CHAPTER 2

P.P.2.1 $i = V/R = 110/15 =$ **7.333 A**

P.P.2.2 (a) $v = iR = 3$ mA[10 kohms] = **30 V**

(b) $G = 1/R = 1/10$ kohms = **100 μS**

(c) $p = vi = 30$ volts[3 mA] = **90 mW**

P.P.2.3 $p = vi$ which leads to $i = p/v = [30 \cos^2 (t)$ mW]/[15cos(t) mA]

or $i =$ **2cos(t) mA**

$R = v/i = 15\cos(t)$V/2cos(t)mA = **7.5 kΩ**

P.P.2.4 5 branches and 3 nodes. The 1 ohm and 2 ohm resistors are in parallel. The 4 ohm resistor and the 10 volt source are also in parallel.

P.P.2.5 Applying KVL to the loop we get:

$-32 + 4i - (-8) + 2i = 0$ which leads to $i = 24/6 = 4$A

$v_1 = 4i =$ **16 V** and $v_2 = -2i =$ **–8 V**

P.P.2.6 Applying KVL to the loop we get:

$-70 + 10i + 2v_x + 5i = 0$

But, $v_x = 10i$ and $v_0 = -5i$. Hence,

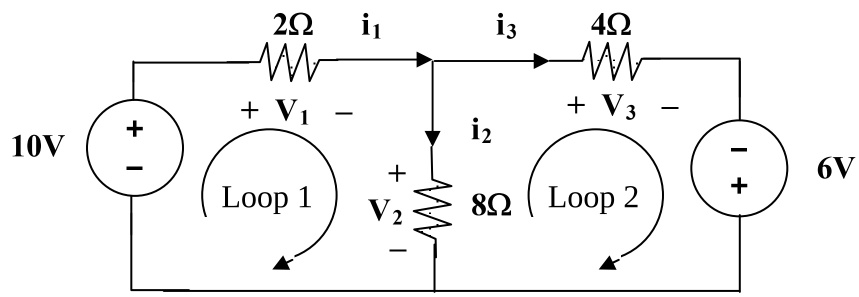
$-70 + 10i + 20i + 5i = 0$ which leads to $i = 2$ A.

Thus, $v_x =$ **20V** and $v_0 =$ **–10 V**

P.P.2.7 Applying KCL, $0 = -9 + i_0 + [i_0/4] + [v_0/8]$, but $i_0 = v_0/2$

Which leads to: $9 = (v_0/2) + (v_0/8) + (v_0/8)$ thus, $v_0 =$ **<u>12 V</u>** and $i_0 =$ **<u>6 A</u>**

P.P.2.8



At the top node, $0 = -i_1 + i_2 + i_3$ or $i_1 = i_2 + i_3$ (1)

For loop 1 $-10 + V_1 + V_2 = 0$
or $V_1 = 10 - V_2$ (2)

For loop 2 $-V_2 + V_3 - 6 = 0$
or $V_3 = V_2 + 6$ (3)

Using (1) and Ohm's law, we get

$$(V_1/2) = (V_2/8) + (V_3/4)$$

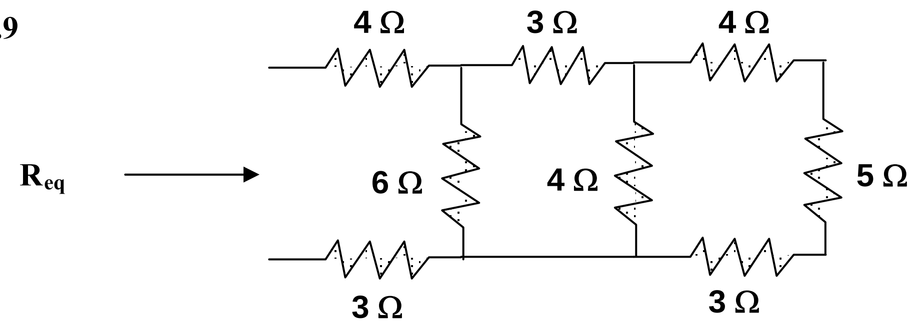
and now using (2) and (3) in the above yields

$$[(10 - V_2)/2] = (V_2/8) + (V_2 + 6)/4$$

or $[7/8]V_2 = 14/4$ or $V_2 =$ **<u>4 V</u>**

$V_1 = 10 - V_2 =$ **<u>6 V</u>**, $V_3 = 4+6 =$ **<u>10 V</u>**, $i_1 = (10-4)/2 =$ **<u>3 A</u>**,
$i_2 = 4/8 =$ **<u>500 mA</u>**, $i_3 =$ **<u>2.5 A</u>**

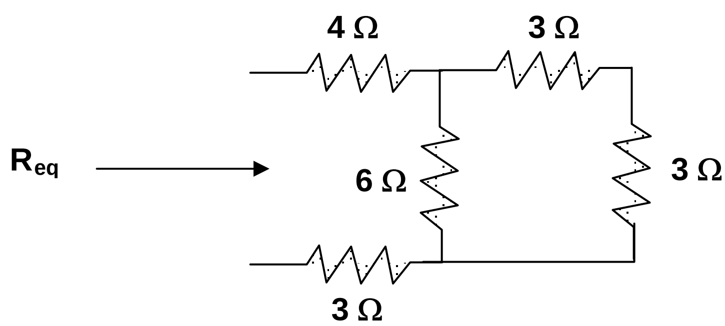
P.P.2.9



Combining the 4 ohm, 5 ohm, and 3ohm resistors in series gives 4+3+5 = 12.

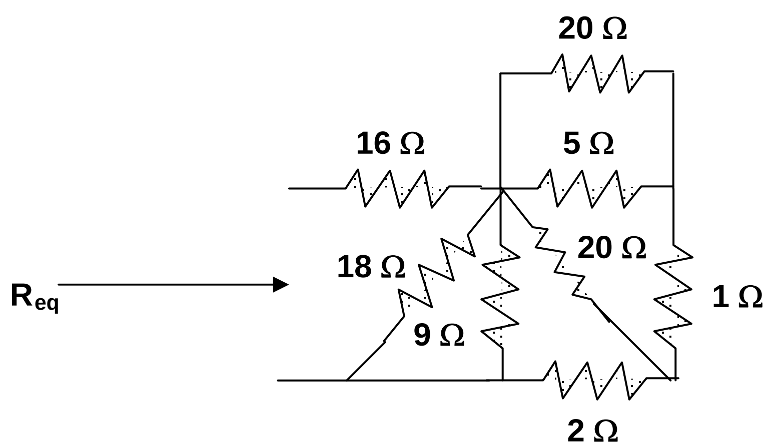
But, 4 in parallel with 12 produces [4x12]/[4+12] = 48/16 = 3ohm.

So that the equivalent circuit is shown below.



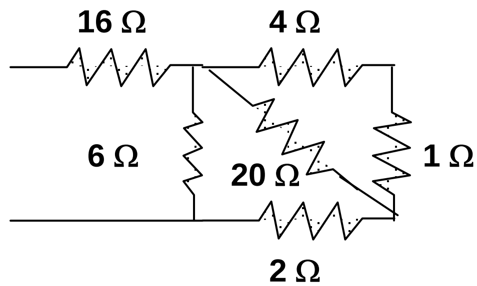
Thus, $\mathbf{R_{eq}}$ = 4 + 3 + [6x6]/[6+6] = **<u>10 Ω</u>**

P.P.2.10

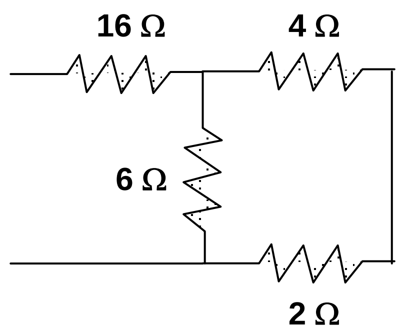


Combining the 9 ohm resistor and the 18 ohm resistor yields [9x18]/[9+18] = 6 ohms.

Combining the 5 ohm and the 20 ohm resistors in parallel produces [5x20/(5+20)] = 4 ohms We now have the following circuit:



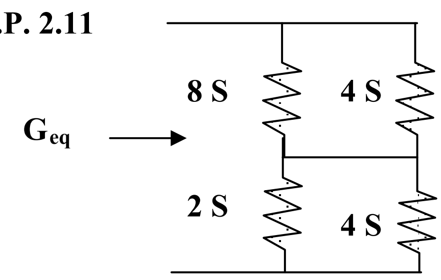
The 4 ohm and 1 ohm resistors can be combined into a 5 ohm resistor in parallel with a 20 ohm resistor. This will result in [5x20/(5+20)] = 4 ohms and the circuit shown below:



The 4 ohm and 2 ohm resistors are in series and can be replaced by a 6 ohm resistor. This gives a 6 ohm resistor in parallel with a 6 ohm resistor, [6x6/(6+6)] = 3 ohms. We now have a 3 ohm resistor in series with a 16 ohm resistor or 3 + 16 = 19 ohms. Therefore:

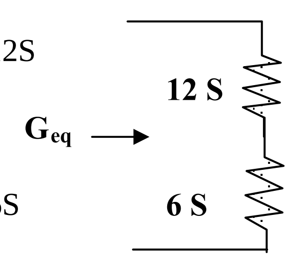
R_{eq} = 19 ohms

P.P. 2.11



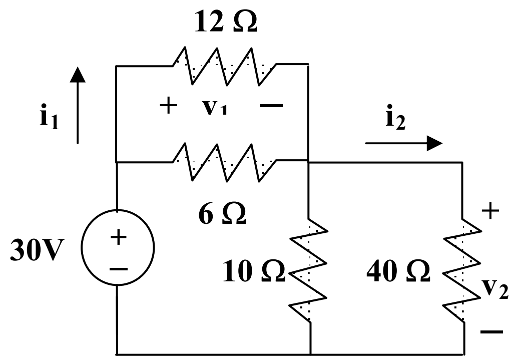
8||4 = 8+4 = 12S

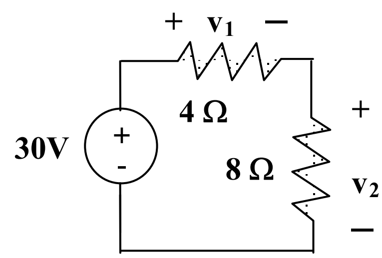
2||4 = 2+4 = 6S



12 S in series with 6 S = {12x6/(12+6)] = 4 or: **G_{eq} = 4 S**

P.P.2.12





6||12 = [6x12/(6+12)] = 4 ohm and 10||40 = [10x40/(10+40)] = 8 ohm.

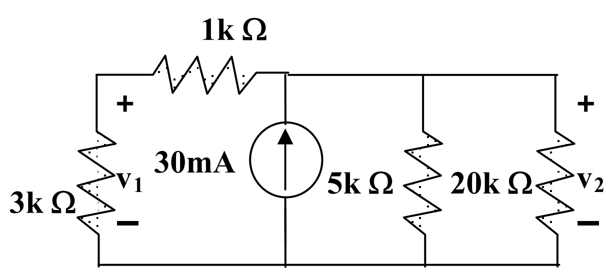
Using voltage division we get:

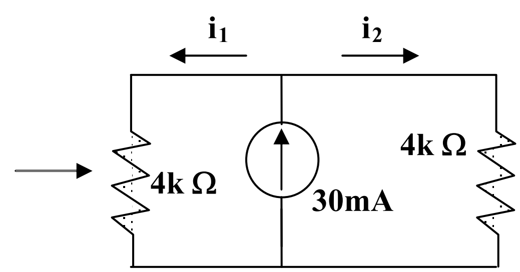
$\mathbf{v_1}$ = [4/(4+8)] (30) = **<u>10 volts</u>**, $\mathbf{v_2}$ = [8/12] (30) = **<u>20 volts</u>**

$\mathbf{i_1}$ = v_1/12 = 10/12 = **<u>833.3 mA</u>**, $\mathbf{i_2}$ = v_2/40 = 20/40 = **<u>500 mA</u>**

$\mathbf{P_1}$ = v_1 i_1 = 10x10/12 = **<u>8.333 watts</u>**, $\mathbf{P_2}$ = v_2 i_2 = 20x0.5 = **<u>10 watts</u>**

P.P.2.13





Using current division, i_1 = i_2 = (30 mA)(4 kohm/(4 kohm + 4 kohm)) = 15mA

(a) $\mathbf{v_1}$ = (3 kohm)(15 mA) = **<u>45 volts</u>**
$\mathbf{v_2}$ = (4 kohm)(15 mA) = **<u>60 volts</u>**

(b) For the 3k ohm resistor, $\mathbf{P_1}$ = v_1 x i_1 = $45x15x10^{-3}$ = **<u>675 mw</u>**
For the 20k ohm resistor, $\mathbf{P_2}$ = $(v_2)^2$ /20k = **<u>180 mw</u>**

(c) The total power supplied by the current source is equal to:
P $= v_2 \times 10$ mA $= 60 \times 30 \times 10^{-3}$ = **<u>1.8 W</u>**

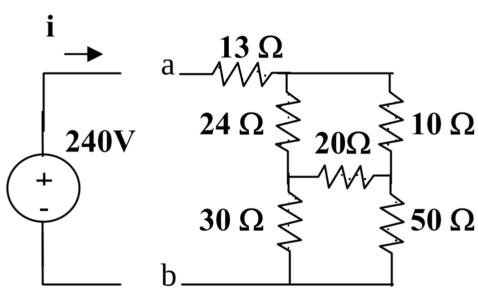
P.P.2.14

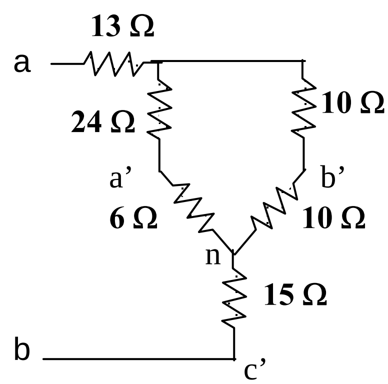
$\mathbf{R_a} = [R_1 R_2 + R_2 R_3 + R_3 R_1]/ R_1 = [10 \times 20 + 20 \times 40 + 40 \times 10]/10 =$ **<u>140 ohms</u>**

$\mathbf{R_b} = [R_1 R_2 + R_2 R_3 + R_3 R_1]/ R_2 = 1400/20 =$ **<u>70 ohms</u>**

$\mathbf{R_c} = [R_1 R_2 + R_2 R_3 + R_3 R_1]/ R_3 = 1400/40 =$ **<u>35 ohms</u>**

P.P.2.15 We first find the equivalent resistance, R. We convert the delta sub-network to a wye connected form as shown below:





$R_{a'n} = 20 \times 30/[20 + 30 + 50] = 6$ ohms, $R_{b'n} = 20 \times 50/100 = 10$ ohms
$R_{c'n} = 30 \times 50/100 = 15$ ohms.

Thus, $R_{ab} = 13 + [(24 + 6)||(10 + 10)] + 15 = 28 + 30 \times 20/(30 + 20) =$ **<u>40 ohms.</u>**

i $= 240/ R_{ab} = 240/40 =$ **<u>6 amps</u>**

P.P.2.16 **For the parallel case, v = v_0 = 110volts.**
p = vi ⟹ i = p/v = 40/110 = <u>364 mA</u>

For the series case, $v = v_0/N = 110/10 = 11$ volts
i $= p/v = 40/11 =$ **<u>3.64 amps</u>**

P.P.2.17 We use equation (2.61)

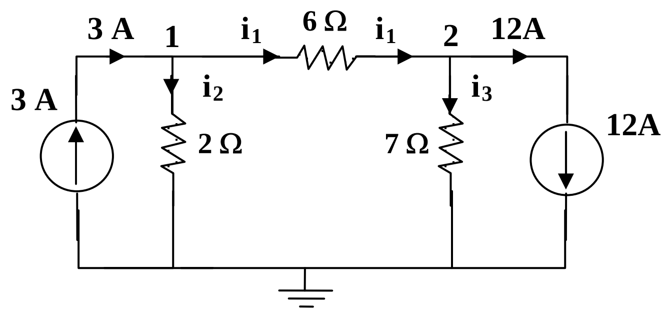
(a) $\mathbf{R_1} = 50 \times 10^{-3}/ (1-10^{-3}) = 0.05/999 =$ **<u>50 mΩ (shunt)</u>**

(b) $\mathbf{R_2} = 50 \times 10^{-3}/(100 \times 10^{-3} - 10^{-3}) = 50/99 =$ **<u>505 mΩ (shunt)</u>**

(c) $\mathbf{R_3} = 50x10^{-3}/(10x10^{-3}-10^{-3}) = 50/9 =$ **<u>5.556 Ω (shunt)</u>**

CHAPTER 3

P.P.3.1



At node 1,

$$-3 + i_1 + i_2 = 0 \text{ or } \frac{v_1 - v_2}{6} + \frac{v_1 - 0}{2} = 3$$

or $4v_1 - v_2 = 18$ (1)

At node 2,

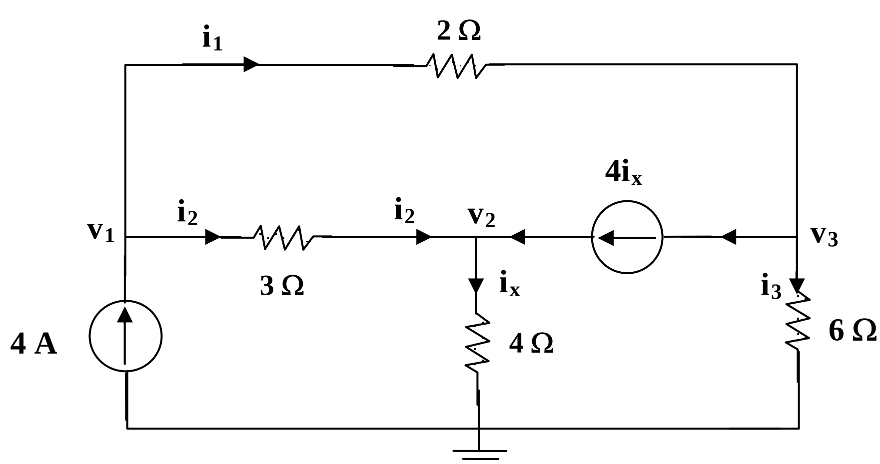
$$-i_1 + i_3 + 12 = 0 \text{ or } i_1 = 12 + i_3 \text{ or } \frac{v_1 - v_2}{6} = 12 + \frac{v_2 - 0}{7}$$

or $7v_1 - 13v_2 = 504$ (2)

Solving (1) and (2) gives

$v_1 =$ **–6 V**, $v_2 =$ **–42 V**

P.P.3.2



At node 1,

$$-4 + i_1 + i_2 = 0 = -4 + \frac{v_1 - v_3}{2} + \frac{v_1 - v_2}{3}$$

or $5v_1 - 2v_2 - 3v_3 = 24$ (1)

At node 2,

$-i_2 + i_x - 4i_x = 0 = -i_2 - 3i_x = 0$ where $i_x = [(v_2-0)/4]$ or

$\frac{v_1 - v_2}{3} + 3\frac{v_2}{4} = 0$ which leads to $4v_1 + 5v_2 = 0$ (2)

At node 3,

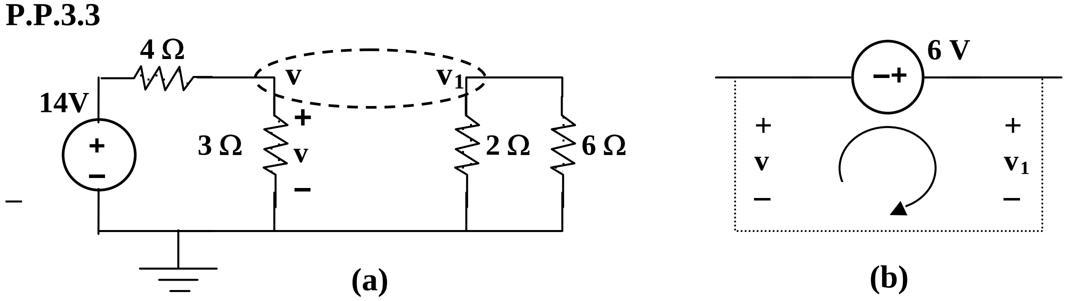
$$-i_1 + i_3 + 4i_x = 0 = \frac{v_3 - v_1}{2} + \frac{v_3 - 0}{6} + 4\frac{v_2}{4}$$

or $-3v_1 + 6v_2 + 4v_3 = 0$ (3)

Solving (1) to (3) gives

$v_1 =$ **32 V**, $v_2 =$ **–25.6 V**, $v_3 =$ **62.4 V**

P.P.3.3



(a) (b)

At the supernode in Fig. (a),

$$\frac{14 - v}{4} = \frac{v}{3} + \frac{v_1}{2} + \frac{v_1}{6}$$

or $42 = 7v + 8v_1$ (1)

Applying KVL to the loop in Fig. (b),

$-v - 6 + v_1 = 0 \longrightarrow v_1 = v + 6$ (2)

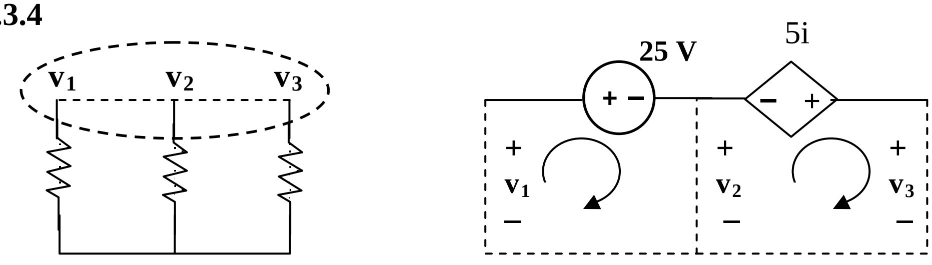
Solving (1) and (2),

$$v = \mathbf{-400\ mV}$$

$$v_1 = v + 6 = 5.6,\ i_1 = \frac{v_1}{2} = 2.8$$

$$i_1 = \mathbf{2.8\ A}$$

P.P.3.4



(a) **(b)**

From Fig. (a),

$$\frac{v_1}{2} + \frac{v_2}{4} + \frac{v_3}{3} = 0 \longrightarrow 6v_1 + 3v_2 + 4v_3 = 0 \qquad (1)$$

From Fig. (b),

$$-v_1 + 25 + v_2 = 0 \longrightarrow v_1 = v_2 + 25 \qquad (2)$$

$$-v_2 - 5i + v_3 = 0 \longrightarrow v_3 = v_2 + 2.5v_1 \qquad (3)$$

Solving (1) to (3), we obtain

$$v_1 = \mathbf{7.608\ V},\ v_2 = \mathbf{-17.39\ V},\ v_3 = \mathbf{1.6305\ V}$$

P.P.3.5 We apply KVL to the two loops and obtain

$-45 + 2i_1 + 12(i_i - i_2) + 4i_1 = 0$ or

$-45 + 18i_i - 12i_2 = 0$ which leads to $3i_i - 2i_2 = 7.5$ (1)

$12(i_2 - i_1) + 9i_2 + 30 + 3i_2 = 0$ or

$30 + 24i_2 - 12i_1 = 0$ which leads to $-3i_1 + 6i_2 = -7.5$
(2)

From (1) and (2) we get

$$i_1 = \mathbf{2.5\ A},\ i_2 = \mathbf{0A}$$

P.P.3.6 For mesh 1,

$$-16 + 6i_1 - 2i_2 - 4i_3 = 0 \longrightarrow 3i_1 - i_2 - 2i_3 = 8 \qquad (1)$$

For mesh 2,

$$10i_2 - 2i_1 - 8i_3 - 10i_0 = 0 = -i_1 + 5i_2 - 9i_3 \qquad (2)$$

But $i_0 = i_3$,

$$18i_3 - 4i_1 - 8i_2 = 0 \longrightarrow -2i_1 - 4i_2 + 9i_3 = 0 \qquad (3)$$

From (1) to (3),

$$\begin{bmatrix} 3 & -1 & -2 \\ -1 & 5 & -9 \\ -2 & -4 & 9 \end{bmatrix} \begin{bmatrix} i_1 \\ i_2 \\ i_3 \end{bmatrix} = \begin{bmatrix} 8 \\ 0 \\ 0 \end{bmatrix}$$

$$\Delta = \begin{vmatrix} 3 & -1 & -2 \\ -1 & 5 & -9 \\ -2 & -4 & 9 \\ 3 & -1 & -2 \\ -1 & 5 & -9 \end{vmatrix} = 135 - 8 - 18 - 20 - 108 - 9 = -28$$

$$\Delta_1 = \begin{vmatrix} 8 & -1 & -2 \\ 0 & 5 & -9 \\ 0 & -4 & 9 \\ 8 & -1 & -2 \\ 0 & 5 & -9 \end{vmatrix} = 360 - 288 = 72$$

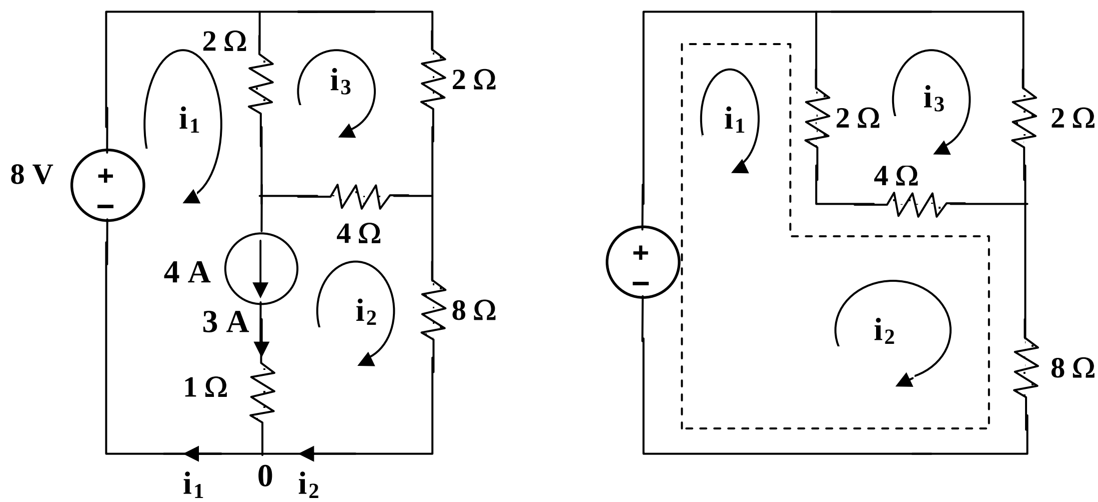
$$\Delta_2 = \begin{vmatrix} 3 & 8 & -2 \\ -1 & 0 & -9 \\ -2 & 0 & 9 \\ 3 & 8 & -2 \\ -1 & 0 & -9 \end{vmatrix} = 144 + 72 = 216$$

$$\Delta_3 = \begin{vmatrix} 3 & -1 & 8 \\ -1 & 5 & 0 \\ -2 & -4 & 0 \\ 3 & -1 & 8 \\ -1 & 5 & 0 \end{vmatrix} = 32 + 80 = 112$$

$$i_1 = \frac{\Delta_1}{\Delta} = \frac{72}{-28} = -2.571,\ i_2 = \frac{\Delta_2}{\Delta} = \frac{216}{-28} = -7.714,\ i_3 = \frac{\Delta_3}{\Delta} = \frac{112}{-28} = -4\text{A}$$

$$I_o = i_3 = \mathbf{-4\ A}$$

P.P.3.7



(a) (b)

For the supermesh,

$$-8 + 2i_1 - 2i_3 + 12i_2 - 4i_3 = 0 \text{ or } i_1 + 6i_2 - 3i_3 = 4 \qquad (1)$$

For mesh 3,

$$8i_3 - 2i_1 - 4i_2 = 0 \text{ or } -i_1 - 2i_2 + 4i_3 = 0 \qquad (2)$$

At node 0 in Fig. (a),

$$i_1 = 4 + i_2 \longrightarrow i_1 - i_2 = 4$$

Solving (1) to (3) yields

$$i_1 = \mathbf{4.632\ A},\ i_2 = \mathbf{631.6\ mA},\ i_3 = \mathbf{1.4736\ A}$$

P.P.3.8 $G_{11} = 1/(1) + 1/(20) + 1/(5) = 1.25$, $G_{12} = –1/(5) = –0.2$,
$G_{33} = 1/(4) + 1 = 1.25$, $G_{44} = 1/(1) + 1/(4) = 1.25$,
$G_{12} = –1/(5) = –0.2$, $G_{13} = –1$, $G_{14} = 0$,
$G_{21} = –0.2$, $G_{23} = 0 = G_{26}$,
$G_{31} = –1$, $G_{32} = 0$, $G_{34} = –1/4 = –0.25$,
$G_{41} = 0$, $G_{42} = 0$, $G_{43} = 0.25$,
$i_1 = 0$, $i_2 = 3+2 = 5$, $i_3 = –3$, $i_4 = 2$.

Hence,

$$\begin{bmatrix} \mathbf{1.25} & \mathbf{-0.2} & \mathbf{-1} & \mathbf{0} \\ \mathbf{-0.2} & \mathbf{0.2} & \mathbf{0} & \mathbf{0} \\ \mathbf{-1} & \mathbf{0} & \mathbf{1.25} & \mathbf{-0.25} \\ \mathbf{0} & \mathbf{0} & \mathbf{-0.25} & \mathbf{1.25} \end{bmatrix} \begin{bmatrix} \boldsymbol{v_1} \\ \boldsymbol{v_2} \\ \boldsymbol{v_3} \\ \boldsymbol{v_4} \end{bmatrix} = \begin{bmatrix} \mathbf{0} \\ \mathbf{5} \\ \mathbf{-3} \\ \mathbf{2} \end{bmatrix}$$

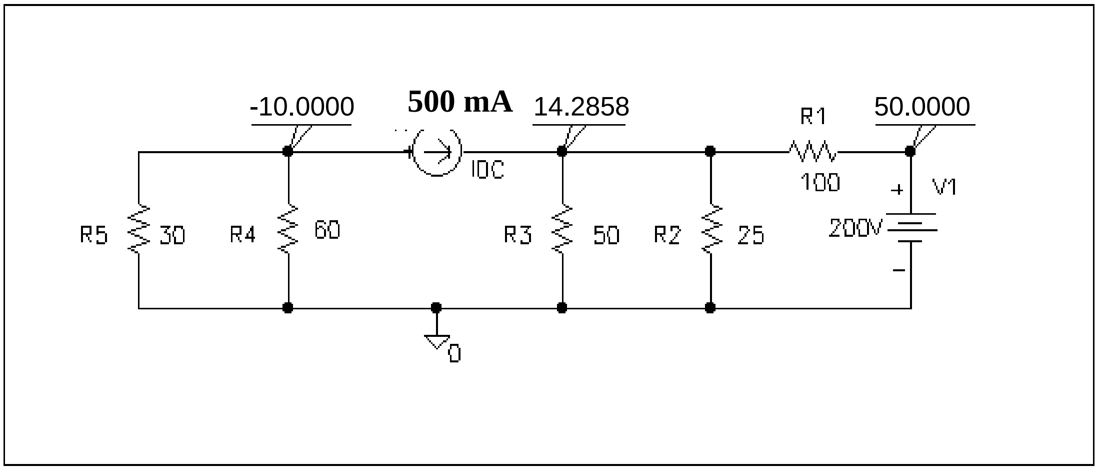
P.P.3.9 $R_{11} = 50 + 20 + 80 = 150$, $R_{22} = 20 + 30 + 15 = 65$,
$R_{33} = 30 + 20 = 50$, $R_{44} = 15 + 80 = 95$,
$R_{55} = 20 + 60 = 80$, $R_{12} = –40$, $R_{13} = 0$, $R_{14} = –80$,
$R_{15} = 0$, $R_{21} = –40$, $R_{23} = –30$, $R_{24} = –15$, $R_{25} = 0$,
$R_{31} = 0$, $R_{32} = –30$, $R_{34} = 0$, $R_{35} = –20$,
$R_{41} = –80$, $R_{42} = –15$, $R_{43} = 0$, $R_{45} = 0$,
$R_{51} = 0$, $R_{52} = 0$, $R_{53} = –20$, $R_{54} = 0$,
$v_1 = 30$, $v_2 = 0$, $v_3 = –12$, $v_4 = 20$, $v_5 = –20$

Hence the mesh-current equations are

$$\begin{bmatrix} \mathbf{150} & \mathbf{-40} & \mathbf{0} & \mathbf{-80} & \mathbf{0} \\ \mathbf{-40} & \mathbf{65} & \mathbf{-30} & \mathbf{-15} & \mathbf{0} \\ \mathbf{0} & \mathbf{-30} & \mathbf{50} & \mathbf{0} & \mathbf{-20} \\ \mathbf{-80} & \mathbf{-15} & \mathbf{0} & \mathbf{95} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{-20} & \mathbf{0} & \mathbf{80} \end{bmatrix} \begin{bmatrix} \boldsymbol{i_1} \\ \boldsymbol{i_2} \\ \boldsymbol{i_3} \\ \boldsymbol{i_4} \\ \boldsymbol{i_5} \end{bmatrix} = \begin{bmatrix} \mathbf{30} \\ \mathbf{0} \\ \mathbf{-12} \\ \mathbf{20} \\ \mathbf{-20} \end{bmatrix}$$

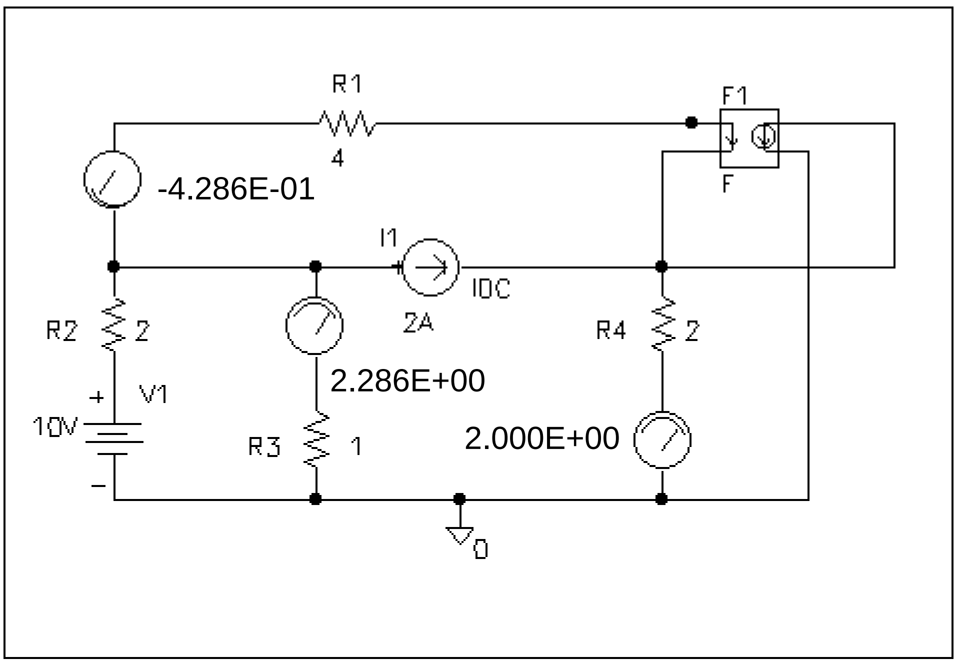
P.P.3.10 The schematic is shown below. It is saved and simulated by selecting Analysis/Simulate. The results are shown on the viewpoints:

$v_1 =$ **–10 V**, $v_2 =$ **14.286 V**, $v_3 =$ **50 V**



P.P.3.11 The schematic is shown below. After saving it, it is simulated by choosing Analysis/Simulate. The results are shown on the IPROBES.

i_1 = **–428.6 mA**, i_2 = **2.286 A**, i_3 = **2 A**



P.P.3.12 For the input loop,

$$-5 + 10 \times 10^3 I_B + V_{BE} + V_0 = 0 \qquad (1)$$

For the outer loop,

$$-V_0 - V_{CE} - 500 I_0 + 12 = 0 \qquad (2)$$

But $V_0 = 200 I_E$ (3)

Also $I_C = \beta I_B = 100 I_B$, $\alpha = \beta/(1 + \beta) = 100/(101)$

$$I_C = \alpha I_E \longrightarrow I_E = I_C/(\alpha) = \beta I_B/(\alpha)$$

$$I_E = 100 (101/(100)) I_R = 101 I_B \qquad (4)$$

From (1), (3) and (4),

$$10{,}000 I_B + 200(101) I_R = 5 - V_{BE}$$

$$I_B = \frac{5 - 0.7}{10{,}000 + 20{,}000} = 142.38 \mu A$$

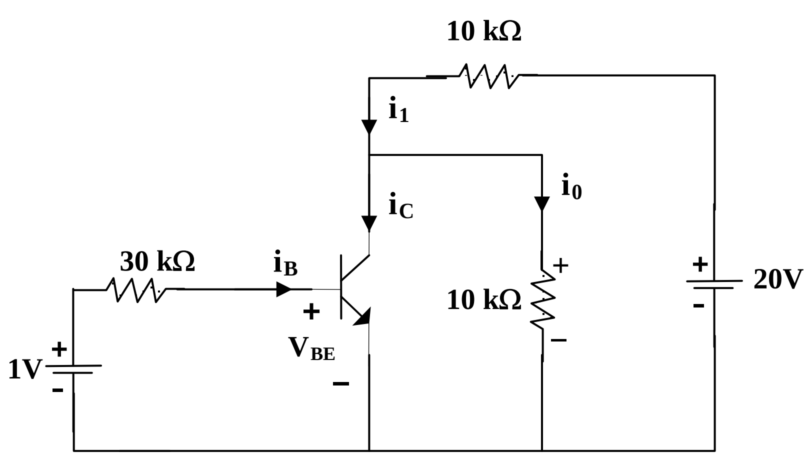
$V_0 = 200 I_E = 20{,}000 I_B =$ **2.876 V**

From (2),

$$V_{CE} = 12 - V_0 - 500 I_C = 9.124 - 500 \times 100 \times 142.38 \times 10^{-6}$$

$V_{CE} =$ **1.984 V {often, this is rounded to 2.0 volts}**

P.P.3.13



$$i_B = \frac{1-0.7}{30k} = 10\mu A,\ \ i_C = \beta i_B = 0.8\ mA$$

$$i_1 = i_C + i_0 \qquad (1)$$

Also, $-10ki_0 - 10ki_1 + 20 = 0 \longrightarrow i_1 = 2\ mA - i_0$ (2)

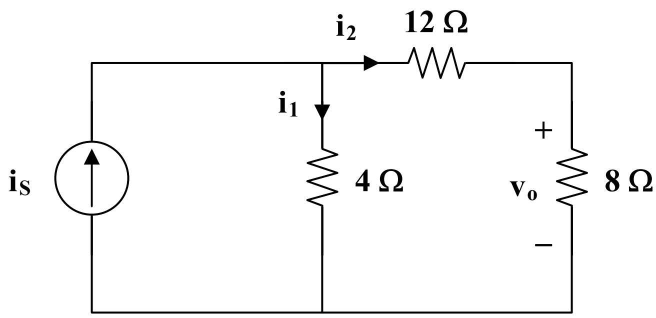
Equating (1) and (2),

$$2\ mA - i_0 = 0.8\ mA + i_0 \longrightarrow i_0 = \mathbf{600\ \mu A}$$

$$v_0 = 20\ ki_0 = 20x10^3\ x600x10^{-6} = \mathbf{12\ V}$$

CHAPTER 4

P.P.4.1



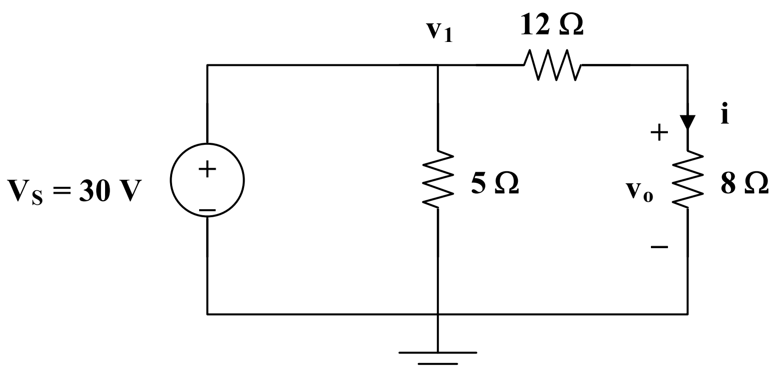
By current division, $i_2 = \frac{4}{4+12+8} i_s = \frac{1}{6} i_s$

$$v_0 = 8i_2 = \frac{4}{3} i_s$$

When i_s = 30 A, $v_0 = \frac{4}{3}(30) = \mathbf{40\ V}$

When i_s = 45 A, $v_0 = \frac{4}{3}(45) = \mathbf{60\ V}$

P.P.4.2

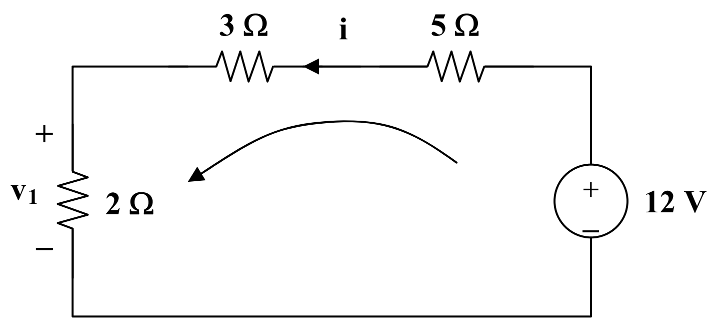


Let v_o = 1 volt. Then i = $\frac{1}{8}$ and $v_1 = \frac{1}{8}(12 + 8) = 2.5$

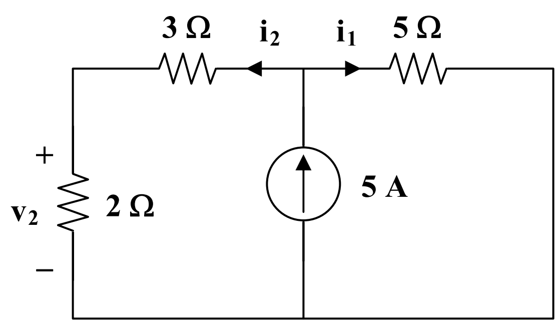
giving v_s = 2.5V.

If v_s = 40V, then v_0 = (40/2.5)(1) = **16 V**

P.P.4.3 Let $v_0 = v_1 + v_2$, where v_1 and v_2 are contributions to the 12–V and 5–A sources respectively.



(a)



(b)

To get v_1, consider the circuit in Fig. (a).

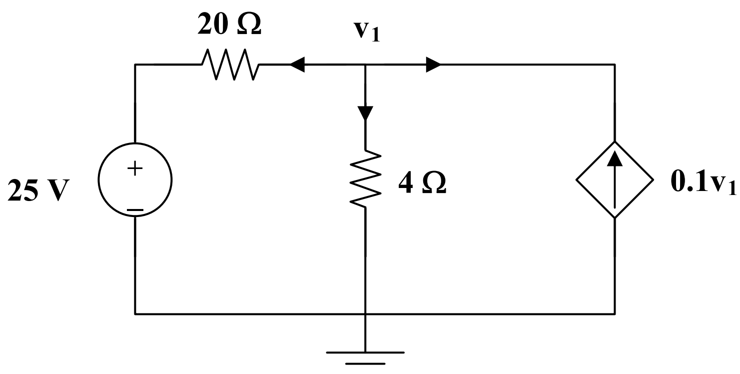
$(2 + 3 + 5)i – 12 = 0$ or $i = 12/(10) = 1.2$ A
$v_1 = 2i = 2.4$ V

To get v_2, consider the circuit in Fig. (b).

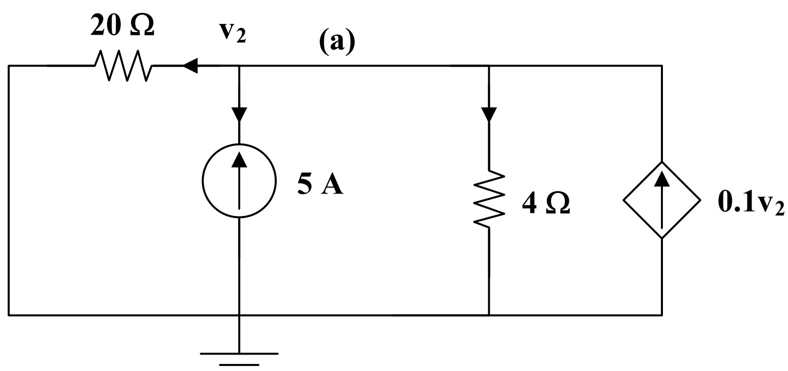
Since the resistors are equal (5 = 2 + 3) then the current divides equally and $i_1 = i_2 = 5/2 = 2.5$ and $v_2 = 2i_2 = 5$ V

Thus,
$v = v_1 + v_2 = 2.4 + 5 =$ **7.4 V**

P.P.4.4 Let $v_x = v_1 + v_2$, where v_1 and v_2 are due to the 25-V and 5-A sources respectively.



(a)



(b)

To obtain v_1, consider Fig. (a).

$$-0.1v_1 + \frac{v_1 - 25}{20} + \frac{v_1 - 0}{4} = 0 \quad \text{or} \quad 0.2v_1 = 25/20 = 1.25 \text{ or } v_1 = 6.25 \text{ V}$$

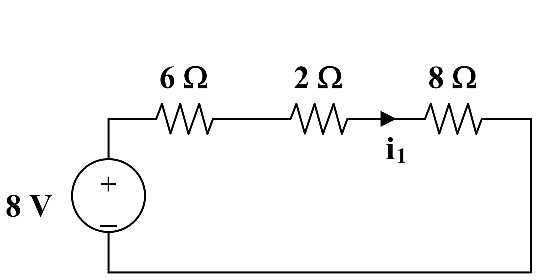
For v_2, consider Fig. (b).

$$-5 - 0.1v_2 + \frac{v_2 - 0}{20} + \frac{v_2 - 0}{4} = 0 \text{ or } 0.2v_2 = 5 \text{ or } v_2 = 25 \text{ V}$$

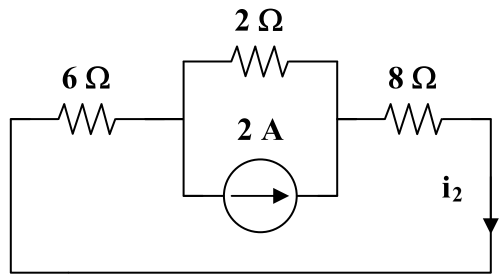
$v_x = v_1 + v_2 =$ **31.25 V**

P.P.4.5 Let $i = i_1 + i_2 + i_3$

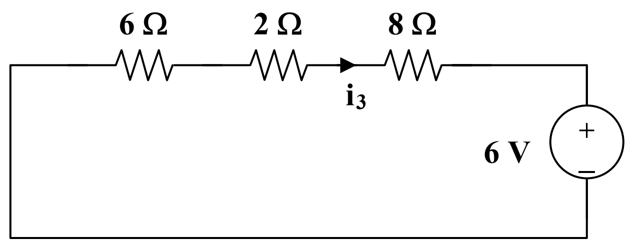
where i_1, i_2, and i_3 are contributions due to the 8-V, 2-A, and 6-V sources respectively.



(a)



(b)



(c)

For i_1, consider Fig. (a), $i_1 = \dfrac{8}{6+2+8} = 0.5\,\text{A}$

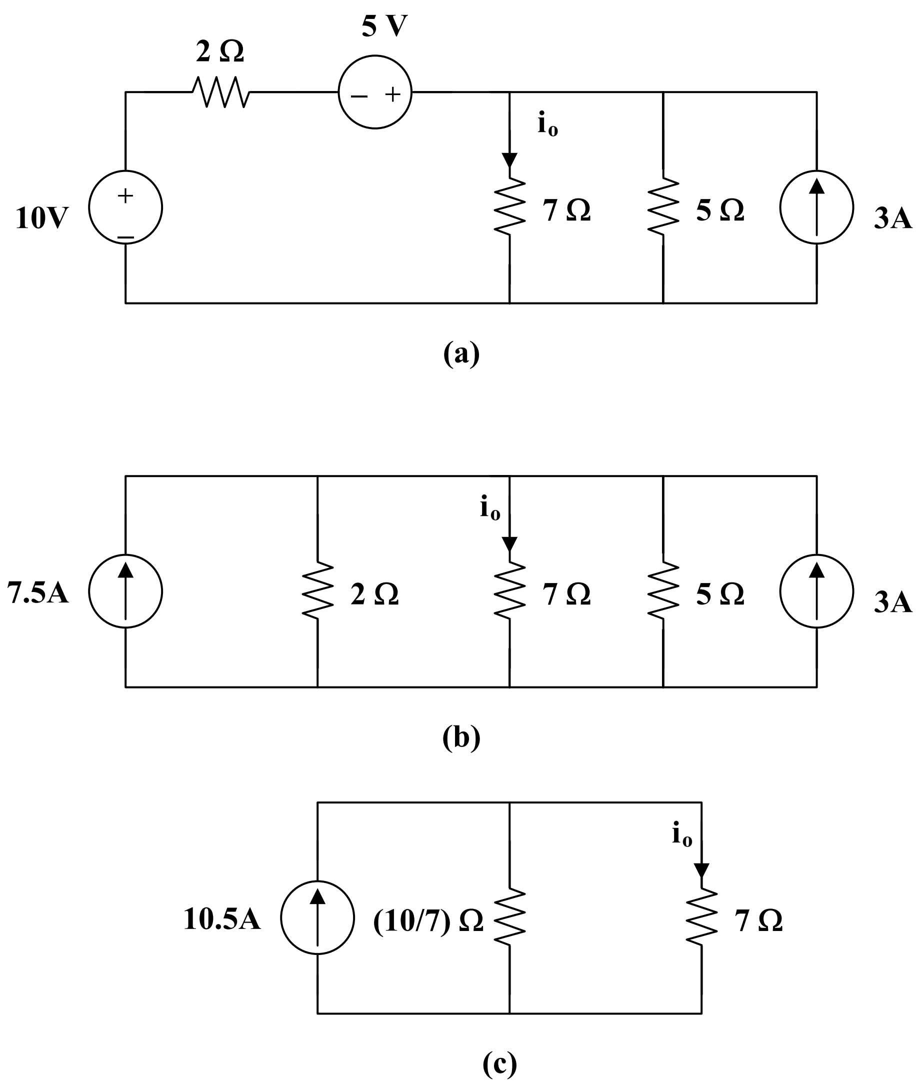
For i_2, consider Fig. (b). By current division, $i_2 = \dfrac{2}{2+14}(2) = 0.25$

For i_3, consider Fig. (c), $i_3 = \dfrac{-6}{16} = -0.375\text{A}$

Thus, $i = i_1 + i_2 + i_3 = 0.5 + 0.25 - 0.375 =$ **375 mA**

P.P.4.6 Combining the 6-Ω and 3-Ω resistors in parallel gives $6 \| 3 = \dfrac{6x3}{9} = 2\Omega$.

Adding the 1-Ω and 4-Ω resistors in series gives 1 + 4 = 5Ω. Transforming the left current source in parallel with the 2-Ω resistor gives the equivalent circuit as shown in Fig. (a).

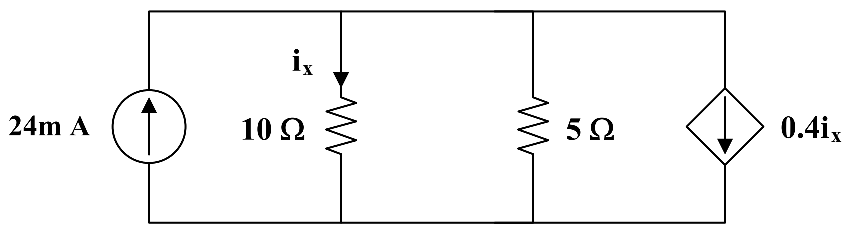


Adding the 10-V and 5-V voltage sources gives a 15-V voltage source. Transforming the 15-V voltage source in series with the 2-Ω resistor gives the equivalent circuit in Fig. (b). Combining the two current sources and the 2-Ω and 5-Ω resistors leads to the circuit in Fig. (c). Using circuit division,

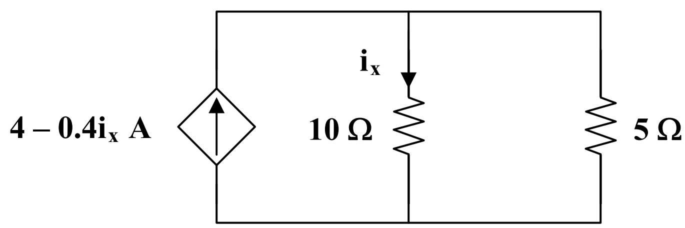
$$i_o = \frac{\frac{10}{7}}{\frac{10}{7}+7}(10.5) \quad = \mathbf{1.78\ A}$$

P.P.4.7 We transform the dependent voltage source as shown in Fig. (a). We combine the two current sources in Fig. (a) to obtain Fig. (b). By the current division principle,

$$i_x = \frac{5}{15}(0.024 - 0.4i_x) \longrightarrow i_x = \mathbf{7.059\ mA}$$

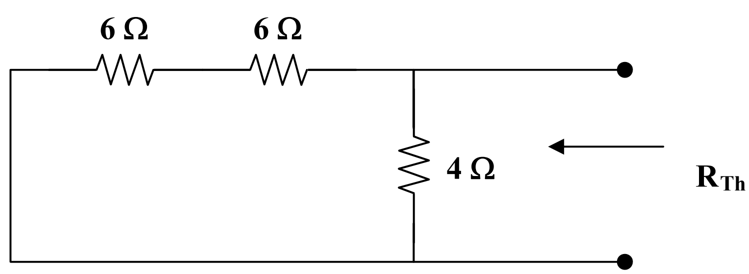


(a)

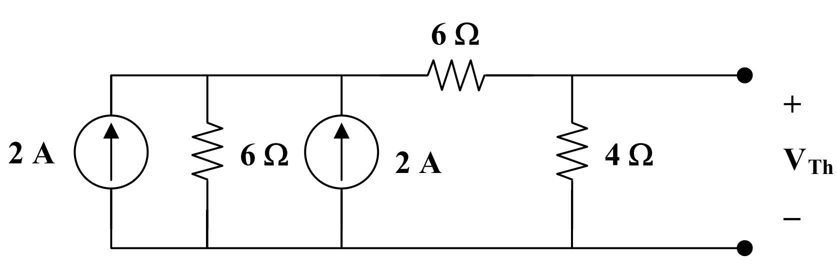


(b)

P.P.4.8 To find R_{Th}, consider the circuit in Fig. (a).



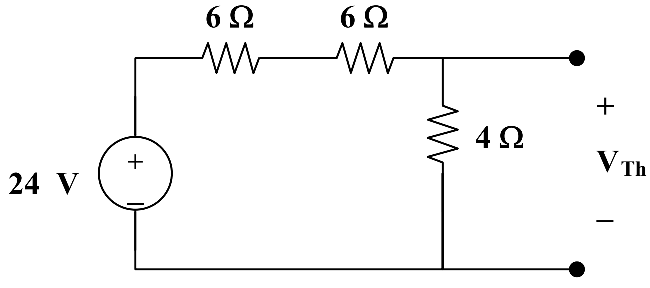
(a)



(b)

$$R_{Th} = (6+6)\|4 = \frac{12x4}{18} = \mathbf{3\Omega}$$

To find V_{Th}, we use source transformations as shown in Fig. (b) and (c).



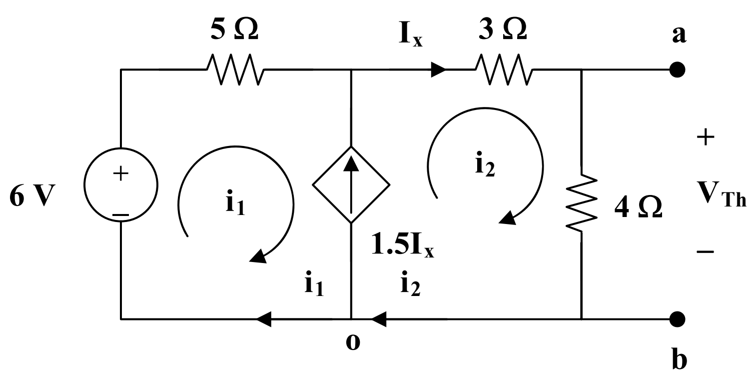
(c)

Using current division in Fig. (c),

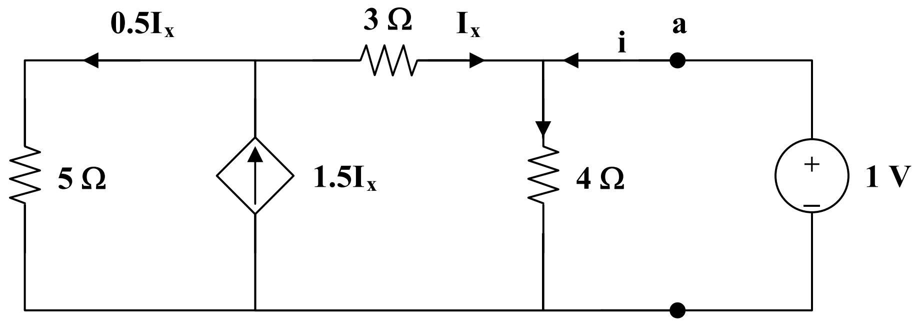
$$V_{Th} = \frac{4}{4+12}(24) = \mathbf{6\ V}$$

$$i = \frac{V_{Th}}{R_{Th}+1} = \frac{6}{3+1} = \mathbf{1.5\ A}$$

P.P.4.9 To find V_{Th}, consider the circuit in Fig. (a).



(a)



(b)

$I_x = i_2$
$i_2 - i_1 = 1.5I_x = 1.5i_2 \longrightarrow i_2 = -2i_1$ (1)

For the supermesh, $-6 + 5i_1 + 7i_2 = 0$ (2)

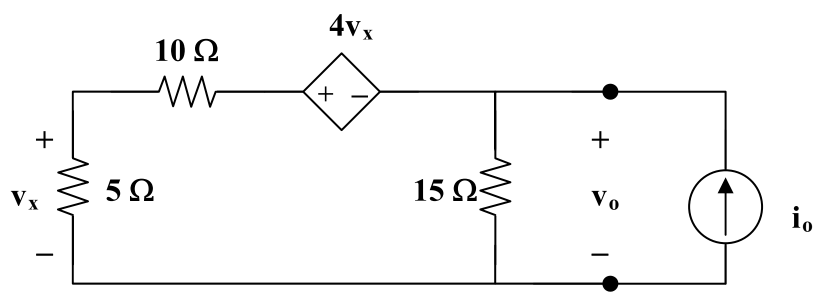
From (1) and (2), $i_2 = 4/(3)$A

$V_{Th} = 4i_2 =$ **5.333V**

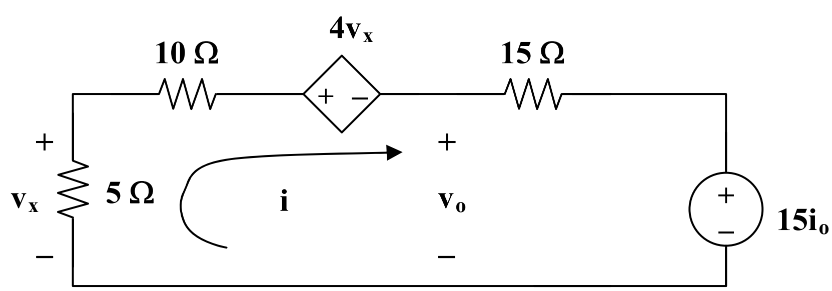
To find R_{Th}, consider the circuit in Fig. (b). Applying KVL around the outer loop,

$$5(0.5I_x) - 1 - 3I_x = 0 \longrightarrow I_x = -2$$
$$i = \frac{1}{4} - I_x = 2.25$$
$$R_{Th} = \frac{1}{i} = \frac{1}{2.25} = \mathbf{444.4\ m\Omega}$$

P.P.4.10 Since there are no independent sources, $V_{Th} =$ **0**



(a)

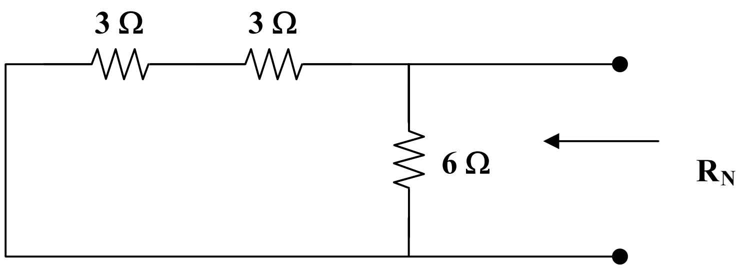


(b)

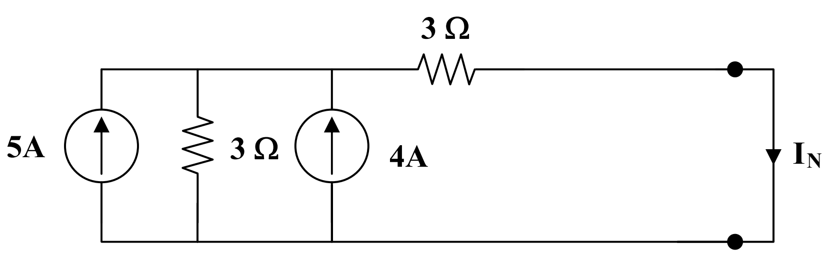
To find R_{Th}, consider Fig.(a). Using source transformation, the circuit is transformed to that in Fig. (b). Applying KVL,).

But $v_x = -5i$. Hence, $30i - 20i + 15i_o = 0 \longrightarrow 10i = -15i_o$
$v_o = (15i + 15i_o) = 15(-1.5i_o + i_o) = -7.5i_o$
$R_{Th} = v_o/(i_o) =$ **-7.5Ω It needs to be noted that this negative resistance indicates we must have an active source (a dependent source).**

P.P.4.11



(a)

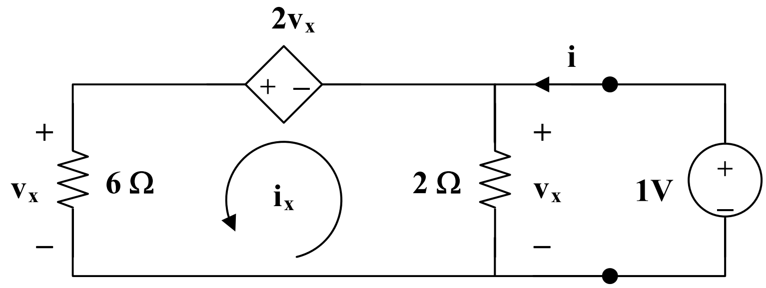


(b)

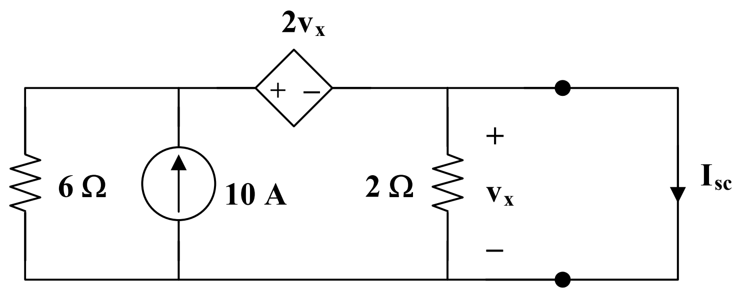
From Fig. (a), $R_N = (3+3)\|6 =$ **$3\ \Omega$**

From Fig. (b), $I_N = \frac{1}{2}(5+4) =$ **4.5A**

P.P.4.12



(a)



(b)

To get R_N consider the circuit in Fig. (a). Applying KVL, $6i_x - 2v_x - 1 = 0$

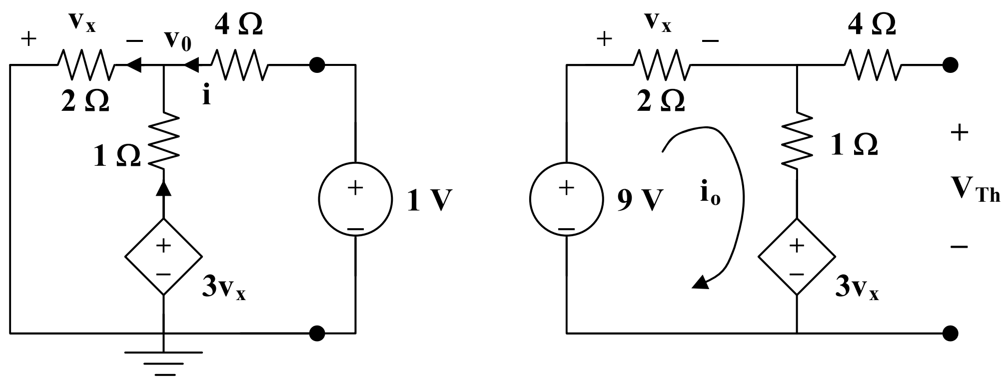
But $v_x = 1$, $6i_x = 3 \longrightarrow$ $i_x = 0.5$

$$i = i_x + \frac{v_x}{2} = 0.5 + 0.5 = 1$$

$$R_N = R_{Th} = \frac{1}{i} = \mathbf{1\Omega}$$

To find I_N, consider the circuit in Fig. (b). Because the 2Ω resistor is shorted, $v_x = 0$ and the dependent source is inactive. Hence, $I_N = i_{sc} =$ **10A**.

P.P.4.13 We first need to find R_{Th} and V_{Th}. To find R_{Th}, we consider the circuit in Fig. (a).



(a) **(b)**

Applying KCL at the top node gives

$$\frac{1-v_o}{4}+\frac{3v_x-v_o}{1}=\frac{v_o}{2}$$

But $v_x = -v_o$. Hence

$$\frac{1-v_o}{4}-4v_o=\frac{v_o}{2} \longrightarrow v_o = 1/(19)$$

$$i=\frac{1-v_o}{4}=\frac{1-\frac{1}{19}}{4}=\frac{9}{38}$$

$R_{Th} = 1/i = 38/(9) = 4.222\Omega$

To find V_{Th}, consider the circuit in Fig. (b),

$$-9 + 2i_o + i_o + 3v_x = 0$$

But $v_x = 2i_o$. Hence,

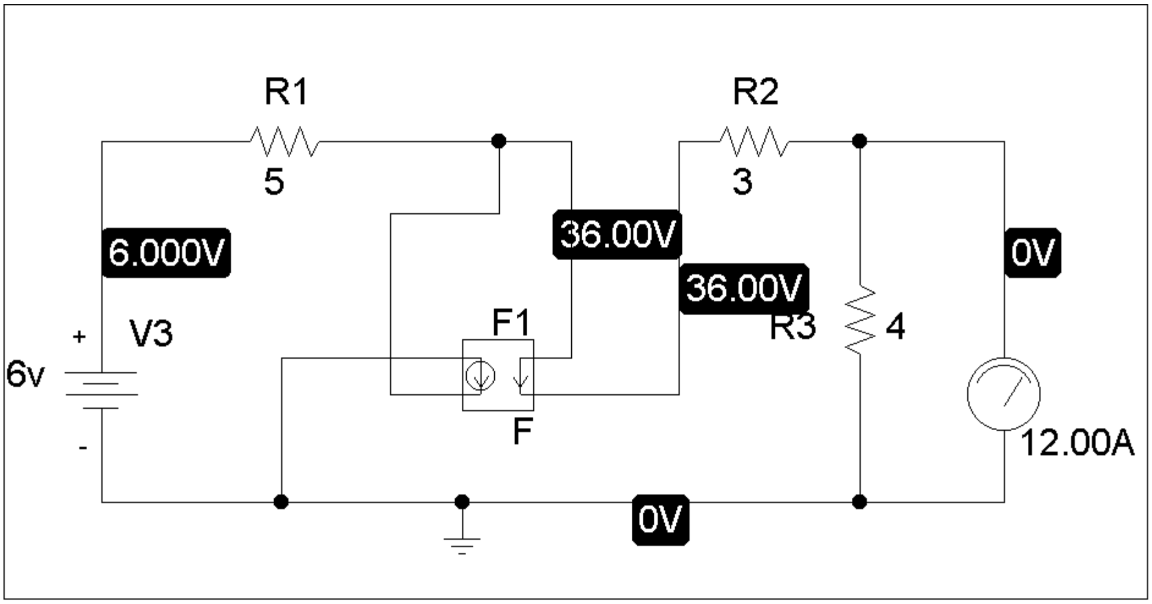
$$9 = 3i_o + 6i_o = 9i_o \longrightarrow i_o = 1A$$

$$V_{Th} = 9 - 2i_o = 7V$$

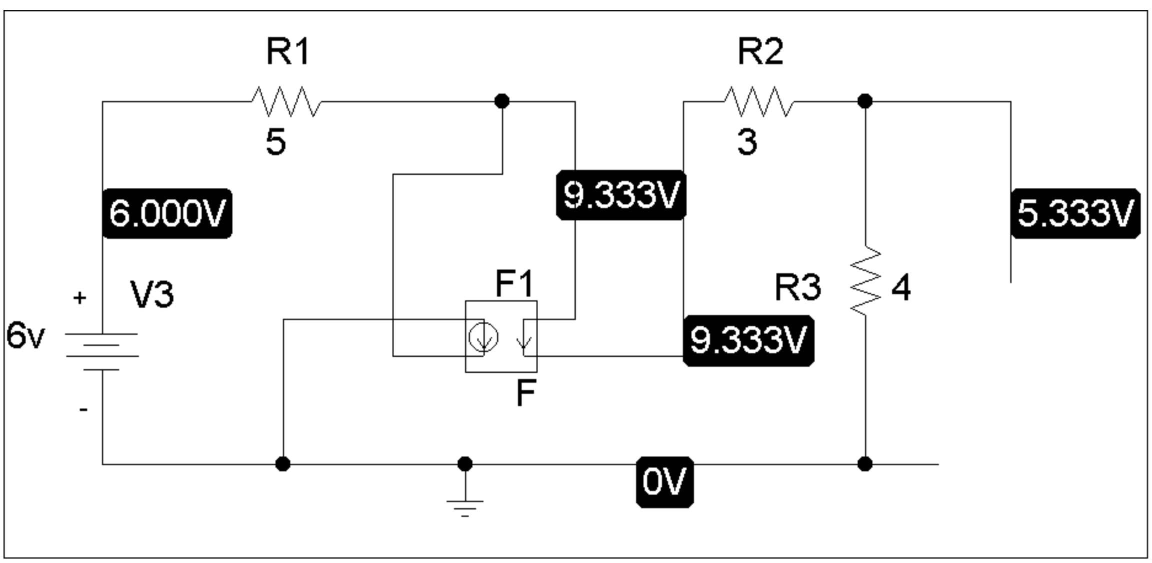
$R_L = R_{Th} =$ **4.222 Ω**

$P_{max} = \frac{v_{Th}^2}{4R_L}=\frac{49}{4(4.222)}=$ **2.901 W**

P.P.4.14 We will use PSpice to find V_{oc} and I_{sc} which then can be used to find V_{Th} and R_{th}.

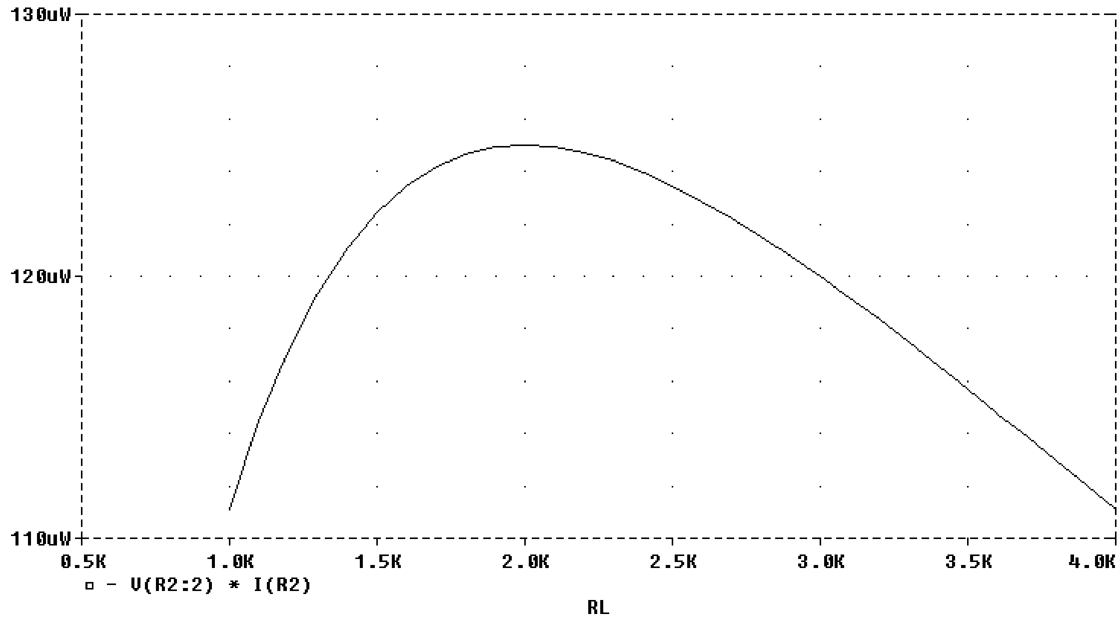


Clearly I_{sc} = 12 A

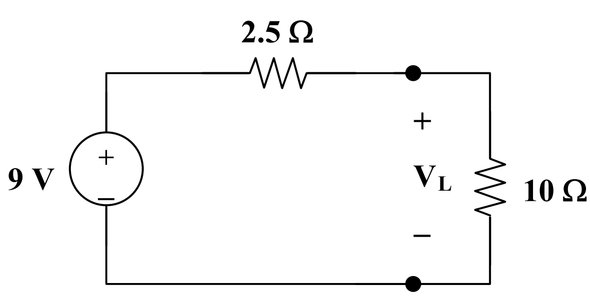


Clearly V_{Th} = I_{oc} = **5.333 volts**. R_{Th} = Voc/Isc = 5.333/12 = **444.4 mΩ**.

P.P.4.15 The schematic is the same as that in Fig. 4.56 except that the 1-kΩ resistor is replaced by 2-kΩ resistor. The plot of the power absorbed by R_L is shown in the figure below. From the plot, it is clear that the maximum power occurs when R_L = 2kΩ and it is **125 μW**.



P.P.4.16 V_{Th} = 9V, $R_{Th} = \left(v_{oc} - V_L\right)\dfrac{R_L}{V_L} = (9-1)\dfrac{20}{8} = 2.5\Omega$



$$V_L = \frac{10}{10+2.5}(9) = \mathbf{7.2\ V}$$

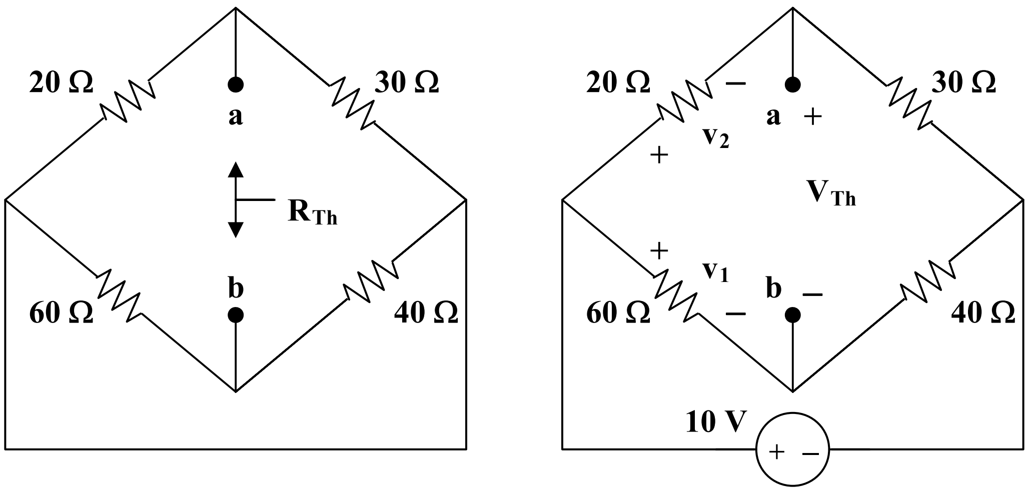
P.P.4.17 $R_1 = R_3 = 1k\Omega$, $R_2 = 3.2k\Omega$

$$R_x = \frac{R_3}{R_1} R_2 = R_2 = \mathbf{3.2\ k\Omega}$$

P.P.4.18 We first find R_{Th} and V_{Th}. To get R_{Th}, consider the circuit in Fig. (a).

$$R_{Th} = 20\|30 + 60\|40 = \frac{20x30}{50} + \frac{60x40}{100}$$

$$= 12 + 24 = 36\Omega$$



(a) (b)

To find V_{Th}, we use Fig. (b). Using voltage division,

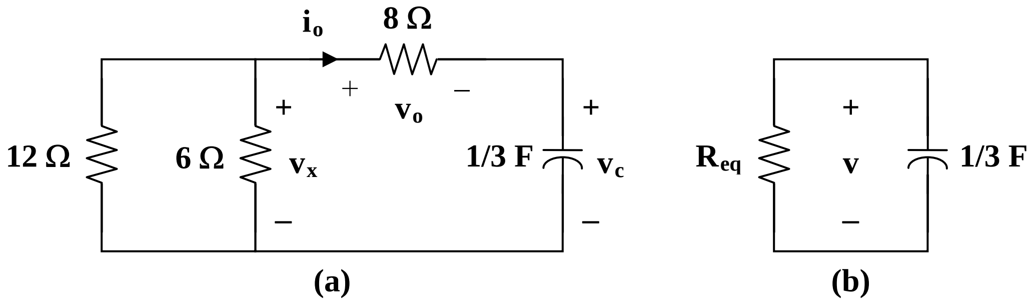
$$v_1 = \frac{60}{100}(16) = 9.6, \quad v_2 = \frac{20}{50}(16) = 6.4$$

But $-v_1 + v_2 + v_{Th} = 0$ ⟶ $v_{Th} = v_1 - v_2 = 9.6 - 6.4 = 32V$

$$I_G = \frac{V_{Th}}{R_{Th} + R_m} = \frac{3.2}{3.6 + 1.4} = \mathbf{64mA}$$

CHAPTER 7

P.P.7.1 The circuit in Fig. (a) is equivalent to the one shown in Fig. (b).



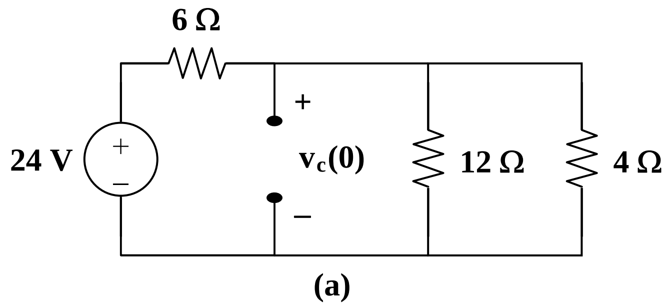
$$R_{eq} = 8 + 12 \,||\, 6 = 12\ \Omega$$
$$\tau = R_{eq}C = (12)(1/3) = 4\ \text{s}$$
$$v_c = v_c(0)\,e^{-t/\tau} = 60\,e^{-t/4} = \mathbf{60e^{-0.25t}\ V}$$

$$v_x = \frac{4}{4+8} v_c = \mathbf{20e^{-0.25t}\ V}$$

$$v_x = v_o + v_c \longrightarrow v_o = v_x - v_c = -40\,e^{-0.25t}\ V$$

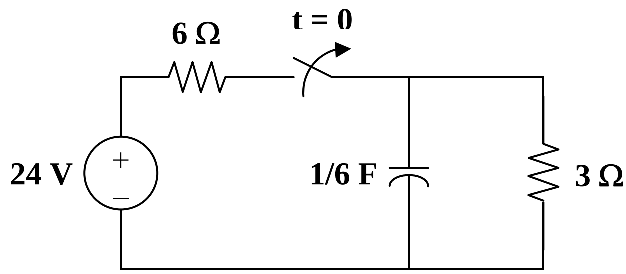
$$i_o = \frac{v_o}{8} = \mathbf{-5e^{-0.25t}\ A}.$$

P.P.7.2 When t < 0, the switch is closed as shown in Fig. (a).



$$R_{eq} = 4 \,||\, 12 = 3\ \Omega \qquad v_c(0) = \frac{3}{3+6}(24) = 8\ \text{V}$$

When t > 0, the switch is open as shown in Fig. (b).



(b)

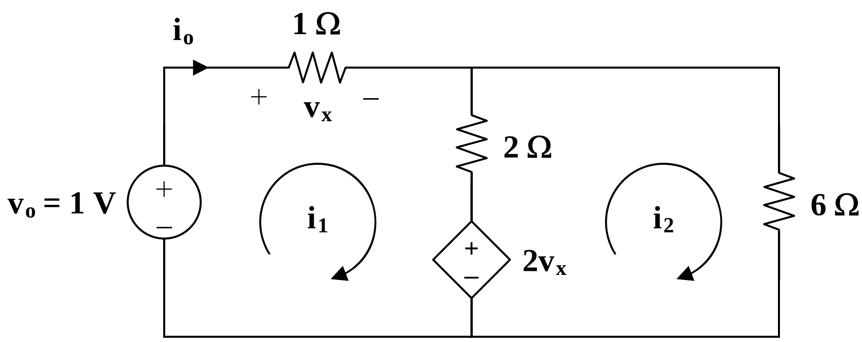
$$\tau = R_{eq}C = (3)(1/6) = 1/2 \text{ s}$$

$$v(t) = v_c(0)e^{-t/\tau} = \mathbf{8e^{-2t}\ V}$$

$$w_c(0) = \frac{1}{2}Cv_c^2(0) = \frac{1}{2} \times \frac{1}{6} \times 64 = \mathbf{5.333J}$$

P.P.7.3 This can be solved in two ways.

Method 1: Find R_{th} at the inductor terminals by inserting a voltage source.



Applying mesh analysis gives

Loop 1: $-1 + 3i_1 - 2i_2 + 2v_x = 0$, where $v_x = 1i_1$

$5i_1 - 2i_2 = 1$ (1)

Loop 2: $8i_2 - 2i_1 - 2v_x = 0 = 8i_2 - 2i_1 - 2i_1$

$i_2 = \frac{1}{2}i_1$ (2)

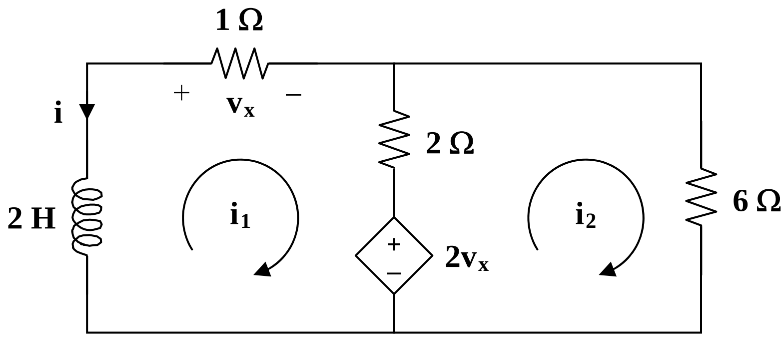
From (1) and (2), $5i_1 - 1i_1 = 1$ or

$i_o = i_1 = (1/4)$ A

$$R_{th} = \frac{v_o}{i_o} = 4\,\Omega, \qquad \tau = \frac{L}{R} = \frac{2}{4} = \frac{1}{2}\,s$$

$$i(t) = 12e^{-2t}\ A$$

Method 2: We can obtain i using mesh analysis.



Applying KVL to the loops, we obtain

Loop 1: $$2\frac{di_1}{dt} + 3i_1 - 2i_2 + 2v_x = 0 \qquad \text{where } v_x = 1i_1$$

$$2\frac{di_1}{dt} + 5i_1 - 2i_2 = 0 \qquad (3)$$

Loop 2: $$8i_2 - 2i_1 - 2v_x = 0$$

$$i_2 = \frac{1}{2}i_1 \qquad (4)$$

Substituting (4) into (3) yields

$$2\frac{di_1}{dt} + 5i_1 - 1i_1 = 0$$

or $$\frac{di_1}{dt} + 2i_1 = 0$$

$$i_1 = Ae^{-2t}$$

$$i = -i_1 = Be^{-2t}$$

$$i(0) = 12 = B$$

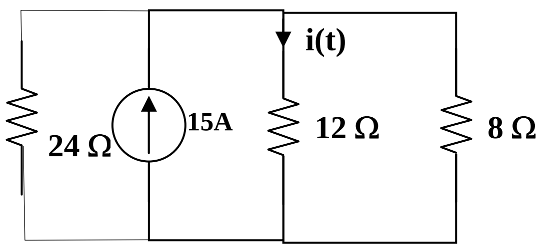
$$i(t) = 12e^{-2t}\ A$$

Therefore,

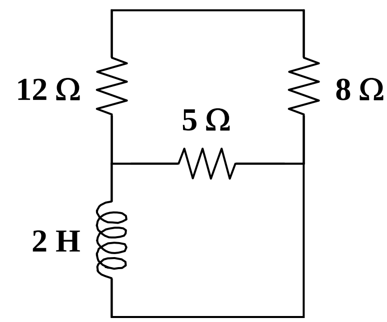
$$i(t) = \mathbf{12e^{-2t}\ A}$$

and $v_x(t) = -1i(t) = \mathbf{-12e^{-2t}\ V}$ for all $t > 0$.

P.P.7.4 For t < 0, the equivalent circuit is shown in Fig. (a).



(a)



(b)

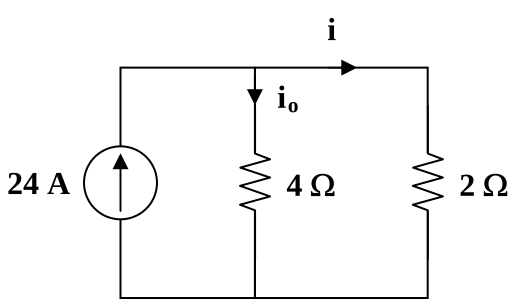
$$i(0) = 15[1/\{(1/24)+(1/12)+(1/8)\}]/12 = (15x24/6)/12 = 5\ A$$

For t > 0, the current source and 24-ohm is cut off and the RL circuit is shown in Fig. (b).

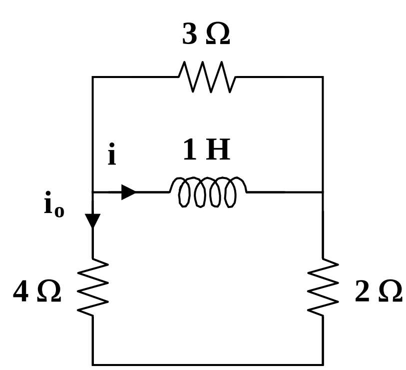
$$R_{eq} = (12+8)\,||\,5 = 20\,||\,5 = 4\,\Omega, \qquad \tau = \frac{L}{R_{eq}} = \frac{2}{4} = 0.5$$

$$i(t) = i(0)e^{-2t} = \mathbf{5e^{-2t}\ amps}, \text{ for all } t > 0.$$

P.P.7.5 For t < 0, the switch is closed. The inductor acts like a short so the equivalent circuit is shown in Fig. (a).



(a)



(b)

$$i = \frac{4}{4+2}(24) = 16\ A, \qquad i_o = 24 - 16 = 8\ A, \qquad v_o = 2i\ = 32\ V$$

For t > 0, the current source is cut off so that the circuit becomes that shown in Fig. (b). The Thevenin equivalent resistance at the inductor terminals is

$$R_{th} = (4+2)\,||\,3 = 2\,\Omega, \qquad \tau = \frac{L}{R_{th}} = \frac{1}{2}$$

$$i_o = \frac{3(-i)}{6+3} = \frac{-1}{3}i = -5.333e^{-2t}\ A \qquad \text{and} \qquad v_o = -2i_o = 10.667e^{-2t}V$$

Thus,

$$i = \begin{cases} 16\text{ A} & t<0 \\ 16e^{-2t}\text{ A} & t>0 \end{cases} \quad i_o = \begin{cases} 8\text{ A} & t<0 \\ -5.333e^{-2t}\text{ A} & t>0 \end{cases} \quad v_o = \begin{cases} 32\text{ V} & t<0 \\ 10.667e^{-2t}\text{V} & t>0 \end{cases}$$

P.P.7.6 $$i(t) = \begin{cases} 0 & t<0 \\ 10 & 0<t<2 \\ -10 & 2<t<4 \end{cases}$$

$$i(t) = 10[u(t) - u(t-2)] - 10[u(t-2) - u(t-4)]$$
$$i(t) = \mathbf{10[u(t) - 2u(t-2) + u(t-4)]A}$$

Let $I = \int_{-\infty}^{t} i\, dt$.

For $t < 0$, $I = 0$.

For $0 < t < 2$, $I = \int_0^t 10\, dt = 10t$

For $2 < t < 4$, $I = \int_0^2 10\, dt - 10\int_2^t dt = 20 - 10t\Big|_2^t = 40 - 10t$

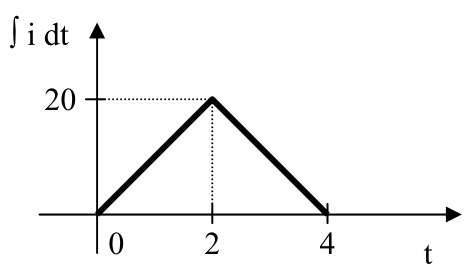
For $t > 4$, $I = 20 - 10t\Big|_2^4 = 0$

Thus,

$$I = \begin{cases} 0 & t<0 \\ 10t & 0<t<2 \\ 40-10t & 2<t<4 \\ 0 & t>4 \end{cases}$$

or $I = \mathbf{10[r(t) - 2r(t-2) + r(t-4)]}\underline{\mathbf{A}}$

which is sketched below



P.P.7.7 $$i(t) = \begin{cases} 2-2t & 0<t<2 \\ -6+2t & 2<t<3 \\ 0 & \text{otherwise} \end{cases}$$

$$i(t) = (2-2t)[u(t) - u(t-2)] + (-6+2t)[u(t-2) - u(t-3)]$$

$$i(t) = 2\,u(t) - 2t\,u(t) + 4(t-2)\,u(t-2) - 2(t-3)\,u(t-3)$$
$$i(t) = \mathbf{[2\,u(t) - 2\,r(t) + 4\,r(t-2) - 2\,r(t-3)]\,A}$$

Remember the singularity function, r(t), is a ramp function equal to t for all values of t > 0 and equal to zero for all values of t < 0.

P.P.7.8
h(t) = –4[u(t) – u(t–2)] + (3t–8)[u(t–2) –u(t–6)]
h(t) = –4u(t) + 4u(t–2) +3tu(t–2) – 8u(t–2) – 3tu(t–6) + 8u(t–6)
h(t) = –4u(t) + (4–8+6)u(t–2) +3(t–2)u(t–2) – 3(t–6)u(t–6) + (–18+8)u(t–6)
h(t) = –4u(t) + 2u(t–2) + 3(t–2)u(t–2) – 3(t–6)u(t–6) – 10u(t–6)
h(t) = **–4u(t) +2u(t–2) + 3r(t–2) – 10u(t–6) – 3r(t–6)**.

P.P.7.9 (a)
$$\int_{-\infty}^{\infty}\left(t^3 + 5t^2 + 10\right)\delta(t+3)\,dt = t^3 + 5t^2 + 10\Big|_{t=-3}$$
$$= -27 + 45 + 10 = \mathbf{28}$$

(b)
$$\int_{0}^{10}\delta(t-\pi)\cos(3t)\,dt = \cos(3\pi) = \mathbf{-1}$$

P.P.7.10 For t < 0, the capacitor acts like an open circuit.
$$v(0^-) = v(0^+) = v(0) = 15$$

For t > 0, [(v(∞)–15)/2] + [(v(∞)–(–7.5))/6] = 0 or (4/6)v(∞) = 7.5–1.25 = 6.25 or

v(∞) = 9.375 V

$$R_{th} = 2\,||\,6 = \frac{3}{2}\,\Omega, \qquad \tau = R_{th}C = \frac{3}{2}\times\frac{1}{3} = \frac{1}{2}$$

$$v(t) = v(\infty) + \left[\,v(0) - v(\infty)\right]e^{-t/\tau} = 9.375 + (15–9.375)e^{-2t}$$

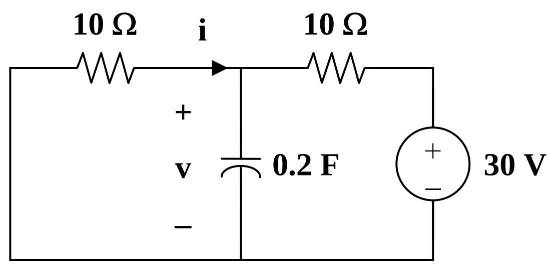
v(t) = **(9.375 + 5.625e^{-2t}) V for all t > 0**

At t = 0.5, v(0.5) = 6.25 + 3.75e^{-1} = 6.25 + 1.3795 = **7.63 V**

P.P.7.11 For t < 0, only the left portion of the circuit is operational at steady state.
$$v(0^-) = v(0^+) = v(0) = 20, \qquad i(0) = 0$$

For t > 0, $20u(-t) = 0$ so that the voltage source is replaced by a short circuit.

Transforming the current source leads to the circuit below.



$$v(\infty) = \frac{5}{15}(30) = 10$$

$$R_{th} = 5 \,||\, 10 = \frac{10}{3}\,\Omega, \qquad \tau = R_{th}C = \frac{10}{3} \times 0.2 = \frac{2}{3}$$

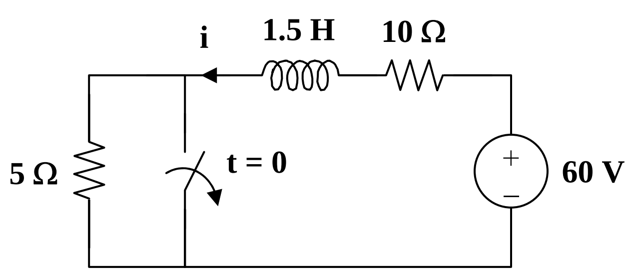
$$v(t) = v(\infty) + \left[\, v(0) - v(\infty) \right] e^{-t/\tau}$$
$$v(t) = 10 + (20 - 10)\, e^{-3t/2}$$
$$v(t) = 10\left(1 + e^{-1.5t}\right)$$

$$i(t) = \frac{-\,v(t)}{5} = -2\left(1 + e^{-1.5t}\right)$$

$$i(t) = \begin{cases} \mathbf{0} & \mathbf{t < 0} \\ \mathbf{-\,2\left(1 + e^{-1.5t}\right) A} & \mathbf{t > 0} \end{cases}$$

$$v(t) = \begin{cases} \mathbf{20\ V} & \mathbf{t < 0} \\ \mathbf{10\left(1 + e^{-1.5t}\right) V} & \mathbf{t > 0} \end{cases}$$

P.P.7.12 Applying source transformation, the circuit is equivalent to the one below.



At t < 0, the switch is closed so that the 5 ohm resistor is short circuited.

$$i(0^-) = i(0) = \frac{60}{10} = 6\ A$$

For t > 0, the switch is open.

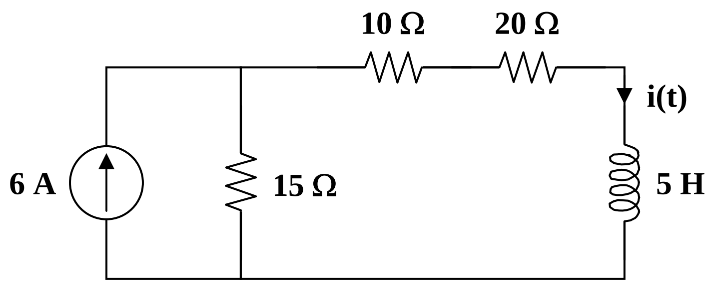
$$R_{th} = 10+5 = 15, \qquad \tau = \frac{L}{R_{th}} = \frac{1.5}{15} = 0.1$$

$$i(\infty) = \frac{60}{10+5} = 4A$$

$$i(t) = i(\infty) + \left[\, i(0) - i(\infty)\right] e^{-t/\tau}$$
$$i(t) = 4 + (6-4)e^{-10t}$$

i(t) = **(4 + 2e^{-10t}) A for all t > 0**

P.P.7.13 For 0 < t < 2, the given circuit is equivalent to that shown below.



Since switch S_1 is open at $t = 0^-$, $i(0^-) = 0$. Also, since i cannot jump, $i(0) = i(0^-) = 0$.

$$i(\infty) = \frac{90}{15+10+20} = 2\text{ A}$$
$$R_{th} = 45\,\Omega, \quad \tau = \frac{L}{R_{th}} = \frac{5}{45} = \frac{1}{9}$$
$$i(t) = i(\infty) + \left[\, i(0) - i(\infty)\right] e^{-t/\tau}$$
$$i(t) = 2 + (0-2)e^{-9t}$$
$$i(t) = 2(1-e^{-9t})\text{ A}$$

When switch S_2 is closed, the 20 ohm resistor is short-circuited.

$$i(2^+) = i(2^-) = 2(1-e^{-18}) \cong 2$$

This will be the initial current

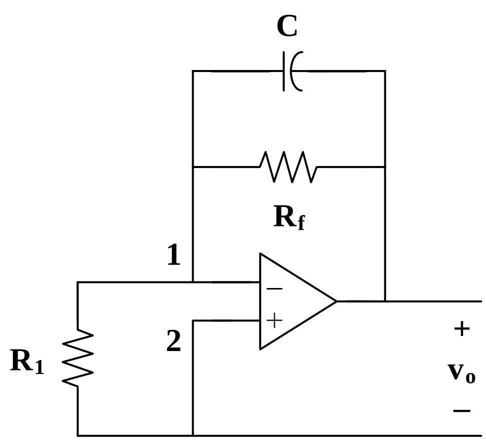
$$i(\infty) = \frac{90}{15+10} = 3.6\text{ A}$$
$$R_{th} = 25\,\Omega, \quad \tau = \frac{5}{25} = \frac{1}{5}$$
$$i(t) = i(\infty) + \left[\, i(2^+) - i(\infty)\right] e^{-(t-2)/\tau}$$
$$i(t) = 3.6 + (2-3.6)e^{-5(t-2)}$$
$$i(t) = 3.6 - 1.6e^{-5(t-2)}$$

Thus, $i(t) = \begin{cases} \mathbf{0} & \mathbf{t < 0} \\ \mathbf{2(1 - e^{-9t})\ A} & \mathbf{0 < t < 2} \\ \mathbf{3.6 - 1.6e^{-5(t-2)}\ A} & \mathbf{t > 2} \end{cases}$

At $t = 1$, $\quad i(1) = 2(1 - e^{-9}) = \mathbf{1.9997\ A}$

At $t = 3$, $\quad i(3) = 3.6 - 1.6e^{-5} = \mathbf{3.589\ A}$

P.P.7.14 The op amp circuit is shown below.



Since nodes 1 and 2 must be at the same potential, there is no potential difference across R_1. Hence, no current flows through R_1. Applying KCL at node 1,

$$\frac{v}{R_f} + C\frac{dv}{dt} = 0 \longrightarrow \frac{dv}{dt} + \frac{v}{CR_f} = 0$$

which is similar to Eq. (7.4).

Hence,

$$v(t) = v_o\, e^{-t/\tau}, \ \tau = R_f C$$

$$v(0) = v_o = 4, \qquad \tau = (50 \times 10^3)(10 \times 10^{-6}) = 0.5$$

$$v(t) = 4e^{-2t}\ \text{V}, \quad t > 0$$

Alternatively, since no current flows through R_1, the feedback loop forms a first order RC circuit with $v(0) = 4$ and $\tau = R_f C = 0.5$. Hence,

$$v(t) = 4e^{-2t}\ \text{V}, \quad t > 0$$

To get to v_o from v, we notice that v is the potential difference between node 1 and the output terminal, i.e.

$$0 - v_o = v \longrightarrow v_o = -v \ \text{ or } \ v_o(t) = \mathbf{-4e^{-2t}\ V, \quad t > 0}$$

P.P.7.15 Let v_1 be the potential at the inverting terminal.

$$v(t) = v(\infty) + \left[v(0) - v(\infty) \right] e^{-t/\tau}$$

where $\tau = RC = 100 \times 10^3 \times 10^{-6} = 0.1$, $v(0) = 0$

$$v_1 = 0 \text{ for all t}$$

$$v_1 - v_o = v \qquad (1)$$

For t > 0, the switch is closed and the op amp circuit is an inverting amplifier with

$$v_o(\infty) = \frac{-100}{10}(4 \text{ mV}) = -40 \text{ mV}$$

From (1),

$$v(\infty) = 0 - v_o(\infty) = 40 \text{ mV}$$

Thus, $v(t) =$ $\mathbf{40(1 - e^{-10t})u(t)\ mV}$

$$v_o = v_1 - v = -v$$

$v_o =$ $\mathbf{40(e^{-10t} - 1)u(t)\ mV}$

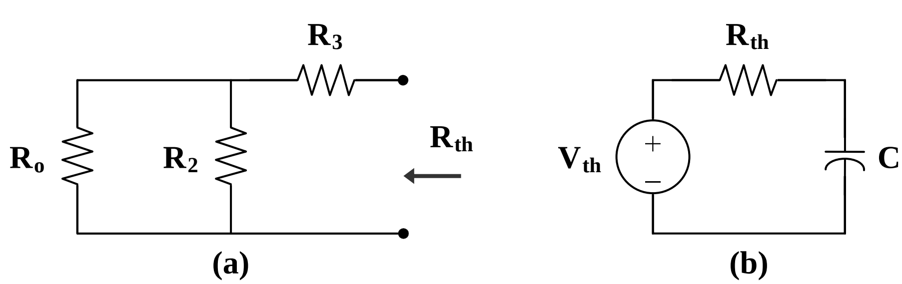
P.P.7.16 This is a noninverting amplifier so that the output of the op amp is

$$v_a = \left(1 + \frac{R_f}{R_1}\right) v_i$$

$$v_{th} = v_a = \left(1 + \frac{R_f}{R_1}\right) v_i = \left(1 + \frac{40}{20}\right) 4.5\,u(t) = 13.5\,u(t)$$

To get R_{th}, consider the circuit shown in Fig. (a), where R_o is the output resistance of the op amp. For an ideal op amp, $R_o = 0$ so that

$$R_{th} = R_3 = 10 \text{ k}\Omega$$



$$\tau = R_{th} C = 10 \times 10^3 \times 2 \times 10^{-6} = \frac{1}{50}$$

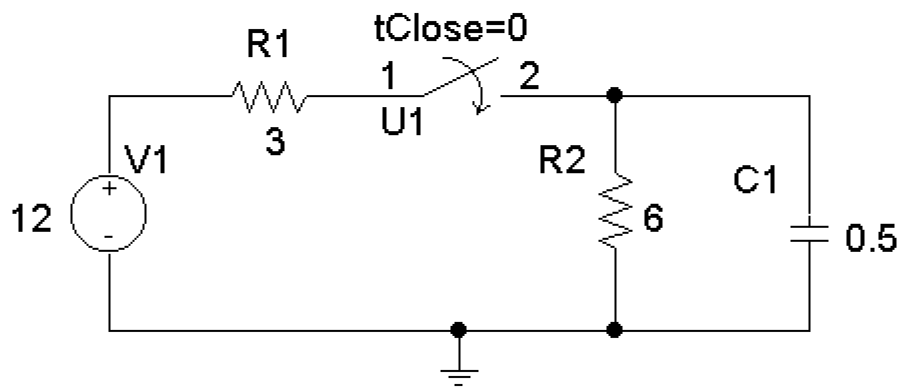
The Thevenin equivalent circuit is shown in Fig. (b), which is a first order circuit.

Hence,

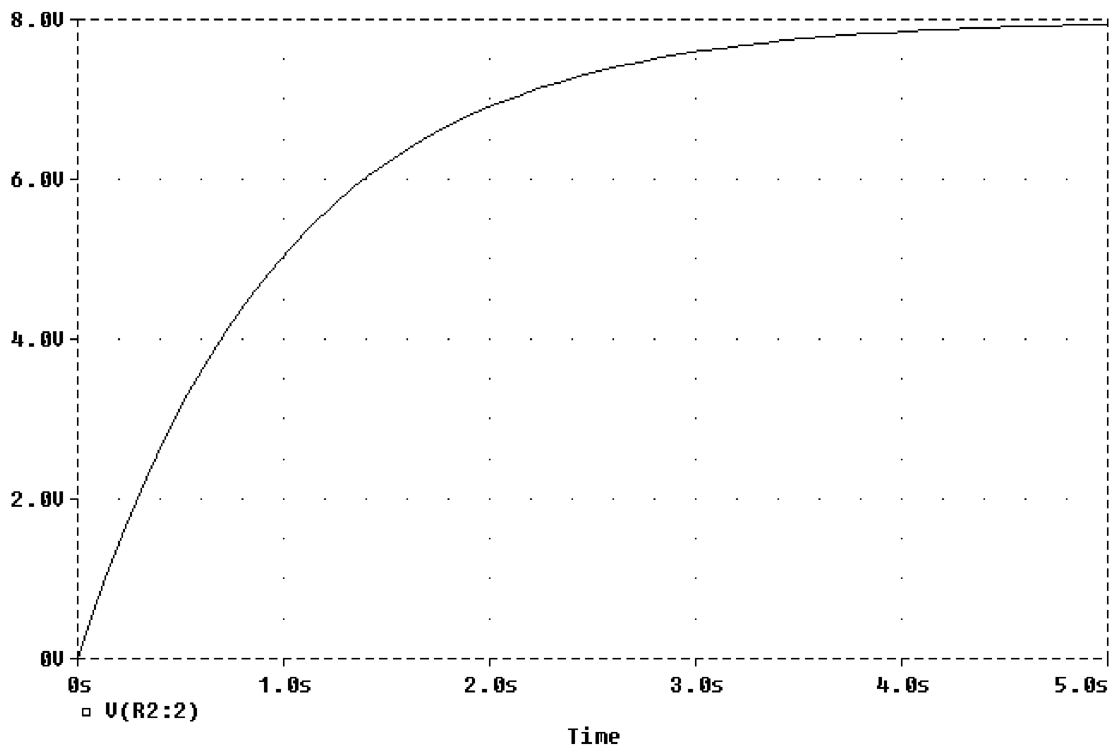
$$v_o(t) = 13.5\left(1 - e^{-t/\tau}\right)u(t)$$

$$v_o(t) = \mathbf{13.5(1 - e^{-50t})u(t)\ V}$$

P.P.7.17 The schematic is shown in Fig. (a). Construct and save the schematic. Select Analysis/Setup/Transient to change the Final Time to 5 s. Set the Print Step slightly greater than 0 (20 ns is default). The circuit is simulated by selecting Analysis/ Simulate. In the Probe menu, select Trace/Add and display V(R2:2) as shown in Fig. (b).

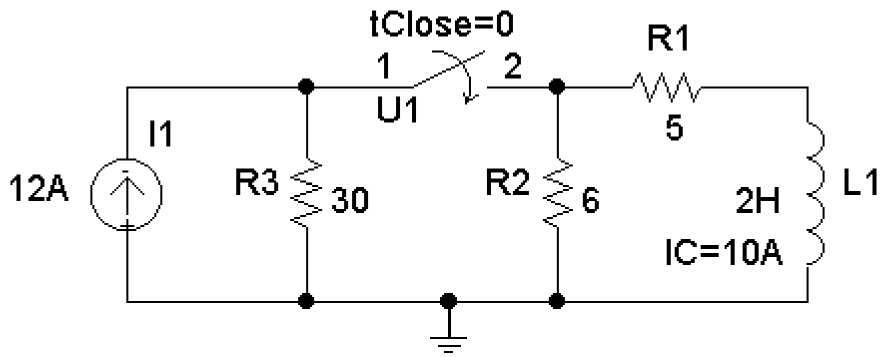


(a)

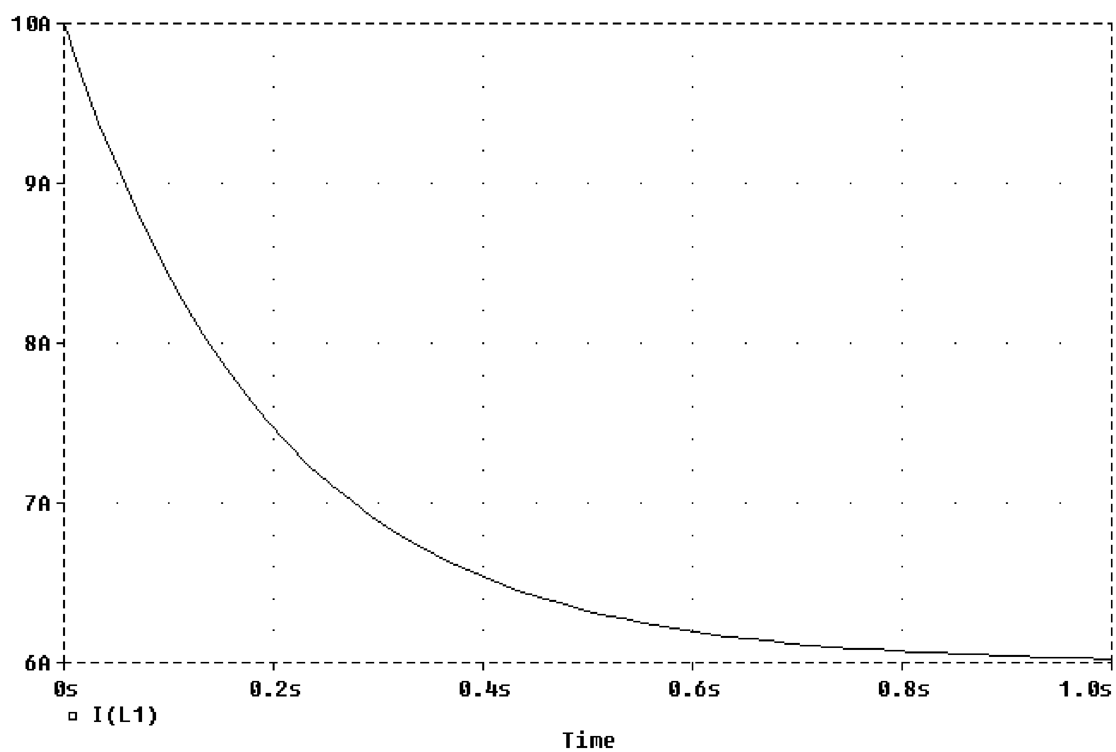


(b)

P.P.7.18 The schematic is shown in Fig. (a). While constructing the circuit, rotate L1 counterclockwise through 270° so that current i(t) enters pin 1 of L1 and set IC = 10 for L1. After saving the schematic, select Analysis/Setup/Transient to change the Final Time to 1 s. Set the Print Step slightly greater than 0 (20 ns is default). The circuit is simulated by selecting Analysis/ Simulate. After simulating the circuit, select Trace/Add in the Probe menu and display I(L1) as shown in Fig. (b).

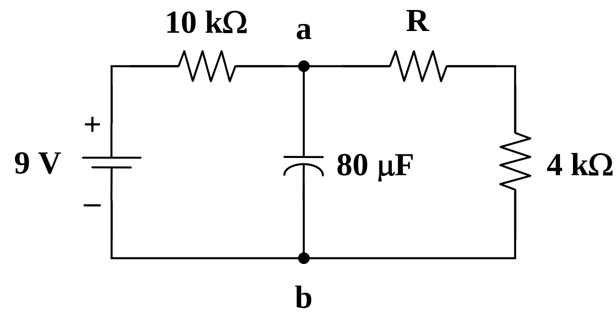


(a)



(b)

P.P.7.19 $v(0) = 0$. When the switch is closed, we have the circuit shown below.



We find the Thevenin equivalent at terminals a-b.

$$R_{th} = (R+4) \,||\, 10 = \frac{10(R+4)}{R+14}$$

$$v_{th} = v(\infty) = \frac{R+4}{R+14}(9)$$

$$v(t) = v(\infty) + \left[\, v(0) - v(\infty)\right] e^{-t/\tau}, \qquad \tau = R_{th}C$$

$$v(t) = v(\infty)\left(1 - e^{-t/\tau}\right)$$

Since $v(0) = 0$,

$$i(t) = \frac{v(t)}{R+4} = \frac{9}{R+4}\left(1 - e^{-t/\tau}\right) \text{ mA}$$

Assuming R is in kΩ,

$$120 \times 10^{-6} = \frac{9}{R+14}\left(1 - e^{-t_0/\tau}\right) \times 10^{-3}$$

$$(0.12)\frac{R+14}{9} = 1 - e^{-t_0/\tau}$$

or $$e^{-t_0/\tau} = 1 - \frac{0.12R + 1.68}{9} = \frac{7.32 - 0.12R}{9}$$

$$t_0 = \tau \ln\left(\frac{9}{7.32 - 0.12R}\right)$$

$$t_0 = \frac{10(R+4)}{R+14} \times 80 \times 10^{-6} \times \ln\left(\frac{9}{7.32 - 0.12R}\right)$$

When R = 0,

$$t_0 = \frac{40 \times 80 \times 10^{-6}}{14} \times \ln\left(\frac{9}{7.32}\right) = 0.04723 \text{ s}$$

When R = 6 kΩ,

$$t_0 = \frac{100}{20} \times 80 \times 10^{-6} \times \ln\left(\frac{9}{6.6}\right) = 0.124 \text{ s}$$

The time delay is **between 47.23 ms and 124 ms**.

P.P.7.20 (a) $q = CV = (2x10^{-3})(80) =$ **160 mC**.

(b) $W = \frac{1}{2}CV^2 = \frac{1}{2}(2\times10^{-3})(6400) =$ **6.4 J**

(c) $\Delta I = \frac{\Delta q}{\Delta t} = \frac{0.16}{0.8\times10^{-3}} =$ **200 A**

(d) $p = \frac{\Delta w}{\Delta t} = \frac{6.4}{0.8\times10^{-3}} =$ **8 kW**

(e) $\Delta t = \frac{\Delta q}{\Delta I} = \frac{0.16}{5\times10^{-3}} =$ **32 s**

P.P.7.21 $\tau = \frac{L}{R} = \frac{500\times10^{-3}}{200} = 2.5 \text{ ms}$

$$i(0) = 0, \qquad i(\infty) = \frac{110}{200} = 550 \text{ mA}$$

$$i(t) = 550\left(1 - e^{-t/\tau}\right) \text{ mA}$$

$$350 \text{ mA} = i(t_0) = 550\left(1 - e^{-t_0/\tau}\right) \text{ mA}$$

$$\frac{35}{55} = 1 - e^{-t_0/\tau} \longrightarrow e^{-t_0/\tau} = \frac{20}{55}$$

$$e^{t_0/\tau} = \frac{55}{20}$$

$$t_0 = \tau \ln\left(\frac{55}{20}\right) = 2.5\ln\left(\frac{55}{20}\right) \text{ ms}$$

$t_0 =$ **2.529 ms**

P.P.7.22 (a) $t = 5\tau = \frac{5L}{R} = \frac{5\times20\times10^{-3}}{5} =$ **20 ms**

(b) $W = \frac{1}{2}LI^2 = \frac{1}{2}\left(20\times10^{-3}\right)\left(\frac{12}{5}\right)^2 =$ **57.6 mJ**

(c) $V = L\frac{di}{dt} = 20\times10^{-3}\left(\frac{12/5}{2\times10^{-6}}\right) =$ **24 kV**

CHAPTER 9

P.P.9.1 amplitude = **30**

phase = **–75°**

angular frequency (ω) = 4π = **12.57 rad/s**

period (T) $= \frac{2\pi}{\omega} =$ **0.5 s**

frequency (f) $= \frac{1}{T} =$ **2 Hz**

P.P.9.2 $i_1 = -4\sin(\omega t + 55°) = 4\cos(\omega t + 55° + 90°)$

$i_1 = 4\cos(\omega t + 145°)$, $\omega = 377$ rad/s

Compare this with

$i_2 = 5\cos(\omega t - 65°)$

indicates that the phase angle between i_1 and i_2 is

145° + 65° = 210°

Thus, **i_1 leads i_2 by 210°**

P.P.9.3 (a) (5 + j2)(-1 + j4) = -5 + j20 – j2 – 8 = -13 + j18

$5\angle 60°$ = 2.5 + j4.33

(5 + j2)(-1 + j4) – $5\angle 60°$ = -15.5 + j13.67

$[(5 + j2)(-1 + j4) - 5\angle 60]^*$ = **-15.5 – j13.67** = **$20.67\angle 221.41°$**

(b) $3\angle 40°$ = 2.298 + j1.928

10 + j5 + $3\angle 40°$ = 12.298 + j6.928 = $14.115\angle 29.39°$

–3 + j4 = $5\angle 126.87°$

$$\frac{10 + j5 + 3\angle 40°}{-3 + j4} = \frac{14.115\angle 29.39°}{5\angle 126.87°} = 2.823\angle -97.48°$$

$2.823\angle -97.48°$ = –0.3675 – j2.8

$10\angle 30°$ = 8.66 + j5

$$\frac{10 + j5 + 3\angle 40°}{-3 + j4} + 10\angle 30° + j5 = \mathbf{8.293 + j7.2}$$

P.P.9.4 (a) v = 7 cos(2t + 40°)

The phasor form is

V = $7\angle 40°$ V

(b) Since –sin(A) = cos(A + 90°),

$i = -4\sin(10t + 10°) = 4\cos(10t+10° + 90°)$

$i = 4\cos(10t + 100°)$

The phasor form is

$\mathbf{I} = \mathbf{4\angle 100°\ A}$

P.P.9.5 (a) Since $-1 = 1\angle\pm180°$ (we can use either sign)

$\mathbf{V} = -25\angle 40° = 25\angle(40°-180°) = 25\angle-140°$

The sinusoid is

v(t) = **25 cos(ωt – 140°) V** or **25 cos(ωt+220˚) V**

(b) $\mathbf{I} = j(12 - j5) = 5 + j12 = 13\angle 67.38°$

The sinusoid is

i(t) = 13 cos(ωt + 67.38°) A

P.P.9.6 Let $v(t) = -10\sin(\omega t-30˚) + 20\cos(\omega t+45˚)$

$= 10\cos(\omega t-30˚+90˚) + 20\cos(\omega t+45˚)$

Taking the phasor of each term

$\mathbf{V} = 10\angle 60° + 20\angle 45°$

$\mathbf{V} = 5 + j8.66 + 14.142 + j14.142$

$\mathbf{V} = 19.142 + j22.8 = 29.77\angle 49.98˚$

Converting **V** to the time domain

v(t) = **29.77 cos(ωt + 49.98°) V**

P.P.9.7 Given that

$$2\frac{dv}{dt} + 5v + 10\int v\,dt = 50\cos(5t - 30°)$$

we take the phasor of each term to get

$$2j\omega\,\mathbf{V} + 5\,\mathbf{V} + \frac{10}{j\omega}\mathbf{V} = 50\angle\text{-}30°, \qquad \omega = 5$$

$$\mathbf{V}\,[j10 + 5 - j(10/5)] = \mathbf{V}\,(5 + j8) = 50\angle\text{-}30°$$

$$\mathbf{V} = \frac{50\angle\text{-}30°}{5 + j8} = \frac{50\angle\text{-}30°}{9.434\angle 58°}$$

$$\mathbf{V} = 5.3\angle\text{-}88°$$

Converting **V** to the time domain

v(t) = **5.3 cos(5t – 88°)V**

P.P.9.8 For the capacitor,

$\mathbf{V} = \mathbf{I} / (j\omega C)$, where $\mathbf{V} = 10\angle 30°$, $\omega = 100$

$\mathbf{I} = j\omega C\,\mathbf{V} = (j100)(50\text{x}10^{-6})(10\angle 30°)$

$\mathbf{I} = 50\angle 120°$ mA

i(t) = **50 cos(100t + 120°) mA**

P.P.9.9 $\mathbf{V}_s = 20\angle 30°$, $\omega = 10$

$$\mathbf{Z} = 4 + j\omega L = 4 + j2$$

$$\mathbf{I} = \mathbf{V}_s / \mathbf{Z} = \frac{20\angle 30°}{4 + j2} = \frac{20\angle 30°(4 - j2)}{16 + 4} = 4.472\angle 3.43°$$

$$\mathbf{V} = j\omega L\,\mathbf{I} = j2\,\mathbf{I} = (2\angle 90°)(4.472\angle 3.43°) = 8.944\angle 93.43°$$

Therefore, $v(t) = \mathbf{8.944 \sin(10t + 93.43°)\ V}$

$i(t) = \mathbf{4.472 \sin(10t + 3.43°)\ A}$

P.P.9.10

Let $\mathbf{Z}_1$ = impedance of the 1-mF capacitor in series with the 100-Ω resistor

$\mathbf{Z}_2$ = impedance of the 1-mF capacitor

$\mathbf{Z}_3$ = impedance of the 8-H inductor in series with the 200-Ω resistor

$$\mathbf{Z}_1 = 100 + \frac{1}{j\omega C} = 100 + \frac{1}{j(10)(1\times 10^{-3})} = 80 - j100$$

$$\mathbf{Z}_2 = \frac{1}{j\omega C} = \frac{1}{j(10)(1\times 10^{-3})} = -j100$$

$$\mathbf{Z}_3 = 200 + j\omega L = 200 + j(10)(8) = 200 + j80$$

$$\mathbf{Z}_{in} = \mathbf{Z}_1 + \mathbf{Z}_2 \parallel \mathbf{Z}_3 = \mathbf{Z}_1 + \mathbf{Z}_2\,\mathbf{Z}_3 / (\mathbf{Z}_2 + \mathbf{Z}_3)$$

$$\mathbf{Z}_{in} = 100 - j100 + \frac{-j100x(200 + j80)}{-j100 + 200 + j80}$$

$$\mathbf{Z}_{in} = 100 - j100 + 49.52 - j95.04$$

$$\mathbf{Z}_{in} = \mathbf{[149.52 - j195]\ \Omega}$$

P.P.9.11 In the frequency domain,

the voltage source is $\mathbf{V}_s = 20\angle 100°$

the 0.5-H inductor is $j\omega L = j(10)(0.5) = j5$

the $\frac{1}{20}$-F capacitor is $\frac{1}{j\omega C} = \frac{1}{j(10)(1/20)} = -j2$

Let $\mathbf{Z}_1$ = impedance of the 0.5-H inductor in parallel with the 10-Ω resistor

and $\mathbf{Z}_2$ = impedance of the (1/20)-F capacitor

$$\mathbf{Z}_1 = 10 \parallel j5 = \frac{(10)(j5)}{10 + j5} = 2 + j4 \qquad \text{and} \qquad \mathbf{Z}_2 = -j2$$

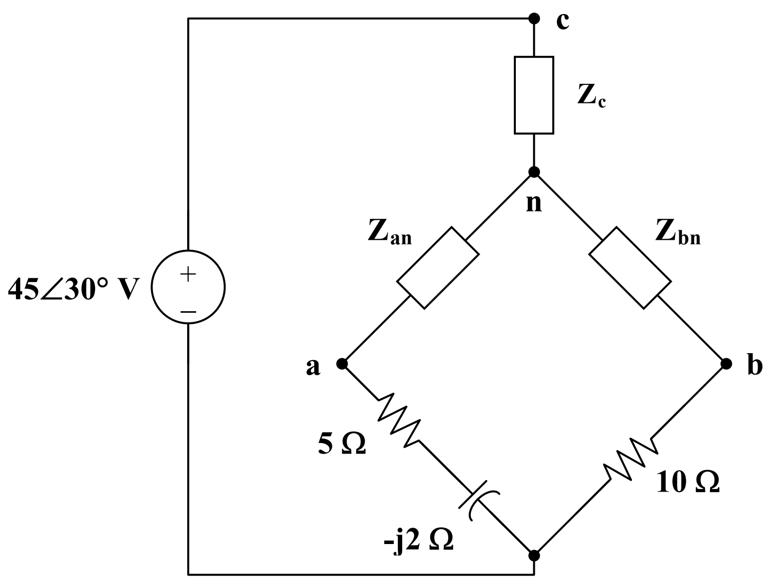
$$\mathbf{V}_o = \mathbf{Z}_2 / (\mathbf{Z}_1 + \mathbf{Z}_2)\,\mathbf{V}_s$$

$$\mathbf{V}_o = \frac{-j2}{2 + j4 - j2}(50\angle 30°) = \frac{-j(50\angle 30°)}{1 + j} = \frac{50\angle(30° - 90°)}{\sqrt{2}\angle 45°}$$

$$\mathbf{V}_o = 35.36\angle -105°$$

$v_o(t) = \mathbf{35.36 \cos(10t - 105°)\ V}$

P.P.9.12 We need to find the equivalent impedance via a delta-to-wye transformation as shown below.



$$\mathbf{Z}_{an} = \frac{j4(8+j5)}{j4+8+j5-j3} = \frac{4(-5+j8)}{8+j6} = 0.32 + j3.76$$

$$\mathbf{Z}_{bn} = \frac{-j3(8+j5)}{8+j6} = \frac{3(5-j8)(8-j6)}{100} = -0.24 - j2.82$$

$$\mathbf{Z}_{cn} = \frac{j4(-j3)}{8+j6} = \frac{12(8-j6)}{100} = 0.96 - j0.72$$

The total impedance from the source terminals is

$$\mathbf{Z} = \mathbf{Z}_{cn} + (\mathbf{Z}_{an} + 5 - j2) \parallel (\mathbf{Z}_{bn} + 10)$$

$$\mathbf{Z} = \mathbf{Z}_{cn} + (5.32 + j1.76) \parallel (9.76 - j2.82)$$

$$\mathbf{Z} = \mathbf{Z}_{cn} + \frac{(5.32+j1.76)(9.76-j2.82)}{(5.32+j1.76)+(9.76-j2.82)}$$

$$\mathbf{Z} = 0.96 - j0.72 + 3.744 + j0.4074$$

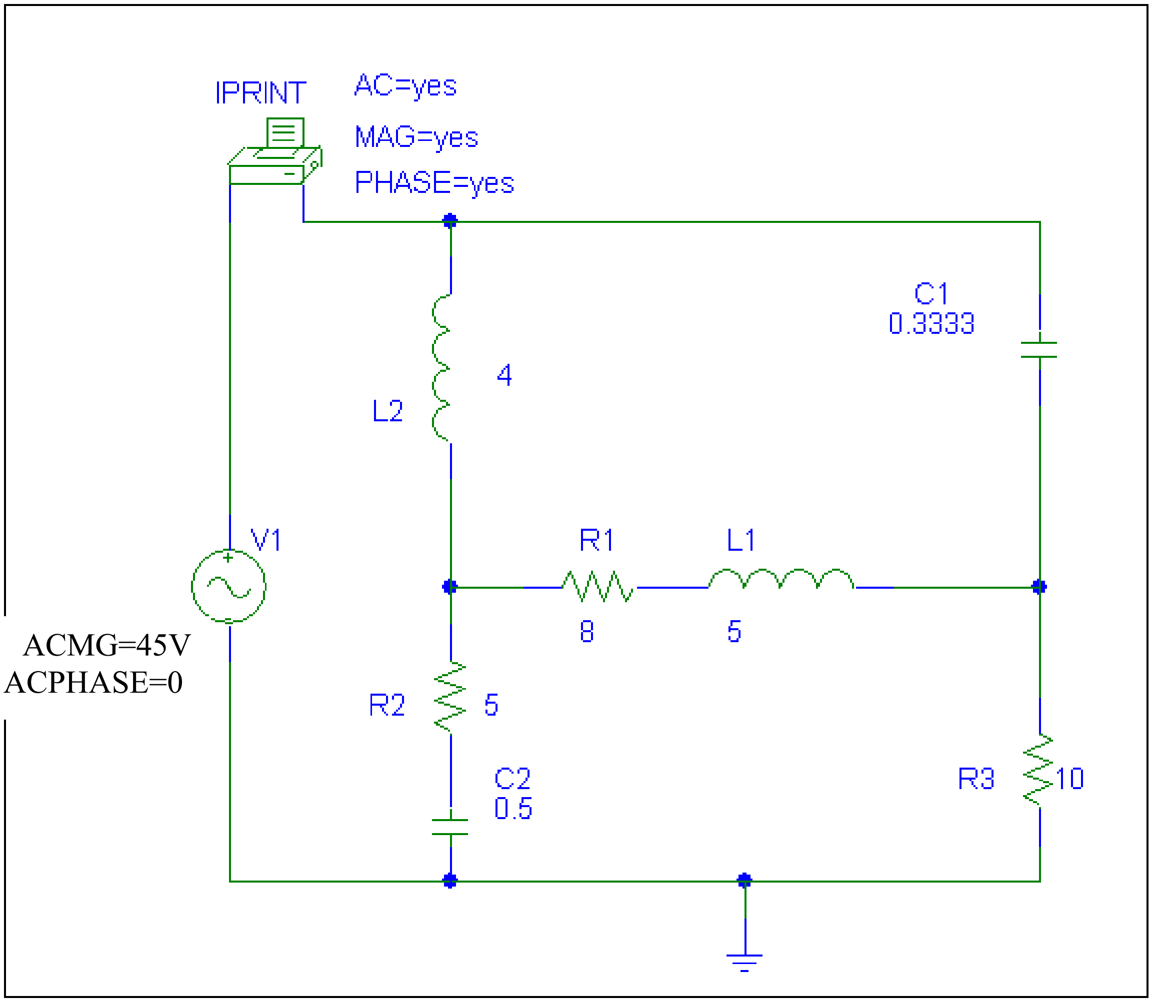
$$\mathbf{Z} = 4.704 - j0.3126 = 4.714\angle -3.802°$$

Therefore,

$$\mathbf{I} = \mathbf{V} / \mathbf{Z} = \frac{45\angle 30°}{4.714\angle -3.802°}$$

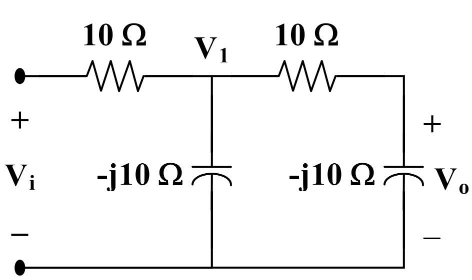
$$\mathbf{I} = \mathbf{9.546\angle 33.8°\ A}$$

Let us now check this using PSpice. The solution produces the magnitude of I = 9.946E+00, and the phase angle = 33.803E+00, which agrees with the above answer.

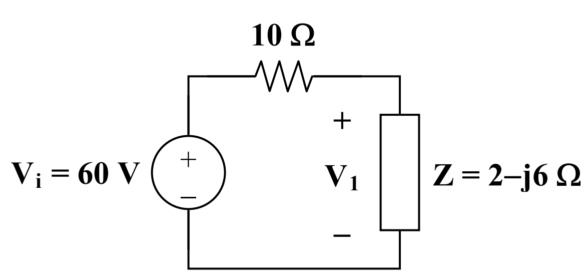


P.P.9.13 To show that the circuit in Fig. (a) meets the requirement, consider the equivalent circuit in Fig. (b).

$$\mathbf{Z} = \text{-j}10 \parallel (10 - \text{j}10) = \frac{\text{-j}10(10 - \text{j}10)}{10 - \text{j}20} = \frac{\text{-j}(10 - \text{j}10)}{1 - \text{j}2} = 2 - \text{j}6\ \Omega$$



(a)



(b)

$$\mathbf{V}_1 = \frac{2 - j6}{10 + 2 - j6}(60) = \frac{60}{3}(1 - j)$$

$$\mathbf{V}_o = \frac{-j10}{10 - j10}\mathbf{V}_1 = \left(\frac{-j}{1 - j}\right)\left(\frac{60}{3}\right)(1 - j) = -j20$$

$$\mathbf{V}_o = 20\angle -90^\circ$$

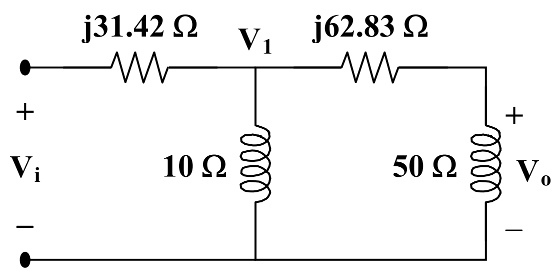
This implies that the RC circuit provides a 90° lagging phase shift.
The output voltage is = **20 V**

P.P.9.14

the 1-mH inductor is $j\omega L = j(2\pi)(5 \times 10^3)(1 \times 10^{-3}) = j31.42$

the 2-mH inductor is $j\omega L = j(2\pi)(5 \times 10^3)(2 \times 10^{-3}) = j62.83$

Consider the circuit shown below.



$$\mathbf{Z} = 10 \,||\, (50 + j62.83) = \frac{(10)(50 + j62.83)}{60 + j62.83}$$

$$\mathbf{Z} = 9.205 + j0.833 = 9.243\angle 5.17^\circ$$

$$\mathbf{V}_1 = \mathbf{Z} / (\mathbf{Z} + j31.42)\,\mathbf{V}_i = \frac{9.243\angle 5.17^\circ}{9.205 + j32.253}(10)$$

$$= [(9.243\angle 5.17^\circ)/(33.54\angle 74.07^\circ)]10 = 2.756\angle -68.9^\circ$$

$$\mathbf{V}_o = \frac{50}{50 + j62.83}\mathbf{V}_1 = \frac{50(2.756\angle -68.9^\circ)}{80.297\angle 51.49^\circ} = 1.7161\angle -120.39^\circ$$

Therefore,

magnitude = **1.7161 V**
phase = **120.39°**
phase shift is **lagging**

P.P.9.15 $\mathbf{Z}_x = (\mathbf{Z}_3 / \mathbf{Z}_1)\,\mathbf{Z}_2$

$\mathbf{Z}_3 = 12\ \text{k}\Omega$

$\mathbf{Z}_1 = 4.8\ \text{k}\Omega$

$\mathbf{Z}_2 = 10 + j\omega L = 10 + j(2\pi)(6\times10^{6})(0.25\times10^{-6}) = 10 + j9.425$

$$\mathbf{Z}_x = \frac{12k}{4.8k}(10 + j9.425) = 25 + j23.5625\ \Omega$$

$R_x = 25,\qquad X_x = 23.5625 = \omega L_x$

$$L_x = \frac{X_x}{2\pi f} = \frac{23.5625}{2\pi(6\times10^{6})} = 0.625\ \mu\text{H}$$

i.e. **a 25-Ω resistor in series with a 0.625-μH inductor**.

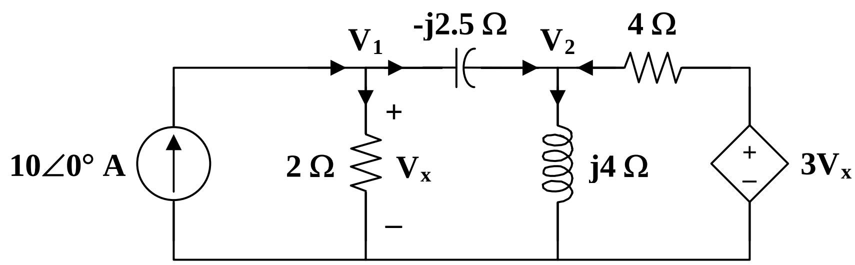
CHAPTER 10

P.P.10.1 $10\cos(2t) \longrightarrow 10\angle 0°, \quad \omega = 2$

$2\text{ H} \longrightarrow j\omega L = j4$

$0.2\text{ F} \longrightarrow \dfrac{1}{j\omega C} = -j2.5$

Hence, the circuit in the frequency domain is as shown below.



At node 1, $10 = \dfrac{\mathbf{V}_1}{2} + \dfrac{\mathbf{V}_1 - \mathbf{V}_2}{-j2.5}$

$100 = (5 + j4)\,\mathbf{V}_1 - j4\mathbf{V}_2 \qquad (1)$

At node 2, $\dfrac{\mathbf{V}_2}{j4} = \dfrac{\mathbf{V}_1 - \mathbf{V}_2}{-j2.5} + \dfrac{3\mathbf{V}_x - \mathbf{V}_2}{4}$ where $\mathbf{V}_x = \mathbf{V}_1$

$-j2.5\mathbf{V}_2 = j4(\mathbf{V}_1 - \mathbf{V}_2) + 2.5(3\mathbf{V}_1 - \mathbf{V}_2)$

$0 = -(7.5 + j4)\,\mathbf{V}_1 + (2.5 + j1.5)\,\mathbf{V}_2 \qquad (2)$

Put (1) and (2) in matrix form.

$$\begin{bmatrix} 5 + j4 & -j4 \\ -(7.5 + j4) & 2.5 + j1.5 \end{bmatrix} \begin{bmatrix} \mathbf{V}_1 \\ \mathbf{V}_2 \end{bmatrix} = \begin{bmatrix} 100 \\ 0 \end{bmatrix}$$

where $\Delta = (5 + j4)(2.5 + j.15) - (-j4)(-(7.5 + j4)) = 22.5 - j12.5 = 25.74\angle -29.05°$

$$\begin{bmatrix} \mathbf{V}_1 \\ \mathbf{V}_2 \end{bmatrix} = \frac{\begin{bmatrix} 2.5 + j1.5 & j4 \\ 7.5 + j4 & 5 + j4 \end{bmatrix}}{22.5 - j12.5} \begin{bmatrix} 100 \\ 0 \end{bmatrix}$$

$$\mathbf{V}_1 = \frac{2.5 + j1.5}{22.5 - j12.5}(100) = \frac{2.915\angle 30.96°}{25.74\angle -29.05°}(100) = 11.325\angle 60.01° V$$

$$\mathbf{V}_2 = \frac{7.5 + j4}{22.5 - j12.5}(100) = \frac{8.5\angle 28.07°}{25.74\angle -29.05°}(100) = 33.02\angle 57.12° V$$

In the time domain,

$v_1(t) =$ **11.325cos(2t + 60.01°) V**

$v_2(t) =$ **33.02cos(2t + 57.12°) V**

P.P.10.2 The only non-reference node is a supernode.

$$\frac{75-\mathbf{V}_1}{4} = \frac{\mathbf{V}_1}{j4} + \frac{\mathbf{V}_2}{-j} + \frac{\mathbf{V}_2}{2}$$

$$75-\mathbf{V}_1 = -j\,\mathbf{V}_1 + j4\mathbf{V}_2 + 2\mathbf{V}_2$$

$$75 = (1-j)\mathbf{V}_1 + (2+j4)\mathbf{V}_2 \qquad (1)$$

The supernode gives the constraint of

$$\mathbf{V}_1 = \mathbf{V}_2 + 100\angle 60° \qquad (2)$$

Substituting (2) into (1) gives

$$75 = (1-j)(40\angle 60°) + (3+j3)\mathbf{V}_2$$

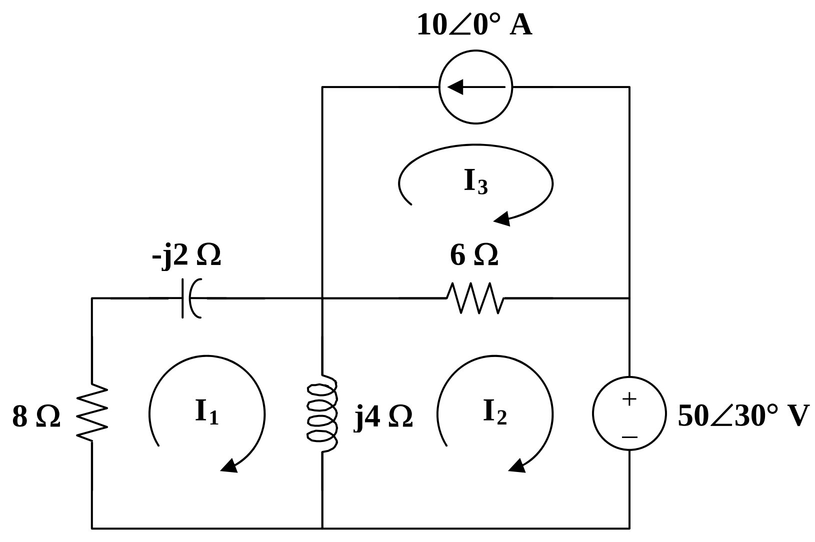
$$\mathbf{V}_2 = \frac{75-(1-j)(100\angle 60°)}{3+j3} = \frac{71.62\angle 210.72°}{4.243\angle 45°} = 16.881\angle 165.72°$$

$$\mathbf{V}_1 = \mathbf{V}_2 + 100\angle 60° = (-16.358+j4.17) + (50+j86.6)$$

$$\mathbf{V}_1 = 33.64 + j90.77$$

Therefore, $\mathbf{V}_1 =$ **96.8∠69.66° V**, $\mathbf{V}_2 =$ **16.88∠165.72° V**

P.P.10.3 Consider the circuit below.



For mesh 1, $(8 - \text{j}2 + \text{j}4)\mathbf{I}_1 - \text{j}4\mathbf{I}_2 = 0$

$$(8+\text{j}2)\mathbf{I}_1 = \text{j}4\mathbf{I}_2 \qquad (1)$$

For mesh 2, $(6+j4)\mathbf{I}_2 - j4\mathbf{I}_1 - 6\mathbf{I}_3 + 50\angle 30° = 0$

For mesh 3, $\mathbf{I}_3 = -10$

Thus, the equation for mesh 2 becomes

$$(6 + j4)\mathbf{I}_2 - j4\mathbf{I}_1 = -60 - 50\angle 30° \qquad (2)$$

From (1), $\mathbf{I}_2 = \dfrac{8 + j2}{j4}\mathbf{I}_1 = (0.5 - j2)\mathbf{I}_1$ (3)

Substituting (3) into (2),

$$(6 + j4)(0.5 - j2)\mathbf{I}_1 - j4\mathbf{I}_1 = -60 - 50\angle 30°$$

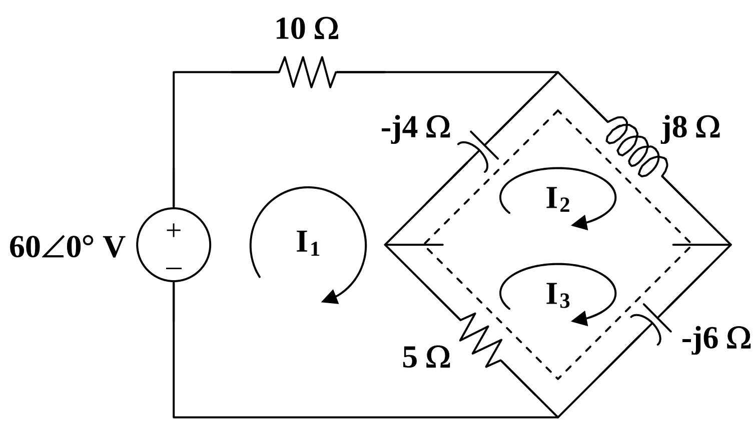
$$(11 - j14)\mathbf{I}_1 = -(103.3 + j25)$$

$$\mathbf{I}_1 = \frac{-(103.3 + j25)}{11 - j14}$$

Hence, $\mathbf{I}_o = -\mathbf{I}_1 = \dfrac{103.3 + j25}{11 - j14} = \dfrac{106.28\angle 13.605°}{17.804\angle -51.843°}$

$\mathbf{I}_o =$ **$5.969\angle 65.45°$ A**

P.P.10.4 Meshes 2 and 3 form a supermesh as shown in the circuit below.



For mesh 1, $-60 + (15 - j4)\mathbf{I}_1 - (-j4)\mathbf{I}_2 - 5\mathbf{I}_3 = 0$

$$(15 - j4)\mathbf{I}_1 + j4\mathbf{I}_2 - 5\mathbf{I}_3 = 60 \qquad (1)$$

For the supermesh, $(j8 - j4)\mathbf{I}_2 + (5 - j6)\mathbf{I}_3 - (5 - j4)\mathbf{I}_1 = 0$ (2)

Also, $\mathbf{I}_3 = \mathbf{I}_2 + 2.4$ (3)

Eliminating $\mathbf{I}_3$ from (1) and (2)

$$(15 - j4)\mathbf{I}_1 + (-5 + j4)\mathbf{I}_2 = 72 \qquad (4)$$

$$(-5 + j4)\mathbf{I}_1 + (5 - j2)\mathbf{I}_2 = -12 + j14.4 \qquad (5)$$

From (4) and (5),

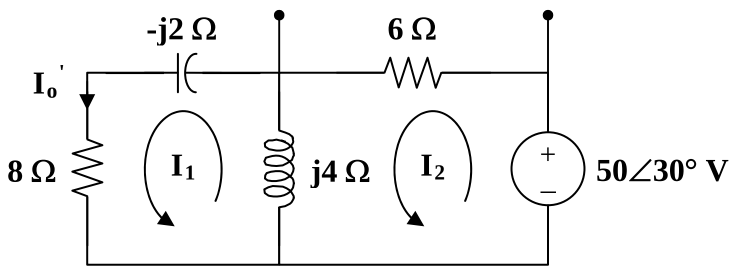
$$\begin{bmatrix} 15 - j4 & -5 + j4 \\ -5 + j4 & 5 - j2 \end{bmatrix} \begin{bmatrix} \mathbf{I}_1 \\ \mathbf{I}_2 \end{bmatrix} = \begin{bmatrix} 72 \\ -12 + j14.4 \end{bmatrix}$$

$$\Delta = \begin{vmatrix} 15 - j4 & -5 + j4 \\ -5 + j4 & 5 - j2 \end{vmatrix} = 58 - j10 = 58.86\angle -9.78°$$

$$\Delta_1 = \begin{vmatrix} 72 & -5 + j4 \\ -12 + j14.4 & 5 - j2 \end{vmatrix} = 357.6 - j24 = 358.4\angle -3.84°$$

Thus, $\mathbf{I}_o = \mathbf{I}_1 = \dfrac{\Delta_1}{\Delta} = \mathbf{6.089\angle 5.94°\ A}$

P.P.10.5 Let $\mathbf{I}_o = \mathbf{I}_o' + \mathbf{I}_o''$, where $\mathbf{I}_o'$ and $\mathbf{I}_o''$ are due to the voltage source and current source respectively. For $\mathbf{I}_o'$ consider the circuit in Fig. (a).



(a)

For mesh 1, $(8 + j2)\mathbf{I}_1 - j4\mathbf{I}_2 = 0$

$$\mathbf{I}_2 = (0.5 - j2)\mathbf{I}_1 \qquad (1)$$

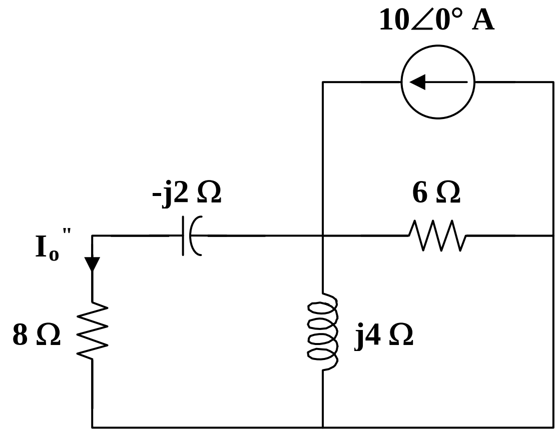
For mesh 2, $(6 + j4)\mathbf{I}_2 - j4\mathbf{I}_1 - 50\angle 30° = 0 \qquad (2)$

Substituting (1) into (2),

$$(6 + j4)(0.5 - j2)\mathbf{I}_1 - j4\mathbf{I}_1 = 50\angle 30°$$

$$\mathbf{I}_o' = \mathbf{I}_1 = \frac{50\angle 30°}{11 - j14} = 0.4 + j2.78$$

For $\mathbf{I}_o''$ consider the circuit in Fig. (b).



(b)

Let $\mathbf{Z}_1 = 8 - \text{j}2\,\Omega$, $\mathbf{Z}_2 = 6 \,||\, \text{j}4 = \dfrac{\text{j}24}{6 + \text{j}4} = 1.846 + \text{j}2.769\,\Omega$

$$\mathbf{I}_o'' = \frac{\mathbf{Z}_2}{\mathbf{Z}_1 + \mathbf{Z}_2}(10) = \frac{(10)(1.846 + j2.769)}{9.846 + j0.77} = 2.082 + j2.65$$

Therefore, $\mathbf{I}_o = \mathbf{I}_o' + \mathbf{I}_o'' = 2.48 + j5.43$

$\mathbf{I}_o = \mathbf{5.97\angle 65.45° \ A}$

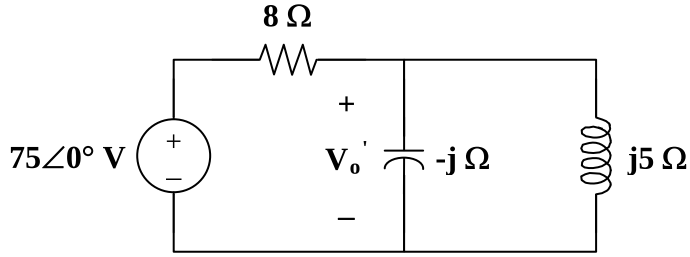
P.P.10.6 Let $v_o = v_o' + v_o''$, where v_o' is due to the voltage source and v_o'' is due to the current source. For v_o', we remove the current source.

$$75\sin(5t) \longrightarrow 75\angle 0°, \quad \omega = 5$$

$$0.2\text{ F} \longrightarrow \frac{1}{\text{j}\omega\text{C}} = \frac{1}{\text{j}(5)(0.2)} = \text{-j}$$

$$1\text{ H} \longrightarrow \text{j}\omega\text{L} = \text{j}(5)(1) = \text{j}5$$

The circuit in the frequency domain is shown in Fig. (a).



(a)

Note that $\quad -j \,||\, j5 = -j1.25$

By voltage division,

$$\mathbf{V}_o' = \frac{-j1.25}{8 - j1.25}(75) = 11.577\angle -81.12°$$

Thus, $\quad v_o' = 11.577\sin(5t - 81.12°)V$

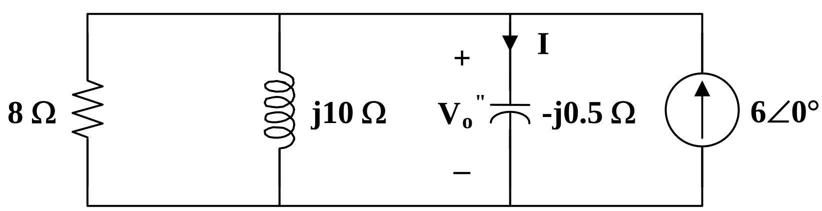
For v_o'', we remove the voltage source.

$$6\cos(10t) \longrightarrow 6\angle 0°, \quad \omega = 10$$

$$0.2\text{ F} \longrightarrow \frac{1}{j\omega C} = \frac{1}{j(10)(0.2)} = -j0.5$$

$$1\text{ H} \longrightarrow j\omega L = j(10)(1) = j10$$

The corresponding circuit in the frequency domain is shown in Fig (b).



(b)

Let $\quad \mathbf{Z}_1 = -j0.5, \quad \mathbf{Z}_2 = 8 \,||\, j10 = \frac{j80}{8 + j10} = 4.878 + j3.9$

By current division,

$$\mathbf{I} = \frac{\mathbf{Z}_2}{\mathbf{Z}_1 + \mathbf{Z}_2}(6)$$

$$\mathbf{V}_o'' = \mathbf{I}(-j0.5) = \frac{\mathbf{Z}_2}{\mathbf{Z}_1 + \mathbf{Z}_2}(6)(-j0.5) = \frac{-j(14.631 + j11.7)}{4.878 + j3.4}$$

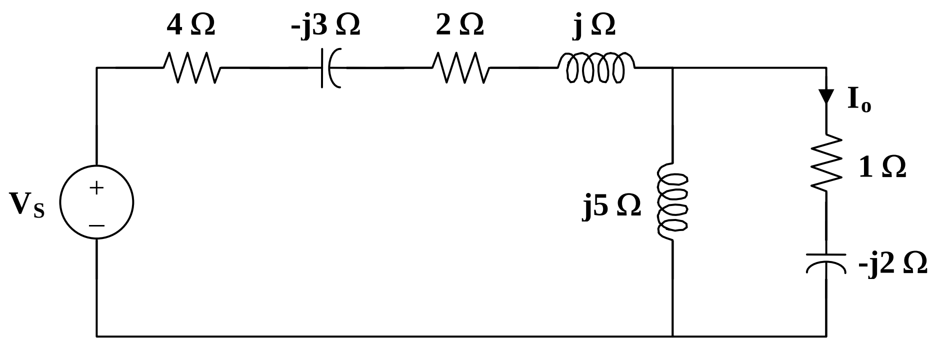
$$\mathbf{V}_o'' = \frac{18.735\angle -51.36°}{5.94\angle 34.88°} = 3.154\angle -86.24°$$

Thus, $\quad v_o'' = 3.154\cos(10t - 86.24°)$

Therefore, $\quad v_o = v_o' + v_o''$

$v_o =$ **[11.577sin(5t – 81.12°) + 3.154cos(10t – 86.24°)] V**

P.P.10.7 If we transform the current source to a voltage source, we obtain the circuit shown in Fig. (a).

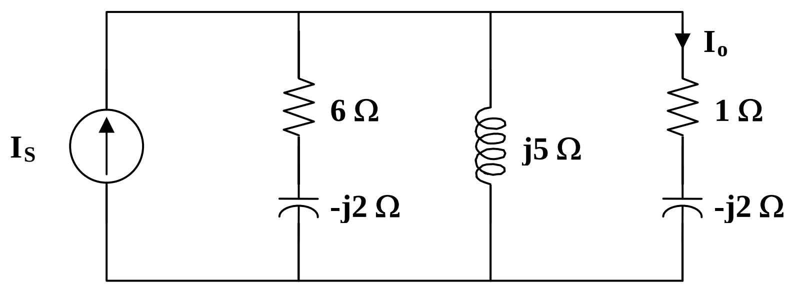


(a)

$$\mathbf{V}_s = \mathbf{I}_s\,\mathbf{Z}_s = (j12)(4 - j3) = 36 + j48$$

We transform the voltage source to a current source as shown in Fig. (b).

Let $\mathbf{Z} = 4 - \text{j}3 + 2 + \text{j} = 6 - \text{j}2$. Then, $\mathbf{I}_s = \dfrac{\mathbf{V}_s}{\mathbf{Z}} = \dfrac{36 + j48}{6 - j2} = 4.5 + j9$.



(b)

Note that $\mathbf{Z} \parallel \text{j}5 = \dfrac{(6 - \text{j}2)(\text{j}5)}{6 + \text{j}3} = \dfrac{10}{3}(1 + \text{j})$.

By current division,

$$\mathbf{I}_o = \frac{\frac{10}{3}(1 + j)}{\frac{10}{3}(1 + j) + (1 - j2)}(4.5 + j9)$$

$$\mathbf{I}_o = \frac{-60 + j120}{13 + j4} = \frac{134.16\angle 116.56°}{13.602\angle 17.1°}$$

$$\mathbf{I}_o = \mathbf{9.863\angle 99.46°\ A}$$

P.P.10.8 When the voltage source is set equal to zero,

$$\mathbf{Z}_{th} = 10 + (\text{-j4}) \,||\, (6 + \text{j2})$$

$$\mathbf{Z}_{th} = 10 + \frac{(\text{-j4})(6+\text{j2})}{6\text{ - j2}}$$

$$\mathbf{Z}_{th} = 10 + 2.4 - \text{j3.2}$$

$$\mathbf{Z}_{th} = \mathbf{(12.4 - j3.2)\ \Omega}$$

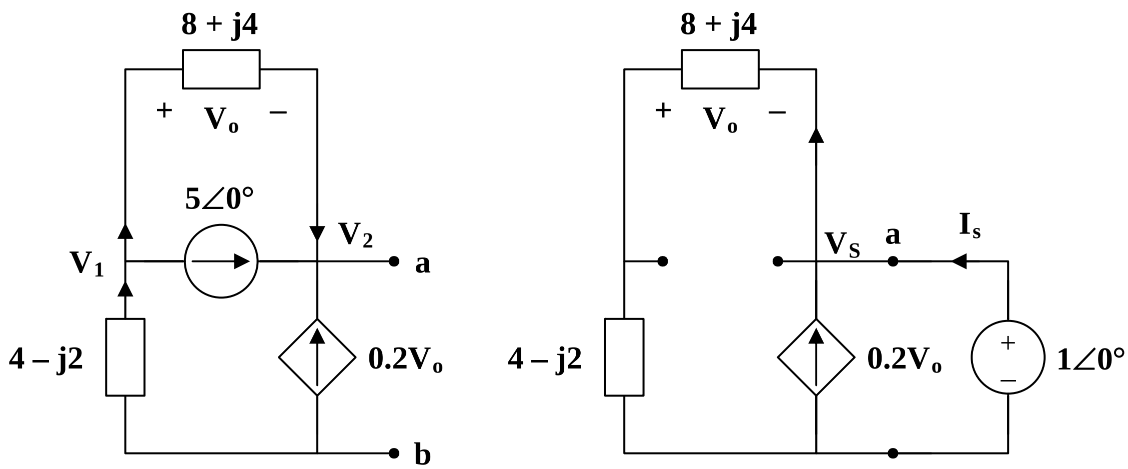
By voltage division,

$$\mathbf{V}_{th} = \frac{\text{-}j4}{6 + j2 - j4}(100\angle 20°) = \frac{(\text{-}j4)(100\angle 20°)}{6 - j2}$$

$$\mathbf{V}_{th} = \frac{(4\angle\text{-}90°)(100\angle 20°)}{6.325\angle\text{-}18.43°}$$

$$\mathbf{V}_{th} = \mathbf{63.24\angle{-51.57°}\ V}$$

P.P.10.9 To find $\mathbf{V}_{th}$, consider the circuit in Fig. (a).



(a) (b)

At node 1,
$$\frac{0 - \mathbf{V}_1}{4 - j2} = 5 + \frac{\mathbf{V}_1 - \mathbf{V}_2}{8 + j4}$$

$$\text{-}(2 + j)\mathbf{V}_1 = 50 + (1 - j0.5)(\mathbf{V}_1 - \mathbf{V}_2)$$

$$50 = (1 - j0.5)\mathbf{V}_2 - (3 + j0.5)\mathbf{V}_1 \qquad (1)$$

At node 2,
$$5 + 0.2\mathbf{V}_o + \frac{\mathbf{V}_1 - \mathbf{V}_2}{8 + j4} = 0,$$
where $\mathbf{V}_o = \mathbf{V}_1 - \mathbf{V}_2$.

Hence, the equation for node 2 becomes

$$5 + 0.2(\mathbf{V}_1 - \mathbf{V}_2) + \frac{\mathbf{V}_1 - \mathbf{V}_2}{8 + j4} = 0$$

$$\mathbf{V}_1 = \mathbf{V}_2 - \frac{50}{3 + j0.5} \qquad (2)$$

Substituting (2) into (1),

$$50 = (1 - j0.5)\mathbf{V}_2 - (3 + j0.5)\mathbf{V}_2 + (50)\frac{3 + j0.5}{3 - j0.5}$$

$$0 = -50 - (2 + j)\mathbf{V}_2 + \frac{50}{37}(35 + j12)$$

$$\mathbf{V}_2 = \frac{-2.702 + j16.22}{2 + j} = 7.35\angle 72.9°$$

$$\mathbf{V}_{th} = \mathbf{V}_2 = \mathbf{7.35\angle 72.9°\ V}$$

To find $\mathbf{Z}_{th}$, we remove the independent source and insert a 1-V voltage source between terminals a-b, as shown in Fig. (b).

At node a, $\mathbf{I}_s = -0.2\mathbf{V}_o + \dfrac{\mathbf{V}_s}{8 + j4 + 4 - j2}$

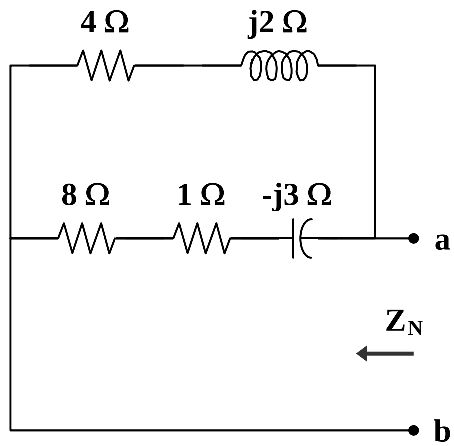
But, $\mathbf{V}_s = 1$ and $-\mathbf{V}_o = \dfrac{8 + j4}{8 + j4 + 4 - j2}\mathbf{V}_s$

So, $\mathbf{I}_s = (0.2)\dfrac{8 + j4}{12 + j2} + \dfrac{\mathbf{1}}{12 + j2} = \dfrac{2.6 + j0.8}{12 + j2}$

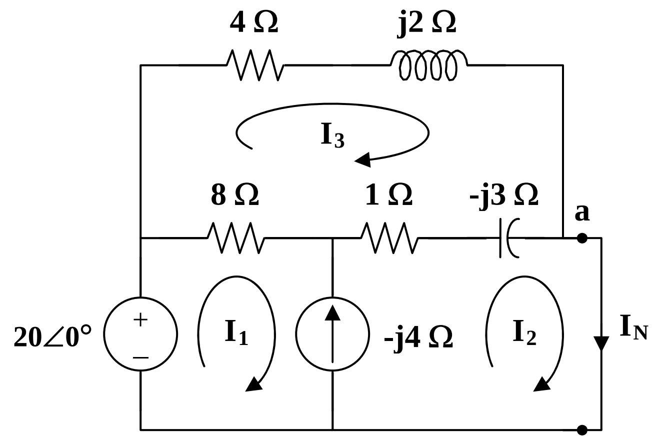
and $\mathbf{Z}_{th} = \dfrac{\mathbf{V}_s}{\mathbf{I}_s} = \dfrac{1}{\mathbf{I}_s} = \dfrac{12 + j2}{2.6 + j0.8} = \dfrac{12.166\angle 9.46°}{2.72\angle 17.10°}$

$$\mathbf{Z}_{th} = \mathbf{4.473\angle{-7.64°}\ \Omega}$$

P.P.10.10 To find $\mathbf{Z}_N$, consider the circuit in Fig. (a).



(a)



(b)

$$\mathbf{Z}_N = (4 + j2) \,||\, (9 - j3) = \frac{(4 + j2)(9 - j3)}{13 - j}$$

$$\mathbf{Z}_N = \mathbf{(3.176 + j0.706)\ \Omega}$$

To find $\mathbf{I}_N$, short-circuit terminals a-b as shown in Fig. (b). Notice that meshes 1 and 2 form a supermesh.

For the supermesh, $-20 + 8\mathbf{I}_1 + (1 - j3)\mathbf{I}_2 - (9 - j3)\mathbf{I}_3 = 0$ (1)

Also, $\mathbf{I}_1 = \mathbf{I}_2 + j4$ (2)

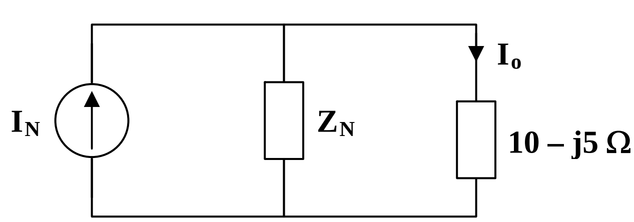
For mesh 3, $(13 - j)\mathbf{I}_3 - 8\mathbf{I}_1 - (1 - j3)\mathbf{I}_2 = 0$ (3)

Solving for $\mathbf{I}_2$, we obtain

$$\mathbf{I}_N = \mathbf{I}_2 = \frac{50 - j62}{9 - j3} = \frac{79.65\angle{-51.11°}}{9.487\angle{-18.43°}}$$

$$\mathbf{I}_N = \mathbf{8.396\angle{-32.68°}\ A}$$

Using the Norton equivalent, we can find $\mathbf{I}_o$ as in Fig. (c).



(c)

By current division,

$$\mathbf{I}_o = \frac{\mathbf{Z}_N}{\mathbf{Z}_N + 10 - j5}\mathbf{I}_N = \frac{3.176 + j0.706}{13.176 - j4.294}(8.396\angle\text{-}32.68°)$$

$$\mathbf{I}_o = \frac{(3.254\angle 12.53°)(8.396\angle\text{-}32.68°)}{13.858\angle\text{-}18.05°}$$

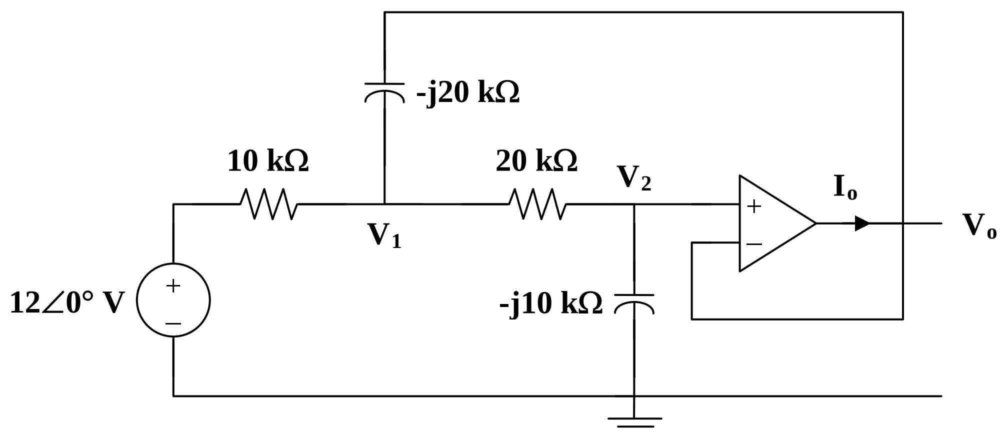
$$\mathbf{I}_o = \mathbf{1.9714\angle{-2.10}°\ A}$$

P.P.10.11

$$10\text{ nF} \longrightarrow \frac{1}{j\omega C_1} = \frac{1}{j(5\times 10^3)(10\times 10^{-9})} = \text{-j20 k}\Omega$$

$$20\text{ nF} \longrightarrow \frac{1}{j\omega C_2} = \frac{1}{j(5\times 10^3)(20\times 10^{-9})} = \text{-j10 k}\Omega$$

Consider the circuit in the frequency domain as shown below.



As a voltage follower, $\mathbf{V}_2 = \mathbf{V}_o$

At node 1,
$$\frac{12 - \mathbf{V}_1}{10} = \frac{\mathbf{V}_1 - \mathbf{V}_o}{\text{-}j20} + \frac{\mathbf{V}_1 - \mathbf{V}_o}{20}$$

$$24 = (3 + j)\mathbf{V}_1 - (1 + j)\mathbf{V}_o \qquad (1)$$

At node 2,
$$\frac{\mathbf{V}_1 - \mathbf{V}_o}{20} = \frac{\mathbf{V}_o - 0}{\text{-}j10}$$

$$\mathbf{V}_1 = (1 + j2)\mathbf{V}_o \qquad (2)$$

Substituting (2) into (1) gives

$$24 = j6\mathbf{V}_o \qquad \text{or} \qquad \mathbf{V}_o = 4\angle\text{-}90°$$

Hence, $v_o(t) = 4\cos(5000t - 90°)\, V$

$v_o(t) =$ **4sin(5,000t) V**

Now, $\mathbf{I}_o = \dfrac{\mathbf{V}_o - \mathbf{V}_1}{-j20k}$

But from (2) $\mathbf{V}_o - \mathbf{V}_1 = -j2\mathbf{V}_o = -8$

$$\mathbf{I}_o = \frac{-8}{-j20k} = -j400\ \mu A$$

Hence, $i_o(t) = 400\cos(5000t - 90°)\ \mu A$

$i_o(t) =$ **400sin(5,000t) μA**

P.P.10.12 Let $Z = R \parallel \dfrac{1}{j\omega C} = \dfrac{R}{1 + j\omega RC}$

$$\frac{V_s}{V_o} = \frac{R}{R + Z}$$

The loop gain is

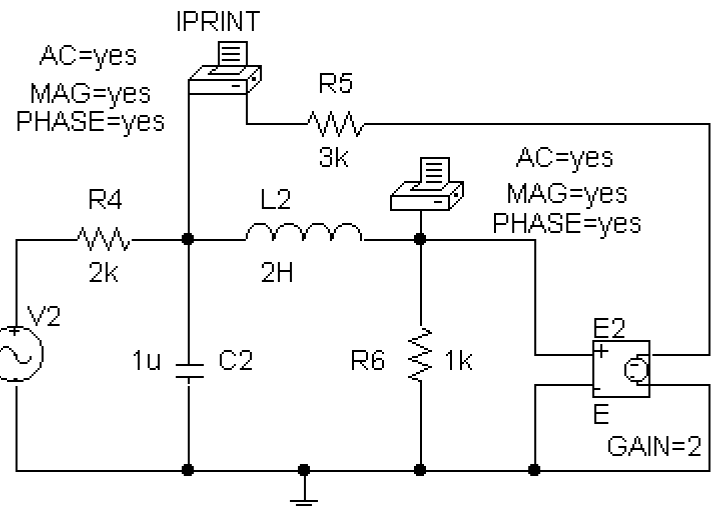
$$1/G = \frac{V_s}{V_o} = \frac{R}{R + Z} = \frac{R}{R + \dfrac{R}{1 + j\omega RC}} = \frac{1 + j\omega RC}{2 + j\omega RC}$$

where $\omega RC = (1000)(10 \times 10^3)(1 \times 10^{-6}) = 10$

$$1/G = \frac{1 + j10}{2 + j10} = \frac{10.05\angle 84.29°}{10.2\angle 78.69°}$$

G = $\mathbf{1.0147\angle{-5.6°}}$

P.P.10.13 The schematic is shown below.



Since $\omega = 2\pi f = 3000 \text{ rad/s} \longrightarrow f = 477.465 \text{ Hz}$. Setup/Analysis/AC Sweep as Linear for 1 point starting and ending at a frequency of 447.465 Hz. When the schematic is saved and run, the output file includes

Frequency	IM(V_PRINT1)	IP(V_PRINT1)
4.775E+02	1.088E-03	-5.512E+01

Frequency	VM($N_0005)	VP($N_0005)
4.775E+02	5.364E-01	-1.546E+02

From the output file, we obtain

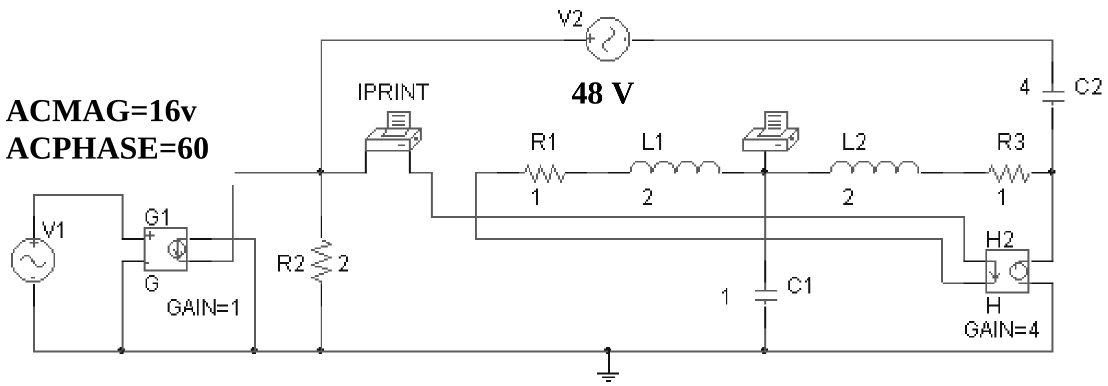
$\mathbf{V}_o = 0.2682\angle\text{-}154.6° \text{ V}$ and $\mathbf{I}_o = 0.544\angle\text{-}55.12° \text{ mA}$

Therefore,

$v_o(t) =$ **536.4 cos(3,000t – 154.6°) mV**

$i_o(t) =$ **1.088 cos(3,000t – 55.12°) mA**

P.P.10.14 The schematic is shown below.



Since PSpice does not allow the use of complex impedances, we need to convert the complex impedances into values of capacitance and inductance. We select ω = 1 rad/s which generates f = 0.15915 Hz. We use this to obtain the values of capacitances, where $C = 1/\omega X_c$, and inductances, where $L = X_L/\omega$. Since AC current sources in PSpice does not allow the use of phase angles but AC voltages do, we can replace the current source with a voltage controlled current source. Thus we not have created an AC current source with a magnitude and a phase.

To obtain the desired output use Setup/Analysis/AC Sweep as Linear for 1 point starting and ending at a frequency of 0.15915 Hz. When the schematic is saved and run, the output file includes

Frequency	IM(V_PRINT1)	IP(V_PRINT1)
1.592E-01	10.336E+00	1.580E+02

Frequency	VM($N_0004)	VP($N_0004)
1.592E-01	39.368E+00	4.478E+01

From the output file, we obtain

$$\mathbf{V_x} = \mathbf{39.37\angle 44.78° \ V} \qquad \text{and} \qquad \mathbf{I_x} = \mathbf{10.336\angle 158° \ A}$$

P.P.10.15 $C_{eq} = \left(1 + \frac{R_2}{R_1}\right)C = \left(1 + \frac{10\times10^6}{10\times10^3}\right)(10\times10^{-9}) = \mathbf{10\ \mu F}$

P.P.10.16 If $R = R_1 = R_2 = 2.5\ k\Omega$ and $C = C_1 = C_2 = 1\ nF$

$$f_o = \frac{1}{2\pi RC} = \frac{1}{(2\pi)(2.5\times10^3)(1\times10^{-9})} = \mathbf{63.66\ kHz}$$

CHAPTER 11

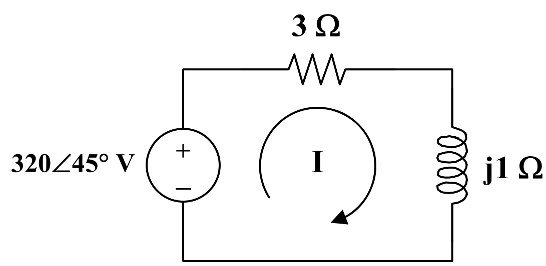
P.P.11.1 $i(t) = 33\sin(10t + 60°) = 33\cos(10t - 30°)$
$v(t) = 330\cos(10t + 20°)$

$$p(t) = v(t)\,i(t) = (330)(33)\cos(10t + 20°)\cos(10t - 30°)$$
$$p(t) = \frac{1}{2}\cdot 10890[\cos(20t + 20° - 30°) + \cos(20 - (-30°))]$$
$$\text{p(t)} = \mathbf{(3.5 + 5.445\cos(20t–10^{\circ}))\ kW}$$
$$\text{P} = \frac{1}{2}\text{V}_\text{m}\text{I}_\text{m}\cos(\theta_\text{v} - \theta_\text{i}) = \mathbf{3.5\ kW}$$

P.P.11.2 $\mathbf{V} = \mathbf{I}\,\mathbf{Z} = 1320\angle 8°$

$$\text{P} = \frac{1}{2}\text{V}_\text{m}\text{I}_\text{m}\cos(\theta_\text{v} - \theta_\text{i})$$
$$P = \frac{1}{2}(1320)(33)\cos(8° - 30°) = \mathbf{20.19\ kW}$$

P.P.11.3



$$\mathbf{I} = \frac{320\angle 45°}{3 + j} = 101.19\angle 26.57°$$

For the resistor,
$$\mathbf{I}_R = \mathbf{I} = 101.19\angle 26.57°$$
$$\mathbf{V}_R = 3\mathbf{I} = 303.6\angle 26.57°$$
$$P_R = \frac{1}{2}V_m I_m = \frac{1}{2}(303.6)(101.19) = \mathbf{15.361\ kW}$$

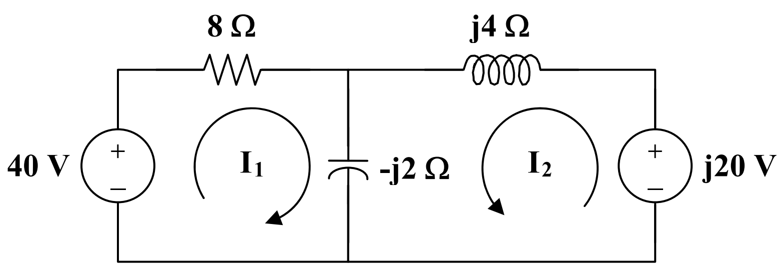
For the inductor,

$$\mathbf{I}_L = 101.19\angle 26.57°$$
$$\mathbf{V}_L = j\,\mathbf{I}_L = 101.19\angle(26.57° + 90°) = 101.19\angle 116.57°$$
$$P_L = \frac{1}{2}(101.19)^2 \cos(90°) = \mathbf{0\ W}$$

The average power supplied is

$$P = \frac{1}{2}(320)(101.19)\cos(45° - 26.57°) = \mathbf{15.361\ kW}$$

P.P.11.4 Consider the circuit below.



For mesh 1,

$$-40 + (8 - j2)\mathbf{I}_1 + (-j2)\mathbf{I}_2 = 0$$
$$(4 - j)\mathbf{I}_1 - j\mathbf{I}_2 = 20 \qquad (1)$$

For mesh 2,

$$-j20 + (j4 - j2)\mathbf{I}_2 + (-j2)\mathbf{I}_1 = 0$$
$$-j\mathbf{I}_1 + j\mathbf{I}_2 = j10 \qquad (2)$$

In matrix form,

$$\begin{bmatrix} 4 - j & -j \\ -j & j \end{bmatrix}\begin{bmatrix} \mathbf{I}_1 \\ \mathbf{I}_2 \end{bmatrix} = \begin{bmatrix} 20 \\ j10 \end{bmatrix}$$

$$\Delta = 2 + j4, \quad \Delta_1 = -10 + j20, \quad \Delta_2 = 10 + j60$$

$$\mathbf{I}_1 = \frac{\Delta_1}{\Delta} = 5\angle 53.14° \quad \text{and} \quad \mathbf{I}_2 = \frac{\Delta_2}{\Delta} = 13.6\angle 17.11°$$

For the 40-V voltage source,

$$\mathbf{V}_s = 40\angle 0°$$
$$\mathbf{I}_1 = 5\angle 53.14°$$
$$P_s = \frac{-1}{2}(40)(5)\cos(-53.14°) = \mathbf{-60\ W}$$

For the j20-V voltage source,

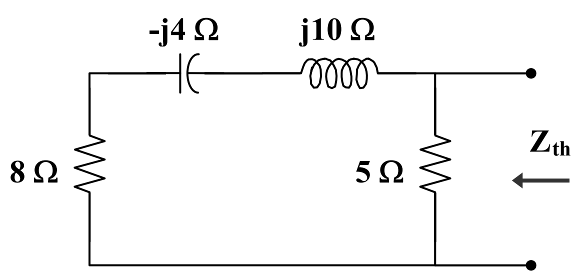
$$\mathbf{V}_s = 20\angle 90°$$
$$\mathbf{I}_2 = 13.6\angle 17.11°$$
$$P_s = \frac{-1}{2}(20)(13.6)\cos(90° - 17.11°) = \mathbf{-40\ W}$$

For the resistor,

$$I = |\mathbf{I}_1| = 5$$
$$V = 8|\mathbf{I}_1| = 40$$
$$P = \frac{1}{2}(40)(5) = \mathbf{100\ W}$$

The average power absorbed by the inductor and capacitor is **zero watts**.

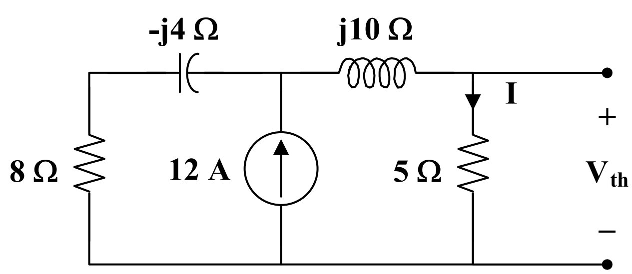
P.P.11.5 We first obtain the Thevenin equivalent circuit across $\mathbf{Z}_L$. $\mathbf{Z}_{Th}$ is obtained from the circuit in Fig. (a).



(a)

$$\mathbf{Z}_{Th} = 5 \,||\, (8 - j4 + j10) = \frac{(5)(8 + j6)}{13 + j6} = 3.415 + j0.7317$$

$\mathbf{V}_{Th}$ is obtained from the circuit in Fig. (b).



(b)

By current division,

$$\mathbf{I} = \frac{8 - j4}{8 - j4 + j10 + 5}(12)$$

$$\mathbf{V}_{Th} = 5\mathbf{I} = \frac{(60)(8-j4)}{13+j6} = 37.5\angle\text{-}51.34°$$

$\mathbf{Z_L} = (\mathbf{Z_{Th}})^* =$ **[3.415–j0.7317] Ω**

$$P_{max} = \frac{|\mathbf{V}_{Th}|^2}{8R_L} = \frac{(37.5)^2}{(8)(3.415)} = \mathbf{51.47\ W}$$

P.P.11.6 We first find $\mathbf{Z}_{Th}$ and $\mathbf{V}_{Th}$ across R_L.

Let $\mathbf{Z}_1 = 80 + j60$

$$\mathbf{Z}_2 = 90 \parallel (\text{-}j30) = \frac{(90)(\text{-}j30)}{90 - j30} = 9(1 - j3)$$

$$\mathbf{Z}_{Th} = \mathbf{Z}_1 \parallel \mathbf{Z}_2 = \frac{(80+j60)(9-j27)}{80+j60+9-j27} = 17.181 - j24.57\ \Omega$$

$$\mathbf{V}_{Th} = \frac{\mathbf{Z}_2}{\mathbf{Z}_1+\mathbf{Z}_2}(120\angle 60°) = \frac{(9)(1-j3)}{89+j33}(120\angle 60°)$$

$$\mathbf{V}_{Th} = 35.98\angle\text{-}31.91°$$

$$R_L = |\mathbf{Z}_{Th}| = \mathbf{30\ \Omega}$$

The current through the load is

$$\mathbf{I} = \frac{\mathbf{V}_{Th}}{\mathbf{Z}_{Th} + R_L} = \frac{35.98\angle\text{-}31.91°}{47.181 - j24.57} = 0.6764\angle\text{-}4.4°$$

The maximum average power absorbed by R_L is

$$P_{max} = \frac{1}{2}|\mathbf{I}|^2 R_L = \frac{1}{2}(0.6764)^2(30) = \mathbf{6.863\ W}$$

P.P.11.7 $i(t) = \begin{cases} 16t & 0 < t < 1 \\ 32 - 16t & 1 < t < 2 \end{cases}$ T = 2

$$I_{rms}^2 = \frac{1}{T}\int_0^T i^2\,dt = \frac{1}{2}\left[\int_0^1 (16t)^2\,dt + \int_1^2 (32-16t)^2\,dt\right]$$

$$I_{rms}^2 = \frac{256}{2}\left[\int_0^1 t^2\,dt + \int_1^2 (4 - 4t + t^2)\,dt\right]$$

$$I_{rms}^2 = 128\left[\frac{1}{3} + \left(4t - 2t^2 + \frac{t^3}{3}\right)\Big|_1^2\right] = \frac{256}{3}$$

$$I_{rms} = \sqrt{\frac{256}{3}} = \mathbf{9.238\ A}$$

$$P = I_{rms}^2 R = (9.238^2)(9) = \mathbf{768\ w}$$

P.P.11.8 T = π , $v(t) = 100\sin(t), \quad 0 < t < \pi$

$$V_{rms}^2 = \frac{1}{T}\int_0^T v^2\ dt = \frac{1}{\pi}\int_0^\pi (100\sin(t))^2\ dt$$

$$V_{rms}^2 = \frac{10^4}{\pi}\int_0^\pi \frac{1}{2}\left[1 - \cos(2t)\right] dt = 5000$$

$$V_{rms} = \mathbf{70.71\ V}$$

$$P = \frac{V_{rms}^2}{R} = \frac{5000}{6} = \mathbf{833.3\ W}$$

P.P.11.9 The load impedance is

$$\mathbf{Z} = 60 + j40 = 72.11\angle 33.7°\ \Omega$$

The power factor is

$$\text{pf} = \cos(33.7°) = \mathbf{0.8321\ lagging}$$

Since the load is inductive

$$\mathbf{I} = \frac{\mathbf{V}}{\mathbf{Z}} = \frac{320\angle 10°}{72.11\angle 33.7°} = 4.438\angle -23.69°\ A$$

The apparent power is

$$\mathbf{S} = \mathbf{V_{rms}}(\mathbf{I_{rms}})^* = 0.5(320)(4.438)\angle(10° - (-23.69°)) = \mathbf{710\angle 33.69°\ VA}$$

P.P.11.10 The total impedance as seen by the source is

$$\mathbf{Z} = 10 + j4 \,||\, (8 - j6) = 10 + \frac{(j4)(8 - j6)}{8 - j2}$$

$$\mathbf{Z} = 12.69\angle 20.62°$$

The power factor is

$$\text{pf} = \cos(20.62°) = \mathbf{0.936}\quad \mathbf{(lagging)}$$

$$I_{rms} = \frac{V_{rms}}{Z} = \frac{165\angle 0°}{12.69\angle 20.62°} = 13.002\angle -20.62°$$

The average power supplied by the source is equal to the power absorbed by the load.

$$P = I_{rms}^2 R = (13.002)^2(11.88) = 1{,}062\ W = \mathbf{2.008\ kW}$$

or

$$P = V_{rms} I_{rms}\, pf = (165)(13.002)(0.936) = \mathbf{2.008\ kW}$$

P.P.11.11

(a) $\mathbf{S} = \mathbf{V}_{rms}\mathbf{I}^*_{rms} = (110\angle 85°)(0.4\angle -15°)$

$\mathbf{S} = \mathbf{44\angle 70°\ VA}$

$S = |\mathbf{S}| = \mathbf{44\ VA}$

(b) $\mathbf{S} = 44\angle 70° = 15.05 + j41.35$

$P = \mathbf{15.05\ W}$, $\quad Q = \mathbf{41.35\ VAR}$

(c) $pf = \cos(70°) = \mathbf{0.342}$ **(lagging)**

$$\mathbf{Z} = \frac{\mathbf{V}_{rms}}{\mathbf{I}_{rms}} = \frac{110\angle 85°}{0.4\angle -15°} = 275\angle 70°$$

$\mathbf{Z} = \mathbf{94.06 + j258.4\ \Omega}$

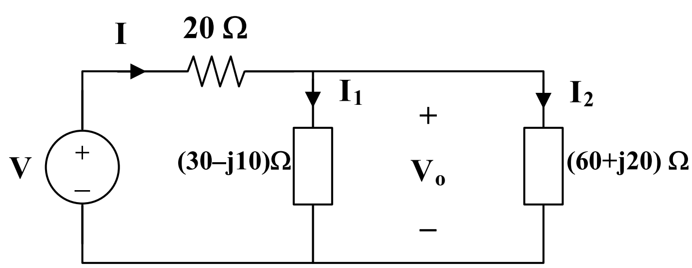
P.P.11.12

(a) If $\mathbf{Z} = 250\angle -75°$, $\quad pf = \cos(-75°) = \mathbf{0.2588}$ **(leading)**

(b) $$Q = S\sin\theta \longrightarrow S = \frac{Q}{\sin\theta} = \frac{-100\ kVAR}{\sin(-75°)} = \mathbf{103.53\ kVA}$$

(c) $$S = \frac{V_{rms}^2}{|\mathbf{Z}|} \longrightarrow V_{rms} = \sqrt{S\cdot|\mathbf{Z}|} = \sqrt{(103530)(250)} = \mathbf{5.087\ kV}$$

P.P.11.13 Consider the circuit below.



Let $\mathbf{I}_2$ be the current through the 60-Ω resistor.

$$P = I_2^2 R \longrightarrow I_2^2 = \frac{P}{R} = \frac{240}{60} = 4$$

$\mathbf{I}_2 = 2$ (rms)

$$\mathbf{V}_o = \mathbf{I}_2\,(60 + j20) = 120 + j40$$

$$\mathbf{I}_1 = \frac{\mathbf{V}_o}{30 - j10} = 3.2 + j2.4$$

$$\mathbf{I} = \mathbf{I}_1 + \mathbf{I}_2 = 5.2 + j2.4$$

$$\mathbf{V} = 20\mathbf{I} + \mathbf{V}_o = (104 + j48) + (120 + j40)$$

$$\mathbf{V} = 224 + j88 = \mathbf{240.7\angle 21.45^\circ\ V_{rms}}$$

For the 20-Ω resistor,

$$\mathbf{V} = 20\mathbf{I} = 204 + j48 = 114.54\angle 24.8^\circ$$

$$\mathbf{I} = 5.2 + j2.4 = 5.727\angle 24.8^\circ$$

$$\mathbf{S} = \mathbf{V}\,\mathbf{I}^* = (114.54\angle 24.8^\circ)(5.727\angle -24.8^\circ)$$

$$\mathbf{S} = \mathbf{656\ VA}$$

For the (30 – j10)-Ω impedance,

$$\mathbf{V}_o = 120 + j40 = 126.5\angle 18.43^\circ$$

$$\mathbf{I}_1 = 3.2 + j2.4 = 4\angle 36.87^\circ$$

$$\mathbf{S}_1 = \mathbf{V}_o\,\mathbf{I}_1^* = (126.5\angle 18.43^\circ)(4\angle -36.87^\circ)$$

$$\mathbf{S_1} = 506\angle -18.44^\circ = \mathbf{[480 - j160]\ VA}$$

For the (60 + j20)-Ω impedance,

$$\mathbf{I}_2 = 2\angle 0^\circ$$

$$\mathbf{S}_2 = \mathbf{V}_o\,\mathbf{I}_2^* = (126.5\angle 18.43^\circ)(2\angle -0^\circ)$$

$$\mathbf{S_2} = 253\angle 18.43^\circ = \mathbf{[240 + j80]\ VA}$$

The overall complex power supplied by the source is

$$\mathbf{S}_T = \mathbf{V}\,\mathbf{I}^* = (240.67\angle 21.45^\circ)(5.727\angle -24.8^\circ)$$

$\mathbf{S_T}$ = 1378.3∠–3.35° = **[1376–j80] VA**

P.P.11.14

For load 1,

$$P_1 = 2000\,, \qquad \text{pf} = 0.75 = \cos\theta_1 \longrightarrow \theta_1 = \text{-}41.41°$$

$$P_1 = S_1\cos\theta_1 \longrightarrow S_1 = \frac{P_1}{\cos\theta_1} = 2666.67$$

$$Q_1 = S_1\sin\theta_1 = \text{-}176.85$$

$$\mathbf{S}_1 = P_1 + jQ_1 = 2000 - j1763.85 \quad \text{(leading)}$$

For load 2,

$$P_2 = 4000\,, \qquad \text{pf} = 0.95 = \cos\theta_2 \longrightarrow \theta_2 = 18.19°$$

$$S_2 = \frac{P_2}{\cos\theta_2} = 4210.53$$

$$Q_2 = S_2\sin\theta_2 = 1314.4$$

$$\mathbf{S}_2 = P_2 + jQ_2 = 4000 + j1314.4 \quad \text{(lagging)}$$

The total complex power is

$$\mathbf{S = S_1 + S_2 = [6\text{–}j0.4495]\ kVA}$$

$$\text{pf} = \frac{P}{|\mathbf{S}|} = \frac{6000}{6016.18} = \mathbf{0.9972 \quad (leading)}$$

P.P.11.15

$$\text{pf} = 0.85 = \cos\theta \longrightarrow \theta = 31.79°$$

$$Q = S\sin\theta \longrightarrow S = \frac{Q}{\sin\theta} = \frac{140}{\sin(31.79°)} = 265.8\text{ kVA}$$

$$P = S\cos\theta = 225.93\text{ kW}$$

For $\text{pf} = 1 = \cos\theta_1 \longrightarrow \theta_1 = 0°$

Since P remains the same,

$$P = P_1 = S_1\cos\theta_1 \longrightarrow S_1 = \frac{P_1}{\cos\theta_1} = 225.93$$

$$Q_1 = S_1\sin\theta_1 = 0$$

The difference between the new Q_1 and the old Q is Q_c.

$$Q_c = 140\text{ kVAR} = \omega C V_{rms}^2$$

$$C = \frac{140\times10^3}{(2\pi)(60)(110)^2} = \mathbf{30.69\ mF}$$

P.P.11.16 The wattmeter measures the average power from the source.

Let $\mathbf{Z}_1 = 4 - j2$

$$\mathbf{Z}_2 = 12 \,||\, j9 = \frac{(12)(j9)}{12 + j9} = 4.32 + j5.76$$

$$\mathbf{Z} = \mathbf{Z}_1 + \mathbf{Z}_2 = 8.32 + j3.76 = 9.13\angle 24.32°$$

$$\mathbf{S} = \mathbf{V}\,\mathbf{I}^* = \frac{|\mathbf{V}|^2}{\mathbf{Z}^*} = \frac{(120)^2}{9.13\angle -24.32°} = 1577.2\angle 24.32°\ VA$$

$$P = |\mathbf{S}|\cos\theta = \mathbf{1.437\ kW}$$

P.P.11.17 Demand charge $= \$5 \times 32{,}000 = \$160{,}000$
Energy charge for the first $50{,}000$ kWh $= \$0.08 \times 50{,}000 = \$4{,}000$
The remaining energy $= 500{,}000 - 50{,}000 = 450{,}000$ kWh
Charge for this bill $= \$0.05 \times 450{,}000 = \$22{,}500$
Total bill $= \$160{,}000 + \$4{,}000 + \$22{,}500 =$ **\$186,500**

P.P.11.18 Energy consumed $= 800\text{ kW} \times 20 \times 26 = 416{,}000$ kWh

The power factor of 0.88 exceeds 0.85 by 3×0.01. Hence, there is a power factor credit which amounts to an energy credit of

$$416{,}000 \times \frac{0.1}{100} \times 3 = 1248\text{ kWh}$$

Total energy billed $= 416{,}000 - 1{,}248 = 414{,}752$ kWh
Energy cost $= \$0.06 \times 414{,}752 =$ **\$24,885.12**

CHAPTER 12

P.P.12.1 For the abc sequence, $\mathbf{V}_{an}$ leads $\mathbf{V}_{bn}$ by 120° and $\mathbf{V}_{bn}$ leads $\mathbf{V}_{cn}$ by 120°.

Hence,
$$\mathbf{V}_{an} = 110\angle(30° + 120°) = \mathbf{110\angle 150°\ V}$$
$$\mathbf{V}_{cn} = 110\angle(30° - 120°) = \mathbf{110\angle{-90}°\ V}$$

P.P.12.2

(a)
$$\mathbf{V}_{ab} = \mathbf{V}_{an} - \mathbf{V}_{bn} = 120\angle 30° - 120\angle{-90}°$$
$$\mathbf{V}_{ab} = (103.92 + j60) + j120$$
$$\mathbf{V}_{ab} = \mathbf{207.8\angle 60°\ V}$$

Alternatively, using the fact that $\mathbf{V}_{ab}$ leads $\mathbf{V}_{an}$ by 30° and has a magnitude of $\sqrt{3}$ times that of $\mathbf{V}_{an}$,
$$\mathbf{V}_{ab} = \sqrt{3}(120)\angle(30° + 30°) = \mathbf{207.8\angle 60°\ V}$$

Following the abc sequence,
$$\mathbf{V}_{bc} = \mathbf{207.8\angle{-60}°\ V}$$
$$\mathbf{V}_{ca} = \mathbf{207.8\angle \pm 180°\ V}$$

(b)
$$\mathbf{I}_a = \frac{\mathbf{V}_{an}}{\mathbf{Z}}$$

$$\mathbf{Z} = (0.4 + j0.3) + (24 + j19) + (0.6 + j0.7)$$
$$\mathbf{Z} = 25 + j20 = 32\angle 38.66°$$

$$\mathbf{I}_a = \frac{120\angle 30°}{32\angle 38.66°} = \mathbf{3.75\angle{-8.66}°\ A}$$

Following the abc sequence,
$$\mathbf{I}_b = \mathbf{I}_a\angle{-120}° = \mathbf{3.75\angle{-128.66}°\ A}$$
$$\mathbf{I}_c = \mathbf{I}_a\angle{-240}° = \mathbf{3.75\angle 111.34°\ A}$$

P.P.12.3
The phase currents are

$$\mathbf{I}_{AB} = \frac{\mathbf{V}_{AB}}{\mathbf{Z}_{\Delta}} = \frac{120\angle -20°}{20\angle 40°} = \mathbf{6\angle{-60}° \ A}$$

$$\mathbf{I}_{BC} = \mathbf{I}_{AB}\angle -120° = \mathbf{6\angle 180° \ A}$$

$$\mathbf{I}_{CA} = \mathbf{I}_{AB}\angle 120° = \mathbf{6\angle 60° \ A}$$

The line currents are

$$\mathbf{I}_{a} = \mathbf{I}_{AB}\sqrt{3}\angle -30° = 6\sqrt{3}\angle -90° = \mathbf{10.392\angle{-90}° \ A}$$

$$\mathbf{I}_{b} = \mathbf{I}_{a}\angle -120° = \mathbf{10.392\angle 150° \ A}$$

$$\mathbf{I}_{c} = \mathbf{I}_{a}\angle 120° = \mathbf{10.392\angle 30° \ A}$$

P.P.12.4 In a delta load, the phase current leads the line current by 30° and has a magnitude $\frac{1}{\sqrt{3}}$ times that of the line current. Hence,

$$\mathbf{I}_{AB} = \frac{\mathbf{I}_{a}}{\sqrt{3}}\angle 30° = \frac{9.609}{\sqrt{3}}\angle 65° = \mathbf{5.548\angle 65° \ A}$$

$$\mathbf{Z}_{\Delta} = 18 + j12 = 21.63\angle 33.69° \ \Omega$$

$$\mathbf{V}_{AB} = \mathbf{I}_{AB}\mathbf{Z}_{\Delta} = (5.548\angle 65°)(21.63\angle 33.69°)$$
$$\mathbf{V}_{AB} = \mathbf{120\angle 98.69° \ V}$$

P.P.12.5 $\mathbf{Z}_{Y} = 12 + j15 = 19.21\angle 51.34°$

After converting the Δ-connected source to a Y-connected source,

$$\mathbf{V}_{an} = \frac{240}{\sqrt{3}}\angle(150° - 30°) = 138.56\angle -15°$$

$$\mathbf{I}_{a} = \frac{\mathbf{V}_{an}}{\mathbf{Z}_{Y}} = \frac{138.56\angle -15°}{19.21\angle 51.34°} = \mathbf{7.21\angle -66.34° \ A}$$

$$\mathbf{I}_{b} = \mathbf{I}_{a}\angle -120° = \mathbf{7.21\angle 173.66° \ A}$$
$$\mathbf{I}_{c} = \mathbf{I}_{a}\angle 120° = \mathbf{7.21\angle 53.66° \ A}$$

P.P.12.6
For the source,

$$\mathbf{S} = 3\,\mathbf{V}_p\,\mathbf{I}_p^* = (3)(120\angle 30°)(3.75\angle 8.66°)$$
$$\mathbf{S} = -1350\angle 38.66° = \mathbf{[-1.054.2 - j0.8433]\ kVA}$$

For the load,

$$\mathbf{S} = 3\left|\,\mathbf{I}_p\,\right|^2 \mathbf{Z}$$

where $\mathbf{Z} = 24 + j19 = 30.61\angle 38.37°$
$\mathbf{I}_p = 3.75\angle -8.66°$

$$\mathbf{S} = (3)(3.75)^2\,(30.61\angle 38.37°)$$
$$\mathbf{S} = 1291.36\angle 38.37° = \mathbf{[1.012+j0.8016]\ kVA}$$

P.P.12.7 $\mathrm{P} = \mathrm{S}\cos\theta \longrightarrow \mathrm{S} = \dfrac{\mathrm{P}}{\cos\theta} = \dfrac{30\times 10^3}{0.85} = 35.29\ \mathrm{kVA}$

$$\mathrm{S} = \sqrt{3}\,\mathrm{V_L}\,\mathrm{I_L} \longrightarrow \mathrm{I_L} = \frac{\mathrm{S}}{\sqrt{3}\,\mathrm{V_L}} = \frac{35.29\times 10^3}{\sqrt{3}\,(440)} = \mathbf{46.31\ A}$$

Alternatively,

$$\mathrm{P_p} = \frac{30\times 10^3}{3} = 10\ \mathrm{kW}, \qquad \mathrm{V_p} = \frac{440}{\sqrt{3}}\ \mathrm{V}$$

$$\mathrm{P_p} = \mathrm{V_p}\,\mathrm{I_p}\cos\theta$$

$$\mathrm{I_p} = \frac{\mathrm{P_p}}{\mathrm{V_p}\cos\theta} = \frac{(10\times 10^3)\sqrt{3}}{(440)(0.85)} = \mathbf{46.31\ A}$$

P.P.12.8
(a) For load 1,

$$\mathrm{V_p} = \frac{\mathrm{V_L}}{\sqrt{3}} = \frac{840}{\sqrt{3}}$$

$$\mathbf{I}_{a1} = \frac{\mathbf{V}_a}{\mathbf{Z}_p} = \frac{840\angle 0°}{\sqrt{3}}\cdot\frac{1}{30 + j40} = 9.7\angle -53.13°$$

$$\mathbf{S}_1 = \frac{\mathrm{V_{rms}^2}}{\mathbf{Z}^*} = \frac{(840)^2}{50\angle -53.15°} = 14.112\angle 53.13°\ \mathrm{kVA}$$

For load 2,

$$S_2 = \frac{P_2}{\cos\theta_2} = \frac{48}{0.8} = 60 \text{ kVA}$$

$$Q_2 = S_2 \sin\theta_2 = (60)(0.6) = 36 \text{ kVAR}$$

$$\mathbf{S}_2 = 48 + j36 \text{ kVA}$$

S = **S₁** + **S₂** = **[56.47 + j47.29] kVA**

$\mathbf{S} = 73.65\angle 39.94° \text{ kVA}$

with $\text{pf} = \cos(39.94°) = 0.7667$

(b) $Q_c = P(\tan\theta_{old} - \tan\theta_{new})$

$Q_c = (56.47)(\tan 39.94° - \tan 0°) = 47.29 \text{ kVAR}$

For each capacitor, the rating is **15.76 kVAR**

(c) At unity pf, **S** = P = 56.47 kVA

$$I_L = \frac{\mathbf{S}}{\sqrt{3}\,V_L} = \frac{56470}{\sqrt{3}\,(840)} = \mathbf{38.81\ A}$$

P.P.12.9

The phase currents are

$$\mathbf{I}_{AB} = \frac{\mathbf{V}_{AB}}{\mathbf{Z}_{AB}} = \frac{440\angle 0°}{10 - j5} = 39.35\angle 26.56° \;= 35.2 + j17.595$$

$$\mathbf{I}_{BC} = \frac{\mathbf{V}_{BC}}{\mathbf{Z}_{BC}} = \frac{440\angle -120°}{16} = 27.5\angle -120° = -13.75 - j23.82$$

$$\mathbf{I}_{CA} = \frac{\mathbf{V}_{CA}}{\mathbf{Z}_{CA}} = \frac{440\angle 120°}{8 + j6} = 44\angle 83.13° \;= 5.263 + j43.68$$

The line currents are

$\mathbf{I_a} = \mathbf{I_{AB}} - \mathbf{I_{CA}}$ = (35.2+j17.595) – (5.263+j43.68)

= 29.94–j26.08 = $\mathbf{39.71\angle{-41.06}°\ A}$.

$\mathbf{I_b} = \mathbf{I_{BC}} - \mathbf{I_{AB}}$ = –48.95–j41.42 = $\mathbf{64.12\angle{-139.8}°\ A}$.

$\mathbf{I_c} = \mathbf{I_{CA}} - \mathbf{I_{BC}}$ = 19.013+j67.5 = $\mathbf{70.13\angle 74.27°\ A}$.

P.P.12.10
The phase currents are

$$\mathbf{I}_{AB} = \frac{220\angle 0°}{-j5} = j44$$

$$\mathbf{I}_{BC} = \frac{220\angle 0°}{j10} = 22\angle 30°$$

$$\mathbf{I}_{CA} = \frac{220\angle 120°}{10} = 22\angle -120°$$

The line currents are

$$\mathbf{I}_a = \mathbf{I}_{AB} - \mathbf{I}_{CA} = (j44) - (-11 - j19.05)$$
$$\mathbf{I}_a = 11 + j63.05 = \mathbf{64\angle 80.1°\ A}$$

$$\mathbf{I}_b = \mathbf{I}_{BC} - \mathbf{I}_{AB} = (19.05 + j11) - (j44)$$
$$\mathbf{I}_b = 19.05 - j33 = \mathbf{38.1\angle -60°\ A}$$

$$\mathbf{I}_c = \mathbf{I}_{CA} - \mathbf{I}_{BC} = (-11 - j19.05) - (19.05 + j11)$$
$$\mathbf{I}_c = -30.05 - j30.05 = \mathbf{42.5\angle 225°\ A}$$

The real power is absorbed by the resistive load

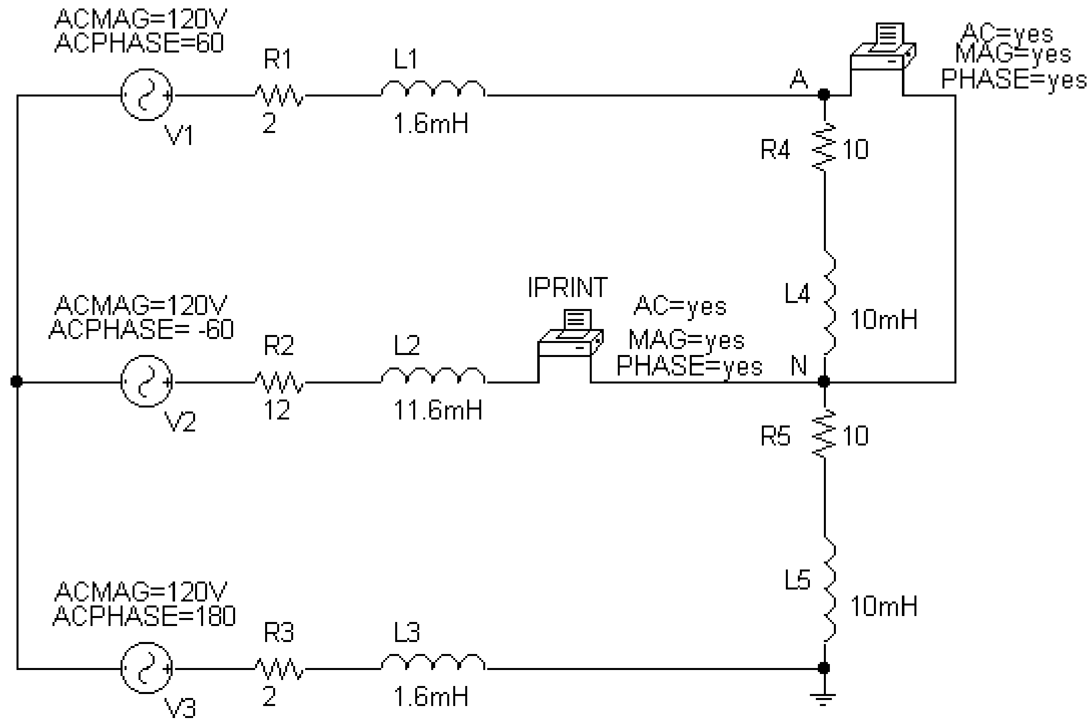
$$P = |\mathbf{I}_{CA}|^2 (10) = (22)^2 (10) = \mathbf{4.84\ kW}$$

P.P.12.11 The schematic is shown below. First, use the **AC Sweep** option of the **Analysis Setup**. Choose a *Linear* sweep type with the following *Sweep Parameters* : *Total Pts* = 1, *Start Freq* = 100, and *End Freq* = 100. Once the circuit is saved and simulated, we obtain an output file whose contents include the following results.

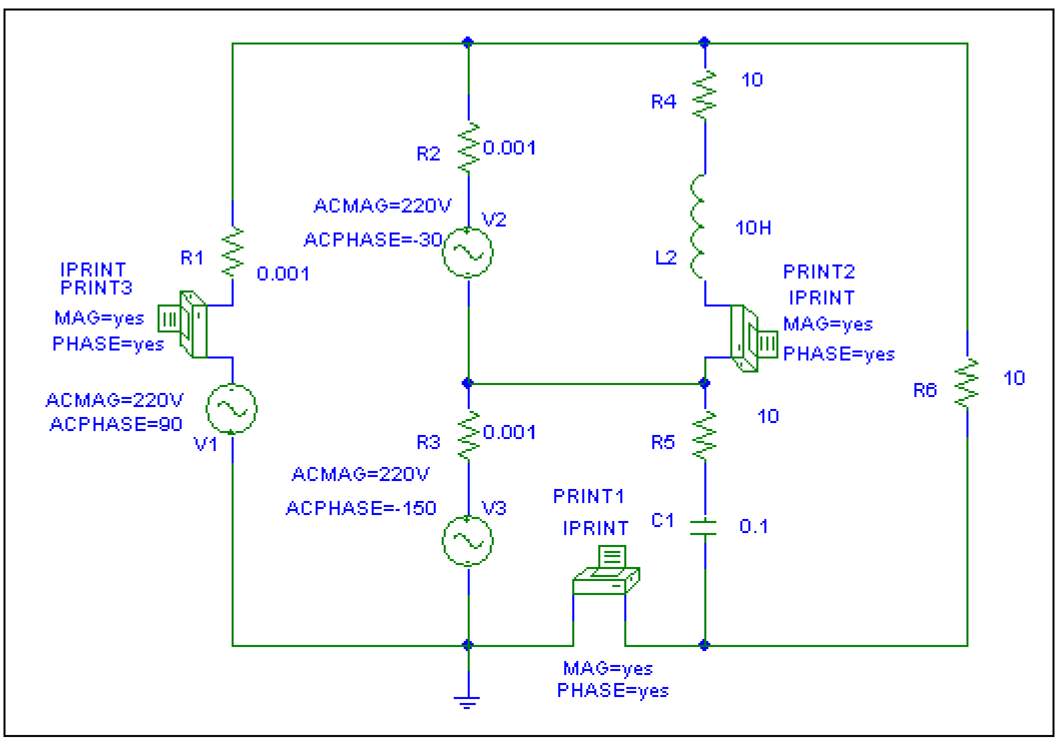
FREQ	IM(V_PRINT1)	IP(V_PRINT1)
1.000E+02	8.547E+00	-9.127E+01
FREQ	VM(A,N)	VP(A,N)
1.000E+02	1.009E+02	6.087E+01

From this we obtain,

$$\mathbf{V}_{an} = \mathbf{100.9\angle 60.87°\ V},\quad \mathbf{I}_{bB} = \mathbf{8.547\angle -91.27°\ A}$$



P.P.12.12 The schematic is shown below.



In this case, we may assume that $\omega = 1\ \text{rad/s}$, so that $f = 1/2\pi = 0.1592$ Hz. Hence, $L = X_L/\omega = 10$ and $C = 1/\omega X_c = 0.1$.

Use the **AC Sweep** option of the **Analysis Setup**. Choose a *Linear* sweep type with the following *Sweep Parameters* : *Total Pts* = 1, *Start Freq* = 0.1592, and *End Freq* = 0.1592. Once the circuit is saved and simulated, we obtain an output file whose contents include the following results.

FREQ	IM(V_PRINT1)	IP(V_PRINT1)
1.592E-01	3.724E+01	8.379E+01

FREQ	IM(V_PRINT2)	IP(V_PRINT2)
1.592E-01	1.555E+01	-7.501E+01

FREQ	IM(V_PRINT3)	IP(V_PRINT3)
1.592E-01	2.468E+01	-9.000E+01

From this we obtain,

$$\mathbf{I}_{ca} = \mathbf{24.68\angle -90^\circ\ A} \qquad \mathbf{I}_{cC} = \mathbf{37.25\angle 83.79^\circ\ A} \qquad \mathbf{I}_{AB} = \mathbf{15.55\angle{-75.01}^\circ A}$$

P.P.12.13

(a) If point o is connected to point B, $P_2 = \mathbf{0\ W}$

$P_1 = \mathrm{Re}(\mathbf{V}_{AB}\,\mathbf{I}_a^*)$

$P_1 = (440)(39.71)\cos(0^\circ + 41.06^\circ) = \mathbf{13.175 kW}$

$P_3 = \mathrm{Re}(\mathbf{V}_{CB}\,\mathbf{I}_c^*)$

where $\mathbf{V}_{CB} = -\mathbf{V}_{BC} = 240\angle(-120^\circ + 180^\circ) = 240\angle 60^\circ$

$P_3 = (440)(70.13)\cos(60^\circ - 74.27^\circ) = \mathbf{29.91 kW}$

(b) Total power is = (13.175+29.91) kW = **43.08 kW**.

P.P.12.14 $V_L = 208\ V$, $P_1 = -560\ W$, $P_2 = 800\ W$

(a) $P_T = P_1 + P_2 = -560 + 800 = \mathbf{240\ W}$

(b) $Q_T = \sqrt{3}\,(P_2 - P_1) = \sqrt{3}\,(800 + 560) = \mathbf{2.356\ kVAR}$

(c) $\tan\theta = \dfrac{Q_T}{P_T} = \dfrac{2355.6}{240} = 9.815 \longrightarrow \theta = 84.18^\circ$

$\mathrm{pf} = \cos\theta = \mathbf{0.1014}$ (**lagging / inductive**)

It is inductive because $P_2 > P_1$

(d) For a Y-connected load,

$$I_p = I_L, \qquad V_p = \frac{V_L}{\sqrt{3}} = \frac{208}{\sqrt{3}} = 120 \text{ V}$$

$$P_p = V_p I_p \cos\theta \longrightarrow I_p = \frac{80}{(120)(0.1014)} = 6.575 \text{ A}$$

$$Z_p = \frac{V_p}{I_p} = \frac{120}{6.575} = 18.25$$

$$\mathbf{Z}_p = Z_p\angle\theta = \mathbf{18.25\angle 84.18°\ \Omega}$$

The impedance is **inductive**.

P.P.12.15 $\mathbf{Z}_\Delta = 30 - j40 = 50\angle -53.13°$

The equivalent Y-connected load is

$$\mathbf{Z}_Y = \frac{\mathbf{Z}_\Delta}{3} = 16.67\angle -53.13°$$

$$V_p = \frac{440}{\sqrt{3}} = 254 \text{ V}$$

$$I_L = \frac{V_p}{|\mathbf{Z}_Y|} = \frac{254}{16.67} = 15.24$$

$$P_1 = V_L I_L \cos(\theta + 30°)$$

$$P_1 = (440)(15.24)\cos(-53.13° + 30°) = \mathbf{6.167\ kW}$$

$$P_2 = V_L I_L \cos(\theta - 30°)$$

$$P_2 = (440)(15.24)\cos(-53.13° - 30°) = \mathbf{802.1 W}$$

$$P_T = P_1 + P_2 = \mathbf{6.969\ kW}$$

$$Q_T = \sqrt{3}(P_2 - P_1) = \sqrt{3}(802.1 - 6167)$$

$$Q_T = \mathbf{-9.292\ kVAR}$$

CHAPTER 13

P.P. 13.1 For mesh 1,

$$141.42+j141.42 = 4(1 + j2)\mathbf{I_1} + j\mathbf{I_2} \qquad (1)$$

For mesh 2, $$0 = j\mathbf{I_1} + (10 + j5)\mathbf{I_2} \qquad (2)$$

For the matrix form $$\begin{bmatrix} 141.42 + j141.42 \\ 0 \end{bmatrix} = \begin{bmatrix} 4 + j8 & j \\ j & 10 + j5 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix}$$

$$\Delta = j100,\ \ \Delta_2 = 141.42–j141.42$$

$$\mathbf{I_2} = \Delta_2/\Delta = (141.42–j141.42)/j100$$

$$\mathbf{V_o} = 10I_2 = 10(–1.4142–j1.4142) = \mathbf{20\angle–135° \ V}$$

P.P. 13.2 Since $\mathbf{I_1}$ enters the coil with reactance 2Ω and $\mathbf{I_2}$ enters the coil with reactance 6Ω, the mutual voltage is positive. Hence, for mesh 1,

$$100\angle 60^o = (5 + j2 + j6 – j\ 3x2)\mathbf{I_1} – j6\mathbf{I_2} + \mathbf{j3I_2}$$

or $$100\angle 60^o = (5 + j2)\mathbf{I_1} – j3\mathbf{I_2} \qquad (1)$$

For mesh 2, $$0 = (j6 – j4)\mathbf{I_2} – j6\mathbf{I_1} + j3\mathbf{I_1}$$

or $$\mathbf{I_2} = 1.5\mathbf{I_1} \qquad (2)$$

Substituting this into (1), $$100\angle 60^o = (5 – j2.5)\mathbf{I_1}$$

$$\mathbf{I_1} = (100\angle 60^o)/(5.59\angle –26.57^o) = \mathbf{17.889\angle 86.57^o\ A}$$

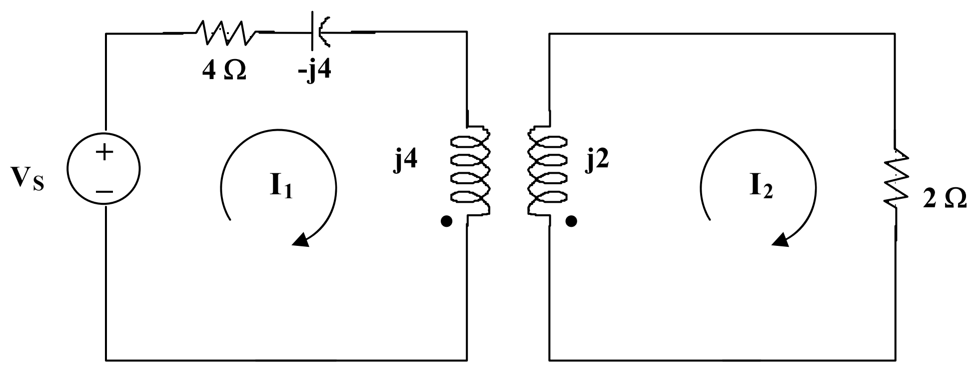
$$\mathbf{I_2} = 1.5\mathbf{I_1} = \mathbf{26.83\angle 86.57^o\ A}$$

P.P. 13.3 The coupling coefficient is, $k = m/\sqrt{L_1 L_2} = 1/\sqrt{2x1} = \mathbf{0.7071}$

To obtain the energy stored, we first obtain the frequency-domain circuit shown below.

$$100\cos(\omega t)\ \text{becomes}\ 100\angle 0^o,\ \omega = 2$$

1H becomes $j\omega 1 = j2$
2H becomes $j\omega 2 = j4$
(1/8) F becomes $1/j\omega C = -j4$



For mesh 1, $100 = (4 - j4 + j4)\mathbf{I_1} - j2\mathbf{I_2}$

or $50 = 2\mathbf{I_1} - j\mathbf{I_2}$ (1)

For mesh 2, $-j2\mathbf{I_1} + (2 + j2)\mathbf{I_2} = 0$

or $\mathbf{I_1} = (1 - j)\mathbf{I_2}$ (2)

Substituting (2) into (1), $(2 - j3)\mathbf{I_2} = 50$

$$\mathbf{I_2} = 50/(2 - j3) = 13.87\angle 56.31^o$$

$$\mathbf{I_1} = 19.658\angle 11.31^o$$

In the time domain, $i_1 = 19.658\cos(2t + 11.31^o)$
$i_2 = 13.87\cos(2t + 56.31^o)$

At $t = 1.5$, $2t = 3 \text{ rad} = 171.9^o$

$i_1 = 19.658\cos(171.9^o + 11.31^o) = -19.62$ A
$i_2 = 13.87\cos(171.9^o + 56.31^o) = -9.25$ A

The total energy stored in the coupled inductors is given by,

$$W = 0.5L_1(i_1)^2 + 0.5L_2(i_2)^2 - 0.5M(i_1i_2)$$
$$= 0.5(2)(-19.62)^2 + 0.5(1)(-9.25)^2 - (1)(-19.62)(-9.25)$$
$$= \mathbf{246.2\ J}$$

P.P. 13.4 $\mathbf{Z_{in}} = 4 + j8 + [3^2/(j10 - j6 + 6 + j4)]$

$$= 4 + j8 + 9/(6 + j8)$$

$$= \mathbf{8.58\angle 58.05^o\ \Omega}$$

The current from the voltage is,

$$\mathbf{I} = \mathbf{V/Z} = 40\angle 0^o/8.58\angle 58.05^o = \mathbf{4.662\angle{-58.05^o}\ A}$$

P.P. 13.5 $L_1 = 10,\ L_2 = 4,\ M = 2$

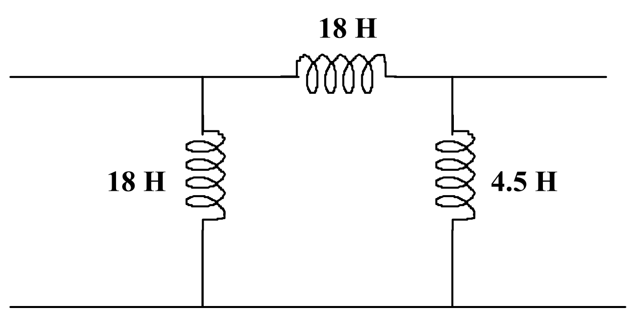
$$L_1L_2 - M^2 = 40 - 4 = 36$$

$$L_A = (L_1L_2 - M^2)/(L_2 - M) = 36/(4 - 2) = \mathbf{18\ H}$$

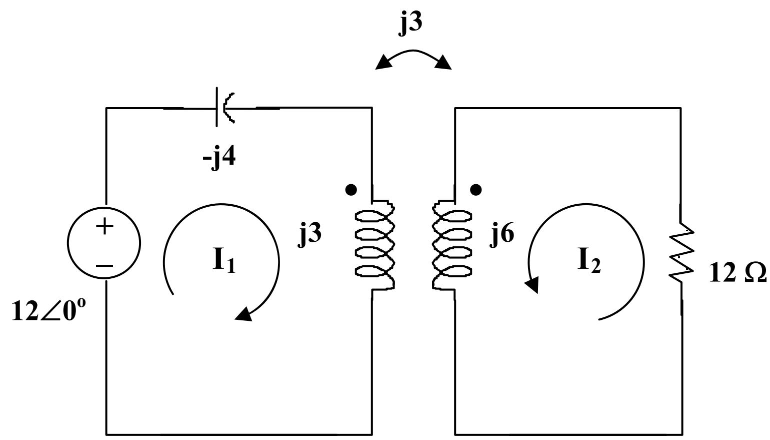
$$L_B = (L_1L_2 - M^2)/(L_1 - M) = 36/(10 - 2) = \mathbf{4.5\ H}$$

$$L_C = (L_1L_2 - M^2)/M = 36/2 = \mathbf{18\ H}$$

Hence, we get the π equivalent circuit as shown below.



P.P. 13.6 If we reverse the direction of I_2 so that we replace I_2 by $-I_2$, we have the circuit shown in Figure (a).



(a)

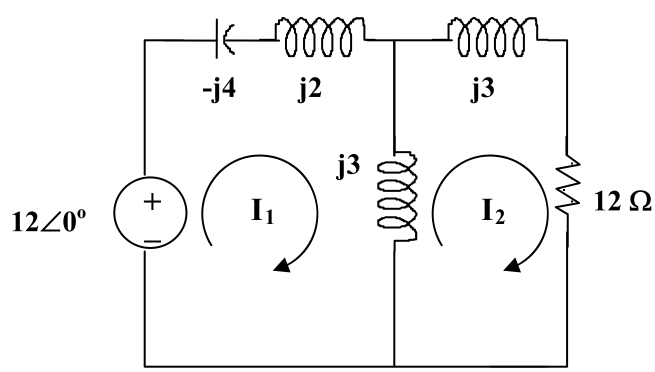
We now replace the coupled coil by the T-equivalent circuit and assume $\omega = 1$.

$$L_a = 5 - 3 = 2\text{ H}$$

$$L_b = 6 - 3 = 3\text{ H}$$

$$L_c = 3\text{ H}$$

Hence the equivalent circuit is shown in Figure (b). We apply mesh analysis.



(b)

$$12 = i_1(-j4 + j2 + j3) + j3i_2$$

or $12 = ji_1 + j3i_2$ (1)

Loop 2 produces, $0 = j3i_1 + (j3 + j3 + 12)i_2$

or $i_1 = (-2 + j4)i_2$ (2)

Substituting (2) into (1), $12 = (-4 + j)i_2$, which leads to $i_2 = 12/(-4 + j)$

$$I_2 = -i_2 = 12/(4 - j) = \mathbf{2.91\angle 14.04^o\ A}$$

$$I_1 = i_1 = (-2 + j4)i_2 = 12(2 - j4)/(4 - j) = \mathbf{13\angle -49.4^o\ A}$$

P.P. 13.7

(a) $n = V_2/V_1 = 110/2200 = \mathbf{1/20}$ (a step-down transformer)

(b) $S = V_1I_1 = 2200x5 = \mathbf{11\ kVA}$

(c) $I_2 = I_1/n = 5/(1/20) = \mathbf{100\ A}$

P.P. 13.8 The 16 – j24-ohm impedance can be reflected to the primary resulting in

$$Z_{in} = 2 + (16 - j24)/16 = 3 - j1.5$$

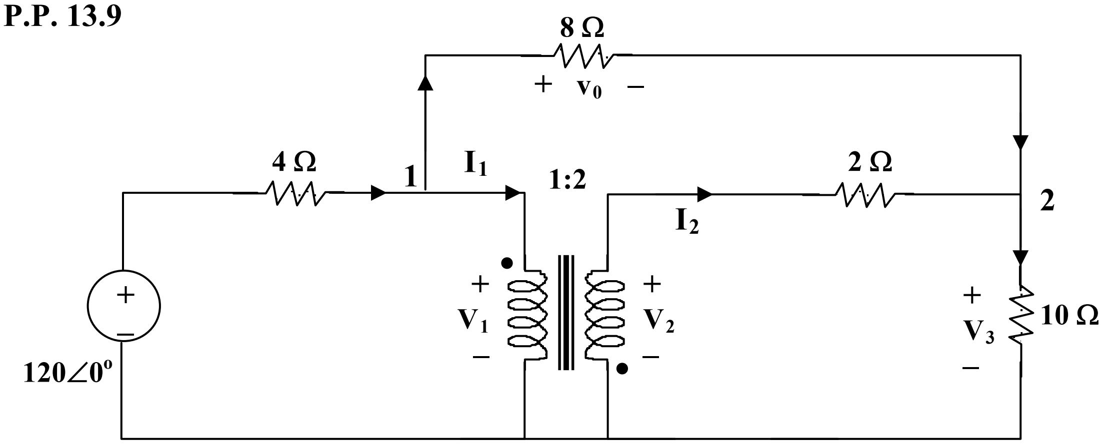
$$I_1 = 240/(3 - j1.5) = 240/(3.354\angle -26.57°) = 71.56\angle 26.57^o$$

$$I_2 = -I_1/n = -17.89\angle 26.57^o$$

$$V_o = -j24i_2 = (24\angle -90^o)(-17.89\angle 26.57^o) = \mathbf{429.4\angle 116.57^o V}$$

$$S_1 = V_1I_1 = (240)(71.56\angle 26.57^o) = \mathbf{17.174\angle -26.57^o\ kVA}.$$

P.P. 13.9



Consider the circuit shown above.

At node 1, $(120 - \mathbf{V_1})/4 = \mathbf{I_1} + (\mathbf{V_1} - \mathbf{V_3})/8$ (1)

At node 2, $[(\mathbf{V_1} - \mathbf{V_3})/8] + [(\mathbf{V_2} - \mathbf{V_3})/2] = (\mathbf{V_3})/8$ (2)

At the transformer terminals, $\mathbf{V_2} = -2\mathbf{V_1}$ and $\mathbf{I_2} = -\mathbf{I_1}/2$ (3)

But $I_2 = (\mathbf{V_2} - \mathbf{V_3})/2 = -\mathbf{I_1}/2$ which leads to $\mathbf{I_1} = (\mathbf{V_3} - \mathbf{V_2})/1 = \mathbf{V_3} + 2\mathbf{V_1}$.

Substituting all of this into (1) and (2) leads to,

$(120 - \mathbf{V_1})/4 = \mathbf{V_3} + 2\mathbf{V_1} + (\mathbf{V_1} - \mathbf{V_3})/8$ which leads $240 = 19\mathbf{V_1} + 7\mathbf{V_3}$ (4)

$[(\mathbf{V_1} - \mathbf{V_3})/8] + [(-2\mathbf{V_1} - \mathbf{V_3})/2] = \mathbf{V_3}/8$ which leads to
$\mathbf{V_3} = -7\mathbf{V_1}/6$ (5)

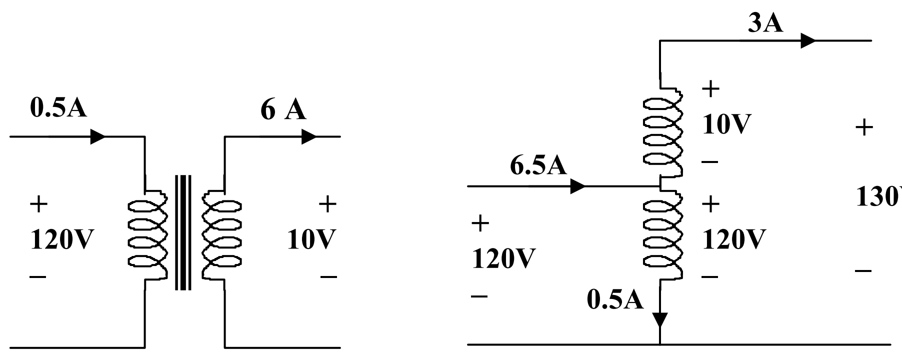
From (4) and (5),

$$240 = 10.833\mathbf{V_1} \text{ or } \mathbf{V_1} = 22.155 \text{ volts}$$

$$\mathbf{V_3} = -7\mathbf{V_1}/6 = -25.85 \text{ volts}$$

$$\mathbf{V_o} = \mathbf{V_1} - \mathbf{V_3} = \mathbf{48\ volts}$$

P.P. 13.10 We should note that the current and voltage of each winding of the autotransformer in Figure (b) are the same for the two-winding transformer in Figure (a).



(a) (b)

For the two-winding transformer,

$$\mathbf{S_1} = 120\text{x}0.5 = 60 \text{ VA}$$

$$\mathbf{S_2} = 6(10) = 60 \text{ VA}$$

For the autotransformer,

$$\mathbf{S_1} = 120(6.5) = 780 \text{ VA}$$

$$\mathbf{S_2} = 130(6) = \mathbf{780\ VA}$$

P.P. 13.11 $(\mathbf{I_2})^* = \mathbf{S_2/V_2} = 16{,}000/1000 = \mathbf{16\ A}$

Since $\mathbf{S_1} = \mathbf{V_1(I_1)}^* = \mathbf{V_2(I_2)}^* = \mathbf{S_2}$, $\mathbf{V_2/V_1} = \mathbf{I_1/I_2}$, $1000/2500 = \mathbf{I_1}/32$,

or $\mathbf{I_1} = 1000\text{x}16/2500 = \mathbf{6.4\ A}$.

At the top, KCL produces $\mathbf{I_1 + I_o} = \mathbf{I_2}$, or $\mathbf{I_o} = \mathbf{I_2 - I_1} = 16 - 6.4 = \mathbf{9.6\ A}$.

P.P. 13.12

(a) $S_T = (\sqrt{3})V_LI_L$, but $S_T = P_T/\cos\theta = 40\text{x}10^6/0.85 = 47.0588$ MVA

$$I_{LS} = S_T/(\sqrt{3})V_{LS} = 47.0588\text{x}10^6/[(\sqrt{3})12.5\text{x}10^3] = \mathbf{2.174\ kA}$$

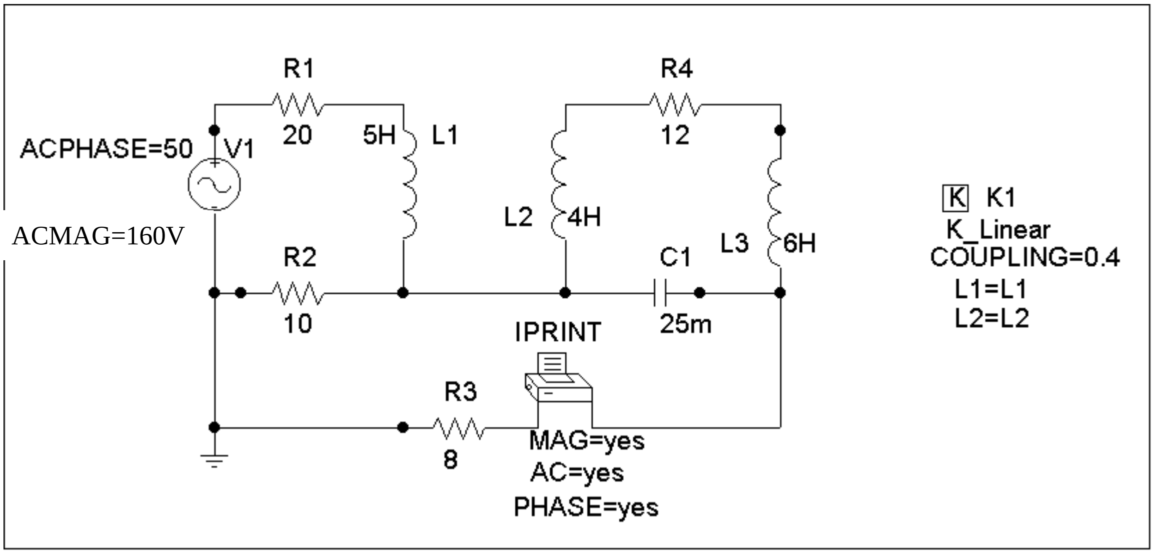
(b) $V_{LS} = 12.5$ kV, $V_{LP} = 625$ kV, $n = V_{LS}/V_{LP} = 12.5/625 = \mathbf{0.02}$

(c) $I_{LP} = nI_{LS} = 0.02\text{x}2173.6 = \mathbf{43.47\ A}$

or $I_{LP} = S_T/[(\sqrt{3})v_{LP}] = 47.0588\text{x}10^6/[(\sqrt{3})625\text{x}10^3] = \mathbf{43.47\ A}$

(d) The load carried by each transformer is $(1/3)S_T = \mathbf{15.69\ MVA}$

P.P. 13.13 The process is essentially the same as in Example 13.13. We are given the coupling coefficient, $k = 0.4$, and can determine the operating frequency from the value of $\omega = 4$ which implies that $f = 4/(2\pi) = 0.6366$ Hz.



Saving and then simulating produces,

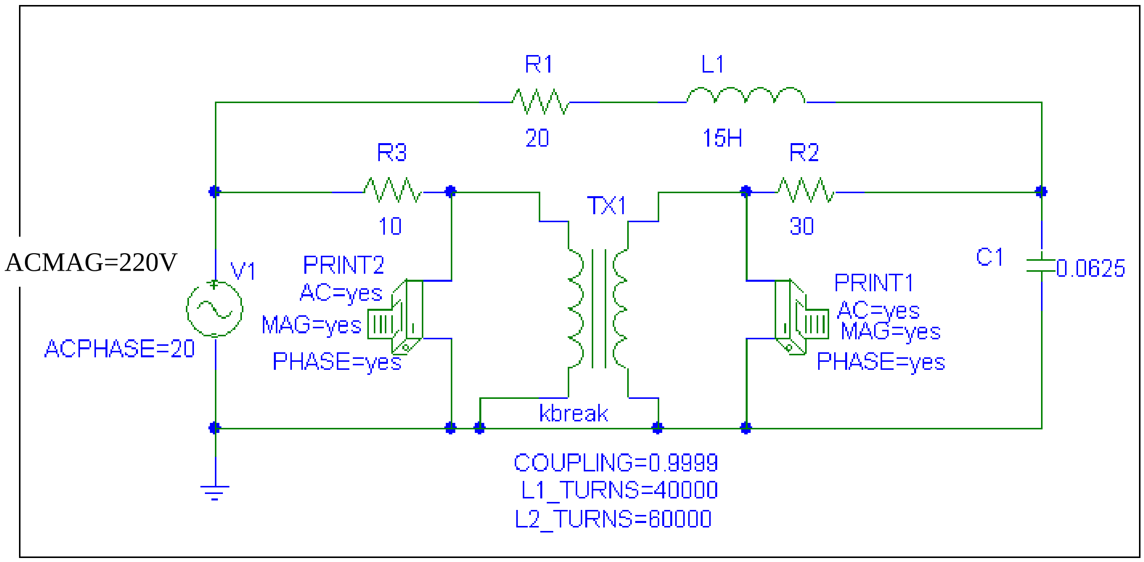
$i_o = \mathbf{2.012cos(4t + 68.52^o)\ A}$

P.P. 13.14 Following the same basic steps in Example 13.14, we first assume $\omega = 1$. This then leads to following determination of values for the inductor and the capacitor.

$$j15 = j\omega L \text{ leads to } L = 15 \text{ H}$$

$$-j16 = 1/(\omega C) \text{ leads to } C = 62.5 \text{ mF}$$

The schematic is shown below.



FREQ	VM($N_0005,0)	VP($N_0005,0)
1.592E-01	1.530E+02	2.185E+00

FREQ	VM($N_0001,0)	VP($N_0001,0)
1.592E-01	2.302E+02	2.091E+00

Thus,

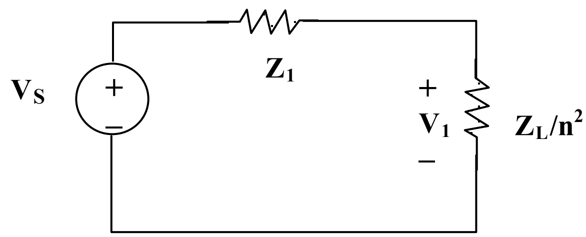
$$\mathbf{V_1 = 153\angle 2.18°\ V}$$

$$\mathbf{V_2 = 230.2\angle 2.09°\ V}$$

Note, if we divide V_2 by V_1 we get $1.5046\angle{-.09}^\circ$ which is in good agreement that the transformer is ideal with a voltage ratio of 1:1.5 (or 2:3)!

P.P. 13.15 $V_2/V_1 = 120/13{,}200 = \mathbf{1/110} = 1/n$

P.P. 13.16



As in Example 13.16, $n^2 = \mathbf{Z_L/Z_1} = 400/(2.5\text{x}10^3) = 4/25$, $n = \mathbf{0.4}$

By voltage division, $\mathbf{V_1} = \mathbf{V_s}/2$ (since $\mathbf{Z_1} = \mathbf{Z_L}/n^2$), therefore $V_1 = 60/2 = 30$ volts, and

$$V_2 = nV_1 = (0.4)(30) = \mathbf{12\ volts}$$

P.P. 13.17

(a) S = 12x60 + 350 + 4,500 = **5.57 kW**

(b) $I_P = S/V_P$ 5570/2400 = **2.321 A**

CHAPTER 14

P.P.14.1 $\mathbf{H}(\omega) = \dfrac{\mathbf{V}_o}{\mathbf{V}_s} = \dfrac{\mathbf{j\omega L}}{\mathbf{R + j\omega L}}$

$$\mathbf{H}(\omega) = \frac{j\omega L/R}{1 + j\omega L/R} = \frac{j\omega/\omega_0}{1 + j\omega/\omega_0}$$

where $\omega_0 = \dfrac{R}{L}$.

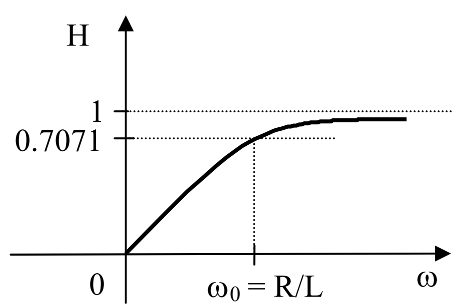
$$H = \left|\mathbf{H}(\omega)\right| = \frac{\omega/\omega_0}{\sqrt{1 + (\omega/\omega_0)^2}} \qquad \phi = \angle\mathbf{H}(\omega) = \frac{\pi}{2} - \tan^{-1}\left(\frac{\omega}{\omega_0}\right)$$

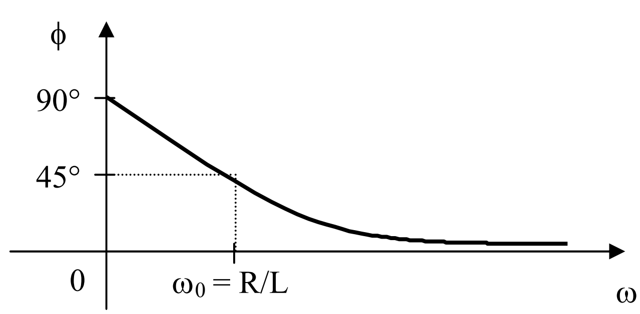
At $\omega = 0$, $H = 0$, $\phi = 90°$

As $\omega \to \infty$, $H = 1$, $\phi = 0°$

At $\omega = \omega_0$, $H = \dfrac{1}{\sqrt{2}}$, $\phi = 90° - 45° = 45°$

Thus, the sketches of H and ϕ are shown below.





P.P.14.2 The desired transfer function is the input impedance.

$$\mathbf{Z}_i(s) = \frac{\mathbf{V}_o(s)}{\mathbf{I}_o(s)} = \left(10 + \frac{1}{s/20}\right) \| (6+2s)$$

$$\mathbf{Z}_i(s) = \frac{(10+20/s)(6+2s)}{10+20/s+6+2s} = \frac{10(s+2)(s+3)}{s^2+8s+10}$$

The poles are at

$$p_{1,2} = \frac{-8 \pm \sqrt{64-40}}{2} = \mathbf{-1.5505,\ -6.449}$$

The zeros are at

$$z_1 = \mathbf{-2}, \qquad z_2 = \mathbf{-3}.$$

P.P.14.3 $$\mathbf{H}(\omega) = \frac{1 + j\omega/2}{(j\omega)(1 + j\omega/10)}$$

$$H_{db} = 20\log_{10}\left|1 + j\omega/2\right| - 20\log_{10}\left|j\omega\right| - 20\log_{10}\left|1 + j\omega/10\right|$$

$$\phi = -90° + \tan^{-1}(\omega/2) - \tan^{-1}(\omega/10)$$

The magnitude and the phase plots are as shown in Fig. 14.14.

P.P.14.4 $$\mathbf{H}(\omega) = \frac{(50/400)j\omega}{(1 + j\omega/4)(1 + j\omega/10)^2}$$

$$H_{db} = -20\log_{10}\left|8\right| + 20\log_{10}\left|j\omega\right| - 20\log_{10}\left|1 + j\omega/4\right| - 40\log_{10}\left|1 + j\omega/10\right|$$

$$\phi = 90° - \tan^{-1}(\omega/4) - 2\tan^{-1}(\omega/10)$$

The magnitude and the phase plots are as shown in Fig. 14.16.

P.P.14.5 $$\mathbf{H}(\omega) = \frac{10/400}{(j\omega)\left(1 + \frac{j\omega 8}{40} + \left(\frac{j\omega}{20}\right)^2\right)}$$

$$H_{db} = -20\log_{10}\left|40\right| - 20\log_{10}\left|j\omega\right| - 20\log_{10}\left|1 + j\omega/5 - \omega^2/400\right|$$

$$\phi = -90° - \tan^{-1}\left(\frac{0.2\omega}{1 - \omega^2/400}\right)$$

The magnitude and the phase plots are as shown in Fig. 14.18.

P.P.14.6

The gain is = 40 db = $20\log_{10}$(gain) or the gain = 100.

A zero at $\omega = 5$, $1 + j\omega/5$

A pole at $\omega = 10$, $\dfrac{1}{1 + j\omega/10}$

Two poles at $\omega = 100$, $\dfrac{1}{(1 + j\omega/100)^2}$

Hence,

$$\mathbf{H}(\omega) = \frac{100(1 + j\omega/5)}{(1 + j\omega/10)(1 + j\omega/100)^2} = \frac{100(1/5)(5 + j\omega)}{(1/100{,}000)(10 + j\omega)(100 + j\omega)^2}$$

$$\mathbf{H}(\omega) = \frac{2{,}000{,}000\,(s + 5)}{(s + 10)(s + 100)^2}$$

P.P.14.7

(a) $Q = \dfrac{\omega_0 L}{R} \longrightarrow \omega_0 = \dfrac{QR}{L} = \dfrac{(50)(4)}{25 \times 10^{-3}} = 8 \times 10^3 \text{ rad/s}$

$$\omega_0 = \frac{1}{\sqrt{LC}} \longrightarrow C = \frac{1}{\omega_0^2 L} = \frac{1}{(64 \times 10^6)(25 \times 10^{-3})}$$

$C = \mathbf{0.625\ \mu F}$

(b) $B = \dfrac{\omega_0}{Q} = \dfrac{8 \times 10^3}{50} = \mathbf{160\ rad/s}$

Since $Q > 10$,

$$\omega_1 = \omega_0 - \frac{B}{2} = 8000 - 80 = \mathbf{7920\ rad/s}$$

$$\omega_2 = \omega_0 + \frac{B}{2} = 8000 + 80 = \mathbf{8080\ rad/s}$$

(c) At $\omega = \omega_0$, $P = \dfrac{V_{in}^2}{2R} = \dfrac{100^2}{8} = \mathbf{1.25\ kW}$

At $\omega = \omega_1$, $P = 0.5 \cdot \dfrac{V_{in}^2}{2R} = \mathbf{0.625\ kW}$

At $\omega = \omega_2$, $P = 0.5 \cdot \dfrac{V_{in}^2}{2R} = \mathbf{0.625\ kW}$

P.P.14.8 $\omega_0 = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{(20\times10^{-3})(5\times10^{-9})}} = 10^5 = \mathbf{100\,krad/s}$

$$Q = \frac{R}{\omega_0 L} = \frac{100\times10^3}{(10^5)(20\times10^{-3})} = \mathbf{50}$$

$$B = \frac{\omega_0}{Q} = \frac{10^5}{50} = \mathbf{2\ krad/s}$$

Since $Q > 10$,

$$\omega_1 = \omega_0 - \frac{B}{2} = 100{,}000 - 1{,}000 = \mathbf{99\,krad/s}$$

$$\omega_2 = \omega_0 + \frac{B}{2} = 100{,}000 + 1{,}000 = \mathbf{101\,krad/s}$$

P.P.14.9 $\mathbf{Z} = j\omega 0.01 + 20\,||\,\frac{2000}{j\omega} = j\omega 0.01 + \frac{20}{1 + j\omega/100}$

$$\mathbf{Z} = j\omega 0.01 + \frac{20(1 - j\omega/100)}{1 + \omega^2/10^4}$$

$$\text{Im}(\mathbf{Z}) = 0 \quad \longrightarrow \quad \omega 0.01 - \frac{0.2\omega}{1 + \omega^2/10^4} = 0$$

$$\omega = \frac{20\omega}{1 + \omega^2/10^4} \quad \longrightarrow \quad 1 + \omega^2/10^4 = 20$$

Clearly, ω = **435.9 rad/s**

P.P.14.10 $\mathbf{H}(s) = \frac{\mathbf{V}_o}{\mathbf{V}_i} = \frac{R_2\,||\,sL}{R_1 + R_2\,||\,sL}, \qquad s = j\omega$

$$\mathbf{H}(s) = \frac{sR_2L}{R_1R_2 + sR_1L + sR_2L}$$

$$\mathbf{H}(\omega) = \frac{j\omega R_2L}{R_1R_2 + j\omega L(R_1 + R_2)}$$

$$H(0) = 0$$

$$H(\omega) = \lim_{\omega\to\infty} \frac{jR_2L}{R_1R_2/\omega + jL(R_1 + R_2)} = \frac{R_2}{R_1 + R_2}$$

i.e. a **highpass filter**.

The corner frequency occurs when $H(\omega_c) = \frac{1}{\sqrt{2}} \cdot H(\infty)$.

$$\mathbf{H}(\omega) = \left(\frac{R_2}{R_1 + R_2}\right)\left(\frac{j\omega L}{j\omega L + R_1 R_2/(R_1 + R_2)}\right)$$

$$\mathbf{H}(\omega) = \left(\frac{R_2}{R_1 + R_2}\right)\left(\frac{j\omega}{j\omega + k}\right), \qquad \text{where } k = \frac{R_1 R_2}{(R_1 + R_2) L}$$

At the corner frequency,

$$\frac{1}{\sqrt{2}} \cdot \frac{R_2}{R_1 + R_2} = \frac{R_2}{R_1 + R_2} \cdot \left|\frac{j\omega_c}{j\omega_c + k}\right|$$

$$\frac{1}{\sqrt{2}} = \frac{\omega_c}{\sqrt{\omega_c^2 + k^2}} \longrightarrow \omega_c = k = \mathbf{\frac{R_1 R_2}{(R_1 + R_2) L}}$$

Hence, $$\mathbf{H}(\omega) = \left(\mathbf{\frac{R_2}{R_1 + R_2}}\right)\left(\mathbf{\frac{j\omega}{j\omega + \omega_c}}\right)$$

and the corner frequency is

$$\omega_c = \frac{(100)(100)}{(100 + 100)(2 \times 10^{-3})} = \mathbf{25\ krad/s}$$

P.P.14.11 $B = 2\pi(20.3 - 20.1) \times 10^3 = 400\pi$

Assuming high Q,

$$\omega_0 = \frac{\omega_1 + \omega_2}{2} = \frac{(2\pi)(40.4 \times 10^3)}{2} = 40.4\pi \times 10^3 \text{ rad/s}$$

$$Q = \frac{\omega_0}{B} = \frac{40.4\pi \times 10^3}{400\pi} = \mathbf{101}$$

$$B = \frac{R}{L} \longrightarrow L = \frac{R}{B} = \frac{20 \times 10^3}{400\pi} = \mathbf{15.915\ H}$$

$$Q = \frac{1}{\omega_0 CR} \longrightarrow C = \frac{1}{\omega_0 QR}$$

$$C = \frac{1}{(40.4\pi \times 10^3)(101)(20 \times 10^3)} = \mathbf{3.9\ pF}$$

P.P.14.12 Given $H(\infty) = 5$ and $f_c = 2$ kHz

$$\omega_c = 2\pi f_c = \frac{1}{R_i C_i}$$

$$R_i = \frac{1}{2\pi f_c C_i} = \frac{1}{(2\pi)(2\times10^3)(0.1\times10^{-3})}$$

$$R_i = 795.8 \cong \mathbf{800\ \Omega}$$

$$H(\infty) = \frac{-R_f}{R_i} = -5 \longrightarrow R_f = 5R_i = 3{,}978 \cong \mathbf{4\ k\Omega}$$

P.P.14.13 $Q = 10$, $\omega_0 = 20$ krad/s

$$B = \frac{\omega_0}{Q} = 2 \text{ krad/s}$$

$$\omega_1 = \omega_0 - \frac{B}{2} = 19 \text{ krad/s}$$

$$\omega_2 = \omega_0 + \frac{B}{2} = 21 \text{ krad/s}$$

Since $\omega_1 = \frac{1}{C_2 R}$,

$$C_2 = \frac{1}{\omega_1 R} = \frac{1}{(19\times10^3)(10\times10^3)} = \mathbf{5.263\ nF}$$

$$C_1 = \frac{1}{\omega_2 R} = \frac{1}{(21\times10^3)(10\times10^3)} = \mathbf{4.762\ nF}$$

$$K = \frac{R_f}{R_i} = 5 \longrightarrow R_f = 5R_i = \mathbf{50\ k\Omega}$$

P.P.14.14 $$K_f = \frac{\omega'_c}{\omega_c} = \frac{2\pi\times10^4}{1} = 2\pi\times10^4$$

$$C' = \frac{C}{K_m K_f} \longrightarrow K_m = \frac{C}{C' K_f} = \frac{1}{(15\times10^{-9})(2\pi\times10^4)} = \frac{10^4}{3\pi}$$

$$R' = K_m R = \frac{10^4}{3\pi}(1) = 1.061 \text{ k}\Omega$$

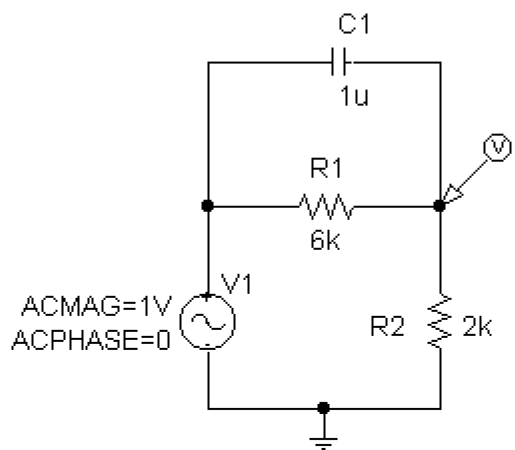
$$L' = \frac{K_m}{K_f} L = \frac{10^4}{3\pi}\cdot\frac{2}{2\pi\times10^4} = 33.77 \text{ mH}$$

Therefore,

$$R'_1 = R'_2 = \mathbf{1.061\ k\Omega}$$

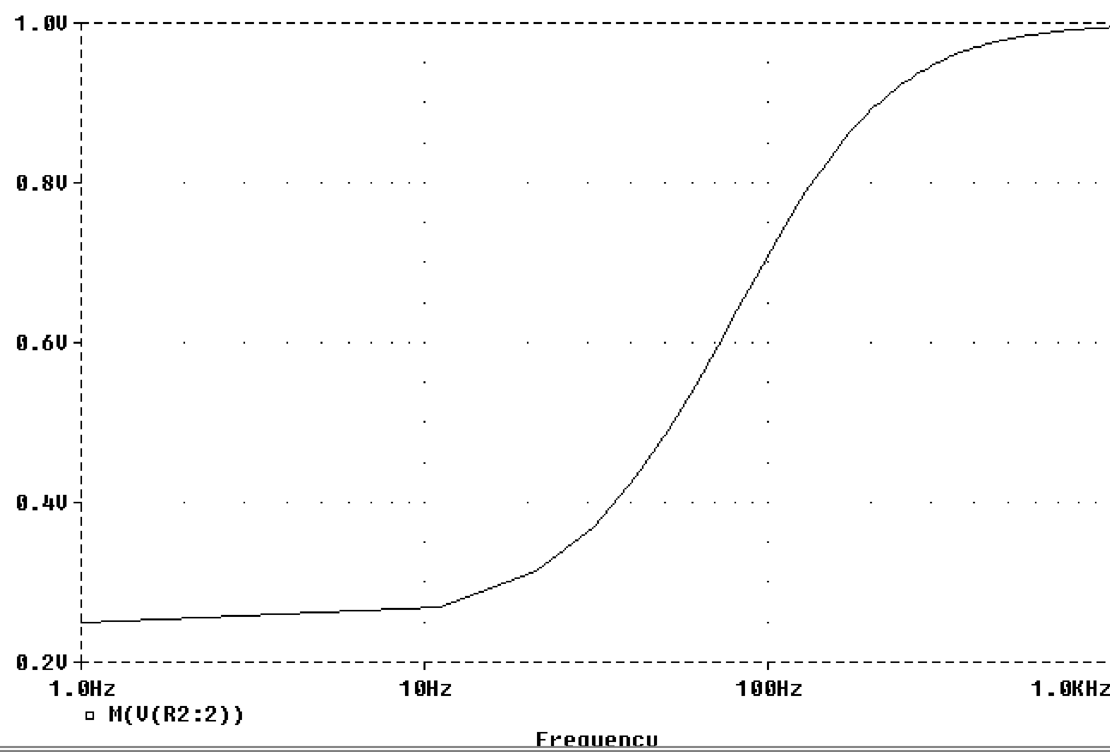
$C_1' = C_2' = \mathbf{15\ nF}$
$L' = \mathbf{33.77\ mH}$

P.P.14.15 The schematic is shown in Fig. (a).

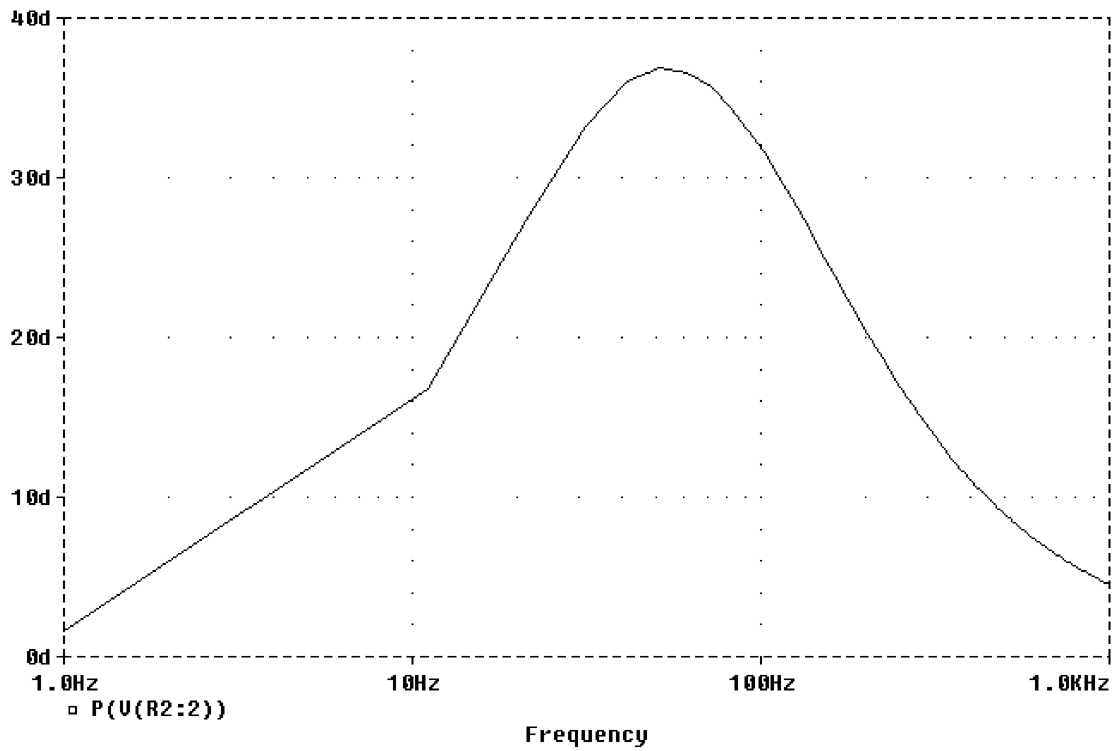


(a)

Use the **AC Sweep** option of the **Analysis Setup**. Choose a *Linear* sweep type with the following *Sweep Parameters* : *Total Pts* = 100, *Start Freq* = 1, and *End Freq* = 1K. After saving and simulating the circuit, we obtain **the magnitude and phase plots are shown in Figs. (b) and (c)**.

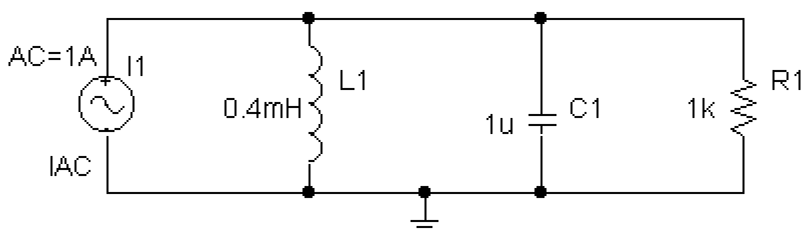


(b)



(c)

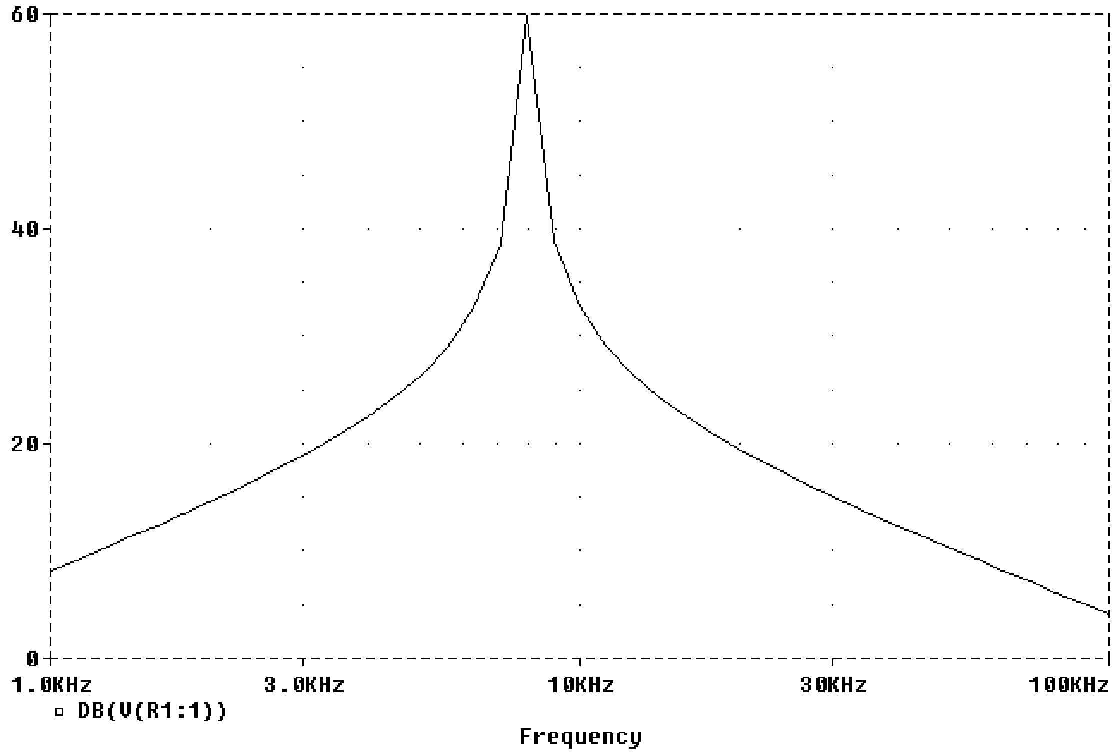
P.P.14.16 The schematic is shown in Fig. (a).



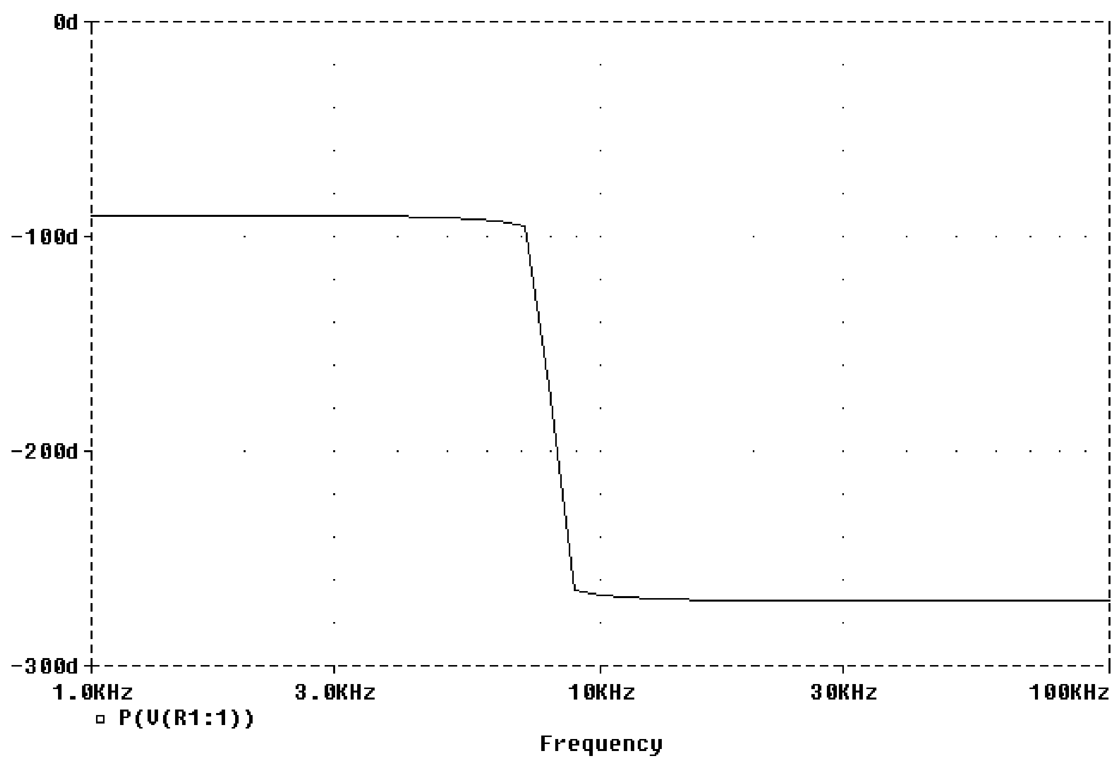
(a)

Use the **AC Sweep** option of the **Analysis Setup**. Choose a *Decade* sweep type with these *Sweep Parameters* : *Pts/Decade* = 20, *Start Freq* = 1K, and *End Freq* = 100K. Save and simulate the circuit.

For the magnitude plot, choose DB( ) from the **Analog Operators and Functions** list. Then, select the voltage V(R1:1) and OK. Another option would be to type DB(V(R1:1)) as the **Trace Expression**. For the phase plot, choose P( ) from the **Analog Operators and Functions** list. Then, select the voltage V(R1:1) and OK. Another option would be to type VP(R1:1) as the **Trace Expression**. **The resulting magnitude and phase plots are shown in Figs. (b) and (c)**.


60
40
20
0
1.0KHz
3.0KHz
10KHz
30KHz
100KHz
DB(V(R1:1))
Frequency

(b)


0d
-100d
-200d
-300d
1.0KHz
3.0KHz
10KHz
30KHz
100KHz
P(V(R1:1))
Frequency

(c)

P.P.14.17 $\omega_0 = 2\pi f_0 = \dfrac{1}{\sqrt{LC}}$

or $C = \dfrac{1}{4\pi^2 f_0^2 L}$

For the high end of the band, $f_0 = 108$ MHz

$$C_1 = \frac{1}{4\pi^2 (108^2 \times 10^{12})(4 \times 10^{-6})} = 0.543 \text{ pF}$$

For the low end of the band, $f_0 = 88$ MHz

$$C_2 = \frac{1}{4\pi^2 (88^2 \times 10^{12})(4 \times 10^{-6})} = 0.818 \text{ pF}$$

Therefore, C must be adjustable and be in the range **0.543 pF to 0.818 pF**.

P.P.14.18

For BP_6, $f_0 = 1336$ Hz and it passes frequencies in the range $1209 \text{ Hz} < f < 1477 \text{ Hz}$.

$$B = 2\pi(1477 - 1209) = 1683.9$$

$$L = \frac{R}{B} = \frac{600}{1683.9} = \mathbf{356\ mH}$$

$$C = \frac{1}{4\pi^2 f_0^2 L} = \frac{1}{4\pi^2 (1336)^2 (0.356)} = \mathbf{39.83\ nF}$$

P.P.14.19 $C = 10\ \mu\text{F}$ and $R_1 = R_2 = 8\ \Omega$

$$2\pi f_c = \frac{1}{R_1 C} \longrightarrow f_c = \frac{1}{2\pi R_1 C} = \frac{1}{(2\pi)(8)(10 \times 10^{-6})} = \mathbf{1.989\ kHz}$$

$$L = \frac{R_2}{2\pi f_c} = \frac{8}{(2\pi)(1.989 \times 10^3)} = \mathbf{0.64\ mH}$$