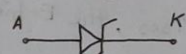
Junction Analysis:

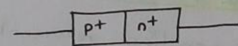
01
5/8/15

Topic: Zener Diode: Breakdown mechanisms, Characteristics, effect of temperature, Application as voltage regulator and backward diode.

Varactor diode: Working and characteristics

Zener diode





- It's a two terminal device with their doping levels carefully selected to give the desired characteristics.
- It is a pn junction device, ie operated in the reverse breakdown region.
- Zener can be designed with adequate power dissipation capabilities to operate in the breakdown region.
- Zener is heavily doped than the ordinary diode.

→ From I-V curve, operation of zener diode is same as pn J^n in forward-bias.

- In reverse-bias, beyond V_Z, breakdown of the junction occurs.

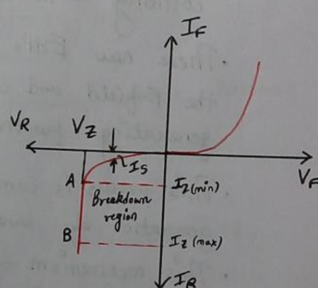


fig: I-V curve of a Zener diode.

→ The breakdown voltage depends upon the amount of doping.

- If the diode is heavily doped, depletion layer will be thin (as in case of zener diode) and, consequently, breakdown occurs at lower reverse voltage and further, the breakdown voltage is sharp.

(whereas a lightly doped diode has a higher breakdown voltage.)

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- The sharp ↑sing reverse current under breakdown conditions are due to the following two mechanisms:- 02
  1) Avalanche breakdown.
  2) Zener breakdown.

  ] Breakdown mechanism's

Avalanche breakdown :-

- As applied reverse-bias ↑ses, the E-field across the junction ↑ses.
- Thermally generated carriers while traversing the junction acquire a large amount of K.E from this E-field.
- As a result the velocity of these carriers ↑ses.
- These energetic electrons disrupt covalent bond by colliding with immobile ions and create new EHPs.
- These new EHPs again acquire sufficient energy from the E-field and collide with other immobile ions thereby generating further EHPs.
- This process is commulative in nature and results in generation of avalanche of charge carriers within a short time.
- This mechanism of carrier generation is known as "Avalanche multiplication."

→ This process results in flow of large amount of current at the same value of V_Z.

· Zener Breakdown:

- When p and n regions are heavily doped, direct rupture of covalent bonds take place because of the strong E-fields, at the junction of PN diode.
- The new EHPs so created ↑se the reverse current in a reverse-biased conditions.
- Such high E-field's exerts a force on the e's in the outermost shell. This force is so high that the e's are pulled away from their parent nuclei and become free carriers. It causes an ↑se in no of free carriers and hence an ↑se in reverse current.

(For heavy doping regions, the depletion region width becomes very small, the E-field across the depletion region becomes v. high (of order of 10^7 V/m), making condition's suitable for zener breakdown).

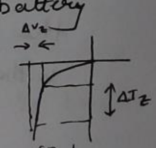
- For lightly doped diodes, zener breakdown voltage becomes high and breakdown is then predominantly by "Avalanche multiplication."

→ Zener breakdown occurs for lower breakdown voltage and Avalanche breakdown occurs for higher breakdown voltage.

→ **Zener resistance :-**

1) Static or dc resistance (R_Z): It is the ratio of total zener diode voltage to total diode current measured at the given operating point ie $R_Z = \frac{V_Z}{I_Z}$.

→ A zener diode can be replaced by an ideal battery in series with a small Zener resistance R_Z.



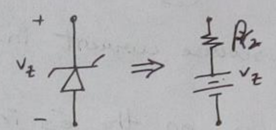
2) Zener or Dynamic resistance (r_Z): $r_Z = \frac{\Delta V_Z}{\Delta I_Z}$

If the dynamic resistance (r_Z) is less, then the Zener diode will be better as a voltage regulator.

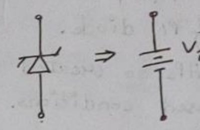
• Zener diode rating's :-

V_Z, $P_{Z(max)}$, $I_{Z(min)}$, $I_{Z(max)}$

"Zener breakdown voltage"



a) Practical zener diode equivalent ckt



b) Ideal diode (zener) equivalent ckt.

→ If $V > V_Z$, zener is in ON state.
For $0 < V < V_Z$, zener is in off state.

1) **$I_{Z(min)}$** : It is the min reverse current where the breakdown becomes stable. This is min value of zener current which must be maintained in order to keep diode in breakdown region. ie $(I > I_{Zmin})$.

2) **$I_{Z(max)}$** : It is the maximum value of zener current above which the diode may be damaged.

• The value of this current is given by the max power dissipation of zener diode.

$$I_{Z(max)} = \frac{P_{Z(max)}}{V_Z}$$

• This parameter gives the max current, a zener diode can handle without exceeding its power rating.

3) **Max Power of a zener (P_Z) :** $P_Z = V_Z I_Z$.
As long as P_Z is less than the max power rating $P_{Z(max)}$, the zener diode can operate in the breakdown region without being destroyed.

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* Effect of temperature on Zener diode:

- V_Z changes with the temperature.
- The % change in the zener voltage (V_Z) for every °C change in temperature is called temperature co-efficient (TC) of a zener diode. It is denoted as TC and expressed as %/°C.

Mathematically, it can be defined as,

$$TC = \frac{\Delta V_Z}{V_Z(T_1 - T_0)} \times 100 \quad — ①$$

where T_1 is the final temperature of the junction
T_0 is generally room temperature at which normal zener voltage / V_Z is specified.
ΔV_Z is the resulting change in the zener voltage due to the temperature variation.

- A +ve value of TC ⇒ An ↑se in V_Z due to ↑se in temperature & vice-versa.
- A -ve value of TC ⇒ An ↑se in V_Z due to ↓se in temperature.

From eq^n ①, we have

$$\Delta V_Z = \frac{V_Z\, TC(T_1 - T_0)}{100} = \frac{T_Z\, TC\, \Delta T}{100}$$

where ΔT - is the change in temperature.

- Sometimes TC for zener is expressed in mV/°C & in such a case, corresponding change in V_Z is

$$\Delta V_Z = TC(T_1 - T_0) = TC \times \Delta T \quad — ②$$

→ For zener with $V_Z < 6V$, TC is -ve, hence V_Z ↓ses with temperature ↑ses.
For zener with $V_Z > 6V$, TC is +ve & hence V_Z ↑ses as temperature ↑ses.

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Low-power Si Zener diodes: $P_D = 400\,mW$

Type IN746 through IN759, 3.3V to 12V

Type number	Nominal V_Z (V)	P_D
IN746	3.3	↑
IN747	3.6	400mW
IN753	6.2	
IN755	7.5	
IN757	9.1	
IN759	12	↓

P_D → Power dissipation

* Application of Zener as voltage regulator:-

- From zener characteristics under under R.B condition, the voltage across zener remains almost constant although the current through the zener ↑ses.

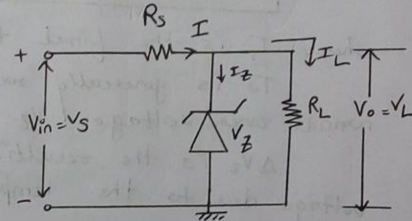

fig 2: Zener as voltage regulator

- Thus, the voltage across the zener diode serves as a reference voltage. Hence, the zener diode can be used as a "voltage regulator."

- In fig 2, it is required to provide constant voltage across load resistance R_L, whereas the I/p voltage may be varying over a range.

- As shown in fig 2, zener diode is reverse-biased and as long as the i/p voltage does not fall below V_Z (zener breakdown voltage), the voltage across the diode will be constant and hence the Load voltage (V_L) will also be constant.

- The performance of a Zener diode voltage regulator may be expressed in terms of the source and load effects and the Line and load regulations.

- From fig 2, when zener voltage regulator has to supply a load current (I_L), the zener diode must be able to pass a max current of ($I_L + I_Z$).
- Care must be taken to ensure that the min. Zener diode current is large enough to keep the zener in reverse-breakdown.

→ The ckt current eq^n is,

$$I = I_Z + I_L = \frac{V_S - V_Z}{R_S} \quad — \text{①}$$

- Resistor R_S is used the control the supply current.

→ Voltage regulator is an electronic circuit which keeps o/p voltage constant irrespective of changes in Line voltage and load current.

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* Backward diode:-

- Zener diodes are normally used under the reverse-bias condition. Their breakdown voltages are normally above 2V.
- Forward conduction in zener occurs in voltage around 0.7V (for Si).
- The breakdown ie zener effect under the R.B condition can also be obtained near zero (around 0.1V).
- Fig 3 shows I-V curve for a backward diode.
- It is called a backward diode becoz it conducts better in the reverse than in the forward direction.

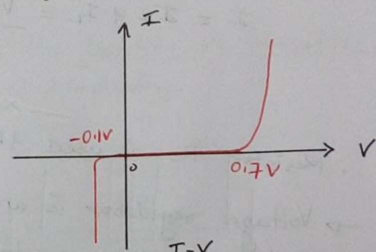

fig 3: Characteristics of backward diode

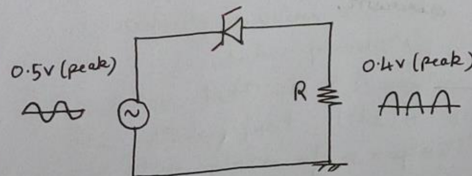

fig 4: Low-level rectifier ckt using backward diode.

- From fig 4, a sine wave with a peak of 0.5V is given as the I/P to the backward diode.
- This voltage (0.5V) is not enough to forward bias the zener diode into conduction, but it is enough to breakdown the diode.
- Hence, the o/p is a rectified half wave signal with a peak of 0.4V (0.1V is lost across the diode).

Application:- Backward diodes are used to rectify weak signals whose peak amplitudes are between 0.1 to 0.7V.

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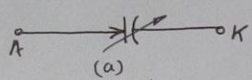
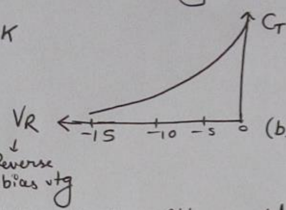
* Varactor diode / Varicap / tuning diode / voltage variable capacitor diode :- 09

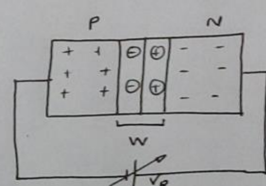


Circuit symbol of varactor diode



Characteristics of varactor diode.

- Varactor is a junction diode with small impurity dose at its junction.
- It has the useful property that its <u>junction</u> or <u>transition</u> capacitance is easily varied electronically.
- A diode when R.B, a depletion region is formed. As $V_R \uparrow$, width(W) of depletion layer ↑ses.



(c) Depletion region in a R.B PN junction

- This depletion region is devoid of majority carriers and acts like an insulator preventing conduction betn N & P regions of the diode, just like a die-lectric, which separates the two plates of a capacitor.
- As the capacitance is inversely ∝nal to the distance betn the plates, in case of varactor $\boxed{C_T \propto \frac{1}{W}}$ ie the transition capacitance C_T varies inversely with the reverse voltage as shown in (b).
- Consequently, an ↑se in R.B vtg → will result in → ↑se in W → ie ↓se in C_T.
- At around 0 vtgs, W is small & C_T is large, when R.B vtg is applied across the varactor, C_T ↓se as shown in (b).

<u>Applications:</u> Varactor diodes are used in FM radio and TV receivers, AFC circuits, self adjusting bridge ckts and adjustable-band-pass filters.

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