Chapter 9

Capacitors

Objectives

- Describe the basic structure and characteristics of a capacitor
- Discuss various types of capacitors
- Analyze series capacitors
- Analyze parallel capacitors
- Describe capacitive dc switching circuits
- Describe capacitive ac circuits

Basics of a Capacitor

- In its simplest form, a **capacitor** is an electrical device constructed of two parallel plates separated by an insulating material called the **dielectric**
- In the neutral state, both plates have an equal number of free electrons
- When a voltage source is connected to the capacitor, electrons are removed from one plate and an equal number are deposited on the other plate
- No electrons flow through the dielectric (insulator)

Basics of a Capacitor

- When the supply is removed from the capacitor, the capacitor retains the stored charge
- The amount of charge that a capacitor can store per volt across the plates is its **capacitance** (C)
- The unit of capacitance is the **farad** (F). One farad is the amount of capacitance when one coulomb of charge is stored with one volt across the plates
- Most capacitors in electronics work have capacitance values of μF (10^{-6} F) or ρF (10^{-12} F)

How a Capacitor Stores Energy

- A capacitor stores energy in the form of an electric field that is established by the opposite charges on the two plates
- A capacitor obeys **Coulomb's law**:

A force exists between two point-source charges that is directly proportional to the product of the two charges and inversely proportional to the square of the distance between the charges

Capacitor Ratings

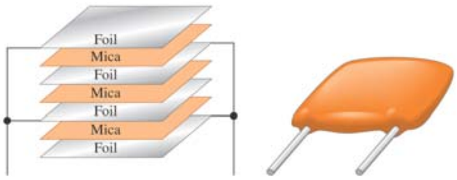
- The voltage rating specifies the maximum dc voltage that can be applied without risk of damage to the device (**breakdown** or **working voltage**) determined by the **dielectric strength**
- Temperature coefficient indicates the amount and direction of a change of capacitance with temperature
  - positive coefficient means that capacitance increases with increasing temp., while a negative coefficient means capacitance decreases with increasing temp.

Characteristics of a Capacitor

- Capacitance is directly proportional to the physical size of the plates as determined by the plate area
- Capacitance is inversely proportional to the distance between the plates
- The measure of a material's ability to establish an electric field is called the dielectric constant (ε)
  - Capacitance is directly proportional to the dielectric constant

Fixed Capacitors

- Stacked-foil mica capacitors are made of alternate layers of metal foil and thin sheets of mica
- Silver mica are formed by stacking mica sheets with silver electrode material screened on them



(a) Stacked layer arrangement

(b) Layers are pressed together and encapsulated.

Fixed Capacitors

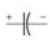
- Ceramic dielectrics provide very high dielectric constants, and relatively large capacitance in a small physical size
- Capacitance ranges are from 1pF to 2.2μF

(a) (b)

Electrolytic Capacitors

- Electrolytic capacitors are polarized so that one plate is positive, and the other negative
- They come in capacitance values from 1μF to 200,000 μF, with voltage ratings to 350 V

(b) Typical radial-lead electrolytics



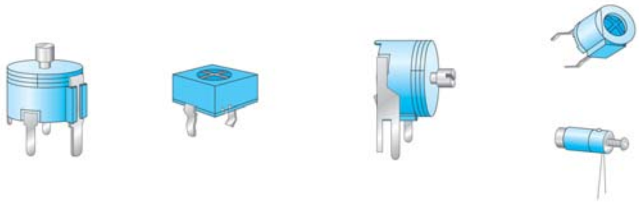
(c) Symbol for an electrolytic capacitor. The straight plate is positive and the curved plate is negative, as indicated.

Electrolytic Capacitors

- Two common types of electrolytic capacitors are Aluminum and Tantalum electrolytics
- The voltage polarity of these devices must be observed, as reversal of polarity will usually result in complete destruction of the capacitor

Variable Capacitors

- Variable capacitors are used in circuits when there is a need to adjust the capacitance value
- Ceramic or mica is a common dielectric
- Capacitance is changed by plate separation



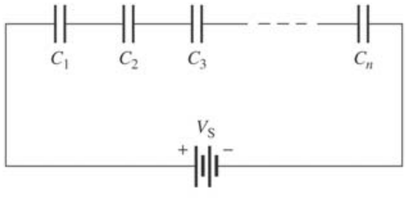
Capacitor Labeling

- Capacitors use several standard labeling methods; we will consider a small ceramic capacitor:
  - values marked as .001 or .01 have units of microfarads
  - values marked as 50 or 330 have units of picofarads
  - a value of 103 or 104 would be 10×10^3 (10,000 pF) or 10×10^4 (100,000 pF) respectively
  - The units may be on the capacitor as pF or μF (μF may be written a MF or MFD)

Series Capacitors

- When capacitors are connected in series, the total capacitance is less than the smallest capacitance value since the effective plate separation increases

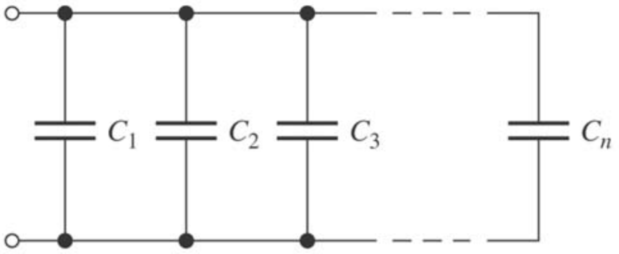
$$1/C_T = 1/C_1 + 1/C_2 + 1/C_3 + \ldots + 1/C_n$$



Parallel Capacitors

- The total parallel capacitance is the sum of all capacitors in parallel

$$C_T = C_1 + C_2 + C_3 + \ldots + C_n$$



Capacitors in DC Circuits

- A capacitor will charge up when it is connected to a dc voltage source
- When a capacitor is fully charged, there is no current
- There is no current through the dielectric of the capacitor because the dielectric is an insulating material
- A capacitor blocks constant dc

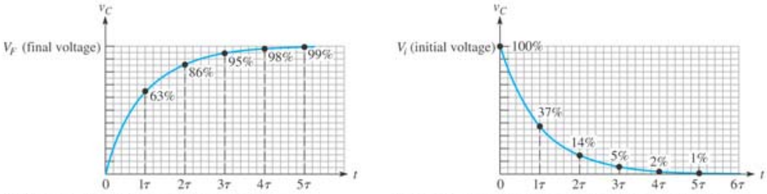
RC Time Constant

- The voltage across a capacitor cannot change instantaneously because a finite time is required to move charge from one point to another (limited by circuit resistance)
- The time constant of a series RC circuit is a time interval that equals the product of the resistance and the capacitance

$$\boldsymbol{\tau = RC}$$

Charging and Discharging

- The charging curve is an increasing exponential
- The discharging curve is a decreasing exponential



(a) Charging curve with percentages of final voltage

(b) Discharging curve with percentages of initial voltage

Transient time

- It takes 5 time constants to change the voltage by 99% (charging or discharging), this is called the **transient time**

Capacitors in ac Circuits

- The instantaneous capacitor current is equal to the capacitance times the instantaneous rate of change of the voltage across the capacitor
- This rate of change is a maximum positive when the rising sine wave crosses zero
- This rate of change is a maximum negative when the falling sine wave crosses zero
- The rate of change is zero at the maximum and minimum of the sine wave

Capacitive Reactance, X_C

- Capacitive reactance (X_C) is the opposition to sinusoidal current, expressed in ohms
- The rate of change of voltage is directly related to frequency
- As the frequency increases, the rate of change of voltage increases, and thus current (*i*) increases
- An increase in *i* means that there is less opposition to current (X_C is less)
- X_C is inversely proportional to *i* and to frequency

Capacitive Reactance, X_C

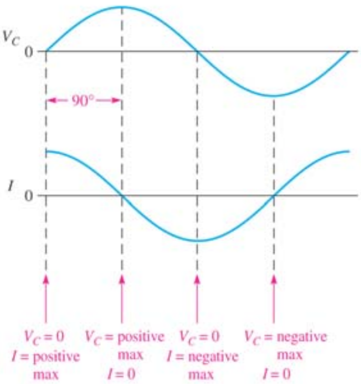
- The relationship between capacitive reactance, capacitance and frequency is:

$$X_C = 1/(2\pi f C)$$

where: X_C is in ohms (Ω)
f is in hertz (Hz)
C is in farads (F)

Analysis of Capacitive ac Circuit

- The current leads the voltage by 90° in a purely capacitive ac circuit



Power in a Capacitor

- Energy is stored by the capacitor during a portion of the voltage cycle; then the stored energy is returned to the source during another portion of the cycle
- **Instantaneous power** (p) is the product of v and i
- **True power** (P_{true}) is zero, since no energy is consumed by the capacitor
- The rate at which a capacitor stores or returns energy is called **reactive power** (P_r); units: (VAR)

Capacitor Applications

- Capacitors are used for filtering in power supplies
- Since capacitors do not pass dc, they are used for dc blocking and ac coupling
- For power line decoupling, capacitors are connected between the dc supply and ground, to suppress unwanted voltage spikes that occur on the dc supply voltage due to fast switching
- Capacitors are used to bypass an ac voltage around a resistor without affecting the dc resistance

Capacitor Applications

- Capacitors are used in filters, to select one ac signal with a certain specified frequency from a wide range of signals with many different frequencies
  - For example, the selection of one radio station and rejecting the others
- Capacitors are used in timing circuits to generate time delays, based on the RC time constant
- Dynamic memories used in computers are simply very tiny capacitors used as a storage element

Summary

- A capacitor is composed of two parallel conducting plates separated by a *dielectric* insulator
- Energy is stored by a capacitor in the electric field between the plates
- Capacitance is measured in units of farads (F)

Summary

- Capacitance is directly proportional to the plate area and inversely proportional to the plate separation
- Dielectric constant is an indication of the ability of a material to establish an electric field
- Dielectric strength is one factor that determines the breakdown voltage of a capacitor
- A capacitor blocks constant dc

Summary

- The time constant for a series RC circuit is the series resistance times the capacitance
- In an RC circuit, the voltage and current in a charging or discharging capacitor make a 63% change during each time-constant interval
- 5 time constants are required for a capacitor to fully charge or to discharge fully. This is called the **transient time**
- Charging and discharging are exponential curves

Summary

- Current leads voltage by 90° in a capacitor
- Capacitive reactance is the opposition to ac, expressed in ohms
- X_C is inversely proportional to frequency and capacitance value
- The true power in a capacitor is zero; that is, there is no energy loss in an ideal capacitor
  - most capacitors have some small energy loss due to leakage resistance