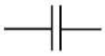
Lecture-1

08 August 2023 15:52

Engineering is applied physics

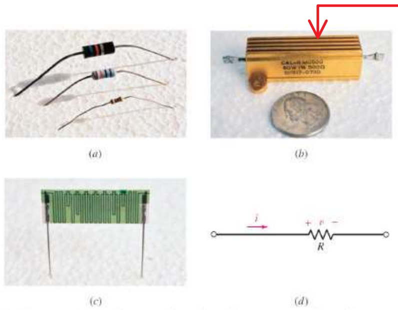
R (Resistor), L (Inductor), C(Capacitor)

- *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		$v = L\dfrac{di}{dt}$
Capacitor		$v = \dfrac{1}{C}\int i dt$

- Two terminal devices can be fully described by one equation(Equation between V and I).

Resistors



(a) (b) (c) (d)

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

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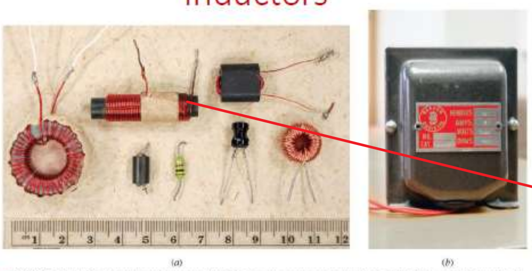
- Why do we have resistors larger in size?? Due to power rating.
- Even though a small resistor can have same resistance as a larger one, it can't handle equal amount of power. If higher current is passed, it may burn out.

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, 2.66 μH ferrite core cylindrical inductor, 215 μH ferrite core inductor designed for VHF frequencies, 45 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) × 8 cm (wide) × 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

- Inductor aren't used in electrical circuit since they are bulky and provide electromagnetic interference.
- Ferrite is a magnetic material but an insulator. Thus no eddy current.
- A problem with tube light is that it can't work with low voltage. On the other hand CFL requires low voltage(<80v).
- All automobile, electric scooters have inductor in spark plug.

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
- 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

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 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:
  - 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)

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

- Name of capacitor comes from dielectric material used.
- Maximum value of capacitance of a ceramic capacitor is 0.4 microfarad.
- Capacitance of capacitor used in fans is 2 microfarad.
- Capacitor blocks DC.
- 10+5sinwt==> Avg voltage is 10, so capacitor charges to 10v.Thus V_Out is V_in -10=5sinwt.
- Capacitor filter is used to remove ripples in a rectified AC

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.

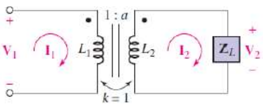


FIGURE 13.25 An ideal transformer is connected to a general load impedance.

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

Independent Voltage Source

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

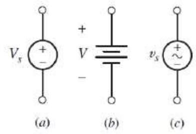


Fig.1 Independent voltage source symbols
(a) DC source symbol,
(b) Battery symbol,
(c) AC source symbol

- Very important thing for a voltage source is to indicate positive and negative else it has no meaning.

Independent Current Source

- Current supplied is completely independent of its terminal voltage.

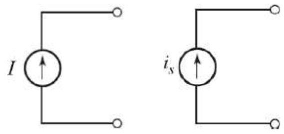


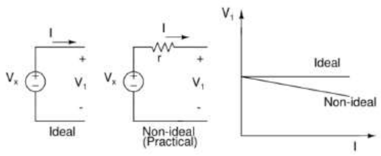
Fig. 2 Circuit symbol for the independent current source

- Very important thing for a current source is to indicate the direction of the current.
- A solar cell is like a current source. When we keep drawing current, current will be constant till a particular voltage, then it will drop.

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).

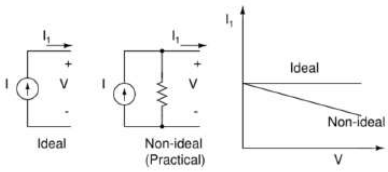
Fig. 3



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

- Mic(Voltage amplifier) is an excellent example of voltage controlled voltage source.
- BJT Transistor is an excellent example of current controlled current source($I_c = \beta * I_b$)

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.

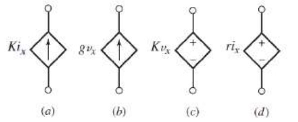


Fig. 4 Circuit symbols for the four different types of dependent sources:
(a) current-controlled current source;
(b) voltage-controlled current source;
(c) voltage-controlled voltage source;
(d) Current controlled voltage source

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

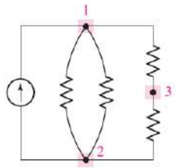


Fig. 5

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

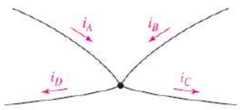


Fig. 6 Example node to illustrate the application of Kirchhoff's current law.

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

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

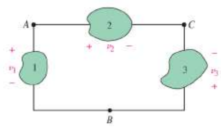
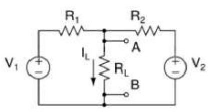


Fig. 7 The potential difference between points A and B is independent of the path selected.

Numerical Example

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 using Node voltage method.**



Steps:

Identify meshes (loops). Assign currents clockwise I_1 and I_2

Use KVL and write mesh equations.

Loop 1: $-V_1 + I_1R_1 + (I_1-I_2)R_L = 0$

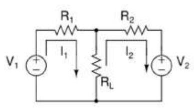
Loop 2: $(I_2-I_1) R_L + I_2 R_2 + V_2 = 0$

Substituting the values of resistors in kΩ, we can rewrite as:

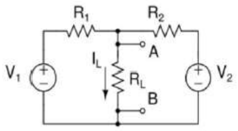
$2.4 I_1 - 1.2 I_2 = 9$ (1)

$-1.2 I_1 + 2.4 I_2 = -12$ (2)

- **Solving, we get**
- **$I_1 = 1.666$ mA**
- **$I_2 = -4.166$ mA**
- **$I_L = I_1 - I_2 = 5.83$ mA**



Node Voltage Method



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 using Node voltage method.**

- Node Voltage method is a simple way of analyzing networks. Please note that in the given network all node voltages except that of node A are known. Once V_A is known, I_L can be easily found out.
- Let us take Node B as our reference node and assume that $V_B = 0$ V
- $I_L = V_A/R_L$
- Applying KCL at Node A, we get: $I_L = V_A/R_L = (V_1 - V_A)/R_1 + (V_2 - V_A)/R_2$
- Since $R_1 = R_2 = R_L$, we can simplify the above equation as: $3\ V_A = V_1 + V_2 = 21$, or $V_A = 7$ V

- Hence, $I_L = 7/1200\ \Omega = 7/1.2\ k\Omega = 5.83$ mA

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.

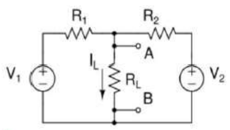
- The principle of superposition states that the *response* (a desired current or voltage) in a linear circuit having more than one independent source can be obtained by adding the responses caused by the separate independent sources *acting alone*.

A passive element is an electrical component that does not generate power, but instead dissipates, stores, and/or releases it. Passive elements include resistances, capacitors, and coils (also called inductors).

Superposition Theorem

- Statement: *In any linear network, the voltage across or the current through any element or source 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:

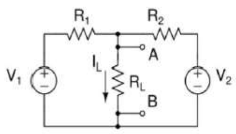
- **In the resistive network shown, $R_1 = R_2 = R_L = 1200\ \Omega$. $V_1 = 9$ V, $V_2 = 12$ V. Evaluate current I_L in mA.**

<u>Procedure</u> (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**

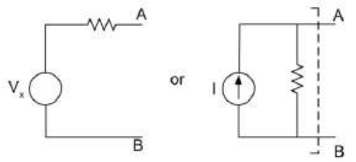
Thevenin's and Norton's Theorems



- Assume that we have to find I_L for a few values of R_L.
- Both Loop method and Node voltage method would involved writing and solving equations for each R_L.

- Very convenient to use Thevenin's or Norton's theorem for such cases.

⟹ Instead replace the network with two terminals A & B by an Equivalent circuit



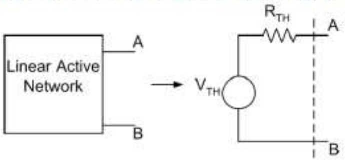
Thevenin (French engineer) OR Norton's Theorem (Bell lab)

Thevenin's Theorem:

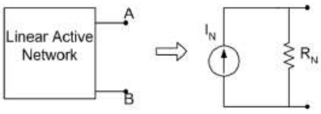
Any linear active network with output terminals AB can be replaced by an ideal voltage source V_{TH} in series with a single resistor(?) R_{TH},

Where $V_{TH} \longrightarrow$ Open circuit voltage measured across the terminals AB

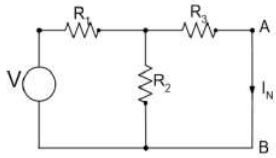
$R_{TH} \longrightarrow$ Equivalent resistance of the network at the terminals AB when all internal sources are set equal to zero.



Norton's Theorem



$I_N \longrightarrow$ Current through the short circuit applied to the terminals AB



$R_N = R_{TH}$

$$I_N = \frac{V}{\left(R_1 + \frac{R_2R_3}{R_2+R_3}\right)}\frac{R_2}{R_3+R_2}$$

Thevenin vs Norton Model

- Both Thevenin and Norton equivalent circuits are very useful in representing practical voltage and current sources.
  - Thevenin and Norton models are equivalent – one equivalent circuit can be converted to the other easily.
- Thevenin's model is useful when the R_{TH} is relatively small, while Norton's model is preferred when $R_{TH} = R_N$ is relatively high.
- Eg.
  - A practical voltage source can be represented by the Thevenin's model with an open circuit voltage (V_{TH}) in series with a small internal resistance (R_{TH})
    - Battery is a good example
  - A practical current source is better represented by the Norton's model with the short circuit current (I_N) connected in parallel with a large resistance.
    - A photodetector or a solar cell is a good example