TÉCNICO LISBOA

Laboratory Report 5: Bandpass filter using OP-AMP

Circuit Theory and Electronics Fundamentals

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Contents

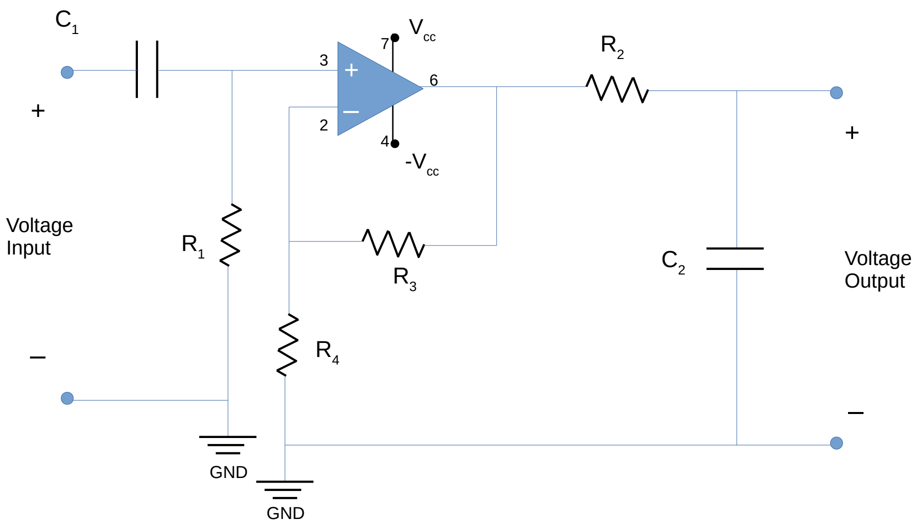
1 Introduction

The objective of this laboratory assignment is to design and implement a BandPass Filter (BPF) with a central frequency of $1kHz$ and a gain at the central frequency of $40dB$.

Next, on table 1 is the list of restrictions for this design:

Name	Maximum Quantity
$741OP-AMP$	1
$1k\Omega Resistor$	3
$10k\Omega Resistor$	3
$100k\Omega Resistor$	3
$220nfcapactior$	3
$1\mu fcapacitor$	3

Table 1: Restrictions for this assignment



As mentioned above, it is also important to refer that we have developed an optimization algorithm (in Octave) in order to find the number of resistors, capacitors and the values of the resistors and capacitors that would lead to the best value of merit, computed in Ngspice with the formula given by the Professor.

2 Simulation Analysis

In this section, we will the obtained results by simulating the circuit in Ngspice.

We started with by using the provided OPAMP model, and further improving by doing incremental modifications, while respecting the suitable parameters.

To decide the final best values, an optimizer was used with octave, that created a new ngspice document in each iteration as to find the suitable and most optimal values.

The obtained values of interest can be found in table 2.

Element	**Value**
Z_{input}	1154.78
Z_{output}	724.0131
Central frequency	991.8981 Hz
Output Voltage Gain	39.94941 dB

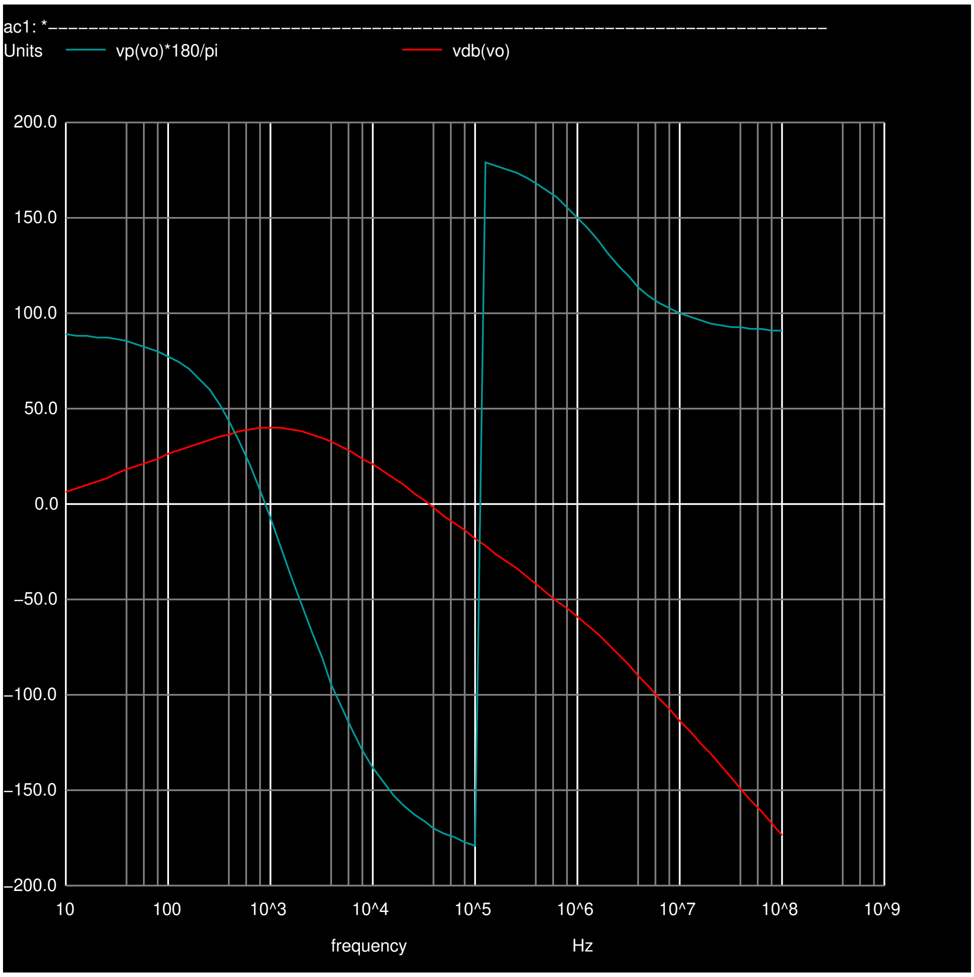
Table 2: Obtained values from Ngspice

Using the given expression for the merit it follows that:

$$Merit = 8.4318e - 06 \tag{1}$$

Finally, below we have the plots for the frequency response.

Figure 2: Frequency response for the simulation analysis



3 Theoretical Analysis

ection, the circuit is analyzed theoretically, according to the ideal op-amp model (Z i = ∞ and Z o = 0), resulting in the following equation

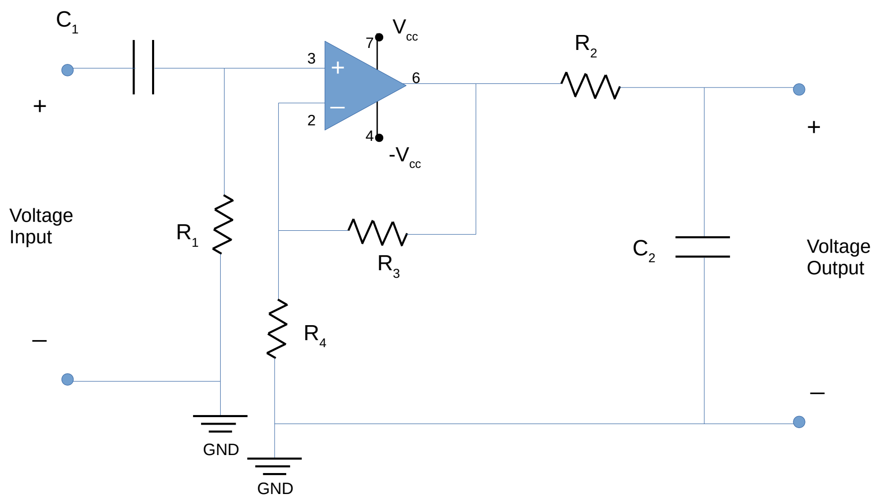


Figure 3: Representation of the BandPass Filter implemented.

In this section we will discuss the theoretical analysis of our circuit, represented in figure 3. The value for the central frequency is 1000Hz and the gain at the central frequency is 40db throughout the calculations. The ideal op-amp model is used so that Z_input is infinite and Z_ouput is null.

The values for the resistors and capacitors used are in table 5. The first part of the circuit composed of R_1 and C_1 form the high-pass filter. It passes all frequencies above the value from equation 3. The signal is then amplified by the op amp by a gain proportional to resistors R3 and R4 according to the following equation. This means the gain is equal to 40.037 dB.

Symbol	Value
R_1	$0.9k\Omega$
R_2	$0.9k\Omega$
R_3	$160k\Omega$
R_4	$1k\Omega$
C_1	$220nF$
C_2	$132.5nF$

Table 3: Values for theoretical analysis

Where $R1$ and $R2$ are the equivalent resistor of one 10kΩ resistor and one 1kΩ resistor in parallel, $R3$ is the equivalent resistor of two 100kΩ resistors in parallel which are in series with another 100kΩ and 10kΩ resistors and $C2$ is the equivalent capacitor of three 1mF capacitors and one 220nF capacitor in series.

$$Gain = 1 + \frac{R_3}{R_4}, \tag{2}$$

$$f = \frac{1}{2\pi * R_2 * C_2}, \tag{3}$$

The signal then passes through the low-pass filter, which is the second part of the circuit. The low-pass filter is composed of the resistor R_2 and capacitor C_2. It passes all frequencies below the value from the following equation. This circuit gives an amplified noinverting signal so the input signal and output signal are in phase.

$$f = \frac{1}{2\pi * R_2 * C_2}, \tag{4}$$

Here we have the table for the values of the gain, input and output impedances calculated at the central frequency and the corresponding equations.

$$|Z_i nput| = |\infty // Z_{C_1} + R_1| = |Z_{C_1} + R1| \tag{5}$$

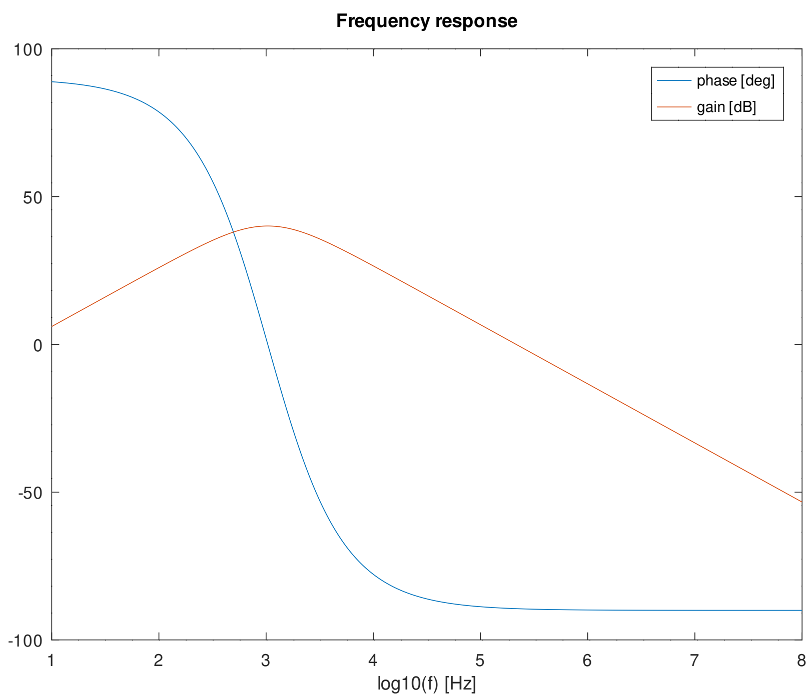
$$|Z_o utput| = |Z_{C_2} // (0 // R2 + R3)| = |Z_{C_2} // R2| \tag{6}$$

Symbol	Value
$Gain$	40.037 dB
Z_{input}	1154.7
Z_{output}	720.25

Table 4: Values for the gain, input and output impedances

Finally, we can obtain the plot for the frequency response V_o(f)/V_i(f) using the incremental circuit, solving the circuit for a frequency vector in log scale with 10 points per decade, from 10Hz to 100MHz.

Figure 4: Frequency response V_o(f)/V_i(f)



4 Conclusion

In this laboratory we dimensioned and implemented a BandPass Filter (BPF) using an OP-AMP.

We can now compare the obtained results by theory and by simulation:

Parameter	**Theoretical Value**	**Simulation Value**
Low Frequency [Hz]	415.55	418.14
High Frequency [Hz]	2531.6	2352.9
Central Frequency [Hz]	1025.7	991.9
$Zinput$	1154.7	1154.8
$Zoutput$	720.25	724.01
Gain [db]	40.037	39.949

Table 5: Comparison of the theoretical and simulation values.

Contrary to our goal for the laboratory, there are some small differences between the results. This could be due to the model applied in Ngspice being much more realistic as well as its parameters being more complex than the one analysed in the theoretical part or the fact that the components of the circuit, specially the OP-AMP, are not linear. This is clearly seen in the plots below (mainly in the phase curve). Despite all of this, the values on the table above are very satisfatory and we are satisfied with our results, considering the model used to be valid.

Final merit obtained was 8.4318e-06 (Ngspice)

Below are the two plots for comparison:

Figure 5: Frequency response V_o(f)/V_i(f)

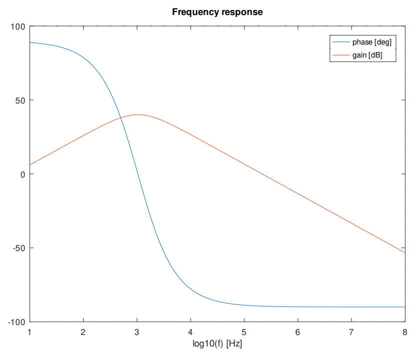


Figure 6: Frequency response for the simulation analysis