Circuit Theory and Electronics Fundamentals

Integrated Masters in Aerospace Engennering, Técnico, University of Lisbon

Laboratory Report 5- Bandpass Filter, Group 28

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1 Introduction

The aim of this laboratory assignment was to dimension and implement a Band Pass Filter (BPF) using an OpAmp (Operational Amplifier) with a central frequency of 1KHz and a gain at central frequency of 40dB. As one should bear in mind, an OP-AMP is a transistor-based amplifier with main features, such as: high gain, high input impedance, low output impedance, differential input. The group was given a finite number of components to build this circuit, which is presented in the figure below. Moreover, it is important to highlight that Ngspice was used to simulate the behaviour of the circuit, allowing us to measure the output voltage gain in the passband, the central frequency, and the input and output impedances at this frequency. On top of that, the theoretical analysis, using the Octave tool, enabled us to compute the frequency response Vo(f)/Vi(f) and the gain, input and output impedances at the central frequency. Octave and Ngspice results were compared side by side.

The quality of the filter is evaluated by the following expression:

$$MERIT = \frac{1}{cost * gaindeviation * centralfrequencydeviation} \tag{1}$$

The circuit is shown below as well as the values associated to each component (in V, Ohm and Farads).

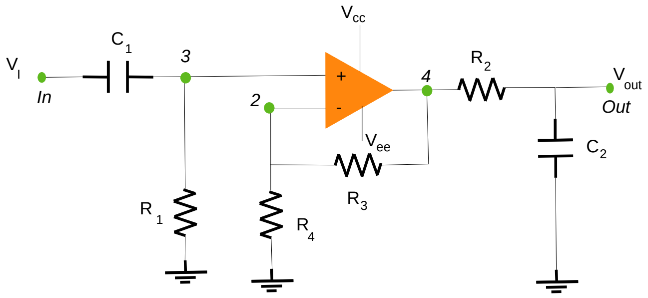


Figure 1: Circuit in analysis.

Name	Value
C1	2.200000e-07
C2	1.100000e-07
R1	1.000000e+03
R2	1.000000e+03
R3	1.500000e+05
R4	1.000000e+03
Vcc	1.000000e+01

Table 1: Used Values of each component: Resistors[Ohm]; Capacitors[F]; Voltages[V]

2 Theoretical Analysis

In this section, a theoretical analysis of the circuit shown in section 1 was conducted.

2.1 Description and Important Mathematical considerations

First, the transfer function, of the circuit was determined. Accordingly to what was learned in lectures and in the presential laboratory class, we reached the following conclusions:

$$T(s) = \frac{Vout(s)}{Vin(s)} = 1 + \frac{Zout(s)}{Zin(s)} = \frac{R1 * C1 * s}{1 + R1 * C1 * s} * (1+)\frac{R3}{R4} * \frac{1}{1 + R2 * C2 * s} \tag{2}$$

We also computed the low cutoff frequency and the high cut off frequency in octave. The central frequency was also calculated. The equations used were the following:

$$\omega_L = \frac{1}{R1 * C1} \tag{3}$$

$$\omega_H = \frac{1}{R2 * C2} \tag{4}$$

$$\omega_0 = \sqrt{\omega_L * \omega_H} \tag{5}$$

AS requested, the input and output impedances were also calculated as follows:

$$Z_{in} = R1 + \frac{1}{j * \omega_0 * C1} \tag{6}$$

$$Z_{out} = \frac{R2}{j * \omega_0 * C2 * (R2 + \frac{1}{j * \omega_0 * C2})} \tag{7}$$

2.2 Final Results

All the important results obtained are shown in the tables and in the figure bellow.

Name	**Value**
Z in	1.000000e+03 + -7.071068e+02j
Z out	6.666667e+02 + -4.714045e+02j

Table 2: Input and output Impedences

Name	**Value**
LowFreq BandPass [rad/s]	4.545455e+03
HighFreq BandPass [rad/s]	9.090909e+03
Central Freq [rad/s]	6.428243e+03
Central Freq [Hz]	1.023087e+03

Table 3: Low cut-off frequency, High cut-off frequency, Central Frequency.

Name	**Value**
Central Freq (Hz)	1.023087e+03
Gain Central Freq (dB)	4.005771e+01

Table 4: Central Frequency(Hz) and Respective Gain(dB).

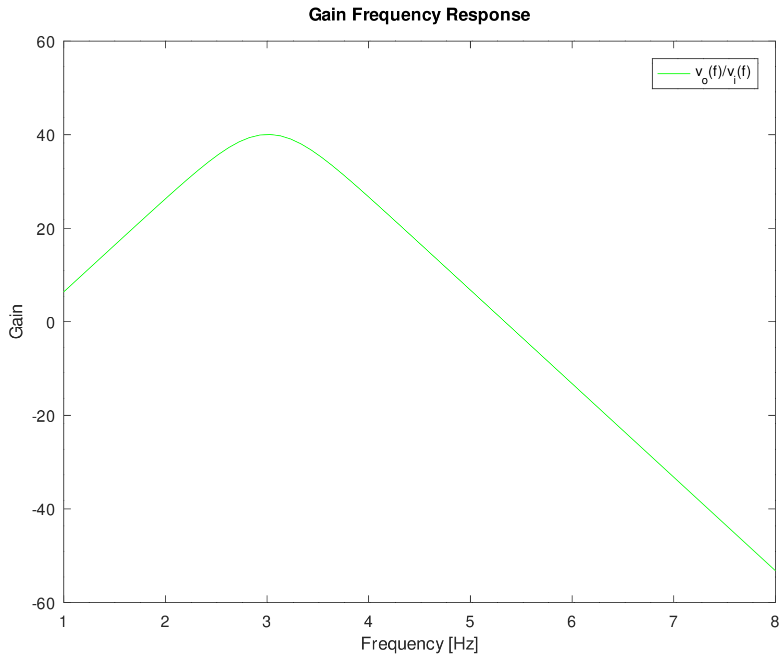


Figure 2: Voltage Gain of the circuit. Octave

Name	**Value**
Cost	1.405788e+04
Merit	3.060781e-06

Table 5: Cost and Merit.

3 Simulation Analysis

In this section, the several steps taken using ngspice in order to conduct the simulation of the band pass filter using an OP-AMP, as requested, will be described. The main focus of the simulation was to determine and optimize the values of the gain, the central frequency and the output and input impedances. The quality and overall figure of merit will then be analysed. The group proceded as follows:

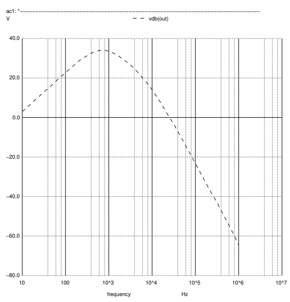
1. Design of the circuit, having as a starting point the circuit presented in section 1

2. In the frequency domain, measure of the output voltage gain, using the function .meas as well as the lower and upper cut off frequencies and the central frequency.

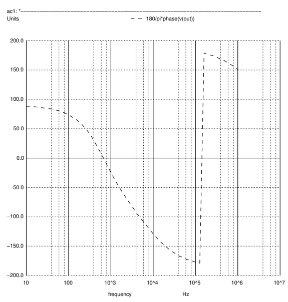
Gain	34.0105
Central Frequency	794.328
Gain deviation	49.8206
Central frequency deviation	205.672

Table 6: Results for ngspice

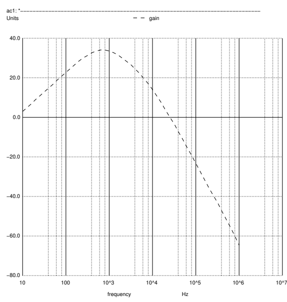
Then, the response of the circuit in dB and the phase were computed. The gain was also determined. In fact, the main goal of the assignement was to design a band pass filter. This means that this filter should cut both low an very high frequencies. THis is precisely what is shown in figure **??**



(a) Output Voltage in dB



(b) Output voltage (phase)



(c) Gain

3. Determination of the input impedance, seen from the input voltage source.

Zin	999.002 + -7.3282 j

Table 7: Input impedance in Ohm

The result obtained for the input impedance, considering the value in Ohm, is high. This is benefitial for the gain, because the voltage in the node In 2 must be as similiar to Vin as possible. Using a voltage divider, the only way to achieve this was to have a very high resistance value.

4. Determination of the output impedance, using a different set up, seen from the load resistance.

Zo	0.0522978 + -7.23396 j

Table 8: Output impedance in Ohm

Conserning the output impedance, an opposite deduction to the one made for the output impedance is mandoratory. Considering a voltage divider, the output impedance must be as low as possible, in order to the output voltage to be as high as possible. Having said that, an analysing tables 7 8, the difference needed between the two is confirmed.

5. Compute of the cost and figure of merit

   To finally understand the efficency of the amplifier, the cost and figure of merit were calculated

Cost	13425.8
Merit	7.26902E-09

Table 9: Cost and Figure of merit

Analysing table 9, the results obtained may be considered satisfying.

4 Comparison

In this section, a global comparison between Octave and Ngspice results will be made. Firstly, one should bear in mind that, in the previous sections, an Operating Point Analysis was performed to find the necessary values for the Incremental Analysis.

As requested we are able to compute the passband frequency in simulation analysis using the measure funtion and the central frequency in the theoretical analysis using Low and High Band Pass Frequencies. The different calculation methods leads the results to a little difference.

Calculus	Value
Gain	34.0105
Central Frequency	794.328
Gain deviation	49.8206
Central frequency deviation	205.672

Table 10: Central frequency [Hz] and respective gain [dB]. (Ngspice)

Name	Value
Central Freq (Hz)	1.023087e+03
Gain Central Freq (dB)	4.005771e+01

Table 11: Central frequency [Hz] and respective gain [dB]. (Octave)

We also computed the impedances as shown in the table bellow.

Calculus	Value [Ohm]
Zin	999.002 + -7.3282 j

Table 12: Cirtcuit impedances. Variables are expressed in Ohm.(Ngspice)

Name	Value [Ohm]
Z in	1.000000e+03 + -7.071068e+02j
Z out	6.666667e+02 + -4.714045e+02j

Table 13: Cirtcuit impedances. Variables are expressed in Ohm.(Octave)

5 Conclusion

As discussed in the introduction, the main goal of this assignment was to project a bandpass filter using an OP-AMP. which should allow maximum voltage gain, spending the less possible on the components used, among the ones available.

Despite strong efforts to match the results obtained in the different analysis, it was concluded that, due to the non-linearity of the components of the circuit, particularly the OP-AMP, it was impossible to obtain the exact same quality using both tools. In fact, the complexity of the parameters of the amplifier used in ngspice, are impossible to be replicated in the theorical analysis. This is believed to be the main reason for the diferrent output of the circuits.

Nevertheless, once the ngspice model is the most similiar to reality, the model used can then be validated.