TÉCNICO LISBOA

Circuit Theory and Electronics Fundamentals

Integrated Master in Aerospace Engineering, Técnico, University of Lisbon

Laboratory Report-T3

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1 Introduction

The main objective od this laboratory assignment is to produce an AC/DC converter using a transformer, an envelope detector and a voltage regulator, in order to convert the AC input voltage, whose amplitude and frequency were given to us, into a DC output voltage of 12V. To achieve this objective affectively, two factors had to be taken into consideration, the voltage ripple and the cost of the circuit. The relationship between these two factors produces the Merit 1, whose value we want to be as high as possible.

$$M = \frac{1}{cost * (ripple(v_o) + average(v_o - 12) + 10^{-6})}. \quad (1)$$

The circuit used to convert the signal is shown in Figure1.

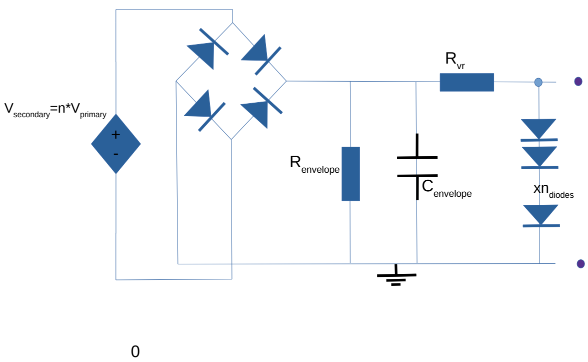

Figure 1: Circuit under analysis.

In the next section (2), we briefly explain the procedure to analyse theoretically the circuit above with the use of Octave maths tool. In Section 3 a simulation analysis is given, where we resorted to Ngspice to simulate the circuit, and a few graphics are presented to understand the results. The report finishes with its conclusion in section 4, where we analyse side by side the theoretical and simulated results and resume the most important points of the lab assignment.

2 Theoretical Analysis

The next subsections explain the theoretical analysis made to predict the voltage in both the envelope detector and voltage regulator. Table1 shows the important values used in the circuit.

Name	Value
$n(transformer)$	4.472136e+00
$R_{envelope}$	8.000000e+04
$C_{envelope}$	8.500000e-05
n_{diodes}	1.800000e+01
R_{vr}	2.810000e+04

Table 1: Chosen parameters.

At first, a transformer with a ratio n:1 was used, leading to the following relation.

$$A_{secondary} = \frac{A_{primary} n}{.} \tag{2}$$

2.1 Envelope Detector

The input voltage in the envelope detector will be $V_secondary$, given by:

$$V_{secondary} = A_{secondary} * cos(w * t). \tag{3}$$

With w = 2πf.

Then, an envelope detector was produced, using a full-wave rectifier (four diodes and a resistor) and a capacitor, as seen in Figure1. The output voltage in the envelope detector will depend if the diodes are on or off.

When the diodes are on, assuming that the diodes are linear components, the voltage in the envelope is equal to the voltage if only a rectifier existed, which means that it will be equal to the abslotute value of $V_{secondary}$.

$$V_{envelope} = |V_{secondary}|. \tag{4}$$

When the diodes are off the voltage in the envelope will be given by:

$$V_{envelope} = A_{secondary} * |cos(w * t_{off})| e^(- \frac{t - t_{off}}{R_{envelope} * C}). \tag{5}$$

Because the voltage is given by a sinusoidal fuction that has a period, in this case, since we used a full bridge rectifier, the time between two consecutive t_{off} will be T/2 and the same applies for t_{on}. This relation enabled us to determine the output voltage in the envelope detector.

To determine t_{off} we used the following expression:

$$t_{off} = \frac{1}{w} * arctg(\frac{1}{w * R_{envelope} * C}) \tag{6}$$

The value of t_{on} is the time were the curves of the rectified signal and the voltage in the envelope when the diodes are off intersect.

Because the voltage is given by a sinusoidal fuction that has a period, in this case, since we used a full bridge rectifier, the time between two consecutive t_{off} will be (T/2) and the same applies for t_{on}. This relation enabled us to determine the output voltage in the envelope detector for every value of t. The obtained results are shown in Figure2.

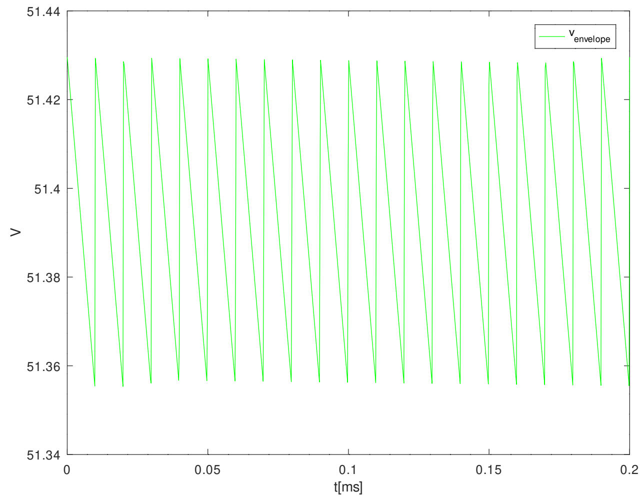

Figure 2: Output Voltage in the Envelope Detector[v].

2.2 Voltage Regulator

The voltage regulator used in this circuit consists in a resistor in series with a limiter circuit (positive voltage limiter) that uses a series of diodes with n_{diodes}. The objective of this part of the circuit is to achieve the required DC voltage of 12V as it was stated before.

In order to predict the final result, an incremental analysis was used, which means that:

$$V_{out} = V_o + v_o \tag{7}$$

Since $V_{envelope}$ is greater than 12V, $V_o = V_{envelope}$. The incremental part is given by the following expression:

$$v_o = \frac{n_{diodes} * r_d}{n_{diodes} * r_d + R_{vr}} * (V_{envelope} - avg(V_{envelope})) \tag{8}$$

With,

$$r_d = \frac{\eta * V_T}{I_s * e^(\frac{12}{n_{diodes} * \eta * V_T})} \tag{9}$$

And $V_T = 0,025V$ (thermal voltage) , $I_s = 1 * 10^(-14)$ (reverse saturation current) and $\eta = 1$ (material constant).

With the chosen parameters of Table1, the obtained values and graphics are shown in the next figures.

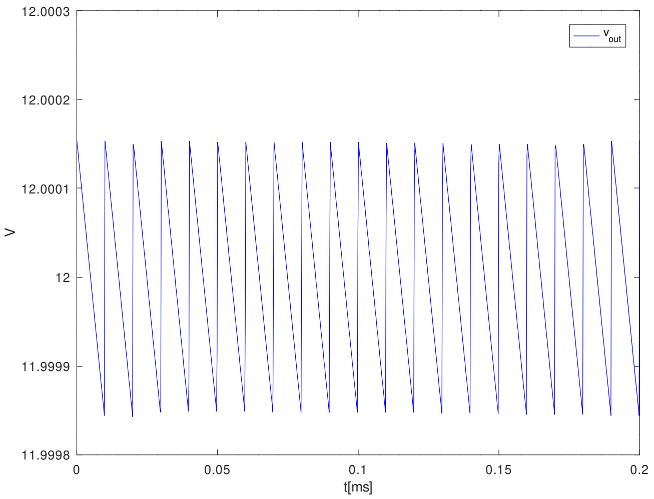

Figure 3: Output Voltage [V].

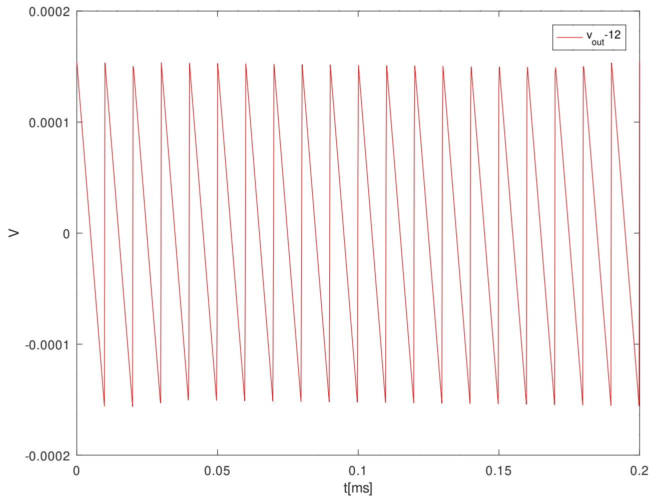

Figure 4: Deviation (v_{out} - 12) [V].

Finally, the important obtained results are shown in the following table:

Name	Value
$average$	1.200000e+01
$deviation$	1.776357e-15
$ripple$	3.104277e-04
$cost$	1.953000e+02
$merit$	1.644147e+01

Table 2: Theoretical Results.

3 Simulation Analysis

The following figures present the obtained results when simulating the circuit using $Ngspice$. The plots are the sime time functions as shown in the previous section.

Starting with the obtained graphic for the voltage in the envelope detector, we have:

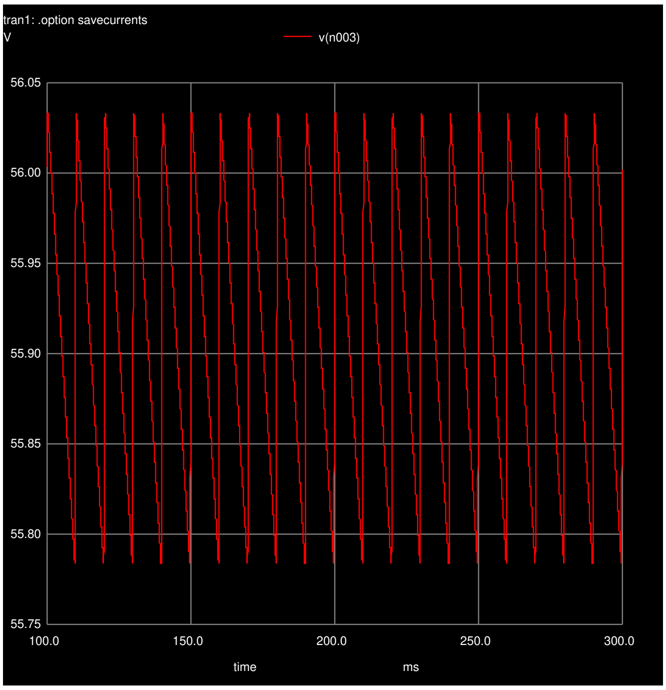

Figure 5: Output Voltage in the Envelope Detector[v].

Next, we have the results of the output voltage and its respective deviation.

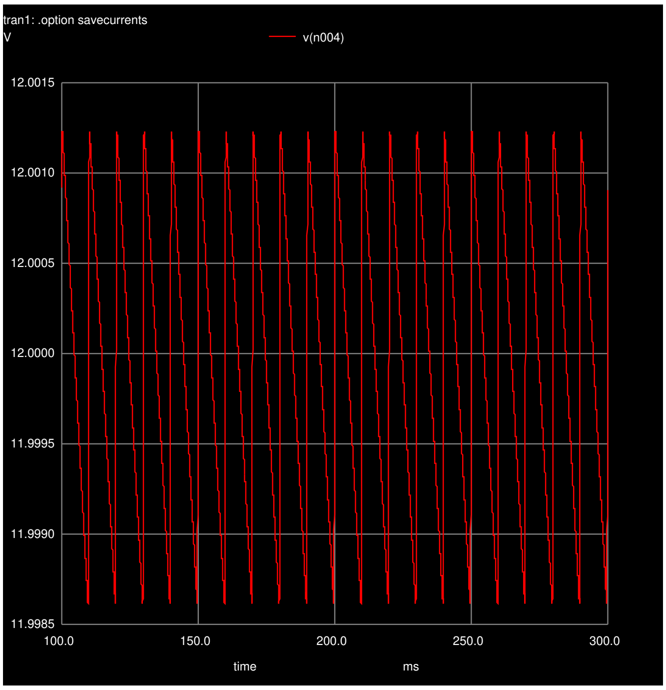

Figure 6: Output Voltage [V].

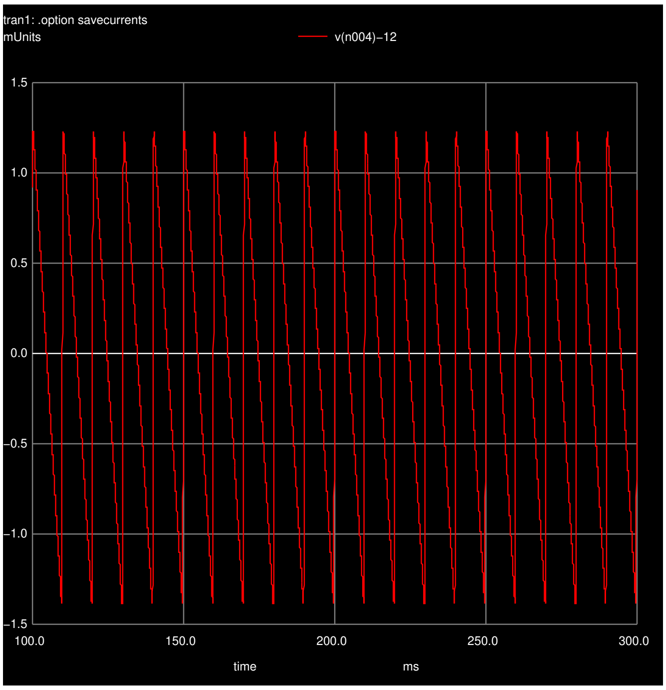

Figure 7: Deviation (v_{out} - 12) [V].

Table3 shows the important simulated results.

Name	**Value**
average	1.199994e+01
deviation	6.423466e-05
ripple	2.617605e-03
cost	1.953000e+02
merit	1.908548e+00

Table 3: Simulated Results.

4 Conclusion

To better understand the similarities and also what differs most in the results using the theoretical and simulated analysis, the tables with the important values are given side by side:

Name	**Value**
$average$	1.200000e+01
$deviation$	1.776357e-15
$ripple$	3.104277e-04
$cost$	1.953000e+02
$merit$	1.644147e+01

Name	**Value**
average	1.199994e+01
deviation	6.423466e-05
ripple	2.617605e-03
cost	1.953000e+02
merit	1.908548e+00

Table 4: Obtained results using Octave and NGSpice, respectivily.

Taking a closer look at these values, one notices that there are some discrepancies. The deviation's value in the theoretical analysis is in the order of 10^-15, while the simulated results are much bigger, in the order of 10^-5 . The ripple differs a bit too from both analysis. These differences have a direct consequence in the value of the merit, since it depends on these quantities. One notices that the theoretical merit (16,44147) is almost ten times bigger than the simulated one (1,908548). These discrepancies were expected, since the diodes were considered to be ideal and many simplifications were made in the theoretical analysis, while the $Ngspice$ tool uses very complex models to simulate the results.

As for the graphics of the voltage in the envelope detector, the output voltage and its deviation, both theoretical and simulated plots are coherent and very similar.

Looking at the obtained results, one must conclude that the merit to take into consideration is the simulated one, since $Ngspice$ has the ability to produce values that are much more similar to reality.

In conclusion, although there are some differences (that were expected), the objective of this lab assignment was accomplished and both methods (theoretical end simulated) were able to convert the AC voltage into the DC voltage asked by the teacher and the obtained values for the merit were also satisfactory.