Circuit Theory and Electronics Fundamentals

Integrated Master in Aerospace Engineering, Técnico, University of Lisbon

Laboratory Report-T4

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1 Introduction

The main objective of this laboratory assignment is to produce an audio amplifier, choosing the architecture of the Gain and Output Stages, in order to obtain the best relationship possible between the cost of the circuit and the obtained resuts. The merit of the circuit is given by:

$$M = \frac{VoltageGain * Bandwidth}{cost * LowerCutofffFreq}. \tag{1}$$

The circuit used to produce the audio amplifier is shown in Figure1.

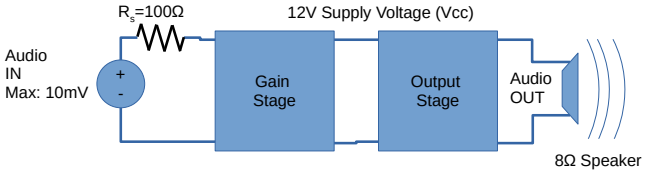

Figure 1: Circuit under analysis.

In the next section (2), we briefly explain the procedure to analyse theoretically the circuit above with the use of Octave maths tool. In Section 3 a simulation analysis is given, where we resorted to Ngspice to simulate the circuit, and a few graphics are presented to understand the results. The report finishes with its conclusion in section 4, where we analyse side by side the theoretical and simulated results and resume the most important points of the lab assignment.

2 Theoretical Analysis

The next subsections explain the theoretical analysis made to predict the output voltages and impedances in both the Gain and Ouput stages, designed by the teacher previously to the lab.

2.1 Gain Stage

Table1 shows the important values used in the circuit for the gain stage.

Name	Value
V_T	2.500000e-02
Vcc	1.200000e+01
$Beta$	1.787000e+02
V_A	6.970000e+01
R_E	1.000000e+02
R_C	3.500000e+03
R_{bias1}	2.300000e+04
R_{bias2}	2.000000e+03
C	4.500000e-04
V_{BEON}	7.000000e-01
R_S	1.000000e+02

Table 1: Gain Stage - Parameters.

The Gain stage circuit containes a coupling capacitor that works as a DC block, separating the DC component of the base of the transistor and the DC component of the input (which is approximately zero). This capacitor blocks some low frequencies. A transistor and resistances were used and also a bypass capacitor. While stabilizing the temperature, resistance R_E lowers the gain so it was necessary to improve it. To do so, this capacitor was used, with the objective of bypassing R_E in order to improve the gain at medium frequencies. This capacitor works as an open-circuit for low frequencies(DC) and as short-circuit for medium frequencies(AC).

First, an operating point analysis was made using the DC model. With the mesh analysis the needed voltages and currents were determined. It also allowed to confrm if the transistor was forwardly biased.

Then, an incremental analysis was made in order to determine the impedances and the incremental circuit gain.

The obtained results are given in Table2.

Name	Value
$Inputimpedance$	9.359215e+02
$Outputimpedance$	3.131224e+03
$Gain$	2.653995e+02

Table 2: Gain Stage - Results.

Taking a closer look at the results given by the Table, one sees that the output impedance of the gain stage has a big value so the circuit cannot be connected to an $8Ohm$ load. This is the reason why an output stage is necessary.

2.2 Output Stage

As previously refered, the output stage is needed to provide a low impedance to the load. The chosen parameters for this circuit are shown in Table3.

Name	Value
$Beta$	2.273000e+02
V_A	3.720000e+01
R_E	2.000000e+02
V_{BEON}	7.000000e-01
V_{in}	3.791166e+00

Table 3: Output Stage - Parameters.

Similar to before, operating point and incremental analysis were produced to obtain the output impedance and gain (which was supposed to be near one).

The obtained results are shown in Table4.

Name	Value
$Inputimpedance$	1.821626e+04
$Outputimpedance$	6.632304e-01
$Gain$	9.960174e-01

Table 4: Output Stage - Results.

As one can see in the results, the gain for the output stage is nearly one, which was the objetive and the output impedance is very small, making it perfect to connect to the load.

2.3 Total Results

In this lab assignement, it was also required to analyse the frequency response of the gain and compute into a graphic. This analysis is shown in Figure2.

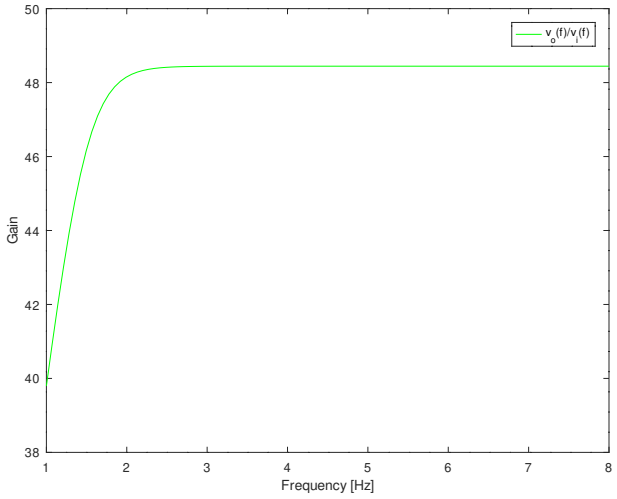

Figure 2: Frequency response of the gain .

Considering the total circuit, the results obtained for the most important quantities are shown in Table5.

Name	**Value**
$Inputimpedance$	9.359215e+02
$Outputimpedance$	1.323807e+01
$Gain$	2.643425e+02
$LowerCut-offFrequency$	3.125716e+01
$Bandwidth$	1.434561e+06
$Cost$	1.229100e+03
$Merit$	9.870730e+03

Table 5: Total Circuit - Results.

Observing these results, one can see that the two stages can be connected without significant signal loss because the output impedance of the gain stage is much smaller than the input impedance of the output stage and the values are quite compatible.

Looking at the values for the output impedance of the circuit, one notices that its value is small and good to connect to the $8Ohm$ load.

3 Simulation Analysis

A simulation analysis was produced in order to better predict the behaviour of the circuit.

Starting with the obtained graphic for the output voltage in the gain stage as a function of time, we have:

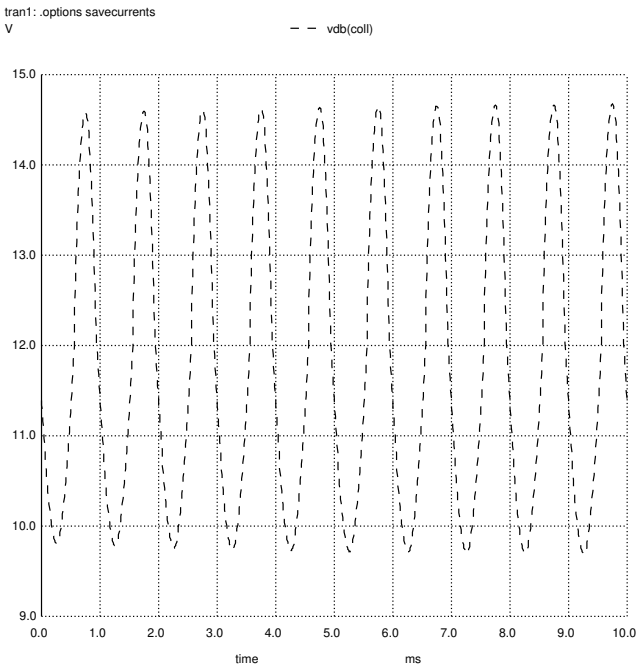

Figure 3: Output Voltage in the Gain Stage[v].

One can see that there is no visible distortion on the sinusoidal signal.

Figures 4 and 5 show the frequency response of the output voltage in the gain stage and output stage, respectively.

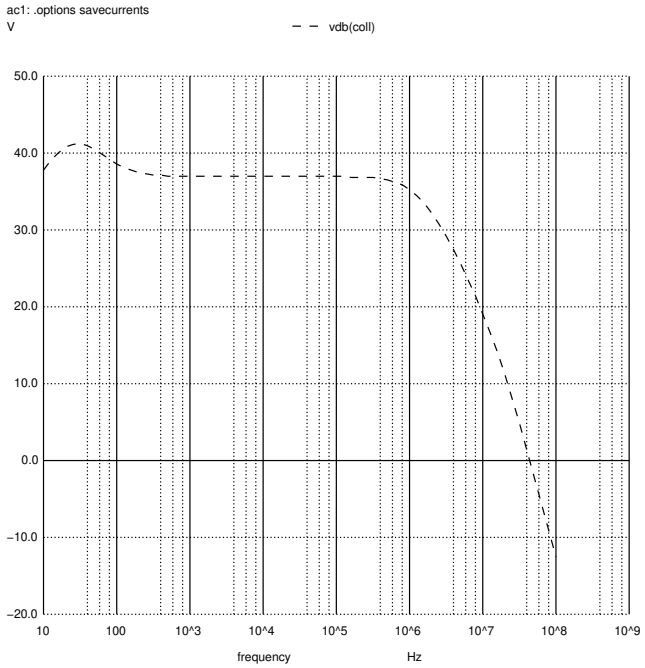

Figure 4: Frequency response: Output Voltage in the Gain Stage..

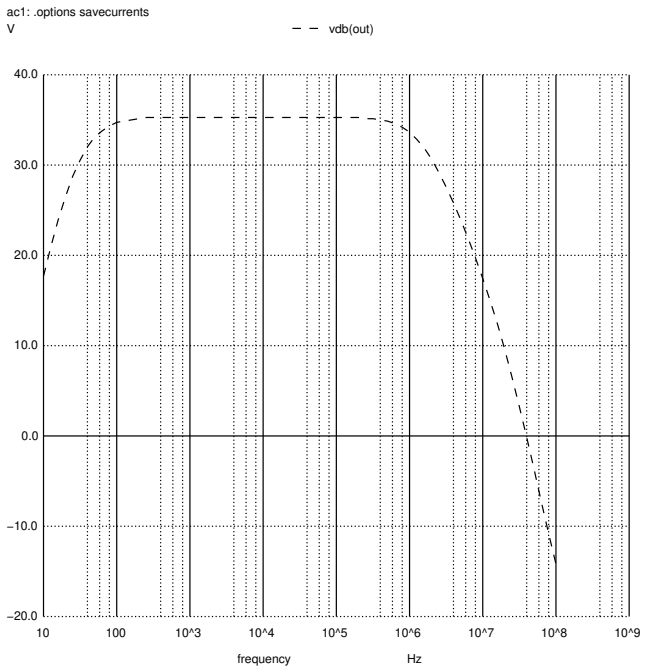

Figure 5: Frequency response: Output Voltage in the Output Stage.

The following graphic shows the frequency response of the gain produced by the circuit.

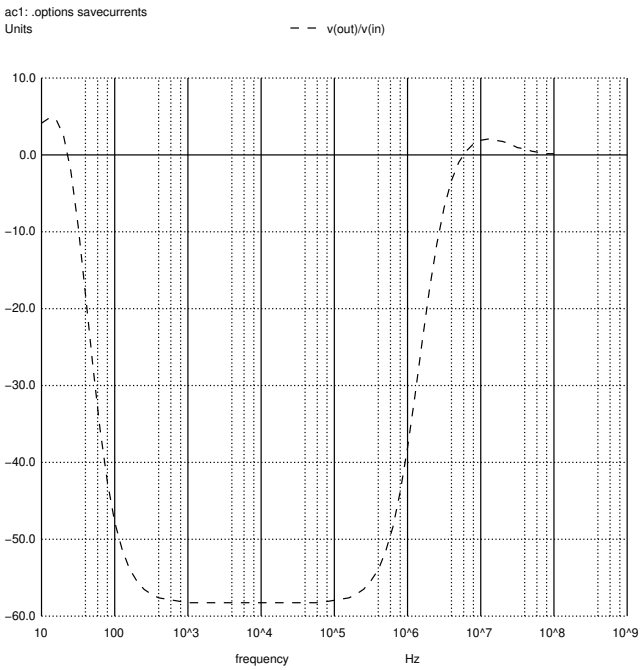

Figure 6: Frequency response: Gain.

Finally, the values for the most important quantities were simulated, resulting in the next tables:

Zin	-907.452 + 136.712 j

Table 6: Input Impedance.

Name	**Value**
Zout	22.9246 + 1.23706 j

Table 7: Output Impedance.

Name	**Value**
lcf	4.267269e+01
gain	5.830171e+01
bandwidth	1.434549e+06
cost	1.229100e+03
merit	1.594629e+03

Table 8: Simulated Results.

4 Conclusion

To better understand the similarities and also what differs most in the results using the theoretical and simulated analysis, the tables with the important values are given side by side:

Name	Value
$Inputimpedance$	9.359215e+02
$Outputimpedance$	1.323807e+01
$Gain$	2.643425e+02
$LowerCut-offFrequency$	3.125716e+01
$Bandwidth$	1.434561e+06
$Cost$	1.229100e+03
$Merit$	9.870730e+03

Table 9: Obtained results using Octave

Name	Value
lcf	4.267269e+01
gain	5.830171e+01
bandwidth	1.434549e+06
cost	1.229100e+03
merit	1.594629e+03

Table 10: Obtained results using NGSpice

Taking a closer look at these values, one notices that there are some discrepancies. These differences have a direct consequence in the value of the merit, since it depends on these quantities. One notices that the theoretical merit (9870.730) is almost nine times bigger than the simulated one (1594.629). These discrepancies were expected, since $Ngspice$ uses a very complex model for the transistors, while the theoretical results are obtained with many simplifications.

The presented results lead to the conclusion that a good compromise was achieved. The values for the lower cut-off frequency and bandwidth are pretty similar to the range of frequencies that a human can hear. Altough these results were very good, it is seen that the gain of the audio amplifier doesn't have a big value in the Ngspice analysis(differences were expected in relation to Octave analysis since the models are very complex in the simulation tool). This leads us to conclude that the gain had to compromised in order to obtain a smaller cost and frequencies between the normal range, leading to a better merit. A bigger gain would lead to a bigger cost and possibly a smaller bandwidth so the values chosen for this lab assignment were the ones that produced better results.

Looking at the obtained results, one must conclude that the merit to take into consideration is the simulated one, since $Ngspice$ has the ability to produce values that are much more similar to reality.

In conclusion, although there are some differences (that were expected), the objective of this lab assignment was accomplished and both methods (theoretical end simulated) were able to amplify the input signal as asked by the teacher and the obtained values for the merit were very satisfactory.