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Circuit Theory and Electronics Fundamentals

T4

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1 Introduction

The goal of this assignment is to design an audio amplifier circuit and, similar to previous projects, analyze it both theoretically and through simulation, resorting to NGSpice. This circuit configuration has the purpose of amplifying an audio signal received and outputting it into a speaker. In this specific case, the input received will be of 10mV and it will output into a 8 Ω speaker.

The path taken by the signal starts in a gain stage, comprised mainly of a NPN transistor, which will amplify it while also increasing its impedance. In order to reduce said impedance, the signal goes through an output stage, which is composed mainly by a PNP transistor, keeping the same amplitude on average, making it suitable for outputting into the speaker without any significant gain loss.

With this information, a gain and output stage were designed, creating the total circuit seen in the following figure:

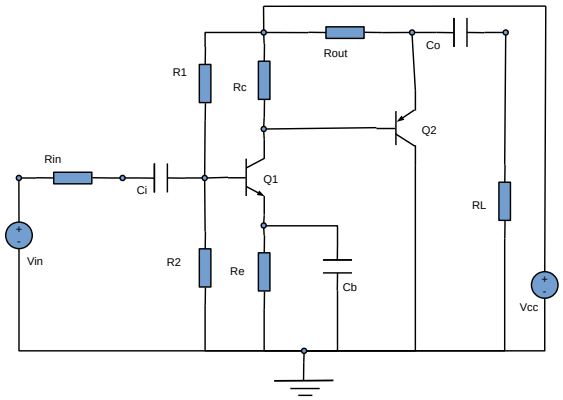

Figure 1: Studied Circuit

In the following table, the values for the components are presented, with the units being V, Ω and F.

R1	2.500000e+04 Ohm
R2	1.600000e+03 Ohm
RC	2.500000e+03 Ohm
Re	1.000000e+02 Ohm
Rout	1.000000e+02 Ohm
Ci	5.000000e-04 F
CB	5.000000e-04 F
Co	3.000000e-04 F

Table 1: Initial Values

The quality of the amplifier will be dictated by the expression below:

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

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

In the Introduction section, it was explained how the circuit was divided into two stages: a Gain Stage and an Output stage. Resorting to this information, it is possible to deduct a Theoretical Model, to which we can apply the Operating Point analysis in order to obtain the values for gain, input and output voltages.

This was made possible by the equations given by the professor and the information transmitted through the lectures.

The values desired for the Gain stage are presented in the table below:

Input impedance	1.408872e+03 Ohm
Output impedance	2.482186e+03 Ohm
Gain	1.848391e+01 V
Gain (dB)	2.533588e+01 dB

Table 2: Gain Stage

The same values but for the output stage are shown in the following table:

Input Impedance	2.082882e+04 Ohm
Output Impedance	-1.429277e+01 Ohm
Gain	1.142163e+00 V
Gain (dB)	1.154565e+00 dB

Table 3: Output Stage

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

Input Impedance	1.408872e+03 Ohm
Output Impedance	-1.668534e+00 Ohm
Gain	1.879067e+01 V
Gain (dB)	2.547884e+01 dB

Table 4: Full circuit

A plot for the frequency response can then be made, as one can observe in the figure below:

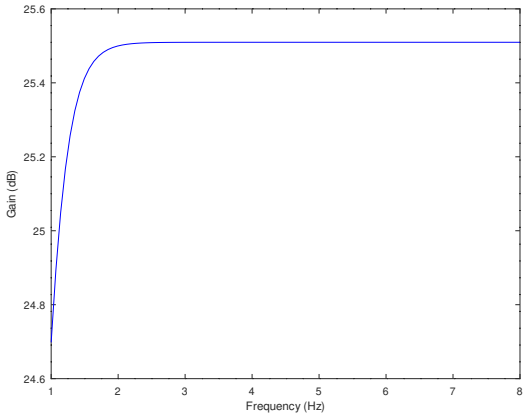

Figure 2: Gain plot - $\frac{V_o(f)}{V_i(f)}$

3 Simulation Analysis

This section of the report provides the reader with the results obtained through NGSpice simulations. The main goal to be achieved through these was to determine and optimize gain values, lower and upper cut off frequencies and the bandwidth. The steps taken were the following:

- Use the complex Phillips transistor model provided by the professor to design the circuit.

- Verify that the transistor operation is in the forward active region (F.A.R mode).

Vec	10.7825
Veb	0.68578
Vec greater than Veb	True

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

Vce	10.0177
Vbe	0.63683
Vce greater than Vbe	True

Table 6: Verification F.A.R. mode for the NPN transistor

- Compute currents and nodal voltages for the OP.

- Measure output voltage gain, lower and upper cutoff frequencies and bandwidth in the frequency domain. The results obtained were the following:

GainDB	26.8744 dB
Bandwidth	1.51843E+06 Hz
FreqCout	28.8695 Hz

Table 7: Results obtained in NgSpice

The values outlined in table 9 allowed the group to understand the purpose behind the different components present in the circuit. The conclusions drawn were that the **coupling capacitors** block DC signals, also having a direct influence in the bandwidth; the **bypass capacitor** acts as a short circuit for higher frequencies (AC) and an open circuit for lower frequencies (DC), bypassing the resistor and neglecting its negative effect on gain, while the **Rc resistor** has a direct effect on gain values.

These effects are directly shown graphically through the graphs presented below.

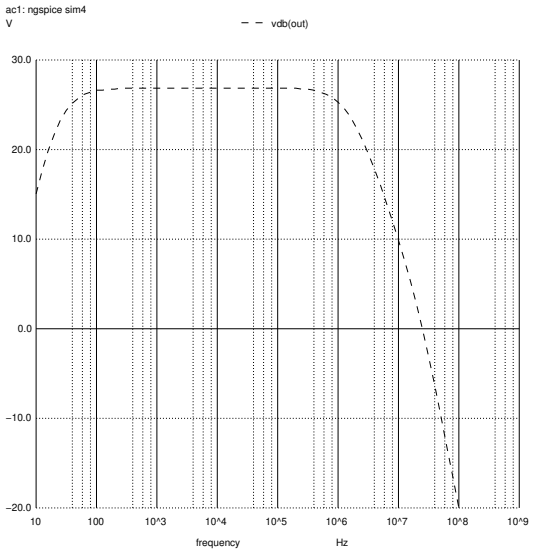

Figure 3: $v_0 - 12$ (Deviation from the desired DC voltages)

- Determine input and output impedance.

Zin	1212.14 Ohm
Zout	0.229229 Ohm

Table 8: Input and Output impedance

- Compute cost and figure of merit to determine whether the amplifier is efficient.

Cost	824.608
Quality	1.16057E+06
Merit	1407.42

Table 9: Merit

4 Conclusion

The first element of this conclusion will be the comparison between theoretical results and the ones obtained using NGSpice. The first comparison will be between the voltages in the collector, base and emitter of the transistor and the currents in each terminal from the Operating Point analysis:

Input Impedance	1.408872e+03 Ohm
Output Impedance	-1.668534e+00 Ohm
Gain	1.879067e+01 V
Gain (dB)	2.547884e+01 dB

Table 10: Theoretical Analysis

Zin	1212.14 Ohm
Zout	0.229229 Ohm
GainDB	26.8744 dB
Bandwidth	1.51843E+06 Hz
FreqCout	28.8695 Hz

Table 11: Simulation Analysis

The second element to the conclusion is the analysis of the project as a whole and final comments:

The main goal of this laboratory assignment was to project an audio amplifier that allowed for maximum gain of voltage, spending the least amount of resources possible. Such objective was fulfilled as the results obtained were the ones to be expected, as the voltage gain is quite significant, despite the cost also being quite significant.

Nevertheless, despite our effort to obtain similar results through the two methods: theoretical calculations and simulations, such was not attainable, mainly due to the non-linearity of the transistors which precluded us from achieving so.

In the end, analyzing the cost-merit relationship through the simulations, one concludes that these are results which ultimately satisfy our intention.