Circuits Theory and Eletronic Fundamentals

Aerospace Engineering Master's Degree

Laboratory Report 5

Group 56

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Contents

1 Introduction

The objetive of this laboratory assignment is to project a bandpass filter (BPF) using an OP-AMP, resistors and capacitors. A bandpass filter is a basic circuit that only allows a certain range of frequencies to pass while blocking higher and lower frequencies. In practice, the non-blocked frequencies will be amplified while the others won't. As in the previous laboratory the main challenge was to seek for the best balance between quality and cost, because the result will be the quocient of those quantities.

In this presentation we will start showing (in section 2) an illustration of the chosen configuration to the bandpass filter (Image 1) and then we present the circuit description. After that, we introduce our results such as the important comments, this is presented in the section 3. This section (section 3) is divided in three important subsections, in the subsection 3.1 is where are presented the theoretical analysis of the circuit and then, in the subsection 3.2, is presented the simulation analysis of the circuit. In the other subsection (subsection 3.3) is where the comparison between the results provided by the theoretical analysis, using octave, and the simulations results, using ngspice, is done as well as the discussion of the results.

As in the last assignment we tested more than one configuration so it is possible to conclude some aspects from experience and that is presented in the section 4.

To conclude is presented a final discussion about this laboratory assignment that can be seen in the section 5.

2 Circuit description

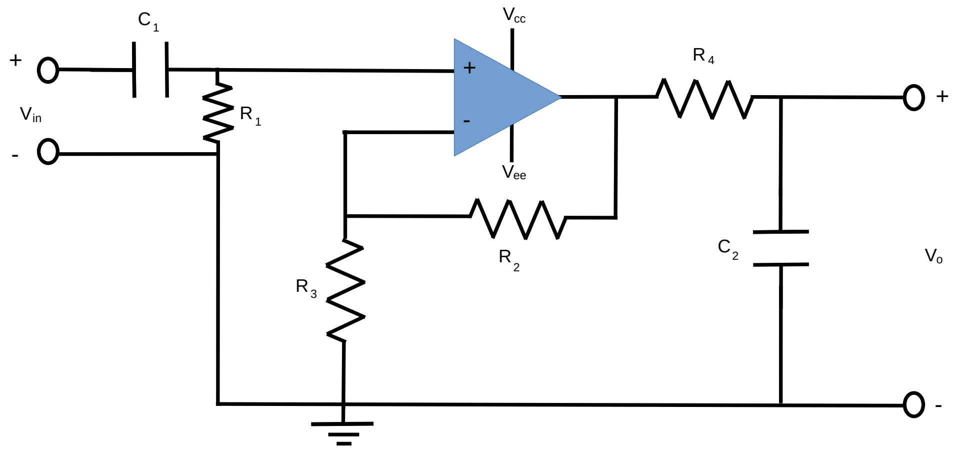


Figure 1: Circuit to be analysed in this report.

In the current section, we will describe the circuit shown in Figure 1. So in this circuit you can see our final configuration to build a bandpass filter. It is composed by 1 input voltage source, 1 OP-AMP uA741, 4 resistors R_1, R_2, R_3 and R_4 and 2 capacitors C_1 and C_2.

In the table 1 it can be seen all the components and their respective values.

Name	Value [Ω or V or F]
Vin	1.0 sin(0 0.010 1000)
R1	1000.000000
R2	150000.000000
R3	1000.000000
R4	1000.000000
C1	0.00000022000
C2	0.00000011000

Table 1: Values of the various components and parameters.

To obtain a value of R_2, which needs a subcircuit, we used a series of one 100KΩ resistor with a parallel of two 100kΩ resistors.

$$R_2 = 100 + \frac{1}{\frac{1}{100} + \frac{1}{100}} k\Omega \tag{1}$$

To obtain a value of C_2, which needs a subcircuit, we used a series of two 220nF capacitors.

$$C_2 = \frac{1}{\frac{1}{220} + \frac{1}{220}} nF \tag{2}$$

3 Circuit Analysis

3.1 Theoretical analysis

In this subsection, the circuit shown above is analysed theoretically using octave to make the calculations.

To start with, we only had to analyse the gain and the impedances (input impedance and output impedance). In order to make the gain easier to understand we started by both impedances. Analysing the circuit we compute the input impedance:

$$ZI = R_1 + \frac{1}{j \cdot w \cdot C_1} \tag{3}$$

Then to compute the output impedance:

$$ZO = R_2 || \frac{1}{j \cdot w \cdot C_2} || R_4 \tag{4}$$

In the table 2 we present the results for input and output impedances (assuming central frequency 1000 Hz) using the previous equations and octave.

Name	Value [Ω]
ZI	1000.000000-723.431560j
ZO	675.131913-723.431560j

Table 2: Impedances at 1000 Hz.

After computing impedances, we must compute the gain. The gain is given by the following expressions:

$$Gain = A_V \cdot A_H \cdot A_L \tag{5}$$

$$A_V = 1 + \frac{R_2}{R_3} \tag{6}$$

$$A_H = \frac{j * w * C_1 * R_1}{1 + j * w * C_1 * R_1} \tag{7}$$

$$A_L = \frac{1}{1 + j * w * C_2 * R_4} \tag{8}$$

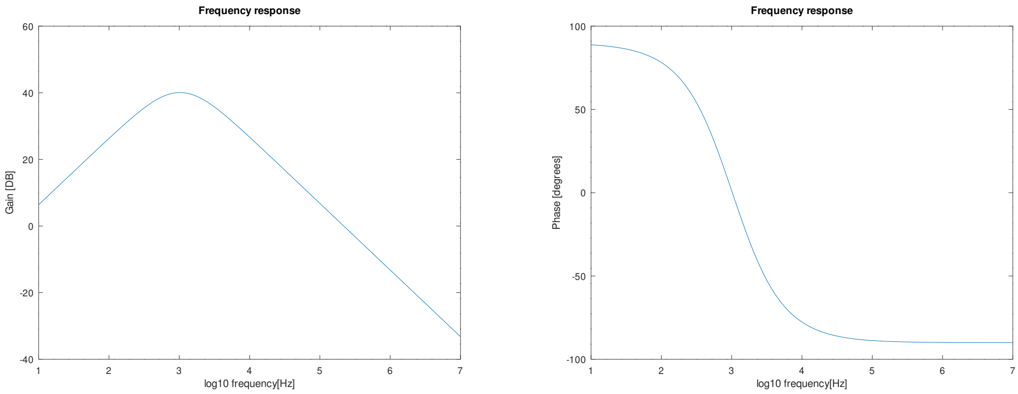
Where A_V is the gain related to the OP-AMP, A_H is the gain related to the first stage where we have an highpass filter and A_L is the gain related to the final stage where we have a lowpass filter.

And using the previous equations we obtained the gain presented in the table 3 (assuming central frequency 1000 Hz).

Name	Value [dB]
Gain	40.055703

Table 3: Gain at 1000 Hz.

To better understand the frequency response of gain, we plot the following graph 2(a), where we can see that low and high frequencies have a low gain and frequencies near to 1000 Hz have the maximum gain. This happens because in the first stage we have an highpass filter that blocks low frequencies and in the final stage we have a lowpass filter that blocks high frequencies. To ensure an high gain, we must focus obtaining an high A_V, because near the central frequency both A_H and A_L will be as close as possible to 1. We can see aswell in graph 2(b) the plot for the theoretical phase of the output voltage which is similar to a normal bandpass filter.



(a) (b)

Figure 2: (a) Gain in frequency response (b) Phase in frequency response

3.2 Simulation analysis

In this subsection, the circuit shown above is simulated with ngspice.

As in the previous subsection we have to analyse the gain and the impedances, as well as the central frequency. We start by the impedances.

To simulate in ngspice the input impedance, we must measure the voltage drop between ground and the input voltage source, and then we divide it by the current that goes through the input voltage source. To simulate the output voltage, we did other script where we turned off the input voltage source and added a voltage source in between v_o and ground.

The results obtained are presented in the tables 4 and 5 and impedances are calculated to 1000 Hz, which is the desired central fequency.

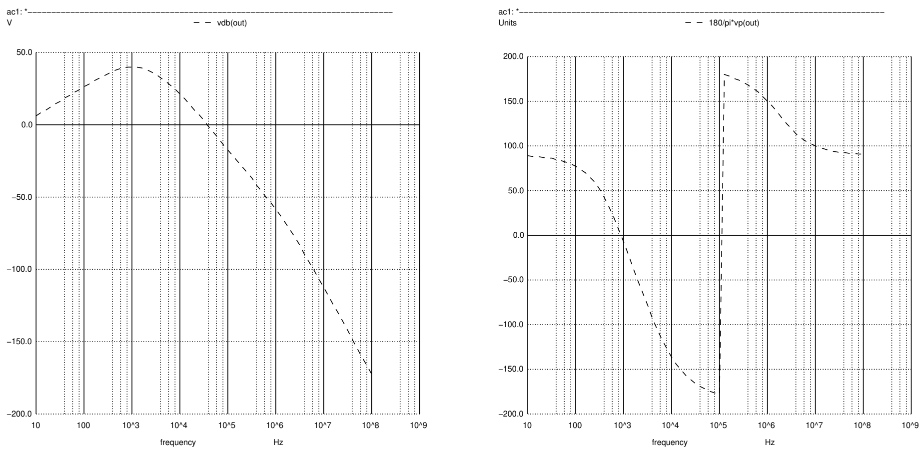
Name	**Value [Ω]**
zi	999.979 -723.583 j

Table 4: Input Impedance at 1000 Hz.

Name	**Value [Ω]**
zout	681.72 -466.75 j

Table 5: Output Impedance at 1000 Hz.

After simulating impedances, we plotted the gain in frequency response as we can see in figure 3(a) and the plot is similar to the theoretical analysis, being the reason the same as before, - it can be seen in the subsection 3.1 - the filters are blocking low and high frequencies and the high quocient of $\frac{R_2}{R_3}$ allows to have a band with high gain - where central frequency is close to 1000 Hz. The gain plot is followed by the phase plot 3(b) of the output voltage, which will be further explored while comparing the theoretical and simulation results.



(a) (b)

Figure 3: (a) Gain in frequency response (b) Phase in frequency response

Nevertheless, we had to compute the central frequency in order to later calculate its deviation. To do this we measured the maximum value of the gain and calculated the frequencies where the gain would be 3 dB lower. Finally to obtain the central frequency we did a geometric average - $\sqrt{(lowcutofffrequency) \cdot (highcutofffrequency)}$ - obtaining the following set of values - table 6:

Name	**Value [Ω]**
lowcutoff	4.036113e+02
highcutoff	2.386174e+03
centralfrequency	9.813699e+02

Table 6: Central frequency.

3.3 Comparation of results

In this subsection we will compare the results of the two previous subsections 3.1 and 3.2, more concretely we will compare the gain and the impedances.

Starting with the impedances, both impedances are similiar in theoretical and simulation analysis, because the OP-AMP is not perfect and ngspice uses a more complex models to analyse it.

Then looking to the gain response, we can see that both of them are similar, but since ngspice uses more complex methods to obtain the gain, we find some differences between them, being important the central frequency and the maximum gain value.

To finish, as we already said, we are going to compare the phase plots of both analysis. In octave we find two roots and two poles because of the presence of two capacitors, but in ngspice we have two roots and four poles. Its is consequency of the OP-AMP. In octave we consider it as an ideal one, but in fact the OP-AMP has capacitors that produce two more poles and ngspice using more complex models is capable of present them.

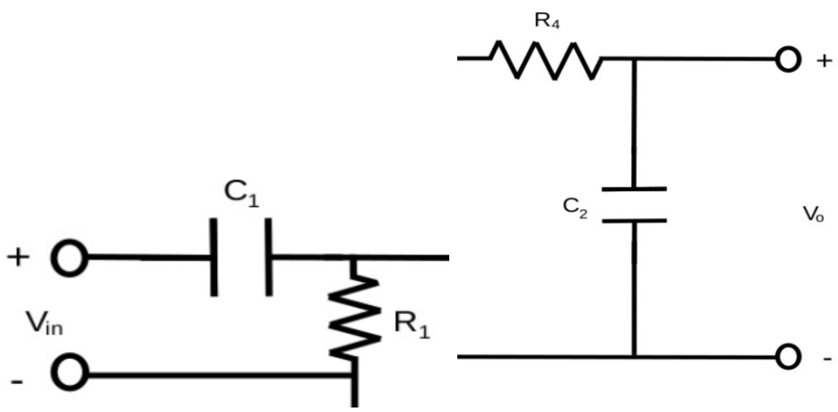
4 Discussion of results

In the past sections and subsections the circuit was analysed in order to calculate the final merit. Before this calculation we will explore some of the decisions made and the reason why.

First of all, we must look at the merit formula, that is presented in the equation 9, so we know what improvements to make in order to increase it.

$$M = \frac{1}{(cost) \cdot (gaindeviation) \cdot (centralfrequencydeviation) + 10^{-6}} \tag{9}$$

Looking at the formula 9 we can say that in order to increase the merit we had to decrease all the parameters in denominator - the cost, the gain deviation and the central frequency deviation. So now it is important to study the impact of changing the components and their respective value of the parameters mentioned before. The use of 2 capacitors - C_1 and C_2 - was essencial to achieve a bandpass filter since on a first stage, where we couple the capacitor C_1 in series with R_1 shown in figure 4(a), we produce an highpass filter, and on a second stage where we couple the C_2 in parallel with R_4 with shown in figure 4(a), where we obtain a lowpass filter. Combining this two filters we obtain a bandpass filter as desired. Also it is worth mentioning that the capacitance values interfere in the obtained results mainly in the central frequency.



(a) (b)

Figure 4: (a) Highpass filter section (b) Lowpass filter section

As for the resistances used their values were chosen keeping in mind the formulas that given the theoretical gain, being essential to have R_2 much higher than R_3.

The results we obtained to the various properties taken in account in the merit formula were the following:

Name	Value [dB or Hz or MU]
gain	3.997705e+01
centralfrequency	9.813699e+02
cost	1.362666e+04
merit	3.884063e-06

Table 7: Circuit final results

Looking to the results shown in table 7, we can see that the gain was around the one we wanted aswell as the central frequency, which are close to 40 dB and 1000 Hz, while keeping the cost low. This results in a good merit considering all the tests done before.

5 Conclusion

In the present laboratory we produced a bandpass filter and improved it. Looking at both analysis and as it has already been said in subsection 3.3, we can say that the results obtained were very accurate since the differences that were already expected weren't very high, being these related with the more complex models used by ngspice.As for the merit we achieved the purpose of the laboratory of trying to maximize its value and we are satisfied with research made in order to complete this objetive. Last but not least, this laboratory assigment conducted to gain more knowledge and lead to a better understanding of OP-AMP and matters related to the course.