

Circuit Theory and Electronics Fundamentals

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T3 Laboratory Report

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1 Introduction

The objective of this laboratory assignment is to study a power converts, in this case alternate current(AC) to direct current(DC). This circuit uses a transformer, a full wave rectifier, a envelop detector and a voltage regulator, which had to be chosen from the lectures. The format of the circuit can be seen in Figure 1. And the circuit chosen can be seen in Figure 2

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

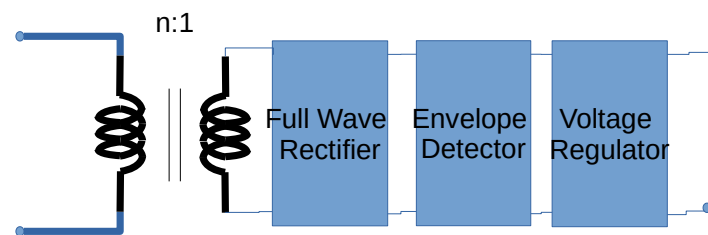


Figure 1: Assigned Circuit.

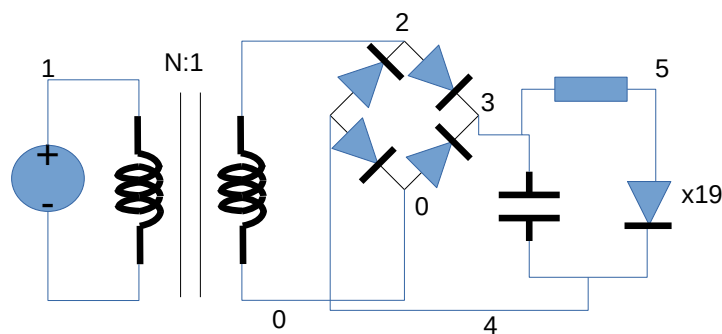


Figure 2: Chosen Circuit.

Note: the diode in the voltage regulator is merely representative, as there are in fact 19 diodes in this subcircuit

2 Simulation Analysis

2.1 Optimizer

In order to maximize the M value, we started with a simple circuit, and tried to make small changes and evaluate their results. The main changes were the value of the parameters of the chosen components, their number, and their location.

We realised that the manual optimization was going to be a long and difficult process, so we decided to create a simple optimizer to do it autonomously.

It has the capacity to change the capacitance of the Capacitor, the resistance of the resistor, the N value of the transformer, and the number of diodes. We found that it worked best if we fixed the values of some of these parameters. The combination that worked best for us was fixing the capacitor value, N value and the Diode Value, and only optimize the the transformer and capacitor. That means that we still had to tinker with the number of diodes and the resistance, but it was much less work intensive than tinkering with all the variables.

The program works by doing small variations of the values and evaluating their effect. It starts with a starting configuration. Then it chooses a parameter to variate at random, and varies it a random amount. Then it checks if it is better than the current best one. The second variation is done to the best performer, the combination with the best M value. This means that the best M value keeps improving if the program finds a best combination at random.

We ended up leaving the program for a few minutes for short optimization sessions, and found that the program had a high tendency to get the average voltage on point with the 12v, as expected. It also ran much faster than we were expecting. It ended up being a win win situation in our eyes, and it can be found in our git repo. Note that upon executing the code, since the results are tied to random values, the final answer might not be exactly the same as ours. It might even be better if it is given enough time.

| Component | Parameter Value |
|---|--------------------------|
| Resistor | 45 k Ω |
| Capacitor | 17.5150173805745 μ F |
| Number of diodes in the Voltage Regulator | 19 Diodes |
| Number of diodes in the full wave rectifier | 4 Diodes |
| N value of the transformer | 7.29150093083668 |
| Total cost | 64.81501 MU |

Table 1: Table of costs. Note that the total cost is sum of the the other values (in this units, with the number of diodes multiplied by 0.1).

2.2 Spice Results

Using the values stated above and using them in a simulated circuit in ngspice as shown in the circuit shown in Figure 2 we obtain the following results.

| Parameter | Value |
|-----------|-----------|
| mean | 11.998890 |
| Ripple | 0.005566 |
| Cost | 64.815017 |
| M | 2.310727 |

Table 2: Spice results. The M value and the cost were calculated by an additional octave script included in the git.

In the following image the blue line represents the voltage at the of the envelope detector, the red represents the voltage obtained by the transformer, and last, the orange represents the output voltage in the voltage detector.

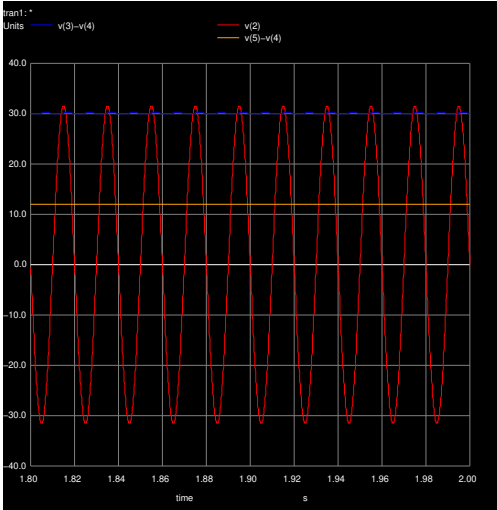


Figure 3: Detailed view

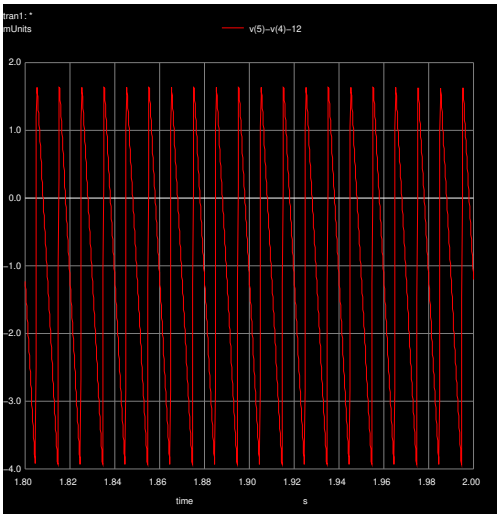


Figure 4: Detailed view

2.3 Simulation values for the theoretical analysis

In the Figure 5 we can see the results of small variations of the voltage values in the current that passes through the diodes (simulated using ngspice).

By definition, the incremental resistance in the diode can be calculated by $\frac{dv}{di} = \frac{1}{\frac{di}{dv}}$.

We then approximate the value of the derivative to its finite derivative, which is the value of the slope in 5.

Lastly, to calculate the value of the incremental resistance of one diode, we divide the value obtained previously by the number of the diodes, leading to a final 65.7894736842105 Ω .

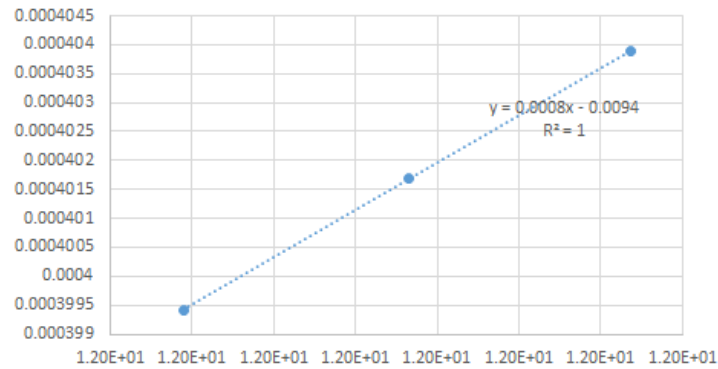


Figure 5: Current (in A) in function of the voltage (in V)

3 Theoretical Analysis

3.1 Voltage rectifier

First the current resulting from the transformer, which is considered ideal is calculated using the formula $V_2/n_2 = V_1/n_1$, thereupon, the circuit is analyzed to understand which diodes from the rectifier are on and off for each signal of current. Next, by using KVL, it is possible to define the tension on the capacitor without addressing its discharge $V_c = A \cos(w.t) - (n_{diodes} \cdot V_{on})$, being A the amplitude of the voltage after being transformed in the inductor.

3.2 Envelope detector

Capacitor discharge: By using KCL, it is possible to write that $i_d = i_c + i_r$ (i_r being the current if the equivalent resistor of voltage regulator). Once the capacitor is charged and because there is fluctuation due to the sinusoidal nature of the voltage coming from the rectifier, there will be a point where $i_r = -i_c$. At this point, the diode will turn off and the capacitor will begin to discharge. This point is called t_{off} and it can be calculated like

$$t_{off} = (1/w) \cdot \text{atan}(1/w/(C \cdot R_{vreg})).$$

The function that defines the discharging is calculated using a formula obtained in the lectures:

$$V_{exp} = (A - 2 \cdot V_{on}) \cdot \cos(w \cdot t_{off}) \exp(-(t - t_{off})/(C R_{vreg}))$$

3.3 Voltage at the Capacitor

The voltage at the capacitor will be the maximum between the sinusoidal function coming from the voltage rectifier and the function of the discharge.

We can decompose this voltage, v_C , in its DC component, V_c , and its AC component, v_c (V_c is the mean of the function and v_c is the function minus V_c).

3.4 Voltage Regulator

Output Voltage: The output voltage, v_O , will be the voltage measured in the nodes of the first and last nodes. This voltage can be decomposed in two components:

$$v_O = V_o + v_o$$

V_o will be equal to number of diodes, n_d times V_{on} .

To get v_o , it is used the incremental model of the diode, where it can be replaced by a resistor r_d . After using voltage divider, one can get the following:

$$v_o = \frac{n_d \cdot r_d}{n_d \cdot r_d + R} \cdot v_s$$

After doing this, the output voltage, v_O , has been calculated.

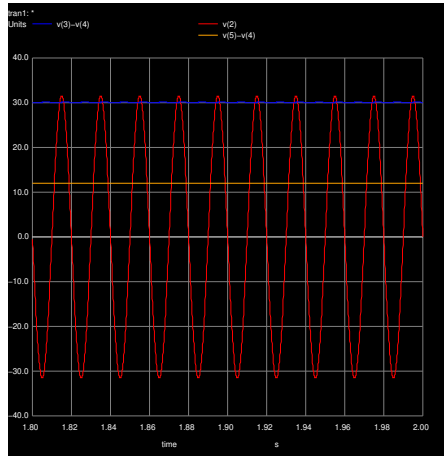
3.5 Results and Comparisons

The results obtained in the simulation and theoretical analysis were similar (as it can be seen in the graphics bellow):

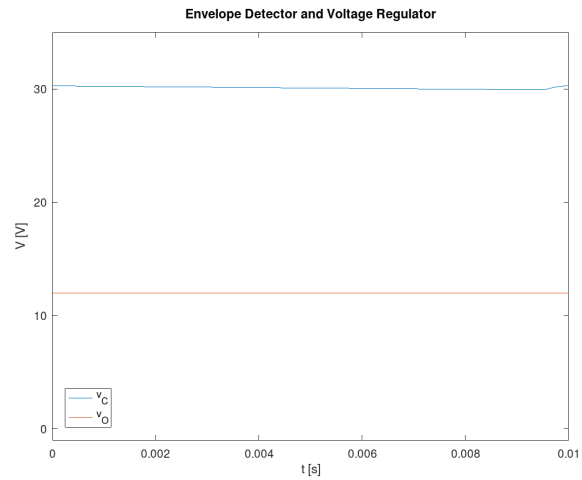
- The value of the voltage drop of the envelope detector is close
- The ripple's order of magnitude is the same

- The value of M is similar

Note that the DC component of the voltage regulator in the theoretical analysis is equal to the one obtained in the simulation because the value of V_{on} used in the theoretical analysis was taken from NGSpice.



(a) Simulation Results

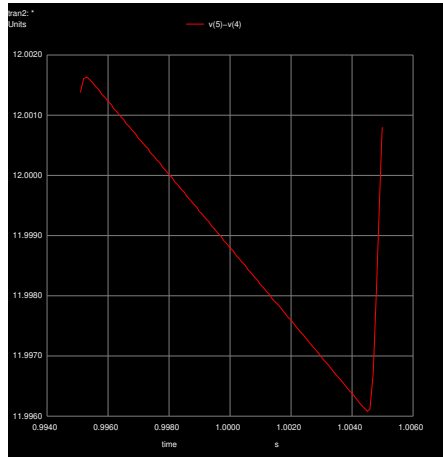


(b) Theoretical Results

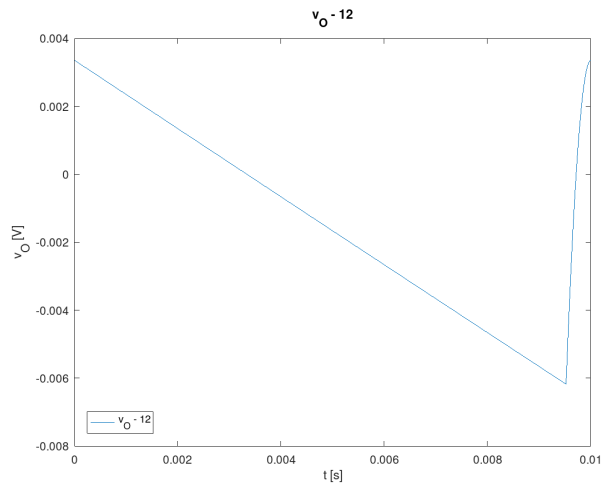
Figure 7: Envelope Detector and Voltage Regulator

| Parameter | Value |
|-----------|-----------|
| mean | 11.998890 |
| Ripple | 0.005566 |
| Cost | 64.815017 |
| M | 2.310727 |

Table 3: Spice results. The M value and the cost were calculated by an additional octave script included in the git.



(a) Simulation Results



(b) Theoretical Results

Figure 9: Deviation from the objective of 12 V

| Parameter | Value |
|-----------------|--------------|
| Output DC level | 11.998660 V |
| Ripple | 0.009528 V |
| Cost | 64.815017 MU |
| M | 1.884083 |

Table 4: Spice results. The M value and the cost were calculated by an additional octave script included in the git.

4 Conclusion

Unlike previous laboratories, this time, the results were not equal.

However, we believe that the differences are not that significant and they can be explained by how NGSpice solves the circuit compared to how it was done in the theoretical analysis.

To solve the circuit, NGSpice used far more advanced simulation methods for the diodes, with many more parameters, while we used an approximated model with V_{on} and an incremental resistor.

This way, the objective should have never been to have equal results, but rather, have results that are "close enough", which we believe it was achieved.