Circuit Theory and Electronics Fundamentals

Integrated Master in Aerospace Engineering, Técnico, University of Lisbon

Lab5: Bandpass filter using OP-AMP

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1 Introduction

The objective of this laboratory assignment is to build a bandpass filter with a central frequency of 1kHz and a gain of 40dB. The circuit created and analysed in this assignment can be seen in Figure 1.
In order to evaluate how successfully our goal has been achieved, we calculate the merit M of our work, using the following expression:

$$M = \frac{1}{cost(*GainDeviation * CentralFreqDeviation + 10^{-6})} \tag{1}$$

where the cost is given by cost = cost of resistors + cost of capacitors + cost of transistors, knowing that each kOhm costs 1 monetary unit (MU), each μF costs 1 MU and each transistor costs 0,1 MU. In Section 2, a theoretical analysis of the circuit is presented, using Octave. In Section 3, the circuit is analysed by simulation using ngspice. The conclusions of this study are outlined in Section 4. In addiction, the results are compared to the theoretical results obtained in Section 2.

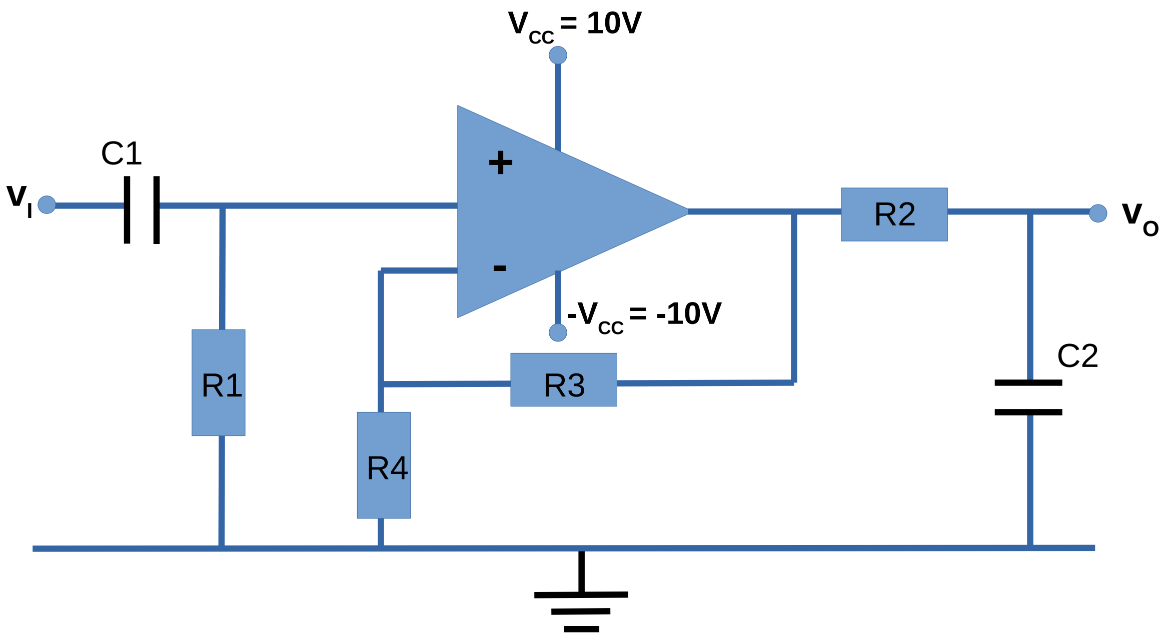

Figure 1: Circuit analysed.

2 Theoretical Analysis

In this section, the circuit shown in Figure 1 is analysed theoretically, according to the ideal op-amp model.
With this model, regarding it is an ideal model, the following equations were obtained for this circuit:

$$Z_i = \infty \tag{2}$$

$$Z_o = 0 \tag{3}$$

$$|Z_i| = |Z_{C1} + R_1||\infty| = |Z_{C1} + R_1| \tag{4}$$

$$|Z_o| = |Z_{C2}||(R_2 + R_3||0)| = |Z_{C2}||R_2| \tag{5}$$

$$v_- = v_+ = \frac{R_1}{R_1 + Z_{C1}} v_I \tag{6}$$

$$T(s) = (\frac{R_1 C_1 s}{1 + R_1 C_1 s})(1 + \frac{R_3}{R_4})(\frac{1}{1 + R_2 C_2 s}) \tag{7}$$

$$LowFrequency = \frac{1}{R_1 C_1} \tag{8}$$

$$HighFrequency = \frac{1}{R_2 C_2} \tag{9}$$

$$CentralFrequency = \sqrt{LowFrequency * HighFrequency} \tag{10}$$

Table 1: Circuit parametres

R_1	1.00000000e+03
R_2	1.00000000e+03
R_3	1.00000000e+05
R_4	1.00000000e+03
C_1	2.20000000e-07
C_2	2.20000000e-07

Solving these equations and using the parametres above, it was possible to compute the frequency response, as well as the values of the cut off and central frequencies, the input and output impedances and the gain at the central frequency. These are shown below.

Table 2: Theoretical Results

$LowFrequency$	7.23431560e+02
$HighFrequency$	7.23431560e+02
$CentralFrequency$	7.23431560e+02
Z_I	1.23424196e+03
Z_O	5.86134309e+02
$Gain$	4.79643109e+01
$Gain(dB)$	3.36183642e+01

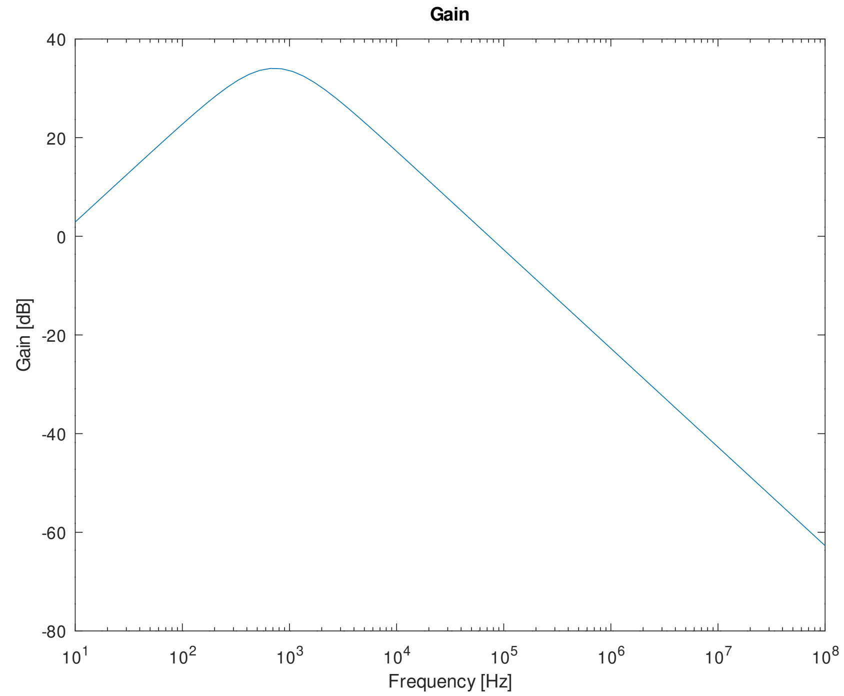

Figure 2: Frequency Response: Gain (dB)

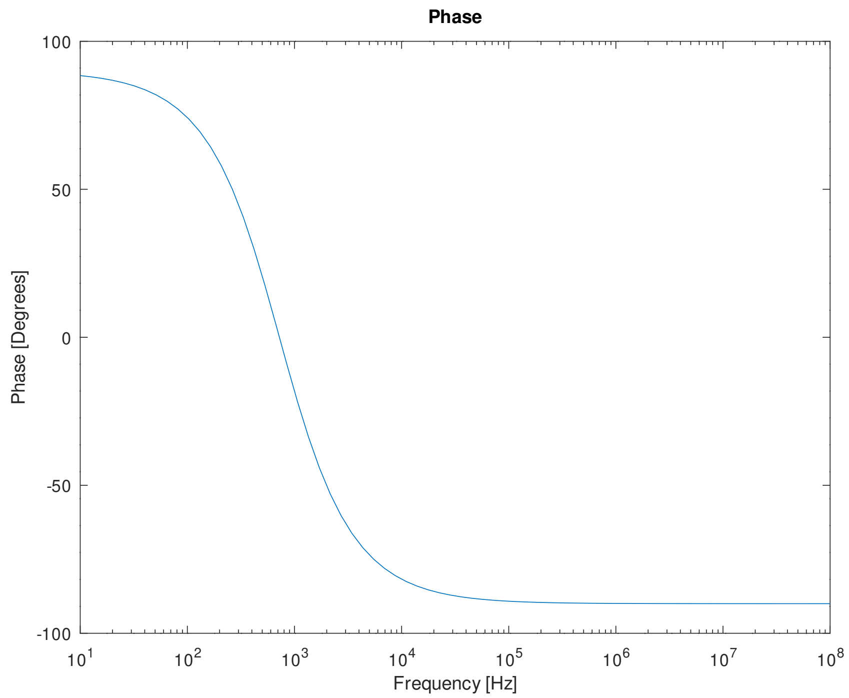

Figure 3: Frequency Response: Phase (Degrees)

3 Simulation Analysis

This section covers circuit simulation in ngspice, where the output voltage gain, the central cutoff frequency and the input and output impedances were measured. In the following graphs, the frequency response of the output voltage is simulated (with magnitude in db and phase degrees).

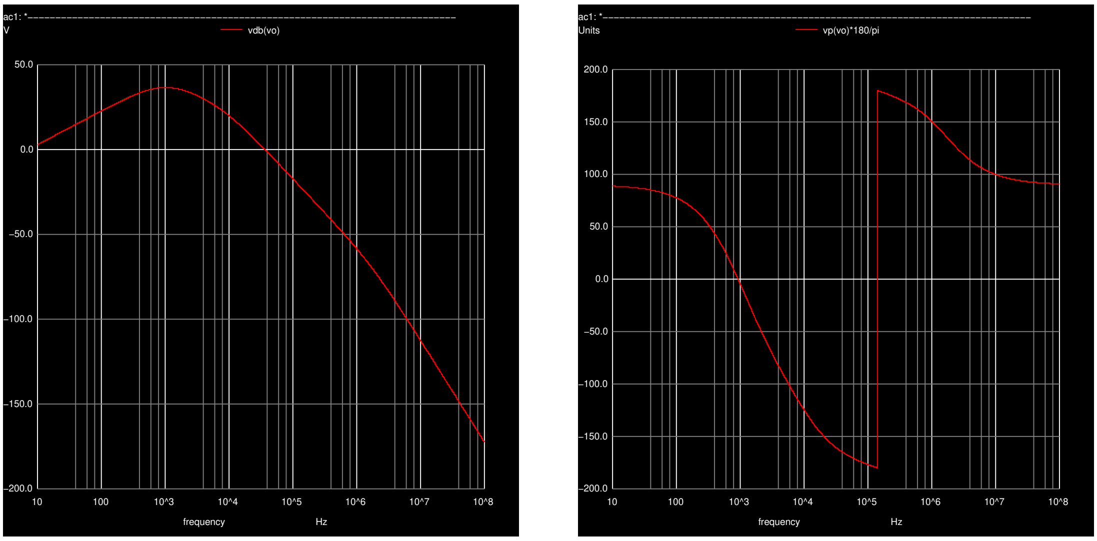

Figure 4: Frequency response of the output voltage gain in the passband.

Also, in the following table the output voltage gain, the central frequency, the input and output impedances and the merit of the circuit are presented, along with the variables used to calculate them.

Name	**Value**
lowfreq	4.053199e+02
highfreq	2.480942e+03
centerfreq	1.002784e+03
outgain	9.432472e+01
gaindeviation	3.466890e+00
freqdeviation	2.783707e+00
cost	1.342623e+04
merit	1.191583e-05
zin	6.909442e+04
zo	9.999731e+02

Table 3: Measured values: Gain, cutoff frequencies, central frquency, input and output impedances, gain deviation, frequency deviation and the cost and merit of the circuit).

4 Conclusion

In order to analysis the similarities or discrepancies in the theoretical analysis and the simulation, the following tables made with ngspice and octave are presented.

Name	Value
lowfreq	4.053199e+02
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centerfreq	1.002784e+03
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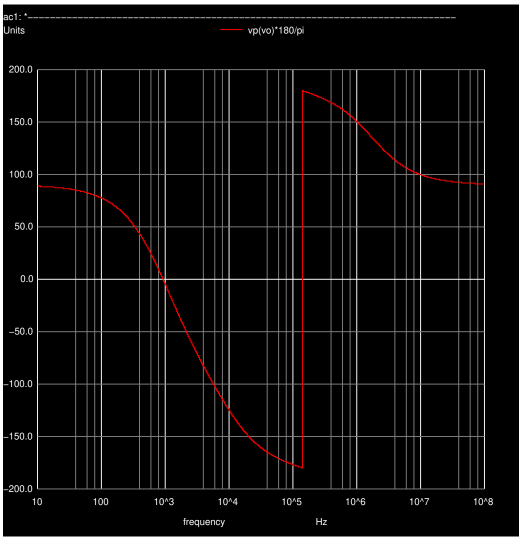
$Gain$	4.79643109e+01
$Gain(dB)$	3.36183642e+01

Table 4: Simulation (left) and Theoretical (right) operating point results.

Comparing the values obtained in Octave and Ngspice, the values and graphs obtained were significantly different. As it can be seen the phase plots for simulation and theoretical analysis are slightly different. This can be explained by the difference between the ideal model for an OP-AMP, used in Octave, and the model, much more complex, used by Ngspice. Taking this into account, both analysis were still able to create an audio amplifier circuit, even if the octave's model is not the best representation of the reality, due to its low complexity.



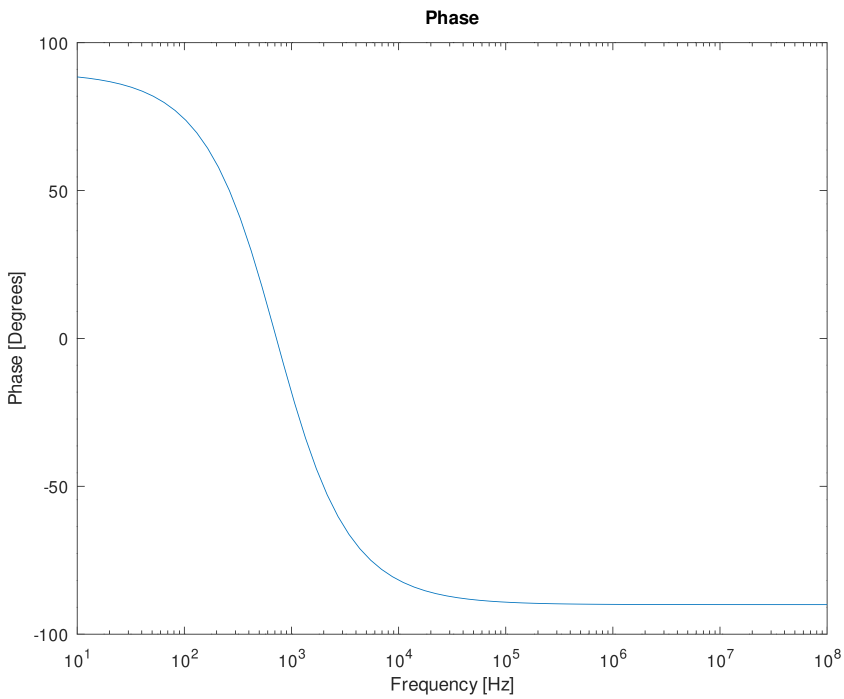


Figure 5: Frequency response of the output voltage gain in the passband: Simulation (above) and Theoretical (below).