Single phase transformer

Types of transformer

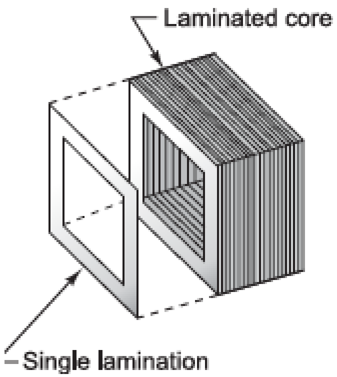


Fig. Hollow Core

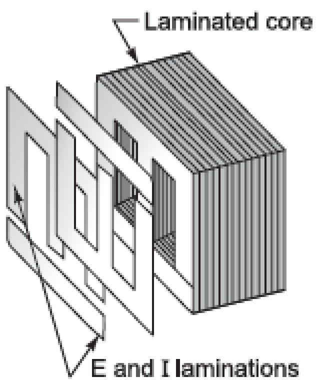
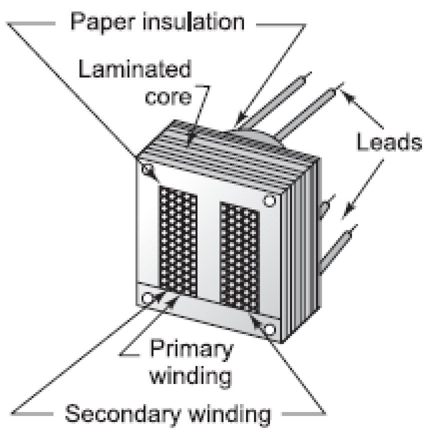


Fig. Shell Type Core

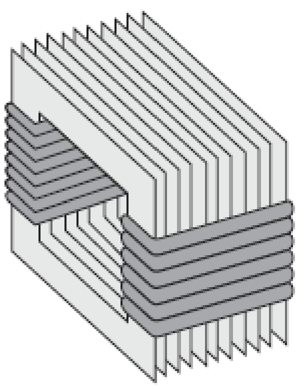
Core:-

- The composition of transformer core depends on voltage ,current and frequency
- The core material used are soft iron and steel
- Air core transformers are used when the voltage source has a high frequency(above 20KHz)
- Iron core transformers are used when the source frequency is a low (below 20KHz)
- In most transformers the core is constructed of laminated steel to provide a continuous magnetic path.
- The steel used for constructing the core is high grade silicon steel called soft steel where hysteresis loss is very low.
- Due to alternating flux certain currents are induced in the core, called as eddy current.
- These current cause considerable loss in the core, called eddy current loss.
- Silicon content in the steel increases it’s resistivity to eddy current loss.
- To reduce eddy current losses further, the core is laminated by a light coat of varnish or by an oxide layer on the surface.
- The two main shapes of cores are as shown in fig.

Transformer Winding



Shell Type Transformer



Core Type Transformer

- A transformer consists of two coils, called windings which are wrapped around a core.
- The winding in which electrical energy is fed is called the primary winding.
- The winding which is connected to the load is called the secondary winding.
- The primary and secondary winding are made up of an insulated copper conductor in the form of a round wire and strip.
- These windings are then placed around the limbs of the core.
- The winding are insulated from each other and the core using cylinders of insulating materials such as press board or Bakelite.

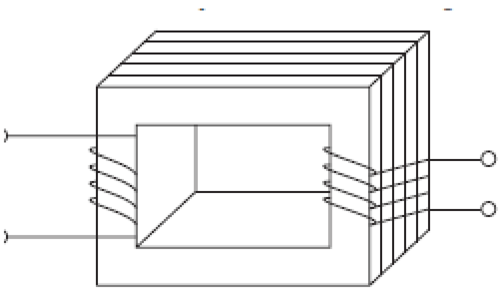
Ref. R.V. Singh Basic Electrical engineering

Comparison of core type and shell type transformer

Core type transformer	Shell type transformer
It consist of magnetic frame with two limbs	It consist of magnetic frame with three limbs
It has a single magnetic circuit	It has a two magnetic circuit
The windings encircles the core.	The core encircles most part of the windings.
It consists of cylindrical windings.	It consists of sandwich type windings.
It is easy to repaired	It is not easy to repair.
It provides better cooling since windings are uniformly distributed in two limbs	It does not provides effective cooling as the windings are surrounded by the core
It is preferred for low voltage transformers.	It is preferred for high voltage transformers.

Ref. R.V. Singh Basic Electrical engineering

Working principle



- When an alternating voltage V_1 is applied to a primary winding , an alternating current I_1 flows in it producing an alternating flux in the core.
- As per Faraday's laws of electromagnetic induction , an emf e_1 is induced in the primary winding.

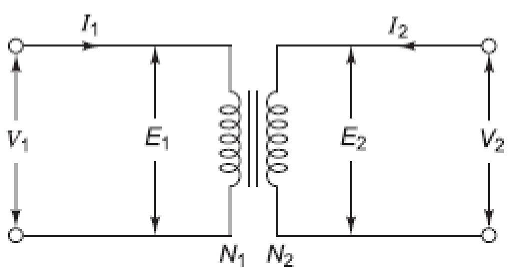
$$e_1 = -N_1 \frac{d\phi}{dt}$$

Where N_1 is the number of turns in the primary winding.

EMF induced in the secondary winding is

$$e_2 = -N_2 \frac{d\phi}{dt}$$

Where N_2 is the number of turns in the secondary winding.



If number of turns in the secondary winding N_2 is greater than the number of turns in the primary winding N1 , the transformer is called a step up transformer.

- If N_2 less than N1 , the transformer is called a step down transformer.

- Step up transformer is used to increase the voltage at the output and step down o decrease the voltage at the output

EMF Equation

$$\phi = \phi_m \sin \omega t$$

As per Faraday's laws of electromagnetic induction, an emf e_1 is induced in the primary winding.

$$e_1 = -N_1 \frac{d\phi}{dt}$$

$$= -N_1 \frac{d}{dt}(\phi_m \sin \omega t)$$

$$= -N_1 \phi_m \omega \cos \omega t$$

$$= N_1 \phi_m \omega \sin(\omega t - 90°)$$

$$= 2\pi f \phi_m N_1 \sin(\omega t - 90°)$$

Maximum value of induced emf $= 2\pi f \phi_m N_1$

Hence, rms value of induced emf in primary winding is given by

$$E_1 = \frac{E_{max}}{\sqrt{2}} = \frac{2\pi f \phi_m N_1}{\sqrt{2}} = 4.44 f \phi_m N_1$$

Similarly, rms value of induced emf in the secondary winding is given by

$$E_2 = 4.44 f \phi_m N_2$$

$$\frac{E_1}{N_1} = \frac{E_2}{N_2} = 4.44 f \phi_m$$

Thus, emf per turn is same in primary and secondary windings and an equal emf is induced in each turn of the primary and secondary windings.

Transformation Ratio(K)

$$E_1 = 4.44 f \phi_m N_1$$

$$E_2 = 4.44 f \phi_m N_2$$

$$\frac{E_2}{E_1} = \frac{N_2}{N_1} = K$$

where K is called the *transformation ratio*.

Neglecting small primary and secondary voltage drops,

$$V_1 \approx E_1 \qquad V_2 \approx E_2$$

$$\frac{E_2}{E_1} = \frac{V_2}{V_1} = \frac{N_2}{N_1} = K$$

In a transformer, losses are negligible. Hence, input and output can be approximately equated.

$$V_1 I_1 = V_2 I_2$$

$$\frac{I_1}{I_2} = \frac{V_2}{V_1} = K$$

For step-up transformers,

$$N_2 > N_1 \qquad K > 1$$

For step-down transformers,

$$N_2 < N_1 \qquad K < 1$$

Ref. R.V. Singh Basic Electrical engineering

Losses in Transformer

- **Types of losses in transformer**
- 1) Iron or core loss
- 2) Copper loss
- **Iron loss:-**
- This loss is due to the reversal of flux in the core.
- It is subdivided into two losses
- i) Hysteresis loss
- ii)Eddy current loss

- **Hysteresis loss:**
- This loss occurs due to setting of an alternating flux in the core.
- It depends on the following factors

i)Area of the hysteresis loop of magnetic material which again depends upon the flux density

ii) Volume of the core

iii) Frequency of the magnetic flux reversal

- Eddy current loss:

- This loss occur due to the flow of eddy currents in the core caused by induced emf in the core

It depends on following factors

i) Thickness of laminated core .

ii) Frequency of the magnetic flux reversal

iii) Maximum value of flux density in the core

Iv) volume of the core

v) Quality of magnetic material used

- Eddy current losses are reduced by decreasing the thickness of laminated and by adding silicon to steel

- **Copper loss:-**
- This loss due to the resistances of primary and secondary windings

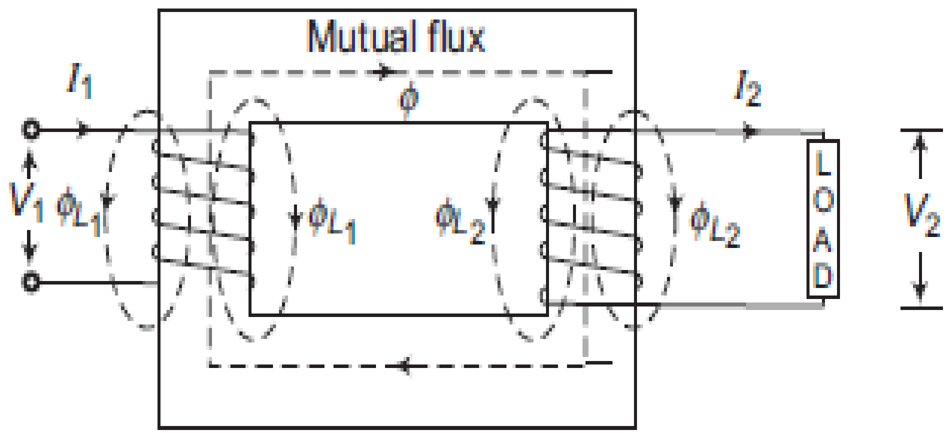
$$W_{Cu}= I_1^2R_1+I^2_2R_2$$

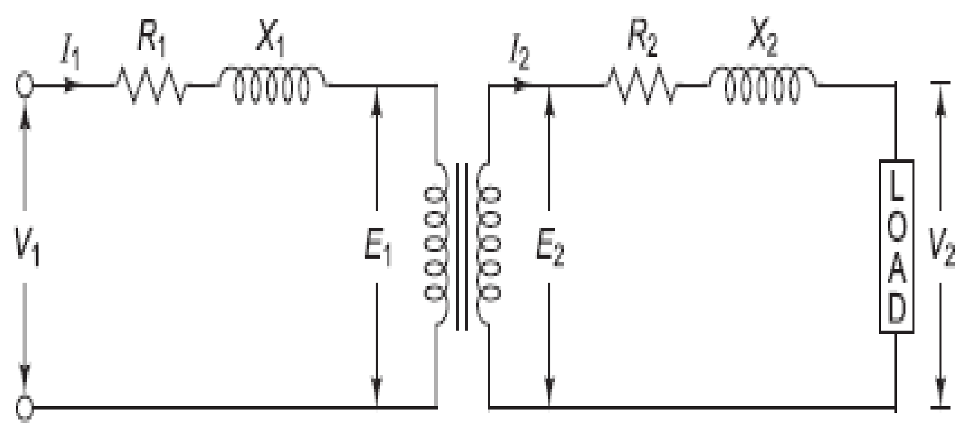
where R_1= primary winding resistance

R_2= secondary winding resistance

Copper loss depends upon the load on the transformer and is proportional to square of load current of kVA rating of the transformer.

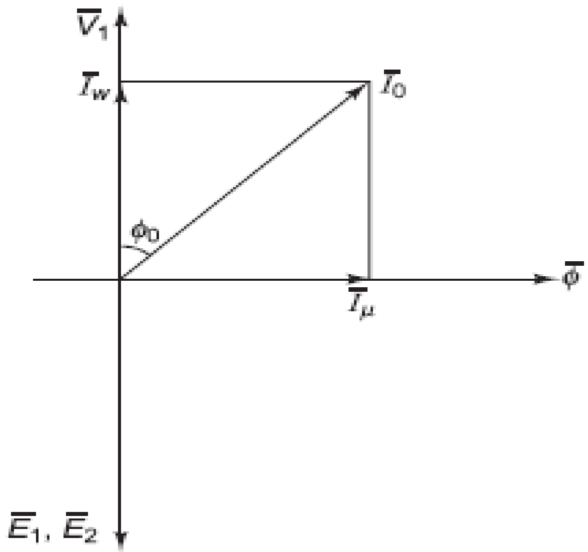
Ideal and practical transformer





Ref. R.V. Singh Basic Electrical engineering

Phasor diagram of transformer on no load



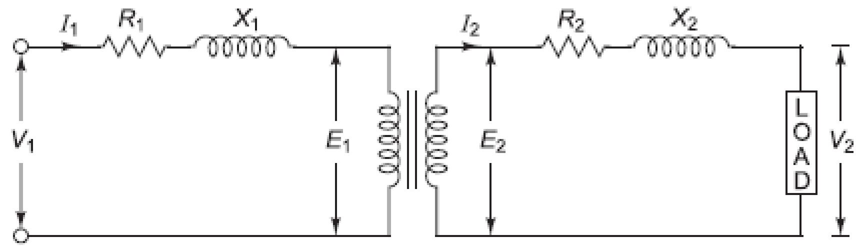
$$I_\mu = I_0 \sin \phi_0$$

$$I_w = I_0 \cos \phi_0$$

$$\overline{I}_0 = \overline{I}_\mu + \overline{I}_w$$

$$I_0 = \sqrt{I_\mu^2 + I_w^2}$$

Phasor diagram of transformer on load



$$\overline{V_1} = \overline{I_1 R_1} + \overline{I_1 X_1} + (-\overline{E_1})$$

$$\overline{E_2} = \overline{I_2 R_2} + \overline{I_2 X_2} + \overline{V_2}$$

where $$\overline{I_1} = \overline{I_0} + \overline{I_2'}$$

Steps for drawing phasor diagram

1. First draw $\overline{V_2}$ and then $\overline{I_2}$. The phase angle between $\overline{I_2}$ and $\overline{V_2}$ will depend on the type of load.
2. To $\overline{V_2}$, add the resistive drop $\overline{I_2 R_2}$, parallel to $\overline{I_2}$ and the inductive drop $\overline{I_2 X_2}$, leading $\overline{I_2}$ by 90° such that

$$\overline{E_2} = \overline{V_2} + \overline{I_2 R_2} + \overline{I_2 X_2}$$

3. Draw $\overline{E_1}$ on the same side such that $E_1 = \dfrac{E_2}{K}$
4. Draw $-\overline{E_1}$ equal and opposite to $\overline{E_1}$.
5. For drawing $\overline{I_1}$, first draw $\overline{I_0}$ and $\overline{I_2'}$ such that

$$I_2' = K\, I_2$$

6. Add $\overline{I_0}$ and $\overline{I_2'}$ using the parallelogram law of vector addition.

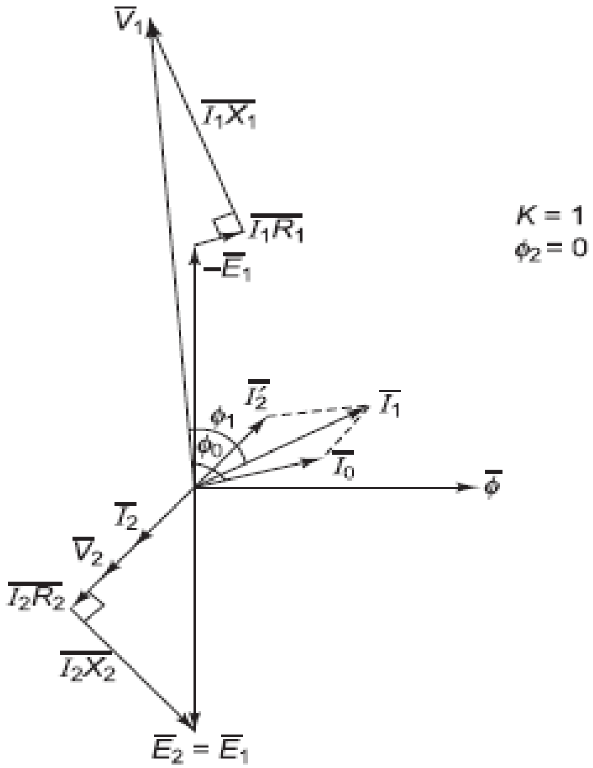
$$\overline{I_1} = \overline{I_0} + \overline{I_2'}$$

7. To $-\overline{E_1}$, add the resistive drop $\overline{I_1 R_1}$, parallel to $\overline{I_1}$ and the inductive drop $\overline{I_1 X_1}$, leading $\overline{I_1}$ by 90° such that

$$\overline{V_1} = -\overline{E_1} + \overline{I_1 R_1} + \overline{I_1 X_1}$$

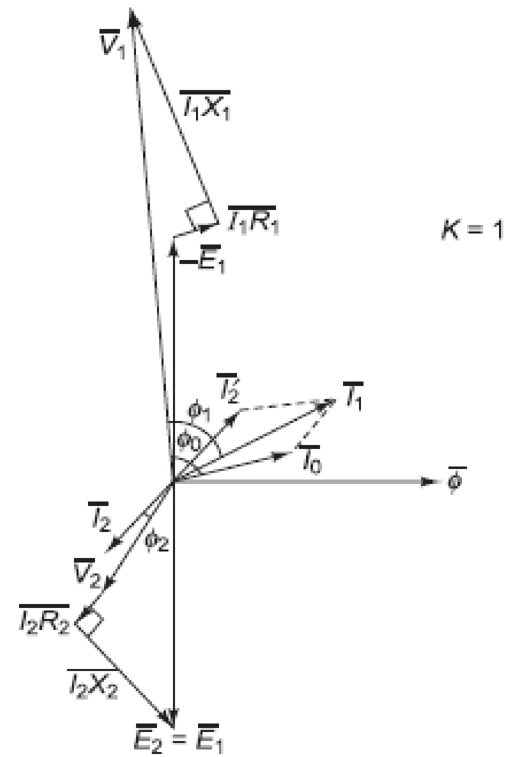
8. Draw flux ϕ such that ϕ leads $\overline{E_1}$ and $\overline{E_2}$ by 90°.

Case (i) Resistive load (unity power factor)



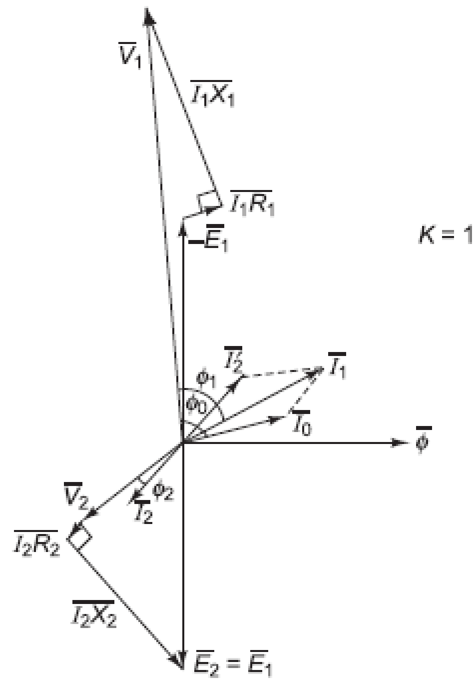
Phasor diagram for resistive load

Case (ii) Inductive load (lagging power factor)



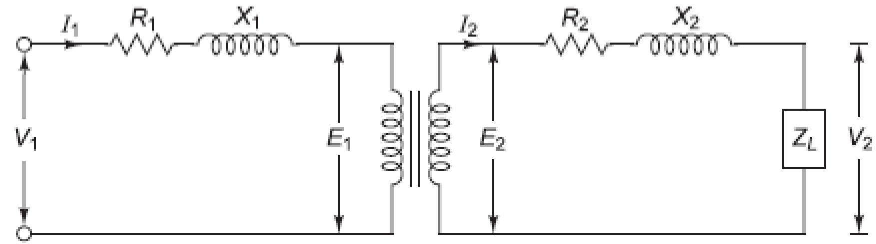
Phasor diagram for inductive load

Case (iii) Capacitive load (leading power factor)

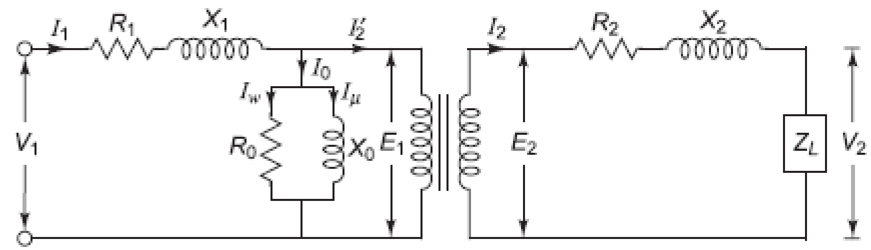


Phasor diagram for capacitive load

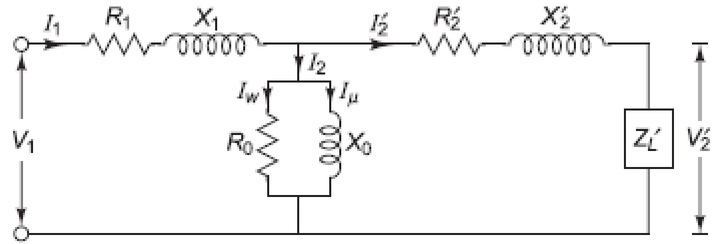
Equivalent circuit



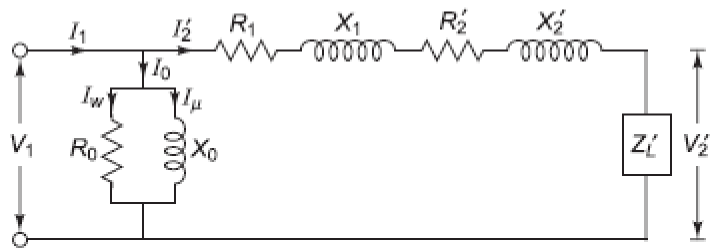
Practical transformer



Practical transformer showing no-load current I_o and its component

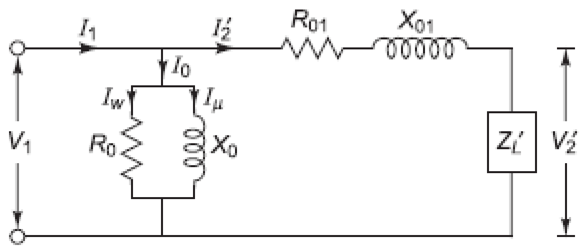


Modified circuit for primary winding

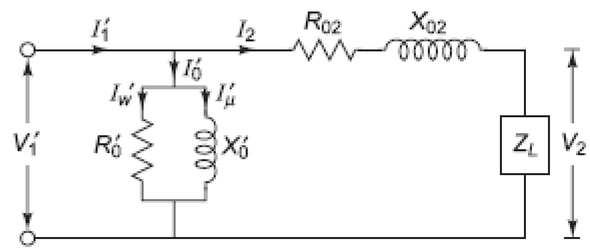


Modified circuit for primary winding

Ref. R.V. Singh Basic Electrical engineering



Equivalent circuit referred to primary winding



Equivalent circuit referred to secondary winding

Voltage Regulation

- When a transformer is loaded, the secondary terminal voltage decreases due to a drop across secondary winding resistance and leakage reactance. This change in secondary terminal voltage from no load to full load conditions, expressed as a fraction of the no-load secondary voltage is called regulation of the transformer.

$$\text{Regulation} = \frac{\begin{pmatrix}\text{Secondary terminal} \\ \text{voltage on no load}\end{pmatrix} - \begin{pmatrix}\text{Secondary terminal voltage} \\ \text{on full-load condition}\end{pmatrix}}{\text{Secondary terminal voltage on no load}}$$

$$= \frac{E_2 - V_2}{E_2}$$

$$\text{Percentage regulation} = \frac{E_2 - V_2}{E_2} \times 100$$

Efficiency of Transformer

Efficiency is defined as the ratio of output power to input power.

Efficiency $$\eta = \frac{\text{Output}}{\text{Input}} = \frac{\text{Output}}{\text{Output} + \text{Losses}} = \frac{\text{Output}}{\text{Output} + \text{Copper loss} + \text{Iron loss}}$$

Also, $$\eta = \frac{\text{Input} - \text{Losses}}{\text{Input}} = \frac{\text{Input} - \text{Copper loss} - \text{Iron loss}}{\text{Input}}$$

Condition for Maximum Efficiency We know that,

$$\eta = \frac{\text{Output}}{\text{Output} + \text{Losses}}$$

Considering secondary side of the transformer,

$$\eta = \frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + W_i + I_2^2 R_{02}}$$

Differentiating both the sides w.r.t. I_2,

$$\frac{d\eta}{dI_2} = \frac{(V_2 I_2 \cos\phi_2 + W_i + I_2^2 R_{02}) V_2 \cos\phi_2 - V_2 I_2 \cos\phi_2 (V_2 \cos\phi_2 + 2 I_2 R_{02})}{(V_2 I_2 \cos\phi_2 + W_i + I_2^2 R_{02})^2}$$

For maximum efficiency, $\frac{d\eta}{dI_2} = 0$

$$(V_2 I_2 \cos\phi_2 + W_i + I_2^2 R_{02}) V_2 \cos\phi_2 = V_2 I_2 \cos\phi_2 (V_2 \cos\phi_2 + 2 I_2 R_{02})$$

$$V_2 I_2 \cos\phi_2 + W_i + I_2^2 R_{02} = V_2 I_2 \cos\phi_2 + 2 I_2^2 R_{02}$$

$$W_i = I_2^2 R_{02}$$

Similarly on primary side,

$$W_i = I_1^2 R_{01}$$

Thus when copper loss = iron loss, the efficiency of the transformer is maximum.

5.1 Diode and Rectifiers EEEE-MBZ/KJSCE

Contents

- Introduction to Semiconductors
- PN Junction
- PN Junction Diode
- IV characteristics of PN Junction Diode
- Applications of Diode

  → Half-wave rectifier

  → Full wave Rectifier with center-tap transformer

  → Full wave Bridge Rectifier

Introduction to Semiconductor Materials

- **Two types of semiconducting materials : silicon and germanium**
  – both have four valance electrons

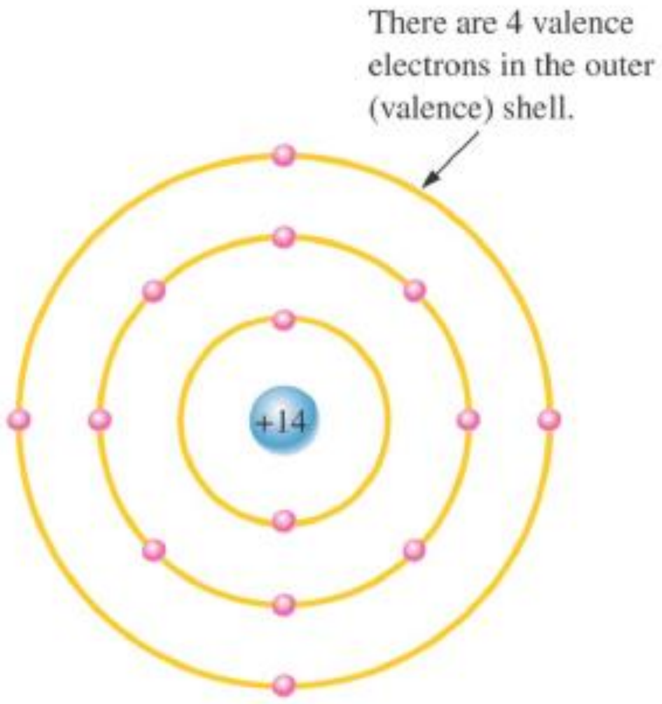
- **When silicon and germanium atoms combine into molecules to form a solid material, they arrange themselves in a fixed pattern called a crystal**

– atoms within the crystal structure are held together by covalent bonds (atoms share valence electrons)

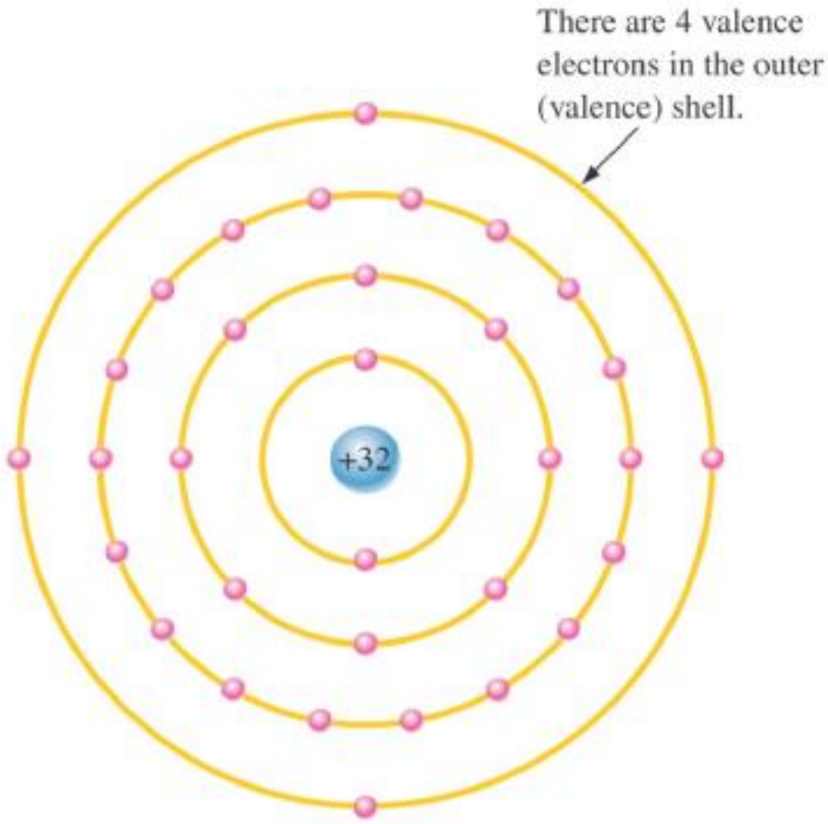
- **An intrinsic crystal is one that has no impurities**

Introduction to Semiconductor Materials..

Diagrams of the silicon and germanium atoms



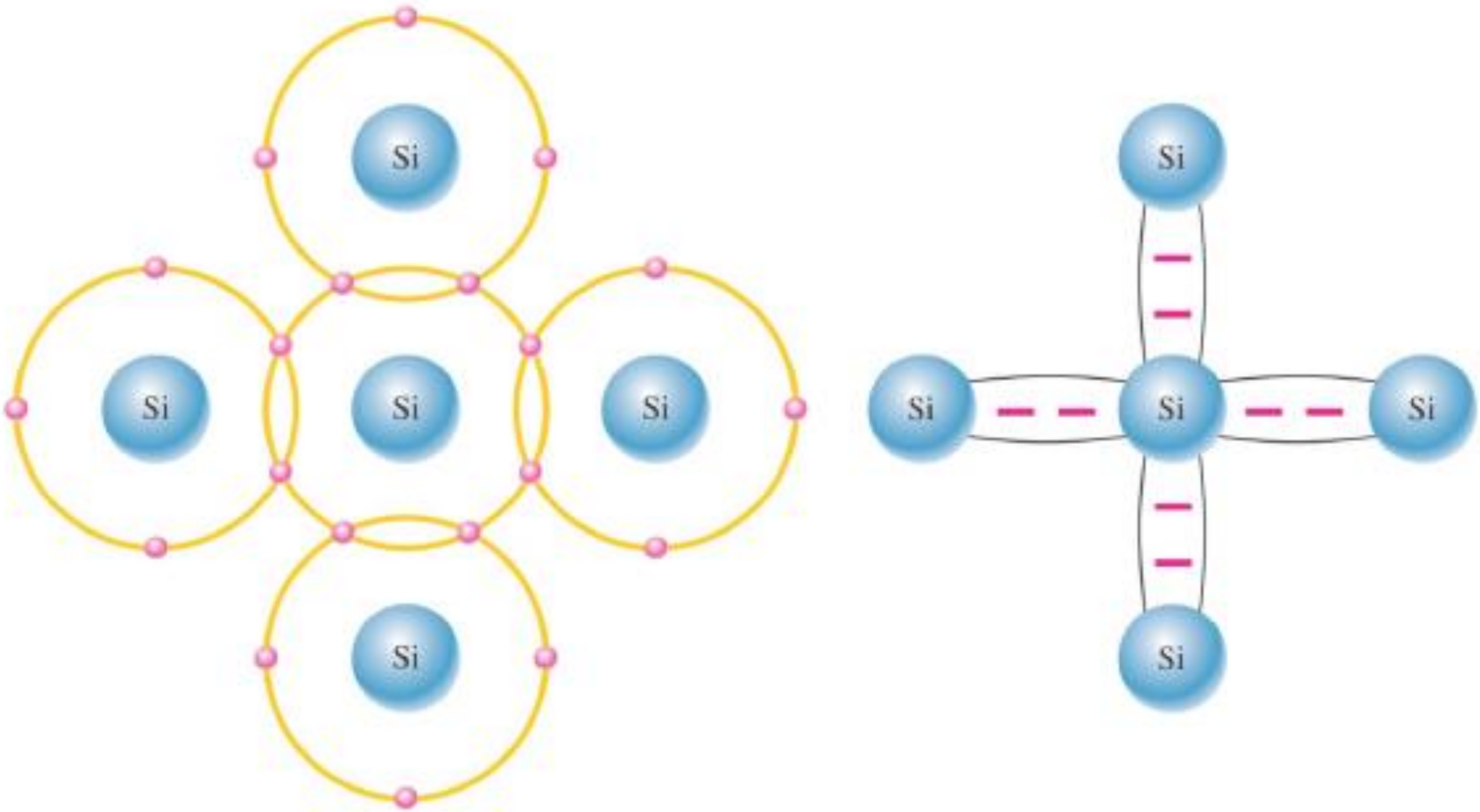
(a) Silicon atom



(b) Germanium atom

Introduction to Semiconductor Materials..

Covalent bonds in a silicon crystal. The actual crystal is 3-dimensional.



(a) The center atom shares an electron with each of the four surrounding atoms creating a covalent bond with each. The surrounding atoms are in turn bonded to other atoms, and so on.

(b) Bonding diagram. The red negative signs represent the shared valence electrons.

Introduction to Semiconductor Materials..

Modified Semiconductor Materials

- **Doping is the process of adding impurities to intrinsic semiconducting materials to increase and control conductivity within the material.**

→ ***n*-type material is formed by adding pentavalent (5 valence electrons) impurity atoms** (Pentavalent impurities : Phosphorous , Arsenic, Antimony)

-- electrons are called majority carriers in *n*-type material

-- holes are called minority carriers in *n*-type material

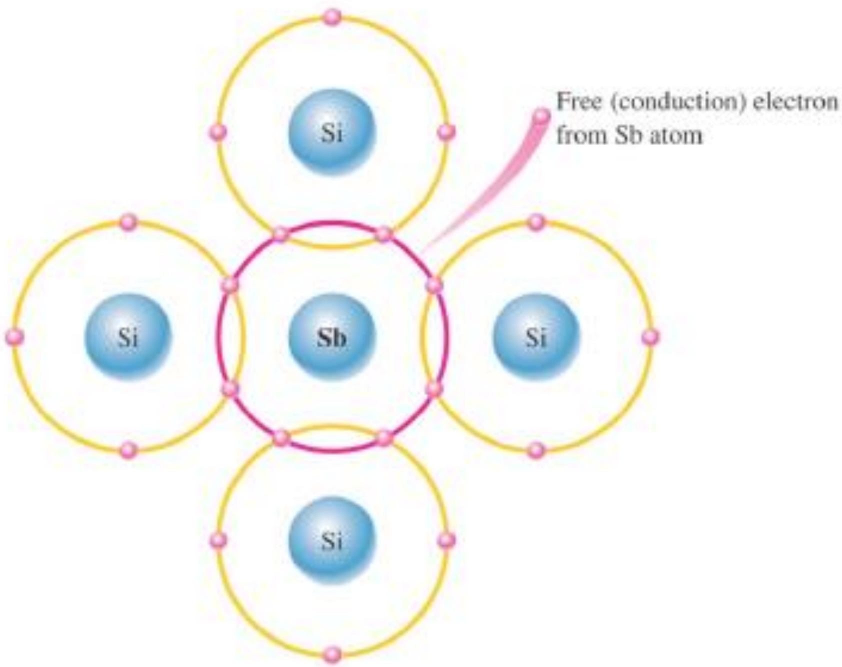
→ ***p*-type material is formed by adding trivalent (3 valence electrons) impurity atoms (**Tri-valent impurities : Boron (B), Gallium (G), Indium(In), Aluminium(Al))

-- holes are called majority carriers in *p*-type material

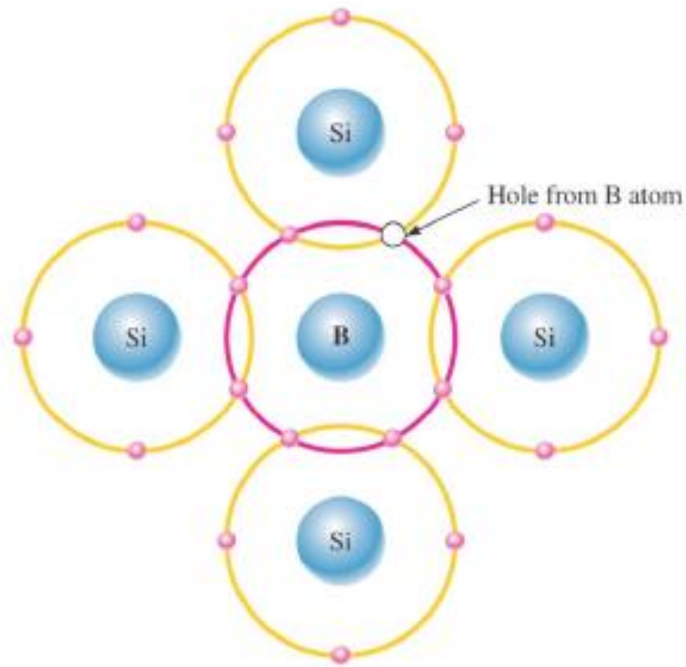
-- electrons are called minority carriers in *p*-type material

Introduction to Semiconductor Materials..

Modified Semiconductor Materials



(a) Pentavalent impurity atom in a silicon crystal. An antimony (Sb) impurity atom is shown in the center. The extra electron from the Sb atom becomes a free electron.



(b) Trivalent impurity atom in a silicon crystal. A boron (B) impurity atom is shown in the center.

P-N Junction

- A **p-n junction** is formed by joining p-type and n-type semiconductors together in very close contact.

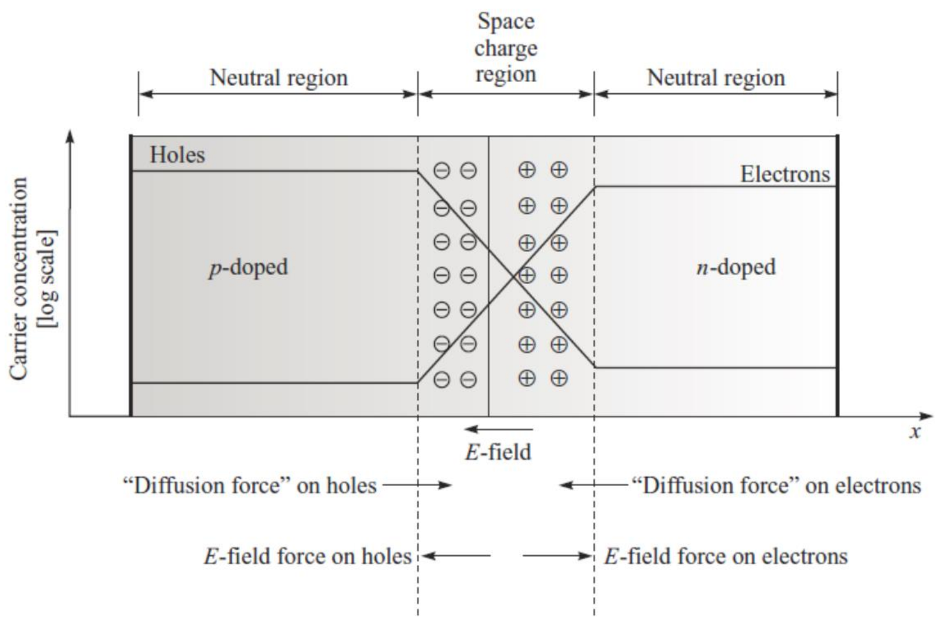
- The term junction refers to the boundary interface where the two regions of the semiconductor meet.

- p-n junctions are created in a single crystal of semiconductor by doping, for example, by ion implantation, diffusion of dopants, or by epitaxy (growing a layer of crystal doped with one type of dopant on top of a layer of crystal doped with another type of dopant)

- p-n junctions are elementary “building blocks” of almost all semiconductor electronic devices such as diodes, transistors, solar cells, LEDs, and integrated circuits; they are the active sites where the electronic action of the device takes place.

p-n junction in thermal equilibrium: with zero bias voltage applied

- The regions nearby the p-n interfaces lose their neutrality and become charged, forming the space charge region or depletion layer

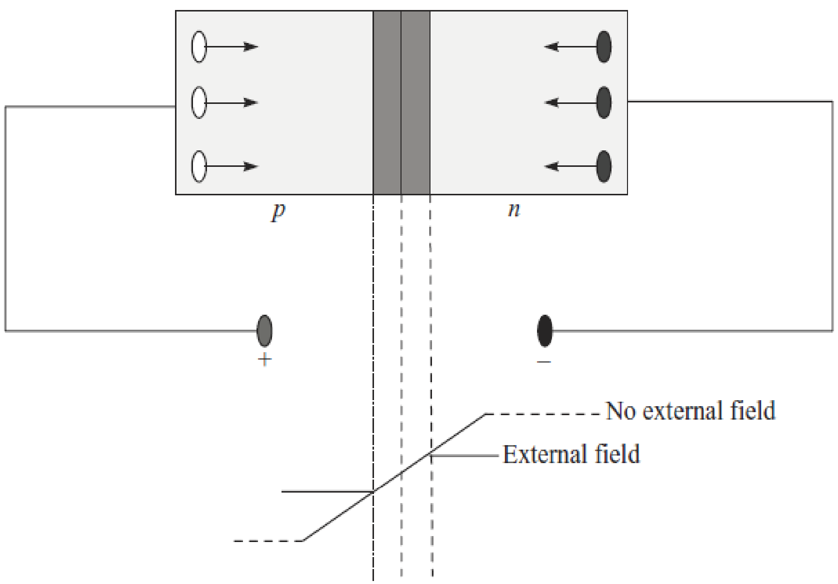


- The electric field created by the space charge region opposes the diffusion process for both electrons and holes.
- There are two concurrent phenomena: the diffusion process that tends to generate more space charge, and the electric field generated by the space charge that tends to counteract the diffusion.

- The space charge region is a zone with a net charge provided by the fixed ions (donors or acceptors) that have been left uncovered by majority carrier diffusion.
- When equilibrium is reached, the charge density is approximated by the displayed step function.
- The region is completely depleted of majority carriers (leaving a charge density equal to the net doping level), and the edge between the space charge region and the neutral region is quite sharp.
- The space charge region has the same charge on both sides of the p-n interfaces, thus it extends farther on the less doped side.

Forward biasing of p-n junction

- When external voltage applied to the junction is in such a direction that it cancels the potential barrier, thus permitting current flow is called forward biasing.
- To apply forward bias, connect +ve terminal of the battery to *p*-type and –ve terminal to *n*-type .
- The applied forward potential establishes the electric field which acts against the field due to potential barrier. Therefore, the resultant field is weakened and the barrier height is reduced at the junction.
- Since the potential barrier voltage is very small, a small forward voltage is sufficient to completely eliminate the barrier.



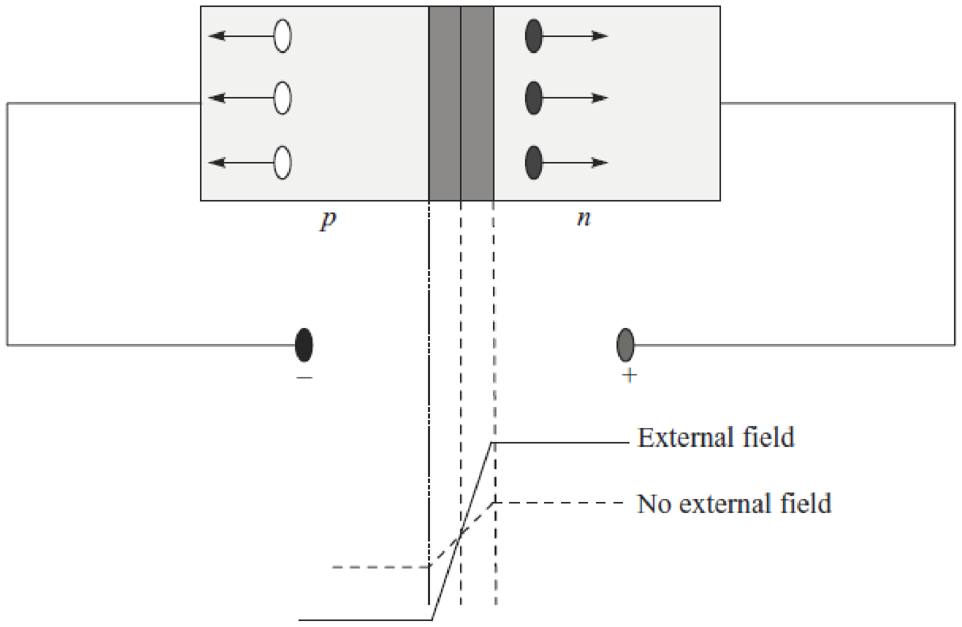
- Once the potential barrier is eliminated by the forward voltage, junction resistance becomes almost zero and a low resistance path is established for the entire circuit. Therefore, current flows in the circuit. This is called *forward current*.

Reverse biasing of *p-n* junction

- When the external voltage applied to the junction is in such a direction the potential barrier is increased it is called reverse biasing.

- To apply reverse bias, connect –ve terminal of the battery to *p*-type and +ve terminal to *n*-type .

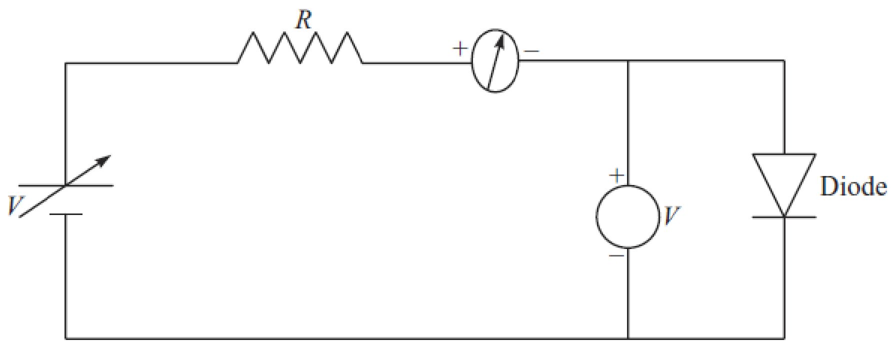
- The applied reverse voltage establishes an electric field which acts in the same direction as the field due to potential barrier. Therefore, the resultant field at the junction is strengthened and the barrier height is increased.

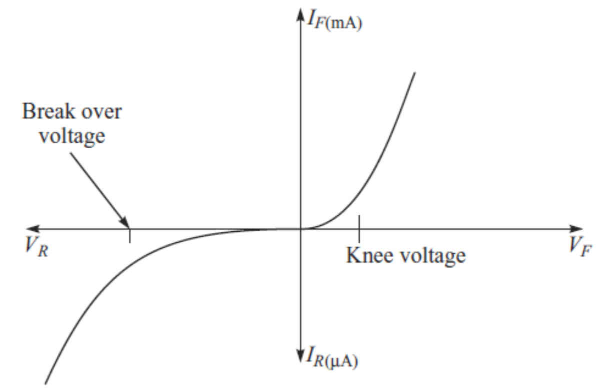


- The increased potential barrier prevents the flow of charge carriers across the junction. Thus, a high resistance path is established for the entire circuit and hence current does not flow.

VOLT-AMPERE (*V-I*) CHARACTERISTICS OF *P-N* JUNCTI ON DIODE

- The *V-I* characteristics of a semiconductor diode can be obtained with the help of the circuit .





- 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 *knee voltage* or *cut-in voltage*.
- The reverse characteristics can be obtained by reverse biasing the diode. It can be noted that at a particular reverse voltage, the reverse current increases rapidly. This voltage is called *breakdown voltage*.

DIODE CURRENT EQUATION

I-V Characteristics of a Real Diode

$$I_D = I_s\left(e^{V_D/nV_T} - 1\right)$$

- I_D is the total diode current
- I_s reverse saturation current
- V_D applied voltage across the diode
- n an ideality factor, value between 1&2.
- V_T thermal voltage:

$$V_T = \frac{kT}{q}$$

$k = 1.38 \times 10^{-23}$ J/K
$q = 1.6\times10^{-19}$ C

DIODE CURRENT EQUATION

With Zero Voltage:

$$V_D = 0, \quad \because I_D = I_s\left(e^{V_D/nV_T} - 1\right) = I_s\left(e^0 - 1\right) = 0$$

Forward-Biased:

-Under forward-biased condition, $V_D > 0$.

-When $V_D >> nV_T$, then

$$e^{\frac{V_D}{nV_T}} >> 1 \quad \text{and} \quad I_D \cong I_S e^{\frac{V_D}{nV_T}}$$

Reversed-Biased:

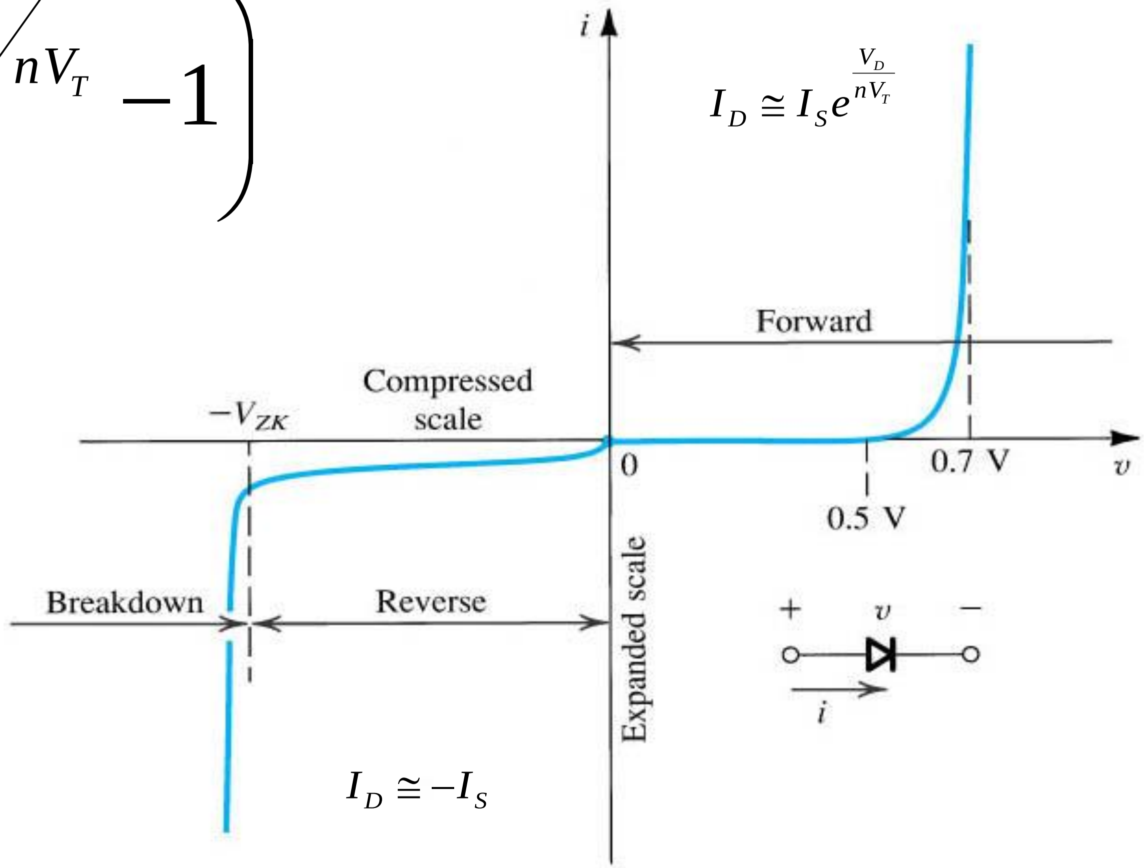
-Under reverse-biased condition, $V_D < 0$.

-When $V_D << nV_T$, then

$$e^{\frac{V_D}{nV_T}} << 1 \quad \text{and} \quad I_D \cong -I_S$$

I-V Characteristics

$$I_D = I_s\left(e^{V_D/nV_T} - 1\right)$$



When $V_D < V_{ZK}$, the diode enters the breakdown region, the reverse current increases sharply. V_{ZK} is known as the zener knee voltage.

Basic Definitions

- ***Knee Voltage or Cut-in Voltage***
  It is the forward voltage at which the diode starts conducting.

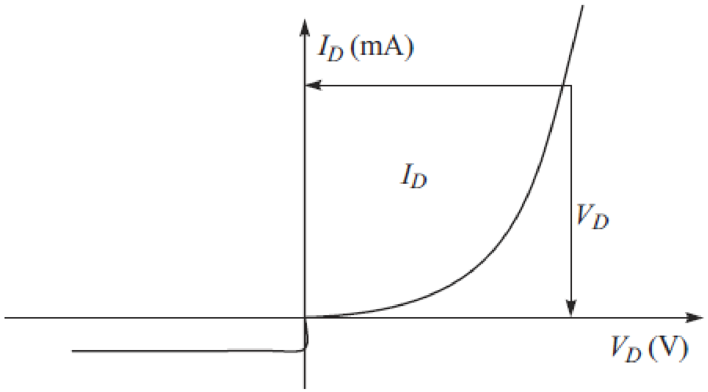
- **Breakdown Voltage**
  It is the reverse voltage at which the diode (p-n junction) breaks down with a sudden rise in reverse current.
- **Peak-inverse Voltage (PIV)**
  It is the maximum reverse voltage that can be applied to a p-n junction without causing damage to the junction. If the reverse voltage across the junction exceeds its peak inverse voltage, then the junction exceeds its peak-inverse voltage, and the junction gets destroyed because of excessive heat. In rectification, care should be taken that reverse voltage across the diode during –ve half cycle of ac doesn't exceed the peak-inverse voltage of the diode.
- **Maximum Forward Current**
  It is the maximum instantaneous forward current that a p-n junction can conduct without damaging the junction. If the forward current is more than the specified rating then the junction gets destroyed due to overheating.
- **Maximum Power Rating**
  It is the maximum power that can be dissipated at the junction without damaging it. The power dissipated across the junction is equal to the product of junction current and the voltage across the junction.

STATIC AND DYNAMIC RESISTANCE OF A DIODE

$$R_F = \frac{V_D}{I_D}$$

DC or Static Resistance

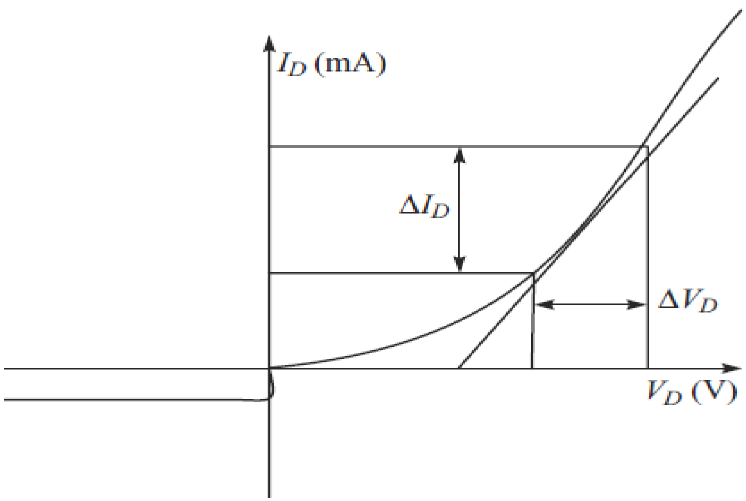
When diode is forward biased, it offers a definite resistance in the circuit. This resistance is known as dc resistance or static resistance (*RF*). It is simply the ratio of the dc voltage (*VD*) across the diode to the dc current (*ID*) flowing through it.



$$r_f = \frac{\Delta V_D}{\Delta I_D}$$

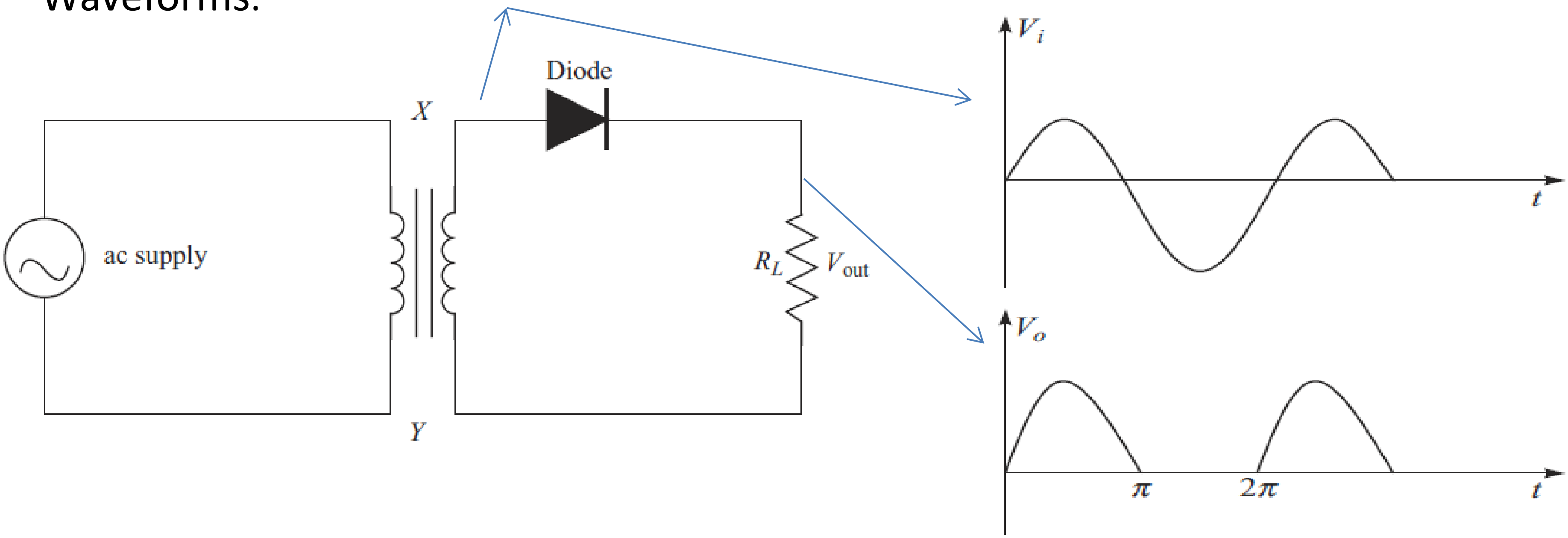
AC or Dynamic Resistance

The ac or dynamic resistance of a diode, at a particular dc voltage, is equal to the reciprocal of the slope of the characteristics at that point



HALF-WAVE RECTIFIER

The circuit diagram of a half-wave rectifier is shown along with the I/P and O/P Waveforms.



- The transformer is employed in order to step-down the supply voltage.
- The diode is used to rectify the ac signal while the pulsating dc is taken across the load resistor RL. During the +ve half-cycle, the end X of the secondary is +ve and end Y is –ve. Thus, forward biasing the diode.
- As the diode is forward biased, the current flows through the load RL and a voltage is developed across it.
- During the –ve half-cycle the end Y is +ve and end X is –ve thus, reverse biasing the diode. As the diode is reverse biased there is no flow of current through RL thereby the output voltage is zero.

Efficiency of a Half wave Rectifier

$$\text{Rectifier efficiency } \eta = \frac{\text{dc power output}}{\text{input ac power}}$$

Let $V = V_m \sin\theta$ be the voltage across the secondary winding

$$r_f = \text{diode resistance}$$
$$R_L = \text{load resistance}$$

dc Power

$$I_{av} = I_{dc} = \frac{1}{2\pi}\int_0^{\pi} i \cdot d\theta = \frac{1}{2\pi}\int_0^{\pi} \frac{V_m \sin\theta}{r_L + R_L} d\theta$$

$$= \frac{V_m}{2\pi(r_f + R_L)}\int_0^{\pi} \sin\theta \, d\theta$$

$$= \frac{2V_m}{2\pi(r_f + R_L)} = \frac{I_m}{\pi}$$

$$P_{dc} = I_{dc}^2 \times R_L$$

$$= \left(\frac{I_m}{\pi}\right)^2 \times R_L$$

ac Power Input

$$P_{ac} = I_{rms}^2 (r_f + R_L)$$

$$I_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} i^2 d\theta}$$

$$I_{rms}^2 = \frac{1}{2\pi}\int_0^{2\pi} i^2 d\theta$$

But $i = I_m \sin\theta$

$$I_{rms}^2 = \frac{1}{2\pi}\int_0^{\pi} (I_m \sin\theta)^2 d\theta$$

$$I_{rms}^2 = \frac{I_m^2}{4}$$

$$I_{rms} = \frac{I_m}{2}$$

$$P_{ac} = \left(\frac{I_m}{2}\right)^2 (r_f + R_L)$$

$$\eta = \frac{P_{dc}}{P_{ac}} = \frac{\left(\frac{I_m}{\pi}\right)^2}{\left(\frac{I_m}{2}\right)^2} \times \frac{R_L}{(r_f + R_L)}$$

$$\eta = \frac{0.406}{1 + \frac{r_f}{R_L}}$$

The efficiency is maximum if *rf* is negligible as compared to *RL*.
Therefore, maximum rectifier efficiency = 40.6%

Ripple Factor

- The pulsating output of a rectifier consists of dc component and ac component (also known as ripple). The ac component is undesirable and accounts for the pulsations in the rectifier output. The effectiveness of a rectifier depends on the magnitude of ac component in the output : the smaller this component, the more effective is the rectifier. " The ratio of rms value of ac component to the dc component in the rectifier output is known as ripple factor".

$$r = \frac{I_{\mathrm{ac}}}{I_{\mathrm{dc}}}$$

Ripple Factor for Half-wave Rectification

$$I_{\mathrm{rms}} = \sqrt{I_{\mathrm{ac}}^2 + I_{\mathrm{dc}}^2} \quad \text{OR} \quad \boldsymbol{I_{ac} = \sqrt{I^2{}_{rms} - I^2{}_{dc}}}$$

$$r = \sqrt{\left(\frac{I_{\mathrm{rms}}}{I_{\mathrm{dc}}}\right)^2 - 1}$$

Divide both RHS and LHS by I_{dc}, we get

we have $I_{\mathrm{rms}} = \dfrac{I_m}{2}$

$$\frac{I_{\mathrm{ac}}}{I_{\mathrm{dc}}} = \frac{1}{I_{\mathrm{dc}}}\sqrt{I_{\mathrm{rms}}^2 - I_{\mathrm{dc}}^2}$$

$$I_{\mathrm{dc}} = \frac{I_m}{\pi}$$

ripple factor $r = 1.21$

It is clear that ac component exceeds dc component in the output of a half-wave rectifier.

Transformer utilization factor

Transformer utilization factor is a quantitative indication of the utilization of VA Rating of Transformer. The more the value of TUF, the more will be the utilization. In other words, the VA rating of required transformer will be less if TUF is more and vice versa.

Transformer Utilization Factor (TUF)

$$= \frac{\text{DC Power Output}}{\text{Effective VA Rating of Transformer}}$$

$$= \frac{\text{Pdc}}{\text{Effective VA Rating of Transformer}}$$

where Pdc is the dc power output

Effective VA Rating of Transformer is the average value of transformer primary and secondary VAs.

DC Power Output, Pdc = Average Current x Average Voltage

Transformer Utilization Factor (TUF) of Half Wave Rectifier

- **DC Power Output, Pdc = Average Current x Average Voltage**

$$P_{dc} = \frac{V_m}{\pi} X \frac{I_m}{\pi} \quad \text{......................(1)}$$

- **VA rating of Transformer**
- The voltage of source is sinusoidal, therefore its rms value will be equal to (Vm/√2).
- The rms value of the source current will be equal to the rms value of the load current. As the rms value of load current for half wave rectifier is equal to (Im/2), therefore the rms value of source current will also be equal to (Im/2).

$$VA_{\ rating} = \frac{V_m}{\sqrt{2}} X \frac{I_m}{2} \quad \text{......................(2)}$$

From equation (1) and (2)

$$TUF = \frac{2\sqrt{2}}{\pi^2} = 0.285$$

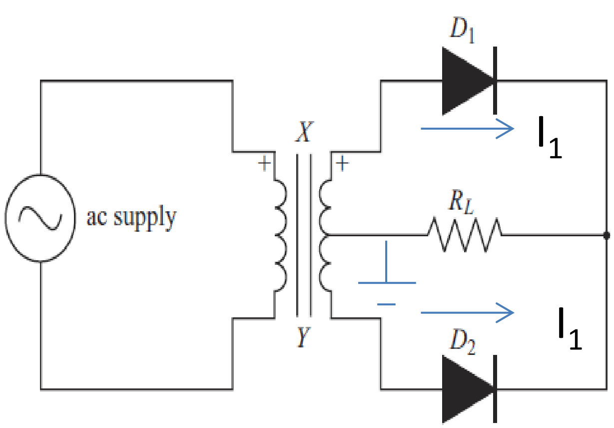
FULL-WAVE RECTIFIER

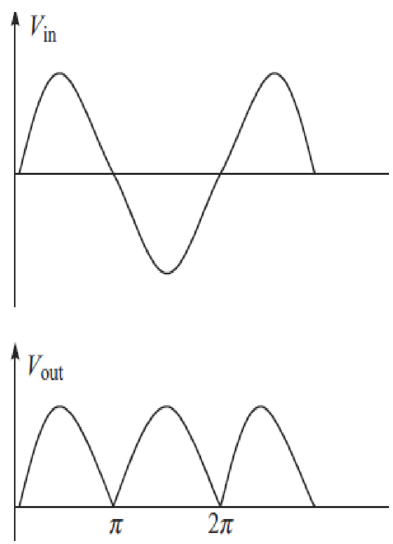
Full-wave rectifiers are of two types:

1. Centre tapped full-wave rectifier 2. Bridge rectifier

Centre Tapped Full-wave Rectifier

- It employs two diodes and a centre tap transformer. The ac signal to be rectified is applied to the primary of the transformer and the dc output is taken across the load, *RL*.
- During the +ve half-cycle end *X* is +ve and end *Y* is –ve. This makes diode *D*1 forward biased and thus a current *i*1 flows through it and load resistor *RL*. Diode *D*2 is reverse biased and the current *i*2 is zero.
- During the –ve half-cycle end *Y* is +ve and end *X* is –ve. Now diode *D*2 is forward biased and thus a current *i*2 flows through it and load resistor *RL*. Diode *D*1 is reversed and the current *i*1 = 0.



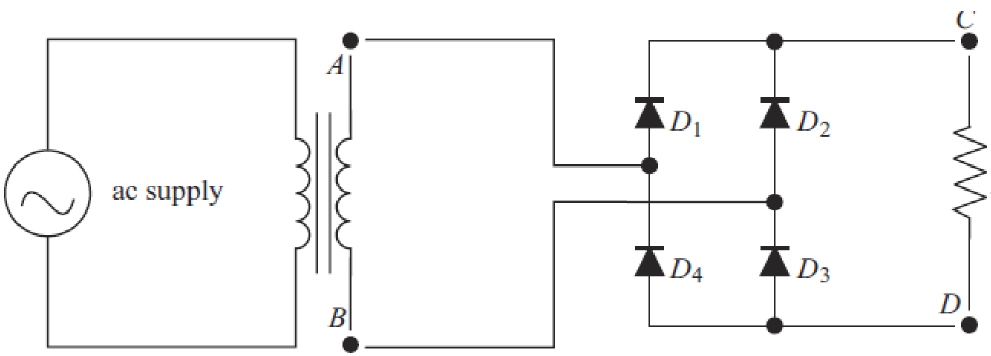


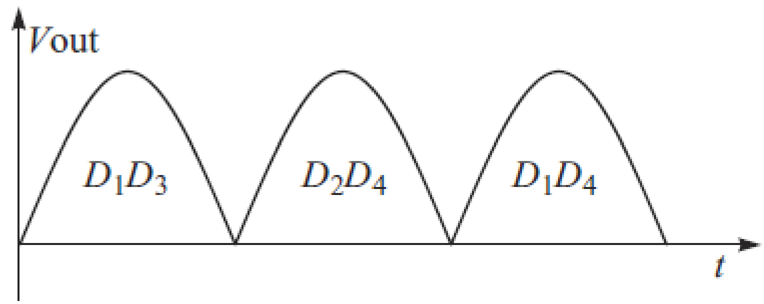
Disadvantages

- Since each diode uses only one-half of the transformer secondary voltage the dc output is comparatively small.
- It is difficult to locate the centre-tap on secondary winding of the transformer.
- The diodes used must have high peak-inverse voltage

Full-wave Bridge Rectifier

- It uses four diodes and one transformer.
- During the +ve half-cycle, end *A* is +ve and end *B* is –ve thus diodes *D*1 and *D*3 are forward bias while diodes *D*2 and *D*4 are reverse biased thus a current flows through diode *D*1, load *RL* (*C* to *D*) and diode *D*3.
- During the –ve half-cycle, end *B* is +ve and end *A* is –ve thus diodes *D*2 and *D*4 are forward biased while the diodes *D*1 and *D*3 are reverse biased. Now the flow of current is through diode *D*4 load *RL* (*D* to *C*) and diode *D*2. Thus, the waveform is same as in the case of centre-tapped full-wave rectifier.





Advantages

- The need for centre-tapped transformer is eliminated.
- The output is twice when compared to centre-tapped full-wave rectifier, for the same secondary voltage.
- The peak inverse voltage is one-half (1/2) compared to centre-tapped full-wave rectifier.
- Can be used where large amount of power is required.

Disadvantages: • It requires four diodes. • The use of two extra diodes causes an additional voltage drop thereby reducing the output voltage.

Efficiency of Full-wave Rectifier

$V = V_m \sin\theta$ be the voltage across the secondary winding

$I = I_m \sin\theta$ be the current flowing in secondary circuit

r_f = diode resistance

R_L = load resistance

dc power output

$$P_{dc} = I_{dc}^2 R_L$$

$$I_{dc} = I_{av} = 2\frac{1}{2\pi}\int_0^{\pi} i \cdot d\theta$$

$$I_{av} = 2\frac{1}{2\pi}\int_0^{\pi} I_m \sin\theta \cdot d\theta$$

$$I_{av} = \frac{2I_m}{\pi}$$

$$P_{dc} = \left(\frac{2I_m}{\pi}\right)^2 R_L$$

ac power output

$$P_{ac} = I_{rms}^2 (r_f + R_L)$$

$$I_{rms} = \sqrt{2\frac{1}{2\pi}\int_0^{\pi} i^2 d\theta}$$

$$I_{rms}^2 = \frac{1}{\pi}\int_0^{\pi} i^2 d\theta$$

$$I_{rms}^2 = \frac{1}{\pi}\int_0^{\pi} (I_m \sin\theta)^2 d\theta$$

$$I_{rms}^2 = \frac{I_m^2}{2}$$

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

$$P_{ac} = \left(\frac{I_m}{\sqrt{2}}\right)^2 (r_f + R_L)$$

$$\eta = \frac{P_{dc}}{P_{ac}} = \frac{\left(\frac{2I_m}{\pi}\right)^2}{\left(\frac{I_m}{\sqrt{2}}\right)^2} \times \frac{R_L}{(r_f + R_L)}$$

$$\eta = \frac{0.812}{1 + \frac{r_f}{R_L}}$$

The efficiency will be maximum if rf is negligible as compared to RL. Hence, maximum efficiency = 81.2%. This is double the efficiency due to half-wave rectifier. Therefore, a full-wave rectifier is twice as effective as a half-wave rectifier.

Ripple Factor for Full-wave Rectification

$$r = \sqrt{\left(\frac{I_{\text{rms}}}{I_{\text{dc}}}\right)^2 - 1}$$

For full-wave rectification, we have $I_{\text{rms}} = \dfrac{I_m}{\sqrt{2}}$

$$I_{\text{dc}} = \frac{2I_m}{\pi}$$

Ripple factor $r = 0.48$

Transformer Utilization Factor (TUF) of Center Tapped Full Wave Rectifier

- **DC Power Output, Pdc = Average Current x Average Voltage**

$$P_{dc} = \frac{2V_m}{\pi} X \frac{2I_m}{\pi} \text{.....................(1)}$$

- **VA rating of Transformer**
- The voltage of source is sinusoidal, therefore its rms value will be equal to (Vm/√2).
- The current in each of the transformer secondary only flows for half cycle, therefore its rms value will be (Im/2).

VA rating of each of the Transformer Secondary $VA_{\,rating} = \frac{V_m}{\sqrt{2}} X \frac{I_m}{2}$

Total VA rating of each of the Transformer Secondary $VA_{\,rating} = 2\frac{V_m}{\sqrt{2}} X \frac{I_m}{2} = \frac{V_m I_m}{\sqrt{2}}$

VA Rating of Transformer Primary: $VA_{\,rating} = \frac{V_m}{\sqrt{2}} X \frac{I_m}{\sqrt{2}} = \frac{V_m I_m}{2}$

Effective VA Ratio of Transformer = (Primary VA + Secondary VA)/2 = $0.6035V_mI_m$

TUF of Center Tapped Rectifier = $[(4I_mV_m)/\pi^2] / [0.6035V_mI_m] = 0.672$

Transformer Utilization Factor (TUF) of bridge Full Wave Rectifier

- **DC Power Output, Pdc = Average Current x Average Voltage**

$$P_{dc} = \frac{2V_m}{\pi} X \frac{2I_m}{\pi} \qquad \text{.....................(1)}$$

- **VA rating of Transformer**
- The voltage of source is sinusoidal, therefore its rms value will be equal to (Vm/√2).
- The current is flowing in the entire secondary winding during positive and negative half cycle..

$$VA_{\ rating} = \frac{V_m}{\sqrt{2}} X \frac{I_m}{2}$$

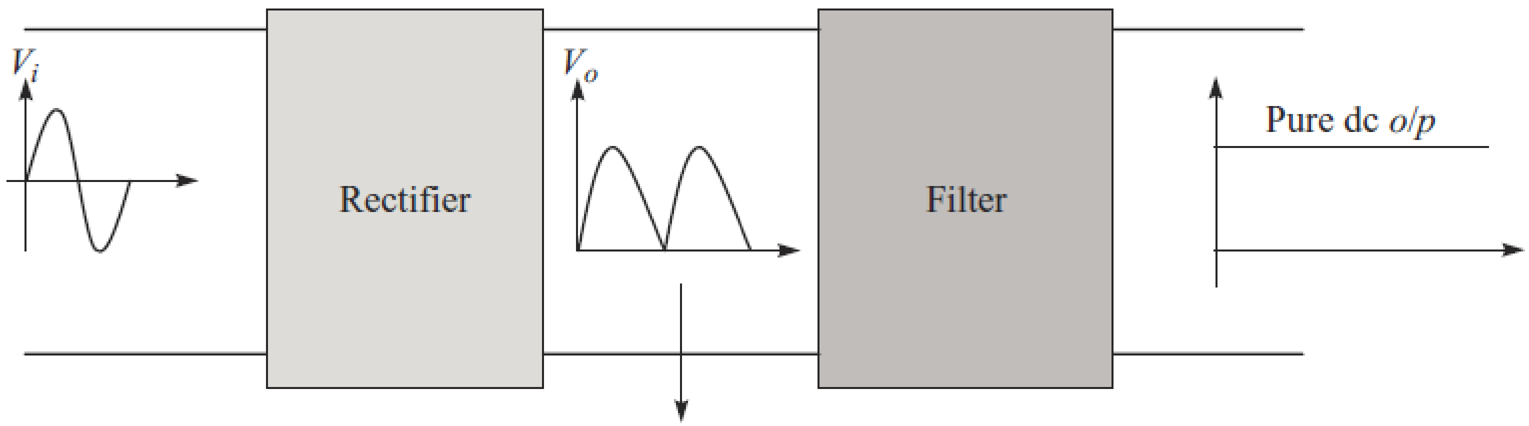
TUF of Center Tapped Rectifier = $[(4I_mV_m)/\pi^2] / [I_mV_m/2] = 0.816$

Comparison of Rectifiers

Particulars	Half-wave rectifier	Centre-tapped full-wave rectifier	Bridge rectifier
1. No. of diodes	1	2	4
2. I_{dc}	I_m/Π	$2I_m/\Pi$	$2I_m/\Pi$
3. V_{dc}	V_m/Π	$2V_m/\Pi$	$2V_m/\Pi$
4. I_{rms}	$I_m/2$	$I_m/\sqrt{2}$	$I_m/\sqrt{2}$
5. Efficiency	40.6%	81.2%	81.2%
6. PIV	V_m	$2V_m$	V_m
7. Ripple factor	1.21	0.48	0.48
8. TUF	0.285	0.672	0.810

FILTERS

- The output of the rectifier is pulsating dc, i.e., the output obtained by the rectifier is not pure dc but it contains some ac components along with the dc o/p. These ac components are called ripples, which are undesirable or unwanted.
- To minimize the ripples in the rectifier output filter circuits are used. These circuits are normally connected between the rectifier and load

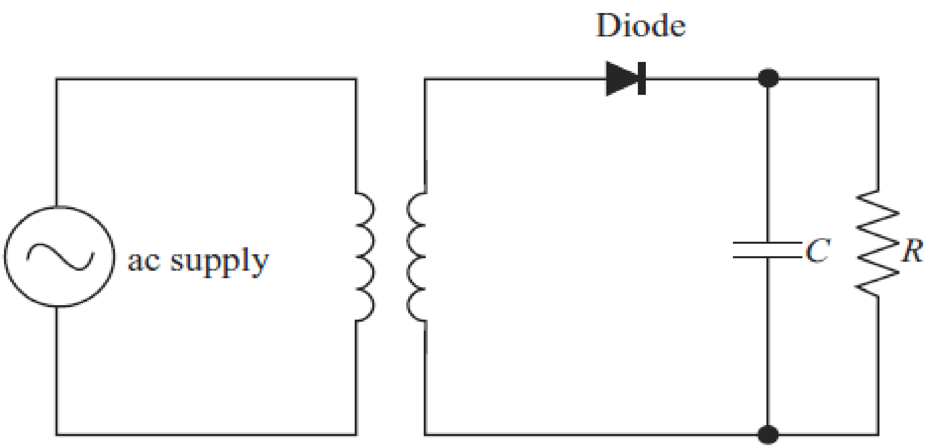


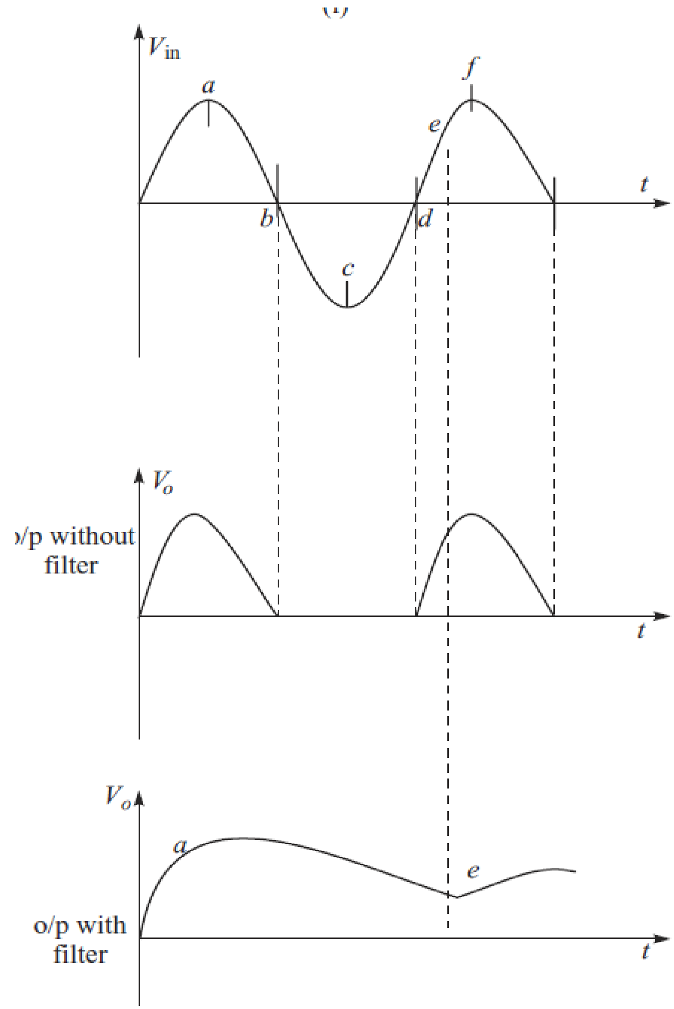
- Filter is a circuit which converts pulsating dc output from a rectifier to a steady dc output. In other words, filters are used to reduce the amplitudes of the unwanted ac components in the rectifier.

- Types of Filters

1. Capacitor filter (C-filter) 2. Inductor filter
3. Choke input filter (LC-filter) 4. Capacitor input filter (Π filter)

Capacitor Filter(C -Filter)





- When the input signal rises from o to a the diode is forward biased therefore it starts conducting since the capacitor acts as a short circuit for ac signal. It gets charged up to the peak of the input signal and the dc component flows through the load, *RL*.

- When the input signal falls from a to b the diode gets reverse biased. This is mainly because of the voltage across the capacitor obtained during the period o to a is more when compared to Vi. Therefore, there is no conduction of current through the diode.

- The charged capacitor acts as a battery and it starts discharging through the load, RL. Meanwhile the input signal passes through b, c, d sections. When the signal reaches the point d the diode is still reverse biased since the capacitor voltage is more than the input voltage. At e the input voltage can be expected to be more than the capacitor voltage. When the input signal moves from e to f the capacitor gets charged to its peak value again. The diode gets reverse biased and the capacitor starts discharging.

Ripple factor for the rectifiers with C-filter

The ripple factor for a half-wave rectifier with C-filter is given by

$$r = 1/2\sqrt{3}\,f_C R_L$$

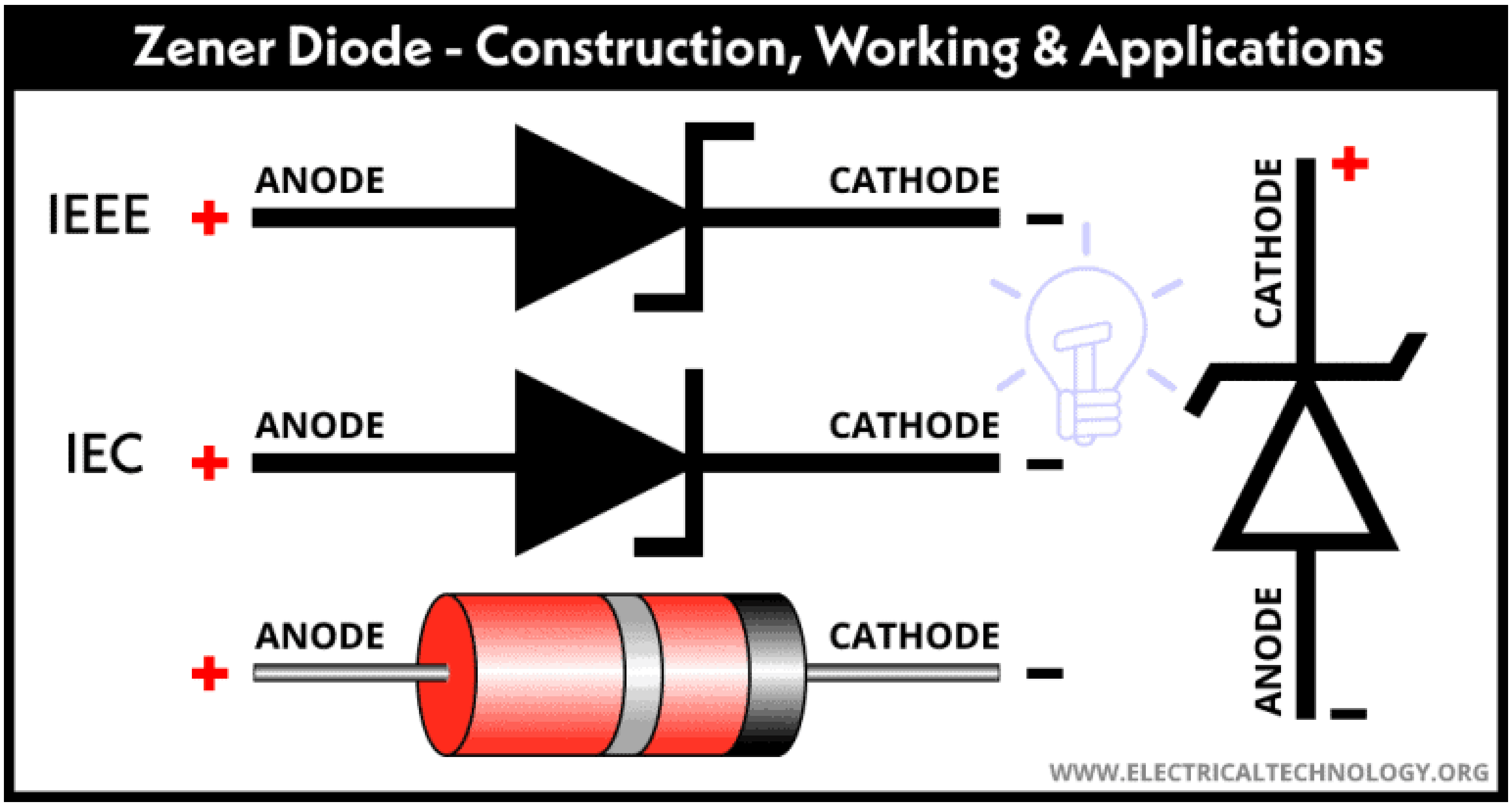
f = the line frequency (Hz)
C = capacitance (F)
R_L = load resistance (Ω)

Ripple factor for full-wave rectifier with C-filter is given by $r = 1/4\sqrt{3}\,f_C R_L$

MODULE 4

Zener diode, LED, Photo Diode AND APPLICATIONS

Zener Diode



Zener Diode - Construction, Working & Applications
IEEE
+
ANODE
CATHODE
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IEC
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ANODE
CATHODE
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ANODE
CATHODE
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A heavily doped p-n junction diode that works in reverse bias conditions is called a Zener Diode.

They are special semiconductor devices that allow the current to flow in both forward and backward directions.

For the Zener diode, the voltage drop across the diode is always constant irrespective of the applied voltage. Thus, Zener diodes are used as a voltage regulator.

A Zener diode can be considered as a highly doped p-n junction diode which is made such that it works in reverse bias condition.

Zener diode that is also known as a breakdown diode is a heavily doped semiconductor device that has been specially designed to operate in the reverse direction.

When the potential reaches the Zener voltage which is also known as Knee voltage and the voltage across the terminal of the Zener diode is reversed, at that point time, the junction breaks down and the current starts flowing in the reverse direction.

This effect is known as the Zener effect.

The diode consists of a very thin depletion region as it is made up of heavily doped semiconductor material.

Zener Diode Working in Reverse Biased

In forward-biased conditions, the Zener Diode works like any normal diode but in the reverse-bias condition, a small leak current flows through the diode.

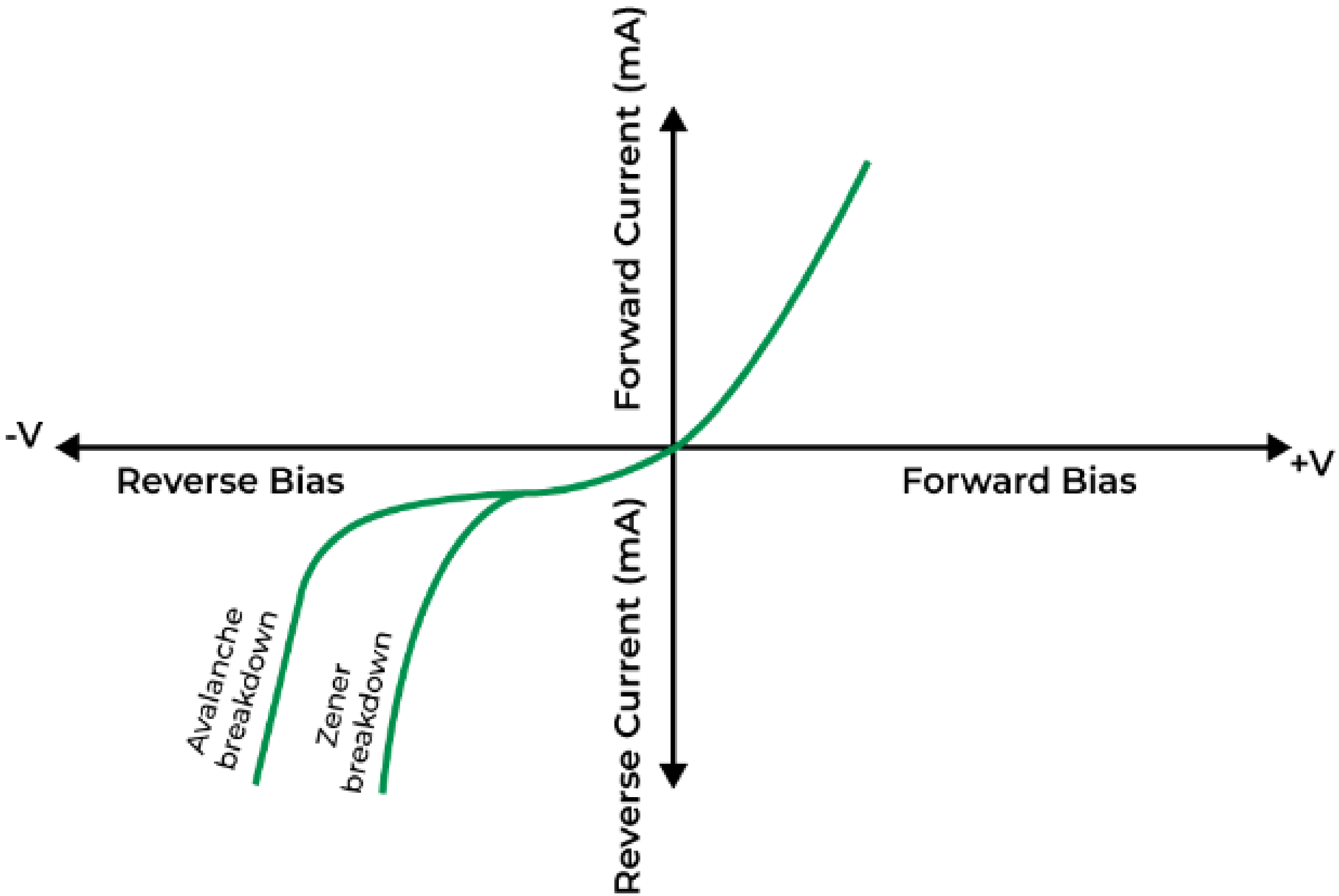
As we keep increasing the reverse voltage it reaches a point where the reverse voltage equals the breakdown voltage.

The breakdown voltage is represented as Vz and in this condition the current start flowing in the diode.

After the breakdown voltage the current increase drastically unit it reaches a stable value.

In reverse bias condition, two kinds of breakdowns occur for Zener Diode which are,
Avalanche Breakdown
Zener Breakdown

VI Characteristics of Zener Diode



Avalanche Breakdown	**Zener Breakdown**
Avalanche breakdown occurs when the high voltage increase the free electron in the semiconductor and a sudden increase in current is seen.	Zener breakdown happens when electrons from the valance band gain energy and reaches the conduction band which then conducts electricity.
Avalanche breakdown is seen in the diodes having breakdown voltage greater than 8 volts.	Zener breakdown is seen in the diodes having breakdown voltage in the range of 5 to 8 volts.
Avalanche breakdown is observed in diodes that are lightly doped.	Zener breakdown is observed in diodes that are highly doped.
In the Avalanche breakdown, the VI characteristics curve is not as sharp as the VI characteristics curve in the Zener breakdown.	Zener Breakdown has a sharp VI characteristics curve.
For Avalanche breakdown increase in temperature increases the breakdown voltage.	For Zener breakdown increase in temperature decreases the breakdown voltage.

Forward Characteristics of Zener Diode

Forward characteristics of the Zener Diode are similar to the forward characteristics of any normal diode.
It is clearly evident from the above diagram in the first quadrant that the VI forward characteristics are similar to other P-N junction diodes.

Reverse Characteristics of Zener Diode

In reverse voltage conditions a small amount of current flows through the Zener diode. This current is because of the electrons which are thermally generated in the Zener diode.
As we keep increasing the reverse voltage at any particular value of reverse voltage the reverse current increases suddenly at the breakdown point this voltage is called Zener Voltage and is represented as Vz.

Applications of Zener Diode

Zener diode is a very useful diode. Due to its ability to allow current to flow in reverse bias conditions, it is used widely for various purposes. Some of the common uses of Zener Diode are discussed below,

Zener diode as Voltage Regulator

Zener diode is utilized as a Shunt voltage controller for managing voltage across little loads. The breakdown voltage of Zener diodes will be steady for a wide scope of current. The Zener diode is associated with corresponding to the heap to make it switch predisposition and when the Zener diode surpasses knee voltage, the voltage across the heap will become consistent.

Zener Diode in Over-Voltage Protection

At the point when the info voltage is higher than the Zener breakage voltage, the voltage across the resistor drops bringing about a short-out. This can be kept away from by utilizing the Zener diode.

Zener Diode in Clipping Circuits

Zener diode is utilized for adjusting AC waveform cutting circuits by restricting the pieces of it is possible that one or both the half patterns of an AC waveform.

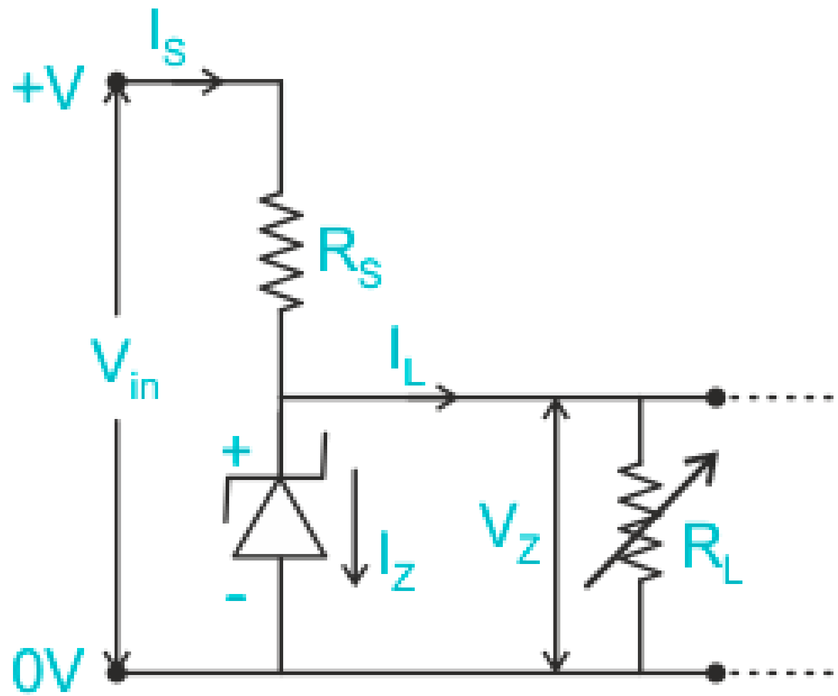
Working of Zener Diode as a Voltage Regulator

The capacity of a Zener diode to keep a constant voltage regardless of changes in source or load current is critical in this application.

A voltage regulation device's general role is to give a constant output voltage to a load connected in parallel to it, regardless of variations in the load's energy drawn (Load current) or fluctuations and instability in the supply voltage.

If the current remains within the limit of the min and max reverse currents, the Zener diode will produce a constant voltage.

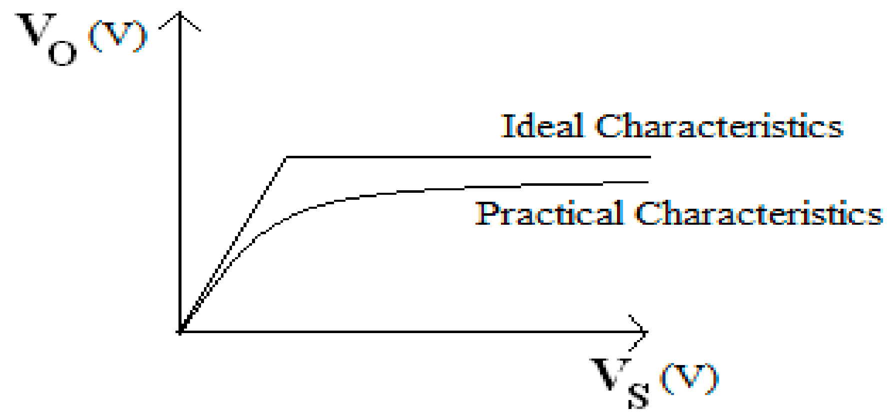
To restrict the current that flows through the Zener diode, a resistor Rs is connected in series with the diode, and also the input voltage Vin is connected across as shown in the image, and the output voltage Vout is chosen to take across the Zener diode with Vout=Vz.



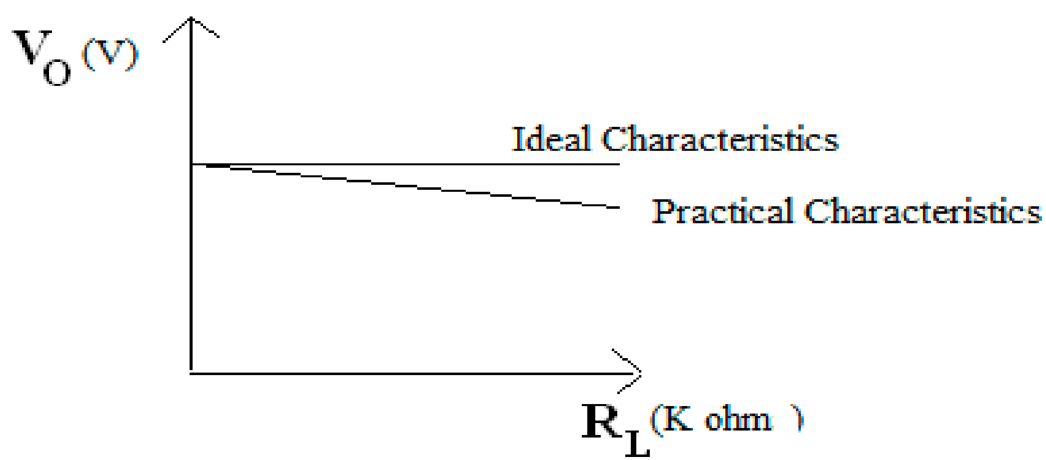
The value of the resistor can be determined by the formula
RS=(Vin−VZ)/Iz
Where, RS is the value of series resistance and Vin is the input voltage and Vz is Zener voltage.

Using this method, it is simple to assure that the resistor value chosen does not result in a current flow greater than the Zener can tolerate.

Line Regulation



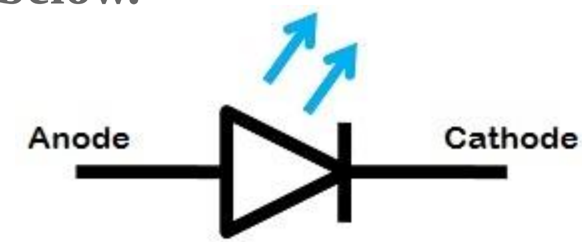
Load Regulation:



Light Emitting Diode : Working & Its Applications

The lighting emitting diode is a p-n junction diode. It is a specially doped diode and made up of a special type of semiconductors. When the light emits in the forward biased, then it is called a light-emitting diode.

The LED symbol is similar to a diode symbol except for two small arrows that specify the emission of light, thus it is called LED (light-emitting diode). The LED includes two terminals namely anode (+) and the cathode (-). The LED symbol is shown below.



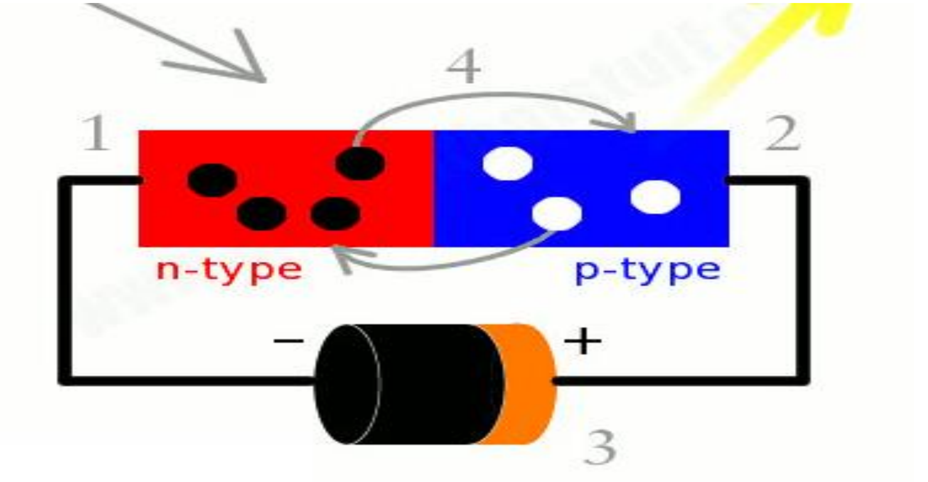
Construction of LED

The construction of LED is very simple because it is designed through the deposition of three semiconductor material layers over a substrate. These three layers are arranged one by one where the top region is a P-type region, the middle region is active and finally, the bottom region is N-type. The three regions of semiconductor material can be observed in the construction. In the construction, the P-type region includes the holes; the N-type region includes elections whereas the active region includes both holes and electrons.

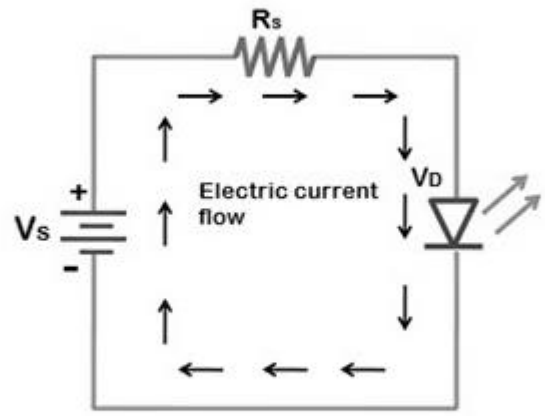
When the voltage is not applied to the LED, then there is no flow of electrons and holes so they are stable. Once the voltage is applied then the LED will forward biased, so the electrons in the N-region and holes from P-region will move to the active region. This region is also known as the depletion region. Because the charge carriers like holes include a positive charge whereas electrons have a negative charge so the light can be generated through the recombination of polarity charges.

How does the Light Emitting Diode Work?

The light-emitting diode simply, we know as a diode. When the diode is forward biased, then the electrons & holes are moving fast across the junction and they are combined constantly, removing one another out. Soon after the electrons are moving from the n-type to the p-type silicon, it combines with the holes, then it disappears. Hence it makes the complete atom & more stable and it gives the little burst of energy in the form of a tiny packet or photon of light.



Light Emitting Diode Circuit for Biasing



Most of the LEDs have voltage ratings from 1 volt-3 volt whereas forward current ratings range from 200 mA-100 mA. If the voltage (1V to 3V) is applied to the LED, then it functions properly due to the flow of current for the applied voltage will be in the operating range. Similarly, if the applied voltage to an LED is high than the operating voltage then the depletion region within the light-emitting diode will break down due to the high flow of current. This unexpected high flow of current will damage the device.

This can be avoided by connecting a resistor in series with the voltage source & an LED. The safe voltage ratings of LEDs will be ranges from 1V to 3 V whereas safe current ratings range from 200 mA to 100 mA.

Here, the resistor which is arranged in between the voltage source and LED is known as the current limiting resistor because this resistor restricts the flow of current otherwise the LED may destroy it. So this resistor plays a key role in protecting the LED.

Mathematically, the flow of current through the LED can be written as
IF = Vs – VD/Rs

Where,
'IF 'is forward current
'Vs' is a voltage source
'VD' is the voltage drop across the light-emitting diode
'Rs' is a current limiting resistor

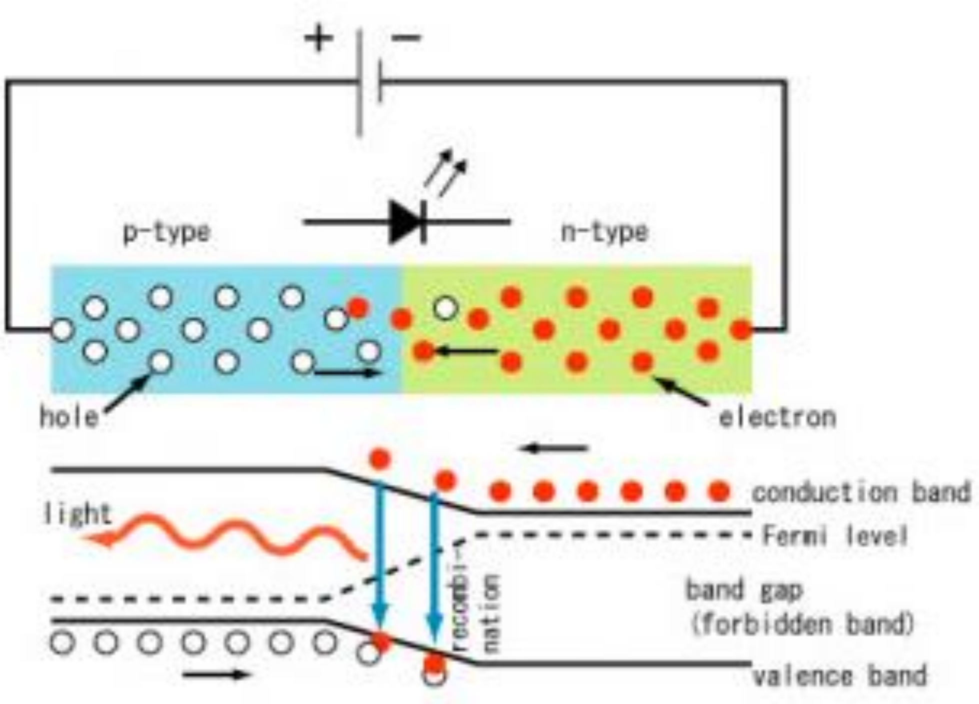
The amount of voltage dropped to defeat the barrier of the depletion region. The LED voltage drop will range from 2V to 3V while Si or Ge diode is 0.3 otherwise 0.7 V.
Thus, the LED can be operated by using high voltage as compared with Si or Ge diodes.
Light-emitting diodes consume more energy than silicon or germanium diodes to operate.

Working Principle of LED

The working principle of the Light-emitting diode is based on the quantum theory.

The quantum theory says that when the electron comes down from the higher energy level to the lower energy level then, the energy emits from the photon.

The photon energy is equal to the energy gap between these two energy levels.



The flow of current in the semiconductors is caused by the flow of holes in the opposite direction of current and the flow of electrons in the direction of the current.

Hence there will be recombination due to the flow of these charge carriers.

The recombination indicates that the electrons in the conduction band jump down to the valence band.

When the electrons jump from one band to another band the electrons will emit the electromagnetic energy in the form of photons and the photon energy is equal to the forbidden energy gap.

Advantages and Disadvantages of LED's

The advantages of light-emitting diode include the following.

The cost of LED's is less and they are tiny.
By using the LED's electricity is controlled.
The intensity of the LED differs with the help of the microcontroller.
Long Lifetime
Energy efficient
No warm-up period
Rugged
Doesn't affect by cold temperatures
Directional
Color Rendering is Excellent
Environmentally friendly
Controllable

The disadvantages of light-emitting diode include the following.

Temperature sensitivity
Temperature dependence
Light quality
Electrical polarity
Voltage sensitivity
Efficiency droop
Impact on insects

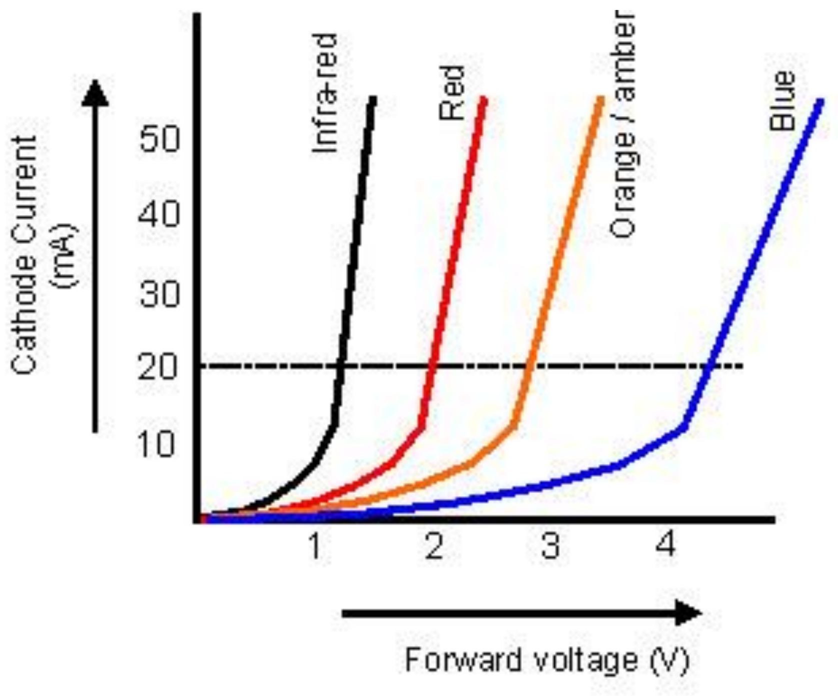
Applications of Light Emitting Diode

There are many applications of LED and some of them are explained below.

LED is used as a bulb in the homes and industries
The light-emitting diodes are used in motorcycles and cars
These are used in mobile phones to display the message
At the traffic light signals led’s are used

I-V Characteristics of LED

There are different types of light-emitting diodes are available in the market and there are different LED characteristics which include the color light, or wavelength radiation, light intensity. The important characteristic of the LED is color. In the starting use of LED, there is the only red color. As the use of LED is increased with the help of the semiconductor process and doing the research on the new metals for LED, the different colors were formed.



The graph shows the approximate curves between the forward voltage and the current. Each curve in the graph indicates a different color. The table shows a summary of the LED characteristics.

WAVELENGTH RANGE (NM)	COLOUR	V_F @ 20MA	MATERIAL
< 400	Ultraviolet	3.1 - 4.4	Aluminium nitride (AlN) Aluminium gallium nitride (AlGaN) Aluminium gallium indium nitride (AlGaInN)
400 - 450	Violet	2.8 - 4.0	Indium gallium nitride (InGaN)
450 - 500	Blue	2.5 - 3.7	Indium gallium nitride (InGaN) Silicon carbide (SiC)
500 - 570	Green	1.9 - 4.0	Gallium phosphide (GaP) Aluminium gallium indium phosphide (AlGaInP) Aluminium gallium phosphide (AlGaP)
570 - 590	Yellow	2.1 - 2.2	Gallium arsenide phosphide (GaAsP) Aluminium gallium indium phosphide (AlGaInP) Gallium phosphide (GaP)
590 - 610	Orange / amber	2.0 - 2.1	Gallium arsenide phosphide (GaAsP) Aluminium gallium indium phosphide (AlGaUInP) Gallium phosphide (GaP)
610 - 760	Red	1.6 - 2.0	Aluminium gallium arsenide (AlGaAs) Gallium arsenide phosphide (GaAsP) Aluminium gallium indium phosphide (AlGaInP) Gallium phosphide (GaP)
> 760	Infrared	< 1.9	Gallium arsenide (GaAs) Aluminium gallium arsenide (AlGaAs)

What is a Photodiode?

It is a form of light sensor that converts light energy into electrical energy (voltage or current).

Photodiode is a type of semi conducting device with PN junction. Between the p (positive) and n (negative) layers, an intrinsic layer is present.

The photo diode accepts light energy as input to generate electric current. It is also called as Photodetector, Photo Sensor or Light Detector.

Photodiode operates in reverse bias condition i.e., the p – side of the photodiode is connected with negative terminal of battery (or the power supply) and n – side to the positive terminal of battery.

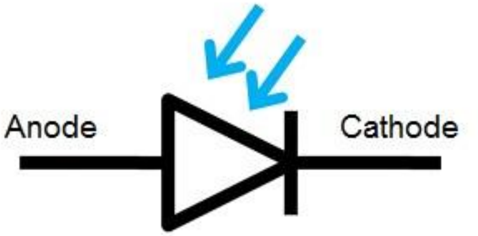
Typical photodiode materials are Silicon, Germanium, Indium Gallium Arsenide Phosphide and Indium gallium arsenide.

Internally, a photodiode has optical filters, built in lens and a surface area. When surface area of photodiode increases, it results in less response time.

Few photo diodes will look like Light Emitting Diode (LED). It has two terminals as shown below.

The smaller terminal acts as cathode and longer terminal acts as anode.

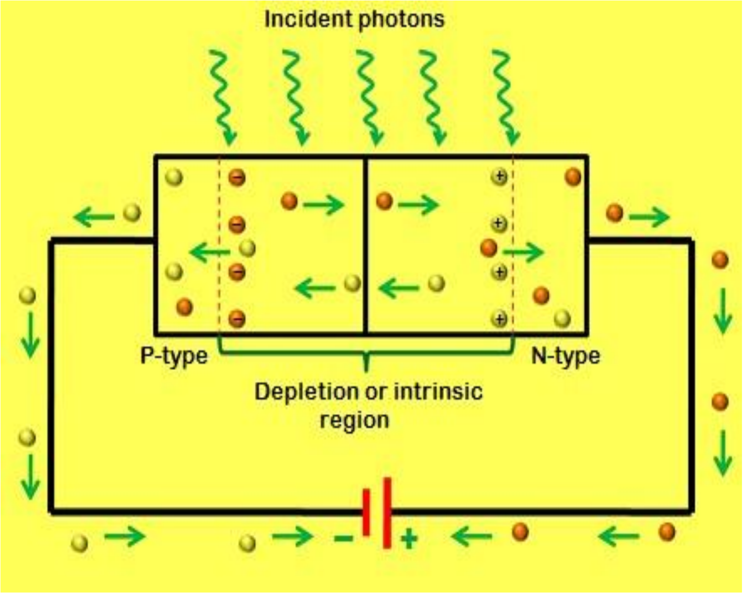
The symbol of the photodiode is similar to that of an LED but the arrows point inwards as opposed to outwards in the LED.



Photodiode symbol

Working of a Photodiode

Generally, when a light is made to illuminate the PN junction, covalent bonds are ionized. This generates hole and electron pairs. Photocurrents are produced due to generation of electron-hole pairs.
Electron hole pairs are formed when photons of energy more than 1.1eV hits the diode. When the photon enters the depletion region of diode, it hits the atom with high energy.
This results in release of electron from atom structure. After the electron release, free electrons and hole are produced.



In general, an electron will have a negative charge and holes will have a positive charge. The depletion energy will have built-in electric field.
Due to that electric field, electron-hole pairs move away from the junction.
Hence, holes move to anode and electrons move to the cathode to produce photocurrent.

The photon absorption intensity and photon energy are indirectly proportional to each other. When energy of photons is less, the absorption will be more. This entire process is known as Inner Photoelectric Effect.

Intrinsic Excitations and Extrinsic Excitations are the two methods via which the photon excitation happens.

Modes of operation of a Photodiode

Photodiode operates in three different modes. They are:

Photovoltaic Mode

Photoconductive Mode

Avalanche Diode Mode

Photovoltaic Mode

This is otherwise called as Zero Bias Mode. When a photodiode operates in low frequency applications and ultra-level light applications, this mode is preferred. When photodiode is irradiated by a flash of light, voltage is produced. The voltage produced will have a very small dynamic range and it has a non-linear characteristic.

Photoconductive Mode

In this mode, photodiode will act in reverse biased condition. Cathode will be positive and anode will be negative. When the reverse voltage increases, the width of the depletion layer also increases. Due to this the response time and junction capacitance will be reduced. Comparatively this mode of operation is fast and produces electronic noise.

Avalanche Diode Mode

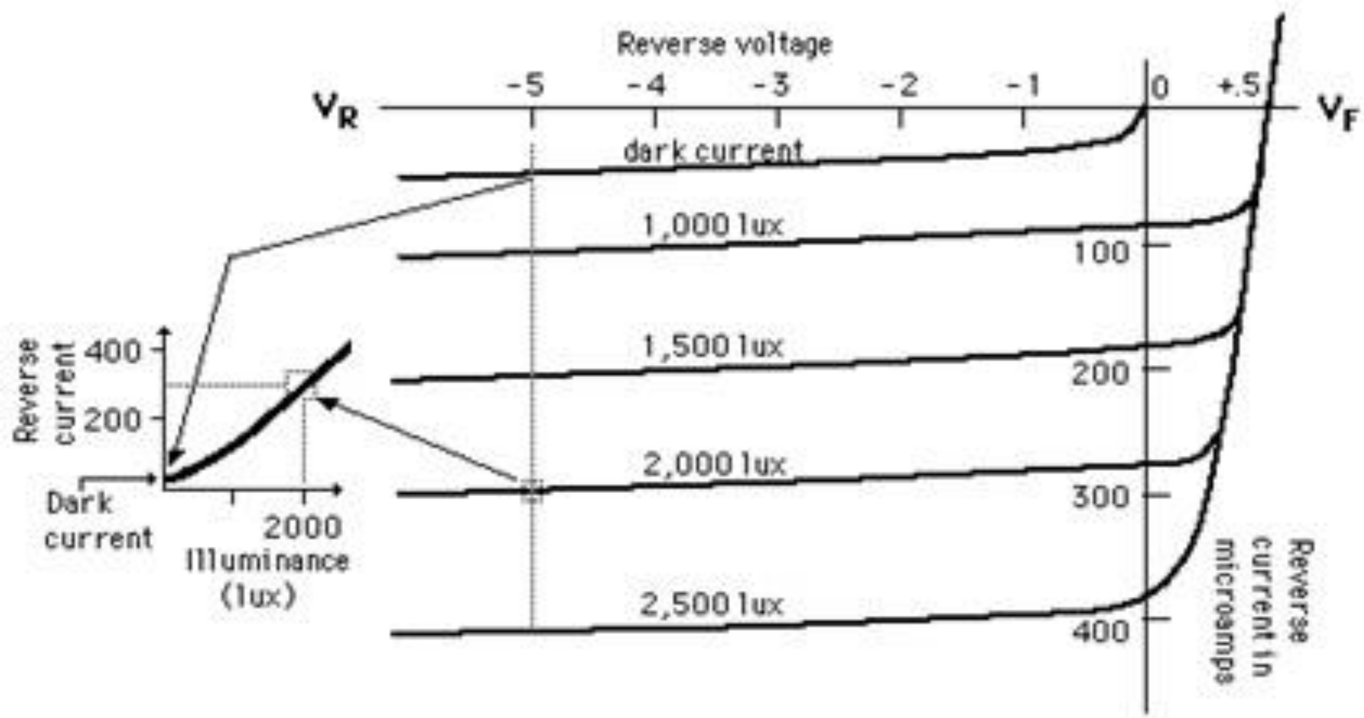
In this mode, Avalanche Diode operates at a high reverse bias condition. It allows multiplication of an Avalanche Breakdown to each photo-produced electron-hole pair. Hence, this produces internal gain within photodiode. The internal gain increases the device response.

V-I Characteristics of Photodiode

Photodiode operates in reverse bias condition. Reverse voltages are plotted along X axis in volts and reverse current are plotted along Y-axis in microampere. Reverse current does not depend on reverse voltage.

When there is no light illumination, reverse current will be almost zero. The minimum amount of current present is called as Dark Current.

Once when the light illumination increases, reverse current also increases linearly.



Applications of Photodiode

Photodiodes are used in many simple day to day applications. The reason for their use is the linear response of photodiode to a light illumination. When more amount of light falls on the sensor, it produces high amount of current. The increase in current will be displayed on a galvanometer connected to the circuit.

Photodiodes help to provide an electric isolation with help of optocouplers.

Photodiodes are also used in safety electronics like fire and smoke detectors. It is also used in TV units.

When utilized in cameras, they act as photo sensors. It is used in scintillators charge-coupled devices, photoconductors, and photomultiplier tubes.

Photodiodes are also widely used in numerous medical applications like instruments to analyze samples, detectors for computed tomography and also used in blood gas monitors.

Bipolar Junction Transistor (BJT)

- Beside diodes, the most popular semiconductor devices is transistors. Eg: Bipolar Junction Transistor (BJT)
- Few most important applications of transistor are: as an amplifier as an oscillator and as a switch
- Amplification can make weak signal strong in general, provide function called Gain
- BJT is bipolar because both holes (+) and electrons (-) will take part in the current flow through the device

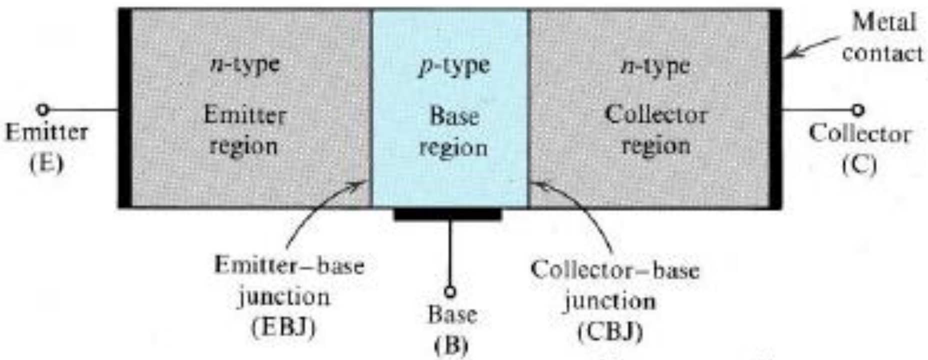
  N-type regions contains free electrons (negative carriers)

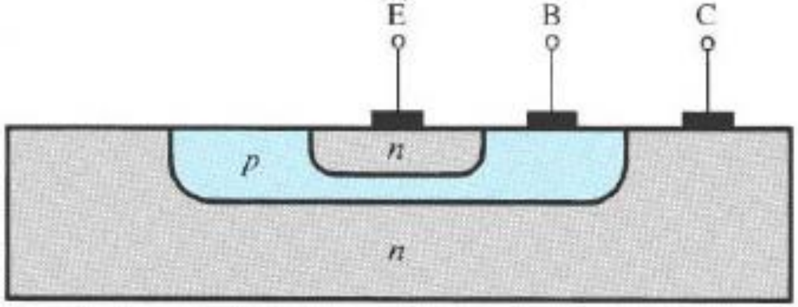
  P-type regions contains free holes (positive carriers)

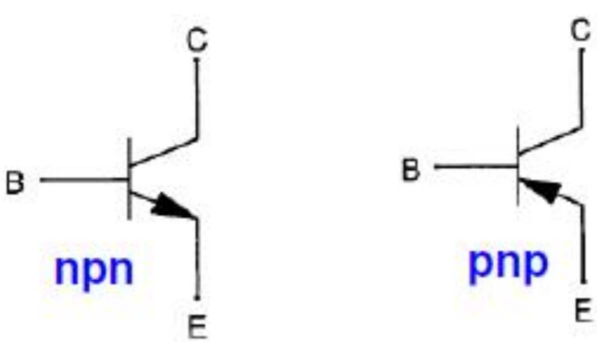
- The word Transistor is an acronym, and is a combination of the words **Trans**fer Var**istor** used to describe their mode of operation way back in their early days of development. There are two basic types of bipolar transistor construction, NPN and PNP, which basically describes the physical arrangement of the P-type and N-type semiconductor materials from which they are made.

Bipolar Junction Transistor (BJT)

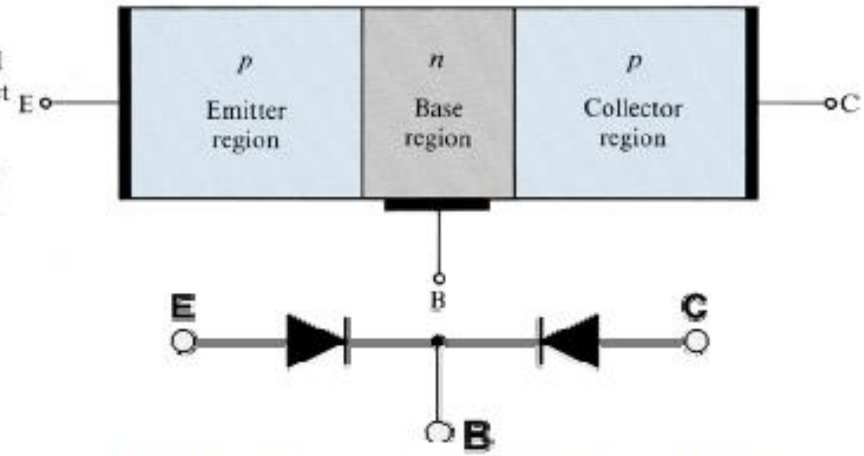
npnTransistor







pnpTransistor



- BJT is a 3 terminal device. namely- emitter, base and collector
- npn transistor: emitter & collector are n-doped and base is p-doped.
- Emitter is heavily doped, collector is moderately doped and base is lightly doped and base is very thin. i.e. $N_{DE} >> N_{DC} >> N_{AB}$

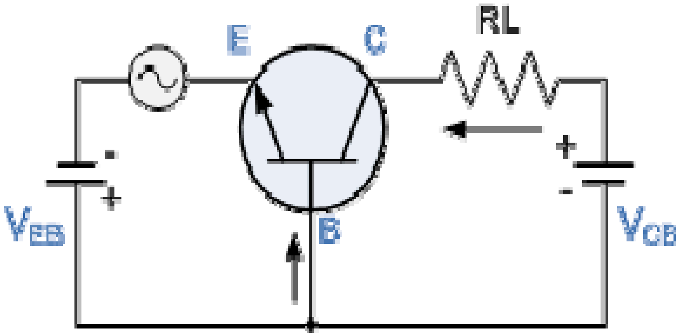
Mode of operation for BJT

Mode	V_{BE}	V_{BC}
Forward active	Forward bias	Reverse Bias
Reverse active	Reverse Bias	Forward Bias
Saturation	Forward bias	Forward bias
Cut off	Reverse Bias	Reverse Bias

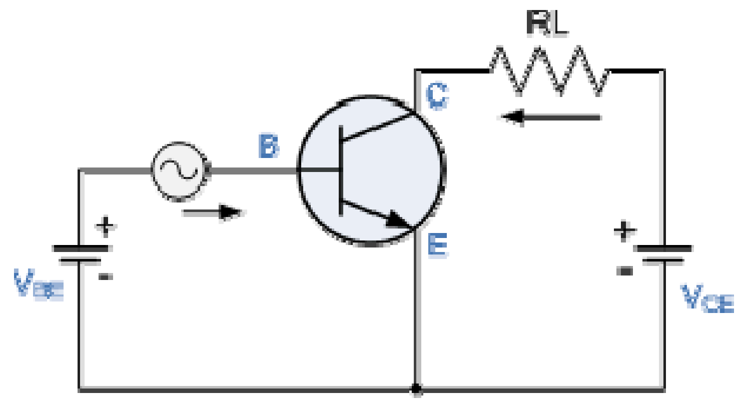
- **Forward active region is widely used and Reverse active region is rarely used**

Different configuration of BJT

Common base configuration

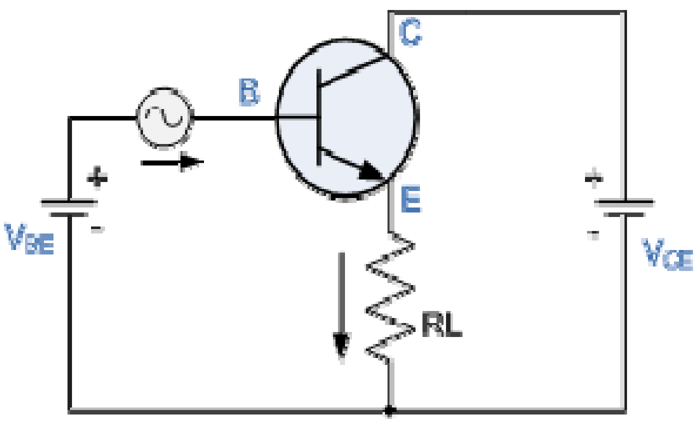


Non-inverting voltage amplifier circuit



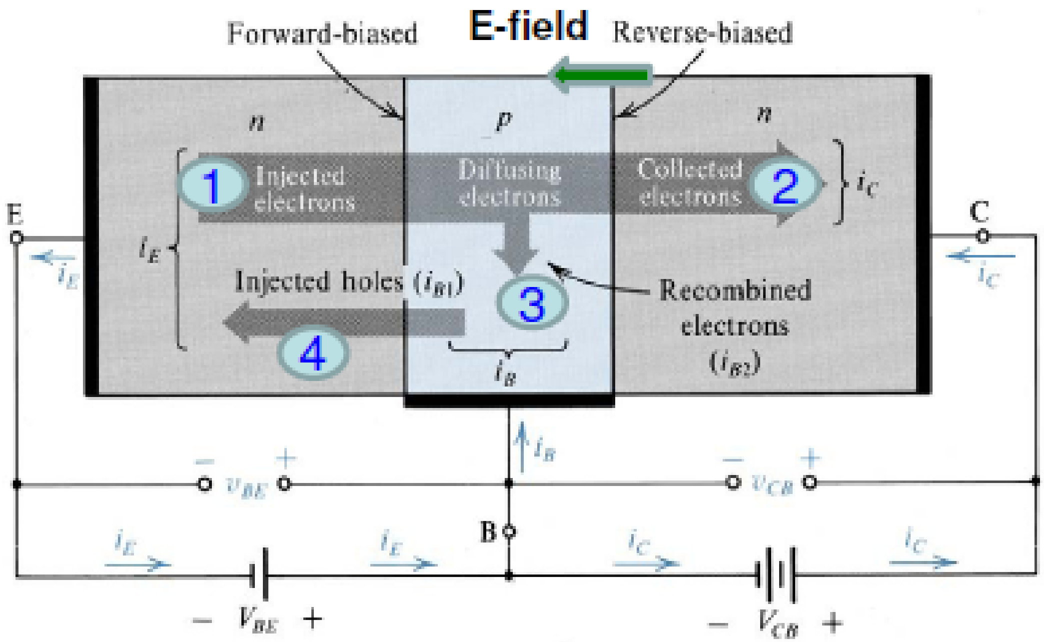
Common emitter configuration

Common collector configuration



This type of configuration is commonly known as a **Voltage Follower** or **Emitter Follower** circuit.

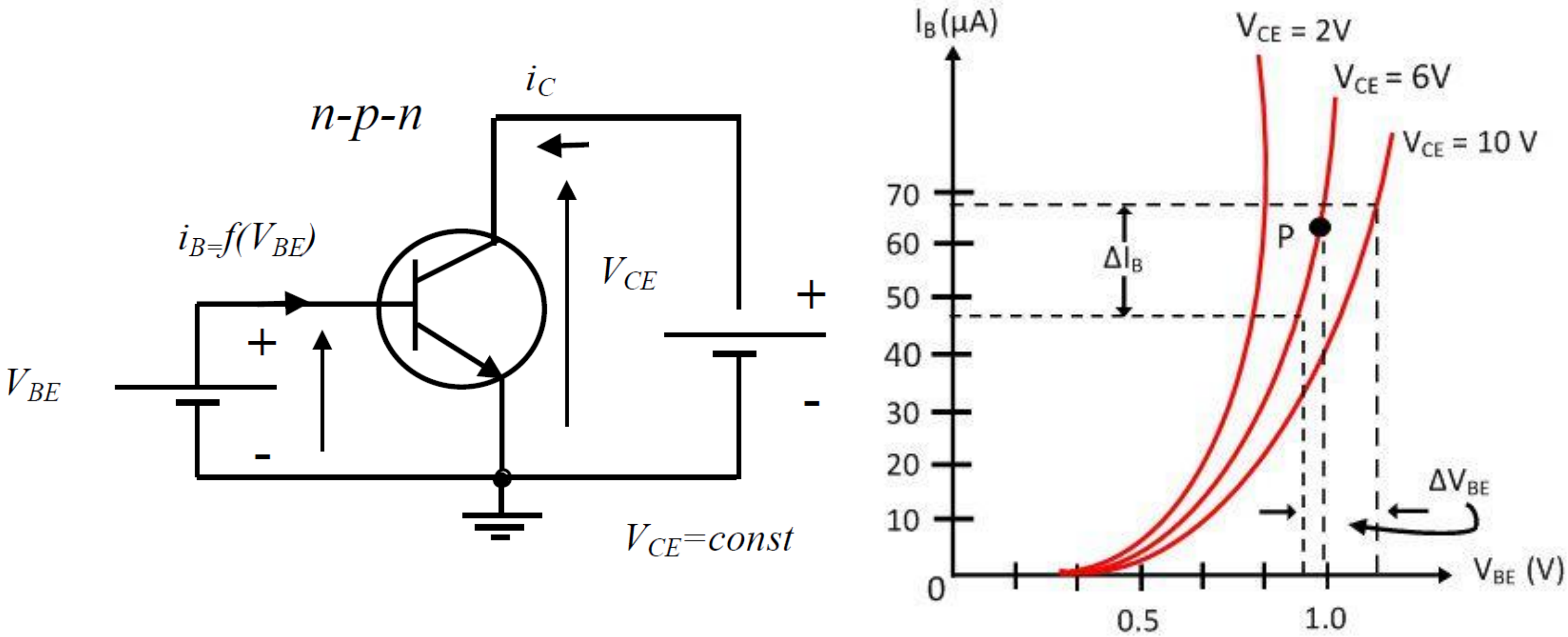
DC operation of npn BJT under forward active mode



- 1 . Forward bias of EBJ causes electrons to diffuse from emitter into base.
- 2. As base region is very thin, the majority of these electrons diffuse to the edge of the depletion region of CBJ, and then are swept to the collector by the electric field of the reverse-biased CBJ.
- 3. A small fraction of these electrons recombine with the holes in base region.
- 4. Holes are injected from base to emitter region. (4) << (1).

- The two-carrier flow from [(1) and (4)] forms the emitter current (I_E).

Input characteristics of BJT in Common Emitter configuration

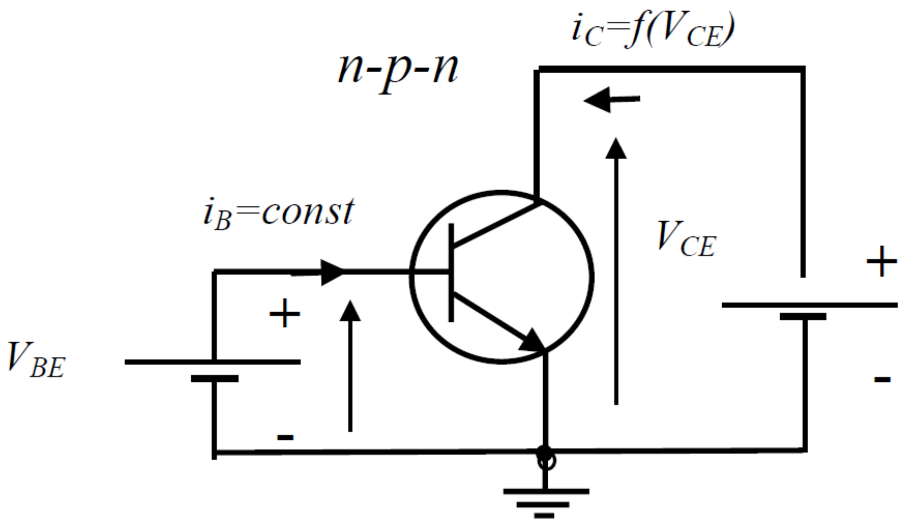


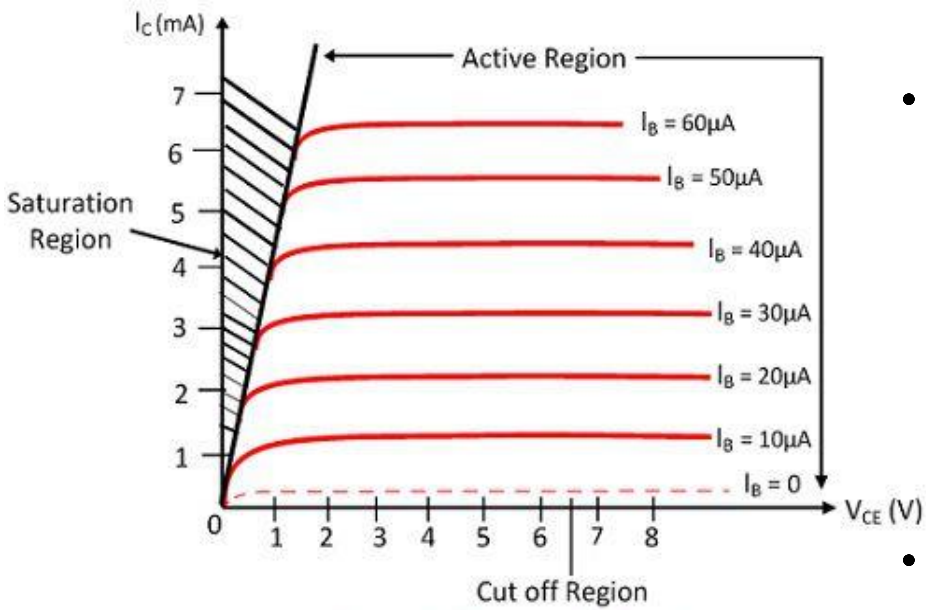
- Input characteristics are like a normal forward biased diode. As VBE increased IB also increased.
- iB(VBE) can be approximated as a step function at VBE ≈0.7V

- **Input Resistance:** The ratio of change in base-emitter voltage V_{BE} to the change in base current ΔI_B at constant collector-emitter voltage V_{CE} is known as input resistance, i.e.,

$$r_i = \frac{\Delta V_{BE}}{\Delta I_B} \text{ at constant } V_{CE}$$

Output characteristics of BJT in CE configuration





Output Characteristic Curve

- In the active region, the collector current increases slightly as collector-emitter VCE current increases. The slope of the curve is quite more than the output characteristic of CB configuration. Active region: iC is a weak function of VCE

- The value of the collector current IC increases with the increase in VCE at constant voltage IB, the value β of also increases.

- When the VCE falls, the IC also decreases rapidly. The collector-base junction of the transistor always in forward bias. In the saturation region, the collector current becomes independent and free from the input current IB. Saturation region: VCE < 0.5V

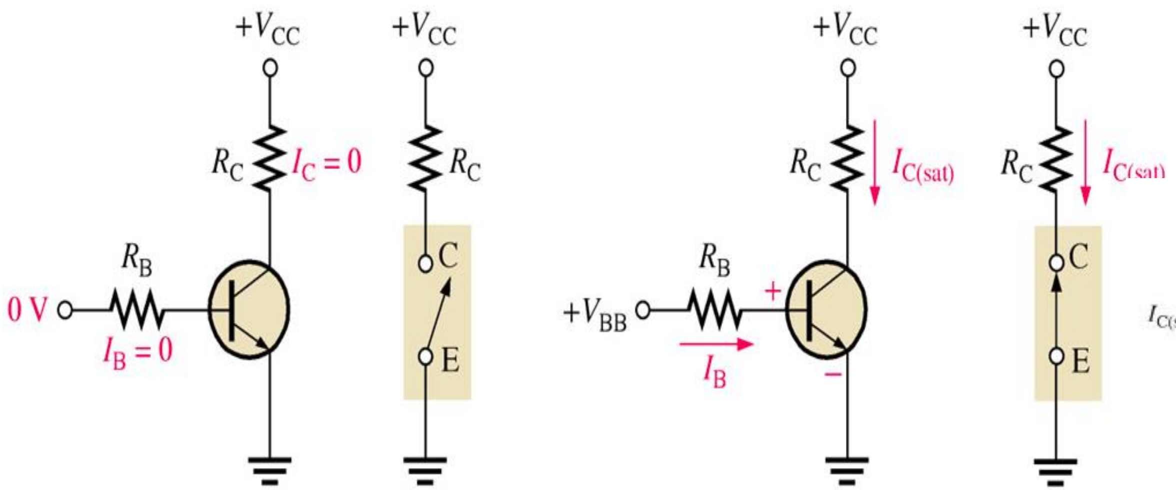
- In the active region IC = βIB, a small current IC is not zero, and it is equal to reverse leakage current ICEO.

Common Emitter Configuration applications

1. Transistor as (Electronic)Switch

A transistor when used as a switch is simply being biased so that it is in cut-off (switched off) or saturation (switched on). Remember that the VCE in cut-off is VCC and 0 V in saturation.

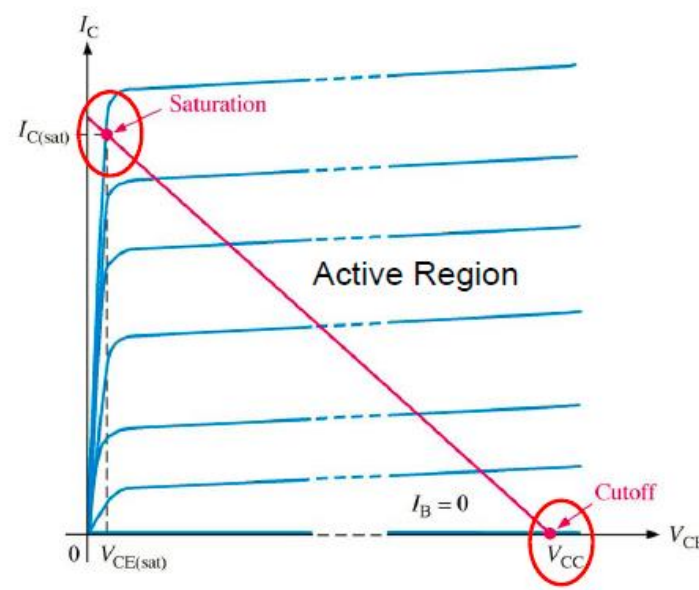
The dc load line graphically illustrates IC(sat) and cut-off for a transistor.



(a) Cutoff — open switch (b) Saturation — closed switch

KVL(Collector-Emitter)

$$\boxed{V_{CE}=V_{CC}-I_CR_C}$$



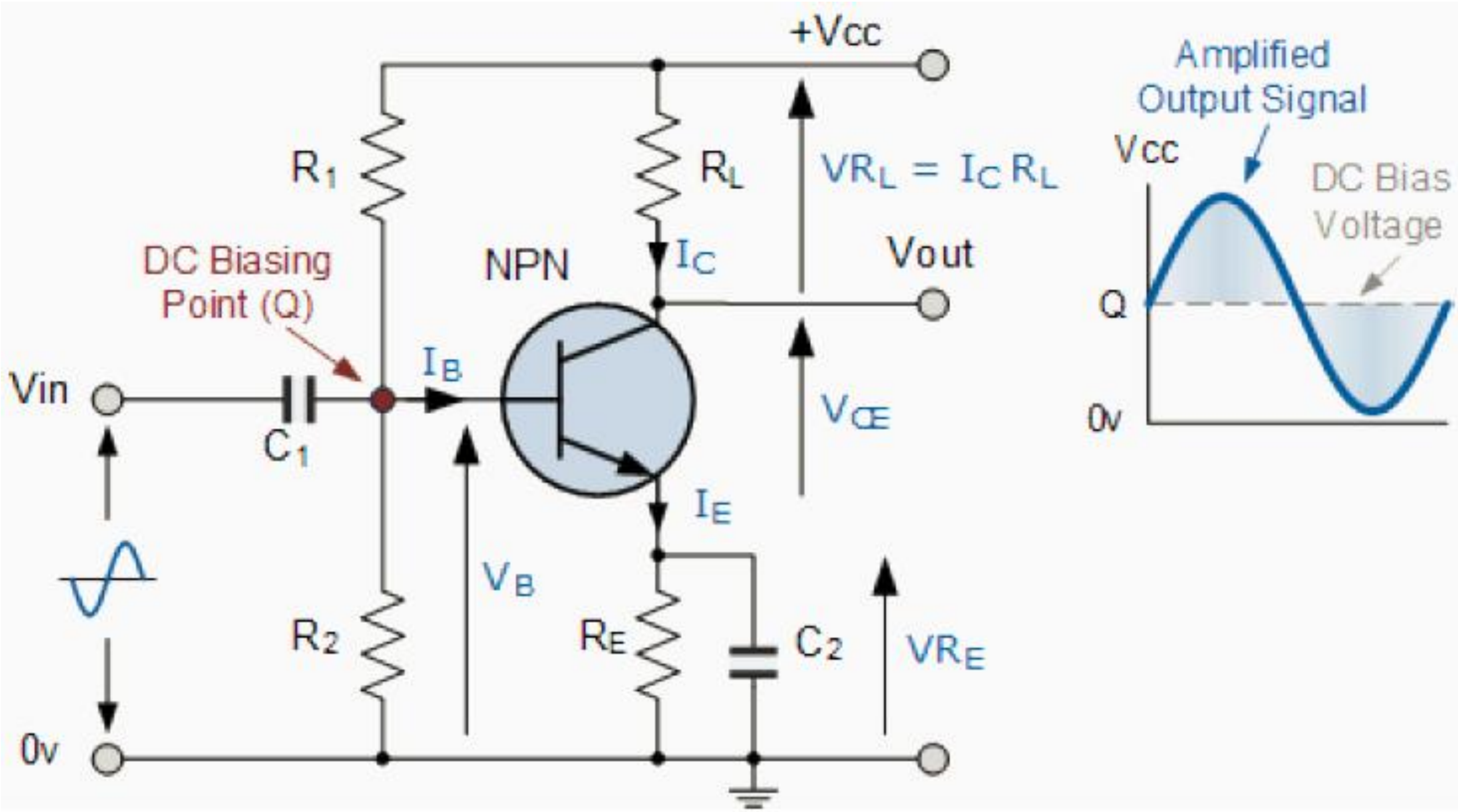
Common Emitter Configuration applications

2. Single Stage Common Emitter Amplifier

- BJT used as a semiconductor switch to turn load currents "ON" or "OFF" by controlling the Base signal to the transistor in ether its saturation or cut-off regions.
- Transistors can also be used in its active region to produce a circuit which will amplify any small AC signal applied to its Base terminal with the Emitter grounded. If a suitable DC "biasing" voltage is firstly applied to the transistors Base terminal thus allowing it to always operate within its linear active region, an inverting amplifier circuit called a single stage common emitter amplifier is produced.
- One such Common Emitter Amplifier configuration of the transistor is called a Class A Amplifier. A "Class A Amplifier" operation is one where the transistors Base terminal is biased in such a way as to forward bias the Base-emitter junction. The result is that the transistor is always operating halfway between its cut-off and saturation regions, thereby allowing the transistor amplifier to accurately reproduce the positive and negative halves of any AC input signal superimposed upon this DC biasing voltage. Without this "Bias Voltage" only one half of the input waveform would be amplified.
- A DC "Load Line" can also be drawn onto the output characteristics curves to show all the possible operating points when different values of base current are applied. It is necessary to set the initial value of Vce correctly to allow the output voltage to vary both up and down when amplifying AC input signals and this is called setting the operating point or Quiescent Point, **Q-point**

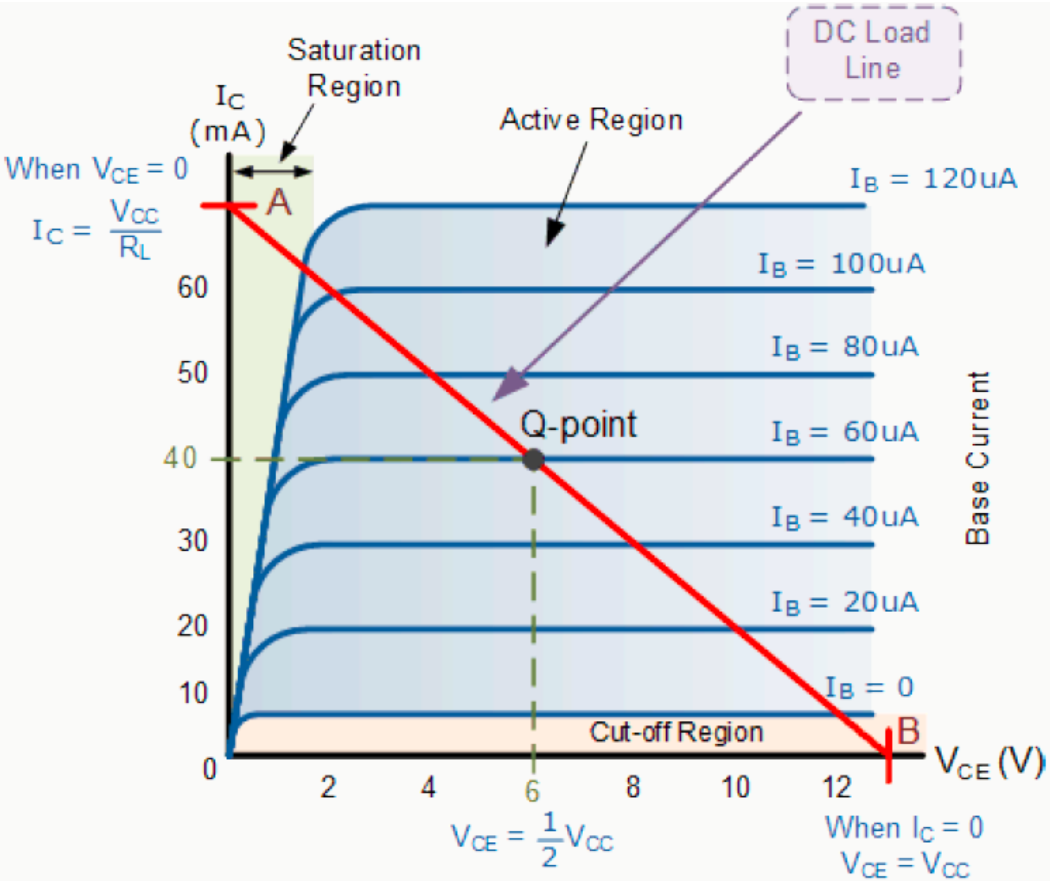
Common Emitter Configuration applications

2. Single Stage Common Emitter Amplifier



Common Emitter Configuration applications

2. Single Stage Common Emitter Amplifier



- Using the output characteristics curves and Ohm´s Law, the current flowing through the load resistor, (RL), is equal to the collector current, Ic entering the transistor which in turn corresponds to the supply voltage, (Vcc) minus the voltage drop between the collector and the emitter terminals, (Vce) and is given as:

$$\text{Collector Current, } I_C = \frac{V_{CC} - V_{CE}}{R_L}$$

- A straight line representing the Load Line of the transistor can be drawn directly onto the graph of curves above from the point of "Saturation" (A) when Vce = 0 to the point of "Cut-off" (B) when Ic = 0 thus giving us the "Operating" or Q-point of the transistor. These two points are joined together by a straight line and any position along this straight line represents the "Active Region" of the transistor.

Common Emitter Configuration applications

2. Single Stage Common Emitter Amplifier

The actual position of the load line on the characteristics curves can be calculated as follows

$$\text{When}: \left(V_{CE} = 0\right) \;\; I_C = \frac{V_{CC} - 0}{R_L}, \;\; I_C = \frac{V_{CC}}{R_L}$$

$$\text{When}: \left(I_C = 0\right) \;\; 0 = \frac{V_{CC} - V_{CE}}{R_L}, \;\; V_{CC} = V_{CE}$$

- Then, the collector or output characteristics curves for Common Emitter Transistors can be used to predict the Collector current, Ic, when given Vce and the Base current, Ib. A Load Line can also be constructed onto the curves to determine a suitable Operating or Q-point which can be set by adjustment of the base current.

Common Emitter Configuration applications

2. Single Stage Common Emitter Amplifier

Design Steps: Approximate Formulae

1. Choose supply voltage Vcc
2. Choose collector current (IC)
3. Choose transistor (hfe or β=??)
4. Find collector Resistor $R_c \approx (V_{cc}/I_c)/2$
5. Find emitter resistance $R_E \approx 0.1V_{cc}/(I_c/2)$
6. Choose emitter bypass capacitor $C_E = (1/2.\pi.f.R_E)$
7. Find base current $I_B = I_C/\beta$
8. Base voltage $V_{BB} = V_E(0.1V_{cc}) + V_{BE}(0.7V)$
9. Find R1 and R2

   $V_{BB} = (V_{cc} \times R_2/R_1+R_2)$

   choose R1 /R2 and find R2/R1 using above equation