THE COLLEGE OF NEW JERSEY

School of Engineering

ELC333-L1 **Spring 2020**

Lab 2

Diode-Based Analysis and Design

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1. Introduction (JB)

1.1 Objectives:

- Characterize the behavior of the Zener Diode.
- Design, construct, and test a dc power supply composed of voltage rectifier, low-pass filter, and voltage regulator.
- Examine the response of this circuit to changes in load.

1.2 Importance:

Zener Diodes have properties that allow us to create circuits we could otherwise not, since their forward bias is much lower than their reverse bias, they can be used to generate DC signals from AC signals when combined with filters and regulators.

1.3 Theory:

Zener Diodes have a larger reverse bias and a smaller forward bias, allowing current to pass through one way much easier than the other. In this lab, the zener diodes used will pass anything above 0.7v through its forward direction while it will only allow 5.1v and higher through its reverse direction. Due to this property, an AC signal of under 5.1v can be converted to a switching dc signal which can be further regulated.

2. Materials and Devices (JB)

- VirtualBench power supply and digital oscilloscope
- Signal Generator
- Digital Multimeter
- 1N4733 Zener Diodes
- 1N4733 Zener Diodes Datasheet

3. Procedure and Analysis (JB, MF, AB)

3.1 Diode Characterization:

Step 1: Acquire 1N4733 Zener Diode from the stock room and download the device's datasheet.

Step 2: Measure the resistance of the diode in both forward and reverse directions using the digital multi-meter (DMM).

Step 3: Using the information in step 2, complete the table below.

Direction	Resistance
Forward	892.55 K ohm
Reverse	Over 10M ohm

Table 1. Resistance of the Zener seen by the DMM

Step 4: Measure the current conducted by diode while both forward and reverse biased using the digital multi-meter (DMM). The schematic shown in Figure 1 demonstrates how this may be done.

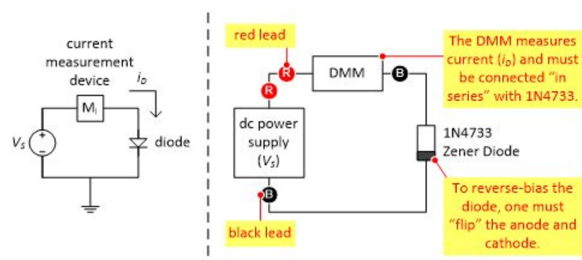

Fig 1: Test Circuit required to measure current flow through 1N4733 Diode

Step 5: Using the information obtained from step 4 complete the table below.

Bias	V_{diode} (V)	I_{diode} (A)
Reverse	-5.750	00.3100
Reverse	-5.500	00.1925
Reverse	-5.250	00.0840
Reverse	-5.000	00.0186
Reverse	-4.500	00.0022
Reverse	-4.000	00.0006
Reverse	-3.000	00.0000
Reverse	-2.000	00.0000
Reverse	-1.000	00.0000
Forward	0.000	0
Forward	0.250	00.0000
Forward	0.500	00.0000
Forward	0.64	00.0001
Forward	0.66	00.0002
Forward	0.68	00.0004
Forward	0.70	00.0008
Forward	0.72	00.0015
Forward	0.74	00.0032
Forward	0.76	00.0061
Forward	0.78	00.0112

Table 2. Voltage-Current Characteristics for the 1N4733 Diode

Step 6: Calculate the value of V_T such that (1) describes the data presented in Table 2, by fitting data obtained in the range: $0.64 \leq V_{diode} \leq 0.78$ V. Show work.

$$i_D = 0.00001\,\mathbf{exp}\left(\frac{v_D}{V_T}\right) \textit{in uA}$$

Equation 1. Behavior of the diode for positive values of V_{diode}

1. By converting i_D to μA and averaging all the forward bias results we get an appropriate i_D value.
2. Averaging all the values of V_D for the forward bias allows us to compute the equation above.
3. $2.13636 \cdot 10^{-9} = 0.00001^{\frac{0.584545455}{V}}$
4. V = 0.337

Step 7: Graph the results from Table 2 along with the trendline defined above.

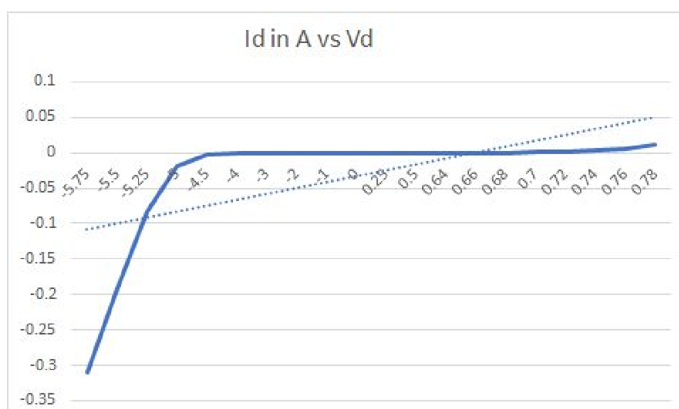

Fig 2. Table 2 Graph with trend line.

Step 8: What is the "nominal" forward-bias voltage across the 1N4733 diode?

The "nominal" forward-bias voltage is 0.72V

Step 9: What is the Zener Voltage associated with the 1N4733 diode? What does this value mean?

The associated Zener Voltage is 5.1v. This means that the diode protects the circuit from voltages above 5.1v.

3.2 Diode Voltage Rectifier:

Step 10: Design a full-wave diode rectifier in PSpice using 1N4149 Zener Diode Model

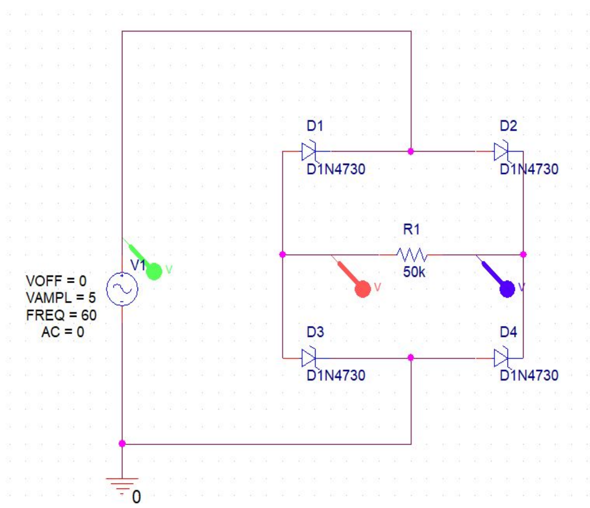

Fig 3. PSpice full-wave diode rectifier.

Step 11: Open a new simulation profile using the button in the top-left corner of the screen.

Step 12: Simulate the transient response of this circuit to 0.05s (approximately 3 cycles). Then copy data to Excel

Step 13: Using the data obtained from Excel create a Graph that compares the simulated input and output of this full-wave diode rectifier.

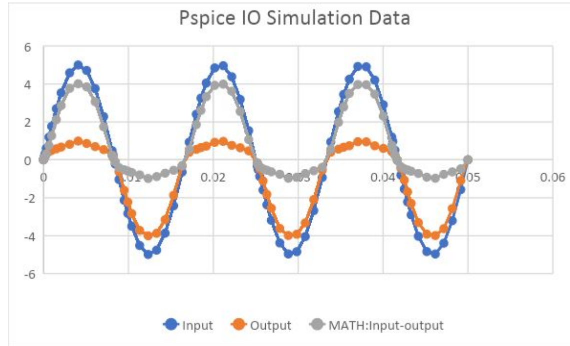

Fig 4. Graph that compares the simulated input and output of full-wave diode rectifier.

Step 14: Build the circuit shown in Figure 3 using 1N4733 Zener Diodes, 1kΩ load resistor, and waveform generator.

Step 15: Include a picture of the hardware.

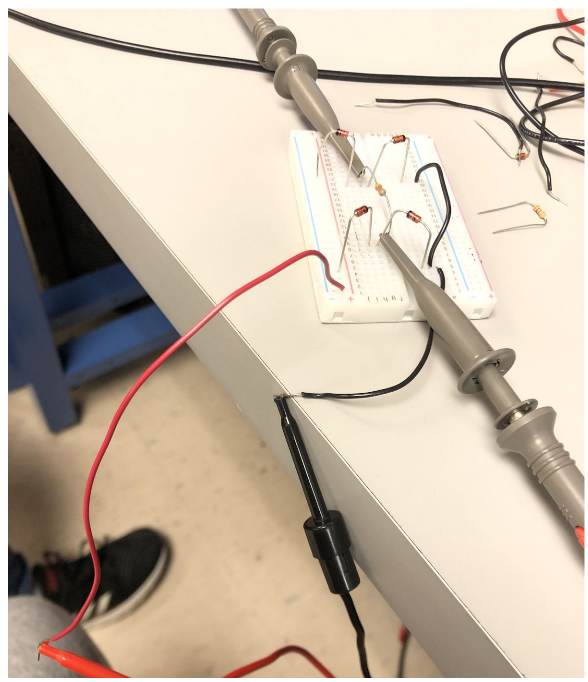

Fig 5. Hardware of the circuit shown in figure 3.

Step 16: Supply the circuit an appropriate input $V_s = 5sin(2\pi 60t)$. Measure both the input and output waveforms using the VirtualBench oscilloscope.

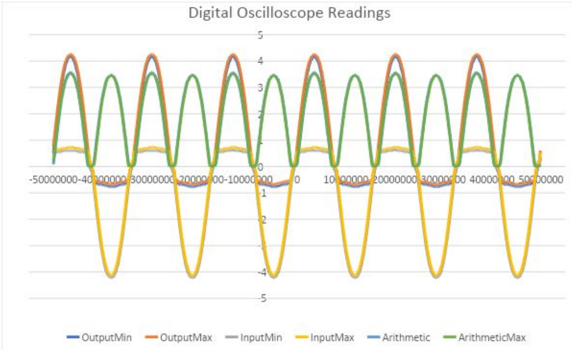

Fig 6. Oscilloscope Readings of I/O waveforms

3.3 Low-Pass filter:

Step 17: Design an RC low-pass filter with corner frequency of 60Hz using (Equation 2) where R = 1kΩ. In the lab report, include a schematic for this circuit. Show calculation of C.

$$f_0 = \frac{1}{2\pi RC}$$

Equation 2. Corner frequency of low-pass filter

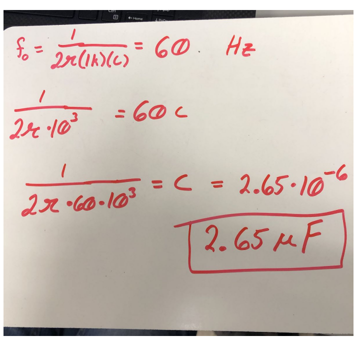

Fig 7. Calculation of the C Value

See Figure 8 for schematic design.

Step 18: In the lab report, include a screenshot of this PSpice schematic.

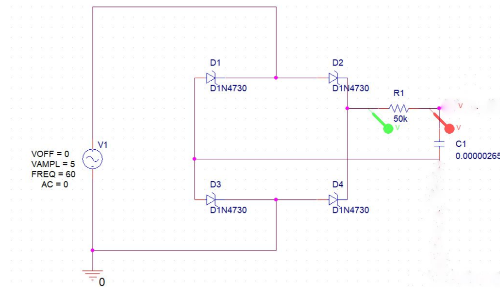

Fig 8. PSpice Schematic of Low Pass RC Filter

Step 19: Simulate the transient response of this circuit to 0.5s (approximately 30 cycles). Use a maximum step-size of 0.1ms. In the lab report, include a graph that compares the simulated input and output of this full-wave diode rectifier. Please graph all simulation data in Microsoft Excel.

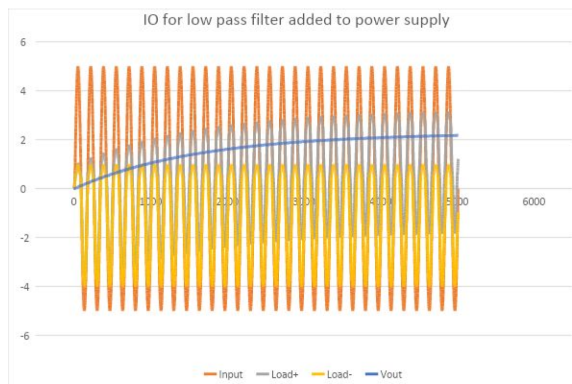

Fig 9. Low Pass I/O Graph

Step 20: Explain what is happening during the first 200ms of this simulation.

During the first 200ms the voltage oscillates very frequently but always maintains about the same amplitude. The values also steadily increase starting from 0 and stabilize around 200ms.

Step 21: Build the circuit

Step 22: Include a picture of this hardware.

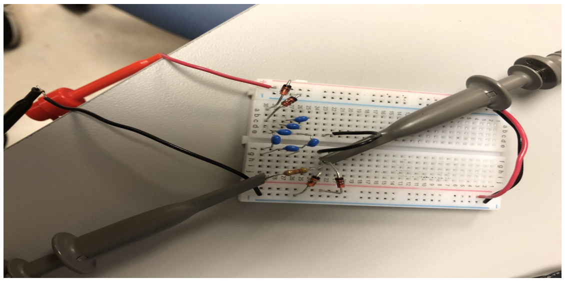

Fig 10. Low Pass Filter Hardware

Step 23: Supply the circuit an appropriate input Vs = 5sin(2π60t). Measure both the input and output waveforms using the VirtualBench oscilloscope. Export this data from the VirtualBench. Store and graph it via Microsoft Excel. Include both waveforms as a single graph in the report.

Fig 11. New I/O Graph for Low Pass Filter

Step 24: What is the average output voltage of this circuit in hardware? How does it compare to the desired value of 2.8V?

The average output voltage of this circuit in hardware was 2.35v. This was a little bit smaller than the expected value of 2.8v.

3.4 Diode Voltage Regulator:

Step 25: Design a voltage regulator to regulate the output at 2.8V. How many diodes (in series) are required?

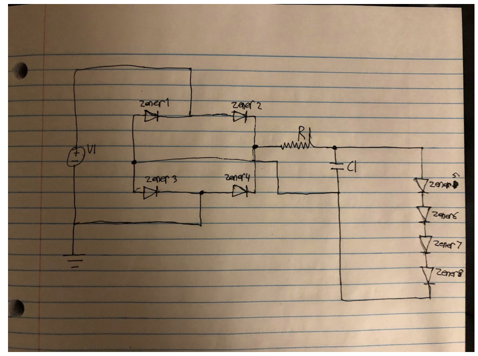

Fig 12. Voltage Regulator Design

Step 26: Implement this circuit in PSpice. The diodes should be placed in parallel with the low-pass filter previously implemented.

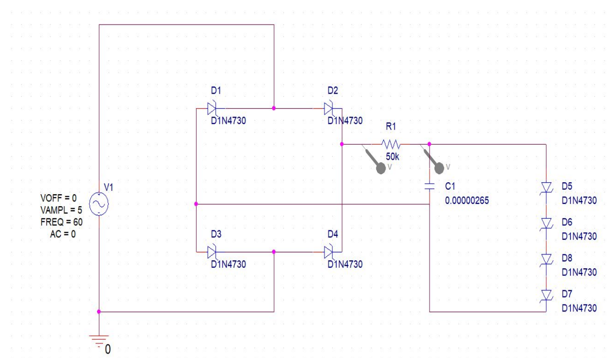

Fig 13. PSpice of the voltage regulator to regulate at 2.8V.

Step 27: Simulate the transient response of this circuit to 0.5s. Use a maximum step-size of 0.1ms.

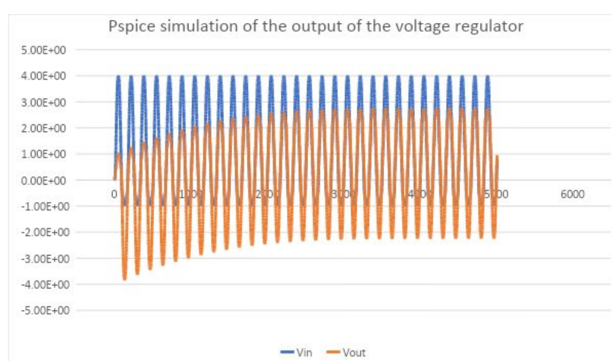

Fig 14. Simulation of the transient response of the circuit in Excel.

Step 28: Complete the DC power supply by placing diode-based voltage regulator at output of the low-pass filter.

Step 29: Include a picture of the hardware.

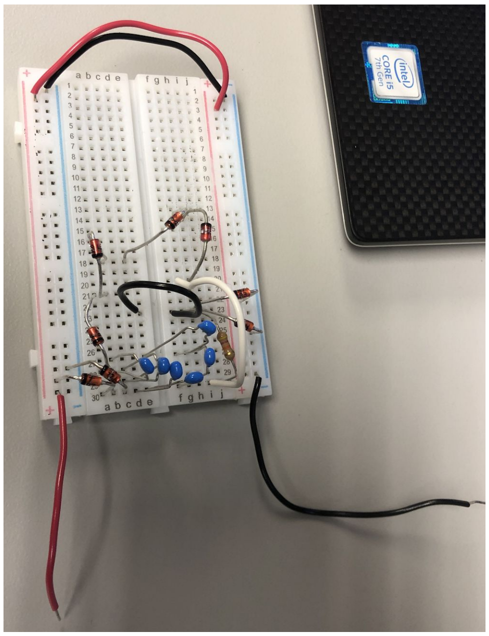

Fig 15. Voltage Regulator to regulate at 2.8V hardware.

Step 30: Supply the circuit an appropriate input Vs = 5sin(2π60t). Measure both the input and output waveforms using the oscilloscope. Export this data from the VirtualBench. Store and graph it via Microsoft Excel. Include both waveforms as a single graph in the report.

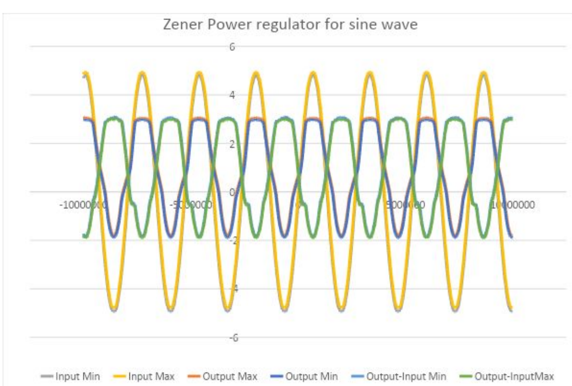

Fig 16. Sine Wave I/O Waveforms Graph

Step 31: How does the average output of the DC power supply in PSpice compare to hardware?

The average output in PSpice is exactly like the average output from the hardware.

3.5 Load Testing:

Step 32: Place a 50kΩ load resistor in parallel with the multi-diode voltage regulator (across VOut). Copy and paste the resulting output waveform into the lab report with oscilloscope measurements for: 1) average and 2) amplitude. Repeat this process for RL = 10kΩ, 5kΩ, and 1kΩ.

Fig 17. 50kΩ load resistor in parallel with the multi-diode voltage regulator

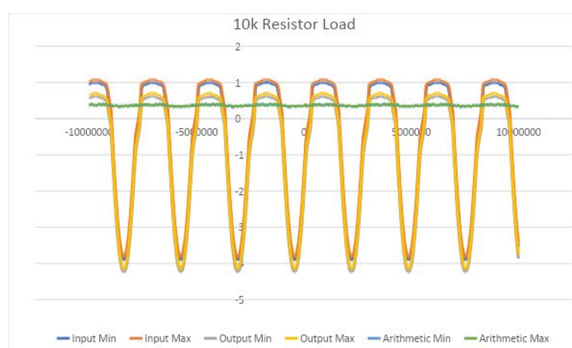

Fig 18. 10kΩ load resistor in parallel with the multi-diode voltage regulator

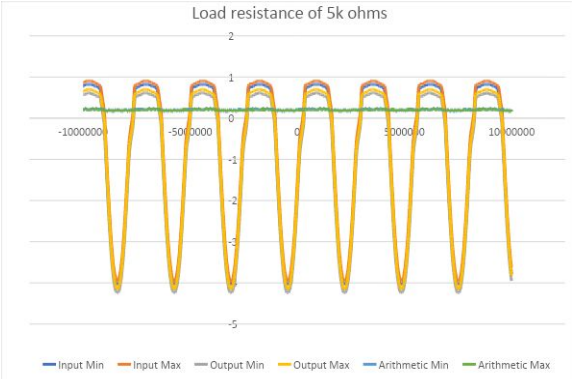

Fig 19. 5kΩ load resistor in parallel with the multi-diode voltage regulator

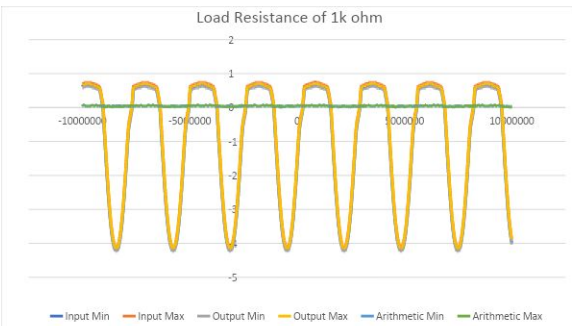

Fig 20. 1kΩ load resistor in parallel with the multi-diode voltage regulator

Step 33: What is the effect of RL on average DC output as well as its ripple? What is its effect on % voltage regulation? Why? Use the equations below to solve.

$$\text{Vripple} = |\mathbf{max}(V_L) - \mathbf{min}(V_L)|$$

Equation 3. Ripple voltage

$$\text{voltage regulation} = \text{Vripple} / V_L\text{nom}$$

Equation 4. Voltage regulator

Vripple = 0.658436 - 0.576132 = 0.082305v

Vreg = 0.082305v/2.8v = 2.9394%

Step 34: Would this design operate correctly for AC input with an amplitude of 50V? Why or why not?

No, this design would not operate correctly with such a high voltage, as Zener diodes will only block 5.1v reverse and 0.7v forwards, thus a maximum voltage of 4.4 can be achieved.

4. Conclusion (MF, AB)

4.1 Background Research

In order to complete the lab, students would need to research the 1N4733 Zener Diode. Students would also need to do research on equation 3 and also with equation 4 in order to complete all the steps. The book Microelectronic Circuits – 6th edition, is useful to understand the equations and Zener diodes. In the students' eyes, the objective of the lab is understanding how 1N4733 Zener Diode works by making circuits with PSpice and hardware.

4.2 Procedure

To complete this lab, the group tested the diodes characterization by using the digital multimeter to view the current with different voltage. There would also be various different circuits such as Figures 3, 8, and 13 to view how the Zener diode would change the voltage. There were also some calculations and making data into graphs that needed to be done with each circuit. There were some challenges with the lab due to the oscilloscope and Virtual Bench that would make students need to use different equipment in order to test the hardware of the circuits. Some suggestion students may have are to make sure that the probes aren't grounded when testing the circuit so the results could be as expected. The steps that students found most interesting were building the circuit with hardware and testing it using Virtual Bench which would give various results.

4.3 Analysis and Results

Following the procedure in this lab generated viable results and gave generally consistent values. The simulations did not have any outside forces acting on them, but it was easy to tell from the hardware when noise and other outside forces were interfering. This is because the values on the multimeter noticeably changed when outside forces were acting upon the circuit. This lab required a great deal of simulated and measured inputs and outputs to be made. In general, most of these values matched well. For the parts of the experiment where the results didn't match perfectly, it was most likely because of some sort of equipment error. Some of the components used may also have been partially or fully fried during the experiment. The most interesting observation from the data was the interestingly shaped graphs that were generated from certain parts of the lab.

4.4 Closing Ideas

One lesson taken away from this lab was that even if a task is spelled out for you, it may not be as straightforward as it seems. This lesson was prevalent in this lab because of the various tasks that had to be completed within just one lab. This experiment will help students excel in the lecture portion of this class because it reinforces and builds upon concepts learned in class. The most positive comment on this experiment is that it was an experiment that used components that were unfamiliar to us (the Zener diodes), so it was good practice using them. The most negative comment on this experiment is that there were a lot of steps and parts that didn't really correlate with each other, which made it a little confusing to work on.

5. References (AB, MF)

- Microelectronics Circuits by Sedra and Smith; OxfordUniversity Press; Latest Edition
- 1N4733 Zener diode datasheet https://www.jameco.com/Jameco/Products/ProdDS/36097VIS.pdf