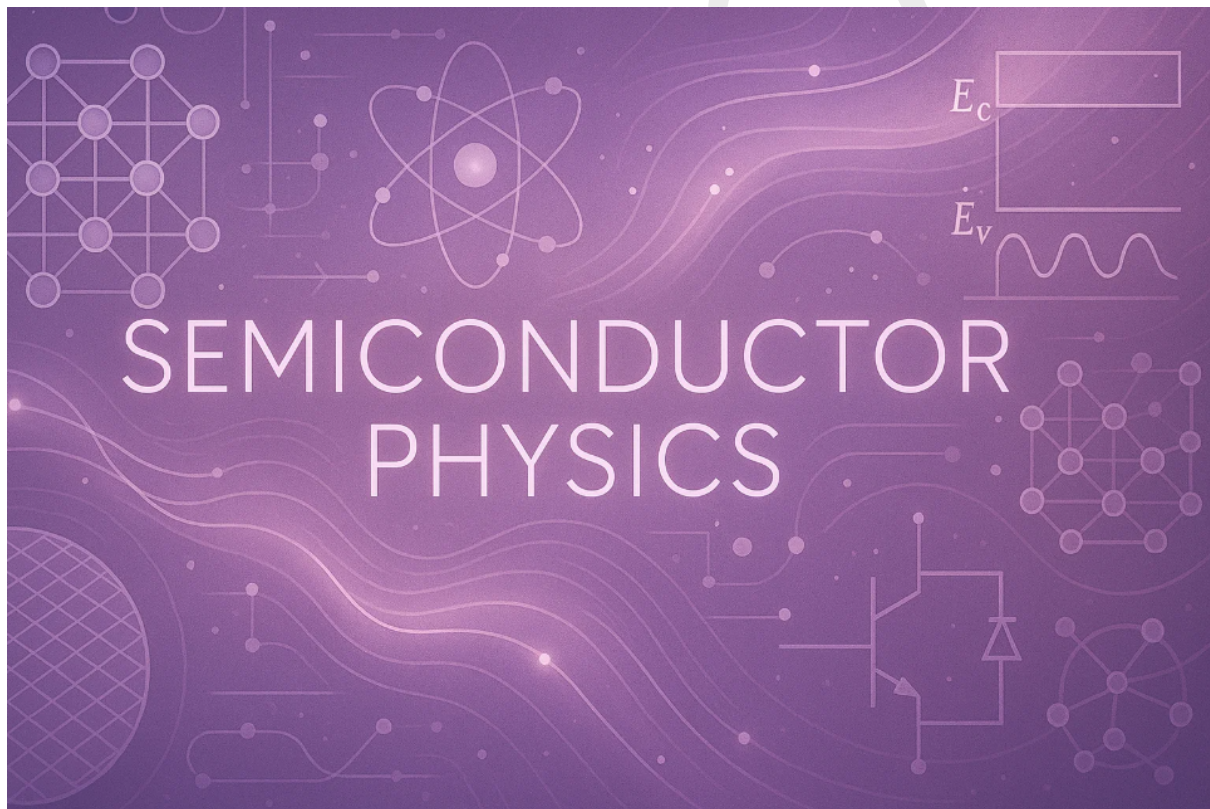


Semiconductor Physics (25SPH-143)

Compiled by : Subhayu





Course Content

Unit 1 : Semiconductor

Ch 1 : Semiconductors - Introduction to Semiconductors, Intrinsic and Extrinsic Semiconductors, Basic Structure of P-N Junction, P-N Junction as a diode, Forward and reverse biasing of P-N Junction diode, Volt-Ampere Characteristics of P-N Junction Diode, Avalanche Breakdown, Zener Breakdown, Zener diode, Volt-ampere Characteristics of Zener Diode, Applications of P-N Junction and Zener diode.

Ch 2 : Rectifier - Introduction to half wave rectifier, full wave rectifier with their construction and working principle, Analysis of Half wave and full wave rectifier, Applications of rectifier.

Unit 2 : Semiconductor Device Operation

Ch 3 : BJT & FET - Introduction to BJT: Formation of PNP / NPN junctions, Transistor Circuit Configuration: CB, CE, CC configuration, Operating regions of Transistor, injection efficiency, base transport factor and current amplification factors, Transistor as a switch and an Amplifier.

Ch 4 : Energy Storage Devices - Introduction to energy storage devices, Selecting Battery: Basic Battery Specifications, common parameters of battery/applications, Different types of Batteries used in different applications, Power Supplies: Linear and SMPS

Unit 3 : Electric Circuits

Ch 5 : Basic Circuit Theory - Introduction to Circuit Elements and its Types, Kirchhoff's Laws-KVL, KCL, Introduction to AC circuits, Study of AC circuits of series RL, RC circuit corresponding Voltage-current Phasor diagram and their relation.

Ch 6 : Transformer - Introduction to Single Phase Transformer, Working Principle and Construction, Transformation ratio, Losses and efficiency of Transformer.

Unit – 1

Semiconductor

Ch 1 : Semiconductors - Introduction to Semiconductors, Intrinsic and Extrinsic Semiconductors, Basic Structure of P-N Junction, P-N Junction as a diode, Forward and reverse biasing of P-N Junction diode, Volt-Ampere Characteristics of P-N Junction Diode, Avalanche Breakdown, Zener Breakdown, Zener diode, Volt-ampere Characteristics of Zener Diode, Applications of P-N Junction and Zener diode.

Ch 2 : Rectifier - Introduction to half wave rectifier, full wave rectifier with their construction and working principle, Analysis of Half wave and full wave rectifier, Applications of rectifier.

Chapter 1

Semiconductors

1.1 Introduction to Semiconductors

Semiconductors are materials whose electrical conductivity lies between that of conductors (like copper) and insulators (like glass). Their conductivity can be controlled by temperature, light, and the addition of impurities.

Key Point

Semiconductors form the backbone of modern electronics — used in devices such as diodes, transistors, solar cells, and integrated circuits.

Types of Materials Based on Conductivity

- **Conductors:** Have high conductivity due to a large number of free electrons.
- **Insulators:** Have very few free electrons, and thus, poor conductivity.
- **Semiconductors:** Have moderate conductivity, which increases with temperature.

Examples

- Common semiconductors: Silicon (Si), Germanium (Ge).
- Compound semiconductors: Gallium Arsenide (GaAs), Indium Phosphide (InP).

1.2 Intrinsic and Extrinsic Semiconductors

1.2.1 Intrinsic Semiconductors

An intrinsic semiconductor is a pure form of semiconductor material without any significant impurities. The number of free electrons is equal to the number of holes.



Important Note

In an intrinsic semiconductor, the concentration of electrons (n) equals the concentration of holes (p), i.e., $n = p = n_i$, where n_i is the intrinsic carrier concentration.

1.2.2 Extrinsic Semiconductors

When impurities are added to an intrinsic semiconductor in a controlled manner to change its conductivity, it becomes an **extrinsic semiconductor**. This process is called **doping**.

Types of Extrinsic Semiconductors

1. **N-type Semiconductor:** Doping with pentavalent impurities (e.g., Phosphorus, Arsenic) adds extra electrons.
2. **P-type Semiconductor:** Doping with trivalent impurities (e.g., Boron, Gallium) creates holes (positive charge carriers).

1.3 Basic Structure of P-N Junction

When a P-type and an N-type semiconductor are joined together, a **P-N junction** is formed. At the junction, electrons from the N-side and holes from the P-side combine, forming a **depletion region** devoid of charge carriers.

Depletion Region

The depletion region acts as an insulating barrier that prevents the flow of majority carriers across the junction.

1.4 P-N Junction as a Diode

A P-N junction diode is a two-terminal electronic device that allows current to flow in one direction only. It is the simplest semiconductor device.





1.5 Forward and Reverse Biasing of P-N Junction Diode

1.5.1 Forward Bias

In forward biasing, the P-side is connected to the positive terminal and the N-side to the negative terminal of a battery.

- The applied voltage reduces the potential barrier.
- The depletion width decreases.
- Current flows easily through the junction.

1.5.2 Reverse Bias

In reverse biasing, the P-side is connected to the negative terminal and the N-side to the positive terminal.

- The potential barrier increases.
- The depletion width widens.
- Only a small leakage current flows due to minority carriers.

Key Observation

Forward bias allows significant current flow, while reverse bias blocks it — hence, the diode acts as a **rectifier**.

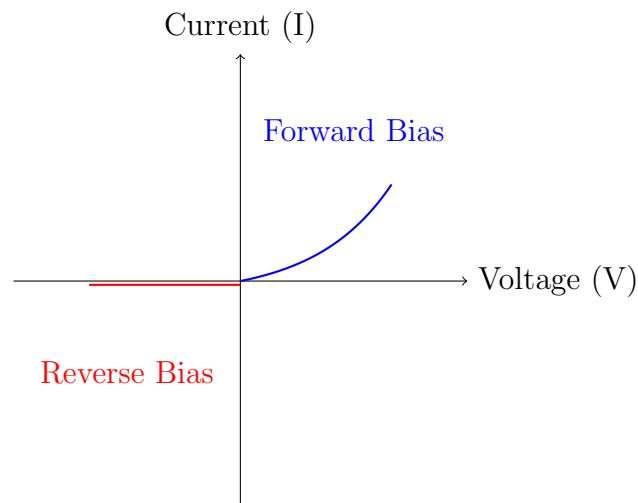
1.6 Volt-Ampere Characteristics of P-N Junction Diode

Forward Bias Characteristics

- Initially, the current is very small.
- After the **threshold voltage** (0.7V for Si, 0.3V for Ge), current increases rapidly.

Reverse Bias Characteristics

- Small reverse saturation current flows due to minority carriers.
- If reverse voltage increases beyond a certain limit, **breakdown** occurs.



1.7 Breakdown Mechanisms

1.7.1 Avalanche Breakdown

Occurs when reverse voltage is so high that free electrons gain enough kinetic energy to knock out other electrons, creating an avalanche of carriers.

1.7.2 Zener Breakdown

Occurs in heavily doped diodes at relatively low voltages due to strong electric fields causing electron tunneling.

Comparison

- **Avalanche breakdown:** occurs in lightly doped diodes, high voltage.
- **Zener breakdown:** occurs in heavily doped diodes, low voltage.

1.8 Zener Diode

A Zener diode is a special-purpose diode designed to operate in the reverse breakdown region without damage.

Characteristics of Zener Diode

- It conducts negligible current under reverse bias until breakdown voltage (V_Z) is reached.
- After V_Z , it maintains nearly constant voltage despite variations in current.



1.9 Applications of P-N Junction and Zener Diode

Applications of P-N Junction Diode

- **Rectifiers:** Convert AC to DC.
- **Signal Demodulation:** Used in radio receivers.
- **Clipping and Clamping Circuits:** Control waveform amplitudes.

Applications of Zener Diode

- **Voltage Regulator:** Maintains constant output voltage.
- **Overvoltage Protection:** Protects circuits from voltage spikes.

1.10 Solved Examples

Example 1

Question: Explain why the conductivity of a semiconductor increases with temperature.

Answer: As temperature increases, more covalent bonds in the semiconductor break, releasing free electrons and generating holes. Thus, the carrier concentration increases, enhancing conductivity.

Example 2

Question: The breakdown voltage of a Zener diode is 5.6V. If the input voltage varies between 7V and 12V, what is the output voltage across the load?

Answer: The Zener diode maintains a constant voltage of 5.6V once breakdown occurs. Hence, the **output voltage** remains fixed at **5.6V**, independent of input variations.

Example 3

Question: Why is a Zener diode always connected in reverse bias?

Answer: Because only in reverse bias does the Zener diode exhibit its voltage-regulating property in the breakdown region, maintaining a stable voltage across its terminals.



Summary

- Semiconductors are materials with controllable conductivity.
- P-N junction acts as a rectifier, allowing current in one direction.
- Breakdown occurs in reverse bias — avalanche or Zener type.
- Zener diode is used for voltage regulation and circuit protection.

Notefity

Chapter 2

Rectifier

2.1 Introduction to Rectifiers

A **rectifier** is an electronic circuit that converts **alternating current (AC)** into **direct current (DC)**. This process is known as **rectification**.

Key Idea

Rectifiers are the foundation of power supply circuits in almost all electronic devices — from phone chargers to computer power units.

There are two main types of rectifiers:

1. **Half-wave rectifier**
2. **Full-wave rectifier**

2.2 Half-Wave Rectifier

2.2.1 Construction

A half-wave rectifier consists of:

- A step-down transformer
- A single P–N junction diode
- A load resistor R_L

2.2.2 Working Principle

When AC is applied:

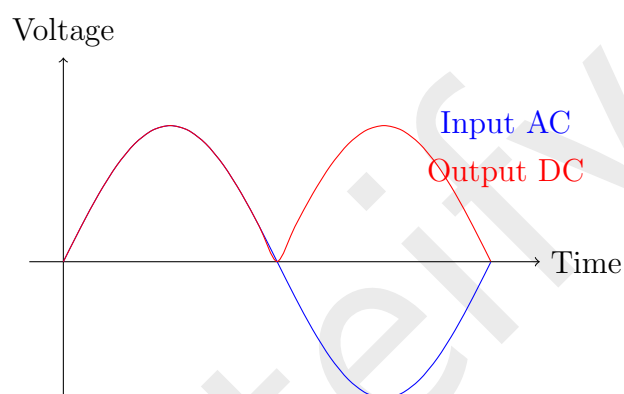


- During the **positive half cycle** of AC input, the diode becomes **forward biased** and conducts current.
- During the **negative half cycle**, the diode is **reverse biased** and blocks current.

Observation

Current flows only during one half of the input cycle — hence, the output DC is **pulsating and discontinuous**.

2.2.3 Waveform Representation



2.2.4 Analysis of Half-Wave Rectifier

Average DC Output Voltage:

$$V_{dc} = \frac{V_m}{\pi}$$

RMS Output Voltage:

$$V_{rms} = \frac{V_m}{2}$$

Rectification Efficiency:

$$\eta = \frac{P_{dc}}{P_{ac}} = 40.6\%$$

Limitation

Half-wave rectifiers are inefficient because they utilize only one half of the AC cycle and produce a highly rippled DC output.

2.3 Full-Wave Rectifier

2.3.1 Types of Full-Wave Rectifiers

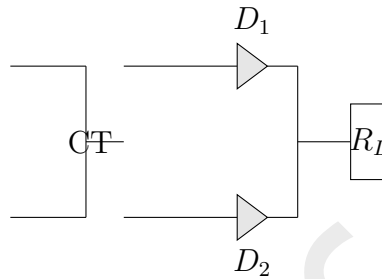
1. Center-tapped full-wave rectifier



2. Bridge full-wave rectifier

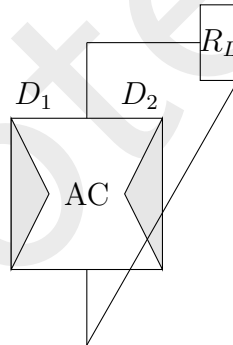
2.3.2 Center-Tapped Full-Wave Rectifier

- Uses a center-tapped transformer and two diodes.
- During each half-cycle, one diode conducts while the other remains reverse biased.



2.3.3 Bridge Rectifier

A more efficient configuration that uses four diodes arranged in a bridge.



2.3.4 Working Principle

- Both halves of the input AC are utilized.
- For each half-cycle, two diodes conduct alternately to produce unidirectional current.

2.3.5 Analysis of Full-Wave Rectifier

Average DC Output Voltage:

$$V_{dc} = \frac{2V_m}{\pi}$$

RMS Output Voltage:

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



Efficiency:

$$\eta = 81.2\%$$

Advantage

Full-wave rectifiers are much more efficient than half-wave ones as they use both half cycles of AC input, producing smoother DC output.

2.4 Applications of Rectifiers

- **Power Supply Units:** Conversion of AC mains to DC voltage.
- **Signal Demodulation:** Extraction of information from amplitude-modulated signals.
- **Battery Charging Circuits:** Provide DC current to charge batteries.
- **Measurement Circuits:** Used in DC meters and detectors.

2.5 Solved Examples

Example 1

Question: A half-wave rectifier has a peak voltage of 10 V. Find the average DC output voltage.

Answer:

$$V_{dc} = \frac{V_m}{\pi} = \frac{10}{3.14} = 3.18 \text{ V}$$

Example 2

Question: Calculate the rectification efficiency of a full-wave rectifier.

Answer:

$$\eta = \frac{P_{dc}}{P_{ac}} = 81.2\%$$

Example 3

Question: Why is a bridge rectifier preferred over a center-tapped rectifier?

Answer: Bridge rectifiers do not require a center-tapped transformer, reducing cost and size. They provide the same DC output using four diodes, offering higher efficiency and reliability.



Summary

- A rectifier converts AC into DC.
- Half-wave rectifiers use one diode; full-wave rectifiers use two or four.
- Full-wave rectifiers are more efficient and give smoother output.
- Rectifiers are key components in power supplies and chargers.

Notefity



Unit 1 : Semiconductor

Solved Questions and Answers

1. What is a semiconductor? Give examples.

Ans. A semiconductor is a material whose electrical conductivity lies between that of a conductor and an insulator. Its conductivity can be modified by temperature, light, or impurities.

Examples: Silicon (Si), Germanium (Ge), Gallium Arsenide (GaAs).

Key Point

Semiconductors are the foundation of modern electronic devices such as diodes, transistors, and ICs.

2. What is the difference between intrinsic and extrinsic semiconductors?

Ans.

- **Intrinsic Semiconductor:** Pure form of semiconductor without impurities. The number of electrons equals the number of holes.
- **Extrinsic Semiconductor:** Doped with specific impurities to increase conductivity. It is of two types:
 - **n-type:** Doped with pentavalent atoms (e.g., Phosphorus).
 - **p-type:** Doped with trivalent atoms (e.g., Boron).

3. Explain the construction of a P-N junction.

Ans. A P-N junction is formed by joining a p-type and n-type semiconductor together, creating a depletion region at the junction where electrons and holes recombine. The junction acts as a potential barrier to charge carriers.

Note

The depletion region is free from mobile charge carriers but contains fixed ions, producing an internal electric field.

4. What happens when a P-N junction diode is forward biased?

Ans. In forward bias, the p-side is connected to the positive terminal and the



n-side to the negative terminal. The depletion layer width decreases and current flows easily through the diode.

5. **Explain reverse biasing of a P-N junction diode.**

Ans. In reverse bias, the p-side is connected to the negative terminal and the n-side to the positive terminal. The depletion layer widens, and only a small leakage current (reverse saturation current) flows.

6. **Describe the V-I characteristics of a P-N junction diode.**

Ans. The V-I curve shows exponential current rise in forward bias and nearly constant small reverse current until breakdown in reverse bias.

Formula

$$\text{Forward current: } I = I_0(e^{\frac{qV}{kT}} - 1)$$

7. **What is Avalanche Breakdown?**

Ans. Avalanche Breakdown occurs under high reverse voltage when free electrons gain enough energy to knock out other electrons, creating an avalanche of charge carriers leading to a large current.

8. **What is Zener Breakdown?**

Ans. Zener Breakdown happens at low reverse voltage due to strong electric fields that pull electrons from valence to conduction band. It occurs in heavily doped diodes and is reversible.

Important

Zener breakdown is utilized in voltage regulation circuits.

9. **What are the applications of a P-N junction diode?**

Ans.

- Rectification (AC to DC conversion)
- Signal demodulation
- Clipping and clamping circuits
- LED and photodiode devices



10. What is a Zener diode and its use?

Ans. A Zener diode is a special-purpose diode designed to operate in the reverse breakdown region without damage. It is used for voltage regulation, waveform clipping, and surge protection.

Application Example

Zener diodes are used as voltage stabilizers in DC power supplies.

11. What is a rectifier?

Ans. A rectifier converts alternating current (AC) into direct current (DC). It uses one or more P-N junction diodes to allow current flow in only one direction.

Types:

- Half-wave rectifier
- Full-wave rectifier (center-tapped or bridge type)

12. Differentiate between half-wave and full-wave rectifier.

Ans.

Half-wave Rectifier	Full-wave Rectifier
Converts only one half cycle of AC to DC	Converts both half cycles of AC to DC
Uses a single diode	Uses two or four diodes
Output frequency = supply frequency	Output frequency = twice the supply frequency
Less efficient	More efficient

Unit – 2

Semiconductor Device Operation

Ch 3 : BJT & FET - Introduction to BJT: Formation of PNP / NPN junctions, Transistor Circuit Configuration: CB, CE, CC configuration, Operating regions of Transistor, injection efficiency, base transport factor and current amplification factors, Transistor as a switch and an Amplifier.

Ch 4 : Energy Storage Devices - Introduction to energy storage devices, Selecting Battery: Basic Battery Specifications, common parameters of battery/applications, Different types of Batteries used in different applications, Power Supplies: Linear and SMPS

Chapter 3

BJT & FET

3.1 Introduction

A transistor is a three-terminal semiconductor device that can amplify or switch electronic signals and electrical power. It acts as a bridge between small input signals and large output responses.

Key Idea

Transistors are the building blocks of modern electronics — used in amplifiers, oscillators, switches, and digital circuits.

3.2 Formation of PNP and NPN Transistors

A Bipolar Junction Transistor (BJT) is formed by joining three regions of semiconductor materials — either **n-p-n** or **p-n-p**.

- **NPN Transistor:** Consists of two n-type regions separated by a p-type base.
- **PNP Transistor:** Consists of two p-type regions separated by an n-type base.

Each transistor has three terminals:

1. **Emitter (E)** – supplies charge carriers.
2. **Base (B)** – thin and lightly doped region controlling the transistor.
3. **Collector (C)** – collects majority charge carriers.

Note

In an NPN transistor, electrons are majority carriers; in a PNP transistor, holes are majority carriers.



3.3 Transistor Circuit Configurations

There are three basic transistor configurations depending on which terminal is common to input and output:

3.3.1 Common Base (CB) Configuration

- Input between emitter and base; output between collector and base.
- Current gain (α) is less than 1.
- High voltage gain and low input impedance.

3.3.2 Common Emitter (CE) Configuration

- Input between base and emitter; output between collector and emitter.
- Moderate input impedance, high output impedance.
- High current and voltage gain.

3.3.3 Common Collector (CC) Configuration

- Input between base and collector; output between emitter and collector.
- High input impedance and low output impedance.
- Used for impedance matching.

Comparison of Transistor Configurations

Parameter	CB	CE	CC
Input Impedance	Low	Medium	High
Output Impedance	High	High	Low
Current Gain	≈ 1	High (β)	High (≈ 1)
Phase Shift	0°	180°	0°

3.4 Operating Regions of a Transistor

A transistor can operate in three regions depending on the biasing of junctions:



1. **Active Region:** Emitter-base junction forward biased and collector-base junction reverse biased. Used for amplification.
2. **Cutoff Region:** Both junctions reverse biased. Transistor acts as an open switch.
3. **Saturation Region:** Both junctions forward biased. Transistor acts as a closed switch.

Important

Transistor as a switch operates between cutoff (OFF) and saturation (ON) regions.

3.5 Current Relations and Gain Parameters

In a transistor,

$$I_E = I_B + I_C$$

3.5.1 1. Current Amplification Factor in CB Configuration (α)

$$\alpha = \frac{I_C}{I_E}$$

Typical value: $0.95 < \alpha < 0.99$

3.5.2 2. Current Amplification Factor in CE Configuration (β)

$$\beta = \frac{I_C}{I_B}$$

and

$$\beta = \frac{\alpha}{1 - \alpha}$$

3.5.3 3. Injection Efficiency (γ)

It is the ratio of the number of carriers injected by the emitter to the total number injected into the base.

$$\gamma = \frac{\text{Emitter Injected Carriers}}{\text{Total Carriers Crossing Junction}}$$

3.5.4 4. Base Transport Factor (β_T)

It indicates how efficiently carriers move through the base.

$$\beta_T = \frac{\text{Carriers Reaching Collector}}{\text{Carriers Entering Base}}$$



3.6 Transistor as a Switch

In switching applications, the transistor operates between two states:

- **Cutoff:** Both junctions reverse biased (OFF state).
- **Saturation:** Both junctions forward biased (ON state).

Example – Transistor as a Switch

Q. Explain how a transistor can operate as a switch.

Ans. When base current is zero, transistor remains in cutoff region (acts as open circuit). When sufficient base current flows, transistor saturates and conducts fully (acts as closed switch).

Thus, digital circuits use transistors to represent logic levels: **0 (OFF)** and **1 (ON)**.

3.7 Transistor as an Amplifier

When operated in the **active region**, a small base current variation causes a large change in collector current, providing amplification of signals.

Example – CE Amplifier Operation

Q. How does a CE transistor amplify an AC signal?

Ans. In CE configuration, a small input signal applied at the base modulates the collector current. The collector resistor converts this current variation into amplified output voltage. The output is inverted (180° phase shift).

3.8 Field Effect Transistor (FET)

A Field Effect Transistor (FET) is a unipolar device where current conduction is due to only one type of charge carrier — either electrons or holes.

3.8.1 Types of FETs

- **JFET** (Junction Field Effect Transistor)
- **MOSFET** (Metal Oxide Semiconductor FET)



Advantages of FET over BJT

- High input impedance
- Low noise operation
- Voltage-controlled device
- Better thermal stability

3.8.2 Working Principle of JFET

In an n-channel JFET, electrons flow from source to drain through a narrow conducting channel. The gate voltage controls the width of this channel, thus controlling the current. Increasing negative gate voltage reduces channel width and drain current.

3.8.3 JFET Characteristics

- **Ohmic Region:** Current increases linearly with V_{DS}
- **Saturation Region:** Current becomes constant (I_{DSS})
- **Cutoff Region:** Gate voltage beyond pinch-off makes $I_D = 0$

$$I_D = I_{DSS} \left(1 - \frac{V_{GS}}{V_P} \right)^2$$

Key Formula

Drain current in JFET follows the square law characteristic: $I_D \propto (V_P - V_{GS})^2$

3.9 Comparison between BJT and FET

Parameter	BJT	FET
Type of Device	Current controlled	Voltage controlled
Charge Carriers	Both electrons and holes	Single type (electrons or holes)
Input Impedance	Low	Very high
Noise Level	High	Low
Thermal Stability	Less	Better



Summary

- BJT works as both switch and amplifier based on biasing regions.
- FET operates as a voltage-controlled device with high input impedance.
- Both are fundamental to analog and digital circuit design.

Notefity

Chapter 4

Energy Storage Devices

4.1 Introduction

Energy storage devices are components or systems that store energy for later use. They play a vital role in modern electrical and electronic systems by providing stable power supply, improving efficiency, and ensuring uninterrupted operation during power interruptions.

Key Idea

Energy storage devices convert electrical energy into chemical, mechanical, or electrostatic energy and release it back when required.

4.2 Types of Energy Storage Devices

- **Electrochemical Storage:** Batteries, Fuel cells, Supercapacitors.
- **Mechanical Storage:** Flywheels, Compressed air, Pumped hydro storage.
- **Electrical Storage:** Capacitors, Supercapacitors.

Among these, **batteries** are the most common and widely used in electronic circuits and systems.

4.3 Selecting a Battery

Choosing the right battery for a particular application depends on several parameters such as capacity, voltage, size, weight, cost, and environmental conditions.



4.3.1 Basic Battery Specifications

- **Nominal Voltage (V_n)** – The rated voltage of a single cell or battery.
- **Capacity (Ah)** – Indicates the total charge a battery can deliver over time.

$$\text{Capacity (Ah)} = \text{Current (A)} \times \text{Time (h)}$$

- **Energy (Wh)** – Product of voltage and capacity.

$$\text{Energy (Wh)} = \text{Voltage (V)} \times \text{Capacity (Ah)}$$

- **Internal Resistance (R_{int})** – Determines voltage drop under load.
- **Cycle Life** – Number of charge/discharge cycles before significant degradation.
- **Self-discharge Rate** – Rate at which a charged battery loses energy when not in use.

Example – Estimating Battery Backup

Q. A 12V, 7Ah battery powers a 21W load. Estimate backup time.

Ans.

$$I = \frac{P}{V} = \frac{21}{12} = 1.75A$$

$$\text{Backup time} = \frac{7}{1.75} = 4 \text{ hours (approximately)}$$

Therefore, the battery can power the load for around 4 hours before depletion.

4.4 Common Parameters and Applications of Batteries

- **Energy Density:** Energy per unit weight or volume.
- **Power Density:** Rate of energy delivery per unit weight.
- **Temperature Range:** Defines operational limits.
- **Charge Retention:** Indicates how long charge can be held.



Applications

- Portable electronics (mobiles, laptops)
- Electric vehicles
- Renewable energy systems (solar, wind)
- Uninterruptible Power Supplies (UPS)
- Medical devices and IoT sensors

4.5 Different Types of Batteries

4.5.1 Primary (Non-rechargeable) Batteries

- **Zinc–Carbon:** Used in clocks, remote controls.
- **Alkaline:** Longer life and better performance.
- **Lithium Primary Cells:** High energy density, used in cameras, pacemakers.

4.5.2 Secondary (Rechargeable) Batteries

- **Lead–Acid Battery:** Common in automobiles and UPS.
- **Nickel–Cadmium (Ni–Cd):** Long life but suffers from memory effect.
- **Nickel–Metal Hydride (Ni–MH):** Higher capacity, eco-friendly alternative.
- **Lithium–Ion (Li–Ion):** High energy density, low self-discharge, used in portable devices.
- **Lithium–Polymer (Li–Po):** Flexible, lightweight, used in drones and wearables.

Comparison of Common Batteries

Battery Type	Voltage per Cell	Applications
Lead–Acid	2V	Cars, UPS systems
Ni–Cd	1.2V	Power tools, cameras
Li–Ion	3.6V	Mobiles, laptops
Li–Po	3.7V	Drones, IoT devices
Alkaline	1.5V	Toys, remotes



4.6 Power Supplies

A power supply converts electrical energy from one form to another and provides regulated voltage to circuits. Batteries are portable power sources, but for stationary systems, we use power supplies like **Linear Power Supplies** and **Switch Mode Power Supplies (SMPS)**.

4.6.1 Linear Power Supply

- Converts AC to DC using a transformer, rectifier, filter, and voltage regulator.
- Provides low noise and stable output.
- Inefficient due to high heat loss.

Working: AC → Transformer (step-down) → Rectifier → Filter → Regulator → DC Output.

Advantages of Linear Supply

- Low ripple and noise.
- Fast transient response.
- Simple circuit design.

4.6.2 Switch Mode Power Supply (SMPS)

- Converts power efficiently using high-frequency switching transistors.
- Steps up or down voltage using DC–DC conversion.
- Lightweight and compact compared to linear supplies.

Working Principle: AC is first rectified to DC, then switched at high frequency and processed through a transformer and rectifier to obtain the desired regulated DC output.



Comparison – Linear vs SMPS

Parameter	Linear Supply	SMPS
Efficiency	40–60%	70–90%
Size	Large	Compact
Cost	Low	High
Noise	Very Low	High (switching noise)
Applications	Audio amplifiers, lab equipment	Computers, TVs, chargers

4.7 Solved Example

Q. A 12V, 1A load is powered by a linear regulator supplied from 20V DC. Calculate efficiency.

Ans.

$$\text{Power input} = 20 \times 1 = 20W$$

$$\text{Power output} = 12 \times 1 = 12W$$

$$\text{Efficiency} = \frac{12}{20} \times 100 = 60\%$$

Therefore, efficiency of the linear power supply is 60%.

Summary

- Batteries are crucial electrochemical energy storage devices.
- Key parameters include capacity, energy density, and cycle life.
- Power supplies provide regulated DC — either through Linear or SMPS designs.
- SMPS offers higher efficiency and compact size but introduces switching noise.

Unit – 3

Electric Circuits

Ch 5 : Basic Circuit Theory - Introduction to Circuit Elements and its Types, Kirchhoff's Laws-KVL, KCL, Introduction to AC circuits, Study of AC circuits of series RL, RC circuit corresponding Voltage-current Phasor diagram and their relation.

Ch 6 : Transformer - Introduction to Single Phase Transformer, Working Principle and Construction, Transformation ratio, Losses and efficiency of Transformer.

Chapter 5

Basic Circuit Theory

5.1 Introduction

Basic Circuit Theory forms the foundation of electrical engineering. It deals with the analysis of electrical circuits that consist of various elements such as resistors, capacitors, and inductors connected in different configurations.

Key Idea

An electrical circuit is a closed conducting path through which current flows. Understanding how voltage, current, and power interact in a circuit helps in analyzing and designing complex systems.

5.2 Circuit Elements and Its Types

5.2.1 1. Active Elements

Active elements can supply energy to the circuit. Examples: Voltage Source, Current Source, Transistors, Operational Amplifiers.

5.2.2 2. Passive Elements

Passive elements cannot generate energy but can store or dissipate it. Examples: Resistors (R), Capacitors (C), and Inductors (L).

- **Resistor (R):** Opposes current flow and dissipates energy as heat. $V = IR$
- **Capacitor (C):** Stores energy in the electric field. $i = C \frac{dV}{dt}$
- **Inductor (L):** Stores energy in the magnetic field. $V = L \frac{di}{dt}$



5.3 Kirchhoff's Laws

Kirchhoff's Laws are fundamental tools for analyzing electrical circuits.

5.3.1 Kirchhoff's Current Law (KCL)

Statement: The algebraic sum of currents entering a junction is equal to the sum of currents leaving the junction.

$$\sum I_{in} = \sum I_{out}$$

Explanation: This law is based on the principle of conservation of electric charge — no charge is lost at a node.

Example – KCL

At a node, currents I_1, I_2 enter and I_3 leaves.

$$I_1 + I_2 - I_3 = 0 \Rightarrow I_3 = I_1 + I_2$$

5.3.2 Kirchhoff's Voltage Law (KVL)

Statement: The algebraic sum of voltages around any closed loop is zero.

$$\sum V = 0$$

Explanation: This law is based on the conservation of energy — the total energy gained per unit charge in a loop equals the total energy lost.

Example – KVL

In a series loop with a 10V source and two resistors $R_1 = 2\Omega$, $R_2 = 3\Omega$:

$$10 - (2I + 3I) = 0 \Rightarrow I = 2A$$

5.4 Introduction to AC Circuits

Alternating Current (AC) circuits involve voltages and currents that vary sinusoidally with time.

$$v(t) = V_m \sin(\omega t) \quad \text{and} \quad i(t) = I_m \sin(\omega t + \phi)$$

where V_m, I_m = amplitude, ω = angular frequency, ϕ = phase difference between voltage and current.



Key Terms

- **RMS Value:** $V_{rms} = \frac{V_m}{\sqrt{2}}$
- **Average Value:** $V_{avg} = \frac{2V_m}{\pi}$
- **Frequency (f):** $f = \frac{\omega}{2\pi}$

5.5 Series AC Circuits and Phasor Relations

5.5.1 1. Series RL Circuit

- Contains a resistor (R) and an inductor (L) connected in series.
- The current lags the voltage by an angle ϕ .

$$V = \sqrt{(IR)^2 + (I\omega L)^2} \quad \text{and} \quad \tan \phi = \frac{\omega L}{R}$$

Phasor Diagram for RL Circuit

The voltage across the resistor V_R is in phase with current I , while voltage across the inductor V_L leads current by 90° . The resultant voltage V is the phasor sum of V_R and V_L .

5.5.2 2. Series RC Circuit

- Contains a resistor (R) and capacitor (C) in series.
- The current leads the voltage by an angle ϕ .

$$V = \sqrt{(IR)^2 + \left(\frac{I}{\omega C}\right)^2} \quad \text{and} \quad \tan \phi = -\frac{1}{\omega RC}$$

Phasor Diagram for RC Circuit

Voltage across the resistor V_R is in phase with current I , and the voltage across the capacitor V_C lags current by 90° . The total voltage V is the phasor sum of V_R and V_C .



5.6 Impedance and Phase Relation

For sinusoidal steady-state analysis, the opposition to current flow is represented as impedance (Z).

$$Z = R + jX \quad \text{where} \quad X = \text{reactance}$$

$$|Z| = \sqrt{R^2 + X^2} \quad \text{and} \quad \phi = \tan^{-1} \left(\frac{X}{R} \right)$$

Types of Reactance

- **Inductive Reactance:** $X_L = \omega L$
- **Capacitive Reactance:** $X_C = \frac{1}{\omega C}$

5.7 Solved Example

Q. An RL series circuit has $R = 10\Omega$, $L = 0.1H$, and is connected to a 50Hz AC supply of 100V. Find current and phase angle.

Ans.

$$X_L = 2\pi fL = 2\pi \times 50 \times 0.1 = 31.4\Omega$$

$$Z = \sqrt{R^2 + X_L^2} = \sqrt{10^2 + 31.4^2} = 33.9\Omega$$

$$I = \frac{V}{Z} = \frac{100}{33.9} = 2.95A$$

$$\phi = \tan^{-1} \left(\frac{31.4}{10} \right) = 72.3^\circ$$

Hence, current lags the voltage by 72.3° .



5.8 Summary

Key Points Recap

- Circuit elements are classified as active and passive.
- Kirchhoff's laws form the base for all network analysis.
- AC circuits have sinusoidal voltages and currents with phase difference.
- In RL circuit – current **lags** voltage; in RC circuit – current **leads** voltage.
- Phasor diagrams visually represent phase relationships.

Chapter 6

Transformer

6.1 Introduction to Single Phase Transformer

A transformer is a static electrical device that transfers electrical energy between two or more circuits through electromagnetic induction. It operates on the principle of mutual induction and is used to step up or step down AC voltages while maintaining the same frequency.

Definition

A **Transformer** is a static device that transfers electrical power from one circuit to another at the same frequency through electromagnetic induction, with the desired change in voltage or current.

6.1.1 Applications of Transformer

- Used in power transmission and distribution.
- Used in voltage regulation.
- Used in electrical isolation.
- Used in electronic devices such as adapters, chargers, and amplifiers.

6.2 Working Principle of Transformer

The working of a transformer is based on the **principle of mutual induction** — when the alternating current flows through the primary winding, it produces a changing magnetic flux that induces an electromotive force (EMF) in the secondary winding.

$$E_1 \propto \frac{d\phi}{dt}, \quad E_2 \propto \frac{d\phi}{dt}$$



According to Faraday's Law:

$$E = -N \frac{d\phi}{dt}$$

where E = induced EMF, N = number of turns, ϕ = magnetic flux.

Key Principle

No mechanical motion is involved in the working of a transformer. Energy transfer occurs only through magnetic coupling between windings.

6.3 Construction of Single Phase Transformer

A single-phase transformer mainly consists of:

1. **Core:** Provides a path for magnetic flux; made of laminated soft iron or silicon steel.
2. **Primary Winding:** Connected to the input supply.
3. **Secondary Winding:** Connected to the output load.

Note

The laminations in the core minimize **eddy current losses** and improve efficiency.

6.4 Transformation Ratio

The transformation ratio defines the relationship between the voltages or turns of the primary and secondary windings.

$$K = \frac{E_2}{E_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2}$$

where E_1, E_2 are the primary and secondary EMFs, N_1, N_2 are the number of turns, I_1, I_2 are the currents in primary and secondary coils.

6.4.1 Types of Transformers Based on Transformation Ratio

- **Step-up Transformer:** $N_2 > N_1 \Rightarrow E_2 > E_1$
- **Step-down Transformer:** $N_2 < N_1 \Rightarrow E_2 < E_1$



Power Relation

In an ideal transformer, the power remains constant on both sides:

$$V_1 I_1 = V_2 I_2$$

6.5 Losses in Transformer

Although transformers are efficient devices, some losses occur during operation.

6.5.1 Core Losses (Iron Losses)

Caused by alternating magnetic flux in the core. It consists of:

- **Hysteresis Loss:** Due to magnetization and demagnetization of the core.
- **Eddy Current Loss:** Due to circulating currents in the core laminations.

6.5.2 Copper Losses

Caused by the resistance of the winding conductors.

$$P_{cu} = I_1^2 R_1 + I_2^2 R_2$$

6.5.3 Leakage Flux Losses

Part of the magnetic flux does not link both windings, causing reduced coupling.

Minimizing Losses

- Use high-grade silicon steel to reduce hysteresis loss.
- Use thin laminated cores to minimize eddy current loss.
- Use conductors of low resistance to reduce copper loss.

6.6 Efficiency of Transformer

The efficiency (η) of a transformer is the ratio of output power to input power.

$$\eta = \frac{\text{Output Power}}{\text{Input Power}} \times 100$$

$$\eta = \frac{V_2 I_2 \cos \phi_2}{V_2 I_2 \cos \phi_2 + P_{core} + P_{cu}} \times 100$$



6.6.1 Condition for Maximum Efficiency

Efficiency is maximum when:

$$P_{cu} = P_{core}$$

Typical Efficiency Values

- Small Power Transformers: 90–95%
- Large Power Transformers: 96–99%

6.7 Solved Examples

Q1. A 1 kVA, 230/115 V transformer has iron losses of 20 W and full-load copper losses of 30 W. Find efficiency at half load and full load for unity power factor.

Ans:

Output power at full load = 1000W

$$\text{At full load: } \eta = \frac{1000}{1000 + 20 + 30} \times 100 = 95.2\%$$

$$\text{At half load: } P_{cu} = (0.5)^2 \times 30 = 7.5W$$

$$\eta = \frac{500}{500 + 20 + 7.5} \times 100 = 95.6\%$$

Hence, efficiency is maximum near half load.

Q2. A transformer has primary voltage 230V, secondary voltage 115V. Calculate the transformation ratio and identify the type.

Ans:

$$K = \frac{E_2}{E_1} = \frac{115}{230} = 0.5$$

Since $K < 1$, it is a step-down transformer.



6.8 Summary

Key Takeaways

- Transformer transfers electrical energy by electromagnetic induction.
- It operates on AC only.
- Step-up and step-down transformers change voltage levels.
- Major losses include core and copper losses.
- Maximum efficiency occurs when copper loss equals core loss.

Notefity



Final Examination – Sample Paper

Total Marks : 60

Time Allotted : 3 hours

Instructions:

- The question paper consists of 3 sections. It is compulsory for students to attempt all questions of Section A and Section B.
- Section A has 5 questions of 2 marks each, Section B has 4 questions of 5 marks each, and Section C has 4 questions of 10 marks each (out of which any 3 are to be attempted).
- Question no. 10 & 11 of Section C are compulsory to be attempted.
- Students to attempt ANY ONE question from question no. 12 & question no. 13 of Section C.

Section A (5x2 = 10 marks)

1. Explain the formation and working of a P–N junction diode.
2. If a transistor has $\alpha = 0.99$, find its β value and current gain.
3. In a single-phase transformer, the primary has 400 turns and the secondary has 100 turns. If the input is 240V, find the secondary voltage.
4. Define active and passive circuit elements with examples.
5. State and explain Kirchhoff's Current Law (KCL) and Voltage Law (KVL) with examples.

Section B (4x5 = 20 marks)

6. What is the Zener breakdown mechanism? How does a Zener diode maintain constant voltage?
7. List the basic battery specifications to be considered while selecting a power source for an electronic circuit.



8. Draw the phasor diagram of a series RLC circuit and explain the phase relationship.
9. For a series RL circuit with $R = 10\Omega$, $L = 0.2H$, and $f = 50Hz$, find the impedance and phase angle.

Section C (3x10 = 30 marks)

10. Explain the working of a P-N junction diode under forward and reverse bias conditions.
 11. Define SMPS. How does it differ from a linear power supply in terms of efficiency and operation?
 12. What are the main losses in a transformer? How can its efficiency be improved?
- OR**
13. Explain the working principle of a single-phase transformer with a neat diagram.