MODULE -3 ELECTRONIC DEVICES

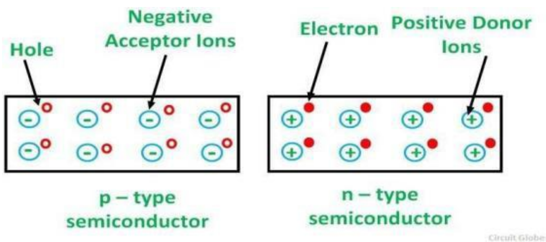
SEMICONDUCTOR

Introduction:

- Based on electrical properties, material are classified as,
  i. **Conductors (Metals):** Allows electric current to pass through it.
  ii. **Insulators:** Doesn't allow electric current to pass through it.
  iii. **Semiconductors:** Electrical conductivity is between that of conductor and insulator.
- Semiconductors are classified as,
  i. **Intrinsic:** Pure semiconductor
  ii. **Extrinsic:** Impure semiconductor, by adding impurity atoms to pure semiconductor
- The process of adding impurity atoms to a pure semiconductor is called **doping**.
- Extrinsic semiconductors are classified as,

N-type: Which are obtained by adding pentavalent impurity atoms such as Arsenic, Antimony, Phosphors, etc,. In N-type semiconductor, current conduction is due to **electrons**, hence electrons are **majority charge carriers** and holes are minority charge carriers. Since donor impurity donates an electron it becomes positive ions and is shown in below figure.

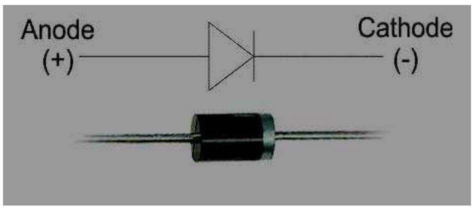
P-type: Which are obtained by adding trivalent impurity atoms such as Aluminum, Bronz etc,. In P-type semiconductor, current conduction is due to **holes**, hence holes are **majority charge carriers** and electrons are minority charge carriers. Since acceptor impurity has accepted electron it becomes negative ions and is shown in below figure.

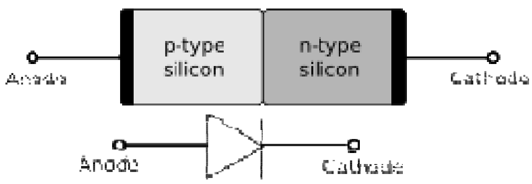


- The term diode refers to a two-electrode or two-terminal device. A semiconductor diode is simply a PN-junction with a connecting lead on each side.
- Diode is a one way device allowing current to flow from anode to cathode under forward bias, but behaving like a open circuit under reverse bias.
- Diode is used as a switch, ON during forward bias and OFF during reverse bias.

PN Junction Diode:

- A PN-junction provided with copper wire connecting leads becomes an electronic device known as **diode**, offering a low resistance when forward biased and high resistance reverse biased. Circuit symbol for a diode is an arrowhead and bar.





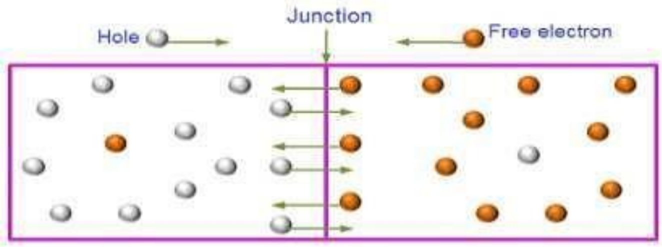
- The arrowhead indicates the conventional direction of current flow when the diode is forward biased (from the positive terminal through the device to the negative terminal).
- The **P-side** of the diode is always the positive terminal and is termed as **anode** and the **N-side** is always the negative terminal and is termed as **cathode**.
- A PN-junction diode can be destroyed when:
  (i) High level of forward current overheats the device.
  (ii) Large reverse voltage causes the junction to breakdown.

Types of Diodes: There are three types of diodes classified according to their forward current or reverse voltage carrying capacity.

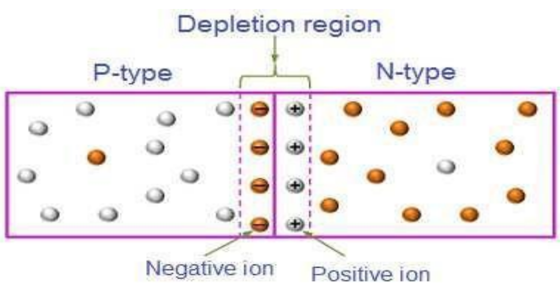
Diode:	Forward Current Capacity:	Reverse Voltage Capacity:
1. Low current diodes	Up to 100 mA	Up to 75 V
2. Medium current diodes	Up to 400 mA	Up to 200 V
3. High current diodes/Power diodes	Few amperes	Several hundreds of volts

P-N Junction:

- P-N junction is formed when a single crystal of semiconductor is added with acceptor impurity one side and donor impurity on the other side as shown in figure.
- Left side of the material is a P-type semiconductor having acceptor ions and positively charged holes. Right side is N-type having donor ions and free electrons.
- Since n-type has high concentration of electrons and p-type has high concentration of holes, there exists concentration gradient across the junction.
- Due to this, charge carriers move from high concentration area towards low concentration area to achieve uniform distribution of charge.
- In p-type excess holes move towards n-side, similarly electrons from n-side move towards p-side, this process is called **diffusion** and diffusion of charge carries takes place on either side as shown in figure.



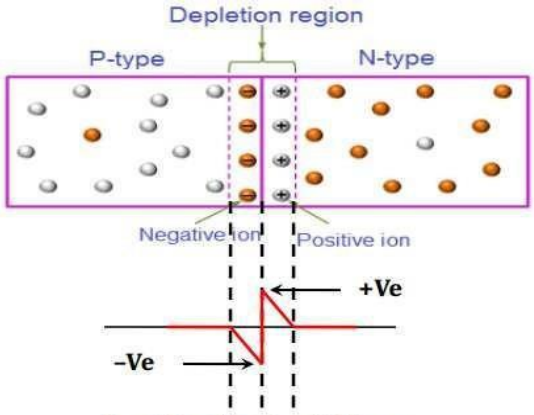
- When migrating electron diffuse into p-type and recombines with acceptor atoms on p-side, acceptor ion accepts this additional electron and becomes **negatively charged immobile ion** and hole disappears.
- When a hole diffuses into n-side they recombine with donor atom, this donor atom accepts additional hole and become **positively charged immobile ion** and electron disappears.
- The formation of immobile ions near the junction is as shown in figure. After diffusion, negative ions are formed on the p-side and positive ions are formed on the n-side.



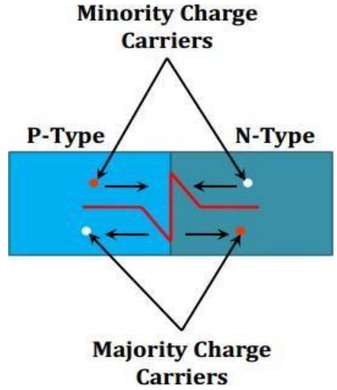
Depletion Region :

- In between immobile charges at the junction, there exists no charge carriers such a region is called **depletion region** or **space charge region**. It prevents further movement of electrons or holes across the junction.
- On n-side, the depletion region consists of donor impurity atoms have lost the free electrons associated with them, become positively charged.
- On p-side, the depletion region consists of acceptor impurity atoms, becomes negatively charged by loosing the hole associated with them.

Junction Barrier Voltage:



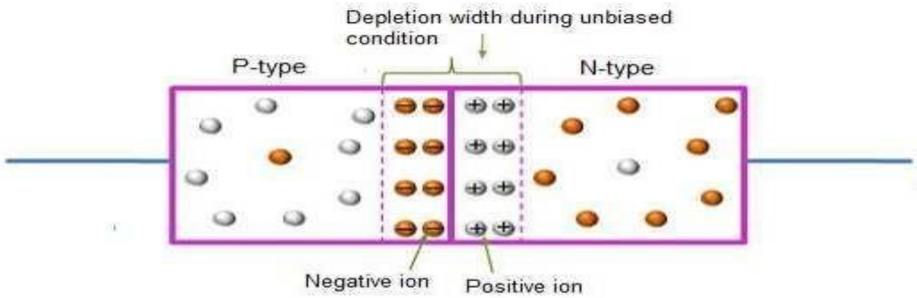
Junction Barrier Voltage



- The operation of PN junction is studied under three different cases: (i) Under no bias, (ii) Under forward bias, and (iii) Under reverse bias.

Under No Bias Condition:

- Under no bias condition, the positive charge on n-side repel the holes to cross from p to n side, negative charge on p-side repel free electrons to enter from n to p side.
- Thus a barrier is setup against further movement of charge carriers, this is called **potential barrier** or **junction barrier**. Potential barrier is of the order of 0.7 V for silicon and 0.3 V for germanium.
- The form of potential energy barrier against flow of electrons from n-side across the junction is shown in fig, the potential barrier of electron is negative due to the charge on an electron is negative.



Unbiased

- Similarly, there is a potential barrier against flow of holes from p-side across the junction, and the potential is positive due to charge on holes is positive.

Forward Biasing of P-N Junction:

- P-N junction is said to be forward biased, when the positive terminal of battery is connected to p-type and negative terminal to n-type as shown in fig.

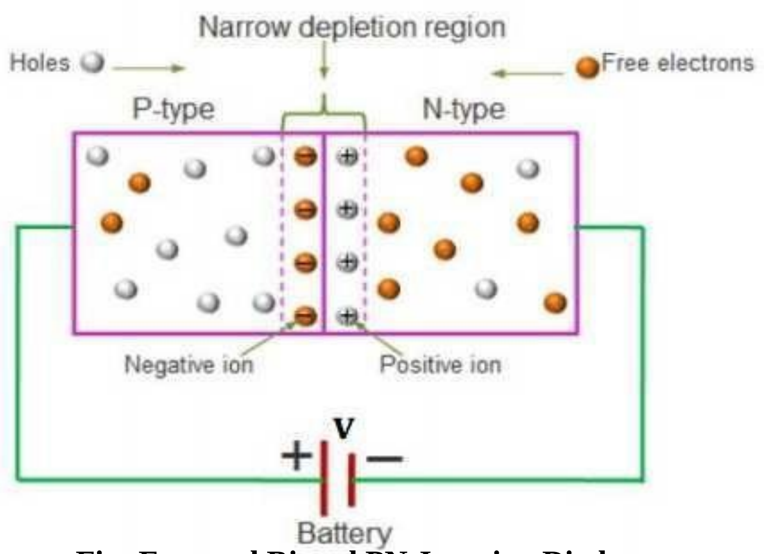


Fig: Forward Biased PN Junction Diode

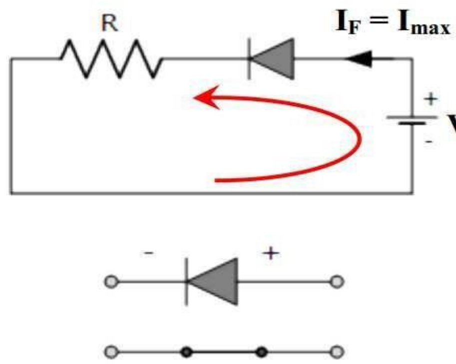


Fig: Circuit Diagram

- The application of forward bias will force electrons to move from n-side to p-side due to the negative polarity of the supply. Since these free electrons gain sufficient energy from supply they move into the p-side, but some electrons enter into depletion region and recombine. The majority of free electrons migrate into p-side and reduces the potential barrier.
- Similarly, forward bias will force holes to move from p-type to n-type due to the positive polarity of the supply. Since the holes in p-side acquire energy from supply and migrate to n-side reducing potential barrier.
- If the applied bias voltage (V) is progressively increased from zero, the barrier potential gets progressively decreases until it effectively disappears and charge carriers easily flow across the junction. Holes moves from left to right, and electrons moves from right to left, hence resulting a large current known as **forward current (I_F)** is the sum of electrons current (I_n) and holes current (I_p)

  Therefore, Forward Current: $I_F = I_n + I_p$

Reverse Biasing of P-N Junction:

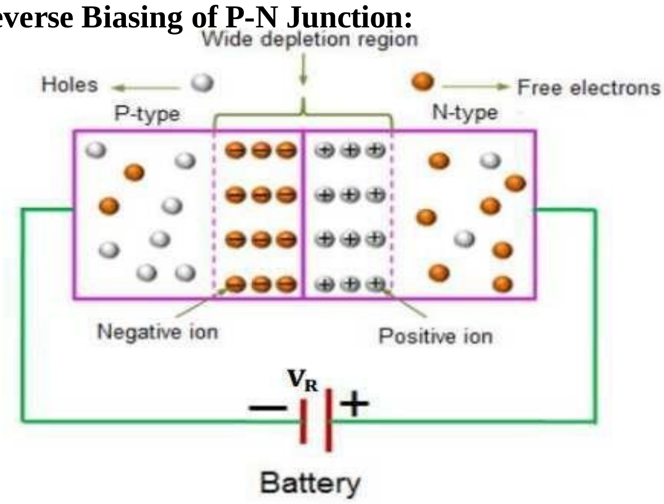


Fig: Reverse Biased PN Junction Diode

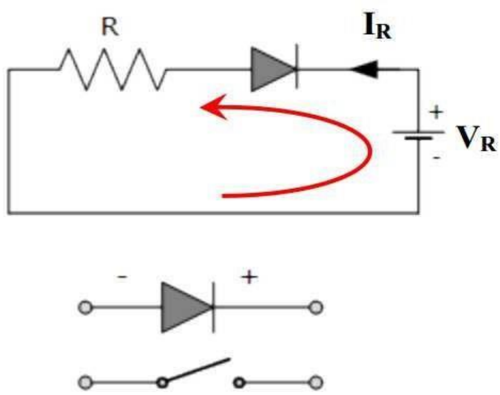


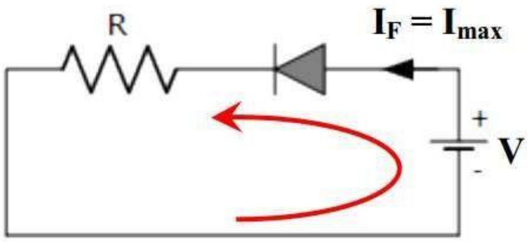
Fig: Circuit Diagram

- P-N junction is said to reverse biased when positive terminal of battery is connected to n-type and negative terminal of battery to p-type.
- On application of external bias V_R, holes from the p-side attracted to the negative terminal of battery and electrons in the n-side are attracted to the positive terminal of battery V_R.
- Since both the majority carriers move away from the junction, as a result the depletion layer gets widened. The wider the depletion layer, greater the difference in potential across the junction as shown in figure.

- When V_R is increased the barrier potential (V_B) also increases, but when barrier potential (V_B) is equal to supply potential V_R, then the barrier stops growing. When this happens, the majority carriers in n and p-type stop moving away from the junction creating an electric field.
- But some minority carriers recombine with majority carriers and when this happens, a very small magnitude of current I_O starts to flow in the electrical circuit in the direction opposite to conventional current hence called **reverse saturation current**.
- The magnitude of I_O is dependent only on junction temperature but independent of applied bias voltage V_R. For silicon it is less than 1 µA and for germanium it may exceed 10 µA.

Characteristics of P-N junction:

- Consider the fig, where positive terminal of the supply connected to P-type and negative terminal of the supply to N-type.



- If the supply voltage (V) is very less compared to cut-in voltage (0.7 V for Silicon and 0.3 V for Germanium) of diode, the barrier potential (cut-in-voltage) blocks the movement of majority carriers and hence the forward current through the diode is very low (less than 100 µA).

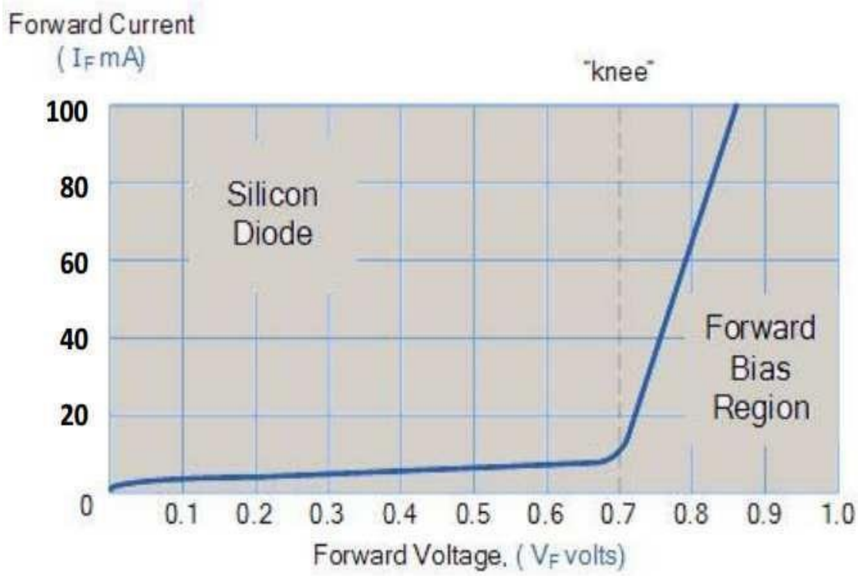


Fig: PN – Junction Forward Characteristics

- If the voltage V is greater than cut-in-voltage then the barrier potential reduces and I_F increases almost linearly.
- The relation between voltage and current is expressed mathematically by,

- At point A, reverse breakdown of the diode occurs and current increases sharply. This point is called as knee point.

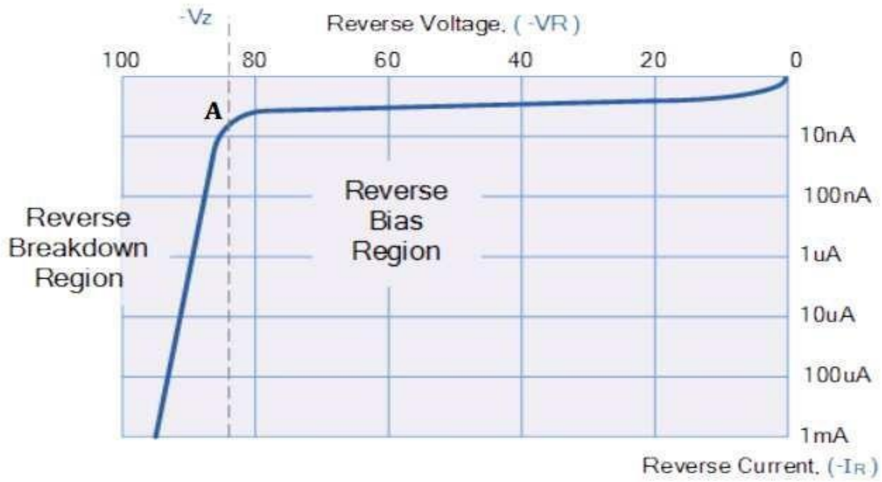
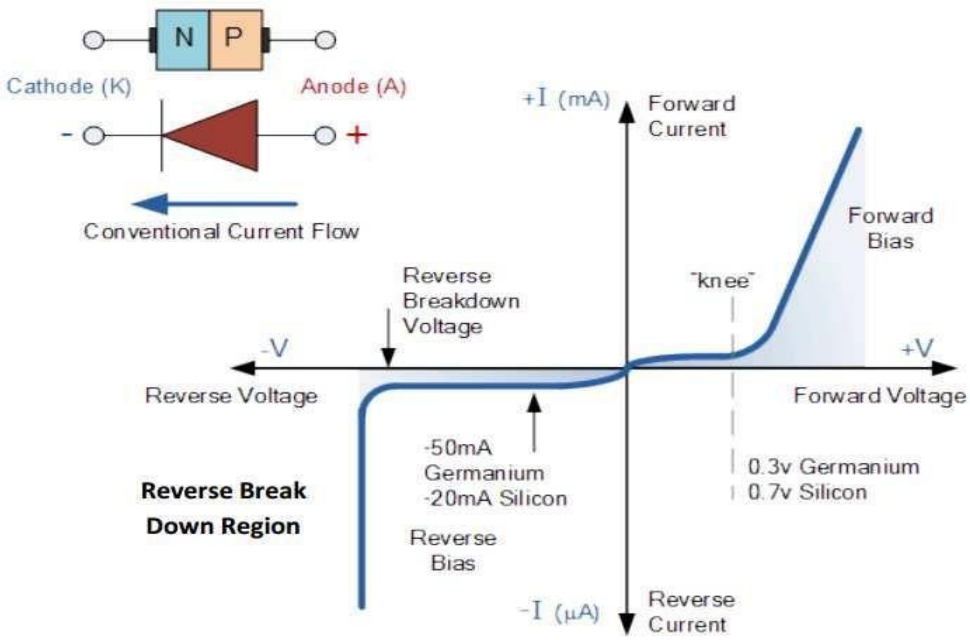


Fig: PN – Junction Reverse Characteristics

- At point A, reverse breakdown of the diode occurs and current increases sharply. This point is called as knee point.

V-I characteristics of Silicon and Germanium Diode:



- The forward and reverse characteristics of silicon and germanium shown in figure.
- Cut-in-voltage of germanium is 0.3V and silicon is 0.7V. The current through the device increases only when applied potential is higher than the cut-in-voltage.
- The reverse saturation current I_O is of the order of nA for silicon diode while it is of the order μA for germanium diode. Reverse breakdown voltage for Si diode (–75V) is higher than that of the Ge diode (–50V).

Rectification

- The most important applications of diodes are **rectification**: conversion of a sinusoidal ac waveform into single polarity half cycles.
  Rectifier: An electrical device used for rectification offers a low resistance to the current in one direction but a very high resistance to the current in the opposite direction. It is a circuit which converts **ac voltage** into **pulsating dc voltage**.
- Rectifier are classified into:
  i. Half wave rectifier
  ii. Full wave rectifier, which is further classified into:
     a. Centre tapped full wave rectifier
     b. Bridge rectifier
- **DC Power Supply:** Converts a sinusoidal ac waveform into dc by rectification and filtering.
  Filtering: It is a process, normally use large reservoir capacitor, which charges to peak input voltage to produce dc output. The capacitor partially discharges between the peaks of the rectified waveform, this result into ripple voltage on the output. The ripples can be reduced by using RC or LC filters.
- Specifications of power supply are: dc output voltage, load current, and ripple voltage. The performance of the power supply is defined in-terms of the output voltage stability, when input voltage or load current changes.

Half – Wave Rectifier:

- The rectifiers which conducts current or voltage only during one half cycle of ac input is called **half wave rectifier**. The below figure shows **half wave rectifier**, where single diode acts as a half wave rectifier. The AC input supply to be rectified is applied through transformer to diode D and series load resistor R_L.

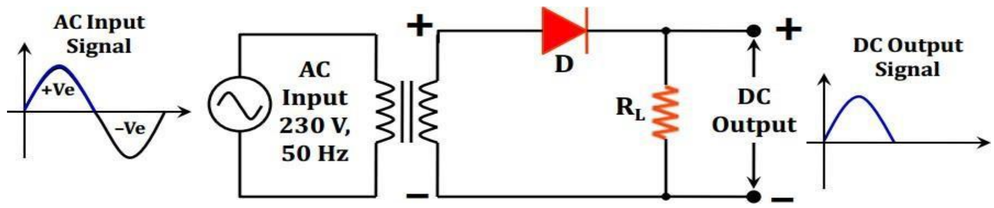


Fig: Half – Wave Rectifier Circuit

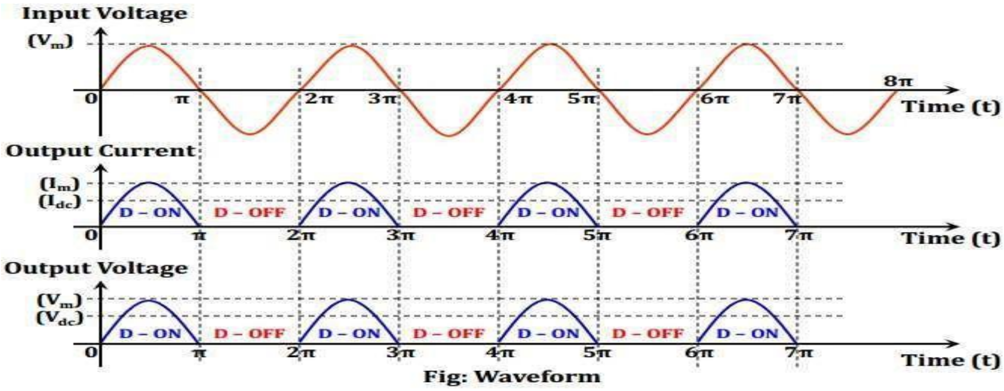


Fig: Waveform

- Input voltage V_i is a sinusoidal waveform it can be represented mathematically as,
  $V_i = V_m \sin wt = V_m \sin\theta$
- **During positive half cycle of V_i,** the diode is **forward biased** and acts as **short circuit**. The current flows through R_L and V_O follows V_i. (Practically $V_o = V_i - V_F$, where V_F is voltage drop across the diode).
  Output Voltage: $V_o = V_m \sin\theta$; for $0 \le \theta \le \pi$
  Output Current: $i = I_m \sin\theta$; for $0 \le \theta \le \pi$

- **During negative half cycle of V_i,** the diode is **reverse biased** and acts as **open circuit** and no current flows through R_L. Therefore no output voltage during this time. (Practically very small negative voltage levels produced by the diode reverse saturation current (I_R). So $V_o = -I_R R_L$).
  Output Voltage: $V_o = 0$; for $\pi \le \theta \le 2\pi$
  Output Current: $i = 0$; for $\pi \le \theta \le 2\pi$

  Maximum load current is give by,
  $$I_m = \frac{V_m}{R_f + R_s + R_L}$$
  Where R_f : Forward resistance of a diode
  R_s : Transformer secondary winding resistance
  R_L : Load resistance

  Advantages:
  1. Only one diode is required.
  2. Centre tap transformer is not required

  Disadvantages:
  1. Ripple factor is too high (γ = 1.21).
  2. Efficiency of rectification is low (η = 40.6%).
  3. DC saturation of transformer secondary winding takes place.
  4. Transformer utilization factor is low.
  5. AC supply delivers power only during half of the time, therefore output is low.

Full Wave Rectifiers:

- The rectifiers which conducts during both positive and negative half cycles of ac input is called **full wave rectifier**. In a full wave rectifiers, the current flows through the load for the entire cycle of input from 0 to 2π and are classified into two types:
  i. Center tapped full wave rectifier
  ii. Bridge rectifier

Center Tapped Full Wave Rectifier:

- It consists of two diodes D_1 and D_2 connected across center tap of secondary and load R_L as shown in figure. Input voltage is supplied from transformer with centre tapped secondary winding. It is essentially combination of two half-wave rectifier circuits, each supplied from one half of the transformer secondary.

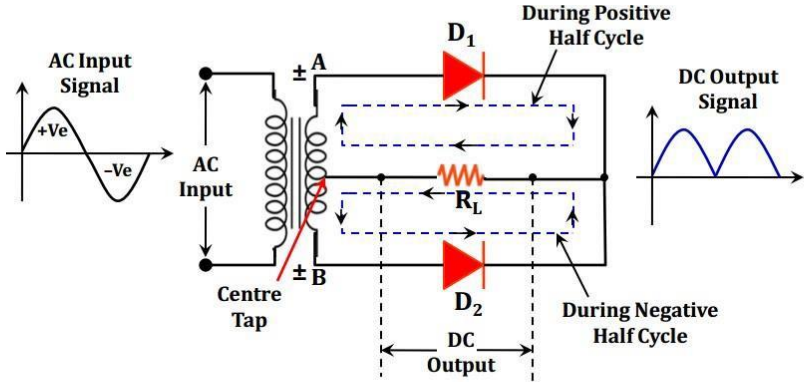


Fig: Centre Tapped Full Wave Rectifier Circuit

- **During positive half cycle** of ac input voltage, terminal A is positive and terminal B is negative, due to center tap transformer. The diode D_1 will be forward biased and hence conduct, while D_2 will be reverse biased and will not conduct. The diode D_1 supplies load current i.e., $\mathbf{i_L = i_{d_1}}$.
- **During negative half cycle** of ac input voltage, terminal A is negative and terminal B is positive, due to center tap transformer. The diode D_2 will be forward biased and hence conduct, while D_1 will be reverse biased and will not conduct. The diode D_2 supplies load current i.e., $\mathbf{i_L = i_{d_2}}$.
- Therefore, the current flows through load resistor (R_L) for both half cycles of ac input voltage. The output waveform is the combination of the two half cycles, that is continuous series of positive half-cycles of sinusoidal waveform.

Output Voltage: $V_o = V_i - V_F$

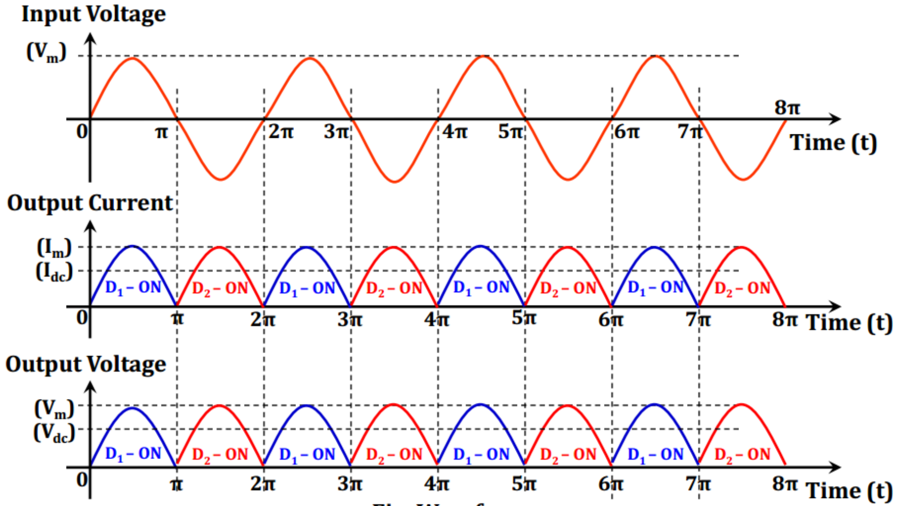


Fig: Waveform

Advantages:

1. Ripple factor is too high (Υ = 0.48).
2. Efficiency of rectification is high (η = 81.2%).
3. No dc saturation of transformer secondary winding takes place.
4. DC output voltage and load current are twice compared to half rectifier.

Disadvantages:

1. It is expensive to manufacture a centre tapped transformer, which produces equal voltages on each half of secondary windings.
2. Difficult to locate the centre tap of secondary winding.
3. The output voltage is half of the secondary voltage.
4. Diodes have high peak inverse voltage, larger in size and costlier.
5. Peak inverse voltage of a diode is twice that of used in half wave rectifier.

Bridge Rectifier:

- The centre tapped transformer used is usually more expensive and requires more space than additional diodes. The most popular type of rectifier used in electronic power supplies are bridge rectifiers.

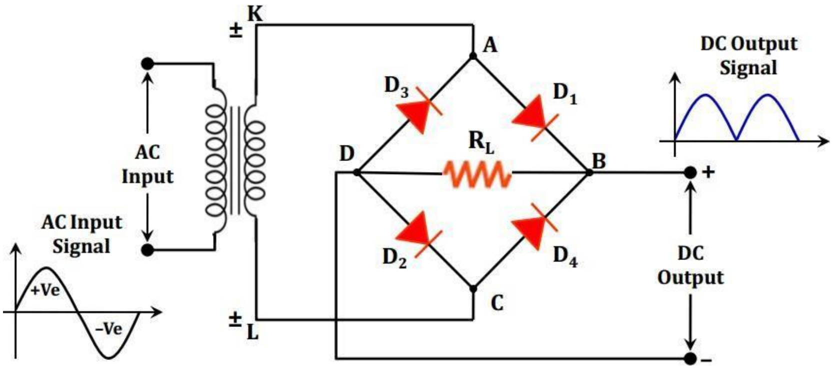
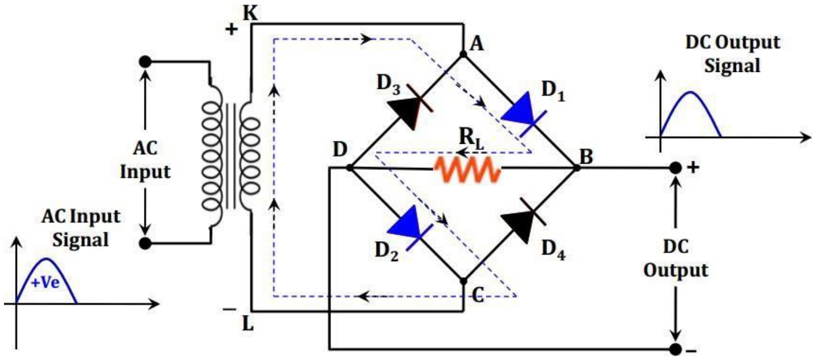


Fig: Bridge Rectifier Circuit

- It requires four identical diodes to form a bridge network. The circuit consists of four diodes D_1, D_2, D_3 and D_4 connected across secondary of transformer and load R_L.
- The secondary of transformer is connected to node points A & C and the load resistor (R_L) is connected to other node points B & D.
- The ac input terminals are connected to junction of D_1, D_3 and junction of D_2, D_4. The positive output terminal is at cathodes of D_1, D_4 and negative output terminal is at anodes of D_2, D_3. Let $\mathbf{V_i = V_m \sin wt}$ be the instantaneous voltage appearing across the secondary.

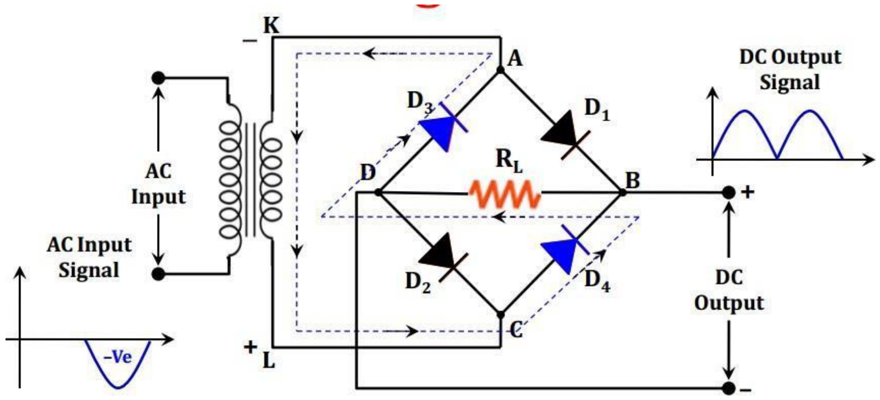
- **During the positive half cycle**, the point K is positive and L is negative, the diodes D_1 and D_2 are forward biased acts like closed switch. Whereas diodes D_3 and D_4 are reverse biased and acts like a open switch. Hence only two diodes D_1 and D_2 are conducts and allow the current to flow through R_L.

Output Voltage: $V_o = V_i - 2V_F$



- **During the negative half cycle**, the point K is negative and L is positive, the diodes D_3 and D_4 are forward biased acts like closed switch. Whereas diodes D_1 and D_2 are reverse biased and acts as open switch. Hence only two diodes D_3 and D_4 are conducts and allow the current to flow through R_L.

  Output Voltage: $V_o = V_i - 2V_F$



- It is observed that, during both half cycles of the input, the output polarity is always positive at the top of R_L and negative at the bottom. Both positive and negative half-cycles of the inputs are passed to the output, but negative half-cycles are inverted, so that output is a continuous series of positive half-cycles of sinusoidal voltage.

- The instantaneous value of current and voltage of transformer secondary is given by,

  $V = V_m \sin\theta$ & $i = I_m \sin\theta$ where $I_m = \dfrac{V_m}{R_s + R_f + R_L}$

Advantages:

1. Transformer cost is less.
2. Peak inverse voltage of diode is one half of the diode used in centre tapped rectifier.
3. Centre tapped transformer is not required.
4. It can be used in applications, where floating output terminals are allowed.

Disadvantages:

1. It requires four diodes.
2. During each half cycle of ac input, two diodes that conducts are in series and therefore voltage drop in the internal resistance of rectifying unit will be twice as compared to centre tapped circuit.

ZENER DIODE

A zener diode is a special type of device designed to operate in the zener breakdown region. Zener diodes acts like normal p-n junction diodes under forward biased condition. When forward biased voltage is applied to the zener diode it allows large amount of electric current and blocks only a small amount of electric current.

Zener diode is heavily doped than the normal p-n junction diode. Hence, it has very thin depletion region. Therefore, zener diodes allow more electric current than the normal p-n junction diodes.

Zener diode allows electric current in forward direction like a normal diode but also allows electric current in the reverse direction if the applied reverse voltage is greater than the zener voltage. Zener diode is always connected in reverse direction because it is specifically designed to work in reverse direction.

Zener diode definition

A zener diode is a p-n junction semiconductor device designed to operate in the reverse breakdown region. The breakdown voltage of a zener diode is carefully set by controlling the doping level during manufacture.

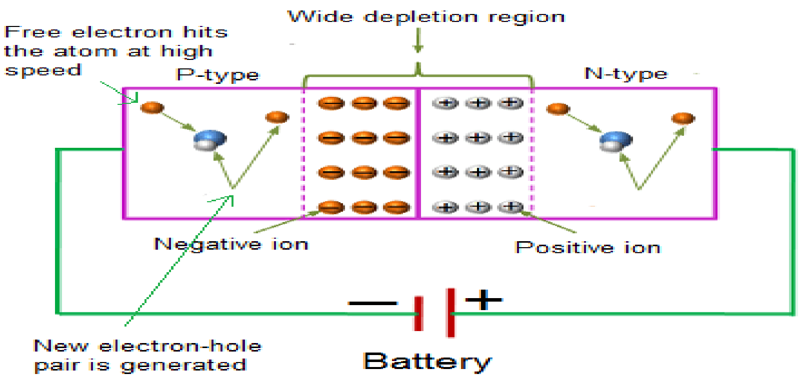
The name zener diode was named after the American physicist Clarance Melvin Zener who discovered the zener effect. Zener diodes are the basic building blocks of electronic circuits. They are widely used in all kinds of electronic equipments. Zener diodes are mainly used to protect electronic circuits from over voltage.

BREAKDOWN IN ZENER DIODE

There are two types of reverse breakdown regions in a zener diode: avalanche breakdown and zener breakdown.

Avalanche breakdown

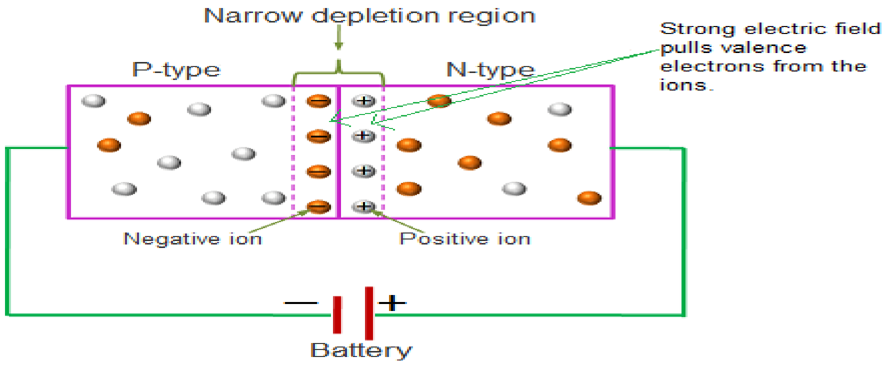
The avalanche breakdown occurs in both normal diodes and zener diodes at high reverse voltage. When high reverse voltage is applied to the p-n junction diode, the free electrons (minority carriers) gains large amount of energy and accelerated to greater velocities.



The free electrons moving at high speed will collides with the atoms and knock off more electrons. These electrons are again accelerated and collide with other atoms. Because of this continuous collision with the atoms, a large number of free electrons are generated. As a result, electric current in the diode increases rapidly. This sudden increase in electric current may permanently destroys the normal diode. However, avalanche diodes may not be destroyed because they are carefully designed to operate in avalanche breakdown region. Avalanche breakdown occurs in zener diodes with zener voltage (V_z) greater than 6V.

Zener breakdown

The zener breakdown occurs in heavily doped p-n junction diodes because of their narrow depletion region. When reverse biased voltage applied to the diode is increased, the narrow depletion region generates strong electric field.

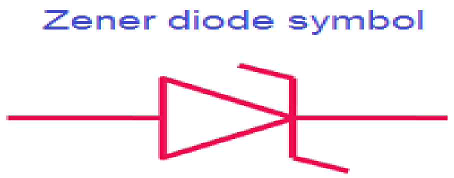


When reverse biased voltage applied to the diode reaches close to zener voltage, the electric field in the depletion region is strong enough to pull electrons from their valence band. The valence electrons which gains sufficient energy from the strong electric field of depletion region will breaks bonding with the parent atom. The valance electrons which break bonding with parent atom will become free electrons. This free electrons carry electric current from one place to another place. At zener breakdown region, a small increase in voltage will rapidly increases the electric current.

- Zener breakdown occurs at low reverse voltage whereas avalanche breakdown occurs at high reverse voltage.
- Zener breakdown occurs in zener diodes because they have very thin depletion region.
- Breakdown region is the normal operating region for a zener diode.
- Zener breakdown occurs in zener diodes with zener voltage (V_z) less than 6V.

Symbol of zener diode

The symbol of zener diode is shown in below figure. Zener diode consists of two terminals: cathode and anode.



In zener diode, electric current flows from both anode to cathode and cathode to anode.

The symbol of zener diode is similar to the normal p-n junction diode, but with bend edges on the vertical bar.

VI characteristics of zener diode

The VI characteristics of a zener diode is shown in the below figure. When forward biased voltage is applied to the zener diode, it works like a normal diode. However, when reverse biased voltage is applied to the zener diode, it works in different manner.

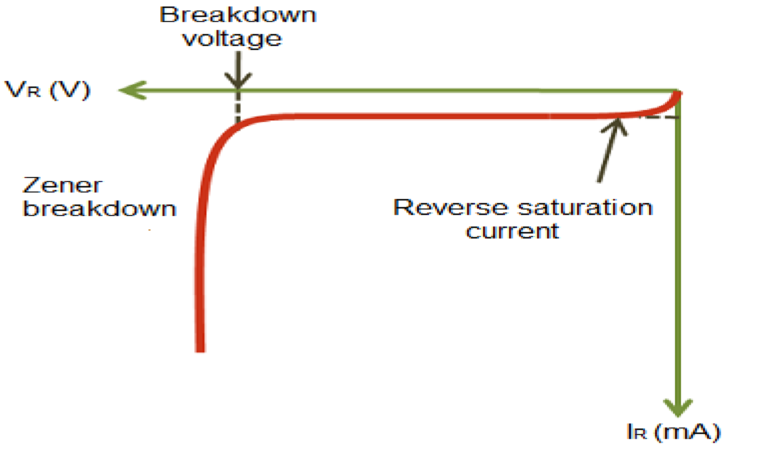


Fig: Zener breakdown

When reverse biased voltage is applied to a zener diode, it allows only a small amount of leakage current until the voltage is less than zener voltage. When reverse biased voltage applied to the zener diode reaches zener voltage, it starts allowing large amount of electric current. At this point, a small increase in reverse voltage will rapidly increases the electric current. Because of this sudden rise in electric current, breakdown occurs called zener breakdown. However, zener diode exhibits a controlled breakdown that does damage the device.

The zener breakdown voltage of the zener diode is depends on the amount of doping applied. If the diode is heavily doped, zener breakdown occurs at low reverse voltages. On the other hand, if the diode is lightly doped, the zener breakdown occurs at high reverse voltages. Zener diodes are available with zener voltages in the range of 1.8V to 400V.

ADVANTAGES OF ZENER DIODE

- Power dissipation capacity is very high
- High accuracy, Small size, Low cost

APPLICATIONS OF ZENER DIODE

- It is normally used as voltage reference
- Zener diodes are used in voltage stabilizers or shunt regulators.
- Zener diodes are used in switching operations
- Zener diodes are used in clipping and clamping circuits.
- Zener diodes are used in various protection circuits

Clipper circuits

Clipper definition

A clipper is a device that removes either the positive half (top half) or negative half (bottom half), or both positive and negative halves of the input AC signal. In other words, a clipper is a device that limits the positive amplitude or negative amplitude or both positive and negative amplitudes of the input AC signal. In some cases, a clipper removes a small portion of the positive half cycle or negative half cycle or both positive and negative half cycles.

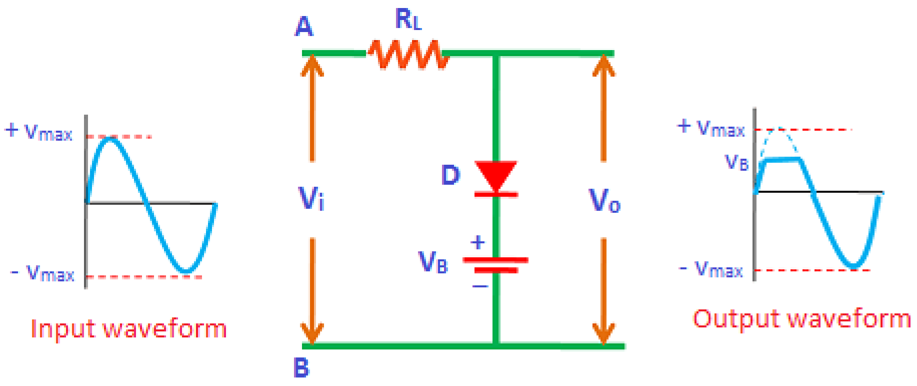
Types of clipper

Clipper circuits are of three types:

- Bias positive clipper
- Bias negative clipper
- Dual side clippers

Bias positive clipper

During the positive half cycle, the diode is forward biased by the input supply voltage V_i and reverse biased by the battery voltage V_B. However, initially, the input supply voltage V_i is less than the battery voltage V_B. Hence, the battery voltage V_B makes the diode to be reverse biased. Therefore, the signal appears at the output. However, when the input supply voltage V_i becomes greater than the battery voltage V_B, the diode D is forward biased by the input supply voltage V_i. As a result, no signal appears at the output.

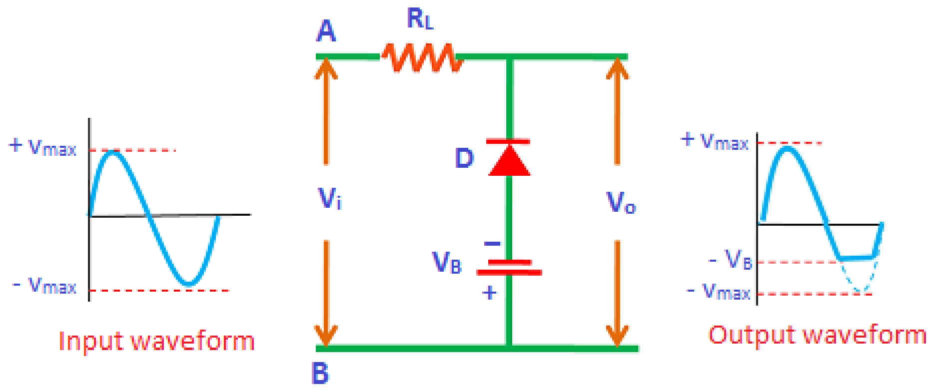


Shunt positive clipper with positive bias

During the negative half cycle, the diode is reverse biased by both input supply voltage and battery voltage. So it doesn't matter whether the input supply voltage is greater or lesser than the battery voltage, the diode always remains reverse biased. As a result, a complete negative half cycle appears at the output.

Bias negative clipper

During the positive half cycle, the diode is reverse biased by both input supply voltage V_i and battery voltage V_B. As a result, the complete positive half cycle appears at the output.

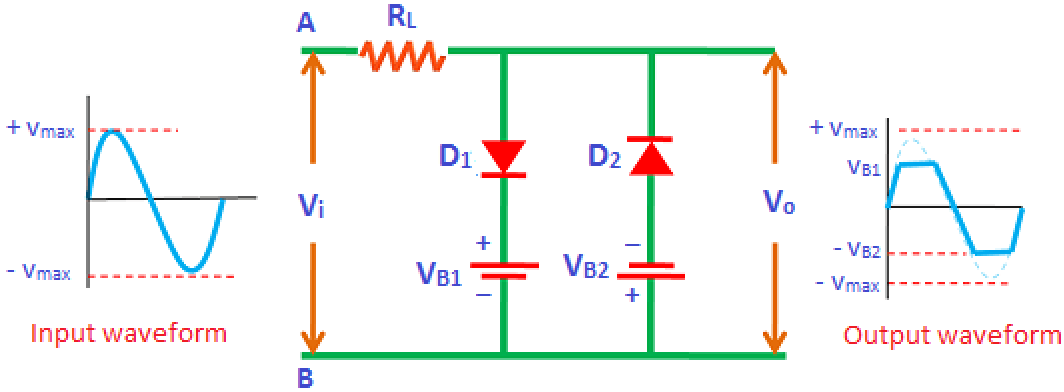


Shunt negative clipper with negative bias

During the negative half cycle, the diode is forward biased by the input supply voltage V_i and reverse biased by the battery voltage V_B. However, initially, the input supply voltage is less than the battery voltage. So the diode is reverse biased by the battery voltage. As a result, the signal appears at the output. However, when the input supply voltage becomes greater than the battery voltage, the diode is forward biased by the input supply voltage. As a result, the signal does not appear at the output.

Dual (combination) clipper

Sometimes it is desired to remove a small portion of both positive and negative half cycles. In such cases, the dual clippers are used.
The dual clippers are made by combining the biased shunt positive clipper and biased shunt negative clipper.
Let us consider a dual clipper circuit in which a sinusoidal ac voltage is applied to the input terminals of the circuit.



Dual (Combination) clipper

During the positive half cycle, the diode D_1 is forward biased by the input supply voltage V_i and reverse biased by the battery voltage V_{B1}. On the other hand, the diode D_2 is reverse biased by both input supply voltage V_i and battery voltage V_{B2}.
Initially, the input supply voltage is less than the battery voltage. So the diode D_1 is reverse biased by the battery voltage V_{B1}. Similarly, the diode D_2 is reverse biased by the battery voltage V_{B2}. As a result, the signal appears at the output. However, when the input supply voltage V_i becomes greater than the battery

voltage V_{B1}, the diode D_1 is forward biased by the input supply voltage. As a result, no signal appears at the output.

During the negative half cycle, the diode D_1 is reverse biased by both input supply voltage V_i and battery voltage V_{B1}. On the other hand, the diode D_2 is forward biased by the input supply voltage V_i and reverse biased by the battery voltage V_{B2}.
Initially, the battery voltage is greater than the input supply voltage. Therefore, the diode D_1 and diode D_2 are reverse biased by the battery voltage. As a result, the signal appears at the output.
When the input supply voltage becomes greater than the battery voltage V_{B2}, the diode D_2 is forward biased. As a result, no signal appears at the output.

Applications of clippers

- Clippers are commonly used in power supplies.
- Used in TV transmitters and Receivers
- They are employed for different wave generation such as square, rectangular, or trapezoidal waves
- Series clippers are used as noise limiters in FM transmitters.

Clamper circuits

Clamper definition

A clamper is an electronic circuit that changes the DC level of a signal to the desired level without changing the shape of the applied signal. In other words, the clamper circuit moves the whole signal up or down to set either the positive peak or negative peak of the signal at the desired level.

A typical clamper is made up of a capacitor, diode, and resistor. Some clampers contain an extra element called DC battery. The resistors and capacitors are used in the clamper circuit to maintain an altered DC level at the clamper output. The clamper is also referred to as a DC restorer, clamped capacitors, or AC signal level shifter.

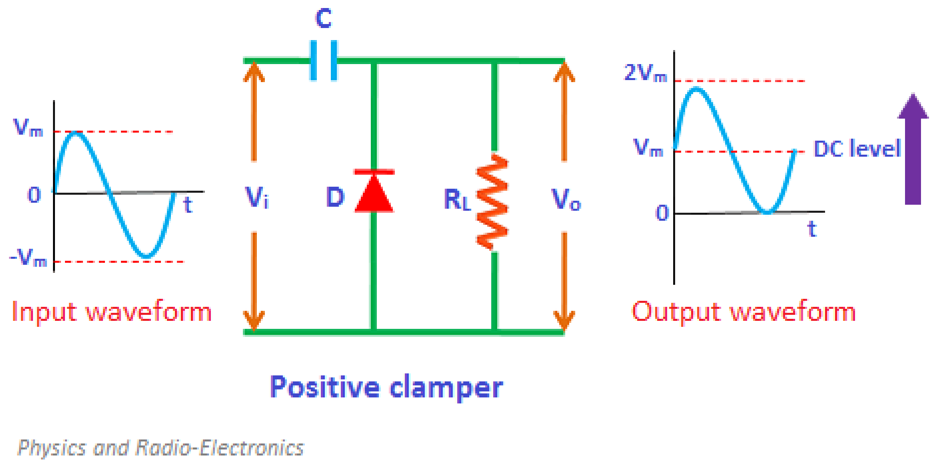
Types of clampers

Clamper circuits are of two types:

- Positive clampers
- Negative clampers

Positive clamper

The positive clamper is made up of a voltage source V_i, capacitor C, diode D, and load resistor R_L. In the below circuit diagram, the diode is connected in parallel with the output load. So the positive clamper passes the input signal to the output load when the diode is reverse biased and blocks the input signal when the diode is forward biased.



During negative half cycle:

During the negative half cycle of the input AC signal, the diode is forward biased and hence no signal appears at the output. In forward biased condition, the diode allows electric current through it. This current will flows to the capacitor and charges it to the peak value of input voltage V_m. The capacitor charged in inverse polarity (positive) with the input voltage. As input current or voltage decreases after attaining its maximum value $-V_m$, the capacitor holds the charge until the diode remains forward biased.

During positive half cycle:

During the positive half cycle of the input AC signal, the diode is reverse biased and hence the signal appears at the output. In reverse biased condition, the diode does not allow electric current through it. So the input current directly flows towards the output.

When the positive half cycle begins, the diode is in the non-conducting state and the charge stored in the capacitor is discharged (released). Therefore, the voltage appeared at the output is equal to the sum of the voltage stored in the capacitor (V_m) and the input voltage (V_m) { I.e. $V_o = V_m + V_m = 2V_m$} which have the same polarity with each other. As a result, the signal shifted upwards.

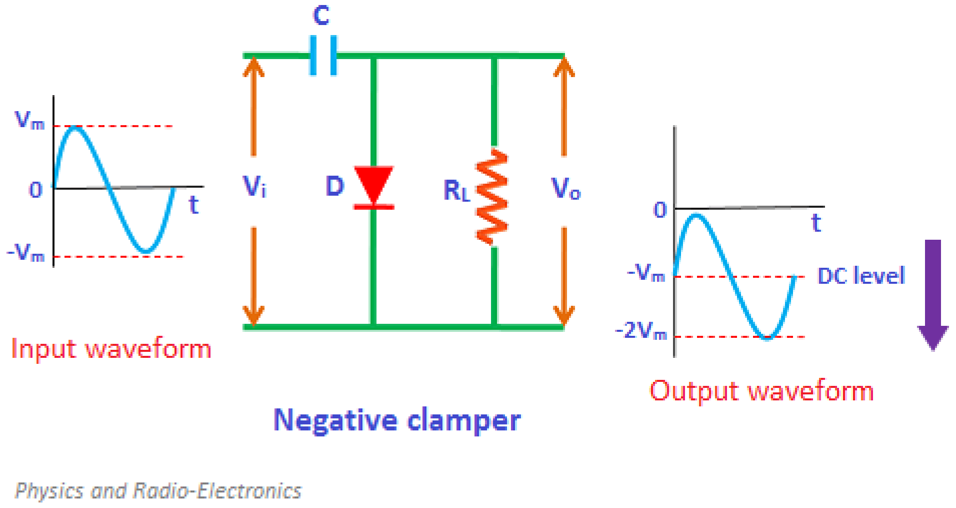
The peak to peak amplitude of the input signal is $2V_m$, similarly the peak to peak amplitude of the output signal is also $2V_m$. Therefore, the total swing of the output is same as the total swing of the input.

The basic difference between the clipper and clamper is that the clipper removes the unwanted portion of the input signal whereas the clamper moves the input signal upwards or downwards.

Negative clamper

During positive half cycle:

During the positive half cycle of the input AC signal, the diode is forward biased and hence no signal appears at the output. In forward biased condition, the diode allows electric current through it. This current will flows to the capacitor and charges it to the peak value of input voltage in inverse polarity $-V_m$. As input current or voltage decreases after attaining its maximum value V_m, the capacitor holds the charge until the diode remains forward biased.



During negative half cycle:

During the negative half cycle of the input AC signal, the diode is reverse biased and hence the signal appears at the output. In reverse biased condition, the diode does not allow electric current through it. So the input current directly flows towards the output.

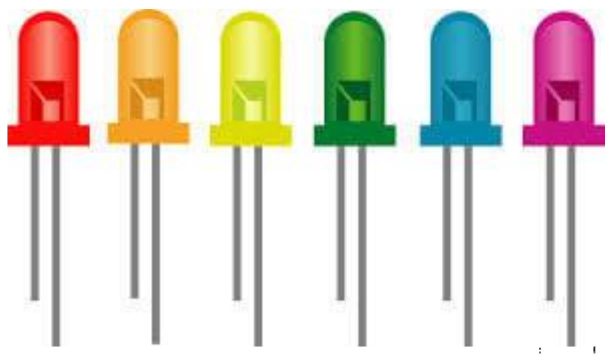
When the negative half cycle begins, the diode is in the non-conducting state and the charge stored in the capacitor is discharged (released). Therefore, the voltage appeared at the output is equal to the sum of the voltage stored in the capacitor ($-V_m$) and the input voltage ($-V_m$) {I.e. $V_o = -V_m - V_m = -2V_m$} which have the same polarity with **each oth**er. As a result, the signal shifted downwards.

Light Emitting Diode (LED)

What is Light Emitting Diode (LED)?

Light Emitting Diodes (LEDs) are the most widely used semiconductor diodes among all the different types of semiconductor diodes available today. Light emitting diodes emit either visible light or invisible infrared light when forward biased. The LEDs which emit invisible infrared light are used for remote controls.

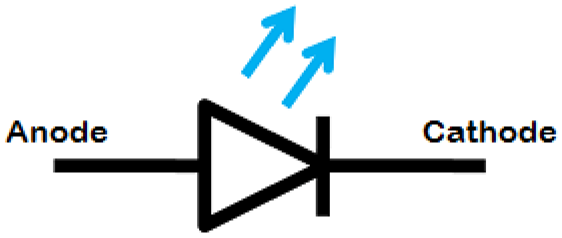
A light Emitting Diode (LED) is an optical semiconductor device that emits light when voltage is applied. In other words, LED is an optical semiconductor device that converts electrical energy into light energy.



When Light Emitting Diode (LED) is forward biased, free electrons in the conduction band recombines with the holes in the valence band and releases energy in the form of light.
The process of emitting light in response to the strong electric field or flow of electric current is called electroluminescence.

Light emitting diode (LED) symbol

The symbol of LED is similar to the normal p-n junction diode except that it contains arrows pointing away from the diode indicating that light is being emitted by the diode.

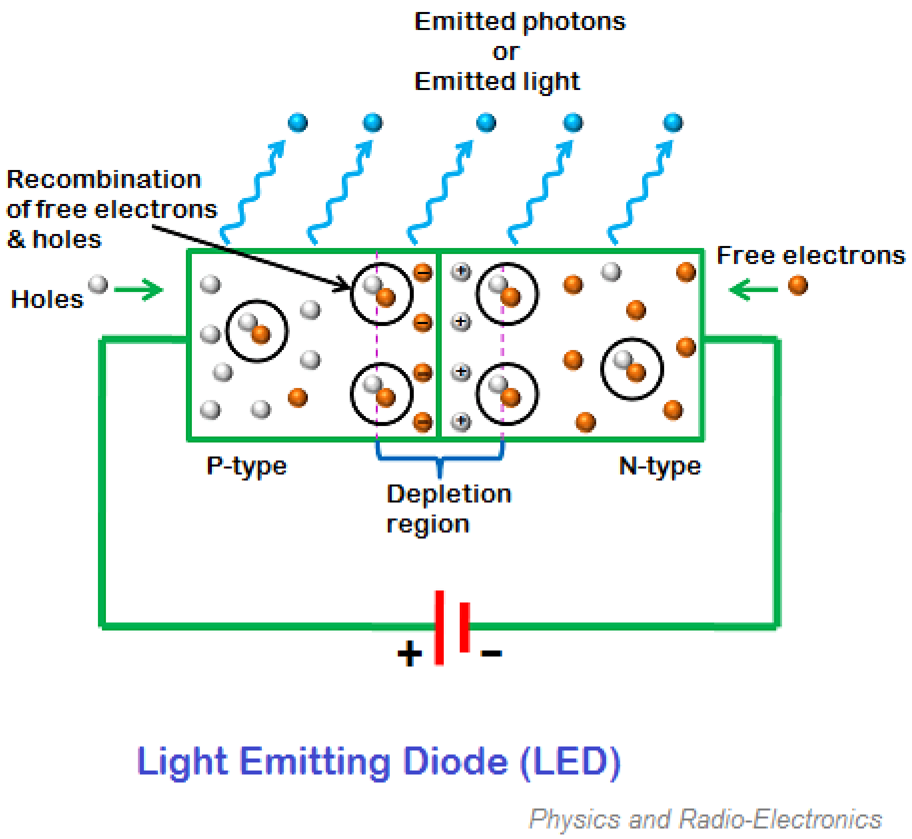


LED symbol

LEDs are available in different colors. The most common colors of LEDs are orange, yellow, green and red.
The schematic symbol of LED does not represent the color of light. The schematic symbol is same for all colors of LEDs. Hence, it is not possible to identify the color of LED by seeing its symbol.

How Light Emitting Diode (LED) works?

Light Emitting Diode (LED) works only in forward bias condition. When Light Emitting Diode (LED) is forward biased, the free electrons from n-side and the holes from p-side are pushed towards the junction. When free electrons reach the junction or depletion region, some of the free electrons recombine with the holes in the positive ions. We know that positive ions have less number of electrons than protons. Therefore, they are ready to accept electrons. Thus, free electrons recombine with holes in the depletion region. In the similar way, holes from p-side recombine with electrons in the depletion region.



Because of the recombination of free electrons and holes in the depletion region, the width of depletion region decreases. As a result, more charge carriers will cross the p-n junction.

Some of the charge carriers from p-side and n-side will cross the p-n junction before they recombine in the depletion region. For example, some free electrons from n-type semiconductor cross the p-n junction and recombines with holes in p-type semiconductor. In the similar way, holes from p-type semiconductor cross the p-n junction and recombines with free electrons in the n-type semiconductor. Thus, recombination takes place in depletion region as well as in p-type and n-type semiconductor. The free electrons in the conduction band releases energy in the form of light before they recombine with holes in the valence band.

In silicon and germanium diodes, most of the energy is released in the form of heat and emitted light is too small. However, in materials like gallium arsenide and gallium phosphide the emitted photons have sufficient energy to produce intense visible light.

Visible LEDs and invisible LEDs

LEDs are mainly classified into two types: visible LEDs and invisible LEDs.

- Visible LED is a type of LED that emits visible light. These LEDs are mainly used for display or illumination where LEDs are used individually without photosensors.
- Invisible LED is a type of LED that emits invisible light (infrared light). These LEDs are mainly used with photosensors such as photodiodes.

What determines the color of an LED?

The material used for constructing LED determines its color. In other words, the wavelength or color of the emitted light depends on the forbidden gap or energy gap of the material.

Different materials emit different colors of light.

- Gallium arsenide LEDs emit red and infrared light.
- Gallium nitride LEDs emit bright blue light.
- Yttrium aluminium garnet LEDs emit white light.
- Gallium phosphide LEDs emit red, yellow and green light.
- Aluminium gallium nitride LEDs emit ultraviolet light.
- Aluminum gallium phosphide LEDs emit green light.

Advantages of LED

- The brightness of light emitted by LED is depends on the current flowing through the LED. Hence, the brightness of LED can be easily controlled by varying the current. This makes possible to operate LED displays under different ambient lighting conditions.
- Light emitting diodes consume low energy.
- LEDs are very cheap and readily available.
- LEDs are light in weight.
- Smaller size.
- LEDs have longer lifetime.
- LEDs operates very fast. They can be turned on and off in very less time.
- LEDs do not contain toxic material like mercury which is used in fluorescent lamps.
- LEDs can emit different colors of light.

Disadvantages of LED

- LEDs need more power to operate than normal p-n junction diodes.
- Luminous efficiency of LEDs is low.

Applications of LED

The various applications of LEDs are as follows

- Burglar alarms systems
- Calculators
- Picture phones
- Traffic signals
- Digital computers
- Multimeters
- Microprocessors
- Digital watches
- Automotive heat lamps
- Camera flashes
- Aviation lighting

BJT and MOSFET

Bipolar Junction Transistor

A bipolar junction transistor or BJT is a three terminal electronic device that amplifies the flow of current. It is a current controlled device. In bipolar junction transistor, electric current is conducted by both free electrons and holes.

Unlike a normal pn junction diode, the transistor has two p-n junctions.

Types of Bipolar Junction Transistors (BJTs)

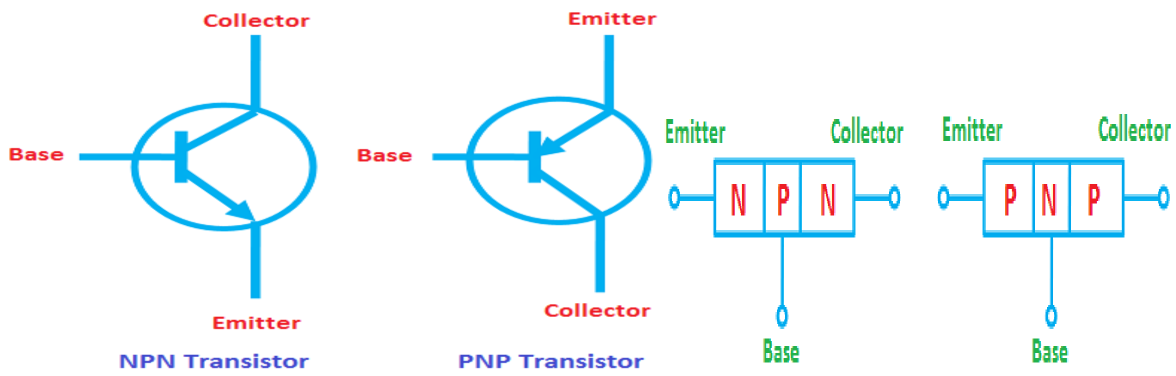
The bipolar junction transistors are formed by sandwiching either n-type or p-type semiconductor layer between pairs of opposite polarity semiconductor layers.

Bipolar junction transistors are classified into two types based on their construction: They are

- NPN transistor
- PNP transistor

NPN transistor

When a single p-type semiconductor layer is sandwiched between two n-type semiconductor layers, the transistor is said to be an npn transistor



PNP transistor

When a single n-type semiconductor layer is sandwiched between two p-type semiconductor layers, the transistor is said to be a pnp transistor.

Both PNP and NPN transistors consist of three terminals: they are emitter, base, and collector.

Terminals of BJT

Emitter:

As the name suggests, the emitter section supplies the charge carriers. The emitter section is heavily doped so that it can inject a large number of charge carriers into the base. The size of the emitter is always greater than the base.

Base:

The middle layer is called base. The base of the transistor is very thin as compared to emitter and collector. It is very lightly doped.

Collector:

The function of the collector is to collect charge carriers. It is moderately doped. That is the doping level of the collector section is in between emitter and base. The size of the collector is always greater than emitter and base. The collector area in the transistor is considerably larger than the emitter area. This is because the collector region has to handle more power than the emitter does and more surface area is required for heat dissipation.

In transistor, the amplification is achieved by passing input current from a region of low resistance to a region of high resistance.

Applications of bipolar junction transistor

The various applications of bipolar junction transistors include:

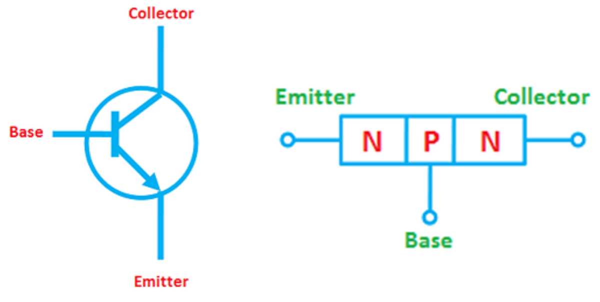
- Televisions
- Mobile phones
- Computers
- Radio transmitters
- Audio amplifiers
-

NPN transistor

When a single p-type semiconductor layer is sandwiched between two n-type semiconductor layers, an npn transistor is formed.

NPN transistor symbol

The circuit symbol and diode analogy of npn transistor is shown in the below figure.



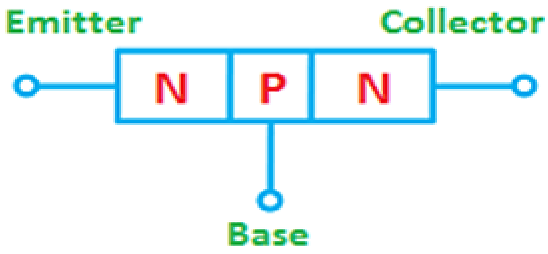
NPN transistor symbol

In the above figure, it is shown that the electric current always flows from p-region to n-region.

NPN transistor construction

The npn transistor is made up of three semiconductor layers: one p-type semiconductor layer and two n-type semiconductor layers.

The p-type semiconductor layer is sandwiched between two n-type semiconductor layers.



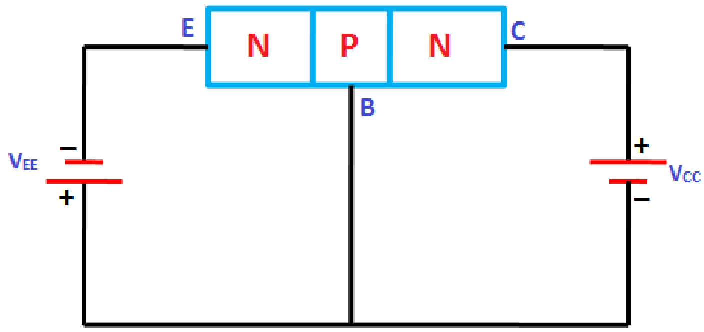
The npn transistor has three terminals: emitter, base and collector. The emitter terminal is connected to the left side n-type layer. The collector terminal is connected to the right side n-type layer. The base terminal is connected to the p-type layer.

The npn transistor has two p-n junctions. One junction is formed between the emitter and the base. This junction is called emitter-base junction or emitter junction. The other junction is formed between the base and the collector. This junction is called collector-base junction or collector junction.

Working of a npn transistor

Biased npn transistor

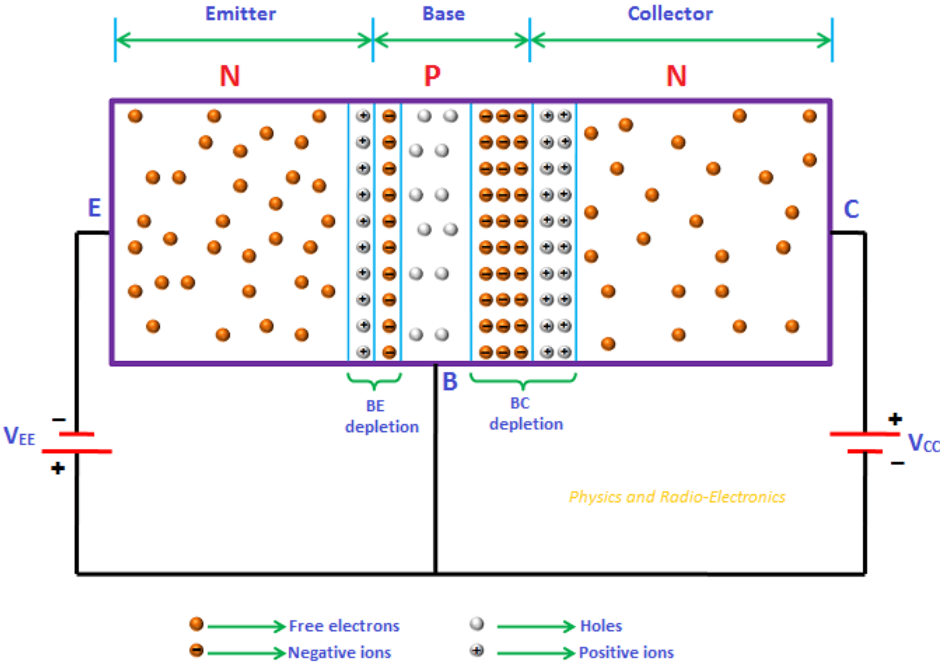
When external voltage is applied to an npn transistor, it is said to be a biased npn transistor. Depending on the polarity of the applied voltage, the npn transistor can be operated in three modes: active mode, cutoff mode and saturation mode.



The npn transistor is often operated in active mode because in active mode the npn transistor amplifies the electric current.

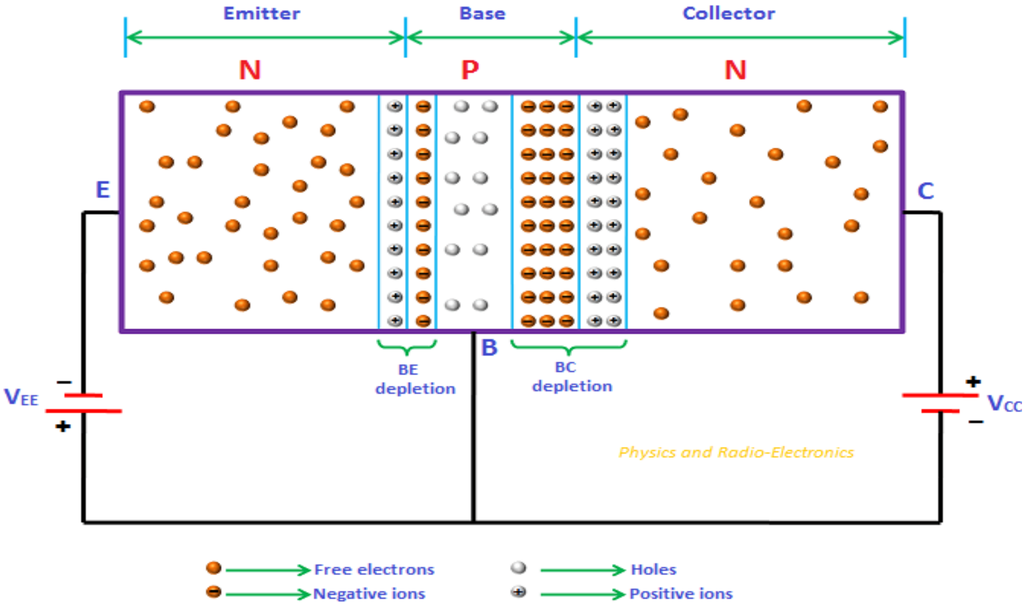
So let’s see how an npn transistor works in active mode.

Let us consider an npn transistor as shown in the below figure. In the below figure, the emitter-base junction is forward biased by the DC voltage V_{EE} and base-collector junction is reverse biased by the DC voltage V_{CC}.



Emitter-base junction:

Due to the forward bias, a large number of free electrons in the left side n-region (emitter) experience a repulsive force from the negative terminal of the DC battery and also they experience an attractive force from the positive terminal of the battery. As a result, the free electrons start flowing from emitter to base. In the similar way, holes in base experience a repulsive force from the positive terminal of the battery and also experience an attractive force from the negative terminal of the battery. As a result, the holes start flowing from base to emitter.



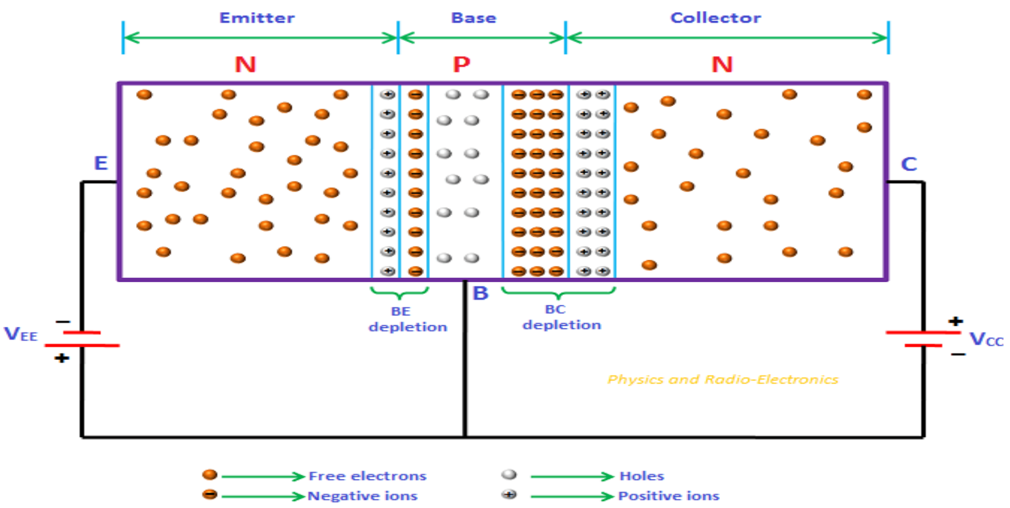
Due to the applied external voltage, each emitter atom has more than one or two free electrons. Hence, each emitter atom donates more than one or two free electrons to more positive ions. As a result, the positive ions become neutral. Similarly, each base atom accepts more number of electrons from more negative ions. As a result, the negative ions become neutral. We know that depletion region is nothing but combination of positive ions and negative ions.

Thus, the depletion width at the emitter-base junction reduces by applying the forward bias voltage.

We know that electric current means flow of charge carriers. The free electrons (negative charge carriers) flow from emitter to base whereas holes (positive charge carriers) flow from base to emitter. These charge carriers conduct electric current. However, the conventional current direction is same as the direction of holes.

Thus, the electric current flows from base to emitter.

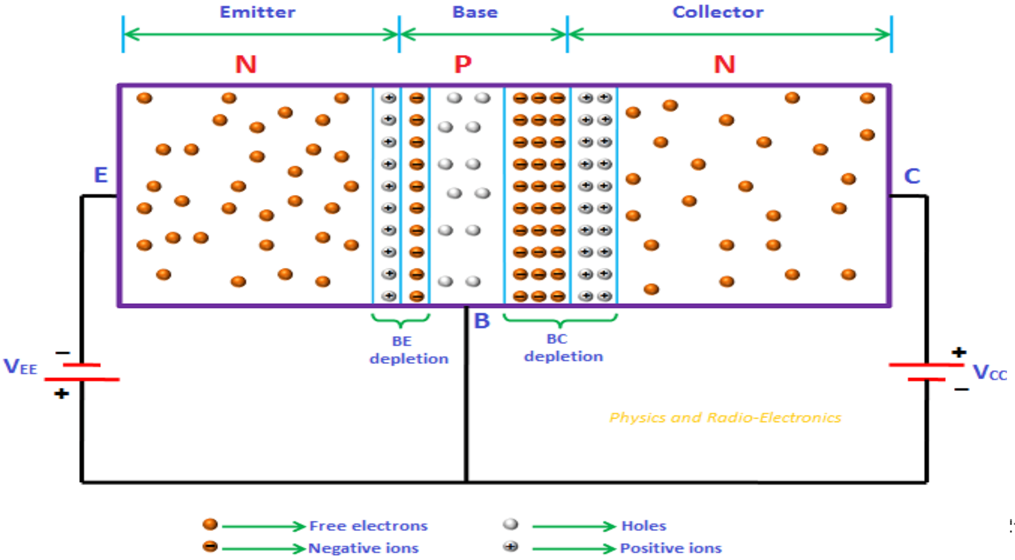
Base-collector junction:



Due to the reverse bias, a large number of free electrons in the right side n-region (collector) experience an attractive force from the positive terminal of the battery. Hence, the free electrons move away from the junction and flow towards the positive terminal of the battery. As a result, a large number of neutral collector atoms loses electrons and becomes positive ions. On the other hand, holes in the p-region (base) experience an attractive force from the negative terminal of the battery. Hence, the holes move away from the junction and flow towards the negative terminal of the battery. As a result, a large number of neutral base atoms gains electrons and becomes negative ions.

Thus, the width of depletion region increases at base-collector junction. In other words, the number of positive and negative ions increases at the base-collector junction.

Collector-base-emitter current:



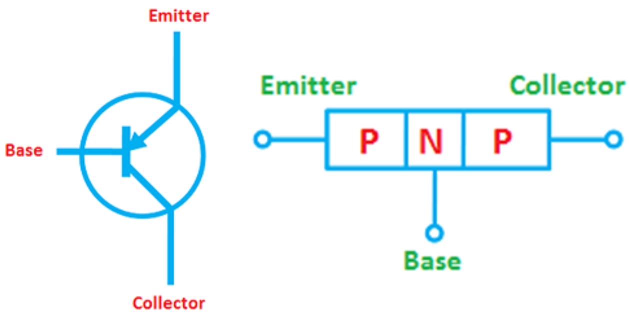
The free electrons that are flowing from emitter to base due to forward bias will combine with the holes in the base. However, the base is very thin and lightly doped. So only, a small percentage of emitter free electrons combines with the holes in the base region. The remaining large number of free electrons will cross the base region and reaches to the collector region. This is due to the positive supply voltage applied at collector. Hence, free electrons flow from emitter to collector. At collector, both the emitter free electrons and collector free electrons produces current by flowing towards the positive terminal of the battery. Therefore, an amplified current is produced at the output.

PNP transistor

When a single n-type semiconductor layer is sandwiched between two p-type semiconductor layers, a pnp transistor is formed.

PNP transistor symbol

The circuit symbol and diode analogy of pnp transistor is shown in the below figure.

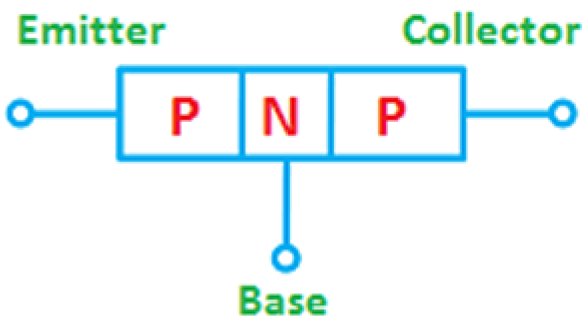


PNP transistor symbol

PNP transistor construction

The pnp transistor is made up of three semiconductor layers: one n-type semiconductor layer and two p-type semiconductor layers.

The n-type semiconductor layer is sandwiched between two p-type semiconductor layers.

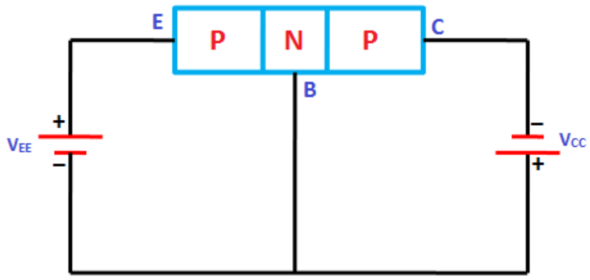


The pnp transistor has three terminals: emitter, base and collector. The emitter terminal is connected to the left side p-type layer. The collector terminal is connected to the right side p-type layer. The base terminal is connected to the n-type layer.

The pnp transistor has two p-n junctions. One junction is formed between the emitter and the base. This junction is called emitter-base junction or emitter junction. The other junction is formed between the base and the collector. This junction is called collector-base junction or collector junction.

Working of a pnp transistor

When external voltage is applied to a pnp transistor, it is said to be a biased pnp transistor. Depending on the polarity of the applied voltage, the pnp transistor can be operated in three modes: active mode, cutoff mode and saturation mode.

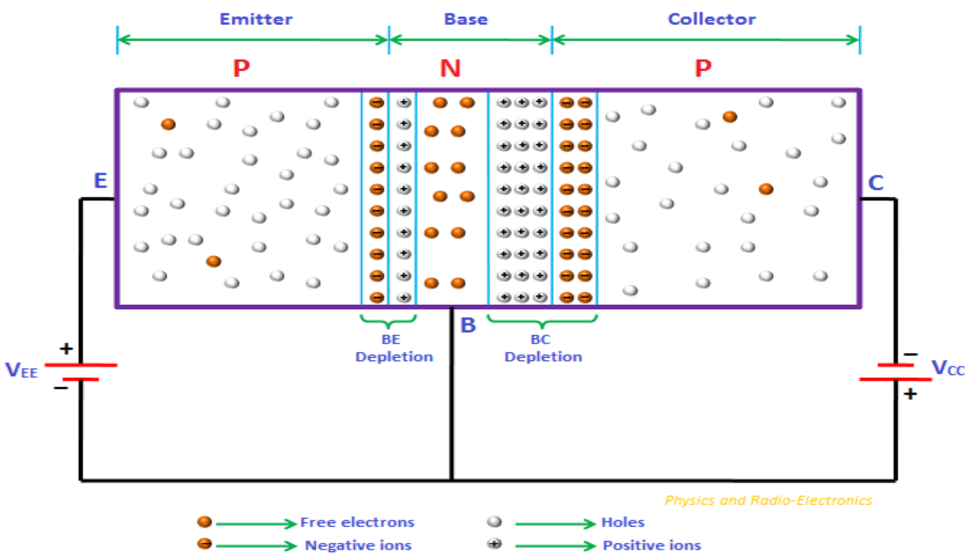


The pnp transistor is often operated in active mode because in active mode the pnp transistor amplifies the electric current.

So let's see how a pnp transistor works in active mode.

Let us consider a pnp transistor as shown in the below figure. In the below figure, the emitter-base junction is forward biased by the DC voltage V_{EE} and base-collector junction is reverse biased by the DC voltage V_{CC}.

Emitter-base junction

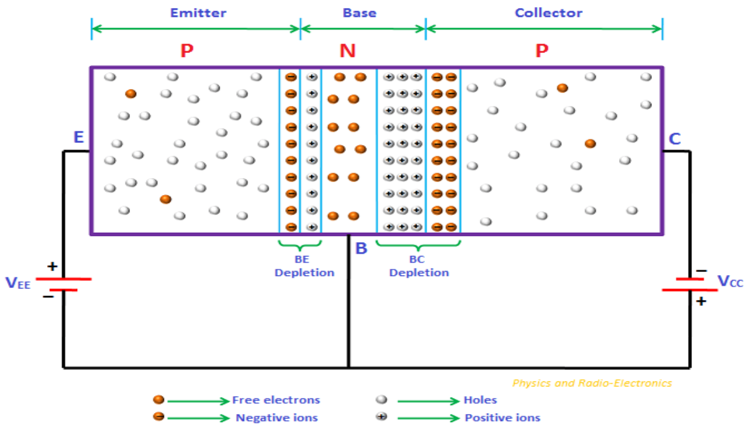


Due to the forward bias, a large number of holes in the left side p-region (emitter) experience a repulsive force from the positive terminal of the DC battery and also they experience an attractive force from the negative terminal of the battery. As a result, the holes start flowing from emitter to base. In the similar way, free electrons in base experience a repulsive force from the negative terminal of the battery and also experience an attractive force from the positive terminal of the battery. As a result, the free electrons start flowing from base to emitter.

The majority carriers holes carry most of the current from emitter to base. Thus, the electric current flows from emitter to base.

This electric current flow reduces the width of the depletion region at emitter-base junction.

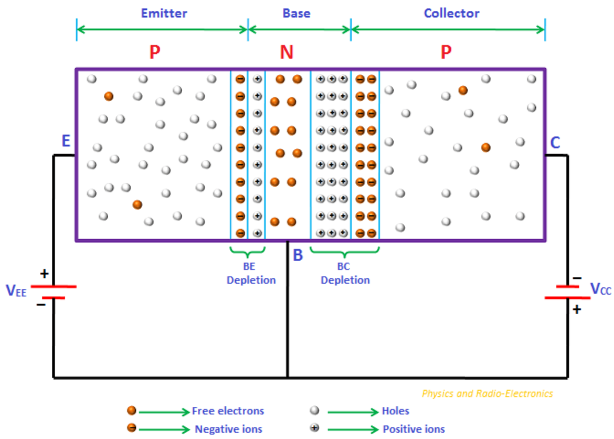
Base-collector junction:



Due to the reverse bias, a large number of holes in the right side n-region (collector) experience an attractive force from the negative terminal of the battery. Hence, the holes move away from the junction and flow towards the negative terminal of the battery. As a result, a large number of neutral collector atoms gains electrons and becomes negative ions. On the other hand, free electrons in the n-region (base) experience an attractive force from the positive terminal of the battery. Hence, the free electrons move away from the junction and flow towards the positive terminal of the battery. As a result, a large number of neutral base atoms loses electrons and becomes positive ions.

Thus, the width of depletion region increases at base-collector junction. In other words, the number of positive and negative ions increases at the base-collector junction.

Emitter-base-collector current:



The holes that are flowing from emitter to base due to forward bias will combines with the free electrons in the base. However, the base is very thin and lightly doped. So only, a small percentage of emitter holes will combine with the free electrons in the base region. The remaining large number of holes will cross the base region and reaches to the collector region. This is due to the negative supply voltage applied at collector. Hence, the holes flow from emitter to collector. At collector, both the emitter holes and collector holes produces current by flowing towards the negative terminal of the battery. Therefore, an amplified current is produced at the output.

MOSFET

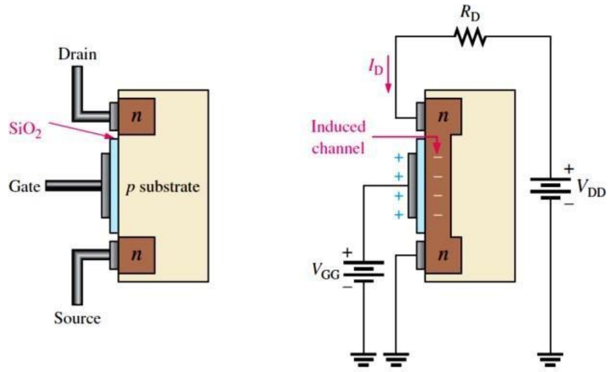
The MOSFET (Metal Oxide Semiconductor Field-Effect Transistor) is a type of FET which has no *pn*-junction structure; instead, the gate of the MOSFET is insulated from the channel by a silicon dioxide (SiO_2) layer. The two basic types of MOSFETs are Enhancement type (E-MOSFET) and Depletion type (D-MOSFET). Of the two types, the Enhancement MOSFET is more widely used. Because polycrystalline silicon is now used for the gate material instead of metal, MOSFETs are sometimes called IGFETs (Insulated-Gate FETs).

The MOSFET has two modes of operation – enhancement mode and depletion mode. An E-MOSFET can be operated only in enhancement mode and has no depletion mode. A D-MOSFET can be operated in either depletion mode or enhancement mode and hence it is also called depletion/enhancement MOSFET.

Enhancement Type MOSFET (E-MOSFET)

Construction

An E-MOSFET can be operated only in enhancement mode and has no depletion mode. An E-MOSFET has no structural channel. The basic structure of an N-channel E-MOSFET is shown in Fig. 11 (a).



(a) Basic construction (b) Induced channel ($V_{GS} > V_{GS(th)}$)

Fig. 11 Construction and operation of N-channel E-MOSFET

A *p*-type substrate is the basic structure upon which *n*-type regions are created by diffusion. An oxide (SiO_2) layer which acts as an insulator covers the entire *p*-type substrate and *n*-type regions. By etching proper openings through the oxide layer, metal contacts for source and drain connections are made to the *n*-regions. The gate contact is formed on the surface of the oxide layer. The gate is electrically insulated from both *n*-type regions and the *p*-type substrate.

Regardless of the polarity of applied voltage, no electrons can flow from source to drain because the *n*-type source, *p*-type substrate and *n*-type drain behave as two *pn*-junctions connected back-to-back and one of the *pn*-junctions is always reverse biased.

Operation

Consider a positive voltage is applied between gate and source as shown in Fig. 11 (b). As the oxide layer is an insulator sandwiched between two conductive regions, a capacitive effect is formed. The metal surface which is gate and the conducting substrate act as the capacitor plates.

When a positive charge is applied to one plate of the capacitor, a corresponding negative charge is induced on the opposite plate due to the electric field between the plates. In this case, the positive potential at the gate induces negative charges in the *p*-type substrate. This charge results from minority carriers (electrons) attracted towards the area of the gate. As the number of electrons reaching the region increases, the N-channel is formed gradually and resistance between source and drain decreases. The greater the gate potential, the lower the channel resistance and higher the drain current I_D. This process is called *enhancement* and the resulting device is called *enhancement type* MOSFET (E-MOSFET).

Fig. 12 shows the symbols of N-channel and P-channel E-MOSFET.

(a) N-channel E-MOSFET (b) P-channel E-MOSFET

Fig. 12 Symbols of E-MOSFET

In a P-channel E-MOSFET, the substrate is of *n*-type and the diffused regions are of *p*-type. When a negative voltage is applied between the gate and source, a P-channel is induced in the *n*-type substrate. The operation of P-channel E-MOSFET can be explained on the same grounds as of N-channel, except the voltage polarities are opposite to those of the N-channel.

SILICON CARBIDE

What is silicon carbide

Silicon carbide may not normally be associated with semiconductor devices, but surprisingly it has been used for many years. In the days of crystal radio sets back in the 1920s and even a bit earlier in some cases, silicon carbide or carborundum as it was known, was used with Cat's Whisker radio detectors. These then became the first widely used silicon carbon or SiC diodes.
Radio communication devices
Silicon carbide is produced at high temperature combining silica - a form of silicon with carbon. This is refined and then processed to provide the required blanks on which the silicon carbide devices are formed. These electronic components may be SiC diodes, SiC FETs or SiC MOSFETs, etc.
Silicon carbide is now being widely used as the semiconductor for many power devices, because of its particular attributes. One key one is the very high breakdown electric field strength and this enables the fabrication of higher voltage semiconductor devices and in particular SiC MOSFETs.
Silicon carbide also possesses a number of other important attributes which mean that it performs particularly well within MOSFETs.

What is a Silicon Carbide MOSFET

Silicon carbide is a semiconductor that is being used in an increasing number of electronic components.
One good example of these is silicon carbide MOSFETs, often just referred to as silicon carbide FETs.
These silicon carbide, SiC MOSFETs or SiC FETs provide some useful improvements in performance over their silicon equivalent electronic components.

In essence these SiC MOSFETs provide a higher blocking voltage, lower on state resistance and higher thermal conductivity than their silicon counterparts.
This means that they are often using to good effect in electronic circuit designs for power switching: switch mode power supplies, voltage converters: step up and step down converters and many more electronic circuit designs.
Although there was initially a price penalty for using these devices, they are now so widely used and the manufacturing processes are so well established that there is little difference, and any cost increases associated with these electronic components can normally be more than made up because of the benefits resulting in smaller circuits, lower heat dissipation and the like.

Advantages of SiC MOSFETs

The use of silicon carbide MOSFETs is well established, particularly within the area of power electronics where the switching characteristics of these electronic components mean that they are particularly suited to many new electronics circuit designs.

Some of the key attributes of SiC MOSFETs arising from the use of silicon carbide rather than silicon include:

- ***High voltage breakdown:*** Silicon carbide has a critical breakdown strength that is 10 times of silicon. This means that smaller and higher voltage SiC MOSFETs can be fabricated. Some SiC MOSFETs have operating voltages of well over 1.5kV, which is a figure well above that which can be achieved using silicon technologies.
  The higher breakdown voltage enables the high breakdown voltages to be achieved whilst also using thinner drift layers.
- ***Current density:*** SiC MOSFETs provide a much higher current density than silicon MOSFETs.
- ***High temperature operation:*** Silicon carbide MOSFETs can operate at much higher temperatures than their silicon equivalents. This means that they can utilise the higher current density that SiC offers without the need for having to be so aware of the actual device temperature.
- ***Low switching losses:*** Silicon carbide technology enables these MOSFETs to have a lower ON resistance. This results in lower resistive losses when the device in ON.
  Also the faster switching speeds that can be attained mean that there is a faster transition between `the ON and OFF states, which again results in lower loss levels. The lower loss can be crucial in electronic circuit designs like voltage converters, switch mode power supplies and the like.
- ***High switching frequencies:*** One of the parameters which can be particularly important with silicon carbide MOSFETs is the higher switching speeds that can be attained. This enables higher frequencies to be used, and this reflects in smaller inductive and capacitive components being needed. Not only does this reduce the size of the overall electronic circuit design, but it also reduces costs as smaller electronic components cost less.

GALLIUM NITRIDE

What is gallium nitride

Gallium nitride is a compound semiconductor material using materials from groups III & V in the periodic table of elements.

Physically the material is very hard, and has a Knoop hardness factor of 14.21 GPa and GaN has some other interesting physical attributes, but it is the electrical properties that are of interest here.

Gallium nitride has a wide bandgap of 3.5eV which is very similar to that of silicon carbide and this makes it very suitable as a semiconductor for a number of devices.

GaN has some very useful properties that make it ideal for a number of power applications. It can tolerate a high operating voltage, handle high levels of power, and it can operate at high frequencies making it ideal for many RF applications from mobile communications, 5G, 6G, etc to aerospace, and satellite communications.

GaN transistor applications

GaN HEMT or transistor technology is used in many areas of electronics circuit design and RF design. The parameters of the GaN transistors that are produced mean that they are applicable for many different applications where high power, high frequency or high performance or any combination of these parameters are required.

- ***Power systems:*** With everything from switch mode power supplies, power switching, electric vehicles and the like needing power switching devices, the GaN HEMT lends itself to many of these applications. The fast switching and low ON resistance of these devices means that efficiency levels are high. The high breakdown voltages also mean that relatively high level switching can be accomplished.
- ***RF power amplifiers:*** The combination of high power capability and high speed means that GaN FET technology is an ideal candidate for RF power amplifiers.
  GaN FET technology offers many advantages from high reliability, and high efficiency levels to the capability to operate at high frequencies. As a result GaN technology is used in many RF power amplifiers for a whole variety of applications including mobile communications where it is used, particularly in base stations for 5G, 6G, etc. It is also used in satellite applications where its high reliability and resilience as well as the high levels of efficiency that can be returned are of great interest.
- ***GaN RF switches:*** Another application for GaN FETs is as RF switches. There are many situations where RF switching is required, and these electronic components provide the ideal means of switching the RF circuitry. They are able to handle much higher power levels than the GaAsFETs that are also used in RF designs for switching.
  GaN FETs are able to use the same basic RF design architecture as GaAsFET switches, but with changes to the electronic comment values, etc. As RF switches, these GaN transistors are able to provide a low switching loss because of their low ON resistance, they have a high level of isolation, excellent linearity and they can handle much higher power levels than GaAsFETs.
- ***GaN low noise amplifiers:*** The high frequency capability of GaN FETs means that they are able to not only operate as a power amplifier, but also on the receiving side as a front end low noise amplifier, LNA. In this role, these electronic components are able to perform well, offering a low noise figure, an essential in this role within an RF circuit design.
  However, in view of their high power capability and general robustness, they are able to tolerate high input power levels, unlike GaAsFETs which can be rather susceptible to overload and ESD. Accordingly GaN FETs are starting to be used in radar installations as one of many examples.
  One advantage of their high tolerance of RF levels is that a circulator may not always be needed. As the circulator will introduce loss, this can reduce the overall receiver sensitivity as well as absorbing some transmitter power.
- ***GaN mixers:*** Gallium nitride FETs are also finding use within high performance RF mixers. Here, the high level of linearity these electronic components can provide and their resilience to high power levels, means that they are replacing GaAsFET based mixers in many new RF designs.
- ***MMIC:*** GaN FET technology is also used within many monolithic microwave ICs, MMICs. With MMICs needing to extend their frequency ranges in a variety of RF design blocks, GaN technology is ideal for use within MMICs that provide a variety of RF functions.