Circuit Theory and Electronics Fundamentals

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

Laboratory 5 Report

Group 7

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June 6th, 2021

Contents

1 Introduction

The objective of this laboratory assignment is to design a bandpass filter circuit using a Operational Amplifier (A741), keeping in mind that it must be cost efficient. The equation utilized for the figure of merit can be seen in Equation 1. The circuit and its organization can be seen in Figure 1. The values used in this circuit for the resistors and capacitor can be found in Table 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.

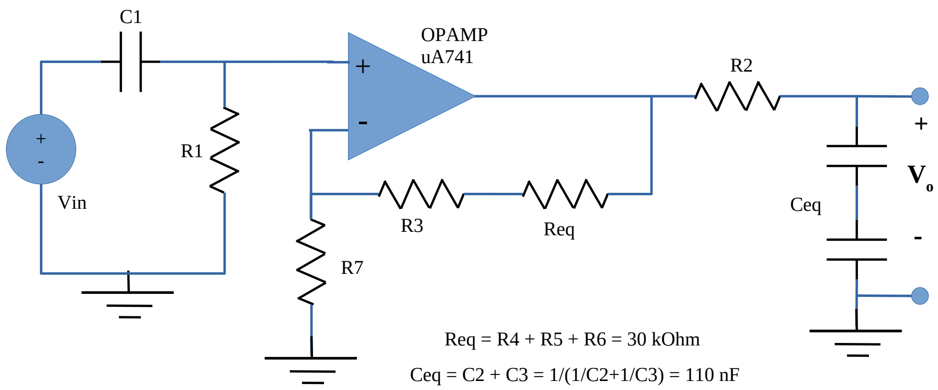

Figure 1: Circuit topography

Name	Value
R_1	1k Ohm
R_2	1k Ohm
R_3	100k Ohm
R_4	10k Ohm
R_5	10k Ohm
R_6	10k Ohm
R_7	1k Ohm
C_1	220n F
C_2	220n F
C_3	220n F

Table 1: Resistor and Capacitor values used in the circuit.

$$Merit = \frac{1}{Cost + FrequencyDeviation + GainDeviation + 10^{-6}} \tag{1}$$

2 Theoretical analysis

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

This circuit consists of an AMP-OP 741 and several resistances and capacitors. To analyse this circuit we considered the AMP-OP to be ideal (Zi = infinite and Zo = 0) and then we used nodal and mesh methods to derive the following equations:

$$|Z_i| = |Z_{C1} + R1//\infty| = |Z_{C1} + R1| \tag{2}$$

$$|Z_o| = |Z_{Ceq}//(R2 + R3 + Req//0)| = |Z_{Ceq}//R2| \tag{3}$$

$$\begin{cases} v_- = v_+ = \frac{R1}{R1+Z_{C1}} v_i \\ v_A = \left(1 + \frac{R3+Req}{R7}\right) v_- \\ v_o = \frac{Z_{Ceq}}{Z_{Ceq}+R2} v_A \end{cases} \tag{4}$$

To obtain the central frequency, we calculated the average between the High Cut-off frequency (wh) and the Low Cut-off frequency (wl):

$$\omega_0 = \sqrt{\omega_L * \omega_H} \tag{5}$$

With these parameters we we're able to obtain a bandpass filter and by solving the previously presented equations we reached the following characteristics and frequency response graphic for the filter:

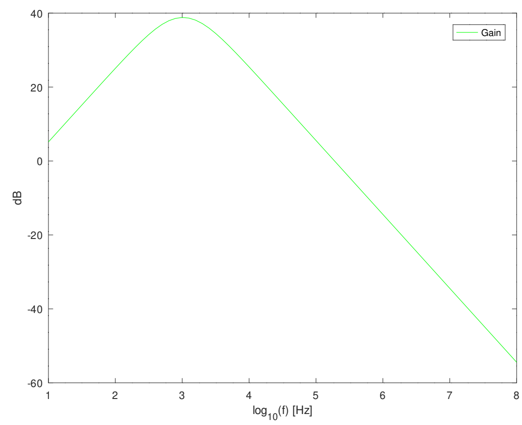

Figure 2: Theoretical frequency response.

Name	Value
Gain	87.313116 V
Gain dB	38.821590 dB
Central Frequency	1000.000000 Hz
Lower Cut Off Frequency	398.107171 Hz
Higher Cut Off Frequency	2511.886432 Hz
Gain Deviation	-1.178410 dB
Frequency Deviation	0.000000 Hz
Bandwidth	2113.779261 Hz

Table 2: Voltage gain, bandwidth, central frequency, frequency and gain devitions.

Name	Value
Input Impedance	1234.241962 Ohm
Output Impedance	822.637497 Ohm

Table 3: Absolute values for input and output impedances.

3 Simulation Analysis

In this section the steps that were made on Ngspice to simulate the bandpass filter will be described. Making use of an OP-AMP and the available components, our focus on the simulation was finding the best values to simulate a bandpass filter with the required characteristics. Said characteristics were the central frequency, which needed to be as close to 1000 Hz as possible, the gain which should be around 40 dB and the output/input impedances.

Starting with the circuit, a circuit was designed using the components available. Then, making use of the available components, different resistors and capacitors in order to reach the requirements of the bandpass filter. The final results are presented in the following table:

Name	Value
Gain	86.7451 V
Gain dB	38.7649 dB
Central Frequency	991.316 Hz
Lower Cut Off Frequency	405.07 Hz
Higher Cut Off Frequency	2426.02 Hz
Gain Deviation	1.2351 dB
Frequency Deviation	8.68415 Hz
Bandwidth	2020.95 Hz

Table 4: Absolute values for input and output impedances of the circuit.

As can be seen in Table 4 this circuit filters both high and low frequencies, which was one of the goals of said circuit. Moreover, we can see that both the central frequencies and gain come close to the desired values, being this result of work made to optimize their values.

Looking at the input impedance, where a high value was desired in order to get the voltages of Vin and In – as close as possible, we can see that this was accomplished in the Table 5.

Name	Value
Input Impedance	1234.31
Output Impedance	825.666

Table 5: Input and output impedances of the circuit.

Moving on to the output impedance, this one should be as low as possible, since what is desired is a high output voltage. To measure the output impedance, a voltage source was used, being its value relatively low as can be seen in the table above

Computing the cost and the quality of the passband filter, a figure of merit was calculated, as can be seen in Table 6, allowing us to understand how efficient our BPF was. An effort was made to optimize its value, trying to make this BPF as good as possible in terms of quality/price.

Name	Value
Cost	133.66
Merit	0.00069754

Table 6: Cost and figure of merit of the simulated circuit.

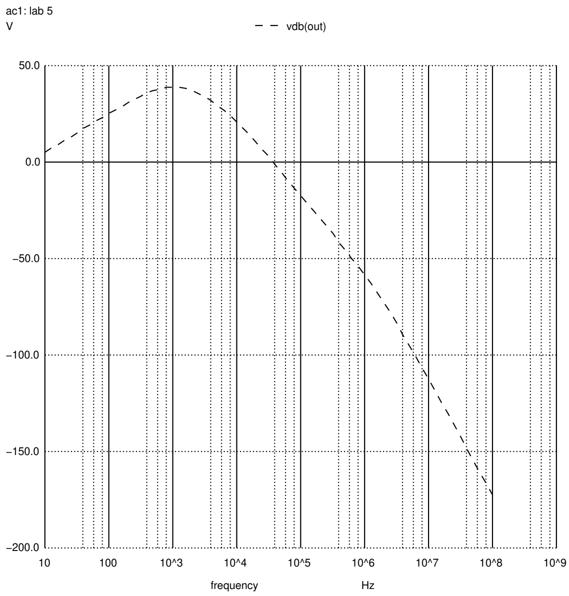

Figure 3: Simulated frequency response.

4 Octave and Ngspice Comparison

In this section a comparison is made between the results obtained on Ngspice (simulation) and the results using a simpler model on Octave (theorical analysis). The results obtained were the following:

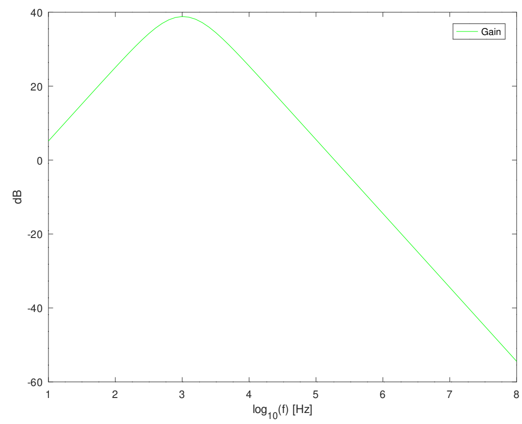

Figure 4: Theorical frequency response.

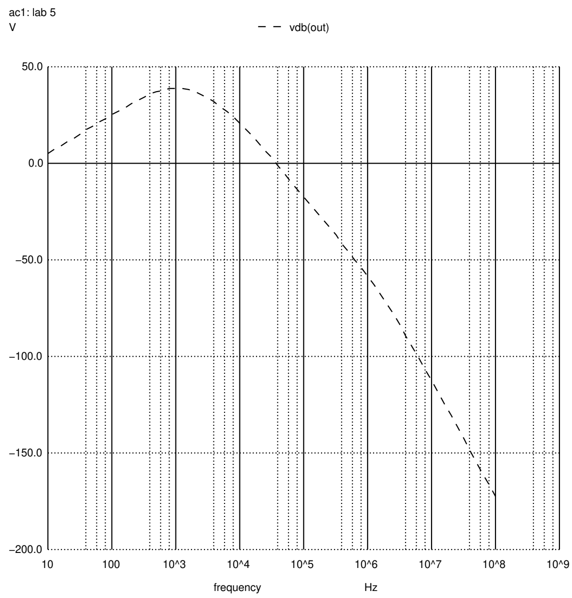

Figure 5: Simulated frequency response.

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Table 7: Gain, frequencies, frequency deviation and input/output impedances. To the left we can observe the results from Octave and on the right the results from Ngspice.

As to be expected, there is some discrepancy due to the differences in the models used to describe the OP-AMP. Taking a closer look at the table, we can see that the output impedances are different due to the fact that in Octave it is assumed the ideal OP-AMP model, in which its output impedance is null. In reality it is not zero, and the Ngspice model takes that into account. On the other hand, we can see that the input impedances and the gain are very similar, this shows how near perfect the OP-AMP is. We should also notice the small discrepancy in the Low Cut-off Frequency and in the High Cut-off Frequency (and consequently in the central frequency/ frequency deviation) which can once again be explained by the different models used to analyse the circuit.

5 Conclusion

The goal of this laboratory assignment was to make a bandpass filter, making use of an OP-AMP, as well of the components that were available. Some of the requirements were that the central frequency needed to be 1000 Hz and that the gain should be as close to 40 dB as possible. One of the main focuses of our work was, with the available components, that were limited, getting the best overall bandpass filter having in consideration the cost of every component.

As was expected, the results obtained in the simulation software Ngspice were different from the ones obtained on octave. The differences are the result of the different models used. The ngspice makes used of much more complex model than the model that was used for the theorical analysis, due to the complexity in model these non-linear components (transistors and diodes).

Taking a closer look at the OP-AMP, and looking at the parameters established on Ngspice, its complexity comes clear, making the model used by Ngspice difficult to replicate in the theorical analysis. As a result, we concluded that one of the main sources of the differences mentioned above is exactly the OP-AMP, due to its complexity.

Having all of this in mind, this lab assignment allowed us to understand how an OP-AMP works, as well as understand its complexity. It enabled us to fully comprehend how, making use of an OP-AMP and some components we can make a filter, specifically a bandpass-filter, making use of resistors and capacitors to adjust its central frequency and gain. Moreover, deepen our study in incremental models, gain and output/input impedances was also rewarding, allowing further understanding in said subjects.

As a conclusion, and despite the differences mentioned, we can state that the projected bandpass filter can fully do what it was projected to do. Making use of Ngspice, we can see that the filter has the required characteristics, so it can be stated that the goal of this laboratory assignment was accomplished. Moreover, further improvement could be made to make the gain closer to 40 dB, resulting in a higher quality of the BPF.