TÉCNICO LISBOA

Circuit Theory and Electronics Fundamentals

Lab 5 - Bandpass Filter using OP-AMP

Aerospace Engineering

Laboratory Report

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Contents

1 Introduction

This report is being made for the subject of Circuit Theory and Electronics Fundamentals and is related to the fifth laboratory being its objective to develop a Bandpass Filter using an Operational Amplifier (OP-AMP). In this laboratory there are some specifications that are followed such as a central frequency of 1kHz and a gain at central frequency of 40dB. There are also limited number of the different components. All in all, the circuit that was implemented is shown in figure 1 and it has three different stages. This stages are the High Pass Stage, the Amplication Stage and a Low Pass Stage and they will be explored on the extend of this report.

In Section 2 a theoretical analysis will be made . Secondly, in Section 3 it will be simulated the circuit using ngspice tools. Following with both results from Section 2 and Section 3 being compared and commented in Section **??**.

Also, it is important to notice that the NGSpice simulation was made using the provided OPAMP model

Finally, the conclusions of this study are outlined in Section 4.

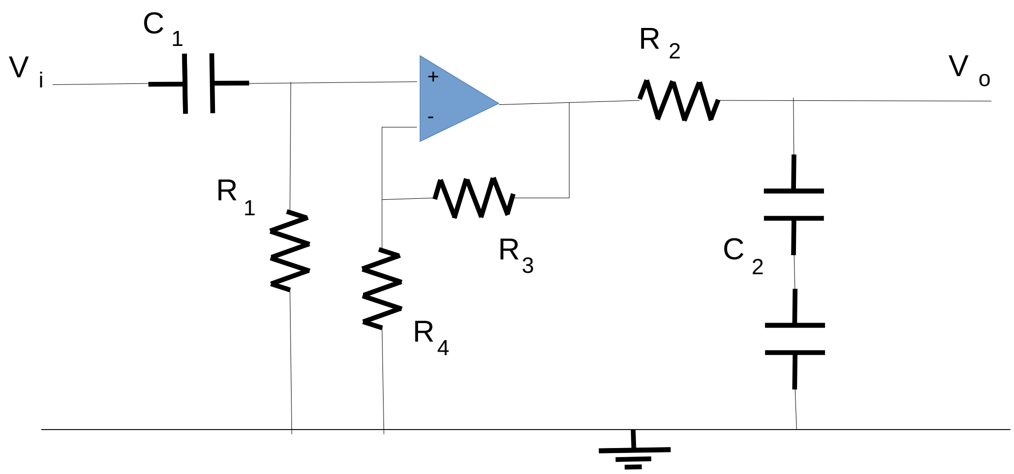

Figure 1: Bandpass Filter using an OP-AMP

2 Theoretical Analysis

Name	Value [Ohm/F]
Resistor 1	1.000000e+03 Ohm
Resistor 2	1.000000e+03 Ohm
Resistor 3	1.000000e+05 Ohm
Resistor 4	1.000000e+03 Ohm
Capacitor 1	2.200000e-07 F
Capacitor 2	1.100000e-07 F

Table 1: TITULO

Name	Value [Ohm/F]
Input Impedance	1.000000e+03
Output Impedance	1.000000e+00

Table 2: TITULO

TEXTO T4 In this section, the circuit shown in Figure 1 will be analysed theoretically. The constants used for the resistors and capacitors can be seen in Table 1.

In order to fully understand the analysis that will be made, it is necessary to bear in mind that there are two stages in this circuit: the gain stage and the output stage, that are presented in Figures **??** and **??**.

The first one, which corresponds to the part that is at the left of the V_{CC}, has the goal of not degradating or distorting the input signal through the circuit, by keeping the input voltage really high, also being the responsible for the amplification of the signal, due to the elevated gain associated. This part of the circuit is made of a NPN BJT, resistors and capacitors. In most of the times, we can't use this stage due to the high output impedance associated to it, being necessary the output stage.

The second one, which corresponds to the part that is at the right of the V_{CC}, presents a low output impedance, especially caused due to the PNP BJT used, that has a lower β_F. It also has resistors and a capacitor. We finally make the needed BJT Amplifier when merging the two parts into one circuit; however, we need to be extremely careful when combining both stages, since it is necessary to ensure that both impedances are compatible. This is why the input impedance of the output stage needs to be much bigger than the output impedance of the gain stage, in order to make sure no signal is lost.

In this circuit, we will do an operating point analysis and then an incremental analysis using the values found in the first analysis. We do so in order to compute the values of the input and output impedances in the two stages and the gains associated as well.

2.1 Gain Stage

For the gain stage, we start by using the KVL and the KCL in order to arrive to the following equation:

$$Z_{I1} = R_B || r_{\pi 1} \tag{1}$$

where Z_{I1} is the input impedance of this stage and $R_B = R_1 || R_2$ We aproximate R_E to zero due to the presence of C_E that is theoretically assumed to be a short-circuit, as well as all capacitors for high frequecies (and behave like open circuits for the low ones). Because it is load-independent, this impedance has the same value of the total input impedance of the circuit. The output impedance is given by

$$Z_{O1} = r_O||R_C \tag{2}$$

For the incremental response, we ”transform” this part of the circuit into a circuit similar to the one presented in Lecture 17 on slide 12. Studying the circuit, we are able to get the following equations:

$$v_{O1} = -g_m \times (r_O||R_C) \times v_\pi \tag{3}$$

$$v_\pi = \frac{R_B||r_{\pi 1}}{R_B||r_{\pi 1} + R_S} \times v_S \tag{4}$$

This way, we are able to get

$$A_{V1} = \frac{v_{O1}}{v_S} = -g_m \times (r_O||R_C) \times \frac{R_B||r_{\pi 1}}{R_B||r_{\pi 1} + R_S} \tag{5}$$

2.2 Output Stage

Just like what we did for the previous stage, by using the KVL and the KCL, we can get the following expressions for the impedances in the OP analysis

$$Z_{I2} = \frac{(g_{m2} + g_{\pi 2} + g_{O2} + g_{E2})}{g_{\pi 2}(g_{\pi 2} + g_{O2} + g_{E2})} \tag{6}$$

$$Z_{O2} = \frac{1}{(g_{m2} + g_{\pi 2} + g_{O2} + g_{E2})} \tag{7}$$

For the incremental analysis, we also transform the circuit, turning it into the one presented in Lecture 17 on slide 15, that can also be seen in Figure **??**. Using the KCL, we get the following expression

$$(\frac{1}{R_E} + \frac{1}{r_O})v_O + \frac{v_O - v_I}{r_\pi} - g_m v_\pi = 0 \tag{8}$$

Knowing that $v_\pi = v_I - v_O$, we can get

$$A_{V2} = \frac{v_{O2}}{v_{I2}} = \frac{g_\pi + g_m 2}{g_{\pi 2} + g_{z2} + g_{O2} + g_{m2}} \tag{9}$$

2.3 Total value

Using the computed value of i_O, we calculate the total impedance Z_{OT}

$$Z_{OT} = \frac{v_O}{i_O} = \frac{1}{g_{O2} + g_{m2}} \frac{r_{\pi 2}}{r_{\pi 2} + Z_{O1}} + g_{E2} + \frac{1}{r_{\pi 2} + Z_{O1}} \tag{10}$$

The total gain is given by

$$A_V = A_{V1} \times A_{V2} \tag{11}$$

We can now see that, since $Z_{O1} << Z_{I2}$, there is no signal degradation or loss between the two stages in the figure below.

The value of the lower cut-off frequency was calculated using the Octave. The meaningful results that we need to compare with simulation are all presented in the tables below

3 Simulation Analysis

This section covers the bandpass filter simulation (using OP-AMP) in NGSpice. As asked we started by using the provided model of the OP-AMP and then the circuit was improved by doing incremental modifications with suitable parameters. In the next tables it is presented the values asked in the lab assignment: output voltage gain, the central frequency and the input and output impedances at this frequency.

Name	Value
Av deviation	32.9164
Freq deviation	0

Table 3: Gain and frequency deviation

Name	Value
AV	36.5323
Central Frequency	1000

Table 4: Gain and Central Frequency

Following with the analysis, below it is presentend the output and input impedances.

Name	Value
Input Impedance	999.991 + -723.534 j

Table 5: Input Impedance

Name	Value
Output Impedance	680.05 + -466.901 j

Table 6: Output Impedance

The graphics below show the frequence response of the output voltage gain in the pass-band.

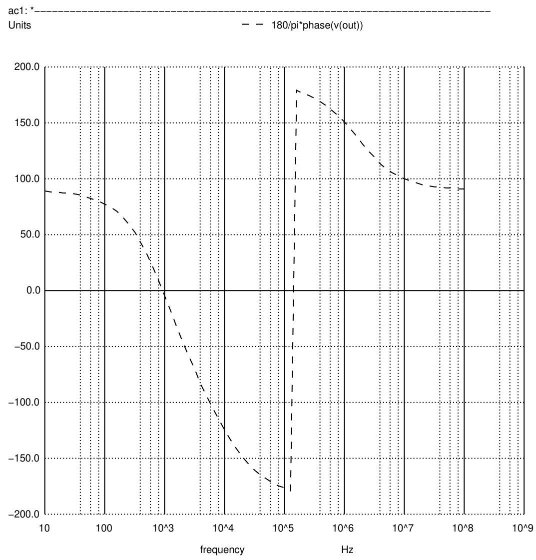

Figure 2: Simulation gain response in phase degree

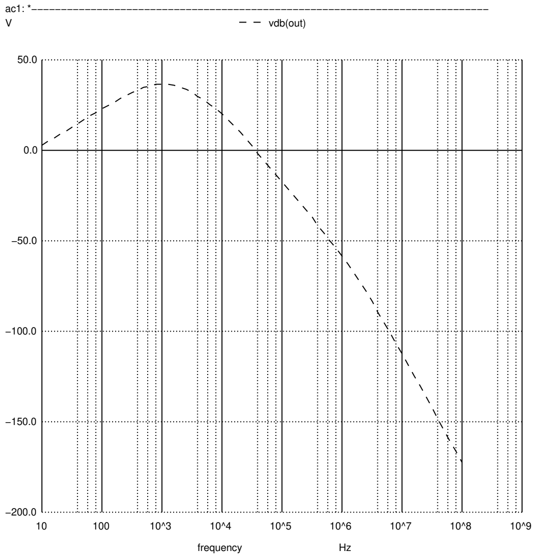

Figure 3: Simulation gain response in dB

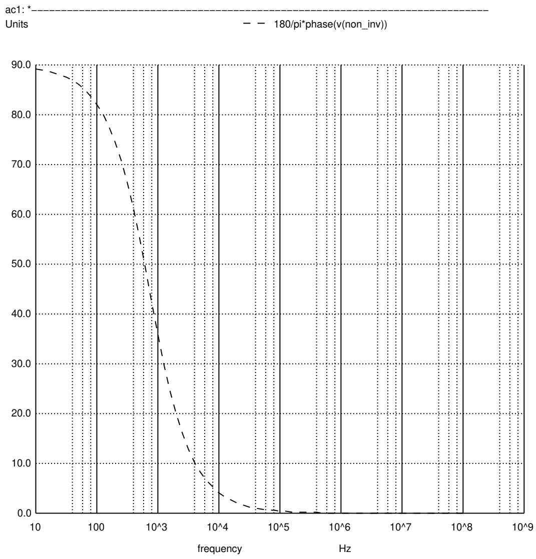

Figure 4: TITULO

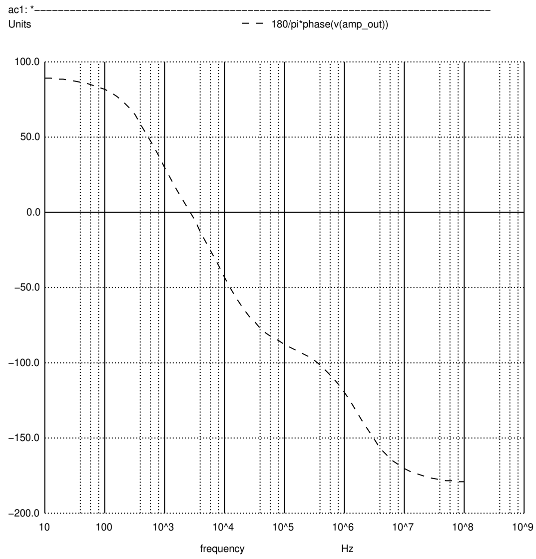

Figure 5: TITULO

Finally, the merit obtained by the group is presentend in the following table. It can be consider that the results were good.

Name	**Value**
cost	13426.8
merit	2.26264E-06

Table 7: Merit

4 Conclusion

The objective of this laboratory assignment was to develop a Bandpass Filter and the main goal was achieved.

However by observing analysis and simulation results side by side it can be seen a difference between the two, the results aren't equal and exactly the same comparing both NGSpice and Octave.

Although, we believe that the differences are not that significant and they can be explained by how NGSpice solves the circuit compared to how it was done in the theoretical analysis, processes that were also explanied on our lectures. To solve this non-linear circuit, NGSpice used far more advanced simulation methods, with many more parameters, while Octave used an approximated model in incremental analysis.

Regarding this fact and despite the differences, the theoretical model provides good results and can be used when there is no simulation tools to use or to quickly confirmed the simulation results obtained.

Nevertheless it was achieved not having the best merit. The merit of the circuit was obtained by trial and error, a method that is not perfect and does not result in the best possible results. In this way, we concluded that in order to obtain good results, we were obliged to "yield" part of the merit.

This way, the objective should have never been to have equal results, but rather, have results that seemed reasonables, which we believe it was achieved. The merit obtained was 531.75, with a cost of 1197.5.