Chapter 13

Inductance and Inductors

Circuit Analysis with Devices:
Theory and Practice
THOMSON DELMAR LEARNING

Inductors

- Common form of an inductor is a coil of wire
  - Used in radio tuning circuits
- In fluorescent lights
  - Part of ballast circuit

Inductors

- On power systems
  - Part of the protection circuitry used to control short-circuit currents during faults

Circuit Analysis with Devices:
Theory and Practice
THOMSON
DELMAR LEARNING

Electromagnetic Induction

- Voltage is induced
  - When a magnet moves through a coil of wire
  - When a conductor moves through a magnetic field

Electromagnetic Induction

- Change in current in one coil can induce a voltage in a second coil
- Change in current in a coil can induce a voltage in that coil

Circuit Analysis with Devices:
Theory and Practice
THOMSON
DELMAR LEARNING

Electromagnetic Induction

- Faraday's Law
  - Voltage is induced in a circuit whenever the flux linking the circuit is changing
  - Magnitude of voltage is proportional to rate of change of the flux linkages with respect to time

Electromagnetic Induction

- Lenz's Law
  - Polarity of the induced voltage opposes the cause producing it

Circuit Analysis with Devices: Theory and Practice
THOMSON DELMAR LEARNING

Induced Voltage and Induction

- If a constant current is applied
  - No voltage is induced
- If current is increased
  - Inductor will develop a voltage with a polarity to oppose increase

Induced Voltage and Induction

- If current is decreased
  - Voltage is formed with a polarity that opposes decrease

9

Iron-Core Inductors

- Have flux almost entirely confined to their cores
- Flux lines pass through the windings
- Flux linkage as product
  - Flux times number of turns

10

Iron-Core Inductors

- By Faraday's law
  - Induced voltage is equal to rate of change of $N\Phi$

Circuit Analysis with Devices:
Theory and Practice
THOMSON DELMAR LEARNING

Air-Core Inductors

- All flux lines do not pass through all of the windings
- Flux is directly proportional to current
- Induced voltage directly proportional to rate of change of current

Self-Inductance

- Voltage induced in a coil is proportional to rate of change of the current
- Proportionality constant is *L*
  - Self-inductance of the coil-units are Henrys (H)

Circuit Analysis with Devices:
Theory and Practice
THOMSON DELMAR LEARNING

Self-Inductance

- Inductance of a coil is one Henry
  - If the voltage created by its changing current is one volt
  - When its current changes at rate of one amp per second

$$v_L = L\frac{\Delta i}{\Delta t}$$

Inductance Formulas

- Inductance of a coil is given by

$$L = \frac{\mu N^2 A}{\ell}$$

- ℓ is the length of coil in meters
- *A* is cross-sectional area in square meters
- *N* is number of turns
- μ is permeability of core

Circuit Analysis with Devices:
Theory and Practice
THOMSON
DELMAR LEARNING

Inductance Formulas

- If air gap is used, formula for inductance is

$$L = \frac{\mu_0 N^2 A_g}{\ell_g}$$

- Where μ_o is permeability of air
- A_g is area of air gap
- ℓ_g is length of gap

THOMSON
DELMAR LEARNING

Computing Induced Voltage

- When using equation

$$v_L = L\frac{\Delta i}{\Delta t}$$

  - If current is increasing, voltage is positive
  - If current is decreasing, voltage is negative
  - $\Delta i/\Delta t$ is slope for currents described with straight lines

17

Circuit Analysis with Devices:
Theory and Practice

THOMSON
DELMAR LEARNING

Inductances in Series

- For inductors in series
  - Total inductance is sum of individual inductors (similar to resistors in series)

$$L_T = L_1 + L_2 + L_3$$

18

Robbins and Miller

Copyright © 2007 Thomson Delmar Learning

Inductances in Parallel

- Inductors in parallel add as resistors do in parallel

$$\frac{1}{L_T} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3}$$

Core Types

- Type of core depends on intended use and frequency range
- For audio or power supply applications
  - Inductors with iron cores are generally used

Circuit Analysis with Devices: Theory and Practice

THOMSON DELMAR LEARNING

Core Types

- Iron-core inductors
  - Large inductance values but have large power losses at high frequencies
- For high-frequency applications
  - Ferrite-core inductors are used

21

Robbins and Miller

Circuit Analysis with Devices: Theory and Practice

THOMSON DELMAR LEARNING

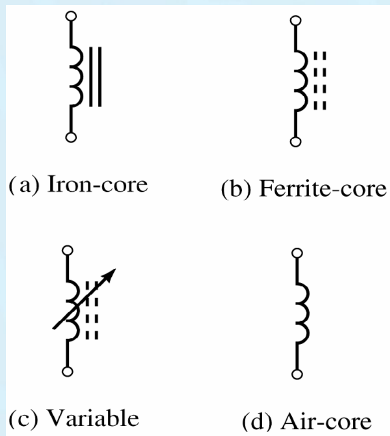
Variable Inductors

- Used in tuning circuits
- Inductance may be varied by changing the coil spacing
- Inductance may be changed by moving a core in or out

22

Robbins and Miller

Circuit Symbols



Stray Capacitance

- Turns of inductors are separated by insulation
  - May cause stray or parasitic capacitance
- At low frequencies, it can be ignored
  - At high frequencies, it must be taken into account
- Some coils are wound in multiple sections to reduce stray capacitance

Stray Inductance

- Current-carrying components have some stray inductance
  - Due to magnetic effects of current
- Leads of resistors, capacitors, etc. have inductance
  - These leads are often cut short to reduce stray inductance

Circuit Analysis with Devices: Theory and Practice
THOMSON DELMAR LEARNING

Inductance and Steady State DC

- Voltage across an inductance with constant dc current is zero
- Since it has current but no voltage, it looks like a short circuit at steady state
- For non-ideal inductors
  - Resistance of windings must be considered

Robbins and Miller
Copyright © 2007 Thomson Delmar Learning

Circuit Analysis with Devices: Theory and Practice

THOMSON DELMAR LEARNING

Energy Stored by an Inductance

- When energy flows into an inductor
  - Energy is stored in its magnetic field
- When the field collapses
  - Energy returns to the circuit

27

Robbins and Miller

Circuit Analysis with Devices: Theory and Practice

THOMSON DELMAR LEARNING

Energy Stored by an Inductance

- No power is dissipated, so there is no power loss
- Energy stored is given by

$$W = \frac{1}{2} L i^2$$

28

Robbins and Miller

Troubleshooting Hints

- Use ohmmeter
- Open coil will have infinite resistance
- Coil can develop shorts between its windings causing excessive current
  - Checking with an ohmmeter may indicate lower resistance