Circuit Theory and Electronics Fundamentals

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T5 - Bandpass filter using OP-AMP

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1 Introduction

The purpose of this laboratory assignment is to make a Bandpass filter using OP-AMP, with the goal to get the highest merit, M, possible while getting a gain of 40 dB and a central frequency of 1 kHz.

$$M = \frac{1}{cost \times (gainDeviation + centralFreqDev + 10^{-6})}$$

Using the simplified circuit shown in Figure 1, we tested different values for the resistors and capacitors and we found that the values in Table 1 yielded the best merit. However, to get to those values, the real circuit in Figure 2 was used.

In Section 2, the circuit is analyzed by simulation using the software Ngspice.

In Section 3, the circuit is analyzed theoretically using the software GNU Octave.

In Section 4, a comparison is done between the results obtained by both analyses, theoretical and simulation, and a practical evaluation.

The conclusions of this study are outlined in Section 5.

Component	Value
C_1	220 nF
C_2	110 nF
R_1	1 $k\Omega$
R_2	1 $k\Omega$
R_3	150 $k\Omega$
R_4	1 $k\Omega$

Table 1: Resistance and Capacitance for the components

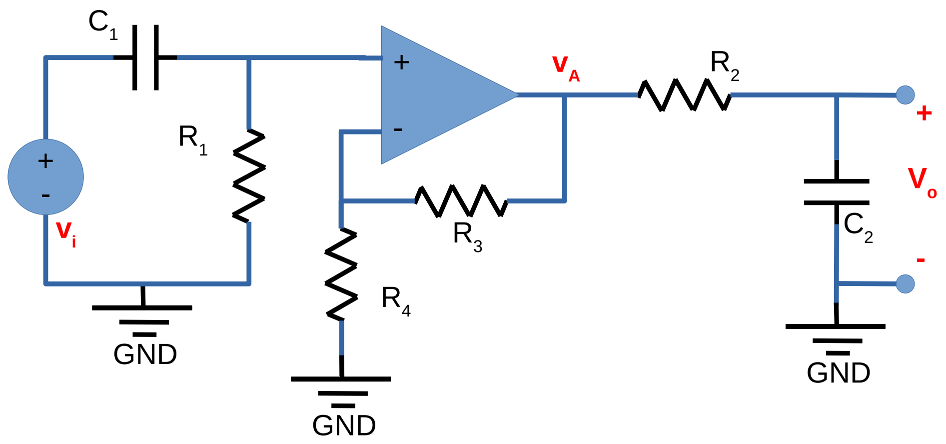

Figure 1: Circuit T5, simplified.

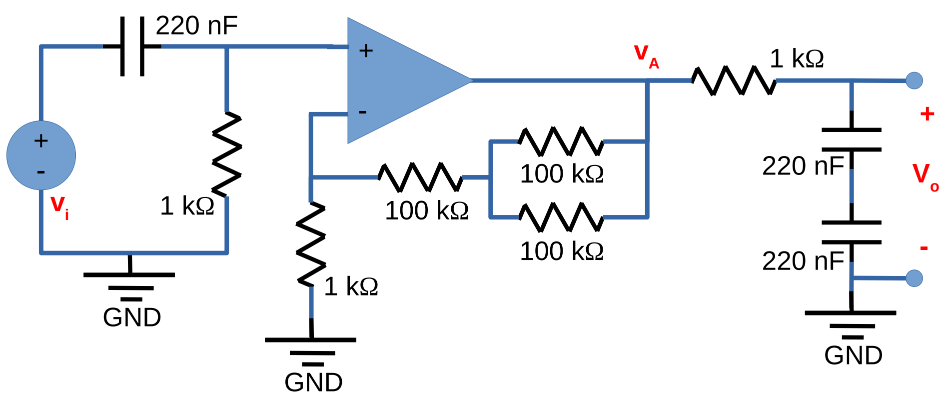

Figure 2: Circuit T5, real.

2 Simulation Analysis

The plots for the frquency response obtained are shown in Figure 3. The impedance at the input and output, the gain, the central frequency, the cost and the merit are presented in Table 2.

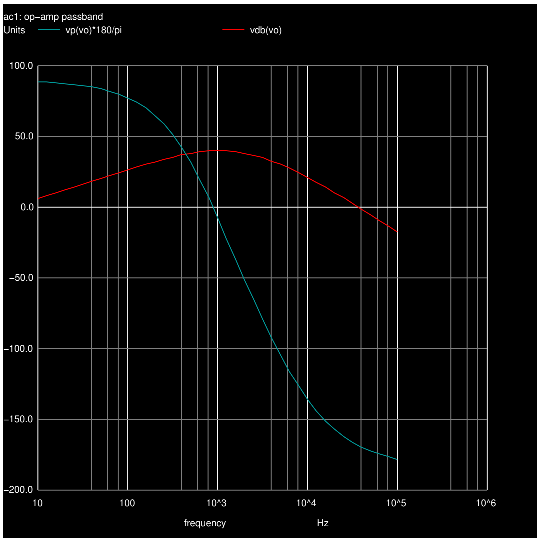

Figure 3: Plots obtained by simulation.

	Value
Zin	999.979 + -723.583 j
∣ Zin ∣	1234.31
Zo	681.72 + -466.75 j
∣ Zo ∣	826.194
voltgain	9.973609e+01
gaindeviation	2.639100e-01
centralfreq	9.813699e+02
centralfreqdev	1.863015e+01
cost	1.362695e+04
merit	3.883972e-06

Table 2: Results obtained by simulation.

To analyze better the deviations, the relative deviations in percentage are shown in Table 3. It is possible to say that these values are exact ($\leq 5\%$).

Deviation	**Value** (%)
gainperc	6.597750e-01
fperc	1.863015e+00

Table 3: Relative deviation (%)

3 Theoretical Analysis

In this section, the circuit is analyzed theoretically, according to the ideal op-amp model ($Z_i = \infty$ and $Z_o = 0$), resulting in the following equations:

$$|Z_i| = |Z_{C1} + R1 /\!/ \infty| = |Z_{C1} + R1| \tag{1}$$

$$|Z_o| = |Z_{C2} /\!/ (R2 + R3 /\!/ 0)| = |Z_{C2} /\!/ R2| \tag{2}$$

$$\begin{cases} v_- = v_+ = \frac{R1}{R1+Z_{C1}} v_i \\ v_A = \left(1 + \frac{R3}{R4}\right) v_- \\ v_o = \frac{Z_{C2}}{Z_{C2}+R2} v_A \end{cases} \tag{3}$$

Solving the previous equations, the results are shown in Figure 4 and in Table 4.

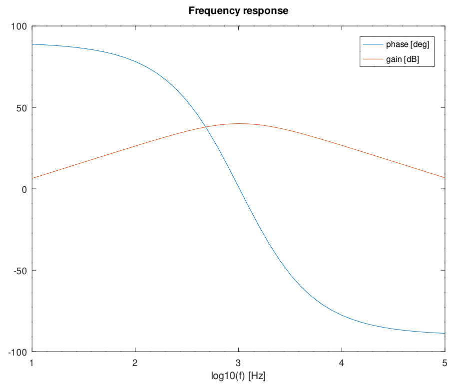

Figure 4: Plots obtained by theo. analysis.

	Value
$LowFreq$	398.107
$HighFreq$	2511.89
$CentralFreq$	1000
Z_I	1234.24
Z_O	822.637
$Gain$	100.643
$Gain\ (dB)$	40.0557

Table 4: Results obtained.

4 Comparison

Comparing the results achieved in the simulation and in the theoretical analysis, Table 5 and Figures 3 and 4, it is possible to see some differences: gain and phase differ for frequencies greater than the central frequency.

This discrepancy may have resulted from assuming an ideal op-amp model in the theoretical analysis. An ideal op-amp does not have capacitors and therefore no poles in the transfer function. A non-ideal op-amp, as used in the simulation, has 2 capacitors and therefore 2 poles in the transfer function, resulting in additional -90º in the phase plot.

	Theoretical	Simulation
$LowFreq$	398.107	403.611
$HighFreq$	2511.89	2386.17
$CentralFreq$	1000	981.37
Z_I	1234.24	1234.31
Z_O	822.637	826.194
$Gain$	100.643	99.7361
$Gain\ (dB)$	40.0557	39.977

Table 5: Comparison between theoretical and simulation values

4.1 Practical results

In the laboratory, it was possible to simulate with real components the circuit in Figure 2. For frequency $f = 1\ kHz$, the results obtained were:

$$v_i = 170\ mV$$
$$v_o = 16,7\ V$$
$$Gain \approx 98,235$$
$$Gain_{dB} \approx 39,85$$
$$Gain\ deviation \approx 0,32\%$$

The results are according to the the simulation analysis. These differences may occur because of the resistors and capacitors tolerance, and the resistance of the wires.

5 Conclusion

In this laboratory assignment, the objective of making a Bandpass filter using OP-AMP shown in Figure 2 has been achieved. The values for the components in Table 1 has a merit of approximately $3,88 \times 10^{-6}$ and a cost of 13626,95 MU, with a gain of 39,98 dB and a central frequency of 981,37 Hz.