

## **Circuit Theory and Electronics Fundamentals**

### **Lab 4 - Audio Amplifier**

### **Aerospace Engineering**

Laboratory Report

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# Contents

<b>1</b>	<b>Introduction</b>	<b>3</b>
<b>2</b>	<b>Theoretical Analysis</b>	<b>4</b>
2.1	Gain Stage . . . . .	4
2.2	Output Stage . . . . .	5
2.3	Total value . . . . .	5
<b>3</b>	<b>Simulation Analysis</b>	<b>7</b>
<b>4</b>	<b>Conclusion</b>	<b>9</b>

# 1 Introduction

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

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 ??.

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 4.

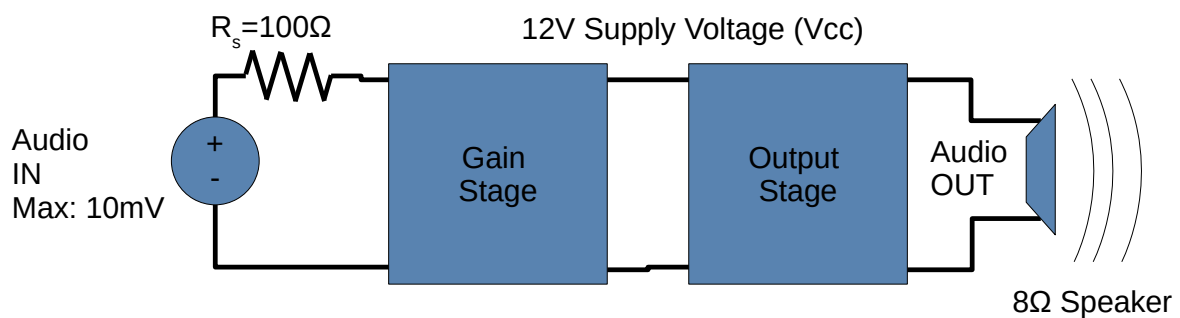


Figure 1: AC/DC converter circuit

## 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	1.800000e-06
CE	7.870000e-05
Cout	2.000000e-04
R1	8.000000e+04
R2	2.000000e+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.

The first one, which corresponds to the part that is at the left of the  $V_{CC}$ , has the goal of not degrading 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  $\beta_F$ . 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 section, 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:

$$Z_{I1} = R_B || r_{\pi 1} \quad (1)$$

where  $Z_{I1}$  is the input impedance of this stage and  $R_B = R_1 || R_2$ . We approximate  $R_E$  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 frequencies (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

$$Z_{O1} = r_o || R_C \quad (2)$$

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:

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

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

This way, we are able to get

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

## 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

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

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

For the incremental analysis, we also transform the circuit, turning it into the one presented in Lecture 17 on slide 15. Using the KCL, we get the following expression

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

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

$$A_{V2} = \frac{v_{O2}}{v_{I2}} = \frac{g_\pi + g_{m2}}{g_{\pi 2} + g_{z2} + g_{O2} + g_{m2}} \quad (9)$$

## 2.3 Total value

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

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

The total gain is given by

$$A_V = A_{V1} \times A_{V2} \quad (11)$$

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

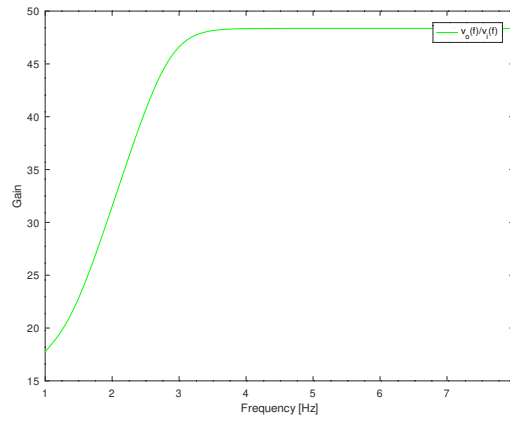


Figure 2: Output voltage of the secondary circuit

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 [V]
Gain stage- AV1	2.627909e+02 V
Output stage stage -AV2	9.963116e-01 V
Bandwidth	9.999045e+06 Hz
Cut Off Frequency	9.545485e+02 Hz

Table 2: Voltage Ripple and Average Voltage for the Envelope Detector

Name	Value [V]
Input impedance (Gain stage)- ZI1	4.844336e+02 Ohm
Output impedance (Gain stage)-ZO1	8.862848e+02 Ohm
Input impedance (Output stage)-ZI2	8.598855e+03 Ohm
Output impedance (Output stage)– ZO2	3.021730e-01 Ohm
Output impedance-ZO	3.981969e+00

Table 3: Voltage Ripple and Average Voltage for the Voltage Regulator

### 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 (), the bandwidth (the difference between the cut off frequencies) and the total gain.

It was also confirmed if the BJTs are on the F.A.R. (forward active region) by comparing  $V_{CE}$  and  $V_{BE}$  for NPN type and  $V_{EC}$  and  $V_{EB}$  for PNP type.

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 F.A.R. confirmation.

Name	Value [A or V]
V(CE)	2.78156
V(BE)	0.70931
V(CE) > V(BE)	Yes

Table 4: F.A.R. confirmation - BC547A (NPN type)

Name	Value [A or V]
V(EC)	4.49605
V(EB)	0.817257
V(EC) > V(EB)	Yes

Table 5: F.A.R. confirmation - BC557A (PNP type)

In the next table it is presented the results asked.

Name	Value [A or V]
VGain	37.9181
Bandwidth	1.55393E+06
COFreq	8793.49

Table 6: Ngspice simulation results

The merit obtained by the groups is presentend in the following table.

Name	Value [A or V]
Cost	123.208
merit	54.3849

Table 7: Cost and merit results

Name	Value [A or V]
Zin	-548.062 + 82.7641 j

Table 8: Merit values

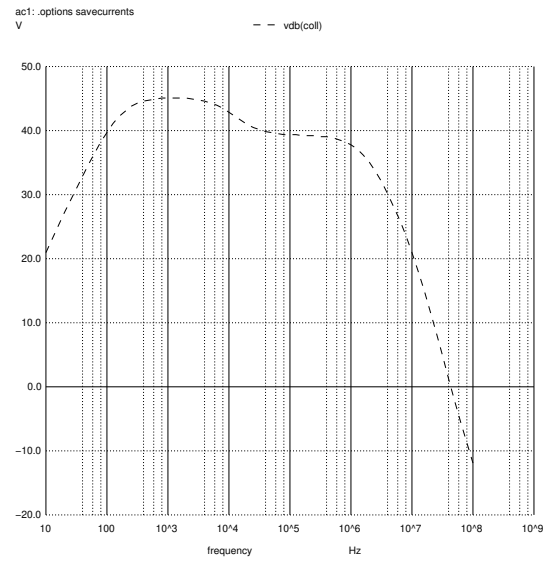


Figure 3: Output Voltage of the envelope detector  $v(4)$

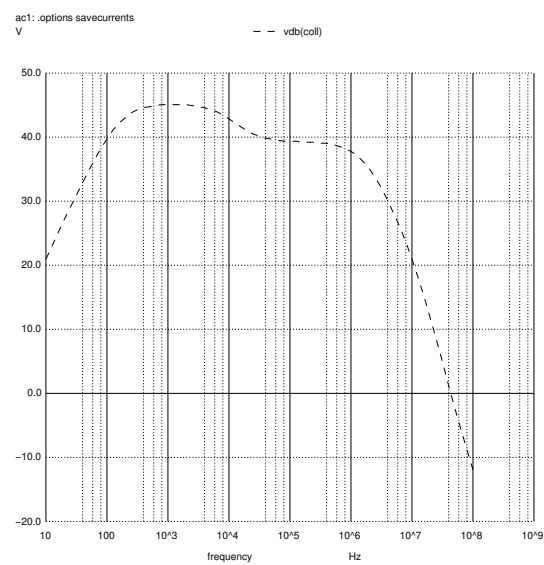


Figure 4: Input Voltage of the secondary circuit ( $v(2)-v(3)$ )



## 4 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 it can be seen a difference between the two. This is the result of using a non-linear circuit whereas the model used by NGSpice is far more complex than the theoretical model used. Regarding this one and despite the differences, the theoretical model gives good results and can be used when there is no simulation tools to use or to quickly confirmed the simulation results obtained.

The objective of this laboratory assignment was to develop an audio amplifier circuit and the main goal was achieved. However 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.

We also note that this time, the results were not equal and exactly the same comparing both NGSpice and Octave.

However, 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 explained on our lectures. To solve the circuit, NGSpice used far more advanced simulation methods for the diodes, with many more parameters, while we used an approximated model with  $V_{on}$  and an incremental resistor.

The error obtained between the average theoretical value and average simulated value is 4.86% which wouldn't be significant in a real life scenario but for a online simulation is a bit significant.

This way, the objective should have never been to have equal results, but rather, have results that seemed reasonable, which we believe it was achieved. The merit obtained was 1.538149e-01.