Instituto Superior Técnico, University of Lisbon

Integrated Master in Aerospace Engineering

Circuit Theory and Electronics Fundamentals

Joana Matos (95799), Ricardo Abreu (95842), Vasco Emídio (95856)

Fourth Laboratory Report

May 12, 2021

Contents

1 Introduction

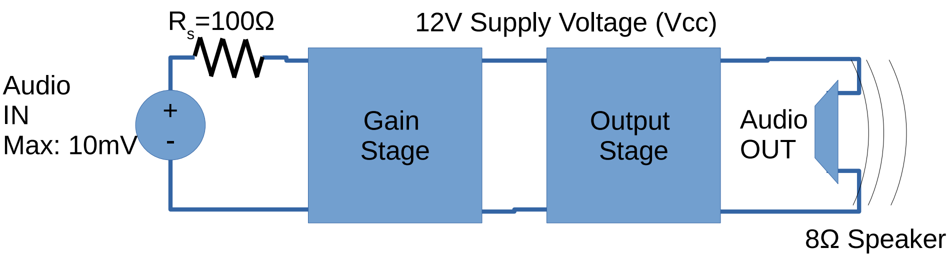


Figure 1: Audio Amplifier Circuit

The objective of this laboratory assignment is to simulate an Audio Amplifier Circuit 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 2.

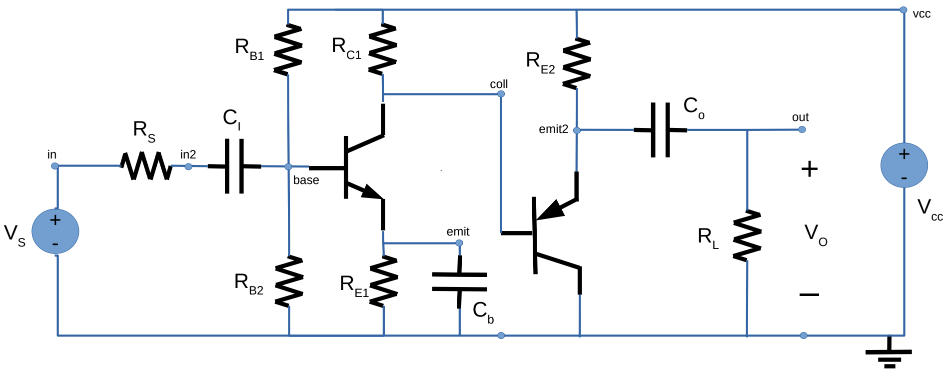


Figure 2: Audio Amplifier Circuit Diagram

In this laboratory, we use two different modles of Phillips BJT's Transistors: BC547A, a NPN transistor used in Gain Stage, and BC557A, a PNP Transistor used in Output Stage. The values of the components are exhibited in the table below.

Name	Value
R_S	1.000000e+02 Ohm
R_{B1}	8.000000e+04 Ohm
R_{B2}	2.000000e+04 Ohm
R_{C1}	9.400000e+02 Ohm
R_{E1}	7.750000e+02 Ohm
R_{E2}	2.335000e+03 Ohm
R_L	8.000000e+00 Ohm
C_I	6.900000e-04 F
C_b	4.180000e-03 F
C_O	2.250000e-03 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 2 is analysed theoretically. We will begin by analyzing the Gain Stage circuit and, after that, the Output Stage circuit. Thus, we will start by computing the Operating Point using the theoretical DC model studied and comparing it to Ngspice's OP.

Then, we will compute the gain and input and output impedances separately for the 2 stages.

Finally, we will compute the frequency response Vo(f)/Vi(f).

2.1 Gain Stage

In this subsection, we will analyze the Gain Stage circuit. Its function is to ensure a high input voltage so that the input signal is not degraded or distorted throughout the circuit. It also has a high gain associated, being responsible for amplifying the signal.

In order to make the analysis task easier, we used Thévenin's equivalent of bias circuit. Its diagram is represented in Figure 3 as well as the NPN BC547A model used in this assignment is shown in table 2.

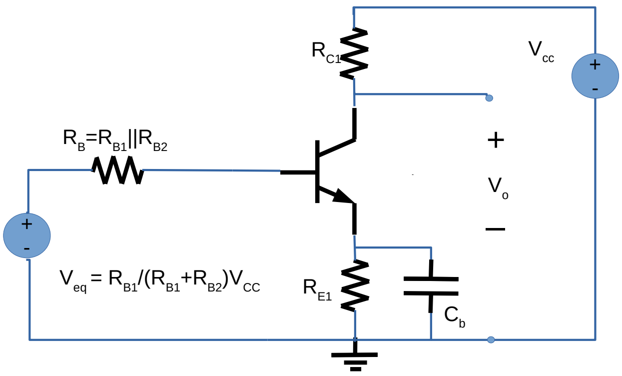


Figure 3: Gain Stage Circuit

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

Table 2: BC547A model

In gain stage circuit, it is important to mention that capacitor C_I is a coupling capacitor, acting as a DC Block, and C_b is a bypass capacitor.

2.1.1 Operating Point

Considering the equations of the lecture 17 and the theoretical DC model studied , we compute the OP. The table 3 presents the results obtained.

Name	Value
R_B	1.600000e+04 Ohm
V_{eq}	2.400000e+00 V
I_{B1}	1.094885e-05 A
I_{C1}	1.956559e-03 A
I_{E1}	1.967508e-03 A
V_{E1}	1.524818e+00 V
V_{O1}	1.016083e+01 V
V_{CE}	8.636016e+00 V

Table 3: OP - Gain Stage

2.1.2 Gain and Input and Output Impedances

Then, we will compute the gain and input and output impedances. In order to do that, we will use the incremental circuit, whose diagram is represented in Figure 4.

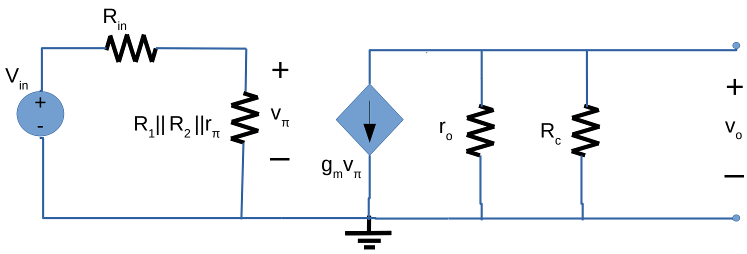


Figure 4: Incremental Gain Stage Circuit

Starting by calculating the gain, after analyzing the circuit, we obtain the following equation:

$$A_v = \frac{v_o}{v_{in}} = -g_m(r_o||R_C)\frac{R_B||r_\pi}{R_B||r_\pi + R_{in}} \tag{1}$$

Notice that the capacitor C_b was used to bypass R_E. Otherwise, the gain will be lower and the lower cutoff frequency too high. This way, CE is an open-circuit for low frequency (DC) and a short-circuit fot higher frequencies (AC).

Table 4 presents the results.

Name	Value
A_{V1}	3.668323e+01 dB

Table 4: Gain - Gain Stage

In order to obtain the impedances, we used the following equations:

$$Z_{I1} = R_B1||R_B2||r_\pi \tag{2}$$

$$Z_{O1} = R_C||R_o \tag{3}$$

The results are presented in Table 5

Name	Value
Z_{I1}	1.998186e+03 Ohm
Z_{O1}	9.158340e+02 Ohm

Table 5: Input and Output Impedances - Gain Stage

Notice that, in this section, we have made the approximation $R_E1 \approx 0$, because it is assumed the capacitors are shor-circuited, i.e. high frequency analysis.

Finally, we should pay attention to the values of the output impedance of gain stage. Its values are high when compared with the load. That's why we need the Output Stage.

2.2 Output Stage

In this subsection, we will analyze the Output Stage circuit, wich presents a lower output impedance. Its diagram is represented in Figure 5 as well as the PNP BC547A model used in this assignment is shown in table 6.

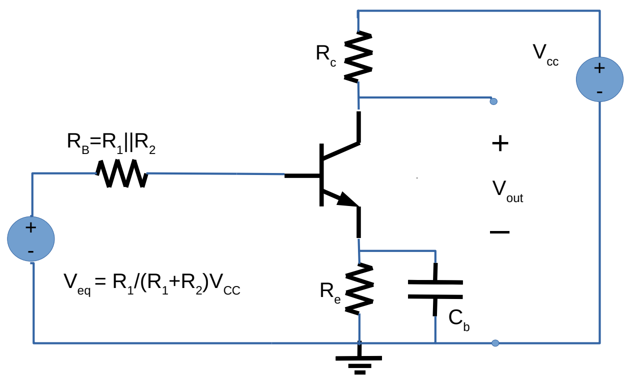


Figure 5: Output Stage Circuit

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

Table 6: BC557A model

2.2.1 Operating Point

Considering the equations of the lecture 17, we compute the OP. The table 7 presents the results obtained.

Name	Value
V_{I2}	1.016083e+01 V
I_{E2}	4.878652e-04 A
I_{C2}	4.857283e-04 A
V_{O2}	1.086083e+01 V

Table 7: Operating Point - Output Stage

It is important to notice that output current I_E is much stronger than in Gain Stage and that part of this current will feed the Load.

2.2.2 Gain and Input and Output Impedances

Then, we will compute the gain and input and output impedances. In order to do that, we will use the incremental circuit, whose diagram is represented in Figure 6.

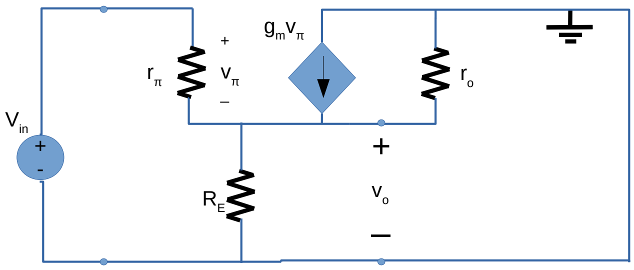


Figure 6: Output Stage Circuit

Starting by calculating the gain, after analyzing the circuit, we obtain the following equation:

$$A_v = \frac{v_o}{v_{in}} = \frac{g_m}{g_\pi + g_E + g_o + g_m} \tag{4}$$

, where g_π, g_E and g_o are the admittances of the respective resistors.

Table 8 presents the results and, as predicted, we obtained almost unitary gain.

Name	Value
A_{V2}	9.736018e-01 dB

Table 8: Gain - Output Stage

In order to obtain the impedances, we used the following equations:

$$Z_{I2} = \frac{g_\pi + g_E + g_o + g_m}{g_\pi(g_\pi + g_E + g_o)} \tag{5}$$

$$Z_{O2} = \frac{1}{g_\pi + g_E + g_o + g_m} \tag{6}$$

The results are presented in Table 9

Name	Value
Z_{I2}	4.431714e+05 Ohm
Z_{O2}	5.011041e+01 Ohm

Table 9: Input and Output Impedances - Output Impedances

2.3 Final

For the final output, it is important to mention that was used another coupling capacitor between the Output stage and the load. So, these outputs are in Table 10.

Name	Value
A_V	3.647396e+01 dB
Z_I	1.998186e+03 Ohm
Z_O	5.393985e+01 Ohm

Table 10: Output Values

This way, the theoretical value of the lower cut-off frequency finally is presented in Table 11.

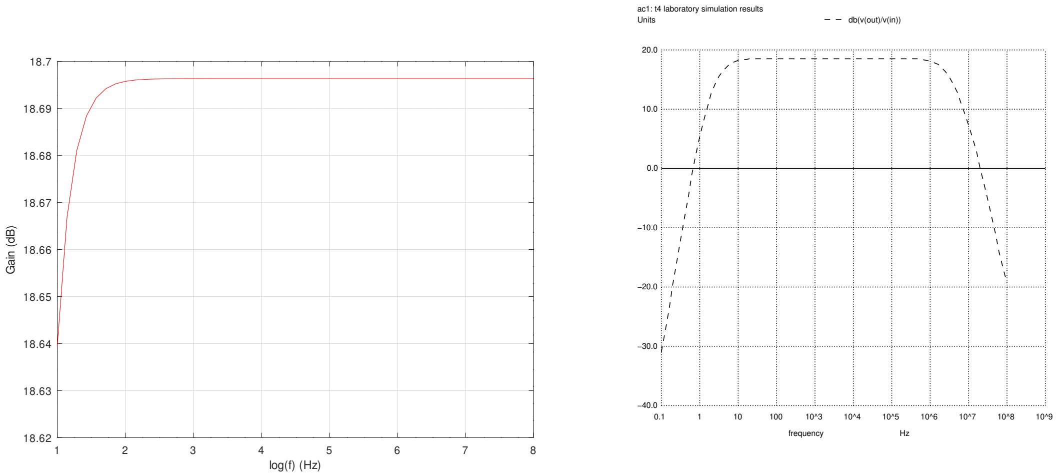
Name	Value
$LowerCOfreq$	4.107518e+00 Hz

Table 11: Lower Cut-Off Frequency

3 Simulation Analysis and Comparison with Theoretical Results

3.1 Operating Point

3.2 Gain



(a) Theoretical

(b) Simulation

Figure 7: Gain

3.3 Impedances

3.4 Operating Point

Formula	Merit
low	3.202582e+00
cost	7.224358e+03
gain	1.857653e+01
bandwidth	3.038871e+06
merit	2.439930e+03

Table 12: LEGENDA

Formula	Merit
zin	2.236262e+00

Table 13: LEGENDA

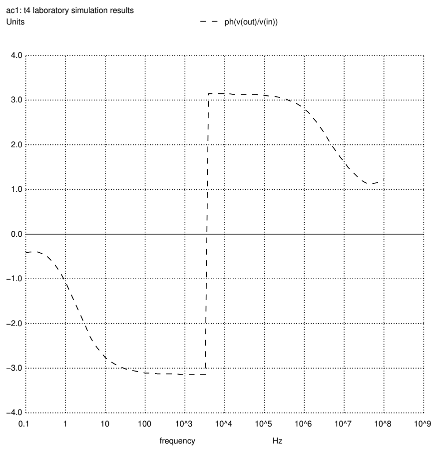


Figure 8: LLLLLLLLLLLLLLLLL

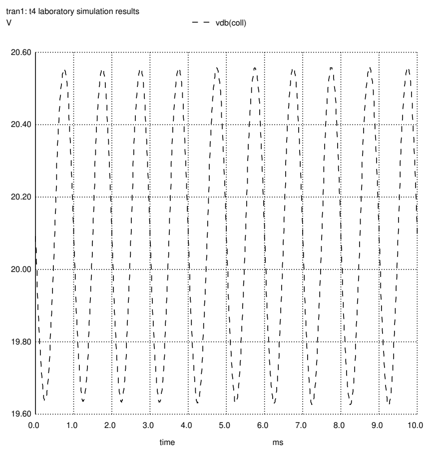


Figure 9: LLLLLLLLLLLLLLLLL

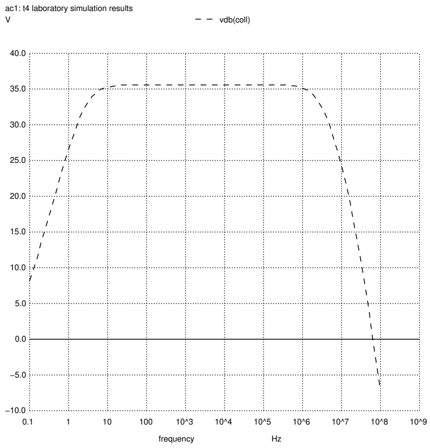


Figure 10: LLLLLLLLLLLLLLLLL

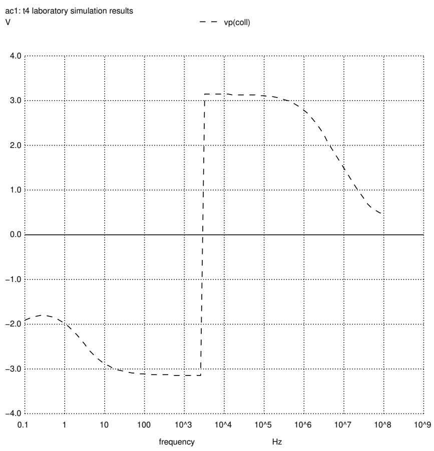


Figure 11: LLLLLLLLLLLLLLLLL

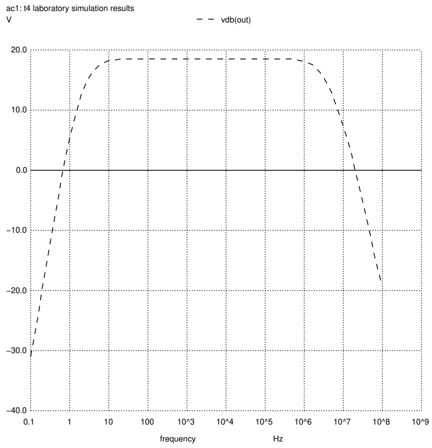


Figure 12: LLLLLLLLLLLLLLLL

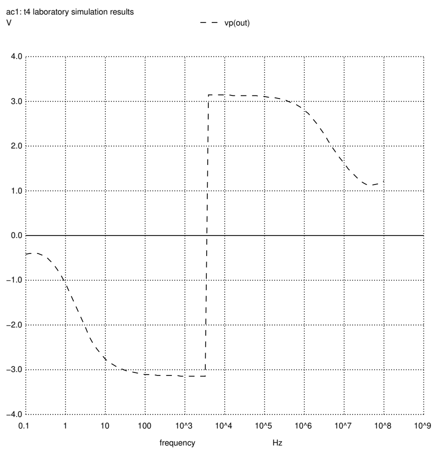


Figure 13: LLLLLLLLLLLLLLLL

4 Conclusion

In this laboratory assignment the objective of analysing an AC/DC converter, made of an envelope detector and a voltage regulator, 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 plotted the output voltages of both the envelope detector and voltage regulator and, in the case of the regulator, we also determine the maximum, minimum and average output voltage, so we could measure the voltage ripple and difference between the output and

12V, to calculate the figure of merit. As previously mentioned, the simulation results had slight differences from the theoretical ones. However, we designed an acceptable AC/DC converter - furthermore, we obtained a low stabilization time and a decent figure of merit, despite the cost being too high.