Circuit Theory and Electronics Fundamentals

Laboratory 3: AC/DC Converter

Integrated Masters in Aerospace and Technological Physics Engineering, Técnico, University of Lisbon

João Peixoto, 95807; Pedro Farinha, 95838; Patrícia Curado, 96559

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1 Introduction

The objective of this laboratory assignment is to simulate and study one circuit that converts AC current in DC current. The main goal was to achieve the best possible value for the merit of the circuit. This merit value depends on the cost of the components that we used, namely capacitors, diodes and resistors. The formula for the merit M is given by

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

where cost = cost of (resistors + capacitors + diodes).

The cost of one resistor is one monetary unit (MU) per kOhm; of one capacitor is 1 MU per μF and of one diode is 0.1 MU per diode. To obtain the best M value, we had to test and create the circuit that optimized M and minimized the value of the ripple, which is the difference between the maximum and minimum voltage values of the output voltage of the circuit. The circuit used is printed in Figure 1.

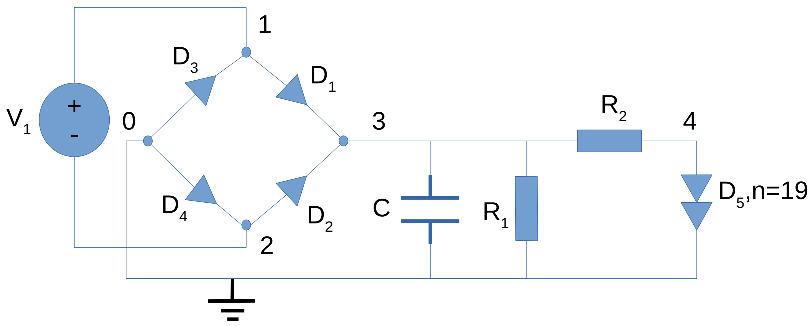


Figure 1: Circuit T3

Given that the diodes are the cheapest components in this circuit it is not odd that they are the predominant component. We use n=19 diodes in series and four more integrated in the full wave bridge rectifier. The values of the components in circuit 1 are in Table 1.

Name	Value
V1	180 V
R1	585 kΩ
R2	413.63 kΩ
C	585 μ F

Table 1: Values for the components in the circuit.

The amplitude value of 180 V is the result of the n:1 transformer between the input 230 V and the envelope detector, with n $= \frac{23}{18}$.

2 Analysis

2.1 Theoretical explanation

This AC/DC converter has two parts: an envelope detector and a voltage regulator. The full-wave bridge rectifier, which is a part of the envelope detector, transforms an AC signal in its absolute value. This part of the converter includes a capacitor, a resistor and four diodes, disposed in a way so that two of them are reverse biased and the other two are forward biased. This way, the sinusoidal signal imposed by the transformer will be transformed in a signal whose waveform is similar with the topography of mountains and valleys. Since the four diodes are disposed in a closed loop, oriented by pairs, only two diodes will work during the same cycle.

With the addition of the smoothing capacitor, we can improve the average DC output of the full wave bridge rectifier circuit. The diodes will turn off at t_{OFF}, turning the circuit into a simple circuit of a resistor and a capacitor in parallel. Thus we can compute this time instant, which after algebraic manipulation gives:

$$t_{OFF} = \frac{1}{\omega}\arctan\left(\frac{1}{\omega RC}\right) \tag{2}$$

So for $t > t_{OFF}$ the output voltage of the envelope detector is given by the expression

$$v_o(t) = A\cos(\omega t_{OFF})e^{-\frac{t-t_{OFF}}{RC}} \tag{3}$$

What this essentially means is that the output voltage of the envelope detector will follow the cosine up to a point where it would start to drop significantly (as the derivative gets more and more negative) and then follow an exponential function with a smaller drop, improving the output DC voltage as desired.

As for the voltage regulator, it is comprised of a resistor R_2 in a series with 19 diodes. This circuit element attenuates oscillations in the input signal (which is the output signal of the envelope detector) without frequency dependence. The final output circuit, v_O, is made of a DC and an AC component, but, ideally, the AC component should be zero. So the procedure is to choose R_2 much bigger than the diodes' incremental resistances, which will reduce the amplitude of the AC component and thus the voltage ripple. The 19 diodes also guarantee that V_O, the DC component, is equal to 19V_{ON}. This way, a DC voltage output of 12V is achieved.

2.2 Comparing the theoretical and the simulated results

Name	Value
$V_{deviation}$	0.000000
V_{ripple}	1.761516e-05
$cost$	1585.930000

Table 2: Theoretical Results: voltages in V and cost in MU.

Name	Value
voltagedeviation	0.000000e+00
voltageripple	3.000000e-05
cost	1.585930e+03
merit	2.034016e+01

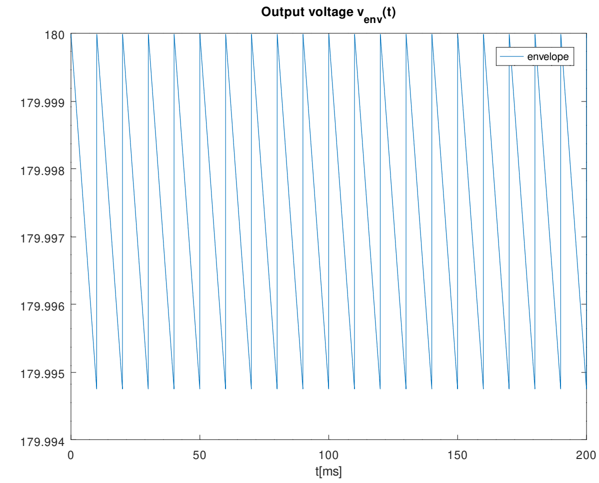
Table 3: Simulated Results: voltages in V and cost in MU.

Right from the beginning it is clear that the values for the voltage deviation and cost are equivalent for the Octave [1] and for the simulated results, which is not surprising given the fact that the cost does not depend on the simulation. However, the V_{ripple} of the simulated results differs from the theoretical V_{ripple} value by a few decimals.

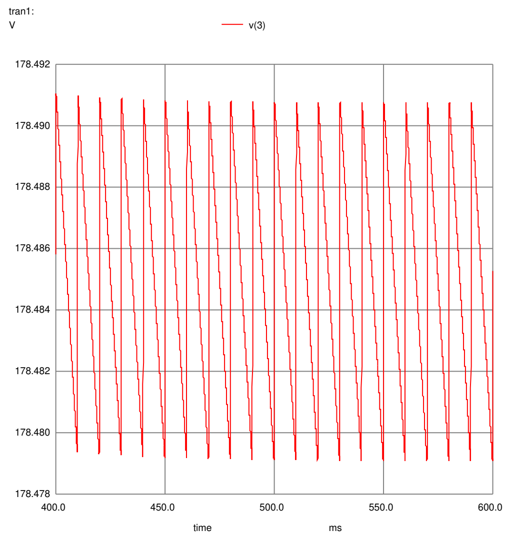
The figure of merit obtained from a cost of 1585.93 MU and the simulation results was 20.3.

The voltage drop of a diode was set as 12/19 in the Octave script so as to get a final DC output of 12V like intended. However, the NgSpice [2] diode model uses a different value for V_{ON}, determined experimentally to be around 0.63V.

In the following graphs are plotted the voltages of the envolpe detector, the output voltage and a slightly modified plot of the output voltage ($V_{output} - 12$). It is important to notice that the time interval of each one of these plots is 200 ms because we have to plot 10 periods for a given a frequency of 50 Hz.



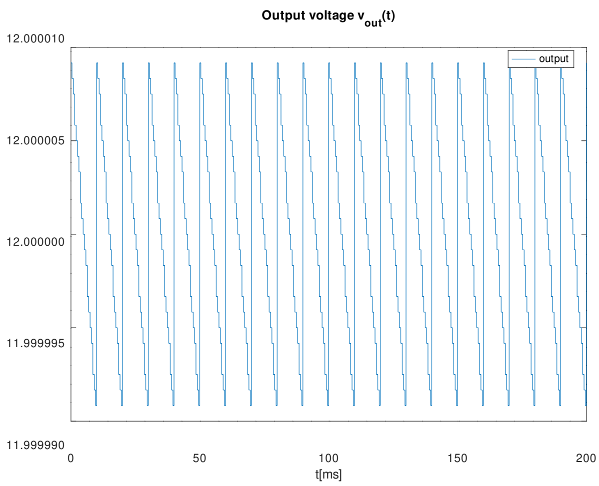
(a) Octave plot



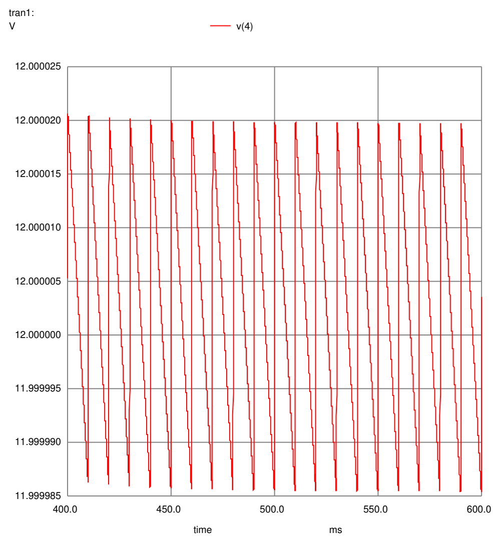
(b) NgSpice plot

Figure 2: $V_{envelope}$ as a function of t

The voltage envelope function plot represents the voltage that comes out of the envelope detector. The Octave plot gives us the maximum peaks of this voltage at 180 V, whereas the NgSpice peaks only achieve 178.491 V.



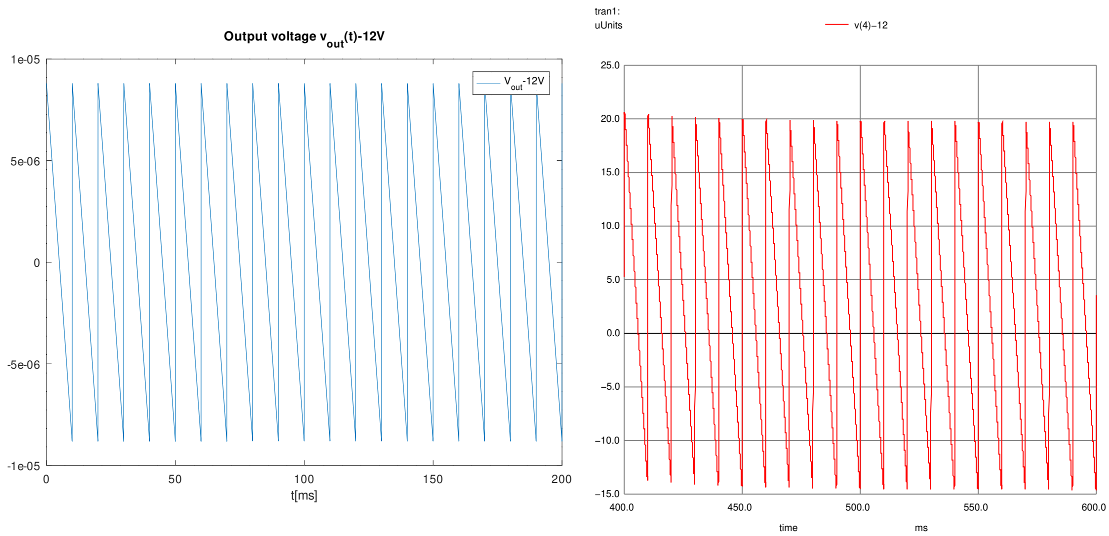
(a) Octave plot



(b) NgSpice plot

Figure 3: V_{outup} as a function of t

These plots represent the voltage that comes out the entire circuit, after getting through the voltage regulator. Both the theoretical and the simulation plots show values around the desired 12 V.



(a) Octave plot

(b) NgSpice plot

Figure 4: V_{output}-12 as a function of t

It should be noted that the NgSpice transient analysis are made between 400ms and 600ms, due to the fact that at 400ms the capacitor will certainly be fully charged. Furthermore, the model that NgSpice uses to define diodes also integrates capacitors. This way at 400ms it is guaranteed that both the capacitor and the diodes will not enter in conflict with the results desired.

3 Conclusion

We conclude that the envelope detector and voltage regulator circuit form an effective AC/DC transformer, which was the objective outlined in the laboratory assignment. Through experimentation, it was possible to come to a result that achieves satisfactory DC output at a reasonable cost, a compromise which is an essential part of engineering.

Without the imposed restriction of the n:1 transformer between the AC input and the envelope detector (or with n $>$ 1), it would be possible to achieve significantly larger merit values, as the voltage ripple would become extremely small. Such a solution was disregarded per the objectives of the assignment.

References

[1] GNU Octave, version 6.2.0 (February 20 2021)

[2] NgSpice, *open-source spice simulator*, version 31