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MIT WORLD PEACE UNIVERSITY | PUNE
TECHNOLOGY, RESEARCH, SOCIAL INNOVATION & PARTNERSHIPS

F. Y. B. Tech Academic Year 2021-22

Trimester:I **Subject:** Basics of Electrical and Electronics Engineering

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Roll No: 109054 **Batch: I3**

Experiment No: 3

Name of the Experiment: Design of voltage regulator using Zener diode.

Performed on: 31st December 2021

Submitted on: 3st January 2022

Aim: Design of voltage regulator using zener diode.

Prerequisite:

- Forward biasing and reverse biasing of Zener diode
- Zener diode characteristics
- Concept of Zener breakdown and breakdown voltage

Objectives:

- To study Zener diode as voltage regulator
- To calculate percentage line regulation
- To calculate percentage load regulation

Components and equipment required:

Sr.No.	Name	Quantity
1	Bread board	1 (One) No.
2	Zener Diode	1 (One) No.
3	Resistor (1KΩ/2.2 KΩ)	1 (One) No.
4	Potentiometer	1 (One) No.

Equipment: Power Supply, Multimeter, Connecting wires, etc.

Theory:

Clarence Zener is the scientist who discovered this electrical property and the device is named after him. Zener diode is a P-N junction diode specially designed to operate in the reverse biased mode. It acts as a rectifier diode when forward biased. When reverse biased, it has a particular voltage known as breakdown voltage at which large current flows through the diode. For rectifier diodes the value of reverse breakdown voltage is larger than that of Zener diode. Zener diodes are specially designed to operate in the reverse breakdown region. When the diode is heavily doped, its depletion region is narrow. When high reverse voltage is applied across the junction, there will be very strong electric field at the junction, and the electron hole pair generation takes place. Thus heavy current flows. This is known as Zener breakdown. Characteristics of Zener diode in reverse biased mode are given in Fig. 3.1.In reverse biased mode, after the breakdown of junction, current through diode increases sharply. But the voltage across it remains almost constant as shown in the Fig. 3.1. This principle is used in voltage regulator using Zener diodes. Fig. 3.2 shows the Zener voltage regulator which consists of a current limiting resistor R_S connected in series with the input voltage V_s and Zener diode D_1 connected in parallel with the load R_L in reverse biased condition. The output voltage V_z is the breakdown voltage of the diode.

The input source current I_S is given by

$$I_S = I_z + I_L \tag{3.1}$$

The drop across the series resistance R_s is given by

$$V_S = V_{in} - V_Z \tag{3.2}$$

And the current flowing through it I_s is given by

$$I_S = \frac{(V_{in} - V_Z)}{R_S} \tag{3.3}$$

From Eq. (3.1) and (3.2), we get,

$$\frac{(V_{in} - V_Z)}{R_S} = I_z + I_L \tag{3.4}$$

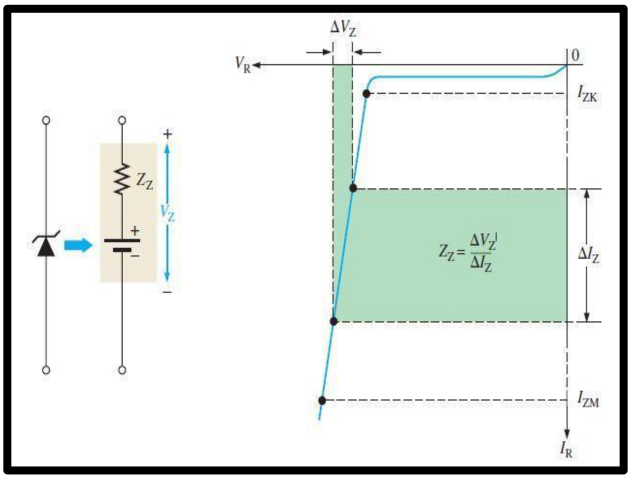


Fig 3.1 Reverse characteristics of Zener Diode

There are two breakdown mechanisms:

- ***Zener Breakdown***
- ***Avalanche Breakdown***

  - ***Zener Breakdown or Zener Effect:***

Zener Breakdown is a type of electrical breakdown mechanism occurs in reverse biased P-N Junctions. This breakdown occurs due to the high electric field density across the depletion region breaks some of the covalent bonds leading to large number of minority carriers. **Zener effect is predominant up to 5.6 V** for silicon diodes and has negative temperature coefficient.

  - ***Avalanche Breakdown or Avalanche Effect:***

Avalanche breakdown is distinct from zener breakdown. It is caused due to collision. A minority carrier in the depletion region gets accelerated by the reverse biased electric field. This may make energy of minority carriers sufficient to release electron hole pairs from covalent bonds through collision. **Avalanche effect is predominant above 5.6 V** for silicon diodes and has positive temperature coefficient.

Thus in a 5.6 V zener diode both zener and avalanche effects are equally predominant thus its positive and negative temperature dependency cancels each other. Thus naturally 5.6 V zener diode is the component of choice in temperature critical applications. Zener Diode is commonly used for making reference voltages for Voltage Regulators and to protect other electronic devices from voltage surges.

Zener Diode as Voltage Regulator:

Zener Diodes are widely used as Shunt Voltage Regulators to regulate voltage across small loads. Zener Diodes have a sharp reverse breakdown voltage and breakdown voltage will be constant for a wide range of currents. Thus we will connect the zener diode parallel to the load such that the applied voltage will reverse bias it. Thus if the reverse bias voltage across the zener diode exceeds the knee voltage, the voltage across the load will be constant.

Circuit Diagram:

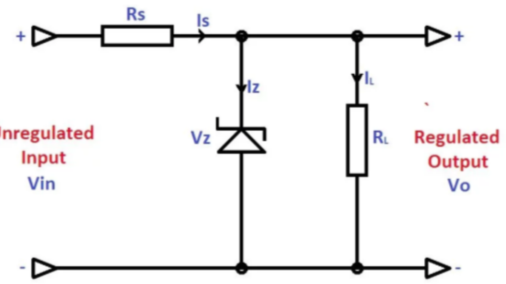


Fig.3.2 Zener Diode as a Voltage Regulator

In the above circuit diagram excess voltage (Vin – Vz) will drop across Rs thus by limiting the current through Zener. For the proper designing of the regulator we should know,

- Unregulated Input Voltage Range
- Required Output Voltage
- Max Load Current Required

The value of resistance Rs should satisfy the following conditions,

- The value of Rs must be small enough to keep the Zener Diode in reverse breakdown region. The minimum current required for a Zener Diode to keep it in reverse breakdown region will be given in its datasheet. For example, a 5.6 V, 0.5 W zener diode has a recommended reverse current of 5 mA. If the reverse current is less than this value, the output voltage Vo will be unregulated.
- The value of Rs must be large enough that the current through the zener diode should not destroy it. That is the maximum power dissipation Pmax should be less than IzVz.

Thus we should find Rsmin and Rsmax. To find the value of Rsmin we should consider the extreme condition that Vin is minimum and load current is maximum.

$$I_S = I_{Zmin} + I_{Lmax} \tag{3.5}$$

$$I_{Lmax} = \frac{V_z}{R_{Lmin}} \tag{3.6}$$

$$V_S = V_{inmin} - V_Z \qquad (3.6)$$

$$R_{Smin} = \frac{V_S}{I_S} \tag{3.7}$$

To find the value of Rsmax we should consider the extreme condition that Vin is maximum and load current is minimum (ie, no load connected).

$$I_S = I_{Zmax} + I_{Lmin} \tag{3.8}$$

$$I_{Zmax} = \frac{P_{Max}}{V_Z} \tag{3.9}$$

$$V_S = V_{inmax} - V_z \tag{3.10}$$

$$R_{Smax} = \frac{V_S}{I_S} \tag{3.11}$$

Line regulation (Regulation with a varying input voltage):

It is defined as the change in regulated voltage with respect to variation in line voltage. In this, input voltage varies but load resistance remains constant. As the input voltage increases, I_s also increases accordingly as per Eq. (3.3). Therefore, Zener current I_z increases. The extra voltage is dropped across the R_s. Though I_z increases, V_z remains constant and V_z is equal to V_{out} and hence output voltage remains constant. If V_{in} decreases, I_z decreases. As load current remains constant, voltage drop across R_s reduces. But even though I_z changes, V_z remains constant and hence output voltage remains constant.

Zener diode as voltage regulator with varying input voltage:

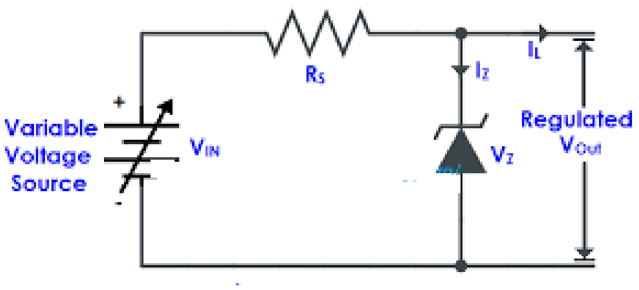


Fig.3.3 Zener diode as voltage regulator

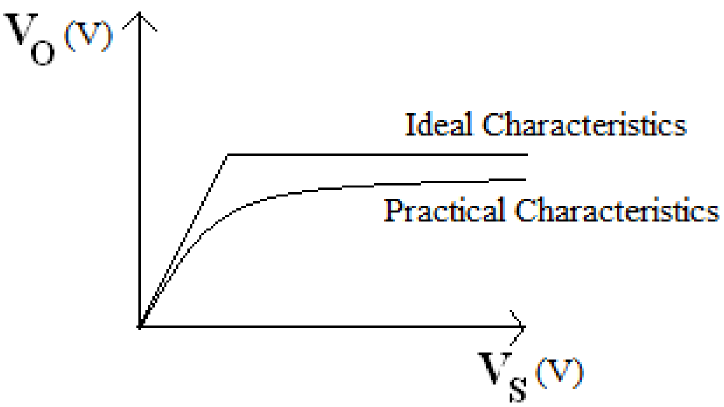


Fig.3.4 Zener diode Line regulator

Load regulation (Regulation with the varying load):

It is defined as change in load voltage with respect to variations in load current. To calculate this regulation, input voltage is kept constant and output load current is varied by changing the load resistance value. Consider output voltage is increased due to increase in the load current. The left side of the Eq. (3.4) is constant as input voltage V_{in}, I_S and R_s is constant. Then as load current changes, the Zener current I_z will also change but in opposite way such that the sum of I_z and I_L will remain constant, compensating the original increase or decrease in I_L. Thus, if the load current increases, the Zener current decreases and sum remain constant. As per the reverse bias characteristics of Zener diode, though I_z changes, V_z remains same and hence output voltage remains fairly constant.

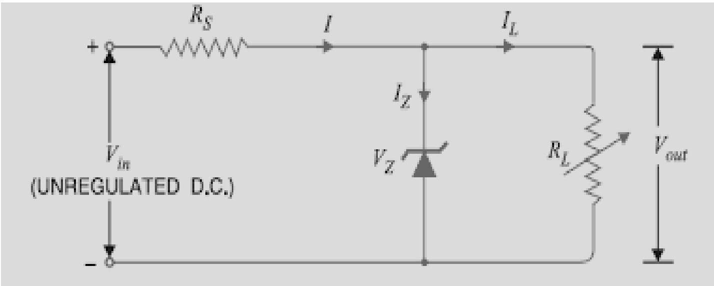


Fig.3.5 Zener diode as voltage regulator

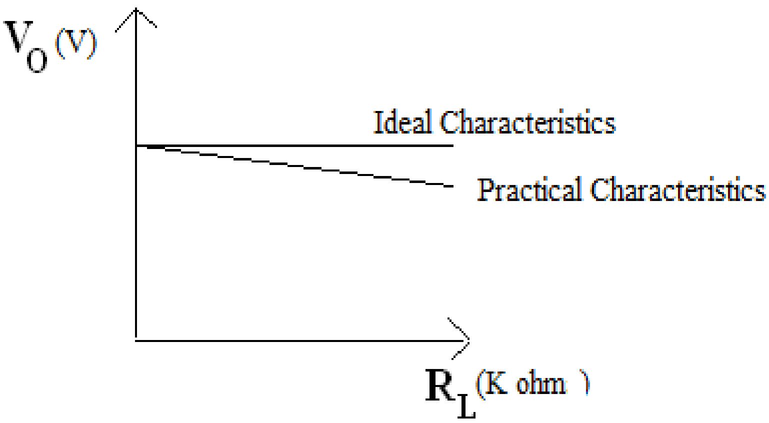


Fig.3.6 Zener diode Load regulator

Procedure:

A) Line Regulation:

1. Make the connections as shown in the Fig. 3.3.
2. Keep load resistance at fixed value; vary DC input voltage from 2V to 30V.
3. Note down output voltages by varying DC input voltage from 2V to 30V.
4. Calculate percentage line regulation by,

$$\% \text{ Line Regulation} = (\Delta V_o/\Delta V_{in}) \times 100 \quad (3.12)$$

Here, V_o is output voltage, V_{in} is input voltage, ΔV_o is the change in output voltage for a particular change in input voltage ΔV_{in}.

B) Load Regulation:

1. For finding load regulation, make connections as shown in the Fig. 3.5.
2. Keep input voltage constant say 10V and vary load resistance value.
3. Note down output voltages for various values of load resistance including no load voltage V_{NL} for maximum load resistance value and full load voltage V_{FL} for minimum load resistance value.
4. Calculate load regulation by % Load regulation = $(V_{NL}-V_{FL})/V_{FL}$ x100 (3.13)

Observation Table:

Line regulation: R_L = Constant = 1.2 k Ω
Line Regulation % = 21%

Sr. No	V_{in}	V_o
1	V_{in1} = 6.5	V_{o1} = 5.24
2	V_{in2} = 7	V_{o2} = 5.35
3	V_{in3} = 7.5	V_{o3} = 5.46
4	V_{in4} = 8	V_{o4} = 5.56
5	V_{in5} = 8.5	V_{o5} = 5.66

Load regulation:
Load Regulation % = 13.62%
V_{in} = Constant = 10 V with $V_{IN} > V_Z$

Sr. No	I_L (mA)	V_o (V)	R_L (Ω)
1	I_{L1} = 20.8	V_{o1} = 5.21	250
2	I_{L2} = 19.5	V_{o2} = 5.28	270
3	I_{L3} = 18.4	V_{o3} = 5.34	290
4	I_{L4} = 17.4	V_{o4} = 5.39	310
5	I_{L5} = 5.92	V_{o5} = 5.92	1000

Note: Students are instructed to do all the necessary calculations on separate sheets.

Conclusion:

It was seen that the Zener diode can be used as a voltage regulator. The circuit to check load and line regulation of that voltage regulator was made in tinkercad. The observations were noted and resulting percentages of Load and line regulation were found to be **13.62 % and 21% Respectively**. Such high values of regulation indicate high internal resistance of the Zener diode itself, which was designed in Tinkercad.

Since the Resistance of the Zener diodes in Tinkercad cannot be changed, a method to improve the efficiency of the circuit can be to introduce another Zener diode in Parallel to the one that we have already attached. In this way not only is the Zener resistance effectively reduced to half, the Line and Load Regulation also improve significantly.

Line Regulation with 1 Zener = 21 %
Line Regulation with 2 Zener = 13 % = **62 %** Increase in Regulation Efficiency.

Load Regulation with 1 Zener = 13 %
Load Regulation with 2 Zener = 8.1 % = **59.5 %** Increase in Regulation Efficiency

So by using 2 Zeners in Parallel, We see about 60% increase in Regulation Effeciency. And 50 % reduction in Zener Resistance offered.

Post Lab Questions:

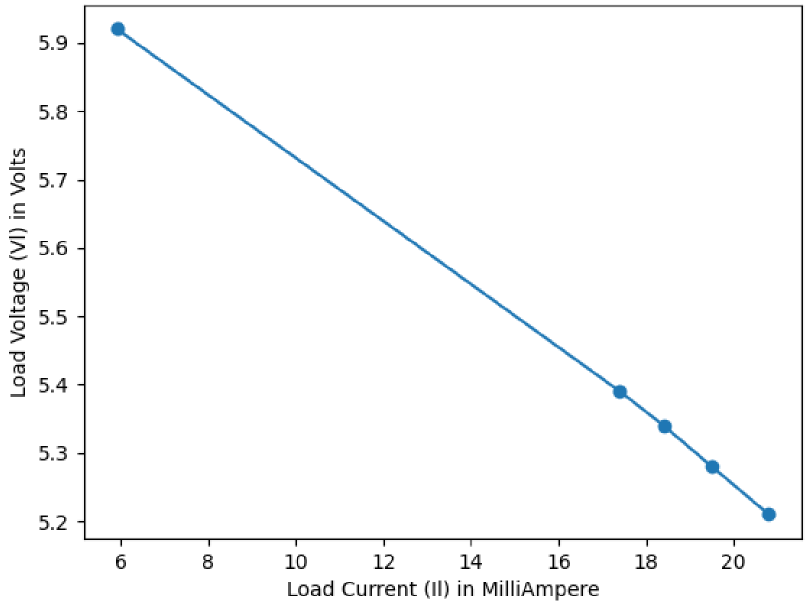
1. Define line regulation and load regulation in voltage regulators.
2. Explain how Zener diode can be used as a voltage regulator?
3. List the specifications of Zener diode.
4. Plot line and load regulation graphs.

Additional links for more information:

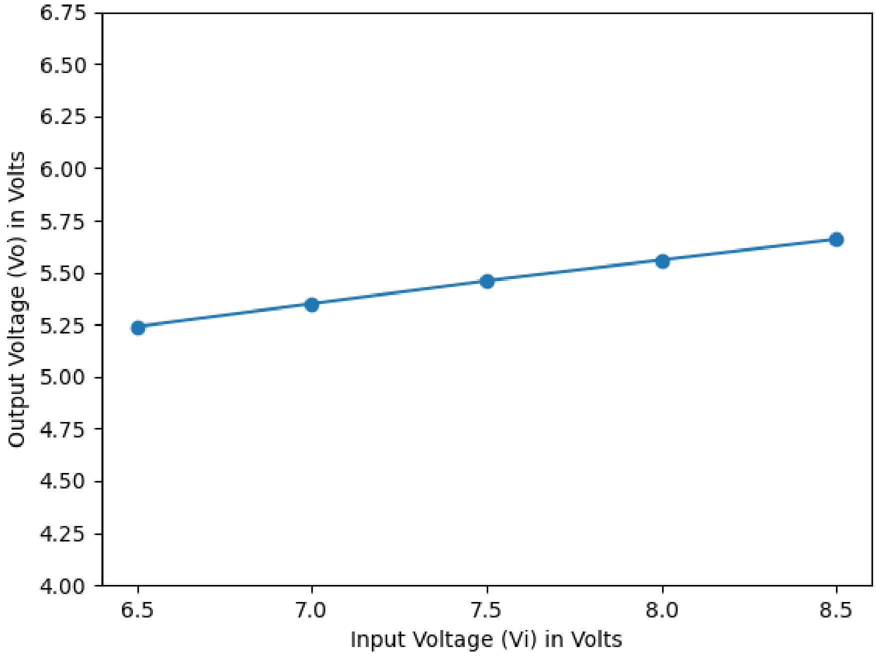
- https://www.youtube.com/watch?v=WdDFI1IRQds
- vlab.amrita.edu

Graphs

Load Regulation



Line Regulation



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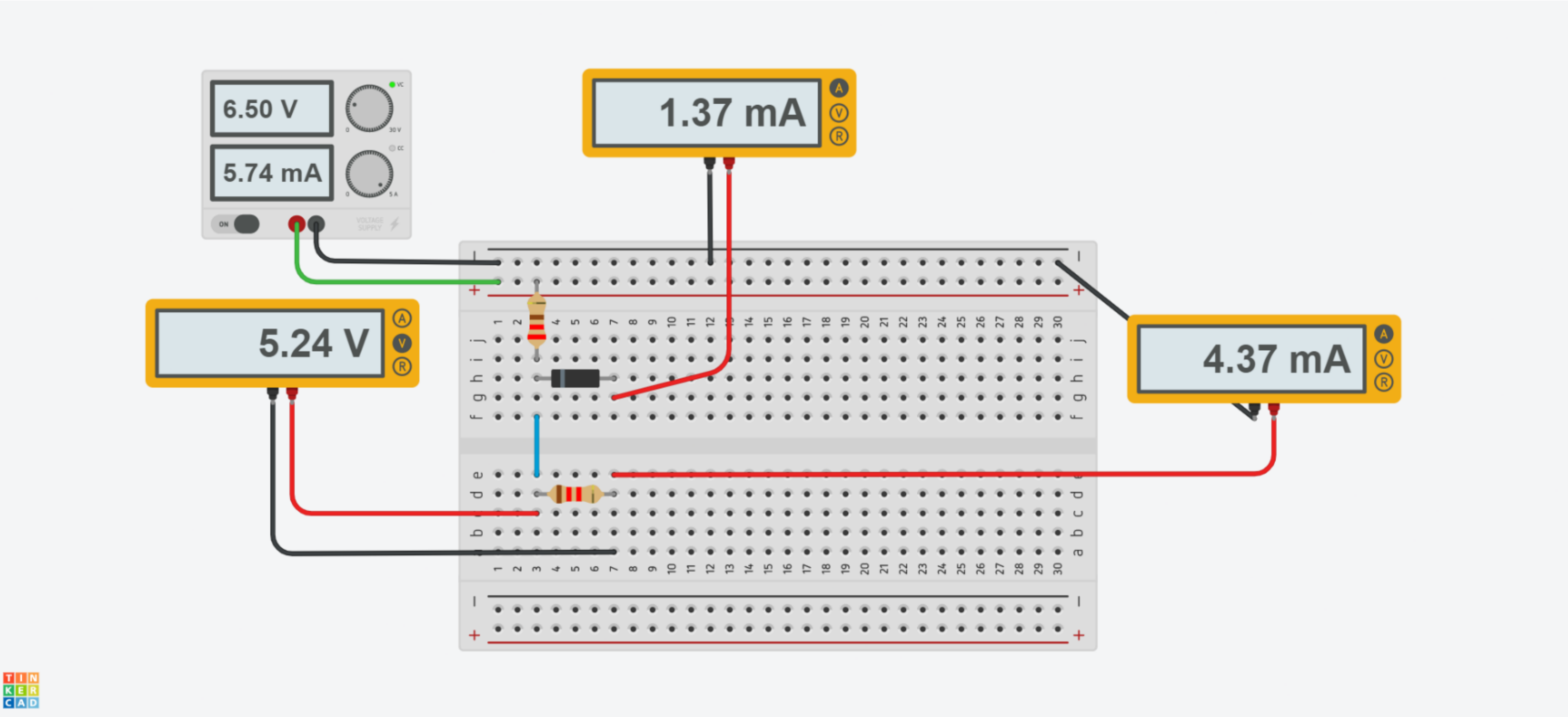
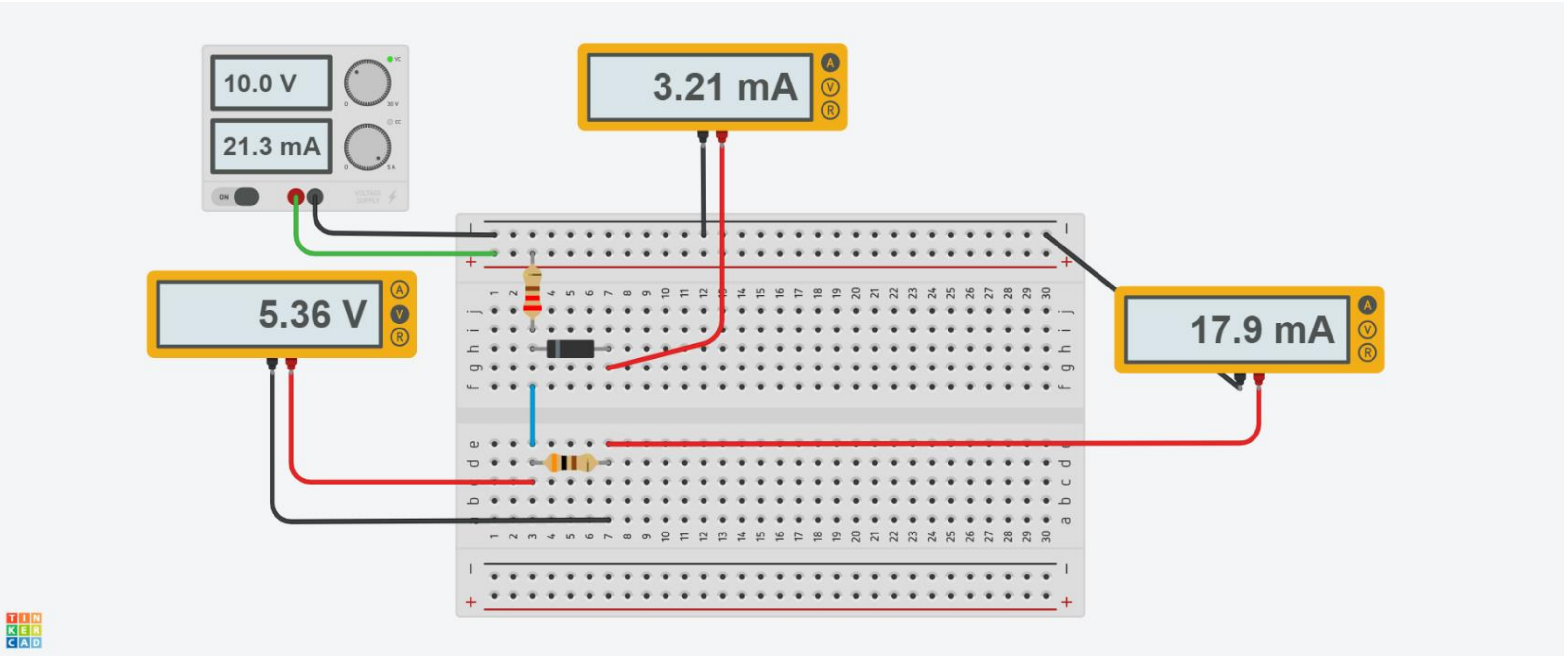
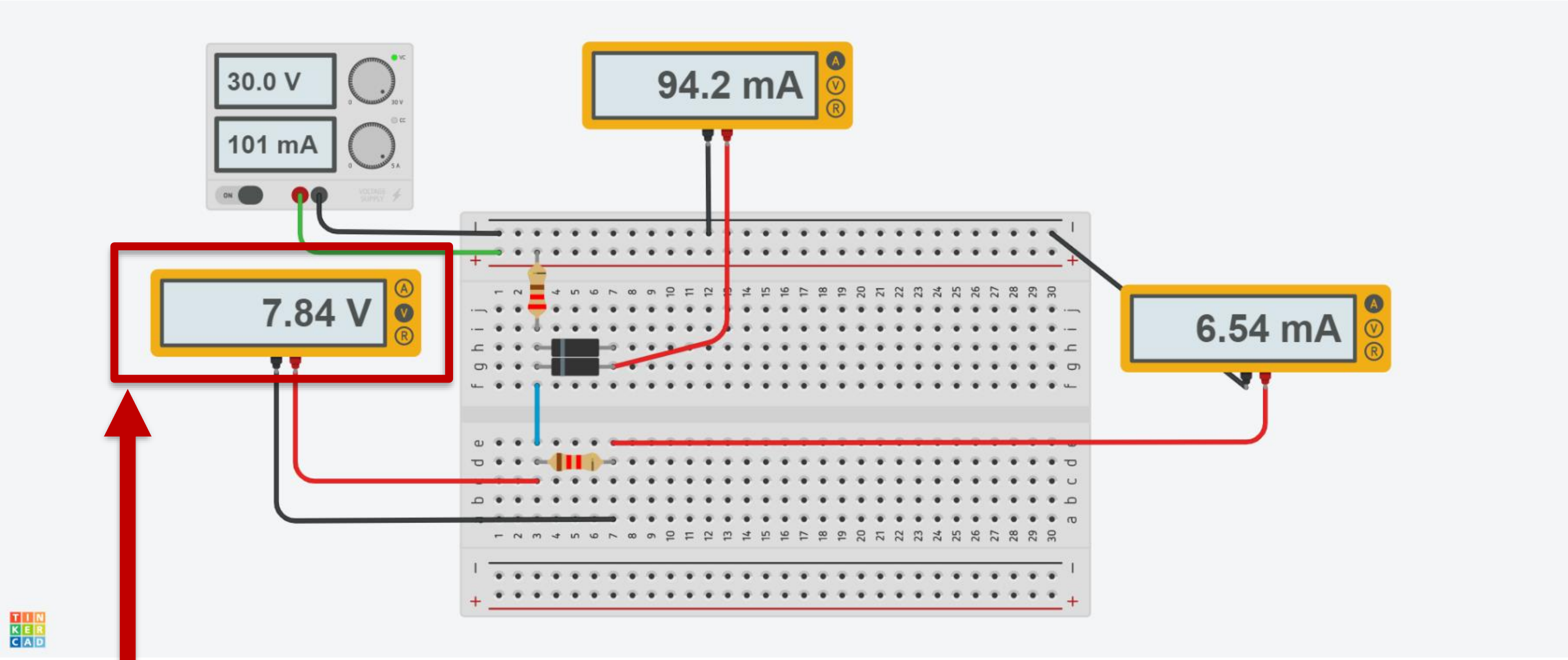
Tinkercad Circuit : Line Regulation



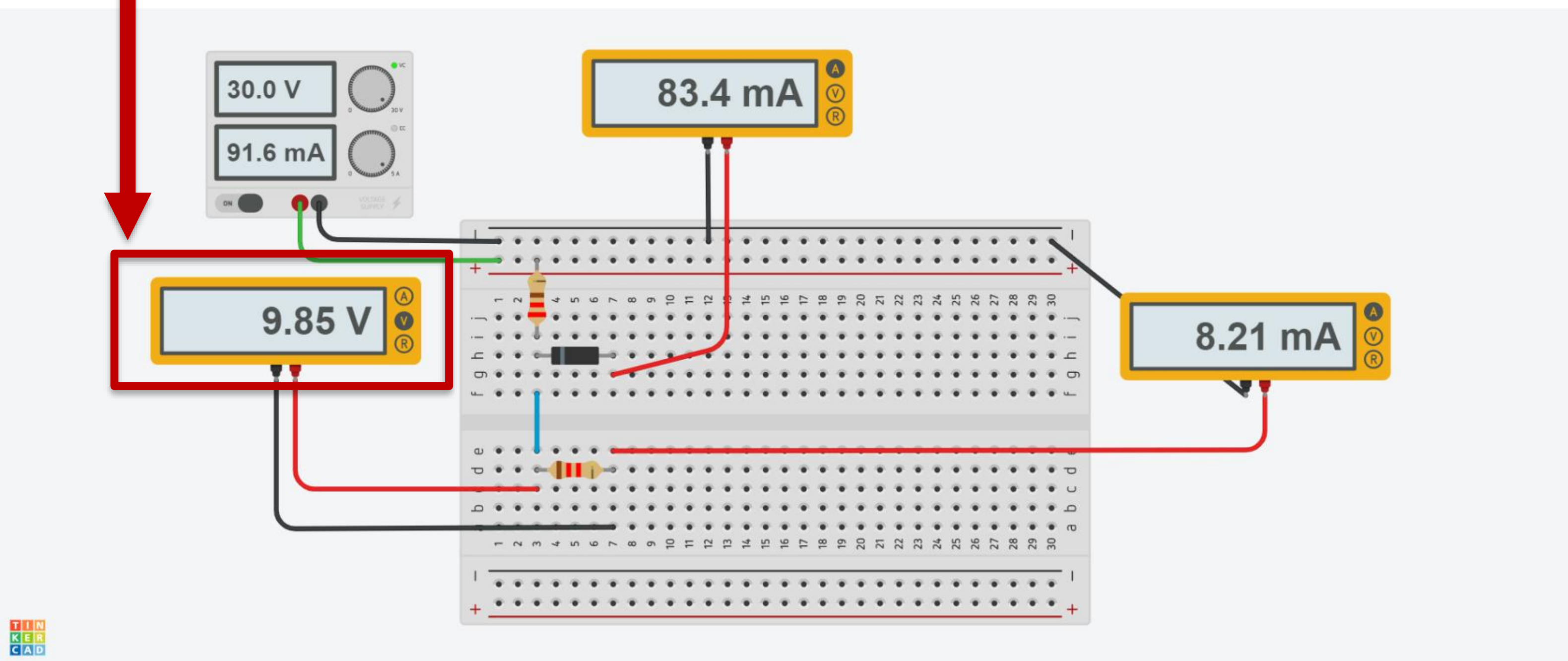
Tinkercad Circuit : Load Regulation.



Tinkercad Circuit for 2 Zener Diodes in Parallel for Line and Load Regulation



Same Input Voltage Results in a Higher output Voltage and Load Current with just 1 Zener diode.



Component List for Line and Load Regulation with 1 Zener

Name	Quantity	Component
P1	1	10 , 5 Power Supply
R1	1	220 Ω Resistor
Meter1	1	Voltage Multimeter
Meter2, Meter3	2	Amperage Multimeter
R2	1	300 Ω Resistor
U1	1	5.1 V Zener Diode

Component List for Line and Load Regulation with 2 Zener

Name	Quantity	Component
P1	1	10 , 5 Power Supply
R1	1	220 Ω Resistor
Meter1	1	Voltage Multimeter
Meter2, Meter3	2	Amperage Multimeter
R2	1	300 Ω Resistor
U1	2	5.1 V Zener Diode

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EXPERIMENT - 3

Zener Diode for line and Load Regulation

Post Lab Questions

Q.1 Define line Regulation and load Regulation in voltage regulators.

→ Line Regulation: It is the ability of a power supply to maintain constant output voltage despite changes to input voltage.

Load Regulation:

Load regulation is the ability to maintain a constant voltage level on the output channel of a power supply despite changes in supply's load.

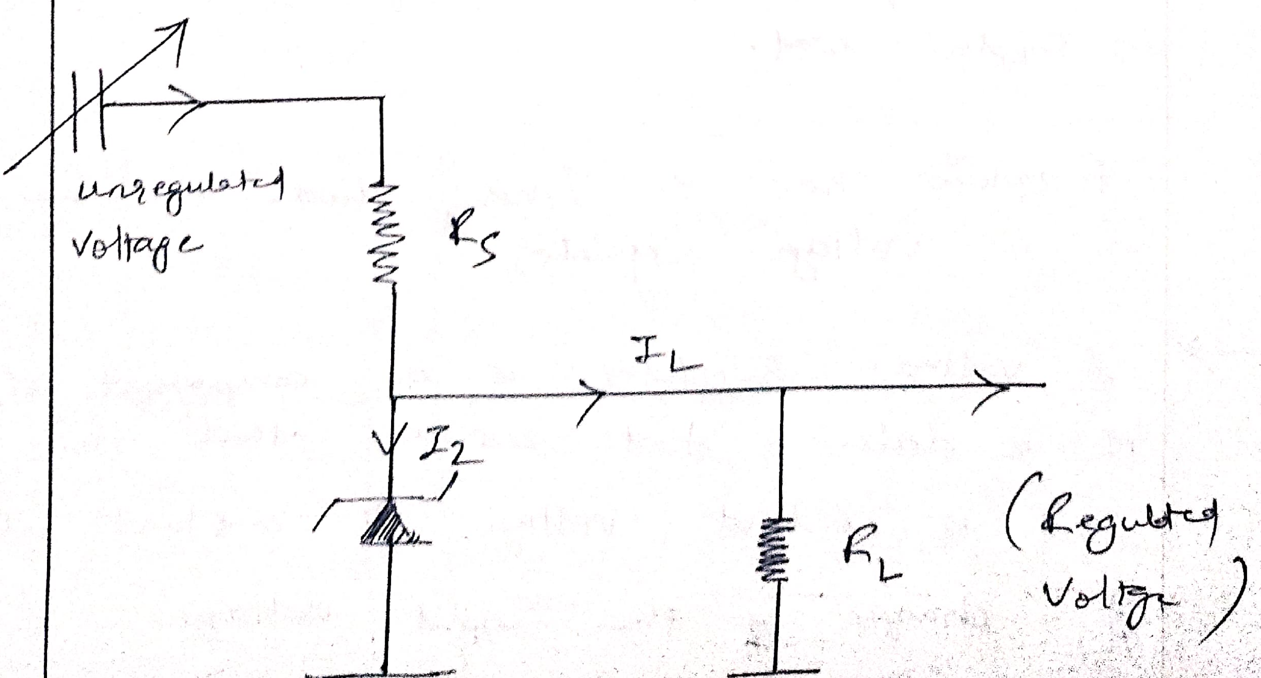
Q.2. Explain how a Zener diode can be used as a voltage regulator.

→ A voltage regulator is a component, circuit or a device that ensures that the load or output voltage is constant despite of changes in the input voltage.

When is Forward Bias, a Zener diode acts like any other diode. That is current flows after a threshold 0.7 V is supplied.

But when is Reverse Bias, a tiny amount of current (μA) flows until the supply voltage $V_S == V_Z$ (The Zener voltage).

After $V_S = V_Z$, say (5 V), The Zener diode allows unrestricted current flow through the circuit; while it is designed in such a way to only drop V_Z across its ends when is reverse bias. Any increase ~~or decr~~ in the voltage is dropped across the source resistance.



Q.3. List ~~Regulation's~~ Specifications of a Zener diode

→ (1) Zener Voltage / Breakdown Voltage : [V_Z] : It is the breakdown Voltage of the diode and can vary from 3V to 200 V.

(2) Current [I_Z max] : The greatest current at the given Zener voltage.

(3) current [$I_{Z min}$] : Base current for diode to break down. (5 mA to 10 mA)

(4) Voltage ~~Reg.~~ Tolerance : It is ordinarily about ± 5 %.

(5) Zener Resistance (R_Z) : Resistance Provided By the zener diode.

(6) Power Rating : (P_Z) : Maximum Power that Zener diode can dissipate across its ends.

(A) Calculations

(1) Line Regulation :

$V_z = 5.10\ V$

$R_S = 220\ \Omega$

$R_L = 1.2\ k\Omega$

From observation table values,

$V_{in(min)} = 6.5\ V$

$V_{in(max)} = 8.5\ V$

So $\Delta V_{in} = 8.5 - 6.5 = 2V$

$V_{out(min)} = 5.24\ V$

$V_{out(max)} = 5.66\ V$

So $\Delta V_{out} = 5.66 - 5.24 = \cancel{5}\ 0.42\ V$

$\therefore$ Percentage Line Regulation =

$$\frac{\Delta V_{out}}{\Delta V_{in}} \times 100 = \frac{0.42}{2} \times 100$$

$$= \underline{\underline{21\ \%}}$$

(2) Load Regulation

$V_Z = 5.10V$

$V_{in} = 10V$ (constant)

$R_S = 220\ \Omega$

R_L = Variable

$V_{Full\ Load} = 5.21\ V$

$V_{NO\ Load} = 5.92\ V$

So Percentage load Regulation =

$$\frac{(V_{NL} - V_{FL})}{V_{FL}} \times 100 = \left(\frac{5.92 - 5.21}{5.21}\right) 100$$

$$= \underline{13.62\ \%}$$

If 2 Zener diodes are used,

(1) Line Regulation,

$\Delta V_{in} = 2\ V$

$\Delta V_{out} = 0.26\ V$

% Regulation = 13 % = $\underline{62\ \%}$ decrease

(2) Load Regulation,

$V_{FL} = 5.18$

$V_{NL} = 5.60$

% Regulation = 8.1 % = $\underline{59.5\ \%}$ decrease