UNIT-III ELECTRONICS

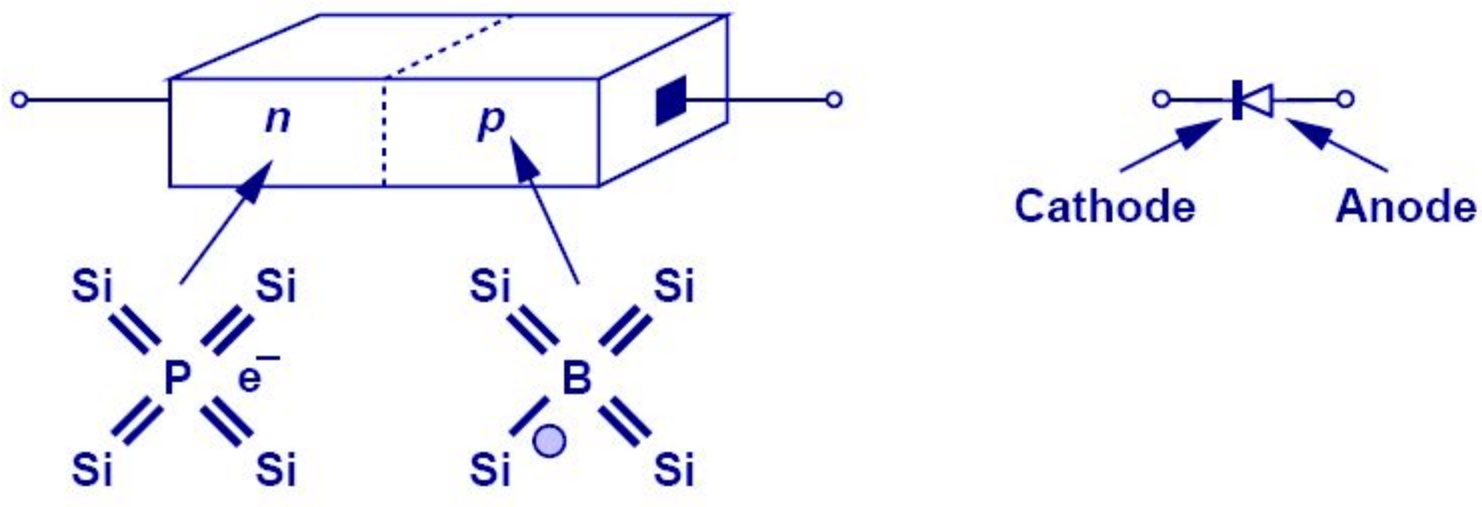
Electronic devices

PN- DIODE

SEMICONDUCTOR DIODE

- Theory of p-n junction
- p-n junction as diode
- p-n diode currents
- Volt-amp characteristics
- Diode resistance
- Temperature effect of p-n junction
- Transition and diffusion capacitance of p-n diode
- Diode switching times

PN Junction (Diode)



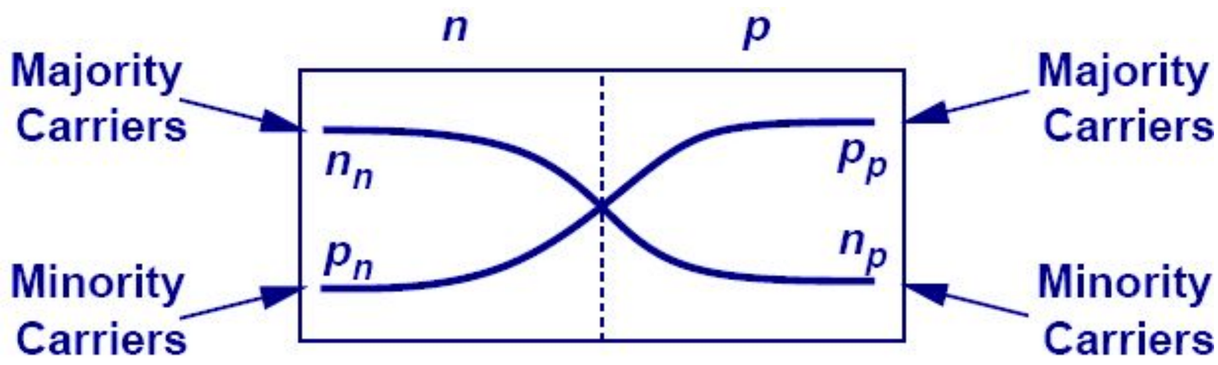
(a) (b)

- When N-type and P-type dopants are introduced side-by-side in a semiconductor, a PN junction or a diode is formed.
- The p-n junction is also called as semiconductor diode .
- The left side material is a p-type semiconductor having –ve acceptor ions and +vely charged holes. The right side material is n-type semiconductor having +ve donor ions and free electrons

p-n junction as diode

- Suppose the two pieces are suitably treated to form pn junction, then there is a tendency for the free electrons from n-type to diffuse over to the p-side and holes from p-type to the n-side . This process is called **diffusion**
- The left side material is a p-type semiconductor having –ve acceptor ions and +vely charged holes. The right side material is n-type semiconductor having +ve donor ions and free electrons.

Current Flow Across Junction: Diffusion



n_n : Concentration of electrons on n side

p_n : Concentration of holes on n side

p_p : Concentration of holes on p side

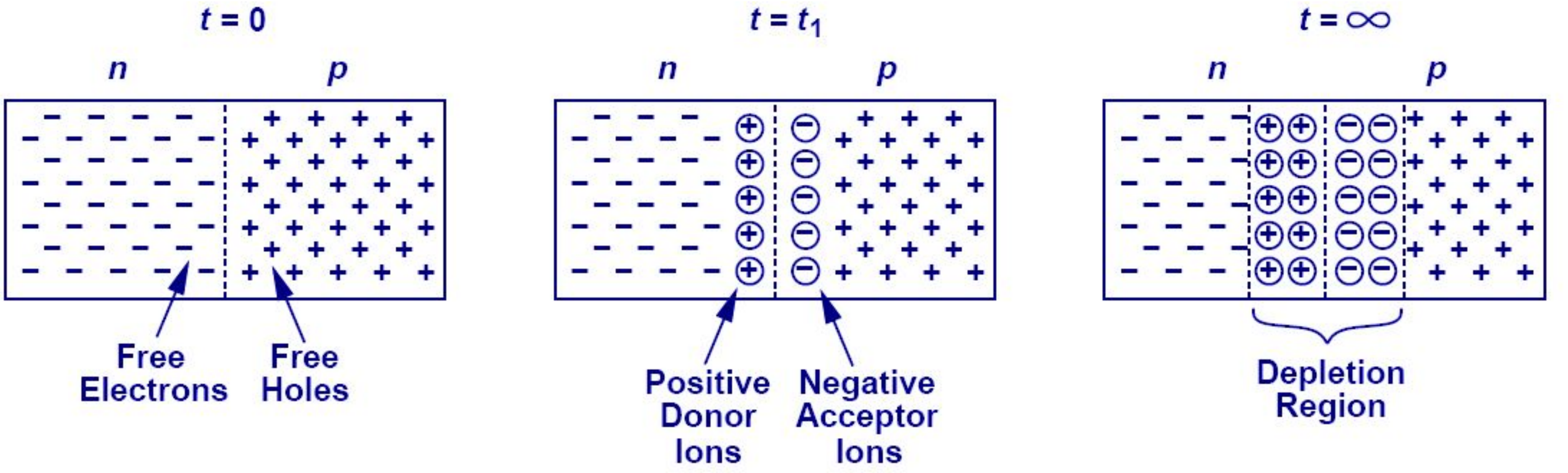
n_p : Concentration of electrons on p side

- Because each side of the junction contains an excess of holes or electrons compared to the other side, there exists a large concentration gradient. Therefore, a diffusion current flows across the junction from each side.

p-n junction as diode

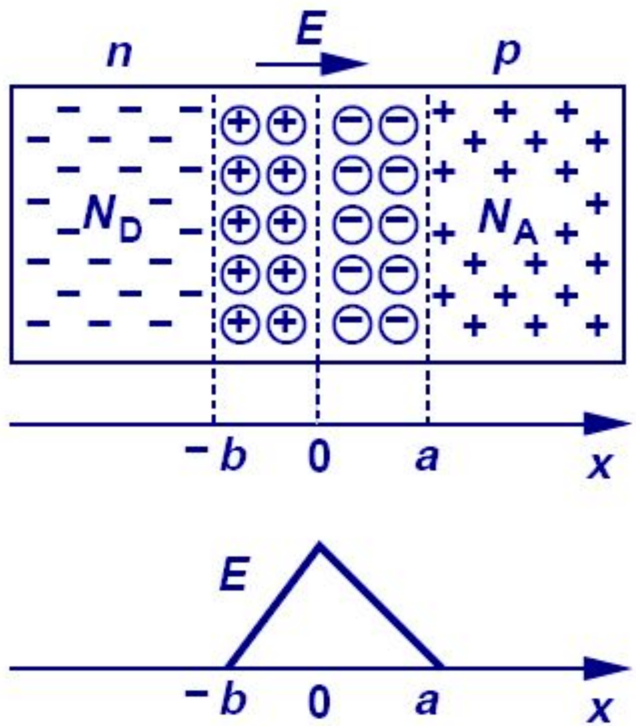
- As the free electrons move across the junction from n-type to p-type, +ve donor ions are uncovered. Hence a +ve charge is built on the n-side of the junction. At the same time, the free electrons cross the junction and uncover the –ve acceptor ions by filling in the holes. Therefore a net –ve charge is established on p-side of the junction.

Depletion Region



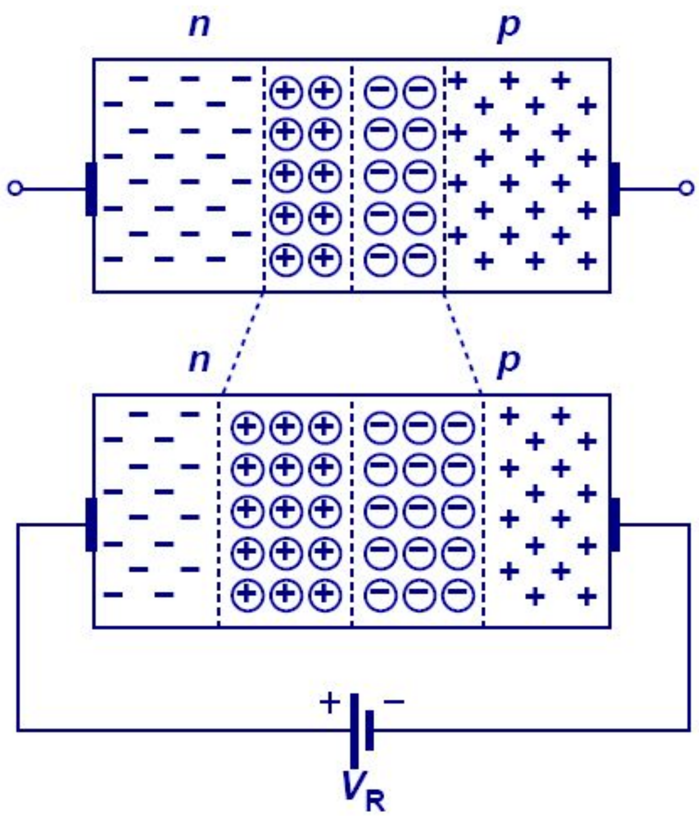
- As free electrons and holes diffuse across the junction, a region of fixed ions is left behind. This region is known as the "depletion region."

Current Flow Across Junction: Drift



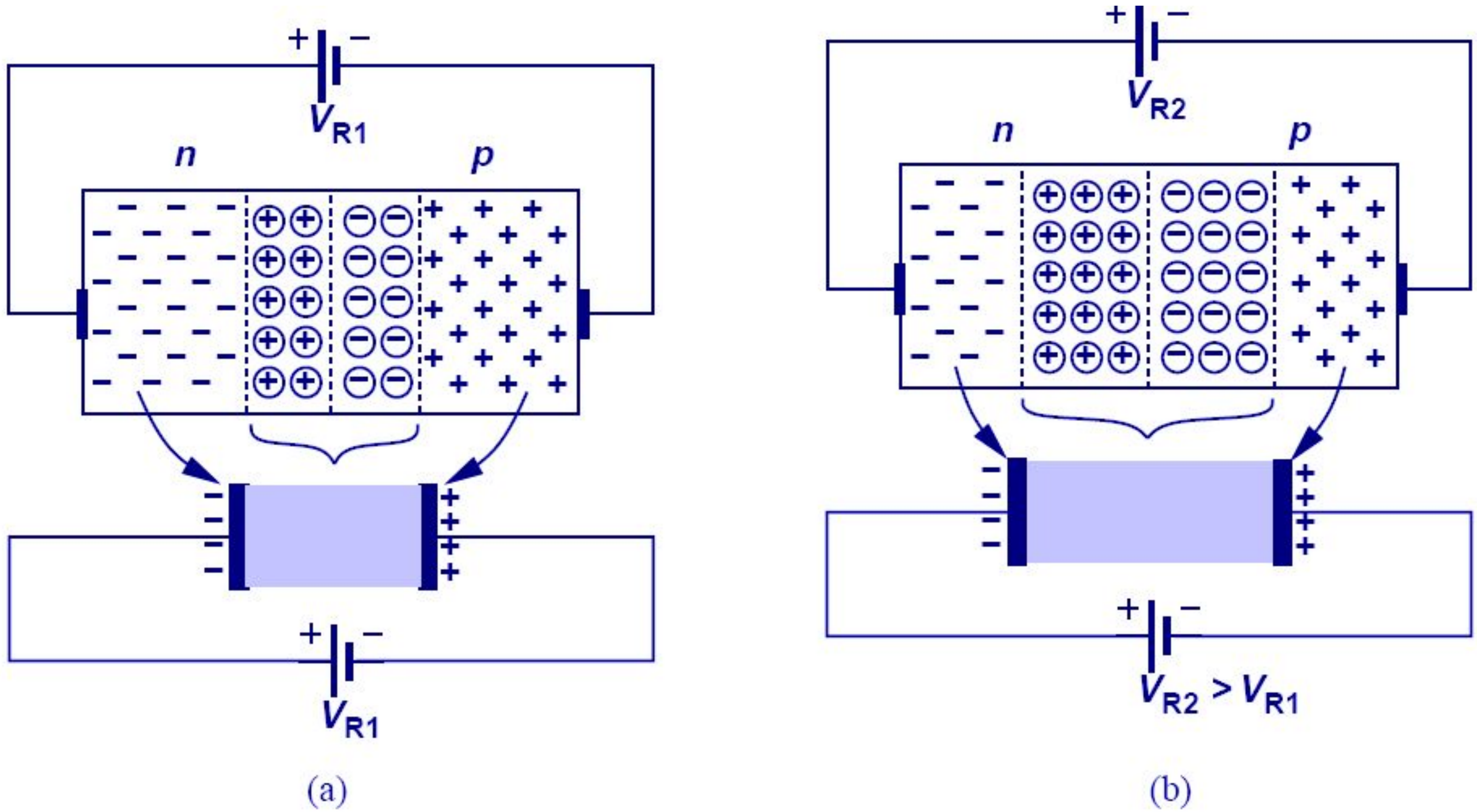
- The fixed ions in depletion region create an electric field that results in a drift current.

Diode in Reverse Bias



- When the N-type region of a diode is connected to a higher potential than the P-type region, the diode is under reverse bias, which results in wider depletion region and larger built-in electric field across the junction.

Reverse Biased Diode's Application: Voltage-Dependent Capacitor



- The PN junction can be viewed as a capacitor. By varying V_R, the depletion width changes, changing its capacitance value; therefore, the PN junction is actually a voltage-dependent capacitor.

p-n junction as diode

- When a sufficient number of donor and acceptor ions is uncovered further diffusion is prevented.
- Thus a barrier is set up against further movement of charge carriers. This is called potential barrier or junction barrier Vo. The potential barrier is of the order of 0.1 to 0.7V.
- **Note:** outside this barrier on each side of the junction, the material is still neutral. Only inside the barrier, there is a +ve charge on n-side and –ve charge on p-side. This region is called depletion layer.

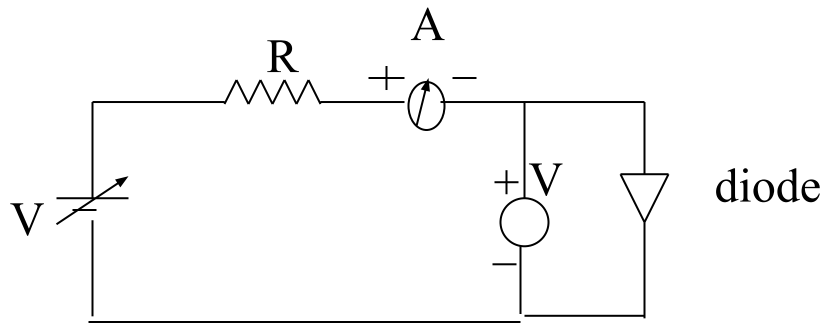
p-n diode currents

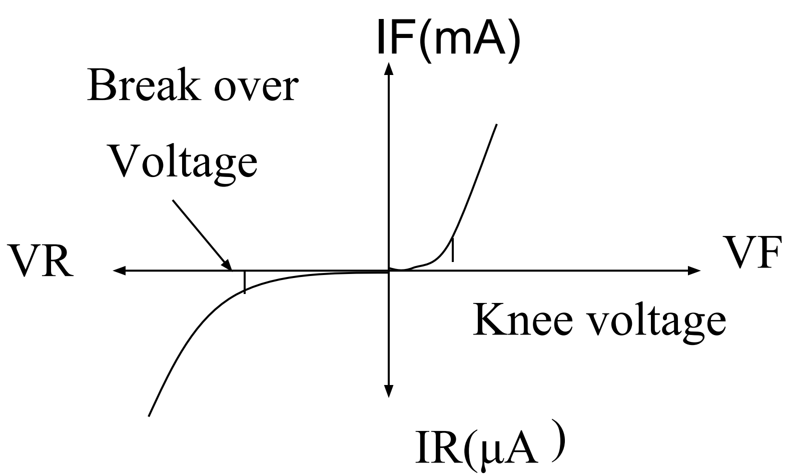
- **<u>Diode current equation</u>**
- The current in a diode is given by the diode current equation
- $I = I_0 (e^{V/\eta VT} - 1)$

Where, I------ diode current

- I0------ reverse saturation current
- V------ diode voltage
- η------- semiconductor constant
- =1 for Ge, 2 for Si.
- VT------ Voltage equivalent of temperature= T/11,600 (Temperature T is in Kelvin)
- Note----- If the temperature is given in 0C then it can be converted to Kelvin by the help of following relation, 0C+273 = K

Volt-amp characteristics

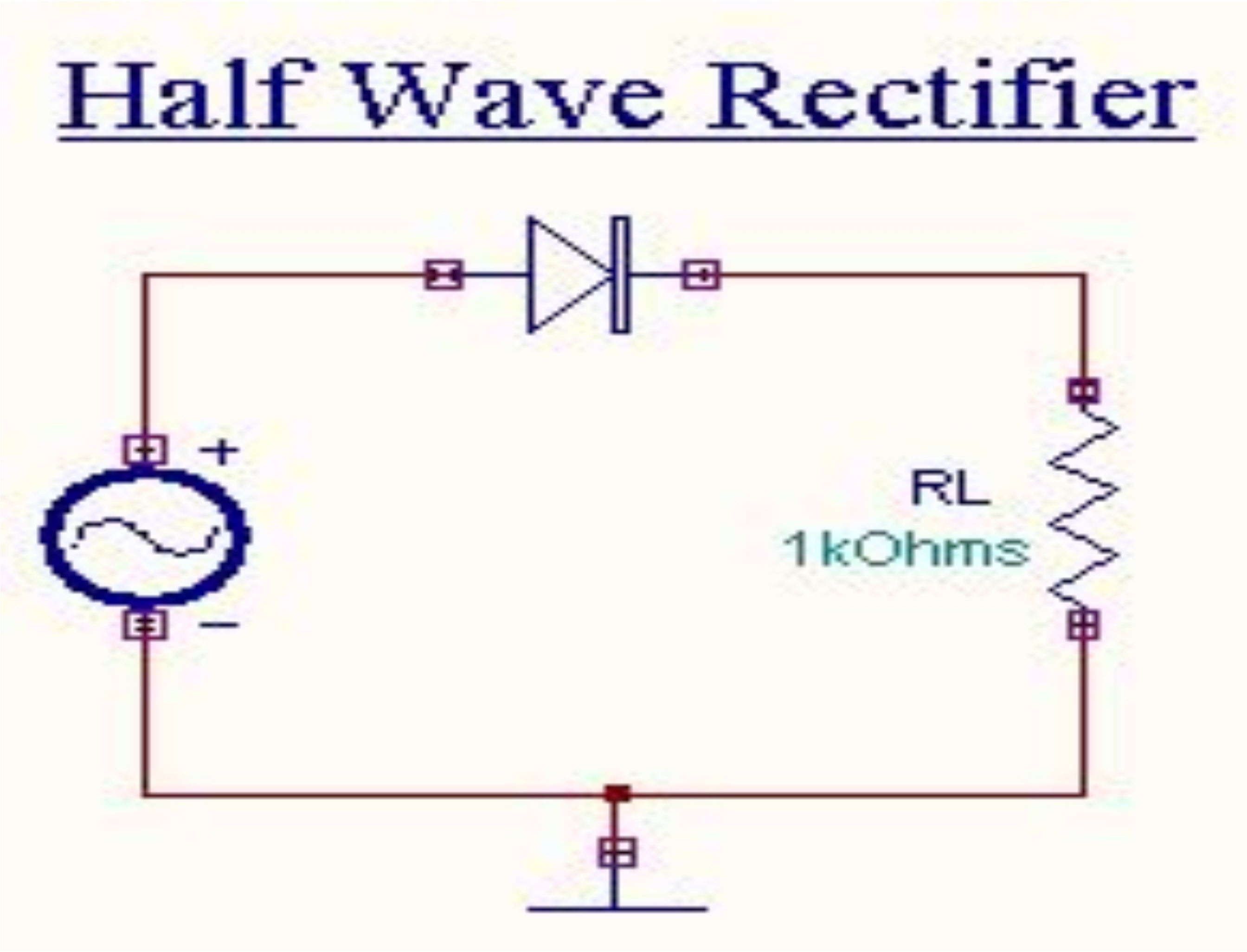




Volt-amp characteristics

- The supply voltage V is a regulated power supply, the diode is forward biased in the circuit shown. The resistor R is a current limiting resistor. The voltage across the diode is measured with the help of voltmeter and the current is recorded using an ammeter.
- By varying the supply voltage different sets of voltage and currents are obtained. By plotting these values on a graph, the forward characteristics can be obtained. It can be noted from the graph the current remains zero till the diode voltage attains the barrier potential.
- For silicon diode, the barrier potential is 0.7 V and for Germanium diode, it is 0.3 V. The barrier potential is also called as knee voltage or cur-in voltage.

HALFWAVE RECTIFIER



HALFWAVE RECTIFIER

- The primary of the transformer is connected to ac supply. This induces an ac voltage across the secondary of the transformer.
- During the positive half cycle of the input voltage the polarity of the voltage across the secondary will forward biases the diode. As a result a current IL flows through the load resistor, RL. The forward biased diode offers a very low resistance and hence the voltage

HALFWAVE RECTIFIER

- Drop across it is very small. Thus the voltage appearing across the load is practically the same as the input voltage at every instant.
- During the negative half cycle of the input voltage the polarity of the secondary voltage gets reversed. As a result, the diode is reverse biased.
- Practically no current flows through the circuit and almost no voltage is developed across the resistor. All input voltage appears across the diode itself.

HALFWAVE RECTIFIER

- Hence we conclude that when the input voltage is going through its positive half cycle, output voltage is almost the same as the input voltage and during the negative half cycle no voltage is available across the load.
- This explains the unidirectional pulsating dc waveform obtained as output. The process of removing one half the input signal to establish a dc level is aptly called half wave rectification.

HALFWAVE RECTIFIER

Peak Inverse Voltage

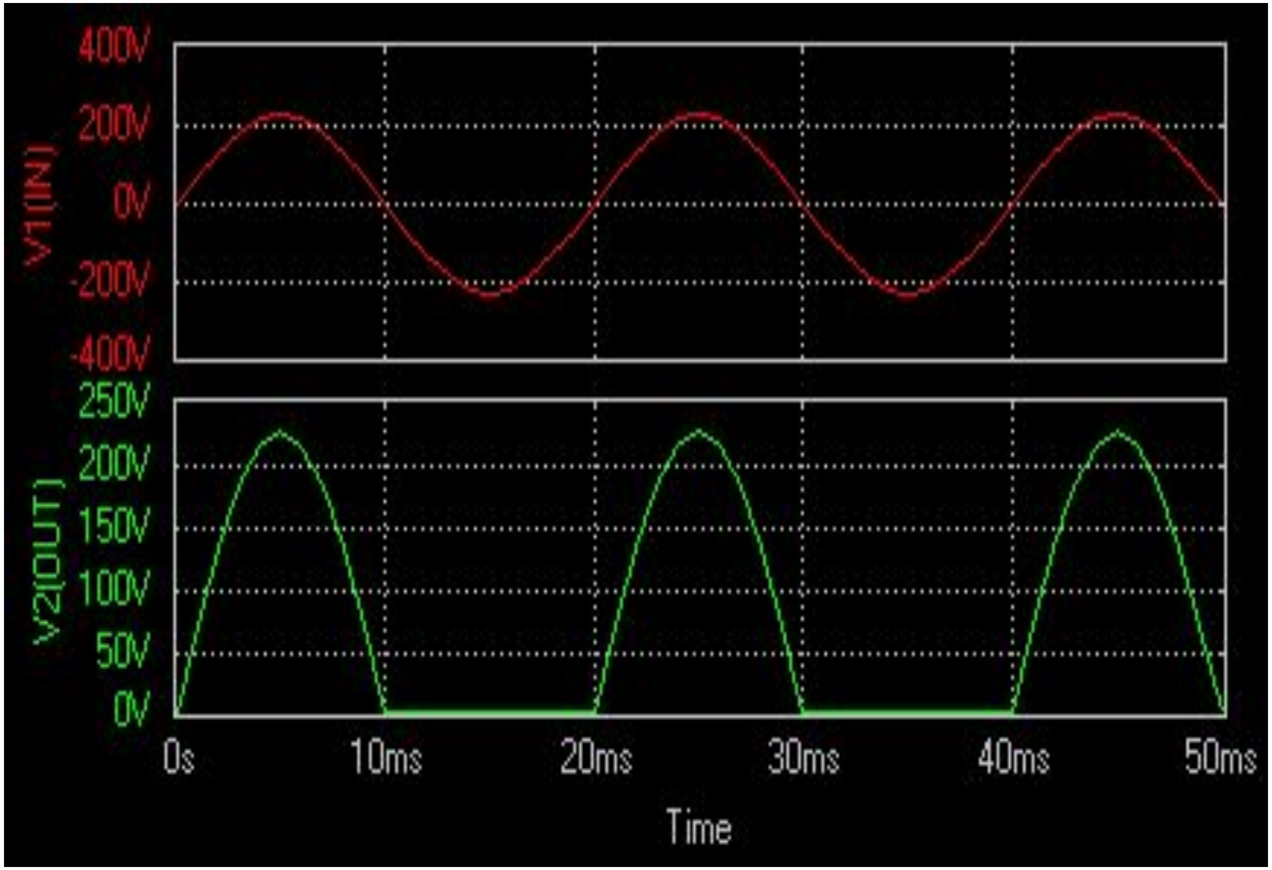
- When the input voltage reaches its maximum value *Vm* during the negative half cycle the voltage across the diode is also maximum. This maximum voltage is known as the peak inverse voltage.

Thus for a half wave rectifier

Let *Vi* be the voltage to the primary of the transformer. *Vi* is given by

where *Vr* is the cut-in voltage of the diode.

Half wave waveform



HALFWAVE RECTIFIER

Ripple Factor

- Ripple factor is defined as the ratio of rms value of ac component to the dc component in the output.

Ripple factor

$$r = \frac{RMS\ value\ of\ the\ ac\ componen.}{dc\ value\ of\ the\ component}$$

HALFWAVE RECTIFIER

The ripple is

$$\gamma = \frac{Vr_{rms}}{V_{dc}} \rightarrow (2)$$

$$V\gamma_{rms} = \sqrt{V_{rms}^{2} - V_{dc}^{2}} \rightarrow (3)$$

$$r = \sqrt{\left(\frac{V_{rms}}{V_{dc}}\right)^{2} - 1} \rightarrow (4)$$

HALFWAVE RECTIFIER

Vav the average or the dc content of the voltage across the load is given by

$$V_{av} = V_{dc} = \frac{1}{2\pi}\left[\int_0^{\pi} V_m \sin \omega t \, d(\omega t) + \int_{\pi}^{2\pi} 0 . d(\omega t)\right] \rightarrow (5)$$

HALFWAVE RECTIFIER

RMS voltage at the load resistance can be calculated as

$$V_{rms} = \left[\frac{1}{2\pi}\int_0^{\pi} V_m^{\,2}\sin^2\omega t\, d(\omega t)\right]^{1/2} \rightarrow (8)$$

$$= V_m\left[\frac{1}{4\pi}\int_0^{\pi}(1-\cos 2\,\omega t)\, d(\omega t)\right]^{1/2} = \frac{V_m}{2} \rightarrow (9)$$

What is Ripple Factor?

Ripple Factor is the ratio of rms value of ac component present in the rectified output to the average value of rectified output. It is a dimensionless quantity and denoted by γ. Its value is always less than unity.

$$\text{Ripple Factor}, \gamma = \frac{\text{RMS value of AC component present in Rectifier Output}}{\text{Average Value of Rectifier Output}}$$

$$\gamma = \frac{I'_{rms}}{I_{dc}} = \frac{V'_{rms}}{V_{dc}}$$

where I'_{rms} and V'_{rms} are the rms value of alternating component of load current and voltage respectively.

HALFWAVE RECTIFIER

Ripple Factor

$$r = \sqrt{\left(\frac{V_m/2}{V_m/\pi}\right)^2 - 1} = \sqrt{\left(\frac{\pi}{2}\right)^2} = \underline{\underline{1.21}} \rightarrow (10)$$

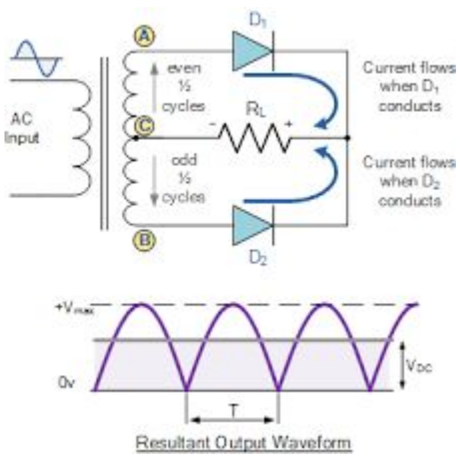
HALFWAVE RECTIFIER

Efficiency Efficiency, is the ratio of the dc output power to ac input power

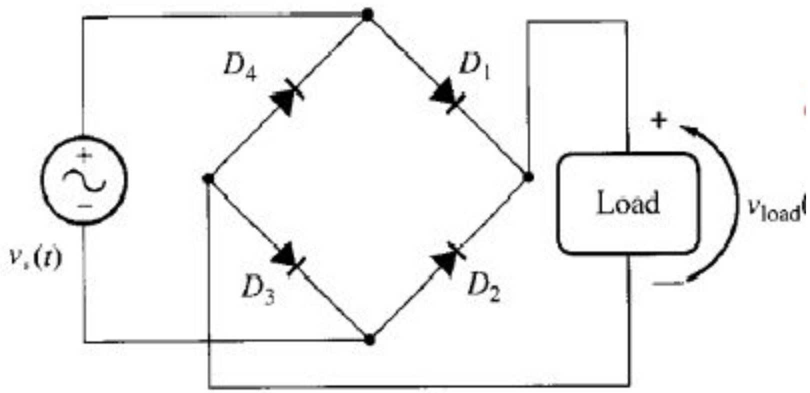
$$\eta = \frac{dc\,output\,power}{ac\,input\,power} = \frac{P_{dc}}{P_{ac}} \rightarrow (11)$$

Full Wave Rectifier

The waveform of fullwave rectifier is
Ripple factor=0.48; efficiency=81.2%; PIV=2Vm



Full Wave Bridge Rectifier

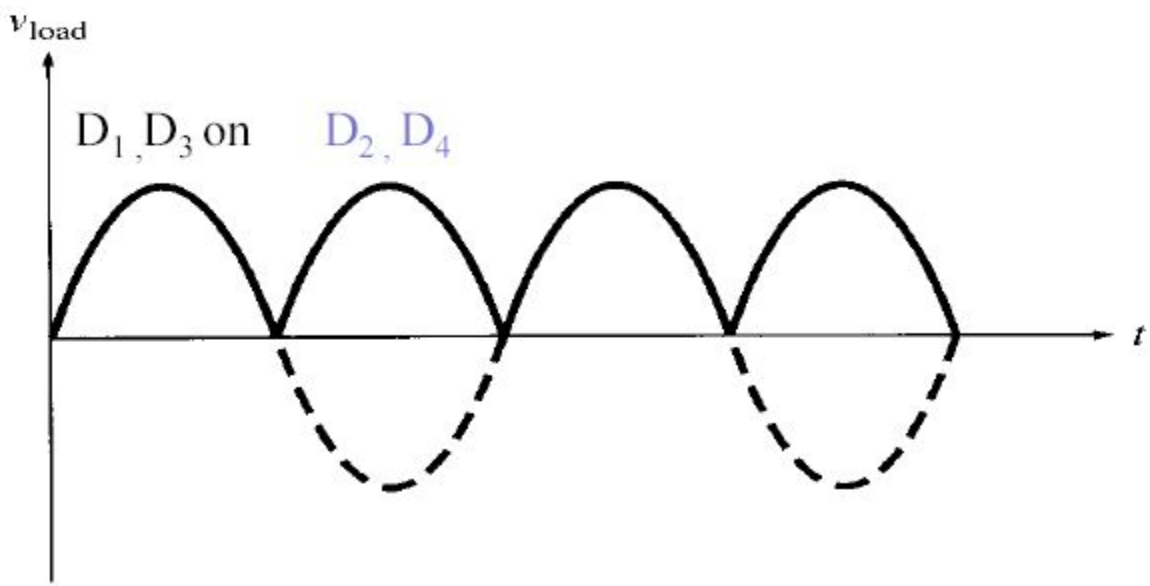


The waveform of fullwave bridge rectifier is

Ripple factor=0.48; efficiency=81.2%; PIV=Vm

The waveform of fullwave rectifier is

Ripple factor=0.48; efficiency=81.2%; PIV=2Vm

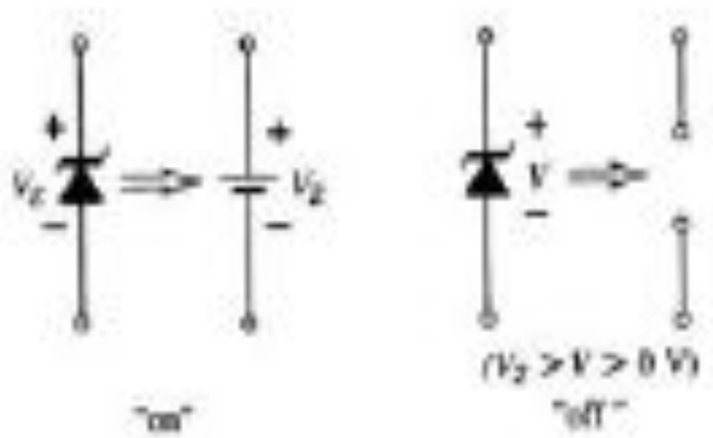


Zener Diode

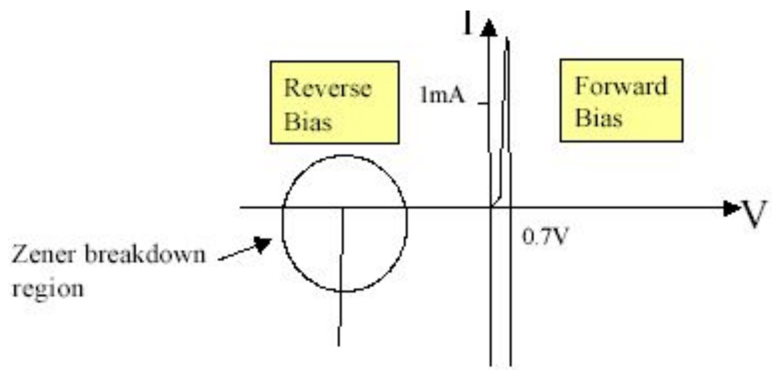
- Zener Diode : Works in the break down region when subjected to reverse bias.
- Large variation in current. Voltage almost constant.
- Used for voltage regulation. Upper limit of current depends on the power dissipation rating of the device.

Zener Diode

Zener diode



V-I Characteristics of Zener Diode



V-I Characteristics of Zener Diode

- Zener diodes are manufactured to have a very low reverse bias breakdown voltage
- Since the breakdown at the zener voltage is so sharp, these devices are often used in voltage regulators to provide precise voltage references. The actual zener voltage is device dependent. For example, you can buy a 6V zener diode.

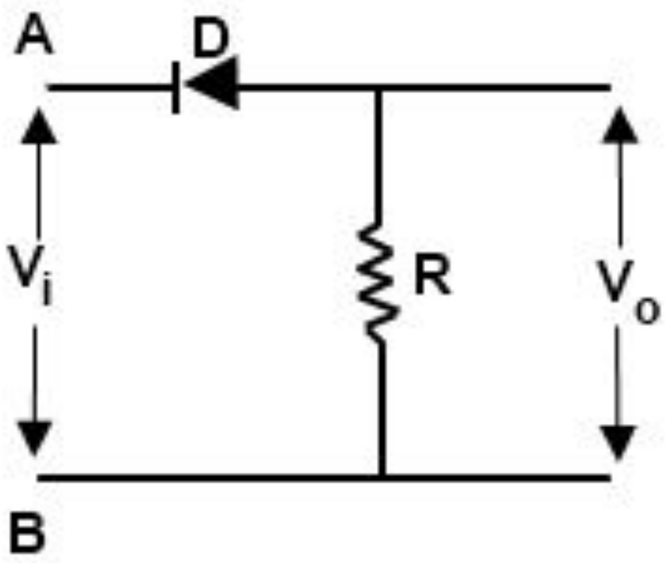
Clipper circuits

- Clipping 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.”

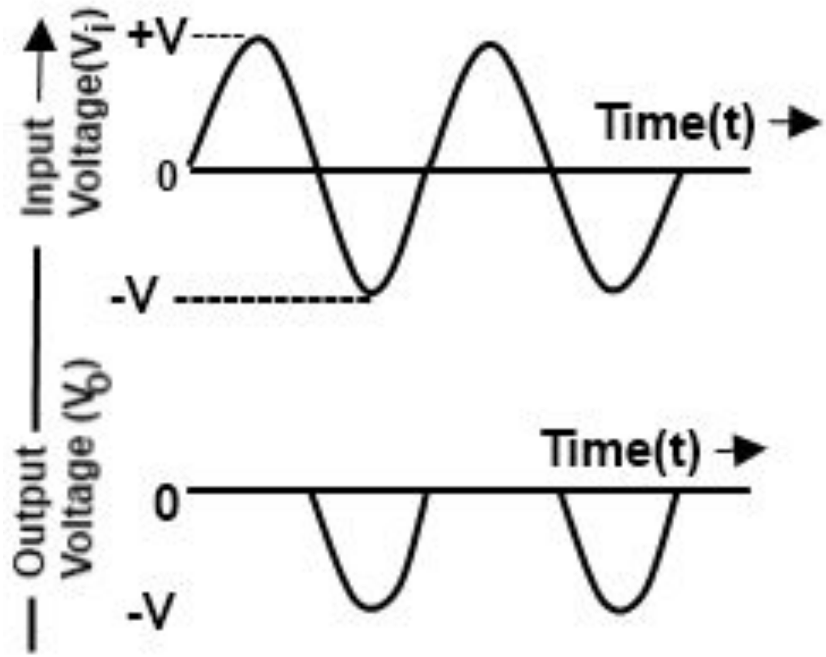
Types of clippers

- **The clipper circuits are of the following types.**
- Series positive clipper
- Series negative clipper
- Shunt or parallel clipper
- Shunt or parallel positive negative
- Clipper Dual (combination)Diode clipper

Series positive clipper

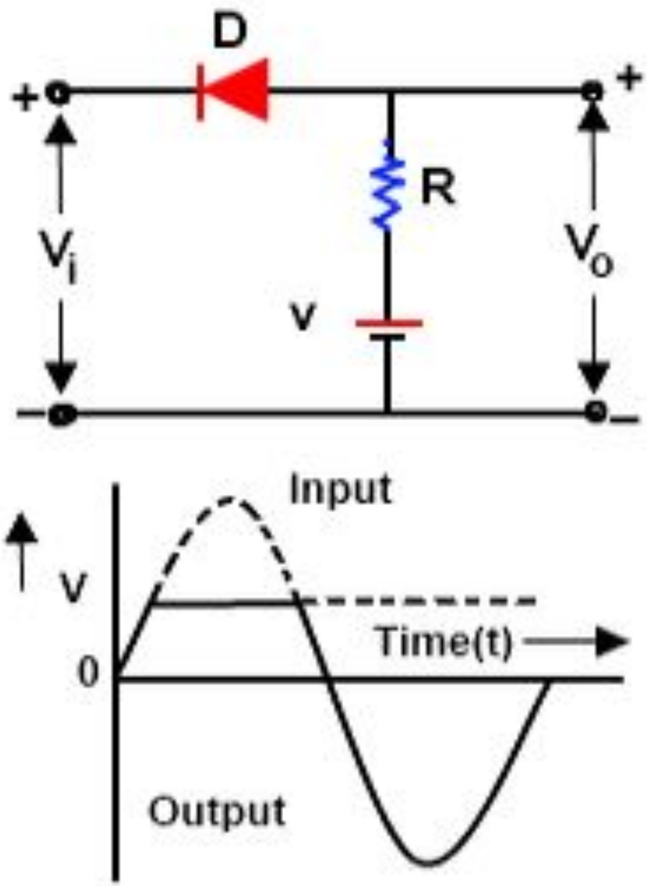


Positive clipper

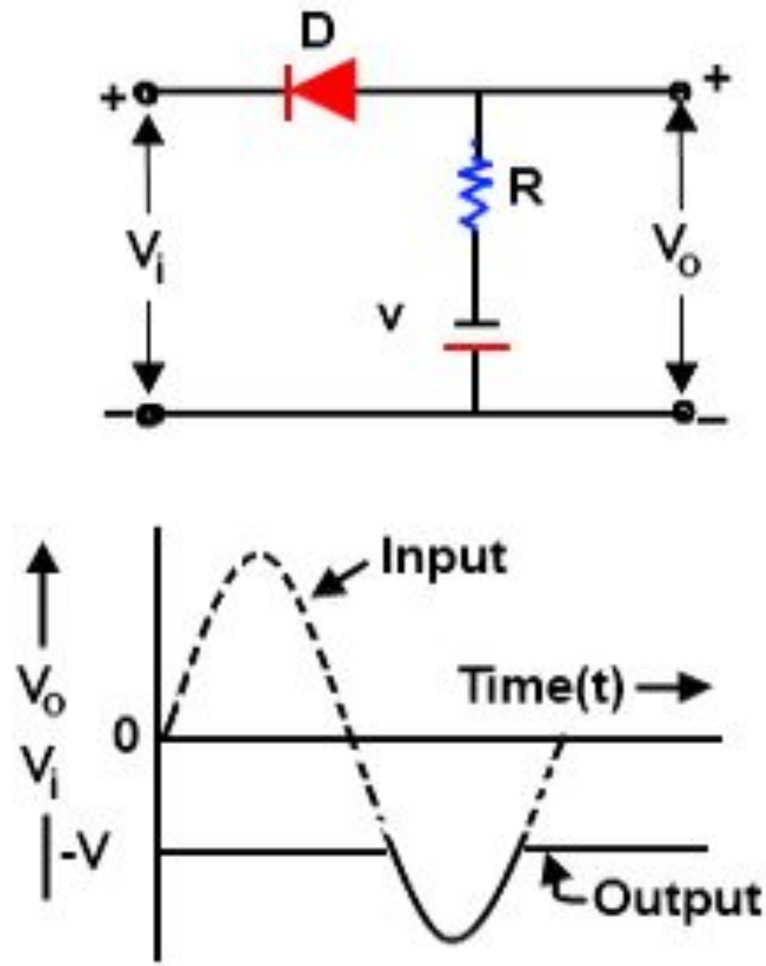


Output voltage

SERIES-POSITIVE CLIPPER WITH BIAS

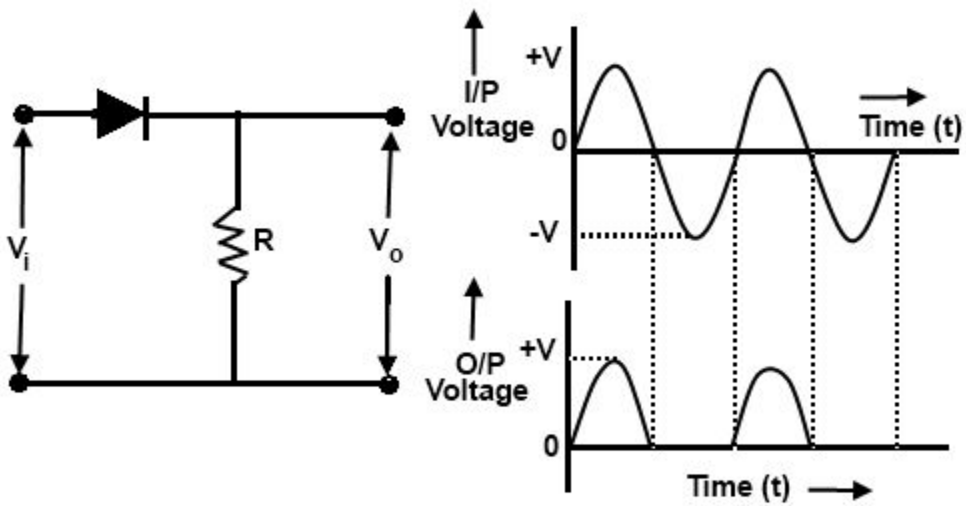


(a) Positive biased

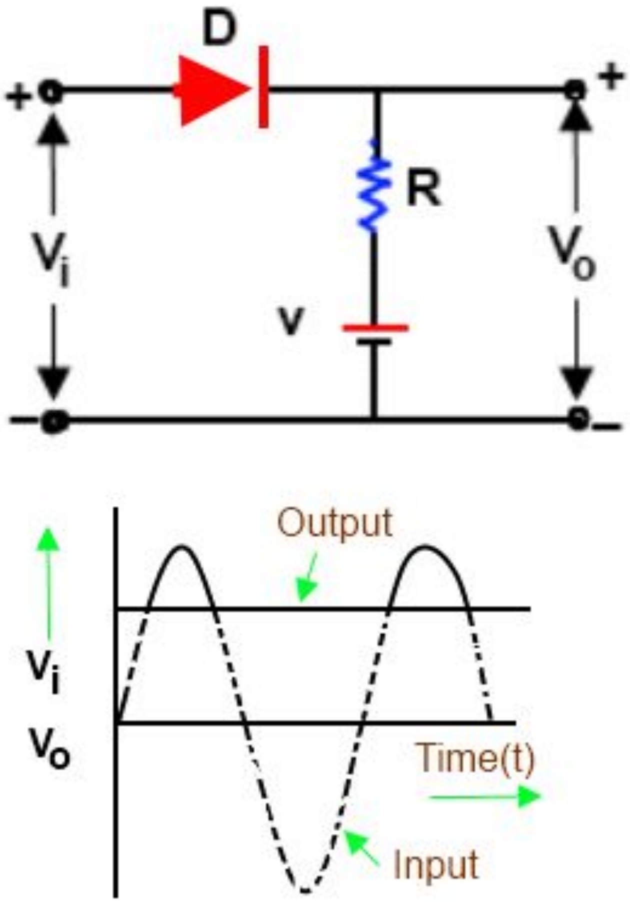


(b) Negative Biased

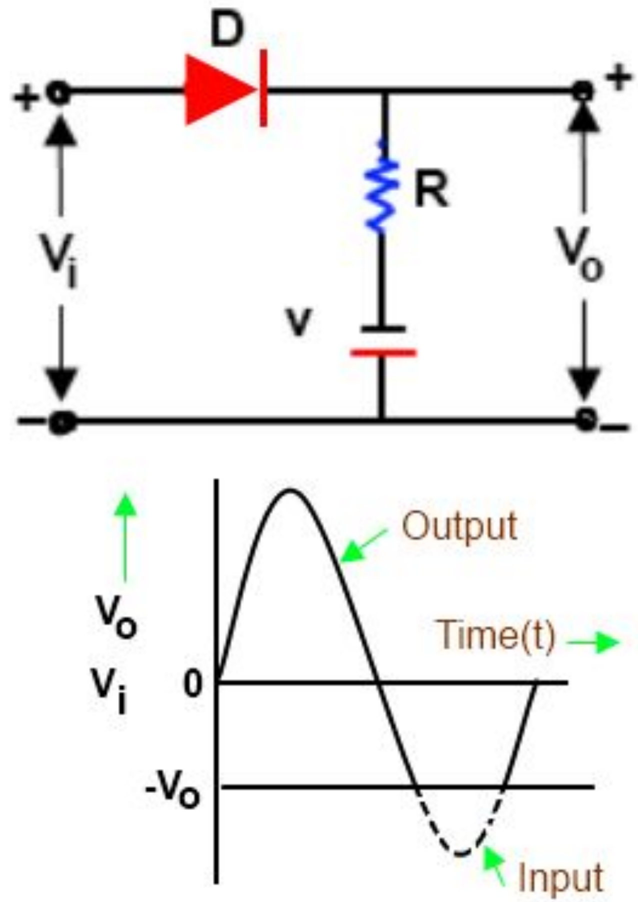
SERIES NEGATIVE CLIPPER



SERIES-NEGATIVE CLIPPER WITH BIAS

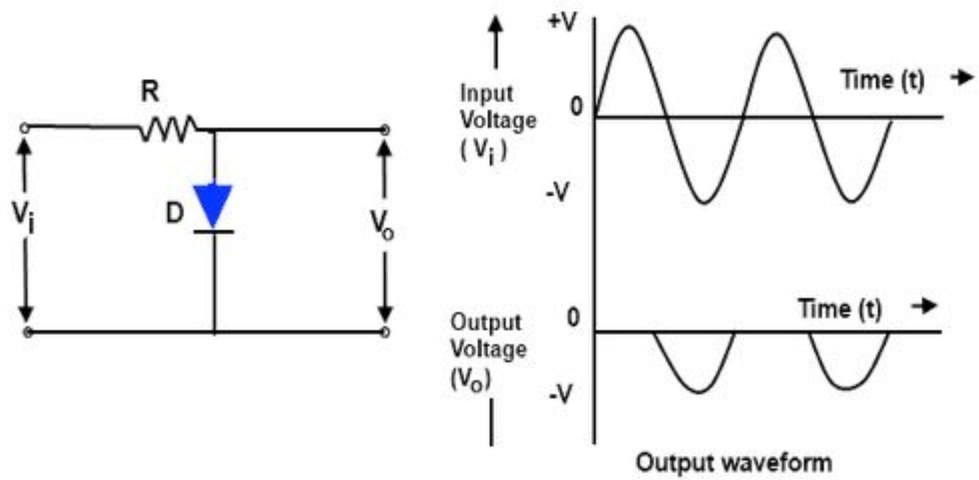


(a) Positive biased

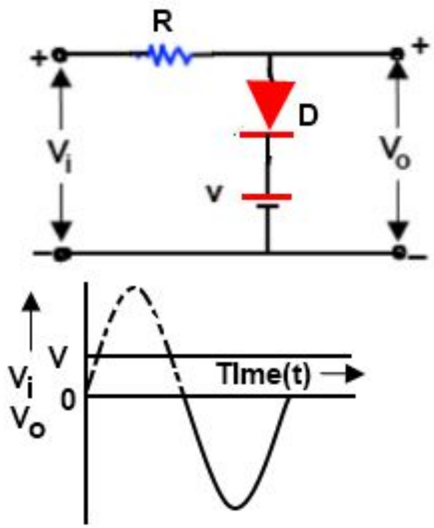


(b) Negative biased

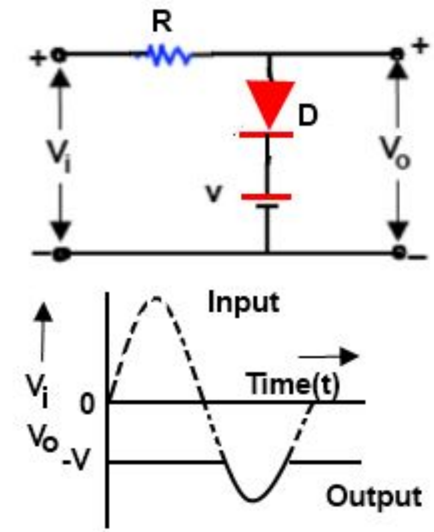
SHUNT OR PARALLEL POSITIVE CLIPPER



SHUNT OR PARALLEL POSITIVE CLIPPER WITH BIAS

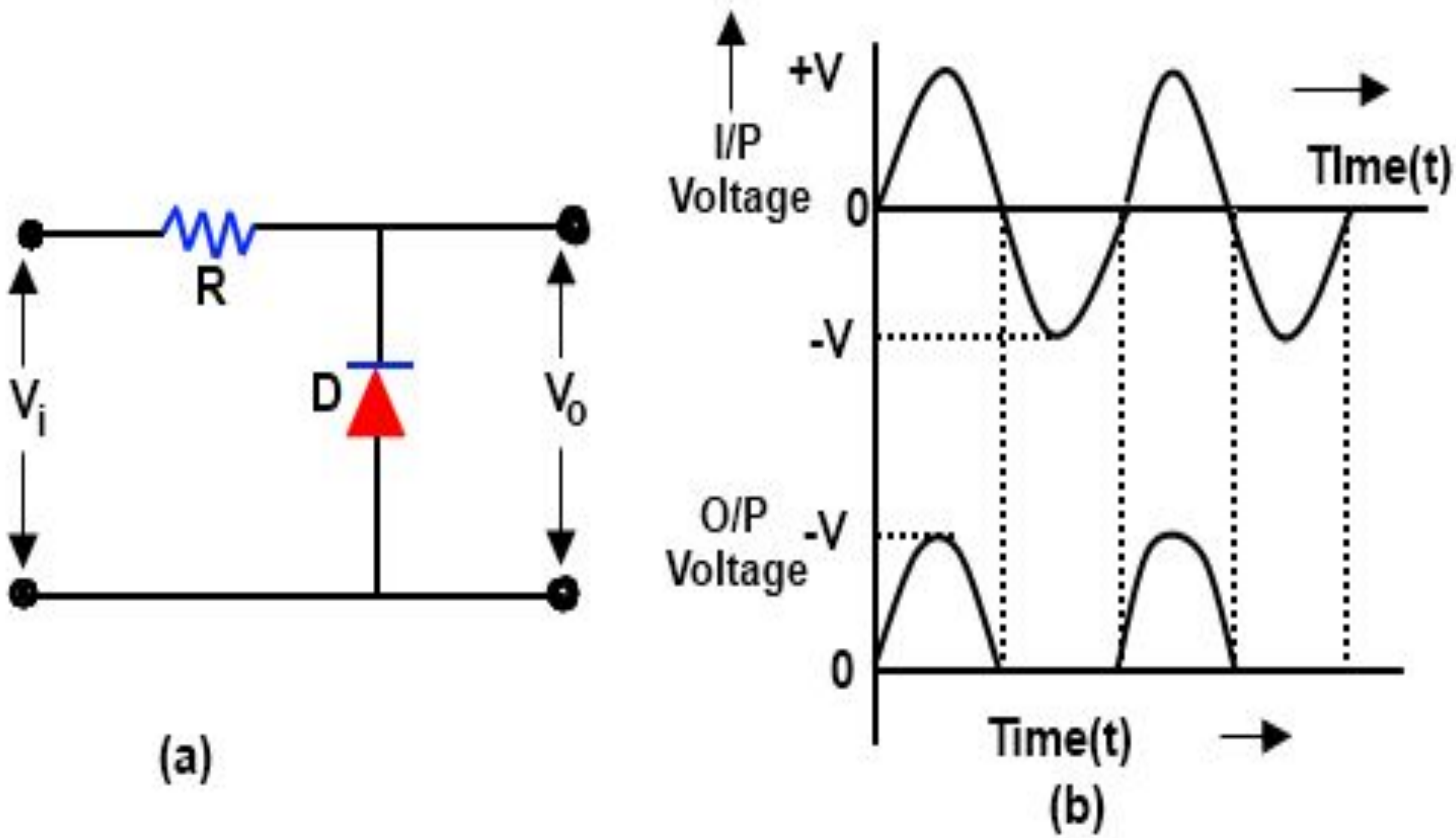


(a) Positive biased

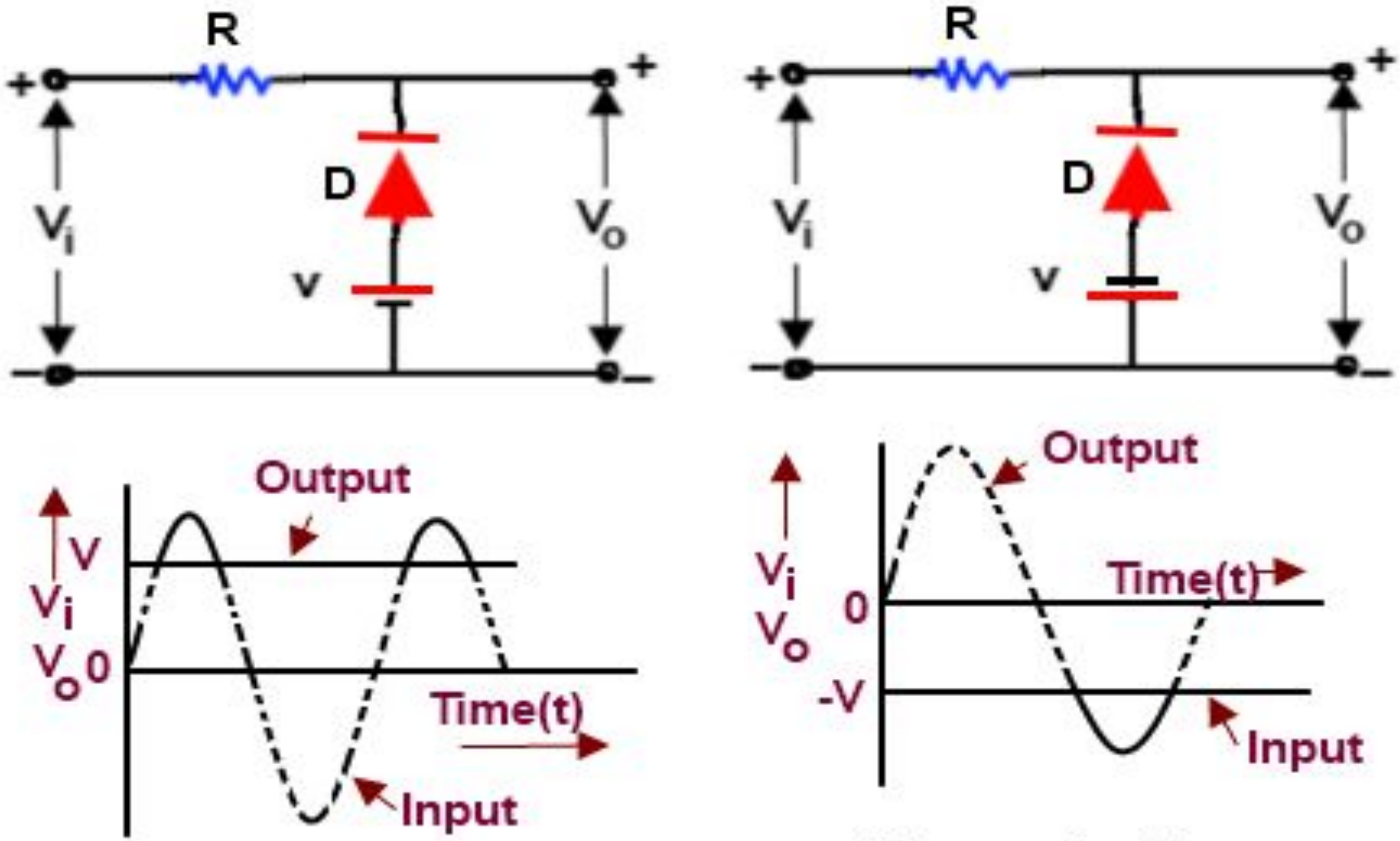


(b) Negative biased

SHUNT OR PARALLEL NEGATIVE CLIPPER



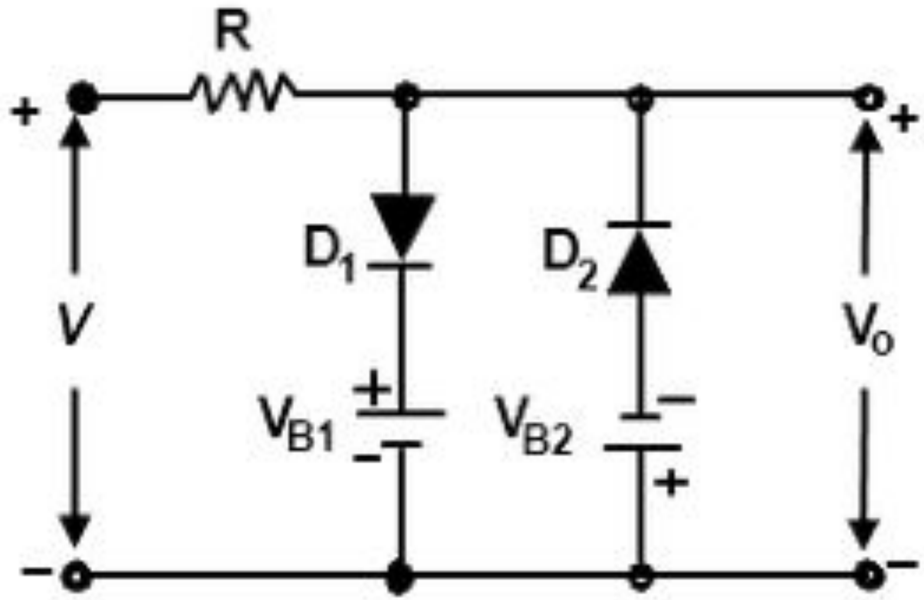
SHUNT OR PARALLEL NEGATIVE CLIPPER WITH BIAS

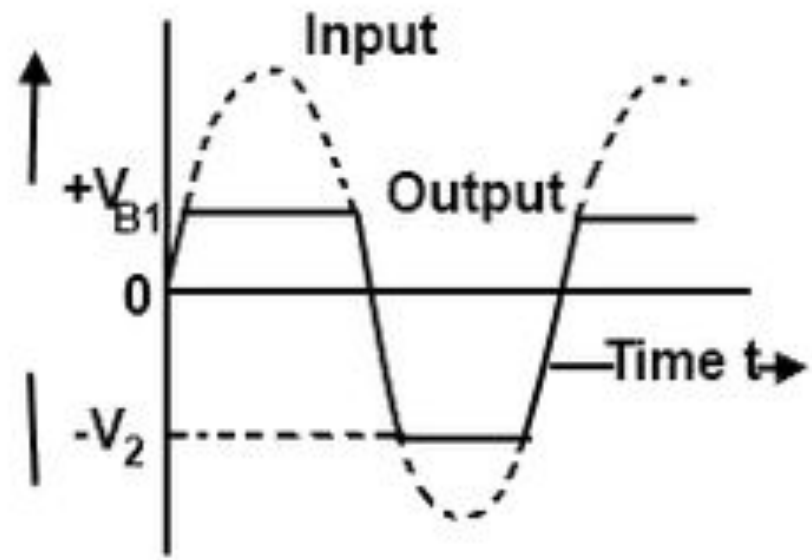


(a) Positive bias

(b) negative bias

DUAL (COMBINATION) DIODE CLIPPER





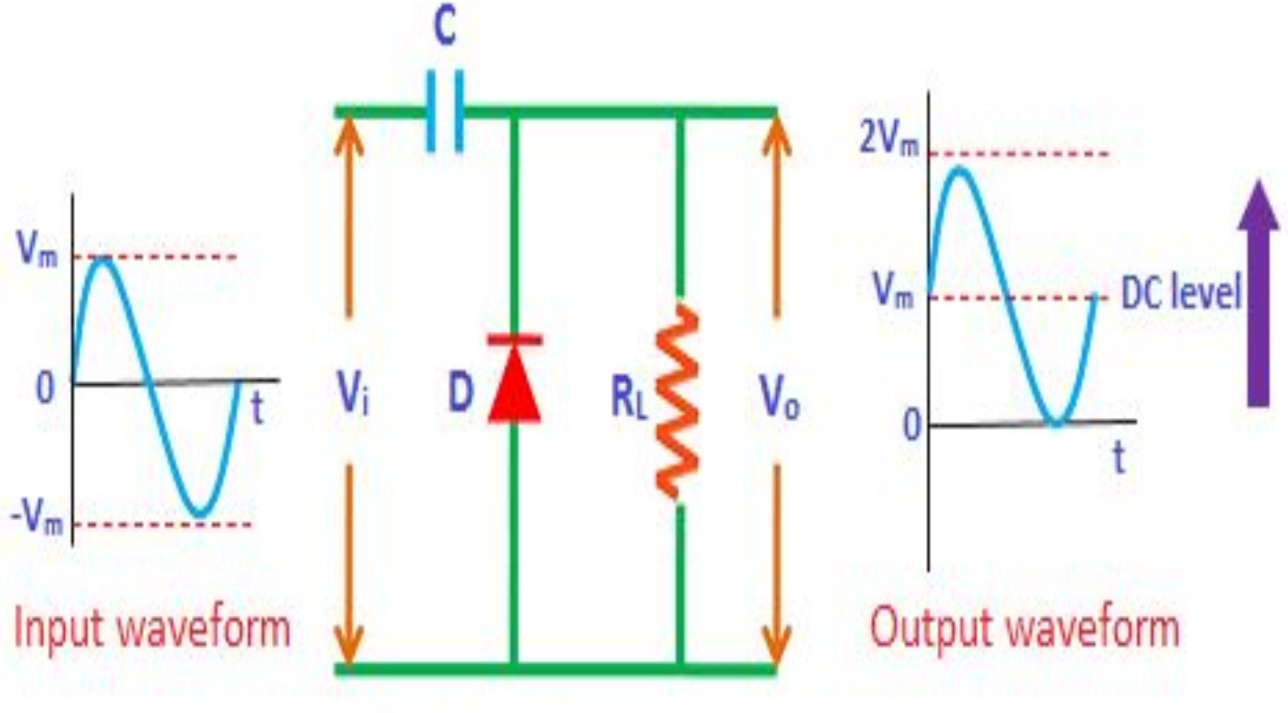
Clamber circuits

- 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.
- the original signal will not get changed, only there is vertical shift in the signal.

Types of clambers

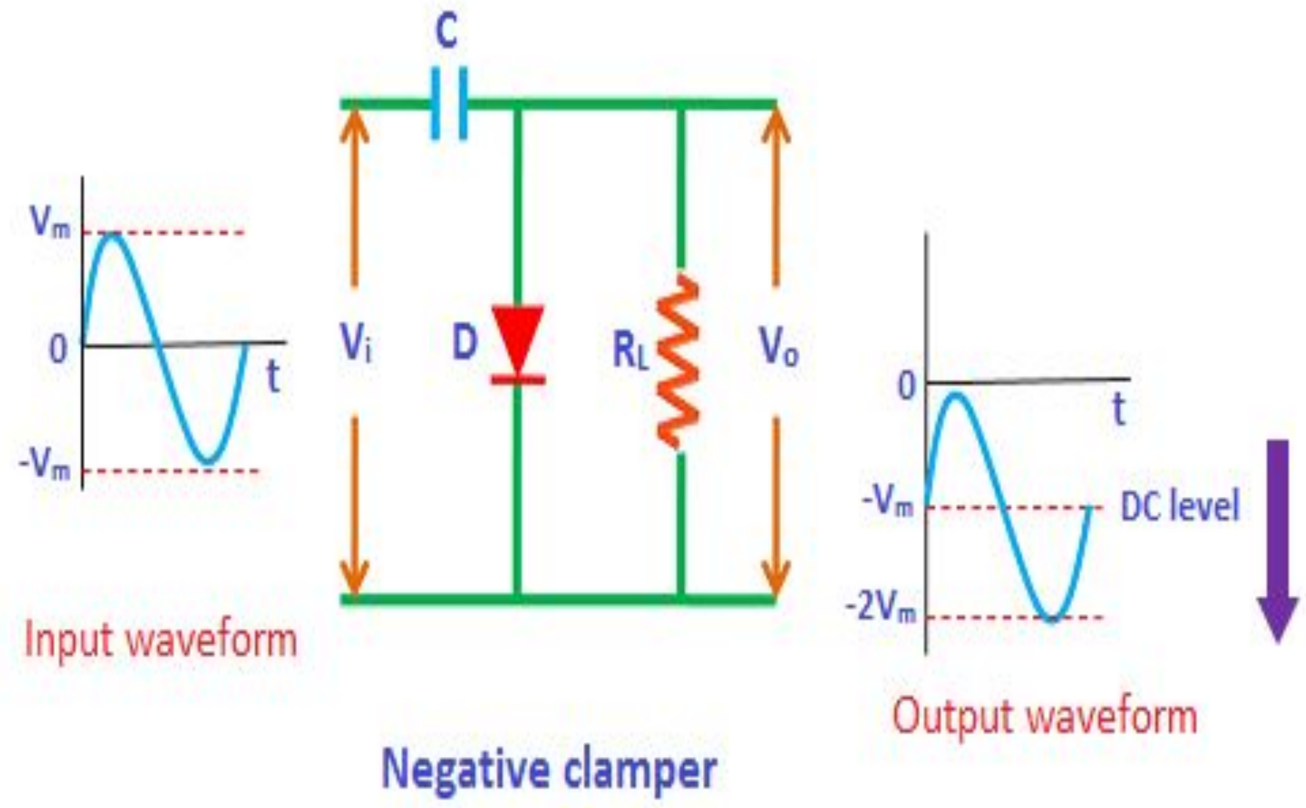
- <u>Positive clamber - Positive clamping</u>
- occurs when negative peaks raised or clamped to ground or on the zero level
- In other words, it pushes the signal upwards so that negative peaks fall on the zero level.
- <u>Negative clamper - Negative clamping</u>
- occurs when positive peaks raised or 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.

Positive clamper

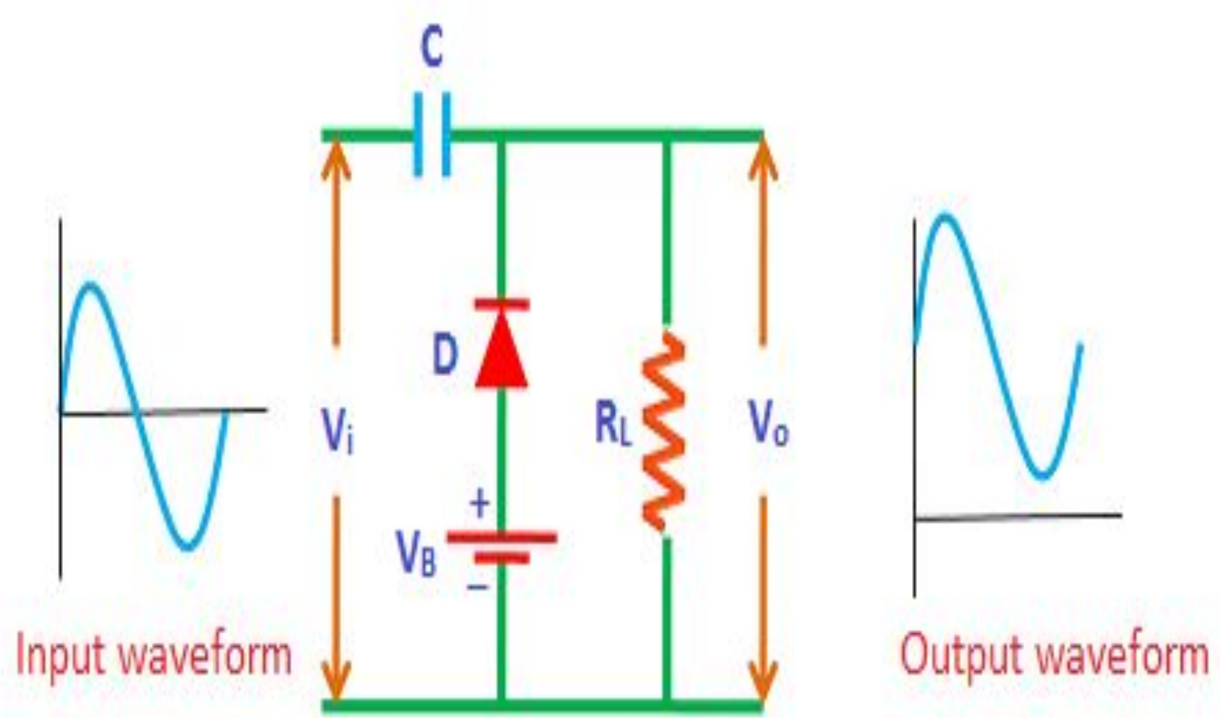


Positive clamper

Negative clamper

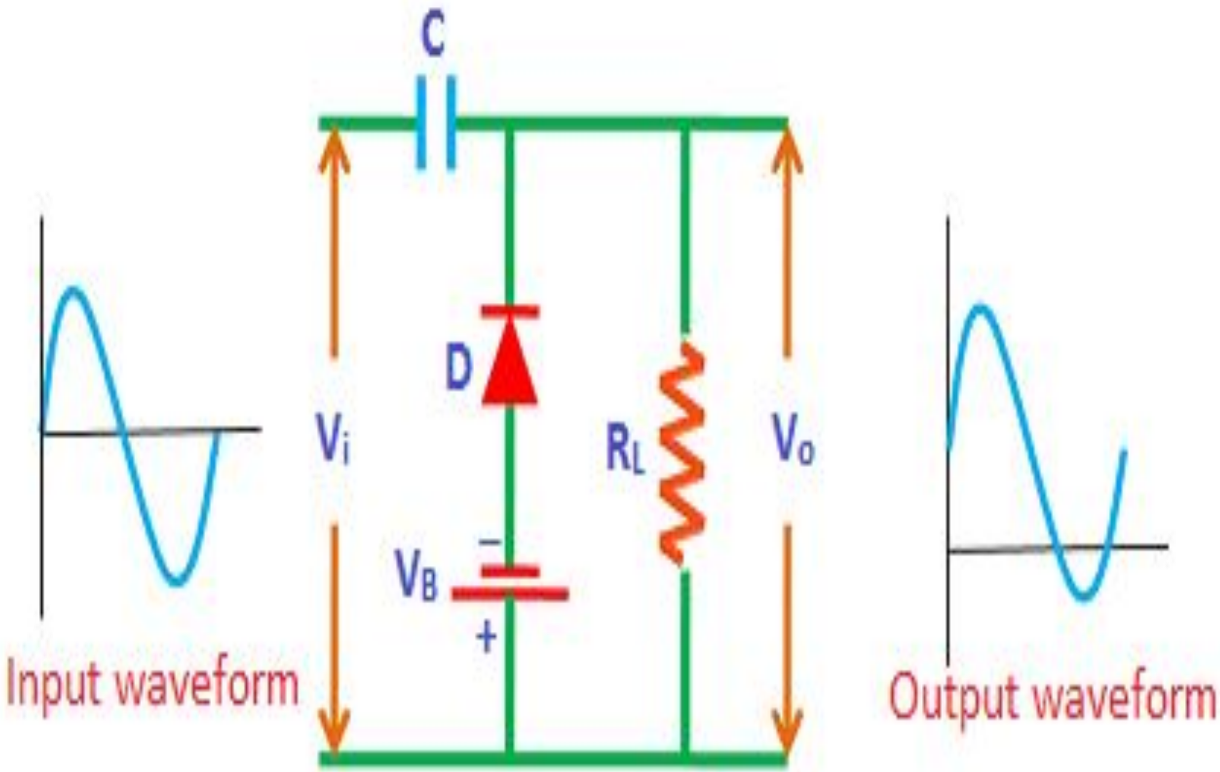


Positive clamper with positive bias



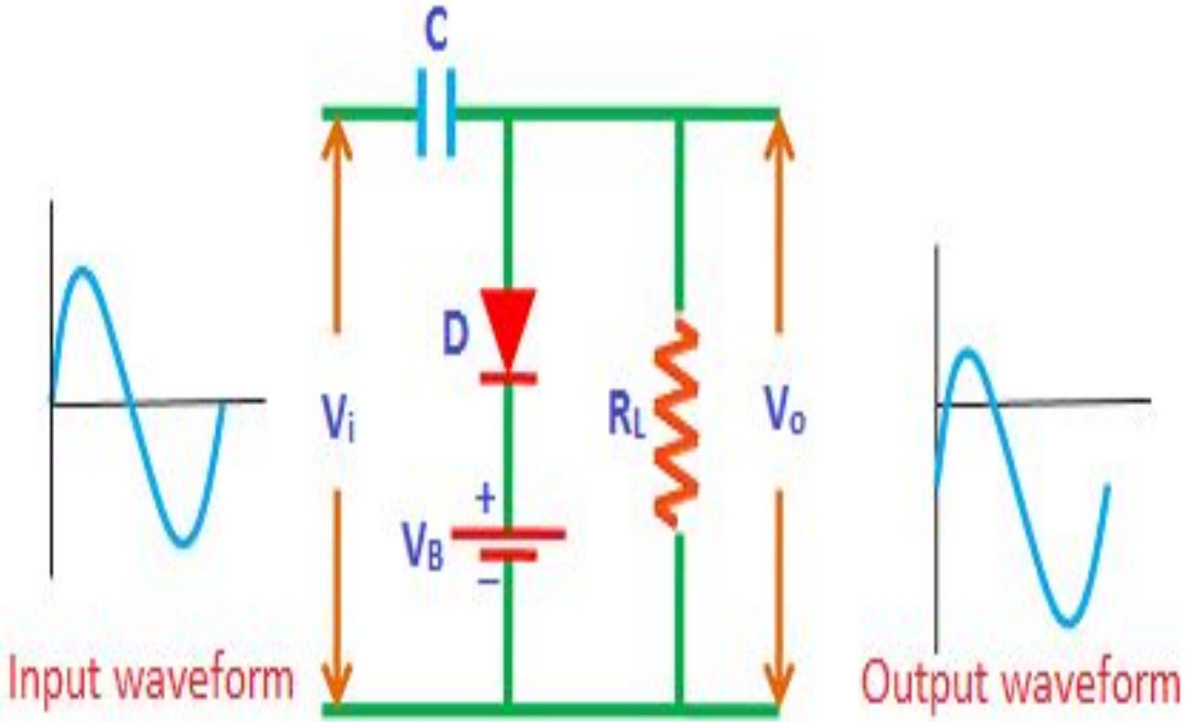
Positive clamper with positive bias

Positive clamper with negative bias



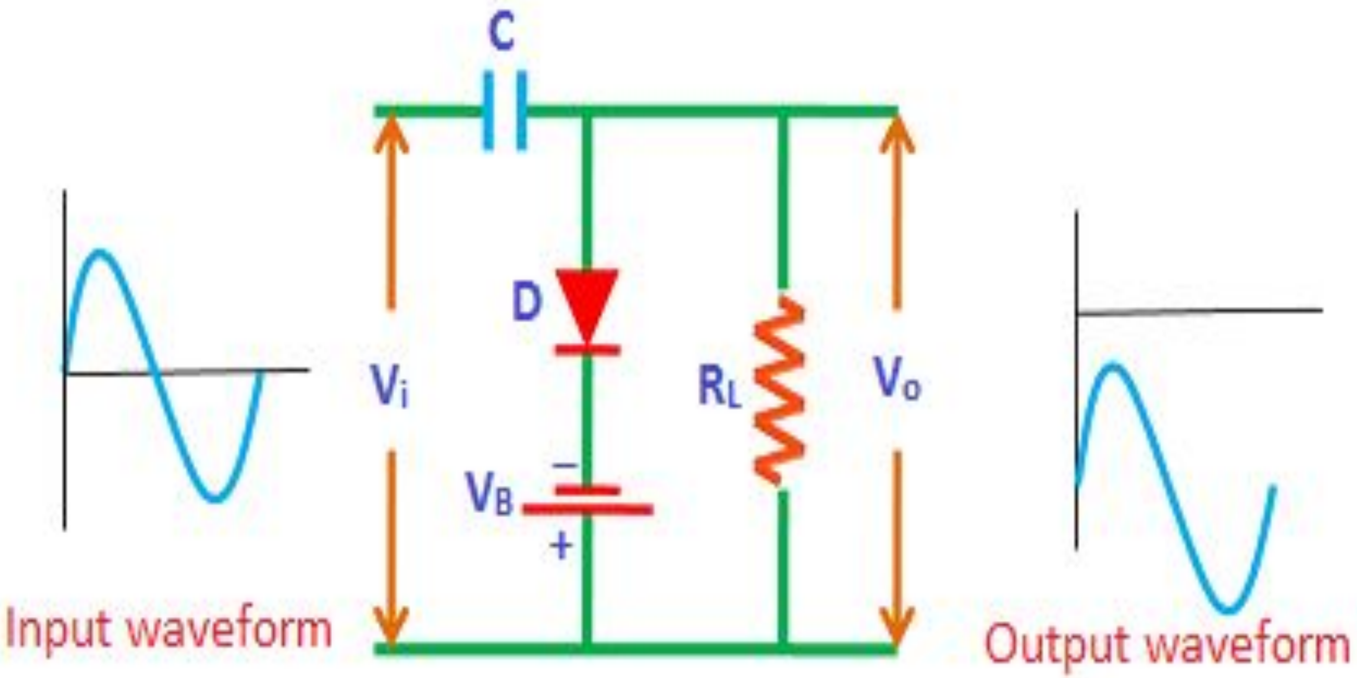
Positive clamper with negative bias

Negative clamper with positive bias



Negative clamper with positive bias

Negative clamper with negative bias



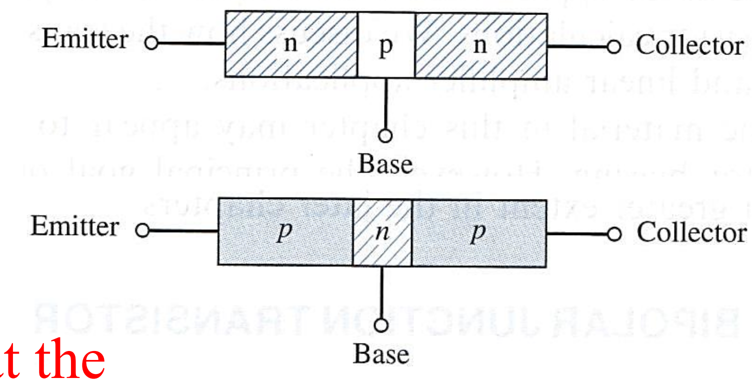
Negative clamper with negative bias

applications

- **Applications of clamping circuits**
- They find some applications in sonar and radar testing
- Used as voltage doublers
- They are used to remove distortions in a circuit
- Used in video processing equipment like TV

Transistor Structures

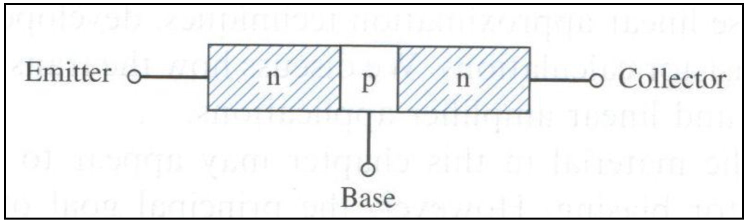
- The **bipolar junction transistor (BJT)** has three separately doped regions and contains two pn junctions.
- Bipolar transistor is a 3-terminal device.
  - Emitter (E)
  - Base (B)
  - Collector (C)

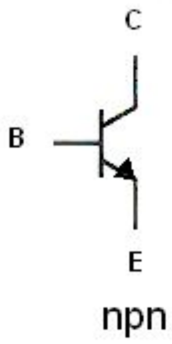


- The basic transistor principle is that the voltage between two terminals controls the current through the third terminal.
- Current in the transistor is due to the flow of both electrons and holes, hence the name **bipolar**.

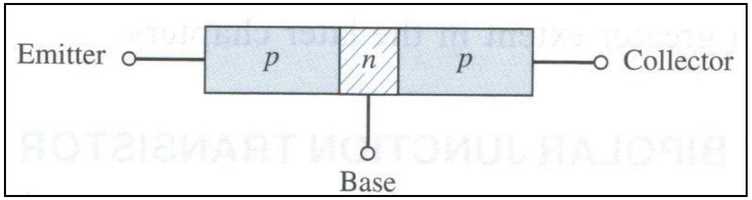
Transistor Structures

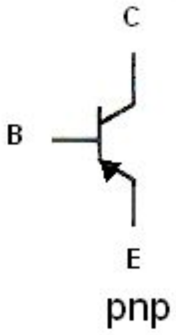
- There are two types of bipolar junction transistor: **npn** and **pnp**.
- The **npn bipolar transistor** contains a thin p-region between two n-regions.





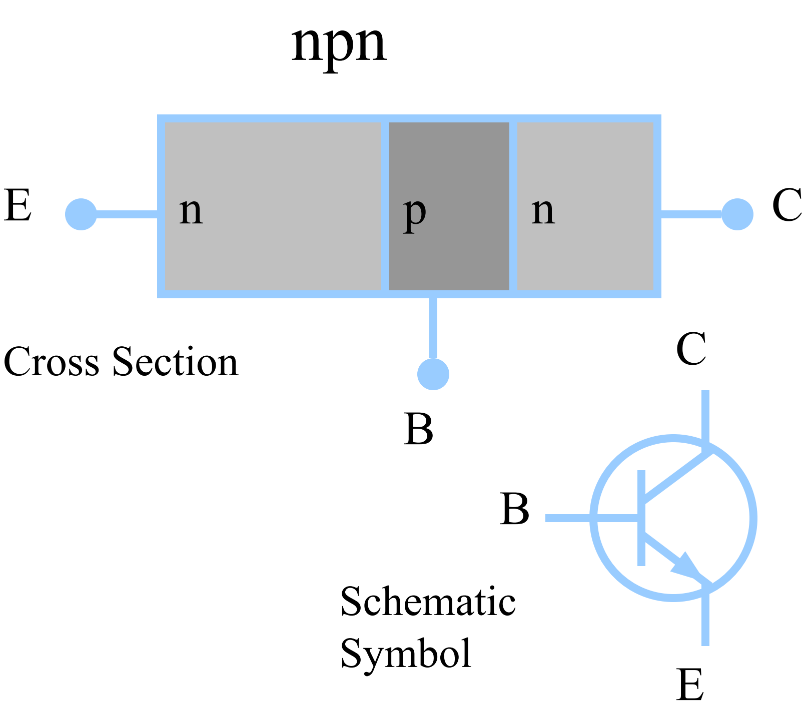
- The **pnp bipolar transistor** contains a thin n-region sandwiched between two p-regions.

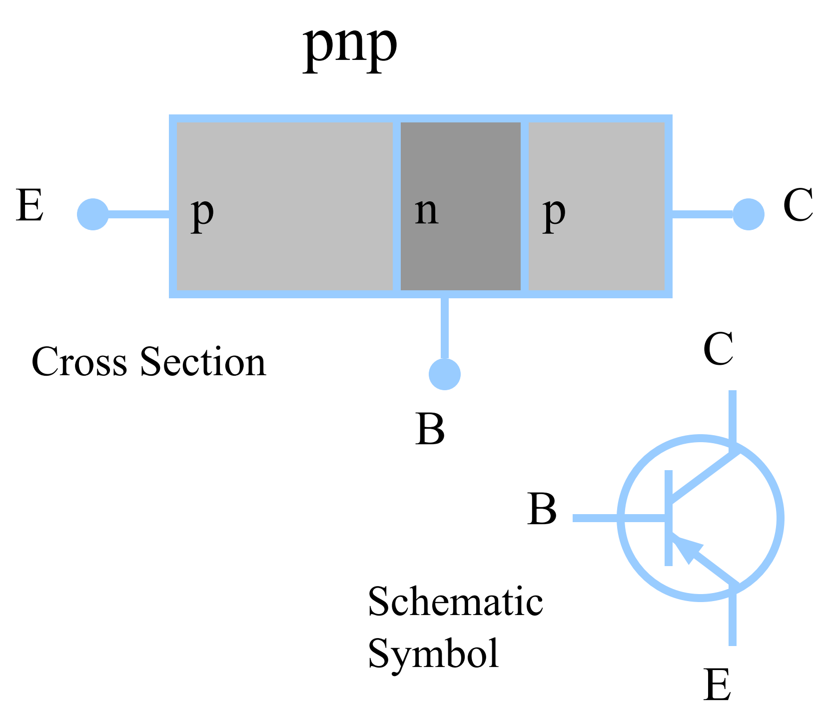




Note: It will be very helpful to go through the Analog Electronics Diodes Tutorial to get information on doping, n-type and p-type materials.

The Two Types of BJT Transistors:

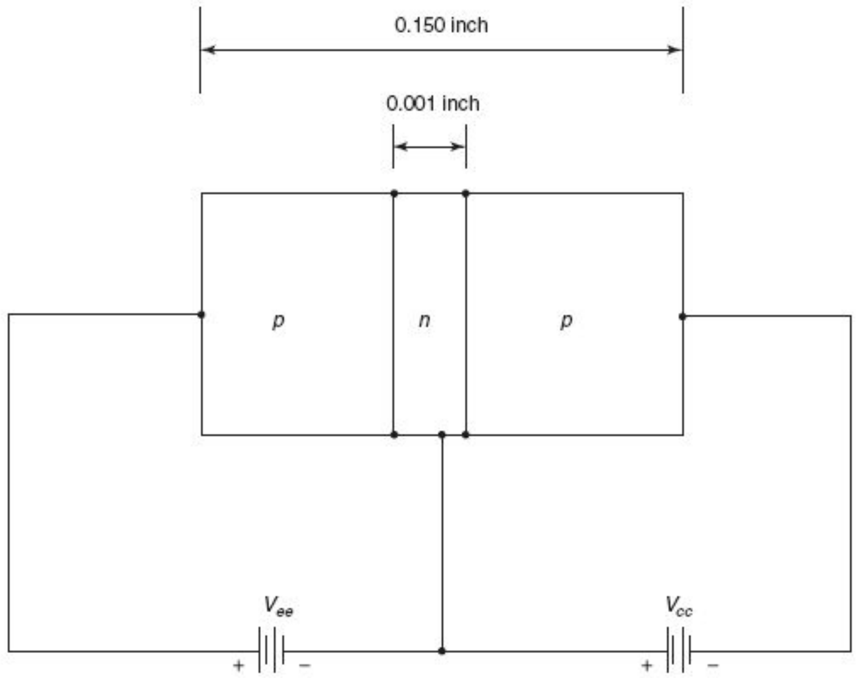




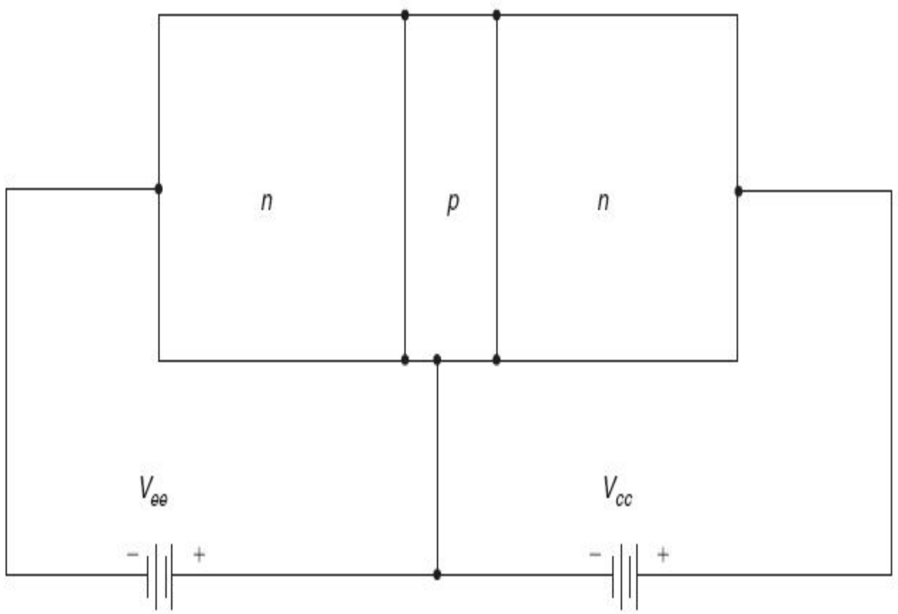
- Collector doping is usually ~ 10^6
- Base doping is slightly higher ~ 10^7 – 10^8
- Emitter doping is much higher ~ 10^{15}

FORMATION OF p–n–p AND n–p–n JUNCTIONS

- When an *n-type thin semiconductor layer is placed between two p-type semiconductors, the resulting* structure is known as the *p–n–p transistor.*
- *The fabrication steps are complicated, and demand stringent* conditions and measurements.
- When a *p-type semiconductor is placed between two n-type semiconductors,* the device is known as the *n–p–n transistor.*



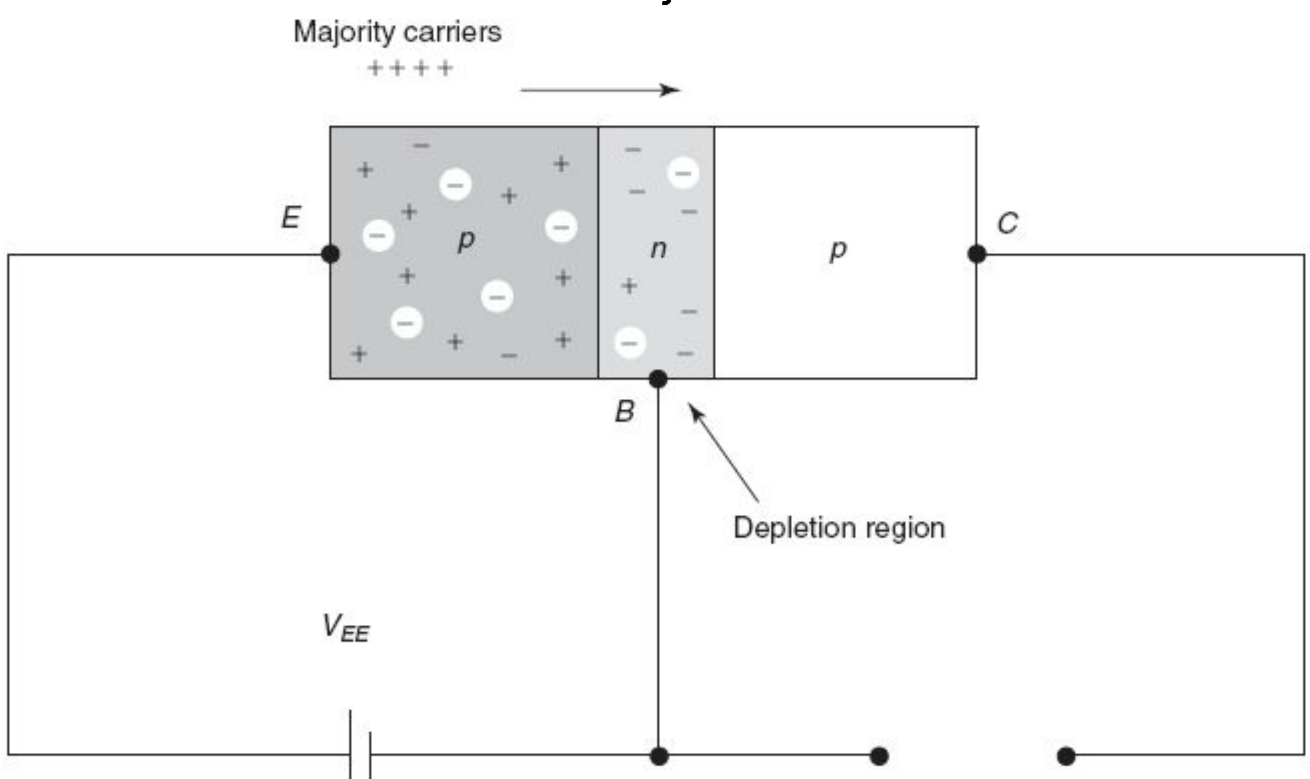
p–n–p transistor



n–p–n transistor

TRANSISTOR MECHANISM

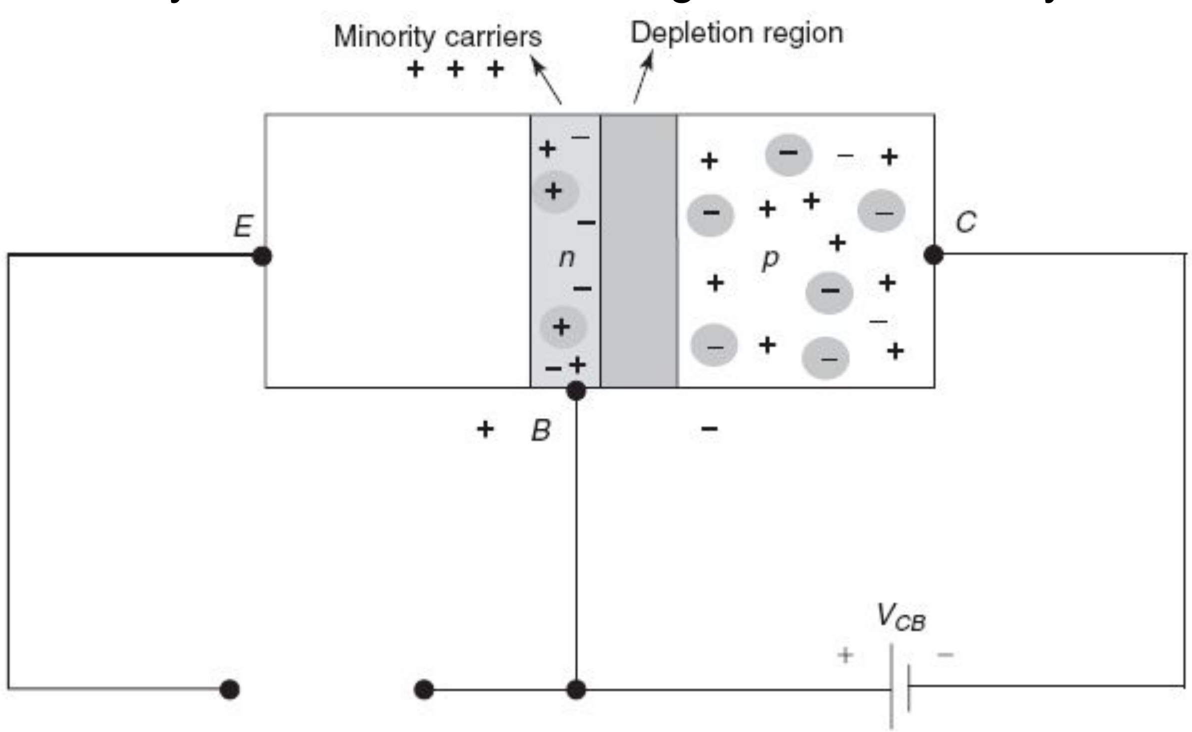
- The basic operation of the transistor is described using the *p–n–p transistor.*
- *The p–n junction of the transistor* is forward-biased whereas the base-to-collector is without a bias.
- The depletion region gets reduced in width due to the applied bias, resulting in a heavy flow of majority carriers from the *p-type to the n-type material gushing down the depletion region and reaching the base.*
- The forward-bias on the emitter–base junction will cause current to flow.



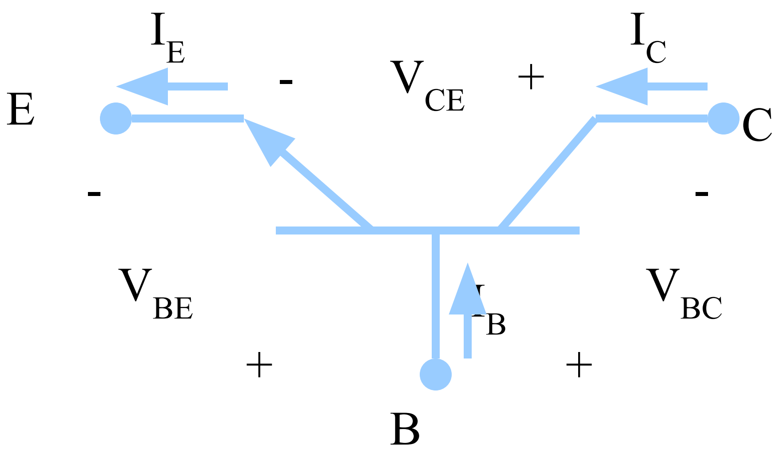
Forward-biased junction of a *p–n–p transistor*

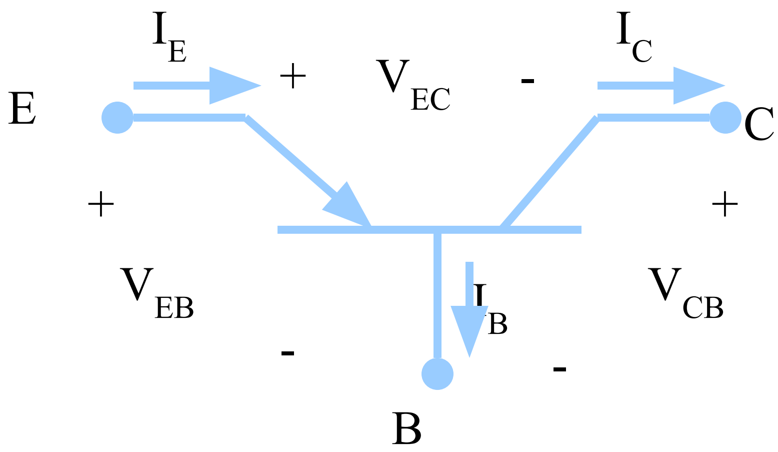
TRANSISTOR MECHANISM

- For easy analysis, let us now remove the base-to-emitter bias of the *p–n–p transistor.*
- The flow of majority carriers is zero, resulting in a minority-carrier flow. Thus, one *p–n junction of a* transistor is reverse-biased, while the other is kept open.
- The operation of this device becomes much easier when they are considered as separate blocks. In this discussion, the drift currents due to thermally generated minority carriers have been neglected, since they are very small.



Reverse-biased junction of a *p–n–p transistor*





npn

$$I_E = I_B + I_C$$
$$V_{CE} = -V_{BC} + V_{BE}$$

pnp

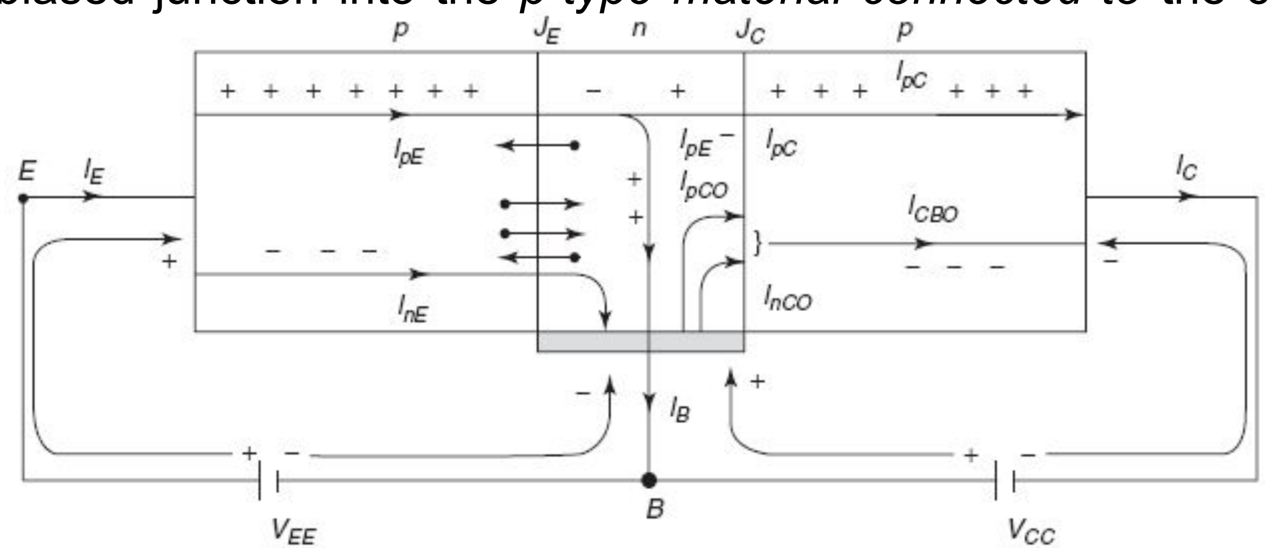
$$I_E = I_B + I_C$$
$$V_{EC} = V_{EB} - V_{CB}$$

Note: The equations seen above are for the transistor, not the circuit.

TRANSISTOR CURRENT COMPONENTS

❖ Current Components in *p–n–p Transistor*

- Both biasing potentials have been applied to a *p–n–p transistor,* with the resulting majority and minority carrier flow indicated.
- The width of the depletion region clearly indicates which junction is forward-biased and which is reverse-biased.
- The magnitude of the base current is typically in the order of microamperes as compared to mill amperes for the emitter and collector currents. The large number of these majority carriers will diffuse across the reverse-biased junction into the *p-type material connected to* the collector terminal

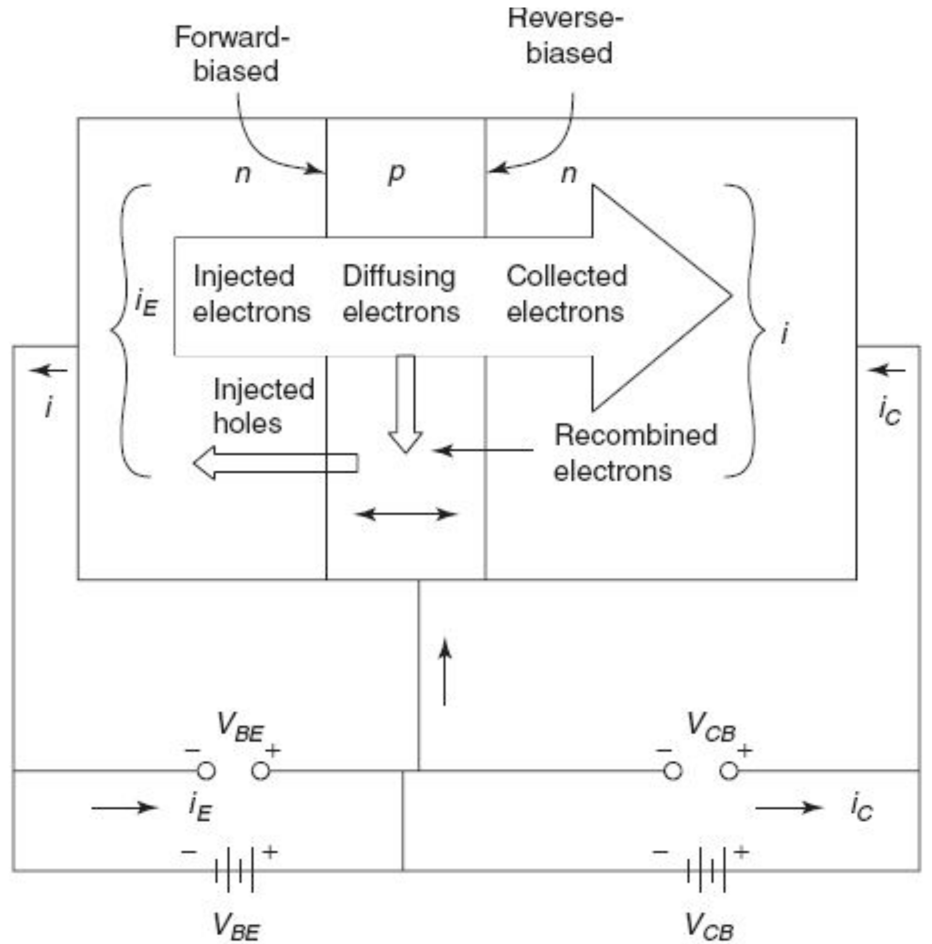


Direction of flow of current in *p–n–p transistor with the base–emitter junction forward-biased* and the collector–base junction reverse-biased

TRANSISTOR CURRENT COMPONENTS

❖ Current Components in an *n–p–n Transistor*

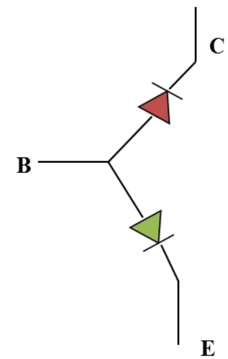
- The operation of an *n–p–n transistor is the same as that of a p–n–p transistor, but with the roles played by* the electrons and holes interchanged.
- The polarities of the batteries and also the directions of various currents are to be reversed.
- Here the majority electrons from the emitter are injected into the base and the majority holes from the base are injected into the emitter region. These two constitute the emitter current.



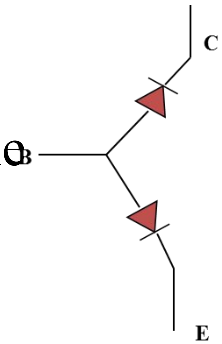
The majority and the minority carrier current flow in a forward-biased *n–p–n transistor*

3 Regions of Operation

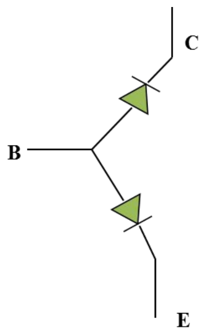
- **Active**
  Operating range of the amplifier.
  Base-Emitter Junction forward biased.
  Collector-Base Junction reverse biased



- **Cutoff**
  The amplifier is basically off. There is voltage but little current.
  Both junctions reverse biased



- **Saturation**
  The amplifier is full on. There is little voltage but lots of current.
  Both junctions forward biased



Biasing the transistor refers to applying voltage to get the transistor to achieve certain operating conditions.

Common-Base Biasing (CB) : input $= V_{EB}$ & I_E
output $= V_{CB}$ & I_C

Common-Emitter Biasing (CE): input $= V_{BE}$ & I_B
output $= V_{CE}$ & I_C

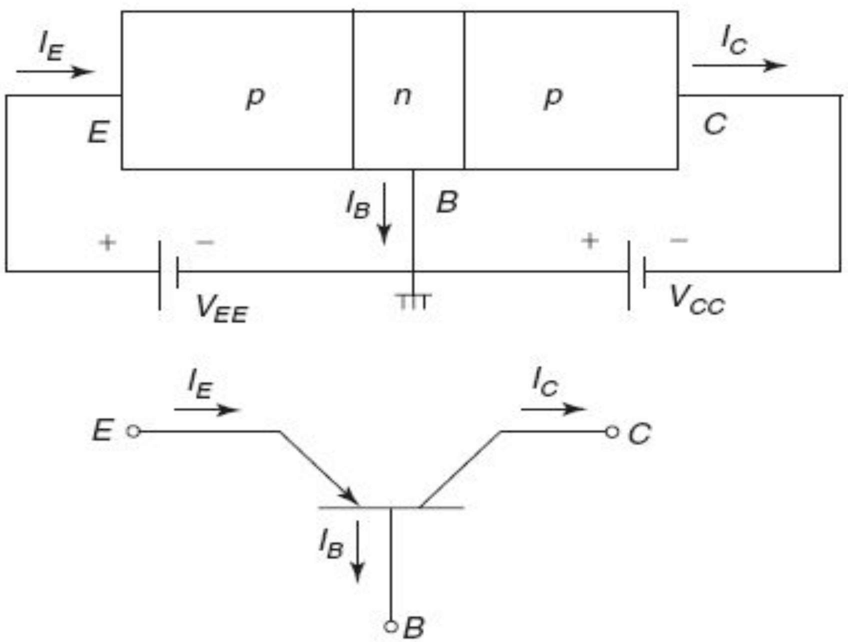
Common-Collector Biasing (CC): input $= V_{BC}$ & I_B
output $= V_{EC}$ & I_E

CB CONFIGURATIONS

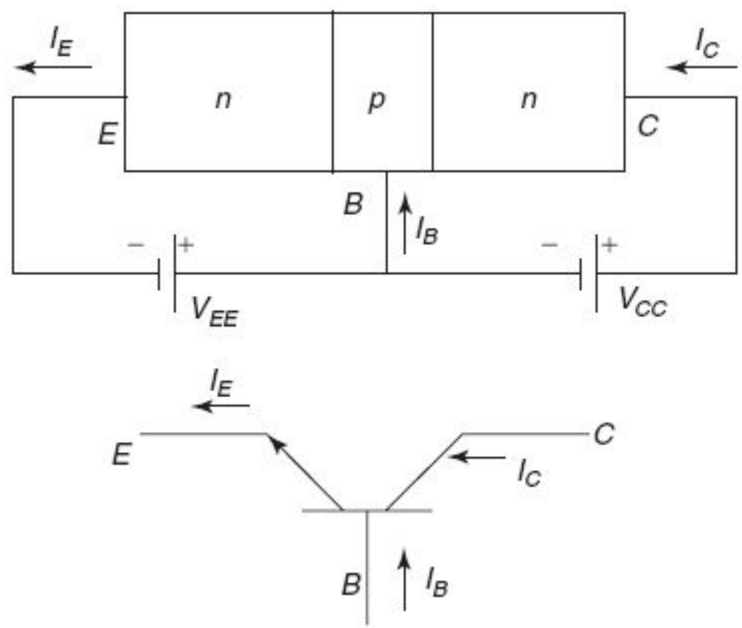
- Depending on the common terminal between the input and the output circuits of a transistor, it may be operated in the common-base mode, or the common-emitter mode, or the common-collector mode.

Common-base (CB) Mode

  - In this mode, the base terminal is common to both the input and the output circuits. This mode is also referred to as the ground–base configuration.



Notation and symbols used for the common-base configuration of a *p–n–p* transistor



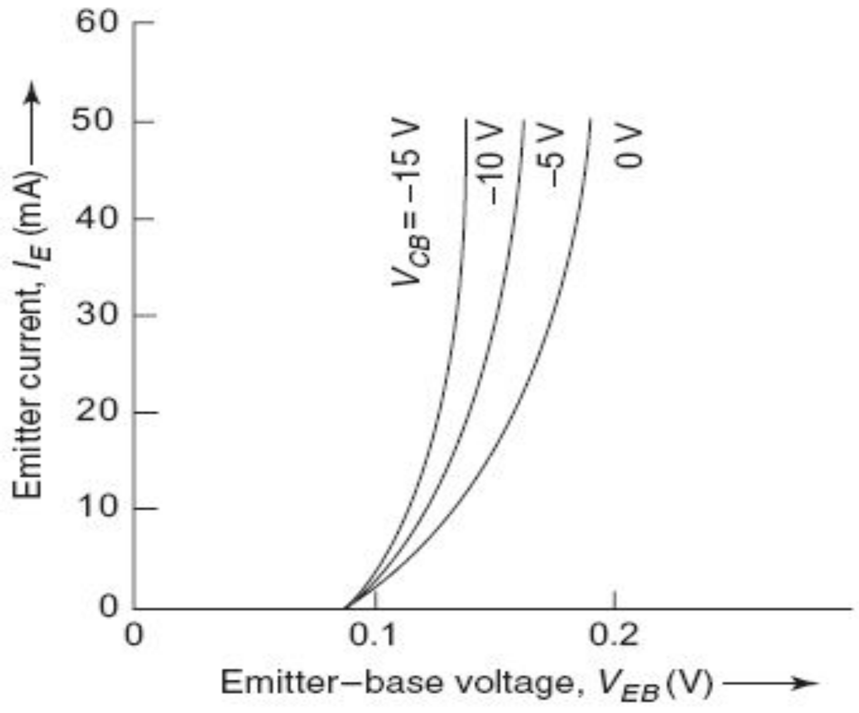
Common-base configuration of an *n–p–n* transistor

TRANSISTOR CHARACTERISTICS

❖The graphical forms of the relations between the various current and voltage variables (components) of a transistor are called *transistor static characteristics.*

❖ **Input Characteristics**

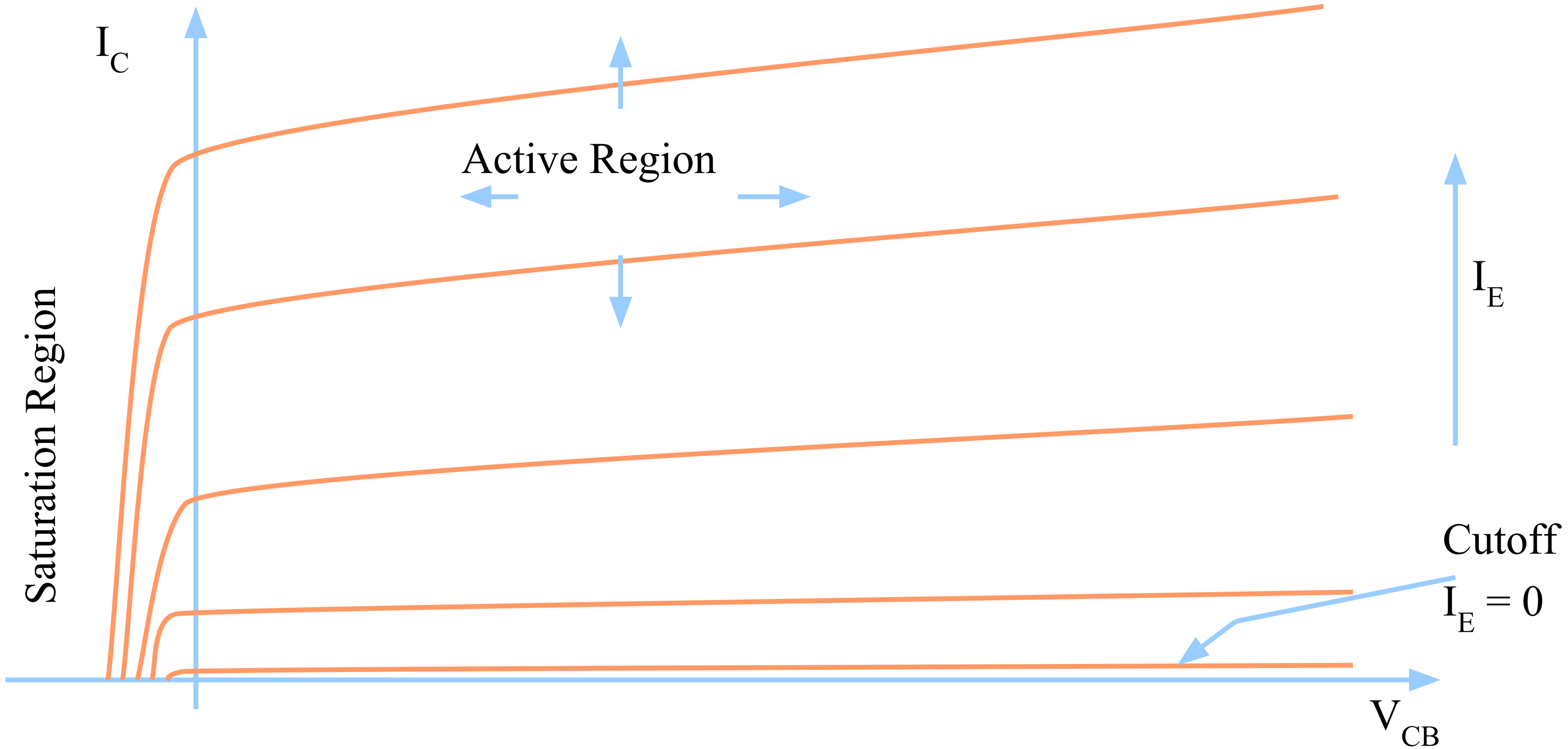
- The plot of the input current against the input voltage of the transistor in a particular configuration with the output voltage as a parameter for a particular mode of operation gives the input characteristics for that mode.
- **Common-base mode**



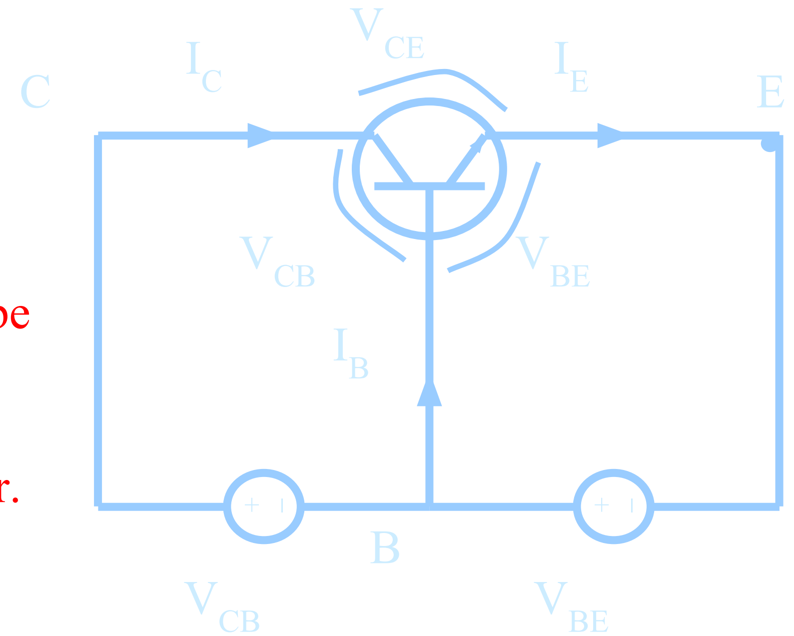
Input characteristics in the CB mode

Although the Common-Base configuration is not the most common biasing type, it is often helpful in the understanding of how the BJT works.

Emitter-Current Curves



Circuit Diagram: NPN Transistor



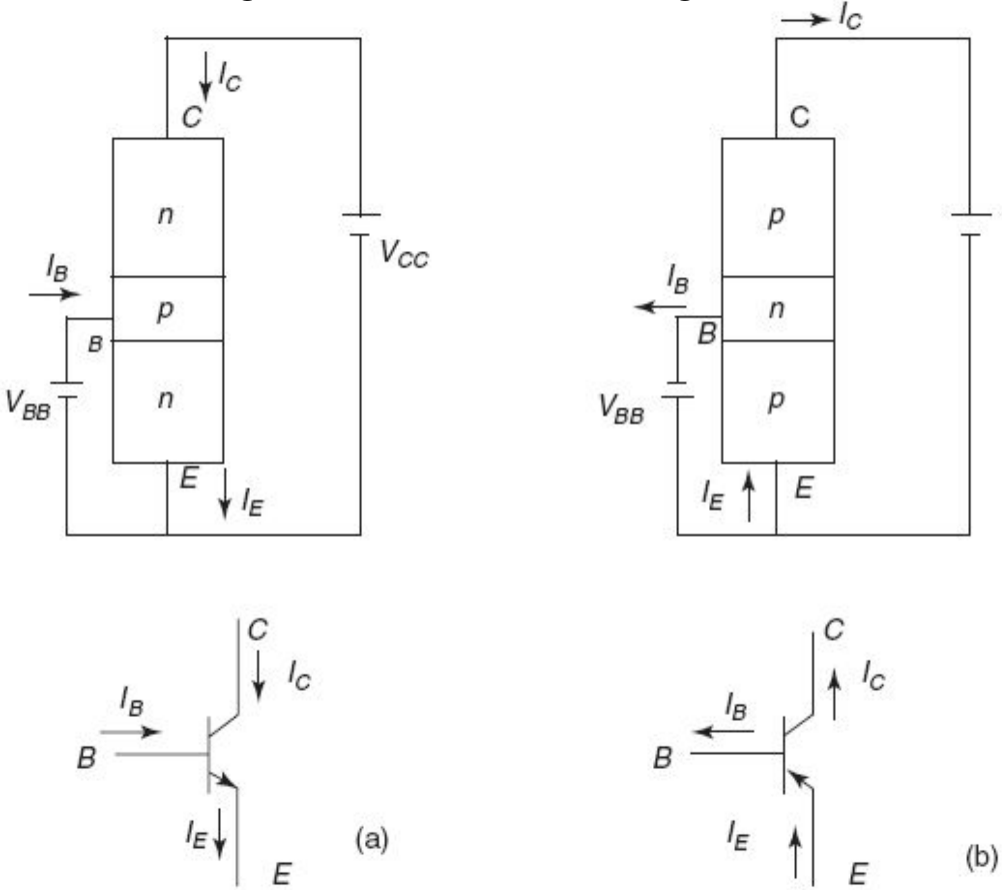
The Table Below lists assumptions that can be made for the attributes of the common-base biased circuit in the different regions of operation. Given for a Silicon NPN transistor.

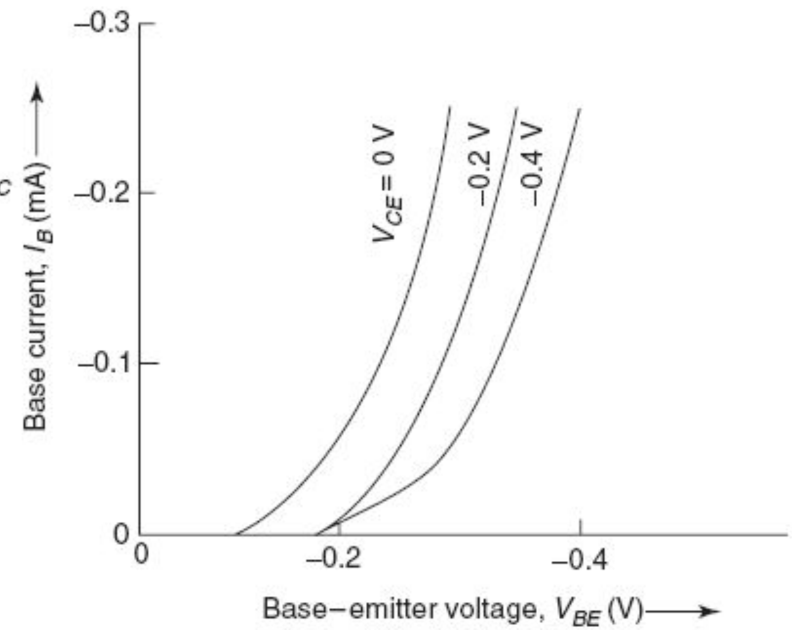
Region of Operation	I_C	V_{CE}	V_{BE}	V_{CB}	C-B Bias	E-B Bias
Active	□I_B	$=V_{BE}+V_{CE}$	~0.7V	□ 0V	Rev.	Fwd.
Saturation	Max	~0V	~0.7V	$-0.7V<V_{CE}<0$	Fwd.	Fwd.
Cutoff	~0	$=V_{BE}+V_{CE}$	□ 0V	□ 0V	Rev.	None /Rev.

CE CONFIGURATIONS

❖ Common-emitter (CE) Mode

- When the emitter terminal is common to both the input and the output circuits, the mode of operation is called the common-emitter (CE) mode or the ground–emitter configuration of the transistor.

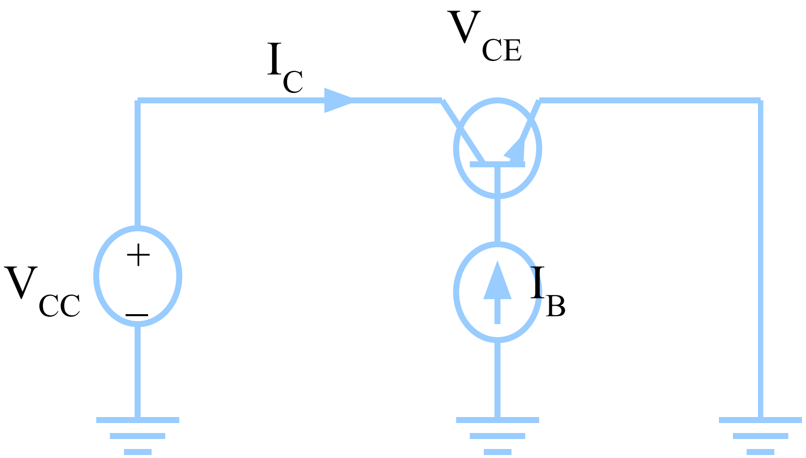




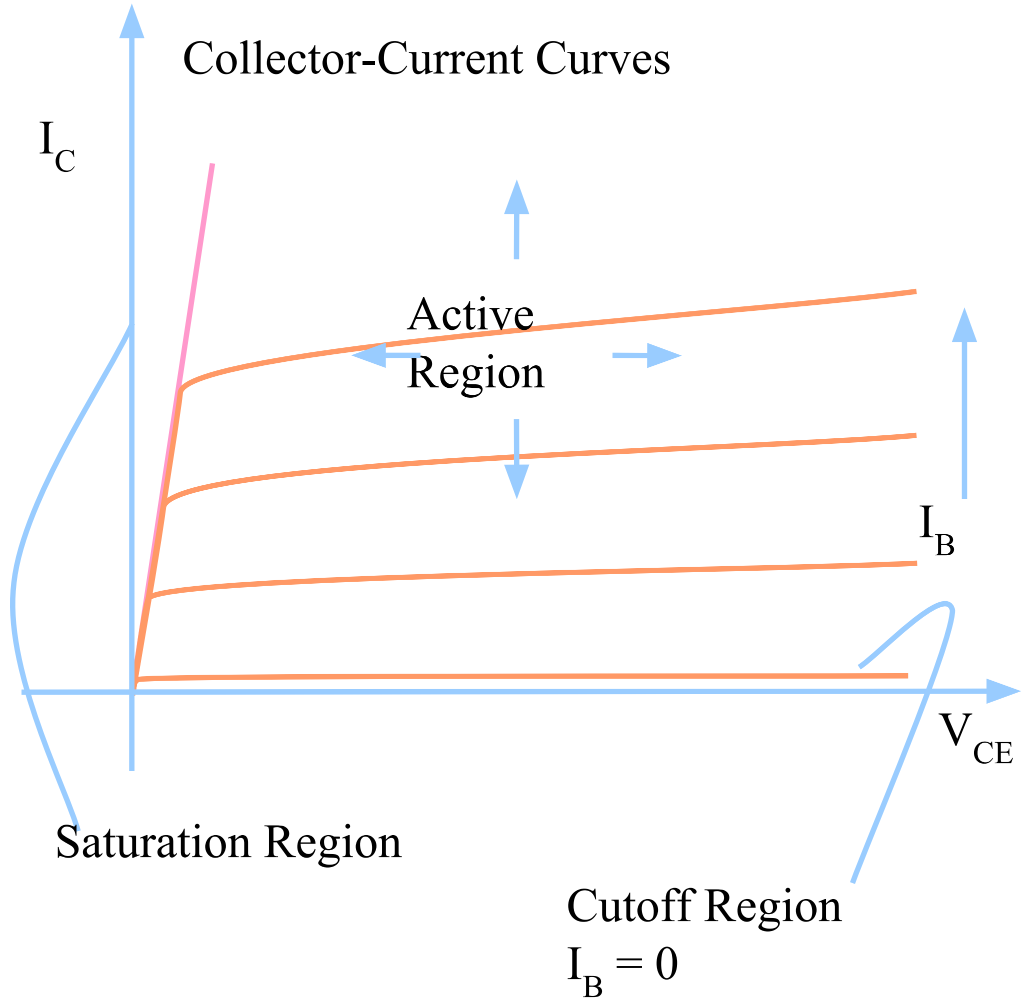
Input characteristics in the CE mode

Notation and symbols for common-emitter configuration (a) *n–p–n transistor* (b) *p–n–p transistor*

Circuit Diagram



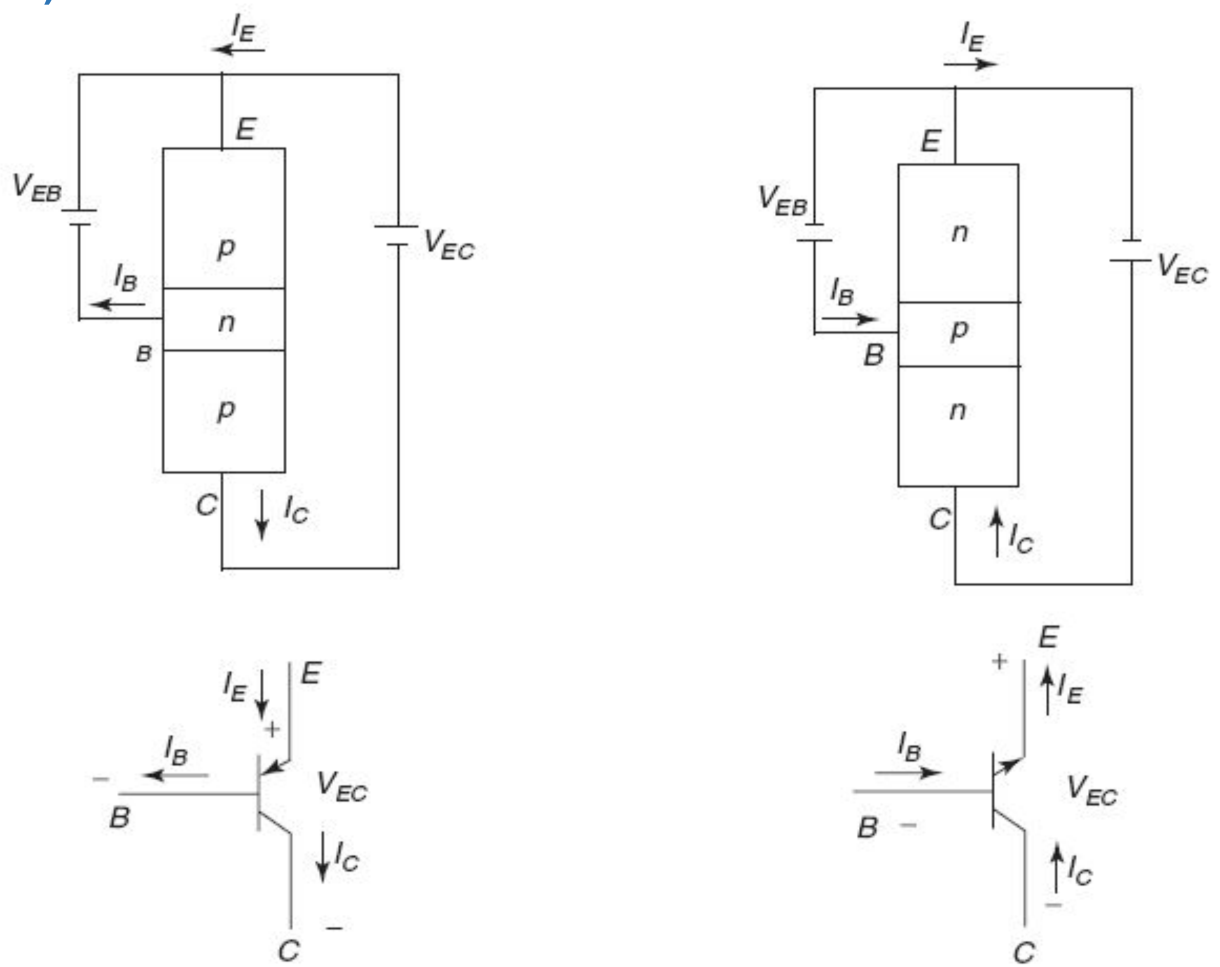
Region of Operation	Description
Active	Small base current controls a large collector current
Saturation	$V_{CE(sat)}$ ~ 0.2V, V_{CE} increases with I_C
Cutoff	Achieved by reducing I_B to 0, Ideally, I_C will also equal 0.



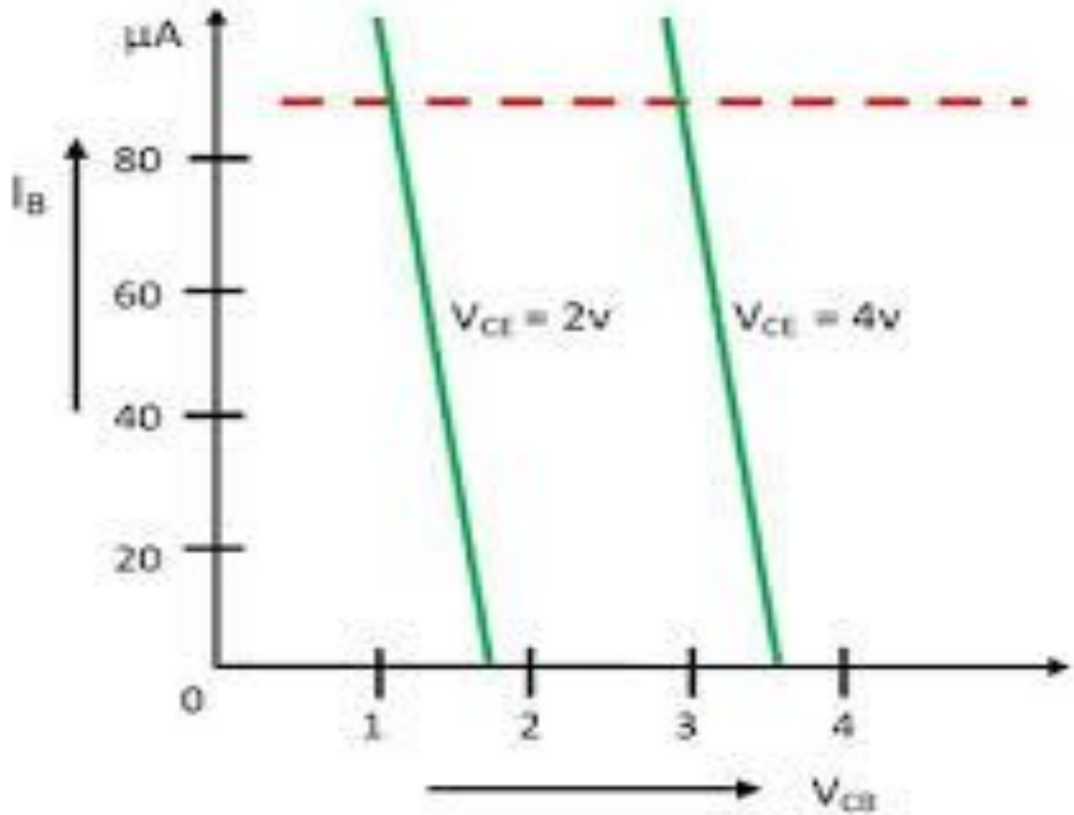
CC CONFIGURATIONS

❖ **Common-collector (CC) Mode**

- When the collector terminal of the transistor is common to both the input and the output terminals, the mode of operation is known as the common-collector (CC) mode or the ground–collector configuration.



Common-collector configuration



Input Characteristic Curve

The Common-Collector biasing circuit is basically equivalent to the common-emitter biased circuit except instead of looking at I_C as a function of V_{CE} and I_B we are looking at I_E.

Also, since $\alpha \sim 1$, and $\alpha = I_C/I_E$ that means $I_C \sim I_E$