Lab 03 Report

Circuit Theory and Eletronic's Fundamentals

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1 Introduction

In this assignment, we present and analyse a possible design of an AC/DC voltage converter, with a desired output voltage of 12V and an input of a sinusodal signal with an amplitude of 220V and a frequency of 50Hz. Thus, we used an envelope circuit composed of an ideal transformer and full wave bridge rectifier in series with a parallel association of a capacitor and a resistor, followed by a voltage regulator encompassing 13 diodes and another resistor. The output voltage was mesured at the terminals of the diode association. Furthermore, a cost/effectiveness analysis was also done, with set prices for the diodes (0.1 monetary unit per diode), resistors (1 monetary unit per kOhm) and capacitors(1 monetary unit per micro-Farad).

We set $R_\beta = 10k\omega \;\; R_\phi = 19k\omega \; C = 10\mu F$ and $n = 2766.4$ together withe 17 diodes fulfilling a total cost of 40.7 MU.

We then began by analysing the circuit by means of simulation with *ngspice* and a theoretical approach using *Octave*. Afterwards the results from both methods were compared followed by a discussion of the efficacy of the AC/DC transformer.

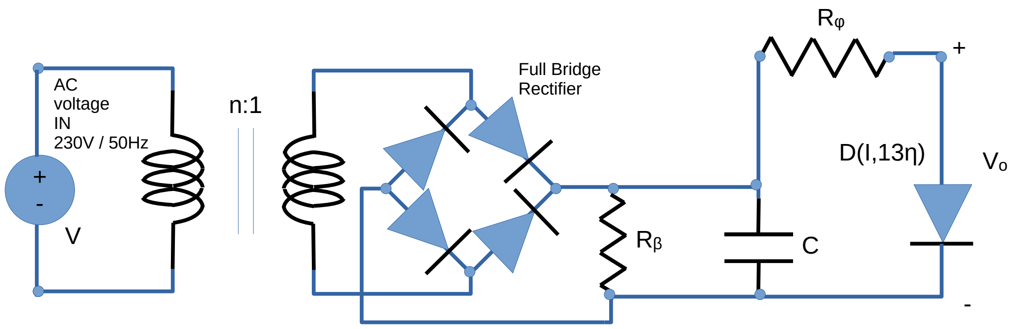


Figure 1: Studied Circuit.

2 Theoretical Analysis

The envelope circuit is composed of a full wave bridge rectifier and a parallel association of a capacitor and a resistance, as shown before. Making use of the ideal diode model we aproximated the voltage at the terminals of the capacitor as $|V_S|$. Therefore the current flowing through the capacitor is negative and increasing in modulus thus at a given instant it matches the current flowing through the resistance and the diode is turned off. The instant at which this occurs, t_{off} can be calculated with

$$t_{off} = \frac{arctan\frac{1}{\omega RC}}{\omega} \tag{1}$$

Afterwards, the circuit becomes a simple RC circuit

$$V_C = A\cos\omega t_{off} e^{\frac{t-t_{off}}{R_\beta C}} \tag{2}$$

At a given instant t_{on} the rectified source voltage will match the capacitor voltage and the diode will turn on again. At this point the advantage of using a full wave rectifier becomes evident. Because we take the absolute value of the source voltage t_{on} is about half a period earlier than it would be had an half wave bridge rectifier been used. Thus we obtained the following plots

It is to be noted that the oscillations of the output voltage occur with twice the frequency of the input signal, hence diminishing the ripple effect.

For the voltage regulator circuit we used the diode equation,

$$I = I_s\left(e^{\frac{V}{\eta V_T}} - 1\right) \tag{3}$$

where

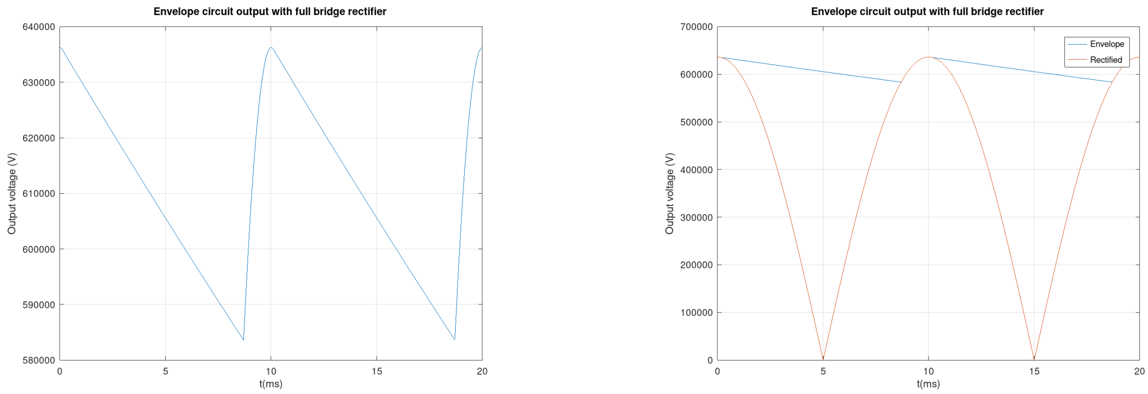


Figure 2: Envelope circuit output

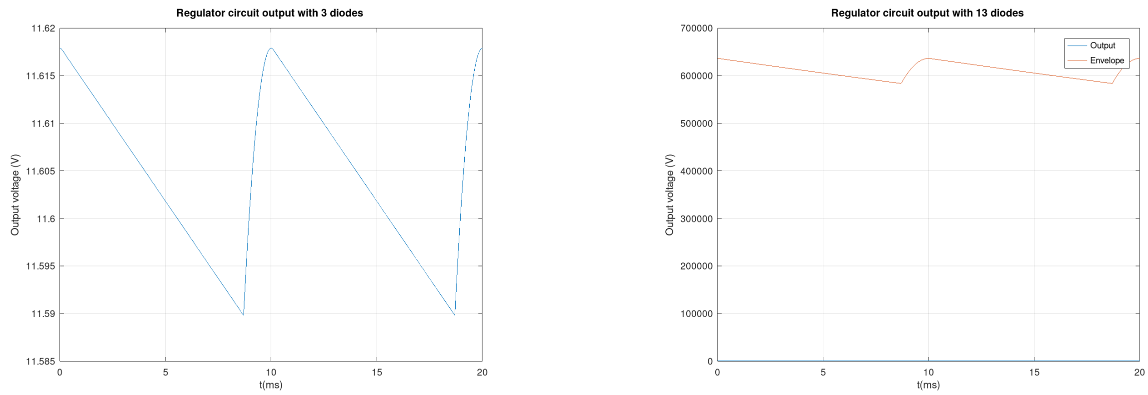


Figure 3: Regulator circuit output

$$I_s = 10^{-14}A$$
$$V_T = 25 \times 10^{-3}V$$
$$\eta = 1$$

in agreement with *ngspice* default diode model used afterwards.

Applying KVL to this circuit yields

$$V_C - R_\phi I_s\left(e^{\frac{V_{out}}{13\eta V_T}} - 1\right) - V_{out} = 0 \tag{4}$$

where V_{out} is the voltage at the terminals of the diode association This equation was solved point by point, using *Octave* method for solving non-linear equations[1], whence obtaining the following plots

It can be observed that the final output signal has kept the same shape has the output from the envelope although the amplitude of the signal has been largely attenuated as has the ripple effect. The ripple can been calculated as

$$ripple = max(V_{out}) - min(V_{out}) \tag{5}$$

[1] https://octave.sourceforge.io/octave/function/fsolve.html

and the DC level was taken as the mean of the voltage over two periods.

Additionally, we also calculated the ripple improvement from the voltage regulator signal compared to the envelope output as

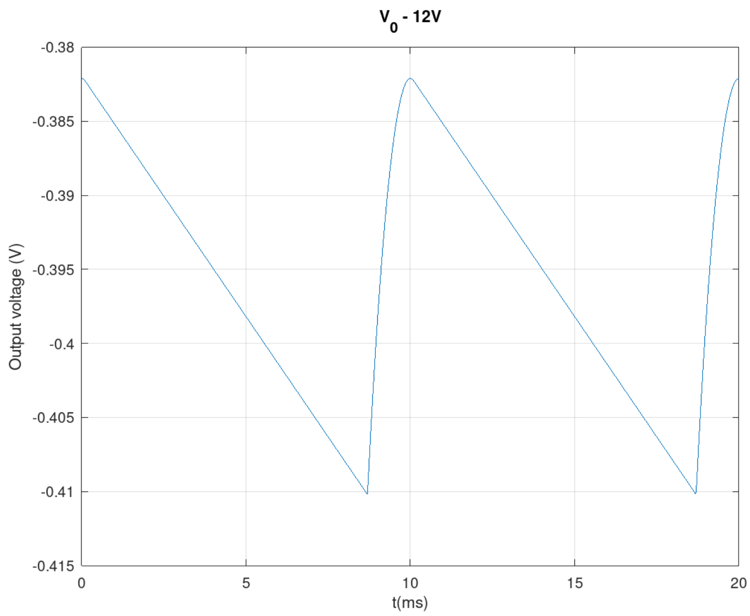
$$improvement = \frac{ripple(Envelope)}{ripple(Regulator) \times 100} \quad (6)$$

We obtained

$$ripple = 0.028074V$$

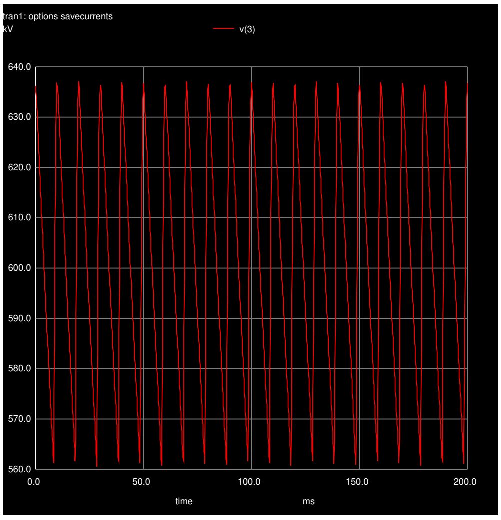
$$ripple\, improvement = 0.000053\%$$

$$DClevel = 11.604554V$$

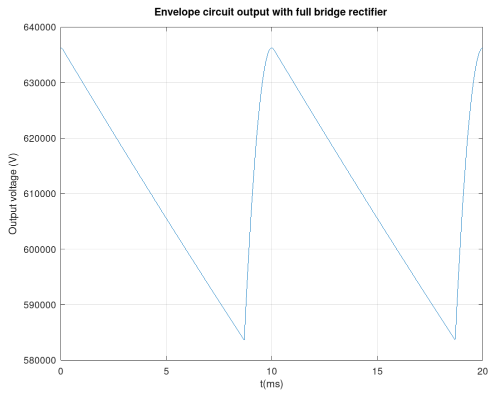


3 Simulation Analysis

Using *ngspice*, we began by analysing the circuit having obtained the following results for the voltage at the terminals of the envelope detector



(a) Capacitor Voltage - Vertical axis in kV - *ngspice*.



(b) Capacitor Voltage - Veritcal axis in V - *Octave*

Figure 4: Envelope circuit output

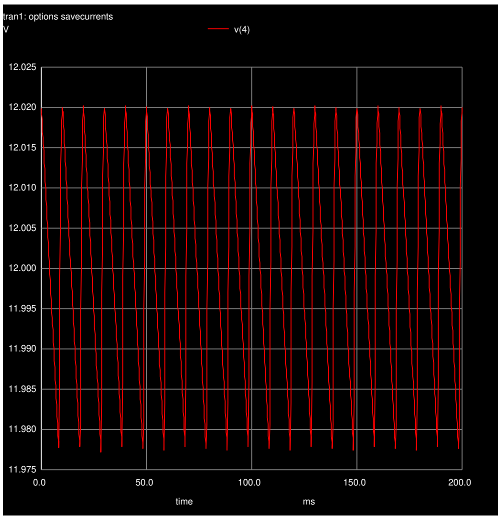
At this point the voltage is already semi-stable, having a small ripple effect, which was corrected with the voltage regulator circuit. It should also be noted that, while the overall shape and frequecy of oscilation is the same, there is a significant difference in the amplitude of the signal which radicates from the ideal diode approximation used in the theoretical analysis.

The output voltage is much more stable, having a signal with far less amplitude. Moreover, the diodes also diminish the overall value of the voltage, lowering the average to approximatly the desired value of 12V.

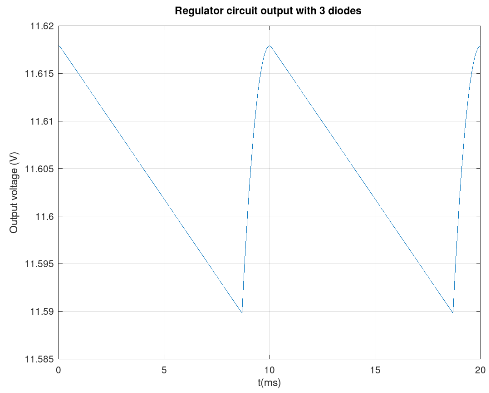
Once again, there are obvious differences from the theoretical analysis: the predicted voltage is much closer to 11V and the amplitude of the oscilation approximatly halved compared to their *ngspice* counterparts. Nontheless, this divergence can be inputed to *ngspice's* much more complex diode model and to the theoretical approximations made in the envelope detector analysis. Therefore, we chose to calculated the Merit figure for the transformer using the simulation results, having thus obtained

dclevel	1.200000e+01
maximum-minimum	4.311000e-02

Table 1: Output voltage DC-Level and Ripple (Maximum - Minimum)

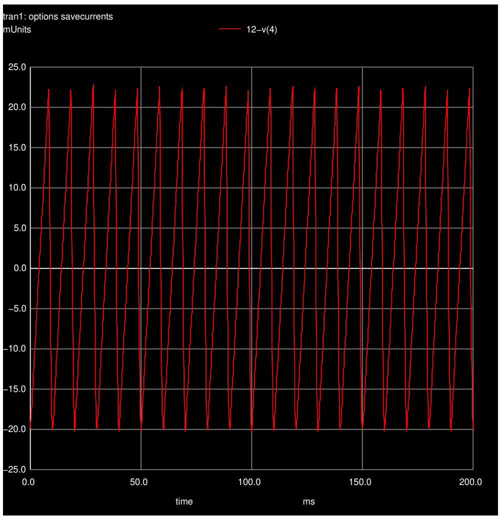


(a) Output Voltage - Vertical axis in V - *ngspice*.

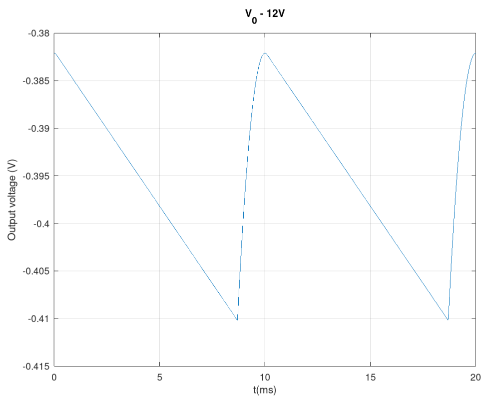


(b) Output Voltage - Veritcal axis in V - *Octave*

Figure 5: Circuit output



(a) Output Voltage-12V - Vertical axis in mV - *ngspice*.



(b) Output Voltage-12V - Veritcal axis in V - *Octave*

Figure 6: Output voltage-12V

4 Conclusion

The theoretical and experimental results had a clear difference, in most part caused by the assumption of an ideal diode. Still, with a very simple circuit, it was possible to attain very pleasent results, having very little ripple with a merit figure of $M = 0.570$. Even though it was still possible to get even more precision, by increasing the resistence, getting more diodes was cheaper, with some what similar results.