Chapter Five:

Additional Analysis Techniques

5.1 Find I_o in the circuit in Fig. P5.1 using linearity and the assumption that $I_o = 1$ mA. CS

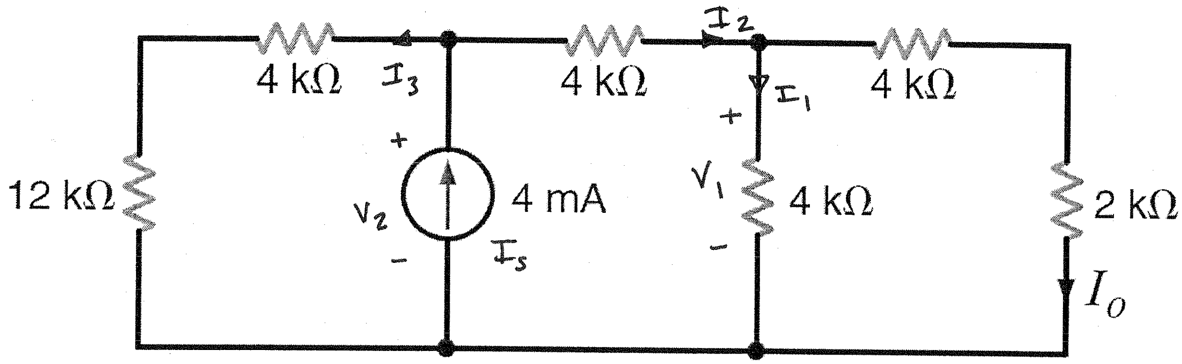


Figure P5.1

SOLUTION: If $I_o = 1mA$

$$V_1 = I_o(4000 + 2000) = 6V$$

$$I_2 = I_1 + I_o = \frac{V_1}{4000} + I_o = 2.5mA$$

$$V_2 = 4000\, I_2 + V_1 = 16V$$

$$I_s = \frac{V_2}{16\times10^3} + I_2 = 3.5mA$$

But I_s is actually 4mA. So

$$I_o = 10^{-3}\left(\frac{4\times10^{-3}}{3.5\times10^{-3}}\right) = 1.14\,mA \qquad \boxed{I_o = 1.14mA}$$

5.2 Find V_o in the network in Fig. P5.2 using linearity and the assumption that $V_o = 1$ V.

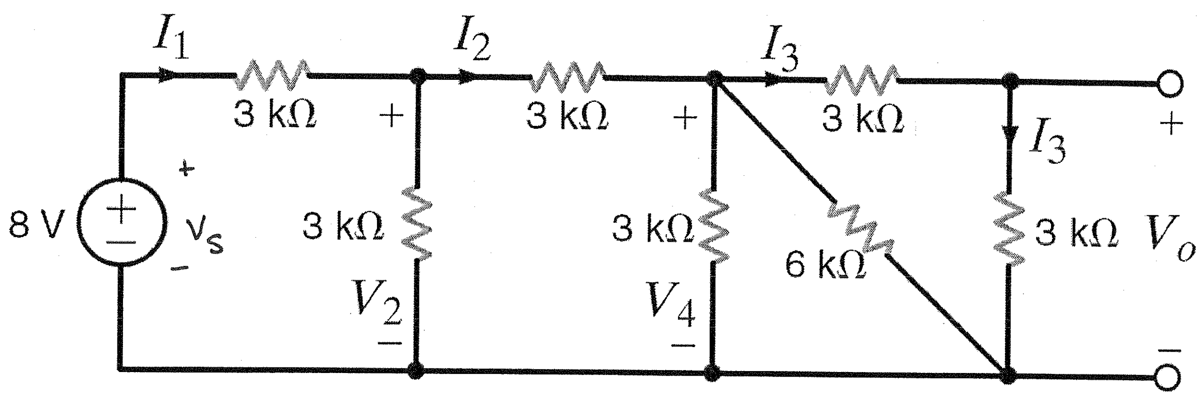


Figure P5.2

SOLUTION:

If $V_o = 1V$, $\quad I_3 = \frac{V_o}{3000} = \frac{1}{3}mA$

$V_4 = I_3(6000) = 2V \quad I_2 = \frac{V_4}{3000} + \frac{V_4}{6000} + I_3 = \frac{4}{3}mA$

$V_2 = 3000\, I_2 + V_4 = 6V$

$I_1 = \frac{V_2}{3000} + I_2 = \frac{10}{3}mA \quad V_s = 3000 I_1 + V_2 = 16V$

But, V_s actually $= 8V$. So

$V_o = (1)\left(\frac{8}{16}\right) = 0.5V \quad \boxed{V_o = 0.5V}$

5.3 Find I_o in the network in Fig. P5.3 using linearity and the assumption that $I_o = 1$ mA. **PSV**

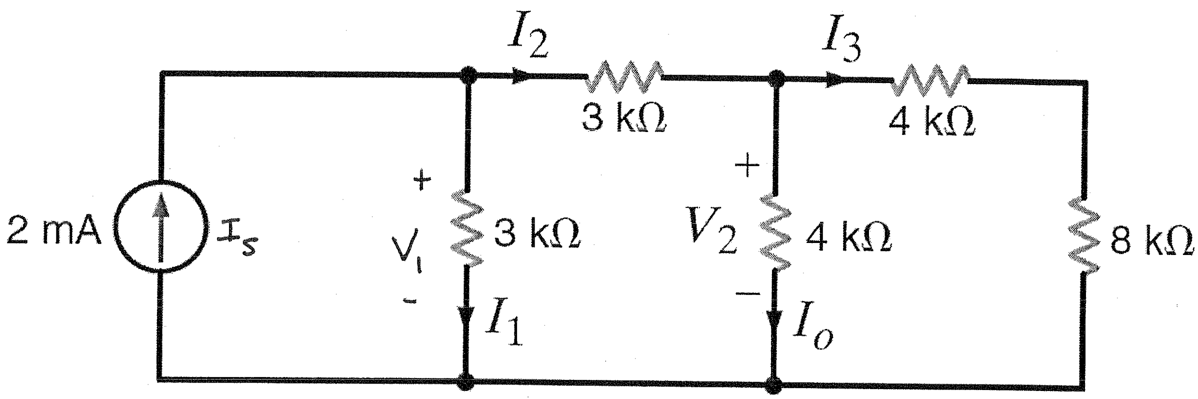


Figure P5.3

SOLUTION: If $I_o = 1mA$,

$V_2 = 4000\, I_o = 4V \qquad I_2 = I_o + \frac{V_2}{12\times10^3} = \frac{4}{3} mA$

$V_1 = 3000\, I_2 + V_2 = 8V$

$I_S = \frac{V_1}{3000} + I_2 = 4mA$

But, I_s actually equals 2mA. So

$I_o = 10^{-3}\left(\frac{2\times10^{-3}}{4\times10^{-3}}\right) = 0.5mA \qquad \boxed{I_o = 0.5mA}$

5.4 Find I_o in the network in Fig. P5.4 using linearity and the assumption that $I_o = 1$ mA.

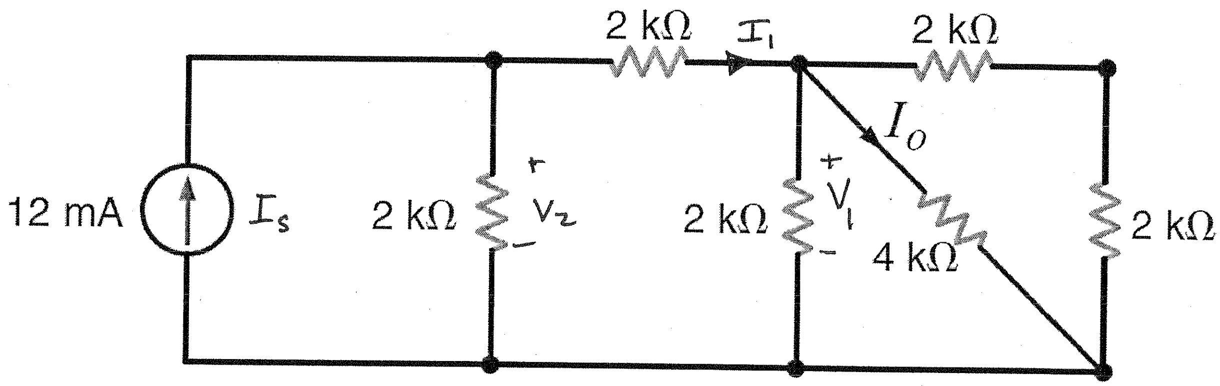


Figure P5.4

SOLUTION: If $I_o = 1mA$, $\quad V_1 = 4000\, I_o = 4V$

$$I_1 = \frac{V_1}{2000} + \frac{V_1}{4000} + I_o = 4mA$$

$$V_2 = 2000\, I_1 + V_1 = 12V \qquad I_S = \frac{V_2}{2000} + I_1 = 10\,mA$$

But, I_s actually equals 12mA. So, I_o is

$$I_o = 10^{-3}\left(\frac{12\times10^{-3}}{10\times10^{-3}}\right) \qquad \boxed{I_o = 1.2mA}$$

5.5 In the network in Fig. P5.5, find I_o using superposition. CS

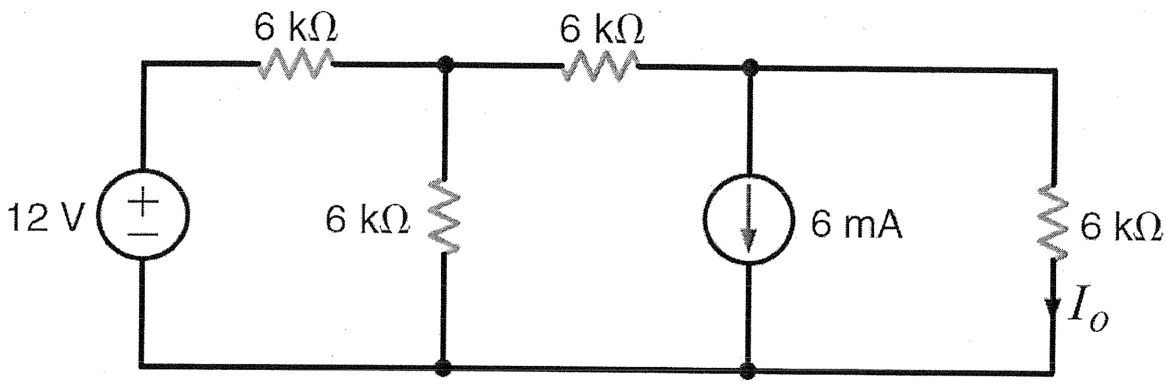
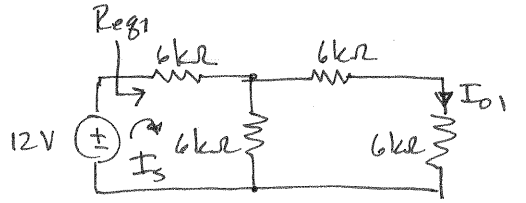


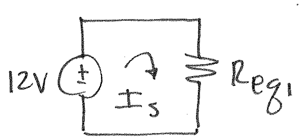
Figure P5.5

SOLUTION:



$$R_{eq_1} = 6000 + [6000 // 12{,}000]$$

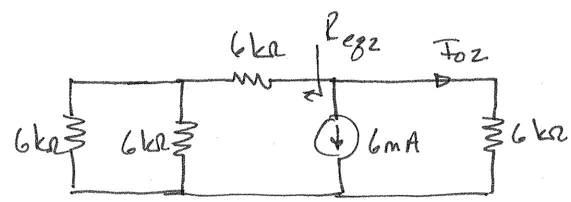
$$= 10k\Omega$$



$$I_s = \frac{12}{R_{eq_1}} = 1.2mA$$

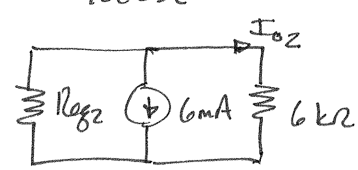
$$I_{o_1} = I_s\left[\frac{6000}{18{,}000}\right] = 0.4mA$$

$$\boxed{I_o = I_{o_1} + I_{o_2} = -3.2mA}$$



$$R_{eq_2} = (6000 // 6000) + 6000$$

$$= 9000\Omega$$



$$I_{o2} = -\frac{6\times10^{-3}(R_{eq2})}{R_{eq2} + 6000}$$

$$I_{o2} = -3.6mA$$

5.6 Find V_o in the network in Fig. P5.6 using superposition.

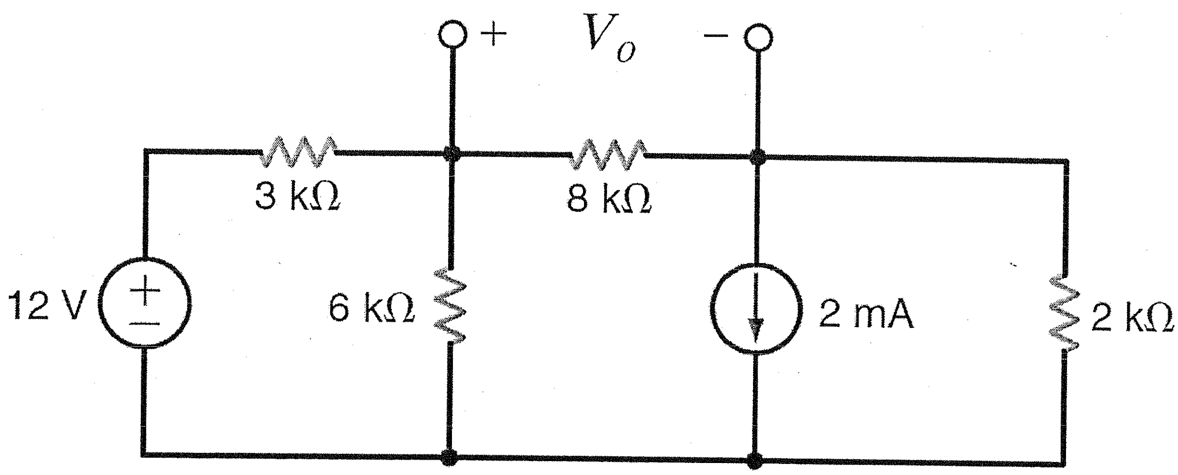
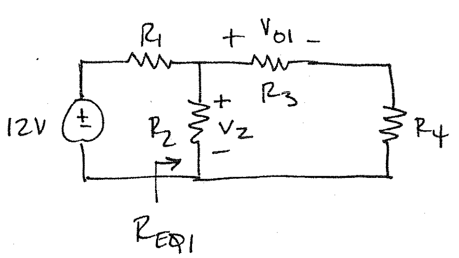
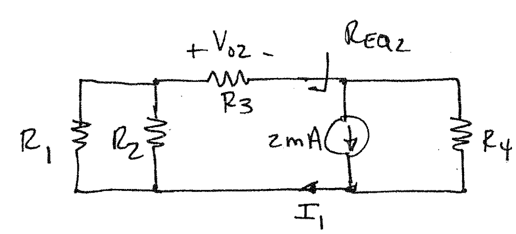


Figure P5.6

SOLUTION:



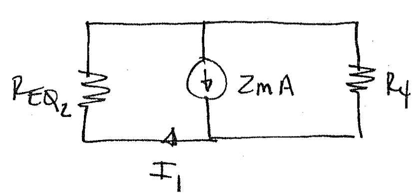


$R_{EQ2} = (R_1 // R_2) + R_3 = 10\,k\Omega$

$R_{EQ1} = R_2 // (R_3 + R_4) = 3.75\,k\Omega$

$V_2 = 12\,(R_{EQ1} / (R_{EQ1} + R_1)) = 6.67V$

$V_{01} = V_2 \left(\frac{R_3}{R_3 + R_4} \right) = 5.33V$



$V_o = V_{01} + V_{02}$

$I_1 = 2 \times 10^{-3} \left(\frac{R_4}{R_4 + R_{EQ2}} \right) = \frac{1}{3}\,mA$

$\boxed{V_o = 8.0\ V}$

$V_{02} = I_1 R_3 = \frac{8}{3} V$

5.7 Find I_o in the network in Fig. P5.7 using superposition. CS

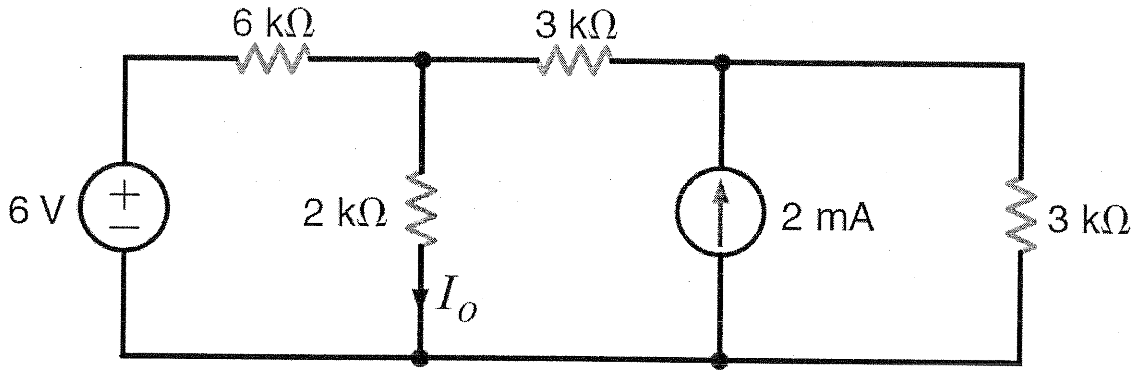
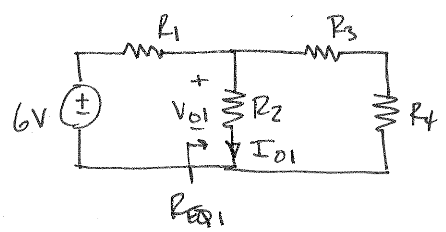
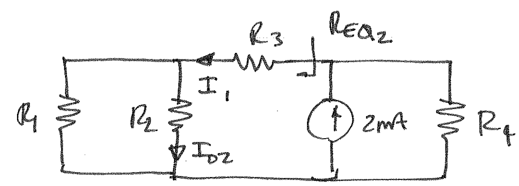


Figure P5.7

SOLUTION:





$R_{EQ2} = (R_1 // R_2) + R_3 = 4.5k\Omega$

$R_{EQ1} = R_2 // (R_3 + R_4)$

$= 1.5k\Omega$

$I_1 = 2\times10^{-3}\left(\frac{R_4}{R_4 + R_{EQ2}}\right) = 0.8mA$

$I_{o2} = I_1\left(\frac{R_1}{R_1 + R_2}\right) = 0.6mA$

$V_{o1} = 6\left(\frac{R_{EQ1}}{R_{EQ1} + R_1}\right) = 1.2V$

$I_{o1} = V_{o1}/R_2 = 0.6mA$

$I_o = I_{o1} + I_{o2}$

$\boxed{I_o = 1.2mA}$

5.8 Use superposition to find V_o in the circuit in Fig. P5.8. **PSV**

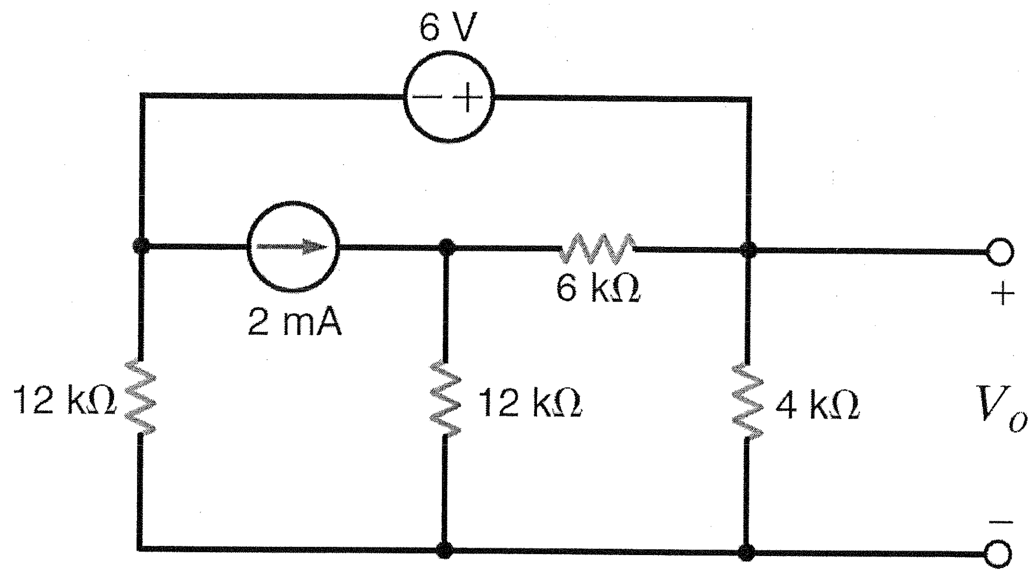
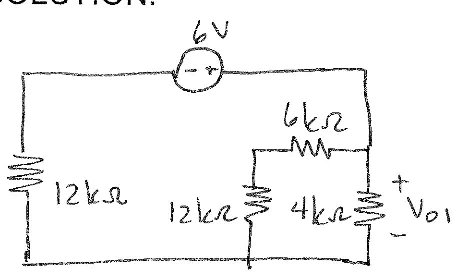
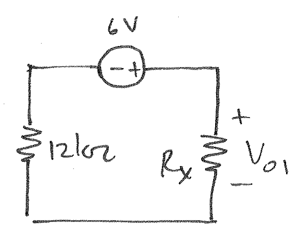


Figure P5.8

SOLUTION:



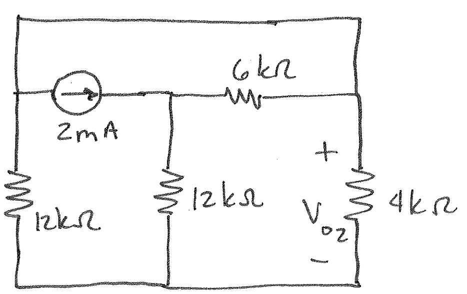


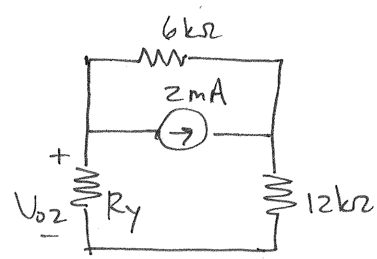
$R_x = 18{,}000 // 4000$

$R_x = 3.27k\Omega$

$V_{01} = 6\left(\frac{R_x}{R_x + 12000}\right)$

$V_{01} = 1.29V$





$R_Y = 4000 // 12000$

$R_Y = 3000\Omega$

$$V_{02} = -R_Y \left\{ 2\times10^{-3} \left[\frac{6000}{18000 + R_Y} \right] \right\}$$

$V_{02} = -1.71V$

$V_o = V_{01} + V_{02} = -0.42V$

$$\boxed{V_o = -0.42V}$$

5.9 Find I_o in the circuit in Fig. P5.9 using superposition.
CS

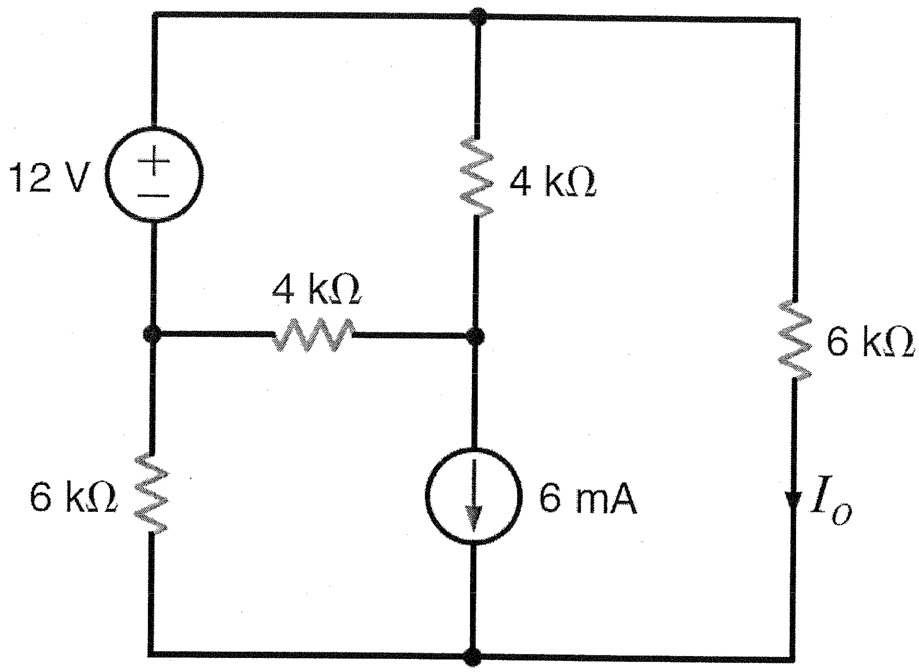
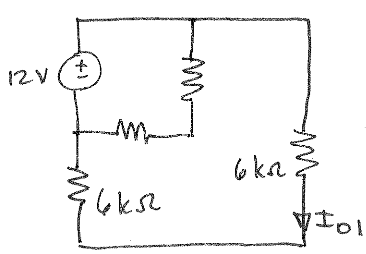
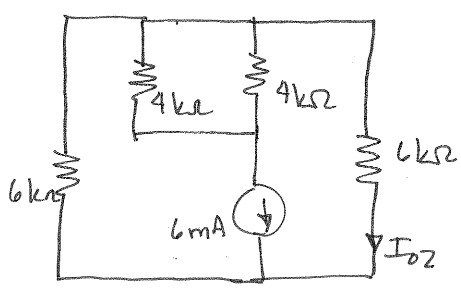


Figure P5.9

SOLUTION:



$12 = I_{o1}\,(6k + 6k)$ $I_{o1} = 1mA$



By current division, $I_{o2} = -6\times10^{-3}\left(\frac{6000}{6000+6000}\right)$

$I_{o2} = -3mA$

$I_{o1} + I_{o2} = I_o \Rightarrow$ $\boxed{I_o = -2mA}$

5.10 Use superposition to find I_o in the circuit in Fig. P5.10.

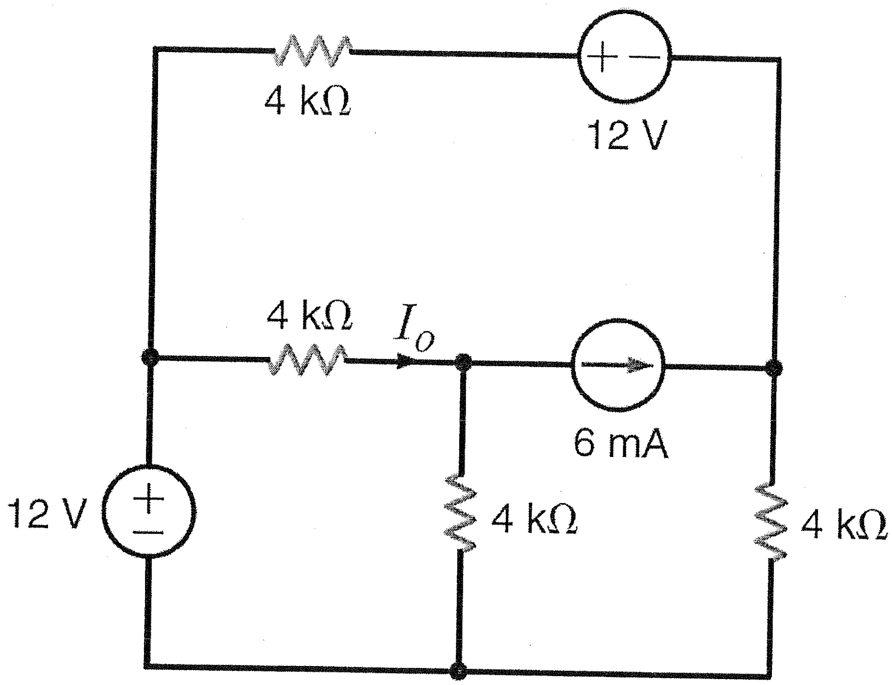
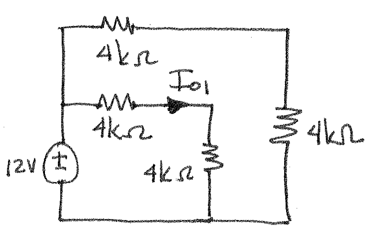
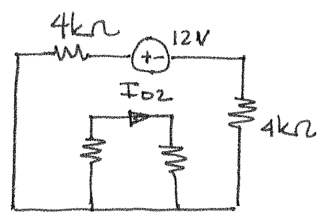


Figure P5.10

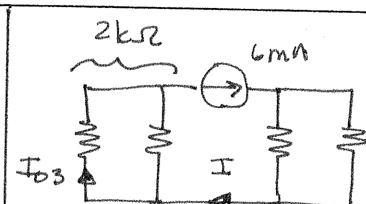
SOLUTION:



$I_{o1} = \frac{12}{8000} = 1.5\text{mA}$



$I_{o2} = 0$



All R = 4kΩ

$I = 6\text{mA}$

$I_{o3} = I\left(\frac{R}{R+R}\right) = 3\text{mA}$

$I_o = I_{o1} + I_{o2} + I_{o3} \Rightarrow$ $\boxed{I_o = 4.5\text{mA}}$

5.11 Find I_o in the network in Fig. P5.11 using superposition.

CS

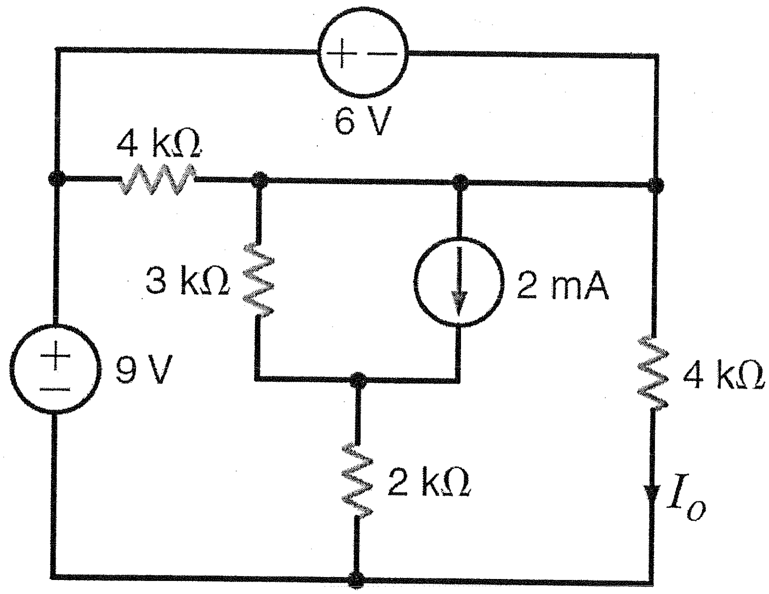
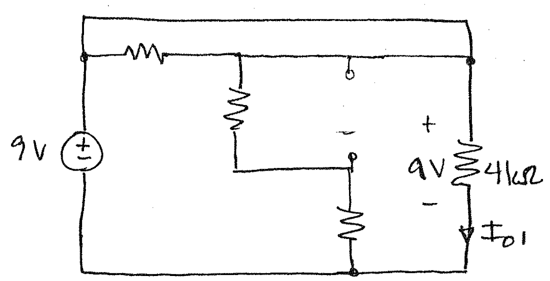
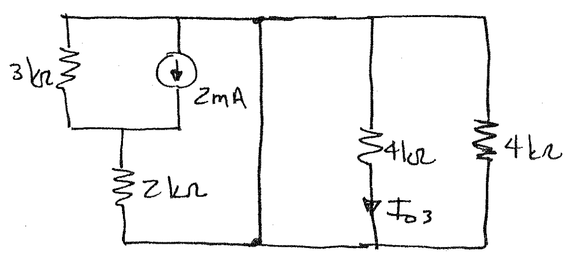


Figure P5.11

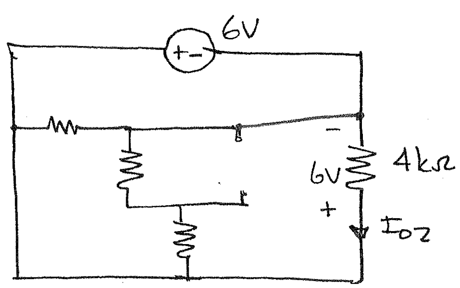
SOLUTION:



$$I_{o1} = \frac{9}{4000} = 2.25\text{mA}$$



$$I_{o3} = 0$$



$$I_{o2} = -\frac{6}{4000} = -1.5\text{mA}$$

$$I_o = I_{o1} + I_{o2} + I_{o3}$$

$$\boxed{I_o = 0.75\text{mA}}$$

5.12 Find V_o in the circuit in Fig. P5.12 using superposition.

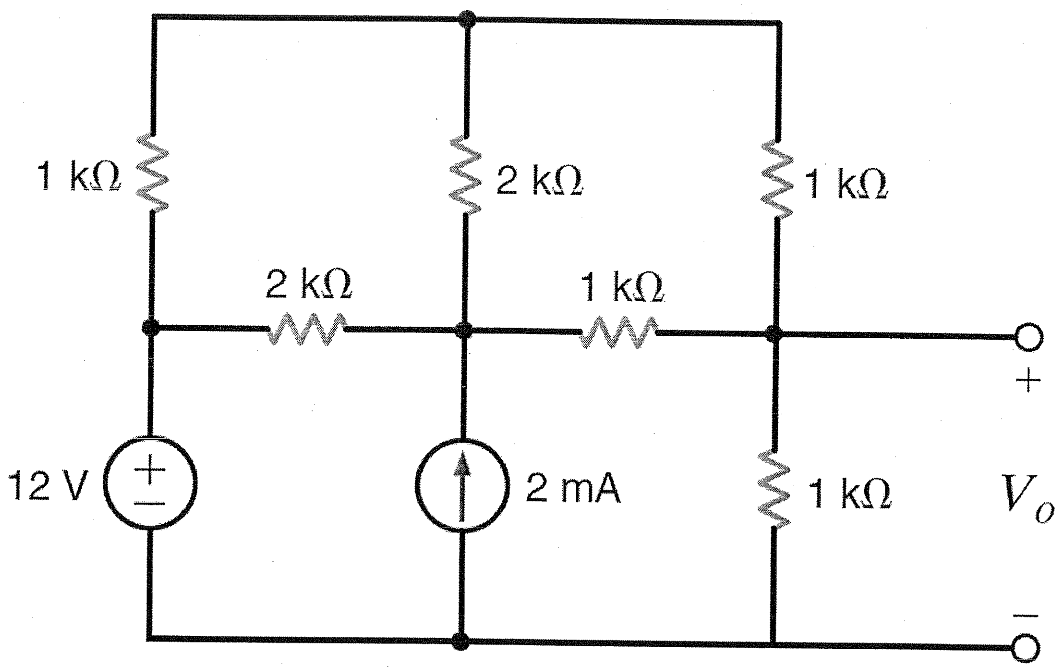
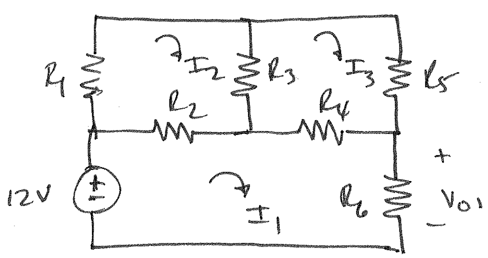


Figure P5.12

SOLUTION:



$R_1 = R_4 = R_5 = R_6 = 1k\Omega$

$R_2 = R_3 = 2k\Omega$

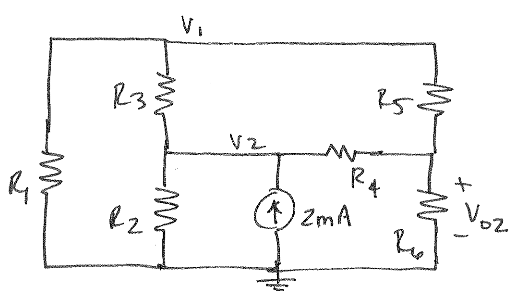
$5000 I_2 - 2000 I_1 - 2000 I_3 = 0$

$-1000 I_1 - 2000 I_2 + 4000 I_3 = 0$

$\Leftarrow \; 12 = 4000 I_1 - 2000 I_2 - 1000 I_3$

$I_1 = 5.49mA$

$V_{o1} = R_6 I_1 = 5.49V$



$$\frac{V_1}{R_1} + \frac{V_1 - V_2}{R_3} + \frac{V_1 - V_{o2}}{R_5} = 0$$

$$\frac{V_2 - V_1}{R_3} + \frac{V_2}{R_2} + \frac{V_2 - V_{o2}}{R_4} = 2\times10^{-3}$$

$$\frac{V_2 - V_{o2}}{R_4} = \frac{V_{o2}}{R_6} + \frac{V_{o2} - V_1}{R_5} \Rightarrow V_{o2} = 0.686V$$

$V_o = V_{o1} + V_{o2}$ $\boxed{V_o = 6.18V}$

5.13 Given the network in Fig. P5.13, use superposition to find V_o.

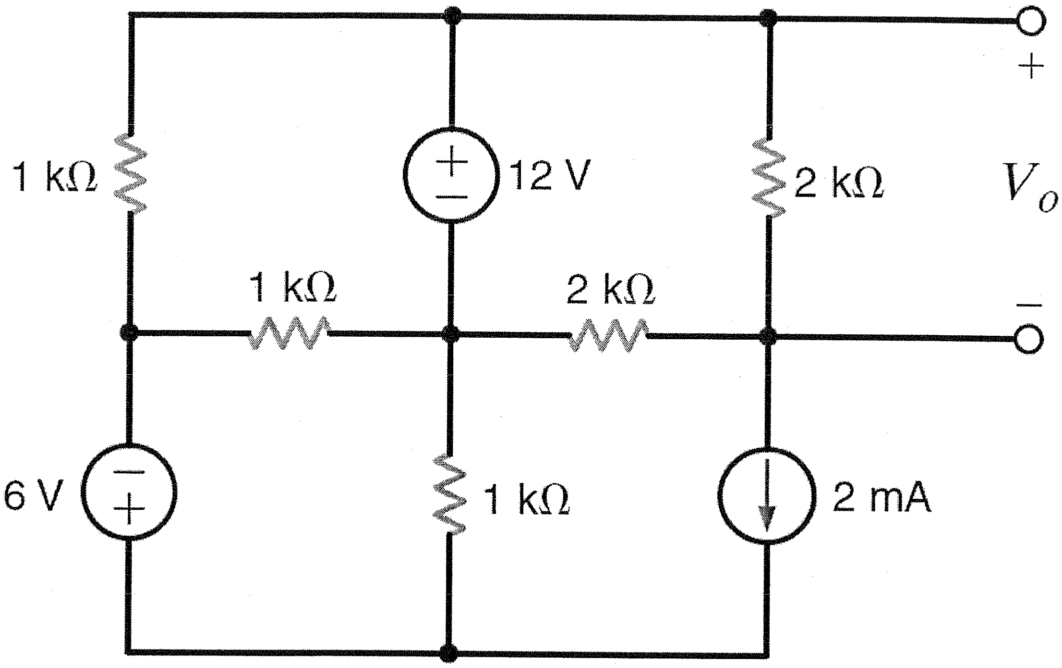
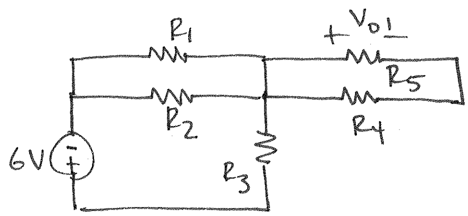


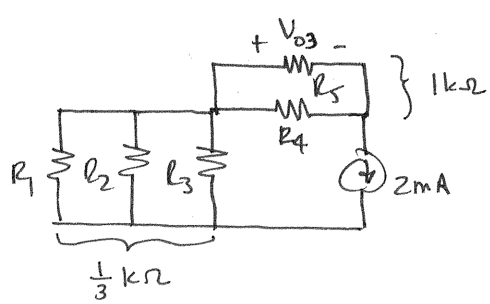
Figure P5.13

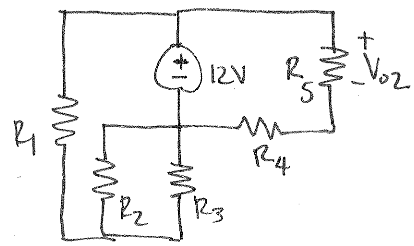
SOLUTION:



$R_1 = R_2 = R_3 = 1\,k\Omega \quad R_4 = R_5 = 2\,k\Omega$

$V_{o1} = 0V$





$V_{o3} = 1000\left(2\times10^{-3}\right) = 2V$

$V_{o2} = 12\left[\frac{R_5}{R_4+R_5}\right]$

$V_{o3} = 2V$

$V_{o2} = 6V$

$V_o = V_{o1} + V_{o2} + V_{o3}$ $\boxed{V_o = 8\,V}$

5.14 Use superposition to find V_o in the circuit in Fig. P5.14.

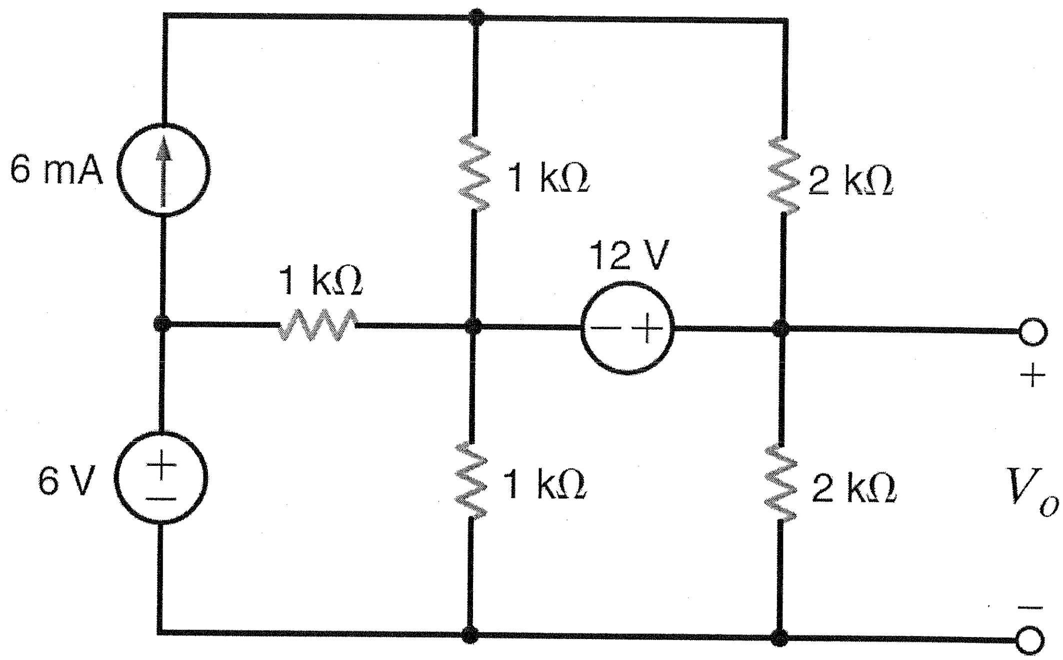
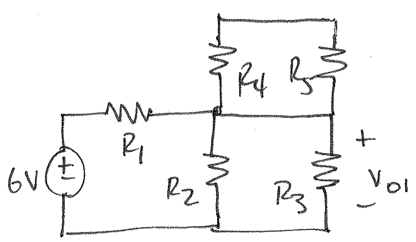


Figure P5.14

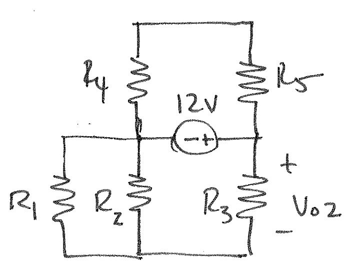
SOLUTION:



$R_1 = R_2 = R_4 = 1k\Omega \qquad R_3 = R_5 = 2k\Omega$

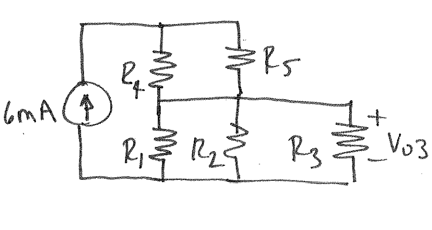
$R_x = R_2 // R_3$

$V_{o1} = 6\left[\frac{R_x}{R_x + R_1}\right] = 2.4V$



$R_y = R_1 // R_2 = 500\Omega$

$V_{o2} = 12\left[\frac{R_3}{R_3 + R_y}\right] = 9.6V$



$R_A = R_4 // R_5 = 667\Omega \qquad R_B = R_1 // R_2 // R_3 = 400\Omega$

$V_{o3} = 6\times10^{-3} R_B = 2.4V$

$V_o = V_{o1} + V_{o2} + V_{o3} \qquad \boxed{V_o = 14.4V}$

5.15 Find V_o in the circuit in Fig. P5.15 using superposition.

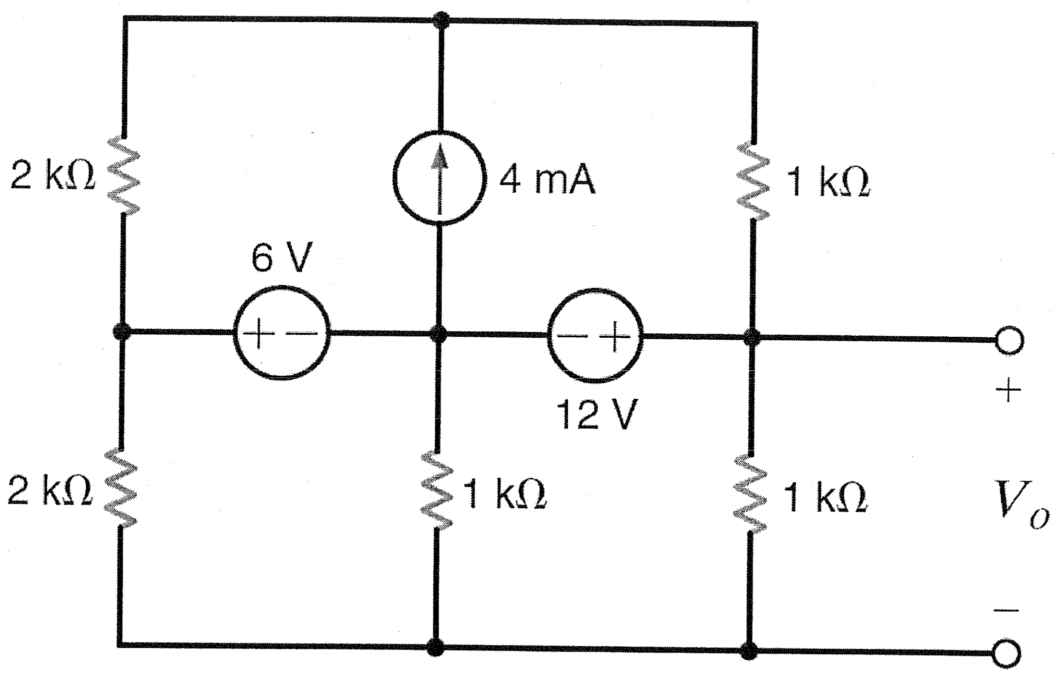
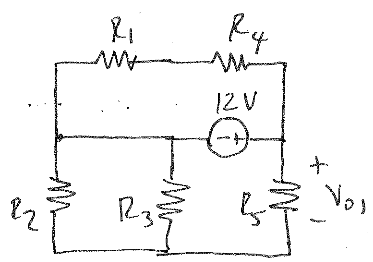


Figure P5.15

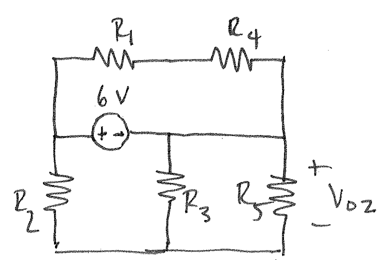
SOLUTION:



$R_1 = R_2 = 2k\Omega \quad R_3 = R_4 = R_5 = 1k\Omega$

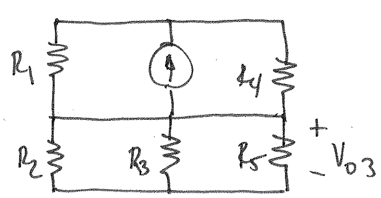
$R_A = R_2 // R_3 = 667\Omega$

$V_{01} = \dfrac{12\ R_5}{R_5 + R_A} \qquad V_{01} = 7.2V$



$R_B = R_3 // R_5 = 500\Omega$

$V_{02} = -\dfrac{6\ R_B}{R_B + R_2} \qquad V_{02} = -1.2V$



$V_{03} = 0V \qquad V_0 = V_{01} + V_{02} + V_{03}$

$\boxed{V_0 = 5.2V}$

5.16 Find I_o in the circuit in Fig. P5.16 using superposition.

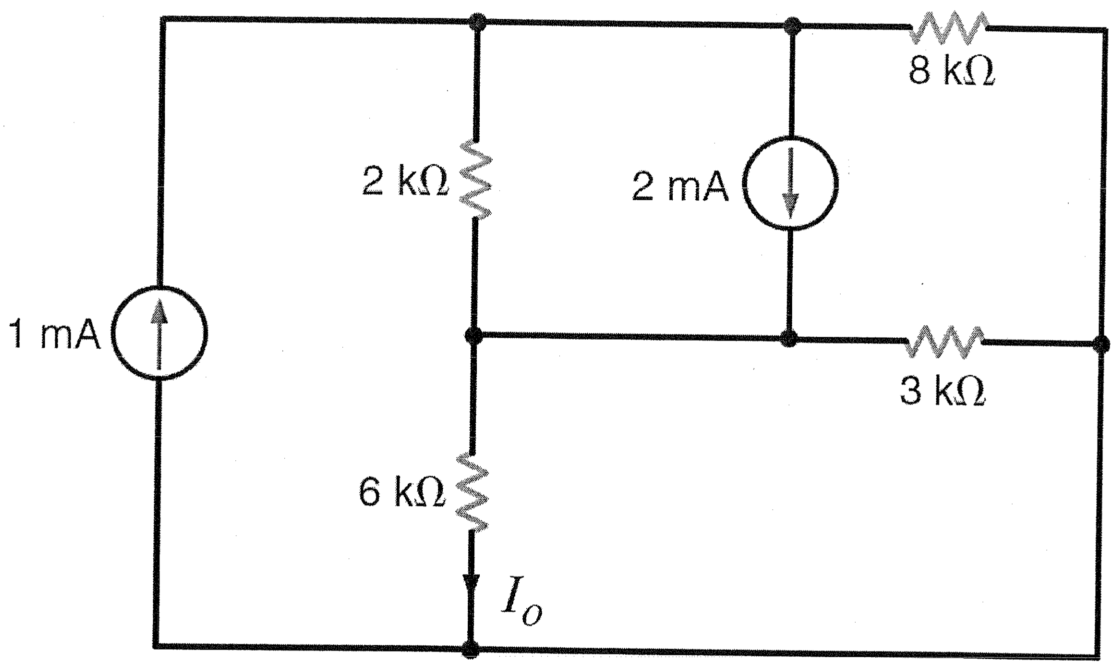
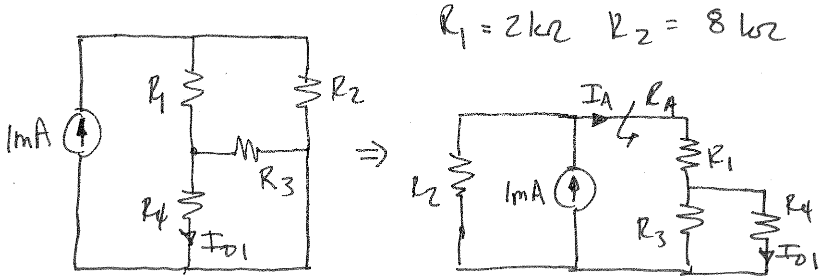


Figure P5.16

SOLUTION:

$R_1 = 2k\Omega \quad R_2 = 8k\Omega \quad R_3 = 3k\Omega \quad R_4 = 6k\Omega$

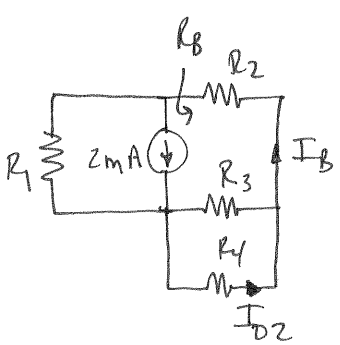


$R_A = R_1 + (R_3 // R_4) = 4k\Omega$

$I_A = 10^{-3}\left[\frac{R_2}{R_2 + R_A}\right]$

$I_A = 0.667\,mA$

$I_{o1} = I_A\left[\frac{R_3}{R_3 + R_4}\right] = 0.222\,mA$



$R_C = R_3 // R_4 = 2k\Omega \quad R_B = R_2 + R_C = 10k\Omega$

$I_B = 2\times10^{-3}\left[\frac{R_1}{R_1 + R_B}\right] = 0.333\,mA$

$I_{o2} = I_B\left[\frac{R_3}{R_3 + R_4}\right] = 0.111\,mA$

$\boxed{I_o = 0.333\,mA}$

5.17 Use superposition to find I_o in the network in Fig. P5.17.

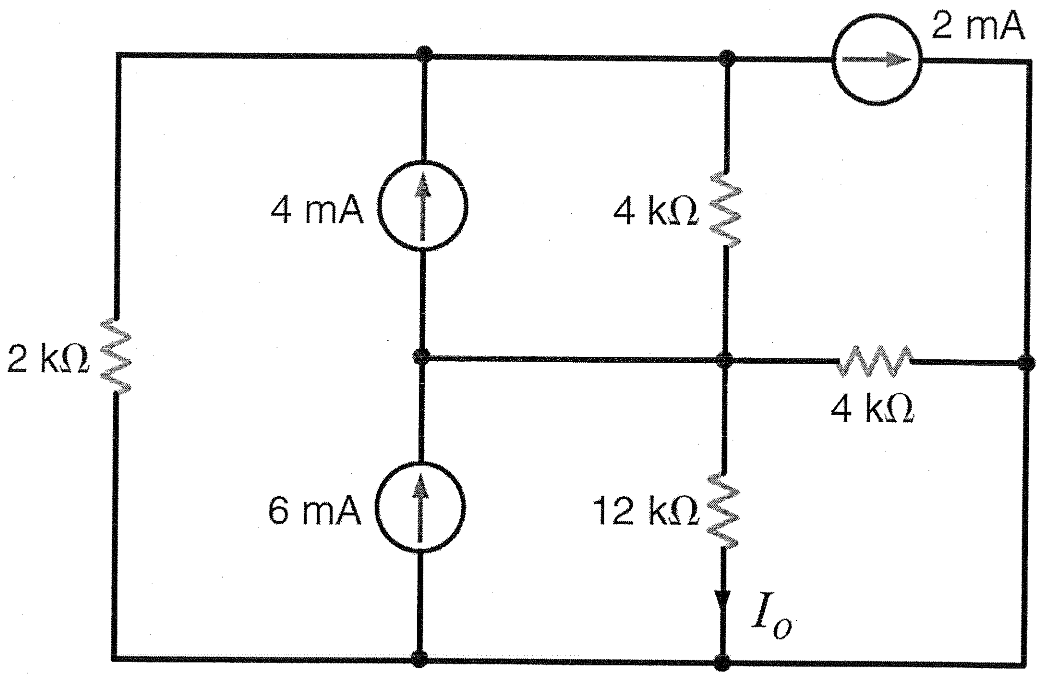
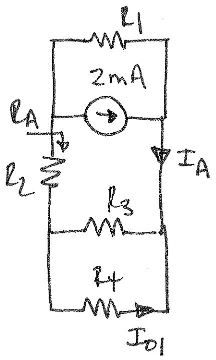


Figure P5.17

SOLUTION:

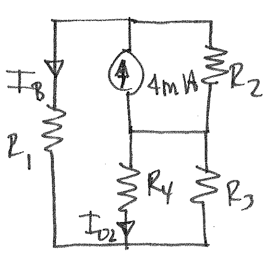


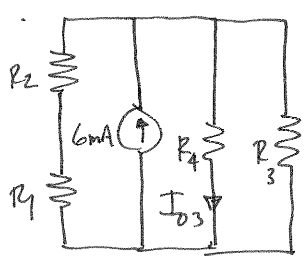
$R_1 = 2k\Omega \quad R_2 = 4k\Omega \quad R_3 = 4k\Omega \quad R_4 = 12k\Omega$

$R_A = R_2 + (R_3 // R_4) = 7k\Omega \qquad I_A = 2\times10^{-3}\left[\frac{R_1}{R_1+R_A}\right]$

$I_A = 0.444mA$

$I_{o1} = -I_A\, R_3 / (R_3 + R_4) = -0.111mA$





$R_C = R_1 + R_2 = 6k\Omega \qquad G_C = 1/R_C$

$G_4 = 1/R_4 \qquad G_3 = 1/R_3$

$I_{o3} = 6\times10^{-3}\, G_4 / (G_C + G_3 + G_4) = 1mA$

$\boxed{I_o = 0.444mA}$

$R_B = R_1 + (R_3 // R_4) = 5k\Omega \qquad I_B = 4\times10^{-3}\, R_2 / (R_2 + R_B) = 1.78mA$

$I_{o2} = -I_B\, R_3 / (R_3 + R_4) = -0.444mA$

5.18 Use superposition to find I_o in the circuit in Fig. P5.18.

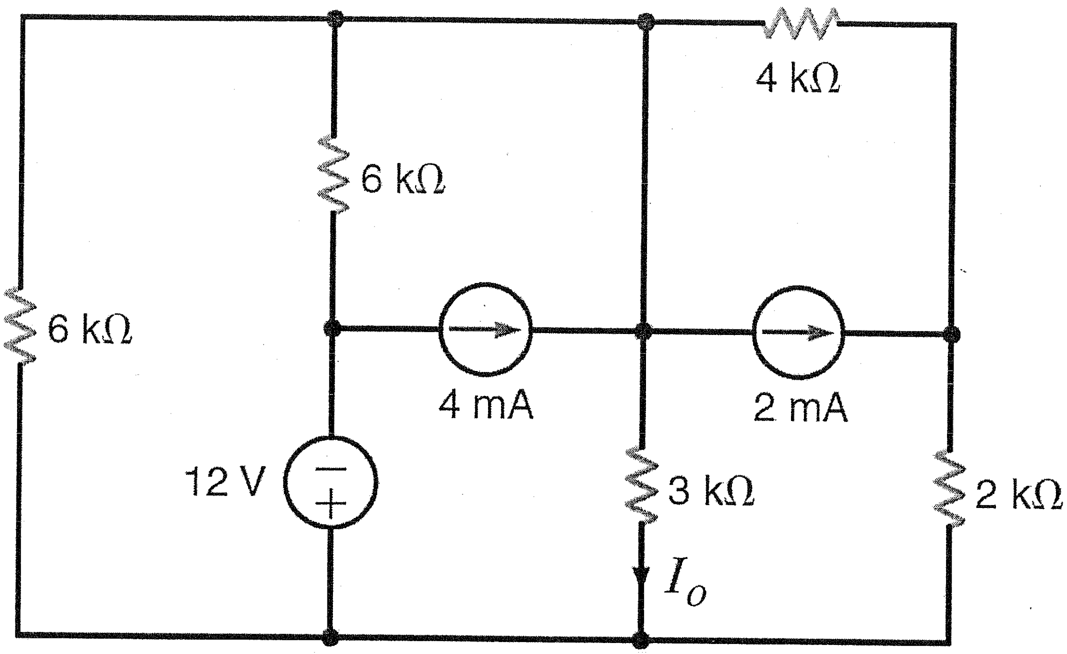
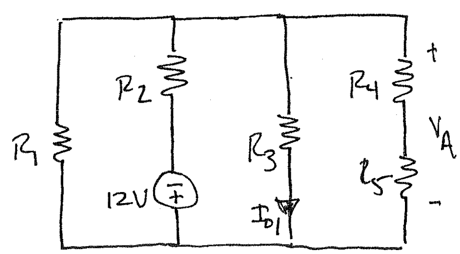


Figure P5.18

SOLUTION:



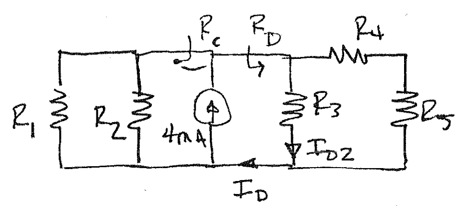
$R_1 = R_2 = 6k\Omega \quad R_3 = 3k\Omega \quad R_4 = 4k\Omega \quad R_5 = 2k\Omega$

$R_A = R_4 + R_5 = 6k\Omega$

$R_B = R_1 // R_3 // R_A = 1.5k\Omega$

$V_A = -12\, R_B / (R_B + R_2) = -2.4V$

$I_{o1} = V_A / R_3 = -0.80mA$



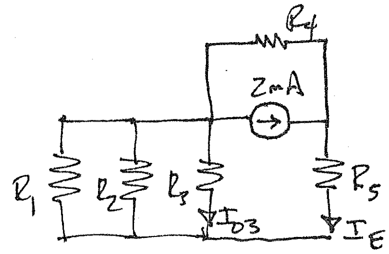
$R_C = R_1 // R_2 = 3k\Omega$

$R_D = R_3 // (R_4 + R_5) = 2k\Omega$

$I_D = 4 \times 10^{-3}\, R_C / (R_C + R_D) = 2.4\ mA$

$$I_{o2} = \frac{I_D\,(R_4 + R_5)}{R_3 + R_4 + R_5}$$

$I_{o2} = 1.6\ mA$



$R_E = R_1 // R_2 // R_3 = 1.5k\Omega$

$R_F = R_5 + R_E = 3.5k\Omega$

$I_E = 2\times10^{-3}\, R_4 / (R_4 + R_F) = 1.07mA$

$$I_{o3} = -\frac{I_E G_3}{G_1+G_2+G_3}$$

$G_1 = 1/R_1 \quad G_2 = 1/R_2 \quad G_3 = 1/R_3$

$I_{o3} = -0.53\ mA$

$I_o = I_{o1} + I_{o2} + I_{o3}$

$\boxed{I_o = 0.267\ mA}$

5.19 Find I_o in the circuit in Fig. P5.19 using superposition.

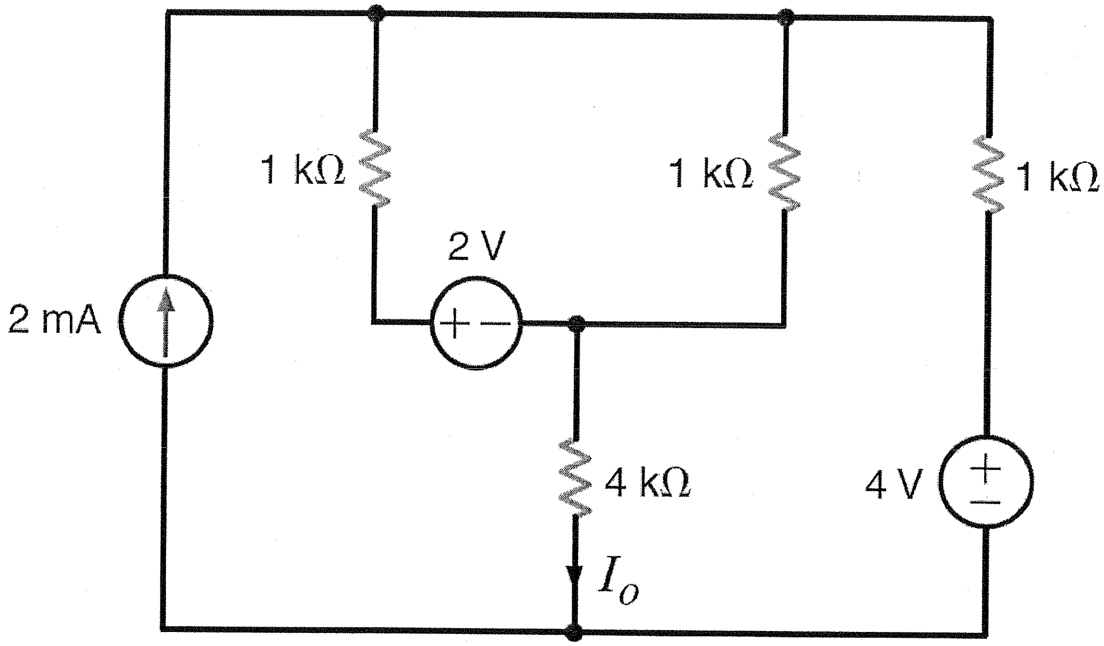
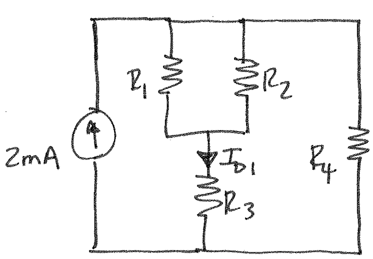


Figure P5.19

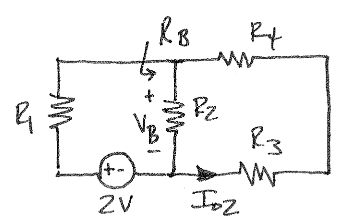
SOLUTION:



$R_1 = R_2 = R_4 = 1k\Omega \quad R_3 = 4k\Omega$

$R_A = (R_1 // R_2) + R_3 = 4.5k\Omega$

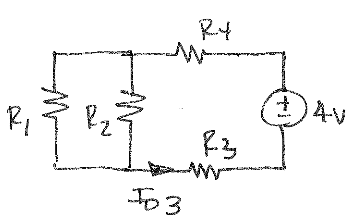
$I_{o1} = 2\times10^{-3} R_4 / (R_4 + R_A) \quad I_{o1} = 0.364mA$



$R_B = R_2 // (R_3 + R_4) = 833\Omega$

$V_B = 2 R_B / (R_1 + R_B) = 0.910V$

$I_{o2} = -V_B / (R_3 + R_4) = -0.182mA$



$R_C = R_1 // R_2 = 500\Omega$

$I_{o3} = 4 / (R_4 + R_C + R_3) = 0.727mA$

$I_o = I_{o1} + I_{o2} + I_{o3} \quad \boxed{I_o = 0.909mA}$

5.20 Use superposition to find I_o in the circuit in Fig. P5.20.

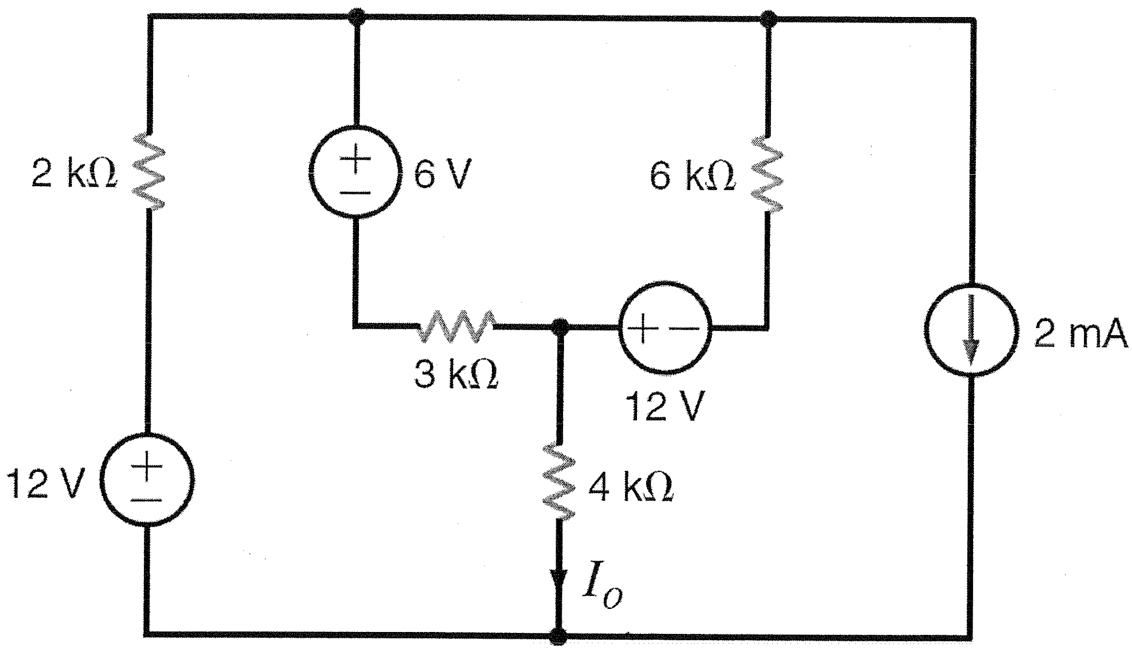
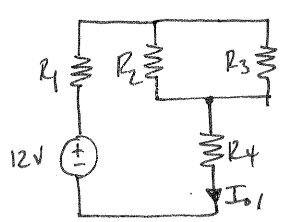


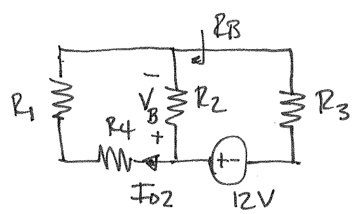
Figure P5.20

SOLUTION:

$R_1 = 2k\Omega \quad R_2 = 3k\Omega \quad R_3 = 6k\Omega \quad R_4 = 4k\Omega$



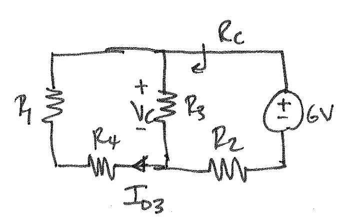
$\Leftarrow R_A = R_2 // R_3 = 2k\Omega \qquad I_{o1} = 12/(R_1 + R_A + R_4) = 1.5mA$



$R_B = (R_1 + R_4) // R_2 = 2k\Omega$

$V_B = 12 R_B / (R_B + R_3) = 3V$

$I_{o2} = V_B / (R_1 + R_4) = 0.5mA$



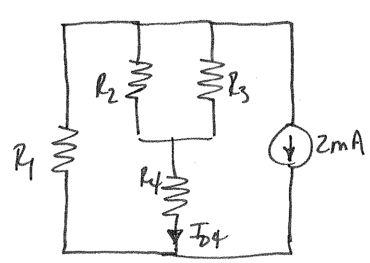
$R_C = (R_1 + R_4) // R_3 = 3k\Omega$

$V_C = 6 R_C / (R_C + R_2)$

$V_C = 3V$

$I_{o3} = -V_C / (R_1 + R_4)$

$I_{o3} = -0.5mA$



$R_D = R_4 + (R_2 // R_3) = 6k\Omega$

$I_{o4} = -2\times10^{-3} R_1 / (R_1 + R_D)$

$I_{o4} = -0.5mA$

$\boxed{I_o = 1mA}$

5.21 Find I_o in the circuit in Fig. P5.21 using superposition.

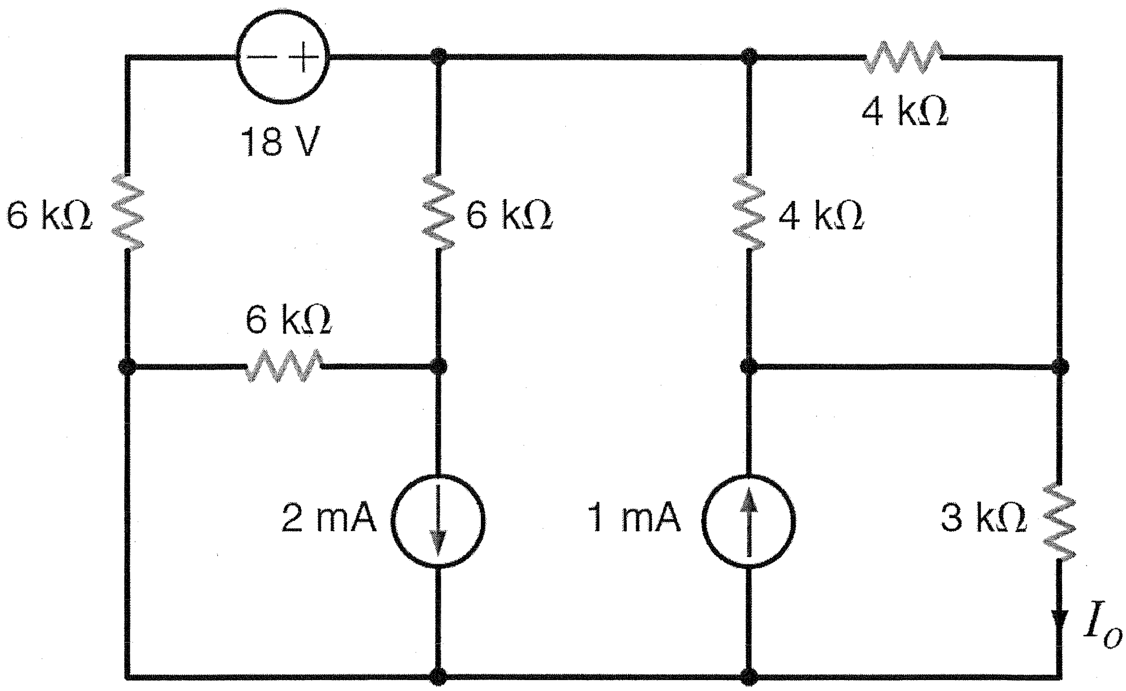
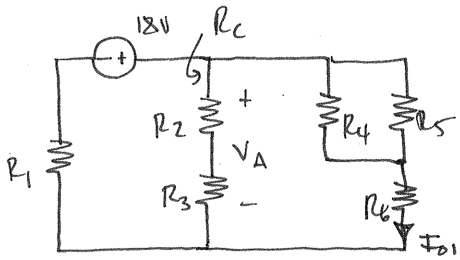


Figure P5.21

SOLUTION:

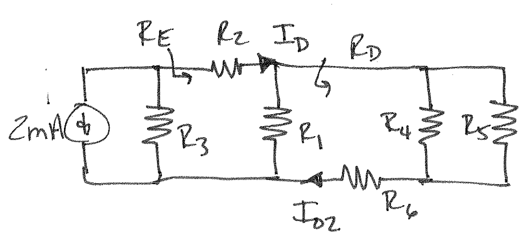


$R_1 = R_2 = R_3 = 6k\Omega \quad R_4 = R_5 = 4k\Omega \quad R_6 = 3\ k\Omega$

$R_A = R_2 + R_3 = 12k\Omega \quad R_B = R_4 // R_5 = 2k\Omega$

$R_C = R_A // (R_B + R_6) = 3.53\ k\Omega$

$V_A = 18R_C / (R_1 + R_C) = 6.67\ V \qquad I_{o1} = V_A / (R_B + R_6) = 1.33\ mA$

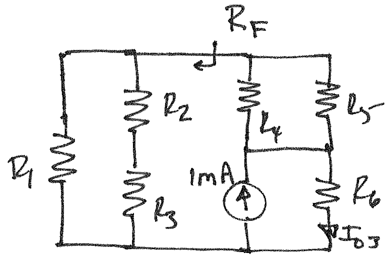


$R_D = R_6 + (R_4 // R_5) = 5k\Omega$

$R_E = R_2 + (R_1 // R_D) = 8.73\ k\Omega$

$I_D = -2\times10^{-3} R_3 / (R_3 + R_E) = -0.815 mA$

$I_{o2} = \dfrac{I_D R_1}{R_1 + R_D} \qquad I_{o2} = -0.444 mA$



$R_F = R_1 // (R_2 + R_3) = 4k\Omega$

$R_G = R_F + (R_4 // R_5) = 6k\Omega$

$I_{O3} = 10^{-3} R_G / (R_G + R_6) = 0.667 mA$

$I_O = I_{O1} + I_{O2} + I_{O3} \Rightarrow \boxed{I_O = 1.55 mA}$

5.22 Use superposition to find I_o in the network in Fig. P5.22.
PSV

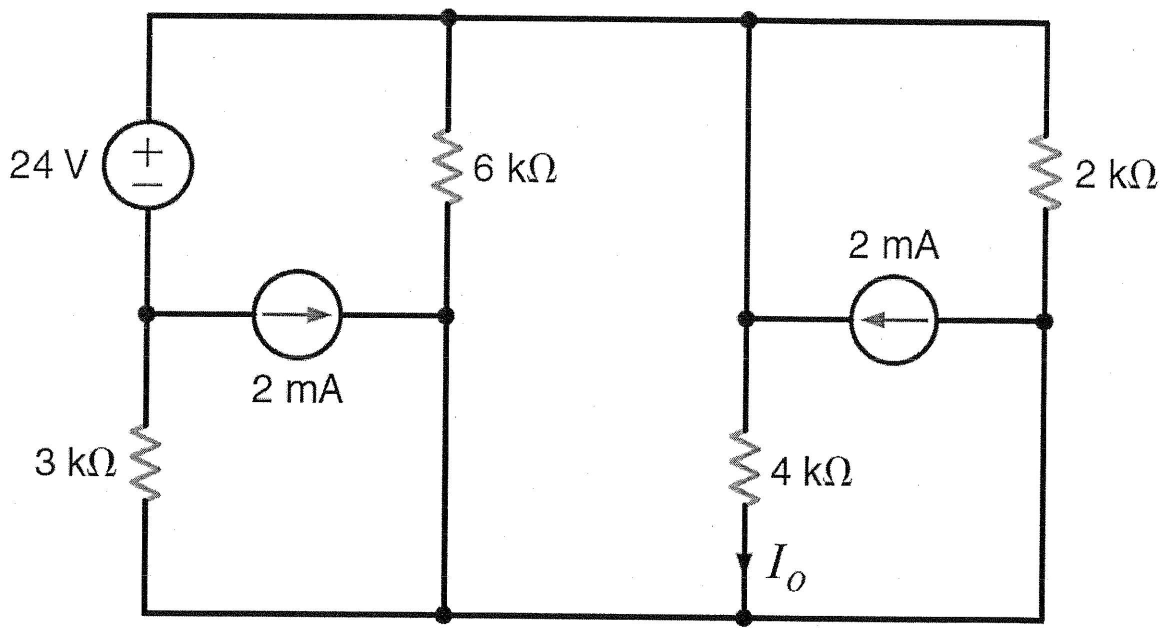
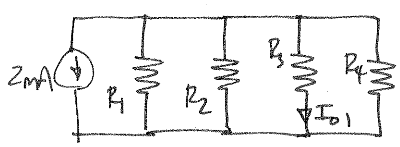


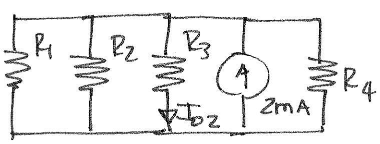
Figure P5.22

SOLUTION:

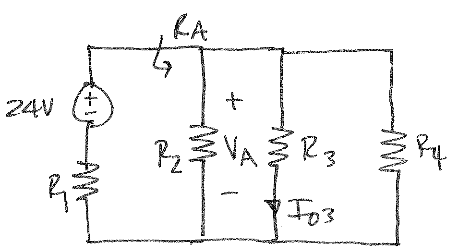


$R_1 = 3k\Omega \quad R_2 = 6k\Omega \quad R_3 = 4k\Omega \quad R_4 = 2k\Omega$

$I_{o1} = -2\times10^{-3}\, G_3 / (G_1 + G_2 + G_3 + G_4) = -0.4mA$



$I_{o2} = 2\times10^{-3}\, G_3 / (G_1 + G_2 + G_3 + G_4) = 0.4mA$



$R_A = R_2 // R_3 // R_4 = 1.091k\Omega$

$V_A = 24\, R_A / (R_A + R_1) = 6.4V$

$I_{o3} = V_A / R_3 = 1.6mA$

$I_o = I_{o1} + I_{o2} + I_{o3}$ $\boxed{I_o = 1.6mA}$

5.23 The loop equations for a two-loop network are

$$I_1 R_{11} + I_2 R_{12} = V_1$$
$$I_1 R_{21} + I_2 R_{22} = V_2$$

What is the relationship among V_1, V_2, and R_{ij} for $I_1 = 0$.

SOLUTION:

$I_2 R_{12} = V_1 \quad \& \quad I_2 R_{22} = V_2$

$\frac{I_2 R_{12}}{V_1} = 1 \quad \& \quad \frac{I_2 R_{22}}{V_2} = 1$

$\frac{I_2 R_{12}}{V_1} = \frac{I_2 R_{22}}{V_2} \Rightarrow \boxed{\frac{V_2}{V_1} = \frac{R_{22}}{R_{12}}}$

5.24 Use the results of Problem 5.23 to find the value of I_x that yields a $V_1 = 0$ V in the network in Fig. P5.24.

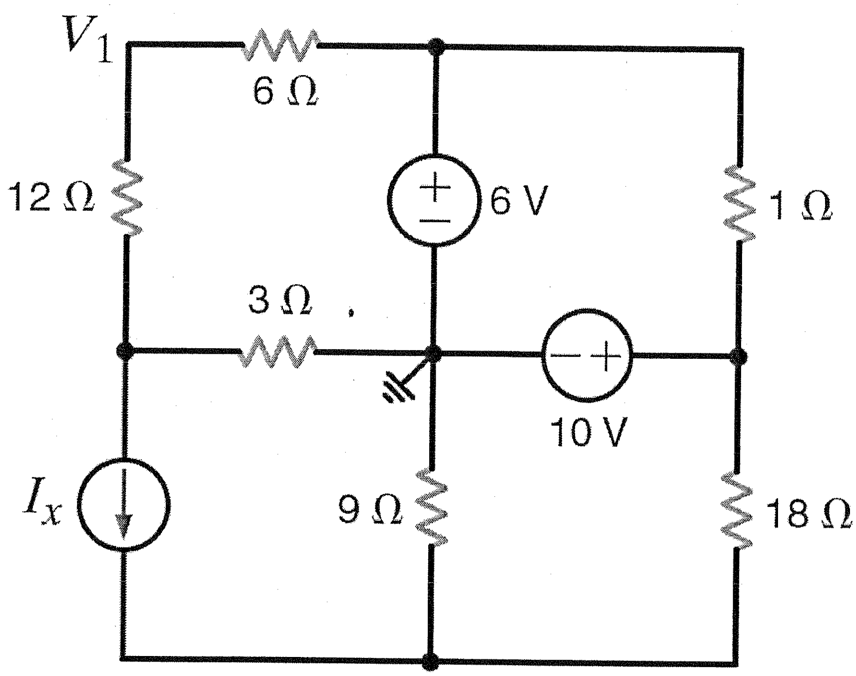


Figure P5.24

SOLUTION:

$V_1 = 6 + 6I_1 = 0 \Rightarrow I_1 = -1\text{A}$

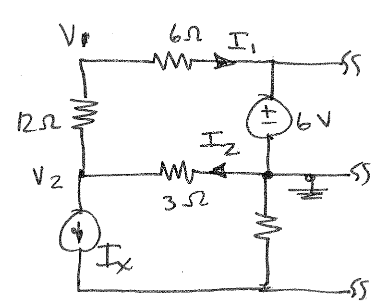
$V_1 - V_2 = -I_1(12) = 12\text{V}$

$V_2 = -12\text{V}$

$I_x = -I_1 + I_2$

$I_2 = (0 - V_2)/3 = 4\text{A}$

$\boxed{I_x = 5\text{A}}$



5.25 A three-node circuit is described by the following equations:

$$G_{11}V_1 + G_{12}V_2 + G_{13}V_3 = I_1$$
$$G_{21}V_1 + G_{22}V_2 + G_{23}V_3 = I_2$$
$$G_{31}V_1 + G_{32}V_2 + G_{33}V_3 = I_3$$

Show that for $V_2 = 0$,

$$I_1\begin{vmatrix} G_{21} & G_{23} \\ G_{31} & G_{33} \end{vmatrix} - I_2\begin{vmatrix} G_{11} & G_{13} \\ G_{31} & G_{33} \end{vmatrix} + I_3\begin{vmatrix} G_{11} & G_{13} \\ G_{21} & G_{23} \end{vmatrix} = 0$$

SOLUTION:

By Cramer's Rule,

$$V_2 = \frac{\begin{vmatrix} G_{11} & I_1 & G_{13} \\ G_{21} & I_2 & G_{23} \\ G_{31} & I_3 & G_{33} \end{vmatrix}}{\begin{vmatrix} G_{11} & G_{12} & G_{13} \\ G_{21} & G_{22} & G_{23} \\ G_{31} & G_{32} & G_{33} \end{vmatrix}} = \frac{-I_1\begin{vmatrix} G_{21} & G_{23} \\ G_{31} & G_{33} \end{vmatrix} + I_2\begin{vmatrix} G_{11} & G_{13} \\ G_{31} & G_{33} \end{vmatrix} - I_3\begin{vmatrix} G_{11} & G_{13} \\ G_{21} & G_{23} \end{vmatrix}}{|G|} = 0$$

So,

$$I_1\begin{vmatrix} G_{21} & G_{23} \\ G_{31} & G_{33} \end{vmatrix} - I_2\begin{vmatrix} G_{11} & G_{13} \\ G_{31} & G_{33} \end{vmatrix} + I_3\begin{vmatrix} G_{11} & G_{13} \\ G_{21} & G_{23} \end{vmatrix} = 0$$

5.26 Use the results of Problem 5.25 to determine the value of V_B such that V_o is zero in the network in Fig. P5.26.

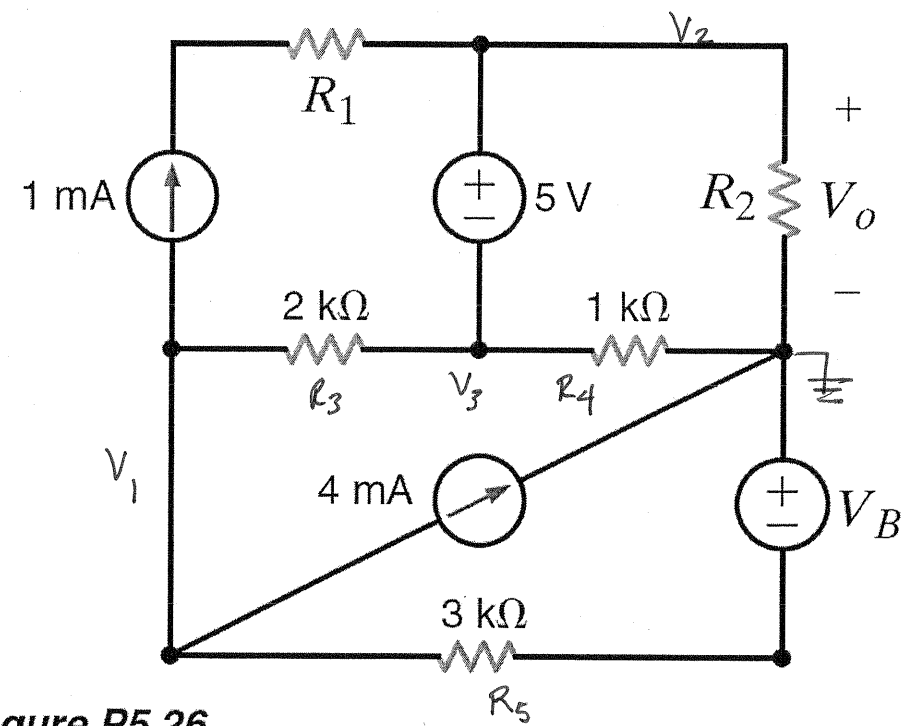


Figure P5.26

Explain why the values of R_1 and R_2 have no impact on your analysis.

SOLUTION:

$$\frac{V_2}{R_2} + \frac{V_3}{R_4} + 4\times10^{-3} + \frac{V_1 + V_B}{R_5} = 0$$

$$\frac{V_1 - V_3}{R_3} + \frac{V_1 + V_B}{R_5} + 10^{-3} + 4\times10^{-3} = 0$$

$$V_2 - V_3 = 5$$

$$10^{-3}\begin{bmatrix} 1/3 & \frac{1000}{R_2} & 1 \\ 5/6 & 0 & -1/2 \\ 0 & 1 & -1 \end{bmatrix}\begin{bmatrix} V_1 \\ V_2 \\ V_3 \end{bmatrix} = \begin{bmatrix} -4 - V_B/R_5 \\ -5 - V_B/R_5 \\ 5 \end{bmatrix}$$

$$-\left(4+\frac{V_B}{R_5}\right)\begin{vmatrix} 5/6 & -1/2 \\ 0 & -1 \end{vmatrix} + \left(5+\frac{V_B}{R_5}\right)\begin{vmatrix} 1/3 & 1 \\ 0 & -1 \end{vmatrix} + 5\begin{vmatrix} 1/3 & 1 \\ 5/6 & -1/2 \end{vmatrix} = V_2 = 0$$

$$-(4 + V_B/R_5)(-5/6) + (5 + V_B/R_5)(-1/3) + 5(-1) = 0$$

$$\boxed{V_B = 20\,V}$$

The current through R_1 is fixed by the 1-mA current source. Thus, the value of R_1 has no impact in our nodal analysis.

Also, when $V_2 = 0$, the current through R_2 is zero regardless of the value of R_2.

5.27 (a) Given the network in Fig. P5.27, find the value of R_2 such that $V_o = 0$ V. (b) Then find the Thévenin and Norton equivalent circuits at *A*-*B* as seen by R_3 using the results of (a).

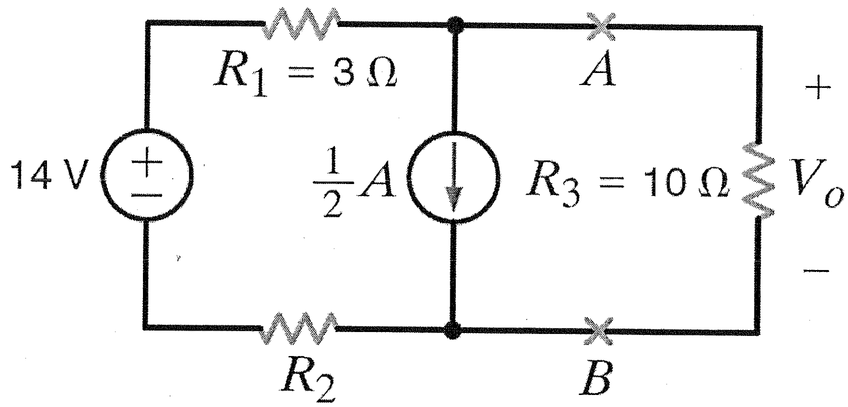
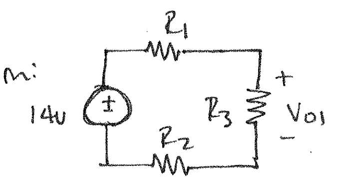
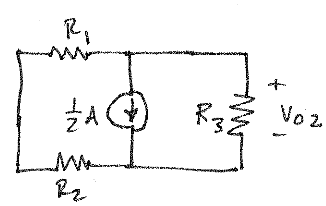


Figure P5.27

SOLUTION:

a) Superposition:





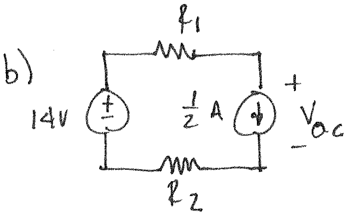
$V_{o1} = 14R_3/(R_1+R_2+R_3)$

$$V_{o2} = -\frac{\frac{1}{2}(R_1+R_2)}{R_1+R_2+R_3} R_3$$

$$V_{o1} + V_{o2} = V_o = 0 = \frac{14R_3}{R_1+R_2+R_3} - \frac{R_1+R_2}{2}\frac{R_3}{R_1+R_2+R_3}$$

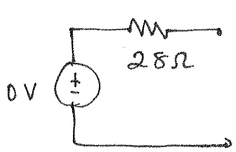
$\boxed{R_2 = 25\,\Omega}$

b)

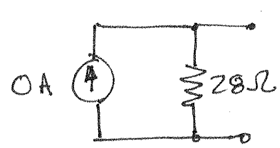


$V_{OC} = 14 - \frac{1}{2}R_1 - \frac{1}{2}R_2 = 0$ V

$R_{TH} = R_1 + R_2 = 28\,\Omega$



Thevenin Eq.



Norton Eq

5.28 Use Thévenin's theorem to find V_o in the network in Fig. P5.28. CS

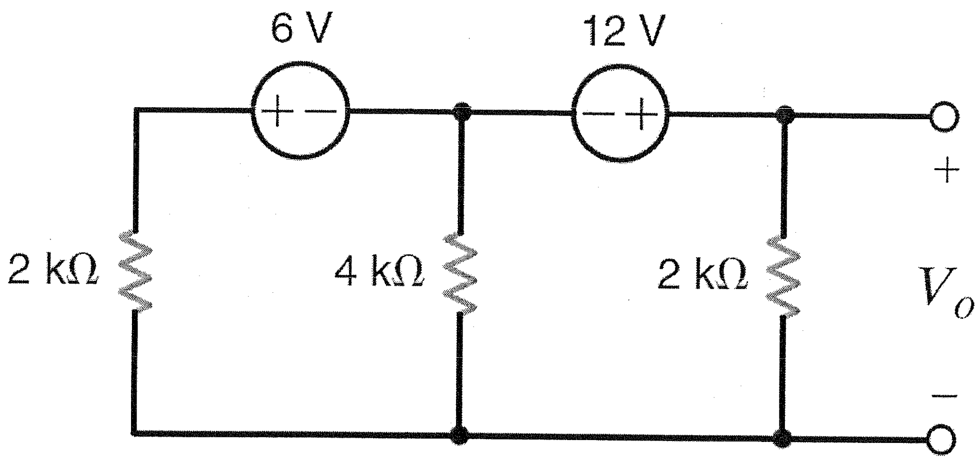
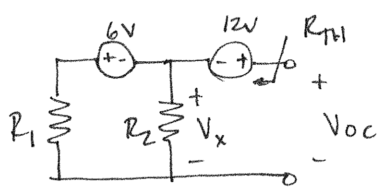


Figure P5.28

SOLUTION:

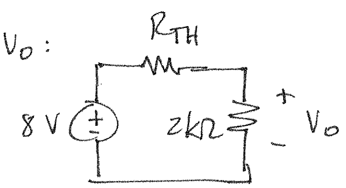


$R_1 = 2k\Omega \quad R_2 = 4k\Omega$

$V_x = -6\, R_2 / (R_1 + R_2) = -4V$

$V_{oc} = 12 + V_x = 8V \qquad R_{TH} = R_1 // R_2 = 1.33 k\Omega$

Find V_o:



$V_o = \dfrac{8(2000)}{2000 + R_{TH}}$ $\boxed{V_o = 4.8V}$

5.29 Find I_o in the network in Fig. P5.29 using Thévenin's theorem.

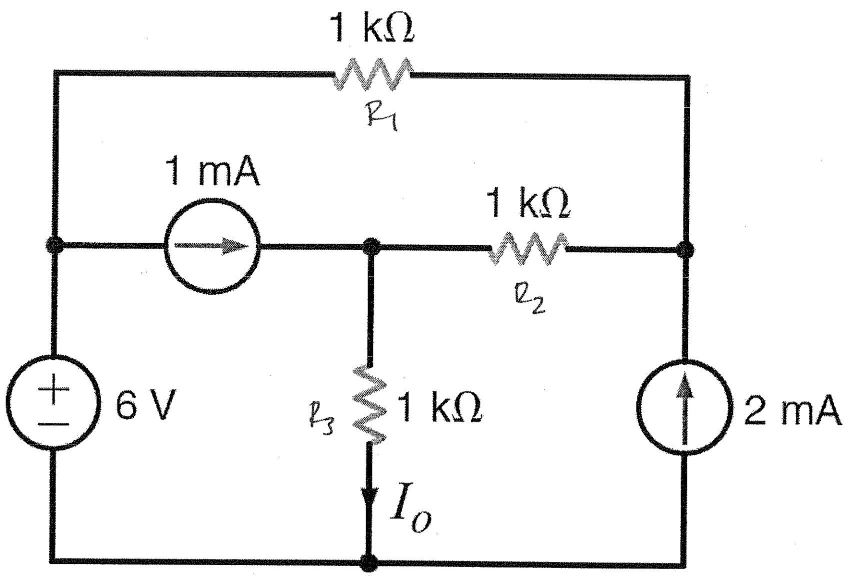
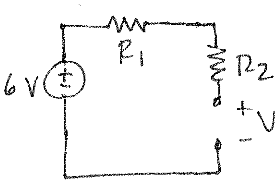
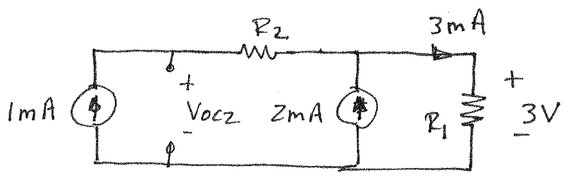


Figure P5.29

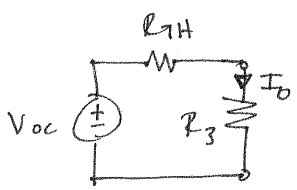
SOLUTION: Superposition !

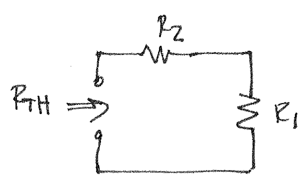




$$V_{oc2} = 10^{-3} R_2 + 3\times10^{-3} R_1 = 4V$$

$$V_{oc} = V_{oc1} + V_{oc2} = 10V$$





$R_{TH} = R_2 + R_1$

$R_{TH} = 2k\Omega$

$I_o = V_{oc} / (R_3 + R_{TH})$

$$\boxed{I_o = 3.33mA}$$

5.30 Find I_o in the circuit in Fig. P5.30 using Thévenin's theorem. CS

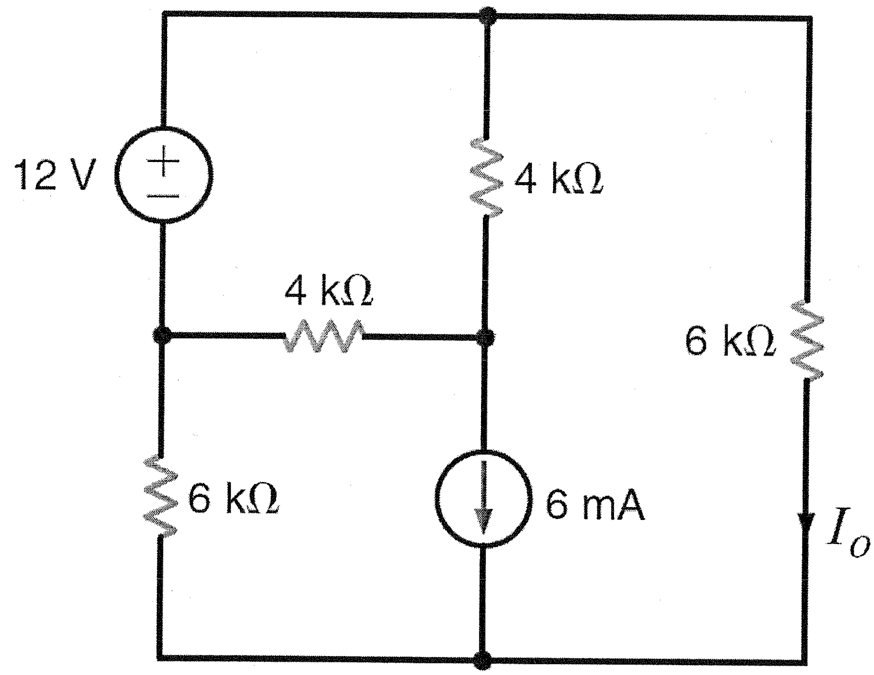
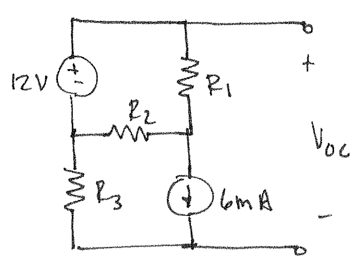
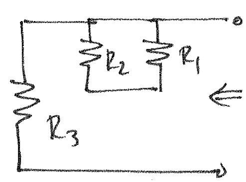


Figure P5.30

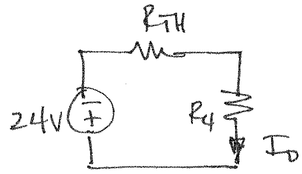
SOLUTION: $R_1 = R_2 = 4k\Omega \quad R_3 = 6k\Omega \quad R_4 = 6k\Omega$



$$12 = V_{oc} + 6\times10^{-3} R_3 \Rightarrow \quad V_{oc} = -24V$$



$\Leftarrow R_{TH} = R_3 = 6k\Omega$



$$I_o = \frac{-24}{R_{TH} + R_4}$$

$$\boxed{I_o = -2mA}$$

5.31 Find V_o in the network in Fig. P5.31 using Thévenin's theorem. **PSV**

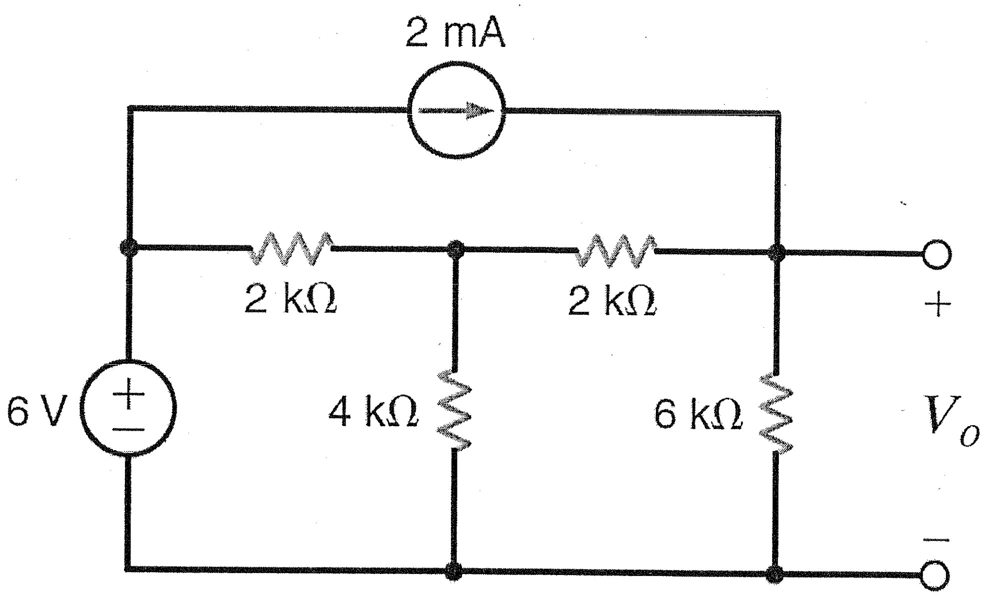
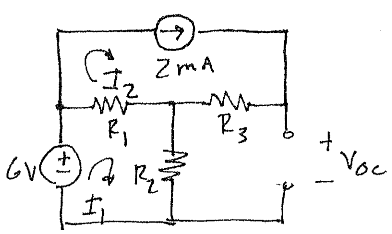


Figure P5.31

SOLUTION: $R_1 = R_3 = 2k\Omega \quad R_2 = 4k\Omega \quad R_4 = 6k\Omega$

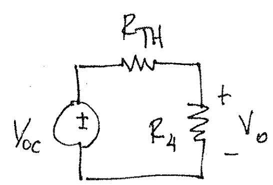


$$6 = 6000 I_1 - 2000 I_2 \qquad I_2 = 2mA$$

$$I_1 = 1.67\,mA$$

$$6 = R_1(I_1 - I_2) + R_3(-I_2) + V_{oc} \Rightarrow V_{oc} = 10.67V$$

$$R_{TH} = R_3 + (R_1 // R_2) = 3.33k\Omega$$



$$V_o = V_{oc} R_4 / (R_{TH} + R_4) \qquad \boxed{V_o = 6.86\,V}$$

5.32 Find V_o in the circuit in Fig. P5.32 using Thévenin's theorem.

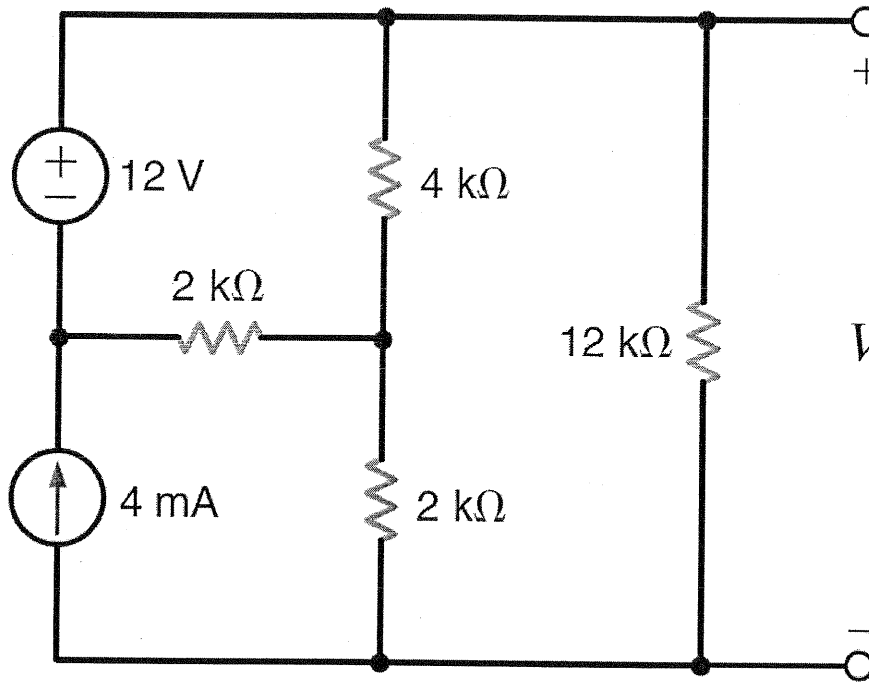
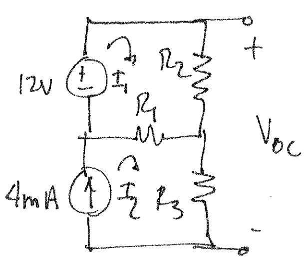


Figure P5.32

SOLUTION:



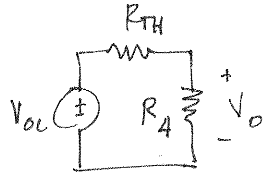
$R_1 = R_3 = 2k\Omega \quad R_3 = 4k\Omega \quad R_4 = 12k\Omega$

$12 = I_1 (R_1 + R_2) - R_1 I_2 \qquad I_2 = 4mA$

$I_1 = 3.33mA$

$R_2 I_1 + R_3 I_2 = V_{oc} = 21.33V$

$R_{TH} = (R_1 // R_2) + R_3 = 3.33k\Omega$



$V_o = \frac{V_{oc} R_4}{R_4 + R_{TH}}$

$\boxed{V_o = 16.70\,V}$

5.33 Find I_o in the network in Fig. P5.33 using Thévenin's theorem. CS

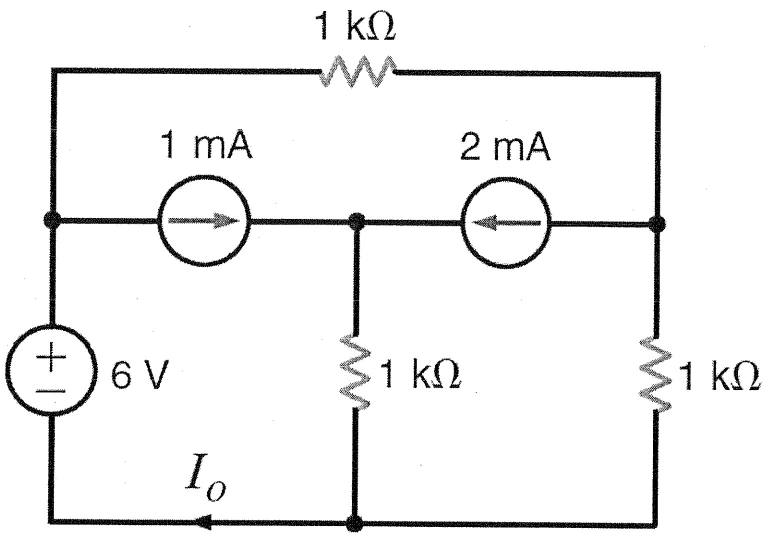
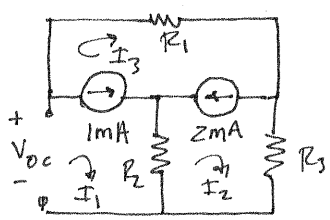


Figure P5.33

SOLUTION:

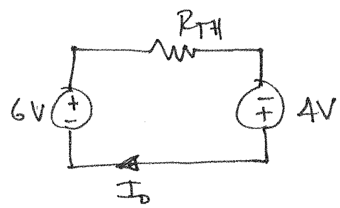


$I_1 = 0 \qquad I_1 - I_3 = 1mA \qquad I_3 - I_2 = 2mA$

$I_3 = -1mA$ & $I_2 = -3mA$

$V_{oc} = R_1 I_3 + R_3 I_2 = -4V$

$R_{TH} = R_1 + R_3 = 2k\Omega$



$6 = I_o R_{TH} - 4 \qquad I_o = \frac{10}{R_{TH}} \qquad \boxed{I_o = 5mA}$

5.34 Find I_o in the network in Fig. P5.34 using Thévenin's theorem.

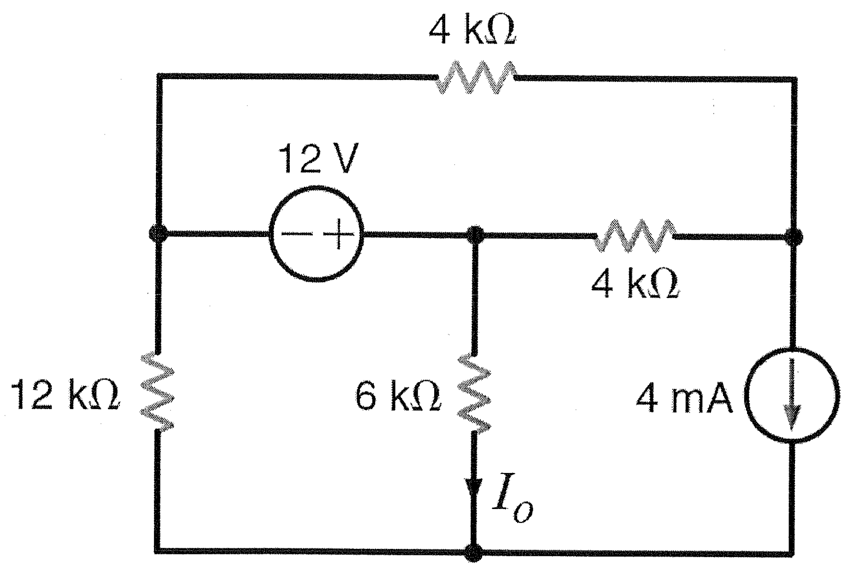
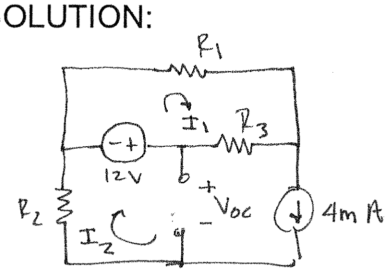


Figure P5.34

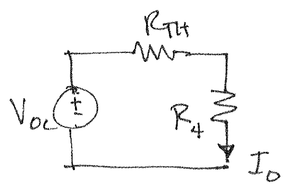
SOLUTION:



$12 = V_{oc} + I_2 R_2$ $\qquad I_2 = 4mA$

$V_{oc} = -36V$

$R_{TH} = R_2 = 12k\Omega$



$I_o = \dfrac{V_{oc}}{R_{TH} + R_4}$ $\qquad R_4 = 6k\Omega$

$\boxed{I_o = -2mA}$

5.35 Find V_o in the circuit in Fig. P5.35 using Thévenin's theorem.

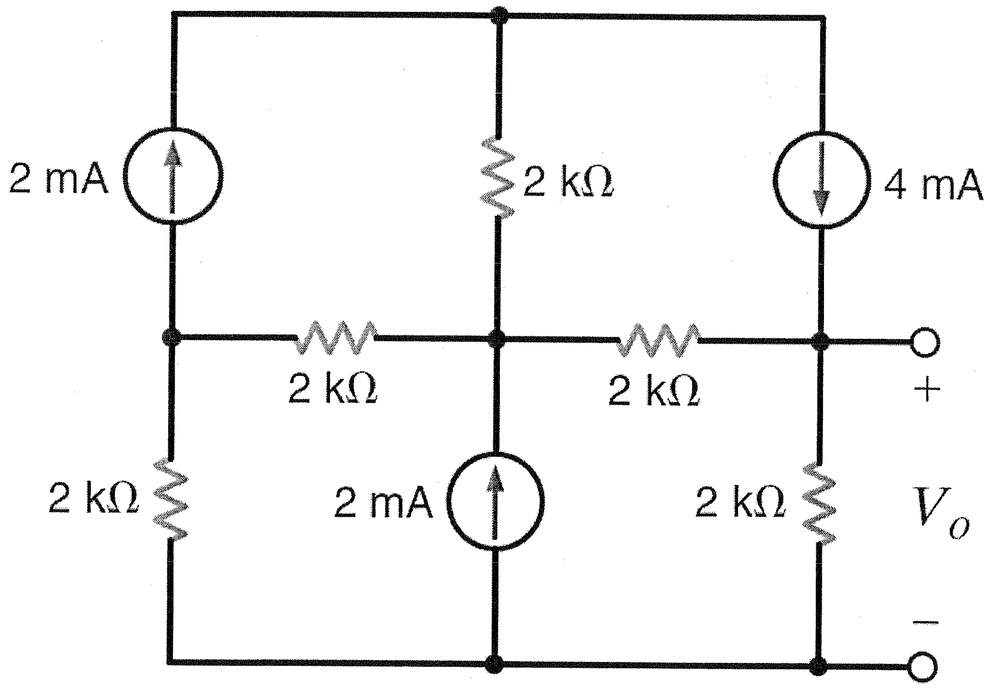
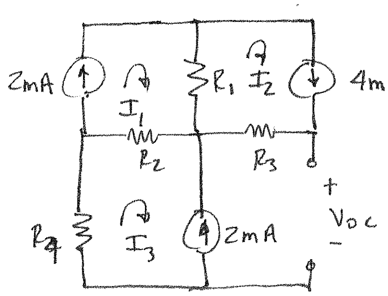


Figure P5.35

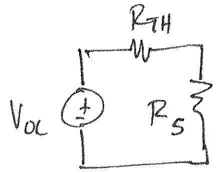
SOLUTION:



$I_1 = 2mA \quad I_2 = 4mA \quad I_3 = -2mA$

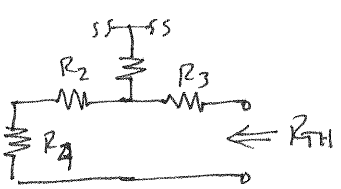
$I_3 R_4 + R_2(I_3 - I_1) + R_3(0 - I_2) + V_{oc} = 0$

$V_{oc} = 20V$



$V_o = \dfrac{V_{oc} R_5}{R_5 + R_{TH}}$

$\boxed{V_o = 5V}$



$R_{TH} = R_4 + R_2 + R_3 = 6k\Omega$

5.36 Find V_o in the network in Fig. P5.36 using Thévenin's theorem. CS

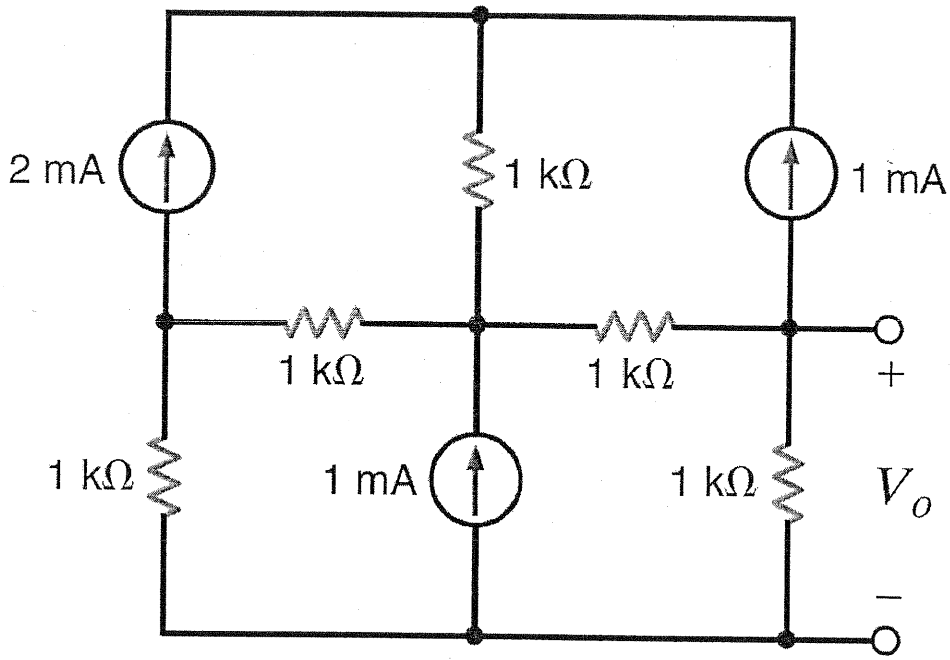
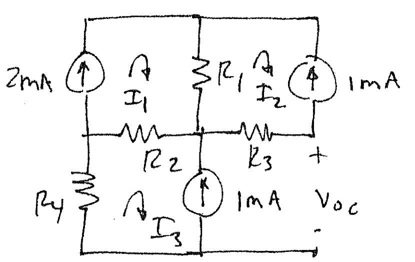


Figure P5.36

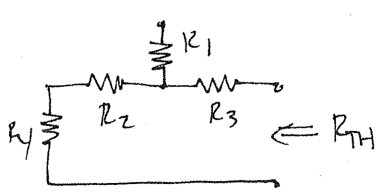
SOLUTION: All $R = 1k\Omega$



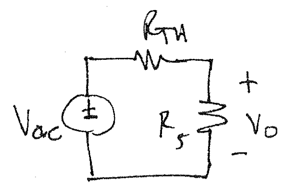
$I_1 = 2mA \quad I_2 = -1mA \quad I_3 = -1mA$

$R_4 I_3 + R_2 (I_3 - I_1) - R_3 I_2 + V_{OC} = 0$

$V_{OC} = 3V$



$R_{TH} = R_4 + R_2 + R_3 = 3k\Omega$



$$V_o = V_{oc} \frac{R_5}{R_{TH} + R_5}$$

$$\boxed{V_{oc} = 0.75V}$$

5.37 Find V_o in the network in Fig. P5.37 using Thévenin's theorem.

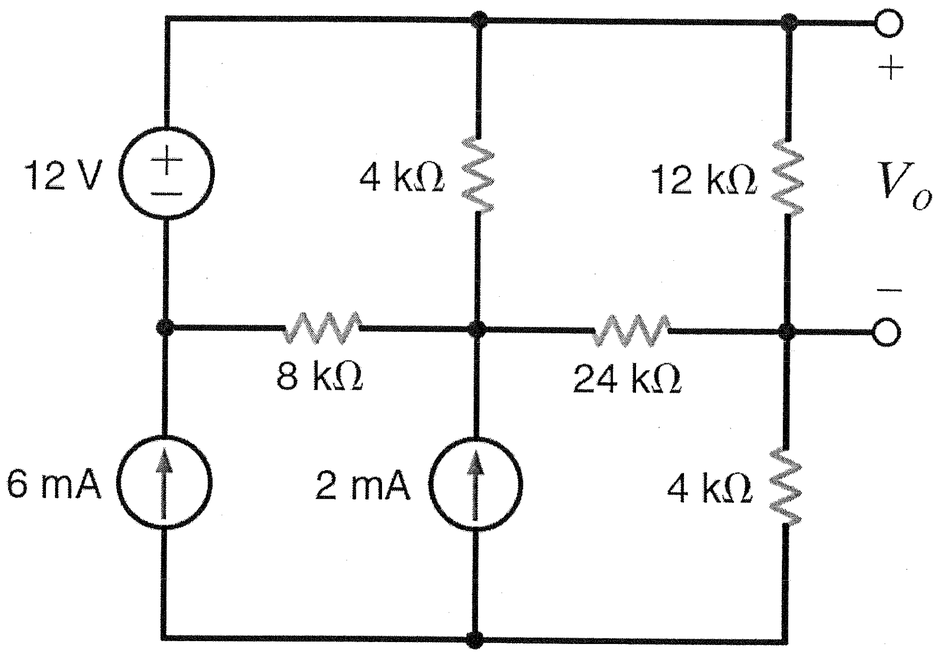
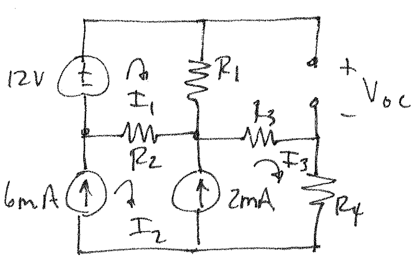


Figure P5.37

SOLUTION:

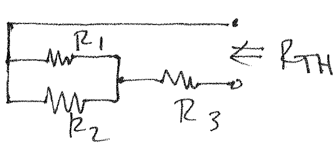


$I_2 = 6mA \quad I_3 - I_2 = 2mA \Rightarrow I_3 = 8mA$

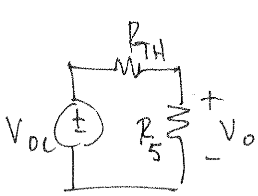
$12 = I_1 R_1 + (I_1 - I_2) R_2 \Rightarrow I_1 = 5mA$

$12 = V_{oc} - I_3 R_3 + R_2 (I_1 - I_2)$

$V_{oc} = 212\,V$



$R_{TH} = (R_1 // R_2) + R_3 = 26.67\,k\Omega$



$V_o = \dfrac{V_{oc} R_5}{R_5 + R_{TH}} \quad R_5 = 12k\Omega \quad \boxed{V_o = 65.79\,V}$

5.38 Use a combination of Thévenin's theorem and superposition to find V_o in the circuit in Fig. P5.38.

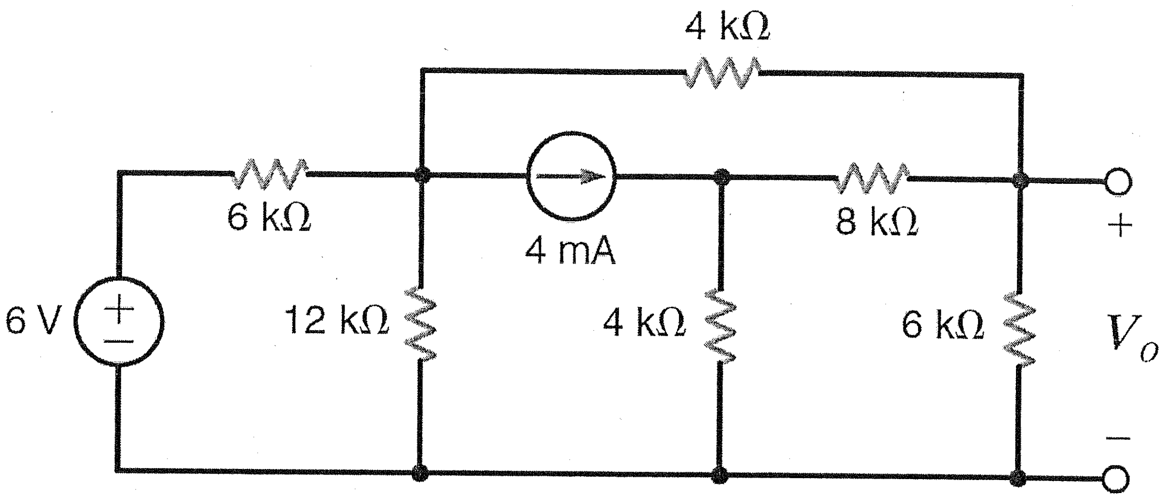
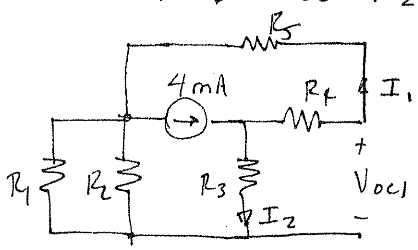


Figure P5.38

SOLUTION: $R_1 = R_6 = 6k\Omega \quad R_2 = 12k\Omega \quad R_3 = R_5 = 4k\Omega \quad R_4 = 8k\Omega$

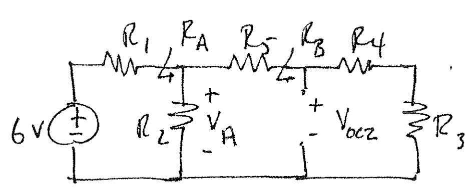


$R_A: R_1 // R_2 = 4k\Omega$

$$I_1 = \frac{4\times10^{-3}(R_3 + R_A)}{R_3 + R_A + R_4 + R_5} = 1.6mA$$

$$I_2 = \frac{4\times10^{-3}(R_4 + R_5)}{R_3 + R_A + R_4 + R_5} = 2.4mA$$

$-I_2 R_3 + I_1 R_4 + V_{oc1} = 0 \qquad V_{oc1} = -3.2V$



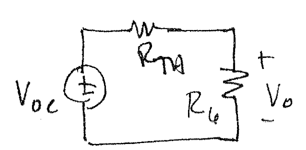
$R_B = R_3 + R_4 = 12k\Omega$

$R_A = R_2 // (R_5 + R_B) = 6.86k\Omega$

$V_A = 6 R_A / (R_1 + R_A) = 3.2V \qquad V_{oc2} = \frac{V_A R_B}{R_B + R_5} = 2.4V$

$R_{TH} = (R_3 + R_4) // [(R_1 // R_2) + R_5] = 4.8k\Omega$

$V_{oc} = -0.8V$



$$V_o = \frac{V_{oc} R_6}{R_6 + R_{TH}}$$

$$\boxed{V_o = -0.444V}$$

5.39 Find V_o in the network in Fig. P5.39 using Thévenin's theorem.

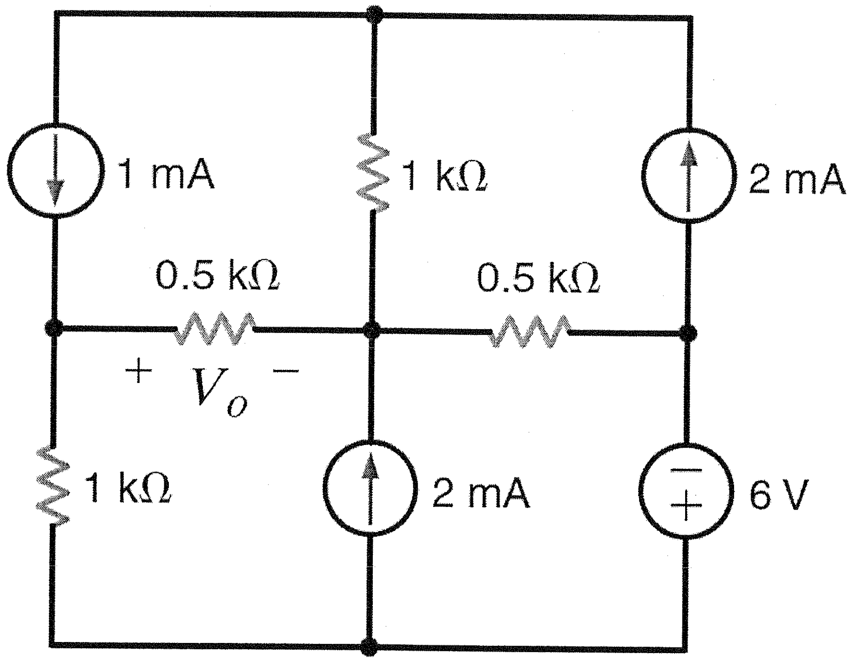
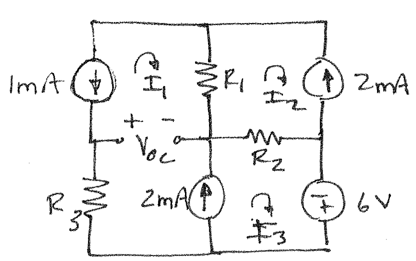


Figure P5.39

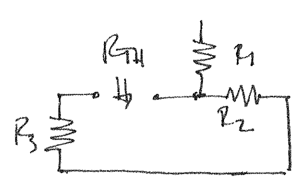
SOLUTION: $R_1 = R_3 = 1k\Omega$ $R_2 = R_4 = 500\Omega$



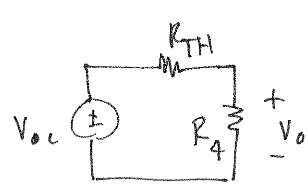
$I_1 = -1mA$ $I_2 = -2mA$ $I_3 - I_1 = 2mA \Rightarrow I_3 = 1mA$

$I_1 R_3 + V_{oc} + R_2 (I_3 - I_2) = 6$

$V_{oc} = 5.5V$



$R_{TH} = R_3 + R_2 = 1.5k\Omega$



$V_o = \frac{V_{oc} R_4}{R_4 + R_{TH}}$

$\boxed{V_o = 1.375V}$

5.40 Find V_o in the network in Fig. P5.40 using Thévenin's theorem.

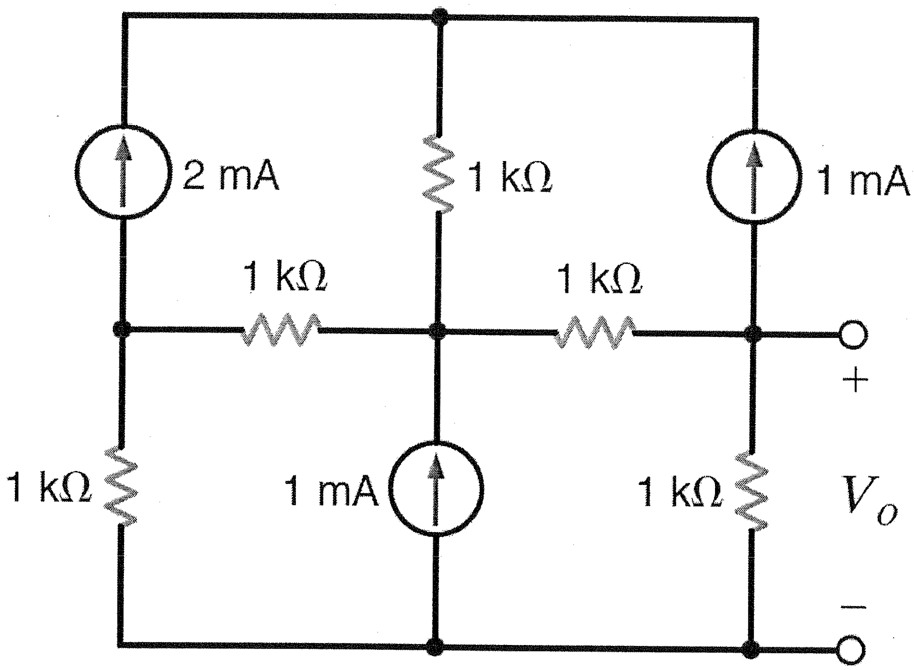
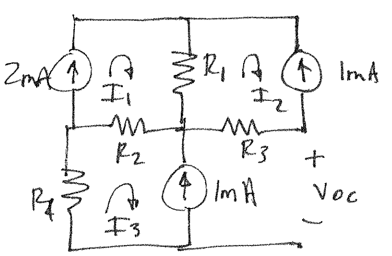


Figure P5.40

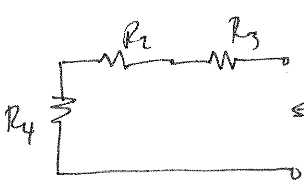
SOLUTION: All $R = 1k\Omega$



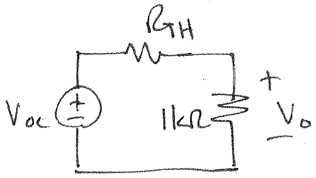
$I_1 = 2mA \quad I_2 = -1mA \quad I_3 = -1mA$

$R_4 I_3 + R_2(I_3 - I_1) + R_3(0 - I_2) + V_{oc} = 0$

$V_{oc} = 3V$



$\leftarrow R_{TH} = R_2 + R_3 + R_4 = 3k\Omega$

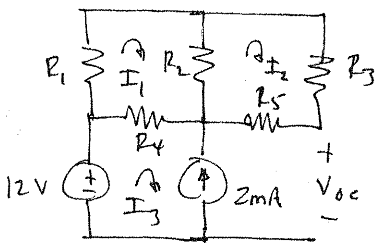


$$V_o = V_{oc}\frac{(1000)}{1000 + R_{TH}}$$

$\boxed{V_o = 0.75V}$

5.41 Solve Problem 5.12 using Thévenin's theorem.

SOLUTION: $R_1 = R_3 = R_5 = R_6 = 1k\Omega \qquad R_2 = R_4 = 2k\Omega$

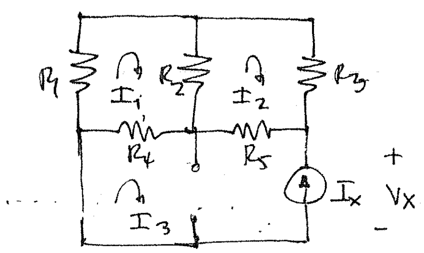


$$-R_2 I_1 + I_2(R_2 + R_3 + R_5) = 0$$

$$I_1(R_1 + R_2 + R_4) - I_2 R_2 - I_3 R_4 = 0$$

$$I_3 = -2mA$$

$$12 = (I_3 - I_1)R_4 - R_5 I_2 + V_{oc} \qquad V_{oc} = 13.5V$$



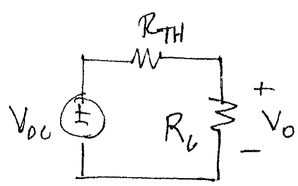
$$I_1(R_1 + R_2 + R_4) - R_2 I_2 - R_4 I_3 = 0$$

$$-R_2 I_1 + I_2(R_2 + R_3 + R_5) - R_5 I_3 = 0$$

$$I_3 = -I_x \qquad \text{Let } I_x = 1mA$$

$$R_{TH} = V_x / I_x \qquad R_{TH} = 1.19k\Omega$$

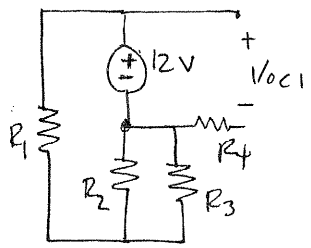
$$V_x + R_4(I_3 - I_1) + R_5(I_3 - I_2) = 0$$



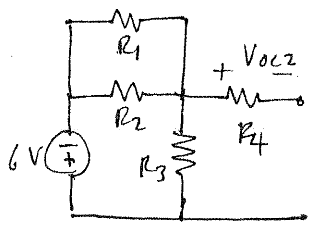
$$V_o = V_{oc} \frac{R_6}{R_6 + R_{TH}} \qquad \boxed{V_o = 6.18V}$$

5.42 Solve Problem 5.13 using Thévenin's theorem.

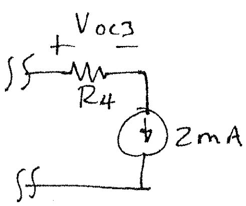
SOLUTION: $R_1 = R_2 = R_3 = 1k\Omega \qquad R_4 = R_5 = 2k\Omega$



$V_{oc1} = 12V$

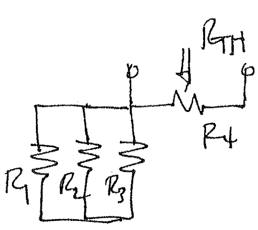


$V_{oc2} = 0V$

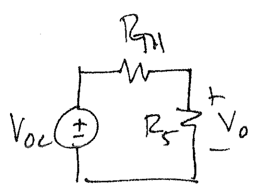


$V_{oc3} = 2\times10^{-3} R_4 = 4V$

$V_{oc} = 16V$



$R_{TH} = R_4 = 2k\Omega$

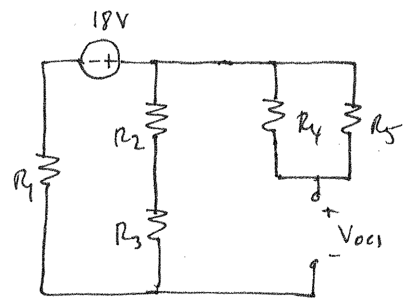


$$V_o = \frac{V_{oc} R_5}{R_5 + R_{TH}}$$

$\boxed{V_o = 8V}$

5.43 Use Thévenin's theorem to solve Problem 5.21.

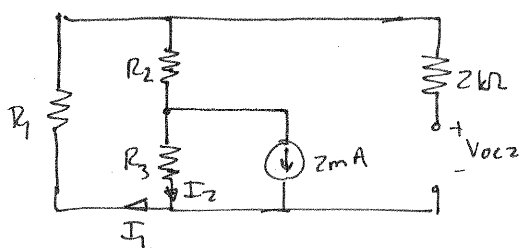
SOLUTION: $R_1 = R_2 = R_3 = 6k\Omega$ $R_4 = R_5 = 4k\Omega$ $R_6 = 3k\Omega$



$$V_{oc1} = 18\left[\frac{R_2+R_3}{R_1+R_2+R_3}\right] = 12V$$

$$R_4 // R_5 = 2k\Omega$$

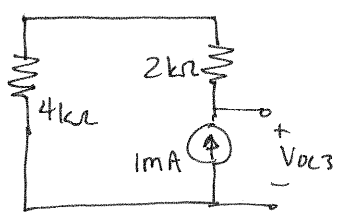
$$R_1 // (R_2+R_3) = 4k\Omega$$



$$I_1 = 2\times10^{-3}\, R_3 / (R_1+R_2+R_3) = \frac{2}{3}\ mA$$

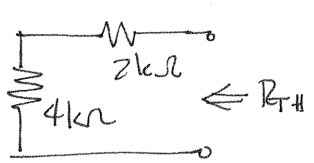
$$I_2 = -2\times10^{-3}(R_1+R_2)/(R_1+R_2+R_3) = -\frac{4}{3}\ mA$$

$$V_{oc2} = I_1 R_2 + I_2 R_3 = -4V$$

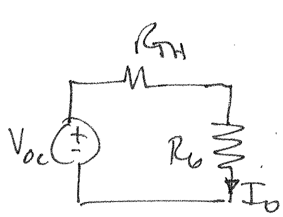


$$V_{oc3} = 10^{-3}(2000 + 4000) = 6V$$

$$V_{oc} = V_{oc1} + V_{oc2} + V_{oc3} = 14V$$



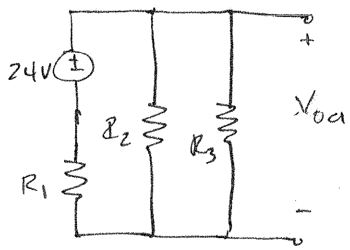
$$R_{TH} = 6k\Omega.$$



$$I_o = \frac{V_{oc}}{R_6 + R_{TH}} \qquad \boxed{I_o = 1.56mA}$$

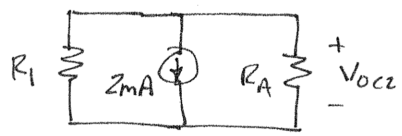
5.44 Use Thévenin's theorem to solve Problem 5.22.

SOLUTION: $R_1 = 3k\Omega$ $R_2 = 6k\Omega$ $R_3 = 2k\Omega$ $R_4 = 4k\Omega$

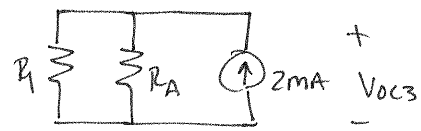


$V_{oc1} = \dfrac{24 R_A}{R_A + R_1}$ $R_A = R_2 // R_3 = 1.5k\Omega$

$V_{oc1} = 8V$



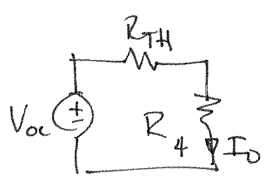
$V_{oc2} = -2\times10^{-3}\,(R_1 // R_A) = -2V$



$V_{oc3} = 2\times10^{-3}(R_1 // R_A) = 2V$

$V_{oc} = V_{oc1} + V_{oc2} + V_{oc3} = 8V$

$R_{TH} = R_1 // R_A = 1k\Omega$



$I_o = \dfrac{V_{oc}}{R_{TH} + R_4}$ $\boxed{I_o = 1.6mA}$

5.45 Given the linear circuit in Fig. P5.45, it is known that when a 2-kΩ load is connected to the terminals *A*-*B*, the load current is 10 mA. If a 10-kΩ load is connected to the terminals, the load current is 6 mA. Find the current in a 20-kΩ load.

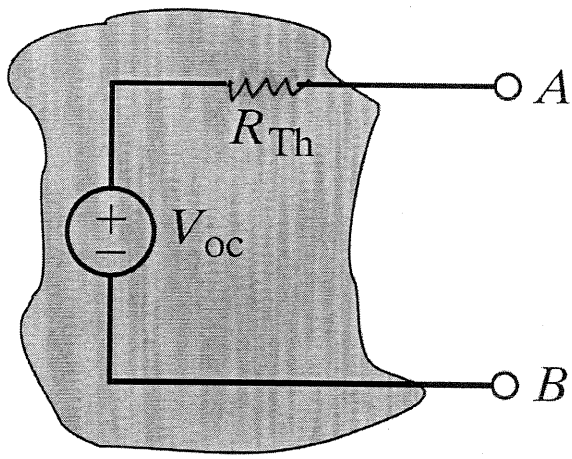
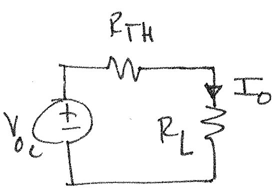


Figure P5.45

SOLUTION:



$$I_o = \frac{V_{oc}}{R_{TH} + R_L}$$

$$\frac{V_{oc}}{R_{TH} + 2000} = 10^{-2} \qquad \frac{V_{oc}}{R_{TH} + 10^4} = 6 \times 10^{-3}$$

$$\frac{R_{TH} + 2000}{R_{TH} + 10^4} = 0.6 \Rightarrow R_{TH} = 10k\Omega \;\; \& \;\; V_{oc} = 120\,V$$

$$\frac{V_{oc}}{10^4 + 2 \times 10^4} = I_o = 4mA \qquad \boxed{I_o = 4mA}$$

5.46 If an 8-kΩ load is connected to the terminals of the network in Fig. P5.46, $V_{AB} = 16$ V. If a 2-kΩ load is connected to the terminals, $V_{AB} = 8$ V. Find V_{AB} if a 20-kΩ load is connected to the terminals. CS

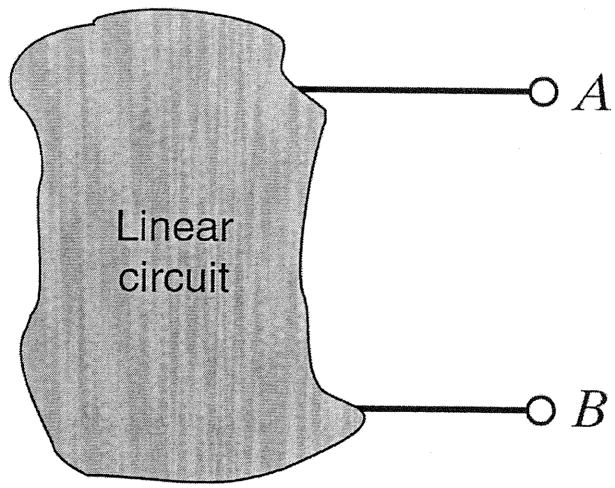
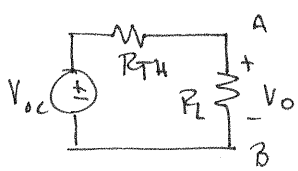


Figure P5.46

SOLUTION:



$$V_o = \frac{V_{oc} R_L}{R_L + R_{TH}}$$

$$\frac{V_{oc}(8000)}{8000 + R_{TH}} = 16 \quad \& \quad \frac{V_{oc}(2000)}{2000 + R_{TH}} = 8 \Rightarrow \frac{8000}{2000}\left(\frac{2000 + R_{TH}}{8000 + R_{TH}}\right) = \frac{16}{8} = 2$$

$R_{TH} = 4\,k\Omega$ & $V_{oc} = 24\,V$

$$V_o = 24\left(\frac{20 \times 10^3}{20 \times 10^3 + 4 \times 10^3}\right) \qquad \boxed{V_o = 20V}$$

5.47 Find I_o in the network in Fig. P5.47 using Norton's theorem.

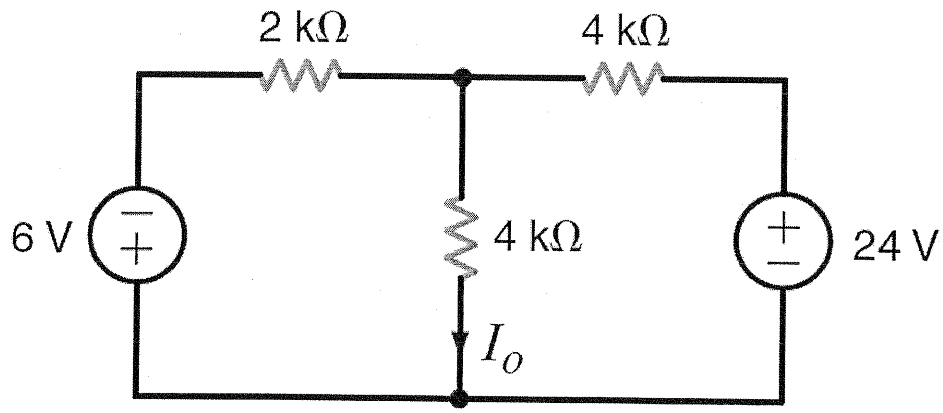
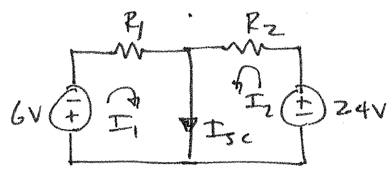


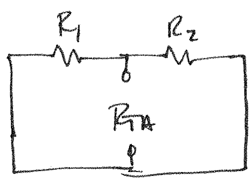
Figure P5.47

SOLUTION: $R_1 = 2k\Omega \quad R_2 = 4k\Omega \quad R_3 = 4k\Omega$

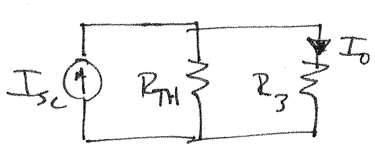


$I_{SC} = I_1 + I_2 \qquad I_1 = -\frac{6}{R_1} = -3\,mA \qquad I_2 = \frac{24}{R_2} = 6mA$

$I_{SC} = 3\,mA$



$R_{TH} = R_1 // R_2 = \frac{4}{3}\,k\Omega$



$I_o = \frac{I_{SC} R_{TH}}{R_{TH} + R_3}$

$\boxed{I_o = 0.75\,mA}$

5.48 Find I_o in the network in Fig. P5.48 using Norton's theorem.

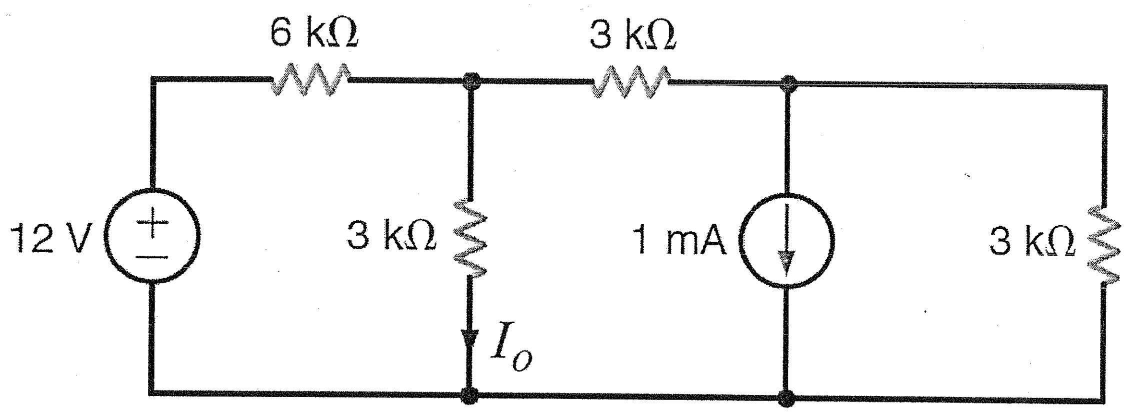
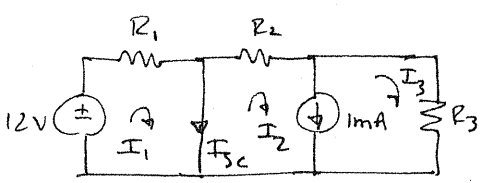


Figure P5.48

SOLUTION: $R_1 = 6k\Omega$ $\quad R_2 = R_3 = R_4 = 3k\Omega$

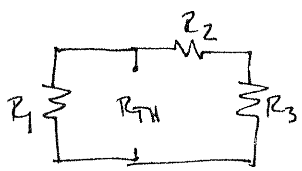


$I_{sc} = I_1 - I_2 \qquad I_2 - I_3 = 1mA$

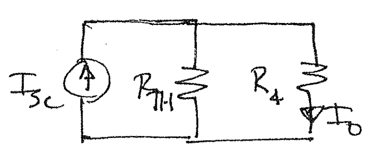
$I_1 = 12/R_1 = 2mA$

$12 = R_1 I_1 + R_2 I_2 + R_3 I_3 \Rightarrow I_2 = \frac{1}{2} mA$

$I_{sc} = I_1 - I_2 = \frac{3}{2} mA$



$R_{TH} = R_1 \,//\, (R_2 + R_3) = 3k\Omega$



$$I_o = \frac{I_{sc} R_{TH}}{R_4 + R_{TH}}$$

$\boxed{I_o = 0.75mA}$

5.49 Use Norton's theorem to find I_o in the circuit in Fig. P5.49.

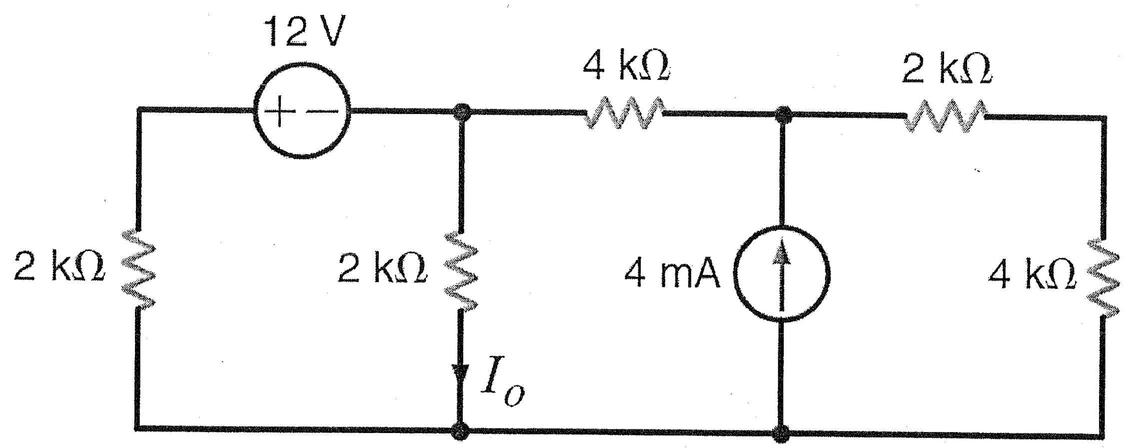
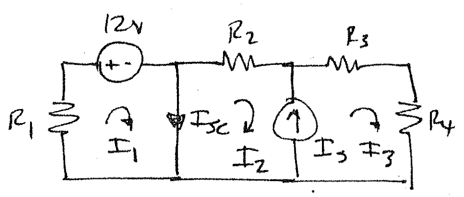


Figure P5.49

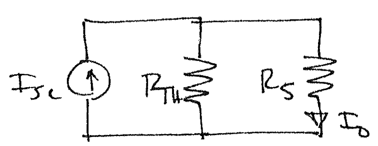
SOLUTION: $R_1 = R_3 = 2k\Omega$ $R_2 = R_4 = 4k\Omega$ $R_5 = 2k\Omega$ $I_S = 4mA$



$I_1 = -12/R_1 = -6\,mA$

$$\left.\begin{aligned} R_2 I_2 + (R_3+R_4)I_3 &= 0 \\ I_3 - I_2 &= 4mA \end{aligned}\right\} \quad I_2 = -2.4mA$$

$I_{SC} = I_1 - I_2 = -3.6mA$ $R_{TH} = R_1 \,//\, (R_2+R_3+R_4) = 5/3\ k\Omega$



$I_o = \dfrac{I_{SC} R_{TH}}{R_{TH}+R_5}$ $\boxed{I_o = -1.64mA}$

5.50 Find I_o in the network in Fig. P5.50 using Norton's theorem. CS

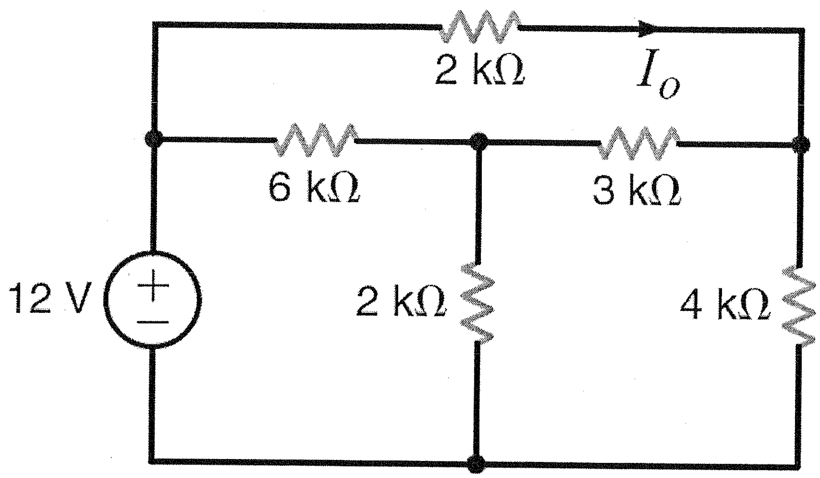
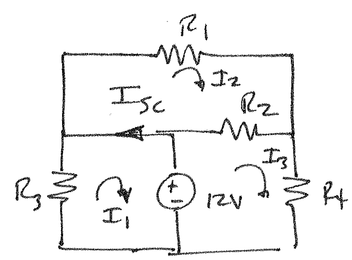


Figure P5.50

SOLUTION: $R_1 = 3\,k\Omega$ $R_2 = 6\,k\Omega$ $R_3 = 4\,k\Omega$ $R_4 = 2\,k\Omega$ $R_5 = 2\,k\Omega$

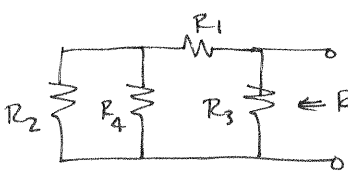
Redraw



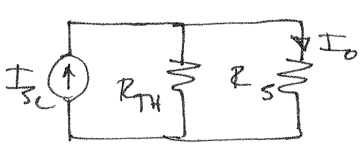
$I_1 = -12/R_2 = -3\,mA$

$$\left.\begin{aligned}(R_1+R_2)I_2 - R_2 I_3 &= 0\\ 12 &= (R_2+R_4)I_3 - R_2 I_2\end{aligned}\right\}\ I_2 = 2\,mA$$

$I_{SC} = I_2 - I_1 = 5\,mA$



$\leftarrow R_{TH} = R_3 // [R_1 + (R_2 // R_4)] = 2.12\,k\Omega$



$I_o = \dfrac{I_{SC} R_{TH}}{R_{TH}+R_5}$

$\boxed{I_o = 2.57\,mA}$

5.51 Use Norton's theorem to find V_o in the network in Fig. P5.51.

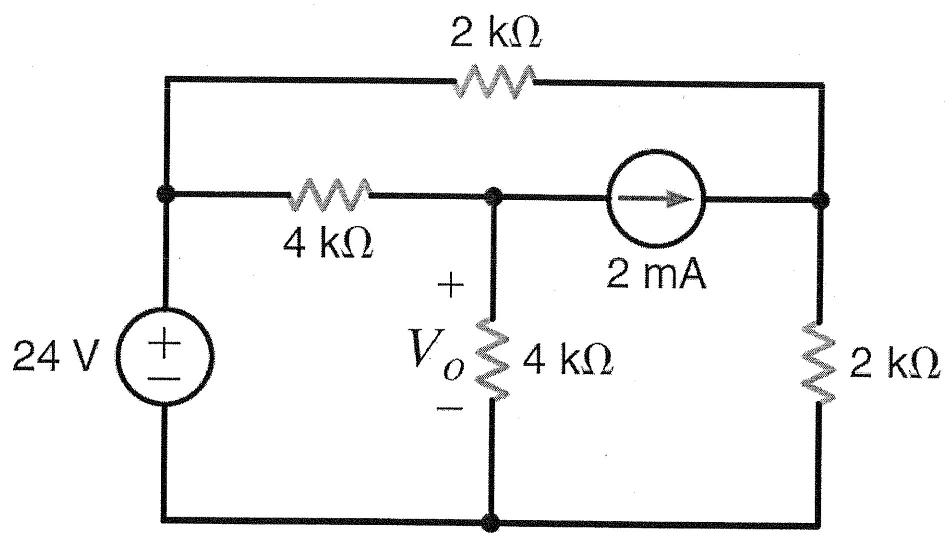
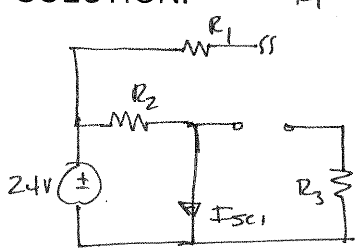
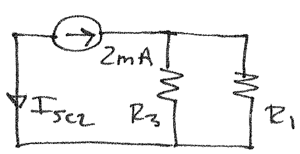


Figure P5.51

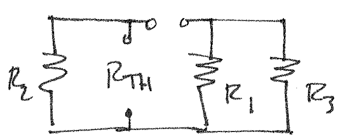
SOLUTION: $R_1 = R_3 = 2k\Omega \qquad R_2 = R_4 = 4k\Omega$

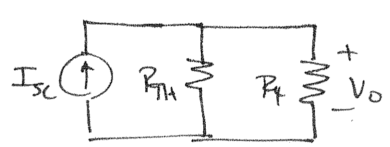


$I_{SC1} = 24 / R_2 = 6mA$



$I_{SC2} = -2mA \qquad I_{SC} = I_{SC1} + I_{SC2} = 4mA$





$R_{TH} = R_2 = 4k\Omega$

$V_o = I_{SC}\,[R_{TH} // R_4] \Rightarrow \boxed{V_o = 8V}$

5.52 Find V_o in the network in Fig. P5.52 using Norton's theorem.

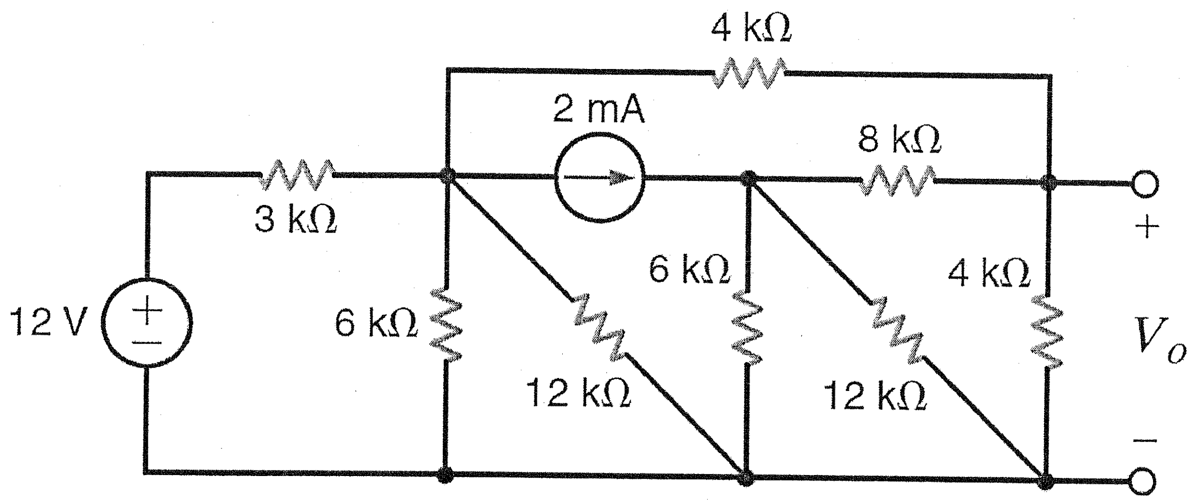
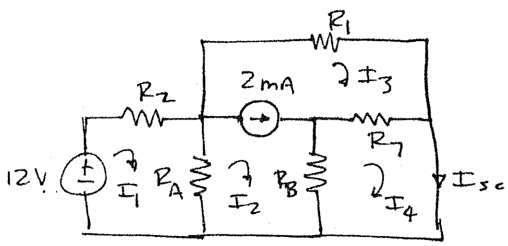


Figure P5.52

SOLUTION:



$R_2 = 3\,k\Omega$ $R_3 = R_5 = 6\,k\Omega$ $R_4 = R_6 = 12\,k\Omega$

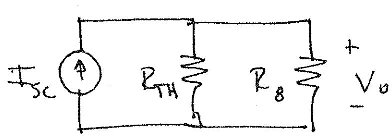
$R_1 = 4\,k\Omega$ $R_7 = 8\,k\Omega$ $R_8 = 4\,k\Omega$

$R_A = R_3 // R_4 = 4\,k\Omega$ $R_B = R_5 // R_6 = 4\,k\Omega$

$I_{sc} = I_4$

$$\left.\begin{aligned} 12 &= I_1(R_2 + R_A) - R_A I_2 \\ I_2 - I_3 &= 2\,mA \\ I_4(R_B + R_7) &- R_B I_2 - R_7 I_3 = 0 \\ 12 &= I_1 R_2 + I_3 R_1 \end{aligned}\right\} \quad I_4 = 1.27\,mA = I_{sc}$$

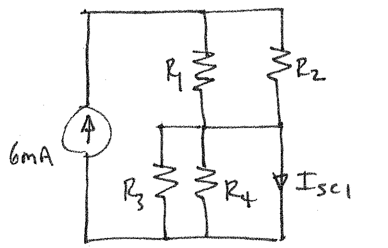
$$R_{TH} = [(R_2 // R_A) + R_1] // (R_B + R_7) = 3.87\,k\Omega$$



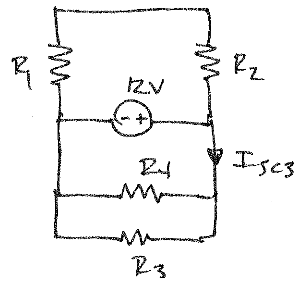
$V_o = I_{sc}(R_{TH} // R_8)$ $\boxed{V_o = 2.49\,V}$

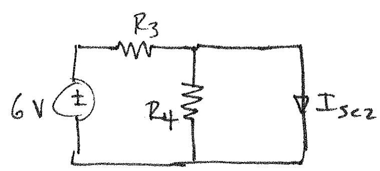
5.53 Solve Problem 5.14 using Norton's theorem.

SOLUTION: $R_1 = R_3 = R_4 = 1k\Omega \qquad R_2 = R_5 = 2k\Omega$



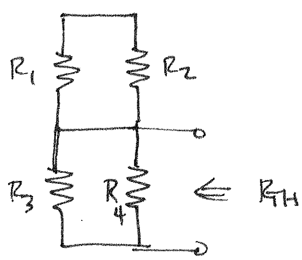
$I_{sc1} = 6mA$



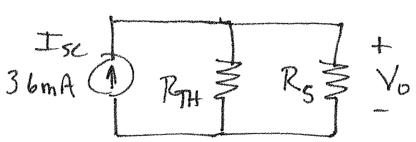


$I_{sc2} = \frac{6}{R_3} = 6mA \qquad I_{sc3} = \frac{12}{R_3 // R_4} = 24mA$

$I_{sc} = I_{s1} + I_{sc2} + I_{sc3} = 36mA$



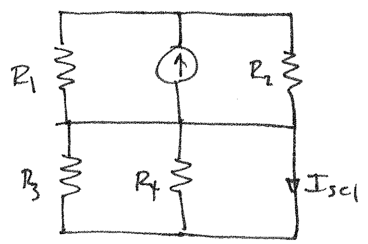
$R_{TH} = R_3 // R_4 = \frac{1}{2} k\Omega$



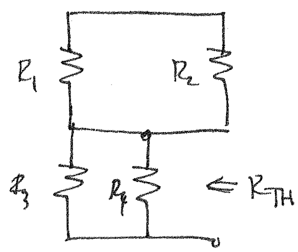
$V_0 = I_{sc} (R_{TH} // R_5) \qquad \boxed{V_0 = 14.4V}$

5.54 Solve Problem 5.15 using Norton's theorem.

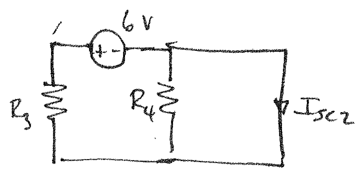
SOLUTION: $R_1 = R_3 = 2k\Omega \qquad R_2 = R_4 = R_5 = 1k\Omega$



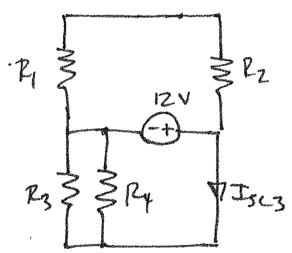
$I_{SC1} = 0A$



$R_{TH} = R_3 // R_4$
$= \frac{2}{3} k\Omega$

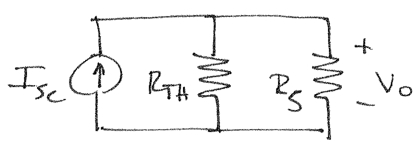


$I_{SC2} = \frac{6}{R_3} = -3mA$



$I_{SC3} = \frac{12}{R_3 // R_4} = 18mA$

$I_{SC} = I_{SC1} + I_{SC2} + I_{SC3} = 15mA$

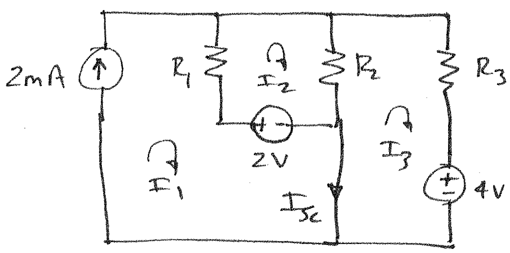


$V_o = I_{SC} \left(R_{TH} // R_5 \right)$

$\boxed{V_o = 6V}$

5.55 Use Norton's theorem to solve Problem 5.19.

SOLUTION: $R_1 = R_2 = R_3 = 1k\Omega$ $\quad R_4 = 4k\Omega$



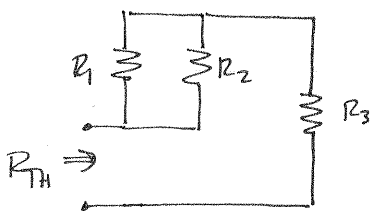
$I_1 = 2mA$

$2 = I_2(R_1 + R_2) - I_1 R_1 - I_3 R_2$

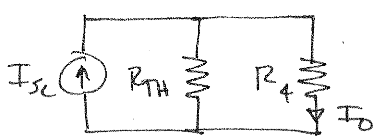
$-4 = -I_2 R_2 + I_3(R_2 + R_3)$

$I_{SC} = I_1 - I_3 \qquad I_3 = -1.33\,mA$

$I_{SC} = 3.33\,mA$



$R_{TH} = (R_1 // R_2) + R_3 = 1.5k\Omega$



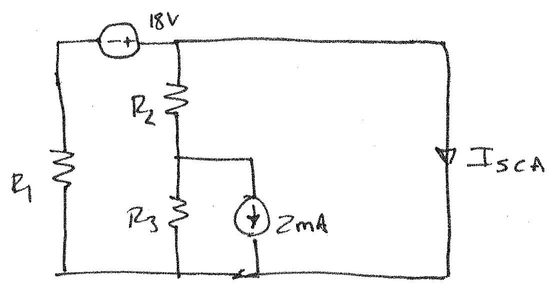
$$I_o = \frac{I_{SC} R_{TH}}{R_{TH} + R_4}$$

$$\boxed{I_o = 0.909\,mA}$$

5.56 Use Norton's theorem to solve Problem 5.21.

SOLUTION: $R_1 = R_2 = R_3 = 6k\Omega$ $R_4 = R_5 = 4k\Omega$ $R_6 = 3k\Omega$

Perform 2 Norton operations.

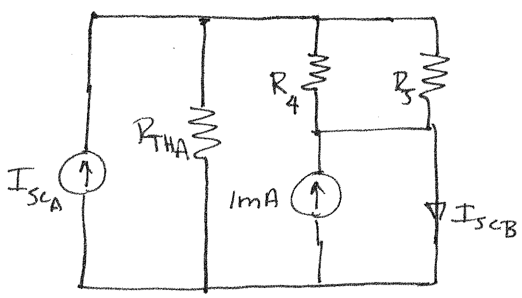


Superposition,

$$I_{SCA} = \frac{18}{R_1} - \frac{2\times10^{-3} R_3}{R_3 + R_2}$$

$$I_{SCA} = 2mA$$

$$R_{THA} = R_1 // (R_2 + R_3) = 4k\Omega$$



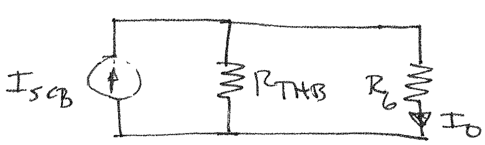
$$R_A = R_4 // R_5 = 2k\Omega$$

Superposition,

$$I_{SCB} = \frac{I_{SCA} R_{THA}}{R_{THA} + R_B} + 10^{-3}$$

$$I_{SCB} = 2.33mA$$

$$R_{THB} = R_A + R_{THA} = 6k\Omega$$



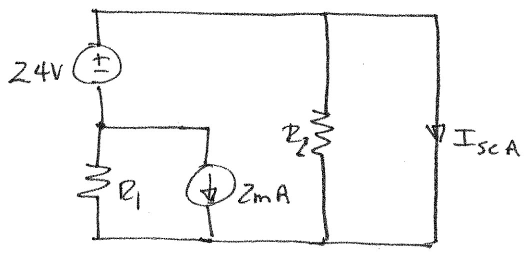
$$I_O = \frac{I_{SCB} R_{THB}}{R_{THB} + R_6}$$

$$\boxed{I_O = 1.55mA}$$

5.57 Use Norton's theorem to solve Problem 5.22.

SOLUTION: $R_1 = 3k\Omega \quad R_2 = 6k\Omega \quad R_3 = 2k\Omega \quad R_4 = 4k\Omega$

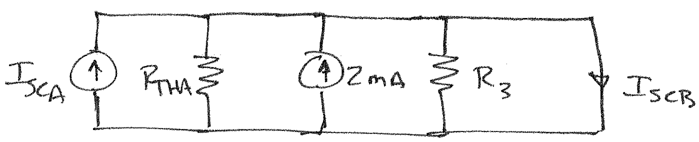
2 Norton operations



Superposition,

$$I_{SCA} = \frac{24}{R_1} - 2\times10^{-3} = 6mA$$

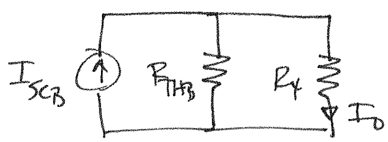
$$R_{THA} = R_1 // R_2 = 2k\Omega$$



$$I_{SCB} = I_{SCA} + 2\times10^{-3}$$

$$I_{SCB} = 8mA$$

$$R_{THB} = R_{THA} // R_3 = 1k\Omega$$



$$I_o = \frac{I_{SCB} R_{THB}}{R_{THB} + R_4}$$

$$\boxed{I_o = 1.6mA}$$

5.58 Find I_o in the circuit in Fig. P5.58 using Norton's theorem. **PSV**

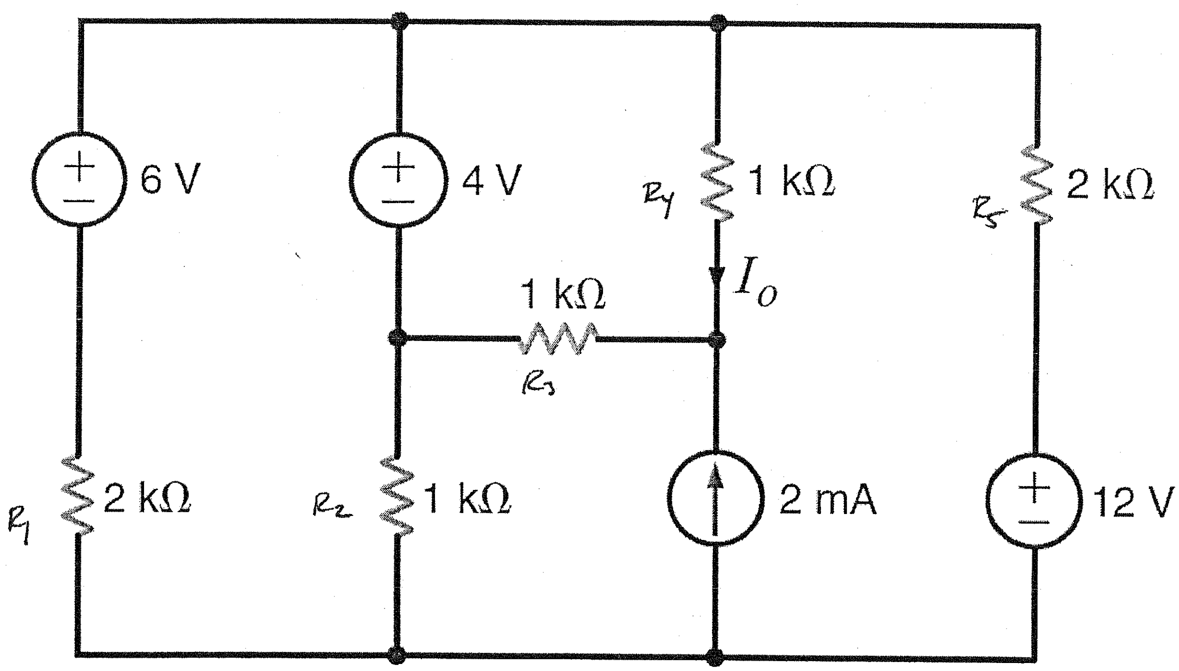
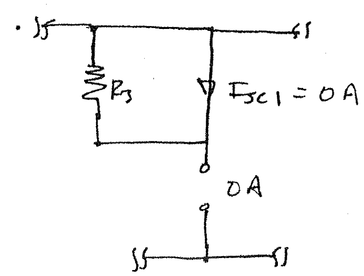
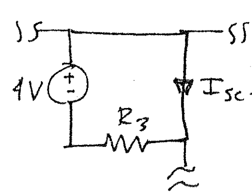


Figure P5.58

SOLUTION: Superposition. Consider effect of 6-V & 12-V sources

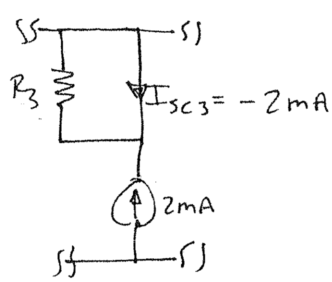


For 4-V source:



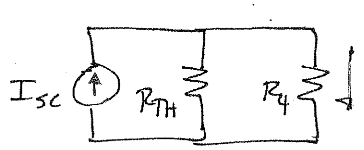
$I_{sc2} = \frac{4}{R_3} = 4mA$

for 2-mA Source



$I_{sc} = I_{sc1} + I_{sc2} + I_{sc3} = 2mA$

$R_{TH} = R_3 = 1k\Omega$



$I_o = \frac{I_{sc} R_{TH}}{R_4 + R_{TH}}$

$\boxed{I_o = 1mA}$

5.59 Find the Thévenin equivalent of the network in Fig. P5.59 at the terminals *A*-*B*. CS

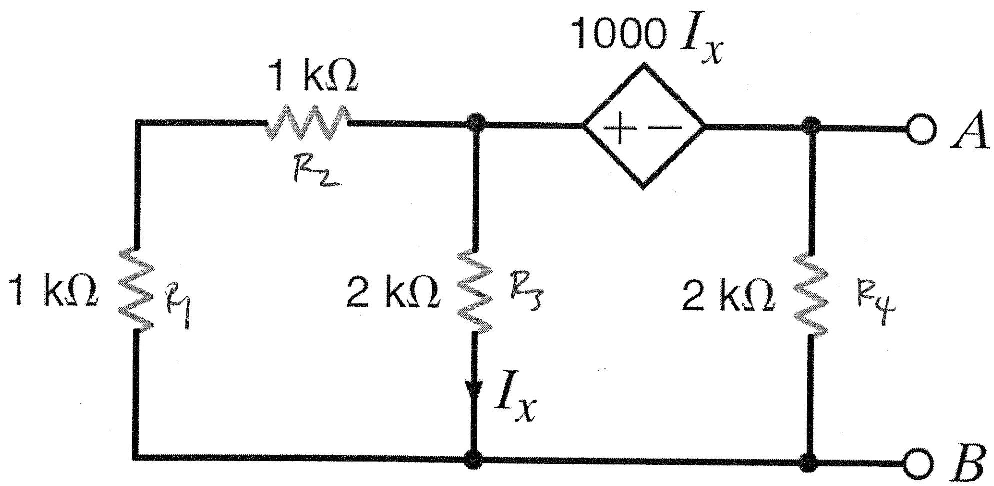
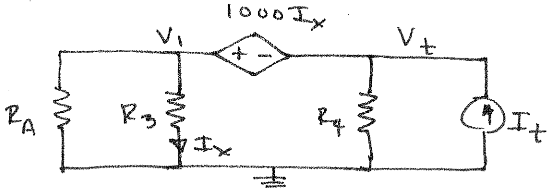


Figure P5.59

SOLUTION:

$V_{oc} = 0\text{V}$



$R_A = R_1 + R_2 = 2\,k\Omega$

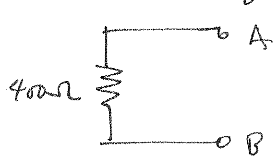
$R_{TH} = V_t / I_t$

$$\left.\begin{aligned} V_1 - V_t &= 1000\, I_x \\ I_x &= V_1 / R_3 \end{aligned}\right\} \quad V_1 = 2V_t$$

$$\frac{V_1}{R_A} + \frac{V_1}{R_3} + \frac{V_t}{R_4} = I_t$$

$$R_{TH} = \frac{V_t}{I_t} = 400\,\Omega$$

Thevenin Eq.



5.60 Find the Thévenin equivalent of the network in Fig. P5.60 at the terminals *A*-*B*. **PSV**

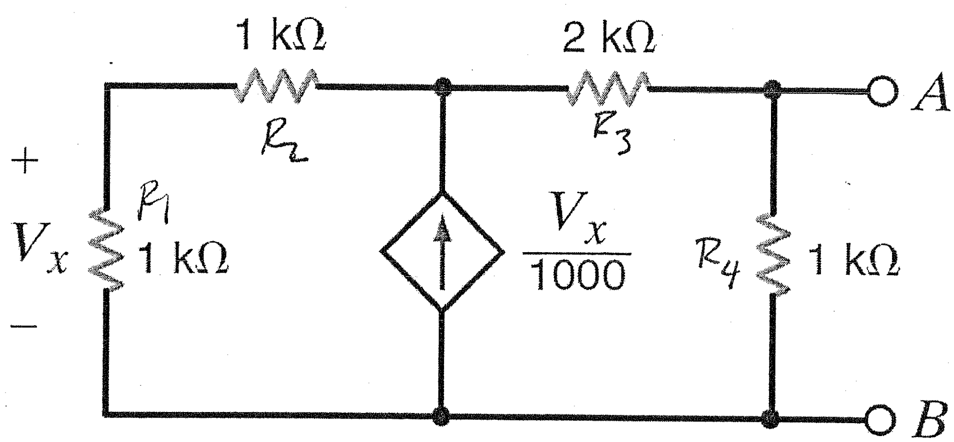
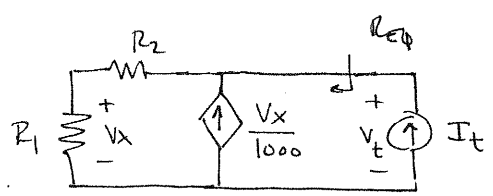


Figure P5.60

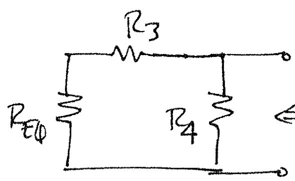
SOLUTION:



$R_{EQ} = V_t / I_t$

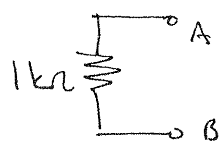
$I_t + \frac{V_x}{1000} - \frac{V_x}{R_1} = 0 \Rightarrow I_t = 0$

$R_{EQ} = V_t / 0 = \infty.$



$\Leftarrow R_{TH} = R_4 // (R_3 + R_{EQ}) = R_4 = 1k\Omega$

Thevenin Eq.



Note: with no internal independent sources, V_{oc} for this network is 0V!

5.61 Find V_o in the network in Fig. P5.61 using Thévenin's theorem.

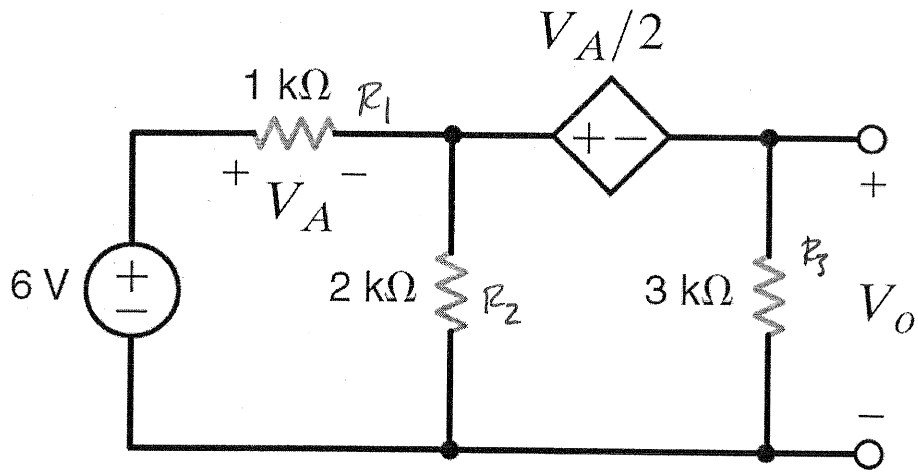
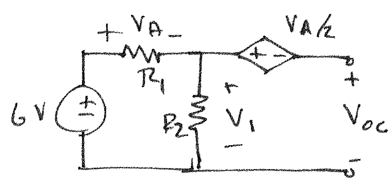


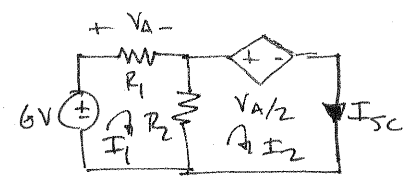
Figure P5.61

SOLUTION:



$$V_1 = \frac{6 R_2}{R_1+R_2} = 4V \qquad V_A = \frac{6R_1}{R_1+R_2} = 2V$$

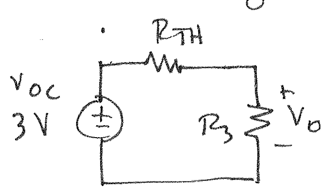
$$V_{oc} = V_1 - \frac{V_A}{2} = 3\text{ V}$$



$$\left.\begin{aligned} 6 &= I_1(R_1+R_2) - I_2 R_2 \\ 0 &= I_2 R_2 - I_1 R_2 + V_A/2 \\ V_A &= I_1 R_1 \end{aligned}\right\} \quad I_{sc} = I_2 = 3\text{mA}$$

$$R_{TH} = \frac{V_{oc}}{I_{sc}} = 1k\Omega$$

Thevenin Eq.



$$V_o = \frac{V_{oc} R_3}{R_{TH}+R_3} \qquad \boxed{V_o = 2.25V}$$

5.62 Use Thévenin's theorem to find V_o in the network in Fig. P5.62. CS

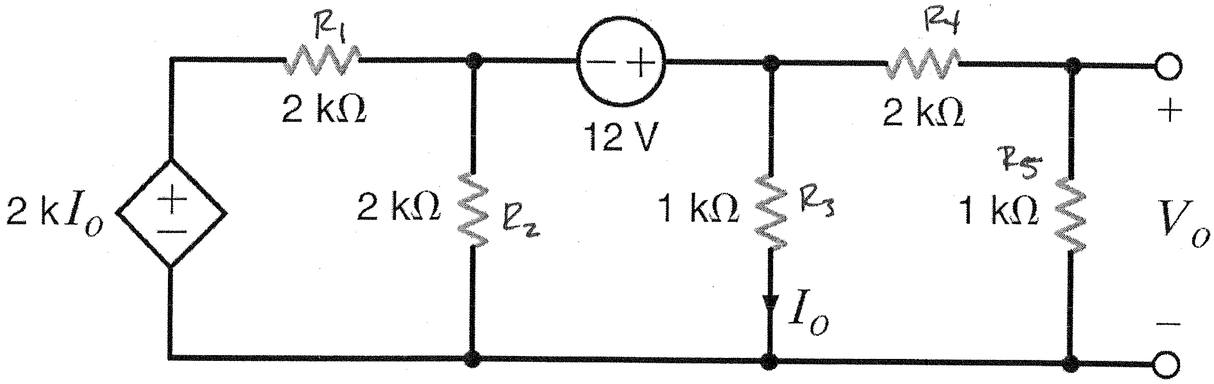
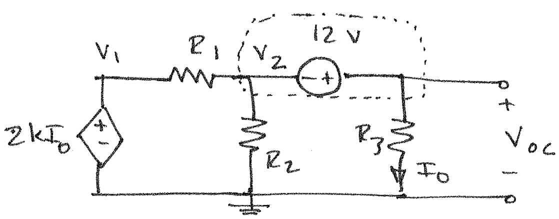


Figure P5.62

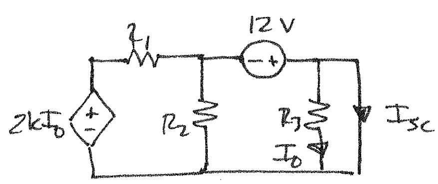
SOLUTION:



$$V_1 = 2kI_o = \frac{2kV_{oc}}{R_3} \quad \& \quad V_{oc} - V_2 = 12$$

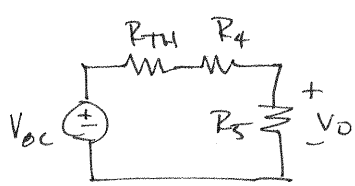
$$\frac{V_2 - V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_{oc}}{R_3} = 0$$

yields $V_{oc} = 12V$



$$I_o = 0 \Rightarrow I_{sc} = \frac{12}{R_1 // R_2} = 12mA$$

$R_{TH} = V_{oc}/I_{sc} = 1k\Omega$



$$V_o = \frac{V_{oc} R_5}{R_{TH} + R_4 + R_5}$$

$$\boxed{V_o = 3\ V}$$

5.63 Use Thévenin's theorem to find I_o in the circuit in Fig. P5.63. **PSV**

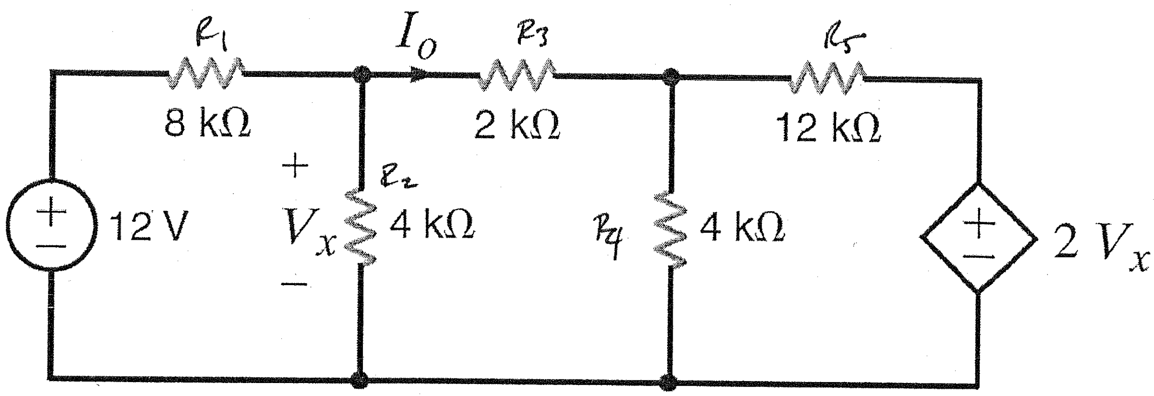
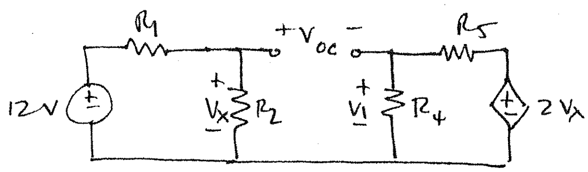


Figure P5.63

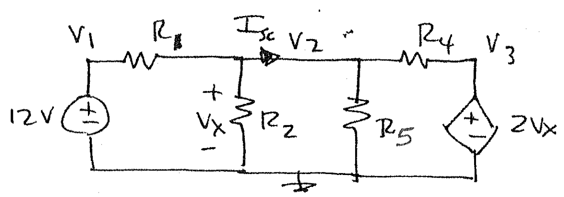
SOLUTION:



$$V_x = \frac{12R_2}{R_1+R_2} = 4V$$

$$V_1 = \frac{2V_x R_4}{R_4+R_5} = 2V$$

$$V_{oc} = V_x - V_1 = 2\text{ V}$$



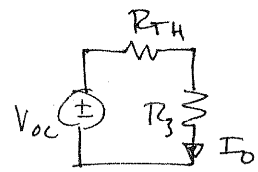
$V_1 = 12V$ $\quad$ $V_3 = 2V_x = 2V_2$

$$\frac{V_2-V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_2}{R_5} + \frac{V_2-V_3}{R_4} = 0$$

$$V_2 = 2.77\text{ V}$$

$$I_{sc} = \frac{V_1-V_2}{R_1} - \frac{V_2}{R_2} = 0.461\text{mA}$$

$$R_{TH} = V_{oc}/I_{sc} = 4.33\text{k}\Omega$$



$$I_o = \frac{V_{oc}}{R_{TH}+R_3}$$

$$\boxed{I_o = 0.316\text{mA}}$$

5.64 Find V_o in the network in Fig. P5.64 using Thévenin's theorem.

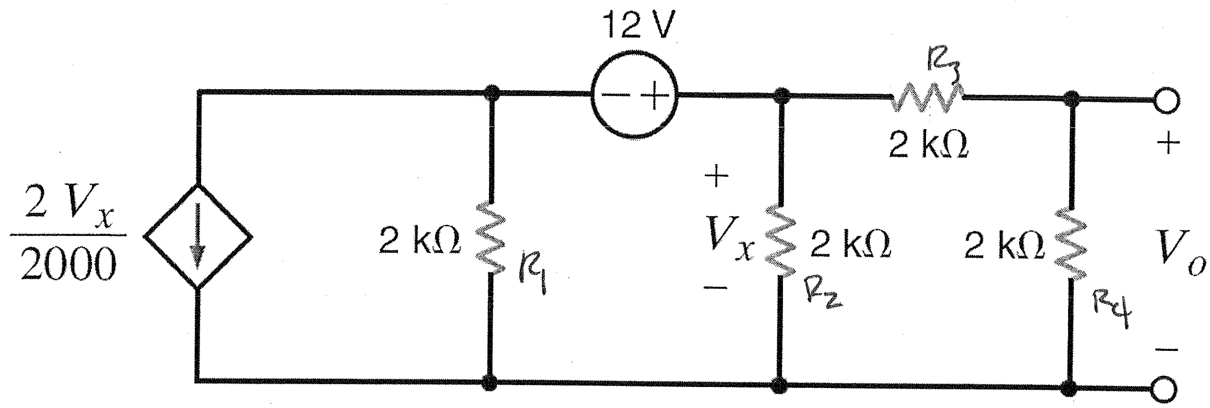
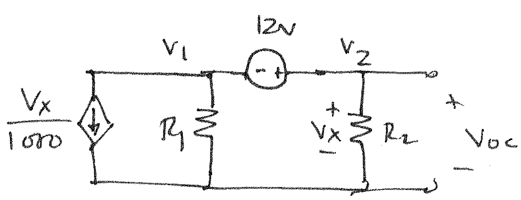


Figure P5.64

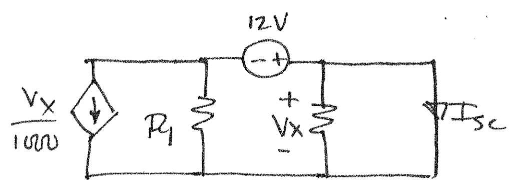
SOLUTION:



$V_2 - V_1 = 12 \qquad V_2 = V_X = V_{oc}$

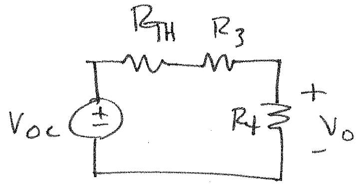
$$\frac{V_X}{1000} + \frac{V_1}{R_1} + \frac{V_2}{R_2} = 0$$

yields $V_2 = 3\,V$



$V_X = 0 \Rightarrow I_{sc} = 12/R_1 = 6\,mA$

$$R_{TH} = \frac{V_{oc}}{I_{sc}} = 500\,\Omega$$



$$V_o = \frac{V_{oc} R_4}{R_{TH} + R_3 + R_4}$$

$$\boxed{V_o = 1.33\,V}$$

5.65 Find V_o in the circuit in Fig. P5.65 using Thévenin's theorem. CS

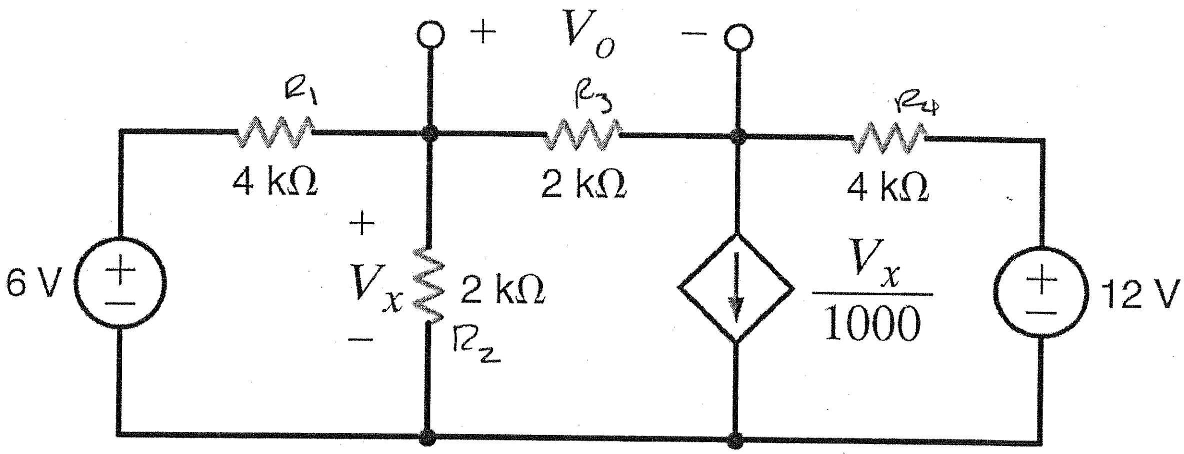
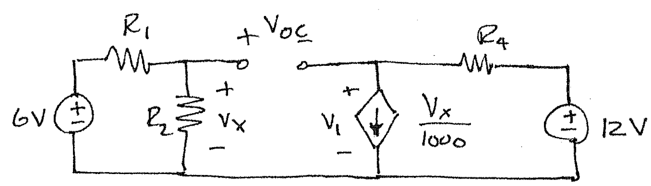


Figure P5.65

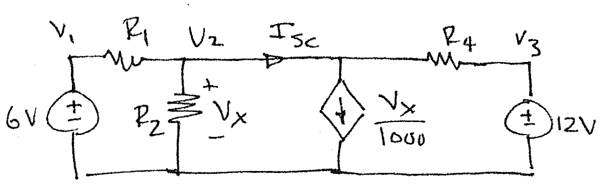
SOLUTION:



$$V_x = 6\,R_2/(R_1+R_2) = 2V$$

$$V_1 = 12 - \frac{V_x R_4}{1000} = 4V$$

$$V_{OC} = V_x - V_1 = -2V$$



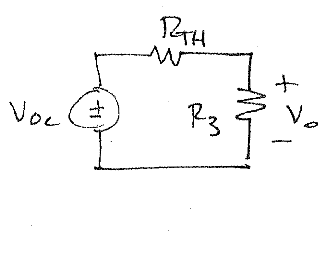
$V_1 = 6V \qquad V_3 = 12V \qquad V_x = V_2$

$$\frac{V_2 - V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_2}{1000} + \frac{V_2 - V_3}{R_4} = 0$$

$$V_2 = 2.25V$$

$$I_{SC} = \frac{V_x}{1000} + \frac{V_2 - V_3}{R_4} = -0.1875\,mA$$

$$R_{TH} = V_{OC}/I_{SC} = 10.67\,k\Omega$$



$$V_o = \frac{V_{OC}\,R_3}{R_3 + R_{TH}}$$

$$\boxed{V_o = -0.316\,V}$$

5.66 Find V_o in the network in Fig. P5.66 using Thévenin's theorem.

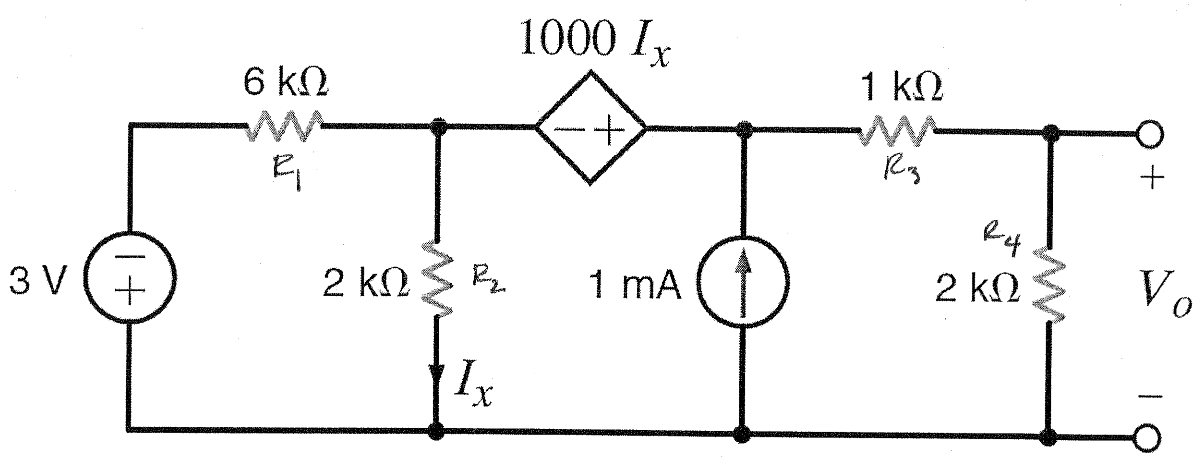
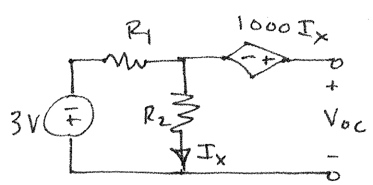


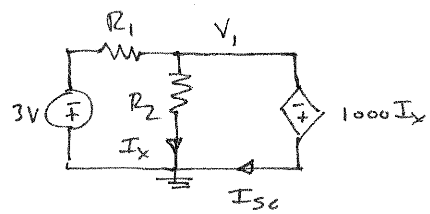
Figure P5.66

SOLUTION:



$$I_x = \frac{-3}{R_1+R_2} = -\frac{3}{8}\ \text{mA}$$

$$-I_x R_2 - 1000 I_x + V_{oc} = 0 \Rightarrow V_{oc} = -1.125\text{V}$$

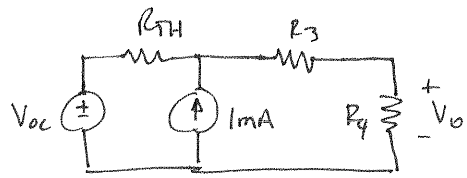


$I_x = V_1 / R_2$ & $V_1 = -1000 I_x$

only solution is $I_x = 0\text{A}$ & $V_1 = 0\text{V}$

$I_{sc} = -3/R_1 = -0.5\text{mA}$

$R_{TH} = V_{oc}/I_{sc} = 2.25\text{k}\Omega$



Superposition:

$$V_o = \frac{V_{oc} R_4}{R_{TH}+R_3+R_4} + \left(\frac{10^{-3} R_{TH}}{R_{TH}+R_3+R_4}\right) R_4$$

$$\boxed{V_o = 0.429\text{V}}$$

5.67 Use Thévenin's theorem to find V_o in the circuit in Fig. P5.67.

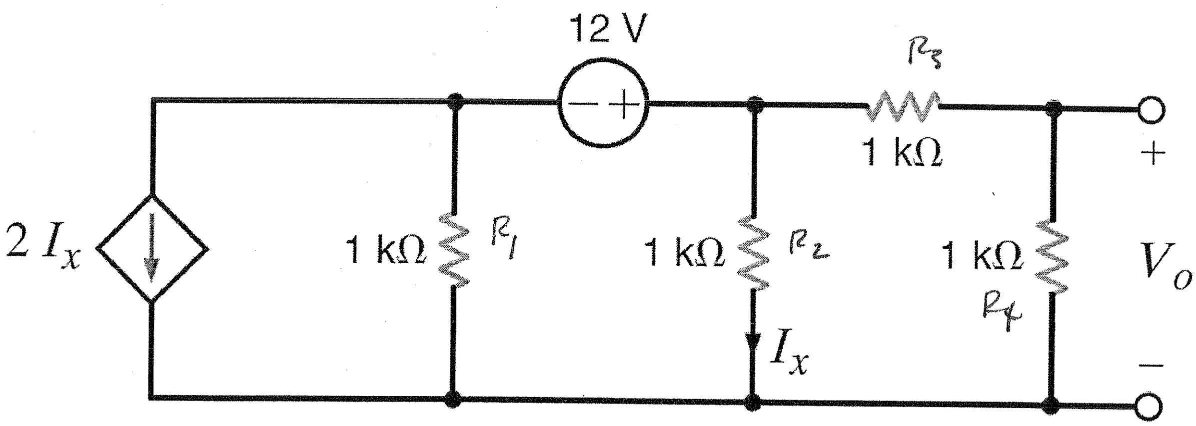
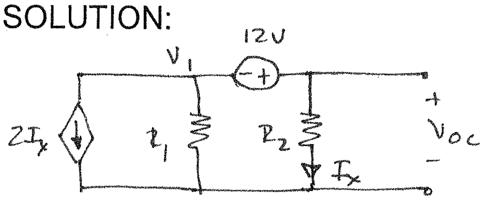


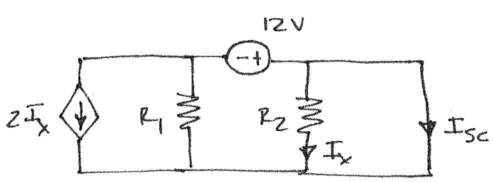
Figure P5.67

SOLUTION:



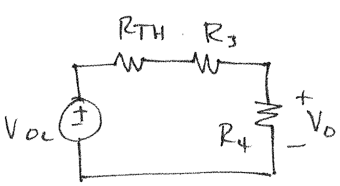
$V_{oc} - V_1 = 12$ $\quad I_x = V_{oc}/R_2$

$\frac{V_1}{R_1} + \frac{V_{oc}}{R_2} + 2I_x = 0 \Rightarrow V_{oc} = 3V$



$I_x = 0$ $\quad I_{sc} = 12/R_1 = 12\,mA$

$R_{TH} = V_{oc}/I_{sc} = 250\Omega$



$V_o = \frac{R_4 V_{oc}}{R_{TH} + R_3 + R_4}$ $\quad \boxed{V_o = 1.33\,V}$

5.68 Use Norton's theorem to find V_o in the network in Fig. P5.68. CS

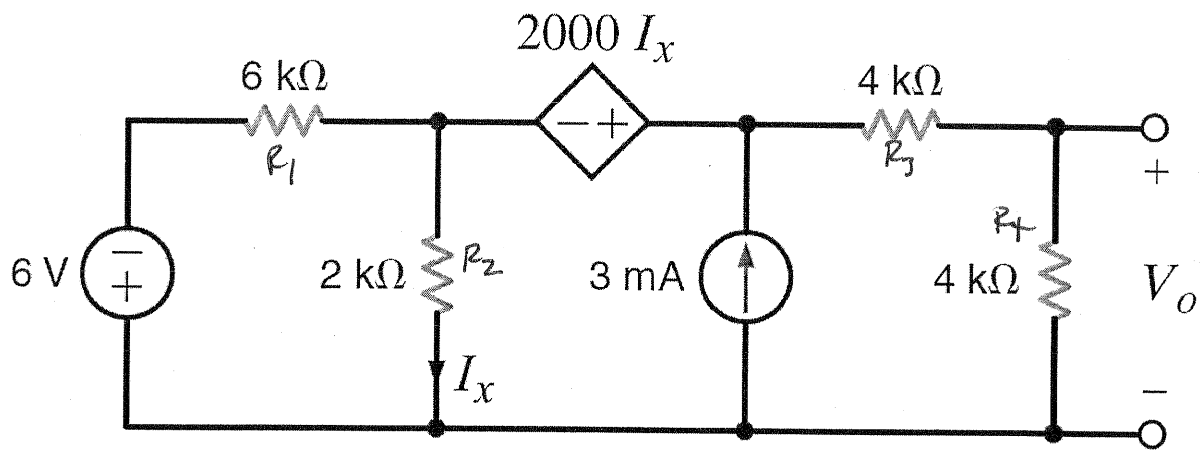
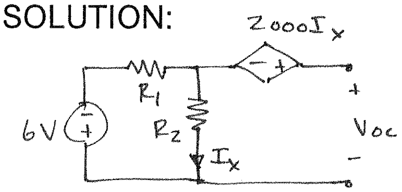


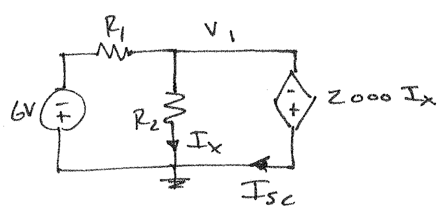
Figure P5.68

SOLUTION:



$$I_x = -6/(R_1+R_2) = -0.75\text{ mA}$$

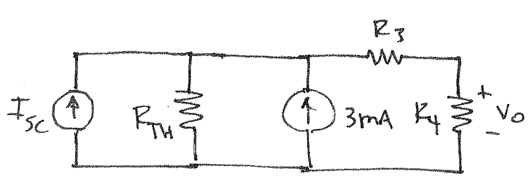
$$-R_2 I_x - 2000 I_x + V_{oc} = 0 \qquad V_{oc} = -3\text{ V}$$



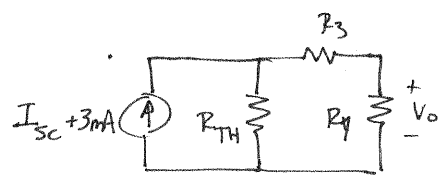
$$V_1 = R_2 I_x \;\&\; V_1 = -2000 I_x \Rightarrow I_x = 0 \;\&\; V_1 = 0$$

$$I_{sc} = -6/R_1 = -1\text{ mA}$$

$$R_{TH} = V_{oc}/I_{sc} = 3\text{k}\Omega$$



$\Rightarrow$



$$V_o = \frac{(I_{sc} + 3\times10^{-3})\, R_{TH}}{R_{TH}+R_3+R_4} R_4$$

$$\boxed{V_o = 2.18\text{ V}}$$

5.69 Find V_o in the network in Fig. P5.69 using Thévenin's theorem.

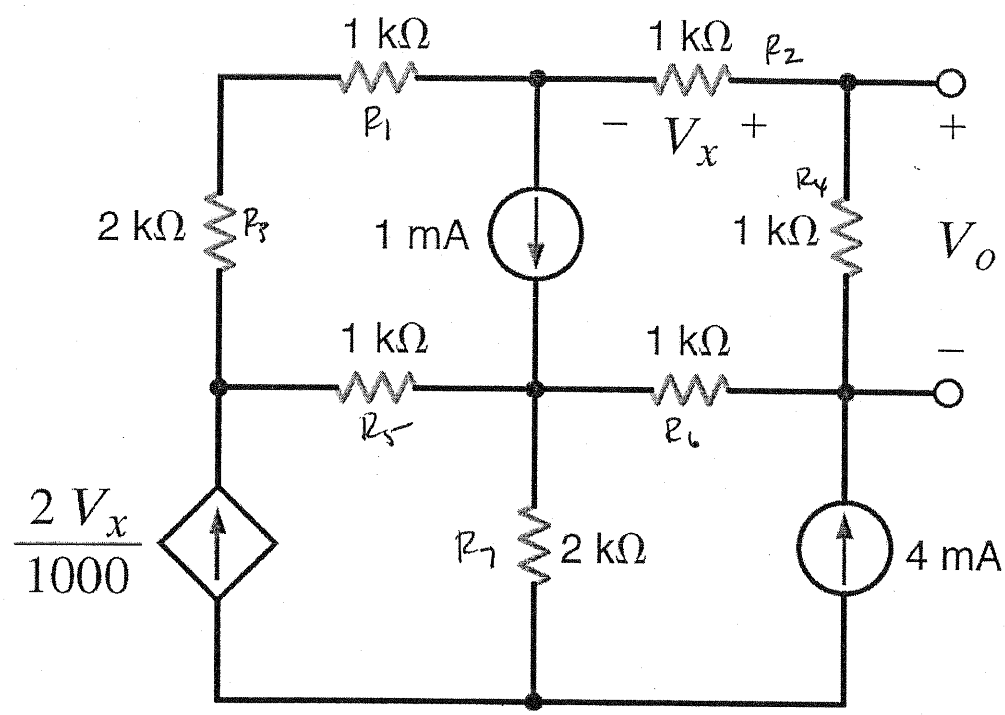
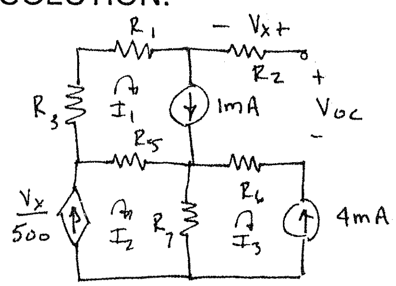


Figure P5.69

SOLUTION:

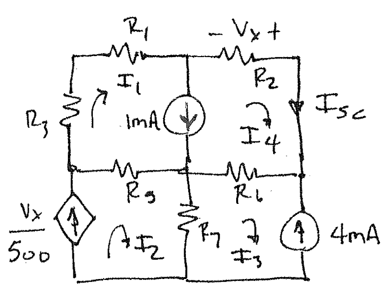


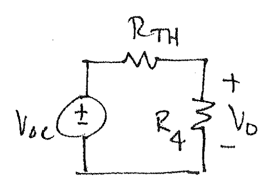
$$\left\{\begin{array}{l} I_1 = 1\,mA \quad I_2 = 2V_x \quad V_x = 0 \quad I_3 = -4mA \\ R_3 I_1 + R_1 I_1 + V_{oc} + R_6(0 - I_3) + R_5(I_1 - I_2) = 0 \\ V_{oc} = -8\,V \end{array}\right.$$

$I_1 - I_4 = 1mA \quad I_2 = 2V_x/1000 \quad V_x = -R_2 I_4 \quad I_3 = -4mA$

$(R_3 + R_1)I_1 + R_2 I_4 + R_6(I_4 - I_3) + R_5(I_1 - I_2) = 0$

$I_{sc} = -1mA \qquad R_{TH} = V_{oc}/I_{sc} = 8\,k\Omega$





$V_o = V_{oc} R_4 / (R_{TH} + R_4)$

$\boxed{V_o = -0.889V}$

5.70 Find V_o in the circuit in Fig. P5.70 using Thévenin's theorem.

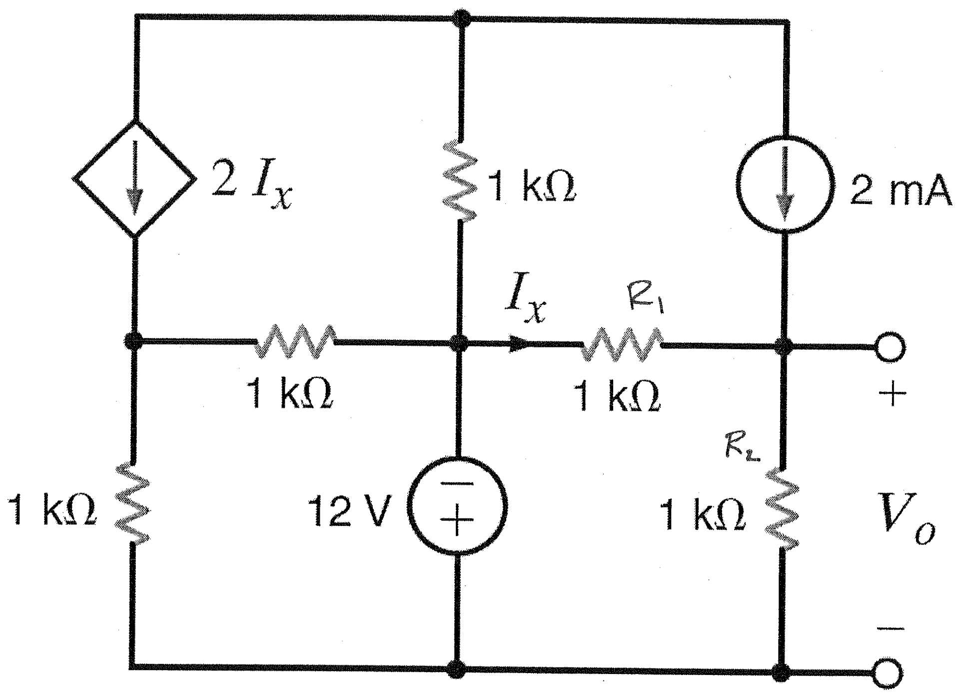
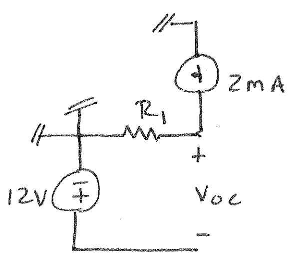


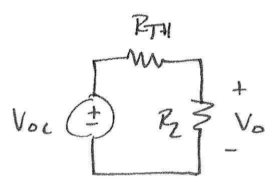
Figure P5.70

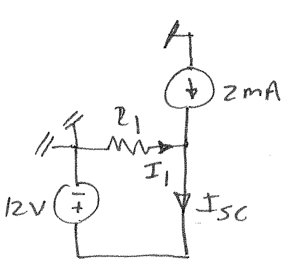
SOLUTION:



$$12 - 2\times10^{-3} R_1 + V_{oc} = 0$$

$$V_{oc} = -10\text{V}$$





$$I_1 = -12/R_1 = -12\text{mA}$$

$$I_{sc} = 2\times10^{-3} + I_1 = -10\text{mA}$$

$$R_{TH} = \frac{V_{oc}}{I_{sc}} = 1\text{k}\Omega$$

$$V_o = \frac{V_{oc} R_2}{R_{TH} + R_2}$$

$$\boxed{V_o = -5\text{V}}$$

5.71 Find V_o in the network in Fig. P5.71 using Thévenin's theorem.

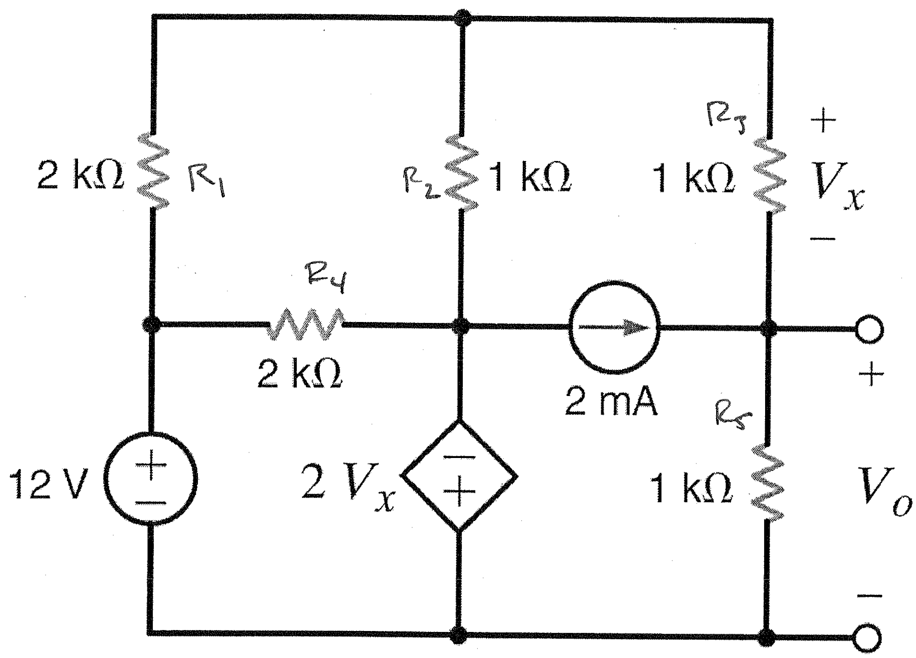
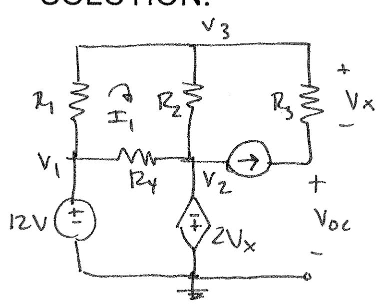


Figure P5.71

SOLUTION:

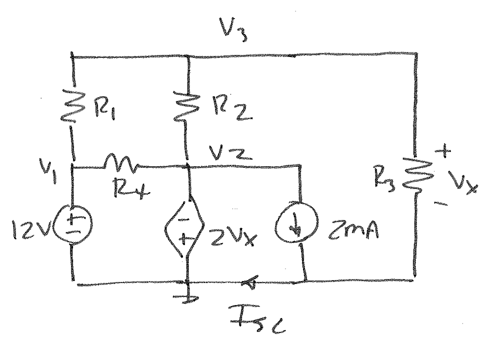


$V_1 = 12V \quad V_2 = -2V_x \quad V_x = V_3 - V_{oc}$

$(V_3 - V_{oc})/R_3 + 2\times10^{-3} = 0$

$$\frac{V_3 - V_1}{R_1} + \frac{V_3 - V_2}{R_2} + \frac{V_3 - V_{oc}}{R_3} = 0$$

yields $V_{oc} = 10V$



$V_1 = 12V \quad V_2 = -2V_x \quad V_x = V_3$

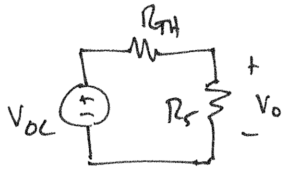
$$\frac{V_3 - V_1}{R_1} + \frac{V_3 - V_2}{R_2} + \frac{V_3}{R_3} = 0$$

yields $V_3 = 1.33\ V$

$I_{sc} = 2\times10^{-3} + V_3/R_3 \quad I_{sc} = 3.33\ mA$

cont

$R_{TH} = V_{oc}/I_{sc} = 3\,k\Omega$



$V_o = \dfrac{V_{oc} R_5}{R_{TH} + R_5}$

$\boxed{V_o = 2.5V}$

5.72 Use Thévenin's theorem to find V_o in the network in Fig. P5.72.

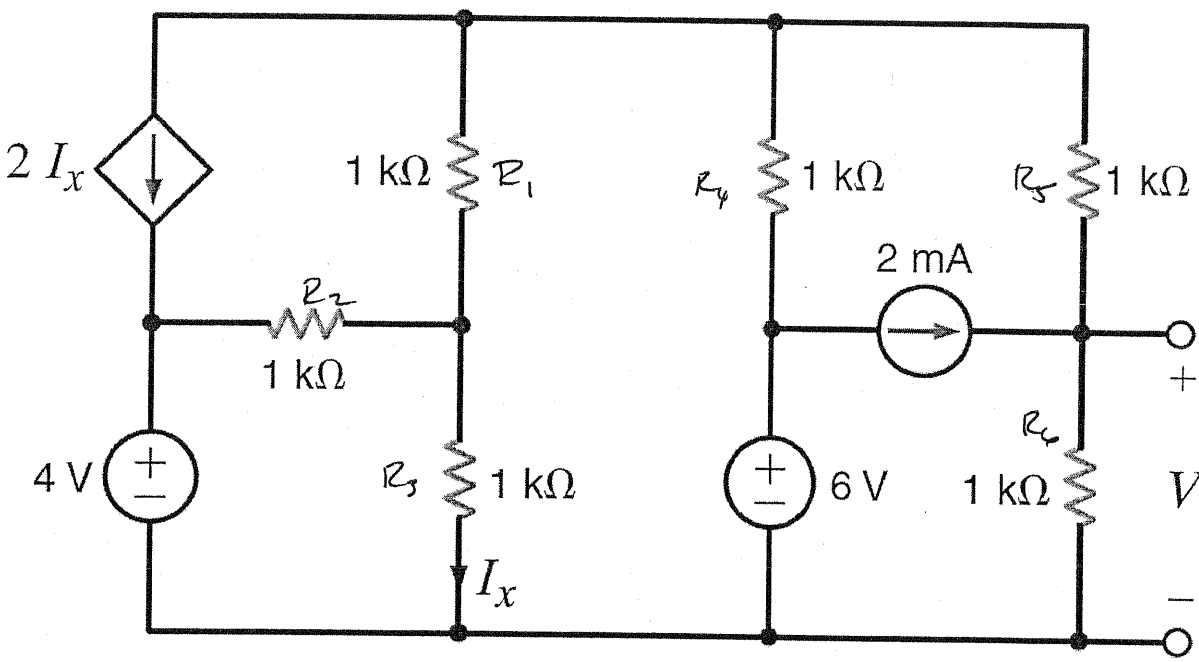
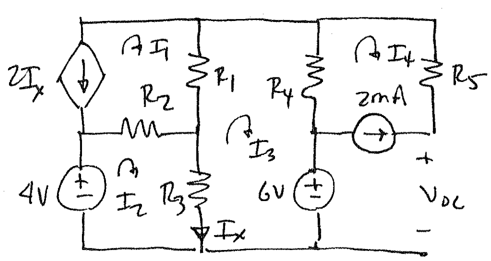


Figure P5.72

SOLUTION:



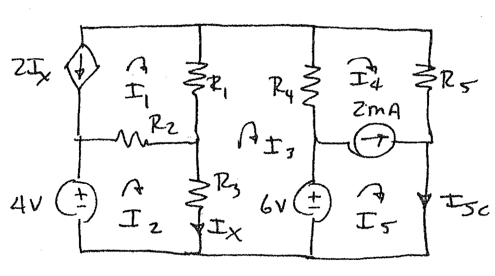
$I_1 = -2I_x \qquad I_x = I_2 - I_3 \qquad I_4 = -2mA$

$4 = (R_2 + R_3)I_2 - R_2 I_1 - R_3 I_3$

$-6 = (R_1 + R_4 + R_3)I_3 - R_3 I_2 - R_1 I_1 - I_4 R_4$

$6 = R_4 (I_4 - I_3) + R_5 I_4 + V_{oc}$

yields $\quad V_{oc} = 4.86V$



$I_1 = -2I_x \qquad I_x = I_2 - I_3 \qquad I_5 - I_4 = 2mA$

$4 = (R_2 + R_3) I_2 - R_2 I_1 - R_3 I_3$

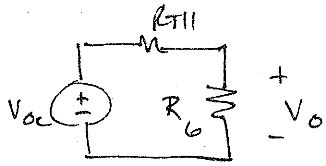
$-6 = (R_1 + R_3 + R_4) I_3 - R_1 I_1 - R_3 I_2 - R_4 I_4$

$6 = R_4 (I_4 - I_3) + R_5 I_4$

yields $\quad I_5 = I_{SC} = 3.4mA$

cont

$R_{TH} = V_{oc} / I_{sc} = 1.43\ k\Omega$



$$\boxed{V_o = 2.0\,V}$$

5.73 Use Thévenin's theorem to find I_o in the network in Fig. P5.73.

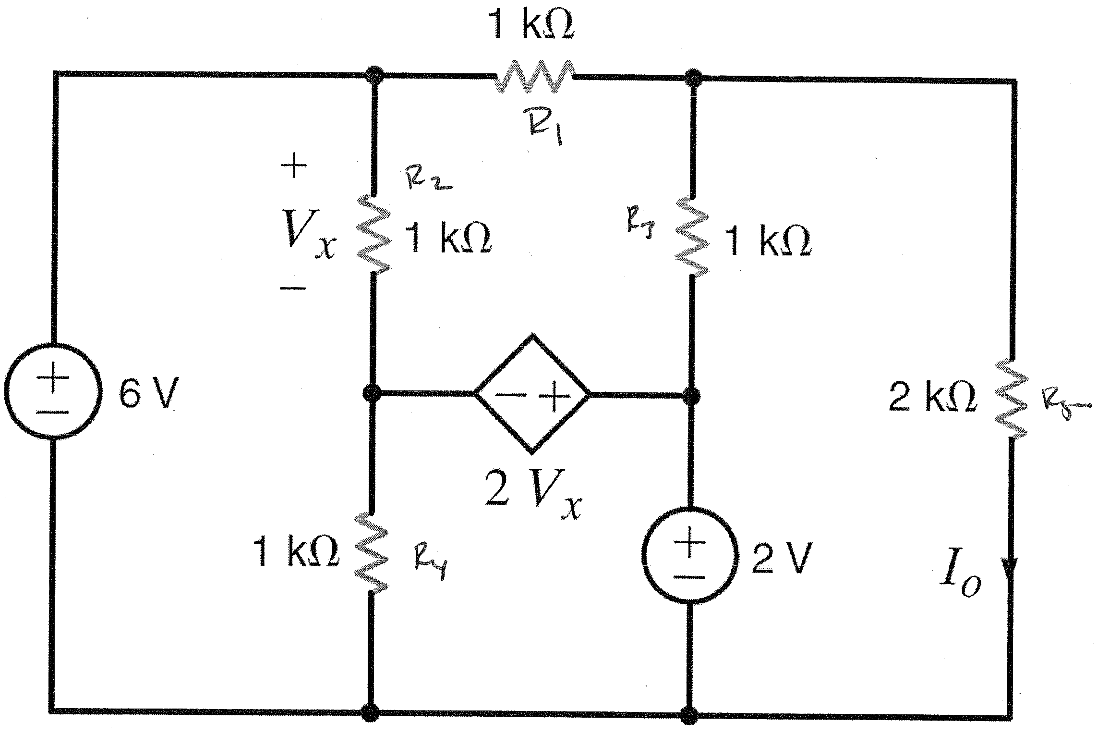
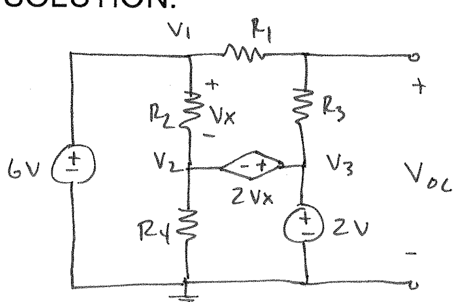


Figure P5.73

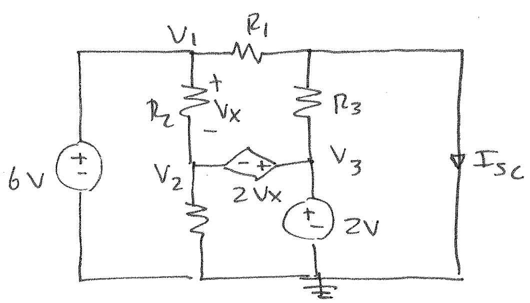
SOLUTION:



$V_1 = 6V \quad V_3 = 2V \quad V_3 - V_2 = 2V_x \quad V_x = V_1 - V_2$

$$\frac{V_{oc} - V_1}{R_1} + \frac{V_{oc} - V_3}{R_3} = 0$$

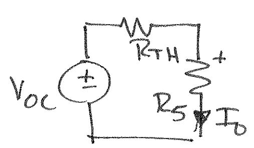
yield $V_{oc} = 4V$.



$V_1 = 6V \quad V_3 = 2V \quad V_3 - V_2 = 2V_x \quad V_x = V_1 - V_2$

$$\frac{V_1}{R_1} + \frac{V_3}{R_3} = I_{sc}$$

yields $I_{sc} = 8mA$



$R_{TH} = V_{oc}/I_{sc} = 500\Omega$

$I_o = V_{oc}/(R_{TH} + R_5)$

$\boxed{I_o = 1.6mA}$

5.74 Using Thévenin's theorem find I_o in the circuit in Fig. P5.74.

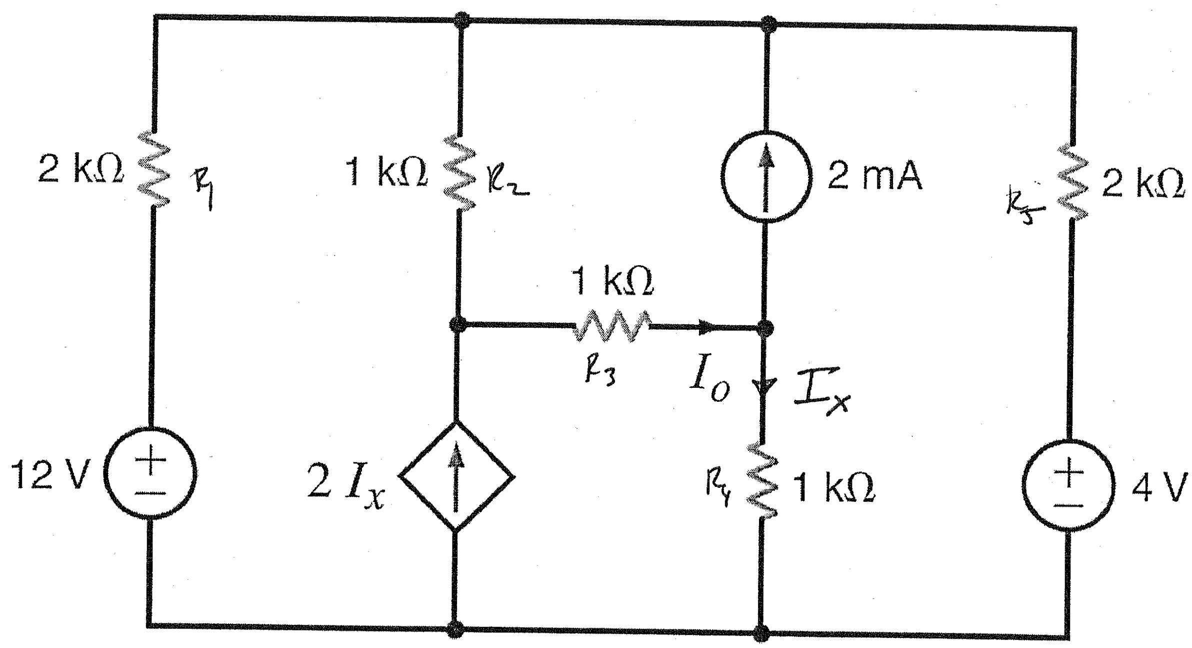
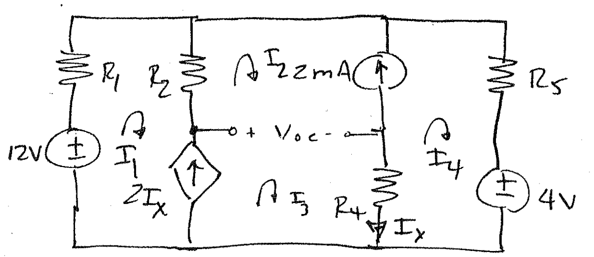


Figure P5.74

SOLUTION: Find Thevenin eq.

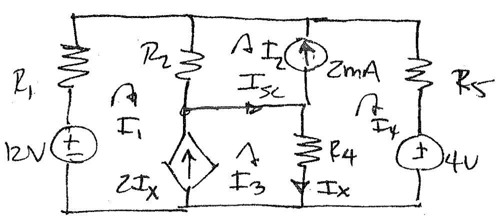


$I_3 - I_1 = 2I_x \quad I_x = I_3 - I_4 \quad I_4 - I_2 = 2mA$

$12 = R_1 I_1 + R_5 I_4 + 4$

$12 = R_1 I_1 + R_2(I_1 - I_2) + V_{oc} + R_4(I_3 - I_4)$

yields $V_{oc} = 12V$

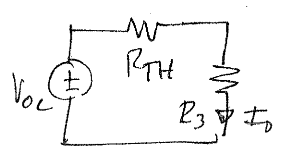


$I_3 - I_1 = 2I_x \quad I_x = I_3 - I_4 \quad I_4 - I_2 = 2mA$

$12 = I_1 R_1 + I_4 R_5 + 4$

$12 = I_1(R_1 + R_2) - I_2 R_2 + I_3 R_4 - I_4 R_4$

yields $I_{sc} = I_3 - I_2 = -4mA \Rightarrow R_{TH} = -3k\Omega$



$I_o = V_{oc} / (R_{TH} + R_3)$ $\boxed{I_o = -6mA}$

5.75 Find I_o in the network in Fig. P5.75 using Thévenin's theorem.

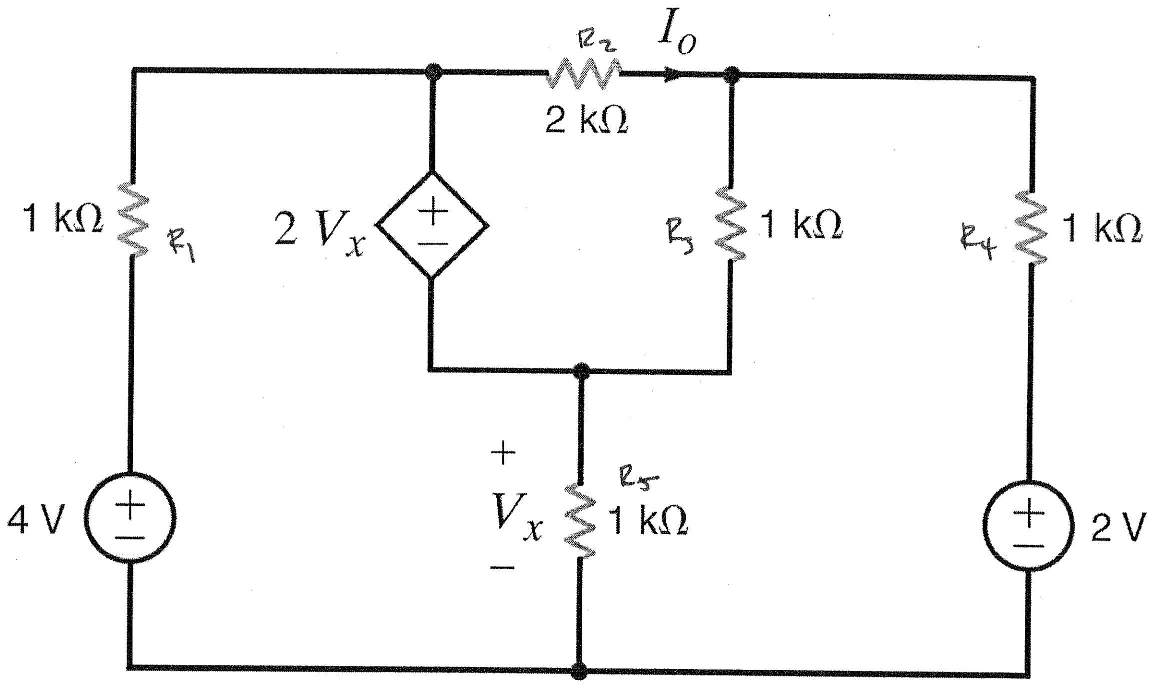
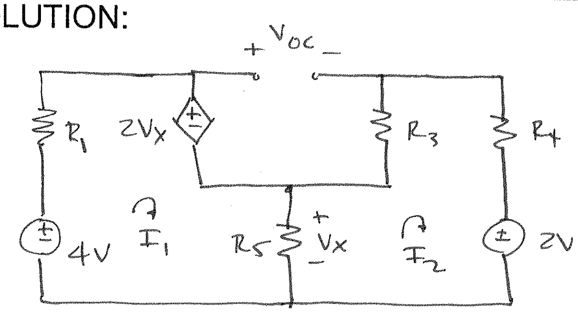


Figure P5.75

SOLUTION:

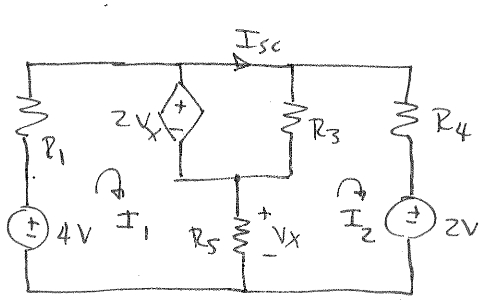


$$4 = I_1(R_1+R_5) - R_5 I_2 + 2V_x$$

$$V_x = R_5(I_1 - I_2)$$

$$-2 = I_2(R_5 + R_3 + R_4) - R_5 I_1$$

$$V_{oc} = 2V_x + R_3 I_2 = 1.78\text{V}$$



$$4 = (R_1+R_5)I_1 - R_5 I_2 + 2V_x \qquad V_x = R_5(I_1 - I_2)$$

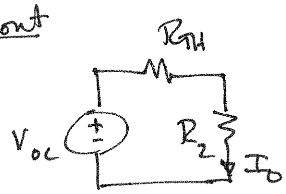
$$-2 = I_2(R_5 + R_3 + R_4) - R_5 I_1 - R_3 I_{sc}$$

$$2V_x = R_3(I_{sc} - I_2)$$

yields $I_{sc} = 2.29\text{ mA}$

$$R_{TH} = V_{oc}/I_{sc} = 777\,\Omega$$

Cont

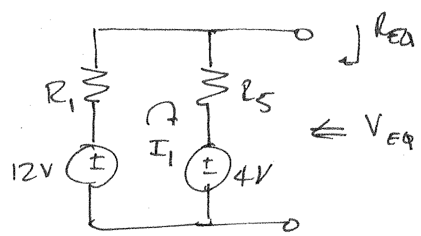


$$I_o = \frac{V_{oc}}{R_{TH} + R_2}$$

$$\boxed{I_o = 0.641\,mA}$$

5.76 Use Thévenin's theorem to find the power supplied by the 2-mA source in the network in Fig. P5.74. **PSV**

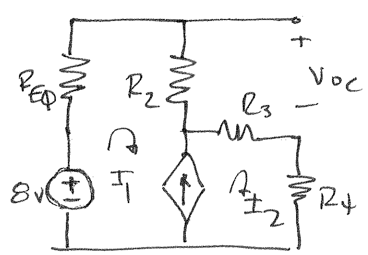
SOLUTION: $R_1 = R_5 = 2k\Omega \qquad R_2 = R_3 = R_4 = 1k\Omega$



$12 = (R_1 + R_5) I_1 + 4 \qquad I_1 = 2mA$

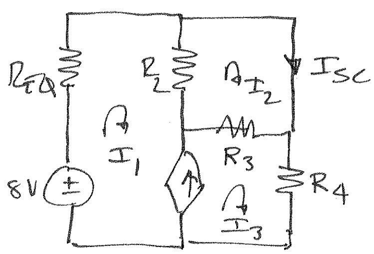
$V_{EQ} = 4 + R_5 I_1 = 8V$

$R_{EQ} = R_1 // R_5 = 1k\Omega$



$8 = I_1(R_{EQ} + R_2) + I_2(R_3 + R_4) \Rightarrow I_1 + I_2 = 4mA$

$8 = I_1(R_{EQ}) + V_{OC} + I_2 R_4 \Rightarrow V_{OC} = 4V$



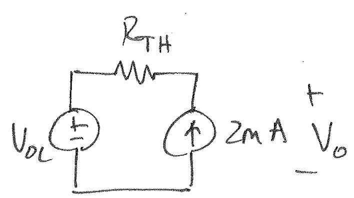
$8 = I_1(R_{EQ} + R_2) - I_2(R_2 + R_3) + I_3(R_3 + R_4)$

$0 = I_2(R_2 + R_3) - R_2 I_1 - R_3 I_3$

$I_{SC} = I_2$

$4mA = I_1 - I_2 + I_3 \qquad I_1 + I_3 = 2I_2$

$I_2 = 4mA = I_{SC}$



$R_{TH} = V_{OC}/I_{SC} = 1k\Omega$

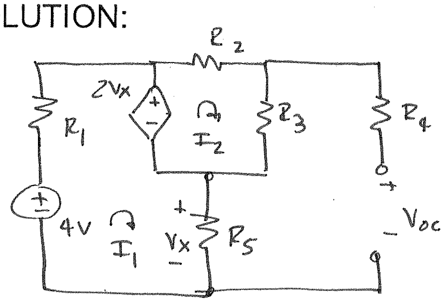
$P_{2mA} = (2\times10^{-3})V_o$

$V_{OC} = -2\times10^{-3} R_{TH} + V_o \Rightarrow V_o = 6V$

$$\boxed{P_{2mA} = 12mW}$$

5.77 Use Thévenin's theorem to find the power supplied by the 2-V source in the circuit in Fig. P5.75.

SOLUTION:



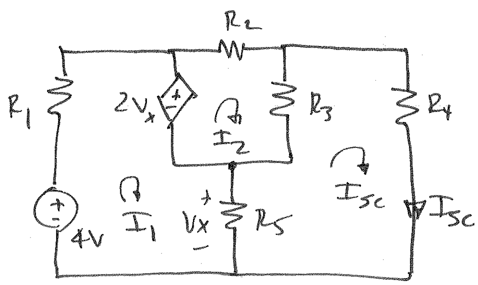
$R_2 = 2k\Omega$ else, $R = 1k\Omega$

$4 = I_1 R_1 + 2V_x + V_x \qquad V_x = I_1 R_5$

$2V_x = I_2 (R_2 + R_3)$

$V_{oc} = R_3 I_2 + I_5 I_1$

yields $V_{oc} = 1.67V$



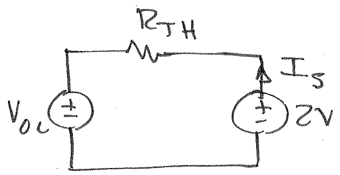
$4 = I_1 (R_1) + 3V_x \qquad V_x = R_5 (I_1 - I_{sc})$

$2V_x = I_2 (R_2 + R_3) - R_3 I_{sc}$

$I_{sc} (R_5 + R_3 + R_4) - R_3 I_2 - R_5 I_1 = 0$

yields $I_{sc} = 0.8mA$

$R_{TH} = V_{oc} / I_{sc} = 2.083 k\Omega$



$I_S = \frac{2 - V_{oc}}{R_{TH}} = 0.16 mA$

$P_{2V} = 2 I_S \qquad \boxed{P_{2V} = 0.32mW}$

5.78 Use source transformation to find V_o in the network in Fig. P5.78. CS

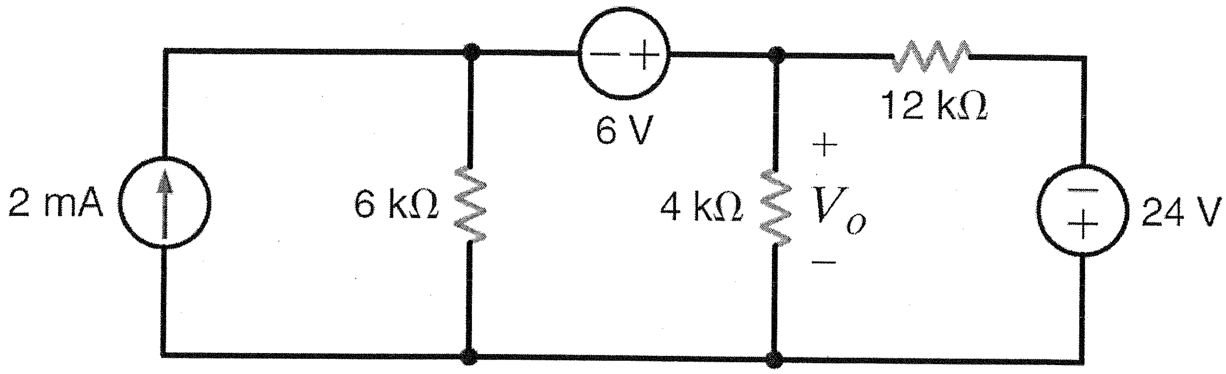
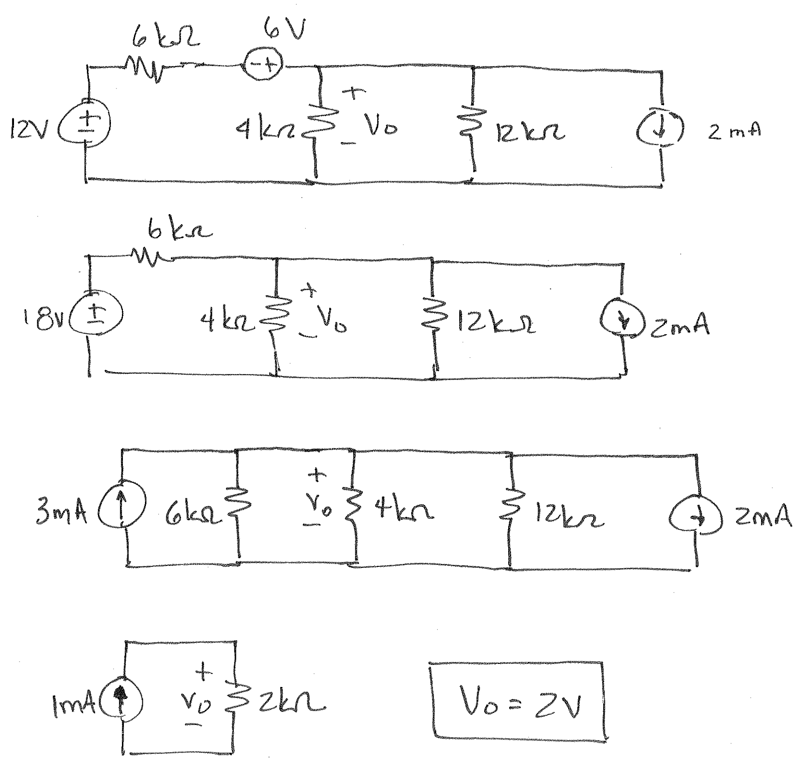


Figure P5.78

SOLUTION:



$\boxed{V_o = 2V}$

5.79 Find V_o in the network in Fig. P5.79 using source transformation.

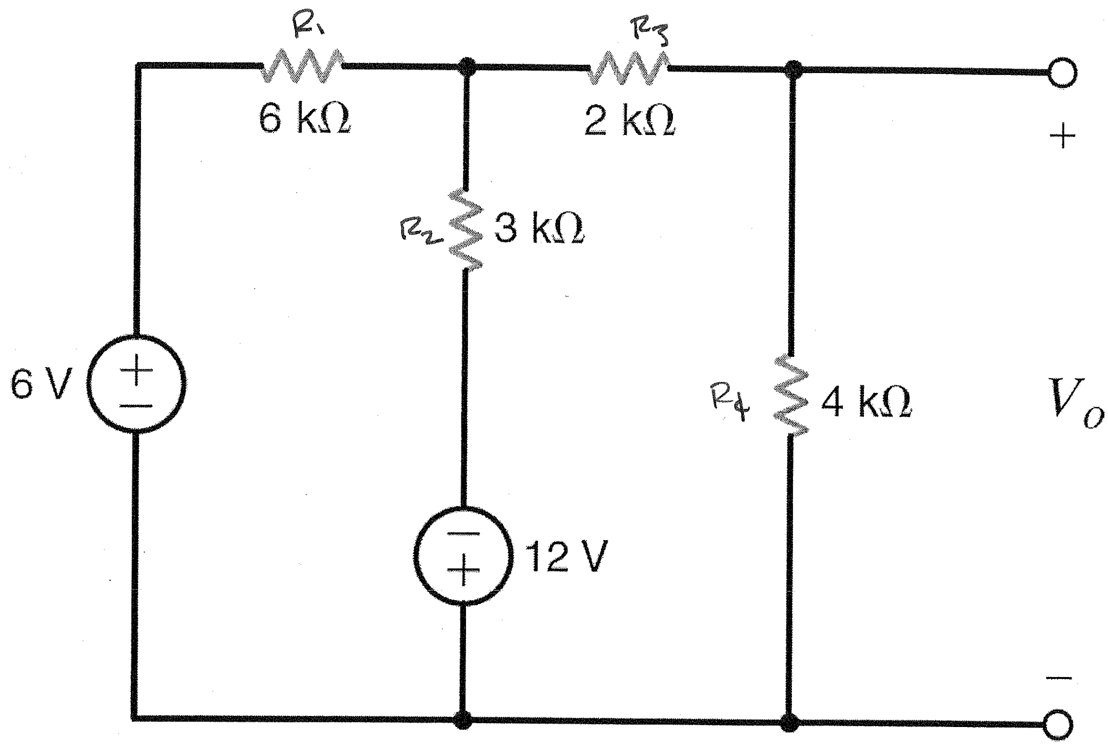
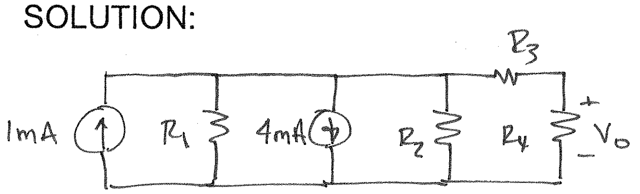
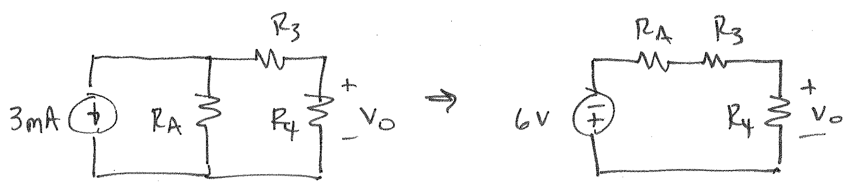


Figure P5.79

SOLUTION:



$R_A = R_1 // R_2 = 2k\Omega$



$$V_o = -6 \frac{R_4}{R_A + R_3 + R_4}$$

$$\boxed{V_o = -3V}$$

5.80 Use source transformation to find I_o in the network in Fig. P5.80. **PSV**

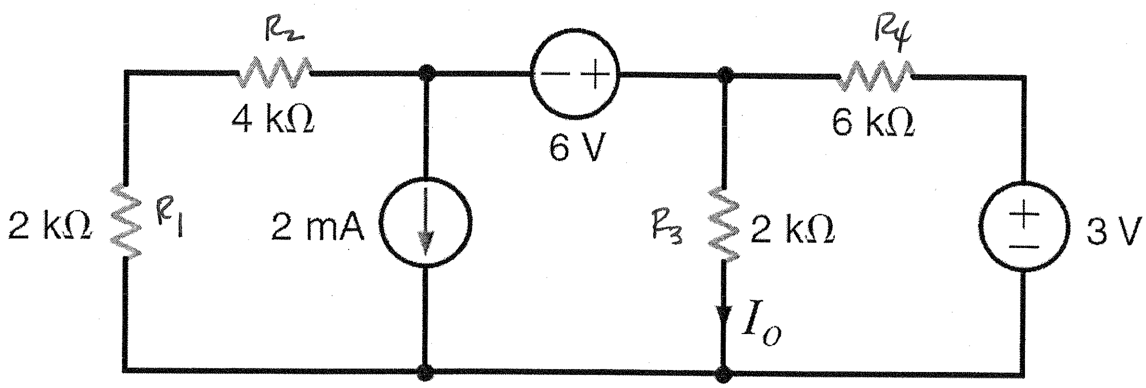
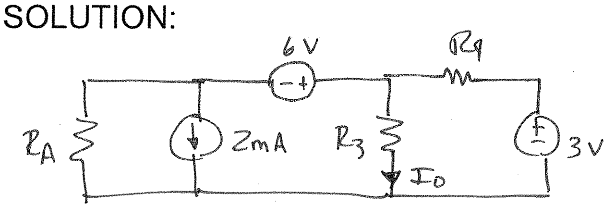
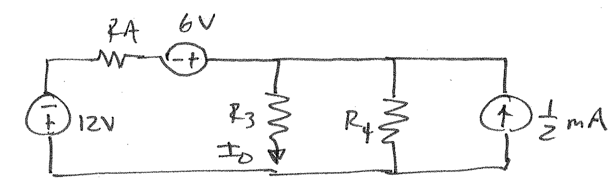


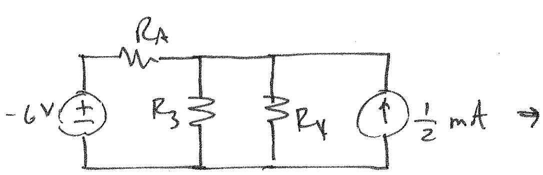
Figure P5.80

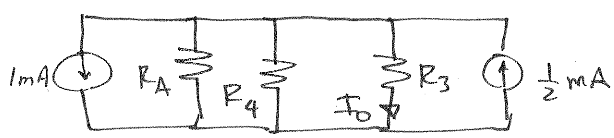
SOLUTION:

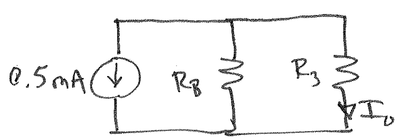




$R_A = R_1 + R_2 = 6k\Omega$







$R_B = R_A // R_4 = 3k\Omega$

$I_o = \dfrac{-0.5 \times 10^{-3} R_B}{R_B + R_3}$

$\boxed{I_o = -0.3mA}$

5.81 Use source transformation to find V_o in the network in Fig. P5.81.

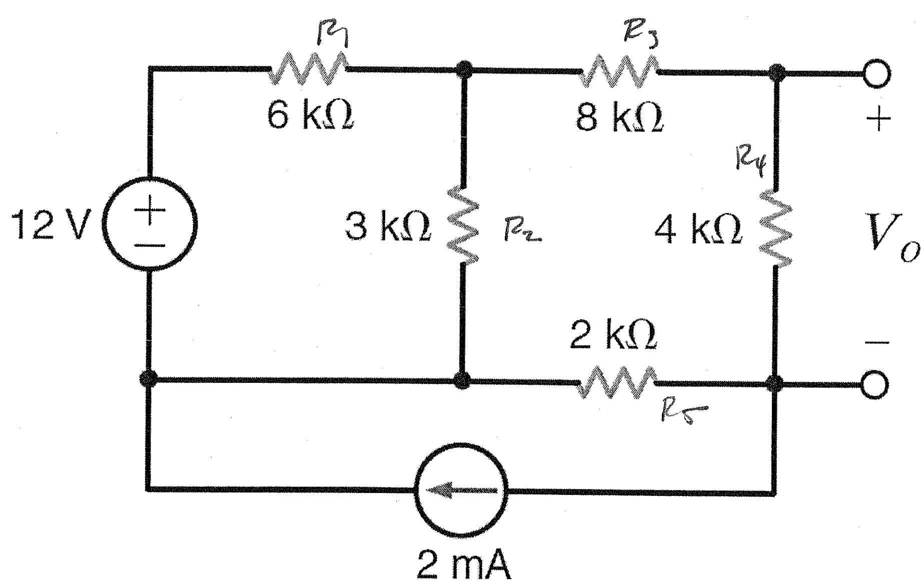
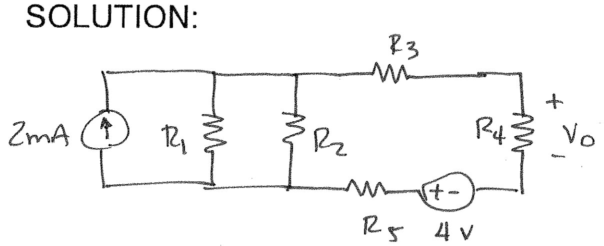
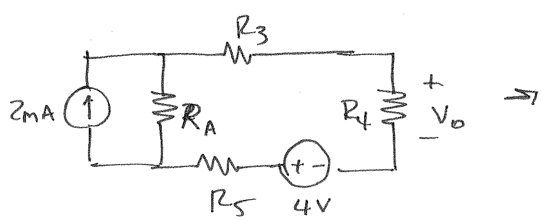


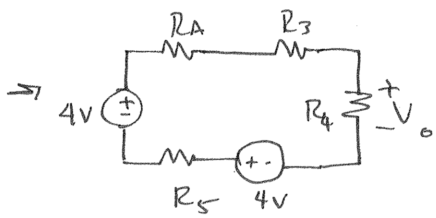
Figure P5.81

SOLUTION:



$R_A = R_1 // R_2 = 2k\Omega$





$$V_o = \frac{8 R_4}{R_A + R_3 + R_4 + R_5}$$

$$\boxed{V_o = 2V}$$

5.82 Find I_o in the network in Fig. P5.82 using source transformation.

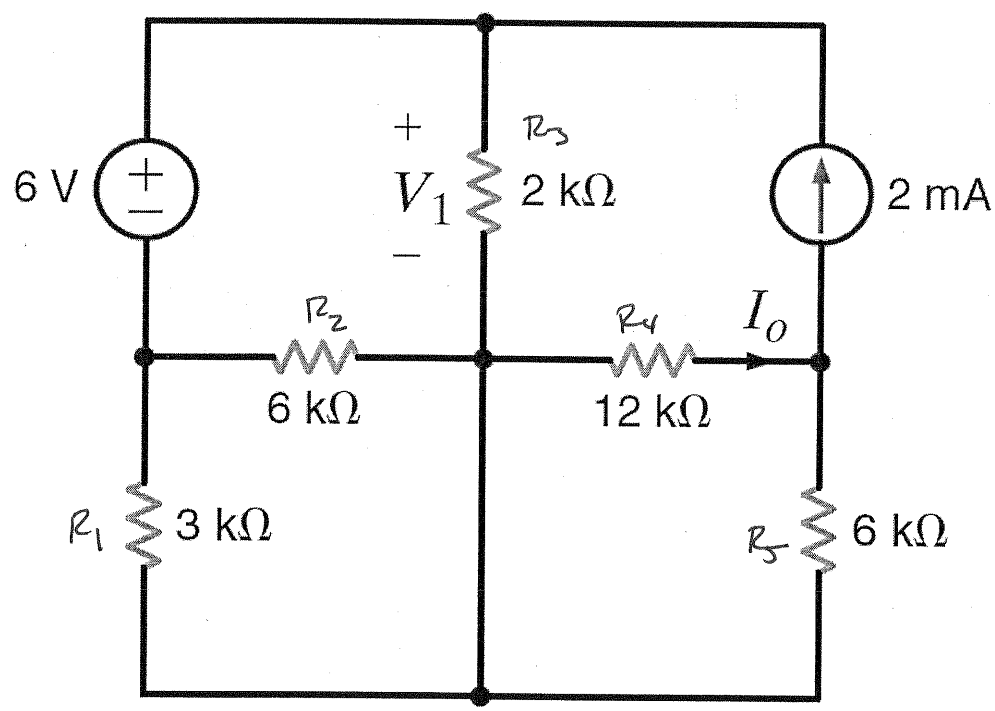
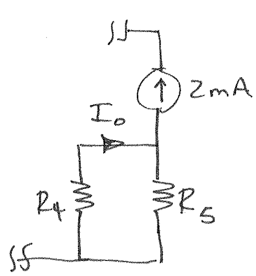


Figure P5.82

SOLUTION:



By current division:

$$I_o = \frac{2 \times 10^{-3} R_5}{R_4 + R_5} \Rightarrow \boxed{I_o = 0.67\,mA}$$

5.83 Find I_o in the network in Fig. P5.83.

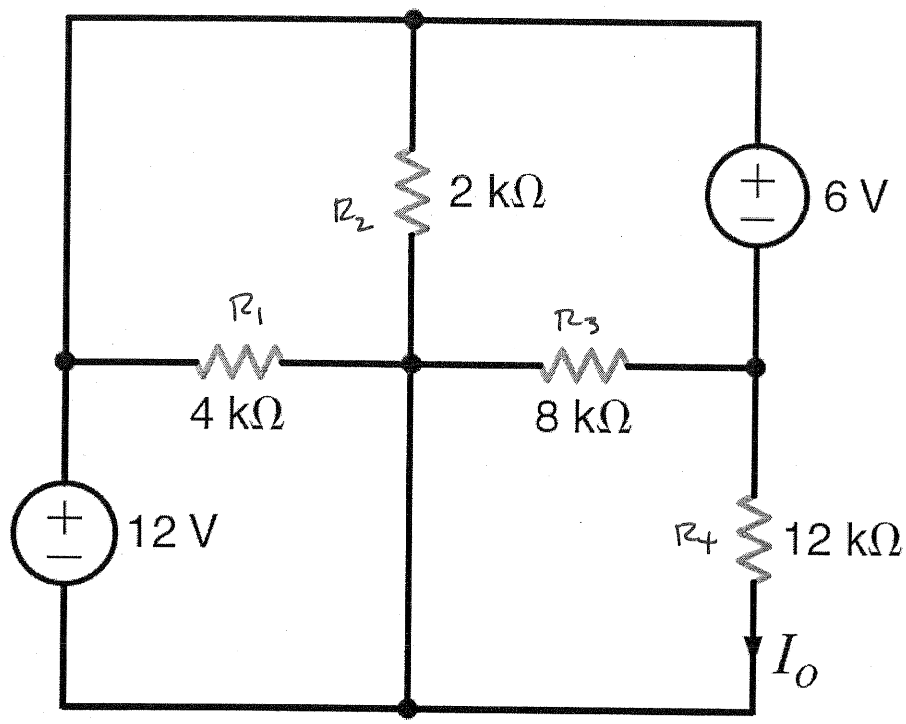


Figure P5.83

SOLUTION:

By KVL: $12 = 6 + R_4 I_o$

$\boxed{I_o = 0.5 mA}$

5.84 Find I_o in the network in Fig. P5.84 using source transformation.

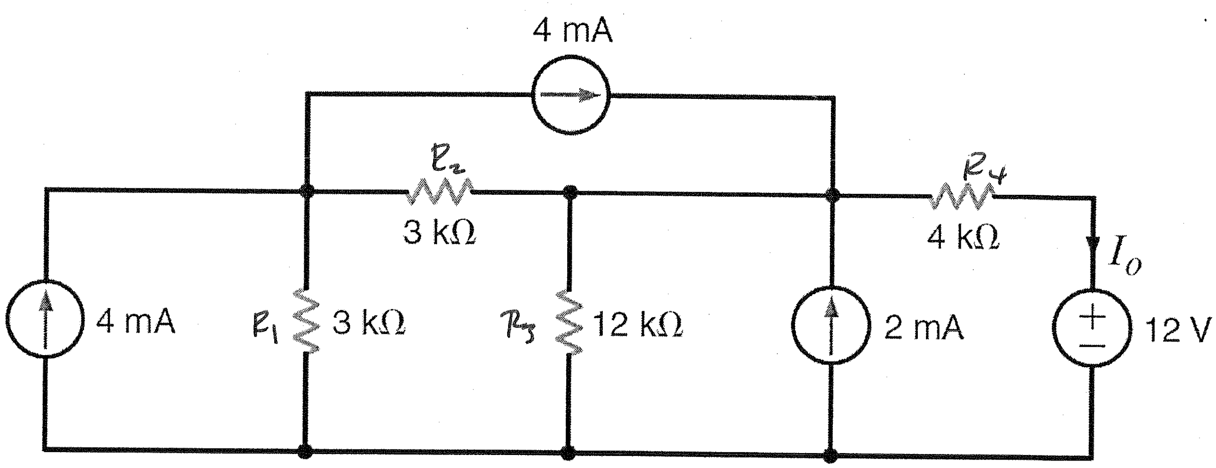
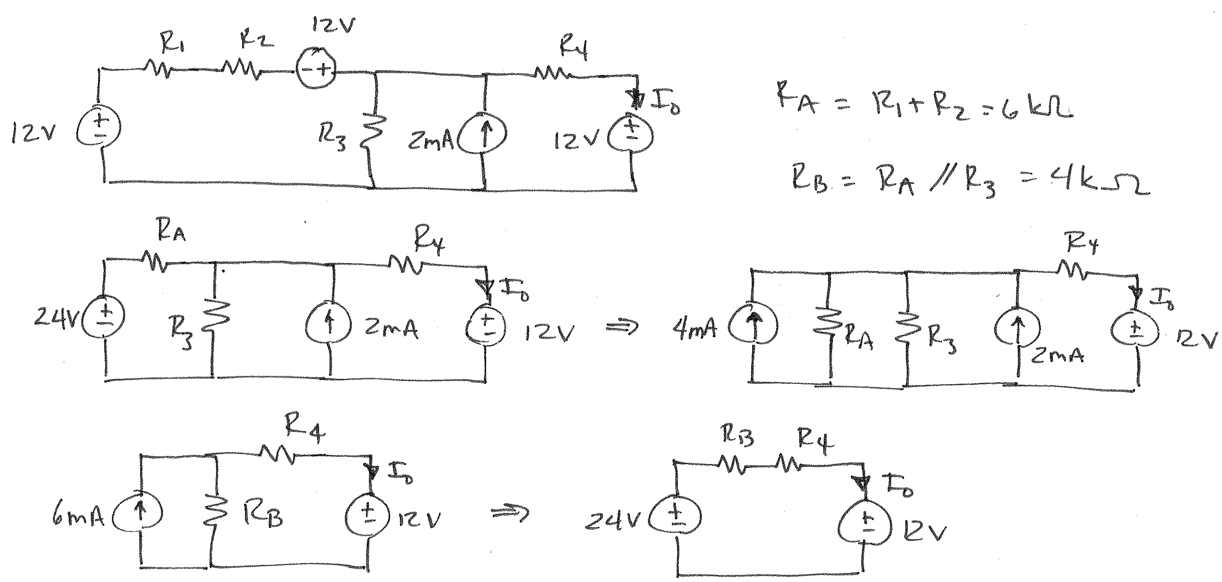


Figure P5.84

SOLUTION:



$R_A = R_1 + R_2 = 6\text{k}\Omega$

$R_B = R_A \,//\, R_3 = 4\text{k}\Omega$

$$I_o = \frac{24 - 12}{R_B + R_4}$$

$\boxed{I_o = 1.5\text{mA}}$

5.85 Use source transformation to find I_o in the circuit in Fig. P5.85. CS

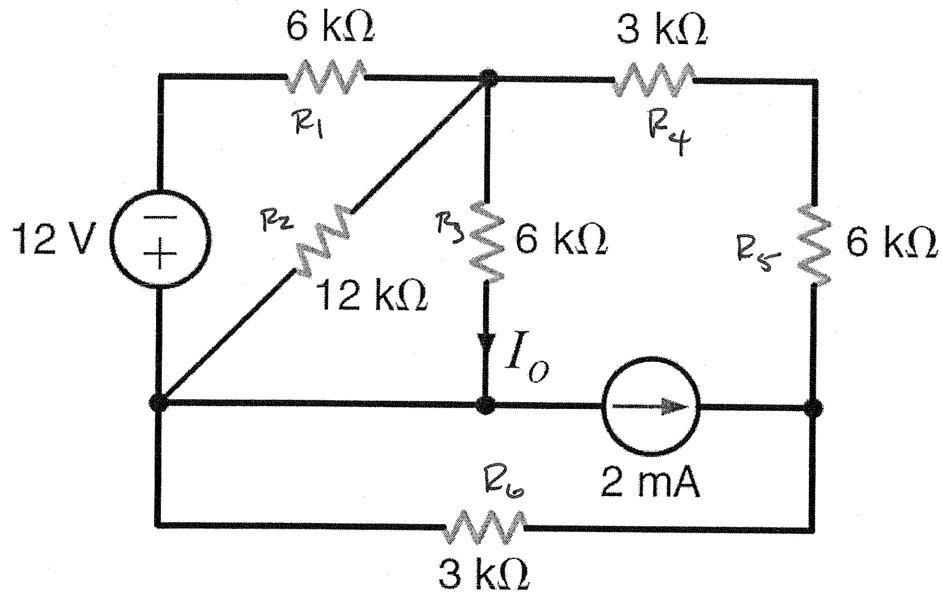
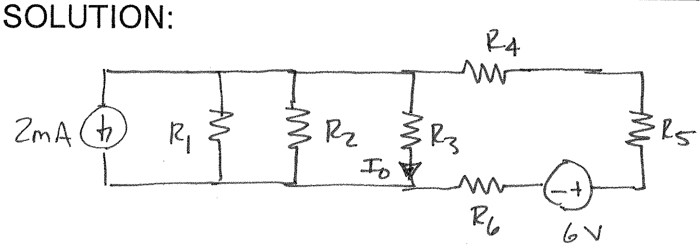


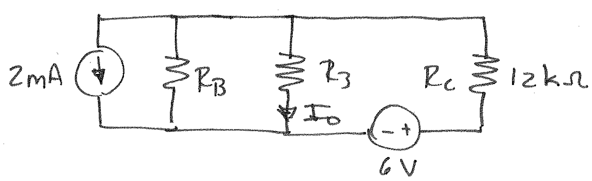
Figure P5.85

SOLUTION:

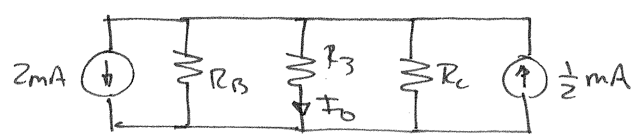


$R_B = R_1 // R_2 = 4k\Omega$

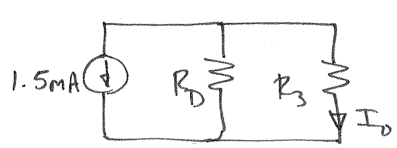
$R_C = R_4 + R_5 + R_6 = 12 k\Omega$



$\Rightarrow$



$R_D = R_B // R_C = 3k\Omega$



$I_o = -1.5\times10^{-3} \dfrac{R_D}{R_D + R_3}$

$\boxed{I_o = -0.5 mA}$

5.86 Find V_o in the network in Fig. P5.86 using source transformation.

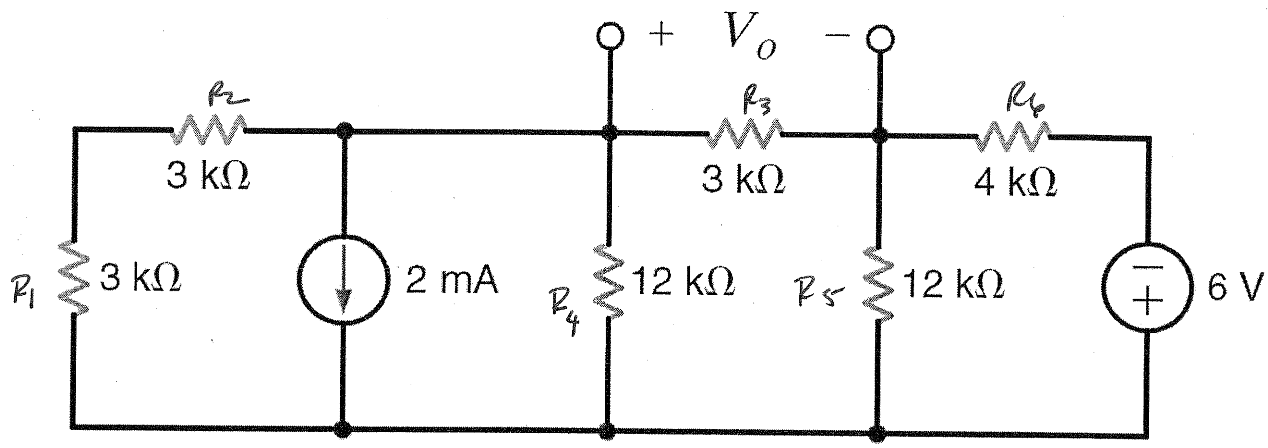
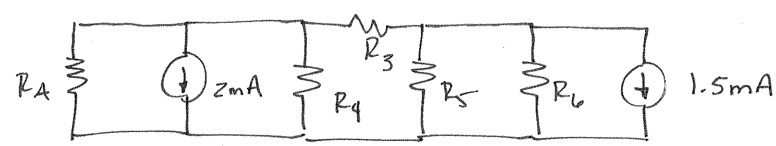


Figure P5.86

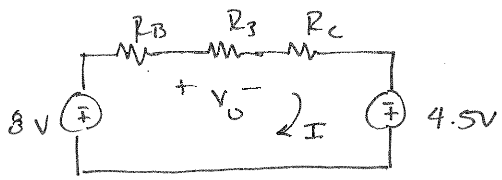
SOLUTION:



$R_A = R_1 + R_2 = 6\,k\Omega$

$R_B = R_A // R_4 = 4\,k\Omega$

$R_C = R_5 // R_6 = 3\,k\Omega$



$$8 + I(R_B + R_3 + R_C) - 4.5 = 0 \Rightarrow I = -0.35\,mA$$

$$\boxed{V_o = I R_3 = -1.05\,V}$$

5.87 Find I_o in the circuit in Fig. P5.87 using source transformation.

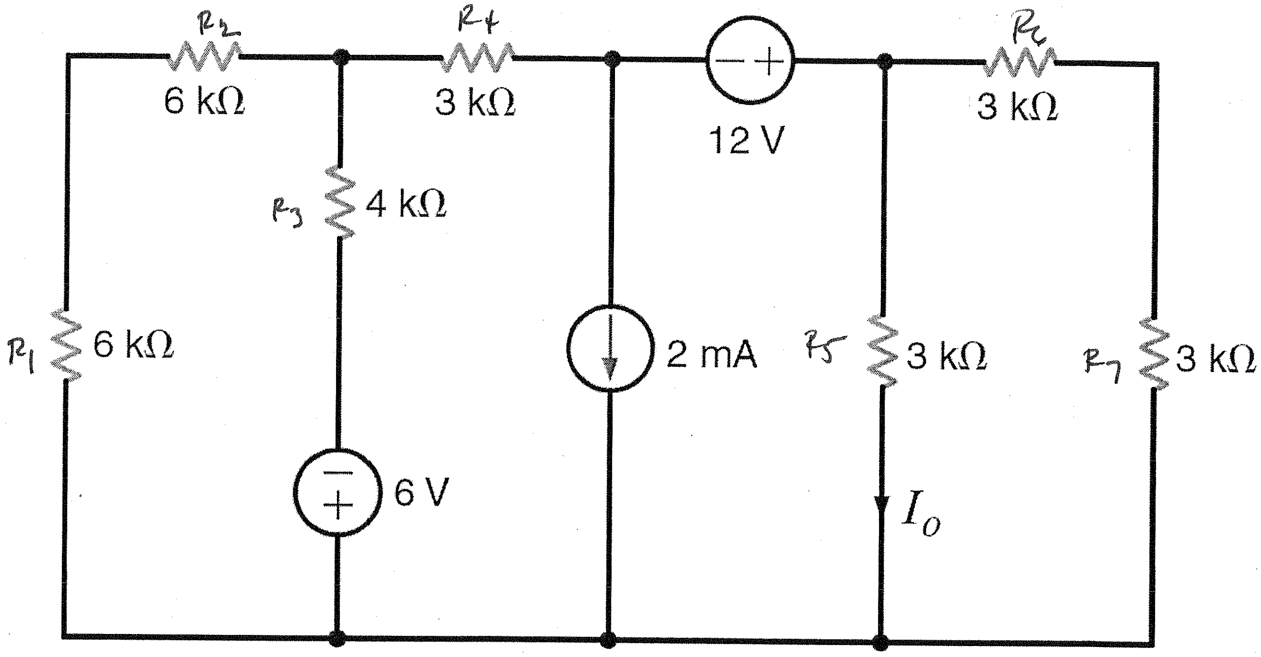
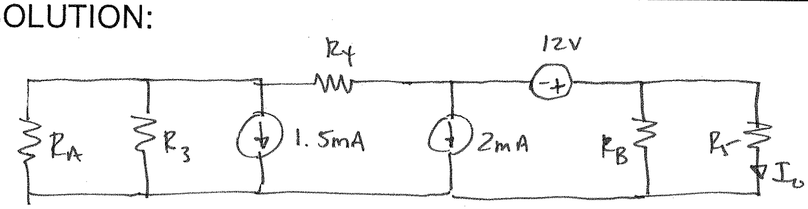


Figure P5.87

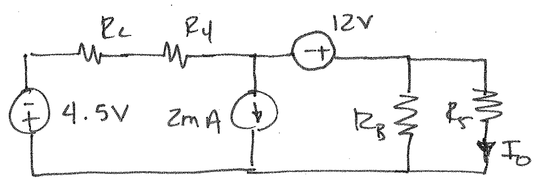
SOLUTION:

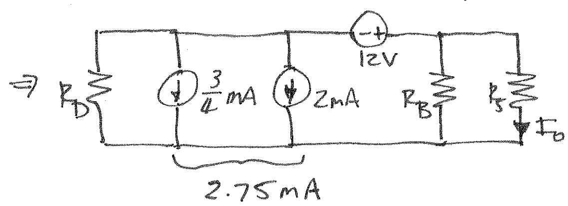


$R_A = R_1 + R_2 = 12k\Omega$

$R_B = R_6 + R_7 = 6k\Omega$

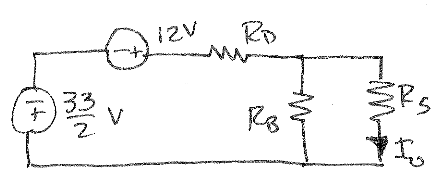
$R_C = R_A // R_3 = 3k\Omega$

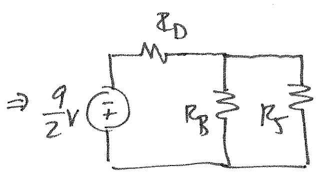


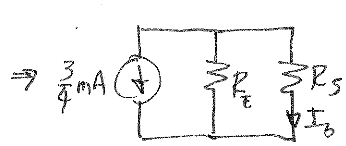


$R_D = R_C + R_4 = 6k\Omega$

$R_E = R_D // R_B = 3k\Omega$







$I_o = -0.375 mA$

5.88 Find I_o in the network in Fig. P5.88 using source transformation. CS

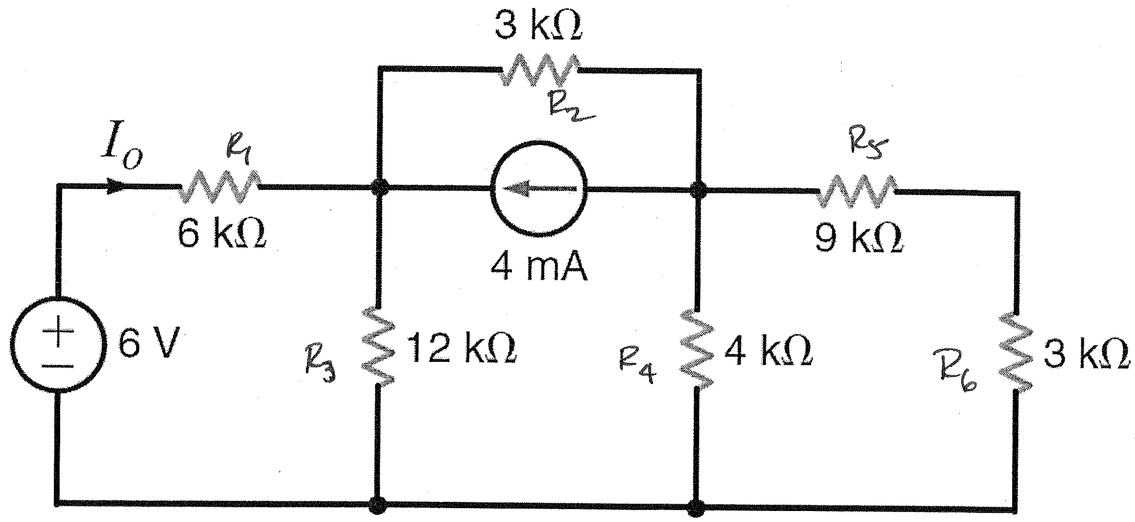
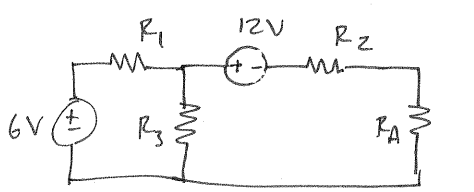


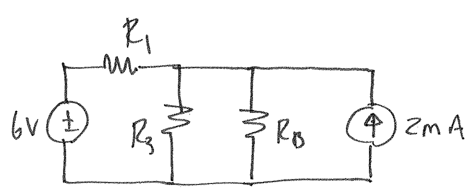
Figure P5.88

SOLUTION:

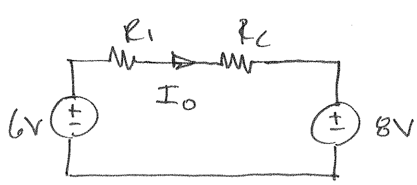


$R_A = R_4 \,//\, (R_5 + R_6) = 3k\Omega$

$R_B = R_2 + R_A = 6k\Omega$



$R_C = R_3 \,//\, R_B = 4k\Omega$

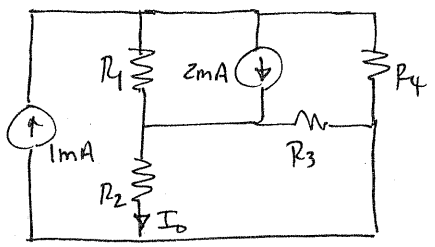


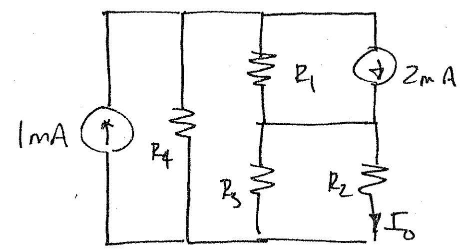
$6 = I_o\,(R_1 + R_C) + 8$

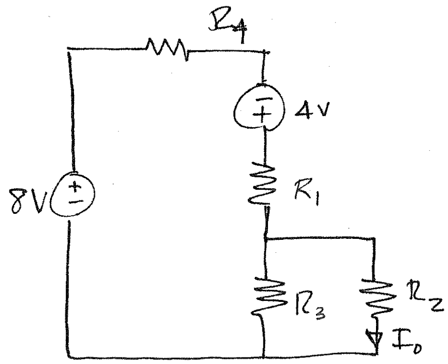
$\boxed{I_o = -0.2mA}$

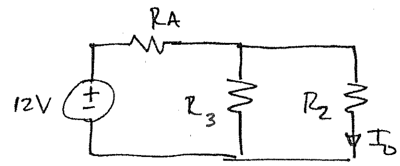
5.89 Solve Problem 5.16 using source transformation.

SOLUTION: $R_1 = 2k\Omega \quad R_2 = 6k\Omega \quad R_3 = 3k\Omega \quad R_4 = 8k\Omega$

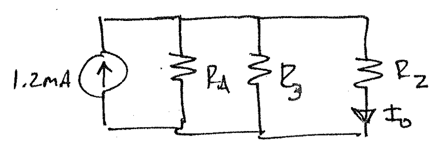




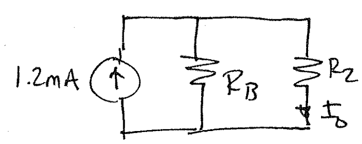




$R_A = R_1 + R_4 = 10k\Omega$



$R_B = R_A // R_3 = \frac{30}{13} k\Omega$

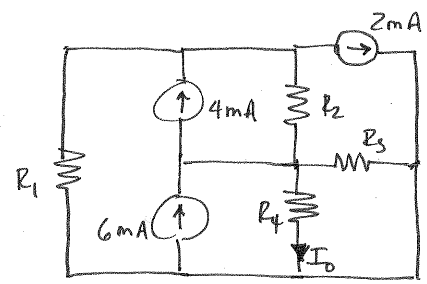


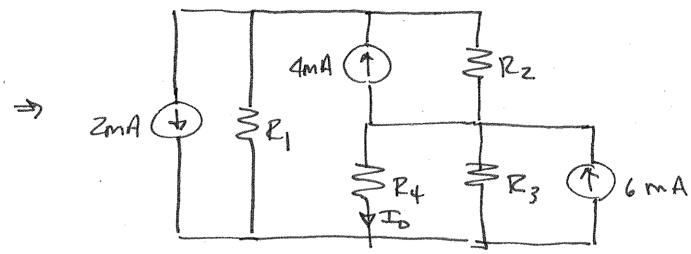
$$I_o = \frac{1.2\times10^{-3} R_B}{R_B + R_2}$$

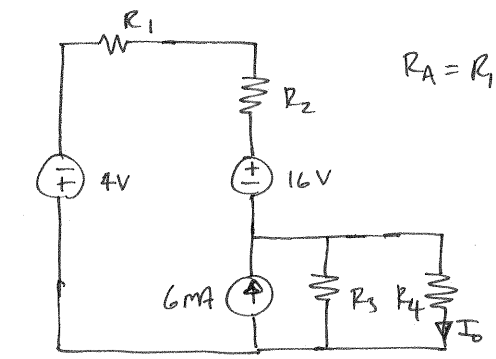
$$\boxed{I_o = 0.33 \text{ mA}}$$

5.90 Solve Problem 5.17 using source transformation.

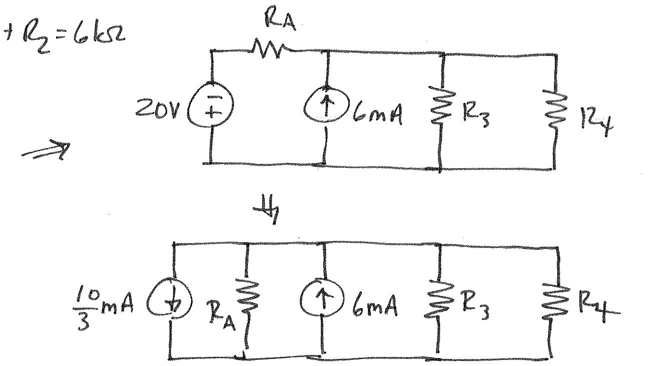
SOLUTION: $R_1 = 2k\Omega$ $R_2 = 4k\Omega$ $R_3 = 4k\Omega$ $R_4 = 12k\Omega$

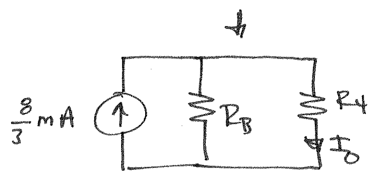






$R_A = R_1 + R_2 = 6k\Omega$





$R_B = R_A // R_3 = 2.4k\Omega$

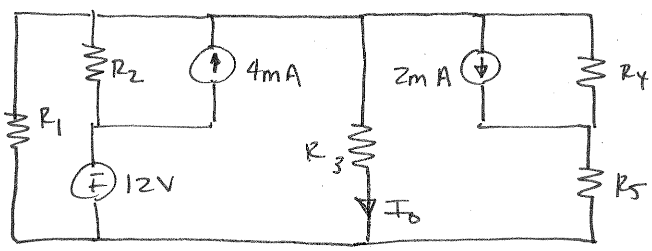
$$I_o = \frac{2.67\times10^{-3}\, R_B}{R_B + R_4}$$

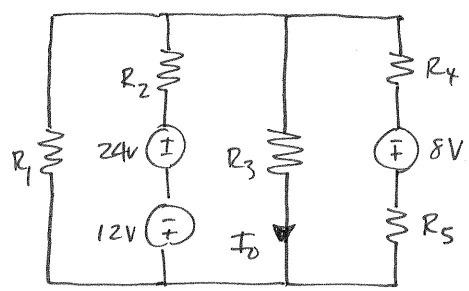
$$\boxed{I_o = 0.444mA}$$

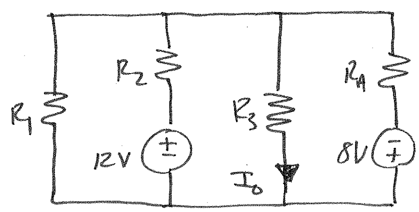
5.91 Use source transformation to solve Problem 5.18.

SOLUTION: $R_1 = R_2 = 6\,k\Omega$ $R_3 = 3\,k\Omega$ $R_4 = 4\,k\Omega$ $R_5 = 2\,k\Omega$

Circuit rearranged.

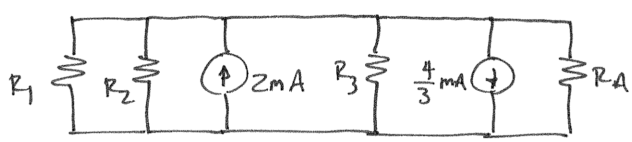


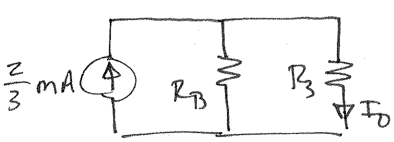




$R_A = R_4 + R_5$

$R_A = 6\,k\Omega$





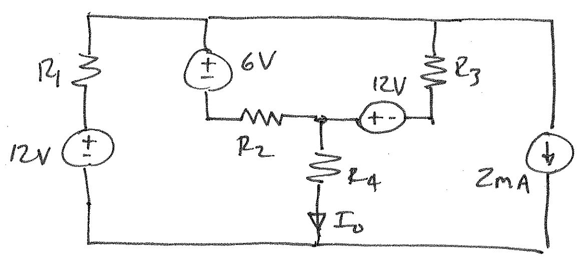
$R_B = R_1 // R_2 // R_A = 2\,k\Omega$

$$I_o = \frac{0.67\times10^{-3}\,R_B}{R_B + R_3}$$

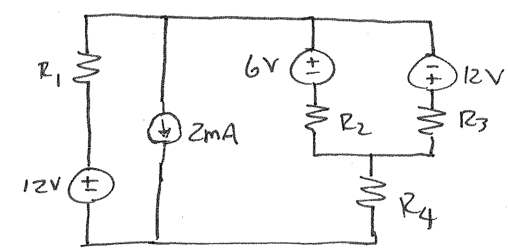
$$\boxed{I_o = 0.267\,mA}$$

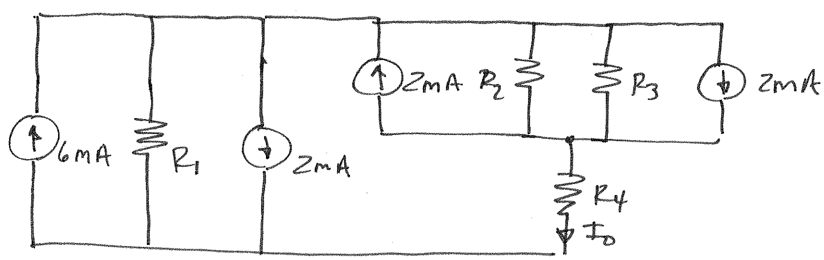
5.92 Use source transformation to solve Problem 5.20.

SOLUTION: $R_1 = 2\,k\Omega$ $R_2 = 3\,k\Omega$ $R_3 = 6\,k\Omega$ $R_4 = 4\,k\Omega$

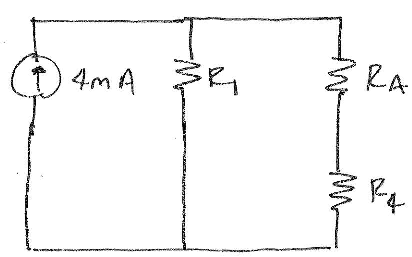


⇒

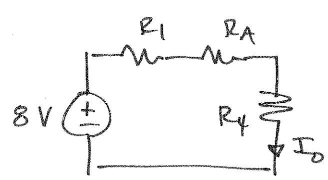




$R_A = R_2 // R_3 = 2\,k\Omega$



⇒



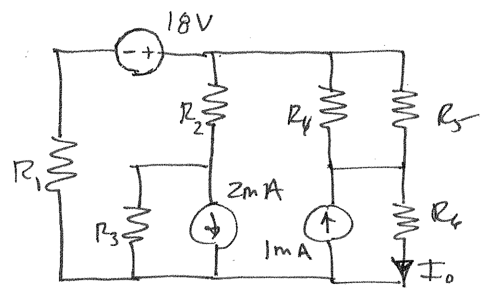
$$I_o = \frac{8}{R_1 + R_A + R_4}$$

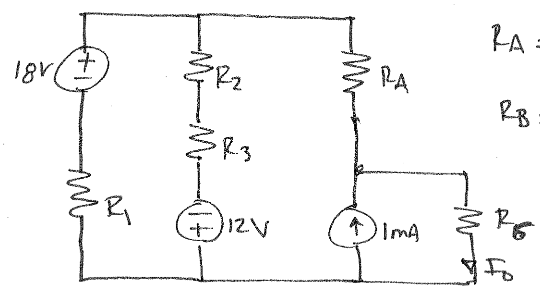
$$\boxed{I_o = 1\,mA}$$

5.93 Use source transformation to solve Problem 5.21.

SOLUTION: $R_1 = R_2 = R_3 = 6\,k\Omega \quad R_4 = R_5 = 4\,k\Omega \quad R_6 = 3\,k\Omega$

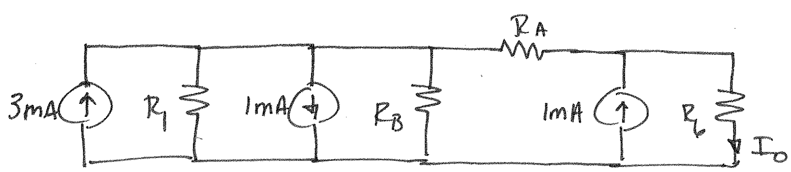
Circuit is rearranged.



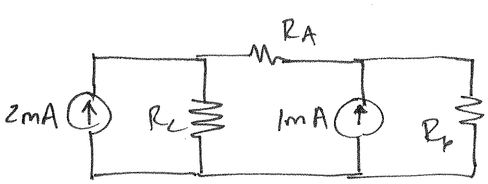


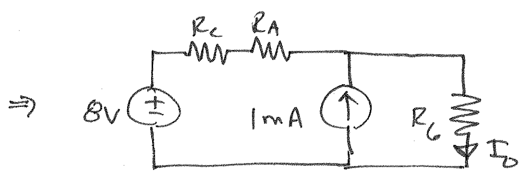
$R_A = R_4 // R_5 = 2\,k\Omega$

$R_B = R_2 + R_3 = 12\,k\Omega$



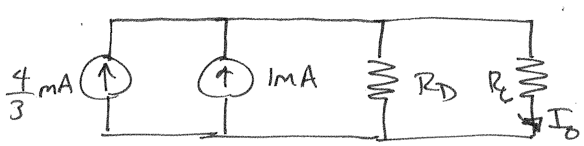
$R_C = R_1 // R_B = 4\,k\Omega$

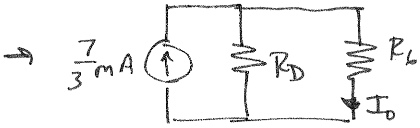




$R_D = R_C + R_A$

$R_D = 6\,k\Omega$





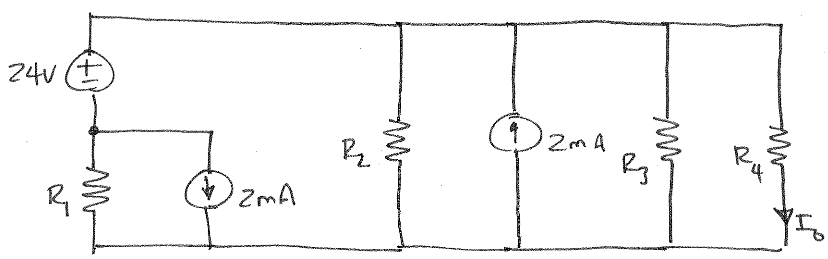
$$I_o = \frac{2.67 \times 10^{-3} R_D}{R_D + R_6}$$

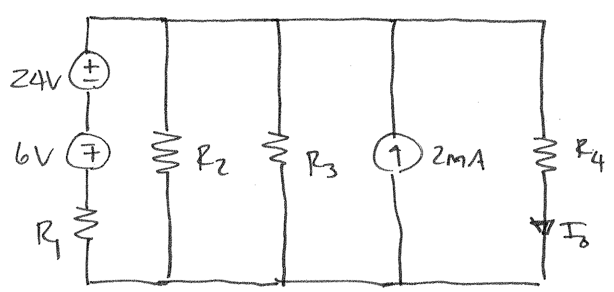
$$\boxed{I_o = 1.55\,mA}$$

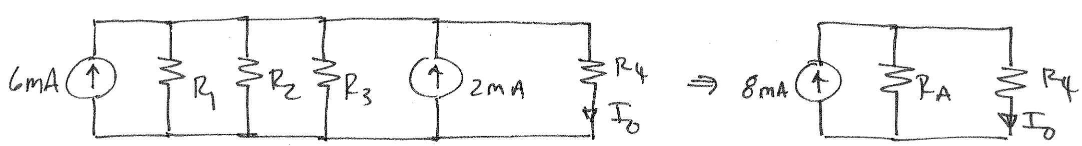
5.94 Solve Problem 5.22 using source transformation.

SOLUTION: $R_1 = 3\,k\Omega \quad R_2 = 6\,k\Omega \quad R_3 = 2\,k\Omega \quad R_4 = 4\,k\Omega$

Circuit is rearranged.







$$R_A = R_1 \,//\, R_2 \,//\, R_3 = 1\,k\Omega$$

$$I_o = \frac{8\times10^{-3}\, R_A}{R_A + R_4}$$

$$\boxed{I_o = 1.6\,mA}$$

5.95 Find R_L in the network in Fig. P5.95 in order to achieve maximum power transfer.

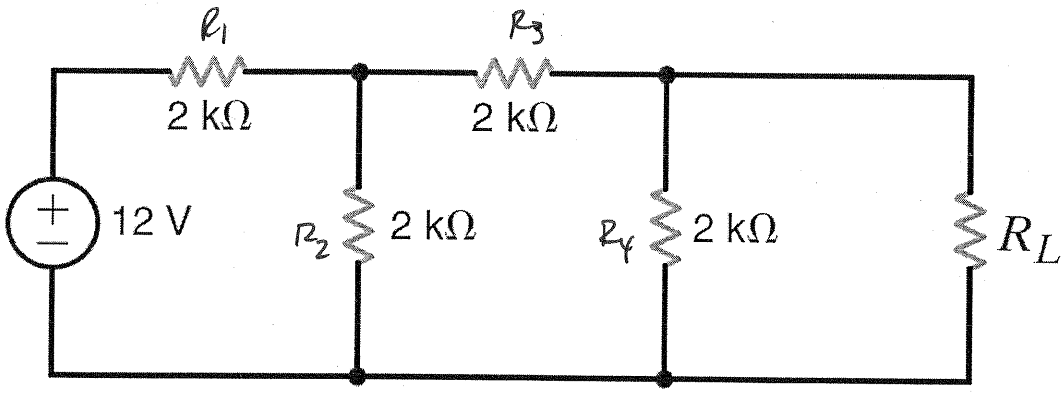
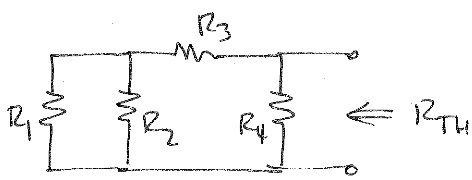


Figure P5.95

SOLUTION: Find R_{TH} !



$$R_{TH} = R_4 // \{ R_3 + (R_1 // R_2) \} = 2000 // \{2000 + 1000\}$$

$$R_{TH} = 1.2\,k\Omega$$

for maximum power transfer, $\boxed{R_L = 1.2\,k\Omega}$

5.96 In the network in Fig. P5.96, find R_L, for maximum power transfer and the maximum power transferred to this load. **PSV**

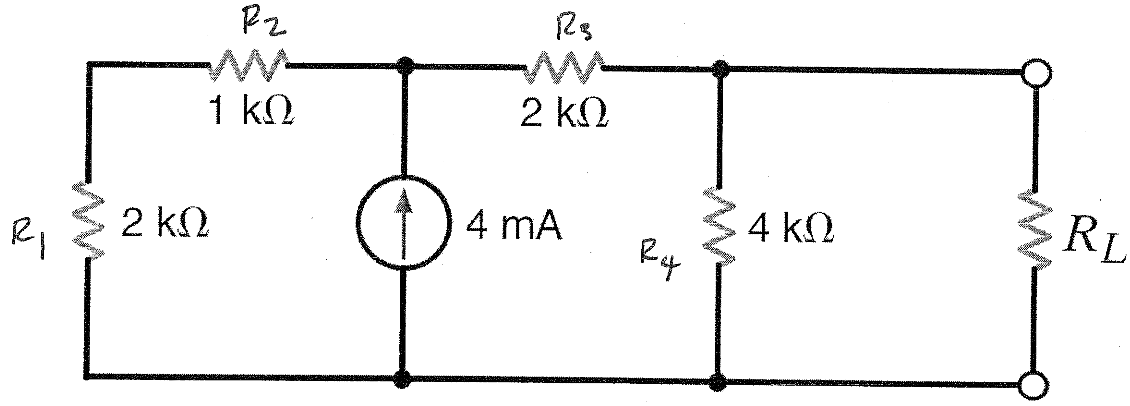
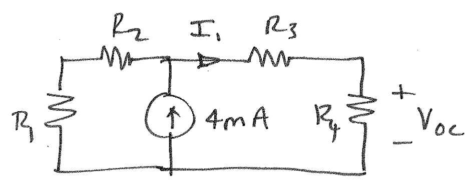


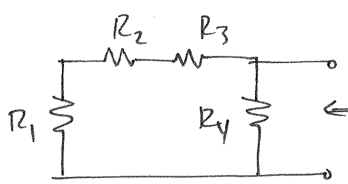
Figure P5.96

SOLUTION: Find Thevenin eq.!

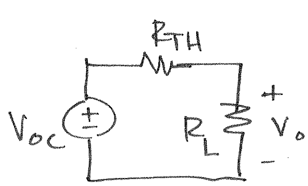


$$I_1 = \frac{4\times10^{-3}\,(R_1+R_2)}{R_1+R_2+R_3+R_4} = 1.33\text{ mA}$$

$$V_{oc} = I_1 R_4 = 5.33\text{ V}$$



$$\leftarrow R_{TH} = R_4 \,//\, (R_1+R_2+R_3) = 2.22\text{ k}\Omega$$



for maximum power transfer, $R_L = R_{TH}$
and $V_o = V_{oc}/2$

$$P_L = V_o^2/R_L = \frac{V_{oc}^2}{4R_{TH}}$$

$$\boxed{P_L = 3.2\text{ mW}}$$

5.97 Find R_L for maximum power transfer and the maximum power that can be transferred to the load in Fig. P5.97.

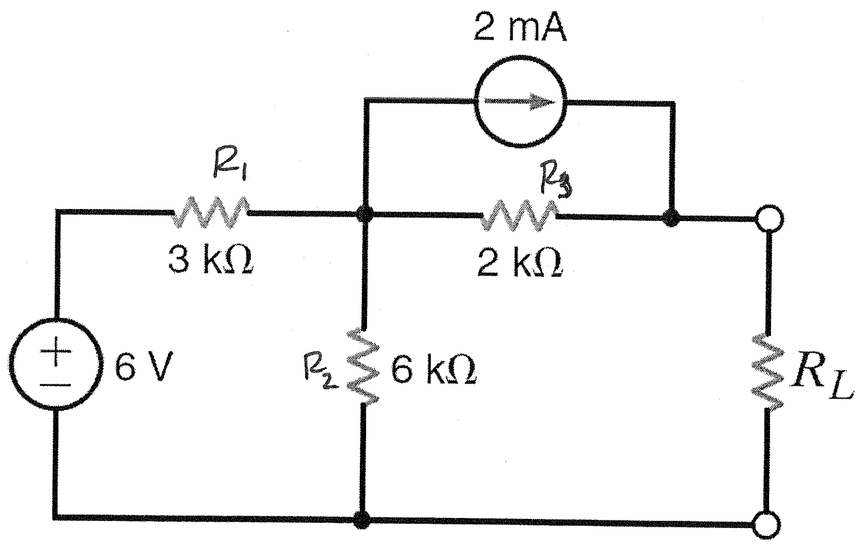
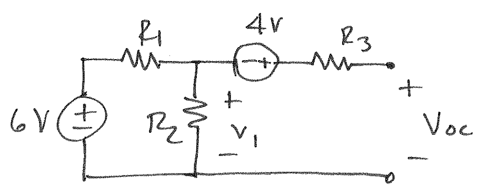


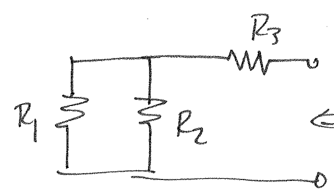
Figure P5.97

SOLUTION: Find Thevenin eq!

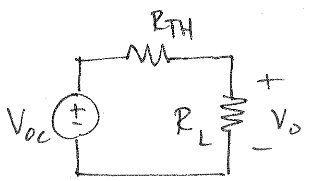


$V_1 = 6R_2/(R_2+R_1) = 4V$

$V_{OC} = 4 + V_1 = 8V$



$\Leftarrow R_{TH} = (R_1 // R_2) + R_3 = 4k\Omega$



for maximum power transfer, $R_L = R_{TH}$ and $V_o = \frac{V_{oc}}{2}$.

$P_L = \frac{V_o^2}{R_L} = \frac{V_{oc}^2}{4R_{TH}}$ $\boxed{P_L = 4mW}$

5.98 Choose R_L in Fig. P5.98 for maximum power transfer.

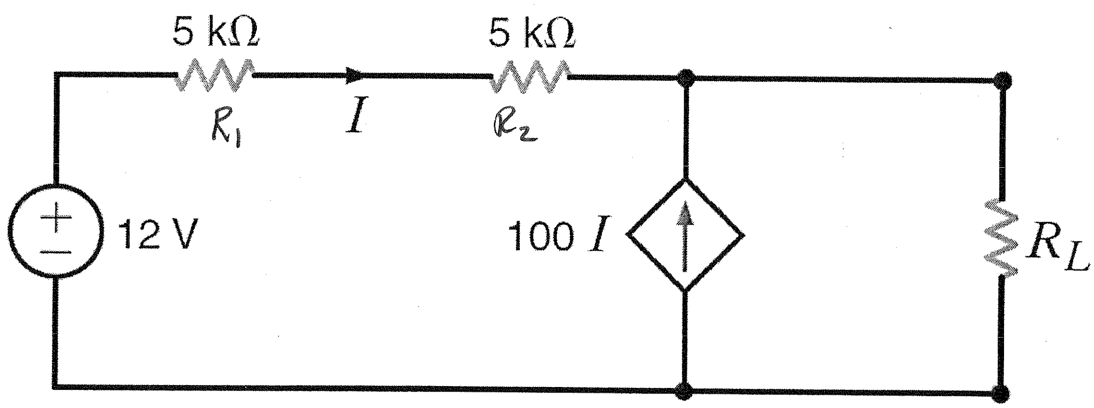
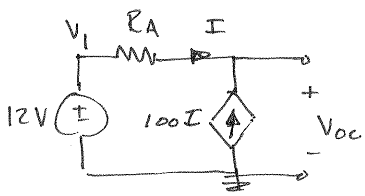


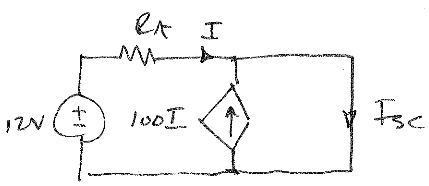
Figure P5.98

SOLUTION: Find R_{TH}



$R_A = R_1 + R_2 = 10k\Omega$ $V_1 = 12V$

$\frac{V_1 - V_{oc}}{R_A} = I = -100I \Rightarrow I = 0$ & $V_{oc} = 12V$



$I_{sc} = I + 100I = 101\,I$

$I = 12/R_A = 1.2mA$

$I_{sc} = 121.2\ mA$

$R_{TH} = V_{oc}/I_{sc} = 99.0\Omega$

for maximum power transfer, $\boxed{R_L = 99.0\Omega}$

5.99 Find the value of R_L in the network in Fig. P5.99 for maximum power transfer. **PSV**

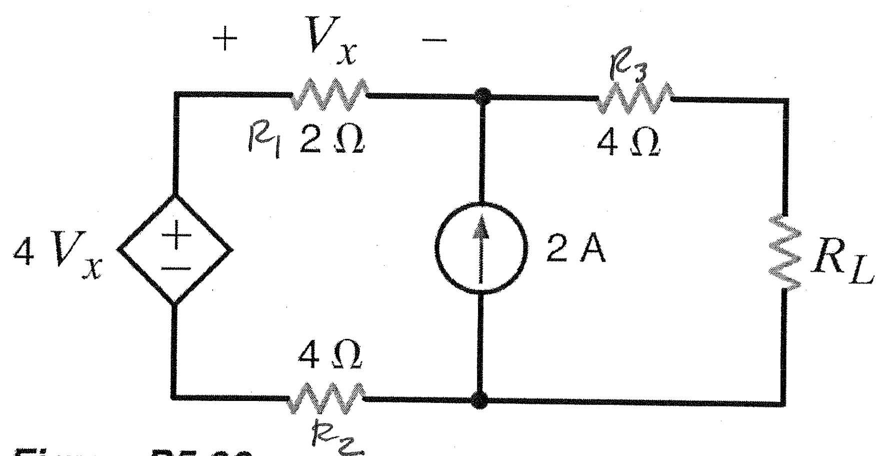
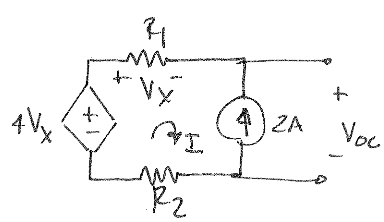


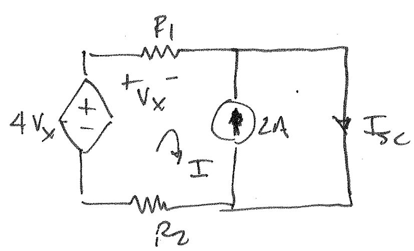
Figure P5.99

SOLUTION: find R_{TH}



$4V_x = 2I + V_{oc} + 4I \qquad I = -2 \qquad V_x = 2I$

$V_{oc} = -4V$

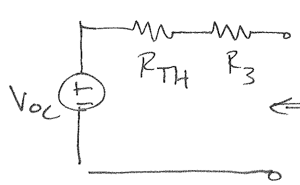


$4V_x = 2I + 4I \qquad V_x = 2I \Rightarrow I = 0$

So, $V_x = 0$

$I_{sc} = 2 + I = 2A$

$R_{TH} = V_{oc}/I_{sc} = -2\Omega$



$\Leftarrow R_{EQ} = R_{TH} + R_3 = 2\Omega$

for maximum power transfer $R_L = R_{EQ}$

$\boxed{R_L = 2\Omega}$

5.100 Calculate the maximum power that can be transferred to R_L in the circuit in Fig. P5.100.

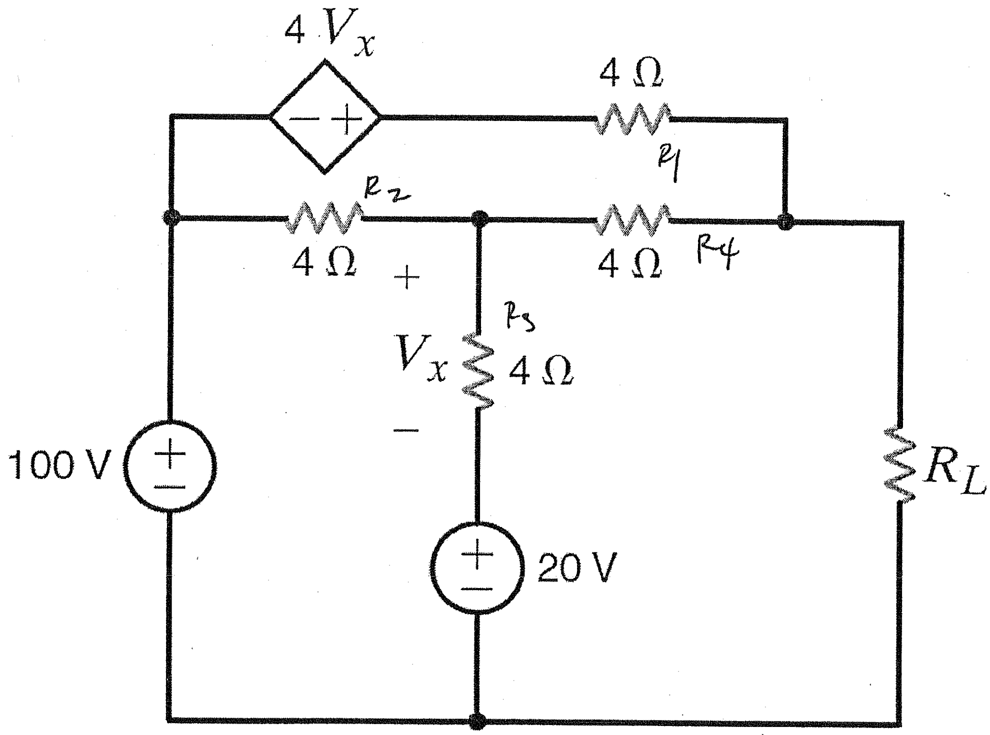
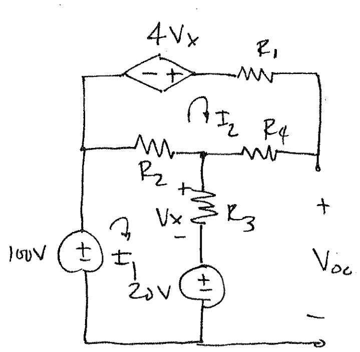
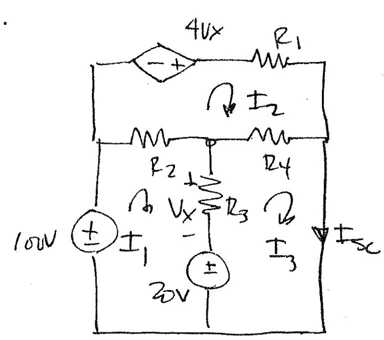


Figure P5.100

SOLUTION: Find R_{TH}.





$100 = I_1(R_2+R_3) - R_2 I_1 - R_3 I_3 + 20$

$4V_x = -R_2 I_1 + I_2(R_1+R_2+R_4) - R_4 I_3$

$20 = -R_3 I_1 - I_2 R_4 + I_3(R_3+R_4)$

$I_{sc} = I_3 \qquad V_x = R_3(I_1 - I_3)$

$I_{sc} = 55A$

$$\left.\begin{array}{l} 100 = I_1(R_3+R_2) - R_2 I_2 + 20 \\ 4V_x = I_2(R_1+R_2+R_4) - I_1 R_2 \\ 20 = -I_1 R_3 - I_2 R_4 + V_{oc} \\ V_x = R_3 I_1 \end{array}\right\} V_{oc} = 660V$$

$R_{TH} = V_{oc}/I_{sc} = 12\ \Omega$

R_L for maximum power transfer is

$\boxed{R_L = 12\Omega}$

5.101 A cell phone antenna picks up a call. If the antenna and cell phone are modeled as shown in Fig. P5.101,

(a) Find R_{cell} for maximum output power.

(b) Determine the value of P_{out}.

(c) Determine the corresponding value of P_{ant}.

(d) Find v_o/v_{ant}.

(e) Determine the amount of power lost in R_{ant}.

(f) Calculate the efficiency $\eta = P_{out}/P_{ant}$.

(g) Determine the value of R_{cell} such that the efficiency is 90%.

(h) Given the change in (g), what is the new value of P_{ant}?

(i) Given the change in (g), what is the new value of P_{out}?

(j) Comment on the results obtained in (i) and (b).

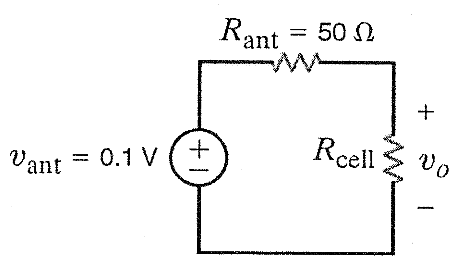


Figure P5.101

SOLUTION:

a) $R_{cell} = R_{ant} = 50\Omega$

b) $P_{out} = v_o^2/R_{cell}$ $\quad v_o = v_{ant} R_{cell}/(R_{cell}+R_{ant}) = 50\text{mV}$, $P_{out} = 50\mu W$

c) $P_{ant} = 2P_{out} = 100\mu W$ (at maximum power transfer)

d) $v_o/v_{ant} = R_{cell}/(R_{cell}+R_{ant}) = 0.5$

e) $P_{R_{ANT}} = P_{out} = 50\mu W$

f) $\eta = P_{out}/P_{ant} = 1/2 = 50\%$

g) $\eta = \frac{P_{out}}{P_{ant}} = \frac{v_o^2/R_{cell}}{v_{ant}^2/(R_{cell}+R_{ant})} = \frac{v_{ant}^2\left(\frac{R_{cell}}{R_{cell}+R_{ant}}\right)^2/R_{cell}}{v_{ant}^2/(R_{cell}+R_{ant})}$

$$\eta = \frac{R_{cell}}{R_{cell}+R_{ant}} = 0.9 \Rightarrow R_{cell} = 450\Omega$$

h) $P_{ant} = v_{ant}^2/(R_{cell}+R_{ant}) = 20\mu W$

i) $P_{out} = 0.9\,P_{ant} = 18\mu W$

j) As η increases a larger PERCENTAGE of P_{ant} is transferred to P_{out}. However, P_{ant} drops faster than η rises. As a result, P_{out} decreases as η moves away from 50%.

5.102 Some young engineers at the local electrical utility are debating ways to lower operating costs. They know that if they can reduce losses, they can lower operating costs. The question is whether they should design for maximum power transfer or maximum efficiency, where efficiency is defined as the ratio of customer power to power generated. Use the model in Fig. P5.102 to analyze this issue and justify your conclusions. Assume that both the generated voltage and the customer load are constant.

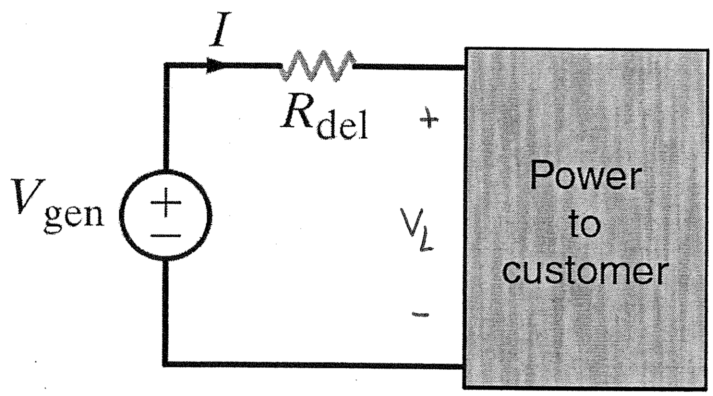


Figure P5.102

SOLUTION:

Specifications: V_{gen} fixed & I fixed.

Issue: optimize η to maximize profits.

$$P_{LOAD} = V_L I = (V_{gen} - IR_{del})I \qquad P_{GEN} = V_{gen} I$$

$$\eta = \frac{P_{LOAD}}{P_{GEN}} = \frac{(V_{gen} - IR_{del})I}{V_{gen} I} = 1 - \frac{IR_{del}}{V_{gen}} = 1 - kR_{del} \qquad k = \frac{I}{V_{gen}}$$

As $R_{del} \to 0$, $\eta \to 100\%$ No power lost in delivery! All generated power can be sold!

5.103 Find R_L for maximum power transfer and the maximum power that can be transferred in the network in Fig. P5.103.

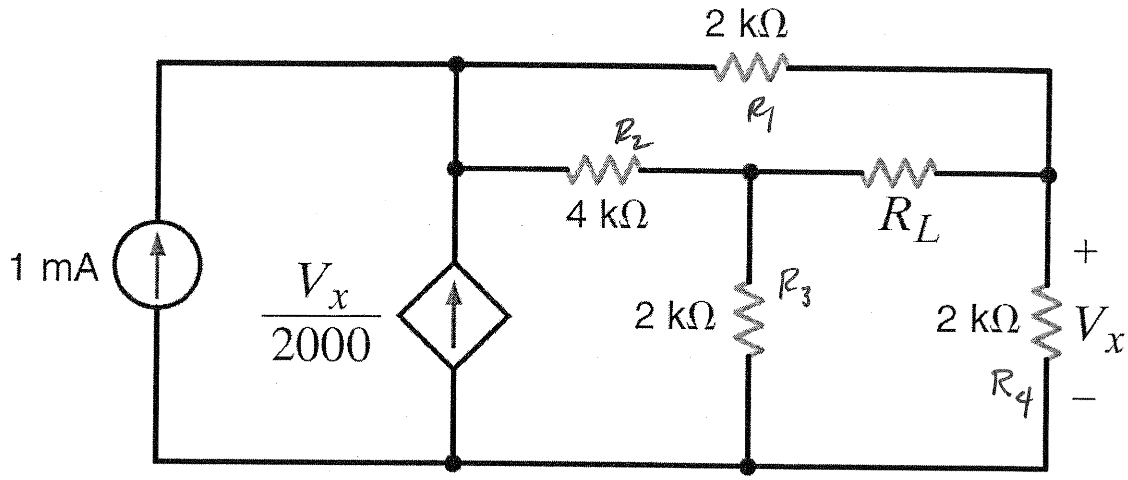
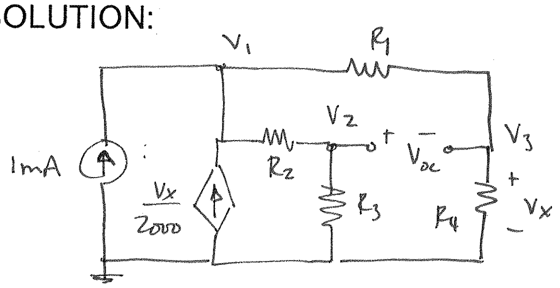


Figure P5.103

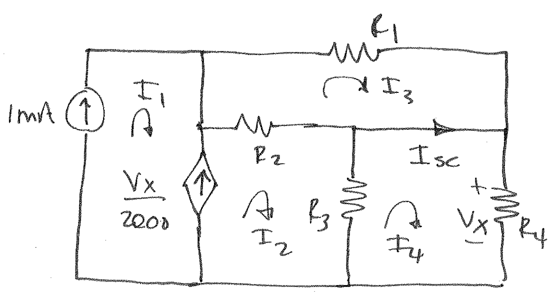
SOLUTION:



$$10^{-3} + \frac{V_x}{2000} = \frac{V_1}{R_2+R_3} + \frac{V_1}{R_1+R_4}$$

$$V_x = \frac{V_1 R_4}{R_1+R_4} = \frac{V_1}{2} \Rightarrow V_1 = 6V$$

$$V_2 = \frac{V_1 R_3}{R_2+R_3} = 2V \qquad V_3 = 3V \qquad V_{oc} = V_2 - V_3 = -1V$$



$I_1 = 1mA \qquad I_2 - I_1 = \frac{V_x}{2000} \qquad V_x = R_4 I_4$

$$I_3(R_1+R_2) - R_2 I_2 = 0$$

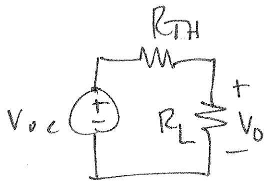
$$I_4(R_3+R_4) - R_3 I_2 = 0$$

$I_4 = 1mA$

$I_3 = \frac{4}{3} mA$

$$I_{sc} = I_4 - I_3 = 10^{-3} - 1.33\times10^{-3}$$

$$I_{sc} = -0.333mA \Rightarrow \boxed{R_{TH} = 3\,k\Omega}$$

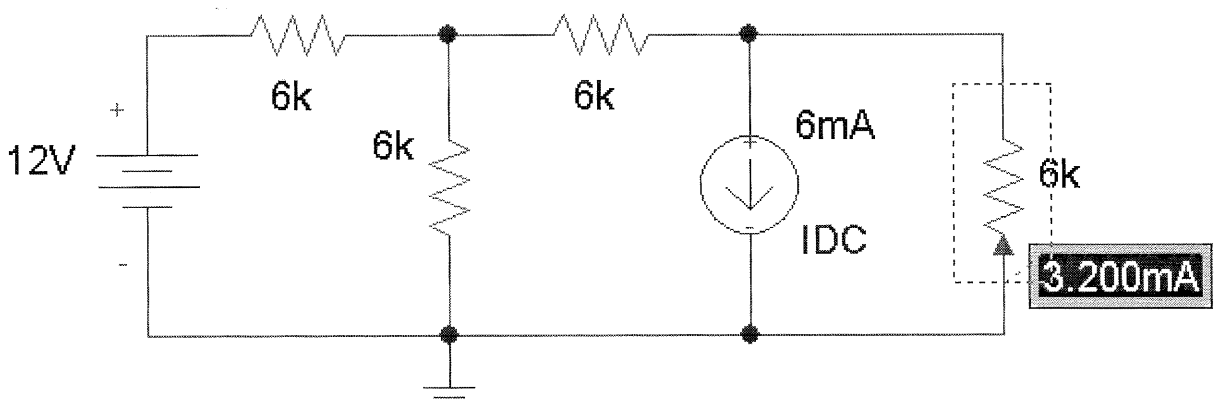


$$P_o = \frac{V_{oc}^2}{4R_{TH}} \Rightarrow \boxed{P_o = 83.3\,\mu W}$$

5.104 Solve Problem 5.5 using PSPICE.

SOLUTION:

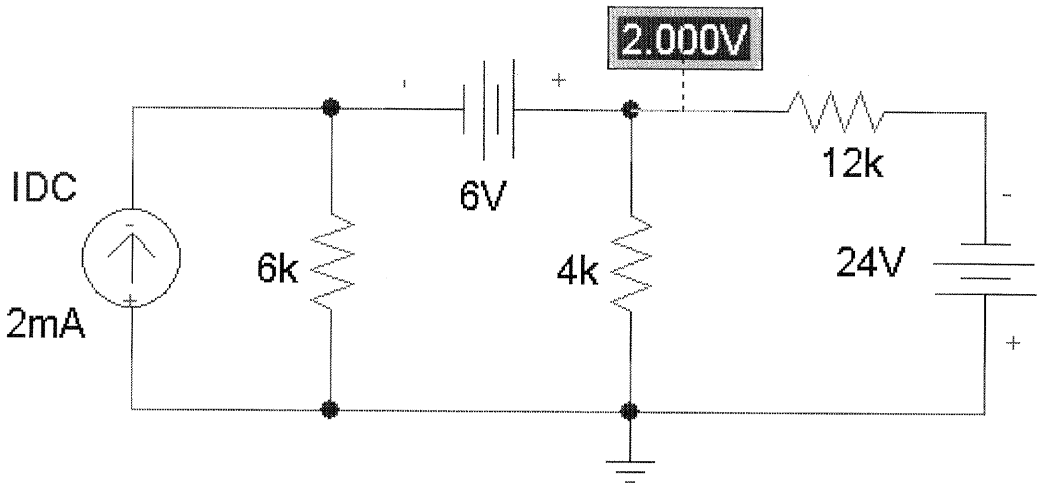
Problem 5.104



5.105 Solve Problem 5.78 using PSPICE.

SOLUTION:

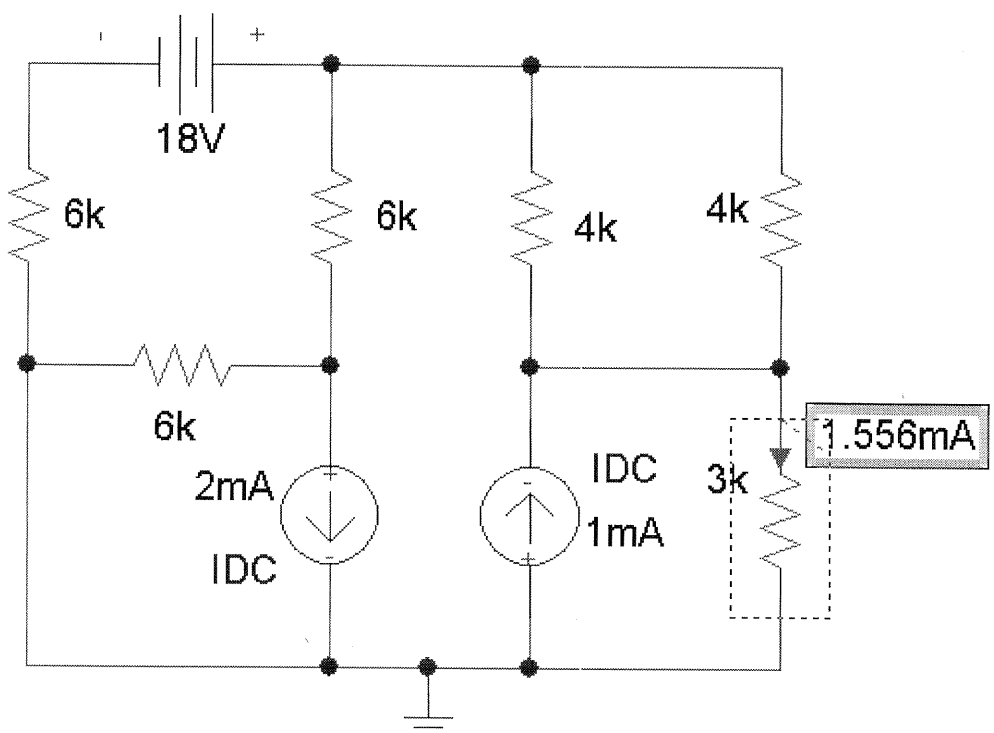
Problem 5.105



5.106 Solve Problem 5.21 using PSPICE.

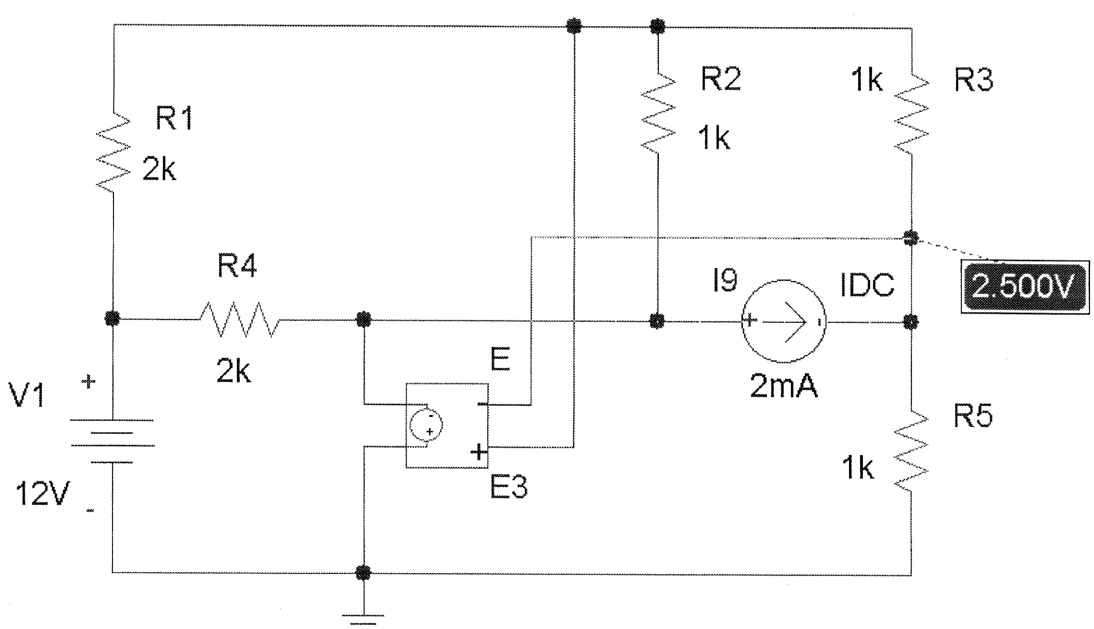
SOLUTION:

Problem 5.106



5.107 Solve Problem 5.71 using PSPICE.

SOLUTION:



5FE-1 Determine the maximum power that can be delivered to the load R_L in the network in Fig. 5PFE-1. CS

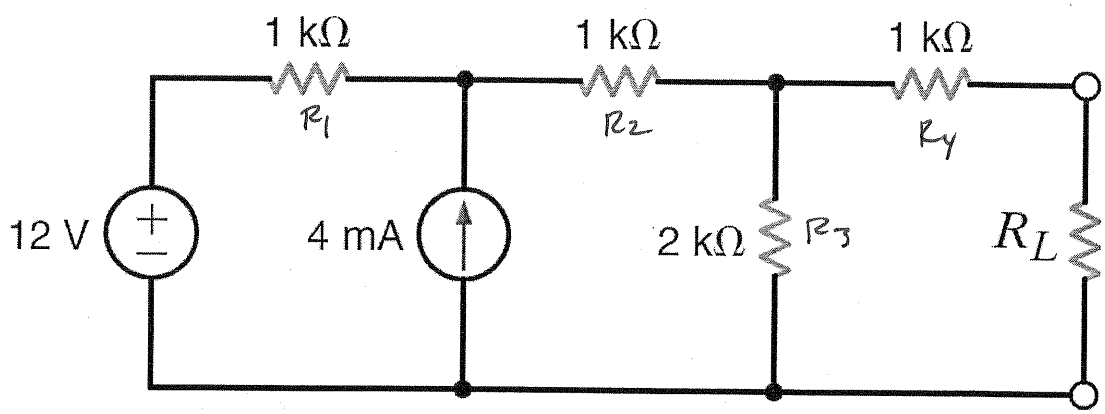
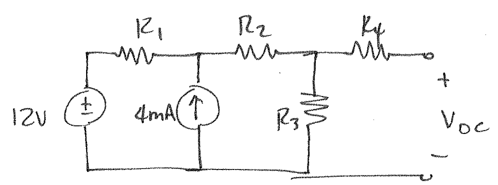


Fig. 4PFE-1

SOLUTION: Find Thevenin Eq.!



$R_{TH} = [(R_1 + R_2) // R_3] + R_4$

$R_{TH} = 2\,k\Omega$

Find V_{OC} by superposition:

V_{OCA} due to 12-V source

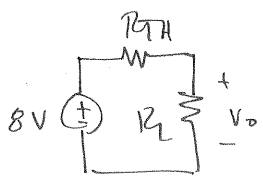
$$V_{OCA} = 12\left[\frac{R_3}{R_1 + R_2 + R_3}\right]$$

$V_{OCA} = 6V$

V_{OCB} due to 4-mA source

$$V_{OCB} = 4\times10^{-3}\left[\frac{R_1}{R_1 + R_2 + R_3}\right] R_3$$

$V_{OCB} = 2V \Rightarrow V_{OC} = 8\,V$



$$P_{O\,max} = \frac{V_{OC}^2}{4R_{TH}}$$

$$\boxed{P_{O\,max} = 8\,mW}$$

5FE-2 Find the value of the load R_L in the network in Fig. 5PFE-2 that will achieve maximum power transfer, and determine the value of the maximum power.

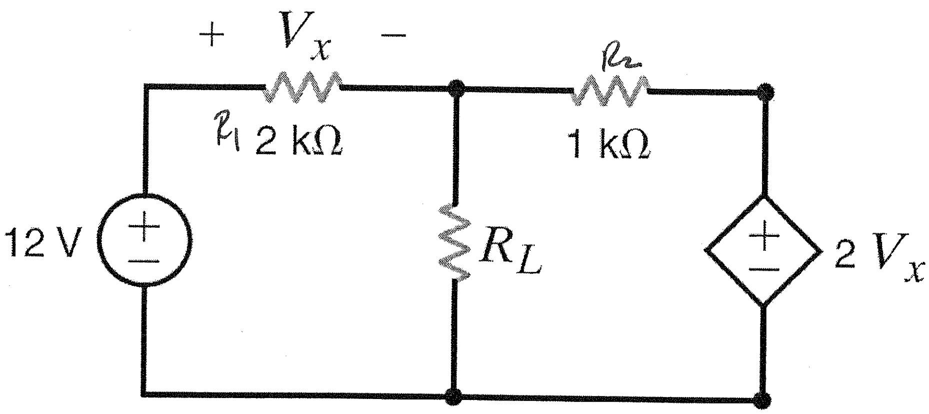
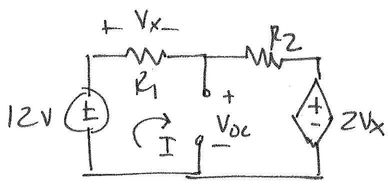


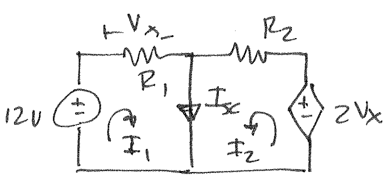
Fig. 5PFE-2

SOLUTION: Need Thevenin Eq.



$12 = IR_1 + IR_2 + 2V_x \qquad V_x = IR_1 \Rightarrow I = \frac{12}{7}mA$

$12 = IR_1 + V_{OC} \Rightarrow V_{OC} = 8.57\,V$



$I_1 = 12/R_1 = 6\,mA \qquad I_2 = 2V_x/R_2$

$V_x = 12V \Rightarrow I_2 = 24\,mA$

$I_{SC} = I_1 + I_2 = 30\,mA$

$R_{TH} = 286\,\Omega$

$P_{o_{max}} = \frac{V_{oc}^2}{4R_{TH}}$

$\boxed{P_{o_{max}} = 64.2\,mW}$

5FE-3 Find the value of R_L in the network in Fig. 5PFE-3 for maximum power transfer to this load.

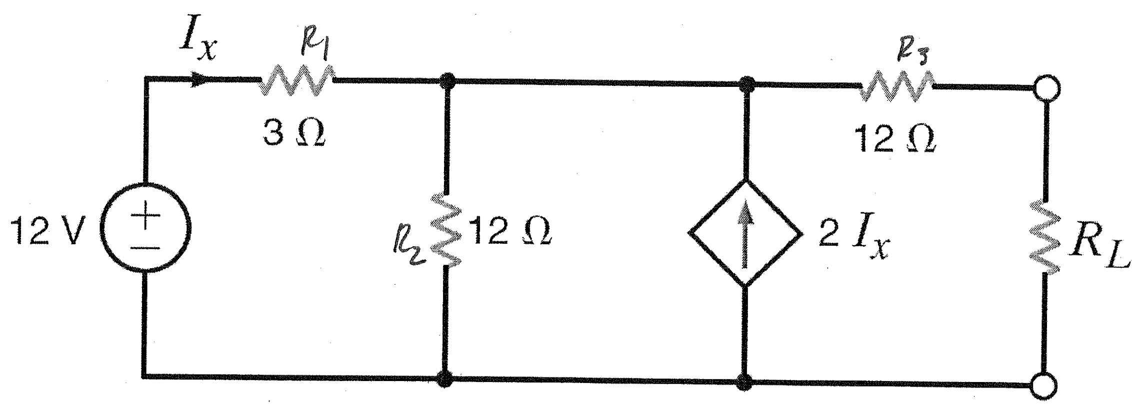
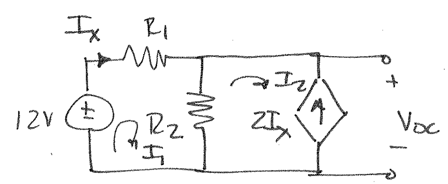


Fig. 5PFE-3

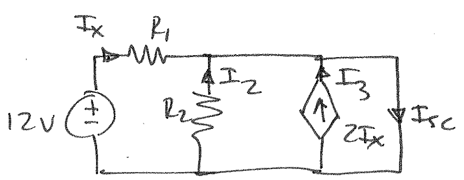
SOLUTION: Need Thevenin Eq.



$12 = (R_1+R_2)I_1 - R_2 I_2 \qquad I_1 = I_x \quad I_2 = -2I_x$

$I_1 = 12/39 \text{ A}$

$V_{oc} = 12 - R_1 I_1 = 11.08\text{V}$

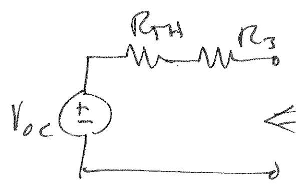


$I_x = 12/R_1 = 4\text{A}$

$I_2 = 0 \qquad I_3 = 2I_x = 8\text{A}$

$I_{sc} = I_x + I_2 + I_3 = 12\text{A}$

$R_{TH} = V_{oc}/I_{sc} = 0.92\Omega$



$\Leftarrow R_{eq} = R_{TH} + R_3 = 12.92\Omega$

for maximum power transfer,

$\boxed{R_L = 12.92\Omega}$