Chapter 10

Capacitors and Capacitance

Capacitance

- Capacitor
  - Stores charge
  - Two conductive plates separated by insulator
  - Insulating material called dielectric
  - Conductive plates can become charged with opposite charges

Definition of Capacitance

- Amount of charge Q that a capacitor can store depends on applied voltage
- Relationship between charge and voltage given by

  $Q = CV$ or $C = Q/V$ (Similar to Ohm's Law)

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Definition of Capacitance

- C is capacitance of the capacitor
- Unit is the farad (F)
- Capacitance of a capacitor
  - One farad if it stores one coulomb of charge
  - When the voltage across its terminals is one volt

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Effect of Area

- Capacitance is directly proportional to amount of charge
- Larger plate will be able to hold more charge

5

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Effect of Area

- Capacitance is directly proportional to plate area
- If plate area is doubled, capacitance is doubled

6

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Effect of Spacing

- As plates are moved closer together
  - Force of attraction between opposite charges is greater
- Capacitance
  - Inversely proportional to distance between plates

Effect of Spacing

- Double the distance between plates
  - Capacitance becomes half as much

Effect of Dielectric

- If a dielectric other than air is used between the plates
  – More charge can build up on the plates
- The factor by which the capacitance increases
  – Dielectric constant or the relative permittivity

9

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Effect of Dielectric

- Permittivity
  – How easy it is to establish electric flux in a material
  – Represented by ε (Greek letter epsilon)

10

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Capacitance of a Parallel-Plate Capacitor

- Directly proportional to plate area
- Inversely proportional to plate separation
- Dependent on dielectric

$$C = \in \frac{A}{d}$$

- A farad is a very large unit

11

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Electric Flux

- Electric fields
  - Force fields in region surrounding charged bodies
- Direction of this field is direction of force on a positive test charge
- Field lines never cross

12

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Electric Flux

- Density of lines indicate field strength
- Electric field lines are indicated by ψ (Greek letter psi)

13

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Electric Fields

- Strength of an electric field is force that field exerts on a small test charge
  - $E = F/Q$
- Electric flux density = total flux/area
  - $D = \psi/A$

14

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Electric Fields

- Flux is due to the charge *Q*
- The number of flux lines coming from a charge is equal to the charge itself
  - $\psi = Q$

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Field of a Parallel-Plate Capacitor

- To move a charge from the negative plate to the positive plate requires work
- Work = Force × distance
- Voltage = Work/charge
- $E = V/d$

Field of a Parallel-Plate Capacitor

- Electric field strength between plates
  - Equal to voltage between them
  - Divided by distance between them

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Voltage Breakdown

- If voltage is increased enough, dielectric breaks down
- This is dielectric strength or breakdown voltage

Voltage Breakdown

- Breakdown can occur in any type of apparatus where insulation is stressed
- Capacitors are rated for maximum operating voltage

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Nonideal Effects

- Leakage current
- Equivalent Series Resistance
- Dielectric Absorption
- Temperature Coefficient

Fixed Capacitors

- Ceramic Capacitors
  - Values change little with temperature, voltage, or aging
- Plastic Film Capacitors
- Mica Capacitors
  - Low cost, low leakage, good stability

Fixed Capacitors

- Electrolytic Capacitors
  - Large capacitance at low cost
  - Polarized
- Surface Mount Capacitors

Variable Capacitors

- Used to tune a radio
- Stationary plates and movable plates
  - Combined and mounted on a shaft
- A trimmer or padder capacitor is used to make fine adjustments on a circuit

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Capacitors in Parallel

- Total charge on capacitors is sum of all charges
- $Q = CV$
- $C_T E = C_1 V_1 + C_2 V_2 + C_3 V_3$
- All voltages are equal

Capacitors in Parallel

- $C_T = C_1 + C_2 + C_3$
- Total capacitance of capacitors in parallel
  - Sum of their capacitances (like resistors in series)

Capacitors in Series

- Same charge appears on all capacitors
- Total *V*
  - Sum of individual voltages (like resistors in parallel)

Capacitors in Series

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

$$\frac{Q}{C_T} = \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3}$$

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

Capacitor Voltage

- Voltage across a capacitor does not change instantaneously
- Voltage begins at zero and gradually climbs to full voltage

Capacitor Voltage

- Full voltage is source voltage
- May range from nanoseconds to milliseconds
  - Depending on the resistance and capacitance

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Capacitor Current

- During charging
  - Electrons move from one plate to another
- Current lasts only until capacitor is charged

Capacitor Current

- Current
  - Large initial spike to zero
- No current passes through dielectric

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Energy Stored in a Capacitor

- A capacitor does not dissipate power
- When power is transferred to a capacitor
  - Stored as energy

$$\text{Energy} = \frac{1}{2}CV^2$$

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Capacitor Failures and Troubleshooting

- Reasons for capacitor's failure
  - Excessive voltage, current, or temperature, or aging
- Test with an ohmmeter
  - Good capacitor will read low, then gradually increase to infinity

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Capacitor Failures and Troubleshooting

- Capacitor short
  - Meter resistance will stay low

Capacitor Failures and Troubleshooting

- If capacitor is leaky
  - Reading will be lower than normal
- If open
  - Stays at infinity