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Experiment 4

Diode Applications

Zener Diode, Voltage Regulator, and Limiter

Introduction:

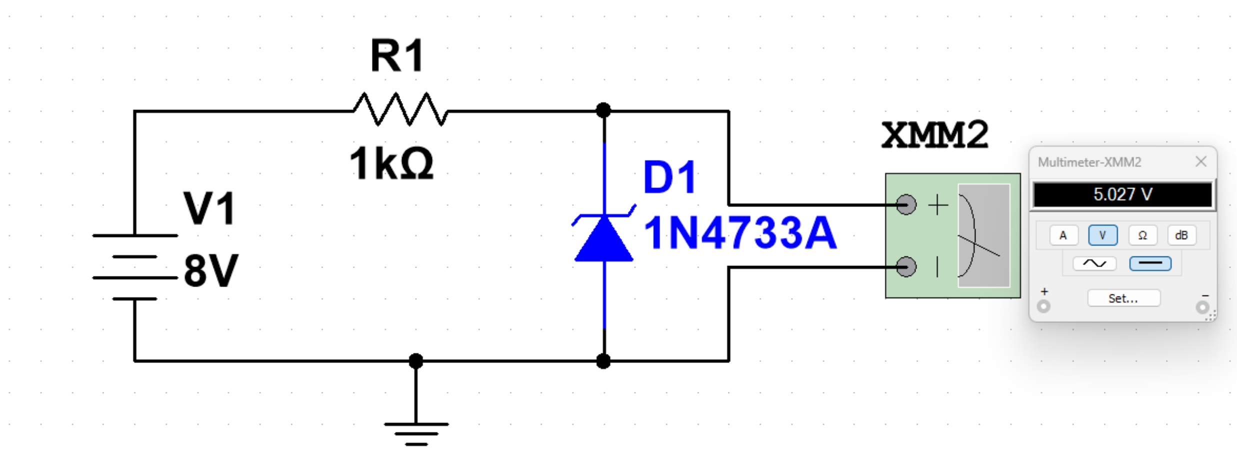
The primary objectives of this lab are to understand the operational characteristics of Zener diodes and to explore their applications in voltage regulation and limitation circuits. Zener diodes are unique in their ability to provide a stable reference voltage despite variations in the load current and supply voltage, which is pivotal in many electronic applications. This lab aims to investigate the Zener diode's behavior in the breakdown region and how it maintains a constant voltage across its terminals, functioning as a voltage regulator. Additionally, we will examine the use of Zener diodes as voltage limiters, understanding how they can protect sensitive electronic components from overvoltage conditions. By constructing circuits as outlined in our lab manual, observing the results, and comparing them against theoretical expectations, we aim to gain a practical understanding of Zener diodes' regulation and limiting capabilities, thereby reinforcing the theoretical concepts covered in our lecture notes and supplementary research.

Bench Parts and Equipment List:

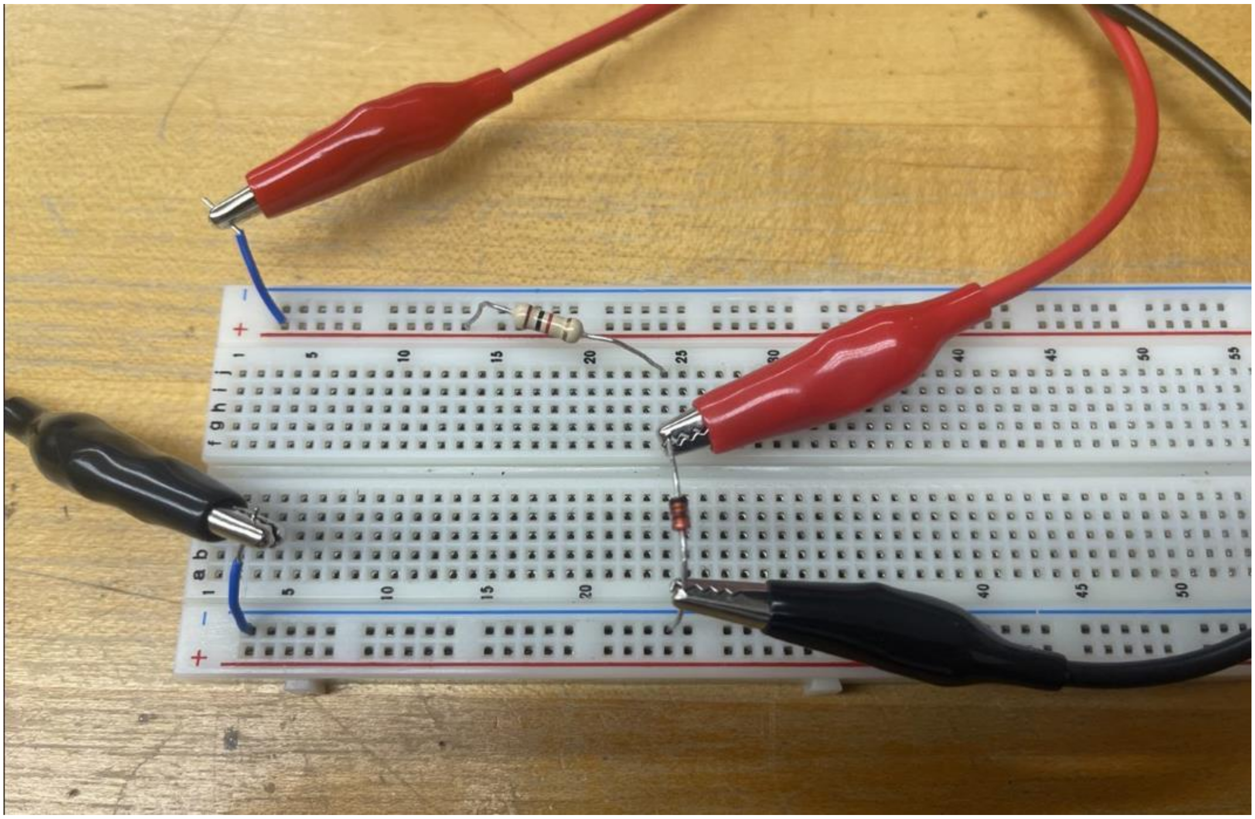
1. **Components:**
    - Two Zener Diodes (1N4733)
    - Resistor (1kΩ)
2. **Equipment:**
    - DC/AC Power Supply
    - Digital Multimeter (DMM)
    - Oscilloscope
    - Breadboard
    - Connecting wires and/or jumper wires

Discussion:

Circuit 1 - Zener Voltage Regulator: In the initial experiment with the Zener voltage regulator circuit, the Zener diode exhibited a stable voltage across it after reaching its breakdown voltage. This behavior is in line with the Zener diode's characteristic to maintain a constant voltage over a wide range of current, confirming its role as a voltage regulator. The measured data showed a slight increase in voltage across the diode as the input voltage was raised, but it remained within a narrow range, demonstrating the effectiveness of the Zener diode in regulating voltage. This confirms the theoretical principle that Zener diodes are designed to operate in this breakdown region to provide a stable output voltage.

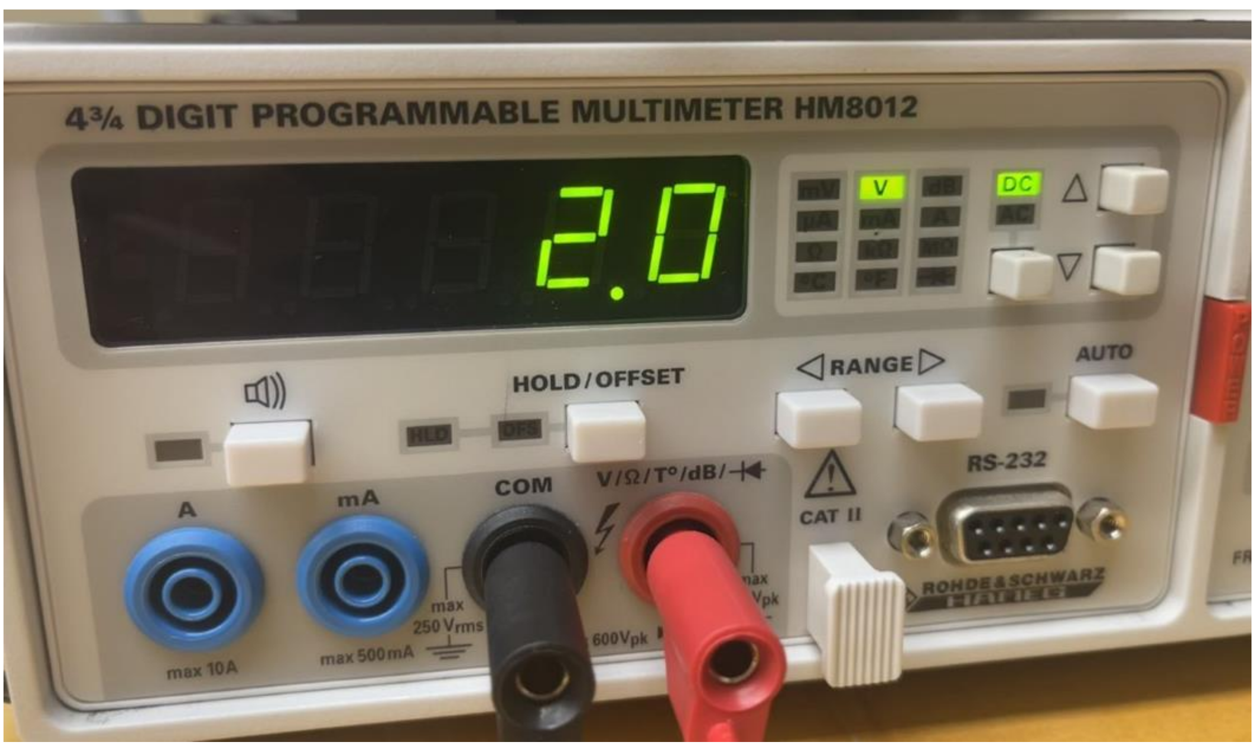


(Figure 1) Multisim Zener Voltage Regulator circuit.



(Figure 2) Zener Voltage Regulator Circuit Bench.

(Figure 3) Tripple Power Supply at 2 V.



(Figure 4) DMM reading 2V across Zener.

Table 1.1

Input DC Voltage	Regulated Voltage (Zener)		
	Calculated (Ideal) [V]	Calculated (Practical) [V]	Measured [V]
2.0 V	2.0	2.0	2
3.0 V	3.0	3.0	3
4.0 V	4.0	4.0	3.78
4.5 V	4.5	5.5	4.03
5.0 V	5.0	4.76 – 5	4.23
5.5 V	5.1	4.76 – 5.5	4.35
6.0 V	5.1	4.76 – 6.0	4.45
6.5 V	5.1	4.76 – 6.13	4.52
7.0 V	5.1	4.76 – 6.13	4.58
8.0 V	5.1	4.76 – 6.13	4.68

Calculations:

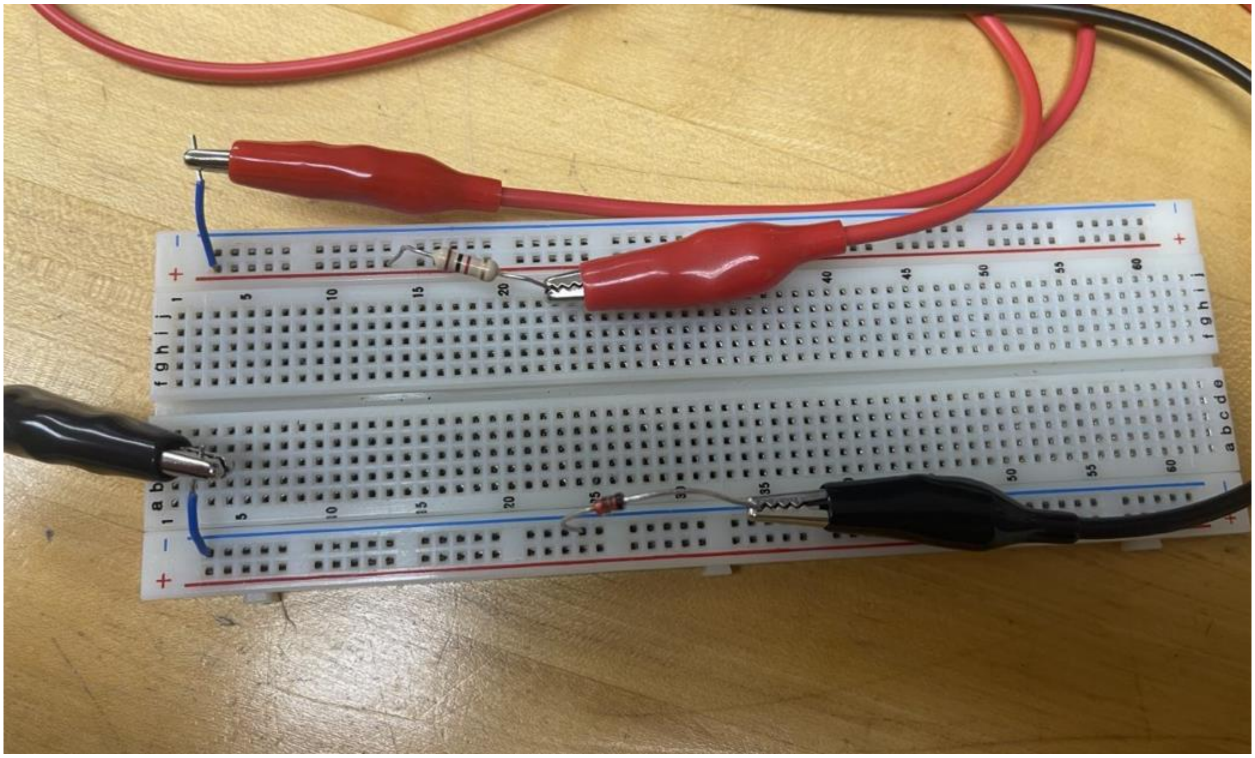
Ideal Zener Voltage:

$$V_{out\ max} = V_z = 5.1\ V$$

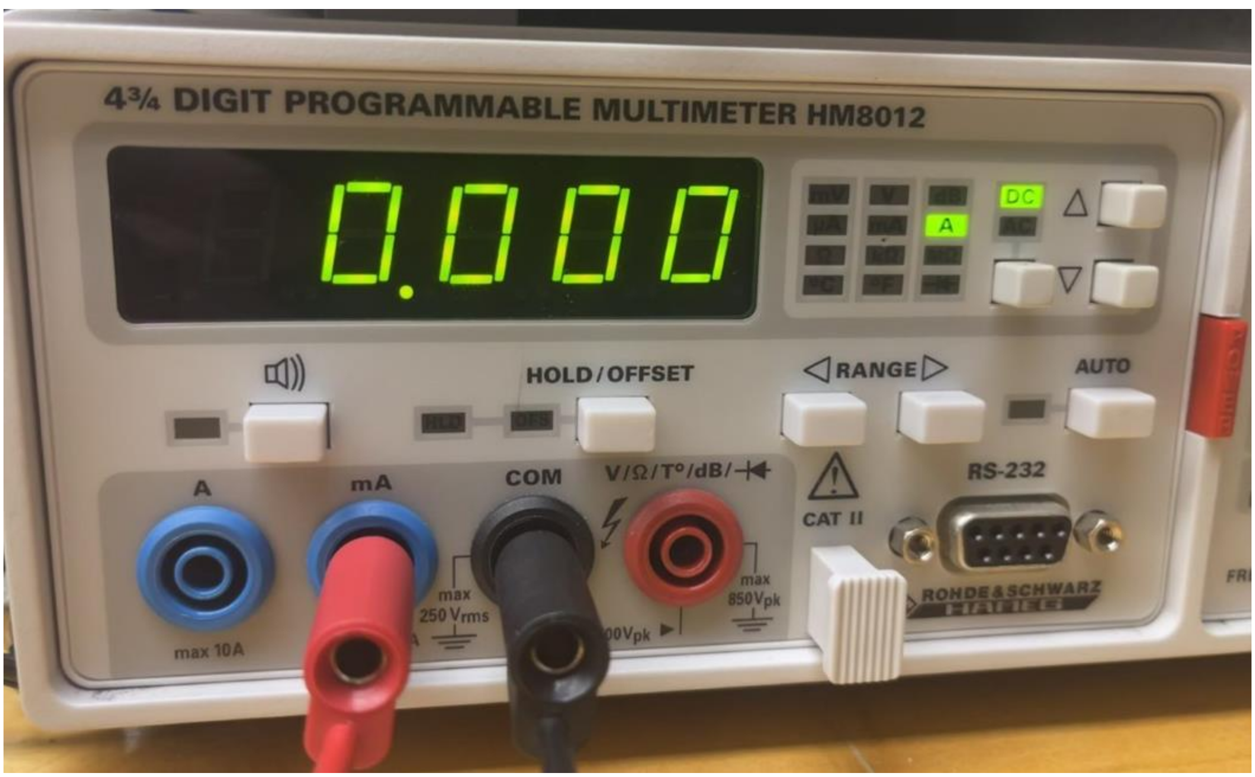
Practical Zener Volage:

$$V_{out\ min} = V_z - (i_z - i_{zk}) * Z_z = 5.1\ V - (49\ mA - 1\ mA) * 7\ \Omega = 4.764\ V$$

$$V_{out\ max} = V_z + (i_{z\ max} - i_z) * Z_z = 5.1 + (169\ mA - 49mA) * 7\ \Omega = 6.129\ V$$



(Figure 5) Bench measuring Current entering Zener.



(Figure 6) Bench measuring Current entering Zener at 2V DC.

(Figure 7) Bench Current measurement at 5.5 V.

Table 1.2

Input DC Voltage	Regulated Current (Zener)		
	Calculated (Ideal) [mA]	Calculated (Practical) [mA]	Measured [mA]
2.0 V	0	0	0
3.0 V	0	0	0.029
4.0 V	0	0	0.252
4.5 V	0	0	0.474
5.0 V	0	0 - 0.234	0.798
5.5 V	0.4	0 - 0.731	1.21
6.0 V	0.9	0 - 1.23	1.59
6.5 V	1.4	0.368 - 1.72	2.02
7.0 V	1.9	0.865 - 2.22	2.49
8.0 V	2.9	1.86 – 3.21	3.34

Calculation Example:

Ideal Zener Calculation:

$$i_z = i_{total} = \frac{V_s - V_z}{R_{total}} = \frac{6\ V - 5.1\ V}{1\ k\Omega} = 900\ \mu A$$

Practical Zener Calculation:

$$i_{min} = \frac{V_{source} - V_{z\,max}}{R_{total} + Z_z} = \frac{6\ V - 6.129\ V}{1\ k\Omega\ \ + 7\ \Omega} = 0\ A$$

$$i_{max} = \frac{V_{source} - V_{z\,min}}{R_{total} + Z_z} = \frac{6\ V - 4.764\ V}{1\ k\Omega\ \ + 7\ \Omega} = 1.23mA$$

Experiment 4
Diode Applications
Zener Diode, Voltage Regulator, and Limiter

Zener Diode Circuit
In general an electrical current does not flow through a diode when configured in reverse bias. Zener diodes are special diodes that work in the breakdown region when reversed biased maintaining relatively constant voltage while the Zener current varies. The voltage regulation depends on the power dissipation of the Zener diode and will stop when the Zener current drops below the recommended knee current.

Zener Voltage Regulator
In many low wattage power supplies the filter-capacitance voltage may have a small amount of undesired ripple voltage. Zener diodes are used to overcome this problem resulting in a constant dc output voltage. This experiment will illustrate how the Zener is used in voltage regulation.

Objective: To observe the Zener diode effect on the operation of a voltage regulator and limiter.

Materials
- Power Supply
- Two Zener Diodes (1N4733)
- Resistor (1kΩ)

Input: DC Power Supply
Output: Voltmeter

1- Build the circuit shown in figure 1.
2- Connect a voltmeter across the Zener diode.
3- Set the value of the DC supply to zero.
4- Set the source voltage to the values shown in table 1.
5- Complete table 1.

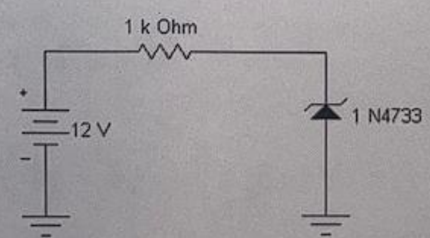


Figure 1

Input DC Voltage	Zener Current			Regulated Voltage (Zener)		
	Calculated (Ideal)	Calculated (Practical)	Measured	Calculated (Ideal)	Calculated (Practical)	Measured
2.0 V	0 A	0 A	0 A	2.0	2.0	2 V
3.0 V	0 A	0 A	.029 mA	3.0	3.0	3 V
4.0 V	0 A	0 A	.252 mA	4.0	4.0	3.78 V
4.5 V	0 A	0 A	.474 mA	4.5	4.5	4.03 V
5.0 V	0 A	0 → .234 mA	.798 mA	5.0	4.76 → 5 V	4.23 V
5.5 V	0.4 mA	0 → 0.731 mA	1.21 mA	5.1	4.76 → 5.5 V	4.35 V
6.0 V	0.9 mA	0 → 1.23 mA	1.59 mA	5.1	4.76 → 6.0 V	4.45 V
6.5 V	1.4 mA	.368 → 1.72 mA	2.02 mA	5.1	4.76 → 6.13 V	4.52 V
7.0 V	1.9 mA	.865 → 2.22 mA	2.49 mA	5.1	4.76 → 6.13 V	4.58 V
8.0 V	2.9 mA	1.86 → 3.21 mA	3.34 mA	5.1	4.76 → 6.13 V	4.68 V

Table 1

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$$I_Z = I_{Total} = \frac{V_S - V_Z}{R_{Total}}$$

$Z_{Z_P} = 7\,\Omega$

$Z_{Z_{ideal}} = 0\,\Omega$

$$I_{min} = \frac{V_{Source} - V_{Z\,Max}}{R_{Total} + Z_Z}$$

$I_{ZK} = 1\,mA$

$I_Z = 49\,mA$

$$I_{max} = \frac{V_S - V_{Z\,Min}}{R_{Total} + Z_Z}$$

$I_{Z\,max} = 169\,mA$

$$V_{out\,Max_{ideal}} = V_Z = 5.1$$

$$V_{out\,min} = V_Z - (I_Z - I_{ZK}) \times Z_Z$$

$$V_{out\,Max} = V_Z + (I_{Z\,max} - I_Z) \cdot Z_Z$$

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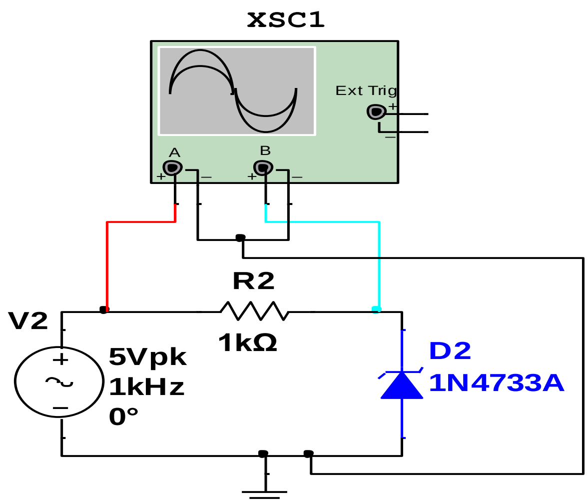
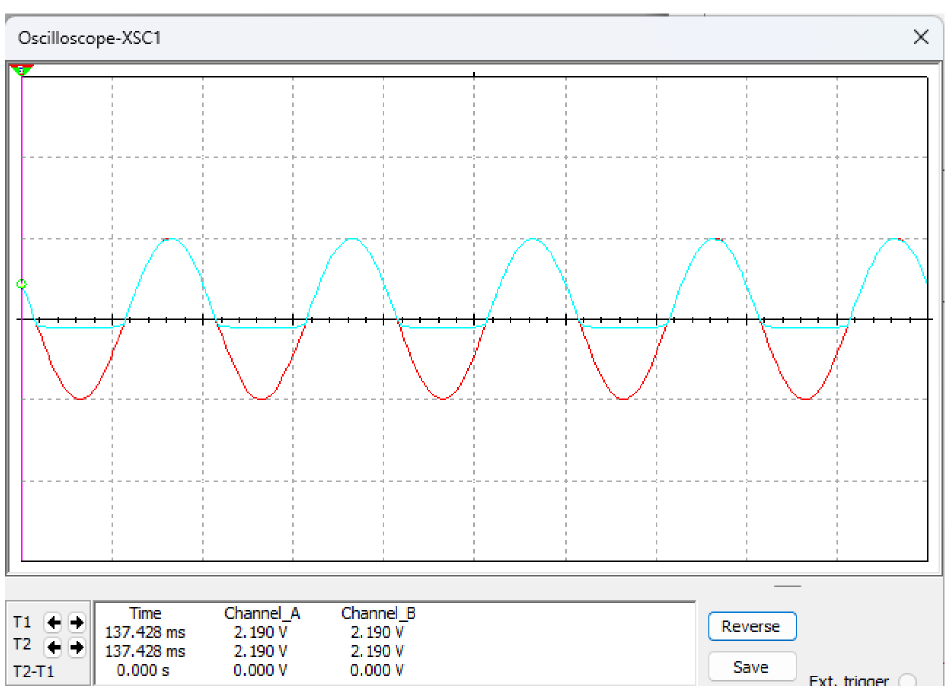
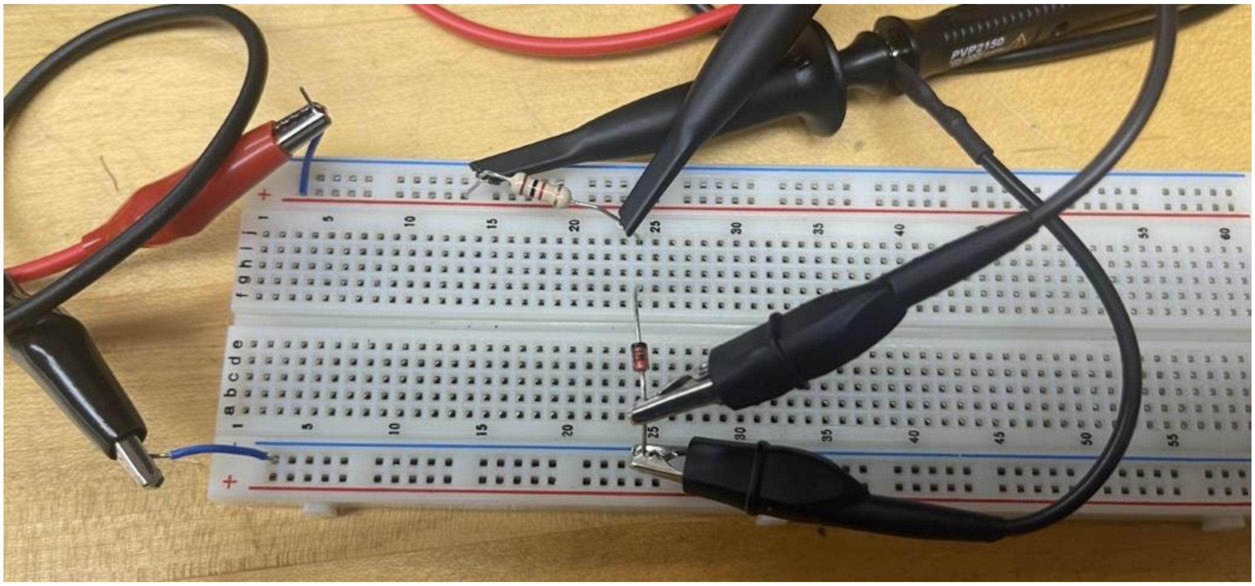
Circuit 2 - Zener Voltage Limiter with AC Signal: The second experiment's focus on the Zener diode as a voltage limiter with an AC input provided valuable insights. As the input voltage was increased beyond the Zener voltage, the diode clipped the excess voltage, limiting the output to a nearly constant value. The oscilloscope traces showed the expected clipping on both the positive and negative halves of the waveform. Some asymmetry in the clipping points suggests real-world circuit elements' non-idealities, yet the overall trend was consistent with the Zener's limiting capabilities.



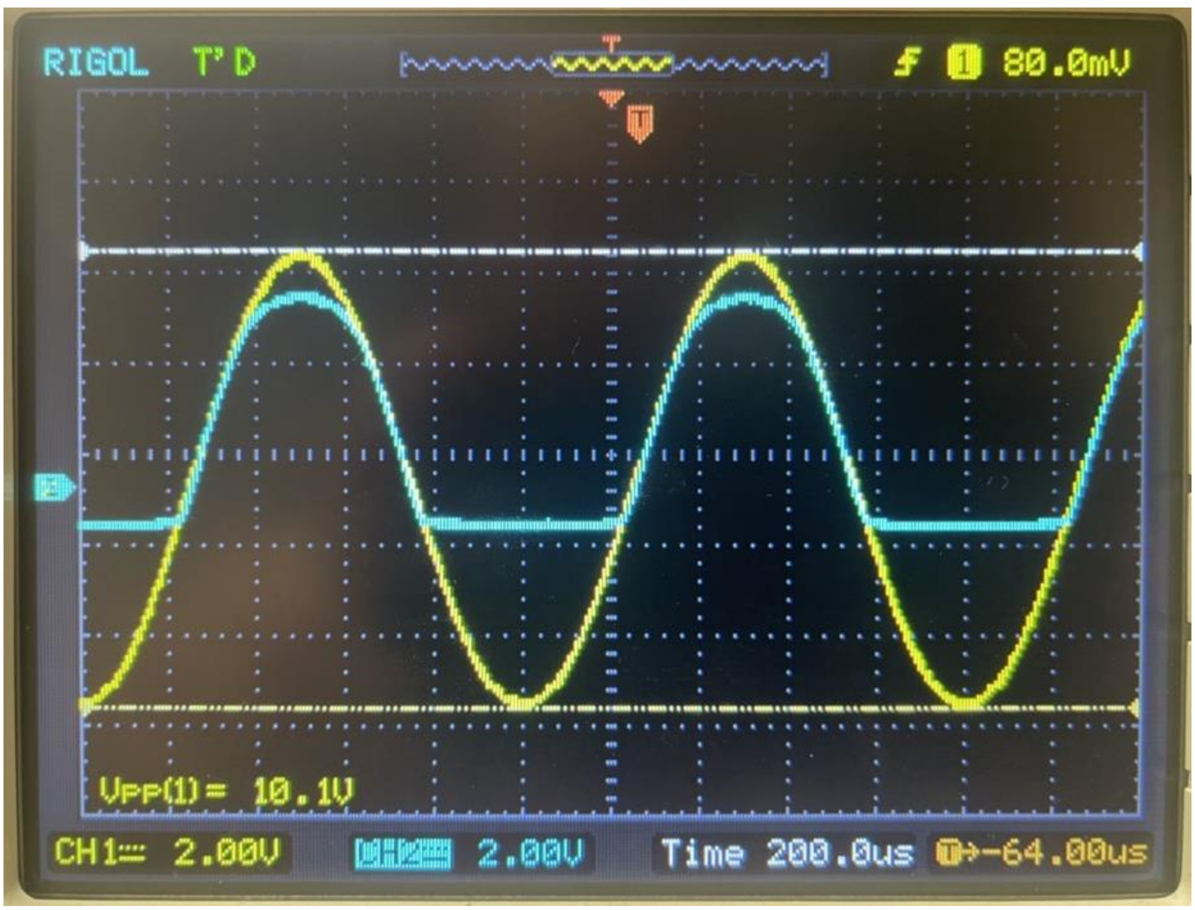
(Figure 8) Zener Voltage limiter with AC (Multisim).



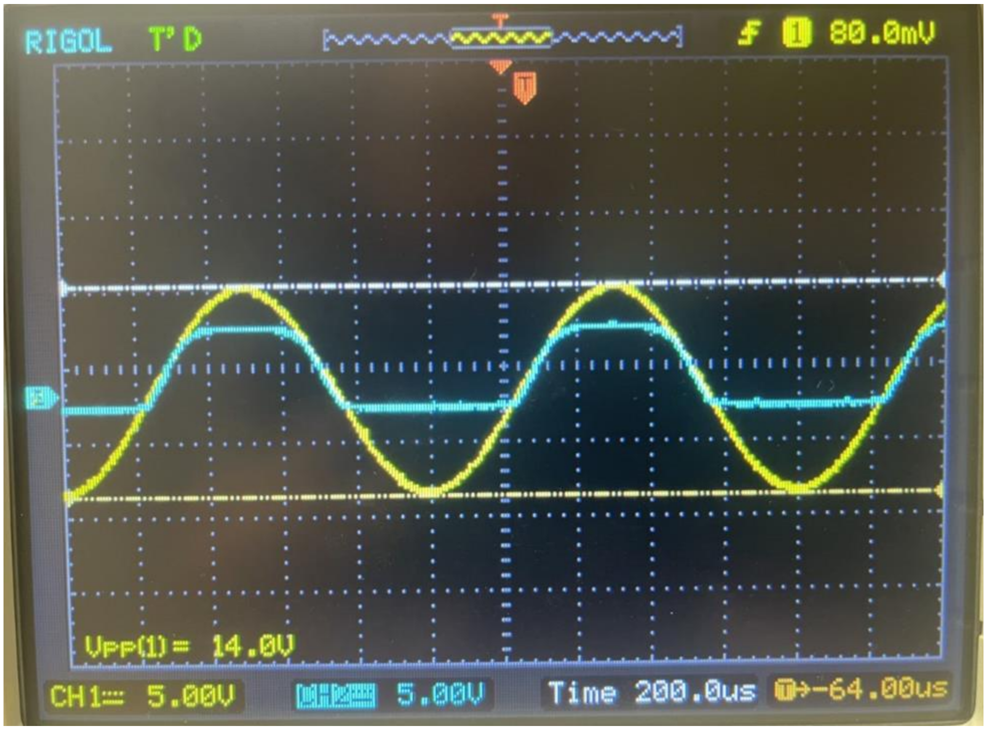
(Figure 9) Oscilloscope Multisim.



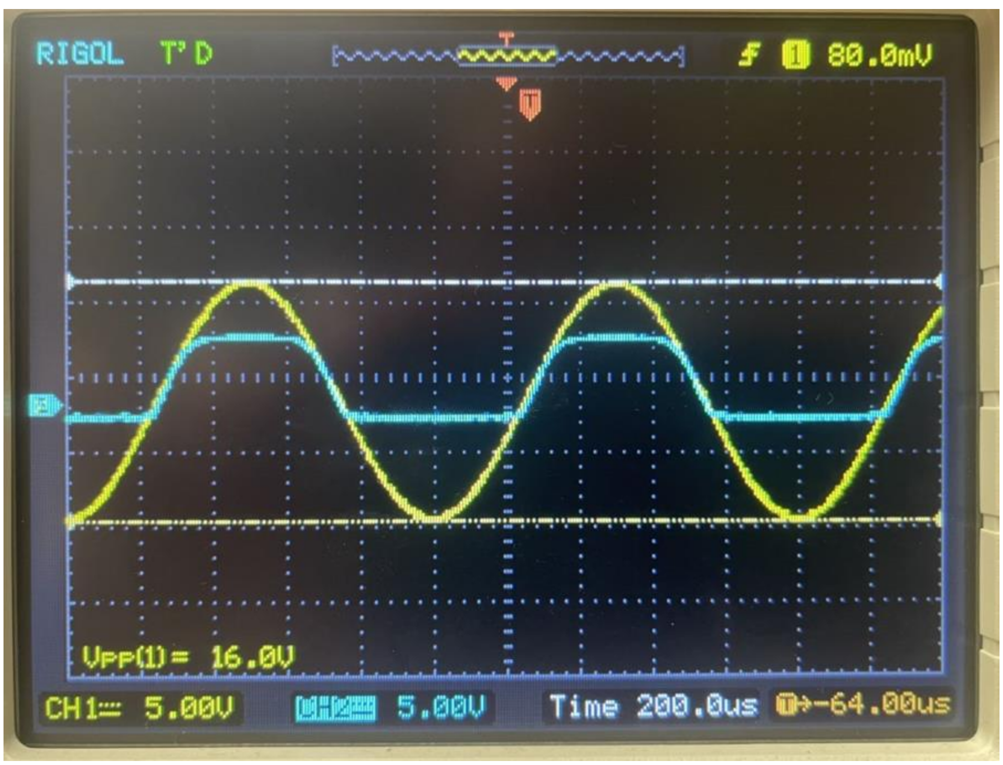
(Figure 10) Zener Voltage limiter with AC (Bench).



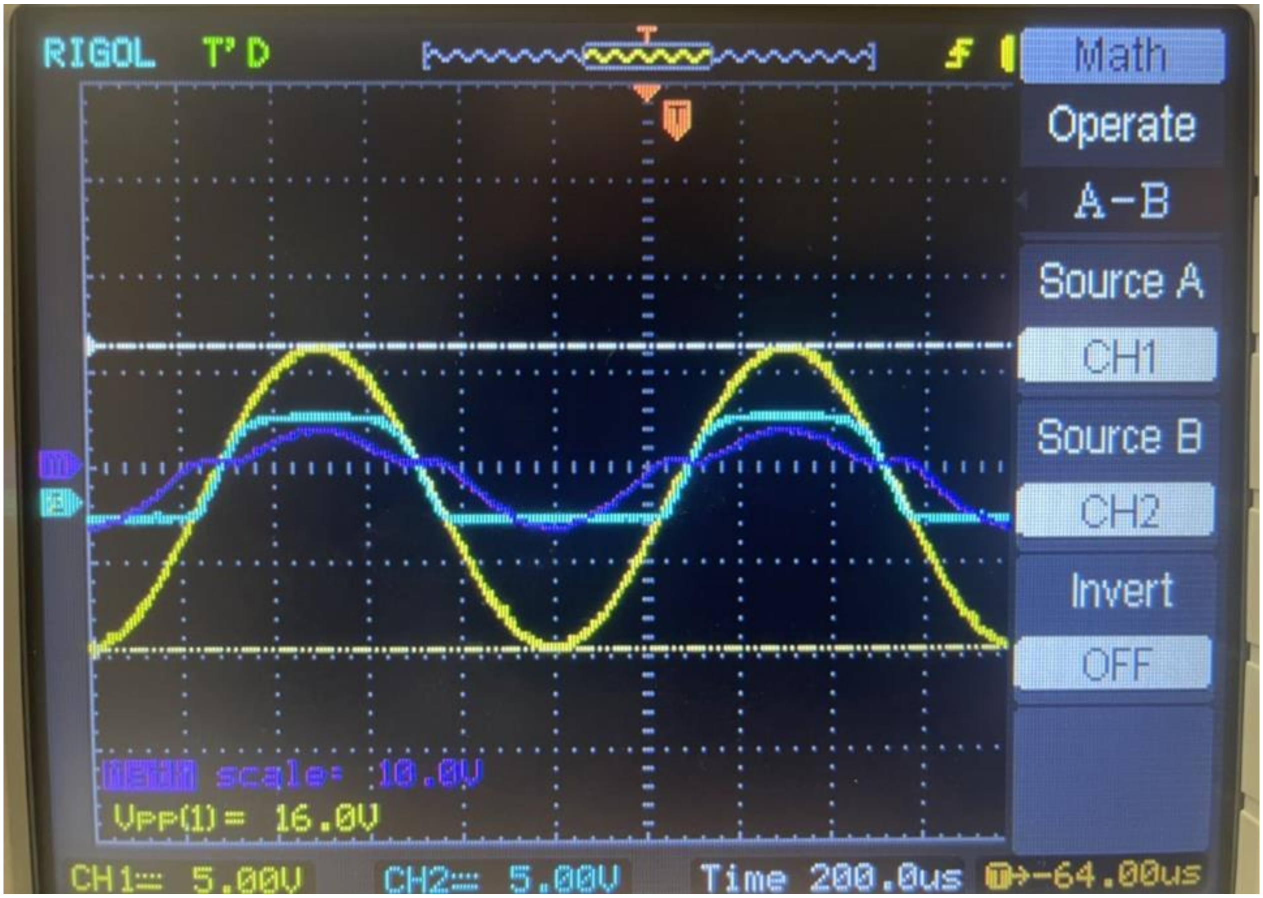
(Figure 11) Oscilloscope Bench.



(Figure 12) Oscilloscope Bench with V_{PP} 14V (Proving Zener Great limiting abilities at higher voltage).



(Figure 13) Oscilloscope Bench 16 V_{pp}.



(Figure 14) Bench Oscilloscope using Math Function A-B.

Voltage Limiter

Like silicon diodes Zener diodes are also used to limit the upper, lower, or both levels of an incoming AC signal to a desired level. The following experiment demonstrates the use of Zener diodes in a voltage limiting circuit.

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1- Build the limiter circuit shown in Figure 2.

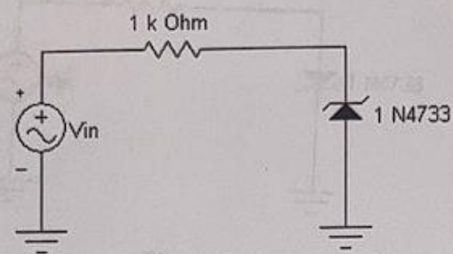


Figure 2

2- Set the input voltage to 5 volts peak @1KHz sinusoidal signal.

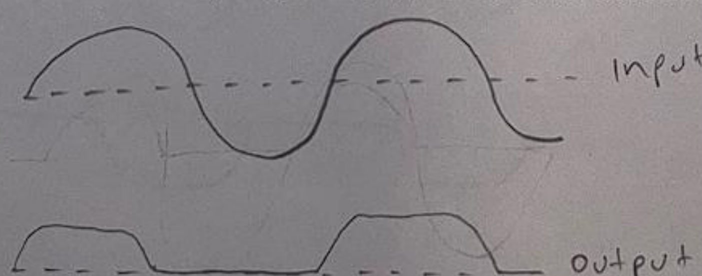
3- Connect one channel of the oscilloscope to the input source.

4- Connect the other channel across the Zener diode.
Note: Superimpose waveforms on top of each other so that center arrows line up and make scales identical.

5- Increase Vin to 7 Vp. What are your observations?

6- Now increase Vin to 8 Vp and move the input voltage waveform above the center zero line and move the output voltage waveform below the center zero line.

7- In the space below, draw the input voltage V_{in} and just below it, draw the output voltage V_Z as observed on the oscilloscope.
Note: The output signal may appear somewhat distorted.



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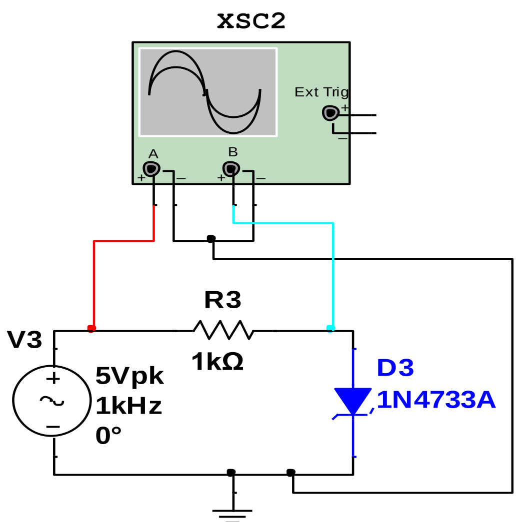
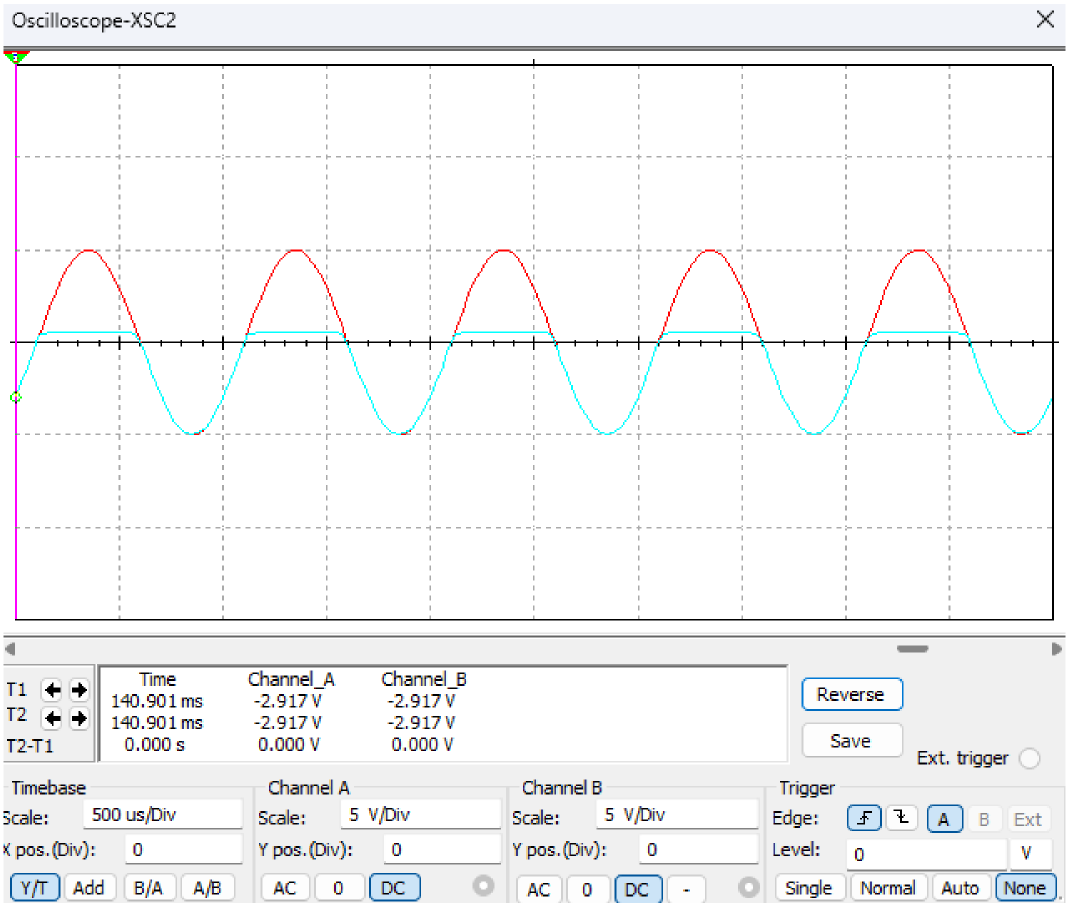
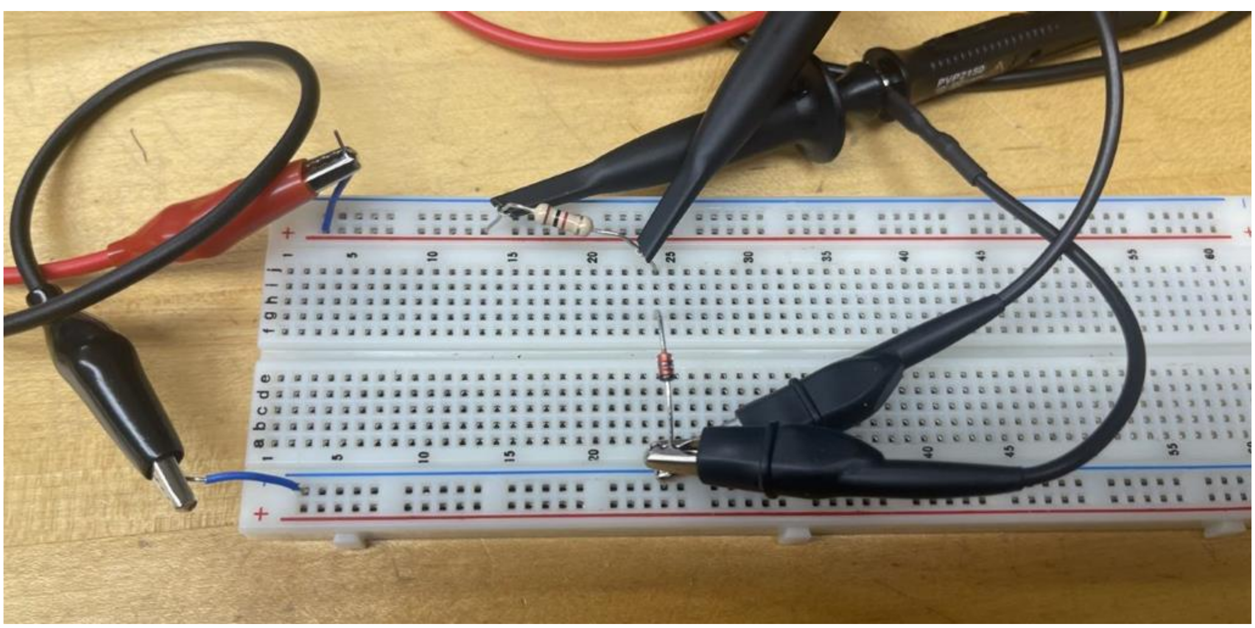
Circuit 3 - Zener Diode with Reversed Polarity: When the Zener diode's polarity was reversed in the third circuit, it ceased to conduct until the reverse breakdown voltage was reached. This is characteristic of the Zener effect, where the diode allows current to flow in reverse once a specific voltage is exceeded. The oscilloscope's display of the waveform before and after the breakdown voltage offered a clear visualization of this principle. Although the diode's behavior in forward bias was not the focus of this lab, it provided a contrast that highlighted the unique reverse-biased operation of Zener diodes.



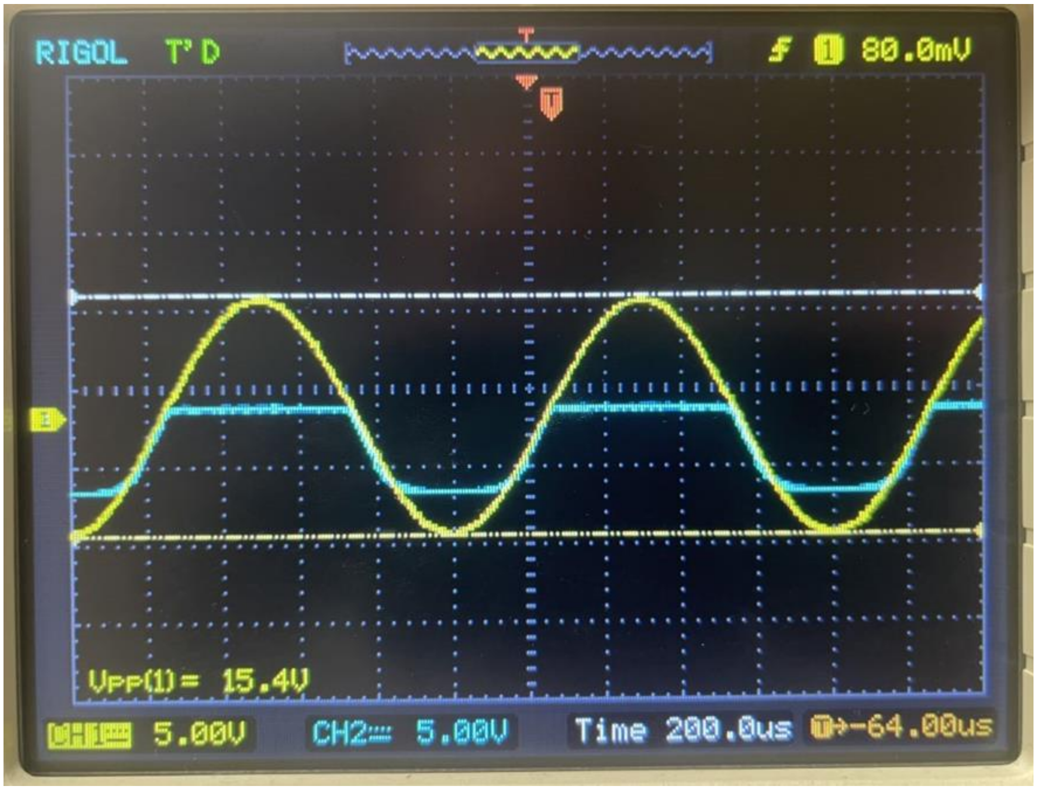
(Figure 15) Zener Reversed polarity AC (Multisim).



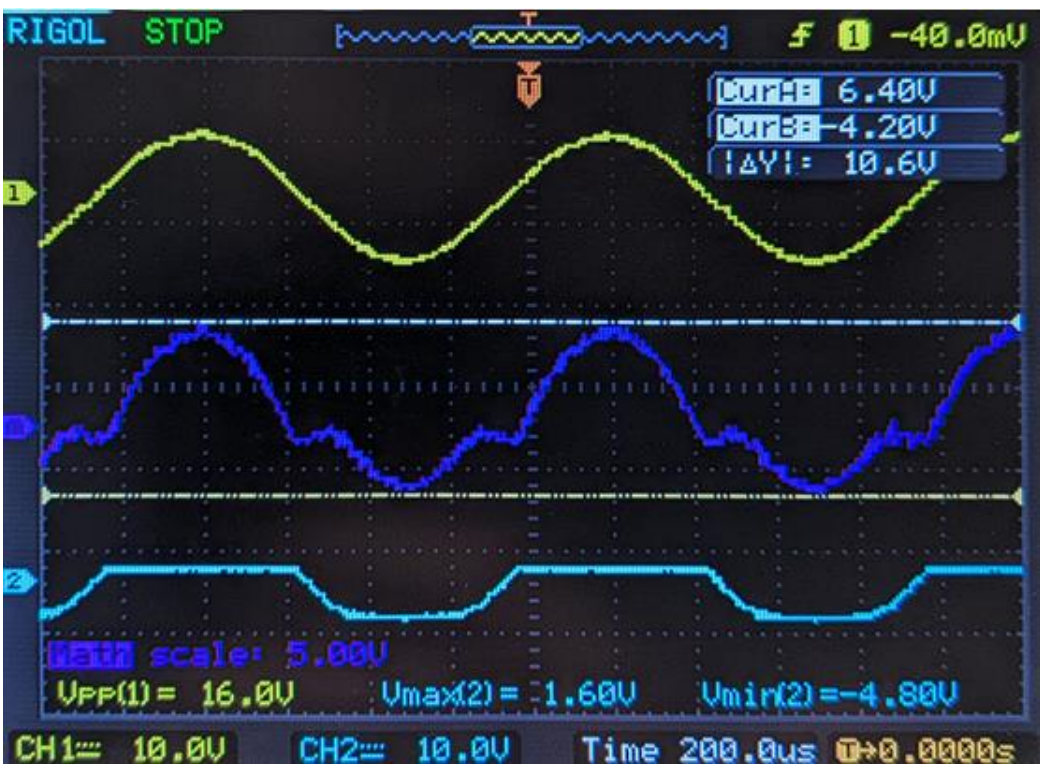
(Figure 16) Oscilloscope Multisim.



(Figure 17) Zener Reversed polarity AC (Bench).



(Figure 18) Zener Reversed polarity AC Bench Oscilloscope.



(Figure 19) Bench Oscilloscope Zener Reversed polarity AC using Math function A-B.

8- Measure Vr = Vin - Vz

- Use Math Mode: A-B
- Then use the Cursors to make your measurement.

9- Reverse the diode as shown in Figure 3 and draw the input and output signals as observed on the oscilloscope.

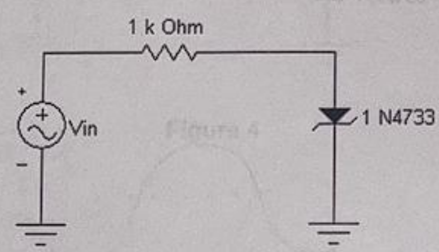


Figure 3

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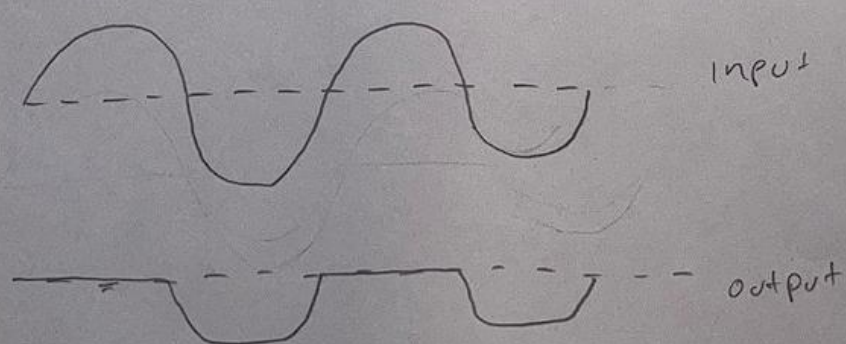
10-Compare your results from steps 7 and 9 against theoretical (expected) results.



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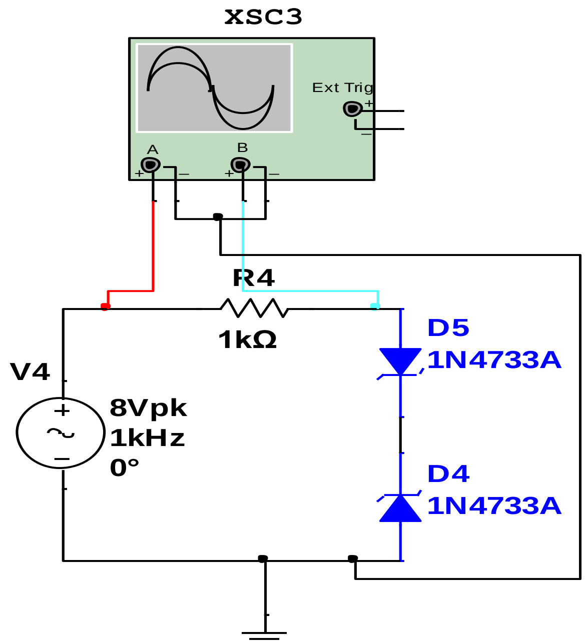
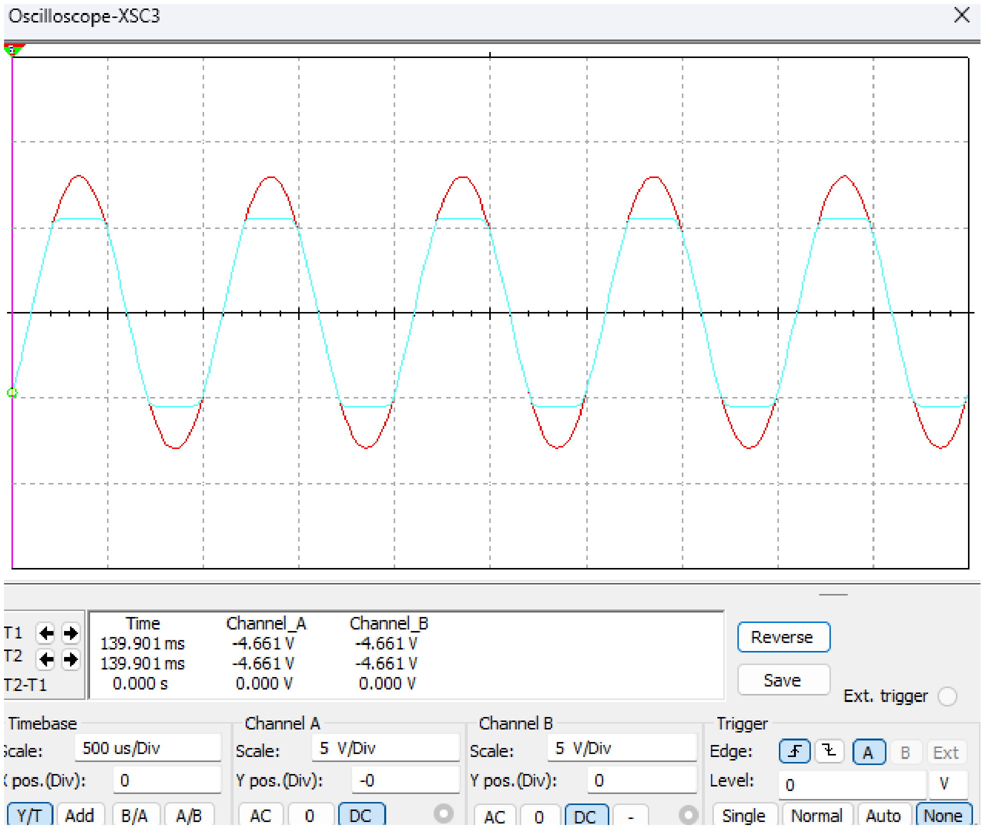
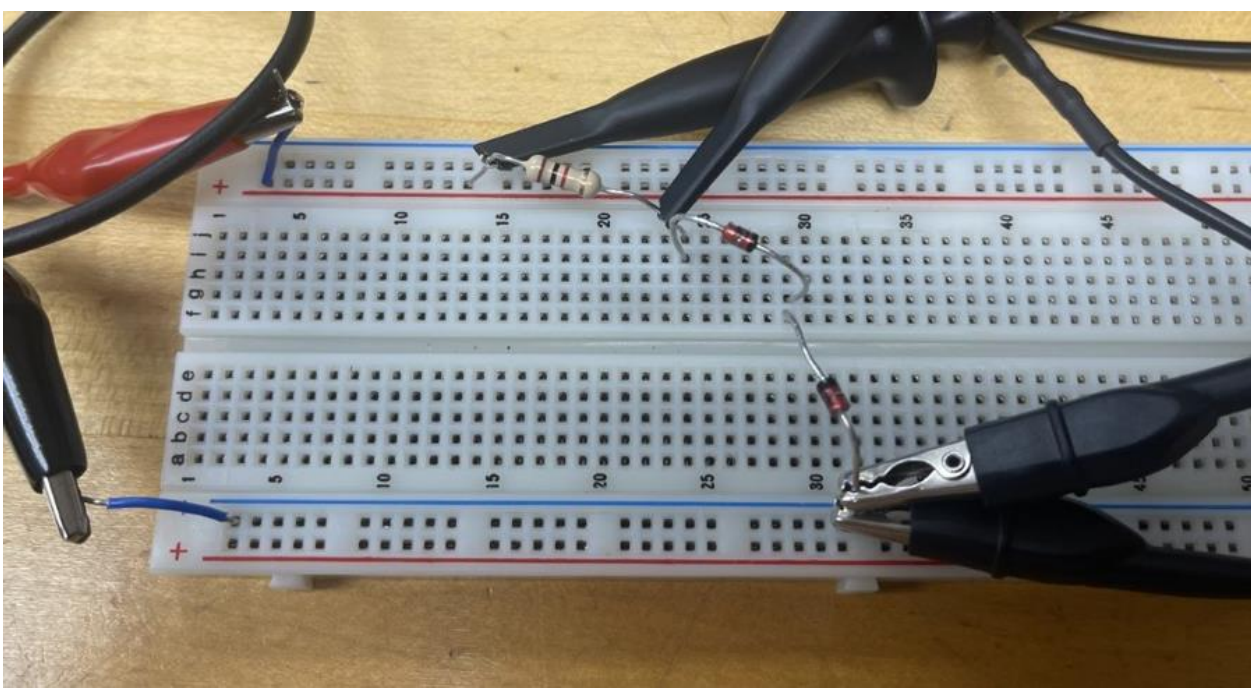
Circuit 4 - Double Zener Limiter in Series: The final circuit with two Zener diodes in series further emphasized the Zener diode's ability to regulate and limit voltage. The output waveform's flat tops on the oscilloscope when the input voltage exceeded the combined Zener voltages of both diodes in series illustrated the diodes' combined voltage-clipping effect. This part of the lab served to demonstrate the scalability of Zener diodes in voltage regulation applications, where multiple diodes can be used in series to achieve higher voltage regulation thresholds.



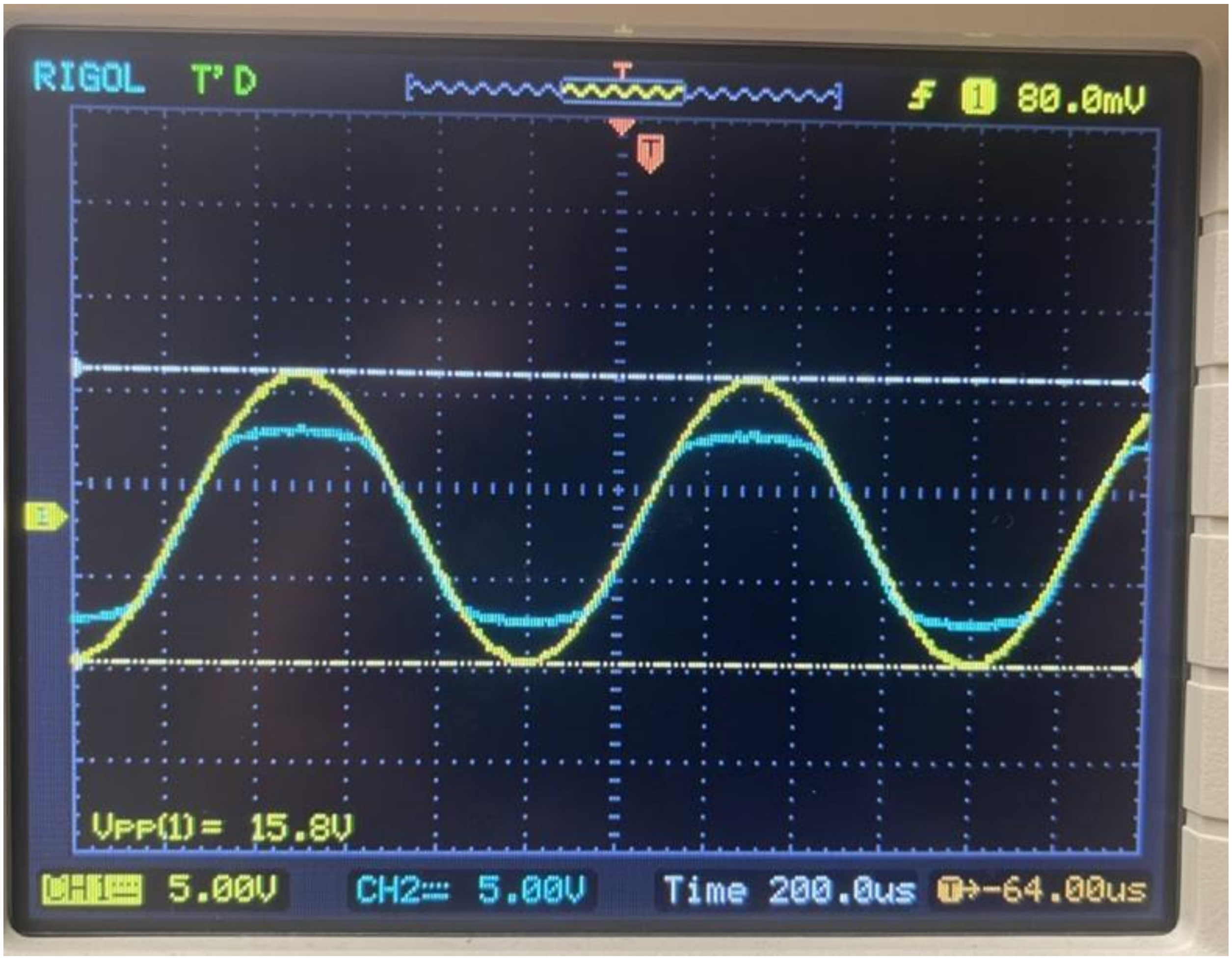
(Figure 20) Double Zener Limiter AC (Multisim).



(Figure 21) Double Zener limiter Oscilloscope Multisim.



(Figure 22) Double Zener Limiter AC (Bench).



(Figure 23) Double Zener limiter Oscilloscope Bench.

11-Insert the second Zener as shown in Figure 4 and draw the output waveform.

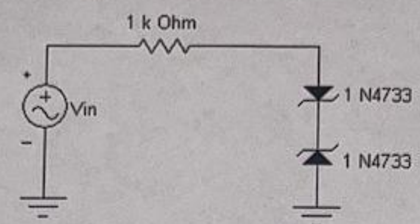


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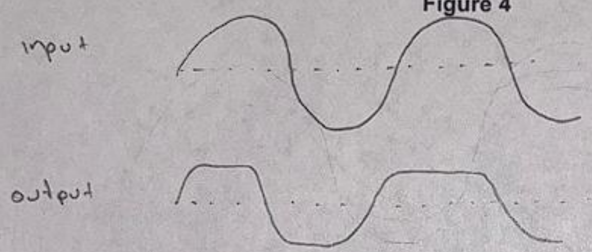
Figure 4



12-Describe below your observation on the data obtained for Figure 2 through Figure 4.

A zener diode in Reverse bias Regulates voltage to a nearly fixed amount

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Conclusion:

The primary objective of this lab was to understand the characteristics and applications of Zener diodes in voltage regulation and voltage limiting circuits. Through the construction and analysis of various circuits, this lab has effectively met its objectives. I learned the practical aspects of how Zener diodes maintain a stable voltage in a circuit despite fluctuations in input voltage and current load, which is vital for creating reliable electronic devices. Additionally, the experiments with the voltage limiter circuits demonstrated the Zener diode's ability to protect against voltage spikes, an essential function in circuit protection. While there were minor discrepancies between the calculated theoretical and measured values, these were valuable lessons in considering real-world component variations and measurement tolerances. Overall, the lab reinforced theoretical concepts with hands-on experience, deepening my understanding of semiconductor devices in electronic circuit design.