Circuits Theory and Electronic Fundamentals

Integrated Master in Engineering Physics, IST, University of Lisbon

Lab 2: RC Circuit Analysis

Alexandre Sequeira (96503), Duarte Marques (96523), João Chaves (96540)

April 8th 2021

Contents

1 Introduction

The objective of this laboratory assignment is to analyse the RC circuit shown in Figure 1. As shown below, the nodes have been numbered, current directions have been assigned to all branches and potential $0V$ has been assigned to one of the nodes. By running the Python script `t2_datagen.py`, the values shown in Table 1 have been obtained.

In Section 2, a theoretical analysis of the circuit and the results obtained with the Octave math tool are presented. In Section 3, the results obtained using the Ngspice simulation tool are shown. The conclusions of this study are outlined in Section 4, in which the theoretical results obtained in Section 2 are compared to those presented in Section 3.

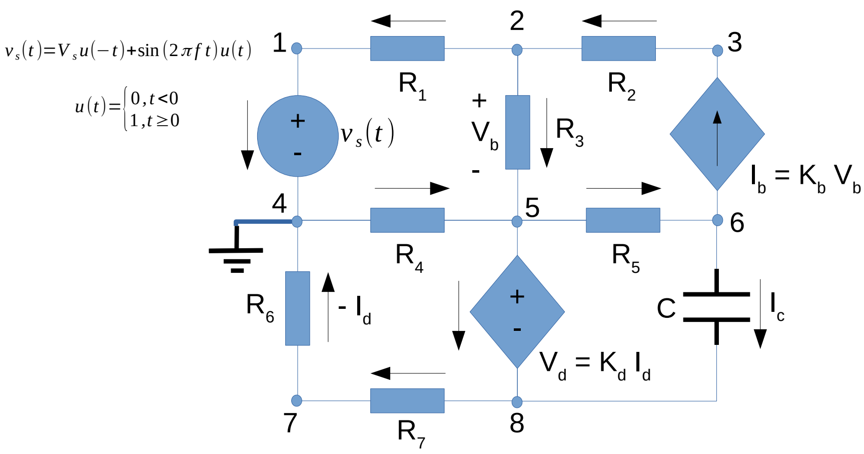


Figure 1: Circuit to be analysed in this laboratory assignment.

Designation	**Value [V, kΩ, mS or μF]**
R_1	1.04053890347
R_2	2.00185929606
R_3	3.06593231919
R_4	4.15163583349
R_5	3.03409481751
R_6	2.05654586148
R_7	1.00587575204
V_s	5.16821048288
C	1.0127707267
K_b	7.29055867767
K_d	8.22649929708

Table 1: Values obtained by running the file `t2_datagen.py`. Resistances R_i and constant K_d are in kΩ, voltage V_s is in volts, capacitance C is in microfarads and constant K_b is in milisiemens.

2 Theoretical Analysis

2.1 Exercise 1

In this exercise, the circuit shown in Figure 1 is analysed theoretically for $t < 0$, by using the node method. The Kirchhoff Current Law (KCL) states that the sum of the currents converging or diverging in a node is null. Using KCL and Ohm's Law (which can also be written as $I = VG$) in nodes not connected to voltage sources and additional equations for nodes related by voltage sources, it is possible to obtain a linear system from which the node voltages V_1 to V_8 are obtained. Using these values and Ohm's Law, the currents in all branches can be determined.

It is worth mentioning that the current passing through the capacitor is given by $i_c = C\frac{dv_c}{dt}$. However, it is assumed that the voltages in the capacitor's terminals have already achieved static values a long time ago, thus $i_c = 0$.

The following linear system is obtained:

$$\begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -\frac{1}{R_1} & \frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3} & -\frac{1}{R_2} & 0 & -\frac{1}{R_3} & 0 & 0 & 0 \\ 0 & -K_b-\frac{1}{R_2} & \frac{1}{R_2} & 0 & K_b & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & -\frac{1}{R_3} & 0 & 0 & \frac{1}{R_3}+\frac{1}{R_4}+\frac{1}{R_5} & -\frac{1}{R_5} & -\frac{1}{R_7} & \frac{1}{R_7} \\ 0 & K_b & 0 & 0 & -\frac{1}{R_5}-K_b & \frac{1}{R_5} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{R_6}+\frac{1}{R_7} & -\frac{1}{R_7} \\ 0 & 0 & 0 & 0 & 1 & 0 & \frac{K_d}{R_6} & -1 \end{pmatrix} \begin{pmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \\ V_5 \\ V_6 \\ V_7 \\ V_8 \end{pmatrix} = \begin{pmatrix} V_s \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \quad (1)$$

The matrix shown above isn't symmetrical because of the presence of dependent sources in this circuit. The values obtained by solving the linear system above, using Octave, are shown in Table 2.

Designation	**Value [A or V]**
I_1	-2.3414328285E-04
I_2	-2.4510896948E-04
I_3	-1.0965686632E-05
I_4	-1.1942751099E-03
I_5	-2.4510896948E-04
I_6	-9.6013182701E-04
I_7	-9.6013182701E-04
I_b	-2.4510896948E-04
I_c	4.3368086899E-19
I_{V_s}	-2.3414328285E-04
I_{V_d}	-9.6013182701E-04
V_1	5.1682104829E+00
V_2	4.9245752881E+00
V_3	4.4339016190E+00
V_5	4.9581953411E+00
V_6	5.7018791952E+00
V_7	-1.9745551353E+00
V_8	-2.9403284589E+00

Table 2: Values of node voltages (in volts) and currents (in amperes). Current I_i corresponds to the current passing through resistance R_i. Node 4 is connected to GND, thus it isn't necessary to show its voltage value ($V_4 = 0$) above.

2.2 Exercise 2

In this exercise, the goal is to obtain R_{eq}, the value of the equivalent resistance as seen from the capacitor's terminals. According to Thévenin's Theorem, it is possible to replace the linear sub-circuit connected to the capacitor's terminals by a voltage source connected with the resistor. In order to calculate R_{eq} by Thévenin's Theorem, we must have $V_s = 0$ (all independent sources of the sub-circuit connected to the capacitor's terminals must be switched off). By replacing the capacitor with a voltage source $V_x = V_6 - V_8$, where V_6 and V_8 are the voltages determined in Section 2.1, the current I_x supplied by V_x can be calculated by applying the node method to this new circuit - using Ohm's Law, the equivalent resistance is computed as $R_x = \frac{V_x}{I_x}$. The linear system and the node voltages and branch currents in this case are the following:

$$
\begin{pmatrix}
1 & 0 & 0 & -1 & 0 & 0 & 0 & 0 \\
-\frac{1}{R_1} & \frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3} & -\frac{1}{R_2} & 0 & -\frac{1}{R_3} & 0 & 0 & 0 \\
0 & -K_b-\frac{1}{R_2} & \frac{1}{R_2} & 0 & K_b & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & K_b-\frac{1}{R_3} & 0 & 0 & \frac{1}{R_3}+\frac{1}{R_4}-K_b & 0 & -\frac{1}{R_7} & \frac{1}{R_7} \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & -1 \\
0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{R_6}+\frac{1}{R_7} & \frac{1}{R_7} \\
0 & 0 & 0 & 0 & 1 & 0 & -\frac{K_d}{R_6} & -1
\end{pmatrix}
\begin{pmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \\ V_5 \\ V_6 \\ V_7 \\ V_8 \end{pmatrix}
=
\begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ V_x \\ 0 \\ 0 \end{pmatrix}
\tag{2}
$$

Designation	Value [A or V]
I_1	-0.0000000000E+00
I_2	0.0000000000E+00
I_3	-0.0000000000E+00
I_4	0.0000000000E+00
I_5	-2.8483643966E-03
I_6	0.0000000000E+00
I_7	-0.0000000000E+00
I_b	0.0000000000E+00
I_{V_x}	-2.8483643966E-03
I_{V_s}	-0.0000000000E+00
I_{V_d}	2.8483643966E-03
V_1	0.0000000000E+00
V_2	-0.0000000000E+00
V_3	0.0000000000E+00
V_5	0.0000000000E+00
V_6	8.6422076540E+00
V_7	0.0000000000E+00
V_8	-0.0000000000E+00

Table 3: Values of node voltages (in volts) and branch currents (in amperes). Current I_i corresponds to the current passing through resistance R_i.

Now, the current going through the equivalent resistor can be calculated as $I_x = I_b - I_5 = -I_{V_x}$ (KCL in node 6). It must be stated that the current going through R_{eq} (i.e., from + to - in R_{eq}) is flowing in the oposite direction of the current "passing through" voltage source V_x, i.e., the current going from + to - in V_x, thus the equation shown before.

Finally, one can compute the time constant as $\tau = R_x C$. The final results are shown in Table 4.

Designation	Value [A or V or Ω or s]
V_x	8.6422076540E+00
I_x	2.8483643966E-03
R_{eq}	3.0340948175E+03
τ	3.0728424132E-03

Table 4: Values determined for V_x [V], I_x [A], R_{eq} [Ω] and τ [s].

This procedure must be done in order to determine R_{eq}, which is used to obtain the time constant. This static analysis also allows us to obtain the initial condition $v_6(0)$, which will also be used to compute the natural and final solutions, because we may consider that, for $t = 0$, $v_s = 0$ and $V_6 - V_8 = V_x$. It is worth noting that, according to the expression for $v_s(t)$ given in Figure 1, $v_s(0) = V_s$, so the change in value for v_s would occur instantaneously afterwards, in an instant $t = \delta$; however, it is valid to consider it to be happening at $t = 0$, because it doesn't change the overall solution.

2.3 Exercise 3

Using the results from the previous exercise, we can infer that the circuit shown in Figure 1 can be simplified into a circuit with the independent voltage source, a resistance R_{eq} and the capacitor. We also have that $v_{6n}(+\infty) = 0$, because, as seen in Table 3, $v_8 = 0$, and it will continue to be that way, and the capacitor will eventually completely discharge. Thus, the general form for the wanted natural solution, as learnt in class, is given by

$$v_{6n}(t) = v_{6n}(+\infty) + [v_{6n}(0) - v_{6n}(+\infty)]e^{-\frac{t}{RC}} = v_{6n}(0)e^{-\frac{t}{RC}} \tag{3}$$

Where t stands for time and R for the (equivalent) resistance. The graph shown below is obtained by plotting Eq. 3 in Octave.

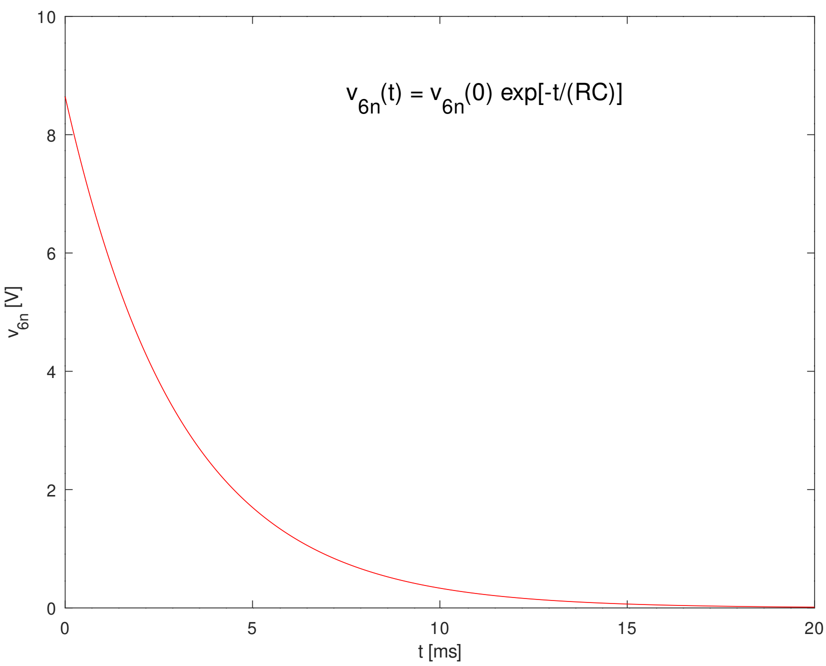


Figure 2: Natural solution $v_{6n}(t)$ in the time interval [0,20] ms.

2.4 Exercise 4

In this exercise, the forced solution for the voltage in node 6, $v_{6f}(t)$, will be determined for the time interval [0,20] ms. Because we are dealing with a forced solution with sinusoidal excitation, given by $v_s(t) = sin(2\pi f t)$, with $f = 1$kHz, it becomes much more efficient to use phasors. As suggested, a phasor voltage source $V_s = 1$ will be used. The correspondant phase is $\phi_{V_s} = 0$; therefore, in this forced solution analysis, the voltages will be considered as given by sin functions, as opposed to cos functions, as was learnt in class. This won't change the overall results, but will be important to take into account when analysing the phases plotted in Sections 2.6 and 3.5. In addition to this, C is replaced by its impedance, Z_C. This impedance is given by $Z_C = \frac{1}{j\omega C}$, with j being the imaginary unit and $\omega = 2\pi f$.

By running nodal analysis as in the previous sections, the following linear system is obtained:

$$\begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -\frac{1}{R_1} & \frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3} & -\frac{1}{R_2} & 0 & -\frac{1}{R_3} & 0 & 0 & 0 \\ 0 & -K_b-\frac{1}{R_2} & \frac{1}{R_2} & 0 & K_b & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & -\frac{1}{R_3} & 0 & 0 & \frac{1}{R_3}+\frac{1}{R_4}+\frac{1}{R_5} & -\frac{1}{R_5}-jwC & -\frac{1}{R_7} & \frac{1}{R_7}+jwC \\ 0 & K_b & 0 & 0 & -K_b-\frac{1}{R_5} & \frac{1}{R_5}+jwC & 0 & -jwC \\ 0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{R_6}+\frac{1}{R_7} & -\frac{1}{R_7} \\ 0 & 0 & 0 & 0 & 1 & 0 & \frac{K_d}{R_6} & -1 \end{pmatrix} \begin{pmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \\ V_5 \\ V_6 \\ V_7 \\ V_8 \end{pmatrix} = \begin{pmatrix} Vs \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \tag{4}$$

The complex amplitudes (phasors) in the nodes, obtained by solving the linear system above, are shown below.

Designation	**Value [V]**
V_1	1.0000000000E+00 + (0.0000000000E+00) i
V_2	9.5285888692E-01 + (3.0604609705E-17) i
V_3	8.5791815826E-01 + (6.0152522014E-16) i
V_4	0.0000000000E+00 + (0.0000000000E+00) i
V_5	9.5936405020E-01 + (-8.5138154658E-18) i
V_6	-5.6445199131E-01 + (-8.6377545528E-02) i
V_7	-3.8205780160E-01 + (3.3905477482E-18) i
V_8	-5.6892583392E-01 + (5.0488962587E-18) i

Table 5: Complex values of the phasors in the nodes (in volts).

Having the value of the phasor V_6, the respective sine function is easily obtained with Octave. It has the same frequency as the voltage source's and its phase and amplitude are given by the phasor shown in Table 5. The sinusoidal forced solution is plotted in Figure 3.

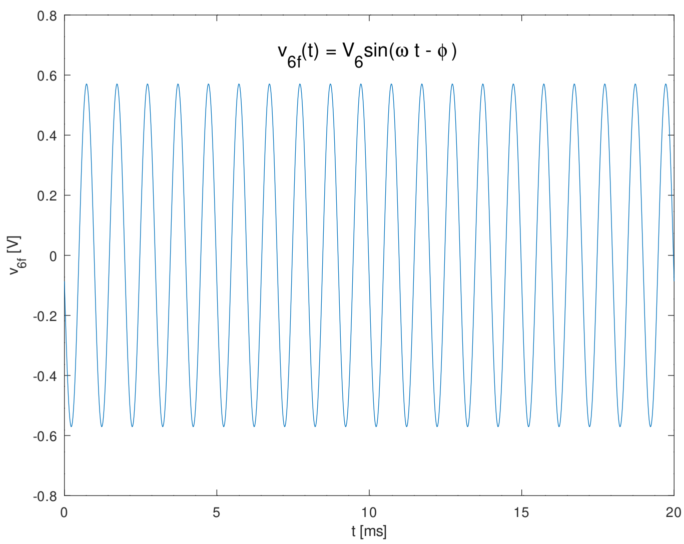


Figure 3: Forced solution $v_{6f}(t)$ in the time interval [0,20] ms. To be noted that V_6 written above refers to the absolute value of the phasor, not the phasor itself. The phase ϕ is the symmetric of the phasor's argument.

2.5 Exercise 5

In Figure 4, the final solution for $v_6(t)$ is plotted alongside $v_s(t)$, which is given by the branch function presented in Figure 1. The value of $v_6(t)$ is given by $v_{6n}(t)+v_{6f}(t)$ for $t > 0$ (obtained by superimposing the natural and forced solutions, previously determined), by the value obtained in Section 2.1 for $t < 0$ and by the value obtained in Section 2.2 for $t = 0$.

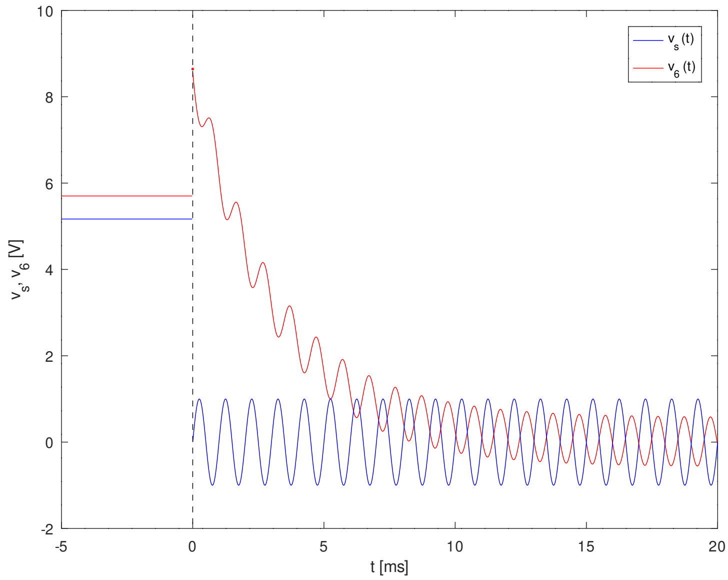
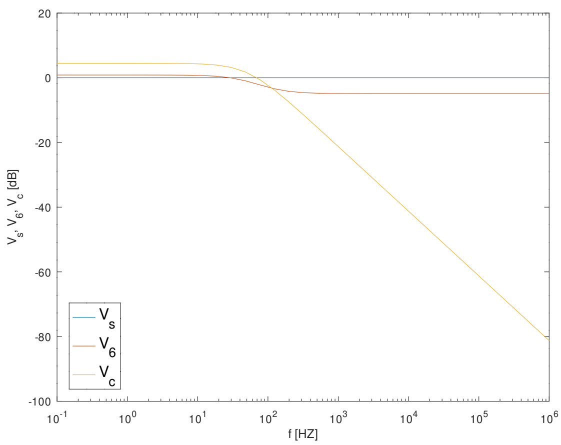


Figure 4: Final solution $v_6(t)$ and $v_s(t)$ in time interval [-5, 20] ms.

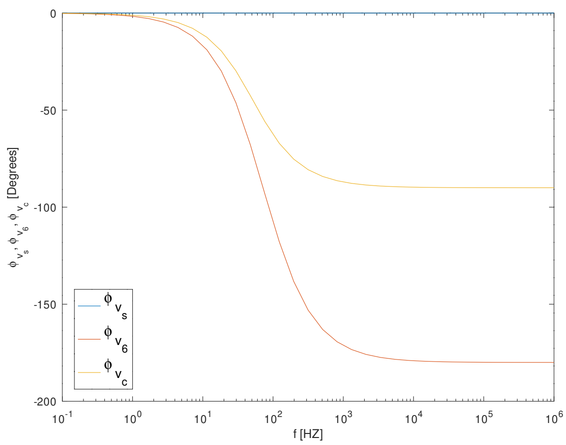
We can notice that neither v_6 nor v_s are continuous functions. What must be continuous is v_c, the voltage drop in the capacitor's terminals; the voltages in the nodes may have discontinuities in order to make sure this stays true. A capacitor cannot be discharged instantaneously: it does it through its equivalent resistor according to the time constant τ.

2.6 Exercise 6

Finally, the magnitudes and the phases of the frequency responses $v_c(f) = v_6(f) - v_8(f)$, $v_6(f)$ and $v_s(f)$ will be plotted for the frequency range 0.1 Hz to 1 MHz. The magnitude and phase of $v_c(f)$ are easily inferred by its respective branch function, given in Figure 1. In its turn, using Octave and the linear system given in Section 2.4, it was possible to get expressions for v_6 and v_8 in terms of frequency, from which the wanted plots were obtained.



(a) Magnitudes of $v_s(f)$, $v_6(f)$ and $v_c(f)$.



(b) Phases of $v_s(f)$, $v_6(f)$ and $v_c(f)$.

The results obtained in Figures (5a) and (5b) seem to behave as predicted. The magnitude and phase of v_s are constant, as they are given by the sine function shown in Figure 1. Again, it is worth mentioning that we are considering the phases of sin functions, not cos functions - this does not change the overall solutions, but it does shift the phases by -$\frac{\pi}{2}$. The impedance of the capacitor, given by $Z_c = \frac{1}{j\omega C}$, with $\omega = 2\pi f$, decreases as the frequency increases. Therefore, the magnitude of the voltage in the capacitor will tend to zero - because the graph is plotted in dB, it tends to $-\infty$. In fact, this magnitude is given by $V_c = \frac{V_s}{\sqrt{1+\omega^2 R^2 C^2}}$, thus its decrease. We can also see that the magnitude of V_6 tends to change to a particular value as the frequency increases; we know that this must be happening in a way that makes it so that the magnitude of $V_6 - V_8 (= V_c)$ tends to zero.

As for the phase of v_c, we can see that it tends to $-\frac{\pi}{2}$ rad $= -90^o$ as the frequency increases. This was to be expected, because the phase delay of the voltage in the capacitor is given by $\phi_{v_c} = \phi_{v_s} - atan(\omega RC) = -atan(2\pi f RC)$. On the other hand, the phase of v_6 seems to tend to $-\pi$ rad, i.e., the voltage in node 6 tends to be in phase opposition with v_s for high frequencies. Something like this had been observed in Figure 4, in which the final solution for $v_6(t)$ and $v_s(t)$ had been plotted for $f = 1$ kHz.

3 Simulation Analysis

3.1 Exercise 1

Similarly to Exercise 1 in the Theoretical Analysis, the voltages in all nodes and currents in all branches are obtained for $t < 0$, situation in which it is considered that these values have been static for a long time. Thus, using Ngspice, an operating point analysis is made. In Table 6, shown below, the simulated operating point results for the circuit presented in Figure 1 are shown alongside those obtained in the Theoretical Analysis. Again, currents designated below as I_i refer to the currents passing through the respective resistances, R_i.

Theoretical	
Designation	**Value [A or V]**
I_1	-2.3414328285E-04
I_2	-2.4510896948E-04
I_3	-1.0965686632E-05
I_4	-1.1942751099E-03
I_5	-2.4510896948E-04
I_6	-9.6013182701E-04
I_7	-9.6013182701E-04
I_b	-2.4510896948E-04
I_c	4.3368086899E-19
I_{V_s}	-2.3414328285E-04
I_{V_d}	-9.6013182701E-04
V_1	5.1682104829E+00
V_2	4.9245752881E+00
V_3	4.4339016190E+00
V_5	4.9581953411E+00
V_6	5.7018791952E+00
V_7	-1.9745551353E+00
V_8	-2.9403284589E+00

Simulation	
Designation	**Value [A or V]**
I_1	-2.341432828e-04
I_2	-2.451089695e-04
I_3	-1.096568663e-05
I_4	-1.194275110e-03
I_5	-2.451089695e-04
I_6	-9.601318270e-04
I_7	-9.601318270e-04
I_b	-2.451089695e-04
I_c	0.0000000000e+00
I_{V_s}	-2.341432828e-04
I_{V_d}	-9.601318270e-04
V_1	5.1682104829e+00
V_2	4.9245752881e+00
V_3	4.4339016190e+00
V_5	4.9581953411e+00
V_6	5.7018791952e+00
V_7	-1.974555135e+00
V_8	-2.940328459e+00

Table 6: Exercise 1 - comparison between theoretical analysis and operating point analysis's results. Currents are in amperes; voltages V_i are in volts.

Comparing the results, we can notice almost no differences. This was to be expected, since the circuit only contains linear components. There is only a small difference between the two values of I_c, although it is negligible. The value that should, in theory, be obtained is zero, because the voltages in the capacitor's terminals should be constant. The small value obtained with Octave must be due to computacional errors in approximations done while solving the linear system.

3.2 Exercise 2

Now, similarly to Exercise 2 in the Theoretical Analysis, we check how the system behaves when $v_s = 0$ and the capacitor is replaced by a voltage souce $V_x = V(6) - V(8)$, where the voltages $V(6)$ and $V(8)$ are taken from the values obtained in Section 3.1. This procedure must be done in order to determine the initial conditions for the voltages in nodes 6 and 8, $v_6(0)$ and $v_8(0)$, respectively, which will be used to obtain the natural and total responses of the circuit in the following sections.

Theoretical	
Designation	**Value [A or V]**
I_1	-0.0000000000E+00
I_2	0.0000000000E+00
I_3	-0.0000000000E+00
I_4	0.0000000000E+00
I_5	-2.8483643966E-03
I_6	0.0000000000E+00
I_7	-0.0000000000E+00
I_b	0.0000000000E+00
I_{V_x}	-2.8483643966E-03
I_{V_s}	-0.0000000000E+00
I_{V_d}	2.8483643966E-03
V_1	0.0000000000E+00
V_2	-0.0000000000E+00
V_3	0.0000000000E+00
V_5	0.0000000000E+00
V_6	8.6422076540E+00
V_7	0.0000000000E+00
V_8	-0.0000000000E+00

Simulation	
Designation	**Value [A or V]**
I_1	0.0000000000e+00
I_2	0.0000000000e+00
I_3	0.0000000000e+00
I_4	0.0000000000e+00
I_5	-2.848364397e-03
I_6	0.0000000000e+00
I_7	0.0000000000e+00
I_b	0.0000000000e+00
I_x	-2.848364397e-03
I_{V_s}	0.0000000000e+00
I_{V_d}	2.8483643966e-03
V_1	0.0000000000e+00
V_2	0.0000000000e+00
V_3	0.0000000000e+00
V_5	0.0000000000e+00
V_6	8.6422076540e+00
V_7	0.0000000000e+00
V_8	0.0000000000e+00

Table 7: Exercise 2 - comparison between theoretical analysis and operating point analysis's results. Currents are in amperes; voltages V_i are in volts.

As seen above, there are no differences between the values obtained in the different analysis (even though the values might not be presented with the same number of decimal points), as expected, due to the linearity of the components. Having the values of the voltages in nodes 6 and 8, we may now determine the natural solution of the system for $t > 0$, which is what will be done next.

3.3 Exercise 3

In this exercise, the natural response of the circuit (i.e., with $v_s = 0$) is simulated by using Ngspice's transient analysis mode. The values of the voltages in nodes 6 and 8 obtained before are utilized as boundary conditions, using Ngspice's directive `.ic`. Figure 6 shows the result obtained for the voltage in node 6 in the time interval [0,20] ms.

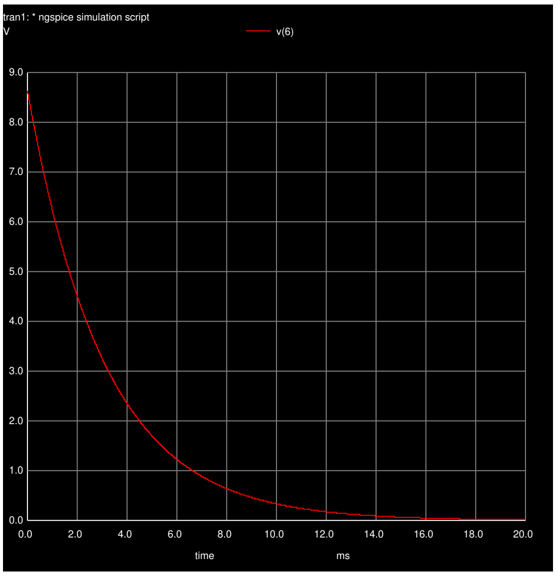


Figure 6: Natural solution $v_{6n}(t)$ (in volts) in the time interval [0,20] ms.

As we can see, the solution is incredibly similar to the one obtained in the Theoretical Analysis, i.e, an exponential, with the initial value given by $v_6(0)$ determined by replacing the capacitor with the voltage source V_x, that decays with time at an apparently equal rate.

3.4 Exercise 4

Having obtained the inicial conditions, we now consider the voltage given in Figure 1 for $t > 0$, $v_s(t) = sin(2\pi ft)$, in order to obtain the total response on node 6 (natural solution + forced solution) by using Ngspice. In Figure 7, the voltages in two nodes are represented: the voltage v(6) in node 6, i.e., the response, and the voltage in node 1, v(1), which corresponds to the stimulus, because the voltage source connects node 1 to GND, as seen in Figure 1. These are both plotted below for $f = 1$ kHz.

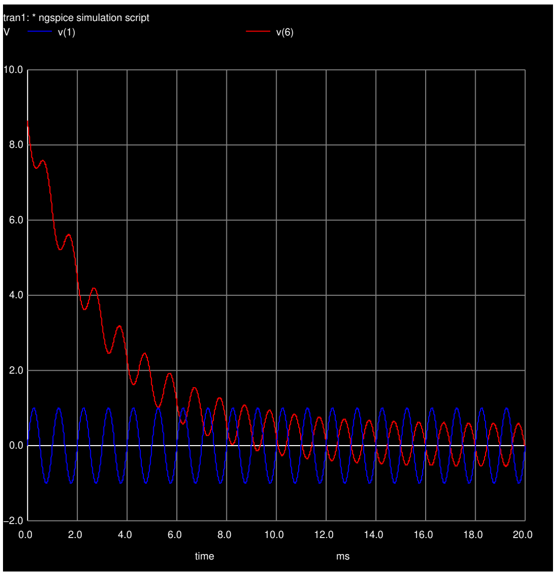
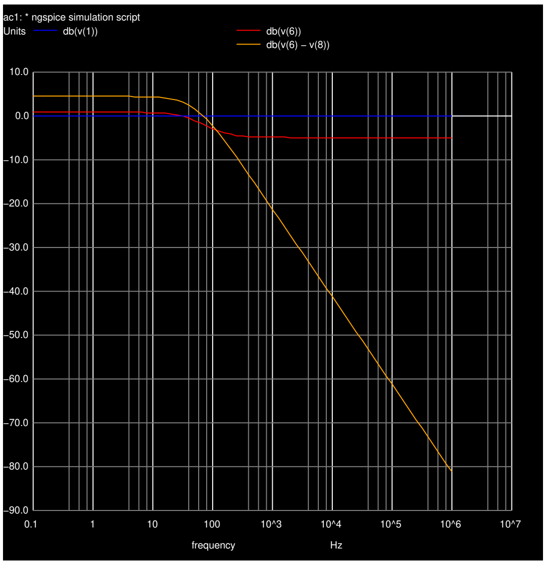


Figure 7: Transient analysis - total response on node 6, $v_6(t)$, and stimulus, $v_s(t) = v_1(t)$, both in volts, in time interval [0,20] ms and for $f = 1$ kHz.

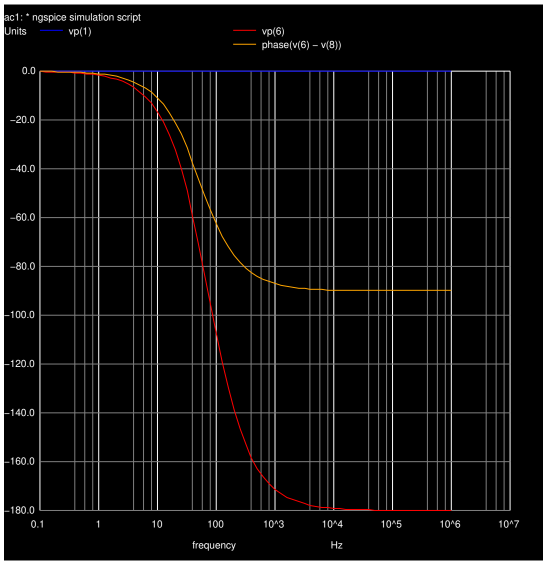
As expected, the plot of the total response corresponds to the sum of an exponential and a sinusoidal function. Both graphs look exactly the same as the one obtained in the theoretical results.

3.5 Exercise 5

In this last section, the frequency analysis was performed on the circuit for frequencies ranging from $f = 0.1$ Hz to $f = 1$ MHz. In Figure (8a), the magnitude responses for v_s, v_6 and v_c are plotted in dB and, in Figure (8b), the respective phases in degrees are all represented. Both graphs use a frequency logscale.



(a) Frequency analysis - magnitudes of $v_s(f) = v_1(f)$, $v_6(f)$ and $v_c(f) = v_6(f) - v_8(f)$ in frequency interval [0.1,10^6] Hz and in dB.



(b) Frequency analysis - phases of $v_s(f)$, $v_6(f)$ and $v_c(f) = v_6(f) - v_8(f)$ in frequency interval [0.1,10^6] Hz and in degrees.

Having obtained graphs incredibly similar to those obtained in Section 2.6 of the Theoretical Analysis, the conclusions regarding these solutions are the same. Firstly, in Figure (8a), we can verify what was learnt in class, since v_c is inversely proportional to the frequency and so, when f increases, v_c tends to zero, thus it tends to $-\infty$ in dB. The phase is also explained by the limit of the $-atan$ when f tends to ∞, as discussed before - it tends to -90^o. As expected, the magnitude and phase of $v_s(= v_1)$ are constant. In contrast, those of v_6 change and depend on the frequency.

For lower frequencies, meaning high impedance on the capacitor, it behaves similarly to a DC circuit, which results in almost constant amplitudes and phases. When $\omega^2 R_{eq}^2 C^2$ gets bigger, we observe a shift in behaviour, as we start noticing v_6's dependence on the frequency. When we aproach high frequencies, meaning low impeadence in the capacitor, it starts behaving as a short circuit and so the amplitude of v_6 should tend to the amplitude of v_8 and its phase tends to -180^o.

4 Conclusion

In this laboratory assignment, the objective of analysing the given RC circuit in different ways has been achieved. Static, time and frequency analysis have been performed both theoretically, using the Octave maths tool, and by circuit simulation, using the Ngspice tool. It is possible to verify that the simulation results matched the theoretical results precisely, with a negligible exception in Section 2.1. 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 shall not differ.

For more complex components, like transistors, it should be expected that the theoretical and simulation models could differ, but this is not the case in this lab assignment.