Circuit Theory and Electronics Fundamentals

Integrated Master's in Aerospace Engineering, Técnico, University of Lisbon

Laboratory 5 Report

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Contents

1 Introduction

In this laboratory assignment, we are asked to create a Band Pass Filter (BPF), in which we are supposed to design its architecture using one 741 OPAMP, resistors and capacitors. The goal is to achieve the best ratio between the cost of the circuit and its quality in terms of the specifications asked (Merit Figure): a central frequency $f_c = 1kHz$ and a central gain of $40dB$.

To build the circuit, we used 4 resistors, 2 capacitors and a 741 OPAMP. A representative image of the circuit can be seen in 1.

In Section 2, a theoretical analysis of the circuit using Octave is presented. In Section 3, the circuit is analysed by simulation with Ngspice software and the results are compared to the theoretical results in Section 5. Some comments about the in-person simulation are stated in Section 4. Conclusions of this study can be found in Section 6.

The components used have the following values:

R3 e resistencias 3 de 100000 em serie + 1 de 10000 em serie + em serie com duas de 10000 em paralelo

Table 1: Values in SI units.

R_1	1000
R_2	1000
R_3	315000
R_4	1000
C_1	220×10^{-9}
C_2	220×10^{-9}

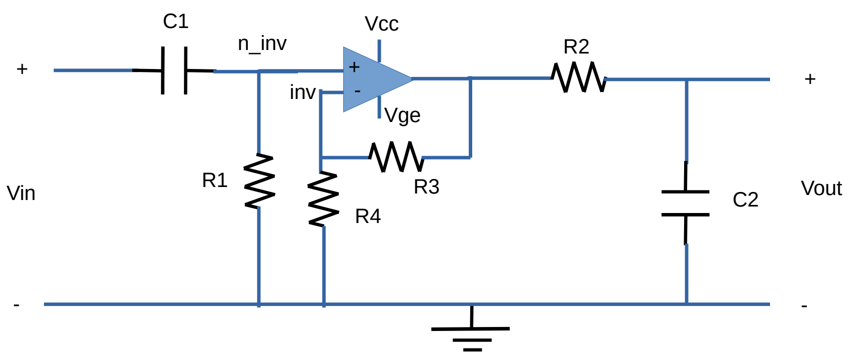


Figure 1: Circuit in study.

2 Theoretical Analysis

In this section, the circuit shown in Figure 1 is analysed theoretically.

The Transfer Function is given by the following equation,

$$T = \frac{R_1 C_1 s}{1 + R_1 C_1 s}\left(1 + \frac{R_2}{R_1}\frac{1}{1 + R_2 C_2 s}\right) \tag{1}$$

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

The frequency of the low pass filter part of the circuit is computed as

$$\omega_L = \frac{1}{R_2 C_2} \tag{2}$$

and the frequency of the high pass filter part of the circuit is given by

$$\omega_H = \frac{1}{R_1 C_1} \tag{3}$$

This leads to a central frequency expressed as

$$\omega_C = \sqrt{\omega_L \times \omega_H} \tag{4}$$

Dividing the value obtained from equation 4 by 2π, we get one of the values of interest of the circuit, which should be of $1kHz$.

Name	Value [Hz]
f_L	723.43
f_H	1446.86
f_O	1023.09

Table 2: Frequencies

The gain of the circuit is given by the formula below,

$$Gain = |\frac{R_1 C_1 \omega_C j}{1 + R_1 C_1 \omega_C j} \times (1 + \frac{R_3}{R_4}) \times \frac{1}{1 + R_2 C_2 \omega_C j}| \quad (5)$$

Also, the input impedance is given by

$$Z_{in} = |R_1 + \frac{1}{j\omega_C C_1}| \quad (6)$$

and the output impedance as

$$Z_{out} = |\frac{1}{j\omega_C C_2 + \frac{1}{R_2}}| \quad (7)$$

Name	Value [dB]
$gain$	105.31
$gain_{dB}$	40.449
Z_{IN}	1758.81
Z_{OUT}	586.13

Table 3: Gain and impedances

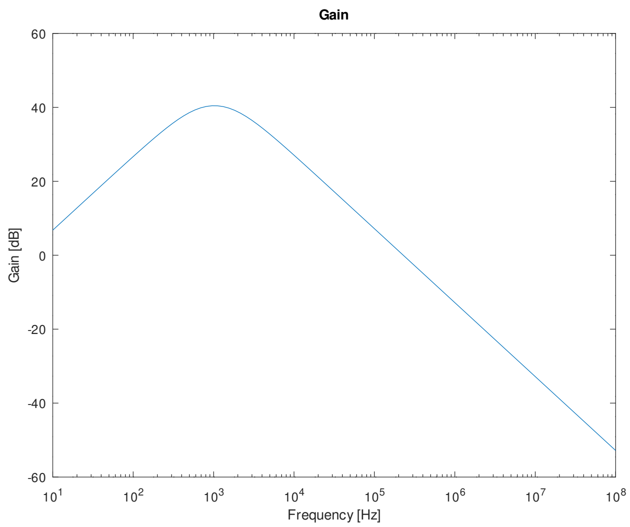


Figure 2: Output voltage gain in order to frequency

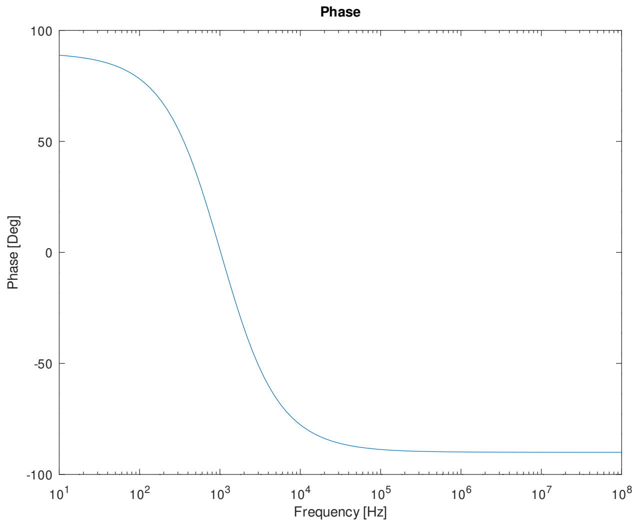


Figure 3: Phase in order to frequency

Here we present the merit figure of our circuit.

Name	Value [Hz] [Mu]
$gain_{dev}$	5.308950
$freq_{dev}$	23.0867
$Cost$	13656.66
$Merit$	2.578715e-06

Table 4: Merit figure

3 Simulation Analysis

3.1 Frequency Analysis

The frequency analysis was done in order to obtain the gain of the circuit as a function of the frequency.

The following plot shows the function we obtained for V_{out}, in dB, and it is also presented a plot with phase.

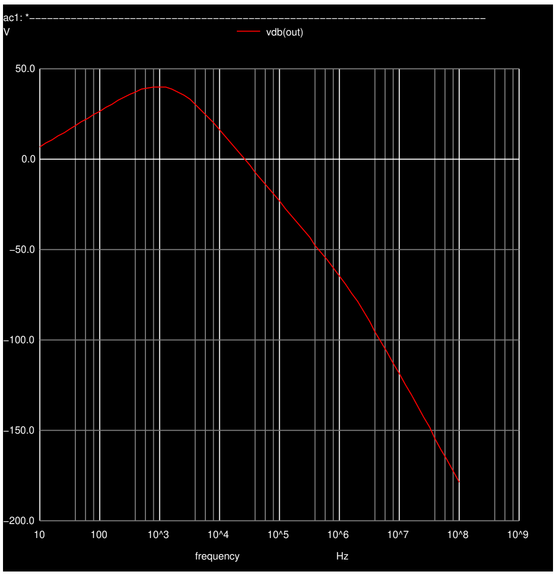


Figure 4: vOUT (dB)

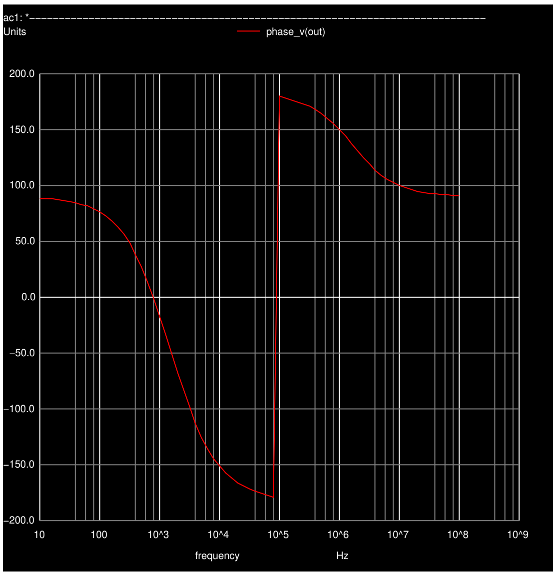


Figure 5: phase (degrees)

From this analysis, we can also obtain the values for the output voltage gain in the passband, the central frequency, and the input and output impedances at this frequency.

Name	Value [dB]
gain	1.005979e+02
gaindb	4.005178e+01
zin	1.759004e+03
zout	5.911203e+02

Table 5: Gain, output and input impedance

We can also obtain the values for the upper, lower cut off and central frequencies.

Name	Value [Hz]
fl	3.867110e+02
fh	2.058741e+03
fo	1.000000e+03

Table 6: Frequencies

3.2 Merit Figure

In this section, we present the costs of the components and the total cost of the circuit, as well as the merit figure.

Name	Value [Hz] [Mu]
gaindev	5.979197e-01
freqdev	0.000000e+00
cost	1.365666e+04
merit	1.224650e-04

Table 7: Merit figure

4 In-person simulation

Due to the lack of time during the laboratory class, we couldn't build the entire circuit. However, we were able to make some measurements of interest.

The V_{cc} tension read in the multimeter was of value $10.097V$ and the V_{cc}^{-} tension was of magnitude $-10.030V$.

The input amplitude of the signal was read and measured with the oscilloscope which registered $0.221V$ and the output amplitude registered $2.450V$. This translates in a gain of about $11.086V$, which is close to the pretended gain.

Due to the pandemic, we couldn't attend laboratory classes during the semester, so this last laboratory assignment showed us that it is not easy to build circuits and that values can vary with lots of outside factors. The programming skills aquired are surely useful, but some hands-on experience in the future will be a good improvement in our skill set.

5 Side-by-side

As a viewer's reference note, the theoretical values are presented on the left and the simulation values on the right.

Name	Value [Hz]	Name	Value [Hz]
f_L	723.43	fl	3.867110e+02
f_H	1446.86	fh	2.058741e+03
f_O	1023.09	fo	1.000000e+03

Table 8: Comparison 1

Name	Value [dB]	Name	Value [dB]
$gain$	105.31	gain	1.005979e+02
$gain_{dB}$	40.449	gaindb	4.005178e+01
Z_{IN}	1758.81	zin	1.759004e+03
Z_{OUT}	586.13	zout	5.911203e+02

Table 9: Comparison 2

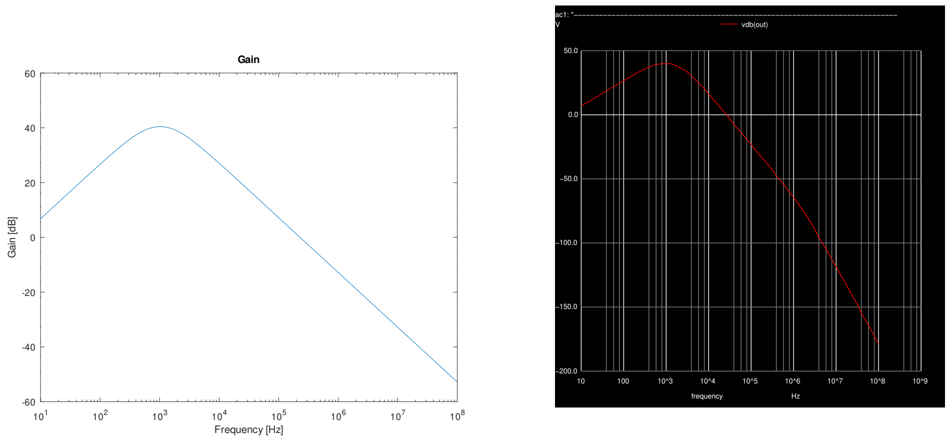
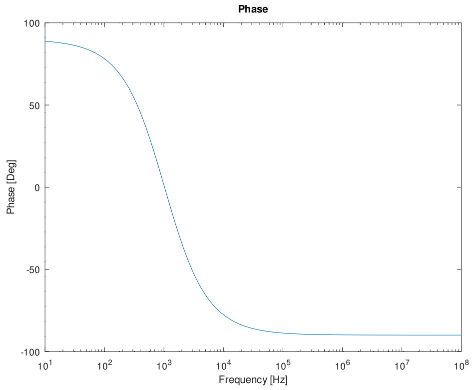


Figure 6: Output voltage gain in order to frequency



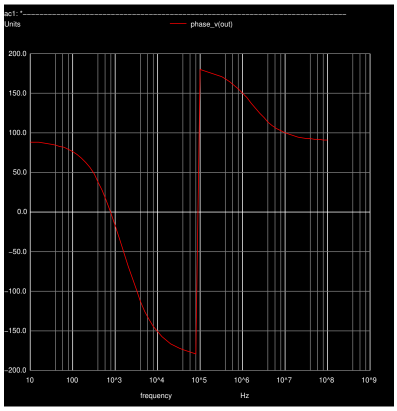


Figure 7: Phase in order to frequency

Name	Value [Hz][Mu]	Name	Value [Hz][Mu]
$gain_{dev}$	5.308950	gaindev	5.979197e-01
$freq_{dev}$	23.0867	freqdev	0.000000e+00
$Cost$	13656.66	cost	1.365666e+04
$Merit$	2.578715e-06	merit	1.224650e-04

Table 10: Comparison 4

We can see that the cost is the same but the merit figure is higher using Ngspice's values, probably due to a higher bandwidth.

6 Conclusion