Circuit Theory and Electronics Fundamentals

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

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Laboratory Assignment - T3

Group nº59

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1 Introduction

The objective of this laboratory assignment is to optimize and study an AC/DC converter circuit. We were given total freedom to choose the architecture of the Envelope Detector and Voltage Regulator circuits. Our goal is to achieve the highest Merit (M) possibe. This value is obtained with the following equations:

$$M = \frac{1}{cost \times (Ripple(vout) + avg(vout - 12) + 10^{-6})}$$

$$cost = cost_{resistors} + cost_{capacitor} + cost_{diodes}$$

$$cost_{resistors} = 1MU/kOhm;\, cost_{capacitors} = 1MU/\mu F;\, cost_{diodes} = 0.1MU/diode$$

For reasons explained later, our circuit, shown in figure 1, contains, in total:

- one voltage source (V_1)
- two inductors (L_1,L_2)
- one resistor (R_1)
- one capacitor (C_1)
- twentyt two diodes (D_1-D_{22})

The circuit can be divided in three parts. The source, the Envelope Detector Circuit and the Voltage Regulator Circuit (Figure 1).

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.

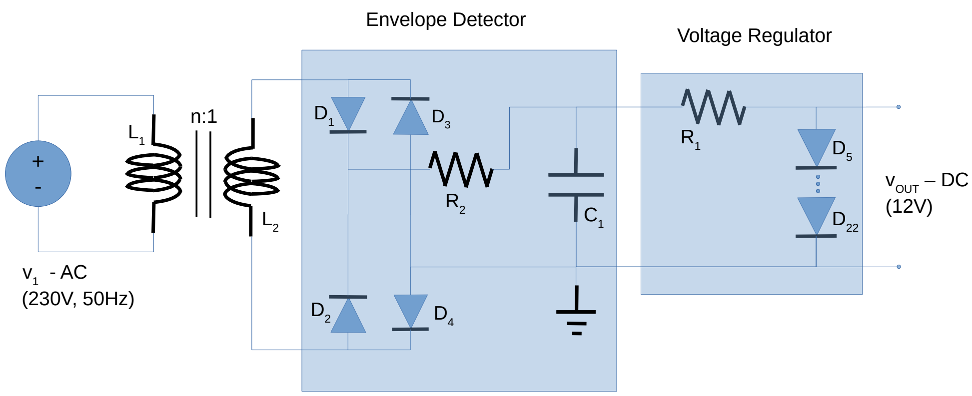

Figure 1: Circuit T3

2 Theoretical Analysis

In this section we will explain the inner workings of the AC/DC converter created and perform a theoretical analysis of each component. For the analysis it was assumed that each component only affects the components that come after it and so does not interfere with the previous analysis. The common Kirchoff laws and diode equations (simplified in some cases) were used to perform the analysis.

2.1 Transformer

The transformer is the component that steps down the supplied voltage. This step is necessary to approximate the supplied 230V to the 12V required. Since it was assumed that the transformer was ideal, its response can me modeled as a simples change in amplitude, that is related with the number of windings by the following equation:

$$V_{out} = \frac{V_{in}}{n}$$

2.2 Envelope Detector

The envelope detector is comprised of two sub-components: The rectifier and a filter. The chosen rectifier for our application was the Full-Wave Bridge Rectifier. The purpose of a rectifier is to turn the AC component of the supply to a DC current. To accomplish this objective the rectifier uses four diodes positioned in a way as to only allow the current to pass one way (shown in diagram). This behavior was achieved in octave by performing the abs() function to the signal and subtracting 2 times the diode's V_{on} voltage (simulating the two diodes the current has to pass through using the V_{on} model).

The filter is comprised of a series resistor and parallel capacitor. Its objective is to stabilize the signal and decrease the voltage ripples caused by the rectifier. This behavior was computed in matlab by comparing the signal voltage at each moment with the equivalent RC circuit voltage, the larger of the two was chosen to be the signal.

$$V_{out} = V_{t_{off}} \cdot e^{-\frac{t-t_{off}}{\tau}}$$

2.3 Voltage Regulator

This component has the objective of limiting the voltage to the desired value and at the same time, by using the non-linear behavior of a diode to decrease oscillations in the signal. The component is comprised of 17 diodes in series to achieve the desired voltage. Incremental analysis performed to find the final output signal.

By solving the following equation using the Newton-Raphson iterative method we can find the operating point voltage.

$$V_0 + R \cdot I_s \cdot (e^{\frac{v}{N \cdot VT}} - 1) - V_e n v = 0$$

Using this result we can find the equivelent resistance for the diodes using the following equation.

$$r_d = \frac{n \eta V_t}{I_s e^{\frac{V_D}{n \eta V_x}}}$$

With this information we can calculate by how much the ripple is decreased.

$$v_0 = \frac{r_d}{r_d + R} \cdot v$$

The output signal is the sum of the DC operating point calculated before and the ripple.

$$V_{out} = N \cdot V_{on} + v_0$$

2.4 Theoretical Results

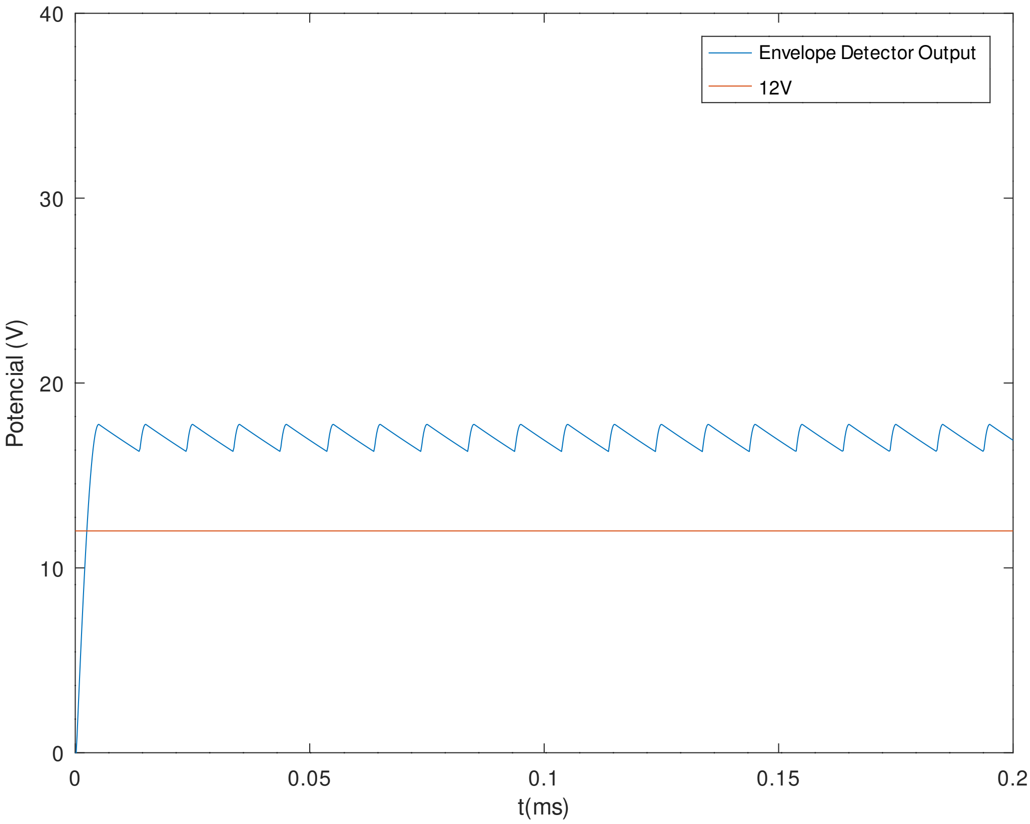

Figure 2: Envelope Detector Circuit v_{out}

3 Simulation Analysis

In this section, Circuit T3 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 output of the currents that pass through all branches. Moreover, function to help determine de minimum, maximum and average 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.

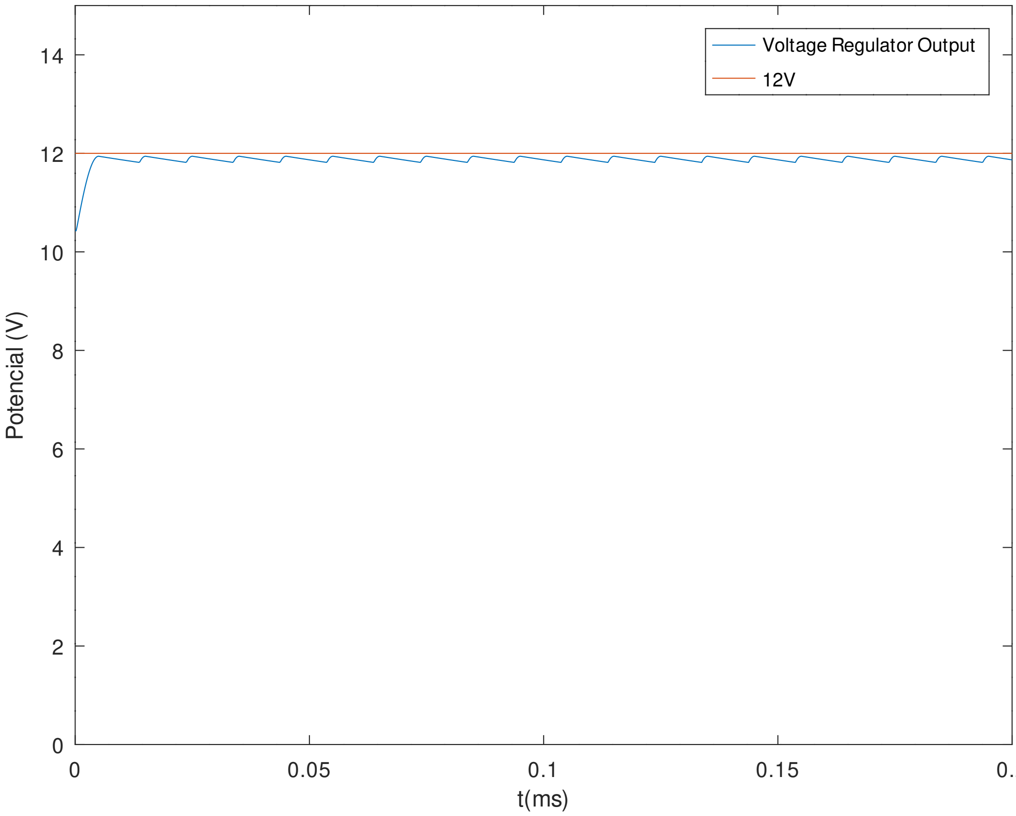

Figure 3: Voltage Regulator Circuit v_{out}

3.1 Simulated results

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

Firstly, a transient analysis between $t = 0ms$ and $t = 150ms$ was performed. This operation only had the goal to provide us a plot (Figure 4) for the v_{out} in the beginning compare it to the desired outup voltage $(12V)$.

Aditionally, a transient analysis between $t = 150ms$ and $t = 350ms$ was carried out. Three plots were obtained. Figure 5 shows the output voltage of the Envelope Detector Circuit. Figure 6 shows the output voltage of the Voltage Regulator Circuit. Finaly, 7 shows the output voltage of the Voltage Regulator Circuit minus $12V$ $(v_{out} - 12)$.

As mentioned before, function to determine the minimum, maximum and average of the plots were also used. Table 1 shows the average, maximum and minimum of the plot in Figure 6, in that order. In adition, the Ripple (Vout(MAX) - Vout(MIN)) is also presented.

Name	**Value [V]**
vout(avg)	1.200000e+01
vout(max)	1.201992e+01
vout(min)	1.197959e+01
ripple(vout)	4.033000e-02

Table 1: Values from Ngspice related to the Voltage Regulator Circuit.

Lastly, the group also used Ngspice to compute the Merit. This was done, only to confirm the value obtained in Subsection 2.4.

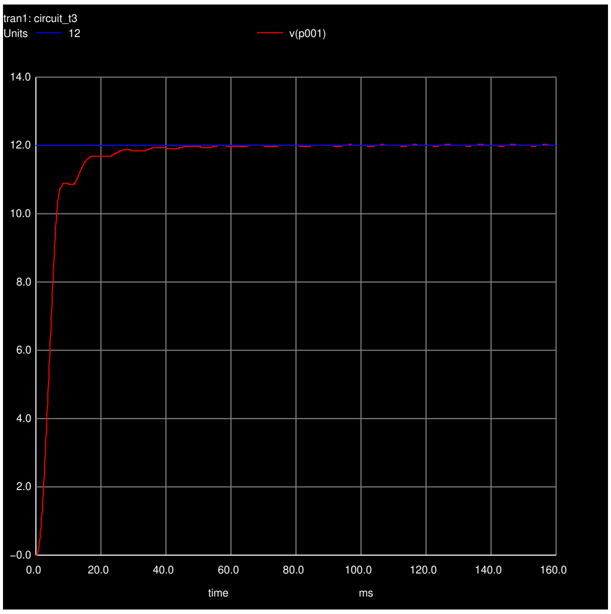

Figure 4: Inicial v_{out}

Name	Value [MU]
cost(resistor)	7.884500e+00
cost(capacitor)	1.000000e+01
cost(diode)	2.100000e+00
cost	1.998450e+01
————————	————————
merit	1.240703e+00

Table 2: Simulated values for the Costs and Merit.

3.2 Comparison

4 Conclusion

In order to perform theoretical and simulational analysis of the circuit Octave and Ngspice were used, respectively. To obtain the theoretical values of the diodes, both Kirchhoff Laws and the V_{on} model were used. Then, in order to graphically obtain the value of V_0 over time, a plot was made and is shown in FIGURE 2. Posteriorly, with the simulation of the circuit we were able to make the same plot as before obtaining approximate results. Finally we proceeded to the optimization of the input values achieving the Merit shown before. Therefore, the objective of the laboratory was achieved succesfuly.

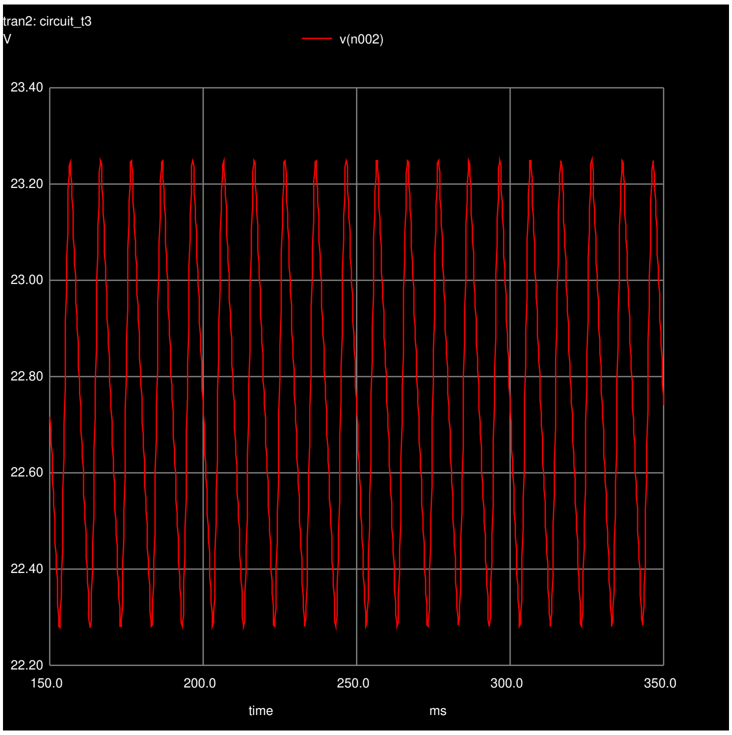

Figure 5: Envelope Detector Circuit v_{out}

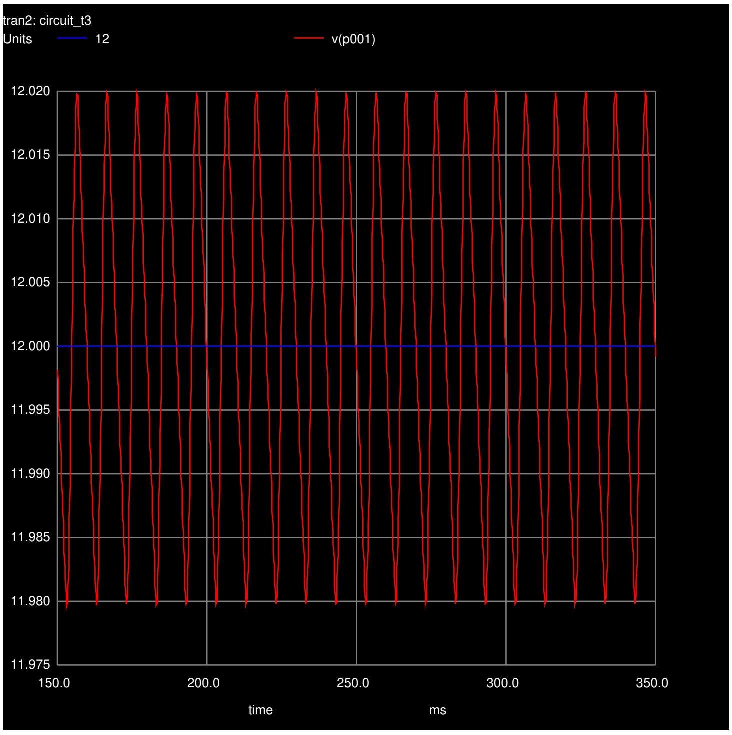

Figure 6: Voltage Regulator Circuit v_{out}

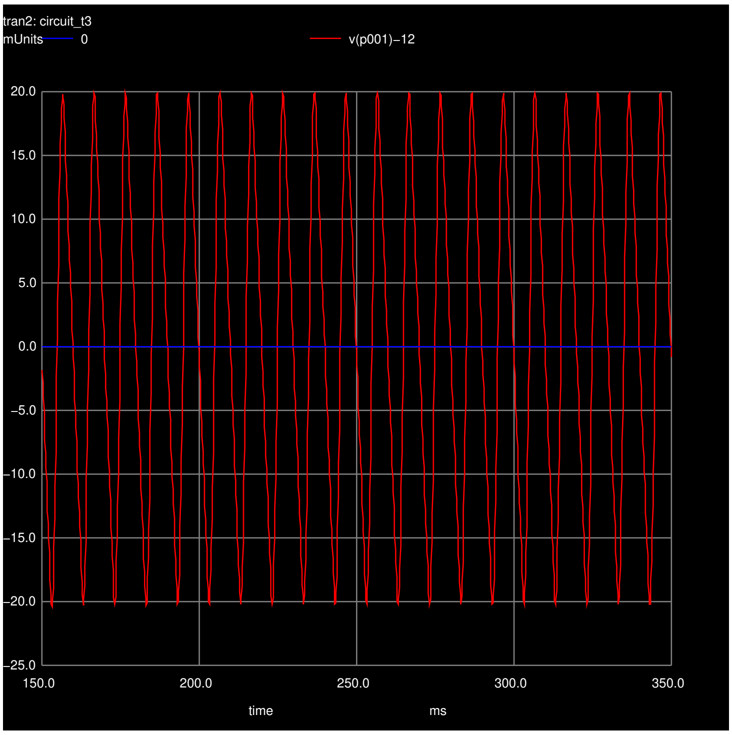

Figure 7: Output AC component + DC deviation
Vout(MAX) - Vout(MIN)