TÉCNICO
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Circuit Theory and Electronics Fundamentals

Lab 5 - Bandpass Filter using OP-AMP

Aerospace Engineering

Laboratory Report

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Contents

1 Introduction

This report is being made for the subject of Circuit Theory and Electronics Fundamentals and is related to the fifth laboratory being its objective to develop a Bandpass Filter using an Operational Amplifier (OP-AMP). In this laboratory there are some specifications that are followed such as a central frequency of 1kHz and a gain at central frequency of 40dB. There are also limited number of the different components. All in all, the circuit that was implemented is shown in figure 1 and it has three different stages. This stages are the High Pass Stage, the Amplication Stage and a Low Pass Stage and they will be explored on the extend of this report.

In Section 2 a theoretical analysis will be made. Secondly, in Section 3 it will be simulated the circuit using ngspice tools. Following with both results from Section 2 and Section 3 being compared and commented in Section 4.

Also, it is important to notice that the NGSpice simulation was made using the provided OPAMP model.

Finally, the conclusions of this study are outlined in Section 5.

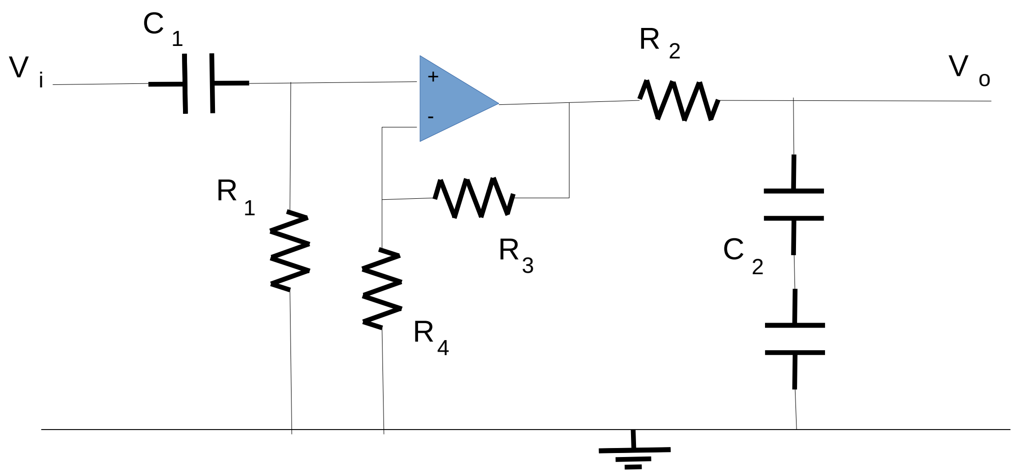

Figure 1: Bandpass Filter using an OP-AMP

2 Theoretical Analysis

In this section, the circuit shown in Figure 1 will be analysed theoretically. The constants used for the resistors and capacitors can be seen bellow.

Name	Value
Resistor 1	1.000000e+03 Ohm
Resistor 2	1.000000e+03 Ohm
Resistor 3	1.000000e+05 Ohm
Resistor 4	1.000000e+03 Ohm
Capacitor 1	2.200000e-07 F
Capacitor 2	1.100000e-07 F

Table 1: Chosen values for the resistors and capacitors

In order to fully understand the analysis that will be made, it is necessary to bear in mind that there are three stages in this circuit: the High Pass Stage, the Amplication Stage and the Low Pass Stage.

The first one lets the high frequency sinals pass, and cuts the ones with lower frequencies.It is made with C_1 and R_1. From this stage, we get the following equations:

$$w_{Low} = \frac{1}{R1 \times C1} \tag{1}$$

$$Gain_{HighPassStage} = \frac{R1 \times C1 \times s}{1 + R1 \times C1 \times s} \tag{2}$$

where $s = 2 \times \pi \times f \times j$

The second stage is used for amplify the sinal, being its main component the Operational Amplifier. It's easy to understand that it's on this stage that the gain is maximum. The components of this stage are the OP-AMP, R_3 and R_4. From here, we can get:

$$Gain_{OpAmp} = 1 + \frac{R3}{R4} \tag{3}$$

The third stage, works essentially for cutting high frequency sinals and letting the lower ones pass. It is made by the remaining components, R_2 and C_2. At last, we get from here:

$$w_{High} = \frac{1}{R2 \times C2} \tag{4}$$

$$Gain_{LowPassStage} = \frac{1}{1 + R2 \times C2 \times s} \tag{5}$$

All in all, we build a Band Pass Filter by cutting the higher and the lower frequencies and letting pass a specific band of sinals.

In order to obtain the gain for the specific central frequency, we need to replace s with $s_{Central}$. We obtain this value by computing firstly the central frequency, which is a geometrical average of the low and high cut frequencies we calculated before.

$$w_{Central} = \sqrt{w_{Low} \times w_{High}} \tag{6}$$

$$s_{Central} = w_{Central} \times j \tag{7}$$

The total gain of this circuit is given by:

$$T(s) = Gain_{HighPassStage} \times Gain_{OpAmp} \times Gain_{LowPassStage} \tag{8}$$

where we replace the variable s with the computed $s_{Central}$

At last, we calculated the input and output impedances, bearing in mind that we are using an ideal OpAmp. Knowing $w_{Central}$, we are able to calculate the impedances of the capacitors.

$$Z_{C1} = \frac{1}{j \times w_{Central} \times C1} \tag{9}$$

$$Z_{C2} = \frac{1}{j \times w_{Central} \times C2} \tag{10}$$

Now, we are able to compute the input and output impedances.

$$Z_{input} = R1 + Z_{C1} \tag{11}$$

$$Z_{output} = Z_{C2} || R2 = \frac{R2 \times Z_{C2}}{R2 + Z_{C2}} \tag{12}$$

Name	**Value**
Input Impedance	1.000000e+03
Output Impedance	6.666667e+02
Central Frequency	1.023087e+03 Hz
Obtained gain (in decibels)	3.656460e+01 dB

Table 2: Computed theoretical values

We also obtained the plot of the theoretical gain response in figure 2 and of the phase response in figure 3 from the frequency of 10Hz until 100MHz.

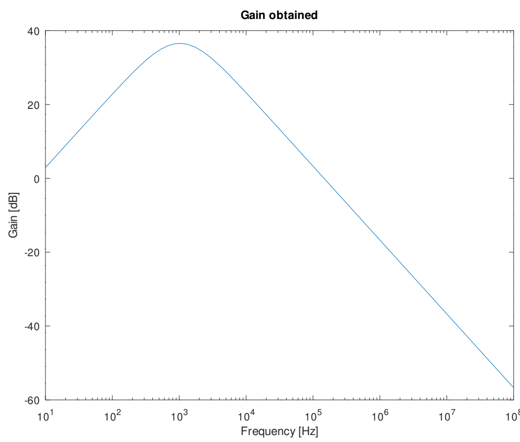

Figure 2: Gain Response Vo(f)/Vi(f)

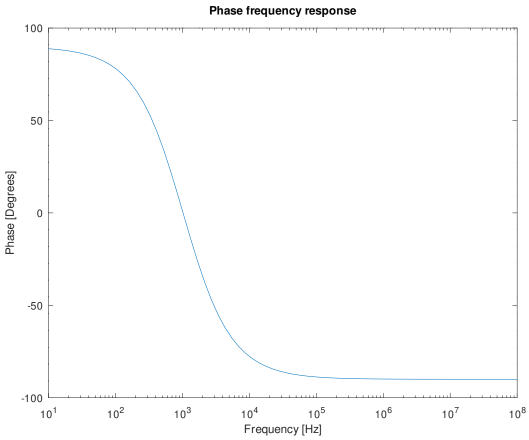

Figure 3: Phase Response Vo(f)/Vi(f)

3 Simulation Analysis

This section covers the bandpass filter simulation (using OP-AMP) in NGSpice. As asked we started by using the provided model of the OP-AMP and then the circuit was improved by doing incremental modifications with suitable parameters. In the next tables it is presented the values asked in the lab assignment: output voltage gain, the central frequency and the input and output impedances at this frequency.

Name	**Value**
Output Voltage Gain	36.5331 dB
Central Frequency	1013.91 Hz

Table 3: Gain and Central Frequency

Following with the analysis, below it is presentend the output and input impedances.

Name	**Value**
Input Impedance	999.999 + -69087.2 j

Table 4: Input Impedance

Name	**Value**
Output Impedance	680.05 + -466.901 j

Table 5: Output Impedance

The graphics below show the frequence response of the output voltage gain in the pass-band.

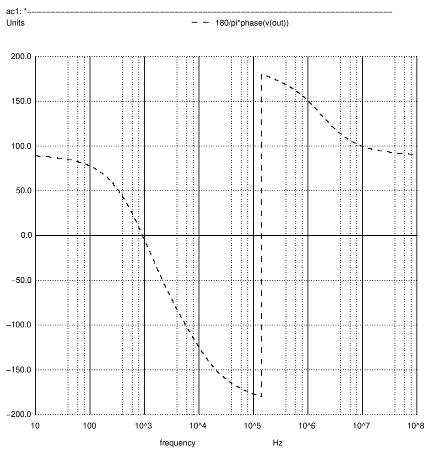

Figure 4: Simulation gain response in phase degree

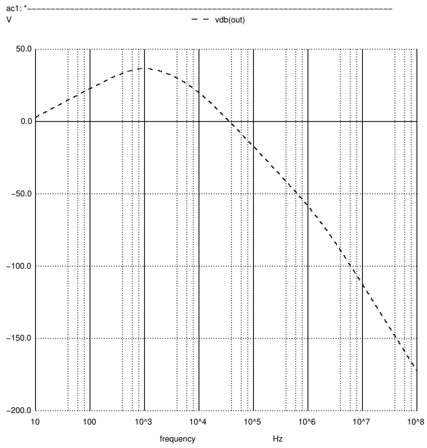

Figure 5: Simulation gain response in dB

Finally, the merit obtained by the group is presentend in the following table. It can be consider that the results were good.

Name	**Value**
Gain Deviation	32.9164
Frequency Deviation	13.911 Hz

Table 6: Gain and frequency deviation

Name	**Value**
Cost	13426.8 MU
Merit	1.59048E-06

Table 7: Merit

4 Side by Side Comparison

After ending both simulation and theoretical analysis processes, the results were presented on their sections. However, for presenting a detailed interpretation of the result both graphics and tables were put side by side.

Regarding the Gain Graphics we can see that their shape is very similar, the circuit has the same response in both NGSpice and Octave what can lead us to conclude that the results in this analysis are positive.

When comparing the Phase Frequency response graphics we can see that they differ, this can be explained one more time by the model used by NGSpice, which is really complex, comparing to the far more simple model used in Octave, where we consider an ideal OpAmp.

Comparing also the output and input impedances, we only what to note that there are small diferences, which means that the aproximation made by octave corresponds with a very high sucess rate to the far more complex model used by NGSpice. We were already expecting differences but being this small is also a positive outcome of this laboratory.

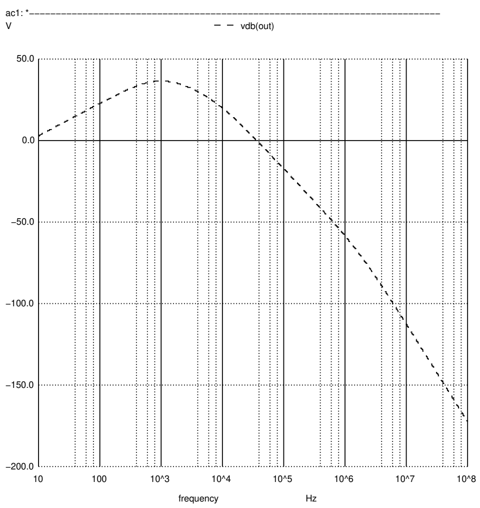

Figure 6: Gain Frequency by NGSpice

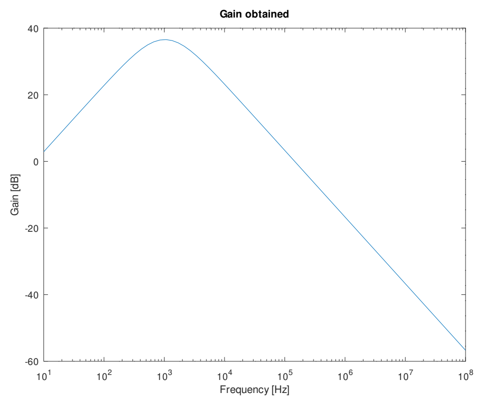

Figure 7: Gain Frequency by Octave

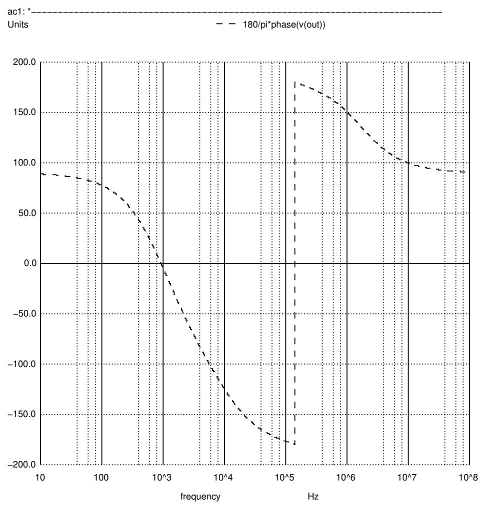

Figure 8: Phase Frequency by NGSpice

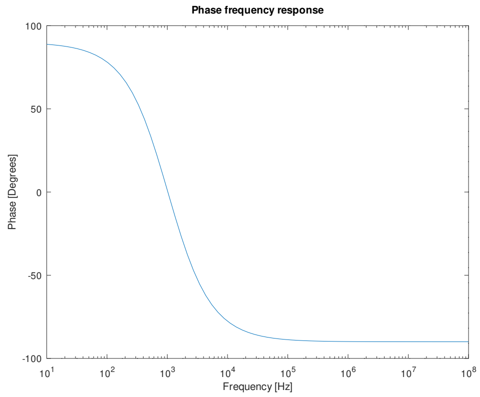

Figure 9: Phase Frequency by Octave

Name	**Value**
Input Impedance	1.000000e+03
Output Impedance	6.666667e+02
Central Frequency	1.023087e+03 Hz
Obtained gain (in decibels)	3.656460e+01 dB

Table 8: Computed theoretical values

Name	**Value**
Output Voltage Gain	36.5331 dB
Central Frequency	1013.91 Hz

Table 9: Gain and Central Frequency

Name	**Value**
Input Impedance	999.999 + -69087.2 j

Table 10: Input Impedance

Name	**Value**
Output Impedance	680.05 + -466.901 j

Table 11: Output Impedance

5 Conclusion

The objective of this laboratory assignment was to develop a Bandpass Filter and the main goal was achieved.

However by observing analysis and simulation results side by side it can be seen a difference between the two, the results aren't equal and exactly the same comparing both NGSpice and Octave.

Although, we believe that the differences are not that significant and they can be explained by how NGSpice solves the circuit compared to how it was done in the theoretical analysis, considering that NGSpice uses a model with more parameters for the Operational Amplifier that Octave this can be the main reason for the differences.

Regarding this fact, the results obtained are reasonables and it was a sucessful analysis of the circuit.

Nevertheless the results were achieved not having the best merit. The merit of the circuit was obtained by trial and error, a method that is not perfect and does not result in the best possible results. In this way, we concluded that in order to obtain good results, we were obliged to "yield" part of the merit.

This way, the objective should have never been to have equal results, but rather, have results that seemed reasonables, which we believe it was achieved. The merit obtained was 1.59048×10^{-06}, with a cost of 13426.8 MU.