Technical and Vocational Stream
Learning Resource Material

Basic Electronics
(Grade 10)
Electrical Engineering

Government of Nepal
Ministry of Education, Science and Technology
Curriculum Development Centre
Sanothimi, Bhaktapur

Publisher: Government of Nepal
Ministry of Education, Science and Technology
Curriculum Development Centre
Sanothimi, Bhaktapur

Layout by Khados Sunuwar

Preface

The curriculum and curricular materials have been developed and revised on a regular basis with the aim of making education objective-oriented, practical, relevant and job oriented. It is necessary to instill the feelings of nationalism, national integrity and democratic spirit in students and equip them with morality, discipline, self-reliance, creativity and thoughtfulness. It is essential to develop linguistic and mathematical skills, knowledge of science, information and communication technology, environment, health and population and life skills in students. It is also necessary to bring the feeling of preserving and promoting arts and aesthetics, humanistic norms, values and ideals. It has become the need of the present time to make them aware of respect for ethnicity, gender, disabilities, languages, religions, cultures, regional diversity, human rights and social values to make them capable of playing the role of responsible citizens with applied technical and vocational knowledge and skills. This learning resource material for Electrical engineering has been developed in line with the Secondary Level Electrical engineering Curriculum with an aim to facilitate the students in their study and learning on the subject by incorporating the recommendations and feedback obtained from various schools, workshops, seminars and interaction programs attended by teachers, students, parents and concerned stakeholders.

In bringing out the learning resource material in this form, the contribution of the Director General of CDC Mr. Yubaraj Paudel and members of the subject committee Dr. Nandabikram Adhikari, Er. Chitra Bahadur Khadka, Mr. Damberdhwaj Angdembe, Er. Sanju Shrestha is highly acknowledged. This learning resource material is compiled and prepared by Er. Rupesh Maharjan, Er. Jaya Prakash maharjan, Er. Rakesh Singh, Er. Bigyan Pokharel. The subject matter of this material is edited by Mr. Badrinath Timsina and Mr. Khilanath Dhamala. Similarly, the language is edited by Mr. Binod Raj Bhatta. CDC extends sincere thanks to all those who have contributed to developing this material in this form.

This learning resource material contains a wide coverage of subject matters and sample exercises which will help the learners to achieve the competencies and learning outcomes set in the curriculum. Each chapter in the material clearly and concisely deals with the subject matters required for the accomplishment of the learning outcomes. The Curriculum Development Centre always welcomes creative and constructive feedback for the further improvement of the material.

2082 BS

Curriculum Development Centre
Sanothimi, Bhaktapur

Table of Content

Guidelines to Teachers

A. Facilitation Methods

The goal of this course is to combine the theoretical and practical aspects of the contents needed for the subject. The nature of contents included in this course demands the use of practical or learner focused facilitation processes. Therefore, the practical side of the facilitation process has been focused much. The instructor is expected to design and conduct a variety of practical methods, strategies or techniques which encourage students engage in the process of reflection, sharing, collaboration, exploration and innovation new ideas or learning. For this, the following teaching methods, strategies or techniques are suggested to adopt as per the course content nature and context.

Brainstorming

Brainstorming is a technique of teaching which is creative thinking process. In this technique, students freely speak or share their ideas on a given topic. The instructor does not judge students' ideas as being right or wrong, but rather encourages them to think and speak creatively and innovatively. In brainstorming time, the instructor expects students to generate their tentative and rough ideas on a given topic which are not judgmental. It is, therefore, brainstorming is free-wheeling, non-judgmental and unstructured in nature. Students or participants are encouraged to freely express their ideas throughout the brainstorming time. Whiteboard and other visual aids can be used to help organize the ideas as they are developed. Following the brainstorming session, concepts are examined and ranked in order of importance, opening the door for more development and execution. Brainstorming is an effective technique for problem-solving, invention, and decision-making because it taps into the group's combined knowledge and creative ideas.

Demonstration

Demonstration is a practical method of teaching in which the instructor shows or demonstrates the actions, materials, or processes. While demonstrating something the students in the class see, observe, discuss and share ideas on a given topic. Most importantly, abstract and complicated concepts can be presented into visible form through demonstration. Visualization bridges the gap between abstract ideas and concrete manifestations by utilizing the innate human ability to think visually. This enables students to make better decisions, develop their creative potential, and obtain deeper insights across a variety of subject areas.

Peer Discussion

Peer conversation is a cooperative process where students converse with their peers to exchange viewpoints, share ideas, and jointly investigate subjects that are relevant or of mutual interest. Peer discussion is an effective teaching strategy used in the classroom to encourage critical thinking, active learning, and knowledge development. Peer discussions encourage students to express their ideas clearly, listen to opposing points of view, and participate in debate or dialogue, all of which contribute to a deeper comprehension and memory of the course material. Peer discussions also help participants develop critical communication and teamwork skills by teaching them how to effectively articulate their views, persuasively defend their positions, and constructively respond to criticism.

Peer conversation is essential for professional growth and community building outside of the classroom because it allows practitioners to share best practices, work together, and solve problems as a group. In addition to expanding their knowledge horizon and deepening their understanding, peer discussions help students build lasting relationships and a feeling of community within their peer networks.

Group Work

Group work is a technique of teaching where more than two students or participants work together to complete a task, solve a problem or discuss on a given topic collaboratively. Group work is also a cooperative working process where students join and share their perspectives, abilities, and knowledge to take on challenging job or project. Group work in academic contexts promotes active learning, peer teaching, and the development of collaboration and communication skills. Group work helps individuals to do more together than they might individually do or achieve.

Gallery Walk

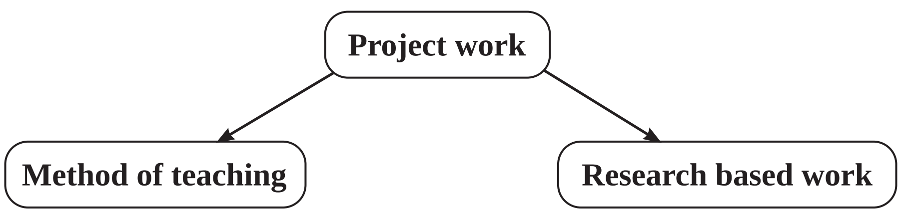
Gallery walk is a critical thinking strategy. It creates interactive learning environment in the classroom. It offers participants or students a structured way to observe exhibition or presentation and also provides opportunity to share ideas. It promotes peer-to-peer or group-to-group engagement by encouraging participants to observe, evaluate and comment on each other’s work or ideas. Students who engage in this process improve their communication and critical thinking abilities in addition to their comprehension of the subject matter, which leads to a deeper and more sophisticated investigation of the subjects at hand.

Interaction

The dynamic sharing of ideas, knowledge, and experiences between people or things is referred to as interaction, and it frequently takes place in social, academic, or professional settings. It includes a broad range of activities such as dialogue, collaboration or team work, negotiation, problem solving, etc. Mutual understanding, knowledge sharing, and interpersonal relationships are all facilitated by effective interaction. Interaction is essential for building relationships, encouraging learning, and stimulating creativity in both in-person and virtual contexts. Students can broaden their viewpoints, hone their abilities, and jointly achieve solutions to difficult problems by actively interacting with others.

Project Work

Project work is a special kind of work that consists of a problematic situation which requires systematic investigation to explore innovative ideas and solutions. Project work can be used in two senses. First, it is a method of teaching in regular class. The next is: it is a research work that requires planned investigation to explore something new. This concept can be presented in the following figure.



Project work entails individuals or teams working together to achieve particular educational objectives. It consists of a number of organized tasks, activities, and deliverables. The end product is important for project work. Generally, project work will be carried out in three stages. They are:

- Planning
- Investigation
- Reporting

B. Instructional Materials

Instructional materials are the tools and resources that teachers use to help students. These resources/materials engage students, strengthen learning, and improve conceptual comprehension while supporting the educational goals of a course or program. Different learning styles and preferences can be accommodated by the variety of instructional resources available. Here are a few examples of typical educational resource types:

- Daily used materials
- Related Pictures
- Reference books
- **Slides and presentation:** PowerPoint slides, keynote presentations, or other visual aids that help convey information in a visually appealing and organized manner.
- **Audiovisual materials:** Videos, animations, podcasts, and other multimedia resources that bring concepts to life and cater to auditory and visual learners.
- **Online Resources:** Websites, online articles, e-books, and other web-based materials that can be accessed for further reading and research.

Maps, charts, and graphs: Visual representations that help learners understand relationships, patterns, and trends in different subjects.

Real-life examples and Case Studies: Stories, examples, or case studies that illustrate the practical application of theoretical concepts and principles.

C. Assessment

Formative Test

Classroom discussions: Engage students in discussions to assess their understanding of concepts.
Quizzes and polls: Use short quizzes or polls to check comprehension during or after a lesson.
Homework exercises: Assign tasks that provide ongoing feedback on individual progress.
Peer review: Have students review and provide feedback on each other's work.

Summative Test

Exams: Conduct comprehensive exams at the end of a unit or semester.
Final Projects: Assign projects that demonstrate overall understanding of the subject.

Peer Assessment

Group projects: Evaluate individual contributions within a group project.
Peer feedback forms: Provide structured forms for students to assess their peers.
Classroom Presentations: Have students assess each other's presentations.

Objective Test

Multiple-choice tests: Use multiple-choice questions to assess knowledge.
True/False questions: Assess factual understanding with true/false questions.
Matching exercises: Evaluate associations between concepts or terms.

Portfolio Assessment

Compilation of work: Collect and assess a variety of student work samples.
Reflection statements: Ask students to write reflective statements about their work.
Showcase events: Organize events where students present their portfolios to peers or instructors.

Observational Assessment

Classroom observations: Observe students' behavior and engagement during class.
Performance observations: Assess practical skills through direct observation.
Field Trips: Evaluate students' ability to apply knowledge in real-world settings.

Passive Components

Introduction to Passive Components

Electronic components are the materials that make up an electronic circuit. They are the building blocks of electronic circuits. They are broadly classified into two types and they are – *Active components and Passive components*.

Active components are those components that are capable of processing or amplifying an electrical signal. They require an external power source to operate and they can manipulate the flow of electrons to achieve the desire circuit functionality. Example: Transistors, diodes, operational amplifier, etc.

Passive components are those components which are not capable of processing or amplifying an electrical signal. These components are required for active components to process or amplify. They cannot amplify electrical signals but can store or dissipate energy. Example: Resistors, capacitors, inductors, etc.

1.1 Resistors- Definition, Types, Characteristics, Color Code, Resistance, Applications

A resistor is an electronic passive component that controls the flow of electric current. A resistor can conduct the electric current in both directions. It is used to limit current, divide voltages. Resistance is the property of the substance which opposes the flow of electric current through it. It is symbolized by '***R***' and its capacity is measured in **ohm** (Ω). Resistors can be combined in series and parallel connection to achieve specific resistance values. On the basis of operating condition resistor can be classified into two categories and they are:

- Fixed Resistor
- Variable Resistor

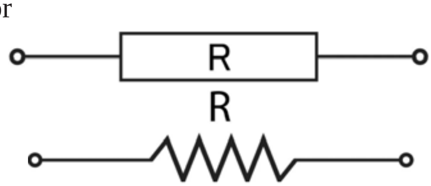


Fig.1. 1: Symbol of resistor

Fixed resistors are those resistors whose resistance values do not change with variation in applied voltage or temperature. They have constant resistance value. Carbon composition resistors, thick film resistors, thin film resistors and wire wound resistors are fixed resistors. Generally, these type of resistors are made from materials like carbon film, metal film, or wire-wound, etc. The manufacture specifies the resistance value through color coding during manufacture of fixed resistors. The size of the resistors varies with the power rating.

Variable resistors are those resistors whose resistance value can be adjusted or varied over a specific range. These type of resistors do not have constant resistance value but they have resistance value in some range. These resistors are commonly used in circuits to control current, voltage, or signal levels. Further, variable resistors are also used in sensor applications such as light sensors, temperature sensors, etc. Potentiometers, rheostats trimmers, photoresistors are the variable resistors.

Characteristics of Resistors

i) Resistors have tendency of resisting the flow of current and this is called as resistance of that resistor. The resistance is measured in Ohm (Ω)

ii) Resistors can have either positive or negative temperature coefficient of resistance depending on the material they are made from.

iii) Resistors have tolerance (expressed in percentage) which indicates the accuracy of the resistor's resistance value.

iv) Resistors have power rating expressed in Watt (W) that it can dissipate safely.

v) Resistors can have constant resistance or variable/adjustable resistance depending upon its type.

vi) Two or more than two resistors can be connected in series, parallel or mixed combination. In series connection, the effective value of resistance is –

$$R_{eff.} = R_1 + R_2 + R_3$$

In parallel connection, the effective resistance is-

$$\frac{1}{R_{eff.}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Color Coding of Resistor

It is a standardized system used to indicate the resistance value, tolerance of resistors. Mostly, carbon composition resistors (fixed resistors) are designed by a color code system. In this system, the bands of different colors are used to identify the values of resistance and tolerance ratings. There are two common systems of color code designation: **Four band**

color code system and **Five band color** code system.

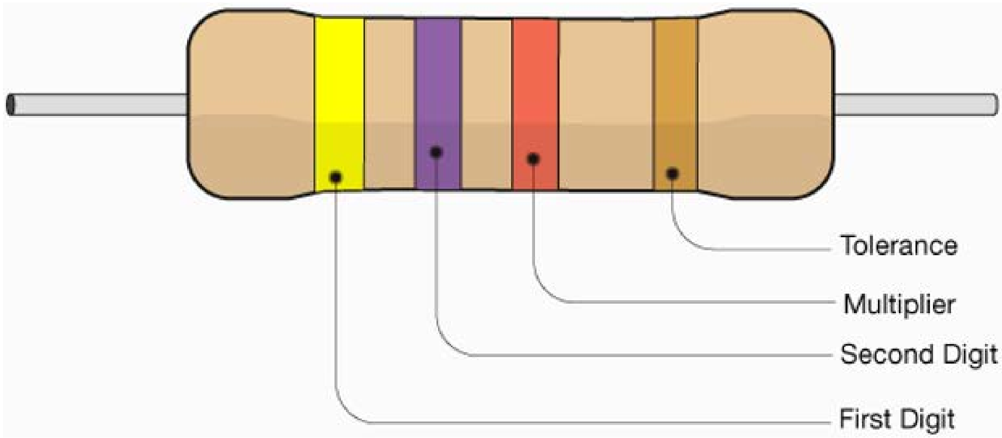


Fig.1. 2: Resistor color code

In Four band color code system, the first two bands represent the significant figures whereas the third band is the multiplier. The fourth band indicates the tolerance band.

The black band indicates the minimum value 0 and the white band indicates the maximum value 9. The gold band indicates the tolerance of 5%, silver band 10% and a plain (Colorless band) represents a tolerance of 20%. The table given below represents the different colors and their value.

Power of 10	Prefix	Abbreviation
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

Table 1. 1: Abbreviation for different power of 10

Color	1st Digit	2nd Digit	Multiplier
Black	0	0	
Brown	1	1	
Red	2	2	
Orange	3	3	
Yellow	4	4	
Green	5	5	
Blue	6	6	
Violet	7	7	
Grey	8	8	
White	9	9	

Table 1. 2: Value of different colors for color code of resistor

Color	% Tolerance
Gold	±5%
Silver	± 10%
No Color	± 20%

Table 1. 3: Tolerance of resistor for different colors

Note: The given sentence helps in memorizing the color code sequence.

B B ROY of **G**reat **B**ritain has **Very Good Wife**.

Here 1st B → **B**lack, 2nd **B**→ **B**rown, 3rd **R**→ **R**ed and so on.

Example: A resistor with four band color code: Yellow, Violet, Red & Gold respectively. The resistance of resistor …………….

Yellow	*Violet*	*Red*	*Gold*
4	7	$x12^0$	±0%
The resistance of resistor = $47*10^2$ Ohm			Nerge

1.2 Capacitors– Definition, Types, Characteristics, Numeric Code, Capacitance, Applications

The term "capacitor" refers to a configuration of conductors separated by a dielectric (insulator) and used to store the electric charges. It is also one of the passive two terminals component used to store electrical energy. Basically, the capacitors are made up of two conducting surfaces separated by a substance called dielectric. The capacitor's conducting surfaces are referred to as its plate and its dielectric include mica, air, paper, etc.

The capacity of a capacitor to hold the charge is known as capacitance. The capacitance is measured in Farad (F). The value of capacitance depends on the shape and size of conducting surface, their separation and the nature of dielectric medium used.

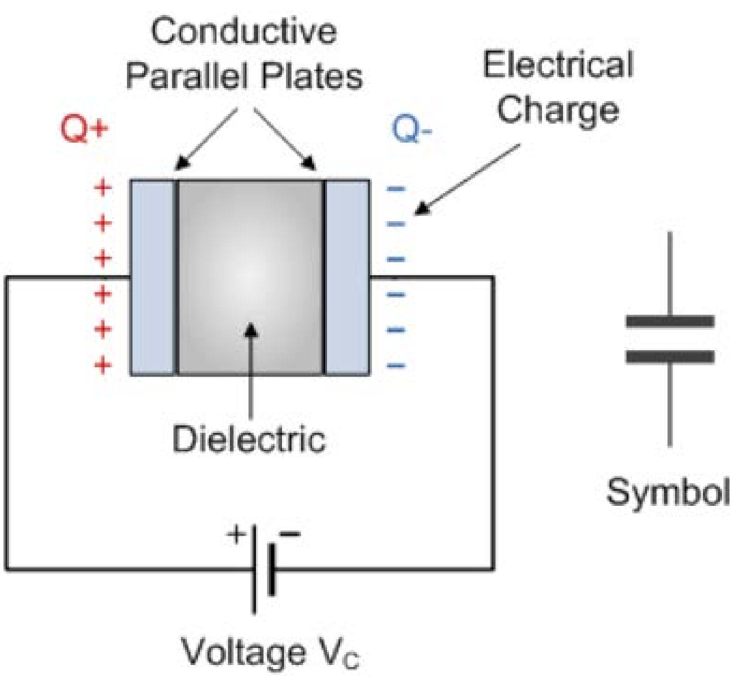


Fig.1. 3: Schematic diagram of capacitor and its symbol

Capacitors can be classified into mainly two types and they are:

i) Fixed Capacitors

a. Non-Electrolytic type

b. Electrolytic type

ii) Variable Capacitors

Fixed Capacitors

Fixed capacitors are those capacitors whose capacitance value is fixed and can't be changed by any means. They are further divided into two types and they are: Non-Electrolytic and Electrolytic capacitors.

Non-Electrolytic capacitors are those capacitors which have no polarity requirement i.e. they can be connected with any polarity of supply. This type of capacitors include paper, mica and ceramic capacitors.

Electrolytic capacitors are those capacitors which are polarized meaning that these capacitors are connected with proper polarity otherwise the capacitor gets damaged. These capacitors have proper defined positive and negative terminal. These capacitors have high capacitance value, and they are often used in power supplies and audio amplifiers.

Fig.1.4: Paper capacitors, mica capacitors and ceramic capacitors

Variable Capacitors

Those capacitors whose capacitance can be adjusted by some mechanism. This simple variable capacitors consist of sets of fixed and moving plates that are meshed with one another. The moving plates are driven by a rotary control shaft and dielectric materials between the plates is air. They are often used in radios and other tuning circuits.

Capacitors are very important component in electrical or electronic circuit. Some characteristics of the capacitors are:

i) Capacitors have two terminals and they are designed to store the charge. The capacity of capacitor to store the charge is called capacitance. The higher the value of the capacitance, the more charge the capacitor can store.

ii) Some capacitors (like electrolytic capacitors) have their defined polarity i.e. positive and negative terminal. The capacitors can have either fixed or variable capacitance.

iii) The group of capacitors can be connected in series, parallel and mixed combination. In series combination, the effective capacitance can be –

$$\frac{1}{C_{eff.}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

In Parallel combination, the effective capacitance can be-

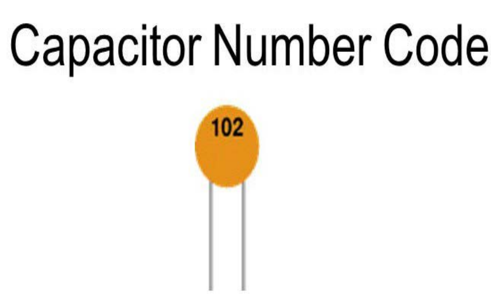
$$C_{eff.} = C_1 + C_2 + C_3$$

iv) The capacitor has the tendency of opposing the change in the voltage in across it.

v) The capacitance of the capacitor is affected by the cross-section area of plate, distance between the plates and the nature of the dielectric used in the capacitor. vi) Capacitors have voltage rating, tolerance, leakage current and temperature coefficient.

Numeric Code of Capacitors

There is a numeric coding for indicating the capacity of the capacitor. It is either represented in two digit code or three digit code. It can further have a letter as a code after third digit. Here, 1st digit and 2nd digit gives the number/value in picofarads (pF). For example- "47" written on capacitor means 47 pF. The first two digits represents the value in picofarads, and the third digit is a amultiplier or number of zeros to be added next to first two digit. For example- 104 means $10*10^4$ pF. Similarly, a letter can be also added after the numeric code to indicate the tolerance.



A number code is often used on small capacitors where printing is difficult:

- the 1st number is the 1st digit,
- the 2nd number is the 2nd digit,
- the 3rd number is the number of zeros to give the capacitance in pF.
- letters indicate tolerance and voltage rating.

For example: **102** means 1000pF = 1nF *(not 102pF!)*

For example: **472J** means 4700pF = 4.7nF (J means 5% tolerance).

Here, the letter used for tolerance of capacitor:

Code	**Tolerance Value**
F	±1%
G	±2%
J	±5%
K	±10%
M	±20%
Z	-20% / +80%

Table 1.4: Numeric Code for tolerance value

Example: Find the capacitance of the capacitor having numeric code as 221K.

Here,

22→ represents the numeric value = 22

1→ represents the multiplier = 10^1

K→ represents the tolerance = ±10%

So, the effective value of capacitance = $22*10^1$ pF ±10%

= 220 pF ±10%

1.3 Inductor–Definition, Types, Characteristics, Inductance, Applications

An inductor is an electrical passive element which opposes the change in the current by means of energy stored in the form of magnetic field. It is represented by a coil of wire in the circuit diagram. An inductor is typically a coil of wire wound around a core made of either air, ferrite, or iron. The capacity to resist the change in the current is known as the inductance of that inductor. In other words, inductance measures the ability of an inductor to store energy in a magnetic field. The inductance of the inductor is measured in Henry (H). The inductance of the inductor is represented by "L". A higher inductance means more energy storage. The inductors are very essential components in many electronic circuits. We can use inductor in filter circuit, Choke, power supplies circuit, tuner, etc.

An inductor can be classified into mainly two types. They are:

i) Fixed Inductors
   a) Air-core inductor
   b) Iron-core inductor
   c) Ferrite core inductor

ii) Variable Inductors

Fig.1.7: Different types of inductor

Air Core Inductor

It is a type of inductor that does not use a magnetic core (such as ferrite or iron). Instead, it has wound around a non-magnetic material like plastic, ceramic or simply air itself. These type of inductors are particularly suited for high frequency applications.

Iron-core Inductor

It is a type of inductor that uses a magnetic core made of iron or a similar ferromagnetic material. The core used in this type of inductor significantly enhances the magnetic field generated by the coil which results in higher inductance value compared to air-core inductors. This type of inductor mostly used in power supplies, motor control, transformers, etc.

Ferrite Core Inductor

This type of inductor uses a magnetic core made of ferrite materials. Ferrite is a ceramic material with the magnetic properties which makes it ideal for higher frequencies application. This type of inductor is used in pulse transformers, power supplies, antenna tuning, etc.

Variable inductors:

A variable inductor is an inductor whose inductance can be adjusted mechanically or electronically. This allows for tuning circuits to specific frequencies or impedance values.

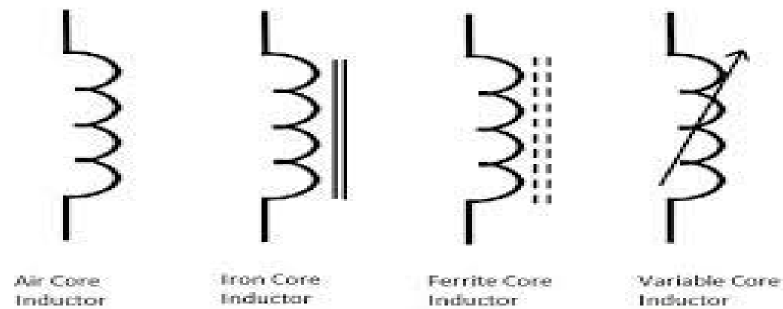


Fig: Symbol for different types of inductor

The electrical characteristics of an inductor are determined by a number of factors including the material of the core (if any), the number of turns, and the physical dimensions of the coil. Some basic characteristics of the inductor are listed below:

i) Inductors opposes the current changes in the circuit.

ii) Inductor store energy in a magnetic field when electric current flows through them.

iii) An inductor exhibit frequency-dependent behavior, i.e. at higher frequency – an inductor has higher reactance.

iv) The inductance of the inductor is affected by the cross-sectional area of the core, length of the core, number of turns and the permeability of the core material.

V) Similar to the resistor and capacitor, the inductor can be connected either in series or parallel in the electrical circuit. Their effective value of inductance can be found same as that of the resistor connected.

1.4 Simple Numerical Related to Resistor Color Code and Capacitor Numeric Code

1. Find the color code of the resistor having a value 331 ±10%.

   → Here, The given value of resistance = $33 \times 10^1 \pm 33$

The values of 3, 3 and 1 resembles with orange, orange and brown respectively.

The tolerance value resembles with silver.

2. Find the value of a resistor having four band color codes – Red, Blue, Yellow and Silver respectively.

→ Here, The significant values of Red and Blue are 2 and 6 respectively and the multiplier is 4 (since Yellow color represents 4). The value of tolerance is 10%.

So, The required value of resistance of resistor = $26*10^4$ ±10%

= 260 k ± 10%

3. Find the capacitance of the capacitor having numeric code as 484 M.

→ Here,

First two-digit i.e. 48 represents the capacitance value.

Multiplier value is represented by the 3rd digit i.e. 10^4 in this case

M→ represents the tolerance value which is equal to

Hence, the capacitance value is 480000 pF

Exercise

Choose the correct answer from the given alternatives.

1. What will be the color-coding of a resistor when the resistance of the resistor in 50+2% ohms?

   a. Green-Black-Brown-Red | b. Green-Black-Black-Brown
   c. Yellow-Brown-Black-Red | d. Green-Black-Black-Red

2. Capacitance of a capacitor is not affected by ………………

   a. Plate area | b. Distance between plates
   c. Dielectric material | d. Frequency

3. What will happen to the capacitance value, if the area of the plates of the capacitor is reduced?

   a. Capacitance value increases | b. Capacitance value reduces
   c. Capacitance value remains same | d. Capacitance value becomes zero

4. Red color bands on resistors are read from ……….

   a. Left to right | b. From both sides
   c. Right to Left | d. Are correct

5. What are the first two bands on the resistors?

   a. Tolerance | b. Decimal multiplier
   c. Two digits | d. All are correct

6. The digit that represents the green band on a resistor is …….

   a. 3 | b. 4 | c. 5 | d. 6

7. …………. is to be added after the first two digits in a decimal multiplier.

   a. Resistance | b. Digits | c. Tolerance | d. Zeros

8. A no band on the resistor means the tolerance is …………

   a. 0.3% | b. 15% | c. 30% | d. 20%

9. Which of the following is the color code for a resistor having its resistance equal to?

   a. Blue, grey, orange, gold | b. Blue, grey, orange, silver
   c. Grey, blue, orange, gold | d. Grey, blue, orange, silver

10. In a resistor, the first three bands from left to right have colors Yellow, Violet and red. What is the value of the resistance of the resistor in ohms?

    a. 6700   b. 540   c. 52000   d. 4700

11. Capacitance of a capacitor is the measure of its ability to ……….

    a. Resist flow of current   b. Store charge

    c. Allow flow of current   d. None of these

12. If a capacitor is marked as 221K, then its value is ……….

    a. pF   b. pF   c. pF   d. pF

Write short answer to the following questions.

1. Define the following terms:

a. Capacitance   b. Inductance   c. Resistance

d. Capacitor   e. Resistor

2. Classify the capacitors and resistors types. Explain each of them in details.

3. Find the color code of the resistor having:

a) 27 k Ω   b) 120M Ω

4. Find the capacitance of the capacitor having numeric code as:

a) 484F   b) 373M   c) 572K

Give long answer to following question

1. Explain the types of inductor. Also draw their symbol. Mention the characteristic of inductor.

Practical works

1. Familiarization with the tools, equipment and materials used in electronics laboratory.
2. Demonstrate the basic working of a multimeter and breadboard.
3. Identification of different types of resistors, inductor and capacitors.
4. Calculate the value of resistor using color code and compare the values to that of measured with multimeter.
5. Calculate the value of capacitor using numeric code and compare the values to that of measured with multimeter.

Unit 2 Basic of Semiconductors

2.1 Introduction of Semiconductor

Semiconductors are materials that have the electrical conductivity between that of a conductor (i.e. like copper) and an insulator (i.e. like rubber). The conductivity of the semiconductor can be controlled by various factors like light, temperature and impurity content. Germanium and Silicon ate the most widely used semiconductors. In other words, we can say the conductivity of the semiconductor is lower than that of conductor and higher than that of insulator.

Semiconductors are very essential in the modern technology because of its unique property. At room temperature, semiconductors have partially filled conduction band, partially filled valence band and a very narrow energy gap (i.e. of the order 1 eV). These semiconductor atoms have four valence electrons, giving them unique electrical properties. At absolute temperature (i.e. 0 K), semiconductor behaves like a perfect insulator. But, when there is increase in temperature, electrons from the valence band jumps to the conduction band. Thus, we can say that with increase in temperature, the conductivity of semiconductor also increases or resistivity of semiconductor decreases. This properties makes them useful in electronic components like diodes, transistors. Some major properties of semiconductors are:

- The semiconductors have intermediate or moderate electrical conductivity at room temperatures.
- The resistivity of semiconductors is less than an insulator and more than a conductor.
- The temperature coefficient of resistance for semiconductors is negative.
- When impurities are added to a semiconductor, the resistivity of the semiconductor changes abruptly.
- There is small energy gap (of 0.1 to 2.5 eV) between the valence and conduction bands.

2.2 Bonds in Semiconductor and its Crystal Structure

Semiconductor has covalent bonding, where atoms share electrons to complete their outer electron shells. Semiconductors (like Silicon, germanium) atoms share electrons to achieve a stable outer electron shell. This covalent bonds are strong and directional bonds. In Silicon or Germanium, each tetravalent Si or Ge atom shares one electron each with four neighboring atom making eight electrons in its outermost orbit. Such bonds can be broken by applying appropriate energy. At higher temperature, some covalent bonds can be broken. The electron set free by breaking the bond leaves a vacancy which is called hole. Thus, each bond breakage results in production of two charge carriers- one electron and hole.

Semiconductors (mostly Silicon and Germanium) exhibit a highly ordered arrangement of atoms in a crystal lattice. This regular plays a crucial role in determining their electrical properties. Most semiconductors crystallize in a diamond cubic structure – a specific arrangement of atoms that maximize covalent bonding. Semiconductors crystal can have other structure like Zincblende structure, Wurtzite structure, etc.

2.3 Semiconductor Materials (Germanium and Silicon) and Characteristics

Semiconductor materials are substance whose electrical conductivity lies between that of conductors and insulators. These materials are essential in modern electronic devices due to their tunable electrical properties. Silicon (Si) is one of the most widely used material in the semiconductor industry due to its abundance, stable properties and compatibility with modern fabrication processes. It belongs to group 14 of the periodic table and has four valence electrons. Germanium (Ge) is a group 14 element. It is one of the earliest materials used in the semiconductor technology. Though silicon has largely replaced germanium in many applications, it still has its application in high-speed and specialized devices due to its unique properties.

Characteristics

- Silicon and Germanium atoms are arranged in a tetrahedral lattice, with each atom covalently bonded to four neighboring atoms.
- Germanium and Silicon has a band gap of 0.7eV & 1.1 eV, which makes them good semiconductor.
- Silicon has high melting point which makes it suitable for high-temperature applications. But, the germanium has lower thermal conductivity compared to silicon.
- Silicon forms a natural oxide layer which provides excellent electrical insulation.

- Germanium is nearly transparent to infrared light making it useful in optical and photonic applications.

2.4 Definition of Energy Levels, Energy Bands, Energy Gap

Energy Level: In semiconductors, the concept of energy levels is crucial for understanding their behavior. An energy level in a semiconductor refers to the specific energies that electrons within the material can occupy. These energy levels arise from the quantum mechanical properties of the atoms in the semiconductor and determine the material's electrical and optical behavior. They dictate how easily electrons can move through a material, which is crucial for various electronic applications.

Energy Bands: An atom has electrons orbiting its nucleus, occupying specific energy levels. When these atoms come together to form a solid, their individual energy levels start to interact and overlap. This interaction leads to the formation of energy bands. An energy band in a semiconductor refers to a range of closely energy levels that electrons can occupy due to the quantum mechanical interactions of atoms in a crystalline structure. The arrangement of energy bands and the size of the band gap determine whether a material behaves as a conductor, insulator or semiconductor.

Energy Gap

The region between the valence band and the conduction band is called energy gap or band gap. It represents the amount of energy required to excite an electron from the valence band to the conduction band. Energy gap is also called as forbidden energy gap because electrons can't stay in this gap. Electrons from valence band can jump to the conduction band if an external energy is applied. This energy should be greater than the energy gap. If the energy is lesser than energy gap then electrons can't jump because there is no energy level between the valence band and conduction band. The forbidden energy gap of Silicon and Germanium is 1.1 eV and 0.7 eV respectively.

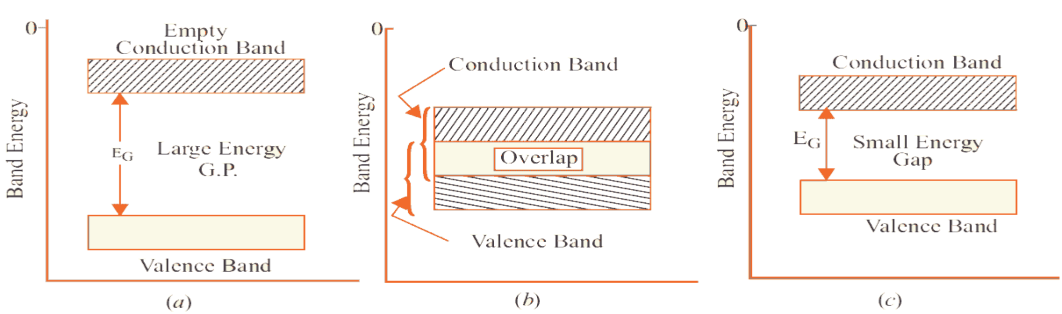


Fig: Energy bands of insulators, conductor and semiconductors respectively

2.5 Hole and Electron Current

Hole current in a semiconductor refers to the movement of positively charged "holes" within the material. These holes are created when an electron leaves its position in the atomic lattice, leaving behind a vacancy. This vacancy appears to move in the opposite direction of the electron's motion. Holes move in the direction opposite to that of electrons. Hole current is influenced by the factors like doping, temperature, electric field, etc. Hole current plays a crucial role in the operation of semiconductor devices such as diodes, transistors and photovoltaic cells.

Electron current in a semiconductor refers to the movement of free electrons which are negatively charged particles through the material. Along with the hole current, it forms the basis of electrical conduction in semiconductors. Electron current is affected by the electric field strength, doping level, temperature, material properties, etc. This current is also very essential for the operation of the semiconductors.

2.6 Types of Semiconductors

Semiconductors are the materials with electrical conductivity between that of conductors and insulators. Their conductivity can be modified by doping, temperature and external fields. Semiconductors can be classified on the basis of the level of doping into following categories. They are:

i) Intrinsic Semiconductor

ii) Extrinsic Semiconductor

   a) N-type semiconductor

   b) P-type semiconductor

Intrinsic Semiconductor: A semiconductor in its pure form is known as intrinsic semiconductor. There is no doping in this type of semiconductor. At room temperature, electron-hole pairs created in the intrinsic semiconductor crystal only due to the thermal excitation. At room temperature, an intrinsic semiconductor does have a moderate conductivity of electricity due to the concentration of free electrons and holes thermally created in the crystal. At absolute zero, this type of semiconductor act as insulator. A semiconductor is not intrinsic if its impurity content is less than one part impurity in 100 million parts of semiconductor. They are rarely used directly in the devices but form the base material for doped semiconductors. Example: Silicon and Germanium.

Extrinsic Semiconductors: Those semiconductors which are intentionally doped with the impurities to enhance the conductivity is known as extrinsic semiconductor. These type of semiconductors are formed by adding some impurities to the pure semiconductor. Adding impurities in the semiconductor either increases the number of holes or number of free electrons depending upon the type of impurities added. The process of adding impurities to a pure semiconductor is known as doping. The material which is used as impurity is called dopant.

Impurities can be classified into two types: Donor impurity (Pentavalent impurity) and Acceptor impurity (Trivalent impurity). When we add pentavalent elements as impurities, the number of free electrons in the extrinsic semiconductor increases. Some example of donor or pentavalent impurity are Arsenic, Phosphorous, Antimony, etc. When we add trivalent elements as impurities, the number of holes in the semiconductor increases. Some example of acceptor or trivalent impurity are Boron, Gallium, Indium, Aluminum, etc.

Depending upon the types of impurity doped, extrinsic semiconductor is classified as following types:

a. N-type Semiconductor
b. P-type Semiconductor

N-type Semiconductor: The material in which pentavalent or donor impurity is doped with intrinsic semiconductor is called N-type semiconductor. Addition of pentavalent impurities contribute a large number of free electrons in the semiconductor. In this type of semiconductor, free electrons are majority carriers and holes are the minority carriers. We commonly use arsenic and antimony as the pentavalent impurity for the doping.

Pentavalent impurity atoms have five electrons in their valence shell. In p-type semiconductor, each impurity atom is surrounded by intrinsic atoms like silicon atoms. Each impurity atom consists of five valence electrons and out of these electrons, four form covalent bonds with four silicon atoms. When fifth electron of impurity atom gets little amount of energy, it detaches from its parent atom. In this way, each impurity atom donates one electron to the conduction band. Thus, in a N-type semiconductor, there are more number of free electrons in the conduction band.

P-type Semiconductor: The material in which trivalent or acceptor impurity is doped with intrinsic semiconductor is called p-type semiconductor. Addition of trivalent impurities contribute a large number of holes in the semiconductor. Here, holes are the majority carriers and electrons are the minority carriers. The trivalent impurity used for doping purpose of p-type semiconductor are boron, gallium and indium.

Trivalent impurity atoms have three electrons in their valence shell. In this type of semiconductor, each impurity atom is surrounded by intrinsic atoms like Silicon atoms. Each impurity atom consists of three valence electrons and these three electrons form covalent bonds with the impurity atom because the impurity atom has only three valence electrons. The vacancy created in the incomplete covalent bond acts as a hole. An electron from neighboring atoms can jump into it. Hence, in a p-type of semiconductor, there are few electrons in the conduction band but a large number of holes in the valence band.

2.7 Majority and Minority Charge Carrier

In semiconductor, majority and minority charge carriers refer to the two types of mobile charge carriers – electrons and holes whose concentrations differ depending on the type of semiconductor (n-type or p-type). Basically, the type of charge carrier present in higher concentration in a semiconductor and dominates the conduction process is said to be majority charge carrier. Similarly, the type of charge carrier present in lower concentration in a semiconductor and exists due to thermal generation or external excitation is said to be minority charge carrier. In case of N-type of semiconductor, electrons are majority charge carriers and holes are minority charge carrier whereas in case of P-type of semiconductor, this is reverse.

2.8 Effects of Temperature on Conductivity of Semiconductor

The conductivity of a semiconductor is highly sensitive to the temperature due to its intrinsic properties and mechanism governing charge carrier generation and movement. In intrinsic semiconductors (i.e. pure silicon or germanium), the conductivity depends on thermally generated electron-hole pairs. So, in intrinsic semiconductor, the conductivity increases exponentially with temperatures as more electrons gain sufficient energy to cross the energy gap from the valence band to the conduction band.

In doped semiconductors, the conductivity depends on the availability of dopant atoms and their ionization as well as intrinsic effects at higher temperatures.

Low Temperatures

Due to low temperature, the dopant atoms may not be fully ionized causing only fewer free carriers available for conduction resulting in low conductivity.

Moderate Temperatures

As the temperature increases, the dopant atoms get ionized providing stable number of majority carriers which enhances the conductivity.

High Temperatures

Conductivity increases sharply due to intrinsic carrier generation caused due to high temperature.

Exercise

Choose the correct answer from the given alternatives.

1. The number of valence electrons of P and Si are ……. Respectively.

   a. 3 and 4 b. 5 and 4 c. 4 and 4 d. 4 and 5

2. Semiconductors have …………… conduction band and ………… valence band.

   a. A lightly filled, a moderately filled b. An almost filled, a moderately filled

   c. An almost empty, an almost filled d. An almost filled, an almost empty

3. The temperature coefficient of resistance in a pure semiconductor is …………………

   a. Zero b. Positive

   c. Negative d. Dependent on size of specimen

4. Valence electrons are the ………………..

   a. Loosely packed electrons

   b. Mobile electrons

   c. Electrons present in the outermost orbit

   d. Electrons that do not carry any chrge

5. The forbidden energy gap for germanium is ……………..

   a. 0.12 eV b. 0.72 eV c. 1.11 eV d. 1.52 eV

6. At room temperature intrinsic carrier concentration is higher in germanium than in silicon because ………..

   a. Carrier mobilities are higher in Ge than Si

   b. Energy gap in Ge is smaller than that in Si

   c. Atomic number of Ge is larger than Si

   d. Atomic weight of Ge is larger than Si

7. What will be the resistance of a semiconductor at a low temperature?

   a. Low b. One c. Zero d. High

8. A pure Ge crystal can be converted to an n-type crystal by doping with …….

   a. Boron b. Gallium c. Arsenic d. Silicon

9. Addition of trivalent impurity to a pure semiconductor creates many ....

a. Free electrons b. Valence electrons c. Holes d. Bound electrons

10. An n-type semiconductor is .....

a. Positively charged b. Neutral

c. Negatively charged d. None of the above

11. How many electrons are there in the valence shell of all semiconductor elements?

a. 8 b. 2 c. 4 d. 0

13. To obtain electrons as the majority carriers in a semiconductor the impurity mixed is ....

a. Monovalent b. Divalent c. Trivalent d. None of these

14. Which is the undoped semiconductor?

a. Intrinsic semiconductor b. Extrinsic semiconductor

c. Both (a) & (b) d. None of these

15. An intrinsic semiconductor behaves as an insulator at ....

a. 100 K b. 100^0C c. 0^0C d. 0 K

16. The Fermi-level in an intrinsic semiconductor is .....

a. Closer to the valence band

b. Nearly midway between conductive and valance band

c. Closer to the conduction band

d. Within the valence band

17. If the energy band gap for a certain semiconductor material is low, which of the following is true?

a. The conductivity of the material is high

b. The energy of the material is low

c. The resistance of the material is high

d. The current density of the material is low

18. Which of the following materials have least energy band gap?

a. Insulator b. Conductor

c. Semiconductor d. All of the above have the same band gap

Write short answer to the following questions.

1. Define semiconductor. Mention major properties of semiconductor.
2. How extrinsic semiconductor is different than that of intrinsic semiconductor. Explain in detail.
3. Explain different types of semiconductors in detail.
4. Explain the construction of a P-type semiconductor.
5. Explain the effects of temperature on the conductivity of semiconductor.

Write long answer to the following questions.

1. Explain the crystal structure of semiconductor and the bonds in semi-conductor.
2. Define energy gap. Describe types of semiconductor in brief.

Practical works

1. Demonstrate animated videos of extrinsic semiconductor and PN junction.
2. Demonstrate videos of PN junction diode working.

Unit 3 Semiconductor Diode

3.1 PN junction

The plane dividing the semiconductor material in which one half is doped with p-type material and the other half with n-type material, these two halves together is called PN junction. A PN junction is a fundamental building block of semiconductor devices, formed by joining p-type and n-type semiconductors. The interface between these two regions exhibits unique electrical properties that are critical for the operation of diodes, transistors and many other electronic components.

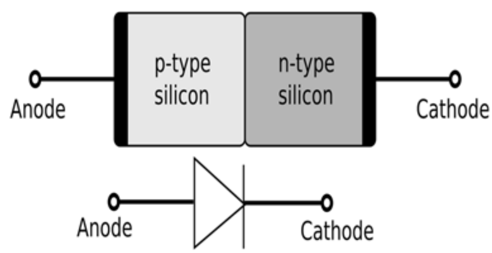


Figure: Structure and Symbol of a PN Junction

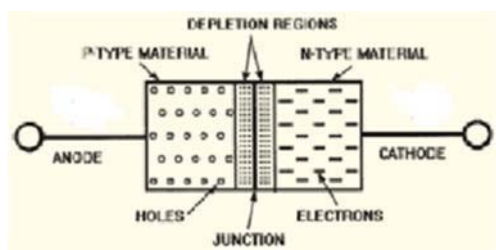


Figure: Structure of a PN junction with depletion layer

Once the PN junction is formed, the following action takes place:

i) P-region has more number of holes than electrons and N-region has more number of electrons than holes. Due to the difference of concentration in two regions, diffusion of holes and electrons take place.

ii) Holes from P-region diffuse into the N region. In the N-region, they combine with electrons.

iii) Electrons from N-region diffuse into the P region. In the P-region, they combine with holes.

iv) The process of diffusion continues only for a short period of time. After a few recombination, a restraining force is set up which is called barrier. As a result, further diffusion can't take place.

v) Due to the diffusion of electrons and holes, a depletion layer is formed. This region is called depletion region because the mobile charge carriers are depleted. Hence this region contains only immobile or fixed ions. The width of depletion region depends upon the doping level of impurity in N-type or P-type semiconductor. For higher doping level, the depletion layer becomes thinner.

3.2 Depletion Region, Depletion Layer, Energy Barrier Potential

Depletion Region

The depletion region forms at junction where free electrons and holes recombine, creating an area with no free charge carriers. In other words, the region having the acceptor and donor ions is called depletion region. This region contains only fixed and immobile positive and negative ions.

Depletion Layer

The depletion layer is a region around the junction of a p-n junction semiconductor where mobile charge carriers (electrons and holes) are absent due to recombination. It plays a crucial role in defining the electrical behavior of the p-n junction.

Energy Barrier Potential

The electric potential established across the junction due to the presence of charged ions is called energy barrier potential. This region is known as barrier potential because it stops the further flow of charge carriers across the junction unless an external voltage is applied. The barrier potential for silicon is 0.7 V and 0.3 V for germanium.

3.3 PN Junction Biasing

The process of applying potential difference across the ends of PN junction to control its electrical behavior is called PN junction biasing. It can also be said that the process of supplying external power supply to the PN junction is called PN junction biasing. There are two main types of biasing are:

i) Forward Biasing

ii) Reverse Biasing

i) Forward Biasing

The process of connecting battery across the PN junction in which positive terminal of the battery is connected to the P-region and negative terminal of the battery is connected to the N-region is called forward biasing.

In this method of biasing, holes are repelled from the positive terminal of the battery and forced towards the junction. Similarly, electrons are repelled from the negative terminal of the battery and forced towards the junction. Because of the energy, some electrons and holes are driven towards the junction where they recombine. This reduces the barrier potential and decreases the width of depletion layer. The movement of electrons and holes cause large current to flow towards the junction. Both electrons and holes move inside the crystal but only free electrons move in the external circuit.

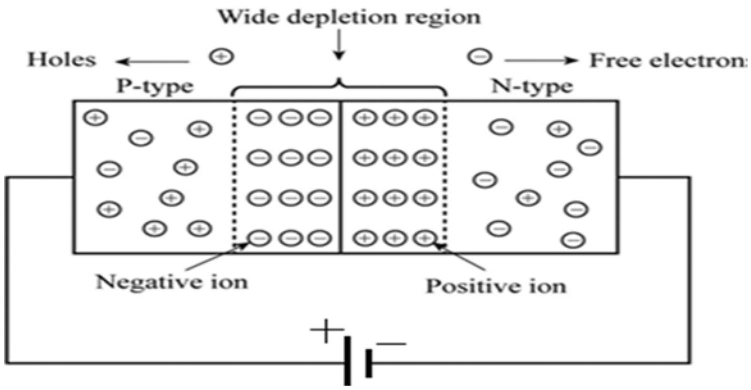
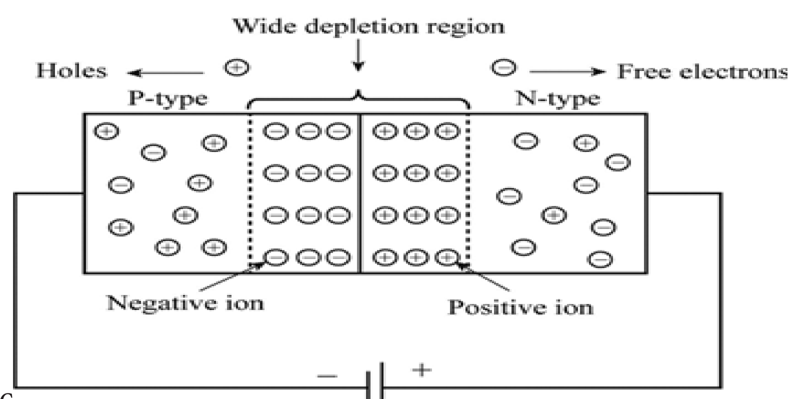


Figure: Forward biasing of a PN junction diode

ii) Reverse Biasing

The process of connecting battery across the PN junction in which positive terminal of the battery is connected to the N-region and negative terminal of the battery is connected to the P-region is called reverse biasing.

In this method of biasing, holes are attracted towards the negative terminal of the battery whereas electrons are attracted towards the positive terminal of the battery. Since both electrons and holes move away from the junction, the width of depletion layer increases. Hence, no current flows and the junction offer high resistance.



€

Figure: Reverse biasing of a PN junction diode

3.4 PN Junction Diode

A PN junction diode is defined as a two-terminal electronic component with one side doped with p-type impurities and the other with n-type impurities. It is a unidirectional semiconductor device. It conducts the electric current in only one direction but offers high resistance in other direction.

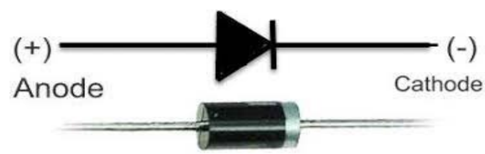


Figure: PN junction diode

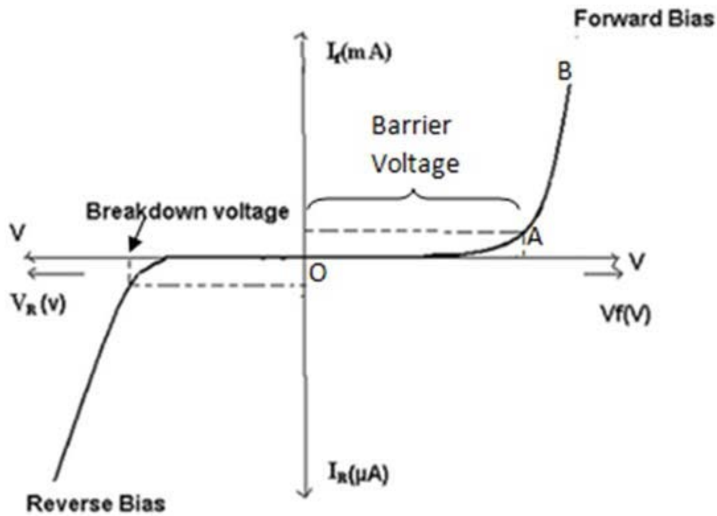


Figure: Characteristics of PN junction diode

The graph plotted for forward biased mode is called forward bias characteristics. Similarly, the graph plotted for reverse biased mode is called reverse bias characteristic. The forward characteristic lies on the first quadrant of the graph whereas the reverse characteristic lies on the third quadrant of the graph.

When a PN Junction diode is forward biased, current flows through the diode when the applied voltage is greater than the barrier potential. The barrier potential of Silicon PN junction diode is about 0.7V and that of Germanium PN Junction diode is about 0.3V. When the applied voltage is less than barrier potential, current does not flow through the diode but the current sharply increases when it reaches the knee voltage. The knee voltage is marked above with the letter 'A'.

When the diode is reverse biased, current do not flow through the diode until a point called avalanche breakdown is reached. When the applied reverse voltage is equal to the avalanche breakdown, excessive current flows through the diode. This excessive current permanently damages the diode.

Applications

i) PN junction diode can be used for rectification (AC to DC conversion)

ii) It can be used as switching application.

iii) It can also be used in signal demodulation.

iv) Light Emitting Diodes (LED)- a type of PN diode can be used for indicator lights, display panels, automotive lighting.

v) Photo diodes can be used in light sensor, solar cell and optical communication.

vi) They are used in clipping and clamping circuits.

3.5 Reverse Breakdown Effects, Avalanche, Zener and Thermal Breakdown

Reverse breakdown is a phenomenon that occurs in a PN junction diode when a sufficiently high reverse voltage is applied across it. The reverse breakdown effect in a PN junction diode refers to the phenomenon where a large reverse current flows when the reverse bias voltage exceeds a critical value called the breakdown voltage. This effect can be caused by either Zener breakdown or avalanche breakdown, depending on the diode's doping level and operating conditions.

In a PN junction diode, the thermal breakdown occurs when the diode's junction temperature rises excessively due to power dissipation causing a permanent damage. This phenomenon is typically the result of a self-reinforcing cycle. When there is high ambient temperature, there is likelihood of thermal breakdown in pn junction diode.

3.6 Introduction of Various Diodes

a) Zener Diode

Zener diode is a heavily doped PN junction diode which is operated at breakdown region of reverse biased mode.

Figure: Zener diode

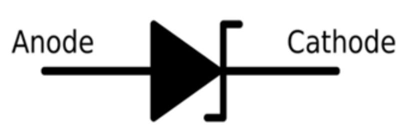


Figure: Symbol of a Zener diode

The reverse breakdown of a PN junction may occur due to one of the effects- Avalanche or zener effect. The avalanche breakdown occurs when the free electrons acquire sufficient energy to ionize a lattice atom. The additional free electrons are accelerated by the reverse field causing more and more ionization. The Zener breakdown occurs when the electric field across the junction, produced due to reverse voltage, is sufficiently high. This force is so strong that the covalent bonds break and it produces large number of charge carriers.

Applications of Zener Diode

i) It is used in voltage regulation.

ii) It is used as peak clippers.

iii) It is used for protecting meters against burn –out from accidental overloads.

iv) It is used as fixed reference voltage in a network for comparing or biasing purposes.

b) LED (Light Emitting Diode)

LED is a semiconductor device (PN Junction diode) which emits light when it is forward biased. The emitted light may be of any color-green, yellow, red, blue, infrared etc. The color of the emitted light depends upon the type of semiconductor used. For instance- gallium arsenide emits infrared, gallium arsenide phosphide emits yellow or red light, gallium phosphide emits red or green, gallium nitride emits blue etc.

When LED is forward biased, the electrons and holes move towards the junction and recombination takes place. During recombination, the electrons lying in the conduction band of N-region fall into the holes lying in the valence band of P- region. The light is emitted as a result of recombination. The amount of light emitted by the LED is directly proportional to the forward current. Higher the forward current, higher is the light output.

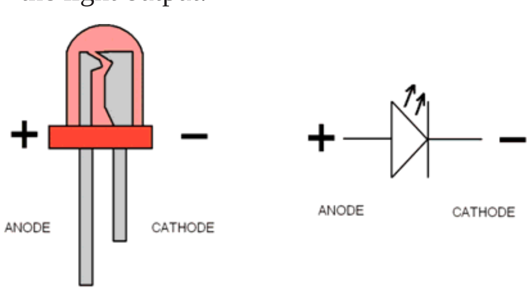


Figure: Structure and Symbol of a LED

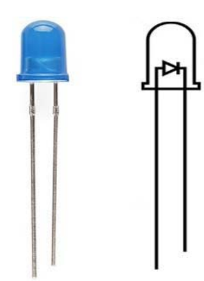


Figure: Leads of a LED

Applications of LED

i) LEDs are used to make lamps.

ii) They are used to make seven segment, sixteen segments and dot matrix displays. Such displays are used in digital clocks, calculators, advertisement boards etc.

iii) They are used to make indicators.

iv) They are used as video displays in cell phones, computers etc.

v) They are used to make traffic light signals.

vi) They are used in optical switching devices.

c) Power Diode

The diode with higher forward current rating and reverse blocking voltage is called power diode. This diode is mainly used in high power applications. It has large PN junction in order to pass large amount of current and dissipate large amount of heat. It also has two terminals (Anode and Cathode) like a signal diode. It allows forward current to flow from anode to cathode when forward biased and doesn't conduct current when reverse biased. Its symbol is similar to that of signal diode.

Figure: Power diodes

Applications of Power Diode

i) It is used to make rectifiers.

ii) It is used as a voltage multiplier.

iii) It is used as freewheeling diode.

d) Varactor Diode

The diode which uses the inherent capacitance of the depletion layer when it is reverse biased is called varactor diode. It is also known as Varicap, Voltcap or tunning diode. It is used as a voltage variable capacitor.

When the reverse biasing voltage is increased, the width of the depletion layer increases. This increases the dielectric thickness which in turn decreases the capacitance. When the reverse biasing voltage is decreased, the width of the depletion layer decreases. This decreases the dielectric thickness which in turn increases the capacitance.

Figure: Varactor diode

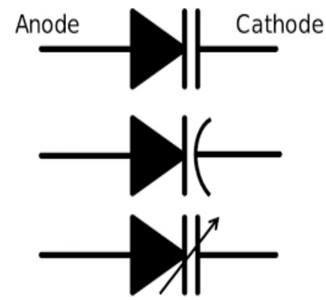


Figure: Symbol of varactor diode

Applications of Varactor Diode

i) It is used as electronic tuners in radio, television and other receivers.

ii) It is used in automatic frequency control devices.

iii) It is used in adjustable band pass filter.

e) Photo Diode

Photodiode is a semiconductor material which converts light energy into an electrical signal. The working function of a photodiode is just opposite to that of LED. This diode is always reverse biased. The amount of current generated is directly proportional to the intensity of the light. It is also termed as photo detector, photo sensor or light detector.

Dark current is the leakage current that flows in the photodiode in the absence of light. The dark current in the photodiode increases when temperature increases.

Figure: Photo diodes

Figure: Symbol of a photo diode

Applications of Photo Diodes

i) It is used in smoke detectors.

ii) It is used in opto-couple circuits.

iii) It is used in optical communication devices.

iv) It is used in medical application like CT scan, pulse oximeters, etc.

Exercise

Choose the correct answer from the given alternatives.

1. With forward biased mode, the p-n junction diode …….
   a. Is one in which width of depletion layer increases
   b. Is one in which potential barrier increases
   c. Acts as closed switch
   d. Acts as open switch

2. In the reverse biasing of a p-n junction diode ……….
   a. The width of the depletion layer decreases
   b. The width of the depletion layer increases
   c. The number of minority charge carriers increase
   d. The number of majority charge carriers increase

3. The resistance of a p-n junction in forward bias is …….
   a. Zero   b. Infinity   c. Very low   d. High

4. The reason of current flow in p-n junction in forward bias is ………
   a. Drifting of charge carriers   b. Drifting of minority charge carriers
   c. Diffusion of charge carriers   d. All of the above

5. What is the meaning of doping a semiconductor?
   a. Increasing its energy   b. Adding impurities to it
   c. Reducing the band gap   d. Heating it to high temperatures

6. For a reverse biased p-n junction ………
   a. P region is positive and the current is due to electrons
   b. P region is positive and the current is due to holes
   c. P region is negative and the current is due to electrons
   d. P region is negative and the current is due to both electrons and hole

7. The increase in the width of the depletion region in a p-n junction diode is due to ……
   a. Both forward bias and reverse bias   b. Increase in forward current
   c. Forward bias only   d. Reverse bias only

8. A p-n junction diode works as insulator if connected ……

a. To AC b. In forward bias c. In reverse bias d. None of these

9. A zener diode is used as ….

a. An amplifier b. Voltage regulator

c. Oscillator d. None of the above

10. A photodiode works on the principle of ……

a. Photo-voltaic effect b. Photo-conductive effect

c. photo-electric effect d. Photo-thermal effect

11. Light Emitting Diode (LED) converts ………

a. Light energy into electrical energy

b. Electrical energy into light energy

c. Thermal energy into light energy

d. Mechanical energy into electrical energy

12. LED is a p-n junction diode which is ………………….

a. Forward biased b. Either forward biased or reverse biased

c. Reverse biased d. Neither forward nor reverse biased

13. LED can emit …….

a. Red light b. Orange light c. Blue light d. All of these

Write short answer to the following questions.

1. Explain the types of biasing methods of PN junction in detail.
2. Explain I-V characteristics of a PN junction diode. Also list out the applications of PN junction diode.
3. Write the differences between forward and reverse biasing of a PN junction.
4. What is zener diode. What are the applications of the Zener diode and Varactor diode.

Write long answer to the following questions.

1. Explain various special diodes along with their any two applications.
2. Illustrate about reverse breakdown effects, avalanche, zener and thermal breakdown.

Project works

1. Demonstrate a simple circuit in breadboard using a battery, resistor, PN diode, LED in both forward and reverse biased mode.
2. Assess diode forward IV characteristics and also observe it in oscilloscope.
3. Assess zener diode reverse IV characteristics.
4. Identify different types of diodes and their terminals.
5. Create a simple circuit on breadboard using diode.
6. Conduct the research on the semiconductor manuals.

Unit 4 Power Supplies

4.1 Rectifier and its Components

The circuits which convert alternating current (AC) into direct current (DC) are known as rectifiers. The process of conversion of alternating current (AC) into direct current (DC) is said to be rectification. It does it by using a diode or a group of diodes. We know that a diode permits current only in one direction and blocks the current in the other. We use this principle to construct various rectifiers. Basically, a rectifier consists of the following components:

- Diodes - Transformer - Filter (Capacitor) - Voltage Regulator

4.2 Basic Rectifier circuits, Types, Working principle, Characteristics and Applications

We can classify rectifiers into two types:

The rectification system can be done in two ways:-

- Half wave rectification
- Full wave rectification

Based on the method of rectification, the rectifiers are of two types:

i) Half Wave Rectifier

ii) Full Wave Rectifier

  a) Center Tapped type full wave rectifier

  b) Bridge type full wave rectifier

Half Wave Rectifier

The half wave rectifier is a type of rectifier which converts half of the AC input signal (positive half cycle) into pulsating DC output signal and the remaining half signal (negative half cycle) is blocked or lost. It is the simplest form of the rectifier. We use only a single diode to construct the half wave rectifier.

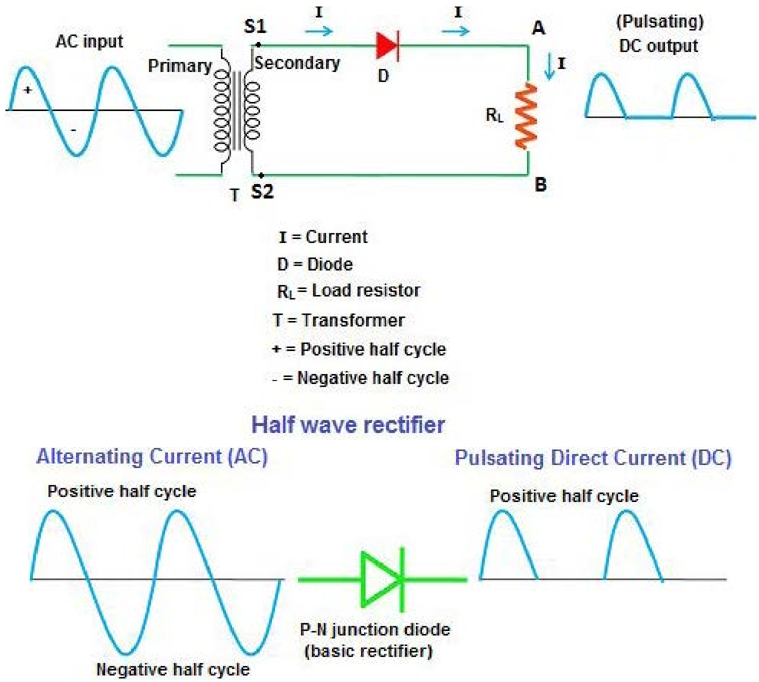


Figure: Half wave rectifier circuit and its output waveform

Working Principle

For positive half cycle, let upper end S1 is positive and lower end S2 is negative so that diode D is in forward biasing mode (conducting mode). Hence at this condition, current flows along S1DABS2, and output signal appears across. For negative half cycle, upper end S1 becomes negative and lower end S2 becomes positive so that diode D is in reverse biasing mode (blocking mode). Hence there is no output signal across the .

In this way, every positive half cycle of AC is conducted through load resistance and negative half cycle of AC is blocked. Thus, output is rectified pulsating half wave.

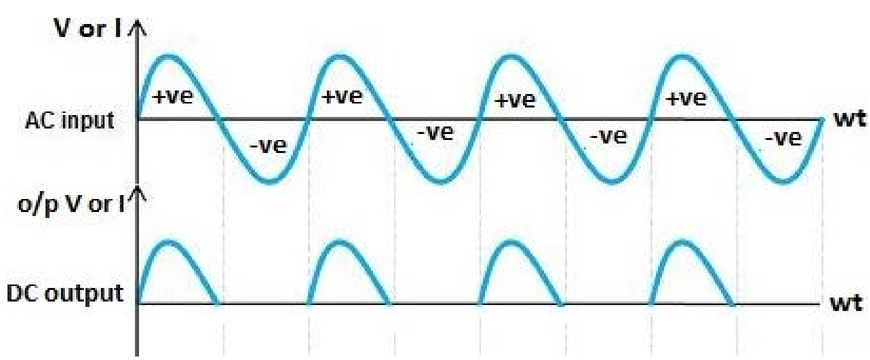


Figure: Half wave rectifier output waveform

Characteristics

Average value of current or output dc current ($I_{avg}\ or\ I_{dc}$) = $\frac{I_m}{\pi}$

RMS current $I_{rms} = \frac{I_m}{2}$

Full Wave Rectifier

A full-wave bridge rectifier converts the whole of the input waveform to one of constant polarity (positive or negative) at its output. It is a type of rectifier which converts the full AC input signal (positive half cycle and negative half cycle) to pulsating DC output signal. Unlike the half wave rectifier, the input signal is not wasted in full wave rectifier. There are two types of full wave rectifier:-

a) Center tapped type full wave rectifier

b) Bridge type Full wave rectifier

Center Tapped Type Full Wave Rectifier

The center-tapped full-wave rectifier circuit uses two diodes D1 and D2 which are connected to the center-tapped secondary winding of the transformer. The center- tapped on the secondary is taken at zero voltage reference point. If the secondary voltage is V2 then the voltage between one end of secondary and center tapped is equal to V2 /2.

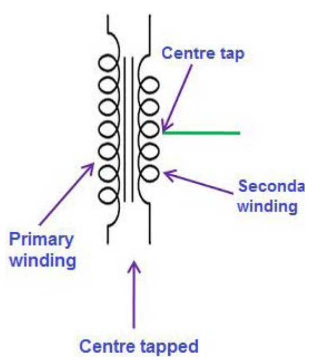


Figure: Center tap transformer

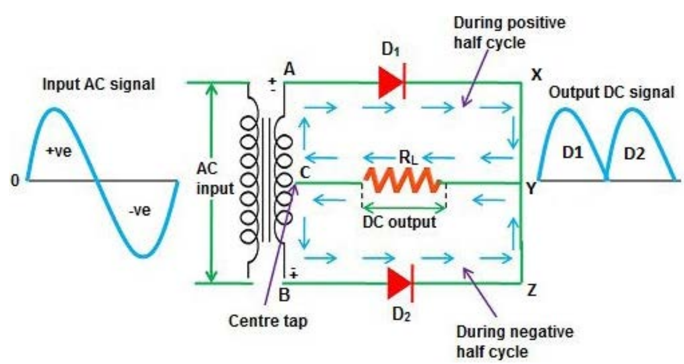


Figure: Center tapped full wave rectifier

Working

For positive half cycle, let upper end A is positive and lower end B is negative so that diode D1 is in forward biasing mode (conducting mode), and diode D2 is reverse biasing mode (blocking mode). Hence at this condition, current flows along AD1XYC, and output signal appears across.

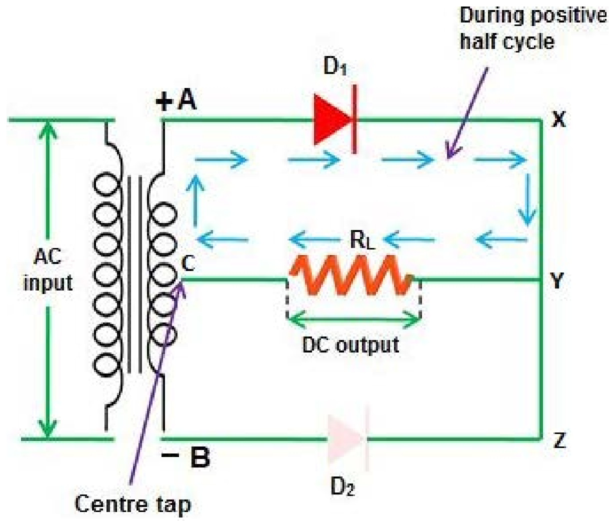


Figure: Center tapped rectifier during positive half cycle

For negative half cycle, upper end A becomes negative and lower end B becomes positive so that diode D1 is in reverse biasing mode (blocking mode) and diode D2 is in forward biasing mode (conducting mode). Hence in the negative half cycle also output signal appear across the , and current flows along BD2ZYC.In this way, every half cycle of AC is conducted through load resistance. Thus, the output is called full wave rectifier.

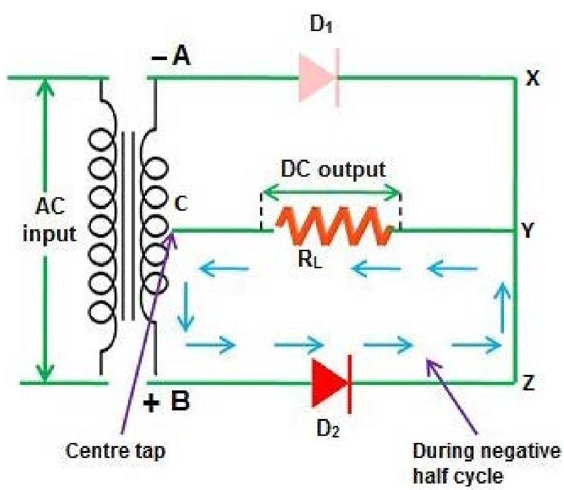


Figure: Center tapped rectifier during negative half cycle

Characteristics

Average value of current or output dc current (I_{avg} or I_{dc}) = $\frac{2I_m}{\pi}$

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

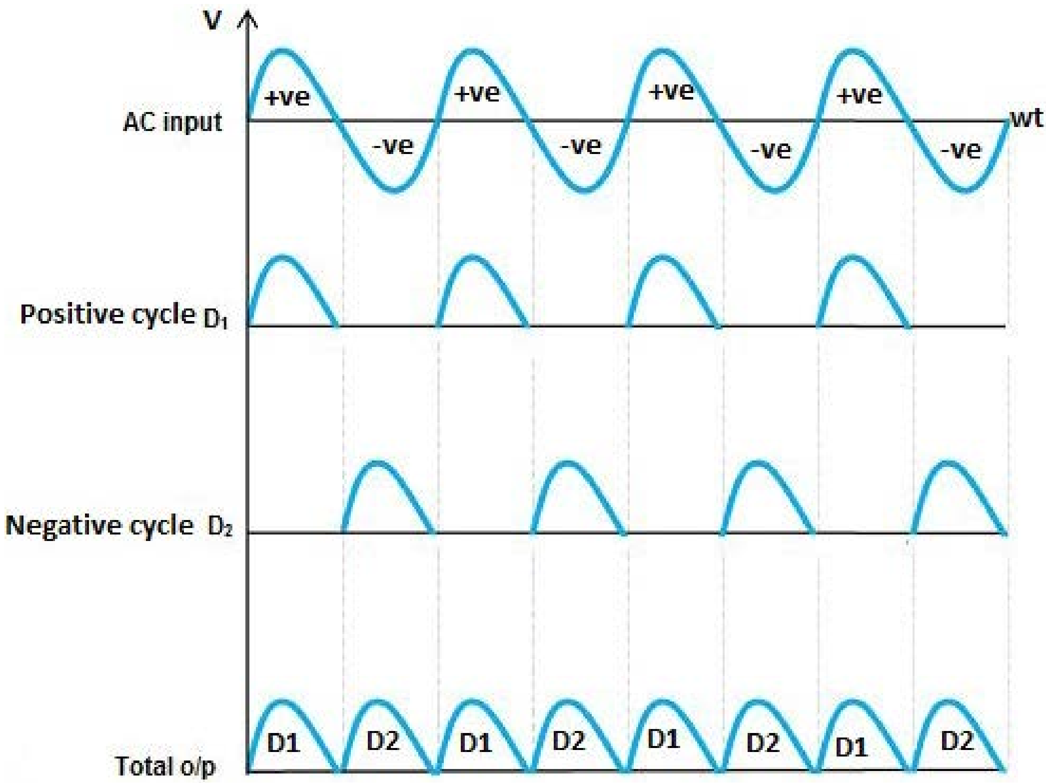


Figure: Output waveform of center tapped full wave rectifier

Bridge Type Full wave Rectifier

A bridge rectifier is a type of full wave rectifier which uses four diodes in a bridge circuit configuration to efficiently convert the Alternating Current (AC) into Direct Current (DC).

Construction

The construction diagram of a bridge rectifier is shown in the below figure. The bridge rectifier is made up of four diodes namely D1, D2, D3, D4 and load resistor RL. The four diodes are connected in a closed loop (Bridge) configuration to efficiently convert the Alternating Current (AC) into Direct Current (DC). The main advantage of this bridge circuit configuration is that we do not require an expensive center tapped transformer, thereby reducing its cost and size.

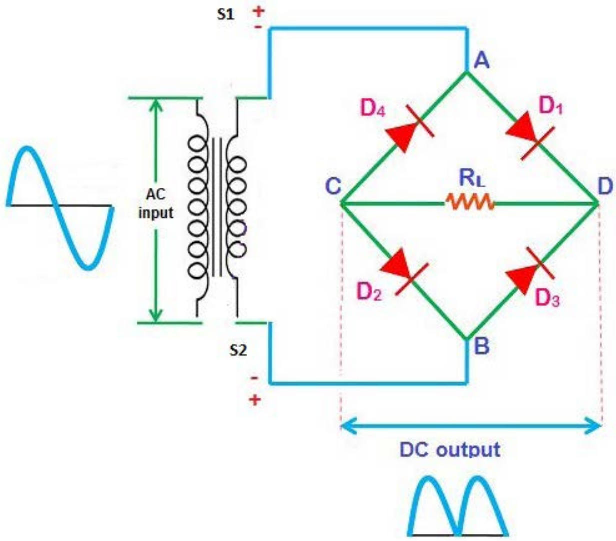


Figure: Full wave bridge rectifier circuit

Working

For positive half cycle, let upper end S1 is positive and lower end S2 is negative so that diodes D1 and D2 is in forward biasing mode (conducting mode), and diodes D3 and D4 is in reverse biasing mode (blocking mode). Hence at this condition, current flows along S1AD1DCBS2, and output signal appears across.

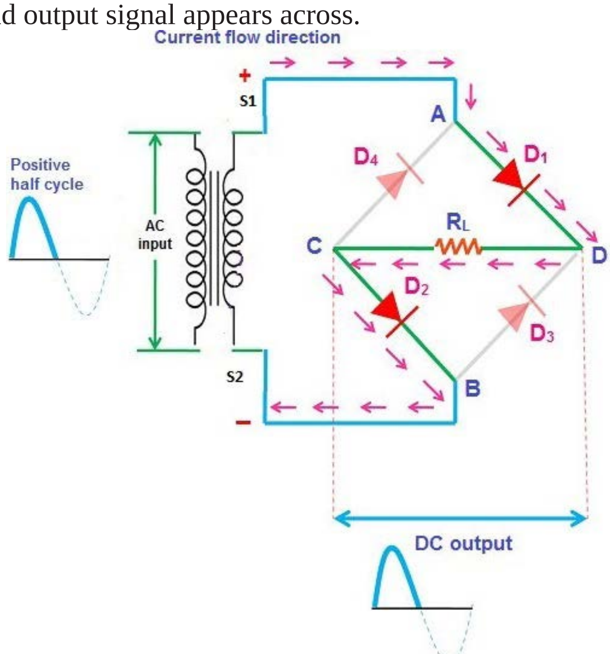


Figure: Full wave bridge rectifier circuit during +ve cycle

For negative half cycle, upper end S1 becomes negative and lower end S2 becomes positive so that diodes D1 and D2 are in reverse biasing mode (blocking mode) and diodes D3 and D4 are in forward biasing mode (conducting mode). Hence in the negative half cycle also output signal appear across the , and current flows along S2BD3DCAS1.In this way, every half cycle of AC is conducted through load resistance. Thus, the output is called full wave rectifier.

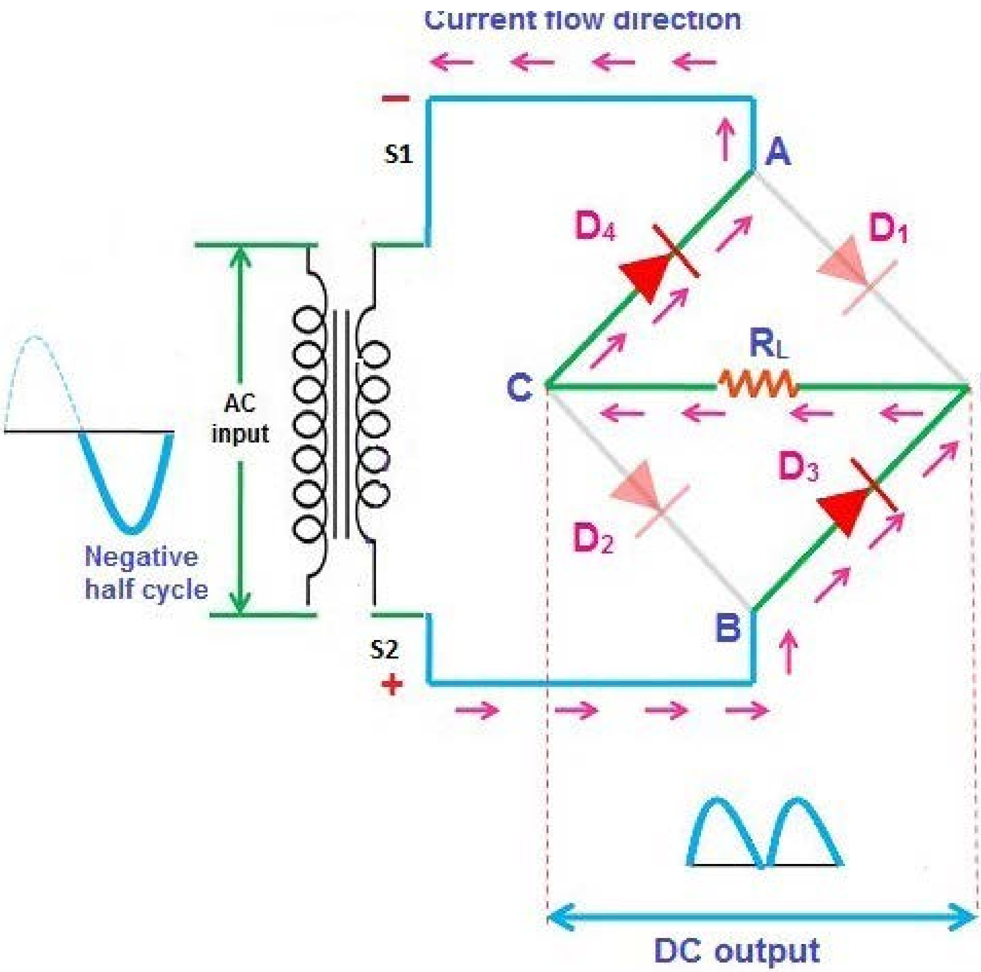


Figure: Full wave bridge rectifier circuit during -ve cycle

Characteristics

Average value of current or output dc current (I_{avg} or I_{dc}) = $\frac{2I_m}{\pi}$

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

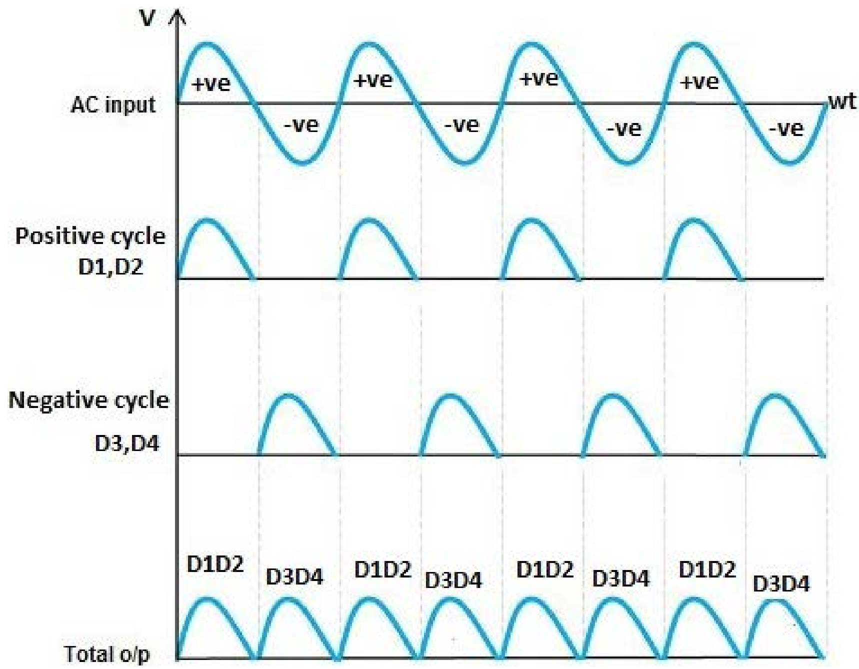


Figure: Output waveform from bridge type full wave rectifier

4.3 Overall Block Diagram of Power Supplies

Most of the electronic devices and circuits require a dc source for their operation. Dry cells and batteries are one form of dc source. They have the advantage of being portable and ripple free. However their voltages are low they need frequent replacement and are expensive as compared to conventional dc power supplies. Since the most convenient and economical source of power is the domestic ac supply. The process of converting ac voltage into dc voltage is called rectification and is consists of

a. Rectifier b. filter and c. voltage regulator circuit

Unregulated Power Supply

An unregulated power supply is one whose dc terminal voltage is affected significantly by the amount of load. As the load draws more current, the dc terminal voltage become less.

Regulated Power Supply

It is that dc power supply whose terminal voltage remains almost constant regardless of the amount of current drawn from it. An unregulated supply can be converted into a regulated power supply by adding a voltage regulating circuit.

Figure: Block diagram of power supply system

A typical power supply consists of four stages as shown in figure above.

1. **Transformer**

   Generally it is used to change the voltage level for the rectification and mostly step down transformer is used.

2. **Rectifier**

   It is a circuit which employs one or more diodes to convert ac voltage into dc voltage.

3. **Filter/Smoothing**

   The function of this circuit is to remove fluctuations or pulsations called ripples present in the output of rectifier.

4. **Voltage Regulator**

   Its main function is to keep the terminal voltage of the dc supply constant even when

   a. Ac input voltage varies

   b. The load varies.

Exercise

Choose the correct answer from the given alternatives.

1. For full wave rectifier, the minimum number of diodes required is…..

   a. 2 b. 3 c. 1 d. 4

2. Which of the following statement is correct?

   a. Rectification efficiency of a half wave rectifier is equal to that of a full wave rectifier

   b. Rectification efficiency of a half wave rectifier is lower than that of a full wave rectifier

   c. Rectification efficiency of a half wave rectifier is higher than that of a full wave rectifier

   d. All of the given options

3. The maximum efficiency of rectification from half-wave rectifier is ……

   a. 40.6% b. 25% c. 50% d. 81.2%

4. The maximum efficiency of rectification from Full-wave rectifier is ……

   a. 25% b. 50% c. 40.6% d. 81.2%

5. Rectifier convert AC signal into …..

   a. Pulsating DC b. DC signal c. Pulsating AC d. Pure DC signal

6. Which type of rectifier uses only one diode?

   a. Full-wave rectifier b. Half-wave rectifier

   c. Center-tapped rectifier d. None

7. Which component is commonly used with a rectifier for smoothing the output dc voltage?

   a. Resistor b. Inductor c. Capacitor d. Transformer

8. In a half-wave rectifier, the output DC voltage is approximately ……… of the peak AC voltage.

   a. 0.318 b. 0.707 c. 0.5 d. 0.637

9. Which electronic component is commonly used for voltage regulation in power supplies?

   a. Diode   b. Zener diode   c. Transistor   d. Resistor

10. Bridge rectifier is an alternative for ……..

   a. Full wave rectifier   b. Peak rectifier

   c. Half wave rectifier   d. None of above

Write short answer to the following questions.

1. Define rectifier. Explain the working principle of half-wave rectifier. Also present the required waveform.
2. How can we obtain the dc output from ac input? Illustrate about importance of rectifier.
3. Compare half-wave and full-wave rectifier.
4. Discuss the working of center-tapped rectifier along with its circuit and waveforms.
5. Explain the working of Full wave rectifier along with neat circuit diagram and waveforms.

Write long answer to the following questions.

1. Draw and explain the block diagram of a regulated DC power supply system, highlighting its main components and their function.
2. Define rectifier and list out different components of rectifier. Explain the working of a full-wave bridge rectifier with a neat circuit diagram and waveforms.

Project works

1. Assess half wave rectifier in breadboard and observe input and output waveforms in oscilloscope.
2. Assess center tapped and bridge full wave rectifier circuits in a breadboard and observe its input and output waveforms in oscilloscope.
3. Fabricate 12V dc output bridge type rectifier circuits in a matrix board.
4. Fabricate 12V dc output power supply using rectifier, filter and voltage regulating components in a matrix board.

Transistors

Unit 5

5.1 Introduction of Transistor

A transistor is a semiconductor device used to amplify or switch electronic signals and electrical power. It is one of the fundamental building blocks of modern electronic devices. Transistors are made of semiconductor materials, typically silicon or germanium and have three terminals for connection to an external circuit. It consists of two PN junctions. So, it can be regarded as a combination of two diodes connected back to back. In short, the working principle of a transistor involves controlling a large collector current with a small base current, enabling amplification and switching.

Basically, one junction of transistor is forward biased and other junction is reverse biased. The forward biased junction has a low resistance path but the reverse biased junction has a high resistance path. Because of this, the weak signal is introduced in the low resistance circuit and output is taken from the high resistance circuit. Thus, we can say a transistor transfers a signal from low resistance to high resistance. The prefix "Trans" means the signal transfer property of the device while the "istor" classifies it as an element in the same family with the resistor. Hence, this device is named as TRANSISTOR. We can find its use from our smartphones to supercomputers. There are different types of transistors available in the market in today's time.

Transistor can be broadly classified into following types:

i) Bipolar Junction Transistor (BJT)

ii) Field Effect Transistor (FET)

5.2 Introduction of Bipolar Junction Transistor (BJT)

A bipolar junction transistor is a three-terminal semiconductor device that consists of two PN junctions which are able to amplify or magnify a signal. It is a current controlled device and three terminals of BJT are base, collector and emitter. If we apply a small amplitude signal to the base, we can obtain the amplified form of signal at the collector of the transistor. This is the amplification provided by the BJT and for this process we need to supply the external source DC power. In addition to this, this BJT can be used as the switch.

This device is named as BJT because the transistor operation is carried out by two types of charge carriers – majority charge carriers and minority charge carriers. The output voltage, current and even power is controlled by the input current in a BJT. So, this device is called a current controlled device.

Configurations

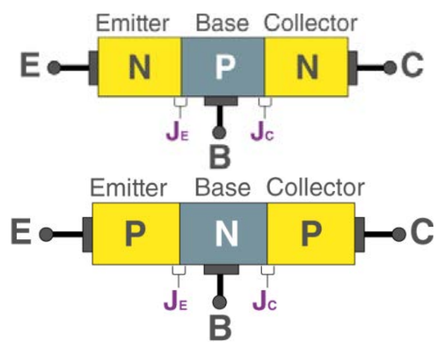


Figure 5.1: Construction of NPN and PNP transistor

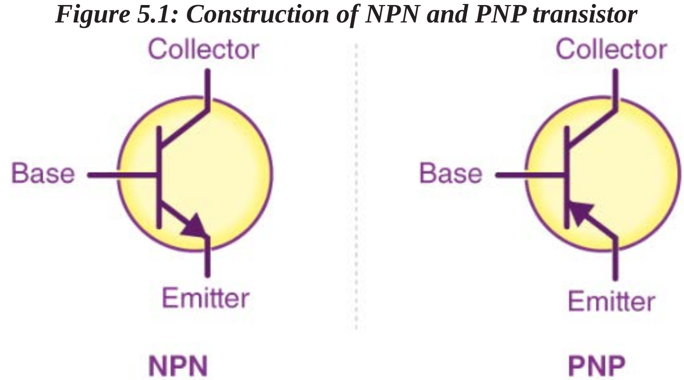


Figure 5.2: NPN and PNP transistor symbol

A transistor has three regions and they are: Emitter, Base and Collector. These regions are connected to each terminals hence they are also called terminals of a BJT.

Emitter

It is one of the terminals of the BJT which supplies charge carriers (i.e. electrons in NPN transistor and holes in a PNP transistor) to the base region. It is an outer region situated in one side of transistor. This region is the most highly doped region.

Base

The base acts as the control terminal regulating the number of carriers that pass from the emitter to the collector. It is thin and lightly doped to allow most carriers from the emitter to reach the collector. It is situated in between the emitter and the collector. This is the smallest region in size.

Collector

The collector collects carriers from the base and emitter allowing current to flow through the transistor. It is moderately doped and larger in size compared to the emitter to handle higher currents. It is designed to dissipate heat and support the flow of carriers.

A BJT has two junctions J_E and J_C – Emitter-Base (EB) Junction and Collector-Base (CB) Junction respectively which is shown in the *figure 5.1*. The junction formed between the emitter and the base is called EB junction and the junction formed between the collector and the base is called CB junction.

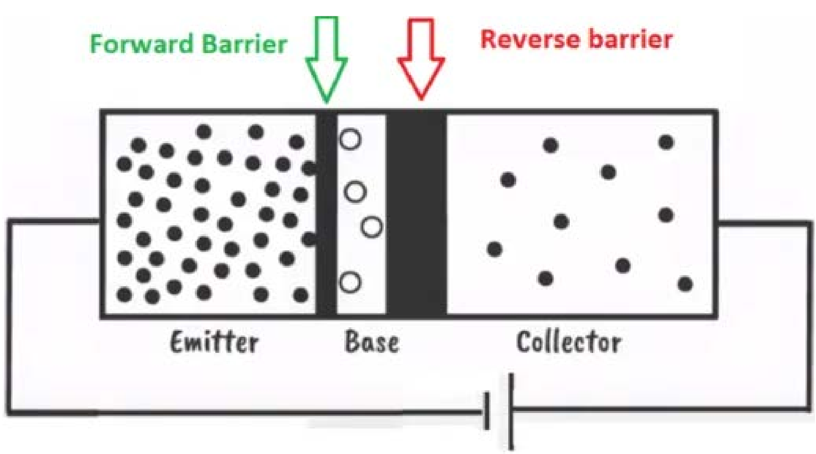
Forward Barrier Region

It is the region between the base and emitter. This region is formed due to attraction of holes in the base region and electrons in the emitter region. Because of this, there is generation of electric field and the value is around 0.7 Volt for silicon semiconductor and 0.3 Volt for germanium semiconductor. We can call it as junction $J_{E.}$

(**Note:** To break this barrier, we need to apply source voltage more than the barrier voltage)

Reverse Barrier Region

It is the region between the base and collector. This region is formed due to the base and collector reverse bias. The resistance of this barrier is infinity and it is denoted by $J_{C.}$



Note: *In BJT Transistor*

Region	Doping Level	Area of Region
Emitter (E)	Highly	Smaller than Collector and Larger than Base
Base (B)	Lightly	Smallest
Collector (C)	Moderately	Largest

5.3 Types of BJT

There are mainly two types of BJT transistor and they are: NPN and PNP.

NPN Transistor

NPN transistor is composed of two N-type semiconductor materials separated by a thin layer of P-type material. The two N-type semiconductors act as emitter and collector respectively while the P-type semiconductor acts as a base. Electrons are the majority charge carriers. In this type of transistor, the arrowhead in an emitter indicates the direction of conventional current flow. Thus, the conventional current will flow from the base to emitter. Its symbol is shown in *figure 5.2*.

PNP Transistor

PNP transistor is composed of two P-type semiconductor materials separated by a thin layer of N-type material. Here, the N-type of semiconductor is sandwiched between two P-type semiconductors. The two P-type semiconductors act as emitter and collector respectively while N-type semiconductor acts as a base. Holes are the majority charge carriers. In this type of transistor, the arrowhead in an emitter points from the P-region towards the N-region. So, the conventional current will flow from the emitter to base. Its symbol is shown in *figure 5.2*.

Out of these two types of transistor, the NPN transistor is widely used. As we know, in NPN transistor the current conduction is mainly due to electrons whereas in PNP transistors, the current conduction is mainly due to holes. So, the conduction in NPN transistor is higher than in PNP transistors as electrons are more mobile than the holes.

Working Principle of NPN Transistors

Let us consider a NPN transistor which is biased for active operation i.e., emitter base junction is forward biased and collector base junction is reverse biased. The forward biased voltage is small and the reversed biased voltage is quite larger.

When emitter is forward biased, a large number of free electrons of N-type emitter region are pushed towards the base. A few numbers of holes also pass from base to the emitter. This flow of electrons and holes constitute emitter current, I_E. Since the base is thin and lightly doped region, only a very small amount of electrons combines with holes to constitute the base current, I_B. The remaining electrons pass towards the collector. These electrons in the collector region constitute collector current, I_C.

The emitter current of a transistor consists of base current and collector current. Base current is only about 2% of the emitter current whereas the collector current is about 98% of the emitter current. Thus emitter current is almost equal to the collector current.

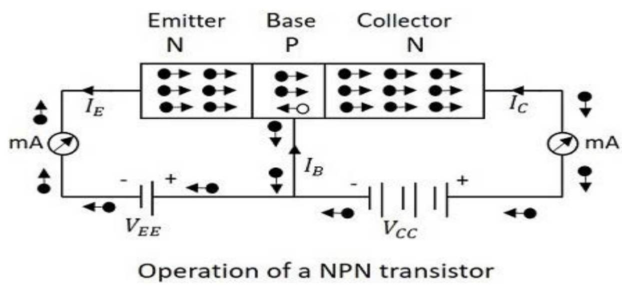


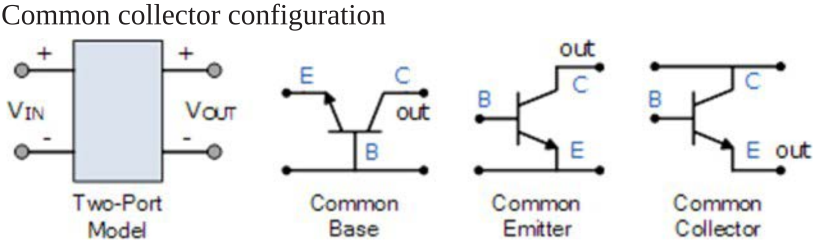
Fig: Working of NPN transistor

Note: The working principle of PNP transistor is similar to NPN transistor.

5.4 Configurations of BJT (CB, CE, CC)

Any of the terminals of a BJT can be made common to input and output. This common terminal is generally grounded or connected to the chassis. Depending upon the common terminals, there are three transistor configurations. They are:

1. Common base configuration
2. Common emitter configuration
3. Common collector configuration



Common Base Configuration

The arrangement in which base of a BJT is made common to both emitter and collector is called common base configuration. The input is applied between the emitter and base and the output is taken between the collector and base.Fig: Common base configuration of NPN and PNP Transistor

In this configuration, emitter base junction is considered as input whereas collector base junction is considered as output.

Common Emitter Configuration

The arrangement in which the emitterof a BJT is made common to both base and collector is called common emitter configuration.

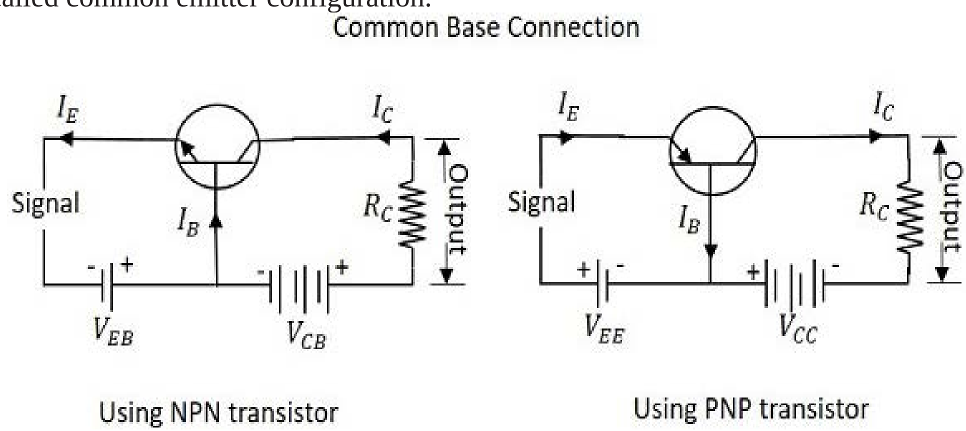
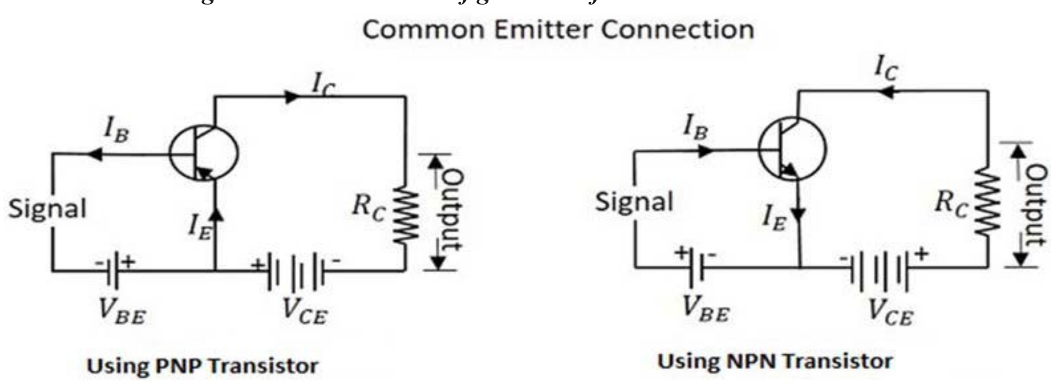


Fig: Common emitter configuration of NPN and PNP transistors



In this configuration, emitter and base are taken as input terminals whereas emitter and collector are taken as output terminals.

Common Collector Configuration

The arrangement in which the collector of a BJT is made common to both emitter and base is known as collector configuration.

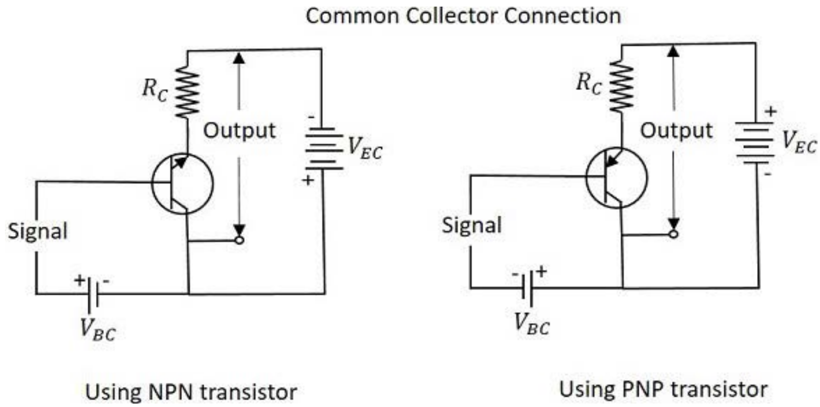


Fig: Common collector configuration of NPN and PNP transistors

Note: Common emitter configuration is the mostly used configuration of a BJT.

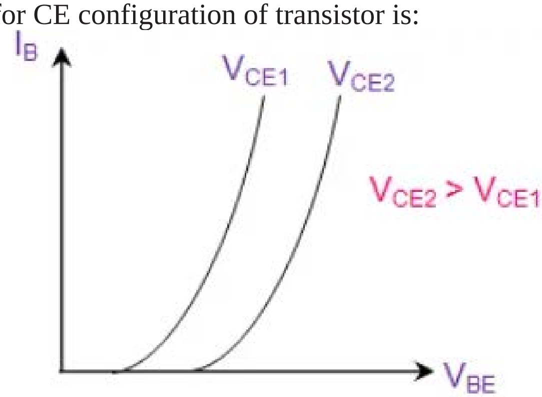
5.5 Characteristics of BJT (input, output and transfer)

Transistor characteristics are the depicted in the grap which represents the relationships between a transistor current and voltage in a specific arrangement. A BJT has three key characteristics which are:

1. Input characteristics (Base-Emitter junction)
2. Output characteristics (Collector-Emitter)
3. Transfer characteristics (Current gain)

Input Characteristics

Input characteristics defines the relationship between the input voltage (V_{BE}) and input current (I_B) while keeping the collector-emitter voltage (V_{CE}) constant. The input junction (Base-Emitter) behaves like a forward-biased diode. The input resistance is low because a small change in input voltage causes a significant change in input current. The graph for input characteristics for CE configuration of transistor is:



Output Characteristics

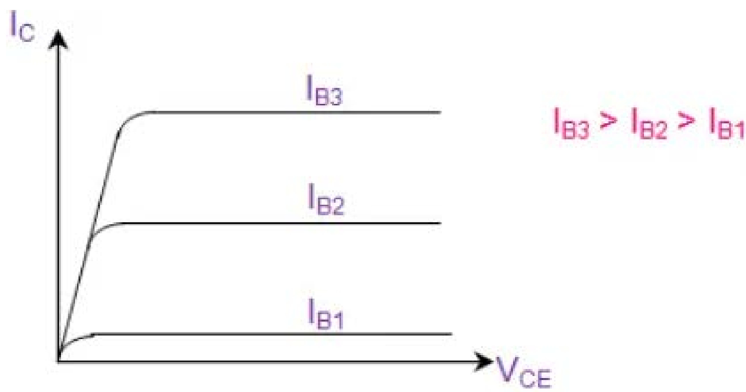
Output characteristic of transistor shows the relationship between output voltage (V_{CE}) and output current (I_C) for different values of base current (I_B). The curve consists of three regions:

i) Cutoff Regions: Transistor is in OFF condition.

ii) Active Region: Used for amplification

iii) Saturation Region: Transistor is fully ON.

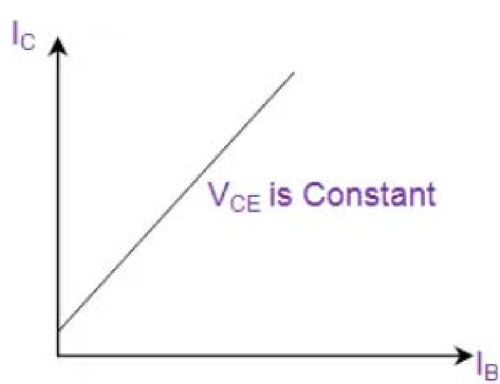
The output resistance is high because output current changes slightly with change in output voltage.



Transfer Characteristics

Transfer characteristic of transistor shows the relationship between the input current (I_B) and output current (I_C). The slope of this curve gives current gain of the transistor. i.e.

This characteristic of transistor is used to analyze the transistor's amplification capability.



Similarly, these characteristic of transistor can be obtained for Common Base (CB) and

Common Collector configuration of transistor.

Input

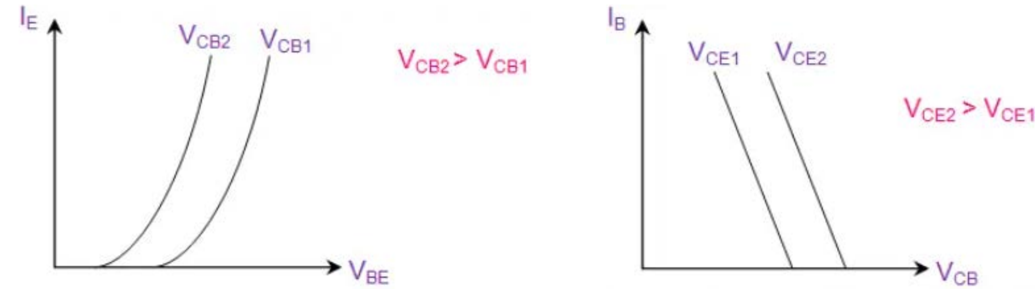


Fig: Input characteristic of BJT for CB and CC configuration respectively

Output

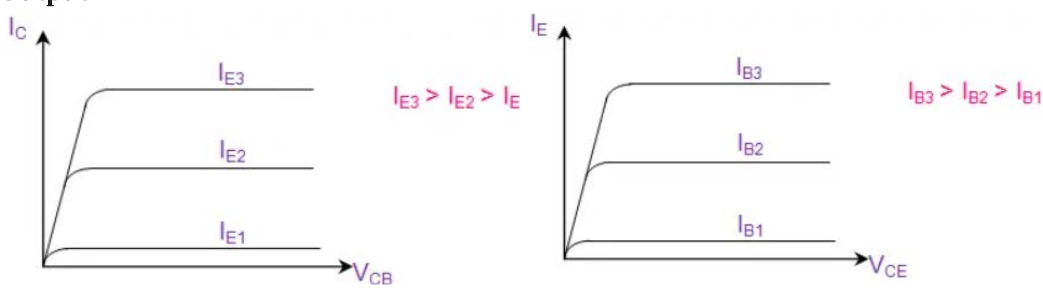


Fig: Output characteristic of BJT for CB and CC configuration respectively

cc

Transfer

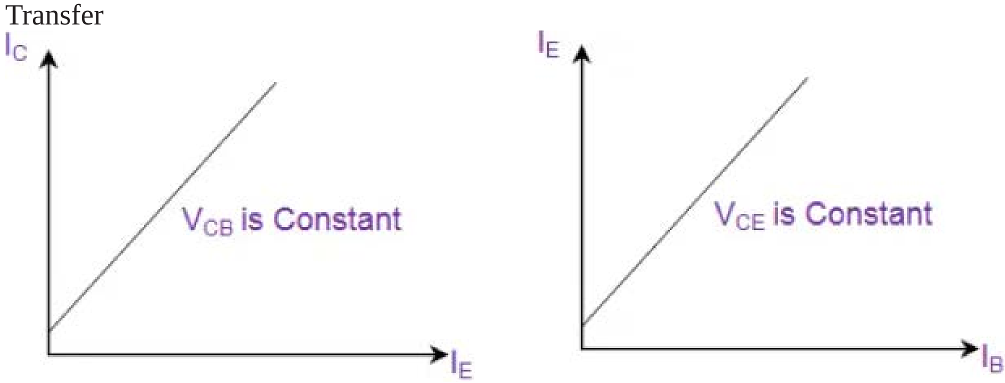


Fig: Transfer characteristic of BJT for CB and CC configuration respectively

5.6 Applications of BJT

1) It can be used as an electric switch.
2) It can be used as an amplifier.
3) It can be used to make digital circuits.

4) It is used in power supply circuits for voltage stabilization.

5) It is used in medical devices like ECG to amplify heart signals.

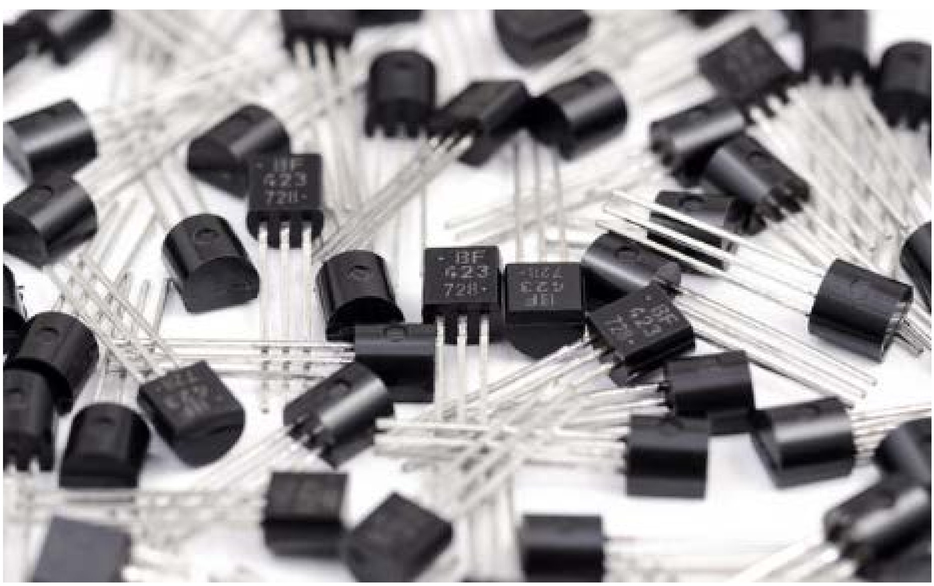
6) It is used in modulation circuits for radio communication.

7) It is used in automation, robotics and process control system.

5.7 Demonstration of Various Types of Transistors, Transistor Rating and Interpretation of Transistor Data Sheet

Transistor is a basic block of modern electronic system. They find its application in various fields. They come in different shape and rating.

BJT datasheet provides electrical, thermal, and mechanical specifications essential for selecting and designing circuit. This datasheet is vital in selecting right transistor based on the voltage, current, gain, speed and thermal limits for applications like amplification, switching and signal processing.



Absolute Maximum Ratings

Stresses exceeding the absolute maximum ratings may damage the device. The device may not function or be operable above the recommended operating conditions and stressing the parts to these levels is not recommended. In addition, extended exposure to stresses above the recommended operating conditions may affect device reliability. The absolute maximum ratings are stress ratings only. Values are at T_A = 25°C unless otherwise noted.

Symbol	Parameter		Value	Unit
V_{CBO}	Collector-Base Voltage	BC546	80	V
		BC547 / BC550	50	
		BC548 / BC549	30	
V_{CEO}	Collector-Emitter Voltage	BC546	65	V
		BC547 / BC550	45	
		BC548 / BC549	30	
V_{EBO}	Emitter-Base Voltage	BC546 / BC547	6	V
		BC548 / BC549 / BC550	5	
I_C	Collector Current (DC)		100	mA
P_C	Collector Power Dissipation		500	mW
T_J	Junction Temperature		150	°C
T_{STG}	Storage Temperature Range		-65 to +150	°C

€

Electrical Characteristics

Values are at T_A = 25°C unless otherwise noted.

Symbol	Parameter		Conditions	Min.	Typ.	Max.	Unit
I_{CBO}	Collector Cut-Off Current		V_{CB} = 30 V, I_E = 0			15	nA
h_{FE}	DC Current Gain		V_{CE} = 5 V, I_C = 2 mA	110		800	
V_{CE}(sat)	Collector-Emitter Saturation Voltage		I_C = 10 mA, I_B = 0.5 mA		90	250	mV
			I_C = 100 mA, I_B = 5 mA		250	600	
V_{BE}(sat)	Base-Emitter Saturation Voltage		I_C = 10 mA, I_B = 0.5 mA		700		mV
			I_C = 100 mA, I_B = 5 mA		900		
V_{BE}(on)	Base-Emitter On Voltage		V_{CE} = 5 V, I_C = 2 mA	580	660	700	mV
			V_{CE} = 5 V, I_C = 10 mA			720	
f_T	Current Gain Bandwidth Product		V_{CE} = 5 V, I_C = 10 mA, f = 100 MHz		300		MHz
C_{ob}	Output Capacitance		V_{CB} = 10 V, I_E = 0, f = 1 MHz		3.5	6.0	pF
C_{ib}	Input Capacitance		V_{EB} = 0.5 V, I_C = 0, f = 1 MHz		9		pF
NF	Noise Figure	BC546 / BC547 / BC548	V_{CE} = 5 V, I_C = 200 µA, f = 1 kHz, R_G = 2 kΩ		2.0	10.0	dB
		BC549 / BC550			1.2	4.0	
		BC549	V_{CE} = 5 V, I_C = 200 µA, R_G = 2 kΩ, f = 30 to 15000 MHz		1.4	4.0	
		BC550			1.4	3.0	

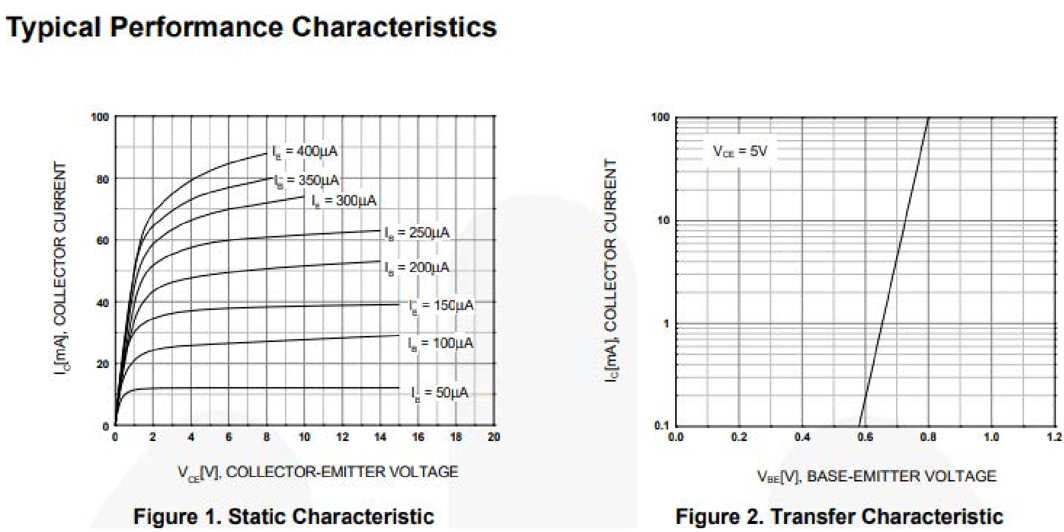


Fig: Data sheet for BC546, BC547,BC548, BC549, BC550 NPN transistor

5.8 Photo Transistor, Characteristics and Application

A photo transistor is a light-sensitive transistor that works like a BJT but with a light-controlled base current instead of an electrical signal. When light falls on the junction, reverse current flows which are proportional to the luminance. It provides large amount of gain. It works in a similar way to photo resistor commonly called LDR (Light Dependent Resistor) but are able to produce both current and voltage. It is used in optical sensing applications like IR detectors, light sensors, and optoelectronic switches.

Characteristics

1) It has two terminals emitter and collector. The base terminal is physically not available since it is light controlled device.
2) The collector is maintained at a higher voltage than emitter to make Base-Collector junction reverse and Base-Emitter junction forward bias.
3) Under no light conditions, there is a flow leakage current called dark current which depends on the temperature.
4) Because of presence of large base and collector region, the Base-Collector junction capacitance is large which affects the switching speed.
5) It has two operation modes i.e. active and switch mode. In active mode, it operates as an amplifier depending on light intensity whereas in switch mode, it has “ON” & “OFF” state.

Application

1) It is used in pulse oximeter for measuring blood oxygen levels.

2) It is used in fitness devices and smart watches.

3) It is used in industrial and security systems like security alarm system.

4) It is used for position sensing in robotics and used in TV remote receivers.

Exercise

Choose the correct answer from the given alternatives.

1. In a common emitter transistor, the current gain β equals to ………., where Ib, Ic, Ie have their usual meanings.

   a. Ib/Ic b. Ie/Ic c. Ic/Ib d. Ic/Ie

2. In a transistor, the ………………. Is moderately doped and largest in size.

   a. Emitter b. Base c. Junction d. Collector

3. In a transistor the ……….. is of moderate size and heavily doped.

   a. Emitter b. Junction c. Base d. Collector

4. When the transistor is used in the cut-off or saturation state, it acts as?

   a. An amplifier b. Zener diode c. A switch d. An AND gate

5. When a transistor is used in common emitter configuration, the …………………

   a. Output is between the base and the emitter

   b. Input is between the base and the emitter

   c. Input is between the collector and the emitter

   d. Output is between the base and the collector

6. In order to use the transistor as an amplifier, it has to operate in the ……………….. region.

   a. Switched region b. Cutoff region

   c. Active region d. Saturation region

7. The emitter of a transistor is ……… doped.

   a. Of moderate size and lightly b. Of moderate size and heavily

   c. Very thin and heavily d. Very thin and lightly

8. A heat sink is generally used with a transistor to …………………

   a. Increase the forward current b. Decrease the forward current

   c. Compensate for excessive doping d. Prevent excessive temperature rise

9. A transistor can be made to operate as a switch by operating it in which of the following regions?

   a. Active region b. Active region, cut-off region

c. Active region, saturation region d. Saturation region, cut-off region

10. Which of the following BJT configuration has highest power gain?

a. Common collector b. Common emitter

c. Common base d. None of these

11. The early effect in BJT is related to ……………………

a. Base narrowing b. Avalanche breakdown

c. Zener breakdown d. Thermal runaway

12. In how many regions can the biased transistor work?

a. Four b. Two c. Three d. Five

Write short answer to the following questions.

1. Explain different configurations of a BJT with proper circuit diagram.
2. Elaborate the construction and working of a NPN transistor with neat diagram.
3. What are the input, output and transfer characteristics of a BJT for common emitter configuration? Explain with suitable graphs.
4. Why BJT is called Bi-polar transistor? Mention the applications of BJT. Also draw the symbols of BJT.
5. What is photo transistor? List out its applicationS.
6. How does a BJT works as switch and amplifier. Explain with suitable circuit.

Write long answer to the following questions.

1. Define transistor. Classify various type of transistor and explain them in short.
2. Describe different configurations of a BJT with neat circuit diagram.

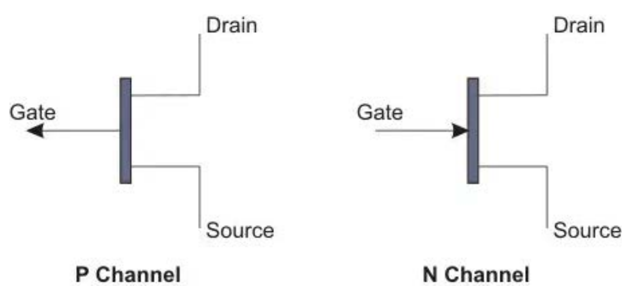
Project work

1. Identify the transistor's terminals by using datasheet and multimeter.
2. Demonstrate BJT works as a switch.
3. Plotting of input and output characteristics of a BJT in CE configuration.
4. Fabricate BJT circuit in a mtrix board.
5. Fabricate basic circuit using transistor like automatic street light controller, alarm circuit, clap switch.

Unit 6 Field Effect Transistors

6.1 Introduce Field Effect Transistor (FET)

Field Effect Transistor is one of the types of transistor and it is considered as unipolar device meaning that current conduction takes place only due to one type of carrier either electron or holes. FET is a voltage controlled device. This means output characteristics of FET are controlled by the input voltage and not by the input current. It has three terminals: Source (S), Gate (G) and Drain (D). The FET can be categorized into two types and they are: Junction Field Effect Transistor (JFET) and Metal Oxide Field Effect Transistor (MOSFET).



Symbol of Field Effect Transistor (FET)

Classification of FET

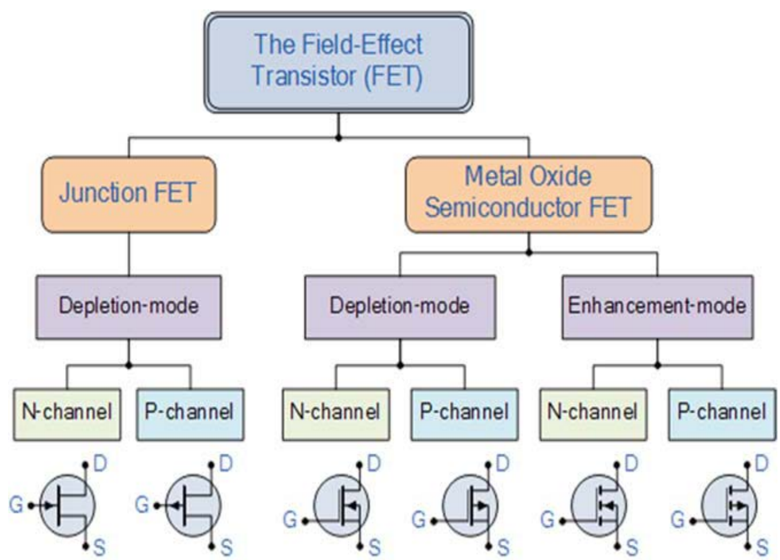


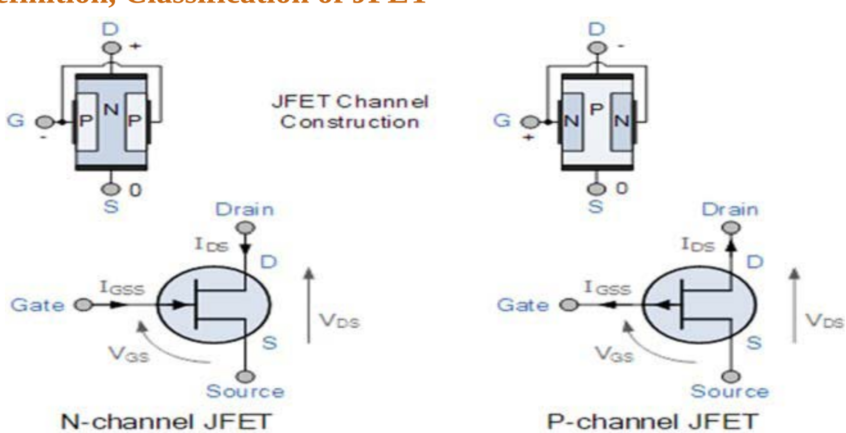
Fig: Classification of FET

1. **Junction Field Effect Transistor (JFET)**
   a. N-channel JFET
   b. P-channel JFET
2. **Metal Oxide Semiconductor Field Effect Transistor (MOSFET)**
   a. Depletion Metal Oxide Semiconductor Field Effect Transistor (DMOSFET)
      a. N-channel DMOSFET
      b. P-channel DMOSFET
3. **Enhancement Metal Oxide Semiconductor Field Effect Transistor (E-MOSFET)**
   a. N-channel EMOSFET
   b. P-channel EMOSFET

Fig: FET

6.2 Introduce Junction Field Effect Transistor (JFET)

6.2.1 Definition, Classification of JFET



A Junction Field Effect Transistor (JFET) is unipolar semiconductor device whose conduction is controlled through voltage. It has very high input impedance. It was first introduced by Shockley in 1952. It is a three terminal semiconductor device. The terminals are Gate (G), Drain (D) and Source (S). The gate is a terminal that regulates the flow of charge carriers. The source is a terminal through which charge carriers enter the semiconductor. The drain is a terminal through which the charge carriers leave the semiconductor.

Classification of JFET

There are mainly two types of the JFET based on the semiconductor used in the channel. They are:

i) N – Channel JFET

ii) P – Channel JFET

N – Channel JFET

It consists of an N-type semiconductor bar with two heavily doped P-type regions on the opposite sides of its middle part. The P-type regions form two PN junctions. The space between the two junctions is known as a channel. Both the P-type regions are connected internally and a single wire is taken out in the form of a terminal known as the gate (G). The electrical connections made to the both ends of the N- type semiconductor are known as Drain and Source.

Whenever a voltage is applied across the drain and source terminals, a current flows through the N-channel. The current consists of only electrons.

P – Channel JFET

It consists of a P-type semiconductor bar with two heavily doped N-type regions on the opposite sides of its middle part. The N-type regions form two PN junctions. The space between the two junctions is known as a channel. Both the N-type regions are connected internally and a single wire is taken out in the form of a terminal known as the gate (G). The electrical connections made to the both ends of the P- type semiconductor are known as Drain and Source.

Whenever a voltage is applied across the drain and source terminals, a current flows through the P-channel. The current consists of only holes.

6.2.2 Regions, Structure, Symbol of JFET

In an N-channel JFET, the arrow points towards the N-channel.

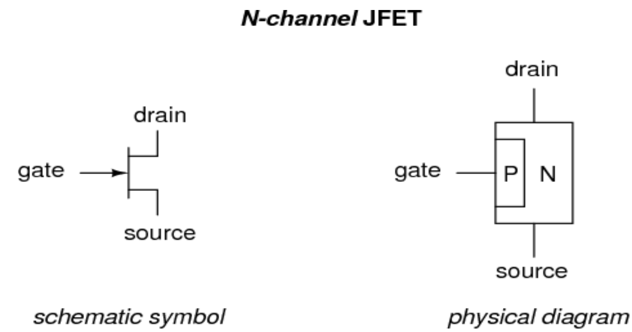
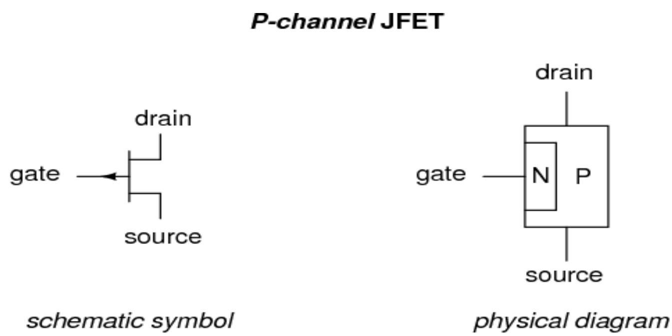


Fig: Symbol & structure of N-channel JFET

In a P-channel JFET, the arrow points away from the P-channel.



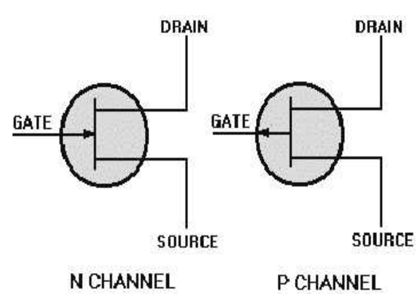
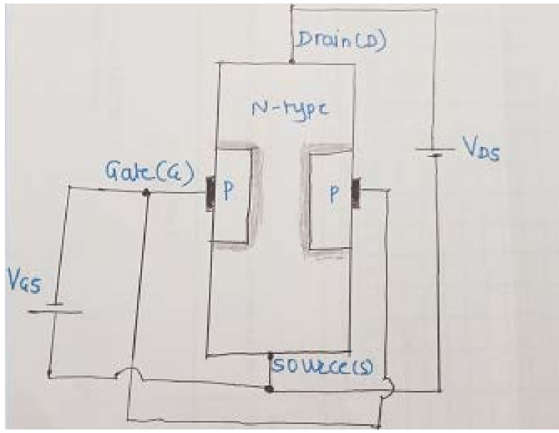


Fig: Symbol & structure of P-channel JFET

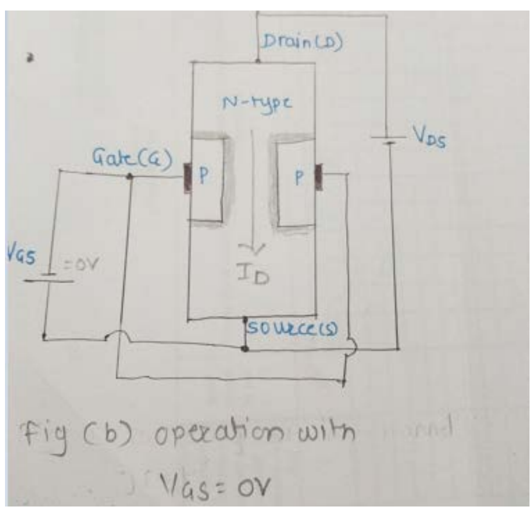
6.2.3 Basic working principle of N- channel and P-channel JFET:

- Following fig. (a) shows biasing condition for working of N-channel JFET
- In above figure battery source voltage VGG is applied between gate to source to make P-N junction reverse bias.
- A positive voltage is applied between drain and source terminal.
- We can consider following condition to observe working of N-channel JFET



A) When VGS =0v

- Following fig(b) shows the N-channel JFET when no bias is applied between gate and source
- When VGS=0v and external voltage VDSis applied between drain and source, the electrons flows from source to drain through the narrow channel.
- This constitute the drain current (ID) and its conventional direction is indicated from drain to source

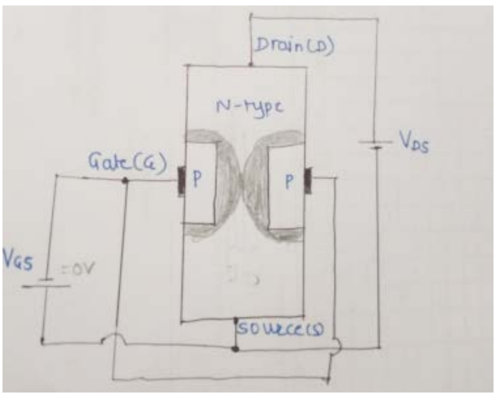


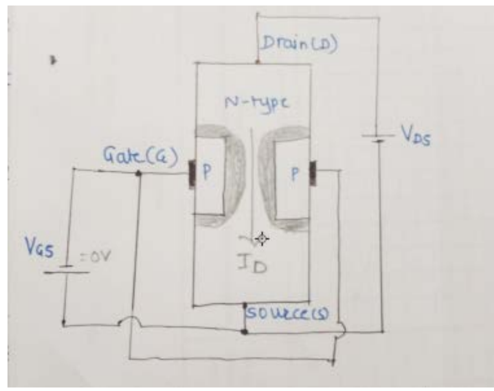
B) When VGS, Increased

- Following fig (c) shows the biasing of N channel JFET when VGS has some finite value
- VGS is applied to make junction between gate to source reverse.
- When this reverse bias voltage VGS is increased the depletion region becomes

more wide. This reduces the effective width of the channel and therefore controls the flow of current through channel.

- When gate to source voltage increased further a stage is reached at which two depletion region touch each other as shown in fig (d).
- At this stage the channel is completely blocked or pinch off and drain current reduced to zero
- The gate to source voltage at which the drain current is zero is called as pinch off voltage (VP).





Note: Similarly, the working principle of P-channel FET is similar to the working principle of N-channel FET.

6.2.4 Application of JFET:

1. It can be used as a low noise amplifier.
2. It can be used as a switch in ADC/DAC circuits.
3. It can be used as a Voltage Variable Resistor (VVR).
4. It can be used as phase shift oscillator.
5. It can be used in the high input impedance amplifiers.
6. A chopper is employed by using the JFET.

6.3 Metal Oxide Semiconductor Field Effect Transistor (MOSFET)

6.3.1 Defination, Classification of MOSFET

It is an abbreviation of Metal Oxide Semiconductor Field Effect Transistor. Like JFET, it has a source, drain and gate. However, unlike JFET, the gate of a MOSFET is insulated from the channel. So, MOSFET is also called IGFET which stands for Insulated Gate Field Effect Transistor.

The IGFET or MOSFET is a voltage controlled field effect transistor that has a "Metal Oxide" Gate electrode which is electrically insulated from the main semiconductor n-channel or p-channel by a very thin layer of insulating material usually silicon dioxide, commonly known as glass.

Classification of MOSFET

There are mainly two types of MOSFET based on mode of operation. They are:

i) Depletion type Oxide Semiconductor Field Effect Transistor (D-MOSFET)

ii) Enhancement type Metal Oxide Semiconductor Field Effect Transistor (E-MOSFET)

Similarly, on the basis of type of channel used, the MOSFET is classified into two catagories which are:

i) P-Channel MOSFET

ii) N-Channel MOSFET

6.3.2 Regions, structure, symbol of MOSFET

The regions, structure of the MOSFET is given below:

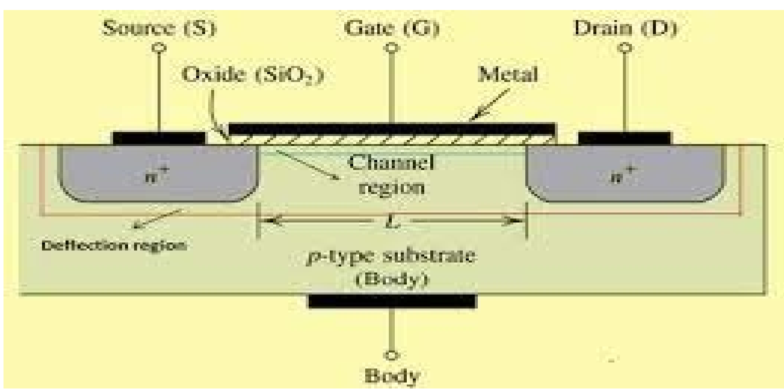
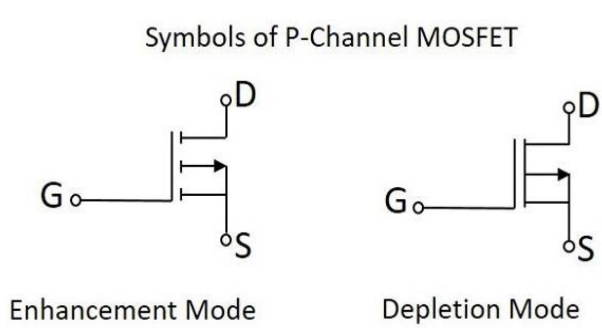


Fig: Construction of MOSFET



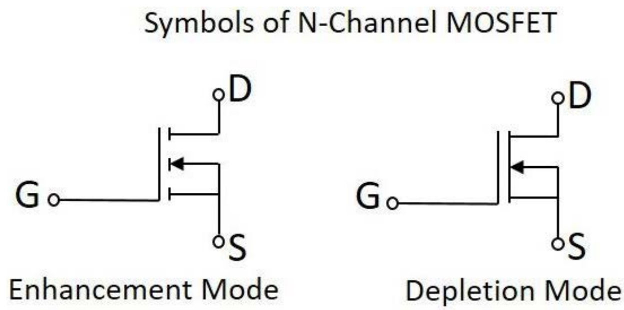
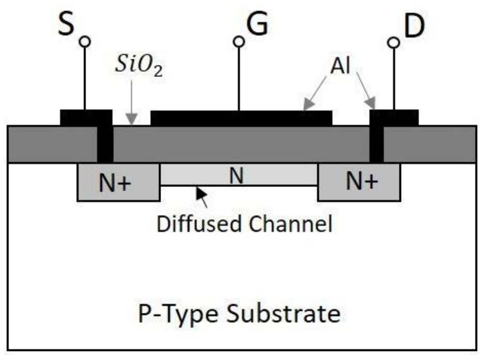


Fig: Symbol of MOSFETs



Structure of N-channel MOSFET

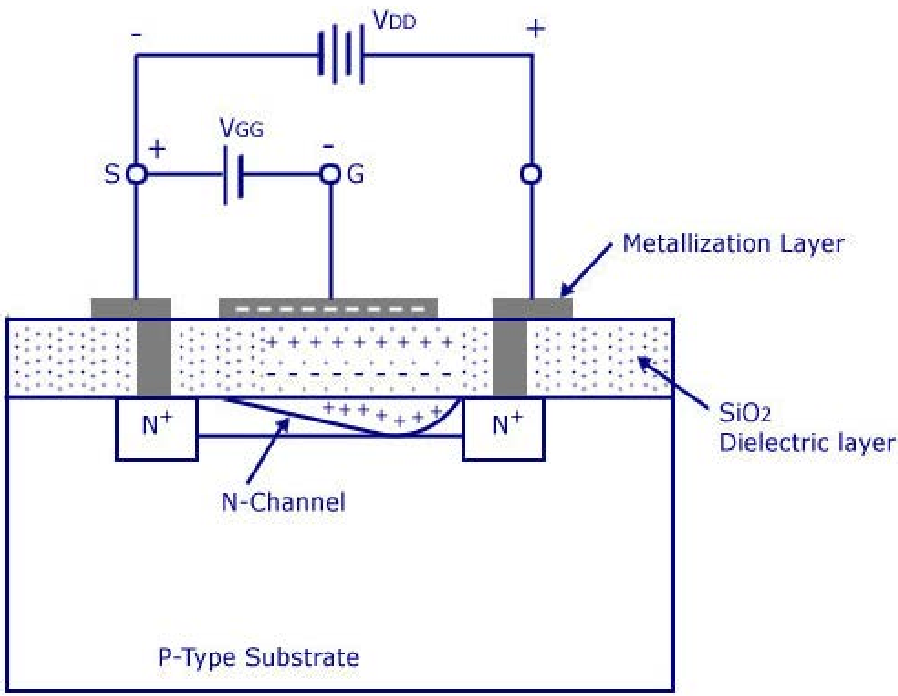
Construction of N-Channel MOSFET

N- Channel MOSFET is formed in a lightly doped P-type substrate or body with two heavily doped N type semiconductors by diffusing, which act as source and drain. A thin layer of Silicon dioxide (SiO2) is grown over the entire surface and holes are made and attached the metal contact or ohmic contact for drain and source terminals. Similarly a metal contact is placed upon the oxide layer to form the gate terminal as shown in figure. The P type substrate is connected to the common or ground or internally connected to the source terminal.

The main difference between the Depletion mode N channel MOSFEST and Enhancement mode N channel MOSFET is the presence of the N channel between drain and source, that i.e. N channel is present in depletion mode and absent in enhancement mode

6.3.3 Basic Working Principle of N-channel Depletion Mode MOSFET

In N channel DEMOSFET the negative voltage is applied between gate and source and positive voltage is applied between drain and source as shown in figure. The working of this MOSFET can be explained in different cases as follow:



Depletion Mode Operation

Case 1 When V_{GS} = 0 and V_{DS} is supplied with +ve voltage,

Since in DEMOSFET, there is the presence of diffused N channel hence even VGS = 0 , there will flow of drain current ID from drain to source. Because of this, DEMOSFET is said to be "Normally Closed" switch or Normally ON MOSFET.

Case 2 when VGS is supplied with –ve voltage

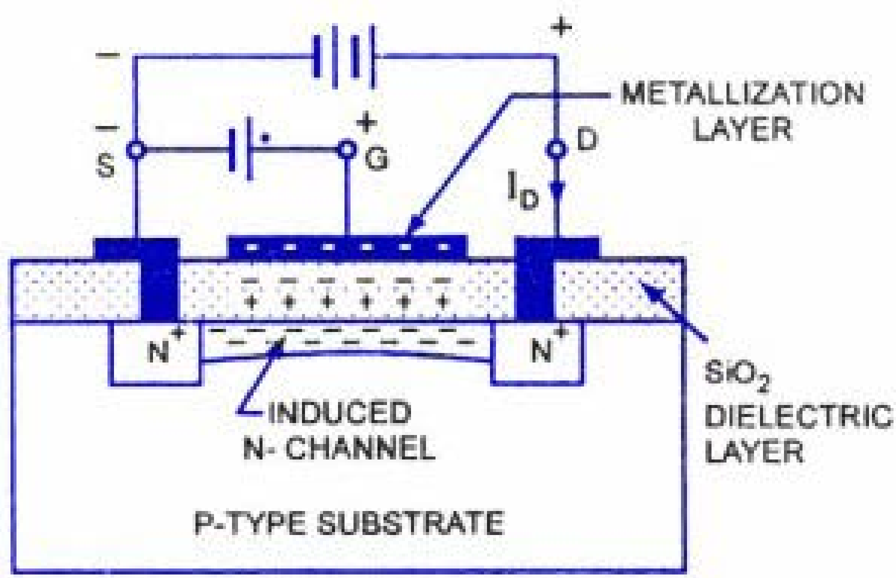
Electrons of diffused N channel are depleted towards substrate and holes are attracted towards SiO2 layer below gate terminal. As a result number of electrons are reduced hence the drain current ID also reduces.

Case 3 When VGS with more –ve voltage

Large number of electrons are depleted towards substrate along with the narrowing the diffused N channel layer. If VGS is further increased, a stage is reached which stops or blocks the flow of current ID. At this condition MOSFET is said to be in OFF condition.

Working of N-Channel MOSFET Enhancement Mode

In N channel E-MOSFET the positive voltage is applied between both gate and source and between drain and source as shown in figure. The working of this MOSFET can be explained in different cases as follow:



Operation of N-Channel E-MOSFET

Case 1 When V_{GS} = 0 and V_{DS} is supplied with +ve voltage,

Since there is no diffused N channel is present in this MOSFET , hence there is no current flow between drain and source even VDS is applied. Because of this the MOSFET is said to be normally open switch or normally OFF MOSFET.

Case 2 when VGS is supplied with +ve voltage

Minority charge carrier electrons of the substrate are attracted towards the SiO_2 layer below gate terminal. Due to presence of oxide layer electrons could not passes through the gate terminal. If VGS is further increased the more number of electrons are accumulated toward oxide layer which enhances the N channel between the drain and source. After this N channel is induced and drain current ID starts to flow from drain to source.

The voltage VGS at which current just start to flow is called threshold voltage. Hence EMOSFET to be ON the voltage VGS should be greater than the threshold voltage.

Case 3 when VGS is supplied with more +ve voltage

More number of electrons are accumulated in induced N channel along with the increased in drain current ID. Thus drain current is controlled by the gate potential. Since the conductivity of the channel is enhanced by the positive bias on the gate so this device is also called the enhancement MOSFET or E- MOSFET.

6.3.4 Applications of MOSFET

1. It can be used as a switching device in inverters, choppers etc.
2. It can be used as an amplifier.
3. It can be used in linear voltage regulators.
4. It is used in various digital circuits.
5. It is used in electronic DC relays, brushless DC motor drives.

Note: Differences between MOSFET and BJT is given below:

MOSFET	BJT
1) They are mainly of two types named as: N-Channel and P-Channel MOSFET.	1) They are also of mainly two types that are named as: NPN and PNP Transistor.
2) MOSFET uses only electrons as a charge carriers.	2) BJT uses both electrons and holes as charge carriers.
3) It has high input resistance.	3) It has low input resistance.
4) It is a four-terminal voltage controlled device.	4) It is a three-terminal current controlled device.
5) It is used in high-current applications.	5) It is used in low-current applications.

Exercise

Choose the correct answer from the given alternatives.

1. FETs are ………………..

   a. Unipolar devices b. Bipolar devices
   c. Both (a) and (b) d. None of these

2. How many terminals are there in a field effect transistor?

   a. 3 b. 2 c. 1 d. 4

3. In a metal oxide semiconductor FET, the metal oxide layer acts as a/an …………

   a. Electric field b. Capacitor c. Dielectric d. Gate

4. For n-JFET, the channel is a/an ……………. Channel and gates are ……………….

   a. N type, P type b. P type, P type c. N type, N type d. P type, N type

5. FET is a ……………….. controlled device.

   a. Current b. Resistance c. Impedance d. Voltage

6. Which of the following is NOT true for JFET?

   a. Drain current is controlled by changing the channel width.
   b. Gate-source p-n junction is always forward biased.
   c. JFET is a voltage-controlled three terminal device.
   d. Gate-source p-n junction is always reverse biased.

7. Which of the following terminals does not belong to the MOSFET?

   a. Drain b. Gate c. Base d. Source

8. The arrow on the symbol of MOSFET indicates ………

   a. That it is a N-channel MOSFET
   b. The direction of electrons
   c. The direction of conventional current flow
   d. That it is a P-channel MOSFET

9. The controlling parameter in MOSFET is ….

   a. Vds b. Ig c. VGS d. IS

10. Choose the correct statement.

a. MOSFET is a unipolar, voltage controlled, two terminal device

b. MOSFET is a bipolar, current controlled, three terminal device

c. MOSFET is a unipolar, voltage controlled, three terminal device

d. MOSFET is a bipolar, current controlled, two terminal device

Write short answer to the following questions.

1. Explain the basic working principle of an N-channel JFET.
2. What are the differences between the MOSFET and JFET?
3. What are the different regions of operation of a MOSFET? Explain briefly.
4. List out five applications of MOSFET and JFET.
5. How does the gate voltage control the current in a JFET?
6. Differentiate between BJT and MOSFET.

Write long answer to the following questions.

1. Define MOSFET. Explain the structure and working of an N-channel MOSFET. List out any two application of MOSFET.
2. Why does E-MOSFET is preferred over BJT in high-speed switching applications? Compare depletion-mode and enhancement-mode MOSFETs with respect to their characteristics.

Project Work

1. Identify the various terminals of a FET.
2. Demonstrate FET as a switch.

Logic Gates

Unit 7

7.1 Introduction to Digital System

A digital system is a system that processes and stores the information in a digital (binary) form using only two states i.e. o (OFF) and 1 (ON). These systems are the foundation of modern technology, including computers, smartphones, calculators and digital watches. Unlike analog systems, which operate on continuous signals, digital systems work with finite, distinct values, making them more robust to noise and easier to design and manipulate. The basic components of a digital system are: Input devices, processing units, memory, output devices and communication Interfaces.

This digital system can provide high precision results and the digital data can be copied and transmitted without loss of quality unlike analog signals. Further, the digital systems are programmable allowing them to perform wide range of tasks through software instructions. Apart from these, the digital systems can be easily scaled to handle more complex tasks by adding components thus enhancing processing power.

7.2 Binary System

Binary Number System is one of the number system that uses either "0" or "1". It is the number system of the computer. It only consists of 2 digits. Here, BINARY means two. It is sometime called as base-2 number system, meaning it uses only two digits: 0 & 1. These digits are called bits (i.e. binary digits). Understanding the binary system is very essential because computers and digital devices process and store all data in binary form. For example, $(101)_2$, $(1111)_2$.

Unlike decimal number system, we can perform all operations like addition, subtraction, multiplication and division for binary number system. Also, we can convert the binary number to any other number and vice-versa.

Addition

Rule for binary addition

$0 + 0 = 0$

1 + 0 = 1

0 + 1 = 1

1 + 1 = 10 (0 with carry over 1)

For Example

i) 1011 + 1101 = 11000 **ii) 11011 + 111 = 100010**

Subtraction:

Rule for binary subtraction

0 – 0 = 0

0 – 1 = 1 (with borrowing 1)

1 – 0 = 1

1 – 1 = 0

For Example

i) 1111 – 1001 = 0110 **ii) 11011 – 1101 = 0110**

Multiplication:

Rule for binary multiplication

0 * 0 = 0

0 * 1 = 0

1 * 0 = 0

1 * 1 = 1

For Example

i) 111* 101 = 100011 ii) 10110 * 1011 = 11110010

7.3 Boolean Algebra

Boolean algebra is one of the branch of the mathematics that deals with binary variables and logical operations. It is named after *George Boole*. It is a two-valued system of algebra that illustrates the logical relationships and operations. It is a system of mathematical logic used for operations in a binary system using three basic operations: OR, NOT and AND.

Boolean algebra is different from the ordinary algebra. Boolean algebra does not have any operations equivalent to division and subtraction. Ordinary algebra deals with the real number whereas the Boolean algebra deals with binary numbers only.

Apart from these, there is no coefficients or exponents involved in the Boolean expressions.

Truth Table

A table that represents the input-output relationship of the binary variables for each gate is termed as the truth table. This truth table depicts the proper relation between the inputs and outputs in tabular form. The size of table depends on the number of input variables. Hence, a truth table can be defined as the table representing the results of the logical operations on all possible combinations of logical values.

Example:

Inputs		**Output**
A	B	Y = (A . B)
0	0	0
0	1	0
1	0	0
1	1	1

7.4 Introduction to Logic Gates and their Types

Logic gates are the electronic components that perform logical operations on binary inputs and produces a single binary output. Logic gates are the primary building blocks of any digital system like computers, microcontrollers, digital watches, etc. It is an electronic circuit holding one or more than one input and only one output. A digital signal represents either a logic level "0" (LOW) or "1" (HIGH). Typically, a logic "0" is considered as zero voltage or ground and a logic "1" as a positive voltage like +5 Volts.

A logic gate can have one or more inputs but has only one output. This output depends on the types of the logic gate and the values of the inputs. The correlation between the input and the output is based on a certain logic. Various types of logic gates are embodied into Integrated Circuit (IC). Each gate has its specific function and graphical symbol. The function of the gate is expressed by means of an algebraic expression.

The logic gates can be classified as basic gate, Universal gate and special purpose gate.

All digital systems can be constructed by only three ***basic logic gates***. They are called basic because they can create any Boolean expression or function, forming the foundation for all other types of logic gates. This basic gates comprises following gates:

i) NOT Gate

ii) AND Gate

iii) OR Gate

Universal logic gates are the gates that can implement any Boolean function without the need to use any other gate types. There are 2 types of universal gates and they are:

i) NAND Gate

ii) NOR Gate

Special Purpose Gates

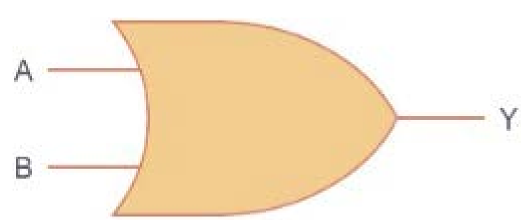
In addition to the basic logic gates and universal gates, there are special purpose logic gates designed for specific functions in digital circuits. These gates simplify complex operations and improve efficiency in digital systems. These gates sometime called as parity gates because they can be used to check or generate parity bits for error detection or correction. This type of gate includes following logic gates:

i) XOR Gate

ii) XNOR Gate

7.4.1 OR Gate

An OR gate functions as logical OR (Addition) operation. OR gate is an electronic circuit, which produces high (1) output when one of the input is high (1) and produces low (0) when all inputs are low (0). It can have two or more inputs and produces a single output. The logic gate symbol and the truth table for a two-input OR gate is presented below:

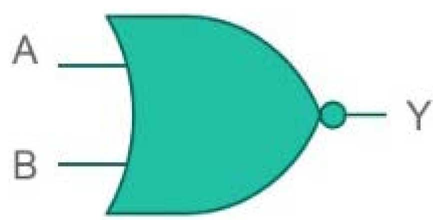


Logical symbol of OR gate

Inputs		Output
A	B	Y = A + B
0	0	0
0	1	1
1	0	1
1	1	1

7.4.2 NOR Gate

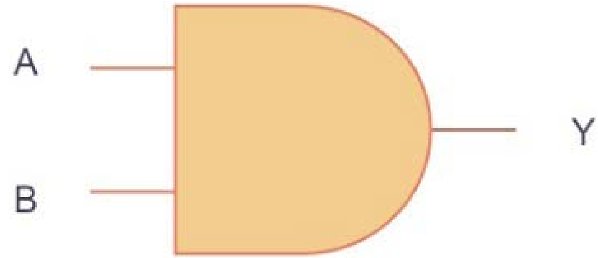
This is one of the universal gate which is the combination of an OR gate followed by a NOT gate. NOR gate symbolizes NOT+OR gate hence the output of this logical gate is exactly the converse of that of the OR gate. This electronic gate produces high “1” output when all inputs are low “0” otherwise, output will be low “0”. It is the complement of the OR gate. It has two or more inputs and produces a single output. The logical symbol and truth table for two-input NOR gate is presented below.



Inputs		Output
A	B	Y = (A + B)’
0	0	1
0	1	0
1	0	0
1	1	0

7.4.3 AND Gate

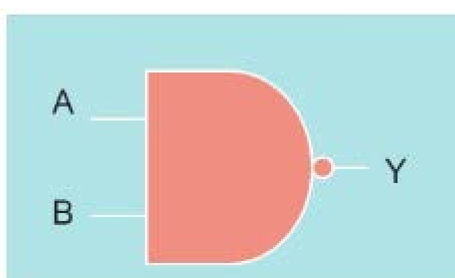
AND gate is an electronic circuit, which produces high “1” as output when all inputs are high “1” otherwise, the output will be low “0”. In other words, one can assume for a logic AND gate, any LOW input will provide a LOW output, and the output is only one if both inputs are a logic high i.e. “1”. This is one of the basic logic gate which implements logical conjunction. The logical symbol and truth table for a two-input AND gate is presented below.



Inputs		Output
A	B	Y = (A . B)
0	0	0
0	1	0
1	0	0
1	1	1

7.4.4 NAND Gate

NAND gate is one of the universal gate which is the combination of AND and NOT gate. It performs the logical negation of the AND gate operation. A NAND gate includes one or more inputs with a single output. This electronic gate produces low "0" output when all the inputs are high "1", otherwise the output will be high "1". It is the complement of AND gate. The logical symbol and the truth table for a two-input NAND gate are presented below.

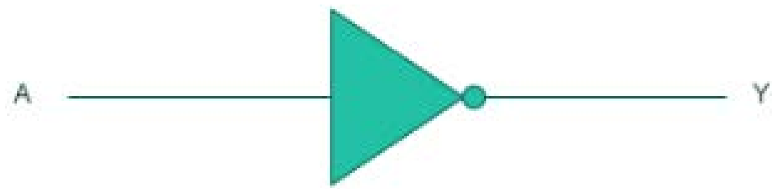


Inputs		**Output**
A	B	Y = (A . B)'
0	0	1

0	1	1
1	0	1
1	1	0

7.4.5 NOT Gate

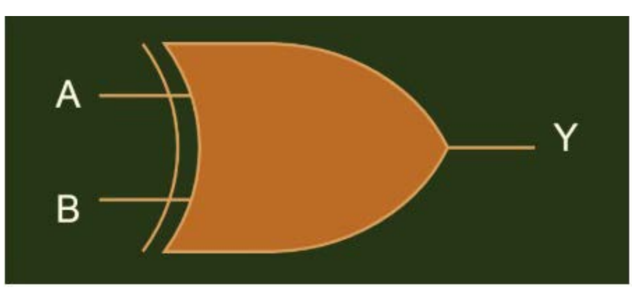
A NOT gate is a single input and single output electronic circuit. It is also called as an inverter. It is an electronic circuit whose output is the complement of the input. It implements logical negation on its single input i.e. if the input is high "1", then the output will be low "0" and if input is low "0", then the output will be high "1". The logical symbol and truth table for a NOT gate is presented below.



Input	Output
A	Y = A'
0	1
1	0

7.4.6 XOR Gate (Exclusive-OR / Ex-OR)

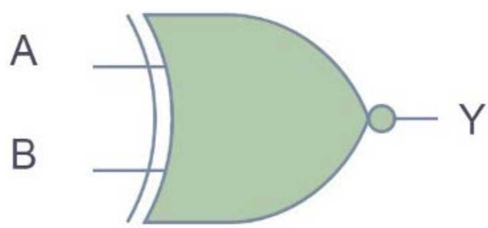
This is one the special purpose type of logic gates which can have two or more inputs but only one output. The XOR gate produces low output "0" when both inputs are same otherwise, the output will be high "1". The plus (+) sign within the circle is used as the Boolean expression of the XOR gate. The logical symbol and truth table for a two-input XOR gate is presented below.



Inputs		Output
A	B	Y = A B
0	0	0
0	1	1
1	0	1
1	1	0

7.4.7 XNOR (Exclusive-NOR / Ex-NOR)

The Ex-NOR gate is built by connecting the exclusive-OR gate and the NOT gate. It carries out the logical negation of the exclusive disjunction operation on its inputs. It can have two or more inputs and a single output. This gate produces high "1" output when all inputs are either low "0" or high "1". This means that both inputs should be equal for the output to be logic high "1". The dot (.) sign within the circle is used as the Boolean expression for the XNOR gate. The logical symbol and the truth table for a two-input XNOR gate is presented below.



Inputs		Output
A	B	Y = A B
0	0	1
0	1	0
1	0	0
1	1	1

Note:

NAND and NOR gate is regarded as the universal gate. Why?

- NAND and NOR gates are known as the universal gate, since it is possible to implement any logical expression using either NAND or NOR gate. NAND gates are sufficient to implement any Boolean expression.

- Similarly, only NOR gate are sufficient to implement any Boolean expression.
- The proper combination of either NAND gate or NOR gate can be used to perform each of the AND, OR, NOT operations.

This can be shown by following representation:

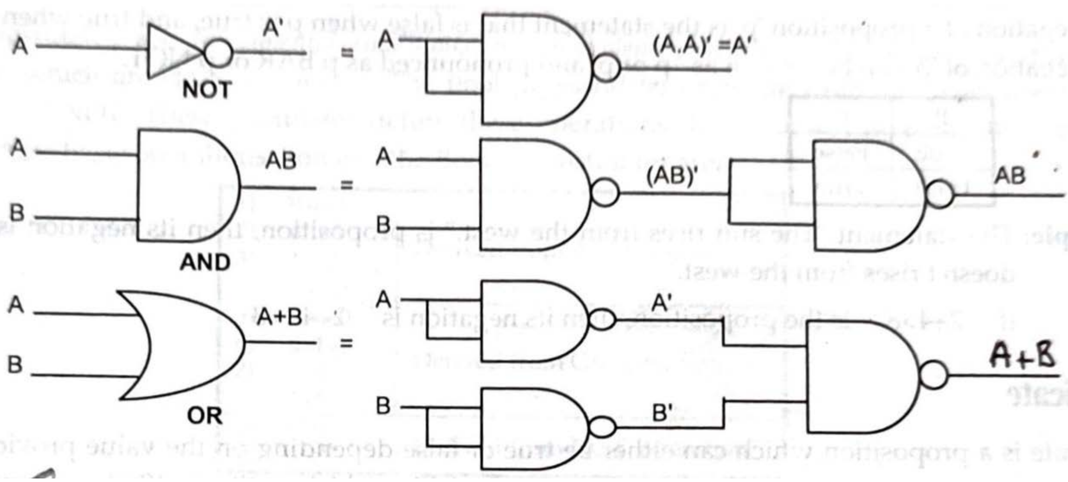


Figure: Universality of NAND gate

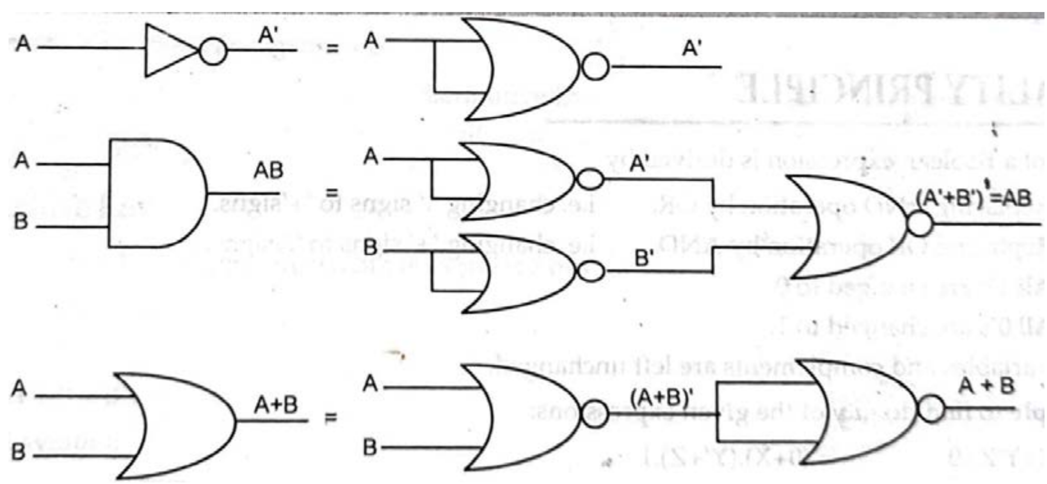


Figure: Universality of OR gate

7.5 Application of Logic Gates

There are numerous applications of logic gates in different fields of engineering and science. Some of them are:

i) Digital logic gates are used for design and implementation of various digital circuits like adders, multiplexers, registers, etc.

ii) Digital logic gates are used to design and implement different components of computer architecture like central processing units (CPU), memory hierarchy, etc.

iii) Digital logic gates are used to represent and manipulate logical expressions and data types in programming language like Java, C++, etc.

iv) Digital logic gates are used to implement various artificial intelligence techniques such as Fuzzy logic systems, neural networks, etc.

v) Digital logic gates are used to implement different error detection and correction techniques such as parity bits, cyclic redundancy checks (CRCs), etc.

Exercise

Choose the correct answer from the given alternatives.

1. What is the output if both inputs of a XNOR gate are at the opposite logic level?

   a. 1 b. 0 c. No output d. Either 1 or 0

2. Which among the following logic gates are known as universal gates?

   a. XOR, NAND, OR b. OR, NOT, XOR

   c. NOR, NAND, XNOR d. NOR, NAND

3. The output of a 2-input OR gate is zero only when its …….

   a. Either input is 0 b. Either input is 1

   c. Both inputs are 1 d. Both inputs are 0

4. What is the output of an AND gate if both inputs are 1?

   a. 0 b. 1

   c. Undefined d. Depends on the voltage

5. Which logic gates give an output of 1 when at least one input is 1?

   a. AND b. OR c. NOT d. XOR

6. What is the Boolean expression for an OR gate?

   a. A.B b. A + B c. A' d. A + B

7. How many inputs are required for a NOT gate?

   a. 0 b. 1 c. 2 d. 3

8. What is the output of an AND gate when both inputs are 1?

   a. 0 b. 1

   c. Undefined d. None of the above

9. A NOT gate is also known as ……

   a. Inverter b. Buffer c. Comperator d. Amplifier

10. How many entries will be there in the truth table of a 3 input NAND gate?

    a. 3 b. 6 c. 8 d. 9

Write short answer to the following questions.

1. Define logic gate. List out various types of logic gates and explain any two of them.
2. List out the Universal gates and explain them with proper logical symbol and truth table.
3. Perform the following operations:

   a. 11101 + 1101 = (?) b. 11111 + 10101 = (?)

   c. 11101 – 1111 = (?) d. 11111 – 11110 = (?)

   e. 10101 * 1011 = (?) f. 11111 * 1001 = (?)

Write long answer to the following questions.

1. Define logic gates. List out the universal logic gates. Why they are called as the universal gate? Explain with proper illustration.
2. Explain OR, AND, NAND, XOR gate with their truth table and logical symbols.

Project Work

1. Implement the various logic gates on the bread board using LEDs, resistor, switches, connecting wires and battery through proper circuitry diagram. And test output for various input conditions of these gates.

References

A text book of electrical engineering, B.L Thereja, A.K. Thereja

A course in utilization of electrical energy-G. Garg

http://www.electrical4u.com

http://www.electricaltechnology.org

A handbook of electrical engineering, S.L.Bhatia

Basics on electrical engineering, P.S.Dhogal

http://www.electricalbasicprojects.com

https://www.allaboutcircuits.com

http://www.electricaltechnology.org

A text book of electrical engineering, B.L Thereja, A.K. Thereja

A handbook of electrical engineering, S.L.Bhatia

Basics on electrical engineering, P.S.Dhogal

http://www.electricalbasicprojects.com

A textbook of electrical engineering, J.B.Gupta

A course in utilization of electrical energy-G. Garg

http://www.electrical4u.com

http://www.electricalbasicprojects.com

https://www.allaboutcircuits.com

http://www.electricaltechnology.org

A text book of electrical engineering, B.L Thereja, A.K. Thereja

A handbook of electrical engineering, S.L.Bhatia

A textbook of electrical engineering, J.B.Gupta