

# Introduction + Lecture 1: Circuit Theory Basics

MS 101 Makerspace

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Joseph John, BGFernandes, Debraj Chakraborty, Kishore Chatterjee, PC  
Pandey, Dinesh K Sharma, Narendra S Shiradkar and Kushal Tuckley

# Instructors for the EE Part of MS101

- Division D3 (Batches B1 to B3)
  - Prof Dinesh K Sharma and Prof Narendra S Shiradkar
- Division D3 (Batches B4 to B6)
  - Prof Kushal Tuckley and Prof Kishore Chatterjee
- Division D4 (Batches B7 to B9)
  - Prof Joseph John and Prof BG Fernandes
- Division D4 (Batches B10 to B12)
  - Prof PC Pandey and Prof Debraj Chakraborty

# 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-world 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 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 and interfacing.
- 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 buy 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 method

# 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



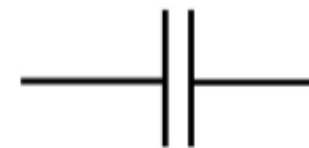
$$v = i R$$

Inductor



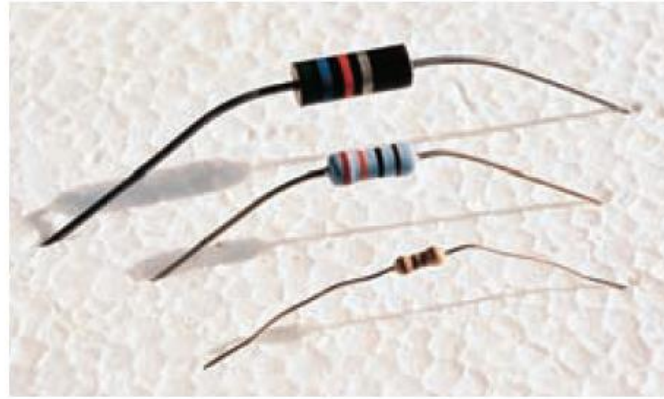
$$v = L \frac{di}{dt}$$

Capacitor

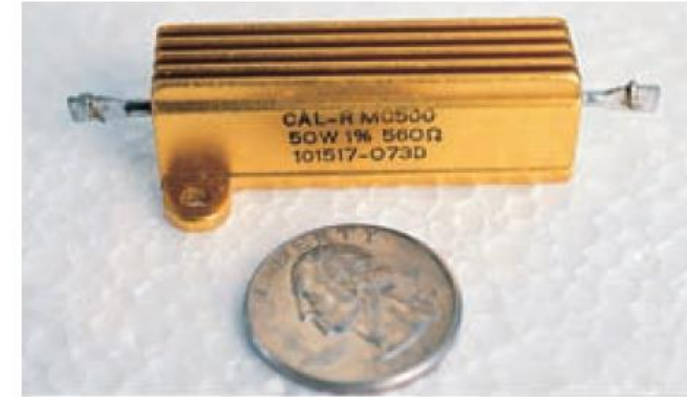


$$v = \frac{1}{C} \int i dt$$

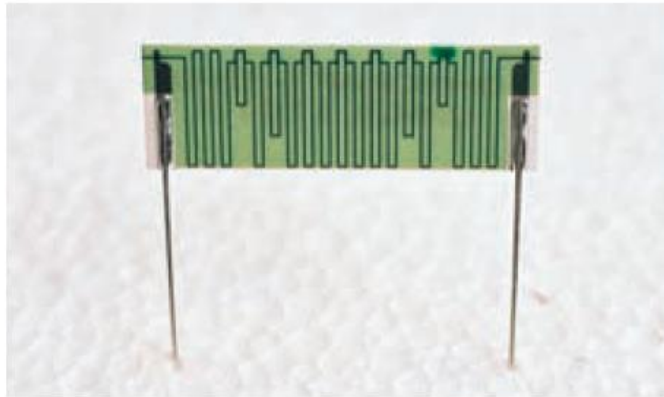
# Resistors



(a)



(b)



(c)



(d)

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

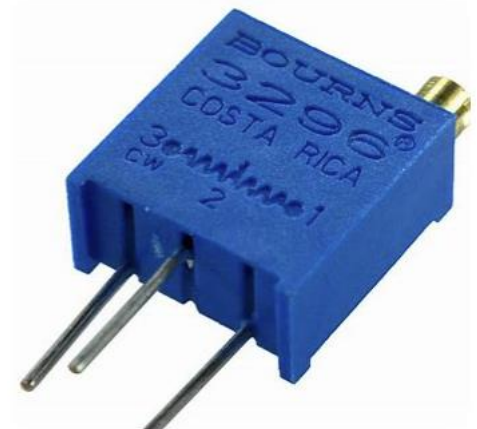
■ **FIGURE 2.24** (a) Several common resistor packages. (b) A  $560\ \Omega$  power resistor rated at up to 50 W. (c) A 5% tolerance 10-teraohm ( $10,000,000,000,000\ \Omega$ ) resistor manufactured by Ohmcraft. (d) Circuit symbol for the resistor, applicable to all of the devices in (a) through (c).

# Resistors: Common Applications in Electronic Circuits

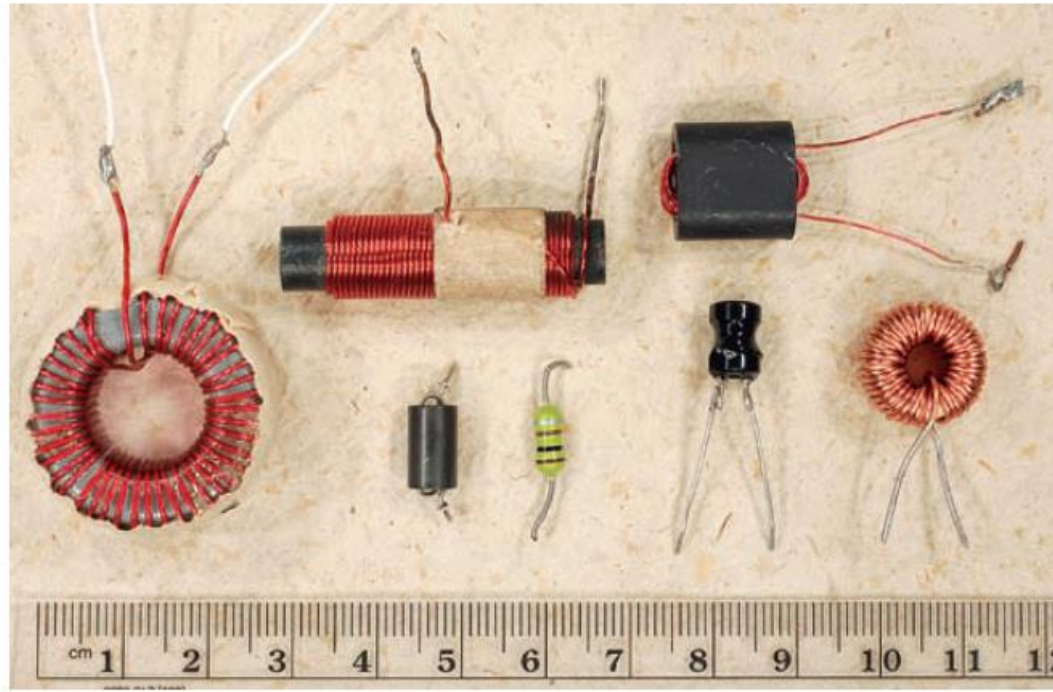
- Extensively used in all electronic circuits (different values and wattages)
- Comes in various sizes (based on the power dissipation capability)
- Most electronic circuits require only small wattage (say 1/8 watt) resistors
- Values and tolerance are generally indicated through colour codes
- Potentiometers (variable resistors) also used in many applications



Potentiometers



# 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:  $287\ \mu\text{H}$  ferrite core toroidal inductor,  $266\ \mu\text{H}$  ferrite core cylindrical inductor,  $215\ \mu\text{H}$  ferrite core inductor designed for VHF frequencies,  $85\ \mu\text{H}$  iron powder core toroidal inductor,  $10\ \mu\text{H}$  bobbin-style inductor,  $100\ \mu\text{H}$  axial lead inductor, and  $7\ \mu\text{H}$  lossy-core inductor used for RF suppression. (b) An  $11\ \text{H}$  inductor, measuring  $10\ \text{cm}$  (tall)  $\times$   $8\ \text{cm}$  (wide)  $\times$   $8\ \text{cm}$  (deep).

Source: Chapter 7, Sec 7.2: WH Hayt, JE Kemmerly, and SM Durbin, Engineering Circuit Analysis, 8<sup>th</sup> 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  $\mu\text{H}$  range
  - RF circuits: small valued inductors (in the nH to  $\mu\text{H}$  range)
  - Compact Fluorescent Tube (CFL) supply –  $\mu\text{H}$  to mH range
- Major disadvantages:
  - Large size
  - Can create disturbance (EMI) in sensitive circuits
- Typical applications
  - Large valued inductors occasionally used in Electric Power circuits

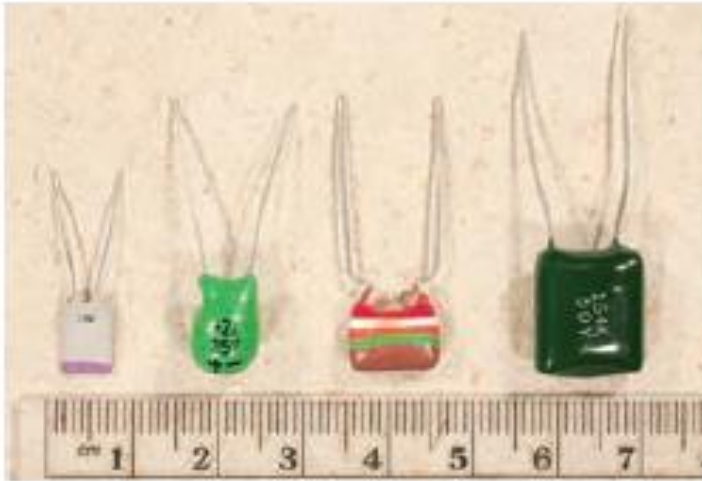
Inductor



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



# Capacitors



(a)



(b)



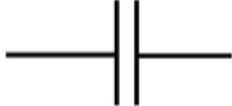
(c)

**FIGURE 7.2** Several examples of commercially available capacitors. (a) Left to right: 270 pF ceramic, 20  $\mu\text{F}$  tantalum, 15 nF polyester, 150 nF polyester. (b) Left: 2000  $\mu\text{F}$  40 VDC rated electrolytic, 25,000  $\mu\text{F}$  35 VDC rated electrolytic. (c) Clockwise from smallest: 100  $\mu\text{F}$  63 VDC rated electrolytic, 2200  $\mu\text{F}$  50 VDC rated electrolytic, 55 F 2.5 VDC rated electrolytic, and 4800  $\mu\text{F}$  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, 8<sup>th</sup> ed., McGraw-Hill Company, 2012

# Capacitors

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

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

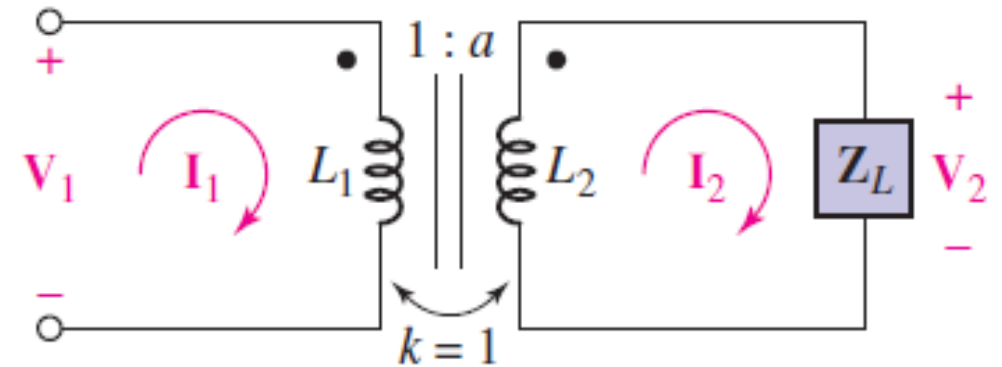
# Capacitors: Common Applications in Electronic Circuits

- Typical uses:
  - C connected in series
    - “DC blocking” or “AC coupling” capacitor connected in series with a resistor to block DC voltage and couple AC voltage (e.g. amplifier circuits).
  - C connected in parallel
    - As a “ripple filter” capacitor at the output of a rectifier circuit (typ. 100 to 1000  $\mu\text{F}$ ) for reducing ripple voltages.
    - As a “bypass” capacitor (100 to 220  $\mu\text{F}$ ) across the emitter resistor in BJT amplifier circuits.
    - As a “de-coupling” capacitor (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 coupled magnetically.
- 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, 8<sup>th</sup> 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, 8<sup>th</sup> ed., McGraw-Hill Company, 2012

# Part B: Active Devices - Independent and Dependent Sources

# Independent Voltage Source

- Terminal voltage is independent of the current through it.

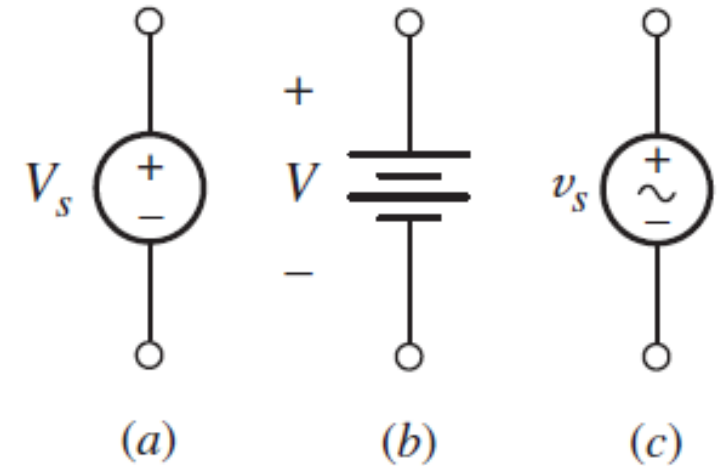


Fig.1 Independent voltage source symbols  
(a) DC source symbol,  
(b) Battery symbol,  
(c) AC source symbol (signs indicating polarity at an arbitrary time instant)

# Independent Current Source

- Current supplied is independent of the voltage across its terminals.

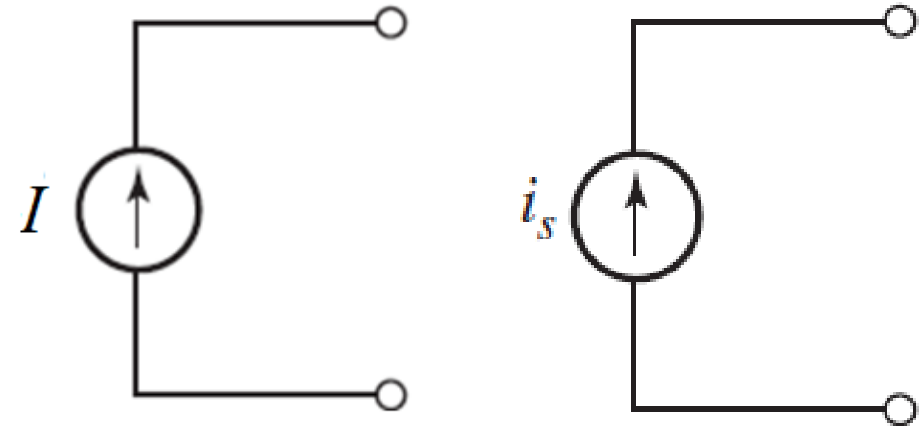


Fig. 2 Circuit symbols for independent current sources

# 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 a non-zero internal resistance.
- 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).

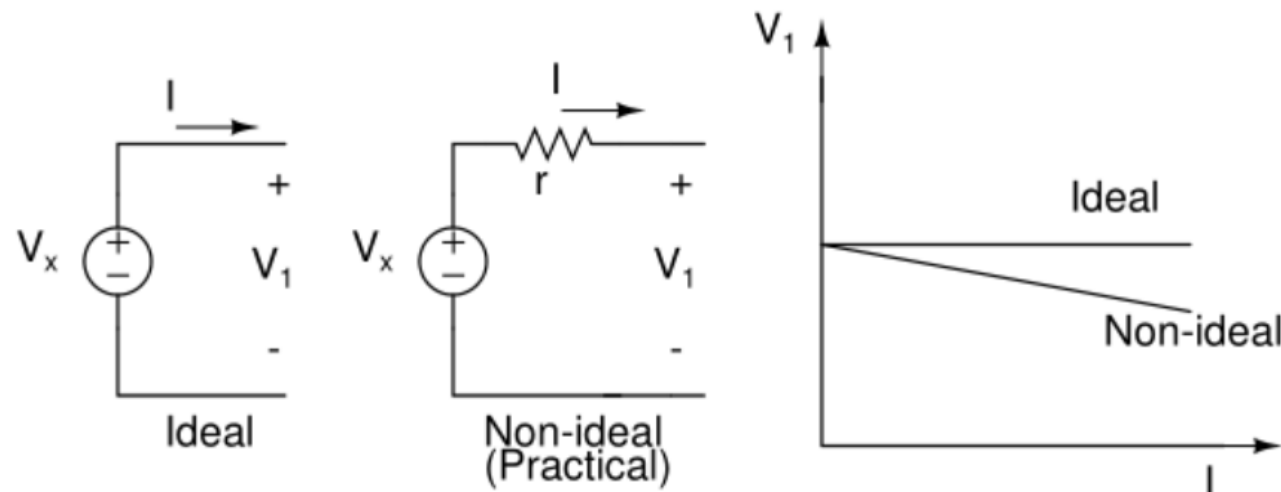


Fig. 3

# Practical Current Sources

- In a practical current source, as the terminal voltage across the load increases, the current supplied by it progressively decreases (see Fig.4).
- This is due to a finite 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 voltage across its terminals is zero (or when the current source is short-circuited).

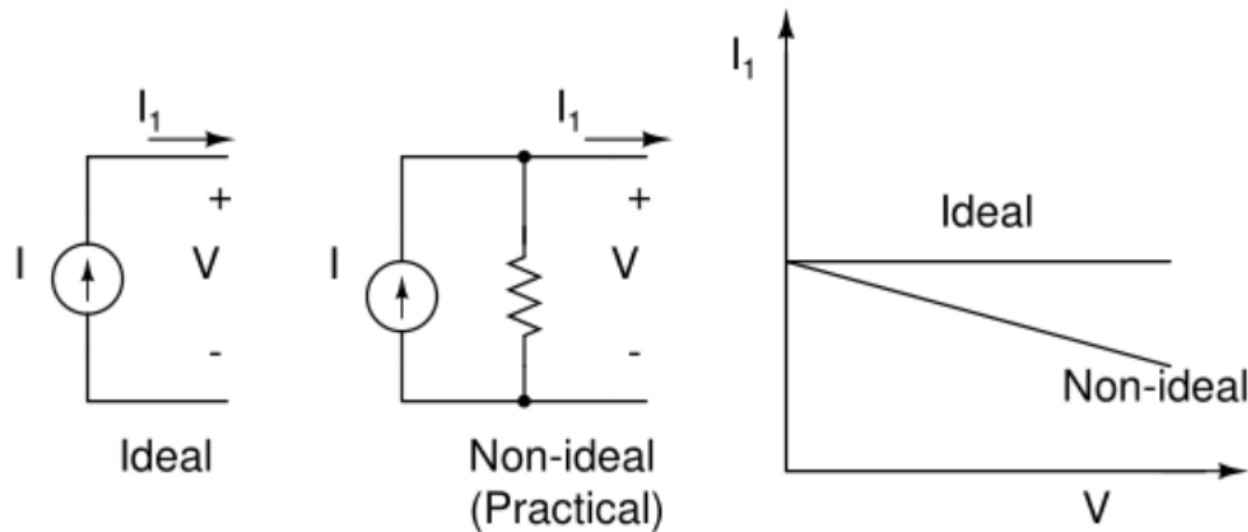


Fig. 4

# 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.

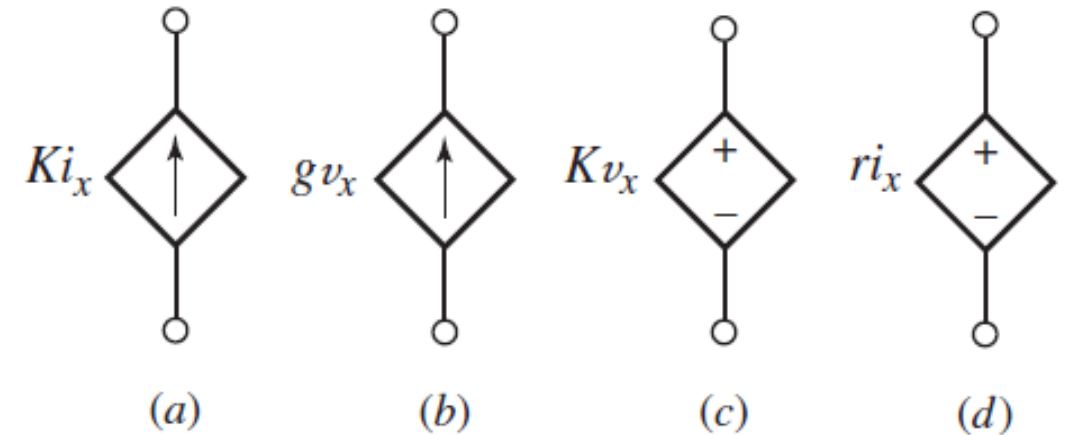


Fig. 4 Circuit symbols for the four different types of dependent sources:  
(a) current-controlled current source;  
(b) voltage-controlled current source;  
(c) voltage-controlled voltage source;  
(d) Current controlled voltage source

# Part C: Kirchhoff's Current and Voltage Laws

# Node, Path, and Loop

- 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

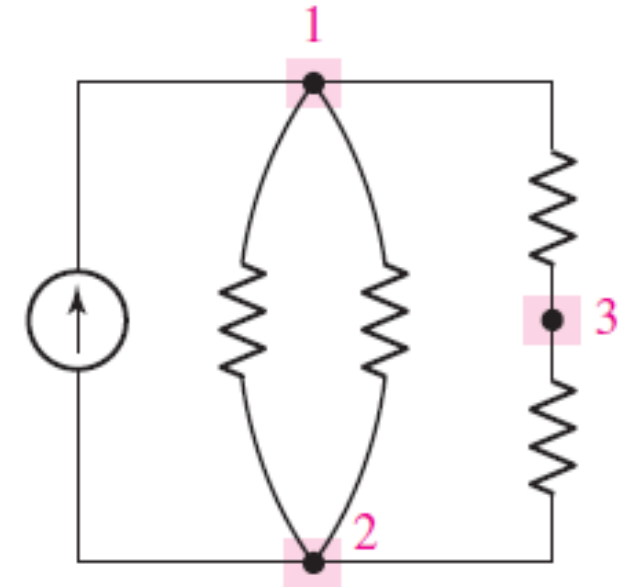


Fig. 5

# 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:

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

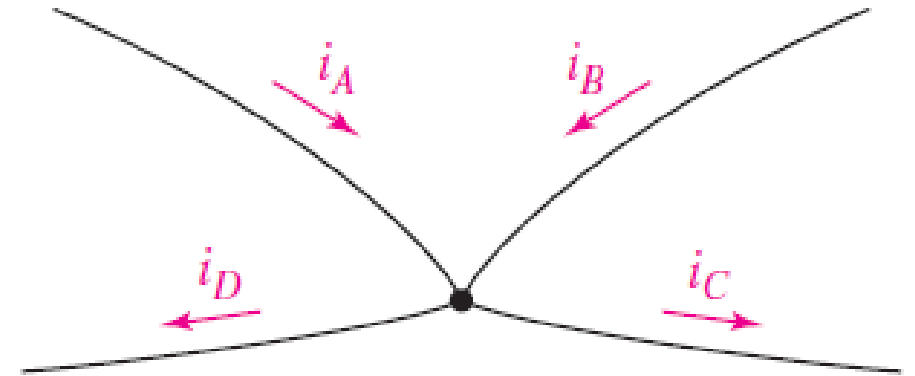


Fig. 6 Example node to illustrate the application of Kirchhoff's current law.

# 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 each voltage first met at the +ve sign as positive and each voltage first met at the -ve sign as negative.
- For the example in Fig. 7, we have

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

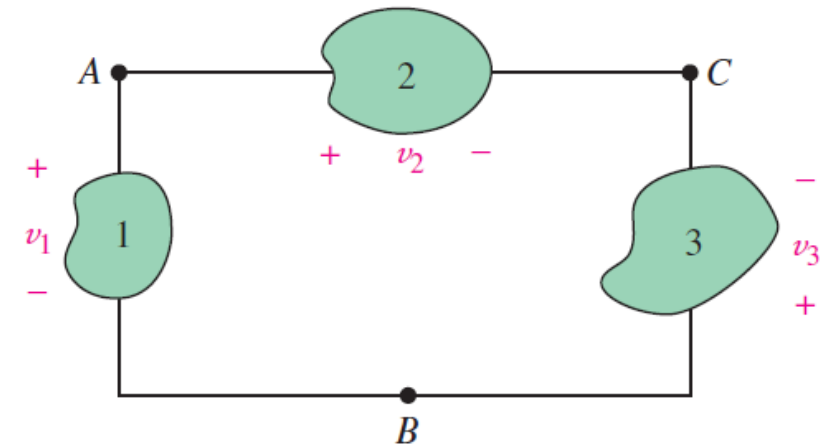


Fig. 7 The potential difference between points A and B is independent of the path selected.

# Part D: Superposition Method

# Superposition Principle

- **Superposition principle**: The output for a weighted sum of inputs is the same weighted sum of the outputs. Let the inputs  $x_1$  and  $x_2$  result in outputs  $y_1$  and  $y_2$ , respectively. The output for an input  $x = ax_1 + bx_2$  is given as  $y = ay_1 + by_2$ . The inputs and outputs can be voltages or currents.
- Devices obeying the superposition principle are linear. The devices not obeying this principle are nonlinear.
- Circuits made of linear devices (e.g. resistors, capacitors, inductors, dependent sources) are called linear circuits.
- The superposition method uses the superposition principle to find a voltage or current due to multiple sources by considering one source at a time.

# Superposition Method

- The Superposition Method states the following:
  - The current through, or voltage across, any device is equal to the algebraic sum of the currents or voltages produced independently by each source.
- It allows us to find a solution for a current or voltage using *only one source at a time*.
- The term *algebraic* appears in the statement because the currents resulting from different sources can have different directions. Similarly, the resulting voltages can have opposite polarities.



# Superposition method...

- To consider the effects of each source, the other sources must be removed.
  - When removing a voltage source, replace it with a direct connection (short circuit) of zero ohms. Any internal resistance associated with the source must remain in the network.
  - When removing a current source, replace it with an open circuit of infinite ohms. Any internal resistance associated with the source must remain in the network.
  - Since the effect of each source will be determined independently, the number of times the circuit is to be analysed is equal to the number of sources.

# Numerical Example (to illustrate Superposition Method)

## Problem statement:

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

## Procedure (by applying Superposition Method)

- Find  $I_L$  due to  $V_1$  alone (say  $I_{L1}$ ).  
 $V_1 = 9 \text{ V}$ ,  $V_2 = 0 \text{ V}$ .  
 $I_{R1} = V_1 / (R_1 + R_2 \parallel R_L) = 9 / (1200 + 600) \text{ A} = 5 \text{ mA}$   
 $I_{L1} = [R_2 / (R_2 + R_L)] I_{R1} = 0.5 * (5) \text{ mA} = 2.5 \text{ mA}$ .
- Find  $I_L$  due to  $V_2$  alone (say  $I_{L2}$ ).  
 $V_1 = 0 \text{ V}$ ,  $V_2 = 12 \text{ V}$ .  
 $I_{R2} = V_2 / (R_2 + R_1 \parallel R_L) = 12 / (1200 + 600) \text{ A} = 20/3 \text{ mA}$   
 $I_{L2} = [R_1 / (R_1 + R_L)] I_{R2} = 0.5 * (20/3) \text{ mA} = 3.33 \text{ mA}$ .
- Hence,  $I_L = I_{L1} + I_{L2}$   
 $= 2.5 + 3.33 = 5.83 \text{ mA}$ .

