

Lab 05 Report

Circuit Theory and Electronic's Fundamentals

Afonso Guerreiro (96501) Diogo Aguiar (96520) Francisco Raposo (96531)
Instituto Superior Técnico
Mestrado em Engenharia Física Tecnológica

May 31, 2021

Contents

1 Introduction	1
2 Theoretical Analysis	3
3 Simulation Analysis	4
4 Conclusion	6

1 Introduction

In this assignment we present and analyse a possible design for an active bandpass filter, by using one 741 OP-AMP with $\pm 5V \pm V_{CC}$, in an architecture with non-inverting feedback. Associations of resistors and capacitors were also used.

Furthermore, a cost/effectiveness analysis was also done, with set prices for the transistors (0.1 monetary unit per transistor), resistors (1 monetary unit per kOhm) and capacitors(1 monetary unit per micro-Farad). COST OF OP-AMP

We used the following components

Name	Value [A or V]
C_1	$1\mu F$
R_1	$80k\Omega$
R_2	$10k\Omega$
R_3	$0.9k\Omega$
R_4	70Ω
C_2	$80\mu F$

Table 1: Values for the components used

The values are presented as parallel or series of individual components as the available material for this circuit was specified, and this series and parallel associations were omitted from the circuit scheme for the sake of simplicity. This architecture has a cost of XXXX MU (we did not consider the cost of the OP-AMP).

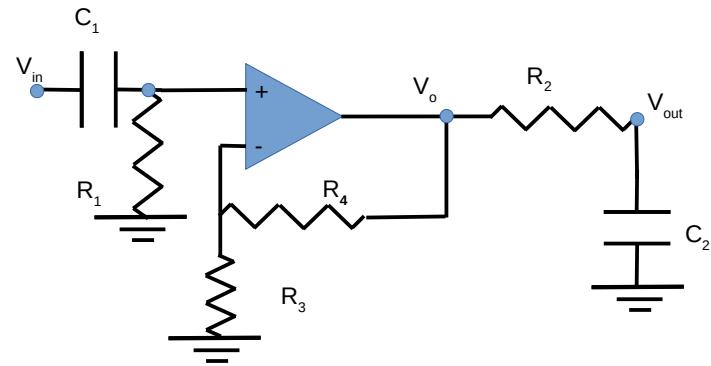


Figure 1: Active bandpass filter circuit.

We then began by analysing the circuit by means of simulation with ngspice and a theoretical approach using Octave. Afterwards the results from both methods were compared followed by a discussion of the efficiency of the speaker.

2 Theoretical Analysis

For the theoretical analysis, we considerer an ideal operational amplifier, i.e., wiht infinite gain, infinite input impedance and zero output impedance. We also assume the OP-AMP is not saturated. In this conditions, the voltage at the minus and plus terminal are the same and no current flows into either.

At the plus terminal we have a simple voltage divider, thus

$$\frac{\tilde{V}_+}{\tilde{V}_{in}} = \frac{j\omega C_1 R_1}{R_1 j\omega C_1 + 1} \quad (1)$$

By applying Kirchoff's laws we arrive at an equation for the voltage at the output,

$$\frac{\tilde{V}_{out}}{\tilde{V}_o} = \left(1 + \frac{R_4}{R_3}\right) \frac{1}{R_2 j\omega C_2 + 1} \frac{1}{R_2 j\omega C_2 + 1} \quad (2)$$

Hence, combining the two we get

$$\text{Gain} = \frac{\tilde{V}_{out}}{\tilde{V}_{in}} = \frac{j\omega C_1 R_1}{R_1 j\omega C_1 + 1} \left(1 + \frac{R_4}{R_3}\right) \frac{1}{R_2 j\omega C_2 + 1} \frac{1}{R_2 j\omega C_2 + 1} \quad (3)$$

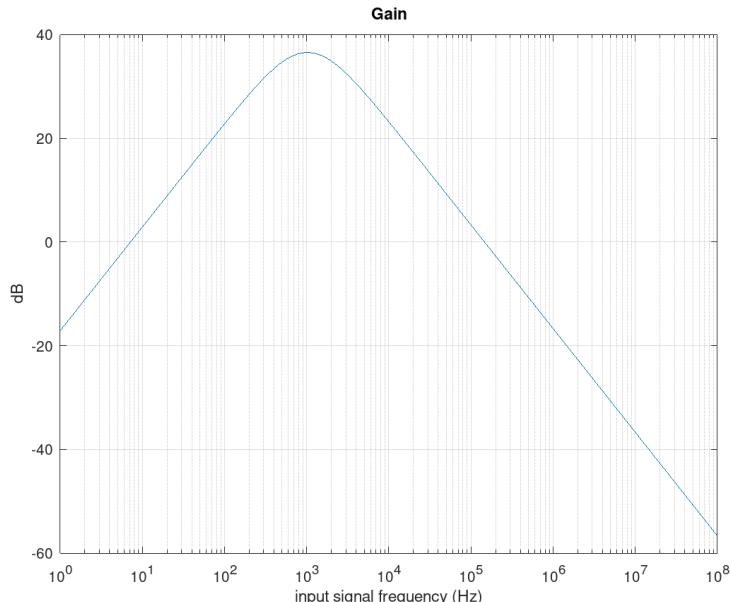


Figure 2: Frequency response of the circuit

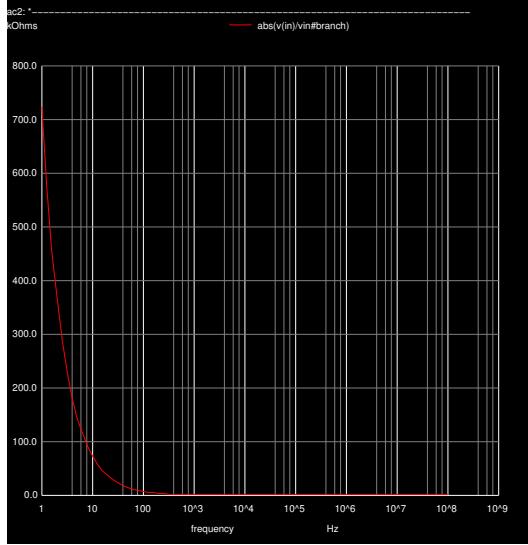
In particular for $f = 1.004690e + 03 \text{Hz}$ ¹ we have

$$\text{Gain} = 36.563331$$

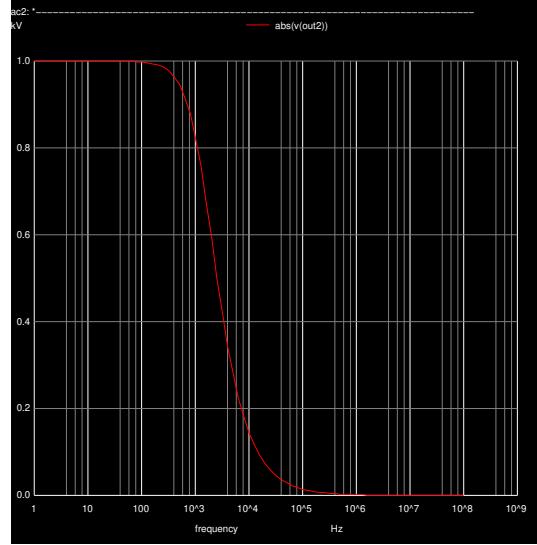
¹This frequency corresponds to the central obtained by the simulation

3 Simulation Analysis

We ran a simulation of the circuit using *Ngspice* with the provided OP-AMP model, thus obtaining the following results, for the frequency analysis of the circuit.



(a) Input impedance of the circuit (kOhm)

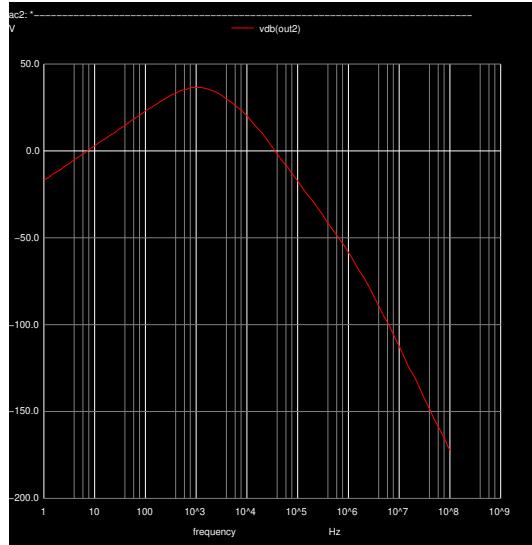


(b) Output impedance of the circuit (kOhm)

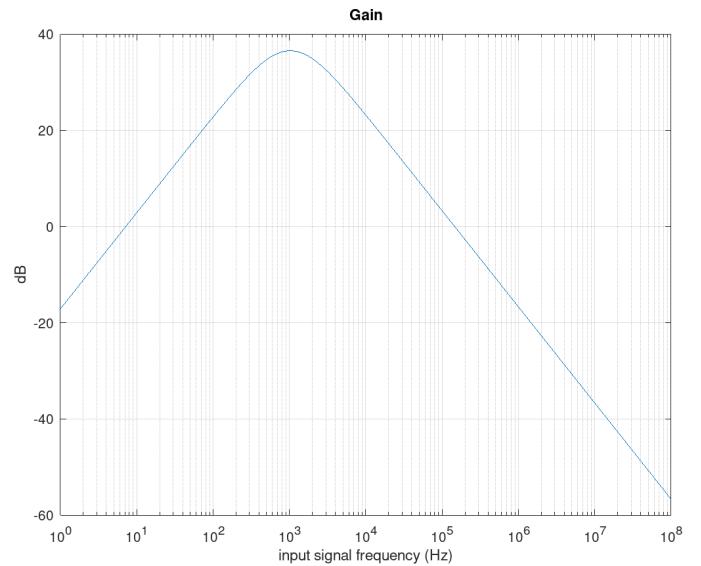
The input impedance is very high for low frequencies, as expected, and seems to diminish progressively for higher frequencies, once again as expected given the frequency dependent behaviour of the capacitor. We also see that for $f \rightarrow \infty$ the input impedance appears to vanish, which is a clear deviation from the theoretical model, which considers it to be infinite for all frequencies. As for the output impedance, the results obtained show the predicted behaviour. The total output impedance is approximately just due to the capacitor resistor association, thus leading to a similar behaviour. It should be noted that the high output impedance values are not ideal to connect to any load, as there can be significant voltage loss. The output voltage gain plot shows a very narrow passband centered at approximately 1kHz. Hence, the circuit effectively acts as a passband filter, although one with very little bandwidth. We did not consider this to be a problem as one of the requirements was a central frequency, $f = \sqrt{f_{lower}f_{upper}}$ of $^2 1\text{kHz}$. The specificity of the value requested led us to think the filter was very directed for 1kHz and neighbouring frequencies. Furthermore, the gain plot obtained with the theoretical analysis is very coherent with the simulation. Both show similar form, peaking at around 1kHz, corresponding to a gain of about 35-40 dB. The significant differences occur for frequencies greater than 0.1MHz, for which *ngspice*'s reveals a much quicker decrease in gain, eventually reaching -150dB where spice never reaches below -100dB. This divergence may be rooted in the aforementioned input impedance which diminishes significantly. What is more, we calculated the gain, input and output impedances at the central frequency.

Once again, the value for the gain is in agreement with the theoretical analysis.

²Upper and lower cut-off frequencies were calculated as the frequencies for which the gain was less 3dB than at its maximum.



(a) *Ngspice's* output voltage gain



(b) Theoretical analysis' output voltage gain

Name	Value [A or V]
f	1.004690e+03
gain	3.652900e+01
z	1.519501e+03
mag(z)	8.236747e+02

Table 2: f denotes the central frequency, Z the input impedance and $\text{mag}(z)$ the output impedance.

XXXXX Hence we obtained, a merit figure of $2,1 \times 10^7$.

4 Conclusion

All in all, the proposed circuit works well as an active bandpass filter with a central frequency and central frequency gain with minor deviation from the ones requested. As mentioned before, the high output impedance, for smaller frequencies, may become problematic and an additional output circuit may eventually be required to reach a smaller output impedance, to avoid voltage loss. Lastly, the results from the theoretical analysis and the simulation are very similar, with divergence for the gain above 0.1MHz and input impedance diminishing heavily at high frequencies. Nonetheless, for frequencies below 0.1MHz, the ideal model for the OP-AMP is very fitting to describe the circuit