

ELE 202

Electric Circuit Analysis

LAB COVER PAGE for Part I submission.

Lab #:	3	Lab Title:	Resistive held works
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Section #:	4
Submission date and time:	June 6 2022
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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 will result in an investigation of Academic Misconduct and may result in a “0” on the work, 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: www.ryerson.ca/senate/current/pol60.pdf.*

ELE 202

Laboratory #3

Resistive Network Analysis Methods – *Nodal and Mesh*

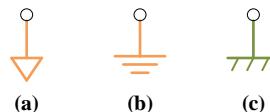
1.0 INTRODUCTION

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.

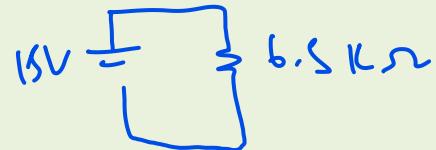
4.0 PRE-LAB: ASSIGNMENT

(a) *Circuit Reference Node*

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

Pre-Lab workspace

$$V_A = 15 \text{ V}$$



$$V_{AB} = 2.308 \text{ V}$$

$$I = 2.3 \text{ mA}$$

$$V_{DC} = 5.07 \text{ V}$$

$$V_C = 7.618 \text{ V}$$

$$V_A = 15 \text{ V}$$

$$V_B = 12.692 \text{ V}$$

$$V_C = 7.622 \text{ V}$$

$$V_{AD} = V_A - V_B = 2.308 \text{ V}$$

$$\frac{15 - 2.3}{12.692} = V_B$$

$$V_{DC} = V_B - V_C = 5.07 \text{ V}$$

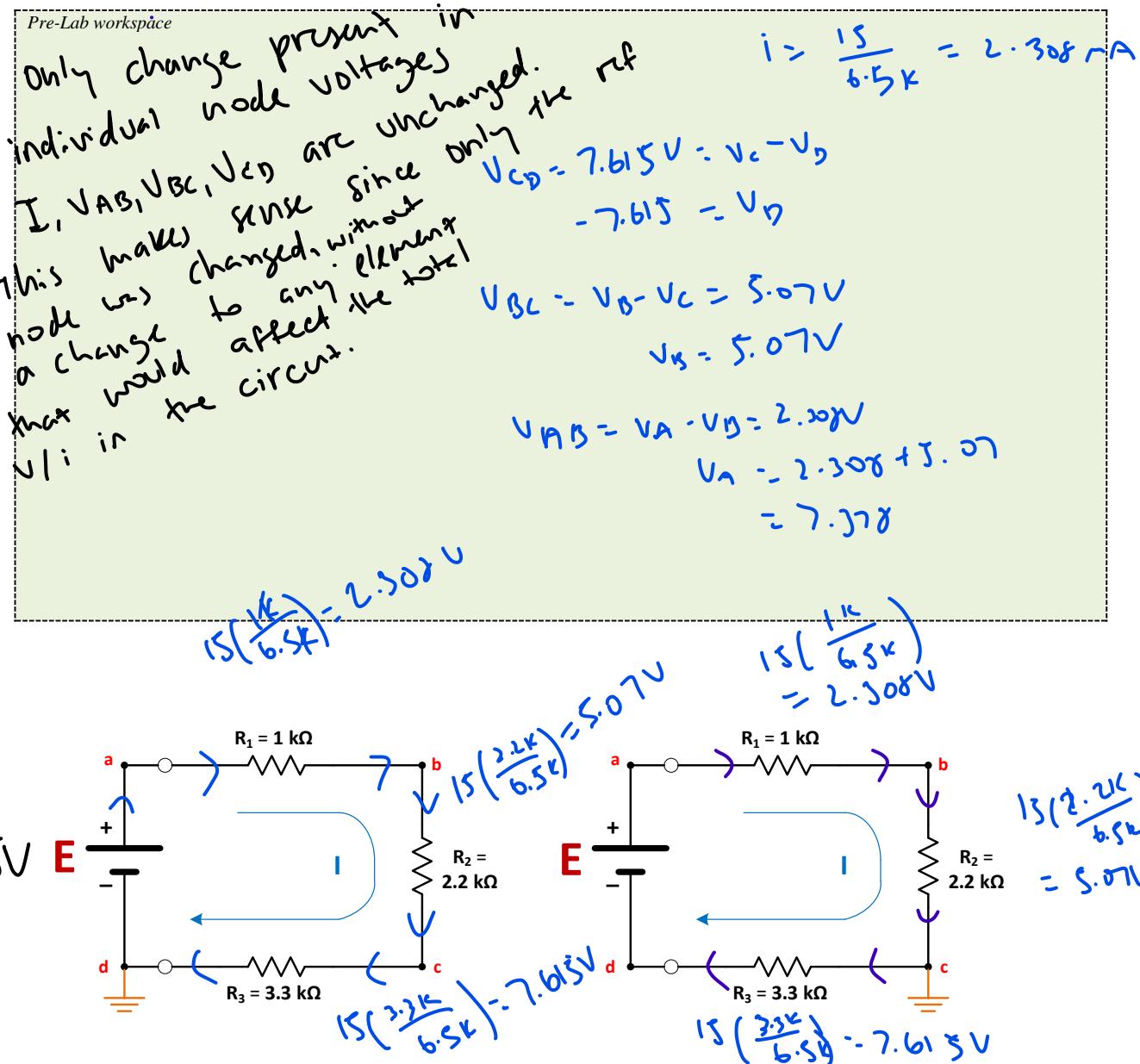
$$\frac{12.692 - 7.622}{7.622} = V_C$$

- (ii) Construct the circuit of **Figure 2.0a** in MultiSIM. With node “d” as the *reference node*, measure the current, I , the node voltages V_a , V_b and V_c , and the voltages across R_1 ($=V_{ab}$), R_2 ($=V_{bc}$), and R_3 ($=V_{cd}$), 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.

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



		Using Reference Node “d”	Using Reference Node “c”
I (mA)	Theoretical value =>	2.3 mA	2.308 mA
	MultiSIM value =>	2.308 mA	2.308 mA
V_a (Volts)	Theoretical value =>	15 V	7.378 V
	MultiSIM value =>	15 V	7.38 V
V_b (Volts)	Theoretical value =>	12.61 V	5.07 V
	MultiSIM value =>	12.61 V	5.077 V
V_c (Volts)	Theoretical value =>	7.622 V	0
	MultiSIM value =>	7.61 V	0
V_d (Volts)	Theoretical value =>	0	-7.613 V
	MultiSIM value =>	0	-7.615 V
V_{ab} (Volts)	Theoretical value =>	2.308 V	2.308 V
	MultiSIM value =>	2.308 V	2.308 V
V_{bc} (Volts)	Theoretical value =>	5.07 V	5.077 V
	MultiSIM value =>	5.077 V	5.077 V
V_{cd} (Volts)	Theoretical value =>	7.61 V	7.613 V
	MultiSIM value =>	7.615 V	7.615 V

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 **V_a**, **V_b** and **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

$A = 15V$

D:

$$0 = \frac{V_B - V_A}{2.2} + \frac{V_B - V_C}{5.1} + \frac{V_B}{3.3}$$

$$\frac{15}{2.2} = 0.9526 V_B - \frac{1}{5.1} V_C$$

$V_B = 8.714 V$

$V_C = 7.608 V$

C:

$$0 = \frac{V_C - V_A}{1.0} + \frac{V_C - V_B}{5.1} + \frac{V_C}{1.0}$$

$$15 = \left(\frac{1}{1} + \frac{1}{5.1} + \frac{1}{1} \right) V_C - \frac{V_B}{5.1}$$

$I_x = \frac{V_B}{3.3} = \frac{8.714}{3.3} = 2.64 \text{ mA}$

$V_x = V_A - V_B = 15 - 7.608 = 7.392 \text{ V}$

(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

 I_A :

$$0 = -15 + 2.2K(i_A - i_C) + 2.3K(i_A - i_B)$$

$$15 = 5.5K i_A - 2.2K i_C - 2.3K i_B$$

 I_B :

$$0 = 3.3K(i_B - i_1) + 5.1K(i_B - i_C) + 1K i_B$$

$$0 = 9.4K i_B - 2.3K i_B - 5.1K i_C$$

$$i_A = 10.249 \text{ mA}$$

$$i_B = 7.606 \text{ mA}$$

$$i_C = 7.31 \text{ mA}$$

 $i_S = i_C$

$$i_X = i_1 - i_2$$

$$\approx 2.641$$

$$V_X = 1K(i_S)$$

$$\approx 7.39 \text{ V}$$

$$i_1 = i_A - i_B$$

$$\approx 2.611 \text{ mA}$$

$$i_2 = i_B - i_C$$

$$\approx -0.218 \text{ mA}$$

(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 \mathbf{I}_1 , \mathbf{I}_2 , \mathbf{I}_3 and \mathbf{I}_X , the branch voltage, \mathbf{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 \mathbf{I}_X , and branch voltage \mathbf{V}_X . State if the *Nodal* and *Mesh* analysis methods yield the same results for the branch current, \mathbf{I}_X and the branch voltage, \mathbf{V}_X . Why?

Pre-Lab workspace

They yield the same result since they apply the same basic circuit laws on the same circuit.

$$0: 1 \times i_3 + 5.1 \times (i_3 - i_1) + 2.2 \times (i_3 - i_2) \\ = 8.3 \times i_3 - 5.1 \times i_2 - 2.2 \times i_1$$

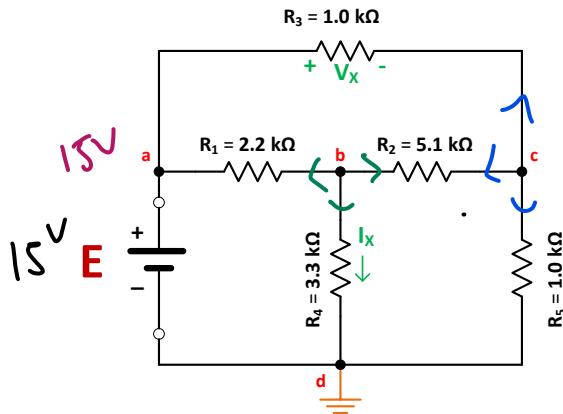


Figure 3.0a: Circuit for Nodal Analysis

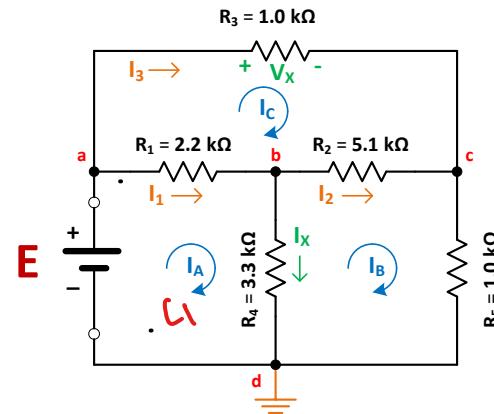


Figure 3.0b: Circuit for Mesh Analysis

$$i_1 = i_A - i_C$$

$$i_X = i_A - i_B$$

	Nodal Analysis	Mesh Analysis
V_a (Volts)	Theoretical value => 15V MultiSIM value => 15V	8.711 V
V_b (Volts)	Theoretical value => 8.711 V MultiSIM value => 8.711 V	
V_c (Volts)	Theoretical value => 7.608 V MultiSIM value => 7.60 V	10.249 mA
I_A (mA)	Theoretical value =>	10.249 mA
I_B (mA)	Theoretical value =>	7.608 mA
I_C (mA)	Theoretical value =>	7.3916 mA
I_X (mA)	Theoretical value => 2.641 mA MultiSIM value => 2.641 mA	7.39 mA
V_x (Volts)	Theoretical value => 7.392 V MultiSIM value => 7.392 V	2.641 V
I₁ (mA)	Theoretical value =>	2.641 mA
I₂ (mA)	Theoretical value =>	6.218 mA
I₃ (mA)	Theoretical value =>	7.3916 mA
		7.392 mA

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

5.0 IN-LAB Experiment: IMPLEMENTATION & MEASUREMENTS

(a) *Circuit Reference Node*

1. Implement the circuit in **Figure 2.0a** on your breadboard using the resistor values as shown. Set the input D.C. source, $E = 15V$ on the power-supply and select node “d” as a *reference* node to which “COM” terminal of the DMM in the Voltmeter setting is connected to allow for direct measurement of the *unreferenced* voltage nodes.
2. With the “-“ (or the reference) terminal of the DMM Voltmeter connected to the selected reference node, directly measure the voltages at nodes “a”, “b”, “c” and “d” (i.e. V_a , V_b , V_c and V_d , respectively). Use the DMM Voltmeter to directly measure the voltage across resistors, $R_1 (=V_{ab})$, $R_2 (=V_{bc})$ and $R_3 (=V_{cd})$. Measure the current, I using the DMM set up as an Ammeter. From the above measured node voltages (V_a , V_b , V_c and V_d), calculate the voltages V_{ab} , V_{bc} and V_{cd} . Record all your results in the below **Table 4.0**.
3. Relocate the circuit reference ground at node “c” shown in **Figure 2.0b**. Repeat steps 1 and 2 above.
4. Turn OFF the Power Supply.

		Using Reference Node “d”	Using Reference Node “c”
I (mA)	Measured value =>	2.36 mA	2.36 mA
V_a (Volts)	Measured value =>	14.992 V	7.41 V
V_b (Volts)	Measured value =>	12.668 V	5.08 V
V_c (Volts)	Measured value =>	7.57 V	0
V_d (Volts)	Measured value =>	0	-7.89 V
V_{ab} (Volts)	Measured value =>	2.32 V	2.32 V
	Calculated value =>	2.308 V	2.308 V
V_{bc} (Volts)	Measured value =>	5.08 V	5.08 V
	Calculated value =>	5.077 V	5.077 V
V_{cd} (Volts)	Measured value =>	7.56 V	7.56 V
	MultiSIM value =>	7.615 V	7.615 V

Table 4.0: Experimental results of the Figure 2.0 circuits

(b) **Nodal and Mesh Analysis**

1. Implement the circuit in **Figure 3.0** on your breadboard using the resistor values as shown. Set the input D.C. source, $E = 15V$ on the power-supply.
2. **Nodal Analysis:** Refer to the circuit of **Figure 3.0a**. Use node “d” as the ground reference node, and measure the node voltages V_a , V_b and V_c with respect to this reference ground. Then measure the branch voltage, V_x across resistor, R_3 and the branch current, I_x through resistor, R_2 .
3. **Mesh Analysis:** Measure the branch currents I_1 , I_2 , I_3 and I_x , and then use these measured branch currents to determine the values of the mesh currents, I_A , I_B and I_C and the branch voltage, V_x . Record all your results in below **Table 5.0**.
4. Turn OFF the Power Supply

		<i>Nodal</i> Analysis	<i>Mesh</i> Analysis	
V_a (Volts)	Measured value =>	14.998 V	$i_x = i_A - i_B$ $i_x + i_B - i_A = 0$ $i = 2.7 + 7.73 = 10.43$ $i_B - i_C = 7.73 - 7.51 = 0.22$	
V_b (Volts)	Measured value =>	8.707 V		
V_c (Volts)	Measured value =>	7.62 V		
I_A (mA)	Calculated value =>	10.43 mA		
I_B (mA)	Calculated value =>			
I_C (mA)	Calculated value =>			
I_x (mA)	Measured value =>	2.713 mA	2.714 mA	
V_x (Volts)	Measured value =>	7.38 V	7.39 V	
I_1 (mA)	Measured value =>	2.92 mA		
I_2 (mA)	Measured value =>			
I_3 (mA)	Measured value =>	7.513 mA		

Table 5.0: Experimental results of the Figure 3.0 circuits

$$i_1 = i_A - i_C$$

$$= 10.43 - 7.51$$

$$\frac{2.92}{8}$$

6.0 POST-LAB: OBSERVATIONS AND ANALYSIS OF RESULTS

1. From observing the results in **Table 4.0** of “*Circuit Reference Node*” experiment for both cases (when reference point at “**d**” and reference point at “**c**”): -
 - a. State clearly which one of the currents, node voltages, or resistor voltages have changed or remain unchanged, and explain why. How do these experimental results compare to your Pre-Lab results in **Table 2.0**?
 - b. Which of the two *reference points* would be your preferred choice? Explain.
 - c. List, and comment on, the possible causes for any discrepancies from what you would expect theoretically or from the simulations?

workspace

a) Unchanged: $I, V_{AS}, V_{BC}, V_{CD}$. Since the only changing element was the location of GND, only nodal voltages were affected by the change.
Changed: V_A, V_D, V_C, V_D

These results match table 2.0

b) Ref point D is my preferred choice. It doesn't create any negative voltage values

c) Slight discrepancies in experimental values were expected due to the usage of imperfect components, however both measured values equalled.

2. For the “**Nodal and Mesh Analysis**” experiment, compare your results in **Table 5.0** with the theoretical values and MultiSIM simulation measurements in **Table 3.0**, and explain.

- a. Specifically, did the *Nodal* and *Mesh* analysis methods yield the same results for the branch current, I_x and the branch voltage, V_x ? Why?
- b. Do your results in **Table 3.0** and **Table 5.0** verify the *Nodal* and *Mesh* analysis techniques? Explain.
- c. List, and comment on, the possible causes for any discrepancies from what you would expect theoretically or from the simulations?

workspace

- a) Yes they yielded the same V_x & I_x values. This makes sense because the 2 circuit analyses were performed on the same circuit.
- b) Yes, Table 3.0 & 5.0 verify the nodal & mesh techniques, since the values found through node & mesh calculations are close to the values found through experimentation
- c) The values found in experimentation differed from those found in calculations by ~ thousandth. This likely occurred due to flaws in the physical elements that don't allow each element to be 100% efficient (as assumed in calculations)

7.0 LAB REPORT REQUIREMENTS & GUIDELINES

Lab reporting is to be completed and submitted separately as **Part I** and **Part II**, noted below:

Part I (**Pre-Lab Work**) => represents **40%** of the pre-assigned Lab weight.

Pre-Lab Work (assignment) of **Section 4.0** that includes handwritten calculations, MultiSIM results, and analysis is to be completed and submitted prior to the start of your scheduled lab. *The grading is commensurate with completeness and accuracy of your handwritten calculations, analysis and MultiSIM simulation circuits/plots.*

Note the following requirements for the document submission for Part I:

- A completed and signed “COVER PAGE – **Part I**” has to be included with your submission, a copy of which is available on D2L. 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.

Part II (**In-Lab Work** and **Post-Lab Work**) => represents **60%** of the pre-assigned Lab weight.

In-Lab Work (**Section 5.0**) and **Post-Lab Work** (**Section 6.0**) that include in-lab results, handwritten analysis and observations are to be completed and submitted by 11.59 p.m. of the same day as your scheduled lab. *The grading is commensurate with: - completeness, correctness and collection of all experimental results (data and waveforms); merits of observation of the correlations between the experimental and pre-lab assignment results; and reasonableness of the answers to questions posed.*

Note the following requirements for the document submission for Part II:

- A completed and signed “COVER PAGE – **Part II**” has to be included with your submission, a copy of which is available on D2L. The report will not be graded if the signed cover page is not included.
- Scan your completed pages of **Section 5.0** and **Section 6.0** (via a scanner or phone images), together with any required In-Lab Oscilloscope screen-shot images.
- Collate and create a .pdf or .docx file of the above, and upload it via D2L **by 11.59 p.m. on the same day** your lab is scheduled. Late submissions will not be graded.

