ELECTRONICS LAB.

PART 4

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Contents

ZENER DIODES

6.1 INTRODUCTION

Zener diode is a P-N silisium semi-conductor component. It behaves like normal diode in forward bias. It allows current to pass when inverse bias voltage reaches I_Z value. It can make voltage regulation by stabilizing E_Z voltage.

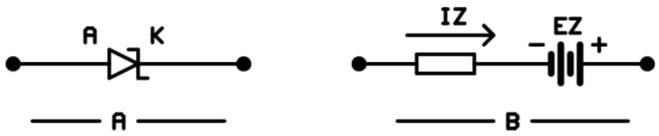

Figure 6. 1

Symbol of zener is shown in Figure 6. 1A. In Figure 6. 1B, its operating equivalent circuit at zener region (**inverse bias**) is shown. Inverse voltage between cathode-anode should be more than E_Z voltage (seen in figure) in order to enable a current flow between from cathode to anode.

6.2 OPERATION OF ZENER DIODE

They work at inverse bias. Operation voltage of Zener diodes is over the breakdown voltage of normal diodes. A conventional solid-state diode will not let significant current flow if it is reverse-biased below its reverse breakdown voltage. Zener permits current to flow in the reverse direction if the voltage is larger than the breakdown voltage known as zener voltage (**E_Z**). Value of current depends on the power of zener. Zener diodes continue to work unless the zener current exceeds maximum value.

Current increases instantaneously when the zener diode starts conduction on inverse bias. This increase should not exceed zener maximum current value (**I_{ZM}**). Because of that "**all zener diodes are used with a serial resistor**"

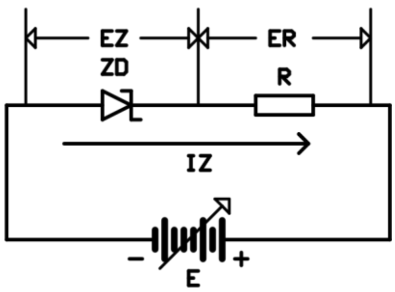

Figure 6. 2

In the circuit above, If E voltage is increased slowly starting from zero (0); the zener voltage will also increase. Resistor voltage is zero because supply voltage has not reached the level of zener breakdown voltage. Circuit current is zero.

When the supply voltage reaches zener breakdown voltage, current begins to flow.

Because **E=**E_Z+E_R, E_R increase with the increase of E. It is important that the E_Z voltage is constant. Even if E voltage is increased, E_Z will approximately constant.

Resistor limits the current in this circuit. The current determined by resistor ($\frac{E_R}{R}$) should not exceed the maximum current value of zener (**I_{ZM}**). Maximum current value (**I_{ZM}**) is calculated by the following formula:

$$I_{ZM} = \frac{P_Z}{E_Z}$$

Various zener diode characteristics are shown in Figure 6. 3 In forward bias zener diodes behave like normal diodes. In inverse bias region, four characteristics drawn represent four different zener diodes. E_Z and I_Z are inverse bias values they're indicated by positive numbers. Zeners have voltage values between 2.4V and 200V and power values between 0.25W and 50W.

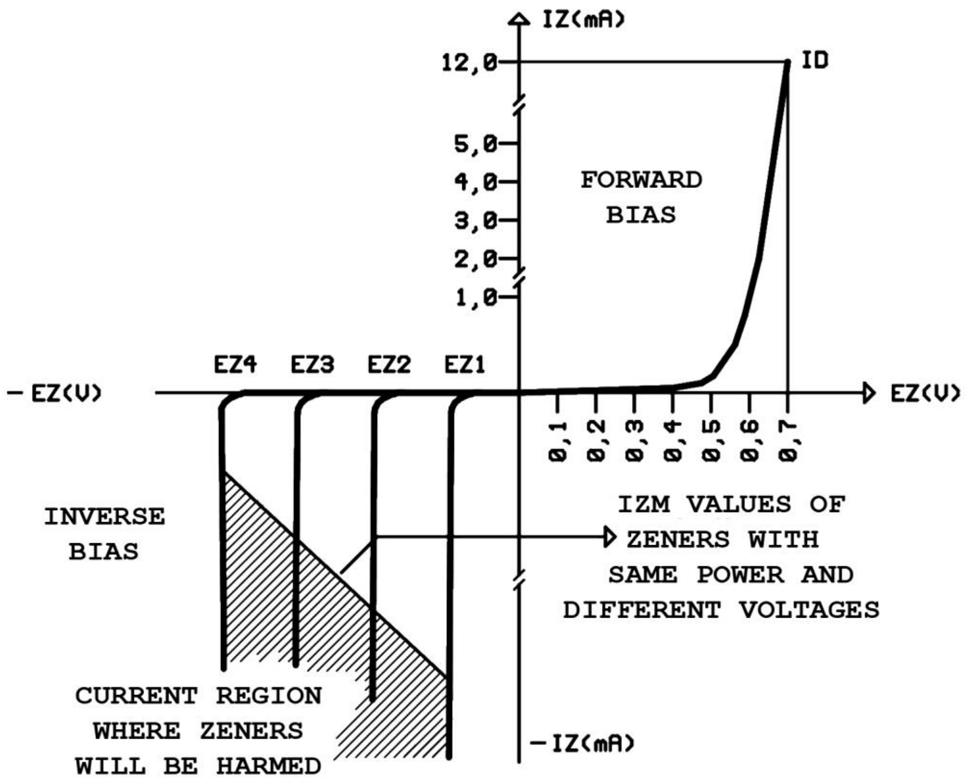

Figure 6. 3

6.3 REGULATION CIRCUIT MADE OF ZENER DIODE

Current flow starts after a specific voltage is reached on the terminals of zener diode. Serial connection of zener in circuit is used to determine the reference point of control circuits.

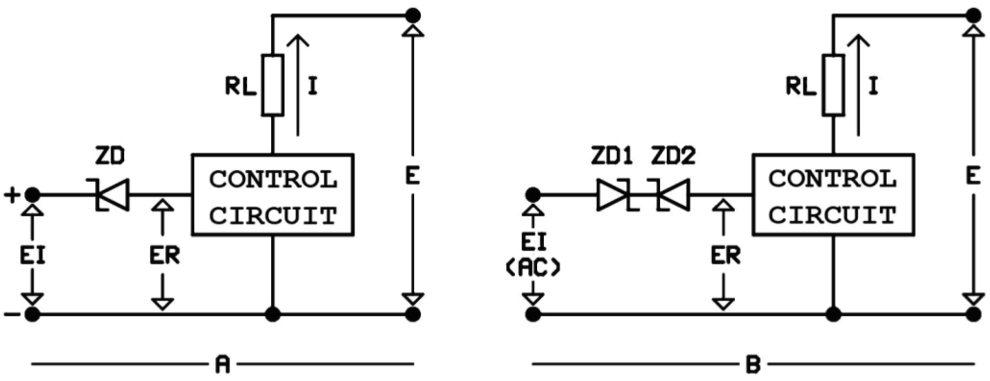

Figure 6. 4

Input voltage (**Ei**) is variable forward voltage in Figure 6. 4 There is no input signal of control circuit for values below the zener diode voltage. At values over zener diode voltage, reference voltage (**ER**) is applied to the control circuit. Depending on this, control circuit allows or prevents load flow. Two zener diodes are connected serial and in opposite direction in order to allow circuit work in AC. In Figure 6. 4B, if the voltage of zener diodes is assumed to be 6Volt each, one of diodes will be forward bias and the other will be inverse biased for every alternation. There will be 6 Volt on the terminals of inverse biased diode and 0,7 Volt on the terminals of forward biased diode. Voltage between two diodes will be 6+0,7=6,7 Volt.

Reference voltage is applied to the input of control circuit when instantaneous value of alternating input voltage is over 6,7 Volt. The circuit can be used disregarding the bias at 6,7 Volt critical voltage in DC.

In small current circuits zener diode can be used as regulator component by connecting parallelly to load, as seen in Figure 6. 5

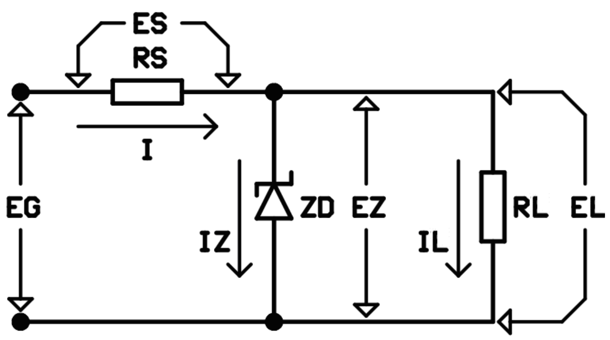

Figure 6. 5

Input voltage is variable forward voltage. Regulation process means stabilizing the load voltage. Increase of input voltage causes circuit current (**I**) to increase. And when the current increases, zener diode current (**IZ**) and the load current (**IL**) also increase. Value of zener current should never exceed maximum zener current (**IZM**). Otherwise, zener diode will be harmed. So, zener diode with appropriate power level should be used. Lower and upper limits of input voltage should be as follows:

Lower limit (**EiA**);
EiA= $(IL.RS) + EZ$
Upper limit (**EiU**);

Zener diode voltage (**EZ**) is the voltage on load. Load current should be constant because the load value is constant. Upper limit of input voltage depends on power of zener diode. Power is symbolized by (**P**).
Power is equal to the multiplication of current (**I**) and voltage (**E**).
Unit of power is WATT.

$$P = E.I$$

In Formula;

P=power (**Watt**)
E=voltage (**Volt**)
I=current (**Amper**).

Maximum current to pass through zener diode (**IZM**):
IZM= $\frac{PZ}{EZ}$
Maximum circuit current (**IM**):
$IM = IZM + IL$

Upper limit (**maximum**) of input voltage (**EiM**):
EiM= $(IM.RS) + EZ$

It is observable in the formulas of lower and upper limits of input voltage that the resistor (**RS**) which is in serial connection to the zener diode is very important. The value of this resistor (**RS**) is calculated at the moment when the input voltage is at lower limit (**EiA**), when the zener diode current (**IZ**) is zero or when circuit current (**I**) is equal to load current (**IL**).

$$RS = \frac{ES}{I}$$

$Ei = Ei - EZ$ ve $I = IL$

$$RS = \frac{Ei - EZ}{I}$$

Example;
A circuit works with 12 Volt and 100mA. This circuit will work with regulation circuit made of zener diode. Input voltage varies between 22V and 27V. Calculate the values of regulation components.

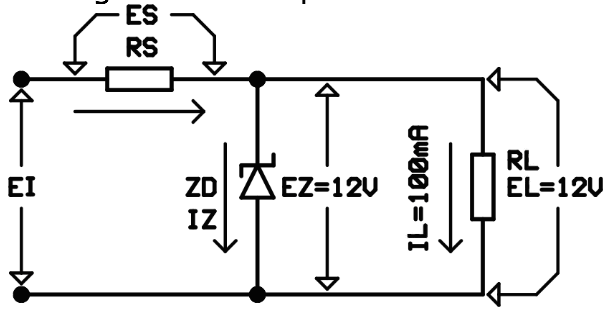

Figure 6. 6

Solution;

EL=EZ, so zener diode will be 12V.
IL=100mA=0,1A

$$RS = \frac{EiA - EZ}{IL} = \frac{22-12}{0,1}$$

RS=100R.
Maximum voltage on RS resistor (**ESM**):
ESM=EiM-EZ
ESM=27-12
ESM=15V
Maximum current to pass through RS resistor (**ISM**):

$$ISM = \frac{ESM}{RS} = \frac{15}{100}$$

$$ISM = 0,15A = 150mA$$

So, the power of RS resistor (**PRS**):

$$PRS = ESM.ISM$$

$$PRS = 15.0,15$$

$$PRS = 2,25WATT$$

Maximum current to pass through zener diode (**IZM**):

$$IZM = ISM - IY$$

$$IZM = 150 - 100$$

$$IZM = 50mA.$$

So, the power of zener diode (**PZD**):
IZM=50mA=0,05A

$$PZD = EZ.IZM$$

$$PZD = 12.0,05$$

$PZD = 0,6$ Watt

The calculated power values are the minimum required values for components. Calculated mathematical values may be different than standard power values. More powerful circuit components are more expensive. Because of that, the components with the closest power value to the calculated values should be chosen.

6.4 RECTIFIER WITH PARALLEL REGULATOR

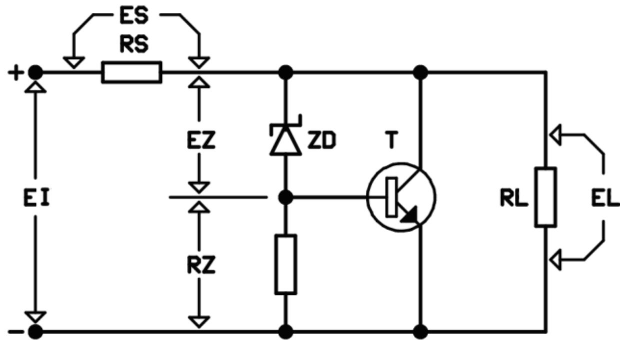

Figure 6. 7

In Figure 6. 7, rectifier with parallel regulator is shown. It is the same of regulator circuit made of zener diode. A transistor is connected to circuit instead of zener diode. This transistor increases load. Circuit load is connected between collector-emitter of transistor. Input voltage (**Ei**) is forward voltage and not regulated.

Input voltage is divided according to following formula:

Ei=ERS+ERZ+EZ

When the load current increases, voltage on the terminals of RS resistor will also increase, because load current also passes through RS resistor. Relatedly, voltage on the terminals of zener diode is constant and voltage on the terminals of RZ decreases. Non-conductance of transistor increases because its base bias goes towards negative and voltage on terminals of load increases. When the load current decreases, voltage on RS resistor decreases. In this situation, voltage on RZ resistor increases and base bias of transistor increases towards positive. So, voltage on load is maintained constant automatically.

Current passes continuously through transistor when there is no load on parallel regulation rectifier.

6.5 RECTIFIER WITH SERIAL REGULATOR

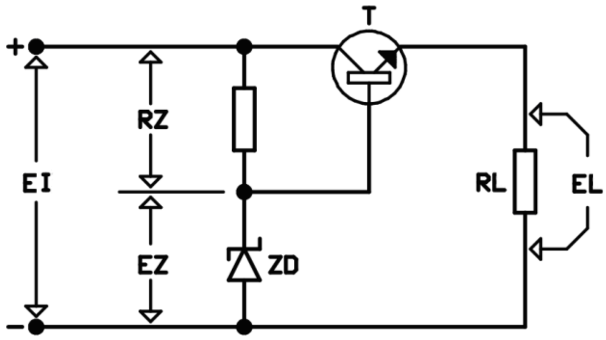

Figure 6. 8

A rectifier circuit with serial regulator is shown in Figure 6. 8 Load is connected serially to the transistor. Input (**Ei**) voltage is forward voltage and not regulated. Input voltage is divided according to following formula

Ei=ERZ+EZ

Base bias of transistor is the voltage on terminals of zener diode. As in the regulator circuit made of zener diode, base bias of transistor is constant in a wide variety of input voltage value. Increase of load current decreases unregulated input voltage. This decrease can not change the voltage on the terminals of zener diode. So, the base bias of transistor is constant. Decrease of input voltage only results in the decrease of voltage on the terminals of RZ resistor. This does not effect the operation of circuit.

Output voltage is lower than the voltage on transistor base as much as 0,7 Volt because the transistor is made of silisium. Threshold voltage of transistors (the value which transistors start working) is 0,7 Volt. This voltage is on the base-collector diode of transistor. The method of removing this problem will be seen in next experiment.

There is no power consumption of power when there is no load in serial regulator rectifiers.

6.6 RECTIFIER WITH IDEAL SERIAL REGULATOR

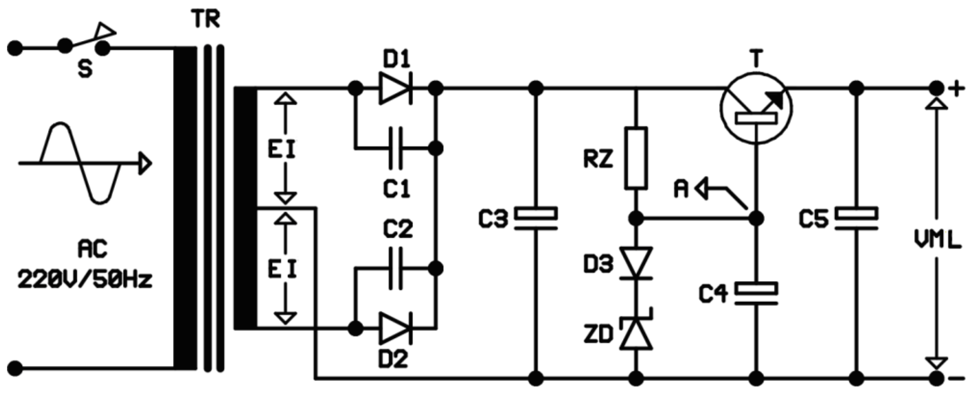

Figure 6. 9

Rectifier with ideal serial regulator is seen in Figure 6. 9. Output voltage is set to be **VML=**6 Volt. TR transformator adapts the city network voltage to 2×9Volt AC in order to use it in full-wave rectifier. Secondary voltage should be more than the (expected) output voltage as much as 3Volt-5Volt. D1-D2 diodes convert AC to DC. C1-C2 capacitors are used to prevent the statics (parasites) from city network. C3 is the primary regulator capacitor. Its capacity should be as high as possible. C3 capacitor is charged to the maximum value of positive alternation on its terminals.

EC3=1,41.Ei
EC3=1,41.9
EC3=12,69

Threshold (working) voltage of C1 capacitor should be at least as much as the threshold voltage of EC3. EC3 voltage is shared between zener diode, D3 diode and RZ resistor.

Zener diode and D2 diode provides the base bias of transistor. Zener diode is chosen as 6 Volt because output voltage is expected to be **VML=**6Volt. D3 diode is silisium diode. Zener diode is inverse biased to circuit while D3 diode is forward biased. D3 diode is used to compensate the threshold voltage on the base-emitter diode of transistor. The voltage on point (**A**) will be the sum of voltages on zener diode and D3 diode, because the silisium semi-conductors have a threshold voltage of 0,7 Volt.

The voltage on point (**A**) is EA;
EA=EZD+ED3
EA=6+0,7
EA=6,7Volt

0,7 Volt of this voltage on base will be on the base-emitter diode and output voltage will be **VML=**6V. C4 capacitor is used to prevent possible changes in base voltage. The capacity of C4 capacitor is enough to be 100μF. Capacity of C3 capacitor should be at least as much as EA.

The most important component of circuit is RS resistor for good regulation. RS resistor controls the total voltage on zener diode and D3 diode. Base current is assumed to be zero.

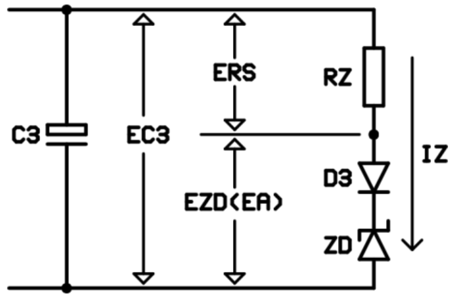

Figure 6. 10

In Figure 6. 10, EC3 voltage is the sum of ERS and EZD voltages. **EA=EZD=**6,7Volt, so the voltage on RS resistor is calculated as follows:

EC3=ERS+EZD
ERS=EC3-EZD
ERS=12,69-6,7
ERS=5,99≈6Volt

Circuit provides and controls the base bias of transistor. Because of this circuit current (**IZ**) is too small. This value is commonly assumed to be **IZ=**20mA in calculations. So, RS is a resistor with a voltage of 6 Volt and 20mA current passes through it.

Value of RS from Ohm’s Law:

$$RS = \frac{ERS}{IZ} = \frac{6}{0{,}02} = 300R(OHM)$$

C5 is the secondary filter capacitor. Its capacity should be as high as possible for the filtering processing. Threshold voltage of C5 capacitor should be at least as much as output voltage (**VML**).

C3 and C5 capacitors can be calculated mathematically as we have previously seen in the experiment regarding the “**effect of capacity to regulation**”. Practically, C3 capacitor can be used between 2200μF and 4700μF, and C5 capacitor can be used between 100μ and 1000μF.