

Capacitors



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What is a capacitor

- A **capacitor** is an electronic component that stores and releases electrical energy.
- Capacitors are commonly used in electronic circuits for functions such as:
 - **Storing energy** (like a small battery).
 - **Smoothing voltage fluctuations** in power supplies.
 - **Filtering signals** in audio and radio systems.
 - **Blocking direct current (DC)** while allowing alternating current (AC) to pass.

Capacitance

- **Capacitance** is the ability of a capacitor to store electrical charge.
- It is measured in **farads** (F), typically expressed in smaller units, such as microfarads (μF) or millifarads (mF).
- Role of Capacitance in Applications
 - **Smoothing and Filtering:** High capacitance helps store energy and release it to smooth out voltage fluctuations in power supplies.
 - **Energy Storage:** Temporarily stores energy for applications like flash photography or backup power.
 - **Signal Coupling and Decoupling:** Blocks DC while allowing AC signals to pass in audio and communication circuits.
 - **Timing:** Used in RC circuits to control timing and frequency, where capacitance determines the time constant.

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

- C : Capacitance, measured in **farads** (F).
- Q : Charge in coulombs (C).
- V : Voltage in volts (V).

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

Parts of a capacitor

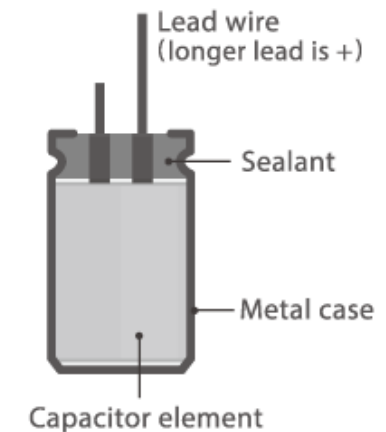
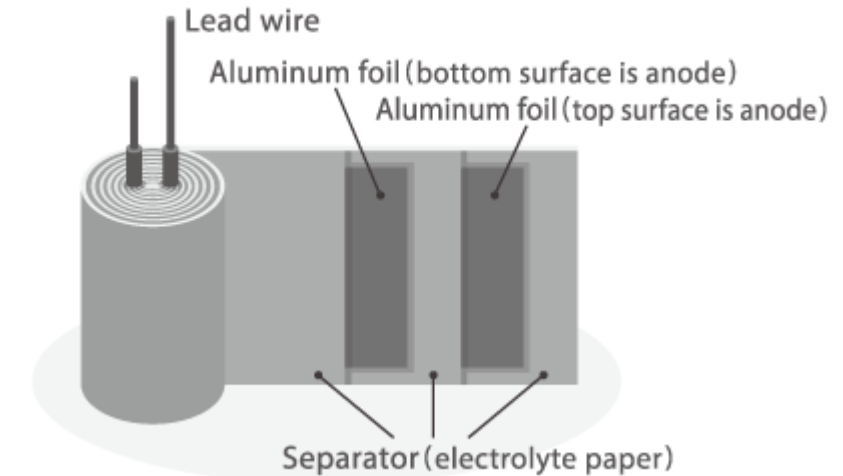
- **Plates:** Store electric charge and create the electric field.
- **Dielectric:** Enhances energy storage by insulating and increasing capacitance.
- **Anode:** Stores positive charge.
- **Cathode:** Completes the circuit and stores negative charge.

Dielectric Material	Dielectric Constant
Vacuum	1
Air	1.006
Polypropylene PP	2.2
Polyphenylene Sulfide PPS	3
Polyester PET	3.3
Polyester PEN	3
Impregnated Paper	2.0 – 6.0
Mica	6.8
Aluminium Oxide	8.5
Tantalum Oxide	27.7
Paraelectric Ceramics (Class1)	5.0 – 9.0
Barium Titanate (Class 2)	3000 - 8000

Electrolytic Capacitor (Components)

Components:

- **Anode (positive plate):** Made from aluminium or tantalum, which is etched to increase surface area.
- **Dielectric:** A thin layer of oxide formed on the surface of the anode through an electrochemical process.
- **Electrolyte (cathode):** A conductive liquid or gel that acts as the negative electrode in the capacitor.
- Encased in an aluminium can or other housing material for protection.



Electrolytic Capacitor (Characteristics)

- **High Capacitance:** Offers large capacitance values (ranging from microfarads to thousands of microfarads), making them suitable for energy storage and filtering applications.
- **Size:** Compact for their capacitance value due to the high surface area of the etched anode and the efficient dielectric.
- **Voltage Rating:** Typically used for low to medium voltage applications, with voltage ratings up to a few hundred volts.
- **Leakage Current:** Small current may flow through the capacitor due to imperfections in the dielectric layer.
- **Limited Lifespan:** Over time, the electrolyte can dry out, especially under high temperatures, leading to performance degradation.

Mica Capacitor (Components)



- **Dielectric:**

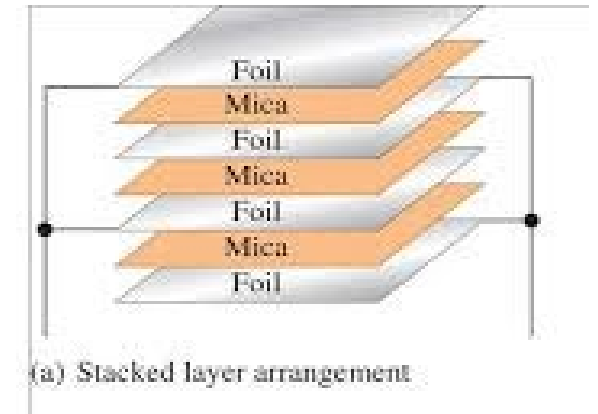
- Made from thin sheets of mica, which are stacked and layered. Mica's stability ensures a consistent and durable dielectric.

- **Plates:**

- Conductive plates (usually made of metal) are layered with mica sheets in between. The assembly is encased in a protective material to prevent damage and environmental effects.

- **Encapsulation:**

- Often sealed with resin or placed in a ceramic case to protect against moisture and contaminants.



(a) Stacked layer arrangement

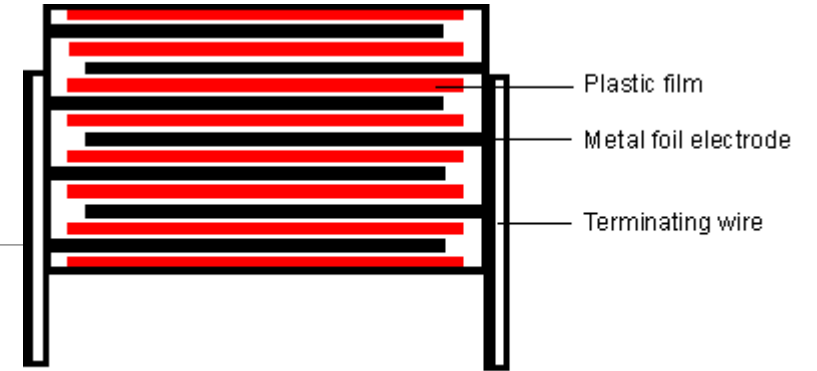


(b) Layers are pressed together and encapsulated.

Mica Capacitors (Characteristics)

- **High Stability:** Mica capacitors maintain their capacitance value over a wide range of temperatures and frequencies.
- **Low Loss:** They exhibit low dielectric loss, making them ideal for high-frequency applications.
- **High Precision:** Typically available with tight tolerance levels, such as $\pm 1\%$ or $\pm 5\%$, for applications requiring accuracy.
- **Low Capacitance Range:** Capacitance values are relatively low, ranging from a few picofarads (pF) to several nanofarads (nF).
- **High Voltage Rating:** Mica capacitors can handle high voltages, often up to several thousand volts.

(Plastic) Film Capacitors



- **Dielectric Material:**

- Made from thin plastic films, such as:
 - **Polypropylene (PP):** Offers excellent electrical properties (good insulator) and high voltage handling.
 - **Polyester (PET):** Known for cost-effectiveness and good performance in general applications.
 - **Polytetrafluoroethylene (PTFE):** Provides high-temperature resistance and low loss.
 - **Polycarbonate (PC):** Used for precision applications (less common today).

- **Plates:**

- Thin layers of metal (aluminium or zinc) are deposited on the plastic film or added as separate metal foils.

- **Encapsulation:**

- The assembled layers are rolled or stacked and then enclosed in a protective casing, such as epoxy or resin, to shield against moisture and environmental damage.

(Plastic) Film Capacitors (Characteristics)

High Stability: Excellent capacitance stability over temperature, frequency, and time.

Low Loss: Minimal energy dissipation makes them efficient in AC and high-frequency circuits.

Wide Range of Capacitance: Available in values from a few picofarads (pF) to several microfarads (μF).

Voltage Ratings: Suitable for both low-voltage (several volts) and high-voltage (up to thousands of volts) applications.

Non-Polarized: Can be used in AC and DC circuits without concern for polarity.

Paper Capacitors (Components)

- **Dielectric Material:** Layers of thin paper are used as the dielectric. The paper is often impregnated with oil, wax, or resin to enhance its insulating properties and protect it from moisture.
- **Plates:** Thin sheets of metal foil or metallized paper act as the capacitor plates. These plates are sandwiched with the paper layers.
- **Encapsulation:** The assembly is rolled into a cylindrical or flattened shape and encased in a protective material like plastic, wax, or resin.
- **Connection:** Leads are attached to the metal plates for electrical connection.

Paper Capacitor (Characteristics)

Capacitance Range: Typically, available in values ranging from a few nanofarads (nF) to several microfarads (μF).

Voltage Ratings: Designed for low to medium voltage applications, usually up to a few hundred volts.

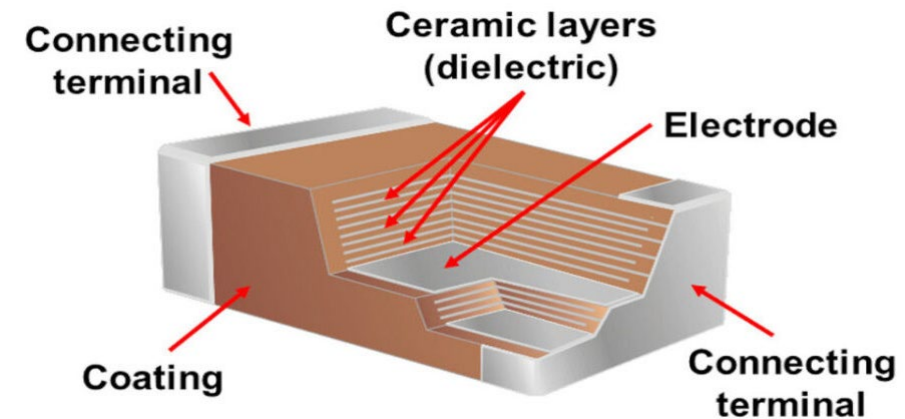
Moisture Sensitivity: Susceptible to degradation due to moisture unless well sealed.

Stability: Moderate stability compared to modern dielectric materials like plastic or ceramic.

Dielectric Loss: Higher dielectric loss than modern capacitors, making them less efficient in AC circuits.

Ceramic Capacitors (Components)

- **Dielectric Material:** Made of ceramic, a non-conductive material with high dielectric constant. Commonly used ceramics include barium titanate and titanium dioxide, which provide high permittivity.
- **Plates:** Thin layers of conductive material, such as silver or palladium, are applied to the ceramic as electrodes.
- **Layering:**
 - **Multilayer Ceramic Capacitors (MLCCs):** Consist of multiple alternating layers of ceramic dielectric and conductive plates, increasing capacitance in a small footprint.
 - **Single-layer Ceramic Capacitors:** Simplified structure, used in older designs or specialty applications.
- **Encapsulation:** The capacitor is typically coated with an epoxy or resin for protection against environmental factors like moisture and dust.

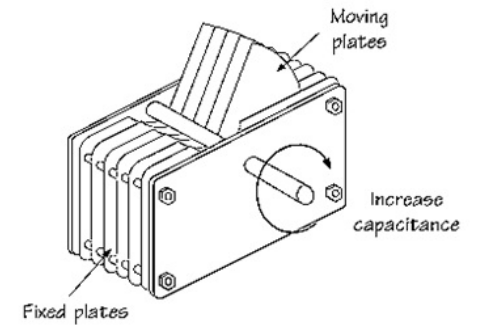


Ceramic Capacitors (Characteristics)

- **Capacitance Range:** Available from a few picofarads (pF) to several microfarads (μF), with higher capacitance values achievable in multilayer designs.
- **Voltage Ratings:** Operate in a wide voltage range, from a few volts to several kilovolts, depending on the design.
- **Temperature Coefficient:** Ceramic capacitors are classified based on their temperature stability:
 - **Class 1:** High precision, stable capacitance over temperature (e.g., NP0, C0G types).
 - **Class 2:** Higher capacitance with some temperature variation (e.g., X7R, Y5V types).
- **Frequency Characteristics:** Low equivalent series resistance (ESR) and high-frequency performance make them ideal for RF and high-speed circuits.
- **Non-Polarized:** Can be used in both AC and DC circuits without concern for polarity.

Variable Capacitor (Components)

- **Plates:** Composed of overlapping conductive plates:
 - **Movable Plates (Rotor):** Can rotate or slide to adjust the overlap area.
 - **Fixed Plates (Stator):** Remain stationary during adjustment.
- **Dielectric Material:** Typically air, ceramic, or plastic. In some designs, a solid dielectric is used to ensure stability.
- **Adjustment Mechanism:** A knob, screw, or motor moves the rotor plates to vary the capacitance.
- **Encapsulation:** Enclosed in a protective casing to reduce interference and environmental effects.

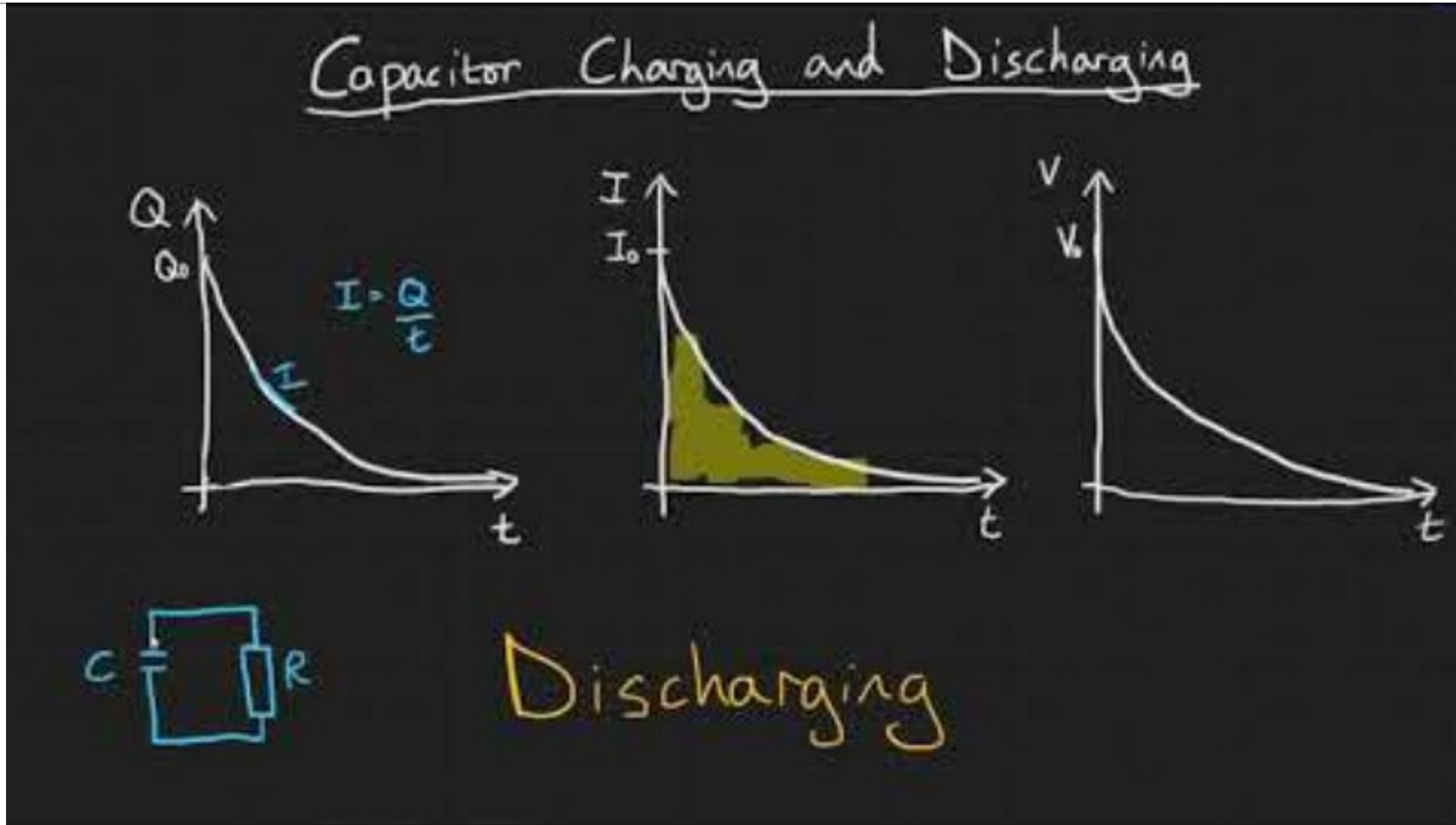


Variable Capacitor (Characteristics)

- **Adjustable Capacitance:** The Capacitance on a variable capacitor can be changed allowing for precise control.
- **Capacitance Range:** Variable capacitors typically have a small capacitance range, e.g., 1 pF to 500 pF.
- **Tuning Ratio:** Represents the ratio between maximum and minimum capacitance values.
- **Voltage Rating:** Generally low, suitable for signal processing circuits.

<https://youtu.be/fVkRDjrRnc4>

Charging and Discharging a Capacitor



Equations

- Equation for **charge**:
 - Charge = Capacitance * Voltage
- **Capacitance** of a parallel plate capacitor:
 - Capacitance = ϵ_0 * (Area of 1 plate/distance between plates)
- **Capacitance** of a parallel plate capacitor with dielectric:
 - Capacitance = Dielectric constant * ϵ_0 * (Area of 1 plate/distance between plates)



ϵ_0 = Permittivity of free space = 8.85×10^{-12}

Capacitance in series

Series Capacitances

$$C_{\text{total}} = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \dots + \frac{1}{C_n}}$$

Capacitance in Parallel

Parallel Capacitances

$$C_{\text{total}} = C_1 + C_2 + \dots + C_n$$