Electronic Basics #14: Capacitors

Introduction to Capacitors

A **capacitor** is a fundamental passive electronic component that stores electrical energy in an **electric field**. Unlike resistors, which dissipate energy as heat, capacitors temporarily hold charge and release it when needed. They are widely used in **power supply circuits, signal processing, timing applications, and filtering**. Capacitors come in different types, such as **ceramic, electrolytic, film, and supercapacitors**, each suited for specific applications based on capacitance value, voltage rating, and response time.

Basic Structure: Parallel Plate Capacitor and Dielectric

A capacitor consists of **two conductive plates** separated by an **insulating material (dielectric)**. When a voltage is applied, opposite charges accumulate on each plate, creating an **electric field** between them. The capacitance (CC) of a parallel plate capacitor is given by:

C=εAdC

where:

- C = capacitance (farads, F)
- ε = permittivity of the dielectric material
- A = surface area of the plates (m²)
- d = distance between the plates (m)

The capacitance increases with **larger plate area and smaller separation distance**.

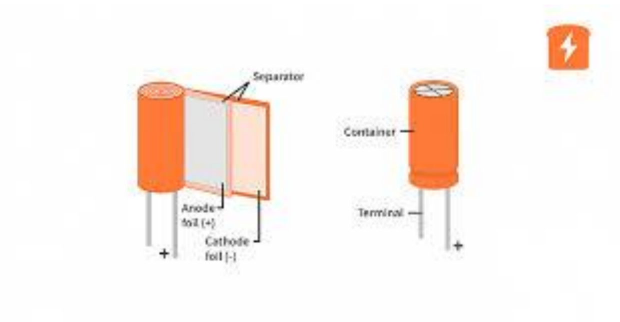

Fig14.1: Capacitor Structure

How Does a Capacitor Work?

When connected to a **power source**, a capacitor **stores electrical charge** until it reaches the applied voltage. It does not allow continuous current flow like a resistor. Instead, it acts as a **temporary charge reservoir**, storing and releasing energy based on the circuit conditions.

- **In DC circuits**, capacitors charge up to the supply voltage and then stop conducting, effectively acting as an **open circuit**.
- **In AC circuits**, capacitors constantly charge and discharge as the voltage changes direction, allowing **AC signals to pass through** while blocking DC.

This charging and discharging behavior make capacitors useful in **energy storage, filtering, and timing applications**.

Increasing Capacitance with Dielectric Material

The **dielectric** placed between the plates enhances capacitance by reducing the electric field strength and increasing charge storage capacity. The capacitance increases by a factor of the **dielectric constant (εr\varepsilon_r)**, given by:

C=$\epsilon_0 \epsilon_r$AdC

where:

- ε0 is the permittivity of free space
- εr is the relative permittivity of the dielectric

Materials like **ceramic, mica, and plastic** are commonly used to improve capacitor efficiency.

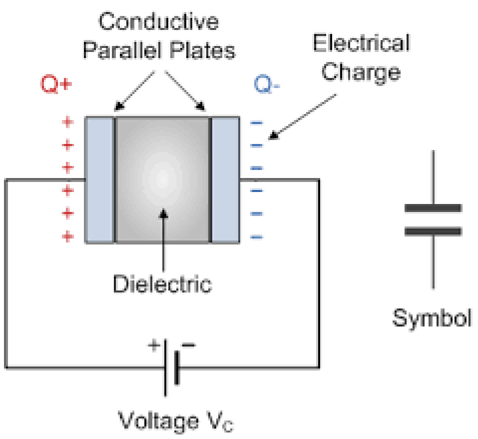

Fig14.2: Charge Storing of a Capacitor and using

a di-electric medium

Switching Operation in DC and AC Circuits

Switching Behavior in DC Circuits

When a capacitor is connected to **DC power**, its behavior can be divided into three stages:

1. **Charging Phase:**
   - When a switch is closed, current starts flowing, and the capacitor begins to charge.
   - The **voltage across the capacitor increases gradually** following the equation:

VC=Vs(1−e−t/RC)V_C

- The **charging current is initially high** and decreases over time as the capacitor approaches full charge.

2. **Fully Charged State (Steady-State):**
   - After a long time ($t \gg RCt$), the capacitor is fully charged, and current stops flowing.
   - The capacitor now acts as an **open circuit**, **blocking further DC current**.
3. **Discharging Phase:**
   - When the power source is disconnected and the capacitor is connected to a load, it **discharges**, releasing stored energy.
   - The voltage across the capacitor decreases exponentially:

VC=Vse−t/RCV_C = V_s e^{-t/RC}

   - This property is used in **memory storage, power backup circuits, and pulsed power applications**.

Switching Behavior in AC Circuits

In **AC circuits**, capacitors continuously charge and discharge as the voltage changes direction. Unlike DC, where a capacitor eventually blocks current, in an AC circuit, the capacitor **allows current to flow by constantly responding to voltage variations**.

1. **Continuous Charging and Discharging:**
   - As AC voltage **increases**, the capacitor stores charge.
   - When AC voltage **reverses polarity**, the capacitor discharges and recharges in the opposite direction.
   - This process **allows AC signals to pass through**, making capacitors useful for **coupling and filtering applications**.
2. **Frequency Dependence:**
   - At **higher frequencies**, a capacitor charges and discharges faster, allowing more current to pass.
   - At **lower frequencies**, the capacitor charges and discharges more slowly, restricting current flow.
   - This property is used in **frequency-dependent circuits like filters and oscillators**.
3. **Phase Shift in AC Circuits:**
   - In a **purely capacitive circuit**, the **current leads the voltage by 90°**.
   - This means the **current reaches its peak before the voltage does**, which is important in **power factor correction and reactive power management**.

Capacitive Reactance and Formula

The **opposition** a capacitor offers to AC is called **capacitive reactance (XCX_C)**, given by:

X_C=1/2πfC

where:

- X_C= capacitive reactance (ohms, Ω)
- f= frequency (Hz)
- C= capacitance (farads)

As frequency increases, X_C **decreases**, meaning capacitors allow higher-frequency signals to pass more easily. This makes them useful in **high-pass filters, signal processing, and AC coupling applications**.

Applications of Capacitors

- **Energy Storage:** Stores energy in flash cameras, UPS systems, and power backup circuits.
- **Signal Filtering:** Removes noise and unwanted frequencies in communication circuits.
- **AC-DC Conversion:** Smooths voltage output in rectifier circuits.
- **Timing Circuits:** Used in clocks, pulse generators, and oscillators.
- **Motor Starters:** Provides phase shift for efficient induction motor operation.
- **Power Factor Correction:** Improves efficiency in AC power systems by compensating for inductive loads.