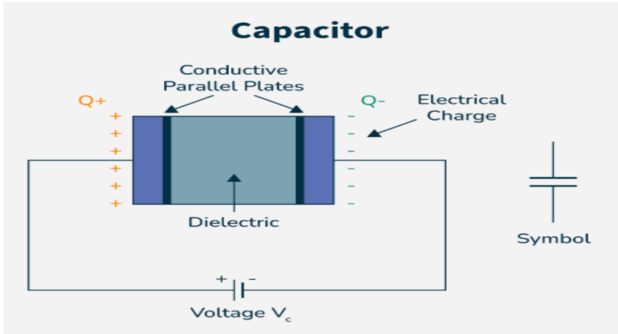
CAPACITORS

DEFINITION: A **capacitor** is a two terminal passive electronic component that stores **electrical energy** in an **electric field**. It's one of the most common and important parts in the circuits.



How a capacitor works

- A capacitor has two conductive plates separated by an insulator (called a *dielectric*).
- When voltage is applied, electrons build up on one plate and are removed from the other.
- This separation of charge creates an electric field, which stores energy.
- Capacitance (F, farads): how much electric charge it can store.

APPLICATIONS OF CAPACITORS:

1. Energy Storage

Capacitors store electrical energy and release it quickly when needed.
Example: Camera flash, defibrillators, UPS systems.

2. Filtering (Power Supplies)

They smooth out fluctuations in voltage by filtering AC ripples from DC supplies.
Example: Laptop chargers, mobile chargers, SMPS.

3. Timing Circuits (RC Circuits)

Capacitors charge and discharge at predictable rates, allowing them to create time delays.
Example: Timers, oscillators, blinkers, clocks.

4. Coupling and Decoupling Signals

- **Coupling:** Allows AC signals to pass but blocks DC.
  Used between amplifier stages.
- **Decoupling:** Stabilizes voltage by removing noise from power lines.

Example: Audio amplifiers, sensors, microcontroller boards.

5. Resonant Circuits (LC Circuits)

Capacitors and inductors create circuits that resonate at specific frequencies.
Example: Radios, antennas, tuning circuits.

6. Motor Starters

Used in **single-phase motors** to create phase shift and improve starting torque.
Example: Fans, refrigerators, air conditioners.

7. Power Factor Correction

Capacitors improve power factor in industrial loads, reducing electricity costs.
Example: Capacitor banks in factories.

8. Snubber Circuits

Protect circuits by absorbing voltage spikes from switching devices.
Example: Inverters, SMPS, power electronics.

9. Memory Storage

In older dynamic RAM (DRAM), each bit is stored as charge in a tiny capacitor.

10. Touch Sensors

Capacitive touchscreens use change in capacitance when a finger touches them.
Example: Smartphones, tablets.

TYPES OF CAPACITORS:

1. Ceramic Capacitors

- **Most common type**
- Small, cheap, non-polarized
- Used for high-frequency and general-purpose applications
- Values: pF to µF **Uses:** Filters, decoupling in circuits, RF applications.

2. Electrolytic Capacitors

- Higher capacitance values
- **Polarized** (must connect + and – correctly)
- Values: µF to thousands of µF **Uses:** Power supply filtering, smoothing DC.

3. Tantalum Capacitors

- Smaller and more stable than electrolytics
- **Polarized**
- Values: µF range
- More expensive **Uses:** Phones, laptops, precision circuits.

4. Film Capacitors

- Made with plastic films (Mylar, polyester, polypropylene)

- Very stable, reliable, and non-polarized
- Values: nF to µF **Uses:** Audio circuits, high-frequency applications, motor run capacitors.

5. Paper Capacitors (Old technology)

- Made with waxed paper
- Non-polarized
- Rare today **Uses:** Vintage equipment, old radios.

6. Mica Capacitors

- Very stable, accurate, and reliable
- Non-polarized
- Values: small (pF to nF) **Uses:** RF circuits, oscillators, precision applications.

7. Supercapacitors (Ultracapacitors)

- Very high capacitance (Farads!)
- Can store a lot of energy
- Non-polarized
- Fast charging/discharging

Uses: Backup power, memory protection, electric vehicles, energy storage.

8. Variable Capacitors

Capacitance can be adjusted manually.

Types:**Air variable capacitors**

Trimmer capacitors **Uses:** Radio tuning, frequency adjustment.

9. Motor Capacitors

Special capacitors used in AC motors.

Types:**Start capacitors**

Run capacitors **Uses:** Ceiling fans, compressors, pumps.

CAPACITANCE: Capacitance is the ability or property of a capacitor to store electric charge when a potential difference (voltage) is applied across it.

Unit: FARADS (F)

Capacitance (C) is defined as:

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

Where:

- C = capacitance (in farads, F)
- Q = charge stored (in coulombs, C)
- V = potential difference (in volts, V)

FACTORS AFFECTING CAPACITANCE OF CAPACITOR:

☆ Overall Formula for a Parallel Plate Capacitor

$$C = \frac{\varepsilon_0 \varepsilon_r A}{d}$$

Here are the **factors affecting the capacitance of a capacitor** clearly and concisely:

1. Area of the Plates (A)

- Larger plate area → **greater capacitance**
- Smaller plate area → less capacitance

Reason: More area allows more charge to accumulate.

$$C \propto A$$

2. Distance Between the Plates (d)

- Smaller distance → **higher capacitance**
- Larger distance → lower capacitance

Reason: When plates are closer, electric field strength increases.

$$C \propto \frac{1}{d}$$

3. Dielectric Material Between Plates

The dielectric increases capacitance by reducing the electric field.

- Higher dielectric constant (**ε_r**) → **greater capacitance**
- Air has $\varepsilon_r = 1$; materials like mica, ceramic, plastic have higher values.

$$C \propto \varepsilon_r$$

4. Permittivity of the Medium (ε)

$$\varepsilon = \varepsilon_0 \varepsilon_r$$

Higher permittivity → higher capacitance.

5. Shape and Geometry of the Capacitor

Different shapes (parallel plate, cylindrical, spherical) have different formulas, affecting capacitance.

DIELECTRICS:

Dielectrics are insulating materials that do not conduct electricity but can store electric charge by getting polarized when an electric field is applied.

In simple words:
👉 *A dielectric is an electrical insulator that increases the capacitance of a capacitor.*

☆ Key Characteristics of Dielectrics

1. Do not allow current to flow (very high resistivity)
2. Become polarized in an electric field
3. Increase capacitance when placed between capacitor plates
4. Reduce electric field strength inside the capacitor

☆ **Types of Dielectrics**

1. Polar Dielectrics

- Molecules have permanent dipole moment
- Example: Water, HCl

2. Non-polar Dielectrics

- Molecules have no permanent dipole moment
- Example: Oxygen, nitrogen, plastics

☆ **Examples of Common Dielectric Materials**

- Air
- Paper
- Glass
- Ceramic
- Plastic (polyester, polypropylene)
- Mica
- Rubber

☆ Functions of Dielectrics in Capacitors

1. Increase capacitance
2. Prevent electrical breakdown
3. Store electric energy
4. Improve mechanical strength
5. Allow compact capacitor design

DIELECTRIC CONSTANT:

The dielectric constant (also called relative permittivity) is a measure of how much a dielectric material can increase the capacitance of a capacitor compared to air or vacuum.

☑ Definition

The dielectric constant (ε_r) is the ratio of:

$$\varepsilon_r = \frac{\text{Permittivity of the material } (\varepsilon)}{\text{Permittivity of free space } (\varepsilon_0)}$$

So, $\varepsilon_r = \frac{\varepsilon}{\varepsilon_0}$

☑

Simple Meaning

It tells how well a material can store electric charge when placed in an electric field.

- If $\varepsilon_r = 1$ → material behaves like vacuum
- If $\varepsilon_r > 1$ → material stores more charge than vacuum

Higher dielectric constant → greater capacitance.

PARALLEL CAPACITANCE:

When capacitors are connected **in parallel**, the **total capacitance increases** because each capacitor adds more plate area for storing charge.

Formula for Parallel Combination

$$C_{\text{total}} = C_1 + C_2 + C_3 + \cdots$$

So you simply add all the capacitances directly.

Capacitors in Series

Capacitors are in **series** when they are connected **end-to-end**, so the same charge flows through each capacitor.

☆ **Total Capacitance in Series**

For capacitors in series:

$$\frac{1}{C_{\text{total}}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \cdots$$

Or for two capacitors:

$$C_{\text{total}} = \frac{C_1 C_2}{C_1 + C_2}$$

☞ **Total capacitance in series is always less than the smallest capacitor.**

ENERGY STORED :

The **energy stored in a capacitor** is the energy required to **separate charges** and store them on the two plates of the capacitor.

Formula for Energy Stored in a Capacitor

The energy (**E**) stored is given by:

$$E = \frac{1}{2} C V^2$$

Where:

- **E** = energy (in joules, J)
- **C** = capacitance (farads, F)
- **V** = voltage across capacitor (volts, V)

Example

A 10 µF capacitor is charged to 5 V.

$$E = \frac{1}{2} C V^2$$

$$E = \frac{1}{2} \times 10 \times 10^{-6} \times 5^2$$
$$E = \frac{1}{2} \times 10^{-5} \times 25$$
$$E = 1.25 \times 10^{-4} \text{ J}$$

SIMPLE PROBLEMS ON SERIES, PARALLEL AND SERIES-PARALLEL COMBINATION OF CAPACITORS.

1. Series combination (Farads)

Problem 1

Three capacitors of 2 F, 3 F and 6 F are connected in series. Find the equivalent capacitance.

Step 1: Write series formula

$\frac{1}{C_{\mathrm{eq}}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$

Step 2: Substitute values

$$\frac{1}{C_{\mathrm{eq}}} = \frac{1}{2} + \frac{1}{3} + \frac{1}{6}$$

Step 3: Add fractions

So $\frac{1}{C_{\mathrm{eq}}} = \frac{3}{6} + \frac{2}{6} + \frac{1}{6} = \frac{6}{6} = 1$

Step 4: Invert to get C_{eq}

$\boldsymbol{C_{\mathrm{eq}} = 1\mathrm{F}}$

Problem 2

Two capacitors of 4 F and 5 F are connected in series across a 90 V dc supply.

a) Find the equivalent capacitance.

b) Find the charge stored.

a) Equivalent capacitance

Step 1: Series formula for two capacitors

$\frac{1}{C_{\mathrm{eq}}} = \frac{1}{4} + \frac{1}{5}$

Step 2: Add fractions

$$\frac{1}{C_{\text{eq}}} = \frac{5}{20} + \frac{4}{20} = \frac{9}{20}$$

Step 3: Invert

$$C_{\text{eq}} = \frac{20}{9} = \mathbf{2.22F}$$

b) Charge stored

Step 4: Use $Q = C_{\text{eq}}V$

$$Q = \frac{20}{9} \times 90 = \frac{20 \times 90}{9} = \mathbf{200\ C}$$

Problem 3

Capacitors of 1 F, 2 F, 3 F and 6 F are connected in series. Determine the equivalent capacitance.

Step 1: Series formula

$$\frac{1}{C_{\text{eq}}} = \frac{1}{1} + \frac{1}{2} + \frac{1}{3} + \frac{1}{6}$$

Step 2: Convert to common denominator 6

Step 3: Add

$$\frac{1}{C_{\text{eq}}} = \frac{6+3+2+1}{6} = \frac{12}{6} = 2\text{F}$$

Step 4: Invert

$$C_{\text{eq}} = \frac{\mathbf{1}}{\mathbf{2}}\ \mathbf{F}$$

Problem 4

A 10 F and a 15 F capacitor are connected in series and the combination is connected to a 60 V source.

a) Find the equivalent capacitance.

b) Find the voltage across each capacitor.

a) Equivalent capacitance

Step 1: Series formula for two capacitors

$\frac{1}{C_{\text{eq}}} = \frac{1}{10} + \frac{1}{15}$

Step 2: Add fractions

LCM of 10 and 15 is 30.

$\frac{1}{C_{\text{eq}}} = \frac{3}{30} + \frac{2}{30} = \frac{5}{30}$

Step 3: Invert

$C_{\text{eq}} = \frac{30}{5} = 6 \text{ F}$

b) Voltages

Step 4: Find common charge using $Q = C_{\text{eq}}V$

$Q = 6 \times 60 = 360 \text{ C}$

Step 5: Use $V = Q/C$ for each capacitor

For 10 F: $V_{10} = \frac{360}{10} = 36 \text{ V}$

For 15 F: $V_{15} = \frac{360}{15} = 24 \text{ V}$

Check: $36 + 24 = 60 \text{ V}$

2. Parallel combination (millifarads)

Problem 5

Three capacitors of 20 mF, 35 mF and 45 mF are connected in parallel. Find the equivalent capacitance.

Step 1: Parallel formula

$C_{\text{eq}} = C_1 + C_2 + C_3$

Step 2: Add directly (same unit mF)

$C_{\text{eq}} = 20 + 35 + 45 = \mathbf{100\ mF}$

Problem 6

Four capacitors of 5 mF, 8 mF, 12 mF and 15 mF are connected in parallel across a 50 V supply.

a) Find the equivalent capacitance.

b) Find the total charge drawn from the supply.

a) Equivalent capacitance

Step 1: Parallel formula

$C_{\text{eq}} = 5 + 8 + 12 + 15 = 40$ mF

Step 2: Add

$C_{\text{eq}} = 40$ mF

b) Total charge

Step 3: Convert to farads (optional for clarity)

$$40\text{mF} = \frac{40}{1000} = 0.04F$$

Step 4: Use $Q = CV$

$Q = 0.04 \times 50 = 2\text{C}$

Problem 7

Two capacitors of 40 mF and 60 mF are connected in parallel to a 24 V battery.

a) Find the equivalent capacitance.

b) Find the energy stored in the combination.

a) Equivalent capacitance

Step 1: Parallel formula

$C_{\text{eq}} = 40 + 60 = 100$ mF

Step 2: Convert to farads

$$100\text{mF} = \frac{100}{1000} = 0.1\text{F}$$

b) Energy stored

Step 3: Use $E = \frac{1}{2}CV^2$

$$E = \frac{1}{2} \times 0.1 \times 24^2$$

Step 4: Calculate

$24^2 = 576$

$E = 0.5 \times 0.1 \times 576 = 0.05 \times 576 = 28.8$ J

Problem 8

A capacitor bank consists of three identical capacitors of 30 mF each connected in parallel.

a) Find the total capacitance of the bank.

b) If the bank is connected to a 100 V source, find the total charge stored.

a) Total capacitance

Step 1: Parallel formula

$C_{\text{eq}} = C_1 + C_2 + C_3 = 30 + 30 + 30 = 90$mF

b) Charge

Step 2: Convert to farads

90mF= 90/1000= 0.09F

Step 3: Use $Q = CV$

$Q = 0.09 \times 100 = 9$ C

3. Series–parallel combination (microfarads)

Problem 9

Two capacitors of 6 μF and 9 μF are connected in series. This series combination is connected in parallel with a 12 μF capacitor.

a) Find the equivalent capacitance of the whole network.

b) If it is connected to a 100 V source, find the total charge supplied.

a) Equivalent capacitance

Step 1: Reduce series pair (6 µF and 9 µF)

$$\frac{1}{C_s} = \frac{1}{6} + \frac{1}{9}$$

Step 2: Add fractions

LCM of 6 and 9 is 18.

$$\frac{1}{Cs} = \frac{3}{18} + \frac{2}{18}$$

$$\frac{1}{C_s} = \frac{5}{18}$$

So $C_s = \frac{18}{5} = 3.6$ µF

Step 3: Now add parallel with 12 µF

$$C_{\text{eq}} = C_s + 12 = 3.6 + 12 = 15.6 \text{ µF}$$

b) Total charge

Step 4: Convert to farads

15.6µF= 15.6×10^{-6} F

Step 5: Use $Q = CV$

$Q = 15.6 \times 10^{-6} \times 100 = 1.56 \times 10^{-3}\ C$

Problem 10

Two 10 µF capacitors are connected in parallel, and this parallel group is connected in series with a 20 µF capacitor.

a) Find the equivalent capacitance.

b) If the combination is connected to a 50 V source, find the charge on each capacitor.

a) Equivalent capacitance

Step 1: Parallel part (two 10 µF)

$C_p = 10 + 10 = 20$ µF

Step 2: Now 20 μF (parallel group) in series with 20 μF

$$\frac{1}{C_{\text{eq}}} = \frac{1}{20} + \frac{1}{20} = \frac{2}{20} = \frac{1}{10}$$

So $C_{\text{eq}} = 10$ μF

b) Charge on each capacitor

Step 3: Total charge from source

Convert: 10μF = $10 \text{ X } 10^{-6}$

$Q_{\text{total}} = C_{\text{eq}} V = 10 \times 10^{-6} \times 50 = 5.0 \times 10^{-4}\ C$ = 0.5mC

Step 4: Series rule – same charge through series elements

The parallel group (20 μF) and the single 20 μF each carry $Q =$ 0.5mC

Step 5: Charge sharing inside parallel group

Both 10 μF capacitors are in parallel at the same voltage.

Voltage across parallel group: $V_p = Q/C_p =$ 0.5mC/20μF

Convert units: 0.5mC= $0.5 \text{ x } 10^{-3}$ C and 20μF= $20 \text{ x } 10^{-6}$ F

$$V_p = \frac{0.5 \times 10^{-3}}{20 \times 10^{-6}} = \frac{0.5}{20} \times 10^3 = 0.025 \times 1000 = 25 \text{ V}$$

Now for each 10 μF:

$Q_{10} = CV = 10 \times 10^{-6} \times 25 = 2.5 \times 10^{-4}$ = 0.25 mC

So each 10 μF has 0.25 mC, and the series 20 μF has 0.5 mC.

Problem 11

Three capacitors of 4 μF each are connected as follows: two of them are in series, and their series combination is in parallel with the third 4 μF capacitor.

a) Find the equivalent capacitance.

b) If connected across a 60 V supply, find the total charge taken from the supply.

a) Equivalent capacitance

Step 1: Series of two 4 μF

$$\frac{1}{C_s} = \frac{1}{4} + \frac{1}{4} = \frac{2}{4} = \frac{1}{2}$$

So $C_s = 2$ μF

Step 2: Parallel with third 4 μF

$C_{\text{eq}} = C_s + 4 = 2 + 4 = 6$ μF

b) Total charge

Step 3: Convert to farads

6 μF = 6 x 10^{-6} F

Step 4: Use $Q = CV$

$Q = 6 \times 10^{-6} \times 60 = 360 \times 10^{-6}$ μC = 0.36 mC

Problem 12

Capacitors of 5 μF, 10 μF and 15 μF are connected such that the 10 μF and 15 μF are in parallel, and this parallel group is in series with the 5 μF capacitor.

a) Find the equivalent capacitance.

b) If a 120 V supply is connected across the network, find the voltage across the 5 μF capacitor.

a) Equivalent capacitance

Step 1: Parallel part (10 μF and 15 μF)

$C_p = 10 + 15 = 25\mu F$

Step 2: Now 5 μF in series with 25 μF

$$\frac{1}{C_{\text{eq}}} = \frac{1}{5} + \frac{1}{25}$$

LCM of 5 and 25 is 25:

$$\frac{1}{C_{\text{eq}}} = \frac{5}{25} + \frac{1}{25} = \frac{6}{25}$$

So $C_{\text{eq}} = \frac{25}{6} \approx 4.17$μF

b) Voltage across 5 μF

Step 3: Total charge from source

Convert $C_{eq} = 25/6$ μF = 25/6 x 10^{-6}

$$Q = C_{eq}V = \frac{25}{6} \times 10^{-6} \times 120$$

$$\frac{25}{6} \times 120 = 25 \times 20 = 500$$

So $Q = 500 \times 10^{-6}$ = 0.5 mC

Step 4: Use series rule (same Q) on 5 μF

For 5 μF: $V_5 = \frac{Q}{C}$.

Convert: $C = 5\mu F$ = 5 x 10^{-6} F, Q= 500×10^{-6} = 0.5 x 10^{-3} C = 0.5 mC

$$V_5 = \frac{0.5 \times 10^{-3}}{5 \times 10^{-6}} = \frac{0.5}{5} \times 10^3 = 0.1 \times 1000 = 100 \text{ V}$$

So the 5 μF capacitor has 100 V across it, and the remaining 20 V appears across the parallel group.

INDUCTOR:

An **inductor** is an electrical component that **stores energy in the form of a magnetic field** when electric current flows through it.

Definition

An **inductor** (also called a **coil** or **choke**) is a passive electronic component made by winding a wire into a coil, that **stores energy in the form of a magnetic field** when electric current flows through it.

*It opposes **changes in current** due to the magnetic field it produces.

*Inductors control current and store energy.

Symbol : L (Inductor is represented by a coil-like symbol:)

Unit: Henry(H)

*The ability of an inductor to store magnetic energy is called **inductance**, measured in **henry (H).**

*** How an Inductor Works**

- When current flows through the coil → a **magnetic field** is produced.
- If current tries to change suddenly → the inductor **opposes** it.
- This is due to **Lenz's Law**, which says the induced emf opposes the change in current.

Different Types of Inductors

Depending on the type of material used, inductors can be classified as follows:

1. Iron Core Inductor
2. Air Core Inductor
3. Iron Powder Inductor
4. Toroidal Inductor
5. Variable Inductor
6. Ferrite Core Inductor, which is divided into:

   *Soft Ferrite

*Hard Ferrite

☆ Applications

- Power supply filters
- Switching circuits.
- Transformers
- Relays
- Radio Frequency tuning circuits
- Energy storage in power supplies
- Induction heating
- Motors and generators

☆ Energy Stored in an Inductor

Energy stored in an inductor is the magnetic energy accumulated in its magnetic field when electric current flows through it.

$$E = \frac{1}{2} L I^2$$

Where, **E** = energy (in joules, J)

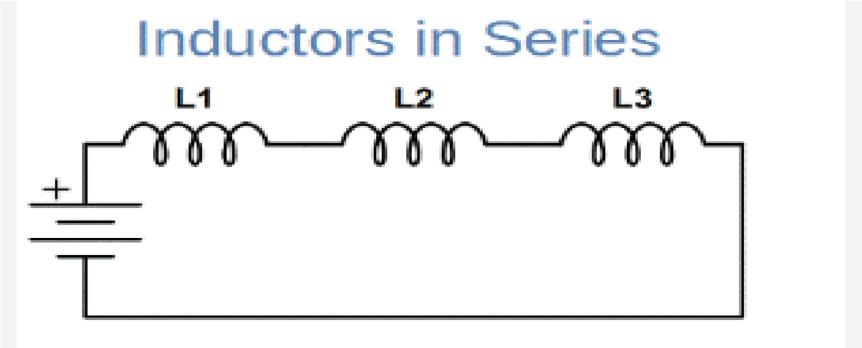
L= Inductance (in henry, H)

Series Connection of Inductors:

When two or more inductors are connected end-to-end so that the same current flows through each inductor, the connection is called a series connection of inductors.

Equivalent Inductance :

$$\boxed{L_s = L_1 + L_2 + L_3 + \cdots}$$



Key Points (Exam Notes)

- Current is **same** in all inductors
- Voltage varies in each inductor
- Inductance **increases** in series

Parallel Connection of Inductors

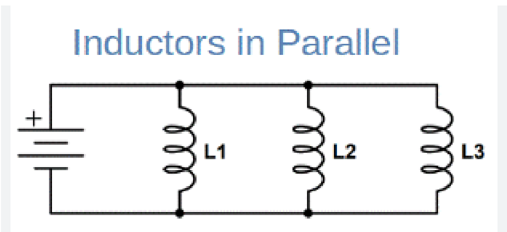
When two or more inductors are connected such that their terminals are joined together and the same voltage is applied across each inductor, the connection is called a parallel connection of inductors.

Equivalent Inductance:

$$\boxed{\frac{1}{L_p} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + \cdots}$$

For two inductors:

$$\boxed{L_p = \frac{L_1 L_2}{L_1 + L_2}}$$



KEY POINTS:

*Same voltage across all inductors

*Current varies in each parallel inductors.