Introduction +
Lecture 1: Circuit Theory Basics

MS 101 Makerspace

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Objective and Major Components of the EE Syllabus

- To give students sufficient background in Electronic Circuits - to design and implement their final project
- Major components of the EE Syllabus (Lectures: 12)
  - Passive Components, Transformer, Independent & dependent sources, KCL, KVL.
  - Electronic devices: pn junction diode, Zener diode, LED, Photodiode, solar cell.
  - Diode circuits – half-wave and bridge rectifiers
  - Operational amplifiers, feedback amplifiers, comparators and Schmitt trigger
  - Logic gates and digital circuits, digital-to-analog converter (DAC), and analog-to-digital converter (ADC)
  - Microprocessors, microcontrollers, memory and I/O devices
  - Microcontroller board (Arduino) with real-word interfacing
  - BJT and MOSFET switches
  - Electromechanical devices: relays, DC motors, Servo motors

Lab Experiments

1) Familiarization with basic measuring instruments and other lab equipment (DMM, DSO, AFG); measurement of frequency response of an RC high-pass filter.
2) Op amp based inverting amplifier; op amp I-to-V converter for displaying the I-V characteristics of rectifier diodes, LEDs, Zener diodes and photodiodes.
3) a) Unregulated DC power supply using transformer and rectifiers (Bridge Rectifier); measurement of ripple voltage.

   b) Regulated DC power supply using a 3-pin regulator IC; measurement of line and load regulations.
4) Familiarization with the Arduino Board.
5) Controlling motors using Arduino boards.

Reference Books

- W H Hayt, J E Kemmerly, and S M Durbin, Engineering Circuit Analysis, 8th ed., Mc Graw-Hill, (Indian Edition), 2013.
- A.S. Sedra and K.C. Smith, Microelectronic Circuits, Oxford University Press, 7th ed. (Indian edition), 2017.
- MA Mazidi, S Naimi, S Naimi, AVR Microcontroller and Embedded Systems: Using Assembly and C, Pearson India, 1st edition 2013.

- *Note: No need to busy these books. E-copies of the required portions will be uploaded on Moodle*

Lecture 1: Circuit Theory Basics

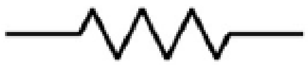
Lecture 1: Circuit Theory Basics

- Part A: Passive electrical devices: R, L, C, and transformer.
- Part B: Independent and dependent sources
- Part C: Kirchhoff's current and voltage laws
- Part D: Superposition Theorem

Part A: Passive Electrical Devices - R, L, C and Transformer

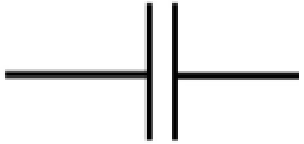
R (Resistor), L (Inductor), C(Capacitor)

- *R*, *L* and *C* are used in electronic circuits
- They are **two-terminal** devices (or **single-port** devices)
  - Can be fully described by their *V-I* characteristic

Resistor

$$v = i\,R$$

Inductor

$$v = L\frac{di}{dt}$$

Capacitor

$$v = \frac{1}{C}\int i\,dt$$

Resistors

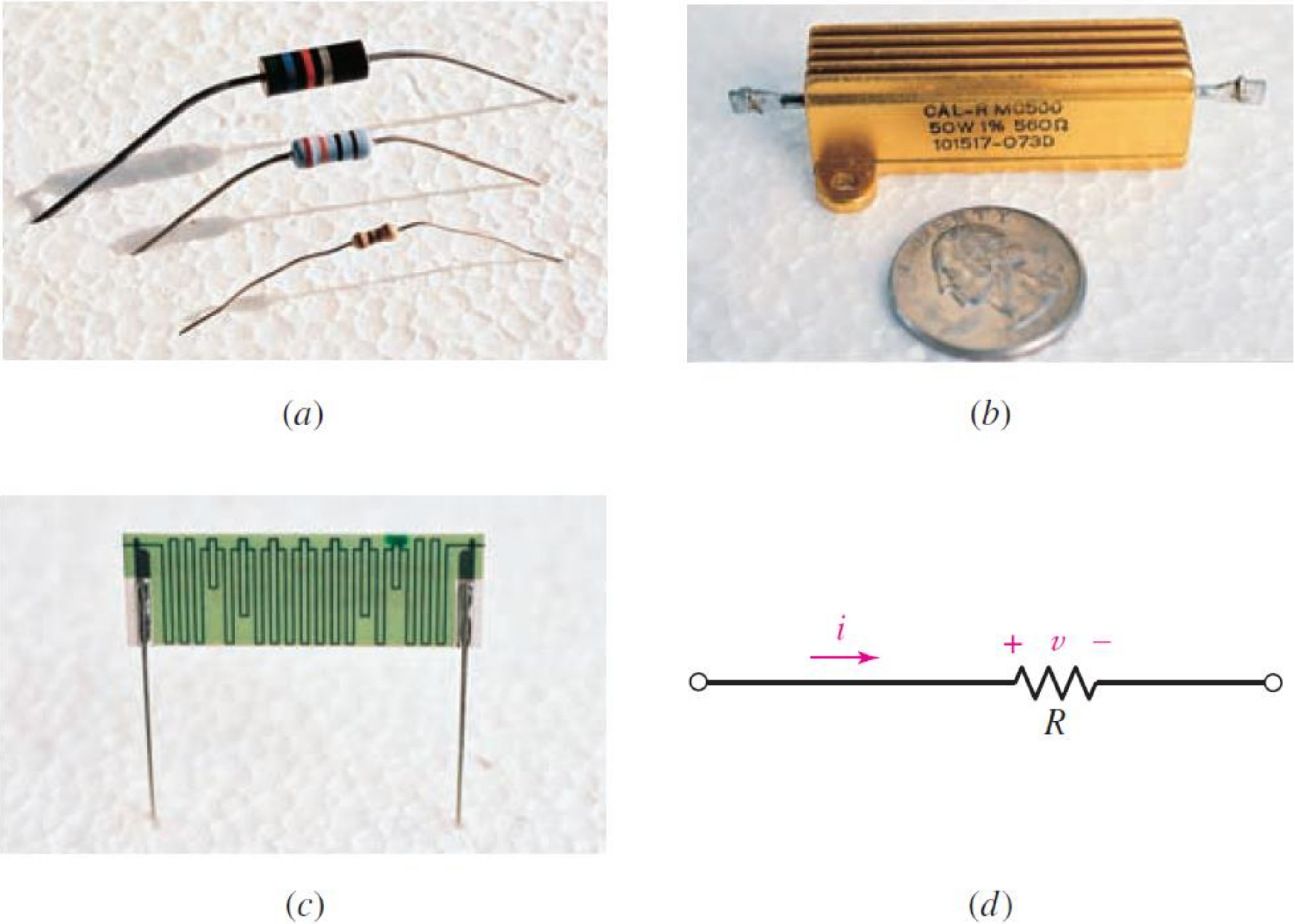


FIGURE 2.24 (*a*) Several common resistor packages. (*b*) A 560 Ω power resistor rated at up to 50 W. (*c*) A 5% tolerance 10-teraohm (10,000,000,000,000 Ω) resistor manufactured by Ohmcraft. (*d*) Circuit symbol for the resistor, applicable to all of the devices in (*a*) through (*c*).

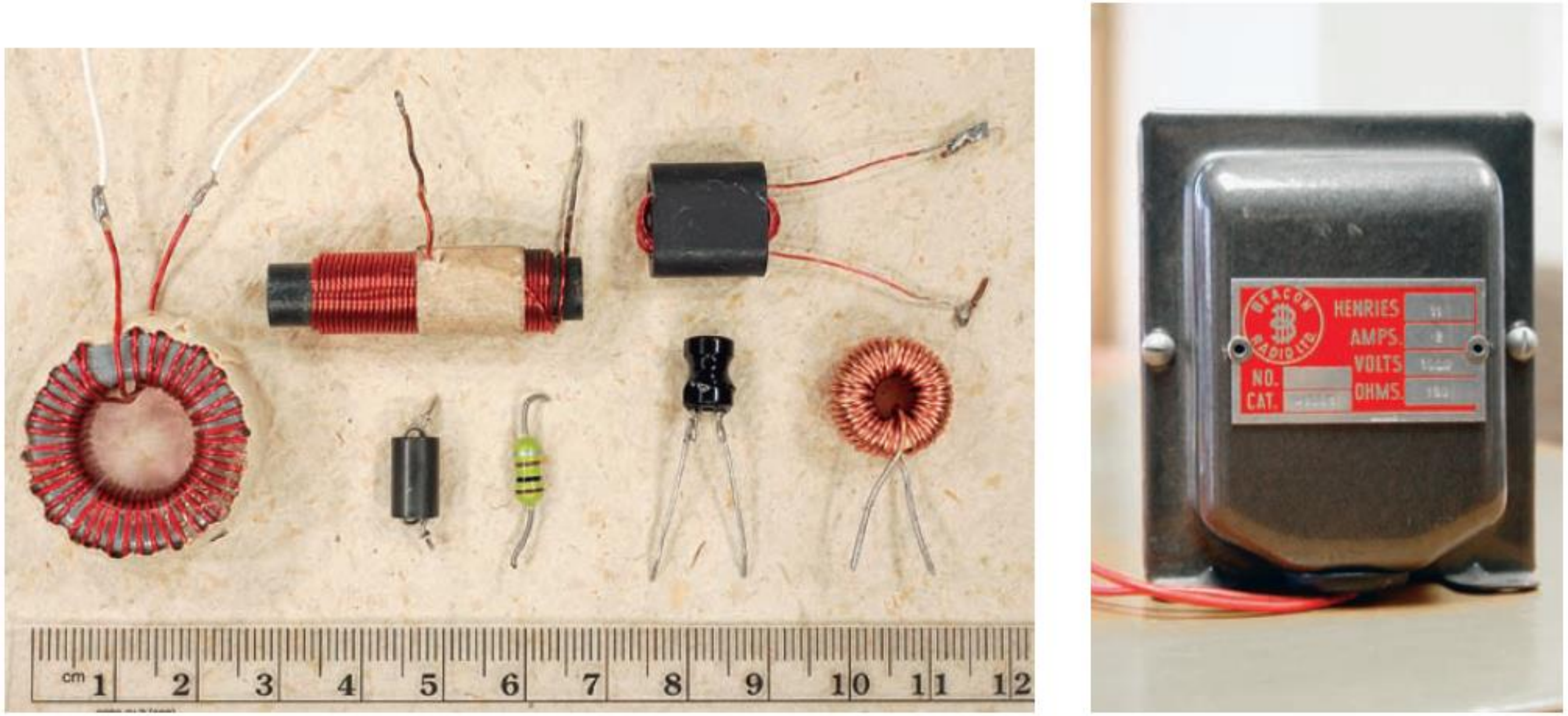
Source: Chapter 2, Sec 2.4: WH Hayt, JE Kemmerly, and SM Durbin, Engineering Circuit Analysis, 8th ed., McGraw-Hill Company, 2012

Resistors: Common Applications in Electronic Circuits

- Extensively used in all electronic circuits (different values and wattages)
- Comes in various sizes (based on the power dissipation capability)

- Most electronic circuits, except DC power supplies require only small wattage (say 1/8 watt) resistors
- Values and tolerance are generally indicated through colour codes
- Potentiometers (variable resistors) also used in many applications

Inductors



(*a*) (*b*)

FIGURE 7.11 (*a*) Several different types of commercially available inductors, sometimes also referred to as "chokes." Clockwise, starting from far left: 287 μH ferrite core toroidal inductor, 266 μH ferrite core cylindrical inductor, 215 μH ferrite core inductor designed for VHF frequencies, 85 μH iron powder core toroidal inductor, 10 μH bobbin-style inductor, 100 μH axial lead inductor, and 7 μH lossy-core inductor used for RF suppression. (*b*) An 11 H inductor, measuring 10 cm (tall) $\times$ 8 cm (wide) $\times$ 8 cm (deep).

Source: Chapter 7, Sec 7.2: WH Hayt, JE Kemmerly, and SM Durbin, Engineering Circuit Analysis, 8th ed., McGraw-Hill Company, 2012

Inductors: Common Applications in Electronic Circuits

- **Inductor property**: current through it cannot change instantaneously; but the voltage across it can.
- Inductors are very seldom used in general purpose electronic circuits, except for special applications
- Typical Applications:
  - Switched-Mode Power Supplies (SMPS) – in the µH range
  - RF circuits: small valued inductors (in the nH to µH range)
  - Compact Fluorescent Tube (CFL) supply – µH to mH range

Inductor

$$v = L\frac{di}{dt}$$

- Major disadvantages:
  - large size, especially when used as chokes (used in fluorescent tubes)
  - Can create disturbance (EMI) in sensitive circuits
- Large valued inductors occasionally used in Electric Power circuits

Capacitors

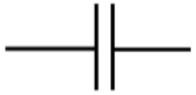
(*a*) (*b*) (*c*)

FIGURE 7.2 Several examples of commercially available capacitors. (*a*) Left to right: 270 pF ceramic, 20 μF tantalum, 15 nF polyester, 150 nF polyester. (*b*) Left: 2000 μF 40 VDC rated electrolytic, 25,000 μF 35 VDC rated electrolytic. (*c*) Clockwise from smallest: 100 μF 63 VDC rated electrolytic, 2200 μF 50 VDC rated electrolytic, 55 F 2.5 VDC rated electrolytic, and 4800 μF 50 VDC rated electrolytic. Note that generally speaking larger capacitance values require larger packages, with one notable exception above. What was the tradeoff in that case?

Source: Chapter 7, Sec 7.1: WH Hayt, JE Kemmerly, and SM Durbin, Engineering Circuit Analysis, 8th ed., McGraw-Hill Company, 2012

Capacitors: Common Applications in Electronic Circuits

- **Capacitor property**: voltage across a capacitor cannot change instantaneously; but the current through it can.
- Typical uses:

Capacitor  $v = \frac{1}{C}\int i\,dt$

  - C connected in series
    - To block DC voltage and to couple only an ac voltage to a circuit (eg. amplifier circuits)
  - C connected in parallel
    - As a filter capacitor at the output of a rectifier circuit (typ 100 to 1000 μF) for reducing ripple voltages.
    - As bypass capacitors (100 to 220 μF) across emitter resistor in BJT amplifier circuits.
    - As de-coupling capacitors (10 nF to 100 nF) across the power supply pins of ICs to smoothen the power supply voltage.
  - C used for timing applications
    - In oscillator and other waveform generators (typ small valued capacitors, say 10 nF to 200 nF)

Transformer

- Transformer:
  - Two coils of wire separated by a small distance, and coupled magnetically through an iron core
- Has two ports, primary and secondary
  - Primary: the input end (left side), to which the ac voltage source V_1 is connected
  - Secondary: the port on the right side to which the load Z_L is connected
- Turns ratio = N_2/N_1, the ratio of the number of secondary turns to the primary turns.
  - $V_2/V_1 = N_2/N_1$
  - $V_2/V_1 < 1$: step-down transformer
  - $V_2/V_1 > 1$: step-up transformer
- DC power supplies and most other common electronic applications use step-down transformers.
  - input V_1 is 230 V rms, and V_2 is typically 12 to 20 V rms.

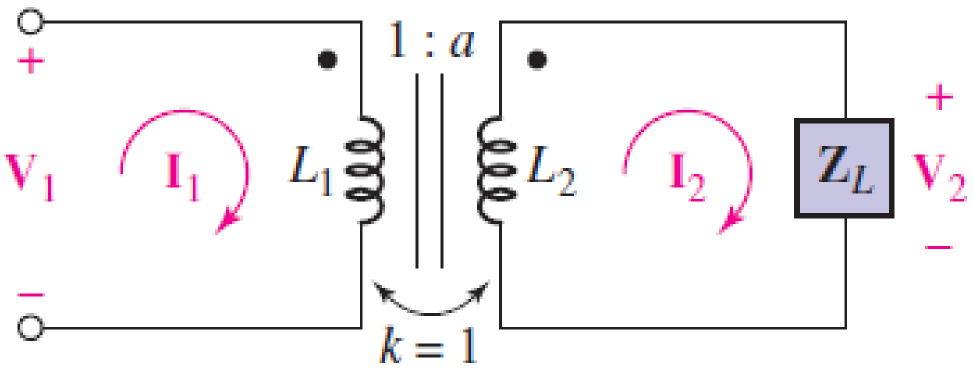


FIGURE 13.25 An ideal transformer is connected to a general load impedance.

Ref: Chapter 13, Sec 13.4: WH Hayt, JE Kemmerly, and SM Durbin, Engineering Circuit Analysis, 8th ed., McGraw-Hill Company, 2012

■ **FIGURE 13.15** A selection of small transformers for use in electronic applications; the AA battery is shown for scale only.

Source: Chapter 13, Sec 13.3: WH Hayt, JE Kemmerly, and SM Durbin, Engineering Circuit Analysis, 8th ed., McGraw-Hill Company, 2012

Part B: Active Devices - Independent and Dependent Sources

Independent Voltage Source

- Terminal voltage is completely independent of the current through it.

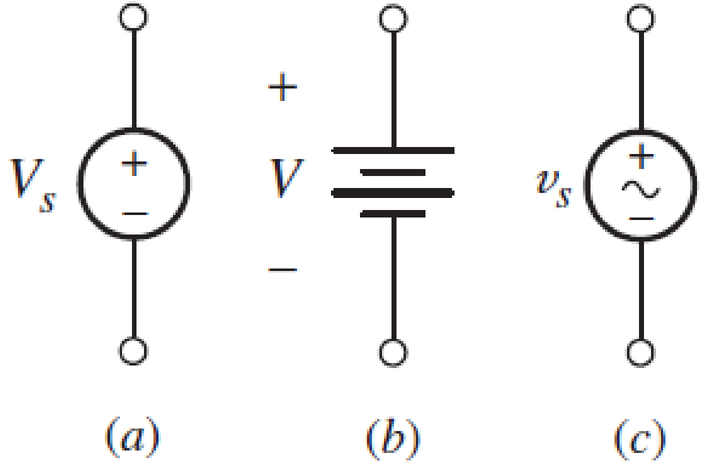


Fig.1 Independent voltage source symbols

(a) DC source symbol,

(b) Battery symbol,

(c) AC source symbol

Independent Current Source

- Current supplied is completely independent of its terminal voltage.

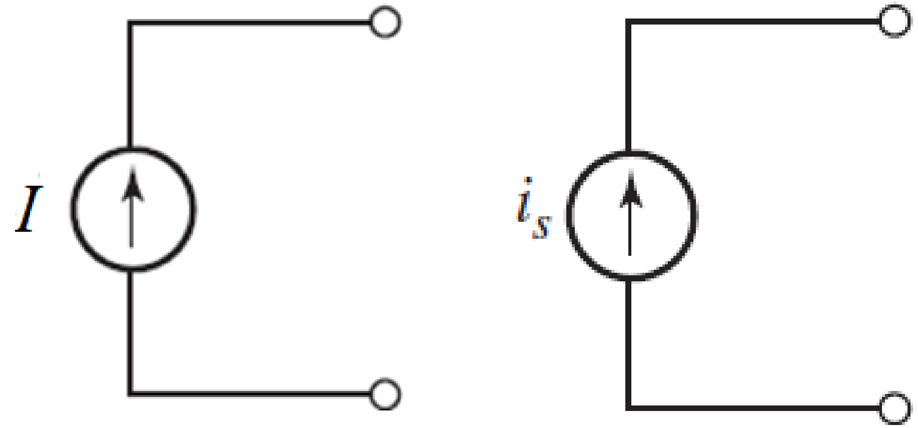


Fig. 2 Circuit symbols for independent current sources

Practical Voltage Sources

- Practical voltage sources are non-ideal.
- As the current supplied by it to a load increases, its terminal voltage progressively decreases (see Fig.3).
- This is due to the non-zero internal resistance present in all practical voltage sources.
- The terminal voltage of a practical voltage source equals that of an ideal one, only when current supplied is zero (or when the voltage source is open-circuited).

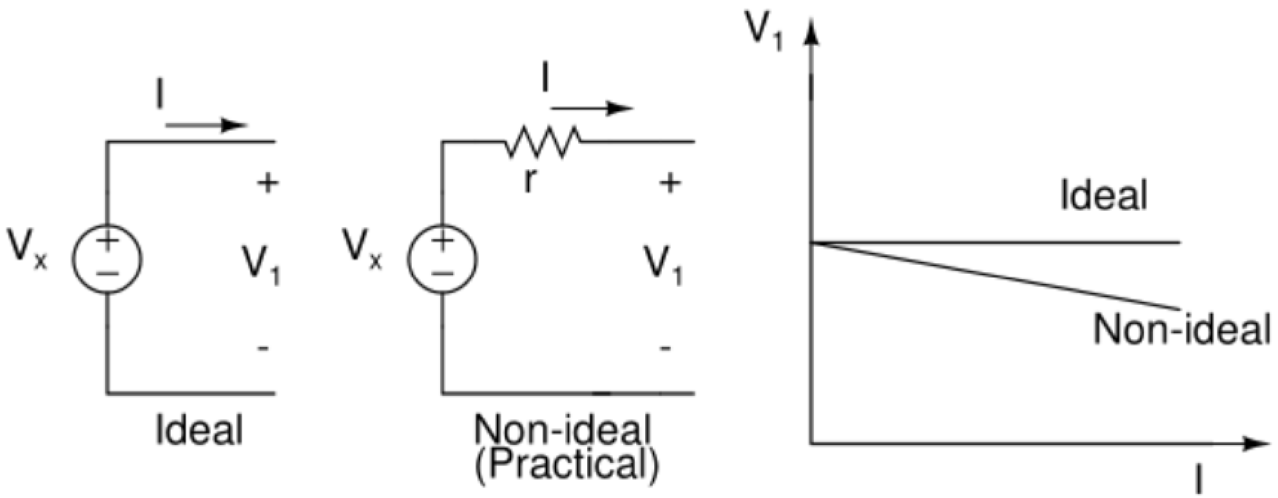


Fig. 3

Practical Current Sources

- In a practical (or non-ideal) current source, as the terminal voltage across the load increases, the current supplied by it progressively decreases (see Fig.4).
- This is due to lower internal shunt resistance in a practical current source.
- The current supplied by a practical current source equals that of an ideal one only when the load across its terminals is zero (or when the current source is short-circuited).

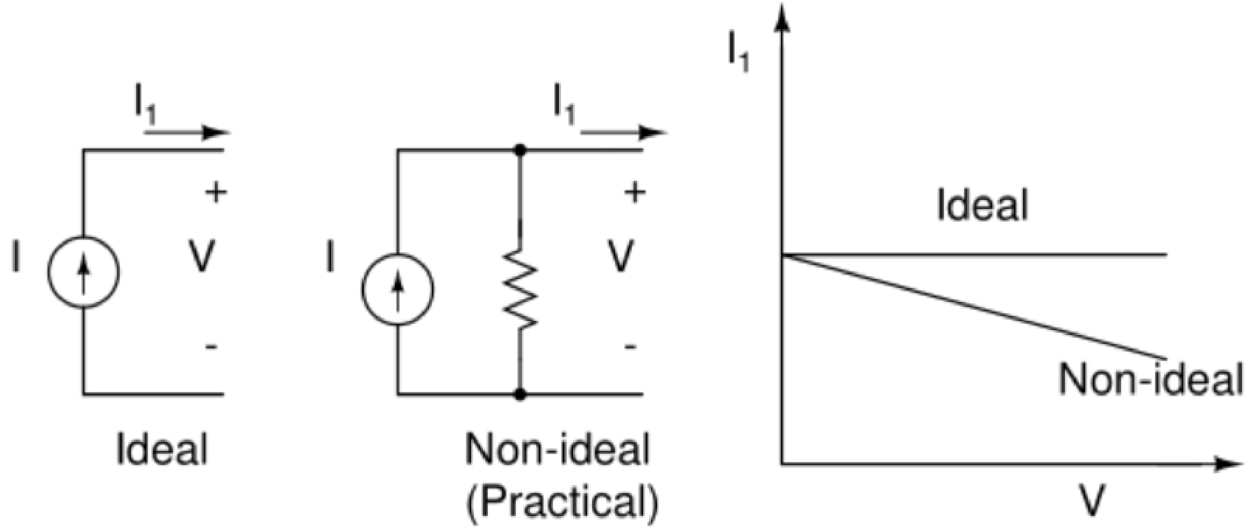


Fig. 4

Dependent Sources

- **Independent sources**
  - the value of the source quantity is not affected in any way by activities in the remainder of the circuit.

- **Dependent (or controlled) sources**
  - The source quantity (voltage or current) is determined by a voltage or current existing at some other location in the system being analyzed.
  - Used in the equivalent electrical models for many electronic devices, such as transistors, operational amplifiers, and integrated circuits.
  - Shown with diamond symbols

Dependent Sources

- Four types as shown
- In Fig 4(a) and (c), *K* is a dimensionless scaling constant.
- In Fig 4(b), *g* is a scaling factor with units of A/V
- Fig. 4(d), *r* is a scaling factor with units of V/A
- The controlling current i_x and the controlling voltage v_x must be defined in the circuit.

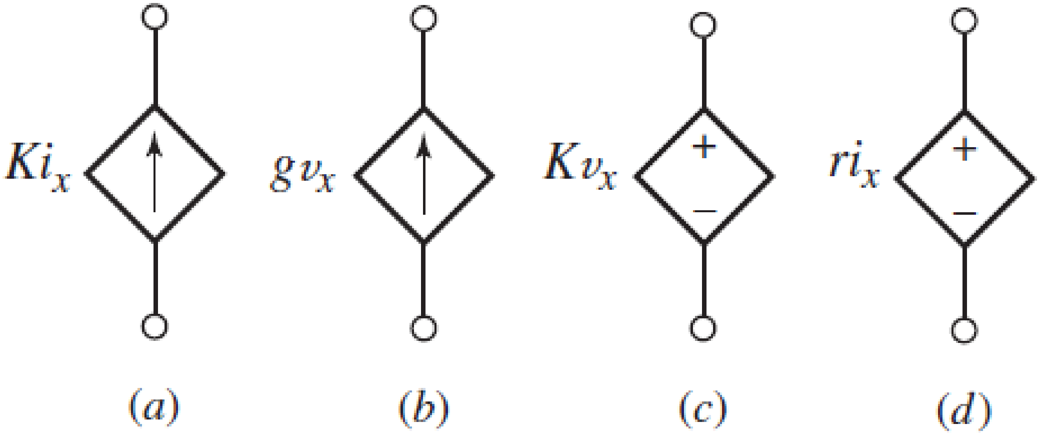


Fig. 4 Circuit symbols for the four different types of dependent sources:

(a) current-controlled current source;

(b) voltage-controlled current source;

(*c*) voltage-controlled voltage source;

(*d*) Current controlled voltage source

Part C: Kirchhoff's Current and Voltage Laws

Kirchhoff's Current and Voltage Laws (KCL and KVL)

- With reference to Fig 5,
- **Node**:
  - 1, 2 and 3 are nodes
- **Path** (moving from node to node without encountering a node more than once):
  - Node 1 to node 3 to node 2 is a path
- **Loop** (when the node at which we started is the same as the node on which we ended, the path is called a *closed path* or a *loop*):
  - Node 1 to node 3 to node 2 and then back to node 1 is a loop or a closed path

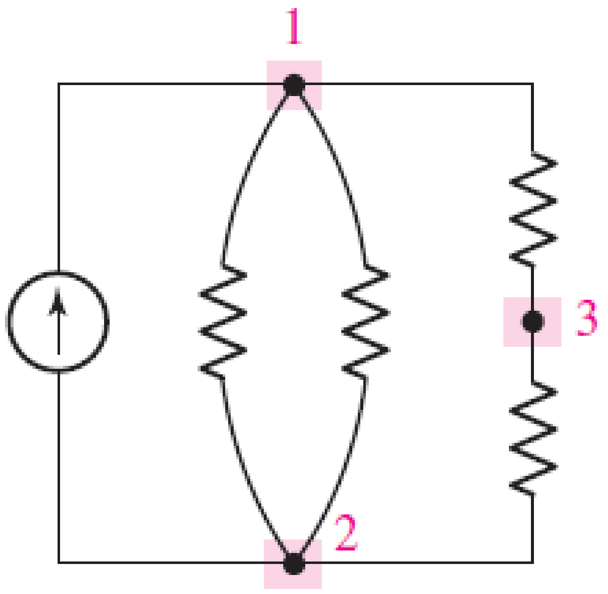


Fig. 5

Kirchhoff's Current Law (KCL)

- Statement: *The algebraic sum of the currents entering any node is zero.*
- (charge cannot accumulate at a node)
- $i_A + i_B + (-i_C) + (-i_D) = 0$

- Or, $i_A + i_B = i_C + i_D$
- i.e. the sum of the currents going in must equal the sum of the currents going out.
- A compact expression for Kirchhoff's current law is:

$$\sum_{n=1}^{N} i_n = 0$$

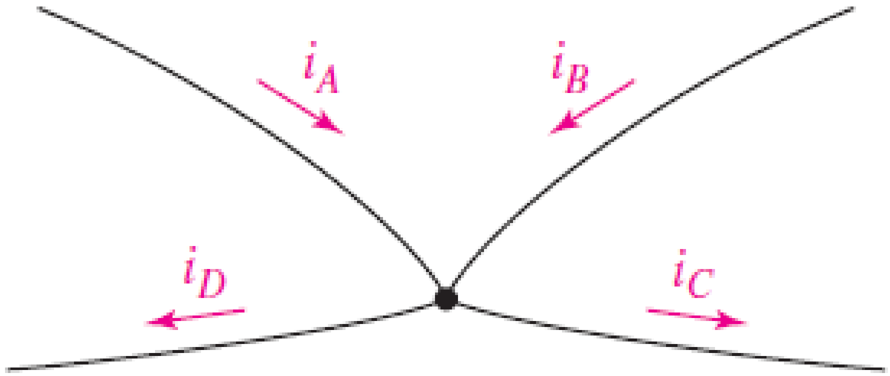


Fig. 6 Example node to illustrate the application of Kirchhoff's current law.

Kirchhoff's Voltage Law (KVL)

- Statement: *The algebraic sum of the voltages around any closed path is zero.*
- i.e. in a closed path, $\sum_{n=1}^{N} v_n = 0$
- Method: Move around the closed path in a clockwise direction and write down directly the voltage of each element whose (+) terminal is entered, and write down the negative of every voltage first met at the (−) sign.
- For the example in Fig. 7, we have

$$-v_1 + v_2 - v_3 = 0$$

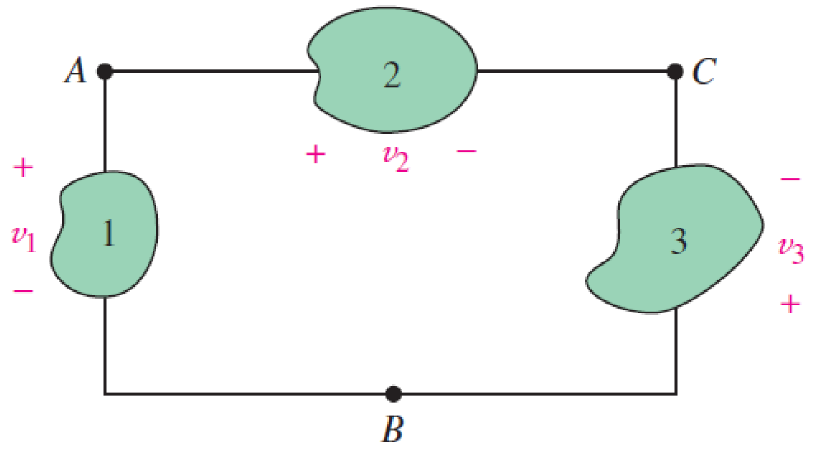


Fig. 7 The potential difference between points A and B is independent of the path selected.

Part D: Superposition Theorem

Linearity and Superposition

- A ***linear element*** is a passive element that has a linear voltage-current relationship.
- A ***linear circuit*** is a circuit composed entirely of independent sources, linear dependent sources, and linear elements.

- The principle of superposition states that the *response* (a desired current or voltage) in a linear circuit having more than one independent source can be obtained by adding the responses caused by the separate independent sources *acting alone*.

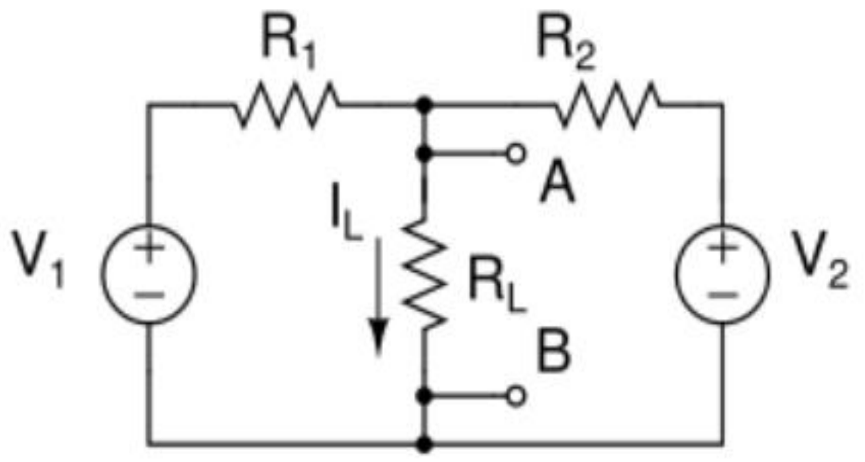
Superposition Theorem

- Statement: *In any linear network, the voltage across or the current through any element may be calculated by adding algebraically all the individual voltages or currents caused by the separate independent sources acting alone, with all other independent voltage sources replaced by short circuits and all other independent current sources replaced by open circuits.*
- Procedure to find the desired response (current or voltage)
  - If there are N independent sources, we must perform N iterations, each having only one of the independent sources active and the others inactive/turned off/zeroed out.
    - A voltage source is made inactive by making its value as 0 V (or by short-circuiting it)
    - A current source is made inactive by making its value as 0 A (or by open circuiting it)

Numerical Example (to illustrate Superposition Theorem)

Problem statement:

- **In the resistive network shown, $R_1 = R_2 = R_L = 1200\ \Omega$. $V_1 = 9$ V, $V_2 = 12$ V. Evaluate current I_L in mA.**



Procedure (by applying Superposition Theorem)

- Find I_L due to V_1 alone (say I_{L1}):
  - i.e. $V_1 = 9$ V, and $V_2 = 0$ V.
  - $I_{L1} = 0.5 \times (9/[1200 + 600]) = 0.0025 =$ **2.5 mA.**
- Find I_L due to V_2 alone (say I_{L2}):
  - i.e. $V_1 = 0$ V, and $V_2 = 12$ V.
  - $I_{L2} = 0.5 \times (12/[1200 + 600]) = 0.00333 =$ **3.33 mA.**

- Hence, $I_L = I_{L1} + I_{L2}$

  $= 2.5 + 3.33 =$ **5.83 mA**