Lecture Notes

Unit:1

Semiconductor Devices and Applications:

Topics Covered:

Semiconductor Devices and Applications: Introduction to P-N junction Diode and V-I characteristics, Half wave and Full-wave rectifiers, capacitor filter. Zener diode and its characteristics, Zener diode as voltage regulator. Regulated power supply IC based on 78XX and 79XX series, Introduction to BJT, its input-output and transfer characteristics, BJT as a single stage CE amplifier, frequency response and bandwidth.

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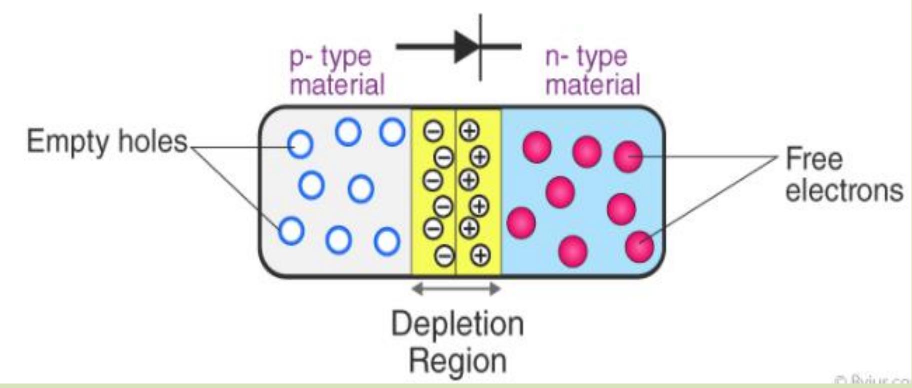
P-N Junction

A p-n junction is an interface or a boundary between two semiconductor material types, namely the p-type and the n-type, inside a semiconductor. In a semiconductor, the p-n junction is created by the method of **doping**. The p-side of the semiconductor has an excess of holes and the n-side has an excess of electrons.



When an electron diffuses from the n-side to the p-side, an ionized donor is left behind on the n-side, a layer of positive charge is developed on the n-side of the junction. Similarly a hole goes from the p-side to the n-side, and ionized acceptor is left behind in the p-side, resulting a layer of negative charges in the p-side of the junction. This region of positive charge and negative charge on either side of the junction is termed as the **depletion region**. Due to this positive space charge region on either side of the junction, an **electric field direction** from a positive charge towards the negative charge is developed. Due to this electric field, an electron on the p-side of the junction moves to the n-side of the junction.

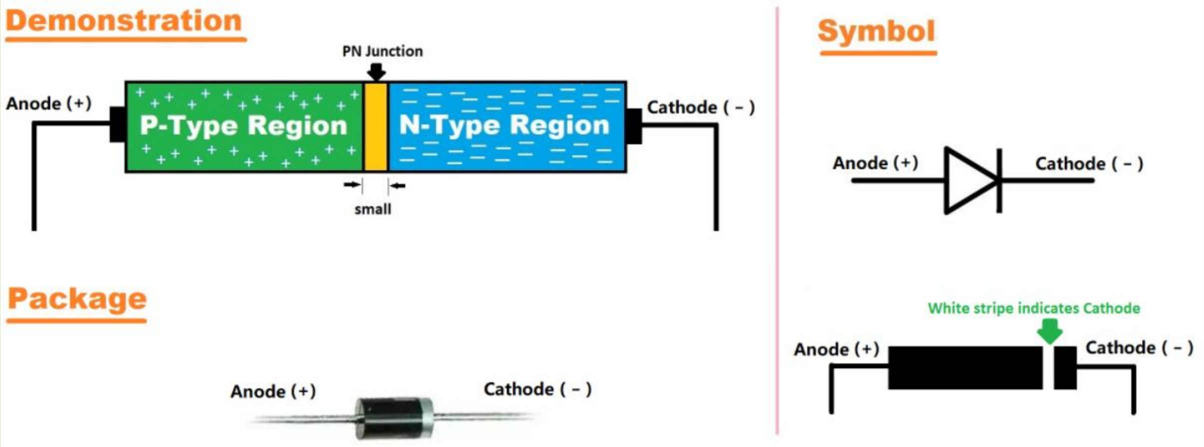
Without any external voltage being applied to the actual PN junction resulting in the junction being in a **state of equilibrium.**

However, if we were to make electrical connections at the ends of both the N-type and the P-type materials and then connect them to a battery source, an additional energy source now exists to overcome the potential barrier.

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, known as the **P-N Junction Diode**.

P-N Junction Diode

P-N junction diode is two-terminal or two-electrode semiconductor device, which allows the electric current in only one direction while blocks the electric current in opposite or reverse direction.



Biasing of P-N Junction Semiconductor Diode

The process of applying the external voltage to a p-n junction semiconductor diode is called biasing. External voltage to the p-n junction diode is applied in any of the two methods.

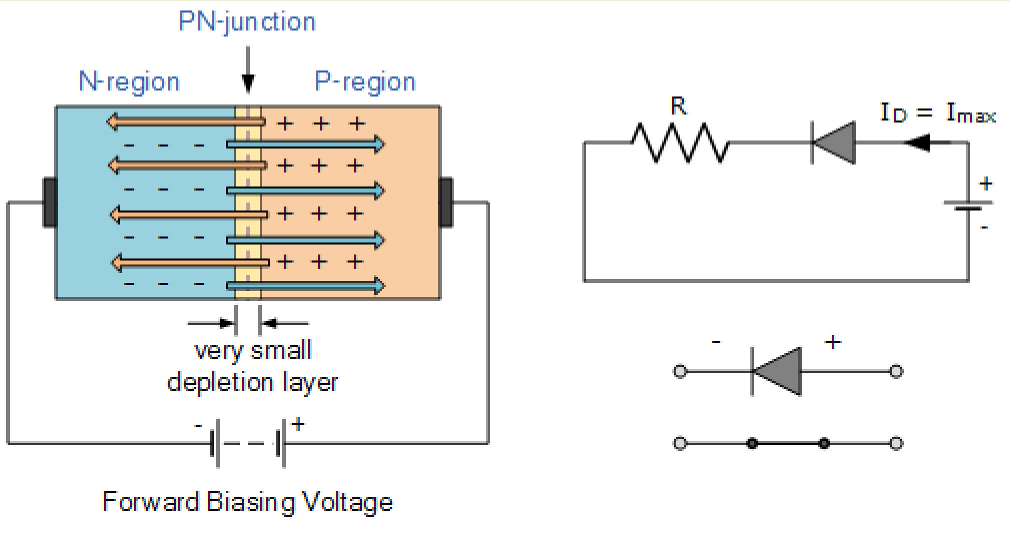
- ***Forward bias**:* The positive terminal of the voltage potential is connected to the p-type while the negative terminal is connected to the n-type. **it allows the electric current flow**.

- ***Reverse bias**:* The negative terminal of the voltage potential is connected to the p-type and the positive is connected to the n-type. **it blocks the electric current flow.**

Forward Bias

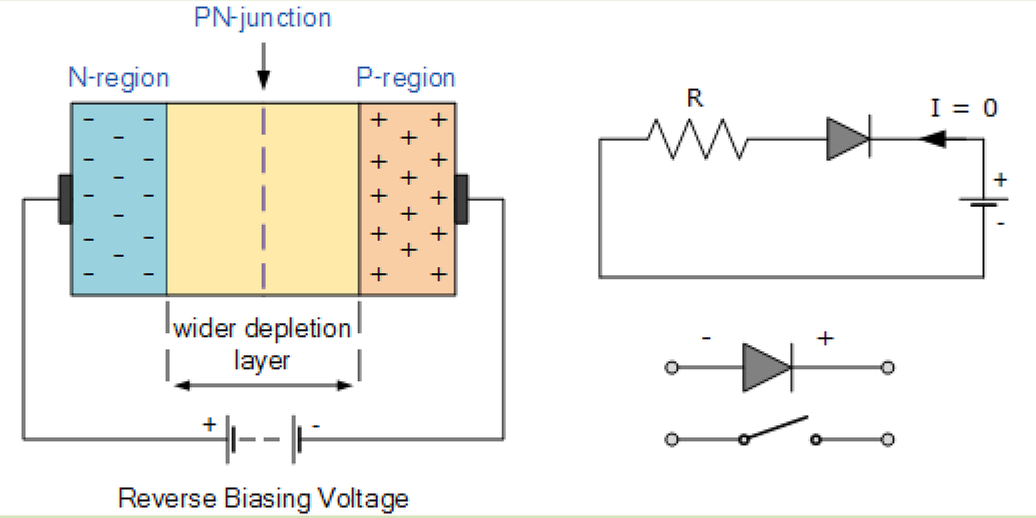
When the p-n junction is forward biased, the **built-in electric** field at the p-n junction and the **applied electric field** are in **opposite directions**. When both the electric fields add up, the resultant electric field has a magnitude lesser than the built-in electric field.

This results in a less resistive and thinner depletion region. The depletion region's resistance becomes **negligible** when the applied **voltage is large**. In silicon, at the voltage of 0.6 V, the resistance of the depletion region becomes completely negligible and the **current flows** across it unimpeded.



Reverse Bias

In this case, the **built-in electric field** and the **applied electric field** are in the **same direction**. When the two fields are added, the resultant electric field is in the **same direction** as the built-in electric field creating a **more resistive**, thicker depletion region. The depletion region becomes more resistive and thicker if the applied voltage becomes larger.



P-N Junction Formula

The formula used in the p-n junction depends upon the built-in potential difference created by the electric field is given as:

$$E_0 = V_T \, ln \left(\frac{N_D N_A}{n_i^2}\right)$$

Where,

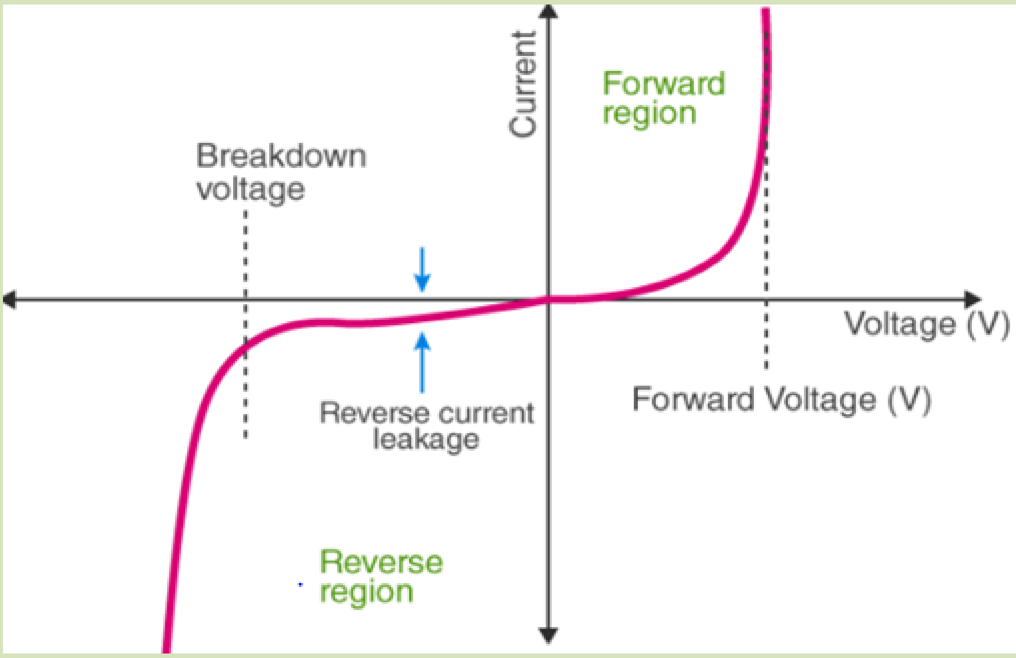
- E_0 is the zero bias junction voltage
- V_T is the thermal voltage of 26mV at room temperature
- N_D and N_A are the impurity concentrations
- n_i is the intrinsic concentration.

How does current flow in PN junction diode?

The flow of electrons from the n-side towards the p-side of the junction takes place when there is an increase in the voltage. Similarly, the flow of holes from the p-side towards the n-side of the junction takes place along with the increase in the voltage. This results in the concentration gradient between both sides of the terminals. Due to the formation of the concentration gradient, there will be a flow of charge carriers from higher concentration regions to lower concentration regions. The movement of charge carriers inside the p-n junction is the reason behind the current flow in the circuit.

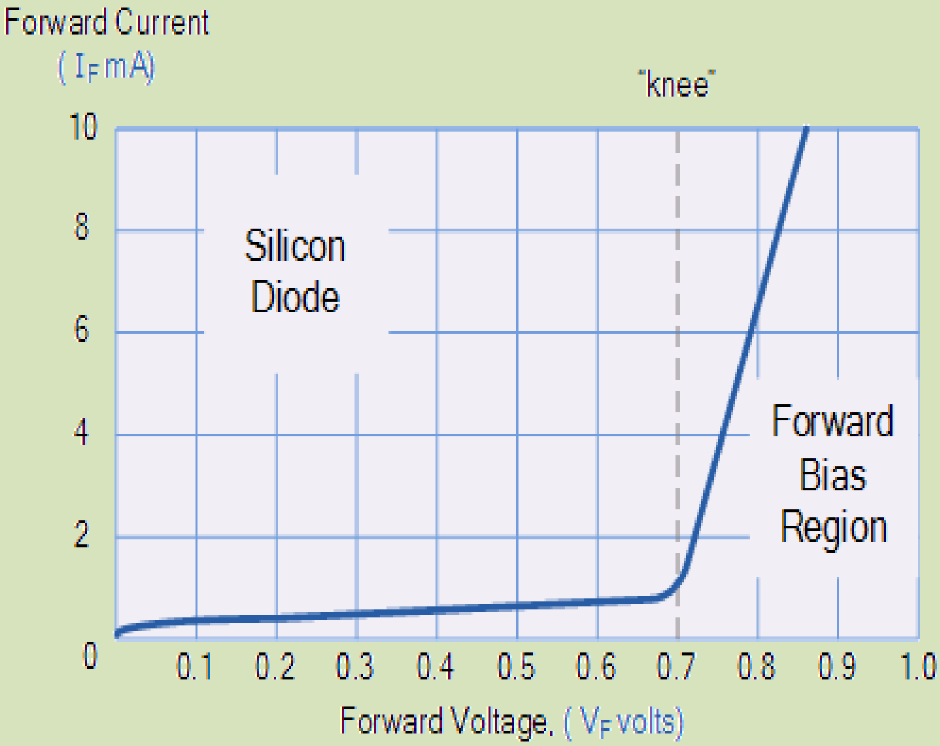
V-I Characteristics of PN Junction Diode

VI characteristics of PN junction diodes is a curve between the voltage and current through the circuit. Voltage is taken along the x-axis while the current is taken along the y-axis. The above graph is the VI characteristics curve of the 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.

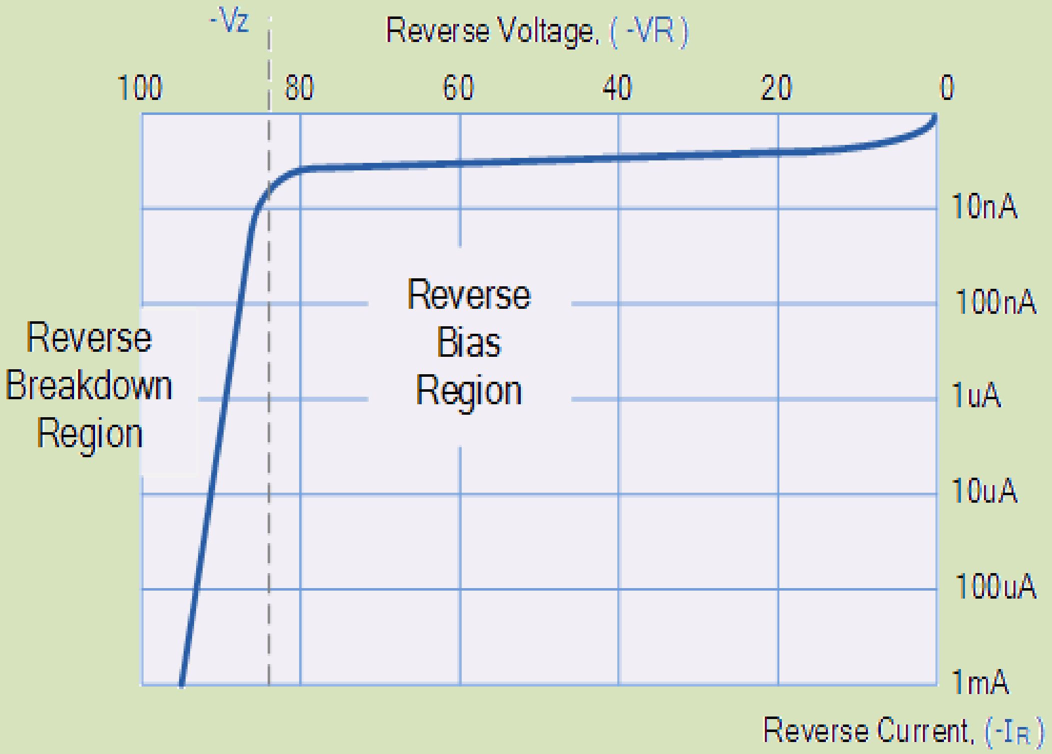
  This is because the negative voltage pushes or repels electrons towards the junction giving them the energy to cross over and combine with the holes being pushed in the opposite direction towards the junction by the positive voltage. This results in a characteristics curve of zero current flowing up 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.



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.

- When the PN junction diode is under **Reverse bias** condition, the p-type is connected to the negative terminal while the n-type is connected to the positive terminal of the external voltage. This results in an increase in the potential barrier. Reverse saturation current flows in the beginning as minority carriers are present in the junction.

  When the applied voltage is increased, the minority charges will have increased kinetic energy which affects the majority charges. This is the stage when the diode breaks down. This may also destroy the diode.



Applications of PN Junction Diode

- p-n junction diode can be used as a photodiode as the diode is sensitive to the light when the configuration of the diode is reverse-biased.
- It can be used as a solar cell.
- When the diode is forward-biased, it can be used in LED lighting applications.
- It is used as rectifiers in many electric circuits and as a voltage-controlled oscillator in varactors.

Half-Wave and Full-Wave Rectifiers

Rectification

Rectification is a method to convert AC (Alternating Current) to DC (Direct Current) include full-wave rectification and half-wave rectification. In both cases, rectification is performed by utilizing the characteristic that current flows only in the positive direction in a diode.

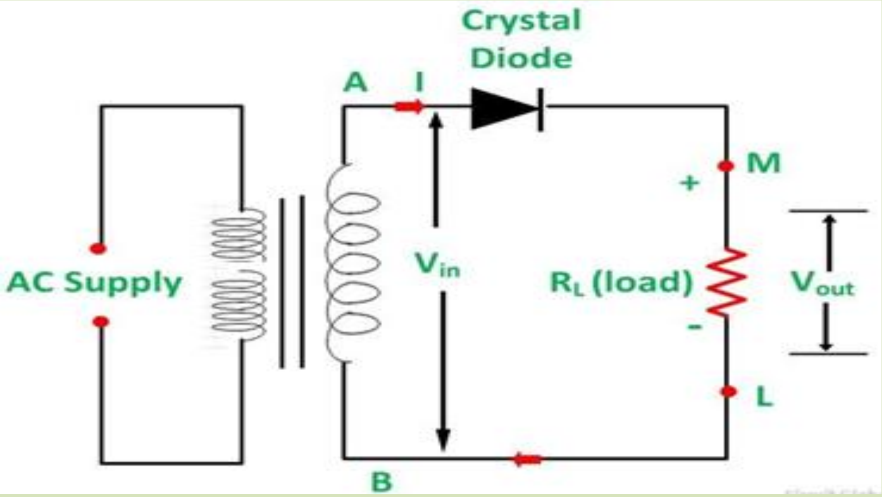
Half -Wave Rectifier

In Half Wave Rectifier, when the AC supply is applied at the input, a positive half cycle appears across the load, whereas the negative half cycle is suppressed. This can be done by using the semiconductor PN junction diode. When the p-n junction diode is forward biased, it gives little resistance and when it is reversing biased it provides high resistance.

During alternate half-cycles, the optimum result can be obtained. The diode allows the current to flow only in one direction. Thus, converts the AC voltage into DC voltage.

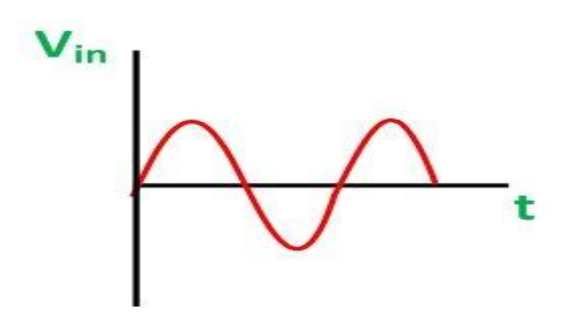
Circuit Diagram of Half Wave Rectifier

In half-wave rectification, only one crystal diode is used. The AC supply to be rectified is generally given through a transformer. It is connected in the circuit as shown in figure.

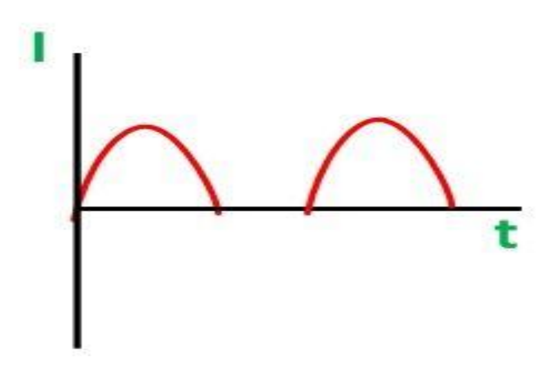


Operation of Half Wave Rectifier

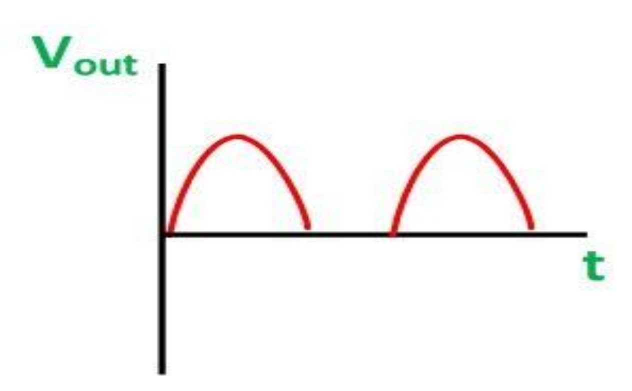
When AC supply is switched ON the alternating voltage (Vin) shown in the figure below appears across the terminal AB at the secondary winding.



- During the **positive half cycle**, terminal A is positive with respect to B and the crystal diode is **forward biased**. Therefore, it **conducts** and **current flows** through the load resistor RL. This **current varies in magnitude** as shown in the wave diagram shown below



Thus, a positive half cycle of the **output voltage** (Vout = iRL) appears across the load resistor RL shown in the figure below.



- During the **negative half cycle**, terminal A is negative with respect to B and the crystal diode is **reverse biased**. Thus, at the output side, there will be **no current** generated, and we cannot get power at the load resistance. A small amount of reverse current will flow during reverse bias due to **minority carriers**.

Characteristics of Half Wave Rectifier

Following are the characteristics of half-wave rectifier:

Ripple Factor

Ripples are the oscillations that are obtained in DC. These ripples are measured with the help of the ripple factor and are denoted by γ. Ripple factor tells us the number of **ripples presents in the output DC**. Higher the ripple factor, more is the oscillation at the output DC and lower is the ripple factor, less is the oscillation at the output DC.

Ripple factor is the ratio of RMS value of the AC component of the output voltage to the DC component of the output voltage.

$$\gamma = \sqrt{\left(\frac{V_{rms}}{V_{DC}}\right)^2 - 1}$$

DC Current

DC current is given as a ratio of I_{max}, which is the maximum DC load current and π

$$I_{DC} = \frac{I_{max}}{\pi}$$

DC Output Voltage

The output DC voltage appears at the load resistor RL which is obtained by multiplying output DC voltage with the load resistor RL. As V_{Smax} is the maximum secondary voltage. The output DC voltage is given as:

$$V_{DC} = \frac{V_{smax}}{\pi}$$

Form Factor

The form factor is the ratio of RMS value of the current to the output DC voltage. For a half-wave rectifier, the **form factor is 1.57**.

Rectifier Efficiency

Rectifier efficiency is the **ratio of output DC power to the input AC power**. For a half-wave rectifier, rectifier **efficiency is 40.6%.**

Full -Wave Rectifier

A full wave rectifier is defined as a rectifier that converts the complete cycle of alternating current into pulsating DC.

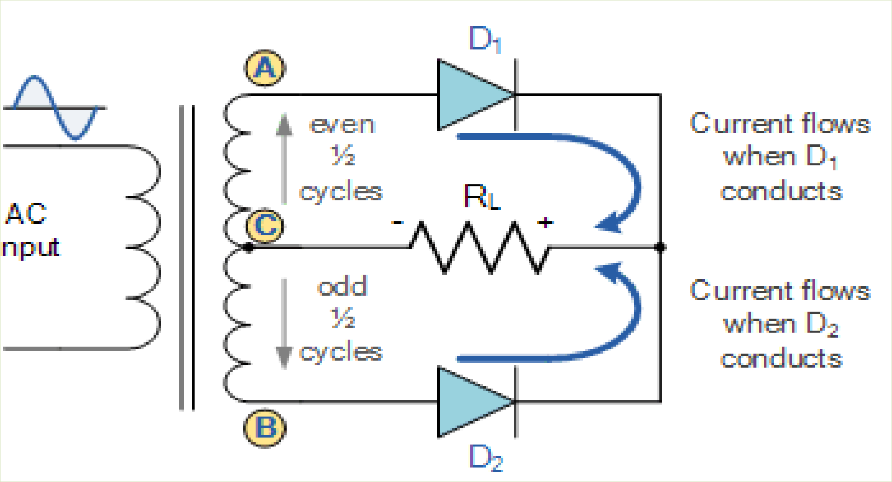
The main **advantage** of a full-wave rectifier over half-wave rectifier is that such as the average **output voltage is higher** in full-wave rectifier, there is **less ripple** produced in full-wave rectifier when compared to the half-wave rectifier.

In **Full Wave Rectification**, when the AC supply is applied at the input, during both the half-cycles (i.e., positive as well as negative) current flows through the load in the same direction. To obtain the same direction of flow of current in the load resistors RL during positive as well as the negative half cycle of input, the two circuits are used. They are named as follows:-

- Center Tapped Full Wave Rectifier
- Full Wave Bridge Rectifier

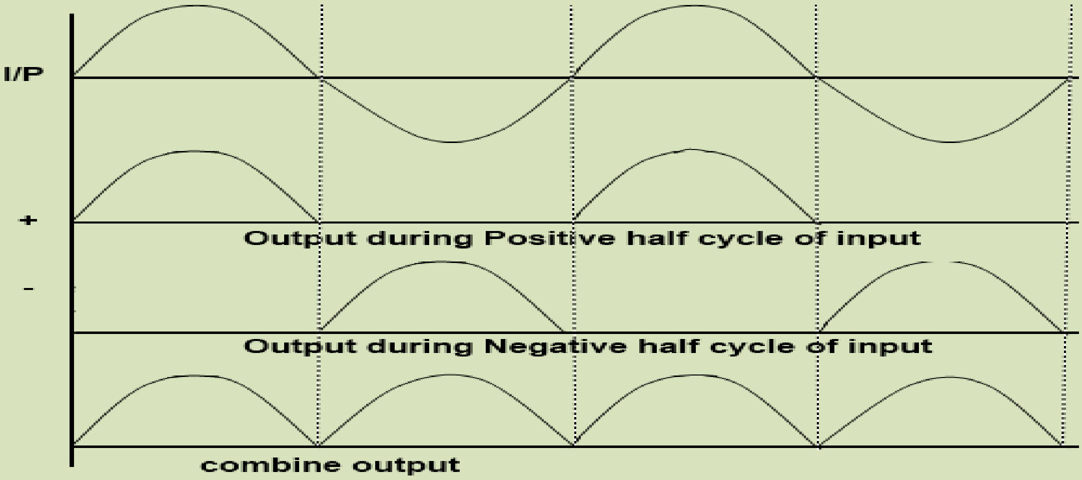
Center Tapped Full-Wave Rectifier

This circuit consists of two power diodes connected to a single load resistance R_L with each diode taking it, in turn, to supply current to the load resistor. A multiple winding transformer is used whose secondary winding is split equally into two halves with a common centre tapped connection, (C). The anode of the centre tapped diodes is connected to the transformer's secondary winding and connected to the load resistor. As shown in circuit diagram below:



- During the **positive half** cycle of the alternating current, the top half of the secondary winding becomes positive thus diode **D1 will conduct** acting as a **short circuit** as indicated by the arrows. While the second half of the secondary winding becomes negative (reverse biased) thus **D2 will not conduct** acting as an **open circuit**

- Similarly, during **negative half** of the cycle, point B is positive during negative half of the cycle with respect to point C, diode **D2 conducts** in the forward direction and **D1 remains reverse biased**.

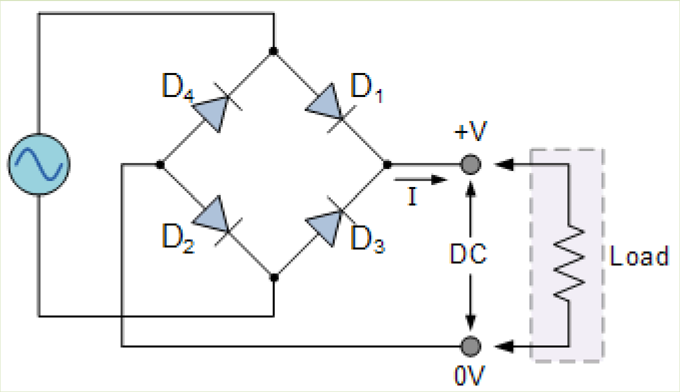


The **current flowing through resistor R**$_L$ **is in the same direction** for both half-cycles. As the output voltage across the resistor R$_L$ is the **phasor sum** of the two waveforms combined, this type of full wave rectifier circuit is also known as a "**bi-phase**" circuit.

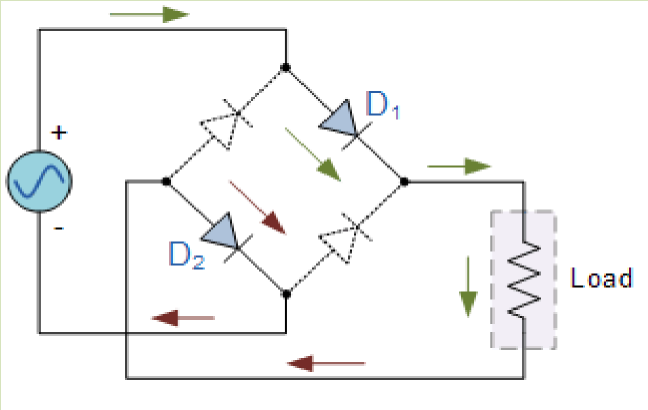
Full-Wave Bridge Rectifier

Another type of circuit that produces the same output waveform as the Center Tapped full-wave rectifier circuit is Bridge Rectifier . It have four individual rectifying diodes connected in a closed loop "bridge" configuration to produce the desired output. It does not require a special center-tapped transformer, so it reduces its size and cost. The single secondary winding is connected to one side of the diode bridge network and the load to the other side.

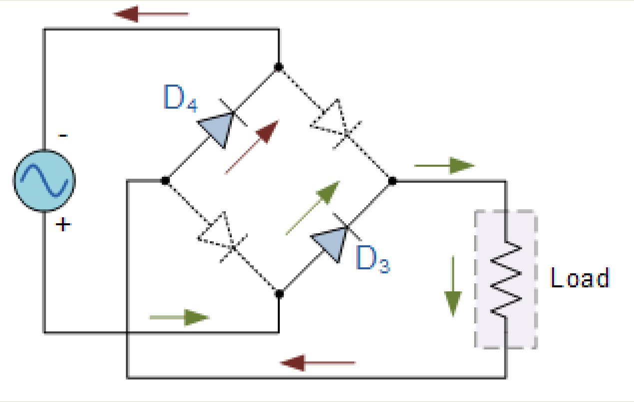
The four diodes labelled D1 to D4 are arranged in "series pairs" with only two diodes conducting current during each half cycle as shown in diagram below:



- During the **positive half** cycle of the supply, diodes D1 and D2 conduct in series while diodes D3 and D4 are reverse biased and the current flows through the load as shown below.

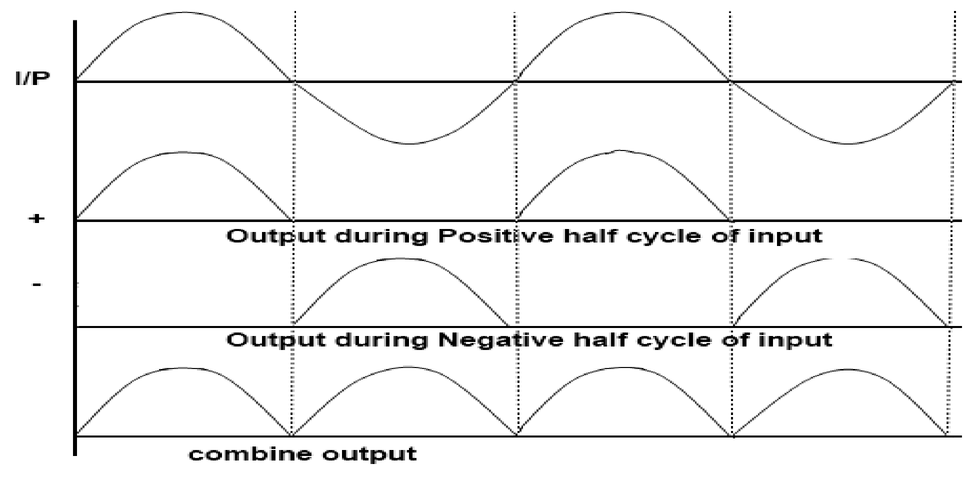


- During the **negative half** cycle of the supply, diodes D3 and D4 conduct in series, but diodes D1 and D2 switch “OFF” as they are now reverse biased, shown in diagram below. The current flowing through the load is the same direction as before.



As the current flowing through the load is unidirectional, so the voltage developed across the load is also unidirectional the same as for the positive half cycle.

The complete waveform, as the output voltage across the resistor load is the phasor sum of the two waveforms combined shown in diagram below:



Bridge Rectifier Output Waveform

Characteristics of Full Wave Rectifier

Following are the characteristics of full-wave rectifier:

Ripple Factor

Ripple factor for a full-wave rectifier is given as:

$$\gamma = \sqrt{\left(\frac{V_{rms}}{V_{DC}}\right)^2 - 1}$$

DC Current

Currents from both the diodes D1 and D2 are in the same direction when they flow towards load resistor R_L. The current produced by both the diodes is the ratio of I_{max} to π, therefore the DC current is given as:

$$I_{DC} = \frac{2I_{max}}{\pi}$$

DC Output Voltage

The output DC voltage is obtained at the load resistor R_L and is given as:

$$V_{DC} = \frac{2V_{max}}{\pi}$$

Form Factor

The form factor is the ratio of RMS value of the current to the output DC voltage. For a full-wave rectifier, the **form factor is 1.11**.

Rectifier Efficiency

Rectifier efficiency is used as a parameter to determine the efficiency of the rectifier to convert AC into DC. It is the **ratio of DC output power to the AC input power**. The rectifier **efficiency of a full-wave rectifier is 81.2%.**

Capacitor Filter

During the process of rectification, the **output generated will not** result in the **pure DC form**. Instead, there is the **presence of ripples** in the output. The ripples are the unwanted AC part present in the output DC. This affects the efficiency of the circuit. The frequencies that are undesirable to the circuit can be filtered by connecting the capacitor filter across the load.

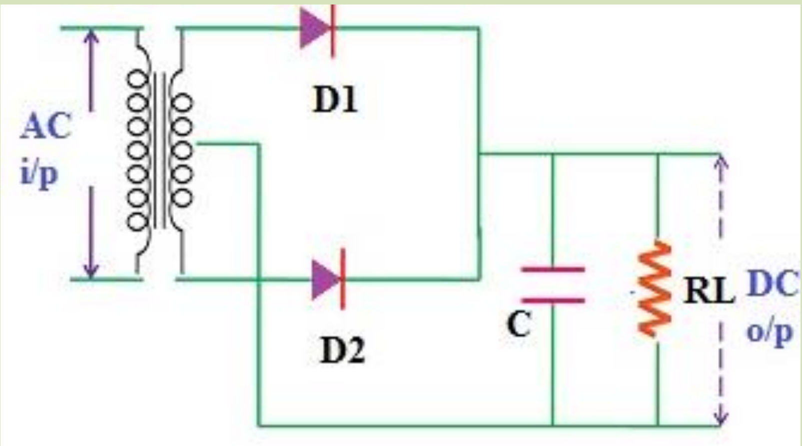
Capacitors that connected across the load in order to filter the generated output are known as the **capacitor filter**.

Full Wave Rectifier with Capacitor Filter

The main function of full wave rectifier is to convert an AC into DC. As the name implies, this rectifier rectifies both the half cycles of the i/p AC signal, but the DC signal acquired at the o/p still have some waves. To decrease these waves at the o/p this filter is used.

In the full wave rectifier circuit using a capacitor filter, the capacitor C is located across the RL load resistor.

The working of this rectifier is almost the same as a half wave rectifier. The only dissimilarity is half wave rectifier has just one-half cycles (positive or negative) whereas in full wave rectifier has two cycles (positive and negative).



- Once the i/p AC voltage is applied throughout the **positive half** cycle, then the **D1** diode gets **forward** biased and permits flow of current while the **D2** diode gets **reverse** biased & blocks the flow of current.

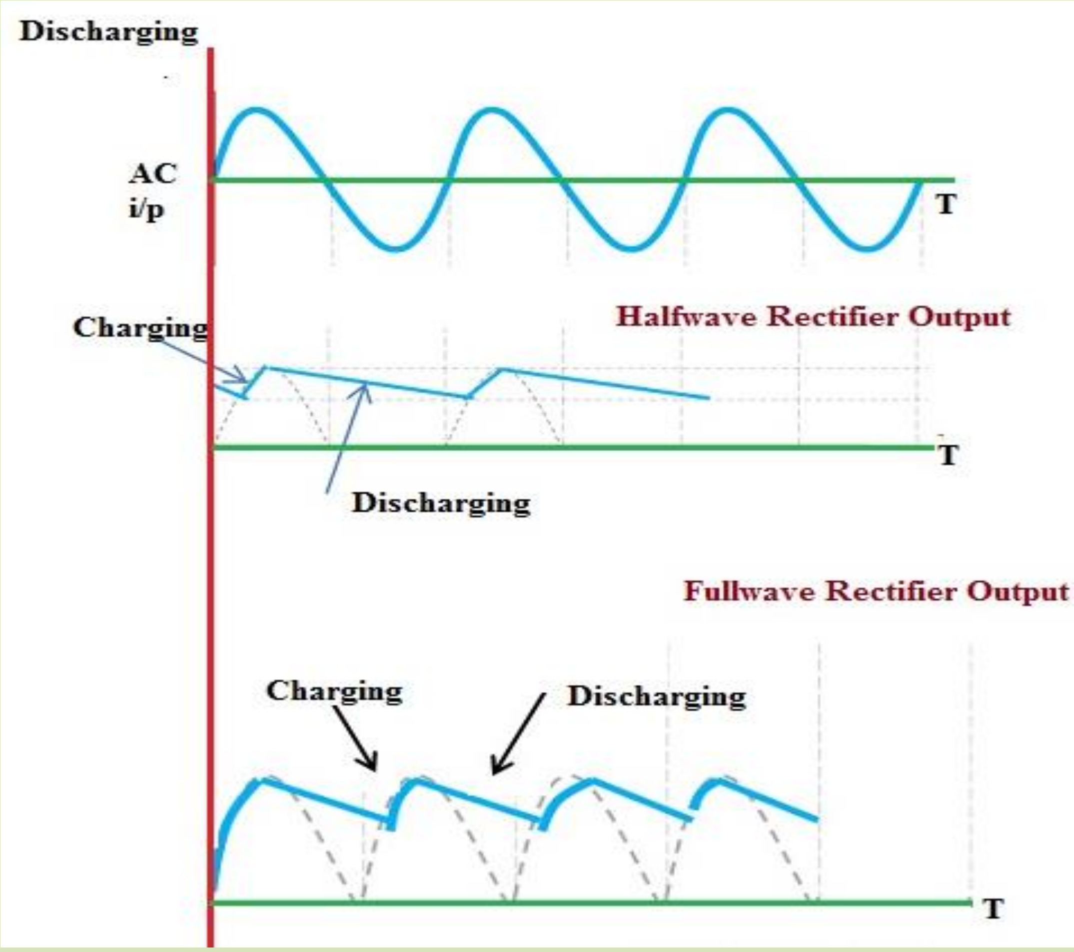
  The current in the **D1** diode gets the filter and **energizes** the **capacitor**. But, the **capacitor charging** will occur just when the voltage which is applied is **superior to the capacitor** voltage (approximately 0.7 V.). So as the applied voltage become high enough, then the capacitor will get charged immediately. Throughout this transmission time, the capacitor gets charged to the highest value of the i/p voltage supply.

- When the i/p AC voltage supply gets the **negative half**-cycle, then the **D1** diode gets **reverse** biased but the **D2** diode is **forward** biased. As the **AC voltage begins falling** & turns into less than the voltage of the capacitor, after that the **capacitor begins discharging gradually**.

  Throughout the **negative half** cycle, the flow of current in the **D2** gets the filter to **charge** the **capacitor**. But, as we know, the capacitor charging occurs **only** while the **applied AC voltage is superior to the voltage of the capacitor**.

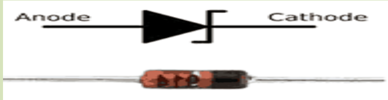
- Again for **next positive half** cycle once the rectifier reaches the positive half cycle, then the diode acquires forward biased & allows the flow of current to make the capacitor charge again.

Thus charging and discharging of the capacitor mainly depends on when the input voltage supply is less or greater than the capacitor voltage. The capacitor filter through a **huge discharge will generate an extremely smooth DC** voltage. Therefore, a smooth DC voltage can be attained with this filter as shown in diagram below.



Hence the analysing above obtained waveform for the capacitor connected across the half-wave and full-wave rectifiers and then the purpose of the connecting capacitor is proven beneficial because it can remove unnecessary ripples from the generated output.

Zener Diode



Ordinary diodes are forward biased and work in the forward direction. They have a large forward current flowing through them with a negligible voltage drop across them. If we operate an ordinary diode in reverse biased, it conducts insignificant current until the voltage applied across them exceeds the reverse breakdown voltage. Once that happens, large current flows through the junction and the diode may get destroyed. The Zener diode is a particular type of diode that solves this problem.

Or we can say a Zener diode is a heavily **doped semiconductor device that is designed to operate in the reverse direction also known as a breakdown diode.**

Working Principle

Zener diode allows electric current in **forward direction** like a normal diode but it 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.

However, when connected in **reverse biased** mode, a small leakage current flows through the diode. As the reverse voltage increases to the predetermined breakdown voltage (Vz), current starts flowing through the diode. The current increases to a maximum, which is determined by the series resistor, after which it stabilizes and remains constant over a wide range of applied voltage.

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

- Avalanche Breakdown
- Zener Breakdown.

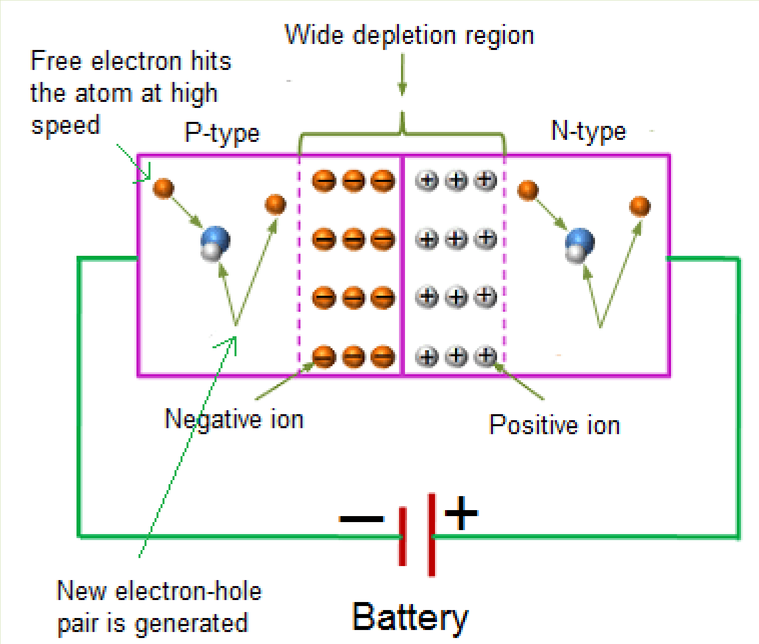
Avalanche Breakdown

As the applied **reverse voltage** tends to **increase** that result in the increment of the width of the depletion region. Even there exist some **minority carriers** which **gain** some **energy** because of increment of reverse voltage.

Due to the gain in kinetic energy of the minority carriers, these free electrons in movement collide with the stationary ions. This results in the **formation of more free electrons.**

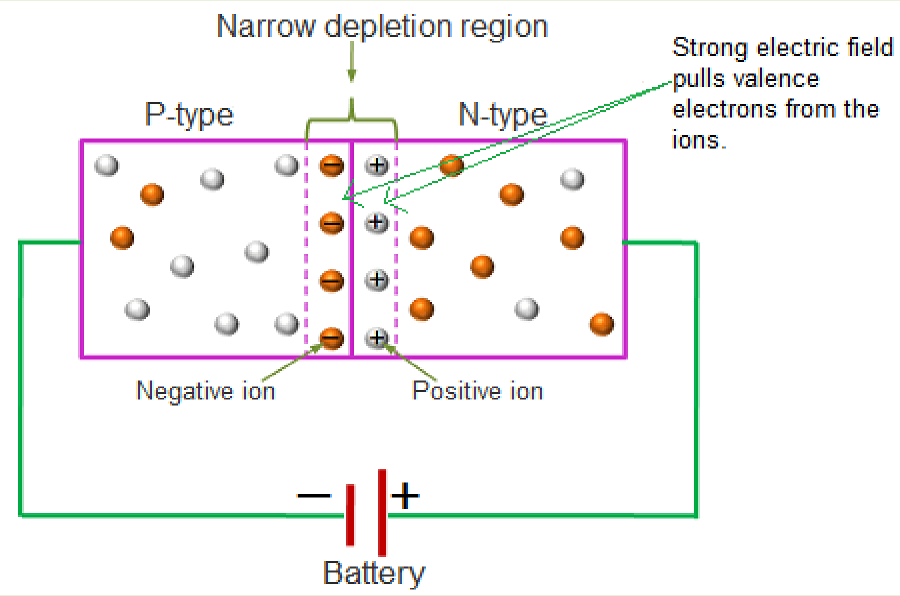
Further, these again collide with remaining stationary ions and this process continues it is referred to as **carrier multiplication.**

Because of carrier multiplication, a huge multiple of free electrons are created and the complete region of the diode becomes conductive resulting in the breakdown known as **avalanche breakdown.**



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.



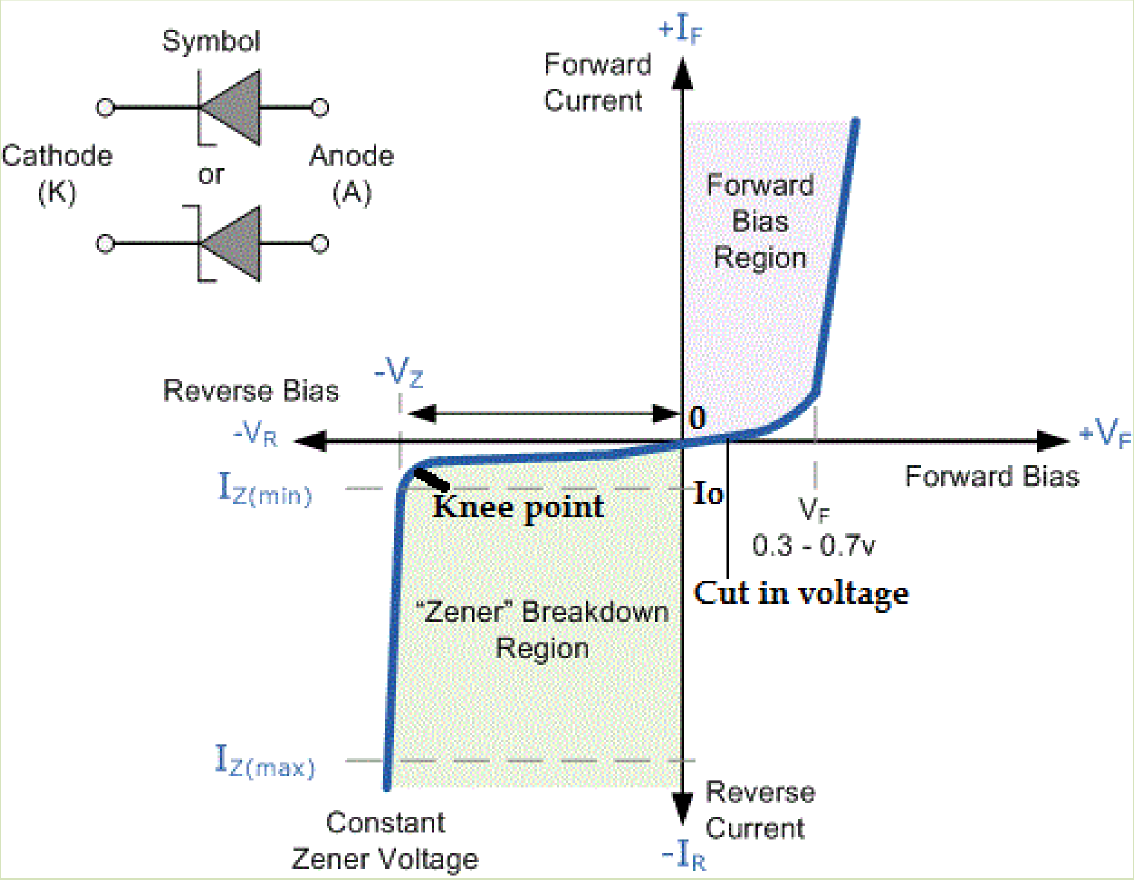
When reverse biased voltage applied to the diode reaches close to zener voltage, the electric field in the depletion region is strong enough to pull electrons from their valence band. The valence electrons which gains sufficient energy from the strong electric field of depletion region will breaks bonding with the parent atom. The valance electrons which break bonding with parent atom will become free electrons. These 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.

V-I Characteristics of Zener Diode

The **first quadrant** is the **forward biased** region. Here the Zener diode acts like an ordinary diode. When a forward voltage is applied, current flows through it. But due to higher doping concentration, higher current flows through the Zener diode.

In the **third quadrant**, When a **reverse voltage** is applied to a Zener voltage, initially a small reverse saturation current Io flows across the diode. This current is due to thermally generated minority carriers. As the **reverse voltage** is **increased**, at a certain value of reverse voltage, and current increases **drastically** and **sharply**.

This is an indication that the **breakdown** has **occurred**. Known as breakdown voltage or Zener voltage, it is denoted by Vz.



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**.

Zener Diode as a Voltage Regulator

Voltage Regulator

A voltage regulator is a device that **regulates the voltage** level. It essentially steps down the input voltage to the desired level and keeps it at that same level during the supply. This ensures that even when a load is applied the voltage doesn’t drop. The voltage regulator is mainly used for two main reasons, and they are:

- To vary or regulate the output voltage
- To keep the output voltage constant at the desired value in spite of variations in the supply voltage.

Voltage regulators are used in computers, power generators, alternators to control the output of the plant.

Why Zener Diode used as a Voltage Regulator?

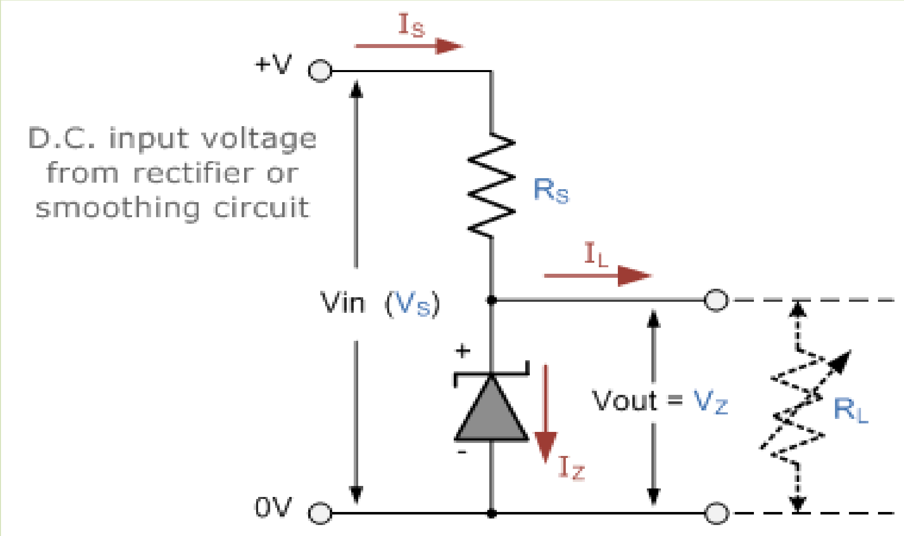
From the I-V characteristics curve above, we can see that the zener diode has a region in its reverse bias characteristics of **almost a constant negative voltage regardless** of the value of the **current flowing** through the diode. This voltage remains almost constant even with large changes in current providing the zener diodes current remains between the breakdown current $\mathbf{I_{Zmin}}$ and its maximum current rating $\mathbf{I_{Zmax}}$**.**

This ability of the zener diode to control itself can be used to great effect to regulate or stabilise a voltage source against supply or load variations. The fact that the voltage across the diode in the breakdown region is almost constant turns out to be an important characteristic of the zener diode as it can be used in the simplest types of voltage regulator applications.

The **function of a voltage regulator is to provide a constant output** voltage to a load connected in parallel with it in spite of the ripples in the supply voltage or variations in the load current. A zener diode will continue to regulate its voltage **until the diodes holding current falls below the minimum** $\mathbf{I_{Zmin}}$ value in the reverse breakdown region.

Zener Diode Regulator

The source resistance **Rs** is connected in series with zener diode **to limit the maximum current flowing** in the diode with voltage source (Vin) connected across the combination. The cathode terminal of zener diode is connected to the positive terminal of the voltage source so that the **zener diode** is **biased in reverse condition** and will be operating in breakdown region. The stabilised output voltage Vout is taken from across the zener diode.



Now to understand working of zener diode regulator considering two situations as:

- When **the load is not connected** across the zener diode, the load current will be zero, ($I_L = 0$) mean **no load current will be conducted** and all the **current** due to the circuit will **pass through** the **zener diode** which **dissipating maximum** amount of **power** that causes overheating of the diode and **damages permanently**.

Selecting the appropriate values of series resistance Rs is also important because it also causes greater diode current, so that maximum power dissipation of the diode should not be exceeded under no load condition.

- Whenever a **load is connected in parallel** with zener diode, the voltage across R_L is always the same as the zener voltage, ($\mathbf{V_R = V_Z}$). But as there is a **minimum zener current** for which the **stabilisation** of the voltage is effective required thus the **zener current must stay above this value operating under load condition at all the time**. The upper limit of current is of course dependent upon the power rating of the device. **Thus the supply voltage V_S must be greater than V_Z**.

Then to **summarise** a little. A zener diode is always operated in its reverse biased condition. As such a simple voltage regulator circuit can be designed using a zener diode to maintain a constant DC output voltage across the load in spite of variations in the input voltage or changes in the load current.

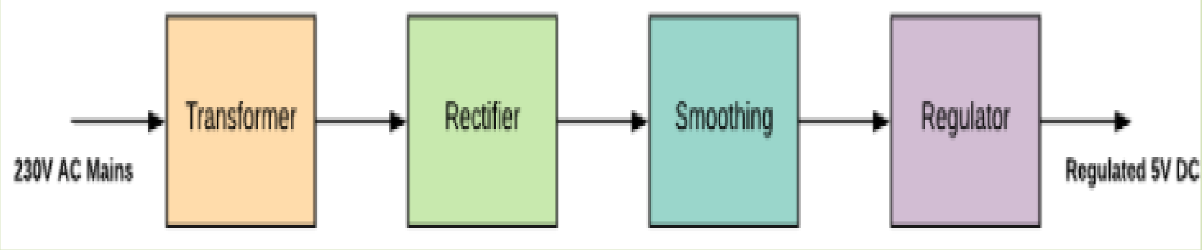
The zener voltage regulator consists of a current limiting resistor R_S connected in series with the input voltage V_S with the zener diode connected in parallel with the load RL in this reverse biased condition. **Thus the stabilised output voltage is always selected to be the same as the breakdown voltage V_Z of the diode.**

Regulated Power Supply

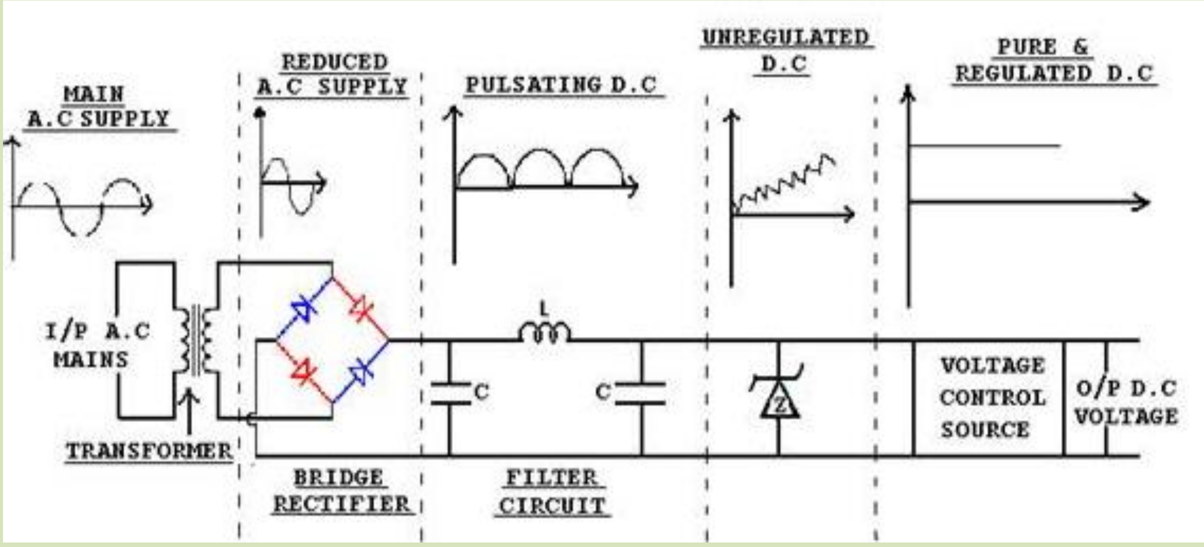
The **IC Regulated power supply (RPS)** is one kind of electronic circuit, designed to provide the stable DC voltage of fixed value across load terminals irrespective of load variations. The main function of the regulated power supply is to **convert an unregulated alternating current (AC) to a steady direct current (DC)**. The RPS is used to confirm that if the input changes then the output will be stable. This power supply is also called a **linear power supply**, and this will allow an AC input as well as provides steady DC output.

Block Diagram of Regulated Power Supply

The block diagram of a regulated power supply mainly includes a step-down transformer, a rectifier, a DC filter, and a regulator. The Construction & working of a regulated power supply is discussed below.



Circuit Diagram of Regulated Power Supply



The function of each block of the regulated power supply is as described below:

- *TRANSFORMER* and AC SUPPLY

  A power supply can be used for providing the necessary amount of power at the precise voltage from the main source like a battery. A transformer alters the AC mains voltage toward a necessary value and the main function of this is to step up and step down the voltage. A step down transformer is used for this purpose before rectification to get the voltage of required value. The transformer consists of two windings. The primary winding is connected to A.C 220 V and the required ac voltage is obtained from secondary winding.

- RECTIFIER

  A bridge rectifier is used to convert the ac into pulsating dc the rectifier employed usually a bridge rectifier due to its advantages over any other type of rectifier. Thus the output of the rectifier is pulsating dc.

- FILTER

  A filter comprising of capacitors and an inductor is used for filtration of the rectifier output. Filter is used to remove the ripples from the output of rectifier and so smooth it out. The dc output at the filter output is dependent upon the ac mains and applied load.

- VOLTAGE REGULATOR

  A voltage regulator in the regulated power supply is essential for keeping the dc output voltage constant even if there is variation in ac or the load.

From the above information, finally, we can conclude that an RPS changes unregulated alternating current to a stable direct current. RPS mainly used in mobile phone chargers, regulated power supplies in different appliances, various oscillators & amplifiers

Types of Regulators

There are two types of regulators −

- Fixed voltage regulator
- Adjustable voltage regulator

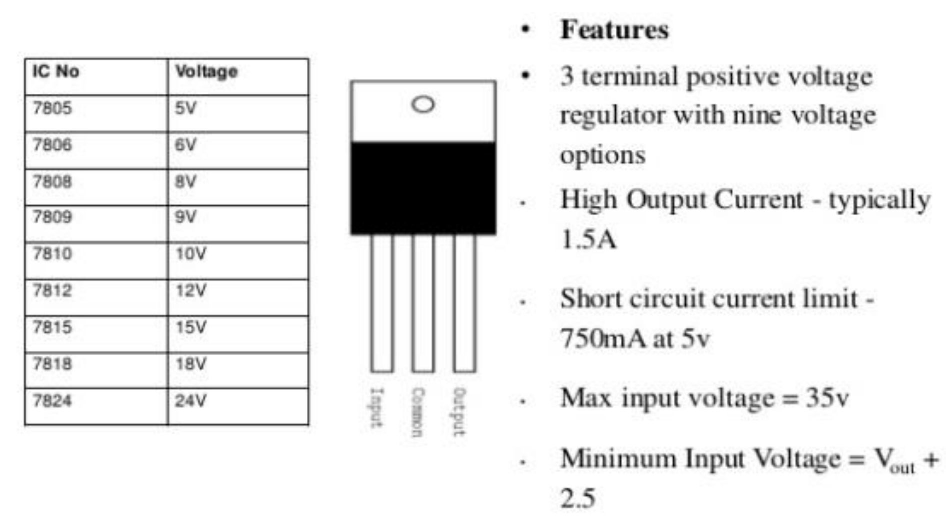
This chapter discusses about fixed type voltage regulator as 78xx and 79xx

Fixed Voltage Regulator

A fixed voltage regulator produces a fixed DC output voltage, which is either positive or negative. **78xx** voltage regulator ICs produce **positive fixed DC** voltage values, whereas, **79xx** ICs produce **negative fixed DC** voltage values. A negative fixed voltage regulator is same as the positive fixed voltage regulator in design, construction & operation. The only difference is in the polarity of output voltages.**78xx and 79xx** ICs can be used in combination to provide **positive and negative** supply voltages in the same circuit.

The following points are to be noted while working with 78xx and 79xx voltage regulator ICs :

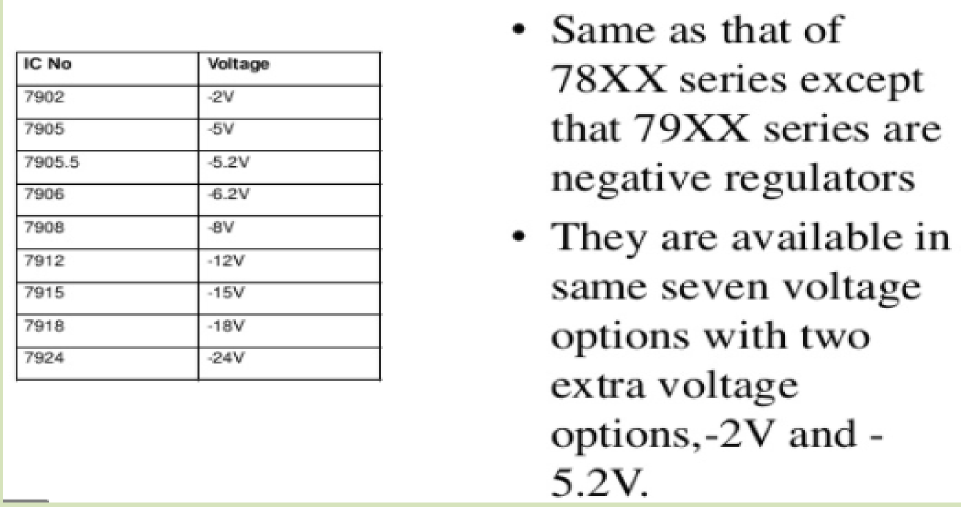
- “xx” corresponds to a two-digit number and represents the amount (magnitude) of voltage that voltage regulator IC produces.
- Where xx can be 05/06/08/09/12/15/18/24 for 78xx as shown in table below with respective output voltages in positive magnitude.



IC No	Voltage
7805	5V
7806	6V
7808	8V
7809	9V
7810	10V
7812	12V
7815	15V
7818	18V
7824	24V

- **Features**
- 3 terminal positive voltage regulator with nine voltage options
- High Output Current - typically 1.5A
- Short circuit current limit - 750mA at 5v
- Max input voltage = 35v
- Minimum Input Voltage = V_{out} + 2.5

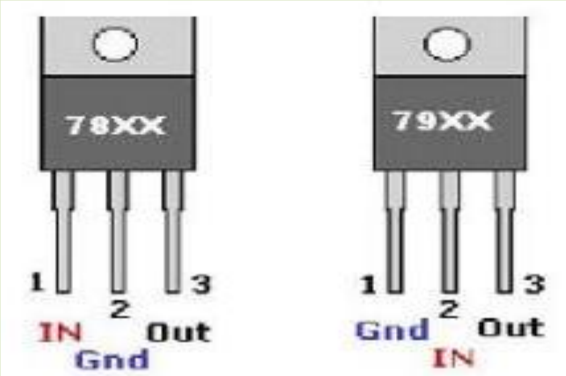
- Here xx can be 02/05/5.2/6.2/08/09/12/15/18/24 for 79xx as shown in table below with respective output voltages but in negative magnitude.



IC No	Voltage
7902	-2V
7905	-5V
7905.5	-5.2V
7906	-6.2V
7908	-8V
7912	-12V
7915	-15V
7918	-18V
7924	-24V

- Same as that of 78XX series except that 79XX series are negative regulators
- They are available in same seven voltage options with two extra voltage options,-2V and -5.2V.

- Both 78xx and 79xx voltage regulator ICs have 3 pins each and the third pin is used for collecting the output from them. The purpose of the first and second pins of these two types of ICs is different as:
- The first and second pins of **78xx** voltage regulator ICs are used for connecting the **input** and **ground** respectively. The first and second pins of **79xx** voltage regulator ICs are used for connecting the **ground** and **input** respectively.



Following are the **features** of this **78XX** voltage regulator:

- It is 3 terminal positive voltage regulator
- Output current: 1 A
- Output voltages: 5/6/8/9/10/12/15/18/24V

- Thermal overload protection
- Short circuit protection
- Output transistor safe operating area protection

Following are the **features** of this **79XX** voltage regulator:

- It is 3 terminal negative voltage regulator
- Fixed output voltages: -5V/-8V/-12V/-15V
- Output current: 1.5A
- Thermal short circuit and safe area protection
- High ripple rejection
- This IC allows output voltage to be easily boosted above the preset value with a resistor divider.

- *Assignment: 1*

- Applications of p-n and zener diode
- Write advantages, disadvantages and application of half and full wave rectifiers.
- Explain capacitor filter for half wave rectifier.

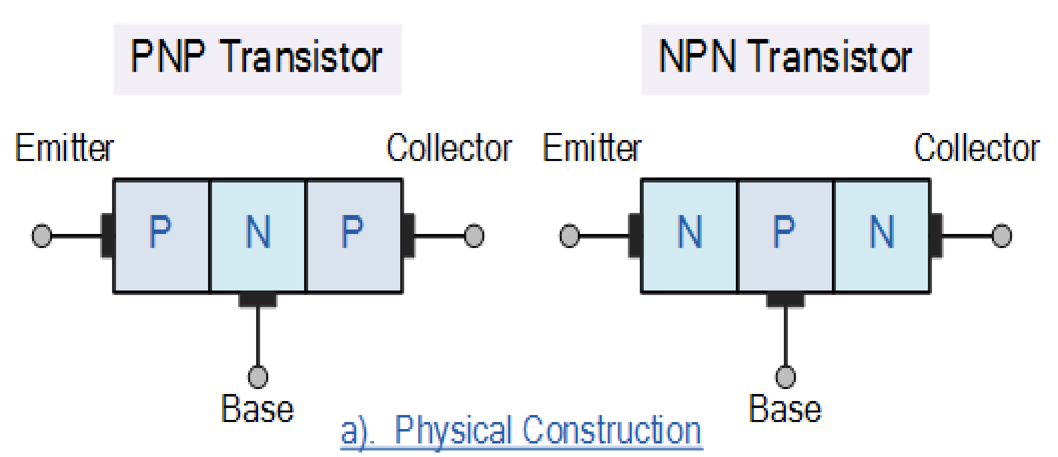
Bipolar Junction Transistor

A bipolar junction transistor is a three-terminal semiconductor device that consists of two p-n junctions which are able to amplify or magnify a signal. It is a current controlled device. The three terminals of the BJT are the base, the collector, and the emitter.

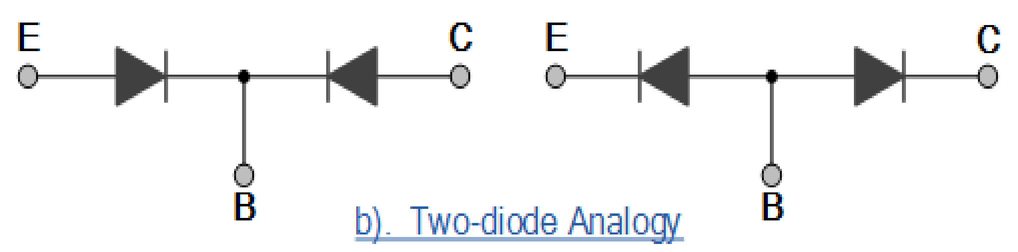
A BJT is a type of transistor that uses both electrons and holes as charge carriers. A signal of small amplitude if applied to the base is available in the amplified form at the collector of the transistor. This is the amplification provided by the BJT. But it does require an external source of DC power supply to carry out the amplification process.

Bipolar Junction Transistor Symbol

There are two types of bipolar junction transistors – NPN transistors and PNP transistors. A diagram of these two types of bipolar junction transistors is given below.



a). Physical Construction



b). Two-diode Analogy

Types of Bipolar Junction Transistor

There are two types of bipolar junction transistors:

- PNP bipolar junction transistor
- NPN bipolar junction transistor

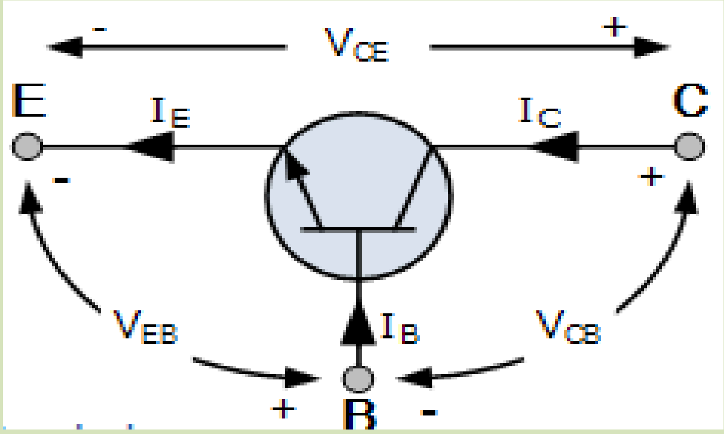
Operation of Bipolar Junction Transistor

There are three operating regions of a bipolar junction transistor:

- Active region: The region in which the transistors operate as an amplifier.
- Saturation region: The region in which the transistor is fully on and operates as a switch such that collector current is equal to the saturation current.
- Cut-off region: The region in which the transistor is fully off and collector current is equal to zero.

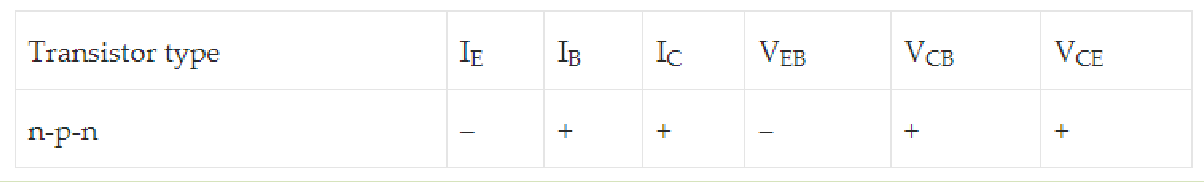
NPN Bipolar Junction Transistor

In an **n-p-n bipolar transistor** one p-type semiconductor resides between two n-type semiconductors the diagram below an n-p-n transistor is shown



Now IE, IC is emitter current and collect current respectively and VEB and VCB are emitter-base voltage and collector-base voltage respectively.

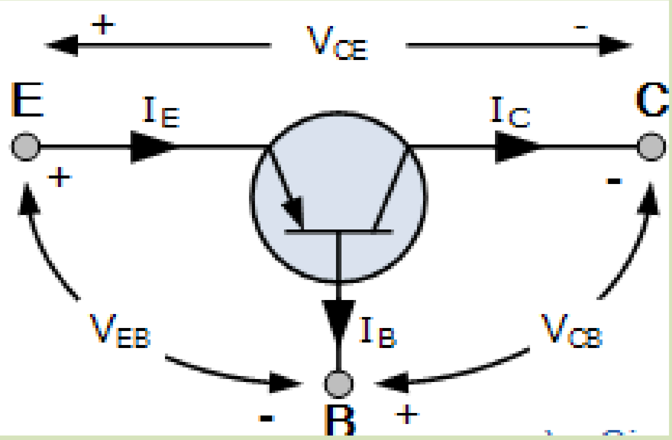
According to the convention if for the emitter, base and collector current IE, IB and IC current goes into the transistor the sign of the current is taken as positive and if current goes out from the transistor then the sign is taken as negative. We can tabulate the different currents and voltages inside the n-p-n transistor.



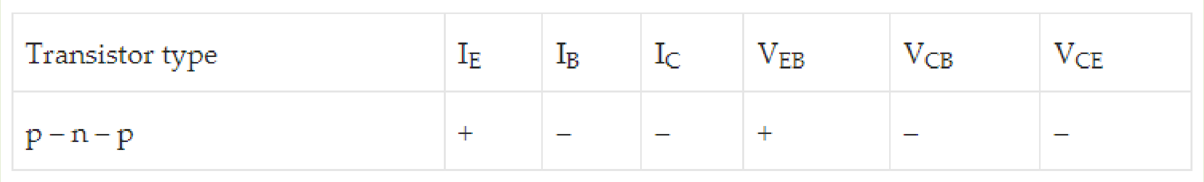
Transistor type	I_E	I_B	I_C	V_{EB}	V_{CB}	V_{CE}
n-p-n	–	+	+	–	+	+

PNP Bipolar Junction Transistor

Similarly for **p-n-p bipolar junction** transistor, an n-type semiconductor is sandwiched between two p-type semiconductors. The diagram of a p-n-p transistor is shown below.



For p-n-p transistors, current enters into the transistor through the emitter terminal. Like any bipolar junction transistor, the emitter-base junction is forward biased and the collector-base junction is reverse biased. We can tabulate the emitter, base and collector current, as well as the emitter-base, collector base and collector-emitter voltage for p-n-p transistors also.



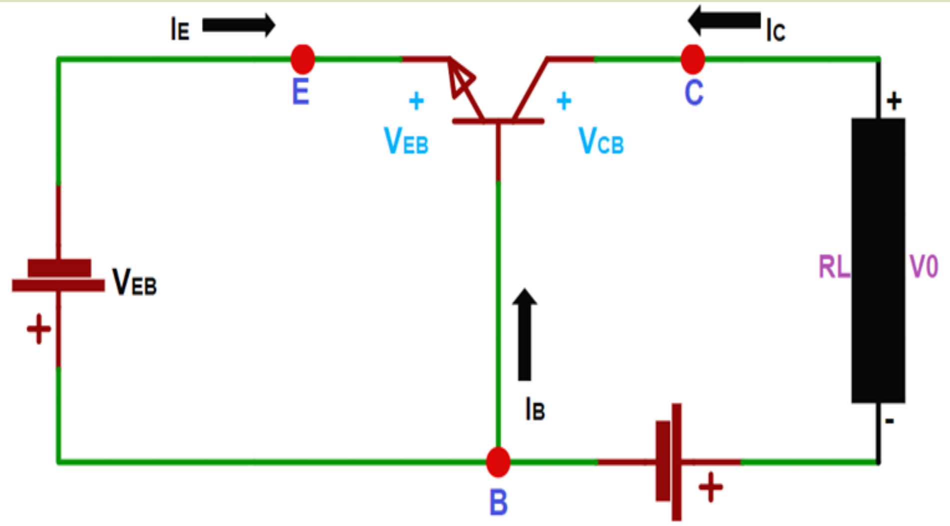
Transistor type	I_E	I_B	I_C	V_{EB}	V_{CB}	V_{CE}
p – n – p	+	–	–	+	–	–

Working of Transistor (BJT)

Practically the working of a transistor is very simple, it can be used as a switch or as an amplifier. But for basic understanding lets start with how **transistor as a switch** works in a circuit.

When a control voltage is provided to the base pin, the required **base current (I_B)** flows into the base pin which is controlled by a **base resistor**. This current turns on the transistor (switch is closed) and allows the current to flow from collector to emitter. This current is called the **collector current (I_C)** and the voltage across the collector and emitter is called V_{BE}. As you can see in the image, we are using a low-level voltage like 5V to drive a higher voltage load of 12V using this transistor.

Now for the theory, consider an NPN transistor, the BE junction is **forward biased** and the CB junction is **reverse biased**. The width of the depletion region at the Junction CB is higher when compared with the depletion region of the Junction BE. When the BE junction is forward biased it decreases the barrier potential, hence the electrons start flowing from the emitter to the base. The base region is very thin and it is lightly doped when compared with other regions, hence it consists of a very small number of holes, the electrons that are flowing from the emitter will recombine with the holes present in the base region and start to flow out of the base region in the form of the base current. A large number of electrons that are left will move across the reverse bias collector junction in the form of the collector current.



Based on the Kirchoff's Current Law, we can frame the current equation as

$\mathbf{I_E = I_B + I_C}$

The base current is very small as compared to emitter and collector current

Therefore $\mathbf{I_E \sim I_C}$

Where, I_E, I_B, and I_C are the emitter, base, and collector current respectively.

Similarly, when you consider the PNP Transistor, they operate in the same way as the NPN transistor, but in NPN transistors the majority charge carriers are holes (Positively charged particle) but in the NPN transistor the charge carriers are the electrons (negatively charged particle).

Bipolar Junction Transistors Characteristics

Transistor Characteristics are the plots which represent the relationships between the current and the voltages of a transistor in a particular configuration. By considering the transistor configuration circuits to be analogous to two-port networks, they can be analysed using the characteristic-curves which can be of the following types

- **Input Characteristics**: These describe the changes in input current with the variation in the values of input voltage keeping the output voltage constant.

- **Output Characteristics**: This is a plot of output current versus output voltage with constant input current.

- **Current Transfer Characteristics**: This characteristic curve shows the variation of output current in accordance with the input current, keeping output voltage constant.

BJT can be connected in three different configurations by keeping one terminal common and using the other two terminals for the input and output. These three types of configurations respond differently to the input signal applied to the circuit because of the **static characteristics** of the BJT.

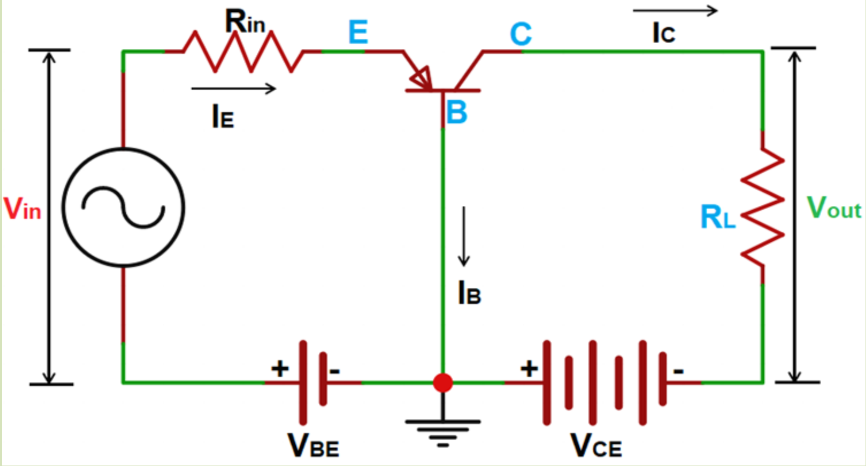
The three **different configurations of BJT** are listed below.

- Common Base (CB) configuration
- Common Emitter (CE) configuration
- Common Collector (CC) Configuration

Among these, the Common Base configurations will have voltage gain, but no current gain, whereas the Common Collector Configuration has current gain, but no voltage gain and the Common Emitter Configuration will have both current and voltage gain.

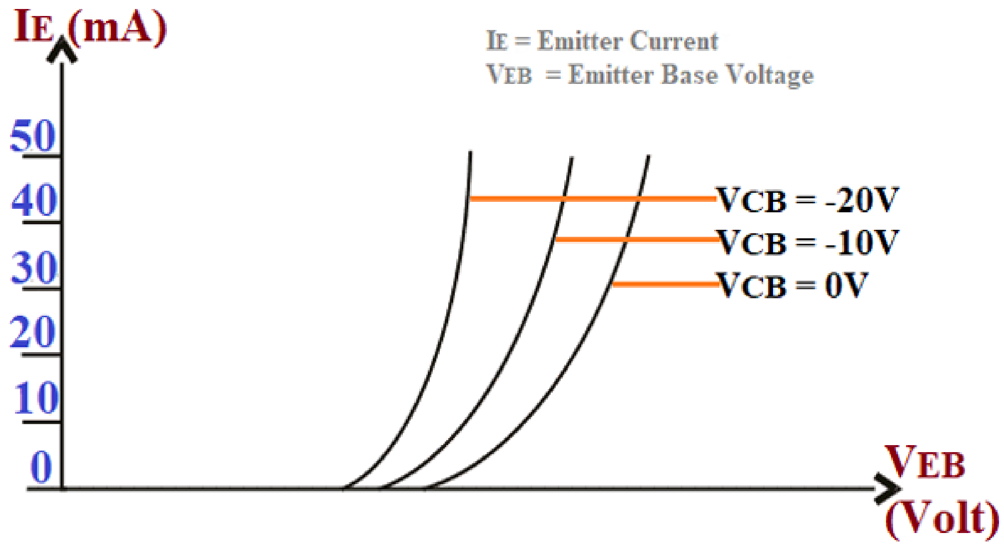
Common Base (CB) Configuration

The Common Base configuration is also called as the **grounded base configuration**, where the base of the BJT is connected as a common between both the input and output signal. The input to the BJT is applied across the Base and Emitter Terminals and the output from the BJT is obtained across the Base and Collector terminal. The input current (I_E) flowing through the emitter will be quite higher when compared with both the Base current (I_B) and the Collector Current (I_C) as the emitter current is the sum of both the Base current and Collector current. Since the collector current output is less than the Emitter current input the **current gain of this configuration will be unity (1) or less**.



Input characteristics

The input Characteristic curve for the Common Base configurations is drawn between the emitter current I_E and the voltage between the base and emitter V_{EB}. During the Common base configuration, the Transistor gets **forward biased** hence it will show characteristics similar to that of the forward characteristics of a p-n diode where the I_E increases for fixed V_{EB} when V_{CB} increases.



This leads to the expression for the input resistance as:

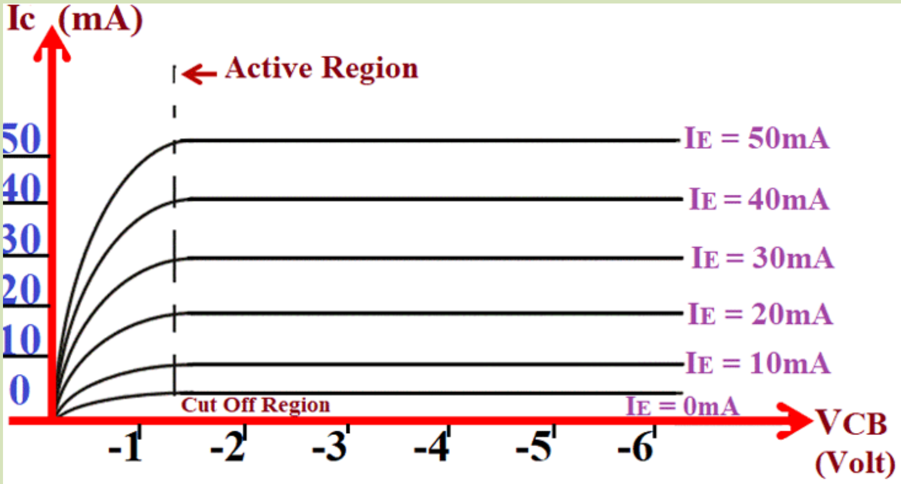
$$R_{in} = \frac{\Delta V_{BE}}{\Delta I_E}\bigg|_{V_{CB}=constant}$$

Output Characteristics

The output characteristics of the Common Base configuration are given between the collector current IC and the voltage between the collector and base V_{CB}, here the emitter Current I_E is the measuring parameter.

Based on the operation, there are three different regions in the curve, at first, the active region, here the BJT will be operating normally and the emitter junction is reverse biased.

Next come the **saturation region** where both the emitter and collector junctions are **forward biased**. Finally, the **cut off region** where both emitter and the collector junctions are reverse biased.

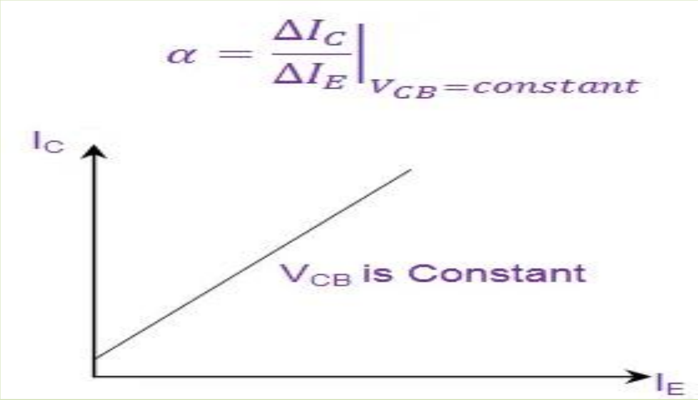


From the graph the output resistance can be obtained as:

$$R_{out} = \left.\frac{\Delta V_{CB}}{\Delta I_C}\right|_{I_E=constant}$$

Current Transfer Characteristics for CB Configuration of Transistor

The current transfer characteristics for CB configuration which illustrates the variation of I_C with the IE keeping V_{CB} as a constant. The resulting current gain has a value less than 1 and can be mathematically expressed as:

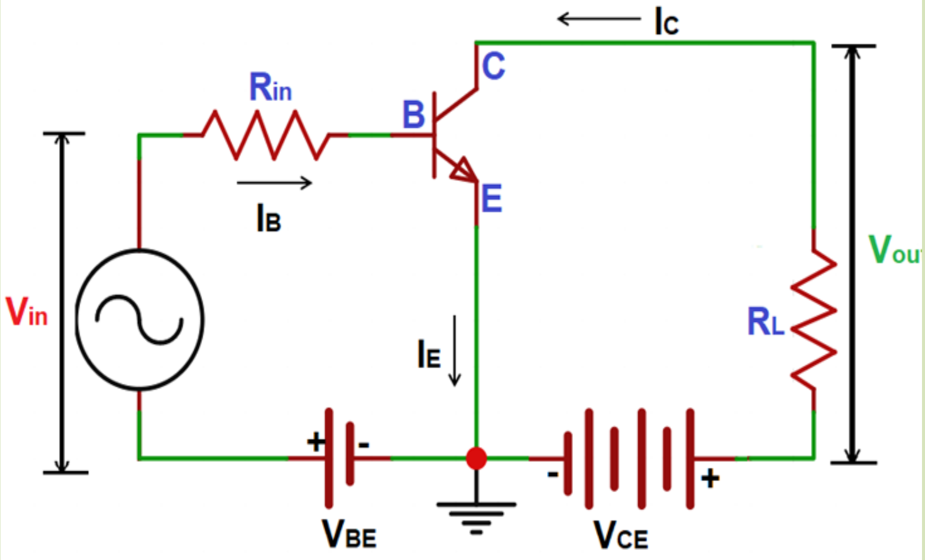


$$\alpha = \left.\frac{\Delta I_C}{\Delta I_E}\right|_{V_{CB}=constant}$$

Common Emitter (CE) Configuration

The Common Emitter Configuration is also called the grounded emitter configuration where the emitter acts as the common terminal between the input applied between the base and emitter and the output obtained between the collector and the emitter.

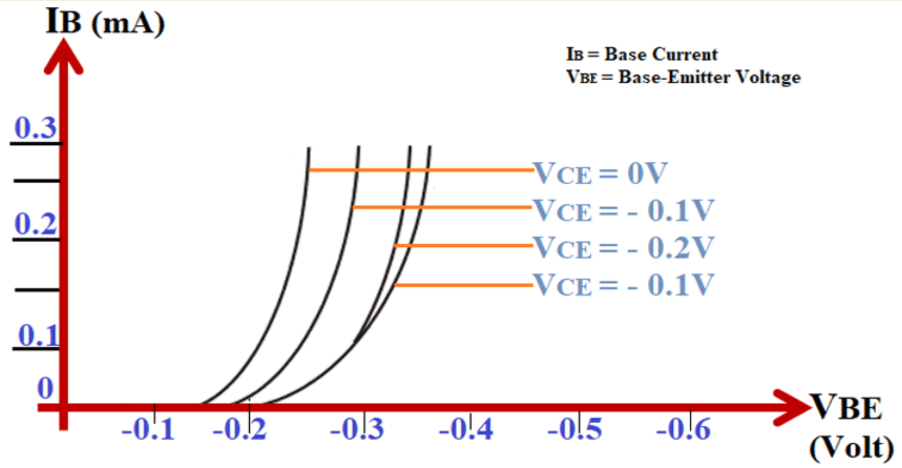
This configuration produces the **highest current and power gain** when compared with the other two types of configurations, this is because of the fact that the input impedance is low as it is connected to a forward-biased PN junction whereas the output impedance is high as it is obtained for the reverse-biased PN junction.



Input Characteristics

The input characteristics of the Common Emitter configuration are drawn between the base current I_B and the voltage between the base and emitter V_{BE}. Here the Voltage between the Collector and the emitter is the most common parameter.

If we observe see there will not be much difference between the characteristic curve of the previous configuration except for the change in parameters.

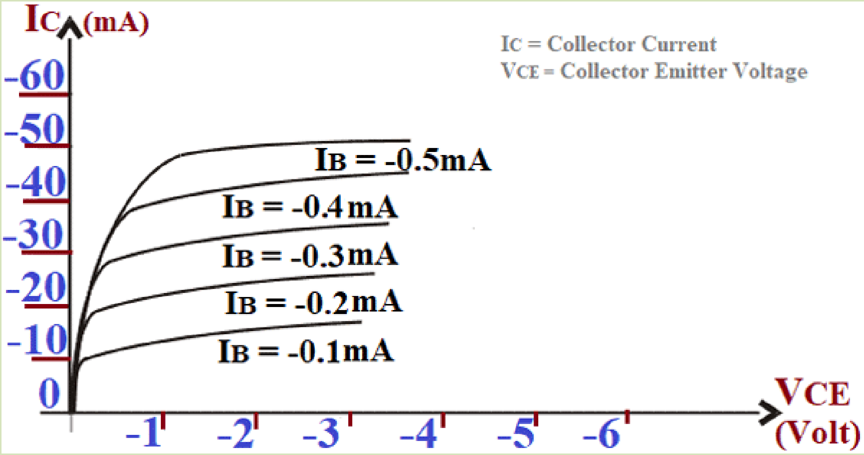


From the graph the input resistance of the transistor can be obtained as

$$R_{in} = \frac{\Delta V_{BE}}{\Delta I_B}\bigg|_{V_{CE}=constant}$$

Output Characteristics

The output characteristics are drawn between the Collector Current I_C and the voltage between the collector and the Emitter V_{CE}. The CE configuration also has the three different regions, in the **active** region the collector junction is reverse biased and the emitter junction is forward biased, in the **cut-off** region, the emitter junction is slightly **reverse** biased and the collector current is not completely **cut off**, and finally, in the **saturation** region, both the collector and the emitter junctions are forward biased.



From the graph shown, the output resistance can be obtained as:

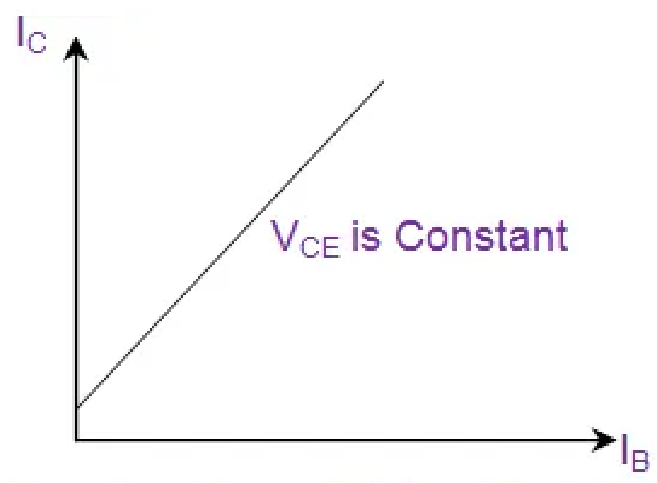
$$R_{out} = \left.\frac{\Delta V_{CE}}{\Delta I_C}\right|_{I_B=constant}$$

Current Transfer Characteristics for CE Configuration of Transistor

This characteristic of CE configuration shows the variation of I_C with I_B keeping V_{CE} as a constant. This can be mathematically given by

$$\beta = \left.\frac{\Delta I_C}{\Delta I_B}\right|_{V_{CE}=constant}$$

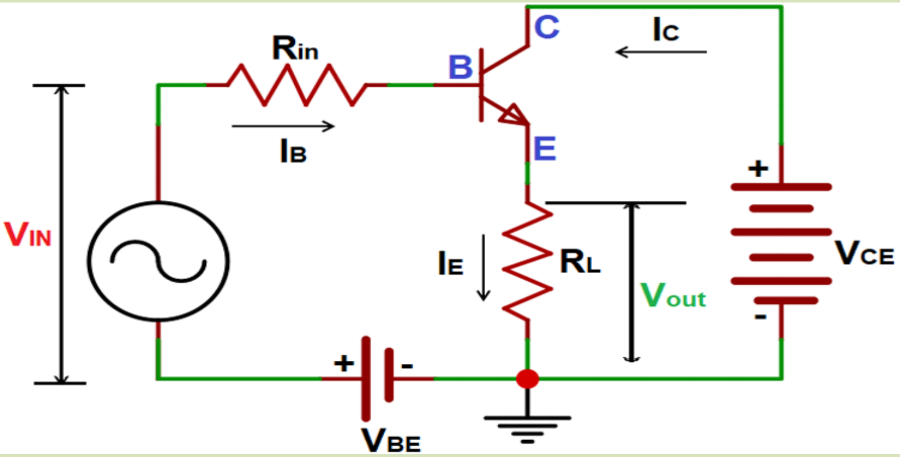
This ratio is referred to as common-emitter current gain and is always greater than 1.



Common Collector (CC) Configuration

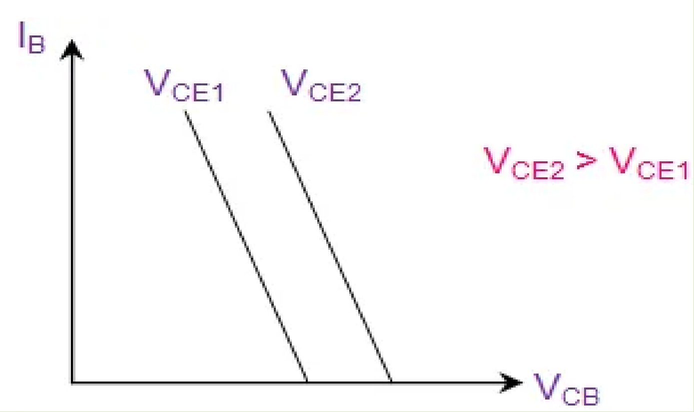
The Common Collector Configuration is also called the grounded Collector configuration where the collector terminal is kept as the common terminal between the input signal applied across the base and the emitter, and the output signal obtained across the collector and the emitter. This configuration is commonly called as the **Voltage follower or the emitter follower circuit**.

This configuration will be useful for **impedance matching applications** as it has very high input impedance, in the region of hundreds of thousands of ohms while having relatively low output impedance.



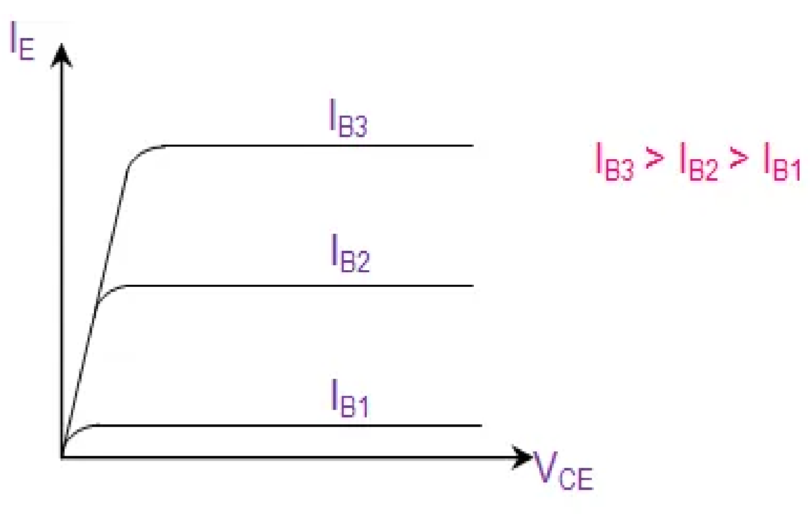
Input Characteristics

The input characteristics for CC configuration which describes the variation in I_B in accordance with V_{CB}, for a constant value of Collector-Emitter voltage, V_{CE}.



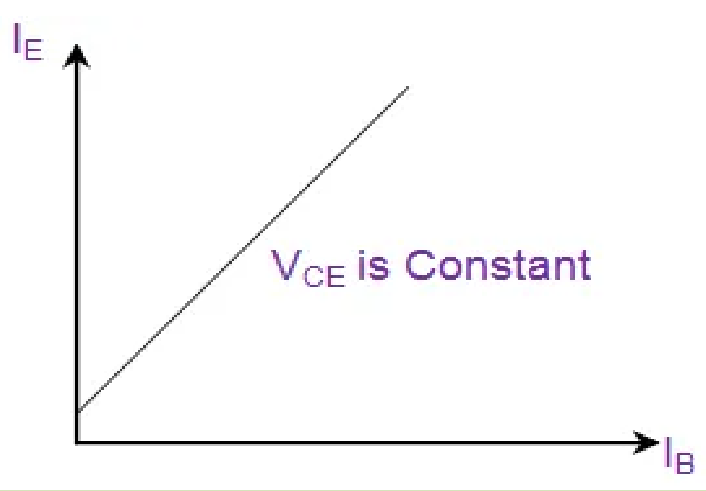
Output Characteristics

The output characteristics for the CC configuration which exhibit the variations in I_E against the changes in V_{CE} for constant values of I_B.

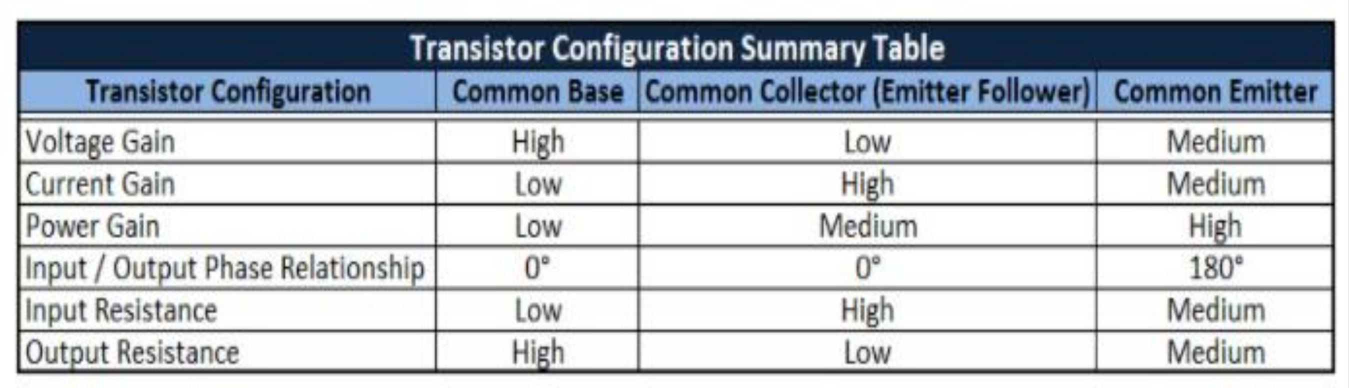


Current Transfer Characteristics for CC Configuration of Transistor

This characteristic of CC configuration shows the variation of IE with IB keeping VCE as a 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

Single Stage CE Amplifier

The Figure below show single stage CE amplifier.

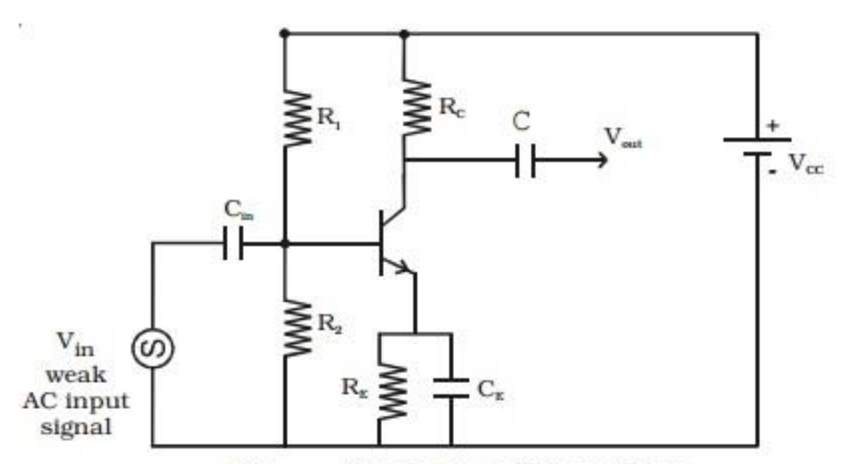


Fig Single stage CE amplifier

The different circuit elements and their functions are described as follows.

(i) **Biasing circuit**: The resistances R_1, R_2 and R_E form the biasing and stabilization circuit.

(ii) **Input capacitance C_{in}**: This is used to couple the signal to the base of the transistor. If this is not used, the signal source resistance will come across R_2 and thus change the bias. The capacitor **C_{in}** allows only a.c. signal to flow.

(iii) **Emitter bypass capacitor C_E**: This is connected in parallel with R_E to provide a low reactance path to the amplified a.c. signal. If it is not used, then amplified a.c. signal flowing through R_E will cause a voltage drop across it, thereby shifting the output voltage.

(iv) **Coupling capacitor C**: This is used to couple the amplified signal to the output device. This capacitor C allows only a.c. signal to flow.

Working

When a weak input a.c. signal is applied to the base of the transistor, a small base current flows. Due to transistor action, a much larger a.c. current flows through collector load R_C, a large voltage appears across R_C and hence at the output. Therefore, a weak signal applied to the base appears in amplified form in the collector circuit. Voltage gain (A_v) of the amplifier is the ratio of the amplified output voltage to the input voltage.

Frequency response and bandwidth

The voltage gain (Av) of the amplifier for different input frequencies can be determined. A graph can be drawn by taking frequency (f) along X-axis and voltage gain (A_v) along Y-axis. The frequency response curve obtained will be of the form as shown in Fig. It can be seen that the gain decreases at very low and very high frequencies, but it remains constant over a wide range of mid-frequency region.

Lower cut off frequency (f_L) is defined as the frequency in the low 1

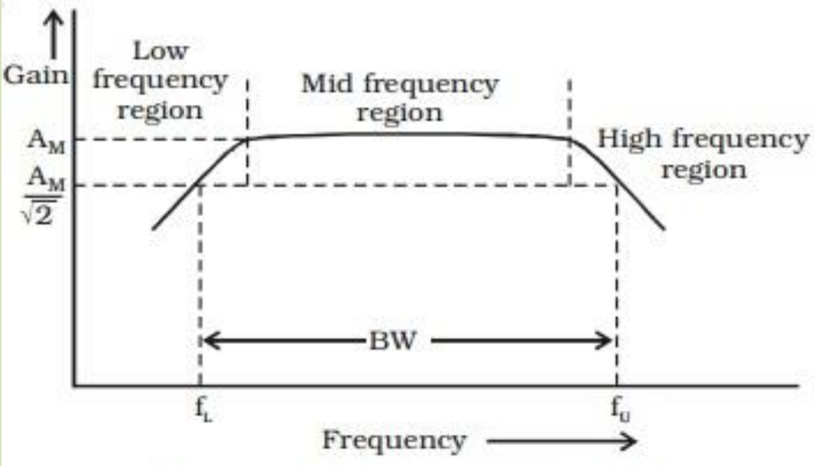


Fig *Frequency response curve*

Frequency range at which the gain of the amplifier is $_2$ times the mid frequency gain (A_M). Upper cut off frequency (f_U) is defined as the frequency in the high frequency range at which the gain of the amplifier is 1/rt(2) times the mid frequency gain (A_M).

Bandwidth is defined as the frequency interval between lower cut off and upper cut off frequencies.

$$BW = f_U - f_L$$

- ## *Assignment: 2*

- *Why transistor is called current controlled device?*
- *Compare CE, CB and CC configuration of BJT*

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