GE 104 : Introduction to electrical engineering

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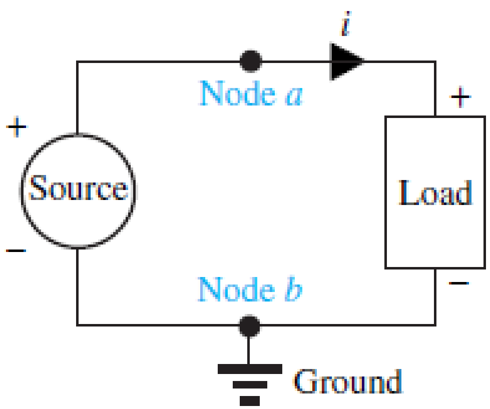
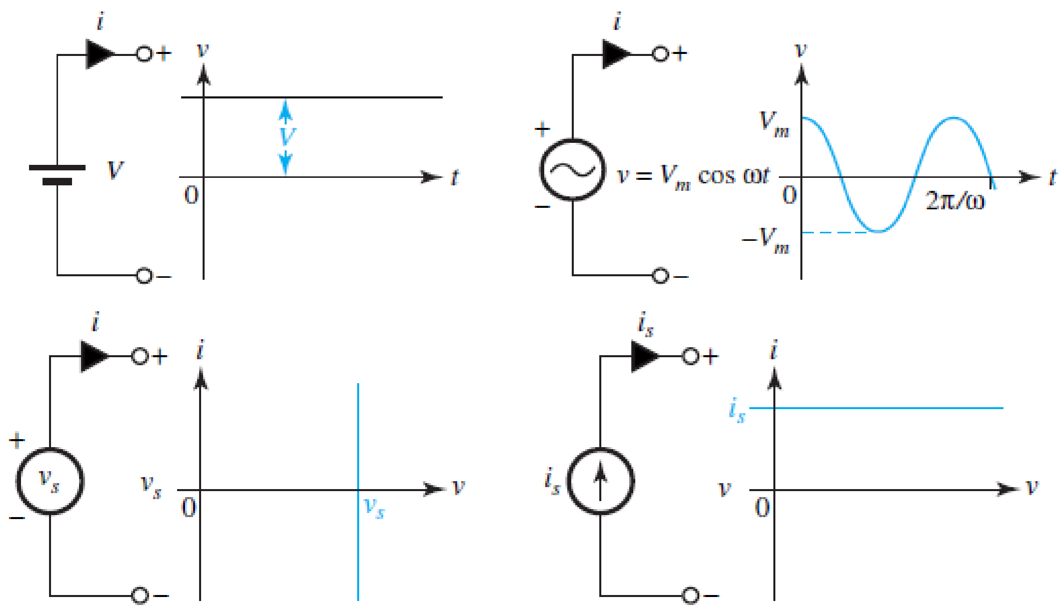
1. Energy and Power

$$v = \frac{dw}{dq}$$ *v is voltage ; potential difference between two charge particle*

Power $$p = \frac{dw}{dt} = \left(\frac{dw}{dq}\right)\left(\frac{dq}{dt}\right) = vi$$

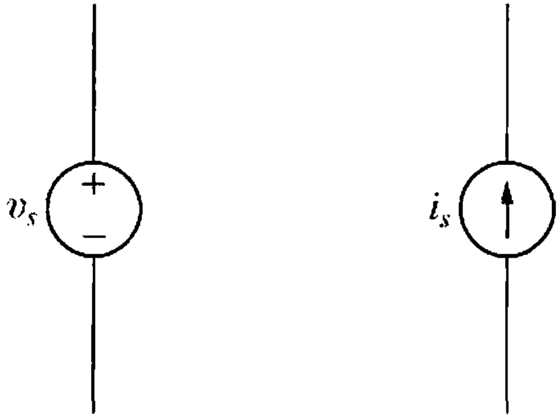
2. Sources and loads



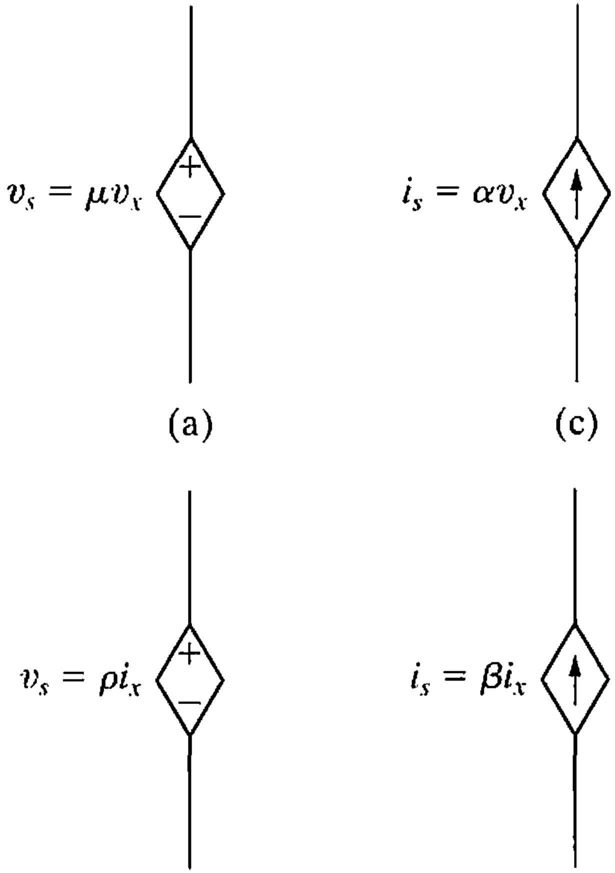


DC voltage ; AC voltage ; Ideal voltage and current source

3. Sources



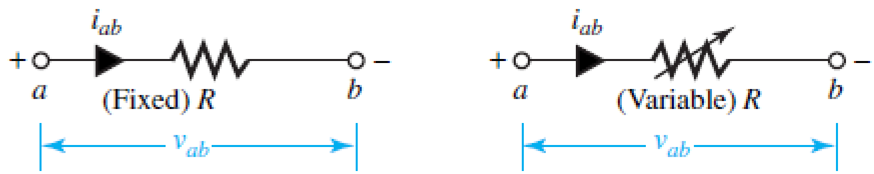
Idea Voltage and current source



Dependant sources- (a) Voltage controlled voltage (b) Voltage controlled current (c) current controlled Voltage (d) current controlled current

4. Lumped Circuit Elements

- *Resistance*
- *Inductance*
- *Capacitance*



$i_{ab} = v_{ab}/R = Gv_{ab}$

$$i = v/R = Gv, \text{ or } v = iR$$

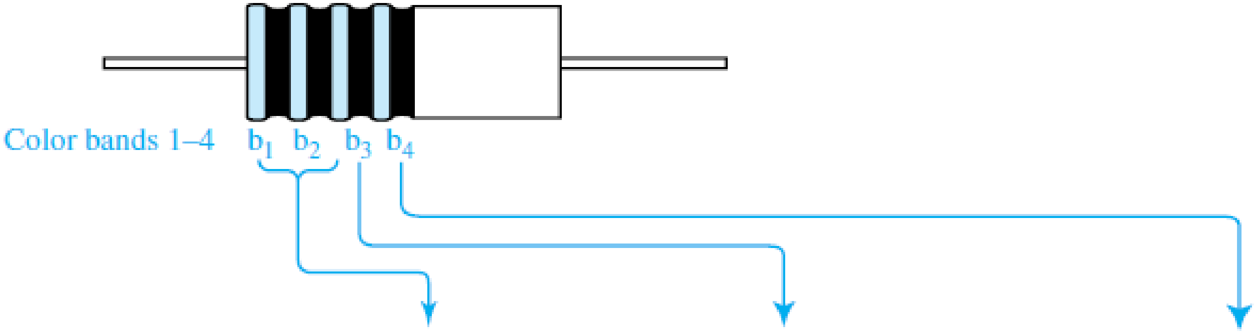
$$R = \frac{\rho l}{A} = \frac{l}{\sigma A}$$

Temperature dependency on resistivity

$$\rho_{T2} = \rho_{T1}\left(\frac{T_2 + T}{T_1 + T}\right)$$

Type	Material	$\rho(\Omega \cdot \text{m})$
Conductors (at 20°C)	Silver	16×10^{-9}
	Copper	17×10^{-9}
	Gold	24×10^{-9}
	Aluminum	28×10^{-9}
	Tungsten	55×10^{-9}
	Brass	67×10^{-9}
	Sodium	0.04×10^{-6}
	Stainless steel	0.91×10^{-6}
	Iron	0.1×10^{-6}
	Nichrome	1×10^{-6}
	Carbon	35×10^{-6}
	Seawater	0.25
Semiconductors (at 27°C or 300 K)	Germanium	0.46
	Silicon	2.3×10^{3}
Insulators	Rubber	1×10^{12}
	Polystyrene	1×10^{15}

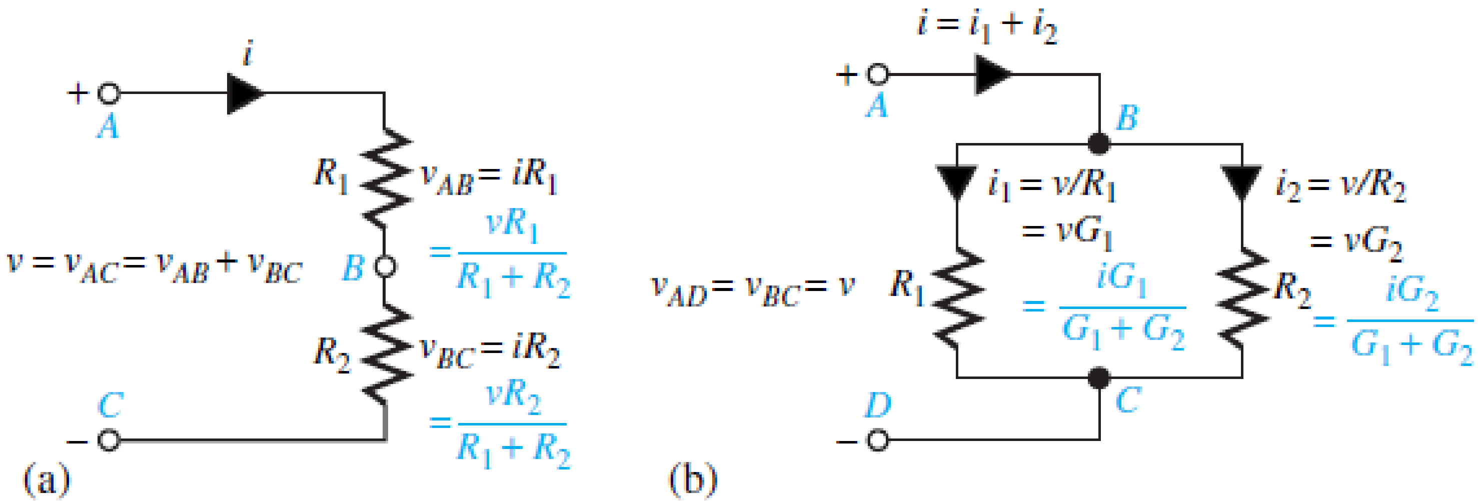
5. Lumped Circuit Elements (Resistance)

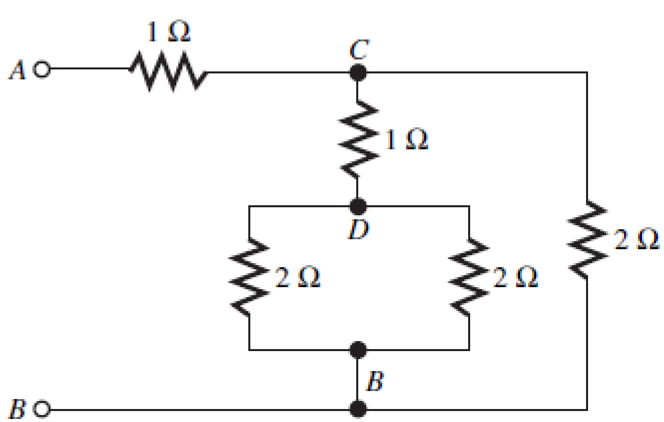


Color of Band	Digit of Band	Multiplier	% Tolerance in Actual Value
Black	0	10^0	—
Brown	1	10^1	—
Red	2	10^2	—
Orange	3	10^3	—
Yellow	4	10^4	—
Green	5	10^5	—
Blue	6	10^6	—
Violet	7	10^7	—
Grey	8	10^8	—
White	9	—	—
Gold	—	10^{-1}	$\pm$ 5%
Silver	—	10^{-2}	$\pm$ 10%
Black or no color	—	—	$\pm$ 20%

Resistance value $= (10b_1 + b_2) \times 10^{b_3}\ \Omega$.

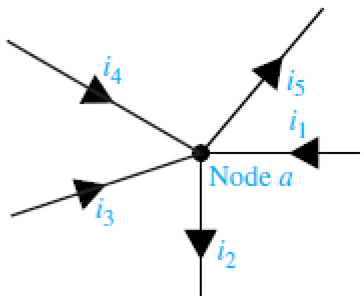
5. Resistance (Parallel & series)





6. Kirchhoff’s Laws

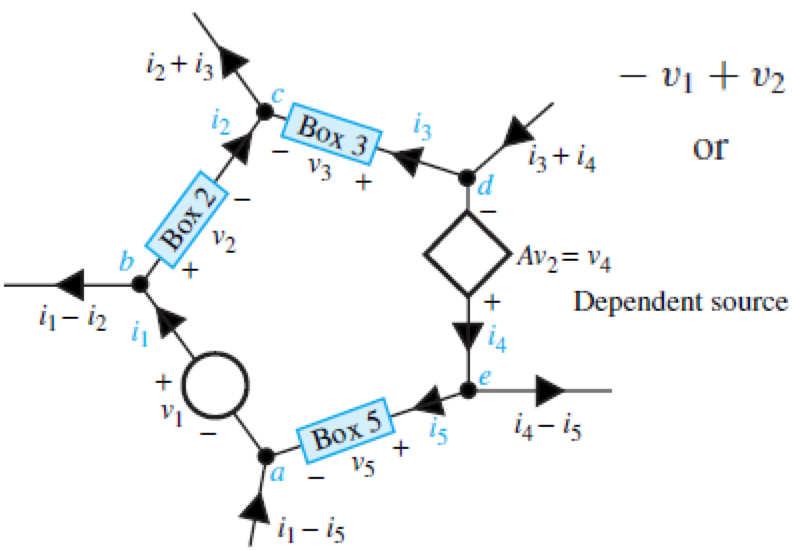
- *kirchhoff’s Current Law (KCL)*



$$i_1 - i_2 + i_3 + i_4 - i_5 = 0 \qquad \text{or} \qquad -i_1 + i_2 - i_3 - i_4 + i_5 = 0$$

$$\text{or} \qquad i_1 + i_3 + i_4 = i_2 + i_5$$

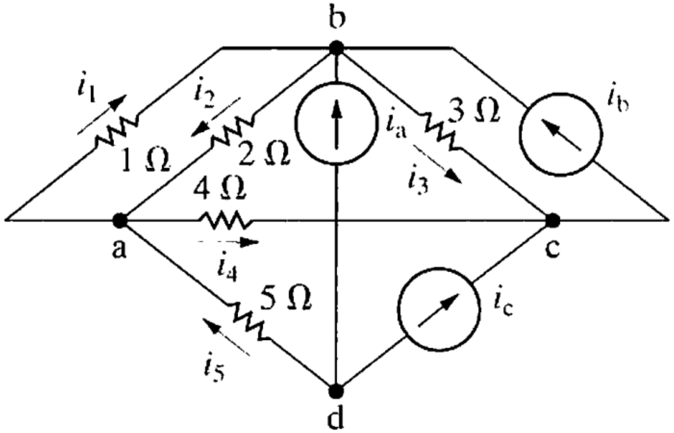
- *kirchhoff’s Voltage Law (KVL)*



$$-v_1 + v_2 - v_3 - v_4 + v_5 = 0 \qquad \text{or} \qquad v_1 - v_2 + v_3 + v_4 - v_5 = 0$$

$$\text{or} \qquad v_1 + v_3 + v_4 = v_2 + v_5$$

6. Example

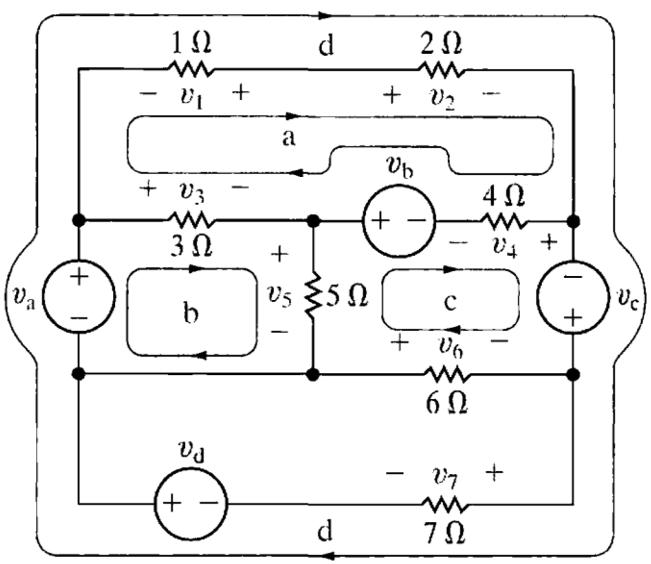


node a $\quad i_1 + i_4 - i_2 - i_5 = 0,$

node b $\quad i_2 + i_3 - i_1 - i_b - i_a = 0,$

node c $\quad i_b - i_3 - i_4 - i_c = 0,$

node d $\quad i_5 + i_a + i_c = 0.$



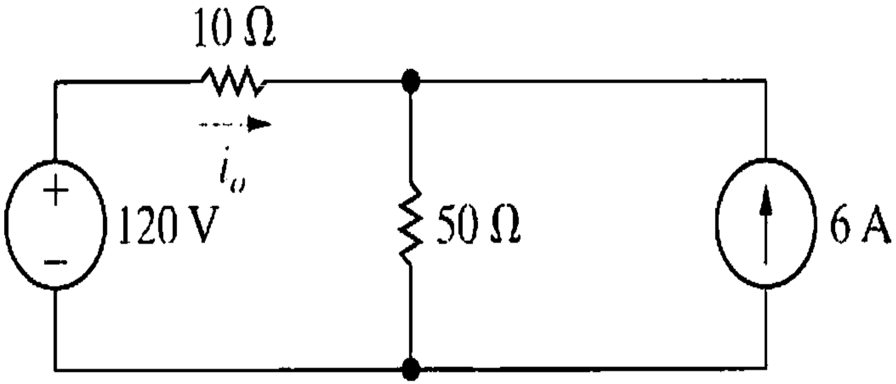
path a $\quad -v_1 + v_2 + v_4 - v_b - v_3 = 0,$

path b $\quad -v_a + v_3 + v_5 = 0,$

path c $\quad v_b - v_4 - v_c - v_6 - v_5 = 0,$

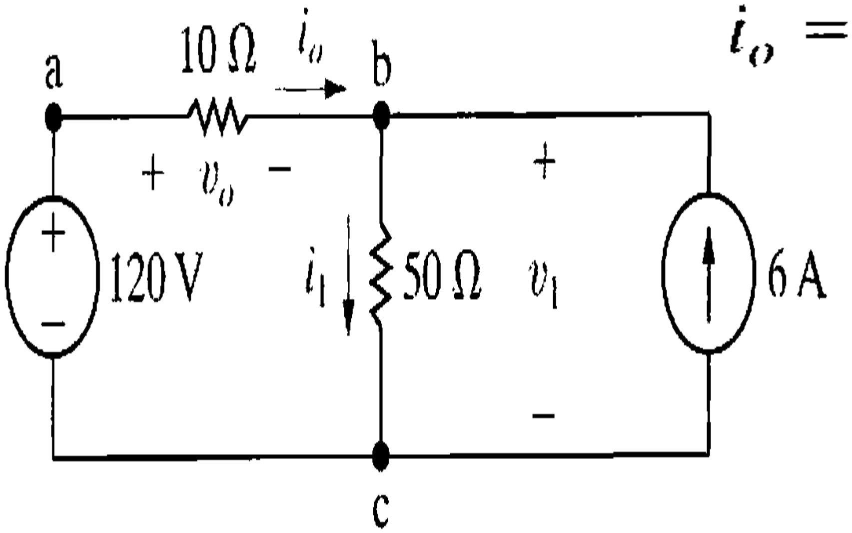
path d $\quad -v_a - v_1 + v_2 - v_c + v_7 - v_d = 0.$

6. Example



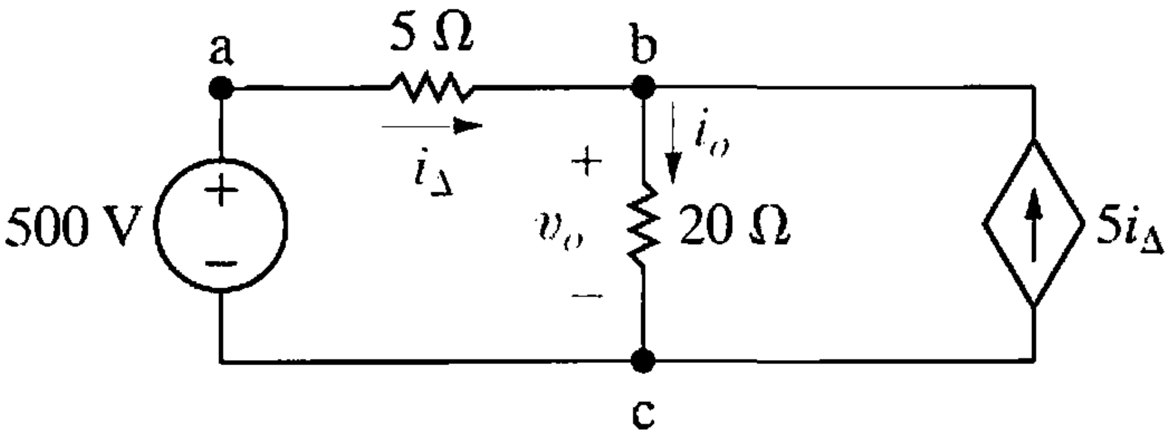
$$i_1 - i_o - 6 = 0.$$

$$-120 + 10i_o + 50i_1 = 0.$$



$$i_o = -3 \text{ A} \quad \text{and} \quad i_1 = 3 \text{ A}.$$

6. Example –Dependant source



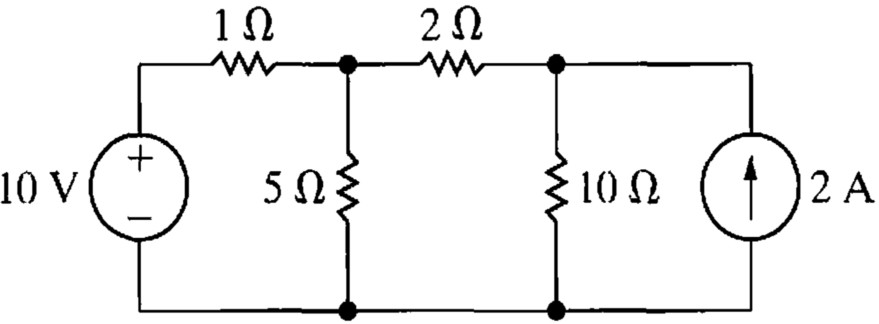
$$500 = 5i_\Delta + 20i_o.$$

$$i_o = i_\Delta + 5i_\Delta = 6i_\Delta.$$

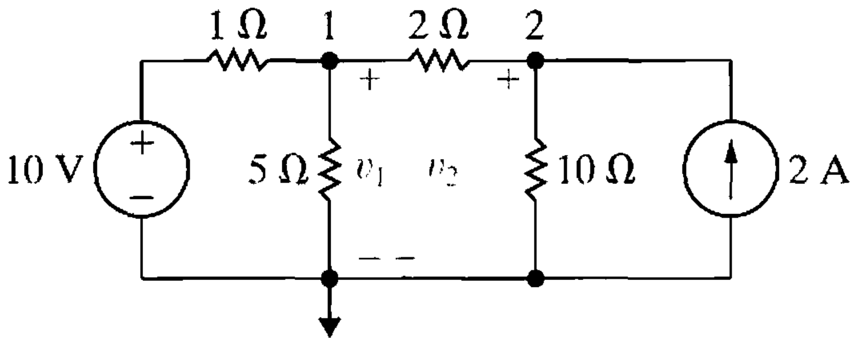
$$i_\Delta = 4 \text{ A},$$

$$i_o = 24 \text{ A}.$$

7. Nodal Analysis



$$\frac{v_1 - 10}{1} + \frac{v_1}{5} + \frac{v_1 - v_2}{2} = 0.$$

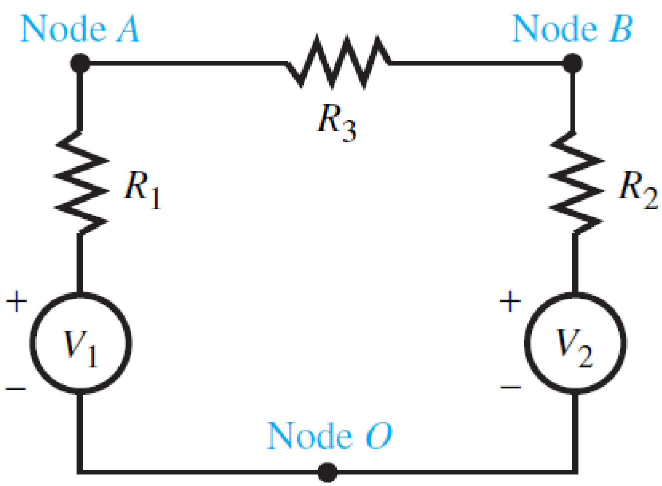


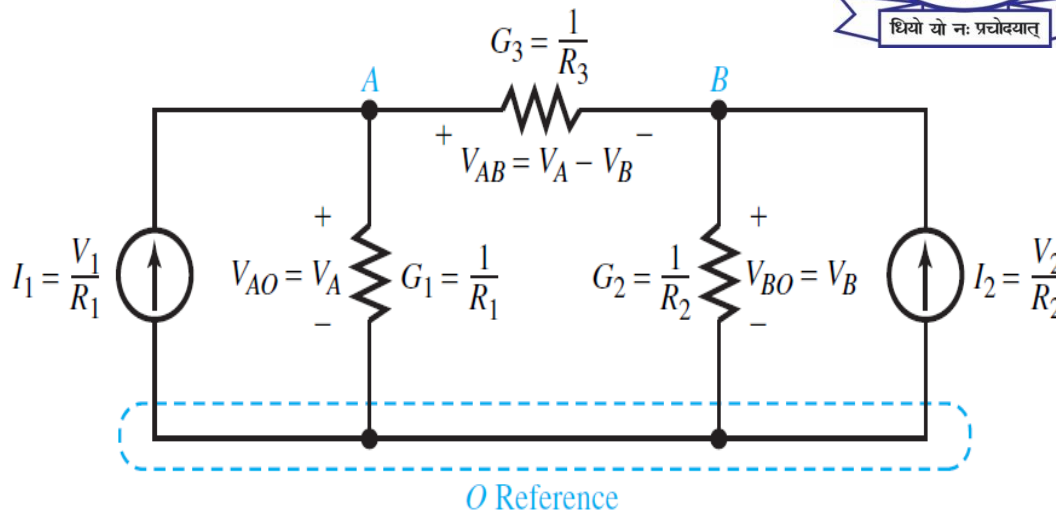
$$\frac{v_2 - v_1}{2} + \frac{v_2}{10} - 2 = 0.$$

$$v_1 = \frac{100}{11} = 9.09 \text{ V}$$

$$v_2 = \frac{120}{11} = 10.91 \text{ V}.$$

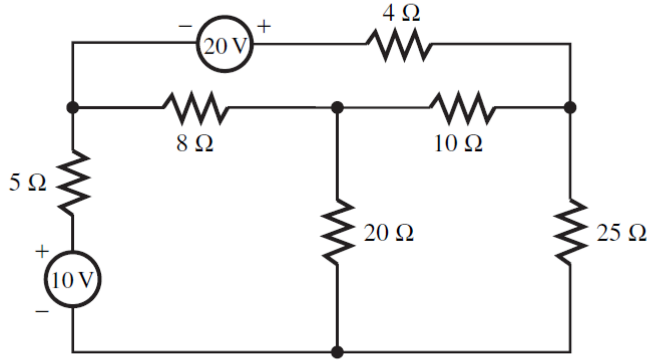
7. Nodal Analysis

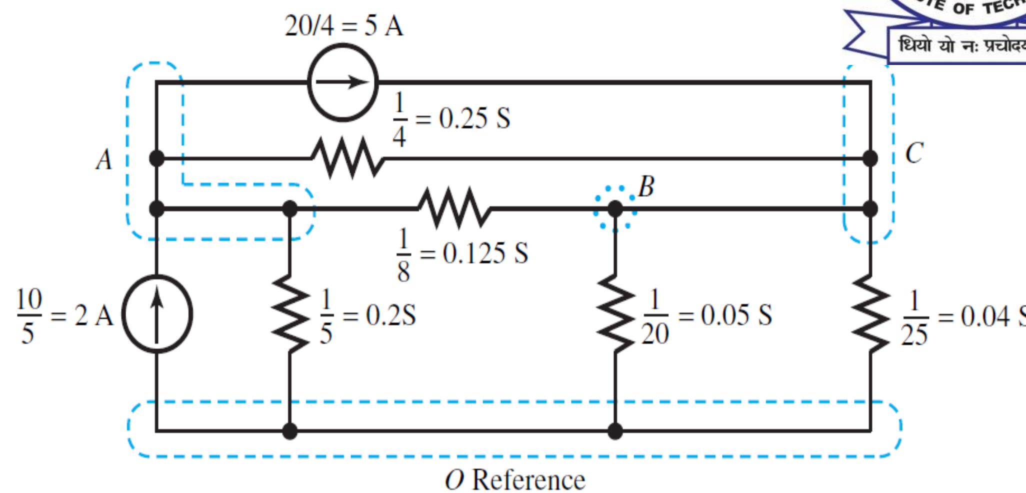




$$
\begin{array}{rcrcccrcl}
G_{11}V_1 & - & G_{12}V_2 & - & \cdots & - & G_{1N}V_N & = & I_1 \\
-G_{21}V_1 & + & G_{22}V_2 & - & \cdots & - & G_{2N}V_N & = & I_2 \\
 & \vdots & & & & & & \vdots & \\
-G_{N1}V_1 & - & G_{N2}V_2 & - & \cdots & + & G_{NN}V_N & = & I_N
\end{array}
$$

7. Nodal Analysis – Example



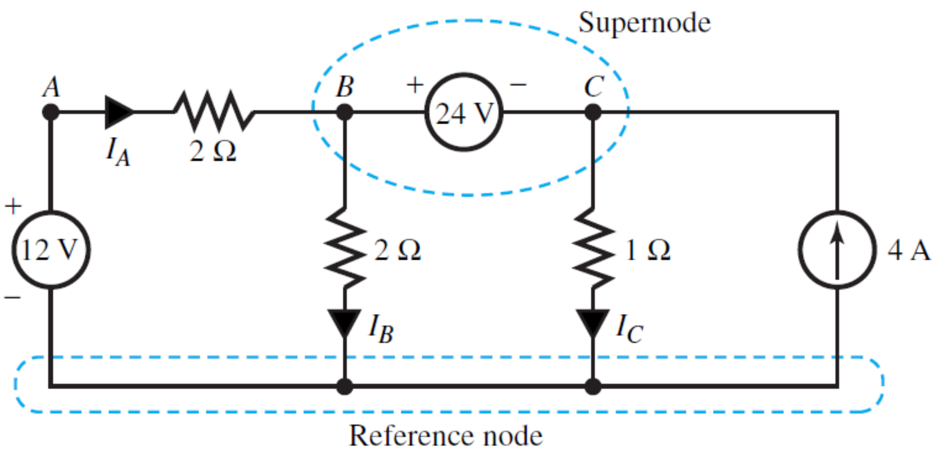


$$\begin{aligned}
&\text{Node } A\text{:} \quad (0.2 + 0.125 + 0.25)V_A - 0.125V_B - 0.25V_C &&= 2 - 5 = -3\\
&\text{Node } B\text{:} \quad -0.125V_A + (0.125 + 0.05 + 0.1)V_B - 0.1V_C &&= 0\\
&\text{Node } C\text{:} \quad -0.25V_A - 0.1V_B + (0.25 + 0.1 + 0.04)V_C &&= 5
\end{aligned}$$

$$\begin{array}{rcrcrcr}
0.575\ V_A & - & 0.125\ V_B & - & 0.25\ V_C & = & -3\\
-0.125\ V_A & + & 0.275\ V_B & - & 0.1\ V_C & = & 0\\
-0.25\ V_A & - & 0.1\ V_B & + & 0.39\ V_C & = & 5
\end{array}$$

$$V_A = 4.34\ V; \qquad V_B = 8.43V; \qquad V_C = 17.77\ \text{V}$$

7. Nodal Analysis – Example



$$V_B - V_C = 24\ \text{V}$$

$$I_A - I_B - I_C + 4 = 0 \qquad \text{or} \qquad \frac{12 - V_B}{2} - \frac{V_B}{2} - \frac{V_C}{1} + 4 = 0$$

$$V_B + V_C = 10$$

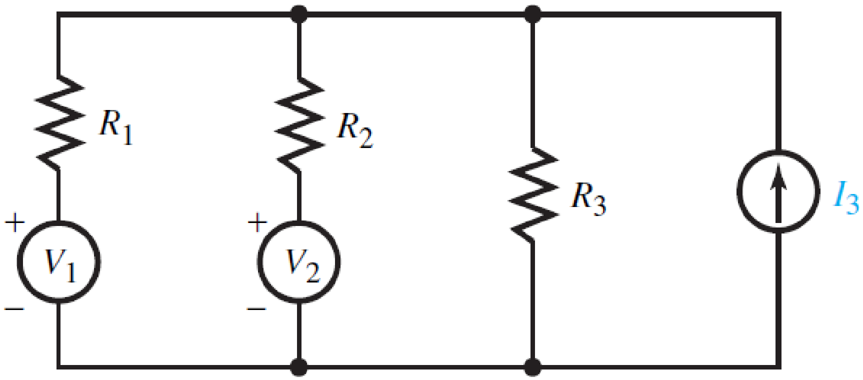
$$V_B = 17\ \text{V} \qquad \text{and} \qquad V_C = -7\ \text{V}$$

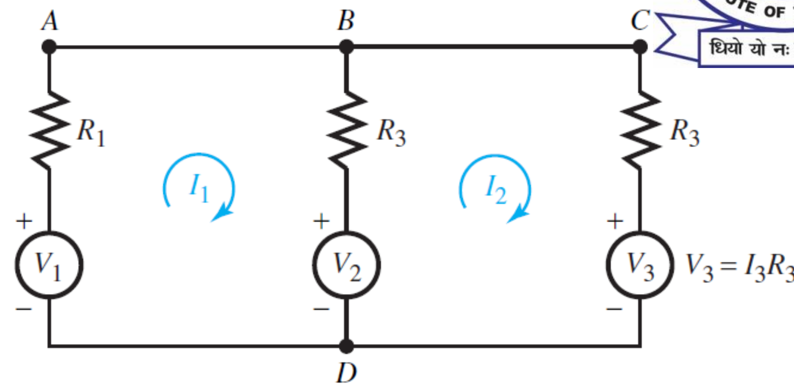
$$I_A = \frac{12 - V_B}{2} = \frac{12 - 17}{2} = -2.5\ \text{A}$$

$$I_B = \frac{V_B}{2} = \frac{17}{2} = 8.5\ \text{A}$$

$$I_C = \frac{V_C}{1} = \frac{-7}{1} = -7\ \text{A}$$

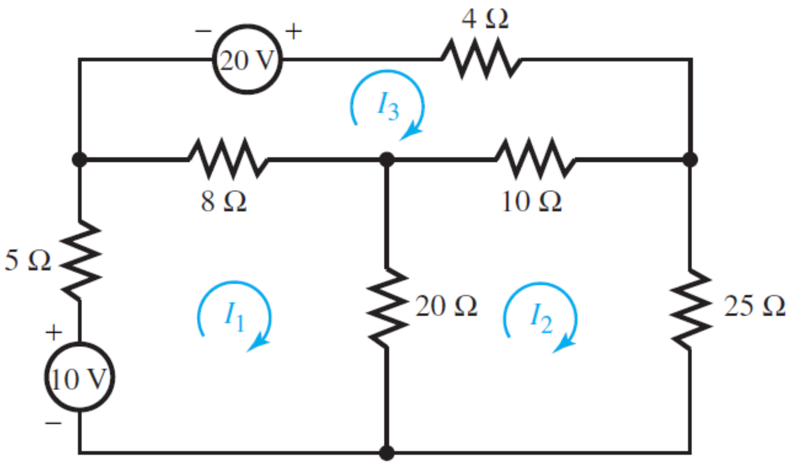
7. Mesh current Analysis





$$
\begin{array}{ccccccccc}
R_{11}I_1 & - & R_{12}I_2 & - & \cdots & - & R_{1N}I_N & = & V_1 \\
-R_{21}I_1 & + & R_{22}V_2 & - & \cdots & - & R_{2N}I_N & = & V_2 \\
 & \vdots & & & & & & \vdots & \\
-R_{N1}I_1 & - & R_{N2}V_2 & - & \cdots & + & R_{NN}I_N & = & V_N
\end{array}
$$

7. Mesh current Analysis -Example



Loop 1 with mesh current I_1: $(5+8+20)I_1 - 20I_2 - 8I_3 = 10$

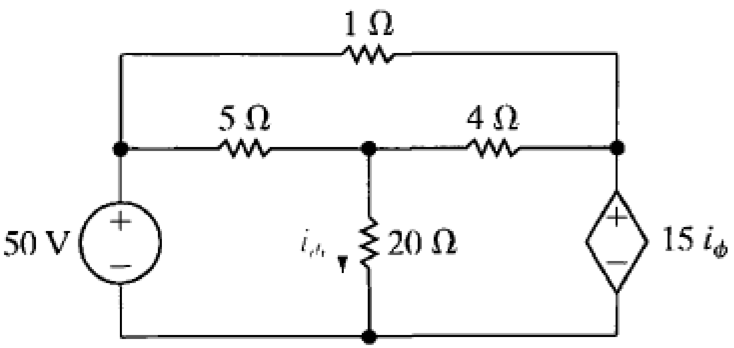
Loop 2 with mesh current I_2: $-20I_1 + (20+10+25)I_2 - 10I_3 = 0$

Loop 3 with mesh current I_3: $-8I_1 - 10I_2 + (4+10+8)I_3 = 20$

$$\begin{array}{rcrcrcr} 33I_1 & - & 20I_2 & - & 8I_3 & = & 10 \\ -20I_1 & + & 55I_2 & - & 10I_3 & = & 0 \\ -8I_1 & - & 10I_2 & + & 22I_3 & = & 20 \end{array}$$

$I_1 = 1.132$ A; $\quad I_2 = 0.711$ A; $\quad I_3 = 1.645$ A

7. Mesh current Analysis -Example



$$50 = 5(i_1 - i_2) + 20(i_1 - i_3),$$

$$0 = 5(i_2 - i_1) + 1i_2 + 4(i_2 - i_3),$$

$$0 = 20(i_3 - i_1) + 4(i_3 - i_2) + 15i_\phi.$$

$$i_\phi = i_1 - i_3,$$

$$50 = 25i_1 - 5i_2 - 20i_3,$$

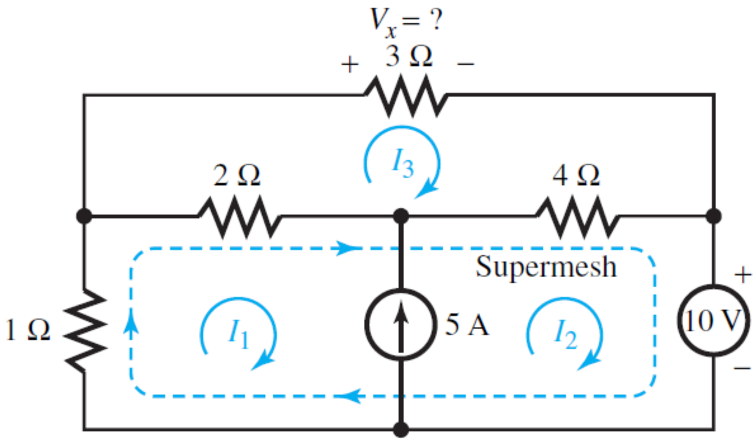
$$0 = -5i_1 + 10i_2 - 4i_3,$$

$$0 = -5i_1 - 4i_2 + 9i_3.$$

$$i_2 = 26 \text{ A},$$

$$i_3 = 28 \text{ A}.$$

7. Mesh current Analysis –Home work



$$I_2 - I_1 = 5$$

$$1I_1 + 2(I_1 - I_3) + 4(I_2 - I_3) + 10 = 0$$

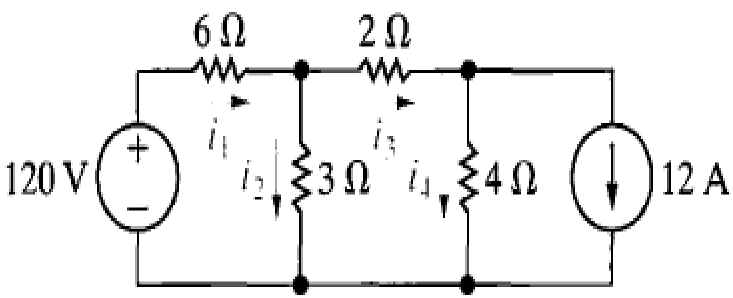
KVL equation for mesh 3

$$3I_3 + 4(I_3 - I_2) + 2(I_3 - I_1) = 0$$

8. Super position theorem

$$f(Kx) = Kf(x) \qquad \text{(homogeneity)}$$

$$f(x_1 + x_2) = f(x_1) + f(x_2) \qquad \text{(additivity)}$$

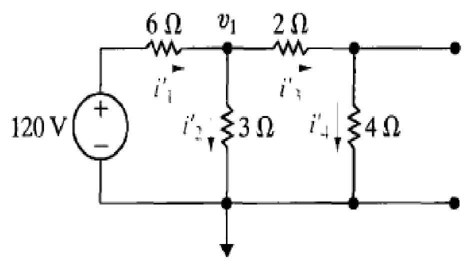


$$i_1 = i_1' + i_1'' = 15 + 2 = 17 \text{ A},$$

$$i_2 = i_2' + i_2'' = 10 - 4 = 6 \text{ A},$$

$$i_3 = i_3' + i_3'' = 5 + 6 = 11 \text{ A},$$

$$i_4 = i_4' + i_4'' = 5 - 6 = -1 \text{ A}.$$



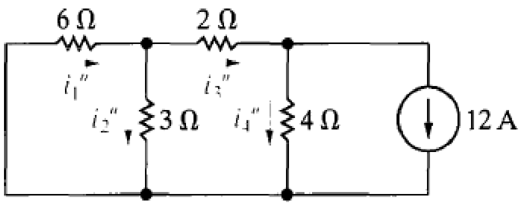
$$\frac{v_1 - 120}{6} + \frac{v_1}{3} + \frac{v_1}{2+4} = 0,$$

$$v_1 = 30 \text{ V}.$$

$$i_1' = \frac{120 - 30}{6} = 15 \text{ A},$$

$$i_2' = \frac{30}{3} = 10 \text{ A},$$

$$i_3' = i_4' = \frac{30}{6} = 5 \text{ A}.$$



$$\frac{v_3}{3} + \frac{v_3}{6} + \frac{v_3 - v_4}{2} = 0,$$

$$\frac{v_4 - v_3}{2} + \frac{v_4}{4} + 12 = 0.$$

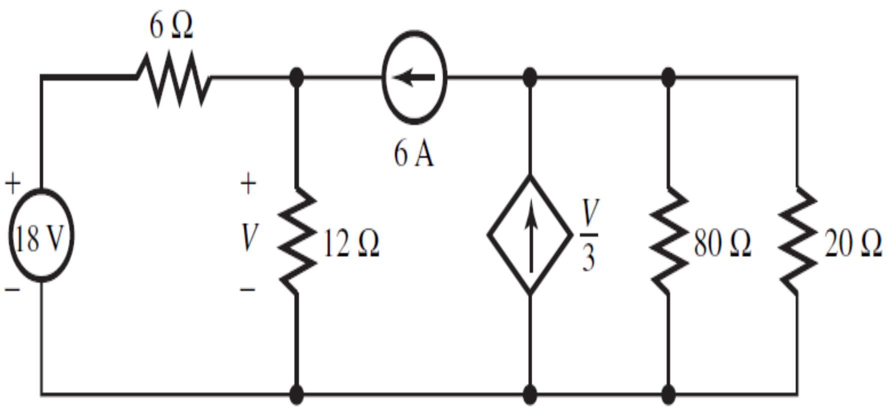
$$i_1'' = \frac{-v_3}{6} = \frac{12}{6} = 2 \text{ A}$$

$$i_2'' = \frac{v_3}{3} = \frac{-12}{3} = -4 \text{ A}$$

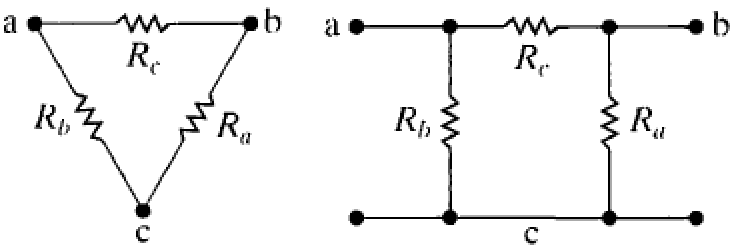
$$i_3'' = \frac{v_3 - v_4}{2} = \frac{-12 + 24}{2} = 6 \text{ A}$$

$$i_4'' = \frac{v_4}{4} = \frac{-24}{4} = -6 \text{ A}$$

8. Super position theorem- example



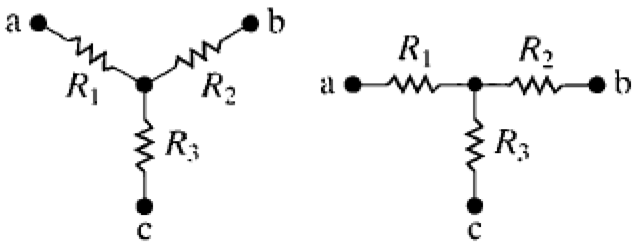
9. Star-delta and delta-star



$$R_{ab} = \frac{R_c(R_a + R_b)}{R_a + R_b + R_c} = R_1 + R_2,$$

$$R_{bc} = \frac{R_a(R_b + R_c)}{R_a + R_b + R_c} = R_2 + R_3,$$

$$R_{ca} = \frac{R_b(R_c + R_a)}{R_a + R_b + R_c} = R_1 + R_3.$$



Δ-to-Y

$$R_1 = \frac{R_b R_c}{R_a + R_b + R_c},$$

$$R_2 = \frac{R_c R_a}{R_a + R_b + R_c},$$

$$R_3 = \frac{R_a R_b}{R_a + R_b + R_c}.$$

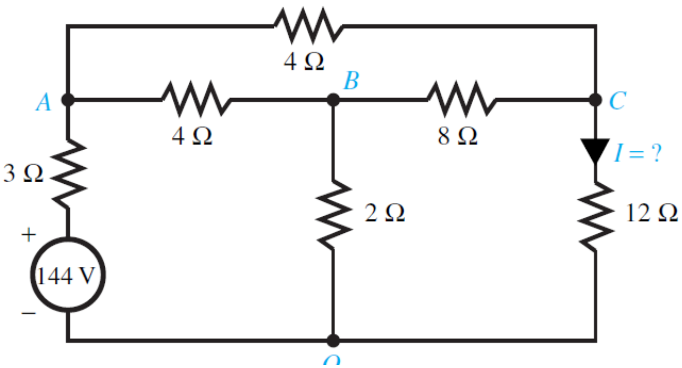
Y-to-Δ

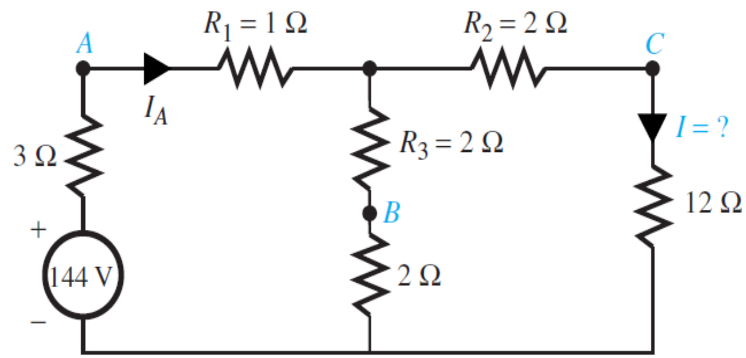
$$R_a = \frac{R_1R_2 + R_2R_3 + R_3R_1}{R_1},$$

$$R_b = \frac{R_1R_2 + R_2R_3 + R_3R_1}{R_2},$$

$$R_c = \frac{R_1R_2 + R_2R_3 + R_3R_1}{R_3}.$$

9. Star- Delta transform Example





$$R_1 = \frac{4 \times 4}{4+8+4} = 1\ \Omega$$

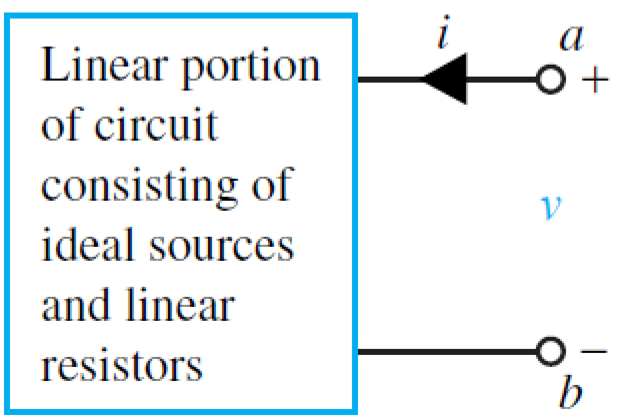
$$R_2 = \frac{4 \times 8}{4+8+4} = 2\ \Omega$$

$$R_3 = \frac{4 \times 8}{4+8+4} = 2\ \Omega$$

$$I_A = \frac{144}{(3+1)+(4\,\|\,14)} = \frac{81}{4}\ \text{A}$$

$$I = \frac{81}{4} \times \frac{4}{18} = \frac{9}{2} = 4.5\ \text{A}$$

10. The Thevenin and norton theorem

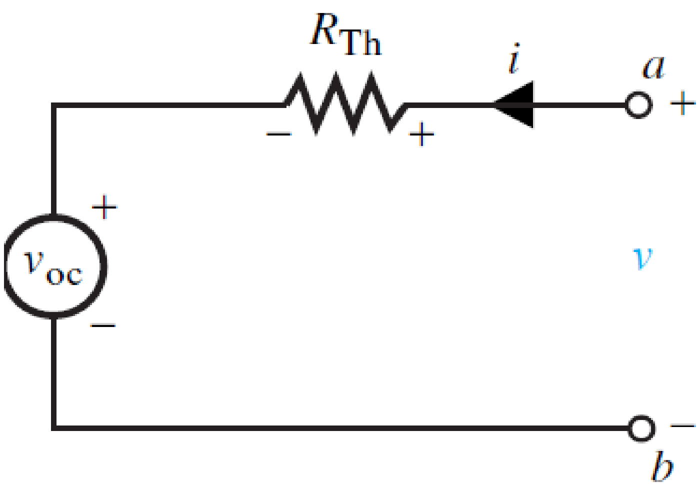


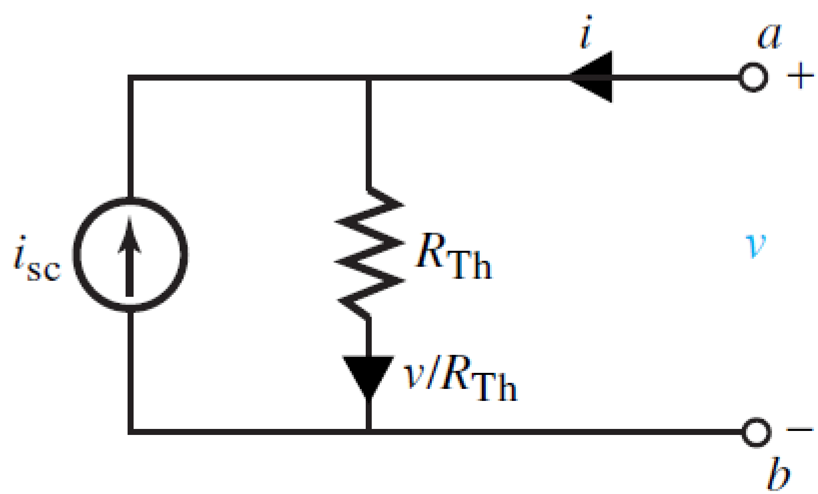
$$v = R_{\mathrm{Th}} i + v_{\mathrm{oc}}$$

$$R_{\mathrm{Th}} = v/i\,|_{v_{\mathrm{oc}}=0}$$

$$v_{\mathrm{oc}} = v|_{i=0}$$

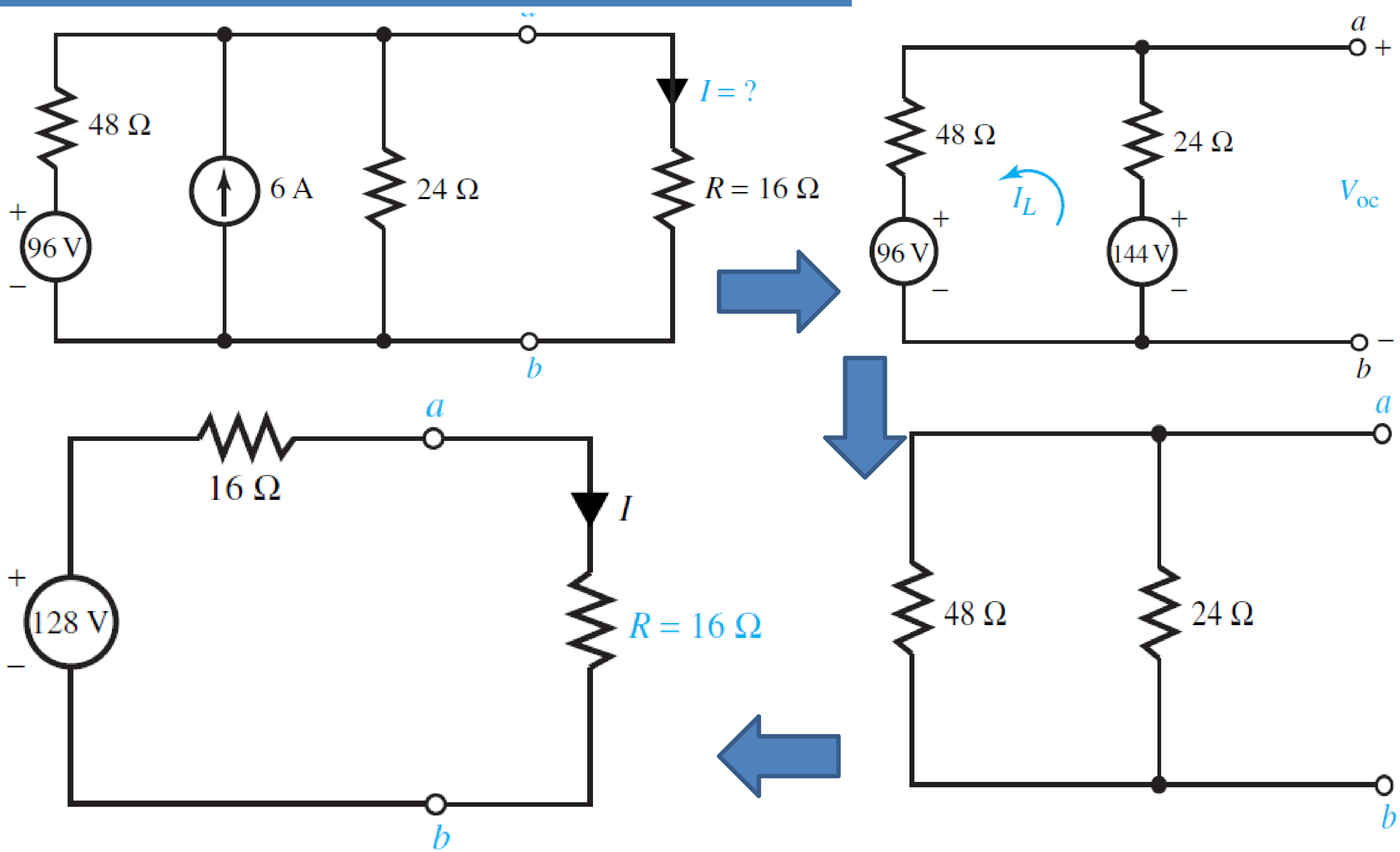
$$i = \frac{v}{R_{\mathrm{Th}}} - \frac{v_{\mathrm{oc}}}{R_{\mathrm{Th}}} = \frac{v}{R_{\mathrm{Th}}} - i_{\mathrm{sc}}$$



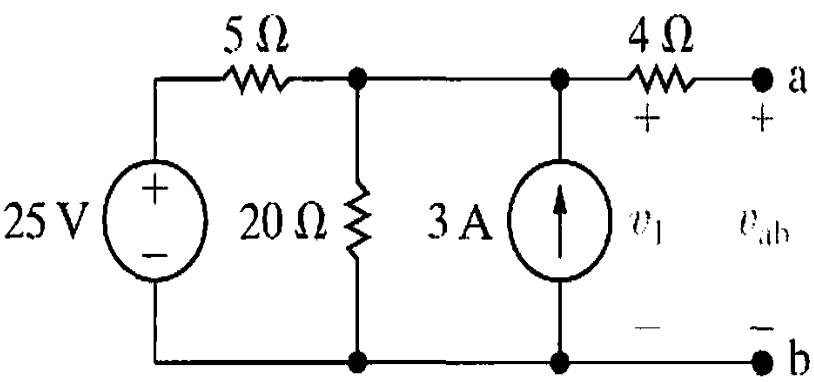


Thevenin Equivalent **Norton Equivalent**

10. The Thevenin theorem - example

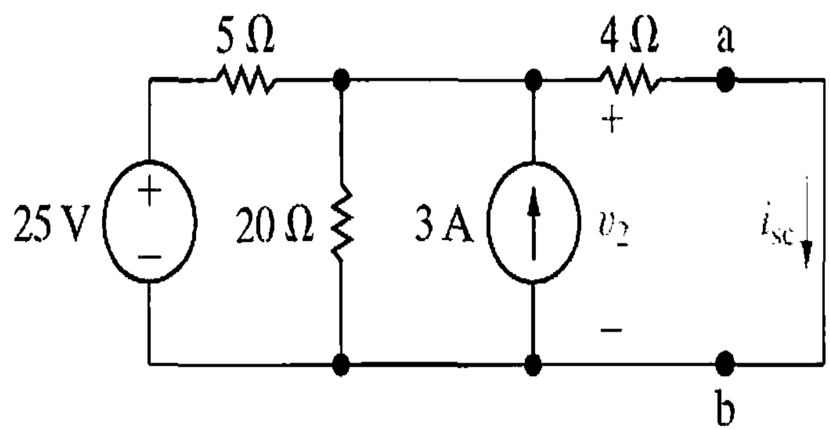


10. The Thevenin theorem - example



$$\frac{v_1 - 25}{5} + \frac{v_1}{20} - 3 = 0.$$

$$v_1 = 32 \text{ V}.$$

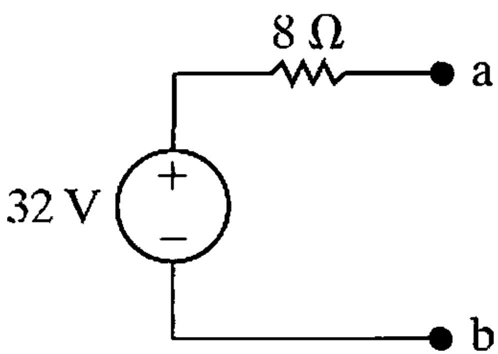


$$\frac{v_2 - 25}{5} + \frac{v_2}{20} - 3 + \frac{v_2}{4} = 0.$$

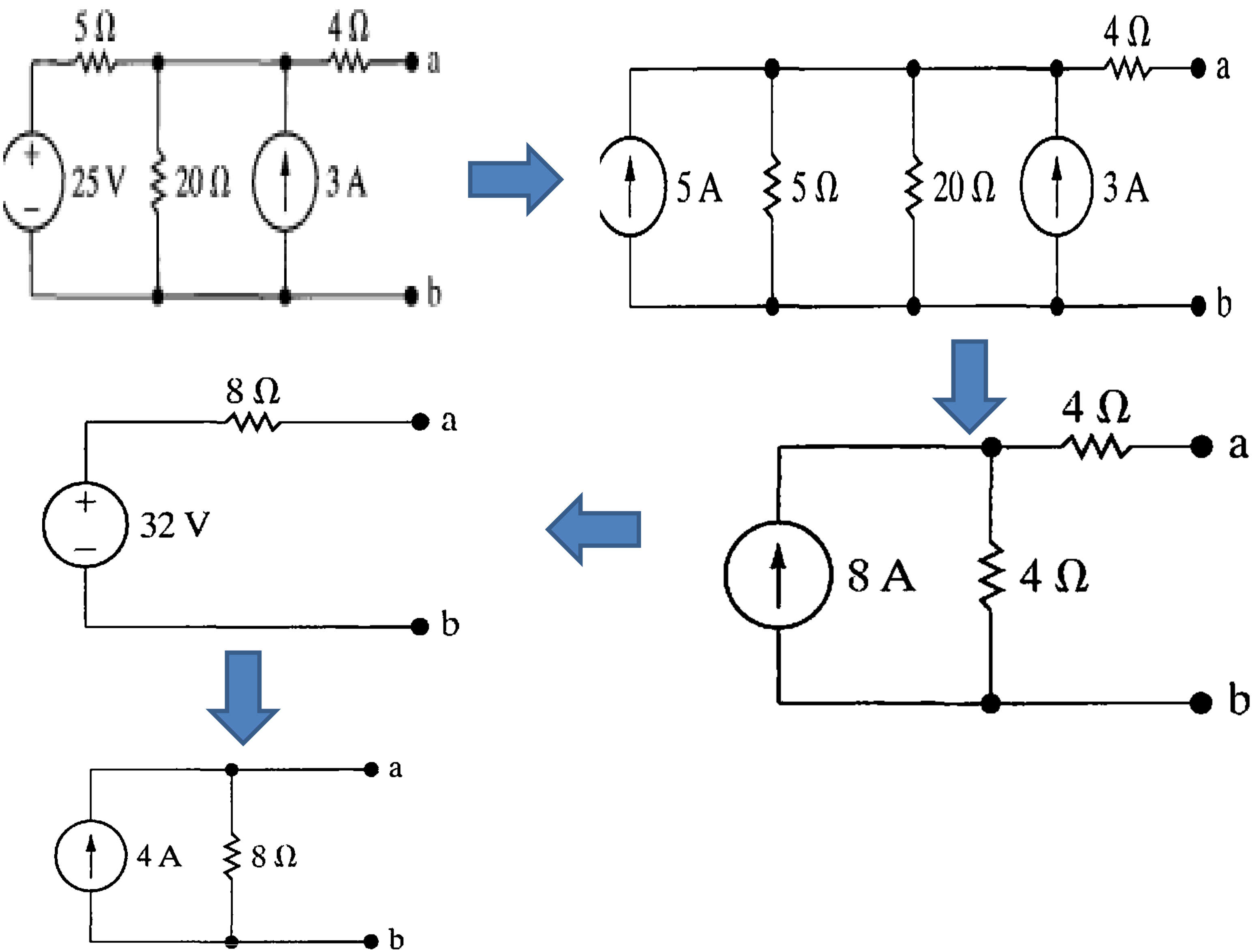
$$v_2 = 16 \text{ V}.$$

$$i_{sc} = \frac{16}{4} = 4 \text{ A}.$$

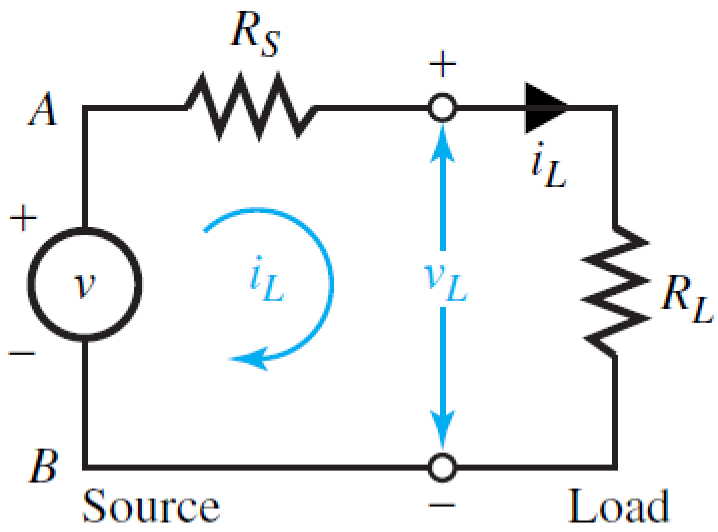
$$R_{Th} = \frac{V_{Th}}{i_{sc}} = \frac{32}{4} = 8\ \Omega.$$



10. The Norton theorem - example



11. Maximum power transfer theorem



$$P_L = i_L^2 R_L$$

$$i_L = \frac{v^2}{R_S + R_L}$$

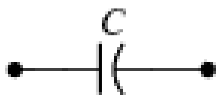
$$P_L = \frac{v^2}{(R_S + R_L)^2} R_L$$

$$\frac{dP_L}{dR_L} = \frac{v^2(R_L + R_S)^2 - 2v^2 R_L (R_L + R_S)}{(R_L + R_S)^4} = 0$$

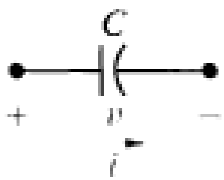
$$(R_L + R_S)^2 - 2R_L(R_L + R_S) = 0$$

$$R_L = R_S$$

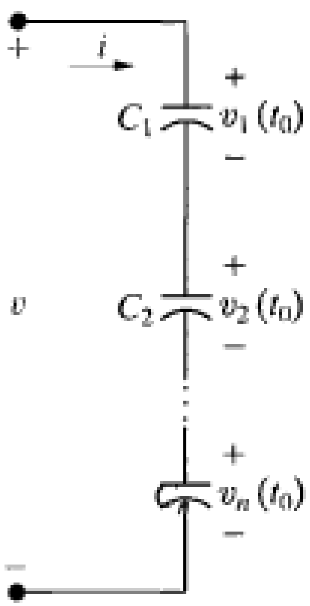
12. Capacitor Principle

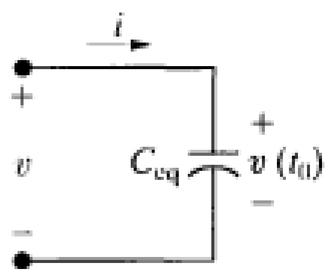


$$i = C\frac{dv}{dt},$$



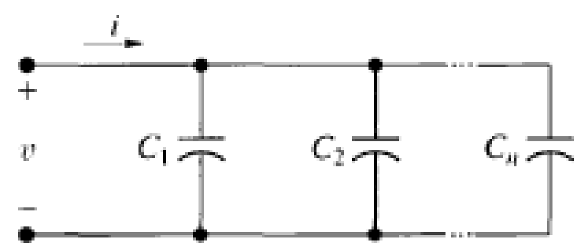
$$i\,dt = C\,dv \quad \text{or} \quad \int_{v(t_0)}^{v(t)} dx = \frac{1}{C}\int_{t_0}^{t} i\,d\tau. \qquad p = vi = Cv\frac{dv}{dt}.$$



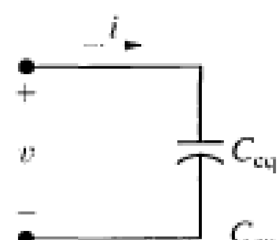


$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \cdots + \frac{1}{C_n}$$

$$v(t_0) = v_1(t_0) + v_2(t_0) + \cdots + v_n(t_0)$$



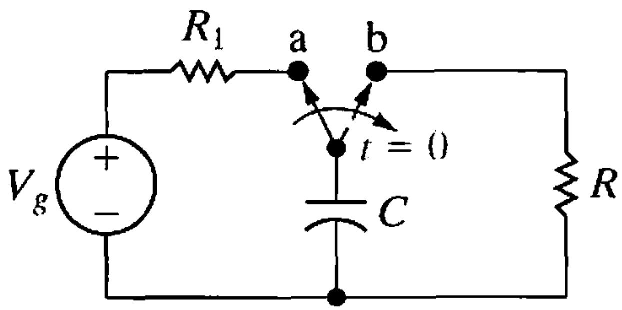
(a)



$$C_{eq} = C_1 + C_2 + \cdots + C_n$$

https://www.youtube.com/watch?v=f_MZNsEqyQw

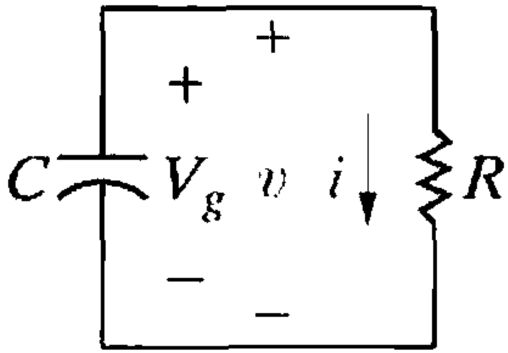
12. Natural response of RC circuit



$$C\frac{dv}{dt} + \frac{v}{R} = 0.$$

$$v(t) = v(0)e^{-t/RC}, \quad t \geq 0.$$

$$\tau = RC.$$

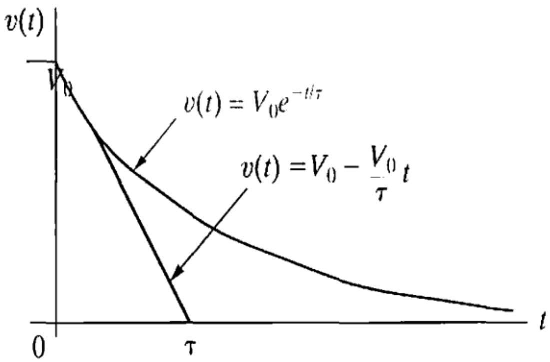


$$i(t) = \frac{v(t)}{R} = \frac{V_0}{R}e^{-t/\tau}, \quad t \geq 0^+,$$

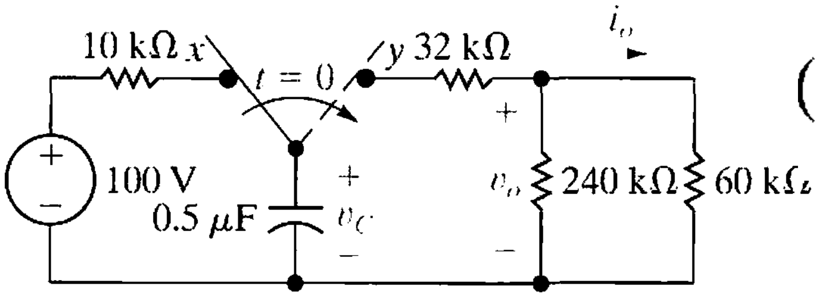
$$p = vi = \frac{V_0^2}{R}e^{-2t/\tau}, \quad t \geq 0^+,$$

$$w = \int_0^t p\,dx = \int_0^t \frac{V_0^2}{R}e^{-2x/\tau}\,dx$$

$$= \frac{1}{2}CV_0^2(1 - e^{-2t/\tau}), \quad t \geq 0.$$



12. Natural response of RC circuit - example



time constant

$$(0.5 \times 10^{-6})(80 \times 10^{3})$$

$$v_C(t) = 100e^{-25t}\ \mathrm{V}, \quad t \geq 0.$$

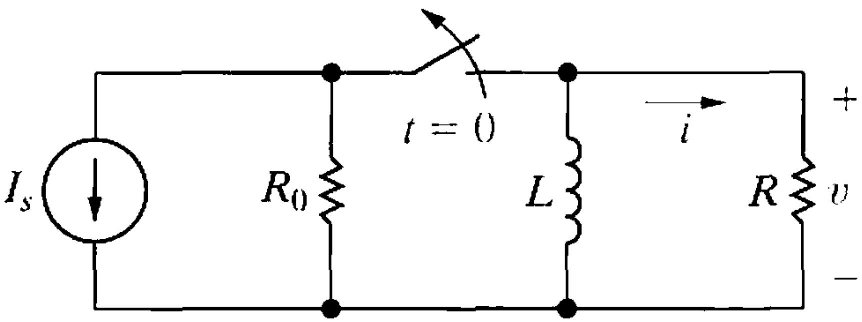
$$v_o(t) = \frac{48}{80} v_C(t) = 60e^{-25t}\ \mathrm{V}, \quad t \geq 0^+.$$

$$i_o(t) = \frac{v_o(t)}{60 \times 10^3} = e^{-25t}\ \mathrm{mA}, \quad t \geq 0^+.$$

$$p_{60\mathrm{k}\Omega}(t) = i_o^2(t)(60 \times 10^3) = 60e^{-50t}\ \mathrm{mW}, \quad t \geq 0^+.$$

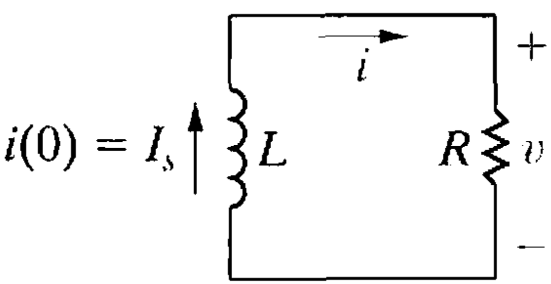
$$w_{60\mathrm{k}\Omega} = \int_0^{\infty} i_o^2(t)(60 \times 10^3)\, dt = 1.2\ \mathrm{mJ}.$$

13. Natural response of RL circuit

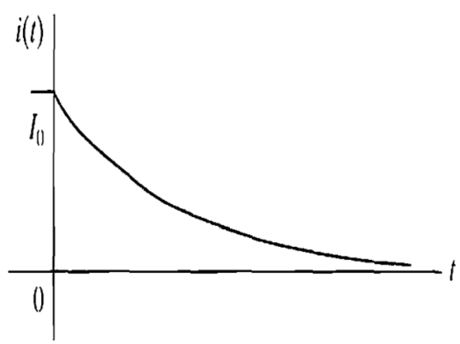


$$L\frac{di}{dt} + Ri = 0,$$

$$\frac{di}{dt}dt = -\frac{R}{L}i\,dt.$$



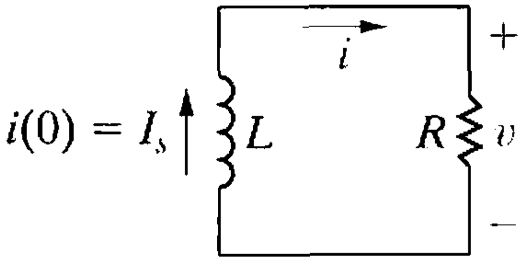
$$\frac{di}{i} = -\frac{R}{L}dt. \qquad \ln\frac{i(t)}{i(0)} = -\frac{R}{L}t.$$



$$i(t) = i(0)e^{-(R/L)t}. \qquad i(0^-) = i(0^+) = I_0,$$

$$i(t) = I_0 e^{-(R/L)t}, \qquad t \geq 0,$$

13. Natural response of RL circuit



$$p = vi, \quad p = i^2R, \quad \text{or} \quad p = \frac{v^2}{R}.$$

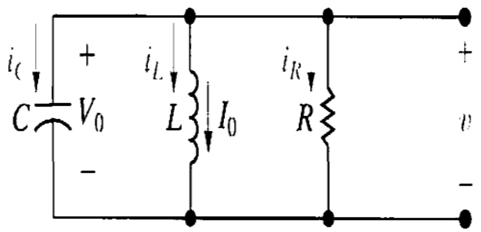
$$p = I_0^2 R e^{-2(R/L)t}, \quad t \geq 0^+.$$

$$w = \int_0^t p\,dx = \int_0^t I_0^2 R e^{-2(R/L)x}\,dx$$

$$= \frac{1}{2(R/L)} I_0^2 R (1 - e^{-2(R/L)t})$$

$$= \frac{1}{2} L I_0^2 (1 - e^{-2(R/L)t}), \quad t \geq 0.$$

13. Natural response of Parallel RLC circuit



$$s^2 + \frac{s}{RC} + \frac{1}{LC} = 0.$$

$$s_1 = -\frac{1}{2RC} + \sqrt{\left(\frac{1}{2RC}\right)^2 - \frac{1}{LC}},$$

$$s_2 = -\frac{1}{2RC} - \sqrt{\left(\frac{1}{2RC}\right)^2 - \frac{1}{LC}}.$$

$$\frac{1}{R}\frac{dv}{dt} + \frac{v}{L} + C\frac{d^2v}{dt^2} = 0.$$

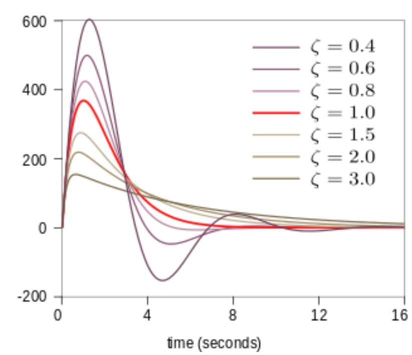
$$\frac{d^2v}{dt^2} + \frac{1}{RC}\frac{dv}{dt} + \frac{v}{LC} = 0. \qquad v = Ae^{st},$$

$$s_1 = -\alpha + \sqrt{\alpha^2 - \omega_0^2},$$

$$s_2 = -\alpha - \sqrt{\alpha^2 - \omega_0^2},$$

$$As^2e^{st} + \frac{As}{RC}e^{st} + \frac{Ae^{st}}{LC} = 0,$$

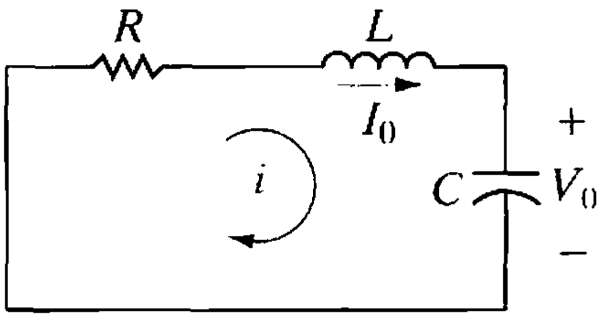
$$Ae^{st}\left(s^2 + \frac{s}{RC} + \frac{1}{LC}\right) = 0,$$



$$\alpha = \frac{1}{2RC} \qquad \omega_0 = \frac{1}{\sqrt{LC}}$$

$$\zeta = \frac{\alpha}{\omega_0}$$

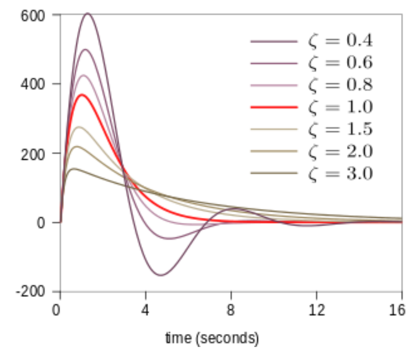
13. Natural response of series RLC circuit



$$\omega_0^2 < \alpha^2, \omega_0^2 > \alpha^2, \text{ or } \omega_0^2 = \alpha^2,$$

overdamped, underdamped, or critically damped

$$\frac{d^2 i}{dt^2} + \frac{R}{L}\frac{di}{dt} + \frac{i}{LC} = 0.$$



$$s^2 + \frac{R}{L}s + \frac{1}{LC} = 0.$$

$$s_{1,2} = -\frac{R}{2L} \pm \sqrt{\left(\frac{R}{2L}\right)^2 - \frac{1}{LC}},$$

$$i(t) = A_1 e^{s_1 t} + A_2 e^{s_2 t} \text{ (overdamped)},$$

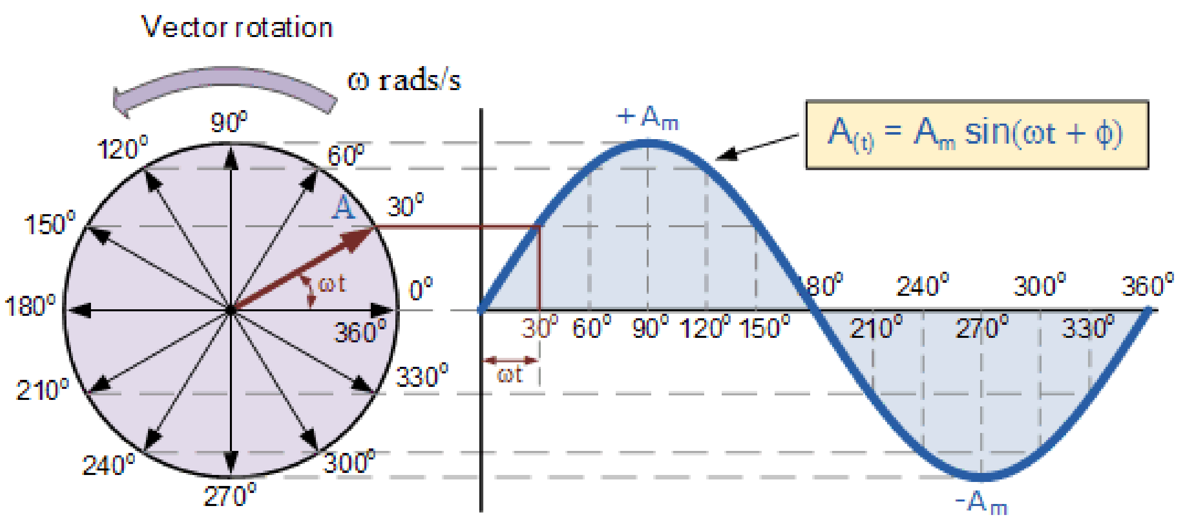
$$i(t) = B_1 e^{-\alpha t}\cos\omega_d t + B_2 e^{-\alpha t}\sin\omega_d t \text{ (underdamped)}.$$

$$i(t) = D_1 t e^{-\alpha t} + D_2 e^{-\alpha t} \text{ (critically damped)}.$$

$$s_{1,2} = -\alpha \pm \sqrt{\alpha^2 - \omega_0^2}.$$

$$\alpha = \frac{R}{2L} \text{ rad/s}, \quad \omega_0 = \frac{1}{\sqrt{LC}} \text{ rad/s}.$$

14. Single phase AC circuits

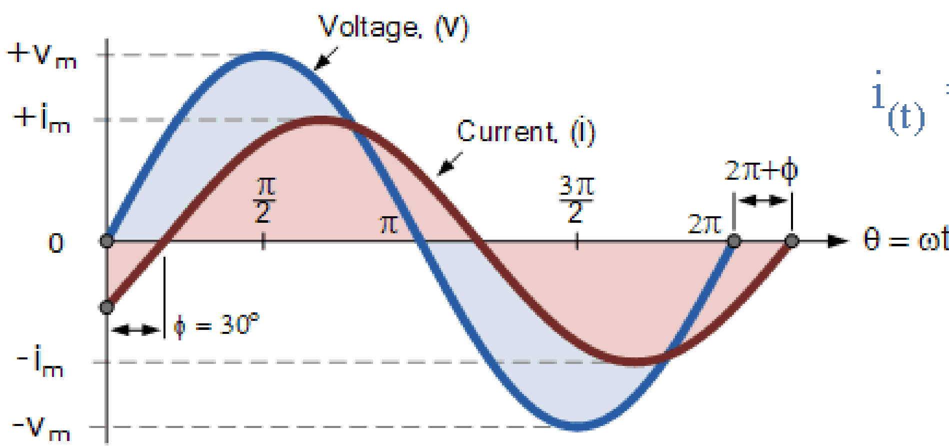


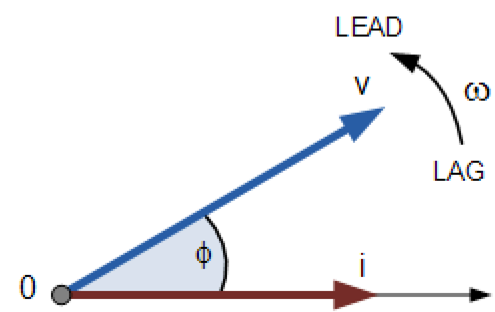
Rotating Phasor

Sinusoidal Waveform in the Time Domain

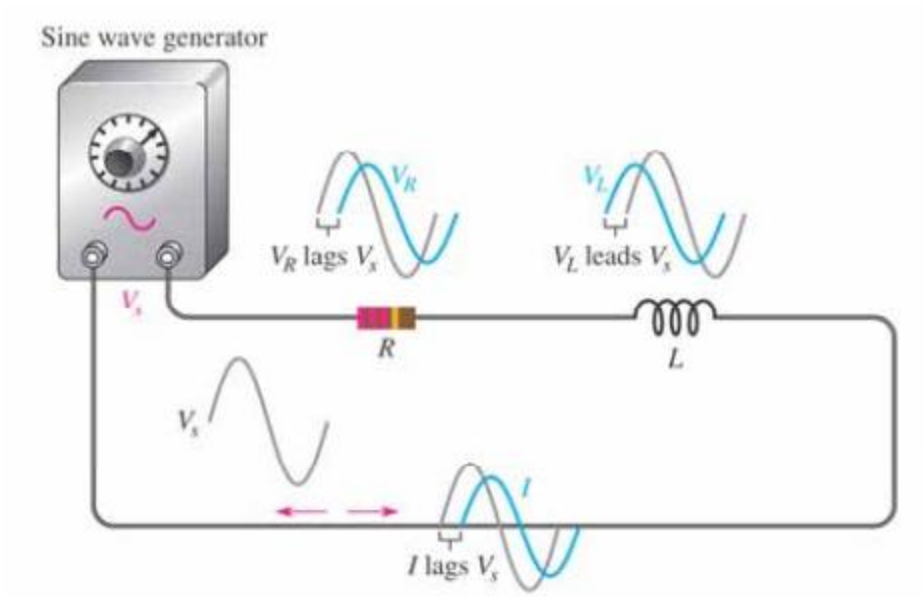
$$v_{(t)} = V_m \sin(\omega t)$$

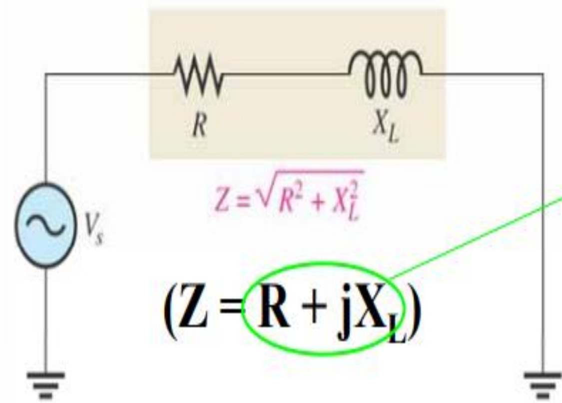
$$i_{(t)} = I_m \sin(\omega t - \phi)$$





15. Series RL circuits



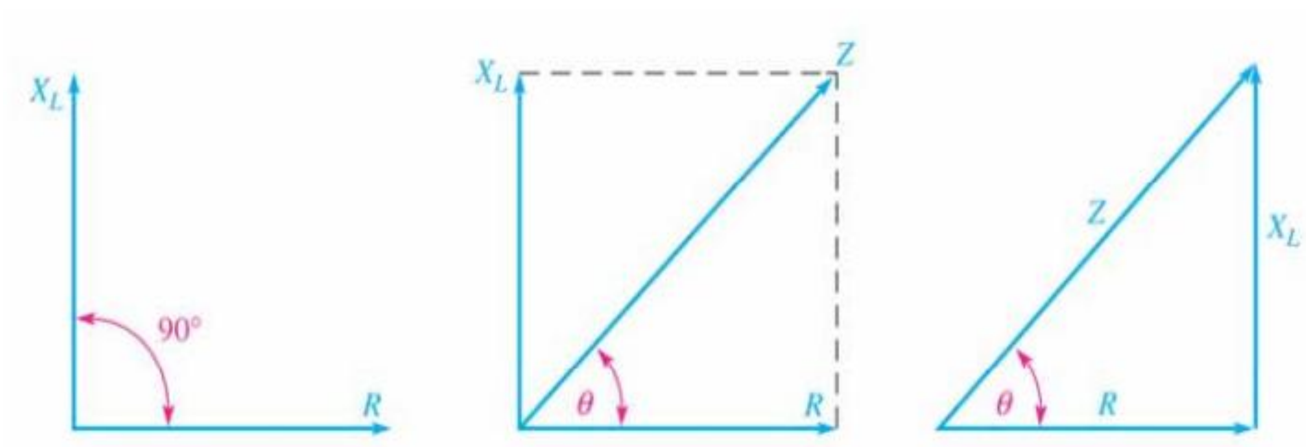


$(Z_L = j\omega L = jX_L)$

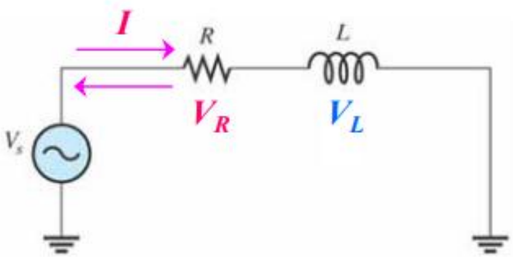
$(Z = R + Z_L = R + jX_L)$

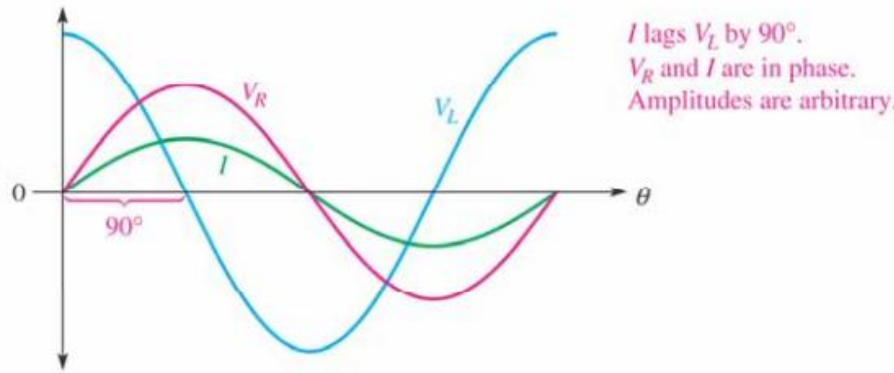
$$Z = \sqrt{R^2 + X_L^2}$$

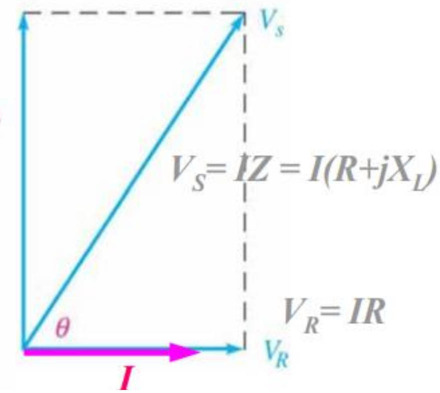
$$\theta = \tan^{-1}(X_L/R)$$



15. Relationship I and V in series RL circuit

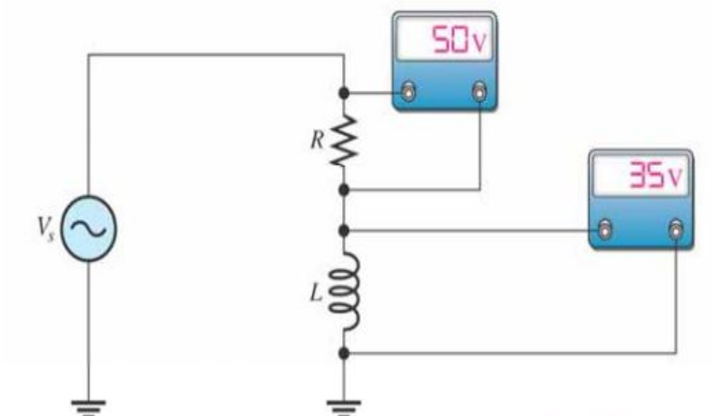






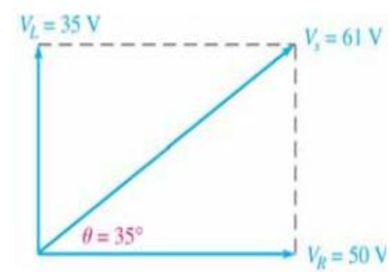
$$V_S = \sqrt{V^2_R + V^2_L}$$

$$\theta = \tan^{-1}(V_L/V_R)$$

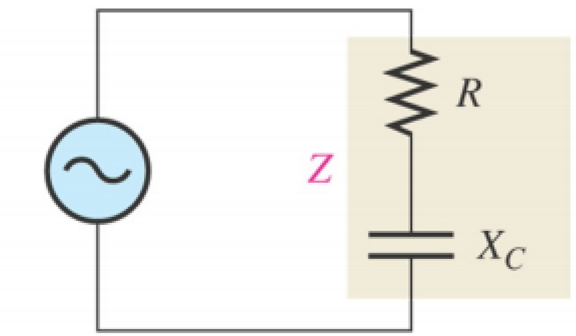


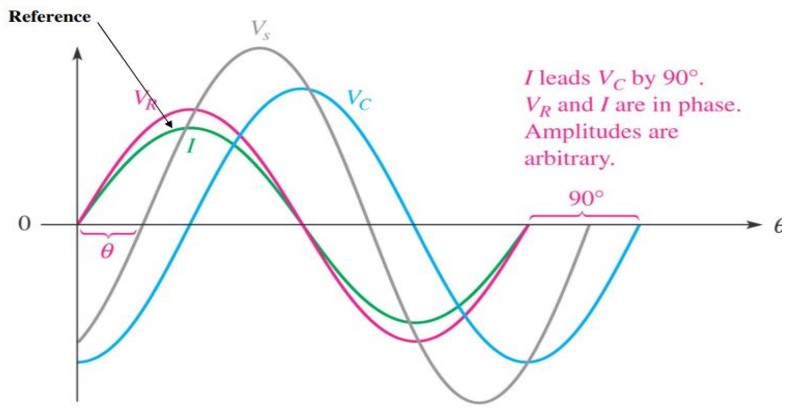
$$V_S = \sqrt{(50)^2 + (35)^2} = 61 \text{ V}$$

$$\theta = \tan^{-1}(35/50) = \tan^{-1}(0.7) = 35^{\circ}$$

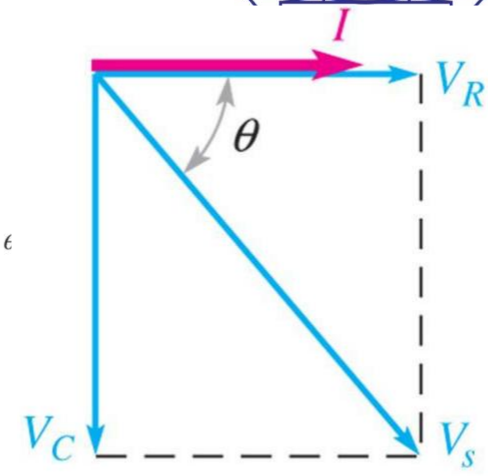


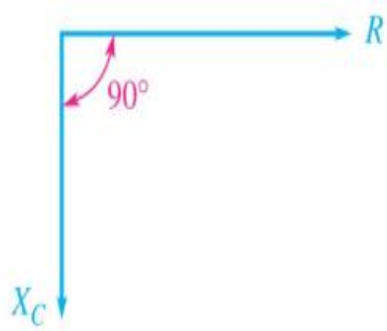
15. Series RC circuits

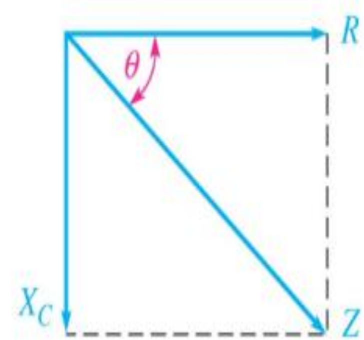


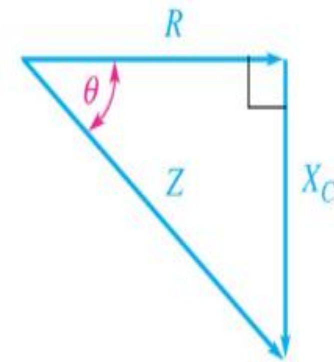


I_t is the used as the Reference Wave





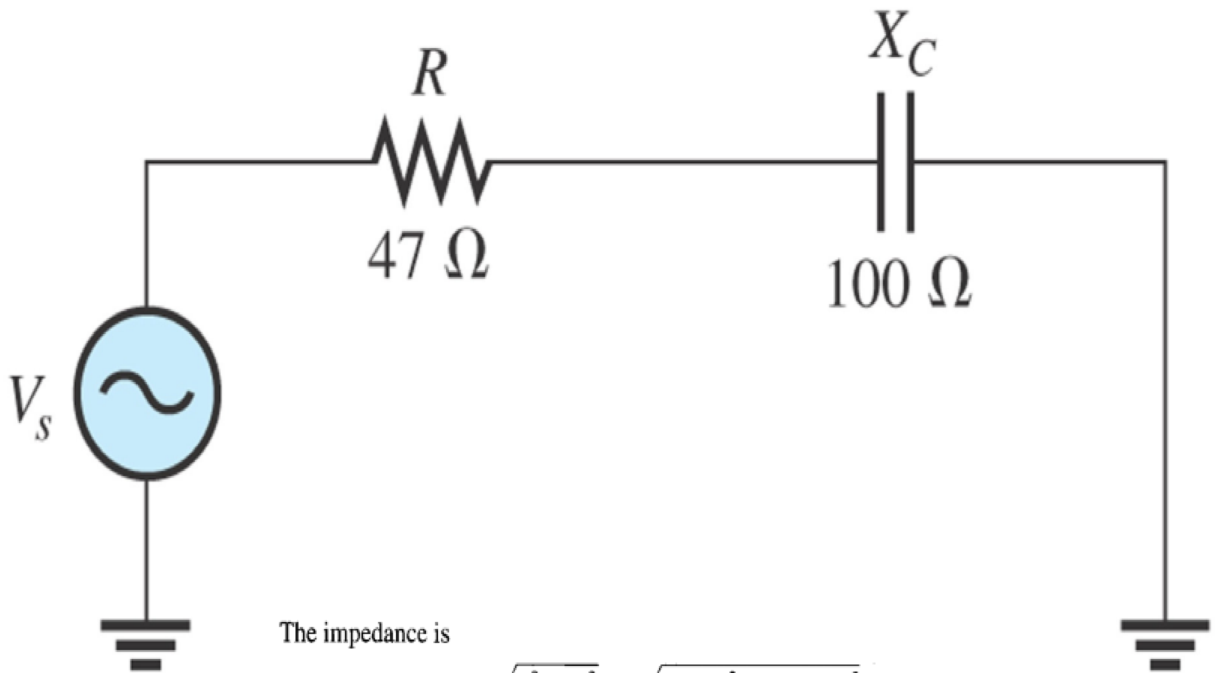




$$Z = \sqrt{R^2 + X_C^2}$$

$$\theta = \tan^{-1}(X_C/R)$$

15. Series RC circuits- example



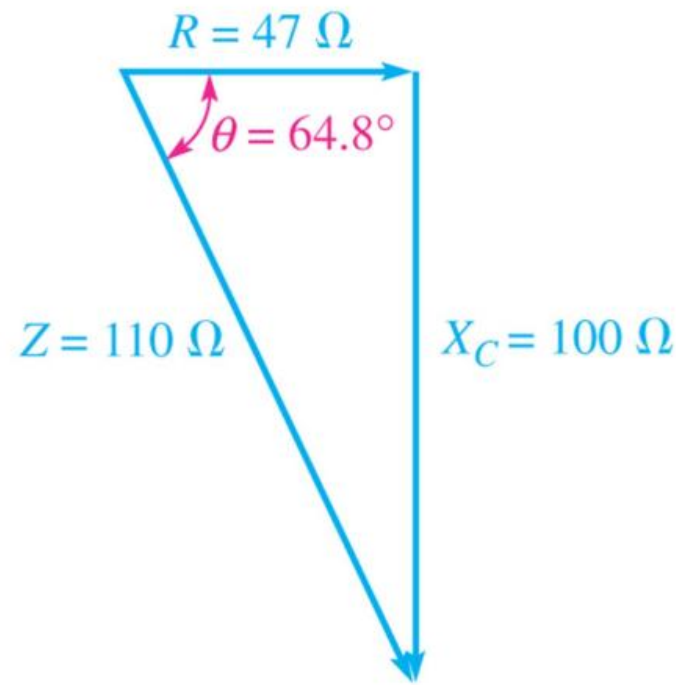
The impedance is

$$Z = \sqrt{R^2 + X_C^2} = \sqrt{(47\ \Omega)^2 + (100\ \Omega)^2} = \mathbf{110\ \Omega}$$

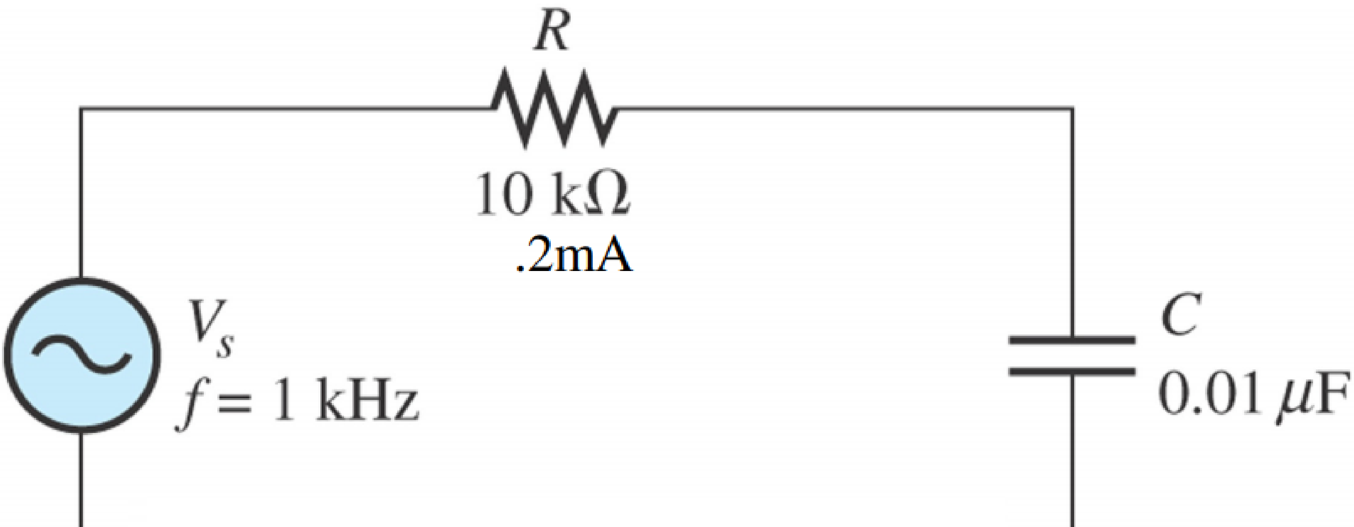
The phase angle is

$$\theta = \tan^{-1}\left(\frac{X_C}{R}\right) = \tan^{-1}\left(\frac{100\ \Omega}{47\ \Omega}\right) = \tan^{-1}(2.13) = \mathbf{64.8°}$$

The source voltage lags the current by 64.8 Degrees



15. Series RC circuits- example



The capacitive reactance is

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(1000\ \text{Hz})(0.01\ \mu\text{F})} = 15.9\ \text{k}\Omega$$

The impedance is

$$Z = \sqrt{R^2 + X_C^2} = \sqrt{(10\ \text{k}\Omega)^2 + (15.9\ \text{k}\Omega)^2} = 18.8\ \text{k}\Omega$$

Applying Ohm's law yields

$$V_s = IZ = (0.2\ \text{mA})(18.8\ \text{k}\Omega) = \mathbf{3.76\ V}$$

The phase angle is

$$\theta = \tan^{-1}\left(\frac{X_C}{R}\right) = \tan^{-1}\left(\frac{15.9\ \text{k}\Omega}{10\ \text{k}\Omega}\right) = \mathbf{57.8°}$$