Circuit Theory and Electronics Fundamentals

Integrated Master in Aerospace Engineering, Técnico, University of Lisbon

Laboratory Report-T5

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1 Introduction

The main objective of this laboratory assignment is to implement a BandPass Filter (BPF) with a central frequency of 1kHz and a gain at the central frequency of 40dB, reaching the best figure of merit possible. In order to this, the architecture of the circuit had to be chosen following a few restrictions in terms of the components that were allowed to use. The merit of the circuit is given by:

$$M = \frac{1}{cost * (voltagegaindeviation + centralfrequencydeviation + 10^-6)}. \quad (1)$$

The circuit used to produce the BandPass Filter is shown in Figure1.

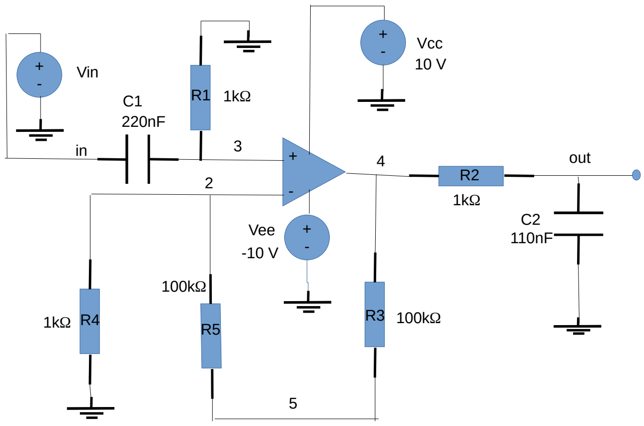

Figure 1: Circuit under analysis.

In the next section (2), we briefly explain the procedure to analyse theoretically the circuit above with the use of Octave maths tool. In Section 3 a simulation analysis is given, where we resorted to Ngspice to simulate the circuit, and a few graphics are presented to understand the results. The report finishes with its conclusion in section 4, where we analyse side by side the theoretical and simulated results and resume the most important points of the lab assignment.

2 Theoretical Analysis

In this section, the explanation of the theoretical analysis of the circuit showed in the introduction is given. For this analysis the ideal model for the OP-AMP was used, in which Z_{in} is infinite and Z_{out} is zero.

First, the lower and upper cut-off frequencies were computed. These calculations using Octave were based on:

$$\omega_L = \frac{1}{R1 * C1}. \tag{2}$$

$$\omega_H = \frac{1}{R2 * C2}. \tag{3}$$

Consequently, the central frequency was determined using the following expression:

$$\omega_C = \sqrt{\omega_L * \omega_H}. \tag{4}$$

The next step was to determine the transfer fuction of the circuit, in order to compute the frequency response of the gain and also to get the gain at the central frequency as requested. An analysis of the circuit culminated in the following expression for this function:

$$T(s) = \frac{V_{out}(s)}{V_{in}(s)} = \frac{R1 * C1 * s}{1 + (R1 * C1 * s)} * (1 + \frac{R3 + R5}{R4}) * \frac{1}{1 + (R2 * C2 * s)}. \tag{5}$$

With $s = j * w$.

Using this expression and substituting s by $j * \omega_C$, the gain at the central frequency was determined. With these results, Table1 was produced:

Name	**Value**
$LowerCut-offFrequency[Hz]$	7.234316e+02
$UpperCut-offFrequency[Hz]$	1.446863e+03
$CentralFrequency[Hz]$	1.023087e+03
$Gain[dB]$	4.254210e+01

Table 1: Frequency and gain.

Using the transfer function, a frequency analysis was made. With this, we were able to produced two graphics that show the frequency response of both the gain(dB) and phase(degrees). Figures 2 and 3 show exactly this:

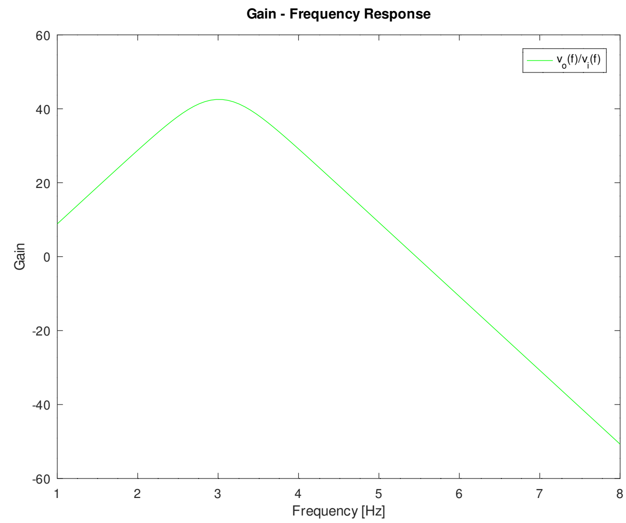

Figure 2: Frequency response - Gain(dB) .

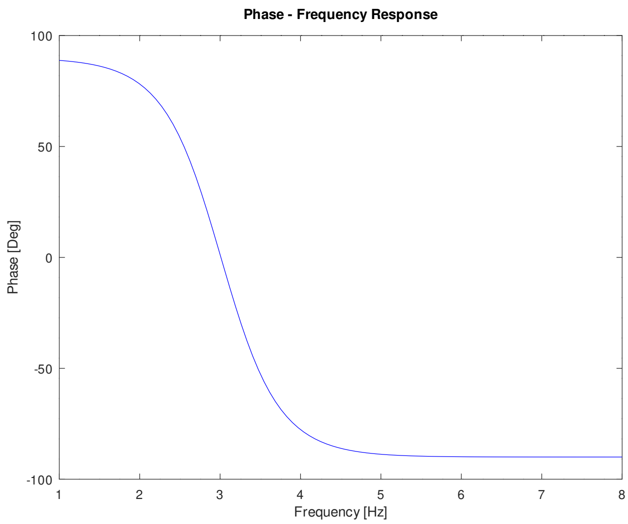

Figure 3: Frequency response - Phase(degrees) .

After this frequency analysis, the input and output impedances were computed using the value for the central frequency previously calculated. These impedances were obtained using the expressions below:

$$Z_{in} = R1 + \frac{1}{j * \omega_C * C1}. \tag{6}$$

$$Z_{out} = \frac{1}{\frac{1}{R2} + j * \omega_C * C2}. \tag{7}$$

With these calculations, the obtained results for the theoretical impedances were:

Name	Value
$Inputimpedance$	1.224745e+03
$Outputimpedance$	8.164966e+02

Table 2: Input and output impedances at central frequency.

Finally, the gain and frequency deviations were computed (comparing to the values of 40dB for the gain and 1kHz for the central frequency) and also the cost and merit. With this, Table3 was produced in order to evaluate the circuit in terms of its efficiency:

Name	Value
$GainDeviation[V]$	1.340000e+00
$CentralFrequencyDeviation[Hz]$	2.308672e+01
$Cost$	1.352633e+04
$Merit$	3.026597e-06

Table 3: Merit calculations.

3 Simulation Analysis

A simulation analysis was produced in order to better predict the behaviour of the circuit. The used script resorted to the OP-AMP model provided previously to the class and then few modifications were made to produce the final circuit.

Starting with the frequency response of the output voltage and phase in the pass band, we have:

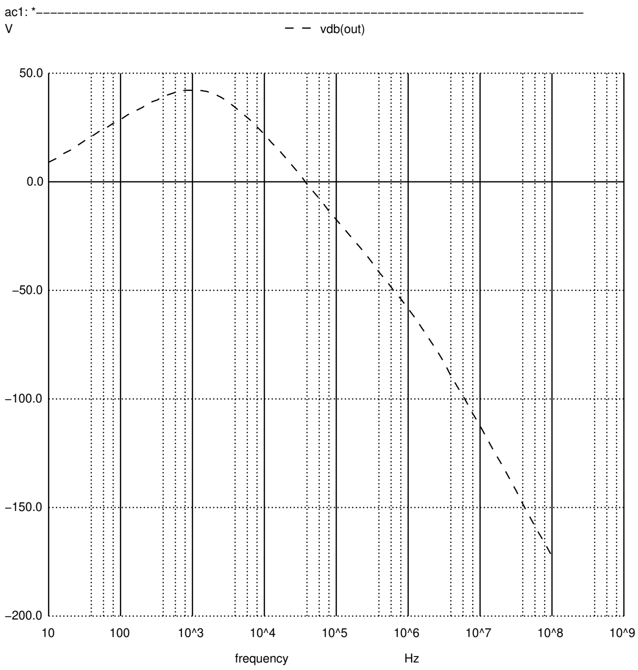

Figure 4: Frequency response - Output voltage.

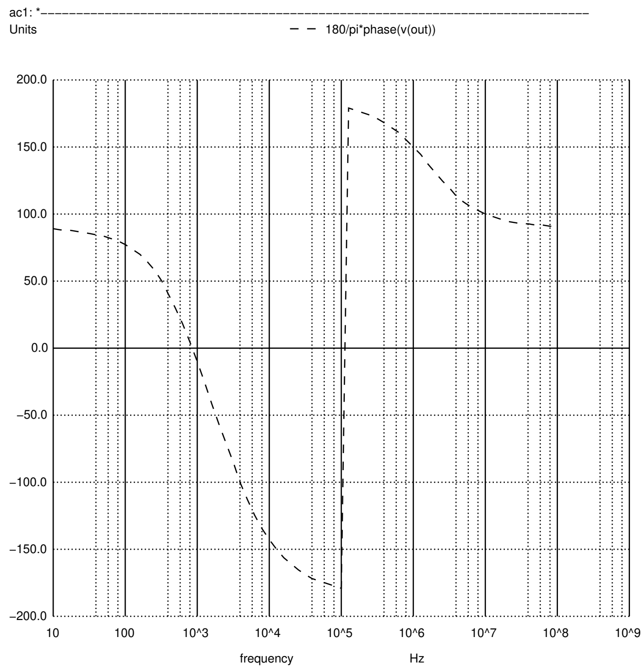

Figure 5: Frequency response - Phase.

By a frequency analysis, we were able to determine the low and high cut-off frequencies and, consequently, the central frequency. The following table shows these results and also the gain at the central frequency:

Lower Cut-off frequency [Hz]	398.932
Upper Cut-off frequency [Hz]	2283.74
Central Frequency [Hz]	954.492
Gain [dB]	42.3917

Table 4: Frequency results.

Then, using the Ngspice tool, the input and output impedances were obtained:

Zin	999.024

Table 5: Input Impedance.

Name	Value
Zout	681.72

Table 6: Output Impedance.

In the introduction, a formula for the merit of the circuit was given, depending on the cost, gain and central frequency deviations (in relation to the values given by the teacher). Finally, the values for these quantities were simulated, resulting in the next table:

Name	Value
Gain deviation [V]	1.31699
Central frequency deviation [Hz]	45.5084
Cost	13526.3
Merit	1.57884E-06

Table 7: Simulated Results.

4 Conclusion

To better understand the similarities and also what differs most in the results using the theoretical and simulated analysis, the tables with the important values are given side by side:

Name	Value	Name	Value
$GainDeviation[V]$	1.340000e+00	Gain deviation [V]	1.31699
$CentralFrequencyDeviation[Hz]$	2.308672e+01	Central frequency deviation [Hz]	45.5084
$Cost$	1.352633e+04	Cost	13526.3
$Merit$	3.026597e-06	Merit	1.57884E-06

Table 8: Obtained results using Octave

Table 9: Obtained results using NGSpice

Taking a closer look at these values, one notices that there are some discrepancies. These differences have a direct consequence in the value of the merit, since it depends on these quantities. However, one notices that the theoretical merit does not differ that much from the simulated one.

The differences between the analysis were expected and could be caused due to the aproximations made during the theoretical analysis while Ngspice uses much more complex models to predict the same quantities, since some of the components of the circuit are not linear.

Looking at the values for the impedances shown in the previous sections 2 and 3, one sees a few discrepancies, due to, once again, the ideal models used in the theoretical analysis that are much simpler than the ones used in the simulation tool.

Looking at the gain and central frequency deviations in both analysis, one concludes that these values are very satisfactory, since they do not differ much from the values given by the teacher prior to the lab assignment.

In fact, the value for the merit is quite small since the cost of this circuit is very big, mainly because of the OP-AMP. Taking that into consideration, the obtained values were within the expected.

As usual, the merit to take into consideration is the simulated one, since $Ngspice$ has the ability to produce values that are much more similar to reality.

It is also important to compare the graphics obtained in both methods(see below), since they give valuable information to compare the results. One sees that the curves represented are very similar, both in the frequency analysis of the gain and the phase, which leads us to conclude that the these figures were well produced and the theory behind them is correct.

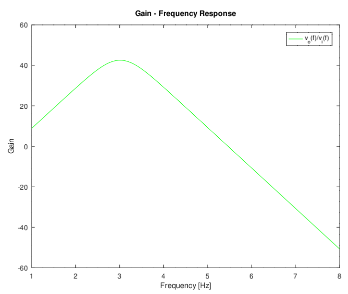

Figure 6: Gain [dB] using Octave

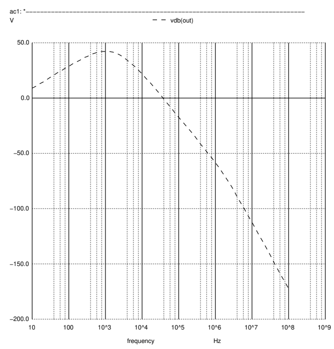

Figure 7: Gain [dB] using Ngspice

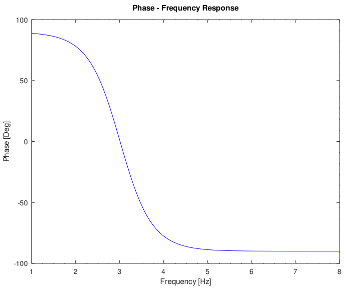

Figure 8: Phase [degrees] using Octave

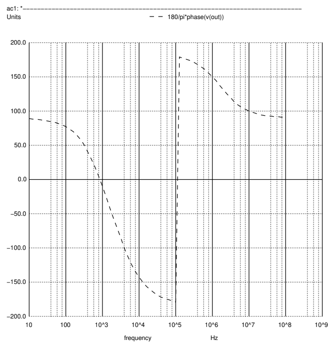

Figure 9: Phase [degrees] using Ngspice

In conclusion, although there are some differences (that were expected), the objective of this lab assignment was accomplished and both methods (theoretical end simulated) were able to filter the unwanted frequencies, both very low and very high.