Capacitors

YORK COLLEGE & UNIVERSITY CENTRE

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).

$$1\,\mathrm{F} = \frac{1\,\mathrm{C}}{1\,\mathrm{V}}$$

Parts of a capacitor

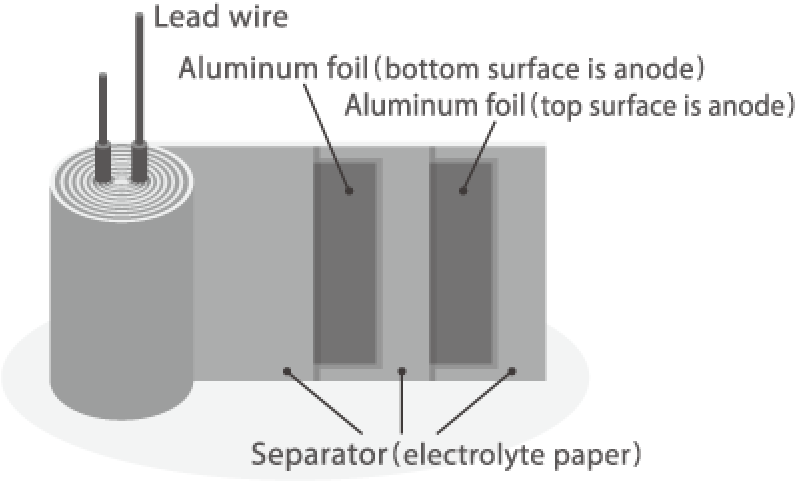
- **Plates**: Store electric charge and create the electric field.
- **Dielectric**: Enhances energy storage by insulating and increasing capacitance.
- **Anode**: Stores positive charge.
- **Cathode**: Completes the circuit and stores negative charge.

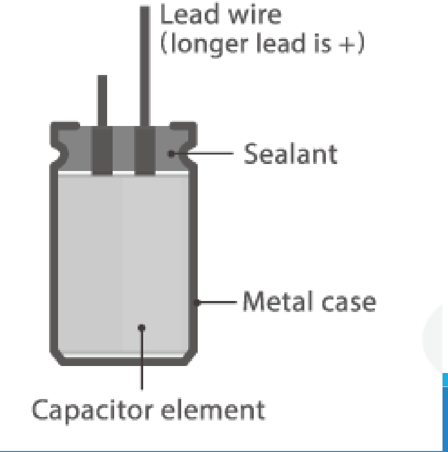
Dielectric Material	Dielectric Constant
Vacuum	1
Air	1.006
Polypropylene PP	2.2
Polyphenylene Sulfide PPS	3
Polyester PET	3.3
Polyester PEN	3
Impregnated Paper	2.0 – 6.0
Mica	6.8
Aluminium Oxide	8.5
Tantalum Oxide	27.7
Paraelectric Ceramics (Class1)	5.0 – 9.0
Barium Titanate (Class 2)	3000 - 8000

Electrolytic Capacitor (Components)

Components:

- **Anode (positive plate)**: Made from aluminum 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.
- **Cathode terminal**: Often made of a conductive metal foil in contact with the electrolyte.
- Encased in an aluminium can or other housing material for protection.



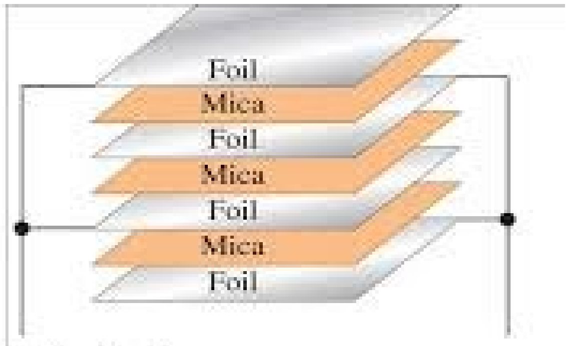


Electrolytic Capacitor (Characteristics)

- **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.



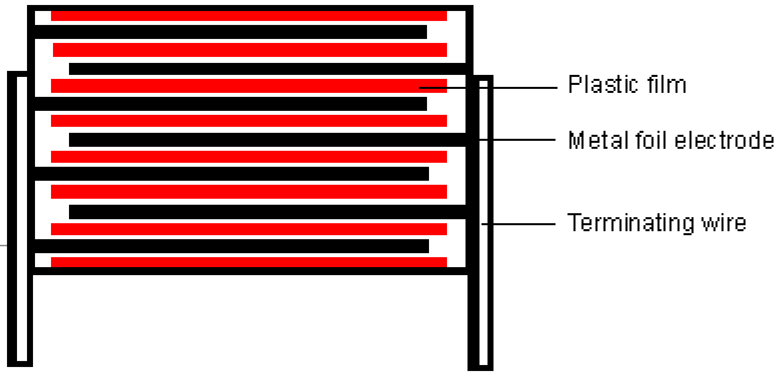
(a) Stacked layer arrangement


(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 ±1% or ±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 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 fewnanofarads (nF) to several microfarads (µF).

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

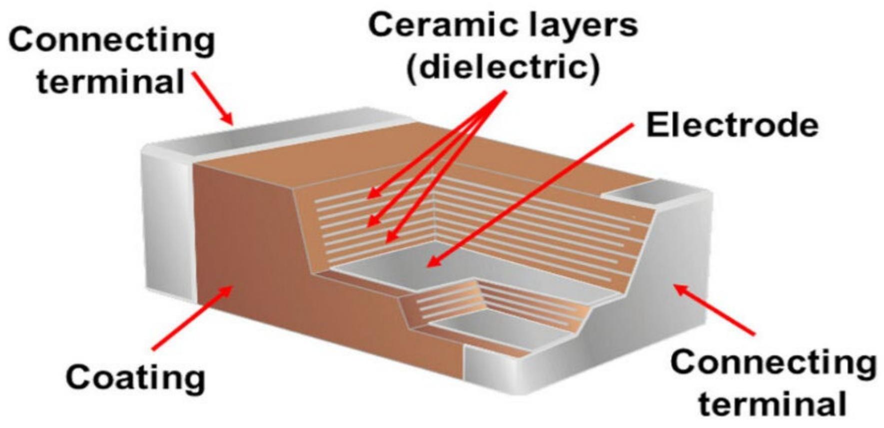
Moisture Sensitivity: Susceptible to degradation due to moisture unless well sealed.

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.

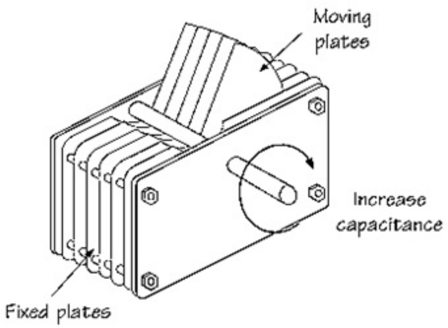


Ceramic Capacitors (Characteristics)

- **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.

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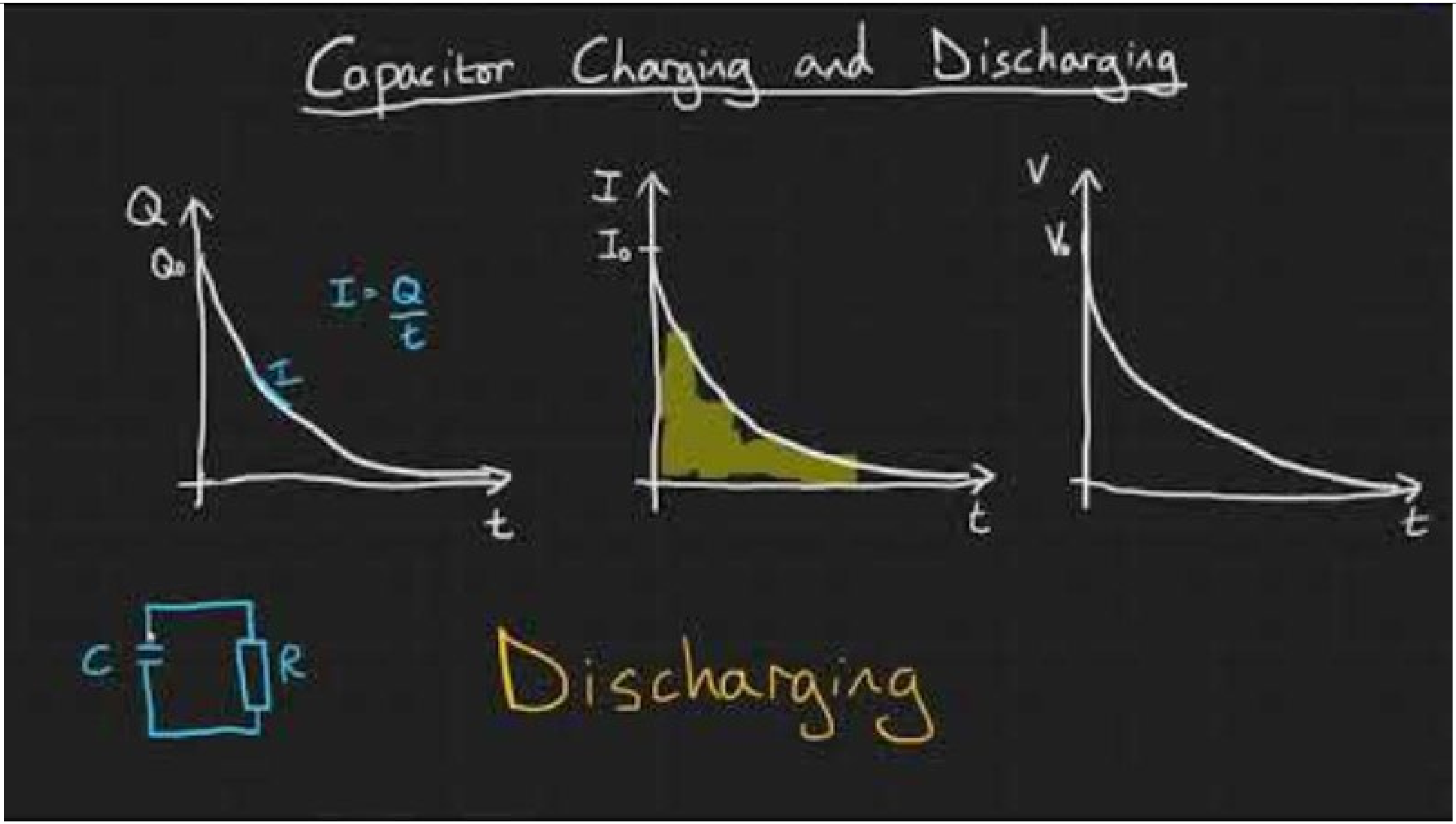
Charging and Discharging a Capacitor



Equations

- Equation for **charge**:
  - Charge = Capacitance * Voltage
- **Capacitance** of a parallel plate capacitor:
  - Capacitance = ε0 * (Area of 1 plate/distance between plates)
- **Capacitance** of a parallel plate capacitor with dielectric:
  - Capacitance = Dielectric constant * ε0 * (Area of 1 plate/distance between plates)

E0 = Permittivity of free space = 8.85×10^{-12}

Capacitance in series

Series Capacitances

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

Capacitance in Parallel

Parallel Capacitances

$$C_{total} = C_1 + C_2 + \ldots C_n$$