Chapter:3 Diode and Transistors

INTRODUCTION - IDEAL DIODE

During forward bias, an Ideal Diode acts like a perfect conductor, while when reverse-biased, it acts like an ideal insulator. The ideal diode properties are resistance, threshold voltage, breakdown voltage, and current magnitude.

In this article, we will look into the characteristics curve of an ideal diode and see its behavior for forward and reverse biased conditions. We will also discuss the properties an ideal diode offers in its different modes of biasing and to conclude our discussion, we will look into the difference between an ideal and a conventional diode.

WHAT IS AN IDEAL DIODE?

As the name suggests, an ideal diode is a diode that has all of its properties perfectly without any flaws. Diodes may operate either forwardly or reversely biased. Thus, these two modes of operation can be analysed separately to determine the characteristics of the ideal diode.

MODES OF OPERATION OF IDEAL DIODE

The two modes of operation of the ideal diode are

- Forward Bias
- Reverse Bias

Ideal Diode Circuit Symbol

The circuit symbol of an ideal diode is the simple representation of a diode by a triangle device. This symbol becomes a short or open circuit when forward and reverse-biased, respectively.

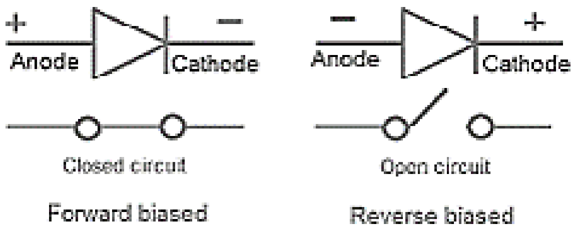

Figure 3.1: Circuit symbol of an ideal diode

In forward bias, the current flows from p to n side, and in reverse bias, there is supposed to be a small current from n to p, but since we are dealing with an ideal diode, the reverse current would be zero.

The ideal diode conducts forward current when a forward voltage is applied across the anode to the cathode. In contrast, it does not conduct reverse current when a reverse voltage is applied across the anode to the cathode.

EFFECT OF TEMPERATURE ON DIODE CHARACTERISTICS

We have already discussed that, the current that a PN junction diode can conduct at a given voltage is dependent upon the operating temperature. An increased temperature will result in a large number of broken covalent bonds increasing the large number of majority and minority carriers. This amounts to a diode current larger than its previous diode current. The above phenomenon applies both to forward and reverse current.

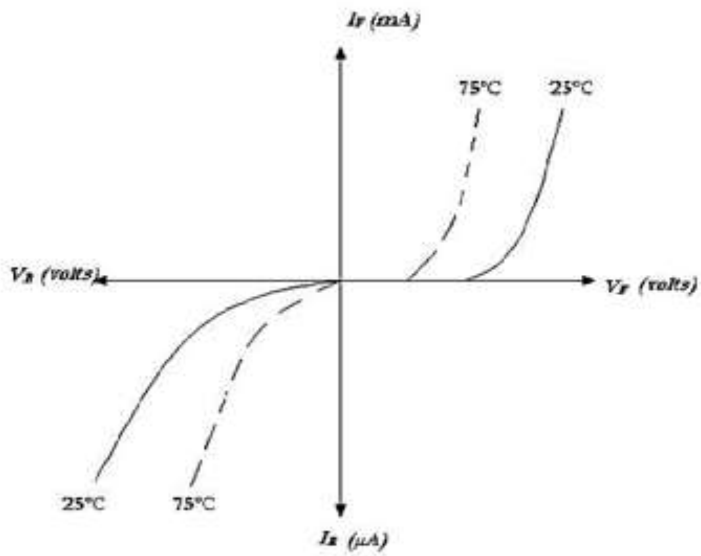

Figure 3.2: Effect of temperature on diode characteristics

The effect of increased temperature on the characteristics curve of a PN junction diode is as shown in above figure. It may be noted that the forward characteristics shifts upwards with increase in temperature. On the other hand, the reverse characteristics shifts downwards with the increase in temperature.

WHAT IS A SEMICONDUCTOR DIODE?

A semiconductor diode is a p-n junction diode. It is a two-terminal device that conducts current only in one direction. The figure below represents the symbol for the p-n junction diode, which symbolizes the direction of the current. By applying an external voltage V we can vary the potential barrier.

Semiconductor Diode Symbol

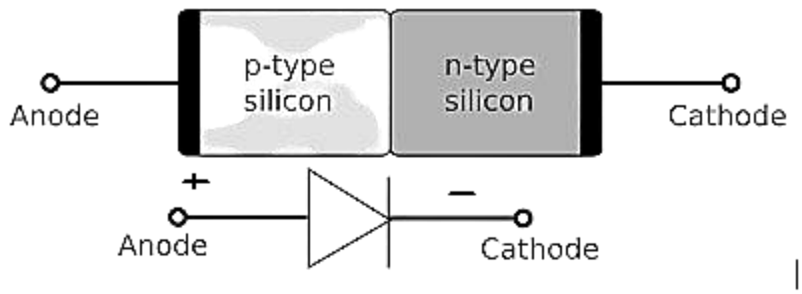

Figure 3.3: Semiconductor Diode Symbol

A p-n junction is denoted by the symbol shown in the figure above. Here, the direction of the arrow indicates the permissible direction of the current.

UNBIASED DIODE:

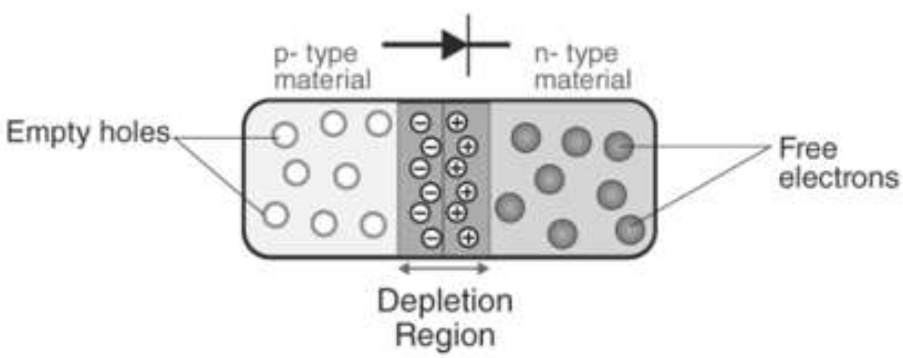

Figure 3.4: Unbiased diode

When an electron diffuses from the n-side to the p-side, an ionised donor is left behind on the n-side, which is immobile. As the process goes on, a layer of positive charge is developed on the n-side of the junction.

Similarly, when a hole goes from the p-side to the n-side, an ionized acceptor is left behind on the p-side, resulting in the formation of 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 with the 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. This motion is termed the drift. Here, we see that the direction of the drift current is opposite to that of the diffusion current.

- An unbiased condition of a diode is when there is no external energy source.
- An unbiased diode sets the electric field across the depletion layer between the n-type and the p-type material.
- This is caused due to the imbalance in free electrons due to doping.
- This barrier potential is approximately 0.7V for a silicon diode at room temperature.
- In unbiased conditions, the p-side is positive, and the n- side is negative. So, an unbiased diode is a diode that is not connected to a battery or is not connected to any voltage source.

BIASING CONDITIONS FOR THE P-N JUNCTION DIODE

There are three biasing conditions for the P-N junction diode, and this is based on the voltage applied:

- Zero bias: No external voltage is applied to the P-N junction diode.
- 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.
- Reverse bias: The negative terminal of the voltage potential is connected to the p-type and the positive is connected to the n-type.

P-N JUNCTION DIODE UNDER FORWARD BIAS

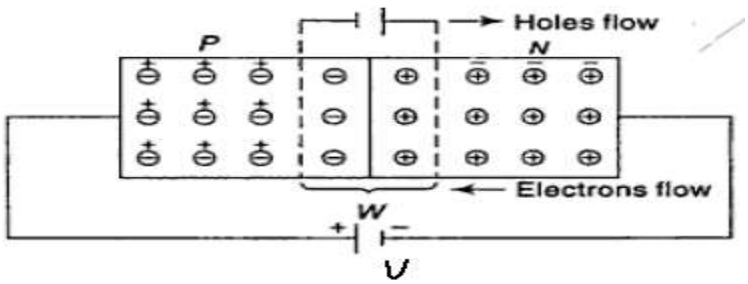

Figure 3.5: P-N junction diode under forward bias

When we apply the external voltage across the semiconductor diode in such a way that the p-side is connected to the positive terminal of the battery and the n-side is connected to the negative terminal, then the semiconductor diode is said to be forward-biased. In this case, the built-in potential of the diode and thus the width of the depletion region decreases, and the height of the barrier gets reduced. The overall barrier voltage, in this case, comes out to be V0-V, which is the difference between the built-in potential and the applied potential.

As we supply a small amount of voltage, the reduction in the barrier voltage from the above-given formula is very less and thus only a small number of current carriers cross the junction in this case. Whereas, if the potential is increased by a significant value, the reduction in the barrier height will be more, thus allowing the passage of more number of carriers.

P-N JUNCTION DIODE UNDER REVERSE BIAS

Reverse-biased-PN-junction-diode

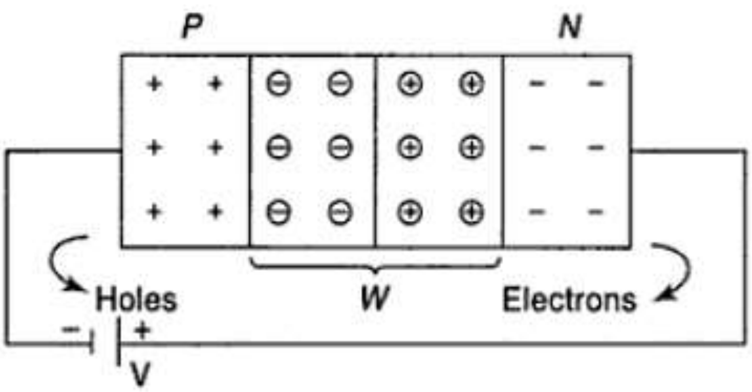

Figure 3.6: P-N Junction diode under Reverse Bias

When we apply the external voltage across the semiconductor diode in such a way that the positive terminal of the battery is connected to its n-side and the negative terminal of the battery is connected to the p-side of the diode, then it is said to be in the condition of reverse bias. When an external voltage is applied across the diode, as the direction of the external voltage is the same as that of the barrier potential, the total voltage barrier sums up to be (V_0+V). Also, the width of the depletion region increases. As a result of this, the motion of carriers from one side of the junction to another decreases significantly.

Semiconductor Diode Characteristics

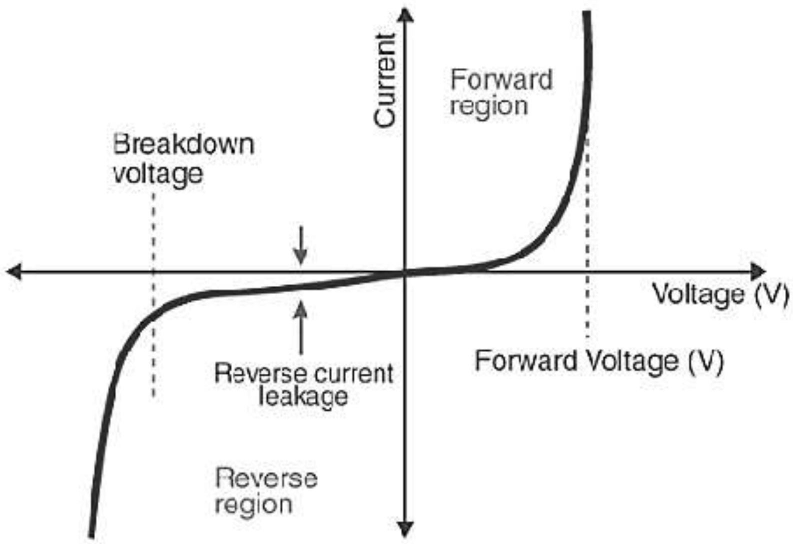

Figure 3.7: Semiconductor Diode Characteristics

SURGE CURRENT

WHAT IS SURGE CURRENT IN DIODE?

Surge current in diode is the maximum allowable value of the current that the diode can conduct in the forward bias condition. The diode gets damaged when the diode's forward current is more than the surge current rating of the diode. Therefore, the diode's surge current rating is desired to be more than the diode's inrush current. The surge current rating is infinite for an ideal diode.

The surge current in the diode is influenced by various factors as follows:

- The surge current capability of the diode is highly influenced by the metallization layer and the bond foot arrangement. The surge current capability of the diode is more when the metallization layer is thicker and it is less for the diode that has thinner metallization layers.
- The location and size of the contact area of the bond wires influence the surge current capability of the diode. Diode has better surge current capability when it has high bond foot area.

- The typical range of surge current rating of the diode is 10 to 12 times of its rated current.

DIODE AS A SWITCH

Working of Diode as a Switch

Whenever a specified voltage is exceeded, the diode resistance gets increased, making the diode reverse biased and it acts as an open switch. Whenever the voltage applied is below the reference voltage, the diode resistance gets decreased, making the diode forward biased, and it acts as a closed switch.

The following circuit explains the diode acting as a switch.

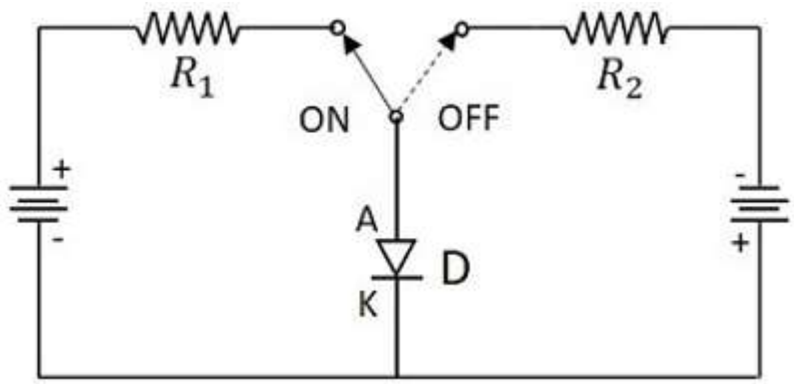

Figure 3.8: Switching circuit using diode

A switching diode has a PN junction in which P-region is lightly doped and N-region is heavily doped. The above circuit symbolizes that the diode gets ON when positive voltage forward biases the diode and it gets OFF when negative voltage reverse biases the diode.

RECTIFIER

The main application of p-n junction diode is in rectification circuits. These circuits are used to describe the conversion of a.c signals to d.c in power supplies. Diode rectifier gives an alternating voltage which pulsates in accordance with time. The filter smoothes the pulsation in the voltage and to produce d.c voltage, a regulator is used which removes the ripples.

There are two primary methods of diode rectification:

HALF WAVE RECTIFIER

In a half-wave rectifier, one half of each a.c input cycle is rectified. When the p-n junction diode is forward biased, it gives little resistance and when it is reversed biased it provides high resistance. During one-half cycles, the diode is forward biased when the input voltage is applied and in the opposite half cycle, it is reverse biased. During alternate half-cycles, the optimum result can be obtained.

Working of Half Wave Rectifier

The half-wave rectifier has both positive and negative cycles. During the positive half of the input, the current will flow from positive to negative which will generate only a positive half cycle of the a.c supply. When a.c supply is applied to the transformer, the voltage will be decreasing at the secondary winding of the diode. All the variations in the a.c supply will reduce, and we will get the pulsating d.c voltage to the load resistor.

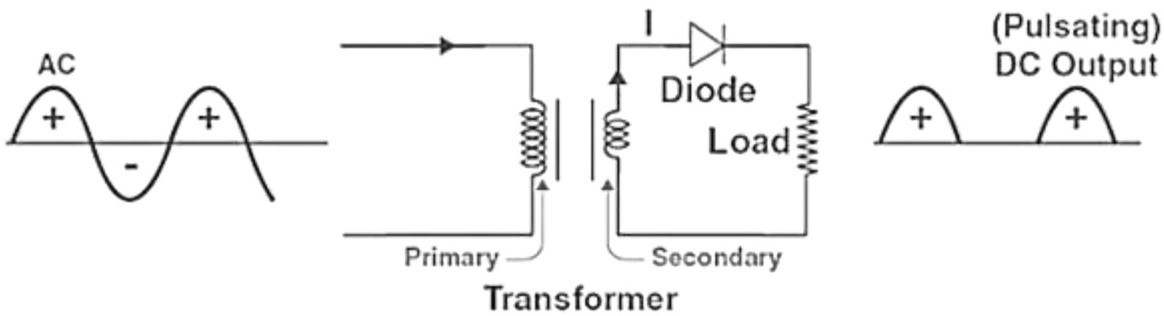

Figure 3.9: Half wave rectifier

In the second half cycle, the current will flow from negative to positive and the diode will be 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 which are corrected by using filters such as inductors and capacitors. 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.

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

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

DC Current

DC current is given as:

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

Where,

Imax is the maximum DC load current

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. The output DC voltage is given as:

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

Where,

V_{Smax} is the maximum secondary voltage

Form Factor

The form factor is the ratio of RMS value to the DC value. 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%.

Advantages of Half Wave Rectifier

- Affordable
- Simple connections
- Easy to use as the connections are simple
- Number of components used are less

Disadvantages of Half Wave Rectifier

- Ripple production is more
- Harmonics are generated
- Utilization of the transformer is very low
- The efficiency of rectification is low

Applications of Half Wave Rectifier

Following are the uses of half-wave rectification:

- Power rectification: Half wave rectifier is used along with a transformer for power rectification as powering equipment.
- Signal demodulation: Half wave rectifiers are used for demodulating the AM signals.
- Signal peak detector: Half wave rectifier is used for detecting the peak of the incoming waveform.

FULL WAVE RECTIFIER

What Is Full Wave Rectifier?

Electric circuits that convert AC to DC are known as rectifiers. Rectifiers are classified into two types as Half Wave Rectifiers and Full Wave Rectifiers. Significant power is lost while using a half-wave rectifier and is not feasible for applications that need a smooth and steady supply. For a more smooth and steady supply, we use the full wave rectifiers. In this article, we will be looking into the working and characteristics of a full wave rectifier.

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

Unlike halfwave rectifiers that utilize only the halfwave of the input AC cycle, full wave rectifiers utilize the full cycle. The lower efficiency of the half wave rectifier can be overcome by the full wave rectifier.

Full Wave Rectifier Circuit

The circuit of the full wave rectifier can be constructed in two ways. The first method uses a centre tapped transformer and two diodes. This arrangement is known as a centre tapped full wave rectifier. The second method uses a standard transformer with four diodes arranged as a bridge. This is known as a bridge rectifier.

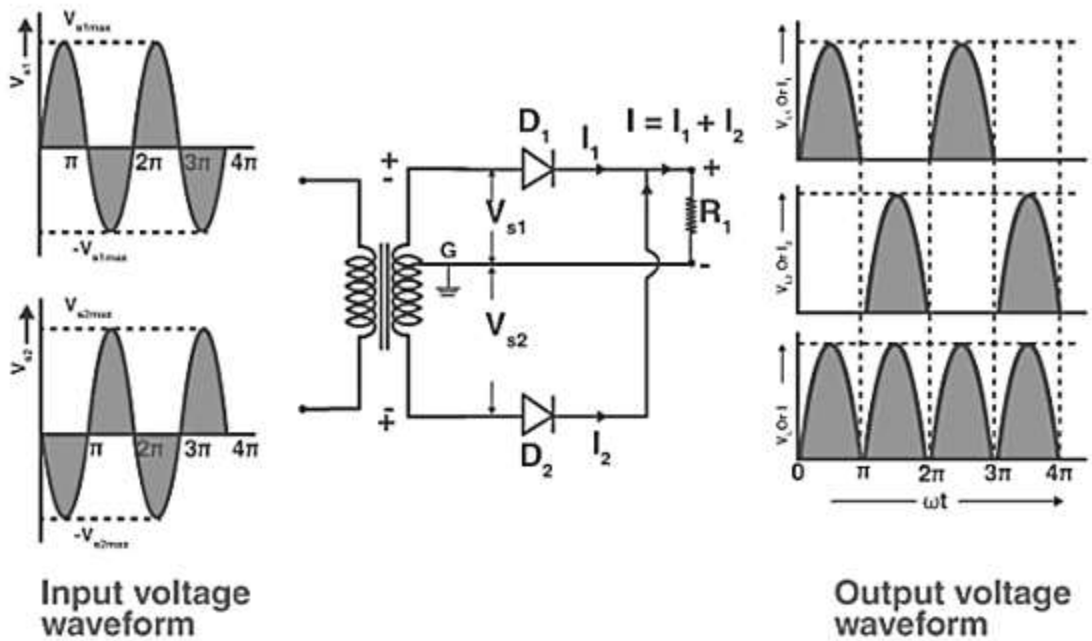

Figure 3.10: Centre tap full wave rectifier

The circuit of the full wave rectifier consists of a step-down transformer and two diodes that are connected and centre tapped. The output voltage is obtained across the connected load resistor.

Working of Full Wave Rectifier

The input AC supplied to the full wave rectifier is very high. The step-down transformer in the rectifier circuit converts the high voltage AC into low voltage AC. The anode of the centre tapped diodes is connected to the transformer's secondary winding and connected to the load resistor. During the positive half cycle of the alternating current, the top half of the secondary winding becomes positive while the second half of the secondary winding becomes negative.

During the positive half cycle, diode D1 is forward biased as it is connected to the top of the secondary winding while diode D2 is reverse biased as it is connected to the bottom of the secondary winding. Due to this, diode D1 will conduct acting as a short circuit and D2 will not conduct acting as an open circuit

During the negative half cycle, the diode D1 is reverse biased and the diode D2 is forward biased because the top half of the secondary circuit becomes negative and the bottom half of the circuit becomes positive. Thus in a full wave rectifiers, DC voltage is obtained for both positive and negative half cycle.

Peak Inverse Voltage

Peak inverse voltage is the maximum voltage a diode can withstand in the reverse-biased direction before breakdown. The peak inverse voltage of the full-wave rectifier is double that of a half-wave rectifier. The PIV across D1 and D2 is 2Vmax.

DC Output Voltage

The following formula gives the average value of the DC output voltage:

$$V_{dc} = I_{av}R_L = \frac{2}{\pi} I_{max} R_L$$ or $$V_{DC} = \frac{2V_{max}}{\pi}$$

DC Current

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

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

Where, Imax is the maximum DC load current

RMS Value of Current

The RMS value of the current can be calculated using the following formula:

$$I_{rms} = \frac{I_{max}}{\sqrt{2}}$$

Ripple Factor

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

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

Form Factor

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

The form factor of the full wave rectifier is calculated using the formula:

$$K_f = \frac{RMS\ value\ of\ current}{Average\ value\ of\ current} = \frac{I_{rms}}{I_{dc}} = \frac{I_{max}/\sqrt{2}}{2I_{max}/\pi} = \frac{\pi}{2\sqrt{2}} = 1.11$$

Peak Factor

The following formula gives the peak factor of the full wave rectifier:

$$K_p = \frac{Peak\ value\ of\ current}{RMS\ value\ of\ current} = \frac{I_{max}}{I_{max}/\sqrt{2}} = \sqrt{2}$$

Rectification Efficiency

The rectification efficiency of the full-wave rectifier can be obtained using the following formula:

$$\eta = \frac{DC\ Output\ Power}{AC\ Output\ Power}$$

The efficiency of the full wave rectifiers is 81.2%.

Advantages of Full Wave Rectifier

- The rectification efficiency of full wave rectifiers is double that of half wave rectifiers. The efficiency of half wave rectifiers is 40.6% while the rectification efficiency of full wave rectifiers is 81.2%.
- The ripple factor in full wave rectifiers is low hence a simple filter is required. The value of ripple factor in full wave rectifier is 0.482 while in half wave rectifier it is about 1.21.

- The output voltage and the output power obtained in full wave rectifiers are higher than that obtained using half wave rectifiers.

The only **disadvantage** of the full wave rectifier is that they need more circuit elements than the half wave rectifier which makes, making it costlier.

Disadvantages of Full Wave Rectifier

- Very expensive

Applications of Full Wave Rectifier

Following are the uses of full-wave rectifier:

- Full-wave rectifiers are used for supplying polarized voltage in welding and for this bridge rectifiers are used.
- Full-wave rectifiers are used for detecting the amplitude of modulated radio signals.

BRIDGE RECTIFIER

Many electronic circuits require a rectified DC power supply to power various electronic basic components from the available AC mains supply. Rectifiers are used to convert an AC power to a DC power. Among the rectifiers, the bridge rectifier is the most efficient rectifier circuit. We can define bridge rectifiers as a type of full-wave rectifier that uses four or more diodes in a bridge circuit configuration to efficiently convert alternating (AC) current to a direct (DC) current. In the next few sections, let us learn more about its construction, working, and more.

Construction

The construction of a bridge rectifier is shown in the figure below. The bridge rectifier circuit is made of four diodes D1, D2, D3, D4, and a load resistor RL. The four diodes are connected in a closed-loop configuration to efficiently convert the alternating current (AC) into Direct Current (DC).

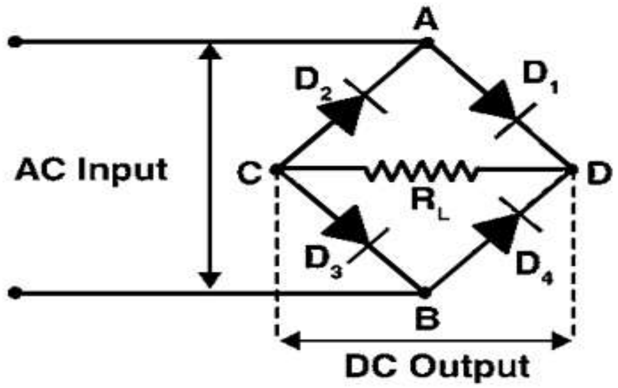

Figure 3.11: Bridge Rectifier

The main advantage of this configuration is the absence of the expensive centre-tapped transformer. Therefore, the size and cost are reduced. The input signal is applied across the terminals A and B, and the output DC signal is obtained across the load resistor RL connected between terminals C and D. The four diodes are arranged in such a way that only two diodes conduct electricity during each half cycle. D1 and D3 are pairs that conduct electric current during the positive half cycle/. Likewise, diodes D2 and D4 conduct electric current during a negative half cycle.

Working

When an AC signal is applied across the bridge rectifier, terminal A becomes positive during the positive half cycle while terminal B becomes negative. This results in diodes D1 and D3 becoming forward biased while D2 and D4 becoming reverse biased. The current flow during the positive half-cycle is shown in the figure 3.12.

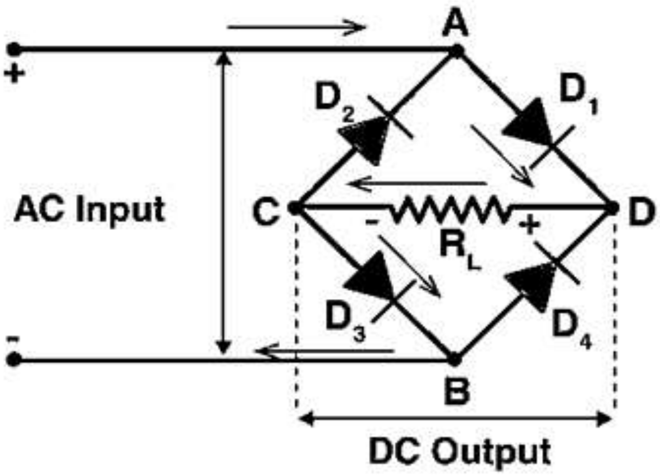

Figure 3.12: Current flow during the positive half cycle

During the negative half-cycle, terminal B becomes positive while terminal A becomes negative. This causes diodes D2 and D4 to become forward biased and diode D1 and D3 to be reverse biased.The current flow during the negative half cycle is shown in the figure below:

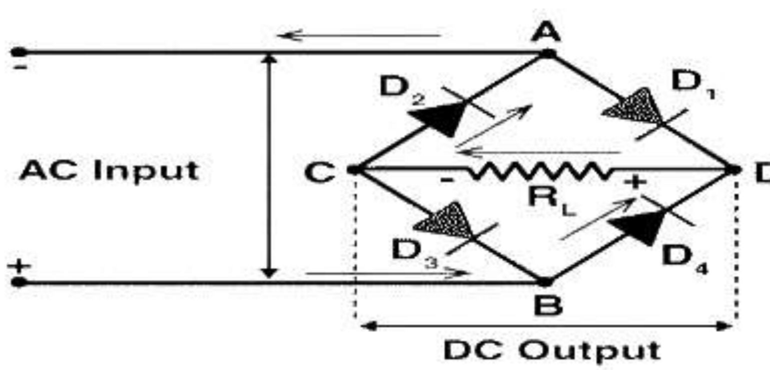

Figure 3.13: The current flow during the negative half cycle

From the figures 3.12& 3.13 given above, we notice that the current flow across load resistor RL is the same during the positive and negative half-cycles. The output DC signal polarity may be either completely positive or negative. In our case, it is completely positive. If the diodes' direction is reversed, we get a complete negative DC voltage.

Thus, a bridge rectifier allows electric current during both positive and negative half cycles of the input AC signal.

The output waveforms of the bridge rectifier are shown in the below figure.

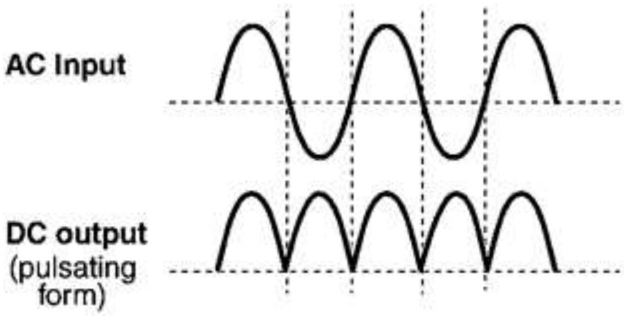

Figure 3.14: Output waveforms of the bridge rectifier

Characteristics of Bridge Rectifier

Ripple Factor

- The smoothness of the output DC signal is measured by a factor known as the ripple factor. The output DC signal with fewer ripples is considered a smooth DC signal while the output with high ripples is considered a high pulsating DC signal.
- Mathematically, the ripple factor is defined as the ratio of ripple voltage to pure DC voltage.
- The ripple factor for a bridge rectifier is given by

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

- For bridge rectifiers, the ripple factor is 0.48.

Peak Inverse Voltage

The maximum voltage that a diode can withstand in the reverse bias condition is known as a peak inverse voltage. During the positive half cycle, the diodes D1 and D3 are in the conducting state while D2 and D4 are in the non-conducting state. Similarly, during the negative half cycle, diodes D2 and D4 are in the conducting state, and diodes D1 and D3 are in the non-conducting state.

Efficiency

The rectifier efficiency determines how efficiently the rectifier converts Alternating Current (AC) into Direct Current (DC). Rectifier efficiency is defined as the ratio of the DC output power to the AC input power. The maximum efficiency of a bridge rectifier is 81.2%.

$$\eta = \frac{DC\ Output\ Power}{AC\ Output\ Power}$$

Advantages

- The efficiency of the bridge rectifier is higher than the efficiency of a half-wave rectifier. However, the rectifier efficiency of the bridge rectifier and the centre-tapped full-wave rectifier is the same.

- The DC output signal of the bridge rectifier is smoother than the output DC signal of a half-wave rectifier.

- In a half-wave rectifier, only half of the input AC signal is used, and the other half is blocked. Half of the input signal is wasted in a half-wave rectifier. However, in a bridge rectifier, the electric current is allowed during both positive and negative half cycles of the input AC signal. Hence, the output DC signal is almost equal to the input AC signal.

Disadvantages

- The circuit of a bridge rectifier is complex when compared to a half-wave rectifier and centre-tapped full-wave rectifier. Bridge rectifiers use 4 diodes while half-wave rectifiers and centre-tapped full wave rectifiers use only two diodes.

- When more diodes are used more power loss occurs. In a centre-tapped full-wave rectifier, only one diode conducts during each half cycle. But in a bridge rectifier, two diodes connected in series conduct during each half cycle. Hence, the voltage drop is higher in a bridge rectifier.

FILTER CIRCUIT

The ripple in the signal denotes the presence of some AC component. This ac component has to be completely removed in order to get pure dc output. So, we need a circuit that smoothens the rectified output into a pure dc signal.

A filter circuit is one which removes the ac component present in the rectified output and allows the dc component to reach the load.

The following figure shows the functionality of a filter circuit.

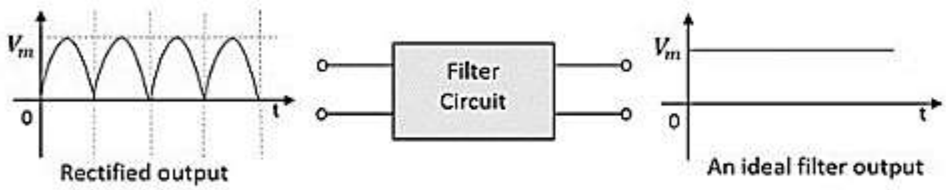

Figure 3.15: Filter circuits

A filter circuit is constructed using two main components, inductor and capacitor. We have already studied in Basic Electronics tutorial that

1) An inductor allows dc and blocks ac.
2) A capacitor allows ac and blocks dc.

Let us try to construct a few filters, using these two components.

CHOKE FILTER

Definition: Choke filter consists of an inductor connected in series with rectifier output circuit and a capacitor connected in parallel with the load resistor. It is also called L-section filter because the inductor and capacitor are connected in the shape of inverted L. The output pulsating DC voltage from a rectifier circuit passes through the inductor or choke coil.

The inductor has low DC resistance and extremely high AC reactance. Thus, ripples get filtered through choke coil. Some of the residual ripples if present in filtered signal from inductor coil will get bypassed through the capacitor. The reason behind this is that capacitor allow AC and block DC.

Significance of Choke Filter or L-section filter

Choke filter came into existence due to shortcomings of the series inductor and shunt capacitor filter. A series inductor filter filters the output current but reduces the output current (RMS value and Peak value) up to a large extent. And the shunt capacitor filter performs filtering efficiently but increases the diode current. The excess of current in a diode may lead to its destruction.

Moreover, the ripple factor of series inductor filter is directly proportional to the load resistance it means as the load resistance increases, ripple factor also starts increasing. And in the case of shunt capacitor, the ripple factor is inversely proportional to the value of load resistance. It implies that in shunt capacitor filter the ripple factor decreases with increase in load resistance and increases with the decrease in load resistance.

Thus, for better performance, we need a filter circuit in which ripple factor is low and do not vary with the variation in load resistance. This can be achieved by using the combination of series inductor filter and shunt capacitor filter. The voltage stabilization property of shunt capacitor filter and current smoothing property of series inductor filter is utilized for the formation of choke filter or L-section filter.

The combination of series inductor filter and shunt capacitor filter is generally used for most of the applications. The combination results in two types, i.e. L-section filter and Pi filter. In this article, we will discuss the working of L-section or choke filter and in next article, we will discuss Pi filter in detail.

Working of Choke Filter or L-section filter

When the pulsating DC signal from the output of the rectifier circuit is feed into choke filter, the AC ripples present in the output DC voltage gets filtered by choke coil. The inductor has the property to block AC and pass DC. This is because DC resistance of an inductor is low and AC impedance of inductor coil is high. Thus, the AC ripples get blocked by inductor coil.

Although the inductor efficiently removes AC ripples, a small percentage of AC ripples is still present in the filtered signal. These ripples are then removed by the capacitor connected in parallel to the load resistor. Now, the DC output signal is free from AC components, and this regulated DC can be used in any application.

If the inductor of high inductive reactance (XL), greater than the capacitive reactance at ripple frequency is used than filtering efficiency gets improved.

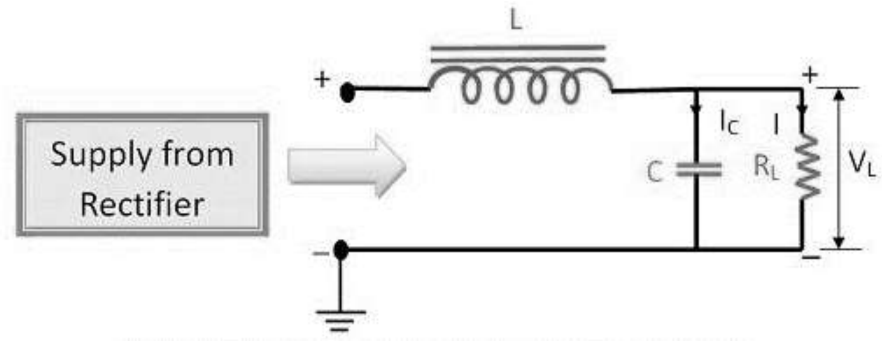

Figure 3.16: Choke input or L section filter

Waveform of Choke Filter or L-section Filter

The waveform of DC output signal with a filter and without filter is shown in the below diagram.

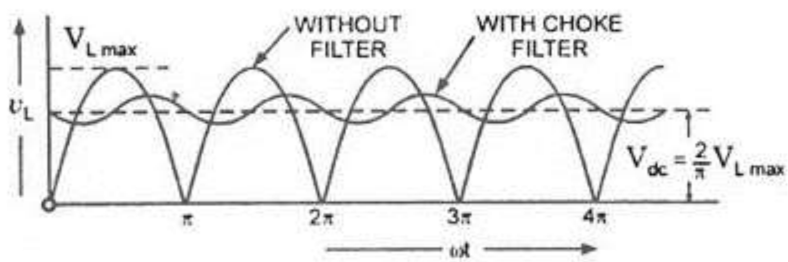

Figure 3.17: Choke filter output voltage waveform

Advantages of Choke Filter or L-section Filter

It provides better voltage regulation.The ripple factor can be varied according to the need.

Disadvantages of Choke Filter or L-Section filter

Bulky Size:

These kinds of filters were popular in ancient time but it has become obsolete now due to bulky size of inductors and capacitors.

Not suitable for low voltage power Supplies:

These are not suitable for low voltage power supplies. IC regulators or active filters are used in such devices.

It is the combination of series inductor filter and shunt capacitor filter. The advantages of both these filters are utilized to form Choke input filters. And the disadvantages of both of these filters are removed in choke filter.

Capacitor input filter or **Shunt Capacitor Filter**

The Shunt capacitor filters comprise of capacitor along with the load resistor. In this, the capacitor is connected in parallel with respect to the output of rectifier circuit and also in parallel with the load resistor. During conduction, the capacitor starts charging and stores energy in the form of the electrostatic field. The capacitor will charge to its peak value because the charging time constant is almost zero.

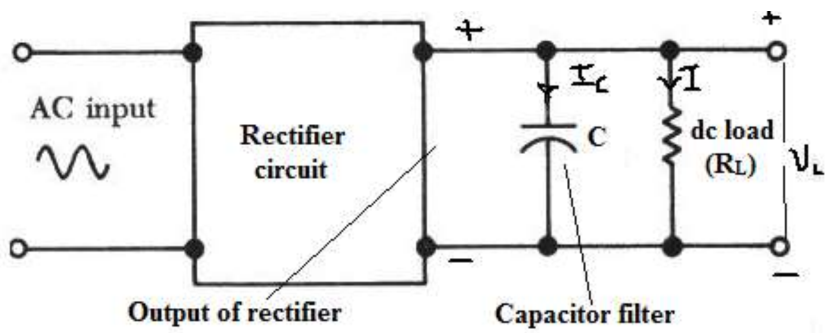

Figure 3.18: Capacitor input filter

During non-conduction, the capacitor will discharge through the load resistor. Thus, in this way, the capacitor will maintain constant output voltage and provide the regulated output. The shunt capacitor filters use the property of capacitor which blocks DC and provides low resistance to AC. Thus, AC ripples can bypass through the capacitor.

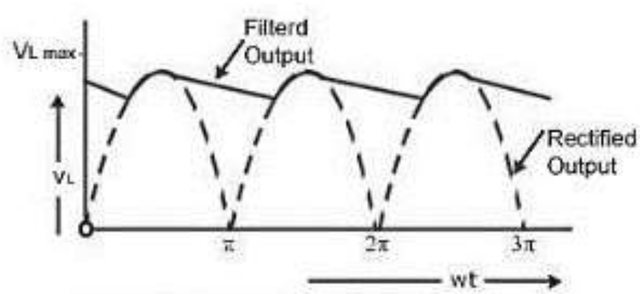

Figure 3.19 : Output voltage waveform

If the value of capacitance of the capacitor is high, then it will offer very low impedance to AC and extremely high impedance to DC. Thus, the AC ripples in the DC output voltage gets bypassed through parallel capacitor circuit, and DC voltage is obtained across the load resistor.

Advantages of capacitor-filters are:

1. Cheaper
2. smaller in size
3. readily available

Disadvantages of the filter-capacitor are:

1. It is sensitive to temperature change
2. Its capacitance reduces with time.

CLIPPER CIRCUITS

A clipper is a device which limits, remove or prevents some portion of the wave form (input signal voltage) above or below a certain level In other words the circuit which limits positive or negative amplitude, or both is called chipping circuit. The clipper circuits are of the following types.

1. Series positive clipper
2. Series negative clipper
3. Shunt or parallel positive clipper
4. Shunt or parallel negative clipper
5. Dual (combination)Diode clipper

SERIES POSITIVE CLIPPER

In a series positive clipper, a diode is connected in series with the output, as shown in Fig 3.20. During the positive half of the input voltage, the terminal A is positive with respect to B. These reverse biases the diode and it acts as an open switch Therefore all the applied voltage drops across the diode and none across the resistor As a result of this there is no output voltage during the positive half cycle of the input voltage.

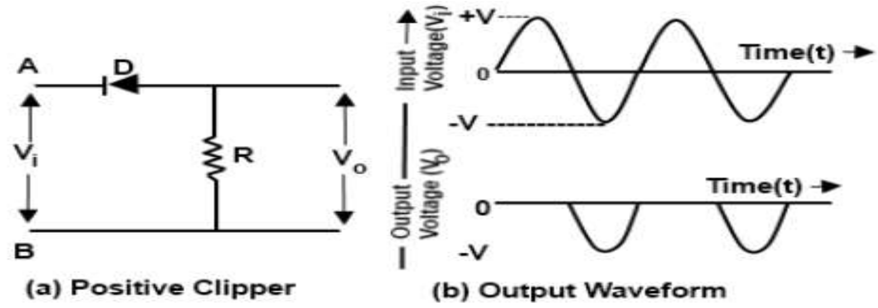

Figure 3.20: Series Positive Clipper

During the negative half cycle of the input voltage the terminal B is positive with respect to A. Therefore it forward biases the diode and it acts as a closed switch. Thus there is on voltage drop across diode during the negative half cycle of the input voltage. All the input voltage is dropped across the resistor as shown in the output wave form. Clippers prevent either or both polarities of a wave form exceeding a specific amplitude level. However a positive Clipper is that which removes or clips the positive half completely. Hence the circuit of the Fig 3.20 is called a positive Clipper Here it may he noted the diode acts a series switch between the source and load. Due to this reason the circuit is called series positive clipper.

SERIES-POSITIVE CLIPPER WITH BIAS

Sometimes it is desired to remove a Small portion of positive or apposite halt cycle of the signal voltage (input signal). For this purpose a biased clipper is used Fig 3.21 shows the circuit of a biased series positive clipper.

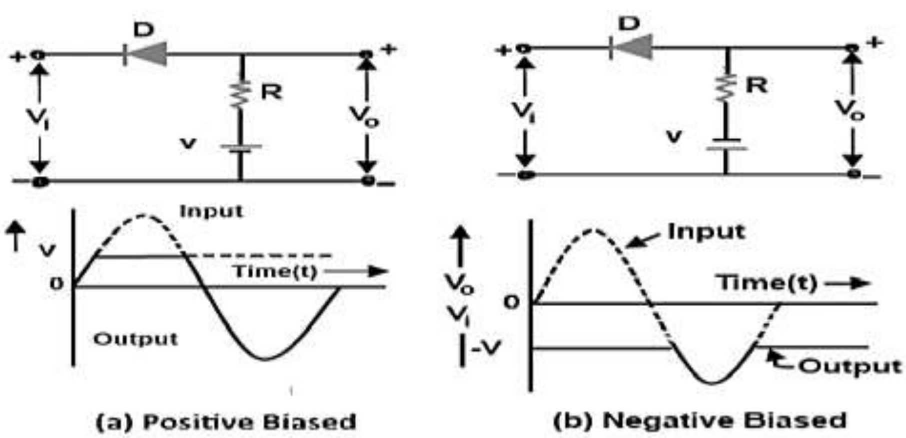

Figure 3.21: Biased series positive clipper

It may be observed that the clipping takes place during the positive cycle only when the input voltage is greater thence battery voltage (i.e. Vi > VB). The chipping level can be shifted up or down by varying the bias voltage (VB)

SERIES NEGATIVE CLIPPER

In a series negative clipper a diode is connected in a direction appositive to that of a positive clipper Fig 3.20 shows the circuit of a negative clipper.

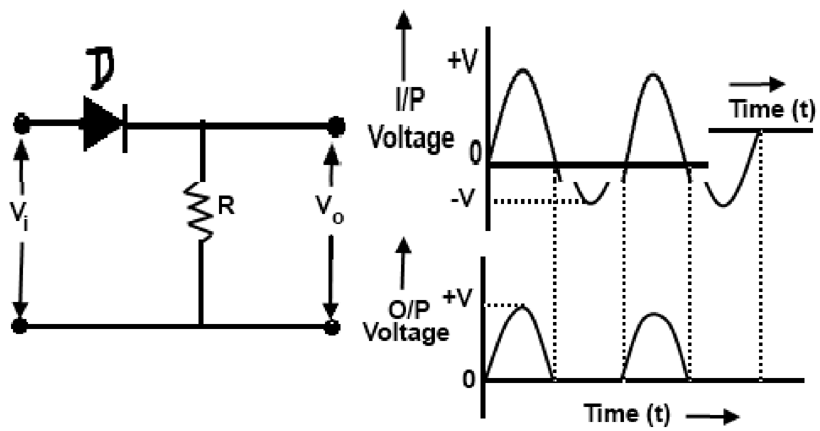

Figure 3.22: Series Negative Clipper

During the positive half cycle of the voltage, the terminal A is positive with respect to the terminal B Therefore the diode is forward biased and it acts it as a closed switch as a result, all the input voltage appears across the resistor as shown in Fig 3.22. During the negative half cycle of the input voltage, the terminal B is positive with respect to the terminal A. Therefore the diode is reverse biased and it acts as an open switch, Thus there is no voltage drop across the resistor during the negative half cycle as shown in the output waveform. It may be observed that if it is desired to remove or clip the negative half-cycle of the input, the only thing is to be done is to reverse the polarities of the diode in the circuit.

SERIES-NEGATIVE CLIPPER WITH BIAS

The Fig 3.23 shows the circuit of a biased series negative diver. In this circuit clipping take place during the negative half cycle only when the input voltage Vi > VB she clipping level can be shifted up or down by varying the bias voltage (-VB)

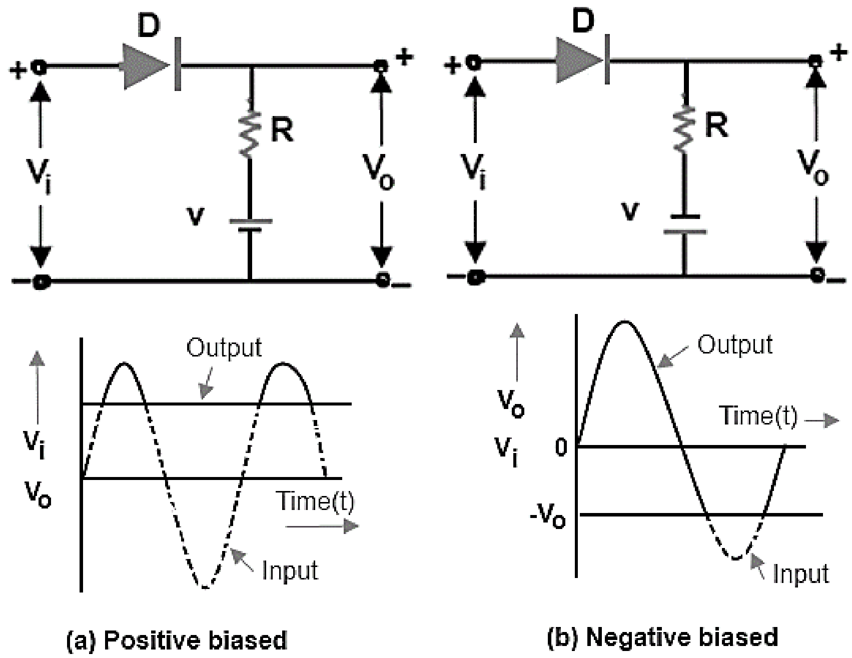

Figure 3.23: Biased series negative clipper

SHUNT OR PARALLEL POSITIVE CLIPPER

A parallel clipper circuit uses the same diode theory and circuit operation a resistor and diode are connected in series with the input signal and the output signal is developed across the diode. The output is in parallel with the diode hence the circuit name parallel clipper the parallel clipper can limit either the positive or negative alternation of the input signal Fig.3.24 shows the circuit of a shunt positive clipper. In this circuit, the diode acts as a closed switch when the input voltage is positive (i.e. Vi > 0 and as an open switch when the input voltage is negative (i.e. Vi< 0) the output waveform is the same as that of a series positive clipper in the parallel clippers the alp will develop when the diode is cut off.

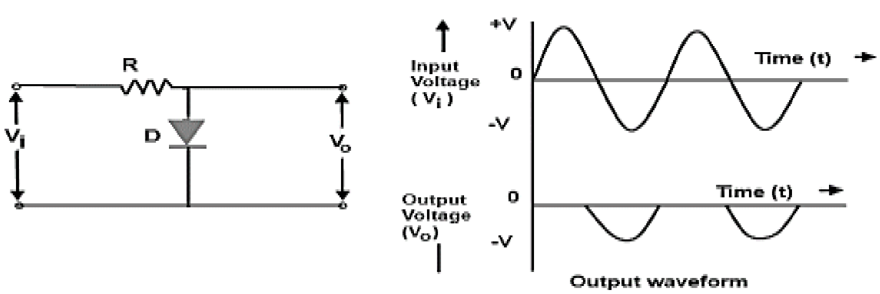

Figure 3.24: Shunt or parallel positive clipper

SHUNT OR PARALLEL POSITIVE CLIPPER WITH BIAS

As is in Fig 3.25, positive terminal of the battery is connected to the cathode of the diode. This causes the diode to be reversed biased at all times except when the input signal is more positive the bias voltage(i e Vi > VB). it will be interesting to know that if the polarity of the bias voltage is reversed , the resulting circuits will be as shown in Fig 3.25(b) Here the input signal lying above the voltage —VB is clipped the waveforms of the of the output voltage are also shown with figures

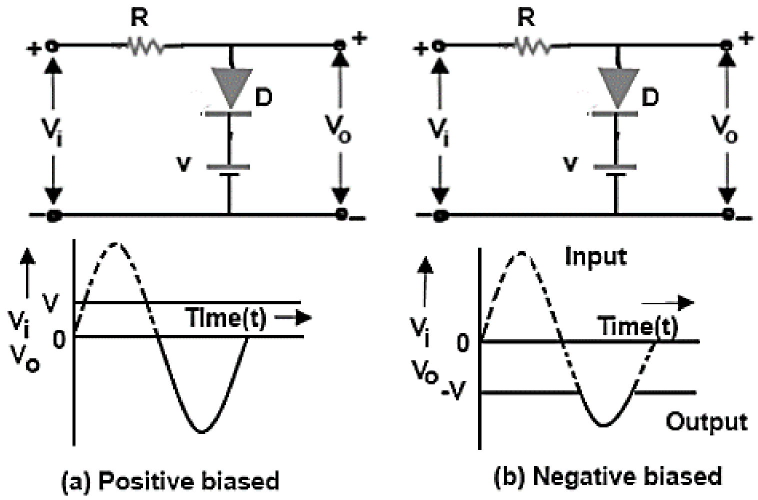

Figure 3.25 : Biased shunt /parallel positive clipper

SHUNT OR PARALLEL NEGATIVE CLIPPER

The negative clipper has allowed to pass the positive half cycle of the input voltage and clipped the negative half cycle completely Fig 3.26 shows the shunt (parallel) negative clipper.

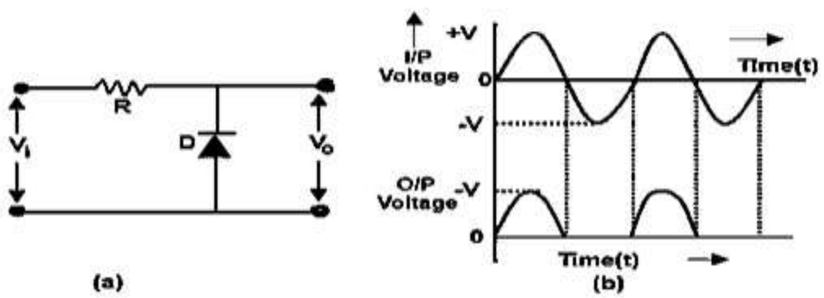

Figure 3.26: Shunt or Parallel negative clipper

In such a circuit the diode acts as a closed switch for a negative input voltage (i.e. Vi < O) and as an open switch for a positive input voltage (i.e. Vi O) the output waveform of the Circuit is the same as that of series negative clipper.

SHUNT OR PARALLEL NEGATIVE CLIPPER WITH BIAS

In such a circuit clipping take place during the negative half cycle only when the input voltage (Vi < VB) the clipping level can be shifted up or down by varying the bias voltage (—VB). It will be interesting to know that if the polarity of the bias voltage is reversed, then the resulting circuits will be as shown in Fig 3.27 (b) Here the entire signal below the voltage level VII has been clipped off .

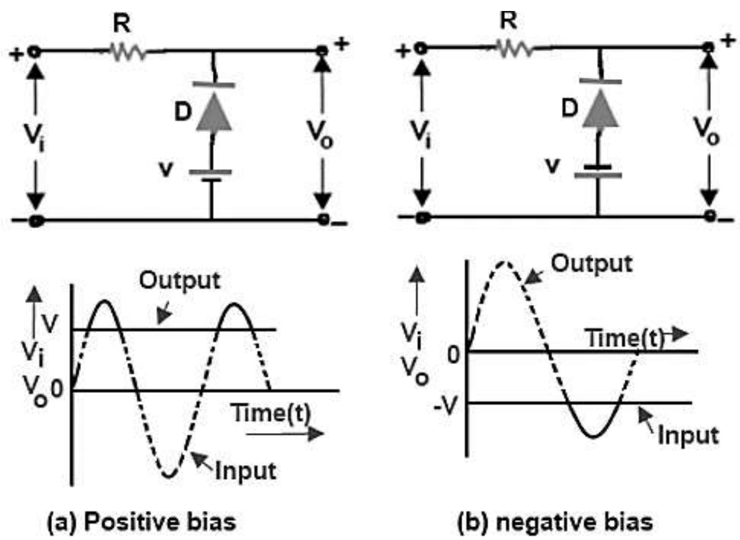

Figure 3.27: Biased shunt /parallel negative clipper

DUAL (COMBINATION) DIODE CLIPPER

The type of clipper combines a parallel negative clipper with negative bias (D1 and B2) and a parallel positive bias (D1 and B1). Hence the combination of a biased positive clipper and a biased negative clipper is called combination or dual diode clipper. Such a clipper circuit can clip at both two in dependent levels depending upon the bias voltages. Fig 3.28(a) show the circuit of a dual (combination) clipper.

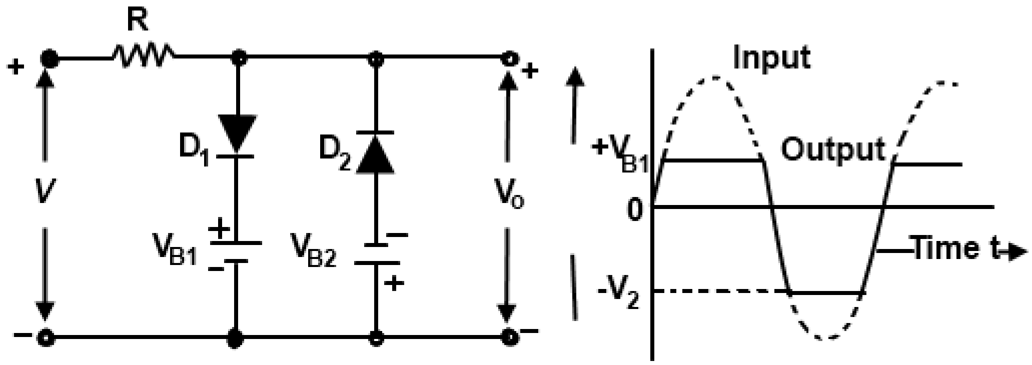

Figure 3.28: Dual diode clipper

Let us suppose a sinusoidal ac voltage is applied at the input terminals of the circuit. Then during the positive half cycle, the diode D1 is forward biased, while diode D2 is reverse. biased. Therefore the diode D1 will conduct and will acts as a short circuit. On the other hand, diode D2 will acts as an open circuit. However, the value of output voltage cannot exceed the voltage level of VB1 as Shown in Fig 3.28.

Similarly during the negative input half cycle the diode D2 acts as a short circuit while the diode D1 as an open circuit However the value of output voltage cannot exceed the voltage level of VB2 It may be noted that the clipping levels of the circuit be varied by changing the values of VB1 and VB2 If the values of VB1 and VB2 are equal, the circuit will clip both the positive and negative half cycles at the same voltage level. Such a circuit is known as a symmetrical clipper

CLAMPING CIRCUITS

Certain applications in electronics require that the upper or lower extremity of a wave be fixed at a specific value In such applications ,a clamping/clamper circuits are used.

A circuit that places either the positive or negative peak of a signal at a desired D.C level is known as a clamping circuit. A clamping circuit introduces (or restores) a D.C level to an A.C signal. Thus a clamping circuit is also known as D.C restorer, or D.C reinserted or a baseline stabilizer. The following are two general types of clamping.

Positive clamping occurs when negative peaks raised or clamped to ground or on the zero level In other words, it pushes the signal upwards so that negative peaks fall on the zero level.

Negative clamping occurs when positive peaks raised or clamped to ground or on the zero level In other words, it pushes the signal downwards so that the positive peaks fall on the zero level.

In both cases the shape of the original signal has not changed, only there is vertical shift in the signal Fig. 3.29 shows the clamping wave form

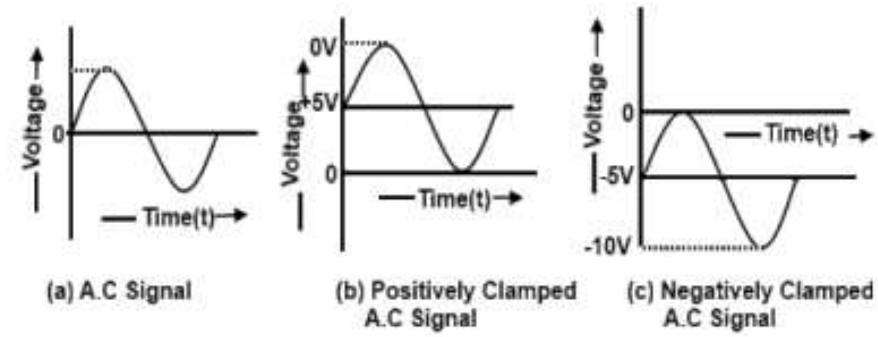

Figure 3.29: clamper circuits demonstration

DIODE CLAMPERS

POSITIVE CLAMPER

The Fig 3.30 shows the circuit of a positive clamper It consists of a diode and a capacitor the clamper output is taken across the load resistance R.

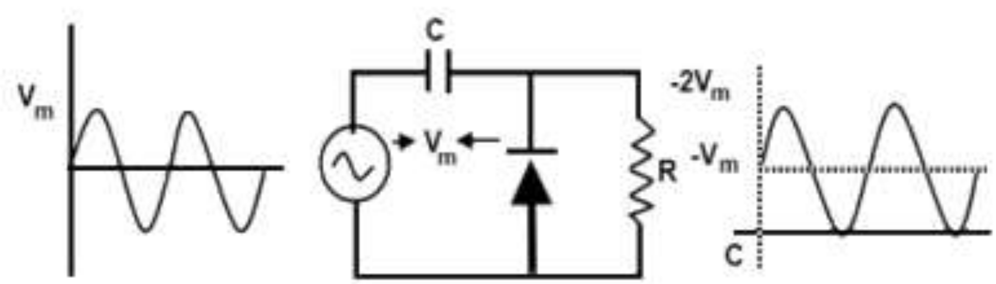

Figure 3.30 : Positive clamper

POSITIVE CLAMPER WITH BIAS

Biased clamper circuit operates in exactly the same manner as unbiased clampers. The different is only that a dc bias voltage is add in series with the diode and resistor. A biased clamper means that the clamping can be done at any voltage level other than zero.

The Fig 3.31(a) shows the circuit of positive clamper with positive biased Here a battery of 10 V is added in such a way that the clamping take place positively at 10V. Similarly, it is possible to clamp the input wave form positively at -10V by reversing the battery connections as shown in Fig 3.31(b).

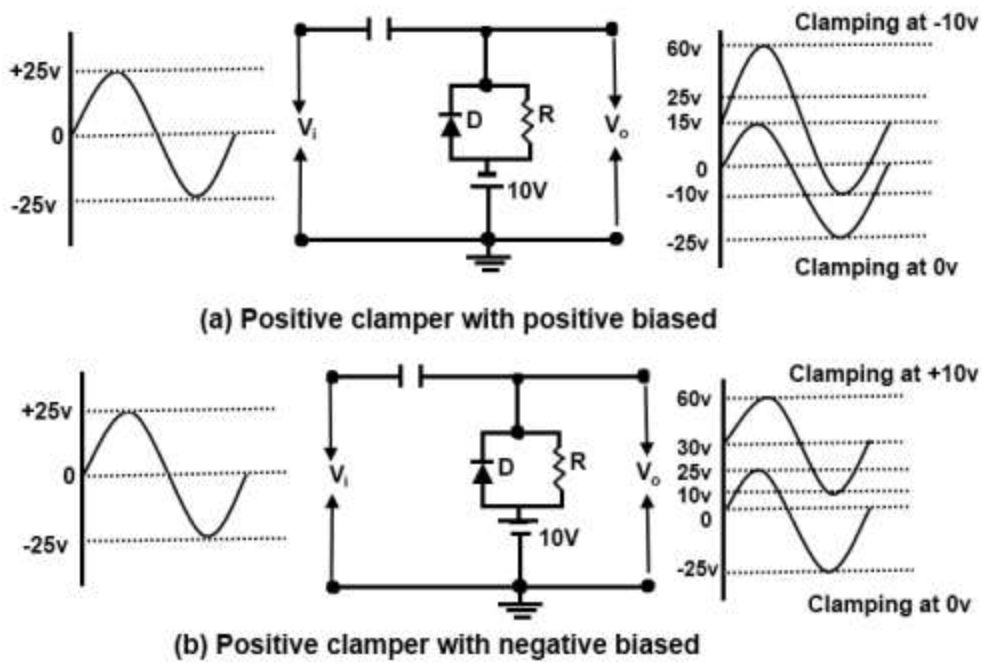

Figure 3.31: Positive Clamper with Bias

NEGATIVE CLAMPER

The Fig 3.32 shows the circuit of a negative clamper.During the positive half cycle of the input signal, the capacitor is charged to Vm, with the polarity shown in Fig 3.32. Observe that voltage across the capacitor is opposing the input voltage V. This gives negative clamped voltage and is called negative clamper circuit.

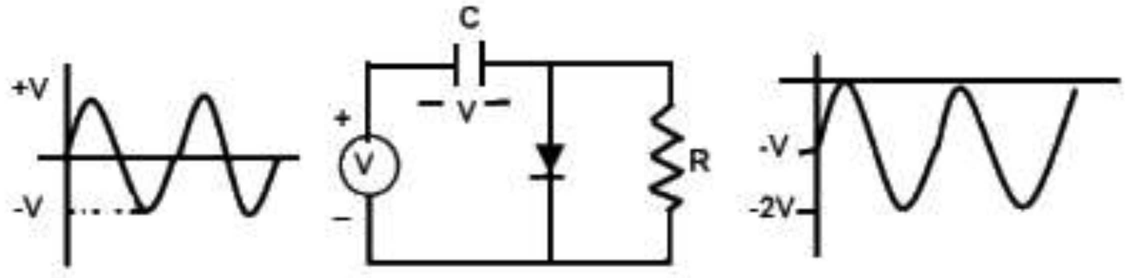

Figure 3.32: Negative Clamper

NEGATIVE CLAMPER WITH BIAS

The Fig 3.33 (a) shows the circuit of negative clamper with positive bias. With no input signal the capacitor charges to the battery voltage and the output is positive because the negative side of the batter is grounded. The output waveform is clamped to +10V, the value of the battery. Since this is a negative clamper (cathode to ground), the top of the output wave touch the +10V reference line.

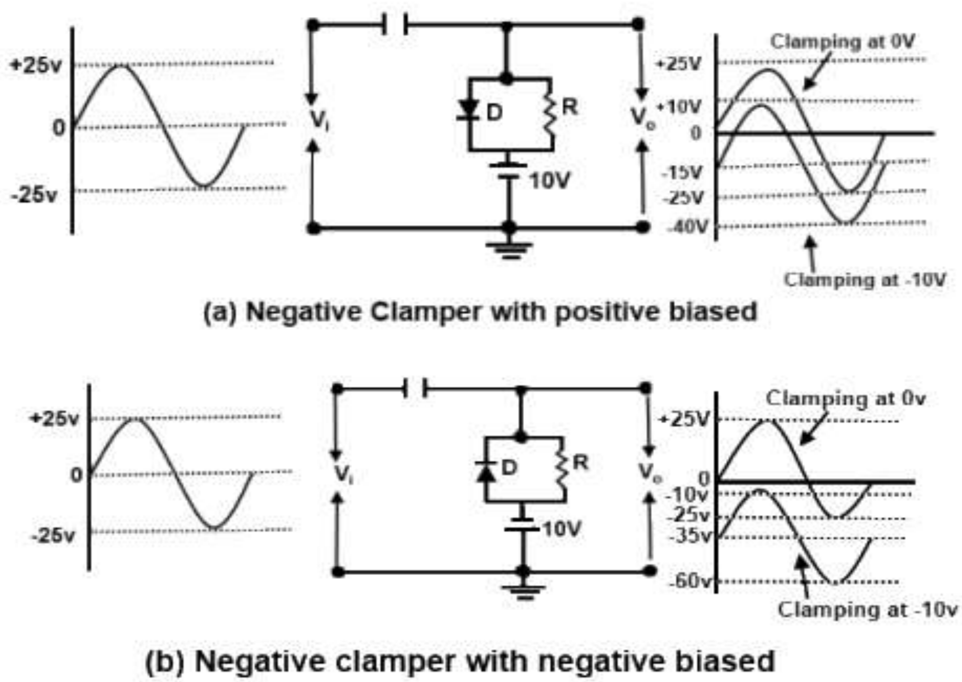

Figure 3.33: Negative Clamper with Bias

Similarly it is possible to clamp the input waveform negatively at by reversing the battery connections as shown in Fig 3.33(b)

USES OF CLAMPING CIRCUITS

Clamping circuit are used to shift any part of the input signal waveform and can be maintained at a specified voltage level Such circuit are used in television receivers to restore the original d.c reference signal (corresponding to the brightness level of the picture) to the video Signal The clamping of peak (i.e. 2Vm, 3Vm, 4Vm etc.,) Such to circuit are known as voltage multipliers These circuit are used to supply power to thigh voltage/low current devices like cathode ray tubes used in Television receivers, oscilloscopes and computer displays.

APPLICATIONS OF CLIPPERS AND CLAMPERS

The applications of clippers are:

- They are frequently used for the separation of synchronizing signals from the composite picture signals.
- The excessive noise spikes above a certain level can be limited or clipped in FM transmitters by using the series clippers.
- For the generation of new waveforms or shaping the existing waveform, clippers are used.
- The typical application of a diode clipper is for the protection of transistors from transients, as a freewheeling diode connected in parallel across the inductive load.
- A frequently used half-wave rectifier in power supply kits is a typical example of a clipper. It clips either positive or negative half-wave of the input.
- Clippers can be used as voltage limiters and amplitude selectors.

The applications of clampers are:

- The complex transmitter and receiver circuitry of the television clamper is used as a baseline stabilizer to define sections of the luminance signals to preset levels.
- Clampers are also called direct current restorers as they clamp the waveforms to a fixed DC potential.
- These are frequently used in test equipment, sonar, and radar systems.

- For the protection of the amplifiers from large errant signals, clampers are used.
- Clampers can be used for removing the distortions
- For improving the overdrive recovery time clampers are used.
- Clampers can be used as voltage doublers or voltage multipliers.

These are all the detailed applications of both clippers and clampers. Clippers and clampers circuits are used for molding a waveform to a required shape and specified range.

VOLTAGE MULTIPLIERS

There are applications where the voltage needs to be multiplied in some cases. This can be done easily with the help of a simple circuit using diodes and capacitors. The voltage if doubled, such a circuit is called as a Voltage Doubler. This can be extended to make a Voltage Tripler or a Voltage Quadrupler or so on to obtain high DC voltages.

To get a better understanding, let us consider a circuit that multiplies the voltage by a factor of 2. This circuit can be called as a **Voltage Doubler**. The figure15 shows the circuit of a voltage doubler. The input voltage applied will be an AC signal which is in the form of a sine wave as shown in the figure below.

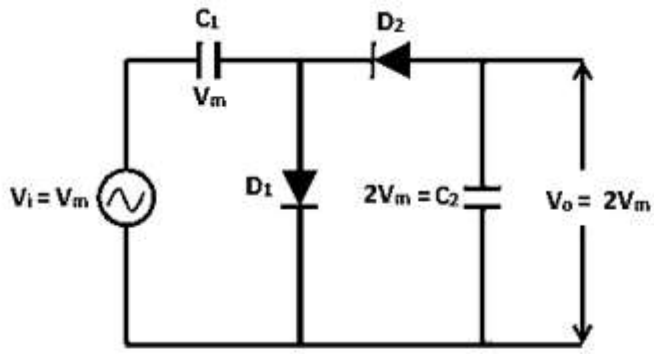

Figure 3.34: Voltage multiplier

Working:

The voltage multiplier circuit can be understood by analysing each half cycle of the input signal. Each cycle makes the diodes and the capacitors work in different fashion. Let us try to understand this.

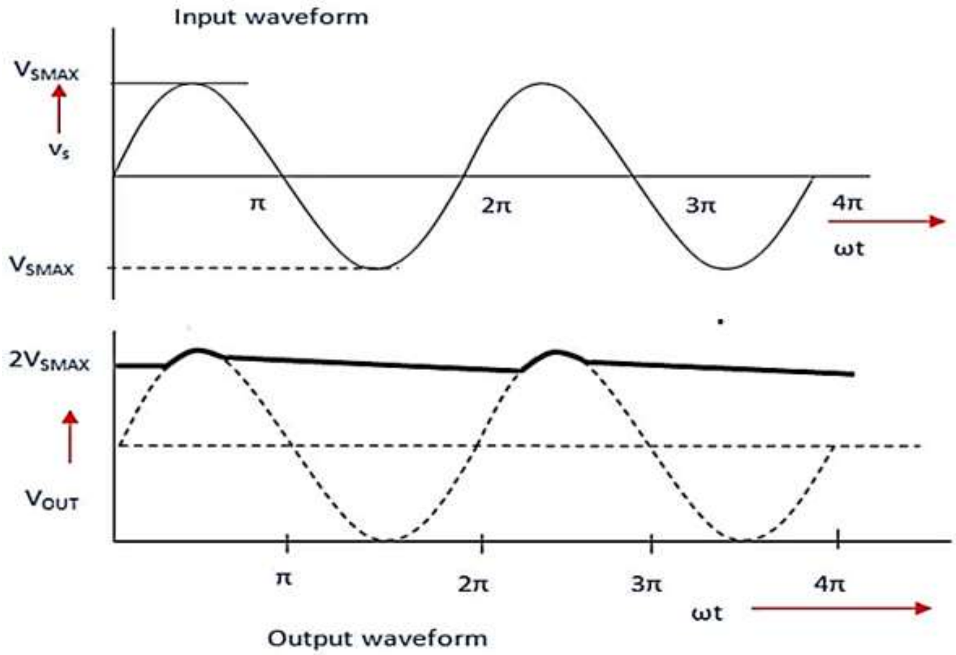

Figure 3.35: Input / output waveform

During the first positive half cycle − When the input signal is applied, the capacitor C1 is charged and the diode D1is forward biased. While the diode D2 is reverse biased and the capacitor C2 doesn't get any charge. This makes the output V0 to be Vm. This can be understood from the following figure.

Hence, during 0 to π, the output voltage produced will be Vmax. The capacitor C1 gets charged through the forward biased diode D1 to give the output, while C2 doesn't charge. This voltage appears at the output.

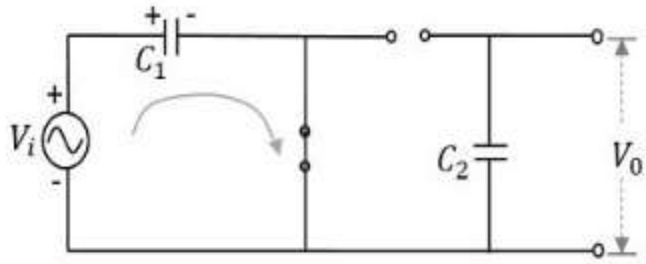

Figure 3.36: During the first positive half cycle

During the negative half cycle − After that, when the negative half cycle arrives, the diode D1 gets reverse biased and the diode D2gets forward biased. The diode D2 gets the charge through the capacitor C2 which gets charged during this process. The current then flows through the capacitor C1 which discharges. It can be understood from the following figure.

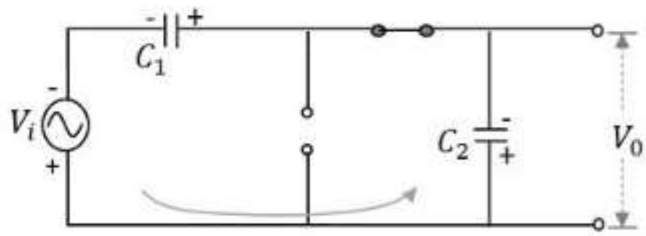

Figure 3.37: During the negative half cycle

Hence during π to 2π, the voltage across the capacitor C2 will be Vmax. While the capacitor C1 which is fully charged, tends to discharge. Now the voltages from both the capacitors together appear at the output, which is 2Vmax. So, the output voltage V0 during this cycle is 2Vmax

During the next positive half cycle − the capacitor C1 gets charged from the supply and the diode D1gets forward biased. The capacitor C2 holds the charge as it will not find a way to discharge and the diode D2 gets reverse biased. Now, the output voltage V0 of this cycle gets the voltages from both the capacitors that together appear at the output, which is 2Vmax.

During the next negative half cycle − the next negative half cycle makes the capacitor C1 to again discharge from its full charge and the diode D1 to reverse bias while D2 forward and capacitor C2 to charge further to maintain its voltage. Now, the output voltage V0 of this cycle gets the voltages from both the capacitors that together appear at the output, which is 2Vmax.

Hence, the output voltage V0 is maintained to be 2Vmax throughout its operation, which makes the circuit a voltage doubler.

Application

Voltage multipliers are mostly used where high DC voltages are required. For example, cathode ray tubes and computer display.

Bipolar Junction Transistors (BJT)

General configuration and definitions

The transistor is the main building block “element” of electronics. It is a semiconductor device and it comes in two general types: the Bipolar Junction Transistor (BJT) and the Field Effect Transistor (FET). Here we will describe the system characteristics of the BJT configuration and explore its use in fundamental signal shaping and amplifier circuits. The BJT is a three terminal device and it comes in two different types. The ***npn*** BJT and the ***pnp*** BJT. The BJT symbols and their corresponding block diagrams are shown on Figure 3.38.

The BJT is fabricated with three separately doped regions. The ***npn*** device has one p region between two n regions and the ***pnp*** device has one n region between two p regions. The BJT has two junctions (boundaries between the n and the p regions). These junctions are similar to the junctions we saw in the diodes and thus they may be forward biased or reverse biased. By relating these junctions to a diode model the ***pnp*** BJT may be modelled as shown on Figure 3.39.

The three terminals of the BJT are called the Base (B), the Collector (C) and the Emitter (E).

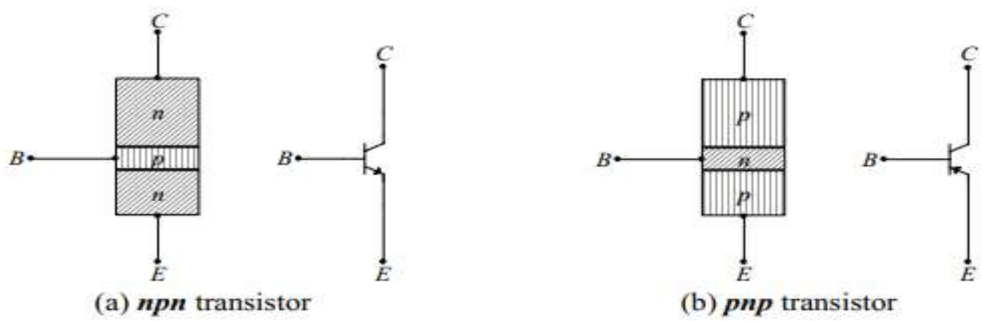

Fig 3.38. BJT schematics and structures. (a) *npn* transistor, (b) *pnp* transistor

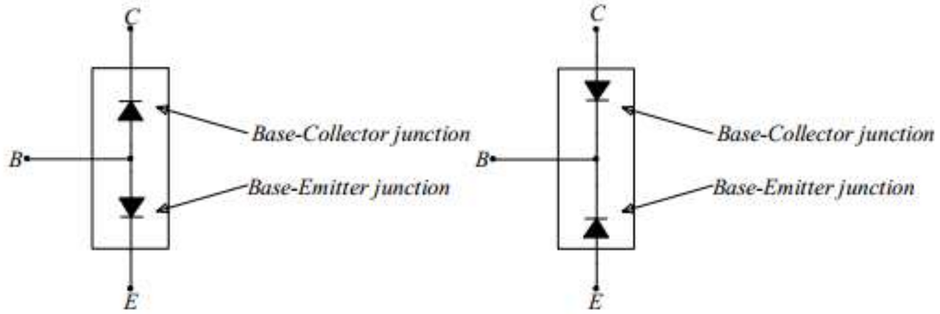

Fig 3.39. BJT schematics modelling structures. (a) *npn* transistor, (b) *pnp* transistor

Since each junction has two possible states of operation (forward or reverse bias) the BJT with its two junctions has four possible states of operation.

Here it is sufficient to say that the structure as shown on Figure 3.38 is not symmetric. The n and p regions are different both geometrically and in terms of the doping concentration of the regions. For example, the doping concentrations in the collector, base and emitter may be 10^{15}, 10^{17} and 10^{19} respectively. Therefore, the behavior of the device is not electrically symmetric and the two ends cannot be interchanged. Before proceeding let's consider the BJT ***npn*** structure shown on Figure 3.40.

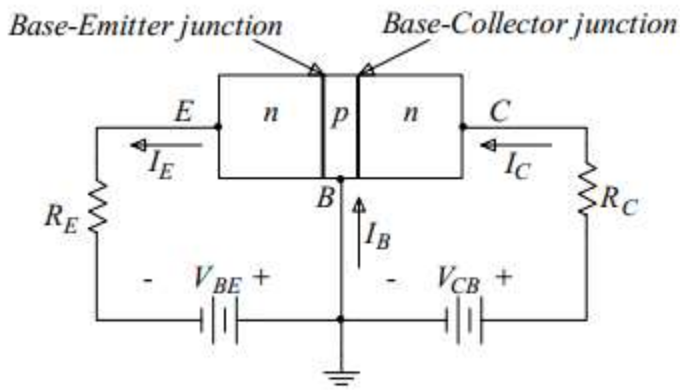

Fig. 40 BJT *npn* structure

With the voltage V_{BE} and V_{CB} as shown, the Base-Emitter (B-E) junction is forward biased and the Base-Collector (B-C) junction is reverse biased.

The current through the B-E junction is related to the B-E voltage as

$$I_E = I_s\left(e^{V_{BE}/V_T} - 1\right) \qquad (1)$$

Due to the large differences in the doping concentrations of the emitter and the base regions the electrons injected into the base region (from the emitter region) results in the emitter current I_E. Furthermore, the number of electrons injected into the collector region is directly related to the electrons injected into the base region from the emitter region.

Therefore, the collector current is related to the emitter current which is in turn a function of the B-E voltage.

The collector current and the base current are related by

$$I_C = \beta\, I_B \qquad (2)$$

And by applying KCL we obtain

$I_E = I_C + I_B$ (3)

And thus from equations 2 and 3 the relationship between the emitter and the base currents is

$I_E = (1+\beta)I_B$ (4)

And equivalently

$I_C = (\beta/(1+\beta))\, I_E$ (5)

The fraction $(\beta/(1+\beta))$ is called α.

For the transistors of interest $\beta = 100$ which corresponds to $\alpha = 0.9$ $I_C \simeq I_E$.

The direction of the currents and the voltage polarities for the npn and the pnp BJTs are shown on Figure 3.41.

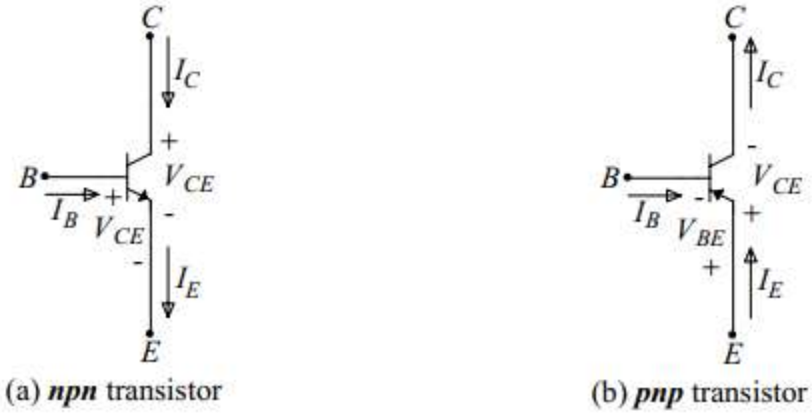

Figure 3.41 Current directions and voltage polarities for *npn* (a) and *pnp* (b) BJTs

Modes of operation

The two junctions of BJT can be either forward or reverse-biased.
The BJT can operate in different modes depending on the junction bias.
The BJT can operate in different modes depending on the junction bias.
Switching applications utilize both the cutoff and saturation modes.

Mode	**EBJ**	**CBJ**
Cutoff	Reverse	Reverse
Active	Forward	Reverse
Saturation	Forward	Forward

Operation of the *npn* transistor in the active mode:

Electrons in emitter regions are injected into base due to the forward bias at EBJ.
Most of the injected electrons reach the edge of CBJ before being recombined if the base is narrow.
Electrons at the edge of CBJ will be swept into collector due to the reverse bias at CBJ.

Emitter injection efficiency $\gamma = \dfrac{i_{En}}{i_{En} + i_{Ep}}$

Base transport factor$(\alpha_T) = {i_{Cn}}/{i_{En}}$

Base transport factor$(\alpha) = {i_{Cn}}/{i_E} = \gamma\alpha_T < 1$

Terminal currents of BJT in active mode:

i_E(Emitter current) = i_{En}(electron injection from E to B) + i_{Ep}(hole injection from B to E)

i_C(Collector current) = i_{Cn}(electron drift) + i_{CBO}(CBJ reverse saturation current with emitter open)

i_B(Base current) = i_{B1}(hole injection from B to E) + i_{B2}(recombination in base region)

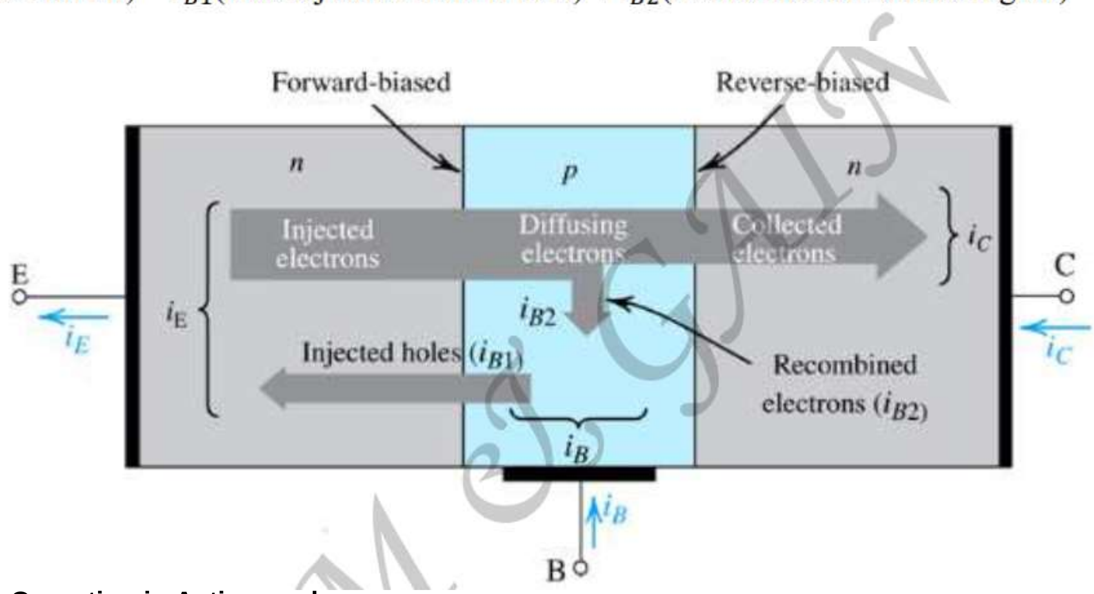

Fig 3.42: Operation in Active mode

Transistor i-v characteristics

A**. Transistor Voltages**

Three different types of voltages are involved in the description of transistors and transistor circuits. They are:

Transistor supply voltages: V_{CC} , V_{BB} .
Transistor terminal voltages: V_C , V_C , V_E
Voltages across transistor junctions: V_{BE} , V_{CE} , V_{CB}
All of these voltages and their polarities are shown on Figure 3.43 for the ***npn*** BJT.

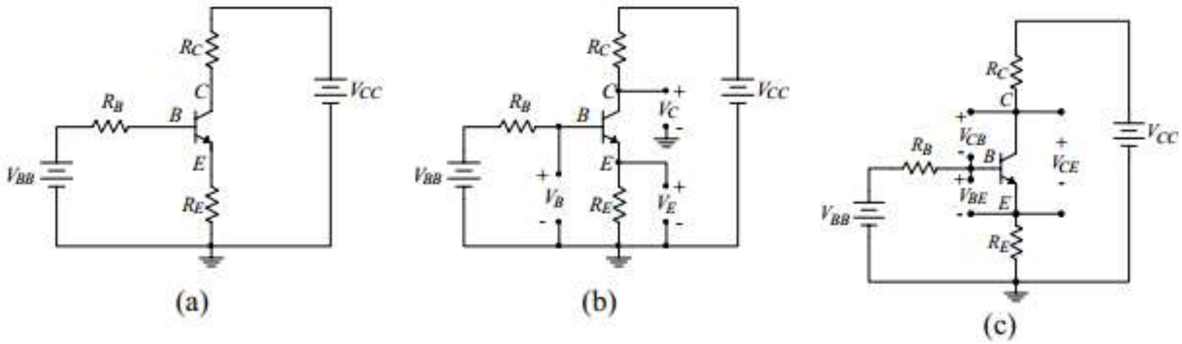

Figure 3.43. Voltages and their polarities

Transistor Operation and Characteristic i-v curves

The three terminals of the transistors and the two junctions, present us with multiple operating regimes. In order to distinguish these regimes we have to look at the i-v characteristics of the device. The most important characteristic of the BJT is the plot of the collector current, I_C, versus the collector-emitter voltage, V_{CE}, for various values of the base current, I_B as shown on the circuit of Figure 3.44.

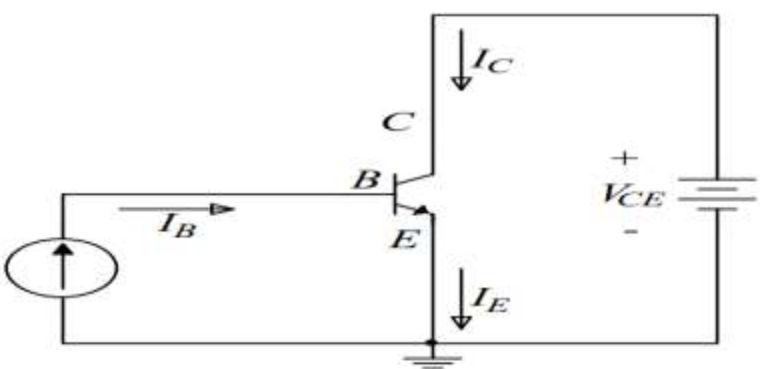

Figure 3.44. Common emitter BJT circuit for determining output characteristics

Figure 3.45 shows the qualitative characteristic curves of a BJT. The plot indicates the four regions of operation: the saturation, the cutoff, the active and the breakdown. Each family of curves is drawn for a different base current and in this plot $I_{B4} > I_{B3} > I_{B2} > I_{B1}$

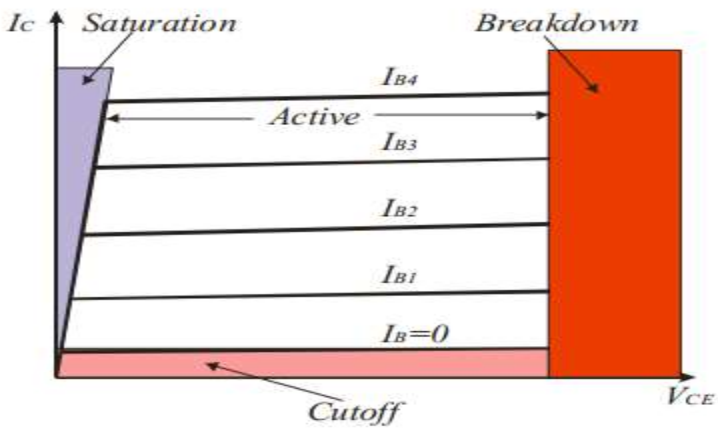

Figure 3.45. BJT characteristic curve

The characteristics of each region of operation are summarized below.

1. **cutoff region:**

Base-emitter junction is reverse biased. No current flow.

2. **saturation region:**

Base-emitter junction forward biased, Collector-base junction is forward biased I_C reaches a maximum which is independent of I_B and β. No control.

$V_{CE} < V_{BE}$

3. **active region:**

Base-emitter junction forward biased Collector-base junction is reverse biased Control, $I_C = \beta\ I_B$ (as can be seen from Figure 3.45 there is a small slope of I_C with V_{CE}.

$V_{BE} < V_{CE} < V_{CC}$

4. **breakdown region:**

I_C and V_{CE} exceed specifications damage to the transistor.

BJT as a switch:

Consider the circuit shown on Figure 3.46. If the voltage v_i is less than the voltage required to forward bias the base-emitter junction then the current I_B =0 and thus the transistor is in the cutoff region and $I_C = 0$ Since $I_C = 0$ the voltage drop across Rc is zero and so $Vo=Vcc$.

If the voltage v_i increases so that forward biases the base-emitter junction the transistor will turn on and

$$I_B = \frac{v_i - V_{BE}}{R_B} \quad (6)$$

Once the transistor is on we still do not know if it is operating in the active region or in the saturation region. However, KVL around the C-E loop gives

$$V_{CC} = I_C R_C + V_{CE} \quad (7)$$

And so

$$V_{CE} = V_{CC} - I_C R_C \quad (8)$$

Note that $V_{CE} = V_0$ as shown on Figure 3.46.

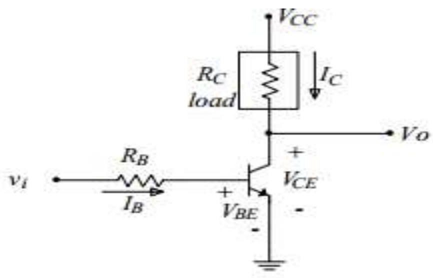

Figure 3.46. npn BJT switch circuit

Equation (8) is the load line equation for this circuit. In graphical form it is shown on Figure 3.47.

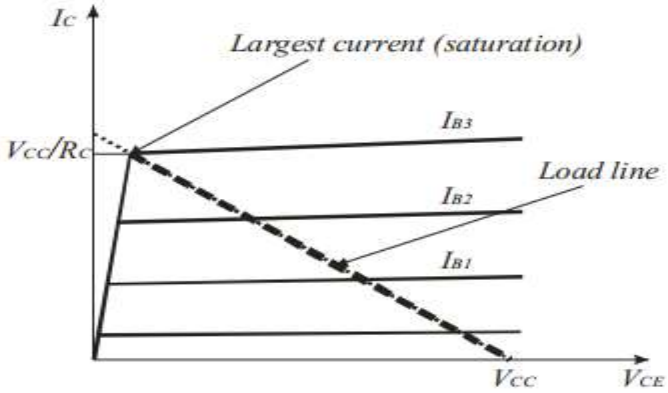

Figure 3.47. Graphical form of load equation

As the base current increases the transistor may operate at points along the load line (thick dashed line on Figure 3.47). In the limit, the base current I_{B3} results in the largest current I_C. This is the saturation current and when the transistor operates at this point it is said to be biased in the saturation mode. In saturation, the base-collector junction is forward biased and the relationship between the base and the collector current is not linear.
Therefore the collector current at saturation is

$$I_c(sat) = \frac{V_{CC} - V_{CE}(sat)}{R_C} \qquad (9)$$

In saturation the collector-emitter voltage, V_{CE}, is less than the V_{BE}. Typically, the V_{CE} at saturation is about 0.2 Volts.

The transistor as an amplifier

A BJT circuit with a collector resistor R_C can be used as a simple voltage amplifier. Base terminal is used the amplifier input and the collector is considered the amplifier output.

$$0V \leq V_{BE} < 0.5V \;\&\; i_C = 0$$
$$V_O = V_{CE} = V_{CC}$$

Cutoff mode:

The voltage transfer characteristic (VTC) is obtained by solving the circuit from low to high V_{BE}.

Active mode: $V_{BE} > 0.5V \;\&\; i_C \neq 0$

$$V_O = V_{CC} - i_C R_C$$

Saturation mode:

V_{BE} further increases.

$$V_{CE} = V_{CE(sat)} = 0.2V$$
$$V_O = 0.2V$$

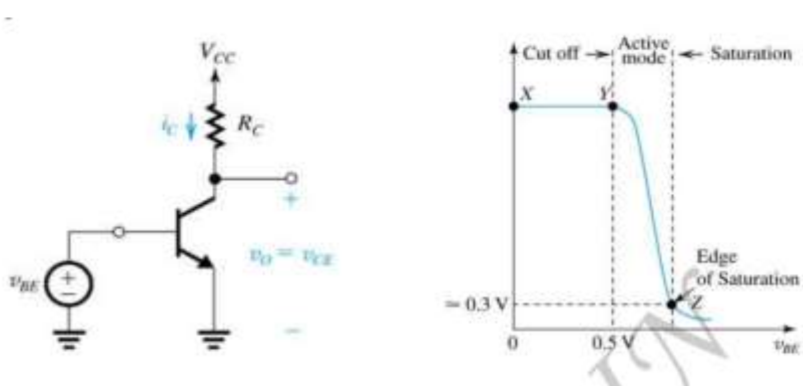

Fig 3.48: BJT as an amplifier

Gain and Bandwidth

Gain and bandwidth in an amplifier are inversely proportional to each other and their relationship is summarized as the unity-gain bandwidth. Unity-gain bandwidth defines the frequency at which the gain of an amplifier is equal to 1. If the GBWP of an operational amplifier is 1 MHz, it means that the gain of the device falls to unity at 1 MHz. Hence, when the device is wired for unity gain, it will work up to 1 MHz (GBWP = gain × bandwidth, therefore if BW = 1 MHz, then gain = 1) without excessively distorting the signal.

Transistor Configuration

Depending upon the terminals which are used as a common terminal to the input and output terminals, the transistors can be connected in the following three different configuration.

1. common base configuration
2. common emitter configuration
3. common collector configuration

Common base configuration

In this configuration base terminal is connected as a common terminal.

The input is applied between the emitter and base terminals. The output is taken between the collector and base terminals.

Input characteristics: The output (CB) voltage is maintained constant and the input voltage (EB) is set at several convenient levels. For each level of input voltage, the input current I_E is recorded. I_E is then plotted versus V_{EB} to give the common-base input characteristics.

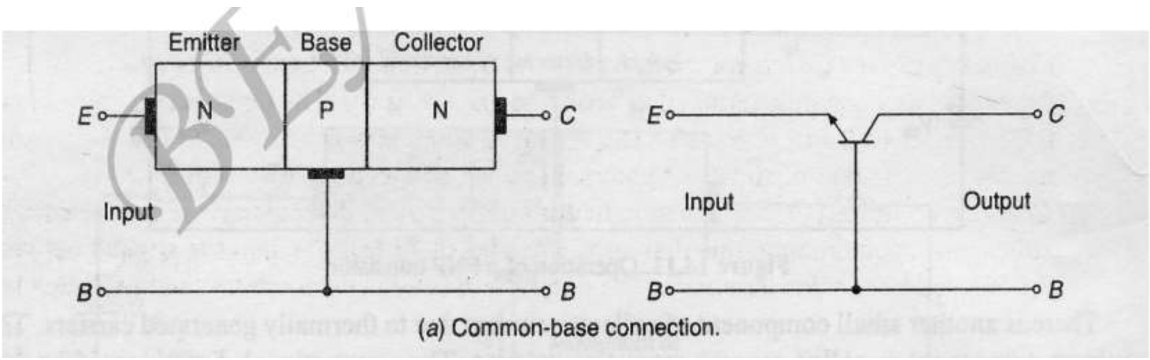

Fig 3.49: BJT common base connection

Output characteristics: The emitter current I_E is held constant at each of several fixed levels. For each fixed value of I_E, the output voltage V_{CB} is adjusted in convenient steps and the corresponding levels of collector current I_C are recorded. For each fixed value of I_E, I_C is almost equal to I_E and appears to remain constant when V_{CB} is increased.

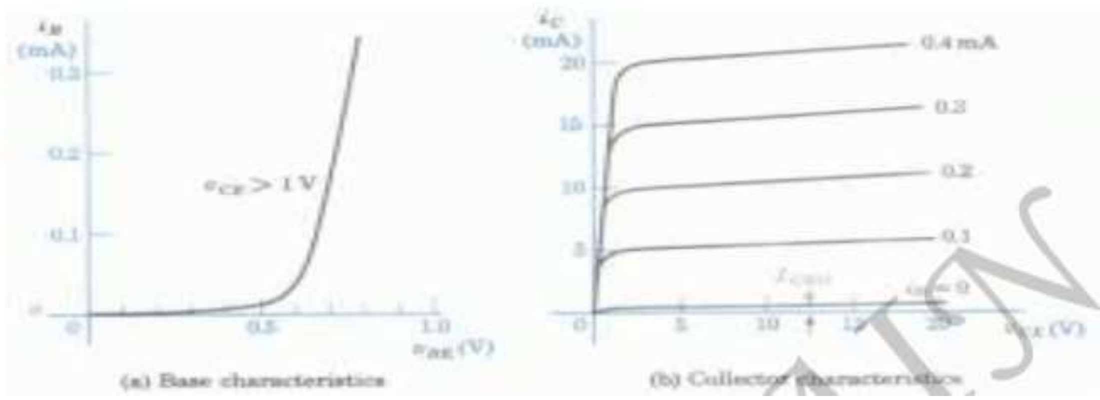

Fig 3.50: BJT common base characteristics and collector characteristics

Common emitter configuration:

In this configuration emitter terminal is connected as a common terminal.

The input is applied between the emitter and base terminals. The output is taken between the collector and base terminals.

Input characteristics: The output voltage V_{CE} is maintained constant and the input voltage V_{BE} is set at several convenient levels. For each level of input voltage, the input current I_B is recorded. I_B is then plotted versus V_{BE} to give the common-base input characteristics.

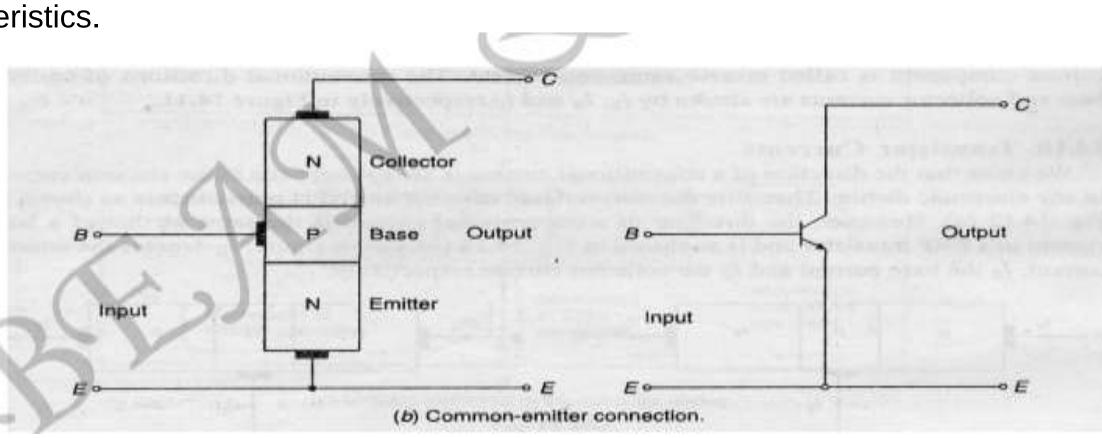

Fig 3.51: BJT common emitter connection

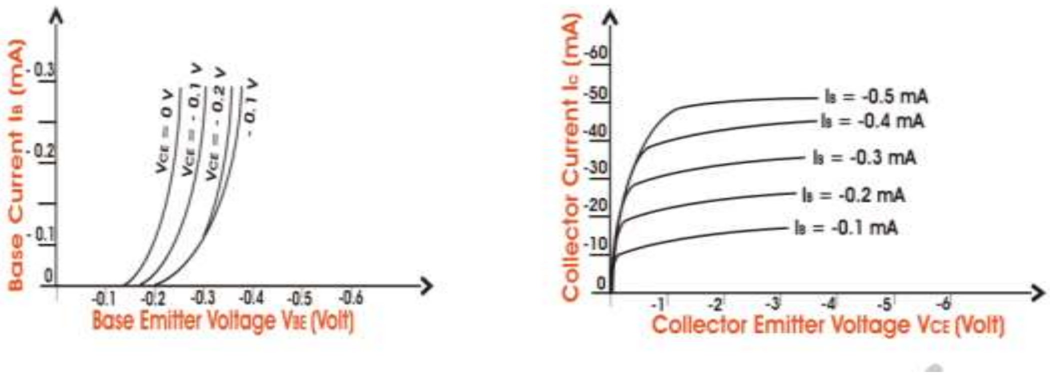

Fig 3.52: BJT base emitter voltage and collector emitter voltage

Output characteristics: The Base current $\mathbf{I_B}$ is held constant at each of several fixed levels. For each fixed value of $\mathbf{I_B}$**,** the output voltage $\mathbf{V_{CE}}$ is adjusted in convenient steps and the corresponding levels of collector current $\mathbf{I_C}$ are recorded. For each fixed value of $\mathbf{I_B}$, $\mathbf{I_C}$ level is Recorded at each $\mathbf{V_{CE}}$ step. For each $\mathbf{I_B}$ level, $\mathbf{I_C}$ is plotted versus $\mathbf{V_{CE}}$ to give a family of characteristics

Common collector configuration:

In this configuration collector terminal is connected as a common terminal.

The input is applied between the base and collector terminals. The output is taken between the emitter and collector terminals.

Input characteristics: The common-collector input characteristics are quite different from either common base or common-emitter input characteristics. The difference is due to the fact that the input voltage **(VBC)** is largely determined by **(VEC)** level.

VEC = VEB + VBC, VEB = VEC – VBC

Output characteristics: The operation is much similar to that of C-E configuration. When the base current is **ICO**, the emitter current will be zero and consequently no current will flow in the load. When the base current is increased, the transistor passes through active region and eventually reaches saturation. Under the saturation conditions all the supply voltage, except for a very small drop across the transistor will appear across the load resistor.

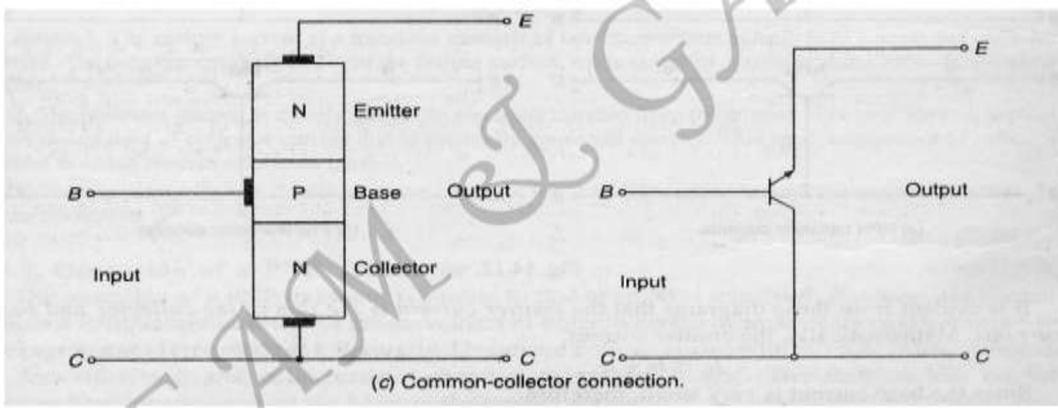

Fig 3.53: BJT common collector connection

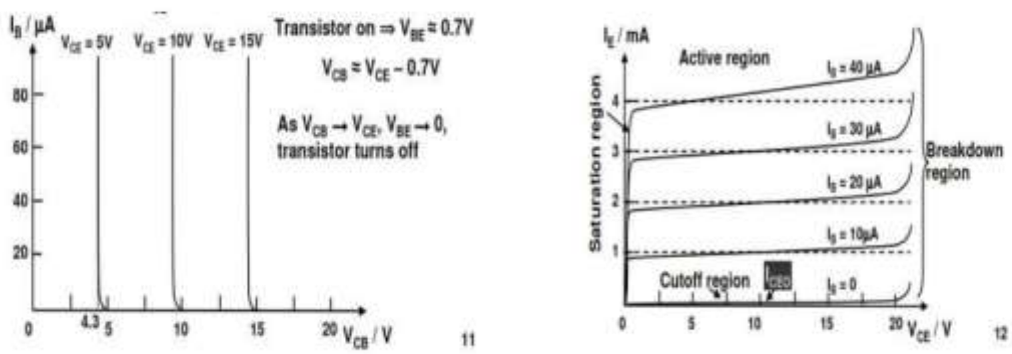

Fig 3.54: BJT common collector voltages and base current

Biased and Unbiased BJT

Unbiased transistor is a transistor with its terminals not connected to any source. Biasing a transistor is applying a suitable DC voltage across the transistor terminals to operate the transistor in the desired region

Transistor Biasing is the process of setting a transistors DC operating voltage or current conditions to the correct level so that any AC input signal can be amplified correctly by the transistor.

Necessary of transistor biasing:

- To active an transistor, biasing is essential. For proper working it is essential to apply to apply voltages of correct polarity across its two junctions.
- If it is not biased correctly, it would work inefficiently and produce distortion in the output signal
- Q-point is not middle Output signal is distorted & the signal is clipped.
- Further for various applications, BJT is biased as shown in table

Region of operation	Base Emitter Junction	Collector base junction	Application
Cut off	Reverse bias	Reverse bias	As a switch
Active	Forward bias	Reverse bias	As amplifier
Saturation	Forward bias	Forward bias	As a switch

In order to have these applications, we need to connect external DC power supplies with correct polarities & magnitude. This process is called as biasing of transistor.

Stability Factor

The stability of Q point of transistor amplifier depends on the following three parameters:

1. Leakage current ICO   2. βdc   3. Base to emitter voltage

The effect of these parameters can be expressed mathematically by defining the stability factors

1. Stability factor $S = \frac{\Delta I_C}{\Delta I_{CO}} \Big|_{\text{Constant } V_{BE} \text{ \& } \beta_{dc}}$

   This represents the change in collector current due to change in reverse saturation current ICO. The other two parameters that means VBE & βdc are assumed to be constant.
2. Stability factor $S'' = \frac{\Delta I_C}{\Delta V_{BE}} \Big|_{\text{Constant } I_{CO} \text{ \& } \beta_{dc}}$

   S‟ represents the change in IC due to change in VBE at constant ICO & βdc
3. Stability factor $S''' = \frac{\Delta I_C}{\beta dc} \Big|_{\text{Constant } I_{CO} \text{ \& } V_{BE}}$

   Total change in collector current
   ΔIC= S. ΔICO + S‟. ΔVBE + S”. βdc

• Ideally the values of all the stability factors should be zero and practically they should be as small as possible.

• Practically the value of S is significantly higher than the other two stability factor. Hence while comparing the biasing circuits, the values of S is more significant.

Voltage Divider Bias:

The most famous circuit based on -the prototype of emitter bias is called the voltage divider bias (VDB).

Recall the steps of analyzing the emitter bias circuit:

1. V_E
2. I_E
3. I_C
4. Voltage drop across R_C
5. V_C
6. V_{CE}

The three most important steps are:

1. I_E
2. V_C
3. V_{CE}

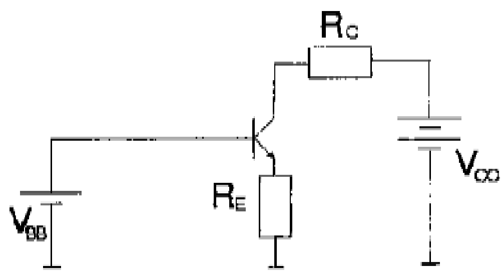

Fig 3.55. Emitter Biased Circuit

<u>Problem:</u> Sometimes the voltage from the V_{CC} power supply is too large to apply directly at the base.

<u>Solution:</u>

- extra power supply for the base
- or ==> VDB

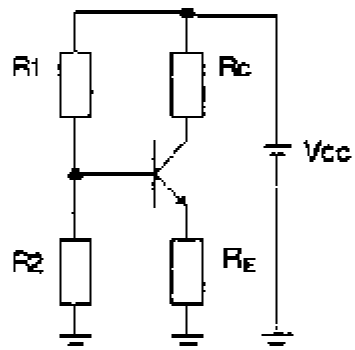

Fig 3.56. VDB Circuit

The voltage drop across R_2 is applied directly to the base, which means:

$V_2 = V_B$

1. step: find voltage drop across R_2
2. step: subtract 0.7V to get V_E

VDB analysis

Design errors of 5% or less are acceptable, because of resistor tolerances.

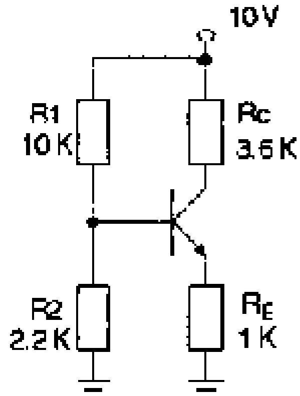

Fig 3.57. VDB Example Circuit

Find the base voltage:

Assumption: Base current is so small that it has no effect on the voltage divider.

5% error - > base current is 20 times smaller than the divider current.

$$I = \frac{V_{CC}}{R_1 + R_2} = \frac{10V}{12.2K\Omega} = 0.82mA$$

$V_B = I * R_2 = 0.82$ mA * 2.2KW = 1.8V

$V_E = V_B - V_{BE} = 1.8V - 0.7V = 1.1V$

$$I_E = \frac{V_E}{R_E} = \frac{1.1V}{1K\Omega} = 1.1mA$$

$V_C = V_{CC} - (R_C * I_C) = 10V - (3.6KW * 1.1\ mA) = 6.04V$

$V_{CE} = V_C - V_E = 6.04V - 1.1V = 4.94V$

Checking the assumption:

5% error --> $I_B = \frac{I}{20} = \frac{0.82mA}{20} = 41\mu A$

The current gain can vary from 30 to 300.

$$I_B = \frac{I_C}{30} = \frac{1.1mA}{30} = 36\mu A$$

Even under the worst-case condition the calculation is within the 5% limit, hence the assumption can be done.

<u>Summary of Process and Formulas</u>

Divider current $I = \frac{V_{CC}}{R_1 + R_2}$

Base voltage $V_B = I * R_2$

Emitter voltage $V_E = V_B - V_{BE}$

Emitter current $I_E = \frac{V_E}{R_E}$

Collector voltage $V_C = V_{CC} - (I_C * R_C)$

Collector emitter voltage $V_{CE} = V_C - V_E$

<u>HO:</u> What will change if the emitter resistor increases to 2KW? (Unchanged voltage divider)

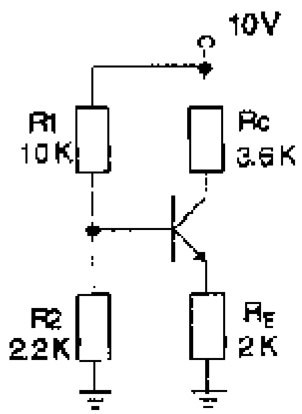

Fig 3.58. VDB Circuit

Solution:

I = 0.82 mA

V_B = 1.8V

V_E = 1.1V

$$I_E = \frac{V_E}{R_E} = 0.55mA$$

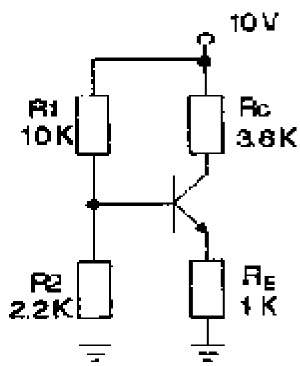

Fig 3.59. VDB Circuit

$V_C = V_{CC}$ - (R_C * I_C) = 8.02V

$V_{CE} = V_C - V_E$ = 6.92V

VDB Load-Line and Q-Point

Saturation point:

Visualize short between collector and emitter

$V_{RC} = V_{CC} - V_E$ = 10V - 1.1V = 8.9V

$$I_{c(sat)} = \frac{V_{RC}}{R_C} = \frac{8.9V}{3.6K\Omega} = 2.47mA$$

Cutoff point:

Visualize open between collector and emitter

$-V_{CE\ (cut)} = V_{CC} - V_E$ = 8.9V

Q-point:

$$I_C \approx I_E = \frac{V_E}{R_E} = \frac{1.1V}{1K\Omega} = 1.1mA$$

$V_C = V_{CC}$ - (I_C * R_C) = 10V - (1.1 mA * 1KW) = 6.04V

$V_{CE} = V_C - V_E$ = 6.04V - 1.1V = 4.94V

Now we plot these values and get the load line and the Q-point:

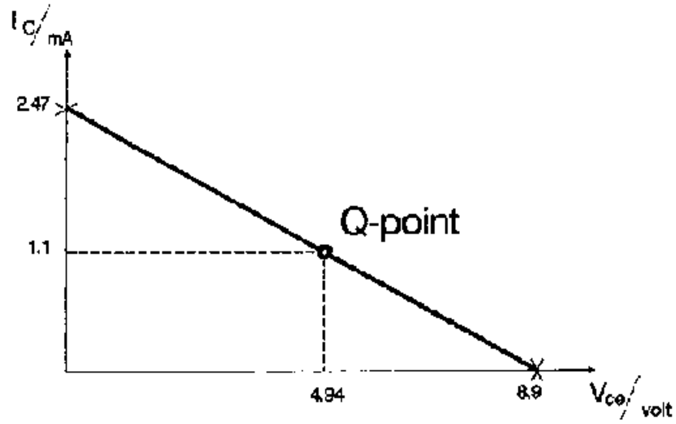

Fig 3.60. Output curve with load line and Q-point

The values V_{CC}, R_C, R_1, and R_2 are controlling saturation current and cutoff voltage. To move the Q-point is possible by varying the emitter resistance (R_C).

Get the Q-point in the Middle of the Load Line

To set the Q-point is a important preparation as you will see later on.

Effect of R_E:

R_E too large -- > Q-point moves into cutoff
R_E too small --> Q-point moves into saturation

Q - point in the middle of the load line:

Half the value of $I_{C\ (sat)}$ and redesign R_E

$I_{C\ (sat)}$ = 2.47 mA ==> 1.23 mA

$$R_E = \frac{V_E}{1.23\text{mA}} = 894\Omega$$

Look for the nearest standard value:

=910 ohm

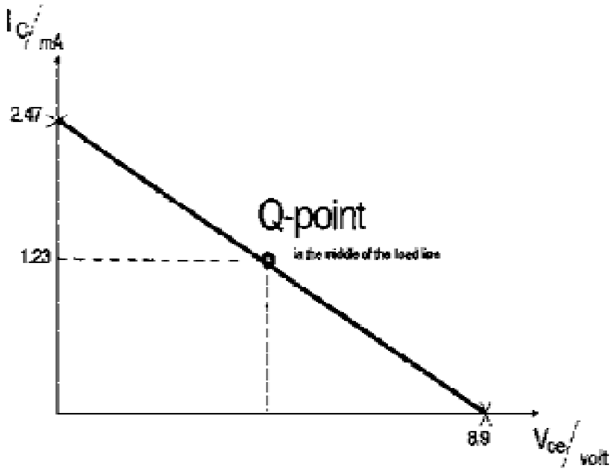

Fig 3.61. Output curve, Q-point in the middle

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