1.2 ZENER DIODE

1.2.1 Principle

A Zener diode is a special purpose diode prepared by sandwiching heavily doped P-type and N-type semiconductors. Zener diode is specially designed to operate in breakdown region called **Zener breakdown,** where current is limited only by external resistance and the power dissipation of the diode. i.e., once the applied voltage under reverse bias is equal to breakdown voltage, the current increases very rapidly and the diode voltage stays essentially constant. This property of Zener diode can be used for voltage regulation. The satisfactory explanation for the breakdown of the junction is given by an American Scientist C.E. Zener in 1934, and hence the device is named after him. In Zener diode, at low reverse voltage below 6 V, **Zener breakdown** becomes predominant and higher reverse voltage above 6 V, **avalanche breakdown** becomes predominant.

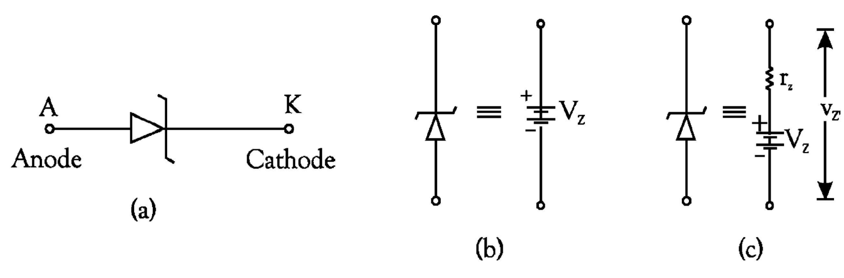
Avalanche Breakdown: Due to applied reverse bias, the minority charge carriers cross the depletion region and gain enough kinetic energy to knock bound electrons out of the covalent bonds. These electrons will in-turn collide with other atoms and will increase the number of electrons and holes available for conduction. This multiplication effect of free carriers is called avalanche breakdown.

Zener Breakdown: Due to heavy doping, the Zener diode will have extremely narrow depletion region of the order of only 150 – 200 Å, hence, there exists a high electric field, in the order of 10^6 V/cm across the junction. This field provides a high electrical force which is responsible for tearing electrons out of the covalent bonds directly, rather than by collision. This is Zener breakdown.

1.2.2 Construction

A Zener diode is a silicon P-N junction heavily doped diode always operated in reverse bias and it has sharp breakdown voltage called Zener voltage (V_Z). The corresponding reverse current flowing through the Zener is called Zener current (I_Z). Such a characteristic is obtained by addition of suitable quantities of an impurity material to silicon.

The symbol of Zener diode is shown in Fig. 1.14 (a), and the equivalent circuit is shown in Fig. 1.14 (b) & (c). When the Zener diode is operated in the breakdown region, it can be considered as a constant voltage source.

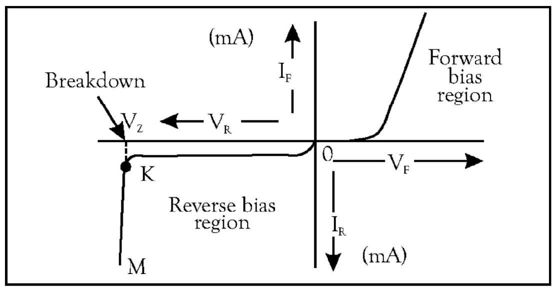


1.2.3 V I Characteristics

The V-I characteristics of a Zener diode is shown in Fig. 1.15.

(i) During forward bias, the Zener diode acts like ordinary P-N junction diode and its characteristic is shown in first quadrant of the graph.

(ii) During reverse bias, at a particular reverse voltage called Zener voltage (V_Z), Zener breakdown occurs and it acts like constant voltage source. Thus a Zener diode of a known breakdown voltage can be used as reference voltage in voltage regulators.



Zener Diode Specifications

(1) **Zener Voltages**

The manufacturers specify the value of breakdown voltage known as the Zener voltage, V_Z at some value of test current, I_{ZT}. This is on the linear portion of the reverse characteristic and corresponds to approximately one-quarter of the maximum power dissipation capability of the diode. Zener diodes are available at various V_Z values from 2.4 to 200 V with accuracies between 5% and 20%, depending upon the cost.

(2) **Power Dissipation**

Power dissipation in the Zener diode is the product of V_Z and reverse current, I_Z, with maximum power ratings ranging from 150 mW to 50 W.

(3) **Breakover current**

Since there is some curvature of the reverse characteristic at low values of I_Z, there may be some specified value of current, I_{ZK} in the neighborhood of the breakover knee, where the voltage across the diode starts to differ greatly from V_Z.

(4) **Dynamic Impedance**

The Zener dynamic impedance, Z_Z, is defined as:

$$Z_Z = \frac{\Delta V_Z}{\Delta I_Z} \qquad ...(1.2)$$

This impedance is usually evaluated in the region of the specified test current I_{ZT}, and is the reciprocal of the slope of the reverse characteristic. Ideally, Z_Z is zero for a perfectly vertical breakdown curve, but in practice may vary from several ohms to several hundred ohms, depending upon the particular Zener diode voltage and the operating current. This specification provided by the manufacturer, will helps to describe how "vertical" is the reverse characteristic of Zener diode.

(5) **Zener diodes used in Practical Circuits**

1N4728 – 1N4732 series Zener diodes are commonly used in electronic circuits with following specifications:

Series No.	Nominal Zener voltage (V_Z in Volts) at nominal I_{ZT}	Test Current I_{ZT} (mA)
1N4728	3.3	76
1N4729	3.6	69
1N4730	3.9	64
1N4731	4.3	58
1N4732	4.7	53

1.2.4 Applications

The important applications of Zener diode are:

(1) As a voltage regulator in regulated power supplies.
(2) As a fixed reference voltage in transistor biasing circuits.
(3) As peak clippers and limiters in wave shaping circuits.
(4) As a meter protector against damage from accidental applications.

1.2.5 Comparison of Zener Diode with P N Junction Diode

S. No.	Zener Diode	P N Junction Diode
1	A Zener diode is a silicon P-N junction heavily doped diode always operated in reverse bias breakdown condition.	Comparatively lightly doped and operated in forward bias condition.
2	Dynamic Zener resistance is very small in reverse breakdown region	The resistance in reverse bias is very high.
3	In operating region current flows from N-region to P-region within the diode.	In operating region current flows from P–region to N–region within the diode
4	Power dissipation capacity of Zener diode is high.	Power dissipation capability of P-N diode is very low compared to Zener diode.
5	Zener diode is mainly used in voltage regulators	P-N junction diode is mainly used in rectifiers and other wave shaping circuits.

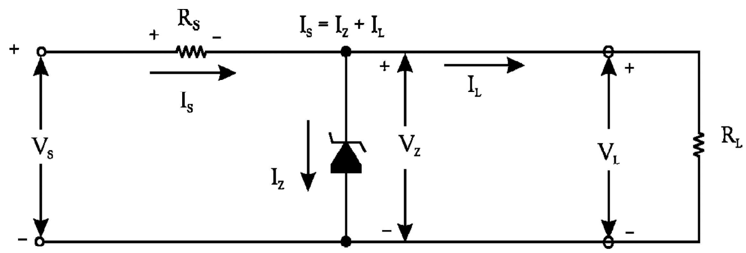
1.7.3 Zener Diode Voltage Regulators

Principle

A voltage regulator provides constant output voltage irrespective of small variations in input voltage. Zener diode is specially designed to operate in breakdown region called Z**ener breakdown**, where current is limited only by external resistance and the power dissipation of the diode. i.e., once the applied voltage under reverse bias is equal to breakdown voltage, the current increases very rapidly and the diode voltage (V_Z) stays essentially constant. This property of Zener diode can be used for voltage regulation.

Circuit

Fig. 1.31 shows a circuit of Zener diode shunt regulator. Since the Zener is connected in parallel (or shunt) with the load, therefore the circuit is known as shunt regulator. A resistance, (R_S) is connected in series with the Zener to limit current in the circuit. Therefore, the resistance R_S is also known as series current limiting resistor. The output voltage (V_L) is taken across the load resistance (R_S). For proper operation, the input voltage (V_S) must be greater than the Zener voltage (V_Z). This ensures that Zener operates in the reverse breakdown region.



The input current (*i.e.*, current through the limiting resistor) is given by

$$I_S = \frac{V_S - V_Z}{R_S}$$

where V_S is the dc input voltage to the regulator and V_Z is the Zener voltage.

If the reverse resistance of Zener diode is r_Z, then there is a voltage drop across it which is equal to $I_Z . r_Z$. Therefore, the voltage across the terminals of the Zener diode is

$$V_L = V_Z + I_Z . r_Z \qquad \text{...(1.21)}$$

If the Zener resistance is negligible, then the load voltage, $V_L = V_Z$ and the current through the load resistance is given by the relation,

$$I_L = \frac{V_L}{R_L} \text{ and } I_Z = I_S - I_L \qquad \text{...(1.22)}$$

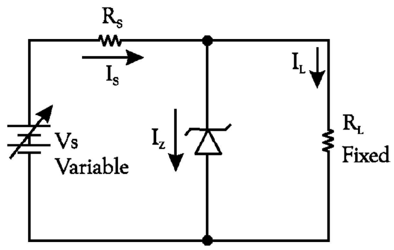
Working

The working of Zener diode regulator may be discussed under the two heads, namely regulation with varying input voltage and regulation with varying load resistance.

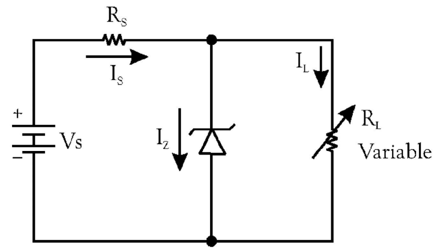
1. Regulation with varying input voltage: Consider the regulator circuit as shown in Fig. 1.32 (a). Here the load resistance (R_L) is kept fixed and the input voltage (V_S) varies within the limits.

(i) If the input voltage increases, the input current (I_S) also increases. This increases the current through Zener diode, without affecting the load current (I_L). The increase in input current will also increase the voltage drop across series resistance (R_S), thereby keeping the load voltage (V_L) as constant.

(ii) On the other hand, if the input voltage decreases, the input current (I_S) also decreases. As a result, the current through Zener (I_Z) will also decreases. Consequently, the voltage drop across series resistance (R_S) will be reduced. Thus the load voltage (V_L) and load current (I_L) remains constant.



(a) Varying input voltage.



(b) Varying load resistance.

2. Regulation with varying load resistance: Consider the regulator circuit as shown in Fig. 1.32 (b). Here the input voltage (V_S) is kept fixed and the load resistance (R_L) varies. The variation of load resistance changes the load current (I_L) through it, thereby changing load voltage (V_L) across it.

(i) When the load resistance (R_L) decreases, the load current (I_L) increases. This causes the Zener current (I_Z) to decrease. As a result of this, the input current and the voltage drop across series resistance (R_S) remains constant. Thus the load voltage (V_L) remains constant.

(ii) On the other hand, if the load resistance increases, the load current decreases. As a result, the Zener current increases. This again keeps the values of input current and voltage drop across series resistance (R_S) as constant. Thus the load voltage (V_L) remains constant.

Optimum Value of Current Limiting Resistor (R_S):

The value of current limiting resistor must be properly selected to fulfill the following two requirements:

1. When the input voltage is minimum and the load current is maximum, sufficient current must be supplied to keep the Zener diode within its breakdown region (or regulating region).
2. When the input voltage is maximum and the load current is minimum, the Zener current must not increase the maximum rated value.

The optimum value of current limiting Resistor (R_S) can be determined by using the following two equations for maximum and minimum values of Zener current:

$$I_{Z(\max)} = \frac{V_{S(\max)} - V_Z}{R_S} - I_{L(\min)} \qquad \text{...(i)}$$

$$I_{Z(\min)} = \frac{V_{S(\min)} - V_Z}{R_S} - I_{L(\max)} \qquad \text{...(ii)}$$

From equation (i), we find that the minimum value of current limiting resistor,

$$R_{S(\min)} = \frac{V_{S(\max)} - V_Z}{I_{Z(\max)} + I_{L(\min)}} \quad \text{...(1.23)}$$

and from equation (ii), the maximum value of current limiting resistor,

$$R_{S(\max)} = \frac{V_{S(\min)} - V_Z}{I_{Z(\min)} + I_{L(\max)}} \quad \text{...(1.24)}$$

The value of current limiting resistor (R_S) should be chosen in such a way that its value should be between R_S(max) and R_S(min) i.e.,

R_S (min) < R_S < R_S (max)

Disadvantages of Zener-diode Shunt Regulator:

Following are the disadvantages of a Zener diode shunt regulator:

1. The maximum load current, which can be supplied to load resistor (R_L) is limited to I_Z (max) - I_Z (min) which is usually of few milli amperes.
2. A large amount of power is wasted in the Zener-diode and the series resistance (R_S) in comparison with the load power.
3. The regulation factor and the output resistance are not very low.

SOLVED PROBLEMS

1. *A variation of 0.02 V across a 3.8 V Zener produces a current change from 20 mA to 22 mA. Calculate the dynamic resistance of the device ?*

Solution:

Given : The change in Zener voltage = ΔV_Z = 0.02 V

The change in Zener current = ΔI_Z = 22 – 20 = 2 mA

The dynamic resistance r_Z = $\Delta V_Z / \Delta I_Z$ = $0.02 / 2 \times 10^{-3}$ = 10 Ω

2. *A 4.7 V Zener has a resistance of 15Ω. What is the terminal voltage, when the current is 20 mA?*

Solution:

Given V_Z = 4.7 volts; r_Z = 15Ω and I_Z = 20 mA = 20×10^{-3} A.

We know that the terminal voltages of a Zener diode,

Then $V_Z = (V_Z + I_Z \cdot r_Z) = 4.7 + (20 \times 10^{-3}) \times 15 = 5$ V.

Rectifiers:

3. *The input of a Half wave rectifier is V = 200 sin 40 ~~t. If R_L = 1KΩ, and forward resistance of the diode is 30~~ Ω, find (i) The dc current through the diode, (ii) The ac value of current in the circuit, (iii) dc output voltage, (iv) dc power input, (v) Rectifier efficiency ?*