PNS school of Engineering & Technology

Nishamani Vihar, Mershaghai, Kendrapara

Department of Electronics & Telecommunication Engineering

LECTURE NOTES

ON

Basic Electronics (Th-4b)

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Lecture in ETC ENGG.

1 Overview of Electronic Components and Signals

UNIT SPECIFICS

This unit discusses the following topics:

- Passive and active components
- Resistors, capacitors and inductors
- Diodes and their applications
- Bipolar Junction Transistors and their applications
- Field Effect Transistors, MOS and CMOS and their applications
- Signals: DC/AC, voltage/current, periodic/non-periodic signals
- Average, rms, peak values of signals
- Different types of signal waveforms
- Voltage and current sources

The practical applications of the topics are discussed for generating further curiosity as well as improving problem solving capacity. Besides giving a number of multiple choice questions as well as questions of short and long answer types belonging to different categories following lower and higher order of Bloom's taxonomy, number of numerical problems are provided for practice.

The related practicals are provided based on the content of Unit 1, followed up by a "Know More" section. This section mainly contains "micro project and activities" that highlights the practical activity, examples of some interesting applications focusing on self-learning, creativity and developing outcomes in all the domains of learning. This has been incorporated so that the supplementary information provided through this part, becomes beneficial for the users of the book. It is important to note that for getting more information on various topics of interest, QR code of videos and websites have been provided that can be scanned and viewed for relevant supportive knowledge in between as well as in the "Know More" section. In the end, list of references and suggested readings are given in the unit so that one can go through them for further reading and practice.

RATIONALE

The wired world and human beings are dependent on electricity to perform many activities. Number of applications are controlled by electrical and electronic circuits, from miniature ones in integrated circuits in mobile phones and music players, to the computers and TV sets, to massive ones that carry power to the homes.

This unit is a basic theme in the study of fundamentals of electrical and electronics engineering. In this unit, working of components like resistors, capacitors, inductors, diodes, BJT, FET that are basic constituents of any circuit are described. Signals that aids in analyzing, processing and validating the circuits and an overview of active sources which can deliver or absorb energy continuously are also explained in this unit.

PRE-REQUISITE

1. Science: Effects of Current , Chemical Substances-Nature and Behaviour (Class X)
2. Applied Chemistry: Atomic Structure, Engineering Materials (Semester I)
3. Applied Physics-I: Physical world, Units and Measurements (Semester I)
4. Mathematics-1: Trigonometry, Algebra (Semester I)

UNIT OUTCOMES

Upon completion of this unit, the student will be able to:

U1-O1: Classify electronic and electrical components.
U1-O2: Suggest suitable discrete components for a given application.
U1-O3: Describe the construction and working principle of a given semiconductor devices.
U1-O4: Interpret parameters of continuous electrical signals.
U1-O5: Compare ideal and practical active sources.

Unit-1 Outcomes	**EXPECTED MAPPING WITH COURSE OUTCOMES** (1- Weak Correlation; 2- Medium correlation; 3- Strong Correlation)					
	CO-1	**CO-2**	**CO-3**	**CO-4**	**CO-5**	**CO-6**
U1-O1	3	-	-	-	-	-
U1-O2	3	-	-	-	-	-
U1-O3	3	-	-	-	-	-
U1-O4	-	-	-	-	-	-
U1-O5	-	-	-	-	-	-

Georg Simon Ohm (1789-1854) began his research with the electrochemical cell, invented by Italian scientist Alessandro Volta. His practical experiments showed the mathematical links and he found that there is a direct proportionality between the potential differences (voltage) applied across a conductor and the resultant electric current, provided the temperature does not change. This relationship is known as Ohm's law and is now a cornerstone of electrical circuit design.

1.1 PASSIVE COMPONENTS

1.1.1 Introduction

Teenagers as well as children love to play jig saw puzzles. Number of discrete parts have to be properly placed together in the puzzle to develop a complete picture. Each part has a specific role in the developed picture. Similarly, for any electrical or electronics application, circuits or systems are developed in which each component has a specific meaningful role for the application to become operational. In fact, it is possible to assemble a circuit without really understanding the different parts involved. One can just connect components together like jigsaw puzzle to match an electronic schematic. That said, in order to debug an existing circuit or design one, it is important to actually understand how the individual electrical components work and how to use them together. In this topic working of components like resistors, capacitors, and inductors that are basic constituents of any circuit will be described.

1.1.2 Types of Circuit Elements

Electronic elements also known as components that make up a circuit are connected together by conductors to form a complete circuit. They can be classified into two main categories depending on whether they deliver or absorb energy from the circuit:

a. Passive components
b. Active components

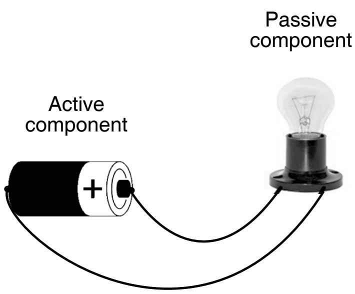


Fig. 1.1: A basic circuit

A passive component can only receive energy, which it can either dissipate or absorb. An active component supplies energy to an electric circuit, and hence has the ability to electrically control the flow of charge. An example of a basic circuit made up of two electronic elements, a cell and a bulb has been illustrated in Fig.1.1.

Discrete components

The components, which are discrete in nature i.e. with just one circuit element, are called discrete components. These components may be active or passive in nature. They are widely used in electrical and electronic circuits. Some of the discrete components are Resistors, Capacitors, Inductors, Semiconductor diodes, Transistors. The term discrete component should be understood as it is used to differentiate discrete components from integrated circuits (ICs) which contain multiple different circuit elements.

Resistor

Definition of a passive component

A passive component is an electronic component when connected in a circuit can only receive energy, which it can either dissipate, absorb or store it in an electric field or a magnetic field. Passive elements do not need any form of electrical power to operate. As the name 'passive' suggests – passive devices do not provide gain or amplification. Common examples of passive components include Resistors, Inductors, Capacitors.

1.1.3 Resistance

Resistance is the opposition to current flow in an electrical circuit. It is described as the property of a substance due to which it opposes the flow of current through it. Resistance is not same for all materials. Conductors like copper, aluminum etc. offer small resistances whereas insulating materials like Bakelite, glass, rubber, mica, dry wood, p.v.c. (polyvinyl chloride), etc. offer high resistance.

The higher the resistance provided by a material, the lower the flow of electrons or current through the material. The property of resistance is used in a wide variety of applications and appliances such as computer mother board, televisions and incandescent lamps. The SI unit for resistance is the ohm, symbolized by the Greek letter Ω (omega) and also represented by letter R. Resistance of a material is one ohm when a current of one ampere passes through a material with a voltage of one volt. The current is proportional to the voltage across the terminal ends. This ratio is represented by Ohms law:

$$R = \frac{V}{I} \qquad \text{...(1.1)}$$

The resistance R offered by a conductor depends on the following four factors:

a. It varies directly as its length, 'l'.

b. It varies inversely as the cross-section area 'A' of the conductor.

c. It is dependent upon the nature of the material.

d. It also depends on the temperature of the conductor.

Neglecting the last factor for the present,

$$R \, \alpha \frac{l}{A} \;\; or \;\; R = \frac{\rho \, l}{A} \qquad \text{...(1.2)}$$

Where ρ is a constant depending on the nature of the material and is known as its specific resistance or resistivity. The unit of specific resistance is ohm-meter.

Resistors

The resistor is an electrical component with two terminals. It is one of the most important components in a circuit as it allows the user to precisely control the amount of current and voltage in the circuit.

Resistors can be divided in terms of construction type as well as resistance material. A resistor though very small, is often made up of copper wires coiled around a ceramic rod and an outer coating of insulating paint. This is called a wire-wound resistor, and the number of turns and the size of the wire determine the precise amount of resistance. Smaller resistors, those that are designed and used for low-power circuits, are often made out of carbon film, which replaces the wound of copper wire that can be bulky. Fig. 1.3 shows Colour Coding of carbon film resistors, which is described in

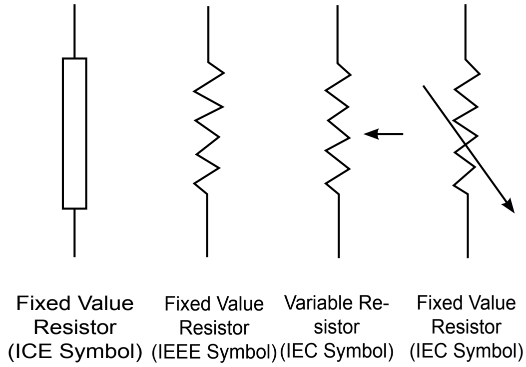


Fig. 1.2: Symbol of Resistors

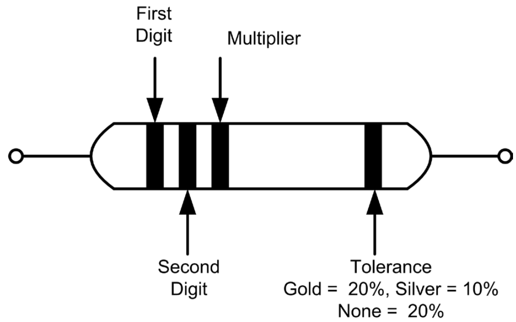


Fig. 1.3: Colour Coding of Resistors

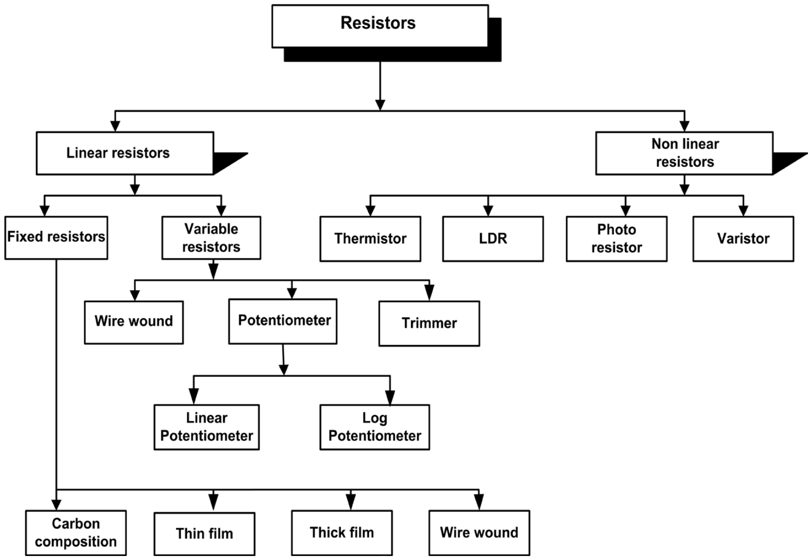


Fig. 1.4: Classification of Resistors

Power rating or wattage

- The maximum amount of heat dissipated by a resistor at maximum specified temperature without damage to resistor is called power rating of a resistor.
- It is expressed in watt (W) at specified temperature.
- When resistor is used at higher temperature, power rating will be decreased.
- The normal available resistors have power ratings of 1/8 W, 1/4 W, 1/2 W, 1 W, 2 W.
- The size of a resistor depends on its power handling capacity. Small resistors are designed to handle low powers,as size of resistor increases power handling capacity also increases.

Conductance and conductivity

The reciprocal of resistance is called as Conductance, represented by letter 'G'. Whereas resistance of a conductor measures the opposition which it offers to the flow of current, the conductance measures the inducement which it offers to its flow. From Eq. 1.2

$$R = \rho \frac{l}{A} \qquad G = \frac{1}{\rho} \frac{l}{A}$$

$$G = \sigma \frac{A}{l} \qquad \text{...(1.3)}$$

where σ is called the conductivity or specific conductance of a conductor. The unit of conductance is Siemens (S). The unit of conductivity is Siemens/metre (S/m).

Effect of temperature on resistance

One of the factors that effects resistance of any material is temperature.The effect of rise in temperature is:

a. to increase the resistance of pure metals.

b. to decrease the resistance of carbon, electrolytes, and insulators.

c. to increase the resistance of alloys, though in their case, the increase is relatively small.

Temperature coefficient of resistance

Let a metallic conductor having a resistance of R_0 at 0°C be heated of t°C and let its resistance at this temperature be R_t. Then, considering normal ranges of temperature, it is found that the increase in resistance, $R_t – R_0$ depends

a. directly on its initial resistance

b. directly on the rise in temperature

c. on the nature of the material of the conductor.

$$\text{or } R_t - R_0 \; \alpha \; R_0 \times t \text{ or}$$
$$R_t - R_0 = \alpha R_0 t \qquad ...(1.4)$$

where α (alpha) is a constant and is known as the temperature coefficient of resistance of the conductor. Rearranging Eq. (1.4) results in

$$R_t = R_0 + \alpha R_0 t = R_0 (1+ \alpha t) \qquad ...(1.5)$$

1.1.4 Inductors

Inductor is a two-terminal component that temporarily stores energy in the form of a magnetic field. It is usually called as a coil. The main property of an inductor is that it opposes any change in current. An inductor is also considered as passive element of circuit, because it can store energy in it as a magnetic field, and can deliver that energy to the circuit, but not in continuous basis. The energy absorbing and delivering capacity of an inductor is limited..

According to the Faraday's law of Electromagnetic induction, when the current flowing through an inductor changes, the time-varying magnetic field induces a voltage in the conductor. According to Len's law, the direction of induced EMF opposes the change in current that created it. Hence, induced EMF is opposite to the voltage applied across the coil. This is the property of an inductor.

An inductor blocks any AC component present in a DC signal. The inductor is sometimes wrapped upon a core, for example a ferrite core. Fig.1.5 shows an inductor with various parts labelled.

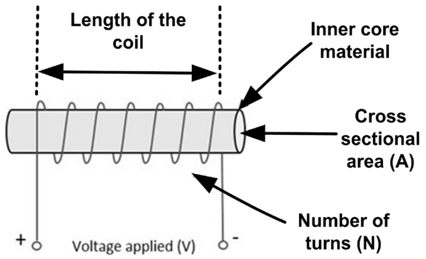


Fig.1.5: Parts of an inductor

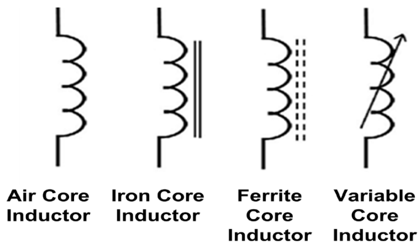


Fig.1.6: Symbol of inductors

Symbol and units

The symbols of various types of inductors are as given in Fig.1.6. The unit of inductance is Henry i.e. H. In actual practice, Henry is an extremely large unit. Therefore, much smaller units are used like millihenry (mH) or microhenry (μH). 1 mH = 1×10^{-3} H and 1μH = 1×10^{-6} H.

Factors affecting inductance

The inductance of a coil depends upon the following parameters:

1. Number of turns, N
2. Core material

3. Length of winding 4. Dimension of coil former

Storage of energy in inductor

One of the basic properties of electromagnetism is that the current when flows through an inductor, a magnetic field gets created perpendicular to the current flow. This keeps on building up. It gets stabilized at some point, which means that the inductance won't build up after that. When the current stops flowing, the magnetic field gets decreased. This magnetic energy gets turned into electrical energy. Hence energy gets stored in this temporarily in the form of magnetic field.

Coil Tutorial

Q Factor of an inductor

- The ability of an inductor to store energy as compared to the dissipation of energy within the inductor is called Quality (or Q) factor. It is also known as figure of merit.
  The Q factor is given by,

$$Q = \frac{Energy\ Stored}{Energy\ Dissipated} \quad ...(1.6)$$

- A high Q factor means little energy dissipation with respect to energy storage, while a low Q factor means energy dissipation as large as energy storage.
- The value of Q factor for coils may range between 5 to 100.
- It may be noted that smaller the value of DC resistance of a coil, higher is the value of Q factor. The high Q coils are preferred in tuning circuits, because it makes the circuit more selective and sensitive

1.1.5 Capacitors

A capacitor is a passive component that has the ability to store the energy in the form of potential difference between its plates. It resists a sudden change in voltage. The charge is stored in the form of potential difference between two plates, which form to be positive and negative depending upon the direction of charge storage.

A non-conducting region is present between these two plates which is called as dielectric. This dielectric can be vacuum, air, mica, paper, ceramic, aluminium etc. The name of the capacitor is given as per the dielectric used.

Symbol and units

The standard units for capacitance is Farads. Generally, the values of capacitors available will be in the order of micro-farads, pico-farads and nano-farads.

The symbol of a capacitor is as shown in Fig.1.7.

The capacitance of a capacitor is proportional to the distance between the plates and is inversely proportional to the area of the plates. Also, the higher the permittivity of a material, the higher will be the capacitance. The permittivity of a medium describes how much electric flux is being generated per unit charge in that medium.

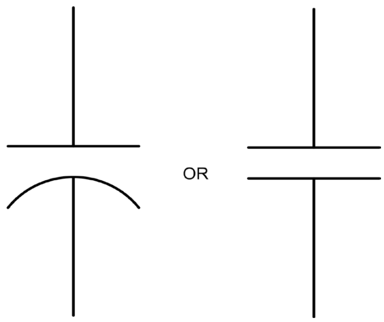


Fig.1.7: Symbol of a Capacitor

Dielectric materials used in a capacitor

The dielectric materials used in manufacturing of capacitor are as under:

1. Air
2. Mica
3. Glass
4. Ceramic
5. Porcelain
6. Polystyrene
7. Fibre
8. Bakelite
9. Waxed paper
10. Electrolyte

Functions of a capacitor

The important functions of a capacitor in the electric circuit are as given below :

1. It opposes the flow of direct current (D.C.) through it.
2. It bypasses the alternating current (A.C.) through it very easily.
3. It stores the electric energy in it.
4. It removes the ripple from D.C. power supply.
5. It opposes any change of voltage in the circuit.

Capacitor Types

1.1.6 Series and Parallel Circuits

Resistors connected in such a way that current from one flow only into another are said to be connected in series. The series combination of two resistors as shown in Fig.1.1.8 acts, as far as the voltage source is concerned, as a single resistor having a value equal to the sum of the two resistances.

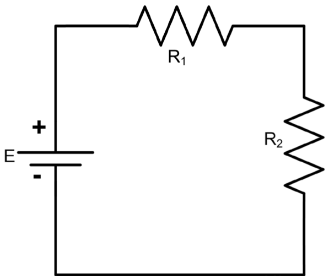


Fig. 1.8: Series circuit

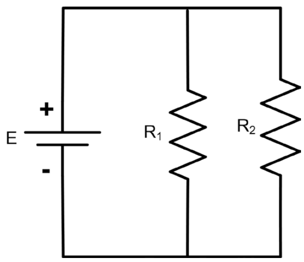


Fig. 1.9: Parallel circuit

For circuits having resistances connected in parallel as shown in Fig. 1.9 Similar to resistance, when capacitance and inductances are connected in series and parallel in circuits, Table 1.1 shows the formula for equivalent value.

Table 1.1: Formulas for Parallel and Series connection of elements

Type of Connection	Resistor	Inductor	Capacitor
Series	$R = R_1 + R_2$	$L = L_1 + L_2$	$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2}$
Parallel	$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$	$\frac{1}{L} = \frac{1}{L_1} + \frac{1}{L_2}$	$C = C_1 + C_2$

Applications of passive components in Real life

Passive components are used in number of devices. Some of the uses will be explained in later units.

Resistors

Following are the applications of resistors:

1. Potential dividers
2. Current control
3. D.C. power supplies
4. Filter circuit networks
5. Amplifier circuits
6. Heating element

Some other applications include

- For protection purposes, e.g. fusible resistors.
- Wire wound resistors find application where balanced current control, high sensitivity, and accurate measurement are required like in shunt with ampere meter.
- Photo resistors find application in flame detectors, burglar alarm, in photographic devices, etc.

Capacitors

The important applications of capacitor in electronic circuits are as given below :

1. It is used for the storage of energy.
2. It is used in the filter circuits to minimize the ripple voltage.
3. It is used in the tuning circuits for selection of frequency.
5. It is used for starting the motor, for running the motor
6. It is used for equipment like SMPS, Modem.

Inductors

The important applications of inductors are as given below:

1. It is used to minimize the ripples alternating current in a circuit.
2. It is used for allowing the flow of direct current.
3. It is used in filter circuits to minimize the ripple voltage or ripple factor.
4. It is used in tuning circuits of radio transmitters and receivers to select the frequency.
5. It is used in devices like Relays, Electric Motors, Transformers, Sensors

Solved Problems

Example 1.1.1: Five resistors with resistances of 2.2 Meg ohms, 470 KΩ, 220 KΩ, 55 KΩ, and 1.6 Mega ohms are connected in series. Calculate the total or equivalent resistance of this series combination?

Solution: For series combination of resistances, the equation is

$$Req = R_1 + R_2 + R_3 + R_4 + R_5$$

However, there is a note of caution that all the resistances must be expressed in terms of the same unit. In terms of kilo ohms we have

Req = 2200 + 470 + 220 + 55 + 1600

Req = 4545 kΩ

Req = 4.545 Mega ohms

Example 1.1.2: Four resistors with resistances of 1 kΩ, 2 kΩ, 4 kΩ, and 8 kΩ are connected in parallel. Calculate the equivalent resistance of this combination?

Solution: For parallel combination of resistances, the equation is

$$\frac{1}{\mathrm{Req}} = \frac{1}{\mathrm{R_1}} + \frac{1}{\mathrm{R_2}} + \frac{1}{\mathrm{R_3}} + \frac{1}{\mathrm{R_4}}$$

$$\frac{1}{\mathrm{Req}} = \frac{1}{1} + \frac{1}{2} + \frac{1}{4} + \frac{1}{8}$$

$$= 0.125 + 0.250 + 0.500 + 1.000$$

$$= 1.875$$

Then $$\mathrm{Req} = \frac{1}{1.875} = 0.53\mathrm{k}\Omega$$

1.2 ACTIVE COMPONENTS

1.2.1 Introduction

Automation, Digitization and Smart system requires use of active components. Active components play a vital role in all engineering disciplines and engineering application ranging from domestic to industrial, space, defense, agriculture, medical, transportation, education and entertainment. All electronic products are based on functioning of active components.

The components which operation changes as per external energy are termed as active components. Active components performance relies on external energy. Active components are suitable for rectifying, amplifying and switching applications. Two main types of active components are: 1) Tube devices 2) Semiconductor devices.

Now a days tube devices are not commonly used as they exhibits many drawbacks such as low speed of operation, larger size, difficult for mounting and expensive than semiconductor components. Semiconductor active components are also called as solid state components. These are made up of semiconductor materials. Active semiconductor components have many advantages such as: high speed of operation ,compactness, easy for mounting and cheaper than tube devices. Commonly used active components are diode, BJTs (Bipolar Junction Transistors) , FET (Field Effect Transistor), MOSFET (Metal Oxide Semiconductor FET), SCR (Silicon controlled Rectifier), DIAC, UJT (Uni Junction Transistor), TRIAC , IGBT, PUT and Integrated circuits.

Semiconductor material has electrical conductivity less than conductor and more than insulator. Its conductivity changes as per application of external energy. Pure semiconductor materials are called as intrinsic semiconductor. Commonly used pure semiconductor materials are Silicon (Si) and Germanium (Ge). To improve conductivity i.e. free charge carriers, impurity is added to intrinsic semiconductor. The process of addition of impurity to intrinsic semiconductor is called as doping. Due to doping process intrinsic semiconductor is converted into impure semiconductor. This impure semiconductor material is called as extrinsic semiconductor. Depend on type of impurity material added to intrinsic semiconductor, two types of extrinsic semiconductor are obtained such as P type and N type material. By using these two extrinsic semiconductor active components are constructed. To obtain P type extrinsic semiconductor trivalent material and to obtain N type extrinsic semiconductor pentavalent impurity material is added. In P type material positive charge carrier Holes are majority charge carrier while in N type.

1.2.2 P N Junction Diode

A P-N junction diode is formed by connecting P and N type semiconductors. As soon as the P-N junction is formed, it results in the following processes:

1. Holes from P region near the junction diffuse into N region and combine with free electrons. Similarly, free electrons from N region and near the junction enter P region to recombine with holes.
2. These re-combinations near the junction do not continue for a long because electrons trying to diffuse into P region are now repelled by the negative immobile ions and the holes from P region are repelled by positive immobile ions in the N region. So total recombination of holes and electrons cannot occur.
3. Due to few re-combinations near the junction, a region is formed on both sides with no charge carriers. It contains only negative and positive immobile ions. This region is called depletion region or space-charge region Fig.1.10 shows P N junction with depletion region.

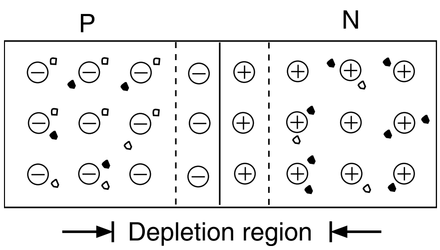


Fig. 1.10: P N Junction

The electric field between the acceptor and donor ions is called barrier. The potential difference between the two sides of barrier, i.e., barrier potential is about 0.7 V for Si and 0.3 V for Ge P-N junction. P-N junction diode is a two terminal device. The terminal connected to the P region is called anode. The terminal connected to N region is called cathode. There are two electrodes, hence the name diode (DI + electrode).The symbol of a P-N junction diode is as shown in Fig. 1.11.

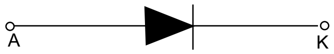


Fig. 1.11: P N junction Diode symbol

1.2.2.1 Operation of P-N junction diode

The P N junction diode can be operated in two states or conditions namely forward bias state and reverse bias state. When anode is at higher potential with respect to cathode, the diode is said to be in forward bias, i.e., connecting positive terminal of the external battery to anode and negative terminal to the cathode. Fig. 1.12 shows diode forward bias connection. Holes from the P region are repelled by the positive terminal of the battery and move towards the junction. Similarly electrons from N region move towards the junction. So the width of depletion region decreases.

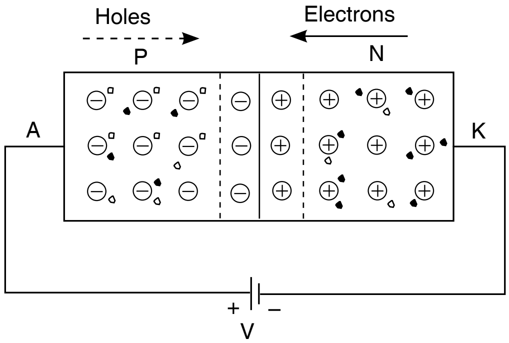


Fig. 1.12: Diode-Forward bias

The direction of conventional current is the direction of movement of holes, i.e., from anode to cathode. If the battery voltage is increased, the current also increases. Very little current flows due to minority carriers in opposite direction.

When the anode is at lower potential with respect to cathode (negative w.r.t. cathode), the P-N junction is said to be reverse biased, i.e. negative terminal of the external battery is connected to the anode and positive terminal to the cathode. Holes from P region are attracted towards the negative terminal of the battery and the electrons from N region move towards the positive terminal of the battery. Since the carriers move away from the junction, the width of depletion region increases. Thus there is no current due to majority carriers. But there is very small current from cathode to anode due to minority carriers. These are very less in number so the current is also very small.

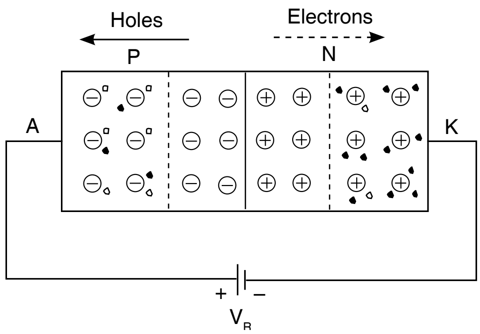


Fig. 1.13: Diode-Reverse bias

1.2.2.2 Characteristics of a diode

V I Characteristics of a device shows device operation for various applied input voltages. The forward and reverse characteristics of diode is as shown in Fig. 1.14.

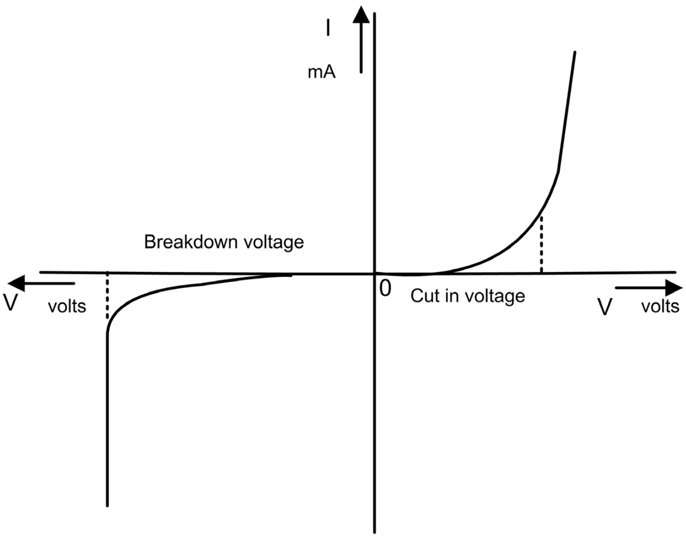


Fig. 1.14: Diode V–I characteristics

The diode connected in a DC circuit offers a definite resistance which is called DC resistance or static resistance. It is the ratio of DC voltage across the diode to the DC current through the diode (Eq. 1.10).

$$R_F = \frac{V}{I} \qquad \text{...(1.7)}$$

As seen from the forward characteristics nature, the static resistance is small in few ohms in forward bias condition. Also it is clearly seen from the reverse characteristics that the current is very small so the static resistance is high in mega ohms.

1.2.2.3 Diode parameters

Following parameters are specified by the manufacturers:

a. The Maximum Forward Current (I_{Fmax}): The maximum current in the forward bias which the diode can withstand safely. Beyond this, the diode will be damaged.
b. Inverse Voltage (PIV): The maximum reverse voltage that can be applied safely to a diode.
c. Forward and reverse static and dynamic resistance
d. Junction capacitance

1.2.2.4 Diode applications

PN junction diode is a basic semiconductor component used in variety of electronic circuits. These electronics circuits are used in various engineering applications. Major applications of PN junction diode are

1 Diodes are used to construct rectifier circuits to convert A signals to DC signals.
2 In wave shaping circuit diode is used to clip or clamp input signal.
3 Diodes are used in digital circuits as a switching element.
4 To construct all types of DC power supply, battery charger, voltage multiplier and eliminator diode plays important role.

V-I Characteristics of Junction Diode

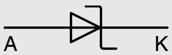
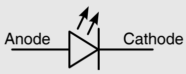
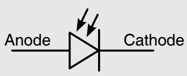
5 In communication systems, for signal demodulation i.e. detection of information signal and in computers for reset circuits diodes are used.

6 To avoid D.C. saturation of inductive relay or motor, diode is connected across it.

1.2.2.5 Types of diodes

PN junction diode operation, VI characteristics and applications are depends on material used doping construction and physical dimensions. Table 1.2 shows basic three types of diodes their features and applications.

Table 1.2: Types of Diodes

Sr. No	Diode with symbol	Features	Applications
1	Zener Diode 	1 Doping concentration is very high than normal P N junction diode. 2 Normally operated in reverse biased. 3 It exhibits zener breakdown in reversed biased condition. 4 It is made up of silicon.	Zener diode is used for 1 Voltage regulation in regulated D C power supply. 2 Meter protection circuits 3 Spike guard circuits.
2	Light Emitted Diode (LED) 	1 Special semiconductor materials are used such as GaAs, GaAsP, GaP, SiC. 2 When this diode is forward biased then it emits light. Wavelength i.e. color of emitted light depends on doping material. 3 Emission of light energy due to injection of charge carrier is a basic working principle of LED 4 It is available in various sizes. 5 Emitted light intensity is proportional to current flowing through it.	LED is used for 1 Power indicator for various electrical and electronics appliances. 2 In electronic appliances as a display device. 3 Constructing seven segment and matrix display. 4 Opto coupler, remote control 5 Light sources for distance measurement and other similar instruments. 6 Optical switching and communication systems.
3	Photo Diode 	1 Special semiconductor material is used. 2 It covert light intensity into current. 3 It is normally operated in reverse biased.	Photo diode is used for 1 Light sensing. 2 Burglar alarm. 3 Opto coupler. 4 Auto flash camera.

1.2.3 Transistors

A bipolar junction transistor (BJT) is basically a silicon or germanium crystal having two P-N junctions formed by sandwiching either P-type or N-type semiconductor between a pair of opposite types. BJT is normally called a transistor. It is capable of amplifying weak signals. Thus the current in transistor (or BJT) flows due to positive as well as negative polarity charge carriers. Therefore, a transistor (BJT) is called a bipolar device.

1.2.3.1 Construction of Transistor

Transistor is a solid state semiconductor two junction, three region and three terminal device. Three terminals are emitter, base and collector. From constructional details, two types of transistors are PNP transistor and NPN transistor. When a thin layer of a P-type semiconductor is sandwiched between two layers of an N-type semiconductor, it is known as an NPN transistor. Fig.1.15 shows constructional details of NPN transistor. In BJT emitter region is heavily doped as compare to collector region. Collector region has large physical area where as base region is having lower doping concentration as compare to collector region. So always emitter current is largest in BJT. In NPN BJT emitter current is base to emitter (outward direction) the emitter current is the sum total of the collector and base currents.

$$i.e. \quad I_E = I_B + I_C \qquad \text{...(1.8)}$$

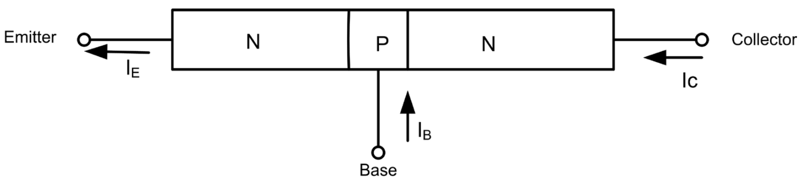


Fig. 1.15: Structural diagram of NPN BJT

Fig. 1.16 shows schematic symbol of NPN and PNP BJT.

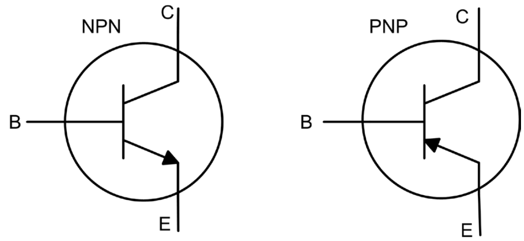


Fig. 1.16: Schematic symbol of NPN and PNP BJT

1.2.3.2 Configuration of transistor

BJT can be operated in any one of three configurations. Three configurations for BJT are 1) Common Base (CB) configuration 2) Common Emitter (CE) configuration 3) Common Collector (CC) configuration. Table 1.2. shows comparison of three configurations. For any configuration, the input is not applied to collector terminal and in any configuration, output is taken from base terminal.

Table 1.3: Comparision of Transistor Configuration

Sr. No.	Parameters	Common Base	Common Emitter	Common Collector
1	Input terminal	Emitter	Base	Base
2	Output terminal	Collector	Collector	Emitter
3	Input impedance	Low	Medium	High
4	Output impedance	Very high	Medium	Low
5	Current gain	Nearly one	High	Very high
6	Voltage gain	High	Higher than CB	Nearly one

7	Power gain	Medium	High	Low
8	Thermal stability	High	Low	High
9	Applications	Low noise preamplifier (wide band)	AF voltage amplifier	Impedance matching, buffer

$$\alpha_{dc} = I_c / I_E \quad ...(1.9)$$

Current gain beta (β):The ratio of collector current I_C to base current IB for a constant collector to emitter voltage V_{CE} in the CE configuration is called current gain beta(β).It is given by a relation as shown in eq.1.2.4 The value of beta (β) ranges from 20 to 250.

$$\beta_{dc} = I_C / I_B \quad ...(1.10)$$

From eq. 1.11, 1.12 and 1.13 relation between α and β can be obtained as

$$\alpha = \beta /(1+\beta) \quad ...(1.11)$$
$$\beta = \alpha / (1- \alpha) \quad ...(1.12)$$

Specifications for transistor:

1. Maximum collector-to-emitter voltage, $V_{CE(max).}$
2. Maximum collector current, $I_{C(max).}$
3. Collector-to-emitter cut-off voltage, $V_{CEO.}$
4. Collector cut-off current, $I_{CEO.}$
5. Collector-to-emitter break down voltage, $BV_{CBO.}$
6. Maximum collector dissipation, $P_{D.}$
7. Collector saturation voltage, $V_{CE(sat).}$
8. DC current gain (h_{FE})

1.2.3.3 Applications of transistors

Transistor can be operated in any one of the three operating mode. Three operating modes for BJT are 1) Cutoff state 2) Active state 3) Saturation state. Table 1.4 summarizes the junction biasing required to operate transistor in one of three operating states.

Table 1.4: Operating State and Junction Biasing

Sr. No.	Operating State	Base Emitter Junction	Base Collector Junction	Application
1.	Cut off state	Reverse Biased	Reversed Biased	--
2.	Active State	Forward Bias	Reverse Bias	Amplifier
3.	Saturation State	Forward Bias	Forward Bias	Switching

Transistor are having wide applications in all fields of electronics. It is most commonly used for amplifier circuit. Amplifier increases amplitude of input signal.

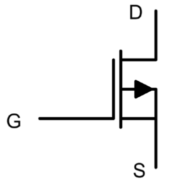
1. Amplifier
2. Timers and time delay circuits
3. Switching circuits
4. Oscillator
5. Multivibrator
6 Electronic switch
7. Wave shaping in clipping circuits
8. Modulator
9. Detector (or demodulator)
10. Logic circuits

1.2.4 FET

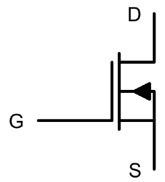
The FIELD EFFECT TRANSISTOR (FET) is a semiconductor solid state active device. Field effect transistor is an example of a uni-polar transistor. In FET output current is either due to electrons or due to holes. As the input applied electrical field i.e. voltage controls the output current so it is called as field effect transistor.

1.2.4.1 FET construction

There are mainly two types of field effect transistors, the Junction Field Effect Transistor (JFET) and the Metal Oxide Semiconductor Field Effect Transistor (MOSFET). JFET's may be made with either an N channel or P channel. In the construction of the N-channel FET, gate is made up of P type semiconductor and for P Channel FET, N type semiconductor material is used. Fig.1.17 shows schematic symbols for FETs. FET has three terminals: 1) Source 2) Drain 3) Gate. Source and drain terminals are connected to channel. Channel is unevenly doped. In a channel source area is having higher doping as compare to drain area.



(a) N-channel JFET



(b) P-channel JFET

Fig. 1.17: FET Symbols

The important feature of the FET is that it is often simpler to fabricate and occupies less space on a chip than BJT. Voltage applied on gate V_{GS} control channel current. For this purpose gate source is reversed bias. So depletion layer width extends in channel area. Drain is also reversed bias with respect to source. Charge carriers pushed from source area and move towards drain. This forms the channel current. The V_{GS} at which channel current becomes zero is called as pinch off voltage. When V_{GS} is zero the current flowing through the channel is maximum. It is called as saturation state drain current I_{DSS}.

1.2.4.2 Comparison between BJT and FET

Transistor and uni-polar transistor(FET) can be compared as given in Table 1.5, on the basis of operation, construction, characteristics and their advantages.

Table 1.5: Comparison between BJT and FET

Sr. No.	Bi-polar Junction Transistor	Field Effect Transistor
1.	It is a semiconductor device consisting of three terminals known as Base, Emitter and Collector.	FET is a semiconductor device having three terminals as Gate, Source and Drain.
2.	Conduction is due to holes and electrons. Hence, it is a bipolar device.	Conduction is due to either holes or electrons. Hence, FET is a unipolar transistor.

3.	BJT is a current controlled device.	FET is a voltage controlled device.
4.	Its operation depends upon the flow of majority as well as minority carriers.	Its operation depends upon the flow of majority carriers only.
5.	The input impedance of BJT is low.	The input impedance of FET is high.
6.	The device is noisy.	It is less noisy than bipolar transistor.
7.	There are two types of BJT's N-P-N and P-N-P.	There are two types of FETs N-channel and P-channel.
8.	BJT is difficult to construct and occupies more space.	FET is simpler to fabricate and occupies less space.
9.	BJT circuits give high gain band width product.	Relatively gives low gain band width product.
10.	Emitter-base junction is forward biased and collector-base is reverse biased.	Gate to source as well as drain to source are both reverse biased. Effectively source area is forward biased
11.	It has poor thermal stability.	It has thermal stability.
12.	BJT cannot be used as a voltage variable resistor.	FET can be easily used as voltage variable resistor.

1.2.4.3 Applications of FET

FET is operated in the constant current region of its output characteristics for the linear applications. The FET is useful as a voltage variable resistor (VVR) or Voltage Dependent resistor. It is called as active load. FET is used in many electronic circuits application such as:

1. RF and AF Amplifier
2. Oscillator
3. Switching circuits
4. Buffer in measuring instruments
5. Communication receivers
6. Signal mixer circuits of TV
7. Memory devices
8. Digital circuits

1.2.5 MOS devices

Insulated gate field effect transistor is called as metal oxide semiconductor field effect transistor. MOSFET. It has insulation layer of SiO_2 between gate and channel. So it offers very high input impedance than FET.

1.2.5.1 Types of MOSFET

From constructional details two types of MOSFETs are 1) Depletion type MOSFET 2) Enhancement type MOSFET. Depletion type MOSFET has a physical channel , insulated gate and substrate. It has four terminals Source , Drain, Gate and substrate. Substrate is connected to device body. According to channel type two type of depletion MOSFETs are 1) N channel Depletion MOSFET 2) P channel Depletion MOSFET. Depletion type MOSFET are also called as Normally ON MOSFET. Two operating modes of depletion type MOSFETs are 1) Depletion Mode 2) Enhancement mode. In depletion mode gate is maintained at negative potential. To operate Depletion type MOSFET in enhancement mode, gate is maintained at positive potential. Fig. 1.18 shows circuit symbols of depletion type MOSFETs.

Fig. 1.18: Depletion type MOSFET

Enhancement type MOSFET has no depletion mode of operation and it operate only in enhancement mode. N channel MOSFET and P channel MOSFETs are also known as NMOS and PMOS devices. Fig. 1.19 shows circuit symbols of enhancement type MOSFETs.

Fig. 1.19: Enhancement type MOSFETs

1.2.5.2 MOSFET applications

Some of the applications of MOSFET are as follows:

1. Suitable for high current and voltage switching applications
2. Traction system
3. AC drives
4. Multiphase inverters

1.2.6 CMOS

P Channel MOSFET and N Channel MOSFETs are used together to form Complementary Metal Oxide Semiconductor device (CMOS). These devices are commonly used for digital circuits fabrications. Logic gates, counters, microcontroller and memories are constructed using CMOS devices. CMOS devices offers features such as low power consumption and compact. Integrated circuits are constructed using these devices. Fig. 1.20 shows construction of CMOS device.

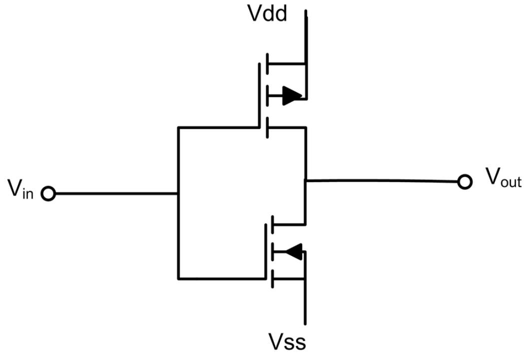


Fig. 1.20: CMOS device

1.2.7 Comparison between Passive and Active Components

Table 1.6 Represents the comparison in brief between passive and active components on major aspects.

Table 1.6: Comparison between passive and active components

Sr. No.	Criteria	Passive Components	Active Components
1.	Nature of source	Passive components utilize power or energy from the circuit.	Active components deliver or control power or energy to the circuit.
2.	Examples	Resistor, Capacitor, Inductor etc.	Diodes, BJT, FET, Integrated circuits etc.
3.	Power Gain	They are incapable of providing power gain.	They are capable of providing power gain.
4.	Flow of current	Passive components cannot control the flow of the current.	Active components can control the flow of current.
5.	Requirement of external source	They do not require any external source for the operations.	They require an external source for the operations.
6.	Nature of energy	Passive components are energy acceptor.	Active components are energy donor.

Activities

1. After learning Topic No. 1.1 and 1.2 of this unit, student should try to identify and prepare list on various gadgets available at home using active and passive components.
2. Student shall refer data book to know about active and passive components with their major specifications and prepare a presentation with two components each of different varieties.

Classifications of Electronic Components

Solved Problems

Example 1.2.1: In BJT three terminals currents are I_1 = 100 mA. I_2 = 93 mA and I_3 = 7 mA. Identify terminal names.
Solution: BJT has three terminals: 1) Emitter 2) Base 3) Collector. Out of the three terminal currents, emitter current is always largest.
As in given data, I_1 is largest so it current flowing through Emitter terminal.

$$I_E = I_C + I_B$$
$$100 \text{ mA} = 93 \text{ mA} + 7 \text{ mA}$$

In BJT, base current is smallest. So I_3 current is flowing through Base terminal.
Therefore I_2 current is flowing through Collector.

Example 1.2.2: Justify that current gain α in CB transistor configuration is less than and nearly equal to 1.
Solution: The current gain of a BJT in CB configuration is given by, Current gain.

$$\alpha = I_C/I_E$$
$$I_E = I_C + I_B$$

Since I_B is very small as compared to I_E, the term I_B/I_E will be very small as compared to 1.
So ,the value of current gain α will be less than 1.

Example 1.2.3: If α of a transistor is 0.9, calculate β.
Solution: Given: $\alpha = 0.9$

$$\beta = \alpha /(1-\alpha)$$
$$= (0.9) /(1-0.9) = 9$$

Example 1.2.4: If β is 100, calculate alpha.
Solution: Given : $\beta = 100$
Current gain $\alpha = \beta / (1+ \beta)$

$$= 100 /101 = 0.99$$

1.3 SIGNALS AND ACTIVE SOURCES

1.3.1 Introduction

The signals can be in different forms like audio, visual which convey information, mechanical signals for physical activities and electrical signals for power delivery. The classification of signals helps in analyzing, processing and validating the circuits. Signals can be classified by any of their physical characteristics, their mathematical representation or on their use. The underlying topic gives a brief overview on the type of signals with special focus on understanding the basic concepts of alternating current and direct current signals.

1.3.2 Classification of Signals

Signals are broadly classified as continuous time signals and discrete time signals. A continuous time signal is one whose mathematical function is defined continuously in the time domain, where as a discrete time signal is defined at specific time instants. Fig. 1.21 and 1.22 shows typical continuous and discrete time signals.

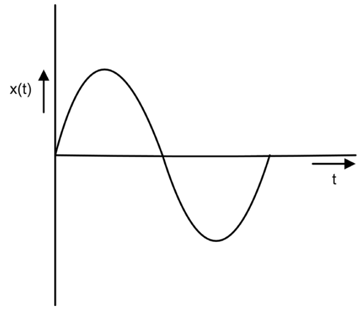


Fig. 1.21: Continuous time signal

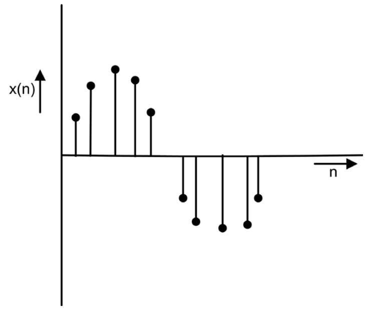


Fig. 1.22: Discrete time signal

The above signals are further classified as

i. Deterministic and Non-deterministic signals
ii. Periodic and Non-periodic signals

1.3.3 Deterministic and Non-Deterministic Signals

Deterministic signals are those signals whose nature and amplitude can be predicted at any instant of time. The mathematical function of a deterministic continuous time signal and that of a discrete time signal is given as

$$x(t)=A\ sin\omega t \qquad ...(1.13)$$
$$x(n)=\begin{cases}1, & n\geq 0\\ 0, & otherwise\end{cases} \qquad ...(1.14)$$

Eq.1.21 as represented above is a sine function with maximum amplitude is A and is varying sinusoidally with time whereas equation 1.22 represents a discrete time signal with amplitude equals to one for the sampling instants n and zero for all other sampling instants.

Non deterministic signals also known as random signals are not predictive in nature. The pattern of such signals are irregular and cannot be defined by simple mathematical function. For example, the thermal noise created due to the movement of electrons in a semiconductor material. Fig.1.23 and 1.24 shows a deterministic time and a non-deterministic signal.

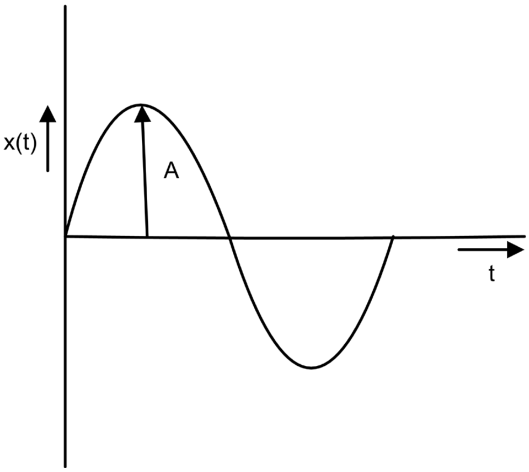


Fig. 1.23: Deterministic Signal

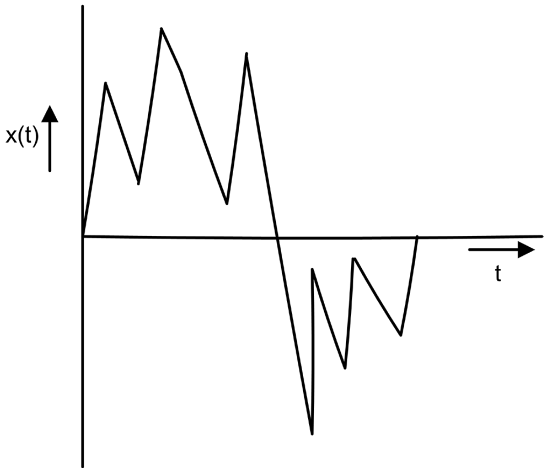


Fig. 1.24: Non-deterministic Signal

1.3.4 Periodic and Non-periodic Signals

A continuous time signal is said to be periodic if it repeats itself after a specific interval of time. The mathematical equation of a periodic signal is represented as

$$x(t) = x(t + T), -\infty < t < \infty \qquad ...(1.15)$$

Where T is the period of the signal. The smallest value of T that satisfies the given equation 1.23 is called the fundamental time period T_O of the signal.

A signal which does not repeat itself after specific interval of time or signals that do not satisfy equation 1.23 are known as non-periodic or aperiodic signals. For example, the signals created by a microphone or signals generated from a radio station.

1.3.5 Electrical Signals

There are two electrical signals in use today, for powering equipments of industries and for appliance used either in offices or houses. The most common electrical signal used is the Alternating current (AC) signal. The major advantage being the relative ease by which it can be generated and amplified, low cost of transmission of the signal from the generating station to the end consumers and the most important it is easier to interrupt an AC signal if any fault occurs in the electrical system. Almost all the major heavy duty equipment's used in industries and the domestic appliances used in household

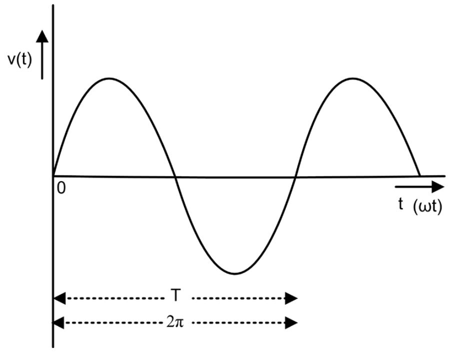


Fig. 1.25: Alternating Current signal

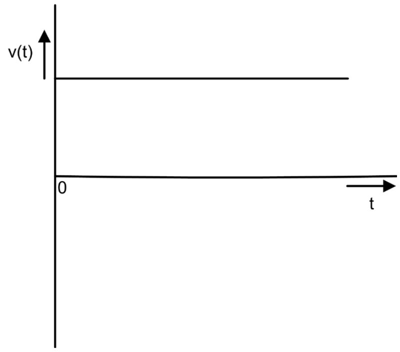


Fig. 1.26: Direct Current signal

are powered by AC signal. In recent years with the advances made in the development of discrete active components the increased use of DC signals for powering equipment's and appliance is going to be a reality Fig. 1.25 and 1.26 shows an AC and DC signal.

The Alternating Current (AC) is a sinusoidal time-varying signal. As the name suggests it goes through a series of different values both positive and negative in a time period T, after which it is continuously repeats the same series in a cyclic manner. It is generated by generators at power plants. The generated voltage is then stepped up using transformers and is then delivered through transmission and distribution networks to factories and residential houses where the voltage is stepped down as per requirement. For a residential household the voltage requirement is 230 V at 50 Hz. To understand an AC signal, the following terms are important.

AC vs. DC

1.3.5.1 Period and cycle

The period of an alternating current or voltage is the smallest value of time which separates the recurring value of the alternating quantity. The period of time which separates this recurring value is denoted by T as shown as in Fig. 1.27. The complete set of one positive and negative values of an alternating current or voltage signal is called a cycle. A cycle is also referred in terms of angular velocity ω as shown in equation 1.24 where one cycle is said to be 360° or 2π radian of angular measure.

$$\omega = \frac{2\pi}{T} \qquad ...(1.16)$$

1.3.5.2 Frequency

Frequency is the number of cycles per second. In rotating machine, one complete cycle is produced when the conductors placed on the stator are cut by the flux from the pair of poles fixed to the rotor of the machine during one complete revolution of the rotor. For a *p* pole machine the number of cycles per second is P/2, and if the speed of rotor rotation is in revolutions per second (rps), the equation for frequency in cycles per second or Hertz is

$$f = \frac{np}{2} \qquad ...(1.17)$$

Since T expressed in seconds is the time period for one cycle, the frequency term can also be expressed as

$$f = \frac{1}{T} \qquad ...(1.18)$$

The most common power plant frequencies in use are the 50 Hz and 60 Hz. In India the frequency of the generating voltage is 50 Hz, whereas in North America, Europe and in many countries of other continents, the frequency of generation is 60 Hz.

1.3.5.3 Waveform

The shape of the curve on a x- y plane resulting from a plot of the instantaneous voltage or current on the y-axis against the time on the x-axis is its waveform or wave shape. The x-axis expressed in terms of time in seconds can be also expressed in terms of radians or degrees.

In practice the Alternating voltage (AC) and current generated approximates a sine wave very closely. Therefore, the calculation of the AC voltage and current are based on sine waves. A true sine wave is shown in Fig.1.29 and is represented as.

$$v(t)=V_m \sin \omega t \quad ...(1.19)$$

where ωt also known as the time angle is expressed in radians, v is the instantaneous value of the voltage and V_m, the maximum /peak value of the sinusoidal voltage variation.

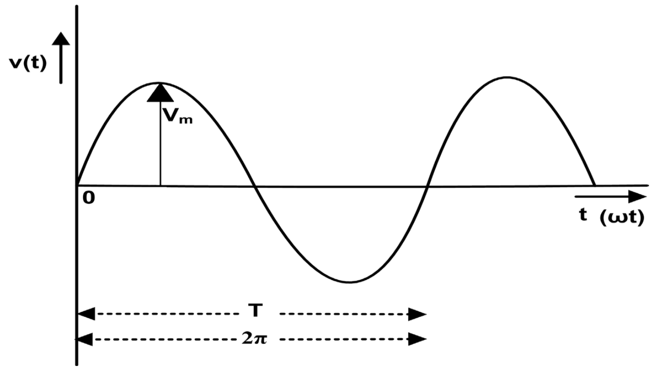


Fig. 1.27: AC Voltage sine waveform

1.3.6 Voltage and Current Sources

In topic 1.1 of this unit, three passive elements were discussed, namely the resistor which absorbs energy and the other two i.e. the inductor and capacitor that can store energy from an active source and deliver it back to the same source. Sources of electrical energy which can deliver or absorb energy continuously are called active sources. The active sources are further classified as voltage source and current source according to their voltage–current characteristics.

1.3.7 Ideal and Non-Ideal Sources

The voltage and current sources are further classified as ideal and non-ideal/practical voltage and current source according to the voltage-current (V-I) characteristics.

1.3.7.1 Ideal voltage source

An ideal voltage source delivers energy with a voltage across its output terminal and is independent of the current from the source. The circuit representation of an ideal sinusoidal voltage source given by $v(t)= V_m \sin \sin \omega t$ and its V-I characteristics are shown Fig.1.28 and 1.29 respectively. The reference polarity at the voltage source terminals labelled with + and - sign as shown in Fig.1.28 is during the positive half cycle when the voltage *v(t)* is positive. The actual polarities at the voltage source terminal change in sign once during each cycle.

From the V-I characteristics of an ideal voltage source it is observed that the voltage represented as v_T is independent of the current *i(t)* flowing out from the source, where v_T is the value of source voltage *v(t)* at any given time instant.

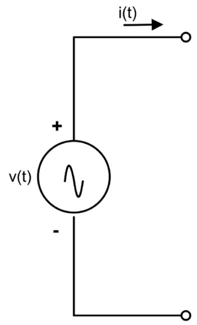


Fig. 1.28: Circuit representation of ideal voltage source

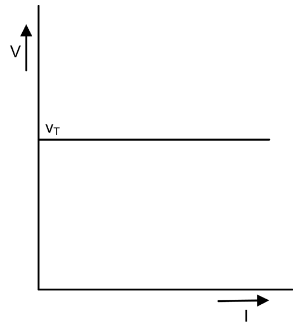


Fig. 1.29: V-I characteristic of ideal voltage source

1.3.7.2 Ideal current source

An ideal current source delivers energy with a current through the output terminals that is independent of the voltage across the terminals of the current source. The circuit representation of an ideal sinusoidal current source given by $i(t)= I_m \sin \sin \omega t$ and its V-I characteristics are shown in Fig. 1.30 and 1.31 respectively. From Fig. 1.31, it is observed that the current i_T being the value of source current *i(t)* at a given time instant is independent of the voltage across the terminals of the current source.

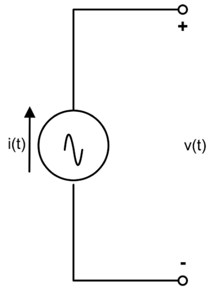


Fig. 1.30: Circuit representation of ideal current source

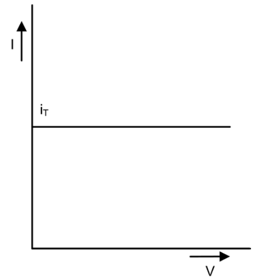


Fig. 1.31: V-I characteristic ideal current source

1.3.7.3 Non-ideal or practical voltage source

In a practical voltage source, energy is obtained by a conversion process. For example, in a voltage source generator, the conversion is from mechanical to electrical energy. Similarly, for a battery source, the chemical energy is converted to electrical energy. Conversion of energy results in losses and this is taken care of by connecting an internal resistance R_{in} in series with the voltage source generator . The circuit representation of a practical voltage source is shown in Fig.1.32 and its V-I characteristics in Fig.1.33. It can be seen from the V-I characteristics that the terminal voltage v_T decreases with increase in the current *i*. The terminal voltage equation is given by

$$v_T = v - iR_{in} \qquad \ldots(1.20)$$

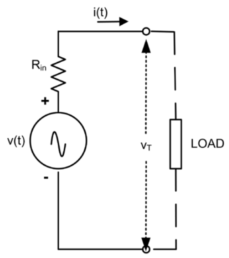


Fig. 1.32: Circuit representation of a practical voltage source

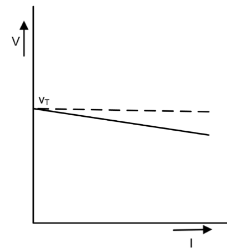


Fig. 1.33: V-I characteristics of practical voltage source

1.3.7.4 Non-ideal or practical current source

In a practical current source, the loss is represented by connecting an internal resistance R_{in} parallel with the current source. The circuit representation and the V-I characteristics of a practical current source is shown in Fig.1.34 and Fig.1.35 respectively. It can be seen from the V-I characteristics that the terminal current i_T decreases with increase in the terminal voltage *v*. The equation of the terminal current is given by

$$i_T = i - \frac{v}{R_{in}} \qquad \text{...(1.21)}$$

Electronic circuit using bipolar junction transistors and circuits using photovoltaic cells are often explained by using current sources in their equivalent circuit.

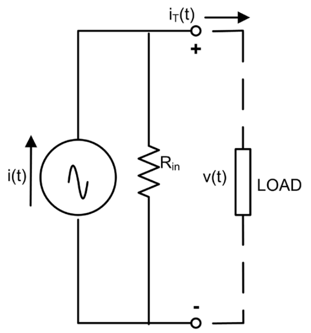


Fig. 1.34: Circuit representation of current source

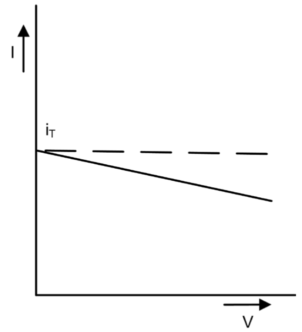


Fig. 1.35: V-I characteristic of current source

1.3.8 Dependent Voltage and Current Source

The independent voltage and current sources are independent of any other current or voltage existing in the circuit to which it is connected. In dependent sources, the voltage across or current through the terminals of a voltage/ current dependent sources are determined either by the voltage/ current existing somewhere else in the circuit. Accordingly, the dependent sources are classified as (i) Voltage dependent voltage source (ii) Current dependent voltage source (iii) Current dependent current source (iv) Voltage dependent current source. The symbols for the dependent sources are shown in Fig. 1.36 and 1.37. k_V, k_r, k_C and k_I are real numbers, where k_r, k_C are trans-resistance and trans-conductance respectively and k_V, k_I are dimensionless

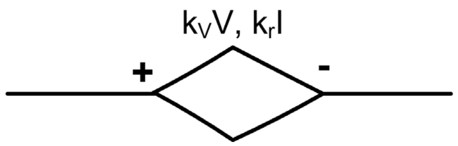


Fig. 1.36: Symbol of dependent voltage source

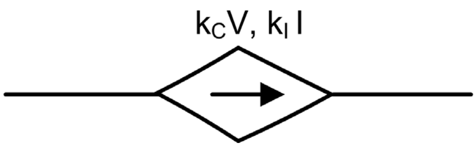


Fig. 1.37: Symbol of dependent current source

Applications

Discrete signals are used for processing the analog signals obtained from sensors, like observing the temperature of a person using Digital thermometer, mobile communication, video streaming, smart watches etc. The active sources are part of our daily life. For example, the 1.5 V cell used to power the wall clock, remote control unit of TV, Air conditioners, 12V battery for ignition and lighting system of vehicles etc. are all active DC source. Similarly, the domestic appliances used in our homes like Refrigerator, washing machine, fluorescent tube lights, ceiling fan etc. use single phase AC source.

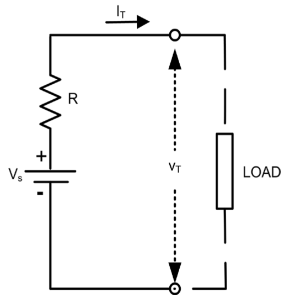
Activities

The students will

1. List the applications of continuous and discrete signals.
2. Prepare a list of gadgets which uses continuous and discrete signals.

Solved Problems

Example 1.3.1 A battery source as an ideal voltage source in series with a resistor is feeding a load connected to the terminals as shown. The voltage V_T at the terminal is 130 V and the current I_T drawn is 10 A. The load at the terminals is now changed and accordingly the voltage at the terminal is 100 V and the current drawn is 25 A. Calculate the raring of voltage Source V_s and the resistor R. Draw the VI characteristic.



raring of voltage Source V_s and the resistor R. Draw the V-I characteristic

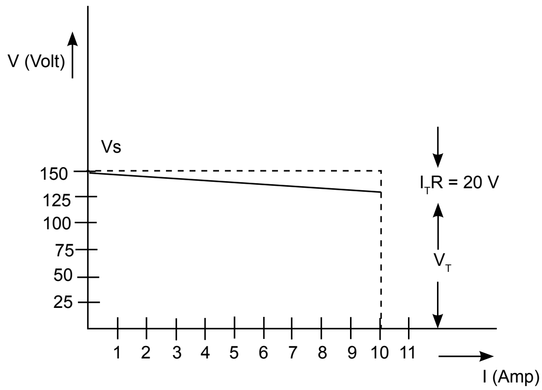
Solution: The terminal voltage in terms of source voltage, terminal current and series resistor is given by

$$V_T = V_s - I_T R \quad \text{...(1)}$$

Using equation (1), the terminal voltage for two different load conditions are as under

$$130 = V_S - 10R \quad \text{...(2)}$$
$$100 = V_S - 25R \quad \text{...(3)}$$

Substituting V_S from equation (2) in (3), the value of series resistor R = 30/(15) = 2 Ω
Substituting the value of R in equation (2), we get the value of V_S = 150 Volt



Example 1.3.2 A practical current source consists of a 3 milliamp ideal current source which has an internal resistance of 1000 ohm. Calculate the open circuit terminal voltage and the power dissipated in internal resistor.

Solution: The equation of a practical current source is given as

$$i_T = i - v/R_{in} \quad \text{...(4)}$$

For the given problem as no load is connected to the terminals of the current source, the current $i_T = 0$. Therefore (iv) modifies to $v = iR_{in}$, where v is the terminal voltage. Putting the value of i and R_{in}, $v = 3$ Volt

UNIT SUMMARY

Point-wise summary to be provided at the end of each unit.

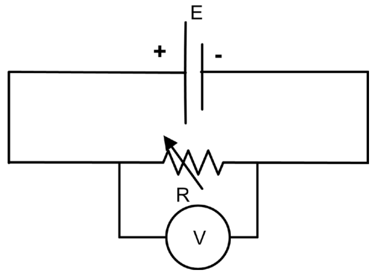
- Passive and active components form the two main types of circuit elements.
- Electrical symbols are used to represent both active and passive components.
- Resistance (R) is a property of a material used for describing the opposition provided to the flow of current.
- A capacitor stores energy in the form of electric charges.
- An inductor is a passive component that is used to store energy in the form of magnetic energy when electricity is applied to it.
- Semiconductor components are active solid state components.
- Diode, BJT and FET are basic discrete active components.
- Diode is a unidirectional device used mainly for rectification.
- BJT is a current operating three terminal device mainly used for amplification and switching operation.
- FET is a voltage operating device having high input impedance. PMOS and NMOS are combined together to construct CMOS.
- Signals are classified broadly as continuous time signals and discrete signals.
- The Electrical Signal used for domestic and Industrial application are classified as AC signals and DC signals.
- The AC and DC signal sources are classified as Ideal and Practical source according to their voltage-current characteristics
- The dependent voltage and current source are used for analysis of circuits containing active components like BJT, JFET.

EXERCISES

A- Objective Questions

Instruction: Please select the most appropriate answer.

Sr. No.	MCQs	Sr. No.	MCQs
1.1	With rise in temperature the resisteance of pure metal a. Increases b. Decreases c. Remains constant d. First increases and then decreases	1.7	For opto-coupler, the pair of diodes that is used is a. Zener diode and PN junction diode b. Zener and LED c. Zener diode and Photo diode d. LED and Photodiode
1.2	The insulating medium between the two plates of capacitor is known as a. electrode b. capacitive medium c. conducting medium d. dielectric	1.8	A length of wire having a resistance of 1.0 Ω is cut into four equal parts. These four parts are bunded together side by side to form a thicker wire. The resistance of thicker wire will be a. 4 Ω b. 1/16 Ω c. 1/4 Ω d. 16 Ω
1.3	The most common used semiconductor is a. Carbon b. Silicon c. Germanium d. Gallium	1.9	In BJT, terminal currents are I_1 = 5mA, I_2 = 95 mA and I_3 = 100 mA, then the appropriate option is a. $I_1 = I_B$, $I_2 = I_C$, $I_3 = I_E$ b. $I_1 = I_B$, $I_2 = I_E$, $I_3 = I_C$ c. $I_1 = I_C$, $I_2 = I_B$, $I_3 = I_E$ d. $I_1 = I_E$, $I_2 = I_C$, $I_3 = I_E$

1.4	For voltage regulation, the diode that is suitable is a. P N junction b. Light emitting c. Photo d. Zener	1.10	In the circuit diagram shown, if the battery with E volt has some finite internal resistance and if the resistance R is decreased the voltmeter reading will  a. Remain constant b. Increase c. Decrease d. Will be equal to E
1.5	The signal x (t) is said to be non-periodic signal if a. the equation x (t) = x (t + T) is satisfied for all values of T b. the equation x (t) = x (t + T) is satisfied for only one value of T c. the equation x (t) = x (t + T) is satisfied for no values of T d. the equation x (t) = x (t + T) is satisfied for only odd values of T		
1.6	In an ideal voltage source the source voltage and terminal voltage can be related as a. terminal voltage is higher than the source voltage b. terminal voltage is equal to the source voltage c. terminal voltage is always lower than source voltage d. terminal voltage cannot exceed source voltage		

B- Subjective Questions

1. A very long string of 500 multi-colored outdoor lights is installed on a house. After applying power, the home owner notices two bulbs are burnt out. Are the lights connected in series or parallel?
2. There capacitors of 5 F, 10 F and 15 F are connected in series across a 100 V supply. Determine the equivalent capacitance.
3. List out two applications each of inductor photodiode, MOSEFT and active DC source.
4. Compare BJT with FET on the basis of power requirement, input impedance, thermal stability and compactness.
5. Two light bulbs are used for lightening the kitchen and store room. One light bulb draws 300 mA when the voltage across it is 240 V. Another light bulb in the store room draws 240 mA when the voltage across it is 240 V. Calculate the total resistance of the light bulbs?
6. Suggest type of diode suitable to detect light abstraction in burglar alarm.
7. Justify ‘In BJT, emitter terminal current is maximum current’.
8. Calculate value of β, if value of α is 0.92.
9. A practical source of a Bipolar Junction Transistors consists of 3 Amp ideal current source with an internal resistance of 500 ohms. To the terminals of the practical current source a load resistor of 250 ohms is connected. Find the voltage across the load terminal and the power absorbed by the load resistor.
10. List the differences between ideal and practical sources.

2 Overview of Analog Circuits

UNIT SPECIFICS

This unit discusses the following topics:

- Basics of Op Amp IC 741
- Op Amp parameters
- Ideal Op Amp characteristics
- Op Amp open loop configuration
- Op Amp close loop configuration
- Op Amp Inverting mode amplifier
- Op Amp Non-inverting mode amplifier
- Op Amp as an adder
- Op Amp as a differentiator
- Op Amp as an integrator

The practical applications of the topics are discussed. Multiple choice questions as well as subjective questions and number of numerical problems are provided for practice. Related practical, followed up by a "Know More" section containing micro projects and activities, video resources along with ICT are given. A list of references and suggested readings are given in the unit so that one can go through them for further practice and enhancement of learning.

RATIONALE

Operational Amplifier (Op-Amp) is the most versatile and Integrated Circuit (IC). An IC is a small semiconductor based electronic device or a microchip on which thousands and hundreds of discrete electrical components, such as resistors, capacitors and transistors, are fabricated. Op Amp is used to develop various applications of analog electronic circuits and is highly popular. This unit is intended to develop the skills to build, test, and diagnose the Op Amp based electronic circuits. This unit deals with various aspects of analog circuits based on Op Amp that are used in various industrial , consumer and domestic applications.

PRE-REQUISITE

1. Science: Effects of Current (Class X)
2. Applied Physics-I: Physical world, Units and Measurements (Semester I)
3. Mathematics-1: Algebra (Semester I)

UNIT OUTCOMES

Upon completion of this unit, the student will be able to:

U2-O1: Describe Op Amp parameters.

U2-O2: Explain Op Amp configurations.

U2-O3: Describe Op Amp as an inverting and non-inverting amplifier.

U2-O4: Use Op Amp for basic applications.

Unit-2 Outcomes	Expected Mapping with Course Outcomes (1- Weak Correlation; 2- Medium correlation; 3- Strong Correlation)					
	CO-1	CO-2	CO-3	CO-4	CO-5	CO-6
U2-O1	1	3	-	-	-	-
U2-O2	1	3	-	-	-	-
U2-O3	1	3	-	-	-	-
U2-O4	2	3	-	-	-	-

Robert John Widlar (1937-1991)
known as a legendary chip designer was instrumental for the design of first mass-produced operational amplifier ICs. A self-taught radio engineer, Walter Widlar worked for the WGAR (1220 AM) radio station and designed pioneering ultra-high frequency transmitters. The world of electronics surrounded him since birth. Widlar invented the basic building blocks of linear integrated circuits including the Widlar current source, the Widlar band gap voltage reference[] and the Widlar output stage. Widlar, together with David Talbert in 1964 created the first mass- produced operational amplifier ICs . This led to Fairchild Semiconductor and National Semiconductor, becoming the leaders in linear integrated circuits. National Semiconductor where he worked as a contractor produced a series of advanced linear ICs including the first ultra-low-voltage operational amplifier (LM10).

2.1 FUNDAMENTALS OF OPERATIONAL AMPLIFIERS

2.1.1 Introduction

Now a days electronic circuits plays a vital role in all engineering field application. Two main types of electronic circuits are analog electronic circuit and digital electronic circuit. Rectifier, amplifier and oscillator are most commonly used analog electronic circuits. These circuits can process continuous signals i.e. linear or analog signals. Therefore analog circuits are also called as linear electronics circuits. Rectifier circuit is used to convert A.C. signals in to D.C. signals. Diodes are used for rectifier circuits. Amplifier is used to increase amplitude of input signals. Amplifier can be constructed using discrete components such as BJT or FET. Analog circuits constructed using discrete components shows many drawbacks such larger size, more power consumption and less reliability. To overcome these drawbacks integrated circuits (IC) are used. Operational amplifiers known commonly as Op Amps are very popular building blocks in electronic circuits. Op-amps are used for a variety of applications such as AC and DC signal amplification, filters, oscillators, voltage regulators, comparators and in most of the consumer and industrial applications.

2.1.2 Basics of Op Amp

Operational amplifiers are a direct coupled high gain amplifier usually consisting of one or more differential amplifier followed by level shifter and output stage. The term "operational" is used in the name because these amplifiers were initially used in mathematical operations.

An operational amplifier is represented by the symbol given in Fig. 2.1. The most commonly used Op Amp IC is μA 741, which is manufactured by many manufacturers. Two prefix characters in IC number indicates manufacturer. Table 2.1 shows prefix and manufacturer names. Fig. 2.2 shows pin configuration of IC 741. Table 2.2 shows pin functions for IC 741.

Table 2.1: Prefix Characters and Manufacturer names for IC 741

Prefix Characters	Name of Manufacturer
AD	Analog Devices
LM	National Semiconductor
MC	Motorola
NE/ SE	Signetics
OP	Precision Monolithic
TI	Texas Instruments
μA	Fairchild

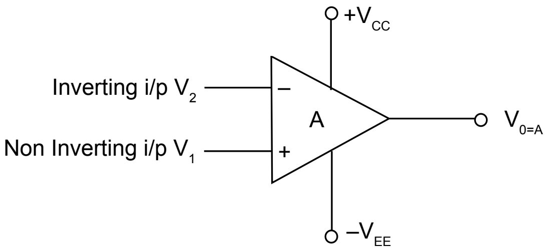


Fig. 2.1: Symbol of Op Amp

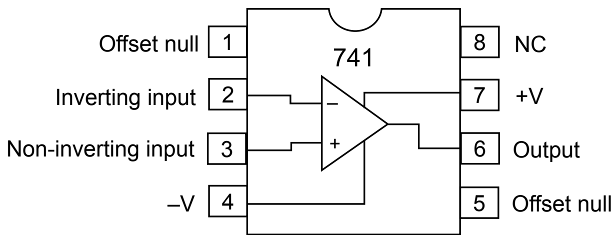


Fig. 2.2: Pin out diagram of IC 741 (μA 741)

Table 2.2: Pin Functions of IC 741

Pin No.	Pin Label	Pin Function
1	Offset Null	It is used to remove or minimize offset voltage. It is used along with Pin No. 5.
2	Inverting Input	This is denoted by minus (–) sign on symbol. A signal applied to this input appears as an amplified but phase inverted signal at the output.
3	Non-Inverting Input	This is denoted by plus (+) sign symbol. A signal applied to this terminal appears at the output as an amplified signal which has the same phase as that of input signal.
4	-V_{CC}	Biasing power supply pin for negative supply Normally - 15 V is applied.
5	Offset Null	It is used to remove or minimize offset voltage. It is used along with Pin No. 1.
6	Output	Single ended output from Op Amp is available from this pin.
7	+VCC	Biasing Power supply pin for positive supply Normally + 15 V is applied.
8	NC	Not connected.

2.1.2.1 Packages

Three popular packages that are available are as follows:

1. The dual-in-line package (DIP)
2. The metal can (TO) package
3. The flat package or flat pack

Op Amp packages may contain single, two (dual) or four (quad) op-amps in a single IC. Typical package has 8 terminals, 10 terminals and 14 terminals. The widely used very popular type, μA741 is a single Op Amp IC and it is available in various packages as shown in Fig.2.3. The μA747 is a dual 741 and comes in either a 10-pin can or a 14-pin DIP.

a. Dual-in-line plastic (DIP) package   b. TO-5 style package with straight leads   c. Flat pack

Fig. 2.3: Various IC packages of 741 Op Amp

2.1.2.2 Op Amp parameters

The operational amplifier is simply a high gain, direct coupled amplifier. It is usually designed to amplify the signals extending over a wide frequency range and is normally used with external feedback networks. There are various parameters of Op Amp, which are necessary for faithful amplification. Op Amp has different electrical parameters like differential input resistance, input offset voltage, output offset voltage and common mode rejection ratio. As the operational amplifier has become an universal building block for circuit and system design, a number of widely accepted design terms have involved, which describe the comparative merits of various Op Amp circuits. In this section, the parameters commonly used to characterize operational amplifier performance are explained.

Op-Amp

Input offset current (I_{io}): The input offset current is the difference between the separate currents entering the input terminals of a balanced amplifier. Referring to Fig.2.4

$$I_{io} = I_{B1} - I_{B2}, \text{ when } V_o = 0 \qquad \ldots(2.1)$$

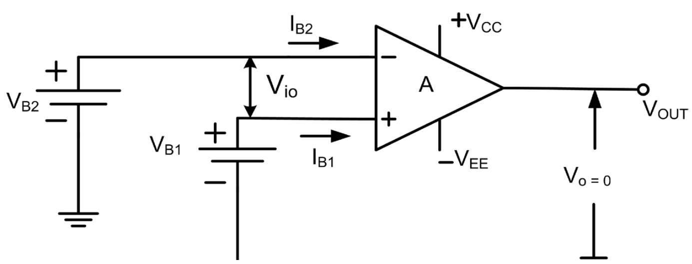


Fig. 2.4: Input bias currents I_{B1} and I_{B2}; and offset voltage V_{io}

Input bias current (I_B): The input bias current I_B is the average value of the current flowing into input terminals with the output at zero volt. From Fig. 2.4,

$$I_B = (I_{B1} + IB_2) / 2, \text{ when } V_o = 0 \qquad \ldots(2.2)$$

Input offset current drift: It is defined as the ratio of the change of input offset current to the change of temperature.

$$Input\ offset\ current\ drift = \Delta Iio / \Delta T \qquad \ldots(2.3)$$

Input offset voltage (V_{io}): It is that voltage required to apply between the input terminals to get output voltage zero, with no input signal.
Input offset voltage drift : It is defined as the ratio of the change of input offset voltage to the change in temperature.

$$Input\ offset\ voltage\ drift = \Delta Vio / \Delta T \qquad \ldots(2.4)$$

Output offset voltage: It is the output voltage of the Op Amp when the input terminals are grounded. For ideal Op Amp this parameter, it is 0V. For practical Op Amp this parameter value must have very low value. To minimize it offset null pins are used.

Common mode range: It is the maximum range of input voltage that can be simultaneously applied to both inputs without causing cut-off or saturation of amplifier stages.

Input differential range: It is the maximum difference signal that can be applied safely to the Op Amp input terminals.

Output voltage range: It is the maximum output swing that can be obtained without significant distortion.

Full power bandwidth: It is the maximum frequency range over that the full output voltage swing can be obtained.

Power Supply Rejection Ratio (P.S.R.R.): The power supply rejection ratio is the ratio of the change in input offset voltage to the corresponding change in one power supply voltage, with other power supply voltages held constant.

Slew rate (Sr): This is the maximum rate of change of output voltage. It is also defined as the rate of change of the closed loop amplifier's output voltage. It is expressed in V/µS unit. Maximum operating frequency of Op Amp depends on slew rate.

$$Fmax = slew\ rate / (2\pi\ V_p) \qquad \ldots(2.5)$$

Unity gain bandwidth: This is the frequency range from direct current i.e. 0 Hz to that frequency at which the open-loop gain crosses unity.
Input impedance (Z_i): It is defined as the ratio of input voltage Vi to the input current Ii.

$$Input\ impedance\ Z_i = V_i / I_i \qquad \ldots(2.6)$$

Output voltage swing: The AC output is the maximum unclipped peak to peak output voltage that an Op Amp can produce. Since the quiescent output is ideally zero, the AC output voltage can swing positive or negative. This also indicates the values of positive and negative saturation voltages of the OPAMP. The output voltage never exceeds these limits for a given supply voltages $+V_{CC}$ and $-V_{EE}$. For 741 IC, it is ± 13 V.

Common mode rejection ratio (CMRR): The ability of differential amplifier to reject a common mode signal is expressed by its common mode rejection ratio. It is the ratio of differential mode gain Ad to the common mode A_{cm}. It is usually expressed in decibel (db).

$$CMRR = A_d / A_{cm} \qquad \ldots(2.7)$$

To calculate CMRR in dB

$$CMRR \text{ in } dB = 20 \log_{10} (A_d / A_c) \quad \text{...(2.8)}$$

Differential input resistance (Ri): It is equivalent resistance measured at either input terminal with other terminal grounded.

2.1.3 Ideal Op Amp

The ideal Op Amp has the following properties:

1. Its input impedance is infinite ($Z_i = \infty$).
2. Its output impedance is zero ($Z_o = 0$).
3. It has infinite voltage gain ($A_V = \infty$).
4. It has infinite bandwidth i.e. its open-loop gain tends to infinity. i.e. it provides a constant gain for all frequency ranges.
5. Common Mode Rejection Ratio (CMRR) is infinite.
6. It produces zero output voltage when $V_1 = V_2$.
7. Characteristics do not drift (swing) with temperature.

Ideal Op Amp

The ideal operational amplifier is shown in Fig. 2.5. A signal appearing at the negative terminal (V_2) is inverted at the output, a signal appearing at the positive terminal (V_1) appears at the output with no change in sign. Hence, the negative terminal is called the "inverting" terminal and the positive terminal the "non-inverting" terminal. In general, the output voltage is directly proportional to $V_d = V_1 - V_2$. The constant of proportionality (A_V) is called the voltage gain of the amplifier.

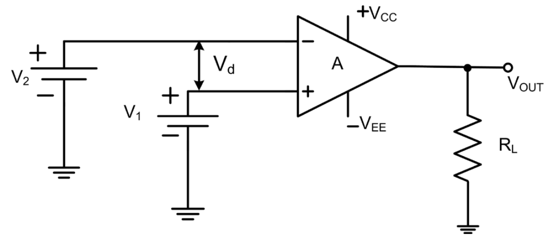


Fig. 2.5: Ideal op-amp

In practice, when Op Amp is selected for some specified application then its parameters are observed from data sheets. Table 2.3 shows some essential parameter values for IC741.

Table 2.3: IC741 parameters

Sr. No.	Parameter	Typical Value (at 25^0 C)
1.	Input impedance	2 MΩ
2.	Output impedance	75 Ω
3.	CMRR	90 dB
4.	Supply Voltage	+/- 18 V
5.	Input offset voltage	1mV
6.	Input offset current	20 mA
7.	Input bias Current	80 mA
8.	Differential Input Voltage	+/- 15 V
9.	Bandwidth	1 MH_Z
10.	Slew Rate	0.5 V /$_{\mu}$S

2.1.4 Op Amp Configurations

Op Amp can be operated in any one of two configurations. Two configurations are: Open loop configuration and close loop configuration.

2.1.4.1 Op Amp Open loop configuration

The Op Amp without feedback is known as open loop configuration of Op Amp.

Open-loop gain (A_{OL}): If 'V_d' is the differential input voltage of an Op Amp, it is very small and V_o is the output voltage, then open-loop gain can be defined as the ratio of the output voltage V_o to the differential input voltage V_d. It is termed as open-loop gain because possible feedback connection between output and input terminals are absent.

The open-loop gain, $A_{OL} = Vo\ /\ Vd.$ …(2.9)

In open loop as feedback is absent ,so gain is infinite and non-controllable. To control gain and operate Op Amp as per requirement feedback is essential. Feeding some part or complete output signal to input is called as feedback.

2.1.4.2 Op Amp Close loop configuration

The Op Amp without feedback is not very useful device, since the extremely small voltage at the input will cause it to go into saturation at the output. Hence, it is necessary to apply feedback to get finite voltage gain. When feedback is applied, the characteristics of the Op Amp are determined largely by the feedback network Amp with feedback is called as close loop configuration.

Closed-loop gain (ACL): The gain of the amplifier is called closed-loop gain because the feedback resistor closes a loop from the Op Amp output terminal to the inverting input terminal i.e. negative terminal.

Closed-loop gain, $A_{CL} = Vo\,/\,Vi$ …(2.10)

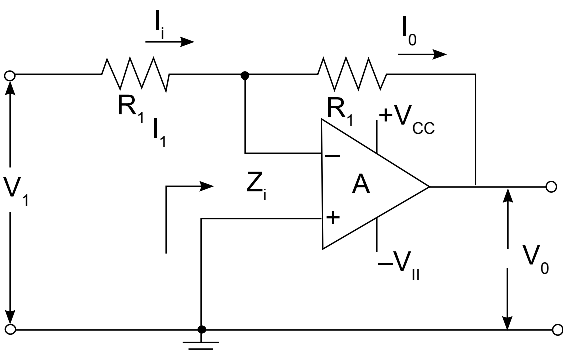


Fig. 2.6: Op-amp close-loop configuration

It is found that the closed-loop gain for inverting amplifier shown in Fig.2.6 which is called as inverting amplifier is equal to – (R_f/R_1).

Output impedance (Zo): The closed-loop output impedance $Z_{o(CL)}$ of an O_p Ampis defined as the ratio of the open-loop output impedance Zo(OL) to the loop gain. Thus,

$$Z_o(CL) = Z_o(OL)/Loop\ gain \qquad ...(2.11)$$

where, $Loop\ gain = Open\text{-}loop\ gain - Closed\text{-}loop\ gain.$

The virtual ground: To illustrate the features of an operational amplifier, consider the feedback circuit, Fig. 2.7 in which negative voltage feedback is produced by the resistor R_f connected between the input and output. Note that the feedback is negative because of phase inversion in the amplifier. The feedback ratio in operational feedback can vary from unity for a high impedance source to $R/(R + R_f)$ for a low impedance source since, the feedback voltage is sufficiently connected in parallel with the input signal source. It is convenient to analyse the operational feedback circuit by applying Kirchhoff's current law to the branch point S. Since, the amplifier input impedance is large, the current in this branch is negligible, which means the current in R equals the current in R_f.

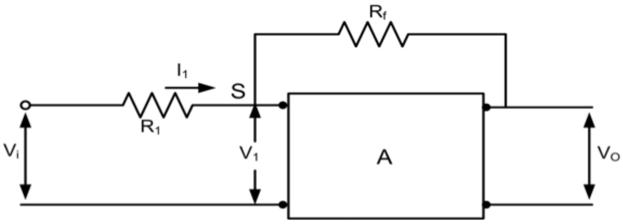


Fig. 2.7: Block diagram of Op Amp with feedback

$$\frac{V_i - V_1}{R} = \frac{V_1 - V_o}{R_f}$$

Introducing $V_1 = \frac{-V_O}{A}$ and rearranging, $V_o\left(1+\frac{1}{A}+\frac{Rf}{A}\right) = -\frac{R_f}{R} . V_i$

Since, the gain is very large, $V_o = -\frac{Rf}{R} . V_i$

which means that the output voltage is just the input voltage multiplied by the constant factor – (R_f / R). If precision resistors are used for R_f and R, the accuracy of this multiplication operation is quite good.

The branch point 'S' has a special significance in op-amps. This may be illustrated by determining the effective impedance between S and ground, which is given by the ratio V_1 to the input current I_1.

$$Zs = \frac{V_I}{l_i} = \frac{V_I R_f}{V_I - V_o} = \frac{R_f}{1 - \frac{V_o}{V_1}} = \frac{R_f}{1+A} \qquad \ldots(2.13)$$

where, the right hand side of equation has been inserted for the input current. According to equation 2.1.13, the impedance of S to ground is very low if the gain is large. The typical values are $R_f = 10^5$ ohms and $A = 10^4$ so that the impedance is 10 ohms. The low impedance results from the negative feedback voltage, which cancels the input signal at 'S' and tends to keep the branch point at ground potential. For this reason, the point 'S' is called virtual ground. Although 'S' is kept at ground potential by feedback action, no current to ground exists at this point.

2.1.5 Op Amp operating modes

The Op Amp can be effectively utilized in linear application by providing feedback from the output to the input. If the signal fed back is out of phase by 180^0 with respect to the input, then feedback is called as negative feedback or degenerative feedback. The commonly used closed loop operating modes are

a. Inverting amplifier
b. Non-inverting amplifier

2.1.5.1 Op Amp Inverting mode amplifier

The inverting operational amplifier configuration is one of the simplest and most commonly used op amp operating mode. In inverting mode amplifier, the output is exactly 180^0 out of phase with respect to input (i.e. if a positive voltage is applied, output will be negative). Output is an inverted (in terms of phase) amplified version of input. The inverting operational amplifier configuration is a closed loop mode application of Op Amp. It uses negative feedback, which means that the feedback signal opposes input signal.

$$V_O = -(R_f/R_1)*V_i \qquad \ldots(2.14)$$

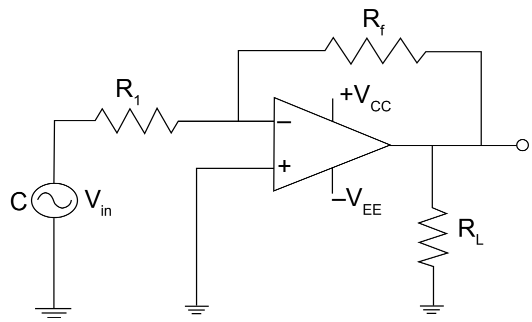


Fig. 2.8: Inverting Amplifier

The circuit diagram shown in Fig. 2.8 is the operational amplifier used in inverted mode. In this mode of operation, the positive input terminal of the amplifier is grounded and the input signal e1 is applied to the negative input terminal through resistor R_1. The feedback applied through R_f from the output to the input terminal is negative. The inverting operation performed by circuit is determined by the feedback resistor R_f and the input resistor R_1.

Considering that the Op Amp is ideal meaning thereby that it has infinite gain. With infinite voltage gain, the potential difference between the input terminals must be zero. In the circuit the voltage between input terminals is forced to zero by the negative feedback around the amplifier. As the input impedance of the amplifier is infinite, the input current to the amplifier is zero. Hence for ideal op-amp, following two conditions must be satisfied:

i. The potential difference between the amplifier terminals is zero.

ii. The current into each input terminal is zero.

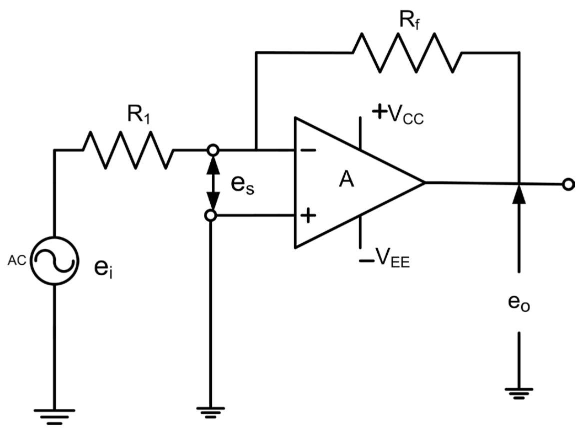


Fig. 2.9: Operational amplifier in inverting mode

Note that the first condition will follow on the assumption that the input voltage of the amplifier is infinite. Thus, a finite output divided by zero input gives infinite gain which is nothing but the characteristic of an op-amp. The voltage $e_s = 0$ implies that the terminal (1) has same potential as that of terminal (2). But terminal (2) is grounded, hence terminal (1) is also virtually grounded. Hence, there is a virtual ground at negative terminal.

Thus, the current 'i_1' flowing through R_1 also flows through R_f. Since the input current is very small, it can be approximated to zero. For any input voltage applied at the inverting input, the input differential voltage is negligible and input current is zero. Hence the inverting input appears to be a ground. The term virtual ground signifies a point which voltage with respect to ground is zero and yet no current can flow into the point.

Therefore, $i_1 = i_f$, …(2.15)

$$\frac{e_I - e_s}{R_I} = \frac{e_s - e_o}{R_f}$$

As, $e_s = 0$,

$$\frac{e_I - o}{R_I} = -\frac{o - e_o}{R_f}$$

$$\frac{e_I}{R_I} = \frac{-e_o}{R_f}$$

$$\frac{e_o}{e_I} = -\frac{R_f}{R_I} \qquad ...(2.16)$$

Here, (e_o / e_i) ratio is termed as closed-loop gain ACL of the inverting amplifier. It is a negative quantity because the closed-loop amplifier reverses the sign of the input signal, i.e. the output is out of phase with input. The gain depends on the ratio of R_f/R_i.

It shows that the input impedance depends only on the external resistor R1. The output impedance is defined as the impedance seen at the output of the Op Amp, when the input terminal is set equal to zero. The ratio of feedback resistance and input resistance can be set to any value, even to less than 1. Because of this property Op Amp is popular in majority of applications.

1 It give phase difference of 180^0 between input and output.

2 Input impedance is lower.

3 Smaller bandwidth as compared to non-inverting amplifier.

2.1.5.2 Op Amp Non-inverting mode amplifier

The non-inverting amplifier configuration is one of the most popular and widely used forms of operational amplifier circuit. The op amp non-inverting amplifier circuit provides a high input impedance along with all the advantages gained from using an operational amplifier.

Non-inverting amplifier is one in which the output is in phase with respect to input(i.e. if input is positive voltage, output will be positive). Output is a Non inverted(in terms of phase) amplified version of input.

$$V_o = (1+(R_f/ R_1))*V_i \qquad …(2.17)$$

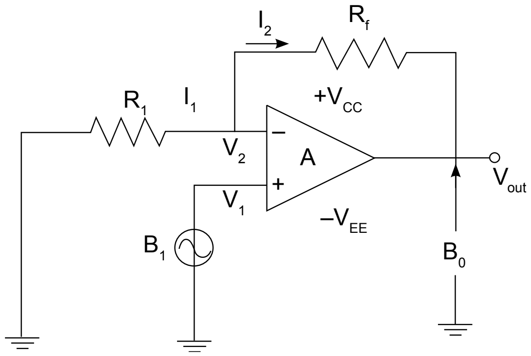


Fig. 2.10: Non-inverting Amplifier

The circuit diagram of an ideal Op Amp in the non-inverting mode is shown in Fig.2.10. In this case, the input signal is applied directly to the non–inverting (positive) input terminal of the amplifier and the feedback resistor R_f is connected between the output terminal and negative input terminal.

The R_1 is connected between the inverting terminal and ground, similar to previous case, $e_s = 0$. Therefore, voltage e_1 from the negative terminal to ground is equal to the input voltage e_2. Note that e_1 is not equal to zero in this case, meaning that non-inverting circuit has no virtual ground at either one of its input terminals.

Since, $e_1 = e_2 \quad e_1 = i_1 \qquad R_1 = e_o \dfrac{R_1}{R_1 + R_f} = e_2$

Thus,
$$\frac{e_0}{e_2} = \frac{R_f + R_1}{R_1}$$

Or
$$\frac{e_0}{e_1} = \frac{R_f + R_1}{R_1}$$

But $\dfrac{e_0}{e_2}$ is closed-loop gain.

Thus,
$$A_{CL} = \frac{R_f + R_1}{R_1} = \frac{R_f}{R_1} + \frac{R_1}{R_1} = \frac{R_f}{R_1} + 1$$

$$A_{CL} = \frac{e_0}{e_2} = \left(1 + \frac{R_f}{R_1}\right) \qquad \text{...(2.18)}$$

Thus, the closed-loop gain of a non-inverting amplifier is always greater than or equal to unity and is determined by R_1 and R_f. If $R_f = 0$ and $R_1 = \infty$, then the gain is exactly equal to one and the amplifier acts as a voltage follower i.e. the output voltage follows the input voltage exactly. The advantage of such a voltage follower and of non-inverting circuits in general is impedance buffering. Such amplifier circuits are widely used to provide isolation of signal source and load thus, preventing undesired interactions or loading effects.

Advantages of Non-inverting Amplifier

1. There is no phase shift between input and output.
2. The input impedance is higher than inverting configuration.
3. Larger bandwidth as compared to inverting amplifier.
4. Circuit uses negative feedback.

Solved Problems

Example 2.1.1: The output voltage of Op Amp changes by 40 V in 8µS. Calculate slew rate of Op Amp.

Solution:

Slew Rate = dV/dt
= 40V/8 µS
= 5 V/µS

Example 2.1.2: For the inverting amplifier mode of Op Amp R_f = 10 KΩ and R_i = 2 KΩ .Calculate close loop voltage gain A_{CL}.

Solution: The close loop voltage gain in inverting mode = – R_f / R_1
= – (10 KΩ /2 KΩ)
= – 5

Example 2.1.3: For the non-inverting amplifier mode of Op Amp R_f = 10 KΩ and R_i = 1 KΩ .Calculate close loop voltage gain A_{CL} and feedback factor.

Solution:

The close loop voltage gain in non-inverting mode = 1+ (R_f / R_1)
= 1 +(10 KΩ /1 KΩ)
= 11

Feedback factor β = R_1 /(R_1 + R_f)
= 1 KΩ /(1 KΩ +10 KΩ)
= 0.09

Example 2.1.4: Calculate the CMRR of Op Amp that has a differential gain of 300000 and common mode gain is 12.66.

Solution:

CMRR is the ratio of differential mode gain to common mode gain.

$$\text{CMRR} = A_d / A_C$$
$$= 300000/12.66$$
$$= 13850.41$$
$$\text{CMRR in dB} = 20 \log_{10}(A_d/A_C)$$
$$= 82.82 \text{ dB}$$

Example 2.1.5: Calculate the feedback resistor value if in Non-inverting Op Amp amplifier input resistor is of 4 KOhm and required gain for specific application is 13.

Solution:

Given that Op Amp operating mode is Non-inverting amplifier mode.

$$\text{Input resistance value } R_{in} = 4 \text{ KOhm}$$
$$\text{Gain} = 13$$
$$\text{Gain} = 1+(R_f/R_{in})$$
$$13 = 1+ (R_f/4 \text{ KOhm})$$
$$13 - 1 = R_f/4 \text{ KOhm}$$
$$12 = R_f/4 \text{ KOhm}$$
$$R_f = 48 \text{ KOhm}$$

2.2 Applications of Operational Amplifiers

The Op Amp was originally developed for requirement of analog computer. As Op Amp is a high gain direct coupled amplifier with feature of externally voltage gain controlled, it finds many applications in signal processing and conditioning applications. Due to its low cost, high performance and versatile nature, it is used in many analog electronics circuits.

It is always used in close loop mode with negative feedback and the voltage gain is controlled by external component Ri and Rf .When the power supply is connected there is output even when the two inputs are grounded this is called offset. It can be made zero by connecting 10 KΩ POT between pin 1 and 5 and connecting wiper to Pin 4.

2.2.1 Op Amp as an Adder

Adder and substractor circuit using Op Amp is used to perform arithmetic operations like addition, subtraction etc Op Amp adder is also called as summing amplifier In adder and subtractor circuit the input signal can be added and subtracted to the desire value by selecting appropriate values for the external resisters. These arithmetic functions employed in analog circuits. This circuit can be used to add AC or DC signals. This circuit provides an output voltage proportional to or equal to the algebraic sum of two or more input voltage each multiplied by a constant gain factor. In inverting configuration of an OP Amp if more than one input is given to inverting terminal then resultant circuits work as summing amplifier or adder.

The Op Amp

$$V_o = -(R_f / R_i) * (V_1 + V_2) \quad \text{...(2.19)}$$

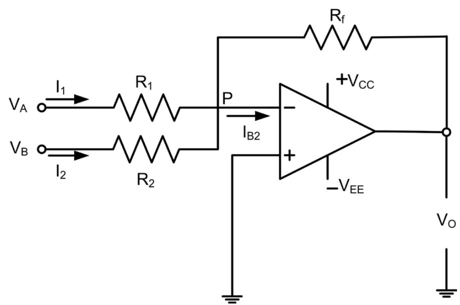


Fig. 2.11: Op Amp as an Adder circuit

Here, the voltages are amplified and then added.

Applying KCL at inverting input node,

$$i_1 + i_2 = i_f + I_{B_2}$$

As Op Amp is ideal, $I_{B_2} = 0$

$$i_1 + i_2 = i_f$$

$$\frac{V_A - V_p}{R_1} + \frac{V_B - V_p}{R_2} = \frac{V_p - V_o}{R_f}$$

Due to virtual ground, $V_p = 0$.

$$\frac{V_A}{R_1} + \frac{V_B}{R_2} = \frac{V_o}{R_f}$$

$$V_0 = -R_f\left(\frac{V_A}{R_1} + \frac{V_B}{R_2}\right)$$

$$V_0 = -\left(\frac{R_f}{R_1}V_A + \frac{R_f}{R_2}V_B\right)$$

If $R_1 = R_2 = R$

$$V_0 = -\frac{R_f}{R}[V_A + V_B] \quad \text{...Summing amplifier (2-20)}$$

If $R_1 = R_2 = R_f = R$

$$V_o = -(V_A + V_B)$$

If $R_1 = R_2 = 2R_f$

If $R_1 = R_2 = 2R_f$, the circuit behaves as an averaging circuit. Then the output voltage is

$$V_0 = -\frac{V_1 + V_2}{2} \quad \text{....(2-21)}$$

2.2.2 Op Amp as a differentiator

In differentiator circuit, the reactance, X_C is connected to the input terminal of the inverting amplifier while the resistor, R_f forms the negative feedback element across the operational amplifier. The differentiator circuit performs the mathematical operation of differentiation and "produces a output voltage which is directly proportional to the input voltages rate-of-change with respect to time". The faster or larger the change to the input voltage signal, the greater the input current, the greater will be the output voltage change becoming more of a "spike" in shape. The input signal to the differentiator is applied to the capacitor. The capacitor blocks DC content so there is no current flow to the amplifier summing point. Resulting in zero output voltage. The capacitor only allows AC type input voltage changes to pass through and whose frequency is dependent on the rate of change of the input signal.

The differentiator circuit performs the mathematical operation of differentiation i.e. the output waveform is the derivative of the input waveform. The differentiator may be constructed from a basic inverting amplifier if an input resistor R_1 is replaced by a capacitor C_{in}.

The expression for the output voltage can be obtained as the output V_o is equal to R_f C_{in} times the negative rate of change of the input voltage V_{in} with time. The (–) sign indicates a 180^0 phase shift of the output waveform V_O with respect to the input signal. Since the differentiator performs the reverse of the integrator function.

The circuit in which the output voltage waveform is derivative of the input waveform is called as a differentiator. The output voltage is given by equation

$$V_O = -R_F C_1 \frac{dV_{in}}{dt} \quad \text{...(2.22)}$$

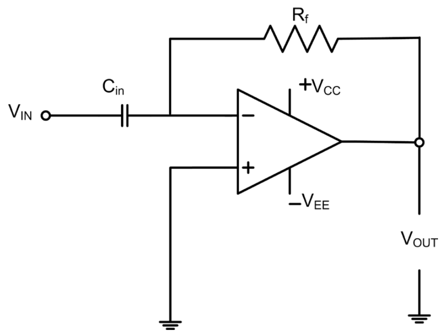


Fig. 2.12: Op Amp Integrator circuit

Fig. 2.13 shows output voltage waveform of an Op Amp differentiator circuit for a square and sinusoidal voltage input waveform.

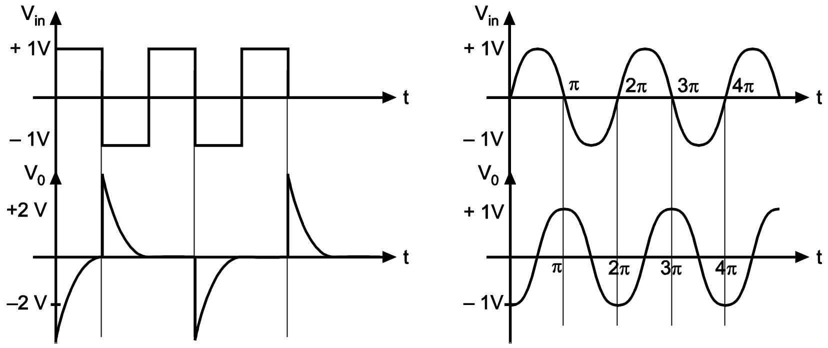


Fig. 2.13: Ideal output waveforms using square and sine waves respectively

If the input is a sine wave the output will be a cosine wave or if the input is a square wave, the output will be trigger pulses as shown.

Applications: The differentiator is used in wave shaping circuits to detect the high frequency components in an input signal and also as a rate of change of detector in FM modulators. The differentiator acts as high pass filter.

2.2.3 Op Amp as an integrator

The circuit in which the output voltage waveform is the integral of the input voltage waveform is called as integrator or integration amplifier. Integrator circuit is obtained by using a basic inverting amplifier. If the feedback resistor R_F is replaced by a capacitor C_F as shown in Fig.2.14, then the circuit acts as integrator. In integrator circuit the position of the capacitor and resistor have been reversed as that of differentiator circuit. Operational amplifier can be configured as analog integration. In an integrating circuit, the output is the integration of the input voltage with respect to time. An integrator circuit which consists of active devices is called an Active integrator. An active integrator provides a much lower output resistance and higher output voltage than is possible with a simple RC circuit. Integrator circuits are usually designed to produce a triangular wave output from a square wave input. Integrating circuits have frequency limitations while operating on sine wave input signals.

Integration is a process of continues additions. The most popular application of an integrator is to produce a ramp of output voltage which is linearly increasing or decreasing voltage. If the input voltage is step voltage, then output voltage will be ramp or linearly changing voltage. Integrators are widely used in ramp or sweep generator, in filter, analog computer etc.

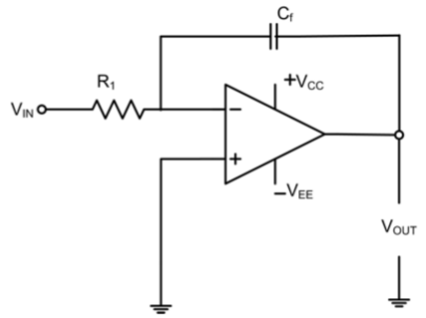


Fig. 2.14: Op Amp Integrator circuit

The output voltage is given by equation $$V_o = \frac{1}{R_1 C_F}\int_0^t V_{in}\,dt + C \qquad ...(2.23)$$

From above equation the output voltage is directly proportional to the negative integral of the input voltage and inversely proportional to the time constant R_1C_F.

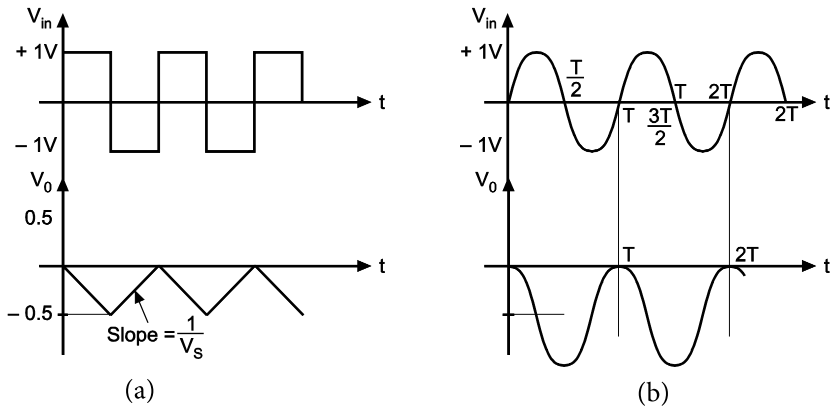


Fig. 2.15: Ideal output waveforms using square and sine wave respectively

If the input is a sine wave, the output will be a cosine wave or if the input is a square wave, the output will be the triangular wave as shown with $R_1C_F = 1$. When $V_{in} = 0$, the integrator work as an open-loop amplifier as C_F acts as an open circuit, $C_F = \infty$. The input offset voltage V_{i0} and the input current charging capacitor C_F produce the error voltage at the output of the integrator. Therefore, to reduce the error voltage at the output, a resistor R_F is connected across the feedback capacitor C_F.

The integrator is most commonly used in analog computers and analog to digital converter (ADC) and signal-wave shaping circuits. The integrator act as a low pass filter. The cut off frequency is inversely proportional to feedback components resistor R_f and capacitor C_f.

Cutoff frequency for integrator i.e. low pass filter is given by equation 2.24.

$$F_1 = 1/(2\pi R_1 C_f) \qquad \ldots(2.24)$$

Applications

Analog circuits are build using Op Amp. Op Amp has wide range of applications in domestic and industrial applications. In various automation, entertainment appliances analog circuits are used. Following type of Op Amp based analog circuits are used in many electronic devices.

- Precision Rectifier
- Zero Crossing Detector
- Frequency to Voltage Converter
- Signal Processing
- Active Filter
- Sample and Hold Circuit
- Instrumentation Amplifier
- Log and antilog Amplifier
- Voltage to Current Converter
- Voltage to Frequency Converter
- Analog to Digital converter
- Signal Conditioning
- Peak Detector
- Computational Building Blocks
- Analog Multiplier and Divisor
- Current to voltage Converter
- Linear and Switching Regulators
- Digital to Analog Converter
- Biomedical Instrumentation
- Oscillators
- Analog Computer

Activity for inquisitiveness and curiosity

Student shall form a group of 5 - 6 students and undertake activity(ies) for developing inquisitiveness and curiosity under the guidance of faculty. A sample is given below:

1. Select a small application circuit of Op Amp. One of the circuit given under Applications in this unit can be selected.
2. Choose an appropriate Op Amp IC with the help of data sheet.
3. Select the electronic component of proper value as per the requirement of circuit.
4. Test the IC and other components needed for the application.
5. Mount the electronic component on breadboard as per circuit diagram.
6. Test the circuit for the given application.
7. Compare the observed output with the expected output.

Solved Problems

Example 2.2.1: For an Op Amp integrator, if cut off frequency is 159 Hz, R_{in} = 1 KΩ and R_f = 100 KΩ, Calculate the value of feedback capacitance.

Solution:

Given $R_{in} = 1\ K\Omega,\ R_f = 100\ K\Omega$ and Fc = 159 Hz

$$F_1 = 1/(2\pi R_f C_f)$$
$$159 = 1/2\pi R_{in} C_f$$
$$159 = 1/2 \times 3.14 \times 100 \times 10^3 \times C_f$$
$$C_f = 1/2 \times 3.14 \times 100 \times 159 \times 10^3$$
$$= 1.0 \times 10^{-8}$$
$$= 0.01\mu F$$

Example 2.2.2: A differentiator has feedback resistor of 10 KΩ and input capacitor value is 0.01 μF Calculate the cut off frequency.

Solution:

Given for differentiator circuit R_f = 10 KΩ and input capacitor C_{in} = 0.01 μF

Cut off frequency of differentiator is given by $f_1 = 1/\ 2\pi R_f\ C_{in}$

$$f_1 = 1/2 \times 3.14 \times 10 \times 10^3 \times 0.01 \times 10^{-6}$$
$$= 1.59\ KHz$$

Example 2.2.3: Calculate output of two input inverting summing amplifier with feedback resistor of 4 KΩ and two inputs are V_1 = 3V and V_2 = 4V Two input resistors are R_1= 4KΩ and R_2 = 8KΩ

Solution: Given that the Op Amp operating mode is inverting configuration

$$R_f = 4\ \text{K}\Omega$$
$$R_1 = 4\text{K}\Omega$$
$$R_2 = 8\ \text{K}\Omega$$
$$V_1 = 3\ \text{V and } V_2 = 4\ \text{V}$$
$$\text{V}_o = -\left[\frac{R_f}{R_1}V_A + \frac{R_f}{R_2}V_B\right]$$
$$= -\ [(4/4) \times 3 + (4/8) \times 4] = -\ [3 + 2]$$
$$\text{V}_o = -\ 5\ \text{V}$$

SUMMARY

- The operational amplifier, more commonly known as Op Amp, is an analog circuit.
- Op Amps perform many arithmetic functions, linear and nonlinear operations in the analog or continuous domain.
- Op Amps are also used in several kinds of analog amplifiers and active filters.
- Op Amp with close configuration having negative feedback can be used in inverting and non – inverting amplifier mode.
- In inverting and non–inverting amplifier mode, close loop gain of amplifier depends on feedback resistor and input resistor.
- Non-inverting amplifier with unity gain is used as an analog buffer.

EXERCISES

A. Objective Questions

Instruction: Please select the most appropriate answer.

Sr. No.	MCQs	Sr. No.	MCQs
2.1	The feedback path of Op Amp integrator consists of a. Resistor b. Capacitor c. Inductor d. Diode	2.4	For biasing, Op Amp IC 741 requires a. single power supply b. two power supplies c. four power supplies d. no power supply
2.2	If input signal is fed to inverting input through capacitor and feedback path consists of resistor, then that Op Amp circuit is called as a. Adder circuit b. Integrator circuit c. Differentiator circuit d. Non-inverting amplifier	2.5	For the differentiator circuit to operate as high pass filter, time constant of circuit must be a. High b. Very high in comparison to the time period of input signal c. Small d. Very small in comparison to the time period of inpput signal
2.3	Two input terminals of Op Amp are known as a. High and low b. Inverting and Non-inverting c. Phase and neutral d. Integrator and differentiator	2.6	For inputs averaging circuit, a. R_{in} = Rf /4 b. R_{in} = Rf + 4 c. R_{in} = Rf d. R_{in} = Rf X 16

3 Overview of Digital Electronics

UNIT SPECIFICS

This unit discusses the following topics:

- Number system and conversions
- Boolean laws and theorem
- Logic gates
- Flip flops and its types
- Use of flip flops as counter
- Introduction to Integrated Circuits

The student self-learning activities at the end of each topic along with problem solving examples and ICT references are created for generating further curiosity and creativity as well as improving problem solving capacity. A number of multiple choice questions as well as subjective questions following increased levels of Bloom's taxonomy, assignments through a number of problems provided in the books listed under references and suggested readings are given in the unit so that one can go through them for practice.

A "Know More" section has been introduced, so that the supplementary information provided becomes beneficial for the users of the book. In this section, based on the unit content, "Micro Project" activity and QR code of video resources are provided to learn more about some of the sub-topics covered.

RATIONALE

Digital systems are extensively used for computation, data processing, communication and in measurement and control. The main reason being Digital systems are more reliable, less affected by noise, easier to design and fabricated on IC chips. The unit will aid to understand the fundamental concepts of digital systems and their application in digital devices and integrated circuits.

PRE-REQUISITE

1. Mathematics: Set, Real Numbers, Proofs in Mathematics (Class X)

UNIT OUTCOMES

Upon completion of this unit, the student will be able to:

U3-O1: Simplify the given expression using Boolean laws and theorem.

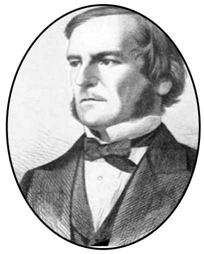
U3-O2: Explain the various types of logic gates.

U3-O3: Use the given flip-flop to construct the specific type of counter.

U3-O4: Suggest appropriate TTL digital IC for gates.

Unit 3 Outcomes	Expected Mapping with Course Outcomes (1- Weak Correlation; 2- Medium correlation; 3- Strong Correlation)					
	CO-1	CO-2	CO-3	CO-4	CO-5	CO-6
U3-O1	-	-	3	-	-	-
U3-O2	2	-	3	-	-	-
U3-O3	2	-	3	-	-	-
U3-O4	3	-	3	-	-	-

George Boole (1815-1864)
Boolean algebra was introduced by George Boole, Professor of Mathematics at University College, Cork, Ireland in his first book 'The Mathematical Analysis of Logic' in 1847. Boolean algebra is the branch of algebra in which the values of the variables are the truth values 'true' and 'false', usually denoted as '1' and '0', respectively. In elementary algebra, where the values of the variables are numbers and the prime operations are addition and multiplication, the main operations of Boolean algebra are the AND, OR and NOT. Boolean logic is credited with laying the foundations for all modern electronic digital computers.



3.1 BOOLEAN OPERATION AND BOOLEAN ALGEBRA

3.1.1 Introduction

Electronic circuits and systems are of two types, Analog and Digital. Analog circuits are those in which the voltage and current vary continuously between a maximum and minimum value. Digital circuits are those where the voltage level assume a finite value. In all modern digital systems ,there are just two distinct voltage levels. Each voltage level however is a narrow band of finite voltage value. The digital systems use the binary system, where the binary digit 1 used to represent a high voltage level and binary digit 0 is used to represent low voltage level. The digital system is then called a positive logic system. Digital systems are also called as switching circuits or logic circuits. The circuits use Boolean algebra. The Boolean algebra is a system of mathematical logic consisting of a set of elements and operators for analysis and synthesis of logic circuits. The algebra differs from both the decimal and the binary number system algebra and is evaluated by a set of rules and laws.

3.1.2 Number System and Conversions

Number system relates quantities and symbols. The number system represents a value of a given number with respect to its given base. Human beings use the decimal number system for their everyday activities whether counting or measurement. The digital system uses the binary number system. The base value determines the unique representation of a given number and therefore different number system has different representation of the same number.

3.1.2.1 Decimal Number System

The Decimal number system has a base 10 as it uses ten independent symbols i.e. symbols 0, 1, 2, 3, 4, 5, 6, 7, 8 to 9 to represent a number in decimal system. For example, the number 10 is represented by the symbols 0 and 1, where symbol 0 is the least significant digit (right most digit) and symbol 1 is the most significant digit (left most digit). In decimal system each digit position represents a specific power of base 10. For example, the decimal number

$$(3456)_{10} = 3 \times 10^3 + 4 \times 10^2 + 5 \times 10^1 + 6 \times 10^0$$

The right most digit is of the order of 10^0 (unit or ones), the second right most digit is of the order of 10^1 (tens), the third right most bit is of the order of 10^2 (hundreds) , the fourth right most bit (thousands) and so on. In general, a decimal number system with decimal point is represented as

$$D_3D_2D_1D_0.D_{-1}D_{-2}$$

The decimal digit represented by coefficient D_k represents any of the decimal digits from 0 to 9 and the subscript k indicates the position value and hence the power of base i.e. base 10 to which the coefficient must be applied. For the decimal number as shown above, it will be as follows

$$D_3 \times 10^3 + D_2 \times 10^2 + D_1 \times 10^1 + D_0 \times 10^0 + D_{-1} \times 10^{-1} + D_{-2} \times 10^{-2}$$

3.1.2.2 Binary Number System

The binary system has two independent symbols namely 0 and 1. The base of this number system is therefore 2. The decimal number $(2)_{10}$ in binary system is represented as $(10)_2$. A binary digit is called a bit. Like decimal number system the binary system is a positional weight system, where each bit represents a specific power of base 2. The right most bit of a binary system is called the Least Significant Bit (LSB) and the left most bit is called the Most Significant Bit (MSB). In general, a binary number system with binary point is represented as

$$b_3\ b_2\ b_1b_0.b_{-1}b_{-2}$$

The binary bit represented by coefficient b_k represents either bit 0 or bit 1 and the subscript k indicates the position value and hence the power of base i.e. base 2 to which the coefficient must be applied. For the binary number as shown above it will be as follows

$$b_3 \times 2^3 + b_2 \times 2^2 + b_1 \times 2^1 + b_0 \times 2^0 + b_{-1} \times 2^{-1} + b_{-2} \times 2^{-2}$$

3.1.2.3 Octal and Hexadecimal Number System

Octal number system

The octal number system was used by early microcomputers. In octal number system there are eight independent symbols 0, 1, 2, 3, 4, 5, 6 and 7. Therefore the base is 8. The octal number system is also a positional number system, wherein each digit of the octal system represents a specific power of base 8.

Hexadecimal number system

The digital computer system uses binary number system. Although it is easier for machines to process data in binary system, the binary numbers are long and are too lengthy to be handled by human beings. To overcome this problem, the hexadecimal number system was developed and it has become the most popular number system for data processing in digital systems. The independent symbols used are 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E and F. Therefore, the base is 16. It is also a positional number system.

3.1.3 Number Conversion

Number System Conversions

3.1.3.1 Binary to Decimal Conversion

Binary numbers are converted to decimal numbers by their positional weight system. In this method each binary bit is multiplied by the corresponding position weight and thereafter the result of each product terms are added to obtain the decimal number. For example convert 1101.11_2 to decimal

$$1101.11 = 1 \times 2^3 + 1 \times 2^2 + 0 \times 2^1 + 1 \times 2^0 + 1 \times 2^{-1} + 1 \times 2^{-2}$$

$$= 8 + 4 + 0 + 1 + 0.5 + 0.25 = 13.75_{10}$$

3.1.3.2 Decimal to Binary Conversion

The integer part of the decimal number system is successively divided by 2 till the quotient is zero to get the binary integer. The last reminder is the MSB. Similarly, the fractional part is successively multiplied by 2 till the product is zero or till the desired accuracy is obtained. For example convert 35.875_{10} to binary. The integer part is first successively divided by 2 as shown.

2	35	Reminder
2	17	1
	8	1
2	4	0
2	2	0
2	1	0
	0	1 (**MSB**)

The answer is 100011, obtained by reading the reminders from bottom to top as shown by arrow. Now convert the fraction part by successively multiplying it by 2 and keep noting the integer part as shown.

$$0.875 \times 2 = 1.75, \text{ Integer } =1$$
$$0.750 \times 2 = 1.50, \text{ Integer } =1$$
$$0.500 \times 2 = 1.00, \text{ Integer } =1$$

Now reading the integers in the forward direction we get (.111). Combining the integer and fractional part, the binary equivalent of 38.875_{10} results as 100011.111_{2}.

3.1.4 Binary Arithmetic

3.1.4.1 Binary Addition

The addition of two binary bits follow the following rules:

0 + 0 = 0; 0 + 1 = 1; 1 + 0 = 0; 1 + 1 = 0 and carry 1

Add the following binary numbers 1011.011 and 111.010

```
  1 0 1 1 . 0 1 1
  + 1 1 1 . 0 1 0
1 0 0 1 0 . 1 0 1
```

The addition of carry ahead is done in a manner similar to decimal addition

3.1.4.2 Binary Subtraction

The binary subtraction follows the following rules:

0 – 0 = 0; 1 – 0 = 1; 1 – 1 = 0; 0 – 1 = 1 with a borrow of 1 i.e. equivalent to 10 – 1

Subtract the binary number 111.111 from 1010.010

```
1 0 1 0 . 0 1 0
- 1 1 1 . 1 1 0
0 0 1 0 . 0 1 1
```

In digital computers for simplifying the subtraction operation complements are used. There are two types of complement for each number system. For a base b system the complements are the (b-1)'s complement and the b's complement . For a binary number system, the two types are the 1's and 2's complement.

3.1.5 Boolean Laws and Theorems

3.1.5.1 Boolean Algebra

The Boolean algebra is an algebraic system developed for systematic treatment of logic. It is defined with a set of elements, a set of operators and a number of postulates. Unlike ordinary algebra negative number and fraction do not exist. No subtraction or division operations are there in Boolean Algebra. The basic laws of Boolean algebra are

Commutative law: A binary operator plus (+) or dot (.) on a set S is said to be commutative if

1. A+B = B + A
2. A.B = B.A

where A and B are elements of S

Associative law: A binary operator plus (+) or dot (.) on a set S is said to be associative if

1. (A + B) +C = A + (B + C)
2. (A.B).C = A. (B.C)

where A, B and C are elements of S

Distributive law:

1. (A + B).C = A.B + B.C
2. A+ (B.C) = (A + B). (A + C)

AND, OR and NOT law : The table 3.1 shows the basic Boolean laws.
where A= {0,1} and the complement of A is represented as A'

Sr.No.	OR law	AND law	NOT (Complement) law
1	A + 0 = A	A . 0 = 0	A" = A
2	A + 1 = 1	A . 1 = A	If A = 0, then A' = 1
3	A + A = A	A . A = A	If A = 1, then A' = 0
4	A + A' = 1	A . A' = 0	

De Morgan's Theorem: The theorem represents two laws
Law 1: (A + B)' = A'. B'
The law states that complement of a sum of two variables is equal to the product of the individual complements.
Law 2: (A.B)' = A' + B'
The law states that the complement of the product of two variables is equal to the sum of the individual complements,

Activity

Prepare a presentation on the digital codes used for information processing by digital circuits

Solved Problems

Example 3.1.1: Convert the following decimal number 452_{10} to binary.
Solution:

2	450	Reminder
2	225	0
2	112	1
2	56	0
2	28	0
2	14	0
2	7	0
2	3	1
2	1	1
	0	1

452_{10} = $\mathbf{(111000010)_2}$

Example 3.1.2: Write the first ten decimal digits to base 3.
Solution:
For a base 3 system the symbols are 0, 1 and 2. The remaining decimal numbers are obtained by successively dividing the decimal number by base 3. Decimal digit 3 is written as 10_3 and similarly decimal digit 4 to 9 is written as:

Decimal number	Equivalent in base 3	Decimal number	Equivalent in base 3	Decimal number	Equivalent in base 3
4	11	5	12	6	20
7	21	8	22	9	23

3.2 LOGIC GATES

A Boolean function is an expression formed with binary variables using the binary operators AND, OR, NOT, parentheses and equal sign. A binary variable can take the value 0 or 1. For example a Boolean function $F = x + y$ is equal to 1, if either variable x, y or both are equal to 1, otherwise F = 0. A Boolean function may be represented by a truth table. The truth table of a n variable Boolean function F consists of a column listing the 2^n combinations of the n variables and a column showing the value of F either 0 or 1 for each of the 2^n combinations.

3.2.1 Positive and Negative Logic

Logic Gate Simulator

The voltage level which represents a binary variable equal to logic-1 or logic-0. When the higher voltage represents logic-1 and lower voltage as logic-0, then the logic system is termed as positive logic. For example, a digital system may define logic-1 if the variable voltage level is equal to its nominal value say + 5.0 V. Similarly, logic-0 will be defined if the voltage level of the variable has a nominal value equal to 0 V. On the other hand, the logic system is termed as negative logic, when the higher voltage i.e. + 5 V represents logic-0 and the lower voltage i.e. 0 V represents logic-1. In general, all digital circuits accept binary signals with in the allowable tolerance level. A voltage between 0 V and 0.8 V represents logic - 0 and voltage between 3V to 5V represents logic-1.

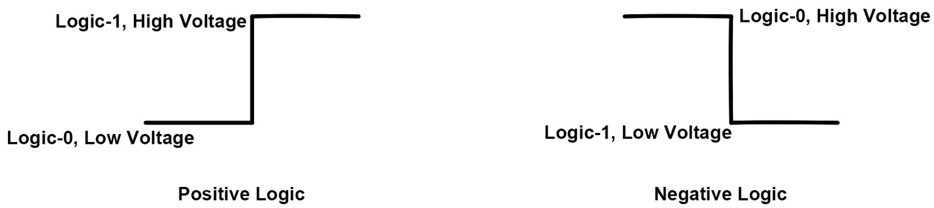


Fig. 3.1: Logic signal

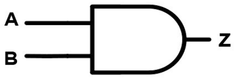
3.2.2 Types of Logic Gates

Boolean Expressions using Logic

The fundamental building block of any digital system are the logic gates. The name logic gates imply that the output of the gate is based on the ability of the device to make decisions, according to its present input. The three types of basic gates are the AND, OR and NOT. The inputs and outputs of logic gates can occur only in two level. These two level are logic-1, termed as HIGH/TRUE and logic-0 termed as LOW/FALSE.

3.2.2.1 AND GATE

An AND gate is a logic circuit whose output assumes logic-1 when each one of its input are at logic-1. Even if one of the inputs is at logic-0, the output assumes logic-0. The AND gate has two or more inputs, but only one output. The logic symbol, Boolean expression and truth table of an AND gate is shown in Fig. 3.2.



Logic Symbol

Z = A . B

Boolean Expression

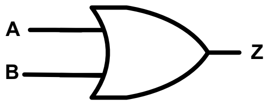
A	B	Z
0	0	0
0	1	0
1	0	0
1	1	1

Truth table

Fig. 3.2: AND Gate

3.2.2.2 OR GATE

An OR gate is a logic circuit in which the gate output assumes logic-0 when each one of its input are at logic-0. Even if one of the inputs is at logic-1, the output assumes logic-1. The OR gate has two or more inputs, but only one output. The logic symbol, Boolean expression and truth table of an OR gate is shown Fig, 3.3.



Logic Symbol

Z = A + B

Boolean Expression

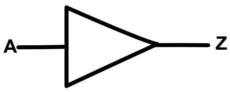
A	B	Z
0	0	0
0	1	1
1	0	1
1	1	1

Truth table

Fig. 3.3: OR Gate

3.2.2.3 NOT GATE

The NOT gate, also known as INVERTER gate has only one input and one output. The output of a NOT gate will always be the complement of its input. The logic symbol, Boolean expression and truth table of a NOT gate is shown in Fig. 3.4.



Logic Symbol

Z = A’

Boolean Expression

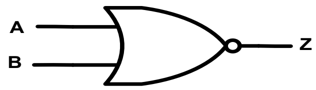
A	Z
0	1
1	0

Truth table

Fig. 3.4: NOT Gate

3.2.2.4 UNIVERSAL GATES

The NAND and NOR gates can realize the logic function of all the three basic gates i.e. AND, OR and NOT. Therefore, these gates are called as Universal gates. Fig. 3.5 shows below the logic symbol, Boolean expression and truth table.



Logic Symbol

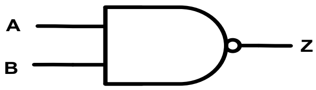
$Z = (A + B)'$

Boolean Expression

A	B	Z
0	0	1
0	1	0
1	0	0
1	1	0

Truth table

NOR Gate



Logic Symbol

$Z = (A . B)'$

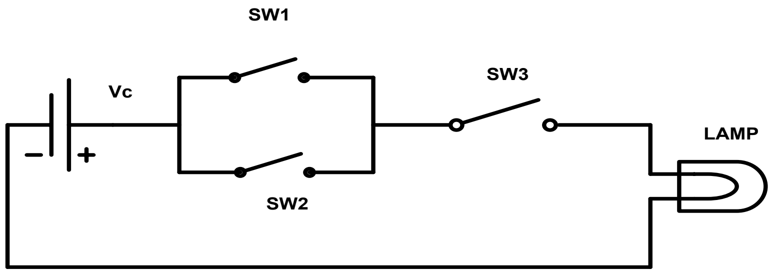
Boolean Expression

A	B	Z
0	0	1
0	1	1
1	0	1
1	1	0

Truth table

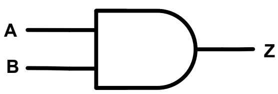
Fig. 3.5: NOR and NAND Gate

Activity:
Implement the circuit shown below using logic gates

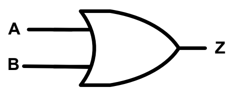


Solved Problems

Example 3.2.1: Which of the logic gate is represented by the expression Z = (A' + B')'
Solution: Using DeMorgans theorem first law the above expression (A' + B')' = A''. B'' = A.B
The above Boolean expression can be implemented by using AND gate.



Example 3.2.2: Implement the Boolean expression Z = A + A'B using OR gate.
Solution: Applying Distributive law, the Boolean Expression Z can be rewritten as
Z = (A+A'). (A + B), As per OR law, A + A' =1
Therefore, Z = 1. (A + B) = A + B



3.3 FLIP FLOPS AND COUNTERS

Digital circuits are broadly classified as combinational circuits and sequential circuits. In combinational circuits the output at any instant of time depends on the inputs present at that time. Examples of combinational circuit are Adders, Subtractors, Encoders, Decoders, Comparators, Multiplexers etc. In sequential circuit the output not only depend on the present input, but also on the past state stored in the memory element. The examples are Flip flops, Registers, Counters etc. The sequential circuits are of two types, Synchronous and Asynchronous. In synchronous sequential circuit, the circuit behaviour can be defined from the knowledge of its signals at discrete instant of time. The discrete instant of time is defined by the clock signal. In asynchronous sequential circuit, the circuit behaviour depends upon the order at which the change in the logic level of the input signal takes place. Table 3.2 shows the comparison between an asynchronous and synchronous sequential circuit.

Table 3.2: Comparison between Synchronous and Asynchronous sequential circuits

Sr.No.	Asynchronous sequential circuits	Synchronous sequential circuit
1.	Memory elements are unclocked flip-flops.	Memory elements are clocked flip-flops.
2.	Change in input signals can affect memory elements at any instant of time.	Change in input signals can affect the memory elements only when the clock signal is present.
3.	Absence of clock signal makes operation of asynchronous circuits faster.	The operating speed depends on the frequency of the clock signal.

3.3.1 Types of Flip-Flops

The most important memory element and the basic building block of a sequential circuit is the flip-flop. A flip-flop has got two stable states and can remain in that state indefinitely. Its state can be changed only by applying the proper input signals. The flip-flop is also called a one-bit memory element.

The flip flops are made of using two cross coupled NAND or NOR gates. There are several different arrangements for making flip-flops. Each type of flip-flop has different characteristics so as to implement a particular application.

3.3.1.1 Basic Flip-flop (S-R Latch)

The simplest type of flip-flop is called an S-R latch. It has two inputs labelled as S (SET) and R (RESET) and two outputs Q and its complement Q'. The state of the latch corresponds to the value of Q either 1 or 0. The analysis of the S-R latch as shown in Fig. 3.6 using NAND gates can be summarized as follows

When the input S = 0 and input R = 1, it will SET the flip-flop i.e. Q = 1 and will remain in the SET state even after S returns to zero.

When the input R = 0 and S = 1, it will RESET the flip-flop i.e. Q = 0 and will remain in the RESET state even after R returns to zero.

When the input S = 1 and R = 1, the flip-flop state will remain as it is i.e. if Q = 1, it will remain as Q = 1 (SET condition) and if Q = 0 it will remain as Q = 0 (RESET condition).

When the inputs S = 0 and R = 0, the output state becomes undefined as both Q and its complement i.e. Q = Q'= 1. This input condition is invalid and should not be used.

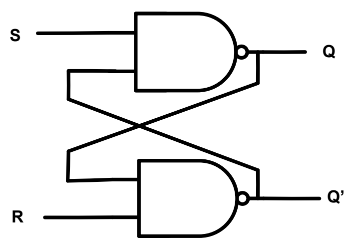
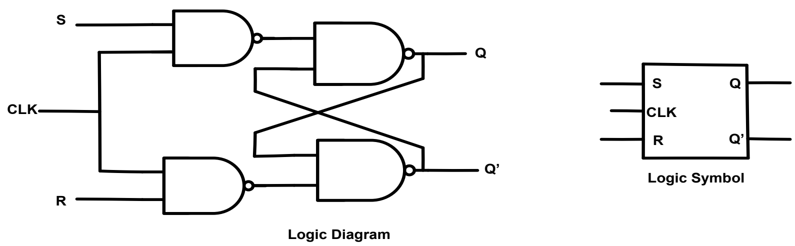


Fig. 3.6: S-R latch using NAND gates

3.3.1.2 Clocked S-R flip flop

The basic S-R latch discussed above is also called as an asynchronous S-R flip-flop, the reason being the output state changes at any time, the input signal condition changes. A clocked flip-flop requires clock signal and will change the state of the flip-flop only when the clocked signal is HIGH (logic-1). These type of flip flops are called level triggered flip flops. A clocked flip-flop is also called as a synchronous sequential circuit. Fig. 3.7 shows the logic diagram, logic symbol and truth table of a clocked S-R flip-flop using NAND gates. From the logic diagram shown, it is seen that when the clock signal is LOW (logic-0), the output of both the input NAND gates is HIGH. In this case, the flip-flop state will remain unchanged. When the clock signal becomes HIGH (logic-1), the S and R input will be passed through the NAND gates and the final output of the flip-flop Q will change according to the input signals S and R.



CLK	S	R	Q_t	Q_{t+1}	State
1	0	0	0	0	No Change
	0	0	1	1	
	0	1	0	1	RESET
	0	1	1	1	
	1	0	0	0	SET
	1	0	1	0	
	1	1	0	X	Undefined
	1	1	1	X	

Truth table

Fig. 3.7: Clocked S-R flip-flop

3.3.1.3 D Flip Flop

From the truth table it is seen that when input S and R = 1, the output state is undefined. To avoid this condition a single input clocked flip-flop as shown in Fig. 3.8 where the R input is obtained by complementing the S input. This single input flip-flop is called as D flip flop or delay/data flip-flop. When D = 1, S = 1 and R = 0, causing the flip-flop to SET, with clock signal HIGH. Similarly, when D = 0, S = 0 and R = 1, causing the flip-flop to RESET.

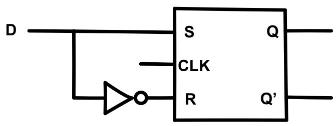
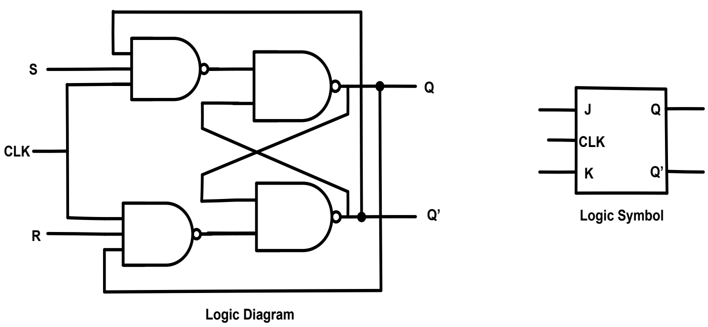


Fig. 3.8: D – flip flop

3.3.1.4 J-K Flip-flop

The most popular and widely used flip-flop. The working of the J-K flip-flop is identical to that of a clocked S-R flip flop as shown in Fig. 3.7. The only difference is that it has no undefined states like that of an S-R flip-flop. Fig. 3.9 shows the logic diagram, logic symbol and truth table of a J-K flip-flop. When J = K = 1, the flip-flop toggles it changes its present state i.e. if Q = 1 it will change to 0 and if Q = 1 then the state will change to 0.



CLK	J	K	Q_t	Q_{t+1}	State
1	0	0	0	0	No Change
	0	0	1	1	
	0	1	0	1	RESET
	0	1	1	1	
	1	0	0	0	SET
	1	0	1	0	
	1	1	0	1	Toggle
	1	1	1	0	

Truth table

Fig. 3.9: J-K Flip-Flop

3.3.1.5 T flip-flop

When both the inputs of a J- K are connected together as shown in Fig. 3.10 and labelling the common terminal as T, the flip-flop is known as T flip-flop. When T=0, both J = K = 0 and the flip flop state remains unchanged. When T = 1, both J = K =1 and the flip-flop toggles its states. The T flip flop is also known as Toggle flip-flop.

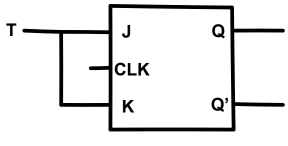


Fig. 3.10: T flip flop

3.3.2 Counters

Counter is a sequential circuit which is used to count the clock pulse. A digital counter consists of a set of flip-flop whose state changes in response to the clock pulse applied at the input of the counter. Each of the counts of a counter is called the states. The number of states depend on the number of flip-flops used for the counter and the sequence of the states depends on the interconnection between the flip-flops. For example, a 2-bit counter requires two flip-flops and the number of states are 4. The sequence of states for an up-counter and down-counter is shown in Fig. 3.11 (a) and (b) respectively. A 2-bit counter is also called a modulus or mod-4 counter as the number of states which the counter passes before reaching the original state is also called the modulus of the counter. The modulus of an N bit counter is 2^N .

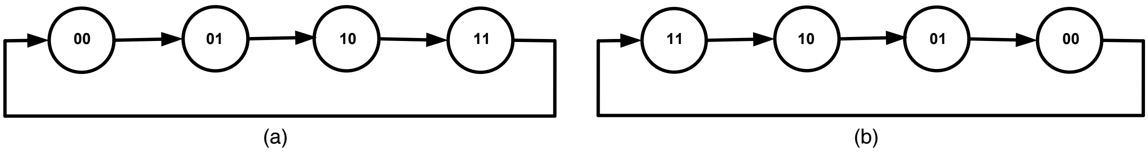


Fig. 3.11: State Diagram of (a) 2-bit UP counter (b) 2-bit DOWN counter

Counters are divided into asynchronous counters and synchronous counters.

1. In asynchronous counters also known as ripple counters, the flip-flops are connected in such

   a way that the output of the first FF becomes the clock pulse for the second FF and so on. The main drawback of these counters is their low speed.
2. In synchronous counters all the flip-flops are clocked by the same clock pulse simultaneously.

   The synchronous counters also known as parallel counters are faster than asynchronous counters.

3.3.2.1 Asynchronous Counter

A 2-bit up counter is shown in Fig. 3.12. As shown there are two J-K flips flops with their inputs J = K = 1. From the truth table of Fig. 3.9, it is seen that the flip flops will toggle their present states whenever their clock pulse are HIGH i.e. at logic -1. The counter starts counting from 00 (State 0) to 11 (State 3) as shown in state diagram, Fig. 3.11(a). The output Q_1 represents the MSB and Q_0 the LSB. Fig. 3.13 shows a 2-bit down counter.

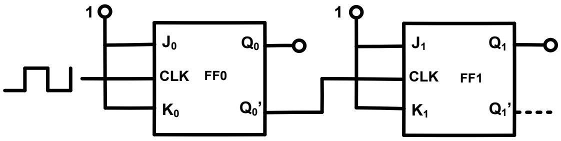


Fig.3.12: 2-bit UP Asynchronous counter

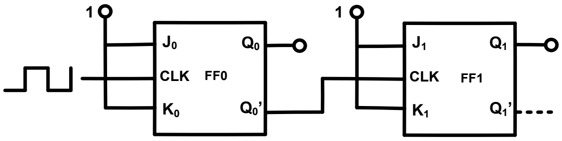


Fig.3.13: 2-bit DOWN Asynchronous counter

3.3.2.2 Mod-10 Asynchronous Counter

The Mod-10 counter is also called decade counter. The number of flip flops required is 4. With 4 flip-flops there are sixteen states, count value sequence starting from $(0000)_2$ to $(1111)_2$. A decade counter has only 10 valid states i.e. count value from $(0000)_2$ to $(1001)_2$. The remaining states are invalid i.e. count value from $(1010)_2$ to $(1111)_2$. For this a feedback logic circuit has to be provided which will clear or reset all the flip-flops as soon as the count value reaches $(1010)_2$. Fig. 3.14 shows a decade counter with the feedback circuit, where output Q_3 is the MSB and Q_0 is the LSB.

Resisters and Counters

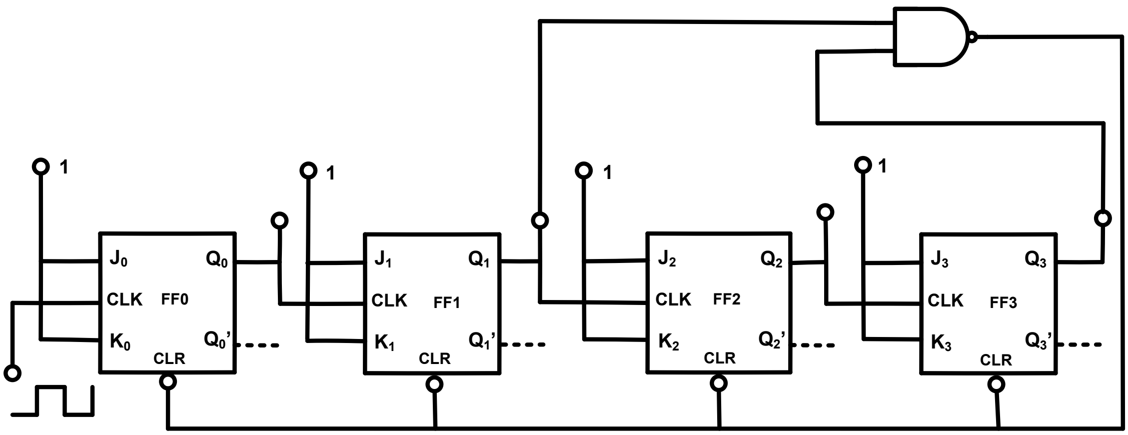


Fig.3.14: 4-bit Decade counter

Activities

1. Find out the applications of D and T flip-flop.
2. Prepare a presentation on the application of counters in our day to day life.

Solved Problems

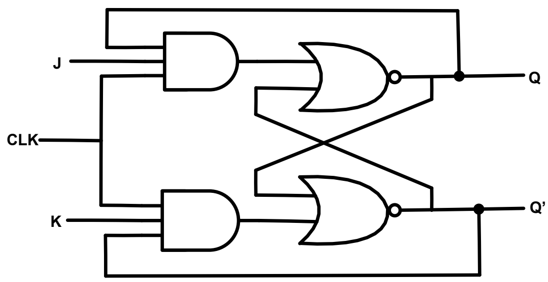
Example 3.3.1: State number of flip-flops required to make a MOD-16 counter?

Solution: The general expression of the number of flip-flops is given as $2^n = N$, where n is the number of flip-flops used for realizing the given count and N is the number of states or the modulus, N = 16 given

$2^n = 16$ or n = 4. The number of flip-flops required = 4

Example 3.3.2: Draw the logic diagram of a J-K flip-flop using NOR gates.

Solution



Logic Diagram

3.4 DIGITAL IC'S

3.4.1 Introduction to Integrated Circuits

Integrated circuits

The Integrated Circuits (IC's) are small silicon semiconductor crystal having components like resistors, diodes, capacitors, transistors, FET's. The components are interconnected to form an electronic circuit. The semiconductor crystal called a chip is mounted on a metal, plastic or ceramic package and the terminal points of the electronic circuit are made available to the external pins to form the IC. The main advantage of an IC is its small size, reduced power consumption, high reliability, high speed of operation and the most important low cost. Integrated circuits come in two types of package, the flat pin and the dual in line (DIP) package. Integrated circuits are classified as Linear and Digital. Linear IC's operate with continuous signals and are widely used as amplifiers, filters, comparators and converters etc., Digital IC's operate with binary signals and are made up of interconnected digital gates. Digital IC's are classified not only by their logic operation, but by the logic circuit family to which it belongs. The IC's include flip-flops, logic gates, counters, memory chips, microcontrollers etc. The different logic circuit family of Digital IC's are

- Transistor-transistor logic (TTL)
- Diode transistor logic (DTL)
- Resistor transistor logic (RTL)
- Emitter coupled logic (ECL)
- Metal Oxide Semiconductor (MOS)
- Complementary metal oxide semiconductor (CMOS)
- Integrated injection logic (I^2L)

3.4.2 Digital IC Specification Terminology

The most useful specification terms of a Digital IC's are as under

Threshold Voltage: The voltage level at the input of the logic gate that causes a change in the output voltage level i.e. from one logic level to the other.

Power Dissipation: The power required by the gate to operate at a specified frequency and is given in milliwatts.

Propagation Delay: The time taken by the input signal to propagate from the gate input to the output.

Fan-in: It is defined as the number of inputs that the gate is designed to handle

Fan-out: It is defined as the maximum number of loads (inputs of other gates) which the output of a gate can handle without overloading it.

Noise Margin: The ability of a logic circuit to tolerate noise voltage at its input terminals and thus avoiding circuit malfunction is known as noise immunity. The measure of the noise immunity in terms of voltage level is called noise margin.

Operating temperature: The IC's contain electronic components and are temperature sensitive. A temperature range is specified between which the IC operate satisfactorily. For a commercial digital IC, it is between 0 to 70° C.

3.4.3 Transistor Transistor Logic (TTL)

The Transistor Transistor Logic (TTL) family is most popular among the logic family. The basic logic operation in TTL family is performed by transistors. The TTL use transistors either in the cut off region or in the saturation region. The advantages of TTL logic families are its low cost and good speed. The major disadvantages are high power dissipation and low noise immunity. The basic TTL logic circuit is the NAND gate. Fig. 3.15 shows the circuit diagram of a two input NAND gate.

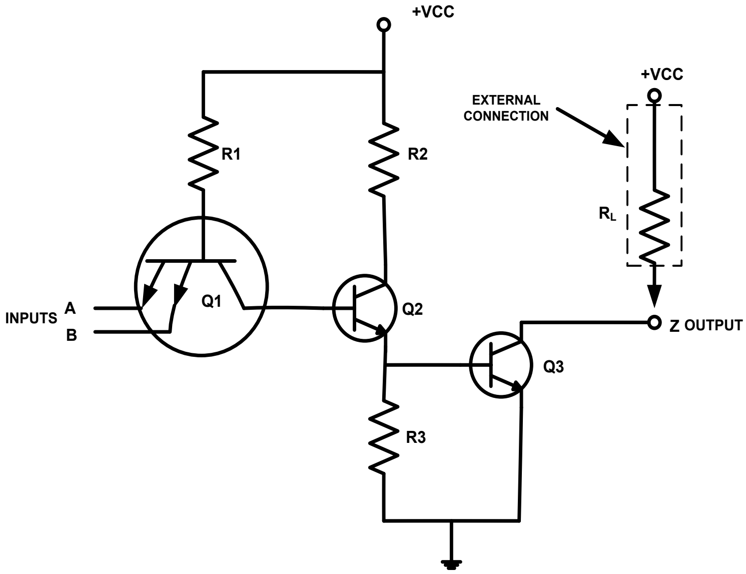


Fig. 3.15: A two input TTL logic NAND gate

3.4.4 TTL Sub families

The TTL subfamilies are classified as (1) Standard TTL, 74 series, (2) Low power TTL, 74L series, (3) High speed TTL, 74H series, (4) Schottky TTL, 74S series, (5) Low power Schottky TTL, 74LS series, (6) Fast TTL, 74F series. Table 3.2 shows the comparison of subfamilies in terms of IC performance specification. Table 3.3 shows some of the most commonly used IC's under TTL subfamilies for realization of basic digital circuits.

Character-ization of digital logic families

Table 3.2: Comparison of TTL subfamilies

Sr. No	Performance Specification	74	74L	74H	74S	74LS	74 F
1.	Propagation delay (ns)	9	33	6	3	9.5	4
2.	Power dissipation (milliWatt)	10	1	23	20	2	1.2
3.	Maximum clock frequency (MHz)	35	3	50	125	45	70
4.	Fan out	10	20	10	20	20	20
5.	Noise margin (V)	0.4	0.4	0.4	0.7	0.5	0.5

Table 3.3: Popular Digital TTL IC's

Sr. No	IC Description	Sr. No	IC Description
1.	7402 Quad 2-Input NOR gate	6.	74LS83, 4-bit full adder
2.	74F00 Quad 2-Input NAND gate	7.	74LS138, 3-8-bit binary decoder
3.	74LS08 Quad 2-Input AND gate	8.	74F74, D type flip-flop
4.	74LS32 Quad 2-Input OR gate	9.	7473, Dual J-K flip-flop
5.	7404 Hex Inverter	10.	7490, Decade counter

3.4.5 Digital IC's application

Digital IC's are mostly used in computers. The reason being the input and output signals are fixed at two levels as in a binary system. They include

- Flip flops
- Multiplexers
- Programmable logic devices
- Timers
- Clock chips
- Microprocessors
- Counters
- Memory Chips
- Microcontrollers

Activities

1. Use datasheets of logic gate ICs and note down the specification terminology.
2. Identify the application of the following IC's: 555, 741, 7445, 7404, 7473, 7490

Solved Problems

Example 3.4.1: Describe in brief the evolution of IC's from SSI to VLSI.

Solution: Digital IC's are categorized according to the number of logic gates on the silicon substrate. According to the level of complexity they are classified as:

- **Small Scale Integration (SSI)** - IC's with less than 12 gate circuits. Examples are flip-flops.
- **Medium Scale Integration (MSI)** - IC's with logic gate circuits between 12 to 100. Examples are counters, registers etc.
- **Large Scale Integration (LSI)** - IC's with gate circuit between 100 to 9999 on a single crystal. Example memory like RAM, ROM etc.
- **Very Large Scale Integration (VLSI)** - IC's with gate circuit between 10,000 to 99,999 on a single crystal. Example microprocessor.

UNIT SUMMARY

Digital systems are more reliable, less affected by noise, easier to design and fabricated on IC chips.

- The digital system uses binary number system.
- The Boolean algebra is an algebraic system developed for systematic treatment of logic with a set of elements, a set of operators and a number of postulates.
- The fundamental building block of any digital system are the logic gates.
- The three types of basic logic gates are the AND, OR and NOT.
- The inputs and outputs of logic gates occur in two levels, logic-1, termed as HIGH/TRUE and logic-0 termed as LOW/FALSE.
- NAND and NOR gates are called as Universal gates as they can realize the logic function of all the three basic gates i.e. AND, OR and NOT.
- Digital circuits are broadly classified as combinational circuits and sequential circuits.
- In combinational circuits, the output at any instant of time depends on the inputs present at that instant of time.
- Sequential circuits are of two types, Synchronous and Asynchronous.
- The basic building block of a sequential circuit is the flip-flop, which is also called a one-bit memory element.
- A flip-flop has got two stable states and can remain in that state indefinitely. Its state can be changed only by applying the proper input signals.
- The simplest type of flip-flop is called an S-R latch, which has two inputs labelled as S (SET) and R (RESET) and two outputs Q and its complement Q'.
- A digital counter is a sequential circuit, consisting of flip-flops whose state changes in response to the clock pulse applied at the input of the counter.

- Counters used to count the clock pulse, are divided into asynchronous counters and synchronous counters.
- In asynchronous counters also known as ripple counters, the flip-flops are connected in such a way that the output of the first FF becomes the clock pulse for the second FF and so on.
- In synchronous counters, also known as parallel counters all the flip-flops are clocked by the same clock pulse simultaneously.
- Digital IC's operate with binary signals and are made up of interconnected digital gates.
- Transistor Transistor Logic (TTL) in which basic logic operation is performed by transistors is most popular among the logic family.

EXERCISES

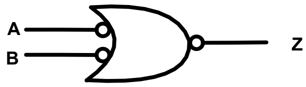
A. Objective Questions

Instruction: Please select the most appropriate answer.

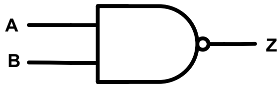
Sr. No.	MCQs	Sr. No.	MCQs
3.1	The longest out of the following is a. Byte b. Nibble c. Word d. bit	3.4	SR flip-flop using NAND gates cannot accept following inputs: a. S = R =0 b. S=1, R=0 c. S = R = 1 d. S=0, R = 1
3.2	Identify the gate for which "Z is FALSE only if "A" is TRUE and "B" is TRUE" is applicable. a. NAND b. NOR c. AND d. OR	3.5	Counter is used to count the number of a. Flip flops b. Registers c. bits d. pulse
3.3	Flip flops are a. Chip b. Memory element c. Adders d. Comparators	3.6	The IC's used in watch and calculators are a. TTL b. ECL c. MOS d. CMOS

B. Subjective Questions

1. State why binary number system are used in digital systems.
2. What procedures are adopted in converting a decimal number into a number whose number system is with base b.
3. Perform the arithmetic operation on the binary numbers given below:
   (a)10111.101 + 110111.01 (b) 10001.01-1111.11
4. Verify by truth table method the Boolean expression: A + A'B + AB = A + B
5. Demonstrate by truth table the validity of the following Boolean laws
   (a) Associative law (b) Distributive law
6. Explain positive logic and negative logic in digital circuits.
7. Verify by truth table that the output of the gates shown in Fig. (a) & (b) are same.



(a)



(b)

8. Draw logic diagram and truth table for a D and T type flip-flop.
9. Draw the circuit diagram for a 3-bit ripple counter using T flip flop.
10. State the differences between a linear IC and digital IC.

KNOW MORE

Micro-Project

Undertake one or two micro project(s) /activit(ies) in a group of 5 - 6 students under the guidance of faculty and present it as group with individual participation as well. A sample micro-project problem is given below:

a. A cooling unit is controlled by three variables: temperature (T), humidity (H) and the time of the day (T). The cooling unit is turned ON under the following conditions:
   i. The temperature exceeds 78° F and the time of the day is between 8.00 AM and 5.00 PM.
   ii. The humidity exceeds 85%, the temperature exceeds 78° F and the time of the day is between 8.00 AM and 5.00 PM.
   iii. The humidity exceeds 85% and the time of the day is between 8.00 AM and 5.00 PM.

b. Develop a circuit using logic gates using digital IC's to turn ON the cooling unit.
   Note: The cooling unit to be considered as Switching 'ON' an incandescent lamp.

Video Resources

Digital Electronics Circuits

Digital Circuits

Use of ICT

Course on Electronics and Communi-cation Engineering

REFERENCES AND SUGGESTED READINGS

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4 A.P. Malvino, D.P. Leach and G. Saha, *Digital Principles and Applications*, Mcgraw Hill Educations, 2017.