Analog Electronics

Unit 1

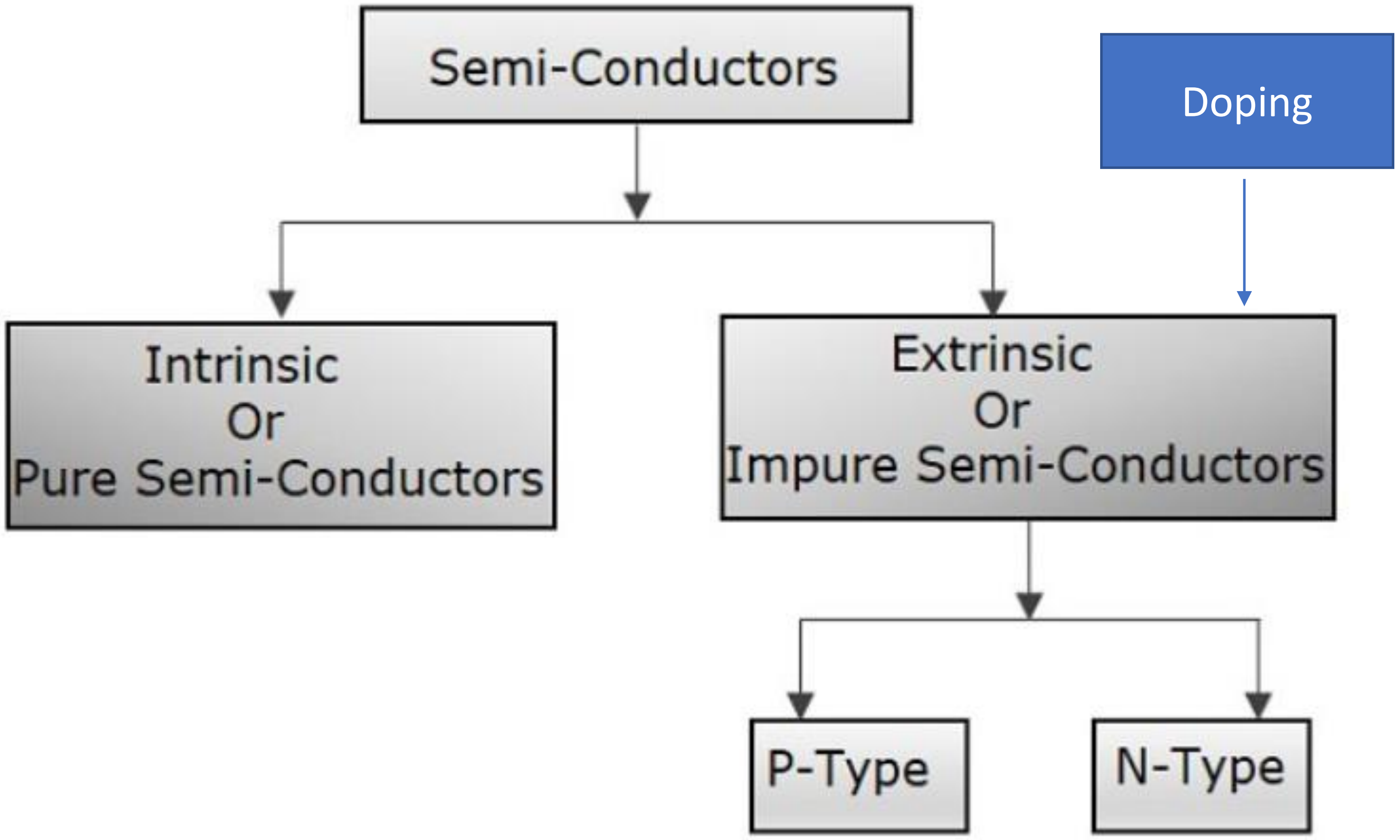
Review of Semiconductors: Energy band structure of Insulator, Semiconductor and Metal, Intrinsic and extrinsic semiconductor.

P-NJunction Diodes, and its application:, clipping and clamping circuits, Rectifiersand filters, Zener diode and regulators.

Semiconductors

- A **semiconductor** is a substance whose resistivity lies between the conductors and insulators.
  - Semiconductors have the resistivity which is less than insulators and more than conductors.
  - Semiconductors have **negative temperature co-efficient**.
  - The **resistance** in semiconductors, **increases with the decrease in temperature** and vice versa.
  - The **Conducting properties** of a Semiconductor **changes**, when a **suitable metallic impurity is added** to it, which is a very important property

Classification of semiconductors

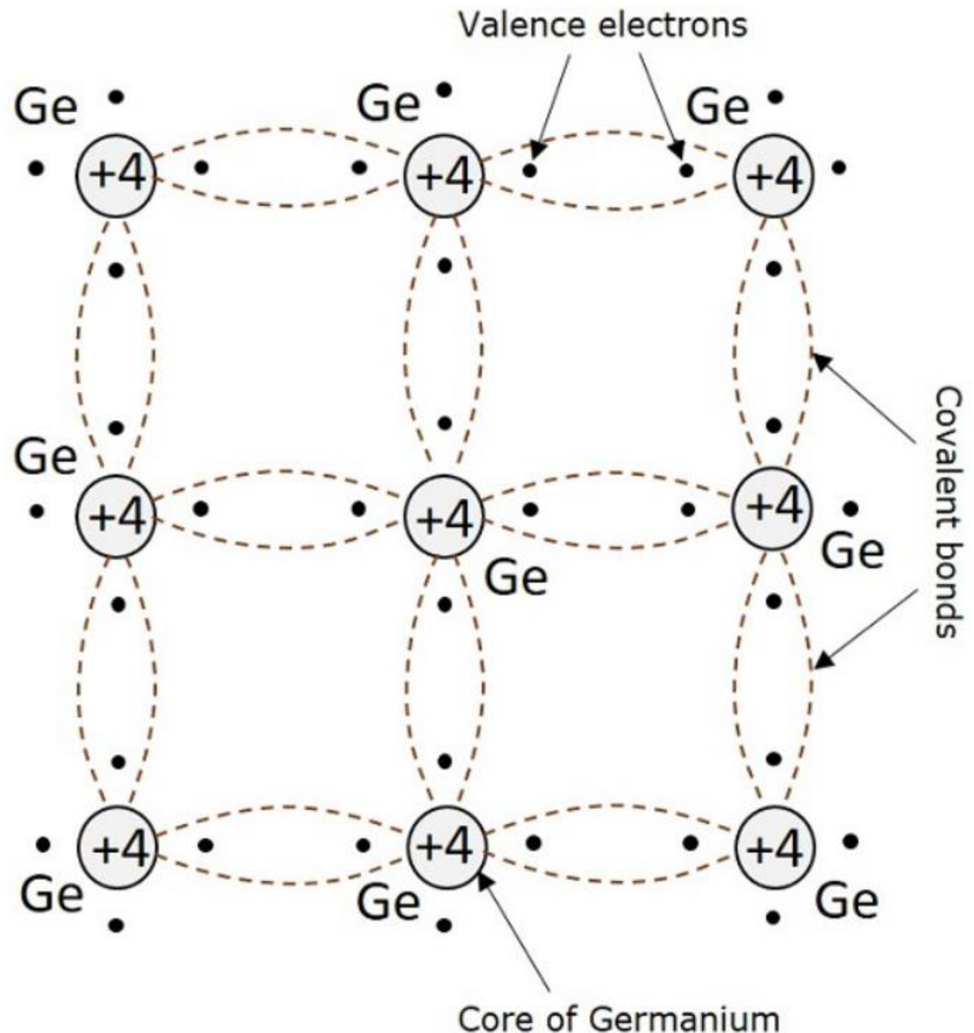


Conduction in Semiconductors

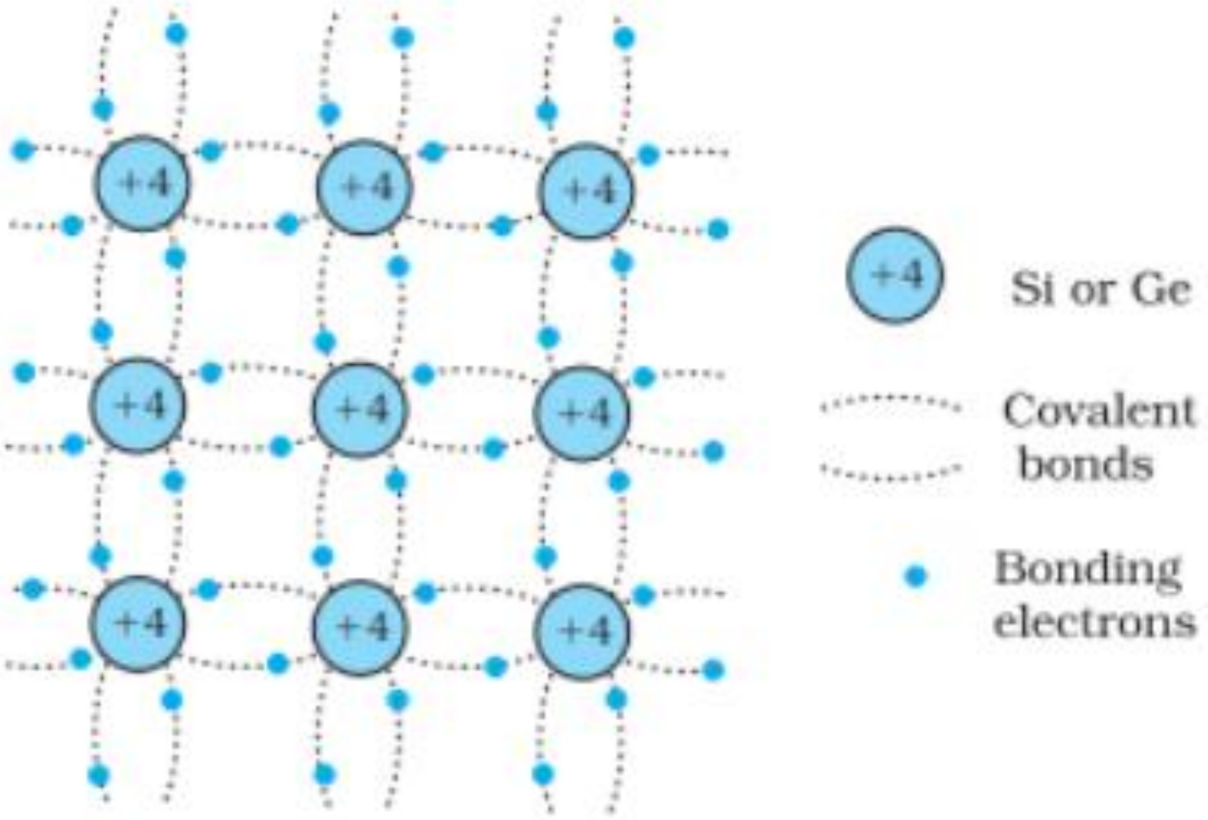
- **Valence electrons:** The outermost shell has the electron which are loosely attached to the nucleus
- Such an atom, having valence electrons when brought close to the other atom, the valence electrons of both these atoms combine to form "**Electron pairs**"
- This bonding is not so very strong and hence it is a **Covalent bond (Sharing)**

Germanium

Electronic configuration:
2 (First orbit), 8, 18,
4 (Last orbit) (Valence els)
Stable Ge (8 els)



Hole generation and movement



Schematic two-dimensional representation of Si or Ge structure showing covalent bonds at low temperature (all bonds intact). +4 symbol indicates inner cores of Si or Ge.

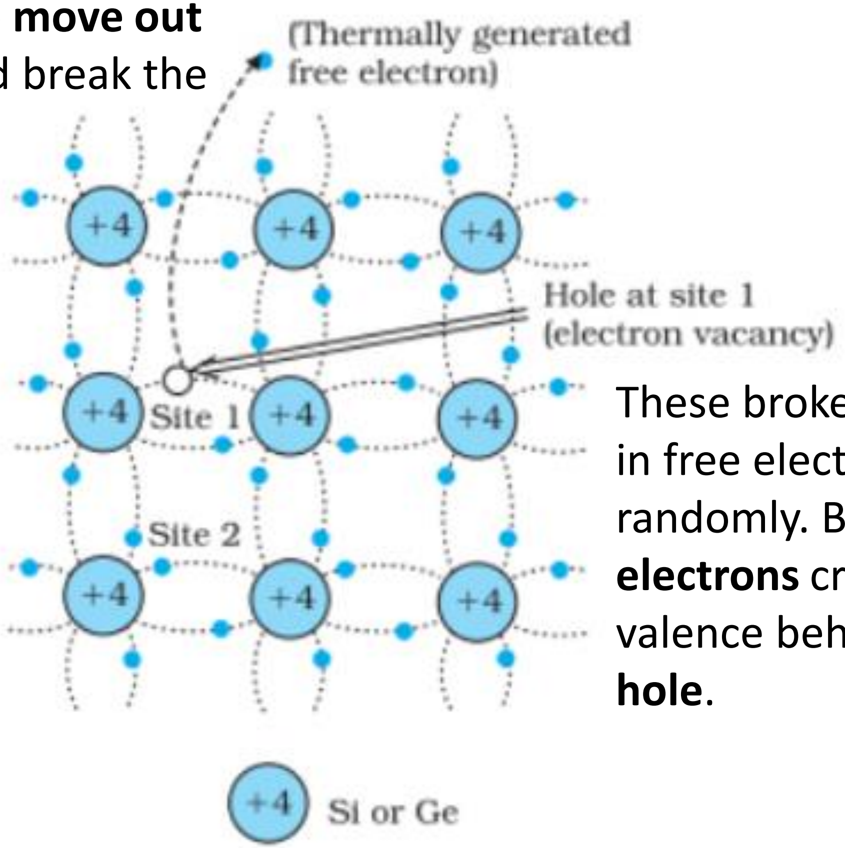
Cont.

(Higher Energy level)CB (Max Freedom) E1

Temperature (E1-E2)

(Lower Energy level)VB (Bonded) E2

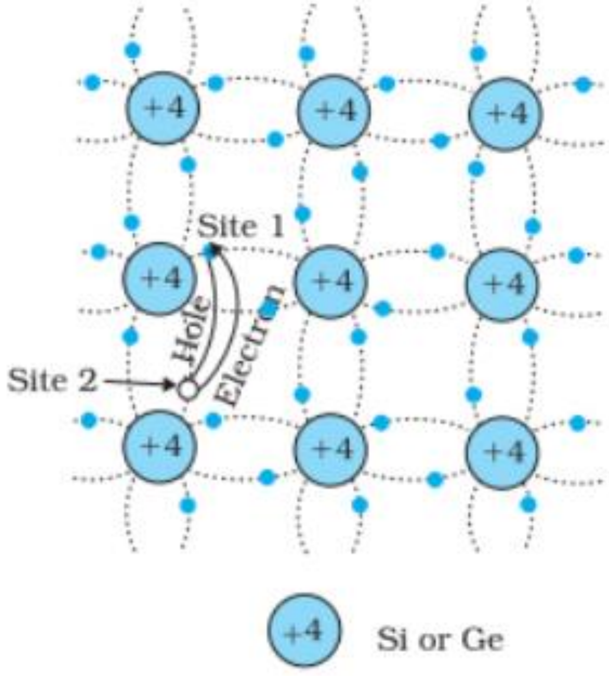
thermal energy
the crystal, some
end to move out
ce and break the
nds.



model of generation of hole at site 1 and conduction electron due to thermal energy at moderate temperatures.

These broken covalent bonds, result in free electrons which wander randomly. But the **moved away electrons** creates an empty space or valence behind, which is called as a **hole**.

This **hole** which represents a **missing electron** can be considered as a **unit positive charge** while the electron is considered as a unit negative charge.



Simplified representation of possible thermal motion of a hole. The electron from the lower left hand cova (site 2) goes to the earlier hole site1, leaving a hole at its site indicating apparent movement of the hole from site 1 to site 2.

Current in semiconductor

Under an electric field, these holes move towards the negative potential generating hole current (I_h). Hence, the total current (I) is:

$$I = I_e + I_h$$

Cont.

Electron-hole generation and recombination

Absorb Energy

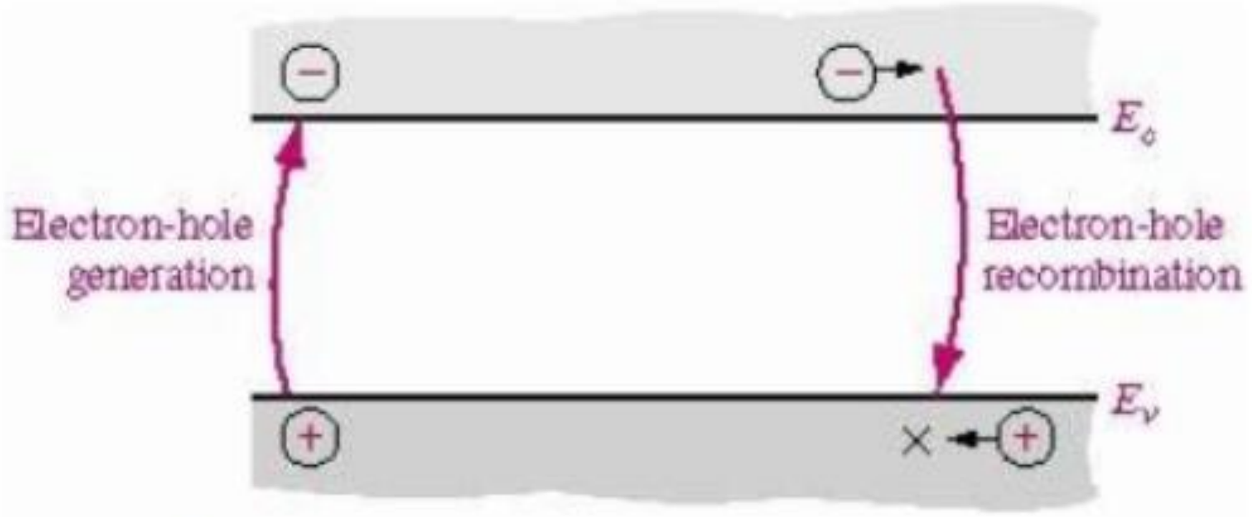
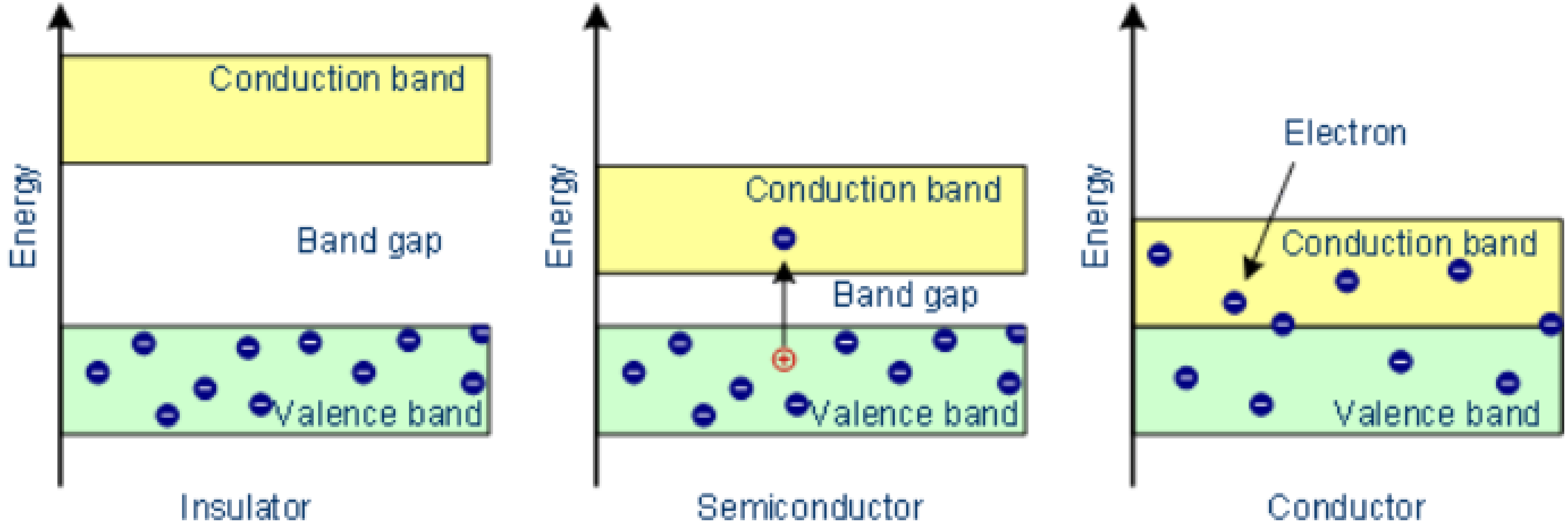


Figure 6.1 | Electron-hole generation and recombination.

Energy Release (Heat or Light)

In the **steady state**, the **thermal generation rate is balanced by the recombination rate**

Energy band structure of Insulator, Semiconductor and Metal



Intrinsic Semiconductors

- A Semiconductor in its extremely **pure form** is said to be an **intrinsic semiconductor**.
- The properties of this pure semiconductor are as follows −
  - The **electrons and holes are solely** created by **thermal excitation**.
  - The number of free **electrons is equal** to the number of **holes**.
  - The **conduction capability is small** at room temperature.
- In order to **increase** the c**onduction** capability of intrinsic semiconductor, it is better to add some impurities.
- This process of adding impurities is called as **Doping**.
- Now, this **doped intrinsic semiconductor** is called as an **Extrinsic Semiconductor**

Doping

- Generally pentavalent and trivalent impurities
- **Pentavalent Impurities**
  - The **pentavalent** impurities are the ones which has **five valence electrons** in the outer most orbit. Example: Bismuth, Antimony, Arsenic, Phosphorus
  - The pentavalent atom is called as a **donor atom** because it **donates one electron to the conduction band** of pure semiconductor atom.
- **Trivalent Impurities**
  - The **trivalent** impurities are the ones which has **three valence electrons** in the outer most orbit. Example: Gallium, Indium, Aluminum, Boron
  - The trivalent atom is called as an **acceptor atom** because it accepts one electron from the semiconductor atom.

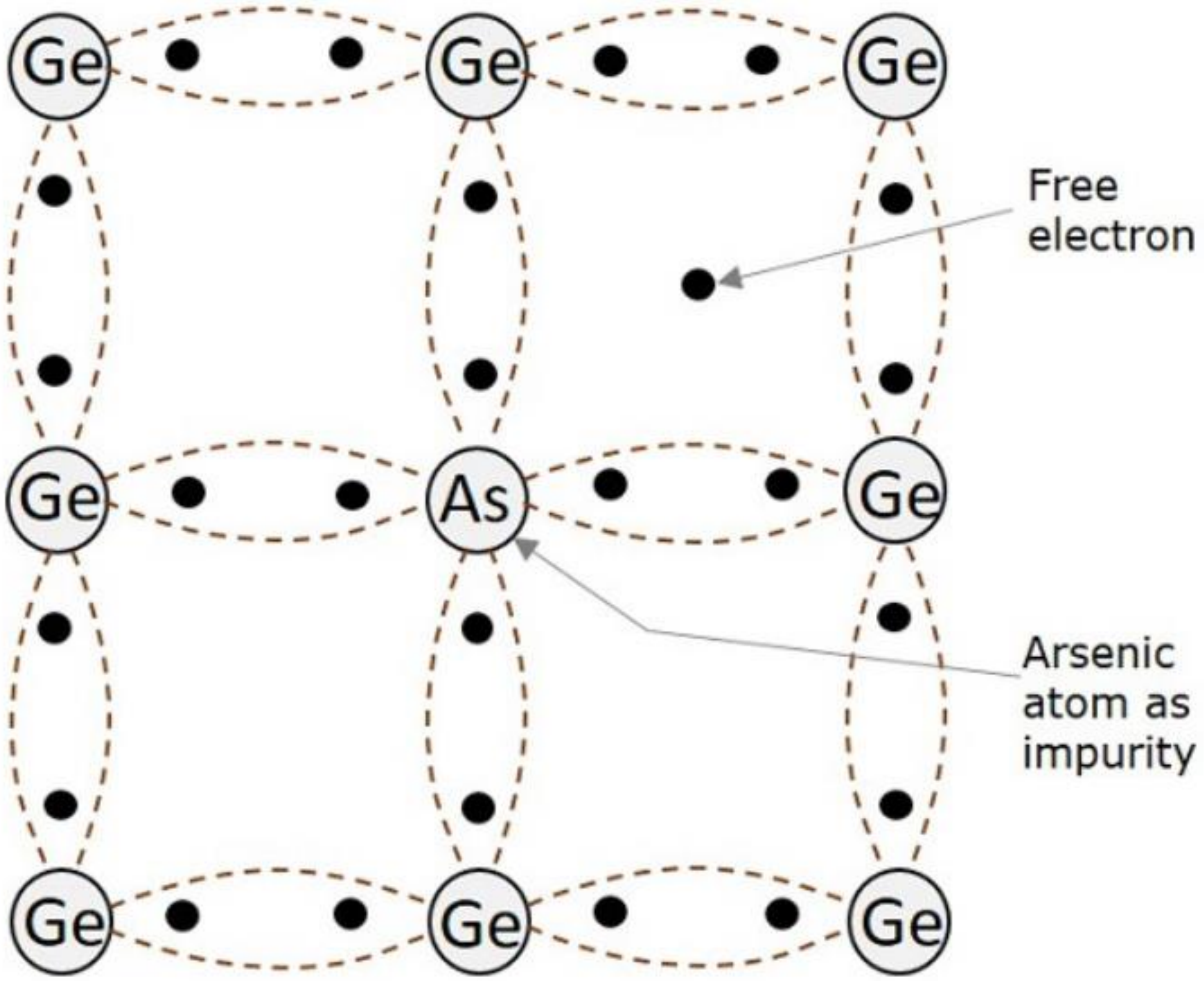
Extrinsic Semiconductor

- An impure semiconductor, which is formed by doping a pure semiconductor is called as an **extrinsic semiconductor**.
- There are two types of extrinsic semiconductors depending upon the type of impurity added.
- They are **N-type extrinsic semiconductor and P-Type extrinsic** semiconductor.

N-Type Extrinsic Semiconductor

• **N-type extrinsic semiconductor**: Conduction takes place through electrons, the **electrons are majority** carriers, and the **holes are minority carriers**.

•As there is no addition of positive or negative charges, the electrons are electrically neutral



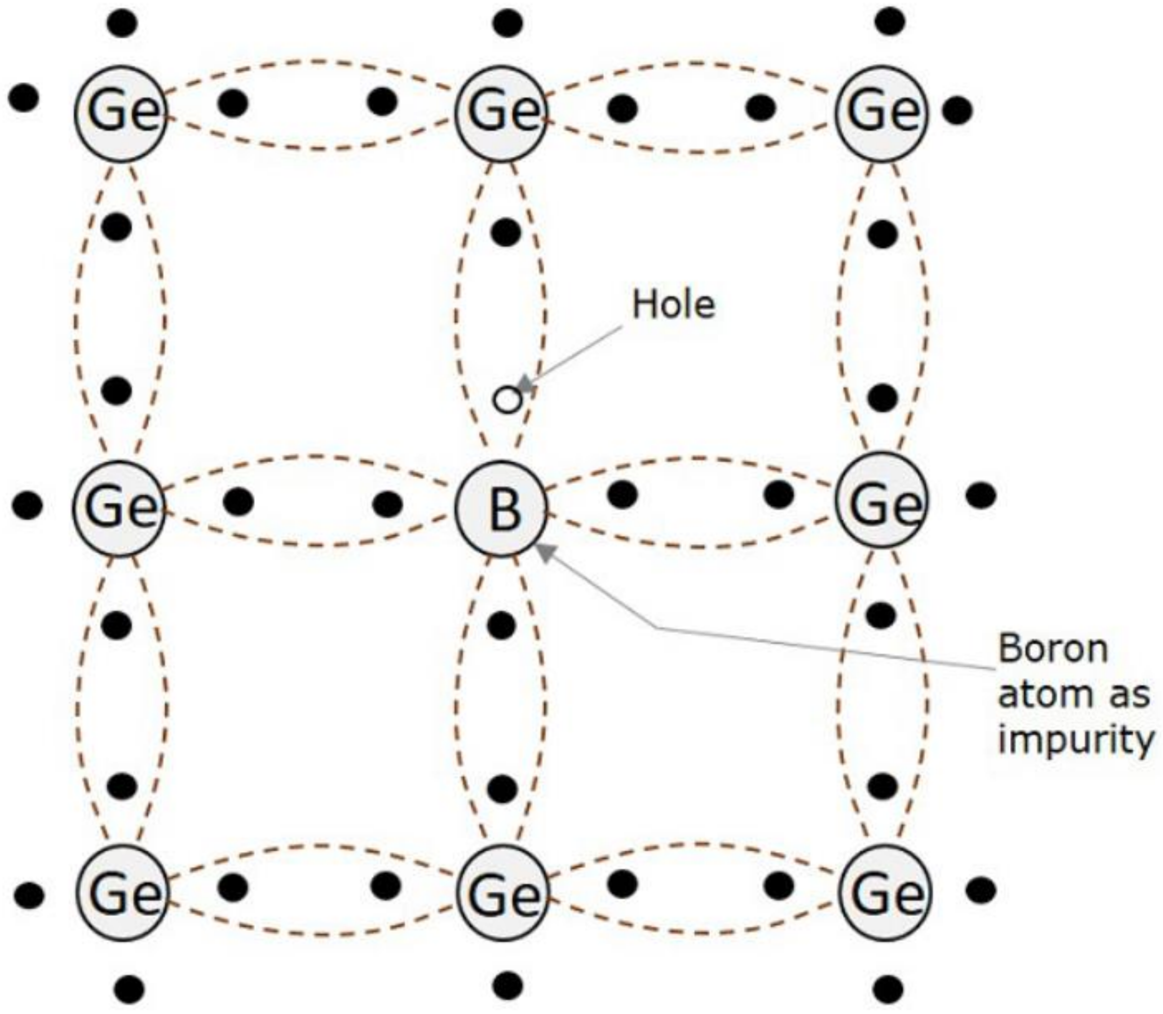
P-Type Extrinsic Semiconductor

•**P-type extrinsic semiconductor**: conduction takes place through holes; the **holes are majority** carriers while the **electrons are minority** carriers.

•The impurity added here provides holes which are called as **acceptors**, because they **accept electrons from the germanium atoms**.

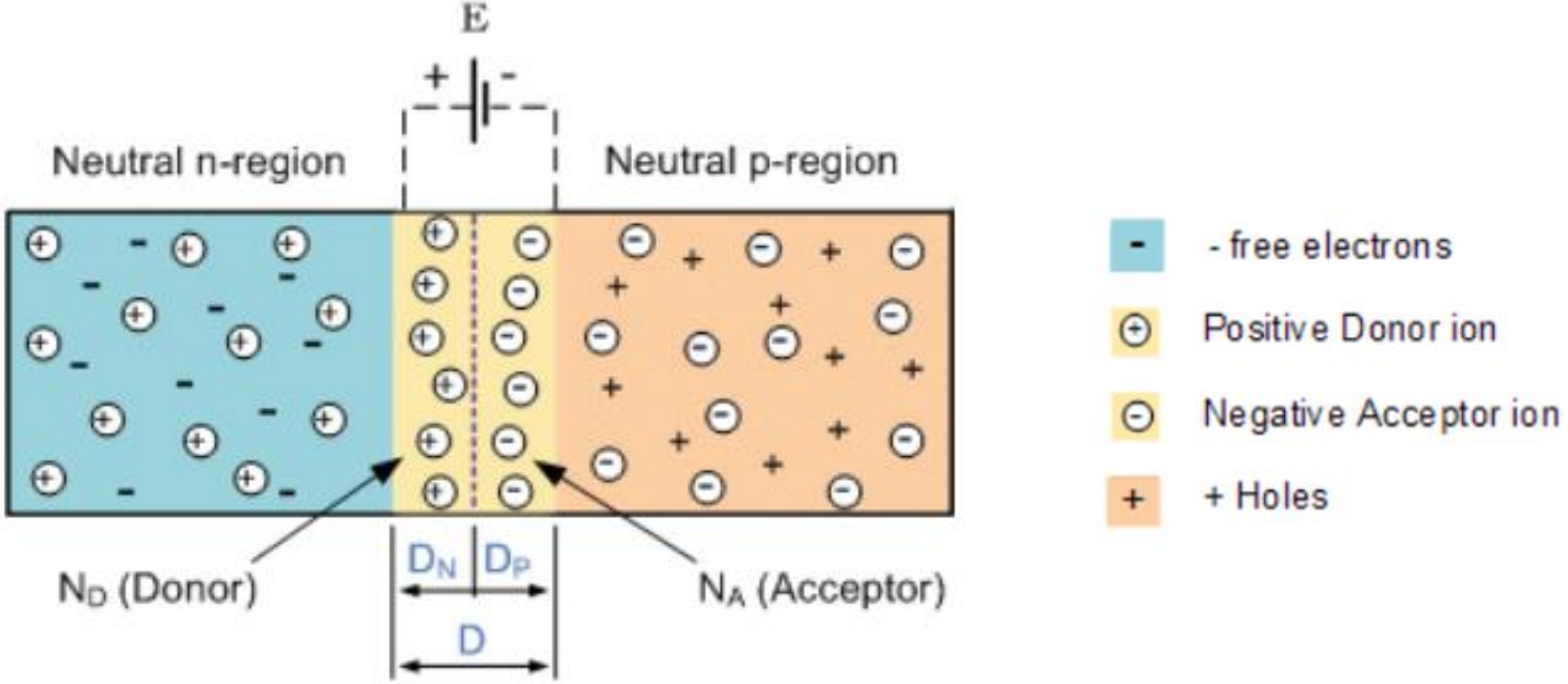
•As the number of mobile holes remains equal to the number of acceptors, the Ptype semiconductor remains electrically neutral.

•In this P-type conductivity, the **valence electrons move from one covalent bond to another**, unlike N-type

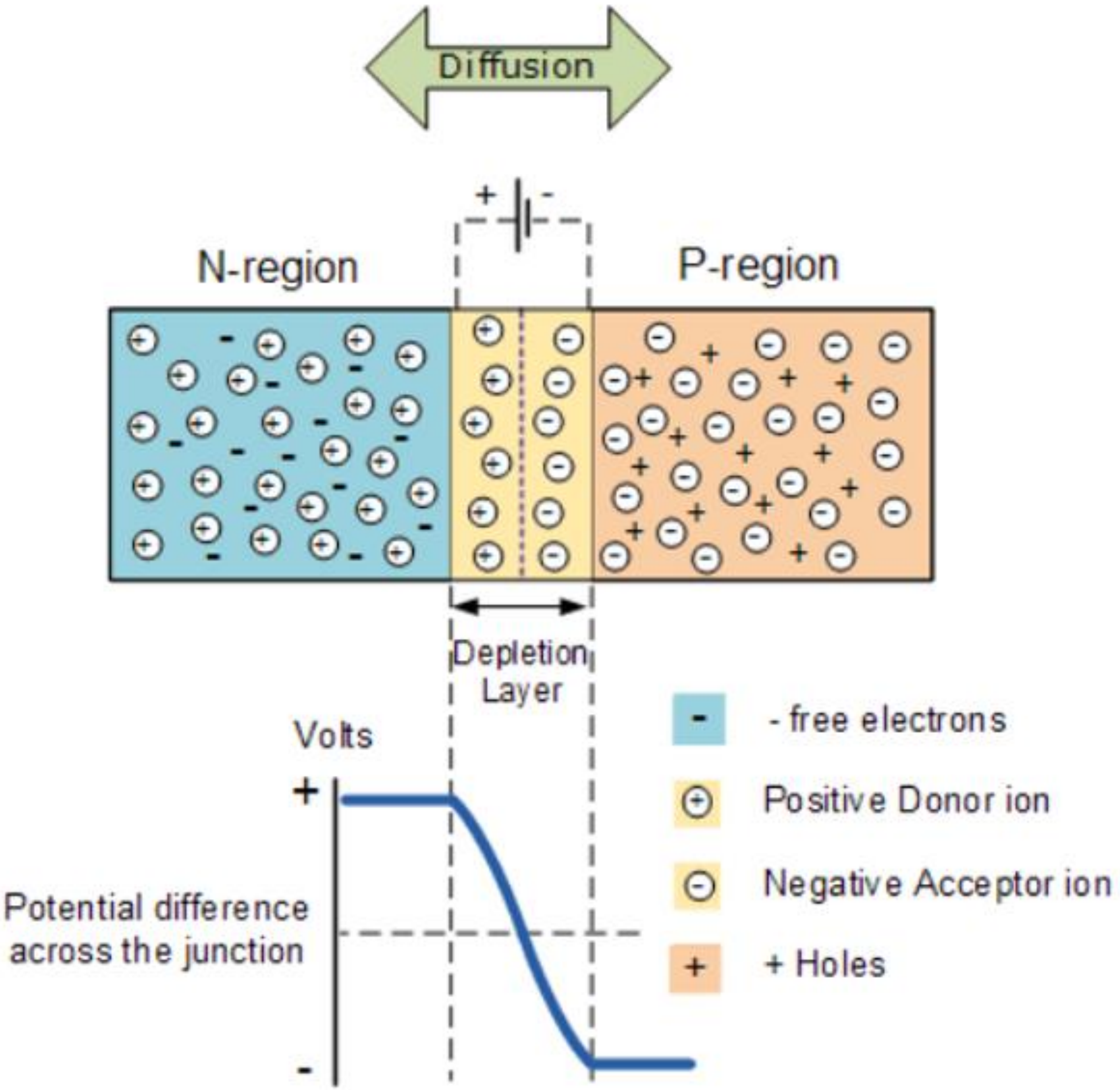


P-N Junction Diode

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

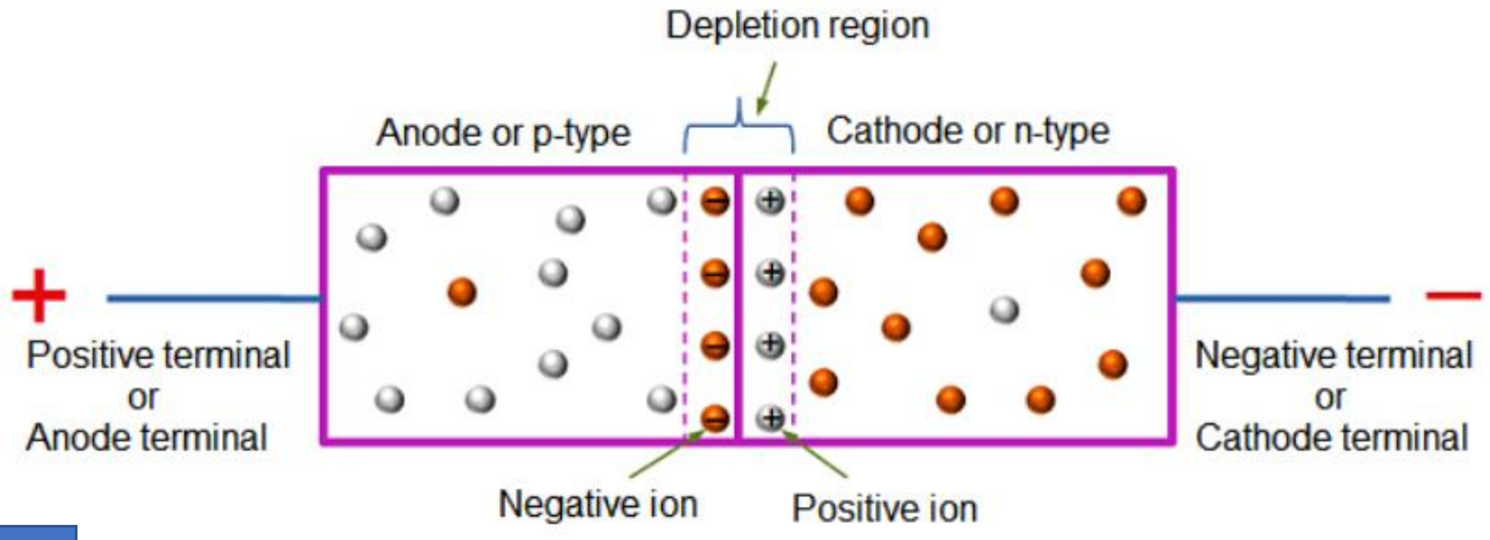


PN Junction

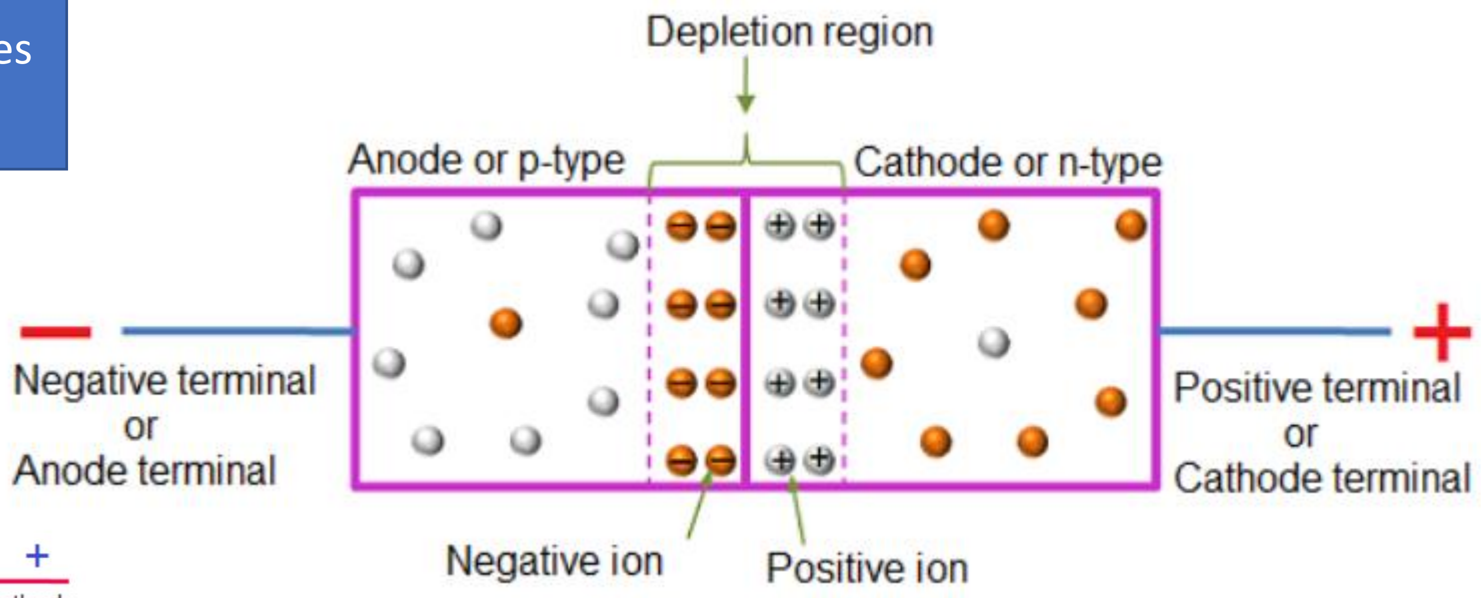

Diffusion
N-region
P-region
Depletion Layer
Volts
Potential difference across the junction
- free electrons
Positive Donor ion
Negative Acceptor ion
+ Holes

PN Junction biasing

Higher Force = 1el and 1Hole (KE) = A = EHP (KE) =A = EHP(KE) = Sufficient Charges = Current



Forward biased



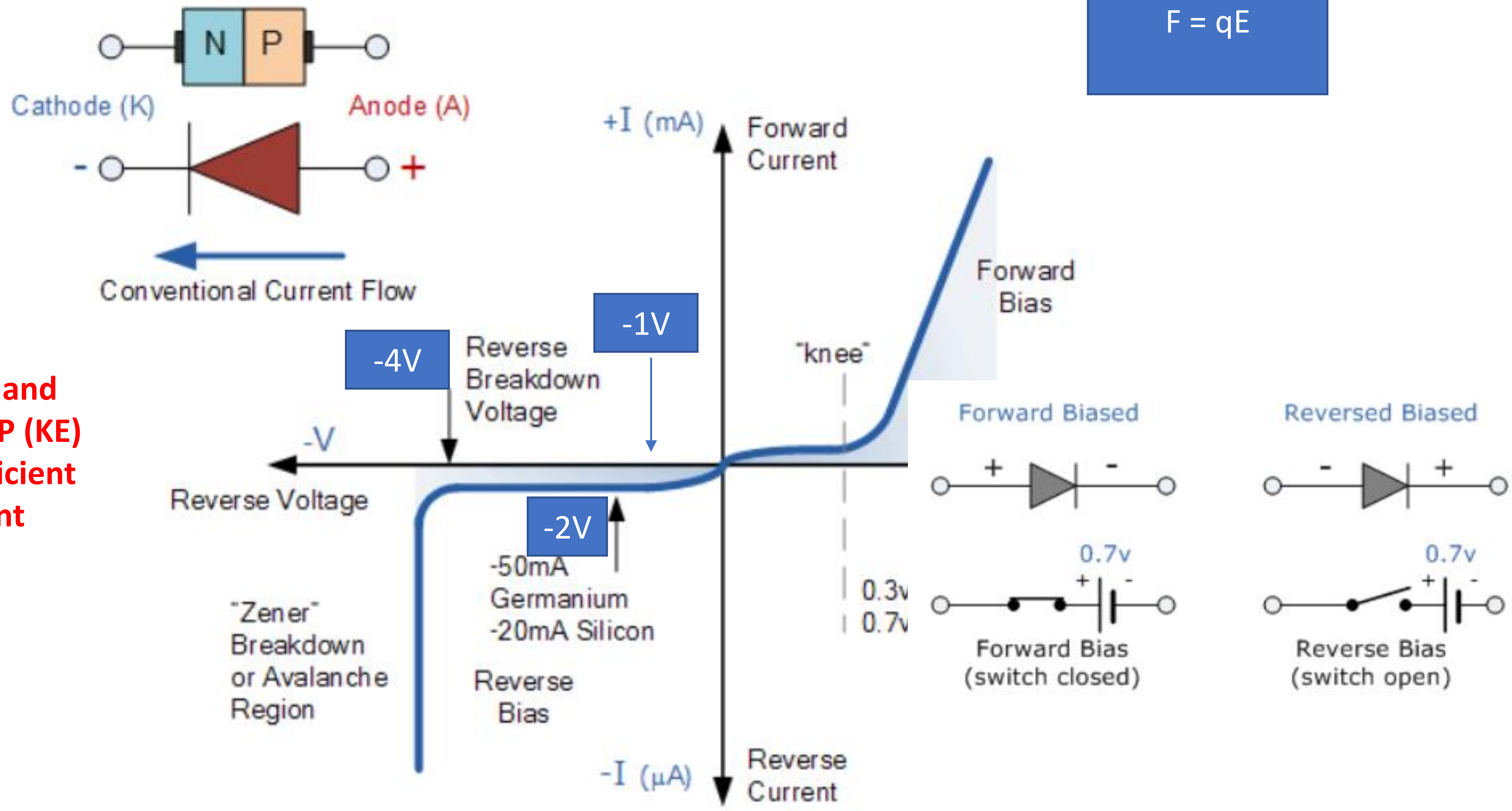
Reverse biased

Forward biased

Reverse biased

PN Junction Diode V-I Characteristics

$E = -dVr/ dx$
$F = qE$



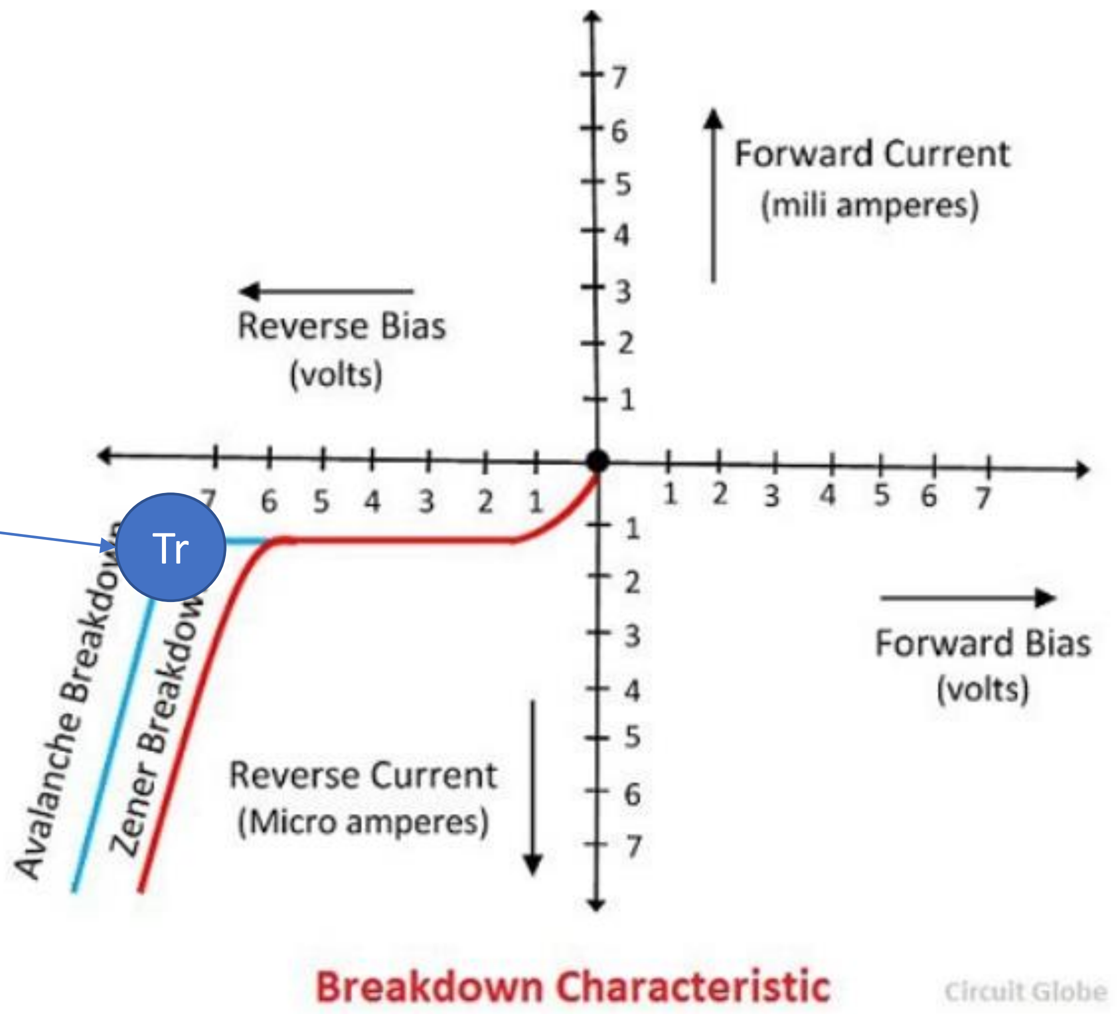
Higher Force = 1el and 1Hole (KE) = A = EHP (KE) =A = EHP(KE) = Sufficient Charges = Current

Breakdown

Breakdown Characteristic Graph

The graphical representation of the Avalanche and Zener breakdown is shown in the figure below.

Multiplicative Action (Chain reaction)

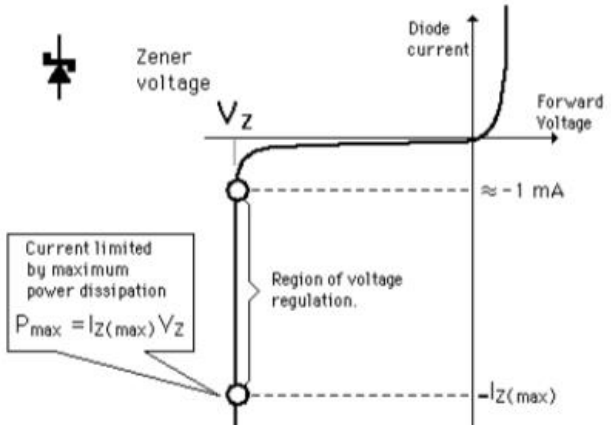


What is Breakdown?

- Deleterious effect that occurs in the presence of **<u>high electric field.</u>**
- Causes **<u>high resistance</u>** elements to allow flow of **<u>high current.</u>**

Avalanche/Zener Breakdown

- 'Zener diode' and 'avalanche diode' are terms often used interchangeably.
- Both refer to breakdown of a diode under reverse bias.



Avalanche/Zener Breakdown (con't)

- ***Reverse bias*** = Very little current flow
  = Open circuit

- As <u>Reverse voltage</u> $\uparrow$ a point is reached where <u>current</u> $\uparrow$ dramatically, therefore <u>dynamic resistance</u> $\downarrow$.

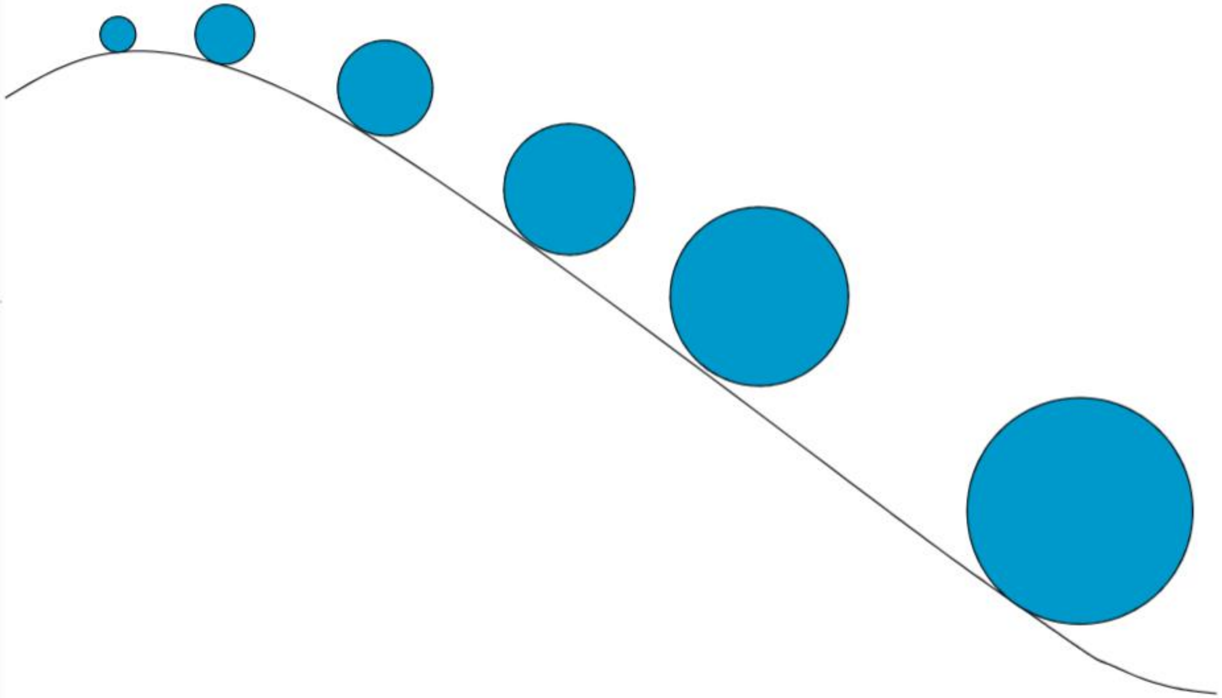
$\Rightarrow$ Very few electrons make it through depletion region with high velocity

$\Rightarrow$ These electrons collide with atoms in the depletion region and free more electrons (Process called <u>*Multiplication*</u>).

$\Rightarrow$ <u>Results</u> in higher and higher current flow

Avalanche Breakdown (con't)

By analogy, the process is named because a single carrier can spawn literally thousands of additional carriers through collisions, just as a single snowball can cause an avalanche.

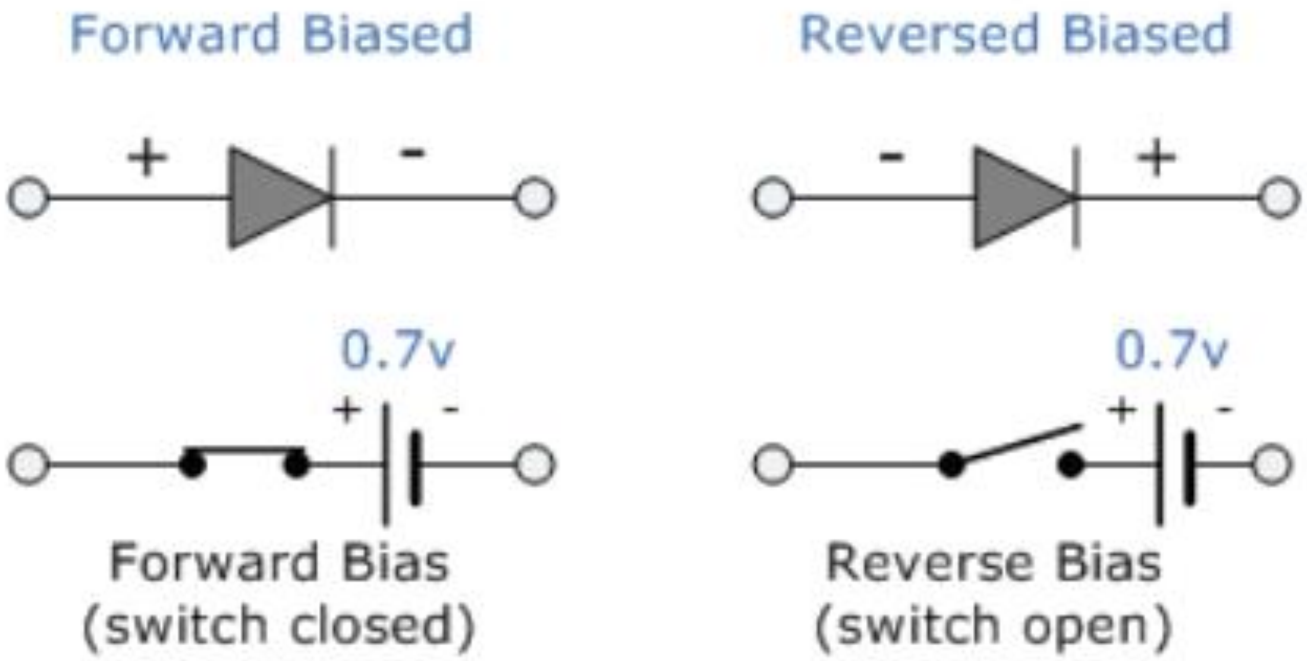


Zener Breakdown (DR = 1:10^4) ND(1:10^8)

- The **width of the depletion region** depends on the **doping** of the P and N-type semiconductor material.
- If the material is **heavily doped**, the **width** of the depletion region becomes **very thin.**
- The phenomenon of the **Zener breakdown** occurs in the **very thin depletion region**.
- The thin depletion region has more numbers of free electrons. The reverse bias applies across the PN junction develops the electric field intensity across the depletion region.
- The **strength of the electric field intensity becomes very high.**

P-N Junction Diodes application

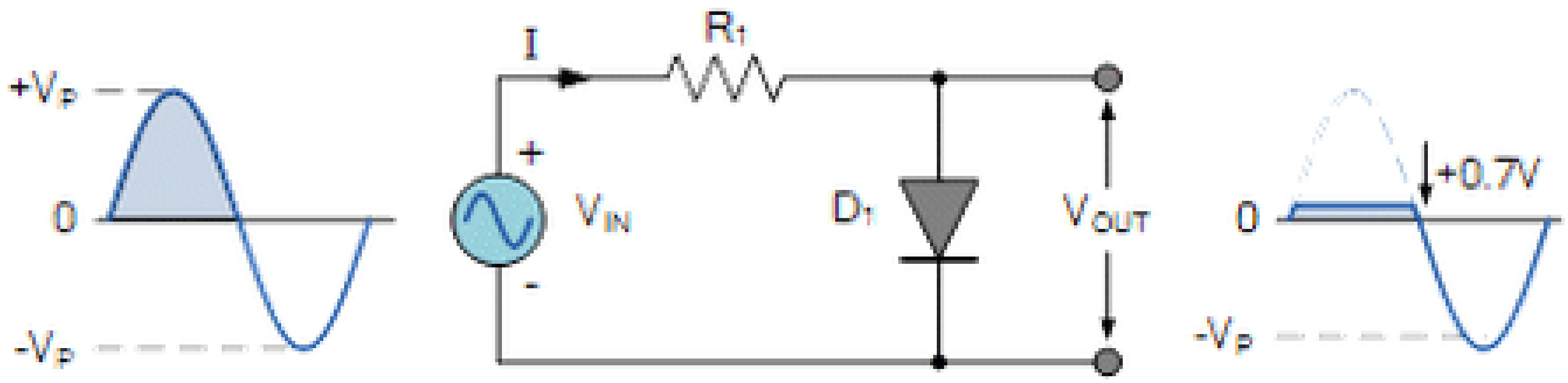
- Clipping and clamping circuits
- Rectifiers
- Filters
- Zener diode and regulators



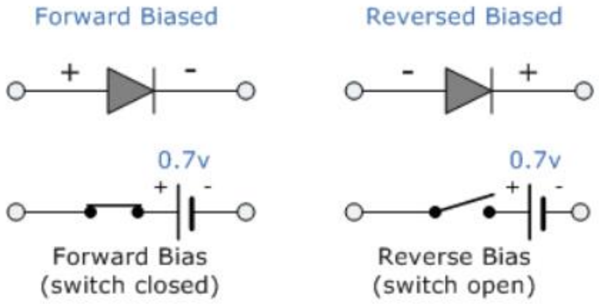
Clipping and clamping circuits (Clipper and Clamper)

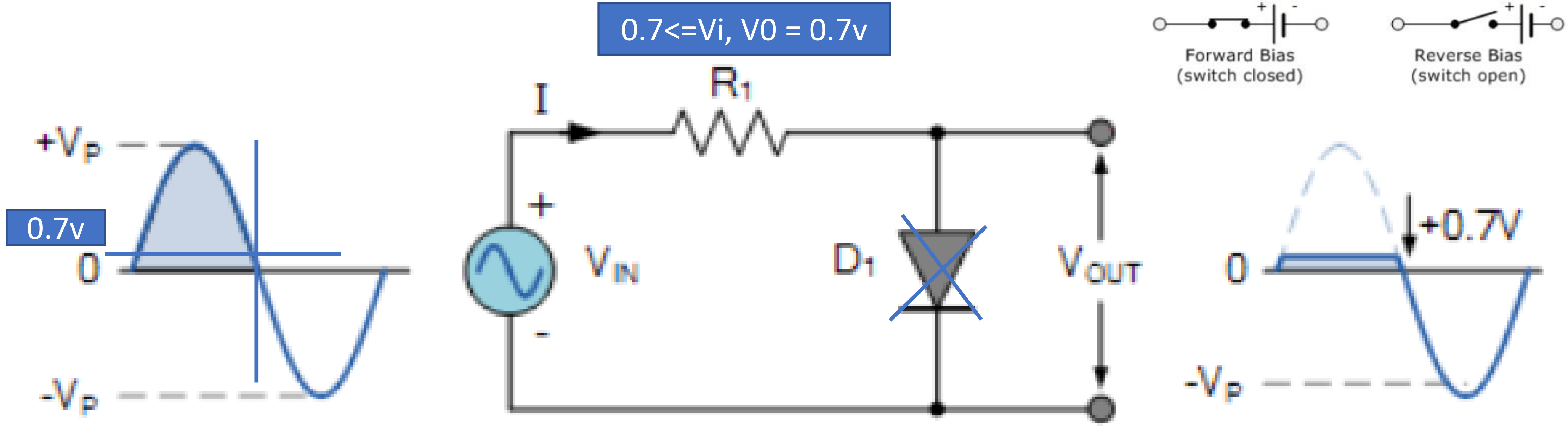
Diode Clipping Circuits

The **Diode Clipper**, also known as a *Diode Limiter*, is a **wave shaping circuit** that takes an input waveform and **clips or cuts off** its top half, bottom half or both halves together.

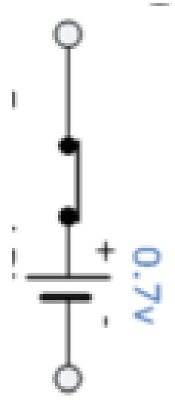


Positive Diode Clipping Circuits

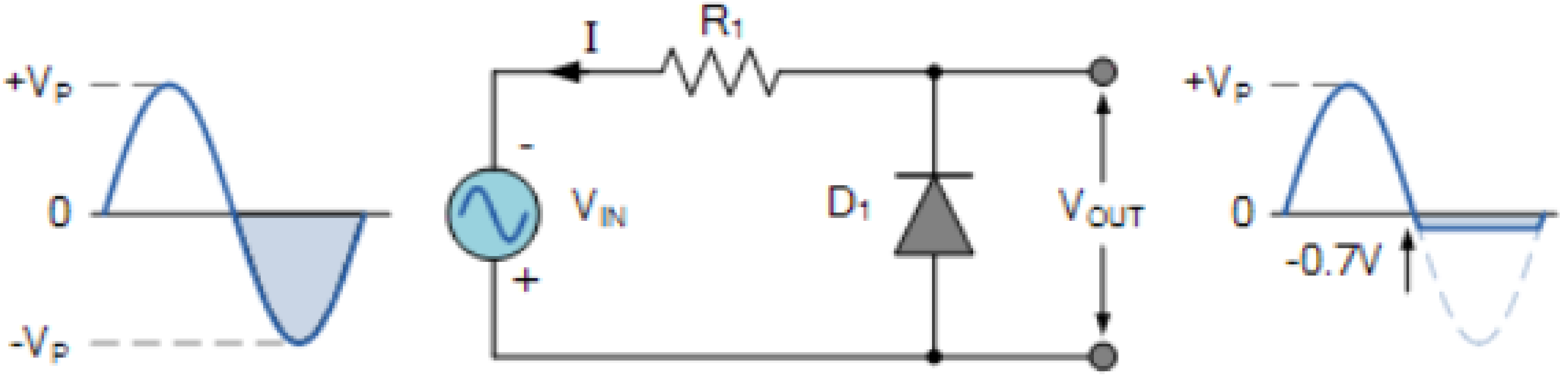




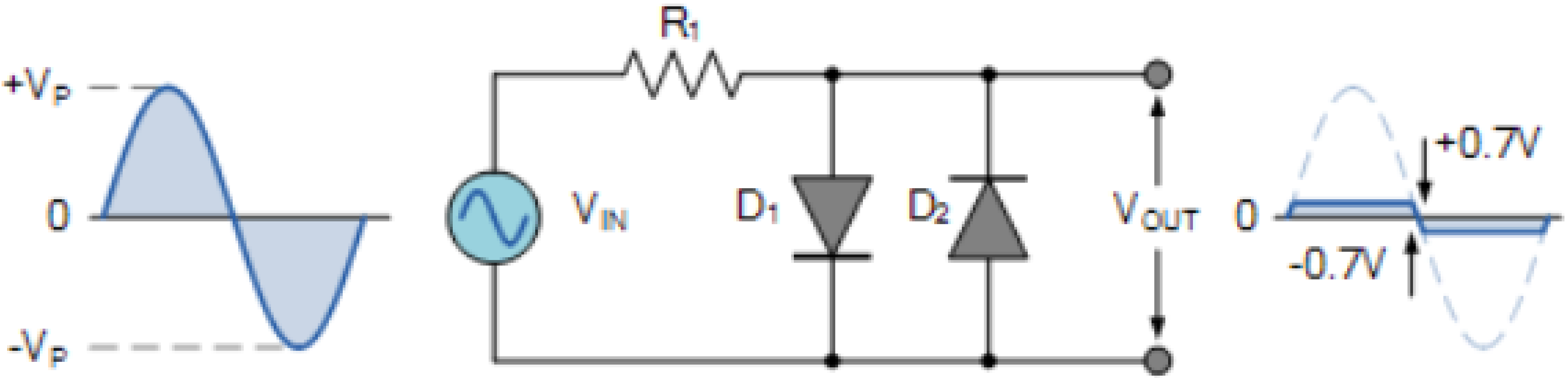
- In +ve cycle when IP voltage is greater then the 0.7(si) and 0.3ge the diodes begins to conduct and holds the voltage across itself constant at 0.7V until the sinusoidal waveform falls below this value.
- Thus the output voltage which is taken across the diode **can never exceed 0.7 volts** during the **positive half cycle**.



Negative Diode Clipping Circuits



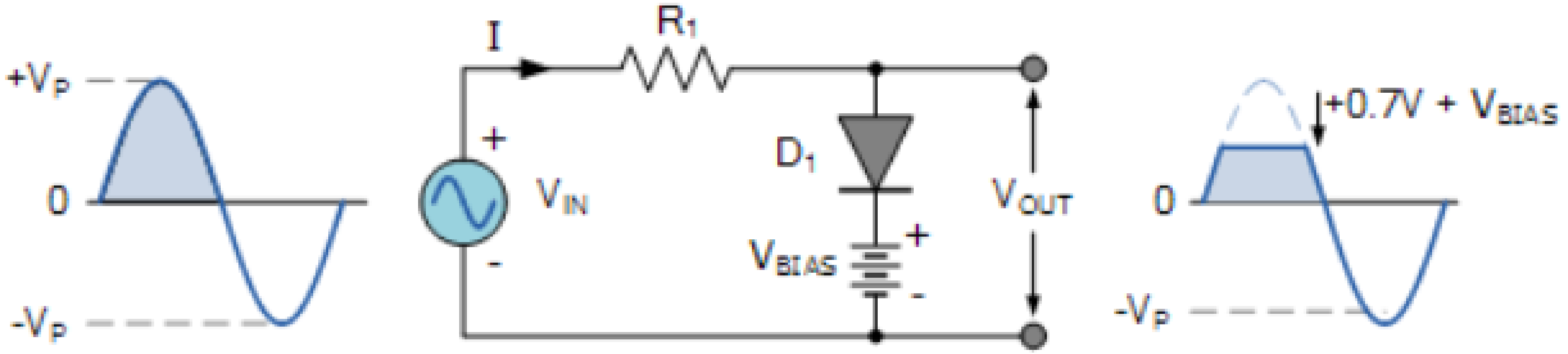
Clipping of Both Half Cycles



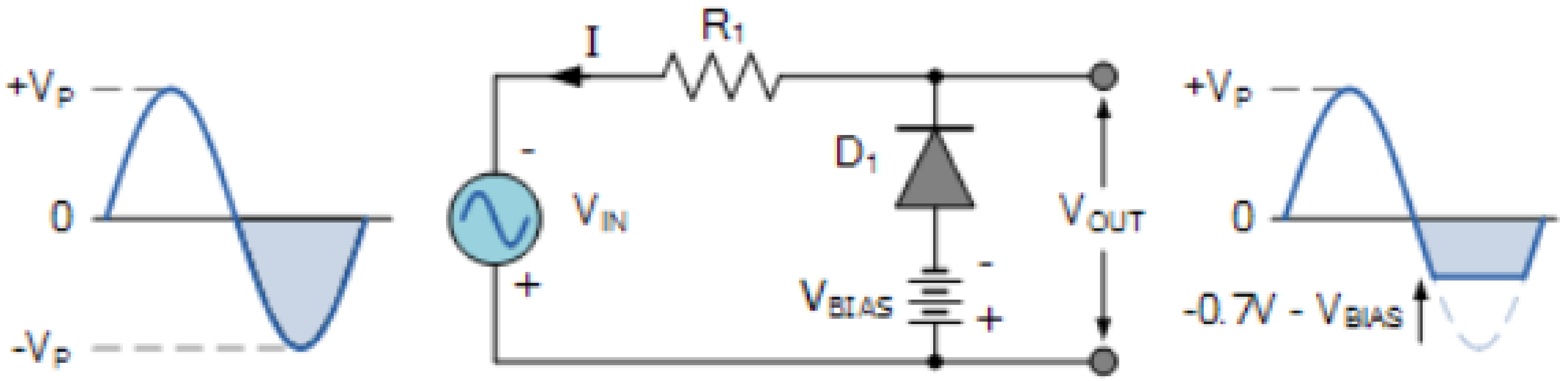
Biased Diode Clipping Circuits

To produce diode clipping circuits for **voltage waveforms at different levels**, a bias voltage, V_{BIAS} is added in series with the diode to produce a combination clipper as shown.

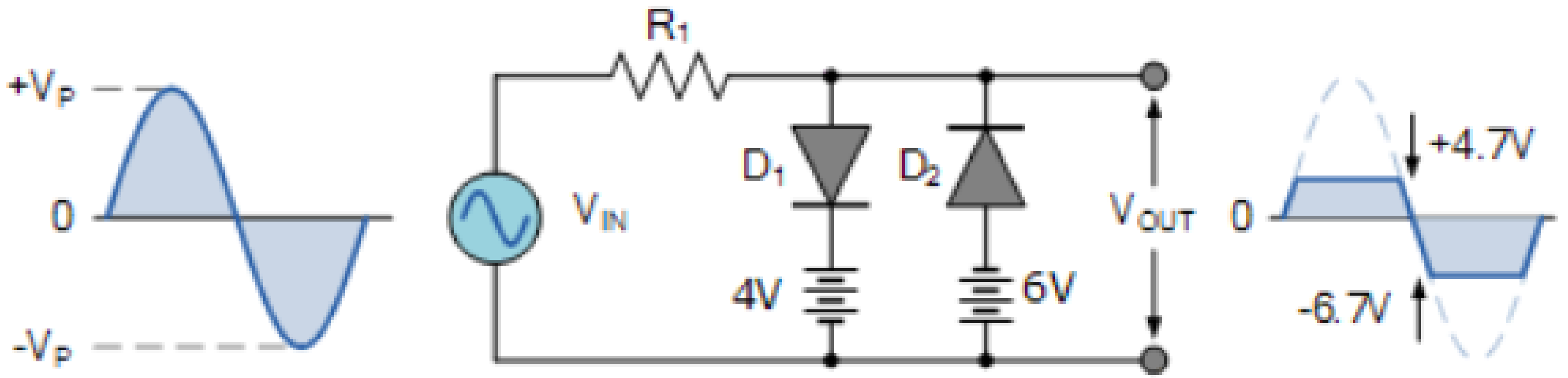
Positive Bias Diode Clipping



Negative Bias Diode Clipping

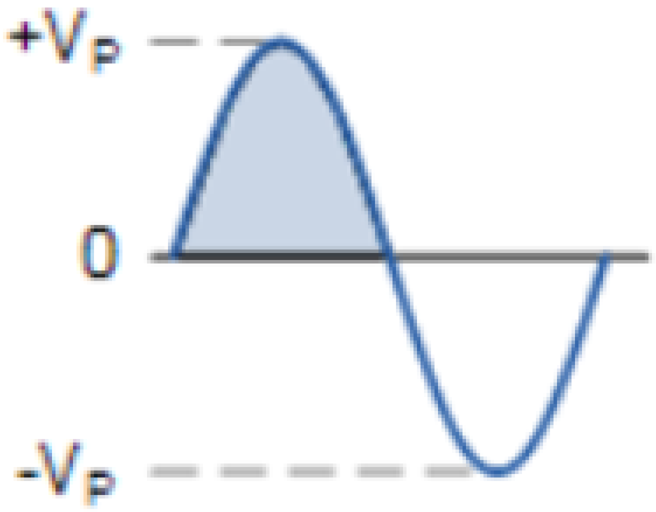


Diode Clipping of Different Bias levels



Clamper Circuits

- A Clamper Circuit is a circuit that **adds a DC level** to an **AC signal.**
- The positive and negative peaks of the signals can be placed at desired levels using the clamping circuits.
- As the DC level gets shifted, a clamper circuit is called as a **Level Shifter**.
- Clamper circuits consist of energy storage elements like **capacitors**. A simple clamper circuit comprises of a **capacitor, a diode, a resistor and a dc battery** if required.

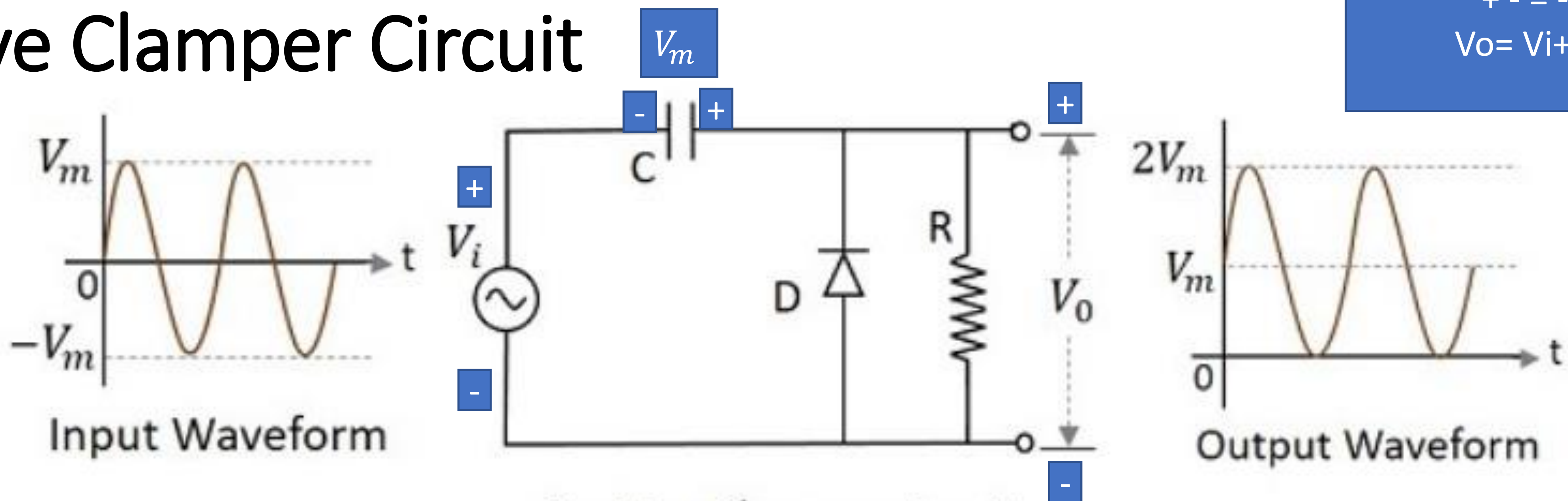


Types of Clampers

There are few types of clamper circuits, such as

- Positive Clamper
- Positive clamper with positive V_r
- Positive clamper with negative V_r
- Negative Clamper
- Negative clamper with positive V_r
- Negative clamper with negative V_r

Positive Clamper Circuit



Positive Clamper circuit

+ - = - +
Vo= Vi+Vm

In order to maintain the time period of the wave form, the **tau** must be greater than, half the time period

Discharging time of the capacitor should be slow.

$$\tau = Rc$$

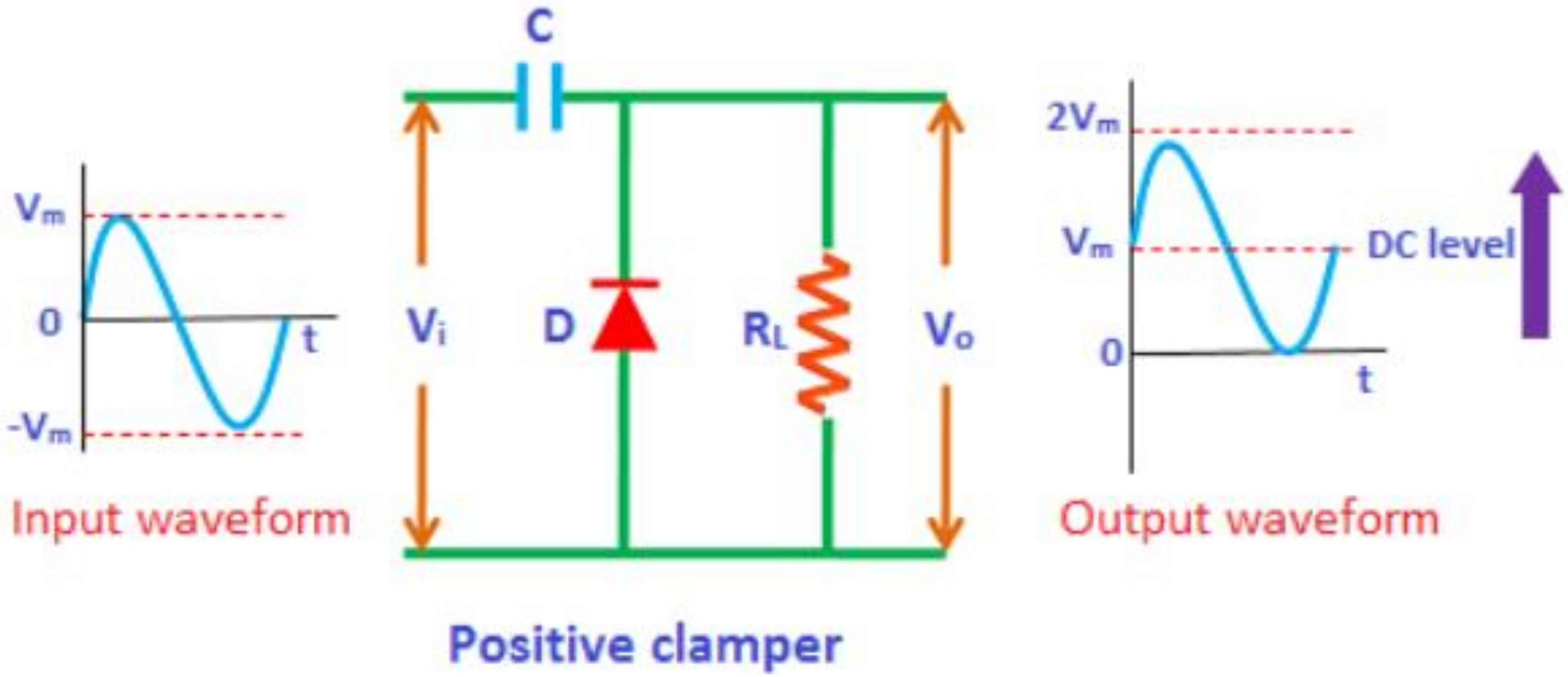
Where

- R is the resistance of the resistor employed
- C is the capacitance of the capacitor used

$$V_0 = V_i + V_m$$

Vi = 0
Vo = Vm,
Vi = Vm
Vo = 2Vm
Vi = -Vm
Vo = 0

Cont.

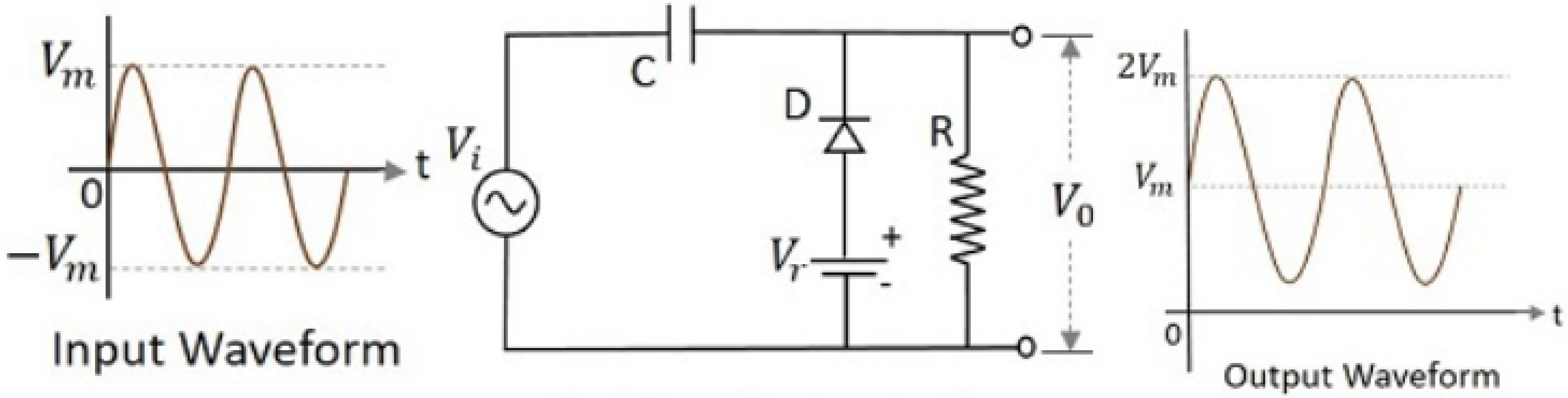


C
V_m
0
t
$-V_m$
Input waveform
V_i
D
R_L
V_o
$2V_m$
V_m
DC level
0
t
Output waveform
Positive clamper

Biased Clamper

Positive Clamper with Positive V_r

A Positive clamper circuit if biased with some positive reference voltage, that voltage will be added to the output to raise the clamped level. Using this, the circuit of the positive clamper with positive reference voltage is constructed as below.

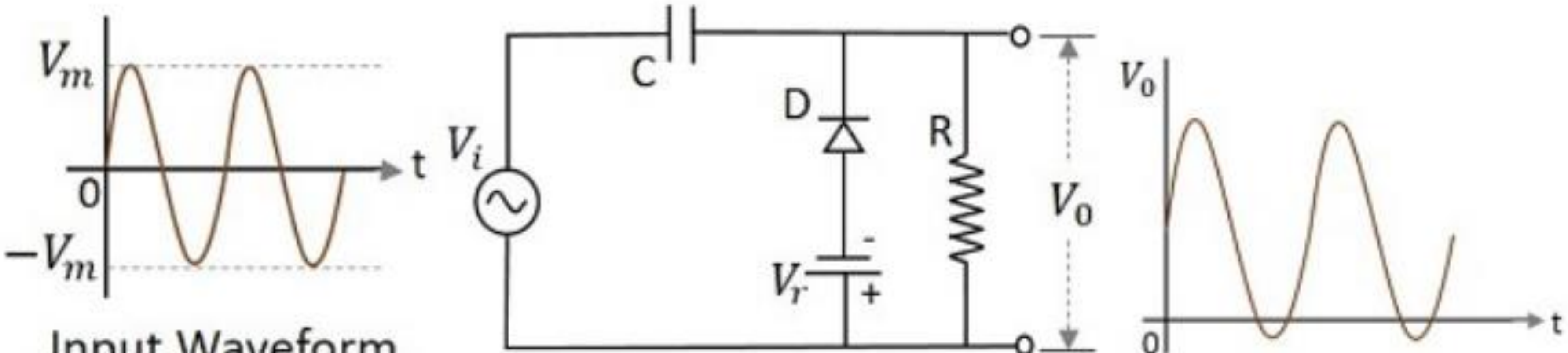


Positive Clamper with positive reference V_r

FB Voltage for diode = -Vm-Vr

Positive Clamper with Negative V_r

A Positive clamper circuit if biased with some negative reference voltage, that voltage will be added to the output to raise the clamped level. Using this, the circuit of the positive clamper with positive reference voltage is constructed as below.



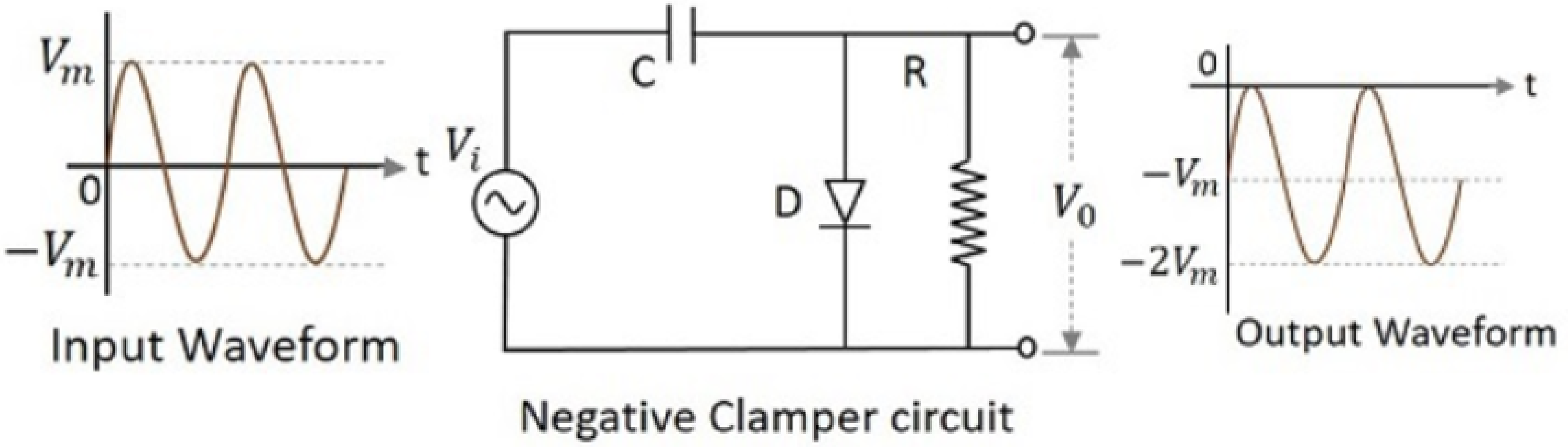
Input Waveform

Positive Clamper with negative reference V_r

Output Waveform

Negative Clamper

A Negative Clamper circuit is one that consists of a diode, a resistor and a capacitor and that shifts the output signal to the negative portion of the input signal. The figure below explains the construction of a negative clamper circuit.

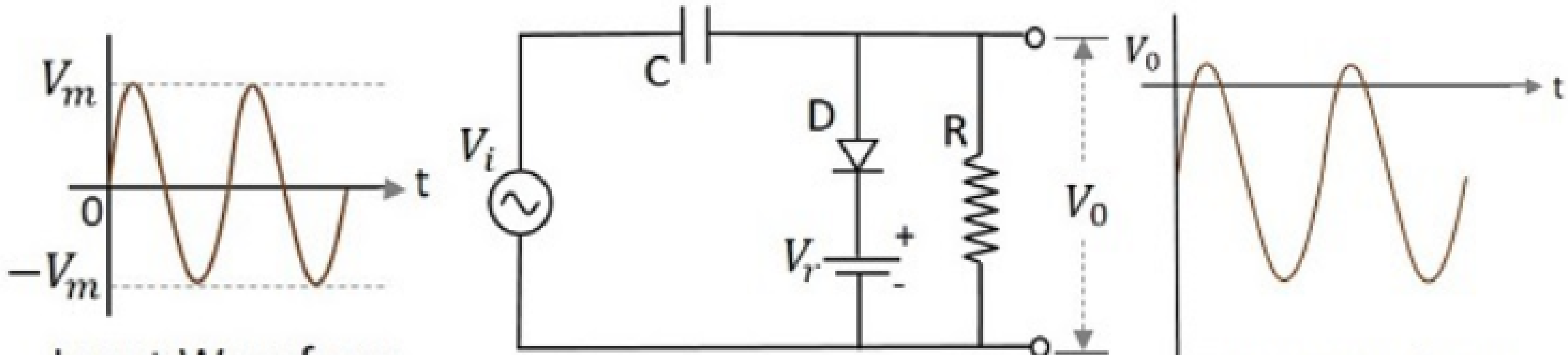


During the positive half cycle, the capacitor gets charged to its peak value v_m. The diode is forward biased and conducts. During the negative half cycle, the diode gets reverse biased and gets open circuited. The output of the circuit at this moment will be

Vo = Vi-Vm

Negative clamper with positive V_r

A Negative clamper circuit if biased with some positive reference voltage, that voltage will be added to the output to raise the clamped level. Using this, the circuit of the negative clamper with positive reference voltage is constructed as below.



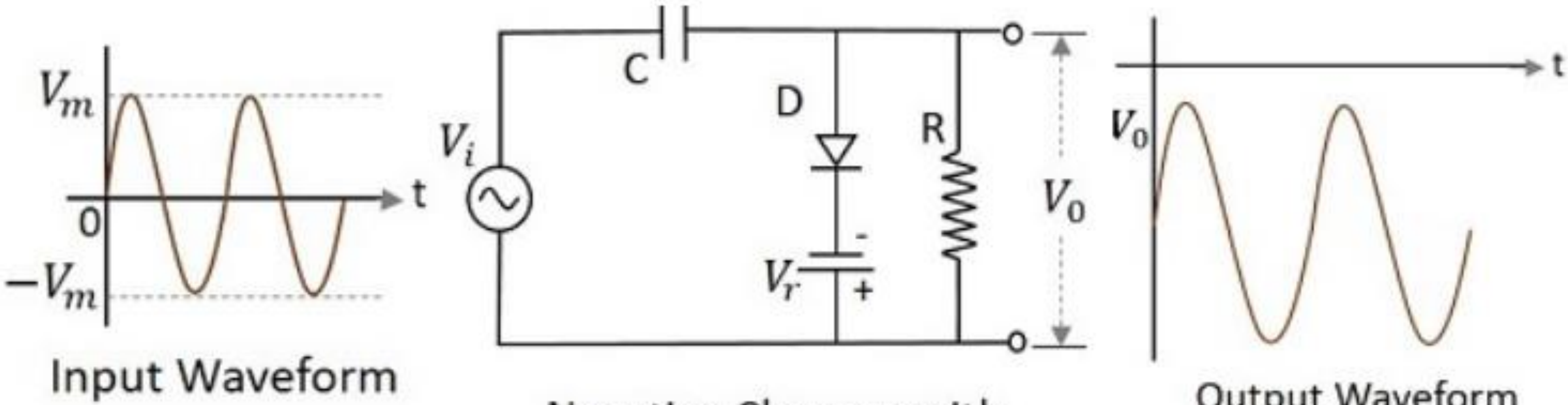
Input Waveform

Negative Clamper with positive reference V_r

Output Waveform

Negative Clamper with Negative V_r

A Negative clamper circuit if biased with some negative reference voltage, that voltage will be added to the output to raise the clamped level. Using this, the circuit of the negative clamper with negative reference voltage is constructed as below.



Negative Clamper with negative reference V_r.

Applications

There are many applications for both Clippers and Clampers such as

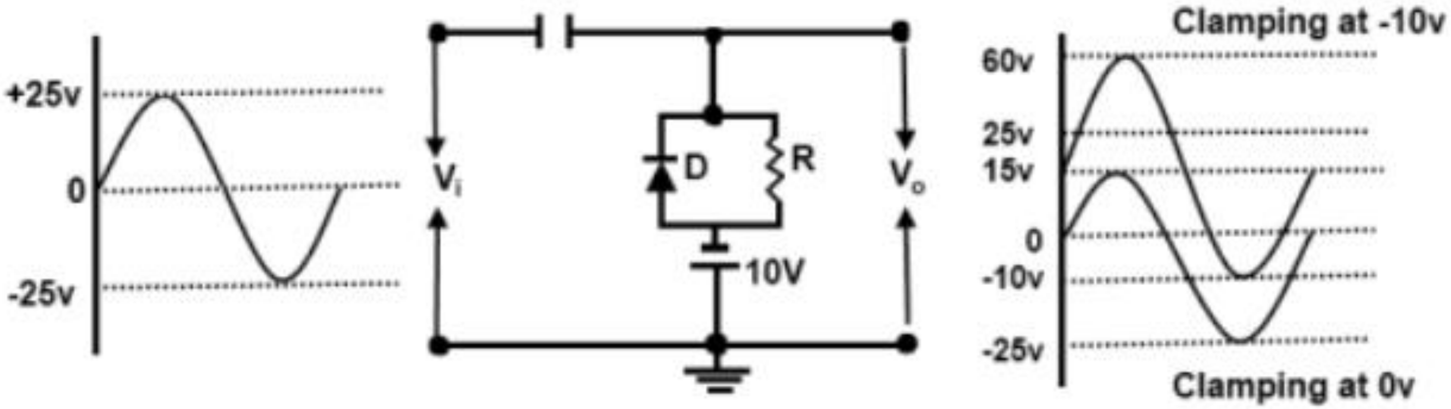
Clippers

- Used for the generation and shaping of waveforms
- Used for the protection of circuits from spikes
- Used for amplitude restorers
- Used as voltage limiters
- Used in television circuits
- Used in FM transmitters

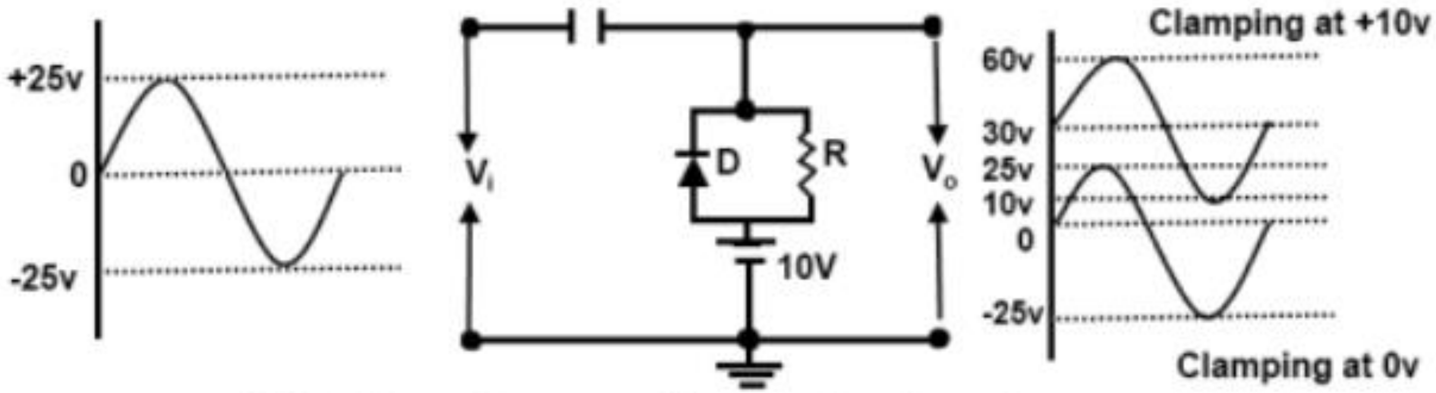
Clampers

- Used as direct current restorers
- Used to remove distortions
- Used as voltage multipliers
- Used for the protection of amplifiers
- Used as test equipment
- Used as base-line stabilizer

Examples



(a) Positive clamper with positive biased



(b) Positive clamper with negative biased

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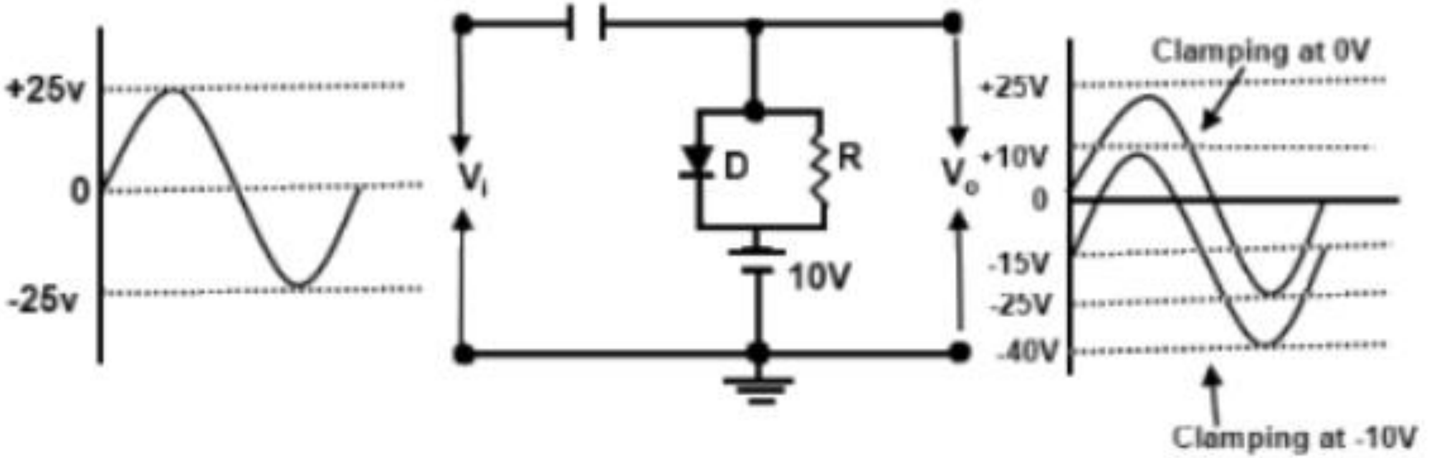
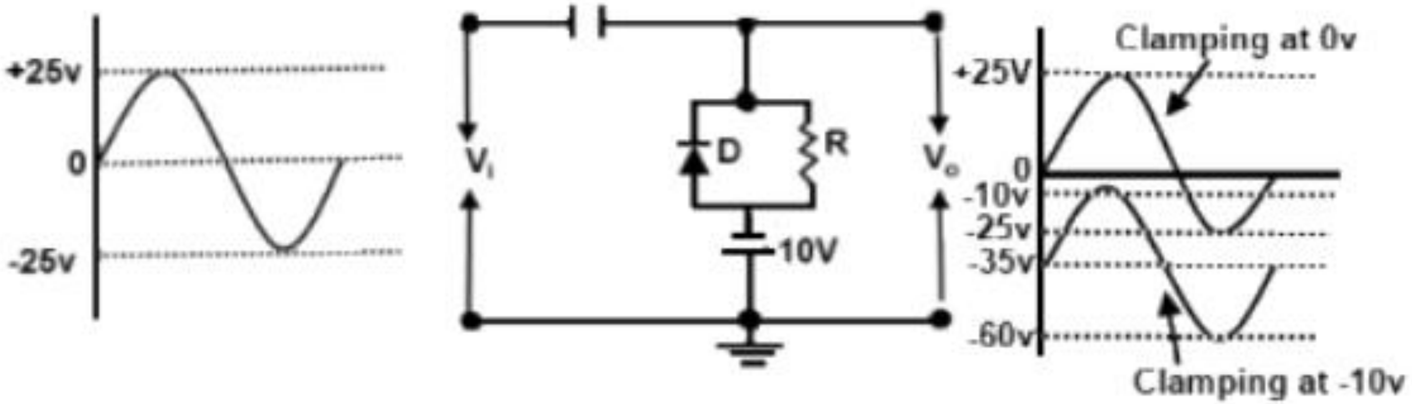
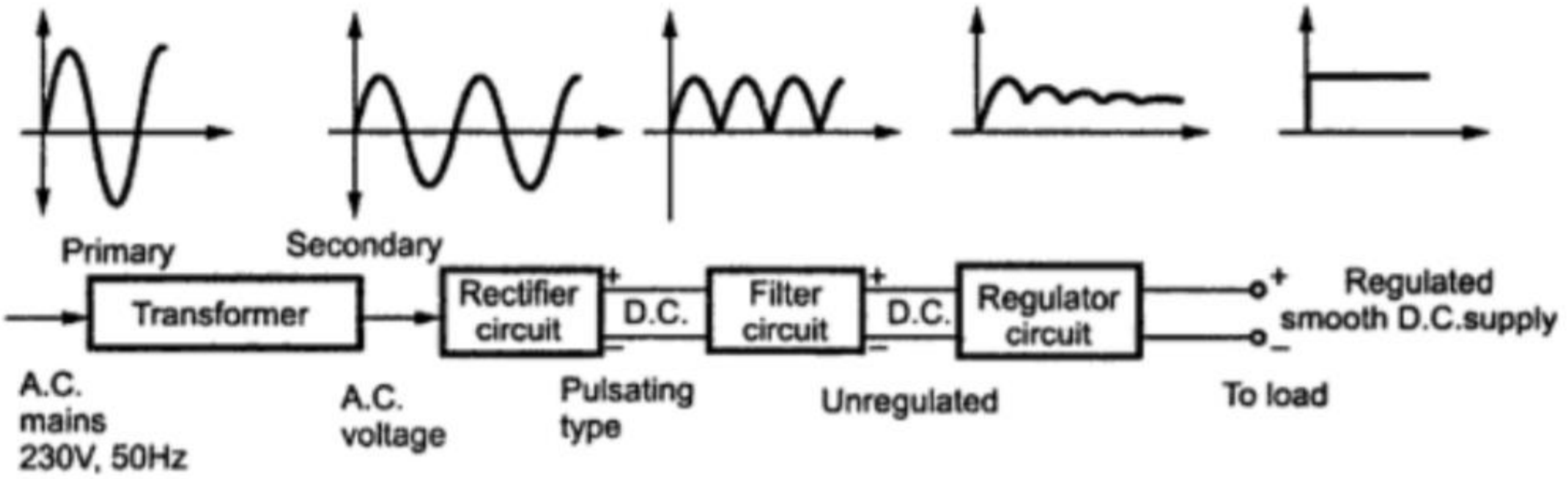


(a) Negative Clamper with positive biased



Rectifiers and filters

A **rectifier** is a device which converts a.c. voltage to pulsating d.c. voltage, using one or more p-n junction diode.



Block Diagram of a typical DC Power Supply

Types of Rectifier

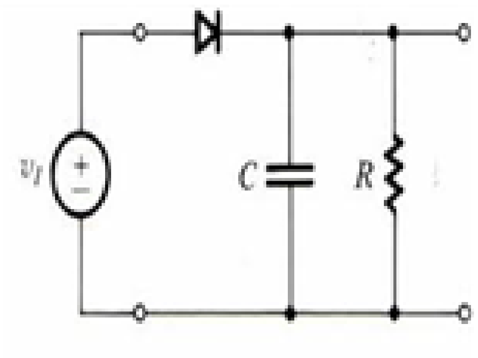
Rectifier

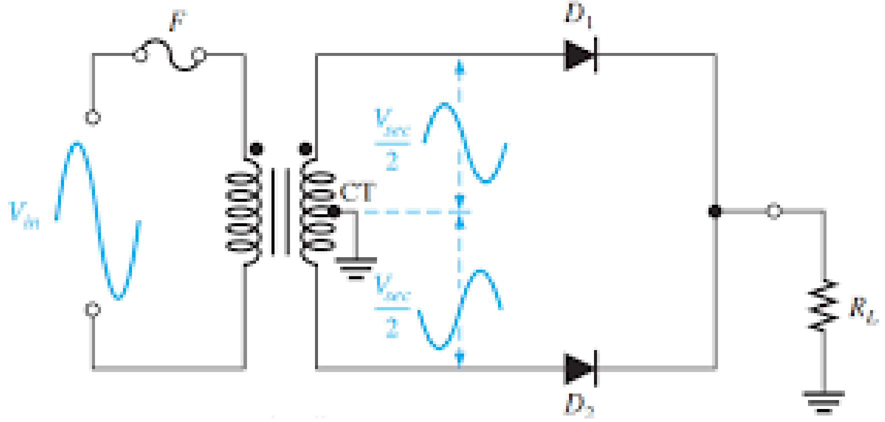
Half wave rectifier

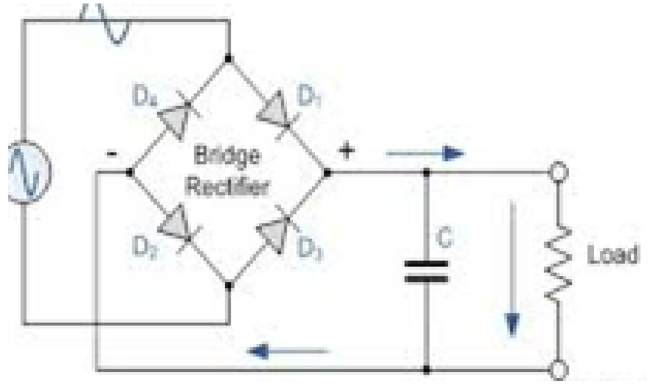
Full wave rectifier

Center Tapped Full Wave Rectifier

Bridge Rectifier

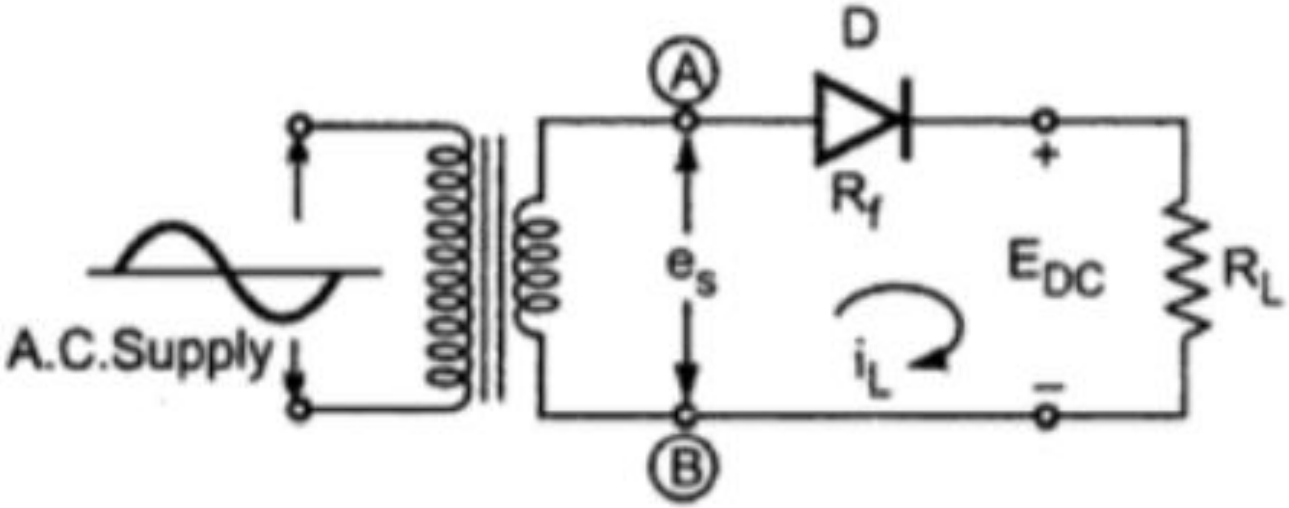


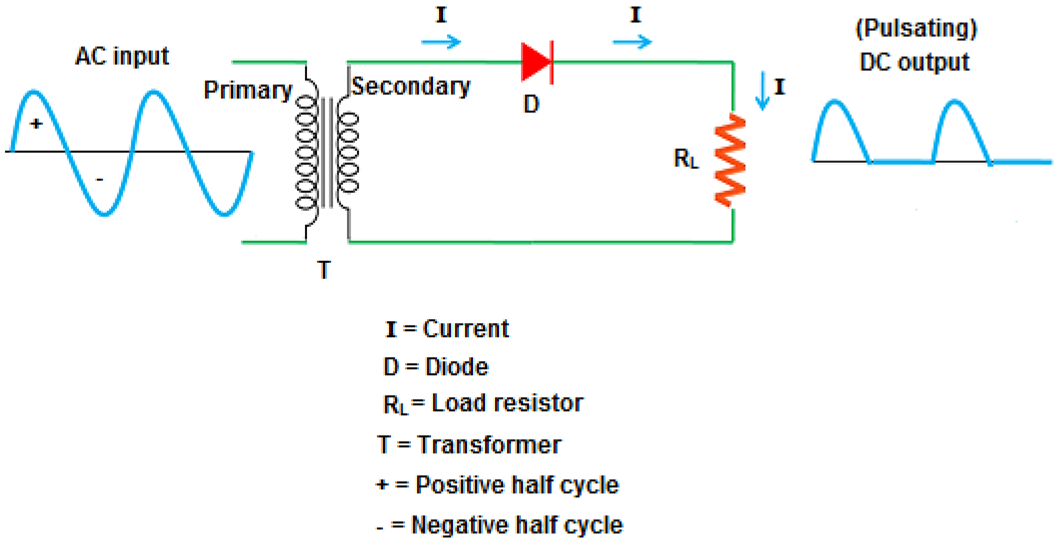




Half Wave Rectifier:

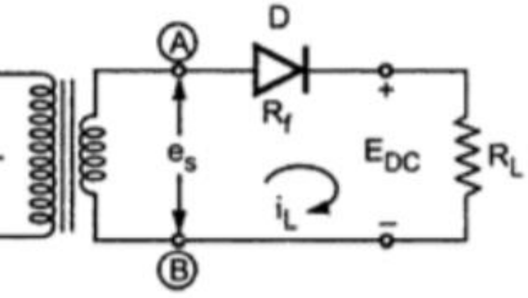
- A Type of rectifier that converts only the **half cycle** of the alternating current (AC) into direct current (DC) is known as halfwave rectifier





Half wave rectifier

Characteristic of Rectifier



a) **Waveform of the load current :** As rectifier converts a.c. to pulsating d.c., it is important to analyze the nature of the current through load which ultimately determines the waveform of the load voltage.

b) **Regulation of the output voltage :** As the load current changes, load voltage changes. Practically load voltage should remain constant. So concept of regulation is to study the effect of change in load current on the load voltage.

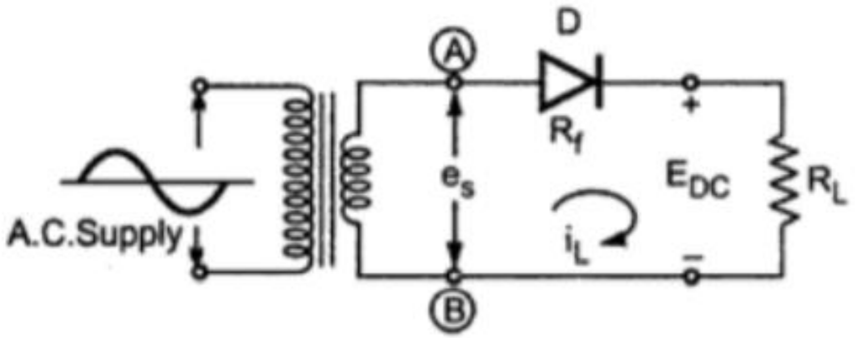
c) **Rectifier efficiency :** It signifies, how efficiently the rectifier circuit converts a.c. power into d.c. power.

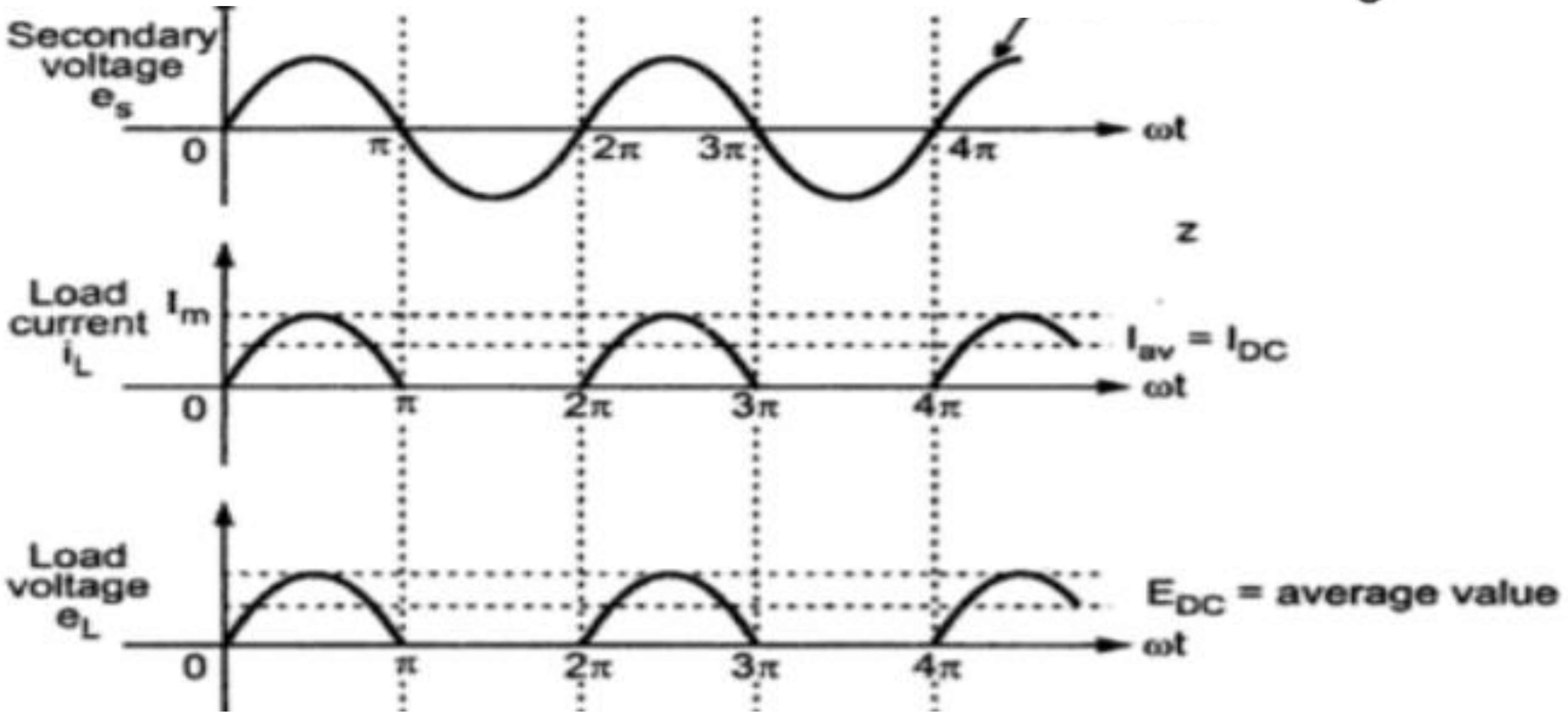
d) **Peak value of current in the rectifier circuit :** The peak value is the maximum value of an alternating current in the rectifier circuit. This decides the rating of the rectifier circuit element which is diode.

e) **Peak value of voltage across the rectifier element in the reverse direction (PIV) :** When the diode is not conducting, the reverse voltage gets applied across the diode. The peak value of such voltage decides the peak inverse voltage i.e. PIV rating of a diode.

f) **Ripple factor :** The output of the rectifier is of pulsating d.c. type. The amount of a.c. content in the output can be mathematically expressed by a factor called ripple factor.

Operation of the ckt





Cont.

Average DC Load Current (I_{DC})

The average or dc value of alternating current is obtained by integration.

For finding out the average value of an alternating waveform, we have to determine the area under the curve over one complete cycle i.e. from 0 to 2π and then dividing it by the base i.e. 2π.

Mathematically, current waveform can be described as,

$$i_L = I_m \sin \omega t \qquad \text{for } 0 \le \omega t \le \pi$$

$$i_L = 0 \qquad \text{for } \pi \le \omega t \le 2\pi$$

where I_m = peak value of load current

$$\therefore \quad I_{DC} = \frac{1}{2\pi}\int_0^{2\pi} i_L \, d(\omega t) = \frac{1}{2\pi}\int_0^{2\pi} I_m \sin(\omega t)\, d(\omega t)$$

As no current flows during negative half cycle of ac input voltage, i.e. between $\omega t = \pi$ to $\omega t = 2\pi$, we change the limits of integration.

$$\therefore \quad I_{DC} = \frac{1}{2\pi}\int_0^{\pi} I_m \sin(\omega t)\, d(\omega t)$$

$$= \frac{I_m}{2\pi}[-\cos(\omega t)]_0^{\pi} = -\frac{I_m}{2\pi}[\cos(\pi) - \cos(0)]$$

$$= -\frac{I_m}{2\pi}[-1-1] = \frac{I_m}{\pi}$$

$$\therefore \quad I_{DC} = \frac{I_m}{\pi} = \text{average value}$$

Cont.

Average DC Load Voltage (E_{DC})

It is the product of average D.C. load current and the load resistance R_L.

$$E_{DC} = I_{DC} R_L$$

Substituting value of I_{DC},

$$E_{DC} = \frac{I_m}{\pi} R_L = \frac{E_{sm}}{(R_f + R_L + R_s)\pi} R_L$$

$$I_m = \frac{E_{sm}}{R_f + R_L + R_s}$$

The winding resistance R_s and forward diode resistance R_f are practically very small compared to R_L.

$$\therefore \quad E_{DC} = \frac{E_{sm}}{\pi\left[\frac{R_f + R_s}{R_L} + 1\right]}$$

But as R_f and R_s are small compared to R_L, $(R_f + R_s)/R_L$ is negligibly small compared to 1. So neglecting it we get,

$$\therefore \quad E_{DC} \approx \frac{E_{sm}}{\pi}$$

Cont.

R.M.S. Value of Load Current (I_{RMS})

The R.M.S means squaring, finding mean and then finding square root. Hence R.M.S. value of load current can be obtained as,

$$I_{RMS} = \sqrt{\frac{1}{2\pi}\int_0^{\pi}(I_m \sin\omega t)^2 \, d(\omega t)}$$

$$= \sqrt{\frac{1}{2\pi}\int_0^{\pi}\left(I_m{}^2 \sin^2 \omega t \, d(\omega t)\right)}$$

$$= I_m\sqrt{\frac{1}{2\pi}\int_0^{\pi}\frac{[1-\cos(2\omega t)]\,d(\omega t)}{2}}$$

$$= I_m\sqrt{\frac{1}{2\pi}\left\{\frac{\omega t}{2}-\frac{\sin(2\omega t)}{4}\right\}_0^{\pi}}$$

$$= I_m\sqrt{\frac{1}{2\pi}\left(\frac{\pi}{2}\right)} \qquad \text{as } \sin(2\pi) = \sin(0) = 0$$

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

$$\therefore \quad I_{RMS} = \frac{I_m}{2}$$

Cont.

D.C. Power Output (P_{DC})

The d.c. power output can be obtained as,

$$P_{DC} = E_{DC} I_{DC} = I_{DC}^2 R_L$$

$$\text{D.C. Power output} = I_{DC}^2 R_L = \left[\frac{I_m}{\pi}\right]^2 R_L = \frac{I_m{}^2}{\pi^2} R_L$$

$$\therefore \quad P_{DC} = \frac{I_m{}^2}{\pi^2} R_L$$

where

$$I_m = \frac{E_{sm}}{R_f + R_L + R_s}$$

$$\therefore \quad P_{DC} = \frac{E_{sm}{}^2 R_L}{\pi^2 [R_f + R_L + R_s]^2}$$

Cont.

A.C. Power Input (P_{AC})

The power input taken from the secondary of transformer is the power supplied to three resistances namely load resistance R_L , the diode resistance R_f and winding resistance R_s. The a.c. power is given by,

$$P_{AC} = I_{RMS}^2[R_L + R_f + R_s]$$

but $$I_{RMS} = \frac{I_m}{2} \quad \text{for half wave,}$$

$$\therefore \quad P_{AC} = \frac{I_m^2}{4}[R_L + R_f + R_s]$$

Cont.

Rectifier Efficiency (η)

The rectifier efficiency is defined as the ratio of output d.c. power to input a.c. power.

$$\therefore \quad \eta = \frac{\text{D.C. output power}}{\text{A.C. input power}} = \frac{P_{DC}}{P_{AC}}$$

$$\therefore \quad \eta = \frac{\frac{I_m^2}{\pi^2} R_L}{\frac{I_m^2}{4}[R_f + R_L + R_s]} = \frac{(4/\pi^2)R_L}{(R_f + R_L + R_s)}$$

$$\therefore \quad \eta = \frac{0.406}{1 + \left(\frac{R_f + R_s}{R_L}\right)}$$

If $(R_f + R_s) << R_L$ as mentioned earlier, we get the maximum theoretical efficiency of half wave rectifier as,

$$\%\eta_{max} = 0.406 \times 100 = 40.6\,\%$$

Cont.

Ripple Factor (γ)

$$\text{Ripple factor} \quad \gamma = \frac{\text{R.M.S. value of a.c. component}}{\text{Average or d.c.component}}$$

Now the output current is composed of a.c. component as well as d.c. component.

Let I_{ac} = r.m.s. value of a. c. component present in output

I_{DC} = d.c. component present in output

I_{RMS} = R.M.S. value of total output current

$$\therefore \quad I_{RMS} = \sqrt{I_{ac}^2 + I_{DC}^2}$$

$$\therefore \quad I_{ac} = \sqrt{I_{RMS}^2 - I_{DC}^2}$$

Now $\quad \text{Ripple factor} = \dfrac{I_{ac}}{I_{DC}} \quad$ as per definition

$$\therefore \quad \gamma = \frac{\sqrt{I_{RMS}^2 - I_{DC}^2}}{I_{DC}}$$

$$\therefore \quad \gamma = \sqrt{\left(\frac{I_{RMS}}{I_{DC}}\right)^2 - 1}$$

This is the general expression for ripple factor and can be used for any rectifier circuit.

Cont.

Now for a half wave circuit,

$$I_{RMS} = \frac{I_m}{2} \quad \text{while} \quad I_{DC} = \frac{I_m}{\pi}$$

$$\therefore \qquad \gamma = \sqrt{\left[\frac{\left(\frac{I_m}{2}\right)}{\left(\frac{I_m}{\pi}\right)}\right]^2 - 1} = \sqrt{\frac{\pi^2}{4} - 1} = \sqrt{1.4674}$$

$$\therefore \qquad \gamma = 1.211$$

This indicates that the ripple contents in the output are 1.211 times the d.c. component i.e. 121.1 % of d.c. component. The ripple factor for half wave is very high which indicates that the half wave circuit is a poor converter of a.c. to d.c. The ripple factor is minimised using filter circuits along with rectifiers.

Cont.

Peak Inverse Voltage (PIV)

The Peak Inverse Voltage is the peak voltage across the diode in the reverse direction i.e. when the diode is reverse biased. In half wave rectifier, the load current is ideally zero when the diode is reverse biased and hence the maximum value of the voltage that can exist across the diode is nothing but E_{sm}.

$$\therefore \quad \text{PIV of diode} = E_{sm} = \text{Maximum value of secondary voltage}$$

$$= \pi E_{DC}\big|_{I_{DC}=0}$$

This is called PIV rating of a diode. So diode must be selected based on this PIV rating and the circuit specifications.

Cont.

Transformer Utilization Factor (T.U.F.)

The factor which indicates how much is the utilization of the transformer in the circuit is called Transformer Utilization Factor (T.U.F.)

The T.U.F. is defined as the ratio of d.c. power delivered to the load to the a.c power rating of the transformer. While calculating the a.c. power rating, it is necessary to consider r.m.s. value of a.c. voltage and current.

The T.U.F. for half wave rectifier can be obtained as,

$$\text{A.C. power rating of transformer} = E_{RMS}\, I_{RMS}$$

$$= \frac{E_{sm}}{\sqrt{2}} \cdot \frac{I_m}{2} = \frac{E_{sm}\, I_m}{2\sqrt{2}}$$

Remember that the secondary voltage is purely sinusoidal hence its r.m.s. value is $1/\sqrt{2}$ times maximum while the current is half sinusoidal hence its r.m.s. value is $1/2$ of the maximum, as derived earlier.

$$\text{D.C. power delivered to the load} = I_{DC}^2\, R_L$$

Cont.

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

$$\therefore \qquad \text{T.U.F.} = \frac{\text{D.C. Power delivered to the load}}{\text{A.C. Power rating of the transformer}}$$

$$= \frac{\left(\frac{I_m}{\pi}\right)^2 R_L}{\left(\frac{E_{sm} I_m}{2\sqrt{2}}\right)}$$

Neglecting the drop across R_f and R_s we can write,

$$E_{sm} = I_m R_L$$

$$\therefore \qquad \text{T.U.F} = \frac{{I_m}^2}{\pi^2} \cdot \frac{R_L . 2\sqrt{2}}{{I_m}^2 R_L}$$

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

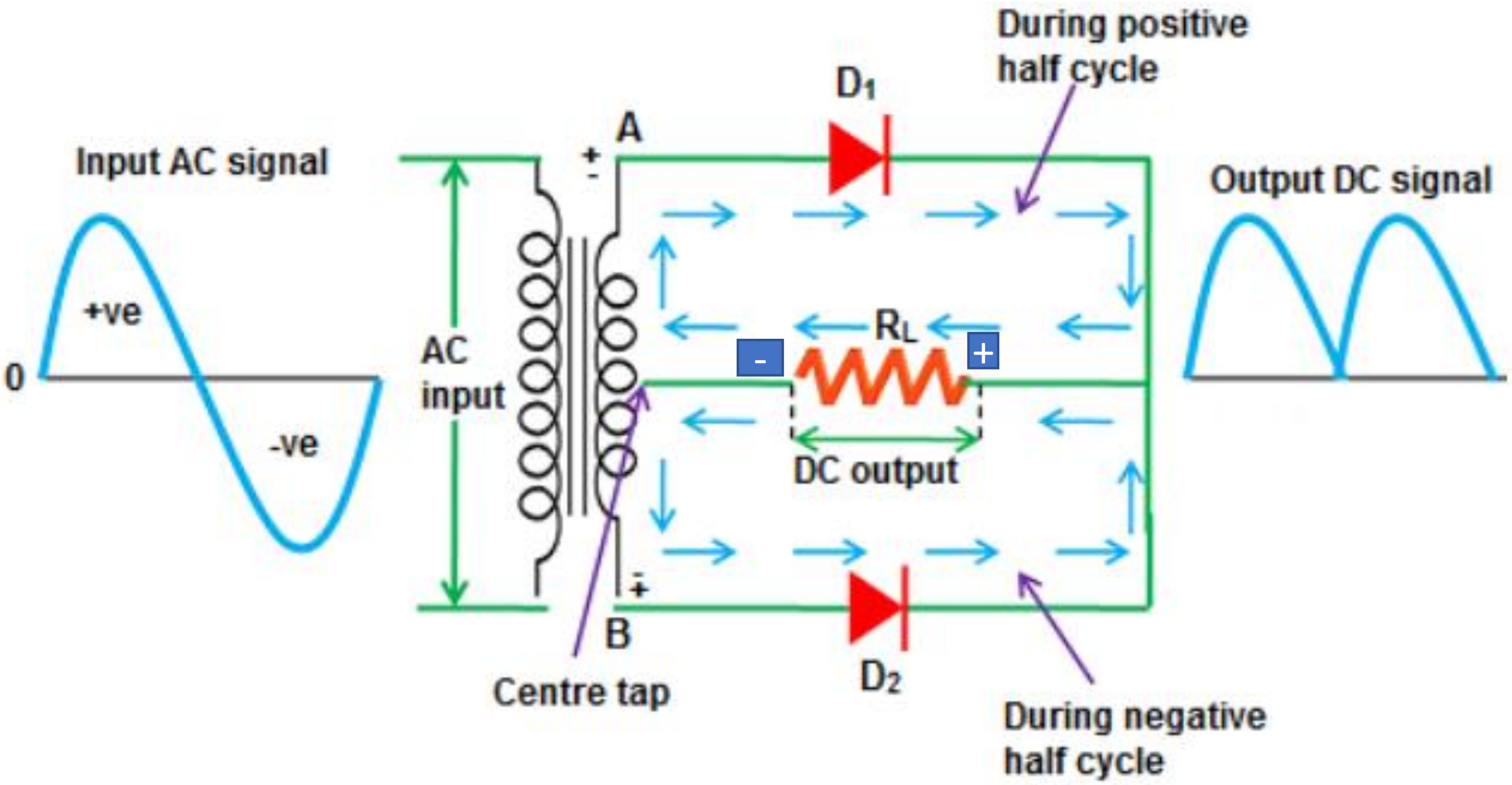
$$= 0.287$$

The value of T.U.F. is low which shows that in half wave circuit, the transformer is not fully utilized.

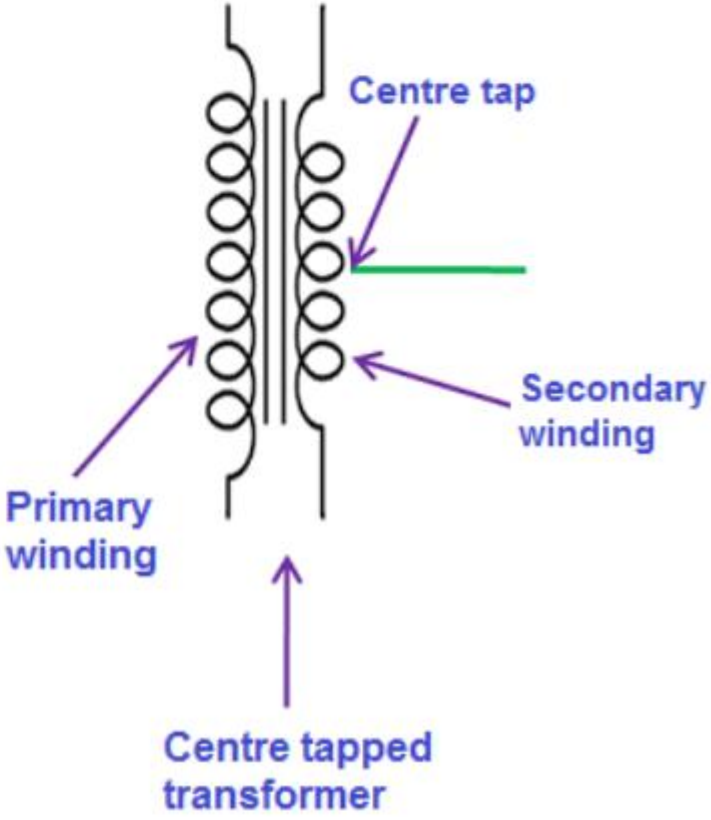
FULL WAVE RECTIFIER DEFINITION

A full wave rectifier is a type of rectifier which converts both half cycles of the AC signal into pulsating DC signal.

Centre tapped FWR

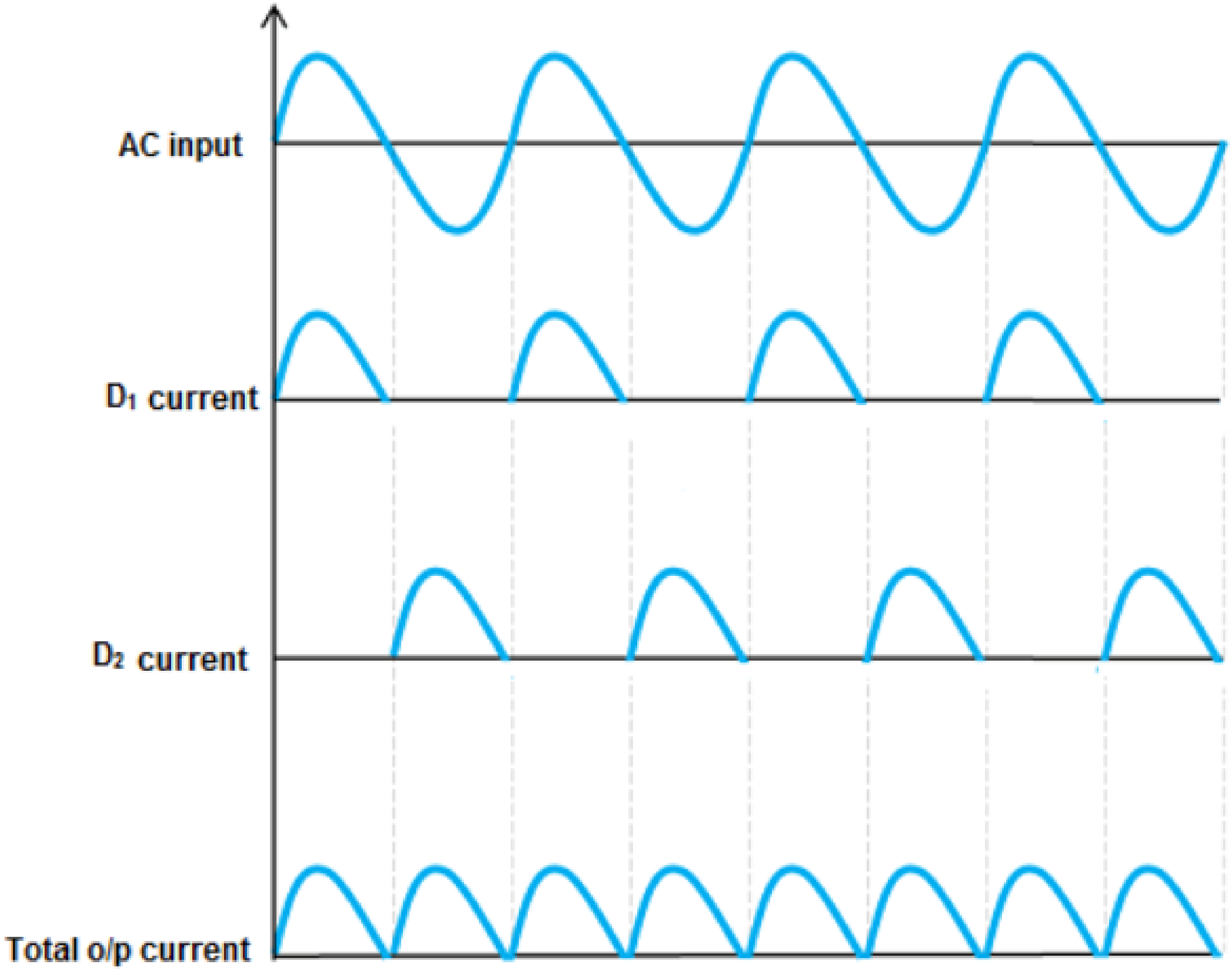


Centre tapped transformer



Cont.

Output waveforms of full wave rectifier



Cont.

Characteristics of full wave rectifier

Root mean square (RMS) value of load current I_{RMS}

The root mean square (RMS) value of load current in a full wave rectifier is

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

Root mean square (RMS) value of the output load voltage V_{RMS}

The root mean square (RMS) value of output load voltage in a full wave rectifier is

$$V_{RMS} = I_{RMS} R_L = \frac{I_m}{\sqrt{2}} R_L$$

Cont.

DC output current

At the output load resistor R_L, both the diode D_1 and diode D_2 currents flow in the same direction. So the output current is the sum of D_1 and D_2 currents.

The current produced by D_1 is I_{max} / π and the current produced by D_2 is I_{max} / π.

So the output current $I_{DC} = 2I_{max} / \pi$

Where,

I_{max} = maximum DC load current

DC output voltage

The DC output voltage appeared at the load resistor R_L is given as

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

Where,

V_{max} = maximum secondary voltage

Cont.

Rectifier efficiency

Rectifier efficiency indicates how efficiently the rectifier converts AC into DC. A high percentage of rectifier efficiency indicates a good rectifier while a low percentage of rectifier efficiency indicates an inefficient rectifier.

Rectifier efficiency is defined as the ratio of DC output power to the AC input power.

It can be mathematically written as

$$\eta = \text{output } P_{DC} \,/\, \text{input } P_{AC}$$

The rectifier efficiency of a full wave rectifier is 81.2%.

The rectifier efficiency of a full wave rectifier is twice that of the half wave rectifier. So the full wave rectifier is more efficient than a half wave rectifier

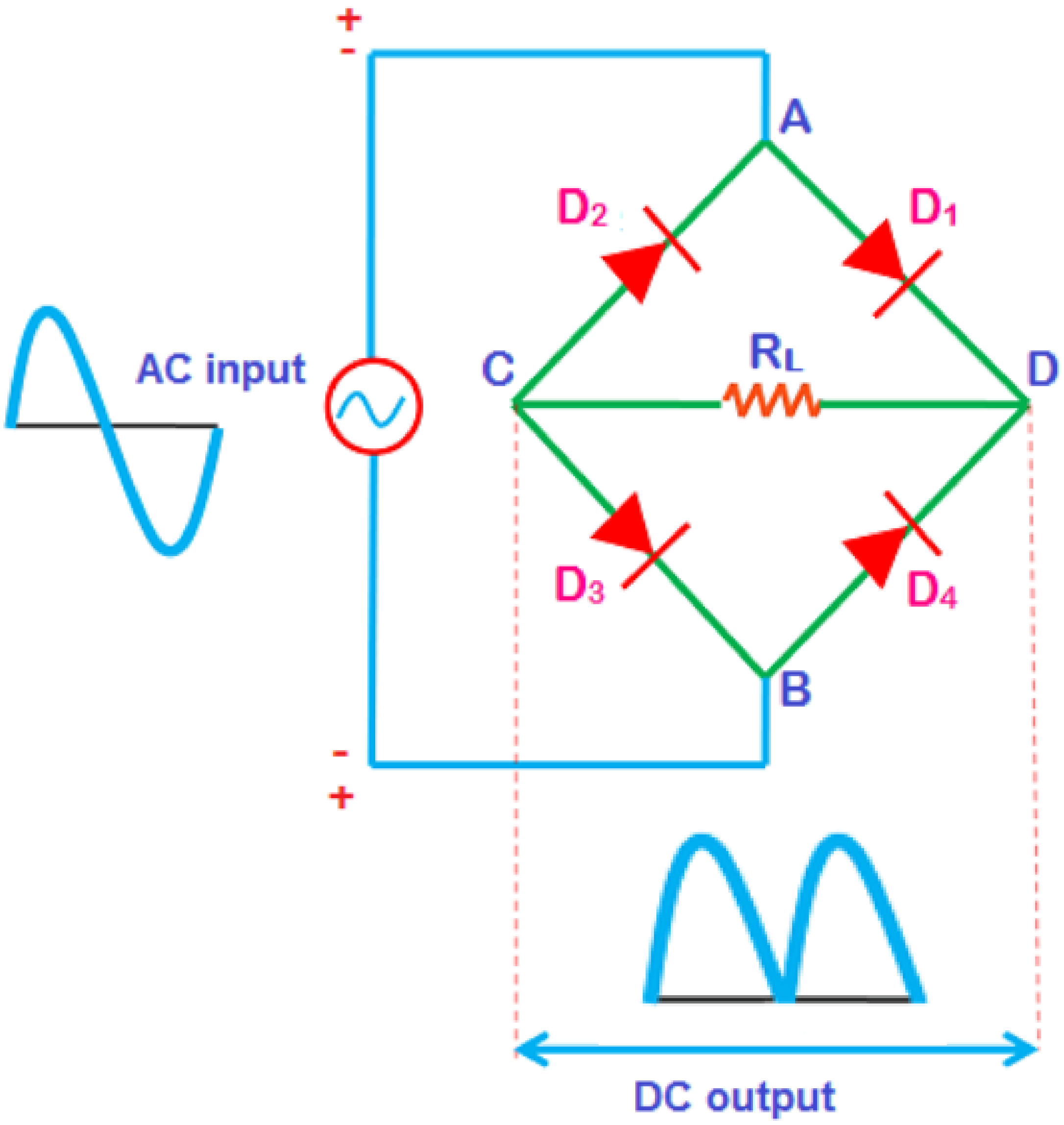
Cont.

Peak inverse voltage (PIV)

Peak inverse voltage or peak reverse voltage is the maximum voltage a diode can withstand in the reverse bias condition. If the applied voltage is greater than the peak inverse voltage, the diode will be permanently destroyed.

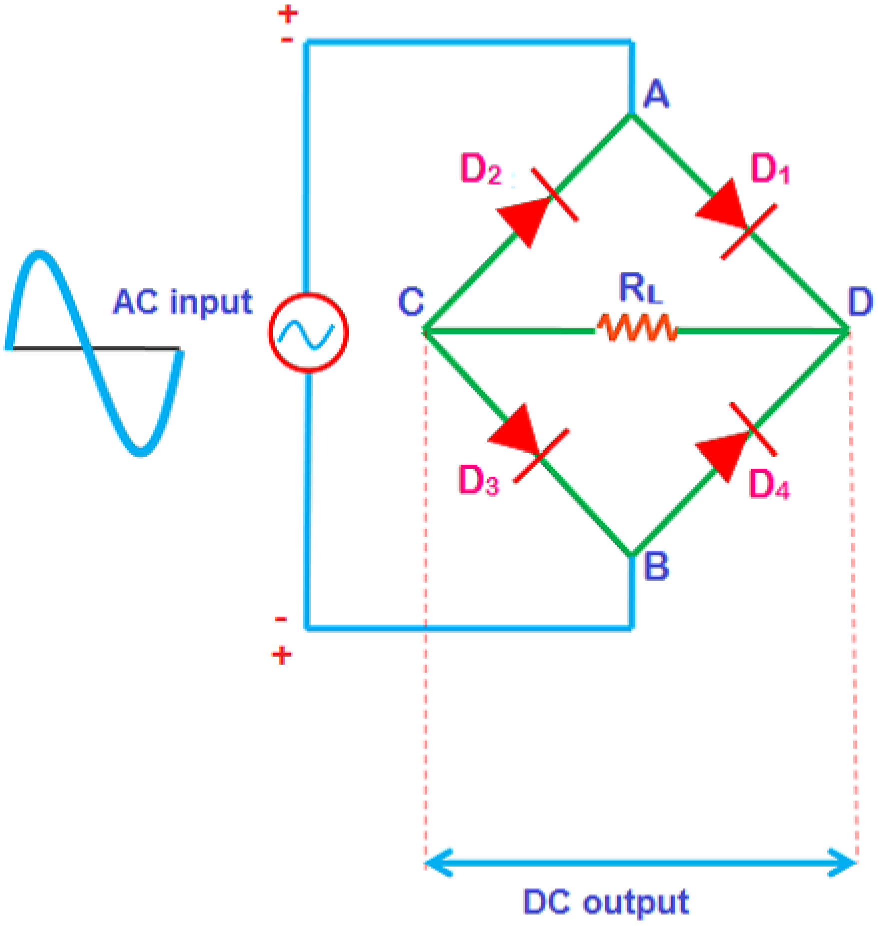
The peak inverse voltage (PIV) = $2V_{smax}$

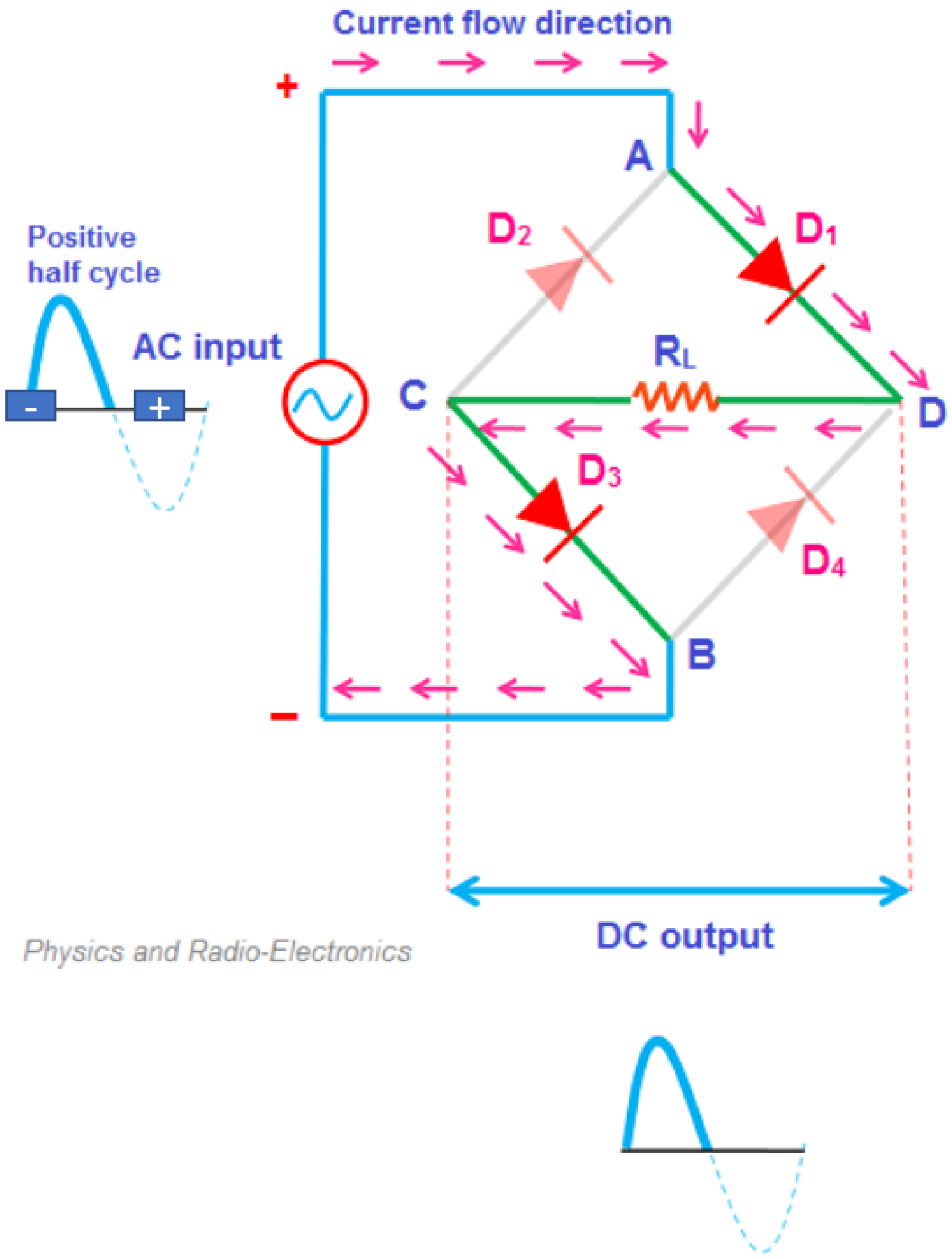
Bridge Rectifier



Cont.

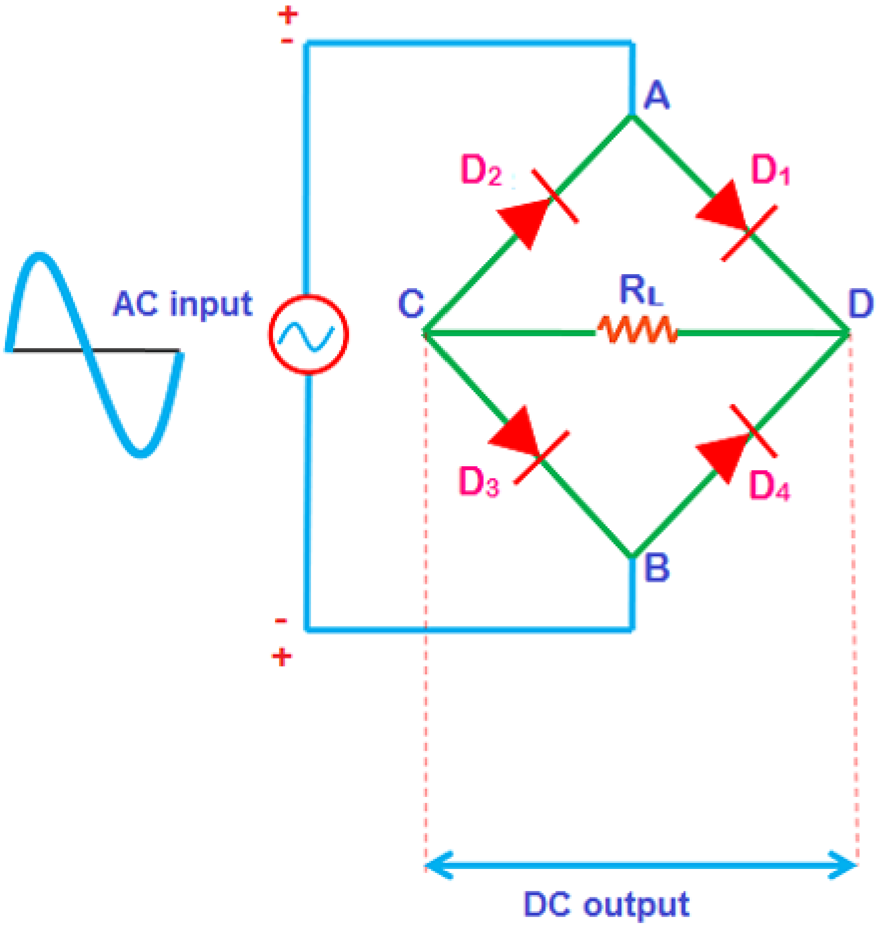
The current flow direction during the positive half cycle is shown in the figure A (I.e. A to D to C to B).

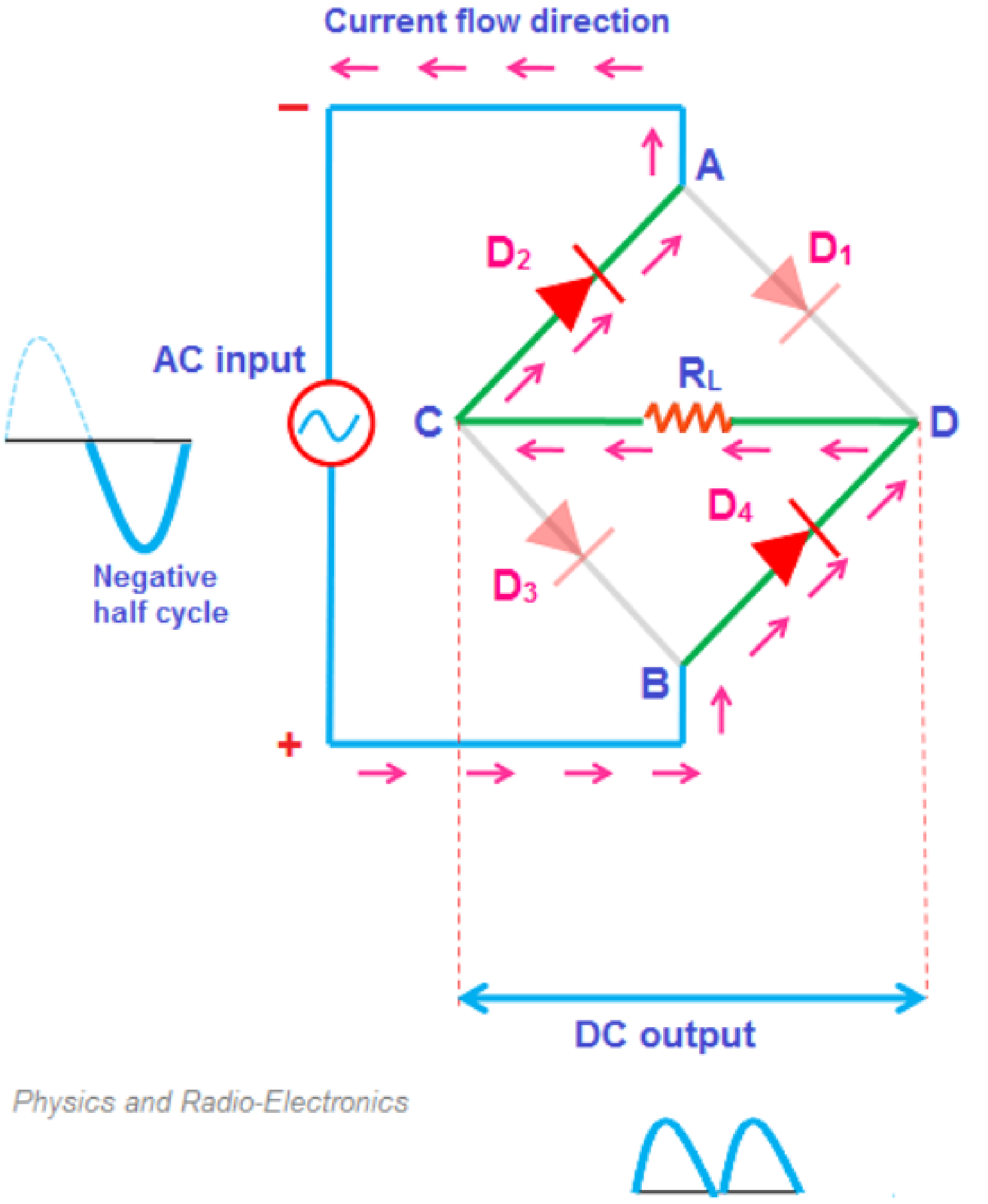




Cont.

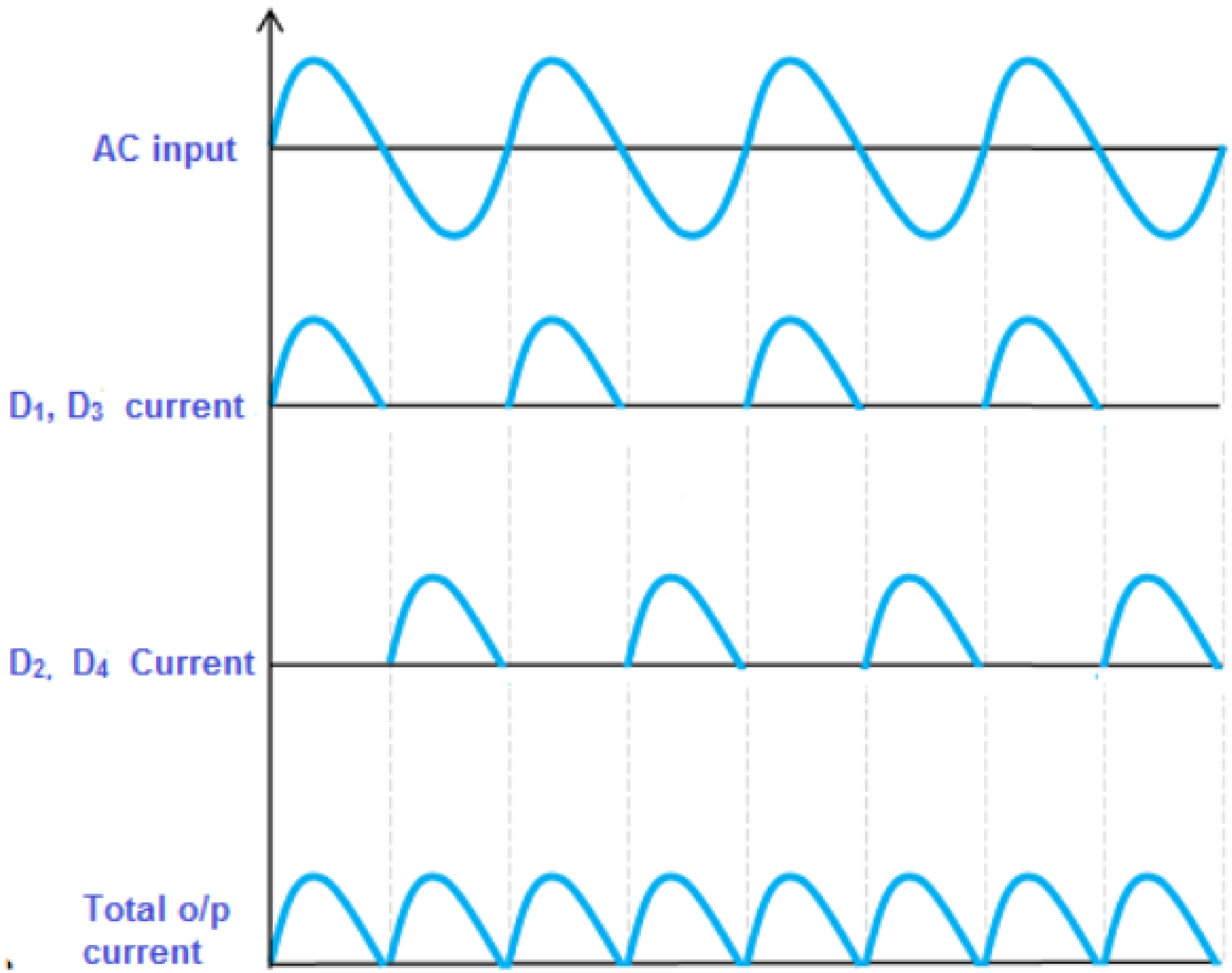
The current flow direction during negative half cycle is shown in the figure B (I.e. B to D to C to A).





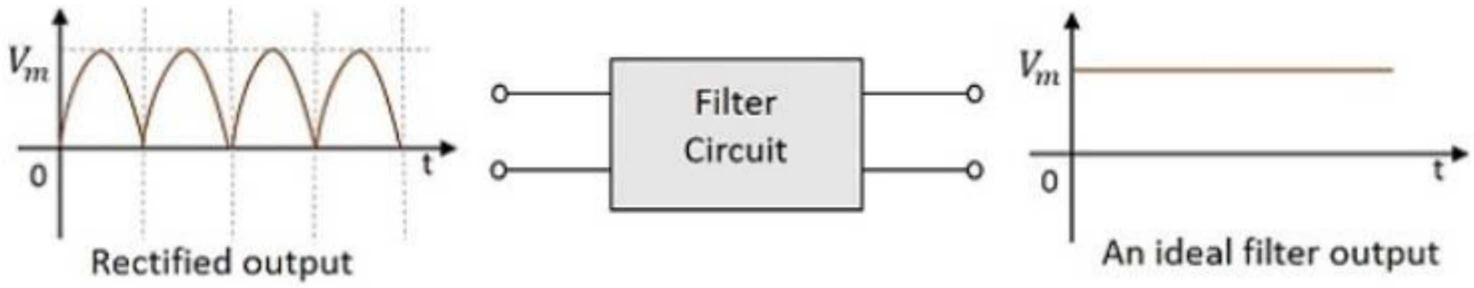
Cont.

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



Filters

- The ripple in the signal denotes the presence of some AC component. This ac component has to be completely removed in order to get pure dc output. So, we need a circuit that **smoothens** the rectified output into a pure dc signal.
- A **filter circuit** is one which removes the ac component present in the rectified output and allows the dc component to reach the load.
- The following figure shows the functionality of a filter circuit.



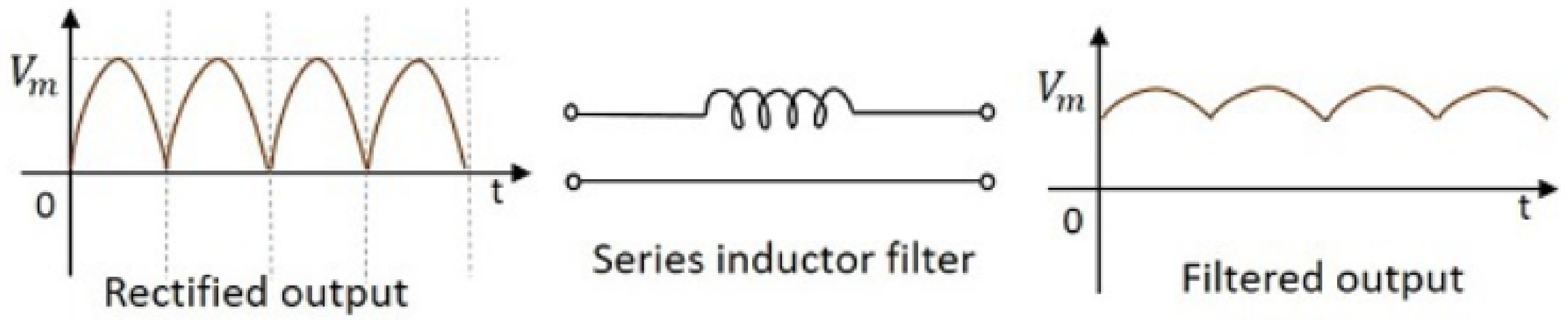
Cont.

- A filter circuit is constructed using two main components, inductor and capacitor. We have already studied in Basic Electronics tutorial that
- An inductor allows **dc** and blocks **ac**.
- A capacitor allows **ac** and blocks **dc**.

Cont.

Series Inductor Filter

As an inductor allows dc and blocks ac, a filter called **Series Inductor Filter** can be constructed by connecting the inductor in series, between the rectifier and the load. The figure below shows the circuit of a series inductor filter.

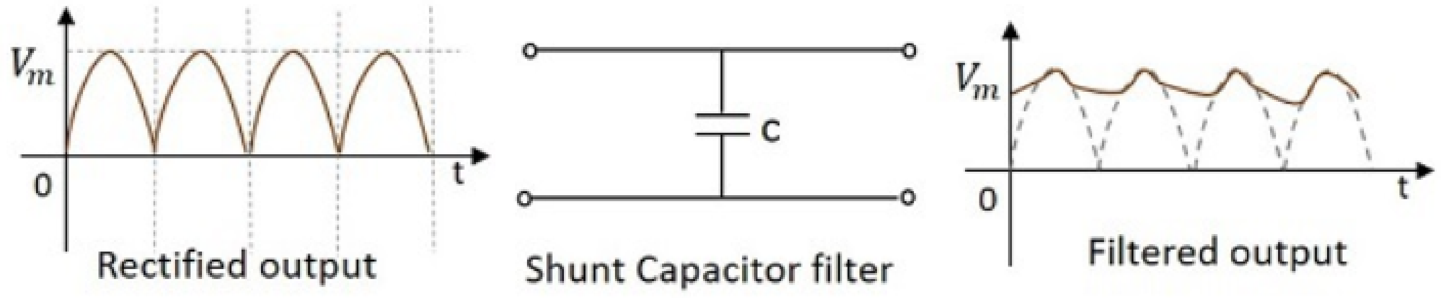


The rectified output when passed through this filter, the inductor blocks the ac components that are present in the signal, in order to provide a pure dc. This is a simple primary filter.

Cont.

Shunt Capacitor Filter

As a capacitor allows ac through it and blocks dc, a filter called **Shunt Capacitor Filter** can be constructed using a capacitor, connected in shunt, as shown in the following figure.



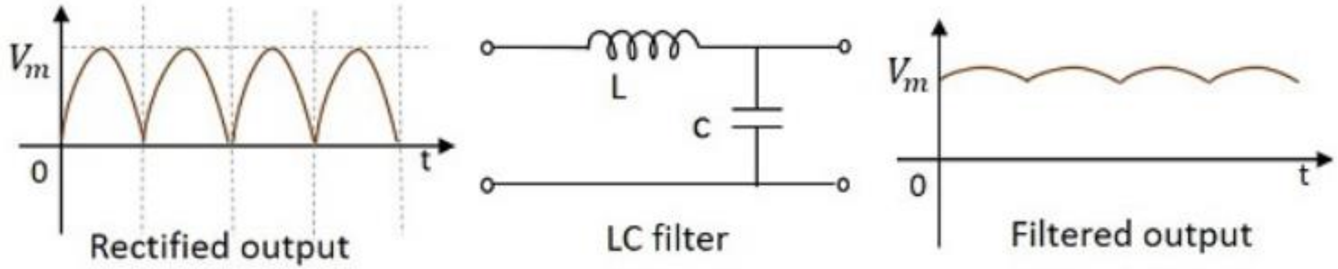
The rectified output when passed through this filter, the ac components present in the signal are grounded through the capacitor which allows ac components. The remaining dc components present in the signal are collected at the output.

The above filter types discussed are constructed using an inductor or a capacitor. Now, let's try to use both of them to make a better filter. These are combinational filters.

Cont.

L-C Filter

A filter circuit can be constructed using both inductor and capacitor in order to obtain a better output where the efficiencies of both inductor and capacitor can be used. The figure below shows the circuit diagram of a LC filter.



The rectified output when given to this circuit, the inductor allows dc components to pass through it, blocking the ac components in the signal. Now, from that signal, few more ac components if any present are grounded so that we get a pure dc output.

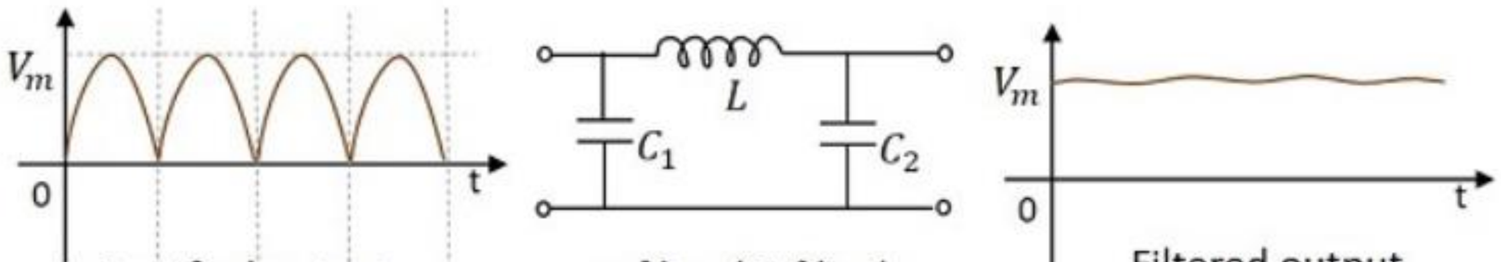
This filter is also called as a **Choke Input Filter** as the input signal first enters the inductor. The output of this filter is a better one than the previous ones.

Cont.

Π- Filter $Pi filter$

This is another type of filter circuit which is very commonly used. It has capacitor at its input and hence it is also called as a **Capacitor Input Filter**. Here, two capacitors and one inductor are connected in the form of π shaped network. A capacitor in parallel, then an inductor in series, followed by another capacitor in parallel makes this circuit.

If needed, several identical sections can also be added to this, according to the requirement. The figure below shows a circuit for π filter $Pi - filter$.



Rectified output π filter (Pi-filter) Filtered output

Cont.

Working of a Pi filter

In this circuit, we have a capacitor in parallel, then an inductor in series, followed by another capacitor in parallel.

- **Capacitor C_1** − This filter capacitor offers high reactance to dc and low reactance to ac signal. After grounding the ac components present in the signal, the signal passes to the inductor for further filtration.
- **Inductor L** − This inductor offers low reactance to dc components, while blocking the ac components if any got managed to pass, through the capacitor C_1.
- **Capacitor C_2** − Now the signal is further smoothened using this capacitor so that it allows any ac component present in the signal, which the inductor has failed to block.

Thus we, get the desired pure dc output at the load.

Assignment 1

1. Define Characteristics of Centre Taped rectifier with derivations

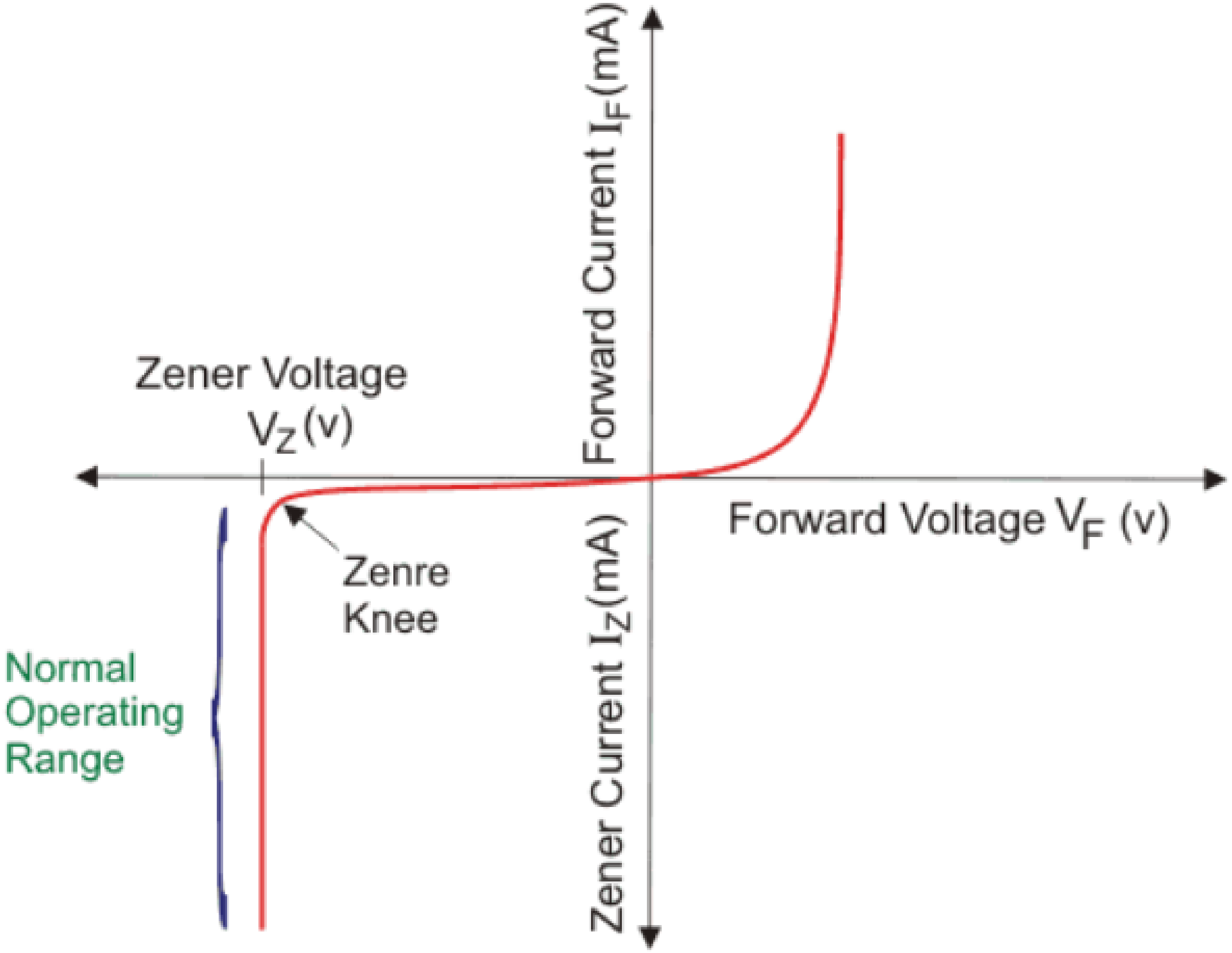
2. Define Characteristics of bridge rectifier with derivations

Zener Diode as Voltage Regulator

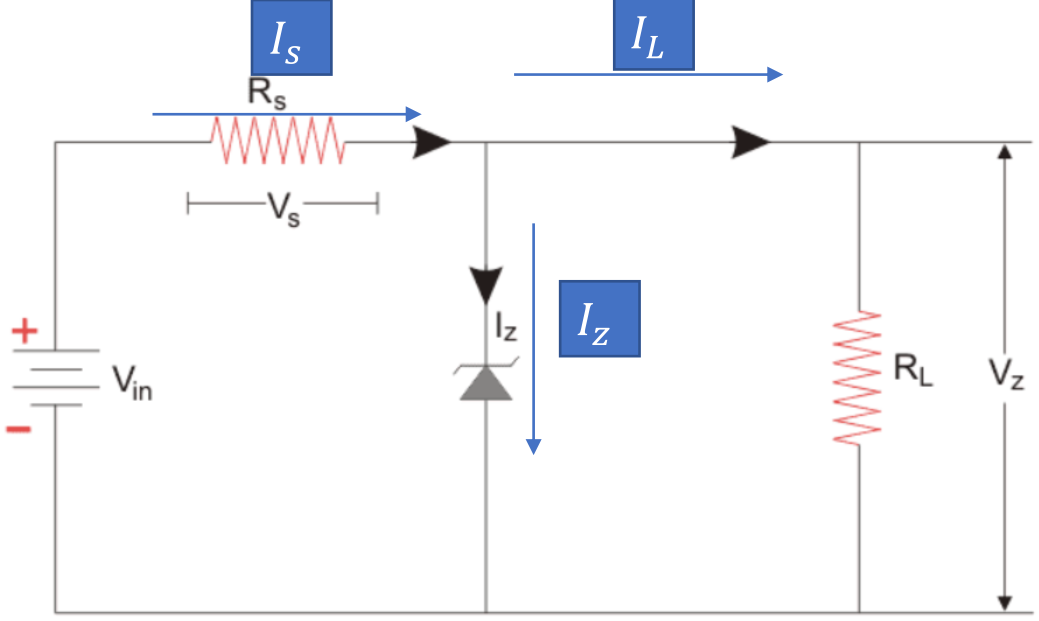
- A Zener diode is one of the specially designed diodes that predominately works in reverse biased conditions.
- They are more heavily doped than ordinary diodes, due to which they have narrow depletion region.
- While regular diodes get damaged when the voltage across them exceeds the reverse breakdown voltage, Zener diodes work exclusively in this region.
- The depletion region in Zener diode goes back to its normal state when the reverse voltage gets removed.
- This particular property of Zener diodes makes it useful as a **voltage regulator**.

Zener diode Characteristics

- When we apply a reverse voltage to a Zener diode, a negligible amount of current flows through the circuit.
- When a voltage higher than Zener breakdown voltage is applied, Zener breakdown occurs.
- Zener breakdown is a phenomenon where a significant amount of current flows through the diode with a negligible drop in voltage.
- When we increase the reverse voltage further, the voltage across the diode remains at the same value of Zener breakdown voltage whereas the current through it keeps on rising as seen in the graph above.
- Here in the graph V_z refers to the Zener breakdown voltage. Zener breakdown voltage typically can range from 1.2 V to 200 V depending on its application.



Zener Diode as Voltage Regulator



For example, we want that the voltage across a load in our circuit does not exceed, let’s say, 12 volts. Then we can select a Zener diode with a breakdown voltage of 12 volts and connect it across the load. Then even if the input voltage exceeds that value, the voltage across the load will never exceed 12 volts.

$I_S = I_L + I_Z$

(Vin-Vz)/Rs = Vz/RL + Iz

Here the Zener diode is connected across the load R_L. We want the voltage across the load to be regulated and not cross the value of V_z. Depending on our requirement, we choose the suitable Zener diode with a Zener breakdown voltage near to the voltage we require across the load. We connect the Zener diode in reverse bias condition. When the voltage across the diode exceeds the Zener breakdown voltage, a significant amount of current starts flowing through the diode. As the load is in parallel to the diode, the voltage drop across the load is also equal to the Zener breakdown voltage. The Zener diode provides a path for the current to flow and hence the load gets protected from excessive currents. Thus the Zener diode serves two purposes here: **Zener diode as a voltage regulator** as well as it protects the load from excessive current.

Zener Diode Example

A 5.0V stabilized power supply is required to be produced from a 12V DC power supply input source. The maximum power rating P_Z of the zener diode is 2W. Using the zener regulator circuit above calculate:

a). The maximum current flowing through the zener diode.

$$\text{Maximum Current} = \frac{\text{Watts}}{\text{Voltage}} = \frac{2w}{5v} = 400mA$$

b). The minimum value of the series resistor, R_S

$$R_S = \frac{V_S - V_Z}{I_Z} = \frac{12 - 5}{400mA} = 17.5\Omega$$

c). The load current I_L if a load resistor of 1kΩ is connected across the zener diode.

$$I_L = \frac{V_Z}{R_L} = \frac{5v}{1000\Omega} = 5mA$$

d). The zener current I_Z at full load.

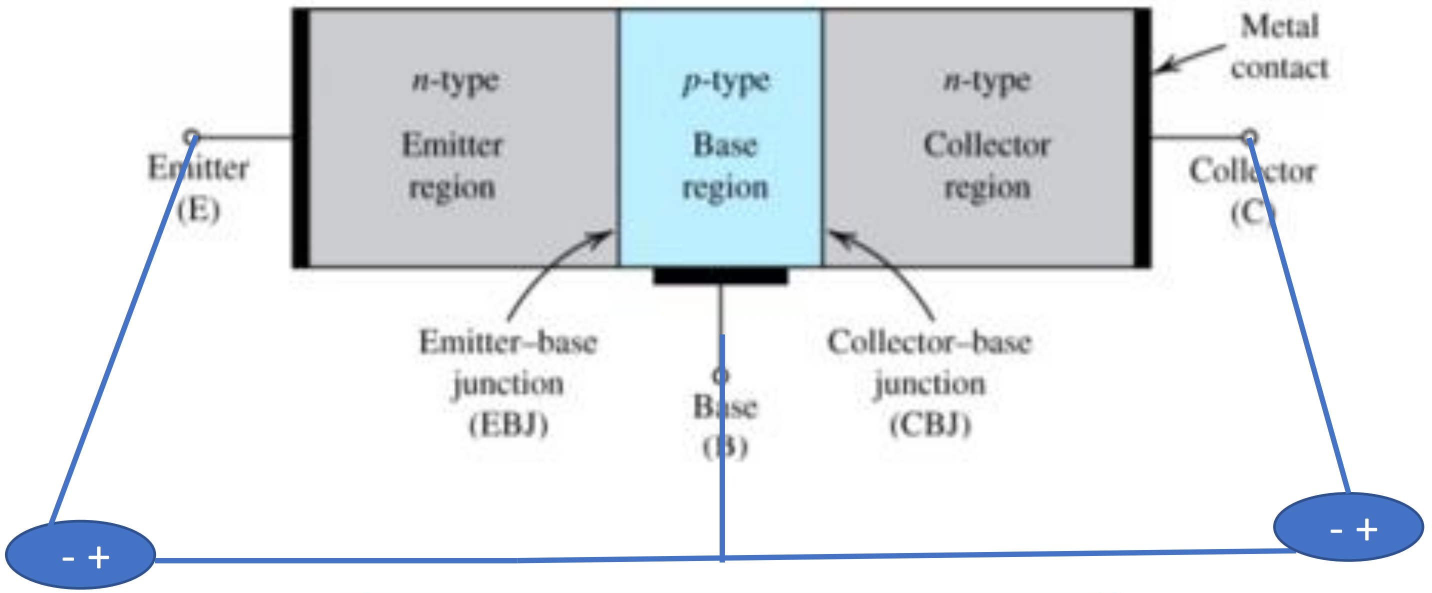
$$I_Z = I_S - I_L = 400mA - 5mA = 395mA$$

Chapter 2

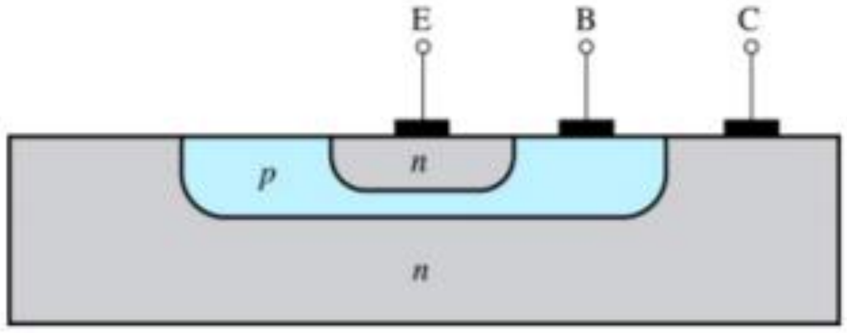
Bipolar Junction Transistor (BJT): Introduction, Physical behavior, ~~Ebers-Moll model~~, Common Base and Common Emitter characteristics, load line, operation point, active, saturation and cut off mode of operations. DC Model. ~~Bias stabilization: Need for stabilization, fixed bias and self-bias circuits,~~

Bipolar Junction Transistor (BJT)

Simplified physical structure



An implementation on an IC



- Device is constructed such that BJT does NOT act as two diodes back to back (when voltages are applied to all three terminals).

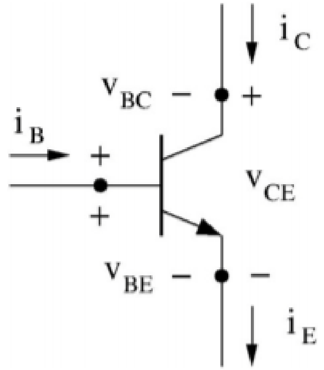
- Device construction is NOT symmetric
  - "Thin" base region (between E & C)
  - Heavily doped emitter
  - Large area collector

Cont.

BJT iv characteristics includes <u>four</u> parameters

NPN transistor

Vbc+Vce = Vbe



Circuit symbol and
Convention for current directions
(Note: $v_{CE} = v_C - v_E$)

- Six circuit variables: (3 i and 3 v)
- Two can be written in terms of the other four:

$$\text{KCL}: \quad i_E = i_C + i_B$$

$$\text{KVL}: \quad v_{BC} = v_{BE} - v_{CE}$$

- BJT iv characteristics is the relationship among (i_B , i_C, v_{BE}, and v_{CE})
- It is typically derived as

$$i_B = f\,(v_{BE})$$

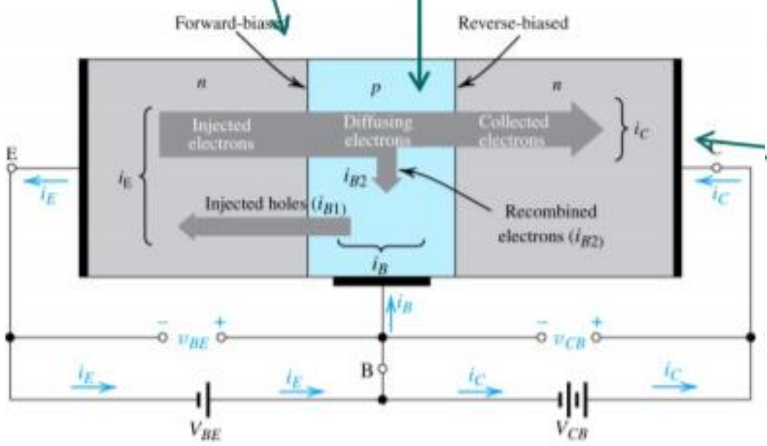
$$i_C = g\,(i_B, v_{CE})$$

Cont. BJT operation in the "active" mode

BE junction is forward biased ($v_{BE} = V_{D0}$)

As Emitter is heavily doped, a large number of electrons diffuse into the base (only a small fraction combine with holes)

The number of these electrons scales as e^{v_{BE}/V_T}



- If the base is "thin" these electrons get near the depletion region of BC junction and are swept into the collector if $v_{CB} \geq 0$ ($v_{BC} \leq 0$: **BC junction is reverse biased**!)

$$i_C = I_S e^{v_{BE}/V_T}$$

- In this picture, i_c is independent of v_{BC} (and v_{CE}) as long as

$$v_{BC} = v_{BE} - v_{CE} = V_{D0} - v_{CE} \leq 0$$

$$v_{CE} \geq V_{D0}$$

Active mode:

$$i_B = \frac{i_C}{\beta} = \frac{I_S}{\beta} e^{v_{BE}/V_T}$$

$$i_C = I_S e^{v_{BE}/V_T}$$

$$v_{CE} \geq V_{D0}$$

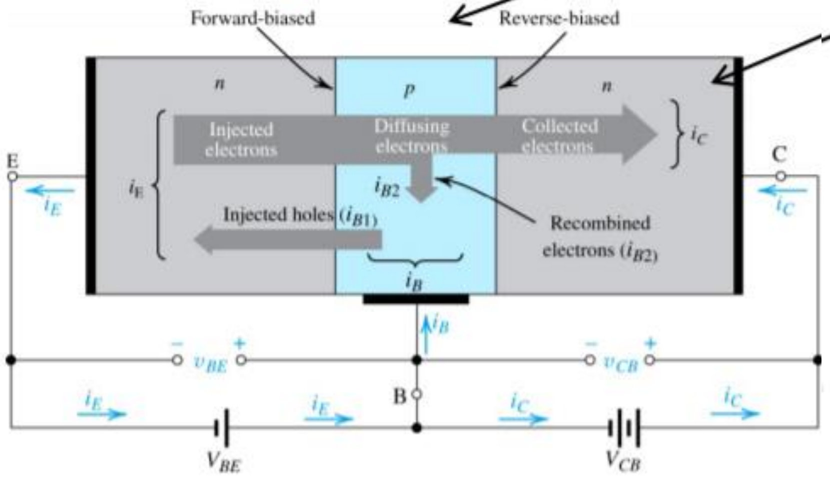
- Base current is also proportional to e^{v_{BE}/V_T} and therefore, $i_C : i_B = i_C/\beta$

Cont.

BJT operation in saturation mode

BE junction is forward biased ($v_{BE} = V_{D0}$)

Similar to the active mode, a large number of electrons diffuse into the base.



- For $v_{BC} \geq 0$ **BC junction is forward biased** and a diffusion current will set up, reducing i_C.

1. Soft saturation: $v_{CE} \geq 0.3$ V (Si)*
   $v_{BC} \leq 0.4$ V (Si), diffusion current is small and i_C is very close to its active-mode level.
2. Deep saturation region: $0.1 < v_{CE} < 0.3$ V (Si)
   or $v_{CE} \approx 0.2$ V = V_{sat} (Si), i_C is smaller than its active-mode level ($i_C < \beta\, i_B$).
   - Called saturation as i_C is set by outside circuit & does not respond to changes in i_B.
3. Near cut-off: $v_{CE} \leq 0.1$ V (Si)
   Both i_C & i_B are close to zero.

"Deep" Saturation mode:

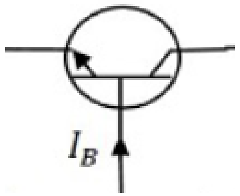
$$i_B = \frac{I_S}{\beta} e^{v_{BE}/V_T}$$

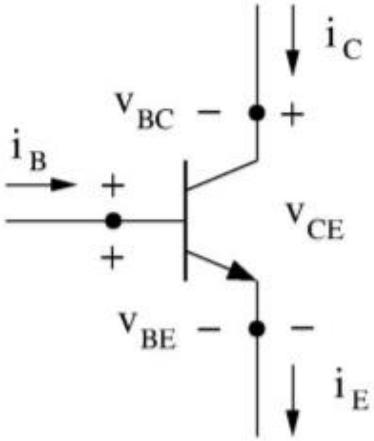
$$i_C < \beta\, i_B$$

$$v_{CE} \approx V_{sat}$$

Cont.

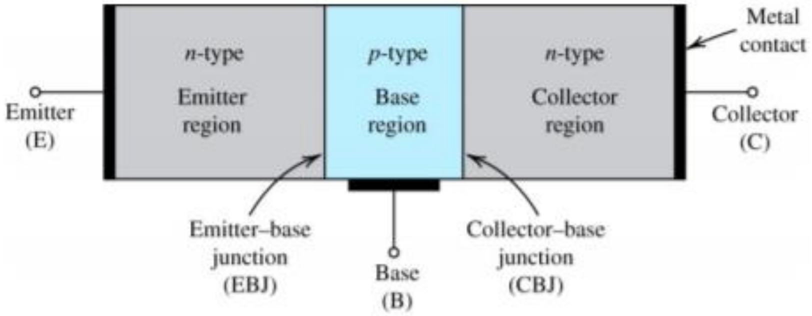
BJT iv characteristics includes four parameters

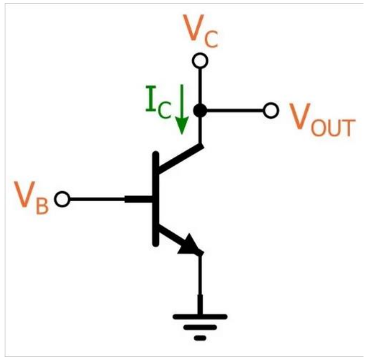




Circuit symbol and
Convention for current directions
(Note: $v_{CE} = v_C - v_E$)

Simplified physical structure



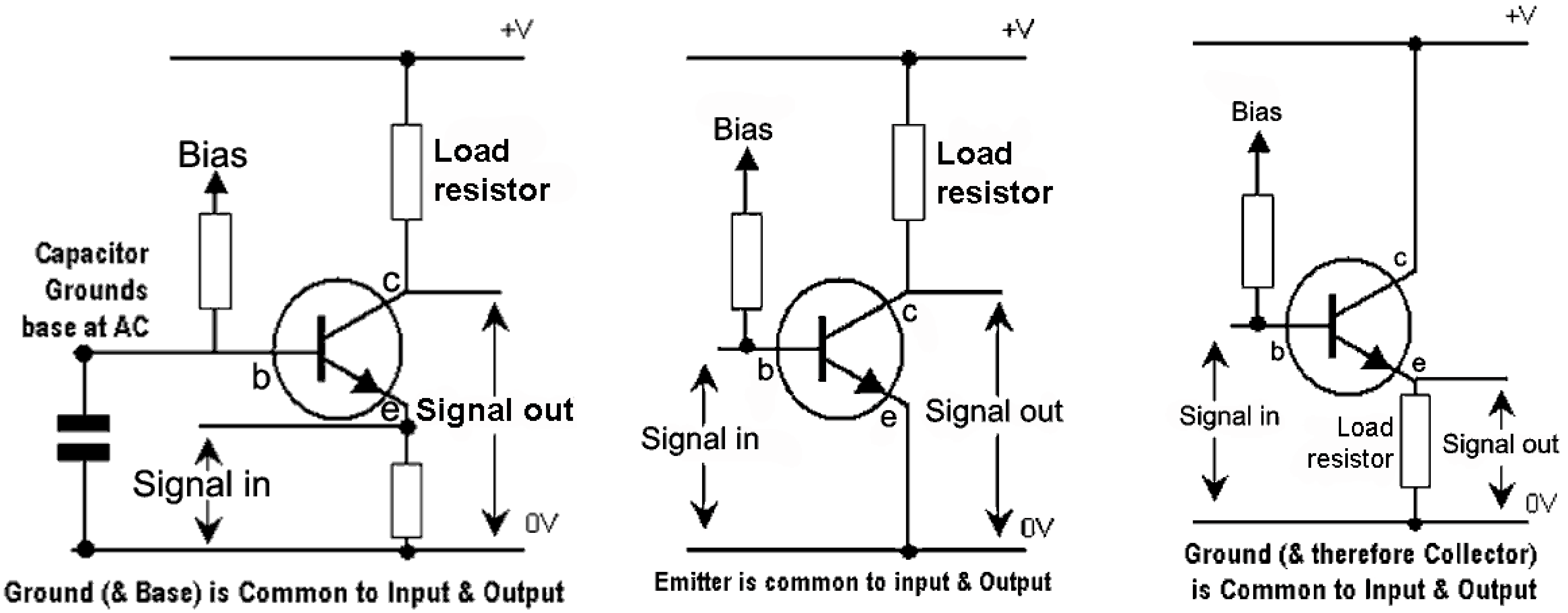


- BJT iv characteristics is the relationship among (i_B , i_C, v_{BE}, and v_{CE})
- It is typically derived as

$$i_B = f\,(v_{BE})$$

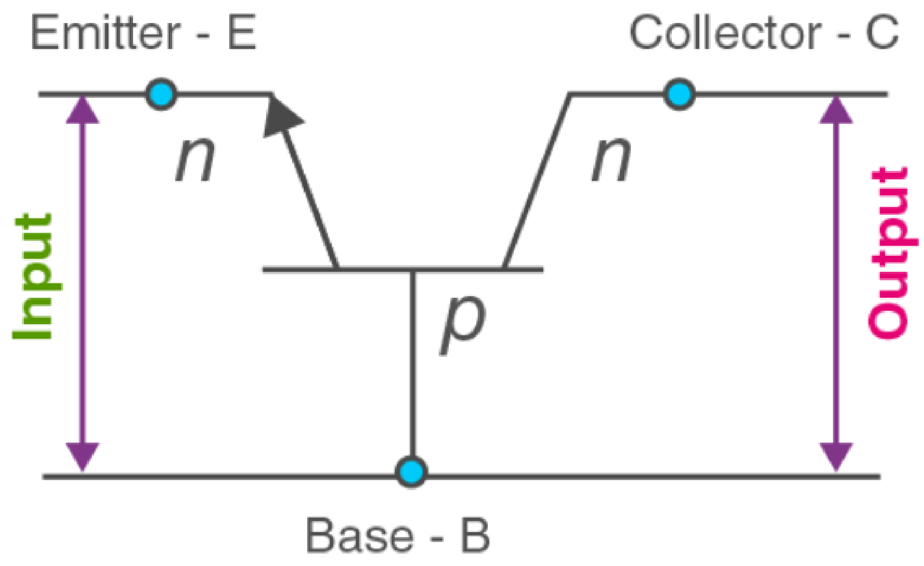
$$i_C = g\,(i_B, v_{CE})$$

BJT Configurations

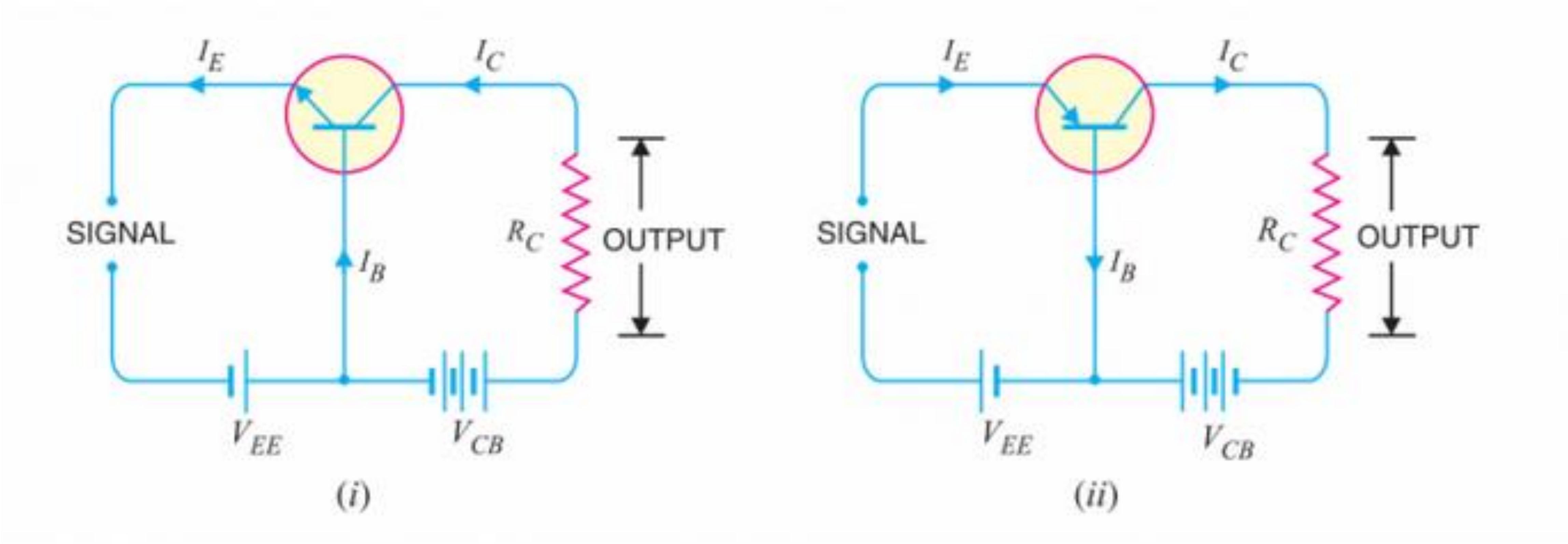


Common Base (CB) Configuration of Transistor

- In CB Configuration, the base terminal of the transistor will be connected common between the output and the input terminals.



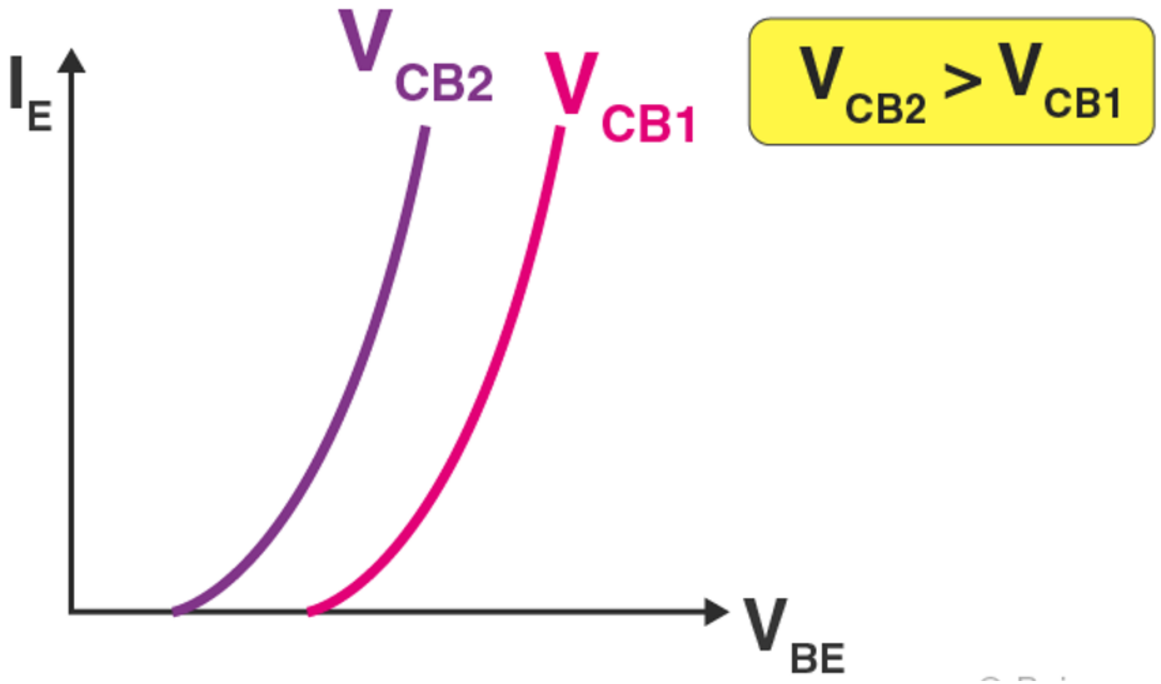
Active Mode Biasing (NPN and PNP Tx)



Transistor Characteristics

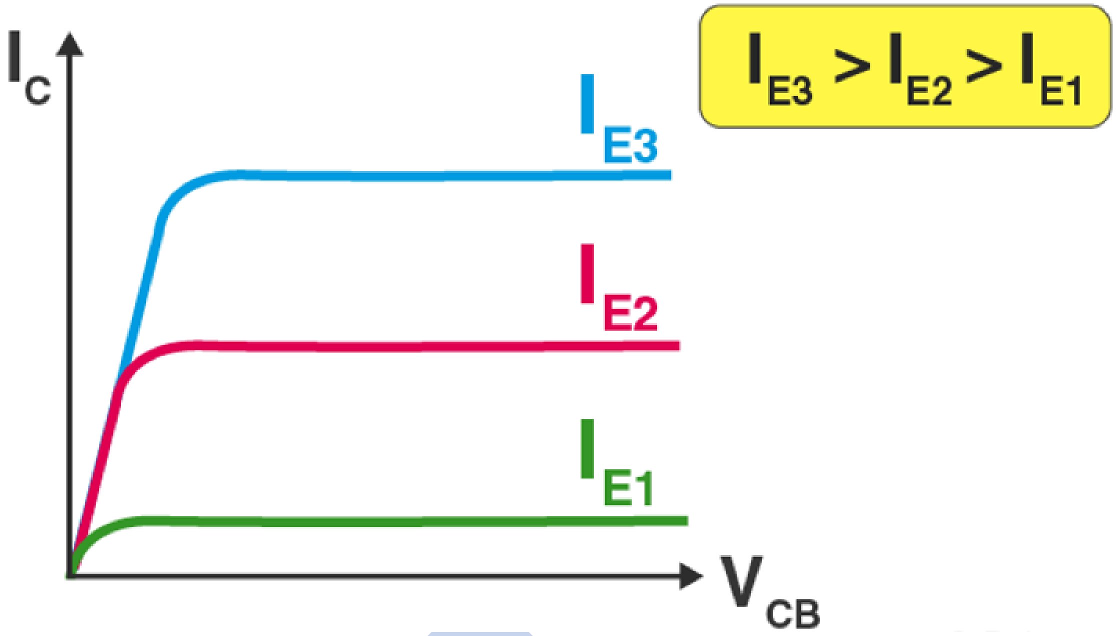
Input Characteristics

The variation of emitter current(I_E) with Base-Emitter voltage(V_{BE}), keeping Collector Base voltage(V_{CB}) constant.



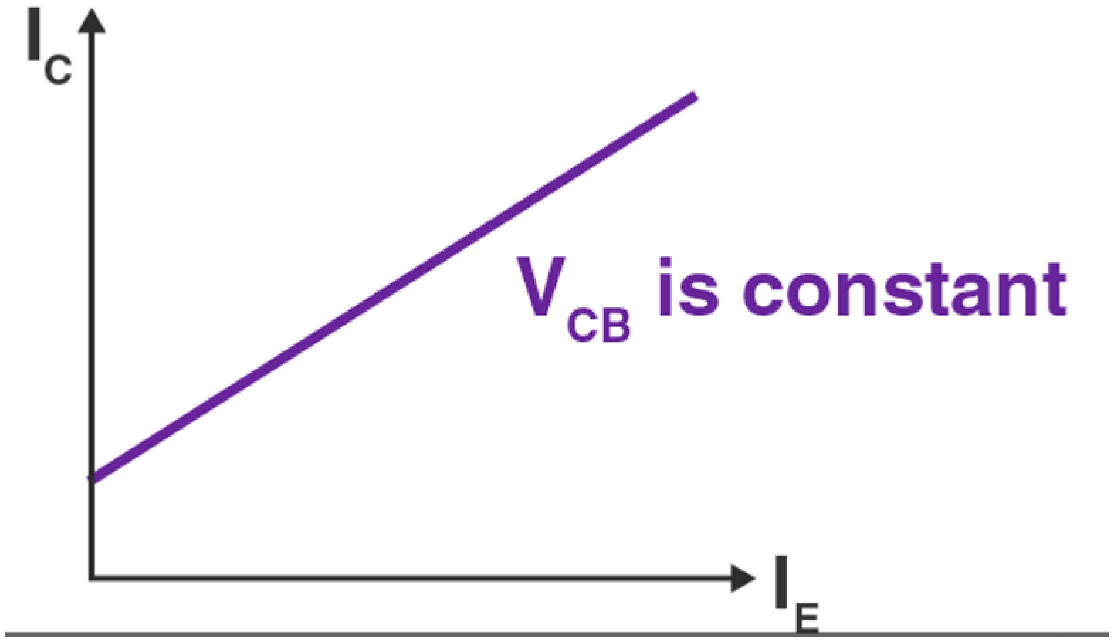
Output Characteristics

The variation of collector current(I_C) with Collector-Base voltage(V_{CB}), keeping the emitter current(I_E) constant



Cont.

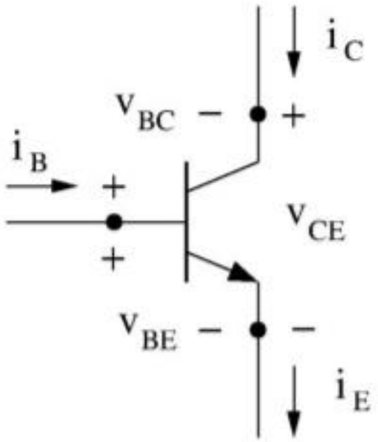
- **Current Transfer Characteristics**
- The variation of collector current(I_C) with the emitter current(I_E), keeping Collector Base voltage(V_{CB}) constant



$$\alpha = \frac{\Delta I_C}{\Delta I_B} | V_{CB} = Constant$$

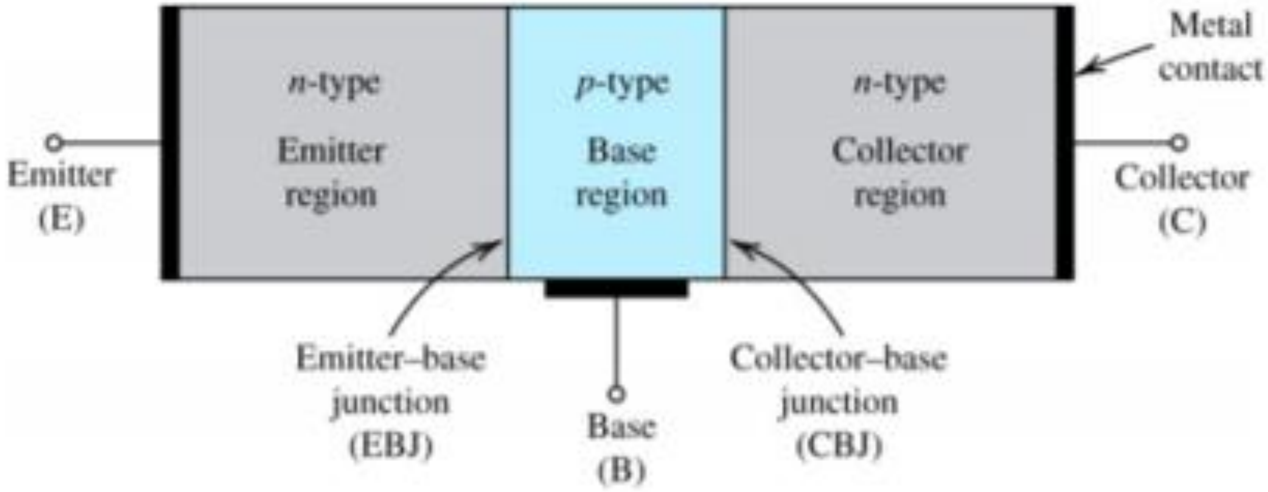
CE Configuration

BJT iv characteristics includes four parameters



Circuit symbol and
Convention for current directions
(Note: $v_{CE} = v_C - v_E$)

Simplified physical structure



- BJT iv characteristics is the relationship among (i_B , i_C, v_{BE}, and v_{CE})
- It is typically derived as

$$i_B = f\,(v_{BE})$$

$$i_C = g\,(i_B, v_{CE})$$

Cont.

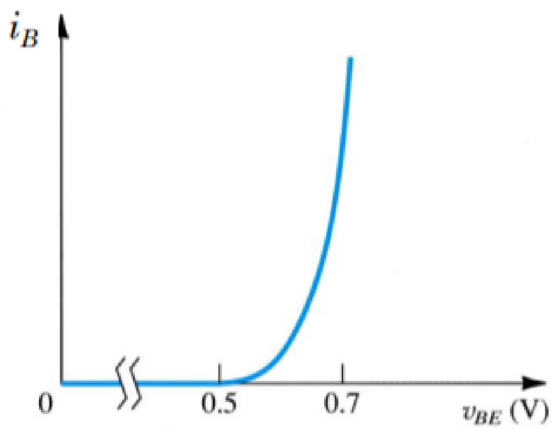
BJT iv characteristics:

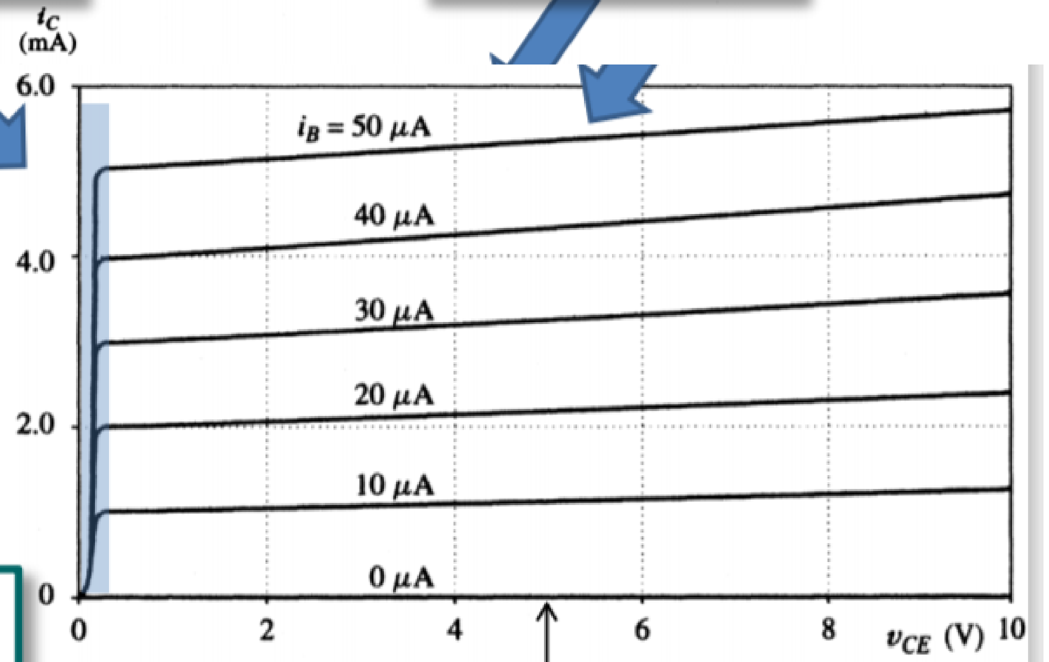
$i_B = f(v_{BE})$ & $i_C = g(i_B, v_{CE})$

Saturation:
BE is forward biased, BC is forward biased

1. Soft saturation: $0.3 \le v_{CE} \le 0.7\ \text{V}, \quad i_C \approx \beta\, i_B$
2. Deep saturation: $0.1 \le v_{CE} \le 0.3\ \text{V}, \quad i_C < \beta\, i_B$
3. Near cut-off: $v_{CE} \le 0.1\ \text{V}, \quad i_C \approx 0$

Active:
BE is forward biased
BC is reverse biased
$i_C = \beta\, i_B$





Cut-off :
BE is reverse biased
$i_B = 0, \quad i_C = 0$

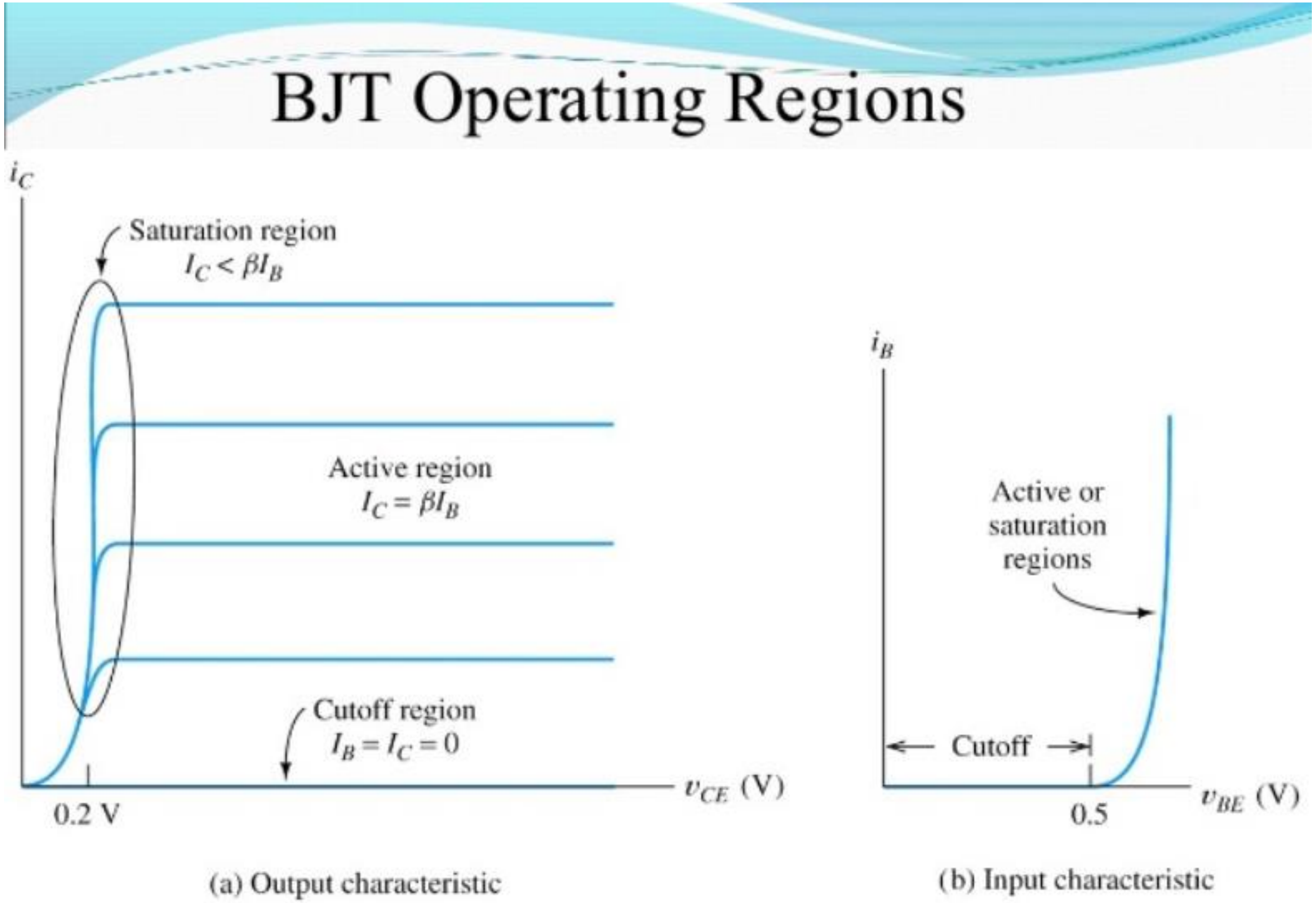
Cont.

NPN BJT iv equations

		"Linear" model
Cut-off : **BE is reverse biased**	$i_B = 0, \quad i_C = 0$	$i_B = 0, \quad i_C = 0$ $v_{BE} < V_{D0}$
Active: **BE is forward biased** **BC is reverse biased**	$i_B = \frac{i_C}{\beta} = \frac{I_S}{\beta} e^{v_{BE}/V_T}$ $i_C = I_S e^{v_{BE}/V_T}\left(1 + \frac{v_{CE}}{V_A}\right)$	$v_{BE} = V_{D0}, \quad i_B \geq 0$ $i_C = \beta\, i_B, \quad v_{CE} \geq V_{D0}$
(Deep) Saturation: **BE is forward biased** **BC is reverse biased**	$i_B = \frac{I_S}{\beta} e^{v_{BE}/V_T}$ $v_{CE} \approx V_{sat}, \quad i_C < \beta\, i_B$	$v_{BE} = V_{D0}, \quad i_B \geq 0$ $v_{CE} = V_{sat}, \quad i_C < \beta\, i_B$

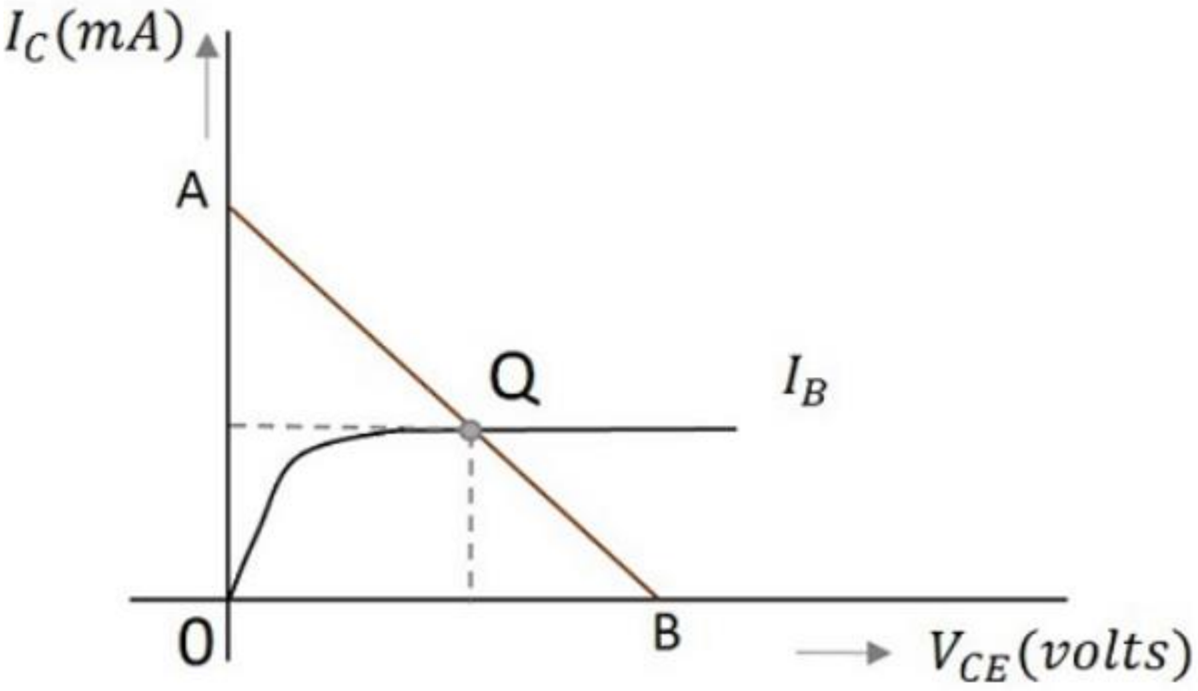
$$\boxed{\text{For Si, } V_{D0} = 0.7 \text{ V}, \quad V_{sat} = 0.2 \text{ V}}$$

Load line and Operating point



Cont.

- When a value for the maximum possible collector current is considered, that point will be present on the Y-axis, which is nothing but the **saturation point**. As well, when a value for the maximum possible collector emitter voltage is considered, that point will be present on the X-axis, which is the **cutoff point**.
- When a line is drawn joining these two points, such a line can be called as **Load line**. This is called so as it symbolizes the output at the load. This line, when drawn over the output characteristic curve, makes contact at a point called as **Operating point**.
- This operating point is also called as **quiescent point** or simply **Q-point**. There can be many such intersecting points, but the Q-point is selected in such a way that irrespective of AC signal swing, the transistor remains in active region. This can be better understood through the figure below.



- The load line has to be drawn in order to obtain the Q-point. A transistor acts as a good amplifier when it is in active region and when it is made to operate at Q-point, faithful amplification is achieved.

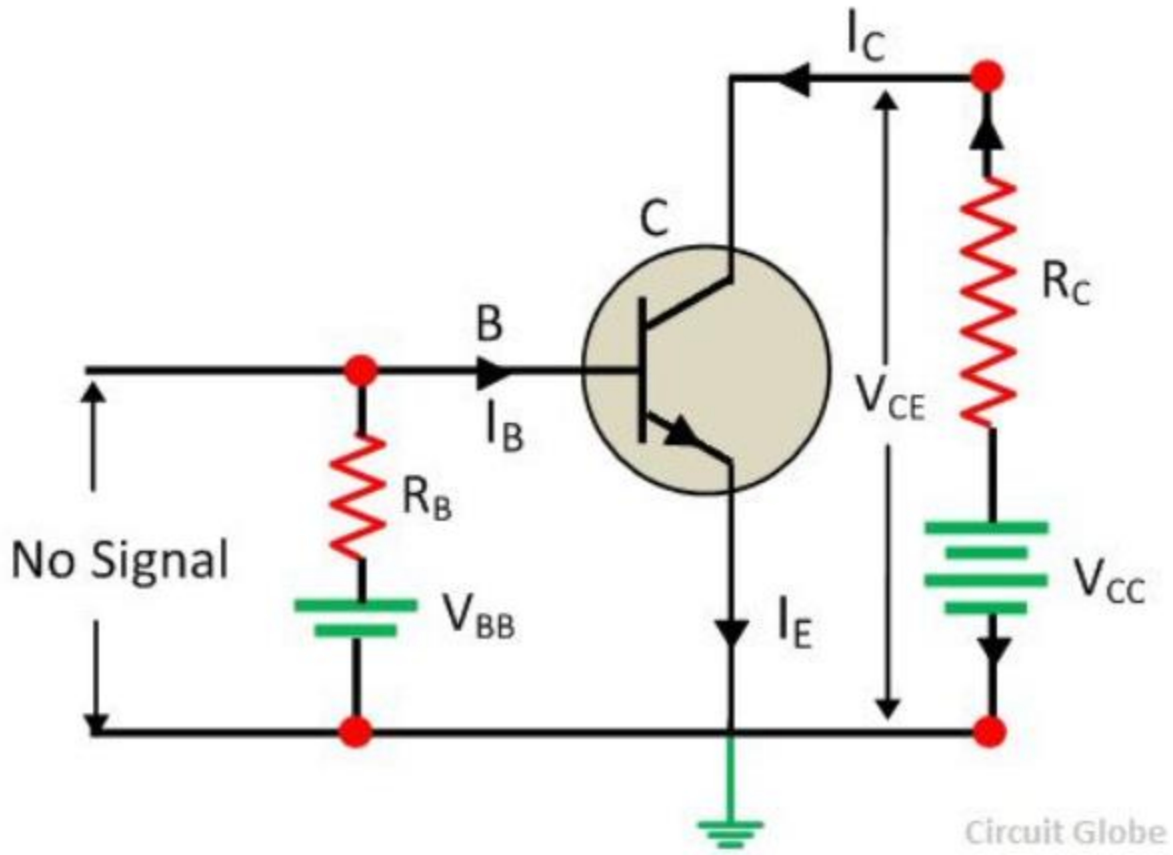
DC Load line

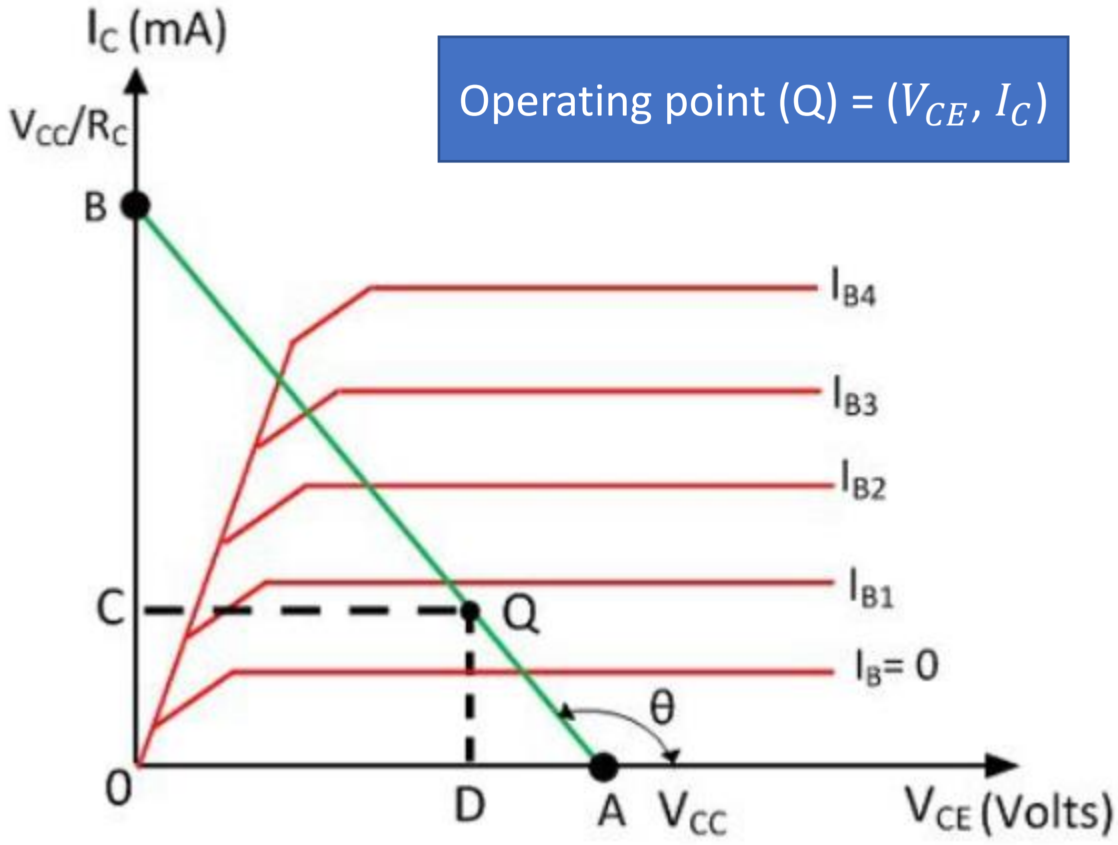
When the transistor is given the bias and no signal is applied at its input, the load line drawn at such condition, can be understood as **DC** condition.

The value of collector emitter voltage at any given time will be

$$V_{CE} = V_{CC} - I_C R_C$$

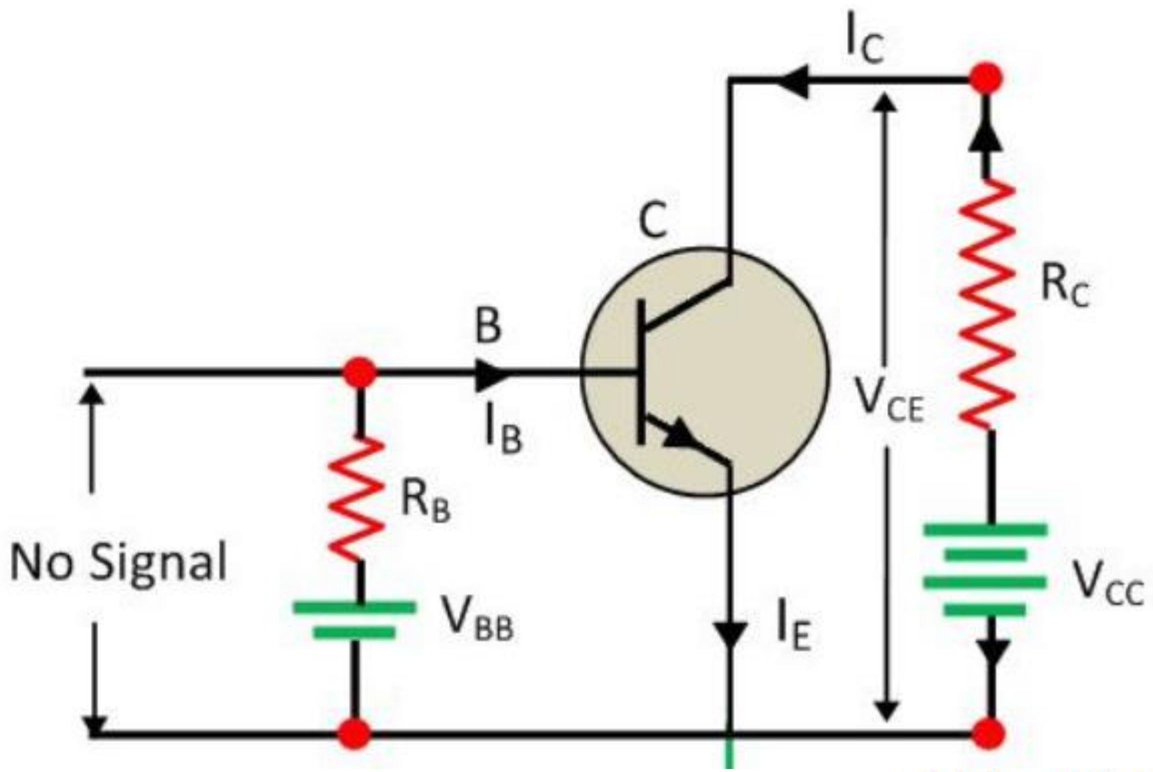
As V_{CC} and R_C are fixed values, the above one is a first-degree equation and hence will be a straight line on the output characteristics. This line is called as **D.C. Load line**. The figure below shows the DC load line.





Operating point (Q) = (V_{CE}, I_C)

Cont.



By applying Kirchhoff's voltage law to the collector circuit, we get,

$$V_{CC} = V_{CE} + I_C R_C$$

$$V_{CE} = V_{CC} - I_C R_C \dots .equ(1)$$

The above equation shows that the V_{CC} and R_C are the constant value, and it is the first-degree equation which is represented by the straight line on the output characteristic. This load line is known as a DC load line. The input characteristic is used to determine the locus of V_{CE} and I_C point for the given value of R_C. The end point of the line are located as

1. The collector-emitter voltage V_{CE} is maximum when the collector current I_C = 0 then from the equation (1) we get,

$$V_{CE} = V_{CC} - 0 \times R_C$$

$$V_{CE} = V_{CC}$$

The first point A (OA = V_{CC}) on the collector-emitter voltage axis shown in the figure above.

Cont.

2. The collector current I_C becomes maximum when the collector-emitter voltage V_{CE} = 0 then from the equation (1) we get.

$$0 = V_{CC} - I_C R_C$$

$$I_C = \frac{V_{CC}}{R_C}$$

This gives the second point on the collector current axis as shown in the figure above.

By adding the points A and B, the DC load line is drawn. With the help of load line, any value of collector current can be determined.