American International University- Bangladesh
Faculty of Engineering (FE)
Department of Electrical and Electronic Engineering (EEE)
EEE 2104: Electronic Devices Lab

Title of the Experiment: Study of Study of Zener Diode.

Objectives:
The objectives of this experiment are to
1. Study the Zener diode's *I-V* characteristics.
2. Study Zener diode-based voltage regulator circuits at different conditions.

Theory:
A Zener diode is a diode that allows current to flow in the forward direction in the same manner as an ideal diode but also permits it to flow in the reverse direction when the voltage is above a certain value known as the breakdown voltage, Zener knee voltage, Zener voltage, avalanche point, or peak inverse voltage. If the voltage is increased beyond this certain value, there is a sudden rapid rise in current causing the destruction of the device. The basic function of the Zener diode is to maintain a specific voltage across its terminals within given limits of line or load voltage. Usually, it is used to provide a stable reference voltage for power supplies and other equipment. Figure 1 shows a Zener diode-based circuit that maintains a 10 V reference voltage. When a reverse voltage equal to the Zener voltage is applied, the reverse current is limited only by the small value of Zener resistance and the circuit series resistance, *R*.

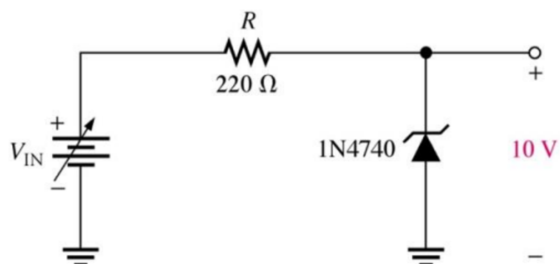


Figure 1: Zener diode circuit that maintains a 10 V across the load.

A Zener diode is much like a normal diode, the exception is that it is placed in the circuit in reverse bias mode and operates in reverse breakdown. The typical characteristic curve in Fig. 2 illustrates the operating range (ash color region) for a Zener diode. Note that its forward characteristics are just like a normal diode as in Fig. 2.

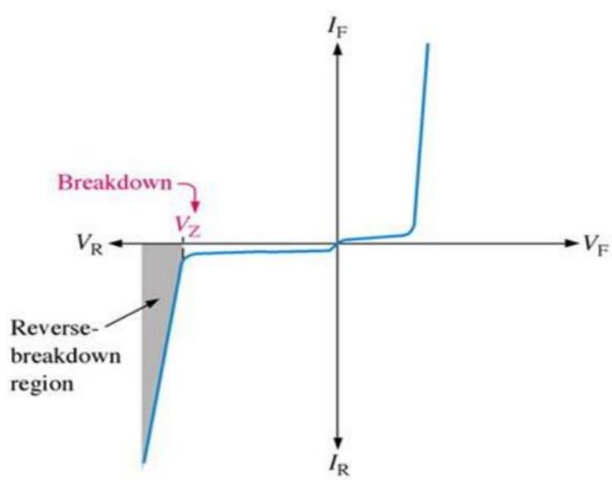


Figure 2: The normal operating region of a Zener diode is shaded.

The doping process determines the Zener diode's breakdown characteristics. One of the most important features of the characteristic curve in the reverse direction is called the Zener voltage (V_z), which is the voltage at which avalanche or Zener breakdown occurs. This region is shown in Fig. 3.
There are two types of Zener diodes based on the breakdown voltage ranges, such as

1. Low voltage Zener diodes
2. High voltage Zener diodes.

Low voltage Zener diodes have operating Zener breakdown less than 5 V. Those designed to operate more than 5 V, operate mostly in avalanche breakdown range, are known as high voltage Zener diodes. Zener diodes are available with breakdown voltage ranges from 1.8 V to 200 V.
At a particular Zener voltage, there is a minimum and maximum current called the Zener knee or minimum (I_{ZK}) and maximum (I_{ZM}) currents. The minimum Zener current (I_{ZK}) is necessary to cause the Zener diode to avalanche, that is, to work in the Zener mode. The maximum Zener current (I_{ZM}) is necessary to limit the power dissipation in the Zener diode in the Zener mode. This is illustrated in Fig. 3.
The resistance of the Zener diode in the breakdown region is called the dynamic resistance that can be obtained by finding the slope of the line in the breakdown region (i.e., in the third quadrant). For most applications, it is desirable that dynamic resistance (R_z) should have as low a value as possible. The small value of R_z is reflected in the steep slope of the Zener characteristics in the reverse direction and this is the reason why the Zener diode finds so many applications as a voltage reference regulator circuit, in voltage surge protection, and in waveform shaping circuits.

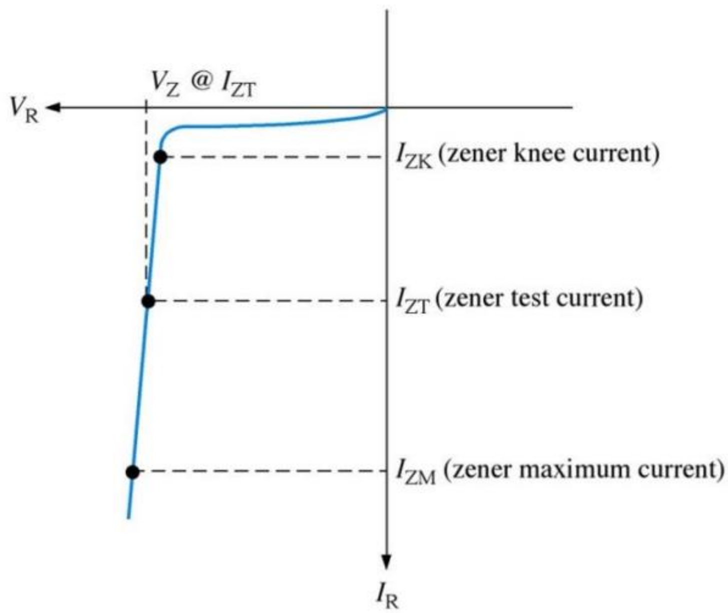
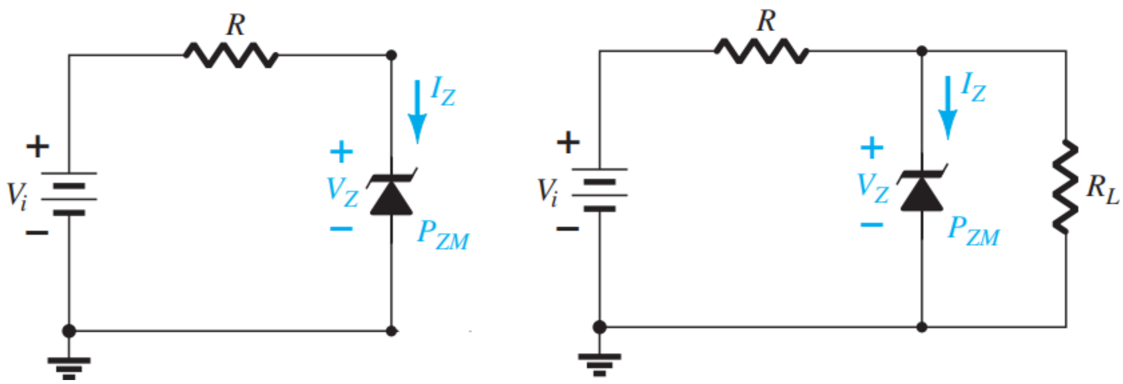


Figure 3: The minimum and maximum ranges of operating current for a Zener to maintain its voltage effectively.

A Zener diode can be operated in both forward and reverse-biased modes. In forward-biased mode, the anode of the Zener is connected to the positive terminal of the battery, and the cathode of the Zener is connected to the negative terminal of the battery. Then it will act as a normal diode. In reverse-biased mode, the anode of the Zener is connected to the negative terminal of the battery, and the cathode of the Zener is connected to the positive terminal of the battery as shown in Fig. 4 (a). In the latter mode, the Zener diode can act as a voltage regulator.
A voltage regulator is designed to keep the output voltage of a circuit at a constant value, independent of the input voltage and independent of the load current. A Zener diode connected in parallel to the load is the simplest form of such a voltage regulator circuit shown in Fig. 4 (b). If the voltage across the load tries to rise, then the Zener diode takes more current. The increase in current through the resistor causes an increase in voltage drop across the resistor and causes the voltage across the load to remain at its correct value. Similarly, if the voltage across the load tries to fall, then the Zener diode takes less current. The current through the resistor and the voltage across the resistor both fall. The voltage across the load remains at its correct value.



(a) (b)

Figure 4: Zener diode-based circuit diagram: (a) Characteristics study; (b) Voltage regulator study.

Pre-Lab Homework:

Students will be provided with the upcoming lab manuals, and they will be asked to prepare the theoretical (operations/working principle) information on the topic from the textbook.

Besides, they must implement the circuit (as given in Figures 5-6) using a MultiSIM simulator. Observe the input-output wave shapes and take the snapshots using the snipping tool. Measure the values of different key parameters and fill up the tables (Tables 1, 2, 3, and 4) based on the simulation results.

Apparatus:

SL#	Apparatus	Quantity
1	Zener Diode	1
2	Resistance (100 Ω, 220 Ω, 470 Ω)	1 each
3	Potentiometer (0-20 kΩ, 0-1 kΩ)	1 each
4	Project Board	1
5	Function Generator	1
6	Oscilloscope	1
7	DC milliammeter (0-500 mA)	1
8	Multimeter	1
9	Connecting Leads	10

Precaution!

The following is a list of some of the special safety precautions that should be taken into consideration when working with diodes:

1. **Never remove or insert a diode into a circuit with voltage applied.**
2. **Ensure a replacement diode into a circuit is in the correct direction.**
3. **Make sure the correct connection of the transformer.**
4. **When testing a diode, ensure that the test voltage does not exceed the diode's-**
   a. **Maximum allowable voltage.**
   b. **Ensure a replacement diode into a circuit is in the correct direction.**

Experimental Procedures:

(A) Study of Zener diode characteristics:

1. Measure the actual value of the 470 Ω resistor.
2. Connect the circuit as shown in Fig. 5 (a).
3. Connect the multimeter (voltmeter mode) and milliammeter to measure the line (V_R) and diode voltages (V_D).

4. Turn on the DC power supply with the voltage control nob at 0 V.
5. Rotate the voltage control nob from 0 to +15 V gradually with a step of 0.1 V to 1 V and then 1 V to 15 V as shown in Table 1 (a).
6. Measure the voltage across the two terminals of the supply voltage, diode, and resistor for all cases.
7. Turn off the DC power supply.
8. Calculate the diode current (I_d) and fill up Table 1 (a).
9. Now, connect the circuit as shown in Fig. 5 (b).
10. Repeat steps 3-8 but fill up Table 1 (b).
11. Record the images of the circuit diagram.
12. Plot the I_d -V_D and I_Z -V_Z characteristic curves for the Zener diode in the forward and reverse-biased modes.
13. Determine the knee voltage and static and dynamic resistance of the Zener diode from the forward curve.

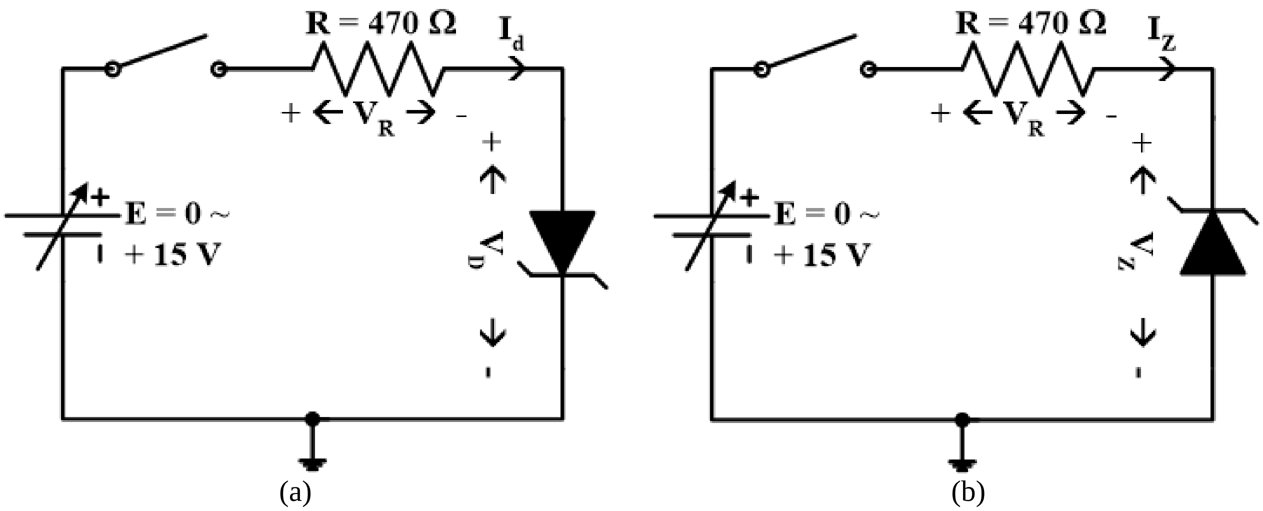


Figure 5: Circuit diagram for the determination of Zener diode's (a) forward and (b) reverse characteristics

Table 1 (a) Data for the I_d – V_D Curve

Source Voltage, E_s (V)	Diode Voltage, V_D (V)	Resistor Voltage, V_R (V)	Diode Current, I_d (mA)
0			
0.1			
0.2			
0.3			
0.4			
0.5			
0.6			
0.7			
0.8			
0.9			
1.0			
2.0			
3.0			

Source Voltage, E_s (V)	**Diode Voltage, V_D (V)**	**Resistor Voltage, V_R (V)**	**Diode Current, I_d (mA)**
4.0			
5.0			
6.0			
7.0			
8.0			
9.0			
10.0			
12.0			
15.0			

Table 1 (b) Data for the $I_Z - V_Z$ Curve [Put minus sign (–) before V_Z and I_Z]

Source Voltage, E_s (V)	**Diode Voltage, V_Z (V)**	**Resistor Voltage, V_R (V)**	**Diode Current, I_Z (mA)**
0			
0.1			
0.2			
0.3			
0.4			
0.5			
0.6			
0.7			
0.8			
0.9			
1.0			
2.0			
3.0			
4.0			
5.0			
6.0			
7.0			
8.0			
9.0			
10.0			
12.0			
15.0			

(B) Study of Zener diode voltage regulation characteristics against the source voltage variation:

1. Measure the actual value of the potentiometers.
2. Connect the circuit as shown in Fig. 6.
3. Connect the multimeter (voltmeter mode) and milliammeter.
4. Turn on the DC power supply with the voltage control nob at 0 V.
5. Set line resistance, R = 470 Ω and load resistance, R_L = 10 kΩ.
6. Rotate the voltage control nob from 0 V to +15 V gradually with a step of 1 V as shown in Table 2.
7. For each step, measure line voltage, V_R, load voltage, V_L, line current, I, Zener current, I_Z, and load current I_L.
8. Record all the data in Table 2.
9. Record the images of the circuit diagram during data collection.
10. Turn off the DC power supply.

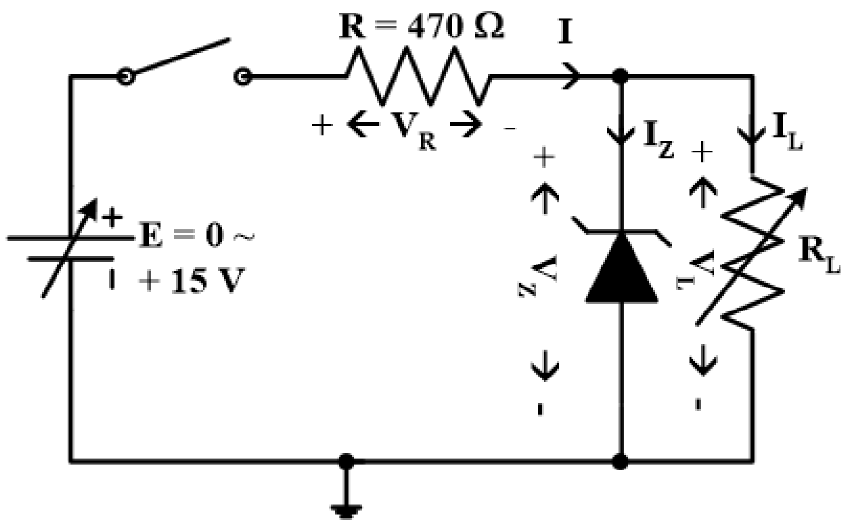


Figure 6: Circuit diagram for the determination of Zener diode's voltage regulation characteristics

Table 2 Data for the voltage regulation curve against the source voltage variation

Source Voltage, E_s (V)	Line Voltage, V_R (V)	Load Voltage, V_L (V)	Line Current, I (mA)	Zener Current, I_Z (mA)	Load Current, I_L (mA)
0.0					
1.0					
2.0					
3.0					
4.0					
5.0					
6.0					
7.0					
8.0					
9.0					
10.0					
12.0					
15.0					

(C) Study of Zener diode voltage regulation characteristics against the load resistance variation:

1. Measure the actual value of the potentiometers.
2. Connect the circuit as shown in Fig. 6.
3. Connect the multimeter (voltmeter mode) and milliammeter.
4. Turn on the DC power supply with the voltage control nob at +15 V.
5. Set line resistance, R = 100 Ω and load resistance, R_L = 1 kΩ using the 50 kΩ potentiometer.
6. Rotate the resistance control nob from 1 kΩ to 20 kΩ gradually with a step of 1 kΩ as shown in Table 3.
7. For each step, measure line voltage, V_R, load voltage, V_L, line current, I, Zener current, I_Z, and load current I_L.
8. Record all the data in Table 3.
9. Record the images of the circuit diagram during data collection.
10. Turn off the DC power supply.

Table 3 Data for the voltage regulation curve against the load resistance variation

Load Resistance, R_L (kΩ)	Line Voltage, V_R (V)	Load Voltage, V_L (V)	Line Current, I (mA)	Zener Current, I_Z (mA)	Load Current, I_L (mA)
0.0					
1.0					
2.0					
3.0					
4.0					
5.0					
6.0					
7.0					
8.0					
9.0					
10.0					
12.0					
14.0					
16.0					
18.0					
20.0					

(D) Study of Zener diode voltage regulation characteristics against the line resistance variation:

1. Measure the actual value of the potentiometers.
2. Connect the circuit as shown in Fig. 6.
3. Connect the multimeter (voltmeter mode) and milliammeter.
4. Turn on the DC power supply with the voltage control nob at +15 V.
5. Set load resistance, R_L = 10 kΩ and line resistance, R = 470 Ω using the 1 kΩ potentiometer.
6. Rotate the resistance control nob from 0 Ω to 1 kΩ gradually with a step of 100 Ω as shown in Table 4.
7. For each step, measure line voltage, V_R, load voltage, V_L, line current, I, Zener current, I_Z, and load current I_L.
8. Record all the data in Table 4.
9. Record the images of the circuit diagram during data collection.
10. Turn off the DC power supply.

Table 4 Data for the voltage regulation curve against the line resistance variation

Line Resistance, *R* (Ω)	**Line Voltage, V_R (V)**	**Load Voltage, V_L (V)**	**Line Current, *I* (mA)**	**Zener Current, I_Z (mA)**	**Load Current, I_L (mA)**
0.0					
100.0					
200.0					
300.0					
400.0					
500.0					
600.0					
700.0					
800.0					
900.0					
1000.0					

Questions:

1. Show the differences between simulated and measured values. Comment on the results and interpret the experimental and simulation data.
2. Determine the breakdown voltage (V_Z) and Zener resistance (R_Z) from the plot.
3. What are the marked differences between the characteristic curves between the Zener Diode and that of an ordinary P-N junction Diode?
4. Determine whether a Silicon or a Germanium diode was used in this experiment. Justify your answer.
5. What are the effects of varying the source voltage, line, and load resistances on the line voltage, load voltage, line current, Zener current, and load current? From the data of Tables 2-4, plot the following curves and then explain the voltage regulation impacts:
   a) V_L vs. I_L [Tables 2-4]
   b) V_L vs. E_s [Table 2]
   c) V_L vs. I_Z [Tables 2-4]
   d) V_L vs. R_L [Table 3]
   e) Voltage regulation vs. R_L [Voltage regulation, $V_{reg} = \frac{V_{NL}-V_{FL}}{V_{FL}} \times 100\%$; typical values of Zener rating (as shown in the Table of Appendix A) should be used as the no-load voltage (V_{NL}) and the voltage across any load resistance (R_L) is the full load volage (V_{FL})]
   f) V_L vs. R
6. Assume that the Zener diode rating is 5 V, 100 mA. Then for the circuit under experiment, what will be the maximum input voltage?
7. Give your own suggestions regarding this experiment.
8. Discuss the overall aspects of the experiment. Did your results match the expected ones? If not, explain.

References:

[1] Robert L. Boylestad, Louis Nashelsky, Electronic Devices and Circuit Theory, 9th Edition, 2007-2008
[2] Adel S. Sedra, Kenneth C. Smith, Microelectronic Circuits, Saunders College Publishing, 3rd ed., ISBN: 0-03-051648-X, 1991.
[3] American International University–Bangladesh (AIUB) Electronic Devices Lab Manual.
[4] David J. Comer, Donald T. Comer, Fundamentals of Electronic Circuit Design, John Wiley & Sons Canada, Ltd., ISBN: 0471410160, 2002.
[5] Resistor values: *https://www.eleccircuit.com/how-to-basic-use-resistor/*, accessed on 20 September 2023.

List the references that you have used to answer the "Discussion" section.

Appendix A:

The Zener or the reverse breakdown voltage ranges from 2.4 V to 200 V, sometimes it can go up to 1 kV while the maximum for the surface-mounted device is 47 V. The standard Zener diode values for the commonly available BZXC family of diodes are shown below in the table. They usually engineer the reverse conduction voltage to occur at popular values. The table below shows a typical range of reverse conduction voltages, V_z, and their associated reverse currents, I_z.

V_z (V)	I_z (mA)
2.7	360
3.0	330
3.3	300
3.9	280
4.3	250
4.7	215
5.1	200
5.6	190
6.2	170
6.8	155
7.5	140
8.2	130
9.1	120
10	105
12	88
15	71
22	52