its scope: **Development of** vacuum tube devices, semiconductor devices, integrated circuits, microprocessors & microcontrollers. **Applications of electronics** – entertainment, communication, defense, industrial & medical. **Impact of electronics on quality of life**	
2. PRINCIPLES OF ELECTRICITY, NETWORK THEOREMS AND AC PRINCIPLES	21 Hours
Charge, Potential difference, DC and AC:	11 Hours
Charge-positive and negative charges, properties of charges, S.I Unit of charge, Charge of an Electron, Number of electrons in one Coulomb of charge, Electric Current-definition (charge/sec), its unit and direction of current- conventional current and the electronic current. Potential difference and its unit related to electric circuit, Direct current (DC) and Alternating Current (AC)-representation and examples of DC & AC sources. **Ohm's law**-statement & limitations, application to circuits. Resistance and its unit, Electric Power-definition, unit of power, electric energy-definition and Power dissipation in resistors -Power formulae and Energy formula. ($P = VI, P = \frac{V^2}{R}$ $P = I^2R$ & kWh). **Combinations of resistors**-series, parallel-derivations of the expressions, series – parallel - circuits and problems. open and short circuit – Problems.	
D.C Sources and Network theorems (for DC circuits)**:**	7 Hours
Introduction to secondary DC sources like dry cells and other type of batteries, internal resistance of sources, Voltage sources: Definitions, Conversion of voltage source to current source and vice versa.	

Kirchhoff's current law and **Kirchhoff's voltage law,** current and voltage division**,** problems up to two loops on Kirchhoff's laws. **Network theorems**: Thevenin's theorem, statements, respective equivalent circuits for dc networks. Super position theorem, statement, analysis with two voltage sources, Maximum power transfer theorem- statement (no derivation) all theorems with respect to DC circuit. Problems on each theorem.	
A.C principles:	3 Hours
Expression for the instantaneous voltage $v = V_m \sin(\omega t)$ (no derivation), definitions of frequency, time period, peak value, r.m.s value, effective value and average value with reference to sinusoidal waveform. Different types of non sinusoidal waveforms square, triangular and saw tooth- mention only.	
3. MEASURING INSTRUMENTS	4 Hours
Electronic Instruments: Voltmeter (AC/DC), ammeter (AC/DC) & Ohm meter – photograph of each one, symbol & uses of each, with diagrams study front panel details of a typical multimeter and a dual channel oscilloscope, use of oscilloscope for measurement of voltage (AC/DC), time period & frequency, precautions while using electronic instruments.	
Medical electronic Instruments: Electrocardiography (ECG), sphygmomanometer (blood pressure instrument), glucometer, ultrasound scan, pulse oximeter, clinical digital thermometer – use of each one.	
4. PASSIVE ELECTRONIC COMPONENTS	22 Hours
Comparison of passive and active components- Passive and active components, their examples. **Resistors:** resistance of conductor & its unit, specification of resistors, temperature coefficient of resistor, specific resistance, types of resistor **–** fixed and variable, Fixed resistors - carbon composition, metal film & SMD resistor, constructional aspects in brief and applications of resistors. **Wire wound resistor:** Construction, applications.	3 Hours

Variable resistors: Potentiometer – carbon composition type – construction and uses, Preset. Importance of power rating in resistors. **Color coding of resistors (4 bands & 5 bands),** tolerance, and problems.	
Capacitors:	6 Hours
Definition of Capacitance and its unit – Principle of capacitor, factors affecting the capacitance of capacitor, parallel plate capacitor (mention $C = \varepsilon_0 A/d$ and $C = \varepsilon_0 \varepsilon_r A/d$-no derivation), energy stored in a capacitor $E = \frac{1}{2}CV^2$ (no derivation), dielectric and examples, role of dielectric in capacitor.	
Types of Capacitors – fixed and variable. **Fixed capacitors:** Ceramic, Polystyrene, SMD capacitor and Electrolytic capacitor - construction and applications. variable capacitors like ganged capacitor and trimmer - their applications Importance of voltage rating in capacitors. **Capacitive networks -** derivation of expressions for effective capacitance of capacitors connected in series or in parallel trouble shooting in capacitors - open short, leakage.	
Inductors:	10 Hours
Review of laws of electromagnetic Induction **Definitions of self, mutual inductances and unit of Inductance.** **Inductor -** factors determining the inductance of inductor $\left(L = \frac{\mu N^2 A}{\ell}\right)$ **Energy stored in an inductor** i.e., $E = \frac{1}{2} LI^2$ (no derivation), **Fixed Inductors:** Air core, iron core, ferrite core - construction and applications. Expressions for series and parallel combination of inductors neglecting the mutual inductance (no derivations), choke and relays.	
Transformers: Principle (mutual induction), Turns ratio, voltage ratio and current ratio - relation between them, step up and step down transformers, Centre tapping in transformers, problems, applications of transformers, Efficiency in transformers, AF & IF	

transformers, pulse transformer.	
Transducers:	3 Hours
Definition of transducer, pressure transducers - microphone and loud speaker – construction, working and applications, Temperature transducers [Thermistor–Negative Temperature Coefficient (NTC) and Positive Temperature Coefficient (PTC) - only mention], LM 35 temperature sensor, LDR, Applications of temperature transducer.	
5. APPLICATION OF D.C AND A.C TO PASSIVE COMPONENTS	14 Hours
D.C applied to Passive components:	2 Hours
Transient phenomenon, transient period, Charging & discharging of a capacitor in RC circuit - expressions (mention only-no derivations), definition of Time constant, graphical representations for charging & discharging of a capacitor. Growth and decay of current in RL circuit - expressions (no derivations), definition for Time constant, graphical representations for growth and decay of current. Problems on RC & RL circuits.	
A.C applied to Passive components:	12 Hours
Concept of phase and phase difference. **AC applied to resistive circuit:** Phasor representation of voltage and current waveforms. **AC applied to capacitive circuit:** Circuit diagram, Expression for instantaneous current and voltage for a sinusoidal input voltage, Phasor representation of voltage and current, definition of phase, phase difference - Lead and lag concepts. **AC applied to inductive circuit:** Circuit diagram, Expression for instantaneous current and voltage for a sinusoidal input voltage**, Phasor representation of voltage and current**, definition of phase, phase difference - Lead and lag concepts. Resistance, reactance and impedance. Capacitive reactance and inductive reactance-definitions and expressions. **Power in AC circuit:** Power factor, active and reactive power. **Series RLC circuits:** Impedance, impedance equation (mention	

only), variation of impedance with respect to frequency. **Series Resonance** - Condition for resonance, Resonant frequency, Half power frequencies, BW, Quality factor in terms of f_r & BW. **Frequency & phase response of RC circuits:** Brief note on filters and its application. Low pass and high pass filters – frequency response and phase response graph and Cutoff frequency, problems.	
6. SEMICONDUCTORS, DIODES AND APPLICATIONS OF DIODES	26 Hours
Semiconductor theory:	4 Hours
Band theory of solids - valence band, conduction band and the forbidden energy gap, Classification of solids as conductors, semiconductors and insulators on the basis of their conductivity and on the basis of energy band diagrams, examples for each. **Types of semiconductors** - Intrinsic and Extrinsic. **Intrinsic semiconductors:** Definition, lattice structure (two dimensional), concept of holes and electrons (their generation and flow in the bands), effect of temperature, thermal generation and recombination of electrons and holes.	
Extrinsic semiconductors: Definition, doping, doping elements - trivalent and pentavalent, meaning of donor and acceptor impurities. **Types of Extrinsic Semiconductors**: n type and p type, their formation, in each case study of lattice structure (two dimensional).	
pn junction:	4 Hours
Formation of pn junction, diffusion of charge carriers, depletion region - formation of depletion region, barrier width and barrier potential, semiconductor diode. **Forward biased pn junction:** Diagram, Effect on width of the depletion region, resistance and current flow. **Reverse biased pn junction:** Diagram, Effect on width of the depletion region, resistance and concept of leakage current (in germanium and silicon), junction capacitance (during reverse bias)	

and its variation with applied reverse bias voltage, brief note on breakdown mechanisms.	
Junction Diode	8 Hours
Circuit symbol, Diode equation $\left[I = I_O(e^{\frac{V}{\eta V_T}} - 1) \right]$ - Numerical problems need not be discussed. Ideal and practical diodes, Equivalent circuit of a practical diode (barrier potential in series with R_f). **V-I static characteristics -** Circuits to study the forward bias and reverse bias characteristics, characteristic curves, knee voltage, forward bias resistance from characteristic curve. Study of various terms related to diode like PIV and power rating (qualitative), diode approximations, Comparison of Germanium and Silicon diodes. **Wave shaping circuits –** clippers – series positive clippers, series negative clippers, clampers - positive clampers, negative clampers.	
Rectification – Need for rectification, Principles, Half wave rectifier, Full wave rectifier (centre tapped and bridge type): Circuit, working of rectifiers considering transformers at the input, input and output wave forms for the rectifiers. Expression for Load regulation - mention only. Expressions (no derivations) for average output voltage V_{av}, average output current I_{av}, V_{rms} and I_{rms}. Efficiency 'η' (expression - no derivation), Ripple and Ripple factor ϒ (expression- no derivation) for each case, comparison of rectifiers. Concept of negative voltage rectifiers. Problems.	
Filters:	2 Hours
Need for filters, series inductor filter, shunt capacitor filter and Inductive input L type filter, - circuit diagram, working and waveforms for each type, bleeder resistance.	
Special purpose diodes & voltage regulators:	8 Hours
Zener diode: schematic symbol, Zener and avalanche breakdown, V-I characteristics of Zener diode, its application in voltage regulation-study of line and load regulation, Calculation of minimum load resistance required for regulation - problems with constant input & variable input voltage.	

Design of practical regulated power supplies – Design of a rectifier for a given DC voltage, Fixed positive regulated power supply using 7812, Fixed negative regulated power supply using 7912 & Adjustable regulated power supply using LM317. Specifications of DC regulated power supply. Light Emitting Diode (LED) - symbol, construction - type of materials used, working in brief and applications. Varactor diode, IR emitter diode, photo diode, tunnel diode & Schottkey diode - symbol, and applications. Seven segment display: LED display - pin configuration showing the different segments-a, b, c, d, e, f, g and dp. Common Anode and Common Cathode display. Display of digits 0 to 9, use of current limiting resistors for each segment, applications. LCD (Liquid Crystal Display), Comparison of L.E.D displays with L.C.D displays.	
7. BIPOLAR JUNCTION TRANSISTOR	7 Hours
Transistor working-npn (in active mode), Symbols, currents I_B, I_C and I_E, Three basic configurations of transistor – CE, CB and CC. DC current gains α and β and the relationship between them. Input and output characteristics of a transistor in CE configuration. Meaning of cutoff, saturation, and active regions. Photo transistor, Opto-coupler & IR receiver transistor – working in brief, symbol & applications	
8. INTRODUCTION TO DIGITAL ELECTRONICS	18 Hours
Introduction, importance of Digital Electronics, representation of digital and Binary signals, Positive and Negative logic. **Number systems –** Need for the study of various number systems, Decimal number system, and Binary number system – advantage, bit, nibble, byte, memory representation using Bytes, hexadecimal number systems, conversion from one system to another. Binary addition, subtraction, multiplication and division, 1's complement, 2's complement, 1's complement and 2's complement method for subtraction of binary numbers (subtraction of a binary number of smaller value from a number of larger value), sign magnitude binary number.	

Boolean algebra and Logic gates: **Boolean Algebra:** Introduction to Boolean Algebra, Basic Boolean operators (OR, AND and NOT operators), Basic Laws and theorems of Boolean Algebra, De Morgan's theorems and their verification, Boolean identities, Simplification of Boolean expressions, **Basic Logic gates**: OR gate and AND gate: Logic symbol, truth table and realization using diodes, NOT gate - using transistor, logic symbol and truth table**.** (Positive logic is to be dealt in all cases). Construction of logic circuits for logic expressions. DTL - NAND, DTL - NOR gates – working and truth table. **Pulse (clock) generator using 555** - Astable multivibrator - frequency & duty cycle, monostable pulse generator – pulse width.	
9. PRACTICAL ELECTRONIC COMPONENTS, THEIR SPECIFICATIONS AND PCB **[Note: photographs, important specifications, part numbers (wherever possible) of each component to be mentioned]** Components part numbers, data sheet, package Resistors – CFR, MFR, SMD resistor, wire wound resistor, fusible Resistor. Potentiometer & trimmer resistors Capacitors – Mica, ceramic, polystyrene, electrolytic, SMD capacitor, trimmer capacitor Inductors – air core, iron core, ferrite core Electromagnetic relay Transformers – Iron core, ferrite core Diodes – rectifying diodes, diode bridge module, switching diodes, Zener diode, LEDs, seven segment display, LCD display. Transistors – npn & pnp transistors Sensors: speaker, microphone, temperature sensor, thermistor, LDR, IR emitter diode, IR receiver transistor Regulators- Fixed regulator: 78XX series, 79XX series, PCB Design & development	4 Hours
Note: Numerical Problems are to be solved for all the expressions wherever appear in the syllabus.	

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Contents

Chapter 1

Introduction to Electronics

Electronics and its Scope

The word 'electronics' is derived from electron mechanics. Electronics is the science and technology of the motion of electrons in gas, vacuum, or in semiconductor devices which serves as a base for electrical signals thereon. An Electrical signal may represent information by the voltage, current, frequency, or total charge. The Institute of Radio Engineers has given a definition of electronics as **"the field of science and engineering, which deals with electron devices and their utilization."** Experiments with beams of negative particles were performed by Joseph John ("J.J.") Thomson, which led to the conclusion in 1897 that they consisted of light weight particles with a negative electric charge, nowadays known as electrons. Electronics can be broadly divided into Analog and Digital Electronics. In Analog electronics, electronic systems with a continuously variable signal, in contrast to digital electronics where signals usually take only two different levels.

Electronics deals principally with the communication of information and/or data handling. Until around 1960, electronics was considered as an integral part of electrical engineering. But due to the tremendous advancement over the last few decades, electronics has now gained its rightful place. The advancement has been so fast that many sub-branches of electronics such as Computer Science Engineering, Communication Engineering, Control and Instrumentation Engineering, Information Technology are now full-fledged courses in many universities. Everyone is familiar with electronics, be it the television, the computer, internet or the cellular phone. An Electronics Engineer knows and understands the functioning of these devices. He acquires the capability to further improvise these devices as per the needs of the user.

Electronic engineering technicians have opportunities in installation, operation and maintenance of electronic equipments and systems. Defence, space and other large research organisations employ electronic engineers in design and development of complex devices and systems for signal processing and telecommunication. Industries involved in design and fabrication of the devices, integrated circuits, embedded systems, electronic equipments etc have also provided large scale placements for engineers with this specialisation. Installation and maintenance of electronic equipments used for health care in hospitals, equipments and systems for instrumentation and control in process industries, automation systems of assembly line in production industries, etc are also handled by electronics technicians.

Knowledge of computer hardware, networking equipments and communication systems enabled electronics engineering graduates to annexe an edge in the IT job market. The skills and understanding developed in the course enables them to be preferred, as software professionals by IT.

Development of Electronics

Vacuum tube devices

Electronics began its orgin in 1904 when J.A. Fleming developed a vacuum tube diode having two electrodes anode and cathode. Useful electronics came in 1906 when vacuum tube triode was invented by Lee De Forest. Later, around 1925, tetrode and pentode tubes were developed.

John Ambrose Fleming first demonstrated his device to convert an alternating current signal into direct current. A triode is an electronic amplification device having three active electrodes. The term triode most commonly applies to a vacuum tube with three elements: the filament or cathode, the grid, and the plate or anode. The triode vacuum tube was the first electronic amplification device, which propelled the electronics age ahead, by enabling amplified radio technology and long-distance telephony. Triodes were widely used in consumer electronics until the 1950s.

Vacuum tubes found their applications in the early generation electronic devices such as television, radio, and even early computer. Other vacuum tube devices include the X-Ray Tubes, Cathode Ray Tubes and Magnetrons. Vacuum tubes are also used in television screens and computer monitor screen - even as we speak now they have been replaced by LCD/LED screens.

Semiconductor devices

Semiconductor devices are electronic components that exploit the electronic properties of semiconductor materials, primarily silicon and germanium. Silicon is the most commonly used material in device fabrication because of its high temperature and high voltage withstanding ability and also silicon is abundantly available in nature.

Semiconductor devices have replaced thermionic devices or vacuum tubes in most of the applications. They use electronic conduction in the solid state as opposed to the gaseous state or thermionic emission in a high vacuum.

The advantages of semiconductor over vacuum tubes are low space requirement, less power consuming and reliable. Semiconductor devices are manufactured both as single discrete devices and as integrated circuits (ICs), which consist of two to billions of devices manufactured and interconnected on a single semiconductor substrate or wafer.

Some of the Two-terminal semiconductor devices are Rectifier Diode, DIAC, Laser diode, Light-emitting diode (LED), Photocell, infrared diode, PIN diode, Schottky diode, Solar cell, Tunnel diode, Zener diode.

Some of the Three-terminal semiconductor devices are Bipolar Junction Transistor, Field-effect transistor, MOSFET, IGBT, Silicon controlled rectifier, TRIAC, Unijunction transistor

Transistor (BJT)

The era of semiconductor electronics began with the invention of the junction transistor in 1948. Bardeen, Brattain and Shockley were awarded the Nobel Prize in Physics in 1956 for this invention. This was the first Nobel award given for an engineering device in nearly 50 years. Soon transistors were replacing the bulky vacuum tubes in different electronic circuits.

Earlier, transistors were made from germanium as it was easier to purify a sample of germanium. In 1954, silicon transistors were developed. These afforded operations upto 200°C, whereas germanium device could work well only upto 75°C. Today, almost all semiconductor devices are fabricated using silicon.

Field-Effect Transistor (FET)

In 1951, Shockley proposed the junction field-effect transistor (JFET), using the effect of applied electric field on the conductivity of a semiconductor. A reliable JFET was produced in 1958.

The techniques to make reliable JFETs led to an even more important device called metal oxide-semiconductor field-effect transistor (MOSFET). Subsequent improvements in processing and device design, and the growth of the computer industry have made MOS devices the most widely used transistors.

Power Devices

In 1956, Bell Telephone Laboratory invented PNPN device which was defined as thyristor or silicon controlled rectifier (SCR). In 1958 General Electric Company developed commercial thyristor. SCRs are used to control high voltage dc transmission lines, high current rectifiers, single phase and three phase power conversion.

Insulated gate bipolar transistor (IGBT) devices can be used for DC to AC inverters. Most of the motor control drives are based on power devices. Power devices can be used for AC to AC voltage controller, AC to DC rectifiers, DC to DC choppers and DC to AC inverters. Now power diodes, power transistor, SCRs, TRIACs, MOSFETs, and IGBTs are available with voltage rating of several thousand volts and current rating up to several thousand amps.

Integrated circuits

Jack Kilby conceived the concept of building an entire electronic circuit on a single semiconductor chip. Design and fabrication of integrated circuit (ICs) is called ‘microelectronics’. All active and passive components and their interconnections could be integrated on a single chip, during the manufacturing process. This drastically reduced the size and weight, as well as the cost per active component.

The first semiconductor chips held two transistors each. Subsequent advances added more and more transistors and as a consequence more individual functions or systems were integrated over time. Depending on the number of components included in integrated circuits the scale of integration is referred to SSI, MSI, LSI, VLSI, ULSI and GSI. The microprocessor is a VLSI device. Current technology has moved far past this mark and today's microprocessors, microcontrollers have many millions of gates and billions of individual transistors. Year of invention and scale of integration is listed as follows.

1951 — Discrete transistors

1960 — Small-Scale Integration (SSI), fewer than 100 components

1966 — Medium-Scale Integration (MSI), 100 to 1000 components

1969 — Large-Scale Integration (LSI), 1000 to 10000 components

1975 — Very-Large-Scale Integration (VLSI), 10000 to 10^6 components

1990 — Ultra Large Scale Integration (ULSI), 10^6 to 10^7 components

2001 — Giant Scale Integration (GSI), greater than 10^7 components

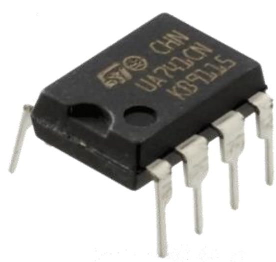
Digital Integrated Circuits

The growth of computer industry evolved new IC development. In turn, the new IC concepts resulted in new computer architecture. Speed, power consumption, and component density are important considerations in digital ICs. Transistor-transistor logic (TTL), emitter-coupled logic (ECL) and integrated-injection logic technologies were developed.

The use of MOSFETs is very attractive because very high component-densities are obtainable. Originally, reliable fabrication employed PMOS devices, in which operation depended on holes flow. Improved fabrication methods led to the use of N-channel MOS (NMOS). These gave higher speed performance. Later, the complementary metal oxide semiconductor (CMOS) technology employing both PMOS and NMOS in a circuit was used.

MOSFETs find its major application in semiconductor memories. Using MOS technology, 16000-bit random access memory (RAMs) stores data with modification available in 1973, 64000-bit RAMs in 1978, and 288000-bit in 1982. By now we have more than billion-bit chips available. Read-only memories (ROMs) stores the data without modifying, were first introduced in 1967. Subsequent developments led to programmable ROMs (PROMs) and erasable PROMs (EPROMs) in which data stored could be removed (erased) and new data stored.

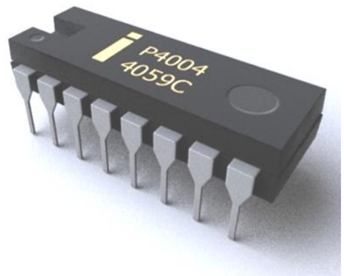
Analog Integrated Circuits



The first operational amplifier (OP AMP) was developed in 1964. Since then the OP AMP has become "workhorse" in analog signal processing. Other circuits and systems developed subsequently are analog multipliers, digital-to-analog (D/A) and analog-to-digital (A/D) converters, and active filters.

In operational amplifiers many individual components are fabricated to work as an amplifier. Operation amplifiers with high power handling capabilities are developed. Operational amplifier performs mathematical operations like addition, subtraction, multiplication, division. In addition it performs differentiation, integration, logarithmic etc on signals. Analog integrated circuits replaced discrete amplifiers and oscillators constructed by transistors and passive components.

Microprocessor



Intel developed and delivered the first commercially available microprocessor 4004 device in early 1970's. Microprocessor is an integrated circuit which consists of CPU, control unit, data and address buses. The 4004 was not much powerful as it could add and subtract 4-bit data only at a time. But it was amazing in those days that everything was on one chip.

Prior to the 4004, engineers built computers either from collection of chips or from discrete components (transistors wired one at a time). The machines then were not portable, they were bulky and required more power. The 4004 changed the scene with all its circuitry on a single chip. The 4004 powered one of the first portable electronic calculator named 'Busicom'. These 4-bit microprocessors, intended for use in calculators, required very little power nevertheless, they demonstrated the future potential of microprocessor – an entire CPU on a single piece of silicon. The trends in processor design had an impact on historical development of microprocessors from different manufacturers.

General-purpose microprocessors in personal computers are used for computation, text editing, multimedia display, and communication over the internet. Many more microprocessors are part of embedded systems, providing digital control of a multiple of objects from appliances to automobiles later to cellular phones and industrial process control. The disadvantage of microprocessor is that, all the input and output ports, memories must be interfaced externally. This disadvantage is eliminated by the development of microcontroller wherein all the input, output ports and memories slots are integrated within the chip.

Microcontrollers

The microcontroller was invented at Texas Instruments (TI) in the early 1970s, around the same time as the first microprocessor was being invented at Intel. Early microcontrollers were simply microprocessors with built-in memory such as RAM and ROM. Later, microcontrollers evolved into a wide array of devices tailored for specific embedded systems.

In 1971, the first microcontroller was invented by two engineers at Texas Instruments, Gary Boone and Michael Cochran created the TMS 1000, which was a 4-bit microcontroller with built-in ROM and RAM. The microcontroller was used internally at TI from 1972 until 1974, and was refined over the years. In 1974, TI offered the TMS 1000 for sale to the electronics industry.

Now major manufacturers of microcontroller are Microchip and Atmel corporations. Microcontrollers are used in automatically controlled products and devices, such as automobile engine control systems, implantable medical devices, remote controls, office machines, appliances, power tools, toys and other embedded systems. We can now find microcontrollers in all kinds of electronic equipment. Any device that measures, stores, controls, calculates, or displays information must have a microcontroller chip inside.

A microcontroller usually contains Central Processing Unit (CPU), Random Access Memory (RAM), Read Only Memory (ROM), Input/output ports, Timers and Counters, Interrupt Controls, Analog to Digital converters, Digital to Analog converters, Serial interfacing ports, Oscillatory circuits.

Nanoelectronics - future trend in electronics

Nanoelectronics refer to the use of nanotechnology on electronic components, especially transistors. Although the term nanotechnology is generally defined as utilizing technology less than 100 nm in size, nanoelectronics often refer to transistor devices that are so small. In 1965 Gordon Moore observed that silicon transistors were undergoing a continual process of scaling downward, an observation which was later codified as Moore's law. Since his observation transistor minimum feature sizes have decreased from 10 micrometers to the 28-22 nm range in 2011. The field of nanoelectronics aims to enable the continued realization of this law by using new methods and materials to build electronic devices with feature sizes on the nanoscale.

Applications of Electronics

1. Entertainment

Radio broadcasting in the early 20th century brought the first major consumer product, the broadcast receiver. Audio equipment like radio, tape recorder, music system, a public address system, video equipment, television receiver, computer etc gives best entertainment. Satellite radio can be received in a much wider geographical area than terrestrial FM radio stations. Use of Set Top Box for the reception of digital TV, in particular, high definition broadcasting, Internet TV and the delivery of multimedia content are becoming common. A computer with or without internet provides audio video entertainment. Songs, movies, games, TV channels, FM stations can be played on the mobile phones to have entertainment at any time anywhere. Electronic gadgets provides entertainment from a new born to age old person.

2. Communication

Advancement of electronics resulted in a fastest communication. By mobile phones, internet, email it is possible to communicate anywhere in the world within seconds. With the internet we can access information in our finger tips. An email containing voice, video, and data can be sent or received within fractions of second around the world. Virtual Private Network (VPN), Wide Area Network (WAN), Video Conferencing, etc are important communication services available on the Internet. Common methods of Internet access include dial-up, landline, broadband, Wi-Fi, satellite and latest generation (XG) cell phones. Communication satellites became feasible because of microelectronics. Satellites orbiting earth relay analog and digital signals carrying voice, video, and data to and from one or many locations worldwide. With the invention of optical fiber cable we can send the information with the light rays without degradation of signals over a long distance.

3. Defence Applications

Defence services are using electronic equipment. Radar, sonar and infrared systems are used to detect and locate enemy jet fighters, war-ships and submarines, and then to control the aiming and firing of guns. Guided missiles are completely controlled by electronic means. Electronic circuits provide a means of secret communication between the head-quarter and different units. Such a communication has become absolutely essential. Missiles controlled by electronic signals can target enemies very accurately over long distances. Electronic security systems are used across the border to guard the country.

4. Industrial Applications

Use of automatic control systems in different industries is increasing day by day. Control of thickness, quality, weight and moisture content of a product developed/manufactured can be easily done by such systems. Robots are programmed to faithfully carry out specific repetitive actions with a high degree of accuracy as well as they work in toxic conditions. Use of computers has made processing of task simple and convenient. Some of the machines are controlled by the computer programs to check accuracy in work, where quality of the product is important. Using computers, data of the employee will be stored for accounting purposes. Electronics fire detectors, burglar alarms, smoke detectors and CC camera provides security to industries. Even the power stations, which generate thousands of megawatts of electricity, are controlled by electronic devices and circuits.

5. Medical Applications

Development of medical electronic equipments provides best healthcare. Doctors and scientists are finding new uses of electronic systems in the diagnosis and treatment of different diseases. The quality and availability of health care are becoming increasingly dependent on radically new diagnostic and monitoring instruments provided by electronics. Electrocardiographs (ECG), X-rays, short-wave diathermy units, ultrasound scanning machines, endoscopy, thermometers, blood-pressure measuring instruments, blood-sugar measuring instruments etc. are in common use. In summary, the initial impact of integrated electronics on health care is now visible, and consequently it is apparent that we are beginning a new era of revolutionary advances in medical instrumentation.

Impact of electronics on quality of life

Electronic technology has significantly transformed the way we live, we communicate, we do our everyday tasks and we have entertainment. It is all because of advanced technology in electronics that made it possible to achieve something with convenience. Since the dawn of electronics, almost everything has been automated to make daily tasks as whole lot easier and faster than ever before. In a sense, electronic technology has increasingly become a part of our lives especially in this millennial age.

Medical electronic equipments are used to detect and cure the diseases. Healthcare may indeed present the most promising opportunity to improve the quality of life in our society through electronics.

Technology has brought sweeping changes to the look and form of modern entertainment. Computer-generated imagery (CGI) has vastly improved the quality of special effects, allowing climax of movie scenes and superhero stunts to look more realistic than ever.

Electronics has simplified many difficult tasks in the industry and household work. The electronic devices are taking care of difficult, routine and time consuming industrial and household work. A packing machine packs thousand of components in an hour. A security system guards home, office or industry. Electronic quality control equipments are used to test the quality of the product developed.

Many crucial processes are made easy with the use of electronics. The machines are now taking the place of humans. The robots can perform all the difficult tasks with its powerful batteries. A robot can work without rest and it also works in toxic conditions where human beings are not able to work.

Electronic systems make the transport system better, accident proof, environment friendly. Use of GPS systems in the vehicles are used to trace the vehicle from the distant place.

There is no need to mention that how the invention of computers changed the face of the world. Computers can store huge amount of data and information. The internet has become the largest and the most effective communication platform. Nobody can think of this world without computers and internet. Information can reach people within seconds over the internet. Internet has also brought various different, innovative communication means like emailing, chatting, and the voice conversation. With internet we can book air tickets, check the bank balance, make money transfer, shop online, pay electricity bills etc., any where at any time. Online trading became popular with the internet and email. We can use digital library for studying. A digital library is a library in which collections are stored in digital formats (as opposed to print, microform, or other media) and accessible via computers. The digital content may be stored locally, or accessed remotely via computer networks. With ATM we can get transactions such as: deposits, withdrawals, obtaining account information, and other types of transactions, often through interbank networks. E-learning provides online learning of class work through the internet.

In the late 1970s, average consumers in a developed country probably had a TV, a Hi-Fi system, and a VCR in their homes. Today, the same consumers have a digital TV, PC, DVD-recorder, game consoles, set-top box, and may be regularly using portable devices such as mobile phones, digital cameras, MP-3 players, and camcorders.

Digital cameras and digital televisions help us to experience live shows and improve the quality of pictures. Satellite TV's and satellite radios enables the broadcasting of all the important events across the globe.

Following the trend, the home appliance industry has observed an increased adoption of electronics content in consumer goods such as washers and dryers, refrigerators, air conditioners, microwave ovens, etc.

Mobile phones have broadened the horizons of communication. Today, no one can imagine life without mobile phone. Over the last couple of years, cell phone applications such as text messaging, gaming, music, banking, internet, e-mail, global positioning system (GPS) and many others have been revolutionizing the cell phone. With the new world smart phones, applications are nearly endless.

Smart phones are phones that offer PC like functions, while still letting us to be able to talk on them. These phones offer advanced versions of normal applications such as e-mail and other internet applications. They make it easier to access the internet by using advanced operating systems almost like windows for your phone.

Electronics has penetrated every aspect of everybody's life. There are so many fields where the use of electronics have made life easier than before, be it medicine, corporate world, aviation, education, entertainment etc. It has made an impact on all the sectors.

Electronics gives best healthcare, better entertainment, fastest communication, highest security, all together it gives us pleasant comfort.

Questions

One mark Questions

1. What is electronics?
2. Who discovered electron?
3. Who invented Vacuum tube diode?
4. Who invented Vacuum tube triode?
5. How many electrodes are present in vacuum tube triode?
6. Name the most commonly used semiconductor material in device fabrications.
7. Who invented transistor?
8. Who invented integrated circuits?
9. In which year Op Amp was developed?
10. What is internet?
11. Who invented JFET?
12. Expand MOSFET.
13. Expand RAM.
14. Expand PROM.
15. Expand SCR.
16. Expand IGBT.
17. What are voltage controllers?
18. What are rectifiers?

19. What are choppers?
20. What are inverters?
21. What is an IC?
22. Expand VLSI.
23. Name any one application of Op-Amp.
24. What is a microprocessor?
25. What is a microcontroller?
26. When was microcontroller invented?
27. Who developed the first microprocessor?
28. Who developed the first microcontroller?
29. Expand FM.
30. Expand WAN.

Two mark Questions

31. Give a brief note on scope of electronics.
32. What are the job opportunities available in the field of Electronics?
33. Name two semiconductor materials used in device fabrication.
34. Name few power semiconductor devices.
35. Distinguish between microprocessor and microcontroller.
36. Mention few applications of electronics.
37. Write a note on role of electronics in entertainment.
38. Discuss the application of electronics in communication.
39. Write a note on defence applications of electronics.
40. Write a brief note on industrial applications of electronics.
41. Write a note on role of electronics in medical science.
42. Name any two medical electronic equipment.
43. List the household electronic equipment.
44. Write the applications of a cell phone.
45. Mention few applications of internet.

Chapter 2

Principles of Electricity, Network Theorems and AC principles

Dr. William Gilbert

Introduction: Electricity is an important part of our modern civilization and it is hard to imagine life without it. The word electricity originated by a **Greek term 'elektron'** by Dr. William Gilbert. The term elektron means amber which soon gave rise to the English words "electric" and electricity. The Greek philosopher, Thales of Melitus (640-546 BC) discovered that when a piece of amber is rubbed with a fur or wool, it attracted straw or feather due to static electricity. Several other materials also like glass rod, ebonite rod also exhibited the same property of static electricity.

Charge: Suspend two glass rods side by side and rub both the rods with silk. It is observed that rods repel with each other. Similar action takes place if two ebonite rods are suspended when rubbed with fur. However, when a glass rod rubbed with silk is brought near an ebonite rod rubbed with fur, they were found to attract each other. This experiment demonstrated the existence of two types of charges i.e. positive charge and negative charge. **Charge is a property of certain particles which is responsible for electrical force.** A particle with charge will experience a force in an electric field (or in a magnetic field if the charge is moving). A material can be charged by using different methods such as friction, conduction, induction, electric field and heating.

Activity: During winter season, comb your hair with a dry comb. Hold the comb near the small bits of paper, it attracts them. [It shows that the comb is charged by friction between hair and comb. A kind of force produced between hair and comb is called electrostatic force.]

Properties of charges:

1. Like charges repel each other and the unlike charges attract each other.
2. Charges are conserved. It is not possible to neither destroy nor create charges.
3. Charges reside only on the outer surface of a charged conductor.
4. Charge is not affected by motion.
5. Charge is quantized; i.e., charge can take only integral values. ($Q = \pm ne$).
6. The magnitude of the charge on a single electron (-e) or proton (+e) is 1.60218×10^{-19} C.

If n electrons pass through a cross section of a conductor in time t, then total charge passed is $Q = ne$.

The SI unit of charge is coulomb and is denoted by 'C'**.** This unit is named after Charles Augustin de Coulomb, a French Physicist who measured the force between charges.

Charge is said to be one Coulomb if one ampere of current flows in one second.

Charge on a single electron is 1.60218×10^{-19}C.

Therefore, $\mathbf{1C} = \dfrac{1 \text{ electron}}{1.60218 \times 10^{-19}}$ = **Charge on 6.25×10^{18} electrons.**

Thus one coulomb of charge consists of 6.25×10^{18} electrons

Electric current: The movement of charges through a conductive material constitutes electric current. The strength of **electric current is defined as the rate of flow of charge** through a cross section of a conductor.

If **Q** is the net amount of charge flowing through a cross-section of a conductor in a time't' sec, then the steady current **I** is given by

$$\textbf{Current} = \frac{\textbf{charge}}{\textbf{time}} \qquad \mathbf{I = \frac{Q}{t} = \frac{ne}{t}}$$

If 'dQ' is the small amount of charge flowing in a small change in time 'dt' then the current 'i' is given by,

$$\boxed{i = \frac{dQ}{dt}}$$

Ampere:

The unit of electric current is said to be 1 ampere, if 1 coulomb of charge flows through a cross-section of a conductor in 1 second.

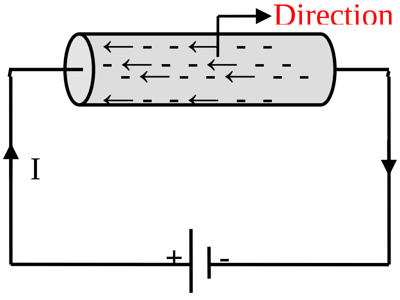
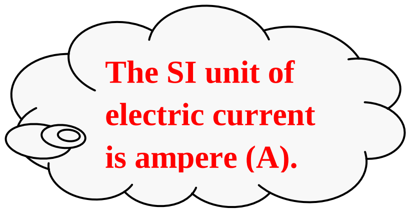


Fig. 2.1



Direction of current: Electrons flow from negative terminal to the positive terminal of the battery through the external (solid) conductor as illustrated in fig. 2.1. But the **direction of conventional electric current is opposite to the direction of flow of electrons.** Conventional current flows from positive terminal of the battery through the conductor to the negative terminal of the battery.

Potential difference and its unit: The amount of work done in moving a unit charge from one point to the other point in a closed circuit is called potential difference.

$$\boxed{\text{Potential difference} = \frac{\text{Work done}}{\text{Charges transferred}}}$$

If 'w' is the amount of work done in moving a charge 'Q' between the two points in a closed circuit, then the potential difference 'V' between the two points is given by,

$$V = \frac{W}{Q}$$

The SI unit of potential difference is volt. The potential difference between two points is said to be 1 volt if 1 joule of work is done in moving 1 coulomb of electric charge from one point to another.

$$1\ \text{V} = \frac{1\ \text{J}}{1\ \text{C}}$$

Direct Current (DC): The current that flows only in one direction and its magnitude remain constant with time is called direct current (DC). Fig. 2.2(a) shows a DC source connected across a bulb and fig. 2.2(b) shows graphical representation of DC or voltage.

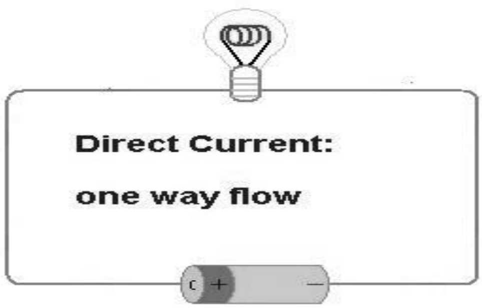


Fig. 2.2(a)

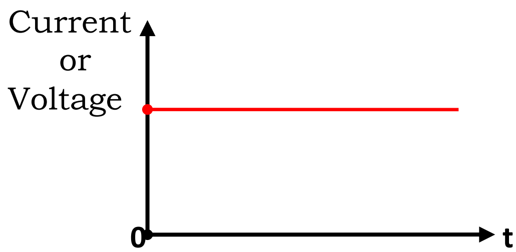


Fig. 2.2(b)

Alternating Current (AC): The current whose magnitude and direction changes continuously and periodically with time is called alternating current. AC flows in one direction during one half cycle and in the opposite direction during the next half cycle. Fig. 2.3(a) shows AC is connected across a bulb. Fig. 2.3(b) shows ac voltage wave form.

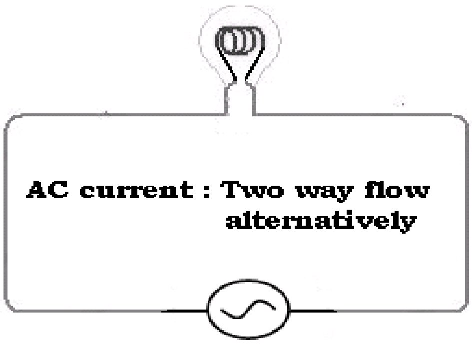


Fig. 2.3(a)

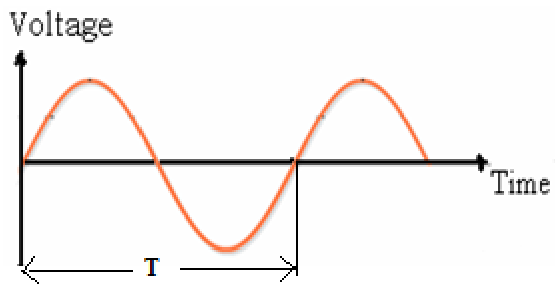
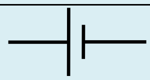


Fig. 2.3(b)

Comparison between the direct current and the alternating current

Direct Current	Alternating current
1. DC source symbol. 	AC source symbol. 
2. Direct current remains constant with respect to time.	Alternating current varies periodically with respect to time
3. DC has no frequency.	AC has certain frequency, i.e. $f = \frac{1}{T}$
4. While transmitting DC there is maximum energy loss.	While transmitting AC there is minimum energy loss.
5. Current flows in one direction. Direct current and voltage are represented by I and V respectively.	In AC, current flows in both the direction. Instantaneous alternating current and voltage are represented by i and v respectively.
6. Cells, batteries, Regulated power supply, DC generators are some sources of DC.	AC generators, oscillators, function generators are some sources of AC.

Ohm's law


George Simon Ohm

A German Physicist, George Simon Ohm, stated a law that relates the current and voltage in a solid conductor. **It states that, the current flowing through a conductor is directly proportional to the potential difference across its ends, provided the temperature and other physical conditions remain constant.**

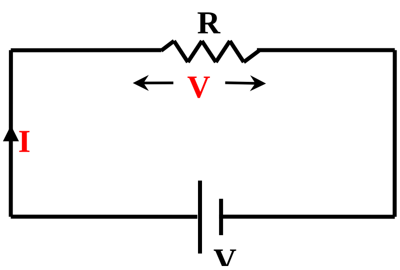


Fig. 2.4

SI unit of resistance is ohm (Ω)

Consider fig. 2.4, 'I' is the current through the conductor of resistance R and 'V' is the potential difference across its ends, then by Ohm's law,

$$I \propto V$$

$$V = I.R$$

Where **'R' is the constant of proportionality** and also called as the **resistance of a resistor**. The value of 'R' depends on the temperature and physical conditions such as dimensions and material of the resistor. The SI unit of resistance is ohm and is denoted by the symbol Ω.

Resistance: It is the property of a conductor that opposes the flow of electric current through it.

Symbol of a resistor:

The relation between current and voltage can be expressed in 3-ways as follows.

1) $V = IR$ 2) $I = \frac{V}{R}$ and 3) $R = \frac{V}{I}$

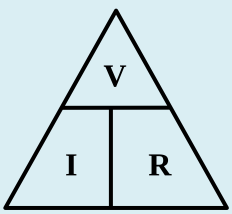


Fig. 2.5(a) A triangular diagram to memorize Ohm's law

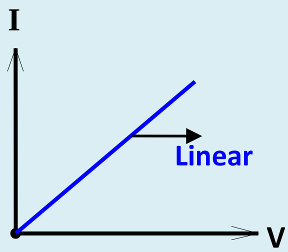


Fig. 2.5(b) V-I characteristics of a linear devices ($V \propto I$)

Fig. 2.5(b) shows the variation of a current is proportional to the applied voltage across a component. Such components are called linear component. A resistor is a linear component.

Limitations of Ohm's law:

1. Ohm's law is not applicable when the physical conditions of a conductor are subjected to change.
2. Ohm's law is not applicable at extreme low and high temperatures.
3. Ohm's law is not applicable for non-linear devices such as electron tube, semiconductors, discharge tubes and electrolytes.
4. Ohm's law is not applicable to arcing devices.

Combination of Resistors:

In electronics, circuits are simplified by simplifying the resistive network. Normally resistors are connected in Series combination or Parallel combination.

Series combination of resistors: When one end of resistor is connected to one end of the other resistor (end to end), they are said to be in series. In this case

1. The current through series resistors remains the same.
2. The voltage divides across series resistor. The voltage drop depends on the value of resistors.

Effective resistance of series combination of resistors (Rs):

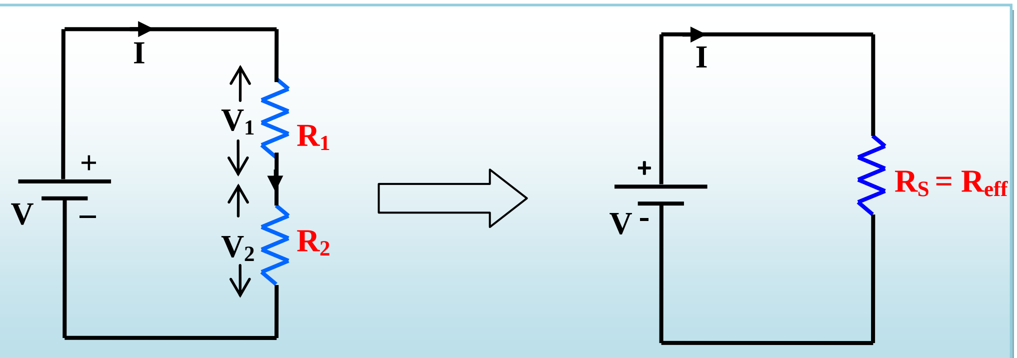


Fig. 2.6(a) Fig. 2.6(b)

Consider the two resistors R_1 and R_2 connected in series across a battery of potential difference 'V' volt as shown in fig. 2.6(a). The current supplied by the battery remains same through the series combination of R_1 and R_2 but the voltage drop across them depends upon their resistance values. Fig. 2.6(b) shows effective resistance R_S of series combination R_1 and R_2 connected to a battery of 'V' volt.

Let 'I' be the current through each resistor and V_1, V_2 be the voltage drops across R_1 and R_2 respectively,

$$V = V_1 + V_2 \qquad \text{...... (1)}$$

By applying Ohm's law to each resistor, we have

$$V_1 = IR_1 \qquad \text{...... (2)}$$

and $$V_2 = IR_2 \qquad \text{...... (3)}$$

Substituting for V_1, V_2 in equation (1) we have

$$V = IR_1 + IR_2$$

Or $$V = I\,(R_1 + R_2) \qquad \text{...... (4)}$$

If R_s or R_{eff} is the effective resistance of the series combination, then by ohm's law the applied voltage will be equal to 'IR_s' as shown in fig. 2.6(b).

i.e. $$V = IR_s \qquad \text{...... (5)}$$

By equating equation (4) and (5), we have

$$IR_S = I\,(R_1 + R_2) \qquad \text{...... (6)}$$

Therefore, $$\boxed{\mathbf{R_{eff} = R_S = R_1 + R_2}}$$

In general, for 'n' number of resistors connected in series we have

$$\boxed{\mathbf{R_{eff} = R_S = R_1 + R_2 + R_3 + \ldots\ldots\ldots\ldots\ldots + R_n}} \qquad \text{...... (7)}$$

From equation (7), the effective resistance of series combination of resistors is equal to the sum of resistances of individual resistors.

Note: The effective resistance of the series combination is always greater than the greatest value of resistance present in the combination.

Parallel combination of resistors:

The two resistors are said to be in parallel when both the ends of one resistor is connected to both the ends of other resistor. In this case

1. The voltage drop across parallel resistors remains the same.
2. The current divides. The current through the resistors depends on the value of resistors.

Effective resistance of Parallel combination of resistors (R_P)

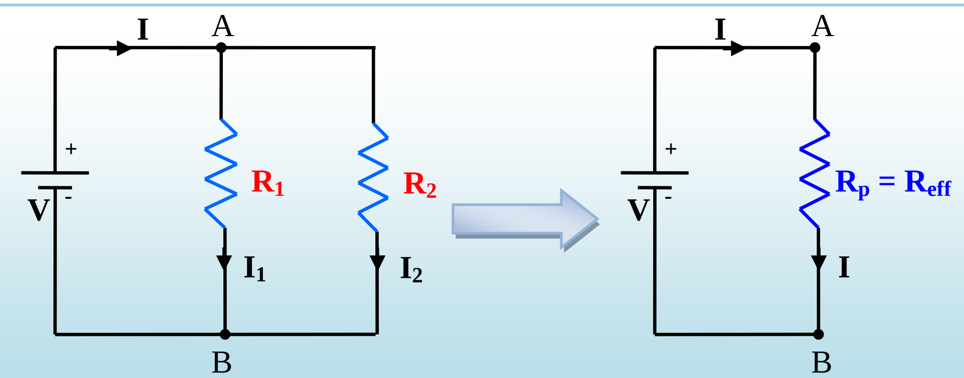


Fig. 2.7(a) Fig. 2.7(b)

Consider two resistors with their respective resistance value R_1 and R_2 connected in parallel across a battery of emf 'V' volt as shown in fig. 2.7(a). At point A, the current 'I' divides into I_1 and I_2 through R_1 and R_2 respectively. The voltage drops across R_1 and R_2 will always be same. Fig. 2.7(b) shows the effective resistance R_p of parallel combination R_1 and R_2 connected to a battery of 'V' volt.

At point 'A', $I = I_1 + I_2$ …… (1)

Then by Ohm's law, we have

$$I_1 = \frac{V}{R_1} \text{ and } I_2 = \frac{V}{R_2}$$

Substituting the values of I_1 and I_2 in equation (1), we have

$$I = \frac{V}{R_1} + \frac{V}{R_2} = V\left[\frac{1}{R_1} + \frac{1}{R_2}\right] \qquad \text{...... (2)}$$

If R_p is the effective resistance of the parallel combination of resistors connected across the same battery of 'V' volt as shown in fig. 2.7(b), then by ohm's law we have $I = \frac{V}{R_P}$ ...... (3)

From equations (2) and (3), we have

$$\frac{V}{R_P} = V\left[\frac{1}{R_1} + \frac{1}{R_2}\right]$$

Therefore, $$\boxed{\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2}} \qquad \text{...... (4)}$$

or $R_P = \frac{R_1 R_2}{R_1+R_2}$ for two resistors in parallel

In general, for 'n' number of resistors connected in parallel, we have

$$\boxed{\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots + \frac{1}{R_n}} \qquad \text{...... (5)}$$

Therefore from equation (5) reveals that, **in case of parallel combination of resistors, the reciprocal of effective resistance is equal to the sum of reciprocals of the individual resistances.**

Note:

1. When two equal resistors are in parallel, total resistance reduces to one half of its resistance value.
2. When three equal resistors are in parallel, total resistance reduces to one third of its resistance value.
3. When n equal resistors are in parallel, total resistance reduces to $1/n^{th}$ of its resistance value.
4. The effective resistance of the parallel combination is always less than the least value of resistance present in the combination.

Series and parallel combination of resistors: Fig 2.8 shows the circuit of series-parallel combination of resistors. The effective resistance of the circuit between the terminals A and D is calculated as given below.

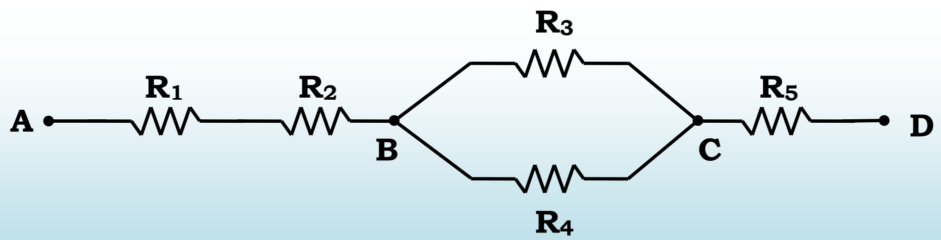


Fig. 2.8

Illustration: R_3 and R_4 are in parallel and the combination is in series with R_1, R_2 and R_5. Thus,

Effective resistance between B and C = $R_3 \,||\, R_4 = \dfrac{R_3R_4}{R_3+R_4}$

The effective resistance between A and D is

$$R_{eff} = R_1 + R_2 + \frac{R_3R_4}{R_3+R_4} + R_5$$

Electric power and Electric energy: The use of electricity is common in our day to day life. 100 watt bulb gives brighter light than a 60 watt bulb. Electricity bill to the power supplying company is paid for the electric energy consumed over a period of month. Thus the power and energy calculations are important in the circuit analysis.

Electric power is the rate of doing work and is measured in watts. Since both the work and energy are equivalent, it can also be defined as the rate at which the electrical energy is supplied by the source. Thus

$$\text{Power} = \frac{\text{Work done}}{\text{time}} = \frac{\text{Energy supplied}}{\text{time}}$$

Where 'P' is the electric power measured in watt (W), work done is in joule (J) and time is in second (S).

The electric power is said to be 1 watt, if 1 joule of work is done in 1 second.

$$P = \frac{W}{t} = \frac{W}{Q} \times \frac{Q}{t}$$

Therefore, $\boxed{P = VI}$

Power dissipation in a resistor: When the current passes through a resistor, the electrons collide with the atoms present in the resistor. The collision of electrons converts electrical energy into heat energy. Thus the electric power is said to be dissipated or consumed in the resistor in the form of heat.

The power dissipation in a resistor can be expressed by three methods as follows. We know that,

$$P = VI \qquad \ldots\ldots (1)$$

From the above equation, two more power relations are derived.

$$P = VI = (IR)\,I = I^2R \qquad \ldots\ldots (2)$$

since $V = IR$

$$P = VI = V\frac{V}{R} = \frac{V^2}{R} \qquad \ldots\ldots (3)$$

since $I = \frac{V}{R}$

$$\boxed{P = VI = I^2R = \frac{V^2}{R}}$$

Observations:

1. Observe the power rating given on the iron box, CFL bulb and mobile charger.
2. You will be given an ordinary bulb, a tube light and a CFL bulb. Which one is more power efficient and why?

Electric energy (E): The amount of power supplied or consumed in certain duration of time is called electric energy. When work is done, energy is utilized. Therefore the total work done is the electric energy.

We know that, the electric power, $P = \frac{W}{t}$

Where, w → electric energy consumed in a time `t'.

Therefore, electric energy, $\boxed{\mathbf{E = w = P \cdot t}}$

Where P is measured in watt, t in second and w in joule.

The electric bill has to be paid to the power supplying company for the electric energy consumed over a period of month or time. Thus the energy calculation in hour is important. Therefore, P is in watt and t is in hour (60 × 60 sec) then,

Electric energy (E) = $w = P \times t$

$$1 \text{ watt-hour} = 1 \text{ W} \times 1 \text{ hr}$$

$$= 1 \text{ W} \times (60 \times 60) \text{ sec}$$

$$\mathbf{1 \text{ Wh} = 3600 \text{ joule}}$$

The S.I. unit of electrical energy is joule.

Commercial unit of electrical energy:

Actually joule (watt-second) is a very small quantity. Therefore it is inconvenient to use this unit where a large quantity of energy is involved. So, for commercial purposes bigger unit of electrical energy i.e., '**kilowatt-hour**' is used which is written in short form as kWh.

One kilowatt-hour is the amount of electrical energy consumed when an electrical appliance having a power rating of 1000 watt is used for 1 hour. kWh is called the commercial unit or Board Of Trade (BOT) unit or simply one unit.

Therefore $\quad 1 \text{ kWh} = 1000 \text{ J/sec} \times [60 \times 60] \text{ sec}$

$$1 \text{ kWh} = 1000 \times 3600 \text{ J}$$

$$1 \text{ kWh} = 3.6 \times 10^6 \text{ J.}$$

Worked examples

1. Find the total charge on five electrons.

Solution: Given: n = 5, Q = ?

We know that $e = 1.602 \times 10^{-19}$ C

$Q = -ne$ (negative sign indicates electrons)

$= -5 \times 1.602 \times 10^{-19}$

$\mathbf{Q = -8.010 \times 10^{-19}}$ **coulomb**

2. Find the number of electrons in 5 coulomb of charge.

Solution: Given: Q = 5 C, n = ?

We know that $e = 1.602 \times 10^{-19}$ C

$Q = \pm ne$

No. of electrons in 1 coulomb, $n = \frac{1}{e}$

Therefore, No. of electrons in 5 coulomb, $n = \frac{5}{e}$

$\mathbf{n = 3.12 \times 10^{19}}$

3. Find the number of electrons flowing in a conductor in one second if 5 amperes of current flows through it.

Solution: Given: t = 1 second, n = ?

We know that $I = \frac{Q}{t} = \frac{-ne}{t}$

$$n = \frac{I \times t}{e} = \frac{5 \times 1}{1.602 \times 10^{-19}} = \mathbf{3.12 \times 10^{19}} \text{ electrons}$$

4. A 60 W light bulb is connected to 220 V power supply. What is the current that flows through the bulb? Find the resistance of the bulb.

Solution: Given: P = 60 W, V = 220 V

I = ? and R = ?

W.k.t $P = VI$

$$I = \frac{P}{V} = \frac{60}{220} = 0.2727 \text{ A}$$

W.k.t $V = IR$

$$R = \frac{V}{I} = \frac{220}{0.2727} = 806.75\ \Omega$$

5. Find the resistance of a filament of the bulb when it is glowing with a current of 200 mA and the applied voltage 230 V.

Solution: Given: $I = 200 \text{ mA} = 200 \times 10^{-3}$ A

$V = 230$ V.

W.k.t $R = \frac{V}{I}$

$$R = \frac{230}{200 \times 10^{-3}} = 1.15 \times 10^{3}\ \Omega = 1.15\ \text{k}\Omega$$

6. A mixer is operated with 230 V of AC supplied with a power rating of 460 W for one minute. Find a) the current flowing through it and b) number of electrons flowing in one minute.

Solution: Given: V = 230 V, P = 460 W, t = 1 minute = 60 sec

I = ? and n = ?

a) W.k.t $P = V I$

$$I = \frac{P}{V} = \frac{460}{230} = \mathbf{2\ A}$$

b) W.k.t $I = \frac{Q}{t} = \frac{ne}{t}$

$$n = \frac{It}{e} = \frac{2 \times 60}{1.602 \times 10^{-19}} = \frac{120 \times 10^{19}}{1.6}$$

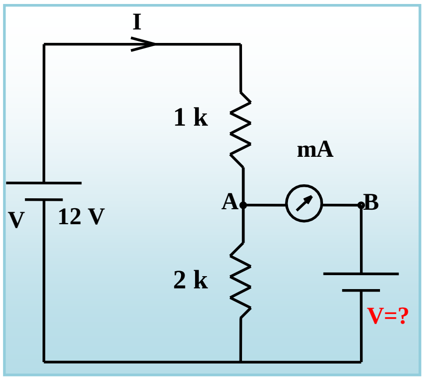
$$\mathbf{n} = \mathbf{750 \times 10^{18}} \text{ electrons}$$

7. Find the power consumed by a telephone when operated with a 9 V and 200 mA of current.

Solution: **Given:** V = 9 V, I = 200 mA = 200 x 10^{-3} A and P = ?

We know that (w.k.t) P = VI = 9 x 200 x 10^{-3} W = 1.8 W

8. Find V if the current through the milliammeter is zero in the given circuit.



Solution: Since the current in the milli ammeter is zero, it indicates that the potential at A is same as potential at B i.e., V volt. So we shall find the potential at A i.e., voltage across 2 k.

The total current $I = \frac{V_T}{R_T} = \frac{12\text{ V}}{1\text{ k} + 2\text{ k}} = 4 \times 10^{-3}$ A

Voltage across 2 k = I x 2 k = 4 x 10^{-3} x 2 x 10^{3} = 8 V

The potential of A is 8 V. Thus the potential at B must also be 8 V so that the current in milliammeter is zero. Therefore V is same as the potential at A.

i.e., V = 8 V.

Note: The current flowing in the circuit is zero when the potential across its terminals is same.

9. Find the total resistance of the series combination of resistors 5 kΩ, 10 kΩ and 15 kΩ.

Solution: W.k.t, for series combination,

The total resistance $R_S = R_T = R_1 + R_2 + R_3$ = 5 k + 10 k + 15 k = 30 kΩ

10. Find the total resistance when the three 30 kΩ resistors are connected in parallel.

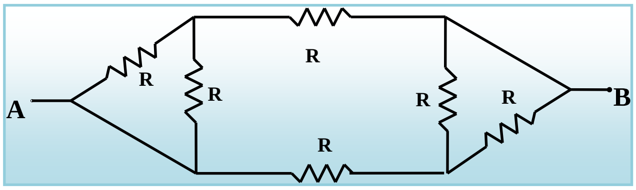
Solution: W.k.t for parallel combination of resistors,

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

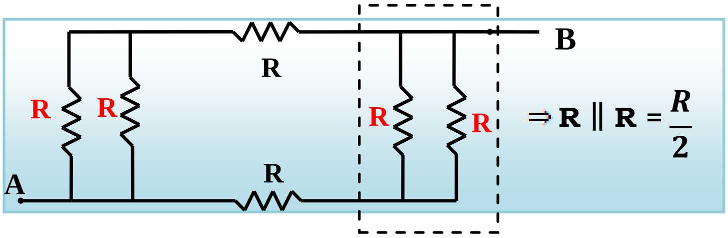
$$\frac{1}{R_T} = \frac{1}{30k} + \frac{1}{30k} + \frac{1}{30k}$$

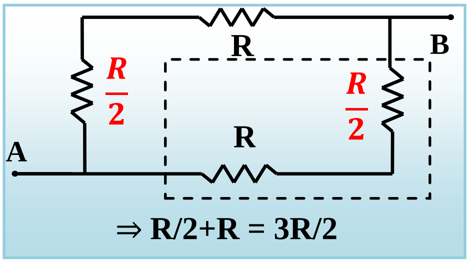
$$\mathbf{R_T = 10\ k\Omega}$$

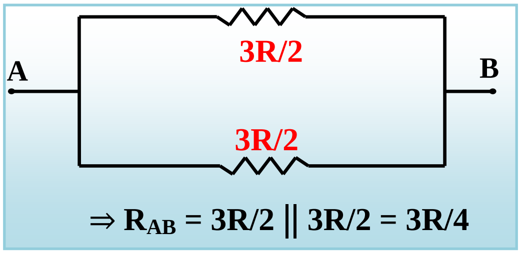
11. Find the total resistance between A and B.



Solution: The above circuit can be simplified as in the diagrams given below.

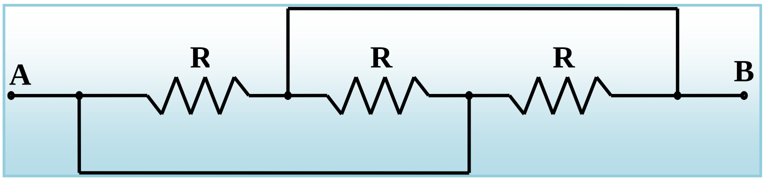




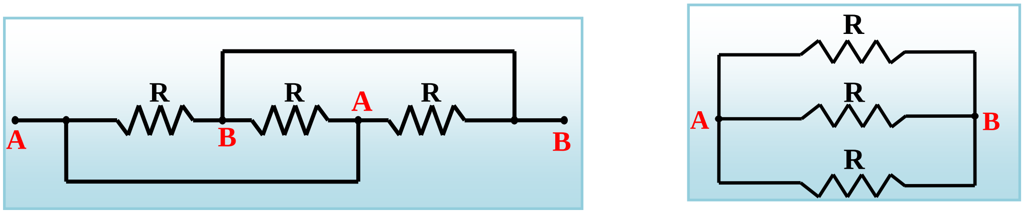


Therefore, total resistance between A and B $= \frac{3R}{4}$

12. Find the resistance between A and B.



Solution: The above circuit can be simplified as in the diagrams given below by marking the common nodes.Rearanging the resistors between the node A and B.



The total resistance between A and B is $\frac{R}{3}$.

DC sources and Network theorems:-

DC (direct current) sources supply dc voltage or current to the circuit or load. Direct current is produced by sources such as cells, batteries, solar cells, DC power supplies etc. A practical dc-source has an internal resistance. Internal resistance of a battery is dependent on the battery size, chemical properties, age, temperature and the discharge current. For a dc voltage source V_S the internal resistance 'r_S' is shown in series with the source as in fig. 2.9. Internal resistance 'r_S' of a source is the resistance offered by the source itself in a circuit.

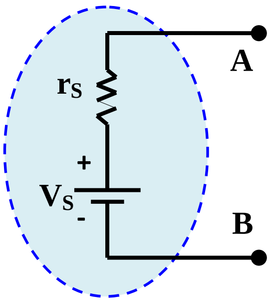


Fig. 2.9

Fact: Since the invention of the first battery (or "voltaic pile") in 1800 by Alessandro Volta and especially since the technically improved Daniell Cell in 1836, batteries have become a common power source for many household and industrial applications.

What is the difference between a Cell and a Battery?

Cell: The cell is a source of an electrical energy. The symbol for a cell used in the circuit diagram is as shown in fig. 2.10(a).

Battery: A battery can be a single cell or combination of cells.
The symbol for a battery used in the circuits is as shown in fig. 2.10(b).
Fig.2.10(c) shows various cells and batteries.

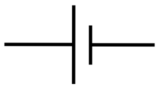


Fig. 2.10(a)

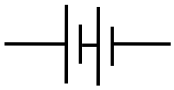


Fig. 2.10(b)

Fig. 2.10(c).

- Series combination of cells gives desired voltage rating.
- Parallel combination of cells gives desired current rating.

Types of batteries:

Primary batteries: These batteries cannot be recharged once they are exhausted. For example, Zinc–carbon batteries and alkaline batteries.

Fig. 2.11

Secondary batteries: These batteries can be recharged. Storage battery is a common example of the secondary battery as shown in fig. 2.11. Examples for secondary batteries are nickel–cadmium (NiCd), nickel–zinc (NiZn) and lithium-ion (Li-ion). Li-ion has the highest share in the market. Li-ion batteries are widely used in mobile phones.

Types of cells:

There are many general types of electrochemical cells. According to the chemical process and design, cells are broadly classified as wet cell and dry cell.

Wet cell: A wet cell battery has a liquid electrolyte. Wet cells were typically fragile glass containers with lead rods hanging from the open top, and needs a careful handling to avoid spillage. Ex: Leclanche cell, Grove cell, Bunsen cell, Chromic acid cell.

Dry cell: A dry cell has the electrolyte immobilized as a paste, with a moisture sufficient to allow current to flow. Unlike a wet cell, a dry cell can operate in any orientation without spilling as it contains no free liquid, making it suitable for portable equipment. Ex: Zinc–carbon cell, alkaline cell. nickel-cadmium (NiCd) and lithium-ion (Li-ion) cell.

Fig. 2.12 Wet cell

Fig. 2.13 Dry cells

Observation: Find the type of battery used in the car, UPS inverters and mobile phones.

Electrical source: It is a device which provides electrical energy to the circuit and is classified into two types.

Voltage source: The electrical energy supplied to the circuit is in the form of voltage.

Current source: The electrical energy supplied to the circuit is in the form of current.

Voltage source:

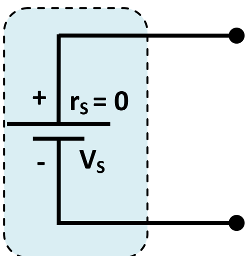


Fig. 2.14(a) Ideal voltage source

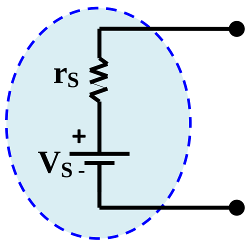


Fig. 2.14(b) Practical voltage source

Ideal voltage source: An ideal voltage source is one that supplies constant voltage to the load irrespective of the load resistance R_L. **Ideal voltage source has zero internal resistance** as shown in fig. 2.14(a). It means that the ideal voltage source supplies a constant voltage across its terminals no matter what current is drawn from it. An ideal voltage source V_S connected across a variable load resistance R_L is shown in fig 2.15(a). The I-V characteristics of an ideal voltage source is as shown in fig. 2.15(b).

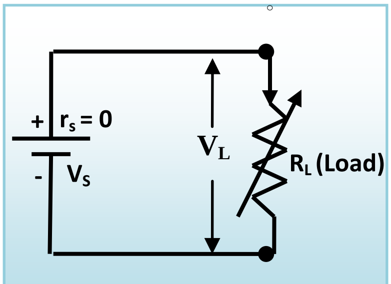


Fig. 2.15(a)
Ideal dc voltage source

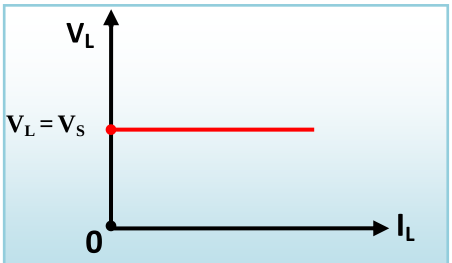


Fig. 2.15(b) I-V Characteristics of ideal dc voltage source

However, a practical dc voltage source shown in fig. 2.14(b) does not exhibit such characteristics as shown in fig 2.15(b) in practice. It is noticed that as the load resistance R_L connected across the source is decreased, the corresponding load current I_L increases while the terminal voltage across the source decreases as in equation (1). It is realized that, voltage drop across the terminals is due to internal resistance of the voltage source. Fig. 2.16(a) shows the practical voltage V_S in series with its internal resistance r_S. The I-V characteristics of the practical voltage source can be described by an equation

$$V_L = V_S - I_L r_S \quad \ldots\ldots (1)$$

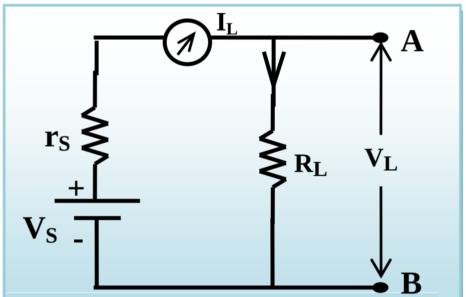


Fig. 2.16(a) Practical dc voltage source

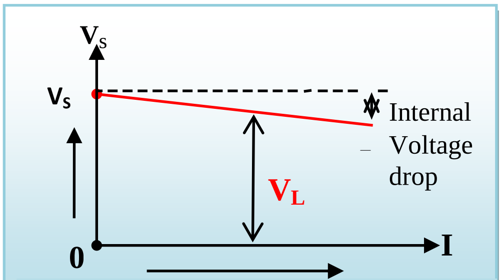


Fig. 2.16(b) I-V Characteristics of practical Voltage source

Current source: Symbol of ideal current source and practical current source are given in fig. 2.17(a) and 2.17(b) respectively.

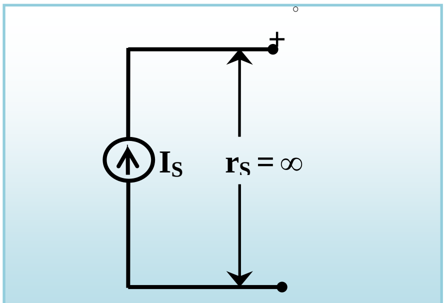


Fig. 2.17(a)

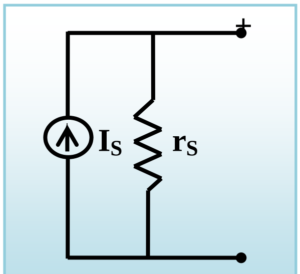


Fig. 2.17(b)

Ideal current source: An ideal current source is one that supplies constant current to the load irrespective of the load resistance. Ideal current source has infinite internal resistance.

Conversion of voltage source into current source:

Fig. 2.18 is a practical voltage source having internal resistance r_S with its terminals A and B. In order to convert a voltage source into its equivalent current source, determine the current I_S through the short circuit (practically source should not be shorted) using the formula,

$$I_S = \frac{V_S}{r_S}$$

Now, voltage source V_S having series internal resistance r_S is replaced by a current source I_S with an internal resistance r_S in parallel as shown in fig. 2.19. The internal resistance r_S is same for both voltage source and current source.

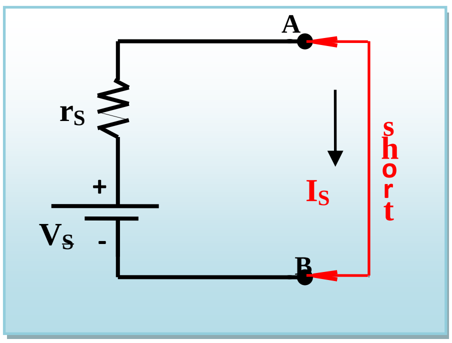


Fig. 2.18

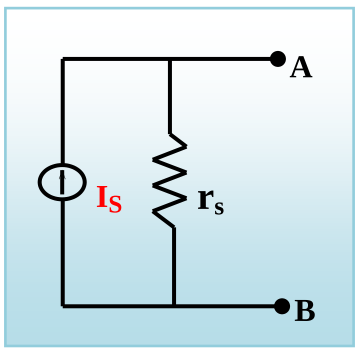


Fig. 2.19

Conversion of current source into voltage source:

Consider a current source I_S with internal resistance r_S as shown in fig. 2.20(a). To convert a current source into its equivalent voltage source, determine the voltage across r_S using the formula

$$\mathbf{V_S = I_S \times r_S}$$

Now, current source with a parallel internal resistance r_S is replaced by a voltage source V_S with the series internal resistance r_S as shown in fig. 2.20(b). The internal resistance r_S is same for both voltage source and current source.

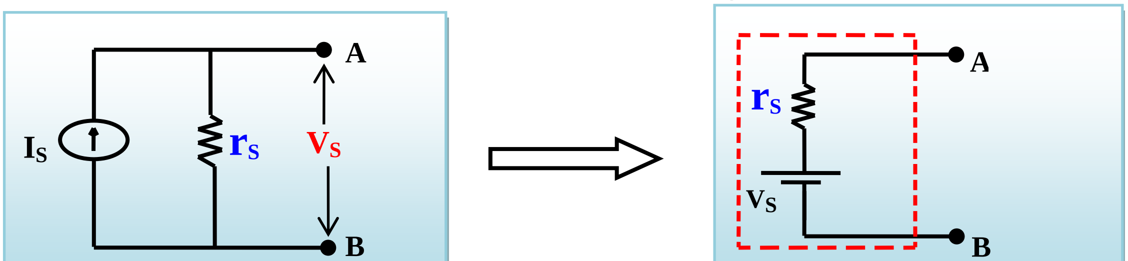


Fig 2.20(a) Current source

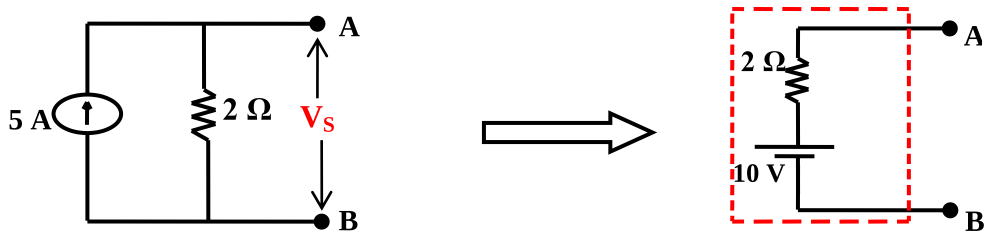
Fig 2.20(b) Voltage source

Illustration:

Convert the current source of 5 A with internal resistance 2 Ω into voltage source.

Solution:

$$V_S = I_S \times r_S = 5 \times 2 = 10 \text{ V}$$
$$r_S = 2\ \Omega$$



Current source

Voltage source

Kirchhoff's laws:

Gustav Robert Kirchhoff

Introduction: With the help of Ohm's law simple circuits consisting of a few elements can be easily analyzed. However, when the circuits are more complicated Ohm's law is not sufficient to analyze the circuits. Thus, Kirchhoff's laws along with Ohm's law help us to analyze the complicated circuits. Some of the terms used in circuit analysis are given below.

Circuit: It is the interconnection of sources, components and devices to form the closed path through which the current flows. In fig. 2.21, Source V_S and resistors R_1, R_2, R_3 are interconnected to form a circuit.

Node: A node or a junction in an electrical circuit is a point where the current divides. In fig. 2.21 points 'b' and 'd' are the nodes.

Branch: A branch is a conductive path through which the same current flows. Fig. 2.21 has three branches (d-a-b, b-c-d, and b-d).

Loop: A loop is any closed path in an electrical circuit. It is a closed path formed by starting at a point, passing through a set of nodes and returning back to the starting point without passing through any node more than once. Fig. 2.21 has three loops, namely, a-b-d-a, b-c-d-b, a-b-c-d-a.

Mesh: A mesh is an independent loop, i.e. it does not have any other loops within it. In fig. 2.21 the two loops (a-b-d-a, b-c-d-b) just identified are also 'meshes' but other loop (a-b-c-d-a) is not a mesh.

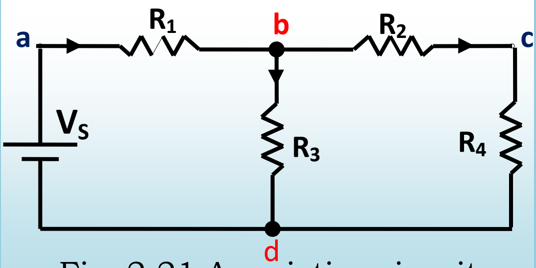


Fig. 2.21 A resistive circuit

Note: All the mesh can be loops, but all the loops cannot be mesh.

Linear network: The parameters of a linear circuit do not change their values with voltage and current. It means that the current and voltage are proportionally varying in a linear circuit. Ex: Circuit consisting of resistor.

Non linear network: The parameters of a circuit change their values with current and voltage. It means that the current and voltage are not proportionally varying to each other. Ex: Circuit consisting of diode, transistor.

Bi-lateral Network: A nework that has same relationship between current and voltage for two possible directions of current as in the case of circuit having resistor, inductor and nonpolar capacitor.

Unilateral Network: A network that has different current and voltage relationships for the two possible directions of a current as in the case of diode and transistor circuit.

Kirchhoff's laws were first introduced in 1847 by the German physicist Gustav Robert Kirchhoff (1824-1887).

Kirchhoff's current law (KCL) or Node rule

Algebraic currents at a node in an electricl network is zero.
KCL states that the sum of currents entering a node is equal to the sum of currents leaving that node.
i.e., $\Sigma \, I_{\text{entering}} = \Sigma \, I_{\text{leaving}}$

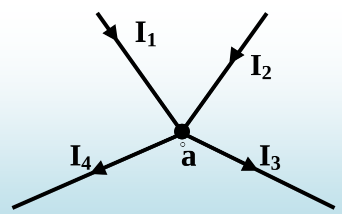


Fig. 2.22 Branch currents

Applying KCL to the node 'a' in fig. 2.22

$$I_1 + I_2 = I_3 + I_4$$

Where the currents I_1 and I_2 are entering the node and I_3 and I_4 are leaving the node.

KCL is based on the law of conservation of charges. That is charges do not accumulate at any point in a circuit. Hence the algebraic sum of currents meeting at a node is zero.

Kirchhoff's voltage law (KVL) or loop rule

KVL states that the algebraic sum of emfs in any closed loop of a network is equal to the algebraic sum of IR drops in that loop.

i.e., Σ emf = Σ IR.

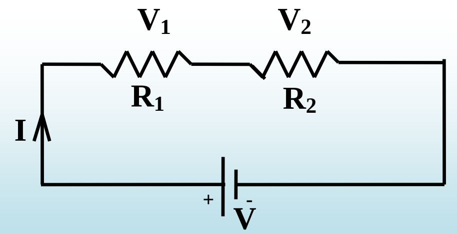


Fig. 2.23

Applying KVL for the circuit given in fig. 2.23

$$V = IR_1 + IR_2$$

$$V = V_1 + V_2$$

KVL law is based on the law of conservation of energy where, voltage is defined as the energy per unit charge. The total amount of energy gained per unit charge must be equal to the amount of energy lost per unit charge. The conservation of energy states that energy can neither be created nor be destroyed; it can only be transformed from one form to another.

While applying KVL for the circuit analysis proper algebraic signs are assigned for both IR and battery emf.

Sign conventions for IR drops and battery emfs:

The **emf** of a voltage source is taken as positive if the direction of the assumed loop current is along the direction of the current supplied by the battery emf as shown in fig. 2.24(a). The emf of a voltage source is taken as negative if the direction of the assumed loop current is opposite to the direction of current supplied by the battery emf as shown in fig. 2.24(b).

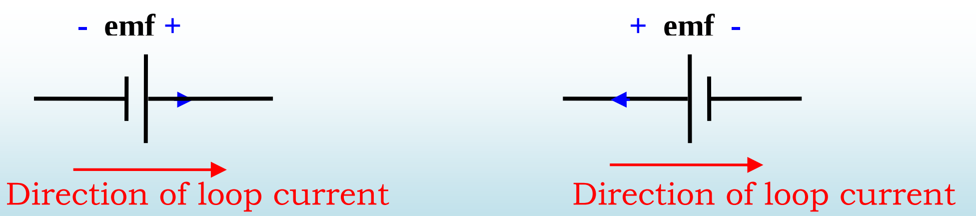


Fig. 2.24(a) emf is taken as +Ve   Fig. 2.24(b) emf is taken as -Ve

IR drops across the resistors is positive if the assumed direction of loop current is in the same direction as that of current flow in a resistor as shown in fig. 2.25(a). Otherwise it is negative as shown in fig. 2.25(b).

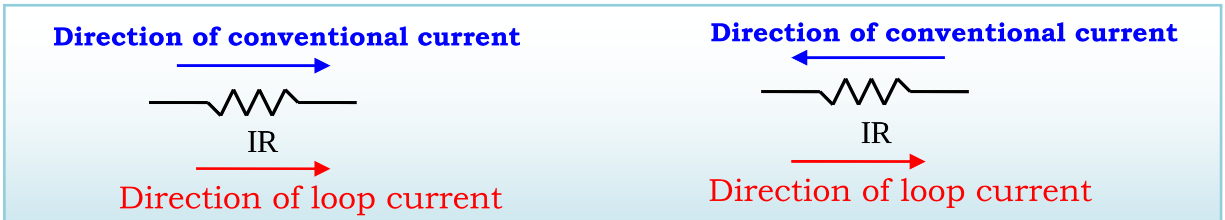


Fig 2.25(a)
IR drop is taken as +Ve

Fig 2.25(b)
IR drop is taken as -Ve

Note: Loop current may be assigned either in clockwise or in anticlockwise direction.

Illustration: Consider the circuit shown in fig. 2.26, the direction of loop current is assigned in clockwise direction. According to the sign conventions, the emf and IR drops will have the following values and signs

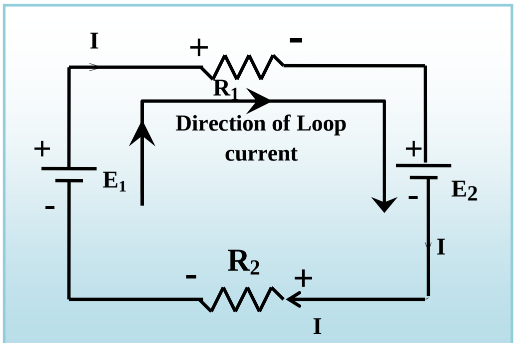


Fig. 2.26

E_1 is + ve,

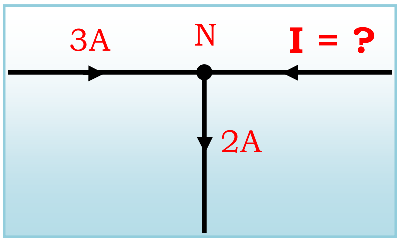
E_2 is – ve.

IR_1 is + ve,

IR_2 is + ve,

Hence according to KVL, $\mathbf{E_1 - E_2 = IR_1 + IR_2}$

Example: Calculate the current I flowing into the node N.



Solution: Applying KCL to the node N, the sum of currents entering the node equals the sum of currents leaving

Thus, 3 A + I = 2 A, $\therefore$ I = -1 A

Circuit analysis using Kirchhoff's laws:

Consider the circuit having branch currents I_1, I_2 and I_1 - I_2 as shown in fig. 2.27.

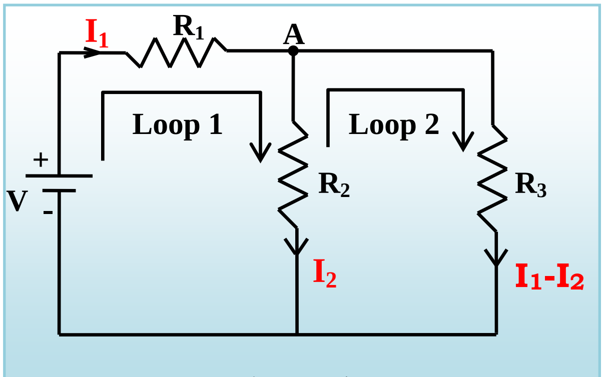


Fig. 2.27

By applying KVL to loop 1

$V = I_1R_1 + I_2R_2$ ......(1)

By applying KVL to loop 2

$0 = (I_1 - I_2)R_3 - I_2R_2$

$0 = I_1R_3 - I_2(R_2 + R_3)$ ......(2)

By simplifying the two simultaneous equations (1) and (2) we can determine the values of I_1, I_2 and I_1-I_2.

Example 1: Find the branch currents in the fig. 2.28.

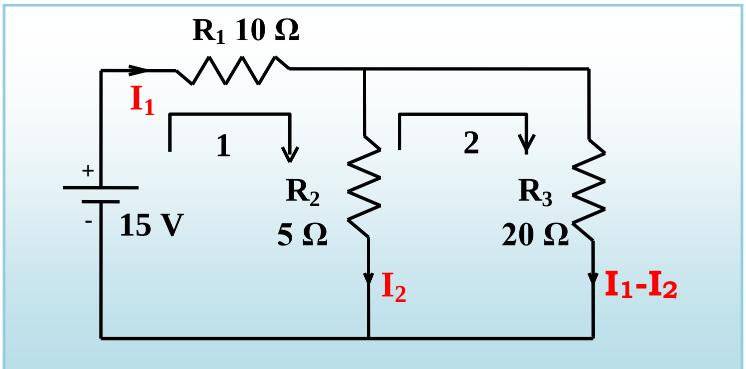


Fig. 2.28

Solution: Consider the circuit having branch currents I_1, I_2 and I_1- I_2

Given $R_1 = 10\ \Omega$, $R_2 = 5\ \Omega$, $R_3 = 20\ \Omega$, $V = 15$ V

Applying KVL to loop1

$15 = 10 I_1 + 5 I_2$ ...... (1)

Applying KVL to loop 2

$0 = 20 (I_1 - I_2) - 5 I_2$

$0 = 20 I_1 - 25 I_2$ ...... (2)

Simplifying the equations (1) and (2)

$75 = 70 I_1$

$I_1 = \frac{75}{70} = 1.07$ A

Substituting I_1 in equation (2)

$0 = (20 \times 1.07) - 25 I_2$

$25 I_2 = 21.4$

$I_2 = \frac{21.4}{25} = 0.856$ A

$I_1 - I_2 = 0.214$ A

Example 2: Analyze sign conventions for solving KVL network having two or more sources in fig. 2.29.

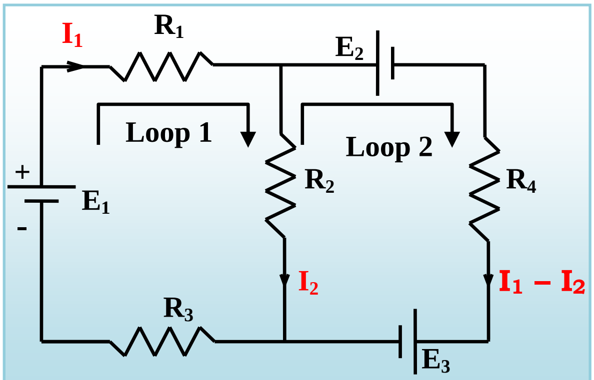


Fig. 2.29

Assume the branch currents I_1, I_2 and ($I_1 - I_2$)

Applying KVL to loop 1 and loop 2

Applying KVL to loop 1

$E_1 = I_1R_1 + I_2R_2 + I_1R_3$

$E_1 = I_1(R_1 + R_3) + I_2R_2$ ......(1)

Applying KVL to loop 2

$- E_2 - E_3 = -I_2R_2 + (I_1 - I_2)R_4$

$- E_2 - E_3 = I_1R_4 - I_2 (R_2 + R_4)$ .... (2)

By simplifying the two simultaneous equations (1) and (2) we can determine the values of I_1, I_2 and ($I_1 - I_2$).

Applications of Kirchhoff's Laws

Voltage divider rule:

Series combination of resistors forms voltage divider circuit. The applied voltage across the series combination of resistors is divided into a number of voltage drops across each resistor.

Consider the two resistors R_1 and R_2 connected in series across the battery of emf V volts as shown in fig. 2.30.

- The current remains same in all the resistors
- The voltage divides across each resistor.

Let the voltage across R_1 and R_2 be V_1 and V_2 respectively.

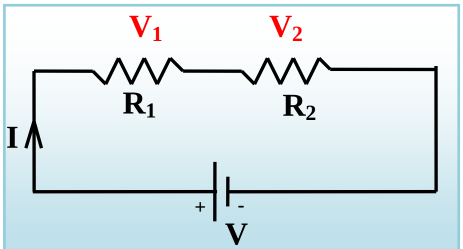


Fig. 2.30

The total current in a circuit $I = \frac{V}{R_T} = \frac{V}{R_1 + R_2}$

Using Ohm's law V_1 and V_2 are calculated as given below

$$V_1 = IR_1 = \frac{VR_1}{R_T} = \frac{V \times R_1}{R_1 + R_2}$$

And

$$V_2 = IR_2 = \frac{VR_2}{R_T} = \frac{V \times R_2}{R_1 + R_2}$$

In general if n-number of resistors are connected in series, voltage across n^{th} resistor is given by

$$V_n = V \times \frac{R_n}{R_T}$$

From the above formula it is clear that **for a series circuit, the voltage drop across any resistance (R_n) is equal to the product of that resistance (R_n) and applied voltage (V) across the circuit divided by the total resistance (R_T) of the circuit.**

Example: Let us find the voltage V_1 and V_2 in a circuit given in fig. 2.31.

According to voltage divider rule $V_n = V \times \frac{R_n}{R_T}$

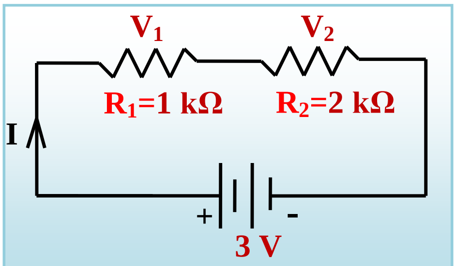


Fig. 2.31

$$V_1 = V \times \frac{R1}{R1+R2}$$

$$V_1 = \frac{3 \text{ x } 1\text{ k}}{1\text{ k}+2\text{ k}} = 1\text{ V}$$

$$\boxed{V_2 = V \times \frac{R_2}{R_1+R_2}}$$

$$V_2 = \frac{3 \text{ x } 2\text{ k}}{1\text{ k}+2\text{ k}} = 2\text{ V}$$

Current divider rule:

Parallel combination of resistors forms a current divider circuit. The supplied current through the parallel combination of resistors is divided into a number of branch current through each resistor.

Consider the two resistors R_1 and R_2 are connected in parallel with a battery of emf V volts as shown in fig. 2.32.

- The voltage remains same across all the resistors
- The current divides through each resistor.

To find the current through any resistor when resistors are in parallel:

Consider the current through R_1 and R_2 to be I_1, I_2 respectivelly. Using Ohm's law I_1 and I_2 can be calculated as given below.

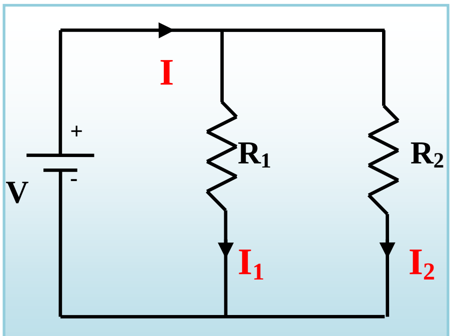


Fig. 2.32

$$I_1 = \frac{V}{R_1} = \frac{IR_T}{R_1} = \frac{I}{R_1} \text{ x } \frac{R_1R_2}{R_1+R_2}$$

$$\text{or} \qquad I_1 = I \text{ x } \frac{R_2}{R_1+R_2}$$

$$I_2 = \frac{V}{R_2} = \frac{IR_T}{R_2} = \frac{I}{R_2} \text{ X } \frac{R_1R_2}{R_1+R_2}$$

Or $\quad I_2 = I \times \frac{R_1}{R_1+R_2}$

In general if n number of resistor are connected in parallel, then $I_n = \frac{IR_T}{R_n}$

It is clear that **the current through any parallel branch is equal to the product of total resistance (R_T) of parallel branches and the main current (I) divided by resistance of the branch through which the current is to be determined.**

Example: Let us find the currents I_1 and I_2 in fig. 2.33.

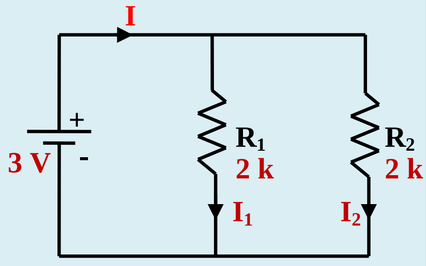


Fig. 2.33

The total current in a circuit

$$I = \frac{V}{R_T} = \frac{V}{\frac{R_1R_2}{R_1+R_2}} = \frac{3\text{ V}}{1\text{ k}} = 3\text{ mA}$$

According to current divider rule $I_n = \frac{IR_T}{R_n}$

We can find the branch currents using current divider rule

$$I_1 = \frac{IR_T}{R_1} = 3\text{ mA} \times \frac{1\text{ k}}{2\text{ k}} = 1.5\text{ mA}$$

$$I_2 = \frac{IR_T}{R_2} = 3\text{ mA} \times \frac{1\text{ k}}{2\text{ k}} = 1.5\text{ mA}$$

Open circuit:

A discontinuity anywhere in the circuit forms an open circuit. In the given figure, circuit is open between the terminal A and B. Consequently, the current in the circuit will be zero and the resistance between the open terminal A and B will be infinite.

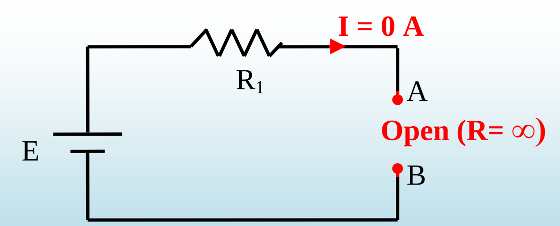


Fig. 2.34

► Open circuit offers infinite resistance.

► The current flowing in open circuit terminals is zero and

► Voltage drop across open circuit is maximum.

Example: For the circuit given in fig. 2.35

- Resistance between A and B is infinity.
- Current through A and B is zero.
- Voltage across A and B is 5 V.

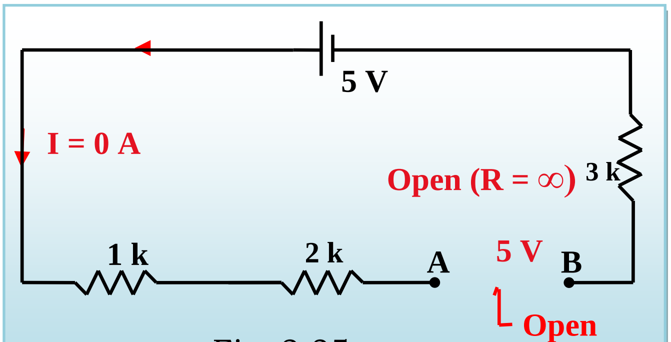


Fig. 2.35

Short circuit:

A short in a circuit has zero resistance. Therefore the current through the short has to be infinite or maximum in the circuit.

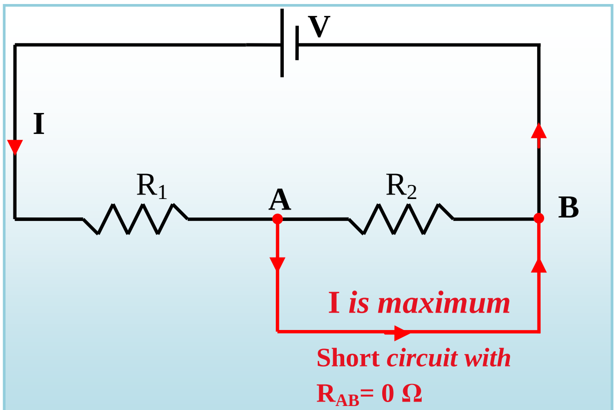


Fig. 2.36

In the fig. 2.36, the resistance R_2 is shorted by a wire. Hence the resistance between A and B will be zero ohm (0 Ω). But the current through the short will be maximum, which is equal to

$$I_{max} = \frac{V}{R_1}$$

1. Short circuit terminal offers zero resistance. Resistance across A and B in fig. 2.36 is

$$R_{AB} = R_2 \,||\, 0 = \frac{R_2 \times 0}{R_2 + 0} = 0\ \Omega$$

2. The current is maximum in a short circuit. $I_{max} = \frac{V}{R_1}$

Network Theorems

Most of the electrical networks cannot be solved by merely applying the laws of series and parallel circuits. Of course, Kirchhoff's laws can always be used but often it makes the solution laborious. Hence various network theorems have been developed which provide a very short and time saving methods to solve these complicated circuits. The following network theorems finds wide application in electronic and transmission circuits.

1. **Super position theorem**
2. **Thevenin's theorem**
3. **Maximum power transfer theorem**

Note: Though only dc networks are considered in this chapter, these theorems are applicable to ac networks as well.

Super position theorem

If there are number of voltage and current sources are acting simultaneously in a network then each source can be treated as if it acts independently of the others. The total current or voltage in any part of a linear circuit equals the algebraic sum of the currents or voltages produced by each source separately.

Statement: In any linear bilateral network consisting of two or more independent sources, the resultant current or voltage in any branch is the algebraic sum of the currents or voltages caused by each independent sources acting alone, with all other independent sources being replaced by their internal resistances.

Procedure for using the superposition theorem

Step-1: Retain one source at a time in the network and replace all other sources by their internal resistances. (An ideal voltage source is replaced by a short circuit and an ideal current source is replaced by an open circuit).

Step-2: Current in various branches and their voltage drops due to single source are determined.

Step-3: This process is repeated for other sources by considering one at a time.

Step-4: Finally, algebraic sum of currents and voltage drops in a branch due to different sources are determined.

Illustration 1: A simple single loop network given in fig. 2.37 is used to illustrate, how the principle of superposition can be used to obtain the current through the resistor and voltage across resistor. **Let V_1 be greater than V_2.** Assume the direction of the current in clock wise direction as shown in the fig. 2.37.

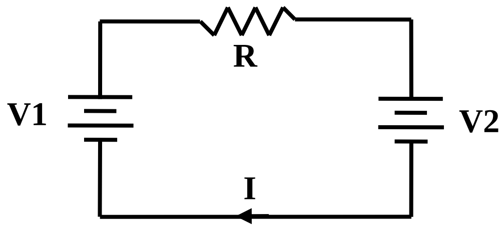


Fig. 2.37

When superposition theorem is used, the response due to one independent source is obtained at a time. The other sources are replaced by their internal resistances.

When the response due to source V_1 alone is considered, source V_2 is replaced by a short circuit. Let the current through the resistor be I_1 as in fig. 2.38.

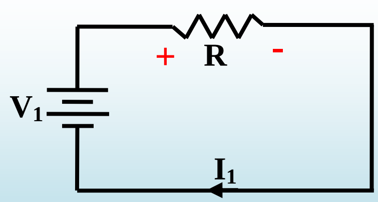


Fig. 2.38

Current through R is $I_1 = \frac{V_1}{R}$ and

Voltage across R is $+V_1$.

When the response due to source V_2 alone is considered, source V_1 is replaced by a short circuit. Let the current through the resistor be I_2, as shown in fig. 2.39.

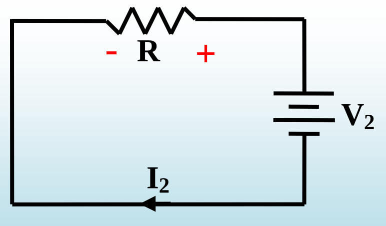


Fig. 2.39

Current through R is $I_2 = \frac{-V_2}{R}$ and

Voltage across R is $-V_2$.

Applying superposition theorem algebraic sum of currents and voltage drops over a resistor due to both sources is taken as

$$I = I_1 + I_2 = \left[\frac{V_1}{R} + \left(\frac{-V_2}{R}\right)\right] = \left[\frac{V_1}{R} - \frac{V_2}{R}\right]$$

$$IR = V_1 - V_2$$

$$V = V_1 - V_2$$

Here the total response is expressed as the algebraic sum of responses, due to each independent source acting alone.

Example: In the fig. 2.37 if V_1 = 12 V, V_2 = 6 V and R= 2 Ω. Find the curent through and voltage across resistor.

Current through the resistor is obtained as

$$I = I_1 + I_2 = \left[\frac{V_1}{R} - \frac{V_2}{R}\right] = 3\ A$$

Voltage across the resistor is obtained as

V = 12 V – 6 V = 6 V.

Illustration 2: A simple network with two loops is used to illustrate, how the principle of superposition can be used to obtain the current through the resistor R_3 in the circuit shown in fig.2.40. The following circuit has two independent practical voltage sources V_1 and V_2.

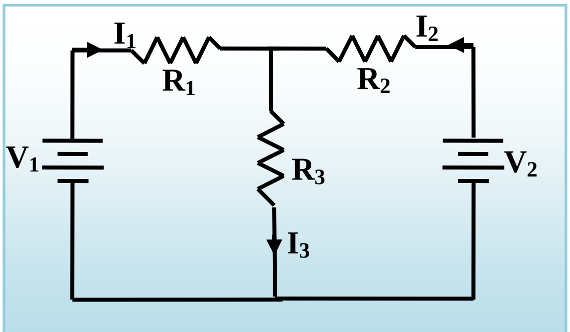


Fig. 2.40

Solution: To show that $I_3 = I_3' + I_3''$

Where, I_3' is the current through R_3 when V_1 alone is considered

and I_3'' is the current through R_3 when V_2 alone is considered.

When V_1 is acting alone, replace V_2 source by short circuit. Then the resultant circuit is given in fig. 2.41.

Let R_{T1} be the total resistance offered by a circuit when only 10 V source is considered.

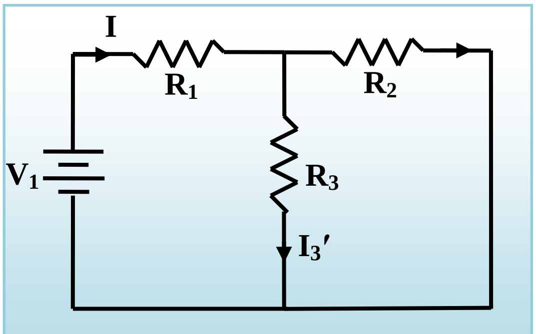


Fig. 2.41

$R_{T1} = (R_2 \,||\, R_3) + R_1$

Total circuit current is $I = \frac{V_1}{R_{T1}}$

Therefore, current through R_3 is calculated using current divider formula

$$I_3' = I \times \frac{R_2}{R_2+R_3}$$

Voltage across $R_3 = V_3' = I_3' R_3$

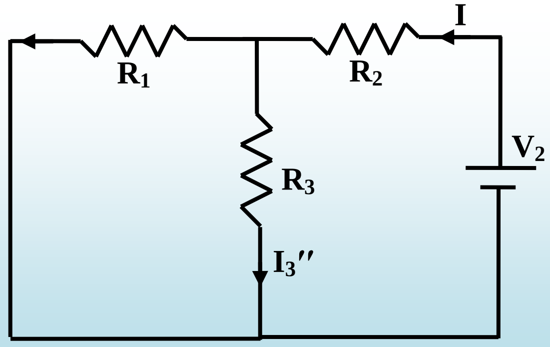


Fig. 2.42

When V_2 is acting alone, replace V_1 source by short circuit. Then the resultant circuit is given in Fig 2.42

Let R_{T2} be the total resistance offered by a circuit when only V_2 source is considered.

$R_{T2} = (R_1 \,||\, R_3) + R_2$

Total circuit current is $I = \frac{V_2}{R_{T2}}$.

Therefore, current through R_3 is calculated using current divider formula

$$I_3'' = I \times \frac{R_1}{R_1+R_3}$$

Voltage across $R_3 = V_3'' = I_3''R_3$

The total Voltage across R_3 is $V_3 = V_3' + V_3''$

Therefore current through R_3 is $I_3 = I_3' + I_3''$

Similarly, currents and voltages across any resistor in the network can be determined by this Theorem.

Example: Find the current through and voltage across 3 Ω in fig. 2.43 using superposition theorem.

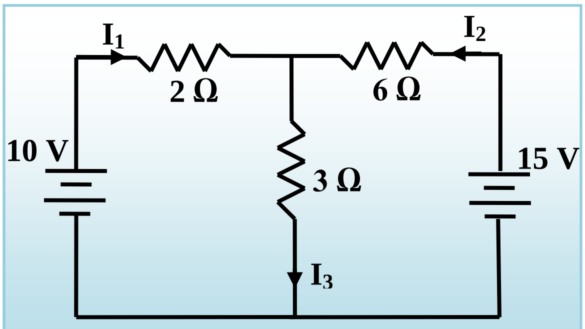


Fig. 2.43

Solution: When 10 V is acting alone, replace 15 V source by short circuit. Then the resultant circuit is given fig. 2.44.

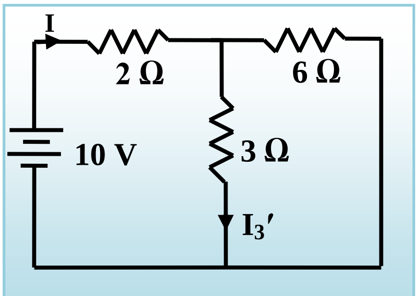


Fig. 2.44

Let R_{T1} be the total resistance offered by a circuit when only 10 V source is considered.

$R_{T1} = (6 \,||\, 3) + 2 = 4\ \Omega$

Total circuit current is $I = \frac{V}{R_{T1}} = \frac{10}{4} = 2.5\ A$

Therefore, current through 3 Ω is calculated using current divider formula

$$I_3{}' = I \times \frac{6}{3+6} = 2.5 \times \frac{6}{9} = 1.666\ A$$

Voltage across 3 Ω $= V_3{}' = I_3{}'R_3 = 1.666 \times 3 = 5\ V$

When 15 V is acting alone, replace 10 V source by short circuit then the resultant circuit is given in fig. 2.45.

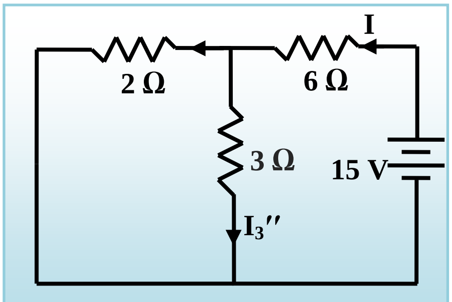


Fig. 2.45

Let R_{T2} be the total resistance offered by a circuit when only 10 V source is considered.

$$R_{T2} = (2 \,||\, 3) + 6 = 7.2\ \Omega$$

The total circuit current $I = \frac{V}{R_{T1}} = \frac{15}{7.2} = 2.083$ A

Therefore, current through 3 Ω is calculated using current divider formula

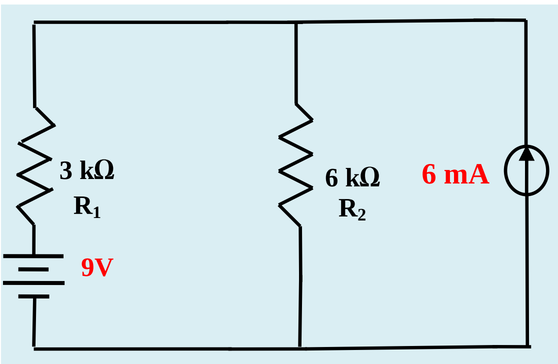
$$\mathbf{I_3}'' = I \times \frac{2}{(2+3)} = 2.083 \times \frac{2}{5} = 0.833 \text{ A}$$

Voltage across 3 Ω is $V''_3 = I''_3 \times 3\ \Omega = 0.833 \times 3 = 2.5$ V

The total Voltage across 3 Ω is $V_3 = V_3' + V_3'' = 5\text{ V} + 2.5\text{ V} = 7.5$ V

Therefore current through R_2 is $I_3 = I_3' + I_3'' = 1.666 + 0.833 = 2.5$ A

Example: Using superposition theorem, calculate the current flowing through 6 kΩ resistor in the circuit given below.



When 6 mA is acting alone: Reduce 9 V to zero.

Then current through 6 kΩ = $I_{R2}' = I \times \frac{R_1}{R_1+R_2} = 6\text{ mA} \times \frac{3\text{ k}}{(3+6)\text{k}} = 2$ mA

When 9 V is acting alone: Open current source.

Then current through 6 kΩ = $I_{R2}'' = \frac{V}{R_1+R_2} = \frac{9}{(3+6)\text{k}} = 1$ mA

There fore total current through 6 kΩ = $I_{R2}' + I_{R2}'' = 3$ mA

Thevenin's theorem:

In **1883, Leon Charles Thevenin,** a French engineer developed a very useful theorem in the electrical analysis. This theorem is very useful to know the amount of power, current or voltage drop in a particular component of a given circuit.

Thevenin's theorem is used to simplify a complex network to a simplified circuit consisting of one voltage source i.e. Thevenin's voltage (V_{Th}) in series with single resistance i.e. Thevenin's resistance (R_{Th}).

Thevenin's statement: **Any two terminal linear bilateral network having several voltage sources and resistors can be replaced by a simple circuit having one voltage source V_{Th} (Thevenin's voltage) in series with one single resistor R_{Th} (Thevenin's resistance).**

Where

- 'V_{Th}' is open circuit voltage between the two terminals and
- 'R_{Th}' is Resistance between the open terminals.

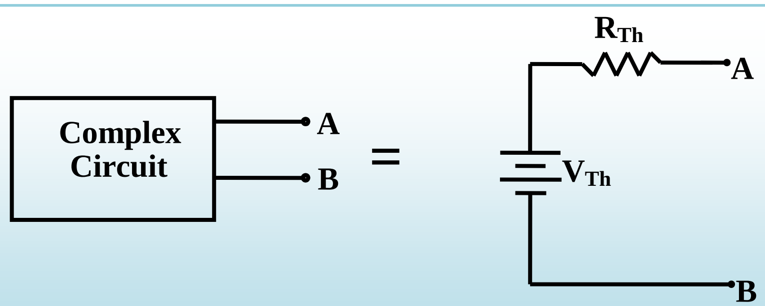


Fig. 2.46(a) Fig. 2.46(b) Thevenin's equivalent

According to Thevenin's Theorem fig. 2.46(a) can be converter into fig. 2.46(b).

NOTE: 'R_{Th}' is the resistance between the open terminals with all the sources replaced by their internal resistances. Ideal voltage source is replaced by short circuit as it has zero internal resistance. Ideal current source is replaced by open circuit as it has infinite internal resistance.

How to Thevenize a circuit?

Step 1: Identify and remove the load resistor R_L (the resistance whose current and voltage are to be found) to convert a circuit as a two terminal network. Mark the two terminals as A and B.

Step 2: **To find V_{Th},** calculate open circuit voltage between terminals A and B.

Step 3: **To find R_{Th},** replace all the voltage sources in the network by their internal resistances. Then find the effective resistance between the terminals A and B looking back into the circuit.

Step 4: **Construct Thevenin's equivalent circuit** having V_{th} in series with R_{th} and reconnect the load resistance R_L which was removed in the step 1.

Step 5: Determine the load current and voltage across R_L using the given formula

$$I_L = \frac{V_{th}}{R_{th}+R_L}$$

$$V_L = I_L R_L$$

Illustration: Let us find Thevenin's equivalent circuit for the fig. 2.47 to the left of the terminal 'A' and 'B'.

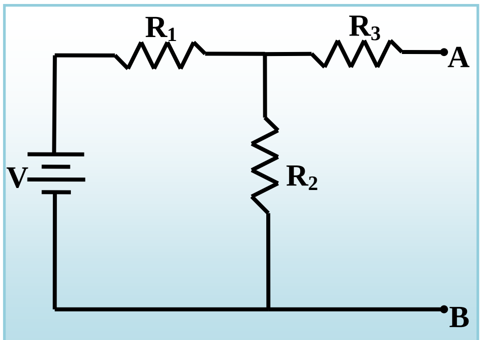


Fig. 2.47

Given circuit is a two terminal network with open terminals A and B.

To find Thevenin's voltage V_{Th}: V_{Th} is the open circuit voltage between A and B ($V_{Th} = V_{AB} = V_{R2}$ since R_3 is open there is no voltage drop across R_3 and hence no current in the open circuit as shown in fig. 2.48).

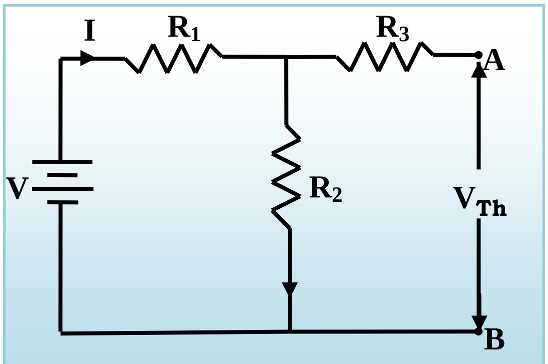


Fig. 2.48

$$V_{Th} = \text{Voltage across } R_2 = IR_2$$

$$V_{Th} = V_{R2} = \frac{V}{R_1+R_2} R_2$$

To find Thevenin's resistance R_{th}: short all the sources and calculate resistance between A and B as shown in fig. 2.49.

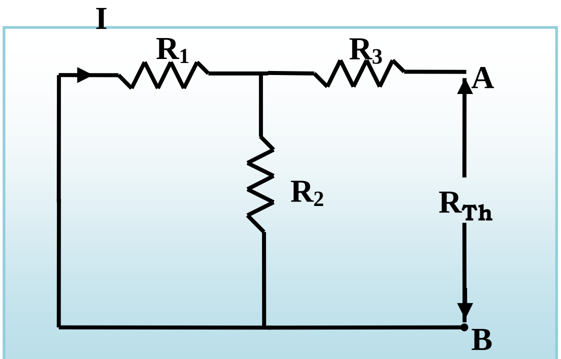


Fig. 2.49

$$R_{Th} = R_{AB}$$

$$R_{Th} = (R_1 \mid\mid R_2) + R_3$$

$$R_{Th} = \frac{R_1 R_2}{R_1+R_2} + R_3$$

Thevenin's equivalent circuit is drawn in fig. 2.50

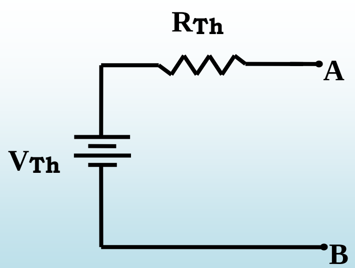


Fig. 2.50

Problems on Thevenin's theorem:

Illustration 1: Find Thevenin's equivalent circuit for the given circuit diagram.

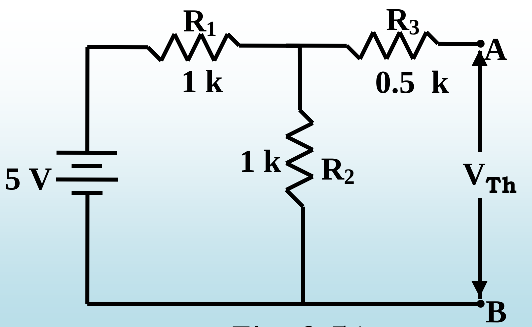


Fig. 2.51

Solution: To find Thevenin's voltage V_{Th}. Calculate open circuit voltage between A and B i.e., V_{Th} as shown in fig. 2.51.

$$V_{Th} = \frac{V}{R_1+R_2} \times R_2$$

$$= \frac{5}{1\,k+1\,k} \times 1\,k$$

$$V_{Th} = 2.5\ V$$

To find Thevenin's resistance R_{Th} short 5V source as shown in fig. 2.52.

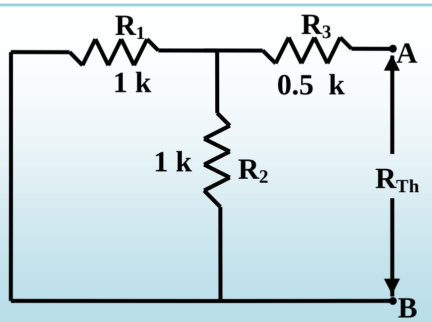


Fig. 2.52

$$R_{Th} = (R_1 \,||\, R_2) + R_3$$

$$R_{Th} = (1\ k \,||\, 1\ k) + 0.5\ k$$

$$R_{Th} = 0.5\ k + 0.5\ k$$

$$R_{Th} = 1\ k$$

Thevenin's equivalent circuit is as shown in fig. 2.53.

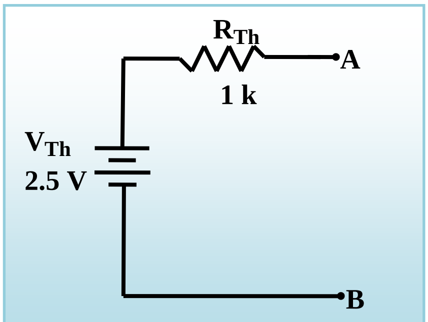


Fig. 2.53

Illustration 2: Find the current flowing through load R_L in fig. 2.54 using Thevenin's theorem.

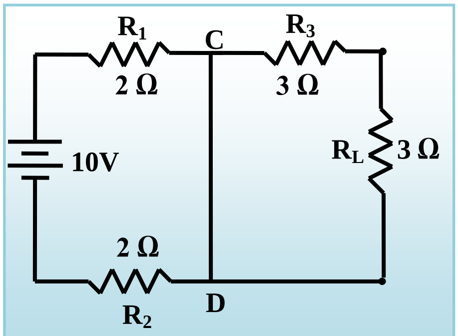


Fig 2.54

Solution: a) To find Thevenin's voltage V_{Th}, remove the load R_L and mark the terminals A and B. Calculate open circuit voltage between A and B i.e., V_{Th} as shown in fig. 2.55.

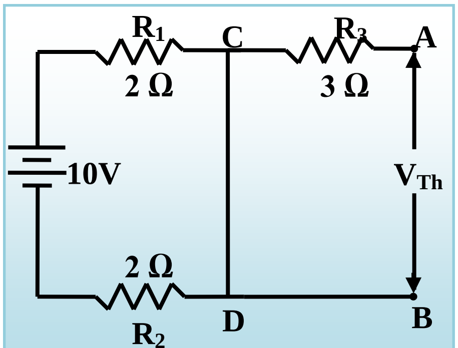


Fig 2.55

V_{Th} = Voltage across C and D = I x 0 Ω

= 0 V

Note: resistance through the short circuit C and D is zero

b) To find Thevenin's resistance R_{Th} short 10 V emf source as shown in fig. 2.56.

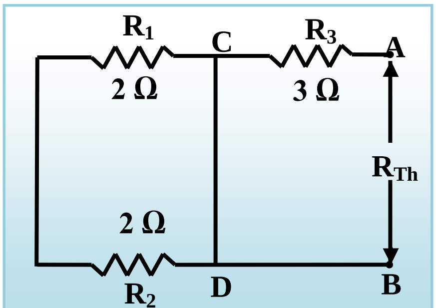


Fig 2.56

$$R_{Th} = R_{CD} + R_{CA} = 0 + 3\ \Omega$$

$$\mathbf{R_{Th} = R_{AB} = 3\ \Omega}$$

c) Draw the Thevenin's equivalent circuit and reconnect the load R_L as shown in fig. 2.57, then I_L is calculated.

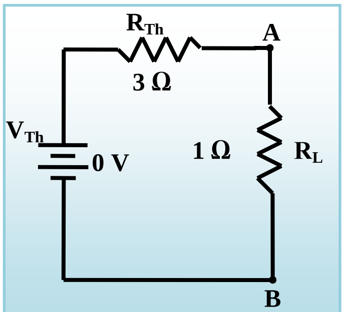


Fig 2.57

$$\text{Load current } I_L = \frac{V_{Th}}{R_{Th}+R_L} = \frac{0}{4} = 0\text{ A.}$$

Illustration 3: Find the current through and voltage across 1 Ω resistor in fig. 2.58.

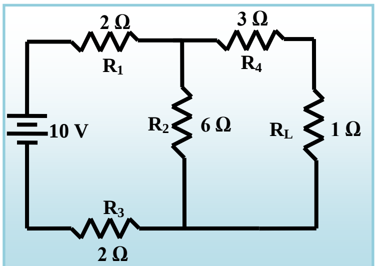


Fig 2.58

Solution:

a) To find Thevenin's voltage V_{Th} remove R_L then calculate open circuit voltage between the terminals A and B as shown in fig. 2.59.

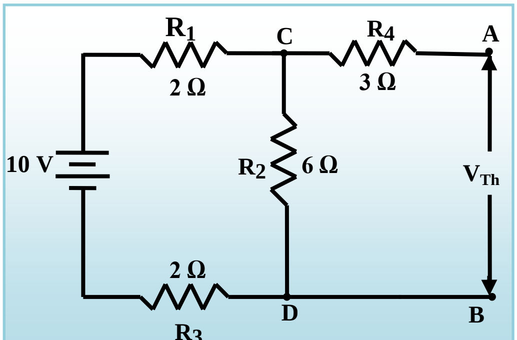


Fig 2.59

(V_{Th} = V_{AB} = V_{CD} as there is no voltage drop across R_4 as the current through open circuit is zero) V_{Th} = V_{CD} = I x R_2

$$V_{Th} = \frac{V}{R_1 + R_2 + R_3} \times R_2$$

$$V_{Th} = \frac{10}{2+6+2} \times 6$$

$$V_{Th} = 6\ V$$

b) To find Thevenin's resistance R_{Th}

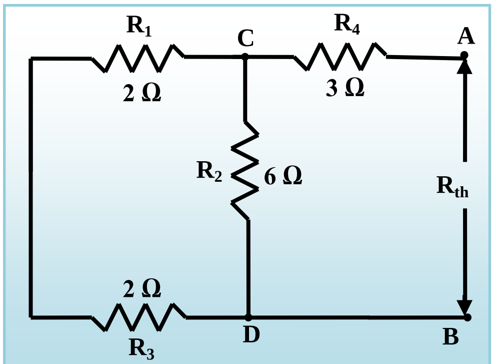


Fig 2.60

Short all emf sources and measure the resistance between A and B as shown in fig. 2.60.

R_{Th} = [(R_1+ R_3) || R_2] + R_4

= (4 || 6) +3

= 2.4 + 3

R_{Th} = 5.4 Ω

c) Draw the Thevenin's equivalent circuit and reconnect the load R_L as shown in fig. 2.61 then. I_L and V_L are calculated.

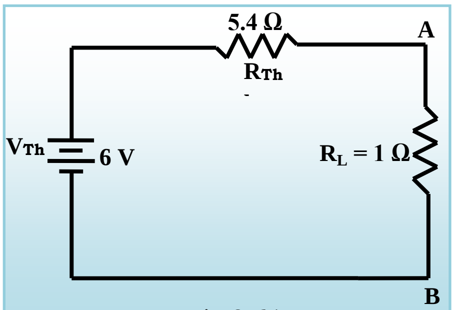


Fig 2.61

$$I_L = \frac{V_{Th}}{R_{Th}+R_L} = \frac{6}{6.4} = 0.93\ A$$

Voltage across R_L is V_L = I_L x R_L
= 0.93 x 1 = 0.93 V

Maximum power transfer theorems

Moritz von Jacobi published the maximum power (transfer) theorem around 1840, it is also referred to as "Jacobi's law".

Transfer of maximum power is very much important in case of transmission lines, antennas and from amplifier to the loudspeaker etc. For the maximum power to be transferred impedance matching is necessary.

An example of impedance matching is between an audio amplifier and a loudspeaker.

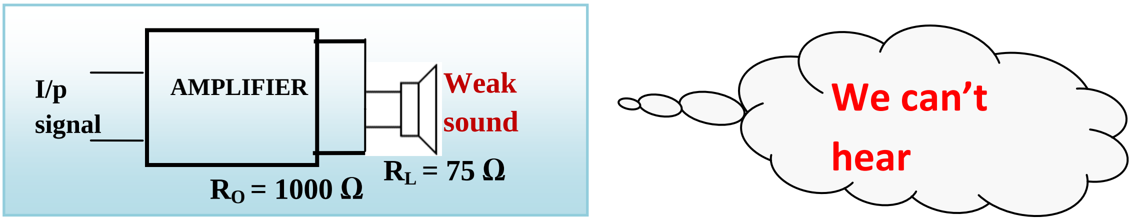


Fig. 2.62

If a 75 Ω loudspeaker is connected to an amplifier with an output impedance of 1000 Ω as in fig. 2.62 improper impedance matching lead to excessive power loss and heat dissipation. Hence very feeble sound is heard.

To obtain maximum sound at the output, the loudspeaker impedance has to be matched with the amplifier output impedance as in fig. 2.63. Thus maximum power transfer theorem helps the circuit designer to transform maximum power to the circuit efficiently.

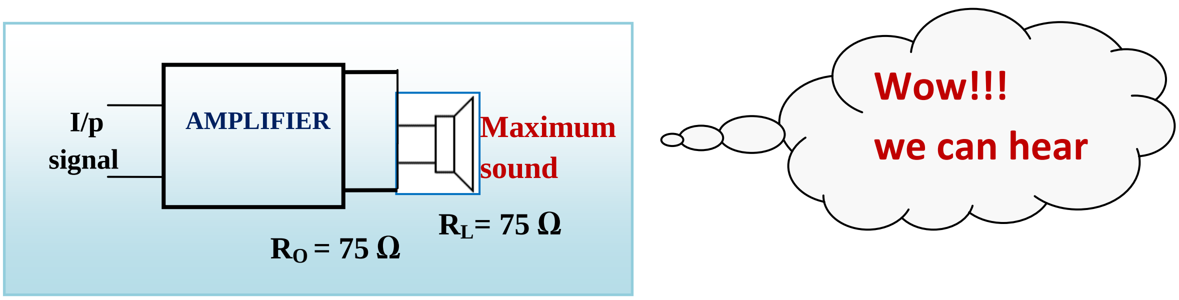


Fig. 2.63

Maximum power transfer theorem states that **"The maximum power is transferred from the source to the load only when the load resistance is equal to the Thevenin's resistance of the given circuit.**

i.e., $R_L = R_{Th}$"

The load receives maximum power when $R_L = R_{Th}$

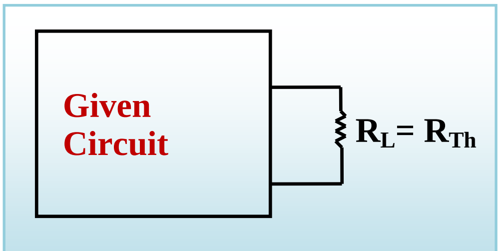


Fig 2.64(a)

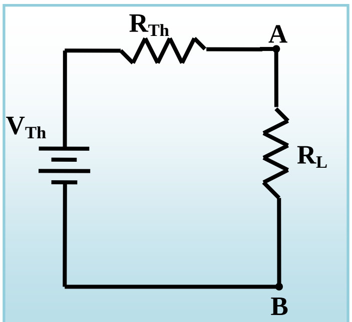


Fig 2.64(b)

Reduce the given circuit 2.64(a) to Thevenin's equivalent circuit 2.64(b). When $R_L = R_{Th}$ voltage divides equally and also the power. Thus

$$P_L = I^2{}_L R_L = \left(\frac{V_{Th}}{R_{Th}+R_L}\right)^2 \times R_L$$

We know that when $R_L = R_{Th}$ maximum power is transferred. Hence the maximum power transferred is

$$P_{L(max)} = \frac{V_{Th}{}^2}{4R_{Th}}$$

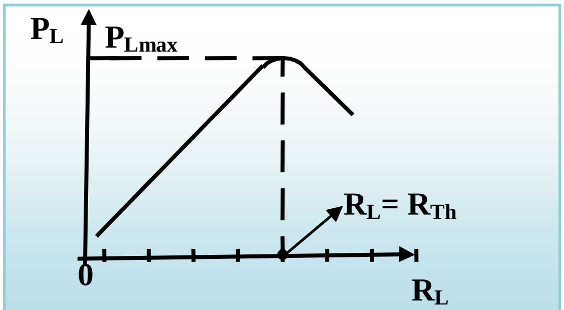


Fig 2.64(c)

Fig. 2.64(c) shows power delivered to load R_L is P_L.

Illustration 1: Consider the network shown in fig.2.65, given RPS (V) = 5 V, R_1 = 1 kΩ, R_2 = 1 kΩ, R_3 = 100 Ω. Calculate the power delivered to R_L.

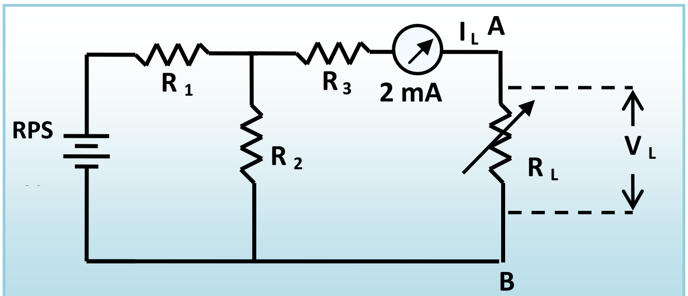
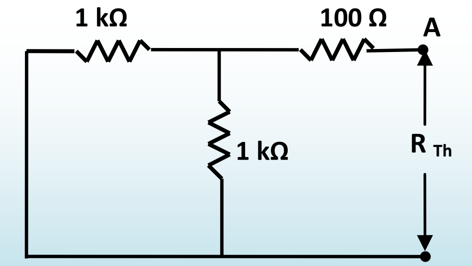


Fig. 2.65

Fig. 2.66 shows an arrangement to find R_{Th}.



R Th = Thevenins resistance

Fig 2.66

To find Thevenin's resistance R_{Th}, remove R_L, short the 5 V source and measure resistance between the open terminals A and B. Then

$$\mathbf{R_{Th} = (1\,k \parallel 1\,k) + 100\,\Omega = 600\,\Omega}$$

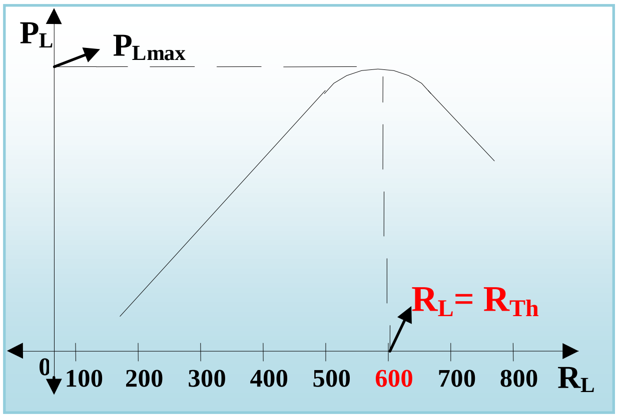


Fig. 2.67

As the load R_L is varied from 100 Ω to 800 Ω the power across the load also varies. By plotting the graph of P_L versus R_L we get the nature of graph as in fig. 2.67. The load **R_L receives maximum power only when R_L = R_{Th} = 600 Ω** as shown in the graph.

$P_L = V_L I_L = I_L^2 R_L = (2 \times 10^{-3})^2 \times 600$

P_L = 2.4 mW

Illustration 2: Find the value of load resistor R_L in fig 2.68 for maximum power transformation.

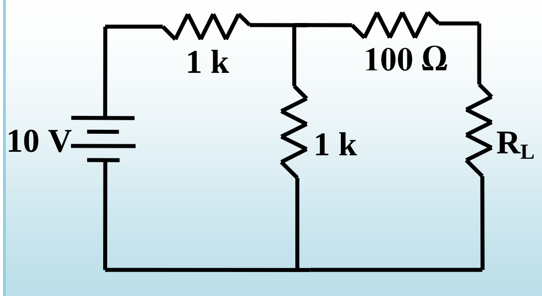


Fig 2.68

Solution: To find Thevenin's resistance of the given circuit

To find Thevenin's resistance R_{Th}, remove R_L, short the 10 V source and measure resistance between the open terminals A and B as shown in fig 2.69.

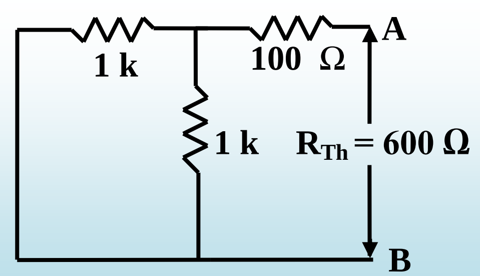


Fig 2.69

$$R_{Th} = (1\ k\ ||\ 1\ k) + 100\Omega$$

$$= 500\ \Omega + 100\ \Omega$$

$$\mathbf{R_{Th} = 600\ \Omega}$$

The maximum power transferred to the load is when $\mathbf{R_L} = \mathbf{R_{Th} = 600\ \Omega}$

Illustration 3: Find the value of the load R_L in fig. 2.70 for the maximum power to be transferred and calculate the maximum power transferred to the load.

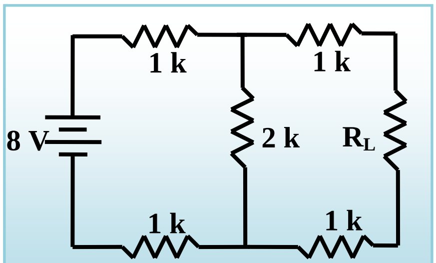


Fig. 2.70

a) To find Thevenin's resistance R_{Th}: remove R_L, reduce 8V source to zero and measure resistance between the open terminals A and B as in fig. 2.71.

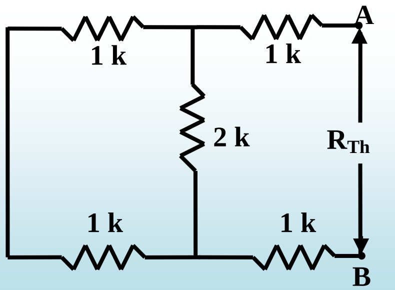


Fig. 2.71

R_{Th} = [(1 k+1 k) || 2 k] +1 k +1 k = 3 k

Therefore When $\mathbf{R_L = R_{Th} = 3\ k\Omega}$ maximum power transferred

b) To find Thevenin's voltage V_{Th}: Calculate open circuit voltage between A and B as shown in fig. 2.72.

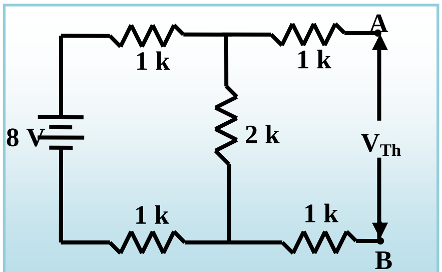


Fig. 2.72

$$V_{Th} = V_{2k} = IR = I \times 2\ k = \frac{8\ V}{1\ k+2\ k+1\ k} \times 2\ k$$

$$\mathbf{V_{Th} = 4\ V}$$

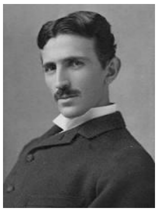
c) The maximum power transferred is $\mathbf{P_{max}} = \frac{V_{Th}^{2}}{4R_{Th}} = \frac{4 \times 4}{4 \times 3\ k} = \mathbf{\frac{4}{3}\ mW}$

AC PRINCIPLES

Alternating current and voltage

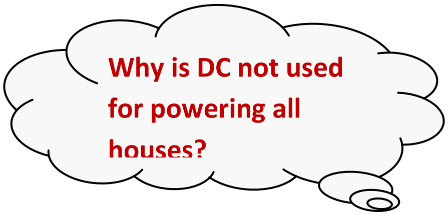
An alternating current or voltage is one whose amplitude varies periodically with respect to time and changes the polarity at regular intervals. The ac sources are ac generator, oscillator, function generator etc.

In India, electric power supplied for the domestic use is sinusoidal alternating current (AC) at a frequency of 50 Hz with a potential difference of 230 V between live wire and neutral wire. AC supply is suitable for powering all house hold electrical devices such as lamps, heaters, motors, mixer, etc.



Nikola Tesla (1856-1943) was a Serbian-American inventor, electrical engineer and mechanical engineer best known for his contributions to the design of the modern alternating current electrical supply system.

Interesting fact



It is true that DC is much safer to work .Thomas Alva Edison favoured direct current distribution to all household electrical devices for safety reasons. Whereas Nikosa Tesla favoured AC for its efficiency at long distance. The reason AC won is because it is simply impossible to transmit DC more than a few miles; the energy losses in the transmission lines becomes too large. AC on the other hand can be stepped up in voltage using transformers and transmitted hundreds of miles with acceptable losses.

Sinusoidal alternating current

A sinusoidal voltage or current is obtained when a coil of wire is rotated at a constant rate in a uniform magnetic field. **AC generator uses the principle of electromagnetic induction.**

When a coil rotates in a uniform magnetic field, it cuts the lines of magnetic flux. According to Faraday's law, voltage is induced across the terminal of the coil. The magnitude of induced voltage keeps changing continuously and also the polarity keeps alternating with time therefore it is called alternating voltage. Fig. 2.73(a) shows a rectangular coil rotating in a magnetic field. As the coil moves from 0° to 90° the induced voltage changes from zero to maximum. If the coil rotates further, the induced voltage starts decreasing and becomes zero, at an angle of rotation $\theta = 180°$. At this stage, the coil has rotated through half the circle. This is half-cycle of revolution, and called as an alternation. As the coil rotates from 180° to 360° the induced voltage undergoes similar changes in magnitude but in the opposite direction.

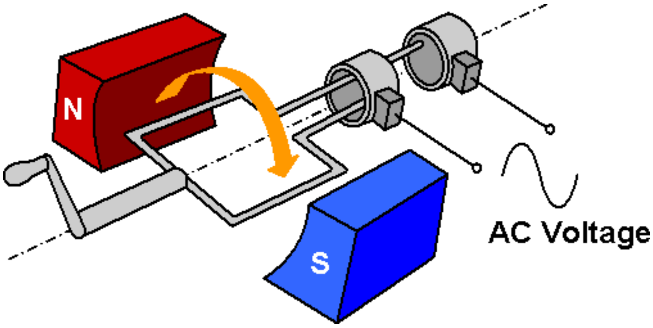


Fig 2.73(a)

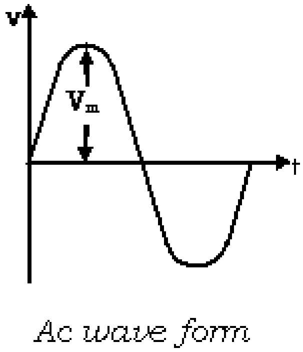


Fig 2.73(b)

AC generator produces sinusoidal voltage and current. The shape of AC waveform is shown in fig. 2.73(b). When the coil rotates with a uniform angular speed ω, then in a small interval of time t, the coil turns through an angle θ given by $\boldsymbol{\theta = \omega t}$

The instantaneous value of the alternating voltage at any instant is represented by the equation $\mathbf{v_i = V_m \sin\theta}$ or $v_i = V_m \sin \omega t$

Where, v_i – instantaneous voltage

V_m – maximum or peak voltage

θ – Phase angle

ω - Angular frequency = $2\pi f$

Some of the terms encountered in the study of AC are as shown in fig. 2.74.

Cycle: One complete set of positive and negative values of an alternating current or voltage is known as a cycle.

Time period (T): It is the time taken to complete one AC cycle. It is denoted by T. It is the reciprocal value of frequency.

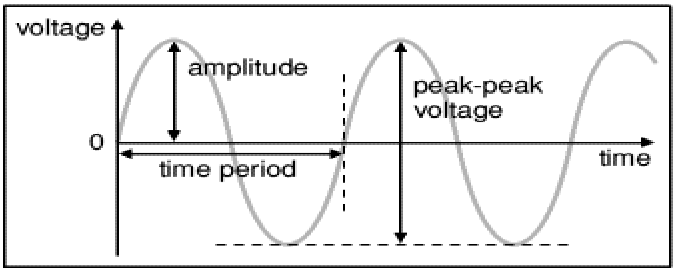


Fig 2.74

If alternating current makes 50 cycles per second then the time period is given by T = 1/50 = 20 mS.

Frequency (f): It is the number of AC cycles completed in one second. Frequency is measured in hertz (Hz).

$$f = \frac{\text{no. of cycles}}{1 \text{ second}} \quad \text{or} \quad f = \frac{1}{T}$$

The unit of frequency is **hertz (Hz).**

Maximum value (V_m or I_m) or peak value (V_p or I_p) of AC: It is the maximum amplitude of voltage or current attained by AC waveform in one half cycle as shown in fig 2.75.

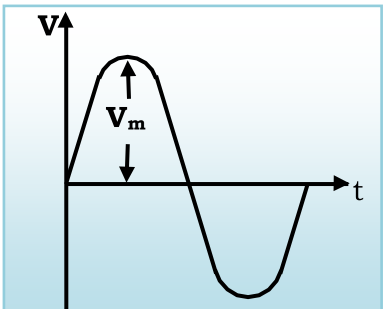


Fig 2.75

Peak to peak value: It is the maximum voltage or current attained in both positive and negative half cycle of AC.

$V_{p\text{-}p} = 2V_m = 2V_p$.

RMS Value (Root Mean Square Value, steady value, effective value):

RMS value is a way of expressing an AC quantity of voltage or current in terms of functionally equivalent to DC. **The RMS value of an ac is the equivalent steady DC value which gives the same heating effect at the same rate in a given resistor.**

Illustration 1: Look into the example given in fig. 2.76. The heating effect produced in 2 Ω by DC 10 V is same as produced by rms 10 V.

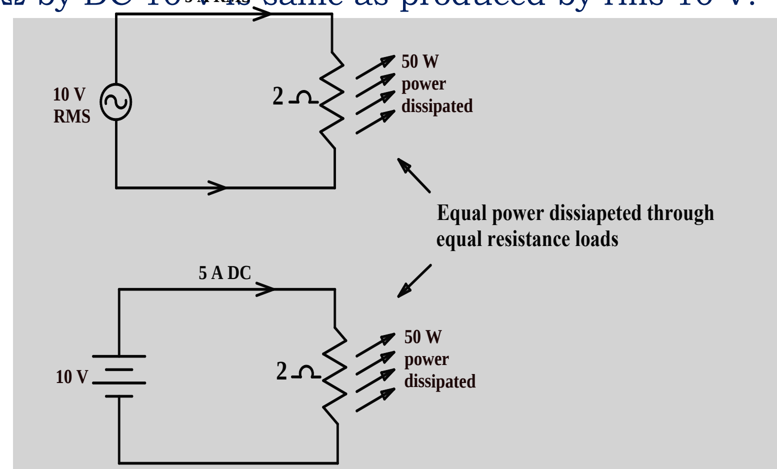


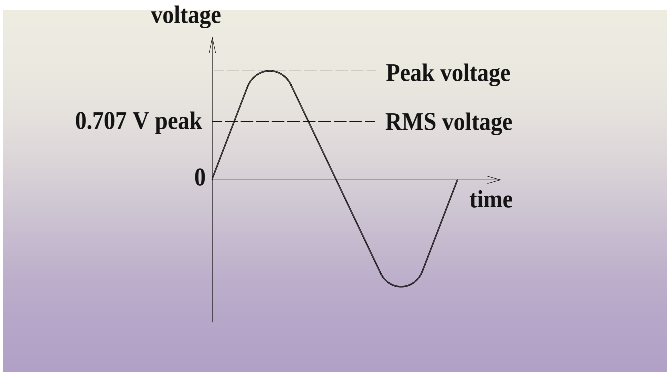
Fig 2.76

RMS value is the square root of mean of squares of instantaneous values of voltage or current taken over one complete cycle.

$$i_{rms} = \frac{\sqrt{\int_0^{2\pi}(i_1{}^2 + i_2{}^2 + i_3{}^2 + \cdots \ldots\ldots\ldots + i_n{}^2)}}{n}$$

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

$$\text{Similarly } V_{rms} = \frac{V_m}{\sqrt{2}}$$



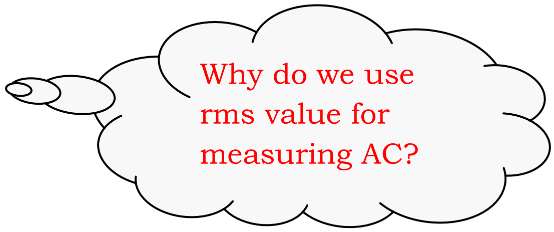


Fig 2.77

Fact: The value of an AC voltage is continuously changing from zero up to the positive peak, through zero to the negative peak and back to zero again. Clearly for most of the time it is less than the peak voltage, so this is not a good measure of its real effect. The root mean square voltage (V_{rms}) which is 0.707 of the peak voltage (V_{peak}).

Observation: If you observe that the AC mains supply at your home is 230 V_{rms}, it means that it's being fed by an AC sine wave with 325.3 V of peak voltage.

Average value (mean value)

This is the arithmetic average of all the instantaneous values of ac. The **average value** of an ac voltage or current is zero over one complete cycle. So, average value of AC is measured either for positive half cycle or for negative half cycle. Therefore, the average value for one-half cycle of a sine wave is $\frac{2}{\pi}$ times the peak value.

$$I_{avg} = \frac{\sqrt{\int_0^{\pi}(i_1{}^2 + i_2{}^2 + i_3{}^2 + \cdots \ldots\ldots\ldots\ldots + i_n{}^2)}}{n}$$

$$I_{avg} = \frac{2\,I_m}{\pi}$$

Similarly, $V_{avg} = \frac{2\,V_m}{\pi}$

NOTE: When an alternating current is passed through a moving coil galvanometer, it shows no deflection, because mean value of alternating current is zero. For one complete cycle, AC flows in one direction during one half cycle and in opposite direction during another half cycle.

Non-sinusoidal AC Waveforms:

Other non-sinusoidal alternating current is used for applications such as scanning circuits, digital circuits, pulse circuits etc. Any waveform that is not a sine or cosine wave is called Non-sinusoidal alternating current waveform. In general alternating current can have any waveform. Examples of Non-sinusoidal alternating current waveforms are shown in fig. 2.78.

1. **Square wave:** A square wave has on time equal to off time.
2. **Triangular wave:** A triangular wave has linearly increasing and linearly decreasing function.
3. **Sawtooth wave:** A sawtooth wave has linearly increasing and suddenly decreasing functions.

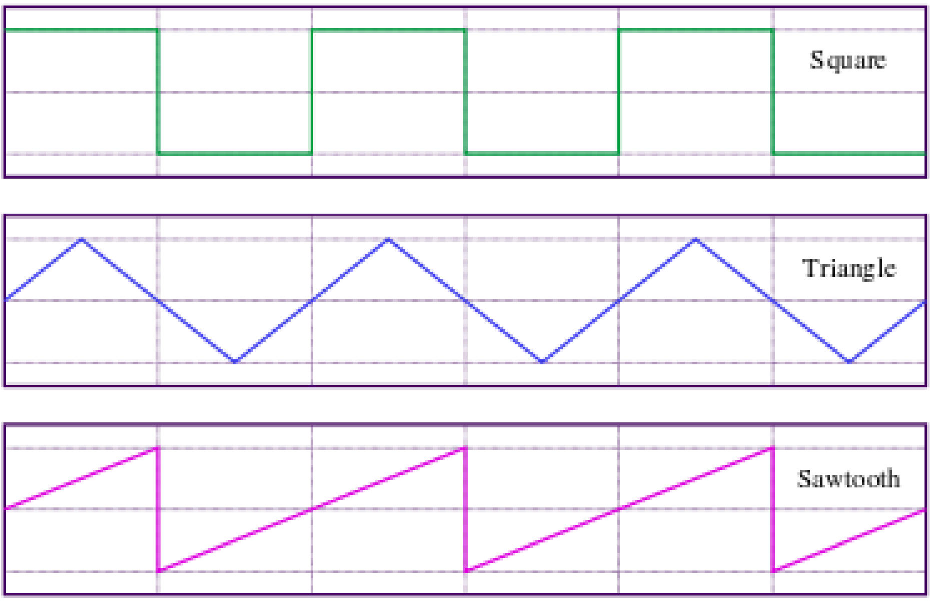


Fig. 2.78

Illustration:

1. Find V_m, V_{p-p}, V_{rms}, V_{avg} and frequency of the given waveform in fig. 2.79.

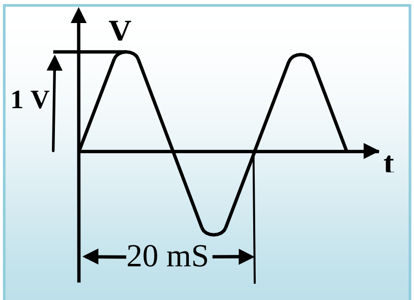


Fig 2.79

Solution:

a) $V_m = 1$ V

b) $V_{p-p} = 2V_m = 2 \times 1 = 2$ V

c) $V_{rms} = \frac{V_m}{\sqrt{2}} = 0.707 \times 1 = 0.707$ V

d) $V_{avg} = \frac{2\,V_m}{\pi} = 0.637 \times V_m = 0.637 \times 1 = 0.637$ V

e) $f = \frac{1}{T} = \frac{1}{20\times10^{-3}} = 50$ Hz

2. Calculate V_m, V_{p-p}, V_{rms}, V_{avg}, time period and frequency of the given waveform in fig. 2.80.

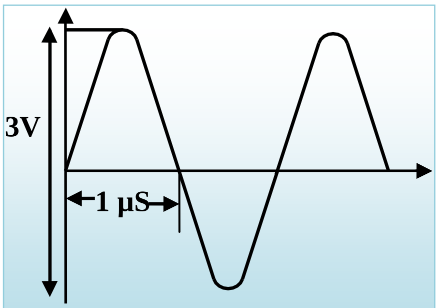


Fig 2.80

Solution:

a) $V_m = \frac{V_{p-p}}{2} = \frac{3}{2} = 1.5$ V

b) $V_{p\text{-}p} = 3$ V

c) $V_{rms} = \frac{V_m}{\sqrt{2}} = 0.707 \times 1.5 = 1.06$ V

d) $V_{avg} = \frac{2\,V_m}{\pi} = 0.637 \times 1.5 = 0.95$ V

e) T = 2 x 1μS = 2 μS

f) $f = \frac{1}{T} = \frac{1}{2\times10^{-6}} = 0.5$ MHz = 500 kHz

3. Calculate $V_{p\text{-}p}$, V_{rms}, V_{avg} and frequency of AC wave form. Given peak voltage is 5 V and time period is 20 mS.

Solution:

a) $V_{p\text{-}p} = V_p \times 5 = 10$ V

b) $V_{rms} = \frac{V_m}{\sqrt{2}} = 0.707 \times 5 = 3.53$ V

c) $V_{avg} = \frac{2\,V_m}{\pi} = 3.18$ V

d) $f = \frac{1}{T} = \frac{1}{20 \times 10^{-3}} = 20$ Hz

EXERCISE PROBLEMS

1. A battery is connected across a conductor. If it transfers 60 C of charge/S and the amount of work done by the battery is 120 joules/S, what is the battery voltage? [Ans: 2 V]

2. A 60 W bulb is connected to a 230 V mains supply. Calculate the current through the bulb. [Ans: 0.261 A]

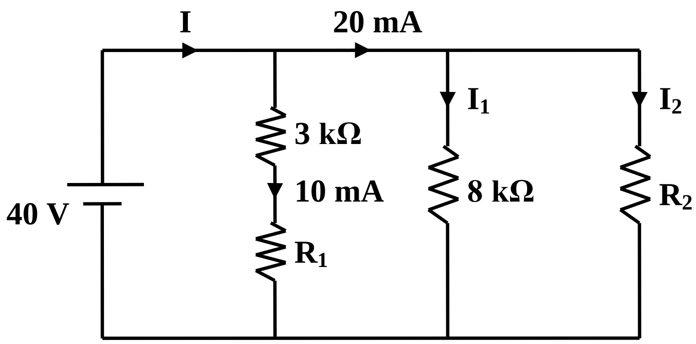
3. A bulb of a car head light is connected to a 12 V battery maintains 2 A of current. What is the power rating of the bulb? [Ans: 24 W]

4. The specifications of an iron box are labeled as 230 AC, 350 W. Calculate the resistance of the iron box. [Ans: 151 Ω]

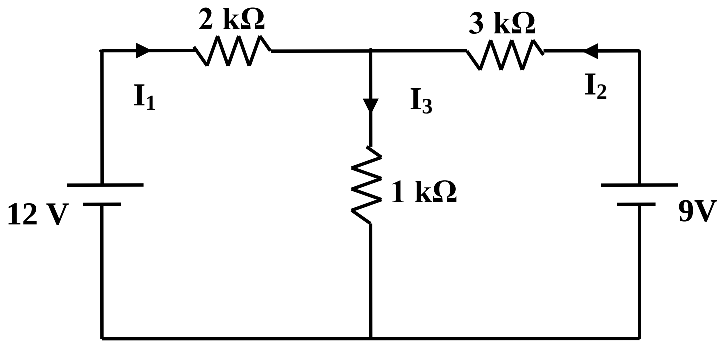
5. An UPS supplies 2 A of current to a bulb of 12 V for 5 minutes. Calculate the amount of charge supplied by the UPS. [Ans: 600 C]

6. A 20 V battery allows 2 A of current through a resistor. What is the current in the same resistor if a 12 V battery is connected? [Ans: 1.2 A]

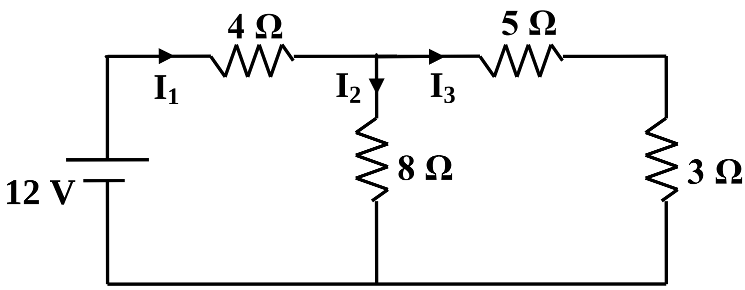
7. In the figure, determine the unknown branch currents and unknown resistance of resistors.
[Ans: I = 30 mA, I_1 = 5 mA, I_2 = 15 mA, R_1 = 1 kΩ and R_2 = 2.67 kΩ]



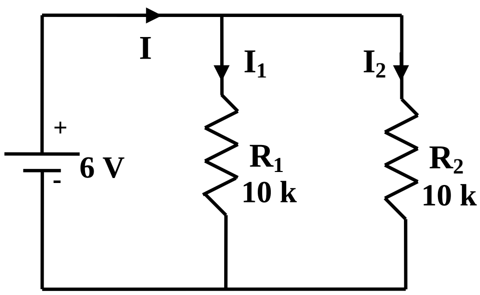
8. Determine the branch currents in the given figure.
[Ans: I_1 = 39/11 mA, I_2 = 15/11 mA, I_3 = 54/11 mA]



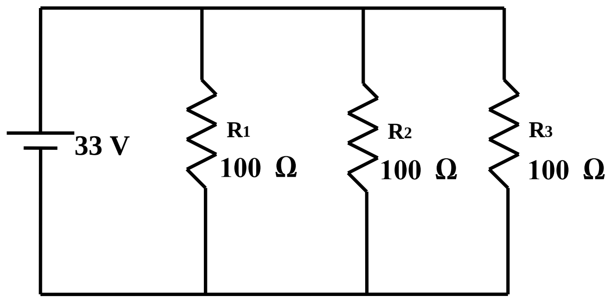
9. Determine the branch currents and voltage drops across each resistor.
[Ans: $I_1 = 1.5$ A, $I_2 = 0.75$ A, $I_3 = 0.75$ A]



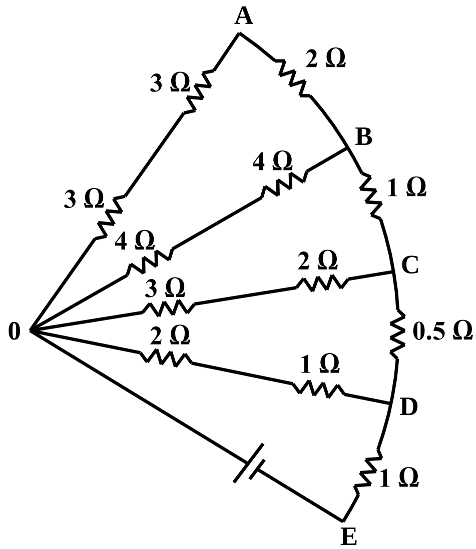
10. Find the total current flowing in the circuit also find the branch current?
[Ans: I = 1.2 mA, $I_1 = 0.6$ mA, and $I_2 = 0.6$ mA]



11. Find the total current and total resistance in the circuit given below.
[Ans: I = 0.99 A, $R_T = 33.33\ \Omega$]

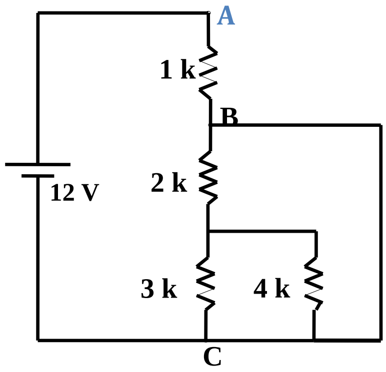


12. How do you create 3 V, 2 V, and 1 V from a 3 V source?
[Ans: By connecting three same value resistor across 3 V supply]
13. Find the total resistance between the terminals O and E in the figure shown below. [Ans: 2.5 Ω]

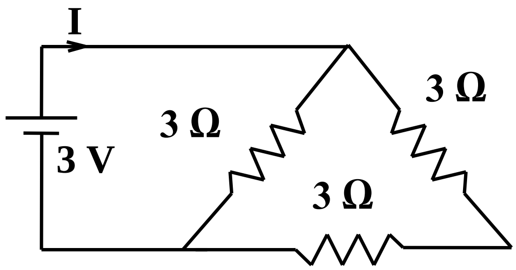


14. Find the following:

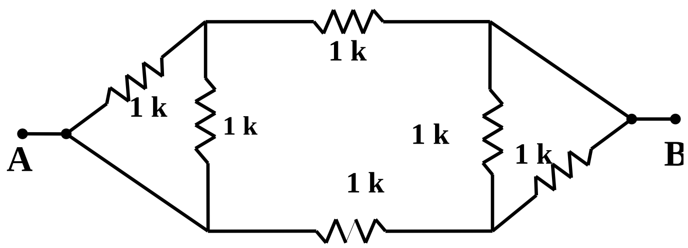
a) Total resistance [R_T = 1 kΩ because 2 kΩ, 3 kΩ, 4 kΩ are shorted]
b) Voltage at A [V_A = 12 V]
c) Potential at B [V_B = 0]
d) Total current flowing in the circuit [I = 12 mA]



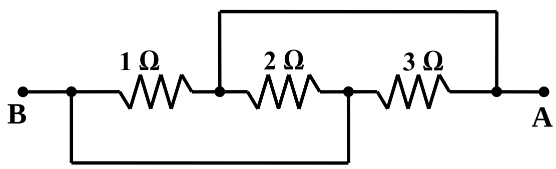
15. Find the current 'I' in the circuit. [Ans: 1.5 A]



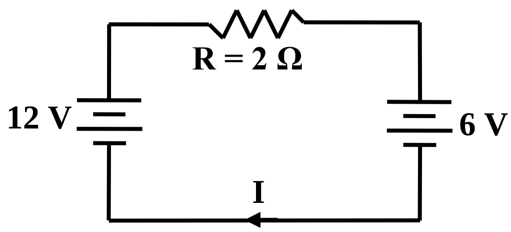
16. Find the total resistance between A and B. [Ans: $\frac{3k}{4}$]



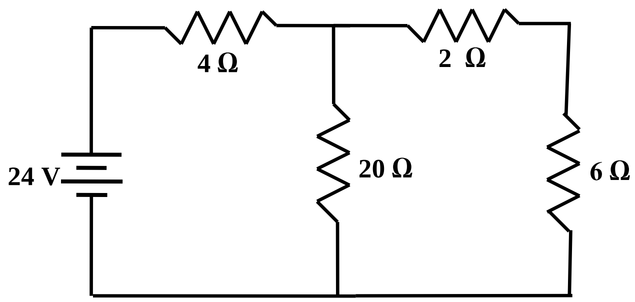
17. Find the resistance between A and B. [Ans: 0.55 Ω]



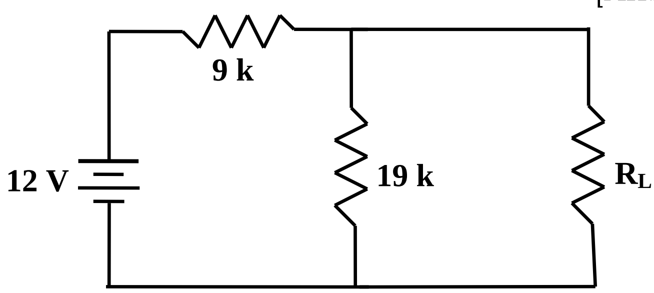
18. Find the current flowing through and voltage across R using super position theorem. [Ans: 3 A, 6 V]



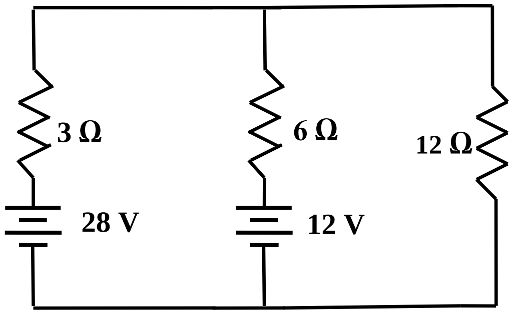
19. Using Thevenin's theorem, find the current through the 20 Ω resistor of the circuit. [Ans: 0.705 A]



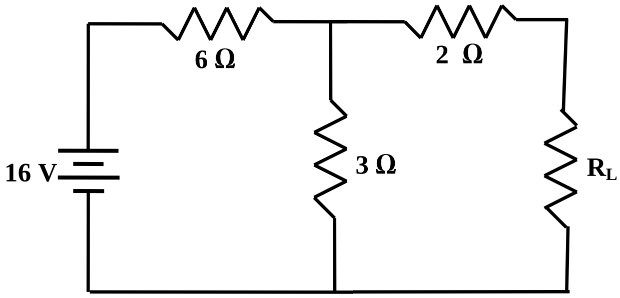
20. What should be the value of load R_L to abstract maximum power from 12 V battery? Hence determine the power transferred. [Ans: 6.1 kΩ, 2.7 mW]



21. Use superposition theorem to find the current through 12 Ω resistor. [Ans: 1.62 A]



22. According to Maximum Power Transfer theorem, what should be the value of load resistance R_L to abstract maximum power from the 16 V battery as shown in figure below. What is the value of this power?
[Ans: 4 Ω, 1.77 W]



23. Determine the time periods of the waveforms having a frequency of
a) 50 Hz b) 100 kHz [Ans: 20 mS, 10 μS]
24. What will be the frequencies of an ac signals having the time periods of
a) 20 μS b) 5 mS [Ans: 50 kHz, 200 Hz]
25. The angular frequency of a waveform is 1000 π radian/second.
Find its frequency and time period. [Ans: 500 Hz, 2 mS]
26. The equation of an alternating voltage is given by v = 325sin(314t). Find the frequency and the rms value of the voltage. [Ans: 50 Hz, 229.8 V]
27. A 220 Ω resistor is connected to 220 V sinusoidal 50 Hz supply. Find the peak, rms and average values of the current and the power dissipated.
[Ans: 1.41 A, 1 A, 0.898 A, 220 W]
28. A 100 W electric bulb connected across a 230 V, 50 Hz power line. What is the rms and peak value of the current flowing through it?
[Ans: I_{rms} = 0.435 A, I_p = 0.614 A]

29. A sinusoidal voltage varies from zero to a maximum value of 200 V. How much is its value at the instances of
    a) 30^0 b) 45^0 c) 90^0 d) 270^0 ? [Ans: 100 V, 141.4 V, 200 V, -200 V]

30. If the peak value is 240 V, find out its effective value. [V_{rms} = 169.70 V]

Questions

One mark questions:

1. What is the unit of electric charge?
2. What is the magnitude of a charge?
3. Define potential difference.
4. Define electric current.
5. What is the unit of electric current?
6. What is the direction of conventional current?
7. What is the direction of electron current?
8. Define DC current.
9. Define ampere.
10. Give an example for DC source.
11. State Ohm's law.
12. Is Ohm's law applicable when the temperature of a conductor continuously changes?
13. Is Ohm's law applicable to semiconductors?
14. Is Ohm's law applicable to insulators?
15. According to Ohm's law how are 'V' and 'I' related?
16. What is the resistance of a conductor?
17. Mention the unit of resistance.
18. What is an electric power?
19. What is an electric energy?
20. Define voltage source.
21. Define current source.
22. What is a node?
23. What is a branch in a circuit?

24. What is a 'loop' in an electrical circuit?
25. What is a closed loop?
26. What is an open loop?
27. What is a mesh in a closed circuit?
28. What is meant by a linear network? Give an example.
29. What is meant by a nonlinear network? Give an example.
30. What is meant by unilateral network?
31. What is meant by bilateral network?
32. State KCL.
33. State KVL.
34. What is the commercial or Board Of Trade (BOT) unit of electrical energy?
35. Define kWh.
36. When will a load receives maximum power from a source?
37. Mention an application of maximum power transfer theorem.
38. How is the Thevenin's resistance of a network determined?
39. How do you measure Thevenin's voltage?
40. How do you measure Thevenin's resistance?
41. How much is the AC voltage supplied to all household electrical devices in India?
42. Mention the unit of frequency.
43. Write the relation between frequency and time period.
44. What is the relation between RMS value and peak value of AC?
45. Give an expression for instantaneous value of AC voltage.

Two marks questions:

46. Mention the types of electrical charge.
47. Mention any two properties of charges.
48. What is the difference between conventional current and electron current?
49. State and explain Ohm's law.
50. Mention the limitations of Ohm's law.
51. Briefly explain about electrical energy.
52. What are primary DC-sources? Give an example.
53. What are secondary DC-sources? Give an example.
54. Draw the circuit of a practical voltage source.
55. Draw the circuit of a practical current source.

56. State Kirchhoff's laws.
57. Draw the V-I characteristics of a practical voltage source.
58. Briefly explain the conversion of voltage source into current source.
59. What is series combination of resistors?
60. What is parallel combination of resistors?
61. State Thevenin's theorem.
62. State Superposition theorem.
63. State maximum power transfer theorem.
64. Draw any two non sinusoidal waveforms.
65. Define frequency and time period. Write their relation.
66. Define peak value and RMS value.

Three/five marks questions:

67. Mention the properties of charges.
68. State and explain KCL.
69. State and explain KVL.
70. Explain how a voltage source is converted into its equivalent current source.
71. Explain how a current source is converted into its equivalent voltage source.
72. Distinguish between DC and AC current.
73. Derive an expression for the effective resistance of two resistors connected in series.
74. Derive an expression for the effective resistance of two resistors connected in parallel.
75. Explain voltage divider rule.
76. Explain current divider rule.
77. State and explain Thevenin's theorem with an example.
78. State and explain maximum power transfer theorem with an example
79. Write the procedure to Thevenise a given circuit with an example.
80. State and explain superposition theorem.
81. Define the following terms. a) Cycle b) Frequency c) Time period d) Peak value.
82. Write a note on AC generation.

83. Define the following terms in an AC signal
    a) Frequency b) Time period c) Peak Value d) Instantaneous voltage
    e) rms value.
84. Define the following terms with respect to an AC signal
    a) Cycle b) Effective value c) Peak to peak value d) Average value.

Chapter 3

Measuring Instruments

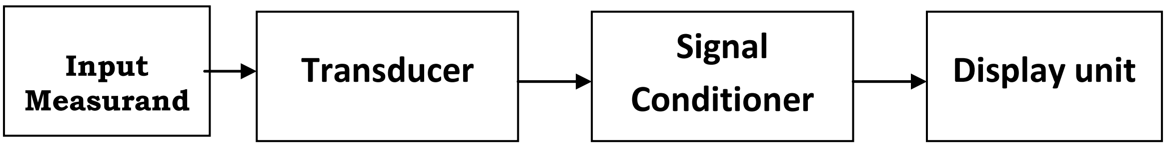
Introduction

Measurement is the process of comparing a given quantity with a predefined standard unit. Instruments are the device used to measure, analyze, evaluate and finally estimate the unknown quantities.

Electronic measuring instrument

Electronic measuring Instruments are constructed using electronic components. They have higher sensitivity, faster response, greater flexibility, easy mode to indicate, record and control.

Essentials of electronic instrument



An electronic instrument mainly consists of three components:

1. **Transducer:**
   It is a sensing element which converts physical quantity to electrical signal and vice versa.

   Ex: Microphone, thermistor, etc.

2. **Signal conditioner:**
   It converts transducer output to a suitable signal for display.

   Ex: Amplifier, filter.

3. **Display unit:**
   It is an output device which displays the measured quantities.

   Ex: Dot Matrix Display, Seven Segment Display.

Types of measuring instruments

There are two types namely

1. Analog instrument:
   Analog measuring instruments have a needle graduated on the scale to indicate the reading.

2. Digital instrument:
   Digital measuring instruments have digital display to indicate the reading.

Electronic measuring instruments

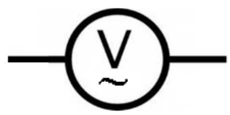
Voltmeter

Voltmeter is an instrument used to measure voltage between two nodes. It is always connected in parallel with the test circuit. A voltmeter is having very high (ideally ∞) internal resistance.

AC Voltmeter:

AC Voltmeter is an instrument used to measure AC voltage. A typical AC voltmeter and its symbols are shown in fig. 3.1 (a) and (b) respectively.

(a) AC Voltmeter

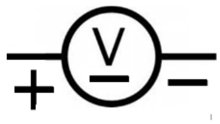


(b) Symbol of AC voltmeter

Fig. 3.1

DC Voltmeter: DC Voltmeter is used to measure DC voltage. A typical DC voltmeter and its symbols are shown in fig. 3.2 (a) and (b) respectively.

(a) DC Voltmeter



(b) Symbol of DC voltmeter

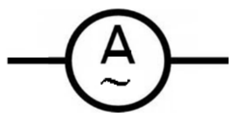
Fig. 3.2

Ammeter

Ammeter is an instrument used to measure current flow through a circuit. It is always connected in series with the test circuit. An ammeter has very low (ideally 0) internal resistance.

AC Ammeter: AC Ammeter is used to measure AC current. A typical AC ammeter and its symbols are shown in fig. 3.3 (a) and (b) respectively.

(a) AC Ammeter

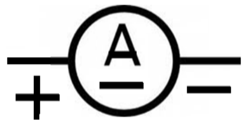


(b) Symbol of AC ammeter

Fig. 3.3

DC Ammeter: DC Ammeter is used to measure DC current. A typical DC ammeter and its symbols are shown in fig. 3.4 (a) and (b) respectively.

(a) DC Ammeter



(b) Symbol of DC ammeter

Fig. 3.4

Ohmmeter

Ohmmeter is used to measure resistance. Ohmmeter works only with the help of a internal battery. As the voltage of the battery is decreased ohmmeter shows error. This error is adjusted by the preset provided. A typical Ohmmeter and its symbols are shown in fig. 3.5 (a) and (b) respectively.

(a) Ohm Meter

(b) Symbol of Ohmmeter

Fig. 3.5

Multimeter

Multimeter is a multipurpose electronic instrument that can measure resistance, DC or AC voltage, current etc. Multimeters are available in analog and in digital type. A digital multimeter is shown in fig. 3.6. Digital multimeter has digital display to indicate reading and a rotary switch to select the quantity to be measured.

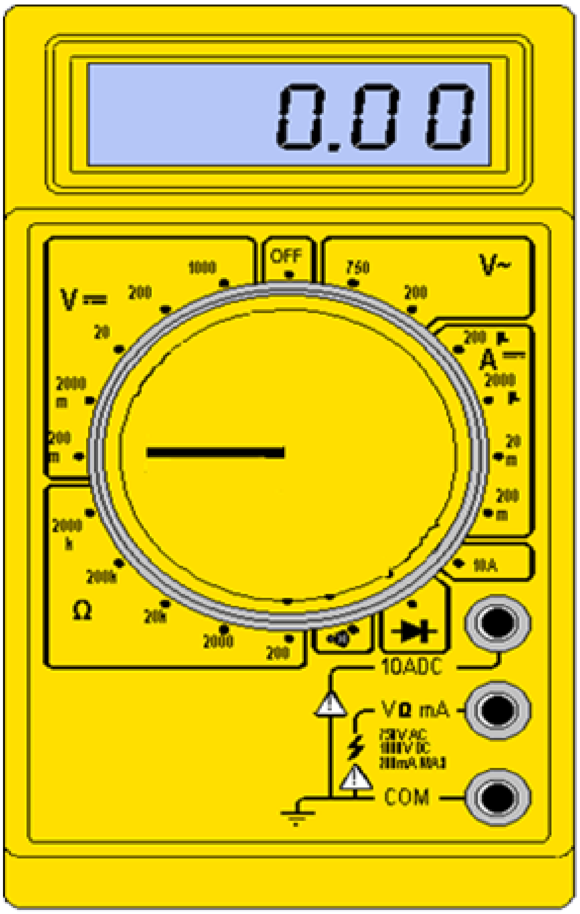


Fig. 3.6 Digital multimeter

Front panel details of a typical multimeter

1. **OFF:** Rotary switch in this position switches off the multimeter.

2. **Function/Range** Switch: Selects the function (voltmeter, ammeter, or ohmmeter) and the maximum range for the measurement.
3. **COM** Input terminal: This terminal is common ground, used in ALL measurements.
4. **VΩ** Input terminal: Used for voltage or resistance measurements.
5. **A** Input terminal: Used for current measurements.
6. **10 A** Input Terminal: Used to measure current of maximum 10A.
7. **V=** Range: These positions are DC voltage ranges.
8. **V~** Range: These positions are AC voltage ranges.
9. **Ω** Range: These position are resistance ranges.
10. **A=** Range: These positions are DC current ranges.
11. **Diode**: This position is used to test a diode.
12. **Buzz**: This position is used to test short.

Merits of multimeter

- Size is small and easily portable.
- Performs several measuring functions.
- Measures with reasonable accuracy.
- It is inexpensive.

Oscilloscope

Oscilloscope is an instrument used to display, measure and analyze parameter of electrical signal. Front view of cathode ray oscilloscope is shown in fig. 3.7.

Oscilloscope controls:

1) **Power on/off Button**: Used to switch on and switch off power.
2) **Intensity Knob**: Used to control the intensity of the electron beam.
3) **Focus Knob**: Used to adjust sharpness of the electron beam.

4) Position:

a) **Y-POS (Vertical position) control Knob**: It moves the trace upward and downward.

b) **X-POS (Horizontal position) control Knob**: It moves the trace left side and right side.

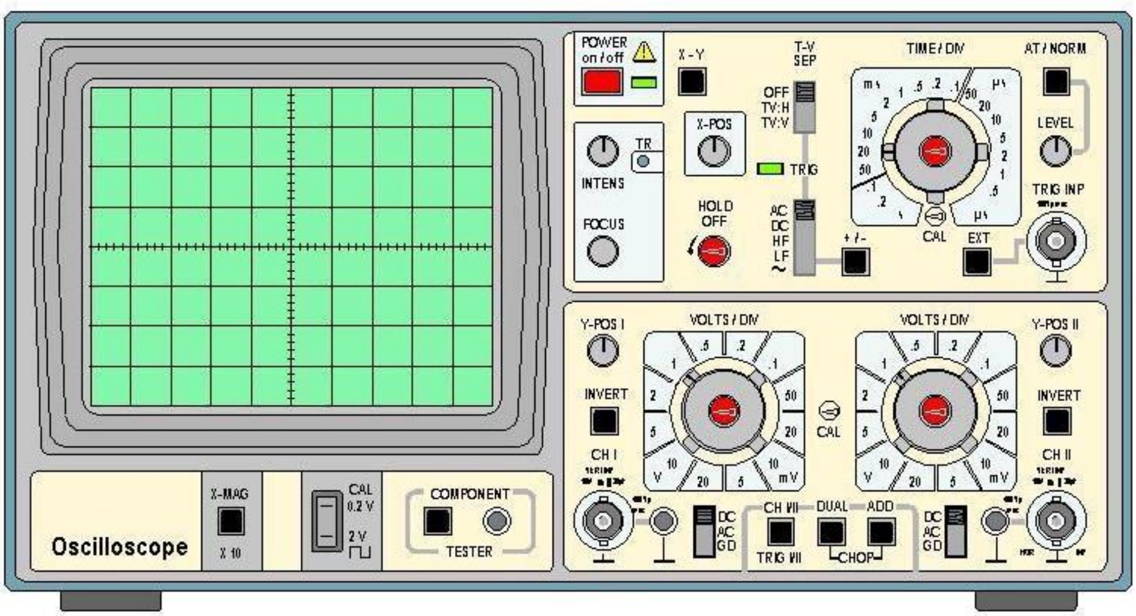


Fig. 3.7. Front panel view of DUAL TRACE Oscilloscope

5) Mode:

a) **CH1 Button** - It is used to display the signal applied to channel 1 input.

b) **CH2 Button** - It is also used to display the signal applied to channel 2 input.

c) **DUAL Button** - It is used to display the signal applied to channel 1 and channel 2 inputs at once.

6) Volt/Division Knob (Volt/Div): This knob is a voltage multiplier used to adjust the signal image vertically.

7) Time/Division Knob (Time/Div): This knob is a time multiplier used to adjust the signal image horizontally.

9) **X and Y-Input connectors**: The electrical signal to be measured is applied to these input terminals.

10) **AC-GND-DC switch**:

a. When the switch is positioned to AC, it displays the signal with AC level.
b. When the switch is positioned to GND, it indicates the ground level of the signal.
c. When the switch is positioned to DC, it displays the signal with DC level.

1. Voltage measurement – AC:

The peak to peak value of signal is adjusted using volt/division control unit. The y-axis value is used to measure peak to peak voltage.

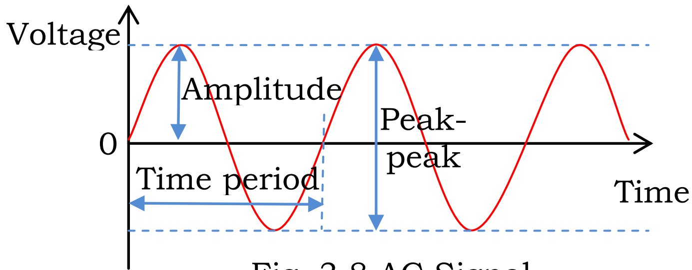


Fig. 3.8 AC Signal

Peak to peak voltage, $V_{p\text{-}p}$ = [height of the trace from peak to peak] $\times \left[\frac{\text{volts}}{\text{div}}\right]$

Peak voltage, $V_p = \frac{V_{p-p}}{2}$

RMS voltage, $V_{rms} = \frac{V_p}{\sqrt{2}}$

2. Time Period and Frequency measurement of AC:

The waveform of AC signal is adjusted on display. The distance between two successive positive or negative peaks is measured and multiplied with time base scale.

Time period T = [distance between any two successive peaks] $\times \left[\frac{\text{time}}{\text{div}}\right]$

Frequency, $f = \frac{1}{T}$ Hz

3. Voltage Measurement – DC:

1. Select any convenient time-base setting.
2. Keep AC-GND-DC switch to GND position.
3. Adjust the position so that the trace lies on centre line at GND.
4. Keep AC-GND-DC switch to DC position.
5. Connect DC voltage to channel input.
6. Trace line shifts upward or downward depending on polarity and signal strength.
7. Take readings of the y-position of the trace and note the volts/div setting
8. DC voltage = $[\text{Y displacement}] \times \left[\frac{\text{volts}}{\text{div}}\right]$ setting.

Application of oscilloscope:

- It is used to study the nature of waveform.
- It is used to measure AC/DC voltage.
- It is used to measure time, time period and frequency.
- It is used to compare frequency and phase of input signals.

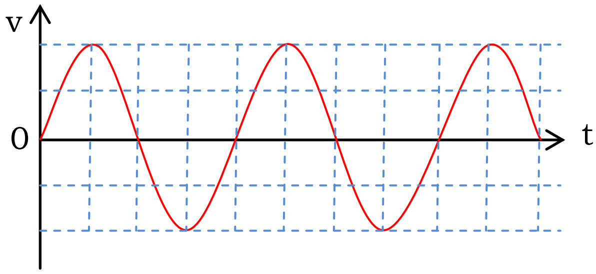
Precautions using electronic instruments

The following precautions are advised while using electronic instruments

1. Study user's manual before using the instrument.
2. DC meters must be connected with proper polarity.
3. Ammeter must be connected in series with the circuit.
4. Voltmeter must be connected in parallel with the circuit.
5. Select proper range of meters for conducting experiment.
6. Don't allow the current or voltage to the meters beyond the maximum limit.
7. Completely switch off the circuit during connection or reconnection of meters.
8. Use the multimeter by selecting proper range and function for quantities to be measured like resistance, voltage AC/DC, current and also select proper terminals (Com, VΩ, I).
9. Don't try to solder or de-solder the circuit when the oscilloscope is connected. Remove oscilloscope connections before soldering or de-soldering.
10. Don't apply high AC voltage (> 230 V) to oscilloscope.

Example

1. Find peak voltage, peak to peak voltage, rms voltage, time period and frequency of the signal shown below. CRO is set at $\left[\frac{\text{volts}}{\text{div}}\right]$ = 5 V and $\left[\frac{\text{time}}{\text{div}}\right]$ = 2 mS.



AC Signal

Peak to peak voltage, $V_{p\text{-}p}$ = [height of the trace from peak to peak] × $\left[\frac{\text{volts}}{\text{div}}\right]$

$$V_{p\text{-}p} = [4] \times [5] = 20\ \text{V}$$

Peak voltage, $V_p = \frac{V_{p-p}}{2} = 10$ V

RMS voltage, $V_{rms} = \frac{V_p}{\sqrt{2}} = 7.07$ V

Time period, T = [distance between any two successive peaks] × $\left[\frac{\text{time}}{\text{div}}\right]$

$$T = [4] \times [2 \times 10^{-3}] = 8 \times 10^{-3} = 8\ \text{mS}$$

Frequency, $f = \frac{1}{T} = \frac{1}{8\ \text{mS}} =$ 125 Hz

Medical Electronic Instruments

The application of electronics in the field of medicine is known as medical electronics. This section helps us to know about medical electronic instruments, usage and various measurements are illustrated here.

ECG: Electro cardio gram

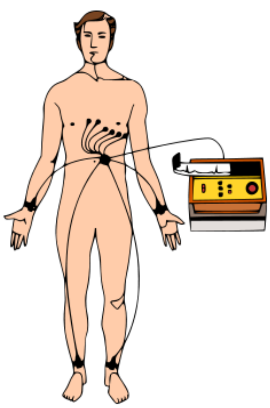


Fig. 3.9

Heart emits a small amplitude electrical signal which can be measured by using a measuring tool called as ECG. The electrocardiogram (ECG or EKG) is a diagnostic tool that is used to assess the electrical and muscular functions of the heart as shown in fig. 3.9.

The ECG is non-invasive and does not hurt. Electrodes are placed on the skin to detect electrical impulse signal that the heart generates. These impulses are recorded by an ECG machine. By this we can predict the proper function of the heart.

BP measurement: Sphygmomanometer

A sphygmomanometer is a device used for measuring arterial pressure.

The blood pressure in the circulation is principally due to the pumping action of the heart. Difference in mean blood pressure is responsible for blood circulation inside the body. A sphygmomanometer is shown in fig. 3.10.

Reference ranges for blood pressure

Stage	Approximate age	Systolic	Diastolic
Infants	1 to 12 months	75–100[19]	50–70[19]
Toddlers	1 to 4 years	80–110[19]	50–80[19]
Preschoolers	3 to 5 years	80–110[19]	50–80[19]
School age	6 to 13 years	85–120[19]	50–80[19]
Adolescents	13 to 18 years	95–140[19]	60–90[19]

Fig. 3.10

Systolic is the blood pressure when the blood is flowing through the arteries to heart. Diastolic is the blood pressure when the blood is flowing through heart to arteries. Systolic is greater than diastolic.

Glucometer

Glucometer is an electronic instrument that measures the concentration of glucose present in the human blood. A small drop of blood, obtained by pricking the skin with a lancet, is placed on a disposable test strip that the meter reads and uses to calculate the blood glucose level. The meter then displays the level in mg/dl (decilitre). The following table shows the values of normal values of glucose level in the blood. Fig. 3.11 shows a glucometer.

Fig. 3.11 Glucometer

Category of a person	Fasting Value		Post Prandial
	Minimum Value	Maximum Value	Value 2 hours after consuming glucose
Normal	70	100	Less than 140
Early Diabetes	101	126	140 to 200
Established Diabetes	More than 126	-	More than 200

Ultra sound scan

An ultrasound scan is a test that uses sound waves to create images of organs and structures inside the body. Since it uses sound waves and not radiation, it is harmless.

Advantages and Applications:

Fig. 3.12 Picture showing the Ultra sound scans Image.

- Help to monitor the growth of an unborn child, and check for the abnormalities.
- Detect abnormalities of heart structures such as the heart valves.
- Detect abnormal widening of blood vessels.

Pulse Oximeter:

Pulse Oximeter is an electronic device that is designed to detect the saturation level of hemoglobin contents of human.

Usually a sensor is placed in the thin part of the body like fingertip or earlobe or in the case of an infant across a foot. Light of two different wavelengths is passed through the patient by a photo detector. By measuring the wavelength of the light detected the value of the hemoglobin content is measured. Fig. 3.13 shows pulse oximeter.

Fig.3.13 Pulse Oximeter

Digital thermometer

Thermometer is an Electronic device that is used to measure the temperature of the human body. The temperature value of the meter is displayed in the LCD screen in digits.

A thermometer has two important elements

1. The temperature sensor.
2. Analog to Digital Converter.

The temperature sensor senses the temperature and converts it into electrical signal. An analog to digital convertor converts the analog signal into digital signal which is displayed in the Liquid Crystal Display.

Advantages:

1. Readings of the digital thermometer is accurate.
2. Digital thermometer is much easier to read than glass thermometer.
3. Readings can be measured very quickly.

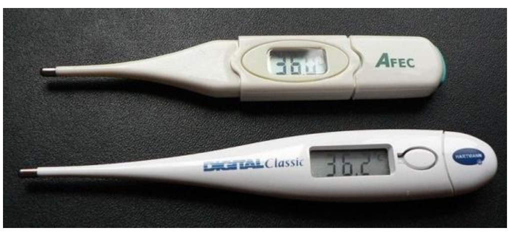


Fig. 3.14 Digital thermometer

Questions

One mark questions

1. What is meant by measurement?
2. What is an ammeter?
3. What is a voltmeter?
4. What is the Ohmmeter?
5. Write the symbol of Ohmmeter.
6. What is a multimeter?
7. What is an oscilloscope?
8. Expand ECG.
9. Mention any one application of an ECG.
10. What is BP measuring instrument?
11. What is glucometer?
12. What is an ultrasound scan?
13. Write an advantage of ultrasound scan?
14. What is a pulse oximeter?
15. What is a thermometer?

Two marks questions

16. Mention the merits of a multimeter.
17. Explain the controls of a multimeter.
18. Write any two application of an oscilloscope.
19. Mention any four controls of an oscilloscope.
20. What are the advantages of digital thermometer?

Chapter 4

Passive electronic components

Introduction

The components used in electronic circuits are classified into two categories. They are passive components and active components. This chapter is focussed on passive components, their constructions, working and specifications.

Passive components

These components normally absorb, store or dissipate energy, but are unable to supply energy to the network e.g. resistor, capacitor, inductor.

Active components

These components are able to supply energy to the circuit. They can also rectify amplify and change energy from one form to another. Example: Vacuum tube diode, semiconductor diode, Zener diode, varactor diode, LED, transistor, FET, SCR, etc.

Resistor

Resistor is a component which is used to limit the flow of current. The passive component which offers a specified value of resistance in the circuit is known as a resistor. Resist means to oppose. All the materials offer a little or more opposition to the flow of electric current through them. The property of the material to oppose the flow of current is known as **resistance.** The resistance of the material is not affected by the direction of flow of current i.e. its effect is same for both AC and DC. The resistance of the material is denoted by R and its SI unit is **ohm (Ω).**

Applications of resistor

Resistors are used to

1. Limit the current in a circuit.
2. Divide the voltage.
3. Protect the circuit elements.
4. Dissipate energy.

Specification of Resistors

Some important specification of resistors are ohms rating, power rating and tolerance.

Ohms rating: It specifies the value of the maximum resistance offered by the resistor when it is used in the circuit.

Power rating: The maximum power a resistor can dissipate safely is called power rating. It is expressed in watts. Since $P = I^2R$, therefore the power dissipation of a resistor depends on the current flowing through it.

Tolerance value: The percentage variation in the resistance value with respect to its marked value is called tolerance. Resistors have tolerance value of about ±1 % to ±20 %.

Temperature coefficient: The resistance of the material also depends on its temperature. Hence temperature coefficient specifies how resistance varies with temperature. In all the conducting materials, resistance increases with increases in temperature but in semiconductor materials, the resistance decreases with an increase in temperature. Temperature coefficient of resistance (α) is expressed as,

$$\alpha = \frac{R_t - R_o}{R_o t}$$

From the above equation,

The temperature coefficient of resistance (α) may be defined as the increase in resistance per °C rise in temperature to its resistance at 0°C.

Where R_t = Resistance at t° C in Ω.

R_o = Resistance at 0°C in Ω.

Illustration1

The resistance of a coil made of copper wire is 100 Ω at 0 °C. Calculate its resistance at 30 °C. Given $\alpha = 0.004/$ °C.

Solution: Given, Resistance at 0 °C, R_o = 100 Ω

Temperature t = 30 °C

Temperature Coefficient, α = 0.004 / °C Hence, resistance at t °C,

$$R_t = R_o (1 + \alpha t)$$

$$= 100 (1 + 0.004 \times 30)$$

$$= 100 \times 1.12$$

$$= 112\ \Omega$$

Specific resistance or resistivity

At constant temperature, resistance of a conductor is directly proportional to the length of the conductor l and inversely proportional to the area of cross section A.

$$R \ \alpha \ \frac{l}{A}$$

$$R = \frac{\rho l}{A}$$

Where, ρ is a constant depending on the nature of the material of the conductor and is known as specific resistance or resistivity of that material.

Consider the equation, $R = \frac{\rho l}{A}$, if l = 1 m and A = 1 m^2, then R = ρ.

Thus, Specific resistance or resistivity of the conducting material is defined as the resistance of a conductor of unit length having unit cross sectional area. The SI unit of specific resistance is Ohm meter (Ωm).

Illustration:

1) The resistance of a wire of length 1 m and of diameter 0.12 mm is 40 Ω. What is its specific resistance?

Solution: Given, l = 1 m, d = 0.12 mm, R = 40 Ω, ρ =?

$$\text{Then, Specific resistance } \rho = \frac{AR}{l}$$

$$= \frac{\pi d^2 R}{4l} = \frac{3.142 \times (0.12 \times 10^{-3})^2 \times 40}{4 \times 1} = 0.45216 \times 10^{-6}\ \Omega m$$

Conductance (G)

Conductance is the property of the material which allows the current to flow through it or in other words conductance is the reciprocal of resistance. It is measured in Siemens.

$$G = \frac{1}{R}$$

Types of Resistors

Resistors are broadly classified into two types, they are

1. Fixed resistor
2. Variable resistor

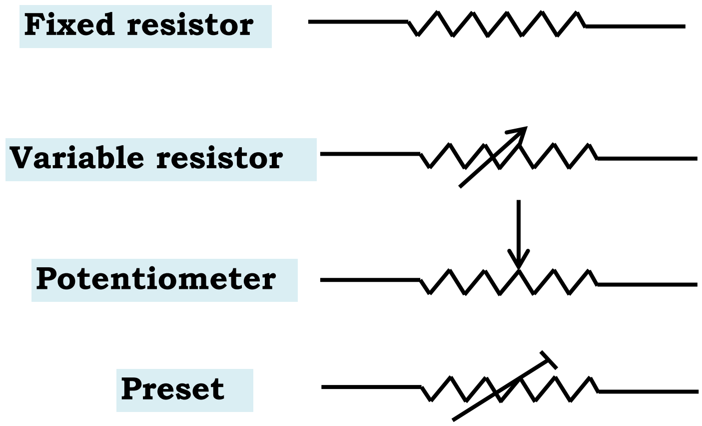
A fixed resistor is one whose resistance value remains constant; however there may be some variation in their value due to temperature variation. They are further classified depending upon the type of material used for construction. They are

1. Carbon composition resistor
2. Metal film resistor
3. Surface mount device (SMD) resistor
4. Wire wound resistor, etc.

A variable resistor is one whose resistance value can be varied over a specified range. They are further classified based on the materials used and type of construction. They are

1. Potentiometer
2. Preset
3. Rheostat, etc.

Circuit symbols of different types of resistor:



Fixed Resistors

Carbon film resistor (CFR)

Carbon composition resistor is made by depositing fine carbon on cylindrical ceramic rod. Carbon composition is deposited in the proportion needed for the desired resistance value. Metal caps with leads of tinned copper wire are joined to the two ends of the carbon coated resistor for external connections. The leads are called axial leads because they are joined axially from the ends. The resistor element is coated with the non-conductive material for insulation and mechanical strength. A band of colors are marked on the body of resistor to identify its value of resistance. Fig. 4.1 shows carbon composition resistor.

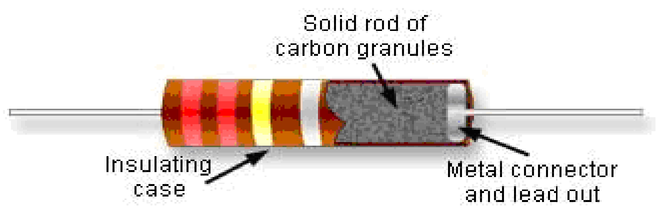


Fig. 4.1 Carbon Composition Resistor

Carbon resistors are commonly available in the range of 1 Ω to 22 MΩ. The power rating is generally 1/8 W to 2 W. The current carrying capability is limited, since their **power rating is low**. They have **high tolerance** because of their **poor stability**. They have tolerance up to 20%.

Applications

1. They are most commonly used because of their small size and low cost.
2. Used in electronic circuits where accuracy is not important.

Metal film resistor (MFR)

Metal film resistor is made by depositing fine film of metal such as nickel, chromium or aluminium on ceramic rod. When the ceramic rod is coated with metal film, the resistance of the rod becomes very low (almost zero). Then the metal film is removed from the rod in the form of a spiral to get a required resistance value as shown in fig. 4.2. In the construction of a metal film resistor, the length, thickness, and width of the metal spiral determines the exact resistance value. Metal caps with leads of tinned copper wire are joined to the two ends of the metal coated resistor for external connections. The resistor element is coated with non conductive material for insulation and mechanical strength. A band of colors are marked on the body of the resistor to identify its value of resistance. Fig. 4.2 shows cross sectional view of metal film resistors.

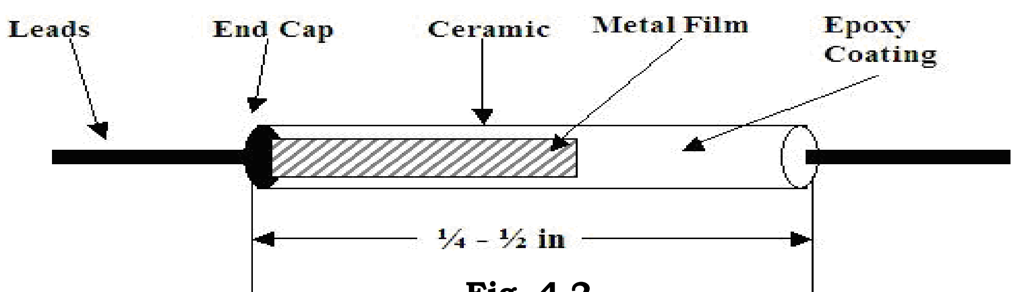


Fig. 4.2

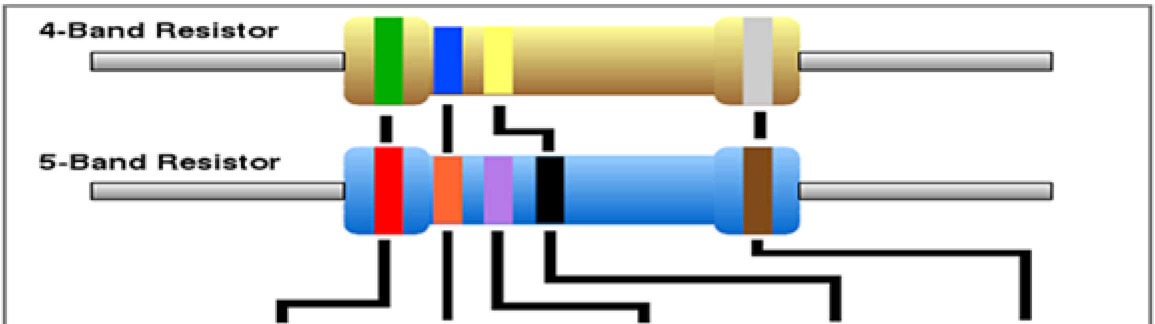
Metal film resistor has more precise value of resistance than carbon film resistors. Like carbon film resistors, metal film resistor is less affected by temperature changes and ageing. They also generate less noise internally. In terms of overall performance, metal film resistors are the best. MFRs are commonly available in the range of 1 Ω to 22 MΩ. The power rating is generally 1/8 W to 2 W. The current carrying capability is limited, since their **power rating is low**. They have **low tolerance** because of their **high stability**. They have tolerance up to 1%.

Applications

1. These resistors are used for numerous high grade applications in certain instruments.
2. Used in instruments which requires accurate and stable resistance value.

Colour Coding of resistors

Some resistors are so tiny that it is difficult to print the resistance value on them. Therefore it is convenient to express their value by painting with a few circular lines (called bands) of different colours on their body. Usually 4 bands and 5 bands are printed on the body of the resistors.



Color	A	B	C	Multiplier	Tolerance
Black	0	0	0	x 1 Ω	
Brown	1	1	1	x 10 Ω	+/- 1%
Red	2	2	2	x 100 Ω	+/- 2%
Orange	3	3	3	x 1 KΩ	
Yellow	4	4	4	x 10 KΩ	
Green	5	5	5	x 100 KΩ	+/- .5%
Blue	6	6	6	x 1 MΩ	+/- .25%
Violet	7	7	7	x 10 MΩ	+/- .1%
Grey	8	8	8		+/- .05%
White	9	9	9		
Gold				x .1 Ω	+/- 5%
Silver				x .01 Ω	+/- 10%
No colour					+/- 20%

Table: 1

For 4 band Resistance R = (10 x A + B) x Multiplier ± Tolerance

For 5 band Resistance R = (100 x A + 10 x B + C) x Multiplier ± Tolerance

Where, A, B and C are numerical values corresponding to the colours.

Colour code may be memorized as follows.

B	**B**	**R**	**O**	**Y**	of	**G**reat	**B**angalore	has	**V**ery	**G**ood	**W**ife
0	**1**	**2**	**3**	**4**		**5**	**6**		**7**	**8**	**9**

Where the capital letters represent respective colours mentioned in the Table:1.

Illustration 1:

1. Consider a carbon resistor having four colour bands - blue, grey, orange and gold.

   R = (10 x A + B) x Multiplier ± Tolerance

   A = I band = Blue = 6
   B = II band = Grey = 8
   Multiplier = III band = Orange = 1 kΩ
   Tolerance = IV band = Gold = ±5%

   R = (10 x A + B) x Multiplier ± Tolerance
   R = (10 x 6 + 8) x 1 kΩ ± 5%
   R = 68 kΩ ± 5%

2. What is the resistance value of carbon resistor having 4 colour bands brown, black, yellow and silver?

   R = (10 x A + B) x Multiplier ± Tolerance
   R = (10 x 1 + 0) x 10 kΩ ± 5%
   R = 100 kΩ ± 10%

Illustration 2:

1. Consider the metal film resistor whose colour bands have the following five colours, orange, yellow, green, blue and gold colours, then

   R = (100 x A + 10 x B + C) x Multiplier ± Tolerance

   A = I band = Orange = 3
   B = II band = Yellow = 4
   C = III band = Green = 5
   Multiplier = IV band = Blue = 1 MΩ
   Tolerance = V band = Gold = ±5%

   R = (100 x 3 + 10 x 4 + 5) x Multiplier ± Tolerance
   R = 345 MΩ ± 5 %.

2. Find the resistance value of metal film resistor whose colour bands have the following five colours - brown, black, black, orange and brown.

   R = (100 x A + 10 x B + C) x Multiplier ± Tolerance
   R = (100 x 1 + 10 x 0 + 0) x 1 kΩ ± 1%
   R = 100 k Ω ± 1 %.

SMD (Surface Mount Device) Resistor

SMD resistor is very small rectangular shaped metal oxide film resistor. Some times it is also known as chip resistor. They have a ceramic substrate body on which a thick layer of metal oxide is deposited. They also have metal terminals or caps at either ends of the body which allow them to be soldered directly on to printed circuit board.

The resistance value of the resistor is controlled by increasing the desired thickness, length or type of deposited film being used. SMD resistors are available with highly accurate and low tolerance values (as low as 0.1 %). These resistors are printed with either 3 or 4 digit numerical code, in which the first two digits represent the first two numbers of the resistance value with the third digit being the multiplier.

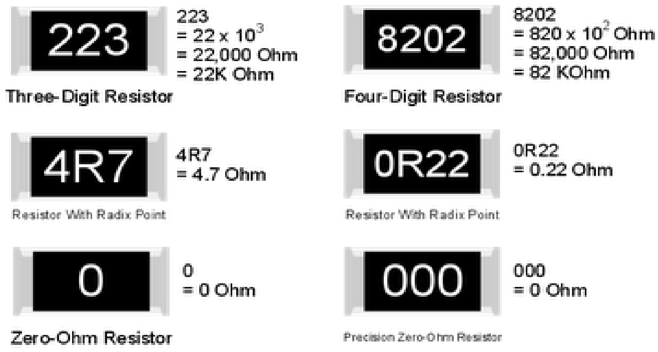


Fig. 4.3 shows SMD resistors.

For example:

1. R = 390 = 39 x 10^0 = 39 Ω
2. R = 392 = 39 x 10^2 = 3.9 kΩ
3. R =105 = 10 x 10^5 =1 MΩ

SMD resistance values below 10 have a letter "R" to denote the position of the decimal point. For example, 4.7 Ω resistor is marked with 4R7.

If SMD resistors have "000" or "0000" markings which are **zero-ohm (0 Ω)** resistors or in other words shorting links, since these components have **zero resistance**.

SMD resistors applications

SMD resistors are used in

1. Electronic circuits where space is the constraint
2. Multilayer PCB designing
3. Electronic pocket calculators
4. Cell phones, etc.

Wire Wound Resistor

Wire wound resistor is made by winding a wire of known length on an insulated base. Generally, porcelain base is used as supporting material and eureka wire (an alloy of 60% nickel and 40% copper) as resistance wire. Two ends of the wire are connected to metal leads. These leads are taken out from the two ends for connection purposes. The entire structure is encapsulated and enamel paint is coated to protect it from atmospheric contamination and to prevent from external electric shock. Finally, their specifications are marked on its body. A wire wound resistor is shown in fig. 4.4. Wire wound resistors are available in the range of 0.01 Ω to 100 kΩ with 5W to 50W power ratings.

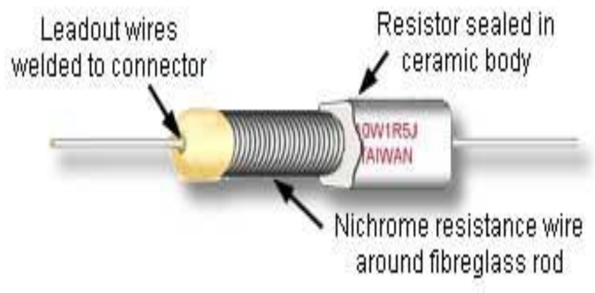


Fig. 4.4 Wire wound resistor

These kinds of resistors have good stability, reliability and high power ratings. It is easy to construct a low value resistor of 0.01 Ω with lowest tolerance value up to 5%. On other hand, it is difficult to construct a high value resistor because their size is quite big which is unsuitable for small sized equipments. They are unsuitable for high frequency circuits because their effective resistance is increased due to presence of inductive reactance in them.

Applications

1. These resistors are used in audio frequency applications.
2. These are used in large current applications and also in ammeters.

Variable resistors

Potentiometer (Carbon composition type)

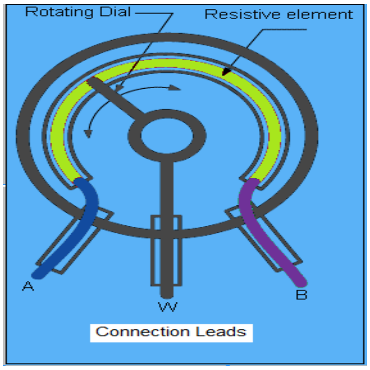


Fig. 4.5 Potentiometer

A potentiometer is a variable resistor, whose values can be varied over a specified range. It consists of circular strip which is almost equal to (¾)th of a ring. A carbon film is deposited on it. A moving arm which is connected to a shaft is mounted in such a manner that by rotating the shaft any resistance value between zero and maximum can be obtained. Fig. 4.5 shows an inner view of a potentiometer. Generally the potentiometer is made of carbon granules. Variation in the potentiometer may be linear or Logarithmic.

Applications

Carbon type potentiometers are used as,

1. Tone controls in Radio and TV sets
2. Volume and Brightness control of TV receivers
3. Speed control in fan regulator

Preset

It is a potentiometer of a very small size. It is generally mounted on the PCB of the equipment. Its ohmic value can be adjusted by means of a small screw driver during alignment of the equipment. These are made in linear as well as in logarithmic types ranging from 100 Ω to 2.2 MΩ.

Applications

1. They are extensively used in TV receivers.
2. They are used in electronic circuits for calibration purposes.

Importance of resistor power rating

When the current flows through a resistor, power is dissipated by the resistor in the form of heat. The maximum power a resistor can withstand without damaging it is known as the **power rating of a resistor.** Every resistor has a maximum power rating which is determined by its physical size. Generally, the greater the size, the more power it can dissipate safely without degrading its performance.

The electrical power dissipation of any resistor in a DC circuit can be calculated using one of the following three formulae.

$$\text{Power (P)} = V\,I = I^2\,R = \frac{V^2}{R}$$

Where V is the voltage across the resistor, I is the current flowing through the resistor and R is the resistance of the resistor in Ohm (Ω).

Resistors of the same ohmic value are available in different power or wattage ratings. CFR and MFR resistors are commonly available in wattage ratings of (⅛) W, (¼) W, (½) W, 1 W, and 2 W. However, it is always better to select a particular wattage resistor that is capable of dissipating two or more times the calculated power. When resistors with higher wattage ratings are required, wire wound resistors are generally used to dissipate the excessive heat.

Note: The common problems in resistors are open, short and ageing of resistor.

1. Open circuited resistor: When large current flows through the resistor, it burns out and opens. An open circuited resistor has infinite resistance and no current flows through the resistor.

2. Short circuited resistor: A short circuit has zero resistance. But practically it is impossible for a resistor to become short.

3. Ageing of resistor: The deterioration in the value of resistor due to long period use is called ageing of resistor. The tolerance value of the aged resistor varies.

Capacitors

A capacitor consists of two conducting plates separated by a layer of an insulating medium called **dielectric**. The conducting plates may be in the form of either circular or rectangular or cylindrical shape. The purpose of a capacitor is to store electric charges in the form of electrical energy.

Any system of two conductors carrying equal and opposite charges of any shape and size separated by a distance is called a capacitor or condenser.

Capacitance: The capability of storing electrical charges by two conducting plates separated by an insulator is known as capacity of capacitance. It is denoted by C**.**

When the capacitor is connected to a battery the current flows in the circuit, which charges one plate with positive charge and the other with negative charge as in fig. 4.6. The quantity of electrical charge stored in the capacitor is directly proportional to the voltage applied across it.

i.e. $Q \propto V$

$$Q = C\,V$$

$$C = \frac{Q}{V}$$

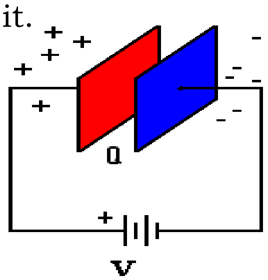


Fig. 4.6

Where, C is the constant of proportionality called capacitance of a capacitor.

Unit of capacitance

SI unit of capacitance is farad and is denoted by F.

A capacitor has a capacitance of one farad, if it carries a charge of one coulomb when its potential is one volt.

$$1\text{F} = \frac{1\,C}{1\,V}$$

Farad is large unit; therefore smaller practical units are used as,

Micro farad, $\mu F = 10^{-6}$ F
Nano farad, $nF = 10^{-9}$ F
Pico farad, $pF = 10^{-12}$ F

Principle of a capacitor

Consider a long metal plate M charged positively to +Q as shown in fig. 4.7(a). Bring another identical long uncharged metal plate N nearby to M. The positive charge on plate M induces an equal amount of opposite charges on the side of plate N facing the plate M.

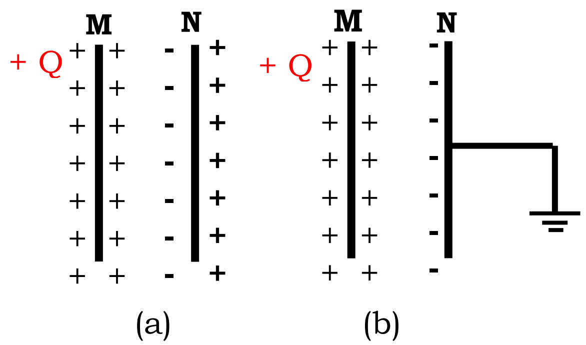


Fig. 4.7

The induced negative charge reduces the potential of plate M, while the induced positive charge increases the potential of plate M. Since the plate N is placed nearer to plate M, the effect of the negative charge is greater than that of the positive charge. Thus, in the presence of plate N the net potential of plate M reduces slightly and consequently the capacitance of plate M increases.

The charges on the outer face of the plate N gets neutralised when it is grounded as shown in Fig. 4.7(b). The induced negative charge is held in position by the electrostatic force of attraction due to +Q on the plate M. The induced negative charge residing on plate N greatly reduces the potential of plate M. As a result, the capacitance of plate M increases. It is clear that when grounded conductor is placed near a charged conductor with a dielectric medium in between, the capacitance of the system increases.

Capacitance of plate M may be further increased by,

(i) Reducing the distance between the plates.
(ii) Placing the higher dielectric constant material in between the plates.

Conclusion: Hence it may be concluded that when grounded conductor is placed near a charged conductor with a dielectric medium in between, the capacitance of the system increases. Capacitor is an efficient device to store charges in the electric field. Its shape can be considered either with two parallel plates, or two circular plates or two cylindrical plates.

Factors affecting the capacitance of a capacitor

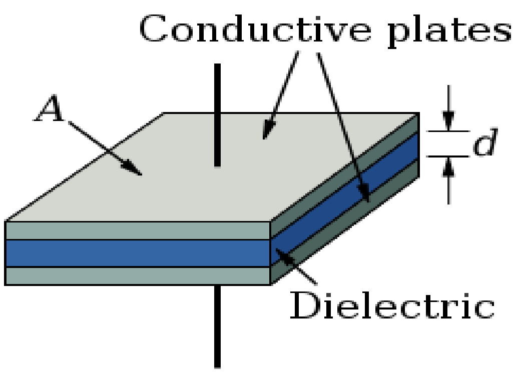


Fig. 4.8

The capacitance of a capacitor is proportional to the cross sectional area of the plates and inversely proportional to the distance between the plates.

$$C \,\alpha\, \frac{\epsilon A}{d} = \frac{\epsilon_0 \epsilon_r A}{d}$$

Where, A - The common area of plates
d - The distance between the plates as in fig. 4.8.
ϵ - The permittivity of the medium
ϵ_o - The permittivity of free space or air or vacuum = 8.854×10^{-12} F/m
ϵ_r - The relative permittivity

Importance of voltage rating of capacitors

The maximum voltage which can be applied across the plates of a capacitor without damaging the dielectric medium is called the voltage rating. The voltage across the capacitor should not be allowed to exceed its rated value. If the applied voltage across the capacitor is increased beyond its rated value the capacitor is exploded. Usually voltage rating of a capacitor is less for AC then DC because in AC internal heat is produced by continuous charge and discharge. The capacitors of rating more than 25% of the working voltage must be chosen for safe operation of the circuit and for long life. Non polar capacitor does not have polarities on their terminal they can be connected in any manner with the circuits. Special care must be taken in using electrolytic capacitors. Polarities '**+**' for positive terminal and '**-**' for negative terminals are marked in electrolytic capacitors. Polarities of electrolytic capacitors must be properly connected with positive terminal towards higher voltage and negative terminal towards lower voltage otherwise the capacitor gets exploded. Capacitor voltage ratings are given for the temperature up to 60^0 C. Higher the temperature results in lower the voltage rating.

Role of Dielectric medium in capacitor

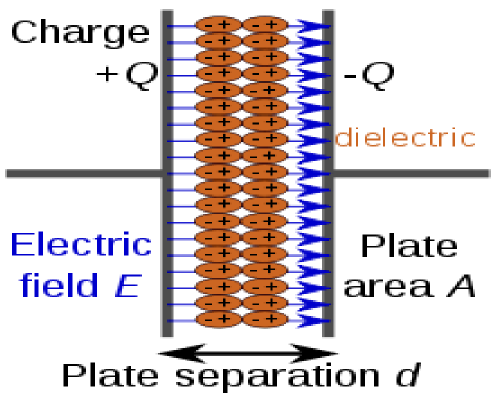


Fig. 4.9

Dielectric medium indicates the ability of an insulator to concentrate electric flux. In the absence of any external electric field, the permanent dipoles (a pair of equal and opposite charges separated by small distance) in a polar dielectric will be oriented in a random manner. Under the action of electric field positive and negative charges in an atom get displaced in opposite direction. This effect induces an electric dipole in the dielectric medium along the direction of the applied field. Hence dielectric medium is said to be polarized. Due to this process electric field is established inside the medium. The developed internal field opposes the external electric field. Usually the net field inside a dielectric is less than the applied field. This decreases potential difference between the plates and consequently more charges are stored in the capacitor. A typically polarized structure inside the dielectric medium is shown in fig. 4.9.

The Table given below shows some of the dielectric materials and their constants.

Name of insulator	Dielectric constant (ϵ_r)
Paper	3.7
Bakelite	4.9
Porcelain	6.0
Mica	5.0
Air	1.006
Polystyrene	2.6
Glass	7.5
Ceramic (Barium strontium oxide)	7500
Ceramic (Strontium titanate)	310
Titanium Ceramic	130

Energy stored in a capacitor

A capacitor C can be charged by connecting a battery of V volt. Capacitor gets charged with Q coulomb of charge. The energy stored in the charged capacitor is measured by the amount of work done in charging the capacitor to a given potential. If V is the voltage across a capacitor of capacitance C, then the electric energy stored in the capacitor is given by

$$\boxed{E = \frac{1}{2} CV^2 \quad \text{joule}}$$

Classification of Capacitors

Capacitors are broadly classified into:

1. Fixed capacitors

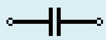
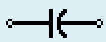
A capacitor having a fixed capacitance value is called as a fixed capacitor.

Types: Paper capacitor, mica capacitor, ceramic capacitor, electrolytic capacitor etc.

2. Variable capacitors

A capacitor whose value can be varied is called variable capacitor.
Types: Gang capacitor, trimmer and padder.

Capacitor symbols

Symbol	**Name**
	Fixed Capacitor
	Electrolytic Capacitor
	Variable Capacitor

Types of fixed Capacitors:

Ceramic Capacitors

Fig. 4.10

Ceramic capacitor consists of two tubular, disc, or rectangular shaped plates. It employs a ceramic dielectric which is a compound of titanium, barium, magnesium and strontium. Aluminium, tin or Silver is used for making the conducting plates of these capacitors. Copper leads are attached to the metal plates. The entire unit is then encapsulated within a protective plastic coating as shown in the fig. 4.10.

Specification

1. Available values - 1 pF to 0.01 µF.
2. Voltage rating - 50 to 10 kV.

Application

1. Suitable for high frequency circuits.
2. Radio frequency, micro wave systems.
3. Computer, industrial, defence equipment, etc.

Polystyrene capacitor

Polystyrene capacitor is made up of two long metal foils separated by a very fine polythene sheet or mylar and rolled together in the form of a cylindrical shape. A connecting wire is joined to each metal foil and the capacitor is encapsulated with a suitable resin binder. Polystyrene capacitor is as shown in the fig. 4.11.

Fig. 4.11

Specification

1. Available range - 10 pF to 1 µF
2. Voltage rating - up to 630 volt

Application

1. They are used in radio frequency (RF) applications.
2. Digital computing apparatus.
3. Measurement of ionization currents in radioactive materials.
4. It is used to measure dosage of X-rays in X-ray therapy, etc.

Electrolytic capacitor

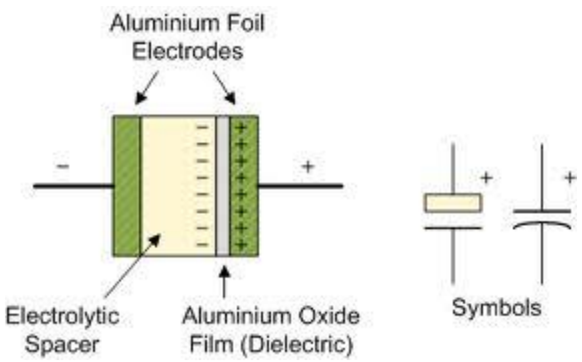


Fig. 4.12

Electrolytic capacitor consists of two aluminium foils with an electrolyte of borax or phosphate or carbonate. In between two aluminium foils, absorbent gauge soaked with an electrolyte is placed to provide the required electrolysis, formation of an oxide film acts like a dielectric medium (an insulator) when DC voltage is applied between the positive plate and the electrolyte. In this type of capacitor there are two leads, longer lead is positive terminal and the shorter lead is negative terminal. Fig. 4.12 shows the electrolytic capacitor.

Owing to the small spacing between the metal foils, high capacitance value can be manufactured. However, it is important that an electrolytic capacitor must be connected with correct polarity. Otherwise, gas forms within the electrolyte and the capacitor may be damaged or even explode. Hence, it is sensitive to polarity.

Specification

1. Available range - 1 μF to10000 μF.
2. Voltage rating - up to 450 volt.

Applications

1. Used as filters to remove ripples in DC power supplies.
2. Used as by pass capacitors.

SMD capacitors (Surface Mount Device capacitor)

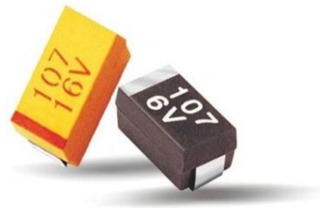


Fig. 4.13

SMD capacitors are rectangular type very compact chip capacitors. They are used in printed circuit boards, because they can be mounted easily on the PCB.

Ceramic SMD capacitors

The SMD capacitor consists of a rectangular block of ceramic dielectric material between the layers of a conductive film, which forms the capacitor plates. This structure gives rise to high capacitance per unit volume. The inner electrodes are connected to the two terminals, either by silver palladium (AgPd) alloy, or silver dipped with a barrier layer of plated nickel and finally covered with a layer of plated tin (NiSn). A typical SMD capacitor is shown in fig. 4.13.

Specification

1. Available Range: 1 pF to 0.1 μF
2. Tolerance: ± 0.25% to ± 5%
3. Voltage rating: 100 V

Applications

SMD capacitor are used in,

1. Avionic systems
2. SONAR systems
3. Satellite systems
4. Digital signal processor based circuits
5. Timing circuits

Variable capacitors

Capacitance value of the capacitor can be varied from zero to its rated value.

Ganged capacitor

Fig. 4.14

Ganged capacitor consists of two sets of plates one is known as stator and the other as rotor. The rotor plates can be rotated through an angle of 180^o. The value of the capacitance can be varied by changing the effective area between the two sets of plates. The capacitance value can be varied from **30 pF to 600 pF**. Air works as dielectric between the plates shown in fig. 4.14. The change in capacitance value of ganged capacitor is given by the relation

$$\boxed{C = \frac{(n-1)\epsilon_o \epsilon_r A}{d}}$$

Where, n = Number of rotating plates

ϵ_o = Permittivity of free space = 8.85×10^{-12} F/m

ϵ_r = Relative Permittivity

A = Area of the plates

d = Distance between the plates

Trimmer


(a)

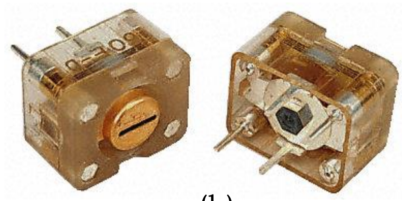

(b)

Fig. 4.15

Parallel plate type: It consists of two alloy metal plates placed parallel to each other. One plate is fitted on Bakelite or a porcelain base and the other one is a tension plate which is fitted in, such that the distance between the two plates can be adjusted by a screw. The variation in distance between the two plates varies the capacitance value of the trimmer. A mica sheet acts as a dielectric medium between the two plates, as shown in fig. 4.15(a). Other types of trimmer are cup type, wire type and disc type.

Padder type: It is also an adjustable capacitor whose capacitance value can be adjusted with the help of a screw. It consists of two or more plate couples. The capacitance value can be varied by changing the distance between the plates. The distance between the plates can be adjusted by the screw provided. Mica sheets are used as dielectric between the plates as shown in fig. 4.15(b).

Specification

1. Available range: 1 - 100 pF
2. Operating voltage: 0 - 100 V

Applications

1. Trimmer and padders are used for frequency setting in radio receivers.
2. In tuning circuits.

Combination of capacitor

In a circuit, capacitors are connected in series and in parallel. Some time series parallel combinations are also made.

Capacitors in series

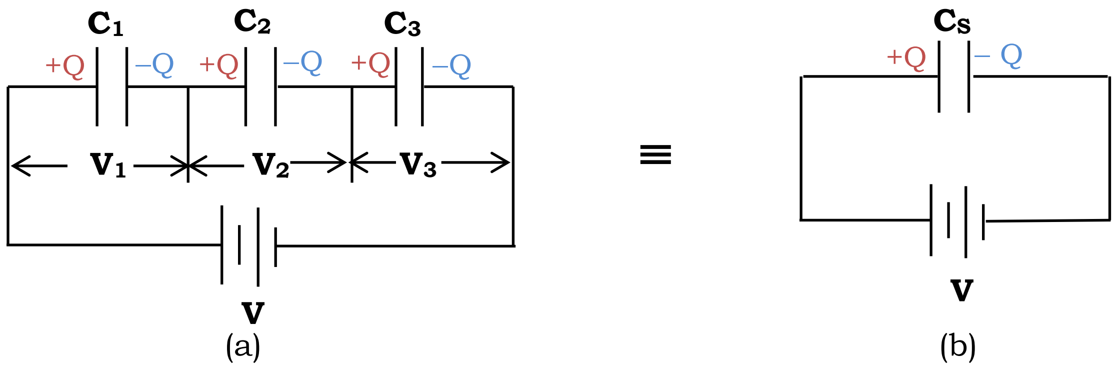


Fig. 4.16

When a number of capacitors are connected end to end they are said to be in series. In this combination the charge on each plate is same and the total potential difference is equal to the sum of potential difference across each of the capacitor.

Consider three capacitors of capacitances C_1, C_2 and C_3 connected in series. Let a battery of emf V volt be connected across the combination as shown in fig. 4.16(a). Applying KVL the total voltage across the capacitors is given by,

$$V = V_1 + V_2 + V_3 \qquad \text{.........} \ (1)$$

If Q is the charge on each capacitor, then

$$V_1 = \frac{Q}{C_1} \quad , \quad V_2 = \frac{Q}{C_2} \quad \text{and} \quad V_3 = \frac{Q}{C_3}$$

Replacing value of V_1, V_2 and V_3 in equation (1), we get

$$V = \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3}$$

Rearranging the above equation, we have

$$\frac{V}{Q} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \qquad \text{.........} \quad (2)$$

Let the combination be replaced by an equivalent capacitance C_S which stores amount of charge Q with the same applied emf as shown in fig. 4.16(b), then

$$\frac{V}{Q} = \frac{1}{C_S} \qquad \text{.........} \ (3)$$

By equating equations (2) and (3),

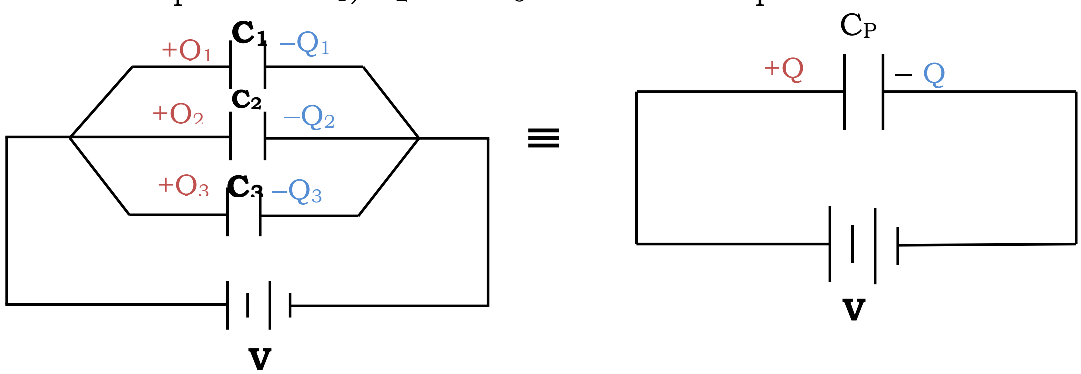
$$\frac{1}{C_S} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

Thus, the reciprocal of the effective capacitance of capacitors connected in series is the sum of the reciprocals of the individual capacitances.

Capacitors in parallel

Capacitors are said to be in parallel, when they are connected between the same two points so that voltage across each of them is same and the total charge is equal to the sum of the charges on the individual capacitors.

Consider three capacitors C_1, C_2 and C_3 connected in parallel as shown in fig. 4.17.



(a) (b)

Fig. 4.17

Let V be the applied voltage across the combination. The voltage across each capacitor is same. The total charge Q gets divided as Q_1, Q_2 and Q_3 across C_1, C_2 and C_3 respectively as shown in fig. 4.17(a).

Then total charge is given by,

$$Q = Q_1 + Q_2 + Q_3 \qquad \text{.........(1)}$$

But we know that, $Q = CV$ then,

$$Q_1 = C_1V, \qquad Q_2 = C_2V \quad \text{and} \qquad Q_3 = C_3V$$

Substitute the above values in equation (1), then

$$Q = C_1V + C_2V + C_3V$$

$$\frac{Q}{V} = (C_1 + C_2 + C_3) \qquad \text{.........} \ (2)$$

C_p is the effective capacitance of capacitances C_1, C_2 and C_3. Let the combination be replaced by an equivalent capacitance C_p with same applied voltage V and stores charge $Q = Q_1 + Q_2 + Q_3$ as shown in fig. 4.17(b). Then,

$$C_p = \frac{Q}{V} \qquad \text{.........} \ (3)$$

From (2) and (3) we get,

$$C_P = C_1 + C_2 + C_3$$

Thus, the effective capacitance of capacitors in parallel is equal to the sum of the individual capacitances.

Trouble shooting in capacitors

Generally the troubles in capacitors are open, short, leakage of current and resistance.

For a good condenser resistance is high at the range of MΩ. An **open** capacitor has infinite resistance and a **short** circuited condenser has zero resistance.

Leakage current and leakage resistance: An ideal condenser holds the charge given to it for infinite time. But in a practical condenser, electrons leak through the dielectric from the negative to positive plate. This results in a small leakage current through the dielectric.

The resistance offered by the dielectric material to the flow of leakage current is called leakage resistance.

Ageing factors: Use of capacitors over a long period may deteriorate the dielectric medium which results in decrease in the value of capacitance.

Worked example

1. Determine the charge on a 20 μF capacitor charged to 18 volt

Solution:

Given C = 20 μF and V_C = 18 volt

We know that, $Q = CV_C$

$= 20 \times 10^{-6} \times 18 = 360 \times 10^{-6} = 360\ \mu C$

2. Two capacitor plates each of effective area $6 \times 10^{-4}\ m^2$ are separated by 1.3×10^{-3} meter. Find its capacitance. The space between the plates is filled with air.

Solution:

We know that,

$$C = \frac{\epsilon_0 A}{d} = \frac{8.854 \times 10^{-12} \times 6 \times 10^{-4}}{1.3 \times 10^{-3}}$$

$$= 40.86 \times 10^{-13}$$

$$C = 4.086 \times 10^{-12} = 4.086\ pF$$

3. How much energy is stored in a 30 μF capacitor with 12 V across its plates?

Solution:

We know that energy stored in capacitor is given by,

$$E = \frac{1}{2} CV^2$$

$$= \frac{1}{2} \times 30 \times 10^{-6} \times 12^2$$

$$E = 2160 \times 10^{-6} = 2160\ \mu J$$

4. Calculate the total capacitances of three capacitors of 10 μF, 20 μF and 30 μF connected in series.

Solution:

The total effective capacitance is given by,

$$\frac{1}{C_S} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

$$\frac{1}{C_S} = \frac{1}{10 \text{ x } 10^{-6}} + \frac{1}{20 \text{ x } 10^{-6}} + \frac{1}{30 \text{ x } 10^{-6}}$$

$$C_S = 5.45\ \mu F.$$

5. The capacitors of 0.001 μF, 0.002 μF and 0.005 μF are connected in parallel. Calculate the effective capacitance.

Solution:

The total effective capacitance is given by,

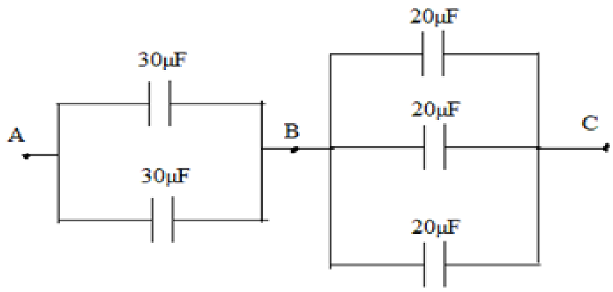
$$C_P = C_1 + C_2 + C_3$$

$$= (0.001 + 0.002 + 0.005) \text{ x } 10^{-6}$$

$$C_P = 0.008\ \mu F.$$

6. Determine the effective capacitance of the combination shown in fig. below.

Solution:



Total capacitance between A and B is given by,

$$C_{AB} = 30 + 30$$

$$= 60\ \mu F$$

Total capacitance between B and C is given by,

$$C_{BC} = 20 + 20 + 20$$

$$C_{BC} = 60\ \mu F$$

Total capacitance between A and C is given by,

$$C_{AC} = 30\ \mu F.$$

Inductors

Electromagnetic induction

Whenever there is a **change** in the number of magnetic lines passing through a loop of wire a voltage (or emf) is generated (or induced) in the loop of wire. This is how an electric generator works. The phenomenon is known as **electromagnetic induction**. This is illustrated with the following experiment shown in fig. 4.18(a), (b) and (c).

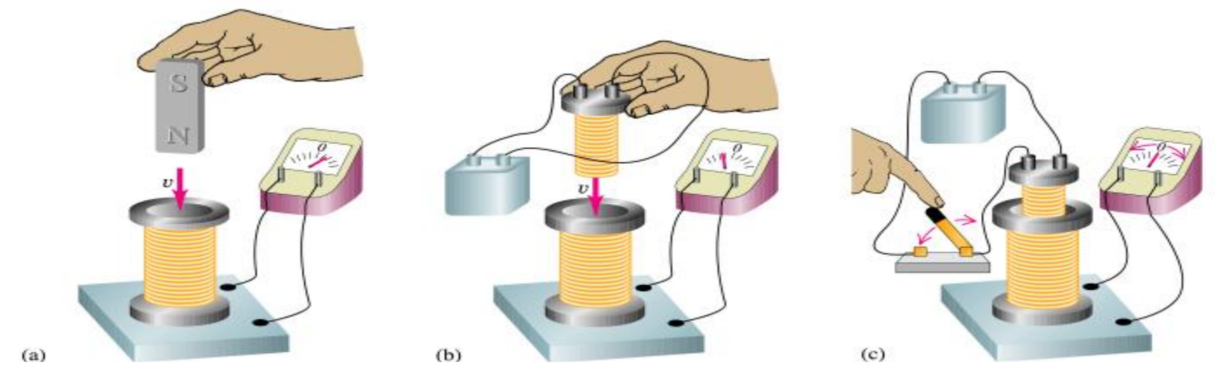


Fig. 4.18

Inductance

Inductance is that property of an element or circuit which when carrying a current is characterized by a formation of magnetic field and storage of magnetic energy.

When a current in the coil changes, the magnetic flux linked with the coil also changes. The change in magnetic flux induces emf in the coil. The polarity of the induced emf 'e' is such that it opposes the change in current through the coil and magnitude of emf 'e' is directly proportional to the rate of change of current.

$$e = -\ L\frac{di}{dt}$$

Where, L is the constant of proportionality known as **inductance** of the coil.

Unit of Inductance

The Inductance is a measure of the energy stored in the coil in the form of magnetic field. The unit of measurement for inductance is **henry**, denoted by **H**. If the current changes in an inductor at the rate of one amp per second inducing an emf of one volt it is said to be one henry**.** Henry is a relatively large unit of inductance, for the smaller units of the henry used are **mH**, **µH**, **nH**.

Self inductance (L)

The phenomenon in which emf is induced in a coil by changing the magnetic flux linking the coil itself is called **self inductance** (**L**) as shown in fig. 4.19. The mathematical expression is given by

$$L = -\frac{e}{di/dt}$$

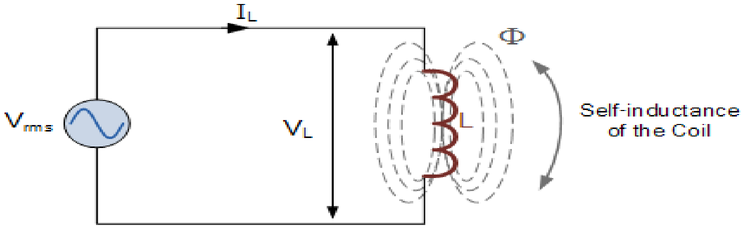


Fig. 4.19

The self inductance of a coil can be expressed as $L = \frac{\mu_o \mu_r N^2 A}{l}$

The unit of self inductance is **henry,** denoted by H.

Factors on which self inductance of a coil depends:

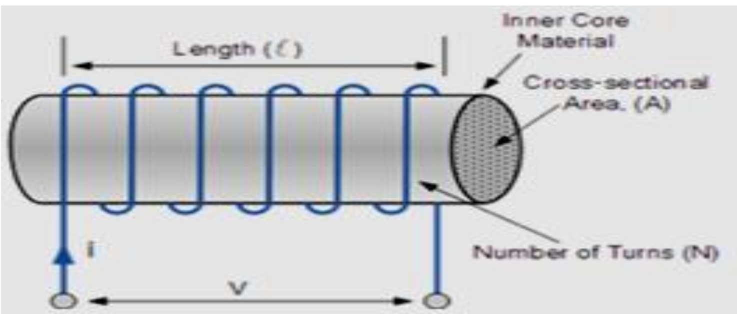


Fig. 4.19a

Self induction of the coil depends on

1. **Cross sectional area of the coil (A):** Larger the area of cross section of the coil greater the inductance.
2. **Number of turns in the coil (N):** The inductance is directly proportional to the square of the total number of turns in it.
3. **Length of the coil (l):** The inductance is inversely proportional to the length of the coil.
4. **Relative permeability of the core (μ_r):** Larger the permeability of the core larger the inductance. Iron core inductor has a higher value of inductance.

Self inductance of a coil is given by,

$$L = \frac{\mu_o \mu_r N^2 A}{l}$$

Where,

l is the length of the coil.
N is the number of turns in the coil
A is the cross sectional area of the coil as in fig. 4.19(a).
μ_o is the permeability of the free space
($\mu_o = 1.257 \times 10^{-6}$ WbA^{-1}m^{-1} or $4\pi x10^{-7}$ WbA^{-1}m^{-1})
μ_r = relative permeability of the coil

Worked example

A 2 cm long air core coil with cross sectional area of 3 cm^2 has 10 turns. Determine the inductance of the coil.

Solution: Given, A = 3 cm^2 = $3x10^{-4}$ m^2
ℓ = 2 cm = $2x10^{-2}$ m
N = 10
$\mu_0 = 4\pi x10^{-7}$ WbA^{-1}m^{-1}
μ_r = 1 for air

Inductance of the coil is given by, $L = \frac{\mu N^2 A}{l} = \frac{\mu_0\, \mu_r N^2 A}{l}$

$$L = \frac{1 \times 4 \times 3.142 \times 10^{-7} \times 10^{2} \times 3 \times 10^{-4}}{2 \times 10^{-2}}$$

$L = 18.852 \times 10^{-7}$

$\boxed{L = 1.8852\ \mu H}$

Mutual Inductance (M)

Consider two coils placed near each other as shown in the fig. 4.20. When a current flows through the primary coil, it produces magnetic flux, some of the magnetic flux gets linked with the secondory coil. Obviously, any change in magnetic flux or current in the first coil will cause a change in the flux linked with the second coil. This will produce an induced emf in the second coil. This phenomenon of inducing an emf in one coil by changing the current or emf in the other coil is called mutual inductance (M) as in fig. 4.20. The mathematical expression is given by

$$M = -\frac{e}{di/dt}$$

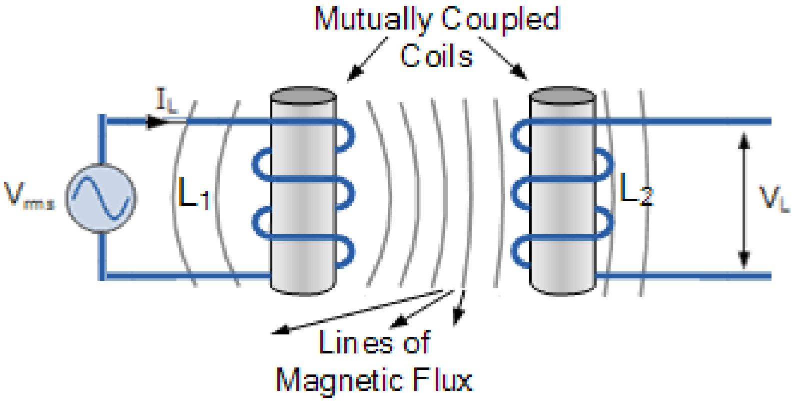


Fig. 4.20

Mutual inductance of a coil can be expressed as

$$M = \frac{\mu_o \mu_r N_1 N_2 A}{l}$$

Where,

l is the length of the coil

N_1 and N_2 are the number of turns in the coils L_1 and L_2

μ_o is the permeability of the free space

($\mu_o = 1.257 \times 10^{-6}$ $WbA^{-1}m^{-1}$ or $4\pi \times 10^{-7}$ $WbA^{-1}m^{-1}$)

μ_r = relative permeability of the coil

A = Area of cross section of core

The unit of mutual inductance is also **henry**, denoted by H.

Worked example:

An iron core of length 20 cm and area of cross section 3 cm^2 is wound with a coil of 200 turns. Over this coil is wound another coil of 250 turns. The relative permeability of iron is 800. Determine the mutual inductance between the two coils.

Solution: Given A = 3 cm^2 = 3×10^{-4} m^2, ℓ = 20 cm = 20×10^{-2} m, N_1 = 200,

N_2 = 250, $\mu_0 = 4\pi \times 10^{-7}$ Wb/Am and μ_r = 800 for Iron

Mutual Inductance of the coil, $M = \frac{\mu_o \mu_r N_1 N_2 A}{l}$

$$M = \frac{4 \times 3.142 \times 10^{-7} \times 800 \times 200 \times 250 \times 3 \times 10^{-4}}{20 \times 10^{-2}}$$

$$\boxed{\mathbf{M = 75.4\ mH}}$$

Inductor

An Inductor is a coil of copper wire wound on a core of some suitable material. Inductor opposes the current whenever there is a change in current through it. However, the opposition offered by an inductor is different for AC and DC circuits. In DC they offer almost no impedance because there is no change in current and they offer high impedance in AC because there is a change in current.

It is manufactured with a specified amount of inductance, having a core made up of iron or the other magnetic materials because these materials intensify the magnetic field. Inductors may also be called as chokes or coils. Electromagnetic induction is the basic concept for an inductor operation.

The symbol of an inductor is shown in fig. 4.21.

Fig. 4.21

Specification of an inductor

- Value of the inductance
- Type of the core used
- Range of frequencies for which the inductors may be used
- Arrangement of the winding

Energy stored in an Inductor

In inductors, due to the change in the current the work will be done and energy is stored in the magnetic field as magnetic energy. The energy stored is given by the relation,

$$E = \frac{1}{2} L I^2 \text{ joule.}$$

Worked example

Find the energy stored in a 5H inductor when a current of a 6 mA is flowing through it.

Solution: Given $L = 5$ H

$I = 6$ mA $= 6 \times 10^{-3}$ A

Energy stored in an inductor is given by, $\mathbf{E = \frac{1}{2} L I^2}$

$$E = \frac{1}{2} \times 5 \times (6 \times 10^{-3})^2$$

$$E = 90 \times 10^{-6} \text{ joule}$$

$$\text{or } E = \mathbf{90\ \mu J}$$

Types of Inductors: Inductors are mainly classified into fixed inductors and variable inductors.

Fixed inductors

Fixed inductors are manufactured for a particular value of inductance only. On basis of the type of core used, inductors are classified as,

i) Air core inductor
ii) Iron core inductor
iii) Ferrite core inductor

Air core inductor

The air core inductor is made of coils of wire wound on an ordinary card board. Since the card board does not have any magnetic property, air is considered as the core. Even if coils are wound on non-magnetic materials like ceramic rod or plastic material they are also called air core coils. Air core inductors are manufactured with the low value of inductance ranging from 1**μH** to 10**mH**.

Fig. 4.22 shows the symbol of an air core inductor.

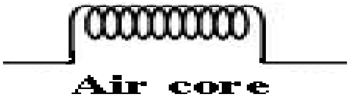


Fig. 4.22

Uses

- The solenoid and the universal winding air core inductors are widely used in communication.
- They are used at frequencies up to 2 MHz (R.F) in radio and T.V equipment.
- Used in R.F chokes, R.F transformers and I.F. transformers.

Iron core inductor

The iron core inductor is made up of a coil of wire wound over a solid or laminated iron core. This core is laminated to avoid eddy current losses. A laminated iron core is made up of thin iron laminations pressed together but insulated from each other. Iron core coils have high inductance values ranging from **1mH** to **1H.** Fig. 4.23 shows the symbol of the iron core inductor.

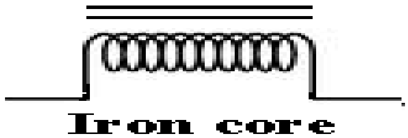


Fig. 4.23

Uses

- These are suitable for audio frequency (AF) applications.
- These are used in radio and TV receivers and transmitters.

Ferrite core inductor

Ferrite core inductor is made up of coils of wire wound on a solid core of highly ferromagnetic substance called ferrite. Ferrite is a solid magnetic material having high permeability consisting of fine particles of iron, cobalt or nickel embedded in an insulator binder. These are available in different shapes and are used at higher frequencies. The symbol of Ferrite core inductor is shown in fig. 4.24.

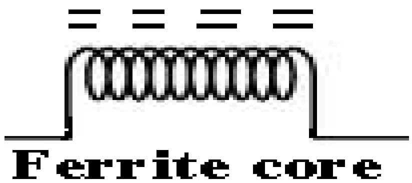


Fig. 4.24

Uses

They are used at higher frequency range for Radio interference suppression.

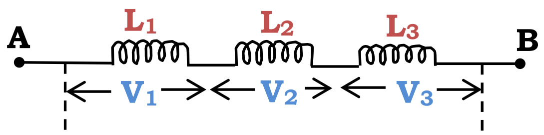
- Used as filter chokes.
- Used for colour T.V raster generation etc.

Combination of inductors

Like resistors and capacitors, inductors can also be connected in series, in parallel or in a complex manner.

Inductors in series

The expression for the equivalent inductance when the inductors are connected in series (without mutual coupling) is given by,

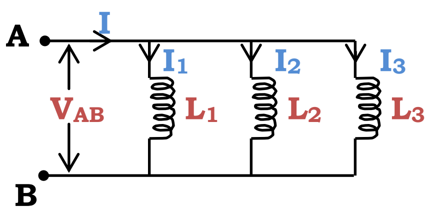


$$\boxed{L_s = L_1 + L_2 + L_3 + \ldots\ldots + L_n}$$

The effective inductance of an inductor in series is equal to the sum of the individual inductances of each coil.

Inductors in parallel

Similarly, the expression for the equivalent inductance when the inductors are connected in parallel (without mutual coupling) is given by,



$$\frac{1}{L_P} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + \ldots\ldots + \frac{1}{L_n}$$

The reciprocal of the effective inductance is equal to the sum of the reciprocal of the individual inductances.

Choke

The name choke comes from the word "choking", that is blocking the high frequencies while passing low frequencies. The functional name of the inductor is often called as a choke. A choke in general is a coil of insulated wire wound on a magnetic core, used as an inductor to block higher-frequency alternating current (AC) in an electrical circuit. The iron core inductor also referred as choke is suitable for audio frequency applications. It is made up of number of turns of thin wire wound on a laminated iron core. This is sealed in a metal case. The wire is made of copper or aluminium and insulated with an enamel coating as shown in Fig. 4.25 They are manufactured up to 5 H.



Fig. 4.25

Uses

Generally chokes are used

- in tube light sets
- as filter chokes in Radio and TV receivers and also in transmitters
- for creating voltage surges in fluorescent lamp sets
- in RF tuning circuits etc.

Relay

Relay is a simple switch which is operated both electrically and mechanically. Relay consists of an electromagnet and also a set of contacts. The switching mechanism is carried out with the help of the electromagnet.

The main operation of a relay comes in places where only a low-power signal can be used to control a circuit. It is also used in places where only one signal can be used to control circuits. The applications of relay started during the invention of telephones and telegraphy. After the invention of computers they were also used to perform Boolean and other logical operations. The high end applications of relay require high power to be driven by electric motors and so on. Such relays are called contactors.

Relay is mainly designed for two basic operations. One is for low voltage application and the other is for high voltage application. For low voltage applications, more preference will be given to reduce the noise of the whole circuit. For high voltage applications, they are mainly designed to reduce a phenomenon called arcing.

The circuit diagram shown below in fig. 4.25(a) uses a SPDT relay circuit that energizes the green light bulb (only) when the pushbutton switch is pressed, and energizes the red light bulb (only) when the pushbutton switch is released:

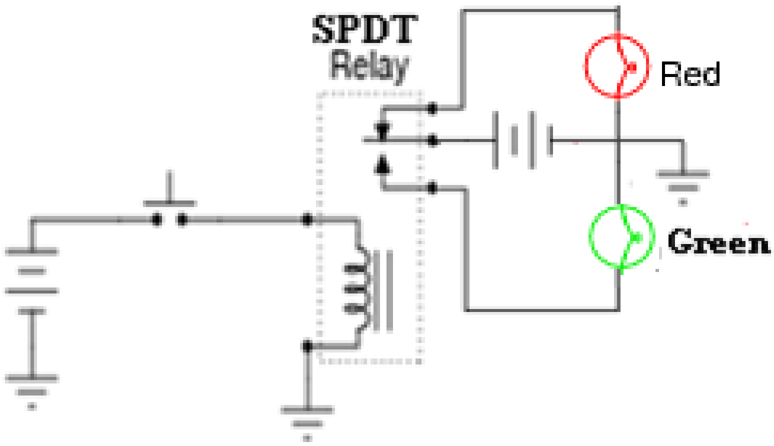


Fig. 4.25a

For this circuit to function as specified, the green light bulb must receive power through the relay's normally-open contact, and the red light bulb through the relay's normally-closed contact. This question also reveals another useful feature of relays, and that is logic inversion. The green light operates in the same mode as the pushbutton switch, but the red light is opposite of the pushbutton switch. With just a single pushbutton operator, two complementary functions may be performed through the use of a SPDT relay.

Specifications of Relay

The important characteristics of relay are,

i) Operating voltage
ii) Operating current
iii) Contact and release time
iv) Material of the Contact point
v) Operating temperature

Application of Relays

They are used,

1. As protective Relay to protect electronic equipments against abnormal conditions like over voltage, over current, short circuit etc.
2. As transmission Relay in communication systems to generate and transmit signals.
3. As counters for counting entry into a place.
4. As an automatic switching device to operate street lights, garage doors, inverters (UPS), bells and buzzers, abnormal conditions like fire, smoke, theft etc.

Advantages of Relays

Relay, in general have the following advantages.

1. Relay requires small power for its operation to control high power circuit which acts as a power amplifier.
2. Load can be turned ON/OFF from a distance and hence the operator is safe from high voltages.
3. There is no sparking while turning the load ON and OFF, as the Relay coil switch carries low current.

Transformer

A **transformer** is a power converter that transfers electrical energy from one circuit to another through coupled conductors. The transformer works on the principle of mutual induction. It converts high voltage of low current into low voltage of high current and vice versa. A varying current in the primary winding creates a varying magnetic flux in the core of the transformer which results in varying magnetic field through the secondary winding. This varying magnetic field induces an electromotive force (EMF) or voltage in the secondary winding. This is called mutual coupling.

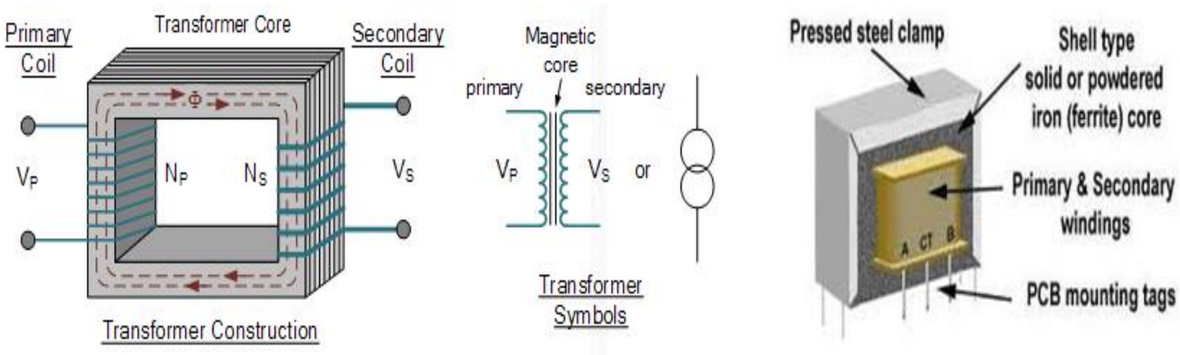


Fig. 4.26

Transformer consists of two coils called primary and secondary coil as shown in fig.4.26. The primary coil is connected to a voltage source that produces an alternating current, while secondary coil is connected across the load. The coils are electrically separated but the power in the primary coil is coupled into the secondary coil.

Voltage/current transformation ratio

The induced voltage in the secondary winding (V_s) is in proportion to the primary voltage (V_p) and is given by the ratio of the number of turns in the secondary (N_s) to the number of turns in the primary (N_p) as given below:

$$\mathbf{T} = \frac{\mathbf{N_s}}{\mathbf{N_p}} = \frac{\mathbf{V_s}}{\mathbf{V_p}}$$

$\boldsymbol{N_s/N_p}$ is known as the **turn's ratio (T)** of a transformer. For example, a transformer with primary and secondary windings of 100 and 150 turns is said to have a turn ratio of 2:3.

A transformer with various voltages, currents and turns are shown in fig. 4.27.

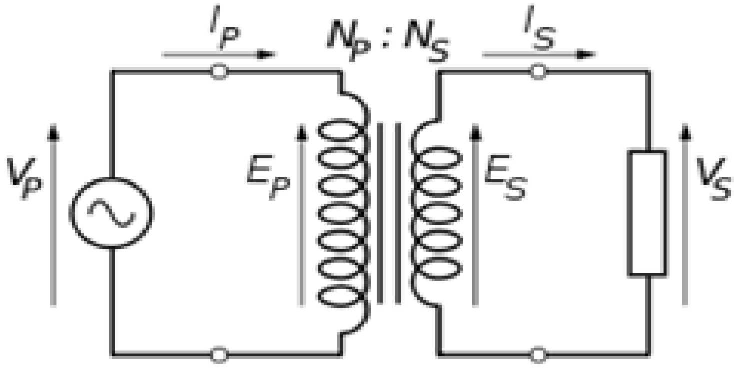


Fig. 4.27

When the secondary coil is connected to a load, the current flows so that electrical power is transmitted from the primary to the secondary. For an ideal transformer, input power P_{in} is equal to the output power P_{out}.

$$\boxed{P_{in} = V_P I_P = P_{out} = V_S I_S}$$

$$\boxed{\frac{V_s}{V_P} = \frac{N_s}{N_p} = \frac{I_P}{I_s}}$$

From the above equation, the ratio of secondary voltage to the primary voltage is known as the **voltage ratio** and **current ratio** is defined as the ratio of primary current to the secondary current.

By proper selection of the ratio of number of turns of the coil, a transformer enables an ac voltage to be stepped up by making N_s greater than N_p (i.e., $\boldsymbol{N_s > N_p}$) known as **step up transformer** and stepped down by making N_s less than N_p (i.e., $\boldsymbol{N_s < N_p}$) known as **step down transformer**.

In certain applications transformer with centre-tapping is necessary in which the secondary winding is exactly tapped at the centre as shown in fig. 4.28. In such case, secondary voltages with respect to centre tap is equal and opposite.

i.e., $V_A = - V_B$.

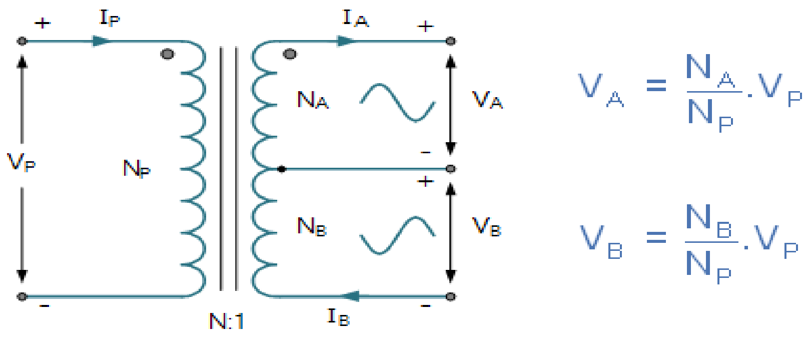


Fig.4.28

Applications of transformers

Transformers are used

- to step-up or step-down ac voltage or current.
- to act as an impedance matching device.
- to electrically isolate one portion of a circuit from the other.
- in home appliances, lights, industrial machineries and other electric equipment.
- in TV, Radio and Telephones.
- in power stations, etc.

Efficiency (η)

Efficiency of a transformer is defined as the ratio of output power to the input power expressed in percentage. It normally ranges from 90% to 95%.

$$\textbf{Efficiency } (\eta) = \frac{\textbf{Output power } (P_{out})}{\textbf{Input power } (P_{in})} \times \mathbf{100}$$

Types of Transformers

- **Power Transformer (PT)** - Designed to operate in ac mains frequency (50 Hz or 60 Hz).
- **Audio Frequency Transformer (AFT)** - Designed to operate in audio frequency range (20 Hz to 20 KHz).
- **Radio Frequency Transformer (RFT)** - Designed to operate in radio frequency range (550 KHz to 1650 KHz).

- **Intermediate Frequency Transformer (IFT)** - Designed to operate in intermediate frequency range at 455 KHz in A.M radios, at 10.8 MHz in F.M radios, at 33.4 MHz in TV audio systems and at 38.9 MHz in TV Video system.
- **Pulse Transformer (PT) –** Designed to trigger power devices such as thyristors. They operated in the frequency range of 2 kHz to 20 kHz.

Audio Frequency Transformer or Communication Transformer (AFT)

Audio Frequency (AF) Transformers (both step up and step down transformer) work at frequencies between about 20 Hz to 20 kHz and are used in audio amplifier circuits. AF transformers are for audio functions. Some common arrangements of audio transformer windings are shown in fig. 4.29(a).

Fig. 4.29(b) shows a centre tapped secondary winding that can be used to select different turn ratio. Some transformers may also have tapping in primary to have wider range of turn ratio.

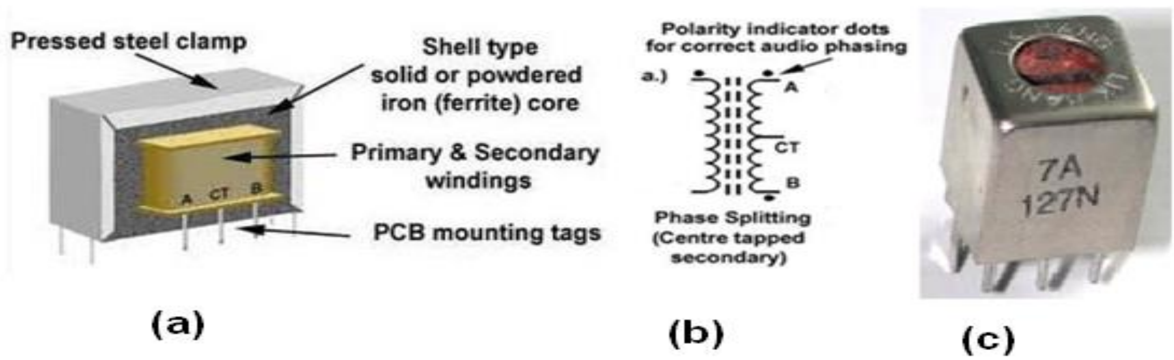


Fig. 4.29

In audio amplifiers, in phase or out of phase of signals are important and phase splitting transformers with centre tapped secondary windings can be used to provide two out of phase signals. The dots near the windings on schematic diagram indicates the relative polarity of the signals on different windings and in this example it shows that the signal from the upper secondary winding (A) will be in phase with the primary signal, while the lower secondary winding (B) will provide a signal out of phase with the primary signal. Fig. 4.29(c) shows transformer used to couple the power output stage of an audio amplifier to the loudspeaker.

Applications

Audio Frequency Transformers are used

- in AF amplifiers for inter stage coupling
- to couple microphone to amplifier
- to couple amplifier to loudspeaker.

Intermediate Frequency Transformer (IFT)

Transformer designed to operate on narrow band of frequencies is called Intermediate Frequency Transformer (IFT). In IF transformer, capacitors are connected across primary and secondary windings and are tuned. The primary and secondary windings may be either air core or ferrite core. The purpose is to provide high impedance and high gain between the coupled stages. These transformers are used as coupling transformers in radios at IF stage. This forms a parallel LC resonant circuit with the transformer primary and therefore has high impedance at one particular frequency. The inductance of such transformers is often made adjustable and the whole assembly is housed inside a metal screening can. The resonant frequency of the circuit can then be fine tuned after assembly.

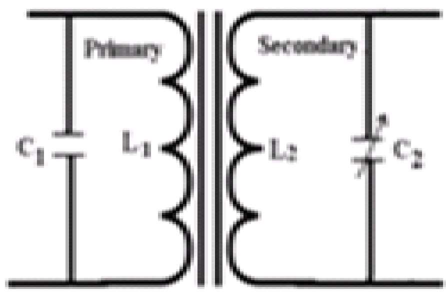


Fig. 4.30: Symbol of IF Transformer

Uses

IF transformers are used as an impedance matching transformer in Radio and TV to couple IF stage to the detector stage.

Pulse Transformer (PT)

Transformer designed to amplify wide band signals to accommodate rapid rise and fall with minimum distortion is called the Pulse Transformer shown in fig. 4.31.

Fig. 4.31

The main requirement of a pulse transformer is that the windings must be tightly coupled to minimize leakage of inductance so that the output pulse will have fast rise time. Good insulation must be provided to get required isolation.

Applications

They are used

- in triggering laser and Thyristors.
- as a coupling device between pulse generator and amplifier for generating and amplifying small pulses.
- for impedance matching between pulse forming circuit and microwave tubes.
- for isolating computer circuits.

Worked example

1. A step down transformer is used to reduce the main supply of 220 V to 10 V. If the primary draws 5 A and secondary 100 A, calculate the efficiency of the transformer.

Solution: Given $V_p = 220$ V

$V_s = 10\ V$
$I_p = 5\ A$
$I_s = 100\ A$

We know that $P_{out} = V_s \times I_s = 10 \times 100 = 1000\ W$
Similarly, $P_{in} = V_p \times I_p = 220 \times 5 = 1100\ W$

Efficiency of the transformer is given by $\eta = \frac{P_{out}}{P_{in}} \times 100 = 91\%$

Transducer

Transducer is a device which converts one form of energy into another. Energy may be electrical, mechanical, pressure, chemical, optical or thermal etc. Transducer may be classified according to their applications, method of energy conversion and nature of the output signal and so on.

Selecting a transducer

The transducer has to be physically compatible with its intended applications. To select a transducer, there are eight parameters to be considered, they are,

1. Operating range
2. Sensitivity
3. Frequency response and resonant frequency
4. Environmental compatibility
5. Minimum sensitivity
6. Accuracy
7. Usage and ruggedness
8. Electrical characteristics

Pressure transducers

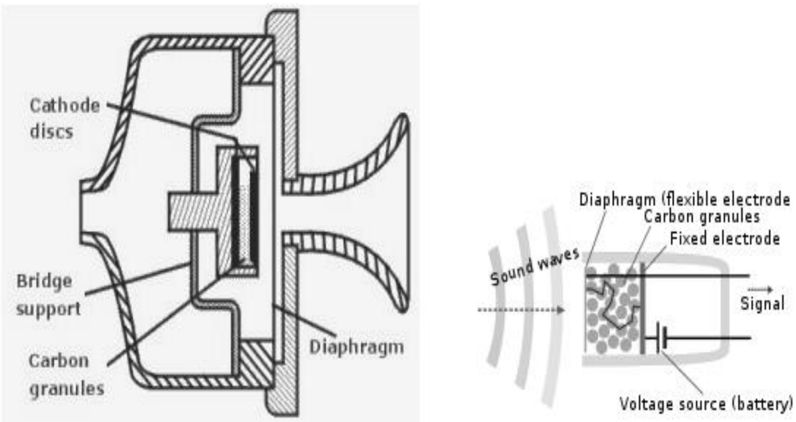
A device that converts pressure variation into electrical signals, likewise it can also convert electrical signal into pressure variation. **Microphone and Loud speaker** are the two common examples of pressure transducer.

Microphone

Microphone is a device that converts sound energy into an electrical audio signal. Microphone is often called as mike and is used in recording sound. The different types of microphones are omni directional microphone (picks up sound from all directions), bidirectional microphone (picks up sound from two directions front or behind) and unidirectional microphone (picks up sound from only one direction). Microphone may be classified according to how they change sound into electric energy. The five main types, in order of increasing complexity are

1. Carbon
2. Crystal and Ceramic
3. Moving coil
4. Ribbon
5. Capacitor types, etc.

Carbon Microphones



(a) (b)

Fig. 4.34

A single-button carbon microphone is used as a telephone transmitter is shown in fig. 4.34(a). The mouthpiece acts as a horn to increase the acoustic pressure on the diaphragm. The displacement of the diaphragm is transmitted directly to the carbon button, which contains carbon granules between two carbon discs.

The front and rear contacts are insulated and brought out to the terminals. An external battery drives current through the button, which has a resistance of 30 Ω to 100 Ω. The resistance varies slightly when the diaphragm is displaced, causing a change in the current and a consequent change in voltage, which is the output of the microphone.

The carbon microphone contains a small enclosure called a button, packed with particles of carbon. The sound input compresses the carbon particles and change the resistance across the enclosures. A dc voltage is used in the circuit to produce current that flows through the carbon as shown in fig. 4.34(b). A thin metal disc called as diaphragm presses against button and vibrates when stuck by sound waves. The vibration causes variations in the current flowing through the carbon and in turn changes the voltage, which is the output of the microphone in terms of electrical signal. Carbon microphones are also known as Button Microphones.

Uses of microphone

Microphones are used in telephones, radios, tape recorders, many public-address systems, hearing aids, etc.

Fig. 4.35 shows a simple Input/output System using Sound Transducers

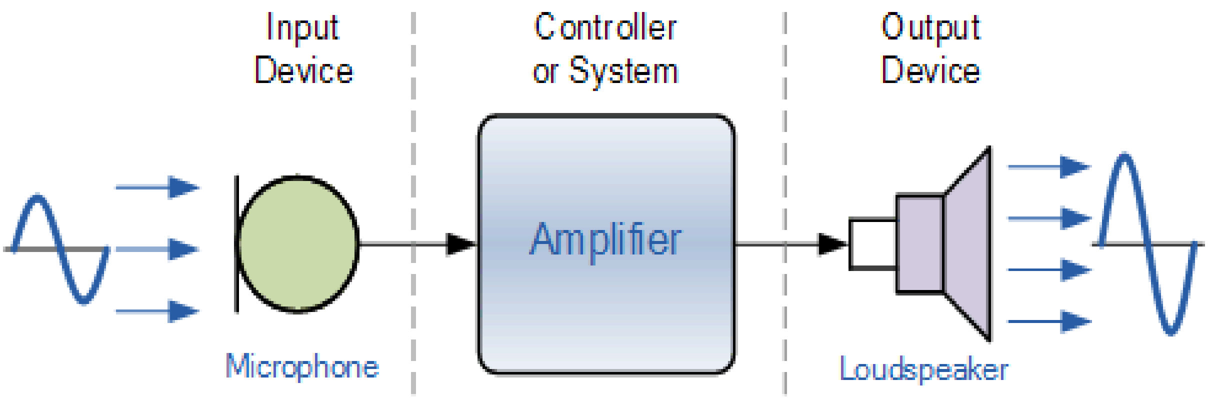


Fig. 4.35

Loudspeaker

A loud speaker is a transducer that changes electric energy into sound waves of varying pressure as in fig. 4.36. Speakers are the part of phonographs, radios, tape players, TV and public address system, etc.

Know more

A loudspeaker (or speaker) is an electro acoustic that produces in response to an electrical input. To adequately reproduce a wide range of frequencies most loudspeaker systems employ more than one driver, particularly for higher sound pressure level or maximum accuracy. Individual drivers are used to reproduce different frequency ranges. The drivers are named **subwoofers** (for very low frequencies); **woofers** (low frequencies); **mid-range speakers** (middle frequencies); **tweeters** (high frequencies); and sometimes **super tweeters** (very high frequency). The terms for different speaker drivers differ, depending on the application. Home stereos use the designation tweeter for the high frequency driver. A two-way system will have a woofer and a tweeter; a three-way system employs a woofer, a mid-range and a tweeter.

Construction

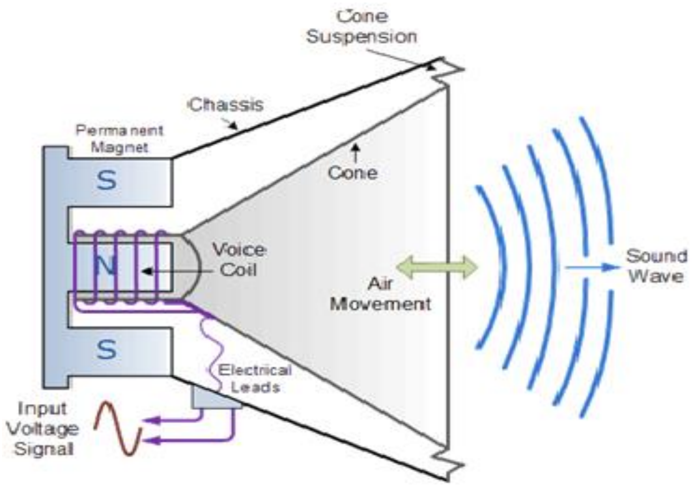


Fig. 4.36

The three main parts of the loudspeaker are

1) a coil of wire called a voice coil

2) a permanent magnet
3) a cone shaped piece of stiff paper or plastic or cloth called a diaphragm.

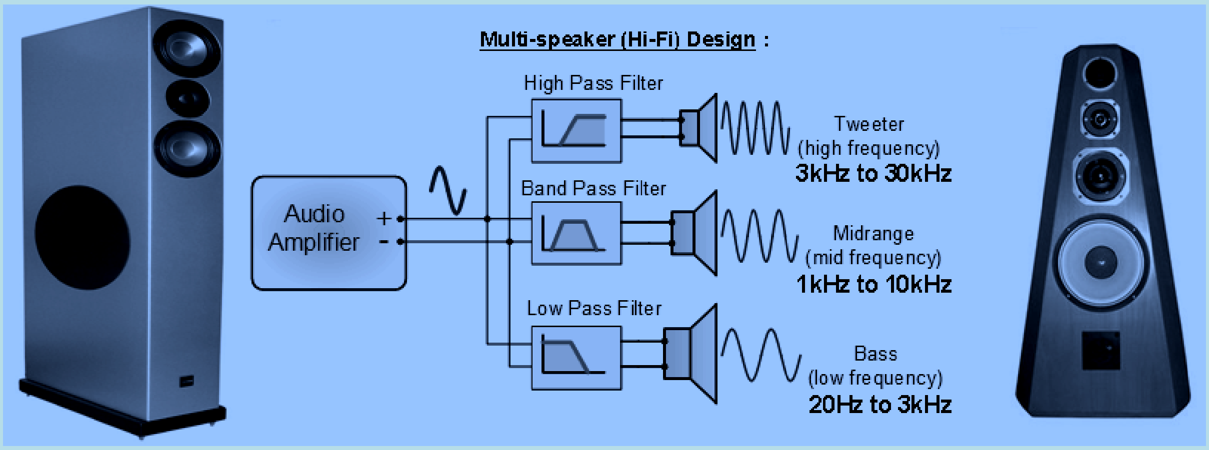
The voice coil consists of about 20 turns of fine wire wrapped around a card board that is typically one inch in diameter. The coil is positioned in the air gap of the fixed magnetic field which fits over the centre of the field magnet. The permanent magnet of a speaker provides a steady magnetic field. The two leads of the voice coil are connected with flexible braided wire to stationary terminals on the speaker frame to which electrical input is applied.

Working

When an audio signal current flows through the voice coil, it produces varying magnetic force in the coil. This varying magnetic force drives the coil i.e., the voice coil moves in and out in accordance with the variations in electrical audio signals. As a result the diaphragm attached to the voice coil vibrates. Due to this the compression and rarefaction in the air produces sound waves. The sound corresponds to the variations in the signal current in the voice coil. Typical cone diameters are 3,5,8,10,12, and 15 inch.

Know more

Multi-Speaker (Hi-Fi) Design:



Three-way speaker system **Four-way, high fidelity speaker system**

Thermistor

The word Thermistor is a contraction of thermally sensitive resistor (i.e., **THERM*al* + *res*ISTOR**). It is a temperature sensitive semiconductor device i.e., whose resistance value varies (increase or decrease) with increase in temperature. They are normally manufactured in the range of 1 Ω to 100 MΩ. The Thermistor acts as the temperature sensor and it is placed on the body whose temperature is to be measured. It is also connected in the electric circuit. When the temperature of the body changes the resistance of the Thermistor changes directly as the temperature since resistance is calibrated against the temperature. The Thermistor can also be used for some control which is dependent on the temperature. If the resistance decreases with increase in temperature then it is called as **Negative Temperature Co-efficient (NTC)** Thermistor. If the resistance increases with increase in temperature then it is called as **Positive Temperature Coefficient (PTC) Thermistor.**

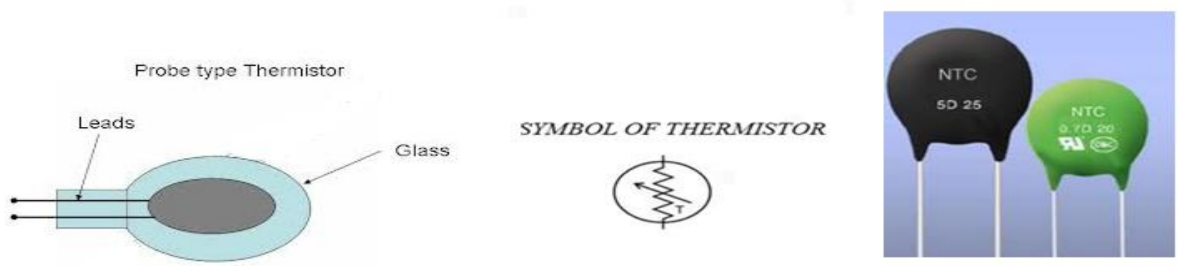


Fig. 4.37(a)

Typical symbol of a Thermistor and the internal view of a Thermistor are shown in the fig. 4.37(a). The characteristic of a Thermistor with temperature is shown in fig. 4.37(b).

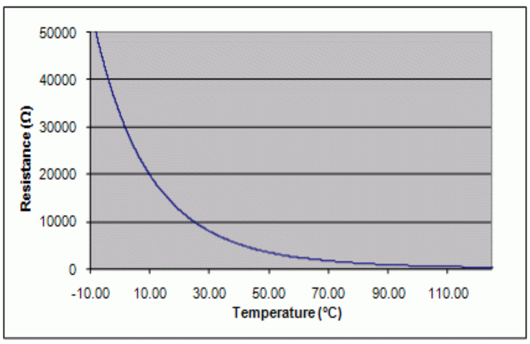


Fig. 4.37(b)

Applications

NTC Thermistor is a non-linear Thermistor which can be used for a limited temperature range. This allows the design of an inexpensive temperature sensing device which can be used

- for measurement of temperature
- for temperature compensation in transistor circuits, measuring equipments, etc.
- in temperature control sensors in Air conditioners, Refrigerators, etc.
- in alarm systems

Temperature sensors

A temperature sensor is a device that gathers data concerning the temperature from a source and converts it to a form that can be understood either by an observer or another device. Temperature sensors come in many different forms and are used for a wide variety of purposes from simple home use to extremely accurate and precise scientific use. They play a very important role in almost all the places where the temperature sensors are used. The **silicon band gap temperature sensor** is an extremely common form of temperature sensor (thermometer) used in electronic equipment. Its main advantage is that it can be included in a silicon integrated circuit at a very low cost. The principle of the sensor is that the forward voltage of a silicon diode is temperature-dependent.

Precision Centigrade Temperature Sensors (LM 35):

General Description: The LM35 series are precision integrated-circuit temperature sensors as shown in fig. 4.38, whose output voltage is linearly proportional to the Celsius (Centigrade) temperature. The LM35 thus has an advantage over linear temperature sensors calibrated in degree Kelvin, as the user is not required to subtract a large constant voltage from its output to obtain convenient Centigrade scaling. The LM35 does not require any external calibration. The LM35 have low output impedance, linear output, and precise inherent calibration makes the processing circuit very easy. It can be used with single power supplies or with plus and minus supplies. It has a very low self-heating. **LM35** measures the temperature more accurately when compared with a Thermistor.

Features :

- Calibrated directly in ° Celsius (Centigrade)
- Linear + 10.0 mV/°C scale factor
- 0.5°C accuracy guaranteeable (at +25°C)
- Rated for full - 55° to +150°C range
- Suitable for remote applications
- Low cost due to wafer-level trimming
- Operates from 4 to 30 volts
- Low impedance output.

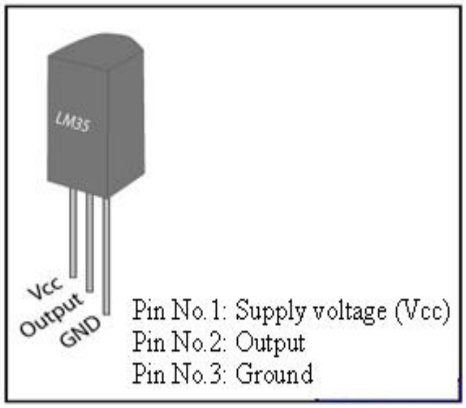


Fig. 4.38

Light dependent resistor (LDR)

Electronic opto-sensors are devices that alter their electrical characteristics in the presence of visible or invisible light. The best known devices of these types are the light dependent resistor (LDR), the photodiode and the phototransistor.

Basic structure of an LDR

The resistor whose resistance value depends on the incident light is called a Light dependent resistors (LDRs). Device consists of a pair of metal film contacts separated by a snake-like track of cadmium sulphide strip, designed to provide the maximum possible contact area with the two metal films. The longer the strip greater is the value of resistance. The structure is housed in a clear plastic or resin case, to provide free access to external light. Practical LDRs are available in a variety of sizes and package styles, the most popular size is having a face diameter of roughly 10 mm. They are available in the form of discs of 0.5 cm to 2.5 cm.

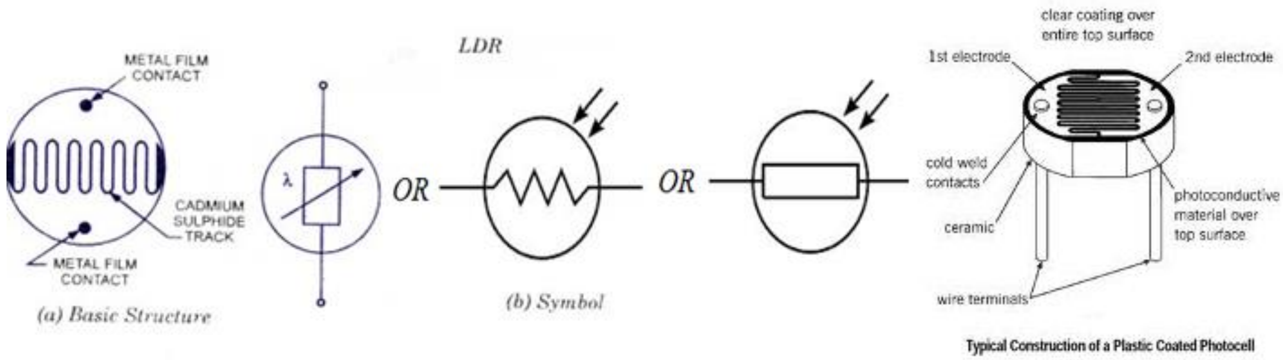


Fig. 4.39 LDR

Its resistance is quite high (sometimes as high as 1MΩ). When they are illuminated with light, electrons are liberated and the conductivity of the material increases, i.e., the strip resistance drops dramatically (decreases). Depending on the illumination of light, the resistance falls down to low value. Similarly, in dark (less illuminated) its resistance increases and is called **dark resistance.**

LDRs are very useful especially in light/dark sensor circuits. LDRs are sensitive, inexpensive, and readily available devices. They have good power rating (power rating is 50 mW to 0.5 W) and voltage handling capabilities, similar, to those of a conventional resistor. Its only significant defect is that they are fairly low acting; taking tens or hundreds of milli-seconds to respond to sudden changes in light level i.e., their switching time is very high. Fig. 4.40 shows the variation of resistance with illumination of light.

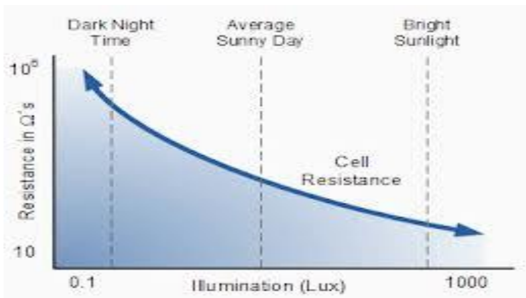


Fig. 4.40

Uses

Useful practical applications of LDR are,

- light and dark-activated switches and alarms
- light beam alarms and reflective smoke alarms
- Counters, etc.

Exercise

1. Identify the resistor values with the four colour bands
   a) Brown – Black – Orange – Silver
   b) Orange – Orange – Orange – Gold
   c) Green – Blue – Red – Gold

   (Ans: (a) 10 kΩ ± 10%, (b) 33 kΩ ± 5%, (a) 5.6 kΩ ± 5%)

2. Complete the following table for the carbon resistor R.

Sl No.	I band	II band	III band	IV band	Value of R	Tolerance
1				Gold	560 kΩ	
2					47 kΩ	± 10 %
3	Orange	Violet	Orange	No colour		
4					820 Ω	± 5 %

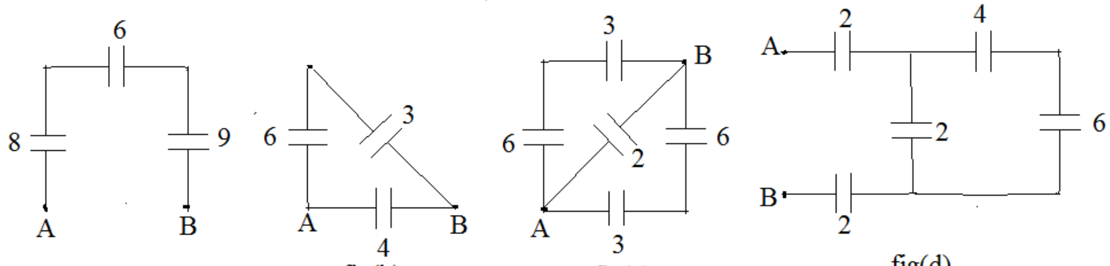
(Ans: (1) Green, Blue, Yellow, ± 5%, (2) Yellow, Violet, Orange, Silver, (3) 37 kΩ ± 20%, (4) Gray, Red, Brown, Gold)

3. Write the colour codes for 5 band colour resistors with the following resistance values.
   1. 10 kΩ ± 2 %
   2. 4.7 kΩ ± 1 %
   3. 152 Ω ± 1 %

   (Ans: (1) Brown, Black, Black, Red, Red (2) Yellow, Violet, Black, Brown, Brown, (3) Brown, Green, Red, Black, Brown)

4. Calculate the resistance of 100 m length of a wire having a uniform cross-sectional area of 0.1 mm^2 if the wire is made of manganin having a resistivity of 50×10^{-8} Ωm. (Ans: 500 Ω)

5. Calculate the value of capacitance for two plates each with common area 3 m^2, separated by 0.2 cm with a dielectric of air. (Ans: 13.28μF)
6. Find the energy stored in a 4 pF capacitor with 6 V across its plates. (Ans 72 pJ)
7. Three capacitors 2 nF, 4 nF and 6 nF are connected such that, the first two are in series and the third is in parallel to them. Find the effective capacitance of the entire combination. (Ans = 7.33 nF)
8. Two capacitors of 60 μF each are connected in parallel. The combination is further connected in series with two capacitors of 30 μF and 75 μF. Calculate the total capacity of the Circuit. (Ans = 18.18 μF)
9. Two capacitors of capacitance 20 μF and 30 μF are connected in series across 200 V dc supply. Find a) the equivalent capacitance b) the charge on each capacitor and c) potential difference across each capacitor. (Ans: C = 12 μF, Q = 2400 μC, V_1 = 120 V and V_2 = 80 V)
10. Two capacitors of capacitances 3 pF and 12 pF are connected in parallel across 30 V dc supply. Determine a) Effective capacitance of the combination b) the charge on each capacitor c) the total charge on the combination. (Ans: C_{eff} = 15 pF, Q_1 = 90 pC, Q_2 = 360 pC, Q = 450 pC)
11. Three capacitors are connected in series across 75 V supply. The voltage across each of them is 20, 25 and 30 V respectively. The charge on each capacitor is 3nC. Find the effective capacitance and also find the individual capacitances. (Ans: C_1 = 0.15 nF, C_2 = 0.12 nF, C_3 = 0.1 nF and C_s = $4\text{x}10^{-11}$ F)
12. Calculate the effective capacitance between the points A and B in the following figures. (All values in μF). (Ans: (a) 2.487 μF, (b) 6.016 μF (c) 6.032 μF (d) 0.955 μF)

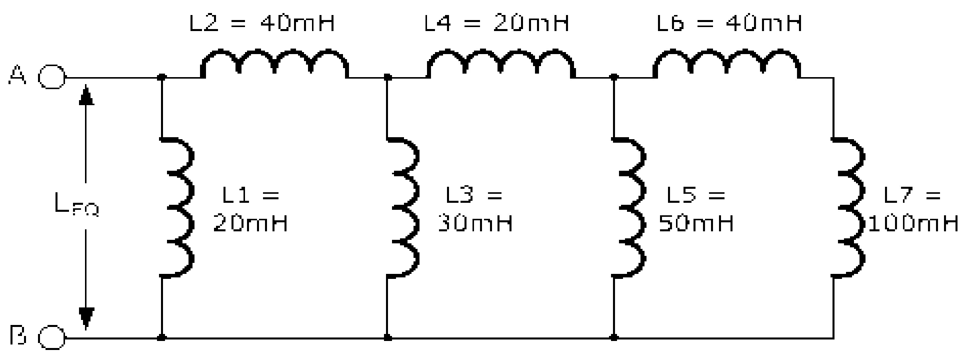


fig(a) fig(b) fig(c) fig(d)

13. For 100 μH and 250 μH inductances , determine the following:

(i) total inductance (by neglecting mutual coupling) when they are in series, and (ii) total inductance (by neglecting mutual coupling) when they are in parallel. (Ans : 350 µH and 71.43 µH)

14. Calculate the energy stored in the magnetic field of 100 mH with a current of 80 mA. (Ans : 320 µJ)
15. Two coils of self inductances of 1.5 H and 3.5 H are connected in series. Calculate the energy stored in the inductor due to current of 10 A through them. (Ans : 250 J)
16. Calculate the inductance of a 50 mm long, 100 turns air core coil with cross sectional are of 0.06 cm^2. (Ans : 1.5 µH)
17. A 5 H inductor is subjected to an electric current that changes at a rate of 4.5 A per second. How much voltage will be dropped by the inductor? (Ans: 22.5 V)
18. Calculate the equivalent inductance of the following inductive circuit.



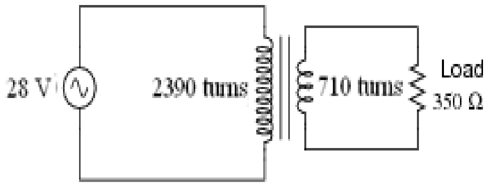
(Ans: 14.97 mH)

19. A step down transformer having a power output of 10 KW and efficiency 90% reduces the voltage from 11 KV to 220 V. Calculate (i) the number of turns in the primary if the secondary has 100 turns and (ii) the current in the primary. (Ans: 5000 and 0.909 A)

20. A transformer has 500 turns in the primary and 250 turns in the secondary. What is the turn's ratio? How much is the secondary voltage with a primary voltage of 220 V? (Ans : 2 : 1 and 110 V)

21. Calculate the voltage output by the secondary winding of a transformer if the primary voltage is 35 V, the secondary winding has 4500 turns, and the primary winding has 355 turns. (Ans : V_s = 443.7 V)

22. Calculate the load current and load voltage in this transformer circuit:



(Ans: I_{load} = 23.77 mA, V_{load} = 8.318 V)

Questions

One mark questions

1. What is an active component?
2. What is a passive component?
3. Give any one example for the passive component.
4. Give any one example for the active component.
5. What is a resistor?
6. Draw the circuit symbol of resistor.
7. What is Ohms rating of a resistor?
8. What does the power rating of a resistor indicate?
9. What is meant by tolerance of a resistor?
10. Define temperature coefficient of a material.
11. Define resistivity or specific resistance of a material.
12. Name any one fixed resistor.
13. Name any one variable resistor.
14. Draw the circuit symbol of potentiometer.
15. What does the fourth band of a 4 band colour coded resistor indicate?
16. What does the fifth band of a 5 band colour coded resistor indicate?
17. What is a SMD resistor?
18. What is the resistance value of SMD resistor with code ‘223’?
19. Define resistor power rating or wattage rating.
20. Draw the circuit symbol of presets.

21. What is a capacitor?
22. What is capacitance of a capacitor?
23. What is the S.I unit of capacitance?
24. What is dielectric constant?
25. Draw the symbol of electrolytic capacitor.
26. Write an expression for energy stored in a capacitor.
27. How do you connect number of capacitors to obtain maximum capacitance value?
28. Which type of capacitor is sensitive to polarity?
29. Write an expression for capacitance of a parallel plate capacitor.
30. What is electromagnetic induction?
31. What is an inductor?
32. What is the unit of inductance?
33. Define unit of inductance.
34. Which has more inductance, a coil with an iron core or with air core?
35. Write an expression for energy stored in an inductor?
36. Write the symbol of inductor.
37. Write the symbol of air core inductor.
38. Write the symbol of iron core inductor.
39. Write the symbol of ferrite core inductor.
40. Write the expression for effective inductance when the inductors are Connected in series.
41. Write the expression for effective Inductance when the inductors are connected in parallel.
42. What is choke?
43. What is relay?
44. What is transformer?
45. Define transformer efficiency.
46. Define turns ratio.
47. Write the relation between turns ratio, voltage ratio and current ratio in a transformer.
48. Write the symbol of transformer.
49. Name the principle of transformer.
50. What is a step up transformer?
51. What is a step down transformer?

52. Could step up transformer be used as a step down transformer?
53. What would be the voltage across the secondary of a transformer with DC voltage across the primary?
54. What is Transducer?
55. What is meant by pressure transducer?
56. What is meant by loud speaker?
57. What is meant by microphone?
58. What is tweeter?
59. What is woofer?
60. Expand NTC.
61. Expand PTC.
62. Define NTC thermistor.
63. Define PTC thermistor.
64. What is meant by thermistor?
65. What is meant by temperature sensors?
66. Write the symbol of thermistor.
67. Give one example for temperature sensor.
68. What for LM 35 is used?
69. What is meant by LDR?
70. Write the symbol of LDR?

Two mark questions

1. Distinguish between active and passive components.
2. Write four important characteristics of resistors.
3. Distinguish between fixed resistor and variable resistor.
4. Write a note on SMD resistor.
5. Write a note on presets.
6. Write a note on power rating of a resistor.
7. Mention the factors on which the capacitance of a capacitor depends.
8. Briefly explain about role of a dielectric in capacitor.
9. Mention any four types of dielectric materials used in capacitors.
10. Write a note on an energy stored in a capacitor.
11. Write a note on leakage current and leakage resistance in capacitor.
12. Name any four types of capacitor.
13. Write a note on trimmers.

14. When an electric current is passed through a coil of wire, what phenomenon occurs?
15. What is Self - inductance? Explain.
16. What is Mutual - inductance? Explain.
17. List the factors on which self – inductance of a coil depends.
18. List the factors on which mutual – inductance of a pair of coil depends.
19. Distinguish between self inductance and mutual inductance.
20. Write the specifications of an inductor.
21. Name the factors on which inductance of a coil depend.
22. Mention the types of inductors.
23. Explain the construction of air core inductor.
24. Write the applications of air core inductor.
25. Explain the construction of iron core inductor.
26. Write the applications of iron core inductor.
27. Explain the construction of ferrite core inductor.
28. Write the applications of ferrite core inductor.
29. Write the applications of chokes.
30. Write the applications of relays.
31. List the advantages of relays.
32. Explain the principle of a transformer.
33. What are step-up and step-down transformers?
34. Explain how the construction of step-up transformer is differ from Step down transformers.
35. Mention the different types of transformers.
36. Why there is no voltage across the secondary if the primary is open?
37. Write the application of a transformer.
38. Write the applications of AF transformer.
39. Write the applications of IF transformer.
40. Write the applications of pulse transformer.
41. Explain briefly the construction of pulse transformer.
42. What is the use of centre tap in transformer? Explain.
43. Give the two examples for pressure transducers.
44. Distinguish between tweeter and woofer.
45. Distinguish between speaker and microphone.
46. Write the applications of speaker.

47. Write the applications of microphone.
48. Write the applications of thermistor.
49. Draw the pin diagram of LM 35.
50. Write the applications of LDR.

Three/five mark questions

1. Explain the construction of a carbon composition resistor.
2. Explain the construction of a metal film resistor.
3. Explain the colour coding method of resistor with one example.
4. Explain the construction of wire wound resistors. Write any one of its application.
5. Explain the construction of carbon composition potentiometer. Write any one application.
6. Explain the principle of a capacitor.
7. Write the constructional features of ceramic capacitor.
8. Write the constructional features of electrolytic capacitor.
9. Write the constructional features of SMD capacitor.
10. Write the constructional features of gang capacitor.
11. Write the constructional features of polyester capacitor.
12. Derive an expression for the equivalent capacitance of two capacitors connected in series.
13. Derive an expression for the equivalent capacitance of two capacitors connected in parallel.
14. Explain the role of dielectric in capacitor construction.
15. Explain the construction and applications of air core inductor.
16. Explain the construction and applications of iron core inductor.
17. Explain the construction and applications of ferrite core inductor.
18. Write a note on chokes also mention the uses of it.
19. Explain the construction and working of electromagnetic relay.
20. Explain the construction and applications of AF transformer.
21. Explain the construction and applications of IF transformer.
22. Explain the construction and working of a loud speaker.
23. Explain the construction and working of a microphone.
24. Explain the construction and working of a Thermistor.
25. Explain the construction and working of a LDR.

Chapter 5

Application of DC and AC to passive components

Introduction

The passive components resistor, capacitor and inductor are used to construct circuits. The behaviour of these passive components is studied for both AC and DC. The resistance offered by the resistor is same for both AC and DC but the capacitance and Inductance behaviour changes for AC and DC. The reactance of inductor and capacitor depends on the frequency of the supply. Circuit constructed using passive components introduce phase difference from input to the output. The knowledge of frequency response and phase response gives an idea on compensator circuit design.

DC Applied to passive components

Transient phenomenon

The word "**Transient means temporary or short duration**". When a DC is applied or removed from a circuit consisting of RC and RL, before the steady state is reached, there is a time period during which the current and voltage changes. This time period is called the **transient period.** The voltage response and current response with respect to time during this transient period is known as **transient phenomenon**.

Charging of a capacitor in RC circuit

Fig. 5.1(a) shows a resistor **R** and a capacitor **C** connected in series with the battery of emf **E** and a switch **S.** When switch S is thrown to position **A** at time t = 0, capacitor C charges through R exponentially with time. Current during charging decreases exponentially with time. Capacitor takes infinite time to charge to supply voltage E as shown in the fig. 5.1(b).

Charging voltage across the capacitor at time t after switch S is closed is given by

$$V_C = E(1 - e^{\frac{-t}{RC}})$$

The current at time t after switch s is closed is given by

$$I = \frac{E}{R}(e^{\frac{-t}{RC}}) = I_o(e^{\frac{-t}{RC}})$$

Where $I_o = \frac{E}{R}$ = Maximum (initial) charging current.

e = 2.718

Charge on capacitor at t is given by $Q = Q_O(1 - e^{\frac{-t}{RC}})$

Where Q_O = EC = Maximum charge

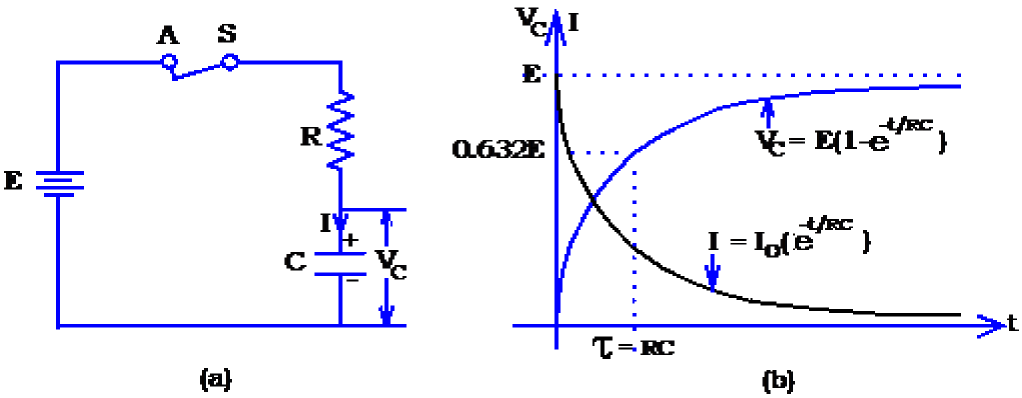


Fig. 5.1

Time constant (τ) in RC circuit

If t = RC = τ, then $V_C = E(1 - e^{\frac{-t}{RC}})$

$= E(1 - e^{-1}) = 0.632E$ or 63.2 % of E

The time constant of an RC circuit is defined as the time taken by the capacitor to charge to 63.2 % of the supply voltage.

Discharging of a capacitor in RC circuit

Discharging of a capacitor can be done after the capacitor is charged to supply voltage E through a resistor R. At time t = 0, the switch **S** is connected to position **B** as shown in fig. 5.2(a). The capacitor starts discharging through R exponentially with time. During discharging current decreases exponentially with time in reverse direction to that of the charging direction. Capacitor takes infinite time to discharge completely as shown in the fig. 5.2(b).

Discharging voltage across the capacitor at time t after switch S is closed is given by

$$V_C = E(e^{\frac{-t}{RC}})$$

The current at time t after switch S is connected to B is given by

$$I = -I_o(e^{\frac{-t}{RC}})$$

Where $I_o = \frac{E}{R}$ = Maximum (initial) discharging current.

Charge on capacitor at t is $Q = Qo(e^{\frac{-t}{RC}})$

Where Q_O = EC = Maximum charge

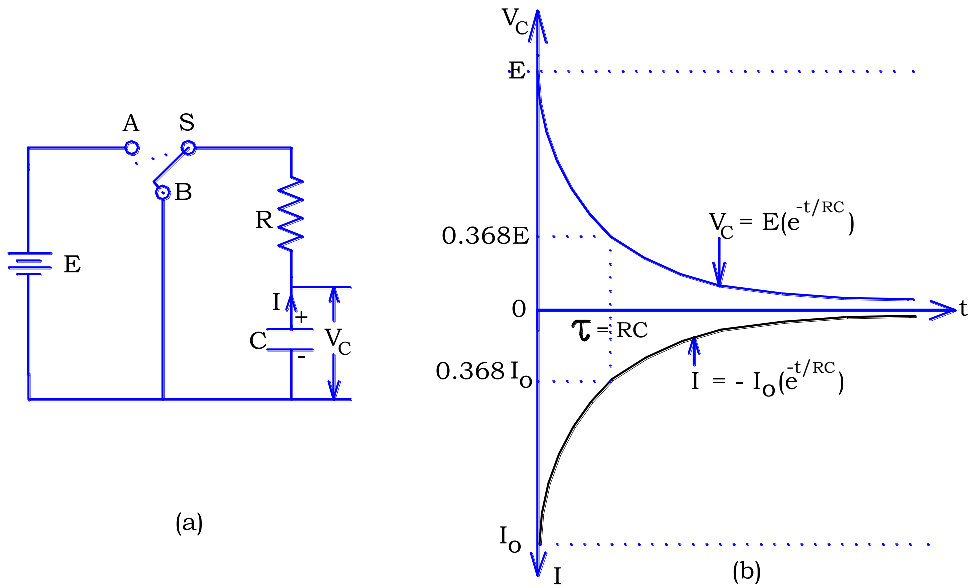


Fig. 5.2

During discharging, voltage across capacitor decreases to 36.8 % of its initial value (E) in time = τ = time constant = RC.

The time constant can also be defined as the time taken by the capacitor to discharge to 36.8 % of its maximum charge.

Growth of current in RL circuit

Fig. 5.3(a) shows a resistor **R** and an inductor **L** connected in series with the battery of emf **E** and a switch **S.** When switch S is thrown to position **A** at time t = 0, current grows exponentially with time as shown in fig 5.3(b). At t = 0, $\mathbf{V_L}$ is maximum and $\mathbf{V_R}$ is zero. As the time increases, V_L decreases exponentially and V_R increases exponentially.

The current I at time t after switch S is closed is given by

$$I = I_o\left(1 - e^{-\left(\frac{R}{L}\right)t}\right)$$

Where $I_o = \frac{E}{R}$ = Maximum current or current at t = ∞.

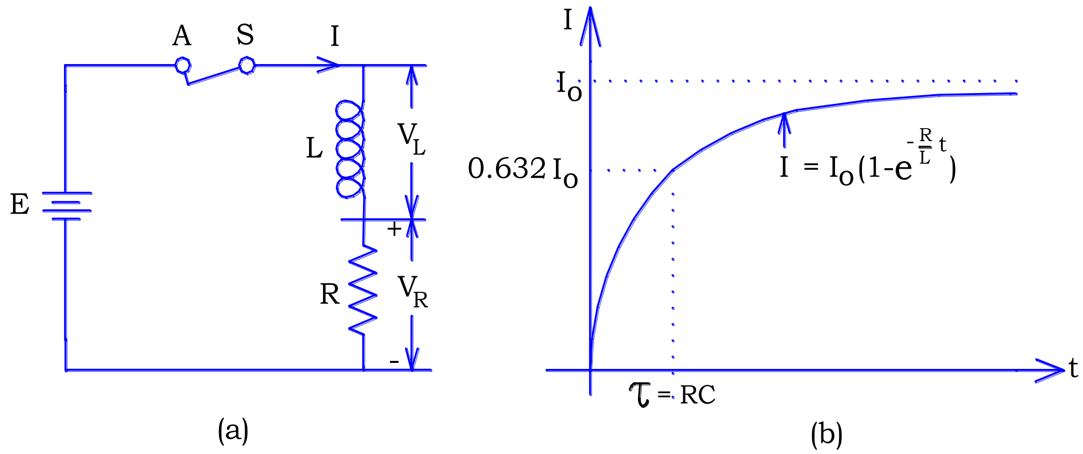


Fig. 5.3

Time constant (τ) in RL circuit

$$\text{If } t = \frac{L}{R} = \tau, \quad \text{then } I = I_o\left(1 - e^{-\left(\frac{R}{L}\right)t}\right)$$

$$= I_o(1 - e^{-1}) = 0.632 I_o \text{ or } 63.2\ \% \text{ of } I_o$$

The time constant of an RL circuit is defined as the time taken by the current to grow 63.2 % of the maximum value.

Decay of the current in RL circuit

Decay of current in RL circuit takes place once the current in the inductor is grown through a resistor R. In the fig. 5.4(a) initially the current in the circuit is grown to maximum value using supply voltage E through a resistor R by placing switch S to position A. At time t = 0, the switch S is connected to position B as shown in fig. 5.4(a). Current starts decaying exponentially with time in the same direction. Fig. 5.4(b) shows the decay of current.

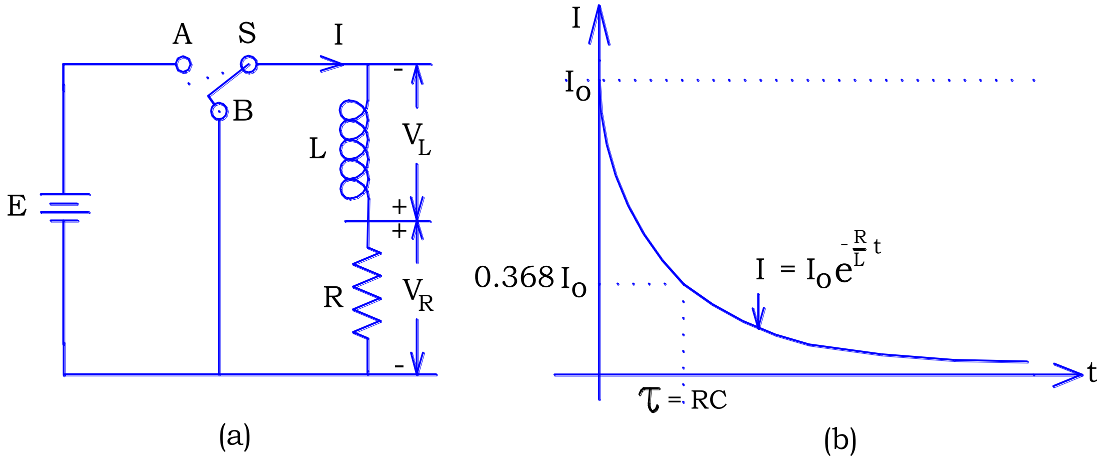


Fig. 5.4

The value of current at time t after switch S is closed to B is given by

$$I = I_o(e^{-\left(\frac{R}{L}\right)t})$$

Where $I_o = \frac{E}{R}$ = Maximum (initial) current.

During decay, the current decreases to 36.8 % of initial value (I_O) in time $t = \tau$ = time constant = $\frac{L}{R}$.

Time constant can also be defined as the time taken by the RL circuit for the current to decay to 36.8% of its maximum value.

Worked examples

1. Determine the time constant of an RC circuit when R = 22 kΩ and C = 0.05 μF

   Solution: R = 22 kΩ, C = 0.05 μF

   $$\tau = RC = 22 \times 10^3 \times 0.05 \times 10^{-6} = 1.1 \text{ mS}$$

2. Determine the voltage across the capacitor and maximum current during charging at t = 1 S in a DC circuit containing R = 1 MΩ and C = 1 μF connected to DC supply of 10 V.

Solution: E = 10 V, R = 1 MΩ, C = 1 μF

$$RC = 1 \times 10^{6} \times 1 \times 10^{-6} = 1\ S$$

$$V_C = 10(1 - e^{\frac{-t}{RC}})$$

$$= E(1 - e^{-1}) = 10 \times 0.632 = 6.32\ V$$

$$I_o = \frac{E}{R} = \frac{10}{1 \times 10^{6}} = 10\ \mu A$$

3. Determine the current through an inductor during the growth at t = 1 S in a DC circuit containing R = 1 Ω and L = 1 H connected to DC supply of 20 V.

Solution: E = 20 V, R = 1 Ω, L = 1 H

$$I_o = \frac{E}{R} = \frac{20}{1} = 20\ A$$

$$I = I_o(1 - e^{-\left(\frac{R}{L}\right)t})$$

$$I = 20(1 - e^{-1})$$

$$I = 12.64 = 12.64\ A$$

4. Determine time constant and peak current of an RL circuit with DC source of 10 V having a resistance R = 100 Ω and L = 100 mH.

Solution: E = 10 V, R = 100 Ω, L = 100 mH

$$\tau = \frac{L}{R} = \frac{100 \times 10^{-3}}{100} = 1\ mS$$

$$I_o = \frac{E}{R} = \frac{10}{100} = 100\ mA$$

AC Applied to passive components

Phase: Phase is the time relationship between the two alternating quantities. The fraction of the time or cycle or angle that has elapsed since an AC voltage or current last passed through a given reference point is called **Phase.** We can compare the phases of the two voltages, two currents or a current with a voltage. For comparison of two AC quantities they must have the same wave shape and frequency but they can be of different amplitudes.

Phasor Diagram: Phasor is a vector having both magnitude and direction. The length of the line indicates the magnitude and arrow mark indicates the direction. If the movement is in anti clock wise direction with respect to the reference axis it is taken as positive and if the movement is in clockwise direction it is taken as negative. In fig. 5.5 OA represents vector having phase angle of +θ and OB represents vector having phase angle of –Φ.

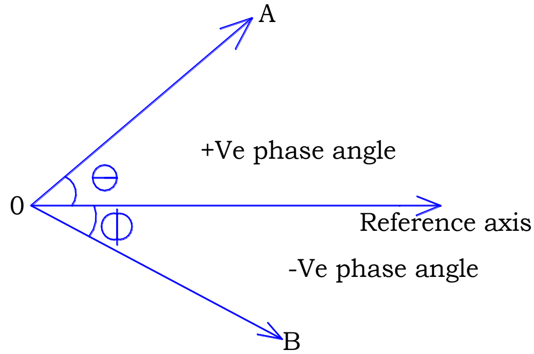


Fig. 5.5

Two AC quantities are said to be in phase when they are in the same direction as represented in the phasor diagram, shown in fig. 5.6.

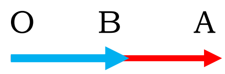


Fig. 5.6

Length indicates their magnitude (OA > OB) in phase, both represented in the same direction from origin.

Two AC quantities are said to be out off phase when they are in different directions as represented in the phasor diagram fig. 5.7 and fig. 5.8. In fig. 5.7

OA is out of phase with OB by 180^0. In fig. 5.8 V_A and V_B having a phase difference of 90^0.

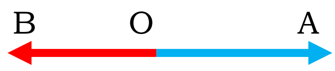


Fig. 5.7

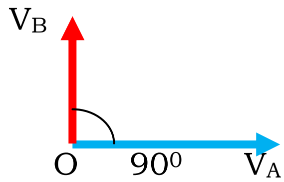
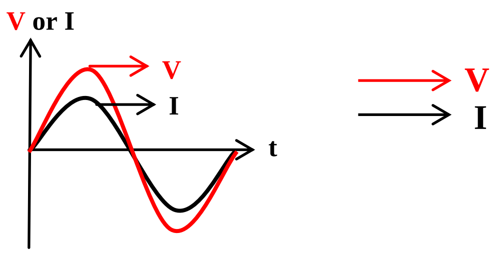
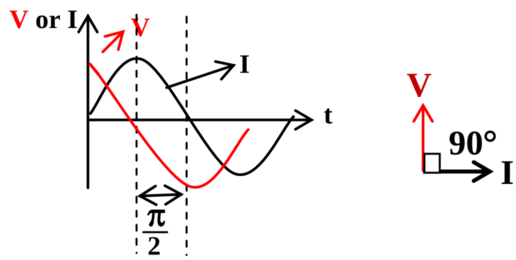


Fig. 5.8

Advantages of Phase diagram

1. Phasor is a simpler technique of showing amplitude and phase angle of the sinusoidal waveforms.
2. It takes less time to represent and analyse AC.
3. The phase angle calculation is easy.

The phase difference between different alternating quantities is shown below.

In phase (0^0) waveforms	**90° phase shift waveforms**
	
V and I are in same phase	V is said to lead I by an angle $\frac{\pi}{2}$ Or I is said to lag V by an angle $\frac{\pi}{2}$

Phase difference: If two alternating quantities do not reach their maximum or zero values simultaneously then they are said to have a **phase difference**.

Phase lead: An AC quantity ahead of another ac quantity is said to be leading

Phase lag: An AC quantity falls behind another ac quantity is said to be lagging

Expression for AC sinusoidal wave

AC sine wave is represented by the expression.

$$\mathbf{v = V_m \sin\omega t}$$

Where v = Instantaneous voltage changing with time.

V_m = Maximum or / peak value of the AC voltage.

$\omega = 2\pi f$ = angular frequency and

t = time

AC Applied to pure resistor

Sine wave represented in equation 1 is applied to resistor R in fig. 5.9(a).

$$\mathbf{v = V_m \sin\omega t} \quad \text{.........1}$$

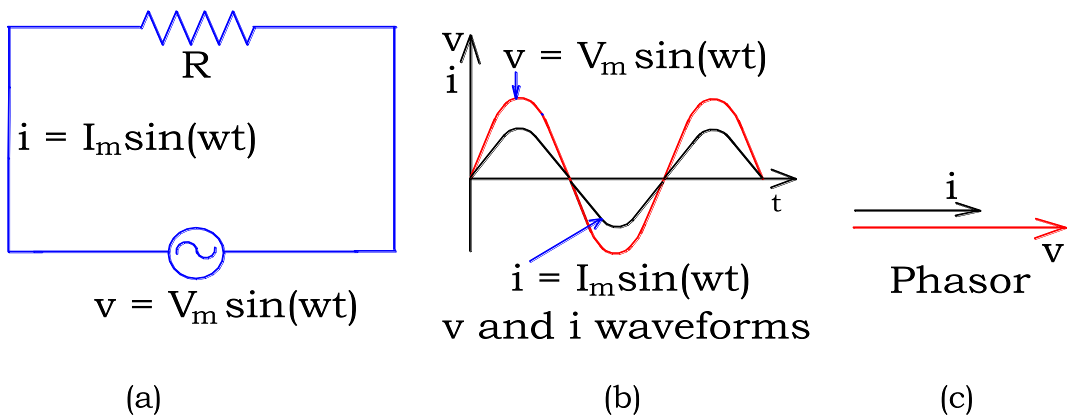


Fig. 5.9

The instantaneous current in the circuit can be written as

$$i = \frac{v}{R} = \frac{V_m \sin\omega t}{R}$$

$$\mathbf{I = I_m \sin\omega t} \quad \text{.........2}$$

Where $I_m = \frac{V_m}{R}$ = Peak value of current

From equations (1) and (2), it is clear that voltage and current are in the same phase. The phase relation between v and i is represented graphically in fig. 5.9(b) and the phasor representation is as shown in fig. 5.9(c).

AC Applied to pure inductor

Sine wave represented in equation 1 is applied to inductor L in fig. 5.10(a).

$$\mathbf{v = V_m \sin\omega t} \qquad \text{.........1}$$

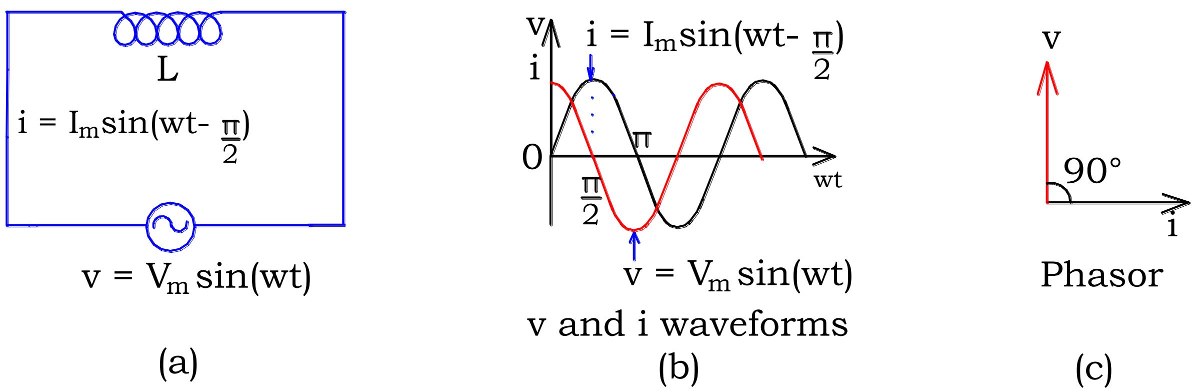


Fig. 5.10

At any instant of time, current in the circuit is given by,

$$\mathbf{i = I_m \sin(\omega t - \tfrac{\pi}{2})} \qquad \text{...... 2}$$

Where $\mathbf{I_m} = \frac{V_m}{X_L}$ = Peak value of current

$\Rightarrow \quad X_L = \frac{V_m}{I_m} = \omega L$ = inductive reactance

From the equations (1) and (2) it is clear that **voltage leads the current by $\frac{\pi}{2}$ or** in other words **current lags behind the voltage by $\frac{\pi}{2}$** in an ac circuit containing pure inductor.

The phase relation between v and i is represented graphically in fig. 5.10(b) and the phasor representation is as shown in fig. 5.10(c).

Inductive reactance (X_L)

Inductance controls the alternating current in the circuit without consuming power. The opposition of an inductor to the alternating current is called the inductive reactance and is denoted by X_L. Its unit is **ohm (Ω).**

The reactance of an inductor is given by the formula $\mathbf{X_L = \omega L = 2\pi f L}$. From the expression it is clear that inductive reactance is directly proportional to both f and L.

NOTE: For DC, $f = 0 \Rightarrow X_L = 0$, indicates inductor is short for DC

For AC, if $f = \text{High} \Rightarrow X_L \propto f = \text{high}$, indicates inductor is open for AC

Worked examples

1. What is the reactance of a 3 mH inductor connected to an AC of 200 V, 120 Hz?

Solution: Inductance L = 3 mH, Frequency f = 120 Hz

$$X_L = \omega L = 2\pi f L = 6.28\ fL$$
$$= 6.28 \times 120 \times 3 \times 10^{-3}$$
$$X_L = 2.261\ \Omega.$$

2. A 2.5 mH inductor is placed in a circuit, where the frequency is 100 kHz and voltage is 50 V. Calculate inductive reactance and peak current?

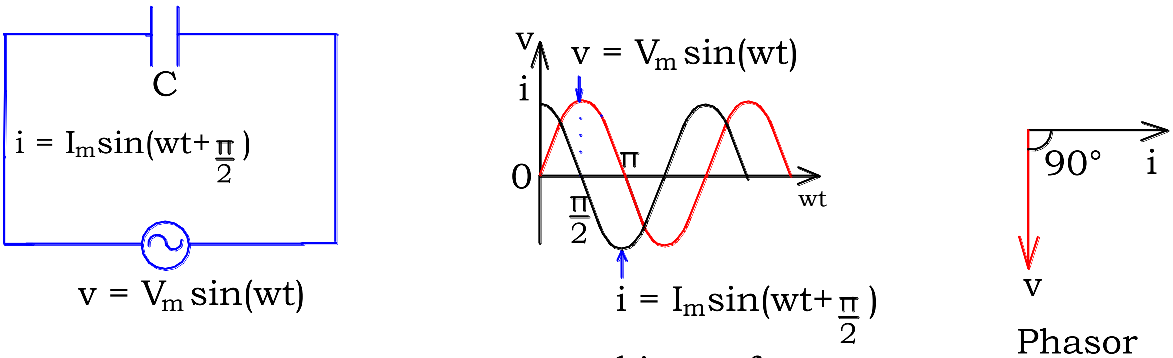
Solution: L = 2.5 mH, F = 100 kHz, V = 50 V

$$X_L = \omega L = 2\pi f L = 6.28\ fL$$
$$X_L = 6.28 \times 100 \times 10^3 \times 2.5 \times 10^{-3}$$
$$X_L = 1570\ \Omega$$
$$I_m = \frac{V_m}{X_L} = \frac{50}{1570} = 31.84\ \text{mA}.$$

AC Applied to pure capacitor

Sine wave represented in equation 1 is applied to a capacitor C in fig. 5.11(a).

$$\mathbf{v = V_m \sin\omega t} \qquad \ldots\ldots\ldots 1$$



v and i waveforms

Phasor

(a) (b) (c)

Fig. 5.11

The instantaneous current in the circuit can be written as

$$\mathbf{i = I_m \sin(\omega t+\frac{\pi}{2})} \qquad \text{...... 2}$$

Where $\mathbf{I_m} = \frac{V_m}{X_C}$ = Peak value of current

$\Rightarrow \quad X_C = \frac{V_m}{I_m} = \frac{1}{\omega C}$ = inductive reactance

From the equations (1) and (2) it is clear that **the current leads the voltage by $\frac{\pi}{2}$ or** in other words **the voltage lags behind the current by an angle $\frac{\pi}{2}$.**

The phase relation between v and i is represented graphically in fig. 5.11(b) and phasor representation is as shown in fig. 5.11(c).

Capacitive reactance: It is the resistance offered by a capacitor for AC. A capacitor's opposition to the alternating current is known as capacitive **reactance** is denoted as $\mathbf{X_C}$**.** The unit of capacitive reactance is **ohm** (Ω). Capacitive reactance is controlled by two factors, the **frequency** and the amount of **capacitance**.

The reactance of a capacitor is given by the formula $X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C}$. From the expression it is clear that the capacitive reactance is inversely proportional to both f and C.

NOTE: For DC, $f = 0 \Rightarrow X_C = \frac{1}{0} = \infty$, indicates capacitor is open for DC

For AC, if f = High $\Rightarrow X_C \propto \frac{1}{f}$ = low, indicates capacitor is short for AC

Worked example

1. What is the capacitive reactance of a 0.01 μF capacitor at 400 Hz?

   Solutions: Given C = 0.01 μF, f = 400 Hz

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C} = \frac{1}{6.28 \times 400 \times 0.01 \times 10^{-6}}$$

$$X_C = 39800\ \Omega = 39.8\ \text{k}\Omega$$

Power in AC Circuits

Power is the important quantity in all electronic circuits and the communication systems. These involve transmission of power from one point to another. The instantaneous power delivered or absorbed by an element in AC circuits is given by **p = v i,** where v and i are instantaneous values of AC voltage and current respectively.
The instantaneous power changes with time and it is difficult to measure, therefore it is convenient to measure the average power delivered.

Average Power

The average of the instantaneous power over one cycle is called **average power (P_{av})**. The average power consumed in an ac circuit is also known as **active power (P_{act})**. It is measured in watt.

Therefore

$$\text{Average power} = \text{Active power} = \mathbf{P_{av} = P_{act} = V_{rms}\, I_{rms} \cos\Phi}$$

$$\text{Where } V_{rms} = \frac{V_m}{\sqrt{2}} \text{ and } I_{rms} = \frac{I_m}{\sqrt{2}}$$

Where Φ is the phase difference between the applied voltage and the resulting current.
Case 1: In a resistive circuit, current and voltage are in phase i.e., Φ is 0^0, the average power dissipated in a resistor is given by

$$\mathbf{P_{av} = V_{rms}\, I_{rms}}, \qquad (\cos\Phi = \cos 0^0 = 1)$$

Case 2: In a purely reactive (inductive or capacitive) circuit, voltage and current are 90^0 out of phase ($\Phi = 90^0$)

$$\mathbf{P_{av} = 0} \qquad\qquad (\cos 90^0 = 0)$$

The reactive elements capacitor, inductor do not absorb power, they return back all the supplied power to the source.

Reactive power

The maximum value of the power consumed in a reactive element is called as reactive power.

Reactive power = $\mathbf{V_{rms}\, I_{rms}\, sin\Phi}$

Apparent power

The power drawn by a circuit from an AC source is called apparent power. It is the product of the rms values of the applied voltage and current. It is measured in VA.

$$\textbf{Apparent power} = \mathbf{P_{ap} = V_{rms}\, I_{rms}}$$

Power Factor

The ratio of active power to apparent power is called power factor.

Since the power dissipated in the circuit is the Real power

Then, Real power = apparent power × power factor

$$\textbf{Power factor} = \frac{\text{Active power}}{\text{Apparent power}} = \frac{V_{rms} I_{rms} \cos\Phi}{V_{rms} I_{rms}} = \mathbf{\cos\Phi}$$

In the ideal situation the apparent power = real power, then the power factor becomes 1 or 100%. The circuit does not consume power to maintain current. This current is called **wattless current**.

Series RLC circuit

Series RLC circuits are used to select a desired band of frequencies and to reject other unwanted frequencies. They are used in TV and Radio receiver to receive the required channel signal at a time by tuning the RLC circuits to resonate at some desired frequency. By proper selection of L and C component values, they can receive all the transmitted information in the bandwidth and reject the frequencies of adjacent stations.

Consider an AC circuit consisting of an inductance (L), a capacitance (C) and a resistance (R) connected in series to an AC source as shown in fig. 5.12 whose frequency is varied.

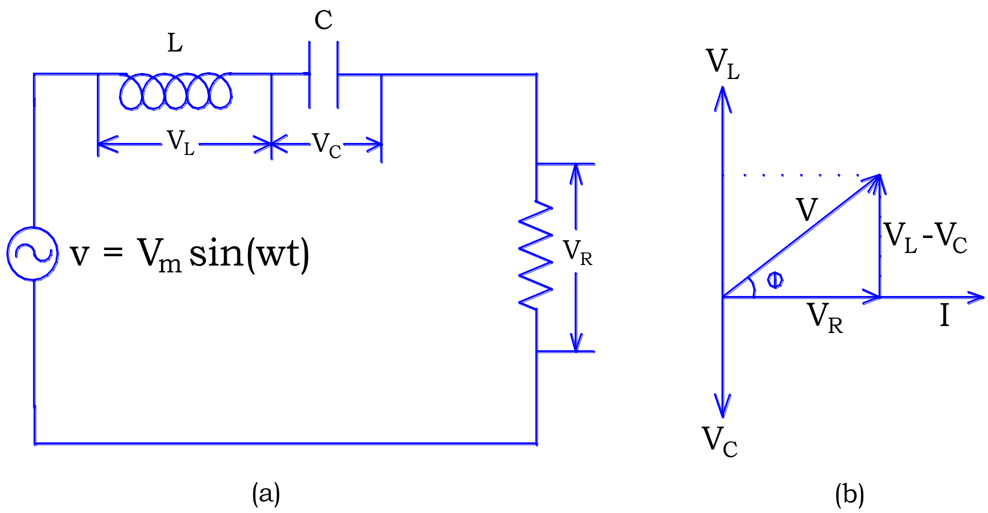


Fig. 5.12

Sine wave represented in equation 1 is applied to the series RLC circuit shown in fig.5.12(a).

$$\mathbf{v = V_m \sin\omega t} \qquad \text{.........1}$$

Let the voltage across R, L and C be V_R, V_L and V_C respectively. Then $V_R = IR$, $V_L = IX_L$ and $V_C = IX_C$. The resultant voltage V across R, L and C is the vector sum of V_R, V_L and V_C.

V_R is in phase with I, V_L leads I by 90° while V_C lags behind I by 90°. Assuming $V_L > V_C$ the various voltage V_R, V_L and V_C can be represented by vectors as shown in fig. 5.12(b). **In a series circuit the current remains same, hence current is taken as reference in the phasor diagram.**

For the vectors $V^2 = V_R^2 + (V_L - V_C)^2$

$$V^2 = I^2R^2 + (IX_L - IX_C)^2$$

$$V^2 = I^2[R^2 + (X_L - X_C)^2]$$

The impedance (Z) of the RLC circuit is therefore,

$$\mathbf{Z} = \frac{\mathbf{V}}{\mathbf{I}} = \sqrt{\mathbf{R}^2 + (\mathbf{X_L} - \mathbf{X_C})^2} \qquad \text{.........2}$$

The phase angle between the current and voltage in series RLC circuit is given by

$$\Phi = \tan^{-1}\left(\frac{X_L - X_C}{R}\right) \qquad \text{.........3}$$

Impedance

Impedance of the series RLC circuit is total opposition offered by R, L and C to AC. Fig. 5.13 shows the variation of impedance with frequency. At resonant frequency f_r inductive reactance $X_L = X_C$. Below f_r, $X_L < X_C$ and above f_r, $X_L > X_C$.

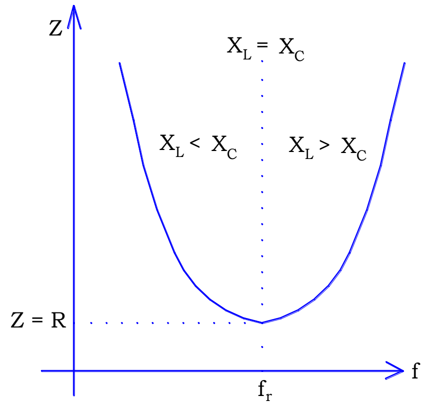


Fig. 5.13

Note:

- If $X_L > X_C$, $\emptyset$ is positive, the current lags the voltage by an angle $\emptyset$ and the circuit is **inductive in nature**.
- If $X_L < X_C$, $\emptyset$ is negative, the current leads the voltage by an angle $\emptyset$ and the circuit is **capacitive in nature.**
- If $X_L = X_C$, then the circuit is said to be in **resonance**. The voltage and current are in phase ($\emptyset = 0$) and the impedance Z is purely **resistive**.

Condition for resonance

At resonance inductive reactance $\mathbf{X_L}$ is equal to capacitive reactance $\mathbf{X_C}$. The frequency at resonance is called the resonant frequency f_r.

At resonance, $X_L = X_C$

$$\omega L = \frac{1}{\omega C}$$

$$2\pi f_r L = \frac{1}{2\pi f_r C}$$

$$\text{Therefore, } f_r = \frac{1}{2\pi\sqrt{LC}}$$

The current will be maximum at resonant frequency and depends on resistance R of the circuit ($I_m \alpha$ R). But f_r is independent of R. The variation of the current with frequency is as shown in fig. 5.14.

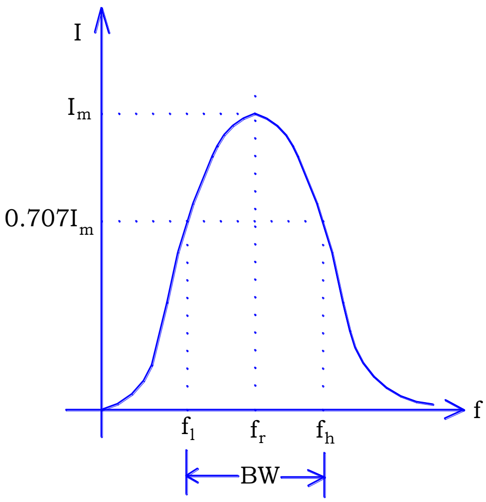


Fig. 5.14

Bandwidth

Bandwidth is the difference between the two frequency points on either side of the resonant frequency, where the current falls to 70.7% of its maximum value.

$$\textbf{Band width} = f_h - f_l$$

The frequencies corresponding to f_h and f_l are called **half power frequencies**. At half power frequencies the power dissipated is half of the power dissipated at the resonant frequency.

Quality factor

Resonance circuits are used to select a band of frequencies. The quality factor indicates the selectivity or sharpness of the resonant circuit.

The quality factor of a circuit is also defined as the ratio of resonance frequency to the bandwidth.

$$Q = \frac{f_r}{\text{Bandwidth}} = \frac{f_r}{f_h - f_l}$$

As the frequency is increased current reaches a maximum value I_m at f_r.

RC filters

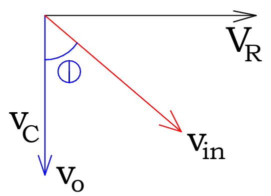
A filter is a circuit that allows a specified range of frequencies and rejects or attenuates the other frequencies.

RC low pass filter

A low pass filter passes all the frequencies below the cut-off frequency f_C and rejects all the frequencies above f_C. Fig. 5.15(a) shows the circuit of a RC low pass filter. The input is applied across the RC circuit and output is taken across the capacitor.

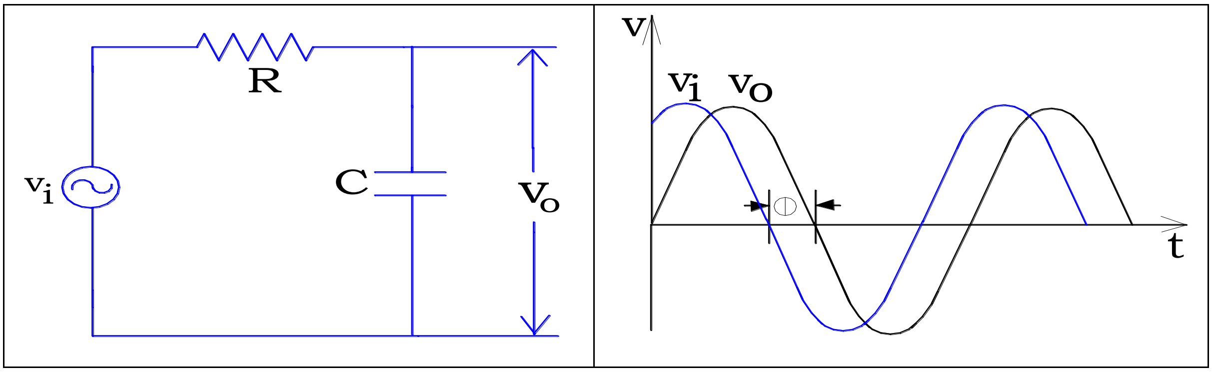
The expression for the voltage gain A_V of RC Low pass filter is given by

$$A_V = \frac{V_o}{V_i} = \frac{iX_C}{iZ} = \frac{X_C}{\sqrt{R^2 + X_C^{\,2}}} = \frac{1}{\sqrt{\frac{R^2}{X_C^{\,2}} + 1}} = \frac{1}{\sqrt{(\omega RC)^2 + 1}}$$



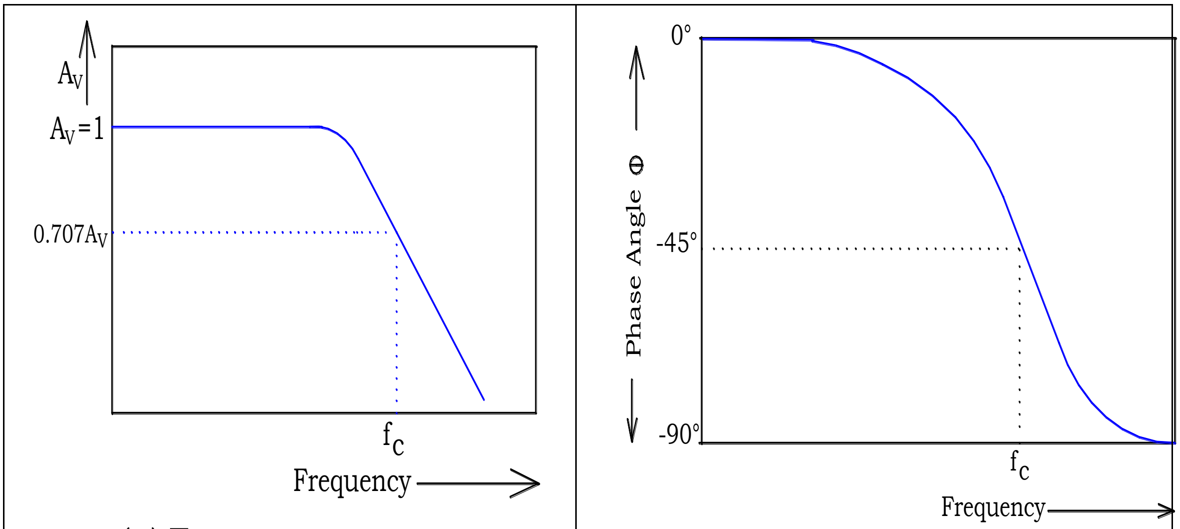
Phase angle is given by $\Phi = -\tan^{-1}\left(\frac{R}{X_C}\right) = -\tan^{-1}(\omega RC)$

Low pass filter is called as a RC lag network because the output voltage lags the input voltage by an angle Φ as shown in fig. 5.15(b). Frequency response and phase responses are shown in fig. 5.16(a) and fig. 5.16(b) respectively.



(a) RC low pass filter (b) Input output waveforms

Fig. 5.15



(a) Frequency response (b) Phase response

Fig. 5.16

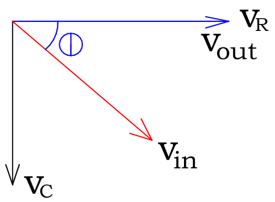
The cut-off frequency of the low pass filter is given by $f_C = \frac{1}{2\pi RC}$

RC high pass filter

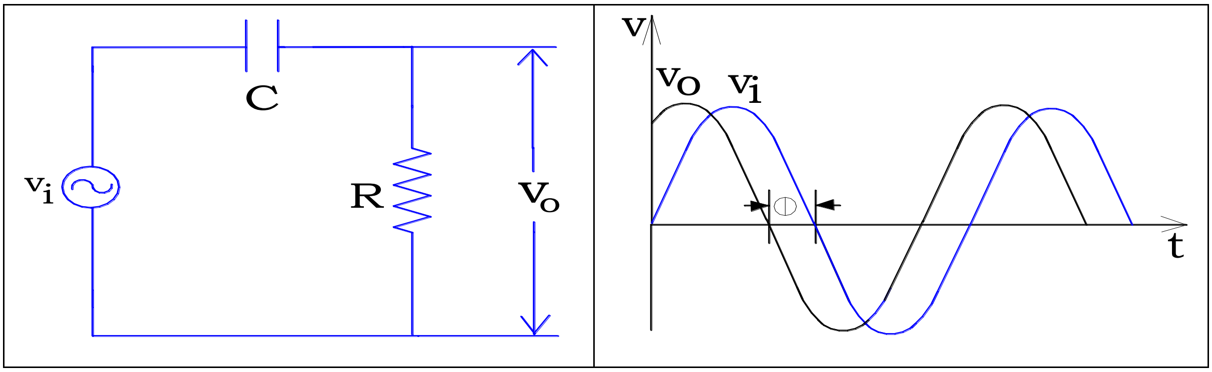
A high pass filter passes all the frequencies above the cut-off frequency f_C and rejects all the frequencies below f_C. Fig. 5.17(a) shows the circuit of a RC high pass filter. The input is applied across the RC circuit and the output is taken across the resistor.

The expression for the voltage gain A_V of RC high pass filter is given by

$$A_V = \frac{V_o}{V_i} = \frac{iR}{iZ} = \frac{R}{\sqrt{R^2 + X_C{}^2}} = \frac{1}{\sqrt{1 + \frac{X_C{}^2}{R^2}}} = \frac{1}{\sqrt{1 + \left(\frac{1}{\omega RC}\right)^2}}$$

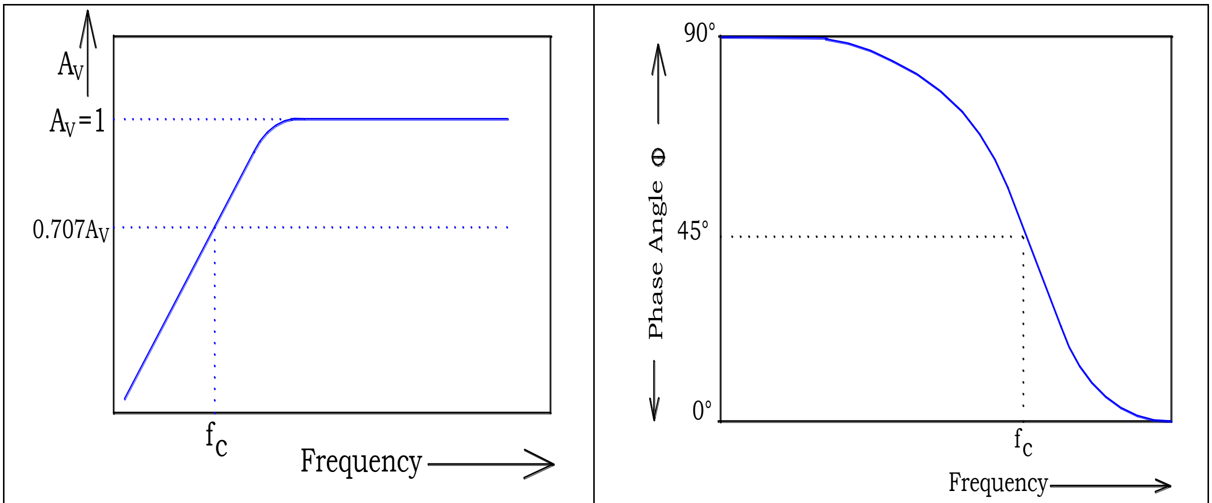


Phase angle is given by, $\Phi = \tan^{-1}\left(\frac{X_C}{R}\right) = \tan^{-1}\left(\frac{1}{\omega RC}\right)$



(a) RC high pass filter (b) Input output waveforms

Fig. 5.17



(a) Frequency response (b) Phase response

Fig. 5.18

High pass filter is called as a RC lead network because the output voltage leads the input voltage by an angle Φ as shown in fig. 5.17(b). Frequency response and phase responses are shown in fig. 5.18(a) and fig. 5.18(b) respectively.

The cut-off frequency of the high pass filter is given by $f_C = \frac{1}{2\pi RC}$

Worked examples:

1. A 10 Ω resistance in series with X_L = 50 Ω and X_C = 25 Ω. The applied voltage is V = 50 mV with 50 Hz. Calculate Z, I and phase angle.

$$X_L - X_C = 50 - 25 = 25\ \Omega.$$

$$Z = \sqrt{\mathbf{R^2 + (X_L - X_C)^2}} = 26.92\ \Omega.$$

$$I = \frac{V}{Z} = \frac{50 \text{ x } 10^{-3}}{26.92} = 1.85 \text{ mA}$$

$$\emptyset = \tan^{-1}\left(\frac{X_L - X_C}{R}\right) = \tan^{-1}\left(\frac{25}{10}\right) = 68.19^0$$

2. An inductor of 20 mH is connected in series with a resistor of 50 Ω. The combination is connected to 220 V, 50 Hz source. Find the current in the circuit.

   Solution: Given L = 20 mH, R = 50 Ω, V = 220 V, f = 50 Hz.

$$\text{The current,} \quad \mathbf{I = \frac{V}{Z}}$$

$$Z = \sqrt{R^2 + (X_L)^2} = \sqrt{50^2 + (2 \text{ x } 3.14 \text{ x } 50 \text{ x } 20 \text{ x } 10^{-3})^2} = 50.39\ \Omega$$

$$I = \frac{220}{50.39} = 4.36 \text{ A}$$

3. A series RL circuit is connected across the ac supply of 150 V, 60 Hz. Find the phase angle if R = 10 Ω and L = 40 mH.

   Solution: Given R = 10 Ω, L = 40 mH, V = 150 V, f = 60 Hz.

$$\Phi = \tan^{-1}\left(\frac{X_L}{R}\right) = \tan^{-1}\left(\frac{\omega L}{R}\right) = \tan^{-1}\left(\frac{2\pi f L}{R}\right)$$

$$= \tan^{-1}\left(\frac{2\pi \times 60 \times 40 \times 10^{-3}}{10}\right) = 56.43^0$$

4. A series RLC circuit has R = 20 Ω, C = 0.01 μF, L = 10 mH. Calculate (a) Resonent frequency.

Solution: Given R = 20 Ω, C = 0.01 μF, L = 10 mH

Resonant frequency, $f_r = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{10 \times 10^{-3} \times 0.01 \times 10^{-6}}} = 15.9$ kHz

Exercise

1. Determine time constant of an RC circuit when resistor is 20 kΩ and Capacitor is 0.05 μF (Ans: τ = 1 mS)
2. The time constant of an RL circuit is 4 mS. if L = 100 mH, calculate the value of resistance. (Ans: R = 25 Ω)
3. What value of resistance must be connected in series with a 20 μF. capacitor to provide a time constant of 0.2 sec? (Ans: R = 10 kΩ)
4. A coil of 100 mH having a resistance of 100 Ω is connected across a source of 200 V, 50 Hz. Find the phase angle and current in the circuit. (Ans: $\Phi = 17.43^0$, I = 1.9 A)
5. A series resonant circuit has R = 100 Ω, C = 0.1 μF produces a resonant frequency of 3 kHz. Find the value of inductance. (Ans: L = 28.17 mH)

One mark questions

1. What is transient period?
2. What is transient phenomenon?
3. Define time constant of RC circuit.
4. Write an expression for the voltage across capacitor during charging.
5. Write an expression for instantaneous current in R-L circuit, during the growth of current.
6. Write an expression for instantaneous current in R-L circuit, during the decay of current.

7. Define the time constant of RL circuit.
8. Define the phase difference between two AC quantities.
9. Two AC quantities are in phase. What is the value of phase angle between them?
10. Draw the waveform of two in phase AC quantities.
11. Draw the waveform of two AC quantities that are 180^0 out of phase.
12. What is a phasor diagram?
13. Write the phasor diagram of two AC quantities that are 90^0 out of phase.
14. What is the phase difference between voltage and current in a purely resistive circuit?
15. Draw the phasor diagram of voltage and current in a purely capacitive circuit?
16. What is capacitive reactance?.
17. Give the unit of capacitive reactance.
18. Write the expression for the capacitive reactance.
19. Define average power.
20. Define power factor.
21. Define impedance.
22. What is the unit of impedance?
23. Write the expression for the impedance of a series RLC circuit.
24. Give the condition for resonance of a series RLC circuit.
25. Write the expression for the resonance frequency of a series resonance circuit.
26. What are half power frequencies?
27. Define quality factor.
28. Write the relation between quality factor, bandwidth and resonance frequency.
29. What is a low pass filter?
30. What is a high pass filter?

Two marks question

1. Draw the graph showing voltage across capacitor during charging.
2. Draw the graph of growth of current in RL circuit.
3. Define capacitive reactance and give the expression for the capacitive reactance.
4. Define Inductive reactance and give the expression for the inductive reactance.
5. Write a brief note on impedance of a circuit.
6. Write a note on the variation of impedance in a series RLC circuit with frequency.
7. Derive an expression for resonance frequency of a series resonance circuit.
8. Draw the circuit diagram of low pass filter and high pass filter.

Three/five marks question

1. Discuss the charging of capacitor in a RC circuit.
2. Discuss the discharging of capacitor in a RC circuit.
3. Discuss the growth of current in a RL circuit.
4. Discuss the decay of current in a RL circuit.
5. Describe the phenomenon of resonance in a series resonant circuit.
6. Derive an expression for resonant frequency of a series resonant circuit.
7. Explain low pass filter with its frequency response.
8. Explain high pass filter with its phase response.

Chapter 6

Semiconductors, diodes and applications of diodes

Introduction

Electronics is the back bone of modern era. It has been invaded in all the fields. The electronic systems at present are constructed using electronic devices made up of semiconductors. Most commonly used semiconductor elements are silicon and germanium. Modern electronics is commonly called as silicon technology. Electronic components such as diodes, transistors and integrated circuits are all made up of semiconductors. Therefore to understand electronics one has to study semiconductors.

Band theory of solids

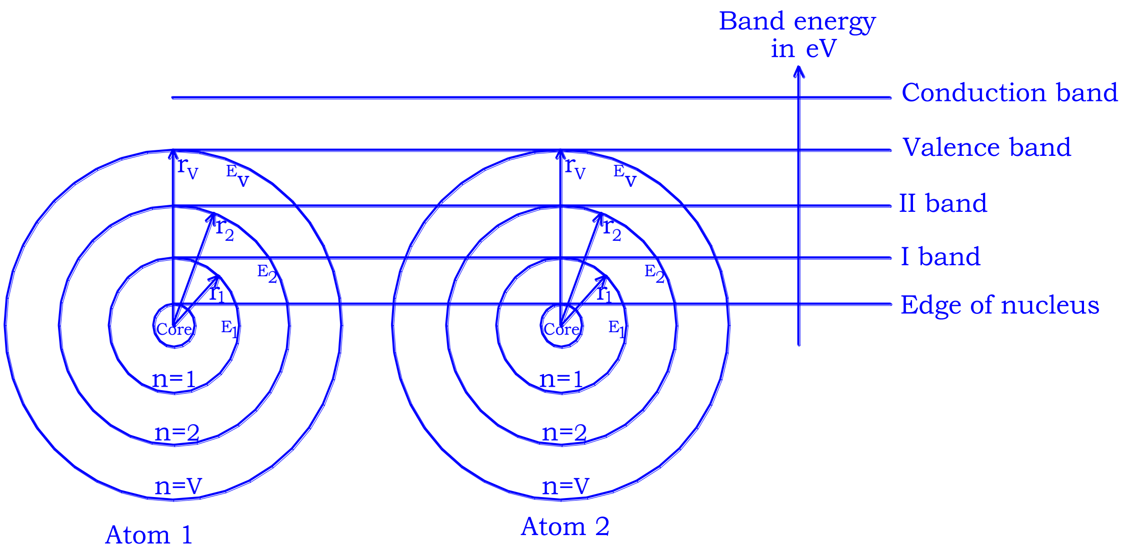


Fig. 6.1 Energy levels and energy bands in a solid

Billions of atoms are present in a solid. Fig. 6.1 shows energy levels and energy bands in a solid. Only two atom of a solid is shown in figure. Horizontal lines indicate energy levels. E_1, E_2, E_V represents energy levels of electrons with orbit numbers n_1, n_2, n_V at the radius r_1, r_2, r_V respectively from the nucleus. All the electrons in I orbit (n = 1) of solid posses I band energy (E_1), all the electrons in the II orbit (n = 2) of solid posses II band energy (E_2) and so on. An atom consists of

1. Protons having positive electric charge
2. Neutrons with electrically neutral and
3. Electrons having negative electric charge.

The proton and neutron together is called nucleus or core and electrons revolve around the nucleus in definite orbits.

1. Charge of an electron $e = 1.602 \times 10^{-19}$ coulomb
2. Mass of an electron $m = 9.1 \times 10^{-31}$ kg
3. Radius of an electron $r = 1.9 \times 10^{-15}$ meter

Highest occupied orbit of an atom is called valence band. Electrons in valence band are called valence electrons. This band is partially or completely filled. Even at ordinary temperature, some valence electrons may get detached from the parent atom and jump into a conduction band. Conduction band is the upper most energy band next to valence band. The conduction band electrons are called free electrons. These free electrons are responsible for the conduction of current in a conductor. Hence, they are called conduction electrons or free electrons.

In any given material there are many energy bands, but only three energy bands are important and are explained below.

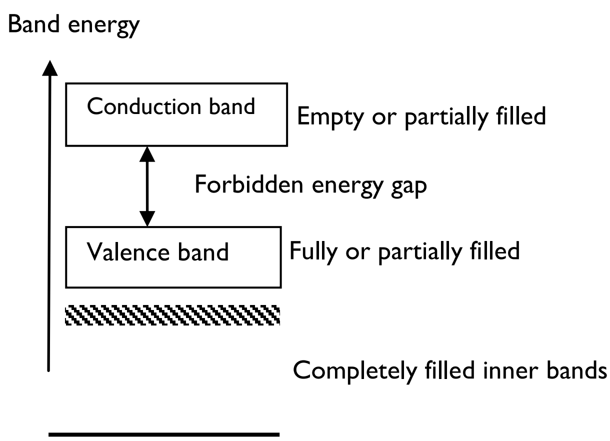


Fig. 6.2 Valence, conduction band and forbidden energy gap.

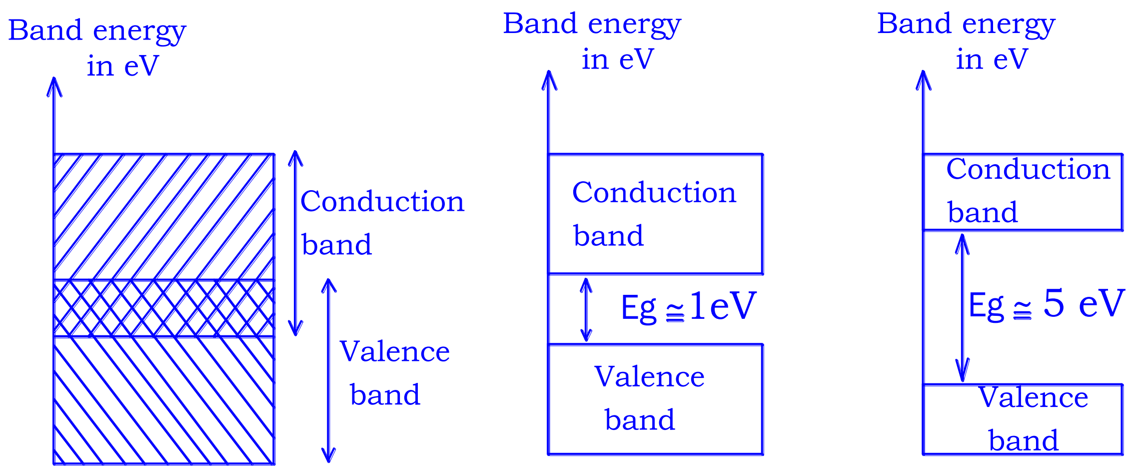
Valence band: Energy level occupied by valence electrons is called valence band.

Conduction band: Energy level occupied by free electrons is called conduction band.

Forbidden energy gap: "The separation between conduction band and valence band in the energy band diagram is known as forbidden energy gap". Energy gap is measured in electron volt (**eV**).

Classification of solids based on energy bands

Based on energy band diagram, solids are classified as conductors, semiconductors and insulators.



(a) Conductor (b) Semiconductor (c) Insulator

Fig. 6.3 Energy band diagrams

Conductors

Conductors are those substances which allow the electric charges to flow through them easily.

Ex: Copper, aluminum etc.

In a conductor the valence band and the conduction band overlap with each other. Due to this overlapping of bands there is no forbidden energy gap present between valence band and conduction band as shown in fig. 6.3(a). Some valence electrons move from valence band to conduction band by themselves without any supply of external energy. Current flows through conductors even for a very small voltage applied.

Insulators

Insulators are those substances which do not allow electric charges to flow through them easily. Ex: Rubber, paper, mica, glass, wood etc.

In an insulator there is a large energy gap of the order of 5 eV between the valence band and the conduction band as shown in fig. 6.3(c). Due to a large energy gap valence electrons cannot jump from the valence band to the conduction band. There are no free electrons present in conduction band at room temperature hence conduction does not take place at room temperature.

Semiconductors

Semiconductors are those substances whose electrical conductivity lies in between conductors and insulators. Ex: Germanium, Silicon etc.

Semiconductors have a small energy gap between valence band and the conduction band of the order of 1 eV as shown in fig. 6.3(b). The energy gap is 0.7 eV for germanium and 1.1 eV for silicon.

At absolute zero degree Kelvin, semiconductor acts as an insulator. However, with increase in temperature the valence electrons start acquiring additional energy and they cross the narrow forbidden gap to enter into the conduction band and acts as a conductor. Thus the conductivity increases with increase in temperature and vice versa.

Atomic structure of Silicon and Germanium.

To understand the important properties of semiconductors, it is necessary to study the structure of these atoms. Atomic structure of silicon and germanium are as shown in fig. 6.4.

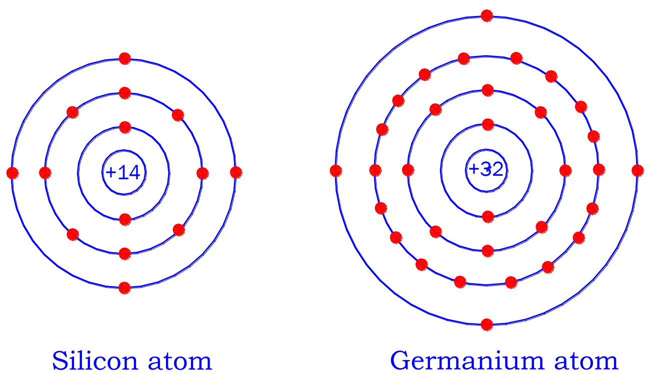
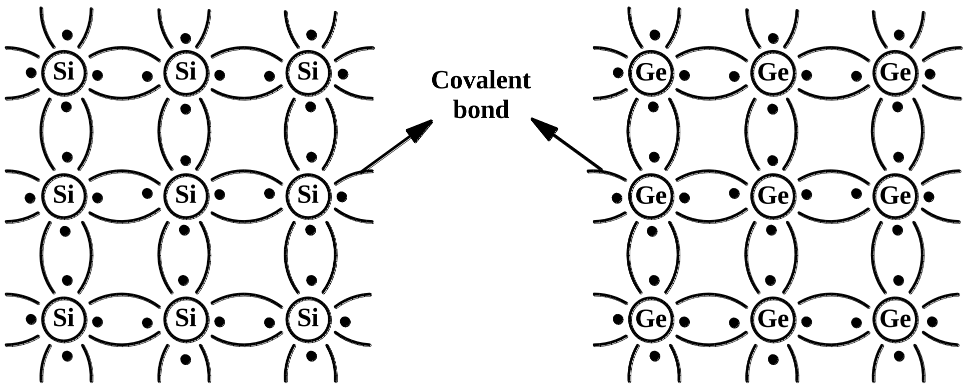


Fig. 6.4 Atomic structure of Si and Ge atom

Lattice structure of semiconductors

Two dimensional view of an atomic structure of a substance is called as a lattice structure.



(a) Silicon crystal b. Germanium crystal

Fig. 6.5 Covalent bonds among silicon and germanium atoms

Lattice structure of silicon and germanium are shown in fig. 6.5. Silicon and germanium have four valence electrons. While forming covalent bond in semiconductors, each silicon (or germanium) atom shares four valence electrons with the neighboring four atoms of silicon (or germanium).

Properties of semiconductors

1. Semiconductors are tetravalent, covalent bonded crystalline substances.
2. Semiconductors are perfect insulator at absolute zero degree temperature.
3. Semiconductors have negative temperature coefficient of resistance.
4. The conductivity of a semiconductor is proportional to impurities added.

Types of semiconductors

Semiconductors are classified as follows

Semiconductors

Intrinsic semiconductor Extrinsic semiconductor

p-type semiconductor n-type semiconductor

Intrinsic semiconductor

Semiconductor in its purest form is called as an intrinsic semiconductor. Ex: Silicon (Si) and germanium (Ge).

The intrinsic semiconductor behaves like a perfect insulator at zero degree kelvin. The behaviour changes with increase in temperature.

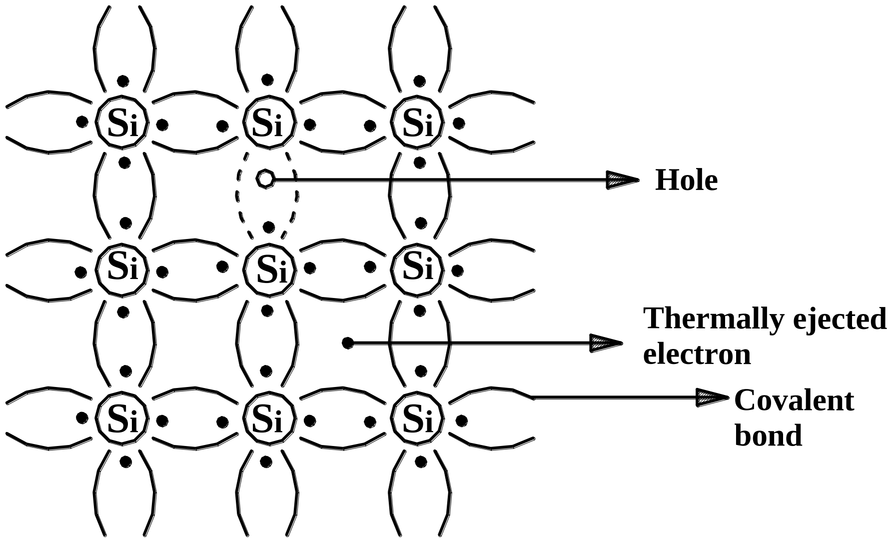


Fig. 6.6 Lattice structure of an intrinsic semiconductors

Conduction in intrinsic semiconductors

At low temperature: At low temperatures, all the valence electrons are tightly bound to the nucleus and there are no free electrons available for conduction. Hence, semiconductor behave as an insulator at absolute zero temperature.

At high temperature: An intrinsic semiconductor at high temperature absorbs heat energy; this causes some valence electrons to gain sufficient energy to jump from the valence band into the conduction band. They now become free electrons and are free to move in the conduction band. The energy required to break the covalent bond is equal to or greater than the energy gap Eg.

When an electron jumps into the conduction band breaking the covalent bond, it causes a deficiency of an electron in the bond structure. This vacancy of an electron in the covalent bond is called as a **hole** as shown in fig. 6.7. The hole behaves like a positive charge equal in magnitude to that of an electron. Hole is able to attract and capture an electron from the adjacent atom.

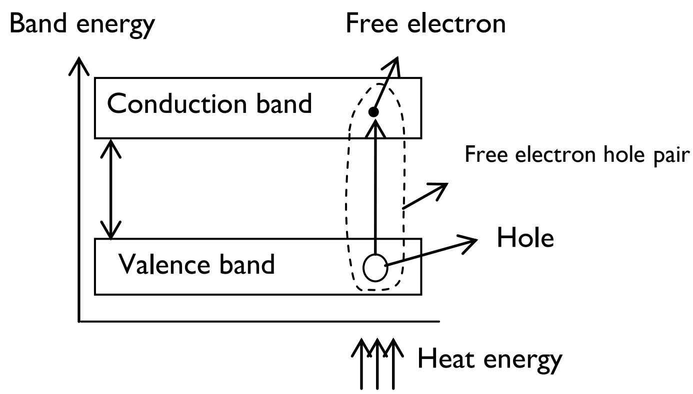


Fig. 6.7 Free electron hole pair generation.

As the temperature increases, covalent bond breaks, an electron jumps from the valence band into the conduction band. This creates a free electron-hole pair. Free electrons and holes are equal in number in intrinsic semiconductors.

When an electric field is applied across an intrinsic semiconductor at temperature greater than 0^0 K, thermally generated free electrons in the conduction band are now easily attracted towards the positive terminal of the power supply. The movement of these free electrons constitutes a current known as an electron current (i_e).

When a voltage is applied across the semiconductor, the hole current i_h flows due to movement of holes in valance band. A hole in the valance band is filled by an electron in the adjacent covalent bond. Now the hole is shifted to new position. This hole, in its new position, may now be filled by an electron from adjacent covalent bond and the hole will correspondingly move in the opposite direction to that of the motion of an electron. The motion of hole constitutes the flow of current called hole current (i_h). Fig. 6.8 shows electron and hole movement in the valance band with an applied voltage. The electrons drift towards the positive terminal and the holes towards the negative terminal, together contributing to the total current i_t.

The total current $i_t = i_e + i_h$

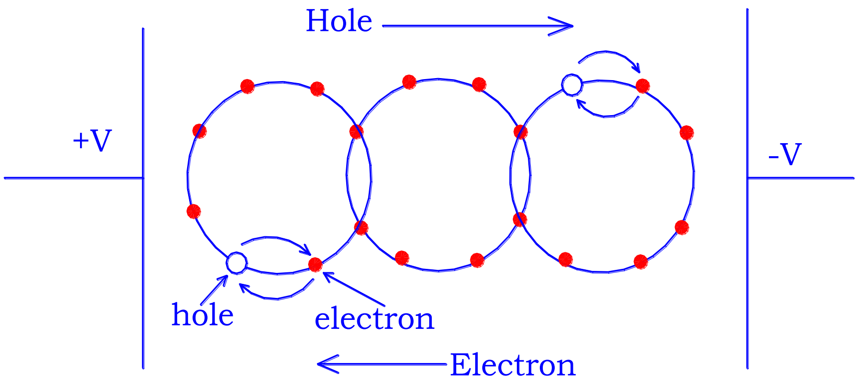


Fig. 6.8 Electron and hole movement in the valence band

Extrinsic semiconductor

A pure semiconductor doped with an impurity atoms is called as extrinsic semiconductor.

Doping: “The process of adding a small amount of an impurity atom to a pure semiconductor is called as doping”. The added impurities are called dopants. The main purpose of adding impurity is to generate large number of electrons or holes in the semiconductor crystal.

Extrinsic semiconductors are of two types.

1. n-type semiconductor.
2. p-type semiconductor.

n-type semiconductor

n-type semiconductors are obtained by doping a pure semiconductor with the pentavalent impurities such as antimony (Sb), arsenic (As), phosphorus (P) etc, the pentavalent dopant atoms are also known as donor atoms or donor impurity, because it donates a free electron to the pure semiconductor.

When an intrinsic semiconductor is doped with a pentavalent impurity such as arsenic, four valence electrons of an arsenic atom forms four covalent bonds with four neighbouring atoms of silicon, as shown in fig. 6.9. The fifth valence electron of an arsenic atom has no chance to form the covalent bond and hence it is given out as free electron. Thus each pentavalent impurity donates one free electron without creating a hole. The semiconductor now has excess of free electrons known as n-type semiconductor.

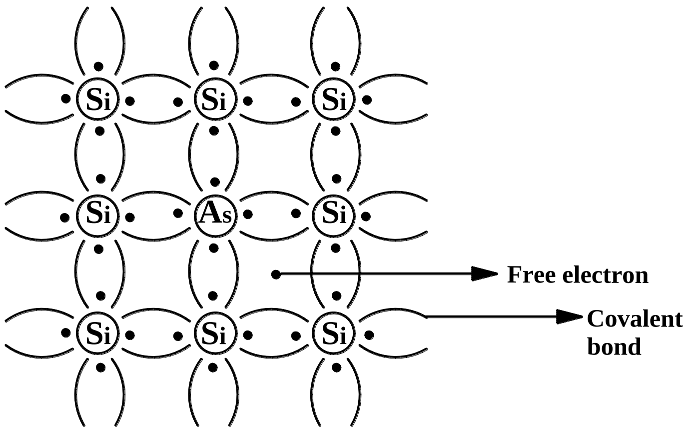


Fig. 6.9 Lattice structure of n-type semiconductor.

The dopant (pentavalent) atom becomes positively charged and it is called as an immobile ion or donar ion.

Majority and minority charge carriers in a n-type semiconductor

As the number of electrons are much greater than the number of holes in a n-type semiconductor, electrons are called as the "majority" charge carriers and holes are called as the "minority" charge carriers. Fig.6.10 shows electrons, holes and donor ions in a n-type semiconductor.

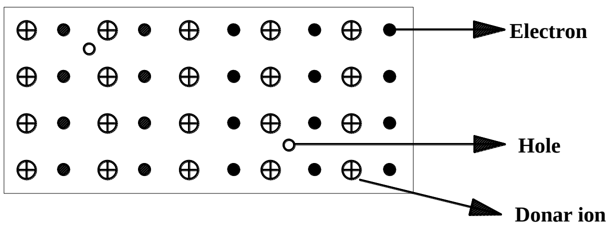


Fig. 6.10 N type semiconductor

p-type semiconductor

p-type semiconductor is obtained by doping a pure semiconductor with the trivalent impurities such as boron (B), aluminium (Al), gallium (Ga) etc, the trivalent doping atoms are known as acceptor atoms or acceptor impurity because, it can accept one valence electron from the semiconductor atom.

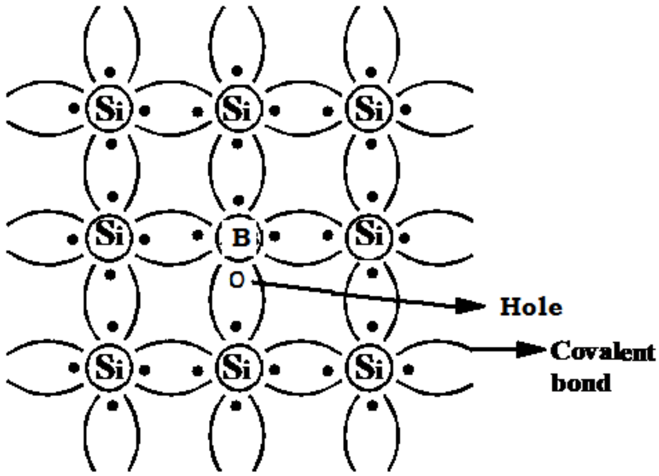


Fig. 6.11. Lattice structure of p-type semiconductor

When a trivalent impurity atom such as boron (B) is added to the silicon crystal, three valence electrons of the boron atom will form covalent bonds with three valence electrons of the three neighbouring silicon atoms. The fourth covalent bond however, remains incomplete, as the boron atom has only three valence electrons. The resulting vacancy is called as a hole shown in fig. 6.11. Thus each trivalent impurity atom (boron) creates, a hole without generating a free electron. Semiconductor now has excess of holes known as a p-type semiconductor.

Majority and Minority carriers in p-type semiconductor

As the number of holes are much greater than the number of free electrons in a p-type semiconductor, holes are termed as the "majority" charge carriers and electrons as the "minority" charge carriers. Free electrons, holes and acceptor ions are shown in fig. 6.12.

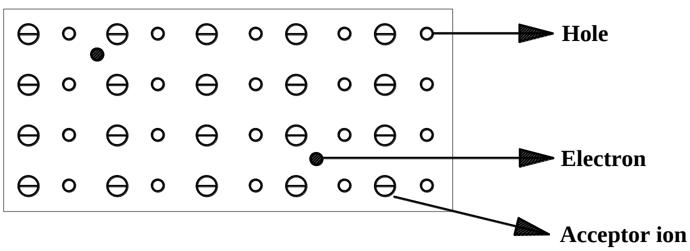


Fig. 6.12 P type semiconductor

p-n Junction

The behaviour of many semiconductor devices, including diode is dependent on the effects that occur at the junction between the n-type and the p-type semiconductor material. A p-n junction is the basic building block of almost all semiconductor electronic devices like diodes, transistors, solar cells, LEDs, integrated circuits, etc. A clear understanding of the junction behaviour and its characteristics is very much important to analyse the working of other semiconductor devices.

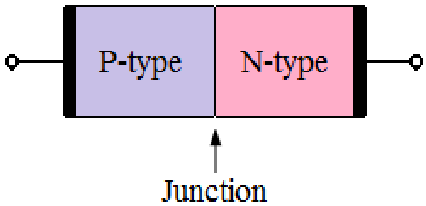


Fig. 6.13 p-n Junction

A p-n Junction is formed by doping a donor impurity into one side and an acceptor impurity into the other side of a single semiconductor crystal such as silicon or germanium.

Formation of Depletion layer

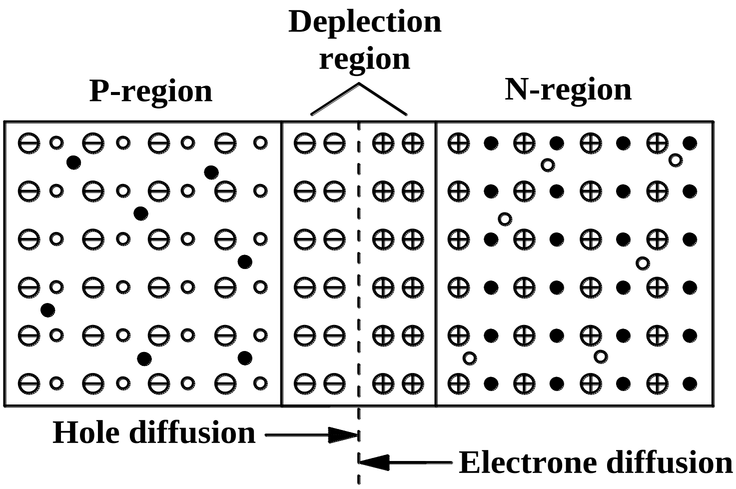


Fig. 6.14

When a p-n junction is formed, p-region contains acceptor ions and positively charged holes, n-region contains donor ions and free electrons. That is the n-type has high concentration of electrons (majority charge carriers) and the p-type has high concentration of holes which results in the concentration gradient across the junction. Due to this, holes move from p to n region and electrons from n to p region. This transfer of electrons and holes across the junction is known as diffusion.

During this process, free electrons from the n-type region will diffuse across the junction to the p-type region where they recombine with holes near the junction. Similarly, holes will diffuse across the junction in the opposite direction and recombine. The recombination of free electrons and holes in the vicinity of the junction leaves a narrow region on either side of the junction that contains immobile charges. This narrow region is known as depletion region or space charge region. It extends into both the p-type and n-type regions as shown in fig. 6.14. The thickness of this region is of the order of 10^{-6} m.

The region near the junction where there is no free electrons and holes is called the depletion region.

In the depletion layer there are no free electrons or holes. The potential barrier in the p-n junction cannot be measured with a voltmeter.

Barrier potential

When a free electron diffuses from n-region into p-region it leaves behind a donor ion. This ion has a positive charge and it is immobile as it is bonded to the surrounding atoms. Likewise a large number of positively charged immobile ions are formed near the junction on n-side.

Similarly, when a hole diffuses from p-region into n-region due to the concentration gradient it leaves behind an acceptor ion on p-side. This ion is a negatively charged immobile ion. Thus when the holes cross the junction large number of negatively charged immobile ions are formed near the junction on p-side.

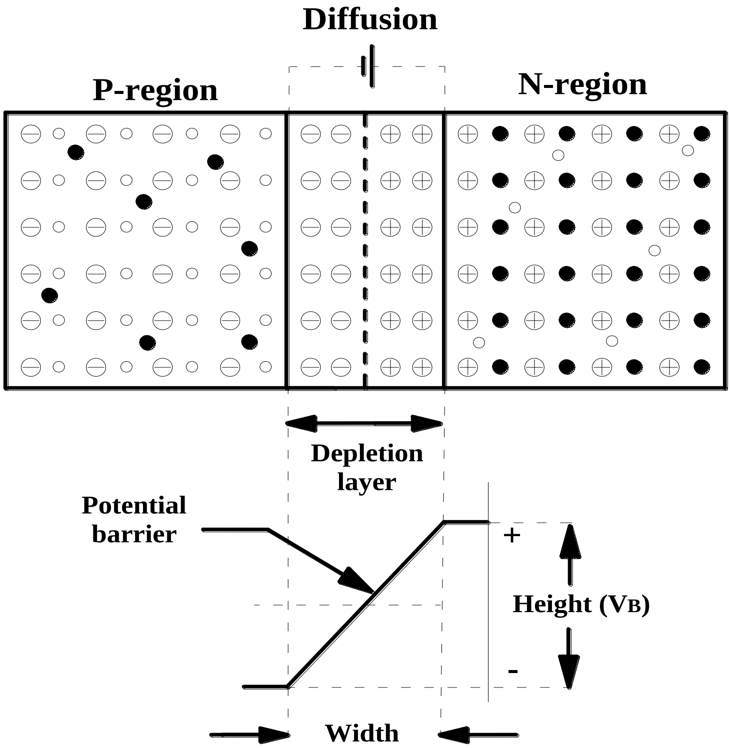


Fig. 6.15

These ions are fixed in the crystal lattice structure and cannot move like free electrons and holes. Thus they make up a layer of fixed charges on the two sides of the junction as shown in fig. 6.15. These charges establish an electric field across the junction directed from the n-region to the p-region. This field produces a potential difference known as a barrier potential or junction barrier V_B which prevents the further diffusion of the charge carriers into opposite regions. The barrier potential V_B represents the height of the barrier (or the potential difference). If the applied voltage is more than the barrier potential, the electrons and holes flow across the junction. The distance from one side of the barrier to the other side is called the width of the barrier. The width of the depletion region and barrier potential V_B depends on the semiconductor and its doping concentration. Typical barrier voltages at 25° C are 0.3 V for Ge and 0.7 V for Si.

Junction diode

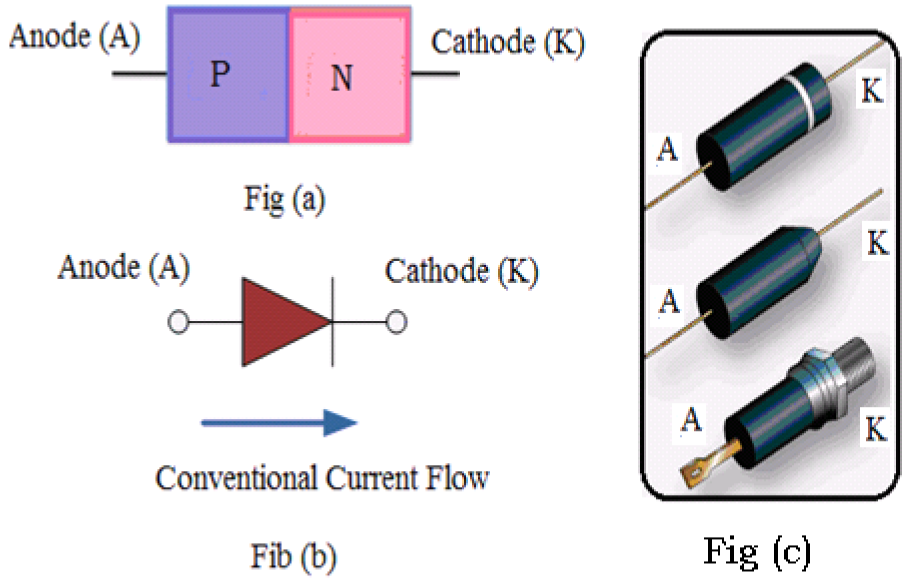


Fig. 6.16

A Junction diode consists of a p-n junction, formed either in a germanium or a silicon crystal. The diode has two terminals namely anode and cathode. The anode refers to a p-region and cathode refers to a n-region as shown in fig. 6.16(a). Its circuit symbol is as shown in fig. 6.16(b). The arrow in the symbol represents the direction of the conventional current flow when the diode is forward biased. It may be noted that the conventional current flow is in the same direction as that of the moment of holes. Fig. 6.16(c) Shows typical diode packages with terminal identification.

Biasing a p-n junction :

When a p-n junction diode is connected to an external source of e.m.f it is said to be biased. The applied voltage is called the bias voltage. The width of the depletion region can be controlled by applying the external voltage source. A p-n junction can be biased in the following two ways.

1. Forward Bias
2. Reverse Bias.

Forward biasing a diode

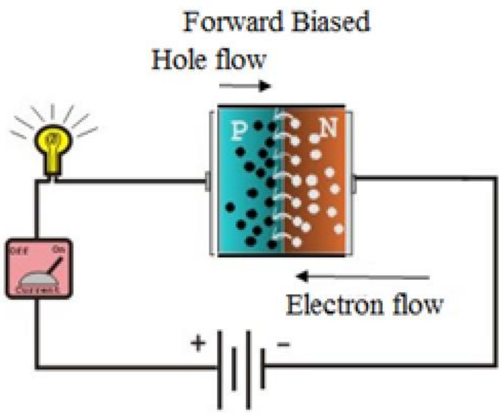


Fig (a)

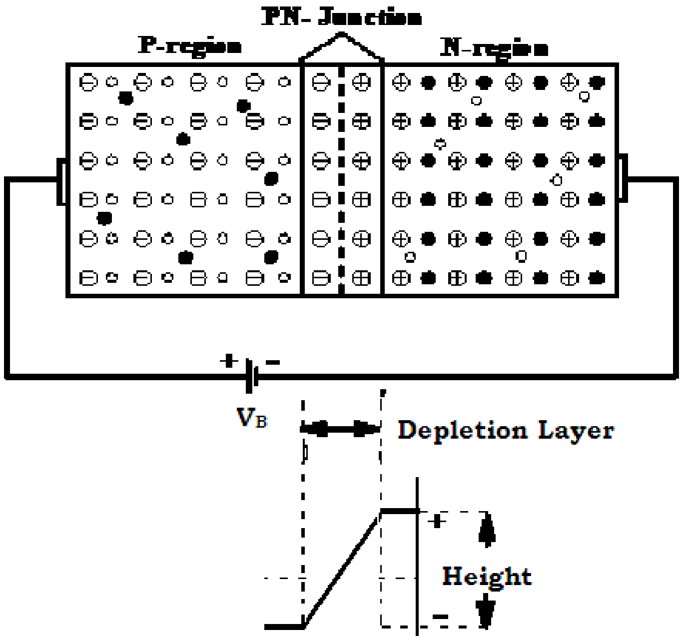


Fig (b)

Fig. 6.17 Forward biased diode

The diode is said to be forward biased when positive terminal of the battery is connected to p-region and negative terminal of the battery is connected to n-region of the diode. Fig. 6.17(a) shows an arrangement of forward biased diode.

Here the forward bias opposes the potential barrier V_B and so the depletion layer becomes thin. When the junction is forward biased, holes in the p-region are repelled from the positive terminal of the battery and are forced to move towards the junction. Similarly, the electrons in the n-region are also repelled by the negative terminal of the battery and are driven towards the junction. This reduces the width and height of the potential barrier (V_B) as shown in fig. 6.17(b). As a result, more majority charge carriers diffuse across the junction.

For every recombination of a free electron and hole that occur in p-region an electron from the negative terminal of the battery enters the n-region.

It then moves towards the junction and one covalent bond is broken in p-region releasing an electron that migrates towards the positive terminal of the battery, that is a new hole appears in p-region and the process continues. Note that there is continuous electron current in the external circuit. However the current in the p-type material is due to the movement of holes, current in the n-type material is due to electrons. Current flows easily in a forward biased diode as long as the applied voltage is greater than the barrier potential (V_B). If the battery potential is further increased, more majority carriers diffuse across the junction, which in turn increases the current. Obviously, the junction offers low resistance in the forward bias.

Reverse biasing a diode

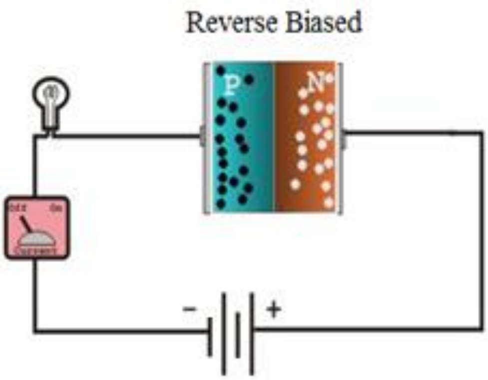


Fig (a)

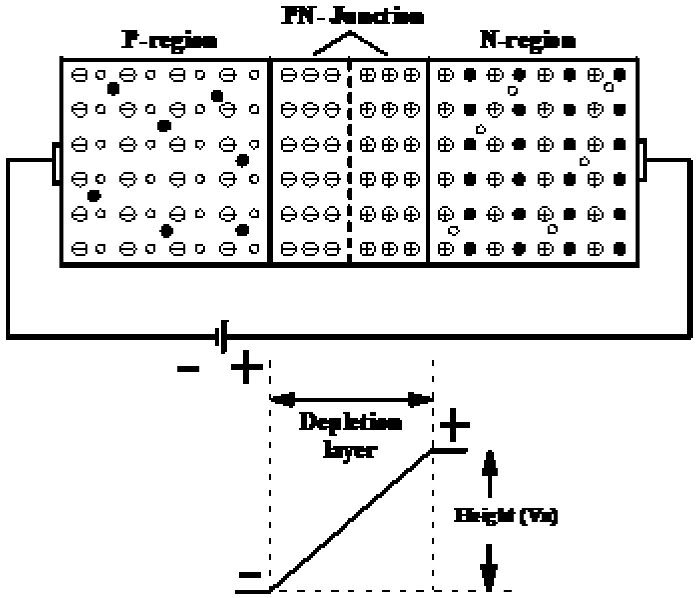


Fig. (b)

Fig. 6.18 Reverse biased diode

The diode is said to be reverse biased when negative terminal of the battery is connected to the p-region and positive terminal of the battery is connected to the n-region of the diode. Fig. 6.18(a) Shows an arrangement of forward biased diode.

Here the direction of the applied voltage is same as that of the direction of the existing barrier potential across the junction. When the junction is reverse biased the holes in the p-region are attracted towards the negative terminal of the battery and the electrons in the n-region attracted towards the positive terminal of the battery. Thus the majority charge carriers are drawn away from the junction. This creates more positive ions in the n-region and more negative ions in the p-region. This action widens the depletion region and increases the barrier potential V_B as shown in fig. 6.18(b) when compared with the unbiased p-n junction. The barrier potential increases with the increase in the applied voltage making it more difficult for the majority charge carriers to diffuse across the junction. Consequently, majority charge carriers are prevented from diffusing across the junction. Hence no current flow through the junction when the diode is reverse biased. Thus the p-n junction offers a very high resistance under the reverse biased condition.

Reverse saturation current (I_s) or leakage current

Increase in reverse bias does not allow the majority charge carriers to diffuse across the junction. However, this potential helps some minority carriers in crossing the junction. Since the minority carriers in the n-region and p-region are produced by thermally generated electron-hole pairs, these minority carriers are extremely temperature dependent and independent of the applied bias voltage. The applied bias voltage acts as a forward bias for these minority carriers and a current of small magnitude flows in the external circuit in the direction opposite to that of the conventional current due to the movement of majority carriers. This current is known as leakage current I_o or reverse saturation current I_s. For silicon it is less than 1μA and for germanium it may exceed 10 μA. I_o is found to double for every 10° C rise for Si and for every 6° C rise in case of Ge. Large minority charge carriers are available in germanium diode when compared to silicon diode.

Reverse breakdown

We have seen that a p-n junction allows a very small current when it is reverse biased. This current is due to the movement of minority carriers. If the reverse bias voltage across the junction is increased to a large value, the reverse current through the junction increases abruptly. The voltage at which the reverse current through the junction increases abruptly is known as reverse break down voltage V_{BR}. At this stage the crystal structure breaks down. Due to this there is a possibility of the device to be destroyed because of overheating. If the excess reverse voltage is removed, the crystal structure can be restored.

Junction capacitance of a diode

When the diode is reverse biased, the existing depletion region exhibits the capacitance property due to immobile ions across the junction known as the junction capacitance of a diode.

Transition capacitance or space charge capacitance (C_T)

In the reverse biased diode the depletion region behaves like a dielectric medium. The depletion width (w) will increase with increased reverse bias voltage. This capacitive effect is called transition or space charge capacitance (C_T). Capacitance 'C_T' is related to width of depletion layer 'w' by the relation

$$C_T = \frac{\epsilon A}{w}$$

Where ϵ = Permittivity of the material,

A = Surface area of the junction,

w = Width of the depletion region.

Since the width of depletion region depends on the amount of reverse bias, capacitance C_T can be controlled with the help of the applied voltage. For a particular diode C_T varies from 80 pF to less than 5 pF as reverse voltage changes from 2 V to 15 V. This feature of the junction capacitance is utilized in varactor diodes.

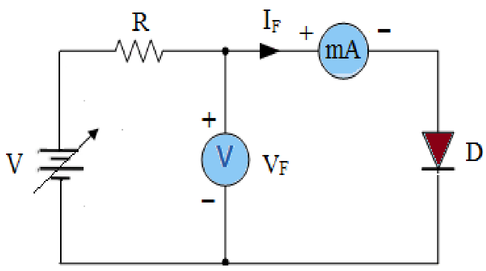
V-I characteristics

The response or behaviour of a p-n junction can be understood with the help of V-I characteristics. The V-I characteristic is a graph of voltage applied across the p-n junction and the current flowing through the p-n junction. An understanding of these graphs helps to know the operation of the device.

The V-I characteristics may be divided into two parts namely

1. Forward characteristics
2. Reverse characteristics.

Forward characteristic of p-n junction diode



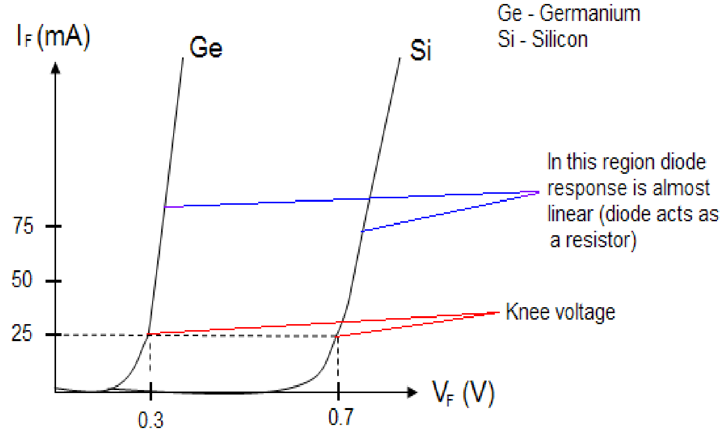


Fig. 6.19

Fig. 6.19(a) shows the circuit for drawing the V-I characteristics of a diode in forward biased condition. The diode is connected to a variable DC source V. Since the current flows easily through a forward biased diode a resistance R included in the circuit to limit the current through it. This current limiting resistor R prevents the forward current from exceeding the permitted value. If forward current I_F exceeds the maximum current rating of the diode, it may get permanently damaged. A voltmeter measures the voltage V_F across the diode. The milliammeter measures the current I_F in the circuit.

Increase the voltage V_F gradually in steps of about 0.1 V and the corresponding forward current I_F are noted. A graph of V_F and corresponding I_F gives the forward characteristic curve as shown in fig. 6.19(b).

From the curve we find that the diode current is zero when V_F is zero. The diode does not conduct well until the applied voltage over comes the barrier potential. When forward voltage is increased above the knee voltage V_k the forward current increases sharply. Even a small increase in the voltage V_F produces a sharp increase in the current I_F.

In the forward bias the voltage beyond which the diode starts conducting rapidly is called as a knee voltage V_k, barrier voltage V_B or cut in voltage. Its value is equal to 0.7 V for silicon and 0.3 V for germanium.

If the forward voltage is increased beyond a certain value an extremely large forward current flows. This can over heat the diode, consequently the diode will be damaged.

The resistance offered by a p-n junction under forward bias is called forward resistance. The forward resistance is defined in two ways.

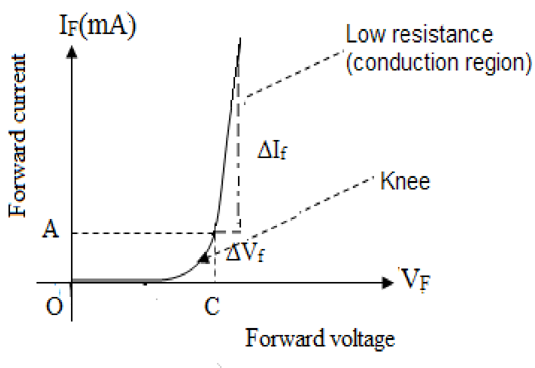
The p-region and n-region both have some resistance. The sum of these resistances is called the bulk resistance of the diode (R_b). This bulk resistance depends on the size of the P and N regions and their level of doping. This resistance has more importance while designing the clipping circuits.

Static forward resistance

Static resistance or DC resistance is the resistance offered by the p-n junction diode when it is used in dc circuit and the applied forward voltage is dc. This resistance is denoted by R_F. It is the ratio of DC voltage across the diode to the resulting DC current flowing through it.

$$R_F = \frac{V_F}{I_F}$$

The static forward resistance can also be obtained from the diode forward characteristic curve as shown in fig. 6.20. For evaluating R_F the portion of the characteristic beyond the knee is considered. In practice this static forward resistance is not used. Instead, the dynamic resistance or AC resistance of the junction is used.



$$R_F = \frac{\text{Forward dc voltage}}{\text{Forward dc current}} = \frac{OC}{OA}$$

Fig. 6.20

Dynamic resistance

The resistance offered by the diode to an AC signal is called its dynamic AC resistance. It is denoted by r_{ac}. AC resistance is defined as the ratio of a small change in the value of forward voltage to the corresponding change in current in the linear portion of the curve.

$$r_{ac} = \frac{\Delta V_f}{\Delta I_f} = \frac{1}{\text{slope}}$$

Reverse characteristic of a p-n junction diode

To obtain the reverse characteristics we use the same circuit as used for forward bias except the diode terminals are reversed and the milliammeter is replaced by a microammeter as shown in fig. 6.21(a).

The reverse voltage is increased gradually till the diode starts conducting and the corresponding reverse currents are noted. On plotting a graph between reverse voltage V_R and reverse current I_R, we get reverse characteristic as shown in fig. 6.21(b).

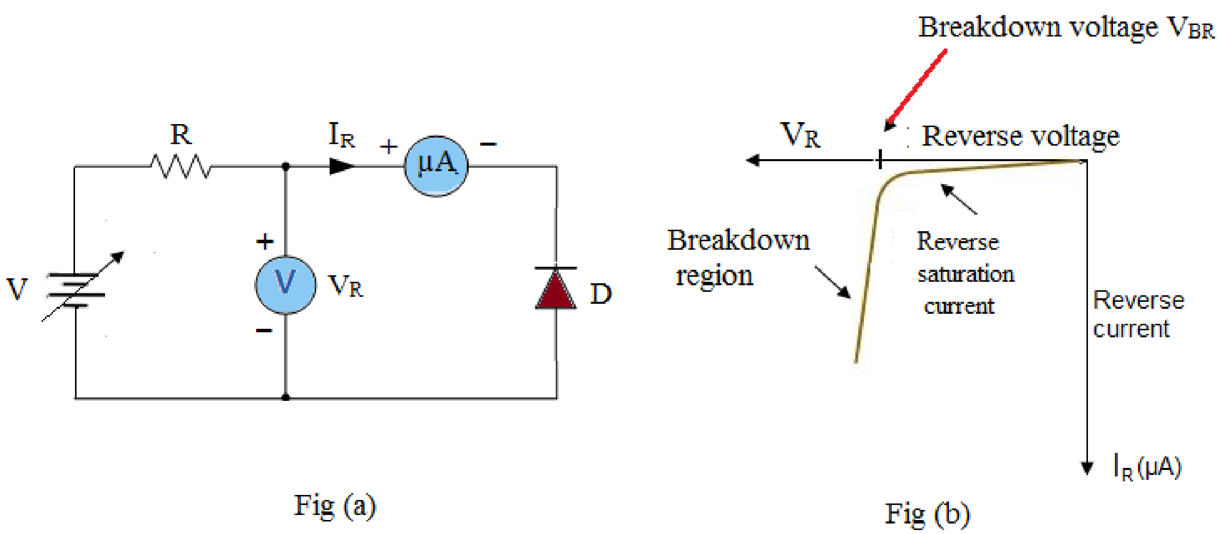


Fig (a)

Fig (b)

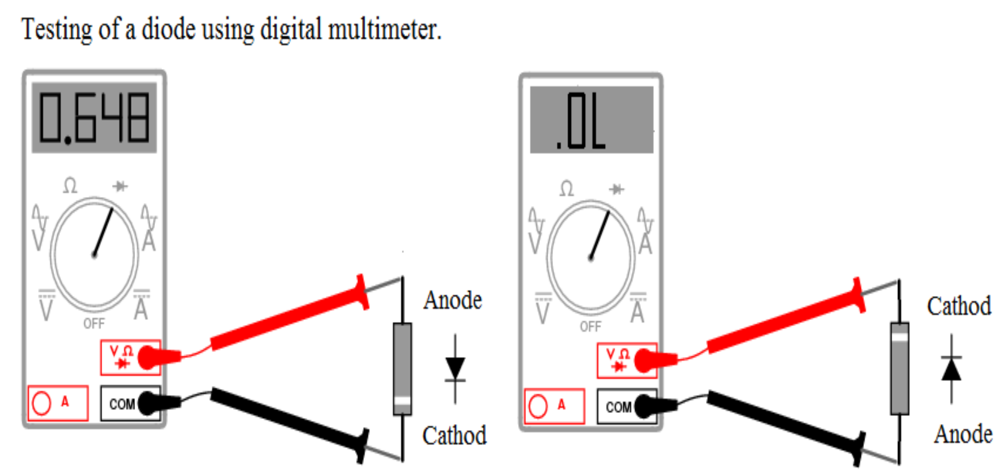
Fig. 6.21

Reverse characteristic curve indicates that, when the applied voltage is below the break down voltage a small constant reverse current (of the order of μA) flows with reverse bias due to minority carriers. This current is called the reverse saturation current (I_s) or leakage current which remains almost constant up to a breakdown voltage V_{BR}.

However, if the reverse bias is increased further, a point is reached where the junction breaks down and the reverse current increases abruptly showing almost zero resistance. In most of the diodes this breakdown is permanent and a diode subjected to this high reverse voltage will be destroyed. Hence when the diodes are operated in the reverse bias, their reverse voltage must be less than the breakdown voltage. This property is used in the construction of Zener diodes used as a voltage regulator. The breakdown in a Zener diode is not destructive due to its special construction.

In motor vehicles diodes are used to allow the current from the alternator to charge the battery when the engine is running. However, when the engine stops, the diode prevents the battery from discharging through the alternator.

Activity: Determine the forward and reverse resistance of a diode using multimeter.



(a) Forward bias (b) Reverse bias

Fig. 6.22

A p-n junction diode can be tested using a digital multimeter. Set the multimeter selector switch in the diode check mode (⯈|). Connect the positive lead of the multimeter to the anode and negative lead to the cathode of the diode as shown in fig. 6.22(a). If multimeter displays resistance of diode, we can assume that the diode is good. This is the test for the diode in a forward bias. Now connect the positive lead of the multimeter to the cathode and negative lead to the anode as shown in fig(b). If the diode is good, multimeter shows OL (Over Load) indicating more resistance in reverse direction.

A defective open diode indicates OL for both the forward bias and reverse bias condition. If a diode is shorted, the meter indicates 0 V in both forward and reverse test.

Diode equation

A diode is one of the simplest semiconductor device, which has the characteristic of passing current in one direction only. However, unlike a resistor, a diode does not behave linearly with respect to the applied voltage. As the diode has an exponential V-I relationship, we cannot describe its operation by simply using an equation of Ohm's law.

The mathematical equation which describes the exact current through a diode, the voltage drop across the junction, the temperature of the junction, and several physical constants is commonly known as the

Diode equation. (or **Shockley's equation**)

$$\text{i.e.,} \qquad I = I_S\left(e^{(V_D/\eta V_T)} - 1\right)$$

Where

I = the diode current,

I_S = the reverse saturation current

V_D = the voltage across the diode

V_T = the thermal voltage and

η = the ideality factor also known as the quality factor or sometimes emission coefficient.

The ideality factor η varies from 1 to 2 depending on the fabrication process and the semiconductor material used in many cases it is assumed to be approximately equal to 1. For Ge diode $\eta = 1$. For Si diode $\eta = 1$ above knee voltage and $\eta = 2$ below knee voltage.

The thermal voltage V_T is defined by

$$V_T = \frac{kT}{q}$$

Where k = The Boltzmann constant = 1.381×10^{-23} JK^{-1}

T = The absolute temperature of the p–n junction

q = The magnitude of charge on an electron

At room temperature (27° C or 300° K) V_T = 26 mV

Diode approximations (Diode equivalent circuits):

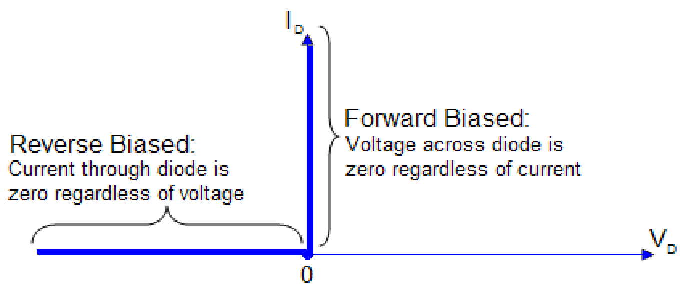
Diode is referred as a non-linear circuit element. For most of the applications non-linear region can be avoided and the device can be modelled by piece-wise linear circuit elements. A convenient method used to represent a diode by a combination of ideal diode and the linear circuit elements is called the diode approximation.

An ordinary switch can acts like an ideal diode, because it has zero resistance when closed and infinite resistance when open.

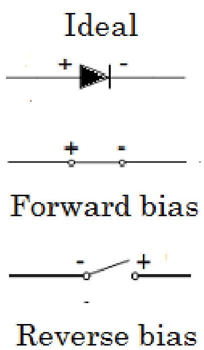
First approximation (Ideal diode)

First approximation of a diode is known as an ideal diode approximation. An ideal diode is a device which conducts with zero resistance (perfect conductor) when forward biased and offers infinite resistance (perfect insulator) when reverse biased. In practice an ideal diode cannot be manufactured. It is only a theoretical approximation of a real diode.

The V-I characteristics of an ideal diode is as shown in fig. 6.23(a). An ideal diode acts as a closed switch when it is forward biased and acts as an open circuit when it is reverse biased as shown in fig. 6.23(b).



(a)



(b)

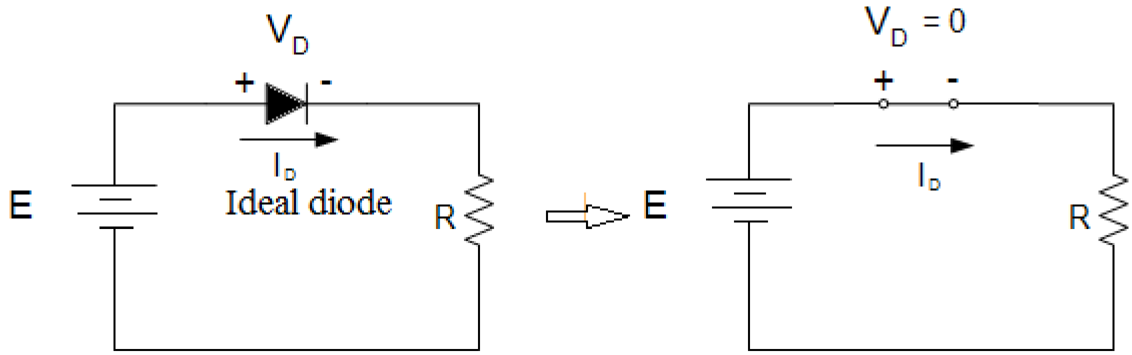


Fig (c)

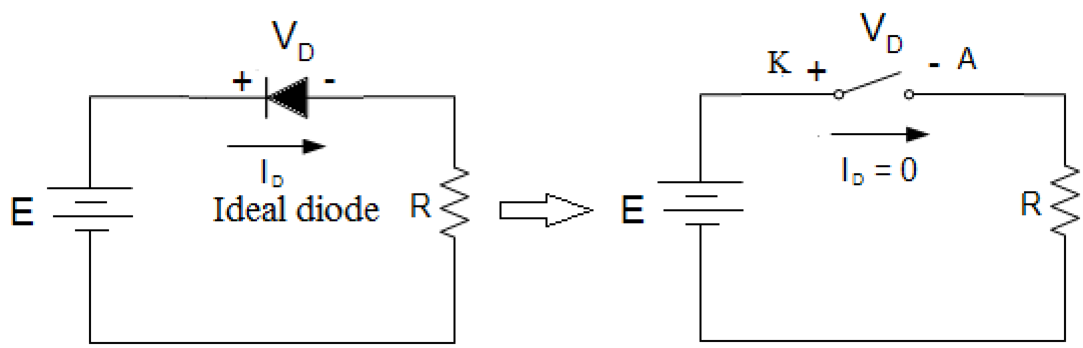


Fig (d)

Fig. 6.23

Fig. 6.23(c) shows a forward biased ideal diode. The current through the diode I_D is given by

$$I_D = \frac{E}{R}$$

Fig. 6. 23(d) shows a reverse biased ideal diode. The voltage across the diode is given by, $V_D = E$.

Second approximation

A semiconductor diode will not conduct current until the forward bias voltage exceeds the knee voltage V_K.

Fig.6.24 (a) shows the graph for the second approximation. The graph shows that current does not flow until 0.7 V for silicon (0.3 V for Ge). Fig. 6.24(b) shows the equivalent circuit of a semiconductor diode. The second approximation treats the diode to acts as a switch in series with a battery of potential V_B. When the applied voltage is greater than V_B then switch closes and the diode voltage is V_B. If the applied voltage is less than V_B the switch opens. Second approximation is used when a more accurate determination of load current and voltage is required.

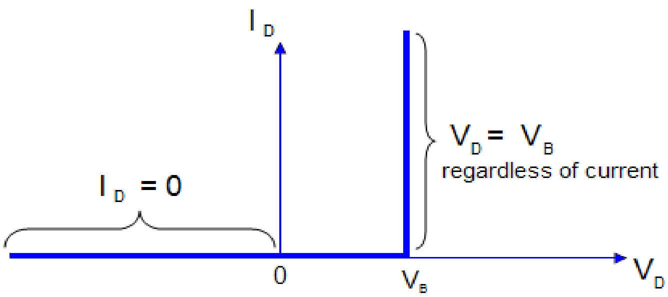


Fig (a)

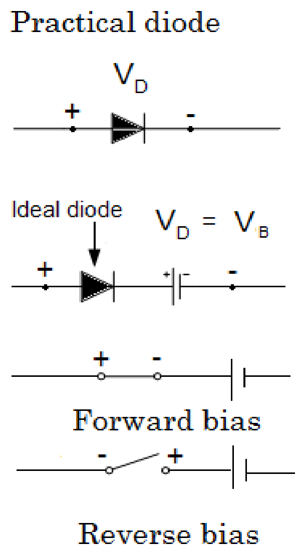


Fig (b)

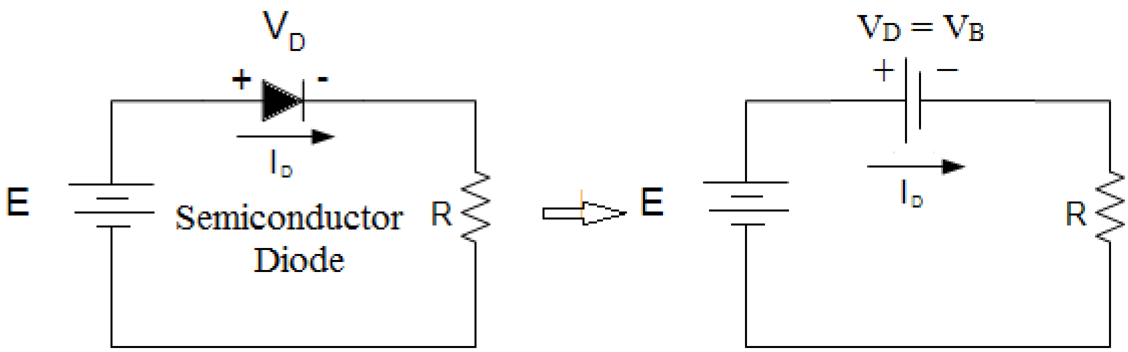


Fig (c)

Fig. 6.24

Consider the forward biased semiconductor diode as shown in fig. 6.24(c).

The current through the diode I_D is given by

$$I_D = \frac{E - V_B}{R}$$

Third approximation

When the diode starts conducting (ON), V_B (0.7 for Si) volt appear across the diode and additional voltage appears across the bulk resistance (R_B). Therefore the total diode voltage is greater than V_B.

Fig. 6.25(a) shows that when the diode turns ON, the current produces a voltage drop across R_B. As R_B is linear, the voltage increases linearly as the current increases. The equivalent circuit for the third approximation is a switch with battery of V_B and a resistor R_B. Therefore the total voltage across the diode is given by,

$$\mathbf{V_D = V_B + I_D R_B}\ .$$

This approximation is used during the original design of the diodes.

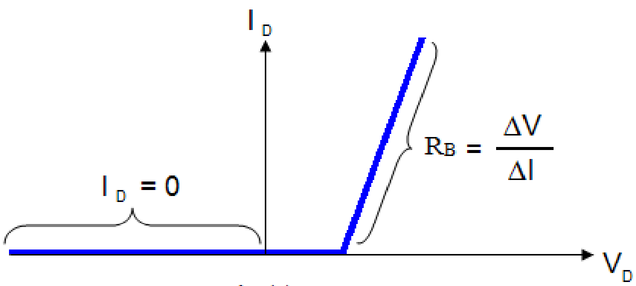


Fig (a)

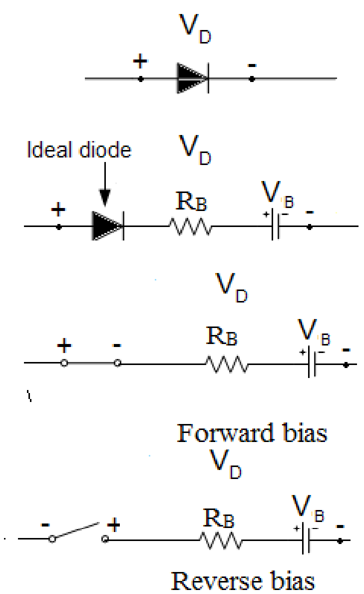


Fig (b)

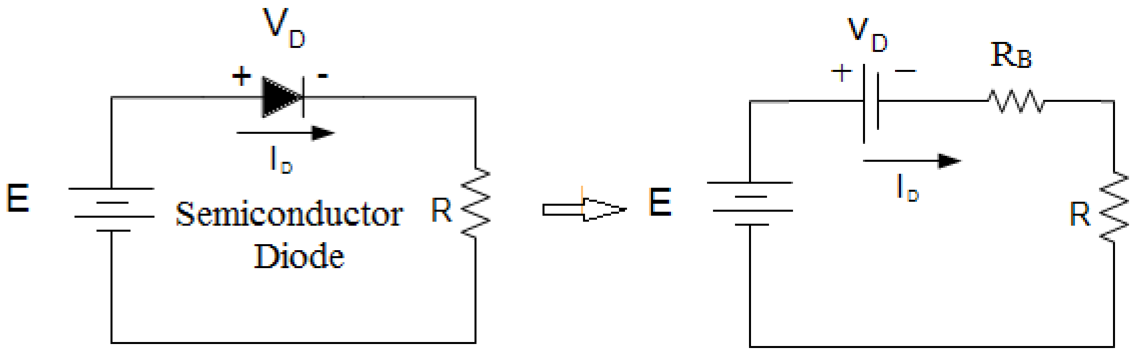


Fig (c)

Fig. 6.25

Consider a forward biased semiconductor diode as shown in fig. 6.25(c). The forward current through the diode is given by

$$I_D = \frac{E - V_D}{R_B + R}$$

Diode Specification

In order to use the diode for a particular application, one must know about its specifications. Some of the important diode specifications are,

1. **Forward current (I_F):** It is the maximum value of forward current a p-junction can carry without damaging.
2. **Forward voltage (V_F):** It is the maximum forward voltage across the diode when it is conducting.
3. **Peak Inverse Voltage (PIV):** It is the maximum reverse voltage applied to the diode without destroying the junction.
4. **Reverse current (I_R):** It is the maximum reverse saturation current at the maximum reverse voltage.
5. **Power rating:** It is the maximum value of power that a diode can dissipate without damaging.

Comparison of Germanium and Silicon diodes

S.No.	Parameter	Germanium diode	Silicon diode
1	Barrier voltage (V_B)	0.3 V	0.7 V
2	Reverse saturation current at 25°C	2 μA	5 nA
3	Power rating	Low	High
4	Maximum safe temperature is	100 °C	170 °C
5	Temperature stability	Poor	Good
6	Peak Inverse Voltage (PIV)	Low (400 V)	High (1200 V)

Applications of a p-n junction diode.

Diodes are used in the following applications

1. Rectifiers or power diodes in DC power supplies
2. AM detector in communication systems
3. FM detector in communication systems
4. Voltage doubler
5. Voltage regulator
6. Voltage tripler
7. Clipper
8. Clamper
9. Tuned diode Oscillator
10. Switch in logic circuits

Exercise:

1. A silicon diode has a bulk resistance of 1.5 Ω and a forward current of 10 mA. What is the forward voltage drop across the diode?

Solution. $V_F = V_B + I_F R_B$

$= 0.7 + (10 \times 10^{-3}) \times 1.5 = 0.715$ V

2. A silicon diode dissipates 2.5 W for a forward current of 1.5 A. Determine the forward voltage drop across the diode and its bulk resistance.

Solution:

$$V_F = \frac{P}{I} = \frac{2.5}{1.5}$$

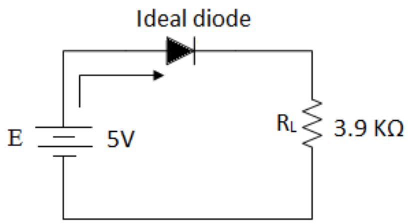
$$V_F = 1.66 \text{ V}$$

$$\text{Forward voltage } V_F = V_B + I_F R_B$$

$$1.66 = 0.7 + 1.5\, R_B$$

$$R_B = 0.64\ \Omega$$

3. Calculate the load voltage and load current for the circuit shown.



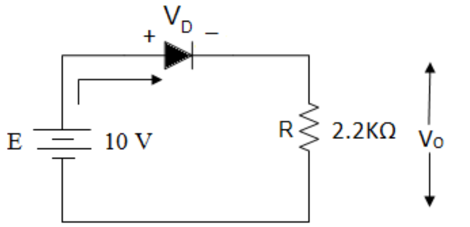
Solution: The ideal diode acts as a short.

$$V_L = E = 5 \text{ V}$$

$$I_L = \frac{E}{R_L} = \frac{5}{3.9 \times 10^3}$$

$$I_L = 1.28 \text{ mA}$$

4. A silicon diode is used in the circuit shown in fig. Determine V_D, V_R and I_D.



Solution. $V_D = 0.7$ V (for silicon)

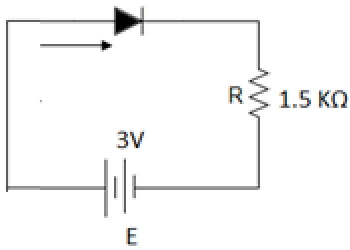
Using equivalent circuit and KVL,

$$V_R = E - V_D$$

$$V_R = 10 - 0.7 = 9.3 \text{ V}$$

$$I_R = \frac{V_R}{R} = \frac{9.3}{2.2 \times 10^3} = 4.22 \text{ mA}$$

5. A circuit using ideal diode is shown in fig. calculate the current in it.

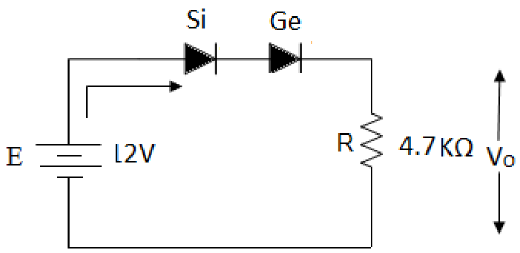


Solution. The diode is forward biased.

Applying Kirchhoff's voltage law, $0 \text{ V} - I_D \times 1.5 \text{ k}\Omega + 3 \text{ V} = 0$

$$I_D = \frac{E}{R} = \frac{3}{1.5 \times 10^3} = 2 \text{ mA}$$

6. For the series diode configuration shown in fig. Determine the current I_D and V_R..



Solution. $V_{D1} = 0.7$ V and $V_{D2} = 0.3$ V, Using equivalent circuit and KVL

$$V_R = E - (V_{D1} + V_{D2})$$

$$V_R = 12 - (0.7 + 0.3) = 11 \text{ V}$$

$$I_R = I_D = \frac{V_R}{R} = \frac{11}{4.7 \times 10^3} = 2.34 \text{ mA}$$

Wave shaping circuits:

Often it is required to change the shape of the signal waveform for the working of an electronic equipment like computer, radar, television receiver etc, It is also necessary to generate one waveform from another circuits which performs this job of producing waves of the desired shape are known as wave shaping circuits. A p-n junction diode is used in non linear wave shaping circuits. Diodes are used to perform the following two important functions

1. Clipping
2. Clamping

The non linear element used in the circuits of clipping and clamping is the diode. Diodes are assumed to be ideal, that is the cut in voltage of the diode is zero.

Clipping circuits.

In many applications we need to limit or control the amplitude of the input signal. Depending on the type of limiting action the circuit is known as limiter or clipper. A circuit used to limit the amplitude of the signal is known as limiter. The function of a clipper circuit is to remove or clip off unwanted portion of the input signal, such circuits are used to protect a device or circuit from damage by a large amplitude signals. One of the most basic clipping circuits is the half-wave rectifier.

A wave shaping circuit used to clip a portion of the input signal without distorting the remaining part of the waveform is called a clipping circuit or clipper.

Series positive clipper

The clipper which removes positive half cycles of the input voltage is called the positive clipper.

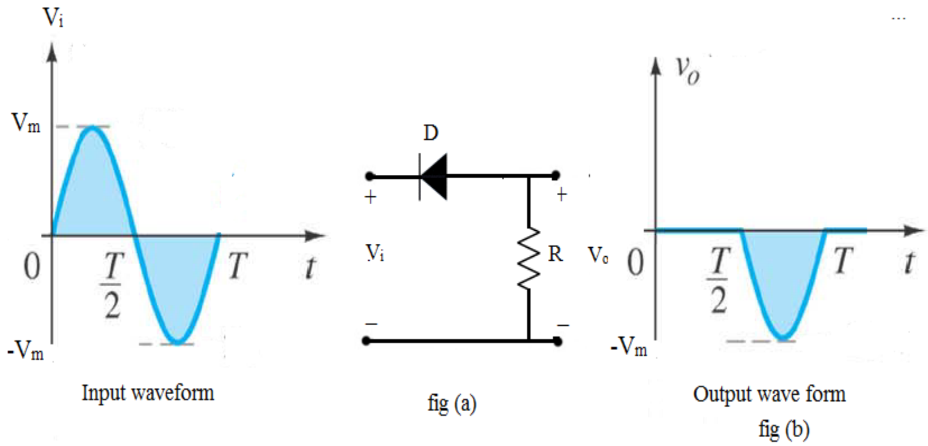


Fig. 6.26

Fig. 6.26(a) shows the circuit of a series positive clipper using a diode D and a resistor R. The purpose of resistor R is to limit the current through the diode when it is forward biased.

During the positive half cycle of the input voltage V_i the diode is reverse biased and acts as an open switch. Hence all the input voltage V_i drops across the diode and none across the resistor R. Consequently output remains at zero and the positive half cycle is clipped off.

During the negative half cycle of the input, the diode is forward biased. Hence it acts like a closed switch across which no voltage is dropped. Thus all the input voltage is dropped across the resistor and hence the negative half cycle appear across the output as shown in fig. 6.26(b).

Series negative clipper

The clipper which removes negative half cycles of the input voltage is called the Negative clipper.

Fig. 6.27(a) shows the circuit of a series negative clipper. Here the diode in connected in a direction opposite to that of a positive clipper. The function of resistor R is to limit the current when the diode is forward biased.

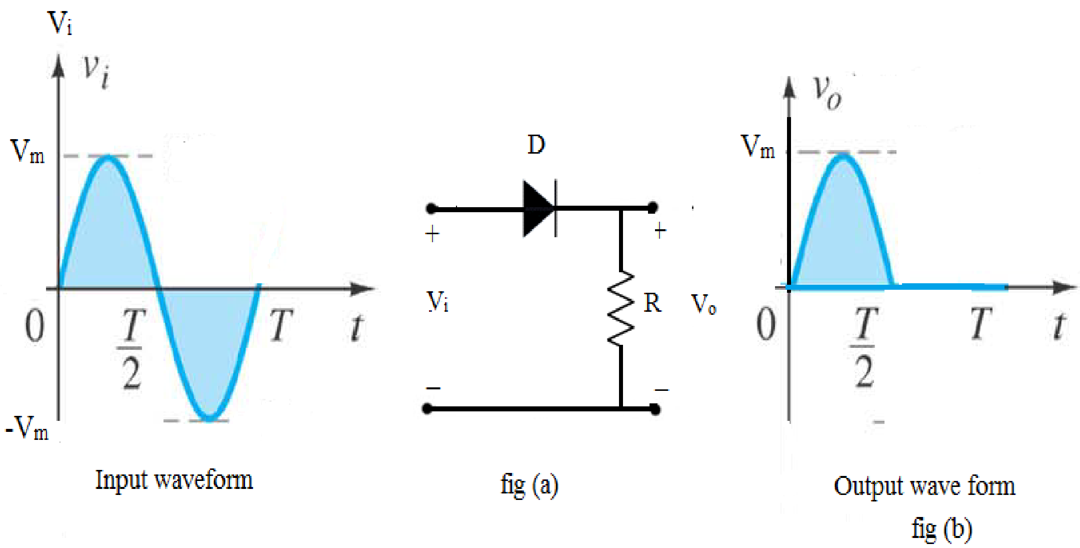


Fig. 6.27

During the positive half cycle of the input voltage V_i, diode D is forward biased and acts as a closed switch. Hence no voltage drops across D. Consequently all the applied input voltage V_i drop across R and hence the positive half cycle appears across the output as shown in fig (b).

During the negative half cycle, the diode D is reverse biased and acts as an open switch. Thus all the input gets dropped across the diode and none across R. Consequently, the output remains at zero and the half cycle is clipped off. The input waveforms to a clipper may be sine, square or any other waveform.

Applications of clipping circuits

They are used

1. In radar and digital computers
2. In radio receivers to remove noise pulses
3. To generate different wave forms such as trapezoidal, square or rectangular waves
4. In FM transmitter as a noise limiter
5. For the protection of sensitive electronic circuits and devices.(moving coil meter or Op-Amp)

Clamping circuits

A circuit which is used to place either the positive peak or negative peak of a signal at a desired dc level is known as a clamping circuit. A clamping circuit (clamper) essentially adds or subtracts a dc component to the signal without changing the shape of the wave form. A clamping circuit basically uses a reactive element like capacitor, active element like resistor and a non linear element like diode.

The following points may be noted regarding clamping circuits

1. A clamper changes the peak value and average value of a waveform where as the frequency remains same.
2. Value of R and C affect the waveform.
3. The discharging time constant of a capacitor should be at least 10 times the period of the input signal.

Positive diode clamper

A circuit which clamps the positive peak of a signal to a desired dc level is called positive clamper.

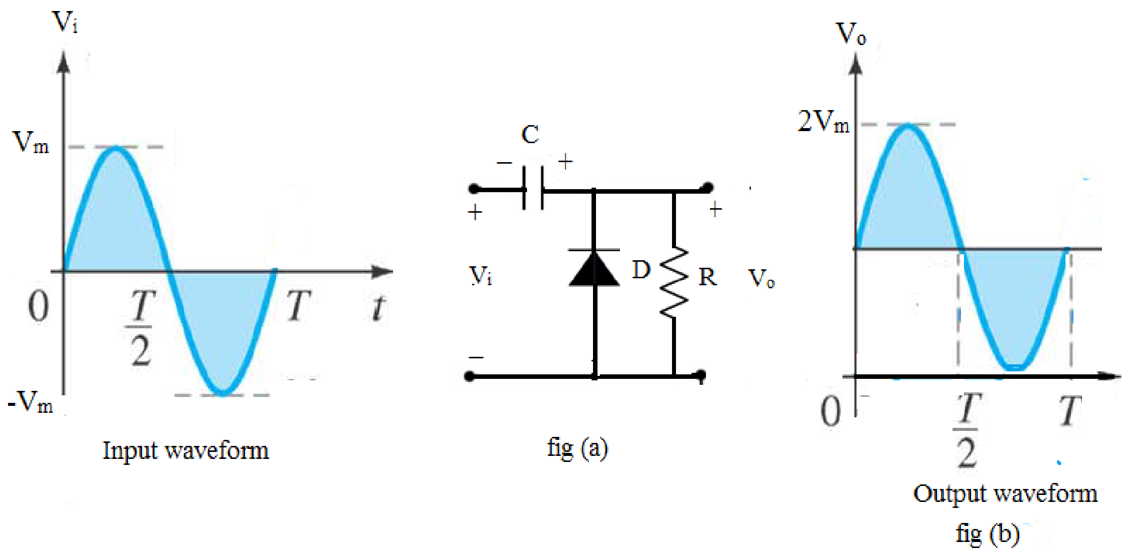


Fig. 6.28

Fig. 6.28(a) shows the circuit of a positive clamper. The discharge path for the capacitor is provided by a resistor R. The values of C and R (τ = CR) are so chosen that the discharge time should be very large. In other words the voltage across the capacitor will not discharge significantly during the non conducting state of the diode.

During the negative half cycle of input V_i, the diode is forward biased and behaves as a short. Thus the resistor R (parallel to D) also gets shorted. Consequently during this negative half cycle the capacitor is charged to V_m. with a polarity as shown in fig. 6.28(b).

During the positive half cycle, the diode becomes reverse biased and acts as an open circuit. Thus there will be no effect on the capacitor voltage. Also R has a very high resistance, so that it cannot discharge significantly during the positive half cycle. Thus the capacitor acts as a battery of voltage V_m. Hence during the positive half cycle, output voltage will be the sum of the input voltage and the capacitive voltage. Since the polarity of the voltage on the capacitor is the same as the input (positive), Hence the peak amplitude of the output is

$$V_{om} = V_m + (V_m) = 2V_m\,.$$

From the output waveform, it is clear that the output has been positively clamped.

Negative diode clamper

A circuit which clamps the negative peak of a signal to a desired dc level is called negative clamper.

Fig. 6.29(a) shows circuit of a negative diode clamper. It consists of a diode D and a capacitor C connected as positive clamper. The only difference in the circuit is that the polarity of the diode is reversed.

During the positive half cycle of the input signal, the diode is forward biased and allows the capacitor C to charge towards the maximum input voltage V_m.

During the negative half cycle, the diode is reverse biased and acts as an open switch. As the discharge time constant of the capacitor is much greater than the time period of the input signal, the capacitor cannot discharge and serves as a battery of voltage $-V_m$. Therefore the output voltage will be equal to the sum of ac input signal and the capacitor voltage $-V_m$. The polarity of the voltage on the capacitor is same as the input (negative), the peak output is given by $V_o = -V_m + (-V_m) = -2V_m$

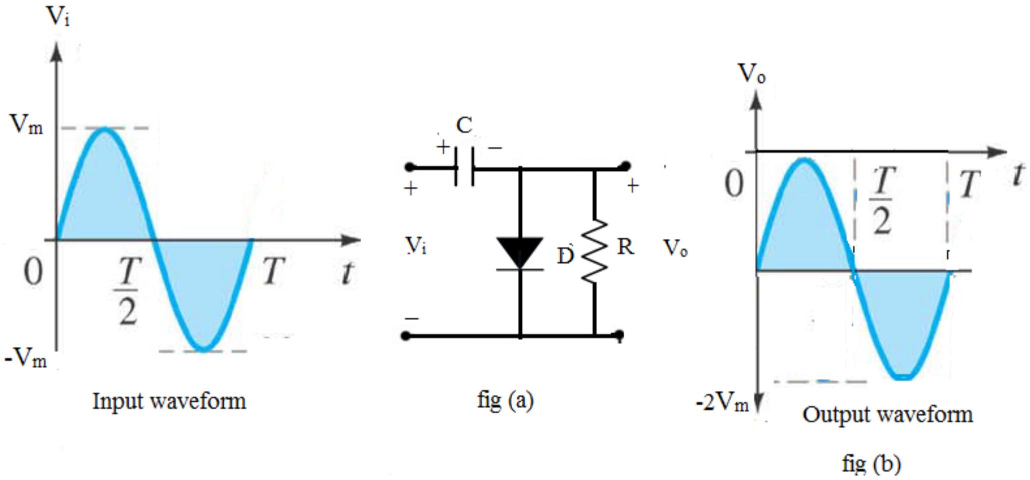


Fig. 6.29

Applications of clamping circuits

They are used

1. In radar and communication circuits.
2. To hold the extreme of the waveform to a particular dc level irrespective of the amplitude of the wave.
3. To change the reference level of video signals in T.V receivers.
4. In analog frequency meter .
5. In capacitance meter.
6. To generate stair case waveform.

RECTIFICATION

The process of converting AC voltage (or current) into a pulsating DC voltage (or current) is known as rectification.

Need for rectification: The electrical power is almost exclusively generated, transmitted and distributed in the form of AC because of its economical consideration. DC supply is required for the operation of most of the electronic devices and circuits. Dry cells and batteries can be used for this purpose but their voltages are low. Nowadays, most of the electronic equipments include the circuit that converts AC to DC. The part of equipment that converts AC to DC is called the DC power supply. The DC power supply consists of transformer, rectifier, filter and voltage regulators.

A circuit which converts AC voltage (or current) into pulsating DC voltage (or current) is called a rectifier.

There are two types of rectifier, they are

1. Half wave rectifier (HWR)
2. Full wave rectifier (FWR)

There are two types in full wave rectifiers

1. Centre-tapped FWR
2. Bridge rectifier

Half Wave Rectifier

A rectifier circuit which rectifies only one half cycles (either positive or negative) of the input AC wave is called half wave rectifier. Fig. 6.30 shows the circuit diagram of a half wave rectifier, which consists of a transformer, diode and load resistor.

During positive half cycle i.e., when **A** is at positive potential the diode is forward biased and conducts because diode acts as a closed switch. A positive half cycle of the voltage is developed across the load resistor **R_L**.

During negative half cycles, when **A** is at negative potential the diode is reverse biased and does not conduct because diode acts as an open switch. Therefore there is no output. The flow of current in the load resistance **R_L** is from **M** to **N**. The output waveform across **R_L** has only positive half cycles.

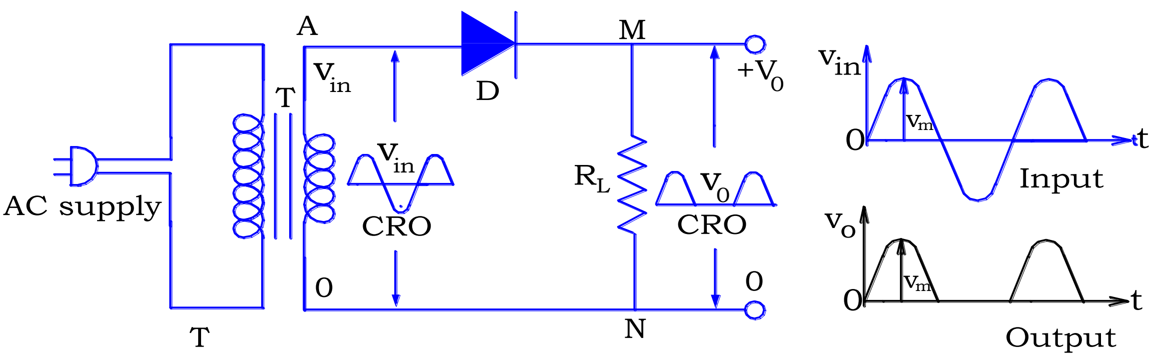


Fig. 6.30 Half wave rectifier

Peak Inverse Voltage (PIV)

PIV is the maximum voltage the rectifying diode can withstand, when it is reverse biased.

During the negative half cycles of the input voltage, the diode is reverse biased, current doesn't flow through the load resistance R_L, hence there is no drop across the load resistance R_L. Consequently the whole of the input voltage appears across the diode. Thus the maximum voltage which appears across the diode is equal to the peak value of the secondary voltage. **PIV = V_m.**

$$\text{Peak current } I_m = \frac{V_{max}}{R_F + R_L}$$

Where R_F is the forward resistance of the diode and R_L is the load resistance.

DC value or Average value

$$V_{av} = V_{dc} = \frac{V_m}{\pi} = 0.318\ V_m$$

Where V_{av} is the average DC voltage across the load and V_m is the peak value of voltage,

$$I_{av} = I_{dc} = \frac{V_{av}}{R_L} = 0.318\ I_m$$

Where I_{av} is the average dc current flowing through the load R_L and I_m is the peak value of current.

RMS value: $\quad V_{rms} = \frac{V_m}{2}$ and $I_{rms} = \frac{V_m}{2R_L} = \frac{I_m}{2}$

Where V_{rms} and I_{rms} are the root mean square values of voltage and current.

Ripple Factor: Ripple factor (γ) is the ratio of the rms value of the AC component of the load voltage to the average value of load voltage.

$$\gamma = \frac{\text{rms value of ac component}}{\text{value of dc component}} = \frac{V_{rms}}{V_{av}} = \sqrt{\left[\frac{I_{rms}}{I_{DC}}\right]^2 - 1} = 1.21 \text{ for HWR}$$

Rectification Efficiency

It is defined as the ratio of dc output power P_{dc} to the ac input power P_{ac}, is given as

$$\eta = \frac{\text{DC power delivered to the load}}{\text{AC input power from the transformer}} = \frac{P_{dc}}{P_{ac}} = 0.406 \text{ or } 40.6\%$$

Full wave rectifier

Rectifier circuit which rectifies both the half cycles of the input AC wave is called as a full wave rectifier.

Centre tapped Full Wave Rectifier

The full wave rectifier circuit which consists of centre tapped transformer, two diodes and a load resistor R_L is shown in Fig. 6.31.

During the positive half cycle, when **A** is at positive potential and **B** is at negative potential, diode $\mathbf{D_1}$ is forward biased and diode $\mathbf{D_2}$ is reverse biased. As a result, $\mathbf{D_1}$ conducts and $\mathbf{D_2}$ does not conduct. A positive half cycle of voltage is developed across the load resistor $\mathbf{R_L}$.

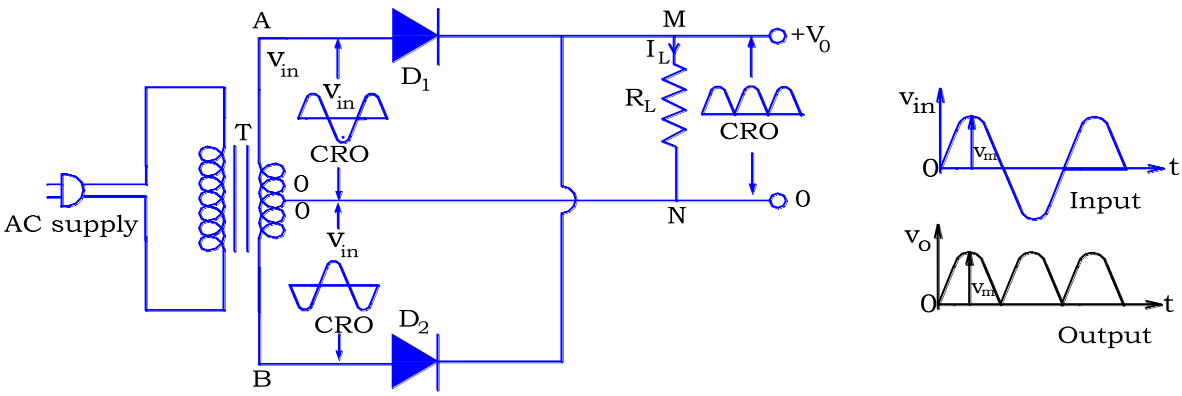


Fig. 6.31 Centre tapped full wave rectifier

During the negative half cycle **A** is at negative potential and **B** is at positive potential, diode $\mathbf{D_2}$ is forward biased and diode $\mathbf{D_1}$ is reverse biased. Now, $\mathbf{D_2}$ conducts and $\mathbf{D_1}$ does not conduct. Again, positive half cycle of voltage developed across the load resistor $\mathbf{R_L}$. But the current in $\mathbf{R_L}$ is always from **M** to **N** for both the half cycle. The average rectified voltage for a full wave rectifier is twice that of the half wave rectifier.

Activity: Study the performance of the circuit shown in fig. 6.31 when the diodes are reversed.

Peak Inverse Voltage

During, first half cycle of the supply, when A is positive, diode D_1 conducts current and offers zero resistance. So, whole of the voltage V_{max} of the upper half winding is developed across the load resistance R_L. Now, voltage across the non conducting diode D_2 is the sum of voltage across the lower half of the transformer secondary and the voltage across the load resistance R_L. Thus PIV of diode $D_2 = V_m + V_m = 2V_m$, Similarly PIV of diode $D_1 = 2V_m$.

Bridge Rectifier

The Bridge rectifier circuit which consists of transformer, four diodes and a load resistor R_L is shown in Fig. 6.32. The four diodes are connected in the form of a bridge. So this rectifier called as bridge rectifier.

During the first half cycle when **A** is at positive potential and **B** is at negative potential, diodes **D_1** and **D_3** are forward biased and conduct. The conducting path is **AD_1MND_3B**. At this time diodes **D_2** and **D_4** are reverse biased and do not conduct. A positive half cycle of voltage is developed across the load resistor **R_L.**

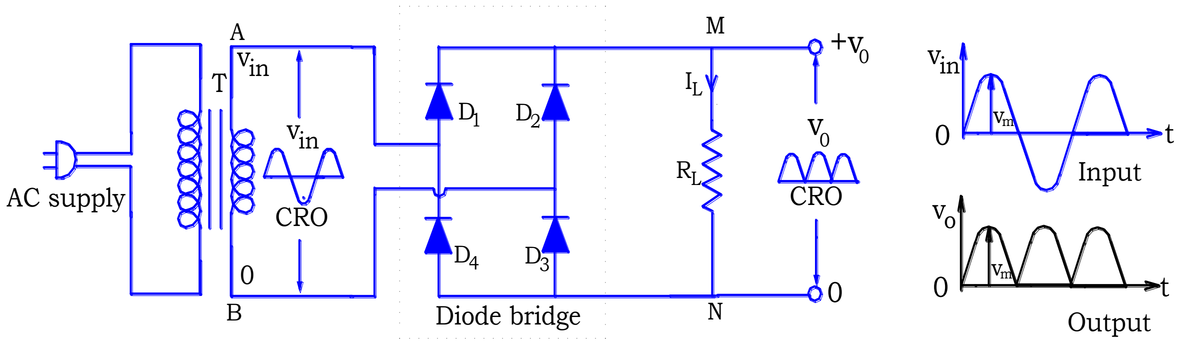


Fig. 6.32. Bridge rectifier

During the next half cycle B is at positive potential and A is at negative potential, diodes **D_2** and **D_4** are forward biased and conduct. The conducting path is **BD_2MND_4A**. At this time diodes **D_1** and **D_3** are reverse biased and do not conduct. A positive half cycle of voltage is developed across the load resistor **R_L.** In both the half cycles current flow through **R_L** is in same direction, that is from **M to N.**

The output wave form across **R_L** has two positive half cycles. The average rectified voltage for a full wave rectifier is twice that of the half wave rectifier.

Peak Inverse Voltage

When A is positive diode D_1 and D_3 are conducting whereas D_2 and D_4 are non conducting being reverse biased. The conducting diodes D_1 and D_3 offers zero resistance. The entire voltage of the transformer secondary winding, V_{max} is developed across the load resistance R_L. The same voltage V_{max} acts across the each non-conducting diodes D_2 and D_4. Thus **PIV = V_m**

Parameters of centre tapped Full wave rectifier and Bridge rectifier

Peak current: Peak value of current flowing through the load resistance R_L in case of centre tapped rectifier is given as

$$\text{Peak current of a centre tapped rectifier } I_m = \frac{V_m}{R_F+R_L}$$

Peak value of current flowing through the load resistance R_L in case of bridge rectifier is given as

$$\text{Peak current for bridge rectifier } I_m = \frac{V_m}{2R_F+R_L}$$

Average Value or DC Value:

$$V_{av} = V_{dc} = \frac{2V_m}{\pi} = 0.636V_m$$

Where V_{av} is the average D.C. voltage across the load and V_m is the peak value of voltage.

$$I_{av} = I_{dc} = \frac{V_{av}}{R_L} = \frac{2V_m}{\pi R_L} = 0.636\, I_m$$

Where I_{av} is the average D.C. current flowing through the load R_L and I_m is the peak value of current.

RMS Value: $V_{rms} = \frac{V_m}{\sqrt{2}}$, and $I_{rms} = \frac{V_m}{\sqrt{2}R_L} = \frac{I_m}{\sqrt{2}}$

Where V_{rms} and I_{rms} are the root mean square value of voltage and current.

Ripple Factor: Ripple factor (γ) is the ratio of the rms value of the AC component of the load voltage to the average value of load voltage.

$$\gamma = \frac{\text{rms value of ac component}}{\text{value of dc component}} = \frac{V_{rms}}{V_{av}} = \sqrt{\left[\frac{I_{rms}}{I_{DC}}\right]^2 - 1} = 0.48 \text{ for FWR}$$

Efficiency: The ratio of the output DC power to the input ac power is called efficiency η, is given by

$$\eta = \frac{\text{DC power delivered to the load}}{\text{AC input power from the transformer}} = \frac{P_{dc}}{P_{ac}} = 0.812 \text{ or } 81.2\%$$

Voltage Regulation

The degree at which a power supply varies in its output voltage under conditions of load variations is measured by the voltage regulation which is usually expressed as percentage. In an unregulated power supply, output voltage changes whenever input supply or load resistance changes. The change in voltage from no-load to full-load condition is called ' voltage regulation'.

$$\text{Percentage regulation} = \frac{V_{NL}-V_{FL}}{V_{FL}} \text{ x } 100\%$$

Where V_{NL} = No-load or open circuit terminal voltage of the supply.

V_{FL} = Full-load terminal voltage of the supply.

Comparison of rectifiers

Particulars	Half wave rectifier	Centre tapped rectifier	Bridge rectifier
1. Number of diodes	1	2	4
2. PIV	V_m	$2V_m$	V_m
3. DC voltage (V_{dc})	$\frac{V_m}{\pi}$	$\frac{2V_m}{\pi}$	$\frac{2V_m}{\pi}$
4. RMS values of voltage (V_{rms})	$\frac{V_m}{2}$	$\frac{V_m}{\sqrt{2}}$	$\frac{V_m}{\sqrt{2}}$
5. RMS values of current (I_{rms})	$\frac{I_m}{2}$	$\frac{I_m}{\sqrt{2}}$	$\frac{I_m}{\sqrt{2}}$
6. Ripple factor (γ)	1.21	0.48	0.48
7. Efficiency (η)	η = 40. 6 %	η= 81.2 %	η = 81.2 %

Negative voltage rectifier

Some circuits like operational amplifiers work with positive and negative power supply together. It is necessary to understand the working of negative voltage rectifiers. Negative rectifier supply is similar to positive rectifier supply. The difference is that the way by which we choose the reference terminal. If the positive terminal of the bridge rectifier already studied in the previous section is made reference or ground terminal and output is taken across the other terminal then the resultant circuit provides negative output voltage. The bridge rectifier is drawn to understand the working of negative voltage rectifier in the fig. 6.33.

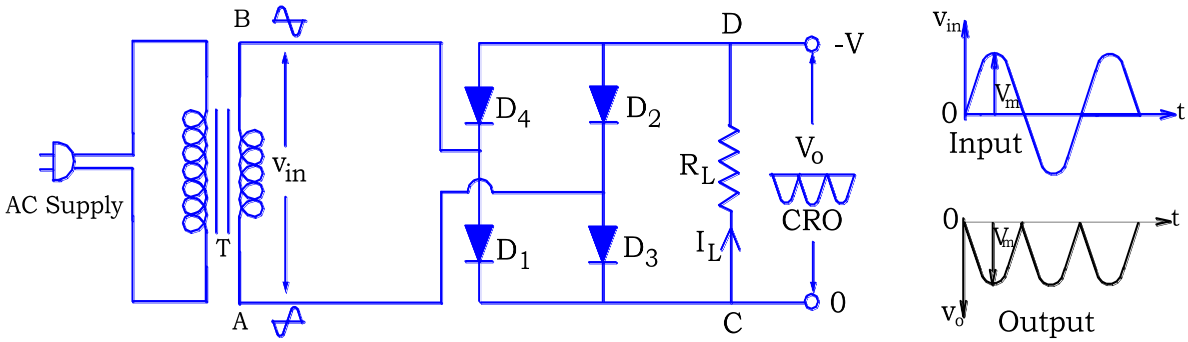


Fig. 6.33 Rectifier to give negative output

Working:

When terminal A become negative with respect to terminal B then diodes D_1 and D_2 are forward biased and conducts, D_3 and D_4 are reverse biased and doesn't conduct. Current flows in the path B-D_1-C-R_L-D-D_2-A. Current in R_L flows from C to D, negative half cycle at terminal A appears across R_L.

When terminal B become negative with respect to terminal A then diodes D_3 and D_4 are forward biased and conducts, D_1 and D_2 are reverse biased and doesn't conduct. Current flows in the path A-D_3-C-R_L-D-D_4-B. Current in R_L flows from C to D, negative half cycle at terminal B appears across R_L. Input and output waveforms are shown in the fig. 6.33.

Output dc voltage is given by $V_{dc} = -\frac{2V_m}{\pi}$

FILTERS

A filter is a circuit which removes the AC component from the rectifier output and allows pure DC to reach the load.

Need for Filters:

The rectifier output of any type is not a pure DC but contains AC component which is undesirable for any electronic equipment. Thus it is obvious that a pure DC is necessary for electronic equipment. In order to remove AC component from the rectifier output, filters are used. Therefore the filter circuit must be placed in between the rectifier and the load.

Series Inductor Filter

The Fig. 6.34 shows a full wave rectifier with series inductor filter. The circuit consists of a low frequency choke in series with load resistor R_L. The fundamental property of an inductor is to oppose any change in current through it. Since the inductor does not allow AC component, it reduces the amplitude of AC with respect to DC component, but in actual practice the output contains a small ripple as shown in the output waveform. The inductance stores energy in the form of magnetic energy and releases it when the output across the load decreases thereby it will have a smoothing effect on the output voltage.

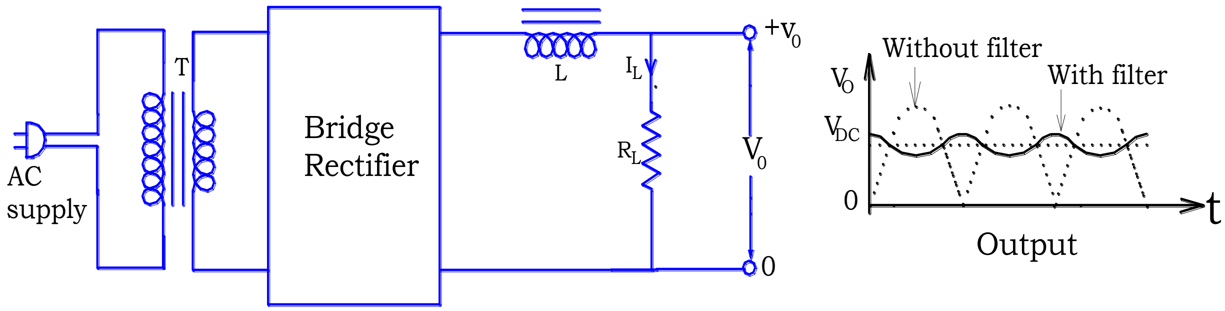


Fig. 6.34 Bridge rectifier with series inductor filter

Shunt capacitor filter

A full wave rectifier with a shunt capacitor filter is shown in Fig. 6.35. The characteristic of a capacitor is to block the flow of DC current and to allow the ripple or AC to flow through it. Therefore, it bypasses the AC component allowing DC to reach the load. Hence the shunt capacitor filter removes most of the AC component.

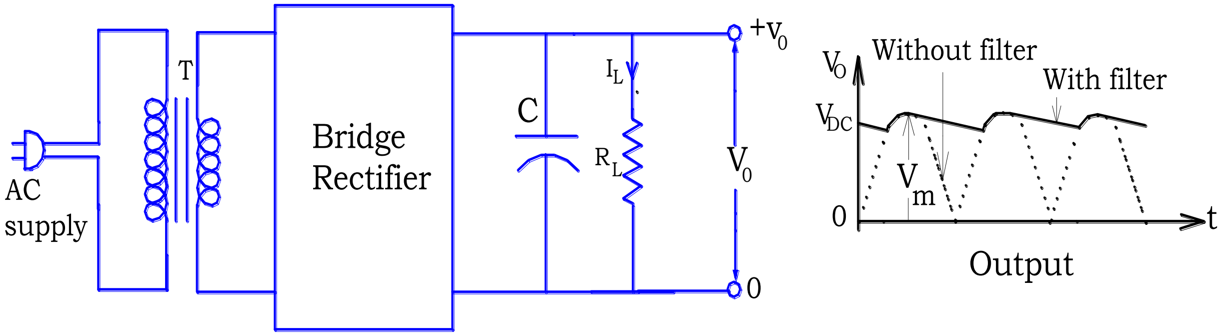


Fig.6.35 Bridge rectifier with shunt capacitor filter

As the rectifier voltage increases, the capacitor gets charged to its maximum value V_m during the positive peak of the rectifier output. When the output voltage of the rectifier begins to decrease, the capacitor discharges through R_L and the voltage across it decrease slowly as shown in the filtered waveform. The discharging time constant depends on value of capacitor C and R_L. Therefore the voltage across the load will decrease slightly because immediately the next voltage peak comes and recharges the capacitor. The process continues for the other cycles and hence ripples can be reduced. The output wave form is shown in fig.6.35.

L-type filter

The fig. 6.36 shows a typical L-type filter. It is a combination of series inductor and a shunt capacitor. This type provides a lower ripple than it is possible with either inductor or capacitor alone. When pulsating output of the rectifier is applied across this filter circuit, the inductor offers high opposition to the passage of AC component and allows DC component. Consequently, the amplitudes of the AC component are reduced by inductor.

AC components are bypassed by the capacitor. The ripples are reduced very effectively when inductive reactance is greater than the capacitive reactance and capacitive reactance is smaller than the load resistance R_L. The circuit works like a DC voltage divider. The output wave form is as shown in fig. 6.36.

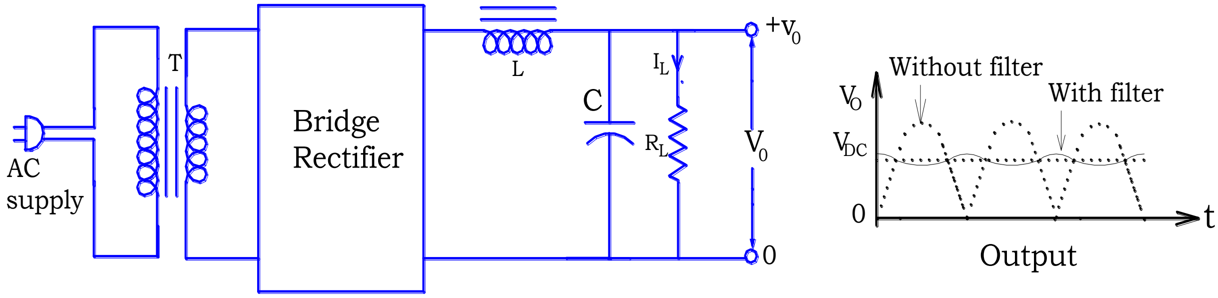


Fig. 6.36 Bridge rectifier with L-Type filter

Bleeder resistor

The operation of an inductor filter is based on the fact that a minimum current must flow through it at all times. To provide the flow of this minimum current at all times through the choke, a resistor called the bleeder resistor (R_B) is placed across the filter output, as illustrated in fig. 6.37. Bleeder resistor is used to maintain a certain minimum current through the choke: even when the load resistor R_L gets open-circuited, and improves the filtering action. The value of a bleeder resistance should be such as to draw only 10% of total load current. The bleeder resistor can serve a number of functions as given below.

1. It improves voltage regulation of the supply.
2. It provides safety to the technicians handling the equipment. When the power supply is switched off, it provides a path for the filter capacitor to discharge through. Without it, the capacitor will retain its charge for quite some time even when the power supply is switched off.

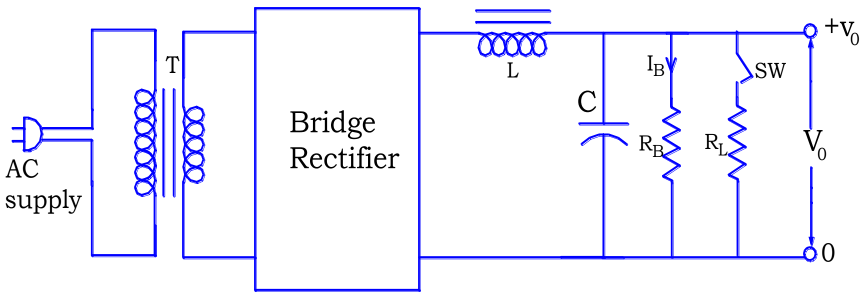


Fig. 6.37 DC power supply with bleeder resistor

Exercise:

1. A half wave rectifier uses a diode with a forward resistance of 50 Ω. If the input ac voltage is 200 V rms and the load resistance is of 1 kΩ, determine
   (i) I_m, I_{dc} and I_{rms}
   (ii) Peak inverse voltage when the diode is ideal
   (iii) Load output voltage
   (iv) DC output power and ac input power
   (v) Ripple factor
   (vi) Rectification efficiency.

Solution:

RMS value of supply voltage, $V_{rms} = 200$ V

Maximum value of supply voltage, $V_m = V_{rms} \times \sqrt{2} = 200 \times \sqrt{2} = 282$ V

Forward resistance, $R_F = 50\ \Omega$

Load resistance, $R_L = 1$ kΩ

(i) Maximum value of current, $I_m = \frac{V_m}{R_F + R_L} = \frac{282}{50+1000} = 0.269$ A

Average value of output current, $I_{dc} = \frac{I_m}{\pi} = 0.085$ A

RMS value of output current; $I_{rms} = \frac{I_m}{2} = 0.134$ A

(ii) Peak inverse voltage, PIV = V_m = 282 V

(iii) Load output voltage, $V_{dc} = I_{dc}R_L = 0.085 \times 1000 = 85$ V

(iv) DC output power, $P_{dc} = I^2_{dc}R_L = (0.085)^2 \times 1000 = 7.225$ W

AC input power, $P_{ac} = I^2_{rms}(R_F + R_L) = (0.134)^2 \times (50 + 1000) = 18.85$ W

(v) Ripple factor, $\gamma = \sqrt{\left[\frac{I_{rms}}{I_{DC}}\right]^2 - 1} = \sqrt{\left[\frac{0.134}{0.085}\right]^2 - 1} = 1.21$

(vi) Rectification efficiency $\eta = \frac{P_{dc}}{P_{ac}} \times 100 = \frac{7.225}{18.85} \times 100 = 38.32$ %

2. A center tapped transformer has a 230 V primary winding and a secondary winding rated at 15 V-0-15 V and is used in a full wave rectifier circuit with a load of 120 Ω. What is the dc output voltage, dc load current and the PIV rating required for diodes?

Solution:

Peak supply voltage, $V_m = V_{rms} \times \sqrt{2} = 15 \times \sqrt{2} = 21.21$ V

Load resistance $= 120\ \Omega$

DC output voltage, $V_{dc} = \frac{2V_m}{\pi} = 13.5$ V

DC load current, $I_{dc} = \frac{2I_m}{\pi} = \frac{2V_m}{\pi R_L} = \frac{2 \times 21.21}{\pi \times 120} = 0.11$ A

PIV rating of diodes $= 2V_m = 2 \times 15\sqrt{2} = 42.43$ V.

3. A 230 V, 50 Hz AC voltage is applied to the primary of 5:1 step down transformer, which is used in bridge rectifier, having a load resistance of 100 Ω. Assuming the diodes to be an ideal, determine the following:
(i) DC output current (ii) DC output voltage (iii) DC power delivered to the load and (iv) PIV of each diode.

Solution:

V_{rms} = RMS value of output voltage of transformer $= \frac{230}{5} = 46$ V

Peak supply voltage, $V_m = V_{rms} \times \sqrt{2} = 65.05$ V

Load resistance $= 100\ \Omega$

(i) Dc load current, $I_{dc} = \frac{2I_m}{\pi} = \frac{2V_m}{\pi R_L} = \frac{2 \times 65.05}{\pi \times 100} = 0.41$ A

(ii) DC output voltage, $V_{dc} = \frac{2V_m}{\pi} = \frac{2 \times 65.05}{\pi} = 41.4$ V

(iii) DC output power delivered to load,

$$P_{dc} = I_{dc}^2 R_L = (0.41)^2 \times 100 = 16.8 \text{ W}$$

(iv) PIV rating of diodes $= 2V_m = 2 \times 65.05 = 130.1$ V

4. The DC voltage supply provides 50 V when the output is unloaded. When connected to a load the output drops to 46 V. Calculate the value of voltage regulation.

Solution:

No load voltage , V_{NL} = 50 V

Full load voltage, V_{FL} = 46 V

$$\text{Percentage regulation} = \frac{V_{NL}-V_{FL}}{V_{FL}} \times 100\% = \frac{50-46}{46} \times 100\% = 8.69\%$$

Special Diodes :

There are a number of two terminal semiconductor devices having a single p-n junction like the semiconductor diode, but they are different from one another based on their operation, application etc. They are,

1. Zener diode
2. Light emitting diode
3. Varactor diode
4. IR emitter diode
5. Photo diode
6. Tunnel diode
7. Schottky diode

Zener diode

Zener diode is a special purpose semiconductor diode always used in reverse bias with a specific reverse breakdown voltage. It is named after C.A. Zener who analyzed the voltage breakdown of insulators. Silicon is preferred over germanium because of its higher temperature and current capability. The breakdown or Zener voltage (V_Z) depends upon the amount of doping. Breakdown occurs due to both Zener effect and avalanche effect.

Zener diode is a heavily doped semiconductor diode. Since doping level is high, the p-n junction becomes narrow and thereby the electric field in the depletion layer increases. When the reverse bias is increased, the electric field at the junction becomes large enough to break covalent bonds and generate electron hole pairs. Consequently reverse current rises abruptly. Such a phenomenon is called Zener breakdown. The process by which covalent bonds in the depletion region are directly broken by a strong electric field is called

Zener breakdown. The reverse voltage at which the Zener breakdown takes place is called Zener breakdown voltage. By varying the amount of doping, it is possible to produce Zener diodes with breakdown voltages from about 2 V to 200 V.

A Zener diode is also called as a voltage reference, voltage regulator or breakdown diode. The schematic symbol and its equivalent circuit are as shown in fig. 6.38.

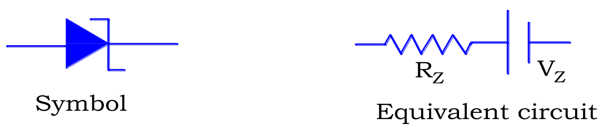


Fig.6.38 Zener diode symbol with equivalent circuit

Avalanche breakdown and Zener breakdown

If the reverse bias of a p-n junction is made high, at a certain voltage the junction breaks down and the current through the junction increases sharply. The voltage at which this phenomenon occurs is called breakdown voltage. The breakdown voltage depends on the doping level. There are two processes by which breakdown occurs. They are:

1. Avalanche breakdown
2. Zener breakdown

Avalanche breakdown

This type of breakdown occurs in lightly doped diodes. Lightly doped diodes have wide depletion region. The increased reverse voltage increases the velocities of minority charge carriers (thermally generated). These highly accelerated carriers collide with the atoms in the depletion region. The covalent bonds are broken and new electron hole pairs are generated. These new minority carriers also pick up sufficient energy from the applied field, collide with other atoms and generate more charge carriers. This process is cummulative and a large number of carriers are generated. This causes a high reverse current to flow. This mechanism of breakdown is known as avalanche breakdown.

Zener breakdown

This type of breakdown occurs in heavily doped diode. Heavily doped diode has narrow depletion layer. When the reverse voltage is increased, a very strong electric field is developed across the junction. High electric field at the junction breaks covalent bonds and generates large number of electron hole pairs. Therefore the diode conducts heavily. Even a small increase of reverse voltage produces a large reverse current. At breakdown, the junction has a very low resistance. This phenomenon is called Zener breakdown.

V-I Characteristics of Zener Diode

There are two types of characteristic curves, they are Forward bias and Reverse bias.

The forward bias characteristic of Zener diode is similar to that of an ordinary forward biased p-n junction diode. However when the diode is reverse biased, a small current flows and remains practically constant until the Zener voltage V_Z is reached. As soon as the applied reverse voltage reaches the Zener voltage of the diode, the reverse current abruptly increases to a very high value.

The V-I characteristics are as shown in fig. 6.39.

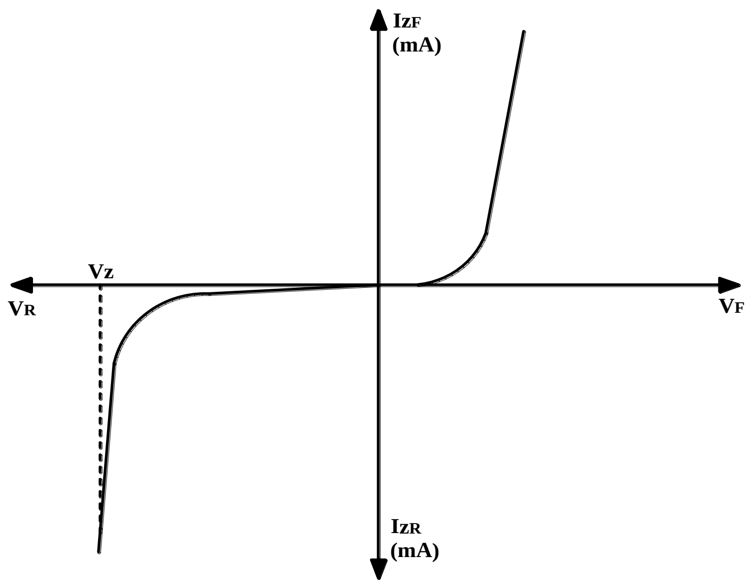


Fig. 6.39

From the above characteristics curve, in the reverse bias, current is independent of the reverse voltage. The maximum current I_Z (max) is the maximum reverse current flowing through the device without damaging the junction. The region between zero and breakdown voltage is called leakage region. At breakdown voltage, the reverse current increases sharply. The breakdown has a sharp knee followed by almost a vertical increase in current. The voltage is almost constant and approximately equal to V_Z.

For normal operation the current through the Zener diode should be less than the maximum reverse current I_Z (max). If the current is greater than I_Z (max), the diode will be destroyed because of excessive power dissipation. Therefore a current limiting resistor must be used to operate the diode within its safe range.

Zener Diode applications

1. It is used as a voltage regulator in DC power supplies.
2. As fixed reference voltage in transistor biasing circuit.
3. In clippers or limiters and in wave shaping circuits.

Zener Diode as a Voltage Regulator

A Zener diode can be used as a voltage regulator (stabilizer) to provide a constant output voltage from a source whose voltage may vary over a sufficient range. The Zener diode also maintains a constant output voltage V_Z across the load with variations in load current.

The two types of voltage regulators using Zener diode are as follows :

1. Variable input voltage (V_S) and fixed load resistor (R_L) – Line Regulation.
2. Variable load resistor (R_L) and fixed input voltage (V_S) – Load Regulation.

Line Regulation

The circuit diagram for the above regulator is as shown in the fig. 6.40.

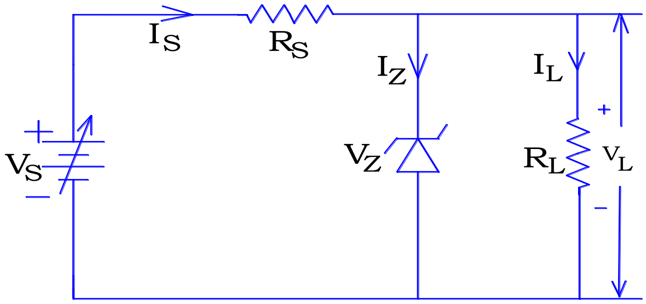


Fig. 6.40 Zener diode line regulator

When the V_S is increased from 0 V, current through the load resistance increases linearly with the applied voltage. The Zener diode does not conduct until the Zener breakdown voltage is reached. Therefore current through Zener diode I_Z is almost zero (only leakage current). If the input voltage is increased further above the Zener breakdown voltage, the Zener diode breaks down and conducts. Further increase in the input voltage, constant voltage is maintained at the output (since $V_Z = V_L$). The voltage fluctuations are adjusted with the series resistor R_S. Once V_S is greater than V_Z, V_L is maintained at a constant value. This type of regulation is called as line regulation.

Load Regulation

The circuit arrangement is as shown in the fig. 6.41.

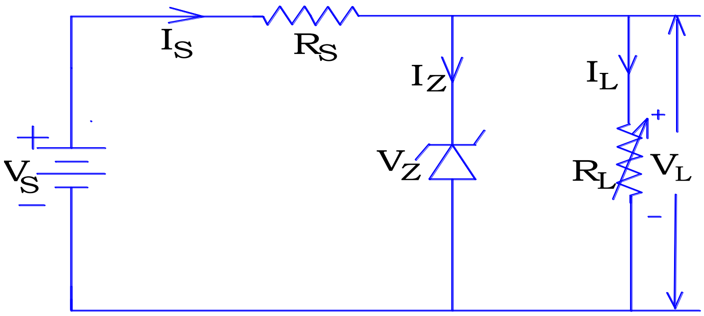


Fig. 6.41 Zener load regulator

This type of regulation can be achieved by placing V_S greater than V_Z. Here V_S is kept constant and the load resistance R_L is varied. If R_L is decreased, current

I_L increases and simultaneously I_Z decreases, but the output voltage $V_L(=V_Z)$ remains constant. If R_L is increased current I_L decreases and simultaneously I_Z increases, but the output voltage $V_L(=V_Z)$ remains constant. Thus the output voltage V_L is at a constant value. This type of regulation is called load regulation.

Calculation of minimum load resistance, R_L (min)

When the Zener diode operates in the breakdown region, the load voltage is constant and is equal to V_Z. The minimum value of load resistance required to maintain V_L constant at V_Z can be calculated as follows:

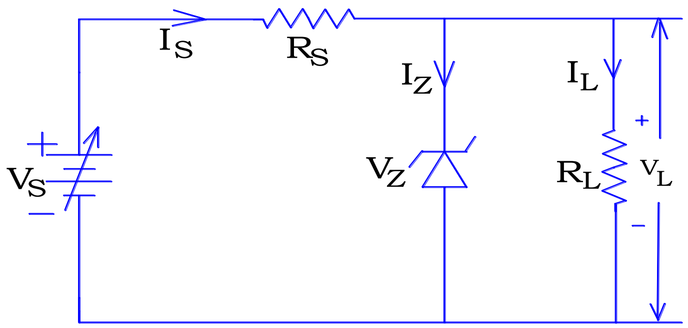


Fig. 6.42

From the fig.6.42 $V_Z = V_L$ is found by applying Thevenin's theorem :

$$V_L = V_Z = V_{TH} = \frac{V_S \text{ x } R_L}{R_L + R_S}$$

To maintain the output voltage constant for minimum load resistance, then V_S is greater than V_Z, replace R_L by R_L(min) and solving for R_L(min).

We have, $V_Z = \dfrac{V_S \text{ x } R_{L(min)}}{R_{L(min)} + R_S}$

Solving for R_L(min) we have, $R_L(min) = \dfrac{R_S \text{ x } V_Z}{V_S - V_Z}$

The above equation is suitable only when the input voltage V_S is greater than V_Z.

Optimum value of current limiting resistor

The value of R_S must be properly selected to fulfill the following requirements:

When the input voltage is minimum and the load current is maximum, sufficient current must be supplied to keep the Zener diode within its regulating region. The optimum value of R_S can be found by using the following equations:

$$I_Z(\max) = \frac{V_{S(\max)} - V_Z}{R_S} - I_{L(\min)}$$

$$I_Z(\min) = \frac{V_{S(\min)} - V_Z}{R_S} - I_{L(\max)}$$

Minimum value of R_S makes the current flow in the Zener diode maximum and vice versa,

$$\text{Therefore,}\quad R_S(\min) = \frac{V_{S(\max)} - V_Z}{I_{Z(\max)} + I_{L(\min)}}$$

$$R_S(\max) = \frac{V_{S(\min)} - V_Z}{I_{Z(\min)} + I_{L(\max)}}$$

Hence the value of R_S should be so chosen that $R_S(\min) < R_S < R_S(\max)$.

Percentage regulation

Regulation is expressed as a percentage. It is a figure of merit used to specify the performance of a voltage regulator.

Line regulation

It is defined as a change in the output voltage (ΔV_L) for a given change in the input voltage (ΔV_S) expressed as a percentage. i.e.,

$$\text{Percentage of line regulation} = \frac{\Delta V_L}{\Delta V_S} \times 100\%$$

Load regulation

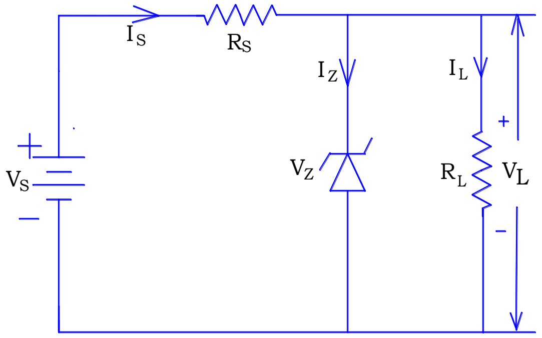
It is defined as a change in the output voltage over a certain range of load current values, usually from minimum current (no load) to maximum current (full load). It is also expressed as a percentage.

$$\text{Percentage of load regulation} = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100\%$$

Where V_{NL} is the output voltage with no load and V_{FL} is output voltage with full load (maximum current).

Worked examples

1. Determine the minimum value of R_L that will turn the Zener diode on in the Zener regulator circuit in fig. below. $V_S = 10$ V, $R_S = 1$ kΩ, $V_Z = 6$ V



Solution; Given $V_S = 10$ V, $R_S = 1$ kΩ, $V_Z = 6$ V

$$R_L(min) = \frac{R_S \times V_Z}{V_S - V_Z} = \frac{1000 \times 6}{10-6} = 1.5\ k\Omega$$

2. For the Zener diode voltage regulator with $V_S = 20$ V, $R_S = 100$ Ω, $V_Z = 12$ V, $R_L = 680$ Ω determine
    a. Load voltage
    b. Voltage drop across series resistance R_S
    c. Current through the Zener diode

Solution; Given $V_S = 20$ V, $R_S = 100$ Ω, $V_Z = 12$ V, $R_L = 680$ Ω

$$\text{We have } R_L(min) = \frac{R_S \times V_Z}{V_S - V_Z} = \frac{100 \times 12}{20-12} = 150\ \Omega$$

Since $R_L > R_L(min)$, the Zener diode is on (Zener diode is operated in breakdown region), Therefore,

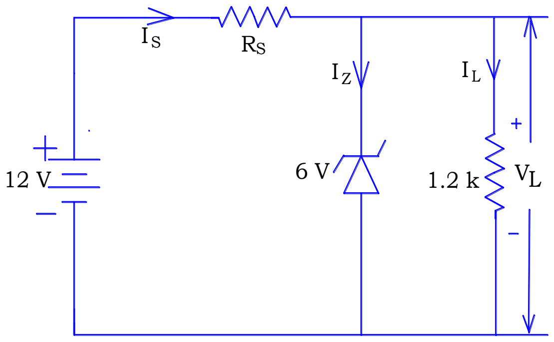
a) load voltage = voltage across Zener V_Z i.e., $V_L = V_Z = 12$ V
b) the voltage across R_S is $V_{RS} = V_S - V_Z = 20 - 12 = 8$ V
c) I_S is the current through R_S, given by $I_S = I_L + I_Z$

$$I_S = V_{RS}/\ R_S = 8/100 = 80 \text{ mA}$$

$$I_L = V_L/\ R_L = 12/680 = 17.65 \text{ mA}$$

$$I_Z = I_S - I_L = 80 \text{ mA} - 17.65 \text{ mA} = 62.35 \text{ mA}$$

3. In the circuit shown in fig. find the value of series resistance R_S, if Zener current is 10 mA.



Solution: Given $V_S = 12$ V, $V_Z = 6$ V, $R_L = 1.2$ kΩ

$$V_L = V_Z = 6 \text{ V}$$

$$I_L = V_Z\ /\ R_L = 6/(1.2 \times 1000) = 5 \text{ mA}$$

$I_Z = 10$ mA, the current through R_S is $I_S = I_Z + I_L$

$$I_S = (10 \times 10^{-3}) + (5 \times 10^{-3}) = 15 \text{ mA}$$

$$R_S = (V_S - V_Z)/I_S = (12 - 6)/(15 \times 10^{-3}) = 400\ \Omega$$

Design of a rectifier for the given DC voltage

Do you know how to design a rectifier for your radio or type-recorder ?

To design a rectifier for electronic equipment like radio, type-recorder etc, it is necessary to know the voltage and current (power) rating of the equipment. Once voltage and current ratings are known it is easy to design rectifier for any equipment. For a given application transformer winding with suitable voltage and current ratings must be selected. Transformers are always rated with rms voltage and rms current specifications. Bridge rectifiers are commonly used in power supplies.

We know that for bridge rectifier

$$V_{dc} = \frac{2V_m}{\pi} = \frac{2\sqrt{2}V_{rms}}{\pi} \qquad \text{........(1)}$$

Therefore $$V_{rms} = \frac{\pi V_{dc}}{2\sqrt{2}} \qquad \text{........(2)}$$

For example to get V_{dc} = 14 V from eqn (2) we get V_{rms} = 15.55 V.

Therefore choose the transformer with a secondary voltage to 16 V or use 15 V which is available in market.

The current rating of the transformer is chosen depending on the current we draw from the transformer (I_{dc}). For the bridge rectifier

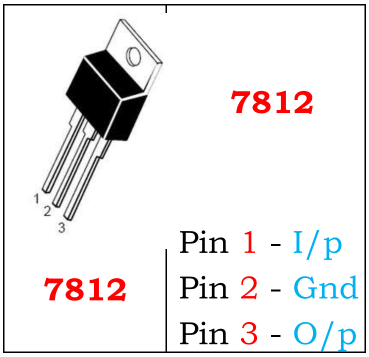
We have $$I_{dc} = \frac{2I_m}{\pi} = \frac{2\sqrt{2}I_{rms}}{\pi} \qquad \text{......(3)}$$

Therefore $$I_{rms} = \frac{\pi I_{dc}}{2\sqrt{2}} \qquad \text{.......(4)}$$

For example to get I_{dc} = 450 mA from eqn (4) we get I_{rms} = 500 mA .

Select the transformer of input; 0 - 230 V and output 0 - 15 V/500 mA to get DC of 14 V and 450 mA. Using design equation (2) select the transformer secondary voltage V_{rms} for a given dc voltage V_{dc} and using the equation (4) select the transformer secondary current I_{rms} for a given I_{dc}.

Fixed positive regulated power supply using 7812



A fixed regulator provides the fixed output voltage. A regulated power supply with +12 V output is as shown in fig. 6.43. IC 7812 regulator have three pins (input, ground, and output). IC 7812 provides regulated +12 V output and current excess of 1 A. Regulators 7812 have dropout voltage of 2 V. For an example to get regulated output of +12 V from the regulator 7812, input to the regulator 7812 must be more than 14 V (V_{dc}). For this transformer secondary terminals of suitable voltage must be selected.

The voltage rating of the transformer $V_{rms} = \frac{\pi V_{dc}}{2\sqrt{2}}$ is chosen keeping $V_{dc} = 14$ V.

The current rating of the transformer $I_{rms} = \frac{\pi I_{dc}}{2\sqrt{2}}$ is chosen depending on the current we draw from the regulator (I_{dc}).

Capacitor C_F is used as a filter capacitor.

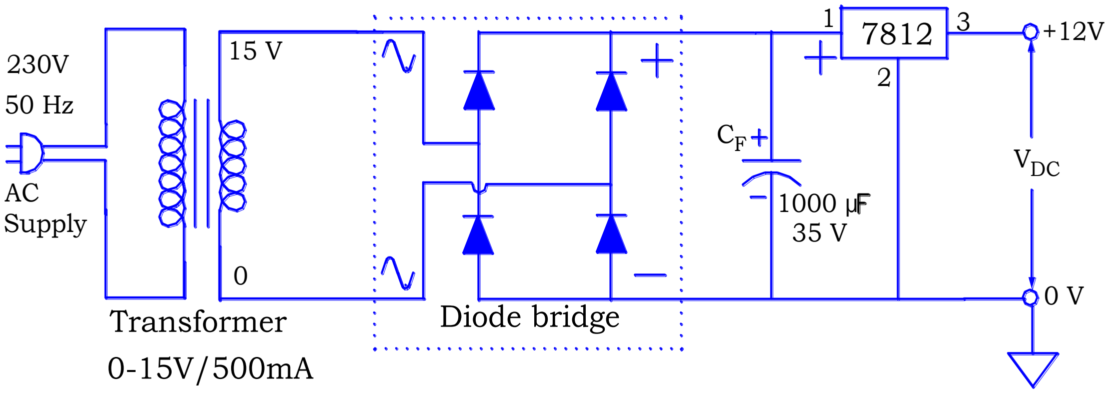
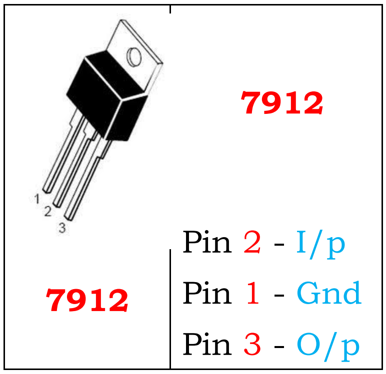


Fig. 6.43 +12V regulator using 7812

Fixed negative regulated power supply using 7912



IC 7912 regulator ICs have three pins (input, ground, and output). A regulated power supply with +12 V output is as shown in fig.6.44. IC 7912 provides regulated -12 V output and current excess of 1 A. Regulators 7912 have dropout voltage of 2 V. For example to get regulated output of -12 V from the regulator 7912, input to the regulator 7912 must be more than 14 V (V_{dc}). For this transformer secondary terminals of suitable voltage must be selected.

The voltage rating of the transformer $V_{rms} = \frac{\pi V_{dc}}{2\sqrt{2}}$ is chosen keeping $V_{dc} = 14$ V.

The current rating of the transformer $I_{rms} = \frac{\pi I_{dc}}{2\sqrt{2}}$ is chosen depending on the current we draw from the regulator (I_{dc}).

Capacitor C_F is used as filter capacitor.

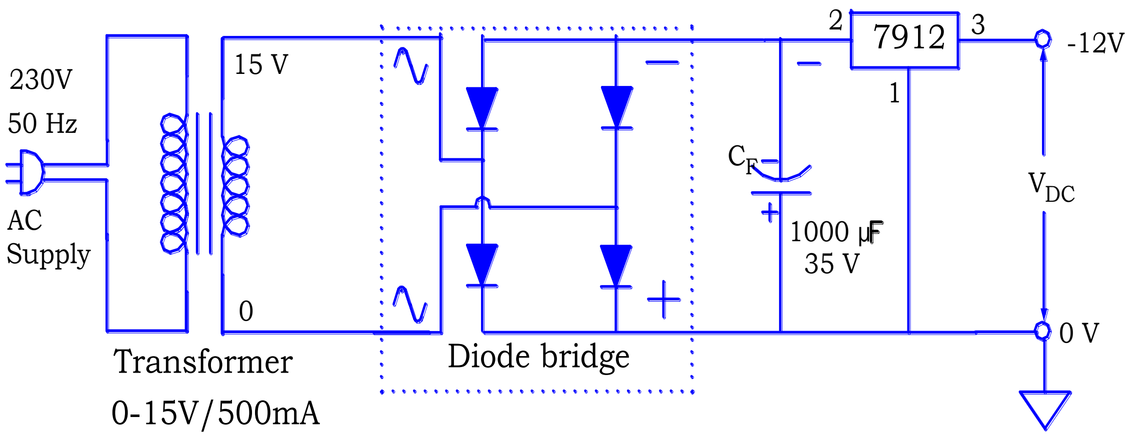
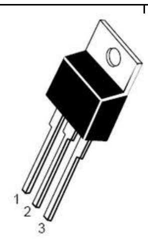


Fig. 6.44 -12V regulator using 7912

Adjustable regulated power supply using LM317 :

An adjustable regulator provides variable output voltage. An adjustable regulated power supply with +1.25 V to +12 V output is as shown in fig. 6.45. LM317 is an adjustable regulator IC having three pins (adjustable, output, and input). Regulator LM317 has dropout voltage of 1.7 V. Transformer secondary ratings must be properly selected for required variable regulator depending on the maximum output voltage V_{dc} and current I_{dc}. To get +12 V output voltage from the regulator we require the dc voltage of rectifier to be equal to +14 V (assumed dropout voltage of LM317 is 2 V).



LM317

LM317

Pin 1 - Adj
Pin 2 - O/p
Pin 3 - I/p

The voltage rating of the transformer $V_{rms} = \frac{\pi V_{dc}}{2\sqrt{2}}$ is chosen for required V_{dc}.

The current rating of the transformer $I_{rms} = \frac{\pi I_{dc}}{2\sqrt{2}}$ is chosen depending on the current we draw from the regulator (I_{dc}).

Expression for the output voltage of the regulator.

$$V_o = +1.25\left(1+\frac{R_2}{R_1}\right) \qquad \text{.........(5)}$$

For example to construct a variable regulator +1.25 V to +12 V

Choose $R_2 = 2\ k\Omega$ potentiometer and $R_1 = 220\ \Omega$

If $R_2 = 0$ (Pot in minimum position) $V_0 = +1.25$ V

If $R_2 = 2\ k\Omega$ (Pot in maximum position) $V_0 = +12.61$ V

Therefore by varying R_2 (2 kΩ pot) from 0 – 2 kΩ we can get the output voltage from +1.25 V to +12.6 V

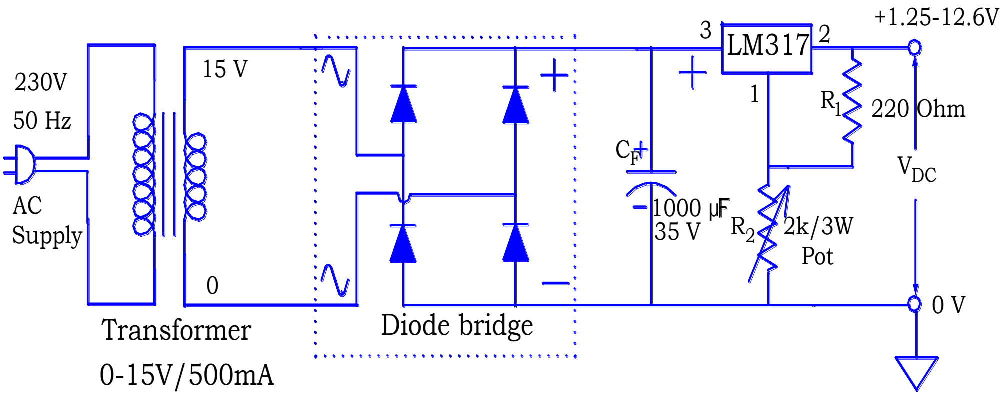


Fig. 6.45 +1.25 to +12V adjustable regulator using LM317

Specifications of DC regulated power supply.

The Important specifications of a DC regulated power supply are.

1. DC output voltage : Maximum output voltage of the power supply.
2. DC output current : Maximum output current of the power supply.
3. Line regulation : Percentage variation in DC output voltage with line AC voltage.
4. Load regulation : Percentage variation in DC output voltage with load resistance.
5. Ripples : AC present in the output DC voltage.
6. Protections : Protection against short circuit and over load.

Light emitting diode (LED)

A p-n junction diode which emits light when forward biased is known as light emitting diode [LED].

The emitted light may be visible or invisible. They emit spontaneous radiation in ultraviolet, visible or infrared regions. The amount of light output is directly proportional to the forward current. Fig. 6.46 shows the symbol of LED.

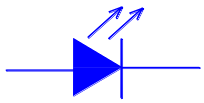


Fig.6.46 Symbol of LED

LED is the main and most universal inherent radiator. The arrows pointing away from the diode symbol represent the light which is transmitted away from the junction. The human eye is sensitive to light with a photon energy (hγ) equal to or greater than 1.8 eV energy gap. Therefore semiconductors having energy band gap larger than this limit may be used. Fig. 6.47 shows the basic structure of an LED.

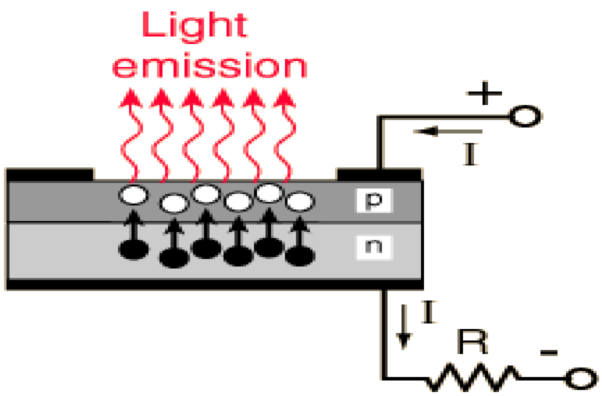


Fig. 6.47 Construction of LED.

A thin p type layer is grown on n type layer by diffusion process. The metal connection made to the p-type layer is an anode and to the n-type layer is a cathode terminal.

When the LED is forward biased, electrons cross the p-n junction from the n-type and recombine with the holes in the p-type i.e., the recombination of electrons and holes takes place. These free electrons are in the conduction band on the n side and are at a higher energy level than the holes in the valence band on the p side. During the process of recombination, the energy is released in the form of light. The light is emitted through the window provided at the top surface of the LED. In ordinary diodes, this energy is radiated in the form of heat.

The LED radiates light in different colours such as **red**, **green**, **yellow**, **blue**, **orange** etc. Also some LEDs emit infrared light (invisible light). The colour of the emitted light depends upon the semiconductor materials used for manufacturing LED's. Gallium arsenide (GaAs) having voltage drop 1.6 V emits infrared radiations, Gallium arsenide phosphide (GaAsP) voltage drop 2 V emits red light, Gallium Nitrate (GaN) having voltage drop 3 V emits blue light and Gallium phosphide (GaP) having voltage drop 4 V emits green light. LED's operates at the voltage levels from 1.2 V to 4 V depending on the device. These consume power rating from 10 to 150 mW. They have long life of about 10,000 hours and can be switched 'ON' and 'OFF' at a very fast speed (≈ 1 nsec). LED's cannot withstand reverse bias for even a very small voltage. For this reason, it is necessary to assure that reverse bias is not applied to the LED.

LED Applications

1. LED's are used in indicator lamps, readout display.
2. In seven segment, sixteen segment and dot matrix displays. Such displays are used to indicate alphanumeric characters and symbols in various systems such as digital clocks, microwave ovens, CD players etc.
3. IR LED's are used in burglar alarm systems.
4. LED's are used in solid state video displays, replacing the cathode ray tubes (CRT's)
5. In the field of optical communication, LED's are used to transfer (or couple) energy from one circuit to another.

Varactor diode

A reverse biased p-n junction diode which acts as a variable capacitor is known as a varactor diode. The varactor diode is also called as varicap or variable voltage capacitance diode or tunable diode.

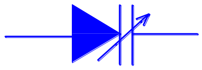


Fig. 6.48 Symbol of Varactor diode

Varactors are operated in the reverse-biased state. The thickness of the depletion region varies with the applied reverse bias voltage. The capacitance of the diode varies with variation in depletion region width.

Applications

The capacitance of varicaps are controlled by the applied reverse voltage, therefore, they have replaced the mechanically tuned capacitors in many applications such as TV receivers, FM receivers, automatic frequency control devices, LC tuned circuits, voltage controlled oscillators etc.

Infrared LED

An infrared LED is a semiconductor diode that converts an electrical energy directly into invisible (infrared) radiation.

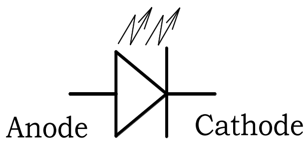


Fig. 6.49 symbol of IR LED

An infrared light-emitting diode (LED) is a type of semiconductor device that emits infrared light which is not visible to the naked eye. An infrared LED operates like a regular LED, but uses different materials to produce infrared light. The wavelength and colour of the light produced depend on the material used in the diode. As the current flows in the diode, electrons and holes recombine. The recombination results in release of energy in the form of photons, which produce infrared light.

Applications

IR LED's are used in remote controls, burglar alarm systems, optical communication systems, speed indicators and touch-less object sensing.

Photo diode

Photo diode is a reverse biased p-n junction diode in which reverse current increases when the junction is exposed to light.

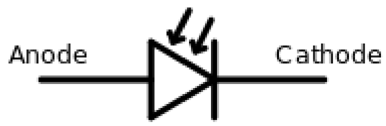


Fig. 6.50 Symbol of photo diode.

When a photon of sufficient energy strikes the photo diode, it excites electrons, thereby creating a free electron and hole pairs. This mechanism is also known as the inner photoelectric effect. If the reverse voltage is applied, these carriers are swept away from the junction by the built-in field of the depletion region. Thus holes move towards the anode, and electrons towards the cathode, and a photocurrent is produced.

Applications ;

1. The photodiodes are used in alarm systems and counting systems.
2. They are used in optical communication systems.
3. Used in opto-couplers.
4. Used in compact disc players.

Tunnel diode [Esaki diode]

Tunnel diode is a heavily doped, very narrow depletion layer diode which exhibits negative resistance characteristics over a part of its operating range.

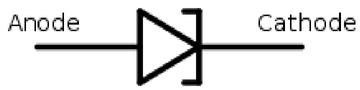


Fig. 6.51 Symbol of a tunnel diode

Tunnel diode at low forward-biased, exhibits an effect called **quantum mechanical tunneling** which gives rise to a region where an increase in forward voltage is accompanied by a decrease in forward current. As the voltage is further increased, the diode begins to behave as a normal diode, where electrons travel by conduction across the p–n junction, and no longer by tunneling through the p–n junction barrier. The most important operating region for a tunnel diode is the negative resistance region.

Applications ;

Tunnel diodes are used in high speed applications such as:

1. Tuned circuits
2. Mixer circuits
3. Low power oscillator
4. High speed computer memories
5. Low noise microwave amplifiers etc.

Schottky diode

The **Schottky diode** (named after German physicist Walter H. Schottky) also known as **hot carrier diode** is a semiconductor diode with a low forward voltage drop and a very fast switching action.

Fig. 6.52 Symbol of Schottky diode

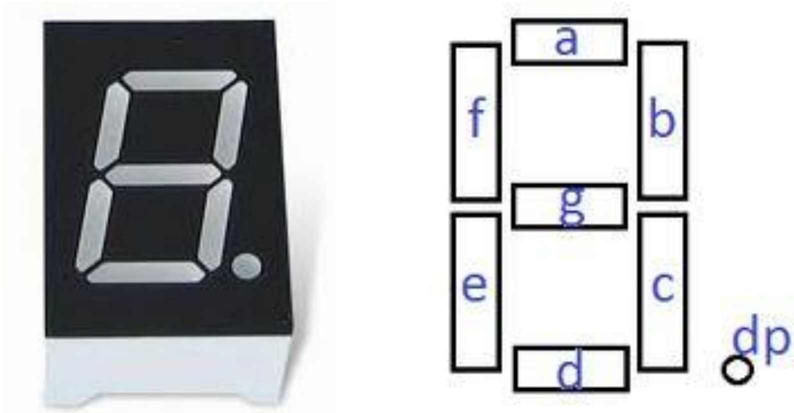
When current flows through a diode a small voltage drops across the diode terminal. A Schottky diode voltage drop is between 0.15 – 0.45 volt. This lower voltage drop can provide higher switching speed and better system efficiency.

Applications

Due to fast switching characteristics, the Schottky diodes are useful for high frequency applications such as digital computers, high speed TTL, radar systems, mixers and detector circuits in communication equipments and analog to digital converters. It is mainly used as a rectifier at signal frequencies above 300 MHz.

Seven segment display

It is a device used to display the alphanumeric characters. Fig. 6.53 shows a seven segment display. It consists of seven rectangular LEDs designated by letters a, b, c, d, e, f and g. Each LED is called a segment because it forms a part of the digit or a letter being displayed. An additional LED is used for the indication of a decimal point (DP). By activating (i.e. forward biasing) one or more LEDs of the display, we can display any digit or character such as 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, b, C, d, E, F etc.



(a) Seven segment display (b) Segments of display

Fig. 6.53

Display of numerals is as shown in fig. 6.54. By forward biasing the LEDs a, b, g, e and d we can display digit 2. Whereas by forward biasing LEDs a, b, and c we get 7.

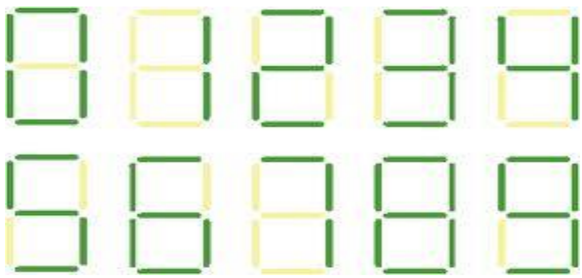


Fig. 6.54 Display of numbers

Types of seven segment display

There are two types of seven segment LED displays:

1. Common anode type
2. Common cathode type

Common Anode Type

Fig. 6.55 shows common anode type seven segment display circuit. In this type all the anode of the LEDs are connected to a positive supply. A current limiting resistors R is connected between the cathode of LED and the switch which is connected to ground. When any selected switches are made 'ON' the cathodes of these LEDs are grounded and LEDs are 'ON', emitting light. If the switch 'S' is opened, the LED circuit is opened and LED stops emitting light.

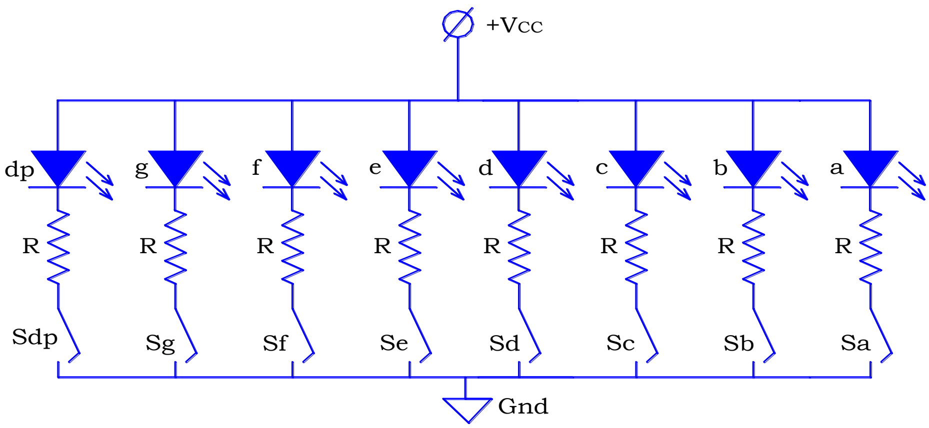


Fig. 6.55 Connection diagram of common anode 7-segment display

Common Cathode Type

Fig. 6.56 shows common cathode type of seven segment display circuit. In this type of display all the cathodes of LEDs are common to negative supply i.e. grounded as shown in fig. 6.56. A current limiting resistor R is connected between each LED and +ve supply through switch S. When the switch S is pressed 'ON' the corresponding anode supplies current to LED and the LED glows. When the switch S is 'OFF' i.e. open, the corresponding LED is put off from power supply and LED stops glowing.

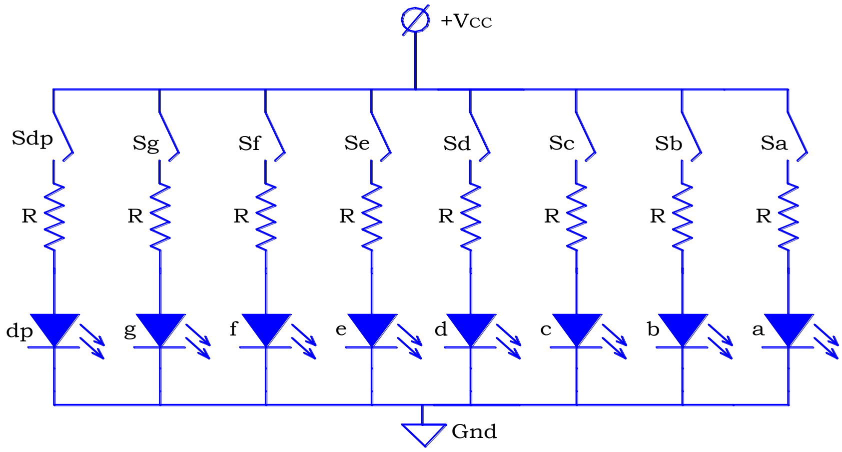


Fig. 5.56 Connection diagram of common cathode 7-segment display

Liquid crystal display (LCD)

It is a popular alphanumeric display using liquid crystal material. A 2 line 16 characters (2x16) LCD display is shown in fig. 5.57. Liquid crystals are materials that exhibit properties of both solids and liquids, that is, they are in an intermediate phase of matter. **Liquid crystal display (LCD)** is an electronic display device that operates by applying a varying electric voltage to the layer of liquid crystal, thereby inducing changes in its optical properties. An electric field (induced by a small electric voltage) can change the orientation of molecules in a layer of liquid crystal and thus affect its optical properties. Such a process is termed as an electro-optical effect which forms the basis for LCDs. For LCDs, the change in optical properties results in orienting the molecular axis either along or perpendicular to the applied electric field. The orientation of molecules helps to view the display. The small electric voltages necessary to orient liquid crystal molecules have been a key feature of the commercial success of LCDs.

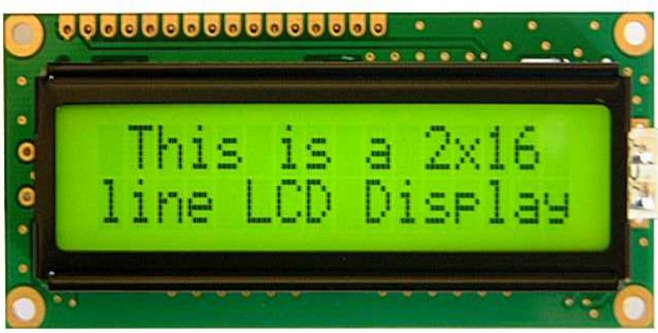


Fig. 5.57 2x16 LCD Display

Applications of LCD display

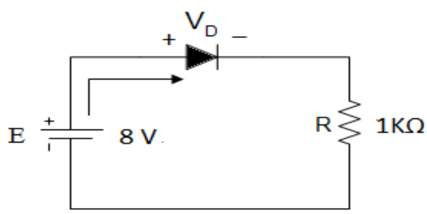
1. They are widely used in calculators and electronic watches, digital clocks, portable electronic games etc.
2. For displaying information up to small distances.
3. In lap-top computers, mobile phones, digital diaries, LCD monitors, and LCD TVs etc.

Comparision between LEDs and LCDs

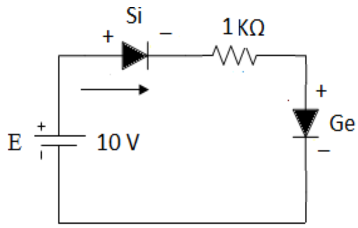
Light Emitting Diode (LED)	Liquid Crystal Display (LCD)
1. It emits light	It reflects light
2. It has more brightness	It has low brightness
3. It requires high power (10 to 250 mW) per character	It requires low power (10 to 20 μW) per character
4. Its operating voltage is 1.6 V to 5 V DC	Its operating voltage is 3 V to 20 V DC
5. It can operate at a very high frequency	It operates only at a low frequency
6. It has wide viewing range	It has narrow viewing range
7. It is easy to mount	It is difficult to mount
8. Its response time is more (50 to 5000 nS)	Its response time is less (50 to 200 mS)

Exercise

1. A germanium diode has a forward current of 50 mA and a forward voltage of 1.5 V. Determine its bulk resistance. (Ans: 24 Ω)
2. Find the value of an applied voltage for Si diode having bulk resistance 25 Ω and a forward current of 2 mA. (Ans: 0.75 V)
3. A germanium diode is used in the circuit shown in fig. Determine V_D,V_R, and I_D. (Ans: 0.3 V, 7.7 V, 7.7 mA)

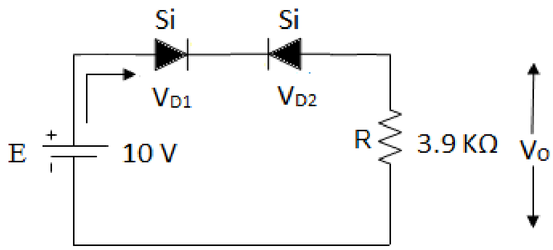


4. Determine the current through 1 KΩ resistor. (Ans: 9 mA)

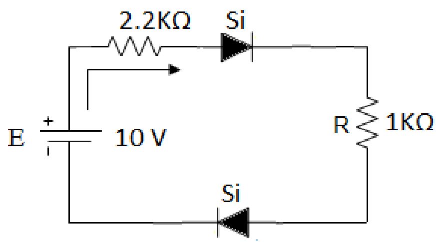


5. Determine I_D, V_{D1}, V_{D2} and V_0 for the circuit shown in figure.

(Ans: I_D = 0 A, V_{D1} = 0V, V_{D2} = 10 V and V_O = 0 V)



6. For the series diode configuration as shown in figure determine the value of current through the circuit. (Ans: 2.60 mA)



7. The load resistance of a full wave rectifier is 500 Ω and the transformer secondary voltage is 80sinωt. Assume the diodes to be an ideal, determine the following: (i) rms values of voltage and current (ii) average values of voltage and current (iii) efficiency of rectifier and (iv) ripple factor.

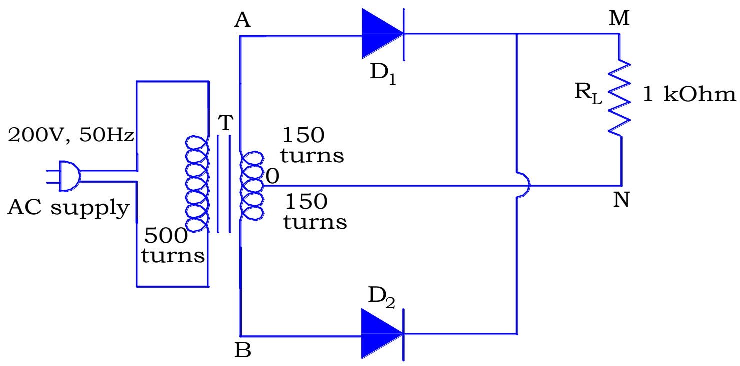
(Ans: V_{rms} = 56.57 V, I_{rms} = 0.113 A, V_{dc} = 50.92 V, I_{dc} = 0.102 A, η = 81.2%, γ = 0.48)

8. A single phase full wave rectifier uses a two diodes with the internal resistance of each being 120 Ω. The transformer rms secondary voltage from the center to each end of secondary is 30 V and load resistance is 200 Ω. Determine (i) rms value of voltage and current and (ii) average value of voltage and current (iii) ripple factor and (iv) efficiency of rectifier.

   (Ans: V_{rms} = 30 V, I_{rms} = 0.141 A, V_{dc} = 27.03 V, I_{dc} = 0.135 A, γ = 0.48, η = 80.66 %)

9. In a power supply the DC output voltage drops from 65 V with no load to 60 V at full load. Calculate the percentage voltage regulation.(Ans: 7.69%)

10. The ideal diodes are used in a full wave rectifier circuit is as shown below. Calculate rms and DC values of the current and voltage.



(Ans: V_{rms} = 60 V, I_{rms} = 0.06 A, V_{dc} = 54.04 V I_{dc} = 0.054 A, η = 81%, γ = 0.48)

11. In a Zener regulator input voltage is 20 V, V_Z = 8.2 V. Find the resistance required in series if I_L = 2 mA and I_Z = 10 mA. (Ans: R_S = 983 Ω)

12. A 10 V Zener diode along with a series resistance is connected across a 25 V supply. Calculate the minimum value of series resistance required if the maximum value of I_Z is 400 mA and I_L is 100 mA. (Ans: R_S = 30 Ω)

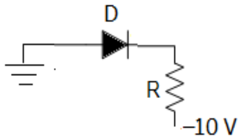
13. Calculate the load current and Zener diode current if V_Z = 6 V. Given V_S = 25 V, R_S = 1.5 kΩ and R_L = 2 kΩ . (Ans: I_L = 3 mA, I_Z = 9.6 mA)

14. Calculate maximum and minimum values of Zener current if V_S = 60-80 V, R_S = 5 kΩ, V_Z = 12V and R_L = 5 kΩ .

    (Ans: I_{Zmin} = 7.2 mA, I_{Zmax} = 11.2 mA)

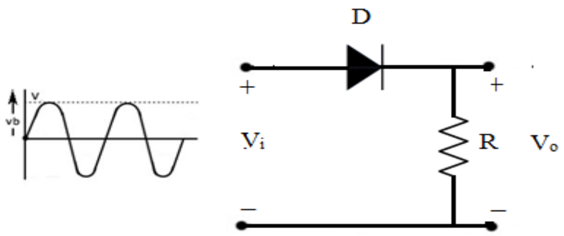
One mark questions

1. What are semiconductors?
2. What are conductors?
3. Define valance band.
4. Define conduction band.
5. What is forbidden energy gap?
6. What is doping?
7. Name any one acceptor impurity.
8. Name any one donor impurity.
9. Name the majority charge carriers in n-type semiconductor.
10. Name the majority charge carriers in p-type semiconductor.
11. What is a p-n junction?
12. Draw the symbol of a p-n junction diode.
13. How p-n junction is formed?
14. What is depletion region?
15. What is potential barrier?
16. What is meant by biasing a p-n junction?
17. What is meant by forward biasing?
18. What is meant by reverse biasing?
19. In the figure shown, is the diode D forward or reverse biased?

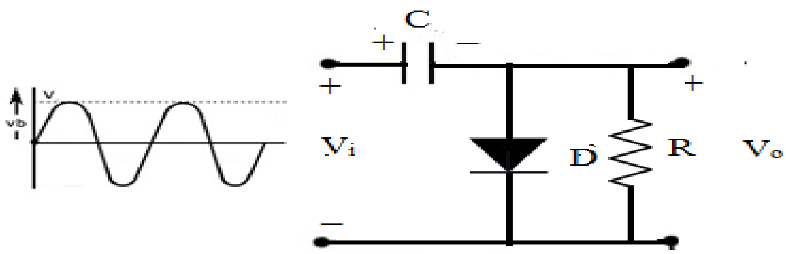


20. In which type of biasing is the p-n junction diode resistance high ?
21. What is the effect of forward bias on the width of a p-n junction?
22. What is the effect of reverse bias on the width of a p-n junction?
23. What is reverse saturation current?
24. Is reverse saturation current dependent of temperature?
25. What do you mean by breakdown of the junction?
26. What is the static resistance of a diode?
27. Define dynamic resistance of a junction diode.
28. Name the capacitive effect exhibited by a p-n junction when it is reverse biased.
29. Give the expression for transition capacitance.
30. What is the value of potential barrier of a silicon diode.
31. Mention the diode equation.
32. What is an ideal diode?
33. Draw the equivalent circuit of a forward biased ideal diode.

34. Draw the equivalent circuit of a reverse biased ideal diode.
35. Draw the equivalent circuit for second approximation of a diode.
36. Draw the equivalent circuit for third approximation of a diode.
37. What is the power rating of a diode?
38. What are wave shaping circuits?
39. What are clippers?
40. What are clampers?
41. Sketch the shape of the output voltage waveform for the circuit shown below assuming the diode to be ideal.



42. Sketch the shape of the output voltage waveform for this circuit shown below assuming the diode to be ideal.



43. What is meant by rectification?
44. What is a rectifier?
45. What is the importance of peak inverse voltage?
46. Mention the value of ripple factor in HWR.
47. What is meant by filter?
48. Mention the property of a p-n junction, which is used for rectification.
49. What is a Zener diode ?
50. Draw the schematic symbol of a Zener diode.
51. Draw the equivalent circuit of a Zener diode.
52. In what respect Zener diode is different from an ordinary diode.
53. Define Zener breakdown voltage.
54. Mention the main application of Zener diode.
55. In what region of the diode curve a Zener diode is operated for voltage regulation.

56. What is line regulation?
57. What is load regulation?
58. Name the active component used for voltage regulation.
59. Name the component used to construct +12 V fixed voltage regulator.
60. Name the component used to construct -12 V fixed voltage regulator.
61. Name the component used to construct adjustable voltage regulator.
62. What is LED?
63. Draw the schematic symbol of LED.
64. In what respect is LED different from an ordinary diode?
65. Under what bias is LED operated?
66. What happens to the light emission in LED as the forward current is increased?
67. What is a varactor diode?
68. Draw the symbol of a varactor diode.
69. Under what bias condition is a varactor diode operated?
70. Name any one application of a varactor diode.
71. What is an infrared LED?
72. Draw the symbol of an IR LED.
73. Name any one application of an IR LED.
74. What is a photodiode?
75. Draw the symbol of a photodiode.
76. Write the applications of a photodiode.
77. In what bias condition is a photodiode normally operated?
78. What is a tunnel diode?
79. Draw the symbol of a tunnel diode.
80. Name the applications of tunnel diode.
81. What is a Schottky diode?
82. Draw the symbol of a Schottky diode.
83. What is the range of voltage drop across the Schottky diode under forward biased condition?
84. Mention the applications of Schottky diode.
85. What is a seven segment LED display?
86. Mention the types of seven segment displays.
87. Mention any one application of a seven segment display.
88. What is a LCD?
89. Does LCD radiate its own light?
90. Mention any two important applications of LCD.

Two marks questions

1. Classify extrinsic semiconductor.
2. Draw the lattice structure of silicon.
3. Mention majority and minority charge carriers in n-type semiconductor.
4. Draw the crystalline structure of a p-type semiconductor.
5. What is meant by biasing?
6. Draw the circuit diagram of a forward biased p-n junction diode.
7. Draw the circuit diagram of a reverse biased p-n junction diode.
8. What is the origin of the reverse saturation current in a p-n junction?
9. Define static and dynamic resistance of a p-n junction diode.
10. What are the typical values of knee voltage for Ge and Si diodes.
11. Explain the phenomenon of diode reverse breakdown.
12. What do you mean by the transition capacitance of a diode?
13. A p-n junction diode is a non linear element. Explain.
14. Distinguish between Ge and Si diode.
15. Define ideal diode. Draw its V-I characteristics.
16. Explain the second approximation of a semiconductor diode.
17. Explain the third approximation of a semiconductor diode.
18. Explain the phenomenon of diode reverse breakdown.
19. Give any two examples for wave shaping circuits.
20. Mention any four applications of a diode.
21. What is meant by clipping? Mention any one application of clipping circuit.
22. What is the difference between positive and negative clipper?
23. What is meant by clamping? Mention any one application of clamping circuit.
24. Write the circuit of series positive clipper and show the input and output waveforms.
25. Write the circuit of series negative clipper and show the input and output waveforms.
26. Write the circuit of positive clamper and show the input and output waveforms.
27. Write the circuit of negative clamper and show the input and output waveforms.

28. Mention the primary conditions of clamping circuits.
29. What is the difference between positive and negative clamper?
30. Mention any two comparisons of three rectifiers.
31. Define ripple factor and give its significance.
32. Draw the circuit diagram of a full wave rectifier indicating the input and output wave forms.
33. How many diodes are used in a (i) Centre tapped full wave rectifier and (ii) Bridge rectifier?
34. What is the maximum rectification efficiency of a full wave rectifier and half wave rectifier?
35. Distinguish between full wave rectifier and half wave rectifier.
36. Distinguish between series inductor filter and shunt capacitor filter.
37. What is Zener break down?
38. Draw the VI Characteristics of Zener diode.
39. Explain the need of a voltage regulator circuit in a power supply.
40. Draw the circuit diagram of +12 V voltage regulator.
41. Draw the circuit diagram of an adjustable voltage regulator.
42. What is voltage regulation? Mention the types of voltage regulation.
43. State any two application of LED.
44. Draw the diagram of seven segment LED display.
45. Name any two elements used in the manufacture of LED.

Three/five marks questions

1. Classify solids based on energy band diagram.
2. Write the properties of semiconductor.
3. Briefly explain about the n-type semiconductor.
4. Briefly explain about the p-type semiconductor.
5. How is the depletion region formed in a p-n junction?
6. Explain the working of a p-n junction when it is forward biased.
7. Explain the working of a p-n junction when it is reverse biased.
8. Draw and explain the V-I characteristics of a p-n junction diode.
9. Explain an experiment to draw the forward and reverse characteristics of a semiconductor diode.
10. Write a note on diode junction capacitance.
11. Write a note on diode specifications.

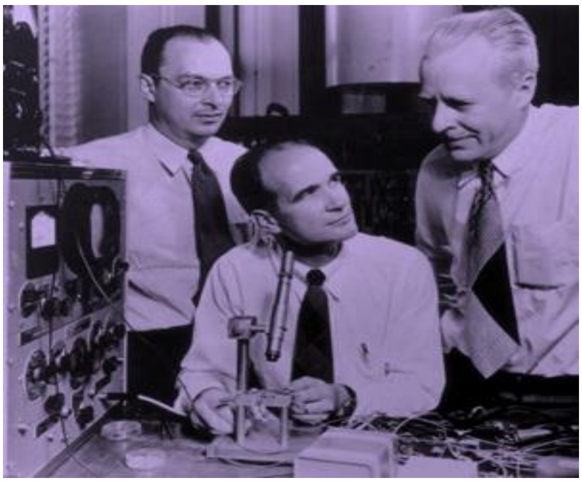
12. Write a note on diode approximations.
13. Explain the action of series positive clipper.
14. Explain the action of series negative clipper.
15. Explain the working of positive clamper.
16. Explain the working of negative clamper.
17. Describe the action of a diode as a half wave rectifier.
18. Explain the working of full wave centre tapped rectifier.
19. Explain the operation of bridge rectifier.
20. Explain the negative voltage rectifier.
21. Explain the working of a series inductor filter.
22. Explain the working of a shunt capacitor filter.
23. Mention any four comparisons of three rectifiers.
24. Explain the characteristics of a Zener diode.
25. Explain the working of a Zener diode as a voltage regulator.
26. Explain the regulated +12 V DC power supply.
27. Explain the regulated -12 V power supply.
28. Explain the working of LED.
29. Explain common anode type of seven segment display.
30. Compare LED display with LCD display.

Chapter 7

Bipolar Junction Transistor

Introduction

Transistors are the building blocks of the Electronics revolution. The technological wonders that we use every day like cell phones, personal computers, fuel-efficient cars, aero planes etc., are due to revolution created by transistors. In 1948, Shockley, Brattain and Bardeen of Bell Labs developed a junction transistor and this invention netted the Bell team towards the Nobel Prize for Physics (1956). It is capable of achieving amplification of weak signals and often superior to that realized with vacuum tubes as they have no filament and hence no heating power. They are mechanically strong and have practically long life and can perform better than vacuum tubes. They are light in weight and consume less power resulting in greater circuit efficiency. Transistors have enabled some of the mankind's biggest leaps in technology.



Bell Labs team of John Bardeen (left), Walter Brattain (middle) and William Shockley (right)

Bipolar Junction Transistor

A transistor is a three terminal bipolar unidirectional current conducting semiconductor device. It is also a combination of two diodes connected back to back. Transistor is called bipolar junction transistor (BJT). The term bipolar refers that the current conduction is due to both majority and minority charge carriers. Transistors are used for amplification and switching purposes. There are two types of transistors, npn and pnp type. An npn transistor consists of one p-region sandwiched between two n-regions as shown in fig. 7.1(a). Similarly a pnp transistor consists of one n region sandwiched between two p regions as shown in fig. 7.1(b). Symbols of npn transistor and pnp transistors are shown in fig. 7.1(c) and fig. 7.1(d) respectively. The arrow in the circuit symbol shows the direction of conventional current flow.

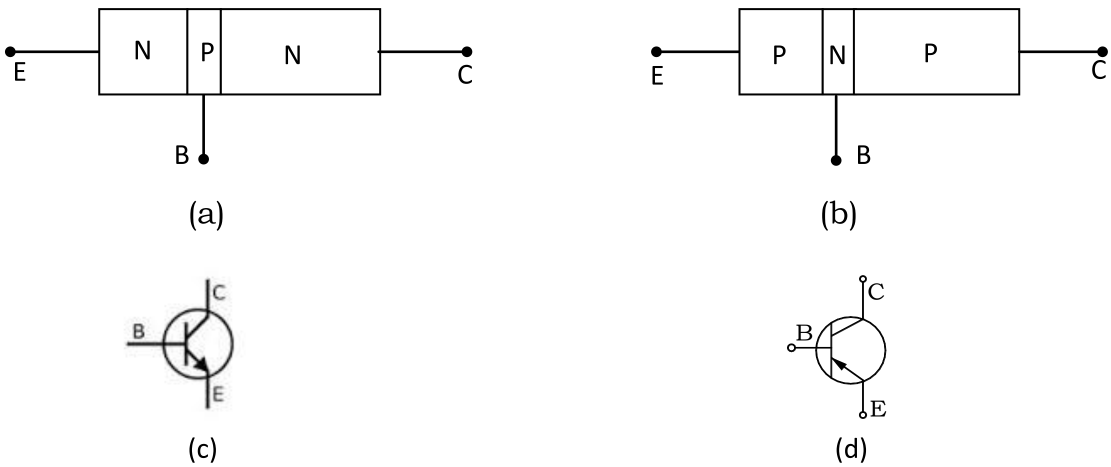


Fig 7.1

There are three terminals in a transistor named, emitter, base and collector. A transistor has two p-n junctions. Emitter and base form the emitter-base junction while the collector and base form the collector-base junction.

Emitter: It is a heavily doped region. It is physically medium in size. When emitter is forward biased with respect to base it supplies a large number of majority charge carriers to collector. (Holes if emitter is p-type and electrons if emitter is n-type).

Base: It is a lightly doped region. It is physically very narrow in size (10^{-6} m). It controls the flow of charge carriers from emitter to collector.

Collector: It is a moderately doped region. It is physically larger in size than emitter to dissipate the heat generated while collecting the majority charge carriers emitted by the emitter.

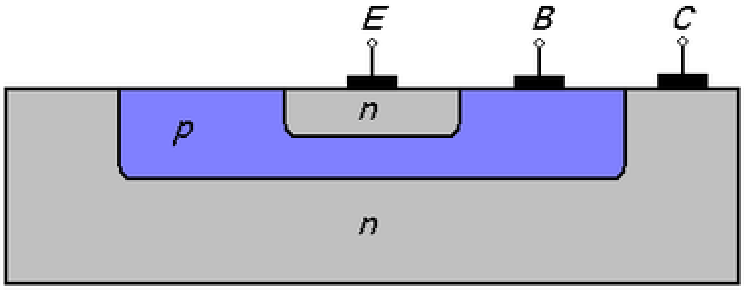


Fig. 7.2 Transistor structure

Transistor structure is as shown in fig. 7.2. The table indicates the doping level, physical dimension and function of the three regions of a transistor.

Transistor region	Doping level	Physical dimension	Function
Emitter	Heavy	Medium	Emits majority charge carriers.
Base	Light	Very narrow	Transfers the majority charge carriers from emitter to collector.
Collector	Moderate	Large	Collects majority charge carriers.

The Emitter-Base junction is forward biased, which offers low resistance. Similarly the Collector-Base junction is reverse biased and provides a high resistance. Therefore a transistor transfers charge carriers from a low resistance region to a high resistance region.

i.e., Transistor = transfer + resistor

Unbiased npn transistor

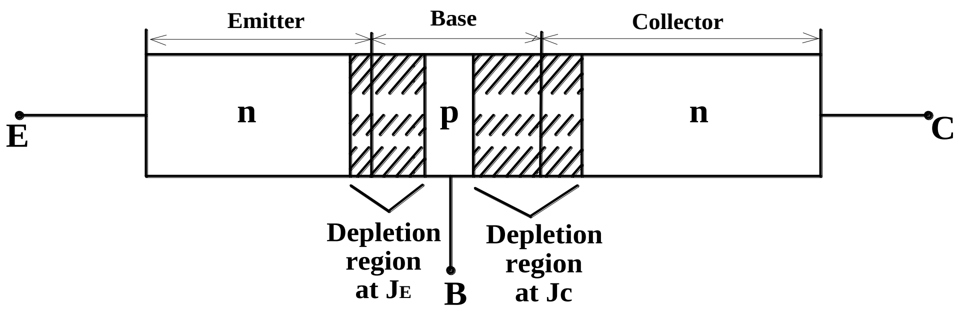


Fig. 7.3 Unbiased npn Transistor

An unbiased transistor means a transistor without an external voltage (biasing) applied. In an unbiased condition due to diffusion process, the depletion region penetrates more deeply into the lightly doped side in order to include an equal number of electron-hole pairs. As shown in the fig 7.3, depletion region at emitter junction penetrates less in to the heavily doped emitter and extends more in to the base region. Similarly, depletion region at collector junction penetrates less in to the moderately doped collector and extends more in to the base region. As the collector is moderately doped than the emitter, the depletion layer width at the collector junction is more than the depletion layer width at the emitter junction.

A transistor has two junctions the three useful ways of biasing these two junctions are given in table.

Region of operation	Emitter base junction	Collector base junction	Application
Active	Forward biased	Reverse biased	Amplifier
Saturation	Forward biased	Forward biased	Closed switch
Cut-Off	Reverse biased	Reverse biased	Open switch

Working of a npn Transistor

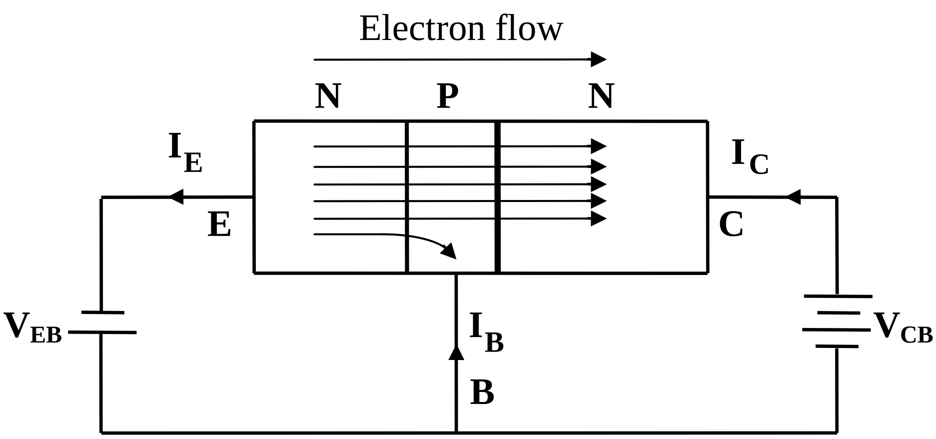


Fig 7.4.

For normal working of a transistor, emitter base junction of transistor is made forward biased and collector base junction is made reverse biased as shown in fig. 7.4. The forward bias causes the electrons in the n-type emitter to flow towards the p-type base. This constitutes the emitter current I_E. These electrons flows through the p-type base and tend to combine with the holes. As the base is lightly doped and very thin, only a few electrons combine with the holes to constitute the base current I_B. The remaining electrons reaches the collector region to constitute the collector current I_C.

$$I_E = I_B + I_C.$$

Transistor Configurations (npn)

To use transistor in practical circuits such as op-amps, switches, oscillators etc., we require four terminals i.e., two for applying the input and two for obtaining the output. Since the transistor has three terminals, one of the terminals is made common for both input and output. Based on the terminal used as the common terminal, the transistor can be used in three different configurations

1. Common base (CB) configuration
2. Common emitter (CE) configuration
3. Common collector (CC) configuration

The Common base (CB) configuration

The **common base** or grounded base configuration shown in fig. 7.5, the base connection is made common to both the input and the output terminals. The input signal being applied between the base and the emitter terminals and the output signal is taken between the base and the collector terminals. It is used in high frequency amplifiers.

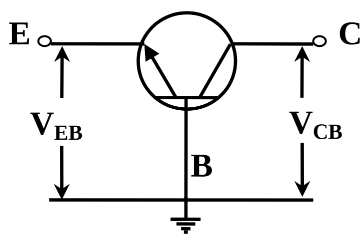


Fig. 7.5 npn transistor CB configuration

Common emitter (CE) configuration

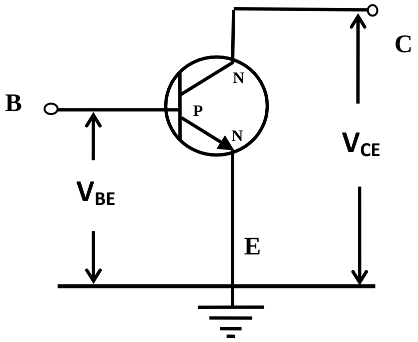


Fig. 7.6 npn transistor CE configuration

The **common emitter** or grounded emitter configuration is shown in fig. 7.6, the emitter terminal is made common to both input and output. The input signal is applied to the base with respect to the emitter and the output signal is taken across the collector and the emitter terminals. This type of configuration is most commonly used in transistor based amplifier circuits.

Common collector (CC) configuration

The **common collector** or grounded collector configuration is shown in fig. 7.7, the collector is made common for both input and output. The input signal is applied to the base with respect to the collector and the output signal is taken across the emitter and the collector terminals. This type of configuration is most commonly used in buffer amplifier and impedance matching circuits.

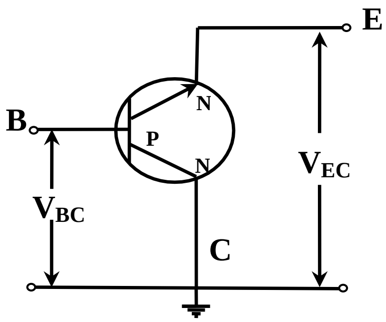


Fig. 7.7 npn transistor CC configuration

DC current gain of the transistor

DC Current gain in CB mode (α_{dc}): α_{dc} is the ratio of collector current to the emitter current in CB mode.

$$\alpha_{dc} = \frac{I_C}{I_E}$$

The value of α is always less than 1.

DC Current gain in CE mode (β_{dc}): β_{dc} is the ratio of collector current to the base current in CE mode.

$$\beta_{dc} = \frac{I_C}{I_B}$$

Relationship between α and β in a transistor

We Know that $I_E = I_B + I_C$ ------ (1)

$$\beta = \frac{I_C}{I_B}$$

Consider $\alpha = \frac{I_C}{I_E}$

Substitute equation (1) in the above equation

$$\alpha = \frac{I_C}{I_B + I_C}$$

Divide both numerator and denominator by I_B

$$\alpha = \frac{\frac{I_C}{I_B}}{1 + \frac{I_C}{I_B}}$$

$$\beta = \frac{I_C}{I_B}$$

$$\therefore \quad \alpha = \frac{\beta}{1+\beta}$$

Similarly we get $\beta = \frac{\alpha}{1-\alpha}$

Example No. 1

An npn Transistor has a DC current gain, β of 200. Calculate the base current I_B when the collector current I_C is 4 mA.

Given: β = 200, I_C = 4 mA and I_B = 20 μA.

$$I_B = \frac{Ic}{\beta} = \frac{4 \times 10^{-3}}{200} = 20\ \mu A$$

Transistor characteristics in CE mode.

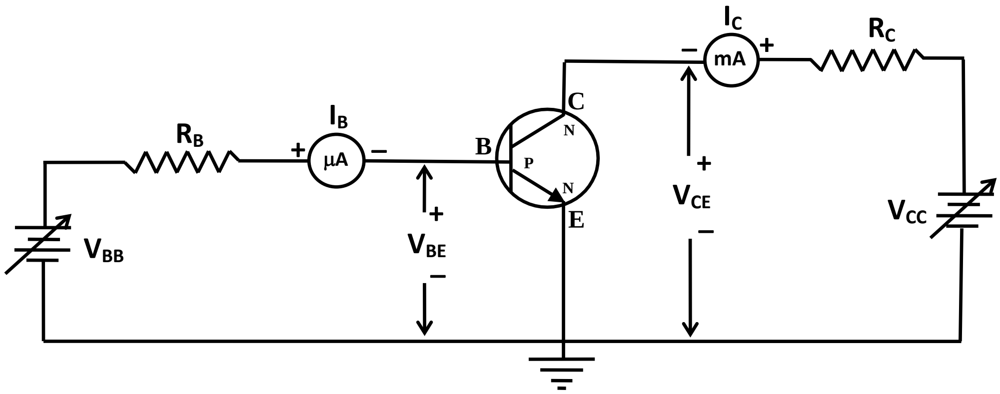


Fig. 7.8

A transistor circuit is said to be in common-emitter configuration if the emitter is made common to both the input and the output as shown in fig. 7.8. More details of a transistor can be studied with the help of curves that relate transistor currents and voltages. There are two types of transistor characteristics. They are:

(a) Input characteristics.

(b) Output characteristics.

(a) Input Characteristics

The input characteristic are the curves of input current I_B with the input voltage V_{BE} for a constant output voltage V_{CE}. Keeping the output voltage V_{CE} constant, increase the input voltage V_{BE} in steps of 0.1 V and note the corresponding base current I_B. The graph is plotted, by taking V_{BE} on the x-axis and I_B along the y axis.

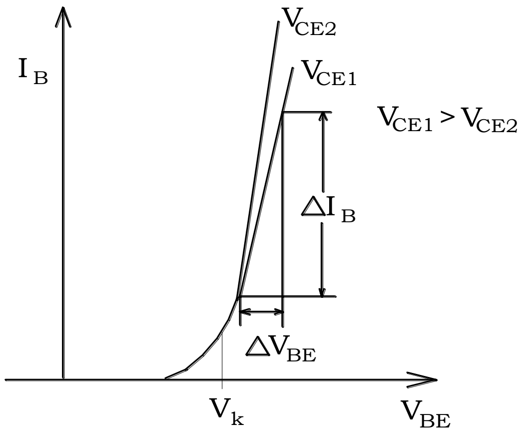


Fig. 7.9

Input characteristics are shown in fig 7.9. The base current I_B is very small up to the knee voltage V_k and after the knee voltage, the base current increases with increase in V_{BE}. The knee voltage is 0.7 V for Si and 0.3 V for Ge. This resembles like the forward characteristic of pn junction. The input resistance R_i can be determined from this curve. It is defined as the ratio of small change in the base to emitter voltage V_{BE} to the corresponding change in the base current I_B at constant collector to emitter voltage V_{CE}. R_i is given by the expression,

$$R_i = \left|\frac{\Delta V_{BE}}{\Delta I_B}\right| \text{ at constant } V_{CE}.$$

(b) Output characteristics

Output characteristics are the curves of output current I_C with the output voltage V_{CE} for a constant input current I_B. To obtain output characteristics, increase V_{CE} in steps by varying V_{CC} and record the corresponding collector current I_C keeping I_B constant. Repeat the same procedure for different values of I_B. The curves are obtained by plotting V_{CE} on the X-axis and I_C on Y-axis for different values of I_B. Fig 7.10 shows the output characteristic curves. The collector current I_C varies with V_{CE} for values between 0 V and 1 V. After this, the collector current I_C becomes almost constant.

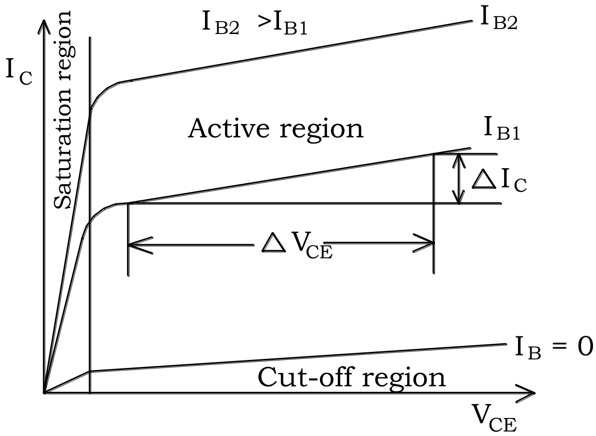


Fig. 7.10

From the output characteristics we can define output resistance R_o by the expression,

$$R_o = \left|\frac{\Delta V_{CE}}{\Delta I_C}\right| \text{ at constant } I_B$$

The output characteristic curves are divided into three regions namely, cut-off region, saturation region and active region.

Cut-Off region: The region below $I_B = 0$ is known as cut-off region. In this region, both the junctions are reverse biased. The collector current is very small. This current is known as reverse leakage current.

Saturation region: In this region, both the junctions are forward biased and collector current is independent of base current.

Active region: In this region, the base-emitter region is forward biased and the collector-base junction is reverse biased. In this region, the curves are almost straight and equally spaced, I_C is proportional to I_B.

Photo Transistor

A phototransistor is a three terminal light sensitive semiconducting device. Phototransistor uses light rather than electricity to cause an electrical current to flow from one side to the other. It is used in a variety of sensors that detect the presence of light. The photo transistor has much larger base and collector areas than that would be used for a normal transistor. It is commonly operated in CE configuration with base open. The collector junction is reverse biased. The current induced by the photo-electric effects will be the base currents of the transistor. When there is no light falling on the junction, there is a small leakage current due to the flow of thermally generated minority carriers known as the dark current. An increase in the light intensity causes corresponding increase in collector current. Fig 7.11 shows the Photo-transistor construction and its characteristics.

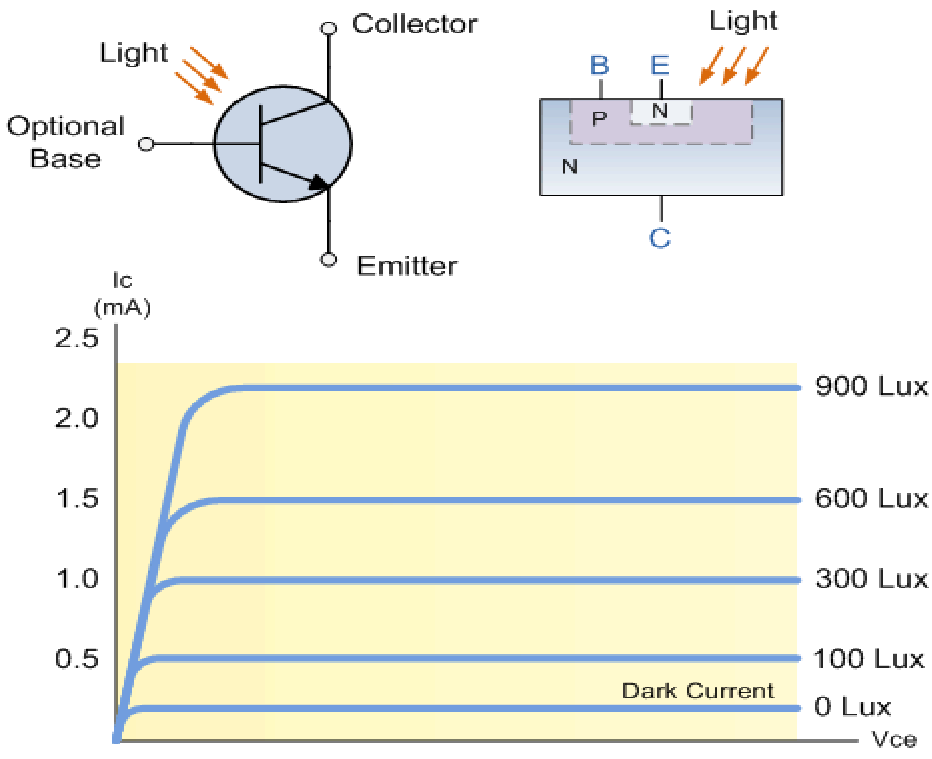
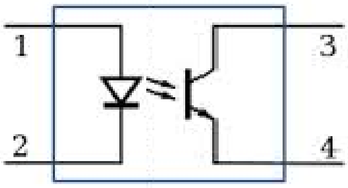


Fig. 7.11 Photo-transistor construction and characteristics

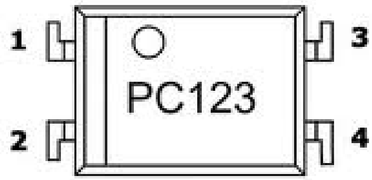
Applications of phototransistors

Phototransistors can be used as ambient light detectors. When used with a controllable light source, like an LED, they are often employed as the detector element for opto-isolators and reflective optical switches.

Optocoupler



(a) Optocoupler internal connection



(b) PC123 Optocoupler IC

Fig 7.12

Electrical isolation can be provided between an input source and an output load by using an optocoupler. Fig. 7.12(a) shows internal connection of a PC123 optocoupler and fig. 7.12(b) shows PC123 optocoupler**.** An **Optocoupler** is also known as an **Opto-isolator** or **Photo-coupler**, is an electronic component that interconnects two electrical circuits by means of an optical interface. The basic design of an opto-coupler consists of an LED that produces light and a photo-sensitive transistor that is used to detect the emitted light. Both the LED and photo-sensitive transistor are enclosed in a light-tight body or package with metal leads for the electrical connections. LED is connected to control circuit which consists of low voltage digital circuits. Photo sensitive transistor is connected to turn on the power devices connected to high voltage circuits to control high power. In this way it provides complete isolation between low voltage digital circuits and high voltage power circuits. If optocoupler is not connected between low voltage digital circuits and high voltage power circuit, the digital circuits will be damaged due to high voltage circuit transients. Further opto isolators are used to trigger power devices such as MOSFET, IGBT etc in inverter circuits used in uninterruptable power supply.

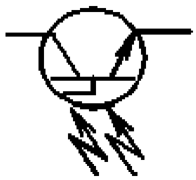
Optocoupler applications

- Used where complete isolation is required between input and output.
- Used in signal isolation and power supply regulation.
- Used in microprocessor input/output switching, DC and AC power control, PC communications.

IR receiver (transistor)

Infrared (IR) receiver transistor or IR transistor is used to pick up IR signal emitted from IR diode. IR transistor (receiver) and IR diode (transmitter) are most commonly found in consumer electronics. The way this technology works is that one component (IR diode) flashes an infrared light in a particular pattern, which another component (IR transistor) picks up IR signal. These transmitters and receivers are found in remote controls for different types of devices, such as television and DVD player. Consumer electronic remote control uses infrared light. A remote control flashes a pattern of invisible light called IR signal using IR diode, which is picked up and then turned on an instruction, by the receiver module. The parts necessary to construct transmitter and receiver are inexpensive, but these systems are limited to line of sight operation. An IR transistor is shown in fig. 7.13(a) and the symbol of IR receiver is shown in fig. 7.13(b).

(a) IR Receiver transistor



(b) Symbol of IR transistor

Fig. 7.13

Exercise

1. Find the value of β if $\alpha = 0.99$. (Ans: $\beta = 99$)
2. Calculate I_E in a transistor for $\beta = 100$ and $I_B = 10\ \mu A$. (Ans: 1.01 mA)
3. A transistor has $\alpha = 0.9$, if $I_E = 10$ mA, calculate the values of β, I_C and I_B. (Ans: $\beta = 9$, $I_C = 9$ mA and $I_B = 1$ mA)
4. A transistor amplifier connected in CE mode has $\beta = 100$ and $I_B = 50\ \mu A$. Calculate the values of I_C, I_E and α. (Ans: $I_C = 5$ mA, $I_E = 5.05$ mA and $\alpha = 0.99$)

One mark questions

1. What is a transistor?
2. Write one important application of a transistor.
3. What is an npn transistor?
4. Draw the symbol of a npn transistor.
5. Draw the symbol of a pnp transistor.
6. Why is transistor called transfer resistor device?
7. How many pn junctions a transistor has?
8. What is an unbiased transistor?
9. What is a biased transistor?
10. Mention the heavily doped region of a transistor.
11. Write the relation between the current components of a transistor.
12. What does an arrow in the circuit symbol of transistor indicate?
13. In which mode of operation the transistor can be used as an amplifier?
14. In which modes of operation the transistor can be used as a switch?
15. What is an opto-coupler?

Two mark question

1. Why is collector of transistor made larger and moderately doped?
2. Distinguish between α_{dc} and β_{dc}.
3. Define α_{dc} and write its expression.
4. Define β_{dc} and write its expression.
5. Distinguish between cut-off region and saturation region.
6. What is a phototransistor? Draw its symbol.
7. Write any two applications of phototransistors.
8. Mention lightly doped and the moderately doped regions of a transistor.
9. What is an IR transistor?
10. Write any two applications of an IR transistor.

Three/Five mark questions

1. Explain the working of an npn transistor.
2. Explain the different types of transistor configurations.
3. Explain CE mode input and output characteristics of a npn transistor. Distinguish between the cutoff, active and saturation regions of a transistor.
4. Draw the output characteristics of a transistor in CE configuration. Show the different regions of operation. What are the biasing requirements for the transistor to operate in these regions?

Chapter 8

Digital Electronics

Introduction

The term digital has become part of our everyday vocabulary because of the dramatic way that digital techniques have become so widely used in almost all areas of life: computers, automation, robots, medical science and technology, transportation, entertainment, space exploration, and so on. Digital term is derived from the way the circuits perform operations by counting digits. It can apply to decimal numbers or any number system. Digital systems are systems that process discrete information. Discrete means distinct or separate or non-continuous manner.

Numerical Representation

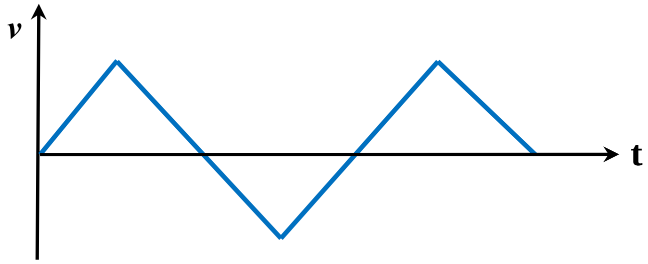
The quantities that are to be measured, monitored, recorded, processed and controlled may be analog or digital, depending on the type of system used. It is important that when dealing with various quantities which represent their values efficiently and accurately. There are basically two ways of representing the numerical value of quantities:

- Analog representation
- Digital representation

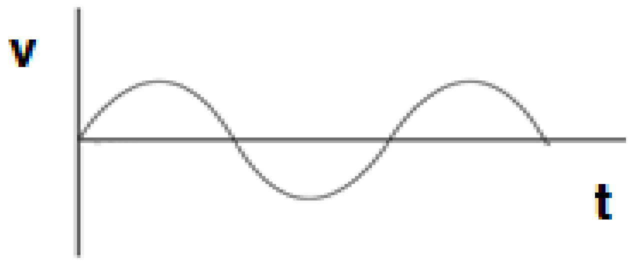
Analog signal

Systems which are capable of processing a continuous range of values varying with respect to time are called analog systems. A signal which can vary over a continuous range of values between minimum and maximum is called analog signal. In analog representation a quantity is represented by a voltage, current or meter movement that is proportional to the value of that quantity. Fig. 8.1(a) and fig. 8.1(b) represents analog signals.

Representation of analog voltage



Triangular Wave
Fig. 8.1(a)

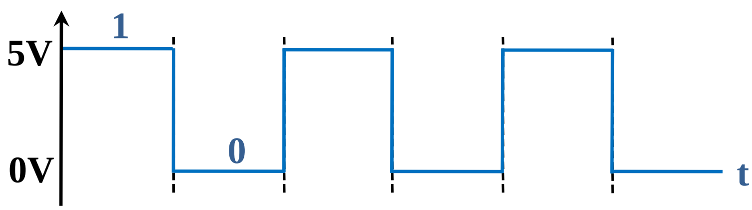


Sinusoidal wave
Fig. 8.1(b)

Digital signal

Systems which process discrete values are called digital systems. A signal which can have only two distinct values is called digital signal. Digital signals are generated by using pulse generator. Fig. 8.2 represents a digital signal.

Representation of digital voltage



Square Wave

Fig.8.2: Digital Signal

Importance of Digital Electronics

- Easier to design.
- Information storage is easy.
- Accuracy and precision are greater.
- Operations can be programmed.
- Digital circuits are less affected by noise, as long as the noise is not large enough to prevent us from distinguishing HIGH from LOW.
- More digital circuitry can be fabricated on IC chips.

Limitations of Digital Techniques

Most physical quantities in real world are analog in nature. These quantities are often the inputs and outputs that are being monitored, operated on, and controlled by a system. Thus conversion to digital format and reconversion to analog format is necessary.

Binary representation

Digital electronics today involves circuits that have exactly two possible states. A signal having only two states is said to be **binary** (bi means “two”). The binary system has two symbols 0 and 1.

The operation of an electronic circuit can be described in terms of its voltage levels. In the case of digital circuit, there are only two voltage states. Clearly one voltage is more positive than the other. Typically, the binary 0 and 1 are represented by two nominal voltage levels.

0 – Low, in terms of voltage it is 0 V
1 – High, in terms of voltage it is 5 V

Many functions of digital circuits follow logic rules. Therefore, they are called as logic circuits. The logic rules are of two types,

1. Positive logic
2. Negative logic

Positive logic

High or 1 is represented for higher voltage levels and LOW or 0 is represented for lower voltage levels. This is called Positive logic. Positive logic is widely used in all digital application. For example logic 1011 is represented in fig. 8.3.

Ex: A = 1011

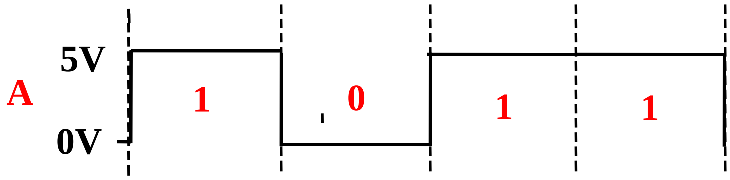


Fig. 8.3

Negative logic

HIGH or 1 represents lower voltage level and logic LOW or 0 represented for higher voltage level**.** This is called Negative logic. This logic is rarely used. For example logic 0100 is represented in fig. 8.4

Ex: A = 0100

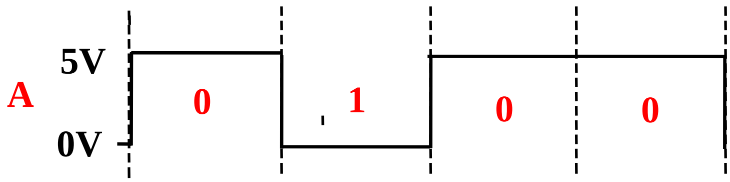


Fig.8.4 Negative logic

Number System

A number system is a mathematical system with base n, where n represents total numbers present in that system.

Radix point: Radix point is a base point used to separate the integer part and the fractional part of a number.

In general, a number in base-n system is represented as,

$$N_r = \underbrace{a_{n-1}\; a_{n-2} \ldots\ldots a_1\; a_0}_{\text{Integer part}} \;\underset{\uparrow\,\text{Radix point}}{.}\; \underbrace{a_{-1}\; a_{-2} \ldots\ldots a_{-m}}_{\text{Fraction part}}$$

There are three number systems which are widely used in digital electronics. They are,

1. Decimal number system
2. Binary number system
3. Hexadecimal number system

Need for the study of various number systems

- The decimal system is the most familiar number system to us because it is a tool that we use every day.
- Unfortunately, the decimal number system is not convenient to implement in digital systems.
- It is very difficult to design electronic equipment using decimal number system due to the reason that it works with 10 different numerals.
- On the other hand, it is very easy to design simple accurate electronic circuits that operate with only two numerals 0 and 1.
- Almost every digital system uses the binary number system as the basic number system of its operations, although other systems are often used in conjunction with binary
- Hexadecimal number system is used to express large binary numbers more concisely.

Weight or place value: Each position in a number has definite value called place value or weight

Base or radix: The number of distinct symbols used in a number system is called base or radix of the number system.

Decimal Number System

- The number system with base 10 is the decimal number system. It uses 10 distinct numerals 0, 1, 2, 3, 4, 5, 6, 7, 8, 9.
- In general, decimal number is the sum of the products of each digit value and its positional value. The following table indicates positional values as power of 10.

10^{n-1}	.....	10^3	10^2	10^1	10^0	.	10^{-1}	10^{-2}	10^{-3}	......	10^{-m}

↑ **Most significant digit** ↑ **Decimal point** ↑ **Least significant digit**

Consider an example – Decimal number 427.89 is equal to,

$(427.89)_{10} = (4x10^2) + (2x10^1) + (7x10^0) + (8x10^{-1}) + (9x10^{-2})$

Binary Number System

A number system that uses only two numerals 0 and 1 is called **Binary Number System.**

In general, binary number is the sum of the products of each bit value and its positional value. The following table indicates positional values as power of two.

2^{n-1}	.....	2^3	2^2	2^1	2^0	.	2^{-1}	2^{-2}	2^{-3}	......	2^{-m}

↑ **Most significant bit** ↑ **Binary point** ↑ **Least significant bit**

Consider an example – Binary number $(101.01)_2$

$(101.01)_2 = (1x2^2) + (0x2^1) + (1x2^0) + (0x2^{-1}) + (1x2^{-2})$

Most significant bit – The left most bit of a binary number which has the highest place value is called most significant bit.

Least significant bit – The right most bit of a binary number which has the least place value is called least significant bit.

Important terms in binary number system

Bit – A binary digit is called a bit. (Bit is the abbreviation of Binary digit). Example: 0 or 1.

Nibble – A group of **four bits** is called a Nibble.
Example: 0110, 1110, etc.

Byte – A group of **eight bits** is called a Byte.
Example: 0110 1010, 1110 0101, etc.

Memory representation using bytes: Memory is the part of the digital system that stores information in binary form. Generally memory is expressed in bytes.

Size of the memory = (Number of bytes at each location) x (Number of memory location)

1 K byte memory = 2^{10} = 1024 bytes

1 M byte memory = 2^{20} bytes

1 G byte memory = 2^{30} bytes

1 T byte memory = 2^{40} bytes

Hexadecimal Number System

A number system that uses sixteen distinct symbols **0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E** and **F** is called hexadecimal Number System. The base of hexadecimal number is 16. In this system A, B, C, D, E and F represents decimal numbers 10, 11, 12, 13, 14 and 15 respectively.

The following table indicates positional value of hexadecimal number system.

16^{n-1}	.....	16^3	16^2	16^1	16^0	.	16^{-1}	16^{-2}	16^{-3}	16^{-4}	......	16^{-m}

↑ ↑ ↑

Most significant digit **Hexadecimal point** **Least significant digit**

Consider an example – Hexadecimal number $(3B9.A2)_{16}$

$(3B9.A2)_{16} = (3x16^2) + (Bx16^1) + (9x16^0) + (Ax16^{-1}) + (2x16^{-2})$

$= (3x256) + (11x16) + (9x1) + (10x0.0625) + (2x0.003906)$

Purpose of using Hexadecimal number system

In digital system, when long binary numbers are used, it is difficult to read and write. Thus machine language is initially programmed using hexadecimal number system. Therefore hexadecimal number system is used to express large binary numbers more concisely.

Table representing decimal, hexadecimal and binary number

Decimal number	Hexadecimal number	Binary number
0	0	0000
1	1	0001
2	2	0010
3	3	0011
4	4	0100
5	5	0101
6	6	0110
7	7	0111
8	8	1000
9	9	1001
10	A	1010
11	B	1011
12	C	1100
13	D	1101
14	E	1110
15	F	1111

Conversion from one number system to another

A number is a symbolic representation of a quantity. Therefore any quantity that can be represented in one number system can also be represented in another number system.

Binary to Decimal conversion

Any binary number can be converted to its decimal equivalent by summing together the product of each bit and its weight. The weights assigned to each bit position is given below.

Binary weight	2^{n-1}	.....	2^4	2^3	2^2	2^1	2^0
Each bit positional value	2^{n-1}	.....	16	8	4	2	1

↑ (MSB) (LSB) ↑

Illustration 1: Convert the binary number $(1111)_2$ to decimal number.

Solution:

$$(1111)_2 = 1 \times 2^3 + 1 \times 2^2 + 1 \times 2^1 + 1 \times 2^0$$
$$= 1 \times 8 + 1 \times 4 + 1 \times 2 + 1 \times 1$$
$$= (15)_{10}$$
$$(1111)_2 = (15)_{10}$$

Illustration 2: Convert the binary number 110011_2 to decimal number.

Solution:

$$(110011)_2 = 1 \times 2^5 + 1 \times 2^4 + 0 \times 2^3 + 0 \times 2^2 + 1 \times 2^1 + 1 \times 2^0$$
$$= 1 \times 32 + 1 \times 16 + 0 \times 8 + 0 \times 4 + 1 \times 2 + 1 \times 1$$
$$(110011)_2 = (51)_{10}$$

Hexadecimal to Decimal conversion

Any hexadecimal number can be converted to its decimal equivalent by summing together the product of each bit and its weight. The weights assigned to each bit position is given below,

Hexadecimal weight	16^{n-1}	...	16^3	16^2	16^1	16^0
Each bit position value	16^{n-1}	...	4096	256	16	1

↑ (MSB) (LSB) ↑

Illustration: Convert the Hexadecimal number $(F09)_{16}$ to decimal number.

Solution:

$$(FO9)_{16} = F \times 16^2 + 0 \times 16^1 + 9 \times 16^0$$
$$= 15 \times 256 + 0 \times 16 + 9 \times 1$$
$$= 3840 + 0 + 9$$
$$(F09)_{16} = (3849)_{10}$$

NOTE: **A = 10**
B = 11
C = 12
D = 13
E = 14
F = 15

Decimal to Binary Conversion

- When converting from **decimal number to binary number** the given decimal number is divided by 2. The result has a quotient and a remainder. The quotient is again divided by 2. The process is continued until the quotient becomes less than 2.

- The remainder after each division is noted. The equivalent binary number is obtained by writing the remainders in reverse order (Bottom to Top).

Illustration 1: Convert the decimal number $(26)_{10}$ to binary number.

Solution: Given – Decimal integer = 26

26 ÷ 2	= 13	with remainder	0→LSB
13 ÷ 2	= 6	with remainder	1
6 ÷ 2	= 3	with remainder	0
3 ÷ 2	= 1	with remainder	1
1 ÷ 2	= 0	with remainder	1→MSB

$\boxed{(26)_{10} = (11010)_2}$

Illustration 2: Convert the decimal number $(13)_{10}$ to binary number.

Solution:

2	13	
2	6 - 1	→ LSB (Top)
2	3 - 0	
2	1 - 1	
	0 – 1	→ MSB (Bottom)

$(13)_{10} = (1101)_2$

Decimal to Hexadecimal Conversion

- When converting from **decimal number to hexadecimal number** the given decimal number is divided by 16. The result has a quotient and a remainder. The quotient is again divided by 16. The process is continued until the quotient becomes less than 16.
- The remainder after each division is noted. The equivalent hexadecimal number is obtained by writing the remainders in reverse order (Bottom to Top).

Illustration 1: Convert the decimal number $(2922)_{10}$ to hexadecimal number.

Solution: Given – Decimal number = 2922

		Remainder	
16	2922	↓	
16	182 -	A	→ LSD (Top)
16	11 -	6	↑
	0 -	B	→ MSD (Bottom)

$$\boxed{(2922)_{10} = (B6A)_{16}}$$

Binary to Hexadecimal Conversion:

- The binary digits are grouped into groups of four bits starting from LSB. Zeros may be added to the left of a number to complete last group of four bits.
- Then each group of four bits is converted to its hexadecimal equivalent.

Illustration 1: Convert the binary number $(11101101)_2$ to Hexadecimal number.

Solution: Given binary number is 11101101

Groups of Four →	1110	1101
	↓	↓
Check for 4- bit →	1110	1101
	↓	↓
Hexadecimal number →	E	D

$$\boxed{(11101101)_2 = (ED)_{16}}$$

Illustration 2: Convert the binary number $(1010101100)_2$ to hexadecimal number.

Solution: Given binary number is 1010101100

4-bit grouping	→	0010	1010	1100
		↓	↓	↓
Hexadecimal number	→	2	A	C

$$\boxed{(1010101100)_2 = (2AC)_{16}}$$

Hexadecimal to Binary Conversion

While converting hexadecimal to binary each digit is converted into its four-bit binary equivalent.

Illustration 1: Convert the hexadecimal number $(DAC)_{16}$ to binary number.

Solution: Given hexadecimal number is DAC

Given hexadecimal number	→	D	A	C
		↓	↓	↓
Each digit decimal equivalent	→	13	10	12
		↓	↓	↓
4 bit binary equivalent	→	1101	1010	1100

$$\boxed{(DAC)_{16} = (1101\ 1010\ 1100)_2}$$

Binary Arithmetic

Binary arithmetic is essential in all digital computer and many other types of digital systems. The arithmetical operations are addition, subtraction, multiplication and division.

Binary Addition

The rules to perform binary addition are

0 + 0 = 0
0 + 1 = 1
1 + 0 = 1
1 + 1 = 0 with a carry 1

Example: Perform the binary addition for the numbers 1110 and 1101.

CARRY →	1	1				
		1	1	1	0	← Augend
		1	1	0	1	← Addend
Sum =	1	1	0	1	1	

Binary subtraction

The rules to perform binary subtraction are

0 - 0 = 0
0 - 1 = 1 with a borrow 1 i.e., 10 - 1 = 1
1 - 0 = 1
1 - 1 = 0

Example: Perform the Binary subtraction for the numbers 1001 from 1101.

		1	1	0	1	← Minuend
	-	1	0	0	1	← Subtrahend
Difference =		0	1	0	0	

Binary Multiplication

Multiplication of the binary numbers is done in the same way as multiplication of the decimal numbers. The rules to perform binary multiplication are

0 × 0 = 0
0 × 1 = 0
1 × 0 = 0
1 × 1 = 1

Example: Perform the Binary multiplication of 100_2 and 10_2

$$\begin{array}{r} \underline{1\ 0\ 0 \times 10} \\ 0\ 0\ 0 \\ \underline{1\ 0\ 0\ +} \\ \underline{1\ 0\ 0\ 0} \end{array}$$

Ans = 1000_2

Binary Division: The rules to perform binary division are

0 ÷ 0 = not defined
0 ÷ 1 = 0
1 ÷ 0 = not defined
1 ÷ 1 = 1

Example: Perform the Binary division of 1010_2 by 10_2

$$\begin{array}{rl} \mathbf{0101} & \longrightarrow \text{Quotient} \\ 10\ \overline{)\,1010} & \\ -\ \underline{10} & \\ 0010 & \\ -\ \underline{10} & \\ \underline{00} & \longrightarrow \text{Reminder} \end{array}$$

$\boxed{\text{Ans} = 0101_2}$

1's and 2's complement of binary number

The 1's complement and the 2's complement of a binary number help to do the subtraction by the method of addition.

1's complement of binary numbers

The 1's complement of a binary number is obtained by changing each 0 to 1 and 1 to 0.

Example: Perform the 1's complement of the given binary number $(101110)_2$

Solution: Given binary number is **1 0 1 1 1 0**

↓ ↓ ↓ ↓ ↓ ↓

1's complement of $(101110)_2$ is **0 1 0 0 0 1**

2's complement of binary numbers

The **2's complement** of a binary number is obtained by adding 1 to the 1's complement of the number.

2's complement = 1's complement + 1 to LSB

Examples 1: Perform the 2's complement of the given binary number 110111_2

Solution: Given binary number = **1 1 0 1 1 1**

↓ ↓ ↓ ↓ ↓ ↓

1's complement of 110111_2 = **0 0 1 0 0 0**

Add 1 to1's complement = **+ 1**

2's complement of 110111_2 = **0 0 1 0 0 1**

$$\boxed{\text{Ans} = (001001)_2}$$

Subtraction of binary numbers using 1's complement method

To subtract a smaller number from a larger number using 1's complement method

Step: 1 Obtain the 1's complement of the subtrahend number.

Step: 2 Add 1's complement of subtrahend to the minuend.

Step: 3 Adding always results in a final carry called **end around carry.** This end around carry is discarded. Add 1 to the LSB of the sum obtained in step 2. The resultant bits give the required answer.

Examples 1: Perform the 1's complement subtraction for the given binary numbers 1101_2 from 1010111_2

Solution:

Step 1: 1's complement the subtrahend

Subtrahend → 0001101_2

1's complement of subtrahend → 1110010_2

Step 2: Add Minuend and 1's complement of subtrahend

Minuend	→		1	0	1	0	1	1	1
1's complement of subtrahend	→		+ 1	1	1	0	0	1	0
		~~1~~	1	0	0	1	0	0	1
Step 3: Add 1									+ 1
Answer			**1**	**0**	**0**	**1**	**0**	**1**	**0**

$\boxed{\text{Ans} = 1001010_2}$

Conform answer: $87_{10} - 13_{10} = 74_{10}$

Subtraction of binary numbers using 2's complement method

To subtract a smaller number from a larger number using 2's complement method

Step 1: Obtain the 2's complement of the subtrahend.

Step 2: Add the 2's complement of subtrahend to the minuend.

Step 3: Adding always results in a final carry called end carry (EC). This end carry bit is discarded. The remaining bits give the required answer.

Example: subtract 101_2 from 1101_2 using 2' s complement method
Solution:

Step 1: 2's complement of the subtrahend

Minuend → 1101_2 = $\mathbf{13_{10}}$

Subtrahend → 0101_2 = $\mathbf{5_{10}}$

1's complement of subtrahend → 1010

+ 1

2's complement of the subtrahend → 1011

Step 2: Add 2's complement of the subtrahend to the minuend

			1	1	0	1
2's complement of subtrahend →		+	1	0	1	1
Step 3: Discard the end carry	~~1~~		1	0	0	0

After discarding the end carry, Answer is $(1000)_2$

Sign magnitude binary numbers

There are many schemes for representing negative integers with patterns of bits. One scheme is **sign-magnitude.** For n-bit word, left-most bit is sign-bit, 0 for positive number and 1 for negative number, and remaining n-1 bits represent integer magnitude. In other words, for larger binary numbers, the MSB always represent the sign and the remaining bits always stand for the the magnitude.

Representing a sign magnitude numbers

Given number is $25_{10} = 11001_2$

Then **0** 11001 = +25

1 11001 = -25

In the above example 0 in the MSB position represents +ve and 1 in the MSB position represents –ve number.

Boolean Algebra

Boolean algebra is the study of 'mathematical theory of logic'. It was initially formulated by George Boole, a mathematician. In Boolean algebra, each variable can only assume one of the two values 1 and 0. It is used in the design, maintenance and analysis of digital circuits.

Boolean operations

The basic logic operations are

1) OR operation (Boolean addition)
2) AND operation (Boolean multiplication)
3) NOT operation (Boolean negation)

OR operation

1) $A + 0 = A$

2) $A + 1 = 1$

3) $A + A = A$

4) $A + \overline{A} = 1$

AND operation

1) $A \cdot 0 = 0$

2) $A \cdot 1 = A$

3) $A \cdot A = A$

4) $A \cdot \overline{A} = 0$

NOT operation

$\overline{\overline{A}} = A$

Basic Laws and Theorems of Boolean Algebra

Commutative laws

1) $A+B = B+A$
2) $AB = BA$

Associative laws

1) $A(BC) = (AB)C$
2) $A+(B+C) = (A+B)+C$

Distributive laws

1) $A(B+C) = AB+AC$
2) $A+BC = (A+B)(A+C)$

Other Boolean laws

1) $A+AB = A$
2) $A+\overline{A}B = A+B$
3) $AB + A\overline{B} = A$

De-Morgan's Theorems

First Theorem: The complement of a logical sum is equal to the logical product of the compliments.

$$\overline{A+B} = \overline{A} \cdot \overline{B}$$

Second Theorem: The complement of a logical product is equal to the logical sum of the compliments.

$$\overline{A \cdot B} = \overline{A} + \overline{B}$$

Proof:

A	**B**	$\overline{A}$	$\overline{B}$	**A+B**	**A·B**	**First Theorem**		**Second Theorem**	
						$\overline{A+B}$	$\overline{A}\cdot\overline{B}$	$\overline{A\cdot B}$	$\overline{A}+\overline{B}$
0	0	1	1	0	0	1	1	1	1
0	1	1	0	1	0	0	0	1	1
1	0	0	1	1	0	0	0	1	1
1	1	0	0	1	1	0	0	0	0

Boolean identities and simplification of Boolean expressions

An expression obtained by relating Boolean variables using Boolean functions is termed as Boolean expression.

1) Prove A+AB = A

Solution: LHS = A + AB

= A(1+ B)

= A·1 [∵ 1 + B = 1]

= A [∵ A·1 = A]

= RHS

∴ A + AB = A

2) Prove $A + BC = (A + B)(A + C)$

Solution : Consider RHS

$$
\begin{aligned}
(A+B)(A+C) &= A\cdot A + A\cdot C + B\cdot A + B\cdot C \\
&= A + AC + AB + BC \\
&= A(1+ C) + AB + BC \\
&= A\cdot 1 + AB + BC \\
&= A + AB + BC \\
&= A(1+ B) + BC \\
&= A\cdot 1 + BC \\
&= A + BC \\
&= LHS
\end{aligned}
$$

$$\therefore\ A+BC = (A+B)(A+C)$$

3) Prove $(A+\bar{A}B) = A+B$

Solution : $LHS = A + \bar{A}B$

We know that $(A+BC) = (A+B)(A+C)$

$$
\begin{aligned}
\therefore\quad (A+\bar{A}B) &= (A+\bar{A})(A+B) \\
&= 1\cdot (A+B) \\
&= A+B \\
&= RHS
\end{aligned}
$$

$$\therefore\ (A+\bar{A}B) = A+B$$

4) Simplify the equation $Y = A\bar{B}C + \bar{A}BC + ABC$

Solution :

$$
\begin{aligned}
Y &= A\bar{B}C + \bar{A}BC + ABC \\
&= A\bar{B}C + BC(\bar{A}+A) \\
&= A\bar{B}C + (BC\cdot 1) \\
&= A\bar{B}C + BC \\
&= C[B+\bar{B}A] \\
&= C(B+A) \\
Y &= BC + AC
\end{aligned}
$$

5) Simplify the equation $Y = AB + A(\overline{B + C})$

Solution:

$$Y = AB + A(\overline{B + C})$$
$$= AB + A\,(\bar{B}\cdot\bar{C})$$
$$= AB + A\,\bar{B}\bar{C}$$
$$= A\,(\,B + \bar{B}\bar{C}\,)$$
$$= A\,(\,B + \bar{C}\,)$$
$$= AB + A\bar{C}$$

6) Simplify the equation $Y = \overline{\left(\overline{\overline{AB}\cdot A}\right)\cdot(\overline{\overline{AB}\cdot B})}$

Solution:

$$Y = \overline{(\overline{\overline{AB}\cdot A})\cdot(\overline{\overline{AB}\cdot B})}$$
$$= \overline{(\overline{\overline{AB}\cdot A})} + \overline{(\overline{\overline{AB}\cdot B})}$$
$$= (\overline{AB}\cdot A) + (\overline{AB}\cdot B)$$
$$= (\bar{A} + \bar{B})A + (\bar{A} + \bar{B})B$$
$$= (\bar{A}\,A + \bar{B}\,A) + \bar{A}\,B + \bar{B}\,B$$
$$= 0 + \bar{B}A + \bar{A}B + 0$$
$$Y = A\bar{B} + \bar{A}B$$

7) Simplify the equation $Y = \overline{AB + AC} + \bar{A}\,\overline{B}\,C$

Solution :
$$Y = \overline{AB + AC} + \bar{A}\,\overline{B}\,C$$
$$= \overline{AB}\cdot\overline{AC} + \bar{A}\,\overline{B}\,C$$
$$= (\bar{A} + \bar{B})(\bar{A} + \bar{C}) + \bar{A}\,\overline{B}\,C$$
$$= \bar{A} + \bar{B}\,\bar{C} + \bar{A}\,\bar{B}\,C$$
$$= \bar{A} + \bar{B}\,(\,\bar{C} + C\,\bar{A}\,)$$
$$= \bar{A} + \bar{B}\,(\,\bar{C} + \bar{A}\,)$$
$$= \bar{A} + \bar{B}\,\bar{C} + \bar{A}\,\bar{B}$$
$$= \bar{A}\,(1 + \bar{B}) + \bar{B}\,\bar{C}$$
$$= \bar{A}\cdot 1 + \bar{B}\,\bar{C}$$
$$= \bar{A} + \bar{B}\,\bar{C}$$

Logic gates

A logic gate is a basic unit of digital circuit which makes logic decision. A logic gate has one or more inputs but only one output. The basic gates are AND gate, OR gate and NOT gate. Universal gates are NAND gate and NOR gate.

Basic Gates:

A logic gate which performs only a specific basic Boolean function is called Basic Gates. Basic gates are used in construction of digital circuits. Basic gates are constructed by using active components (such as diodes and transistors) and passive components (such as resistor).

Ex: Basic Gate	Boolean function (Basic logic Operation)
OR Gate	Boolean addition
AND Gate	Boolean multiplication
NOT Gate	Boolean negation

Timing diagram: A pictorial representation of inputs and output states of a logic circuit is known as timing diagram.

Ex: Timing diagram of AND gate for the inputs A, B and output Y

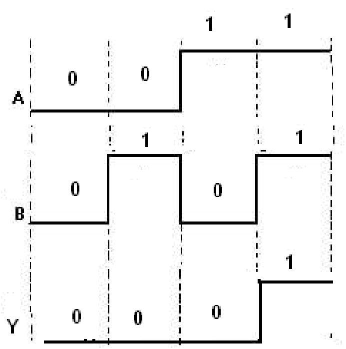


Fig. 8.5 Timing diagram

OR GATE:

OR gate is a basic gate which produces a high output if at least any one of the input is high. It performs Boolean addition.

The symbolic representation of two input OR gate is as shown in Fig. 8.6.

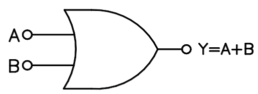


Fig. 8.6 Symbol of OR gate

If A and B are the two input variables and Y is the output variable, then the logic expression for the output is given by **Y = A + B**.

OR Gate using diodes

Construction: OR gate is constructed by using diodes and resistors. The circuit diagram of two input diode OR gate and the symbol of two input OR gate is shown in fig 8.7.

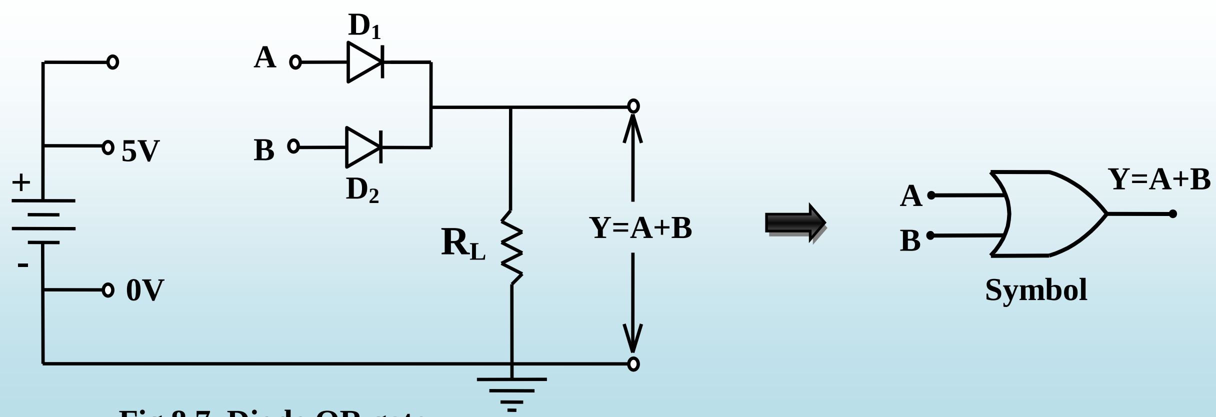


Fig 8.7. Diode OR gate

Working:

Let logic 0 = 0 V (LOW) and Logic 1 = 5 V (HIGH). Since this is a 2 input OR gate, there are four possible cases.

Case 1: When A = 0 and B = 0

When both the input voltages are low, both the diodes D_1 and D_2 are not conducting. Therefore no current flows through resistor R_L. Hence the output Y = 0.

Case 2: When A = 0 and B = 1

In this condition, the diode D_1 is reverse biased and acts like an open switch whereas the diode D_2 is forward biased and conduct. As a result current will flow through the resistor R_L, output Y = 1.

Case 3: When A = 1 and B = 0

In this condition, the diode D_2 is reverse biased and acts like an open switch whereas the diode D_1 is forward biased and conduct. As a result current will flow through the resistor R_L and output Y = 1.

Case 4: When A = 1 and B = 1

In this condition, both the diodes become forward biased and conduct. As a result current will flow through the resistor R_L and output Y = 0. The truth table and its timing diagram are as shown in fig. 8.8(a) and fig. 8.8(b) respectively.

Truth Table		
Inputs		Output
A	B	Y=A+B
0	0	0
0	1	1
1	0	1
1	1	1

Fig 8.8(a)

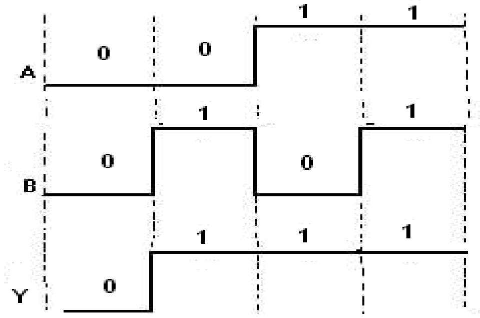


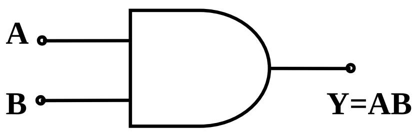
Fig 8.8(b)

Note: Diode in forward bias acts as ON state switch and it conducts. Diode in reverse bias acts as OFF state switch and it does not conduct.

AND Gate:

AND gate is a basic gate which produces a high output if and only if all the inputs are high. It performs Boolean multiplication.

If A and B are the two input variables and Y is the output variable, then the logic expression for the output is given by **Y = AB**. Logic Symbol for two input AND gate, and Timing Diagram are given in fig 8.9.



AND gate symbol

Timing Diagram

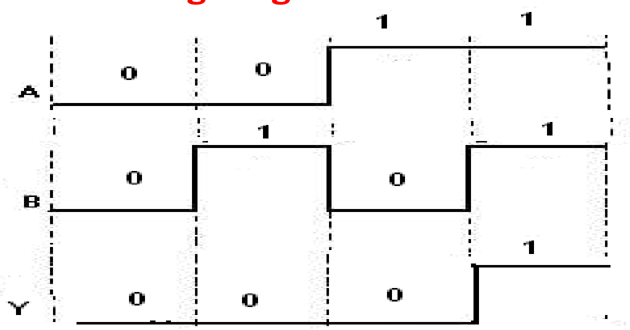


Fig.8.9. Symbol of two input AND gate with timing diagram

Two input diode AND gate

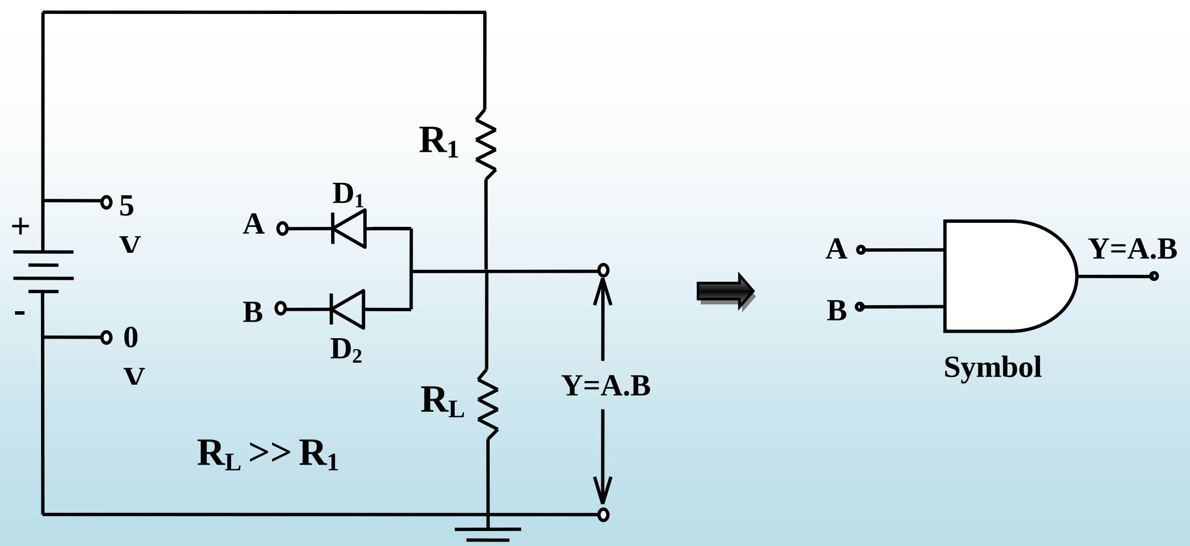


Fig 8.10. Diode AND gate

Working:

Case 1: When A = 0 and B = 0

During this condition cathode terminals of both the diode are directly connected to the ground. Therefore, the diodes D_1 and D_2 are forward biased by the battery V_{CC} through resistor R_1 then D_1, D_2 conducts. The output voltage is equal to knee voltage V_k of the diode. Hence output **Y = 0.**

Case 2: When A = 0 and B = 1

In this case the diode D_1 is grounded and diode D_2 is reverse biased and stop conducting. The diode D_1 will now conduct due to forward biasing. The output voltage is equal to V_k of diode. Hence output **Y = 0.**

Case 3: When A = 1 and B = 0

During the above condition the diode D_1 is reverse biased and stop conducting. The diode D_2 is grounded and therefore it becomes forward biased. The output voltage is equal to V_k of diode. Hence output **Y = 0.**

Case 4: When A = 1 and B = 1

During the above condition both the diodes (D_1 and D_2) are reverse biased and stop conducting. Now current flows through R_L producing a high output voltage across R_L. Hence the output **Y = 1**

Working Table of Diode AND gate

Voltage table		
Inputs		Output
A	B	Y = AB
0 V	0 V	0 V
0 V	5 V	0 V
5 V	0 V	0 V
5 V	5 V	5 V

Truth Table		
Inputs		Output
A	B	Y = AB
0	0	0
0	1	0
1	0	0
1	1	1

NOT Gate:

NOT gate is a basic gate which complements the input signal value. It performs Boolean negation. It is also called as an inverter. It is a logic gate with only one input and one output. Logic Symbol of NOT gate is shown in fig. 8.11.

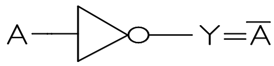


Fig.8.11. Logic symbol of NOT gate

Transistor NOT gate: The circuit of NOT gate using a transistor is shown in fig. 8.12.

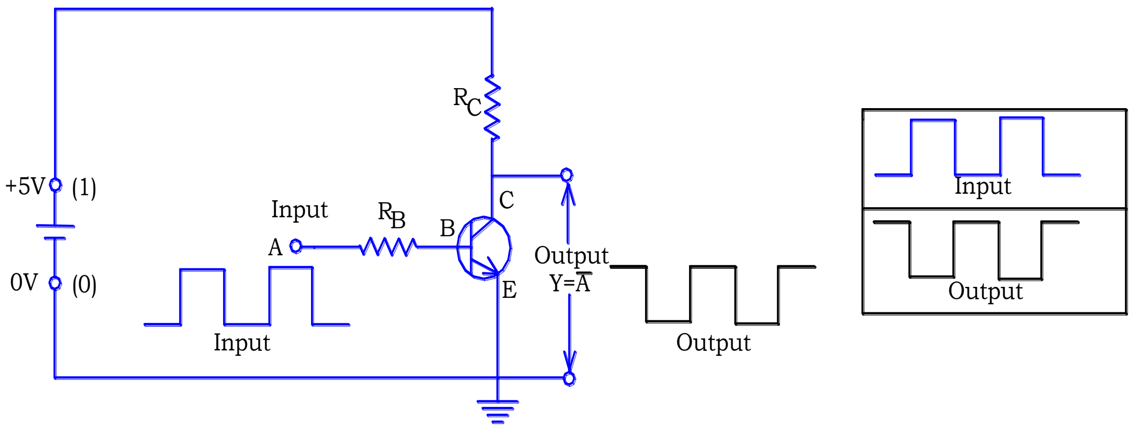


Fig 8.12 Transistor not gate with I/P and O/P waveforms

Working:

Case 1: When A = 0

The base current becomes zero and the transistor is driven to cut-off mode. Hence, the transistor acts like a open switch then supply voltage (5V) appears at the collector. Thus Y = 1.

Case 2: When A = 1

The base current of the transistor flows and the transistor is driven to saturation mode. Hence the transistor acts like a closed switch which in turn drops the potential at the collector to 0 V. Thus Y = 0.

Voltage response   Truth table

Input	Transistor state	Output
A	Q	$Y = \bar{A}$
0 V	Cut off	5 V
5 V	Saturation	0 V

Input	Output
A	$Y = \bar{A}$
0	1
1	0

NAND gate:

NAND gate is a universal gate which performs complement of AND logic. In NAND gate the output is high only when any of the input is low.

The Boolean expression is given by $\mathbf{Y = \overline{AB}}$

The logic circuit symbol is shown in fig 8.13.

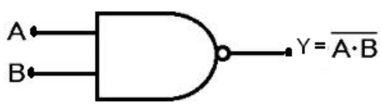


Fig.8.13. Symbol of two input NAND gate

Truth Table		
Inputs		**Output**
A	**B**	$\mathbf{Y = \overline{AB}}$
0	0	1
0	1	1
1	0	1
1	1	0

Diode Transistor Logic (DTL) gates

DTL gates consists of diodes, transistor and resistors. Transistor act as a inverter and diodes are used as switches.

DTL NAND gate

DTL NAND gate is an **universal gate** constructed by using diodes and transistor. The circuit of DTL NAND gate is as shown in fig. 8.14. Diodes D_1 and D_2 along with resistor R_1 form an AND gate while the transistor circuit inverts the output of AND gate.

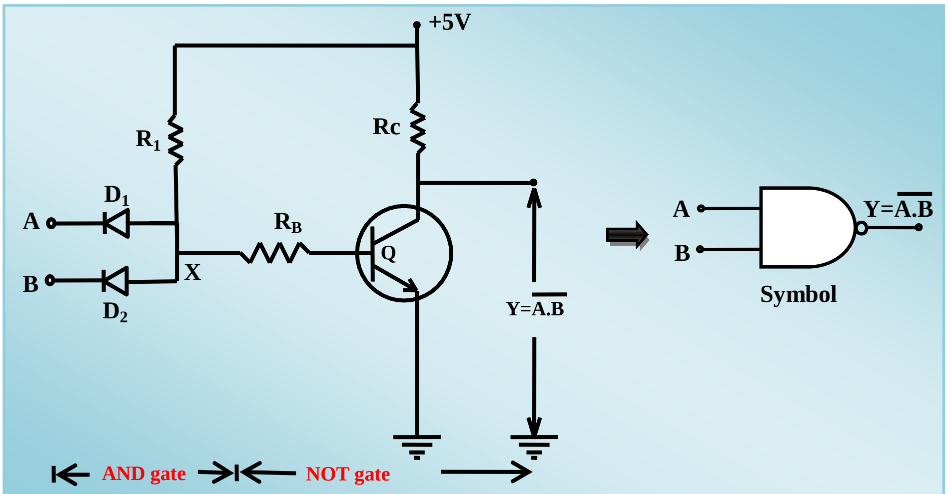


Fig 8.14. DTL NAND gate

Working

Case 1: When A = 0, B = 0

In this case both diodes D_1 and D_2 are forward biased and current flows from the supply through R_1, diodes and input terminals to the ground. Hence no current enter the base terminal of the transistor. The transistor is then said to be operated at cut off region. Therefore, the output Y = 1.

Case 2: When A = 0, B = 1

In this case, D_1 is forward biased and D_2 is reverse biased. Hence, transistor doesn't conduct and the output Y = 1.

Case 3: When A = 1, B = 0

In this case, D_2 is forward biased and D_1 is reverse biased. The transistor again acts as an open circuit. Therefore, the output Y = 1.

Case 4: When A = 1, B = 1

In this case both diodes D_1 and D_2 are reverse biased. They will not conduct. The $+V_{CC}$ supply pass the current through R_1, into the base of the transistor, which drives the transistor into saturation region. Hence, the Y = 0.

Voltage response of NAND gate		
Inputs		Output
A	B	$Y = \overline{A.B}$
0 V	0 V	5 V
0 V	5 V	5V
5 V	0 V	5 V
5 V	5 V	0 V

Truth Table		
Inputs		Output
A	B	$Y = \overline{A.B}$
0	0	1
0	1	1
1	0	1
1	1	0

NOR gate:

NOR gate is an universal gate which performs the complement of OR logic. **In NOR gate the output is high if and only if all the inputs are low.**

If A and B are the two input variables and Y is the output variable, then the logic expression for the output is given by $\mathbf{Y = \overline{A + B}}$

The logic circuit symbol of NOR gate is shown in fig 8.15

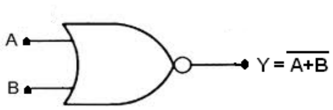


Fig.8.15. Symbol of two input NOR gate

Truth Table		
Inputs		**Output**
A	**B**	$\mathbf{Y=\overline{A + B}}$
0	0	1
0	1	0
1	0	0
1	1	0

DTL NOR gate

DTL NOR gate is a universal gate constructed by using diodes and transistor. The circuit of DTL NOR gate is as shown in fig.8.16. Diodes D_1 and D_2 form OR gate, while the transistor circuit inverts the output of OR gate. Therefore, the whole circuit forms a NOR gate.

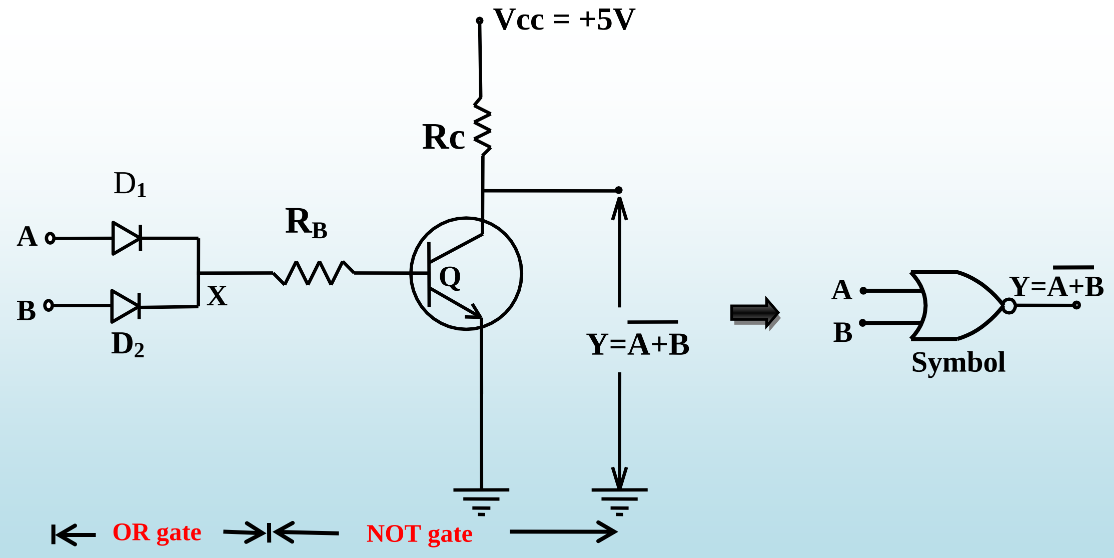


Fig 8.16. DTL NOR gate

Voltage response		
Inputs		Output
A	B	$Y=\overline{A+B}$
0 V	0 V	5 V
0 V	5 V	0 V
5 V	0 V	0 V
5 V	5 V	0 V

Truth Table		
Inputs		Output
A	B	$Y=\overline{A+B}$
0	0	1
0	1	0
1	0	0
1	1	0

Working

Case 1: When A = 0 and B = 0

Here, both the diodes are reverse biased. Therefore no current flows into the base of transistor Q. Hence transistor go to cut off region and acts as a open switch. Therefore output Y = 1.

Case 2: When A = 0 and B = 1

In this case, diode D_1 is reverse biased and D_2 is forward biased. Therefore sufficient current will flow into the base of transistor Q, which drives the transistor into saturation. Therefore output Y = 0.

Case 3: When A = 1 and B = 0

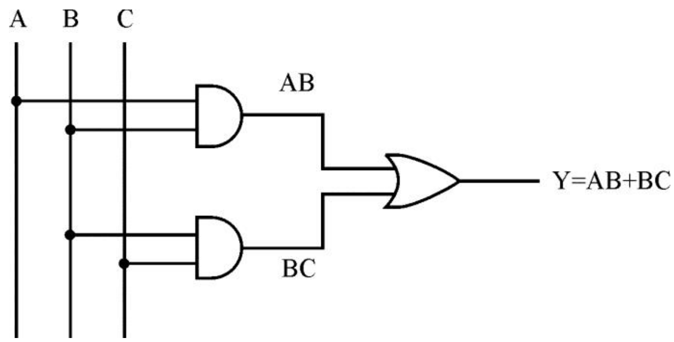
Under this condition, diode D_1 is forward biased and D_2 is reverse biased. Therefore transistor remains in saturation region and output Y = 0.

Case 4: When A = 1 and B = 1

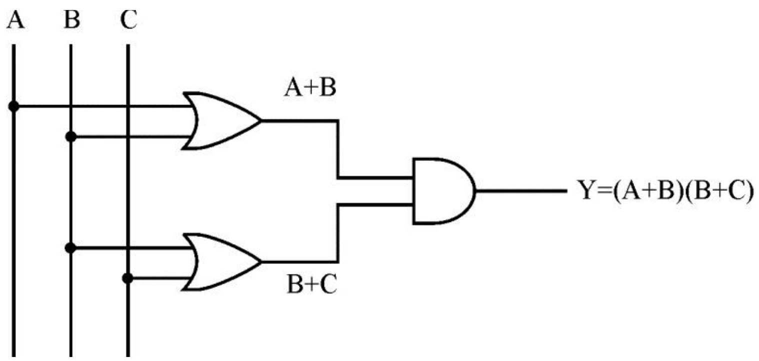
In this case both the diodes are forward biased. Sufficient current flows into the base of transistor and the transistor is driven into saturation. Therefore output Y = 0.

Logic circuits for Logic expressions

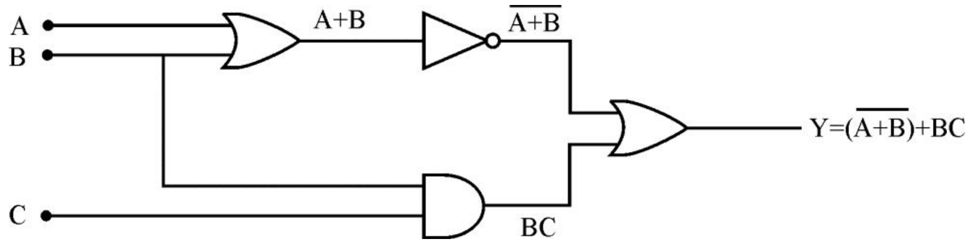
1) Y = AB + BC



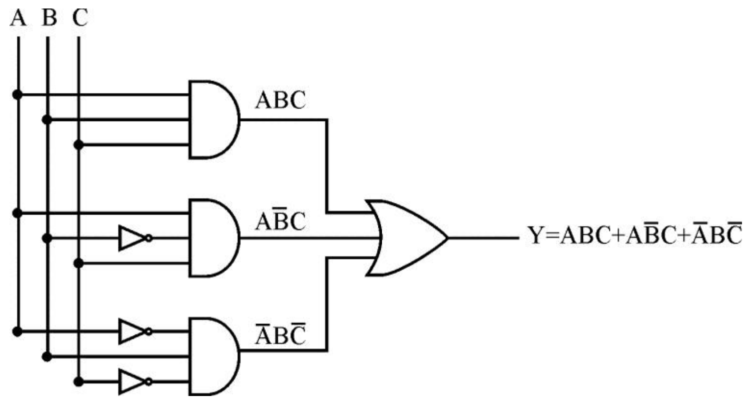
2) Y = (A+B)(B+C)



3) $Y = (\overline{A + B}) + B \cdot C$



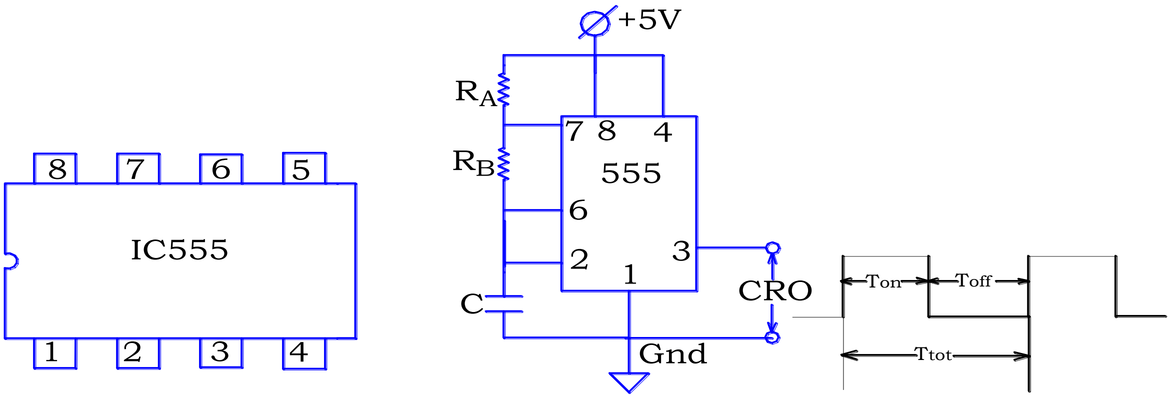
4) $Y = ABC + A\overline{B}C + \overline{A}B\overline{C}$



Pulse (clock) generator using 555.

Astable Multivibrator: The 555 timer is a Transistor - Transistor logic (TTL) integrated circuit. It is used as an oscillator to provide a clock waveform to digital circuits and many more timing applications. It has two distinct output levels. Neither of the output levels is stable. Therefore this circuit is said to be Astable Multivibrator. The timing capacitor is charged toward $+V_{CC}$ through resistors R_A and R_B and then discharged towards ground by R_B only. The frequency of oscillation and duty cycle are accurately controlled by two external resistors and a single timing capacitor.

Pin diagram of 555 timer is shown in fig 8.17(a). Circuit diagram of astable multivibrator using LM555 is as shown in fig. 8.17(b). The output waveform is showing fig. 8.17(c).



(a) Pin diagram of 555 (b) 555 Astable multivibrator (c) Output

Fig. 8.17

The frequency of oscillation is $f = \frac{1}{T} = \frac{1.44}{(R_A+2R_B)C}$

The duty cycle $= \frac{\text{ON time}}{\text{Total time}} = \frac{R_A+R_B}{R_A+2R_B}$

Monostable Pulse Generator

Monostable multivibrator has one stable output state. Output of 555 monostable goes high when the negative going triggering pulse is applied to the pin 2 of 555 timer. With few changes in wiring an astable multivibrator can be converted into monostable pulse generator as shown in fig. 8.18. On period of the output is given by $T_{ON} = 1.1R_1C$. It is widely used in industry for many different timing applications. Input output waveforms are shown in fig. 8.19.

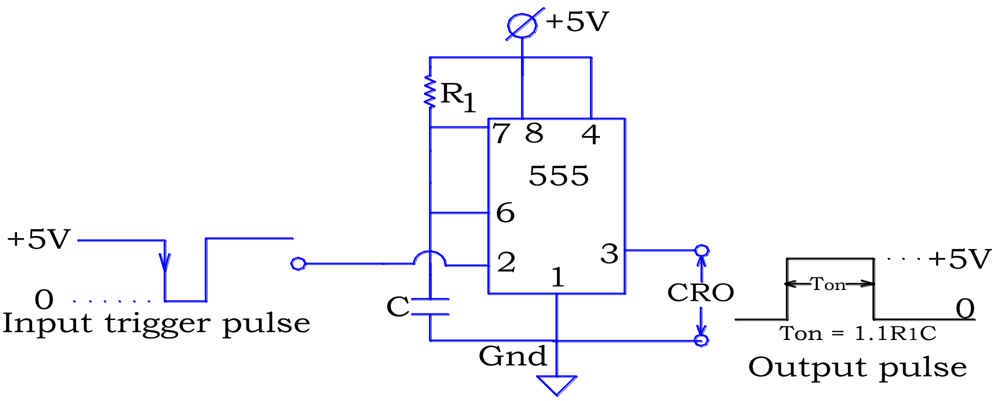


Fig. 8.18 Monostable multivibrator

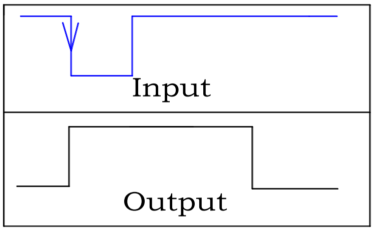


Fig. 8.19 input output waveforms

The Output of the monostable is a positive pulse, and the width of the pulse is given by

$$t = 1.1(R_1C)$$

Questions

One mark questions

1. What is digital signal?
2. What is a bit?
3. What is a nibble?
4. What is a byte?
5. What is meant by radix or base of a number system?
6. How many basic symbols are used in binary number system?
7. How many basic symbols are used in hexadecimal number system?
8. Write the basic symbols used in decimal number system?
9. Write the basic symbols used in binary number system?
10. Write the basic symbols used in hexadecimal number system?
11. What is meant by 1's complement of a binary number?
12. What is meant by 2's complement of a binary number?
13. What is the purpose of 1's and 2's complement of a number system?
14. Write the 1's complement of the binary number 11001.
15. Write the 2's complement of the binary number 11001.
16. What is a logic gate?
17. What is positive logic?
18. What is negative logic?
19. What type of gate is obtained when two switches are in parallel?
20. What is an OR gate?

21. What is an AND gate?
22. What is a NOT gate?
23. Write the logic symbol of an OR gate?
24. Write the logic symbol of an AND gate?
25. Write the logic symbol of a NOT gate?

Two mark questions

1. Distinguish between the digital and analog signals.
2. What is a bit? Give an example.
3. What is a byte? Give an example
4. What is a nibble? Give an example.
5. What is a memory?
6. Perform the binary addition of the number, $1100_2 + 1111_2$.
7. Perform the binary subtraction of the number, $11100_2 - 1111_2$.
8. Perform the binary multiplication of the number, $11100_2 \times 1001_2$.
9. Perform the binary division of the number, 1111_2 by 101_2.
10. What is the binary equivalent of $(DADA)_{16}$?
11. Find the 2's complement of the binary number 0111110000
12. Draw the logic symbol of a NOT gate and write its truth table of AND gate.
13. Write the truth table of AND gate.
14. Write the truth table of OR gate.
15. What is timing diagram? Sketch the timing diagram of NOT gate?
16. Sketch the timing diagram of OR gate.
17. What is positive logic and negative logic?
18. What is NAND gate? Write its circuit symbol.
19. What is NOR gate? Write its circuit symbol.
20. Write the truth table of NAND gate.

Three/five mark questions

1. Subtract 27_{10} from 56_{10} using 2's complement method. $[11101]_2$
2. Convert the given decimal number 89227_{10} to hexadecimal number system. $[15C8B]_H$
3. Subtract 103_{10} from 134_{10} using 1's complement method. $[11111]_2$
4. Subtract 123_{10} from 234_{10} using 2's complement method. $[1101111]_2$

5. Write the purpose of octal and hexadecimal number system.
6. Explain the transistor NOT gate.
7. Write the limitations of digital technology. Explain with a circuit diagram the action of a 2 input diode OR gate.
8. Explain with a circuit diagram the action of a 2 input Diode AND gate.
9. Explain with a DTL circuit the action of 2 input NAND gate.
10. Explain the construction and working of DTL NOR gate

Problems

Convert the following **decimal numbers to binary number**:

1. 37_{10} — $[100101]_2$
2. 375_{10} — $[101110111]_2$
3. 435_{10} — $[110110011]_2$
4. 500_{10} — $[111110100]_2$

Convert the following **binary numbers to decimal number**:

1. 110110_2 — $[54]_{10}$
2. 10001101_2 — $[141]_{10}$
3. 1111111111_2 — $[1023]_{10}$
4. 10110001111_2 — $[1423]_{10}$

Convert the following **decimal numbers to hexadecimal number**:

1. 3338_{10} — $[D0A]_{16}$
2. 23752_{10} — $[5CC8]_{16}$
3. 6779_{10} — $[1A7B]_{16}$
4. 785622_{10} — $[BFCD6]_{16}$

Convert the following **hexadecimal numbers to decimal number**:

1. 194_{16} — $[404]_{10}$
2. $FE5_{16}$ — $[4069]_{10}$
3. $4DD_{16}$ — $[1245]_{10}$
4. $A756_{16}$ — $[42838]_{10}$

Convert the following **Binary numbers to Hexadecimal number**:

1. 100110_2 [26]$_{16}$
2. 10001101_2 [8D]$_{16}$
3. 1100111111_2 [33F]$_{16}$
4. 1011000101_2 [2C5]$_{16}$

Convert the following **Hexadecimal numbers to Binary number**:

1. $CB01_{16}$ [1100 1011 0000 0001]$_2$
2. $2FE52_{16}$ [0010 1111 1110 0101 0010]$_2$
3. $4DD_{16}$ [0100 1101 1101]$_2$

Problems on binary arithmetic

Perform the **binary addition** for the following

1. $10101_2 + 1111_2$ [100100]$_2$
2. $111_2 + 01110_2$ [10101]$_2$
3. $1011111_2 + 111011_2$ [10011010]$_2$
4. $1011011_2 + 1101011_2$ [11000110]$_2$

Perform the **Binary Subtraction** for the following

1. $11101_2 - 10011_2$ [1010]$_2$
2. $111111_2 - 01110_2$ [110001]$_2$
3. $11011111_2 - 111011_2$ [10100100]$_2$
4. $11011011_2 - 1101011_2$ [1110000]$_2$

Perform the **Binary Multiplication** for the following

1. 11101_2 x 10_2 [111010]$_2$
2. 111111_2 x 011_2 [10111101]$_2$
3. 1101111_2 x 110_2 [1010011010]$_2$
4. 110111_2 x 111_2 [110000001]$_2$

Perform the **Binary Division** for the following

1. 1100_2 by 100_2 [11]$_2$
2. 111111_2 by 1001_2 [111]$_2$
3. 10100_2 by 100_2 [101]$_2$
4. 100011_2 by 111_2 [101]$_2$

Perform the **1's complement** for the following **Binary Numbers**

1. 11101_2 $[00010]_2$
2. 11111011_2 $[00000100]_2$
3. 11011010_2 $[00100101]_2$
4. 1101110000_2 $[0010001111]_2$

Perform the **2's complement** for the following **Binary Numbers**

1. 1110111_2 $[0001001]_2$
2. 11101111_2 $[00010001]_2$
3. 11011010_2 $[00100110]_2$
4. 1101110000_2 $[0010010000]_2$

Perform the **Binary Subtraction** for the following using the **1's complement**

1. 11101_2 - 10011_2 $[1010]_2$
2. 111111_2 - 01110_2 $[110001]_2$
3. 110111_2 - 1110_2 $[101001]_2$
4. 1101111_2 - 110111_2 $[111000]_2$

Perform the **Binary Subtraction** for the following using the **1's complement**

1. 55_{10} - 32_{10} $[10111]_2$
2. 55_{10} - 19_{10} $[100100]_2$
3. 88_{10} - 56_{10} $[100000]_2$
4. 58_{10} - 12_{10} $[101110]_2$

Perform the **Binary Subtraction** for the following using the **2's complement**

1. 55_{10} - 42_{10} $[1101]_2$
2. 59_{10} - 18_{10} $[101001]_2$
3. 99_{10} - 56_{10} $[101011]_2$
4. 67_{10} - 12_{10} $[110111]_2$

Perform the **Binary Subtraction** for the following using the **2's complement**

1. 11011_2 - 11001_2 $[10]_2$
2. 101001_2 - 10110_2 $[10011]_2$
3. 110111_2 - 101011_2 $[1100]_2$
4. 10101010_2 - 110111_2 $[1110011]_2$

Chapter-9

Practical Electronic Components, their specifications and PCB

Introduction: Before constructing and testing a circuit a clear idea of the availability of components for the particular applications is necessary. Also it is important to know the specifications of each components used in the circuit or project. All the components are available with their standard ratings. A complete idea on specifications of each component is necessary during the purchase of components from the shops. User should select the component with correct specifications to construct the circuit. If the specifications of the components are improperly selected they may be damaged due to over power, over voltage, over current etc. The circuit is usually constructed on general purpose boards which are readily available in shops. This chapter dealt with commonly used components, their important specifications and development of Printed Circuit Board.

Components part number

Specification of each component contains physical, mechanical and electrical parameters. Each parameter of a device cannot be remembered at all the times. All the specifications of a device are summarized and a part number is given by the manufacturer. Data sheet of the part number provides detailed specifications of the component. **Part number** is a unique code used to identify a particular item (or component) for the convenience of consumers or of manufacturer. Parts to be numbered usually include electrical items (wires, cables, connectors, switches, soldering lugs, crocodile clips), electronic components (diodes, transistors, integrated circuits).

Data sheet

A **datasheet** or **specification sheet** is a document summarizing the performance and other technical characteristics of a component (e.g. an electronic component) or a subsystem (e.g. a power supply). Typically, a datasheet is created by the component or subsystem manufacturer. A data sheet is usually used for technical communication to describe technical characteristics of an item or product. It can be published by the manufacturer to help people choose products or to help to use the products.

A typical datasheet for an electronic component contains the following information:

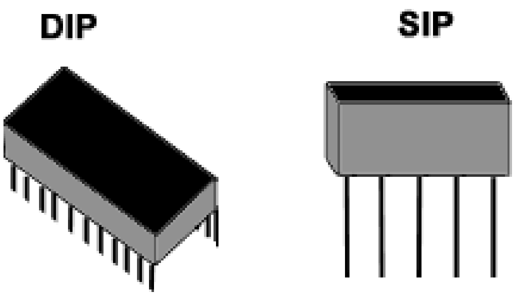
- Manufacturer's name
- Product number and name
- List of available package formats (with images) and ordering codes
- Functional descriptions
- Pin connection diagram
- Absolute minimum, maximum ratings (supply voltage, power consumption, temperatures range, etc.)
- Recommended operating conditions
- Graphs showing variations of parameters
- Input/output wave shape diagram
- Physical details showing dimensions.
- Test circuits.

Package:

A package of an electronic component gives details on body size, mount area, thickness, pins, pitch of the pins, power dissipation, tapping directions etc. Each electronic component has its own electronics package. Once the device is fabricated its terminals are brought out to metal contacts with standard packages. Some time heat sink is attached to the device terminals to dissipate the heat and the heat sink itself acts as a terminal. The package is designed for proper mounting of the device when it is connected to the circuit. Package name gives the physical dimension of the devices. This help to design PCB layout with component dimensions pitch before purchasing the component from the shop.

Some of the packages are

1. Single in-line package (or SIP) has one row of connecting pins.
2. Dual In-line Packages [DIP] or Dual In-Line [DIL] packages are packages with two rows of leads on two sides of the package.



Electronic component specifications:

Commonly available range of component values, power ratings, tolerance and maximum working voltages etc are mentioned in this section. However components are also available above or below the ranges specified as per the requirements of the user.

Resistors

Resistors have two main specifications. The first is its resistance value in ohms. The second is its power rating in watts. There are other specifications such as tolerance, working voltage etc but its power rating and resistance value are the most important specifications.

CFR (Carbon Film Resistor)

Specifications

a) Value: 1 Ω to 22 MΩ

b) Power rating: 1/8 W to 2 W

c) Tolerance: ±5%, ±10%, ±20%

d) Maximum working voltage †: 400 V

† The maximum value of DC voltage or AC voltage (rms) capable of being applied continuously to resistors

MFR (Metal film resistor)

Specifications
a) Value: 1 Ω to 22 MΩ
b) Power rating: 1/8 W to 2 W
c) Tolerance: ±0.1%, ±0.25%, ±0.5%, ±1%
d) Maximum working voltage : 500 V

SMD resistor

Specifications
a) Value: 1 Ω to 10 MΩ
b) Power rating: 1/16 W to 1 W
c) Tolerance: ±0.1%, ±0.25%, ±0.5%, ±1%
d) Maximum working voltage : 250 V

Wire wound resistor

Specifications
a) Value: 0.001 Ω – 100 kΩ
b) Power rating: 2 W to 25 W
c) Tolerance: ±5%
d) Maximum working voltage : 1000 V

Fusible resistor

A fusible resistor acts as an ordinary resistor under normal conditions, and as a fuse under fault conditions. These resistors protect the circuit connected to it by fusing itself under overload.

Specifications
a) Value: 0.1 Ω to 500 Ω
b) Power rating: 2 W to 10 W
c) Tolerance: ±5%
d) Maximum working voltage : 1000 V

Potentiometer

Specifications
a) Value: 100 Ω to 2.2 MΩ
b) Power rating: 1 W to 5 W
c) Value variations: Linear, logarithmic
d) Type: Wire wound, carbon compositions

Trimmer resistor

Specifications
a) Value: 10 Ω to 2.2 MΩ
b) Power rating: 0.25 W to 1 W
c) Screw type: Top screw, Side screw
d) Turns: Single turn, Multi turns

Capacitors

Mica capacitor

Specifications
a) Value: 1 pF to 0.01 μF
b) Maximum voltage ratings: 500 V
c) Maximum Tolerance: ±5%

Ceramic capacitor

Specifications
a) Value: 1 pF to 0.01 μF
b) Maximum voltage ratings: 10 kV
c) Maximum Tolerance: ±10%
d) Temperature range: -25^0 to +85^0 C

Polystyrene (Box) Capacitor

Specifications

a) Value: 10 pF to 1 µF

b) Maximum voltage ratings: 630 V

c) Maximum Tolerance: ±10%

d) Temperature range: -40^0 to $+85^0$ C

Electrolytic capacitor

Specifications

a) Value: 1 µF to 10000 µF polar

b) Maximum voltage ratings: 450 V

c) Maximum tolerance: ±15%

d) Temperature range: -40^0 to $+105^0$ C

SMD capacitor

Specifications

a) Value: 1 pF to 0.1 µF

b) Maximum voltage ratings: 100 V

c) Maximum tolerance: ±10%

d) Temperature range: -55^0 to $+125^0$ C

Variable capacitor - Trimmer capacitor

Specifications

a) Value: 1 pF to 100 pF

b) Maximum voltage ratings: 100 V

Inductors

Air core inductor

Specifications:
a) Value: 1 µH - 10 mH
b) Current rating: 1 mA to 1 A

Iron core inductor

Specifications:
a) Value: 1 mH to 500 mH
b) Maximum current rating: 10 amps

Ferrite core inductor

Specifications:
a) Value: 1 µH to 100 mH
b) Maximum current rating: 5 amps

Electro magnetic relay

Specifications:
a) DC voltages: 6 V, 12 V, 24 V
b) Relay type: SPST, SPDT, DPST, DPDT
c) Current: 1 A to 10 A

Transformers

Iron core transformer

Specifications:
a) Input voltages: 230 V
b) Frequency: 50 Hz
c) Output voltage: on requirement.
d) Output current: 50 mA to 100 A

Ferrite core transformer

Specifications:
a) Input voltages: 230 V
b) Output voltage: on requirement.
c) Output current: 10 mA to 10 A

Diodes

Rectifying diode

Specifications:
a) Current rating: 1 A to several hundred amps
b) Voltage rating: 50 V to several thousand volts
Part numbers:
1N4007 (1 A/1000 V), **1N5408** (3 A/1000 V)

Diode bridge module

Specifications:
a) Current rating: 1 A to several hundred amps
b) Voltage rating: 50 V to several thousand volts
Part number:
DB152 (100 V/1.5 A), **W02** (200 V/1.5 A)

Switching diode

Specifications:

a) Current rating: 10 mA to 2A

b) Voltage rating: 50V to several hundred volts

Part number:

1N4148 (150 mA/75 V), 1N4448 (500 mA/75 V)

Zener diode

Specifications:

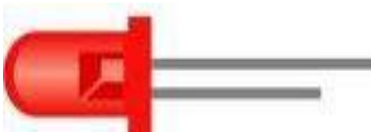
a) Zener break down voltage: 1.8 V to 110 V

b) Wattage rating: 0.25 W to 1 W

Part number:

1N3018 (8.2 V/1 W), 1N3019 (9.1 V/1 W),

Light emitting diode



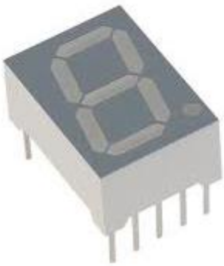
Specifications:

a) Diameter: 3 mm, 5 mm, 8 mm

b) Colour: red, yellow, green

c) Quality: high bright, low bright

Seven segment display



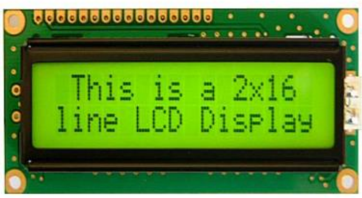
Specifications:

a) Dimension: 0.28” to 5.0”

b) Type: Common anode, common cathode

c) Quality: high bright, low bright

LCD display



LCD display specifications are number of lines (rows), and number of characteristics (column). A two line 16 characteristics (2x16) LCD display is shown. LCD displays are available with different rows and characteristics depending on the requirement.

Transistors

Transistors specification parameters are type (npn/pnp), maximum collector current I_C, maximum collector to emitter voltage V_{CE}, maximum power P_{tot}, case style and typical use such as audio, high frequency, or general purpose. Transistors of various ratings are available as per the requirements of the user.

npn Transistor Part number: **SL100** (500 mA/50 V), **2N2222A** (800 mA/75 V)

pnp Transistors part number: **SK100** (500 mA/50 V), **BC178** (200 mA/25 V)

Transistor case styles

Transistors are available with different case styles like TO-18, TO-39, TO-92, TO-202, TO-220, TO-66, TO-3 etc.

Transducer and Sensors:

Microphone

Micro phones are specified in terms of directivity, frequency response, sensitivity, signal to noise ratio.

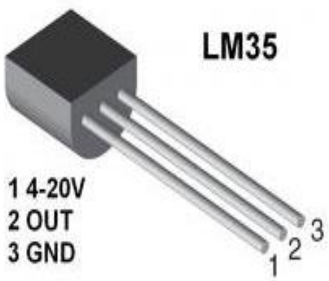
Speaker

Speakers are specified in terms of power, impedance, frequency response, applications like music, computer, phone, public addressing.

Thermistor

Thermistors are specified in terms of rated zero-power resistance (i.e. resistance at 25^0 C), maximum operating temperature range and tolerance range. Thermistors are selected by their resistance value at 25^0 C.

Temperature sensor



Temperature sensors are specified in terms of sensitivity (mV/^{0}C), accuracy, DC supply voltage.
LM 35 is a temperature sensor whose pin 1 must be connected to 4 V to 20 V DC w.r.t. pin 3. Output voltage at pin 2 is proportional to temperature by 10 mV/^{0}C. That is if the temperature is 25^0 C then the output shows 250 mV.

Light Dependent Resistor (LDR)

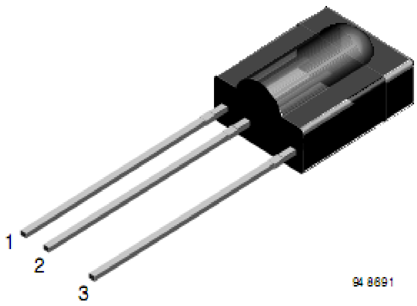
LDR's are specified in terms of rated resistance at 10 lux, sensitivity (Ω/10 lux), temperature range and power dissipations. LDR's are rated by its resistance value at 10 lux.

IR emitter diode

IR emitter diodes are specified in terms of viewing angle, diameter (3 mm, 5 mm), top emitter or side emitter.

Part number: TSAL5300, TSAL5100

IR receiver transistor



IR receiver transistors are specified in terms of receiving range (6-8 m), viewing angle, top or side reception.

Part numbers: TSOP1133, TSOP1156

Pinning:
1 = GND, 2 = V_S, 3 = OUT

Fixed IC voltage regulators

IC voltage regulators gives constant output voltage irrespective of change in input voltage and load current. They are protected against short circuits. There are two types of regulators one type 78XX series fixed positive regulators and others are 79XX series fixed negative regulators.

78XX Series voltage regulator

78XX series regulators

Pin 1 - Input, Pin 2 - Ground, Pin 3- Output

Regulator IC no	O/p voltage (V)
7805	+5
7806	+6
7808	+8
7809	+9
7810	+10
7812	+12
7815	+15
7818	+18
7824	+24

78XX series regulators are three terminals positive voltage regulators available in fixed output voltage options from +5.0 to +24V. These regulators employ short circuit current limiting, thermal shutdown, they can deliver output current in excess of 1 A. The various regulators and their output voltages are given in the table.

79XX Series voltage regulator

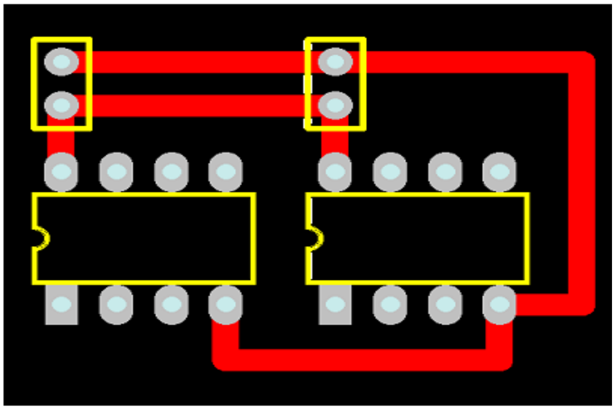
79XX series regultors

Pin 1 - Ground, Pin 2 - Input, Pin 3- Output

Regulator IC no	O/p voltage (V)
7905	-5
7906	-6
7908	-8
7912	-12
7915	-15
7918	-18
7924	-24

79XX series regulators are three terminals negative voltage regulators available in fixed output voltage options from -5.0 to -24 V. These regulators employ short circuit current limiting, thermal shutdown, they can deliver output current in excess of 1 A. The various regulators and their output voltages are mentioned below.

Printed Circuit Board (PCB)



PCB stands for printed circuit boards. They are called "printed" because circuits are printed by copper tracks on glass epoxy board. A PCB consists of a conducting layer that is made up of thin copper lines. Board may be single sided or double sided. Single side PCB have tracks or connections on one side of the board. Double sided PCB can have connections on both side of the board, electronic components are connected by through-hole plating. This is done by copper plating the walls of each hole so as to connect the conductive layers of the PCB. However on both types components are placed on one side of the board.

Advantages of PCB

- The circuit will look neat without any wires fall apart
- Much higher density components are placed with PCB
- Very precise control over the circuit components
- Comfortably fit in odd shaped components
- For production of large volume of circuit boards, the costs become less
- Assembling and soldering of components can be done by fully automated machines
- Assembled circuit can be tested by computer

PCB Design and development

PCB Layout preparation

PCB layout must be drawn using PC. There are many PCB design packages available, a few of which are freeware. Before drawing a layout in PC a complete circuit must be drawn on a paper including pin number of the components used. PCB design is always done from the top of the board, looking through bottom layers as if they were transparent. Prepare computer layout as per the circuit diagram by placing various components on the layout using PCB design software. Draw tracks for connecting one component to other. Pads are inserted to place leaded components. Pad dimension is selected depending on the size of the component leads. Vias connect the tracks from one side to another side of the board by the way of holes in the board. Once the layout is drawn on computer the next step is to take print layout using printer. Take printout on white sheet and get film done on transparent sheet by professional film makers. Film is also prepared by film makers directly by the soft copy of the drawing.

Photo-resist

Film (phot-resist) or mask is placed on copper-clad board. UV light is exposed on copper clad board covered by photo-resist film. UV light does not pass through photo-resists i.e. on the tracks, pads etc. Copper area which is not protected by photo-resist is removed during etching process.

PCB Etching Process

All PCB's are made by bonding a layer of copper over the entire substrate, sometimes on both sides. Etching process has to be done to remove the unnecessary copper after UV exposure, leaving behind only the desired copper tracks. Though there are many methods available for etching, the most common method used is etching by **ferric chloride or hydrochloric acid**. Dip the PCB inside the solution and keep it moving inside. Take it out at times and stop the process as soon as the unwanted copper has gone. After etching, rub the PCB with a little acetone to remove the black colour, thus giving the PCB a shining attractive look. The PCB layout is now complete.

PCB Drilling

The components to be attached to the multi-layered PCB can be done only by vias drilling. That is, a through hole is drilled in the shape of annular rings. Small drill bits are used for the drilling. Usually, a 0.8mm drill bit is used. For high volume production automated drilling machines are used.

Conductor Plating

The layer of the PCB contains copper connections which may not allow good solderability of the components. To make it good solderable, the surface of the material has to be plated with tin, or nickel.

PCB Assembling

PCB assembling includes the assembling of the electronic components on to the respective holes in the PCB. This can be done by through-hole construction or surface-mount construction. In the former method, the component leads are inserted into the holes drilled in the PCB. In the latter method, a pad having the legs similar to the PCB design is inserted and the IC's are placed or fixed on top of them. The common aspect in both the methods is that the component leads are electrically and mechanically fixed to the board with a solder.

Questions

One Mark questions

1. What is a part number?
2. Mention the important specifications of a resistor.
3. For what application fusible resisters are used?
4. What is the important specification of a capacitor?
5. Name the type of capacitor having polarity.
6. Write a part number for a diode.
7. How many pins presents in a diode bridge.
8. Mention any one type of seven segment display.
9. What do we mean 16x2 LCD?
10. Mention one specification of a speaker.
11. Mention a part number of a commonly used temperature sensor?
12. Mention any one case style of transistor.
13. Mention any one part number of a positive voltage regulator?
14. Mention any one part number of a negative fixed voltage regulator?
15. Name the chemicals used for Etching process in PCB designing?

Two Mark questions

1. What do you mean by data sheet?
2. What do we understand by part number of an electronic component?
3. What information does a package details of a component give?
4. What do you mean SIP and DIP packages?
5. Write the any two specification of a transformer.
6. Mention any two types of relays available in the market.
7. Mention any two types of transistors case styles available in market.
8. Write any two specifications of LEDs.
9. Write any one part number for npn and pnp transistors.
10. What is etching process?

Three/Five Mark questions

1. List any four advantages of data sheet.
2. Write the step involved in PCB designing.
3. What are the advantages of PCB?