TÉCNICO LISBOA

Circuit Theory and Electronics Fundamentals

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T2: RC Circuit Analysis

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1 Introduction

The objective of this laboratory assignment is to design an Audio Amplifier, this is a device that can increase the power of a signal so it can be transmited (in our case a voltage that varies with time).

The architecture chosen for the lab is the one detailed bellow.

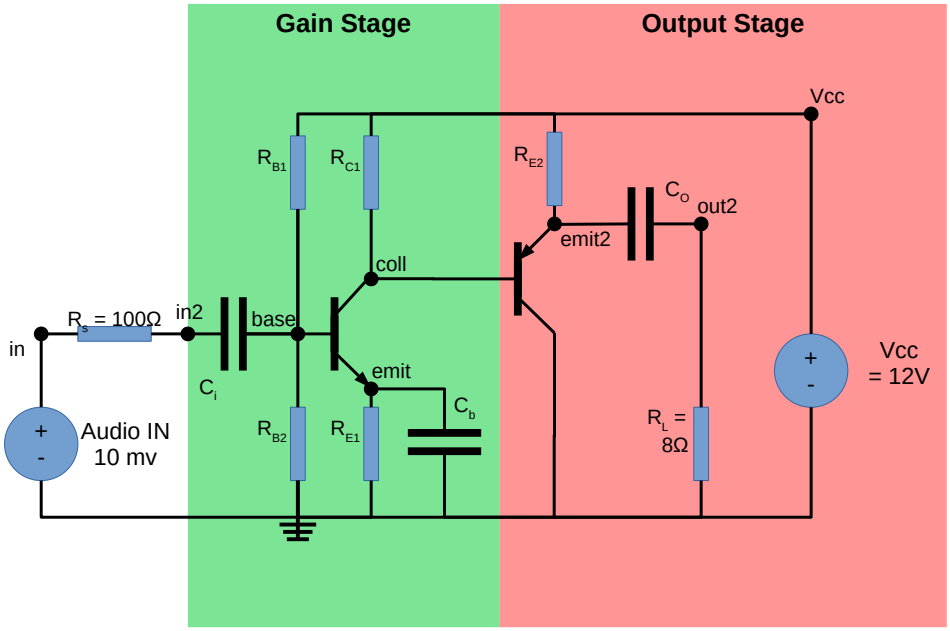

Figure 1: T2 RC circuit.

It can be decomposed in two main stages: the Gain Stage (in green) and the Output Stage (in red).

In the Gain Stage the original signal will be amplified. However, this amplified signal is not apropriate to be connected to our load (the speaker) due to it's high impedance.

Therefore, the signal goes through the Output Stage, that, due to its lowed impedance, makes the signal suitable to be conected to the speaker (which is connected in series).

To perform the Theoretical Analysis we will look into the Gain and Output Stages separatelly.

In Section 2 we will perform the Theortetical Analysis of the circuit, determining the operating point gain, impedances and frequency response.

In Section 3 we will obtain the simulation results to perform the Simulation Analysis.

To finish, we will draw our comparisons in Section 4 and lay our conclusions, looking into any possible differences and determining it's causes.

In the table bellow we list the numerical values of the components used.

Name	**Values**
VT	0.025000 V
BFN	178.700000
VAFN	69.700000 V
VBEON	0.700000 V
BFP	227.300000
VAFP	37.200000 V
VEBON	0.700000 V
VCC	12.000000 V
RB1	55.000000 kOhm
RB2	20.000000 kOhm
RE1	200.000000 Ohm
RC1	800.000000 Ohm
RE2	50.000000 Ohm
C_{input}	0.100000 mF
C_{bypass}	2.500000 mF
C_{output}	1.500000 mF

Table 1: Values of components used in our analysis and simulation.

2 Theoretical Analysis

2.1 Gain Stage

For the gain stage, the incremental stage provided the following results:

Name	Values
Input Z	489.187475 Ohm
Output Z	726.398144 Ohm
Gain	-212.967518
Gain(dB)	46.566267 dB

Table 2: Gain stage theoretical results

From where we reach the conclusion that an output stage in necessary given the magnitude of the output impedance.

2.2 Output Stage

The results of the output stage theoretical model are:

Name	Values
Input Z	9798.924013 Ohm
Output Z	0.195570 Ohm
Gain	0.995423
Gain(dB)	-0.039850 dB

Table 3: Output stage theoretical results

As we can see, the output impedance of this stage is much lower than the input. The output stage is also desirably low, specially when compared with the 8 Ohm of the speakers. At last, the total circuit gain results.

Name	Values
Input Z	489.187475 Ohm
Output Z	3.130696 Ohm
Gain	-197.362138
Gain(dB)	45.905277 dB

Table 4: Total circuit theoretical gain results

The frequency response of the circuit for the output voltage of the circuit, in terms of gain and phase difference, and the lower cut-off frequency are plotted here:

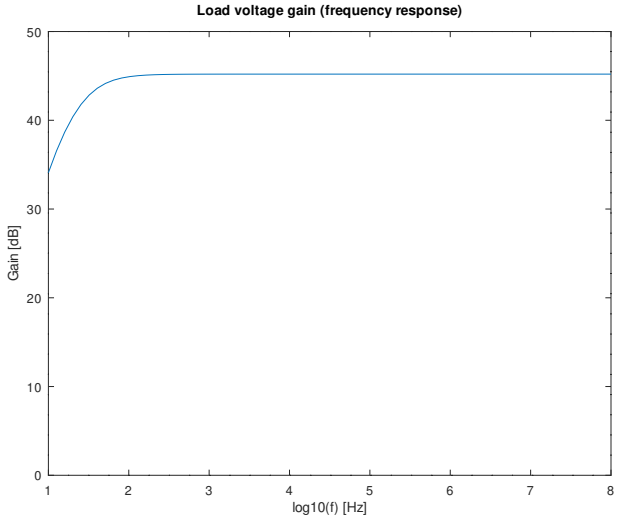

Figure 2: Load output voltage gain (frequency response).

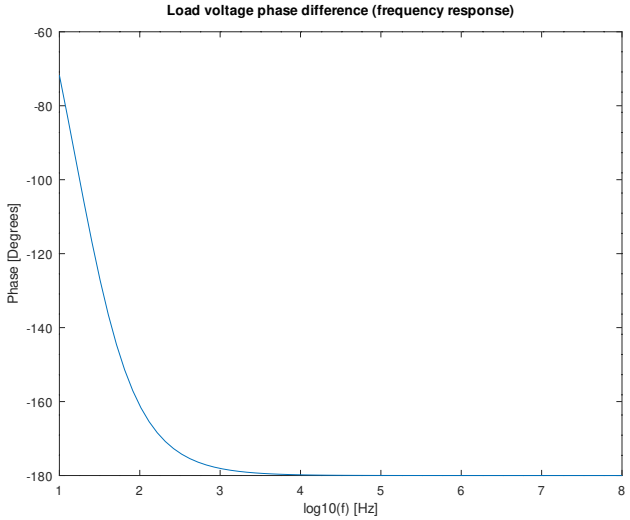

Figure 3: Load output voltage phase difference (frequency response).

Name	**Values**
Gain	182.000877
Gain(dB)	45.201470 dB
Lower cut-off frequency	28.093870 Hz

Table 5: Gain for medium frequencies and lower cut-off frequency of the output voltage signal.

3 Simulation Analysis

Given the input signal of the circuit is sinusoidal the voltage and current values vary with time, and it is relevant to know how the two parameters evovlve with time. We also ran an operating point analysis to confirm the forward-active region operation of the two transients. We also ran a frequency response analysis, in order to see the gain and bandwith of the amplified signal.

3.1 Operating Point Analysis

In the table bellow we can see the resuls obtained from the operating point analysis.

Name	Values [V]
vcc[0]	1.200000e+01
in[0]	0.000000e+00
in2[0]	0.000000e+00
base[0]	2.312800e+00
coll[0]	6.251260e+00
emit[0]	1.607836e+00
emit2[0]	7.092462e+00
out[0]	0.000000e+00

Table 6: Operating point node voltage values of the amplifier circuit.

The voltages in nodes in and in2 are zero, which is expected given that the source as no DC component. Likewise, the the voltage in node out is zero, since the output coupling capacitor blocks the incoming DC voltage.

We can also see that Vcoll ¿ Vbase ¿ Vemit, which is antecipated due to the operation of the npn transistor. Vemit2 ¿ Vcoll ¿ GND, which is also expected, sinse the pnp transistor operation ensures that the voltage drop occurs from the emitter to the collector. Therefore, both our transistors work in the PFA.

3.2 Frequancy Response and Impedances

We measured the input impedance, seen from the source point of view, and the output impedance, see from the output pointe of view.

As we can see in the graphs above, the gain graph has traits of a band-pass filter, filtering frequencies that are not medium.

In the table above we can see the results obtained.

Finally, graph bellow compares the input and output signals, and we can conclude that the objective of the lab as achieved, this is, amplify the input signal. I this case, the imput signal was amplified 50 times.

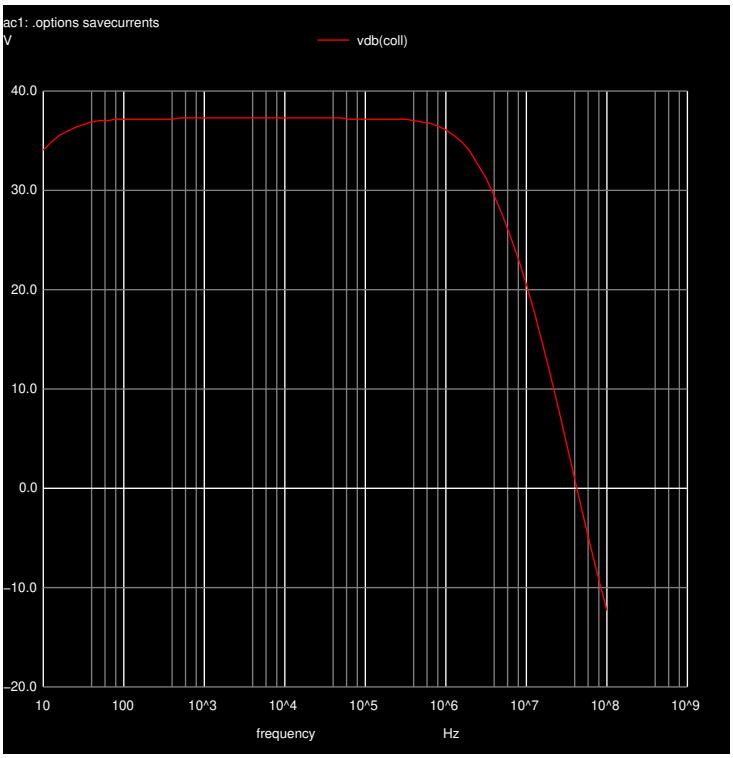

Figure 4: Gain Stage output voltage gain (frequency response).

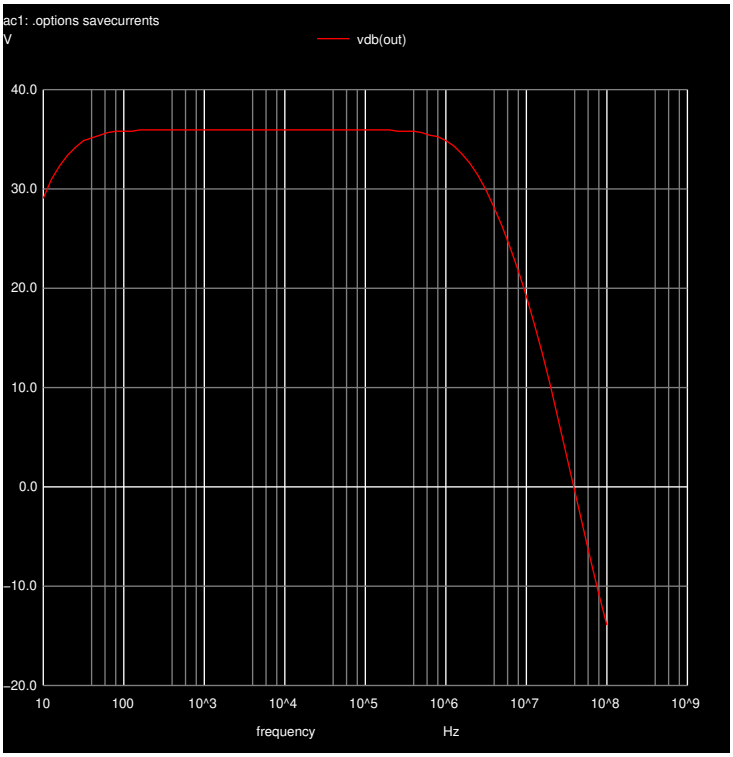

Figure 5: Load output voltage gain (frequency response).

Name	Values
Gain	72.4597
Gain(dB)	37.2019
Lower cut-off frequency	19.9876 Hz
Upper cut-off frequency	2.32455E+06 Hz
Bandwidth	2.32453E+06 Hz
Input impedance	0.633365 kOhm
Output impedance	8.38893 Ohm

Table 7: Output gain, bandwidth, and input and output impedances of the audio amplifier circuit (as a whole).

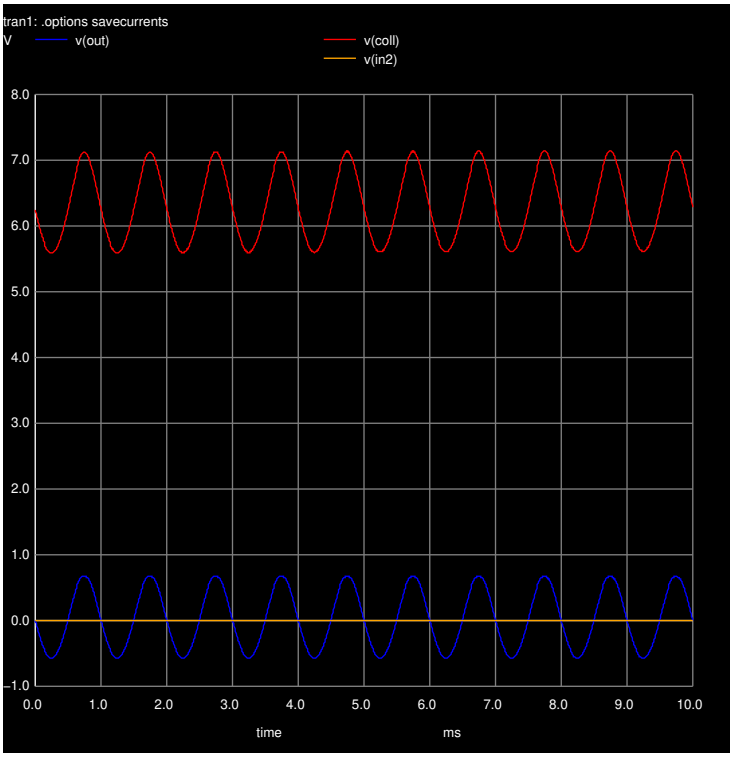

Figure 6: Evolution of the AC signal from input to output.

Name	Values
cost	9.181358e+03
merit	9.178316e+02

Table 8: Cost and merit of the audio amplifier circuit.

4 Conclusion

In this laboratory assignment the objective of creating and analysing an Audio Amplifier has been achieved with success. We have performed theoreticall and simulation analysis, using the Octave for the former and Ngspice for the latter.

We found some discrepancies between both sets of results, which can be atributed, among other things, the fact that the circuit does not start from equilibrium. The fact that the impedance was high made this more evident. While these discrepancies are not ideal, specially for real world aplications, they can be expected and were mitigated.

The table bellow has the Theoretical and Simulation results, allowing for it's comparison.

Theoretical	**Value**	**Simulation**	**Value**
Operating point			
V_{vcc}	12 V	vcc[0]	1.200000e+01 V
V_{in}	0 V	in[0]	0.000000e+00 V
V_{in2}	0 V	in2[0]	0.000000e+00 V
V_{base}	1.876319 V	base[0]	1.878920e+00 V
V_{coll}	6.736022 V	coll[0]	7.214695e+00 V
V_{emit}	1.176319 V	emit[0]	1.184175e+00 V
V_{emit2}	7.436022 V	emit2[0]	8.033675e+00 V
V_{out}	0 V	out[0]	0.000000e+00 V
Frequency response and impedances			
$Gain$	158.174605	Gain	65.5843
$Gain(dB)$	43.982735 dB	Gain(dB)	36.336 dB
$LowerCut - offFreq$	20.432601 Hz	Lower cut-off freq	16.6025 Hz
$UpperCut - offFreq$	-	Upper cut-off freq	2.47423E+06 Hz
$Bandwidth$	-	Bandwidth	2.47421E+06 Hz
$InputImpedance$	729.020826 Ohm	Input impedance	0.856866 kOhm
$OutputImpedance$	3.619271 Ohm	Output impedance	8.18142 Ohm

Table 9: Comparison of the theoretical and simulated data results, regarding the operating point, frequency response and impedances.

We also believe that, given the satisfactory results obtained by us, the model used could be applied in a real life Audio Amplifier.

Finally, this assignment allowed us to gain some further knowledge in the application of the subjects topics.