ECD LAB-2 Zener Regulator

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Introduction

The aim of this lab is to use a Zener diode to regulate a higher voltage into a lower voltage using Zener's breakdown voltage. Essentially the system that is being made is an Overvoltage Protection Circuit that lowers the input voltage for practical use.

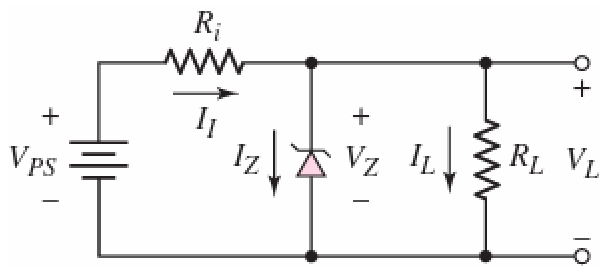

Figure 1: Representative Zener Regulator[1]

a. Determination of Max and Min Zener currents

Using the representative circuit, we can calculate the max and min currents writing KCL on the output node. For KCL we assume that Zener diode is ideal and has an internal resistance of 0 ohms. Since the system is ideal, we can that $V_L = V_Z$ and,

$$I_L = \frac{V_Z}{R_L}$$

We can say that I_L is a constant for this lab as we know the values of V_Z , ideally, and R_L. In such case, this circuit has the variables we have are $V_{PS,}$ I_Z and I_I. The latter two depend on V_{PS}. Therefore, we expect I_Z to be max when V_{PS} is max, and we expect I_Z to be min when V_{PS} is min. We can prove this from the current KCL equation for I_Z:

$$I_Z = \frac{V_{PS} - V_Z}{R_i} + I_L = \frac{V_{PS} - V_Z}{R_i} + \frac{V_Z}{R_L}$$

$$I_{Zmax} = \frac{V_{PSmax} - V_Z}{R_i} - \frac{V_Z}{R_L}$$

$$I_{Zmin} = \frac{V_{PSmin} - V_Z}{R_i} - \frac{V_Z}{R_L}$$

b. Source Regulation and Load Regulation

Source Regulation, can be defined as the change in the output voltage caused by the changes in the input voltage. It gives power supply the ability to have changes in the output at a given range when there are changes in the input voltage [2]. It can be measured as,

$$Source\ Regulation(\%) = \frac{\Delta V_{out}}{\Delta V_{in}} \cdot 100$$

Load Regulation can be defined as power supply's capability to ensure stable output voltage regardless of the changes in output current or load. Therefore, an ideal load regulation should be 0, that is to say that the power supply will always provide stable voltage regardless of the changes in the load [3]. Load regulation can be measured as,

$$Load\ Regulation(\%) = \frac{V_{no,load} - V_{full,load}}{V_{full,load}} \cdot 100$$

The idea is to observe to change at maximum possible load and minimum possible load, which is no load condition so that we can observe the sources capability to supply stable voltage.

Hardware Implementation and Analysis

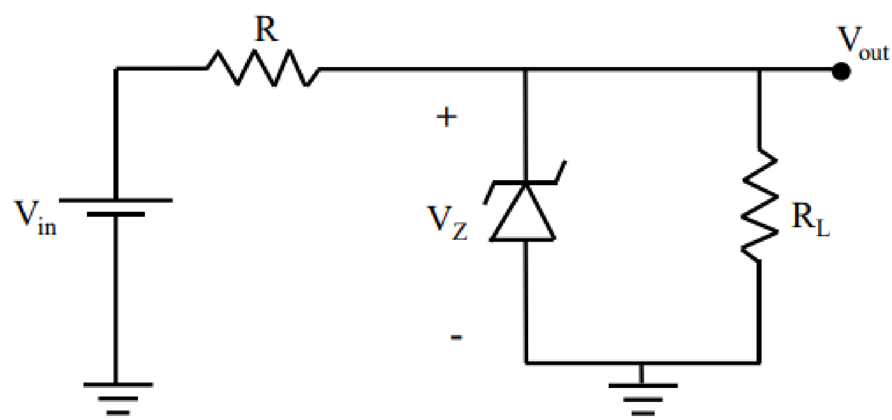

Figure 2: The Circuit to be implemented

a) R Choice

In this part there are some given values to be able to determine value of R.

- $V_{in} = 9V\ and\ 11V\ (in\ order)$
- $R_L = 500\ ohm$
- $V_Z = 5.1V\ breakdown\ voltage$
- The zener is considered ideal

From the preliminary part we can shorten the calcution of R's value range saying that I_Z should be more than 10mA when input is 9V, which would be maximum resistance value, and I_Z

should be less than 100 mA when 11V input is given, which would be minumum resistance value. However, to ensure the validity I will calculate maximum and minumum values of R for both current and voltage cases.

1. $I_Z = 10mA$

To find the total current passing through R we can use Ohm's law on R_L and find the current passing through it to add it with the current passing through the Zener. We can find maximum resistance values when current is minimum.

$$I_L = \frac{V_Z}{R_L} = \frac{5.1V}{500ohm} = 10.2mA$$

$$I = I_Z + I_L = 20.2mA$$

If Vin = 9V,

$$\frac{9V - 5.1V}{R} = 20.2mA$$

$$R = 193ohm$$

If Vin= 11V,

$$\frac{11V - 5.1V}{R} = 20.2mA$$

$$R = 292\ Ohm$$

2. $I_Z = 100mA$

Repeating the same process in a-2 we find the minimum possible values for R :

$$I_L = 10.2mA$$

$$I = I_L + I_Z = 110.2mA$$

If Vin=9V,

$$\frac{9V - 5.1V}{R} = 110.2mA$$

$$R = 35\ Ohm$$

If Vin=11V,

$$\frac{11V - 5.1V}{R} = 110.2mA$$

$$R = 53.5\ Ohm$$

	$V_{in} = 9V$	$V_{in} = 11V$
$I_Z = 10mA$	$R = 193\ Ohm$	$R = 292\ Ohm$
$I_Z = 100mA$	$R = 35\ Ohm$	$R = 53.5\ Ohm$

Table 1: Resistance Values for Different Cyrrents and Voltages

As mentioned before we found the minimum resistance value from 11V and maximum resistance value from 9V input.

$$53.5\ Ohm < R < 193\ Ohm$$

For easier calculations I picked 100 Ohms for R.

- Putting 100 Ohm value into the I_{Zmax} and I_{Zmin} that was written in preliminary part we get $I_{Zmin} = 28.8mA$ and $I_{Zmax} = 48.8mA$.

Moving onto hardware part:

I connected a multimeter in series to measure the current passing through the Zener diode.

When $V_{in} = 9V$,

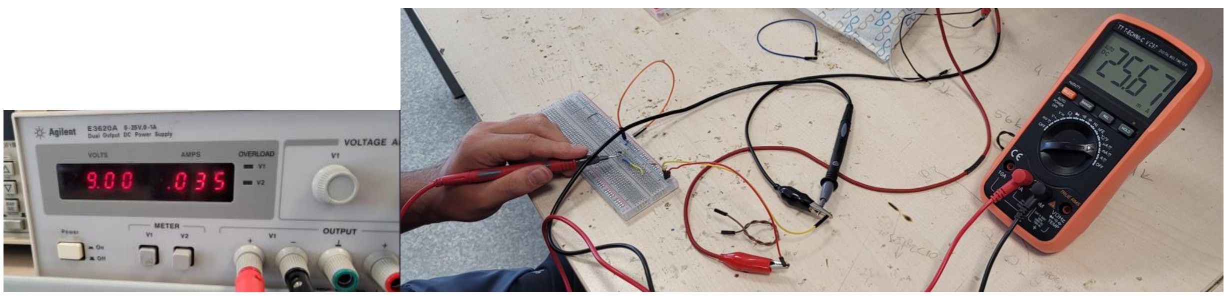

Figure 3&4: 9 Volt input with 25.67mA Zener current

One can see that the voltage supply is also supplying 35mA from which we can find there 9.33mA current is supplied to the Load.

- For expectation of 10.2mA for the load there is 8.5% error which could be caused by the voltage generator or multimeter itself
- The $I_Z = 25.67mA$ which is more than 10mA. Compared to the expected value of 28.8mA, there is 11.5% error. This error may be due to non ideal Zener and resistors.

When $V_{in} = 11V$,

Figure 5 & 6 : 11 Volt input with 44.7mA Zener Current

It can be seen that voltage supply is providing 55mA to the circuit. Therefore, the load current can be calculated as 10.3mA.

- Compared to the expected value of 10.2mA load current there is only %1 error in the actual values.
- The $I_Z = 44.7mA$ is less than 100mA, which is within the expected range. Compared to the expected value of 48.8mA there is 8.4% error. This error could be due to resistor and zener not being ideal.

	Expected Zener Current	Real Zener Current	Error
$V_{in} = 9V$	$28.8mA$	$25.67mA$	11.5%
$V_{in} = 11V$	$48.8mA$	$44.7mA$	8.4%

b) Source Regulation and Zener Resistance

To be able to measure source regulation I needed to use the waveform generator which has a source resistance of 50 Ohms. I had picked 100 Ohm for R initially so I changed it to 47 for data accuracy. This meant that I needed to use 97 Ohm as a value to be able to calculate Zener resistance.

For this part, Vinput = 9.5 + 0.1 sin(2*100) was used. This was created in waveform generator as 4.75V offset with 0.1 sin(2*100) V input.

- RL= 500 ohm
- Rin= 47 ohm

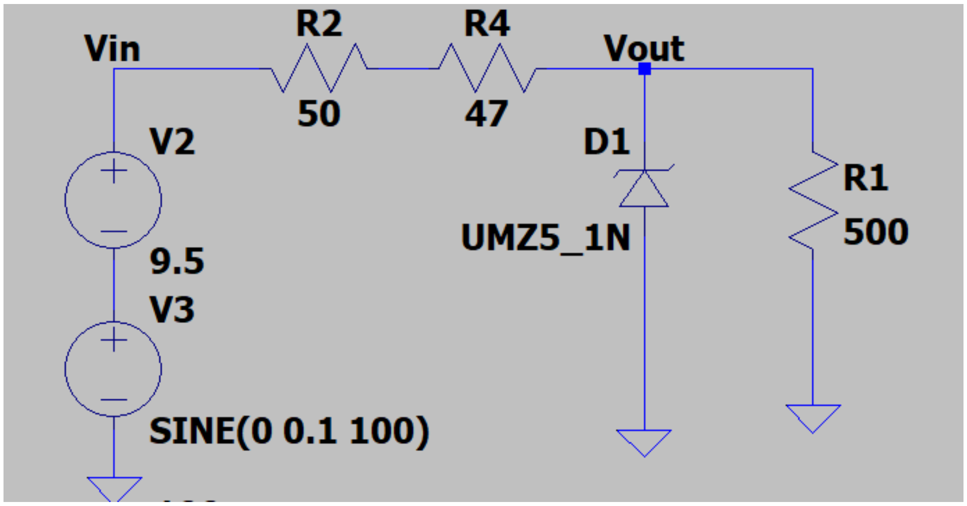

Figure 7: Sample Circuit

1. Source Regulation

Essentially what we need to measure to find source regulation is $\Delta Vin\ and\ \Delta Vout$. To be able to get more accurate results I used external triggering and 1x attenuation factor setting on the probe. Looking at ΔVin:

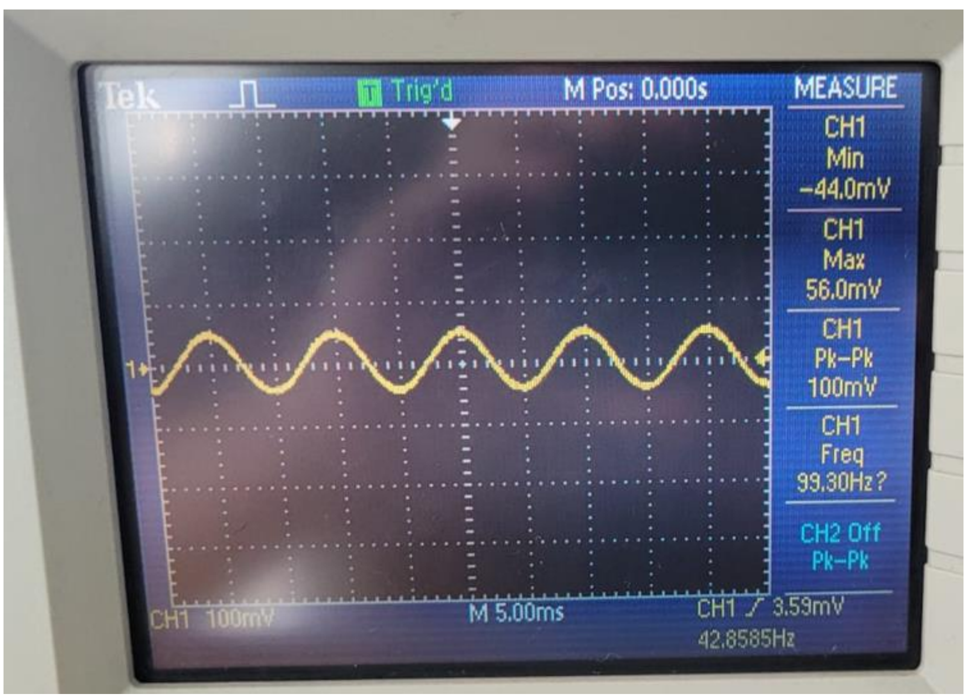

Figure 8: ΔVin value matched with 50 Ohm

As explained in the lab details, waveform generator gives half the input when it's matched with 50 Ohm hence $\Delta Vin = 200mV$. as to be able to give 100mVpeak to peak voltage.

To confirm my suspicion I tried the same case with 100 ohm input:

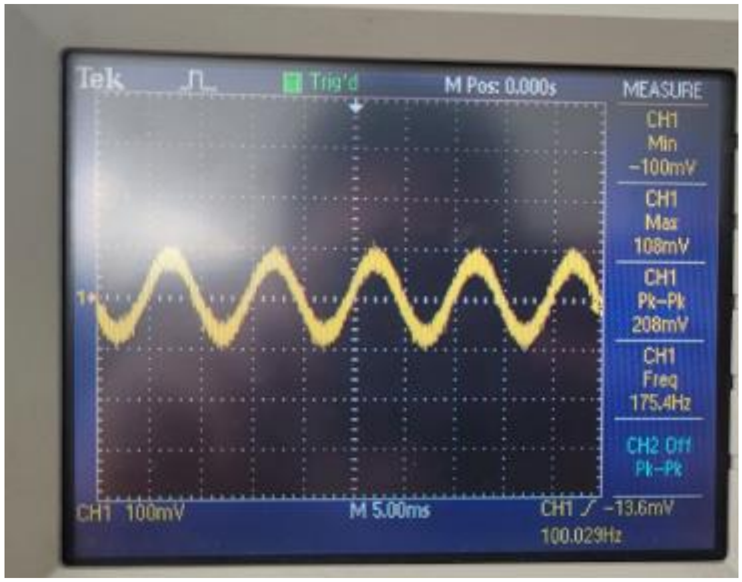

Figure 9: ΔVin with 100 Ohm

As you can see no matching occurred since the $\Delta Vin = 208mV$. Therefore, waveform generator switches in high impedance state and stops doing the voltage division to give half of the Vpp applied. As a result 47ohm was picked as input resistance in this part

Looking at $\Delta Vout$:

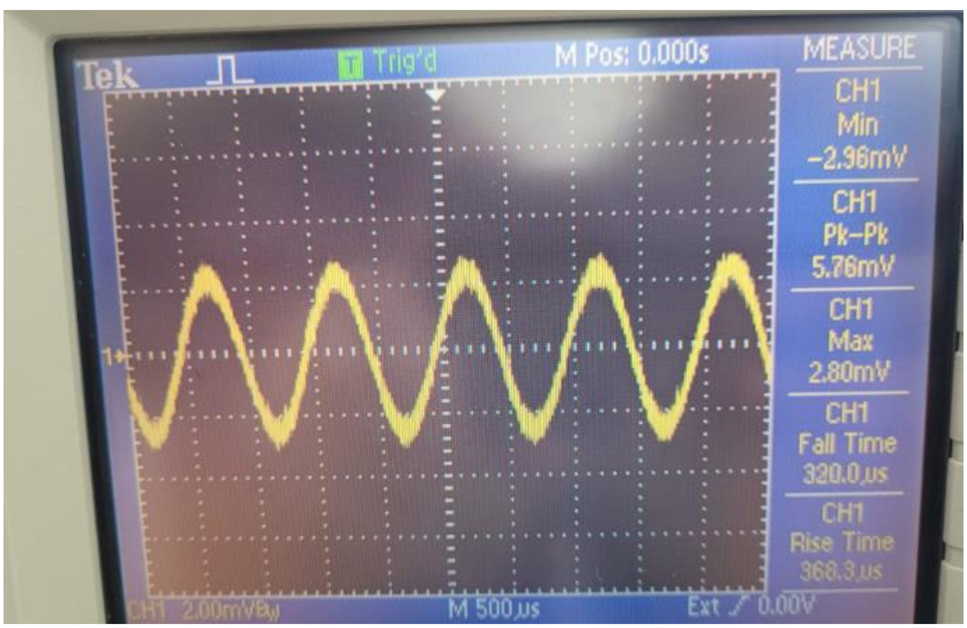

Figure 10: $\Delta Vout$

$\Delta Vout$ Was measured to be $\Delta Vout = 5.76mV$. Now that required values are known,$Source\ Regulation = \frac{\Delta Vout}{\Delta Vin} \cdot 100 = \frac{5.76mV}{200mV} \cdot 100 = 2.88\%$

This value is quite normal as source regulation needs to be as low as possible to be able to create a stable voltage output.

2. Calculation of r_z

We can use the relation between $\frac{\Delta V_{in}}{\Delta V_{out}}$ and write the elements who have effect in this fluctuation:

$$\frac{\Delta V_{in}}{\Delta V_{out}} = \frac{R_L//R_Z}{R_L//R_Z + 50 + R_{in}}$$

From here r_z was found as $r_z = 2.893\ Ohm$. This value is necessary as it affects the $\Delta Vout$.

c) Load Regulation

For load regulation it was wanted in the lab to $R_L\ to\ 100\ Ohms$ and use 10V DC voltage. This part is quite simple as what we need are two values: $V_{no,load}$ and $V_{full,load}$. Essentially the no load condition is an open circuit whereas full load condition is when 100 Ohm are put back in. I also reverted R, the input resistance, back to 100 ohm to have accurate results. Here are the measured values:

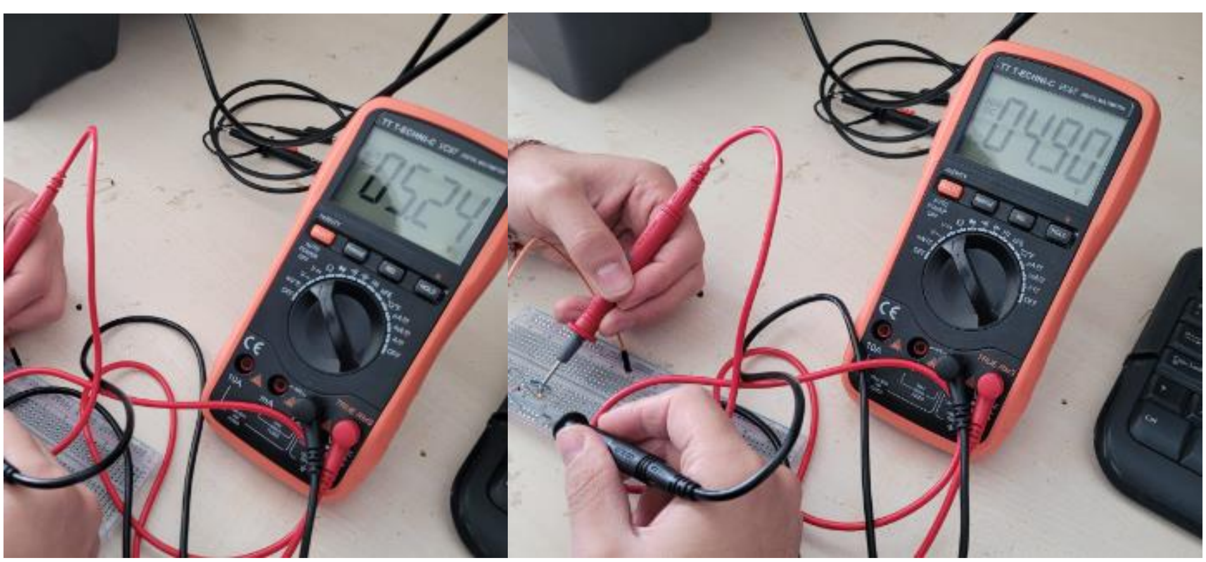

Figure 11 & 12: $V_{no,load} = 5.24V$ and $V_{full,load} = 4.90V$

From here load regulation can be calculated as

$$Load\ Regulation(\%) = \frac{V_{no,load} - V_{full,load}}{V_{full,load}} \cdot 100 = 6.93\%$$

For small voltages this result doesn't mean much but high voltage cases a 7% change may result in problems in the circuit.

Conclusion

This lab's task was to use a Zener diode to regulate voltage and understand the importance of line(source) regulation and load regulation. Though the lab in itself wasn't quite hard as the concepts are quite simple to understand, the correct measurement method with several calculations created some problems grasping what to do.

During the measurement of source regulation I tried using both generators, used oscilloscope without external trigger, tried to get an accurate result in 10x attenuation rate as well. All of these methods were proved to be quite impractial or wrong as this lab required more precise methods to be able to properly calculate source regulation, a concept where even small milivolts can be important.

Overall, the results were within expectations of theory mostly and the simple Zener voltage regulator is a practical method to step down the voltage input. However considering the energy formula it wastes quite a bit of energy as considerable amount of current was measured to pass through it in part a.

Sources

[1] D. Neaman, *Microelectronics Circuit Analysis and Design*. McGraw-Hill Science Engineering, 2007.

[2] "Load Regulation," Sunpower Electronics UK, https://www.sunpower-uk.com/glossary/what-is-load-regulation/ (accessed Oct. 7, 2023).

[3] "Line Regulation," Sunpower Electronics UK, https://www.sunpower-uk.com/glossary/what-is-line-regulation/ (accessed Oct. 7, 2023).