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電路學講義

Circuits Notes

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General Information

1. class: Friday 9:10-12:10, Room 225
2. textbook: *Circuits*, A. B. Carlson, Brooks/Cole, 2000
3. scopes: basic concepts and analysis methods of linear DC and AC circuits in frequency and time domains
4. contents:

   Ch.1 Circuit variables and laws 1.4, 1.5
   Ch.2 Properties of resistive circuits, 2.3-2.5
   Ch.3 Applications of resistive circuits, 3.2, 3.3
   Ch.4 Systematic analysis methods, 4.1-4.4

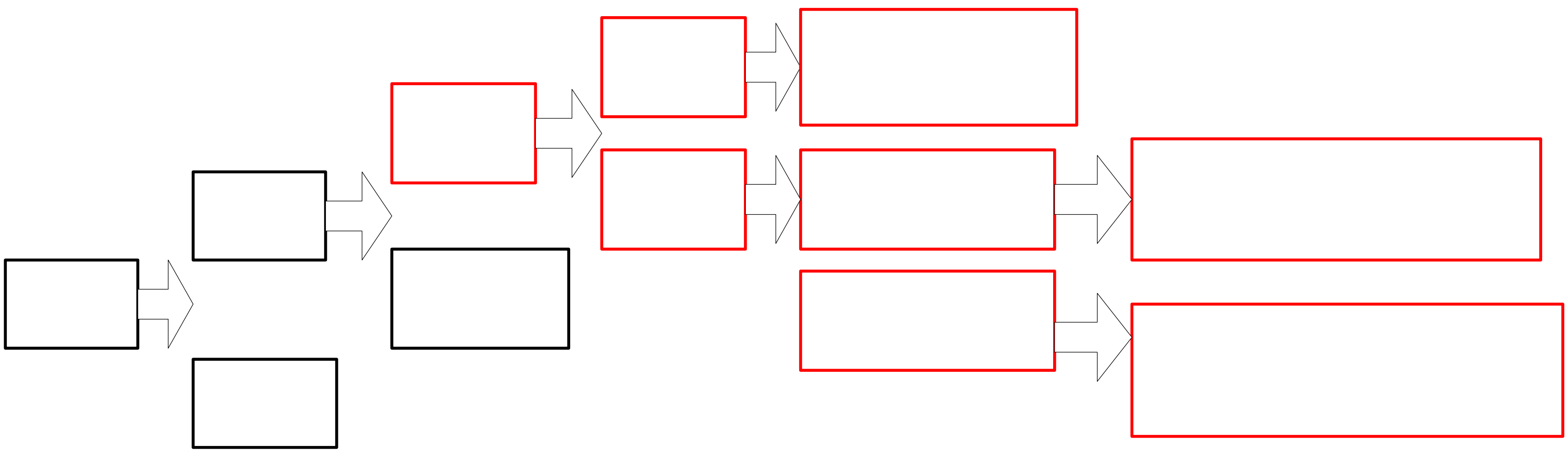
   linear equations

   Ch.5 Energy storage and dynamic circuits, 5.3
   Ch.6 AC circuits, 6.1-6.3
   Ch.7 AC power and three-phase circuits, 7.1, 7.2
   Ch.8 Transformers and mutual inductance (skip)
   Ch.9 Transient response, 9.1-9.4

   linear differential equations (time domain)

Ch.10 Network functions and s-domain analysis (skip)
Ch.11 Frequency response and filters, 11.1, 11.2, 11.4
Ch.12 Fourier series analysis (skip)
Ch.13 Laplace transform analysis, 13.1-13.3
Ch.14 Two-port networks, 14.1-14.3
Ch.15 Stae-variable analysis (skip)

linear equations (frequency domain)



5. total class hour: 51 hours
6. grades: 5 Quiz (Ch. 3, 5, 7, 9, 11) 60%, Final exam. 40%
7. office: room 541, or thc@ew.ee.ntu.edu.tw
8. Notes are available at http://cc.ee.ntu.edu.tw/%7Ethc/ or comm.ntu.edu.tw/faculty.htm

Chapter 1 Circuit variables and laws

1.1-1.3 (optional)

definitions and units of current, voltage, and electrical power, Ohm's law

1.4 Kirchhoff's laws

node, supenode, loop, KVL and KCL, series and parallel connections

1.5 Elementary circuits analysis

voltage source and current source connections, branch variable analysis

1.1-1.3 <u>Optional</u>

1. Definitions

(1) current: equivalent positive charge transfer rate

unit: amp (A)

$$i(t) \equiv \frac{dq(t)}{dt}$$

direction: direction of equivalent positive charge transfer

average current over $t_o \le t \le t_o + T$:

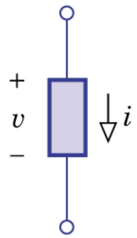
$$i_{av}(t) \equiv \frac{q_T}{T} = \frac{1}{T}\int_{t_0}^{t_0+T} i(t)dt$$

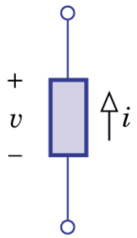
(2) voltage (potential difference): energy change per charge between two points

$$v \equiv \frac{dw}{dq}$$

unit: J/C, volt(V)

+: higher potential, -: lower potential





(a) Passive polarity convention (b) Active polarity convention

(3) electric power: energy transfer rate $p \equiv \frac{dw(t)}{dt} = \frac{dw}{dq}\frac{dq}{dt} = vi$

unit: watt (W)

+: consume power, -: supply power

(a) total energy: $$w_T = \int_{t_0}^{t_0+T} p(t)dt$$

unit: 1Wh=3.6×10^{3}J

(b) battery capacity:

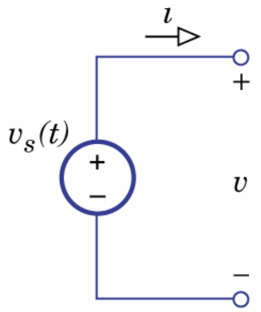
unit: 1Ah=1C/s×3600s=3600C $$q_T = \frac{w_T}{v} = iT$$

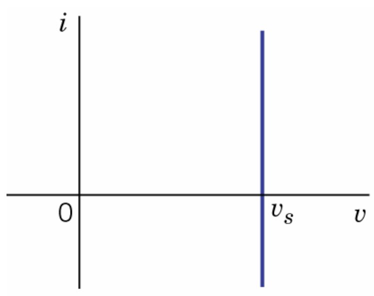
2. Sources

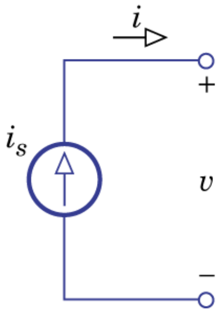
(1) ideal voltage source: a two-terminal element to supply specified voltage

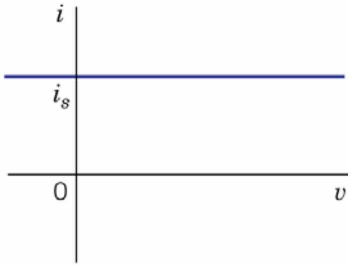
(2) ideal current source: a two-terminal element to supply specified current

Nonlinear elements









3. Ideal linear resistor: a two-terminal energy-consuming linear element described by Ohm's law $v = Ri$

unit: ohm (Ω)

(1) *i-v* curve in I and III quadrants: passive element

(2) conductance: $G \equiv R^{-1}$

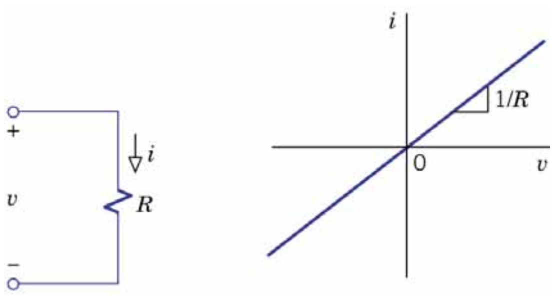
unit: siemens (S)

(3) power dissipation (ohmic loss): $p = vi = i^2R = \dfrac{v^2}{R}$

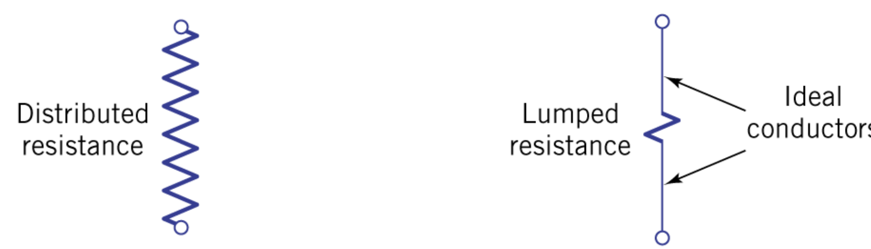
(4) resistivity ρ: $R = \rho \dfrac{l}{A}$ conductivity: σ $\sigma = \dfrac{1}{\rho}$

unit: Ωm

(5) **lumped-parameter model: no dimension or *l*<< λ**



(a) Symbol (b) i–v curve

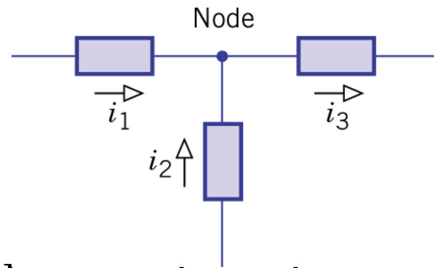


(a) Resistance distributed between two terminals (b) Lumped-parameter model

1.4 Kirchhoff's laws

Basics

1. **node**: a connection point of two or more circuit element
2. **KCL: the algebraic sum of all currents into any node equals zero**



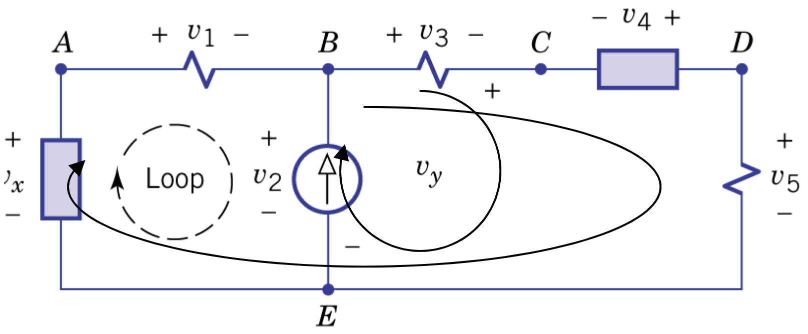
$$\sum_{node} i = i_1 + i_2 + (-i_3) = 0$$

3. **loop**: any path that goes from node to node and returns to the starting node, passing only once through each node (CW direction)
4. **KVL: the algebraic sum of all voltage drops around any loop equals zero**

$$\sum_{loopABEA} v = v_1 + v_2 + (-v_x) = 0$$

$$\sum_{loopABDEA} v = v_1 + v_3 + (-v_4) + v_5 + (-v_x) = 0$$

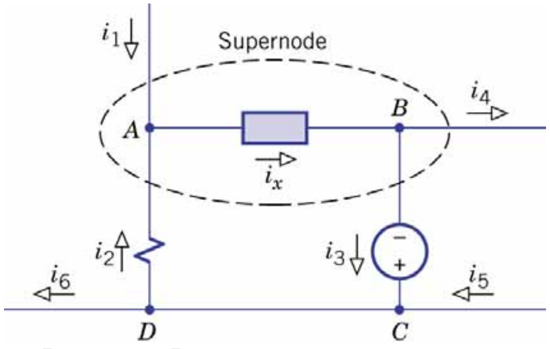
$$\sum_{loopBCEB} v = v_3 + v_y + (-v_2) = 0$$



Discussion

1. KVL and KCL are circuit relations (linear equations), **irrespective** to the element type.
2. *i*-*v* is the relation (linear or nonlinear equation) of circuit element
3. **circuit analysis: to solve *v* and *i* based on equations of KVL, KCL and element *i*-*v* relations**
4. **supernode**: a closed region that contains two or more nodes and whose boundary intersects some connecting wires, each wire being intersected only once

$$\sum_{supernode} i = i_1 + i_2 + (-i_3) + (-i_4) = 0$$



Supernodes save effort when i_x is no need to solve.

5. **series connection: same current through each element**
parallel connection: same voltage across each element

6. Ex.1.7 to solve unknown values in the circuit

$$\sum_{supernodeB} i = i_B + 10 - 10.5 = 0 \rightarrow i_B = 0.5mA$$

$$\sum_{nodeC} i = i_4 - 10 = 0 \rightarrow i_4 = 10mA$$

$$\sum_{nodeA} i = 2 - i_3 - i_B = 0 \rightarrow i_3 = 1.5mA$$

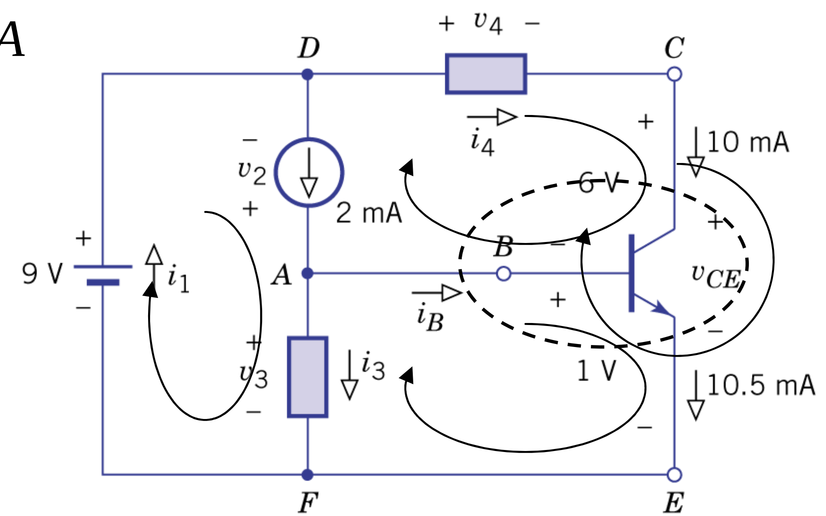
$$\sum_{nodeD} i = i_1 - 2 - i_4 = 0 \rightarrow i_1 = 12mA$$

$$\sum_{loopCEBC} v = v_{CE} - 1 - 6 = 0 \rightarrow v_{CE} = 7V$$

$$\sum_{loopAEFA} v = 1 - v_3 = 0 \rightarrow v_3 = 1V$$

$$\sum_{loopDAFD} v = -v_2 + v_3 - 9 = 0 \rightarrow v_2 = -8V$$

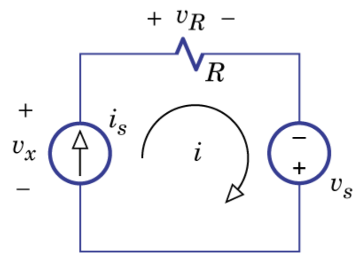
$$\sum_{loopDCBD} v = v_4 + 6 + v_2 = 0 \rightarrow v_4 = 2V$$



1.5 Elementary circuit analysis

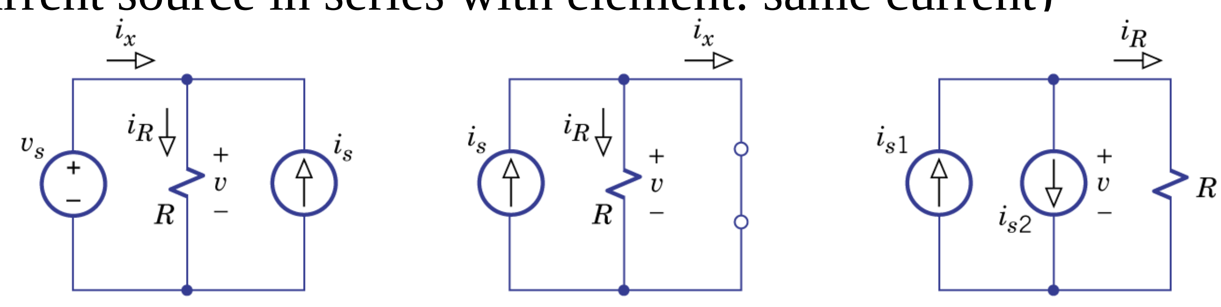
Basics

1. Series circuit: voltage source with series-connected elements (voltage divider), analyze with KVL and Ohm's law
   (voltage source with parallel-connected elements: same voltage)



(a) (b) (c)

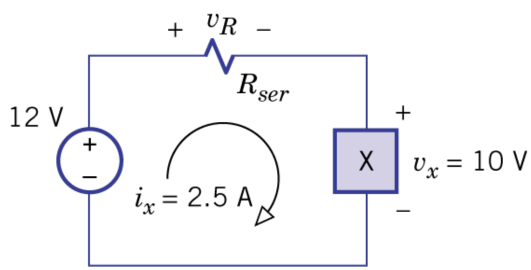
2. Parallel circuit: current source with parallel-connected elements
   (current divider), analyze with KCL and Ohm's law
   (current source in series with element: same current)



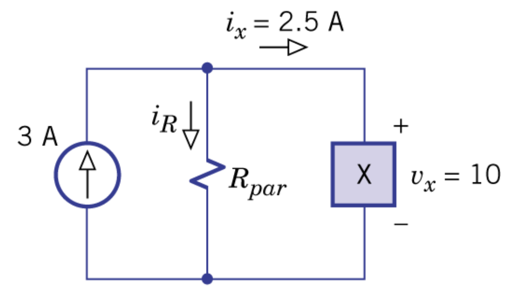
(a) (b) (c)

Discussion

1. Ex. 1.8 a passive element operated with v_x=10V and i_x=2.5A, design the circuit with a 12V voltage source or a 3Acurrent source



(a) Electronic device with series voltage source and resistor



(b) Electronic device with parallel current source and resistor

$$\sum_{loop} v = -12 + 2.5R_{ser} + 10 = 0$$

$$\rightarrow R_{ser} = 0.8\Omega$$

$$\sum_{node} i = 3 - 10R_{par} + 2.5 = 0$$

$$\rightarrow R_{par} = 20\Omega$$

Note: one cannot exchange the voltage and current sources. (ex. 1.16)

2. **Branch variable analysis**

(1) suitable for circuits with partial information

(2) branch variables: current or voltage to be solved

(3) procedures

(a) step 1: properly label the unknown branch variables

(b) step 2: incorporate the partial information in the labels

(c) step 3: apply KVL to loops and KCL to nodes involved with only one unknown

(d) step 4: verify the results

3. Ex.1.9 given v_4=24V, find i_s and power values from two sources

step 1: label i_1 and v_2 as branch variables

step 2: $v_4 = 24 \rightarrow i_4 = 3, v_3 = 21$

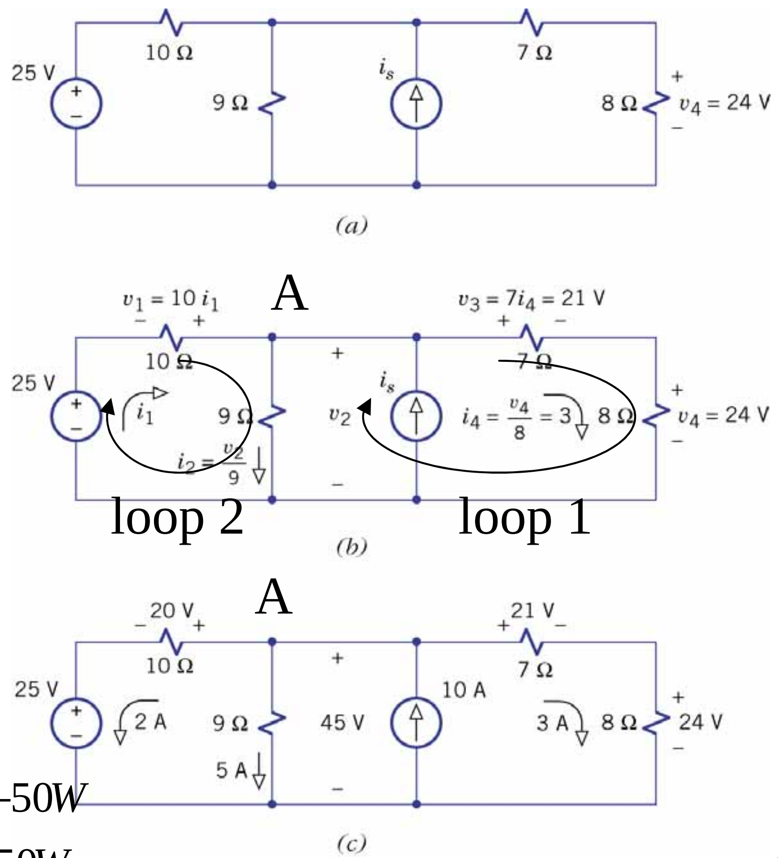
step 3: $\sum_{loop1} v = -v_2 + 21 + 24 = 0 \rightarrow v_2 = 45$

$$\sum_{loop2} v = -25 - 10 i_1 + 45 = 0 \rightarrow i_1 = -2$$

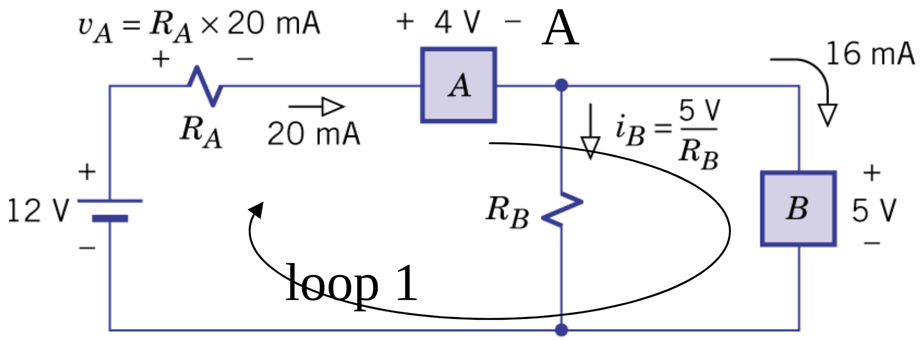
$$\sum_{nodeA} i = -2 - \frac{45}{9} + i_s - \frac{21}{7} = 0 \rightarrow i_s = 10$$

voltage source supplies $p_v = 25 \times -2 = -50W$

current source supplies $p_i = 45 \times 10 = 450W$



4. Ex. 1.10 passive device A operated at 4V, 20mA, and passive device B operated at 5V, 16mA, design a biasing circuit



$$\sum_{loop1} v = -12 + 0.02R_A + 4 + 5 = 0 \rightarrow R_A = 150\Omega$$

$$\sum_{nodeA} i = 0.02 - \frac{5}{R_B} - 0.016 \rightarrow R_B = 1250\Omega$$