Circuit Theory and Electronics Fundamentals

T5 Laboratory Report

Aerospace Engineering, Técnico, University of Lisbon

June 8, 2021

Group 19

João Silva, n 95802
Miguel Cunha, n 95832
Frederico Baptista, n 97196

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;

The bandpass filter was simulated using Ngspice, 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.

The merit was then worked on with some modifications.

The merit is calculated using:

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

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;

Using octave, both the gain, input and the output impedances were computed at the central frequency, since we were analysing a BandPass Filter.

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

It was used an incremental method in order to improve the figure of merit. Starting with a simple circuit and continuously updating it. The final circuit is shown bellow (Fig.1):

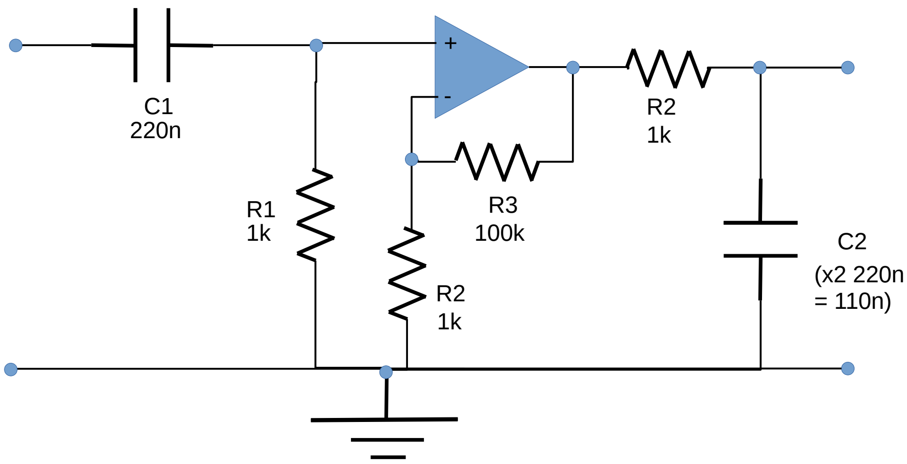


Figure 1: Final circuit

The individual costs of the components used:

Name	Value
R	103kΩ
C	0.330 μS

Figure 2: Costs

2 Simulation analysis

The simulation of the BPF, using the script given by the professor, will be analysed in this section.

2.1 Frequency Response

Right after simulating the circuit the frequency response of the same one both in dB and phase are printed as bellow:

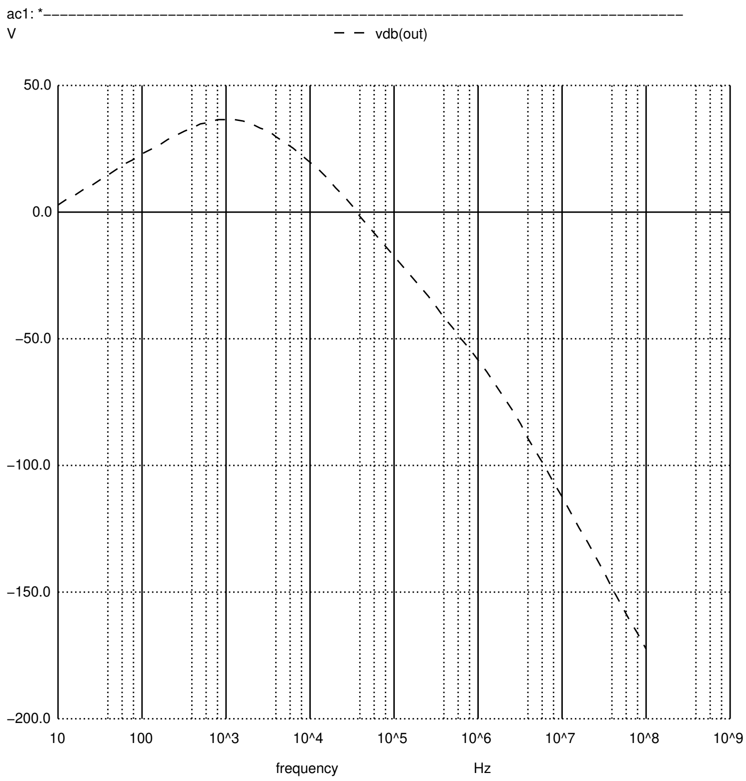


Figure 3: Frequency Analysis in dB

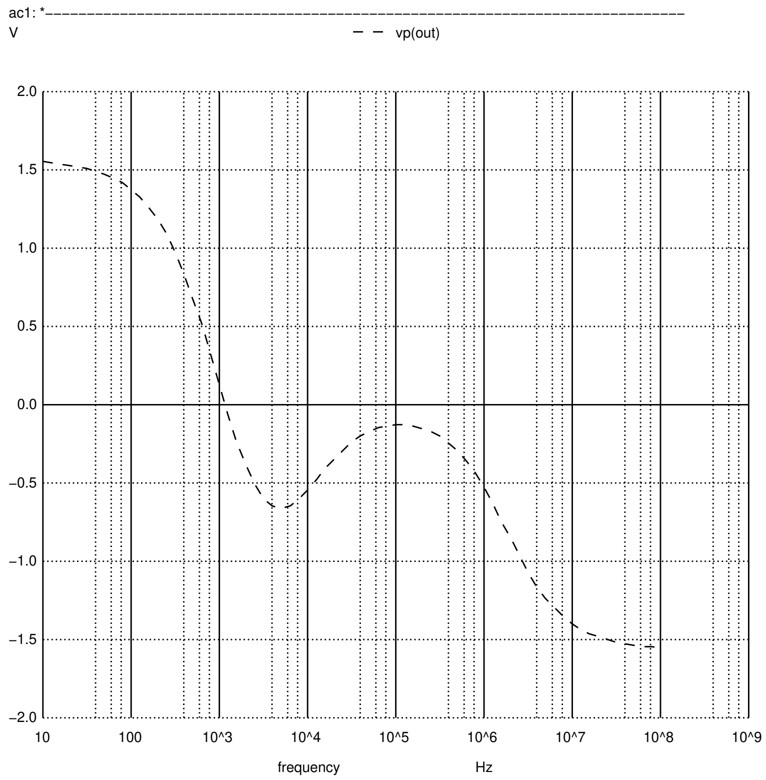


Figure 4: Frequency Analysis - Phase

2.2 Central Frequency in the Passband

Our results were firstly analysed for the 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:

$$CentralFrequency = \sqrt{Lower_{cutoff} Upper_{cutoff}} \tag{2}$$

In the images below the voltage is plotted. The lower and upper cutoff and central frequency values obtained are also in the table below:

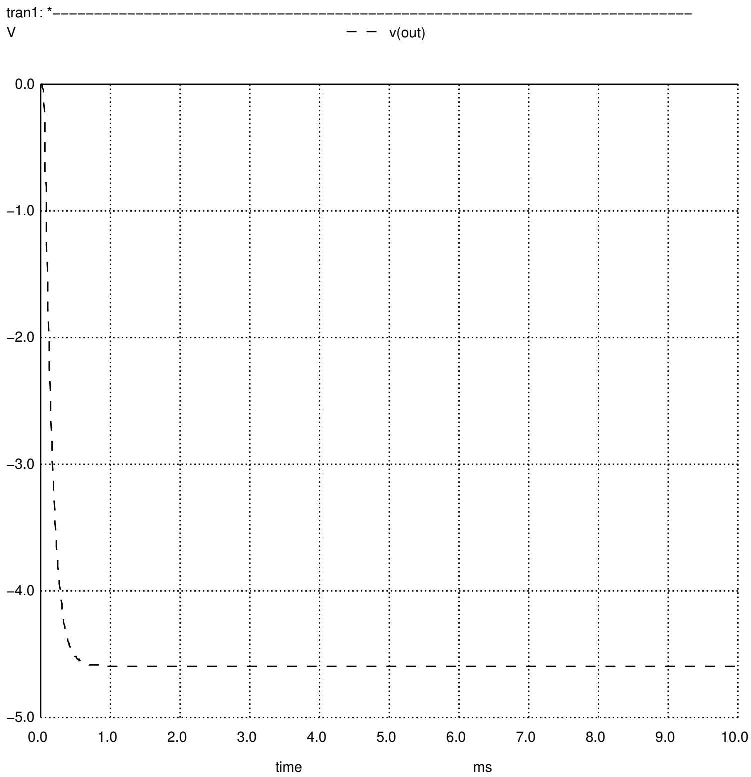


Figure 5: Output Voltage.

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

In this section, the voltage gain in the frequency requested is calculated.

This voltage is the maximum of the difference of the out voltage in dB and the in voltage in dB.

The value obtained is in the table below:

Name	**Value [dB]**
voltagegain	3.650113e+01

Figure 7: Voltage Gain

2.4 Input and Output Impedances

The input and output impedances given by Ngspice are below:

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

Figure 8: Input Impedance

Name	**Value [Ω]**
outputimpedance	-1.99451e-01,1.446496e+01

Figure 9: Output Impedance

3 Theoretical Analysis

3.1 Central Frequency, Voltage Gain, Input and Output impedances

Octave was used to compute the following values: central frequency, voltage gain, input impedance and output impedance.

The following equations were given by the professor:

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

$$Lower_{cutoff} = \frac{1}{R_1 C_1} \tag{4}$$

and

$$Upper_{cutoff} = \frac{1}{R_2 C_2} \tag{5}$$

The Octave values 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

Frequency response is ploted in in dB as shown:

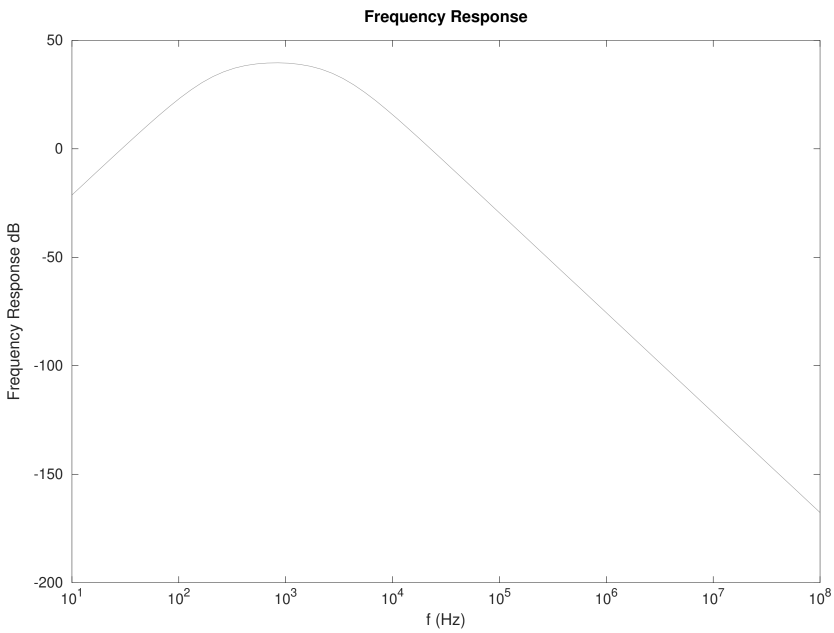


Figure 11: Frequency Response - dB

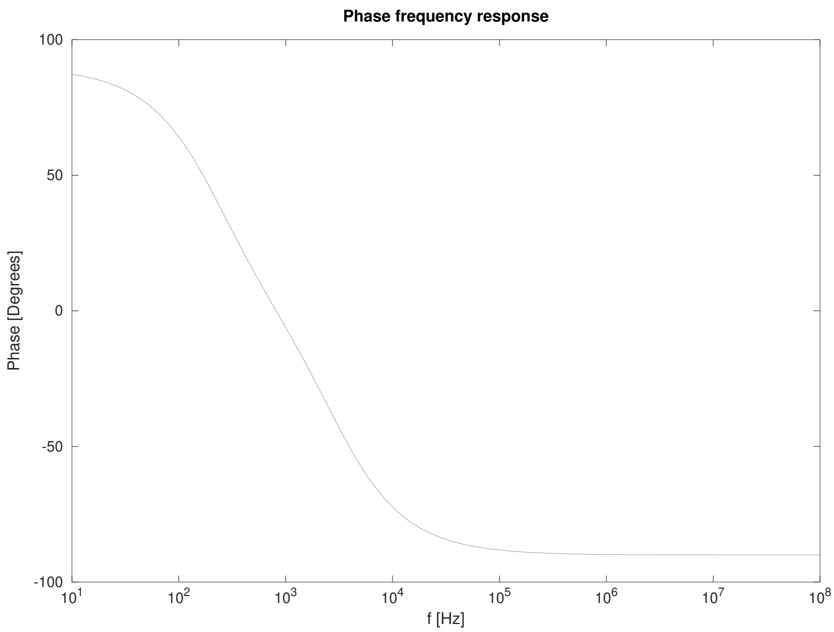


Figure 12: Frequency Response - Phase

4 Conclusion

This assignment made us understand how a band pass filter work and how an OP-AMP circuit relates to and the band and the voltage gain.

As it can be noticed, there are some differences between the theoretical and simulation values obtained, this is the case for the OP analysis and also the impedances. This difference is explained by the use of non-linear components (transistors) that make the OP analysis deviate from the theoretical analysis. Since the linear components have constant circuit parameters, it is really easy for Ngspice to plot and analyse them in perfection in relationship to the theorethical calculations. It cannot be said the same thing for non-linear components, once those circuit parameters vary.

The merit figure as explained before was a very important part of this assignment, since it provides a relation with the ”real world” where everything as a cost and a energy consumption, so it was important that this value was the most accurate as possible. In order to achieve that, the Ngspice's result was used.

As it can be way easier to compare, it is shown below the results from simulation and theoretical analysis side by side:

5 Visual Data

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

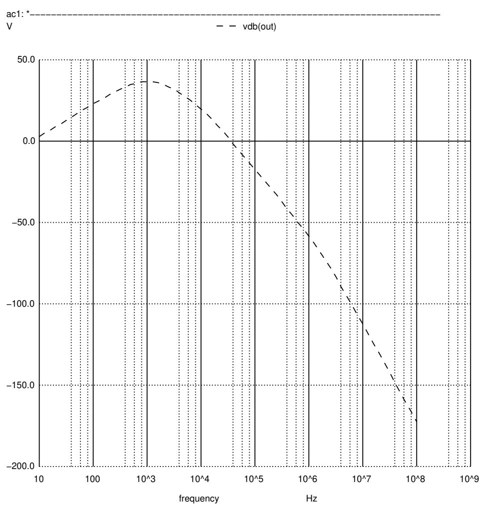


Figure 16: Simulation Gain Frequency Response - dB

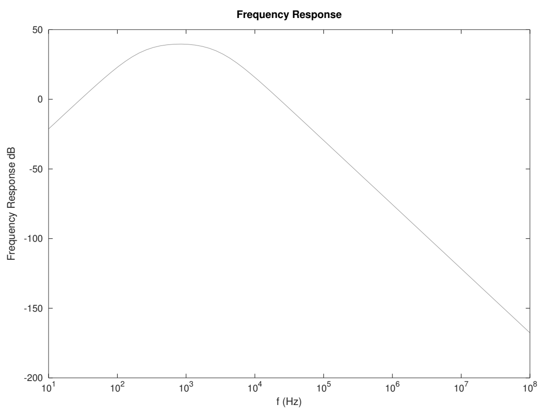
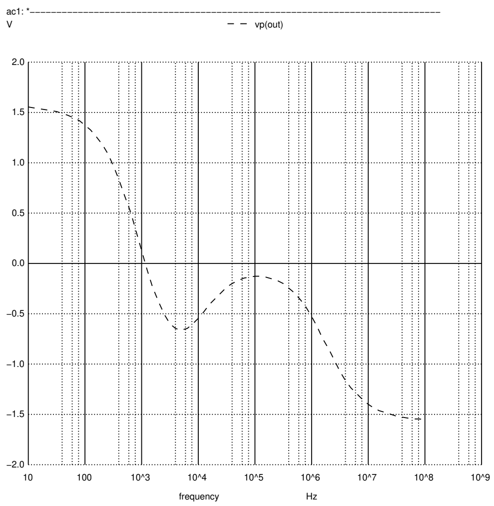


Figure 17: Theoretical Gain Frequency Response - dB



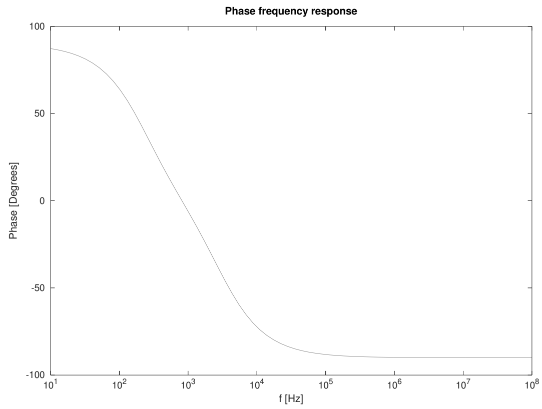


Figure 19: Theoretical Gain Frequency Response - Phase

Figure 18: Simulation Gain Frequency Response - Phase

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

Figure 20: Simulation Input Impedance

Name	**Value [Ω]**
outputimpedance	-1.99451e-01,1.446496e+01

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