Instituto Tecnológico y de Estudios
Superiores de Occidente (ITESO)
Periférico Sur Manuel Gómez Morín 8585,
Tlaquepaque, Jalisco, México, C.P. 45090

Analog Electronic Devices (ESI038 / SE047)

Dr. Esteban Martinez Guerrero

Lab Report No.1 // Diodes: A Regulated DC Power Supply

Omar X. Avelar
Omar de la Mora
Diego I. Romero

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Building a Regulated Power Supply:

Objectives:

+ Find a way to measure the Shockley Equation Parameters of a real life Diode.
+ Use zener and regular diodes on the design to understand their typical applications.
+ Design a simple and regulated DC power supply using resistors, capacitors, rectifier diodes, zener diodes and a transformer.

Approach:

We will be building the circuit shown below to measure the Shockley Equation parameters of a real life diode.

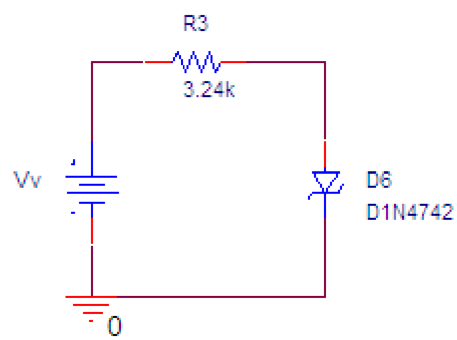

Fig. 1.1 – Circuit used to measure the zener diode parameters.

We are going to measure the voltage drop on the diode and the current flowing through the resistor. We will be taking data as we vary the voltage on the input. After the data has been gathered we will be able to plot the graph of voltage/current and watch how this specific diode behaves.

For the power supply design we will be using a transformer, building a rectifier bridge, and implementing a filter to smooth out the voltage output. The last step involves a zener diode to clip or limit the voltage and reduce the ripple effect caused by the sinusoidal source.

Components:

+ Digital Multimeter.
+ Oscilloscope.
+ 10X Probes.
+ Prototype Board.
+ Lab DC Power Supply.
+ 13 V RMS Transformer.
+ Resistors: [3.3k, 47, 330].
+ 330uF Electrolytic Capacitor.
+ 1N4007 Rectifier Diode X4.
+ 1N4742 @ 12 V.
+ PSPICE Software: Cadence OrCAD 15.7
+ Plotting Software: Excel
+ Regression Software: Graph

Explanation:

As we know, a diode is semiconductor; it is made by putting two materials together (N, P), between the two there is a place called the depletion region. Since these two materials have a different level of charge.

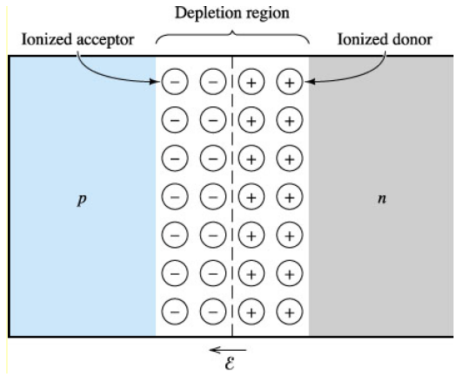

Fig. 1.2– Basic model of a diode.

Since we have two materials with different charge values, an electric field appears in between. As we polarize this material with voltage in the terminals the electric field starts to fight against the electric field the voltage source produces and the resultant electric field starts to diminish until at a given voltage level the resultant electric field starts to go in a direction as the current is supposed to flow.

Therefore in an ideal situation the diode acts as a switch that is on as the diode is polarized directly and acts as an open circuit if the voltage is reversed.

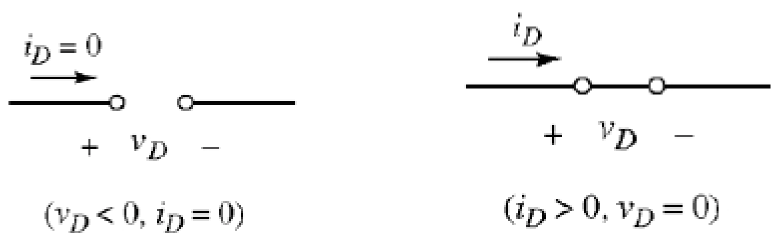

Fig 1.3 - Reverse biased Direct biased

This type of application is vital for building a DC power supply from an AC signal, as we will rectify the negative or positive side of the AC signal, only leaving the rectified signal on the output.

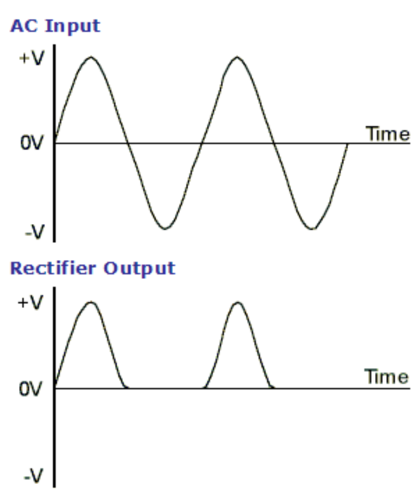

Fig. 1.4 – Half-Wave rectification by a rectifier bridge.

As the positive portion of the signal is extracted (rectified) we must then find a way for the voltage magnitude to vary less, as we know a capacitor is known to prevent sudden voltage drops/spikes then we have to add it to the signal path, this process is called smoothing, and the capacitor used is called the smoothing capacitor. We need to plan the value of that capacitor so we need to take into account the frequency of the signal so it remains charged.

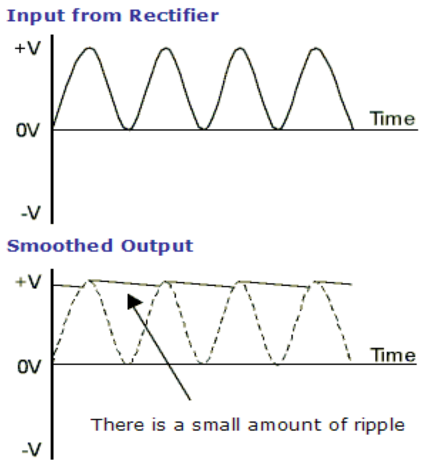

Fig. 1.5 – Smothening of the signal.

The next step is to clip or limit the voltage to reduce the ripple effect caused by the filter with a zener diode on reverse bias; zener diodes have a higher level of impurities in their materials so the magnitude of electric field it' is able to withstand can be greater before it reaches breakdown.

Therefore a zener diode in reverse bias will have a constant voltage drop (defined as Vz) through it as long as it is working and the current flowing is above Iz, and on direct bias it will work as a regular diode.

Diodes can be modeled by an equation which takes into consideration parameters such as Is, Vt, n, VD. This exponential curve is written as follows:

$$I_D = I_s\left(e^{\frac{V_D}{nV_T}} - 1\right)$$

This equation is known as the Shockley Equation and the parameters are known as:

n : Emission coefficent.
Is: Saturation current.
Vt: Thermal voltage.

The thermal voltage is give by these two parameters:

$$V_T = \frac{kT}{q}$$

Where:
k = Boltzmann's constant = 1.38 x 10^(-23) [Joule/Kelvin]
T = Temperature = 273 + (Celsius Temperature) [Kelvins]
q = the electronic charge magnitude = 1.6 x 10^(-19) [Coulombs]

This values can be calculated by experimenation and certain manufacturers give you the information on their datasheets but if needed you can also go on and calculate them with a curve aproximation.

Results:

First we will start by calculating the Shockley parameters, since we need to be precise on our measurements we checked the 3.3k resistor and measured a value of 3.24k.

Then we set the circuit described below and measure.

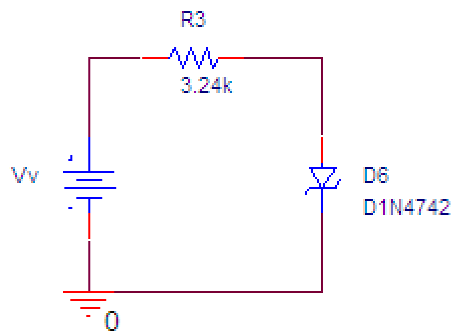

Fig. 1.6 – Circuit in series to measure the current flowing through all the components.

The next table shows the values of our measurements and a graph of

V	I_z
0.38	0
0.46	0
0.5	0
0.52	0
0.62	0.01
0.68	0.05
0.72	0.16
0.76	0.43
0.77	0.64
0.79	1.01
0.8	1.27
0.8	2.51
0.8	3.09
0.8	4.51

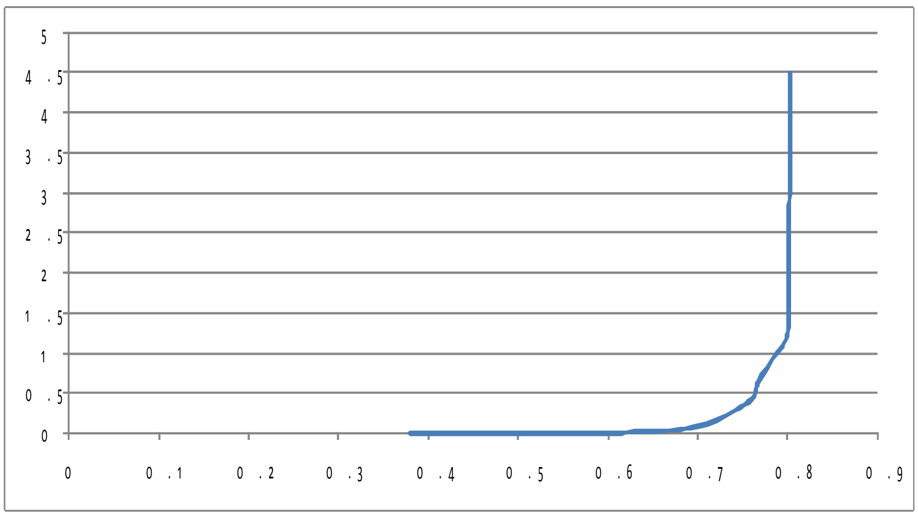

Fig. 1.7 - Forward voltage on our diode.

After drawing the curve that represents the correlation between voltage and current in the diode we can use mathematical analysis software to make the scale semilogarithmic and find the intersection point with the vertical (current) axis.

That point will be the saturation current (Is); we also need to find out Vt, but as we know:

$$V_T = \frac{kT}{q} = \frac{(293\text{K})(1.38\text{x}10^{-23}\,J/K)}{1.6\,x\,10^{-19}\,C} = \mathbf{25.271}\,[\boldsymbol{mv}]$$

That takes us back to our measurements table to get the emission coefficient (n).

$$0.00005 = 100\text{x}10^{-6}\left(e^{\frac{0.68}{n(25.271\text{x}10^{-3})}} - 1\right) \rightarrow \boldsymbol{n = 1.37}$$

As we can see on the figure below Is = 100 [uA] by approaching using the graphical method.

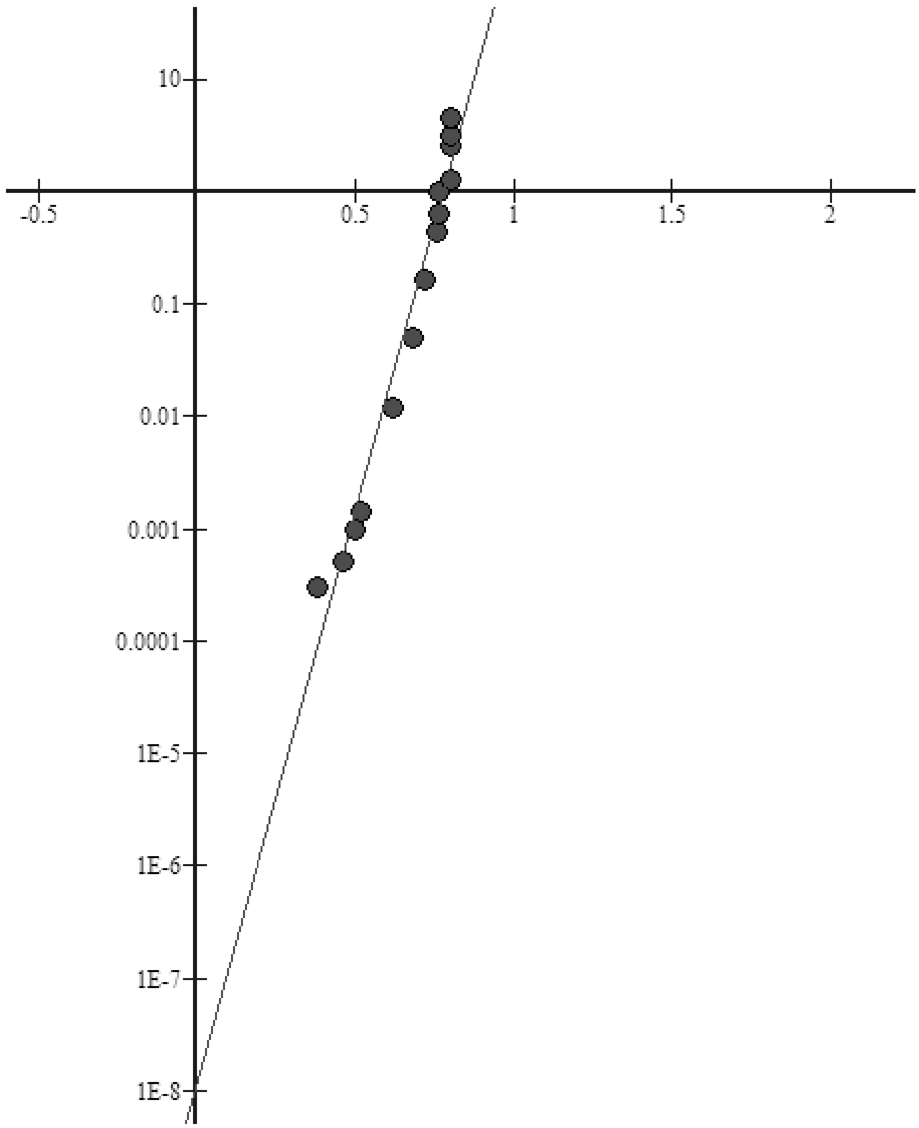

Fig. 1.8 – Semilogarithmic curve of our measurements

And now that we know the value of n we can put the Shockley Equation that simulates this diode.

$$V_D = 100\text{x}10^{-6}\left(e^{\frac{V_D}{1.37(V_T)}} - 1\right)$$

As the DC power supply design has been planned we now can sketch the schematic of the power supply by taking into consideration the process we planned on the explanation.

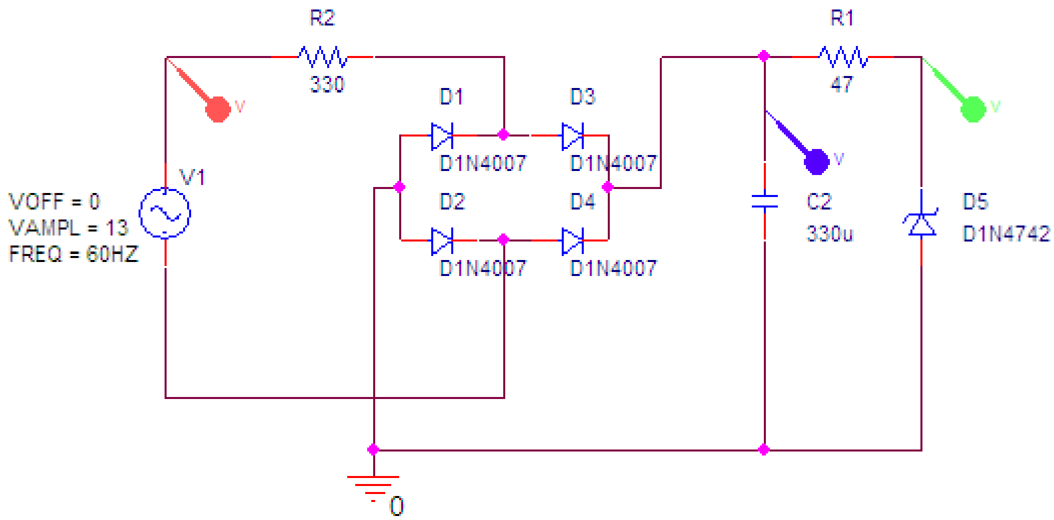

Fig. 1.9 – Power Supply built with a rectifier bridge, transformer, and a capacitor.

Since the speed of discharging is determined by the time constant RC we need to choose the minimum value of this capacitor based on the resistive load the capacitor *sees*. These values will be chosen based on the desired tolerance of voltage change or ripple wanted on the capacitor.

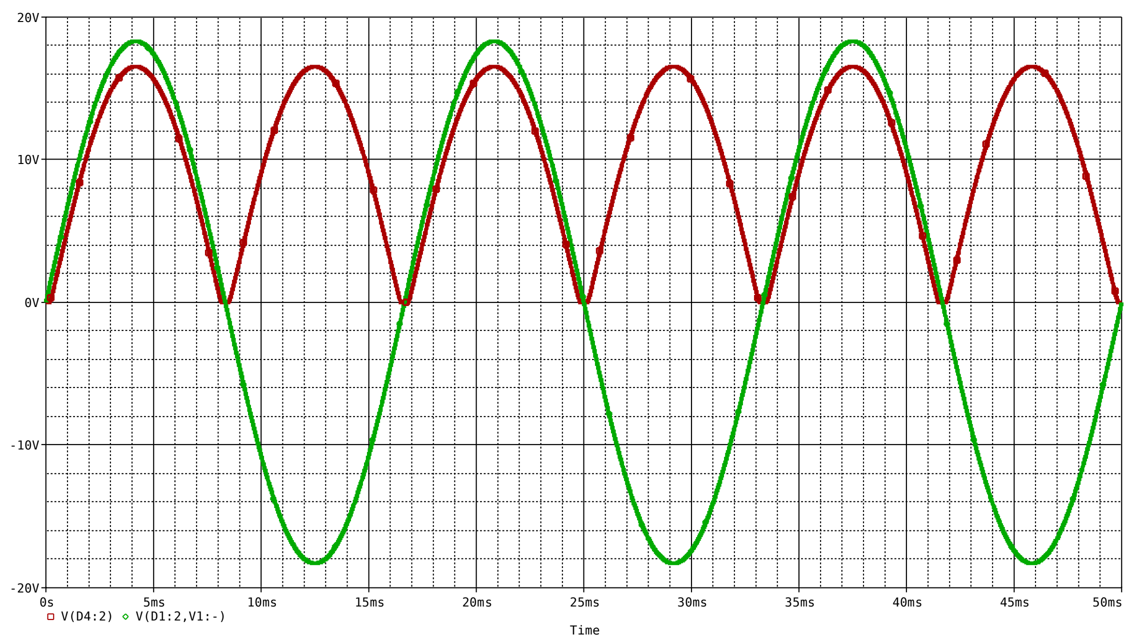

Fig. 1.10 – Rectified signal vs AC Signal.

We have chosen a 330uF capacitor, as the maximum peak of the current is given by:

$$C\frac{dV}{dt}=C\frac{d[\sin(120\pi)]}{dt} = 120C[\cos(120\pi)]\ [A]$$

So the maximum peak we are going to get with a 330uF will be $39.6[mA]$ therefore the maximum transient peak current will not be going over and as the 1N4001 rectifier diodes have a peak tolerance of 1 [A] it is safe to say we are able to use that capacitor value.

We now need to take into consideration that the AC line can have a 20% variation, and by the specifications the current on the load can vary from 0 to 25 [mA]. As the data sheet of the 1N4742 indicates the minimum current needed for it to operate is 0.25 [mA].

By taking into consideration the AC line tolerance we have this next circuit to work with:

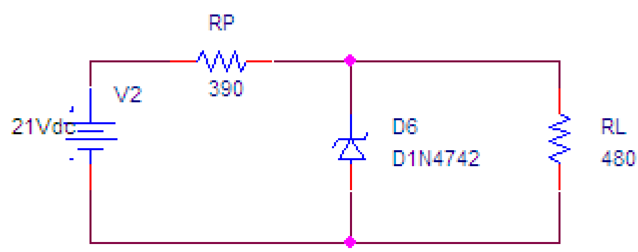

Fig. 1.11 – Protected circuit within our specifications.

So the current flowing through the RP resistor will be 25.5 [mA] at maximum, with 0.5 [mA] going by the diode and 25 [mA] as the maximum by RL.

So the value of the RP resistor is given by: $\frac{21-12}{25.25}=356.4\,\Omega\simeq 390\,\Omega$

And the minimum RL allowed is: $\frac{12}{0.0005}=24\text{k}\,\Omega\simeq 27\text{k}\,\Omega$

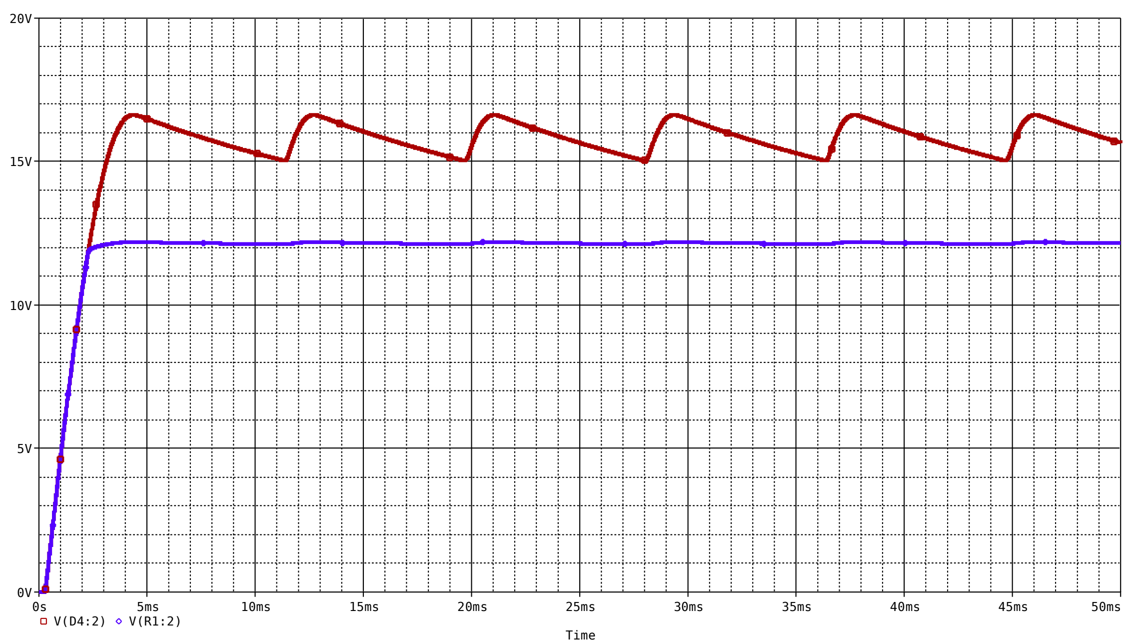

Fig. 1.12 – Ripple effect shown on the red line and blue line keeping the zener voltage constant.

Then after the design was complete we proceeded to build the power supply in the lab and took the next screen captures.

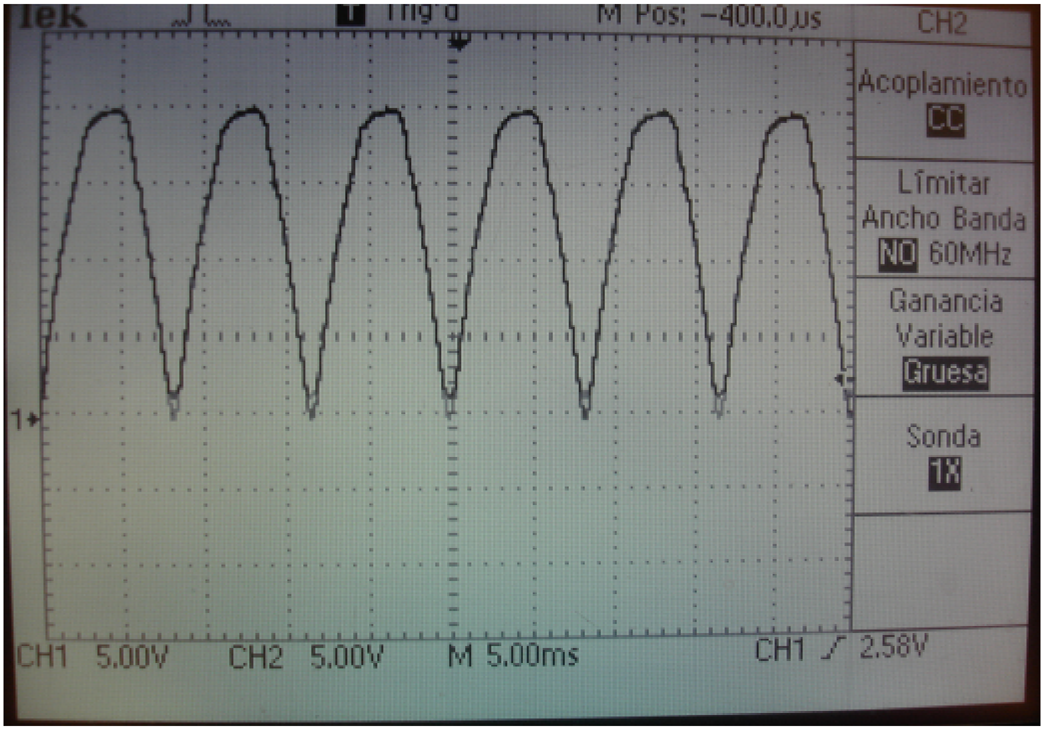

Fig. 1.13 – Rectified Signal.

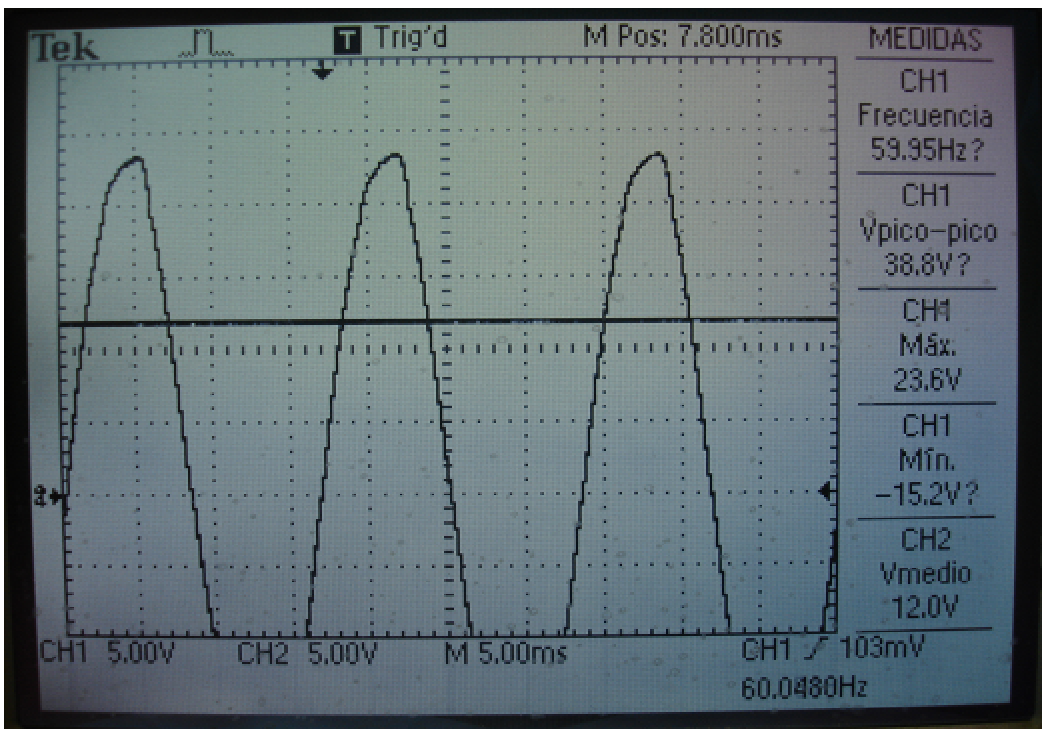

Fig. 1.14 – Rectified and controlled voltage by the zener diode.

Conclusions:

As we have studied the implementations of diodes can vary, they go from switches to clippers. We used those two applications to build a DC power supply to "take out" one polarity from the AC portion and after it was smoothened we used a zener diode clipper to reduce the ripple effect.

The ripple effect can be considered a con in DC Power supplies because it introduces noise to other components that need to have a steady voltage to work such as computers, medical instrumentation, mobile devices and many others.

We also tested our knowledge by analyzing and using a methodology to get the parameters of a diode by using tools such as an oscilloscope, digital multimeter, steady and precise power supply and math analysis software.

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