Group No:

Experiment-03

Study of Zener Diode and Its Application in Voltage Regulation

CSE251 - Electronic Devices and Circuits Lab

Objective

1. To study the I-V characteristics of a zener diode and its application as a voltage regulator.
2. To determine line and load regulations.

Equipments

1. Zener Diode (5 volt) $\times 1$
2. Resistance $(220\Omega, 470\Omega, 10\text{k}\Omega)$
3. POT $10\text{k}\Omega$
4. DC Power Supply
5. Digital Multimeter
6. Breadboard
7. Chords and Wire

Background Theory

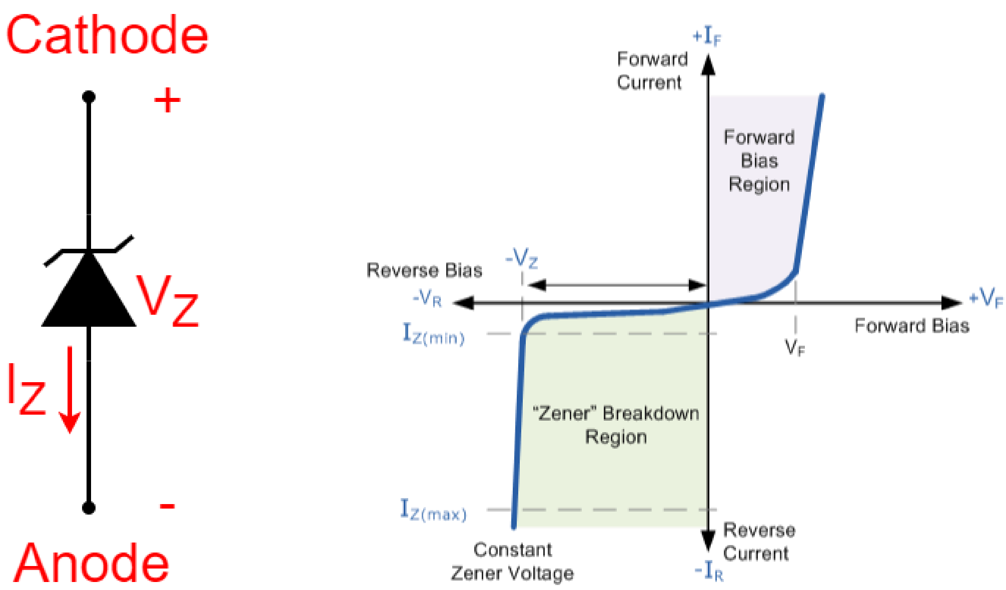


Figure 1: Zener Diode Symbol and IV-characteristics

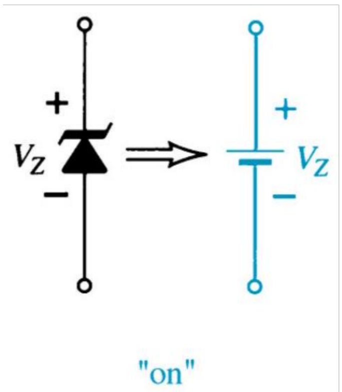
The diodes we have studied before do not operate in the breakdown region because this may damage them. A Zener diode is different. It is a silicon diode that the manufacturer has optimized for operation in the breakdown region. It is used to build voltage regulator circuits that hold the load voltage almost constant despite large

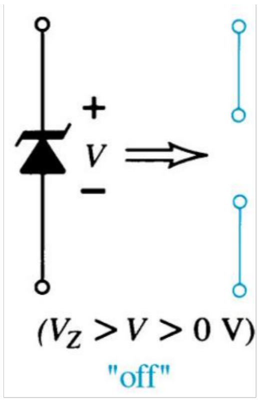
change in line voltage and load resistance. Figures below show the symbol of Zener diode and its operating region.
The Zener diode may have a breakdown voltage from about 2 to 200 V. These diodes can operate in any of the three regions: forward, leakage and breakdown.

- In the forward region it works as an ordinary diode.
- In the leakage region (between zero and breakdown) it has only a small reverse saturation current.
- In the breakdown region it has a sharp knee, followed by an almost vertical increase in current without changing the voltage.
- The voltage is almost constant, approximately equal to Vz over most of the breakdown region.

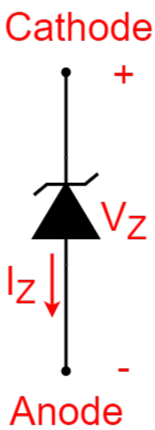
Model Approximations

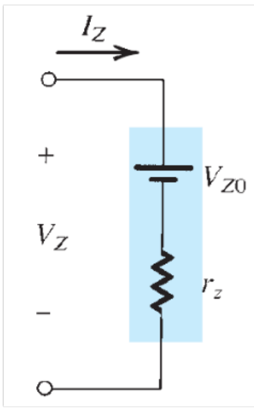
First approximation: When the voltage across the zener diode $V \geq V_Z$, the diode is ON, and it is represented by a battery with constant voltage of V_Z, otherwise the diode is OFF and it is represented by an open circuit.





Second approximation: The Zener diode is modeled with a battery of voltage V_{Z0} in series with resistance r_Z, called the zener resistance, to account for the slight increase in the zener voltage V_Z with the zener current I_Z.





$$V_Z = V_{Z0} + I_Z r_z$$

Voltage Regulation

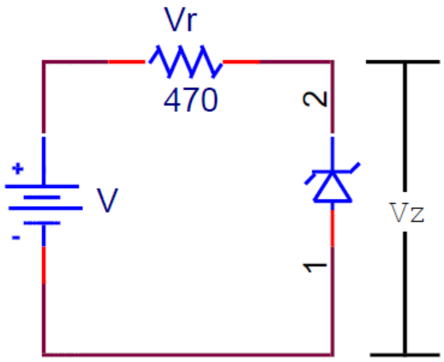
Voltage regulation is a measure of performance of voltage regulator circuits. It is classified as two types:

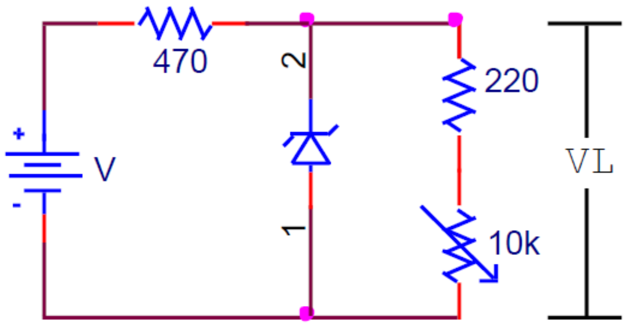
1. Line Regulation
2. Load Regulation

Line Regulation: Line regulation is the variation in the output or the load voltage (V_L) for one volt variation in the input voltage (V_i), expressed mathematically as $\Delta V_L/\Delta V_i$(mV/V).

Load Regulation: Load regulation is the variation in the output or the load voltage (V_L) for one mA variation in the load current (I_L), expressed mathematically as $\Delta V_L/\Delta I_L$ (mV/mA)

Task-01: Experimental Work





Procedure

1. Build the circuit as shown in the left figure.
2. Vary the supply voltage from 0 to 10 volt, in steps of $1v$ and complete Table 1. Try to take more readings with smaller voltage increments ($0.1v$ or $0.2v$) near the breakdown region in order to accurately capture the transition.
3. Now, build the circuit as shown in the right figure.
4. Keep the 10k POT at maximum position and then power up the circuit. Apply $10v$ DC at the input.
5. Gradually decrease the POT resistance and complete Table 2.
6. Replace load with 10kΩ resistance, vary the supply voltage and take readings for Table 3.

Data Table

Table 1

V (volt)	V_R (volt)	V_Z (volt)	$I_Z = V_R/R$ (mA)
0			
1			
2			
3			
4			
4.9			
5			
5.1			
5.2			
5.3			
5.4			
5.5			
6			
7			
8			
9			
10			

Table 2

V_{220} (mV)	V_L (volt)	$I_L = V_{220}/R_{220}$ (mA)
$V_{Start} =$		
$V_{Start} + \Delta =$		
$V_{Start} + 2\Delta =$		
$V_{Start} + 3\Delta =$		
$V_{Start} + 4\Delta =$		
$V_{Start} + 5\Delta =$		
$V_{Start} + 6\Delta =$		
$V_{Start} + 7\Delta =$		
$V_{Start} + 8\Delta =$		
$V_{Start} + 9\Delta =$		

Let,
$V_{220@POT=10k\Omega} = V_{Start} =$
$V_{220@POT=0} = V_{End} =$
Difference, $\Delta = (V_{End} - V_{Start})/9 =$

Table 3

V (volt)	V_L (volt)
0	
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	
15	
16	

Task-02: Calculation

Load Regulation

Pick any two data from Table 2 and calculate the following quantities,

$V_{L1} =$
$I_{L1} =$
$V_{L2} =$
$I_{L2} =$

Load regulation, $\Delta V_L/\Delta I_L =$

Line Regulation

Pick any two data from Table 3 and calculate the following quantities,

$V_{L1} =$

$V_1 =$

$V_{L2} =$

$V_2 =$

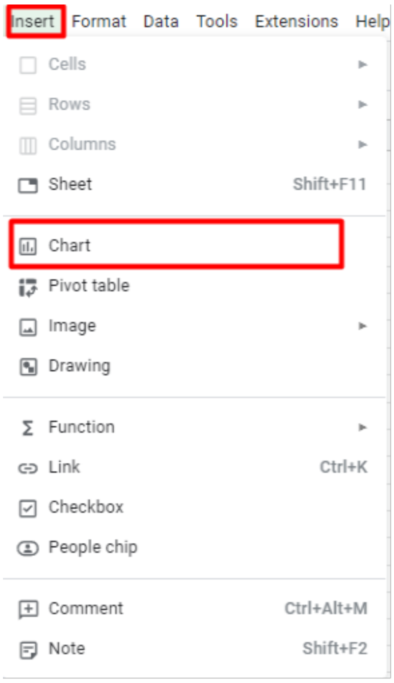
Line regulation, $\Delta V_L / \Delta V =$

Task-03: Plotting Graphs on Spreadsheet (Home Task)

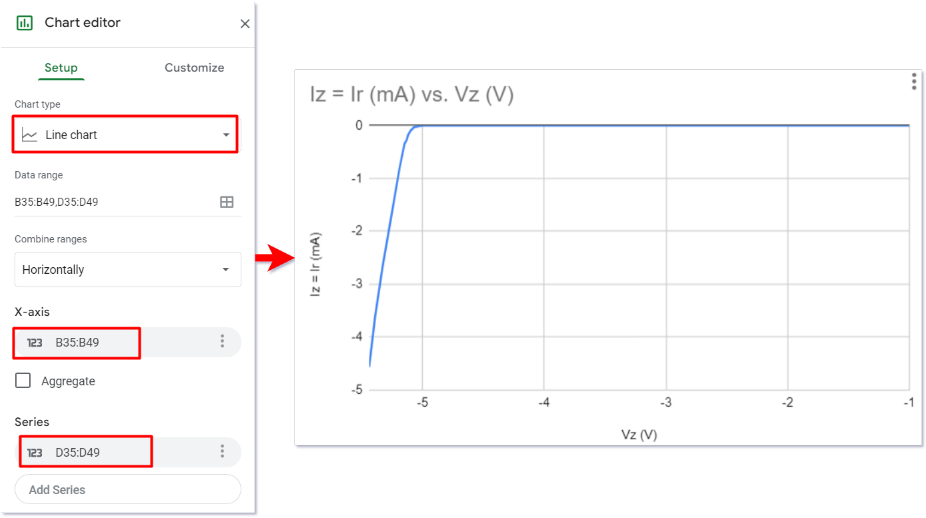
1. Create a Google spreadsheet by visiting https://docs.google.com/spreadsheets
2. Fill in the spreadsheet with the data of Table 1 (refer to your lab sheet). Select both the columns of Vz and Iz (to select a column, click on the column head, e.g.,'B'. Then hold CTRL while clicking the second column, e.g., 'D', to select both columns)

V	Vz (V)	Vr (V)	Iz = Ir (mA)
-1	-1	0	0
-2	-2	0	0
-3	-3	0	0
-4	-4	0	0
-5	-5	0	0
-5.1	-5.07	-0.03	-0.03
-5.2	-5.1	-0.1	-0.1
-5.3	-5.12	-0.18	-0.18
-5.4	-5.13	-0.27	-0.27
-5.5	-5.15	-0.35	-0.35
-6	-5.19	-0.81	-0.81
-7	-5.26	-1.74	-1.74
-8	-5.33	-2.67	-2.67
-9	-5.39	-3.61	-3.61
-10	-5.44	-4.56	-4.56

3. Select Insert → Chart.



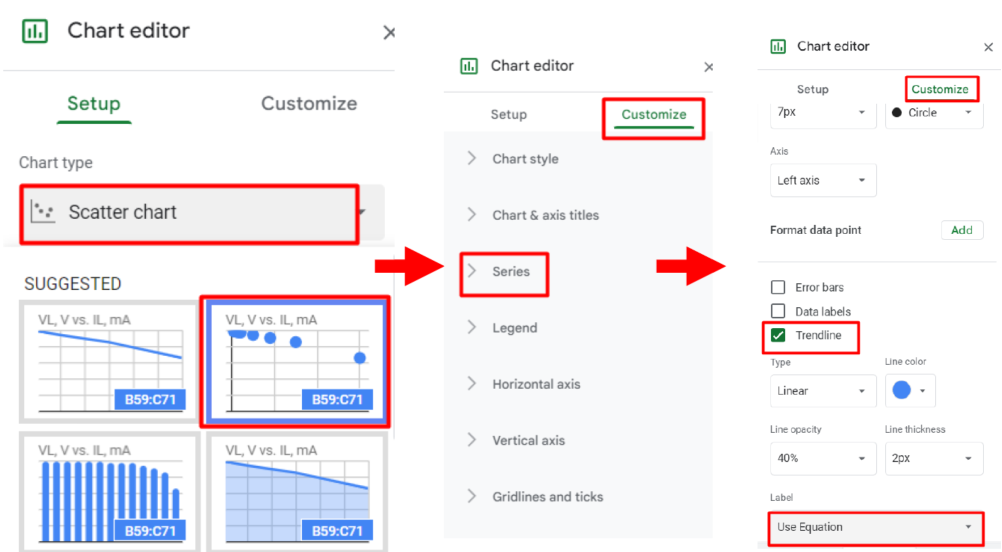
4. A Chart Editor section should pop up at the right side of your screen. If it doesn't show up, then double click on the graph. Go the setup section in the chart editor and change the 'Chart Type' to 'Line Chart'. Keep Vz on the x-axis and Iz on the y-axis (series). Your graph should look like the following:



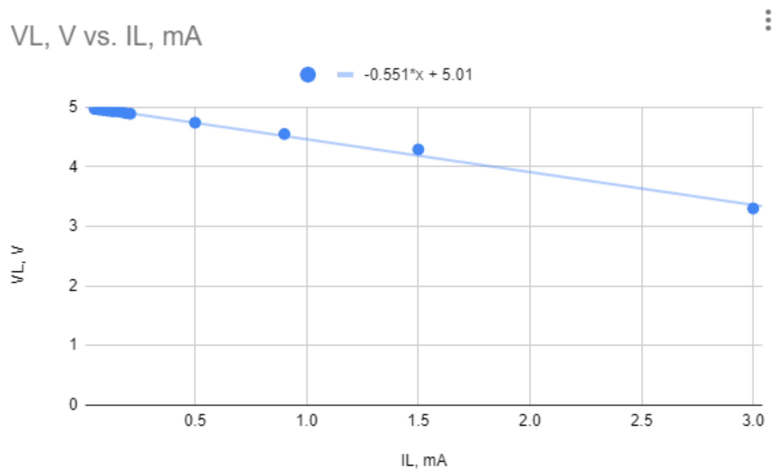
5. Create another table with the data of Table 2 (refer to your labsheet). Select columns of V_L and I_L (I_L = x-axis, V_L = y-axis).

Vr, mV	IL, mA	VL, V
50.2	0.0502	4.97
69.9	0.0699	4.96
90	0.09	4.95
110	0.11	4.94
130	0.13	4.93
150	0.15	4.93
170	0.17	4.92
190	0.19	4.9
210	0.21	4.89
500	0.5	4.74
900	0.9	4.55
1500	1.5	4.29
3000	3	3.3

6. Select Insert → Chart. In the Chart Editor, Select Chart Type → Scatter Chart. Go to Customize section of the chart editor, select 'Series'. Check 'Trendline' and select 'Use Equation' in Label.



7. Your graph should now look like the following figure. The equation represents the equation of the trend-line/graph. The slope of the equation represents the load regulation.

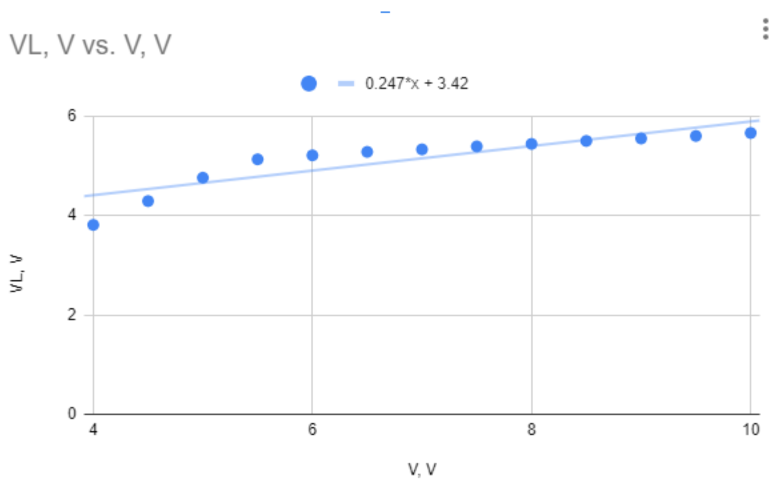


8. Create another table with the data of Table 3 (refer to your labsheet).
Select columns of V_L and V (V = x-axis, V_L = y-axis).

V, V	VL, V
10	5.66
9.5	5.6
9	5.55
8.5	5.5
8	5.44
7.5	5.39
7	5.33
6.5	5.28
6	5.21
5.5	5.13
5	4.76
4.5	4.29
4	3.81

9. Repeat Step-6: Select Insert → Chart. In the Chart Editor, Select Chart Type → Scatter Chart. Go to Customize section of the chart editor, select 'Series'. Check 'Trendline' and select 'Use Equation' in Label.

10. Your graph should now look like the following figure. The equation represents the equation of the trend-line/graph. The slope of the equation represents the load regulation.

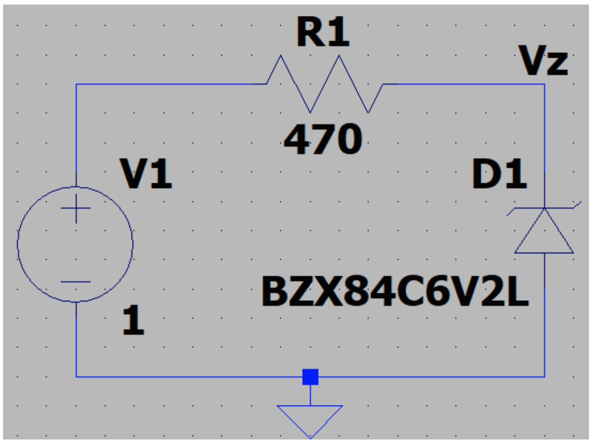


Note: This is a sample data collected from a simulation. Your data may not match with this one.

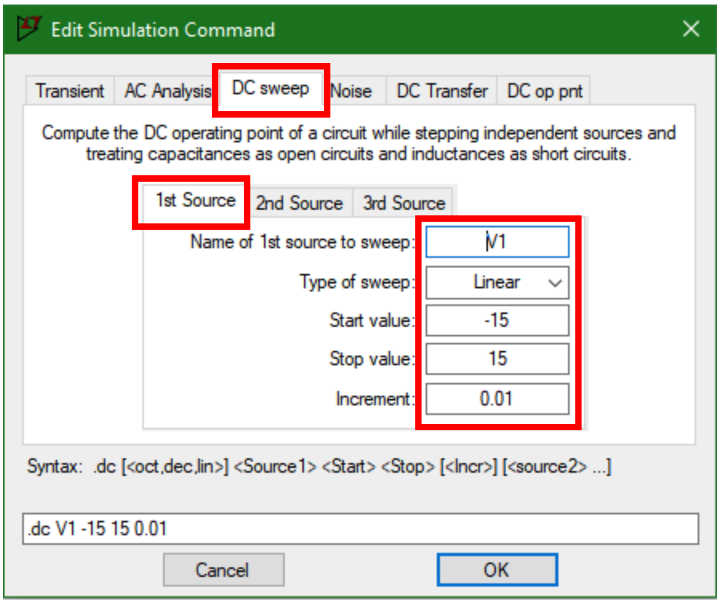
Task-04: Simulation (Home Task)

In this task, we will simulate the experiment in LTspice and verify the results that were obtained in Hardware lab. Follow the following steps for the simulation:

1. Open a new schematic, build the following circuit. To insert a Zener diode, type or find ‘zener’ in the select component symbol window.

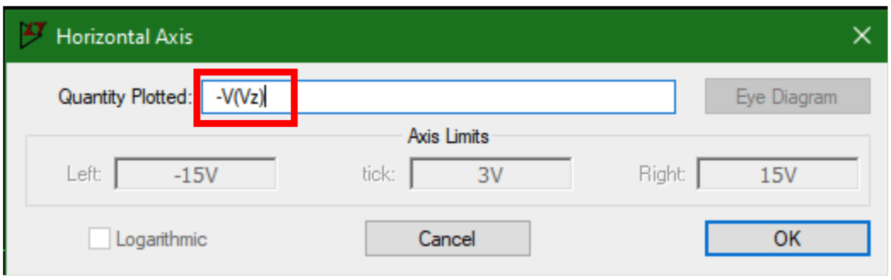


2. Go to the Edit Simulation Command → In the ‘DC sweep’ tab, set the properties to sweep V1 as shown in the figure below.



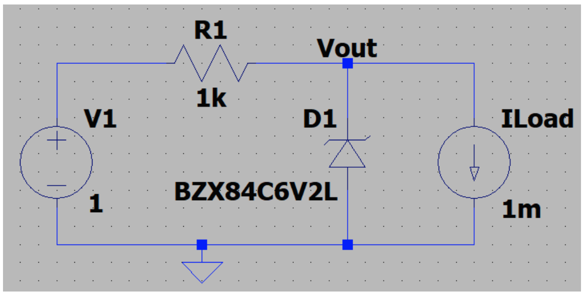
3. Run the simulation.

4. Note that ‘V1’ is plotted along the horizontal axis. Change the horizontal attribute to ‘-Vz’.

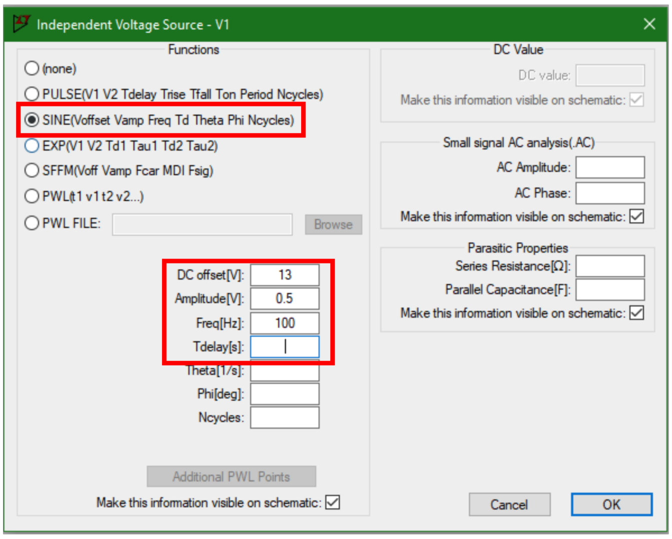


5. Plot the current through the resistor. The plot will look like the following figure. Notice that, in the forward bias condition, the Zener diode acts like an ordinary diode. However, for a particular reverse bias voltage (6.2v in this case) the Zener diode goes into breakdown.

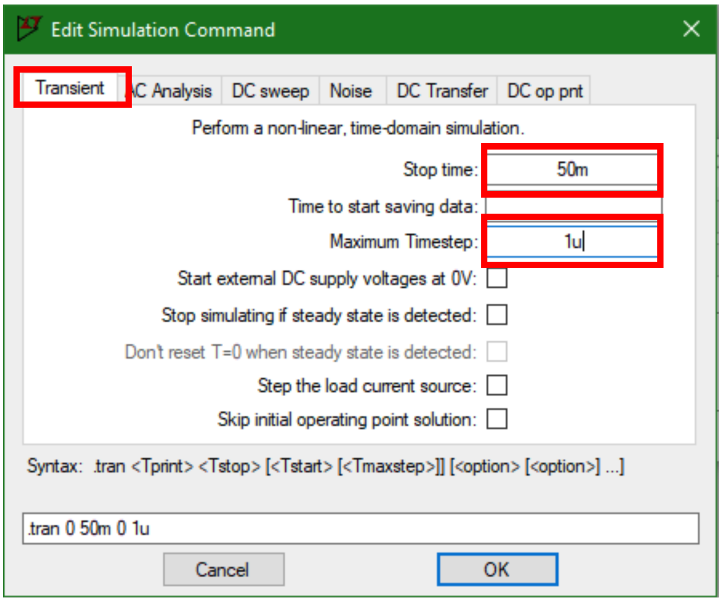
6. We will observe the behaviour of a Zener diode as a voltage regulator and calculate the line regulation. Add a current source in parallel to the diode. We are assuming that the load draws a constant current from the circuit, which we model with a current source in place of a load. Set the current as 1mA.



7. To observe the line regulation (i.e. change in the output voltage for a change in the input voltage, measured in mV/V), we vary the input voltage sinusoidally by 1v above the Zener breakdown down voltage (6.2v for the model used). Right click on the voltage source (V1) → Advanced → Set the properties as shown in the following figure → Click OK.

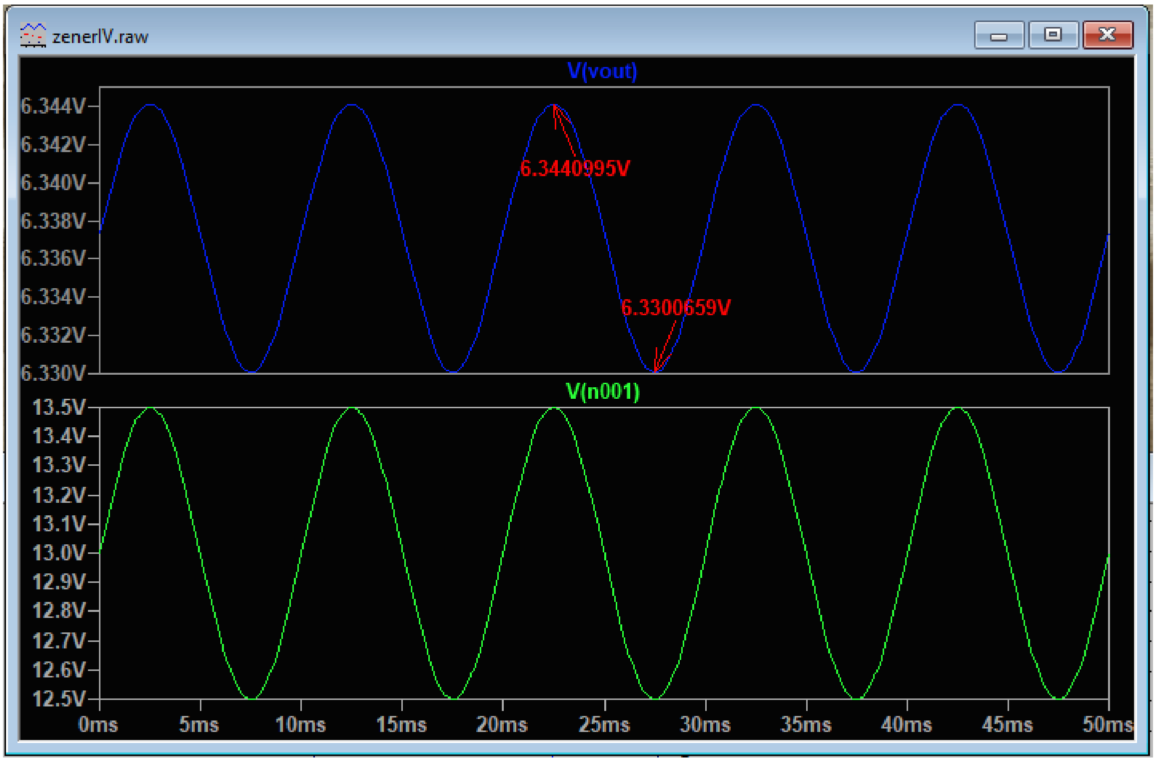


8. Go to the 'Edit Simulation Command' window. In the 'Transient' tab, set the properties 'Stop Time = 50m' and 'Maximum Timestamp = 1u' as shown below.



9. Run the simulation.

10. Plot the input voltage (V1) and the output voltage (Vout) in separate pane as shown in the figure below:

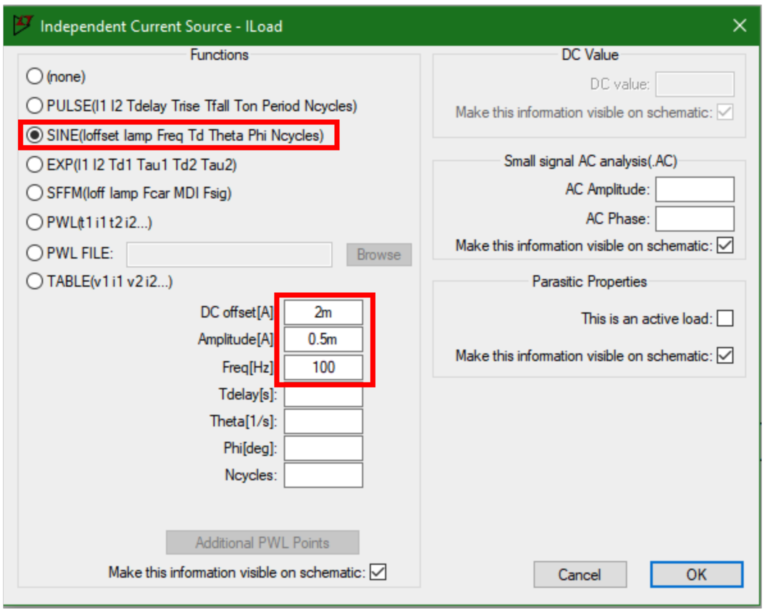


Notice that we set the input voltage to vary sinusoidally by $1v$. From the plot it can be seen that the output voltage varies only a little ($6.33v$ to $6.34v$). So the line regulation is,

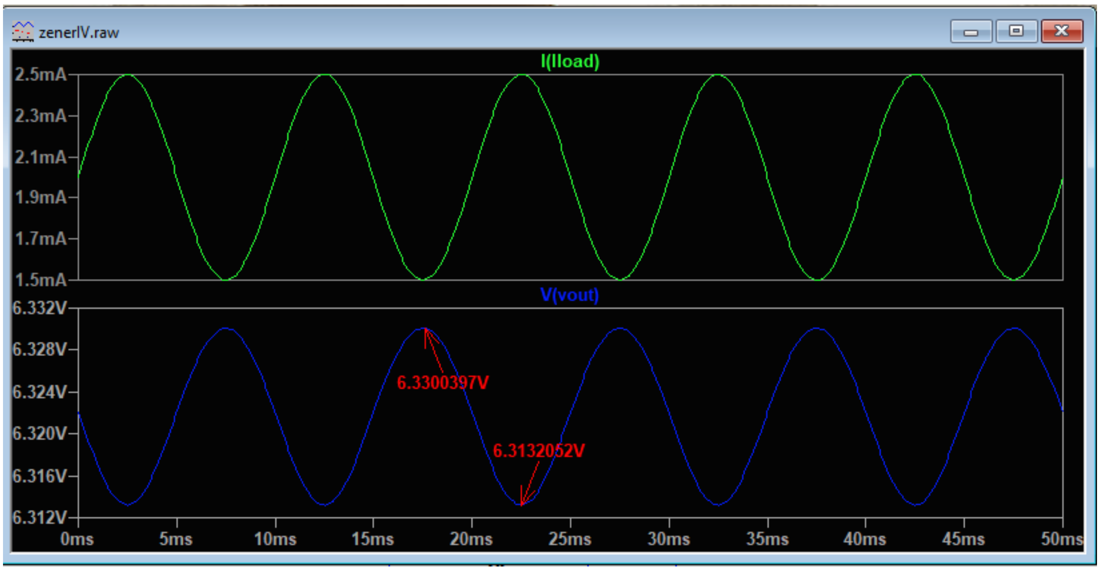
$$\frac{(6.34 - 6.33) \times 1000}{1}(mV/V) = 10(mV/V)$$

11. Now we shall study the load regulation of the Zener diode. Load regulation, measured in mV/mA, is the change in output voltage with respect to load current. To employ this in behaviour, we shall model the current source as a varying load while keeping the supply voltage constant. Set back the voltage (V1) to $13v$ DC. This ensures the breakdown of the Zener diode.

12. Right click on the current source (ILoad) → Advanced.
Set the properties as shown in the following figure → Click OK.



13. Leave the simulation property unchanged and run the simulation. Plot the load current (ILoad) and the output voltage (Vout) in separate panes.



Notice that, we set the load current to vary sinusoidally by $1mA$. From the plot it can be seen that the output voltage varies slightly from $6.3300v$ to $6.3132v$). So, the load regulation is,

$$\frac{(6.3300 - 6.3132) \times 1000}{1}(mV/mA) = 16.8(mV/mA)$$

Task-05: Report

1. Cover page [include course code, course title, name, student ID, group, semester, date of performance, date of submission]
2. Draw the Circuit Diagrams
3. Add the Signed data sheet
4. Plot the I-V characteristics (V_Z vs. I_Z of the Zener Diode in excel) (refer to Table 1)
5. Plot V_L vs. I_L for the data of Table 2 in excel. Determine the load regulation.
6. Plot V_L vs. V for the data of Table 3 in excel. Determine the line regulation.
7. Tabulate your results as in Table 4. Comment on your results.
8. Discussion

Load Regulation (mV/mA)		Line Regulation (mV/V)	
From Experiment (graph)	Theoretical Calculation	From Experiment (graph)	Theoretical Calculation

Table 4