TÉCNICO LISBOA

Circuit Theory and Electronics Fundamentals

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T4 - Audio Amplifier

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1 Introduction

The purpose of this laboratory assignment is to make an Audio Amplifier, with an 8Ω speaker, with the goal to get the highest merit, M, possible.

$$M = \frac{voltageGain \times bandwidth}{cost \times lowerCutoffFreq}$$

Using the circuit shown in Figure 1, we tested different values for the resistors and capacitors and we found that the values in Table 1 yielded the best merit.

In Section 2, the circuit is analyzed by simulation using the software Ngspice.

In Section 3, an approximated theoretical model, using the software GNU Octave, of the circuit in Figure 2 is presented.

In Section 4, a comparison is done between the results obtained by both analyses, theoretical and simulation.

The conclusions of this study are outlined in Section 5.

Component	Value ($k\Omega$ or mF)
R_{in}	0.1
C_i	0.5
R_1	85
R_2	20
R_C	0.7
R_E	0.2
C_B	9
R_{out}	0.2
C_O	6

Table 1: Resistance and Capacitance for the components

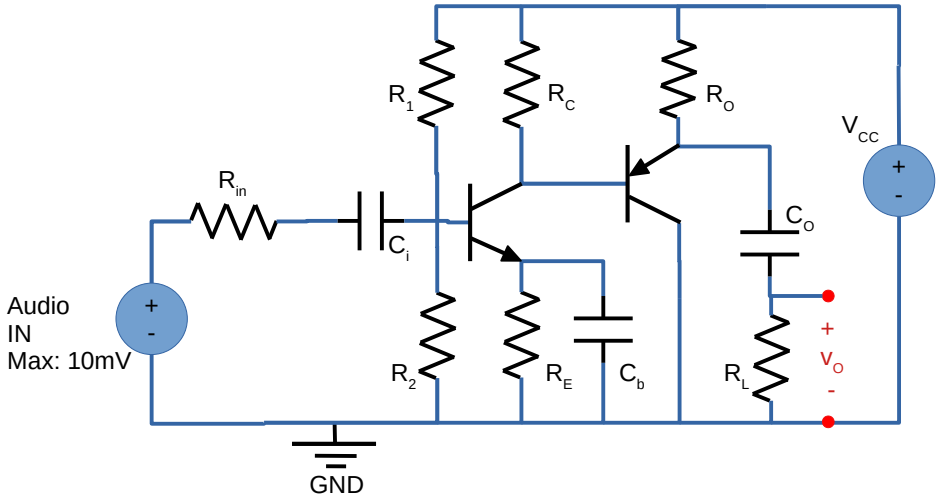

Figure 1: Circuit T4, with transistors.

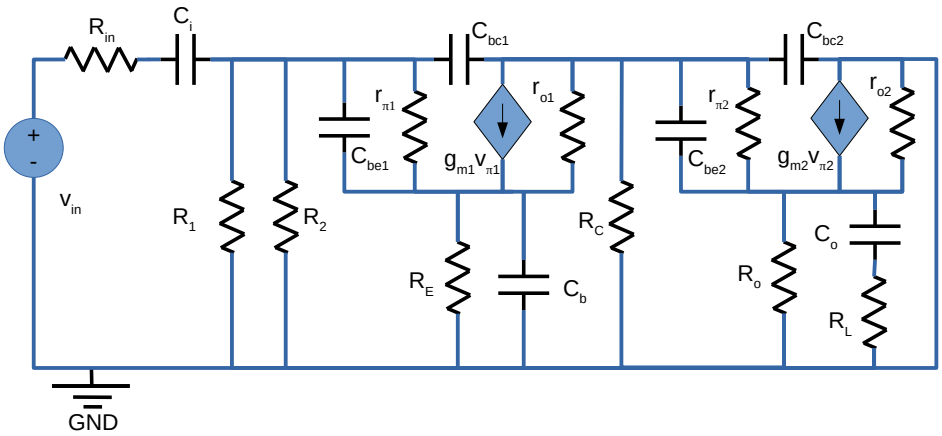

Figure 2: Circuit T4, with transistors equivalent.

2 Simulation Analysis

The plots obtained are shown in Figure 3. The impedance at the input and output, the gain, the lower and upper cut-off frequencies, the bandwidth, the cost and the merit are presented in Table 2.

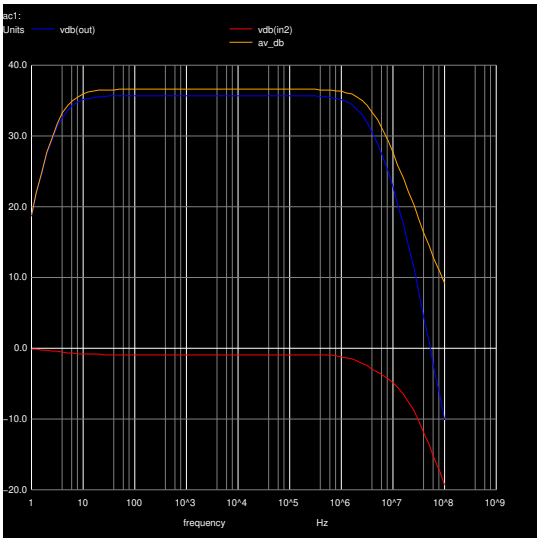

Figure 3: Plots obtained by simulation.

	Value
Zin	920.669 + -15.6465 j
| Zin |	920.802
Zo	5.84822 + 0.0245516 j
| Zo |	5.84827
voltgain	6.756772e+01
voltgaindb	3.659479e+01
lowercof	4.374442e+00
uppercof	3.814485e+06
bandwidth	3.814481e+06
cost	1.560641e+04
merit	3.775279e+03

Table 2: Results obtained by simulation.

3 Theoretical Analysis

In this section, the circuit shown in Figure 2 is analyzed theoretically, according to the following steps.

3.1 Step 1

The circuit was analyzed by operating point in order to obtain the values for the components of the equivalent transistors, r_π, r_o and g_m, as shown in Table 3.

Name	Value (Ω or S)
r_{pi1}	8.51464e+02
r_{o1}	1.28226e+04
g_{m1}	2.09874e-01
r_{pi2}	3.80866e+02
r_{o2}	2.40667e+03
g_{m2}	5.96797e-01

Table 3: Results obtained by theoretical operating point.

3.2 Step 2

Then we calculated the impedances (Ω) and gain for each stage (transistor) and for the total circuit, as shown in Table 4.

	Value
Z_{I_1}	8.08923e+02
Z_{O_1}	6.63764e+02
Z_{I_2}	2.86481e+04
Z_{O_2}	1.65333e+00
$Z_{I_{total}}$	8.08923e+02
$Z_{O_{total}}$	4.46505e+00
$Gain_1$	-123.980102
$Gain_2$	0.986705
$Gain_{total}$	-120.982198
$Gain_{total}\ (dB)$	41.654429

Table 4: Impedances and gain obtained.

By observation, one can say that the 2 stages can be connected without significant signal loss, because the input impedance of the second stage is much greater than the output impedance of the first stage. The same applies for the total input impedance of the circuit and the impedance of the voltage source, and for the impedance of the speaker and the total output impedance of the circuit.

3.3 Step 3

Next, we performed node analysis for $f \in [1; 100M]\ Hz$:

$$\begin{bmatrix} -G_{in} - Y_{cin} & Y_{cin} & 0 & 0 \\ Y_{cin} & -Y_{cin} - G_1 - G_2 - g_{\pi 1} - Y_{be1} - Y_{bc1} & g_{\pi 1} + Y_{be1} & Y_{bc1} \\ 0 & g_{\pi 1} + g_{m1} + Y_{be1} & -g_{\pi 1} - G_E - Y_{cb} - g_{m1} - g_{o1} - Y_{be1} & g_{o1} \\ 0 & -g_{m1} + Y_{bc1} & g_{m1} + g_{o1} & G_C - g_{o1} - Y_{bc1} \end{bmatrix} \begin{bmatrix} v_{ib} \\ v_{i1} \\ v_{e1} \\ v_{o1} \end{bmatrix} = \begin{bmatrix} -v_{i0} G_{in} \\ 0 \\ 0 \\ 0 \end{bmatrix} \tag{1}$$

$$v_{in2} = v_{o1} \tag{2}$$

$$v_{e2} = \frac{g_{\pi 2} + g_{m2} + Y_{be2}}{g_{\pi 2} + G_O + \frac{1}{Z_{co} + R_L} + g_{m2} + g_{o2} + Y_{be2}} v_{i2} \tag{3}$$

$$v_{o2} = \frac{R_L}{R_L + Z_{co}} v_{e2} \tag{4}$$

Solving the previous equations, the results are shown in Figure 4 and in Table 5.

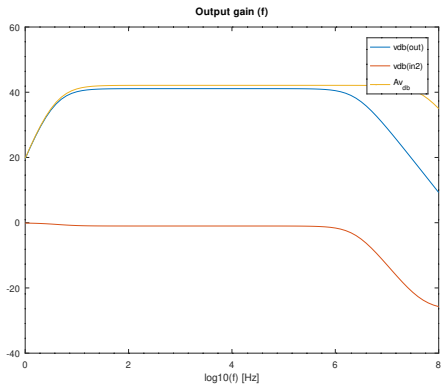

Figure 4: Plots obtained by theo. analysis.

	Value
$lowerCOf$	5.66072e+00
$upperCOf$	4.49647e+07
$bandwidth$	4.49647e+07
$Gain_{total}\ (dB)$	4.21189e+01

Table 5: Results obtained by node analysis.

4 Comparison

Comparing the results achieved in the simulation, Table 6, and in the theoretical analysis, Table 7, for the operating point, it is possible to see a small difference.

This discrepancy may have resulted from the non-linearity of the transistors.

Name	Value (V or A)
@q1[ib]	3.04182e-05
@q1[ie]	5.46615e-03
@q1[ic]	5.43573e-03
vb1	1.79323e+00
vc1	8.19499e+00
ve1	1.09323e+00
vbe1	7.00000e-01
vce1	7.10176e+00
@q2[ib]	6.80029e-05
@q2[ie]	1.55251e-02
@q2[ic]	1.54570e-02
vb2	8.19499e+00
vc2	0.00000e+00
ve2	8.89499e+00
veb2	7.00000e-01
vec2	8.89499e+00

Table 6: Results for op for theoretical analysis.

Name	**Value [A or V]**
@q1[ib]	2.995660e-05
@q1[ie]	-5.54185e-03
@q1[ic]	5.511894e-03
vb1	1.800703e+00
vc1	8.191117e+00
ve1	1.108370e+00
vbe1	6.923325e-01
vce1	7.082747e+00
@q2[ib]	7.063267e-05
@q2[ie]	-1.54453e-02
@q2[ic]	1.537471e-02
vb2	8.191117e+00
vc2	0.000000e+00
ve2	8.910931e+00
veb2	7.198135e-01
vec2	8.910931e+00

Table 7: Results for op for simulation analysis.

Comparing the results achieved in the simulation and in the theoretical analysis, Table 8 and Figures 3 and 4, it is possible to see some differences.

This discrepancy may have resulted from the non-linearity of the transistors, as shown from the behaviour for high frequencies. This may have resulted from the fact that the theoretical analysis uses a linear transistor model, meanwhile the Ngspice simulates a real circuit therefore makes a better approximation to the real transistor model.

	Theoretical	**Simulation**
Z_{I_1}	808.922828	-
Z_{O_1}	663.764277	-
Z_{I_2}	28648.126045	-
Z_{O_2}	1.653334	-
$Z_{I_{total}}$	808.922828	920.802
$Z_{O_{total}}$	4.465050	5.84827
$Gain_1$	-123.980102	-
$Gain_2$	0.986705	-
$Gain_{total}$	-120.982198	67.5677
$Gain_{total}\ (dB)$	41.654429	36.5948
	42.118872	-
$lowerCOf$	5.660723	4.37444
$upperCOf$	44964720.209039	3.81448E+06
$bandwidth$	44964714.548316	3.81448E+06

Table 8: Comparison between theoretical and simulation values

5 Conclusion

In this laboratory assignment, the objective of making an Audio Amplifier shown in Figure 1 has been achieved. The values for the components in Table 1 has a merit of approximately 3775 and a cost of 15606,41 MU, with a gain of 67,57, a lower cut-off frequency of 4,37 Hz and a upper cut-off frequency of 3,81 MHz.