Circuit Theory and Electronics Fundamentals

Masters of Aeroespace Engineer, Técnico, University of Lisbon

Laboratory Report

Group 37

Afonso Magalhães, nº95765
Fábio Monteiro, nº95786
Leonardo Encarnação, nº95816

May 5, 2021

Contents

1 Introduction

The objective of this laboratory assignment is to choose an architecture of the Envelope Detector and Voltage Regulator circuits to build an AC/DC converter. We did this while paying attention to the merit of the project designed.
This merit is calculated exactly as the next equation:

$$M = \frac{1}{cost * (ripple(V_0) + average(V_0 - 12) + 1e - 6)} \tag{1}$$

Being the cost the following:

- cost = cost of resistors + cost of capacitors + cost of diodes
- cost of resistors = 1 monetary unit (MU) per kOhm
- cost of capacitors = 1 MU/μF
- cost of diodes = 0.1 MU per diode

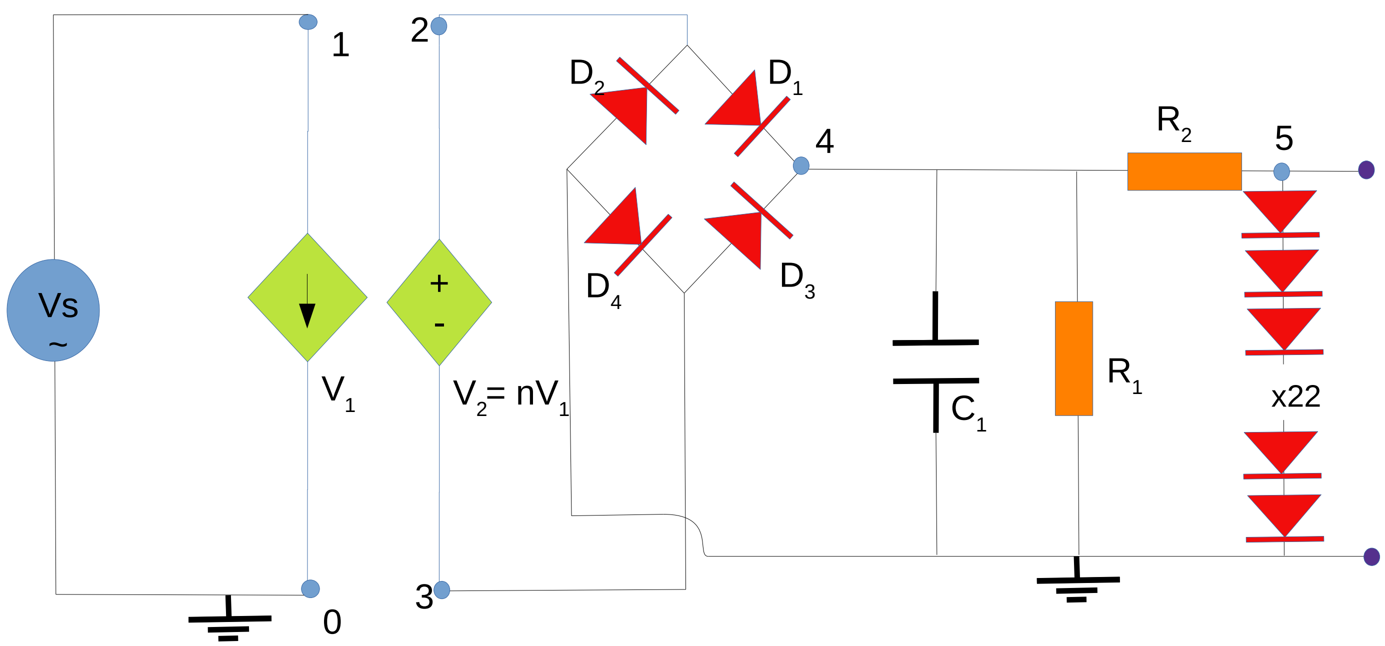


Figure 1: AC/DC Converter

Name - Value	
C	7.347694e-03
R1	9.843700e+04
R2	6.774100e+05
num diodes	2.200000e+01
Transformer Ratio	1.000000e+01

Table 1: Circuit Values

To obtain the best values for the circuit, we've used the matlab simulink to optimize them for the best merit.

In Section 2, a theoretical analysis of the circuit is presented. In Section 3, the circuit is analysed by simulation, and the results are compared to the theoretical results obtained in Section 2. The conclusions of this study are outlined in Section 4.

2 Theoretical Analysis

In this section we will analyse theoretical our AC/DC converter circuit.
To do so, and because there were several things to be analysed, we divided the following subsections in the three different sectors that our circuit has and each one will be detailed separately.
Initially, we used a transformer to turn Vs=230V in a smaller value, being Vr=230/n, with n equal to 11, so that thew rest of the circuit can aproximate it to 12 V that are requested. However, we want a DC voltage and not the initial AC voltage. In order to achieve that, we are going to describe the three different sectors that are in the circuit that is shown in the Introdution.

2.1 First sector: Bridge circuit

The Bridge circuit is composed by the four diodes that are shown in the first figure.
The four diodes labelled D_1 to D_4 are arranged in "series pairs" with only two diodes conducting current during each half cycle. During the positive half cycle of the supple, diodes D_1 and D_4 conduct in series while diodes D_2 and D_3 are reverse biased and the current flows through the load.
Summarizing, these four diodes work as a full wave rectifier which means, they transform the AC current in an equal amplitude unidirectional current, which corresponds to the module of the purple plot in figure 2. To compute all of that we had to take the absolute value of the transformed voltage V_r. To simplify the code in octave we've considered these 4 diodes as ideal, since it's contribution to th4e output is minimum.

2.2 Second sector: Envelope detector circuit (rectifier + capacitor)

Then, we use a capacitor in order to reduce the magnitude of the voltage making it closer to a DC (orange plot). In order to compute this, we discovered when are the diodes ON and OFF.
The equation that describes t_{OFF} is:

$$t_{OFF} = \frac{1}{2 * w * arctan(1/(w * R_1 * C)} \tag{2}$$

It's 2 times the angular frequency just because we are using a full wave rectifier.

However to be more precise, we used the newton raphson method in the expressions obtained using the Kirchoff laws to determine both t_{OFF} and t_{ON}.

Periodically,

$$\begin{cases} V_0 = |V_r| & t < t_{OFF} \\ V_0 = |V_s * cos(w * t_{OFF})| * exp(-(t - t_{OFF})/(R1 * c)) & t > t_{OFF} \end{cases} \tag{3}$$

due to the capacitor.
The ripple voltage is basically max(V_0)- min(V_0).

Name - Value	
Ripple	3.635437e-04
Average	2.299982e+01

Table 2: Ripple and average envelope values

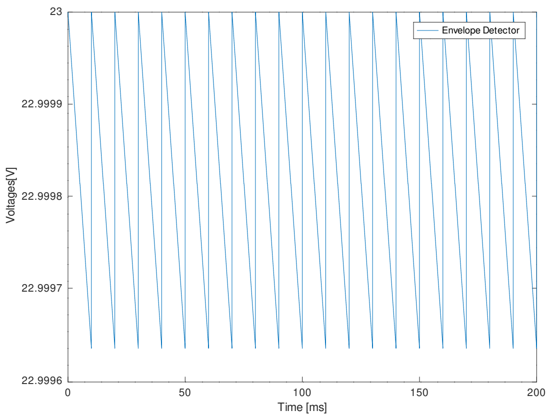


Figure 2: Output Voltage in Envelope Detector

2.3 Third sector: Voltage regulator circuit

At last, in the third sector, a series of 22 diodes reduce the noise making the current an almost perfect DC. By calculating the $v0_average$ from the second sector, we are able to see if the voltage difference between v5 and v0 is limited by the maximum voltage that the diodes can handle. This only happens if the average is greater than that maximum.
Right now, we have the voltage due to the DC so we still need the voltage due to AC. It is possible to compute that in octave, calculating rD which is the resistance of each diode and also:

$$ac_{v0} = num_{diodes} * rD/(num_{diodes} * rd + R2) * (Venvelope - average_{env}) \tag{4}$$

To finish, v0 = ac_{v0} + dc_{v0}. The average must be approximately 12V.

Name - Value	
Ripple	9.614173e-06
Average	1.200000e+01

Table 3: Ripple and average regulator values

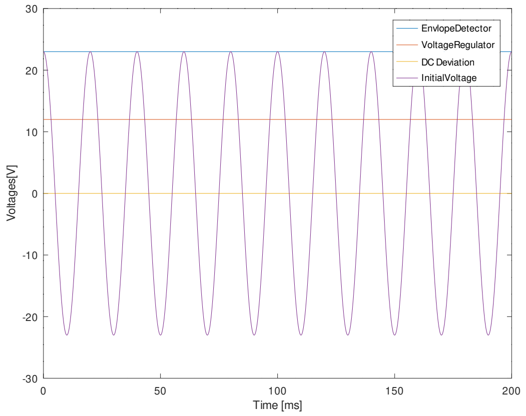


Figure 3: Input voltage of the secondary circuit (v(2)), output Voltage of the Envelope Detector (v(4)), VoltageRegulator (v(5)), and v(5)-12

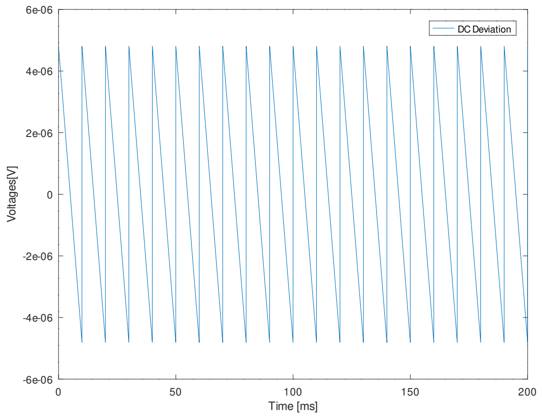


Figure 4: Output AC component

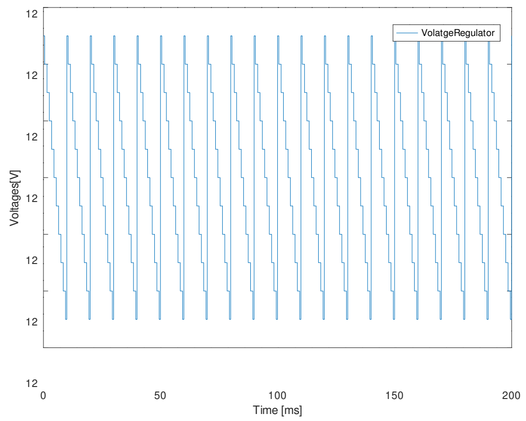


Figure 5: Output Voltage

3 Simulation Analysis

In this section, Ngspice was used in order to simulate the AC/DC converter. Some modifications were made from the original circuit in order of simplification. First of all, the transformer was replaced by an ideal using a depedent current source (instead of the primary) and a dependent voltage source (instead of the secundary) and this allowed us to not having to model a real transformer.
Then, the values of n (parameter of dependency sources), the C (capacitance) of the capacitor and the values of the resistance of the resistors were being adjusted through trial and error in order to achieve the maximum accurary of the output voltage, since the initial goal was to get this value close as possible to 12 V.

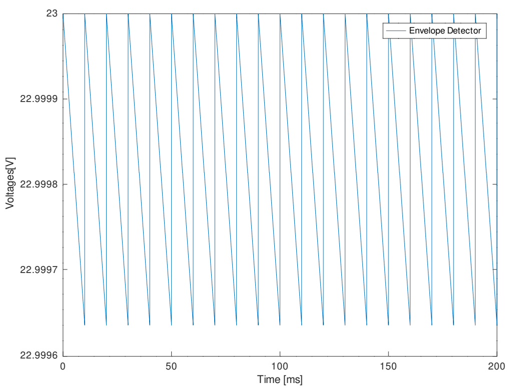
3.1 Second sector: Envelope detector circuit (rectifier + capacitor)

Then we go to the second sector, analysing in NGspice comparation with Octave is clear in figures x e y.
This next table represents the Ngspice results for the output of the envelope.

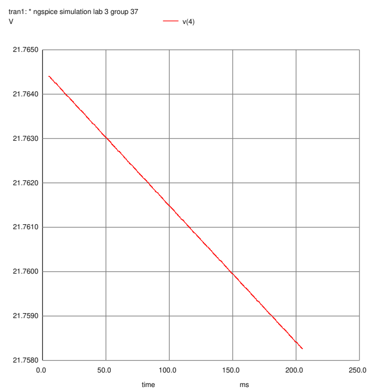
Name - Value	
maximum(v(4))-minimum(v(4))	6.149354e-03
mean(v(4))	2.176133e+01

Table 4: Results for the output of the envelope

After analysis of the tables above, some discrepancies are observed. Nevertheless, these are due to the osilations that naturally occur in ngspice. These happen because the diodes used are non-linear components, which means that a linear relaton between the current and the voltage does not exist. The exponential function that comes into the equations leads to these type of oscilation.



(a) Octave



(b) NGSPICE

Figure 6: Envlope Detector Voltage

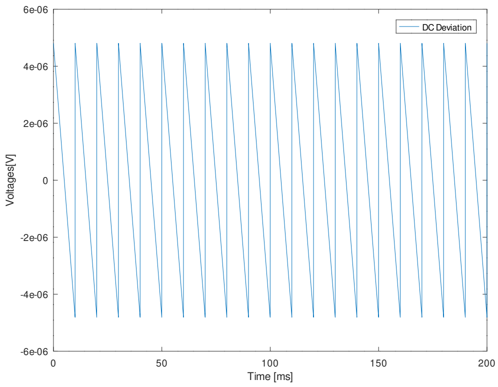
3.2 Third sector: Voltage regulator circuit

Then we go to the third sector, analysing in NGspice comparation with Octave is clear in figures x e y.
This next table represents the Ngspice results for the voltage regulator.

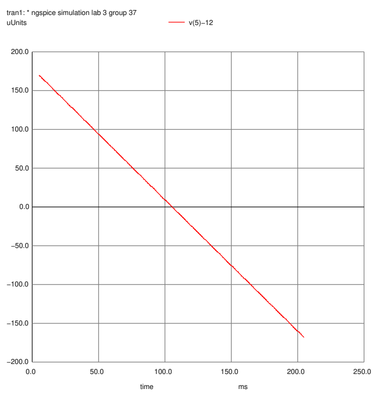
Name - Value	
maximum(v(5))-minimum(v(5))	3.387254e-04
mean(v(5))	1.200000e+01

Table 5: Results for the voltage regulator

The oscilations between theorectial and simulation results that happened in the output voltage of the envelope detector are extended to the voltage regulator for the same reasons. Therefore, it was expected to happen a small discrepancy between the results of both models. Nevertheless, we believe that once theoutput voltage is aproximately 12V, as wanted, the model worked successfuly.
The implemented circuit gave us a MERIT of 0.36 in NGSpice and 11.68 in Octave. This difference in the both merits is due to tha fact that the ripple in NGspice isn't properly the real ripple, because it was caculated by doing the difference between the maximum and the minimum.

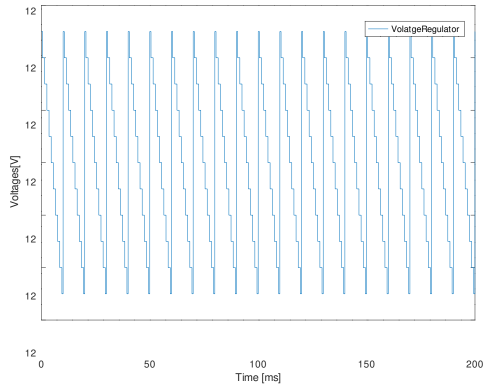


(a) Octave

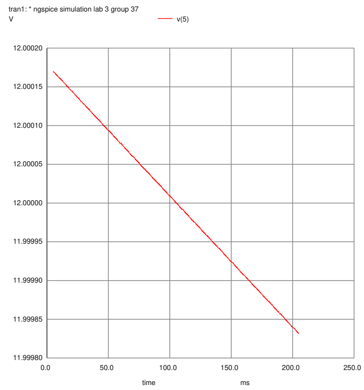


(b) NgSpice

Figure 7: Output AC Component

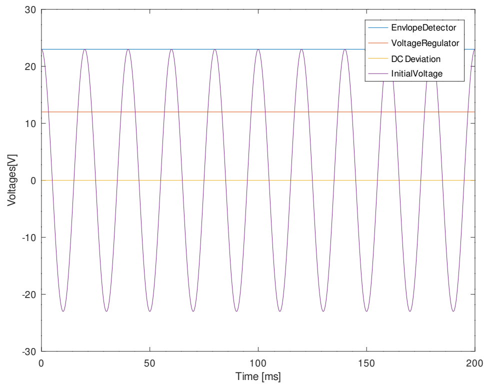


(a) Octave

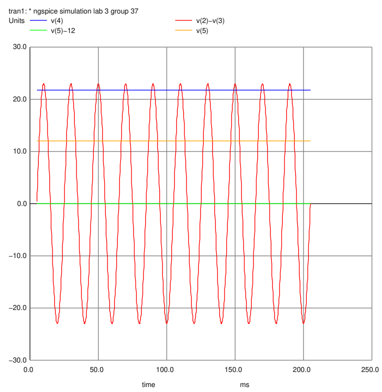


(b) NGSPICE

Figure 8: Output Voltage



(a) Octave



(b) NGSPICE

Figure 9: Input voltage of the secundary circuit (v(2)), output Voltage of the Envelope Detector (v(4)), Voltage Regulator (v(5)), and v(5)-12

4 Conclusion

In this laboratory assignment, the goal especified in the introduction has been achieved with a great merit. All analyses have been performed both theoretically using the Octave maths tool and by circuit simulation using the Ngspice tool. When comparing these last two we conclude that there aren't any disparity between the results and therefore no errors associated. So, we conclude that the architeture that we used can be validated.