BASIC ELECTRICAL ENGINEERING UNIT II

MODULE 1: Electrostatics and Capacitance

MODULE 2: Electromagnetism and Inductance

Additional Text: Electrical and Electronic Principles and Technology by JOHN BIRD, Second Edition

EEE204

Outline

Module 1: Electrostatics and Capacitance

- Electrostatics laws,
- Permittivity,
- Electric field,
- Field intensity,
- Flux density,
- Potential and work done.
- Electric field of a parallel plate capacitor,
- Multi-plate capacitor, capacitors in series and parallel,
- Energy stored in a capacitor.

Module 2: Electromagnetism and Inductance

- Laws of magnetic force,
- Magnetic fields,
- Permeability and magnetomotive force,
- Field intensity,
- Flux density,
- Potential and work done.
- Electromagnetic induction,
- Self and Mutual inductances.
- Inductances in series and parallel,
- Energy stored in an inductor;
- Electrochemical power sources.

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Introduction

WHY STUDY ELECTROSTATICS?

- Electrostatics is the basis of industrial processes such as electrostatic spray painting, and xerography, photography etc.
- We study electrostatic phenomena in this course not simply to understand the applications of static charge, but because the ideas are applicable in other branches of electricity, and the electrical aspects of other sciences.

Demonstration

Try by rubbing a Pen through your hair and move it close to a piece of paper. What do you think is responsible?

Of what used is this phenomenon?



Electrostatics



- Electrostatics is Electric charges at rest (static electricity)
- It is the branch of Physics, which deals with the behavior of stationary electric charges.
- Charges exist in two different kinds called positive and negative, these charges when in combination add algebraically i.e. the charge is a scalar quantity always quantized in integral multiples of electronic charge.
- Charge is a fundamental property of the ultimate particles making up matter, the total charge of a closed system cannot change i.e. net charge is conserved in an isolated system
- Involves electric charges, the forces between them, and their behavior in materials

Electric Forces and Charge



- Arise from the particles in atoms
- Alone: Billions and billions of times as strong as the force of gravity
- In Pairs: Cancel each other out and have no noticeable effect
- In an atom, a positively charged nucleus is surrounded by electrons
- The protons (+) in the nucleus attract the electrons (-), while the electrons repel each other
- This attraction and repulsion behavior gives an object its charge

| Charge of an Electron | $q_e = -1.6 \cdot 10^{-19} C$ |
|--------------------------|-------------------------------|
| Charge of a Proton | $q_p = +1.6 \cdot 10^{-19} C$ |

Electrostatic Laws

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Fundamental Rule:

• Like charges repel; opposite charges attract

Conservation of Charge:

- Electrons are never created nor destroyed, but are simply transferred from one material to another
- No case of the creation or destruction of net electric charge has ever been found
- Electrons are always transferred in whole they cannot be divided into fractions of electrons

Electrostatic Laws



- Coulomb's Inverse Square Law
- Coulomb's inverse square law gives the force between the two charges. According to this law, the force (F) between two electrostatic point charges (q₁ and q₂) is proportional to the product of the charges and inversely proportional to the square of the distance (r) separating the *charges*.



Electrostatic Laws

$$F = K \frac{q_{1} q_{2}}{r^{2}}$$

where \mathbf{K} (*Coulomb constant*) is proportionality constant which depends on the nature of the medium.

This force acts along the line joining the charges. For a dielectric medium of relative permittivity ε_r , the value of **K** is given by,

$$K = \frac{1}{4 \pi \varepsilon_0 \varepsilon_r} = \frac{1}{4 \pi \varepsilon} = 9 \times 10^{-9}$$

where ε = permittivity of the medium. Units of charge = Coulomb (C)

Sample Problem



Two electrons are a meter apart. What is the force between them? What direction is it in?

Two electrons are two meters apart. What is the force between them? What direction is it in?

Electric Field

- Electric charges affect the space around them.
- The space around the charge within which its effect is felt or experienced is called *Electric field*.
- Electric field Intensity (or) Strength of the Electric field, due to a point charge q_a at a given point is defined as the force per unit charge exerted on a test charge q_b placed at that point in the field. $\vec{E} = \frac{\vec{F}_{ba}}{\vec{F}_{ba}} = \frac{q_a}{r_{ba}}$ voltm⁻¹ (or) NC¹

$$\vec{E}_a = \frac{F_{ba}}{q_b} = \frac{q_a}{4\pi\epsilon_0 r^2}$$
 volt \vec{m} (or) NC¹

 Electric Fields have a magnitude and direction hence are vector quantities

Electric lines of force

 An Electric field may be described in terms of lines, of force in much the same way as a magnetic field.

Properties of electric lines of force

- 1.Every Lines of force originates from a positive charge and terminates on negative charge.
- 2.Lines of force never intersect.
- 3. The tangent to Lines of force at any point gives the direction of the electric field E at that point.
- 4. The number of Lines of force per unit area at right angles to the lines is proportional to the magnitude of E.
- 5.Each unit positive charge gives rise to lines of force in free space.







+a



Electric Flux Density



- The Electric flux is defined as the number of lines of force that pass through a surface placed in the electric field.
- The Electric flux (*dφ*) through elementary area ds is defined as the product of the area and the component of electric field strength normal to the area.

Gauss theorem (or) Gauss law



- This Law relates the flux through any closed surface and the net charge enclosed within the surface.
- The Electric flux (φ) through a closed surface is equal to the $1/\epsilon_0$ times the net charge q enclosed by the surface.

$$\phi = \left(\frac{1}{\varepsilon_0}\right) q$$
 (or) $\phi = \left(\frac{q}{\varepsilon_0}\right) = \oint E \, ds \cos\theta$

Electric Flux Density (or) Electric Displacement Vector (D)



• It is defined as the number of Electric Lines of force passing normally through a unit area of cross section in the field. It is given by,

$$D = \frac{\phi}{A}$$

• Unit : Coulomb / m²

Permittivity

Permittivity is defined as the ratio of electric displacement vector (D) in a dielectric medium to the applied electric field strength (E).

$$\varepsilon = \frac{D}{E}$$

Mathematically it is given by,

$$\boldsymbol{\mathcal{E}} = \boldsymbol{\mathcal{E}}_0 \boldsymbol{\mathcal{E}}_r$$

- ε_0 = permittivity of free space or vacuum
- \mathcal{E}_r = permittivity or dielectric constant of the medium

Sample Problem



Electric field strength

$$E = \frac{V}{d} = \frac{200}{0.8 \times 10^{-3}} = 250 \,\mathrm{kV/m}$$

Problem 6. Two parallel plates having a p.d. of 200 V between them are spaced 0.8 mm apart. What is the electric field strength? Find also the electric flux density when the dielectric between the plates is (a) air, and (b) polythene of relative permittivity 2.3

a) For air:
$$\varepsilon_r = 1$$
 and $\frac{D}{E} = \varepsilon_0 \varepsilon_r$

Hence electric flux density

$$D = E\varepsilon_0\varepsilon_r$$

- = $(250 \times 10^3 \times 8.85 \times 10^{-12} \times 1) \text{ C/m}^2$ = $2.213 \,\mu \text{C/m}^2$
- (b) For polythene, $\varepsilon_r = 2.3$

Electric flux density

- $D = E\varepsilon_0\varepsilon_r$ = (250 × 10³ × 8.85 × 10⁻¹² × 2.3) C/m²
 - $= 5.089 \,\mu C/m^2$

Electrostatic Potential (V)



- The electrostatic potential energy of a system of point charges is the work needed to bring the charges from an infinite separation to their final positions
- The Electric potential is defined as the amount of work done in moving unit positive charge from infinity to the given point of the field of the given charge against the electrical force.
- Unit: volt (or) joule / coulomb

• Potential
$$V = -\int_{\infty}^{r} E \cdot dx = -\int_{\infty}^{r} \frac{q}{4\pi\varepsilon_{0} x^{2}} dx$$

$$V = \frac{q}{4\pi\varepsilon_{0}} \left[\frac{1}{r} - \frac{1}{\infty} \right] = \frac{q}{4\pi\varepsilon_{0} r}$$

Electrostatic Potential (V)



- When we bring a point charge q from far away to a region where there are other charges, we must do work (qV), which is stored as electrostatic potential energy. For a system of charges this is the total work needed to assemble the charges.
- When positive charge is placed on an isolated conductor, the **potential**, **V**, of the conductor increases.
- The ratio of the charge to the potential is called the **capacitance** of the conductor.

Capacitance

- The capacitance is a measure of how much charge must be put on the plates to produce a certain potential difference between them. The greater the capacitance the more charge is required.
- In the circuit the battery maintains a potential difference between its terminals, with positive terminal at higher potential.
- When switch is closed, electrons move through electric field along wire, towards the +ve plate, and away from the -ve plate the positive terminal of the battery.





Calculating the potential difference

- In general we can choose a path that follows an electric field line, from the negative to the positive plate. For this path <u>E</u> and <u>ds</u> will have opposite directions, so we can rewrite V as
- The potential difference between the plates of a capacitor is related to the field <u>E</u> by

$$V = -\int_{i}^{f} \underline{E} \cdot d\underline{s}$$



Parallel-plate capacitor

For a parallel-plate capacitor, as shown, experiments show that capacitance C is proportional to the area A of a plate, inversely proportional to the plate spacing d (i.e. the dielectric thickness) and depends on the nature of the dielectric.

$$\mathbf{q} = \mathbf{C}\mathbf{V}$$







Capacitance C is the proportionality constant. It is dependent only on the geometry of the plates, and not on their charge or potential EEE_{204}

parallel-plate capacitor

- Another method used to increase the capacitance is to interleave several plates as shown four plates are shown, forming three capacitors with a capacitance nine times that of one pair of plates.
- If such an arrangement has n plates then capacitance $C \alpha (n-1)$.
- Thus capacitance

$$C = \frac{\mathcal{E}_0 \mathcal{E}_r A(n-1)}{d} farads$$



Capacitance, $C = \frac{\varepsilon_0 \varepsilon_r A}{d}$ farads where $\varepsilon_0 = 8.85 \times 10^{-12}$ F/m (constant) ε_r = relative permittivity A = area of one of the plates, in m^2 , and d = thickness of dielectric in m

Capacitors connected in series and parallel

- Capacitors, like resistors, can be placed in series and in parallel.
- Increasing levels of capacitance can be obtained by placing capacitors in parallel,
- While decreasing levels can be obtained by placing capacitors in series.
- For capacitors in series, the charge is the same on each capacitor



The total capacitance of two capacitors in se-

ries is

$$C_{T} = \frac{C_{1}C_{2}}{C_{1} + C_{2}}$$

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Applying Kirchhoff's voltage law around the closed loop gives

However,

so that

 $E = V_1 + V_2 + V_3$ $V = \frac{Q}{C}$ $\frac{Q_T}{C_T} = \frac{Q_1}{C_T} + \frac{Q_2}{C_T} + \frac{Q_3}{C_T}$

dividing both sides by Q yields



!3

Capacitors connected in series and parallel



• For capacitors in parallel, as shown below, the voltage is the same across each capacitor, and the total charge is the sum of that on each capacitor:



Energy Stored in a Capacitor



- An ideal capacitor does not dissipate any of the energy supplied to it. It stores the energy in the form of an electric field between the conducting surfaces.
- The energy stored by a capacitor is given as:

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

In general,

$$W_C = \frac{1}{2}CV^2 \qquad (J)$$

where V is the steady-state voltage across the capacitor. In terms of Q and C,

$$W_C = \frac{1}{2}C\left(\frac{Q}{C}\right)^2$$
$$W_C = \frac{Q^2}{2C} \qquad (J)$$

or

What does a capacitor look like?





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Applications







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Capacitor

