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Integrated Master in Aerospace Engineering

Circuit Theory and Electronics Fundamentals

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First Laboratory Report

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1 Introduction

The objective of this laboratory assignment is to study a circuit containing a DC voltage source V_a , seven resistors, a voltage-controlled current source I_b and a current-controlled voltage source V_c . The components of this circuit are distributed by 4 elementary meshes and 8 nodes, as seen in Figure 1.

In order to analyse the circuit, the following data were obtained by running the supplied Python script:

Units for the values: V, mA, kOhm and mS

Values:

R1 = 1.00147062639

R2 = 2.0078068512

R3 = 3.11269704405

R4 = 4.10609573471

$R_5 = 3.02670672634$
 $R_6 = 2.01292455078$
 $R_7 = 1.02905244808$
 $V_a = 5.24842063411$
 $I_d = 1.04086013403$
 $K_b = 7.21413591579$
 $K_c = 8.01455113996$

In Section 2, a theoretical analysis of the circuit, performed on Octave using the mesh and node methods, is presented. In Section 3, the circuit is analysed by simulation, using NGSpice, and the results are compared to the theoretical results obtained in Section 2. The conclusions of this study are outlined in Section 4.

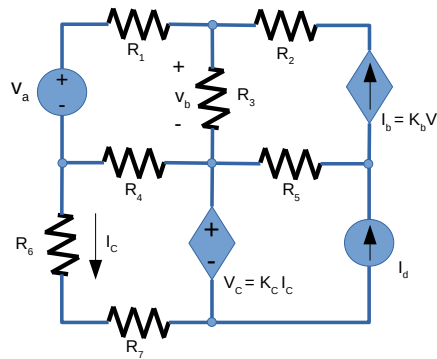


Figure 1: Circuit which will be analysed during this laboratory assignment.

2 Theoretical Analysis

In this section, the circuit shown in Figure 1 is analysed theoretically. We will begin by analyzing the circuit by applying the Mesh Method and, after that, we will analyze it again using the Nodal Method. In order to this, we will use Kirchhoff's circuit laws (KVL and KCL) together with Ohm's Law to obtain the theoretical results.

Note that we defined one of the nodes as GND, which is the central node of the circuit, having then randomly assigned numbers to the remaining ones. This will help us to later simulate the circuit and perform its analysis.

2.1 Mesh Method

— A mesh is a loop that contains no other loops. — The Mesh Method consists of assigning a current with a certain direction to each loop in a circuit, as shown in Figure 2, and then evaluating the circuit based on the new currents defined.

In this way, the KVL equations are applied to loops which do not have current sources or whose current is not known.

Equations obtained to:

Mesh A

$$-V_a + R_1 \cdot I_A + R_3 \cdot (I_A + I_B) + R_4 \cdot (I_A + I_C) = 0 \quad (1)$$

Mesh B

$$I_B = I_b = K_b \cdot V_b = K_b \cdot R_3 \cdot (I_A + I_B) \quad (2)$$

Mesh C

$$I_C = I_c \quad (3)$$

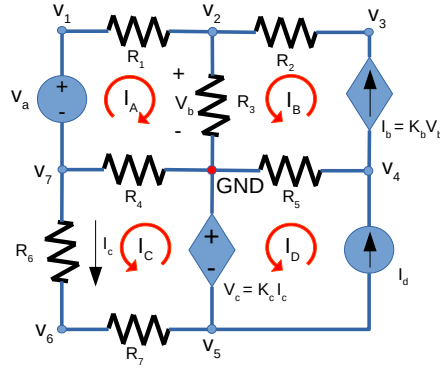


Figure 2: Circuit with each mesh current clockwise or counterclockwise direction assigned, to assist in the analysis of the circuit by the Mesh Method.

$$R_4 \cdot (I_C + I_A) + R_6 \cdot I_C + R_7 \cdot I_C - K_c \cdot I_C = 0 \quad (4)$$

Mesh D

$$I_D = I_d \quad (5)$$

Then, the equations are solved in order to obtain the currents of each mesh.

Matricial Equation obtained:

$$\begin{bmatrix} R_1 + R_3 + R_4 & R_3 & R_4 & 0 \\ K_b \cdot R_3 & K_b \cdot R_3 - 1 & 0 & 0 \\ R_4 & 0 & R_4 + R_6 + R_7 - K_c & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I_A \\ I_B \\ I_C \\ I_D \end{bmatrix} = \begin{bmatrix} V_a \\ 0 \\ 0 \\ I_d \end{bmatrix} \quad (6)$$

The solution of this matricial equation is determined by Octave:

Mesh Current	Ampere[A]
I_A	2.015673e-03
I_B	-2.109620e-03
I_C	-1.157872e-03
I_D	1.040860e-03

Table 1: Mesh Current Values

Knowing these currents, it is possible to determine any nodal voltages and branch currents, using Ohm's Law.

$$I_C = I_c \quad (7)$$

$$V_c = K_c \cdot I_c \quad (8)$$

$$V_b = R_3 \cdot (I_A + I_B) \quad (9)$$

$$I_b = K_b \cdot V_b \quad (10)$$

$$I_{R1} = I_A \quad (11)$$

$$I_{R2} = I_B \quad (12)$$

$$I_{R3} = I_A + I_B \quad (13)$$

$$I_{R4} = I_A + I_C \quad (14)$$

$$I_{R5} = I_B - I_D \quad (15)$$

$$I_{R6} = I_C \quad (16)$$

$$I_{R7} = I_C \quad (17)$$

Name	Value [A or V]
V_b	-2.924287e-01
I_b	-2.109620e-03
V_c	-9.279827e-06
I_c	-1.157872e-03
I_{R1}	2.015673e-03
I_{R2}	-2.109620e-03
I_{R3}	-9.394704e-05
I_{R4}	8.578007e-04
I_{R5}	-3.150480e-03
I_{R6}	-1.157872e-03
I_{R7}	-1.157872e-03

Table 2: Voltages and currents of some circuit components

2.2 Nodal Method

— Nodes connect components in a circuit — The Nodal Method consists of choosing a reference node against which all other voltages are measured. Through the KCL equations and other additional equations, it is possible to determine the voltage at each node.

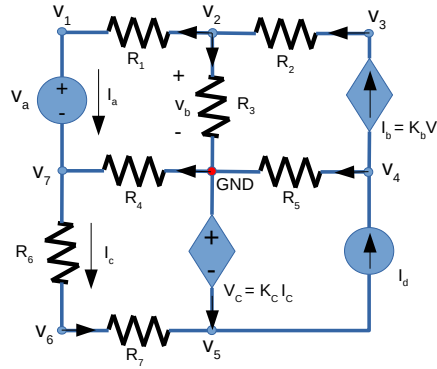


Figure 3: Circuit with each current direction arbitrarily assigned, to assist in the analysis of the circuit by the Nodal Method.

It was assigned potential 0 to the central node in order to proceed with the analysis. Because of that, we can write:

$$V_b = V_2 - 0 = V_2 \quad (18)$$

$$I_b = K_b \cdot V_b = K_b \cdot V_2 \quad (19)$$

We first start by calculating the values of the conductances of the various resistors:

$$G_i = 1/R_i \quad (20)$$

Then we determine the equations obtained by applying KCL in nodes not connected to voltage sources:

Node number 2

$$-(V_2 - V_1) \cdot G_1 - V_b \cdot G_3 + (V_3 - V_2) \cdot G_2 = 0 \Leftrightarrow V_1 \cdot G_1 + V_2 \cdot (-G_1 - G_2 - G_3) + V_3 \cdot G_2 = 0 \quad (21)$$

Node number 3

$$I_b - (V_3 - V_2) \cdot G_2 = 0 \Leftrightarrow V_2(G_2 + K_b) - G_2 \cdot V_3 = 0 \quad (22)$$

Node number 4

$$-(V_4 - 0) \cdot G_5 + I_d - K_b \cdot V_2 = 0 \Leftrightarrow -K_b \cdot V_2 - V_4 \cdot G_5 = -I_d \quad (23)$$

Node number 6

$$V_5 \cdot G_7 + V_6 \cdot (-G_6 - G_7) + V_7 \cdot G_6 = 0 \quad (24)$$

However, we need additional equations for nodes related to voltage sources:

Node number 1

$$(V_2 - V_1) \cdot G_1 - I_a = 0 \Leftrightarrow I_a = (V_2 - V_1) \cdot G_1 \quad (25)$$

Node number 7

$$V_1 \cdot G_1 - G_1 \cdot V_2 - G_6 \cdot V_6 + V_7 \cdot (G_4 + G_6) = 0 \quad (26)$$

Equation (25)+(26)

$$V_1 \cdot G_1 + V_2 \cdot (-G_1) + V_6 \cdot (-G_6) + V_7 \cdot (G_4 + G_6) = 0 \quad (27)$$

Another additional Equations:

$$V_a = V_1 - V_7 \quad (28)$$

$$0 - V_5 = K_c \cdot G_6 \cdot (V_7 - V_6) \Leftrightarrow V_5 + V_6 \cdot K_c \cdot (-G_6) + V_7 \cdot K_c \cdot G_6 = 0 \quad (29)$$

Matricial equation obtained using the nodal method:

$$\begin{bmatrix} G_1 & -G_1 & 0 & 0 & 0 & -G_6 & G_4 + G_6 \\ G_1 & -G_1 - G_2 - G_3 & G_2 & 0 & 0 & 0 & 0 \\ 0 & G_2 + K_b & -G_2 & 0 & 0 & 0 & 0 \\ 0 & K_b & 0 & G_5 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & G_7 & -G_6 - G_7 & G_6 \\ 1 & 0 & 0 & 0 & 0 & 0 & -1 \\ 0 & 0 & 0 & 0 & 1 & -G_6 \cdot K_c & G_6 \cdot K_c \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \\ V_5 \\ V_6 \\ V_7 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ I_d \\ 0 \\ V_a \\ 0 \end{bmatrix} \quad (30)$$

The solution of this matricial equation is determined by Octave:

Node	Voltage[V]
V ₁	1.726209e+00
V ₂	-2.924287e-01
V ₃	-4.528138e+00
V ₄	9.535580e+00
V ₅	9.279827e-06
V ₆	-1.191502e+00
V ₇	-3.522212e+00

Table 3: Nodal Voltages Values

Knowing these voltages, it is also possible to determine any components' voltages, by subtracting the voltages of each node where the component is connected, and branch currents, using Ohm's Law.

$$I_c = (V_7 - V_6) \cdot G_6 \quad (31)$$

$$V_c = K_c \cdot I_c \quad (32)$$

$$V_b = V_2 \quad (33)$$

$$I_b = K_b \cdot V_b \quad (34)$$

Name	Value [A or V]
V_b	-2.924287e-01
I_b	-2.109620e-03
V_c	-9.279827e-06
I_c	-1.157872e-03
I_{R1}	-2.015673e-03
I_{R2}	-2.109620e-03
I_{R3}	-9.394704e-05
I_{R4}	8.578007e-04
I_{R5}	3.150480e-03
I_{R6}	-1.157872e-03
I_{R7}	-1.157872e-03

Table 4: Voltages and currents of some circuit components

By comparing the results for the voltages and the branch currents obtained by both methods, we confirm that both results match precisely. Later, we will verify that the simulation results, using NGSPice, also match the theoretical analysis for both methods. Note that some quantities vary only in signal (for example, the current in R1 obtained by the mesh method is the simmetrical of the current in this branch obtained by the second method) - this happens because the sense of the current assigned for each branch varies for each method. However, this does not affect our results, since it only means that, in case of a negative quantity, the true current sense flowing through the component is, in fact, opposite to the one we assumed.

3 Simulation Analysis

3.1 Operating Point Analysis

Table 5 shows the simulated operating point results for the circuit under analysis. Compared to the theoretical analysis results, we notice that the simulation results are accurate, except for the last decimal places, as a consequence of the scientific notation and the number of significant algharisms used by each program to present the results. Despite that, we realise that the values with more significant algharisms (used in NGSpice) match correctly the rounded values (used in Octave).

In the table, we can see an nineth node (node 8), which has the same voltage value as node 6. This happens because, in NGSPice, when we want to simulate circuits with current-dependent sources, we must add a 0V voltage source in series to a component to sense the current flowing through it. Therefore, an additional node appears in the simulated circuit.

Note that we can not perform additional simulation analysis, namely transient and frequency ones, with phase and magnitude responses and input impedance, because the circuit does not have any electrical component which output is a function of time.

Name	Value [A or V]
@gb[i]	-2.10962e-03
@id[current]	1.040860e-03
@r1[i]	-2.01567e-03
@r2[i]	-2.10962e-03
@r3[i]	-9.39470e-05
@r4[i]	8.578007e-04
@r5[i]	3.150480e-03
@r6[i]	-1.15787e-03
@r7[i]	-1.15787e-03
v1	1.726209e+00
v2	-2.92429e-01
v3	-4.52814e+00
v4	9.535580e+00
v5	9.279827e-06
v6	-1.19150e+00
v7	-3.52221e+00
v8	-1.19150e+00

Table 5: Operating point. A variable preceded by @ is of type *current* and expressed in Ampere; other variables are of type *voltage* and expressed in Volt.

4 Conclusion

In this laboratory assignment the objective of analysing a circuit with resistors, voltage sources and current sources by applying the Nodal and Mesh methods together with Kirchhoff's Circuit Laws and Ohm's Law has been achieved. The theoretical analysis was performed with the help of the Octave math tool and the circuit simulation using the Ngspice tool. The simulation results matched the theoretical results perfectly. This happens mainly because the method used to obtain the theoretical results is the same method Ngspice uses to emulate the described circuit. Another reason why the results match perfectly is that the circuit was composed by simple components. For more complex components, the theoretical and simulation models may differ but it is not the case in this assignment.