AUTOMOBILE MECHATRONICS

Basics of Electrical and Electronics Engg.

UNIT-5

Basics of Semiconductor Diodes:

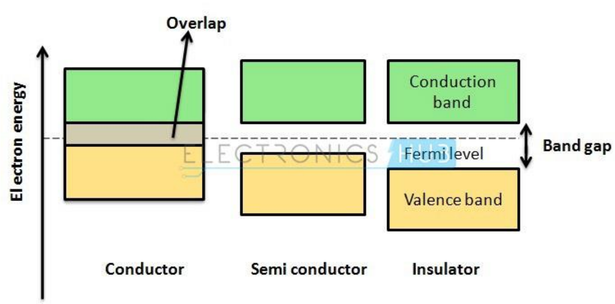
Introduction

- There are two types of semiconductor components in electronic and electrical circuits. They are active and passive components. Diodes are the foremost active components and resistors are the foremost passive components in electronic design circuits. Diodes are essentially unidirectional devices having exponential relationship for the current-voltage characteristics are made from semiconductor materials.

- The three necessary materials that are utilized in electronics are insulators, semiconductors and conductors. These materials are classified in terms of electrical phenomenon. Electrical resistivity conjointly known as electrical resistance is a measure of how efficiently a material refuses the electrical current to flow through it.

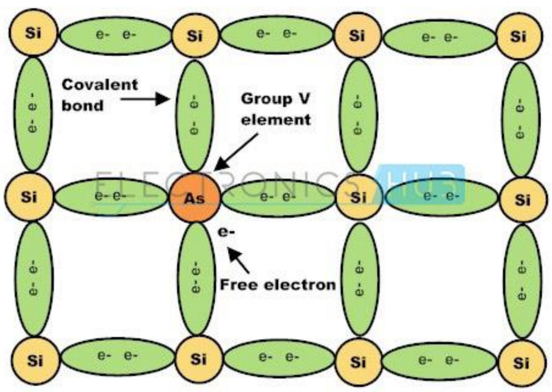
- The quality unit of the electrical resistivity is the ohm meter [Ω m]. A material with low electrical resistivity indicates the effective movement of electrical charge throughout the semiconductor.

- Semiconductors are the materials whose resistivity values are in between insulators and conductors. These materials are neither smart insulators nor smart conductors. They have only a few free electrons because their atoms are tightly bonded in an exceedingly crystalline form are referred to as a "crystal lattice". Samples of semiconductors are silicon and germanium.



- Semiconductors have high importance in the manufacture of electronic circuits and integrated devices. The conductivity of semiconductors can be altered easily by varying the temperature and concentration of doping in the fabrication process. The capability to conduct electricity in semiconductor materials is considerably increased by a adding definite quantity of impurities to the crystalline lattice producing additional free electrons than holes.

- The properties of semiconductor materials change considerably by adding small amounts of impurities to it. The process of shifting the balance between electrons and holes by incorporating impurity atoms in the silicon crystal lattice is called as doping. These impurity atoms are known as dopants. Based on the type of doping material incorporated, semiconductor crystals are classified into two types particularly n-type semiconductors and p-type semiconductors.

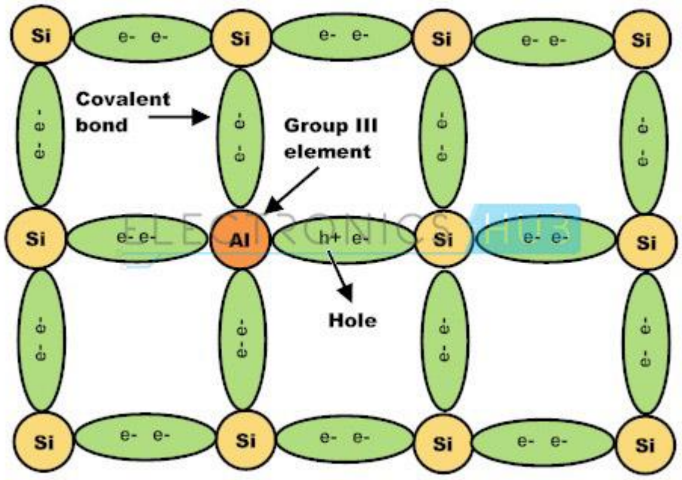


- Group –V elements such as phosphorus, antimony and arsenic are usually classified as N-type impurities. These elements have five valence electrons. When N-type impurities are doped into silicon crystal, four of the five valence electrons form four strong covalent bonds with adjacent crystal atoms leaving one free electron.

- Likewise, every N-type impurity atom produces a free electron in the conduction band which will drift to conduct electric current if a potential is applied to the material. N-type semiconductors can also be referred as Donors.

- Group–III elements such as boron, aluminium, gallium and indium are usually classified as P-type impurities. These elements have three valence electrons. When P-type impurities are doped into silicon crystal, all the three valence electrons form three strong covalent bonds with adjacent crystal atoms.

- There is a deficit of electrons to form the fourth covalent bond and this deficiency is termed as holes. Likewise, every P-type impurity atom produces a hole in the valence band which will drift to conduct electric current if a potential is applied to the material. P-type semiconductors can also be referred as Acceptors.



Conductors:

- Conductors are built with low resistive materials having resistivity values in the order of micro-ohms per meter (μΩ/m). Metals with terribly low electrical resistivity of the order of 1 x ohm meters are called as conductors. These metals have a large number of free electrons.

- These free electrons leave the valence layer of their parental atom and form a drift of electrons known as an electric current. Therefore, metals are superb conductors of electricity.

- Metals like copper, aluminium, gold and silver and other non metals such as carbon are ancient conducting materials. Most of the metallic conductors are good conductors of electricity, having smaller resistance values and high conduction values.

- Throughout the process of conduction, heat flows throughout the body. During conduction this heat flow may be considered as a loss of energy and the loss increases with increase in temperature after it reaches the room temperature i.e., 25°C.

Insulators:

- In distinction to conductors, insulators are made up of non-metals having resistivity values in the order of 1 x ohm meters. Non-metals have only a few or no free electrons flowing through it or within the parental atomic structure as the outermost electrons are tightly bonded in covalent bonds between a pair of atoms. Since the electrons are negatively charged, the free electrons within the valence layer are easily attracted by the positively charged particles within the nucleus.

- Since there are no free electrons, when a positive potential is applied, there will be no electrical current to flow through the material giving insulating properties. Therefore insulators (non-metals) are very poor conductors of electricity.

- Non-metals like glass, plastic, rubber, wood, sand, quartz and Teflon are sensible examples of insulators. Glass insulators are used for prime voltage power transmission. Insulators are used as protectors of warmth, sound and electricity.

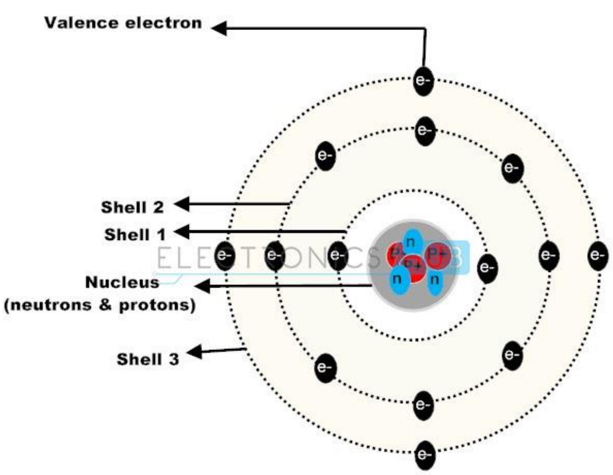
Semiconductors:

- Semiconductors have the electrical properties in between insulators and conductors. Smart examples of perfect semiconductors are silicon (Si), germanium (Ge) and gallium arsenide (GaAs). These elements have only a few electrons within the parental atomic structure that form a crystal lattice.

- Silicon, the basic semiconductor material, contains four valence electrons within the outer shell forming four strong covalent bonds with four adjacent silicon atoms, such that each atom shares an electron with the neighbouring atom creating a strong covalent bond. The silicon atoms are organized in a lattice form, creating them a crystalline structure.

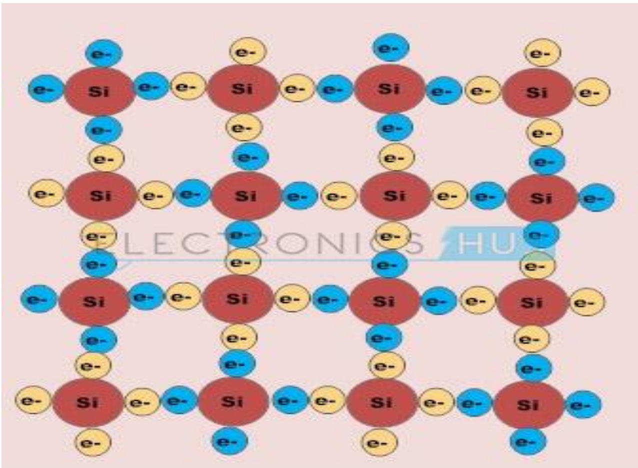
- Conducting electric current is feasible with silicon semiconductor crystal by supplying external potential to the semiconductor and incorporating the impurity dopants into the semiconductor crystal thereby creating positive and negative charged holes.

Structure of Pure Silicon Atom:



The silicon atom has 14 electrons; however the orbital arrangement has solely 4 valence electrons to be shared by alternative atoms. These valence electrons play a crucial role in photo voltaic effect. Large number of silicon atoms bond together to make a crystalline structure.

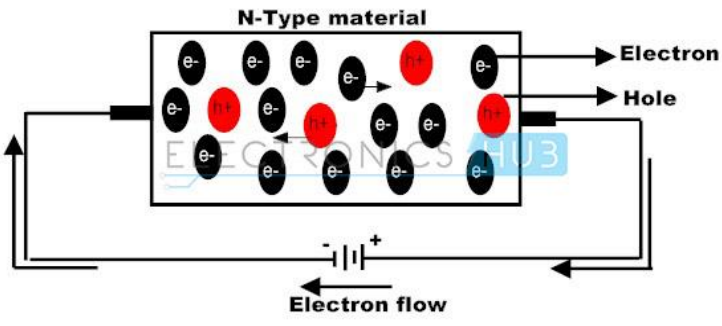
In this structure, each silicon atom shares one of its four valence electrons with their neighboring silicon atoms. The solid silicon crystal composed of a regular series of units of five silicon atoms. This regular and fixed arrangement of silicon atoms are unit is referred to as a crystal lattice.



N-Type Semiconductor:

Impurities like phosphorous, arsenic and antimony are added to the silicon crystalline structure, to transform intrinsic semiconductor into extrinsic semiconductor. These impurity atoms are known as pentavalent impurities as a result of the five valence electrons in the outermost shell to share the free electrons with the neighbouring atoms.

Pentavalent impurity atoms are also known as donors because the five valence electrons in the impurity atom bond with the four valence electrons of silicon forming four covalent bonds, leaving one free electron. Each impurity atom produces a free electron within the conduction band. Once a positive potential is applied to the N-type semiconductor, the remaining free electrons form a drift to produce an electrical current.

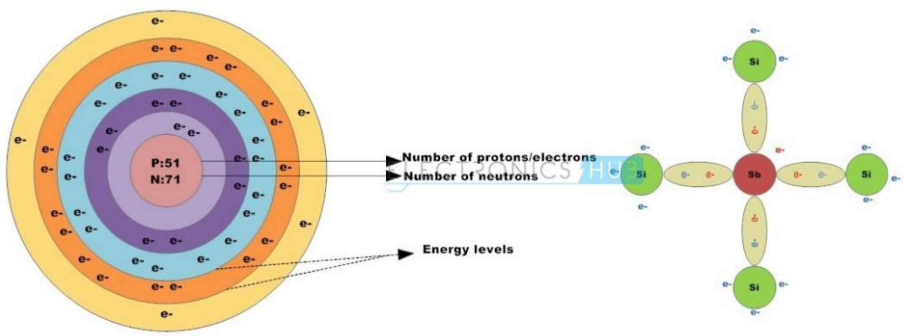


An N-type semiconductor is a better conductor than the intrinsic semiconductor material. The majority charge carriers in N-type semiconductors are electrons and minority charge carriers are holes. The N-type semiconductors are not negatively charged, because the negative charge of donor impurity atoms is balanced by the positive charge within the nucleus.

The major contribution to the electric current flow is negatively charged electrons though there is some amount of contribution by the positively charged holes due to electron-hole pair.

N-type Semiconductor Doping

If group 5 element, such as Antimony impurity is added to the silicon crystal, the Antimony atom builds four covalent bonds with four silicon atoms by bonding the valence electrons of antimony with the valence electrons within the silicon outermost shell, leaving one free electron. Therefore the impurity atom has donated a free electron to the structure so these impurities are referred to as donor atoms.

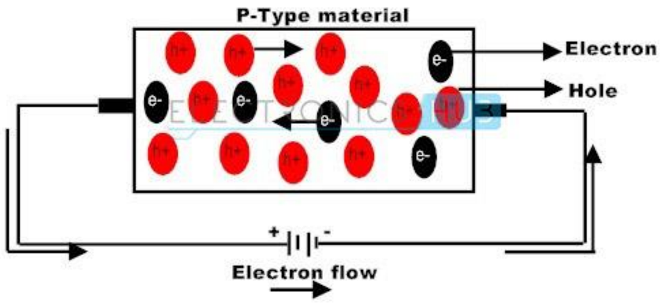


P-Type Semiconductor:

The group 3 elements such as boron, aluminium and indium are supplementary to the silicon crystalline structure having solely three electrons within the outermost shell, form three closed covalent bonds, leaving the hole in the covalent bond structure and therefore a hole in the valence band of the energy level diagram.

This action leaves an abundant number of positively charged carriers referred to as holes in the crystalline structure when there is electron deficiency. These group 3 elements are called as trivalent impurity atoms.

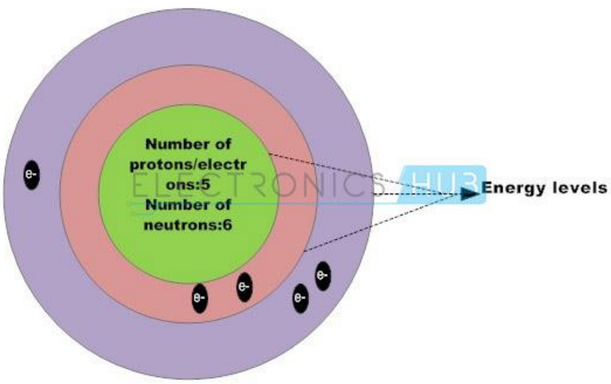
The presence of abundant holes attracts the neighboring electrons to sit in it. As long as the electron fills the holes in the silicon crystal there will be new holes behind the electron as it goes far from it. The newly created holes successfully attract the electrons, creating other new holes leads to the movement of holes, creating a standard electric current flow in the semiconductor.



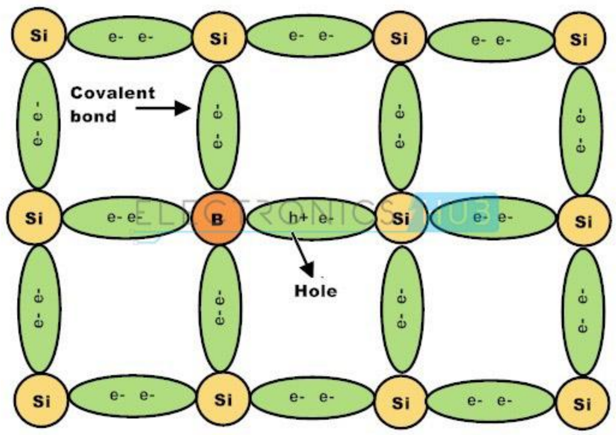
The movement of holes in the silicon crystal seems the silicon crystal as a positive pole. As long as the impurity atoms invariably generate holes, group 3 elements are referred to as acceptors as a result of the impurity atoms are continually accepting the free electrons.

The doping of group 3 elements in silicon crystal leads to P-type semiconductor. In this P-type semiconductor holes are the majority charge carriers and electrons are the minority charge carriers.

P-Type Semiconductor Doping



If group 3 elements such as such as boron, gallium and indium are added to the semiconductor crystal, the impurity atoms having three valence electrons form three strong covalent bonds with the silicon crystal valence electrons leaving one vacancy. This vacancy is called as a hole and it is diagrammatically represented by a small circle or positive sign due to the absence of a negative charge.



In N-type Semiconductors

- The impurity atoms are pentavalent elements.
- Impurity elements with solid crystal give a large number of free electrons.
- Pentavalent impurities are also called as donors.
- Doping gives the less number of holes in relation to the number of free electrons.
- Doping with group 5 elements results in positively charged donors and negatively charged free electrons.

P-type materials are a type of materials formed when group 3 elements (trivalent impurity atoms) are added to the solid crystal. In these semiconductors the current flow is mainly due to the holes.

In P-type Semiconductors

1. The impurity atoms are trivalent elements.
2. Trivalent elements results in excess number of holes which always accepts electrons. Hence trivalent impurities are called as acceptors.
3. Doping gives the less number of free electrons in relation to the number of holes.
4. Doping results in negatively charged acceptors and positively charged holes

Both p-type and N-type are electrically neural on their own because the contribution of electrons and holes required for conducting electrical current are equal due to electron-hole pair. Both boron (B) and antimony (Sb) are called metalloids because they are the most commonly used doping agents for the intrinsic semiconductor to improve the properties of conductivity.

P-N DIODE:

The effect of adding this additional energy source results in the free electrons being able to cross the depletion region from one side to the other. The behaviour of the PN junction with regards to the potential barrier's width produces an asymmetrical conducting two terminal device, better known as the **PN Junction Diode**.

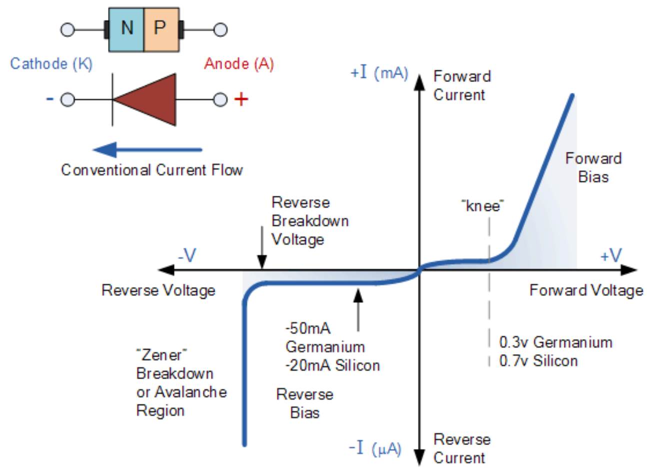
A *PN Junction Diode* is one of the simplest semiconductor devices around, and which has the characteristic of passing current in only one direction only. However, unlike a resistor, a diode does not behave linearly with respect to the applied voltage as the diode has an exponential current-voltage (I-V) relationship and therefore we can not described its operation by simply using an equation such as Ohm's law.

If a suitable positive voltage (forward bias) is applied between the two ends of the PN junction, it can supply free electrons and holes with the extra energy they require to cross the junction as the width of the depletion layer around the PN junction is decreased.

By applying a negative voltage (reverse bias) results in the free charges being pulled away from the junction resulting in the depletion layer width being increased. This has the effect of increasing or decreasing the effective resistance of the junction itself allowing or blocking current flow through the diode.

Then the depletion layer widens with an increase in the application of a reverse voltage and narrows with an increase in the application of a forward voltage. This is due to the differences in the electrical properties on the two sides of the PN junction resulting in physical changes taking place. One of the results produces rectification as seen in the PN junction diodes static I-V (current-voltage) characteristics. Rectification is shown by an asymmetrical current flow when the polarity of bias voltage is altered as shown below.

Junction Diode Symbol and Static I-V Characteristics



But before we can use the PN junction as a practical device or as a rectifying device we need to firstly **bias** the junction, ie connect a voltage potential across it. On the voltage axis above, "Reverse Bias" refers to an external voltage potential which increases the potential barrier. An external voltage which decreases the potential barrier is said to act in the "Forward Bias" direction.

There are two operating regions and three possible "biasing" conditions for the standard **Junction Diode** and these are:

- 1. Zero Bias – No external voltage potential is applied to the PN junction diode.

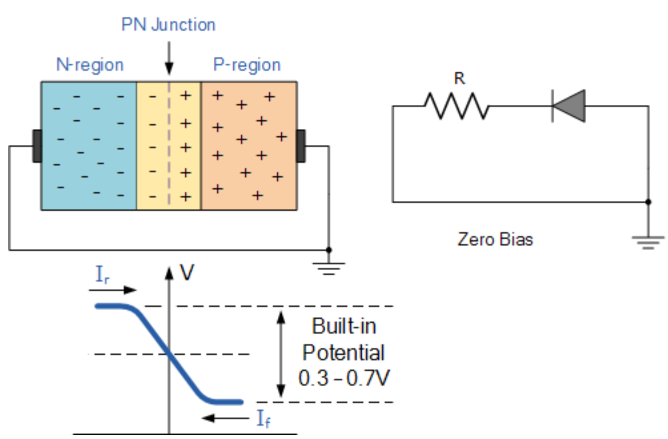
- 2. Reverse Bias – The voltage potential is connected negative, (-ve) to the P-type material and positive, (+ve) to the N-type material across the diode which has the effect of **Increasing** the PN junction diode's width.
- 3. Forward Bias – The voltage potential is connected positive, (+ve) to the P-type material and negative, (-ve) to the N-type material across the diode which has the effect of **Decreasing** the PN junction diodes width.

Zero Biased Junction Diode

When a diode is connected in a **Zero Bias** condition, no external potential energy is applied to the PN junction. However if the diodes terminals are shorted together, a few holes (majority carriers) in the P-type material with enough energy to overcome the potential barrier will move across the junction against this barrier potential. This is known as the "**Forward Current**" and is referenced as I_F

Likewise, holes generated in the N-type material (minority carriers), find this situation favourable and move across the junction in the opposite direction. This is known as the "**Reverse Current**" and is referenced as I_R. This transfer of electrons and holes back and forth across the PN junction is known as diffusion, as shown below.

Zero Biased PN Junction Diode



The potential barrier that now exists discourages the diffusion of any more majority carriers across the junction. However, the potential barrier helps minority carriers (few free electrons in the P-region and few holes in the N-region) to drift across the junction.

Then an "Equilibrium" or balance will be established when the majority carriers are equal and both moving in opposite directions, so that the net result is zero current flowing in the circuit. When this occurs the junction is said to be in a state of "**Dynamic Equilibrium**".

The minority carriers are constantly generated due to thermal energy so this state of equilibrium can be broken by raising the temperature of the PN junction causing an increase in the generation of minority carriers, thereby resulting in an increase in leakage current but an electric current cannot flow since no circuit has been connected to the PN junction.

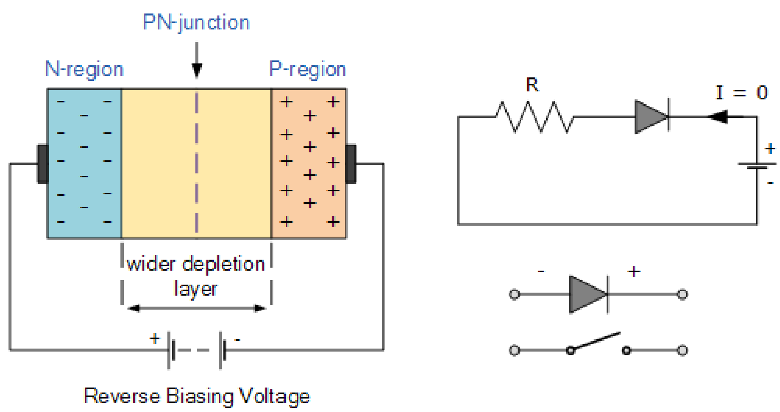
Reverse Biased PN Junction Diode

When a diode is connected in a **Reverse Bias** condition, a positive voltage is applied to the N-type material and a negative voltage is applied to the P-type material.

The positive voltage applied to the N-type material attracts electrons towards the positive electrode and away from the junction, while the holes in the P-type end are also attracted away from the junction towards the negative electrode.

The net result is that the depletion layer grows wider due to a lack of electrons and holes and presents a high impedance path, almost an insulator. The result is that a high potential barrier is created thus preventing current from flowing through the semiconductor material.

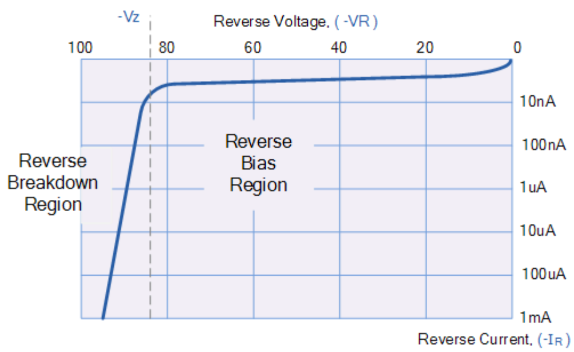
Increase in the Depletion Layer due to Reverse Bias



This condition represents a high resistance value to the PN junction and practically zero current flows through the junction diode with an increase in bias voltage. However, a very small **leakage current** does flow through the junction which can be measured in micro-amperes, (μA).

One final point, if the reverse bias voltage Vr applied to the diode is increased to a sufficiently high enough value, it will cause the diode's PN junction to overheat and fail due to the avalanche effect around the junction. This may cause the diode to become shorted and will result in the flow of maximum circuit current, and this shown as a step downward slope in the reverse static characteristics curve below.

Reverse Characteristics Curve for a Junction Diode



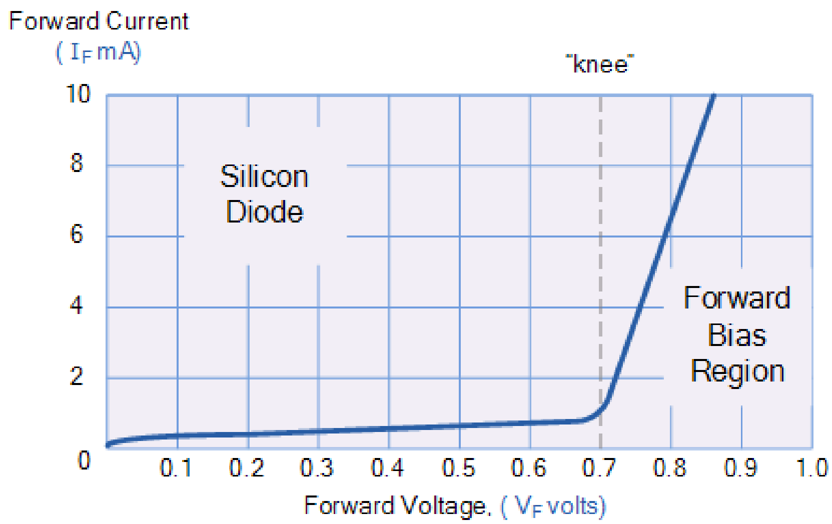
Sometimes this avalanche effect has practical applications in voltage stabilising circuits where a series limiting resistor is used with the diode to limit this reverse breakdown current to a preset maximum value thereby producing a fixed voltage output across the diode. These types of diodes are commonly known as Zener Diodes and are discussed in a later tutorial.

Forward Biased PN Junction Diode

When a diode is connected in a **Forward Bias** condition, a negative voltage is applied to the N-type material and a positive voltage is applied to the P-type material. If this external voltage becomes greater than the value of the potential barrier, approx. 0.7 volts for silicon and 0.3 volts for germanium, the potential barriers opposition will be overcome and current will start to flow.

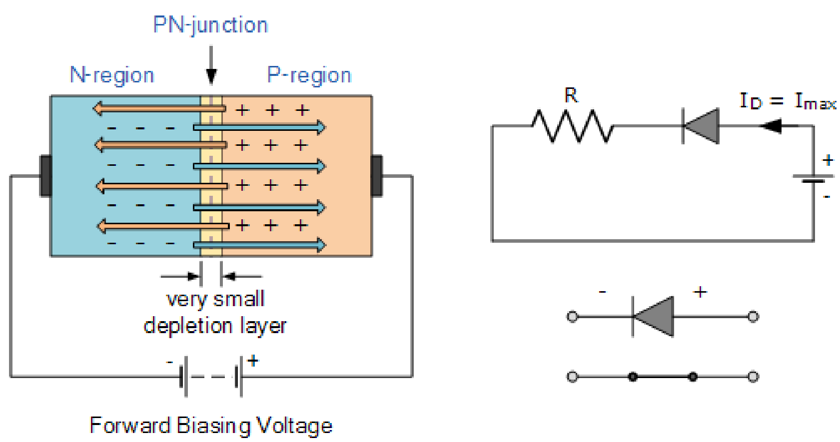
This is because the negative voltage pushes or repels electrons towards the junction giving them the energy to cross over and combine with the holes being pushed in the opposite direction towards the junction by the positive voltage. This results in a characteristics curve of zero current flowing up to this voltage point, called the “knee” on the static curves and then a high current flow through the diode with little increase in the external voltage as shown below.

Forward Characteristics Curve for a Junction Diode



The application of a forward biasing voltage on the junction diode results in the depletion layer becoming very thin and narrow which represents a low impedance path through the junction thereby allowing high currents to flow. The point at which this sudden increase in current takes place is represented on the static I-V characteristics curve above as the "knee" point.

Reduction in the Depletion Layer due to Forward Bias



This condition represents the low resistance path through the PN junction allowing very large currents to flow through the diode with only a small increase in bias voltage. The actual potential difference across the junction or diode is kept constant by the action of the depletion layer at approximately 0.3v for germanium and approximately 0.7v for silicon junction diodes.

Since the diode can conduct "infinite" current above this knee point as it effectively becomes a short circuit, therefore resistors are used in series with the diode to limit its current flow. Exceeding its maximum forward current specification causes the device to dissipate more power in the form of heat than it was designed for resulting in a very quick failure of the device.

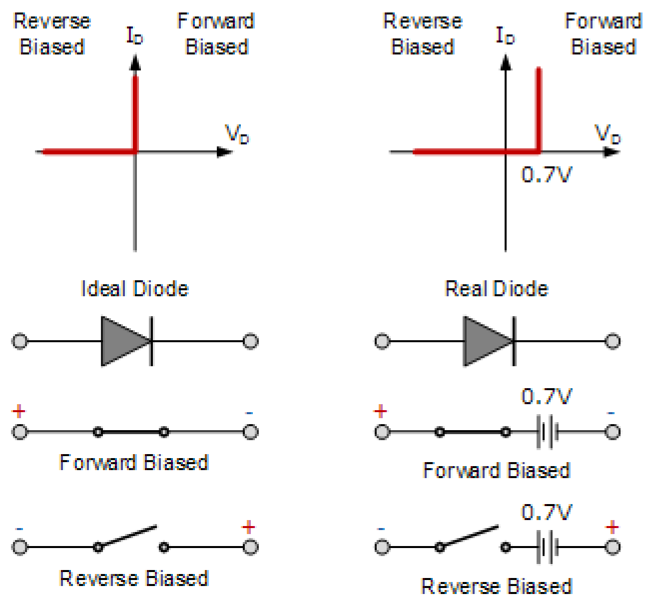
Junction Diode Summary

The PN junction region of a **Junction Diode** has the following important characteristics:

- Semiconductors contain two types of mobile charge carriers, “Holes” and “Electrons”.
- The holes are positively charged while the electrons negatively charged.
- A semiconductor may be doped with donor impurities such as Antimony (N-type doping), so that it contains mobile charges which are primarily electrons.
- A semiconductor may be doped with acceptor impurities such as Boron (P-type doping), so that it contains mobile charges which are mainly holes.
- The junction region itself has no charge carriers and is known as the depletion region.
- The junction (depletion) region has a physical thickness that varies with the applied voltage.
- When a diode is **Zero Biased** no external energy source is applied and a natural **Potential Barrier** is developed across a depletion layer which is approximately 0.5 to 0.7v for silicon diodes and approximately 0.3 of a volt for germanium diodes.
- When a junction diode is **Forward Biased** the thickness of the depletion region reduces and the diode acts like a short circuit allowing full current to flow.
- When a junction diode is **Reverse Biased** the thickness of the depletion region increases and the diode acts like an open circuit blocking any current flow, (only a very small leakage current).

We have also seen above that the diode is two terminal non-linear device whose I-V characteristic are polarity dependent as depending upon the polarity of the applied voltage, V_D the diode is either *Forward Biased*, $V_D > 0$ or *Reverse Biased*, $V_D < 0$. Either way we can model these current-voltage characteristics for both an ideal diode and for a real silicon diode as shown:

Junction Diode Ideal and Real Characteristics

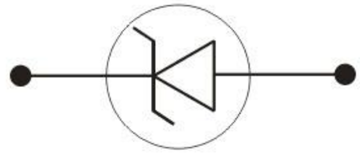


In the next tutorial about diodes, we will look at the small signal diode sometimes called a switching diode which is used in general electronic circuits. As its name implies, the signal diode is designed for low-voltage or high frequency signal applications such as in radio or digital switching circuits.

Signal diodes, such as the 1N4148 only pass very small electrical currents as opposed to the high-current mains rectification diodes in which silicon diodes are usually used. Also in the next tutorial we will examine the Signal Diode static current-voltage characteristics curve and parameters.

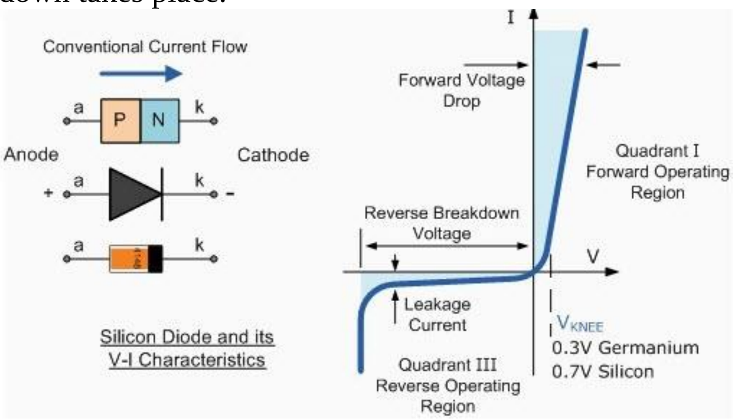
Zener Diode Circuit Working and Applications

The diode is one of the basic components in electronic circuits. When you want to know about voltage considerations you should know about the diodes. The diode is basically made up of semiconductors which have two characteristics, ‘P’ type and ‘N’ type. The ‘P’type and ‘N’ type semiconductors represent positive and negative type semiconductors. ‘P’type semiconductor will have excess amount of holes in configuration and ‘N’ type semiconductor will have excess amount of electrons. If both types of characteristics present in a single crystal then it can be termed as a diode. The positive terminal of the battery connects with the ‘P’ side and the negative side is connected with the ‘N’ side. Let’s discuss about Zener diode working, It is nothing but a simple diode connecting in reverse bias.



Zener Diode

It is mainly a special property of the diode rather than any special type of equipment. The person named Clearance Zener invented this property of the diode that's why it is named after him as a remembrance. The special property of the diode is that there will be a breakdown in the circuit if the voltage applied across a reversely biased circuit. This does not allow the current to flow across it. When the voltage across the diode is increased, temperature also increases and the crystal ions vibrate with greater amplitude and all these leads to the breakdown of the depletion layer. The layer at the junction of 'P' type and 'N' type. When the applied voltage exceeds an specific amount Zener breakdown takes place.



Zener Diode V-I

Zener diode is nothing but a single diode connected in a reverse bias mode and Zener diode can be connected in reverse bias positive in a circuit as shown as picture.we can connect it for different applications.

The circuit symbol of Zener diode is as shown in the figure. For convenience it is used normally. When discussing about the diode circuits we should look through the graphical representation of the operation of the Zener diode. It is called the V-I characteristics of a general p – n junction diode.

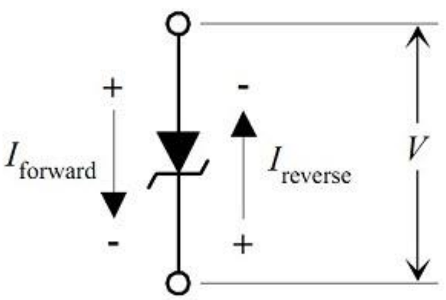
Characteristics of a Zener Diode

The above diagram shows the V-I characteristics of the Zener diode behavior. When the diode is connected in forward bias diodeacts as a normal diode. When the reverse bias voltage is greater than a predetermined voltage then the Zener breakdown voltage occurs. To get breakdown voltage sharp and distinct doping is controlled and the surface imperfections are avoided. In the V-I characteristics above Vz is the Zener voltage. And also the knee voltage because at this point the current is the current is very rapid.

Application of Zener Diode

Zener diode is popularly used as Shunt Regulator or Voltage Regulator. As we have gone through the first part of the article we know what is Zener diode and what is the basic principle of operation. Here the question arises where this type of diodes can be useful. Main application of this type of diodes are as voltage regulator.Over voltage protector, as voltage reference.

Over voltage protection is done by using Zener diodes because there is current flowing through the diode after the reverse bias voltage exceeds a certain voltage . This circuit provides safety for the equipment connected at the terminals. Normally the current should not exceed normal valve but if due to any fault in the circuit the current exceeds the maximum allowable voltage, then the equipment of the system can be damaged. A SCR is used, by it the output voltage is quickly cut down and a fuse blows which disconnects the input source power. The circuit arrangement is shown below for better understanding,



Zener Diode connection

Voltage reference determines the constant supply of power current or voltage as the Zener voltage works. If the supply of current is same then to avoid unstable performance we use Zener diodes. These are used where voltage reference is required like ammeters, ohmmeters and voltmeters.

Zener Diode as Voltage Regulator:

The term regulator means which regulates. The Zener diode can work as a voltage regulator if it is introduced in a circuit. The output across the diode will be constant. It is driven by a current source. As we know if the voltage across the diode exceeds a certain value it would draw excessive current from the supply. The basic diagram of Zener diode as voltage regulator is given below,

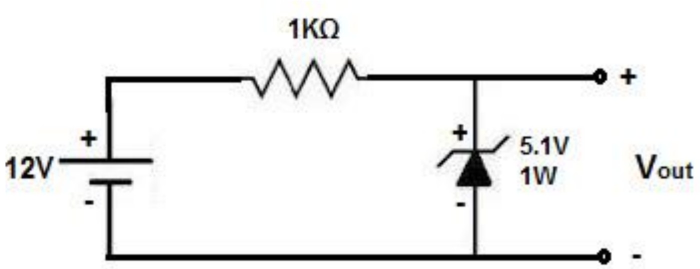
To fix the current through the Zener diode series resistance R is introduced whose value can be chosen from the following equation

Resistor value (ohms) = (V1 – V2) / (Zener current + load current)

The above diagram is of a shunt regulators because the regulating element is parallel to the load element. The Zener diode produces a stable reference voltage across the load which fulfills the criteria of regulator requirement.

The Zener diode allows current to flow in the forward direction in the same manner as an ideal diode. It also permits to flow in the reverse direction when the voltage is above a certain value known as breakdown voltage.

This device is named after Zener. Zener discovered this electrical property. A Zener diode is one in which the reverse breakdown occurs due to electron quantum tunneling under high electric field strength called Zener effect. Many diodes described as Zener diodes rely instead on avalanche breakdown. Both types are used with the Zener effect predominating under 5.6 V and avalanche breakdown above. Regular applications include providing a reference voltage for voltage regulators. This is to protect devices from momentary voltage pulses.



Zener Diode Connectivity

These devices are also encountered in series with a base emitter junction. At transistor stages where selective choice of a device centered around the avalanche or Zener point. It can be used to introduce compensating temperature coefficient balancing of the transistor . DC error amplifier used in a regulated power supply circuit feedback loop system is the on of the example.

These are also used in surge protectors to limit transient voltage spike systems and another application of the Zener diode is the use of noise caused by its avalanche breakdown in a random number generator. Can you tell me some more uses of Zener diode? By commenting….

Introduction to Transistor:

Earlier, the critical and important component of an electronic device was a vacuum tube; it is an electron tube used to control electric current. The vacuum tubes worked but they are bulky, require higher operating voltages, high power consumption, yield lower efficiency and cathode electron-emitting materials are used up in operation..

Transistor is a semiconductor device that can both conduct and insulate. A transistor can act as a switch and an amplifier. It converts audio waves into electronic waves and resistor, controlling electronic current. Transistors have very long life, smaller in size, can operate on lower voltage supplies for greater safety and required no filament current. The first transistor was fabricated with germanium. A transistor performs the same function as a vacuum tube triode, but using semiconductor junctions instead of heated electrodes in a vacuum chamber. It is the fundamental building block of modern electronic devices and found everywhere in modern electronic systems

A transistor is a three terminal device. Namely,

- Base: This is responsible for activating the transistor.
- Collector: This is the positive lead.
- Emitter: This is the negative lead.

The basic idea behind a transistor is that it lets you control the flow of current through one channel by varying the intensity of a much smaller current that's flowing through a second channel.

Bipolar Junction Transistor(BJT)

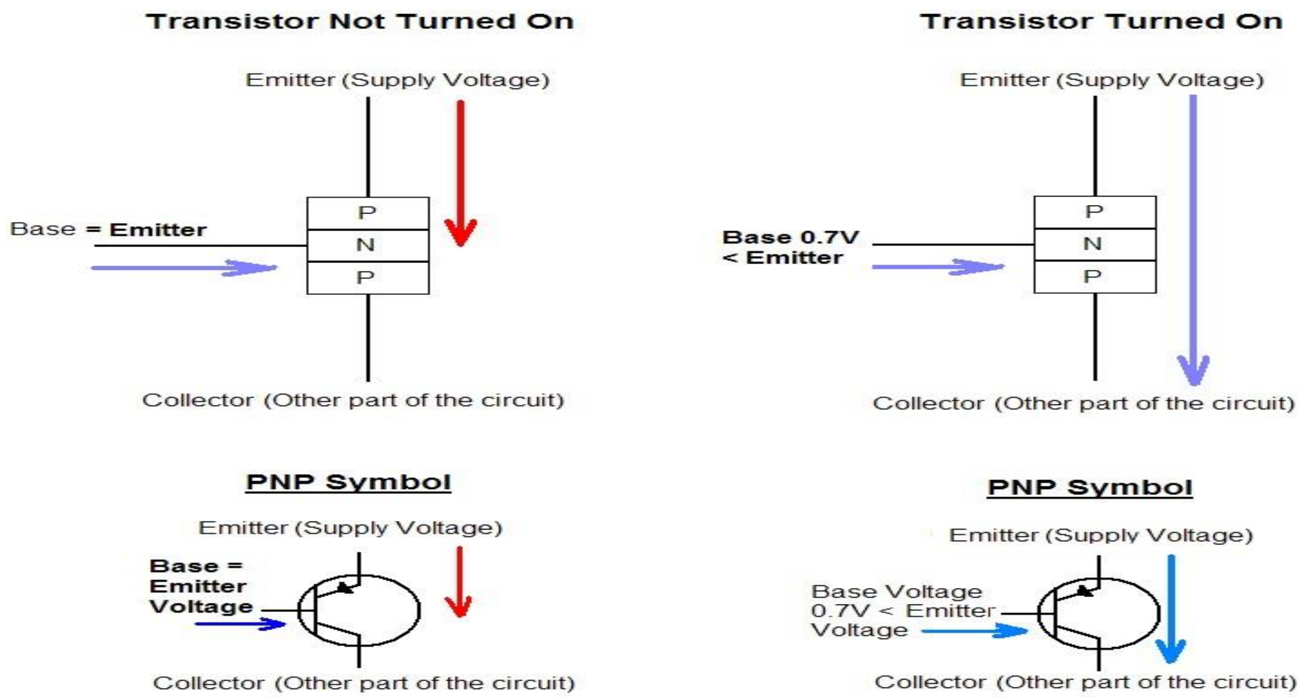
As you can see, transistors come in a variety of different sizes and shapes. One thing all of these transistors have in common is that they each have three leads.

- **Bipolar Junction Transistor:**

A Bipolar Junction Transistor (BJT) has three terminals connected to three doped semiconductor regions. It comes with two types, P-N-P and N-P-N.

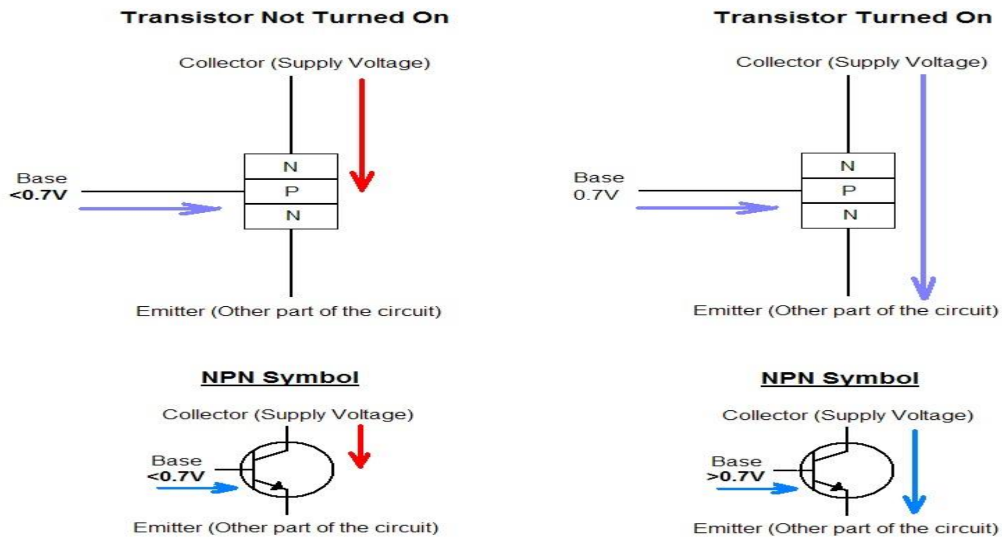
P-N-P transistor, consisting of a layer of N-doped semiconductor between two layers of P-doped material. The base current entering in the collector is amplified at its output.

That is when PNP transistor is ON when its base is pulled low relative to the emitter. The arrows of PNP transistor symbol the direction of current flow when the device is in forward active mode.

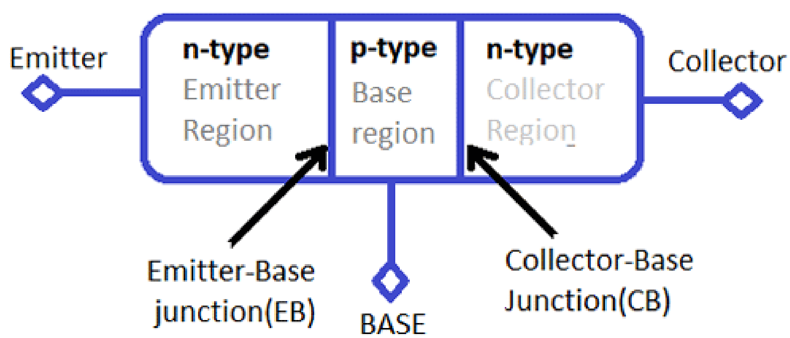


N-P-N transistor consisting a layer of P-doped semiconductor between two layers of N-doped material. By amplifying current the base we get the high collector and emitter current.

That is when NPN transistor is ON when its base is pulled low relative to the emitter. When the transistor is in ON state, current flow is in between the collector and emitter of the transistor. Based on minority carriers in P-type region the electrons moving from emitter to collector. It allows the greater current and faster operation; because of this reason most bipolar transistors used today are NPN.



Transistor consists of three layers of semiconductor, which have an ability to hold current. The electricity conducting material such as silicon and germanium has the ability to carry electricity between conductors and insulator which was enclosed by plastic wires. Semiconducting materials are treated by some chemical procedure called doping of the semiconductor. If silicon is doped with arsenic, phosphorous & antimony, it will obtain some extra charge carriers i.e., electrons, are known as **N-type or negative semiconductor** whereas if silicon is doped with another impurities like as boron, gallium, aluminum, it will obtain fewer charge carriers i.e., holes, are known as a **P-type or positive semiconductor**.



The working concept is the main part to understand how to use a transistor or how it works?, there are three terminals in the transistor:

- **Base:** It gives base to the transistor electrodes.
- **Emitter**: Charge carriers emitted by this.
- **Collector**: Charge carriers collected by this.

Different Configurations of Transistors:

In this transistor tutorial, we will learn about Different Configurations of Transistors. Since a Bipolar Junction Transistor is a 3-terminal device, there are three different configurations of Transistors possible with BJTs. Understanding these different configurations of transistors will help you in better implementation of your application.

We know that generally the transistor has three terminals – emitter (E), base (B) and collector. But in the circuit connections we need four terminals, two terminals for input and another two terminals for output. To overcome these problems we use one terminal as common for both input and output actions.

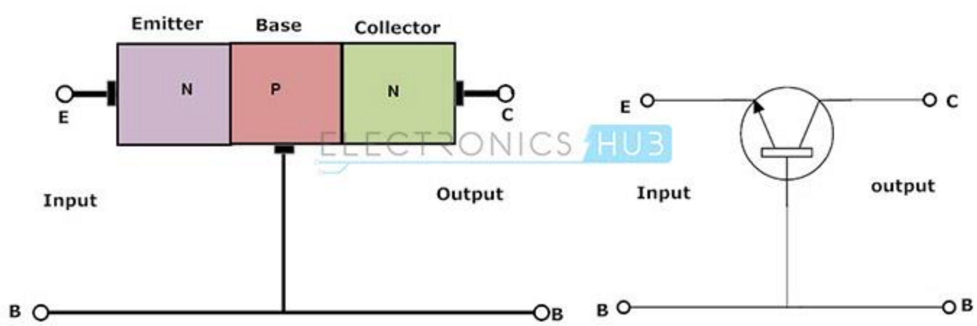
Using this property we construct the circuits and these structures are called transistor configurations. Generally there are three different configurations of transistors and they are common base (CB) configuration, common collector (CC) configuration and common emitter (CE) configuration.

The behavior of these three different configurations of transistors with respect to gain is given below.

- **Common Base (CB) Configuration**: no current gain but voltage gain
- **Common Collector (CC) Configuration**: current gain but no voltage gain
- **Common Emitter (CE) Configuration**: current gain and voltage gain

Now we discuss about these three different configurations of transistors with their input and output characteristics in the below sections.

Common Base Configuration:



In this configuration we use base as common terminal for both input and output signals. The configuration name itself indicates the common terminal. Here the input is applied between the base and emitter terminals and the corresponding output signal is taken between the base and collector terminals with the base terminal grounded. Here the input parameters are V_{EB} and I_E and the output parameters are V_{CB} and I_C. The input current flowing into the emitter terminal must be higher than the base current and collector current to operate the transistor, therefore the output collector current is less than the input emitter current.

The current gain is generally equal or less than to unity for this type of configuration. The input and output signals are in-phase in this configuration. The amplifier circuit configuration of this type is called as non-inverting amplifier circuit. The construction of this configuration circuit is difficult because this type has high voltage gain values.

The input characteristics of this configuration are looks like characteristics of illuminated photo diode while the output characteristics represents a forward biased diode. This transistor configuration has high output impedance and low input impedance. This type of configuration has high resistance gain i.e. ratio of output resistance to input resistance is high. The voltage gain for this configuration of circuit is given below.

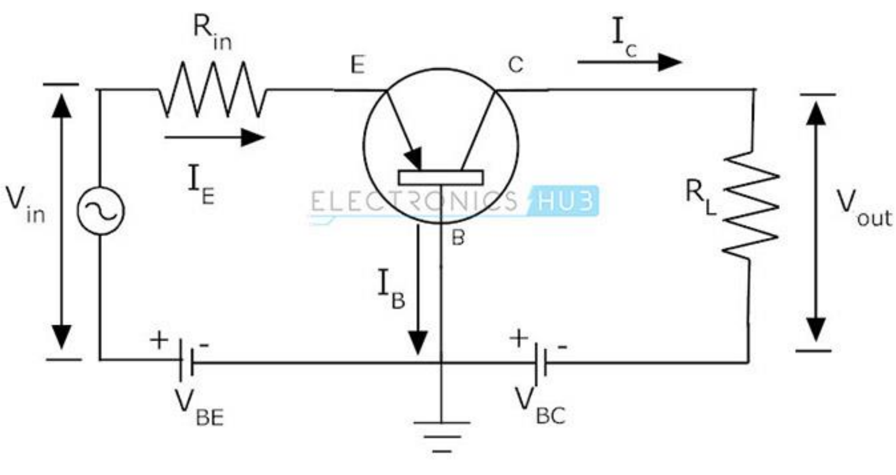
$$A_V = V_{out}/V_{in} = (I_C*R_L) / (I_E*R_{in})$$

Current gain in common base configuration is given as

$$\alpha = \text{Output current/Input current}$$

$$\alpha = I_C/I_E$$

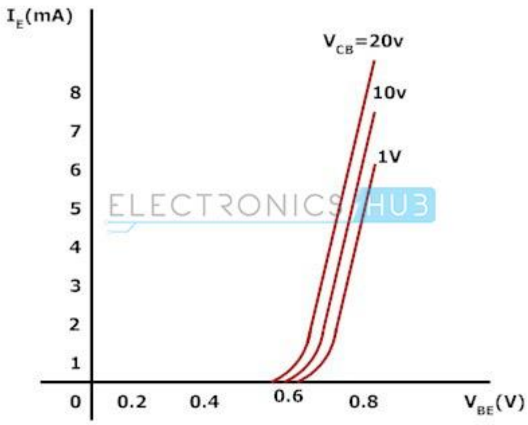
The common base circuit is mainly used in single stage amplifier circuits, such as microphone pre amplifier or radio frequency amplifiers because of their high frequency response. The common base transistor circuit is given below.



Input Characteristics

Input characteristics are obtained between input current and input voltage with constant output voltage. First keep the output voltage V_{CB} constant and vary the input voltage V_{EB} for different points then at each point record the input current I_E value. Repeat the same process at different output voltage levels. Now with these values we need to plot the graph between $I_E$and V_{EB} parameters. The below figure show the input characteristics of common base configuration. The equation to calculate the input resistance R_{in} value is given below.

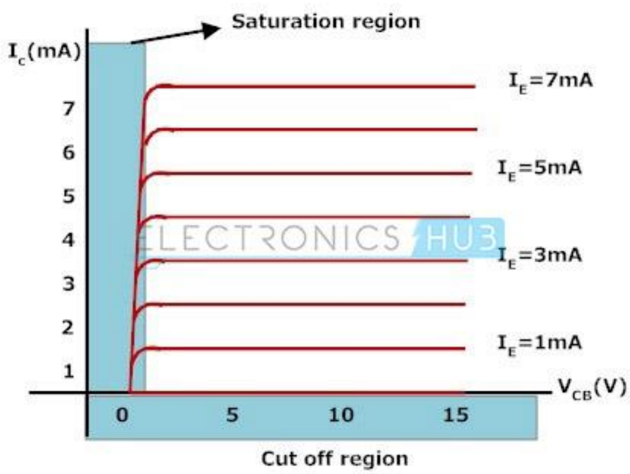
$$R_{in} = V_{EB} / I_E \text{ (when } V_{CB} \text{ is constant)}$$



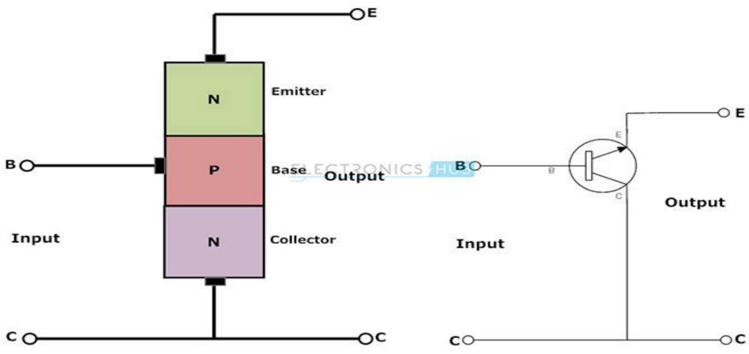
Output Characteristics

The output characteristics of common base configuration are obtained between output current and output voltage with constant input current. First keep the emitter current constant and vary the V_{CB} value for different points, now record the I_C values at each point. Repeat the same process at different I_E values. Finally we need to draw the plot between V_{CB} and I_C at constant I_E. The below figure show the output characteristics of common base configuration. The equation to calculate the output resistance value is given below.

$$R_{out} = V_{CB} / I_C \text{ (when } I_E \text{ is constant)}$$



Common Collector Configuration:



In this configuration we use collector terminal as common for both input and output signals. This configuration is also known as emitter follower configuration because the emitter voltage follows the base voltage. This configuration is mostly used as a buffer. These configurations are widely used in impedance matching applications because of their high input impedance.

In this configuration the input signal is applied between the base-collector region and the output is taken from the emitter-collector region. Here the input parameters are VBC and IB and the output parameters are VEC and IE. The common collector configuration has high input impedance and low output impedance. The input and output signals are in phase. Here also the emitter current is equal to the sum of collector current and the base current. Now let us calculate the current gain for this configuration.

Current gain,

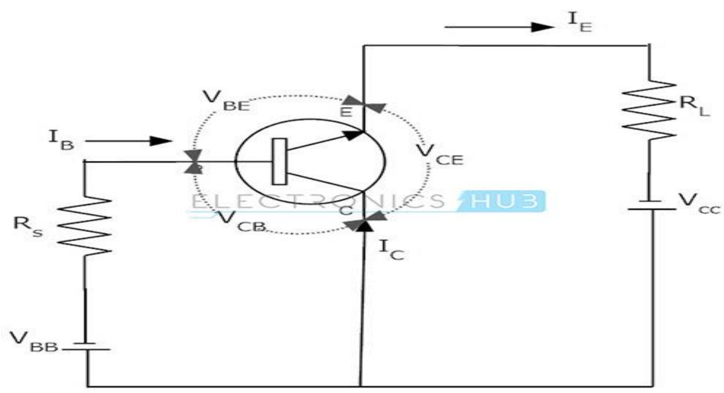
$$A_i = \text{output current}/\text{Input current}$$

$$A_i = I_E/I_B$$

$$A_i = (I_C + I_B)/I_B$$

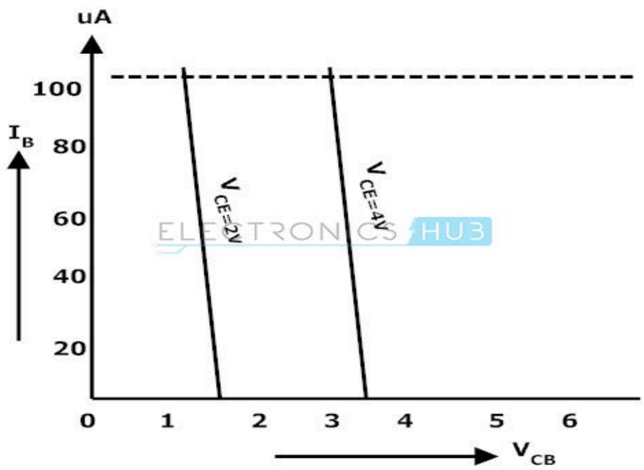
$$A_i = (I_C/I_B) + 1$$

$$A_i = \beta + 1$$



The common collector transistor circuit is shown above. This common collector configuration is a non inverting amplifier circuit. The voltage gain for this circuit is less than unity but it has large current gain because the load resistor in this circuit receives both the collector and base currents.

Input Characteristics



The input characteristics of a common collector configuration are quite different from the common base and common emitter configurations because the input voltage V_{BC} is largely determined by V_{EC} level. Here,

$$V_{EC} = V_{EB} + V_{BC}$$

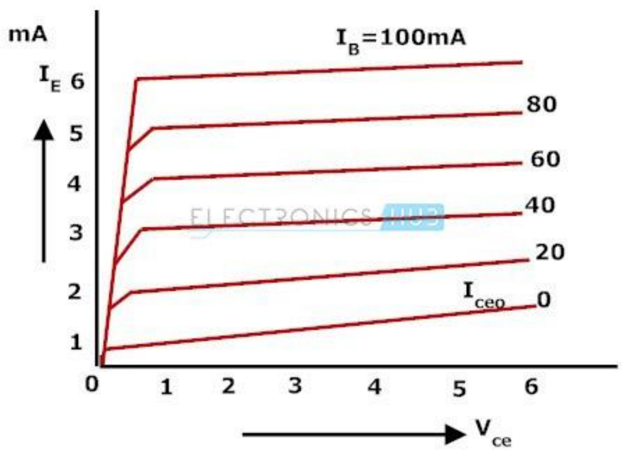
$$V_{EB} = V_{EC} – V_{BC}$$

The input characteristics of a common-collector configuration are obtained between inputs current I_B and the input voltage V_{CB} at constant output voltage V_{EC}. Keep the output voltage V_{EC} constant at different levels and vary the input voltage V_{BC} for different points and record the I_B values for each point. Now using these values we need to draw a graph between the parameters of V_{BC} and I_B at constant V_{EC}.

Output Characteristics

The operation of the common collector circuit is same as that of common emitter circuit. The output characteristics of a common collector circuit are obtained between the output voltage V_{EC} and output current I_E at constant input current I_B. In the operation of common collector circuit if the base current is zero then the emitter current also becomes zero. As a result no current flows through the transistor

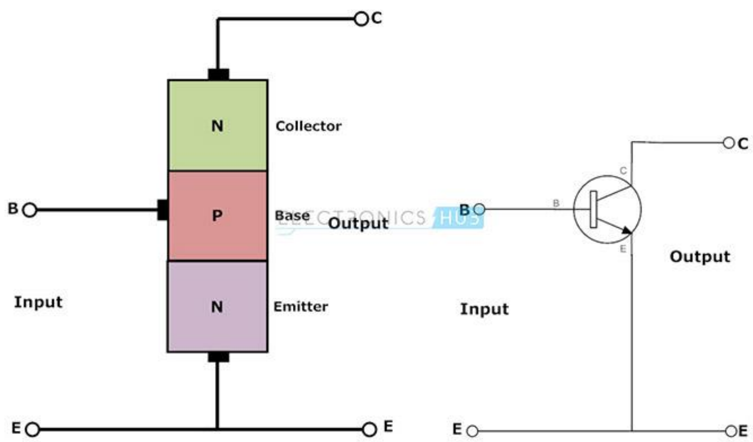
If the base current increases then the transistor operates in active region and finally reaches to saturation region. To plot the graph first we keep the I_B at constant value and we will vary the V_{EC} value for various points, now we need to record the value of I_E for each point. Repeat the same process for different I_B values. Now using these values we need to plot the graph between the parameters of I_E and V_{CE} at constant values of I_B. The below figure show the output characteristics of common collector.



Common Emitter Configuration:

In this configuration we use emitter as common terminal for both input and output. This common emitter configuration is an inverting amplifier circuit. Here the input is applied between base-emitter region and the output is taken between collector and emitter terminals. In this configuration the input parameters are V_{BE} and I_B and the output parameters are $V_{CE}$and I_C.

This type of configuration is mostly used in the applications of transistor based amplifiers. In this configuration the emitter current is equal to the sum of small base current and the large collector current. i.e. $I_E = I_C + I_B$. We know that the ratio between collector current and emitter current gives current gain alpha in Common Base configuration similarly the ratio between collector current and base current gives the current gain beta in common emitter configuration.



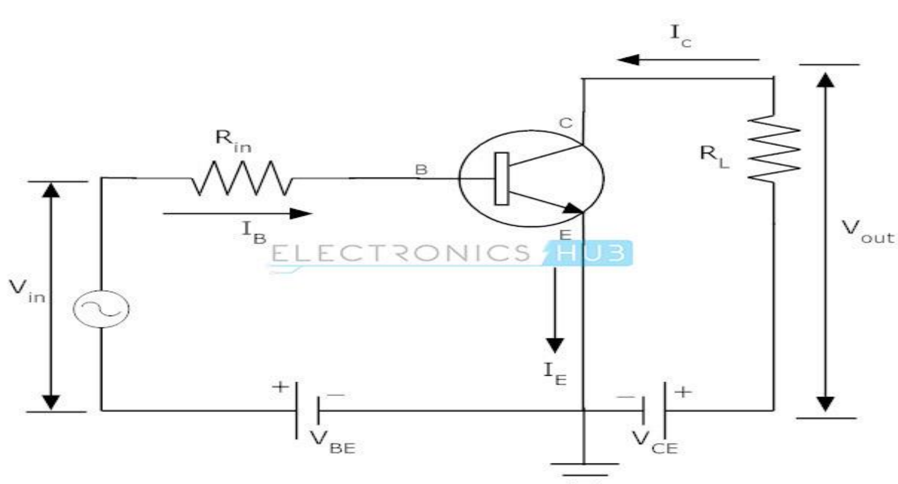
Now let us see the relationship between these two current gains.

$$\text{Current gain } (\alpha) = I_C/I_E$$

$$\text{Current gain } (\beta) = I_C/I_B$$

$$\text{Collector current } I_C = \alpha I_E = \beta I_B$$

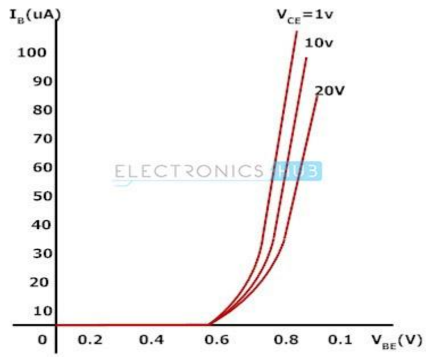
This configuration is mostly used one among all the three configurations. It has medium input and output impedance values. It also has the medium current and voltage gains. But the output signal has a phase shift of 1800 i.e. both the input and output are inverse to each other.



Input Characteristics

The input characteristics of common emitter configuration are obtained between input current I_B and input voltage V_{BE} with constant output voltage V_{CE}. Keep the output voltage V_{CE} constant and vary the input voltage V_{BE} for different points, now record the values of input current at each point. Now using these values we need to draw a graph between the values of I_B and V_{BE} at constant V_{CE}. The equation to calculate the input resistance R_{in} is given below.

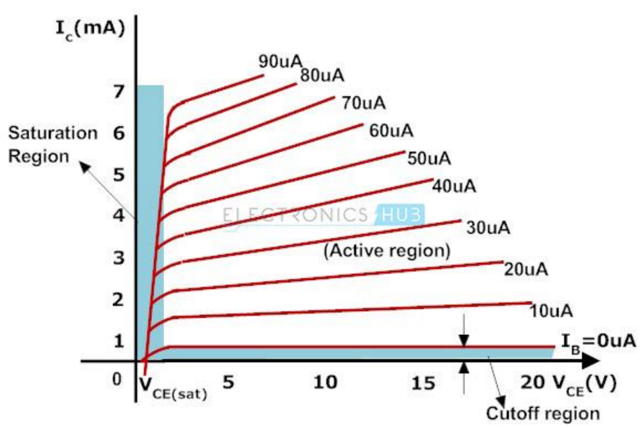
$$R_{in} = V_{BE}/I_B \text{ (when } V_{CE} \text{ is at constant)}$$



Output Characteristics

The output characteristics of common emitter configuration are obtained between the output current I_C and output voltage V_{CE} with constant input current I_B. Keep the base current I_B constant and vary the value of output voltage V_{CE} for different points, now note down the value of collector I_C for each point. Plot the graph between the parameters I_C and V_{CE} in order to get the output characteristics of common emitter configuration. The equation to calculate the output resistance from this graph is given below.

$$R_{out} = V_{CE}/I_C \text{ (when } I_B \text{ is at constant)}$$



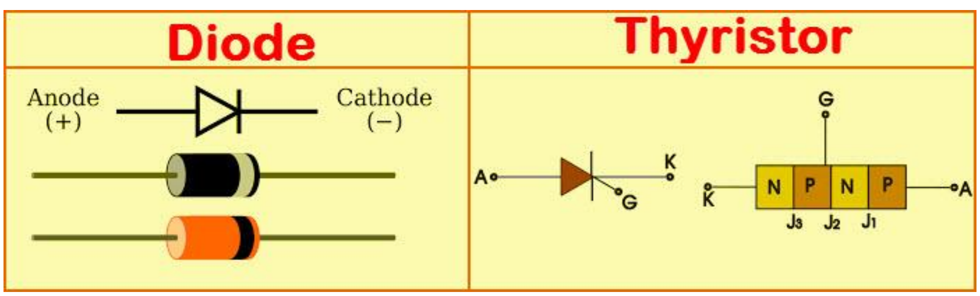
Configurations of Transistors Summary

Transistor Configuration Summary Table			
Transistor Configuration	**Common Base**	**Common Collector (Emitter Follower)**	**Common Emitter**
Voltage Gain	High	Low	Medium
Current Gain	Low	High	Medium
Power Gain	Low	Medium	High
Input / Output Phase Relationship	0°	0°	180°
Input Resistance	Low	High	Medium
Output Resistance	High	Low	Medium

The table which gives the main characteristics of a transistor in the three configurations is given above. The BJT transistors have mainly three types of configurations. They are common-emitter, common-base and common-collector configurations. Among all these three configurations common-emitter configuration is mostly used type. These three have different characteristics corresponding to both input and output signals. And also these three configurations have few similarities.

Characteristics and applications of a thyristor:

Thyristor is a multi-layer semiconductor device and consists of three terminals (anode terminal, cathode terminal, and gate terminal). The diodes are also called as uncontrolled rectifiers as they are unable to control (conducts in forward bias, i.e., when anode voltage is greater than the cathode voltage without any condition).

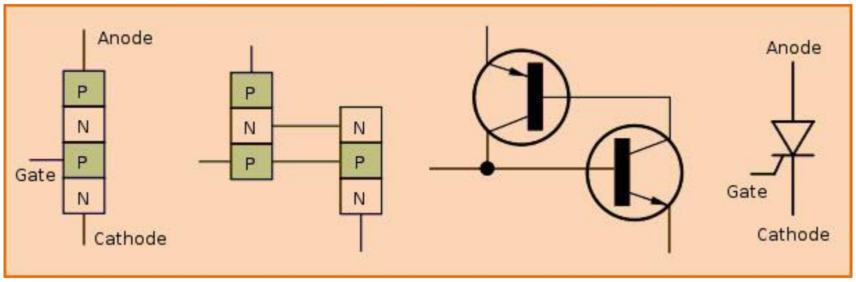


Diode and Thyristor Symbol

But, the thyristors can be controlled, i.e., thyristors starts conduction only when triggering signal is given to the gate terminal (in fact, anode terminal voltage must be greater than cathode terminal voltage). Thus, by giving gate triggering as per requirement, we can control the operation (ON or OFF) of thyristor. Hence, the thyristor is also termed as controlled rectifier and it is made of silicon, it is termed as silicon controlled rectifier.

Thyristor Basics

Generally, the diodes consists of two terminals, termed as two terminal rectifiers and transistors consists of three layers (P-N-P or N-P-N). But, thyristors consists of four layers (P-N-P-N) which are connected in series and having three P-N junctions. The thyristor is represented by the symbol as shown in the figure.



Thyristor Terminals and P-N-P-N Junctions

Thyristor conducts only in one direction, hence, it is termed as unidirectional device. The thyristor can be used as a rectifying diode (controlled rectifier) and also as an open circuit switch by appropriate triggering. Typically silicon, gallium arsenide, silicon carbide, gallium nitride, etc., materials are used to manufacture thyristors. But, silicon is mostly preferred for the manufacturing of thyristors because of its good thermal conductivity, high current capability, high voltage capability, and so on.

Thyristor Function

To better understand about the working of thyristor, let us consider the three modes of thyristor operation. The three modes of operation of silicon controlled rectifier are as follows:

1. Reverse blocking mode
2. Forward blocking mode
3. Forward conducting mode

Reverse Blocking Mode

If the anode terminal and cathode terminal connections of the thyristors are reversed, then the lower diode and the upper diode get reverse biased. Hence, there will be no conduction path, so no current flow and hence, this mode is termed as a reverse blocking mode of thyristor.

Forward Blocking Mode

The thyristor remains switched off until the triggering pulse is given to the gate terminal. Thus, even though the thyristor is in forward biased condition but no current will be there indicating that both the upper diode and lower diode are in forward biased condition but, the junction between these diodes is reverse biased. Hence, no current will flow through thyristor (but no triggering pulse provided to the gate terminal) even though it is forward biased, so, this mode is termed as forward blocking mode.

Forward Conducting Mode

In the thyristor forward conducting mode, the anode terminal voltage will be greater than the cathode terminal voltage and the (third) gate terminal is also triggered appropriately. Thus, we can say that the thyristor is forward biased (Va-anode voltage is greater than Vk-cathode voltage) and also gate is triggered, hence, the thyristor conducts and this mode is termed as forward conducting mode.

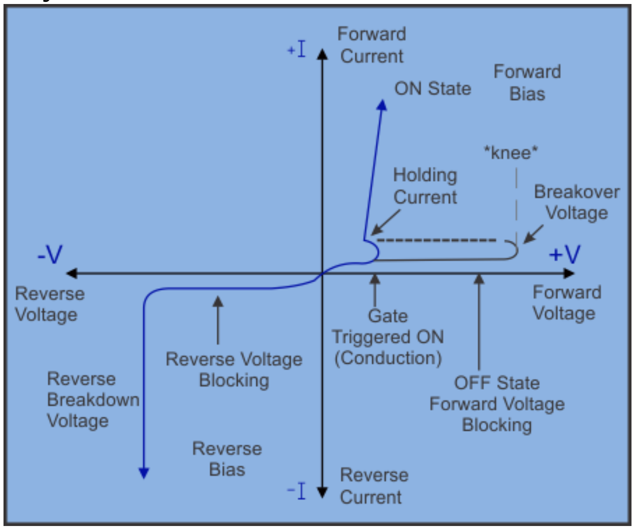
Gate Switching

The proper way of switching on a thyristor is by applying a positive voltage pulse to its gate with respect to the cathode. The junction J2 will become forward bias. The thyristor will switch into conduction state because all three junctions J1, J2, and J3 are forward biased.

During the conduction state, the thyristor acts like a diode. It will conduct current continuously without having any external control. It cannot switch off unless **(a)** the forward voltage is removed or **(b)** the current through the thyristor decreases then a level known as '**holding current**'.

A thyristor is a latching device. When it is triggered using gate input, the device remains latched in on-state. It does not need the continuous gate supply to remain in the conduction state. However, there is a latch; the anode current should not decrease from a limit known as '**latching current**'. The '**latching current**' is greater than the '**holding current**'.

Thyristor Characteristics



Thyristor Characteristics

The above figure shows the thyristor characteristics and also represents different modes of operation of thyristor, such as reverse blocking, forward blocking, and forward conducting mode. The thyristor V-I characteristics represent different parameters such as reverse blocking voltage, breakover voltage, reverse breakdown voltage, forward blocking voltage, holding current, and so on as shown in the above figure.

Thyristor Applications

In general, thyristors are typically used in different electronic circuits which are dealing with huge currents (around 100A) and voltages (around 1kV).

Thyristors are particularly used for reducing the circuit-internal power loss and for controlling power in the circuits. Thyristors are also used for rectification applications, i.e., for converting alternating current into direct current. Thyristors are frequently used to design the AC to AC converters (cycloconverters).

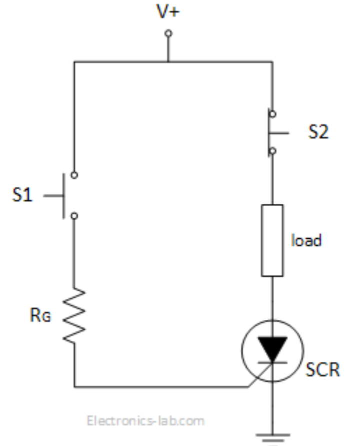
Practical Application of Thyristor

Speed control of induction motor using the thyristor power control technique is one of the practical application of thyristors. This method of controlling AC power to the load is the best technique and is more efficient compared to other techniques.

The main application of thyristors is to control high power circuits.
• They find applications in power supplies for digital circuits.
• AC & DC motor speed controllers consist of thyristors.
• A thyristor is also used in light dimmers.

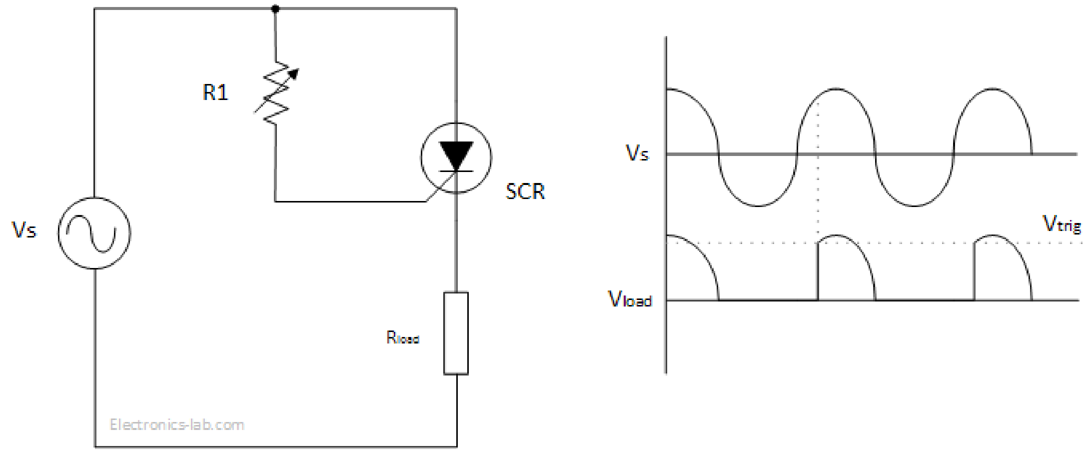
Basic SCR Applications

Basic Latching Circuit



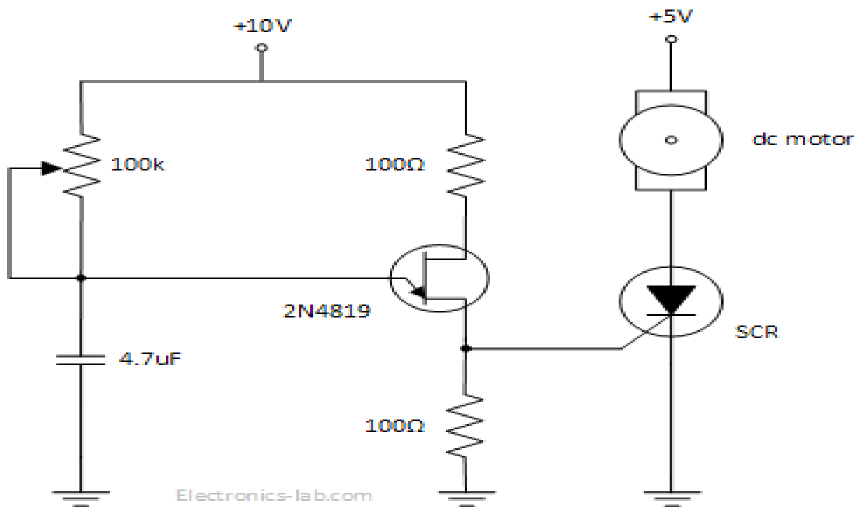
In this circuit a SCR is used to form a basic latching circuit. S1 is a normally open switch and S2 is a normally close switch. When S1 is pushed momentary a small current goes into the gate of SCR and turning it ON, thus powering the load. To turn it off we have to push the S2 push-button so the current through SCR stops. Resistor RG is used to set the gate voltage of SCR.

Power Control Circuit



In this circuit a SCR is used to modify a sinusoidal signal so that the load receives less power than of what would receive if source voltage was applied directly. The sinusoidal signal is applied to the gate of SCR via R1. When the voltage on the gate exceeds the trigger voltage of SCR, it goes to ON state and Vs is applied to the load. During the negative portion of the sine wave the SCR is in OFF state. Increasing R1 has the effect of decreasing the voltage applied to the gate of SCR and thus creating a lag in the conduction time. In this was the load is receiving power for less time and thus the average power to load is lower.

DC motor Speed Controller

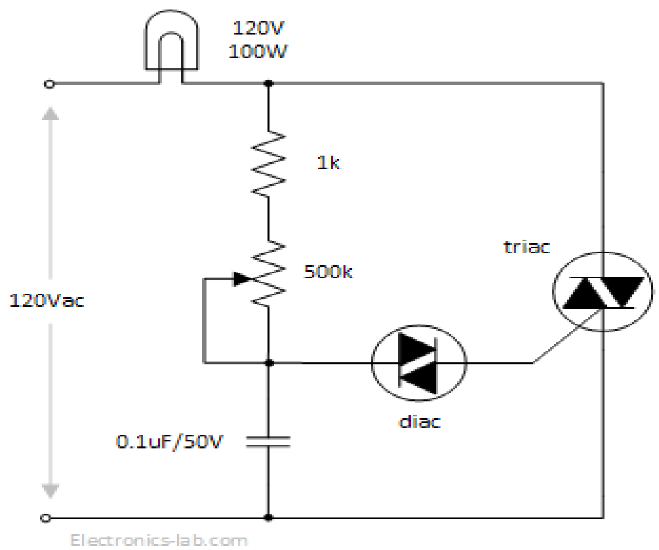


This is a variable speed DC motor controller using a UJT, a SCR and few passive components. UJT along with resistors and capacitor form an oscillator that supplies AC voltage to the gate of

SCR. When the gate voltage exceeds the triggering voltage of SCR, the SCR turns ON and motor is running. By adjusting the potentiometer the output frequency of oscillator is changing and thus the times the SCR triggered is changing, which in turn changes the speed of the motor. In this way the motor is receiving a series of pulses that average over time and the speed is adjusted.

Basic TRIAC Applications

AC Light Dimmer



This is an AC light dimmer formed by a diac, a triac and some passive components. The capacitor is charging through the two resistors and when the voltage on one end of the diac exceeds the breakdown voltage it goes ON and sends a current to the gate of triac putting the triac to ON state and thus powering the lamp. After the capacitor is discharged to a voltage below the breakdown voltage of diac, the diac, triac and lamp turn off. Then the capacitor is charged again and so on. So the lamp is only powered for a fraction of time during the full sinewave. This happens very quickly and the lamp seems dimmed. Brightness is adjusted using the potentiometer.