Circuits Theory and Eletronic Fundamentals

Aerospace Engineering Master’s Degree

Laboratory Report 4

Group 56

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Contents

1 Introduction

The objective of this laboratory assignment is to project an audio amplifier circuit and to do it we used resistors, capacitors and transistors. An audio amplifier is a basic circuit configuration that amplifies the signal received and then send it to a speaker. As in the previous laboratory the main challenge was to seek for the best balance between quality and cost, because the result will be the quocient of those quantities.

In this presentation we will start showing an illustration of the chosen configuration to the audio amplifier circuit (Image 1) and then we present the circuit description and the explanation of why it was chosen. After that, we introduce our results such as the important comments, this is presented in the section 3. This section (section 3) is divided in three important subsections, in the subsection 3.1 is where are presented the theoretical analysis of the circuit and then, in the subsection 3.2, is presented the simulation analysis of the circuit. In the other subsection (subsection 3.3) is where the comparison between the results provided by the theoretical analysis, using octave, and the simulations results, using ngspice, is done as well as the discussion of the results.

As in the last assignment we tested more than one configuration so it is possible to conclude some aspects from experience and that is presented in the section 4.

To conclude is presented a final discussion about this laboratory assignment that can be seen in the section 5.

2 Circuit description

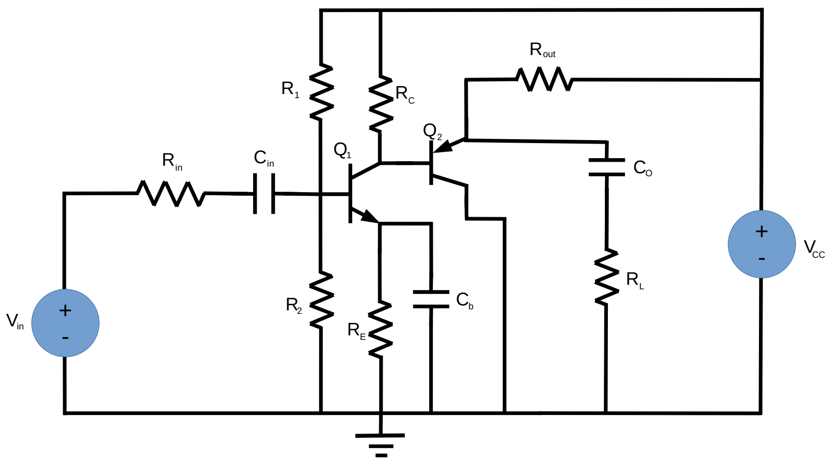


Figure 1: Circuit to be analysed in this report.

In the current section, we will describe the circuit shown in Figure 1. So in this circuit you can see our final configuration to build an audio amplifier circuit. It is composed by 2 input voltage sources ($V_{in}; V_{CC}$), 6 resistors ($R_{in}; R_1; R_2; R_C; R_E; R_{out}$), 3 capacitors ($C_{in}; C_b; C_O$), 2 transistors ($Q_1; Q_2$),respectively NPN and PNP and a output device (speaker) with a 8 Ω resistance. In the table 1 it can be seen all the components and their respective values.

Name	Value [Ω or V or F]
Vcc	12.000000
Vin	10e-2sin(2*pi*f*t)
Rin	100.000000
R1	80000.000000
R2	20000.000000
Rc	900.000000
Re	100.000000
Rout	1000
Cin	1e-3
Cb	5e-3
Co	1e-3

Table 1: Values of the various components and parameters.

3 Circuit Analysis

3.1 Theoretical analysis

In this section, the circuit shown above is analysed theoretically using octave to make the calculations.

To start with, to ensure that the circuit works properly we must see if both transistors are working in forward active region (FAR). In order to achieve that, we started by computing the operational point, using the theoretical DC model. To verify the FAR, we must make sure that in NPN transistor V_{ce} (voltage drop between collector and emitter) must be greater than V_{be} (voltage drop between base and emitter) and in PNP transistor Vec (voltage drop between emitter and collector) must be greater than Veb (voltage drop between emitter and base). The results obtained are shown in the table bellow:

Name	Value [V]
VCE-VBE	2.35210
VEC-VEB	3.95140

Table 2: FAR confirmation

As we can see, both differences are positive so we confirm that transistors are working in forward active region.

Then, we analyse some important aspects about the circuit such as impedances and gains. We divide the circuit in its two stages, common emitter and output stage, in order to compute their individual properties, after that to obtain the total gain and impedances we analyse the whole circuit. Now presenting the tables that allowed us to make some conclusions about these aspects.

Name	Value [Ω or dB]
ZI1	484.43363
ZO1	806.83123
Gain1	47.57639

Table 3: Common emitter properties

Name	Value [Ω or dB]
ZI2	191554.85120
ZO2	3.38821
Gain2	-0.03529

Table 4: Output stage properties

In the table 3 we have the common emitter properties and according to the values we can say that the gain and the input impedance achieve the wanted high values, but the output impedance is too high and because of that we would have degradation of the signal due to low load resistance. To fix this problem we introduce an output stage whose properties are shown in table 4, where we have much lower output impedance and almost an unitary gain, meaning that we won't have significant signal loss. When connected together the final circuit won't keep the output stage impedance neither the gain will be the simple multiplication of both gains, because the circuits interact with each other and the output impedances will be slightly different as the gains (Gainapprox is simple multiplication and Gain is the one obtained building incremental total circuit). Since the differences are small and the final gain is similar to stage one gain we can conclude that they can be connected without a significant signal loss.

Name	Value [Ω or dB]
ZI	484.43363
ZO	6.87899
Gainapprox	47.54110
Gain	47.50460

Table 5: Total circuit properties

To close up the theoretical analysis we compute the frequency response of the circuit. Due to the presence of coupling capacitors we considered that the frequency displayed in x axis corresponds to the frequencies where the capacitor is operating in the bypass region thus the gain being constant.

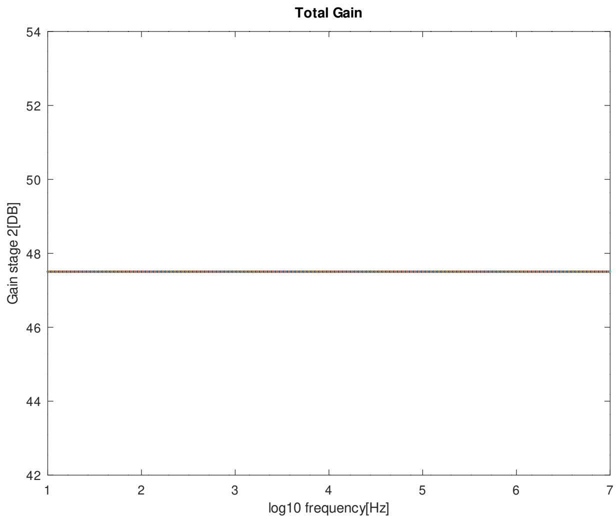


Figure 2: Gain in frequency

3.2 Simulation analysis

In this section, the circuit shown above is simulated with ngspice.

Same as in the theoretical analyses we started by ensuring that both the transistors were working on the forward active region, to achieve this we simulated the operational point and made the calculations for the voltages V_{ce}, V_{be}, V_{ec} and V_{eb}, the same as the ones described before.

Name	Value [V]
vce-vbe	2.622608e+00
vec-veb	4.205394e+00

Table 6: FAR confirmation

Once again we can see that both transistors are operating in FAR.

Now we present the measurements for the output voltage gain, both lower and upper cut off frequencies, bandwidth and input/output impedances.

To measure the output voltage gain we divide the voltage in load by the input voltage obtaining the graph 3.

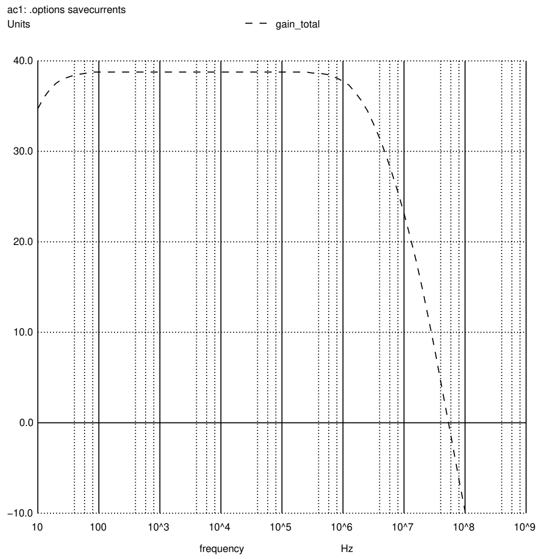


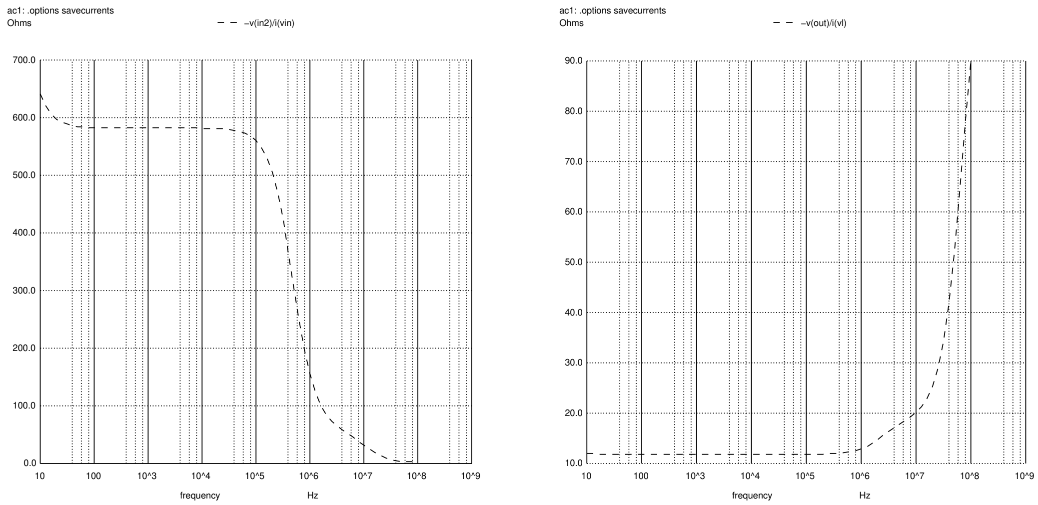
Figure 3: Gain in frequency

To measure the values in table 7 we found the maximum value of output voltage and determined the frequencies where the output voltage was 3 dB lower than the maximum value. The bandwidth was calculated as the difference of cut off frequencies.

Name	**Value [Hz]**
lowcutoff	1.220978e+01
highcutoff	1.915776e+06
bandwidth	1.915764e+06

Table 7: Bandwidth and cut off frequencies

In the figure 4 we can see the output and input impedances measured for the circuit. To calculate the input impedance we measured the current across the voltage source and the voltage drop between the voltage source and the resistor, R_{in}, and finally we made the ratio between that voltage and the current. On the other hand for the output impedance we shut down the input voltage source and we replaced the resistor R_L by an ac voltage source, so that when we made the ratio between the voltage in this voltage source and the current flowing through it we will get the output impedance.



(a) (b)

Figure 4: a) Input impedance in frequency b) Output impedance in frequency

In both stages there are some important components which give the circuit a better behaviour. To start with the coupling capacitors, there is one in the input and one in the output and they allow us to achieve higher length in the bandwidth because they block the Dc component of the input voltage (behaves like an open circuit to low frequencies).

Other important component is the bypass capacitor. It brings to the output a much more stable bandwidth this meaning a wider range of frequencies where the gain is almost maximum, because it will behave like an open circuit to low frequencies and a short circuit to high frequencies.

The last component that we are talking about is the resistor R_C. The incremental analysis shows that the final gain depends proporcionally of R_C so if we increase R_C, the gain also increases.

3.3 Comparation of results

In this subsection, we will compare the results of the two previous subsections, more concretely, we will compare the gain, the impedances and the OP results. Starting with the OP results we already confirm that both are working in FAR but the results are a little different between them as we can see from tables 2 and 6, because in theoretical results we assume the maximum voltage drop possible in V_{be} and V_{eb} so the (V_{ce}-V_{be}) and (V_{ec}-V_{be}) is lower in theoretical results.

Now looking to the impedances of all circuit, they are close to each other but they aren't equal because in theoretical analysis we consider that capacitors behave like short circuits and ngspice doesn't do that (it uses more complex methods to obtain impedances).

To finish we compare the final gain of both analysis, we can observe from graphs 2 and 3 that theoretical analysis has an higher gain than ngspice's and that's because there might be some voltage depletion in the capacitors that is taken in account in ngspice's analysis.

4 Discussion of results

The objetive was improving an audio amplifier and achieve the best merit. The merit is given by equation 1 and the decisions were made in order to increase the numerator (gain and bandwidth) of the equation and decrease the denominator (cost and lower cut off frequency).

$$M = \frac{voltageGain * bandwidth}{cost * lowercutoffFrequency} \tag{1}$$

Before discussing our final results we would like to explain some of the decisions as well as explore the impact of changing of values of some specific components. Two of the most important components that we change are the coupling capacitors. As we already explained we need to have them to increase the bandwidth and if we increase them we would have a better bandwitdh and a lower cut off frequency, but to do that we need to spend more money. So we tried to find the best ratio of those quantities. We also noticed that output capacitor needed to be greater than input capacitor to achieve better results.

The same idea was used in the value for the bypass capacitor, since when we increased its capacitance we are stabilizing the bandwidth as well as increasing its length, being its final value a cumulative of incremental experiences.

Lastely, we explore the influence of the resistance related with R_C and, purely by experience we realized that when increasing its value the gain would increase, but the length of the bandwidth would decrease and vice-versa, so we had to find incrementaly the best result we could achieve.

As for our final circuit, the results we obtained to the various properties taken in account in the merit formula were the following:

Name	**Value [Hz]**
gaint	3.798559e+01
lowcutoff	1.220978e+01
bandwidth	1.915764e+06
cost	6.102308e+03
merit	9.766948e+02

Table 8: Circuit final results

Looking to the table we can see that we achieved a very good bandwidth (we can work in all audible frequencies by humans) and an high gain will keeping the circuit cost relatively low resulting in an acceptable merit.

5 Conclusion

In the present laboratory we produced an audio amplifier circuit and improved it. Looking at both analysis and as it has already been said in subsection 3.3, we can say that the results obtained were very accurate since the differences that were already expected weren't very high, being these related with the more complex models used by ngspice and by some approximations made in the theoretical analysis. As for the merit we achieved the purpose of the laboratory of maximizing its value and we are satisfied with research made in order to complete this objetive. Last but not least, this laboratory assigment conducted to gain more knowledge and lead to a better understanding of both functions of an usual speaker and matters related to the course. Despite being aware that nowadays digital circuits are much more prefered we are still happy in reproducing a working audio amplifier which could easily be used in a speaker.