Circuit Theory and Electronics Fundamentals

Department of Electrical and Computer Engineering, Técnico, University of Lisbon

First Laboratory Report

Group 20
João Maria De Carvalho Coelho Navarro Soeiro, 95803
Bruno Manuel Bento Pedro, 96363
Leonor João Dias Ferreira, 96422

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1 Introduction

In this laboratory assignment a circuit will be analysed theoretically and simulated using the circuit simulator tool NGSPICE. Its main objective is to compare the values of an operating point analysis (voltage and current) from a theoretical analysis using the nodal and mesh methods with the results obtained in NGSPICE circuit simulation. The circuit (Figure 1) is composed of one independent voltage source, one independent current source, one dependent voltage source, one dependent current source, and seven resistors.

In Section 2 of this report, the mesh and nodal methods from theoretical analysis of the circuit are presented. In Section 3, the circuit is analysed by simulation, and the results are commented and compared to the theoretical results obtained in Section 2. The conclusions of this study are outlined in Section 4.

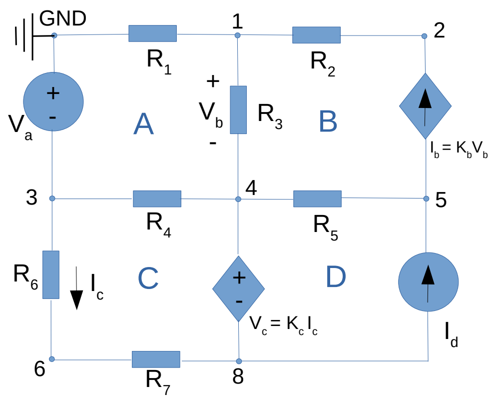

Figure 1: Circuit T1.

2 Theoretical Analysis

In this section, the circuit shown in Figure 1 is analysed theoretically using the mesh and nodal methods.

2.1 Mesh Analysys

The application of the mesh method in this circuit requires 4 currents to be determined. Each one of them will loop in one of the elementary meshes. In order to facilitate the aplication of the method, each mesh was labeled with a letter, as shown in Figure 1, and the designations I_A, I_B, I_C and I_D were assigned to the currents in meshes A, B, C and D, respectively.

Applying the Kirchhoff's Voltage Law (KVL) to each of these meshes, the following equations were obtained:

Mesh A:

$$(R_1 + R_3 + R_4)I_A - R_3 I_B - R_4 I_C = -V_a \tag{1}$$

Mesh B:

$$-K_b R_3 I_A + (K_b R_3 - 1)I_B = 0 \tag{2}$$

Mesh C:

$$R_4 I_A + (-R_6 - R_7 + K_c - R_4)I_C = 0 \tag{3}$$

Mesh D:

$$I_D = I_d \tag{4}$$

Solving this equations as a system of equations matrix in OCTAVE, the following values to the currents are obtained:

Name	Value [A]
I_A	-0.000195
I_B	-0.000204
I_C	0.001010
I_D	0.001005

Table 1: Mesh currents from mesh analysis.

Now, applying the Ohm's Law, it's possible to obtain the node voltages. The following equations result of this application to each node:

Node 1:

$$V_1 = R_1 I_A \tag{5}$$

Node 2:

$$V_2 = V_1 + R_2 I_B \tag{6}$$

Node 3:

$$V_3 = -V_a \tag{7}$$

Node 4:

$$V_4 = V_1 - R_3(-I_A + I_B) \tag{8}$$

Node 5:

$$V_5 = V_4 - R_5(I_B - I_D) \tag{9}$$

Node 6:

$$V_6 = V_3 - R_6 I_C \tag{10}$$

Node 8:

$$V_8 = V_6 - R_7 I_C \tag{11}$$

The Table 2 shows the results from these equations:

Name	**Value [V]**
V_1	-0.202617
V_2	-0.619394
V_3	-5.201027
V_4	-0.174256
V_5	3.485906
V_6	-7.293091
V_8	-8.322033

Table 2: Node voltages from mesh analysis.

2.2 Node Analysys

In order to theoretically analyse the circuit using the nodal method, 8 nodes have been identified, as shown in Figure 1. For 5 of these, the respective equations have been written. The node on the upper left corner was considered to have 0V. This way, its equation doesn't need to be written. The nodes 4 and 8, located on the terminals of the dependent voltage source, were grouped in a supernode in order to facilitate writing the equations. Also, the equation that describes the dependent voltage source was considered and an additional equation was written in node 3.

This way, a 7 equation and 7 unknowns system was determined and put in matrix form in order to solve it in Octave:

$$\begin{bmatrix} -\frac{1}{R_2} - \frac{1}{R_3} - \frac{1}{R_1} & \frac{1}{R_2} & 0 & \frac{1}{R_3} & 0 & 0 & 0 \\ K_b + \frac{1}{R_2} & -\frac{1}{R_2} & 0 & -K_b & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ \frac{1}{R_3} & 0 & \frac{1}{R_4} & -\frac{1}{R_4} - \frac{1}{R_3} - \frac{1}{R_5} & \frac{1}{R_5} & \frac{1}{R_7} & -\frac{1}{R_7} \\ K_b & 0 & 0 & -\frac{1}{R_5} - K_b & \frac{1}{R_5} & 0 & 0 \\ 0 & 0 & \frac{1}{R_6} & 0 & 0 & -\frac{1}{R_6} - \frac{1}{R_7} & \frac{1}{R_7} \\ 0 & 0 & \frac{K_c}{R_6} & -1 & 0 & -\frac{K_c}{R_6} & 1 \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \\ V_5 \\ V_6 \\ V_8 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ -V_a \\ I_d \\ I_d \\ 0 \\ 0 \end{bmatrix}$$

Node equations determined using the Kirchhoff Current Law (KCL):

Node 1:

$$(-\frac{1}{R_2}-\frac{1}{R_3}-\frac{1}{R_1})V_1+\frac{1}{R_2}V_2+\frac{1}{R_3}V_4=0 \tag{12}$$

Node 2:

$$(K_b+\frac{1}{R_2})V_1-\frac{1}{R_2}V_2-K_bV_4=0 \tag{13}$$

Supernode:

$$\frac{1}{R_3}V_1+\frac{1}{R_4}V_3+(-\frac{1}{R_4}-\frac{1}{R_3}-\frac{1}{R_5})V_4+\frac{1}{R_5}V_5+\frac{1}{R_7}V_6-\frac{1}{R_7}V_8=I_d \tag{14}$$

Node 5:

$$K_bV_1+(-\frac{1}{R_5}-K_b)V_4+\frac{1}{R_5}V_6=I_d \tag{15}$$

Node 6:

$$\frac{1}{R_6}V_3+(-\frac{1}{R_6}-\frac{1}{R_7})V_6+\frac{1}{R_7}V_8=0 \tag{16}$$

Additional equations:

$$\frac{K_c}{R_6}V_3-V_4-\frac{K_c}{R_6}V_6+V_8=0 \tag{17}$$

$$V_3=-V_a \tag{18}$$

The results of the previous system of equations are shown in Table 3:

Name	**Value [V]**
v(1)	-0.202617
v(2)	-0.619394
v(3)	-5.201027
v(4)	-0.174256
v(5)	3.485906
v(6)	-7.293091
v(8)	-8.322033

Table 3: Node voltages from node analysis.

After finding the voltages of every node, Kirchoff's Voltage Law was applied in order to check the results. In the upper left and lower right meshes, the sum of all potential differences was, in fact, 0. In the upper right and lower left meshes, the result was, respectively, $-5.551115123125783e-17$ and $-8.881784197001252e-16$, which are both very close to 0.

3 Simulation Analysis

3.1 Operating Point Analysis

Table 4 shows the simulated operating point results for the circuit under analysis. Compared to the theoretical analysis results, one notices the following differences: describe and explain the differences.

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Name	Value [A or V]
@gib[i]	-2.03930e-04
@id[current]	1.004605e-03
@r1[i]	1.948215e-04
@r2[i]	-2.03930e-04
@r3[i]	-9.10887e-06
@r4[i]	1.205214e-03
@r5[i]	-1.20854e-03
@r6[i]	1.010392e-03
@r7[i]	1.010392e-03
v(1)	-2.02617e-01
v(2)	-6.19394e-01
v(3)	-5.20103e+00
v(4)	-1.74256e-01
v(5)	3.485906e+00
v(6)	-7.29309e+00
v(7)	-7.29309e+00
v(8)	-8.32203e+00

Table 4: Operating point. A variable preceded by @ is of type *current* and expressed in Ampere; other variables are of type *voltage* and expressed in Volt.

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4 Conclusion

In this laboratory assignment the objective of analysing an RC circuit has been achieved. Static, time and frequency analyses have been performed both theoretically using the Octave maths tool and by circuit simulation using the Ngspice tool. The simulation results matched the theoretical results precisely. The reason for this perfect match is the fact that this is a straightforward circuit containing only linear components, so the theoretical and simulation models cannot differ. For more complex components, the theoretical and simulation models could differ but this is not the case in this work.

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