LAB 5: BAND-PASS FILTER USING OP-AMP

Circuit Theory and Electronics Fundamentals

Ana Bárbara Azevedo (96504), Artur Gonçalves (96513), Diogo Soares (96519)

June 4, 2021

Contents

1 Introduction

In this laboratory assignment, a Band-Pass filter using an OpAmp was made. It is important to understand that, in order to efficiently succeed on this task, one must find the most reasonable relationship between the money needed and the performance of the amplifier. This relationship is expressed as a figure of merit calculated with

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

The following Figure presents the built circuit:

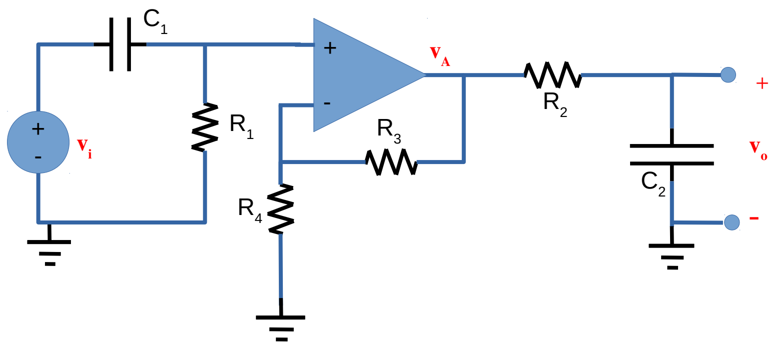

Figure 1: Considered circuit representation.

Component	Value and Units
R_1	1 $k\Omega$
R_2	1 $k\Omega$
R_3	130 $k\Omega$
R_4	1 $k\Omega$
C_1	220 nF
C_2	110 nF

Table 1: Components and their equivalent values.

In Section 2, a theoretical analysis of the circuit is presented, using Circuit Theory and Electronics Fundamentals concepts. After that, in Section 3, the circuit is analysed via simulation, using the software Ngspice. The obtained results are then compared, explaining the reasons behind the differences and similarities found. Finally, one can find the conclusions of this study outlined in Section 4.

2 Theoretical Analysis

In this section, the previously shown circuit is theoretically analised.

First of all, it is important to refer that the available components had specific values for resistors and capacitors. Hence, the previously shown circuit is a simplification of the following:

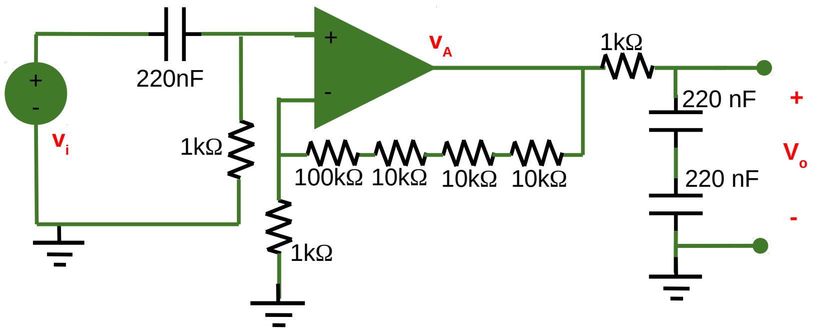

Figure 2: Representation of the circuit using the available components.

In order to compute the input/output impedances, the OpAmp model was considered to have an infinite input impedance and a zero output impedance ($Z_{in} = \infty$ and $Z_{out} = 0$).

Looking at the circuit, to calculate its input impedance Z_i, it was considered that $v_O = 0$ and, as a result, one can write

$$|Z_i| = \left| Z_{C_1} + \frac{1}{\frac{1}{R_1} + \frac{1}{\infty}} \right| = |Z_{C_1} + R_1| \tag{2}$$

Aiming now at the computation of the circuit's output impedance, considering the input voltage source as a short circuit, one obtains:

$$|Z_O| = \left| \frac{1}{\frac{1}{Z_{C_2}} + \frac{1}{R_2 + \frac{1}{\frac{1}{R_3} + \frac{1}{0}}}} \right| = \left| \frac{Z_{C_2} R_2}{Z_{C_2} + R_2} \right| \tag{3}$$

By inspection, equations can be written to calculate the voltages at the OpAmp terminals v_+, v_-, v_A.

$$v_- = v_+ = \frac{R_1}{R_1 + Z_{C_1}} v_i \qquad v_A = v_- \times \left(\frac{R_3}{R_4} + 1 \right) \tag{4}$$

Consequently, the output v_O is given by

$$v_O = v_A \times \frac{Z_{C_2}}{Z_{C_2} + R_2} \tag{5}$$

3 Simulation Analysis and result comparison

The following table presents the output voltage gain in the passband, the central frequency and the input and output impedances at this frequency.

Quantity name	Value [V, MU, Hz or other]
gaindb	3.876491e+01
gaindeviation	1.379498e+01
cutofflow	4.050703e+02
cutoffhigh	2.426023e+03
centralfreq	9.913172e+02
centralfreqdeviation	8.682763e+00
cost	1.345695e+04
merit	3.305983e-06
zin	9.999843e+02,-7.23564e+02
zinabs	1.234307e+03
zout	6.810520e+02,-4.66790e+02
zoutabs	8.256660e+02

Quantity name	Value [V, MU, Hz or other]
$gain_{db}$	3.882159e+01
$gain_{deviation}$	1.268688e+01
$cutoff_{low}$	4.088948e+02
$cutoff_{high}$	2.572826e+03
$central_{freq}$	1.025678e+03
$central_{freq_{deviation}}$	2.567793e+01
zin	1.000e+03-7.234e+02 i
abs(zi)	1.234242e+03
zo	6.767e+02-4.677e+02 i
abs(zo)	8.226375e+02

Table 2: On the left, the values obtained via simulation in Ngspice. On the right, the ones obtained from Octave.

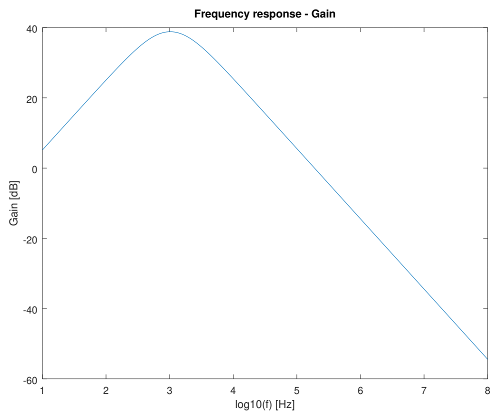

Figure 3: Plot for the gain (dB), obtained with Octave.

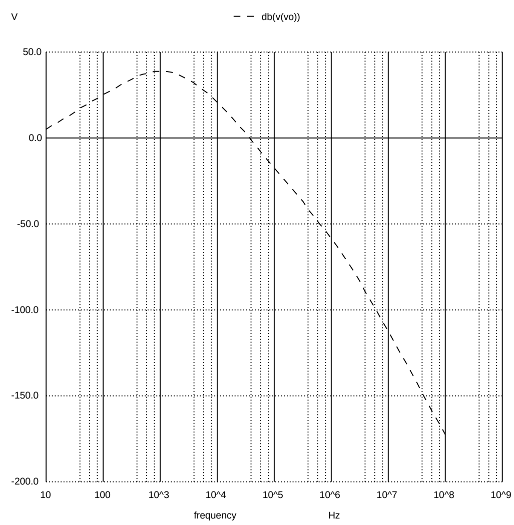

Figure 4: Plot for the gain (dB), obtained with Ngspice.

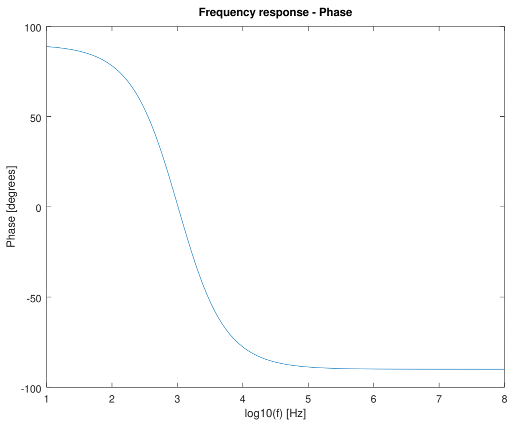

Figure 5: Plot for the phase (degrees), obtained with Octave.

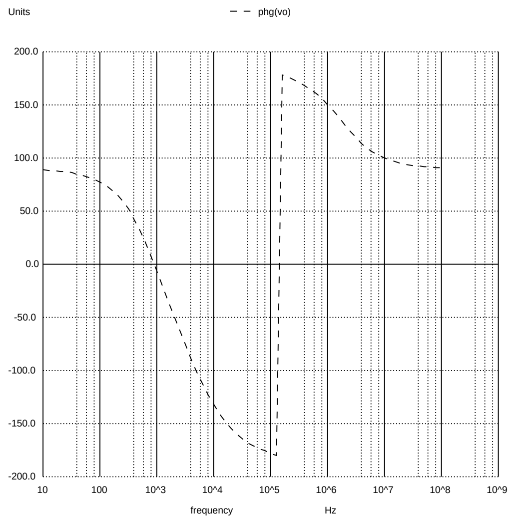

Figure 6: Plot for the phase (degrees), obtained with Ngspice.

Comparing both the simulation and theoretical results, one notices a few differences. In the theoretial analysis, it was assumed an ideal model for the OP-AMP, with perfect impedances (as explained in theoretical analysis). In adition, non-linear components were linearly analysed. On the other hand, Ngspice makes use of a much more sofisticated model with a meriad of parameters.

Related to the phase plot: Octave's shows the evidence of 2 poles (2 capacitors), with a drop of 180 degreees (from 90 to -90 degrees). On the other side, Ngspice's one shows the evidence of 4 poles (4 capacitors considered on the simulation model). Besides that, due to representation range issues, there is a discontinuity in Ngspice's plot although the real variation is continuous.

4 Conclusion

In this work, a band-pass filter circuit was built using an operational amplifier. The resulting merit was 3.305771e-06 and the cost was 1.345695e+04 MU.