Lab 05 Report
Circuit Theory and Eletronic's Fundamentals

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1 Introduction

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

We used the following components

Name	Value
C_1	$220nF$
R_1	1kΩ
R_2	1kΩ
R_3	1kΩ
R_4	100kΩ
C_2	$220nF$ in series with 220 nF

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 ommited from the circuit scheme for the sake of simplicity. This architecture has a cost of 103.66 MU (we did not consider the cost of the OP-AMP).
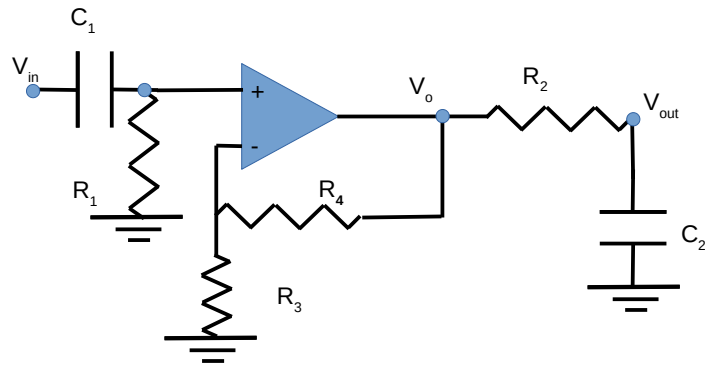
Figure 1: Active bandpass filter circuit.

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 impedence and zero output impedence. 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

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

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

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

Hence, combining the two with get

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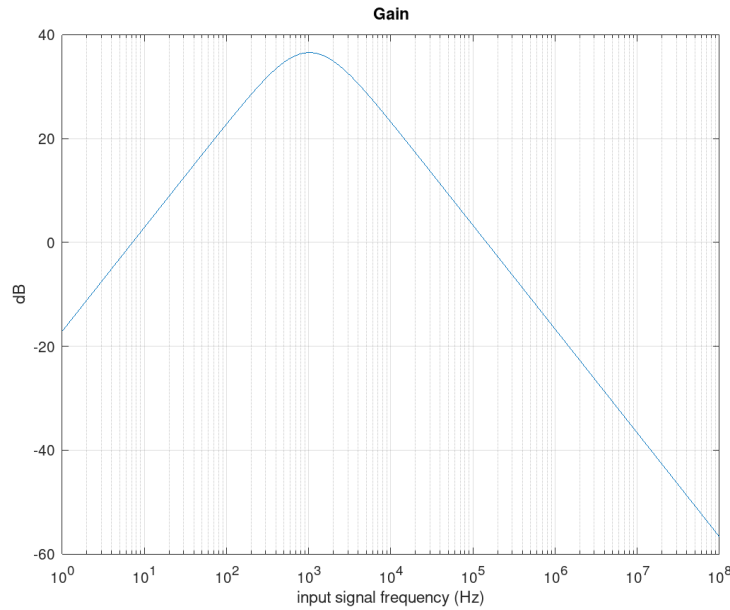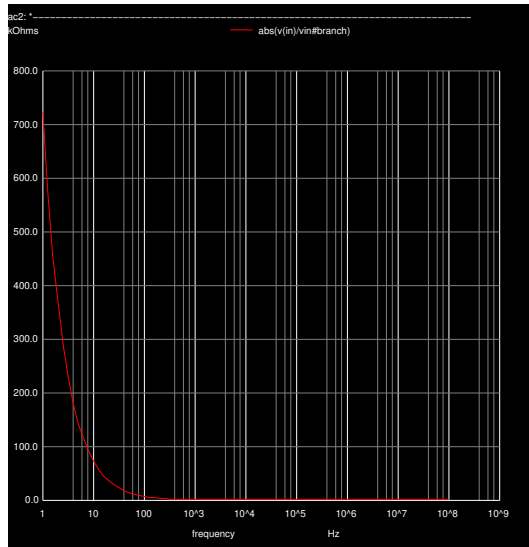

Figure 2: Frequency response of the circuit

In particular for $f = 1.004690e + 03$Hz[1] we have

$$\text{Gain} = 36.563331$$

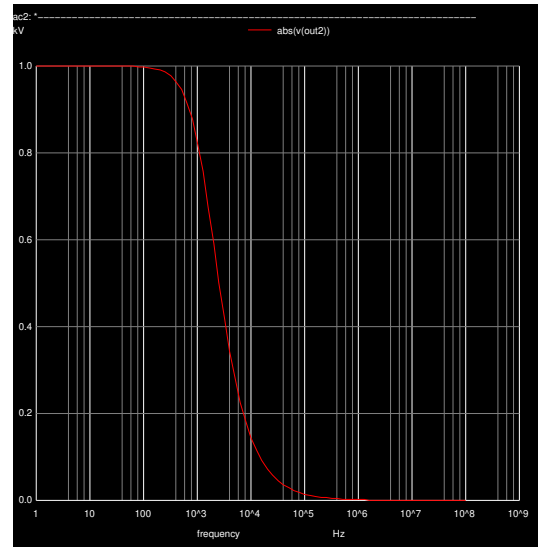[1]This frequency corresponds to the central obtained by the simulation

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.

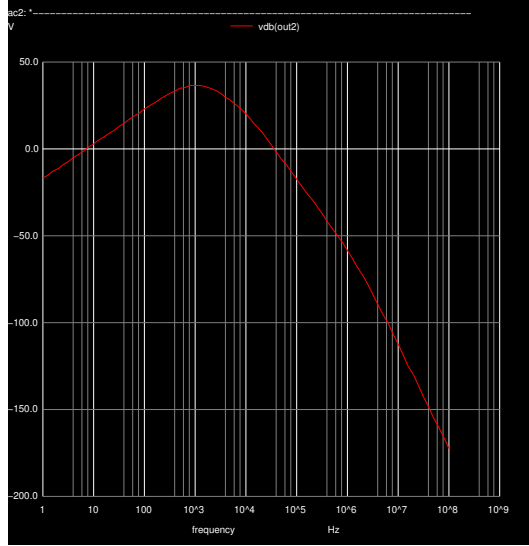(a) Input impedance of the circuit (kOhm)
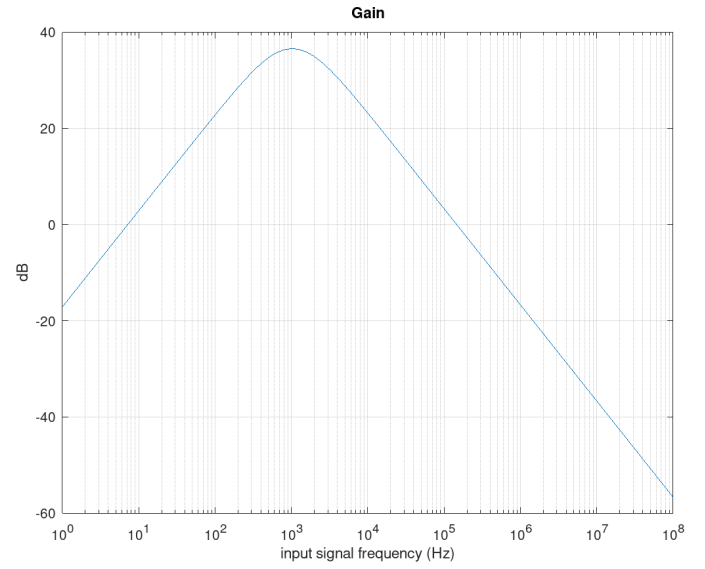

(b) Output impedance of the circuit (kOhm)

The input impendence is very high for low frequencies, as expected, and seems to diminuish progressivly for higher frequencies, once again as expected given the frequency dependent behaviour of the capacitor. We also see that for $f \to \infty$ the input impendence appears to vanish, which is a clear deviation from the theoretical model, which considers it to be infinite for all frequencies. As for the ouput impendence, the results obtained show the predicted behaviour. The total output impedence is approximatly just due to the capacitor resistor association, thus leading to a similar behaviour. It should be noted that the high ouput impedence 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 approximatly 1kHz. Hence, the circuit effectivly acts as a passband filter, although one with very little bandwith. We did not consider this to be a problem as on of the requirements was a central frequency, $f = \sqrt{f_{lower} f_{upper}}$ of[2] 1kHz. 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, correponding to a gain of about 35-40 dB. The significant diferences occur for frequencies greater than 0.1MHz, for which *ngspice's* reveals a much quicker decreace in gain, eventually reaching -150dB where spice never reaches bellow -100dB. This divergence may be rooted in the aformentioned input impedence which diminuishes significantly. What is more, we calculated the gain, input and output impendences at the central frequency.

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

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[2]upper and lower cut-off frequencies were calculated as the frequencies for wich the gain was less 3dB than at it's 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 impedence and mag(z) the output impedence.

Hence we obtainned, a merit figure of $5,926 \times 10^{-4}$.

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 ouput impedence, for smaller frequencies, may become problematic and an additional output circuit may eventually be required to reach a smaller output impedence, to avoit 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 diminuishing heavily at high frequencies. Nontheless, for frequencies bellow 0.1MHz, the ideal model for the OP-AMP is very fitting to describe the circuit.