Circuit Theory and Electronics Fundamentals

Department of Electrical and Computer Engineering, Técnico, University of Lisbon

Fifth Laboratory Report

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1 Introduction

The aim of this laboratory assignment was to design and create a BandPass Filter using an OP-AMP with a central frequency of 1kHz and a gain of 40dB. The architecture of the circuit designed is the one showed in the following diagram of Figure 1. These diagram and circuit is heavily inspired by the one proposed in the ”in person” lab class.

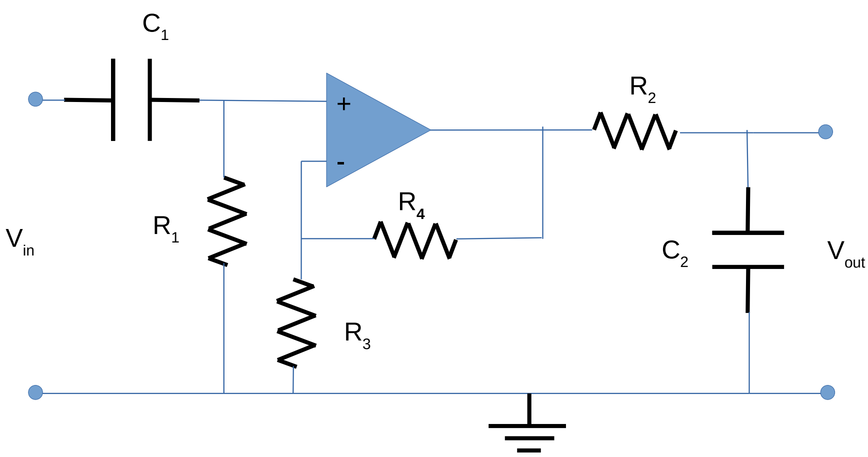


Figure 1: Basic circuit architecture of a BandPass Filter.

To determine the quality of the circuit built and to compare it with others, a Merit figure will be calculated based on the following equation:

$$MERIT = \frac{1}{cost * (GainDeviation + CentralFrequencyDeviation + 10^6)} \quad (1)$$

where the $cost$ value states for sum of the tabulated cost of the components used, $GainDeviation$ states for the gain deviation from 40dB and $CentralFrequencyDeviation$ for the central frequency deviation from 1kHz, of the BandPass Filter.

The values chosen for the circuit components used can be seen in Table 1. These values were chosen after running some theoretical and simulation test analysis and are introduced here because they are the values that ended up being used in the last theorethical and simulation analysis, which are the ones shown in this report.

Name	**Value**
R_1	1.000000e+03 Ohm
R_2	1.000000e+03 Ohm
R_3	1.000000e+05 Ohm
R_4	1.000000e+03 Ohm
C_1	2.200000e-07 F
C_2	2.200000e-07 F

Table 1: Chosen values of the circuit components.

In this laboratory was used a 741 OPAMP model.

In this report, the results obtained in theoretical analysis made in OCTAVE and simulation made in NGSPICE will be shown in their respective sections and, ultimately, compared.

In Section 2, a theoretical analysis of the circuit built is presented using the values of Table 1. In this analysis Gain, input and output impedances at the Central Frequency and frequency response analysis will be done. In Section 3, the circuit is analysed by simulation in NGSPICE also using the values of Table 1. In Section 4 the results from theoretical and simulation analysis are compared. The conclusions of this study are outlined in Section 5.

2 Theoretical Analysis

In this section we will theoretically analyse the circuit of Figure 1 using OCTAVE tools. This analysis will start with the calculation of the output voltage gain and central frequency. Then, the input and output impedances at the central frequency previously calculated will be determined. Finally, a frequency response analysis is presented.

2.1 Output Voltage Gain and Central Frequency

To determine the central frequency, the angular upper (ω_H) and lower (ω_L) frequencies were calculated using the following expressions:

$$\omega_H = \frac{1}{R_2 * C_2} \tag{2}$$

$$\omega_L = \frac{1}{R_1 * C_1} \tag{3}$$

The central frequency is now given by:

$$central frequency = \frac{\sqrt{\omega_L * \omega_H}}{2\pi} \tag{4}$$

The output voltage gain, in dB, was obtained through the following expression

$$Gain = 20 * log(|\frac{R_1 * C_1 * \sqrt{\omega_L * \omega_H} * j}{1 + R_1 * C_1 * \sqrt{\omega_L * \omega_H} * j} * (1 + \frac{R_3}{R_4}) * \frac{1}{1 + R_2 * C_2 * \sqrt{\omega_L * \omega_H} * j}|) \tag{5}$$

The values obtained are shown in Table 2.

Name	Value
Gain	3.406583e+01 dB
Centralfrequency	7.234316e+02 Hz

Table 2: Theoretical output voltage gain and central frequency.

2.2 Input and Output Impedances at Central Frequency

The input impedance at the central frequency determined previously was calculated using the following expression:

$$Z_{in} = |R_1 + \frac{1}{j * \sqrt{\omega_L * \omega_H} * C_1}| \tag{6}$$

And the output impedance at the central frequency was calculated using the following expression:

$$Z_{out} = |\frac{1}{j * \sqrt{\omega_L * \omega_H} * C_2 + \frac{1}{R2}}| \tag{7}$$

Its values are shown in Table 3.

Name	Value
Z_{input}	1.414214e+03 Ohm
Z_{output}	7.071068e+02 Ohm

Table 3: Theoretical input and output impedances at central frequency.

2.3 Frequency Response

The graphic of Figure 2 shows the frequency response of the output voltage gain, in dB, of the BandPass Filter.

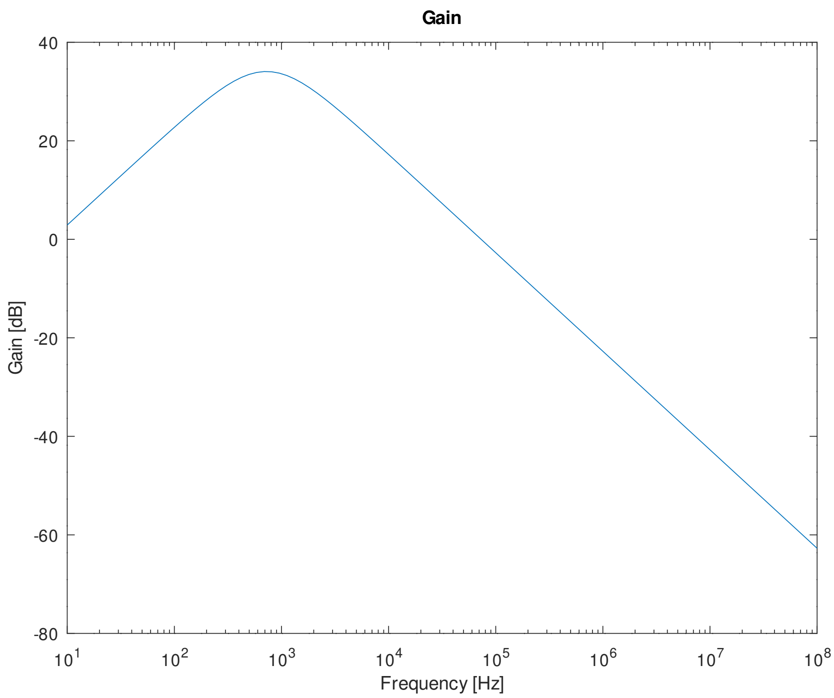


Figure 2: Frequency response of the output voltage gain. The *x axis* represents the frequency in Hertz (Hz) and the *y axis* the Gain in dB.

The graphic of Figure 3 shows the frequency response of the phase, in degrees.

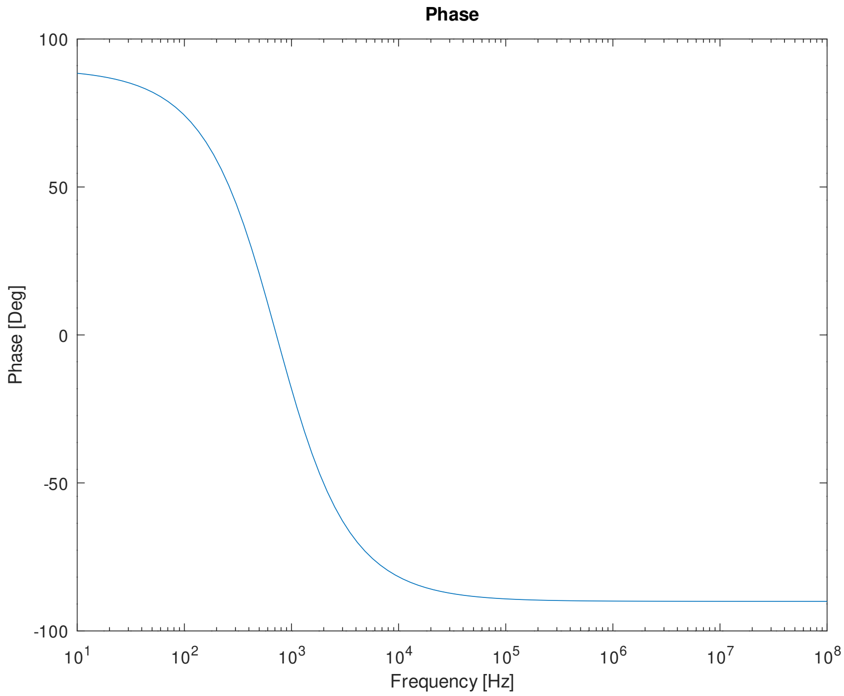


Figure 3: Frequency response of the phase. The *x axis* represents the frequency in Hertz (Hz) and the *y axis* the Phase in degrees.

3 Simulation Analysis

In this section, the circuit built (Figure 1) will be analyzed and simulated using NGSPICE.

Before simulating the circuit shown before, we used NGSPICE tools to simulate different circuit configurations and combinations of values for the various components of the circuit to obtain a decent merit value, while trying to get the central frequency and gain asked.

3.1 Output Voltage Gain and Central Frequency

The gain in dB units is given in the Table 4.

Name	Value [dB]
gain	3.642084e+01

Table 4: Value of simulated output voltage gain.

The Upper, Lower and Central Frequencies are given by the Table 5. These values will be further discussed in the comparison section of this report, but just by observing we can tell these values are within the values expected, especially the central frequency value which is close to the expected 1kHz.

Name	Value [Hz]
lowerfreq	3.999743e+02
upperfreq	2.499041e+03
centralfreq	9.997761e+02

Table 5: Simulated upper, lower and central frequencies

3.2 Input and Output Impedances at Central Frequency

The Table 6 shows the Input Impedance at central frequency from simulation analysis.

Name	Value [kOhm]
zin	9.990174e+02

Table 6: Simulated Input Impedance at central frequency.

The Table 7 shows the Output Impedance at central frequency from simulation analysis.

Name	Value [kOhm]
zout	2.708959e+00

Table 7: Simulated Output Impedance at central frequency.

3.3 Merit Figure

To calculate the merit figure, the values of the output voltage gain deviation from 40dB, the central frequency deviation from 1kHz and the cost of the components used were calculated and can be seen in Table 8, as well as the resulting merit figure.

Name	Value
gaindev	3.579164e+00
centraldev	2.239378e-01
cost	1.342644e+04
merit	1.958399e-05

Table 8: Values obtained for the merit figure calculation.

3.4 Frequency Response

The simulated output voltage gain in terms of frequency is shown in Figure 4.

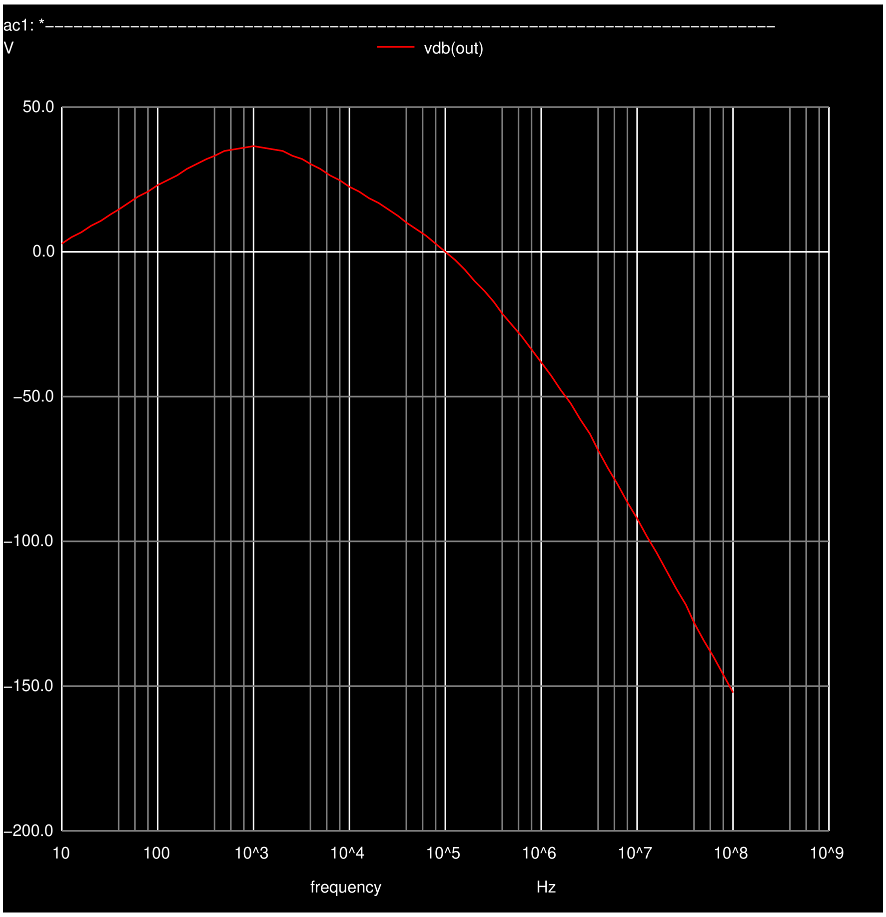


Figure 4: Frequency response of the gain in dB scale. The *x axis* represents the frequency in Hertz (Hz) and the *y axis* the gain in dB.

And the plot of the phase function is given by the graphic of Figure 5.

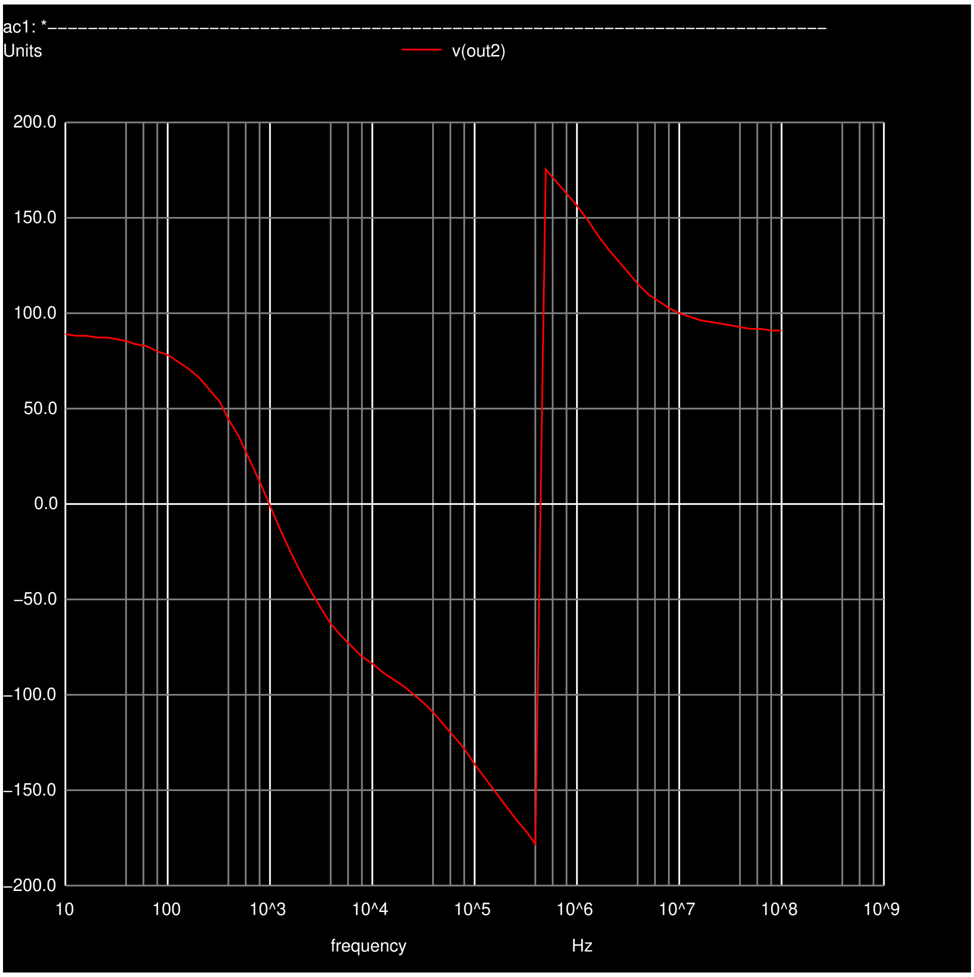
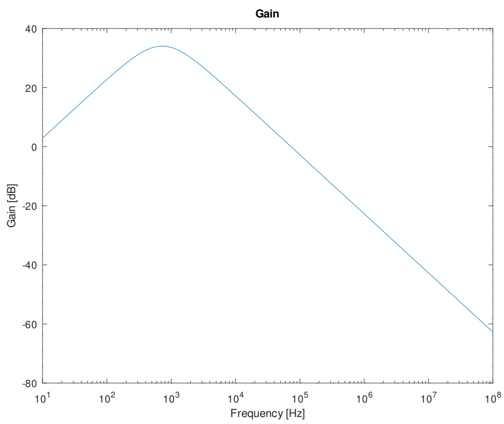


Figure 5: Frequency response of the phase. The *x axis* represents the frequency in Hertz (Hz) and the *y axis* the phase in degrees.

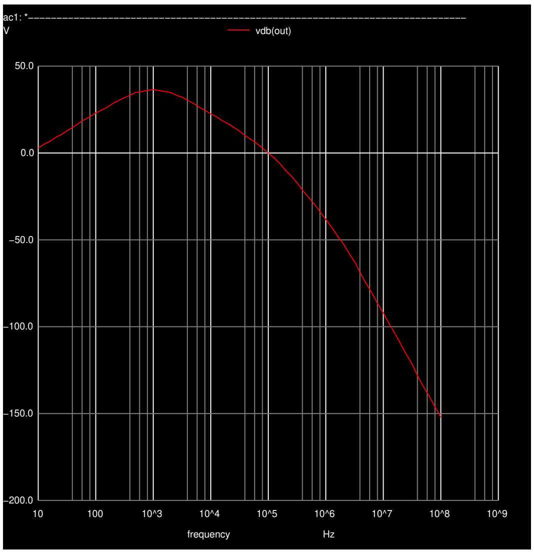
4 Comparison

We will now compare the results of more interest obtained in the theoretical analysis and the simulation analysis.

For the Output voltage gain frequency response these are the graphics obtained theoretically and from simulation, respectively:

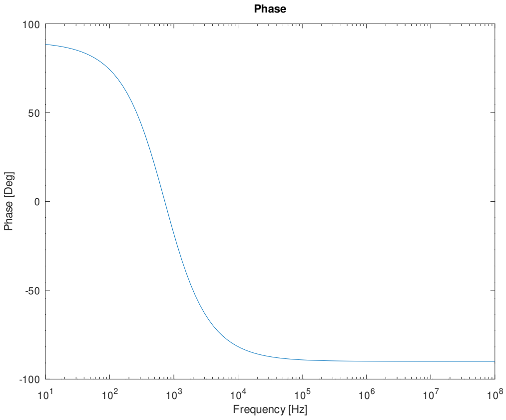


(a) Theoretical gain frequency response.

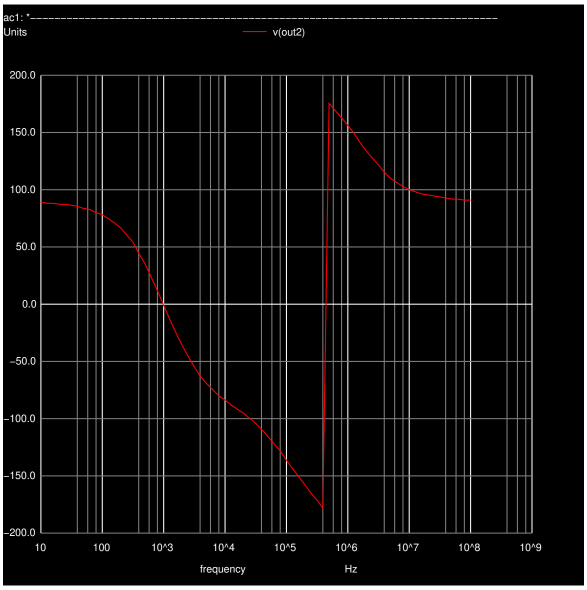


(b) Simulated gain frequency response.

And these are the graphics obtained theoretically and from simulation, respectively, for the phase frequency response:



(a) Theoretical phase frequency response.



(b) Simulated phase frequency response.

As we can see the output voltage gain graphics are very similar and behave almost identically. TThe phase graphics may seem different at a first glance, but observing the plot properties we can see they also behave almost identically at first but after a certain a level of frequency the presence of the two capacitors existent on the NGSPICE OP-AMP model, which is only present in the simulation analysis and not the theoretical, changes the value of the phase through a rapid shift before stabilizing again but with different values, again due to the presence of the capacitors in the model used in the simulation.

For the central frequency, input and output impedance values at central frequancy and gain in dB units, the Theoretical Results were the following:

Name [unit]	**Value**
Gain	3.406583e+01 dB
Centralfrequency	7.234316e+02 Hz
Z_{input}	1.414214e+03 Ohm
Z_{output}	7.071068e+02 Ohm

Table 9: Theoretical Results.

And the Simulation results obtained were:

Name	**Value**
Gain	3.642084e+01 dB
CentralFreq	9.997761e+02 Hz
Z_{in}	9.990174e+02 Ohm
Z_{out}	2.708959e+00 Ohm

Table 10: Simulation Results.

Analyzing these values we notice that there is some difference between the theoretical predicion and the simulation. Especially in the impedance values these differences are noticeable. The differences between the values of impedance can be due to the fact that in the Simulation exists an OP-AMP model that has integrated non-linear components and complex components that will affect the results, while that was not done in the theoretical analysis.

Regarding the frequency values as well the gain values we can also see some differences but now much smaller, both gain values are identical and very close to the pretended 40dB. For the central frequency presents a better value in the simulation analysis versus the theoretical analysis. Once again the complexity of the circuit as well the presence of non-linear components makes the analysis more complex and susceptible to differences between simulation and theoretical analysis.

5 Conclusion

Given the results obtained along the work and showed on this laboratory report, we can say that the objective of building a BandPass Filter using an OP-AMP with output voltage gain of 40dB and central frequency of 1kHz was successfully achieved, mainly considering the simulation analysis. As discussed on the comparison section, the results obtained through theoretical analysis in OCTAVE were slightly worse than the simulation ones, mainly due to the complexity of the OP-AMP model necessary to achieve better results.