Notes for ECE 20001 - EE Fundementals I

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These are lecture notes for fall 2023 ECE 20001 at Purdue. Modify, use, and distribute as you please.

Contents

Course Introduction

This course covers fundamental concepts and applications for electrical and computer engineers as well as for engineers who need to gain a broad understanding of these disciplines. The course starts by the basic concepts of charge, current, and voltage as well as their expressions with regards to resistors and resistive circuits. Essential concepts, devices, theorems, and applications of direct-current (DC), 1st order, and alternating-current (AC) circuits are subsequently discussed. Besides electrical devices and circuits, basic electronic components including diodes and transistors as well as their primary applications are also discussed. For more information, see the syllabus.

Equations

1. $P = \frac{dW}{dt} = IV$
2. $I = \frac{dq}{dt}$
3. $V = \frac{W}{q}$
4. $R = \frac{\rho L}{A}$
5. Ohm's Law: $V = IR$
6. Coulomb's Law: $\vec{F} = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^2}\hat{r}$
7. Kirchhoff's Voltage Law:
8. Conductance: $G = \frac{1}{R}$

Charge, current, voltage, and power

Before we begin a discussion of electrical engineering, we will want an understanding of some important concepts.
Charge: A fundemental property of matter. Charge is measured in units of Coulombs (C) and arises from aggregates of charged fundemental particles like electrons.
Current: The rate of flow of charge. Typically, we think of current as occuring in a circuit, a loop through which charge can flow. Current can be mathematically defined as $I = \frac{dq(t)}{dt}$, where $q(t)$ is the charge at time t. Current therefore has units of Coulombs per second (C/s).
Voltage: The difference in electric potential energy between two points, per unit charge. Voltage thus has units of $\frac{J}{C}$. or Volts (V). Intuitively, a stronger voltage source (such as a battery) will result in a higher current on identical wires. Imagine a voltage source as a concentration of negative charges on one side and positive charges on the other. If we hook both ends up to a conducting wire and place an electron in the wire, it will be repelled from the negative side and attracted to the positive side. The electron has a high potential energy near the concentration of negative charge, and a low potential energy near the positive charges. The difference between these potentials is the voltage. This should make it clear that voltage must always be defined as across two points, each with its electric potential. A good note is that voltage can be negative (if the electric potential at the second point measured is higher) and it may not be constant with time.
Power: The rate of doing work, or changing energy. Mathematically, $P = \frac{dW}{dt} = IV$ and has units of Watts (W).
Passive sign convention: Defines current as going into positive voltage node of a component. The component is labeled a *load* or a *passive device*. We call it this because the component consumes power.

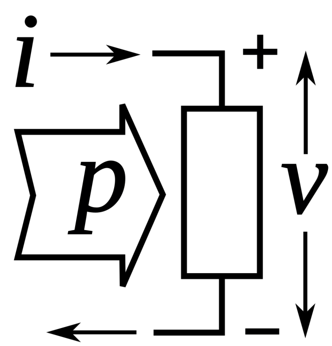


Figure 1: Passive sign convention

It's useful to have an idea of the components of circuit schematics (visual representations of a circuit). Below is a list of the terms that will be used in this course:

- Elements: The term elements means "components and sources."
- Symbols: Elements are represented in schematics by symbols. Symbols for common 2-terminal elements are displayed to the right.
- Lines: Connections between elements are drawn as lines, which we often think of as "wires". On a schematic, these lines represent perfect conductors with zero resistance. Every component or source terminal touched by a line is at the same voltage.

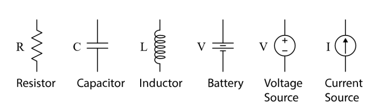
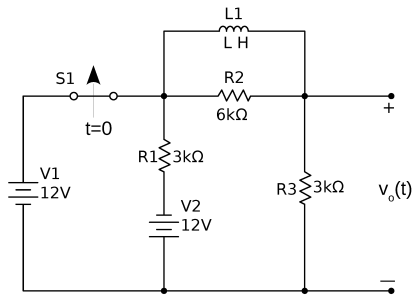


Figure 2: Common circuit symbols

- Dots: Connections between lines can be indicated by dots. Dots are an unambiguous indication that lines are connected. If the connection is obvious, you don't have to use a dot.

Check out the circuit schematic below and see how many components you can identify!



Now, on to what circuits are doing. For interesting things to happen we need electrons flowing through those wires. Current is how quickly electrons are moving along, or in more formal terms the rate of change of charge. That is, $I = \frac{dQ}{dt}$. Its units are amperes (amps) Voltage (or electric potential) is the amount of work done in moving charged particles such as electrons between two points. Whenever we want to separate two oppositely (positive and negative) charged particles or push two similarly-charged particles together, we need to do work to overcome the force between them. The work done in separating them is stored as potential energy. This stored energy is known as electric potential (or voltage) and is measured in volts. Thus, $V = \frac{W}{q}$. Just as with potential energy, voltage is always measured as a difference between two points. Power is the rate at which work is being done, i.e. $P = \frac{dW}{dt}$. This would give power units of J/s, which is known as Watts. Now, by rearranging the equation for voltage, we obtain also $P = iV$. To make sense of this equation consider a light bulb in a circuit, with an electric potential difference of 5 V and a current flowing through of 10 A. The power used by the light bulb is $P = iV = 5 * 10 = 50$ watts, meaning it uses 50 J per second.

(In)dependent sources, connections, resistance and Ohm's Law

Independent and dependent sources are fundamental elements in electrical circuits that provide voltage or current. They are used to model various types of input signals, power supplies, and components within a circuit. Independent sources are voltage sources or current sources that maintain a constant value regardless of the rest of the circuit. They are not influenced by the circuit's current or voltage conditions. There are two main types of independent sources:

- **Independent voltage source**: Maintains a constant voltage across its terminals, regardless of the current flowing through it. It is typically represented by a symbol with a plus sign and a minus sign, indicating the polarity of the voltage. A battery maintaining a constant voltage of 9 V is an example of an independent voltage source.

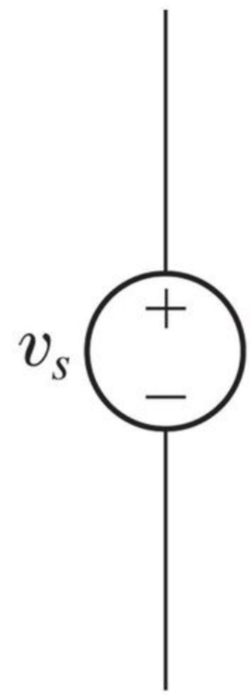


Figure 3: inependent voltage source

- **Independent current source**: Maintains a constant current through its terminals, regardless of the voltage across it. It is usually represented by a symbol with an arrow indicating the direction of current flow. Consider a current source that provides a constant current of 2 amperes. This source will deliver a current of 2A through any component connected to it, regardless of the voltage across the component.

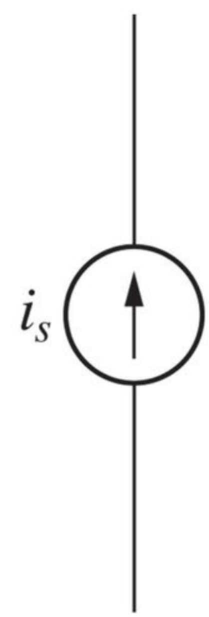
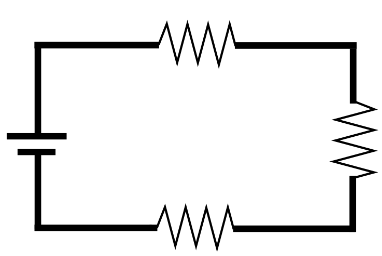


Figure 4: Independent current source

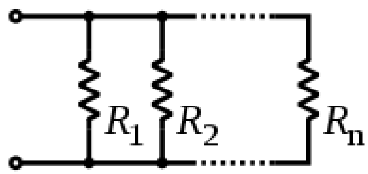
Contrasted with independent sources, there are also dependent sources. Dependent sources are sources whose values are dependent on other variables within the circuit. These sources are used to model components whose behavior changes according to the conditions in the circuit. There are four types of dependent sources:

- **Voltage-Controlled Voltage Source (VCVS)**: This type of dependent source generates a voltage that is proportional to the voltage across a separate part of the circuit.
- **Current-Controlled Current Source (CCCS)**: This type of dependent source generates a current that is proportional to the current flowing through a different part of the circuit.
- **Voltage-Controlled Current Source (VCCS)**: This type of dependent source generates a current that is proportional to the voltage across a different part of the circuit.
- **Current-Controlled Voltage Source (CCVS)**: This type of dependent source generates a voltage that is proportional to the current flowing through a separate part of the circuit.

Series Combination: In a series combination, the elements are connected with end to end in contact, such that current flow is equal in all the elements in the combination



Parallel Combination: When two or more resistances are connected between the same two points, they are said to be connected in parallel combination. In this case voltage is equal across all elements



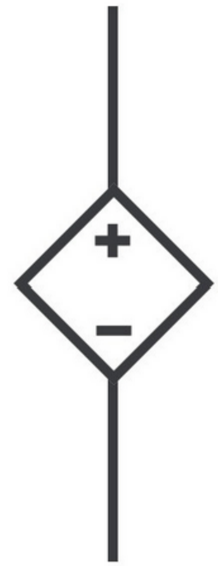


Figure 5: Dependent voltage source

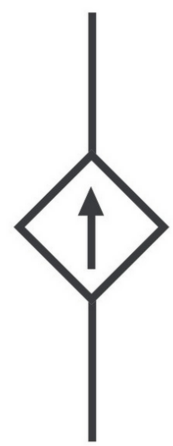


Figure 6: Dependent current source

Turning off a voltage source is equivalent to replacing it with a short circuit (line). Turning off a current source is equivalent to replacing it with an open circuit (broken line). Also equivalent to an open circuit is a resistor with infinite resistance. Resistance is a measure of how hard it is to shove current through a resistor. The harder it is, the higher the resistance. It's given by $R = \frac{\rho L}{A} = \frac{V}{I}$, where ρ is the resistivity, L is the length of the resistor, and A is the cross-sectional area of the resistor. The reciprocal of resistance is conductance ($G = \frac{1}{R}$).