Handout for Circuits and Network Analysis

Fall 2025

These handouts serve as **compact, informal summaries** of grouped lecture topics from the course. Rather than offering detailed lecture-by-lecture notes, the material clusters related concepts into an approachable and streamlined format. These are intended to supplement, not replace, standard textbooks. For more thorough explanations, please consult the references listed below.

Note: These notes are prepared in an informal style and may contain typos or minor errors. If you notice any mistakes, please let me know so I can correct them in future versions.

References:

1. M. E. Van Valkenburg, *Network Analysis*, 3rd Edition, Prentice-Hall of India.
2. C. A. Desoer and E. S. Kuh, *Basic Circuit Theory*, McGraw-Hill.
3. W. H. Hayt Jr., J. E. Kemmerly, and S. M. Durbin, *Engineering Circuit Analysis*, 9th Edition, McGraw-Hill.
4. C. K. Alexander and M. N. O. Sadiku, *Fundamentals of Electric Circuits*, 7th Edition, McGraw-Hill.
5. A. S. Sedra and K. C. Smith, *Microelectronic Circuits*, 8th Edition, Oxford University Press.

Two Terminal Circuit Elements *(In DC circuits)*

- **Philosophy of Circuit Elements:** In circuit theory, the building blocks are commonly referred to as circuit elements. In the context of circuits, the circuit elements are characterized by their terminal behavior, which is the relationship between voltage and current at their terminals. This is commonly referred to as the terminal behavior or $v - i$ characteristics of the circuit element. The internal structure/dynamics of the circuit elements are not considered in this abstraction, allowing for a simplified analysis of circuits.

  The $v - i$ characteristic of a circuit element is the collection of all possible pairs of voltage and current at the terminals of the element. The terminal behavior is often represented graphically as a curve in the $v - i$ plane, where the x-axis represents voltage and the y-axis represents current.

  A little later in this course, we will extend this concept of terminal characteristics to a part of the circuit or ports of the circuit, which will allow us to analyze more complex circuits by breaking them down into simpler parts.

  The terminal characteristics of a circuit element can usually be derived from the physical principles governing the element. However, they can also be determined experimentally by connecting either a variable voltage or current source to the terminals of the element and measuring the resulting current or voltage, respectively.

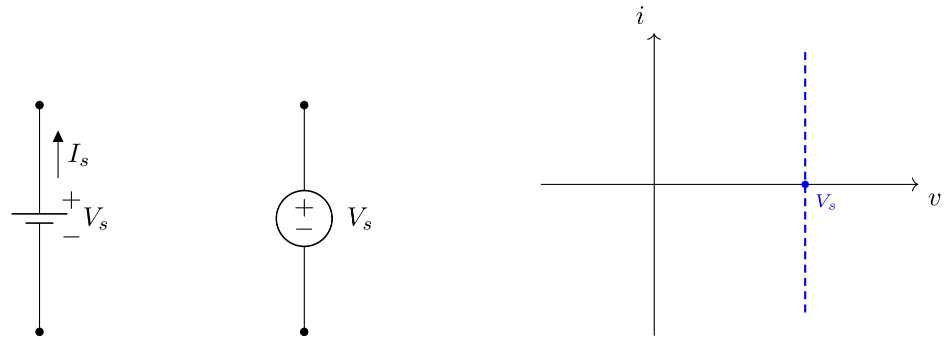
  Note that it may not be possible to experimentally determine the terminal characteristics by having a single type of variable source connected to the terminals of the element. For example, to characterize the terminal behavior of an ideal voltage source, one would need to connect a variable current source to the terminals of the voltage source and measure the resulting voltage (Can you think why a variable voltage source cannot be used to characterize the terminal behavior of an ideal voltage source?).

  To begin with, the circuit elements that are commonly used in DC circuits are introduced. These are the DC voltage source, DC current source and the resistor. Each of these elements has a specific terminal behavior that defines how they interact with the rest of the circuit.

- **Ideal DC Voltage Source:** An Ideal DC voltage source is a circuit element that maintains a constant voltage across its terminals, regardless of the current flowing through it. The constant voltage is commonly referred to as the rated voltage. The circuit representation of a DC voltage source is shown in Fig. 1(a)-(b). The terminal behavior of an ideal DC voltage source is represented by a vertical line in the $v - i$ plane, indicating that the voltage remains constant while the current can vary (shown in Fig. 1(c)).

  The operating points of the ideal DC voltage source lie in either the first or third quadrant of the $v - i$ plane (assuming active sign convention). When the operating point lies in the first quadrant ($P > 0$), indicating that it acts as a source. On the other hand, when the operating point lies in the third quadrant ($P < 0$), it acts as a sink (i.e., it is getting charged).

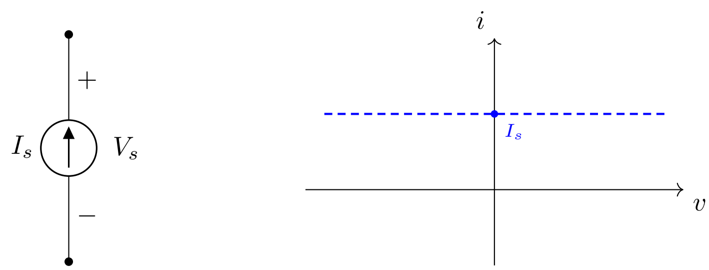
- **Ideal DC Current Source:** An Ideal DC current source is a circuit element that maintains a constant current through its terminals, regardless of the voltage across it. The constant current is commonly referred to as the rated current. The circuit representation of a DC current source is shown in Fig. 2(a). The terminal behavior of an ideal DC current source is represented by a horizontal line in the $v - i$ plane, indicating that the current



(a) Circuit representation (b) Alternate Circuit representation (c) $v - i$ characteristic (under active sign convention)

Fig. 1: DC Voltage Source - circuit representation and its terminal characteristic

remains constant while the voltage can vary (shown in Fig. 2(b)). The operating points of the ideal DC current



(a) Circuit representation (b) $v - i$ characteristic (under active sign convention)

Fig. 2: DC Current Source - circuit representation and its terminal characteristic

source lie in either the first or second quadrant of the $v - i$ plane (assuming active sign convention). When the operating point lies in the first quadrant ($P > 0$), indicating that it acts as a source. On the other hand, when the operating point lies in the second quadrant ($P < 0$), it behaves as a sink.

- **Resistor:** From a circuits point of view, a resistor is a two terminal circuit element that obeys Ohm's law, which states that the voltage across its terminals is proportional to the current flowing through it. The constant of proportionality is referred to as the resistance of the resistor, denoted by R. The resistance of the element is dependent on its material properties and geometry. The circuit representation of a resistor is shown in Fig. 3(a). Mathematically, the terminal behavior of a resistor is given by (under passive sign convention)

$$v = iR \tag{1}$$

For a current currying conductor, the resistance is given by

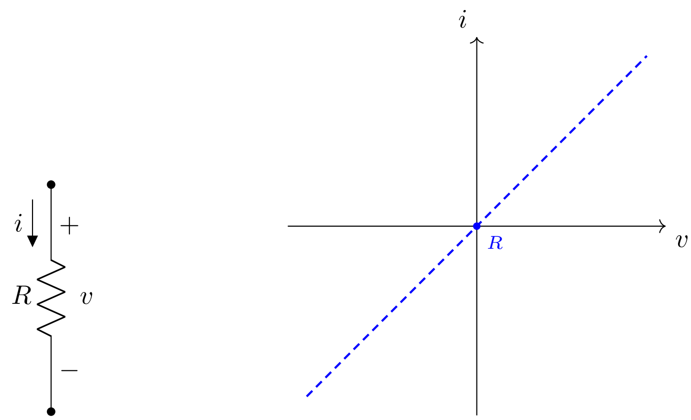
$$R = \frac{\rho L}{A} \tag{2}$$

where ρ is the resistivity of the material, L is the length of the conductor, and A is the cross-sectional area of the conductor. To gain a deeper understanding of how a resistor functions - or to compute its resistance for a given geometry - we can turn to the point form of Ohm's law, which relates the electric field $\vec{E}$ and current density $\vec{J}$ as

$$\mathbf{J} = \sigma \mathbf{E} \tag{3}$$

where σ is the conductivity of the material (the inverse of resistivity).

The terminal characteristics of a resistor is represented by a straight line through origin in the $v - i$ plane (shown in Fig. 3(b)), the slope of which is the inverse of resistance. The operating points of the resistor lie in either the



(a) Circuit representation (b) $v-i$ characteristic (under passive sign convention)

Fig. 3: Resistor - Circuit reporesentation and terminal characteristics

first or third quadrant of the $v - i$ plane (assuming passive sign convention). In both these quadrants $(P > 0)$, indicating that it acts as a sink/load.