

## Circuit Theory and Electronics Fundamentals

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2º Laboratory Report

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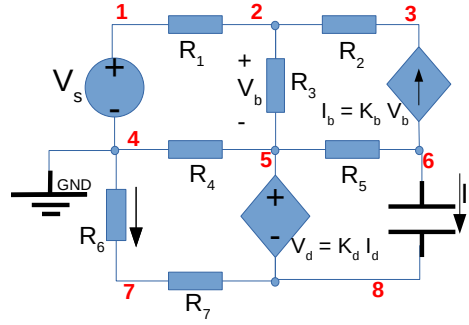


Figure 1: Nodal representation of the circuit.

## 1 Introduction

Name	Value
§R(1)	1.015259 K
§R(2)	2.090689 K
§R(3)	3.108356 K
§R(4)	4.101243 K
§R(5)	3.033480 K
§R(6)	2.009605 K
§R(7)	1.005573 K
!!C	1.015319 u
Vs	5.026261
£Kb	7.161103 m
§Kd	8.185741 K

Table 1: Constants provided by Python. A variable preceded by !! is of type *capacitance* and expressed in Farad ;a variable preceded by § is of type *resistance* and expressed in Ohm;a variable preceded by £ is of type *conductance* and expressed in Siemens; other variables are of type *voltage* and expressed in Volt.

The objective of this laboratory assignment is to find the natural, forced and total solution, with the use of a nodal analysis an the equivalent resistance, which will be used to plot the frequency response of the functions  $v_c(f)$  and  $v_6(f)$ . The circuit can be seen in Figure 1.

In section 2, a theoretical analysis of the circuit is presented. In section 5, the circuit is analyzed by simulation, and the results are compared to the theoretical results obtained in section 2. Finally, in section 6, we conclude our study.

## 2 Theoretical Analysis

In this section, the circuit shown in Figure 1 is analysed theoretically.

### 2.1 Nodal Analysis

The first step we took was analyzing the circuit for  $t \geq 0$  and by applying Kirchhoff's Current and voltage Laws we determined the currents in branches and voltage in nodes respectively. This are the equations used by us.

Using the equations mentioned above, we get the following matrix equation:

$$\begin{bmatrix} G_1 & -(G_1 + G_2 + G_3) & G_2 & 0 & G_3 & 0 & 0 & 0 \\ 0 & K_b + G_2 & -G_2 & 0 & -K_b & 0 & 0 & 0 \\ 0 & K_b & 0 & 0 & -(K_b + G_5) & G_5 & 0 & 0 \\ 0 & 0 & 0 & G_6 & 0 & 0 & -(G_6 + G_7) & G_7 \\ 1 & 0 & 0 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -K_b G_6 & -1 & 0 & K_b G_6 & 1 \\ 0 & G_3 & 0 & G_4 & -(G_3 + G_4 + G_5) & G_5 & G_7 & -G_7 \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \\ V_6 \\ V_7 \\ V_8 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ V_s \\ 0 \\ 0 \end{bmatrix} \quad (1)$$

Using octave we obtain the following table( 2):

Name	Value [mA]
V(1)	5.026261
V(2)	4.779742
V(3)	4.248215
V(4)	0.000000
V(5)	4.815244
V(6)	5.586461
V(7)	-1.871505
V(8)	-2.807975

Table 2: Constants provided by Python. A variable preceded by @ is of type *current* and expressed in Ampere;a variable preceded by \$ is of type *resistance* and expressed in Ohms;a variable preceded by £ is of type *conductance* and expressed in Siemens; other variables are of type *voltage* and expressed in Volt.

Using Ohms law, we can calculate the current flowing through each resistor, which are represented in the following table( 3):

Name	Value [mA]
@G1[i]	-0.254235
@C[current]	0.000000
@R1[i]	-0.242814
@R2[i]	-0.254235
@R3[i]	-0.011422
@R4[i]	1.174094
@R5[i]	-0.254235
@R6[i]	0.931280
@R7[i]	0.931280

Table 3: Constants provided by Python. A variable preceded by @ is of type *current* and expressed in Ampere;a variable preceded by \$ is of type *resistance* and expressed in Ohms;a variable preceded by £ is of type *conductance* and expressed in Siemens; other variables are of type *voltage* and expressed in Volt.

## 2.2 Equivalent Resistance

A set of equations were used, bearing in mind that the Thévenin Theorem was applied. By applying this theorem, all the independent tension sources were considered null, to study the influence of the condenser in the circuit, in order to obtain the circuit's equivalent resistance

in the perspective of the capacitor's extremities. We assumed that the tension  $V_s = 0V$  and there was a passage from a constant value to null value, which was the result of the passage of a non-null current passing through the condenser. Also, since the voltage source interior resistance was null, it's the equivalent to cause a short-circuit to that source.

In node 1 we also considered:

$$V_1 = V_s, V_4 = 0. \quad (2)$$

The Kirchhoff's Laws can also be applied here, leading to the same equations used in the section above, eventhough slightly changed, due the change in the source tension. The rest of the equations can be obtained using the following equation:

$$V_x = V_6 - V_8. \quad (3)$$

With the former equations, we can form the matrix equation used bellow:

$$\begin{bmatrix} G_1 & -(G_1 + G_2 + G_3) & G_2 & 0 & G_3 & 0 & 0 & 0 \\ 0 & K_b + G_2 & -G_2 & 0 & -K_b & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & -1 \\ 0 & 0 & 0 & G_6 & 0 & 0 & -(G_6 + G_7) & G_7 \\ 1 & 0 & 0 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -K_d G_6 & -1 & 0 & K_d G_6 & 1 \\ -G_1 & G_1 & 0 & -(G_4 + G_6) & G_4 & 0 & G_7 & 0 \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \\ V_6 \\ V_7 \\ V_8 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ V_x \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \quad (4)$$

Using octave we get the following data:

Name	Value [V]
V(1)	0.000000
V(2)	0.000000
V(3)	0.000000
V(4)	0.000000
V(5)	0.000000
V(6)	8.394437
V(7)	-0.000000
V(8)	-0.000000

Table 4: Constants provided by Python. The variables are of type *voltage* and expressed in Volt.

Name	Value [mA]
@G1[i]	0.000000
@C[current]	-0.002767
@R1[i]	0.000000
@R2[i]	0.000000
@R3[i]	0.000000
@R4[i]	0.000000
@R5[i]	2.767263
@R6[i]	0.000000
@R7[i]	0.000000

Table 5: Constants provided by Python. A variable preceded by @ is of type *current* and expressed in Ampere.

## 2.3 Natural Solution

In this section we will start by analyzing the natural solution , where t varies from 0 to 20 ms, by using the equivalent resistance we calculated before.

As  $V_0 = V_x$ , the natural solution of the capacitor is

$$V_{6n}(t) = V_x e^{-(t)/CR_{eq}} \quad (5)$$

We can now plot the graph of the solution for t ranging from 0 to 20 ms:

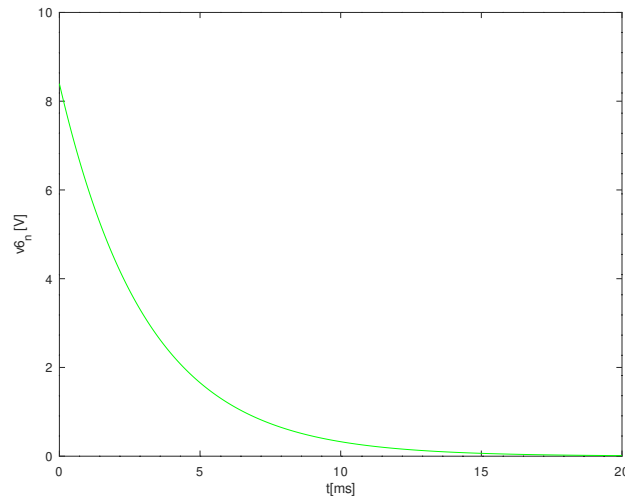


Figure 2: .

## 2.4 Forced Solution

The nodal analysis of this circuit, is done with the source tension phasor being equal to 1 and the condenser having an impedance of  $\frac{1}{j\omega c}$ . After this, we make the same analysis, which can be represented by the following matrix, taking the imaginary components as the real values:

$$\begin{bmatrix} G_1 & -(G_1 + G_2 + G_3) & G_2 & 0 & G_3 & 0 & 0 & 0 \\ 0 & K_b + G_2 & -G_2 & 0 & -K_b & 0 & 0 & 0 \\ 0 & K_b & 0 & 0 & -(K_b + G_5) & Y_c + G_7 & 0 & -Y_c \\ 0 & 0 & 0 & G_6 & 0 & 0 & -(G_6 + G_7) & G_7 \\ 1 & 0 & 0 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -K_d G_6 & -1 & 0 & K_d G_6 & 1 \\ 0 & G_3 & 0 & -G_4 & -(G_3 + G_4 + G_5) & G_5 + Y_c & G_7 & -(G_7 + Y_c) \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \\ V_6 \\ V_7 \\ V_8 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 1 \\ 0 \\ 0 \end{bmatrix}$$

Name	Value [V]
V(1)	1.000000
V(2)	0.950954
V(3)	0.845204
V(4)	0.000000
V(5)	0.958017
V(6)	0.560857
V(7)	0.372345
V(8)	0.558661

Table 6: Constants provided by Python. The variables are of type *voltage* and expressed in Volt.

## 2.5 Total Solution

We can obtain  $v_6(t)$  (the total solution), by superimposing the natural(section 2.2.) and forced solutions (2.3) obtained before. Since we determined the function of the natural solution in section 2.2 we will now determine the forced solution.

The complex equation of the phasor can be written as:

$$v_6 f(t) = V_6 \sin(\omega t + \varphi_s) \quad (6)$$

In the equation above,  $\omega = 2\pi f = 2000\pi$  and  $\Phi$  is the argument of

By superimposing the equations of both the natural and forced solutions, we obtain this equation:

$$v_6(t) = v_6 n(t) + V_6 f(t) = V_6 \sin(\omega t + \varphi_s) + V_x e^{-(1)/R_s C} \quad (7)$$

By plotting this function, for t in range of -5 to 20 ms, we get the graph below:

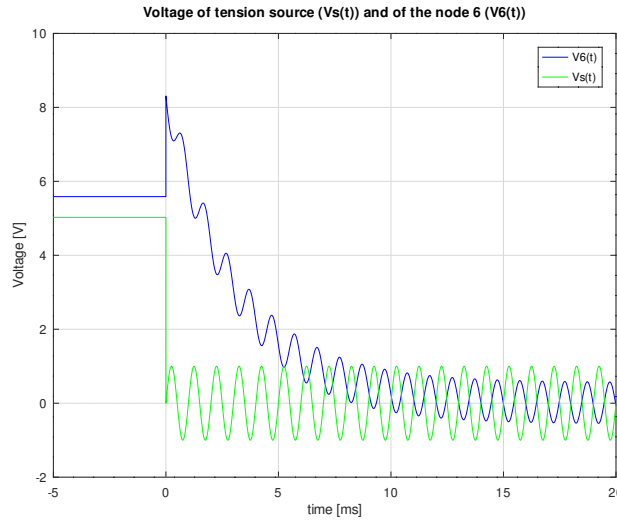


Figure 3: .

## 2.6 Frequency Response

Lastly, we will analyze the frequency response of each phasor, by applying the same method used in section 2.4, with the exception that  $Y_c$  will remain as a variable ( $Y_c(f) = j2\pi fC$ ).

Considering:

$$V_c(t) = V_6(t) - V_8(t) \quad (8)$$

Next we can plot the graphs of  $V_c(t)$  and  $V_6(t)$ , as functions of  $f$  in range of  $10^{-1}$  to  $10^6$  Hz, which will be defined as logarithmic scales.

The magnitude plot has values in dB, which respect the following equation:

$$V_{dB} = 20 \log_{10}(V) \quad (9)$$

The graphics of the plotted functions  $v_c(f)$  and  $v_6(f)$ :

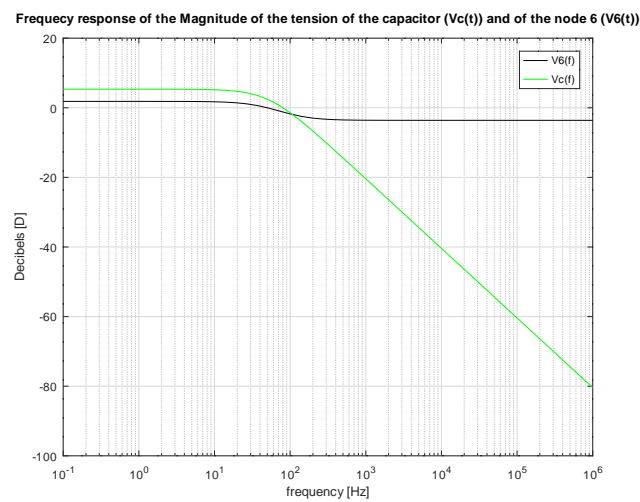


Figure 4: .

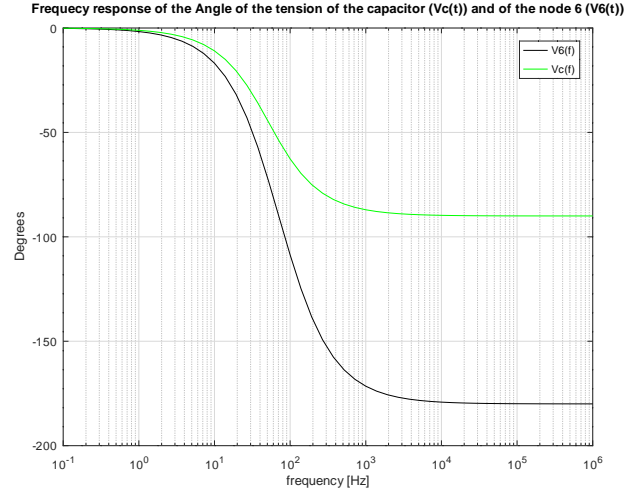


Figure 5: .

### 3 Simulation Analysis

#### 3.1 Operating point Analysis (for $t_{i0}$ and $V_s(t) = 0$ )

Ngspice was used to perform an operating point analysis for  $t_{i0}$  (obtaining the table below) and by setting  $v_s = 0$  and replacing the capacitor with a voltage source  $V_x = V_6 - V_8$ , the voltage and current values, present in tables below, were obtained.



Name	Value [mA]
@c[i]	0.000000e+00
@g1[i]	-2.54235e-04
@r1[i]	2.428134e-04
@r2[i]	-2.54235e-04
@r3[i]	-1.14215e-05
@r4[i]	1.174094e-03
@r5[i]	-2.54235e-04
@r6[i]	9.312805e-04
@r7[i]	9.312805e-04
v(1)	5.026261e+00
v(2)	4.779742e+00
v(3)	4.248216e+00
v(4)	4.815245e+00
v(5)	5.586461e+00
v(6)	-1.87151e+00
v(7)	-2.80798e+00
v(8)	-1.87151e+00

Table 7: Current and voltage results obtained with Ngspice for  $t_i 0$

Name	Value [mA]
@g1[i]	2.140176e-18
@r1[i]	-2.04403e-18
@r2[i]	2.140176e-18
@r3[i]	9.614768e-20
@r4[i]	4.331265e-19
@r5[i]	-2.76726e-03
@r6[i]	4.336809e-19
@r7[i]	8.998149e-19
v(1)	0.000000e+00
v(2)	2.075218e-15
v(3)	6.549660e-15
v(4)	1.776357e-15
v(5)	8.394437e+00
v(6)	-8.71527e-16
v(7)	-1.77636e-15
v(8)	-8.71527e-16

Table 8: Current and voltage results obtained with Ngspice for  $V_s = 0$

### 3.2 Transient Analysis - Natural Response

The first step in order to compute the natural response of  $v_6$  is to set  $v_s(t) = 0$  and set initial conditions so that  $v_6$  and  $v_s$  have the same values obtained in table 10, which ensures that in the start of the transient analysis the capacitor is fully charged. The graphic in figure 11 was obtained by executing a transient analysis, with  $t$  ranging from 0 to 20 ms.

By analyzing the graphic we can see a quick drop in voltage from just a little above 8 ms to 0, which is due to the fact that the capacitor is just discharging and since there are no independent voltage sources, there is no voltage being provided to  $v_6$ .

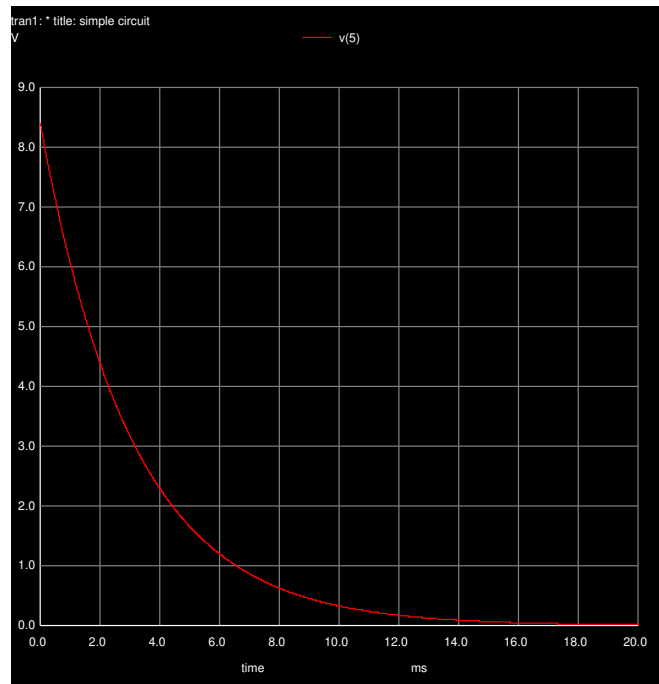


Figure 6: Natural response

### 3.3 Transient Analysis - total Response

Taking in consideration that  $v_s(t) = \sin(2\pi ft)$  and  $f = 1000\text{Hz}$ , the total response can be obtained by performing a transient analysis and the figure 12 can be obtained by plotting  $v_s(t)$  and  $v_6(t)$ .

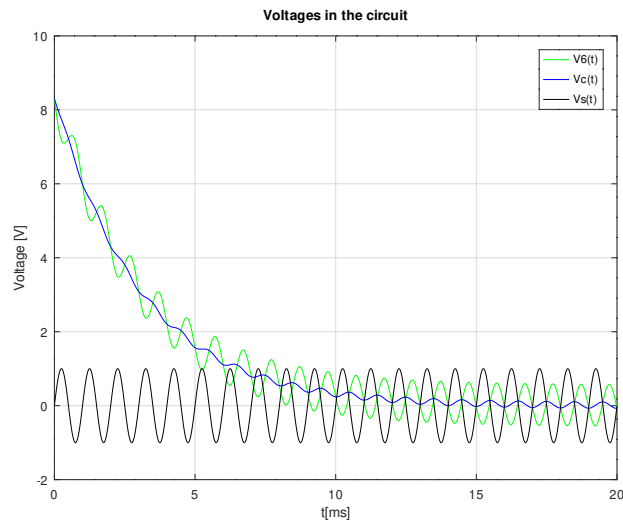


Figure 7: Stinulus voltage , $v_s(t)$ , shown in black and total response,  $v_6(t)$ , shown in green

### 3.4 Frequency Response

By excuting a frequency sweep, throughout the length of the interval  $[0.1, 1000000]$ , we are able to plot the magnitude and phase, which appear below respectively.

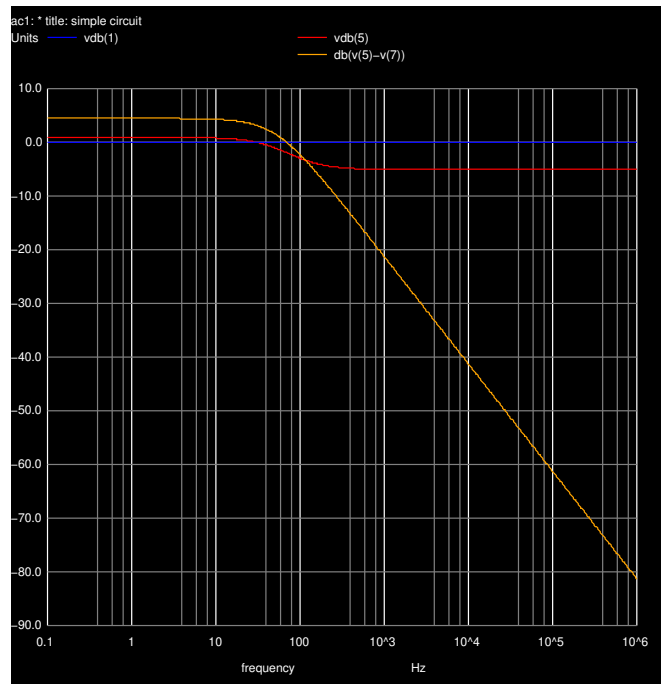


Figure 8: Magnitude plot

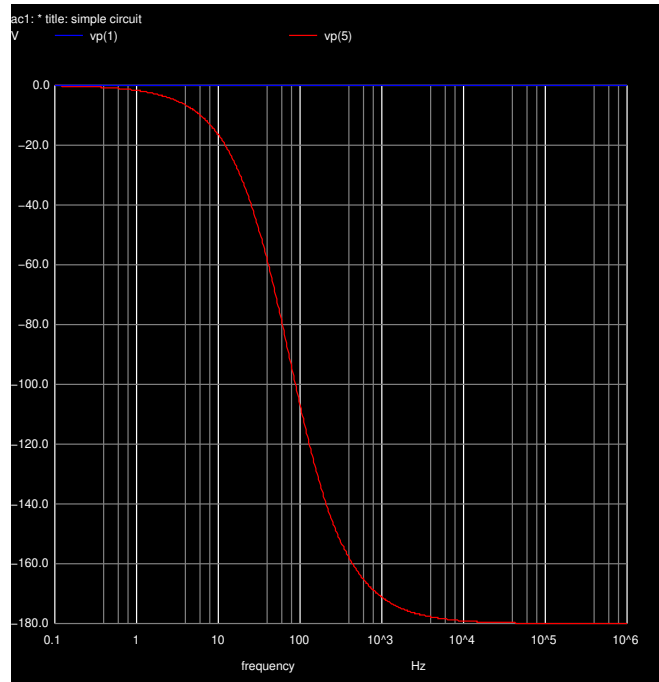


Figure 9: Phase plot

## 4 Conclusion

### 4.1 $V_s$ is constant an non-null

In conclusion, the values we obtained in the simulation agree with the theoretical values obtained for the dc voltage source  $V_s$ , showing negligible errors. These are excellent results which show that the methods we used are legitimate, as expected, and can be used by the simulation program to simulate the circuit.

Nevertheless, the simulator and methods used might produce solutions, which may not occur in a real circuit due to various factors including the Joule effect in the cables that connect the components in the circuit, and other random and systematic errors, which compromise the precision and accuracy of the results. However, the results might still be a good approximation of the real values, which can be verified by analyzing a real representation of the circuit. It's also safe to say that while some relative errors were very close to zero, or in some cases even zero, this is due to approximations made by the simulator (ngspice) and octave.

Name	Value [mA]
V(1)	5.026261
V(2)	4.779742
V(3)	4.248215
V(4)	0.000000
V(5)	4.815244
V(6)	5.586461
V(7)	-1.871505
V(8)	-2.807975

Table 9: Theoretical voltage results obtained with octave

Name	Value [mA]
@c[i]	0.000000e+00
@g1[i]	-2.54235e-04
@r1[i]	2.428134e-04
@r2[i]	-2.54235e-04
@r3[i]	-1.14215e-05
@r4[i]	1.174094e-03
@r5[i]	-2.54235e-04
@r6[i]	9.312805e-04
@r7[i]	9.312805e-04
v(1)	5.026261e+00
v(2)	4.779742e+00
v(3)	4.248216e+00
v(4)	4.815245e+00
v(5)	5.586461e+00
v(6)	-1.87151e+00
v(7)	-2.80798e+00
v(8)	-1.87151e+00

Table 10: Simulation results obtained with Ngspice

#### 4.2 $V_s = 0$ and capacitor are replaced by the voltage source

By analysing the tables below, we can see a pattern of repeated voltages, whose order of magnitude is around  $10^{-5}$ :

Name	Value [mA]
V(1)	0.000000
V(2)	0.000000
V(3)	0.000000
V(4)	0.000000
V(5)	0.000000
V(6)	8.394437
V(7)	-0.000000
V(8)	-0.000000

Table 11: Theoretical voltage results obtained with octave

<b>Name</b>	<b>Value [mA]</b>
@g1[i]	2.140176e-18
@r1[i]	-2.04403e-18
@r2[i]	2.140176e-18
@r3[i]	9.614768e-20
@r4[i]	4.331265e-19
@r5[i]	-2.76726e-03
@r6[i]	4.336809e-19
@r7[i]	8.998149e-19
v(1)	0.000000e+00
v(2)	2.075218e-15
v(3)	6.549660e-15
v(4)	1.776357e-15
v(5)	8.394437e+00
v(6)	-8.71527e-16
v(7)	-1.77636e-15
v(8)	-8.71527e-16

Table 12: Simulation results obtained with Ngspice