Circuit Theory and Electronics Fundamentals

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Laboratory 3 Report

Group 8

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Contents

1 Introduction

The aim of this laboratory assignment is to design and analyse an AC/DC converter that would transform an input AC voltage of amplitude 230V and frequency of 50 Hz to an output DC voltage of amplitude 12V and frequency 50Hz, using an Envelope Detector, a Voltage Regulator and a Transformer. The final circuit is shown below

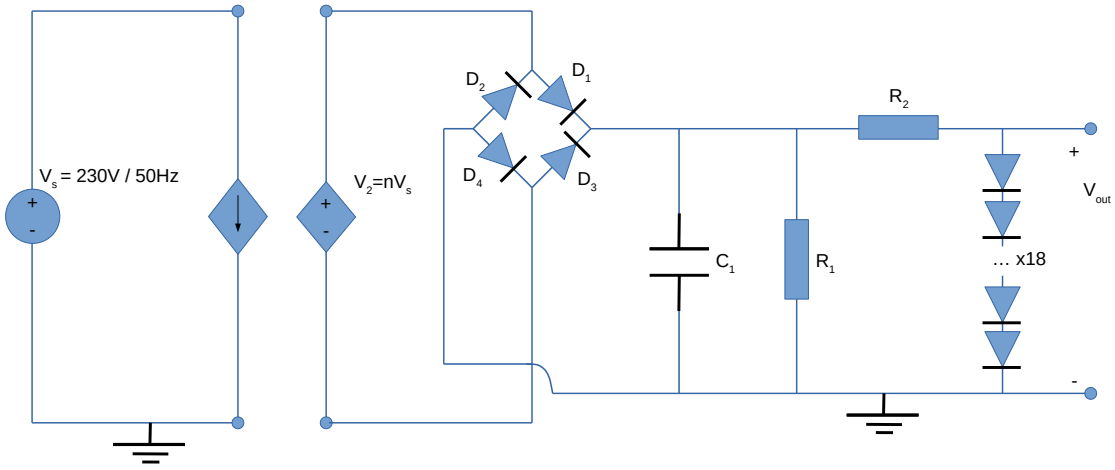

Figure 1: Circuit analysed.

even though the circuit used in the calculations and simulations is the following:

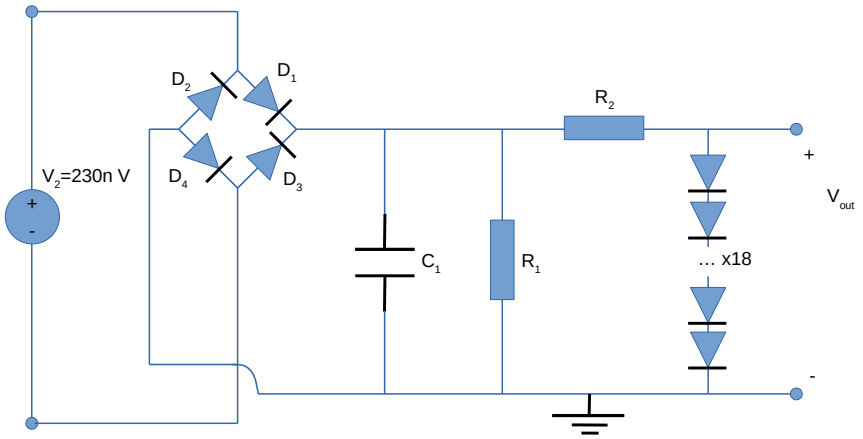

Figure 2: Simplified circuit analysed.

The quality of the circuit, when compared to the others, is determined by calculating the merit of the work:

$$Merit = \frac{1}{cost * (ripple_{reg} + |average_{reg} - 12| + 10^{-6})} \quad (1)$$

The cost of the components are the following: cost of resistors = 1 monetary unit (MU) per kOhm, cost of capacitors = 1 MU/uF and cost of diodes = 0.1 MU per diode.

The ratio of the transformer and the values of the resistors, the capacitor and number of diodes are presented in the following table.

Name	**Value**
n	5.688335e-01
Diodes	18 + 4
#R_1	7.500000e+04
#R_2	7.500000e+04
&C_1	1.500000e-04
£$Cost$	3.022000e+02

Table 1: Variables preceded by # is of type *resistance* and expressed in Ohm; variables preceded by & is of type *capacitance* and expressed in Farad; A variable preceded by £ is of type *cost* and expressed in Unit of Cost; n is adimentional.

In Section 2, the circuit is analysed by simulation using a default model fo the diode in NGSpice. The converter was simulated for 10 periods and the voltage average and ripple were measured using built in functions, and plots of the output of the Envelope Detector and the Voltage Regulator Circuits are presented.

In Section 3, a theoretical analysis of the circuit is presented, using theoretical models of the diodes to predict the output of the Envelope Detector and the Voltage Regulator Circuits. The output DC level and the voltage ripple are calculated as well as the plots for the output deviation and the output of the regulator.

The conclusions of the assigment are outlined in Section 4, which also includes a comparison of the results obtained.

2 Simulation Analysis

2.1 AC/DC converter graphs

In this section we evaluated the AC/DC converter proposed. To simplify the calculations for NGSpice, we have decided to use the circuit 2, since using the ideal model for the transformer was causing NGSpice to slow down significantly. In order to analise the circuit after the transiant period, we have chosen $t \in [10; 200[$ ms.

The graphs for NGSpice are displayed here, alongside the table with the required elements:

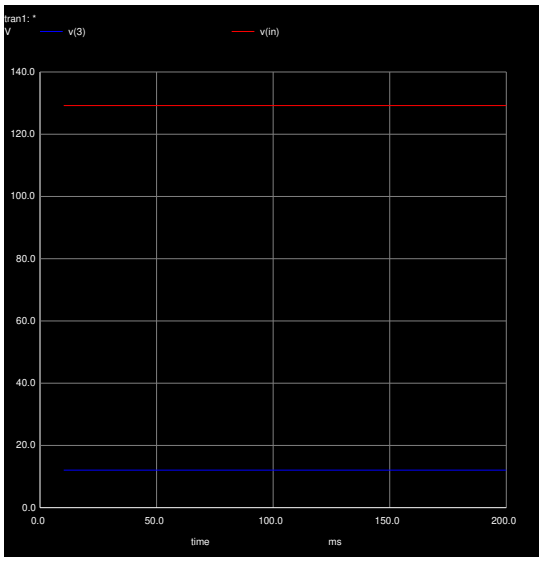

Figure 3: $v_3(t)$ ($v_{OUT}(t)$) and v_{IN} ($v_{Envelope}(t)$)

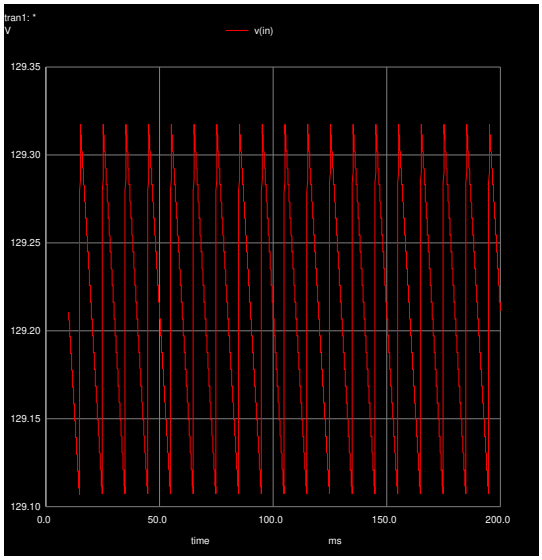

Figure 4: $v_{IN}(t)$ ($v_{Envelope}(t)$)

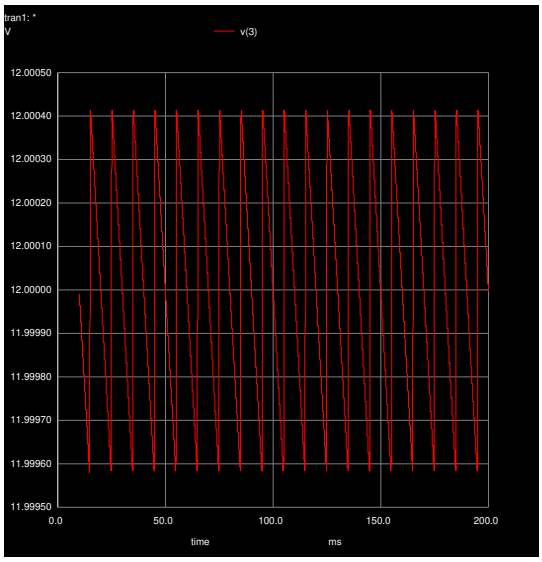

Figure 5: $v_3(t)$ ($v_{OUT}(t)$)

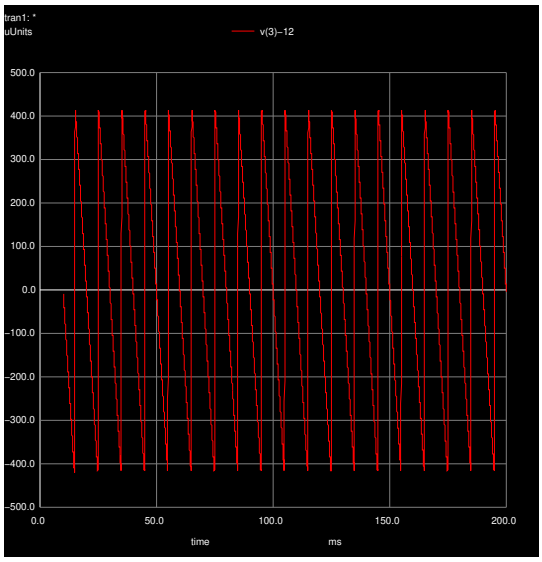

Figure 6: $v_3(t) - 12$ ($v_{out}(t) - 12$)

Table 2 shows the simulated operating point results for the circuit under analysis.

Name	**Value**
mean(v(3))-12	5.094465e-07
vecmax(v(3))-vecmin(v(3))	8.328428e-04
1 / (abs(mean(v(3))-12) + vecmax(v(3))-vecmin(v(3)) + 1u) / (150+150+(18 + 4)*.1)	3.966031e+00

Table 2: Merit is in *per voltage per cost* and expressed in $\text{Volt}^{-1}\text{UC}^{-1}$; other variables are of type *voltage* and expressed in Volt.

3 Theoretical Analysis

The transformer with a n:1 ratio was used, which means that the initial voltage will have its amplitude (230 V) multiplied by a factor n. This way, the voltage at the terminals of the transformer can be represented as a voltage source with an amplitude of $230n$ but with the same frequency as the initial source.

3.1 Step 1: Solution for the Envelope Detector

The output of the transformer will be the input of the Envelope detector, which is made of a rectifier and a capacitor. The rectifier is a full-wave bridge rectifier circuit and is composed of 4 diodes and a resistor, as shown:

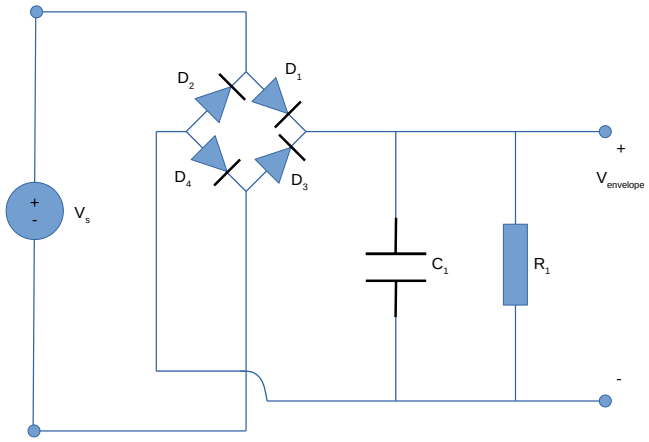

Figure 7: Envelope Detector circuit.

In this case, we have chosen to aproximate the diodes to the ideal model + V_{on}, in which $V_{on} = 0.70V$. Knowing also that only one way is used when the diodes are on, we can further simplify the circuit as shown in Figure 8. We can also say that $V_{in}(t) = V_s(t) - 2V_{on}, V_s(t) - 2V_{on} > 0$ or $V_{in}(t) = 0, V_s(t) - 2V_{on} < 0$.

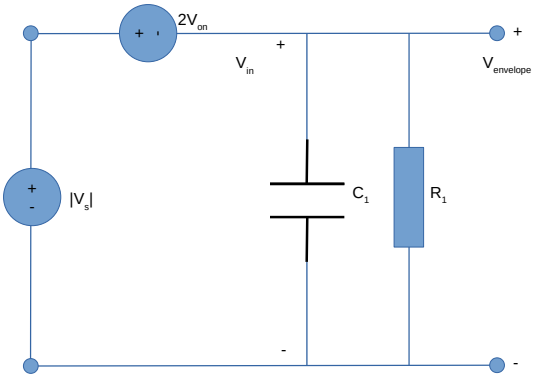

Figure 8: Envelope Detector circuit simplified, when the diodes are on.

Using the full-wave rectifier instead of the half-wave enables the decrease of the ripple withoud increasing the time constant, reducing the costs. This is possible because the voltage that comes out of the transformer will leave the rectifier oscillating at twice the frequency, which reduces the period corresponding to the wave ripple.

To compute the voltage in the capacitor we need to take in account the possibility of the diodes being turned off. This will happen when $V_C > V_{in}$, and, in this case the voltage in the capacitor will decay as:

$$V_C(t) = Ae^{-\frac{t}{RC}}, \tag{2}$$

where A is the voltage right before the diodes are turned off. When the diodes are on, $V_C = V_{in}$. As such, we have to calculate when the diodes are turned off and on. To estimate the first we have noticed that the discharge of the capacitor is limited by equation 2. In other words, knowing that in the moment before being turned off, $V_C = V_{in}$, we just have to evaluate

$$V_C(t) = V_{in}(t-\delta)e^{-\frac{\delta}{RC}} > V_{in}(t). \tag{3}$$

where we assume that the diodes have been turned off.If the expression is true, then the voltage in the diodes becomes negative, what means that it is turned off and voltage in the capacitor decays as described in equation 2. If the expression is false, the voltage in the diodes stays positive, and the diodes stay on. To know when the diodes are turned on again, we just have to know when $V_c(t) < V_{in}(t)$. From that point on, the diodes are turned on, until the innequality 3 is valid again.

The result of this analisys is the following:

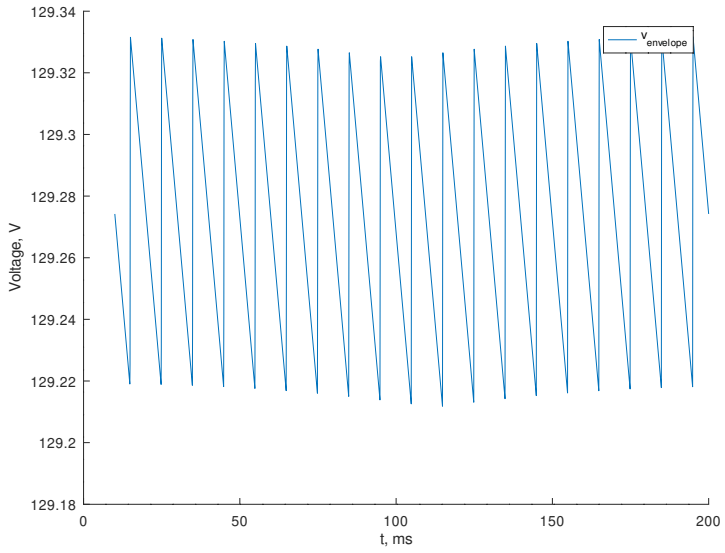

Figure 9: Envelope detector $V_{envelope}$.

3.2 Step 2: Solution for the Voltage Regulator

Then, the output of the Envelope Detector is the input of the Voltage Regulator. The last one is made of a resistor and diodes in series. Its output is the voltage in the diodes, as represented:

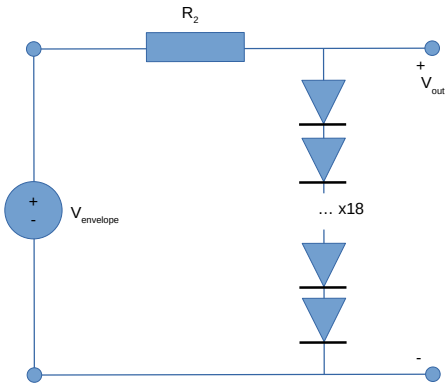

Figure 10: Voltage Regulator.

In the Envolope Detector the diode model used has an ideal diode and a voltage source while in the Voltage Regulator the diode model (where we have said that the emition coefition is ηm, being $m = 18$ the number of diodes in the regulator) has an ideal diode, a voltage source, V_d and a resistor r_d.

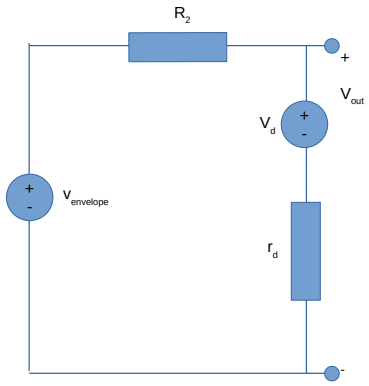

Figure 11: Simplification of the Voltage Regulator.

The steps to know each one of this constants are described in the theory classes: V_d is determined by solving the non linear equation

$$V_d + R * Is * (exp(V_d/(V_T m)) - 1) = V_c. \tag{4}$$

r_d is then calculated with the folowing expression:

$$r_d = V_T * n/(Is * (exp(V_d/(V_T m)))). \tag{5}$$

From here we say that

$$V_D = V_d + ir_d; \text{ where } i = \frac{V_C - V_d}{)}/(R_2 + r_d); \tag{6}$$

Or, in words, i is the current passing through the diode because of the non constant voltage.

The plots for V_{out}, $V_{out} - 12V$ and the pair V_c, V_{out} are the following:

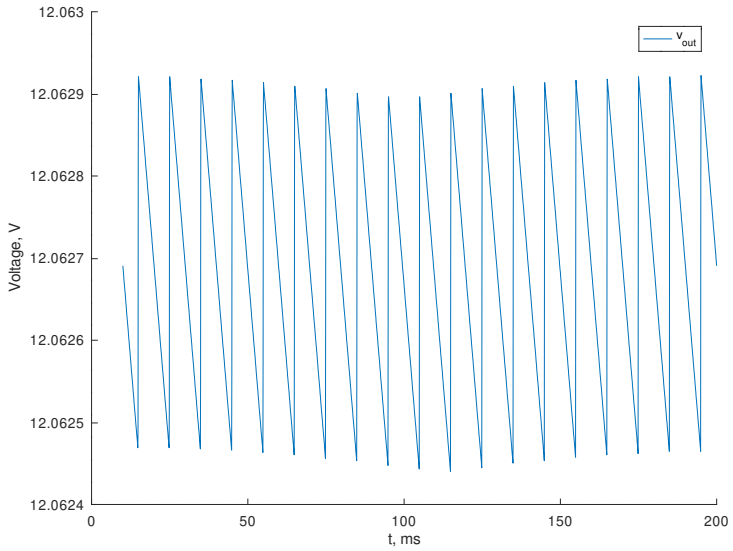

Figure 12: V_{out}.

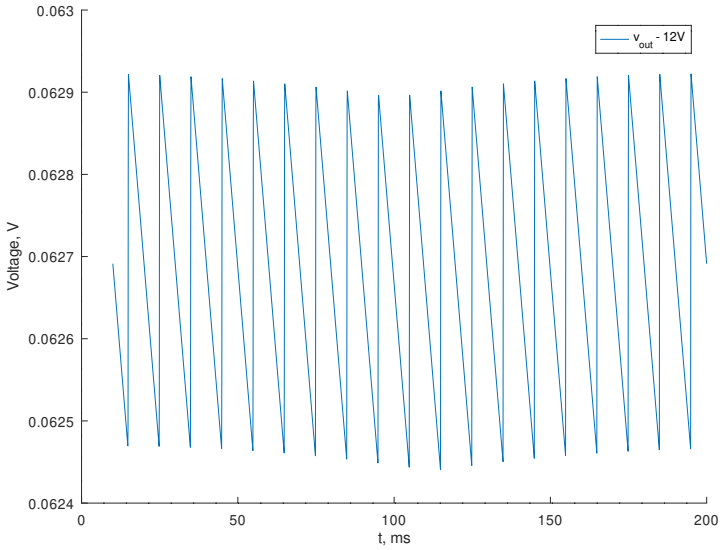

Figure 13: $V_{out} - 12V$.

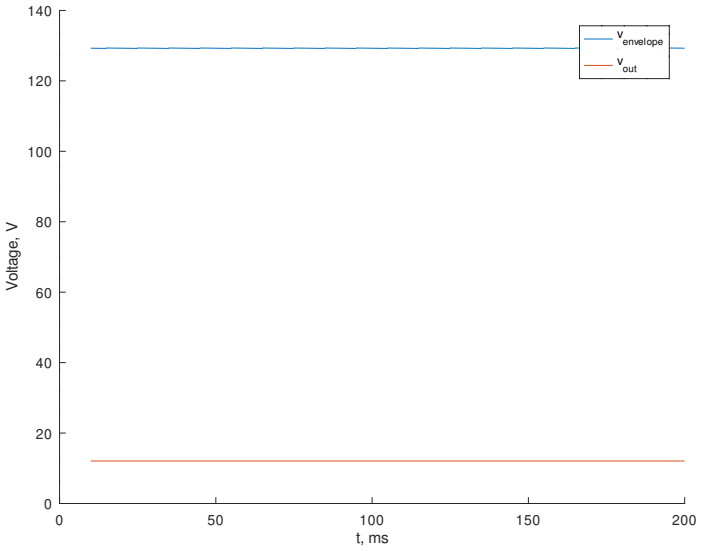

Figure 14: V_c and V_{out}.

The results from the theoretical analysis are the following:

Name	**Value**
$Distance$	6.268559e-02
$Ripple$	4.816450e-04

Table 3: Variables are of type *voltage* and expressed in Volt.

4 Conclusion

The objective of the laboratory is to transform an input AC voltage of 230V in Hz to an output of 12V, while minimizing the ripple, deviation of said 12V and cost. As shown below, the simulation results obtained have non trivial diferences to presented results already expected by the theoretical analysis achieved by Octave and Ngspice simulator. In fact, the relative error between the distances is of the magnitude of 10^5.

The differences in theoretical analysis is the result of the diode model being different from the one used in the simulation model. Theoretical analysis uses a more simplified diode model than the one used in the simulation, although, we can say that in general a theoretical analysis is acceptable, as it is less complex and still presents good results.

The greater the complexity of the models used, the results can be more and more divergent between the theoretical analysis and a simulation, specialy while considering that the envelope is fully independent of the voltage regulator ande vice versa. If it is not the case, then the results would different regardless of other aproximations used in the theoretical analysis.

The tables with the results are the following:

Name	**Value**
mean(v(3))-12	5.094465e-07
vecmax(v(3))-vecmin(v(3))	8.328428e-04
1 / (abs(mean(v(3))-12) + vecmax(v(3))-vecmin(v(3)) + 1u) / (150+150+(18 + 4)*.1)	3.966031e+00

Table 4: Merit is in *per voltage per cost* and expressed in Volt^{-1}UC^{-1}; other variables are of type *voltage* and expressed in Volt.

Name	**Value**
$Distance$	6.268559e-02
$Ripple$	4.816450e-04

Table 5: Variables are of type *voltage* and expressed in Volt.

The Merit result was 3.966 $V^{-1}uc^{-1}$ by Ngspice. It was agreed by the members of the group that the main goal of task was completed.

The obtained plot with NGSpice and Octave are the following:

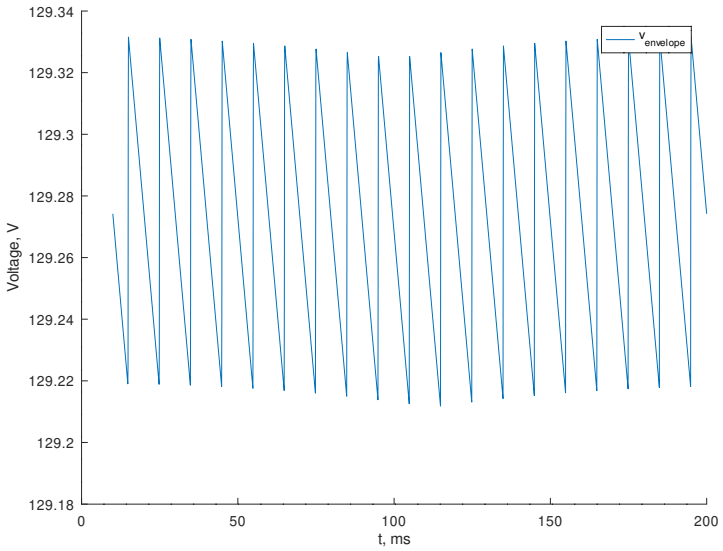

Figure 15: Envelope detector $V_{envelope}$.

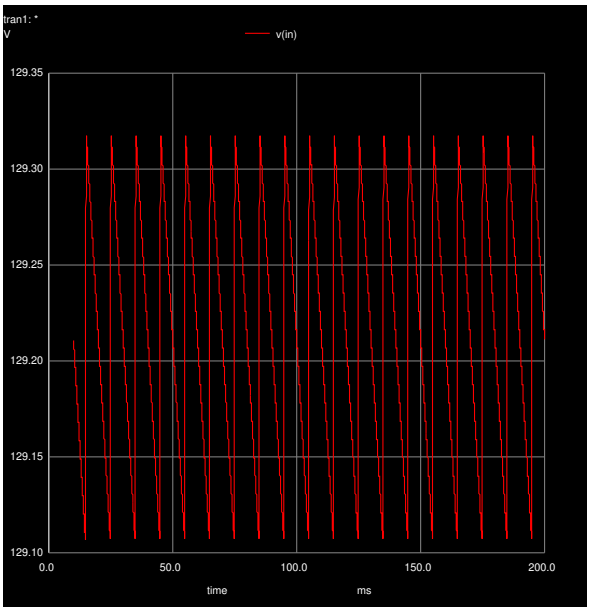

Figure 16: $v_{IN}(t)$ ($v_{Envelope}(t)$)

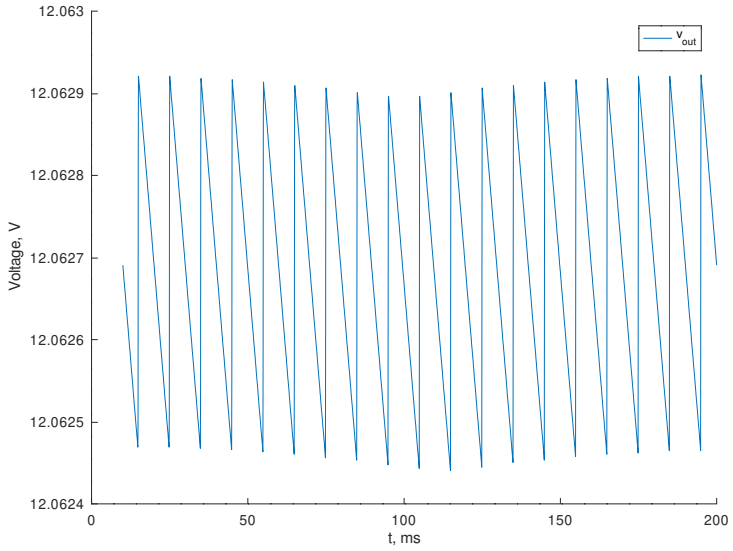

Figure 17: V_{out}.

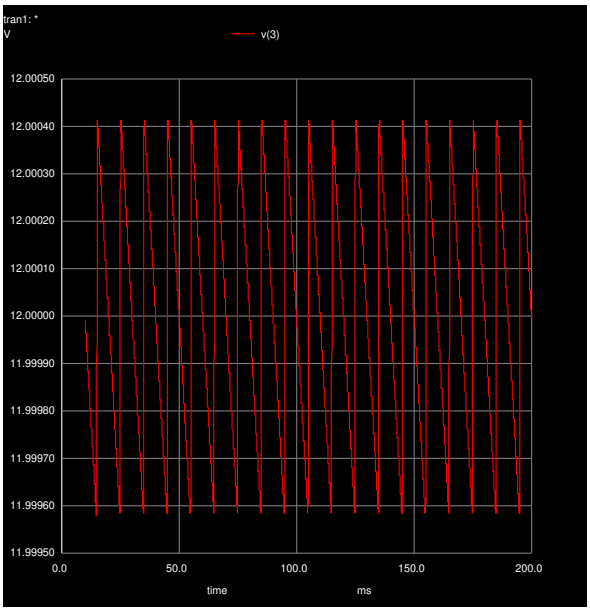

Figure 18: $v_3(t)$ ($v_{OUT}(t)$)

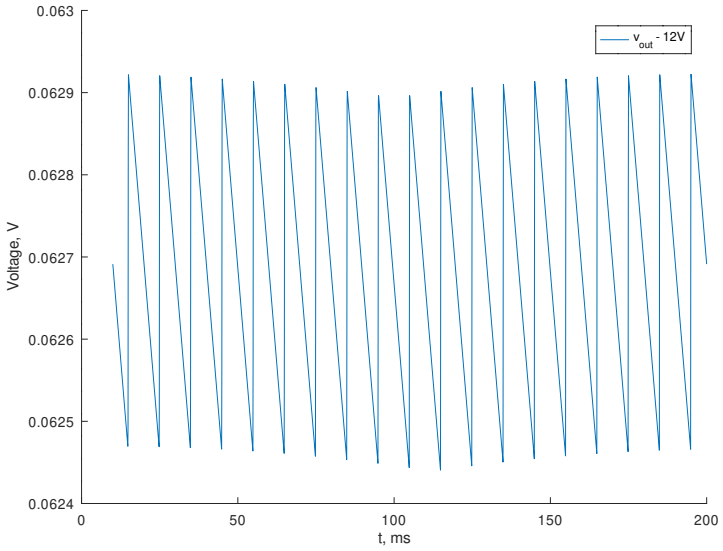

Figure 19: $V_{out} - 12V$.

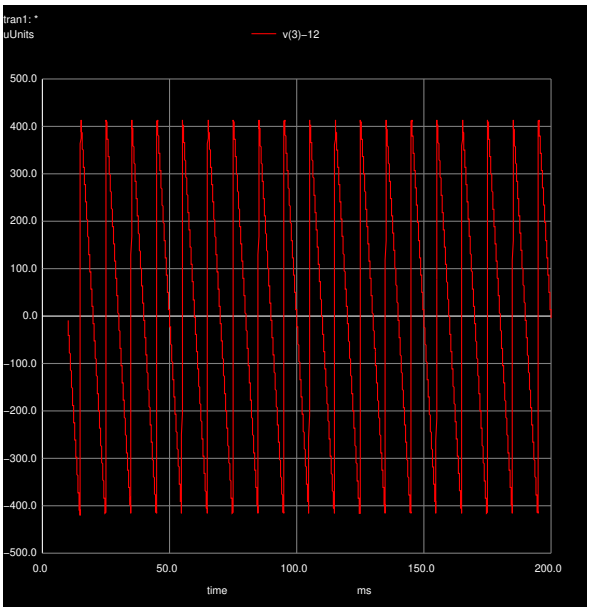

Figure 20: $v_3(t) - 12$ ($v_{out}(t) - 12$)

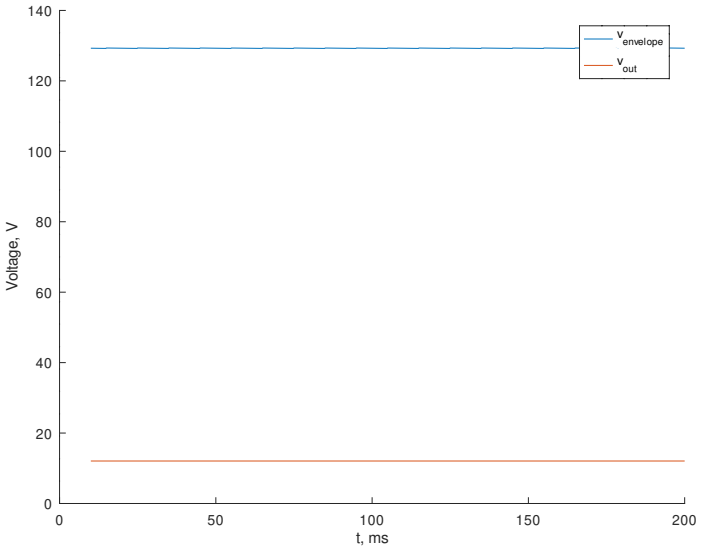

Figure 21: V_c and V_{out}.

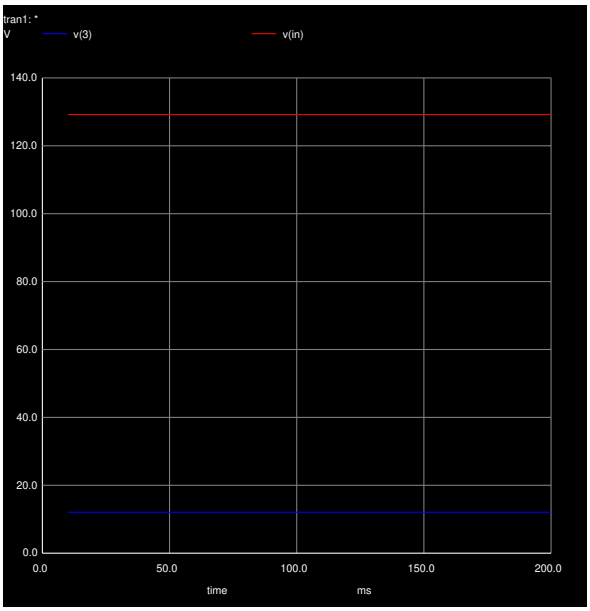

Figure 22: $v_3(t)$ ($v_{OUT}(t)$) and v_{IN} ($v_{Envelope}(t)$)