Circuit Theory and Electronics Fundamentals

T4

Physics Engineering, Técnico, University of Lisbon

May 23, 2021

Contents

1 Introduction

In this assignment we were tasked with the creation of an audio amplifier circuit and its analysis, both theoretically and through NGSpice.

An audio amplifier is a circuit configuration in which an imput signal is received, amplified and sent to a speaker. Our input signal will have a voltage of 10 mV and will be outputted into an 8 Ω speaker.

This circuit comprises 2 stages: a gain stage, where the signal is significantly amplifed with the cost of also increasing its impedance. This stage's main component is a NPN transistor; and an output stage where, in order to bridge the previous problem, reduces the impedance keeping the same signal amplitude. This stage has a PNP transistor as its primary component. This fulfills the goal of having an increased signal without any noticeable gain loss.

However, there can be setbacks in these situations which is why the quality of the designed circuit has a figure of merit that follows the equation below:

$$Merit = \frac{Gain \cdot Bandwidth}{Cost \cdot LowerCutOffFrequency}$$

In the laboratory description, the following general design of the circuit was given:

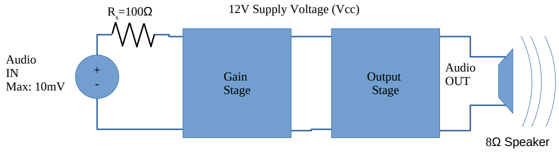

Figure 1: Studied Circuit

The gain and output stages were added to this information, creating the final circuit shown below:

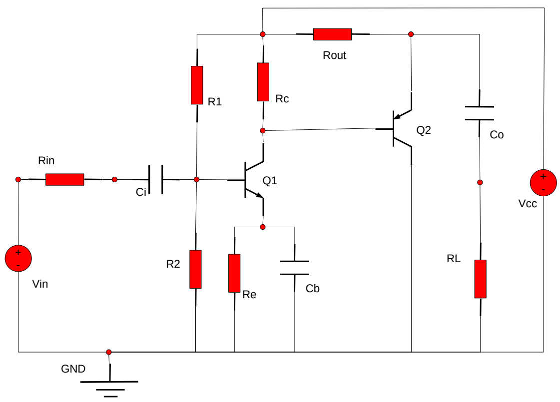

Figure 2: Studied Circuit

In Section 2, a theoretical analysis of the circuit is presented. In Section 3, the circuit is analysed by simulation using NGSpice, with its results being compared to the theoretical results obtained in Section 2 in the Section 4, while also outlining in this section the conclusions of this study.

2 Theoretical Analysis

As previously mentioned, this circuit is characterized by a Gain Stage and an Output Stage.

In this section, we were able to obtain the desired values using the hand calculations provided by the professor and resorting to the Operating Point Analysis.

The values for gain and input and output impedances is shown in both tables below, respectively:

Input impedance	9.999213e+02 Ohm
Output impedance	2.391397e+03 Ohm
Gain	1.049100e+02 V

Table 1: Gain Stage

Input impedance	1.540575e+04 Ohm
Output impedance	1.003207e+00 Ohm
Gain	9.893060e-01 V

Table 2: Output Stage

The values for gain and input and output impedances for the full circuit is shown in the following table:

Input impedance	9.999213e+02 Ohm
Output impedance	1.023534e+01 Ohm
Gain	9.346360e+01 V
Gain	3.941285e+01 dB

Table 3: Full circuit

It is possible to plot the frequency response as well by computing the gain $\frac{V_o(f)}{V_i(f)}$, as one can view in the next graph:

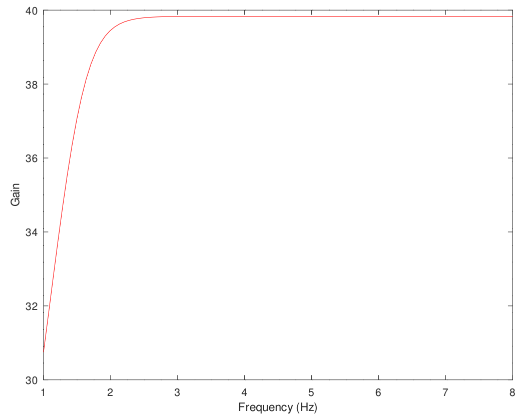

Figure 3: Gain plot - $\frac{V_o(f)}{V_i(f)}$

3 Simulation Analysis

In this part of the report, the NGSpice results for the same analysis as the theoretical will be presented. The purpose of it was to obtain the best possible value for gain, lower and upper cutoff frequencies and bandwidth in order to maximize the merit. We followed a set of steps as follows:

- First, we used the Phillips transistor model provided by the professor to design the circuit.
- Then, we had to verify that the transistor operation was in the forward active region (F.A.R mode).

Vec	8.7489
Veb	0.721996
Vec greater than Veb	True

Table 4: Verification F.A.R. mode for the PNP transistor

Vce	7.85959
Vbe	0.657761
Vce greater than Vbe	True

Table 5: Verification F.A.R. mode for the NPN transistor

- Afterwards, we computed the currents and nodal voltages for the Output Circuit.
- With that, we measured the output voltage gain, lower and upper cutoff frequencies and the bandwidth in the array of values for frequency, obtaining the following values:

Gain DB	32.9643 dB
Bandwidth	1.60197E+06 Hz
CO Freq	57.3351 Hz

Table 6: Results obtained in NgSpice

With these values, we were able to draw some conclusions on the components of this circuit:

Coupling Capacitors

These components are tasked with blocking DC signals. In an amplifier specifically, constant values must be eliminated which is why they are used. However, they also come with the cost of blocking some lower frequencies, which affects the bandwidth.

Bypass Capacitor

In this circuit, the existence a Re resistor to bridge the effect of temperature of DC current passing through it, which comes at the cost of gain reduction, calls for the need of a bypass capacitor, placed in parallel to the previously mentioned resistor so that DC current continues being affected by it while AC current bypasses it completely, not affecting the gain.

RC Resistor

This component is placed in the circuit with the objective of increasing the gain.

The importance of these components can be seen by the effects they have on the graphics below:

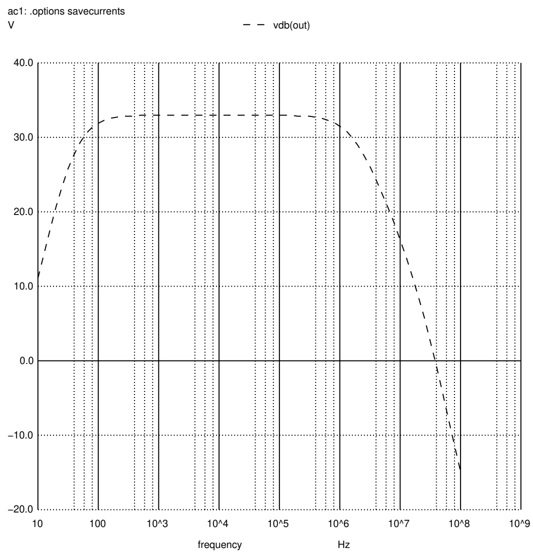

Figure 4: $v_0 - 12$ (Deviation from the desired DC voltages)

- After all that, we determined the Input impedance:

Zin	947.184 Ohm

Table 7: Input impedance

- And then the Output impedance:

Zo	13.8263

Table 8: Output impedance

- Lastly, we were able to figure out whether or not the amplifier is efficient by calculating the cost and merit from the equation shown in the Introduction:

Cost	824.608
Quality	1.24294E+06
Merit	1507.31

Table 9: Merit

4 Conclusion

To finish our work, one can take a look at a direct comparison between the input and output impedences and the resulting gain in decibels obtained through a theoretical analysis and a simulation analysis using Ocatve and Ngspice, respectevely. One can see that the differences are not too significative.

Input impedance	9.999213e+02 Ohm
Output impedance	1.023534e+01 Ohm
Gain	9.346360e+01 V
Gain	3.941285e+01 dB

Table 10: Theoretical Analysis

Zin	947.184 Ohm
Zo	13.8263
Gain DB	32.9643 dB
Bandwidth	1.60197E+06 Hz
CO Freq	57.3351 Hz

Table 11: Simulation Analysis

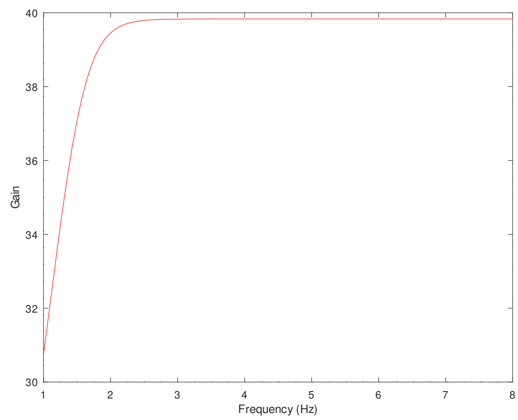

Figure 5: Gain plot - $\frac{V_o(f)}{V_i(f)}$

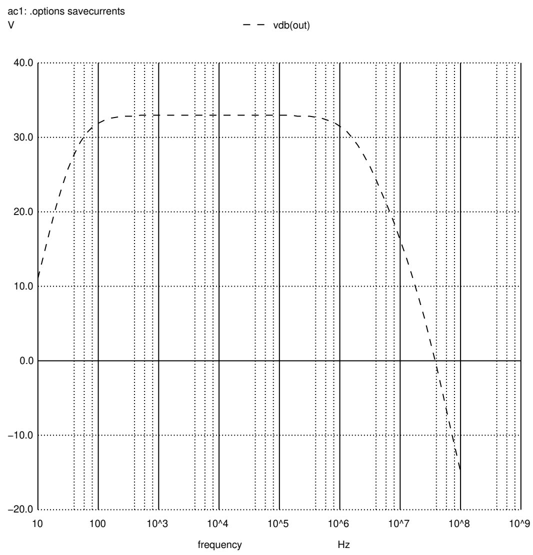

Figure 6: $v_0 - 12$ (Deviation from the desired DC voltages)

To sum it all up, we believe the main goal of this lab assignment was achieved: to design an audio amplifier that has the greatest amount of gain possible, spending as little as possible. In both our calculations, the voltage gain is satisfactory when compared to the resources' cost.

The greatest boundary came with trying to obtain similar results in both simulations, because the values are significantlly different, like it was observed in the beginning of this conclusion. The main reason for this setback is the non-linear behaviour of the transistors, which interferes with the theoretical calculations, splitting them apart from the simulation values.

All in all, both results still satisfy our goals and objectives as the figure of Merit has a valuable considered acceptable by the group.