Circuit Theory and Electronics Fundamentals 2020/2021

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Third Laboratory Report

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Rui Rodrigues, 95844
Tiago Silva, 95850
Tomás Ribeiro, 95854

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1 Introduction

The objective of this laboratory assignment is to study and implement an AC/DC converter circuit while, at the same time, trying to maximize the figure of merit M. The AC/DC converter circuit can be separated into two circuits: an Envelope Detector circuit, that takes a (relatively) high-frequency amplitude modulated signal as input and provides an output (the demodulated envelope of the original signal), and a Voltage Regulator circuit, designed to automatically maintain a constant voltage. The circuit can be seen in Figure 1.

The implementation of the AC-DC converter circuit was made according to the theoretical or simulation principles we were based on, with the construction of two simillar circuits with just a few differences in the components value (such as the resistance of some resistors and the capacitance of the capacitors) and also in the components number (such as the number of diodes). These small adjustments were made in order to compensate the changes in the behaviour of the electric circuits components verified while implementing both the theoretical circuit in GNU Octave and the simulation circuit in NGSpice.

In Section 2, a theoretical introduction is made in order to contextualize all the main principles that sustain our construction and analysis of the circuit. A theoretical AC-DC coverter is built and carefully analysed in Section **??**, where the results are obtained in GNU Octave. Also, in Section **??**, another AC-DC converter is constructed and analysed by simulation through the use of NGSpice to simulate the real electric circuit behaviour. The results of the simulation of Section **??** are then compared to the theoretical results obtained in Section **??** and the comparative results are expressed in Section 4. The figure of merit, calculated according to the components used to build the simulation circuit, can also be found in Section 4. The conclusions of this study are outlined in the final part of the report, in Section 5.

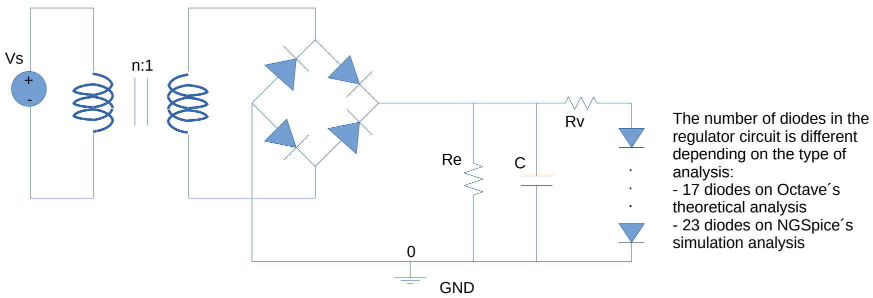

Figure 1: Third laboratory circuit.

2 Theoretical Introduction

Electric power is transported on wires either as a direct current (DC) flowing in one direction at a non-oscillating constant voltage, or as an alternating current (AC) flowing backwards and forwards due to an oscillating voltage. AC is the dominant method of transporting power because it offers several advantages over DC, including lower distribution costs and simple way of converting between voltage levels thanks to the invention of the transformer. AC power that is sent at high voltage over long distances and then converted down to a lower voltage is a more efficient and safer source of power in homes.

AC to DC converters are one of the most important tools in power electronics because a lot of real applications are based on this type of conversions. The AC current to DC current conversion process is known as rectification. This rectifier converts the AC supply into the DC supply at the load end connection. Normally, transformers are used to adjust the AC source to get the step down transformer to reduce the voltage amplitude, so that there is a better operation range for the DC supply.

The output voltage of the full-wave rectifier is not constant, it is always oscillating and thus can't be used in real-life applications. That's why it is required a DC supply with a constant output voltage. This need can be fulfilled by using an adequate filter with an inductor or a capacitor (envelope detector circuit) to make the output voltage smooth and constant.

This capacitor is connected in parallel to the load resistance in a linear power supply. The capacitor is used to increase the DC voltage and to reduce the ripple voltage of the output obtained. This capacitor is also called a reservoir or smoothing capacitor and it is generally followed by a voltage regulator which eliminates the remaining ripples so that the required output can be achieved.

While the rectifier conducts and the potential is higher than the charge across the capacitor, the capacitor stores the energy from the transformer. However, when the output of the rectifier falls below the charge across the capacitor, the capacitor naturally discharges its energy into the circuit. As the rectifier conducts current only in the forward direction, all the energy discharged by the capacitor will flow into the load. There are other types of filters, such as the half wave rectifier, studied in the theoretical classes. However, the efficiency of the full-wave rectifier is double that of a half-wave and the ripple voltage is lower using this four diodes bridge rectifier.

Finnaly, a voltage regulator is a circuit that creates and maintains a fixed output voltage, regardless of changes to the input voltage or load conditions. A simple voltage regulator can be made from a resistor in series with a diode or a series of diodes. The voltage regulators keep the voltages from a power supply within a range that is compatible with the other electrical components.

3 Theoretical Analysis

This theoretical analysis has, as its main purpose, showing how this circuit would behave in theory. this section is divided in two, given that this circuit, as explained in the theoretical introduction, is mainly composed of the two different stages - the gain stage and the output stage. However, there will also be a third subsection which will include the frequency response analysis for the whole circuit.

3.1 The Gain Stage

As already explained in the very first section of this report, the final objective of this lab assignment is to make an amplifier. Given so, this stage will have, as its main goal, to get a voltage gain as high as possible. In this subsection, the OP analysis of circuit will be made (DC current) and the gain, plus the input and output impedances, will be calculated.

3.1.1 OP Analysis

The first subject being analyzed is how does the circuit behave when the current is continuous (DC). This part is crucial when it comes to the study of the rest of the topics, such as the impedances, given that the incremental parameters of the transistors will be calculated based on the values obtained in the OP analysis.

$$\begin{cases} R_{B1} = \\ R_{B2} = \\ R_B = \frac{R_{B1}R_{B2}}{R_{B1}+R_{B2}} \\ V_{BEON} = \approx 0.7V \\ I_E = (1+\beta_F)I_B \\ V_E = R_E I_E \\ V_C = R_C I_C \\ V_O = V_{CC} - V_C \end{cases}$$

3.1.2 Voltage Gain

In order to compute the voltage gain, the values of transistor's incremental parameters are required, given by the expressions below:

$$g_m = \frac{I_C}{V_T} \tag{1}$$

$$r_\pi = \frac{\beta_F}{g_m} \tag{2}$$

$$r_o \approx \frac{V_A}{I_C} \tag{3}$$

$$\frac{v_o}{v_i} = -g_m(R_C||r_o)\frac{r_\pi||R_{B1}||R_{B2}}{R_S + r_\pi||R_{B1}||R_{B2}}v_S \tag{4}$$

In which v_S is the voltage supplied by the source.

3.1.3 Input and Output Impedances

Yet another very important property of this stage to be studied are the impendances, both the input and output ones. The relevance of the impedance, specially the output one, is that it gives an indication about the type of components that can be connected to it. Thus, through deductions made in the theoretical class, the final expressions that give the required values are the following:

$$Z_I = R_{B1}||R_{B2}||r_\pi \tag{5}$$

$$Z_O = R_C||r_o \tag{6}$$

And so, the final results for this stage were obatined:

Gain Stage Computations	
Data	Values

3.2 The Output Stage

As it can be seen from the output impedance obtained in the previous stage, it has a very high value to be connected to the 8Ω of the speaker in the end of the circuit. Therefore, the reasoning of this stage is precisely to solve that issue: to force the output impedance of the amplifier to have a reasonable value to be connected to an 8Ω speaker.

3.2.1 OP Analysis

Just like it was done for the Gain Stage, the operating point analysis for the output stage is also required. The fact that, such as the Gain Stage, this present stage also has a transisor, makes this analysis specially important given that the transistor's incremental parameters depend on the values obtained in this subsection.

3.2.2 Voltage Gain

As it was previously explained, the main justification for the existence of this Output Stage is to make the output impedance compatible with the 8Ω speaker. Given so, the voltage gain of this stage is expected to be 1, because it should simply transport the voltage gain of the previous stage to the already mentioned speaker.

It will be more convenient to work with admitances, therefore:

$$g_\pi = \frac{1}{r_\pi} \tag{7}$$

$$g_E = \frac{1}{R_E} \tag{8}$$

$$g_o = \frac{1}{r_o} \tag{9}$$

By using the Kirchhoff Current Law (KCL), the expression for the voltage gain of this output can be deduced:

$$\frac{v_o}{v_i} = \frac{g_m}{g_\pi + g_E + g_o + g_m} \tag{10}$$

3.2.3 Input and Output Impedances

Of all the computations already made for this stage, the impedances are certainly the most important ones. As it was already mentioned, the output impedance of this stage is supposed to be compatible with the 8Ω speaker so, by using the expressions deducted in class, the formulas that follow next were obtained:

$$Z_I = \frac{g_\pi + g_E + g_o + g_m}{g_\pi(g_\pi + g_E + g_o)} \tag{11}$$

$$Z_O = \frac{1}{g_\pi + g_E + g_o + g_m} \tag{12}$$

This way, the final results for this stage were obatined:

Output Stage Computations	
Data	Values

3.3 Frequency Response Analysis

Something that is of great interest to analyze an amplifier is how its voltage gain will vary accordingly with the frequency. As a consequence of that, this subsection will look forward to study the frequency response of the whole circuit, varying the frequency from an initial value of $10Hz$ to a final value of $10MHz$. It is important to add that, in this final topic of the theoretical analysis, a total number of 10 points per decade will be considered.

$$\frac{v_o(f)}{v_i(f)} = \frac{g_B + g_{m2}}{g_B + g_{e2} + g_{o2} + g_{m2}} \times Av_{GainStage} = \frac{g_B + g_{m2}}{g_B + g_{e2} + g_{o2} + g_{m2}} \frac{(r_\pi || R_{B1} || R_{B2})}{(R_S + r_\pi || R_{B1} || R_{B2})} v_S(-g_m(R_C || r_o) \quad (13)$$

4 Relative Error and Graphic Analysis

5 Conclusion

In this third laboratory assignment, all the major goals of the project were achieved. We concluded with success a further interaction with a new software (Ubuntu), with a simulation software (Ngspice), with a computational language program (GNU Octave) and with a text report editor (LaTeX). The construction and analysis of the circuit was also finished with success through simulation and theoretical interpretation, which allowed a good comparative analysis between the differences presented in the behaviour of a simulated and theoretical electric circuit.

In fact, this assignment allowed us to build two AC-DC converters which were able to transform the current and achieve an output voltage as close to $12v$ as possible. Even though we needed to construct two different electric circuits according to the simulation or theoretical principles we were based on, both of them were succesfuly implemented and achieved the pretended output voltage. The simulation results about the output voltage matched the theoretical results precisely. This accuracy was confirmed by the matemathical calculation of relative errors, which were proved to be really small. Also, the comparative analysis of graphics ploted by both theoretical and simulation tools confirmed the similarity of the results, obtained successfully and with notorious precision.