Circuit Theory and Electronics Fundamentals

T4 Laboratory Report

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Group 19

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1 Introduction

The aim of this laboratory assignment was to create an audio amplifier circuit. The circuit was then analysed both theoretically and using by the use of the simulation tool *Ngspice*. To do so, both the gain and the output stages were designed. The audio maximum input of 10mV is given to this amplifier. Also this system connects to an 8 Ohm speaker. The source has an impedance of 100 Ohms and the circuit is supplied by a 12V Voltage DC source (vcc).

In the gain stage mentioned above, a NPN transistor and a common emitter amplifier with degeneration were used. This allows for a high Z_i and A_V. Nevertheless, Z_o is also very high, which constitutes a problem to be delt with in the output stage. Consequently, in this second stage, a common collecter amplifier and a PNP transistor were used. Not only does it allow to remain a high A_V, but it also reduces the value of Z_o significantly. Therefore, the gain in the common collector amplifier is ≈ 1, which is the desired result.

The quality of the audio amplifier is evaluated by the following expression:

$$merit = \frac{VoltageGain * Bandwidth}{Cost * LowerCutOffFrequency} \quad (1)$$

The circuit is shown below as well as the values associated to each component (in V, Ohm and Farads).

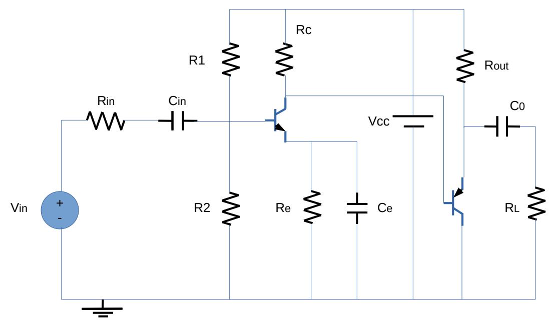


Figure 1: Circuit in analysis

Name	Value
Cin	5.000000e-04
CE	5.000000e-04
Cout	2.000000e-04
R1	5.000000e+04
R2	5.000000e+03
RC	4.900000e+03
RE	3.500000e+03
Rout	3.500000e+03
Vin	1.000000e-02
Vcc	1.200000e+01

Table 1: Used Values of each component.

2 Simulation Analysis

In this section, the several steps taken using ngspice in order to conduct the simulation of the audio amplifier, as requested, will be described. The main focus of the simulation was to determine and optimize the values of the gain, the cut off frequencies, both lower and upper and the bandwidth. The quality and overall figure of merit will then be analysed. The group proceded as follows:

1. Design of the circuit, having as a starting point the circuit given by the professor.

2. Verification of the operation of the transistors in the forward Active region, the called F.A.R mode. The results are shown below.

Vce	10.8198
Vbe	0.591454
Vce greater than Vbe	Correct F.A.R

Table 2: Verification of the F.A.R mode in the NPN transistor

Vec	11.9238
Veb	0.607736
Vec greater than Veb	Correct F.A.R

Table 3: Verification of the F.A.R mode in the NPN transistor

3. OP Analysis

   Then, the OP values of the currents and nodal voltages were computed. These are key to calculate the incremental parameters.

4. In the frequency domain, measure of the output voltage gain, using the function .meas as well as the lower and upper cut off frequencies and the bandwidth.

V Gain	6.29063
Bandwidth	913096
Lower Cut Off Freq	11.5373

Table 4: Results for ngspice

The quantities obtained are desribed in the table 4. The results obtained allowed the group to understand the functions of the different components of the circuit. The conclusions will be outlined.

EFFECT OF THE COUPLING CAPACITORS

The coupling capacitors' main porpuse is to block the DC signals. If studying an incremental model of an audio amplifier, all values that are constant must be eliminated so the transistors are always fowardly conducting. As so, two coupling capacitors were used. Once the capacitors may also block some low frequencies, they have a direct influence in the bandwidth.

EFFECT OF THE BYPASS CAPACITOR

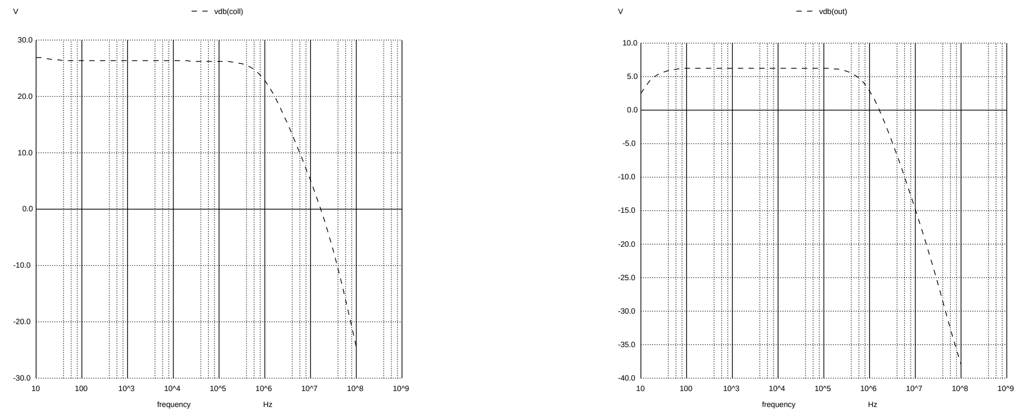
As studied in the lectures, the resistor Re has the funciton of stabelizing the effect of the temperature in the DC voltage. However, it has also a negative effect on the gain, once it lowers it. In order to solve the problem, a bypass capacitor Ce is placed in parallel with the resistor, so that the capacitor bypasses the resistor. In DC mode, the resistor plays its effect in the temperature. In AC, the resistor will not affect the gain. To sum up, the capacitor is a short-circuit for higher frequencies (AC) and a open-circuit for low frequencies (DC).

EFFECT OF RC

IC is the most important current in the circuit because it determines gm, and so directly influences the gain, by increasing it.

GRAPHICAL REPRESENTATION

In the graphics 2a and 2b, a graphic representation of the effect of the components above mentioned can be observed. In fact, in the plot 2b is extremely enlightening as one can intuitevely notice the high bandwidth, the stabilization of the gain, and the gain itself.



(a) Input Voltage

(b) Output voltage

5. Determination of the input impedance, seen from the input voltage source.

Zin	-3851.27 + 795.401 j

Table 5: Input impedance in Ohm

The result obtained for the input impedance, considering the value in Ohm, is high. This is benefitial for the gain, because the voltage in the node In 2 must be as similiar to Vin as possible. Using a voltage divider, the only way to achieve this was to have a very high resistance value.

6. Determination of the output impedance, using a different set up, seen from the load resistance.

Zo	61.2856 + 4.30243 j
Zo(arg)	61.4364

Table 6: Output impedance in Ohm

Conserning the output impedance, an opposite deduction to the one made for the output impedance is mandoratory. Considering a voltage divider, the output impedance must be as low as possible, in order to the output voltage to be as high as possible. Having said that, an analysing tables 5 and 6, the difference needed between the two is confirmed. The output impedance obtained is reasonable compared to the 8 Ohm load resistance. (About 8 times higher)

7. Compute of the cost and figure of merit

   To finally understand the efficency of the amplifier, the cost and figure of merit were calculated

Cost	1264
merit	393.877

Table 7: Cost and Figure of merit

   Analysing table 7, the results obtained may be considered satisfying.

3 Theoretical Analysis

In this section, a theoretical analysis of the circuit was conducted.

The circuit is divided in two different stages. The first one corresponds to the gain stage with a NPN transistor and a second output stage with a PNP transistor. Both the components and their functions will be described in Theoretical and Simulation Analysis as well as the goal of each stage.

3.1 Gain Stage

This stage is responsible for the amplification. This means it has to have a high gain. It also needs to have a high input voltage in order to avoid signal losses. Studying both operating point and incremental analysis it was possible to analyse this stage. Simply analysing the circuit using KVL and KCL, it was obtained $Z_{i1} = R_B||r_{\pi 1}$ and $Z_{o1} = r_{o1}||R_c$. It is important to note that for low frequencies capacitors behave like open circuits and for high frequencies like short circuits as seen and studied in lab 2.

To analyse the incremental response we have to create a model of the transistor. Studying the circuit we get $v_{o1} = -g_m * (r_o||R_c) * v_\pi$ and $v_\pi = \frac{R_B||r_{\pi 1}}{R_B||r_{\pi 1}+R_s} * v_s$ which lead us to $A_{v1} = \frac{v_{o1}}{v_s} = -g_m * (r_o||R_c) * \frac{R_B||r_{\pi 1}}{R_B||r_{\pi 1}+R_s}$.

3.2 Output Stage

Considering that Z_{o1} is too high it is needed a second stage to achieve a lower Z_o. For the DC response of the output stage, the same logic was followed and $Z_{i2} = \frac{(g_{m2}+g_{\pi 2}+g_{o2}+g_{E2})}{g_{\pi 2}(g_{\pi 2}+g_{o2}+g_{e2})}$ and $Z_{o2} = \frac{1}{(g_{m2}+g_{\pi 2}+g_{o2}+g_{E2})}$ were obtained. To get the incremental response it was created another model. Using nodal analysis: $A_{v2} = \frac{v_{o2}}{v_{i2}} = \frac{g_\pi + g_{m2}}{g_{\pi 2}+g_{z2}+g_{o2}+g_{m2}}$.

3.3 Final Results

Finally, i_o was calculated to then compute $Z_o = \frac{v_o}{i_o} = \frac{1}{g_{o2}+g_{m2}\frac{r_{\pi 2}}{r_{\pi 2}+Z_{o1}}+g_{e2}+\frac{1}{r_{\pi 2}+Z_{o1}}}$ using the provided equations. The gain is given by $A_V = A_{V1} * AV2$.

Low cutoff frequency was also computed using octave. All the important results obtained are shown in the tables and in the figure bellow. As it can be seen there will not be a signal loss since $Z_{i2} >> Z_{o1}$.

Name	Value
IB1	6.170669e-07
IC1	1.102699e-04
IE1	1.108869e-04
VColl	1.145968e+01
VBase	1.090909e+00
VEmit	3.881042e-01

Table 8: Operating point currents and Vcoll.

Name	Value
ZI1	4.086926e+03 Ohm
ZO1	4.862307e+03 Ohm
ZI2	1.991309e+04 Ohm
ZO2	-1.854812e+01 Ohm
ZO	5.341311e+00

Table 9: Impedences of both stages and of the full circuit.

Name	Value
Total Gain (AV)	2.479089e+01 V
Bandwidth	1.348390e+06 Hz
Lower Cut Off Frequency	1.000000e+01 Hz

Table 10: Gain, bandwidth and cutoff frequency.

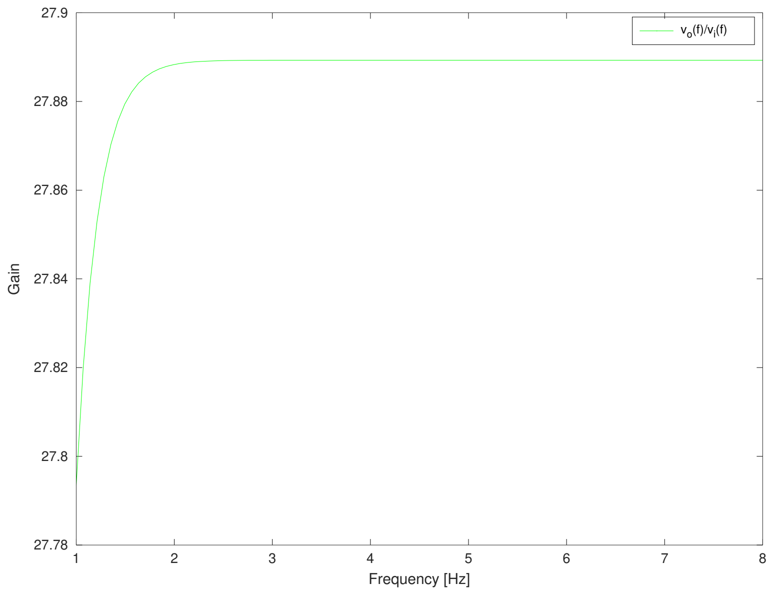


Figure 3: Voltage Gain of the circuit computed in Octave

4 Conclusion

As discussed in the introduction, the main objective was to design and compute an electrical circuit that could recreate an audio amplifier circuit. As so, both theorical analysis and simulation analyses were conducted.

Due to the non-linearity of the components of the circuit, particularly the transistors, it was very difficult to obtain the exact same quality using the tools available. In fact, the complexity of the parameters of the transistors used in ngspice was considered as the main reason for the errors.