TÉCNICO LISBOA

Circuit Theory and Electronics Fundamentals

T4 Laboratory Report

Group 34

José Bento, Nº 95815
Thomas Childs, Nº 95847
Luís Pacheco, Nº 96425

Aerospace Engineering (MEAer), Técnico, University of Lisbon

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1 Introduction

The objective of this laboratory assignment was to create an audio amplifier circuit. The audio amplifier would recieve an audio input of 10mV (maximum) and would connect to an 8 Ohm speaker. The source would have an 100 Ohm impedance and the circuit would be supplied with 12 volts by a DC source (Vcc).

A good voltage amplifier has to have an high gain (A_V) (as we want to amplify), a high input impedance (Z_i) and a low output impedance (Z_o) (so as not to degrade the input and output voltages, respectively). In order to meet this criteria the audio amplifier circuit will have two stages: the gain stage and the output stage, as this seemed like the best way to combine the good and not so good properties of each of the amplifier circuits studied in class.

In the gain stage a common emitter amplifier with degeneration was used because it allows us to have a high Z_i and a high gain A_V. Unfortunately it has a high Z_o as well, which will degrade the output signal. This problem will have to be fixed in the next stage. In this stage an NPN transistor was used.

In the output stage a commom collector amplifier was used because it allows us to maintain the high gain A_V from the previous stage whilst having a low Z_o. This stage is able to maintain the high gain because its high input impedance connects to the lower output impedance (but still an high one) of the previous stage and the gain in this section is ≈ 1. In this stage a PNP transistor was used.

To determine the quality of the audio amplifier, when compared to others, a merit classification system was created. This merit system took into account the cost of the components used, as well as the voltage gain, the cut off frequency and the bandwidth. The merit of the circuit will be determined according to the following equation:

$$MERIT = \frac{VoltageGain * Bandwidth}{Cost * LowerCutOffFrequency} \tag{1}$$

and the cost of the components are the following: cost of resistors = 1 monetary unit (MU) per kOhm, cost of capacitors = 1 MU/uF and cost of transistors = 0.1 MU per diode.

The general layout of the circuit that was implemented can be seen in **Figure ??**. In the next sections the actual architecture implemented for each stage will be analyzed in greater detail.

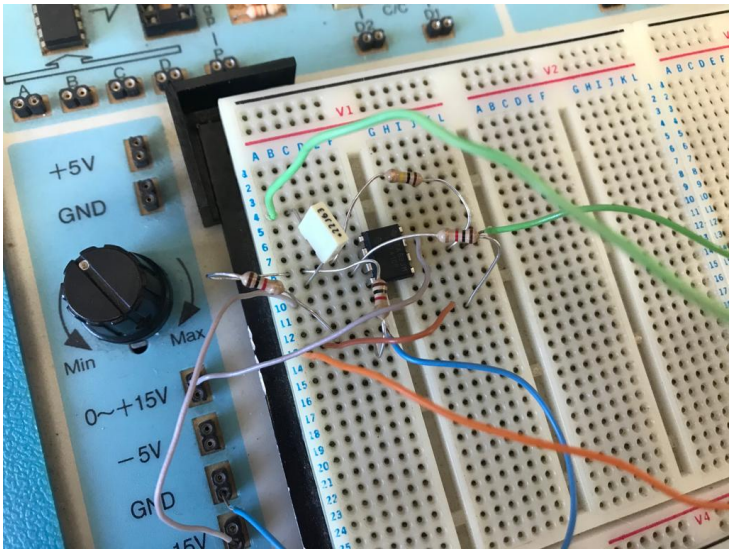

Figure 1: Circuit in study

In Section **??**, a theoretical analysis of the circuit is presented. Here the circuit is analised using the suitable OP (to ensure the transistors are in the Forward Active Region) and incre-

mental theoretical models studied in the class, in order to predict the gain and the input and output impedances for each of the stages. In Section **??**, the circuit is analysed by simulation using the program Ngspice. In Ngspice the Philips BJT'S model BC557A (PNP) and BC547A (NPN) for the transistors were used. The input and output impedances, the lower and upper 3dB cut off frequencies (the difference between them is the bandwidth), as well as the gain, were computed by simulation. The conclusions of this study are outlined in Section **??**, where the theoretical results obtained in Section **??** are compared to the simulation results obtained in Section **??**.

2 Theoretical Analysis

In this section, the circuit shown in **Figure ??** is analysed theoretically.

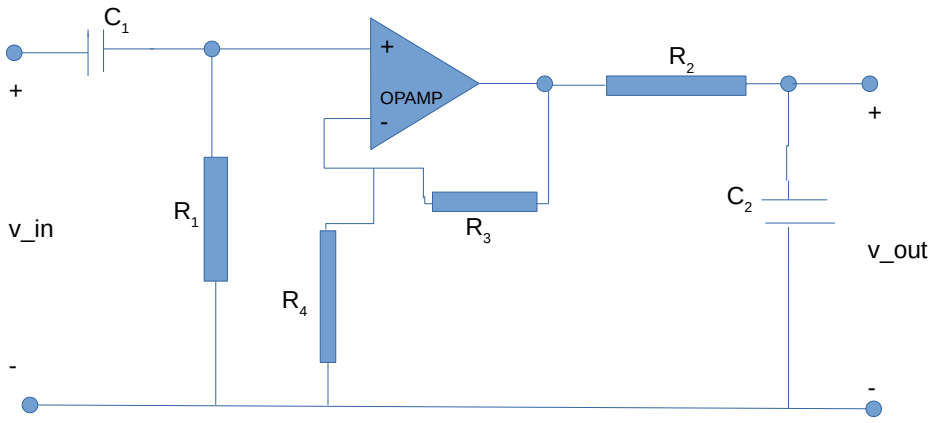

Figure 2: Diagram of the circuit considered for the computations and simulations.

As explained before, in the previous section, the audio amplifier is composed of two stages. In the first stage (the gain stage) the primary objective is to amplify the voltage input signal. To do so this section will have a high gain. This stage also has a high input impedance which avoids the degradation of the input signal. The downside of this stage is its high output impedance that makes it difficult to connect to a speaker without having the signal degrade in the exit. That is why there is an output stage. This stage will have a low output impedance which is very good because it allows us to connect to the speaker while minimizing signal degradation. When we connect the two stages the signal does not degrade very much beacause the output stage input impedance is higher than the output impedance of the gain stage, meaning little or no signal degradation in the transition between stages. This can be seen in one of the following tables. In the output stage the gain is very close to one, meaning than there will be no amplification nor attenuation of the signal.

The main purpose of the bypass capacitor C_E in the gain stage is to avoid a gain loss through resistor R_E and the main purpose of resistor R_E is to stabilize the temperature effect. In DC the temperature effect is most important while in AC the gain is most important . Therefore there needs to be an equilibrium. This components were placed in parallel in order to achive this equilibrium. For lower frequencies (DC) capacitor C_E behaves like an open circuit and the current goes through resistor R_E, stabilizing the temperature effect. For higher frequencies (AC) the capacitor is a short circuit and therefore it is used to bypass the resistor R_E, avoiding lowering the gain (gain is stable in the desired passband).

The human ear perceives frequencies between 20 Hz to 20 kHz and therefore we should chose coupling capacitors that behave like short-circuits for these frequencies, as the coupling capacitors affect the lower cutoff frequency and consequently the bandwidth. The final values considered for the circuit parameters (as named in the above figure) were the following:

Parameter	Value	Units

In the following table is the operating point analysis, both for the theoretical analysis (right) and the Ngspice simulation (left), in order to make a side-by-side comparison. This also includes a flag (last row) that ensures that both BJTs are in the Forward Active Region - if

everything is ok, the flag should read ”ok”. If any (or both) of the transistor are not in this region, the flag should read ”bad”. The condition considered was, for the NPN transistor: $V_{CE} > V_{BE} <=> V_C > V_B$ and for the PNP transistor: $V_{EC} > V_{EB} <=> V_C < V_B$. The operating point results for both the simulation and the theoretical DC model agreed very satisfactorily.

Node Voltage	Simulation	Theoretical	Units

The circuit used to compute the lower cutoff frequency and the gain, theoretically, was the following incremental model (which includes the coupling capacitors given that these are the limiting factors in terms of the lower cutoff frequency). For the upper cutoff frequency it is a little bit more complex given that this is due to the parasitic capacitances of the transistor, which are part of the Ngspice model, but were not considered in the theory.

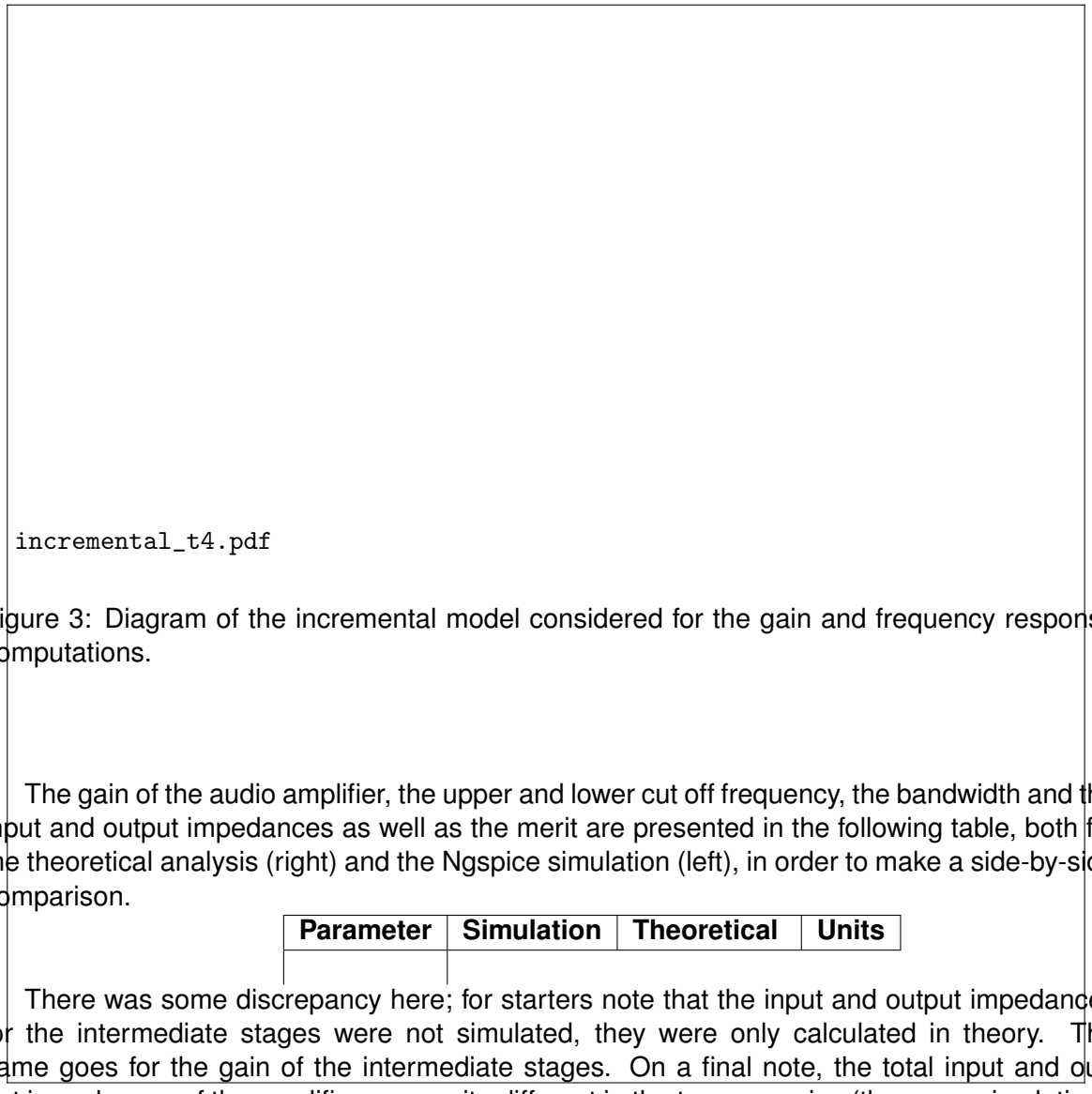

Figure 3: Diagram of the incremental model considered for the gain and frequency response computations.

The gain of the audio amplifier, the upper and lower cut off frequency, the bandwidth and the input and output impedances as well as the merit are presented in the following table, both for the theoretical analysis (right) and the Ngspice simulation (left), in order to make a side-by-side comparison.

Parameter	Simulation	Theoretical	Units

There was some discrepancy here; for starters note that the input and output impedances for the intermediate stages were not simulated, they were only calculated in theory. The same goes for the gain of the intermediate stages. On a final note, the total input and output impedances of the amplifier were quite different in the two scenarios (theory vs simulation), but of the same order of magnitude; the only other significant difference was the lower cut off frequency.

Do note that the upper cutoff frequency here used in the theoretical column was actually obtained from Ngspice: to calculate this frequency in theory, we would need to take into account the parasitic capacitances in the transistor, which proved to be quite more complex and therefore was not used.

The next figures present the plot of gain obtained in the theoretical analysis.

Figure 4: Output voltage gain of the audio amplifier as a function of frequency

3 Simulation Analysis

The circuit used to simulate the output impedance of the amplifier as a whole was the one that can be found in the following figure. The intermediate input and output impedances for the different stages were not simulated.

Figure 5: Diagram of the circuit considered for the simulation of the output impedance of the amplifier .

diagram_t4_zout.pdf

The gain of the audio amplifier, the upper and lower cut off frequency, the bandwidth and the input and output impedances as well as the merit are presented in the following table, both for the theoretical analysis (right) and for the Ngspice simulation (left), in order to make a side-by-side comparison.

Parameter	Simulation	Theoretical	Units

3.1 Output voltage gain in the passband

vo2f.pdf

Figure 6: Output voltage gain in the passband

3.2 The input and output impedances

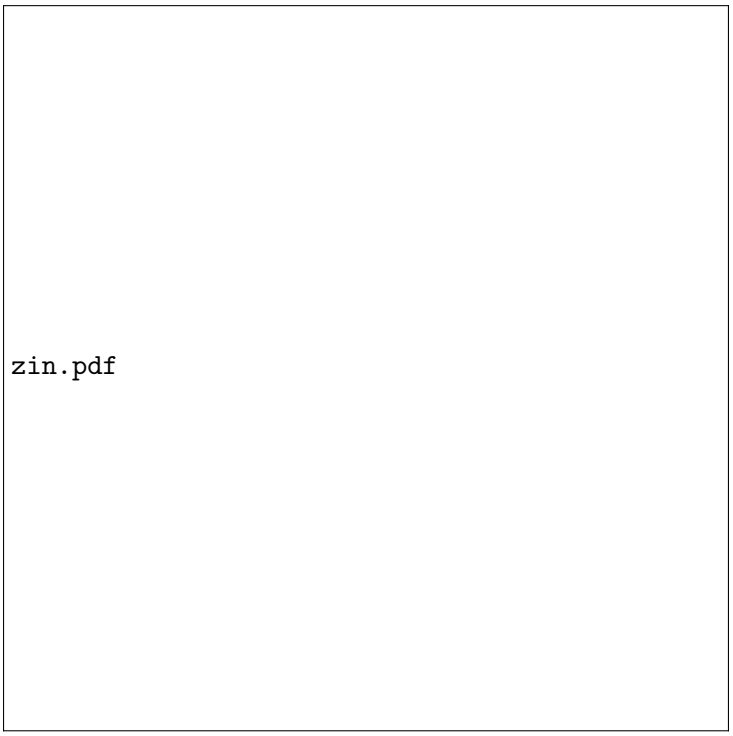

Figure 7: Input impedance of the Audio amplifier circuit

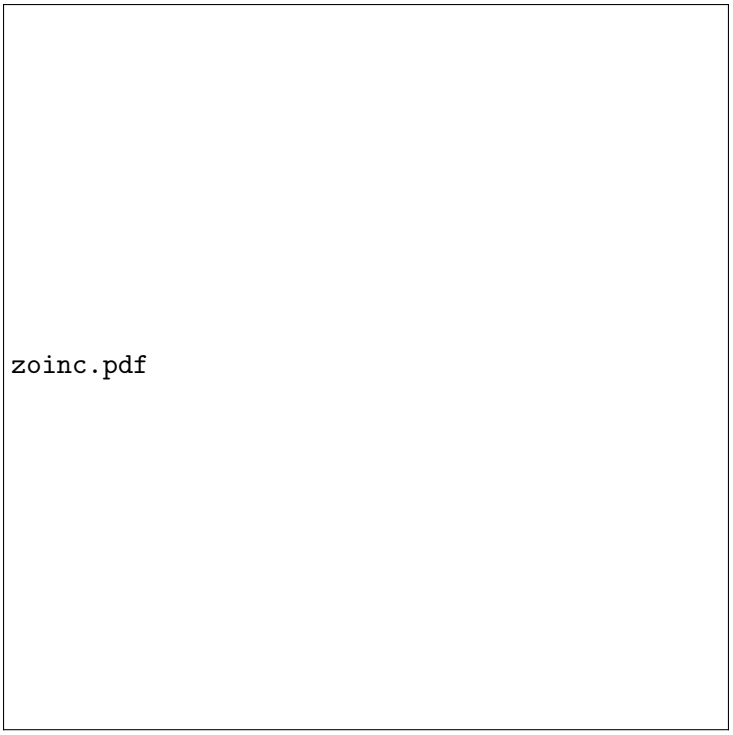

Figure 8: Output impedance of the Audio amplifier circuit

4 Conclusion

In this laboratory assignment, the objective of making an audio amplifier circuit has been achieved.

The circuit created was analysed theoretically using the Octave maths tool, and by circuit simulation, using the Ngspice tool. The theoretical results obtained differed quite a lot from those obtained in the simulation analysis. This difference obtained is due to the fact that the models used for the transistors in the theoretical analysis are very different from those used by Ngspice. The transistor models that were used in Ngspice are way more complex than the ones implemented theoretically - one needs to look no further than the dozens of parameters considered by these models, compared to the handful used in the theoretical analysis, to explain this discrepance.

However, due to the overall satisfactory match we can say that the theoretical model is acceptable due to its relatively lower complexity (one could sketch these equations on the back of a napkin) and its good results. Note that the output impedance (of the amplifier as a whole) were quite close - the simulation matched the theoretical model well - however, the simulated input impedance and the gain, were very much off when compared to the the predicted values - for the input inpedance, the deviation was in the hundreds, and the theoretical gain was over twice the simulated.

The final value settled on for the Merit was 2707.52 using the Ngsice's results and 990.8967 (for the same values) using Octave's theoretical results. This may seem like a great discrepancy, but is in fact fully explained by the discrepancies, already commented, regarding the the lower cutoff frequency (and therefore the bandwith as well) and the gain.