TÉCNICO LISBOA

Circuit Theory and Electronics Fundamentals

Mestrado em Engenharia Física Tecnológica, Técnico, University of Lisbon

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Contents

1 Introduction

The circuit described in the present report is displayed in Figure 1.

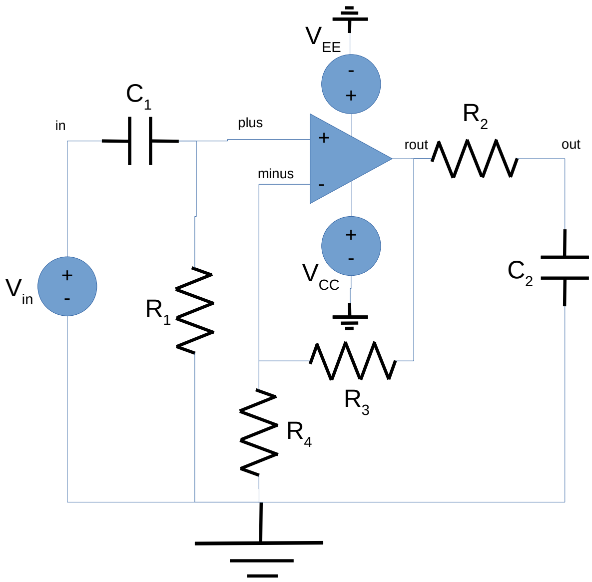


Figure 1: The circuit we will be working with.

The goal of coming up with this circuit was to produce a bandpass filter using an OP-AMP, ideally with a gain of 40dB and a central frequency of 1kHz. As you will see below, most of these goals were completely achieved.

In Section 2, the circuit is analysed by simulating it as a whole, using the *software Ngspice*.

After that, we proceed to the theoretical analysis of this same circuit to verify and compare results with the simulation data. In Section 3, the theoretical analysis is executed in two distinct steps: the first step consists of a operating point analysis, where it's only considered the DC component of the current; the second step, called incremental analysis, takes into account the frequencies of the current in time, therefore, the AC component of the current.

Lastly, in Section 4 the results obtained in the two previous Sections are compared, focusing on the currents and tensions obtained in key points of the circuit. as well as, impedances and gain. The conclusions of this study are outlined in Section 5.

2 Simulation Analysis

We started out by doing a simulation analysis of the circuit that was present above. The OP-AMP used is a subcircuit composed of of 2 capacitors, 5 diodes, a voltage-controled voltage source, a current-controlled current source, 2 voltage-controlled current sources, an independent current source, a current-controled voltage source, 2 transistors, 9 resistors and 6 independent voltage sources, making it an OP-AMP in the model uA741.

In Figure 2, the result for the gain for various frequencies is presented.

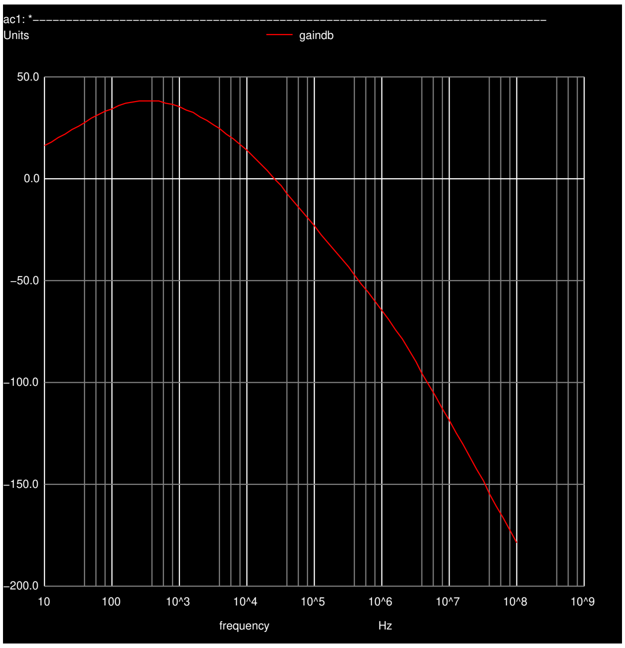


Figure 2: Output Voltage Gain Simulated

It is obvious that we were able to come quite close to the requested gain, but our central frequency is not the desired one. In the tables below the relevant results from the the graph in Figure 2 are presented, which lets us know that the higher cut-off frequency is actually very close to the desired central frequency, which means that our gain is still mostly relevant at 1000Hz.

Variable	Value (dB)
gaindbmax	3.834218e+01

Variable	Value (Hz)
f1	1.165730e+02
f2	9.936323e+02
bandwidth	8.770593e+02
cenfreq	3.403391e+02

In Figure 3, you are also able to see the phase of the circuit throughout the same range of frequencies.

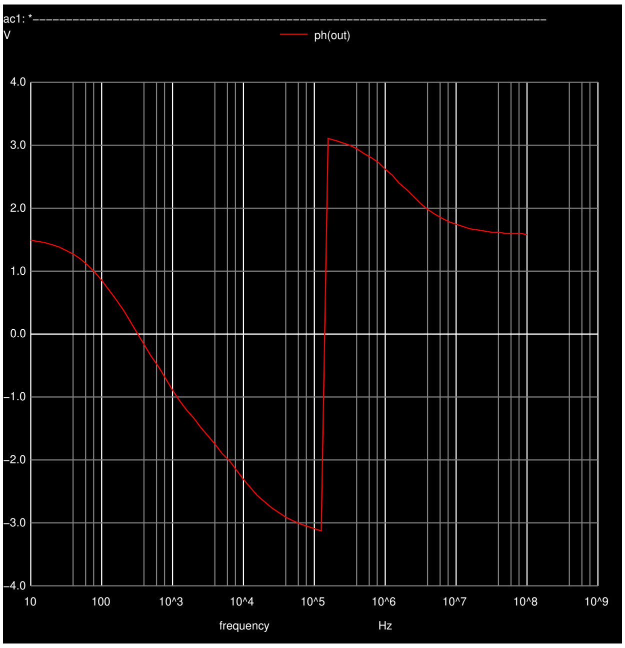


Figure 3: Simulated Phase

The discontinuance at around 10^5Hz is due to the fact that *Ngspice*, the *software* that was used for the simulation, automatically makes it so the values showed for the phase angle are between π and -π, which lead to that.

Another interesting results, which will be useful later on for comparing with the theoretical analysis results, are the input and output impedances. The input impedance is directly taken from dividing the voltage in the input node by the current going through it in the original circuit.

Variable	**Value (Ω)**
zin	9.999982e+02,-3.99820e+02

For us to be able to calculate the output impedance, we had to create a new circuit, similar to the original one. However, in this new circuit, that is displayed in Figure 4, we have turned off the input voltage source and used it as a test source connected to the output terminals.

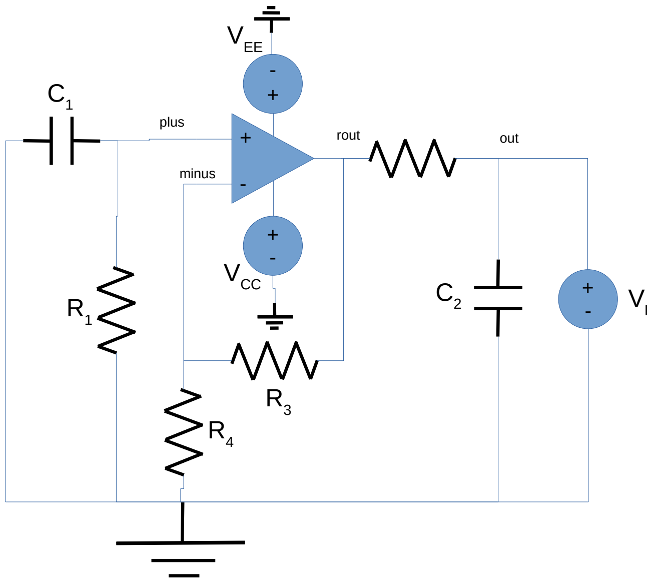


Figure 4: The circuit used to calculate the output impedance.

The value obtained for the output impedance is presented in the table below, calculated by measuring the voltage in the output terminal and, once again, dividing it by the current going through it – the test source is used to measure this current.

Variable	**Value (Ω)**
zout	8.011868e+02,-3.99270e+02

Some last final interesting values are the cost of the whole circuit, in the first table below, and the merit, in the second one.

Variable	**Value (MU)**
opampcost	1.332329e+04
cost	1.342749e+04

Variable	**Value**
merit	5.223670e-02

3 Theoretical Analysis

We start off by analyzing the circuit at the central frequency, the geometric average between the lower and upper cut-off frequencies. In this case, the input impedance is given by the series of resistor R_1 and capacitor C_1 and the output impedance by the parallel of resistor R_2 and capacitor C_2. The gain is given by the quotient between v_{out} and v_{in}, which is calculated taking into account the fact that this OP-AMP is a non-inverting amplifier. We get the results:

Variable	**Value**
gain	8.2787e+01
gaindB	3.8359e+01
Zire	1.0000e+03
Ziim	-4.6904e+02
Zore	8.1967e+02
Zoim	-3.8446e+02

We then do the same type of analysis, but with a vector of frequencies, which means we calculate the gain for $f \in [10, 10^8]Hz$. We present its magnitude in dB and its phase in degrees.

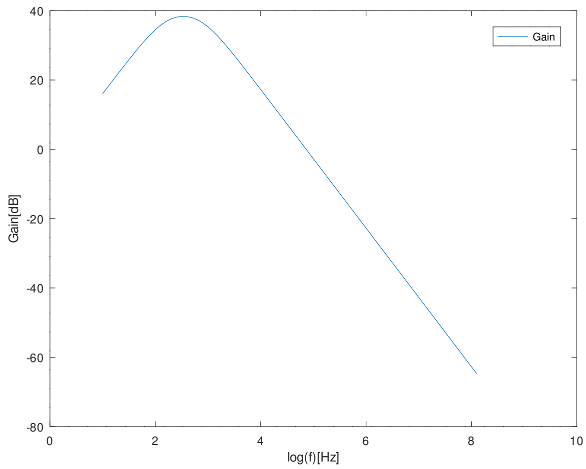


Figure 5: Gain in dB

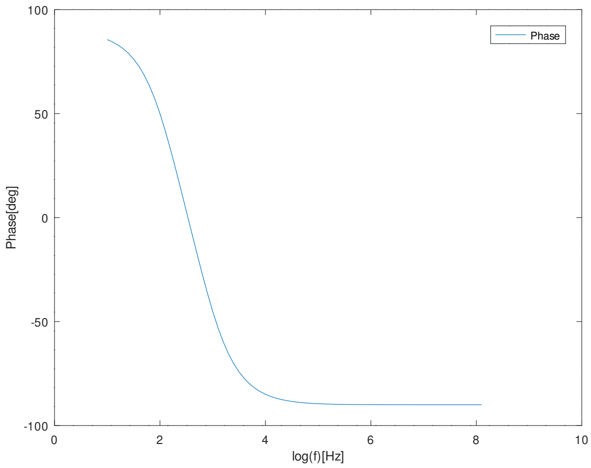


Figure 6: Phase in degrees

4 Comparing the Results

In this section, we will be comparing the results obtained by both the Theoretical Analysis and the Simulation.

In the following tables and plots, we can observe the results already presented in previous sections now side by side, with the first table being the result of the simulation and the second one being the result from the theoretical analysis. These are displayed in this way as a means of easier representation.

4.1 Table Comparison

Variable	Value
gaindbmax	3.834218e+01

Variable	Value
zin	9.999982e+02,-3.99820e+02

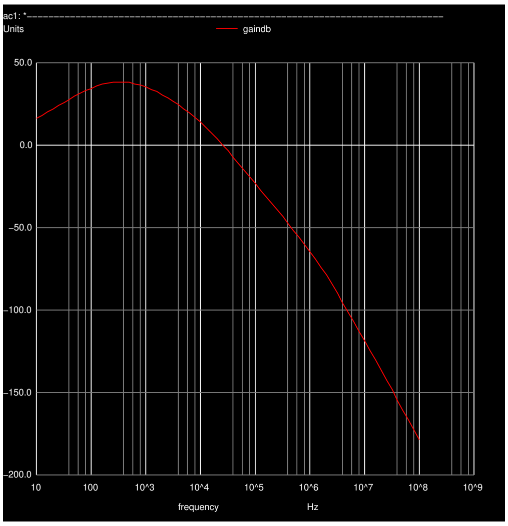
Variable	Value
zout	8.011868e+02,-3.99270e+02

Variable	Value
gain	8.2787e+01
gaindB	3.8359e+01
Zire	1.0000e+03
Ziim	-4.6904e+02
Zore	8.1967e+02
Zoim	-3.8446e+02

Figure 7: Simulation Values (LEFT) and Theoretical Values (RIGHT)

As we can see, the gain, input and output impedance values are preety much the same, which means the linear approximations required to do the theoretical analysis were accurate for the central frequency.

4.2 Plot Comparison



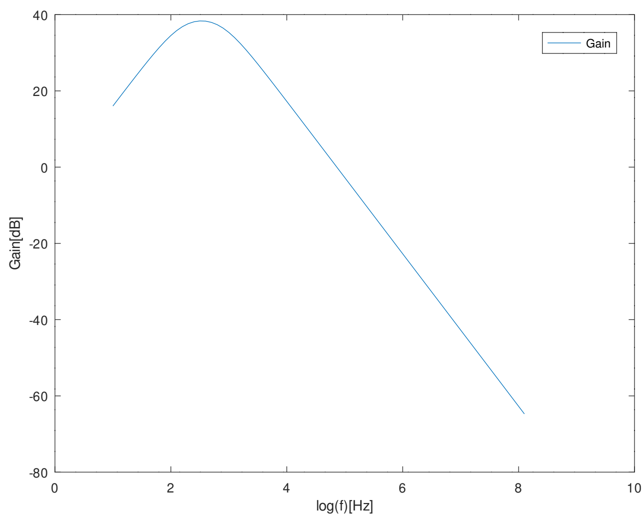
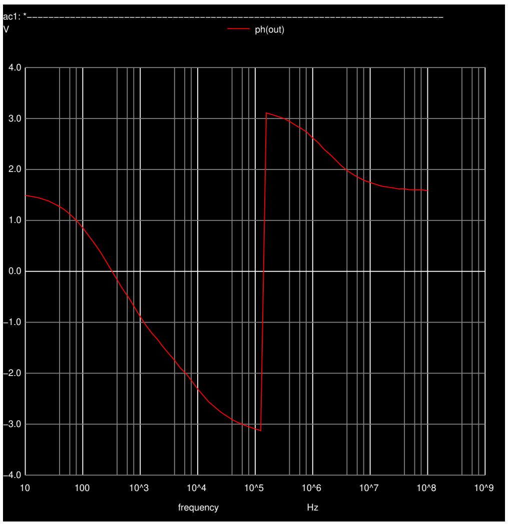
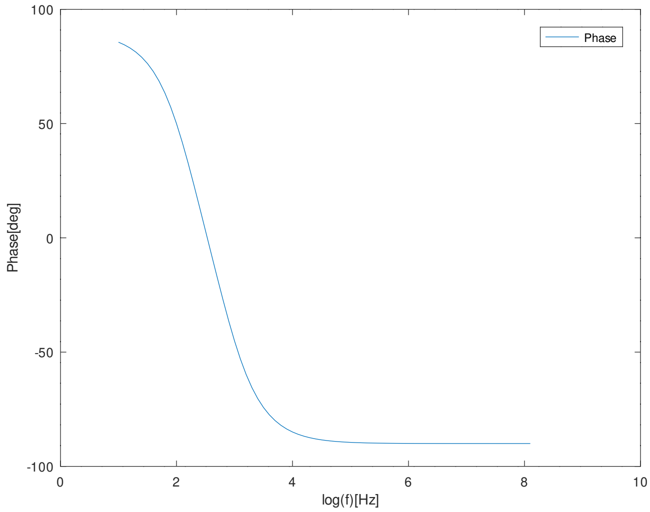


Figure 8: Simulation Gain Values (LEFT) and Theoretial Gain Values (RIGHT)

The plots for the magnitude of the gain were very similar for lower frequencies, reaching essentially the same peak value at essentially the same frequency. However for higher frequencies the approximations no longer make sense, and the graphs might look similar, but differ in terms of slope. This might also explain why the gain's phase plots below differ:


ac1: *
V
ph(out)
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
10
100
10^3
10^4
10^5
10^6
10^7
10^8
10^9
frequency
Hz


100
50
0
-50
-100
Phase[deg]
Phase
0
2
4
6
8
10
log(f)[Hz]

5 Conclusion

In conclusion, it was verified that the theoretical analysis and simulation were very similar, leading to the assessment that the OP-AMP is a considerably linear component. Furthermore, we also concluded that these approximations are much more viable for lower frequencies than for higher frequencies (starting at around 10^4Hz is where you can see the most difference). Even thought the gain was not achieved in the desired central frequency, we were still able to come very close to the central frequency, which was just a few Hz after our upper cutoff frequency.

In general, the study of this circuit, which focused mainly on the usages of an OP-AMP, was a success.

References

[1] Phyllis R. Nelson, *Introduction to SPICE Source Files* Slides

[2] *SPICE 'Quick' Reference Sheet*, Stanford University

[3] Holger Vogt *et al*, *Ngspice's User Manual*, Version 34

[4] *GNU Octave* Documentation Files

[5] José Teixeira de Sousa, *Circuit Theory and and Eletronic Fundamentals* Class Slides
Panquecas:
225g unsalted butter, softened 310g caster sugar 4 eggs 225g self-raising flour 2.5 lemons :lemon: