Circuit Theory and Electronics Fundamentals

Department of Electrical and Computer Engineering, Técnico, University of Lisbon

June 8, 2021

Laboratory Assignment - T5

Group nº59

José Miguel Goulão - 95814
Lourenço Pacheco - 95817
André Gomes - 96352

Contents

1 Introduction

The objective of this laboratory assignment is to create a BandPass Filter (BPF) circuit using one OP-AMP with a gain at central frequency of 40db and a central frequency of 1000Hz. The goal is then to attain the maximum value for the Merit (M) by modifying the circuit and its components with some restricted. The expression for M is as follows:

$$M = \frac{1}{Cost \times (CentralfFreqDev + GainDev + 10^{-6})}$$

$$Cost = Cost_{resistors} + Cost_{capacitors} + Cost_{transistors} + Cost_{diodes}$$

$Cost_{resistors} = 1MU/kOhm; Cost_{capacitors} = 1MU/\mu F; Cost_{diodes} = 0.1MU/diode; Cost_{transistors} = 0.1MU/transistor$

The final circuit, displayed in figure **??**, utilizes the following components:

- three voltage sources (V_{in} - sinusoidal, V_{cc} and V_{ee})
- one 741 OP-AMP
- three resistors (R_1, R_2 and R_3)
- one capacitors (C_1)

The values associated with each component is displayed on Table 1. The OP-AMP used was already provided as well as the voltage source V_{in}.

Name	**Value**
V_{cc}	5.00
V_{ee}	-5.00
$R1$	1.0k
$R2$	100.0k
$R3$	10.0k
C_1	220.0n

Table 1: Components' values.

Theoretical and simulation analysis are presented in Section 2 and Section 3, respectively, and the results of each are then compared. Finally, in Section 4 the conclusions of the laboratory assignment are outlined.

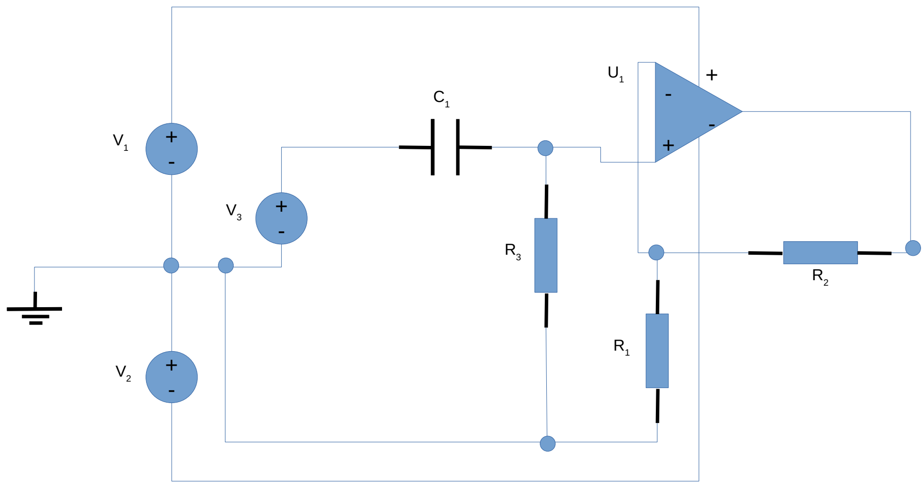

Figure 1: Circuit T5

2 Theoretical Analysis

In this section we will explain the inner workings of the band-pass filter created and perform a theoretical analysis of each component. The voltage divider law was used in cunjunction to the OP-Amp non-inverting amplifier configuration.

2.1 High-Pass Filter

The first stage of the of the band-pass filter is comprised of a High-Pass filter. It is in this stage that the low cut-off frequency is set.

In this stage a combination of a resistor and a capacitor with specific values is set in a way as to have a gain of almost unity for frequencies above a certain threshold (100Hz in our circuit).

Gain of High-Pass filter:

$$\frac{V_o}{V_{in}} = \frac{R_3}{\sqrt[2]{R_3 + \frac{1}{\omega C}}}$$

with R being the resistor value, and $\frac{1}{wC}$ the absolute value of the impeadance of the capacitor (with ω as angular frequency and C the capacitor capacitance).

The treshold frequency is set by the following equation:

$$f = \frac{1}{2\pi f}$$

2.2 OPAMP: Non-inverting amplifier

It is in this stage that the amplification of the signal takes place. At the same time this stage works as a low-pass filter.

The signal amplification is dependent on the ratio of the two resistances (R_1 and R_2 by the following expression:

$$\frac{V_o}{V_{in}} = 1 + \frac{R_2}{R_1}$$

Due to the internal composition of the OP-Amp it also works as the low-pass filter used in the circuit and it set the high cut-off frequency. Since the theoretical octave script assumes a perfect OP-Amp, the cut-off frequency won't exist.

2.3 Circuit frequency response

Due to the use of a capacitor in the circuit, the gain is dependent on the frenquecy of the imput. This response was achieved by calculating the equivelent impedance of the stage with a capacitor for a set of frequencies.

2.4 Theoretical Results

The obtained results were as follows:

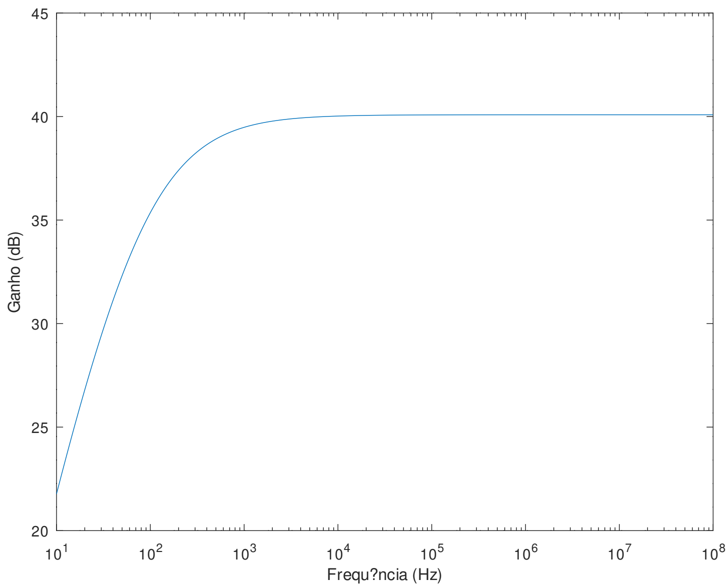

Figure 2: Frequency Response Vo/Vi.

3 Simulation Analysis

In this section, Circuit T4 is reproduced with the help of Ngspice.

Ngspice is a simulator for eletronic circuits that can output a variety of results. This emulator computes the voltages in every node, as well as the potential difference between two given nodes. Apart from that, the group made use of the command *.options savecurrents* which also enables the use of the currents that pass through all branches. Moreover, function to help determine the maximum and interception of the plots were also used.

Firstly, the outcome of the simulation is shown, as well as a brief explanation on how it was achived. Afterwards, a comparison is done between those values and the ones attained in Section 2.

3.1 Simulated results

In this laboratory assignament, the Ngspice script made use of the sames values considered for the Octave script.

Table 2 dislpays the total impedances of the circuit (Input and Output). These are attained by dividing the potencial difference of the sinusoidal voltage source by the current that passes through it at a reasonble instant.

For the Outup impedance a small change in the circuit was done. The original sinusoidal voltage source is connected to the "out" node of the OP-AMP and Ground,a nd in its inicial position is now a short-circuit. Optimally this value should be as close to zero as possible, such is not verified because of the need to improve the Merit.

Name	**Value[Ohm]**
Zin	9.9022 + 0.00223195 j
Abs(Zin)	9.9022
Zout	522.442 + -316.233 j
Abs(Zout)	610.695

Table 2: Total impedance values from Ngspice.

Figure 3 displays vdb_{out} (in decibels) from 10Hz to 100MHz, as well as a constant $(max - 3(dB))$ - this helps to better visualize the passband. The vdb_{out} curve is characteristic of a band pass filter (cutting high and low frequencies).

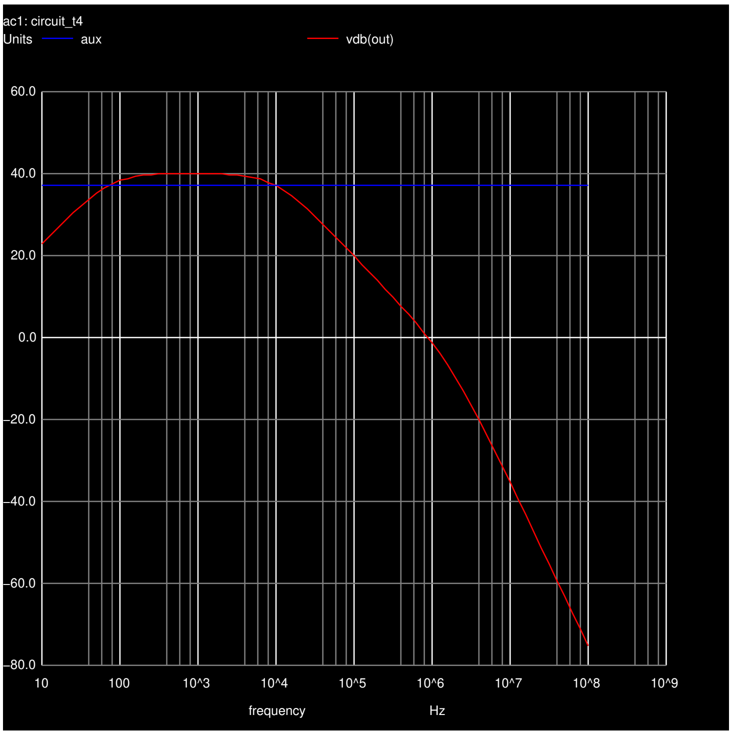

Figure 3: vdb_{out}

This graph is of particular importance because it allows us to obtain the GainDeviation. This is simply given by the absolute value of $(Maximum - 100)$, 40db or 100 (linearly) being the Gain at central frequency. Therefore, the closest the maximum of said graph is to 40dB, the lower its deviation is and the higher the Merit will be. This variable has no units.

Moreover, with the plot in Figure 3, we were able to measure the Central frequency. This variable is given by:

$$CentralFreq = \sqrt(LowerFreq \times UpperFreq)$$

The *L*owerFreq and *U*pperFreq are the frequencies of the intersection points of the vdb_{out} curve and its max minus 3. Its deviation is *C*entralFreq-1000. This variable is given in Hertz (Hz).

Lastly, the group also used Ngspice to compute the Merit. Table 3 shows all the values necessary to compute the Merit, as well as the Merit itself. Note that the total cost is the sum of the costs of resistors, capacitors and transistors of the total circuit (including de OP-AMP).

Name	**Value**
cost	1.343451e+04
gain	1.003168e+02
gaindev	3.167835e-01
centralfreq	8.476811e+02
centralfreqdev	1.523189e+02
———-	————
merit	4.876656e-07

Table 3: Merit and other variables.

4 Conclusion

In order to perform theoretical and simulational analysis of the circuit Octave and Ngspice were used, respectively.

Theoretical methods were used to compute the gain, impedances and frequency responde of both of the stages. Contrary to past lab assignments the theoretical results differ a lot from the simulated results.

Comparing the frequency response graphs we can see that they are quite different for higher frequencies. The most noticeable difference is that the theoretical method does not predict the higher cutoff frequency. This is explained by the fact that the theoretical method considers the OP-Amp as ideal when in reality all of the components have some residual capacitive characteristics which can become noticeable at really high frequencies.

In conclusion, our simulated circuit was able to acheive a decent gain and Merit value and so we considered it a sucess. In addition we were able to understand the functioning principles of a Band-Pass Filter.