Circuits

Exam 1

Fall 2020

1.	/25
2.	/25
3.	/30
4.	/20
Total	/100

Name ____________________

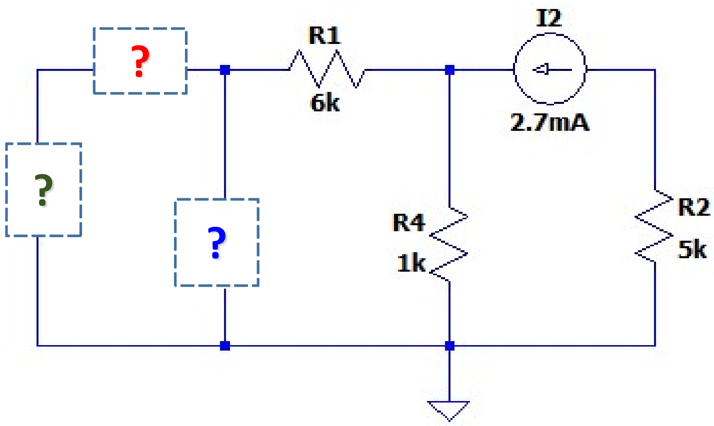
Notes:
1) Your crib sheet is provided in the Exams Team Space.
2) You may use your calculator (only).
3) You cannot use your computer or cell phone during any part of the exam. Doing so results in an automatic 0 for this exam.

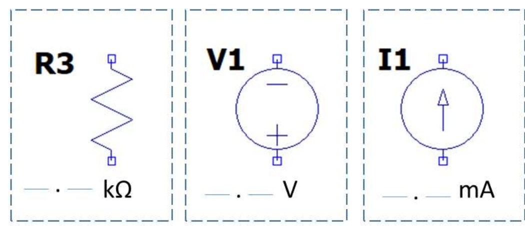
Please sign below:
I have not consulted any person or collaborated with anyone to complete this exam. I did not post and will not post any part of this exam to Chegg.com or any other equivalent websites. I understand that if my exam is found online, I will be given an F for the semester and the academic dishonesty process will be initiated. I did not look for answers on any website to this exam. If any signification portion of this exam is found to match with any other student, I will be given an automatic 0 for the entire exam. Further actions due to academic dishonesty may be warranted after discussion with all parties.

Signature: ____

Problem 1) The Laws: KCL, KVL, Ohm's Law (25 pts)

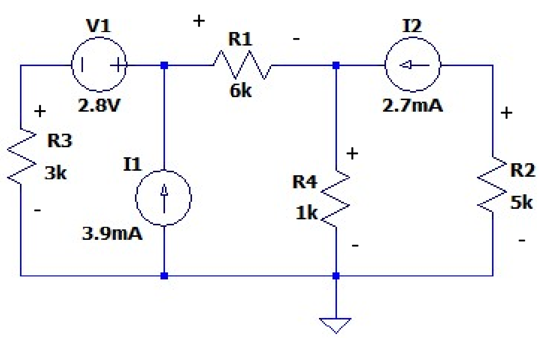
25 pts Using ***KCL and KVL and Ohm's law only***, write ***every step*** to find the voltages across each resistor. ***The answer to the final answer to this problem is not necessary and not graded.*** You have three components R3, V1, and I1. There are three spots for these components to go. Place them in one of the three spots in any orientation you'd like. You must use all three components in the circuit. There are two spaces for you to fill in to give the values for these components. You MUST choose an integer 1-9, for every space you see. For example, for R3 if I choose 1 for the first space and 2 for the second space, the value of R2 is 1.2K ohms. Note: I1 is in mA...





1.1: (1 pt) Step 1: Redraw your circuit below. ***Include your reference marks across each resistor for your passive sign convention "scaffolding" .*** Ground must be where it is originally placed. You can turn your components and give them any polairty you'd like. (Note: Reference marks are absolutely necessary to draw on your circuit. Without them, your 1.2 step will be marked incorrect with no partial credit!)

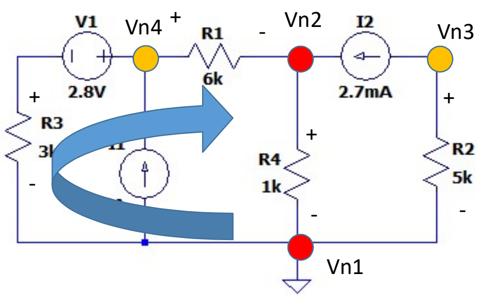
My circuit



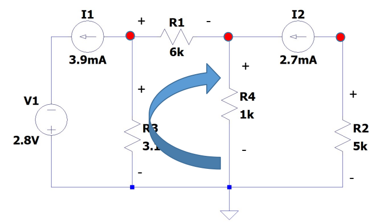
R3 should be 3.1k....

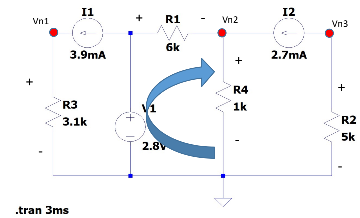
1.2: (10 pts) Step 2: Write the linear independent equations necessary to solve your problem.

My solution



Other solutions.





$R_1 := 6 \cdot 10^3$ $\quad R_2 := 5 \cdot 10^3$ $\quad R_3 := 3.1 \times 10^3$ $\quad R_4 := 1 \times 10^3$ $\quad V_1 := 2.8$

$I_1 := 3.9 \cdot 10^{-3}$ $\quad I_2 := 2.7 \cdot 10^{-3}$

KVL at the left:

$$-V_{R3} - V_1 + V_{R1} + V_{R4} = 0$$

$$V_{R1} - V_{R3} + V_{R4} = V_1$$

(1) $I_{R1} \cdot R_1 - I_{R3} \cdot R_3 + I_{R4} \cdot R_4 = V_1$

KCL at Vn1

$$-I_{R3} + I_1 - I_{R4} - I_{R2} = 0$$

(2) $-I_{R2} - I_{R3} - I_{R4} = -I_1$

KCL at node Vn2:

$$-I_{R1} + I_{R4} - I_2 = 0$$

(3) $-I_{R1} + I_{R4} = I_2$

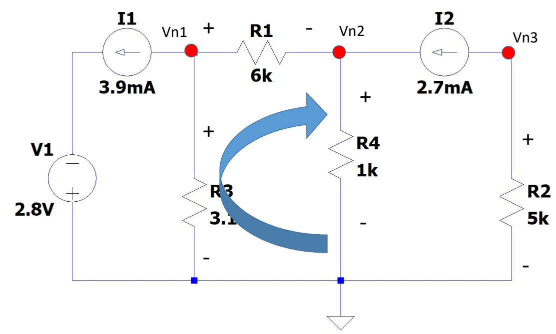
KCL at node Vn3:

$$I_2 + I_{R2} = 0$$

(4) $I_{R2} = -I_2$

***Vn4 was a backup to Vn3 if Vn3 didn't create a matrix that converges. I didn't try to use it...

Other solution 1:



KCL Vn1

$$I_1 + I_{R1} + I_{R3} = 0$$

$$(1) \quad \frac{1}{R_1} \cdot V_{R1} + \frac{1}{R_3} \cdot V_{R3} = -I_1$$

KCL Vn2

$$-I_{R1} + I_{R4} - I_2 = 0$$

$$(2) \quad \frac{-1}{R_1} \cdot V_{R1} + \frac{1}{R_4} \cdot V_{R4} = I_2$$

KCL Vn3

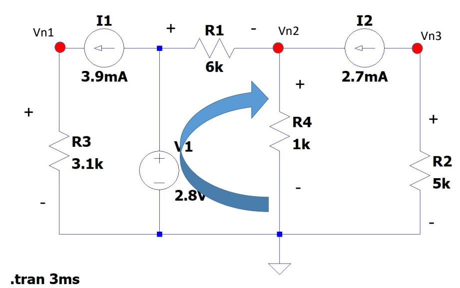
$$I_2 + I_{R2} = 0$$

$$(3) \quad \frac{1}{R_2} \cdot V_{R2} = -I_2$$

KCL loop

$$(4) \quad V_{R1} - V_{R3} + V_{R4} = 0$$

Other solution 2:



KCL Vn1

$$-I_1 + \frac{1}{R_3} \cdot V_{R3} = 0$$

$$(1) \quad \frac{1}{R_3} \cdot V_{R3} = I_1$$

KCL Vn2

$$-I_{R1} + I_{R4} - I_2 = 0$$

$$(2) \quad \frac{-1}{R_1} \cdot V_{R1} + \frac{1}{R_4} \cdot V_{R4} = I_2$$

KVL loop

$$V_1 + V_{R1} + V_{R4} = 0$$

$$(3) \quad V_{R1} + V_{R4} = -V_1$$

KCL Vn3

$$I_2 + I_{R2} = 0$$

$$\frac{1}{R_2} \cdot V_{R2} = -I_2$$

1.3: (5 pts) Step 3: Write your matrices with component values. Also include the matrix equation to find the resitance across every resistor. You do not have to provide your final answer values. If you do, they are not graded.

My solution matrix:

$$M_1 := \begin{pmatrix} R_1 & 0 & -R_3 & R_4 \\ 0 & -1 & -1 & -1 \\ -1 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 \end{pmatrix} \qquad C_1 := \begin{pmatrix} V_1 \\ -I_1 \\ I_2 \\ -I_2 \end{pmatrix}$$

$$M_1^{-1} \cdot C_1 = \begin{pmatrix} 1.207 \times 10^{-3} \\ -2.7 \times 10^{-3} \\ 2.693 \times 10^{-3} \\ 3.907 \times 10^{-3} \end{pmatrix}$$

$$I_{R1} := 1.18 \times 10^{-3} \qquad V_{R1} := R_1 \cdot I_{R1} = 7.08$$

$$I_{R2} := -2.7 \times 10^{-3} \qquad V_{R2} := R_2 \cdot I_{R2} = -13.5$$

$$I_{R3} := 2.72 \times 10^{-3} \qquad V_{R3} := R_3 \cdot I_{R3} = 8.432$$

$$I_{R4} := 3.88 \times 10^{-3} \qquad V_{R4} := R_4 \cdot I_{R4} = 3.88$$

Students should have some simple equation to calculate the voltages across every resistor. It is also fine if they calculated current and then used ohm's law at the end.

The final answer here is not graded and doesn't need to be marked.

Other solution 1 matrix:

$$M_{1other1} := \begin{pmatrix} \frac{1}{R_1} & 0 & \frac{1}{R_3} & 0 \\ \frac{-1}{R_1} & 0 & 0 & \frac{1}{R_4} \\ 1 & 0 & -1 & 1 \\ 0 & \frac{1}{R_2} & 0 & 0 \end{pmatrix} \qquad C_{1other1} := \begin{pmatrix} -I_1 \\ I_2 \\ 0 \\ -I_2 \end{pmatrix}$$

$$M_{1other1}^{-1} \cdot C_{1other1} = \begin{pmatrix} -8.786 \\ -13.5 \\ -7.55 \\ 1.236 \end{pmatrix}$$

$$V_{R1other1} := -8.786$$

$$V_{R2other1} := -13.5$$

$$V_{R3other1} := -7.55$$

$$V_{R4other1} := 1.236$$

Other solution 2 matrix:

$$M_{1other2} := \begin{pmatrix} 0 & 0 & \frac{1}{R_3} & 0 \\ \frac{-1}{R_1} & 0 & 0 & \frac{1}{R_4} \\ 1 & 0 & 0 & 1 \\ 0 & \frac{1}{R_2} & 0 & 0 \end{pmatrix} \qquad C_{1other2} := \begin{pmatrix} I_1 \\ I_2 \\ V_1 \\ -I_2 \end{pmatrix}$$

$$M_{1other2}^{-1} \cdot C_{1other2} = \begin{pmatrix} 0.086 \\ -13.5 \\ 12.09 \\ 2.714 \end{pmatrix}$$

$$V_{R1other2} := 0.086$$

$$V_{R2other1} := -13.5$$

$$V_{R3other1} := 12.09$$

$$V_{R4other1} := 2.714$$

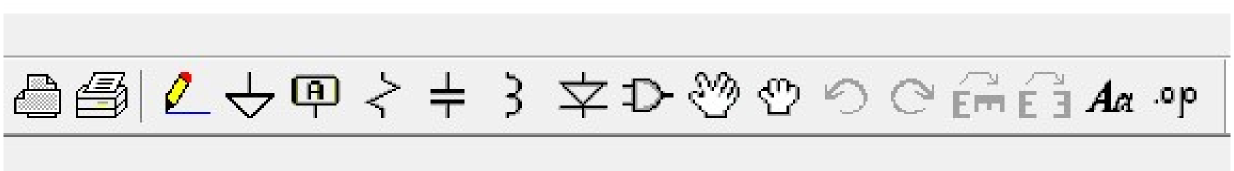
1.4: Simulation and Conceptual Questions

(2 pts) The term "scaffolding" was used in regard to reference marks on your circuit in Step 1.1: What does this refer to when it comes to solving a circuit using the passive sign convention?

It means that the reference marks are there to give a preliminary current or voltage reference to provide a structure for consistent mathematical analysis without need of intuition regarding which way current is flowing for example. These marks are not permanent. The actual direction is determined by polarity.

(2 pts) When you need to CONNECT COMPONENTS WITH A WIRE in LTSpice, what does the symbol look like?

Circle the symbol (you can also redraw it)	Please make a note if you use another SPICE program like PSpice.



This one

(2 pts) When you BEGIN to simulate your circuit, what symbol do you press to start to edit your simulation command. (After you set up your simulation, you also push this icon to start your simulation.)

Draw or describe this symbol (from your memory, it is not in the question above).

Running man

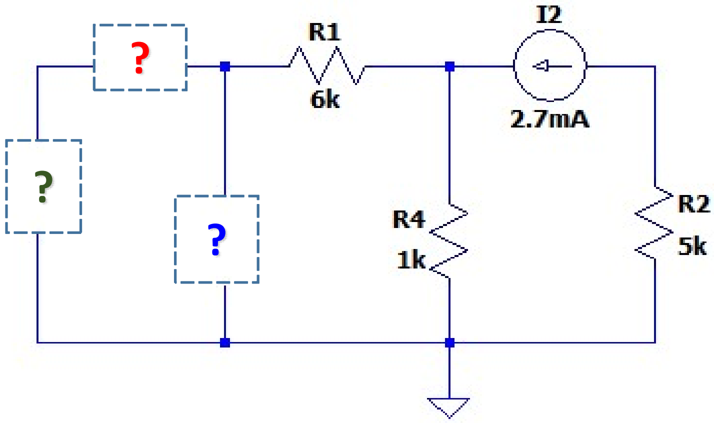
(2 pts) How do you rotate a component in LTSpice? If you use PSpice make a note and answer this question.

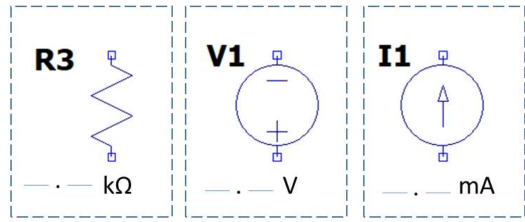
Ctrl-R

(2 pts) What is the purpose of ground in a circuit?

Ground is a common reference point for your entire circuit. Key word is reference or any synonym to this.

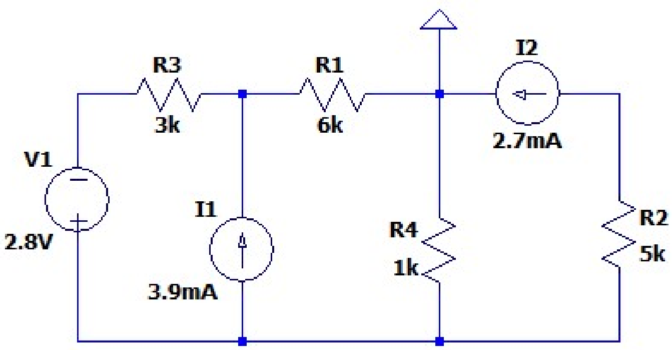
Problem 2) Nose/Mesh Analysis (30 points)





2.1: **5 pts** Rearrange your circuit to create a SUPERNODE problem. You may accomplish this by moving ground and/or moving your components. Describe why your rearrangement resulted in a supernode. (If your circuit already had a supernode in Problem 1, find a way to create ***a different SUPERNODE*** circuit.)

New Circuit Diagram:

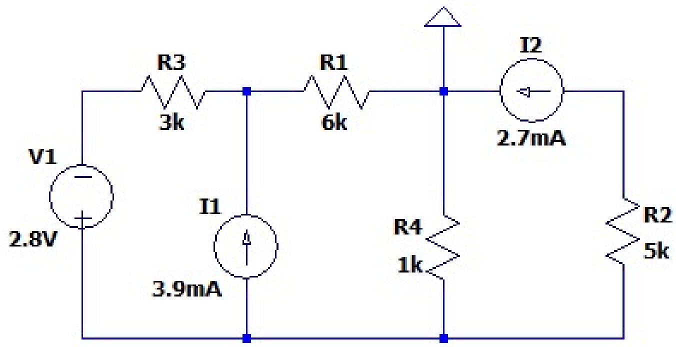


Explanantion of change and why it has a supernode:

I already had a supernode in Problem 1. The only thing I can do is change ground and then move my voltage source again.

2.2: (**5 pts)** Rearrange your circuit to create a SUPERMESH problem. You may accomplish this by moving your components. Describe why you rearrangement resulted in a SUPERMESH. (Your circuit may have already had a supermesh in Problem 1 or the supernode problem above. You can use this circuit configuration again.)

New Circuit Diagram:

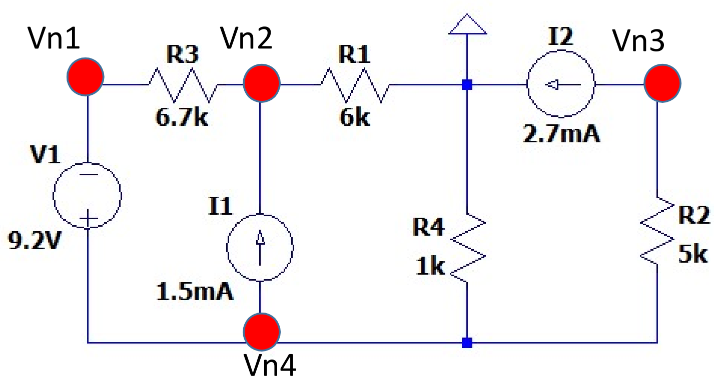


Explanantion of change (or lack of change) and why it has a supermesh:

I moved I1 to be between too mesh loops

2.3: (15 pts) Using NODAL analysis for your SUPERNODE circuit in 2.1: OR MESH analysis for your SUPERMESH circuit in 2.2:, find the voltage across R2 **(VR2)**. Write all relevant equations and matrix (if used) and label your diagram above with nodes or mesh loops for reference. The final answer value is not graded. FOR THIS PROBLEM YOU MUST PICK DIFFERENT COMPONENT VALUES THAN WHAT YOU CHOSE IN PROBLEM 1!

For Nodal Analysis



1. Nodes labeled

2. Ground placed at top between R1 and I2

3. KCL Equation (student don't need to write this one)

$$5 - 1 - 1 = 3$$

4. Supernode definition equation

$$(1) \qquad -V_{n1} + V_{n4} = V_{1p2}$$

5. KCL equations...(going out)

KCL supernode

$$\frac{V_{n1} - V_{n2}}{R_{3p2}} + I_{1p2} + \frac{V_{n4} - 0}{R_4} + \frac{V_{n4} - V_{n3}}{R_2} = 0$$

$$(2) \qquad \frac{1}{R_{3p2}} \cdot V_{n1} - \frac{1}{R_{3p2}} \cdot V_{n2} - \frac{1}{R_2} \cdot V_{n3} + \left(\frac{1}{R_4} + \frac{1}{R_2}\right) \cdot V_{n4} = -I_{1p2}$$

KCL at node Vn2

$$\frac{V_{n2}-V_{n1}}{R_3} - I_1 + \frac{V_{n2}-0}{R_1} = 0$$

(3) $$\frac{-1}{R_{3p2}}\cdot V_{n1} + \left(\frac{1}{R_{3p2}} + \frac{1}{R_1}\right)\cdot V_{n2} = I_{1p2}$$

KCL at node Vn3

$$I_2 + \frac{V_{n3}-V_{n4}}{R_2} = 0$$

$$\frac{1}{R_2}\cdot V_{n3} - \frac{1}{R_2}\cdot V_{n4} = -I_2$$

$R_1 = 6\times 10^3$ $\quad R_2 = 5\times 10^3$ $\quad R_{3p2} := 6.7\cdot 10^3$ $\quad R_4 = 1\times 10^3$ $\quad V_{1p2} := 9.2$

$I_{1p2} := 1.5\cdot 10^{-3}$ $\quad I_2 = 2.7\times 10^{-3}$

$$M_2 := \begin{bmatrix} -1 & 0 & 0 & 1 \\ \frac{1}{R_{3p2}} & -\frac{1}{R_{3p2}} & -\frac{1}{R_2} & \left(\frac{1}{R_4}+\frac{1}{R_2}\right) \\ \frac{-1}{R_{3p2}} & \left(\frac{1}{R_{3p2}}+\frac{1}{R_1}\right) & 0 & 0 \\ 0 & 0 & \frac{1}{R_2} & -\frac{1}{R_2} \end{bmatrix} \qquad C_2 := \begin{pmatrix} V_{1p2} \\ -I_{1p2} \\ I_{1p2} \\ -I_2 \end{pmatrix}$$

$$M_2^{-1}\cdot C_2 = \begin{pmatrix} -11.765 \\ -0.81 \\ -16.065 \\ -2.565 \end{pmatrix}$$

$Vn1 := -11.75$

$V_{n2} := -0.81$

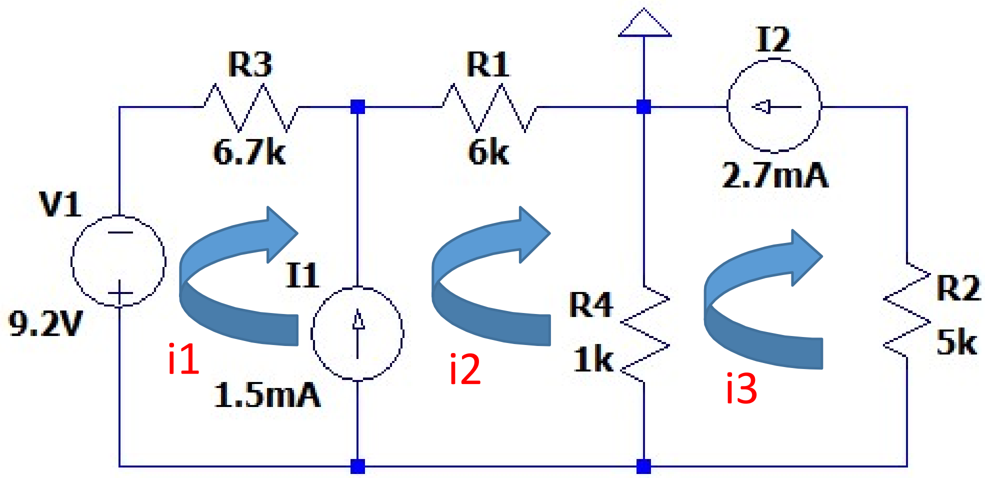
$V_{n3} := -16.065$

$V_{n4} := -2.565$

$V_{R2} := V_{n3} - V_{n4} = -13.5$ V

Need this relationship between labeled nodes. My reference marks are plus on top and minus on bottom. If they get opposite polarity than expected, they should have opposite reference marks.

For Mesh Analysis



Wasted time here...recognition of what i3 is solves this problem but still ok to go through this!

1. Loops labeled

2. Equation to check how many KVLs needed

ALSO short cut

$V_{R2mesh} := -I_2 \cdot R_2 = -13.5$

$3 - 2 = 1 \quad \text{KVL}$

1 supermesh definition

2 total equations...its another win for TEAM Mesh but who's keeping count ;-)

3. supermesh definition

$$i_2 - i_1 = I_{1p2}$$

$$(1) \quad -i_1 + i_2 = I_{1p2}$$

supermesh KVL

$$V_{1p2} + i_1 \cdot R_3 + i_2 \cdot R_1 + i_2 \cdot R_4 - i_3 \cdot R_4 = 0$$

$$(2) \quad R_{3p2} \cdot i_1 + (R_1 + R_4) \cdot i_2 = -(V_{1p2} + I_2 \cdot R_4)$$

constrained loop

$i_3 = -I_2$ substituted above

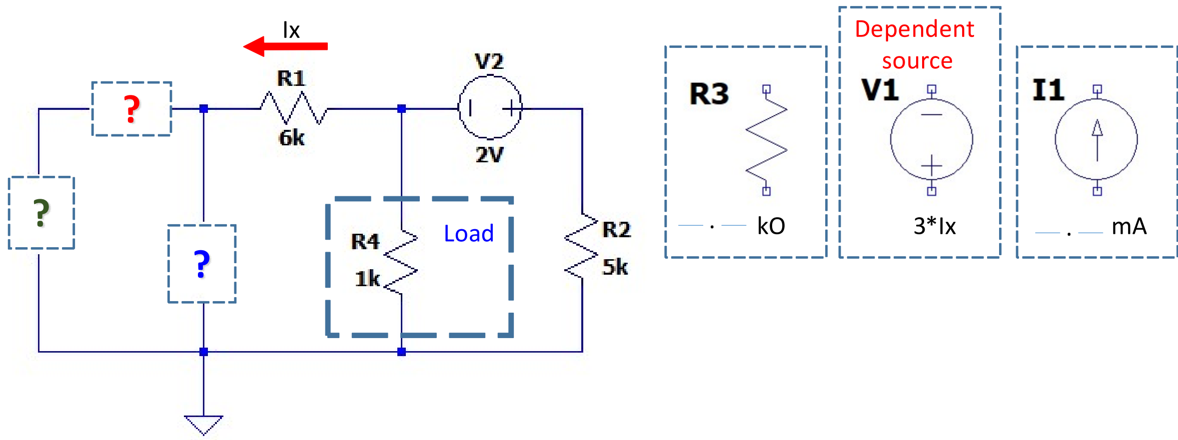
$$M_3 := \begin{bmatrix} -1 & 1 \\ R_{3p2} & (R_1 + R_4) \end{bmatrix} \qquad C_3 := \begin{bmatrix} I_{1p2} \\ -(V_{1p2} + I_2 \cdot R_4) \end{bmatrix}$$

$$M_3^{-1} \cdot C_3 = \begin{pmatrix} -1.635 \times 10^{-3} \\ -1.35 \times 10^{-4} \end{pmatrix}$$

$V_{R2mesh} := -I_2 \cdot R_2 = -13.5$

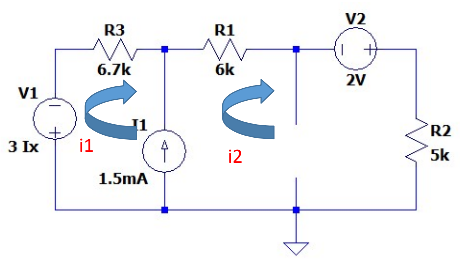
Problem 3) Thevenin/Norton Dependent Circuits (30 pts)

For this problem you my rerrange you component parts using the dependent source with a given value below. The components can be put in any orientation you'd like. You may use other values that are consistent with other parts of the exam or choose completely new ones. **You final answer values ARE graded in this problem.**



Changed the current source to a voltage source V2 because team mesh would be super easy....again.

3.1: ***10 pts*** **R4 is the load.** Find V_{TH} using the Open Circuit method.



Just need one supermesh KVL equation
supermesh KVL definition
dependent source definition
Ix goes to the left over R1

$$V_2 := 2 \qquad I_{1p2} = 1.5 \times 10^{-3}$$

$$R_{3p2} = 6.7 \times 10^{3}$$

supermesh KVL

$$3 \cdot I_x + i_1 \cdot R_{3p2} + i_2 \cdot R_1 - V_2 + i_2 \cdot R_2 = 0$$

(1) $$R_{3p2} \cdot i_1 + (R_1 + R_2) \cdot i_2 + 3 \cdot I_x = V_2$$

supermesh definition

$$M_4 := \begin{pmatrix} R_{3p2} & R_1 + R_2 & 3 \\ -1 & 1 & 0 \\ 0 & 1 & 1 \end{pmatrix}$$

(2) $$-i_1 + i_2 = I_{1p2}$$

dependent source defintion

$$I_x = -i_2$$

$$C_4 := \begin{pmatrix} V_2 \\ I_{1p2} \\ 0 \end{pmatrix} \qquad M_4^{-1} \cdot C_4 = \begin{pmatrix} -8.191 \times 10^{-4} \\ 6.809 \times 10^{-4} \\ -6.809 \times 10^{-4} \end{pmatrix}$$

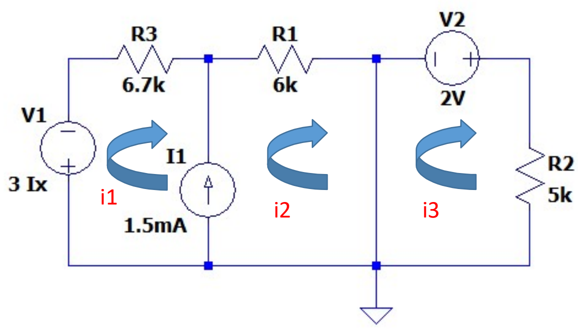
(3) $$i_2 + I_x = 0$$

V_{Th}	(V)

$$i_{2p2} := 6.809 \times 10^{-4}$$

$$V_{TH} := i_{2p2} \cdot R_2 - 2 = 1.405$$

3.2: ***10 pts*** Find INorton uisng short circuit current (Isc).



supermesh KVL

$$M_5 := \begin{pmatrix} R_{3p2} & R_1 & 0 & 3 \\ -1 & 1 & 0 & 0 \\ 0 & 1 & 0 & 1 \\ 0 & 0 & R_2 & 0 \end{pmatrix} \qquad C_5 := \begin{pmatrix} 0 \\ I_{1p2} \\ 0 \\ V_2 \end{pmatrix}$$

$$3 \cdot I_x + i_1 \cdot R_{3p2} + i_2 \cdot R_1 = 0$$

(1) $$R_{3p2} \cdot i_1 + R_1 \cdot i_2 + 3I_x = 0$$

$$M_5^{-1} \cdot C_5 = \begin{pmatrix} -7.085 \times 10^{-4} \\ 7.915 \times 10^{-4} \\ 4 \times 10^{-4} \\ -7.915 \times 10^{-4} \end{pmatrix}$$

supermesh definition

(2) $$-i_1 + i_2 = I_{1p2}$$

dependent source defintion

(3) $I_x = -i_2$

$i_2 + I_x = 0$

$i_2 := 7.915 \times 10^{-4}$

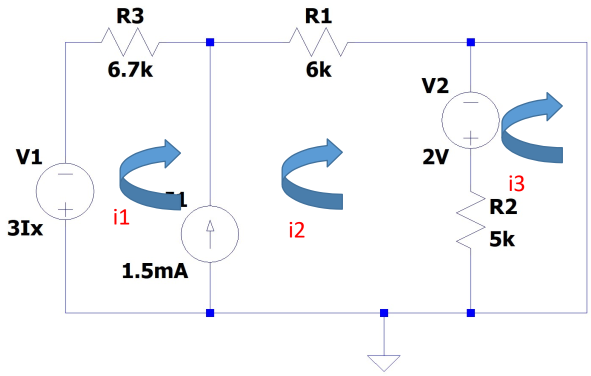
$i_3 := 4 \times 10^{-4}$

loop i3

$i_3 \cdot R_2 = V_2$

$i_{sc} := i_2 - i_3 = 3.915 \times 10^{-4}$

Could also do this problem by switching the parallel components like...



supermesh KVL

$$3 \cdot I_x + i_1 \cdot R_{3p2} + i_2 \cdot R_1 - V_2 + i_2 \cdot R_2 - i_3 \cdot R_2 = 0$$

(1) $R_{3p2} \cdot i_1 + (R_1 + R_2) \cdot i_2 - R_2 \cdot i_3 + 3I_x = V_2$

supermesh definition

(2) $-i_1 + i_2 = I_{1p2}$

$$M_7 := \begin{pmatrix} R_{3p2} & R_1 + R_2 & -R_2 & 3 \\ -1 & 1 & 0 & 0 \\ 0 & -R_2 & R_2 & 0 \\ 0 & 1 & 0 & 1 \end{pmatrix} \qquad C_7 := \begin{pmatrix} V_2 \\ I_{1p2} \\ -V_2 \\ 0 \end{pmatrix}$$

loop i3 $R_2 \cdot i_3 - i_2 \cdot R_2 + V_2 = 0$

(3) $-R_2 \cdot i_2 + R_2 \cdot i_3 = -V_2$

dependent source defintion

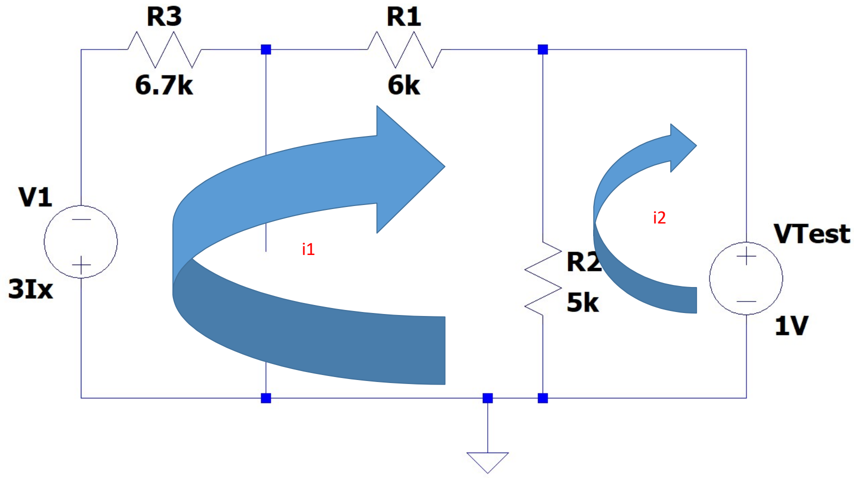
(4) $I_x = -i_2$

$i_2 + I_x = 0$

$$M_7^{-1} \cdot C_7 = \begin{pmatrix} -7.085 \times 10^{-4} \\ 7.915 \times 10^{-4} \\ 3.915 \times 10^{-4} \\ -7.915 \times 10^{-4} \end{pmatrix}$$

$i_{3witched} := 3.915 \times 10^{-4}$

3.3. ***8 pts*** Find Rth using the Test Method.



$V_{Test} := 1$

Things in parallel you can switch around so, I did.

$$3 \cdot I_x + i_1 \cdot R_{3p2} + i_1 \cdot R_1 + i_1 \cdot R_2 - i_2 \cdot R_2 = 0$$

(1) $$\left(R_{3p2} + R_1 + R_2\right) \cdot i_1 - \left(R_2\right) \cdot i_2 + 3 \cdot I_x = 0$$

dependent source definition

$$I_x = -i_1$$

$$M_6 := \begin{pmatrix} R_{3p2} + R_1 + R_2 & -R_2 & 3 \\ 1 & 0 & 1 \\ -R_2 & R_2 & 0 \end{pmatrix}$$

(3) $$i_1 + I_x = 0$$

mesh i2

$$i_2 \cdot R_2 - i_1 \cdot R_2 + V_{Test} = 0$$

$$C_6 := \begin{pmatrix} 0 \\ 0 \\ -V_{Test} \end{pmatrix}$$

$$M_6^{-1} \cdot C_6 = \begin{pmatrix} -7.876 \times 10^{-5} \\ -2.788 \times 10^{-4} \\ 7.876 \times 10^{-5} \end{pmatrix}$$

(4) $$-i_1 \cdot R_2 + i_2 \cdot R_2 = -V_{Test}$$

$$i_{Test} := -\left(-2.788 \times 10^{-4}\right)$$

$$R_{TH} := \frac{V_{Test}}{i_{Test}} = 3.587 \times 10^3$$

R_{Th}	(Ω)

3.4: **2 pts** Verify your answers from 3.1-3:3. (Verify they are correct).

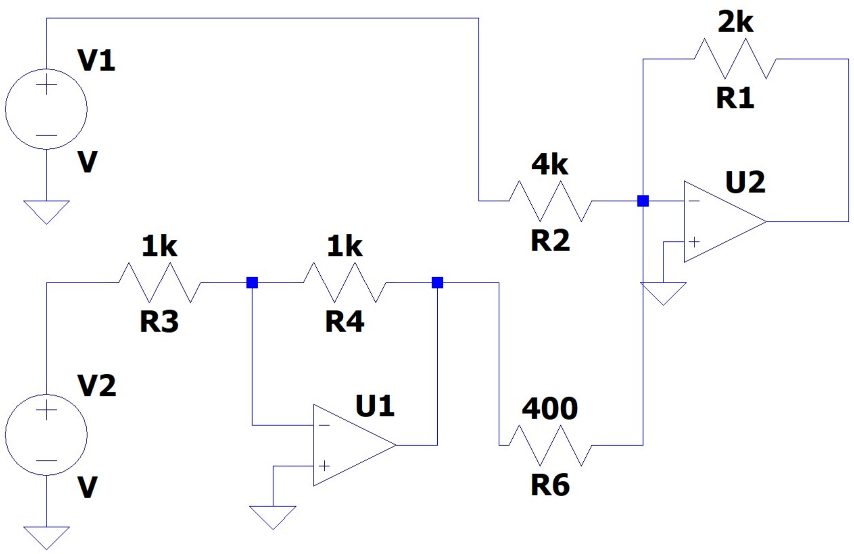
$$\frac{V_{TH}}{i_{sc}} = 3.587 \times 10^3$$

error somewhere..will find

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

4) Cascading Multi-stage Op Amp Circuits and Design Concepts (20 pts)

4.1: ***(10 pts)*** You have 2 inputs, V1 and V2. Design and draw a cascade of op amps that result in the equation -0.5 V1 + 5 V2 when V1 and V2 are both positive values. You are limited to 3 op amps. Make sure to add in your resistor values.



inverting summer but V2 must have a inverting amp before it. need correct ratio of resistors 1/2 in first op amp, 5 is second.

4.2: ***(4 pts)*** Name two voltage divider applications and briefly describe the circuit around it. It cannot be just to "divide the voltage" or to reduce voltage from high voltage to a lower voltage. These answers result in zero points.

examples: bridge circuit, resistive sensor, double voltage divider
filter, needs AC input, capacitor or inductor

4.3: ***(2 pts)*** What is the difference between closed loop gain and open loop gain? Describe how they functions to define op amp characteristics?

Open loop gain is infinity and intrinsic to op amp characteristics..used as ideal characteristic
Closed loop gain is finite and is derived from op amp configuration including the feed back loop, used to help define how the op amp configuration changes an input

4.4: Determine whether the statements about comparators are true or false. You need to write a brief explanation for full credit.

T Comparators are decision circuits that provide a binary output

Explanation: Key words or phrases "saturation, set voltages, depending on input"

F Comparators use a feedback loop.

Explanation: Key words of phrases, "linear region or saturation region"

F Comparators operate in the linear region

Explanation: Key words of phrases "saturation region or high gain"

F Comparators must always output both polarities of a given DC value. (i.e. +5 and -5 V)

Explanation: Key words or phrases "power source voltage"