## PES UNIVERSITY
# Dept. of Electronics and Communication Engineering

### UE25EC141A - Electronic Principles and Devices (4-0-0-4-4)
### Session 2025-26

## UNIT-1 Semiconductor Diode

## CONTENTS

**Introduction to Semiconductors:**

Semiconductors are having property of conduction between insulators and conductors; at absolute zero temperature, semiconductors exhibit the property of insulators but at high temperature semiconductors behaves as controlled conductors.

There are two types of semiconductors visually, Intrinsic semiconductors & Extrinsic Semiconductors. Let us now follow each types of semiconductor study as below.

### i) Intrinsic Semiconductor:

A semiconductor in an extremely pure form is known as an intrinsic semiconductor. In an intrinsic semiconductor, even at room temperature, hole-electron pairs are created.

When the electric field is applied across an intrinsic semiconductor the current conduction takes place by free electrons and holes as shown in fig.1.

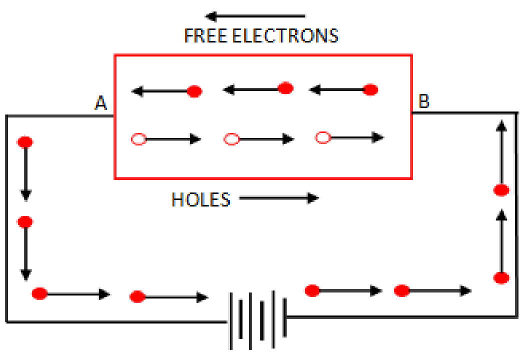



**Fig. 1**

The free electrons are produced due to the breaking up of some co-valent bonds by thermal energy. At the same time holes are created in the covalent-bonds. Under the influence of electric field, conduction takes place by both free electrons and holes. Therefore, the total current inside the semiconductor is the sum of currents due to free electrons and holes.

### ii) Extrinsic Semiconductor:

The conducting properties of an intrinsic semiconductor can be increased by adding small amount of suitable impurities to it. It is then called impure or extrinsic semiconductor.

The process of adding impurities to a semiconductor is known as doping. Generally for every $10^8$ atoms of semiconductor, one impurity atom is added. Depending upon the type of impurity added extrinsic semiconductor is classified into two types, such as:

(a) n-type semiconductor & (b) p-type semiconductor

**N-type Semiconductor**

When a small amount of penta-valent impurity is added to a pure semiconductor, it is known as n-type semiconductor.

The addition of pentavalent impurity provides a large number of free electrons in the semiconductor crystal. Typical examples of pentavalent impurities are arsenic (As), and antimony (Sb).

Such impurities which produce n-type semiconductor are known as donor impurities as they donate free electrons to the semiconductor crystal.

To explain the formation of n-type semiconductor, consider a pure germanium crystal. We know that germanium atom has four valence electrons. When a small amount of pentavalent impurity like arsenic is added to germanium crystal, a large number of free electrons become available in the crystal. The reason is explained below.

Arsenic is pentavalent i.e. its atom has five valence electrons. An arsenic atom fits in the germanium crystal in such a way that its four valence electrons form covalent bonds with four germanium atoms. The fifth valence electron of arsenic atom finds no place in co-valent bonds and thus remains free as shown in fig.2.

Therefore, for each arsenic atom added, one free electron will be available in the germanium crystal.

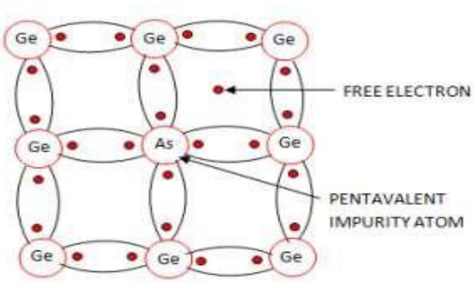



Fig. 2

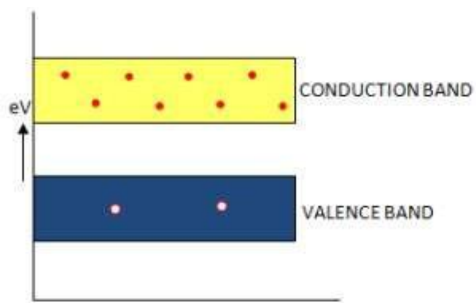



Fig. 3

Fig.3 shows the energy band description of n-type semiconductor.

The addition of pentavalent impurity has produced a number of conduction band electrons i.e. free electrons.

The four valence electrons of pentavalent atom form co-valent bonds with four neighboring germanium atoms. The fifth left over valence electron of the pentavalent atom cannot be accommodated in the valence band and travels to the conduction band.

The following points may be noted carefully:

(i) Many new free electrons are produced by the addition of pentavalent impurity.

(ii) Thermal energy of room temperature still generated a few hole-electron pairs. However, the number of free electrons provided by the pentavalent impurity far exceeds the number of holes. Hence it is called n-type semiconductor (n stands for negative).

(iii) The current conduction in an n-type semiconductor is predominantly by free electrons i.e. negative charges and is called n-type or electron type conductivity.

**P-type Semiconductor**

When a small amount of trivalent impurity is added to a pure semiconductor, it is called p-type semiconductor.

The addition of trivalent impurity provides a large number of holes in the semiconductor. Typical examples of trivalent impurities are gallium (Ga) and indium (In).

Such impurities which produce p-type semiconductor are known as acceptor impurities as the holes created can accept electrons.

To explain the formation of p-type semiconductor, consider a pure germanium crystal.

When a small amount of trivalent impurity like gallium is added to germanium crystal, there exist a large number of holes in the crystal. The reason is explained below:

Gallium is trivalent i.e. its atom as three valence electrons. Each atom of gallium fits into the germanium crystal but now only three co-valent bonds can be formed. It is because three valence electrons of gallium atom can form only three single co-valent bonds with three germanium atoms as shown in fig. 4.

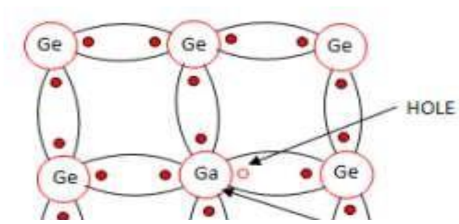



Fig. 4

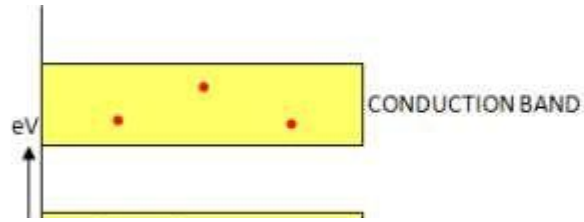



Fig. 5

In the fourth co-valent bond only germanium atom contributes one valence electron while gallium has no valence electron to contribute as its three valence electrons are already engaged in the co-valent bonds with neighboring germanium atoms.

In other word, fourth bond is incomplete; being short of one electron. This missing electron is called a hole. Therefore, for each gallium atom added, one hole is created. Fig.5 shows the energy band diagram of p-type semiconductor. The addition of trivalent impurity has produced a large number of holes. However, there are a few conduction band electrons due to thermal energy at room temperature. But the number of holes far exceeds the number of conduction band electrons.

It is due to the predominance of holes over free electrons that it is called p-type semiconductor (p stands for positive). The current conduction in p-type semiconductor is predominantly by holes i.e. Positive charges and is called p-type or hole-type conductivity.

When a p-type semiconductor is suitably joined to an n-type semiconductor, the contact surface is called pn junction. Most semiconductor devices contain one or more pn junctions. The pn junction is of great importance as it is the main control element for the semiconductor devices.

**Formation of pn Junction**

In actual practice, a pn junction will not be formed if a p-type block is just brought in contact with n-type block. In fact, pn junction is fabricated by special techniques.

**Properties of pn Junction**

At the instant of pn-junction formation, the free electrons near the junction in the n region begin to diffuse across the junction into the p region where they combine with holes near the junction.

As a result n region loses free electrons and this creates a layer of positive charges (pentavalent ions) near the junction. As the electrons move across the junction, the p region loses holes as the electrons and holes combine. The result is that there is a layer of negative charges (trivalent ions) near the junction. These two layer of positive and negative charges form the depletion region or depletion layer. The term depletion is due to the fact that near the junction, the region is depleted i.e emptied of charge carriers (free electrons and holes) due to diffusion across the junction.

The depletion layer is formed very quickly and is very thin as compared to the n region and the p region. Once pn junction is formed and depletion layer is created, the diffusion of free electrons stops. In other words, the depletion layer acts as a barrier to the further movement of free electrons across the junction. The positive and negative charges set up an electric field which acts as a barrier to the free electrons in the n region. This is shown in fig. 6.

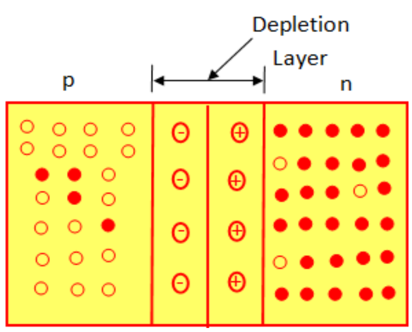



Fig. 6

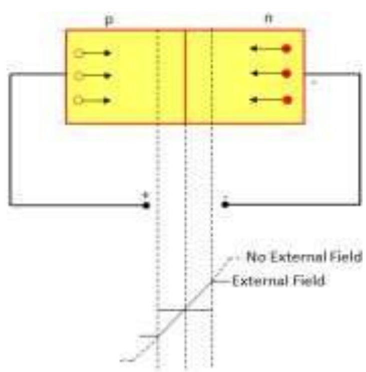



Fig. 7

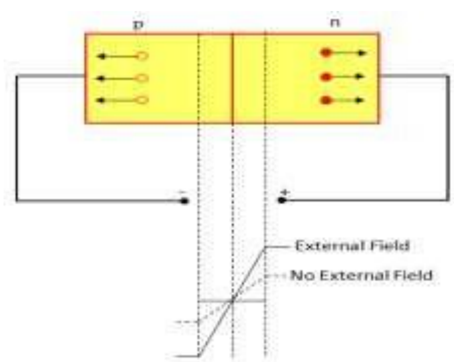



Fig. 8

There exists a potential difference across the depletion layer known as barrier potential (V0). The typical barrier potential is approximately: For silicon, V0= 0.7 V, for germanium, V0= 0.3 V.

**Biasing a pn Junction**

In electronics, the term bias refers to the use of D.C. voltage to establish certain operating conditions for an electronic device. In case of a pn junction, there are following two bias conditions: Forward biasing & Reverse biasing

## 1. Forward Biasing

When external D.C. voltage applied to the junction is in such a direction that it cancels the potential barrier, thus permitting current flow, it is called forward biasing. To apply forward bias, the positive terminal of the battery is connected to p-type and negative terminal is connected to n-type of the pn-junction as shown in fig. 7.

The applied forward potential establishes an electric field which acts against the field due to potential barrier. Therefore, the resultant field is weakened and the barrier height is reduced at the junction as shown in fig. 7.

As potential barrier voltage is very small (0.1 to 0.3 V), therefore, a small forward voltage is sufficient to completely eliminate the barrier. Once the barrier is eliminated by the forward voltage, junction resistance becomes almost zero and a low resistance path is established for the entire circuit. Therefore, current flows in the circuit. This is called forward current.

**2. Reverse Biasing**

When the external D.C. voltage applied to the junction is in such a direction that potential barrier is increased, it is called reverse biasing. To apply reverse bias, the positive terminal of the battery is connected to n-type and negative terminal to p-type of the pn junction as shown in fig. 8.

The applied reverse voltage establishes an electric field which acts in the same direction as the field due to potential barrier. Therefore, the resultant field at the junction is strengthened and the barrier height is increased as shown in fig. 8. The increased potential barrier prevents the flow of charge carriers across the junction. Thus, a high resistance path is established for the entire circuit and hence the current does not flow.

**Current Flow in a Forward Biased pn junction**

Fig .9 shows a forward biased pn junction. Under the influence of forward voltage, the free electrons in n-type move towards the junction, leaving behind positively charged atoms. However, more electrons arrive from the negative terminal of the battery and enter the n-region to take up their places. As the free electrons reach the junction, they become valence electron. As valence electron, they move through the holes in the p-region. The valence electron move towards left side in the p-region, which is equivalent to holes moving to the right side. When the

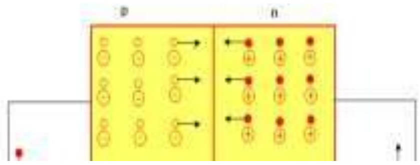
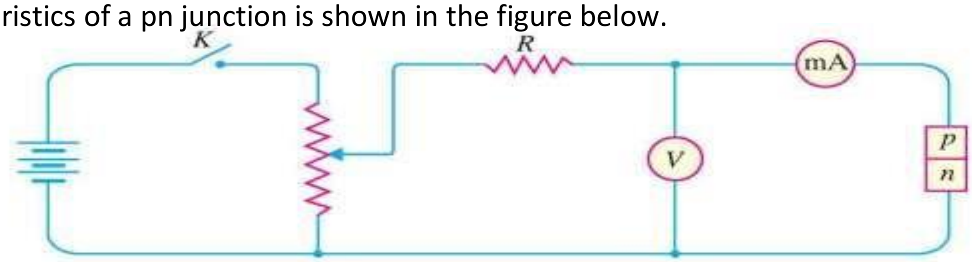


Fig 9: Forward biased PN junction

valence electron reaches the left end of the crystal, they flow into the positive terminal of the battery.

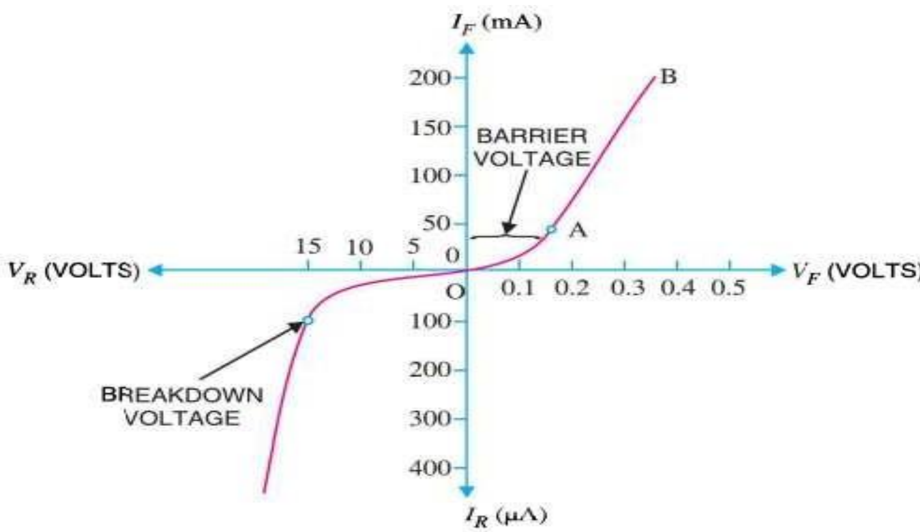
### V-I Characteristics of PN Junction Diode

Volt-ampere (V-I) characteristics of a pn junction or semiconductor diode is the curve between voltage across the junction and the current through the circuit. Normally the voltage is taken along the x-axis and current along y-axis. The circuit connection for determining the V-I characteristics of a pn junction is shown in the figure below.




**Circuit Connection for V-I characteristics of a pn junction**

The characteristics can be explained under three cases, such as: i) Zero bias ii) Forward bias & iii) Reverse bias



**V-I characteristics of a pn junction**

***Case-1: Zero Bias***

In zero bias condition, no external voltage is applied to the pn junction i.e the circuit is open at K. Hence, the potential barrier (ref: pn junction tutorial for better understanding) at the junction does not permit current flow. Therefore, the circuit current is zero at V=0 V, as indicated by point O in above graph.

**Case-2: Forward Bias**

In forward biased condition, p-type of the pn junction is connected to the positive terminal and n-type is connected to the negative terminal of the external voltage. This results in reduced potential barrier. At some forward voltage i.e 0.7 V for Si and 0.3 V for Ge, the potential barrier is almost eliminated and the current starts flowing in the circuit. Form this instant onwards the current increases with the increase in forward voltage. Hence a curve OB is obtained with forward bias as shown in figure above.

From the forward characteristics, it can be noted that at first i.e. region OA, the current increases very slowly and the curve is non-linear. It is because in this region the external voltage applied to the pn junction is used in overcoming the potential barrier. However, once the external voltage exceeds the potential barrier voltage, the potential barrier is eliminated and the pn junction behaves as an ordinary conductor. Hence, the curve AB raises very sharply with the increase in external voltage and the curve are almost linear.

***Case-3: Reverse Bias***

In reverse bias condition, the p-type of the pn junction is connected to the negative terminal and n-type is connected to the positive terminal of the external voltage. This results in increased potential barrier at the junction. Hence, the junction resistance becomes very high and as a result practically no current flows through the circuit. However, a very small current of the order of µA, flows through the circuit in practice. This is knows as reverse saturation current (IS) and it is due to the minority carriers in the junction. As we already know, there are few free electrons in p-type material and few holes in n-type material. These free electrons in p-type and holes in n-type are called minority carriers.

The reverse bias applied to the pn junction acts as forward bias to their minority carriers and hence, small current flows in the reverse direction. If the applied reverse voltage is increased continuously, the kinetic energy of the minority carriers may become high enough to knock out electrons from the semiconductor atom. At this stage breakdown of the junction may occur. This is characterized by a sudden increase of reverse current and a sudden fall of the resistance of barrier region. This may destroy the junction permanently.

**Diode Current Equation (Shockley's Equation)**

**Diode current equation** expresses the relationship between the current flowing through the diode as a function of the voltage applied across it. Mathematically it is given as

$$I = I_0 \left( e^{\frac{qV}{\eta KT}} - 1 \right) \; \ldots\ldots (1)$$

where,

$$K = 1.38 \times 10^{-23} JK^{-1}$$

I is the current flowing through the diode
$I_o$ is the reverse saturation current,
q is the charge on the electron,
V is the voltage applied across the diode,
η is the (exponential) ideality factor.
k is the Boltzmann constant & T is the absolute temperature in Kelvin

If the diode under consideration behaves exactly as that of an ideal diode, then η will be 1. Its value increases from 1 as the difference between the behaviors of the ideal diode and diode under consideration increases: greater is the deviation; greater is the value of η.

The value of η is typically considered to be 1 for germanium diodes and 2 for silicon diodes. However, its exact value for the given diode depends on various factors like electron drift, diffusion, carrier recombination which occurs within the depletion region, its doping level, manufacturing technique and the purity of its materials.
In addition, its value is also seen to vary with the value of current and voltage levels. In most of the cases, its value is found to be within the range 1 to 2.

In forward biased condition, there will a large amount of current flow through the diode. Thus

$$I = I_0 \, e^{\frac{qV}{\eta KT}}$$

the **diode current equation** (equation 1) becomes

On the other hand, if the diode is reverse biased, and then the exponential term in equation (1) becomes negligible. Thus we have

$$I = -I_0$$

the **diode current equation** takes its form when we have the diode operating at room temperature. In this case, T = 300 K, also, $K = 1.38 \times 10^{-23} JK^{-1}$ and $q = 1.6 \times 10^{-19} C$

$$\frac{q}{KT} = \frac{1.6 \times 10^{-19}}{1.38 \times 10^{-23} \times 300} = 0.003865 \times 10^{4} = 38.65\ CJ^{-1}\ or\ 38.65\ V^{-1}$$

By reciprocating, one gets, 25.87 mV which is called thermal voltage. Thus the diode equation at room temperature becomes

$$I = I_0 e^{\frac{V}{0.025 \times \eta}}$$

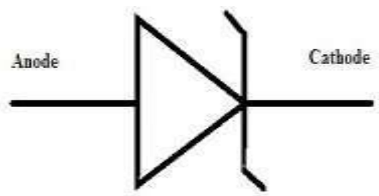
**Zener Diode:**

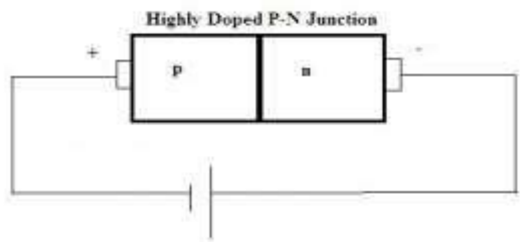
When the reverse bias voltage on a normal crystal diode is increased, a point known as Knee point is reached at a voltage known as breakdown voltage, when the reverse current increases sharply to a high value. This breakdown voltage is also known as Zener Voltage and the sharp increase in current is known as Zener current.

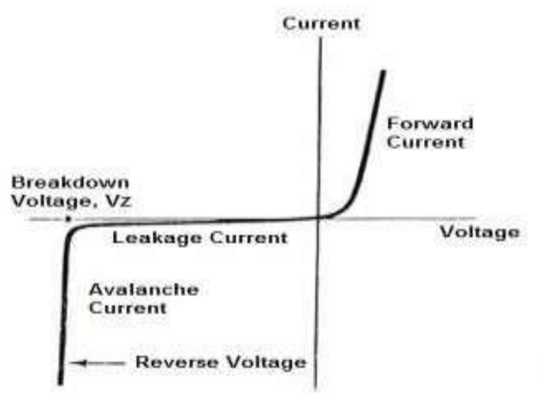
The breakdown voltage of a diode depends on the amount of doping. In a heavily doped diode, the depletion layer is thin, so the breakdown of the junction occurs at a lower reverse bias voltage. On the other hand, a lightly doped diode has a higher breakdown voltage. When an ordinary crystal diode is properly doped so as to have a sharp breakdown voltage, it is known as Zener diode. Below figure shows the symbol & Structure of a Zener diode.

**VI-Characteristics of Zener Diode:**

The graphical representation can give basic characteristics. These are normally termed as V-I characteristics.




As per the above analysis, it is evident that during forwarding bias Zener diode characteristics will remain the same as that of the normal diode. When the applied voltage crosses the value of Zener voltage (Vz) the Zener breakdown takes place. After the breakdown, the flow of the current in the circuit tends to increase immediately.

***Applications of Zener Diode:***

- As it has the property of maintaining the low voltages even though high voltages are applied. These are preferably applicable in voltage regulators.
- It is preferably used in ammeters, voltmeters, and ohmmeters because here the reference voltage is required.

***Power Dissipation of Zener Diode:***

As the points discussed till now make it very clear that Zener diode will be conducting in reverse bias. Generally, the power dissipated is the multiplication of overall current and voltage values. In Zener diode, it is determined as $\mathbf{P = V_Z \times I_R}$

Where $V_Z$ stands for Zener voltage and $I_Z$ represents the reverse current.

## Avalanche Breakdown & Zener breakdown

**Avalanche Breakdown:** As the functionality of the basic diode is already known in reverse bias condition the diode gets affected as it is non-conducting mode. But still there is the movement noticed and that is due to minority carriers. The current generated because of the minority charge is referred to as reverse saturation current and this is responsible for the occurrence of avalanche breakdown.

In the case of the reverse bias, the width of the region will be more. This can affect the working condition of the diode. But in this condition, the minority charges get sufficient kinetic velocity so that it can overcome the barrier of the junction.

Due to this, collisions in between occurs. These are responsible for the generation of free charges. As this process goes on the further generation of carriers takes place resulting in the formation of more number of free carriers. This phenomenon is referred to as carrier multiplication. Hence the flow of reverse current is noticed. This leads to the condition in the diode breakdown referred to an avalanche breakdown. This can damage the junction completely and it is non-refundable.

**Zener breakdown:** In the basic diode, a junction is formed due to the interaction of p-type and n-type. This has the depletion region at the junction. The width of this region is also the factor of the doping concentration. The doping at the junction can be done lightly or heavily. The width of the depletion and the doping levels are inversely related to each other. It means if the junction is heavily doped then the width will be minimum and vice-versa. If the considered junction is of high doping value then undergoes the phenomena of Zener breakdown.

If it has a minimum width of depletion region it suggests that it has the number of free charges present. These tend to cross the junction. Because it has the highest electric intensity of the field the rapid movement in the carriers is noticed. Hence it results in the formation of free carriers and the flow of reverse current can be seen. This eliminates the depletion region. This type of phenomena is known as Zener breakdown.

But in Zener breakdown, the depletion region will retain back once the reverse voltage has been removed.

## Temperature Effects on VI-Characteristics of Diode

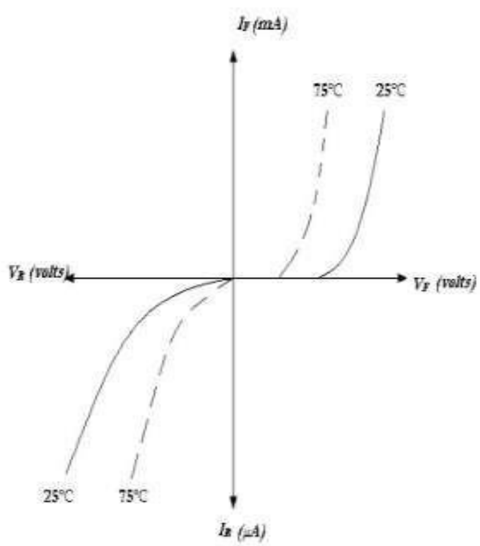
PN junction diode parameters like reverse saturation current, bias current, reverse breakdown voltage and barrier voltage are dependent on temperature. Rise in temperature generates more electron-hole pair thus conductivity increases and thus increases in current

Increase in reverse saturation current with temperature offsets the effect of rise in temperature. Reverse saturation current (IS) of diode increases with increase in the temperature the rise is 7%/ºC for both germanium and silicon and approximately doubles for every 10ºC rise in temperature.

Thus if keep the voltage constant, as increase temperature the current increases.

Barrier voltage is also dependent on temperature it decreases by 2.5mV/ºC for germanium and silicon.

Reverse breakdown voltage (VR) also increases as we increase the temperature.




## Effect of Temperature on pn junction diode

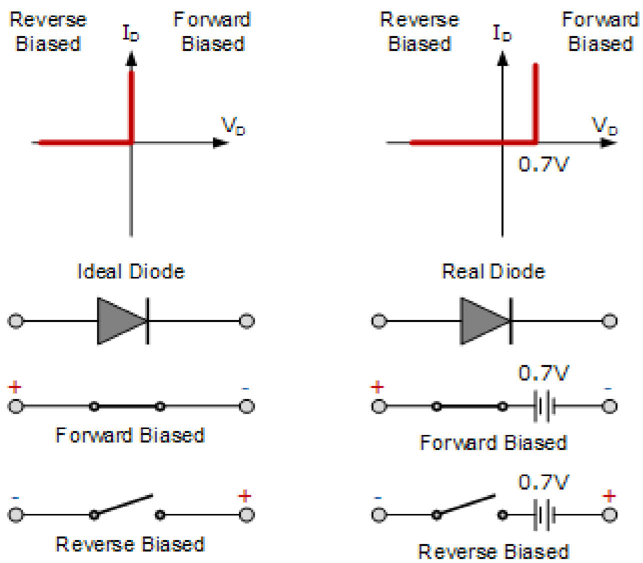
Increase of temperature results in increase in carrier concentration.

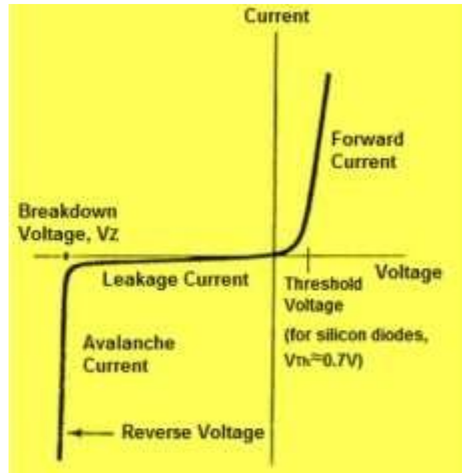
As a result , Knee voltage and reverse breakdown voltage decreases while Reverse saturation current increases

- In the forward-bias region the characteristics of a silicon diode shift to the left at a rate of 2.5 mV per centigrade degree increase in temperature
- In the reverse-bias region the reverse current of a silicon diode doubles for every 10°C rise in temperature

**Junction Diode Ideal and Real Character**

**Ideal and Practical Diode Characteristics:**




**Ideal Diode:** When an ideal diode is forward biased, it offers no resistance & acts like an open switch. Likewise the ideal under reverse bias offers infinite resistance hence, it acts like open switch.

**Practical Diode:** A diode which is said to be forward biased it starts conducting at knee voltage & under reverse bias no current due to majority charges hence a practical diode is considered to be open switch (minority charges current ignored).

**Threshold Voltage:** Ideal diodes do not have a threshold voltage. Once any forward voltage is applied across the diode, it will conduct current instantly across its junctions.

**Forward Current:** Ideal diodes include unlimited forward current when any forward voltage is applied across their terminals. This is due to the ideal condition; the inner resistance of the diode would be zero. The ideal diode would have no inside resistance at all. Since current (Ohms Law I=V/R), an unlimited amount of current would be performed and supplied to an electrical circuit with an ideal diode.

**Breakdown Voltage:** Ideal diodes do not have a breakdown voltage. This is because, the diode has unlimited resistance to reverse voltage. It will not perform any current at all when voltage is applied in reverse.

**Reverse (leakage) Current:** As an ideal diode does not contain a breakdown end, it never performs any reverse current termed leakage current. It is an ideal insulator when voltage is applied in reverse.

**Peak Inverse Voltage:** The Peak Inverse Voltage (PIV) or Maximum Reverse Voltage ($V_{R(max)}$), is the maximum allowable Reverse operating voltage that can be applied across the diode without reverse breakdown and damage occurring to the device. This rating therefore, is usually less than the “avalanche breakdown” level on the reverse bias characteristic curve. Typical values of $V_{R(max)}$), range from a few volts to thousands of volts and must be considered when replacing a diode.

The peak inverse voltage is an important parameter and is mainly used for rectifying diodes in AC rectifier circuits with reference to the amplitude of the voltage were the sinusoidal waveform changes from a positive to a negative value on each and every cycle.

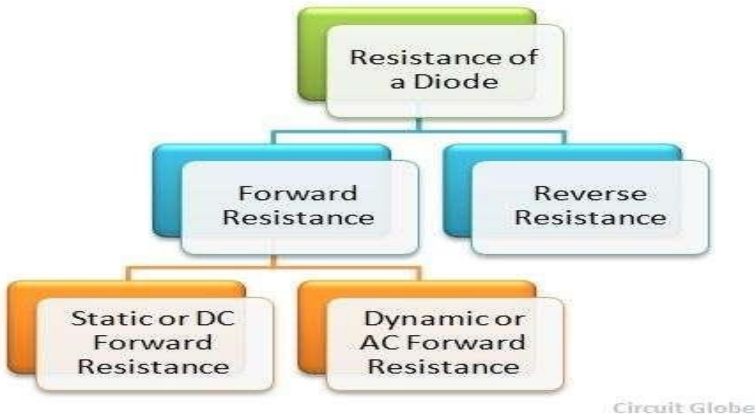
**Total Power Dissipation:** Signal diodes have a Total Power Dissipation, ($P_D$(max) ) rating. This rating is the maximum possible power dissipation of the diode when it is forward biased (conducting). When current flows through the signal diode the biasing of the PN junction is not perfect and offers some resistance to the flow of current resulting in power being dissipated (lost) in the diode in the form of heat.

As small signal diodes are non-linear devices the resistance of the PN junction is not constant, it is a dynamic property then we cannot use Ohms Law to define the power in terms of current and resistance or voltage and resistance as we can for resistors. Then to find the power that will be dissipated by the diode we must multiply the voltage drop across it times the current flowing through it: $P_D = V*I$

**Resistance of a Diode:**

In practice, no diode is an Ideal diode, this means neither it acts as a perfect conductor when forward biased nor it acts as an insulator when it is reverse biased. In other words an actual diode offers a very small resistance (not zero) when forward biased and is called a forward resistance. Whereas, it offers a very high resistance (not infinite) when reverse biased and is called as a reverse resistance.

The various resistances of a diode are as follows.

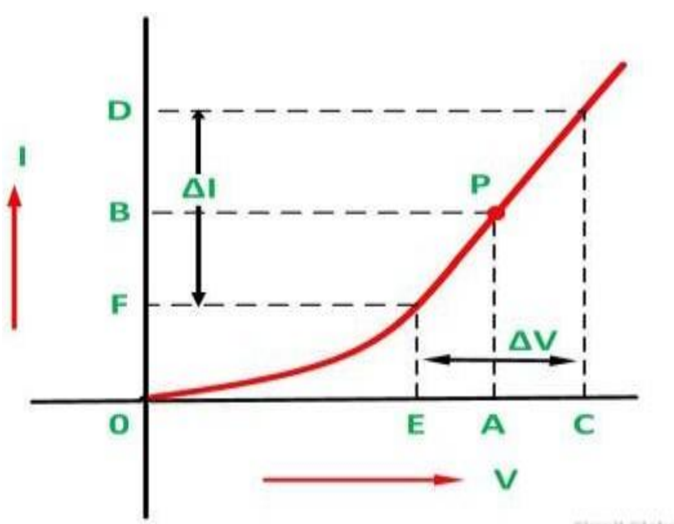



***Forward Resistance***

Under the Forward biased condition, the opposition offered by a diode to the forward current is known as Forward Resistance. The forward current flowing through a diode may be constant, i.e., direct current or changing i.e., alternating current. The forward resistance is classified as Static Forward Resistance and Dynamic Forward Resistance.

**Static or DC Forward Resistance:** The opposition offered by a diode to the direct current flowing forward bias condition is known as its DC forward resistance or Static Resistance. It is measured by taking the ratio of DC voltage across the diode to the DC current flowing through it.

The forward characteristic of a diode is shown below.



It is clear from the graph that for the operating point P, the forward voltage is OA and the corresponding forward current is OB. Therefore, the static forward resistance of the diode is given as

$$R_F = \frac{OA}{OB}$$

**Dynamic or AC Forward Resistance**

The opposition offered by a diode to the changing current flow I forward bias condition is known as its AC Forward Resistance. It is measured by a ratio of change in voltage across the diode to the resulting change in current through it. From the figure A above it is clear that for an operating point P the AC forward resistance is determined by varying the forward voltage (CE) on both the sides of the operating point equally and measuring the corresponding forward current (DF). **The Dynamic or AC Forward Resistance is represented as shown below.**

The value of the forward resistance of a diode is very small, ranging from 1 to 25 Ohms.

I $r_f = \frac{CE}{DF} = \frac{\Delta V}{\Delta I}$ **e (RR)**

Under the Reverse biasing condition, the opposition offered by the diode to the reverse current is known as Reverse Resistance. Ideally, the reverse resistance of a diode is considered to be infinite. However, in actual practice the reverse resistance is not infinite because diode conducts a small leakage current (due to minority carriers) when reverse biased.

The value of reverse resistance is very large as compared to forward resistance. The ratio of reverse to forward resistance is 100000:1 for silicon diodes, whereas it is 40000:1 for germanium diode.

**Diode Approximation/Equivalent Diagrams:**

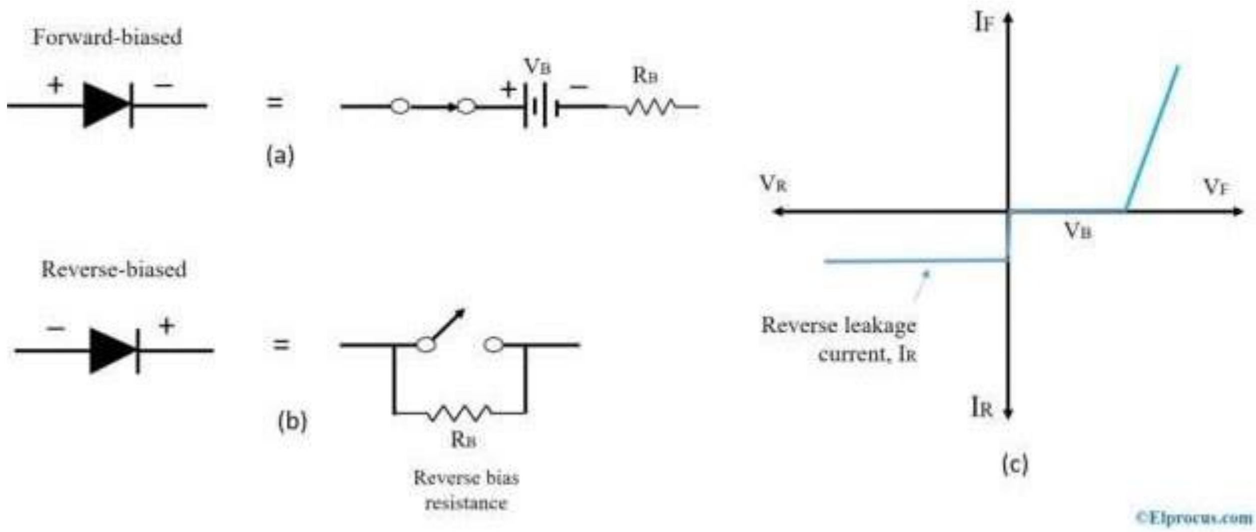
Diode approximation is a mathematical method used to approximate the nonlinear behavior of real diodes to enable calculations and circuit analysis. There are three different approximations used to analyze the diode circuits.

***i) Piecewise Linear Approximation:***

The third approximation of a diode includes voltage across the diode and voltage across bulk resistance, RB. The bulk resistance is low, such as less than 1 ohm and always less than 10 ohms. The bulk resistance, RB corresponds to the resistance of p and n materials. The resistance changes based on the amount of forward voltage and the current flowing through the diode at any given time

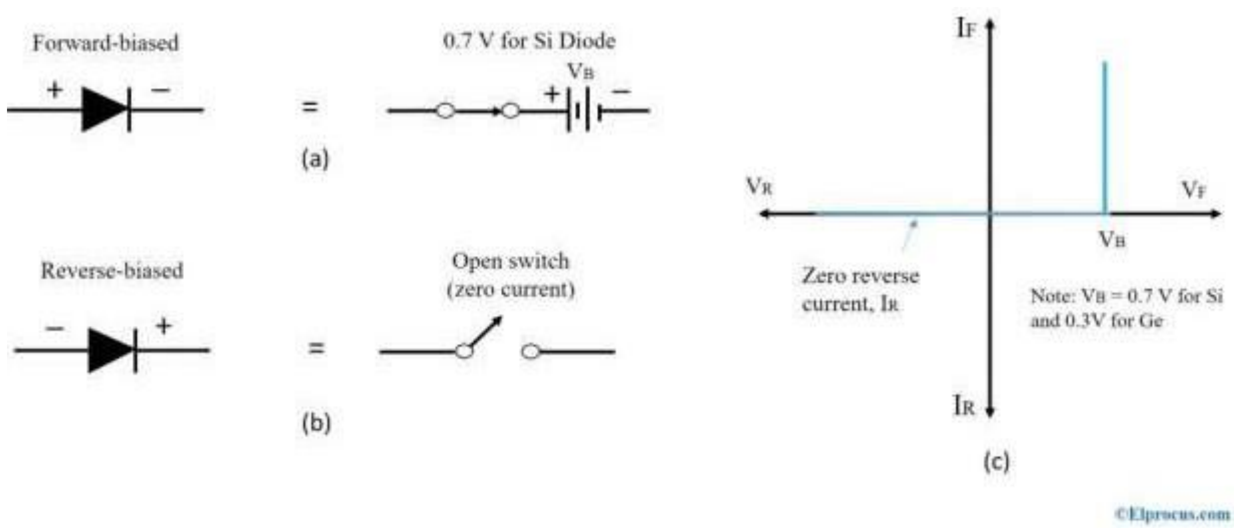
The voltage drop across the diode is calculated using the formula

$V_d = 0.7V + I_d * R_B$



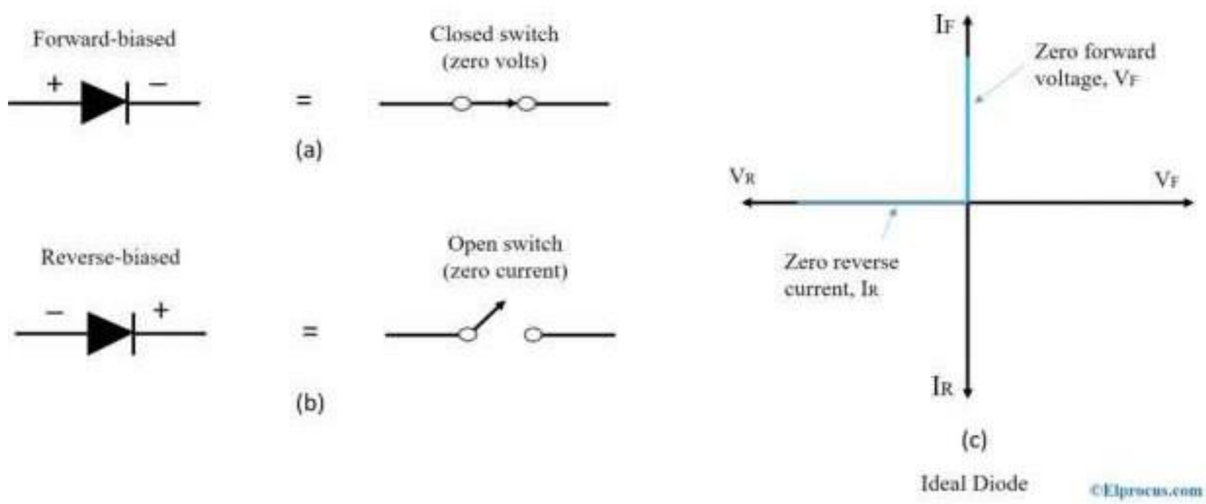

### *ii) Simplified Diode Approximation:*

In the second approximation, the diode is considered as a forward-biased diode in series with a battery to turn on the device. For a silicon diode to turn on, it needs 0.7V. A voltage of 0.7V or greater is fed to turn on the forward-biased diode. The diode turns off if the voltage is less than 0.7V.

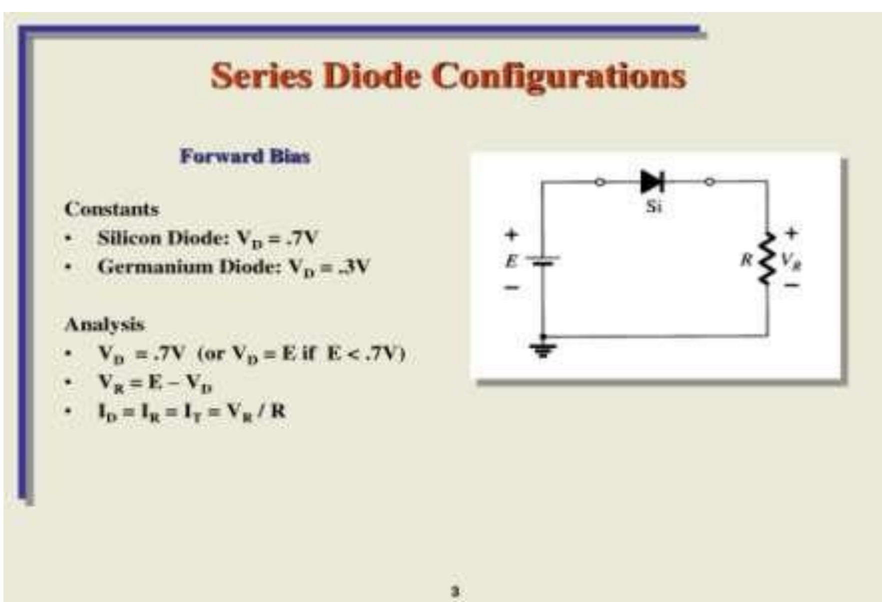


*iii) Ideal Diode Approximation:*

In the first approximation method, the diode is considered as a forward-biased diode and as a closed switch with zero voltage drops. It is not apt to use in real-life circumstances but used only for general approximations where preciseness is not required.




**Series Diode Configuration with a Resistor:**




• It's assumed that the forward resistance of the diode is usually so small compared to the other series elements of the network that it can be ignored.

• In general, a diode is in the “on” state if the current established by the applied sources is such that its direction matches that of the arrow in the diode symbol, and $V_D \geq 0.7V$ for silicon, $V_D \geq 0.3V$ for germanium.

**LOGIC GATES BY USING DIODES**

Logic gates are the basic building blocks of any digital system. It is an electronic circuit having one or more than one input and only one output. The relationship between the input and the output is based on certain logic. Based on this, logic gates are named as AND gate, OR gate and NOT gate.

**OR GATE:**

The OR gate performs logic addition, more commonly known as the OR function.

An OR gate has two or more input signals with only one output signal.

In OR gate, output voltage is *high* if any or all of the input voltages are *high*.

**OR Gate Symbol**

The symbols used for OR gates with 2, 3 and N inputs are shown in Fig 1 (a), (b) and (c) respectively.

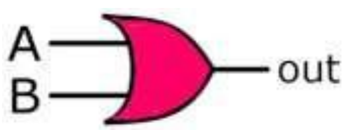



Fig 1 (a)

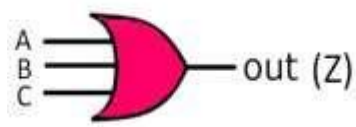



Fig 1 (b)

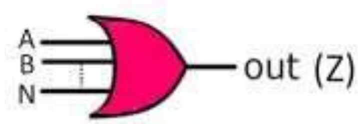



Fig 1 (c)

The inputs A, B, C…N are logic voltage levels and the output Z is a logic voltage level whose values is the result of the OR operation on A, B, C ….and N.

In other words, the OR gate operates in such a way that its output is *high* (logic 1) if and only if one or more inputs are *high*. The OR gate output will be *low* (logic 0) only if all inputs are *low* or at logic o.

Its logic equation is given as:

Z = A OR B OR C ….OR N

$Z = A + B + C + ............+N$

The above equation is known as Boolean equation or the logical equation of the OR gate.

**OR Gate Truth Table**

The logical operation of two-input and three-input OR gate is described in truth table shown in table 1 and table 2 respectively.

| A | B | Z |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 1 |

**Table 1: Truth table of 2-input OR gate**

| A | B | C | Z |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 0 | 0 | 1 | 1 |
| 0 | 1 | 0 | 1 |
| 0 | 1 | 1 | 1 |
| 1 | 0 | 0 | 1 |
| 1 | 0 | 1 | 1 |
| 1 | 1 | 0 | 1 |
| 1 | 1 | 1 | 1 |

**Table 2: Truth table of 2-input OR gate**

The truth table can be expanded for any number of inputs; but regardless of the number of inputs, the output is *high* when any one or more of the inputs are *high*.

**OR Gate can be realized using Diodes as discussed below.**

**DIODE OR GATE:**

Diodes may be used to build an OR gate, as shown in the Fig 2.

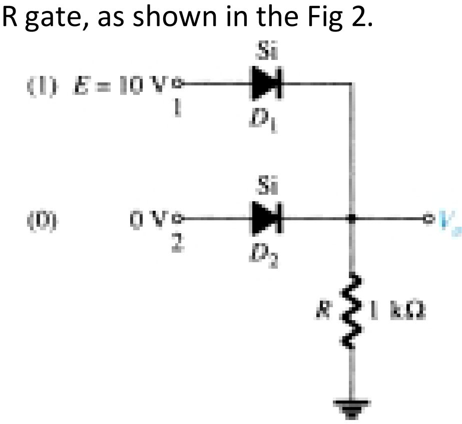



Figure 2

If input voltages at points A, B are *low* then all diode are non-conducting so output voltage, $V_{out}$ is *low*. But if any of the input terminals is at *high* voltage, then diode connected with that particular terminal is forward biased and current flows through the resistance R. The result is that $V_{out}$ is at *high* level.

**AND GATE:**

The AND gate performs logical multiplication, more commonly known as AND function. The AND gate provides high output only when all inputs are high.

The AND gate has two or more inputs and a single output, as shown in the standard logic symbols in fig 1 (a, b & c).

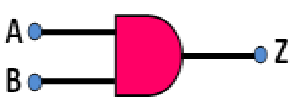



Fig 1 (a),

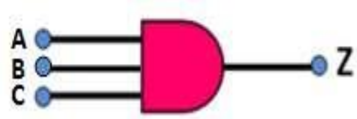



Fig 1 (b)

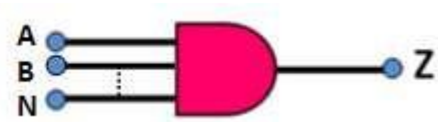



Fig 1 (c)

The input A, B, C….and N are logic voltage levels and output Z is a logic voltage level whose value is the result of the AND operation on A, B, C….and N.

The operation of the AND gate is such that the output is high or 1 if and only if all the inputs are high or 1. Mathematically it is written as:

Z = A AND B AND C …AND n = A.B.C…….n = ABC….n …. (1)

Where A, B, C…..N are input variables and Z is the output variable.

**Truth Table of AND Gate**

The logical operation of the 2-input and 3-input AND gate is described in truth table shown in table 1 and table 2 respectively.

| A | B | Z |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 0 |
| 1 | 0 | 0 |
| 1 | 1 | 1 |

| A | B | C | Z |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 0 | 0 | 1 | 0 |
| 0 | 1 | 0 | 0 |
| 0 | 1 | 1 | 0 |
| 1 | 0 | 0 | 0 |
| 1 | 0 | 1 | 0 |
| 1 | 1 | 0 | 0 |
| 1 | 1 | 1 | 1 |

**AND Gate can be realized using Diodes as discussed below.**

**DIODE AND GATE:**

The fig.2 shows one way to build a 2-input AND gate using diodes.

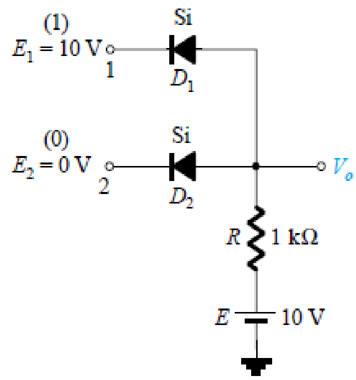



**Figure 3**

The input voltages are labeled A and B, while the output voltage Z.

When voltages of both inputs are high, both the diodes are non-conducting because the diodes are reverse-biased. Since the diodes are off, no current flows through resistor R, and the output is pulled up to the supply voltage $V_{CC}$ (+5). Thus for both inputs high, output is high. But when input voltage of either or both terminals are low, cathode(s) of the diode(s) connected to low input terminal(s) is/are grounded and the diode(s) become(s) forward-biased, resulting in flow of current through resistor R. So in such a condition, voltage of the output terminal becomes low.

## Diode Clippers

**What is a Clipper?**

A **clipper circuit** is used to **remove or "clip" a portion of an input waveform** without distorting the remaining part of the waveform.

- Clippers are also known as **limiters**.
- They operate using the **unidirectional conduction** property of diodes.
- Can be used for **wave shaping**, **amplitude limiting**, and **signal protection**.

**Types of Clippers:**

*1. **Series Clipper***

- Diode is placed **in series** with the load.
- It clips **either the positive or negative half** depending on diode orientation.

*2. **Parallel Clipper (Shunt Clipper)***

- Diode is placed **parallel to the load**.
- When forward-biased, it **short-circuits** the voltage across the load, clipping the waveform.

*3. **Biased Clippers***

- **DC bias voltage** is added in series or parallel with the diode.
- This sets a **clipping level other than 0V**.

*4. **Dual Clippers***

- Two diodes used to **clip both halves** of the waveform.

**Key Concepts:**

| Parameter | Description |
|---|---|
| **Clipping Level** | Voltage at which the waveform starts getting clipped. |
| **Ideal Diode** | Conducts fully in forward bias (0V drop), non-conducting in reverse. |
| **Practical Diode** | ~0.7 V threshold for silicon diodes considered in clipping levels. |

**Series Positive Clipper (without bias)**

- The **series configuration** is defined as one where the **diode is in series with the load.**
- Fig.1 (a) shows the circuit of a series clipper.
- The response of the series configuration of Fig. 1(a) to a variety of alternating waveforms is shown in Fig. 1(b).
- There are **no boundaries on the type of signals** that can be applied to a clipper.

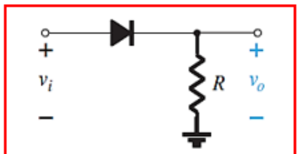



**Fig. 1(a): Series Unbiased Clipper**

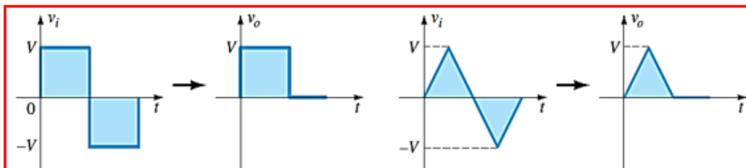



**Fig. 1(b): Input-output Waveforms**

**Series Positive Clipper (with bias)**

- Fig.2 shows the **series clipper with DC supply**. This configuration is called as **biased series clipper**.
- The **addition of a dc supply** to the network as shown in Fig. 2 can have a pronounced effect on the analysis of the series clipper configuration.
- The dc supply can be in the **leg between the supply and output** or in the **branch parallel to the output**.

- The output response is not as obvious because the **dc supply can aid or work against the source voltage.**

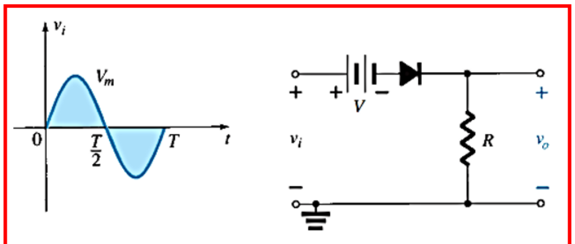



Fig. 2: Series clipper with DC supply

**General instructions for analysis:**

1. **Take careful note of where the output voltage is defined**.
   In Fig. 2 it is directly across the resistor R . In some cases it may be across a combination of series elements.
2. **Try to develop an overall sense of the response by simply noting that how the input supply affects the conventional current direction through the diode.**
   - In Fig. 2, for instance, any positive voltage of the supply will try to turn the diode "ON" by establishing a forward bias current through the diode.
   - However, the added dc supply V will oppose that applied voltage and try to keep the diode in the "OFF" state.
   - The result is that any supply voltage greater than V volts will turn the diode "ON" and conduction can be established through the load resistor. (Note here that we are dealing with an ideal diode, so the turn-on diode voltage is simply 0 V)
   - Therefore, the diode will be "ON" for any voltage $v_i$ that is greater than V volts and "OFF" for any lesser voltage.
3. **Determine the "transition voltage" that will result in a change of state for the diode from the "OFF" to the "ON" state.**
   - This step will help to define a region of the applied voltage when the diode is "ON" and when it is "OFF".
   - For an ideal diode this will occur when VD = 0 V and ID = 0 mA.
   - For the approximate equivalent (non-ideal diode) this is determined by finding the applied voltage when the diode has a drop of 0.7 V across it (for silicon) and ID 0 mA.
   - Note the substitution of the short-circuit equivalent for the ideal diode in **Fig 3**, and the fact that the voltage across the resistor is 0 V because the diode current is 0 mA. The result is $\boldsymbol{v_i - V = 0}$ **or** $\boldsymbol{v_i = V}$ is the applied (transition) voltage.
   - This permits drawing a line on the sinusoidal supply voltage as shown in **Fig. 4** to define the regions where the diode is on and off.

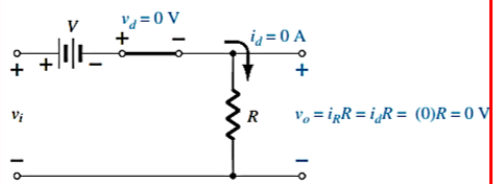



**Fig. 3: Determining applied voltage for the circuit**

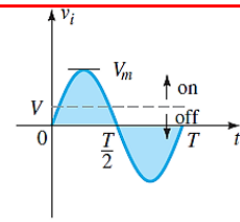



**Fig.4: Define the "ON" and "OFF" regions.**

- For the "ON" region, as shown in **Fig. 5**, the output voltage is defined by-
  - ***$v_o = v_i - V$* ………………… (1)**
- For the "OFF" region, the diode is an open circuit, ID = 0 mA, and the output voltage is
  - ***$v_o = 0$ V* …………………..(2)**

**4. It is often helpful to draw the output waveform directly below the applied voltage using the same scales for the horizontal axis and the vertical axis.**

- For the "ON" condition, **Eq. (1)** can be used to find the output voltage when the applied voltage has its peak value:
  - ***$v_{o\_peak} = V_m - V$* ………………..(3)**
  - Output voltage, ***$v_o$*** is plotted in the **Fig. 6**.

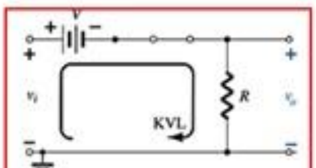



**Fig. 5: Determining $v_o$ for the diode in the "ON" state.**

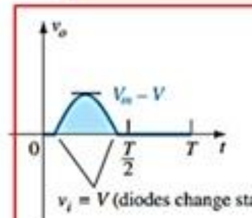



**Fig. 6: Sketching the waveform of $v_o$ above and below the transition level.**

**Parallel Clipper (without bias)**

- In parallel clippers, diode is connected in parallel with the load.
- The analysis of parallel configurations is very similar to that of series configurations.
- The simplest parallel clipper is shown in **Fig 14.**

- In forward bias, diode will be replaced by a short-circuit, thus clipping positive cycle.

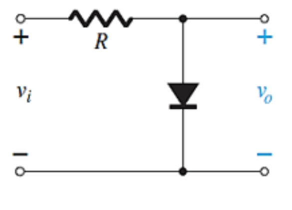


Fig. 14: Parallel Clipper

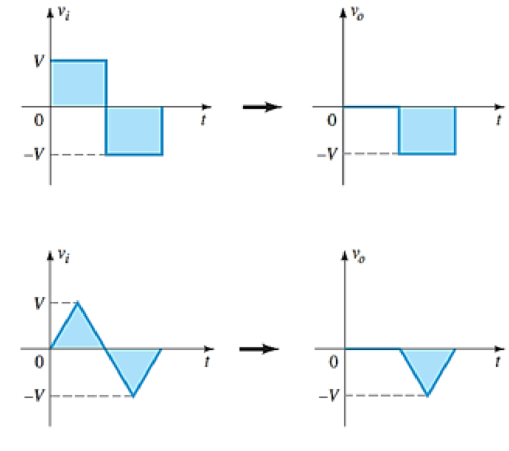


Fig. 15: Response to a parallel clipper.

**Parallel Clipper (with bias)**

**Step 1:** In this example of Fig. 16, the output is defined across the series combination of the 4-V supply and the diode, not across the resistor R.

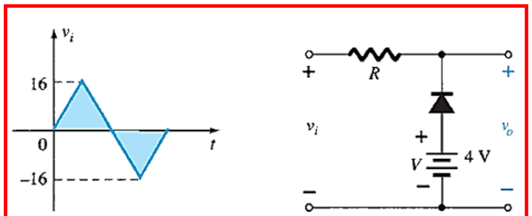


Fig. 16

**Step 2:** The polarity of the dc supply and the direction of the diode strongly suggest that the diode will be in the "ON" state for a good portion of the negative region of the input signal.

When the diode is in its short-circuit i.e. "ON" state the output voltage will be directly across the 4-V dc supply, requiring that the output be fixed at 4 V. In other words, when the diode is "ON" the output will be 4 V.

When the diode is an open circuit i.e. "OFF" state, the current through the series network will be 0 mA and the voltage drop across the resistor will be 0 V. That will result in $v_o = v_i$ .

**Step 3:** The transition level of the input voltage can be found from **Fig. 17,** by substituting the short-circuit equivalent and remembering the diode current is 0 mA at the instant of transition.
The result is a change in state when $v_i$ = 4 V

**Step 4:** In **Fig. 18** the transition level is drawn along with $v_o$ = 4 V when the diode is "ON".

Therefore, for $v_i$ >= 4 V, $v_o$ = $v_i$ …………………(1)
And, for $v_i$ <= 4 V, $v_o$ = 4 V, ………………………(2)
As shown in **Fig. 18**.

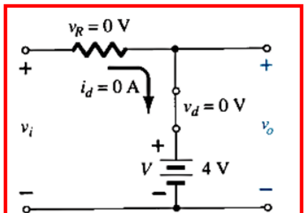


**Fig. 17: Determining the transition level**

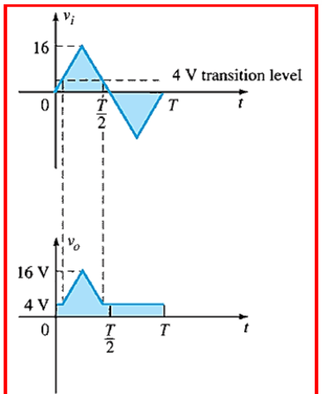


**Fig. 18: Output Sketch**

**Diode Clampers**

**What is a clamper?**

A **clamper circuit** is used to **shift the entire waveform vertically** (upward or downward) without changing its shape.

- It **adds a DC level** to an AC signal.
- The **peak-to-peak amplitude remains unchanged**, only the vertical reference is shifted.
- Clampers use a **diode, a capacitor, and a resistor**.
- Sometimes called a **DC restorer**.

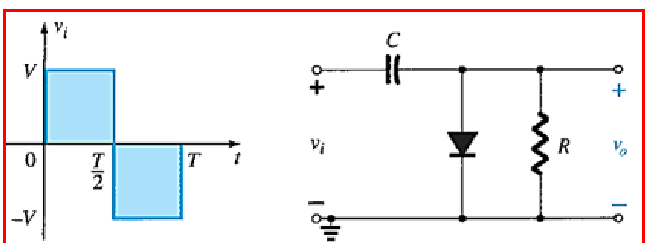


Fig.1: Clamper

*Working Principle:*

- In a clamper, the **capacitor charges during one half of the input waveform**.
- During the next half, this stored voltage is added/subtracted to the signal, effectively shifting it.

**Basic Clamper Configurations:**

| Type | Diode Orientation | Result |
|---|---|---|
| **Positive Clamper** | Anode to ground | Shifts waveform **upward** |
| **Negative Clamper** | Cathode to ground | Shifts waveform **downward** |
| **Biased Clamper** | Battery inserted in series with diode | Shifts waveform by **a controlled DC level** |

**Steps used for analysis:**

**Step 1:** Examine the response of the portion of the input signal that will forward bias the diode.

- For Fig. 2, the diode is forward biased during the positive portion of the signal.
- The short-circuit equivalent for the diode results in V*o* = 0 V for t = 0 to T/2

**Step 2:** During the on period of the diode, assume that the capacitor will charge up instantaneously to a voltage level determined by the surrounding network.

**Step 3:** Assume the capacitor retains its voltage while the diode is "off."

**Step 4:** Track the position and polarity of $v_o$ to ensure correct levels.

- When the input turns negative, the network appears as in Fig. 3, with the diode as an open circuit and voltage stored across the capacitor.

**Step 5:** Check that the total swing of the output matches that of the input. (see Fig. 4)

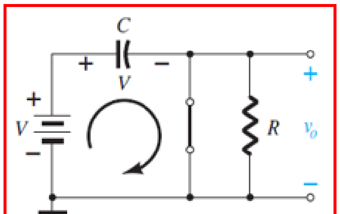



Fig.2

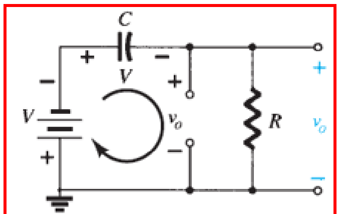



Fig.3

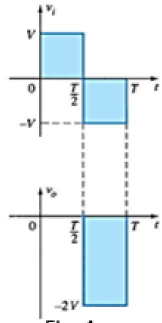



Fig. 4

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