1) Consider the circuit shown in Figure 1 below.

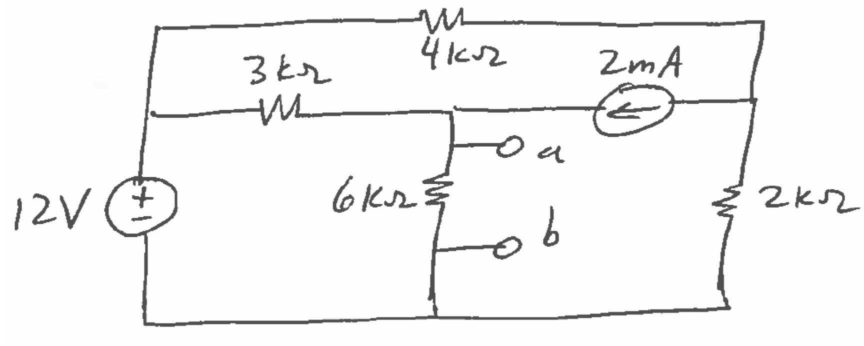

Figure 1. Circuit for Problem 1.

a) Find the Thevenin and Norton equivalent circuit models with respect to nodes a and b. Clearly draw the Thevenin and Norton models with numerical component values and the nodes of interest labeled on the model schematics. *Show your work.* List your numerical model parameters with appropriate units and in proper engineering notation format with two decimal places of precision.

b) Verify your by-hand answers for the Thevenin and Norton model parameters in LTSpice. Write out the answers you got from LTSpice and attach any supporting evidence that you actually simulated the circuit to verify your work. The answers you write out for this part should be the same as the results you provided in part (a); if they don't match **by both sign and magnitude**, expect zero credit. Also, expect zero credit 1) if your by-hand and simulated results agree but the results are incorrect, 2) if you do not perform the LTSpice verification altogether, 3) if you only do the LTSpice verification but not the by-hand solution, or 4) if you do not label key node voltages and/or use properly-oriented 0 V voltage source ammeters for measuring key branch currents in LTSpice.

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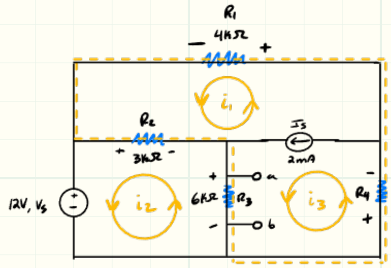


$I_S = i_3 - i_1$ ①

KVL at mesh 1 & 3

$R_4 i_3 + R_1 i_1 + R_2(i_1 - i_2) + R_3(i_3 - i_2) = 0$

$R_4 i_3 + R_1 i_1 + R_2 i_1 - R_2 i_2 + R_3 i_3 - R_3 i_2 = 0$

$(R_1 + R_2) i_1 + (-R_2 - R_3) i_2 + (R_3 + R_4) i_3 = 0$ ②

KVL at i_2

$-R_3(i_3 - i_2) - R_2(i_1 - i_2) + V_s = 0$

$R_3(i_3 - i_2) + R_2(i_1 - i_2) = V_s$

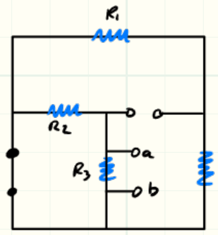
$R_3 i_3 - R_3 i_2 + R_2 i_1 - R_2 i_2 = V_s$

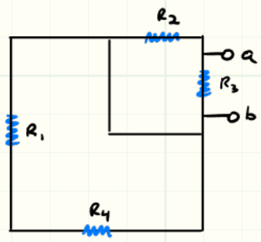
$(R_2) i_1 + (-R_2 - R_3) i_2 + (R_3) i_3 = V_s$ ②

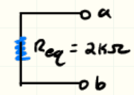
$$\begin{bmatrix} I_S \\ V_s \\ 0 \end{bmatrix} = \begin{bmatrix} -1 & 0 & 1 \\ (R_2) & (-R_2-R_3) & (R_3) \\ (R_1+R_2) & (-R_2-R_3) & (R_3+R_4) \end{bmatrix} \begin{bmatrix} i_1 \\ i_2 \\ i_3 \end{bmatrix} \longrightarrow \begin{bmatrix} i_1 \\ i_2 \\ i_3 \end{bmatrix} = \begin{bmatrix} -1 & 0 & 1 \\ 3k & -9k & 6k \\ 7k & -9k & 8k \end{bmatrix} \begin{bmatrix} 0.002A \\ 12V \\ 0 \end{bmatrix}$$

$i_1 = -2.667mA \quad i_2 = -2.667mA \quad i_3 = -0.667mA$

Finding R_{TH}; Deactivate CKT.







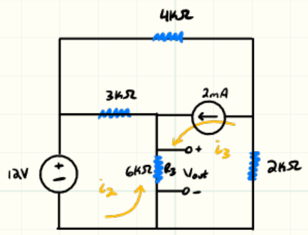
These Resistors don't Count towards R_{eq} because the voltage potential across them is zero

$R_{eq} = \dfrac{R_2 \cdot R_3}{R_2 + R_3}$

$R_{eq} = \dfrac{(3k\Omega \cdot 6k\Omega)}{3k\Omega + 6k\Omega}$

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

$R_{TH} = 2k\Omega$

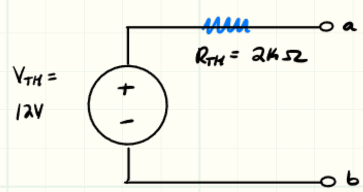


$V_{out} = R_3(i_3 - i_2)$

$V_{out} = 6k(-0.667mA - (-2.667mA))$

$V_{out} = 12V$

$V_{TH} = 12V$

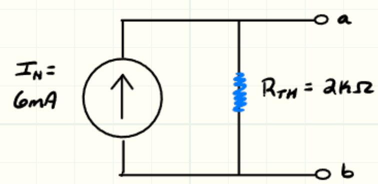


Thevenin

$I_N = \dfrac{V_{TH}}{R_{TH}}$

$I_N = \dfrac{12V}{2k\Omega}$

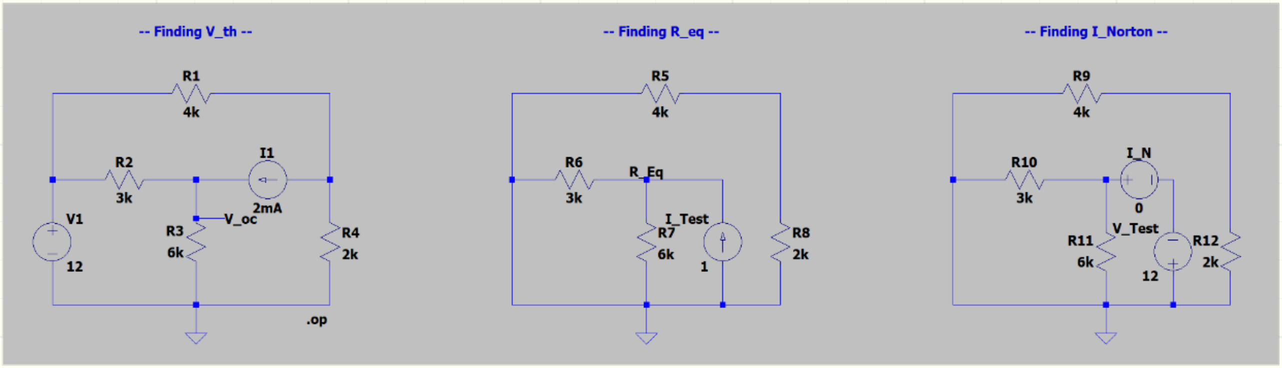
$I_N = 6mA$



Norton

--- Operating Point ---

V(n001):	12	voltage
V(v_oc):	12	voltage
V(n002):	1.33333	voltage
V(r_eq):	2000	voltage
V(n003):	0	voltage
V(n005):	-12	voltage
V(n004):	0	voltage
V(n006):	-12	voltage
I(I1):	0.002	device_current
I(I_test):	1	device_current
I(R2):	0	device_current
I(R3):	-0.002	device_current
I(R4):	0.000666667	device_current
I(R1):	-0.00266667	device_current
I(R6):	0.666667	device_current
I(R7):	0.333333	device_current
I(R5):	0	device_current
I(R8):	0	device_current
I(R10):	0.004	device_current
I(R9):	0	device_current
I(R12):	0	device_current
I(R11):	0.002	device_current
I(V1):	-0.00266667	device_current
I(V_test):	-0.006	device_current
I(I_n):	0.006	device_current



2) Consider the circuit shown in Figure 2 below.

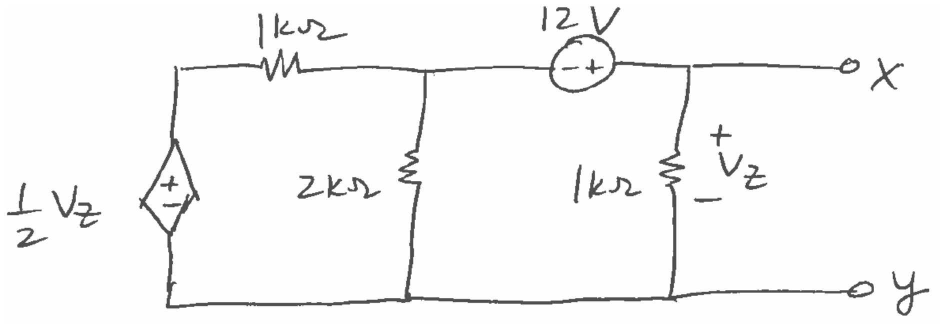


Figure 2. Circuit for Problem 2.

a) Find the Thevenin and Norton equivalent circuit models with respect to nodes x and y. Clearly draw the Thevenin and Norton models with numerical component values and the nodes of interest labeled on the model schematics. *Show your work.* List your numerical model parameters with appropriate units and in proper engineering notation format with two decimal places of precision.

b) Verify your by-hand answers for the Thevenin and Norton model parameters in LTSpice. Write out the answers you got from LTSpice and attach any supporting evidence that you actually simulated the circuit to verify your work. The answers you write out for this part should be the same as the results you provided in part (a); if they don't match **by both sign and magnitude**, expect zero credit. Also, expect zero credit 1) if your by-hand and simulated results agree but the results are incorrect, 2) if you do not perform the LTSpice verification altogether, 3) if you only do the LTSpice verification but not the by-hand solution, or 4) if you do not label key node voltages and/or use properly-oriented 0 V voltage source ammeters for measuring key branch currents in LTSpice.

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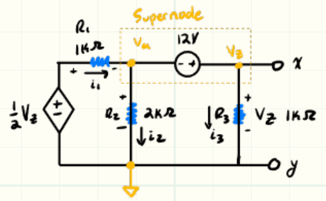
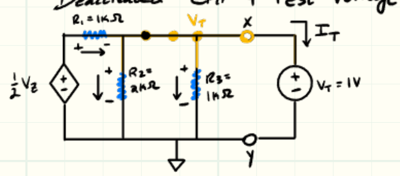


Deactivated Ckt & Test Voltage



KCL @ Supernode

$i_1 = i_2 + i_3$

$G_1(\frac{1}{2}V_z - V_a) = G_2(V_a - 0) + G_3(V_z - 0)$

$\frac{1}{2}G_1V_z - G_1V_a = G_2V_a + G_3V_z$

$0 = G_2V_a + G_3V_z + G_1V_a - \frac{1}{2}G_1V_z$

$0 = (G_1+G_2)V_a + (-\frac{1}{2}G_1 + G_3)V_z$ (1)

$V_s = V_z - V_a$

$12V = -V_a + V_z$ (2)

$\left\{ G_1 = 1/1000\ ℧,\ G_2 = 1/2000\ ℧,\ G_3 = 1/1000\ ℧ \right\}$

$$\begin{bmatrix} 0 \\ 12V \end{bmatrix} = \begin{bmatrix} (G_1+G_2) & (-\frac{1}{2}G_1 + G_3) \\ -1 & 1 \end{bmatrix} \begin{bmatrix} V_a \\ V_z \end{bmatrix}$$

$$\begin{bmatrix} V_a \\ V_z \end{bmatrix} = \begin{bmatrix} 3/2000 & 1/2000 \\ -1 & 1 \end{bmatrix}^{-1} \begin{bmatrix} 0 \\ 12V \end{bmatrix}$$

$V_a = -3V$

$V_z = 9V$

$\underline{V_{TH} = 9V}$

KCL at V_T

$G_1(\frac{1}{2}V_z - V_T) - G_2(V_T - 0) - G_3(V_T - 0) - I_T = 0$

$\frac{1}{2}G_1V_z - G_1V_T - G_2V_T - G_3V_T = I_T$

$\frac{1}{2}G_1V_z + (-G_1 - G_2 - G_3)V_T = I_T$

$\frac{1}{2}(\frac{1}{1000\Omega})(9V) + (-\frac{1}{1000\Omega} - \frac{1}{2000\Omega} - \frac{1}{1000\Omega})(1V) = I_T$

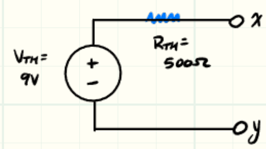
$I_T = 2mA$

$R_{TH} = V_T / I_T = \frac{1V}{2mA}$

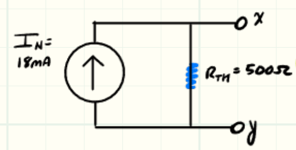
$\underline{R_{TH} = 500\Omega}$

$I_N = \frac{V_{TH}}{R_{TH}} = \frac{9V}{500\Omega}$

$\underline{I_N = 18mA}$



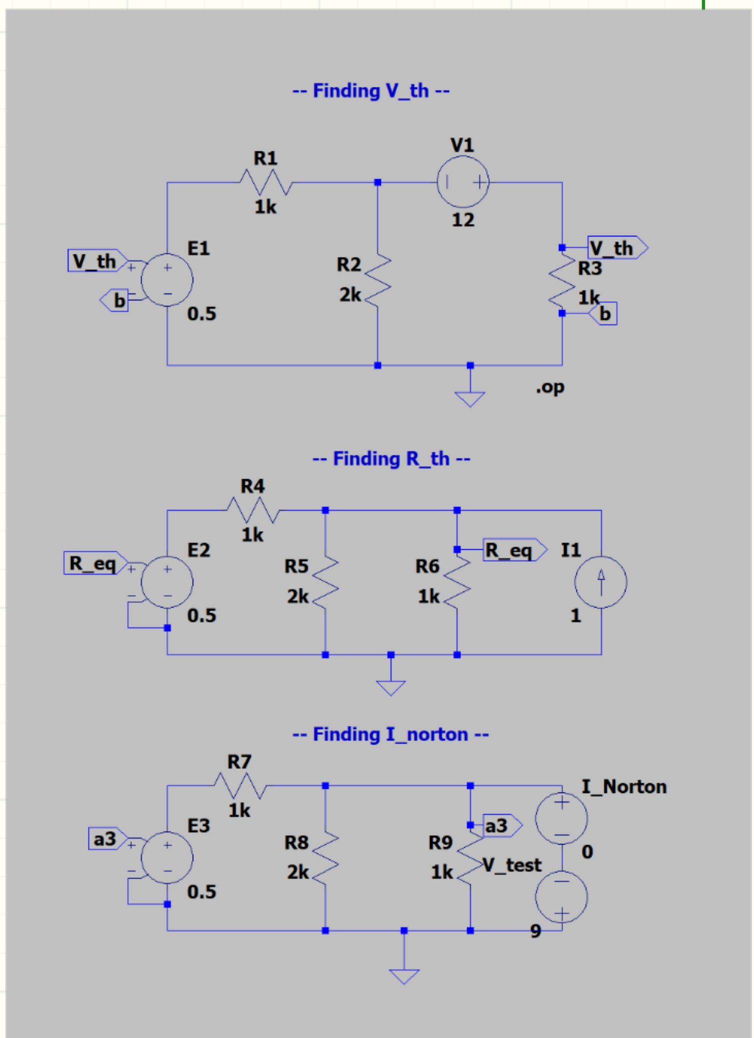
Thevenin



Norton

--- Operating Point ---

V(n001):	4.5	voltage
V(v_th):	9	voltage
V(n002):	-3	voltage
V(n003):	250	voltage
V(r_eq):	500	voltage
V(n004):	-4.5	voltage
V(a3):	-9	voltage
V(n005):	-9	voltage
I(I1):	1	device_current
I(R1):	0.0075	device_current
I(R2):	0.0015	device_current
I(R3):	0.009	device_current
I(R4):	0.25	device_current
I(R5):	-0.25	device_current
I(R6):	-0.5	device_current
I(R7):	0.0045	device_current
I(R8):	0.0045	device_current
I(R9):	0.009	device_current
I(E1):	-0.0075	device_current
I(E2):	0.25	device_current
I(E3):	-0.0045	device_current
I(V1):	-0.009	device_current
I(I_norton):	0.018	device_current
I(V_test):	-0.018	device_current



3) The variable resistor, R_L, in the circuit shown in Figure 3 is adjusted for maximum power transfer to R_L. For the parts below, include appropriate units with your numerical answers in proper engineering notation format. Keep at least two decimal places of precision. *Show your work.*

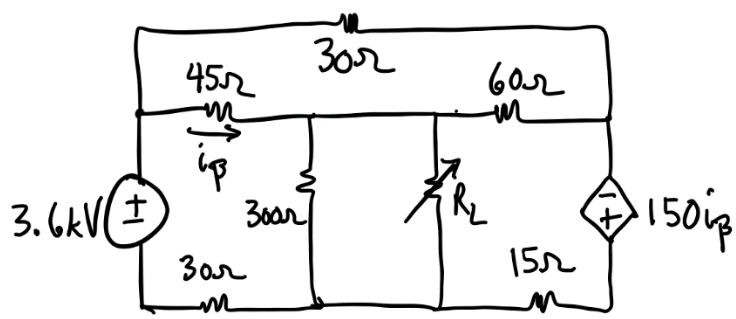


Figure 3. Circuit for Problem 3.

a) Find the numerical value of R_L.

b) Find the maximum power transferred to R_L.

c) Verify your results for parts (a) and (b) in LTSpice. Write out the answers you got from LTSpice and attach any supporting evidence that you actually simulated the circuit to verify your work. The answers you write out for this part should be the same as the results you provided in part (a); if they don't match **by both sign and magnitude**, expect zero credit. Also, expect zero credit 1) if your by-hand and simulated results agree but the results are incorrect, 2) if you do not perform the LTSpice verification altogether, 3) if you only do the LTSpice verification but not the by-hand solution, or 4) if you do not label key node voltages and/or use properly-oriented 0 V voltage source ammeters for measuring key branch currents in LTSpice.

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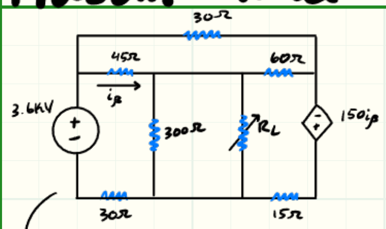
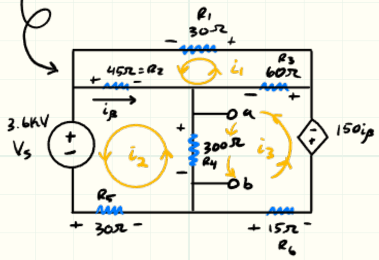




$i_\beta = i_1 - i_2 \longrightarrow 150(i_1 - i_2)$

KVL @ i_1

$R_2(i_1 - i_2) - R_3(i_3 - i_1) + R_1 i_1 = 0$

$R_2 i_1 - R_2 i_2 - R_3 i_3 + R_3 i_1 + R_1 i_1 = 0$

$(R_1 + R_2 + R_3) i_1 + (-R_2) i_2 + (-R_3) i_3 = 0$ (1)

KVL @ i_2

$V_s + R_5(i_2) - R_4(i_3 - i_2) - R_2(i_1 - i_2) = 0$

$-V_s = R_5 i_2 - R_4 i_3 + R_4 i_2 - R_2 i_1 + R_2 i_2$

$-V_s = (-R_2) i_1 + (R_2 + R_4 + R_5) i_2 + (-R_4) i_3$ (2)

KVL @ i_3

$R_6(i_3) + [150(i_1 - i_2)] + R_3(i_3 - i_1) + R_4(i_3 - i_2) = 0$

$R_6 i_3 + 150 i_1 - 150 i_2 + R_3 i_3 - R_3 i_1 + R_4 i_3 - R_4 i_2 = 0$

$(150 - R_3) i_1 + (-150 - R_4) i_2 + (R_3 + R_4 + R_6) i_3 = 0$ (3)

$$\begin{bmatrix} (R_1+R_2+R_3) & (-R_2) & (-R_3) \\ (-R_2) & (R_2+R_4+R_5) & (-R_4) \\ (150-R_3) & (-150-R_4) & (R_3+R_4+R_6) \end{bmatrix} \begin{bmatrix} i_1 \\ i_2 \\ i_3 \end{bmatrix} = \begin{bmatrix} 0 \\ -V_s \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} 135Ω & -45Ω & -60Ω \\ -45Ω & 375Ω & -300Ω \\ 90Ω & -450Ω & 375Ω \end{bmatrix}^{-1} \begin{bmatrix} 0 \\ 3.6KV \\ 0 \end{bmatrix} = \begin{bmatrix} i_1 \\ i_2 \\ i_3 \end{bmatrix}$$

$i_1 = 78A \quad i_2 = 99.6A \quad i_3 = 100.8A$

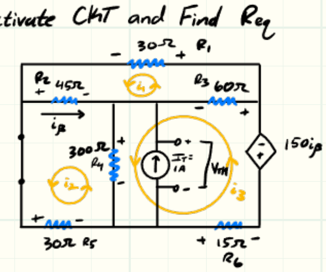
$i_\beta = i_1 - i_2 = [78A - 99.6A] = -21.6A$

$V_{TH} = R_4(i_3 - i_2)$

$V_{TH} = 300Ω(100.8 - 99.6)$

$\underline{V_{TH} = 360V}$

Deactivate CKT and Find R_{eq}



$i_{sc} = i_2 - i_3$

from i_1

$-45 i_1 - 60 i_2 + 135 i_3 = 0$

from i_2

$-3600 + 45 i_1 - 45 i_3 + 30 i_1 = 0$

$70 i_1 - 45 i_3 = 3600$

from i_3

$75 i_2 - 60 i_3 - 150(i_1 - i_3) = 0$

$-150 i_1 + 75 i_2 + 90 i_3 = 0$

$$\begin{bmatrix} 75 & 0 & -45 \\ -150 & 75 & 90 \\ -45 & -60 & 135 \end{bmatrix}^{-1} \begin{bmatrix} 3600 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} i_1 \\ i_2 \\ i_3 \end{bmatrix}$$

$i_1 = 92A$

$i_2 = 96A$

$i_3 = 73.33A$

$i_{sc} = 96 - 92 = 4A$

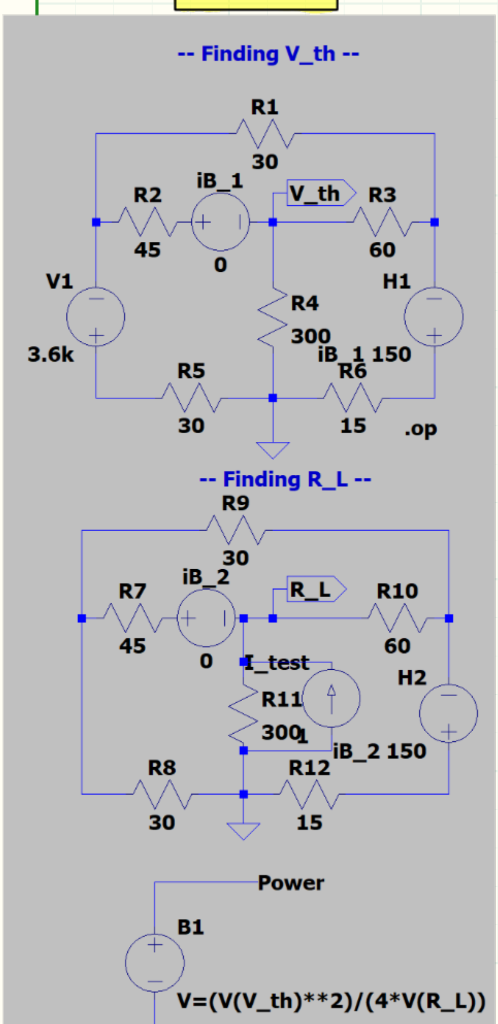
$R_{TH} = \frac{V_{TH}}{i_{sc}} = \frac{360V}{4A}$

$R_{TH} = 90Ω$

$\boxed{R_L = 90Ω}$

b.) $P_L = \frac{(V_{TH})^2}{4R_L} = \frac{(360V)^2}{4(90)}$

$\boxed{P_L = 360W}$



--- Operating Point ---

V(n002):	1728	voltage
V(n001):	-612	voltage
V(p001):	360	voltage
V(v_th):	360	voltage
V(n003):	2988	voltage
V(n004):	-1512	voltage
V(p002):	90	voltage
V(n005):	57	voltage
V(n006):	92	voltage
V(r_l):	90	voltage
V(n007):	-18	voltage
V(power):	360	voltage
I(B1):	0	device_current
I(H1):	100.8	device_current
I(H2):	1.2	device_current
I(I_test):	1	device_current
I(R1):	78	device_current
I(R2):	21.6	device_current
I(R3):	22.8	device_current
I(R4):	1.2	device_current
I(R5):	-99.6	device_current
I(R6):	-100.8	device_current
I(R7):	0.733333	device_current
I(R8):	-1.9	device_current
I(R10):	0.0333333	device_current
I(R9):	1.16667	device_current
I(R11):	0.3	device_current
I(R12):	-1.2	device_current
I(V1):	-99.6	device_current
I(Ib_1):	-21.6	device_current
I(Ib_2):	-0.733333	device_current

4) Current i in Figure 4 below can be written as $i = i_{90V} + i_{40V}$, where i_{90V} and i_{40V} are the components of i due to the 90 V and 40 V voltage sources, respectively.

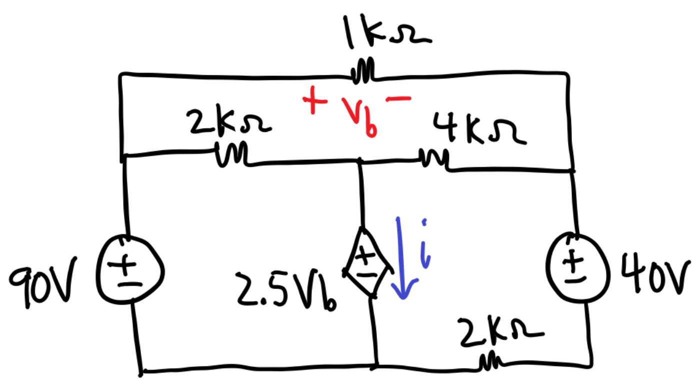


Figure 4. Circuit for Problem 4.

For the parts below, include appropriate units with your numerical answers in proper engineering notation format and with at least two decimal places of precision. Keep at least two decimal places of precision. *Show your work.*

a) Determine the numerical value of i_{90V}.

b) Determine the numerical value of i_{40V}.

c) Using the principle of superposition and the results of parts (a) and (b), determine the numerical value of i.

d) Verify your results for parts (a), (b), and (c) in LTSpice. Write out the answers you got from LTSpice and attach any supporting evidence that you actually simulated the circuit to verify your work. The answers you write out for this part should be the same as the results you provided in part (a); if they don't match **by both sign and magnitude**, expect zero credit. Also, expect zero credit 1) if your by-hand and simulated results agree but the results are incorrect, 2) if you do not perform the LTSpice verification altogether, 3) if you only do the LTSpice verification but not the by-hand solution, or 4) if you do not label key node voltages and/or use properly-oriented 0 V voltage source ammeters for measuring key branch currents in LTSpice.

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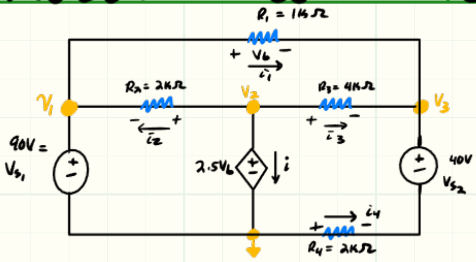


$i = i_{90V} + i_{40V}$

$V_a = 90V$

$V_b = V_1 - V_3$

$V_2 = 2.5V_b$

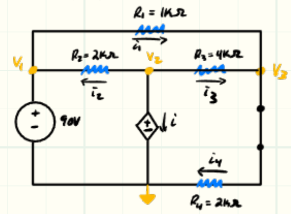
$V_2 = 2.5(V_1 - V_3)$

$V_2 = 2.5(90 - V_3)$

$V_2 = 225 - 2.5V_3$

$$i = -\left(\frac{V_2 - V_1}{2k\Omega} + \frac{V_2 - V_3}{4k\Omega}\right)$$

Superposition (i_{90V}); short 40V source



KCL @ V_3

$i_1 + i_3 - i_4 = 0$

$$\left(\frac{V_1 - V_3}{1k}\right) + \left(\frac{V_2 - V_3}{4k}\right) - \left(\frac{V_3 - 0}{2k}\right) = 0$$

$$\frac{(90V) - V_3}{1k} + \frac{(225 - 2.5V_3) - V_3}{4k} = \frac{V_3}{2k}$$

$$4k\left[\frac{90}{1k} - \frac{V_3}{1k} + \frac{225}{4k} - \frac{3.5V_3}{4k} = \frac{V_3}{2k}\right]$$

$4(90) - 4V_3 + 225 - 3.5V_3 = 2V_3$

$360 + 225 = 9.5V_3$

$V_3 = 61.579V$

$V_2 = 225 - 2.5(61.579V)$

$V_2 = 71.052V$

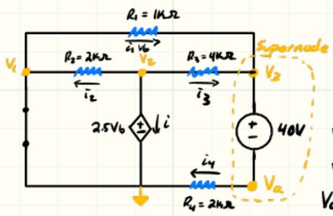
$$i = -\left(\frac{V_2 - V_1}{2k} + \frac{V_2 - V_3}{4k}\right)$$

$$i = -\left(\frac{71.052 - 90}{2k} + \frac{71.052 - 61.578}{4k}\right)$$

$i = -(-0.00947 + 0.00236)$

$\boxed{i_{90V} = 7.11mA}$

Superposition (i_{40V}); short 90V.



$V_1 = 0V$

$V_b = V_1 - V_2$

$V_b = -V_2$

$V_2 = 2.5(V_1 - V_3)$

$V_2 = 2.5(0 - V_3)$

$V_2 = -2.5V_3$

$V_a = V_3 - 40V$

KCL @ Supernode

$i_1 + i_3 - i_4 = 0$

$$\left(\frac{V_1 - V_3}{1k}\right) + \left(\frac{V_2 - V_3}{4k}\right) - \left(\frac{V_a - 0}{2k}\right) = 0$$

$$\left[\frac{0 - V_3}{1k} + \frac{(-2.5V_3) - V_3}{4k} - \frac{(V_3 - 40) - 0}{2k}\right] \cdot 4k = 0$$

$4(-V_3) - 3.5V_3 - 2(V_3 - 40) = 0$

$-4V_3 - 3.5V_3 - 2V_3 + 80 = 0$

$80V = 9.5V_3$

$V_3 = 8.42V$

$V_2 = -2.5V_3$

$V_2 = -2.5(8.42)$

$V_2 = -21.052$

$$i = -\left(\frac{V_2 - V_1}{2k} + \frac{V_2 - V_3}{4K}\right) = -\left(\frac{(-21.052) - (0)}{2000} + \frac{-21.052 - (8.42)}{4000}\right)$$

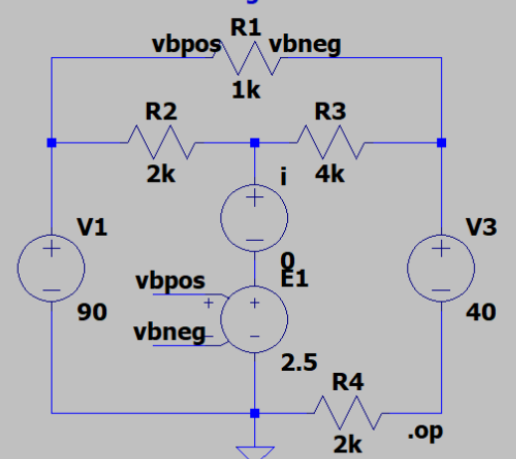
$\boxed{i_{40V} = 17.89mA}$

$i = i_{90V} + i_{40V}$

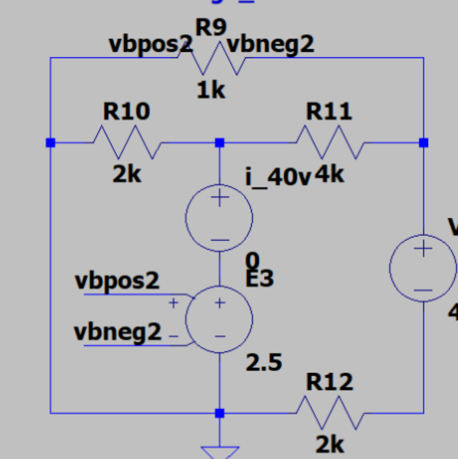
$i = (7.11mA) + (17.89mA)$

$\boxed{i = 25mA}$

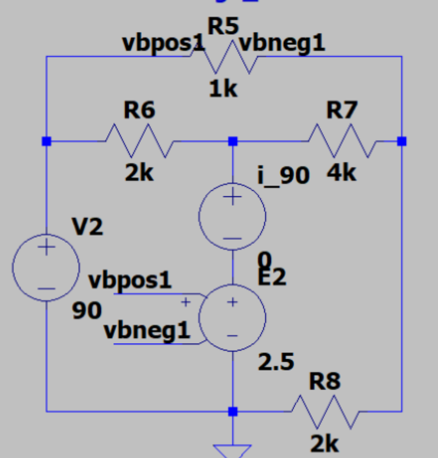
-- Finding total i --



-- Finding i_40v --



-- Finding i_90v --



--- Operating Point ---

I(R12):	-0.0157895	device_current
I(E1):	0.025	device_current
I(E2):	0.00710526	device_current
I(E3):	0.0178947	device_current
I(V1):	-0.04	device_current
I(I):	0.025	device_current
I(V3):	0.015	device_current
I(I_90):	0.00710526	device_current
I(V2):	-0.0378947	device_current
I(I_40v):	0.0178947	device_current
I(V5):	-0.0157895	device_current