ESE112

Introduction to Electrical Circuits

Application - Robotics

- Sensors to get information
  - A device that measures a physical quantity and converts it into a signal (electrical)
  - E.g. Thermistor to measure temperature
    - Type of resistor whose resistance varies with temperature

- Actuators used in navigation
  - Electrical energy is converted in mechanical energy to drive motors
    - Usually interaction of magnetic fields and current-carrying conductors
    - Video of simple motor

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Electric Charge

- Fundamental to all electrical phenomena
- Is a property of atomic particles of which matter exists
  - Protons(+ve), Electrons (-ve)
- Measured in Coulombs (C)
  - 1 C = 6.2 x 10^{18} charged particles

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Voltage & Current

- Charges become mobile if there is force to move them
  - Voltage (V) is the energy required to move a unit charge through an element
    - Potential difference between two points
    - Measured in Volts (V) i.e. 1 Joule/1 Coulomb

- Motion of charges creates Electric Current
  - Current is the rate of flow of charge
    - Measured in Amperes (A) i.e. 1 Coulumb/1sec
    - Current flows from high-potential to low potential
    - The direction of the current is taken to be as the movement of positive charges i.e. opposite to flow of negative charges
Battery - electromotive force

- 2 different metals in a chemical solution
  - One metal +ve charge and other –ve charged
- If a wire (conducting material e.g. copper) is attached from one end of the battery to the other then
  - Electrons flow through the wire to balance the electrical charge
- If a load such as a lightbulb is placed along the wire, the electricity can do work as it flows through the wire.

Battery (contd..)

- House-hold solution
  - Lemon Battery
  - Cu (penny) - +ve
  - Zinc (galvanized nail) –ve
- Commercial
  - AA – Zinc & carbon
  - Alkaline – Zinc & Manganese Oxide
  - Car battery - Lead-acid

AC vs. DC current

- Alternating Current (AC)
  - Current that varies (sinusoidal) with time
    - Wall socket provide AC that alternates 60 times per second
  - Easy to change the voltage, using a device called a transformer

- Direct Current (DC)
  - Batteries, solar or fuel cells produce current that remains constant with time
  - Current always flows in the same direction between two (positive and negative) terminals

Resistance (R)

- Is the opposition to the flow of charge
- Depends on
  - Directly proportional to length of element (l)
  - Inversely proportional to cross-sectional area (A)
  - Inversely proportional to conductivity of the element
- Measured in Ohms (Ω)
- Passive element
  - Element which is not a source of energy
Resistor Color Coding

- Resistors can be 4 band or 5 band
- In 4 band resistors
  - 4\textsuperscript{th} band is tolerance band (gold or silver)
  - 3\textsuperscript{rd} band is multiplier

Source: www.pc-control.co.uk/images/resistor_code2.gif

Relationship between V, I, R

An electric circuit is an interconnection of electrical elements

Ohms Law: \( V = IR \)

Internal resistance

- Easy to forget that resistance in every part of a circuit
- Avoid long connecting wires
  - Simple – longer the wire, longer time it takes for the electrons to travel
- Simulation software used to model electric circuits may not account that compared to a real circuit

Kirchoff's Electrical Laws

- Voltage Law
  - Sum of the Voltage around a closed loop is zero
- Loop: any path that starts and ends at the same point
- Current Law
  - Sum of current entering a node (or junction or closed boundary) is zero
Resistors in Series and Parallel

- **Equivalent Resistance**
  - Resistors in series
    - \( R_{eq} = R_1 + R_2 + \ldots + R_n \)
  - Resistors in Parallel
    - \( \frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} \)

- Using KVL and KCL we can prove Series and Parallel Equivalent Resistance Equations

**Voltage Divider**

\[ V_{cut} = \frac{R_2}{R_1 + R_2} \cdot V_{in} \]

Power (DC resistive circuits)

- Is the rate at which work is performed or energy is transmitted
  - \( P = V \cdot I \)
    - \( 1 \text{J} / 1 \text{C} \cdot 1 \text{C}/1 \text{sec} = 1 \text{J}/1 \text{sec} = 1 \text{Watt} \)
  - Alternatively (using Ohm’s Law)
    - \( P = V \cdot \frac{V}{R} = \frac{V^2}{R} \)

- **Power Rating**
  - Primarily for elements that dissipate electric power and or convert into mechanical power
  - Indicates the max. power than can be safely dissipated by the device

Summary of Symbols

- [Battery]
- [Resistance]
- [Variable Resistance]
- [Ground (reference point in an electrical circuit from which other voltages are measured)]
**Diode**

- Allows electricity to flow in only one direction
- The arrow of the circuit symbol shows the direction in which the current can flow
- Modern diodes are realized from semiconductors

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**Semiconductor**

- Semiconductor material are in between conductors (like metals) and insulators (like glass)
  - In pure form, it is non-conducting
  - E.g. silicon crystal - has 4 electrons in its outer orbital, which form perfect covalent bonds with four neighboring atoms, leaving no electrons to conduct electric current
  - You can change the behavior of silicon and turn it into a conductor by **doping** it. In doping, you mix a small amount of an impurity into the silicon crystal

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**N-Type & P-Type Semiconductors**

- **N-Type Semiconductor**
  - Abundance of electrons
  - N for negative charge
  - E.g. Phosphorous as dopant

- **P-Type Semiconductor**
  - Abundance of positive charge
  - P for positive charge
  - E.g. Boron as dopant

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**Semiconductor Diode**

- At the junction, free electrons from the N-type material fill holes from the P-type material
- This creates an insulating layer in the middle of the diode called the depletion zone
- Electrons and holes start moving and the depletion zone disappears
**LED (Light Emitting Diode)**

- Photons (energy in form of light) are released as a result of moving electrons.
- In an atom, electrons move in **orbitals** around the **nucleus**.
  - Electrons in different orbitals have different amounts of energy.
  - Electrons with greater energy move in orbitals farther away from the nucleus.
- For an electron to jump from a lower orbital to a higher orbital, something has to boost its energy level.
- Conversely, an electron releases energy when it drops from a higher orbital to a lower one.
- This energy is released in the form of a photon.

**LED**

- Anode – Long end
- Cathode – short end
- Typically operate LEDs between 5-20 mA
- Never connect an LED directly to a battery or power supply!
- It will be destroyed almost instantly because too much current will pass through and burn it out.

**Band Gap**