الجامعة الألمانية الأردنية
German Jordanian University

Electronics 1 Lab (CME 2410)

School of Informatics & Computing
German Jordanian University

Laboratory Experiment (4)

Z-Diode Applications & Power Supply

1. *Objective*:

- To determine the load influence on the output voltage of a Z-diode stabilized power supply.
- To determine the input voltage influence on the output voltage of a Z-diode stabilized power supply

2. *Theory:*

Almost every electronic circuit needs a stabilized power supply, which provides a constant voltage independent of input voltage changes delivered from the rectifier or the battery as well as independent of a changing load. In all of these circuits the Z-diode is the core of this circuit.

In low power supplies stabilizing is simply done by a current limiting resistor R1 followed by the Z-diode V1 (see Fig. 5.1). To meet higher demands the current limiting resistor is replaced by an electronic current source and to feed higher loads there is the need of a controlled current amplifier. The Z-diode is still needed as a voltage reference element. Current source as well as the current amplifier makes the power supply circuit looking more sophisticated.

Simple Z-diode stabilization:

The diagram of the basic circuit is shown in Fig. 5.1 with R1 as the current limiting resistor, R_{Load} as the load and V1 as Z-diode.

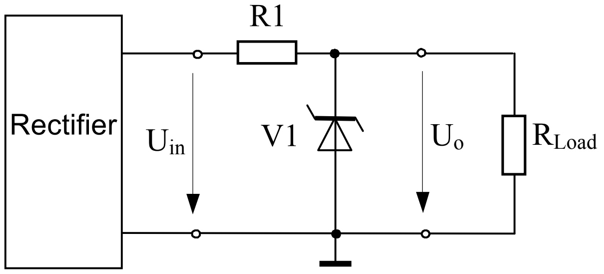

Fig. 5.1 Power supply with Z-diode stabilization

As the Z-diode is always used in the reverse biased mode it is more convenient to display the U/I-characteristic in the form $I_R = f(U_R)$ instead in the forward biased mode $I_F = f(U_F)$ as we do with normal diodes. (We prefer the first quadrant to handle with positive numbers.)

Fig. 5.2 shows the U/I-characteristic of a Z-diode. The individual data sheet will specify the values for the Z-voltage U_Z which is defined at $I_R = I_{Z\,min}$ (for general purpose Z-diodes $I_{Z\,min} = 5\text{ mA}$) and the peak current $I_R = I_{Z\,max}$. Instead of $I_{Z\,max}$ the data sheet might provide the maximum power $P = I_{Z\,max} \cdot V_Z$ the Z-diode can tolerate. In between the limits $I_{Z\,min}$ and $I_{Z\,max}$ the Z-diode will work as a stabilizing element.

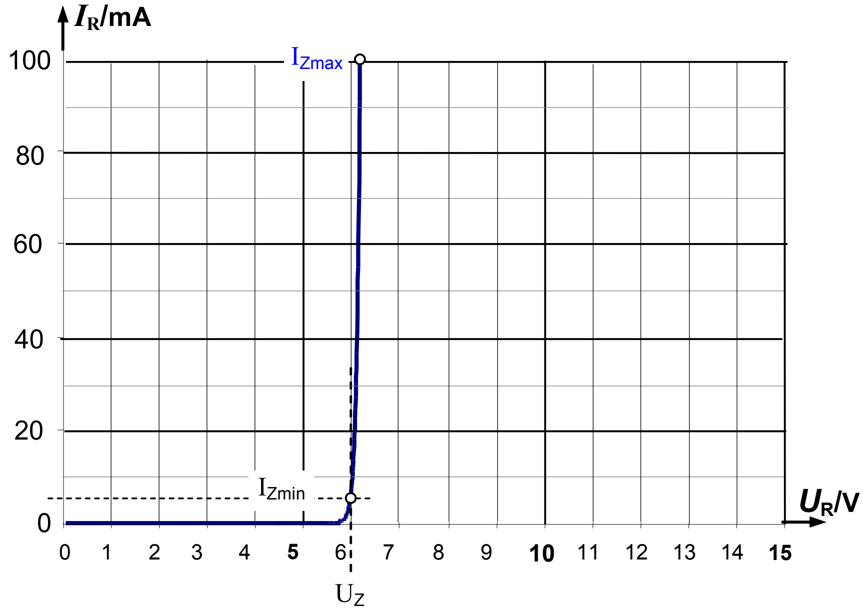

Fig. 5.2 Example for the U/I-characteristic of a Z-diode ($U_Z = 6$ V; $I_{Z\,max} = 100$ mA)

How to choose the current limiting resistor R1:

The current limiting resistor R1 has to be chosen in a way that under operating conditions it ensures the Z-diode will work in between the limits:
$I_R > I_{Z\,min}$ (otherwise there is no regulation any more) and
$I_R < I_{Z\,max}$ (otherwise we could have the diode break-down).

The operation conditions are:

minimum input voltage: $U_{in\,min}$,
maximum input voltage: $U_{in\,max}$,
minimum load: it should be the open circuit: $I_{Load} = 0$,
maximum load (maximum load current): $I_{Load\,max} = \dfrac{U_Z}{R_{Load}}$.

If the condition $I_{Z\,min} < \boldsymbol{I_R} < I_{Z\,max}$ is fulfilled the output voltage U_0 is nearly constant and equal to U_Z.
The 2 limits $I_{Z\,min}$ and $I_{Z\,max}$ result in 2 values for the current limiting resistor **R1$_{max}$** and **R1$_{min}$**. Only one value in between these limits has to be chosen (see below).

In Fig. 5.3 the graphical solution is given to determine the current limiting resistor R1 under different conditions.

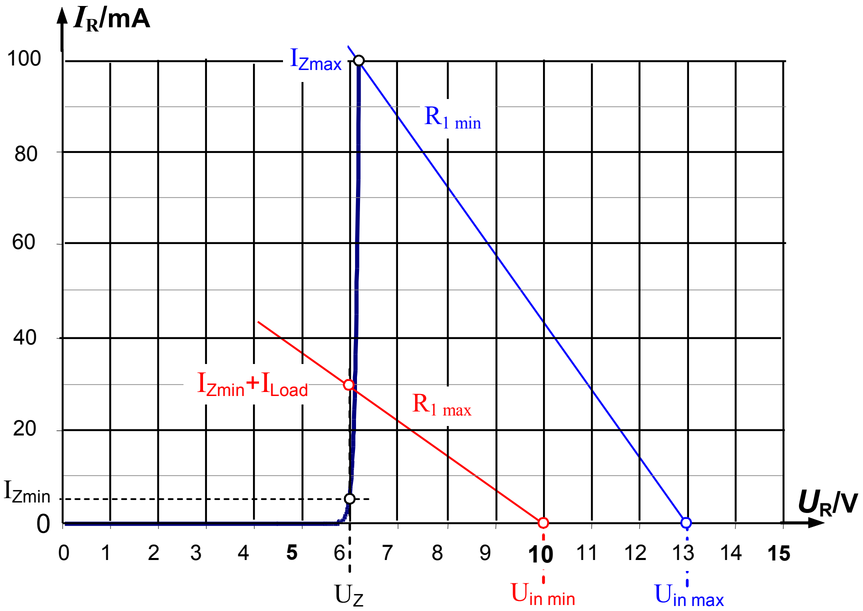

Fig. 5.3 Graphic solution for the current limiting resistor

The input voltage U_{in} followed by the current limiting resistor R1 are regarded as a voltage source. The U/I-characteristic of a source is given by a straight line determined by the open loop voltage $U_0 = U_{in}$ (I = 0, without the load) and the resistance R1 (voltage drop at R1 depending on *I*): $U_0 = U_{in} - \mathrm{R1} \cdot I$.

The meeting point between the straight line (voltage source) and the given non-linear U/I-characteristic is the operating point of the Z-diode.

As we have two different operation conditions for the input voltage ($U_{in\ min}$ **and** $U_{in\ max}$) we will get two different straight lines (see Fig. 5.3) with two different values for the current limiting resistor R1.

(a) **R1 min:**

For minimum load (open loop) all the current will flow across the Z-diode. The actual Z-diode current might exceed the peak current $I_{Z\ max}$ when the maximum input voltage $U_{in\ max}$ is applied.

Under this condition the current limiting resistor R1 is allowed getting lager but never smaller. We are going to determine the minimum value $R1_{min}$.

To determine the numerical value you can use the triangle

$$R1_{min} = \frac{\Delta U}{\Delta I} \approx \frac{U_{in\ max} - U_Z}{I_{Z\ max}}$$

Using the values out of Fig. 5.3

$$R1_{min} \approx \frac{13\ \mathrm{V} - 6\ \mathrm{V}}{100\ \mathrm{mA}} = 70\Omega$$

(b) **R1 max:**

For full load most of the current will flow across the load and the Z-diode is on the verge of getting not enough current $I_{Z\ min}$. This will get worse for the minimum input voltage $U_{in\ min}$.

The current limiting resistor R1 is allowed getting smaller but never larger.

We are going to determine the maximum value $R1_{max}$.

To find the graph of the input voltage source working with this value $R1_{max}$ we need to regard the Z-diode in parallel to the full load as the total load for the source. This is simply done by adding up the minimum Z-diode current $I_{Z\ min}$ and the load current I_{Load} at the

Z-voltage U_Z. The straight line between $U_{in\,min}$ (on the U_R-axis) and $I_{Z\,min} + I_{Load}$ (at U_Z) determines the maximum value $R1_{max}$.

To determine the numerical value you can use the triangle

$$R1_{max} = \frac{\Delta U}{\Delta I} = \frac{U_{in\ min} - U_Z}{I_{Z\,min} + I_{Load}}$$

Using the values out of Fig. 5.3

$$R1_{max} = \frac{10\text{ V} - 6\text{ V}}{5\text{ mA} + 25\text{ mA}} = 133\Omega$$

(c) **Choose the best value for R1:**

The circuit can only be realized with one value for R1 between the limits: $R1_{min} < R1 < R1_{max}$.

Out of the Fig. 5.3 it can be seen that small changes ΔU_{in} result in a shift of the operation point and hence in a change of $\Delta U_R = \Delta U_0$, the stabilized output voltage.
To get the smallest change in output voltage ΔU_0 while accepting big changes in input voltage ΔU_{in} we define a "smoothing factor" *SF* which should be as high as possible. Using the voltage divider rule we get

$$SF = \frac{\Delta U_{in}}{\Delta U_0} = \frac{R1 + r_Z}{r_Z} = \text{Maximum}$$

It is obvious that R1 has to be as high as possible while r_Z should be as small as possible.

We should choose

$$R1 = R1_{max} \text{ - Tolerance},$$

always keeping in mind that all resistors have a range of tolerance (maybe 10%).

To get the best stabilization we should use Z-diodes with a low differential resistance r_Z. Unfortunately these Z-diodes come with a very low value for $I_{Z\,max}$.

Improvements

If the resistor R1 is replaced by a nonlinear current source with $r_1 \gg R1$ we almost get a horizontal line and changes of the input voltage don't affect the output voltage anymore.

The regulation action would be ideal if the U/I-characteristic of the Z-diode was perfectly vertical. Because of the finite value for r_Z this curve presents a certain inclination and the voltage at the diode ends can vary a little when the load current I_{Load} changes. If we use a current amplifier following the Z-diode the load of the Z-diode will nearly be constant and the operation point will be fixed. The inclination of the Z-characteristic has less influence on the output voltage.

There remains only the shift of the Z-characteristic due to temperature. Using a Z-diode working between the avalanche and the field effect $(5\text{ V} < U_Z < 6\text{ V})$ the Z-diode shows a minimal temperature coefficient.

3. Equipment & Instruments:

- Module No. : DL 3155M12
- Function Generator
- Oscilloscope

4. Components List:

R1 = 220 Ω - 1/2W - 5%
R2 = 220 Ω - 1/2W - 5%
R3 = 1 kΩ manual regulation trimmer
V1 = Z-diode - 6.2V - 1W

Electrical Diagram

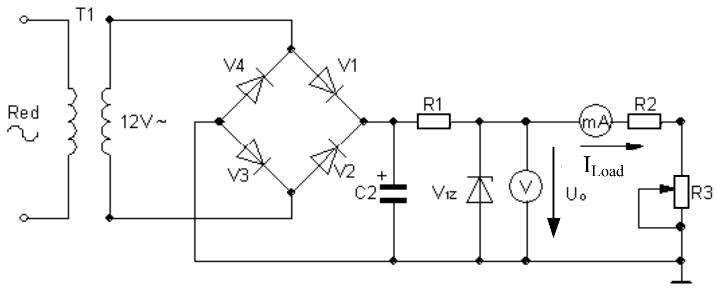

Fig. 5.4

5. Procedure:

Insert the Module 12 in the console and set the main switch to ON;

Uo = f(I_{Load}) CHARACTERISTIC

- connect the jack 3 of the power supply to the jack 1 of the regulator and set the switches S1 to OFF and S2 to ON;
- insert the positive terminal of the digital voltmeter, set to direct current, in the jack 3 of the regulator and the other one in the ground jack;
- Read the value of the no-load voltage with the load R2-R3 disconnected and write the value in Tab. 5.1.;
- insert the positive terminal of the digital milliammeter in the jack 3 of the regulator and the other one in the jack 4;
- adjust the R3 value so to read on the milliammeter a current of 6 mA;
- read the voltage value on the digital voltmeter and write it in Tab. 5.1;
- Repeat the procedure for all the current values written in Tab. 5.1.;
- draw in Fig. 5.5a the output voltage diagram as a function of the load current Uo = f(I_{Load});
- move the positive terminal of the digital milliammeter in the jack 3 of the power supply and the other one in the jack 1 of the regulator;
- read the value of the input current and verify that this one remains constant with the load variation (define the measured quantity in the circuit diagram Fig. 5.4);

Uo = f(Ui) CHARACTERISTIC

- turn, completely counterclockwise the potentiometer R3 so to bring to the maximum value the current on the load;
- adjust the voltage +V for all the values written in Tab.5.2. and for every value of the input voltage survey the corresponding value of the output voltage (define the quantity +V in the circuit diagram Fig. 5.4);
- draw in Fig.5.5-b the diagram of the output voltage as a function of the input voltage Uo = f(Ui);

6. *Results*:

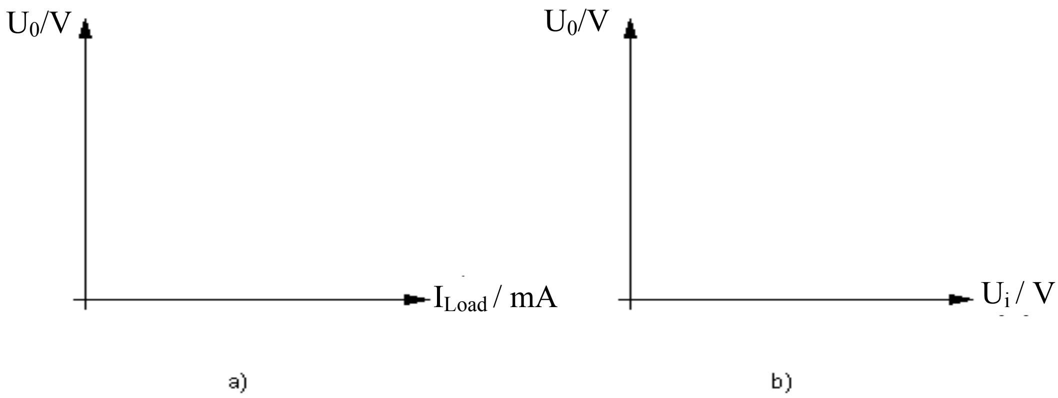

Fig. 5.5

I_{Load} / mA	0	6	9	12	15	18	21	24	25
Uo / V									

Tab. 5.1 Uo = f (I_{load}), Ui = const

$U_{i\,(+V)}$ / V	5	6	7	8	9	10	11	12	13	14
Uo / V										

Tab. 5.2 Uo = f (Ui), full load

7. *Conclusion*:

In this conclusion you should compare the measured range of stabilization with the theoretical values you get out of the graphical solution.

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8. *Questions*:

If the input voltage applied to the Z- regulator is lower than 6.2 V and there is no load what is the value for the output voltage?

1. The same as the input one
2. 0 V
3. 0.6 V
4. 6.2 V

If the load resistance is disjointed and the voltage +V is equal to 15 V, the current in the Z-diode is approximately:

1. 0.6 m A
2. 10 m A
3. 20 m A
4. 40 m A

The power dissipated from the Z-diode in the circuit is higher when:

1. The Z-diode is short-circuited
2. The load resistance is disjointed
3. The load resistance is short-circuited

9. *Design:*

In the following design exercise, refer to the design that was completed in Lab 2.

A. Design a power supply circuit with a bridge full-wave rectifier, a filter and a regulator. The input is 240Vrms AC signal (50 Hz) and the output is a 4.7V DC signal.

B. Build and test the circuit. (Do not use a transformer. Take a stepped-down signal directly from the function generator).

C. Experimentally determine the range of load resistance such that your power supply circuit maintains voltage regulation within +/- 2% of desired output voltage.