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Integrated Master in Aerospace Engineering

Circuit Theory and Electronics Fundamentals

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Fourth Laboratory Report

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1 Introduction

The objective of this laboratory assignment is to simulate a Band Pass Filter using OPAMP as shown in Figure 1.

This way, we should choose the architecture of the Gain and Output amplifier stages, however, we must consider the cost of the components in the circuit. Its diagram is shown in Figure 1.

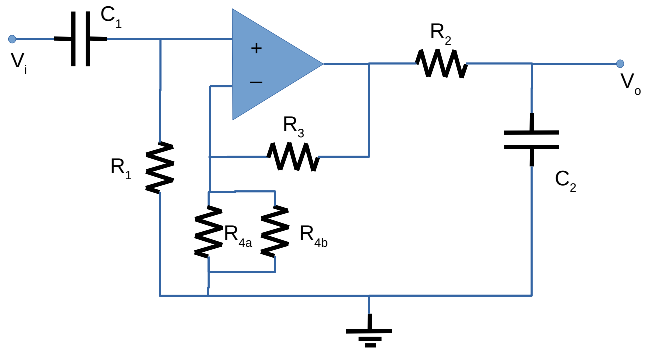

Figure 1: Band Pass Filter Circuit

This circuit is composed by 5 resistors, 2 capacitors and an OPAMP. The values of the components are exhibited in the table below.

Name	Value
R_1	9.090000e+02 Ohm
R_2	1.000000e+03 Ohm
R_3	1.000000e+05 Ohm
R_{4a}	1.000000e+03 Ohm
R_{4b}	1.000000e+04 Ohm
C_1	2.200000e-07 F
C_2	1.803279e-07 F

Table 1: Components Values

In Section 2, a theoretical analysis of the circuit, performed on Octave, is presented. In Section 3, the circuit is analysed by simulation, using NGSpice, and the results are compared to the theoretical results obtained in Section 2. The conclusions of this study are outlined in Section 4.

2 Theoretical Analysis

In this section, the circuit shown in Figure 1 is analysed theoretically. It is important to notice that the purpose is to build a band pass filter circuit using an OPAMP. This way, the considered circuit has a high pass filter, a signal amplifier (OPAMP) and a low pass filter in series, where the capacitor C1 and the resistor R1 act as a high pass filter, while capacitor C2 and resistor R2 function as a low pass filter.

Thus, We will begin by computing the gain, input and output impedances at the central frequency. Then, we will compute the frequency response Vo(f)/Vi(f) , using the incremental circuit, solving the circuit for a frequency vector in log scale with 10 points per decade, from 10Hz to 100MHz.

2.1 Gain, Input and Output Impedances at central frequency

In this subsection, we will compute the gain, input and output impedances at the central frequency.

First, we will calculate low and high cutoff frequencies, w_L and w_H, respectively, as well as central frequency, w_O, which are given by:

$$w_L = \frac{1}{R_1 \cdot C_1} \tag{1}$$

$$w_H = \frac{1}{R_2 \cdot C_2} \tag{2}$$

$$w_O = \frac{1}{\sqrt{w_L \cdot w_H}} \tag{3}$$

Their values are presented in the table below:

Name	Value
w_L	5.000500e+03 rad/s
w_H	5.545455e+03 rad/s
w_O	5.265933e+03 rad/s
f_O	8.380992e+02 Hz

Table 2: Frequencies

Now we can determine the gain at central frequency, wich is given by the following equation:

$$T_{w_O} = \frac{R_1 \cdot C_1 \cdot jw_O}{1 + R_1 * C_1 * jw_O} \cdot (1 + \frac{R_3}{R_4}) \cdot \frac{1}{1 + R_2 \cdot C_2 \cdot jw_O} \tag{4}$$

, where R_4 is the R_{4a} and R_{4b} equivalent resistor.

As well as Z_{in} and Z_{out}, at the central frequency, are determined by:

$$Z_{in} = \frac{R_1 \cdot C_1 \cdot jw_O}{1 + R_1 * C_1 * jw_O} \cdot (1 + \frac{R_3}{R_4}) \cdot \frac{1}{1 + R_2 \cdot C_2 \cdot jw_O} \tag{5}$$

$$Z_{out} = R_1 + \frac{1}{jw_O * C_1} \tag{6}$$

The results are shown in table 3:

Name	Value
$Gain$	3.532348e+01 dB
Z_{in}	9.090000e+02 + j-8.631813e+02 Ohm
Z_{out}	5.258371e+02 + j-4.993320e+02Ohm

Table 3: Results at central frequency

2.2 Frequency response Vo(f)/Vi(f)

Now, considering the transfer function $T(s)$, it is given by:

$$T(s) = \frac{V_out(s)}{V_in(s)} = 1 + \frac{Z_{in}(s)}{Z_{out}(s)} = \frac{R_1 \cdot C_1 \cdot s}{1 + R_1 * C_1 * s} \cdot (1 + \frac{R_3}{R_4}) \cdot \frac{1}{1 + R_2 \cdot C_2 \cdot s} \tag{7}$$

, where $\frac{R_1 \cdot C_1 \cdot s}{1+R_1 * C_1 * s}$, $1 + \frac{R_3}{R_4}$ and $\frac{1}{1+R_2 \cdot C_2 \cdot s}$ represent the gain at high pass filter, OP-AMP and low pass filter, respectively.

This way, the gain frequency response is plotted in the figure below.

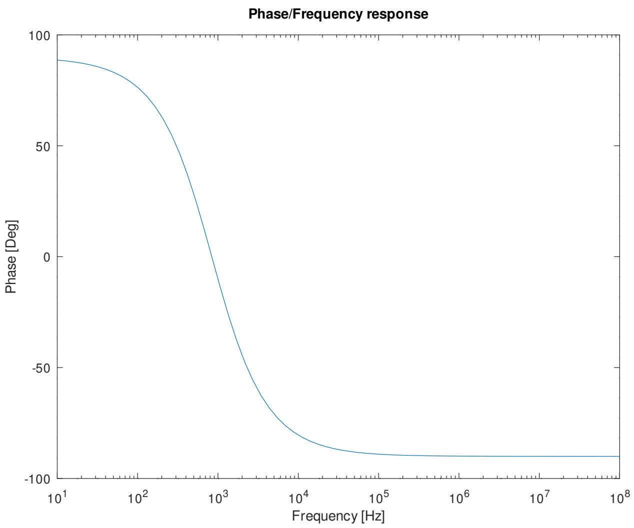

Figure 2: Phase Frequency Response

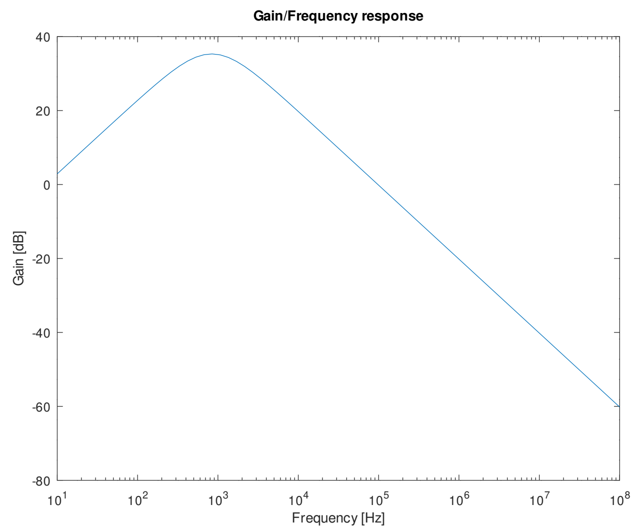

Figure 3: Gain Frequency Response

As we can see there is a maximum for the frequencies in the central frequency, wich is near to 1KHz, otherwise low and high frequencies have a low gain. That was expected because both low and high frequencies were blocked by high and low pass filters.

3 Simulation Analysis

Voltages	V
zin	9.989982e-01

Table 4: NPN Voltages and F.A.R confirmation

Voltages	**V**
zout	9.852105e+00

Table 5: NPN Voltages and F.A.R confirmation

Voltages	**V**
Gain	5.71075
Central Frequency	25616.7
Gain deviation	34.2892
Central frequency deviation	24616.7
Cost	13436.4
Merit	8.81714E-11

Table 6: NPN Voltages and F.A.R confirmation

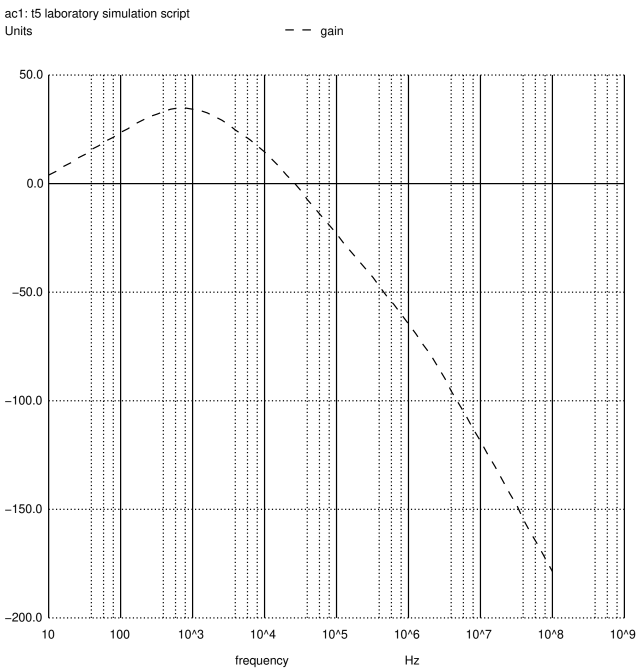

Figure 4: Phase Frequency Response

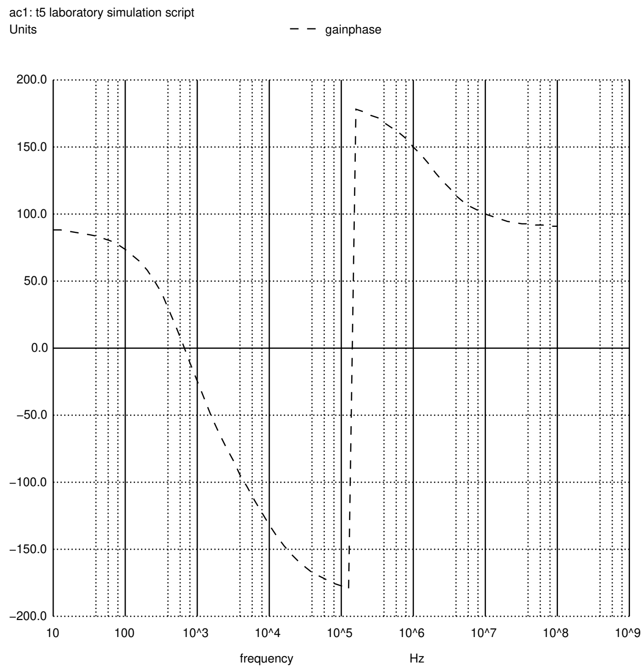

Figure 5: Phase Frequency Response

It is important, in order to guarantee a high compatibility with AUDIO IN and speakers, that we obtain a very high input impedance (Z_I) and a very low output impedance (Z_O). Analysing our results, we notice that despite having a small input impedance (in result of a compromise we had to make to obtain a higher merit figure), the output impedance is very low, as desired.

3.1 Coupling Capacitors

In order to analyse this circuit, we need to understand the coupling capacitors influence. In this BJT amplifier circuit, there are two couplin capacitors, C_{in} and C_O - because their functions are similar, we will focus only on capacitor C_{in}. In the graphics below, we present the frequency response of the circuit, but with C_{in} values drastically differents.

As we can notice, the change in the capacitance of the coupling capacitor does not influence the value of the higher cut-off frequency. However, the increase of that value leads to a larger bandwidth, which is desired.

3.2 Gain.

3.3 Merit

To end this section, we outline below the 4 values that influence the merit figure and the respective value of the merit.

As we can see, we obtained a very high merit value. However, that value was obtained at the cost of degrading the quality of the circuit (for example, the low input impedance.)

4 Conclusion

In this laboratory assignment the objective of building and analysing an Audio Amplifier Circuit, made of a gain stage and an output stage, has been achieved. The theoretical analysis was performed with the help of the Octave math tool and the circuit simulation using the Ngspice tool. For both analysis, we determined the gain and input and output voltages of the circuit, as well as, lower cut-off frequency. We also plotted the frequency responce Vo(f)/Vi(f). At the end, we calculate the merit of our work.

This way, in theoretical analysis, we explained why the two stages could be connected without significant signal loss. And, in simulation analysis, we also explaneid the purpose of the coupling capacitors and their effect on the bandwidth, the purpose of the bypass capacitor and its effect on the gain and the effect of resistor RC on the gain.

As previously mentioned, the simulation results had slight differences from the theoretical ones. However, we designed an acceptable Audio Amplifier Circuit - furthermore, we obtained a decent figure of merit, despite the cost being too high.