Circuit Theory and Electronics Fundamentals

Department of Electrical and Computer Engineering, Técnico, University of Lisbon
Mestrado em Engenharia Aeroespacial

Laboratory 2 Report

Group 7

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1 Introduction

The objective of this laboratory assignment is to study a circuit containing a dependent voltage source (V_c) and independent (I_d, V_a) current and voltage sources, connected to resistors (R_1 to R_7) and to a capacitor (C). The circuit and its organization can be seen in Figure 1.

In Section 2, a theoretical analysis of the circuit is presented. In Section 3, the circuit is analysed by simulation, and the results are compared to the theoretical results obtained in Section 2. The conclusions of this study are outlined in Section 5.

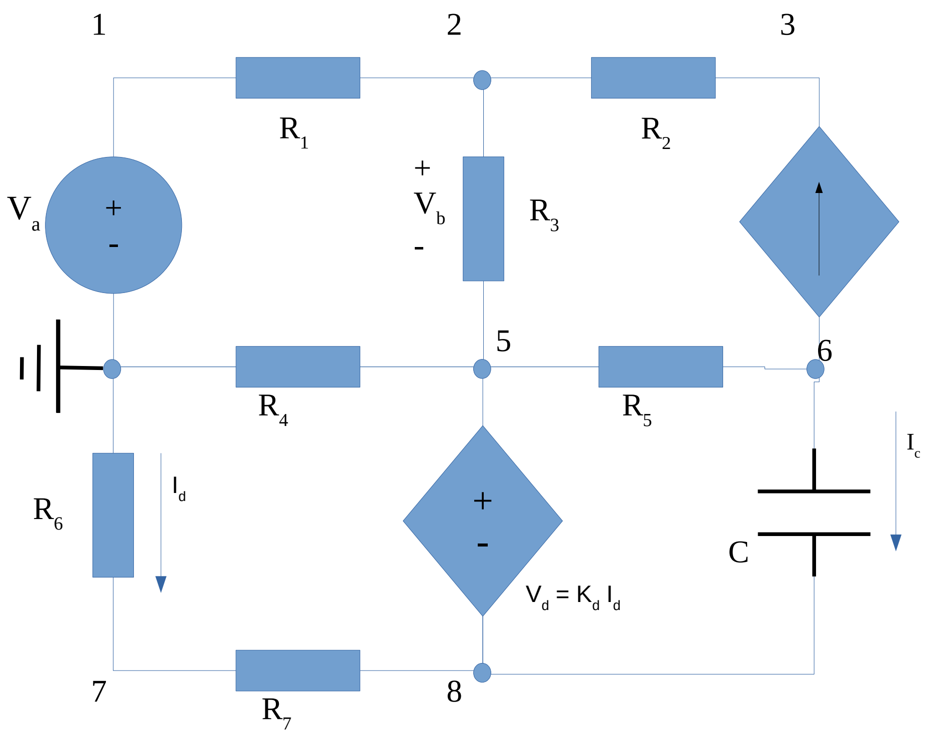

Figure 1: Circuit topography

2 Theoretical Analysis

In this section, the circuit shown in Figure 1 is analysed theoretically, through the method of Node Analysis.

2.1 Node analysis for t<0

$$\begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & G_1 & -G_1-G_3-G_2 & G_2 & G_3 & 0 & 0 & 0 \\ 0 & 0 & G_2+K_b & -G_2 & -K_b & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -G_6-G_7 & G_7 \\ 0 & 0 & 0 & 0 & 1 & 0 & K_c*G_6 & -1 \\ 0 & 0 & -K_b & 0 & G_5+K_b & -G_5 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & G_3 & 0 & -G_3-G_4-G_5 & G_5 & G_7 & -G_7 \end{bmatrix} \begin{bmatrix} V_0 \\ V_1 \\ V_2 \\ V_3 \\ V_5 \\ V_6 \\ V_7 \\ V_8 \end{bmatrix} = \begin{bmatrix} V_s \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \tag{1}$$

The results obtained after implementing the KNL in Octave can be seen in Tables 1 and 2:

Name	Value [V]
V_0	0.000000
V_1	5.044997
V_2	4.825265
V_3	4.353436
V_5	4.856743
V_6	5.556341
V_7	-1.971428
V_8	-2.940751

Table 1: Voltages obtained in the theoretical analysis in Octave.

The currents derived from the results of the node analysis are found in Table 2.

Name	Value [A]
$@I_1$	-0.000219
$@I_2$	-0.000229
$@I_3$	-0.000010
$@I_4$	0.001184
$@I_5$	0.000229
$@I_6$	-0.000964
$@I_7$	-0.000964

Table 2: Currents obtained in the theoretical analysis in Octave.

2.2 Node Analysis for t≥0 (Natural solution)

Here, we made use of Node Analysis to determine the current that passed through the capacitor. By short-circuting the independent voltage source V_s and by swapping the capacitor with a voltage source V_x = V_6 - V_8 we were able to calculate the current that flowed through the capacitor and the equivalent resistance. We short-circuted the independent voltage source because we are using the thevenin/norton theorems to calculate the resistence as seen by the capacitor and we swapped the capacitor with a voltage source as at t = 0 the capacitor begins discharging and it has a voltage of V_x (since it's voltage is at a peak). Node analysis matrix:

$$\begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & G_1 & -G_1-G_3-G_2 & G_2 & G_3 & 0 & 0 & 0 & 0 \\ 0 & 0 & -G_2+K_b & G_2 & -K_b & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -G_6-G_7 & G_7 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & K_c*G_6 & -G_7 & 0 \\ 0 & 0 & K_b & 0 & G_5-K_b & -G_5 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & G_1 & 0 & G_4 & 0 & G_6 & 0 & 0 \end{bmatrix} \begin{bmatrix} V_0 \\ V_1 \\ V_2 \\ V_3 \\ V_5 \\ V_6 \\ V_7 \\ V_8 \\ I_x \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ Vx \\ 0 \\ 0 \end{bmatrix} \tag{2}$$

$$[H]R_eq = (V_x/I_x) \tag{3}$$

Name	Value [A], [V], [Ohm]
$@I_x$	0.002787
V_x	8.497091
R_eq	3048.519938

Table 3: Equivalent current, voltage and resistor obtained in the theoretical analysis in Octave.

$$[H]V_n = V_x * exp(-t/(R_eq * C)) \tag{4}$$

With the results obtained before we ploted the natural solution in Figure 2.

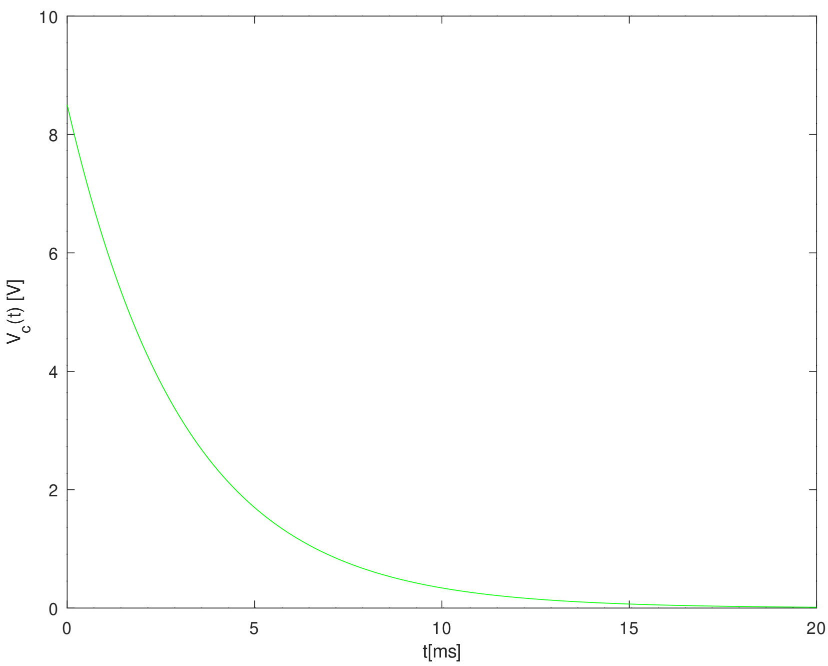

Figure 2: Natural solution for capacitor.

2.3 Node Analysis for t≥0 (Forced solution)

To determine the forced solution we used a phasor voltage source V_s = 1 V and then we applied the Node analysis (in which C was replaced by its impedance.

Node analysis matrix:

$$\begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & G_1 & -G_1-G_3-G_2 & G_2 & G_3 & 0 & 0 & 0 \\ 0 & 0 & -G_2+K_b & G_2 & -K_b & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & G_6-G_7 & G_7 \\ 0 & 0 & 0 & 0 & 1 & 0 & K_c*G_6 & -1 \\ 0 & 0 & K_b & 0 & -G_5+K_b & G_5+Z_c & 0 & -Z_c \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -G_1 & 0 & 0 & G_4 & 0 & G_6 & 0 \end{bmatrix} \begin{bmatrix} V_0 \\ V_1 \\ V_2 \\ V_3 \\ V_5 \\ V_6 \\ V_7 \\ V_8 \end{bmatrix} = \begin{bmatrix} 0 \\ exp(j) \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \tag{5}$$

Name	Value [V]
V_0	0.000000+0.000000i
V_1	0.540302+0.841471i
V_2	1.413094+2.200763i
V_3	3.130463+4.875407i
V_5	1.527668+2.379201i
V_6	0.173959+0.270954i
V_7	0.342253+0.533027i
V_8	0.173972+0.270945i

Table 4: Complex voltages obtained in the theoretical analysis in Octave.

2.4 Final Solution

The final solution is:

$$[H]V_t = V_6 - V_8, for\ t < 0 \tag{6}$$

$$[H]V_t = V_n + abs(v_6) * sen(2 * pi * f * t + acos(Re(v_6)/abs(v_6))), for\ t >= 0 \tag{7}$$

The plot of V_t and V_s is in Figure 3.

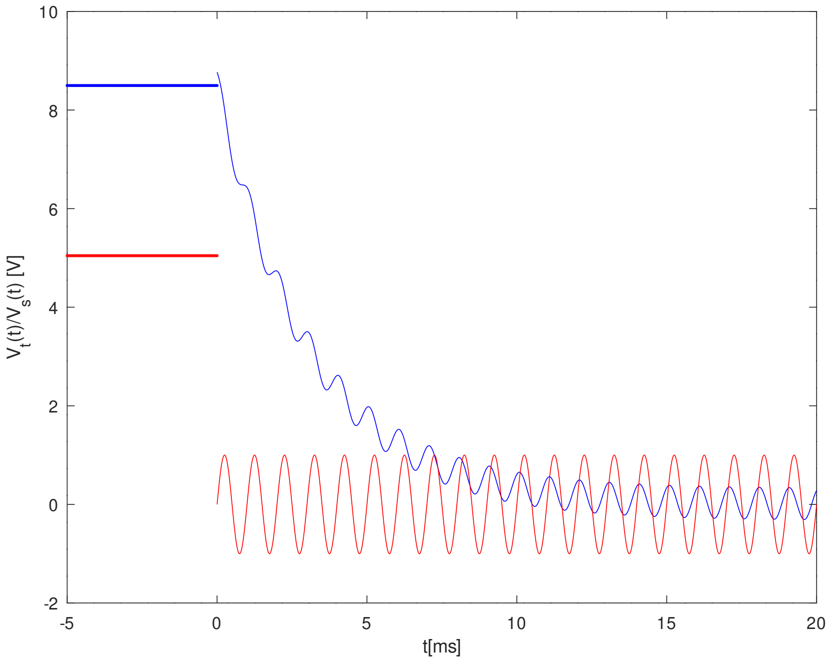

Figure 3: Final solution for V_s and V_t

2.5 Frequency responses

In this subsection we present the frequency responses graphics.

3 Simulation Analysis

3.1 Operating Point Analysis for t$<$0

While using Ngspice we encountered some problems with the use of current-controlled voltage sources. To overcome them, we introduced a dummy 0V voltage source between the resistors 6 and 7. The voltage source V_c depends on the current I_c, which is the current on R_6. However, since Ngspice could not take the current in R_6, we introduced the null voltage source, since the current there will be I_c, which is the current that V_c depends on.

Table 5 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.

Comparing the Tables 1 and 2 with Table 5, we see that the difference between the different voltages and currents is apromixametly null.

Name	**Value [A or V]**
@cd[i]	0.000000e+00
@gib[i]	-2.29488e-04
@rr1[i]	2.194705e-04
@rr2[i]	-2.29488e-04
@rr3[i]	-1.00172e-05
@rr4[i]	1.183566e-03
@rr5[i]	-2.29488e-04
@rr6[i]	9.640960e-04
@rr7[i]	9.640960e-04
v(1)	5.044997e+00
v(2)	4.825265e+00
v(3)	4.353436e+00
v(5)	4.856743e+00
v(6)	5.556341e+00
v(7)	-1.97143e+00
v(8)	-2.94075e+00
v(9)	0.000000e+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.

3.2 Operating Point Analysis for t$>$0 (natural solution)

By short-circuting the independent voltage source V_s and by swapping the capacitor with a voltage source V_x = V_6 - V_8 we were able to calculate the current that flowed through the capacitor and the equivalent resistance. We short-circuted the independent voltage source because we are using the thevenin/norton theorems to calculate the resistence as seen by the capacitor and we swapped the capacitor with a voltage source as at t = 0 the capacitor begins discharging and it has a voltage of V_x (since it's voltage is at a peak).

The current source I_x and voltage V_6 can be found in table 6.

Name	Value [A or V]
@rr5[i]	-2.78728e-03
v(6)	8.497091e+00

Table 6: Operating point of point 2 of the simulation. A variable preceded by @ is of type *current* and expressed in Ampere; other variables are of type *voltage* and expressed in Volt.

The graphic for the natural solution, V_6(t), (using transient analysis) can be seen in Figure 4.

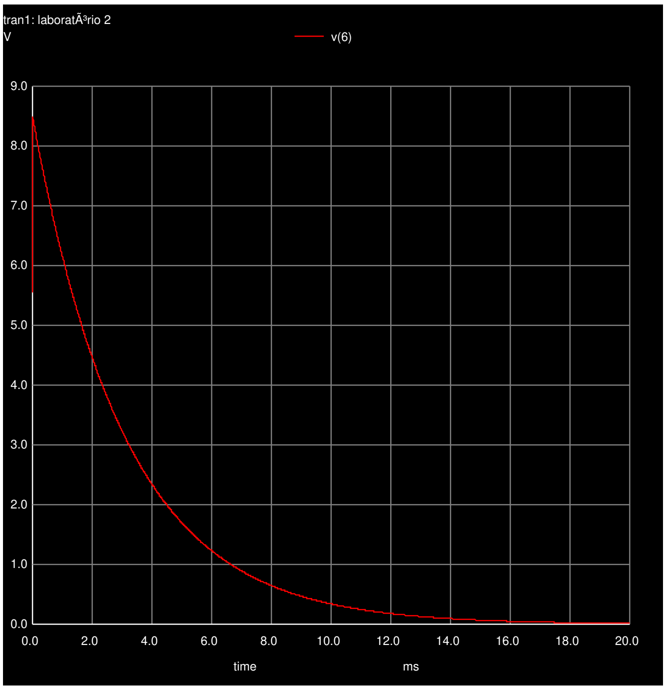

Figure 4: Natural solution for capacitor.

3.3 Operating Point Analysis for t>0 (natural and forced solution)

The graphic for the natural and forced responses on V_6(t) and on V_1 (voltage source):

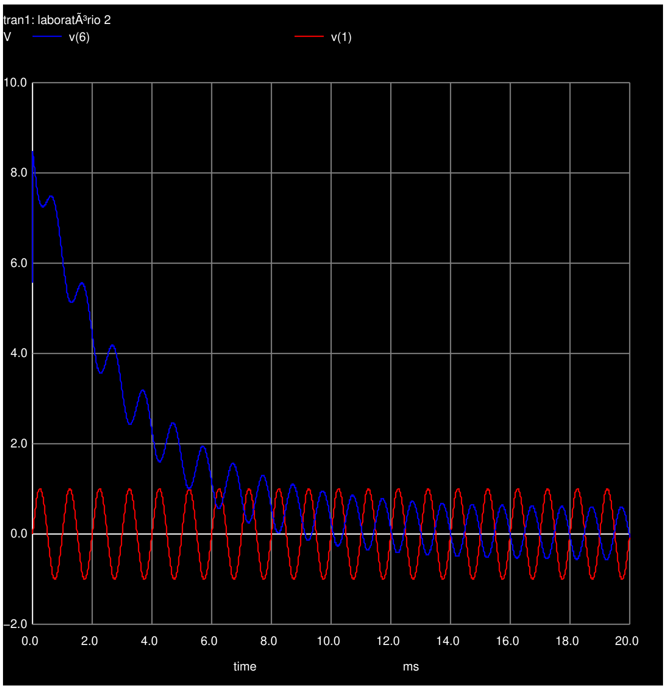

Figure 5: Forced solution of voltage source and capacitor.

3.4 Frequency response

The graphics for the frequency response are seen in Figure 6 and 7.

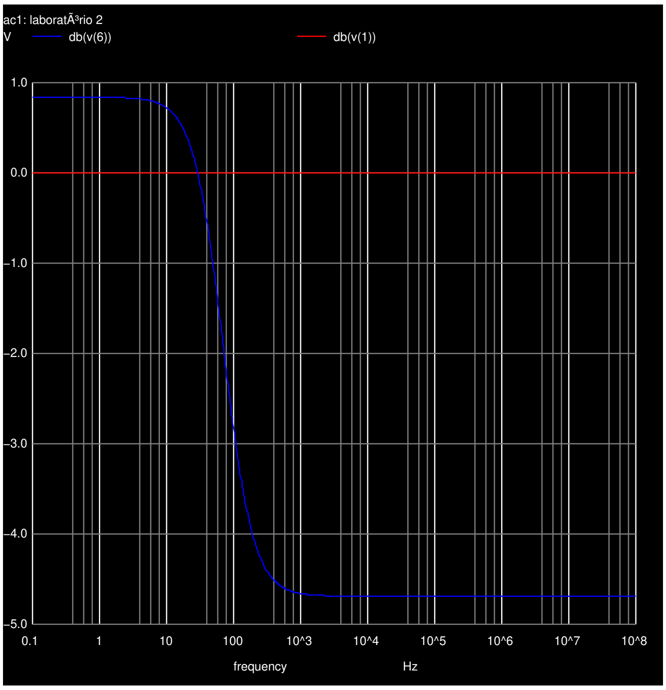

Figure 6: Magnitude in response to frequency changes.

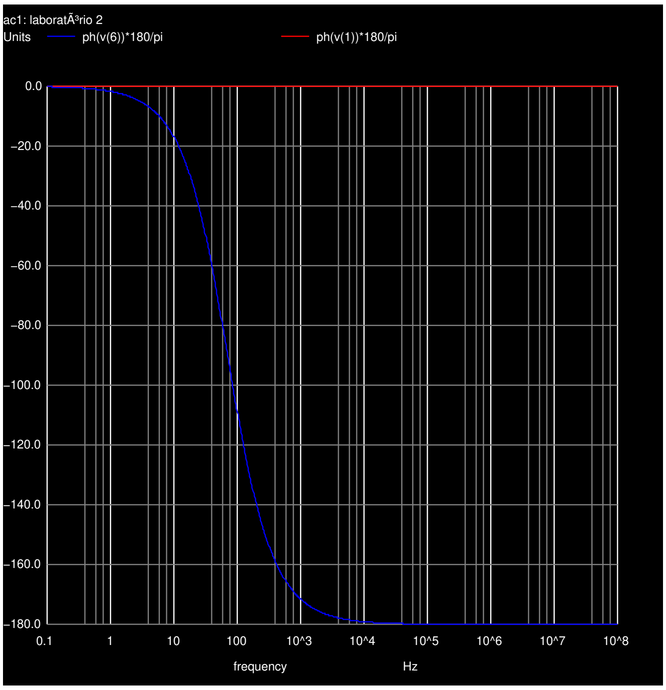

Figure 7: Phase in response to frequency changes.

V_s and V_6 differ since V_6 is connected to a capacitor and therefore it will be the sum of a natural and a forced solution whilst V_s is just a voltage source.

4 Comparing Octave and Ngspice

4.1 Operating Point Analysis for t$<$0

The difference between the results is minimal, as can be seen by comparing the table. The results are equal since the circuit is linear.

4.2 Operating Point Analysis for t¿0 (natural solution)

The graphics are similar, as one would expect since the components are linear and therefore the circuit is linear.

4.3 Operating Point Analysis for t¿0 (forced solution)

The graphics are similar, since the circuit is linear and we are using ideal voltage and current sources.

4.4 Frequency response

As one would expect the graphics are very similar and one can't find any significant discrepancies. This is the result of the circuit being linear

5 Conclusion

The objective of this laboratory assignment as been accomplished as can be seen by the results obtained. The Ngspice simulator is a very powerful tool.

As can be seen by comparing the tables, both octave maths tool and circuit simulator Ngspice data match, almost perfectly, the differences are explained by the rounding of the last decimal case.