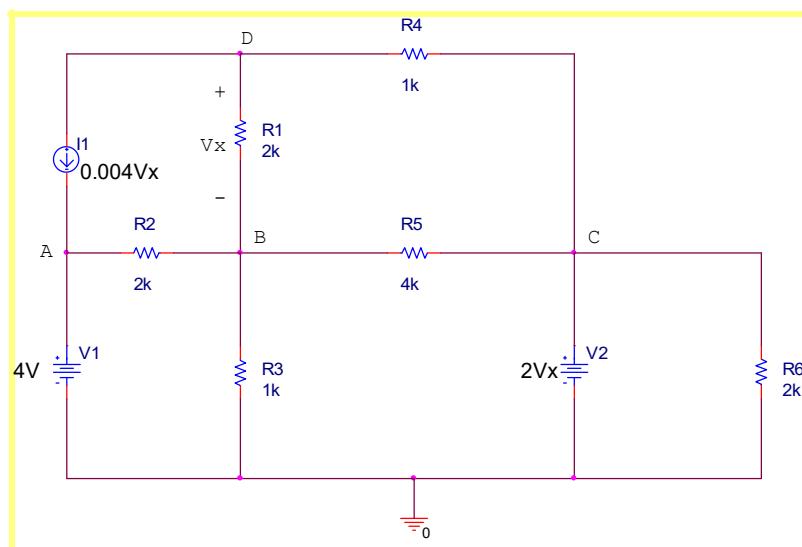


In the circuit above, set up the linear system to analyze the circuit using both mesh and node analysis. You only need to solve for V_x using one of the methods. Be sure to include the following:

- Label the nodes you would use to perform node analysis.
- Clearly write linear system of equations for nodal analysis.
- Clearly write linear system of equation for mesh analysis.
- Find V_x using either method.



KCL at B

$$\frac{V_B - 0}{1k} + \frac{V_B - V_A}{2k} + \frac{V_B - V_C}{4k} + \frac{V_B - V_D}{2k} = 0$$

$$V_A \cdot \frac{-1}{2k} + V_B \left(\frac{1}{1k} + \frac{1}{2k} + \frac{1}{4k} + \frac{1}{2k} \right) + V_C \cdot \left(\frac{-1}{4k} \right) + V_D \left(\frac{-1}{2k} \right) = 0$$

KCL at D

$$0.004V_x + \frac{V_D - V_B}{2k} + \frac{V_D - V_C}{1k} = 0$$

$$V_x(0.004) + V_B \left(\frac{-1}{2k} \right) + V_C \left(\frac{-1}{1k} \right) + V_D \left(\frac{1}{2k} + \frac{1}{1k} \right) = 0$$

$$V_A = 4V$$

$$0 = V_B - V_D + V_x$$

$$0 = V_C - 2V_x$$

You can substitute in or just put it in a matrix...substituting reduces to 2 equations

$$M_1 := \begin{bmatrix} \frac{-1}{2 \cdot 10^3} & \left(\frac{1}{1 \cdot 10^3} + \frac{1}{2 \cdot 10^3} + \frac{1}{4 \cdot 10^3} + \frac{1}{2 \cdot 10^3} \right) & \left(\frac{-1}{4 \cdot 10^3} \right) & \frac{-1}{2 \cdot 10^3} & 0 \\ 0 & \frac{-1}{2 \cdot 10^3} & \frac{-1}{1 \cdot 10^3} & \left(\frac{1}{2 \times 10^3} + \frac{1}{1 \cdot 10^3} \right) & 0.004 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & -1 & 1 \\ 0 & 0 & 1 & 0 & -2 \end{bmatrix}$$

$$C_1 := \begin{pmatrix} 0 \\ 0 \\ 4 \\ 0 \\ 0 \end{pmatrix}$$

$$M_1^{-1} \cdot C_1 = \begin{pmatrix} 4 \\ 0.982 \\ -0.561 \\ 0.702 \\ -0.281 \end{pmatrix}$$

$$V_x = -0.281V$$

Mesh

$$i_1 = -0.004V_x$$

$$(1) \quad i_1 + 0.004V_x = 0$$

$$i_2 \cdot 2k - i_1 \cdot 2k + i_2 \cdot 1k + i_2 \cdot 4k - i_4 \cdot 4k = 0$$

$$(2) \quad i_1 \cdot (-2k) + i_2 \cdot 7k - i_4 \cdot 4k = 0$$

$$-4 + i_3 \cdot 2k - i_1 \cdot 2k + i_3 \cdot 1k - i_4 \cdot 1k = 0$$

$$(3) \quad i_1 \cdot (-2k) + i_3 \cdot (3k) + i_4 \cdot (-1k) = 4$$

$$i_4 \cdot 1k - i_3 \cdot 1k + i_4 \cdot 4k - i_2 \cdot 4k + 2 \cdot V_x = 0$$

$$(4) \quad i_2 \cdot (-4k) + i_3 \cdot (-1k) + i_4 \cdot (5k) + 2V_x = 0$$

$$(5) \quad -2 \cdot V_x + i_5 \cdot 2k = 0$$

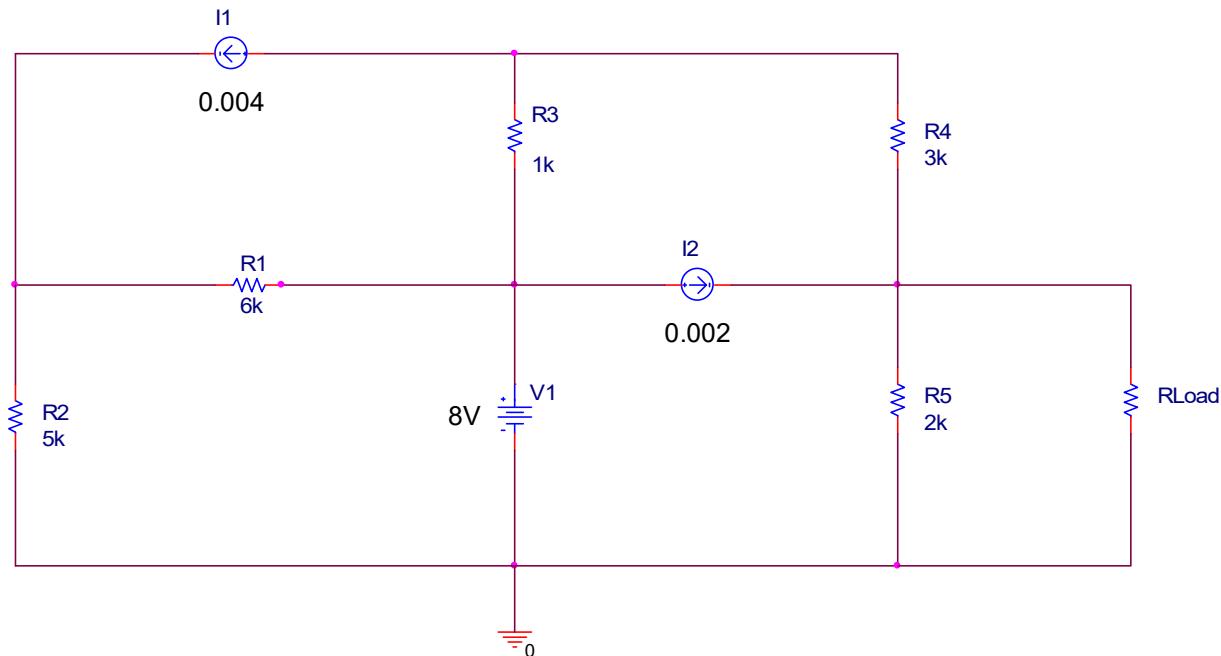
$$(6) \quad V_x = (i_1 - i_2) \cdot 2k$$

$$M_2 := \begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0.004 \\ -2 \cdot 10^3 & 7 \cdot 10^3 & 0 & -4 \cdot 10^3 & 0 & 0 \\ -2 \cdot 10^3 & 0 & 3 \cdot 10^3 & -1 \cdot 10^3 & 0 & 0 \\ 0 & -4 \cdot 10^3 & -1 \cdot 10^3 & 5 \cdot 10^3 & 0 & 2 \\ 0 & 0 & 0 & 0 & 2 \cdot 10^3 & -2 \\ 2 \cdot 10^3 & -2 \cdot 10^3 & 0 & 0 & 0 & -1 \end{pmatrix}$$

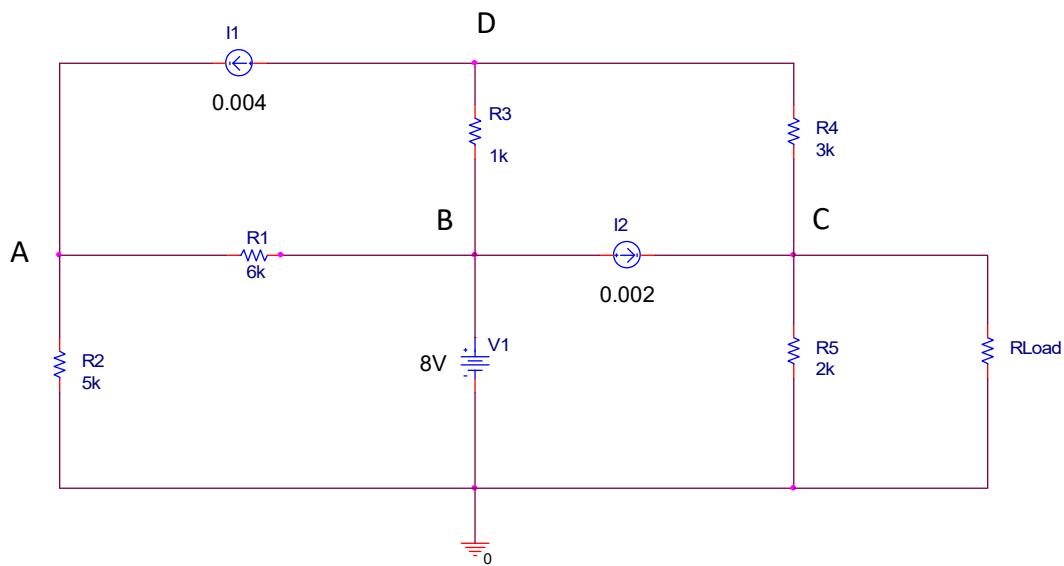
$$C_2 := \begin{pmatrix} 0 \\ 0 \\ 4 \\ 0 \\ 0 \\ 0 \end{pmatrix}$$

$$M_2^{-1} \cdot C_2 = \begin{pmatrix} 1.123 \times 10^{-3} \\ 1.263 \times 10^{-3} \\ 2.632 \times 10^{-3} \\ 1.649 \times 10^{-3} \\ -2.807 \times 10^{-4} \\ -0.281 \end{pmatrix}$$

V_x = -0.281

2) Thevenin/Norton Voltage

On the above circuit, using any method, find the a) thevenin voltage, b) thevenin resistance, and c) norton current. Draw the schematics of the norton and thevenin circuits for full credit. Confirm your values by any method.



Node analysis

At node C

$$\frac{V_C}{2k} - 0.002 + \frac{V_C - V_D}{3k} = 0$$

$$V_C \left(\frac{1}{2k} + \frac{1}{3k} \right) - V_D \cdot \frac{1}{3k} = 0.002$$

$$0.004 + \frac{V_D - 8V}{1k} + \frac{V_D - V_C}{3k} = 0$$

$$-V_C \left(\frac{1}{3k} \right) + V_D \left(\frac{1}{1k} + \frac{1}{3k} \right) = -0.004 + \frac{8}{1k}$$

$$M_3 := \begin{pmatrix} \frac{1}{2 \cdot 10^3} + \frac{1}{3 \cdot 10^3} & \frac{-1}{3 \cdot 10^3} \\ -\frac{1}{3 \cdot 10^3} & \frac{1}{1 \cdot 10^3} + \frac{1}{3 \cdot 10^3} \end{pmatrix}$$

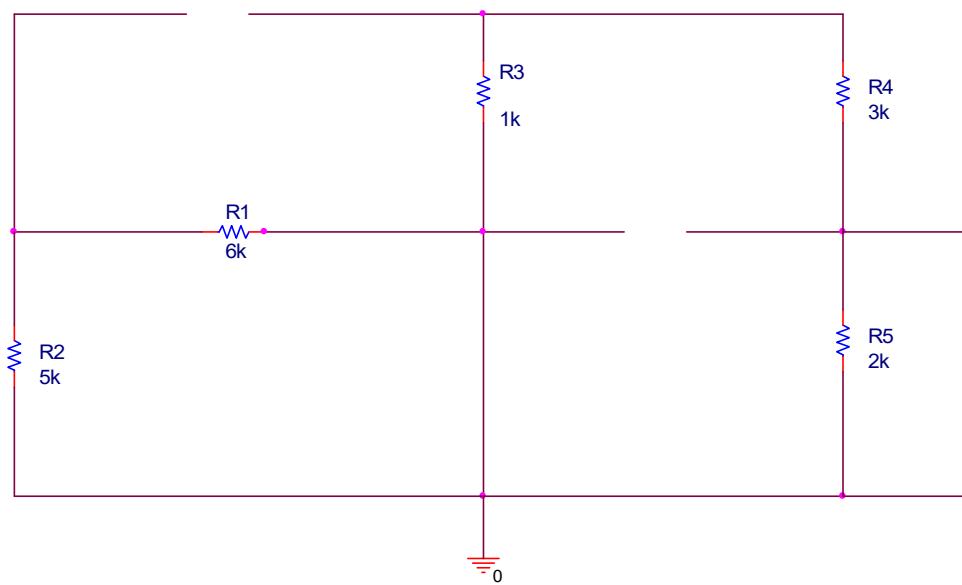
$$C_3 := \begin{pmatrix} 0.002 \\ -0.004 + \frac{8}{1 \cdot 10^3} \end{pmatrix}$$

$$X_1 := M_3^{-1} \cdot C_3$$

$$X_1 = \begin{pmatrix} 4 \\ 4 \end{pmatrix}$$

$$V_C = V_{TH} = 4V$$

RTh



$$R_3 := 1\text{k}\Omega$$

$$R_4 := 3\text{k}\Omega$$

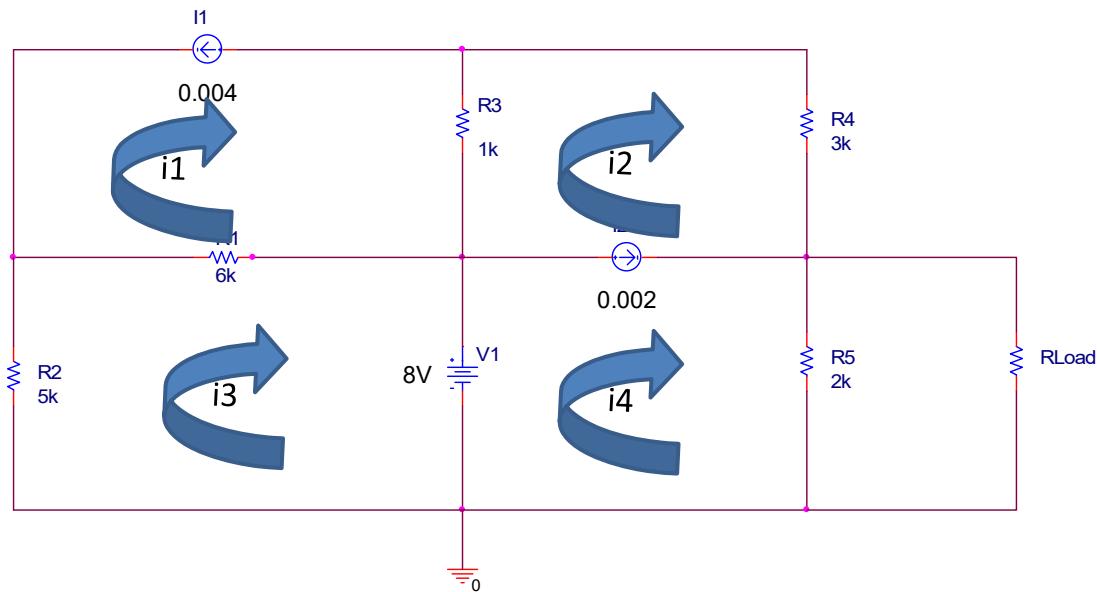
$$R_5 := 2\text{k}\Omega$$

$$R_{34} := R_3 + R_4$$

$$R_{34} = 4 \times 10^3 \Omega$$

$$\frac{R_{34} \cdot R_5}{R_{34} + R_5} = 1.333 \cdot \text{k}\Omega$$

$$I_N$$



Loop 2 and 4 is a supermesh

NOTE: Diagram is technically incorrect, R5 is a short so not included....with short and no RLoad it is correct

$$(1) \quad i_4 - i_2 = 0.002$$

• •

$$-8 + i_2 \cdot 1\text{k} - (-0.004 \cdot 1\text{k}) + i_2 \cdot 3\text{k} = 0$$

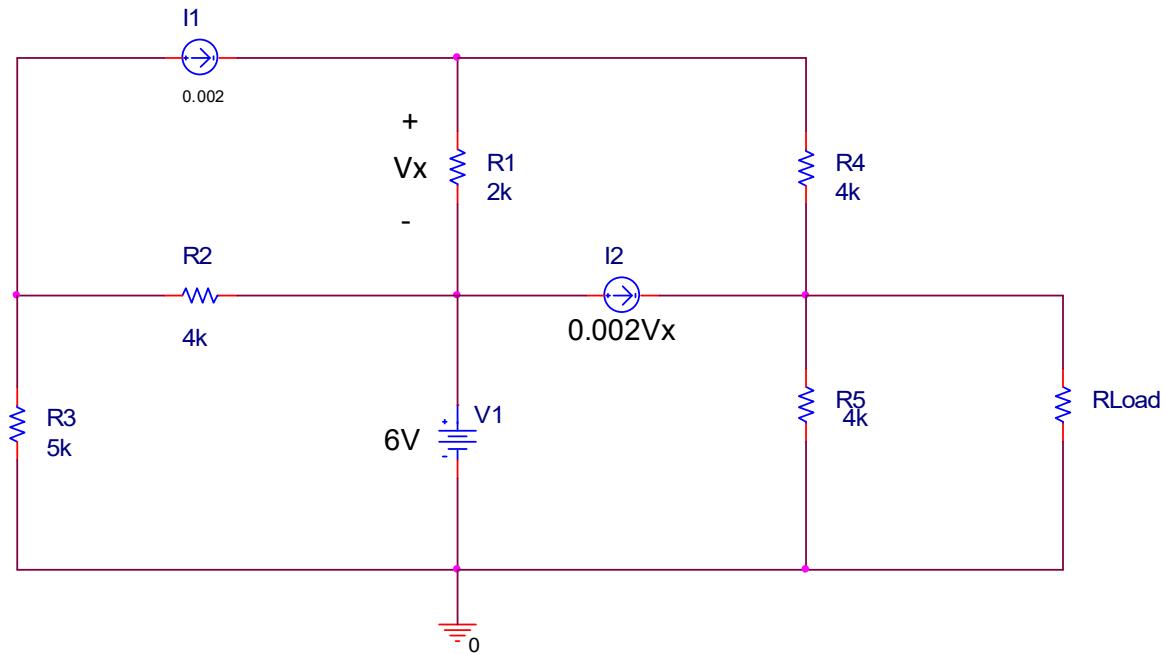
$$(2) \quad i_2(4\text{k}) = 8 + -0.004 \cdot 1\text{k}$$

$$i_2 := 1\text{mA}$$

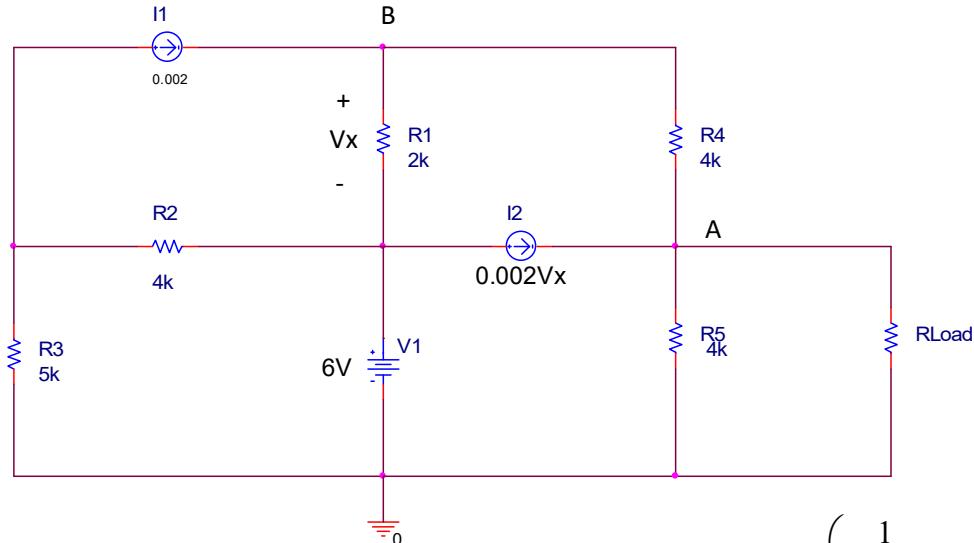
$$i_4 = 0.002 + 0.001$$

$$i_4 = 3\text{mA}$$

3) Thevenin/Norton Voltage



Determine V_{TH} using any analysis method, I_N using any analysis method, and R_{TH} using the test method for the above circuit. Verify your answers.



KCL A:

$$-0.002V_x + \frac{V_A}{4k} + \frac{V_A - V_B}{4k} = 0$$

$$M_5 := \begin{pmatrix} \frac{1}{4 \cdot 10^3} + \frac{1}{4 \cdot 10^3} & \frac{-1}{4 \cdot 10^3} & -0.002 \\ \frac{-1}{4 \cdot 10^3} & \frac{1}{2 \cdot 10^3} + \frac{1}{4 \cdot 10^3} & 0 \\ 0 & -1 & 1 \end{pmatrix}$$

KCL B:

$$-0.002 + \frac{V_B - 6}{2k} + \frac{V_B - V_A}{4k} = 0$$

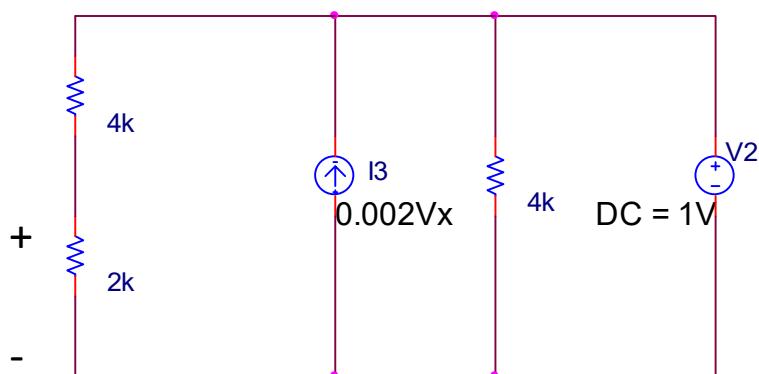
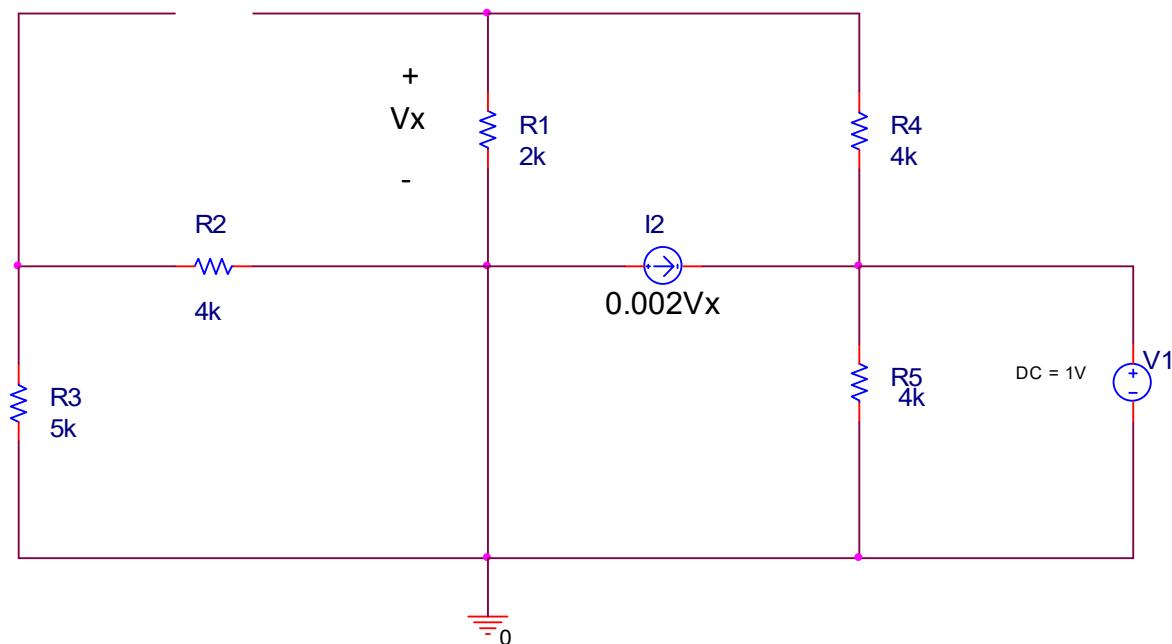
$$V_x = V_B - 6$$

$$V_A = V_{TH} = 12V$$

$$C_5 := \begin{pmatrix} 0 \\ 0.002 + \frac{6}{2 \cdot 10^3} \\ -6 \end{pmatrix}$$

$$M_5^{-1} \cdot C_5 = \begin{pmatrix} -12 \\ 2.667 \\ -3.333 \end{pmatrix}$$

RTH



$$1V \cdot \frac{2k\Omega}{6k\Omega} = 0.333V$$

Current is therefore $0.002 \cdot 0.333 = 6.66 \times 10^{-4} A$

KCL will give i_{test} i_{test} goes to left

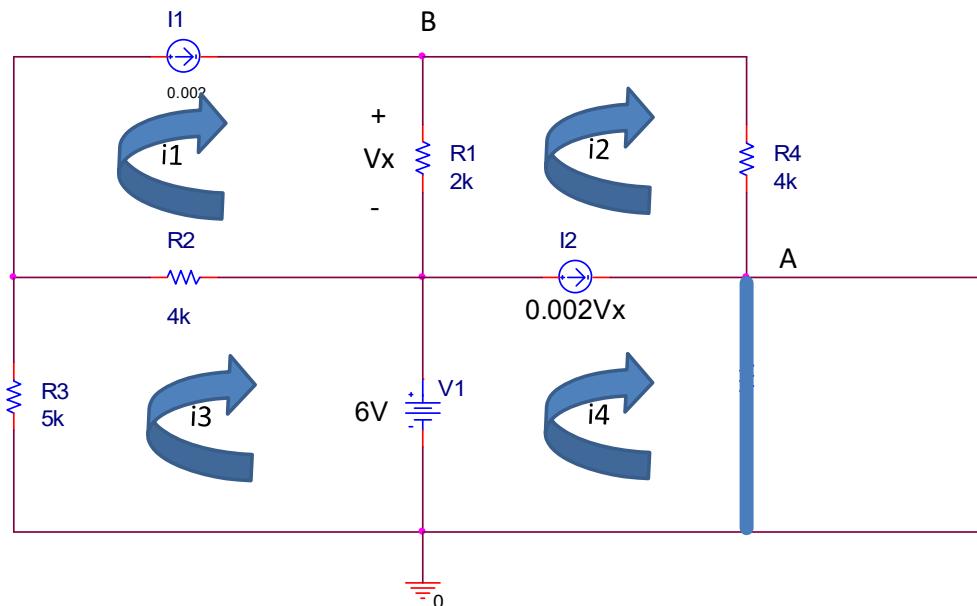
$$-i_{test} + \frac{1V}{4 \cdot 10^3 \Omega} - 0.002 \cdot 0.333 + \frac{1V}{6 \cdot 10^3 \Omega} = 0$$

$$-6.66 \cdot 10^{-4} + \frac{1}{4 \cdot 10^3} + \frac{1}{6 \cdot 10^3} = -2.493 \times 10^{-4}$$

$$i_{test} = -2.5 \cdot 10^{-4} A$$

$$R_{Th} := \frac{1V}{-2.5 \cdot 10^{-4} A} = -4 \cdot k\Omega$$

I_N for check $\frac{12V}{-4k\Omega} = -3 \cdot mA$



$$0.002 \cdot 2 \cdot 10^3 = 4$$

$$i_2 \cdot 4k - 6 + i_2 \cdot 2k - 0.002 \cdot 2k = 0$$

$$i_{2b} := \frac{10}{6 \cdot 10^3} = 1.667 \times 10^{-3}$$

$$V_x = (i_1 - i_2) \cdot 2k$$

$$V_x := (0.002 - 1.667 \cdot 10^{-3}) \cdot 2 \times 10^3$$

$$V_x = 0.666$$

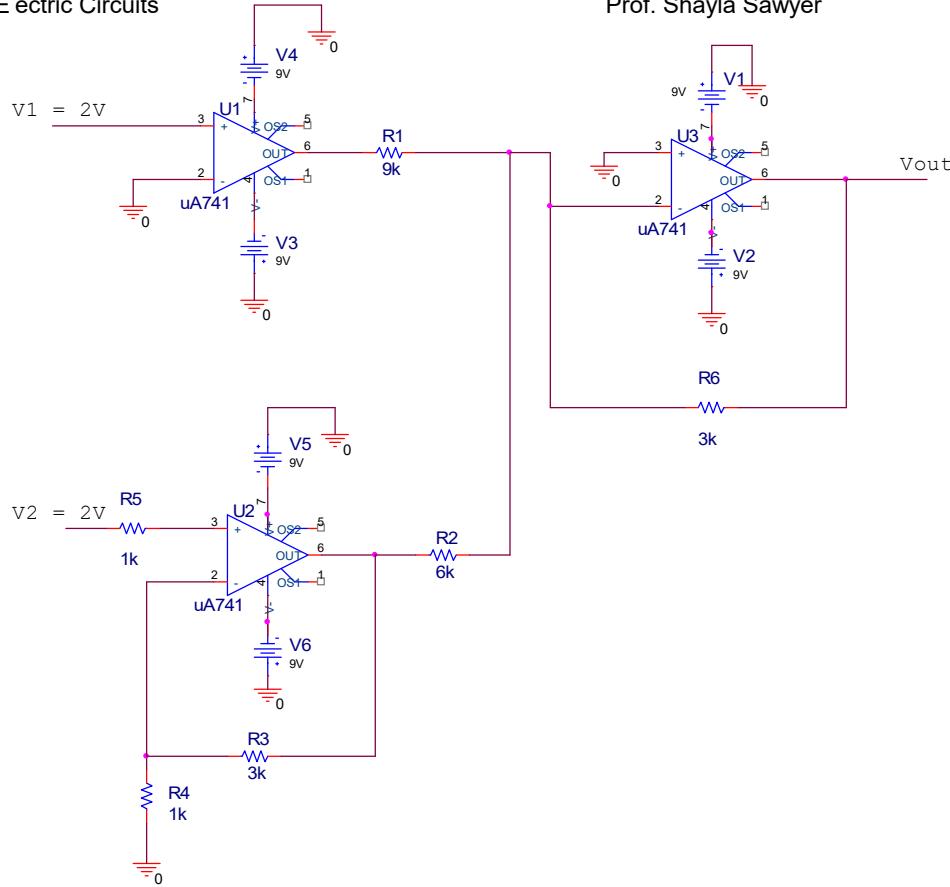
$$i_4 - i_2 = 0.002 V_x$$

$$i_4 := 0.002 \cdot V_x + i_{2b}$$

$$i_4 = 2.999 \times 10^{-3}$$

$$i_{sc} = I_N = 3mA$$

4) Amplifier Circuits



a) Find the output voltage, V_{out} . The voltages to power the op-amps are 9V and -9V.

U1: Comparator, $V_+ > V_-$, $V_{out1} := 9V$

U2: Non inverting amplifier (R5 has no effect since no current is drawn by the amp.)

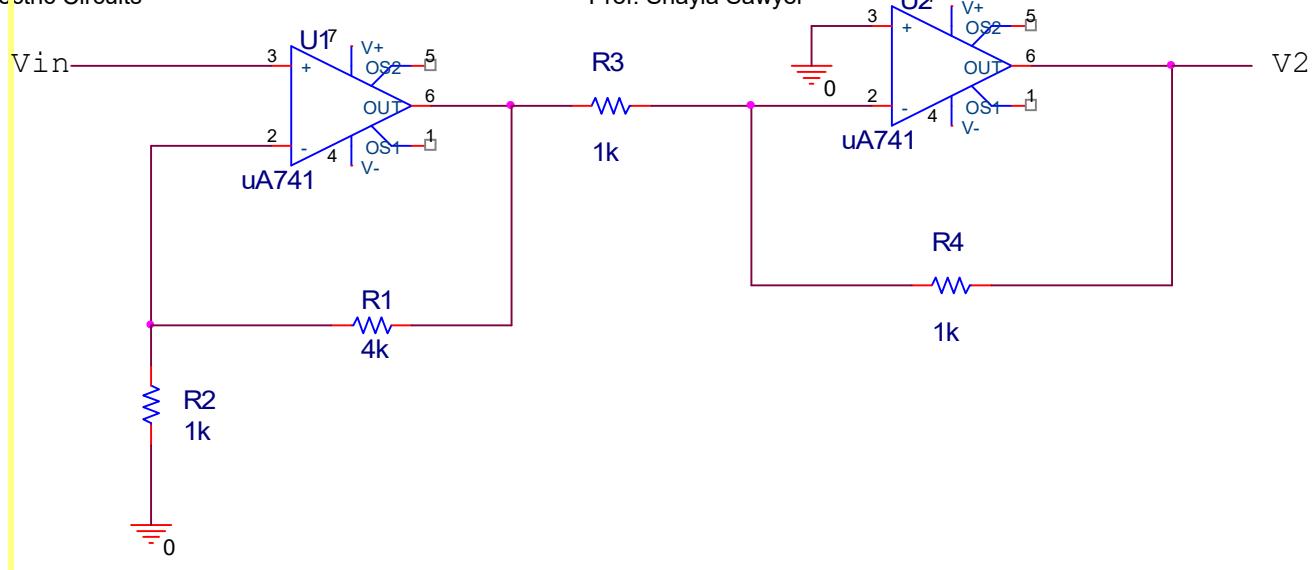
$$V_{out2} := \left(1 + \frac{3000}{1000}\right) \cdot 2V = 8V$$

U3: Summing, inverting amplifier with different gain circuits

$$V_{out} := \frac{-3000}{9000} \cdot V_{out1} + \frac{-3000}{6000} \cdot V_{out2} = -7V$$

5) Amplifier Circuits - Design problem

a) Design a two stage amplifier such that the output of the first stage is $V1 = 5 \cdot V_{in}$ and the output of the second stage is $V2 = -V1$.



U1: is a noninverting amp $V_1 = (1 + 4k/1k)V_{in} = 5V_{in}$

U2: Inverting op amp, $V_2 = (-1k/1k) * V_1 = -5V_{in}$

