Engineering Design *An Introduction*

Chapter 13

Designing Electrical Systems

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Introduction

- Electronic technology
  - Big impact on human existence
- History
  - Late 1700s
    - Mechanical and metallurgical technologies dominated
  - By late 1800s:
    - Internal combustion engines, lighting, heating, telegraph, radio, telephone invented

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Introduction (cont'd.)

- History (cont'd.)
  - 2000s
    - Very rapid growth of electronic technology

The Science of Electricity

- Elements in the periodic table
  - Basic building blocks in nature
- Protons
  - Positive charge
- Neutrons
  - Neutral charge
- Electrons
  - Negative charge

The Science of Electricity (cont'd.)

- Equations for gravitational and electric forces

$$F_g = G\frac{M_1 M_2}{r^2} \qquad F_e = ko\frac{Q_1 Q_2}{r^2}$$

- Gravitational force
  - Always attractive
- Electric force
  - Can be attractive or repulsive

The Science of Electricity (cont'd.)

Figure 13-2: Similarities and differences between gravitational and electrical forces.

Similarities	Differences
Governed by inverse square law	Attractive or repulsive
Force between two bodies	Size of electric forces can be huge
Force is along a line connecting the two bodies	Charge can be very mobile

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Electrical Conductors and Insulators

- Conductor
  - Material that allows a flow of charge
- Insulator
  - Material that does not allow charge to flow
- Copper atom
  - Large number of free electrons
  - Good conductor

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Electrical Conductors and Insulators (cont'd.)

- Conductivity
  - Higher values indicate better conductors
- Resistivity
  - Inverse of conductivity
- Semiconductors
  - Resistivity values in between conductors and insulators

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Figure 13-4: Common conductor materials and their conductive and resistive properties.

Material	Conductivity, σ (Ω^{-1}-m^{-1})	Resistivity, ρ (Ω-m) [$\rho = 1/\sigma$]
Silver	63×10^6	16×10^{-9}
Copper	60×10^6	17×10^{-9}
Gold	45×10^6	22×10^{-9}
Aluminum	38×10^6	26×10^{-9}
Nickel	15×10^6	69×10^{-9}
Iron	10×10^6	96×10^{-9}
Sea water	5	0.2
De-ionized water	5.5×10^{-6}	2×10^5

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Electrical Conductors and Insulators (cont'd.)

- Polyvinyl chloride (PVC)
  - Used in insulating electrical wires
- Oxides
  - Used as insulators in micro-electronic and micro-optical chips

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Figure 13-5: *Common materials used as electric insulators.*

Material	Resistivity, ρ (Ω-m)
Glass (silicon dioxide)	$10^{10} - 10^{14}$
Polyvinyl chloride (PVC) [rubber]	10^{13}
Sulfur	10^{15}
Teflon	$10^{22} - 10^{24}$

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Electrical Resistance

- Total electrical resistance of a piece of material
  - Calculated using $R=\rho L/A$
    - ρ is resistivity
    - L is the length of the material
    - A is the material's cross-sectional area

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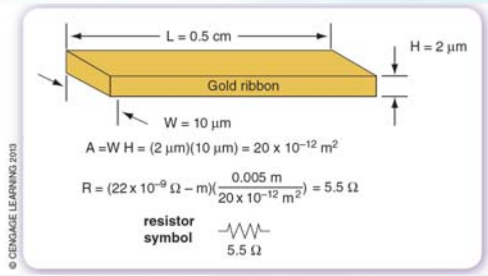

Figure 13-7: Example of a resistance calculation using a wire of rectangular cross-section (or wire "ribbon"). Ribbon wire of this approximate size is not uncommon for certain integrated circuits. Even though gold is a very good conductor, this calculation shows that even a good conductor can have appreciable resistance (5.5 ohms) if the cross-sectional area is small enough. Also shown is the circuit schematic symbol for a resistor.

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Ohm's Law

- Ohm's law
  - One of the first practical and useful laws of electricity
  - Given by V=IR or I=V/R
    - V = voltage
    - I = current
    - R = resistance

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Ohm's Law (cont'd.)

- Current, I
  - Rate of flow of charge
  - Measured in coulombs per second, or amperes
- Types of current
  - Direct current
  - Alternating current

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Ohm's Law (cont'd.)

- Resistance, R
  - Measure of electrical resistance
  - Units of ohms (Ω)
- Voltage, V
  - Measured in volts (V)
  - Measures amount of potential energy that can be imparted to a charge

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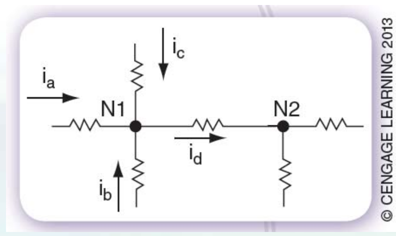
Kirchhoff's Laws

- Kirchhoff's current law
  - The total flow of current into a node must equal the total flow of current out of a node

Figure 13-12: Portion of a circuit containing several resistors showing two nodes, N1 and N2.



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Kirchhoff's Laws (cont'd.)

- Kirchhoff's voltage law
  - The sum of voltages around any closed loop must be equal to zero

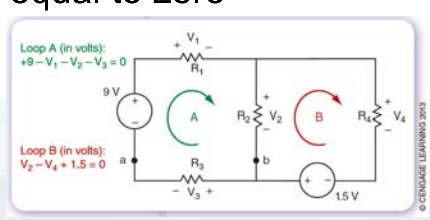

Figure 13-13: A circuit with two loops, one shown in green (A) and the second in red (B). These two loops are used to demonstrate Kirchhoff's voltage law: The sum of voltages around any closed loop is zero.

Magnetism

- Magnetic forces
  - Caused by moving charges
- Types of magnets
  - Permanent magnets
  - Electromagnets

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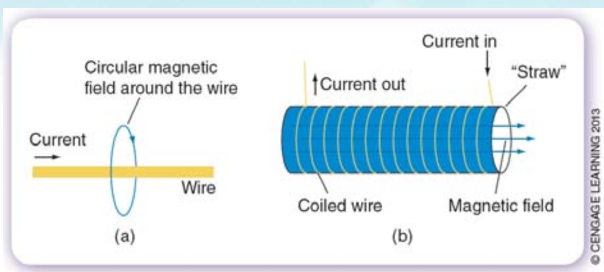

Figure 13-15: Magnetic fields are created by moving charge. Diagram (a) shows how a (circular) magnetic field is formed around a straight wire that carries a constant current. The principle shown in diagram (a) can be used to form a straight magnetic field by coiling the wire into a circular pattern (b), like wrapping a wire around a straw. With coiled wire, the magnetic field is formed "inside" the straw, parallel to the central axis of the straw.

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Major Circuit Components

- Three basic electronic circuit elements
  - Resistors
  - Capacitors
  - Inductors

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Resistors

- Most widely used electrical component
- Carbon resistors are most common
  - And least expensive
- Manufactured to specific tolerances
  - ±20 percent, 10 percent, 5 percent, or 1 percent of stated value

Power Consumption of Resistors

- Consumer electronic equipment
  - Requires low power consumption
- Power formula

  Power = current * voltage or P=IV
- Power through a resistor

$$P=I^2R$$

$$P=V^2/R$$

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Capacitor

- Nonlinear component
  - Complex relationship between voltage and current
- Capable of storing energy
- Consists of two metal plates:
  - Separated by a thin insulating layer

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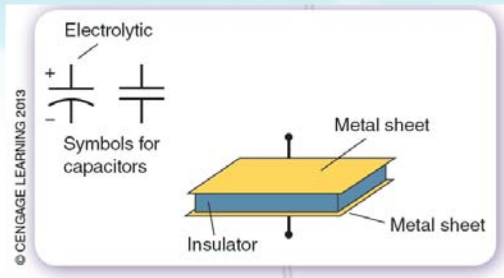

Figure 13-19: Capacitors are essentially two parallel conductors separated by an insulating material. The operation of a capacitor depends on time-varying electric fields. A capacitor is often used to store energy. The symbols for a capacitor are also shown.

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Inductor

- Another nonlinear component
- Capable of storing energy
- Made by coiling wire into a circular fashion
  - Wires typically coated by plastic
- Direction of the magnetic field opposes the flow of current
  - Reduces the current

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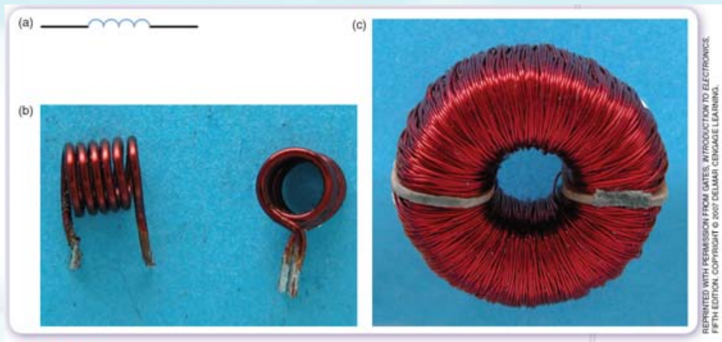

Figure 13-20: An inductor is typically a coil of wire, available in various shapes and sizes. To keep the metal coils from touching one another, the wire is typically coated with a very thin layer of insulation (plastic). The center may be filled with air or other materials, like iron, that will affect the magnitude of the inductance. The operation of an inductor depends on a self-induced magnetic effect. An inductor can store energy. The symbol for an inductor is also shown.

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Electronic Systems Design

- Input
  - Consists of one or more sensors
    - Sensors convert physical phenomenon into information
- Process
  - Modifying the input signal
- Output
  - Processed signal converted to usable form

System Inputs

- Types of inputs and sensors
  - Light (photoresistor)
  - Heat (temperature sensor)
  - Sound (microphone)
  - Position (switch)

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System Outputs

- Displays
  - Provide visual information
- Actuators
  - Make movements
- Transducers
  - Convert an electrical signal into a physical property

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System Outputs (cont'd.)

- Light-emitting diodes
  - Devices that very effectively emit light
  - Use little power
- Actuator examples
  - Direct current (DC) motors
  - Stepper motors
  - Solenoids

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System Processors

- Analog processors
  - Manipulate time-varying continuous signals
- Digital processors
  - Can only process digital information
    - Either a 1 or a 0

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Analog Processors

- Transistors
  - Semiconductor devices that can switch large currents on and off using a small control current
- 555-timer chips
  - Integrated circuit
  - Used to turn something on for a period of time

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Analog Processors (cont'd.)

- Operational amplifiers
  - Circuits that can perform mathematical functionality
  - Known as op-amps

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Digital Processors

- Also known as microprocessors
- Examples of devices that use microprocessors
  - Computers
  - Cell phones
  - Dishwashers
  - Automobiles
  - Many, many more

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Digital Processors (cont'd.)

- Coding
  - Unique series of 1s and 0s can be used to represent unique set of items
- Logic operations
  - INVERT
  - AND
  - OR

Digital Processors (cont'd.)

- Binary numbers
  - Base 2 instead of base 10
- Components of a microprocessor
  - CPU (central processing unit)
  - ALU (arithmetic logic unit)
  - Memory
  - Input/output

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Decimal	Binary
0	00000
1	00001
2	00010
3	00011
4	00100
5	00101
6	00110
7	00111
8	01000
9	01001
10	01010
11	01011
12	01100
13	01101
14	01110
15	01111
16	10000
17	10001

Figure 13-49: A chart showing the numbers 0 through 17 in both decimal and binary systems.

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