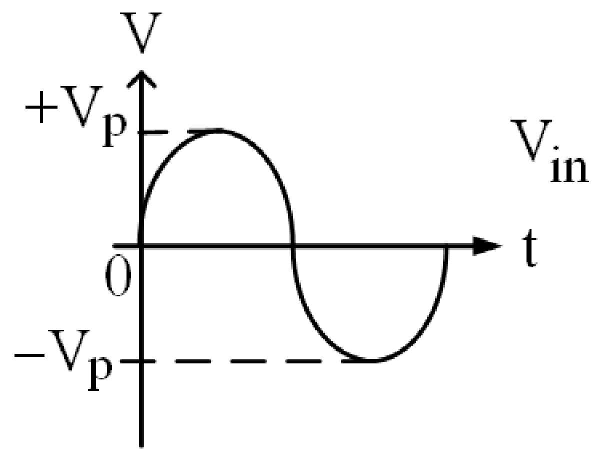
CLASS 12

Clamping diode circuits, zener diode, zener regulator and zener limiter

Steps in analyzing clamping diode circuits:

- **Start the analysis by considering the cycle of the input signal that will fb the diode.**
- **The total output signal swing is equivalent to the total input signal swing.**

Example: the total swing of the shown V_{in} is $V_p-(-V_p)=2\ V_p$



Assumptions during analysis:

- **When the diode is fb, the capacitor will be immediately charged**
- **When the diode is o/c, the capacitor will hold all its charges and thus, its voltage too.**

Positive clamper

With potential barrier considered:

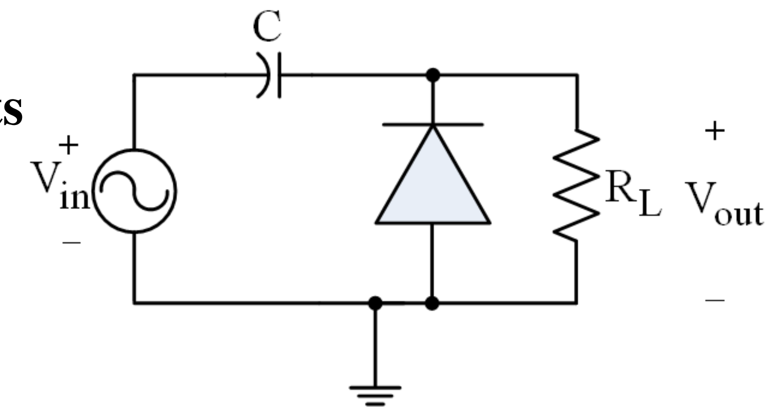
1. **The diode will be fb when V_{in} is at its –ve half cycle. $V_{out} = -V_o$.**
2. **C will be charged and will immediately reach its peak value.**

$$V_p - V_C + V_{p(out)} = 0$$

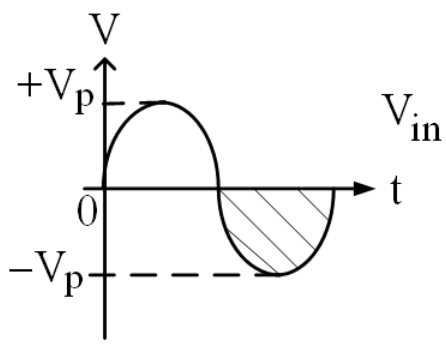
$$V_p + V_{p(out)} = V_C$$

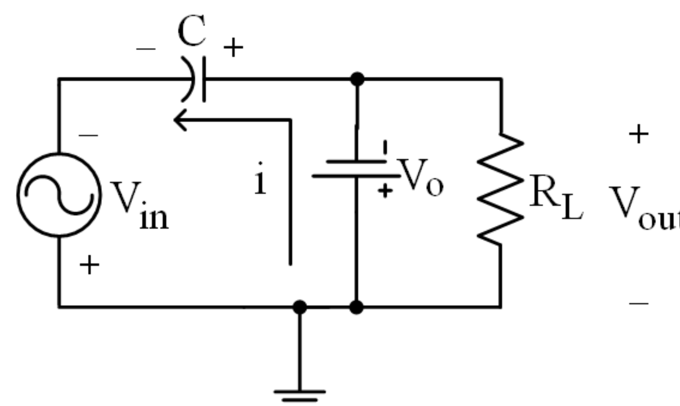
$$V_{p(out)} = -V_o$$

$$V_C = V_p - V_o$$



+ve clamper





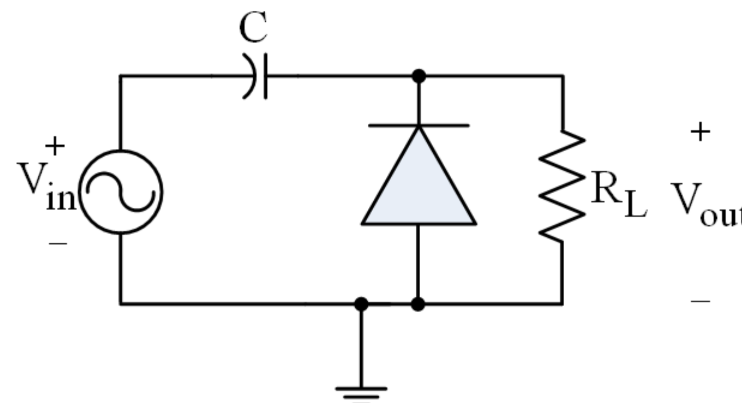
During the +ve half cycle, the diode will be rb. C will hold onto its charges and its voltage too.

$$V_C = V_p - V_o$$

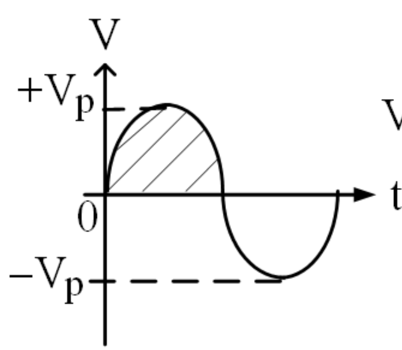
$$-V_p - V_C + V_{p(out)} = 0$$

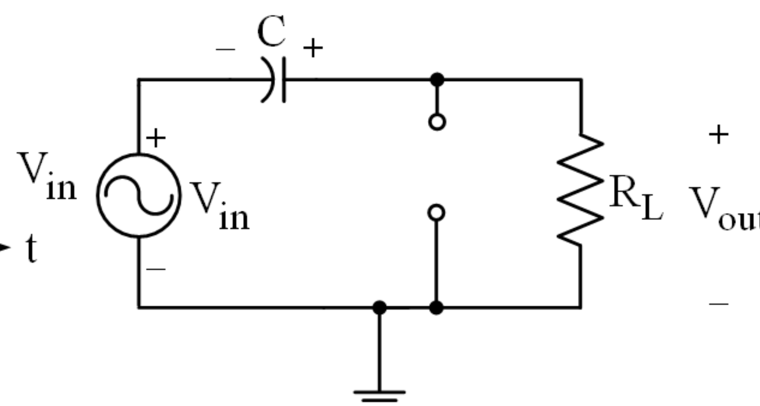
$$-V_p - (V_p - V_o) + V_{p(out)} = 0$$

$$V_{p(out)} = 2V_p - V_o$$



+ve clamper





During the -ve half cycle,

$V_{p(out)} = -V_o$

During the +ve half cycle,

$V_{p(out)} = 2V_p – V_o$

Total swing of the V_{in} is $2V_p$.

Total swing of the V_{out} is :

$2V_p – V_o – (– V_o) = 2V_p$.

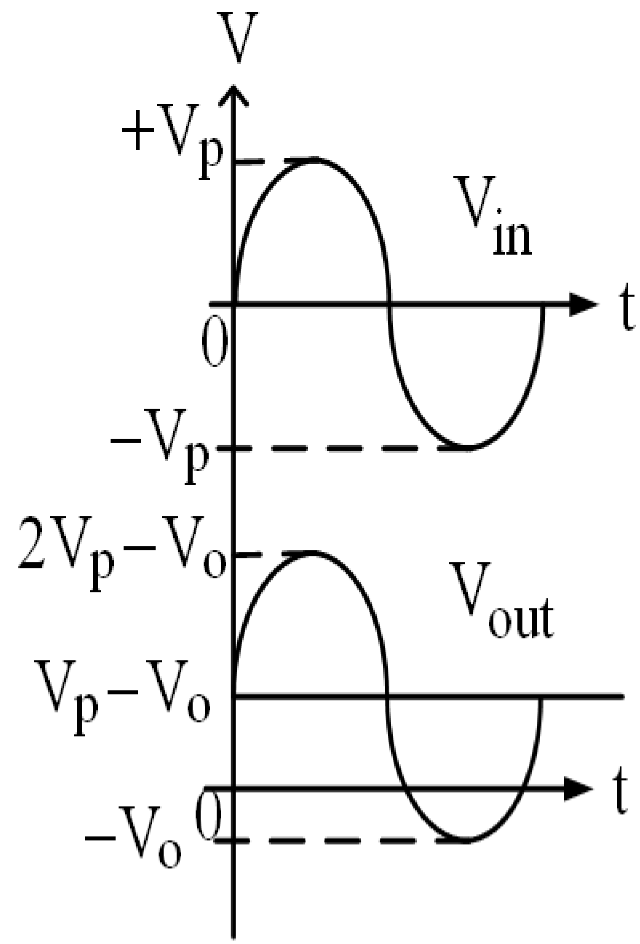
Hence,

Total o/p swing = Total i/p swing.

Half swing = V_p

The dc voltage clamped into the ac signal is $2V_p – V_o – V_p = V_p – V_o$

Now try analyzing the –ve clamper.

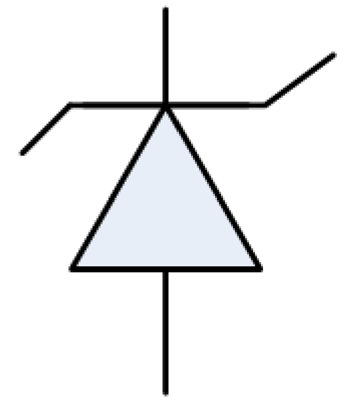


ZENER DIODE

<u>Main application:</u>

Voltage regulation in DC power supply.

<u>Symbol:</u>

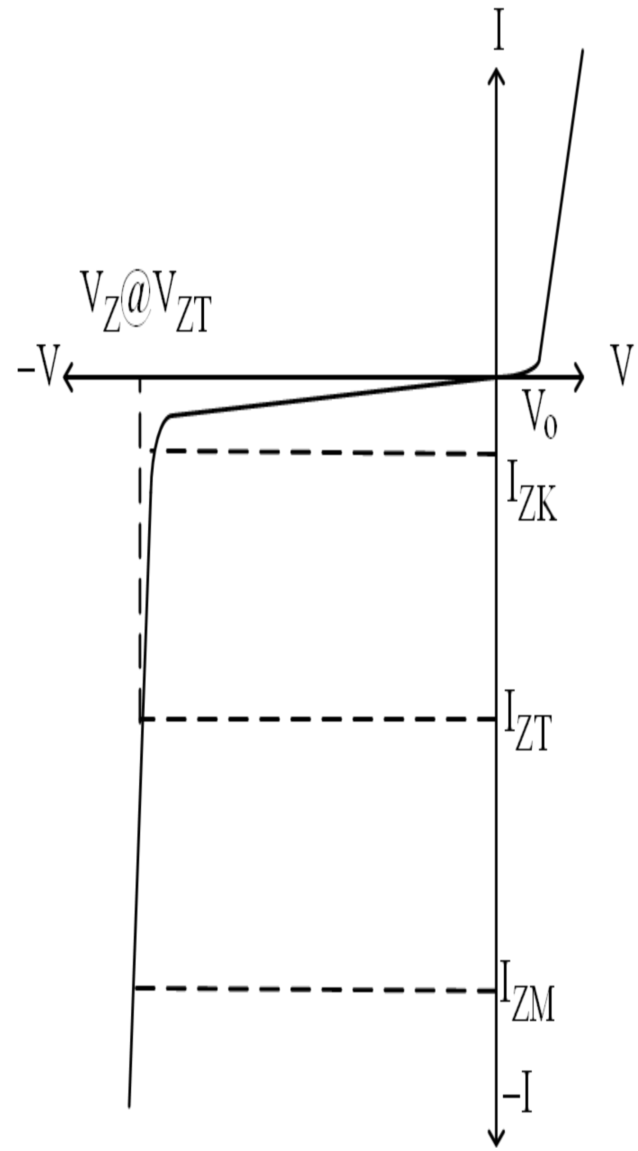


The difference between the zener and the typical rectifying diode is that the former is designed to be used in its reverse breakdown region.

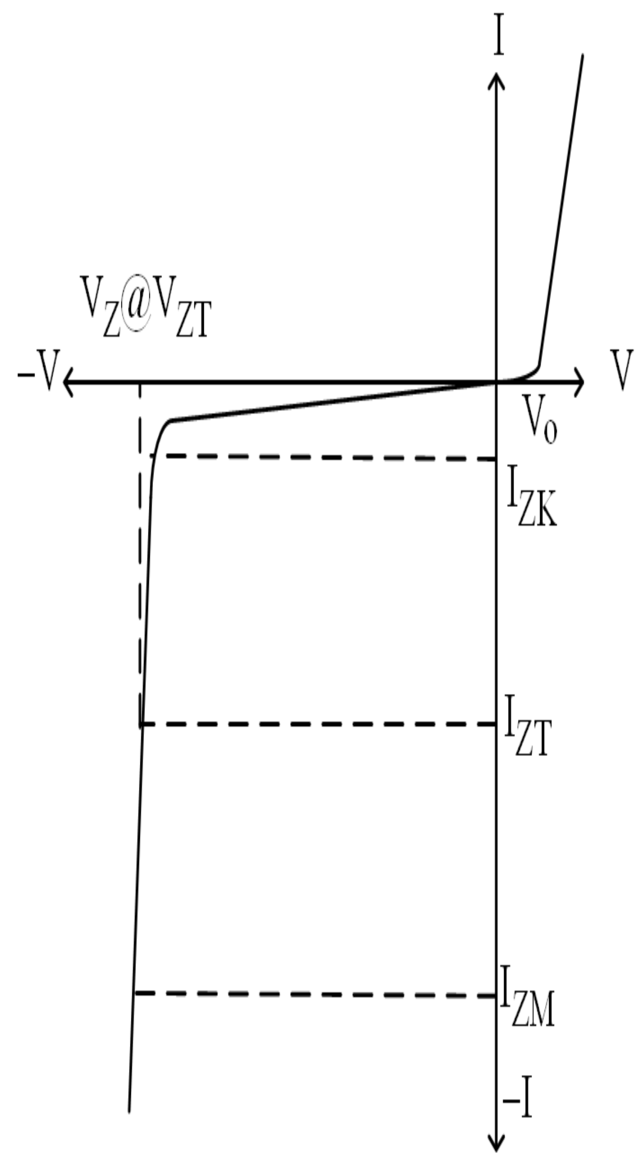
The breakdown voltage of a zener diode is set by controlling the doping level during fabrication.

The zener diode maintains a constant voltage across its terminals during a certain range of reverse current.

- **The diagram shows the reverse characteristic of a zener diode. V_Z is typically determined at the zener test current I_{ZT} and is written as V_{ZT}.**
- **$I < I_{ZK}$, internal resistance of the zener diode is huge. Although V is increased, I is still very small.**
- **I_{ZK} (or knee current) is the minimum current to maintain the diode in its regulating condition. If $I < I_{ZK}$, the voltage across the diode $\neq V_Z$.**
- **I_{ZT} is the test current conducted by the diode's manufacturer. Typically, the manufacturer will provide the value of V_{ZT} at an I_{ZT} in the data sheet.**
- **I_{ZM} is the maximum current that can flow through the diode. $I > I_{ZM}$ diode will be destroyed.**



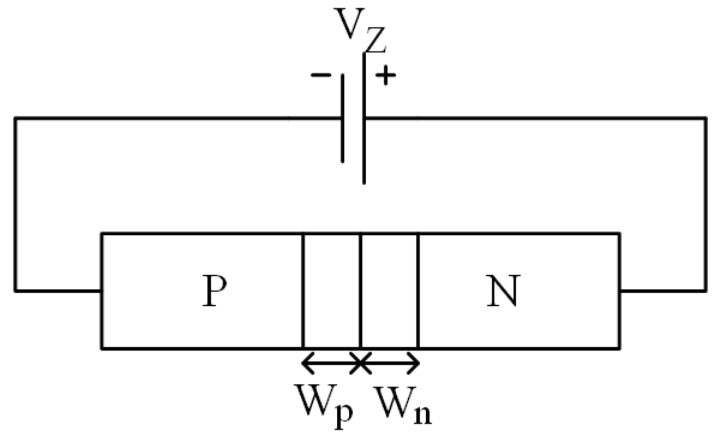
Voltage at $I_{ZK} \leq I \leq I_{ZM}$ is basically constant although in reality the voltage does increase a little bit with the increment of I. In this region, the internal resistance of the zener diode, R_Z, is very small. The reverse current increase tremendously with a very small increase in reverse voltage.



<u>There are two types of reverse breakdown:</u>

1. **Avalanche – just like in the rectifying diodes when they are driven by a high enough reverse voltage.**
2. **Zener – occurs in a zener diode at a small reverse voltage.**

ZENER BREAKDOWN



Doping density is very high (>10^{24}/m^3 or 1 in every 10^5). Width of depletion region in p, $W_p \propto 1/N_a$ and width of depletion region in n,

$W_n \propto 1/N_d$. Hence, if N_a↑ W_p ↓ and if N_d↑ W_n ↓ . Generally, if the doping density ↑, the depletion region becomes very narrow.

$W_p + W_n = dz$

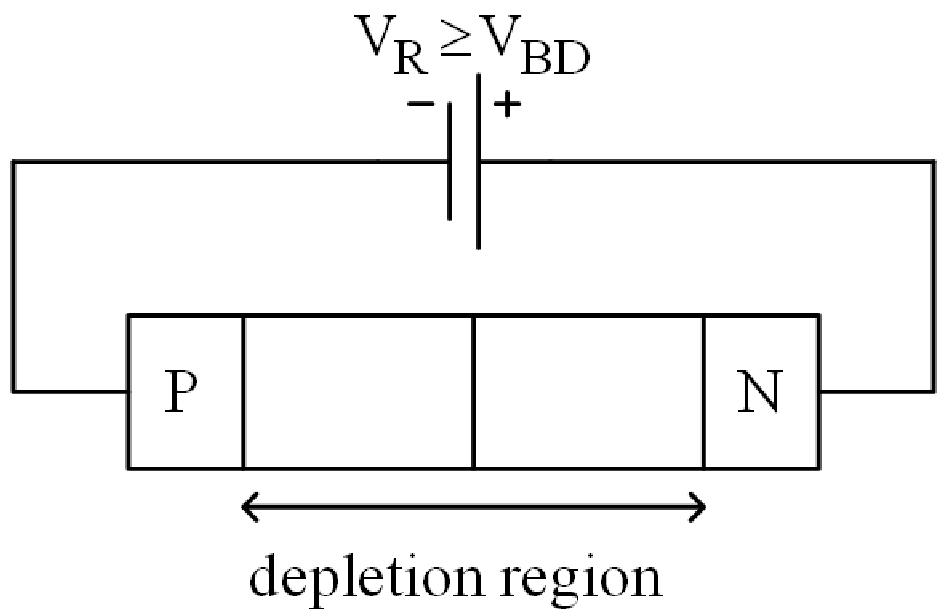
$E_Z = V_Z / dz$

If dz ↓, E_Z ↑ . Thus, the electric field across a junction is so high (~10^6 V/cm) even if the reverse voltage is low.

This very high electric field intensity will break the covalent bonds and enables valence electrons to enter conduction band becoming free electrons. Therefore, the number of current carriers ↑ ↑ ↑.

AVALANCHE BREAKDOWN

If $V_R \geq V_{BD}$, electrons will vibrate very strongly and move very fast. Avalanche of current will occur as the electrons will dissipate energy to the atoms during collisions. Sufficient distance in the depletion region is required to generate secondary, tertiary and subsequent current carriers to produce avalanche current.



- **For the Si zener diode, the breakdown voltage below 4.5 V is contributed mostly by the zener breakdown.**
- **V_Z > 6.7 V, avalanche breakdown is the main contributor to the breakdown.**
- **4.5 V < V_Z < 6.7 V, both breakdowns contribute.**

V_Z can be found from 1.8 V to 200 V.

TEMPERATURE COEFFICIENT

Determines the % of change in the V_Z for every change in temperature.

<u>Example:</u> Zener diode with V_Z = 12 V. The temp. coeff. is 0.1%/°C. This means that when the temp. increases by 1°C, V_Z will increase by 0.012 V.

$\Delta V_Z = V_Z \times TC \times \Delta T$ where TC = temp. coeff.

TC +ve means $V_Z \propto T \rightarrow$ breakdown is caused by avalanche breakdown.

TC -ve means $V_Z \propto 1/T \rightarrow$ breakdown is caused by zener breakdown.

If both breakdowns occur in the zener diode, TC≈0.

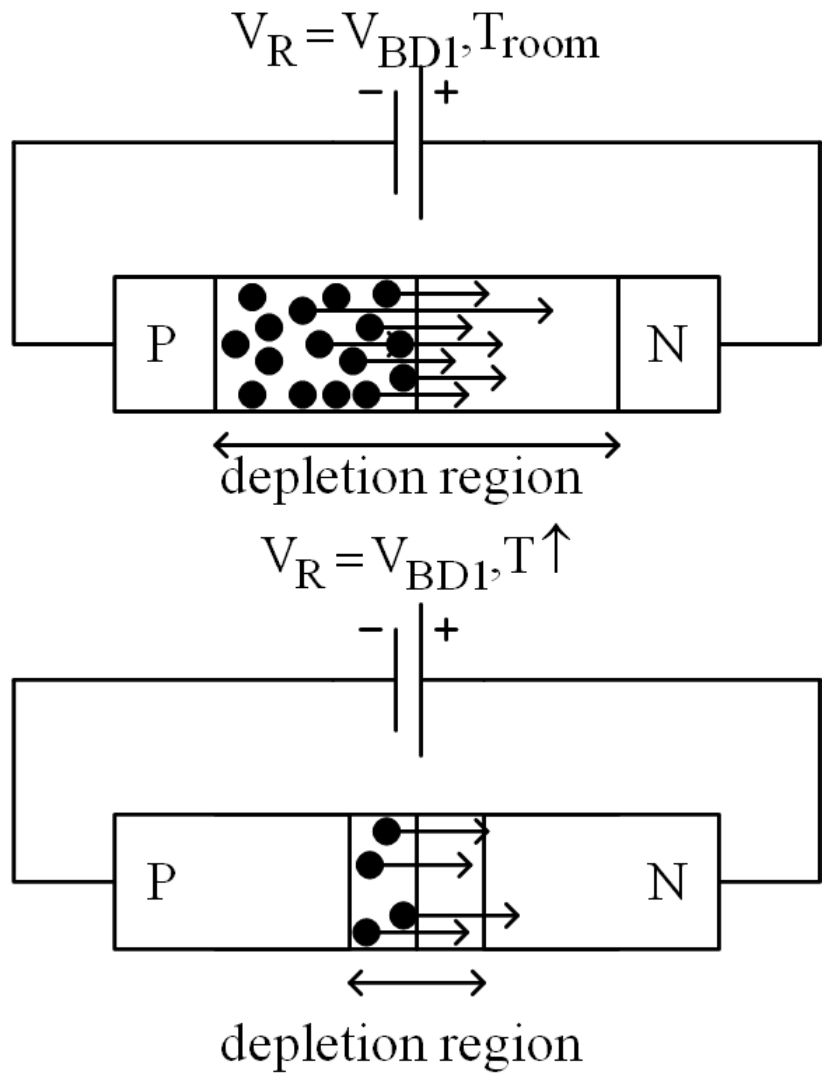
$V_Z \propto 1/T$ if breakdown is caused by zener breakdown.

Doping density ↑ ↑ ↑, depletion region ↓ ↓ ↓ E↑ ↑ ↑. Covalent bonds broken. Valence electrons are able to enter the conduction band and become free. Current carriers ↑ ↑ ↑.

If T↑, the valence electrons energy ↑. Easier for the valence electrons to become free. Hence, voltage required to cause an avalanche of current will become less. Thus, T↑ V_Z ↓.

$V_{BD} \propto T$ if the breakdown is contributed by the avalanche mechanism. At $T = T_{room}$ and $V_R = V_{BD1}$, avalanche of current occurs.

If T↑, width of depletion region ↓. Not enough distance in the depletion region for secondary, tertiary and sebsequent carriers to be generated. Larger reverse voltage is required to provide more energy in order to produce more secondary and tertiary carriers through the breaking of covalent bonds.



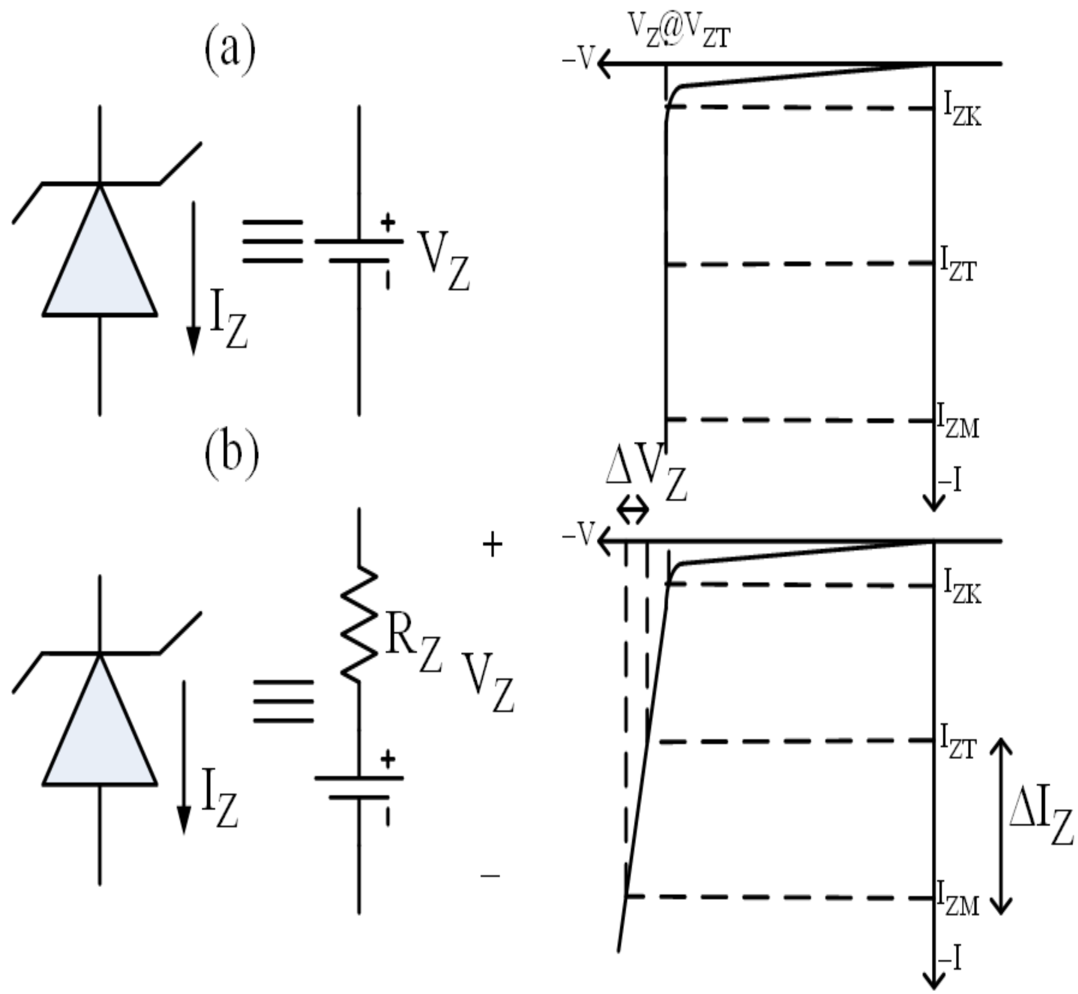
(a) is the ideal equivalent cct of the zener diode.

(b) is the practical equivalent cct of the zener diode.

$V_Z = V_{ZT} \pm \Delta V_Z$

$I_Z = I_{ZT} \pm \Delta I_Z$

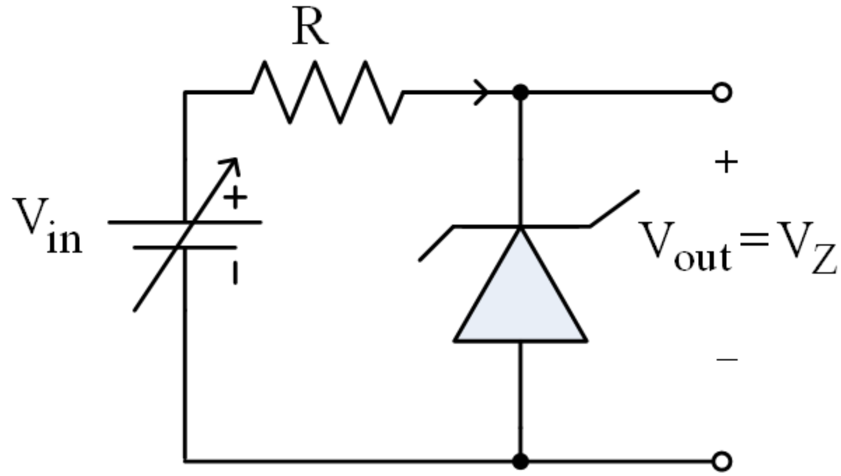
$R_Z = \Delta V_Z / \Delta I_Z$



ZENER DIODE APPLICATION

1. **Output voltage regulation with variable input voltage.**
2. **Output voltage regulation with variable load**
3. **Zener limiter –to limit the AC voltage swing to desired levels**

Output voltage regulation with variable input voltage



I_{ZK} = 4 mA

I_{ZM} = 40 mA

R = 1 kΩ

V_Z = 10 V

Determine the permissible range of V_{in} to fulfill the specifications.

$-V_{in} + I_Z R + V_Z = 0$

$V_{in} = I_Z R + V_Z$

If $I_Z = I_{ZK}$ = 4 mA, V_{in} = (4 m)(1 k) + 10 = 14 V

If $I_Z = I_{ZM}$ = 40 mA , V_{in} = (40 m)(1 k) + 10 = 50 V

The permissible range of V_{in} is 14 V ≤ V_{in} ≤ 50 V.

Output voltage regulation with variable load

Determine the allowed range of R_L.

I_T is fixed since V_{in} and V_{out} are fixed as $V_{out} = V_Z$ and R is also fixed.

$I_T = I_L + I_Z$

If I_L increases, I_Z decreases.

$I_T = (V_{in} - V_Z)/R$

If $I_L = I_{L(min)}$, $I_Z = I_{Z(max)}$

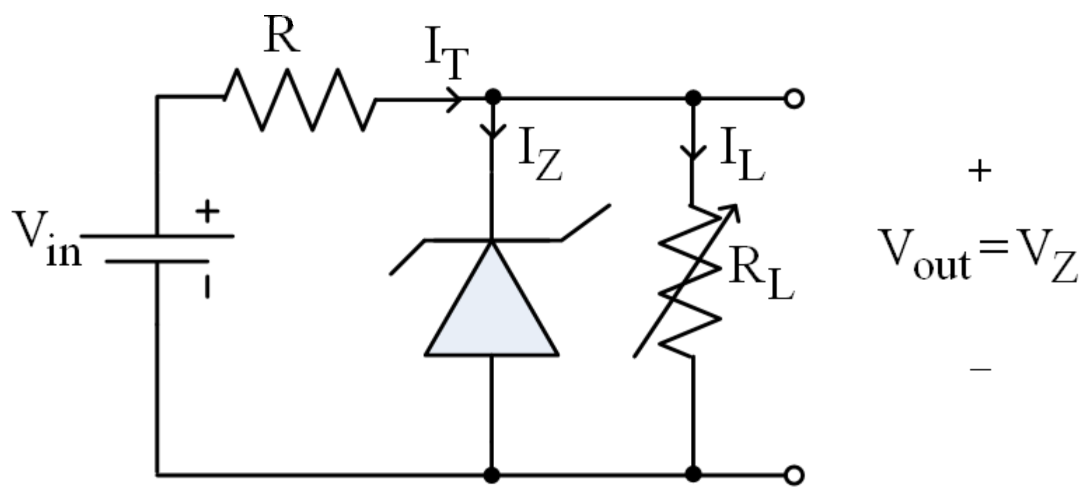
If $I_L = I_{L(max)}$, $I_Z = I_{Z(min)}$

$R_{L(min)} = V_Z / I_{L(max)}$

$R_{L(max)} = V_Z / I_{L(min)}$

Range of allowed R_L is:

$R_{L(min)} \leq R_L \leq R_{L(max)}$.



Determine the allowed range of R_L if

I_{ZK} = 3 mA, I_{ZM} = 90 mA, R = 470 Ω,

V_Z = 12 V and V_{in} = 24 V.

$I_T = (V_{in} - V_Z)/R = (24 - 12)/470 = 25.5$ mA

$I_T = I_L + I_Z$

If $I_Z = I_{Z(max)}$ = 90 mA, this value is larger than I_T , which is an impossible condition. Hence, $I_Z \neq 90$ mA. To determine the practical $I_{Z(max)}$, $I_{L(min)}$ has to be determined. The minimum that I_L can be is 0 A.

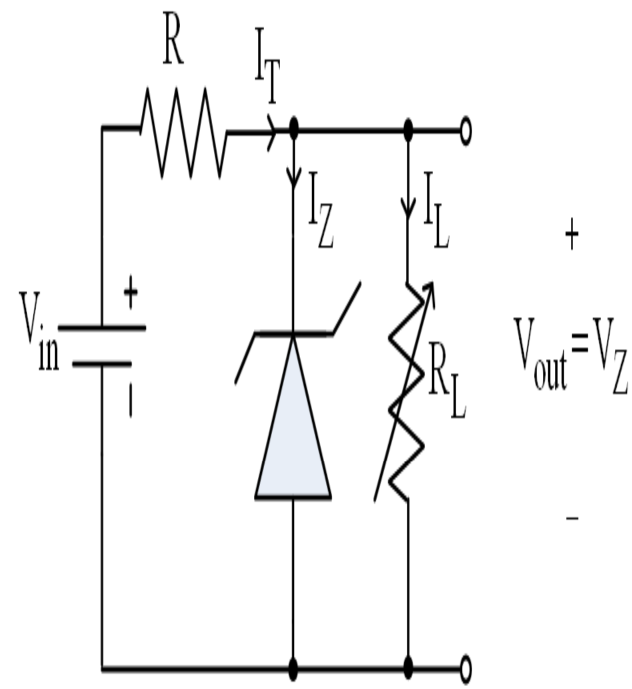
When $I_{L(min)}$ = 0 A, $I_T = I_{Z(max)}$ = 25.5 mA. Since $R_{L(max)} = V_Z / I_{L(min)}$, $R_{L(max)}$ is an o/c.

$I_{Z(min)}$ = 3 mA, thus $I_{L(max)}$ = 25.5 m – 3 m = 22.5 mA

$R_{L(min)} = V_Z / I_{L(max)} = 12 / 22.5\text{ m} = 533\ \Omega$.

Therefore, the range of allowed R_L is:

$533\ \Omega \leq R_L \leq \infty$.



<u>Conclusion on voltage regulation by the zener diode:</u>

- **V_{in} and R_L are chosen so that the zener diode will operate in the breakdown region. This is the operation of the zener diode as a constant voltage device.**

- **The breakdown region is used in this operation as the large change in the current that flows through the diode will only result in a very small change in the zener voltage. Thus, the diode will regulate the load voltage at one fix value although there is a large variation in the load current (i.e. variation in load resistance) or the supply voltage.**

The zener limiter

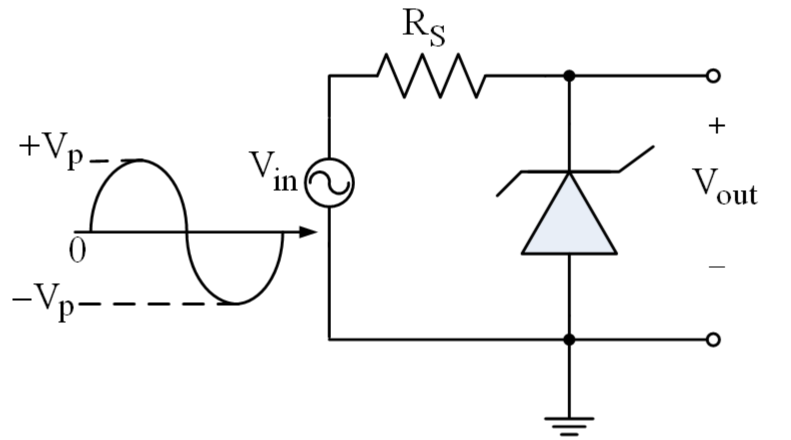
During the +ve half cycle, I is flowing from the cathode to the anode. The zener diode is rb.

(a) If I < I_{ZK} , I ≈ 0 A. The zener diode is represented by an o/c. Hence,

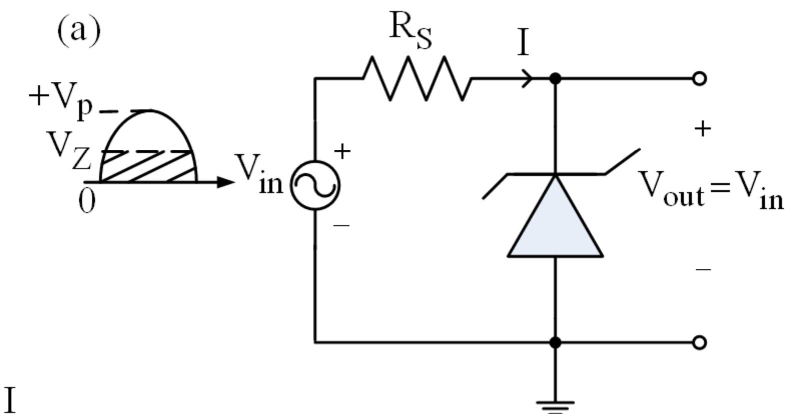
$V_{out} = V_{in}$.

(b) If I > I_{ZK} , the zener diode will regulate at V_Z. Hence,

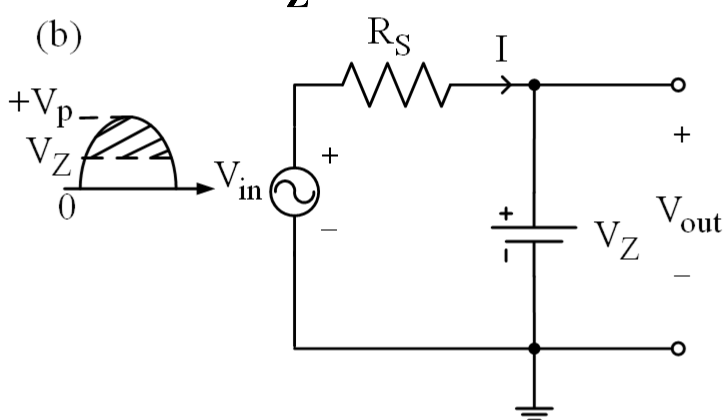
$V_{out} = V_Z$



(a)



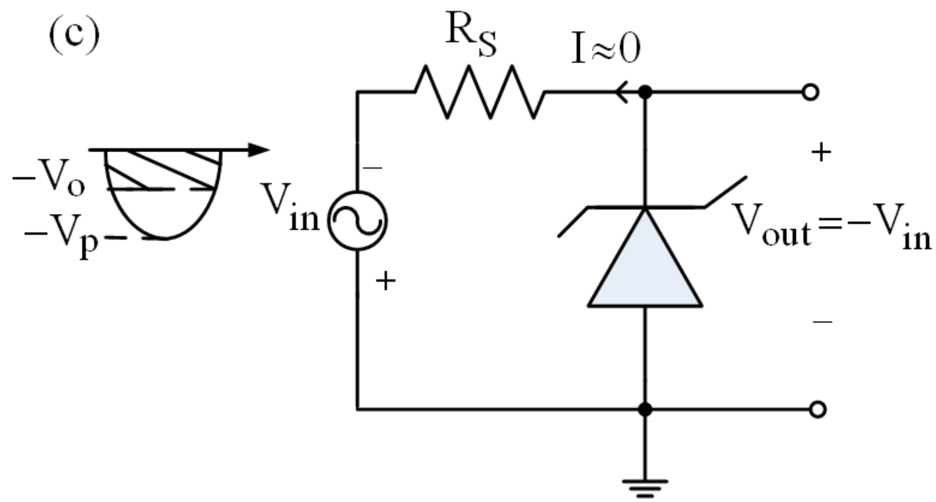
(b)

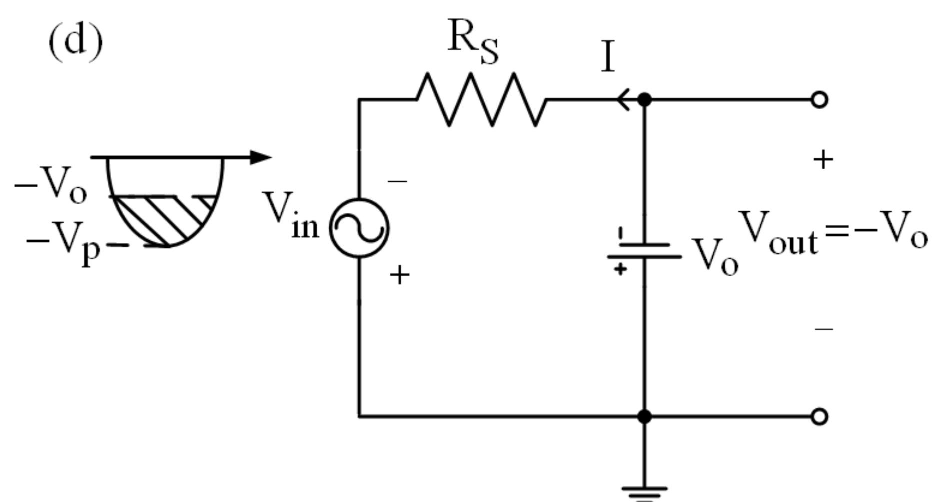


(c) During the –ve half cycle, diode is fb if V_{in} is more –ve than the $-V_o$. If V_{in} is more +ve than the $-V_o$, the diode is still OFF and $I \approx 0$ A. Hence,

$V_{out} = V_{in}$.

(d) If $_{in}$ is more –ve than the $-V_o$, diode is fb and the voltage across the diode is $-V_o$. Hence, $V_{out} = -V_o$.





Overall performance: