CHAPTER - 9

FUNDAMENTALS OF CAPACITORS
CONTENTS:

- Introduction
- Capacitance
- Factors Affecting Capacitance
- Electric Fields
- Types of Capacitors
- Capacitors in Parallel and Series
- Capacitor Current and Voltage
- Energy Stored By A Capacitor
INTRODUCTION

- Capacitor is a circuit component designed to store electrical charge
- It will “charge” to the voltage of the source
- If disconnected from the source, the capacitor will remain charged
- Capacitors are widely used in electrical and electronic applications
  - Radio
  - TV systems
  - Cameras to store the charge that fires the photoflash
  - Pump and refrigeration motors
  - Electric power systems to increase operating efficiency
Capacitance is the electrical property of capacitors.

It is a measure of how much charge a capacitor can hold.
THE UNIT OF CAPACITANCE, the farad, is named after Michael Faraday (1791–1867)
Born in England to a working class family, Faraday received limited education
he was responsible for many of the fundamental discoveries of electricity and magnetism
Lacking mathematical skills
Faraday published his theory in 1844
It is also interesting to note that the development of the field concept grew out of Faraday’s research into magnetism, not electric charge
CAPACITANCE

- A capacitor consists of two conductors separated by an insulator (called a dielectric).
- The dielectric may be air, oil, mica, plastic, ceramic, or other suitable insulating material.

(a) Basic construction  (b) Symbol
CAPACITANCE

- Capacitor after charging
- When the source is disconnected, electrons are trapped on the bottom plate
- Thus, charge is stored
DEFINITION OF CAPACITANCE

- The amount of charge \( Q \) that a capacitor can store depends on the applied voltage.
- \( Q \) is proportional to voltage.

\[
Q = CV
\]

\[
C = \frac{Q}{V} \quad \text{(Farad, F)}
\]

“The capacitance of a capacitor is one farad if it stores one coulomb of charge when the voltage across its terminals is one volt.”
DEFINITION OF CAPACITANCE

Capacitors range in size from picofarads (pF or $10^{-12}$ F) to microfarads ($\mu$F or $10^{-6}$ F)

Example 1. (a) How much charge is stored on a 10-$\mu$F capacitor when it is connected to a 24-volt source? (b) The charge on a 20-nF capacitor is 1.7 $\mu$C. What is its voltage?

Solution:

a. $Q = CV = \left(10 \times 10^{-6} \text{ F}\right)\left(24 \text{ V}\right) = 240 \mu\text{C}$

b. $V = \frac{Q}{C} = \frac{\left(1.7 \times 10^{-6} \text{ C}\right)}{\left(20 \times 10^{-9} \text{ F}\right)} = 85 \text{ V}$
FACTORS AFFECTING CAPACITANCE

- Effect of Area

“Capacitance is directly proportional to plate area”

(a) Capacitor with area $A$ and charge $Q$

(b) Plates with four times the area have four times the charge and therefore, four times the capacitance
 FACTORS AFFECTING CAPACITANCE

- **Effect of Spacing**
  
  "Capacitance is inversely proportional to plate spacing"
FACTORS AFFECTING CAPACITANCE

- **Effect of Dielectric**
  - Capacitance also depends on the dielectric.
  - Dielectric is a factor by which capacitance increases for a number of different materials based on the relative permittivity of air.

<table>
<thead>
<tr>
<th>Material</th>
<th>$\varepsilon_r$ (Nominal Values)</th>
</tr>
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<tbody>
<tr>
<td>Vacuum</td>
<td>1</td>
</tr>
<tr>
<td>Air</td>
<td>1.0006</td>
</tr>
<tr>
<td>Ceramic</td>
<td>30–7500</td>
</tr>
<tr>
<td>Mica</td>
<td>5.5</td>
</tr>
<tr>
<td>Mylar</td>
<td>3</td>
</tr>
<tr>
<td>Oil</td>
<td>4</td>
</tr>
<tr>
<td>Paper (dry)</td>
<td>2.2</td>
</tr>
<tr>
<td>Polystyrene</td>
<td>2.6</td>
</tr>
<tr>
<td>Teflon</td>
<td>2.1</td>
</tr>
</tbody>
</table>
ELECTRIC FIELDS

- Electric fields are force fields that exist in the region surrounding charged bodies.
- Unlike charges attract and like charges repel - a force exists between them.
ELECTRIC FIELDS

- The region where this force exists is called an ELECTRIC FIELD
TYPES OF CAPACITORS

- Fixed Capacitors - are often identified by their dielectric
  - Ceramic
  - Plastic
  - Mica
  - Electrolytic capacitors
  - Aluminum
  - Tantalum oxide
TYPES OF CAPACITORS

- **Variable Capacitors** - has a set of stationary plates and a set of movable plates which are ganged together and mounted on a shaft
  - **Type of Variable:**
    - trimmer or padder capacitor
CAPACITORS IN PARALLEL AND SERIES

- Capacitors in Parallel
  “Total capacitance is the sum of the individual capacitances”

\[ Q_1 = C_1V \]
\[ Q_2 = C_2V \]
CAPACITORS IN PARALLEL AND SERIES

\[ C_T = C_1 + C_2 + \ldots + C_N \]
Example 2. A 10-μF, a 15-μF, and a 100-μF capacitor are connected in parallel across a 50-V source. Determine the following:
   a. Total capacitance
   b. Total charge stored
   c. Charge on each capacitor

Solution:

\[ C_T = C_1 + C_2 + C_3 \]

\[ C_T = 10 \, \mu F + 15 \, \mu F + 100 \, \mu F = 125 \, \mu F \]
Solution:

b. $Q_T = C_T V = (125 \ \mu F)(50 \ V) = 6.25 \ mC$

c. $Q_1 = C_1 V = (10 \ \mu F)(50 \ V) = 0.5 \ mC$

$Q_2 = C_2 V = (15 \ \mu F)(50 \ V) = 0.75 \ mC$

$Q_3 = C_3 V = (100 \ \mu F)(50 \ V) = 5.0 \ mC$

Check:

$Q_T = Q_1 + Q_2 + Q_3$

$Q_T = (0.5 + 0.75 + 5.0) \ mC = 6.25 \ mC$
CAPACITORS IN PARALLEL AND SERIES

Capacitors in Series

“Total capacitance is always smaller than the smallest capacitance”

\[
\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \ldots + \frac{1}{C_N}
\]

\[
C_T = \frac{C_1 C_2}{C_1 + C_2}
\]
Example 3. For the circuit of Figure below, determine $C_T$. 
Example 3. For the circuit of Figure below, determine $C_T$. 

![Circuit Diagram]

- $30 \mu F$ component
- $20 \mu F$ component
- $12 \mu F$ component
CAPACITOR CURRENT AND VOLTAGE

Several points should be noted:

- This movement of electrons constitutes a current.
- This current lasts only long enough for the capacitor to charge. When the capacitor is fully charged, current is zero.
- Current in the circuit during charging is due solely to the movement of electrons from one plate to the other around the external circuit; no current passes through the dielectric between the plates.
CAPACITOR CURRENT AND VOLTAGE

Several points should be noted:

- As charge is deposited on the plates, the capacitor voltage builds.
- The difference in voltage between the source and the capacitor decreases and hence the rate of movement of electrons (i.e., the current) decreases as the capacitor approaches full charge.
“Current in a capacitor exists only while capacitor voltage is changing”

Capacitor voltage. $V_C = E$ when fully charged.
“Current in a capacitor exists only while capacitor voltage is changing”

Current surge during charging. Current is zero when fully charged.

“If the source voltage is increased, additional electrons are pulled from the positive plate”
Capacitor $v-i$ Relationship

$$q = Cv_c$$

$$i_c = \frac{dq}{dt} = \frac{d(Cv_c)}{dt}$$

Since $C$ is constant:

$$i_c = C \frac{dv_c}{dt}$$
ENERGY STORED BY A CAPACITOR

- An ideal capacitor does not dissipate power.
- All of it is stored as energy in the capacitor’s electric field.
- When the capacitor is discharged, this stored energy is returned to the circuit.
- Power is given by $P = vi$ watts.
- Energy, $W$, is; $W = \frac{1}{2}CV^2$ Joules.
Thank You!