TÉCNICO LISBOA

Circuit Theory and Electronics Fundamentals

Lab 4 - Audio Amplifier

Aerospace Engineering

Laboratory Report

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Eva Claro, 95785

Miguel Isidoro, 95834

Pedro Braz, 95837

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1 Introduction

This report is being made for the subject of Circuit Theory and Electronics Fundamentals and is related to the fourth laboratory being its objective to develop an audio amplifier circuit (made of Bipolar Junction Transistors) by choosing the architecture ot the Gain and Output amplifier stages. The circuit is shown in figure 1.

In Section 2 a theoretical analysis will be made and it can be decomposed in two stages: the gain stage where the objective is to have the maximum gain possible and the output stage whose objective is to lower the impedance of the amplifier. 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 4.

Also, it is important to notice that were used two types of BJTs transistors: BC557A (PNP type) and BC547A (NPN type).

Finally, the conclusions of this study are outlined in Section 5.

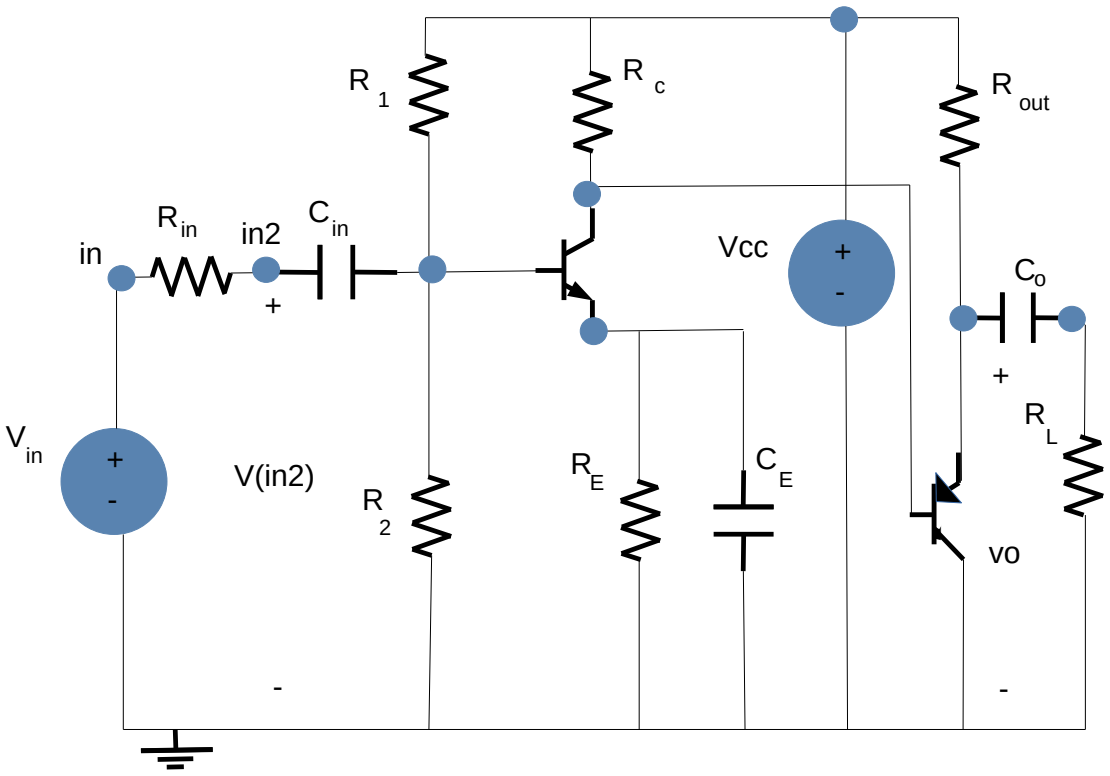

Figure 1: Audio Amplifier Circuit

2 Theoretical Analysis

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.

Name	Value [Ohm/F]
Cin	4.500000e-04
CE	4.500000e-04
Cout	2.000000e-04
R1	7.800000e+04
R2	1.800000e+04
RC	1.000000e+03
RE	1.000000e+02
Rout	1.000000e+02

Table 1: Value of the resistors and capacitors

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 2 and 3.

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.

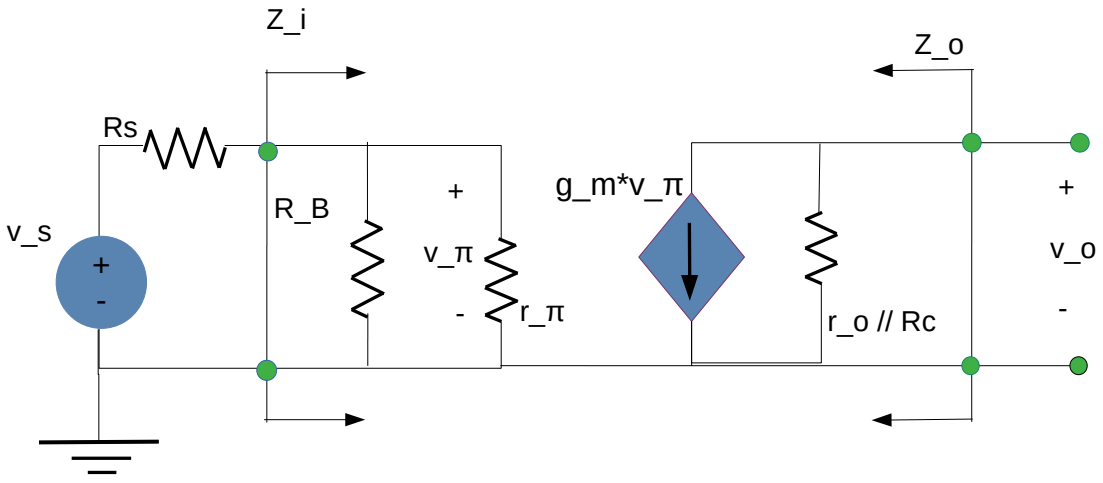

Figure 2: Gain Stage Circuit

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.

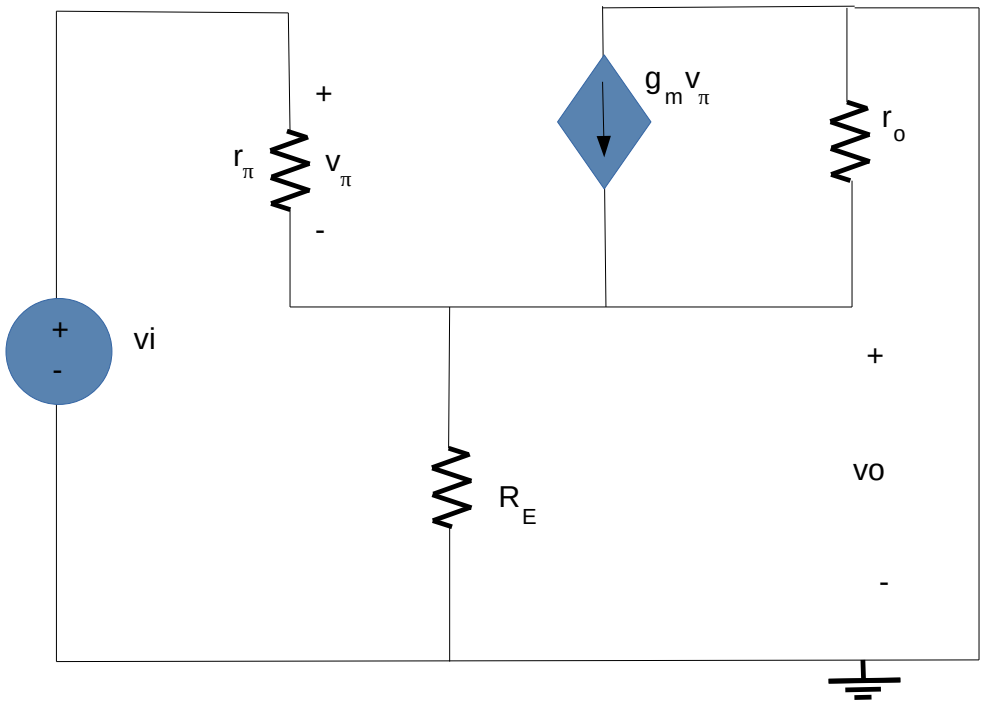

Figure 3: Output Stage Circuit

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 2. 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.

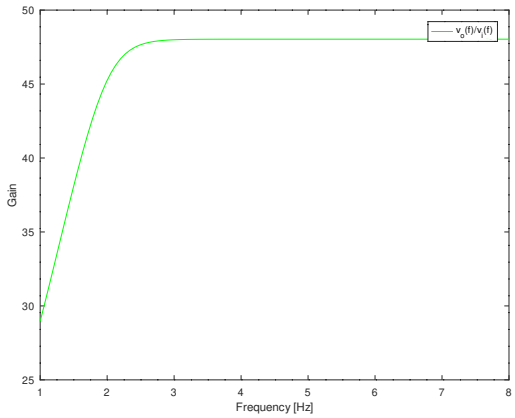

Figure 4: Output voltage of the secondary circuit

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

Name	**Value**
Gain stage- AV1	2.530994e+02 V
Output stage stage -AV2	9.961398e-01 V
Bandwidth	1.653955e+06 Hz
Lower Cut Off Frequency	1.149757e+02 Hz

Table 2: Theoretical values obtained by Octave

Name	**Value**
Imput impedance (Gain stage)- ZI1	5.074833e+02 Ohm
Output impedance (Gain stage)-ZO1	8.913297e+02 Ohm
Imput impedance (Output stage)-ZI2	8.900609e+03 Ohm
Output impedance (Output stage)– ZO2	3.193667e-01 Ohm
Output impedance-ZO	4.019549e+00

Table 3: Input and Output impedances

3 Simulation Analysis

This section covers the audio amplifier circuit simulation using the Ngspice tool.

As asked in the lab assignment, a NPN transistor and a PNP transistor were used in gain stage and output stage respectively. The goal was to calculate the impedances (Z_I and Z_O), the cut off frequencies (upper and lower), the bandwidth (the difference between the cut-off frequencies) and the total gain. Also, the goal was to optimize these values.

It was also confirmed if the BJTs are on the FAR (forward active region) by comparing V_{CE} and V_{BE} for NPN type and V_{EC} and V_{EB} for PNP type. The merit is also calculated in this section.

Later in this report, we will compare this results with the theoretical ones but for now we will just show them.

The Table 4 and 5 shows the BJTs voltages and their FAR confirmation.

Name	**Value**
V(CE)	3.40072 V
V(BE)	0.706641 V
V(CE) greater than V(BE)	Yes

Table 4: FAR confirmation - BC547A (NPN type)

Name	**Value**
V(EC)	5.0447 V
V(EB)	0.810033 V
V(EC) greater than V(EB)	Yes

Table 5: FAR confirmation - BC557A (PNP type)

After the OP analysis where the currents branches and nodal voltages were computed, in the next table it is presented the values asked: voltage gain, lower and upper cut-off frequency and the bandwidth. It was used the .meas function.

Name	**Value**
VGain	37.8892 V
Bandwidth	1.65397E+06 Hz
Lower COFreq	98.4147 Hz
Upper COFreq	1.65407E+06 Hz

Table 6: Ngspice simulation results

EFFECT OF THE COUPLING'S CAPACITOR: To fully analyse this circuit it is fundamental to understand the Coupling's Capacitor behaviour. The main effect of the Coupling's Capacitor is to block the DC signals of the Audio In source. When the capacitance is increased, the cut off frequency is anticipated leading to a larger bandwidth. This results in the capacitor blocking some lower frequencies influencing directly in the bandwidth.

EFFECT OF THE BYPASS CAPACITOR: As studied in classes, the R_e stabilizes the effect of the temperature in the DC voltage. On the other hand, this accomplishment has a negative effect on the gain stage of the audio amplifier, in other words it lowers the gain voltage. By placing the capacitor in parallel with the resistor Re, this resistor becames short for medium and high frequencies (impedance of the capacitor is $\frac{1}{j\omega C}$, having an extreme importance in maximizing the gain for medium and high frequencies.

EFFECT OF THE R_c: It is also relevant to analyse the influence of R_c on the total gain stage of the circuit. The gain increases with R_c as was already predicted in Section 2.

In the following graphics it can be seen how the effect of the previous components and how the the input voltage and output voltage varies with the frequency.

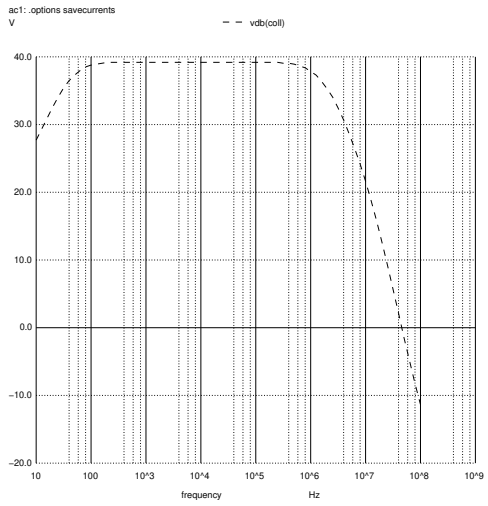

Figure 5: Input Voltage

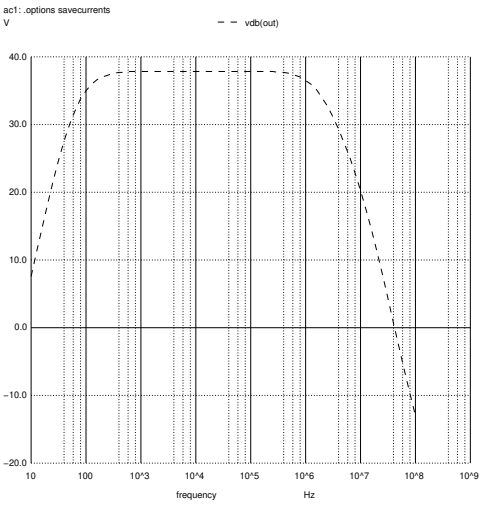

Figure 6: Output Voltage

To guarantee a high compatability between Audio In and the speakers is important to simulate the input and output impedances. To have a similar value for voltage in node In2 and Vin it is necessary a high resistance value. Regarding the output impedance, it must be the lowest possible, in order to have the maximum output voltage.

Name	**Value**
Zin	-591.995 + 89.7708 j Ohm

Table 7: Impedance values

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

Name	**Value**
Cost	1197.5 MU
merit	531.75

Table 8: Cost and merit results

4 Side by Side Comparison

After ending both simulation and theoretical analysis processes, the results were presented on their sections. However, for presenting a prudent interpretation of the result both tables were put side by side.

Name	Value
VGain	37.8892 V
Bandwidth	1.65397E+06 Hz
Lower COFreq	98.4147 Hz
Upper COFreq	1.65407E+06 Hz

Table 9: Simulated results

Name	Value
Gain stage- AV1	2.530994e+02 V
Output stage stage -AV2	9.961398e-01 V
Bandwidth	1.653955e+06 Hz
Lower Cut Off Frequency	1.149757e+02 Hz

Table 10: Theoretical values

5 Conclusion

The objective of this laboratory assignment was to develop an audio amplifier circuit 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.