EEE 313- Electronic Circuit Design

-Lab 02-

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Introduction

The purpose of this lab was to design and analyse a voltage regulator circuit which consists of a zener diode operating in the breakdown region as the main component.

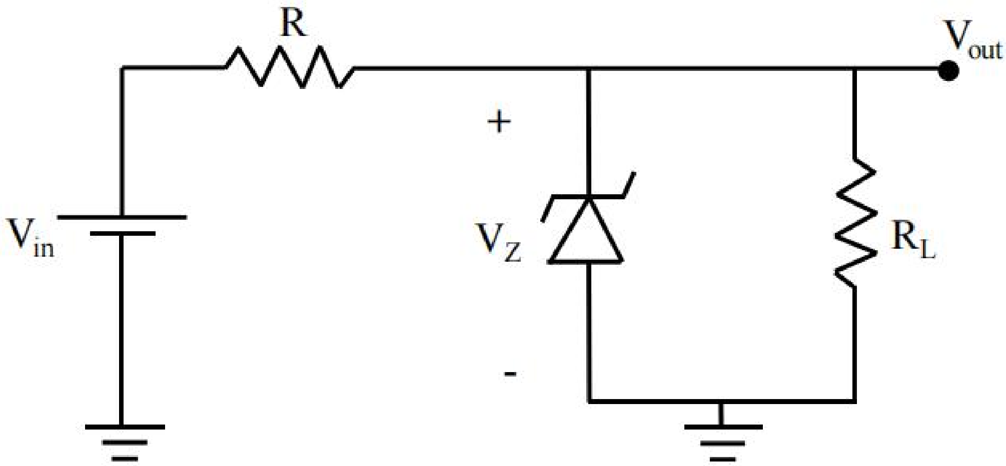

Fig.1. Voltage regulator circuit

Zener Diodes

1) Determination of Zener current limits

Diodes cannot operate with continuously increasing reverse bias voltage, at some point breakdown occurs and the diode starts to pass the current in the reverse- bias direction.This point is called as the breakdown point. Zener diodes are a specific type of diodes which provides a specified breakdown voltage V_{z0}. This voltage value is constant over a wide range of current and temperature values. If the current is within the limits of the diode, we can use this breakdown feature of zener diodes for using them as a constant-voltage reference [1].

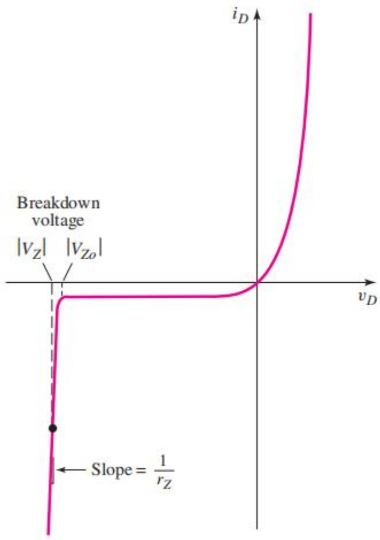

Fig.2. Zener diode I-V characteristics [1]

As can be seen in Fig.2. for a non-ideal diode, it has an internal resistance namely r_z when it is operating in the breakdown region. Hence although we are trying to keep the voltage constant as current varies, there is a small change in the V_{z0} as the current increases.

If we assume that out zener diode is ideal and act as if it doesn't have any internal resistance, we can find the current limits of the circuit by doing KCL at the output node in Fig.1.

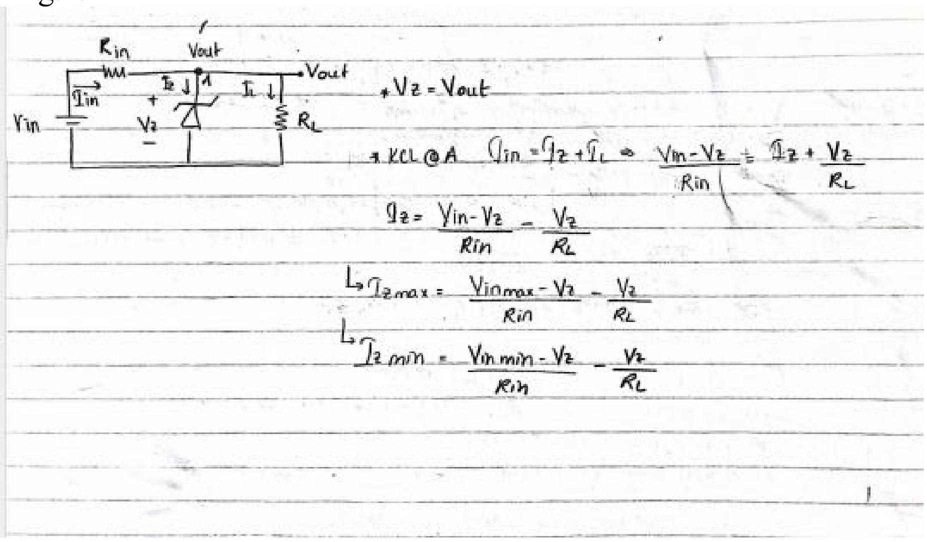

Fig.3. $I_{z\,max}$ and $I_{z\,min}$ calculations

2) Source and load regulations

Source regulation can be defined as the ability to maintain constant output with respect to varying input voltage. It is determined by finding the percentage of the ratio between the change in the output voltage over the change in the input voltage.

$$\text{Source Regulation}(\%) = \frac{\Delta V_{out}}{\Delta V_{in}} * 100 \qquad (1)$$

Load regulation can be defined as the he ability to maintain constant output with respect to varying load. It is determined by finding the percentage of the ratio between the difference of no load output voltage and full load output voltage over full load output voltage.

$$\text{Load Regulation}(\%) = \frac{V_{no-load} - V_{full-load}}{V_{full-load}} * 100 \qquad (2)$$

Hardware Implementation

The hardware implementation of the circuit can be seen in Fig.4.

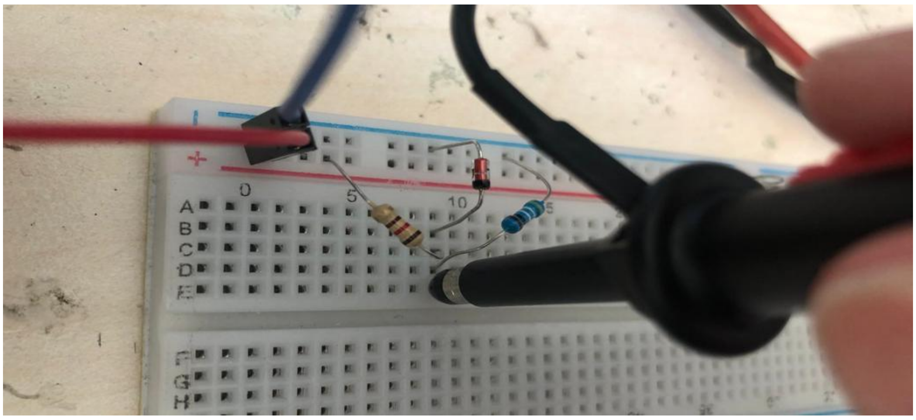

Fig.4 Hardware implementation

Part A) Here are the lab specifications for part a:

-R_L= 500Ω
-V_{in}=10 V,changes between 9 and 11V
- 10mA< I_z <100mA
-V_z= 5.1V (breakdown voltage)

In order to find the suitable R range, we have to repeat same nodal analysis in Fig.3. using both max and min values for V_{in} and I_z. After finding the limits for R for each combination, we have to choose the suitable range where all values of R are corresponds the required specifications. The calculations are as follows:

For V_{inmax}= 11V:

- $R_{inmin} = \frac{V_{inmax} - V_z}{\frac{V_z}{R_L} + I_{zmax}} = 53.53\Omega$

- $R_{inmax} = \frac{V_{inmax} - V_z}{\frac{V_z}{R_L} + I_{zmin}} = 292.07\Omega$

For $V_{in\,min}$= 9V:

- $R_{inmin} = \frac{V_{inmin} - V_z}{\frac{V_z}{R_L} + I_{zmax}} = 35.39\Omega$

- $R_{inmax} = \frac{V_{inmin} - V_z}{\frac{V_z}{R_L} + I_{zmin}} = 193.06\Omega$

If we choose any R value between 53-193 Ω for each case the values stays within the boundaries hence:

$$53\Omega < R < 193\Omega$$

Within these limits, the R value is chosen as 100Ω to simplify the calculations. Using KCL equations obtained in Fig.3., $I_{z\,max}$ and $I_{z\,min}$ values are calculated as:

- $I_{z\,max}$ = 48.8 mA
- $I_{z\,min}$ = 28.8 mA

After calculating the current values, the current is measured using a multi-meter and the hardware results are compared with the expected results.

Voltage (V)	Expected I_z (mA)	Real I_z (mA)	Error (%)
$V_{in\ min} = 9V$	28.8 mA	26.9 mA	6.59%
$V_{in\ max} = 11V$	48.8 mA	46.3 mA	5.1%

Table 1. I_z comparison between experimental and calculated values

Part B)

Here are the lab specifications for part b:

- R_L= 500Ω
- V_{in}= 9.5 + 0.1sinωt
- f = 100 Hz
- V_z= 5.1V (breakdown voltage)

With non ideal zener diode (including internal resistance) we can think the circuit as follows:

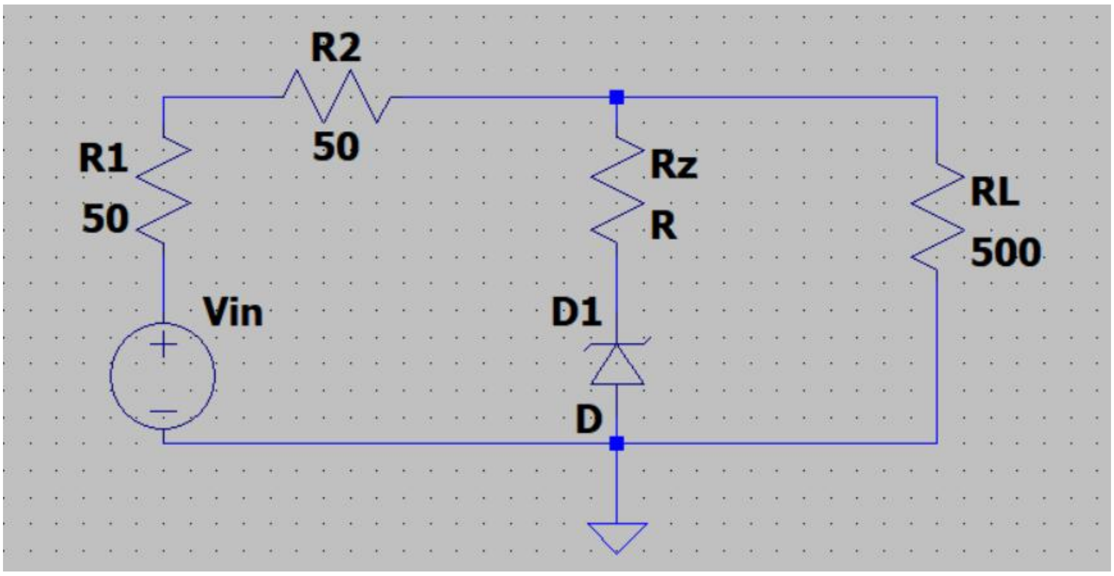

Fig.5 Part b circuit with internal resistance

Here the internal resistance of the signal generator is also considered. In order to apply 9.5V Dc voltage, 4.75V Dc offset voltage is applied.

Coming to the Source regulation calculations, the following figures shows the changes in the output (ΔV_{out}) and input (ΔV_{in}) voltages. Using eq.1. explained above we can find the source regulation.

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

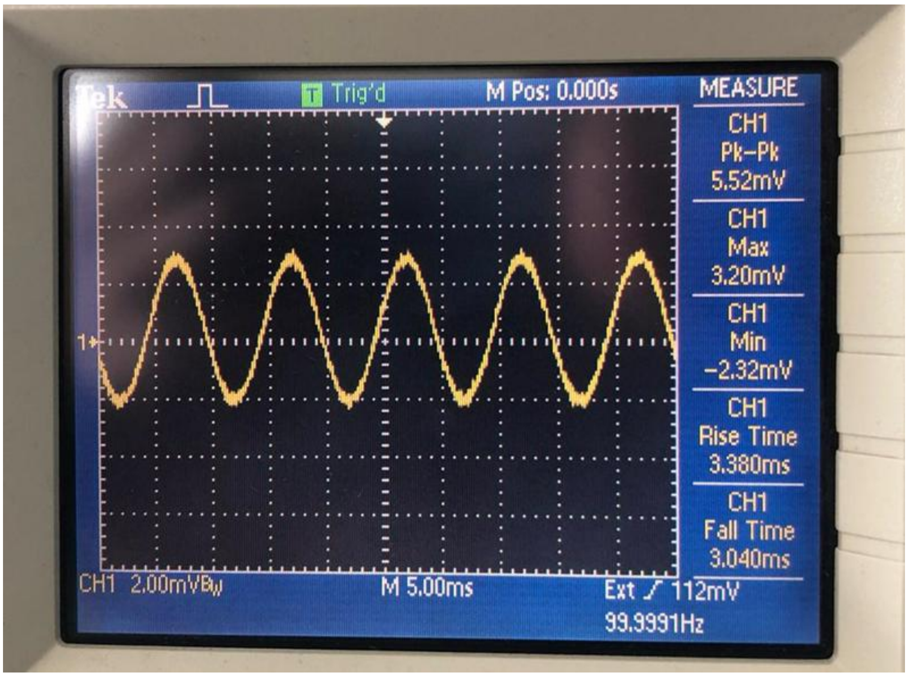

Fig.6 Output deviation (ΔVout= 5.52mV)

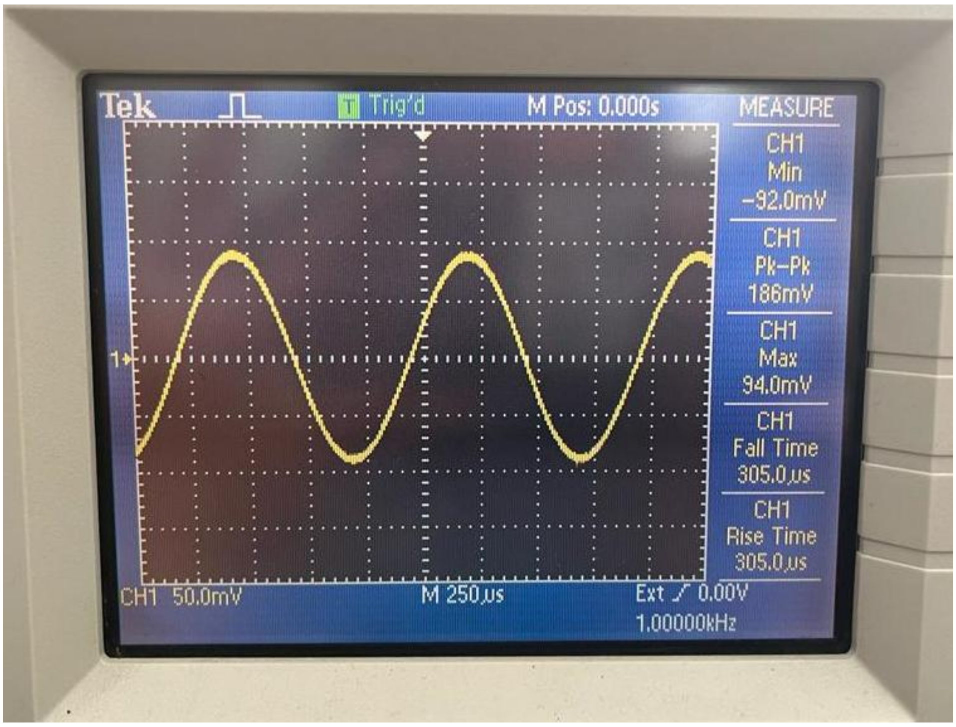

Fig.7 Input deviation (ΔVin= 186mV)

- Source Regulation(%) = $\frac{5.52}{186} * 100$ = 2.96%

To calculate the zener resistance (R_z) we can use the source regulation ratio. Since we are doing small signal AC analysis, the DC zener voltage (V_z) is treated as short circuit. Hence the circuit becomes as follows:

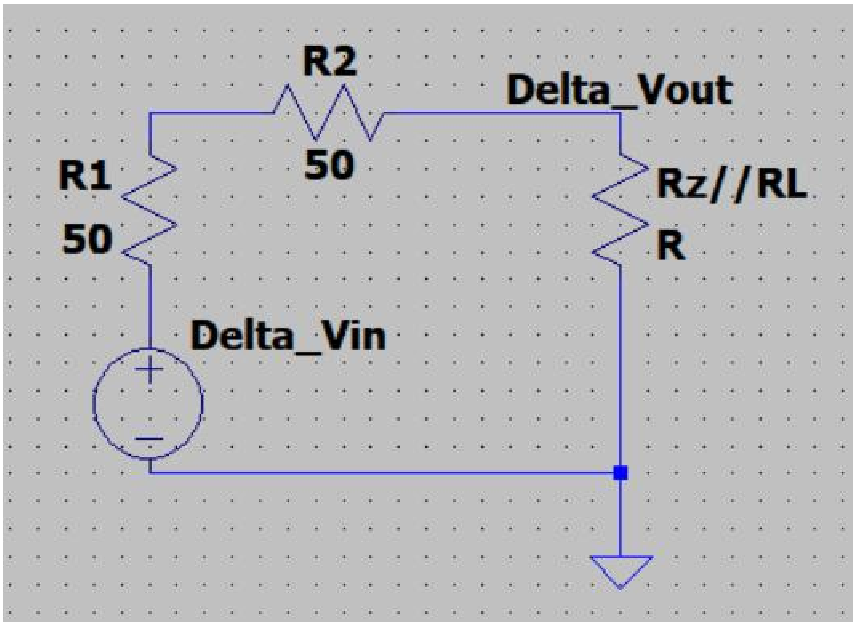

Fig.8 AC analysis circuit

Doing a voltage divider we get

$$\Delta V_{out} = \Delta V_{in}\left(\frac{R_z//R_L}{100+R_z//R_L}\right) \qquad (3)$$

$$\frac{\Delta V_{out}}{\Delta V_{in}} = 0.029 = \frac{R_z//500}{100 + R_z//500} \qquad (4)$$

Solving the equation for R_z we get $R_z = 2.91\Omega$.

Part C)
Here are the lab specifications for part b:

- R_L= 100Ω (full load)
- V_{in}= 10V

For finding the load regulation we can use eq. 2.

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

For finding no load voltage the resistor R_L is taken out from the circuit and for the full load voltage it is placed by a 100Ω resistor. Both cases are measured with a multimeter.

Fig.9 (a) No load Voltage. (b) Full load Voltage.

Placing these values into eq.2. we get,

$$\text{Load Regulation}(\%) = \frac{5.17-4.94}{4.94} = 4.44\%$$

This result shows that the output voltage does not heavily depend on load resistance, ideally this value should be zero.

Conclusion

This lab was useful for understanding the breakdown region working principles of Zener diodes as well as load and source regulation concepts. Using source and load regulations it has shown that the output voltage is not heavily influenced by the changes of the input voltage and the load resistance. This results is very precious since it shows that the system is immune to changes at the load and input which increases the flexibility of the chosen load resistance values or the input values. The only crucial part was to stay within the limits of zener diode, these limits were considered and the input resistance was chosen accordingly.
The hardest part of this lab was to measure the changes in current and voltage when a small AC voltage is applied. Working with mA and mV as units requires precise measurements which is very hard to do considering the error caused by lab equipment. Overall, the lab results were compatible with the theory.

References

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