Circuit Theory and Electronics Fundamentals

Department of Electrical and Computer Engineering, Técnico, University of Lisbon

Fourth Laboratory Report

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1 Introduction

The aim of this laboratory assignment was to design and create an Audio Amplifier circuit, which would receive an input of 10mV (max.) and connect to a 8Ohm speaker. The architecture of the gain and output stages were to be designed by the group according to the diagram of Figure 1.

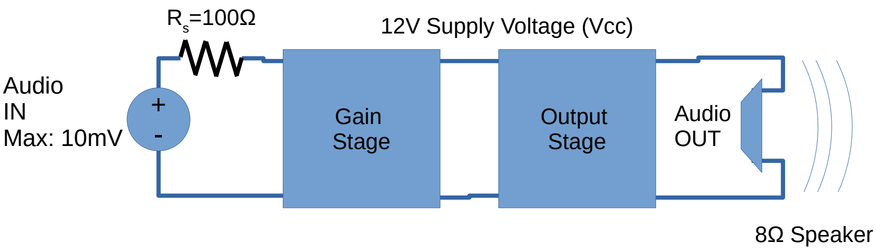

Figure 1: Basic circuit achitecture of an Audio Amplifier.

To determine the quality of the circuit built and to compare it with others, a Merit figure will be calculated based on the following equation:

$$MERIT = \frac{voltageGain * Bandwidth}{cost * LowerCutOffFreq} \tag{1}$$

where the $cost$ value states for sum of the tabulated cost of the components used, $voltageGain$ states for the gain, $Bandwidth$ for the frequency bandwidth and $LowerCutOffFreq$ for the lower cut off frequency, of the audio amplifier.

The Audio Amplifier circuit built to be theoretically analysed and simulated is shown in Figure 2.

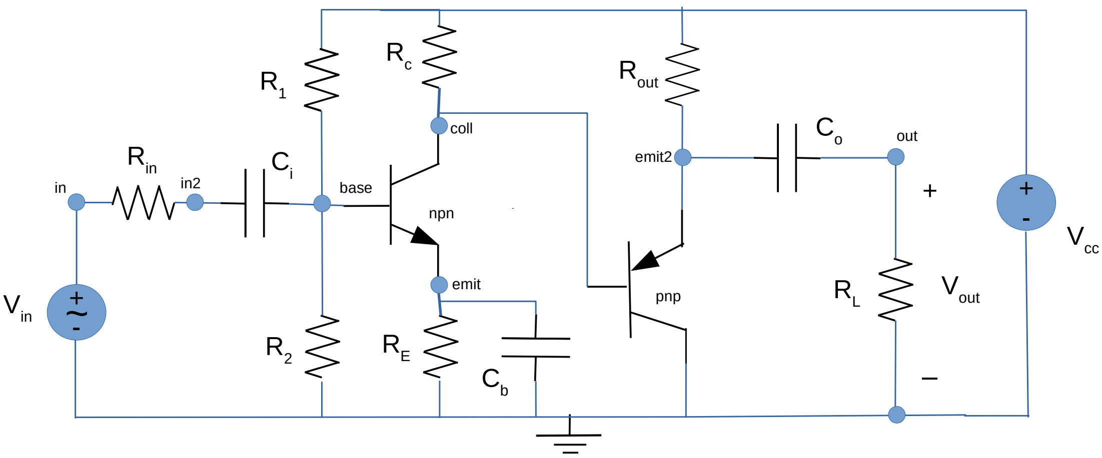

Figure 2: Circuit drawn to build the Audio Amplifier.

The values chosen for the circuit components used can be seen in Table **??**. These values were chosen after running some theoretical and simulation test analysis and are introduced here because they are the values that ended up being used in the last theorethical and simulation analysis, which is the one shown in this report.

Name	Value
V_{CC}	1.200000e+01 V
R_{in}	1.000000e+02 Ohm
R_1	8.000000e+04 Ohm
R_2	2.000000e+04 Ohm
R_c	3.000000e+02 Ohm
R_E	1.000000e+02 Ohm
C_i	1.000000e-03 F
C_b	1.000000e-03 F
C_o	1.990000e-03 F

Table 1: Chosen values of the circuit components.

In this laboratory, two different models of Phillips BJT's Transistors were used: a NPN transistor BC547A used in Gain Stage and a PNP Transistor BC557A used in Output Stage.

In this report, the results obtained in theoretical analysis made in octave and simulation made in Ngspice will be shown in their respective sections and, ultimately, compared.

In Section 2, a theoretical analysis of the circuit built is presented using the values of Table 1. In this analysis a Operating Point, Gain, input/output impedances and frequency response analysis will be done. In Section 3, the circuit is analysed by simulation in NGSPICE also using the values of Table 1. In Section 4 the results from theoretical and simulation analysis are compared. The conclusions of this study are outlined in Section 5.

2 Theoretical Analysis

In this section we will theoretically analyse the circuit of FIgure 2 using OCTAVE tools. This analysis will start with an Operating Point analysis and then the two stages of the circuit will be considered, the gain stage and the output stage, to determine the Gain and the Input and Output Impedances in each one and the total values. At last, a gain's frequency response is presented.

2.1 Operating Point Analysis

The theoretical Operating Point analysis can be seen in Table 2. It will be compared to the simulated Operating Point analysis in Section 4.

Name	Value
V_{base}	2.400000e+00 V
V_{coll}	9.317133e+00 V
V_{emit}	8.992935e-01 V
V_{emit2}	1.001713e+01 V
V_{in}	0.000000e+00 V
V_{in2}	0.000000e+00 V
V_{out}	0.000000e+00 V
V_{CC}	1.200000e+01 V

Table 2: Theoretical operating point analysis.

2.2 Gain and Impedance results

The circuit under analysis is made of 2 main stages: Gain Stage and Output Stage. The Gain Stage is responsible for amplify the input signal and, as we will conclude, has a high input and output impedances. This fact means that to avoid signal degradation when the connection to the speaker is done, it is important to drop the output impedance with the Output Stage, which is expected to haver a lower output impedance value. These 2 stages can be connected without significant signal loss because the Output Stage has a input impedance higher than the output impedance of the Gain Stage.

This subsection will adress the Gain and Input and Output impedances values obtained for both Gain and Output stages, as well as the values considered for the total of the circuit.

2.2.1 Gain Stage

For this subsection we will analyse the part of circuit correspondent to the Gain Stage, in which was used the BC547A model which use the following values:

Name	Value
V_A	69.700000 V
V_{BEON}	0.700000 V
V_T	0.025000 V
$beta$	178.700000

Table 3: BC547A model values.

The Gain and the Input and Output impedances values of the Gain Stage are shown in Table 4.

Name	Value
$Gain_1$	8.565550e+01
Z_{In1}	4.844336e+02 Ohm
Z_{Out1}	2.888805e+02 Ohm

Table 4: Gain Stage - Gain and Impedance values.

2.2.2 Output Stage

For this section we will analyse the part of circuit correspondent to the Output Stage, in which was used the model BC557A that uses the following values:

Name	Value
$beta$	227.300000
V_{AFP}	37.200000 V
V_{BEON}	0.700000 V

Table 5: Output model BC557A values.

The Gain and the Input and Output impedances values of the Output Stage are shown in Table 6.

Name	Value
$Gain_2$	9.825741e-01
Z_{In2}	1.651795e+04 Ohm
Z_{Out2}	1.244280e+00 Ohm

Table 6: Output Stage - Gain and Impedance values.

2.3 Total

The total Gain and the Input and Output impedances values of the circuit are shown in Table 7

Name	Value
$Gain$	8.343592e+01
Z_{In}	4.844336e+02 Ohm
Z_{Out}	2.460696e+00 Ohm

Table 7: Theorethical Gain and Impedance total values.

2.4 Gain Frequency Response

The frequency response of the Gain was obtained using the nodal method and the graphics obtained were the following, these will be compared with the graphics obtained using NGspice in the Conclusion Section of the report.

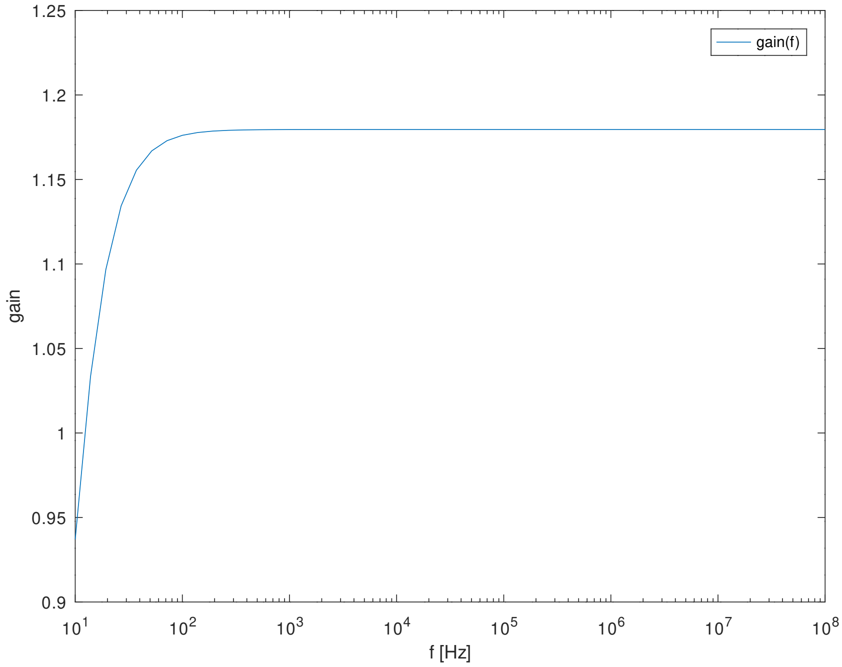

Figure 3: Frequency response of the gain. The *x axis* represents the frequency in Hertz (Hz) and the *y axis* the Gain.

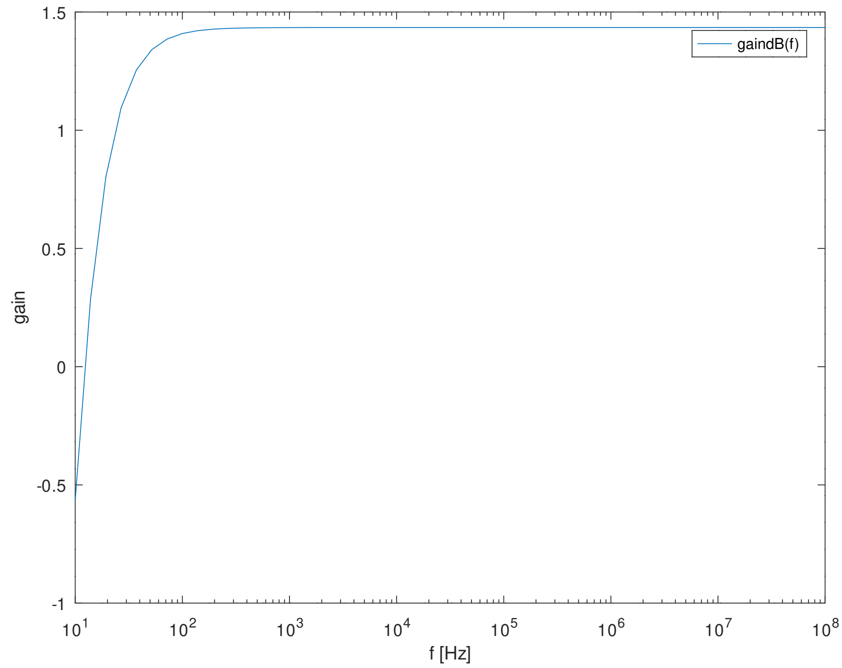

Figure 4: Frequency response of the gain in dB scale. The *x axis* represents the frequency in Hertz (Hz) and the *y axis* the Gain.

3 Simulation Analysis

In this section, the circuit built (Figure 2) will be analyzed and simulated using NGSPICE.

Before simulate the circuit shown before, we used NGSPICE tools to simulate different circuit configurations and combinations of values for the various components of the circuit to obtain a decent merit value, while trying to get good impedance values and gain response and a relatively low cost.

3.1 Operating Point

We calculated the Operating Point for the circuit using NGSPICE tools and obtained the results of Table 8.

Name	**Value [V]**
v(base)	1.612321e+00
v(coll)	9.326959e+00
v(emit)	9.048418e-01
v(emit2)	1.005562e+01
v(in)	0.000000e+00
v(in2)	0.000000e+00
v(out)	0.000000e+00
vcc	1.200000e+01

Table 8: Simulation Operation Point Analysis.

3.2 Gain, Cutoff Frequencies, Bandwidth and Merit Figure

The Gain, lower and upper cutoff frequencies and bandwidth obtained are presented in Table 9, as well as the total cost of the components used in the circuit and the MERIT value. In Table 9, ”up” states for Upper Cutoff Frequency and ”low” for Lower Cutoff Frequency.

Name	**Value**
up	3.983298e+06
low	3.948087e+01
bandwidth	3.983259e+06
gain	4.461287e+01
cost	4.090808e+03
merit	1.100279e+03

Table 9: Main results from simulation analysis. The Upper and Lower Cutoff Frequencies and bandwidth are expressed in Hz. The cost is in MU (monetary units).

A human can ear frequencies between 20 Hz to 20 kHz. The Lower Cutoff Frequency obtained in simulation analysis is a little above 20 Hz, but very close to it. The Upper Cutoff Frequency meets the requirements.

3.3 Input and Output Impedances

The Table 10 shows the Input Impedance from simulation analysis.

Name	Value [kOhm]
zin	6.068763e-01

Table 10: Simulated Input Impedance.

The Table 11 shows the Output Impedance from simulation analysis.

Name	Value [kOhm]
zout	3.634829e-03

Table 11: Simulated Output Impedance.

3.4 Output Voltage Gain in the Passband

The result for the output voltage gain in the passband is shown in Figure 5.

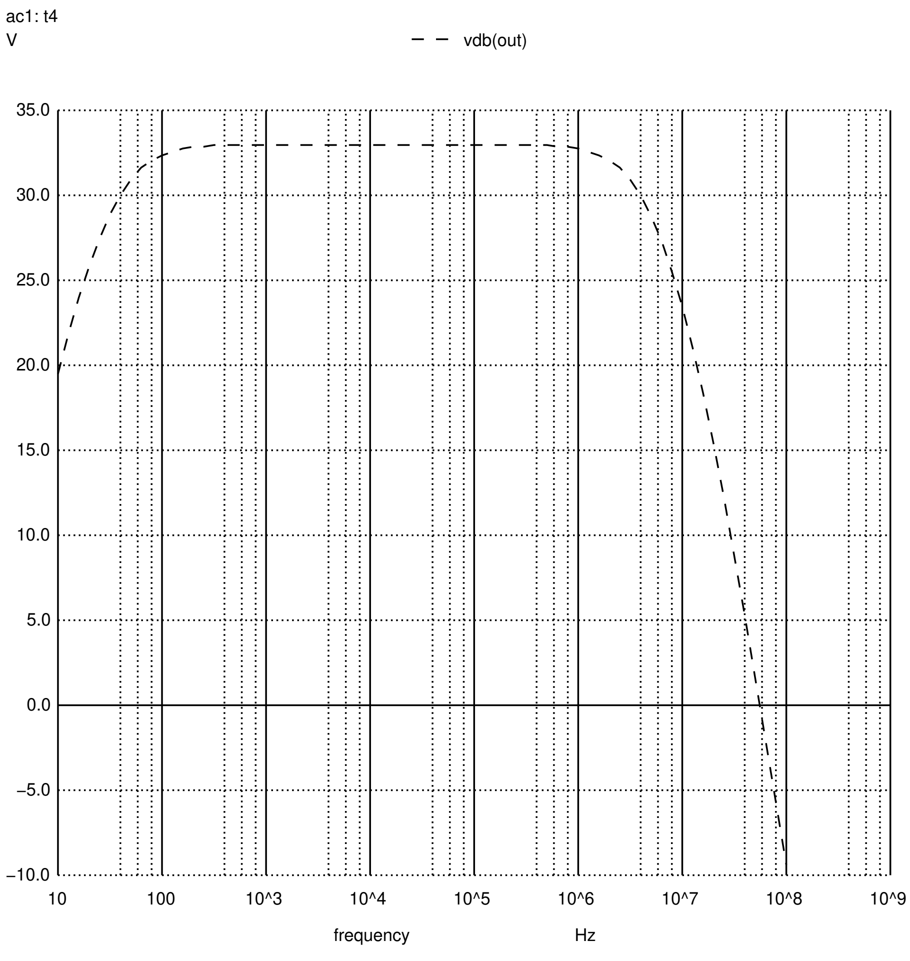

Figure 5: Output voltage gain in the passband.

3.5 Gain Frequency Response

The gain in terms of frequency is shown in Figure 8.

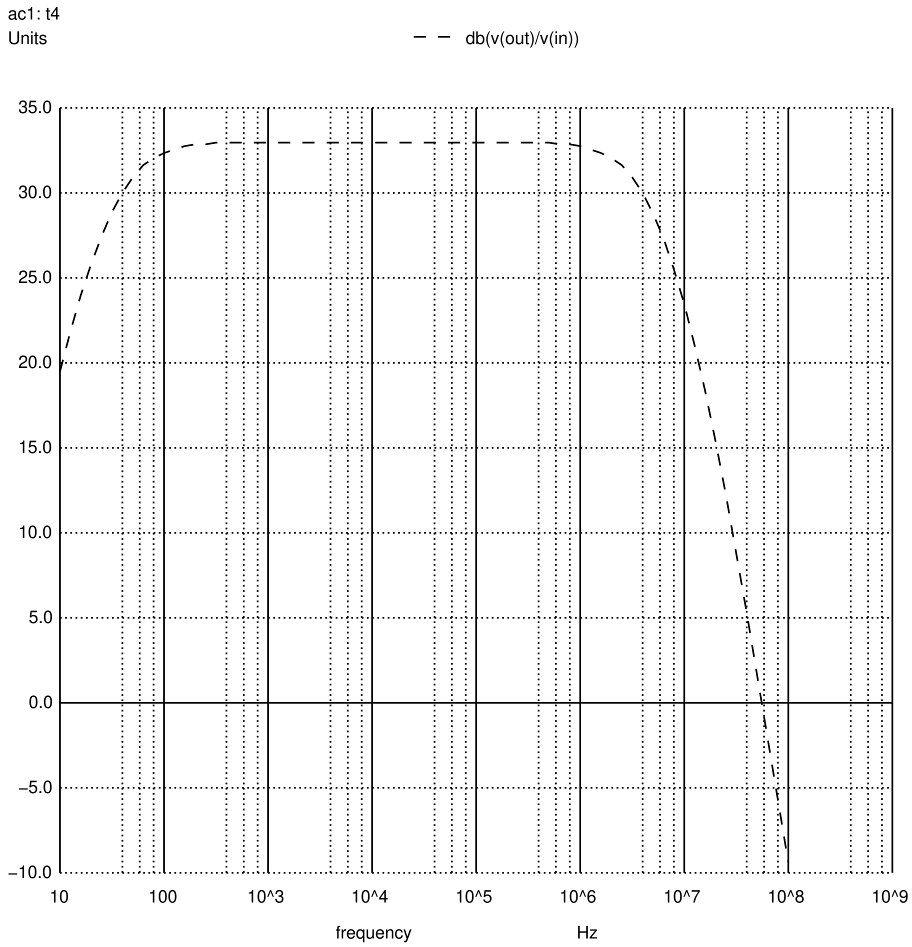

Figure 6: Frequency response of the gain in dB scale. The *x axis* represents the frequency in Hertz (Hz) and the *y axis* the gain in Volts.

4 Comparison

We will now compare the results of more interest obtained in the theoretical analysis and the simulation analysis.

For the impedance values, the Theoretical Results were the following:

Name [unit]	**Value**
Z_I	4.844336e+02 Ohm
Z_O	2.460696e+00 Ohm

Table 12: Theoretical Impedance Results.

And the Simulation results obtained were:

Name	**Value [kOhm]**
zin	6.068763e-01

Table 13: Simulation Input Impedance Result.

Name	**Value [kOhm]**
zout	3.634829e-03

Table 14: Simulation Ouput Impedance Result.

In both cases the Output Impedance is under enough to prevent signal loss when connecting the circuit to a speaker of 8Ohm.

For the Gain Frequency Response this is the graphic obtained theoretically:

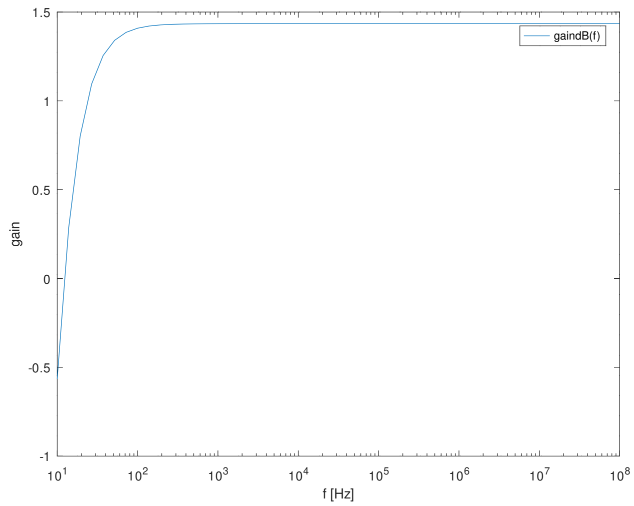

Figure 7: Frequency response of the gain in dB scale. The *x axis* represents the frequency in Hertz (Hz) and the *y axis* the Gain.

And the simulation one is:

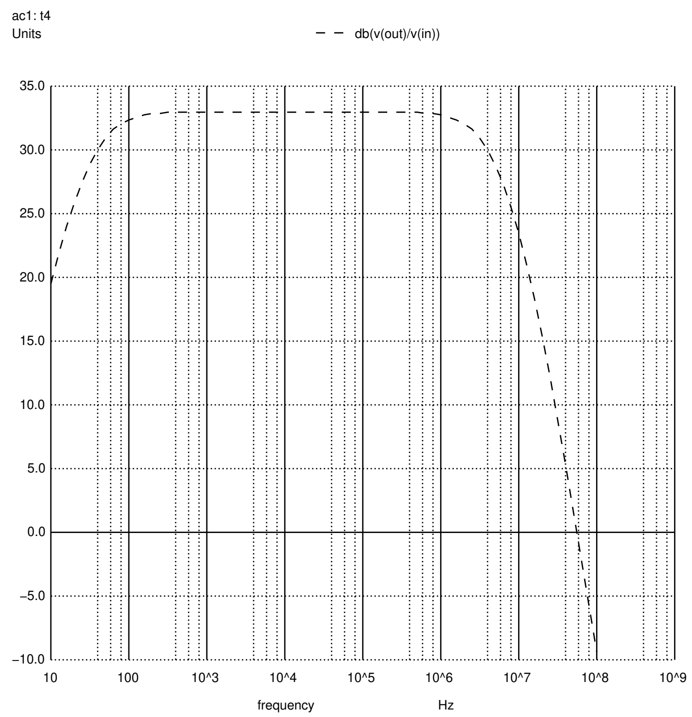

Figure 8: Frequency response of the gain in dB scale. The *x axis* represents the frequency in Hertz (Hz) and the *y axis* the gain in Volts.

Analyzing these values we notice that there is some difference between the theoretical predicion and the simulation. But we can also notice that, besides the differences, the results obtained were relatively good in both analysis. The simulation analysis gave the best results.

The differences seen in the results can be attributed to diverse causes. The differences between the values of impedance can be due to the fact that in the Simulation, these are not calculated for the intermediate stages of the circuit, while that was done in the theoretical analysis.

These differences also can be given to the fact that the circuit is quite complex, and contains non linear elements like transistors which always influences the accuracy of the results obtained, especially in the Simulation Analysis, so it explains the differences in the results obtained.

5 Conclusion

Given the comparison made previously and the results obtained along the work, including a merit figure of more than one thousand, we can say that the objectives for this laboratory assignment were achieved and an Audio Amplifier circuit was built successfully.