Ryerson University
Department of Electrical, Computer, & Biomedical Engineering
Faculty of Engineering & Architectural Science

ELE 202
Electric Circuit Analysis
LAB COVER PAGE for Part I submission.

Lab #:	3	Lab Title:	Resistive Network Analysis Methods Nodal and mesh

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Section #:	22
Submission date and time:	March 3, 2022 3am
Due date and time:	March 3, 2022 2pm

Document submission for Part I:

- A completed and signed "COVER PAGE – **Part I**" has to be included with your submission. The report will not be graded if the signed cover page is not included.
- Your completed handwritten pages of **Section 4.0** should be scanned (via a scanner or phone images), together with the required MultiSIM images. **Note:** *MultiSIM results must be generated using the Department's licensed version of MultiSIM, and the captured screenshots should show your name (at the center-top) and the timestamp (at the bottom-right corner of your screen).*
- Collate and create a *.pdf* or *.docx* file of the above, and upload it via D2L **any time prior to the start of your scheduled lab**. Upload instructions are provided on D2L.

Zero marks will be assigned for the entire lab if this Part I is not submitted prior to your scheduled lab.

**By signing above, you attest that you have contributed to this submission and confirm that all work you have contributed to this submission is your own work. Any suspicion of copying or plagiarism in this work <u>will result in an investigation of Academic Misconduct and may result in a "0" on the work,</u> an "F" in the course, or possibly more severe penalties, as well as a Disciplinary Notice on your academic record under the Student Code of Academic Conduct, which can be found online at: <u>www.ryerson.ca/senate/current/pol60.pdf</u>.*

Ryerson University

Department of Electrical, Computer, & Biomedical Engineering
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ELE 202
Laboratory #3

Resistive Network Analysis Methods – *Nodal and Mesh*

1.0 INTRODUCTION

Electric circuit analysis is the process of finding voltages across and currents through every component element in the network. Relatively simple resistive circuits can be analyzed by directly applying Kirchhoff's laws in combination with Ohm's law, as was done in the previous laboratory exercise. However, as the circuits become structurally more complicated and involve increasingly more component elements, this direct method becomes onerous. To aid in the analysis of such complex circuits, two powerful circuit analysis techniques – ***nodal*** analysis and ***mesh*** analysis – are commonly used.

Nodal analysis is a method of determining the voltage at the nodes in a circuit with respect to a "***reference***" node, using Kirchhoff's Current Law (**KCL**). *Mesh* analysis is a method that is used to solve for the current through any component element in a planar circuit, using Kirchhoff's Voltage Law (**KVL**). Either method used yields the same results; the choice often depends on a personal preference or on the intuitiveness of the analysis method better suited for a particular structural configuration of the circuit elements in a network.

As noted above, *nodal* analysis requires selecting a circuit node as the "***reference***". The *reference* node is commonly referred to as "***ground***" since it is assumed to have, or be at, **zero** potential. A *reference* node is indicated by any of the three symbols in **Figure 1.0**.

Figure 1.0: Common symbols for a *reference* node

The symbol in **Figure 1.0a** can be used to indicate a "*common ground*" reference node. When the potential of the earth is used as a reference, this common ground symbol can be interchanged with the symbol of an "*earth ground*" in **Figure 1.0b**. For most circuits, the symbol in **Figure 1.0b** often gets used to denote a common "***ground***" reference node even when not connected to the earth's potential. The type of ground in **Figure 1.0c** is referred to as a "*chassis ground*" and is used in devices where the case, enclosure, or chassis acts as the reference point for all circuits in the device.

Although *theoretically* the choice of a reference node for a circuit is arbitrary, *practically* the choice for the reference node is often obvious. For example, the node with the most *branches* is usually a good choice. For more practical circuits, the node that represents the **negative terminal** of an input power source to which most circuit branches connect is often an intuitive "***ground***" reference point to use. All *unreferenced* node voltages in a circuit are then defined in an absolute sense with respect to this "***ground***" reference node.

References: (i) Course Textbook: "*Fundamentals of Electric Circuits*" by C. K. Alexander and M. N. O. Sadiku; and (ii) "*Electric Circuits*" by J. W. Nilsson and S. A. Riedel

2.0 OBJECTIVES

- To understand the concept of circuit *reference* node.
- To experimentally verify *nodal* and *mesh* analysis techniques on a D.C. resistive circuit.

3.0 Required LAB EQUIPMENT & PARTS

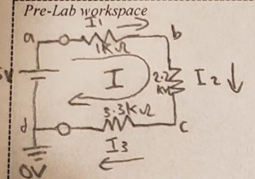
- Digital Multimeter (DMM) and Power Supply
- ELE202 Lab Kit: various components, breadboard, wires and jumpers.

4.0 PRE-LAB: ASSIGNMENT

(a) *Circuit Reference Node*

(i) For the circuit shown in **Figure 2.0a**, the input D.C. source voltage, **E = 15 V** and node "d" is selected as the *reference node* connected to the circuit ground, $\mathbf{V_d = 0\ V}$. Calculate the current, **I** and the voltage at node "a" (=$\mathbf{V_a}$), node "b" (=$\mathbf{V_b}$), and node "c" (=$\mathbf{V_c}$) with respect to the ground *reference node*. From these node voltages, calculate the resistor voltages, $\mathbf{V_{ab}}$, $\mathbf{V_{bc}}$, and $\mathbf{V_{cd}}$ across resistors $\mathbf{R_1}$, $\mathbf{R_2}$ and $\mathbf{R_3}$, respectively. Record all the results in **Table 2.0**.

Pre-Lab workspace



Va = 15V
Vb = V⁺ − V⁻
= 15 − 2.308
= 12.692V

Vc = V⁺ − V⁻
= 12.692 − 5.077
= 7.615V

Apply KVL

$-15 + I \times (1) + I \times (2.2) + I \times (3.3) = 0$

$-15 + I \times (3.3 + 2.2 + 1.0) = 0$

$-15 + I \times (6.5) = 0$

$I \times (6.5) = 15$

$I \times = 2.308\text{mA}$

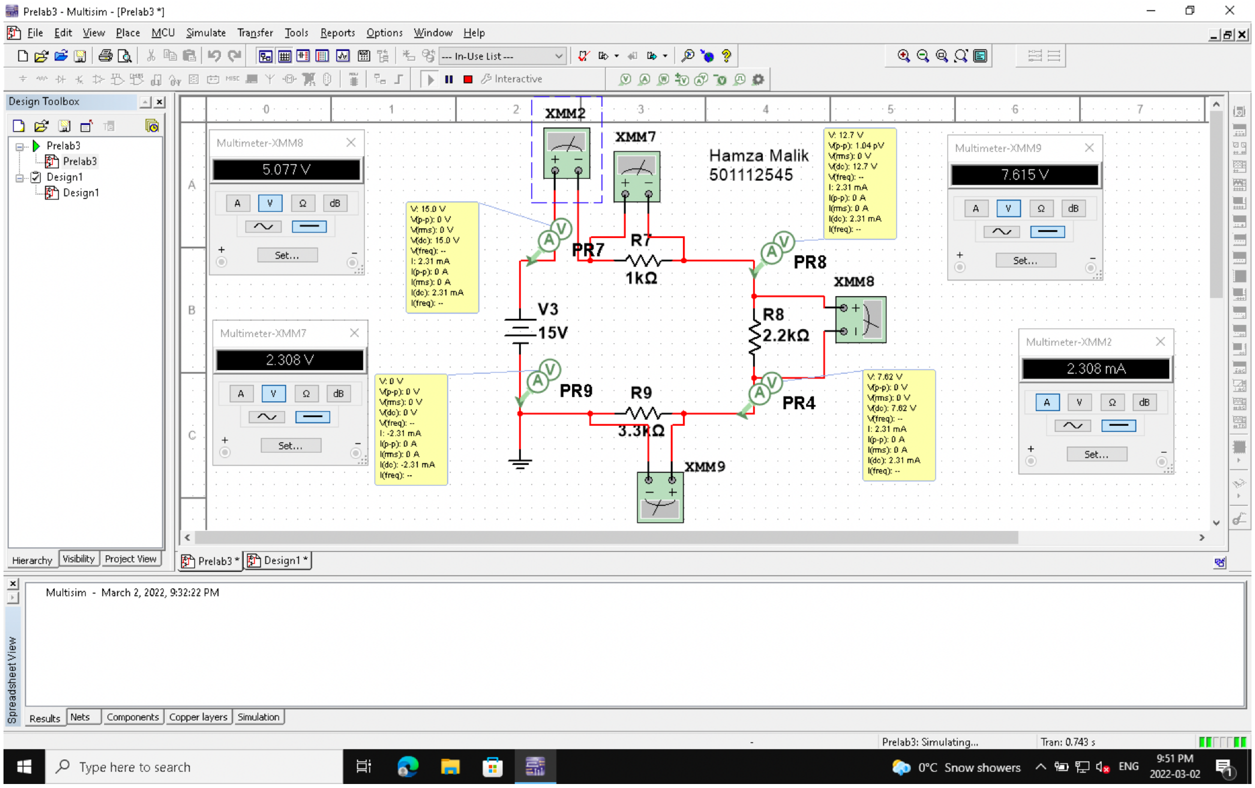
$V_{ab} = IR = (2.308\text{mA})(1\text{k}\Omega) = 2.308\text{V}$

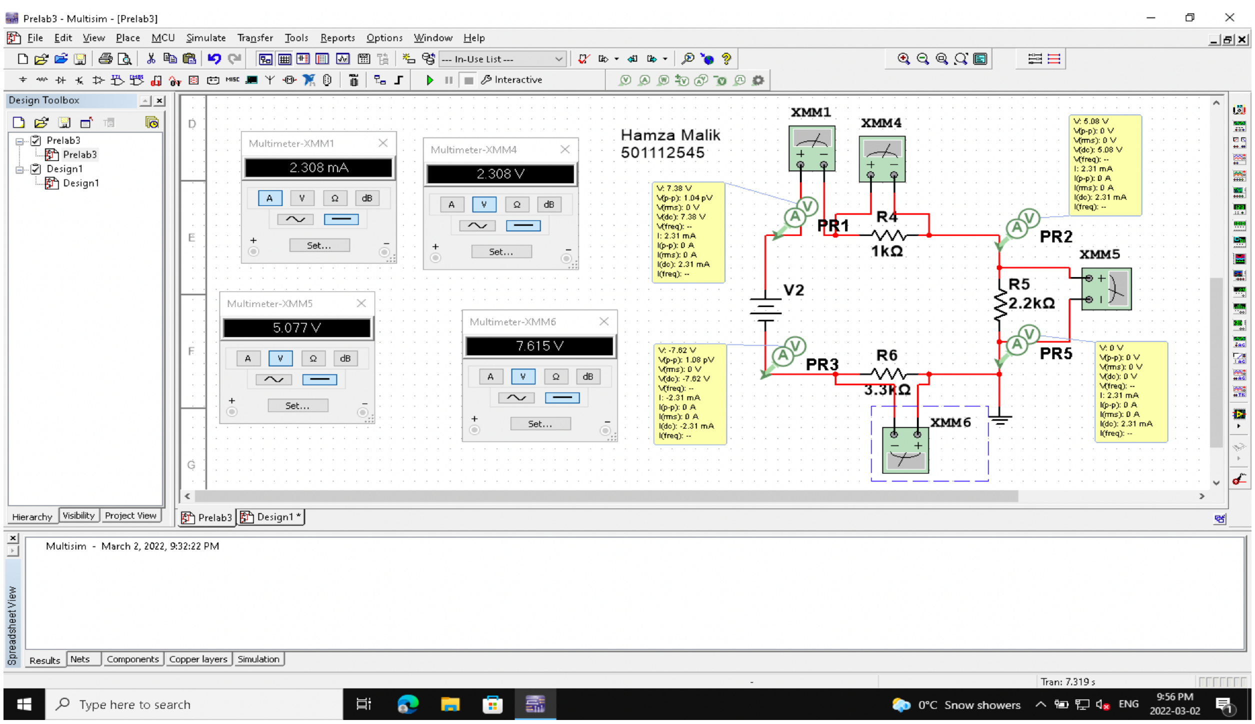
$V_{bc} = IR = (2.308\text{mA})(2.2\text{k}\Omega) = 5.077\text{V}$

$V_{cd} = IR = (2.308\text{mA})(3.3\text{k}\Omega) = 7.615\text{V}$

(ii) Construct the circuit of **Figure 2.0a** in MultiSIM. With node "d" as the *reference node*, measure the current, **I**, the node voltages $\mathbf{V_a}$, $\mathbf{V_b}$ and $\mathbf{V_c}$, and the voltages across $\mathbf{R_1}$ (=$\mathbf{V_{ab}}$), $\mathbf{R_2}$ (=$\mathbf{V_{bc}}$), and $\mathbf{R_3}$ (=$\mathbf{V_{cd}}$), respectively. Record all the results in **Table 2.0**.

- Copy and paste a screenshot showing one MultiSIM readings on the circuit. Include the MultiSIM circuit file (**.ms14**) in your Pre-Lab submission.
- All screenshots should show your name printed on the center-top of the MultiSIM screen and the timestamp at the bottom-lower corner.


Prelab3 - Multisim - [Prelab3 *]
Hamza Malik
501112545
Multimeter-XMM8
5.077 V
Multimeter-XMM7
2.308 V
Multimeter-XMM9
7.615 V
Multimeter-XMM2
2.308 mA
XMM2
XMM7
XMM8
XMM9
PR7
PR8
PR9
PR4
R7
1kΩ
R8
2.2kΩ
R9
3.3kΩ
V3
15V
Multisim - March 2, 2022, 9:32:22 PM
Prelab3: Simulating...
Tran: 0.743 s


Prelab3 - Multisim - [Prelab3]
Hamza Malik
501112545
Multimeter-XMM1
2.308 mA
Multimeter-XMM4
2.308 V
Multimeter-XMM5
5.077 V
Multimeter-XMM6
7.615 V
XMM1
XMM4
XMM5
XMM6
PR1
PR2
PR3
PR5
R4
1kΩ
R5
2.2kΩ
R6
3.3kΩ
V2
Multisim - March 2, 2022, 9:32:22 PM
Tran: 7.319 s

(iii) **Relocate** the circuit ground *reference node* at node "c" as shown in **Figure 2.0b**, thereby making $\mathbf{V_c = 0V}$. Then repeat above steps **(i)** and **(ii)** but with calculations/measurements of node voltages $\mathbf{V_a}$, $\mathbf{V_b}$ and $\mathbf{V_d}$ with respect to reference node "c"; and circuit element voltages across $\mathbf{R_1}$ (=$\mathbf{V_{ab}}$), $\mathbf{R_2}$ (=$\mathbf{V_{bc}}$), and $\mathbf{R_3}$ (=$\mathbf{V_{cd}}$) as before.

(iv) Comment on the results in **Table 2.0** obtained for both cases (when *reference point* at "d" and *reference point* at "c"). State clearly which one of the currents, node voltages, or element voltages have changed or remain unchanged; and explain why.

Pre-Lab workspace

$I = 2.308mA$, $V_c = 0V$

$V_{ab} = IR = (2.308mA)(1k\Omega) = 2.308V$

$V_{bc} = IR = (2.308mA)(2.2k\Omega) = 5.077V$

$V_{cd} = IR = (2.308mA)(3.3k\Omega) = 7.615V$

$V_a = V^+ - V^-$
$= 15 - 7.615$
$= 7.385V$

$V_b = V^+ - V^-$
$= 5.077 - 0$
$= 5.077V$

$V_d = V^+ - V^-$
$= 0 - 7.615$
$= -7.615V$

For figure 2.0a and b everything stayed the same except Va, Vc, and Vd due to the reference node which caused the voltage across Vd and Vc to change.

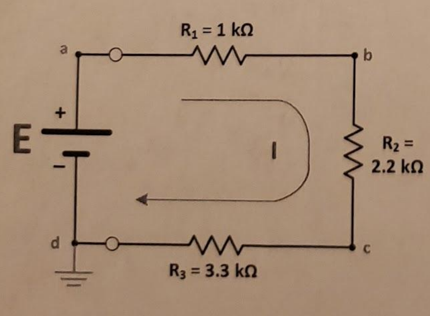


Figure 2.0a: Circuit reference node at "d"

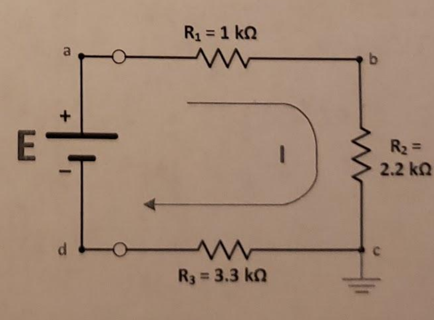


Figure 2.0b: Circuit reference node at "c"

		Using *Reference* Node "d"	Using *Reference* Node "c"
I (mA)	Theoretical value =>	2.308mA	2.308mA
	MultiSIM value =>	2.308mA	2.308mA
$\mathbf{V_a}$ (Volts)	Theoretical value =>	15V	7.385V
	MultiSIM value =>	15V	7.385V
$\mathbf{V_b}$ (Volts)	Theoretical value =>	12.692V	5.077V
	MultiSIM value =>	12.692V	5.077V
$\mathbf{V_c}$ (Volts)	Theoretical value =>	7.615V	0
	MultiSIM value =>	7.615V	0
$\mathbf{V_d}$ (Volts)	Theoretical value =>	0	7.615V
	MultiSIM value =>	0	7.615V
$\mathbf{V_{ab}}$ (Volts)	Theoretical value =>	2.308V	2.308V
	MultiSIM value =>	2.308V	2.308V
$\mathbf{V_{bc}}$ (Volts)	Theoretical value =>	5.077V	5.077V
	MultiSIM value =>	5.077V	5.077V
$\mathbf{V_{cd}}$ (Volts)	Theoretical value =>	7.615V	7.615V
	MultiSIM value =>	7.615V	7.615V

Table 2.0: Theoretical and MultiSIM results of the Figure 2.0 circuits

(b) *Nodal and Mesh Analysis*

Consider the circuits in **Figure 3.0**, and assume input power supply, **E = 15V.**

(i) ***Nodal Analysis:*** Select node "d" as a *ground reference* node as shown in **Figure 3.0a**. Using the *nodal analysis* technique, calculate the node voltages $\mathbf{V_a}$, $\mathbf{V_b}$ and $\mathbf{V_c}$. Using theses calculated node voltages, determine the value of the branch current, I_X and the branch voltage, V_X. Record all your results in **Table 3.0.**

Pre-Lab workspace

KCL @ node Va:

$15V = Va$

KCL @ node Vb:

$\left(\frac{Vb-Va}{2.2}\right)+\left(\frac{Vb-VC}{5.1}\right)+\left(\frac{Vb-0}{3.3}\right)=0$

$\left(-\frac{1}{2.2}\right)Va+\left(\frac{1}{2.2}+\frac{1}{5.1}+\frac{1}{3.3}\right)Vb+\left(-\frac{1}{5.1}\right)VC=0$

$-6.81+(0.953)Vb-(0.196)VC=0$

$(0.953)Vb-(0.196)VC=6.81$ ①

KCL @ node Vc

$\left(\frac{VC-Va}{1}\right)+\left(\frac{VC-Vb}{5.1}\right)+\left(\frac{VC}{1.0}\right)=0$

$-Va+\left(-\frac{1}{5.1}\right)Vb+\left(1+1+\frac{1}{5.1}\right)VC=0$

$-15-(0.196)Vb+(2.196)VC=0$

$-(0.196)Vb+(2.196)VC=15$ ②

Continued on seperate paper. →

b) (i) cont.

① $0.953V_b - 0.196V_c = 6.81$
② $-0.196V_b + 2.196V_c = 15$

$$\begin{bmatrix} 0.953 & -0.196 \\ -0.196 & 2.196 \end{bmatrix} \begin{vmatrix} V_b \\ V_c \end{vmatrix} = \begin{vmatrix} 6.81 \\ 15 \end{vmatrix}$$

$\Delta = (0.953)(2.196) - (-0.196)(-0.196)$
$= (2.0927) - (0.0384)$
$= 2.0543$

$\Delta 1 = \begin{bmatrix} 6.81 & -0.196 \\ 15 & 2.196 \end{bmatrix} = (6.81)(2.196) - (-0.196)(15)$
$= (14.95) - (-2.94)$
$= 17.89$

$\Delta 2 = \begin{bmatrix} 0.953 & 6.81 \\ -0.196 & 15 \end{bmatrix} = (0.953)(15) - (6.81)(-0.196)$
$= (14.29 - (-1.33)$
$= 15.62$

$V_b = 17.89 / 2.0543$
$= 8.71$
$V_c = 15.62 / 2.0543$
$= 7.60$

$I_x = V/R$
$= 8.71 / 3.3$
$= 2.64A$

$V_x = 7.39V$

(ii) Mesh Analysis: Using the *mesh analysis* technique on the circuit shown in **Figure 3.0b**, calculate the mesh currents $\mathbf{I_A}$, $\mathbf{I_B}$ and $\mathbf{I_C}$; and determine the branch currents, $\mathbf{I_1}$, $\mathbf{I_2}$, $\mathbf{I_3}$ and $\mathbf{I_X}$; and the branch voltage, $\mathbf{V_X}$. Record all your results in **Table 3.0**.

Pre-Lab workspace

mesh 1:

$-15+2.2(I_A-I_C)+3.3(I_A-I_B)$

$-15+I_A(2.2+3.3)-I_C(2.2)-I_B(3.3)$

$I_A(5.5)-I_C(2.2)-I_B(3.3)=15$ ①

mesh 2:

$3.3(I_B-I_A)+5.1(I_B-I_C)+I_B(1.0)=0$

$I_B(3.3+5.1+1.0)-I_A(3.3)-I_C(5.1)=0$

$I_B(9.4)-I_A(3.3)-I_C(5.1)=0$ ②

mesh 3:

$+2.2(I_C-I_A)+1.0(I_C)+5.1(I_C-I_B)=0$

$I_C(+2.2+1.0+5.1)+I_A(2.2)-I_B(5.1)=0$

$I_C(8.3)-I_A(2.2)-I_B(5.1)=0$

$I_X=I_A-I_B$
$=2.64$

$V_X=(7.39)(1.0)$
$=7.39V$

$I_1=I_A-I_C=2.86mA$

$$\begin{bmatrix} 5.5 & -3.3 & -2.2 \\ -3.3 & 9.4 & -5.1 \\ -2.2 & -5.1 & 8.3 \end{bmatrix}\begin{bmatrix} I_A \\ I_B \\ I_C \end{bmatrix}=\begin{bmatrix} 15 \\ 0 \\ 0 \end{bmatrix}$$

$$\Delta 1=\begin{vmatrix} 15 & -3.3 & -2.2 \\ 0 & 9.4 & -5.1 \\ 0 & 5.1 & 8.9 \end{vmatrix}$$

$$\Delta 2\begin{vmatrix} 5.5 & 15 & -2.2 \\ -3.3 & 0 & -5.1 \\ 2.2 & 0 & 8.9 \end{vmatrix}$$

$$\Delta 3=\begin{vmatrix} 5.5 & -3.3 & 15 \\ -3.3 & 9.4 & 0 \\ 2.2 & 5.1 & 0 \end{vmatrix}$$

$I_A=\frac{\Delta 1}{\Delta}$
$=10.25mA$

$I_C=\frac{\Delta 3}{\Delta}$
$=7.39mA$

$I_B=\frac{\Delta 2}{\Delta}$
$=7.61mA$

$I_2=I_B-I_C$
$=0.22mA$

$I_3=I_C=7.39mA$

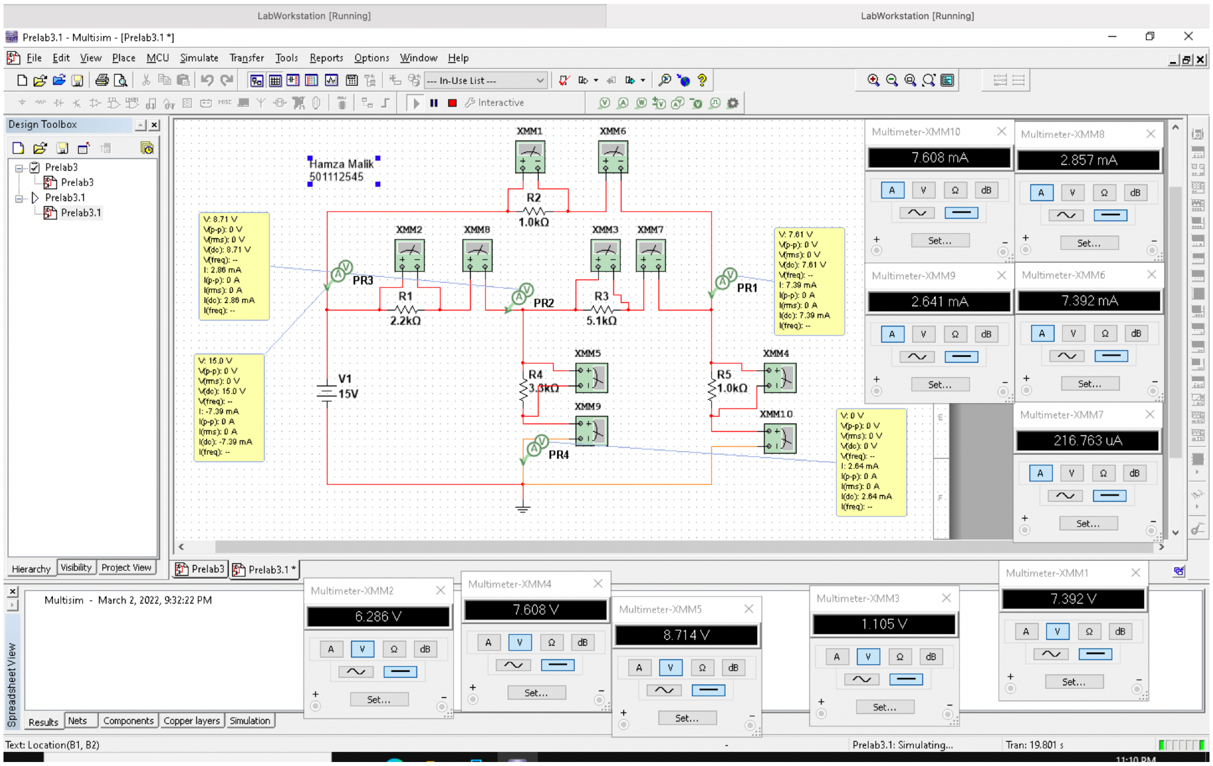
(iii) Construct the circuit of **Figure 3.0** in MultiSIM. Set the input D.C. source, **E** to **15V**, and node "**d**" as the *ground reference* node. Measure the branch currents I_1, I_2, I_3 and I_X, the branch voltage, V_X and the node voltages, $\mathbf{V_a}$, $\mathbf{V_b}$ and $\mathbf{V_c}$. Use the measured branch currents to determine the values of the mesh currents $\mathbf{I_A}$, $\mathbf{I_B}$ and $\mathbf{I_C}$. Record all your results in **Table 3.0**.

- Copy and paste a screenshot showing one MultiSIM readings on the circuit. Include the MultiSIM circuit file (**.ms14**) in your Pre-Lab submission.
- All screenshots should show your name printed on the center-top of the MultiSIM screen

Compare these MutliSIM simulation results in **Table 3.0** with the calculated theoretical values for the node voltages, mesh currents, branch current I_X, and branch voltage V_X. State if the *Nodal* and *Mesh* analysis methods yield the same results for the branch current, I_X and the branch voltage, V_X. Why?

Pre-Lab workspace

~~Everything~~ is different besides the Ix and Vx values. This is because in mesh analysis you have to find the current in each mesh which which is not done properly ~~w~~ on multisim.


LabWorkstation [Running]
LabWorkstation [Running]
Prelab3.1 - Multisim - [Prelab3.1 *]
File Edit View Place MCU Simulate Transfer Tools Reports Options Window Help
--- In-Use List ---
Interactive
Design Toolbox
Prelab3
Prelab3
Prelab3.1
Prelab3.1
Hamza Malik
501112545
XMM1
XMM6
R2
1.0kΩ
XMM2
XMM8
XMM3
XMM7
PR3
R1
2.2kΩ
PR2
R3
5.1kΩ
PR1
V1
15V
R4
3.3kΩ
XMM5
XMM9
PR4
R5
1.0kΩ
XMM4
XMM10
V: 8.71 V
V(p-p): 0 V
V(rms): 0 V
V(dc): 8.71 V
V(freq): --
I: 2.86 mA
I(p-p): 0 A
I(rms): 0 A
I(dc): 2.86 mA
I(freq): --
V: 15.0 V
V(p-p): 0 V
V(rms): 0 V
V(dc): 15.0 V
V(freq): --
I: -7.39 mA
I(p-p): 0 A
I(rms): 0 A
I(dc): -7.39 mA
I(freq): --
V: 7.61 V
V(p-p): 0 V
V(rms): 0 V
V(dc): 7.61 V
V(freq): --
I: 7.39 mA
I(p-p): 0 A
I(rms): 0 A
I(dc): 7.39 mA
I(freq): --
V: 0 V
V(p-p): 0 V
V(rms): 0 V
V(dc): 0 V
V(freq): --
I: 2.64 mA
I(p-p): 0 A
I(rms): 0 A
I(dc): 2.64 mA
I(freq): --
Multimeter-XMM10
7.608 mA
Multimeter-XMM8
2.857 mA
Multimeter-XMM9
2.641 mA
Multimeter-XMM6
7.392 mA
Multimeter-XMM7
216.763 uA
Multimeter-XMM2
6.286 V
Multimeter-XMM4
7.608 V
Multimeter-XMM5
8.714 V
Multimeter-XMM3
1.105 V
Multimeter-XMM1
7.392 V
Set...
Hierarchy
Visibility
Project View
Prelab3
Prelab3.1 *
Multisim - March 2, 2022, 9:32:22 PM
Spreadsheet View
Results
Nets
Components
Copper layers
Simulation
Text: Location(B1, B2)
Prelab3.1: Simulating...
Tran: 19.801 s

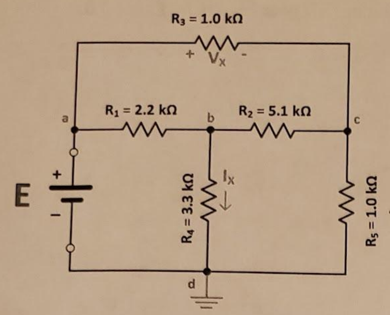


Figure 3.0a: Circuit for *Nodal* Analysis

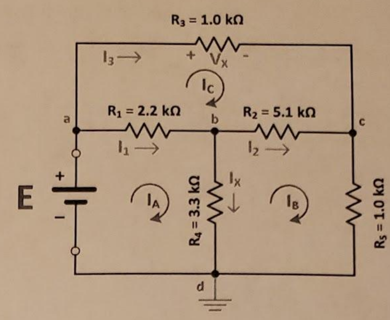


Figure 3.0b: Circuit for *Mesh* Analysis

			Nodal Analysis	*Mesh* Analysis
V_a (Volts)	Theoretical value	=>	15	
	MultiSIM value	=>	15	
V_b (Volts)	Theoretical value	=>	8.71	
	MultiSIM value	=>	8.71	
V_c (Volts)	Theoretical value	=>	7.61	
	MultiSIM value	=>	7.61	
I_A (mA)	Theoretical value	=>		10.25
	MultiSIM derived	=>		10.25
I_B (mA)	Theoretical value	=>		7.61
	MultiSIM derived	=>		7.61
I_C (mA)	Theoretical value	=>		7.39
	MultiSIM derived	=>		7.39
I_X (mA)	Theoretical value	=>	2.64	2.64
	MultiSIM value	=>	2.64	2.64
V_X (Volts)	Theoretical value	=>	7.39	7.39
	MultiSIM value	=>	7.39	7.39
I_1 (mA)	Theoretical value	=>		2.86
	MultiSIM value	=>		2.86
I_2 (mA)	Theoretical value	=>		0.22
	MultiSIM value	=>		0.22
I_3 (mA)	Theoretical value	=>		7.39
	MultiSIM value	=>		7.39

Table 3.0: Theoretical and MultiSIM results of the Figure 3.0 circuits