Circuit Theory and Electronics Fundamentals

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

T5's Laboratory Report

Group 5

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Contents

1 Introduction

The objective of this laboratory assignment is to choose the dimensions and implement a Band-Pass Filter (BPF) with the a central frequency of 1kHz and a gain of 40dB (at central frequency).

The components used:
- One 741 OPAMP;
– At most three 1kΩ resistors;
– At most three 10kΩ resistors;
– At most three 100kΩ resistors;
– At most three 220nF capacitors;
– At most three 1μ F capacitors;

Firstly, we started this laboratory writing an NGspice script that simulates the bandpass filter (BPF), based on the script given, using the provided OPAMP model. This simulation is design to measure the output voltage gain in the passband, the central frequency and the input and output impedances at this frequency.

Then, we have performed incremental modifications to improve the merit, which is calculated using the expression:

$$M = \frac{1}{Cost \times (gain_{deviation} + CentralFrequency_{deviation} + 10^{-6})} \tag{1}$$

Where:

- cost = cost of resistors + cost of capacitors + cost of transistors;

– cost of resistors = 1 monetary unit (MU) per kOhm;

– cost of capacitors = 1 MU/μ F;

– cost of transistors = 0.1 MU per transistor;

After that, using octave, we have created a theoretical analysis able to compute the gain, input and output impedances at the central frequency.

The, we have also computed the frequency response $V_o(f)/V_if$, using the incremental analysis, solving the circuit for a frequency vector in log scale with 10 points per decade, from 10Hz to 100MHz.

Firstly, we have created a simple circuit and then we were updating the circuit to improve the figure of merit. The final circuit obtainned is the one shown below in figure (Fig.1):

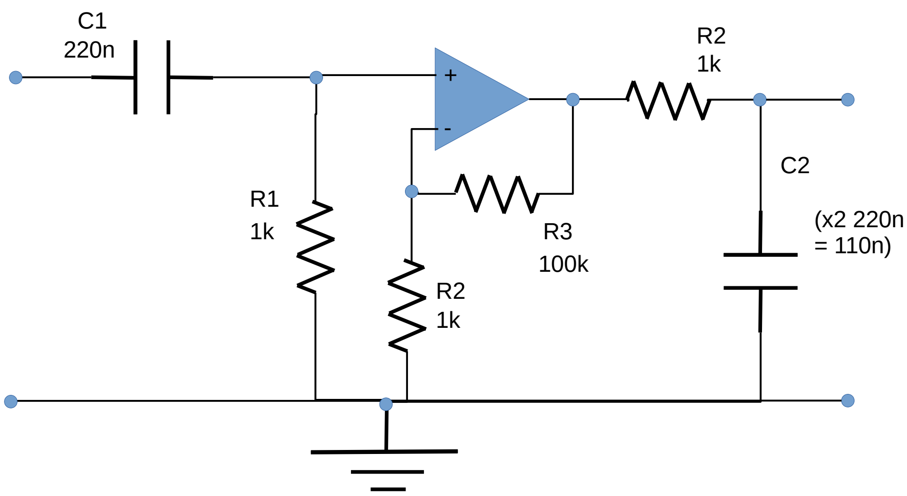

Figure 1: Final circuit

The individual costs of the components used:

Name	Value
R	103kΩ
C	0.330 μS

Figure 2: Costs

2 Simulation analysis

As said in the introduction, the first step to this laboratory assignment was to simulate a BPF using the script given by the professor in NGSpice.

2.1 Frequency Response

Right after simulating the circuit we output the frequency response of the same one both in dB and phase.

The graphs we got are below:

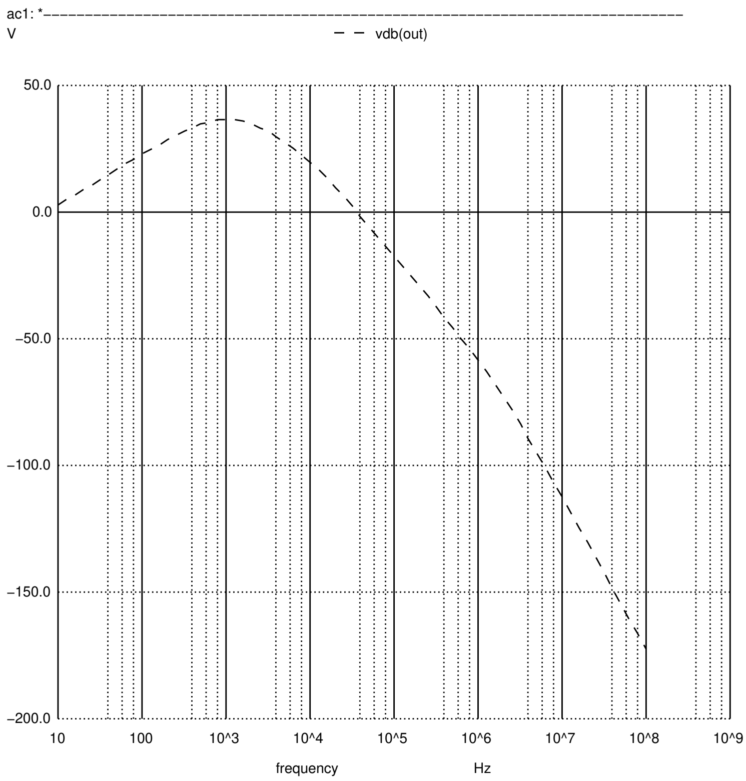

Figure 3: Frequency Analysis in dB

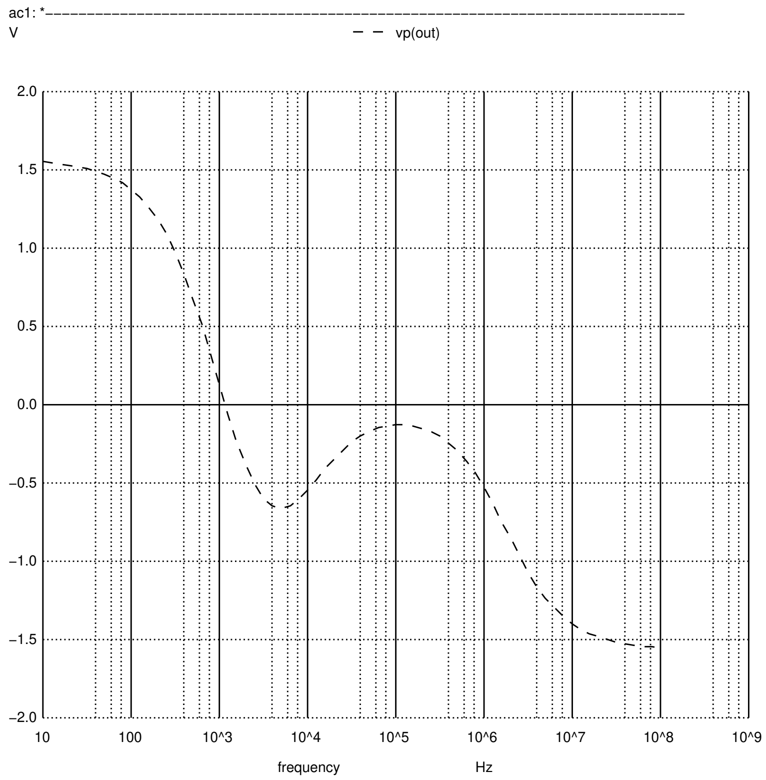

Figure 4: Frequency Analysis - Phase

2.2 Central Frequency in the Passband

Firstly, we started our simulation analysis showing our results for the a requested value in the laboratory assignment which was the central frequency in the passband. This was achieved by using the given equation by the professor:

$$CentralFrequency = \sqrt{Lower_cutoffUpper_cuttoff} \quad (2)$$

In the images below we can see th output voltage plotted. The lower and upper cutoff and central frequency values obtained are also in the table below:

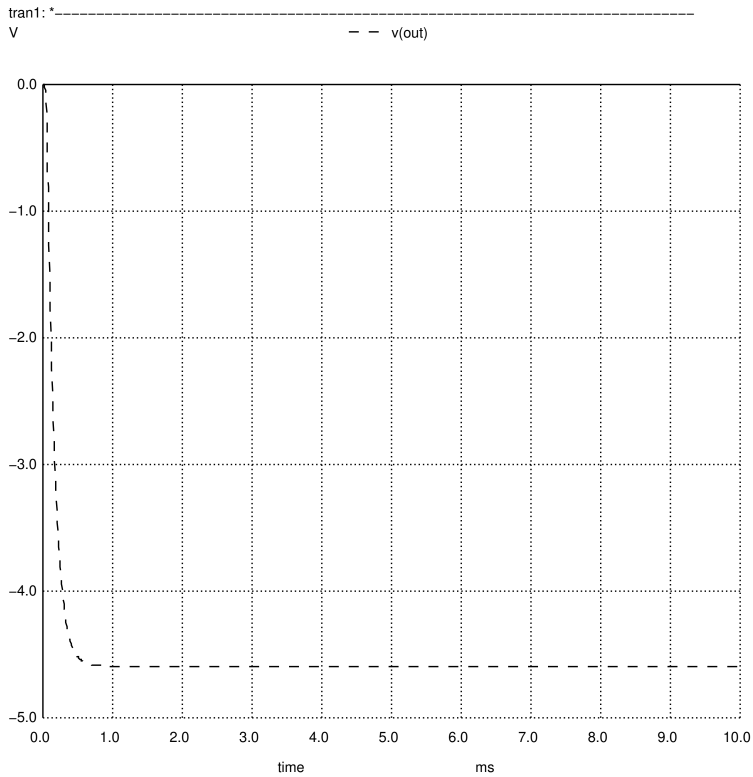

Figure 5: Output Voltage.

Name	**Value [Hz]**
lower	4.042442e+02
upper	2.460783e+03
central	9.973752e+02

Figure 6: Central Frequency Gain

2.3 Output Voltage Gain

After getting the central frequency in the previous subsection, in this section we will calculate the voltage gain in this frequency.

We did this by making the maximum of the difference of the out voltage in dB and the in voltage in dB.

The value we got is in the table below:

Name	Value [dB]
voltagegain	3.650113e+01

Figure 7: Voltage Gain

2.4 Input and Output Impedances

Lastly, we made NGSpice give us the input and output impedances.

The results we got are in the tables below:

Name	Value [Ω]
inputimpedance	-9.99012e+02,7.142435e+00

Figure 8: Input Impedance

Name	Value [Ω]
Error(parse.c–checkvalid): outimpedance: no such vector.	

Figure 9: Output Impedance

3 Theoretical Analysis

3.1 Central Frequency, Voltage Gain, Input and Output impedances

Using the equations provided by the professor, we wrote an Octave script in order to compute the following values: central frequency, voltage gain, input impedance and output impedance.

Mainly these equations were used:

$$T(s) = \frac{R_1 C_1 s}{1 + R_1 C_1 s}(1 + \frac{R_3}{R_4})\frac{1}{1 + R_2 C_2 s} \tag{3}$$

and the same equation described in the simulation section for the central frequency where:

$$Lower_cutoff = \frac{1}{R_1 C_1} \tag{4}$$

and

$$Upper_cutoff = \frac{1}{R_2 C_2} \tag{5}$$

The values obtained are in the table below:

Name	Value [Hz, dB or Ω]
Central Frequency	8.141678e+02
Voltage Gain dB	3.964755e+01
Input Impedance	5.000000e+02
Output Impedance	2.396034e+02

Figure 10: Central Frequency, Voltage Gain, Input and Output impedances

3.2 Frequency Response

Taking into account the all circuit, we can obtain the frequency response both in dB and phase:

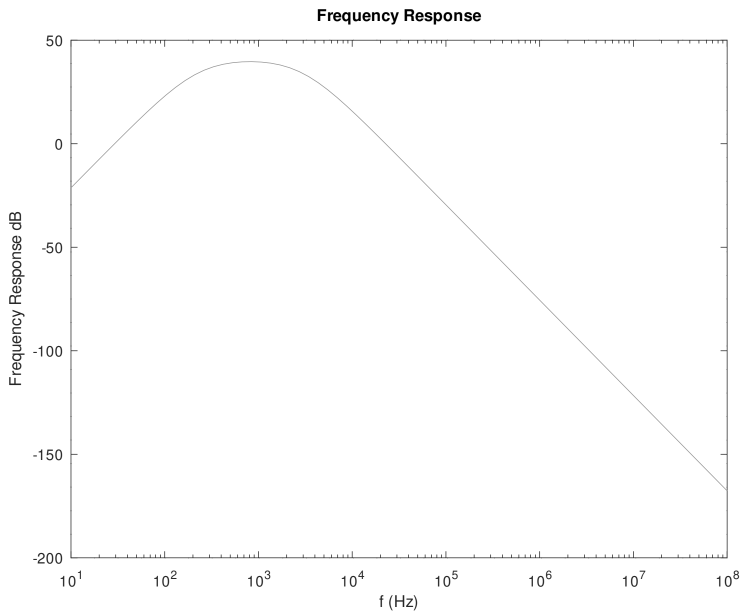

Figure 11: Frequency Response - dB

Figure 12: Frequency Response - Phase

4 Conclusion

Summing up, this laboratory provided us the opportunity to understand how a band pass filter using an OP-AMP circuit works with how each component relates to the band and the voltage gain.

Similarly to the previous lab assignment, there are some differences between the theoretical and simulation values obtained, this is the case for the OP analysis and also the impedances, for example. This can be explained by the non linear components used in this laboratory: the transistors. In the first 2 lab assignments only linear components were used and because of that the simple theoretical analysis made matched perfectly the simulation analysis, as it should. This was no longer the case in this assignment.

As for the merit figure calculation, we used Spice's values as they provide the most accurate results.

Finally, we are going to compare the results from simulation and theoretical analysis side by side:

Name	Value
merit	1.580376e-03

Figure 13: Merit Figure Table

Name	Value [Hz or dB]
central	9.973752e+02
voltagegain	3.650113e+01

Figure 14: Central Frequency, Voltage Gain - Simulation

Name	Value [Hz or dB]
Central Frequency	8.141678e+02
Voltage Gain dB	3.964755e+01

Figure 15: Central Frequency, Voltage Gain - Theoretical

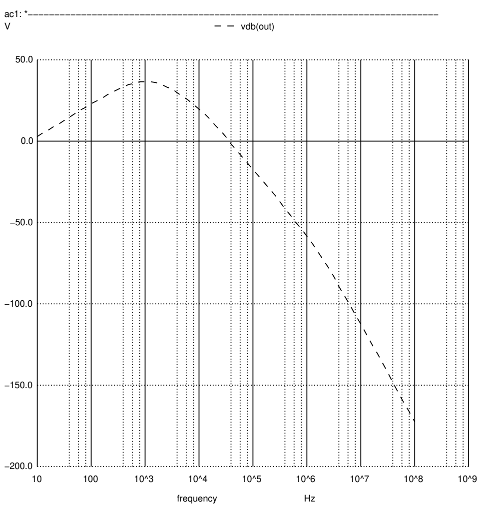

Figure 16: Simulation Gain Frequency Response - dB

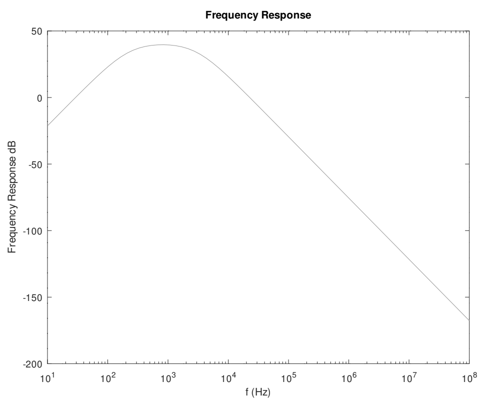

Figure 17: Theoretical Gain Frequency Response - dB

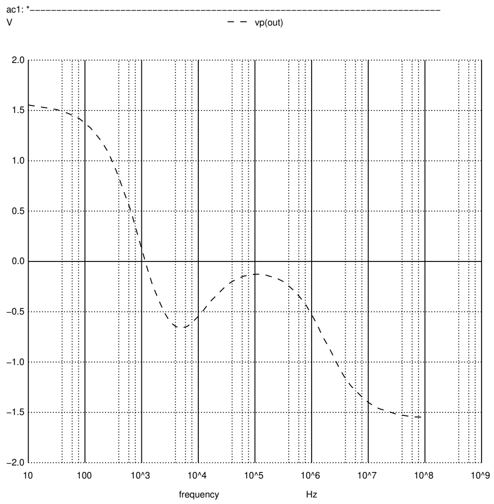

Figure 18: Simulation Gain Frequency Response - Phase

Figure 19: Theoretical Gain Frequency Response - Phase

Name	Value [Ω]
inputimpedance	-9.99012e+02,7.142435e+00

Figure 20: Simulation Input Impedance

Name	Value [Ω]
Error(parse.c–checkvalid): outimpedance: no such vector.	

Figure 21: Simulation Output Impedance

Name	Value [Ω]
Input Impedance	5.000000e+02
Output Impedance	2.396034e+02

Figure 22: Theoretical Input and Output Impedances