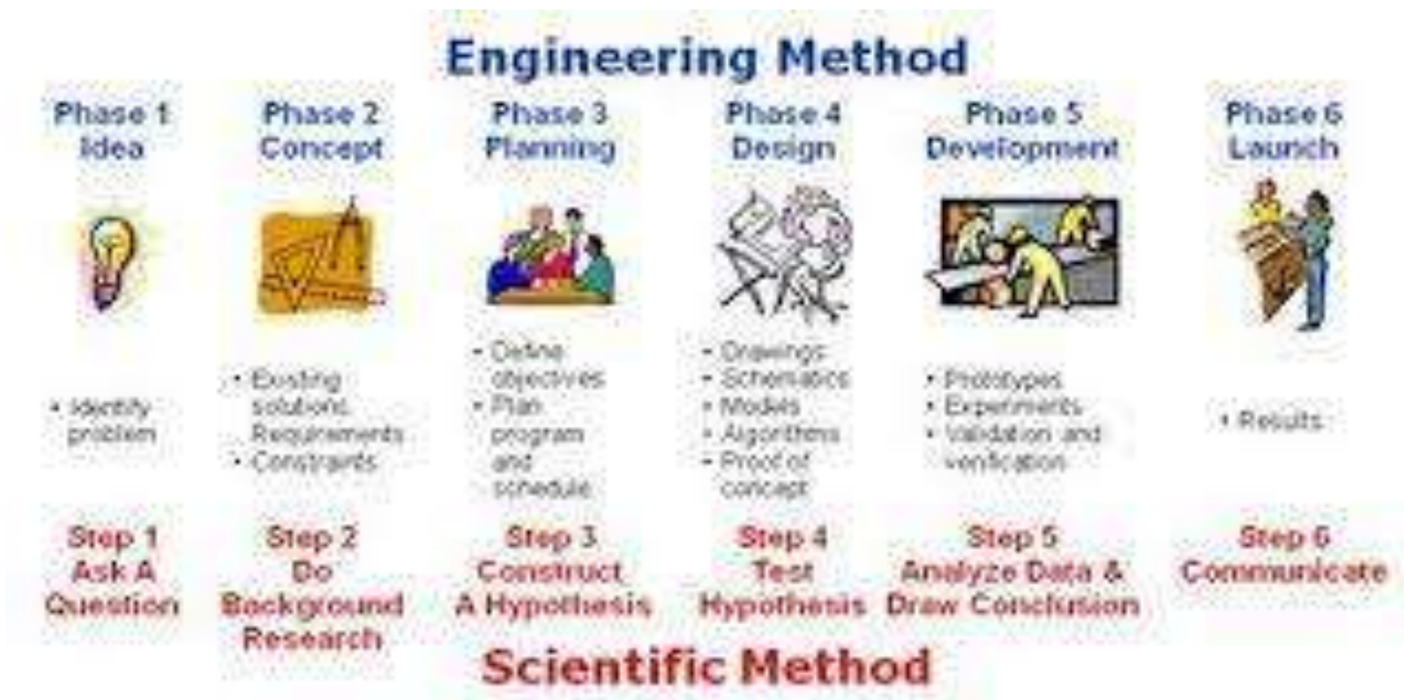
Why I choose Engineering ??

What is Engineering ????

Real life problem understanding and try to give best solution.



What is computer Science ?

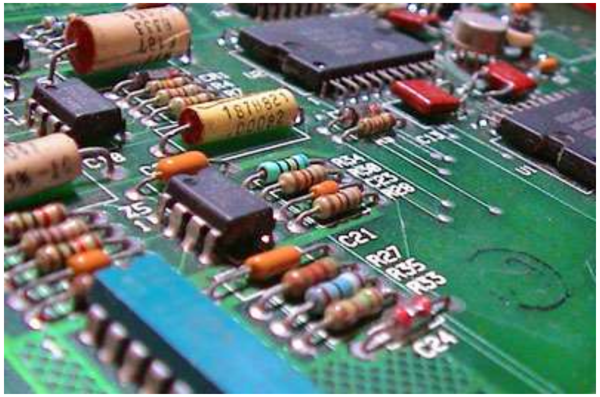
Importance of Electronics ……

Why to study B.ETC in Computer science ?

Basic Electronics

(EC- 10001)

Electronics means….“The branch of physics and technology concerned with the design of circuits using transistors and microchips , and with the behaviour and movement of electrons in a semiconductor , conductor, vacuum or gas .”



Course Overview

- **Unit 1:** Properties of semiconductor material and it application as p-n junction diode, diode characteristics and Breakdown mechanisms, Half-wave, full-wave rectifiers with filters, Zener diode.
- Transistor constructions, operations and their characteristics.Transistor Biasing ,amplifiers,load line analysis, Concept of JFET and MOSFET.

Contd...

- **Unit 2**: Operational Amplifier (Op-amp) and application: - Introduction to Op-amp and its Characteristics . Application of Op-Amp as Inverting amplifier, Non-inverting Amplifier, Summing,Difference amplifier and comparator.

Contd…

- **Unit 3**: Introduction to Digital Electronics:- Different number systems and its conversions, Logic gates and truth tables of OR, AND, NAND, EX-OR. Combinational circuit and Sequential circuit.

Course Overview

- **Unit 4:** Miscellaneous Electronic Devices:- SCR,opto-electronic devices and fiber techniques, Introduction and describing sensor performance,Fundamentals of Analog communication techniques (AM, FM)

Course Outcomes of BETC

- CO1:To understand the properties of semiconductors .
- CO2:To analyze different types of diodes, study of simple electronic circuits using diodes.
- CO3:Different types of transistor , its configurations.Application of transistor in amplifier and switch.
- CO4:The ability to know about OP-AMP and its applications.
- CO5:To understand different types of digital gates .Its application in digital circuits.
- CO6:Realize the importance of various analog and digital electronic systems, and electronic devices.

Contd…

- **Text Books**
- *Electronics –Fundamentals & Applications –D. Chattopadhyay and P. C. Rakshit – 11th Edition (New Age International)*

- **Reference Books**
- *Electronic Devices & Circuits – R. L. Boylestad & L. Mashelsky – 10th Edition (Pearson)*
- *Electronic Principles – A. Malvino & D. J. Bates – 7th Edition (TMH)*
- *Digital Principles and Applications– A. Malvino and Leach – 7th Edition (TMH)*
- *Integrated Electronics – J. Millman, Halkias & Parikh – 2nd Edition (TMH)*

Evaluation Scheme

Theory			
Total Marks	End Semester	Mid Semester	Internal
100	50	20	30

Thank You

AEC

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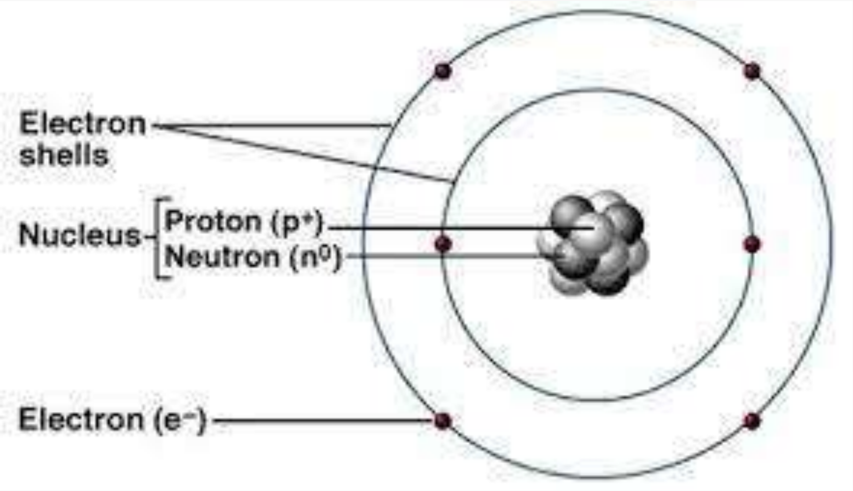
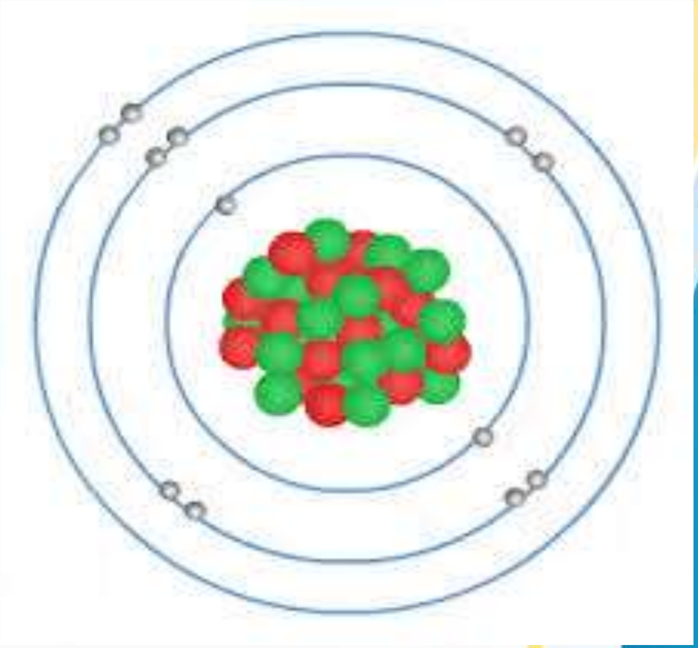
Bhubaneswar

Atomic Structure

- Atoms consist of positive charged nucleus and electrons are revolving around them in different permitted orbits.
- Each orbits have $2n^2$ number of electrons where 'n' is orbit number.
- Electrons jump to higher orbit by gaining energy and fall back to lower orbit by emitting light or heat.

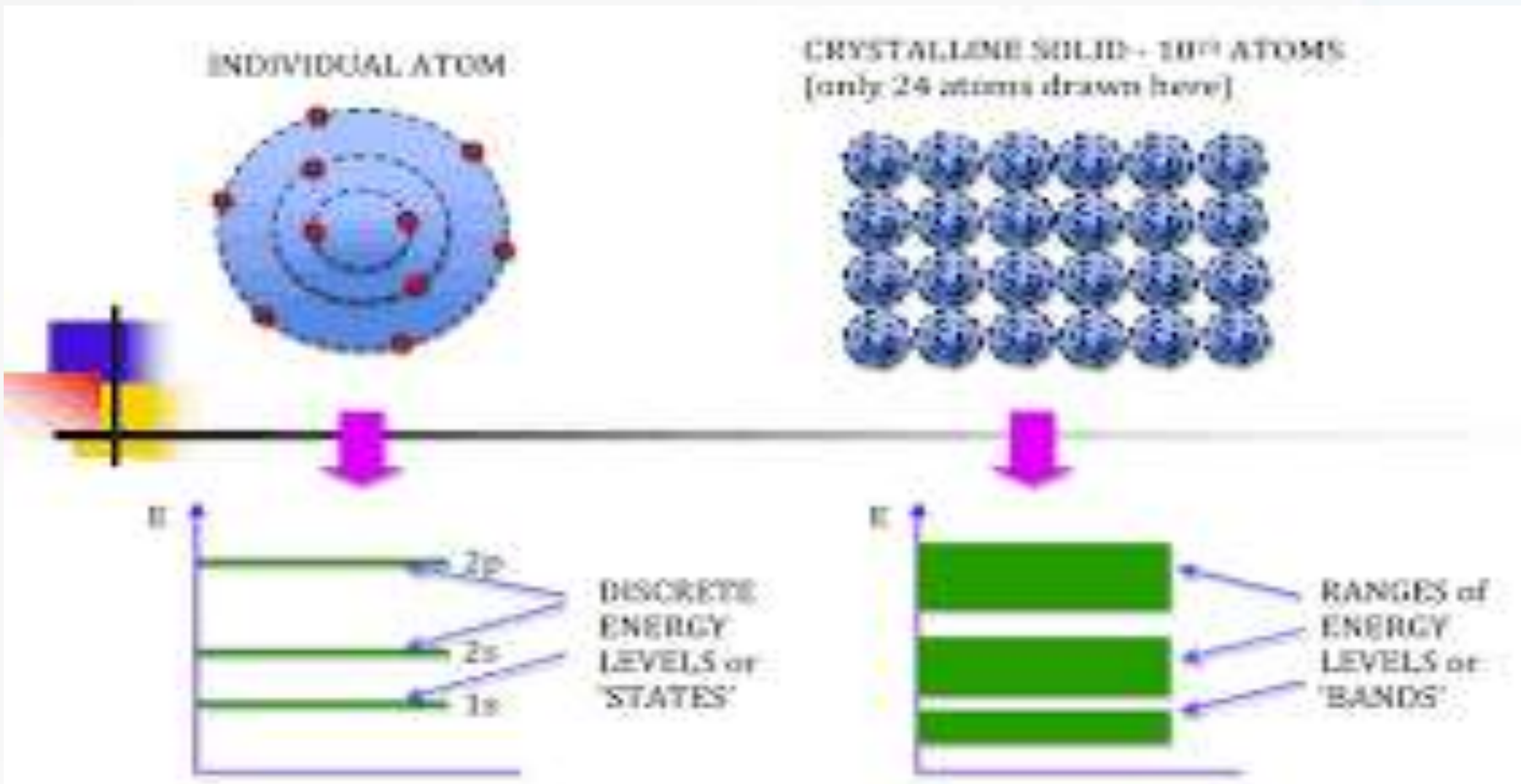




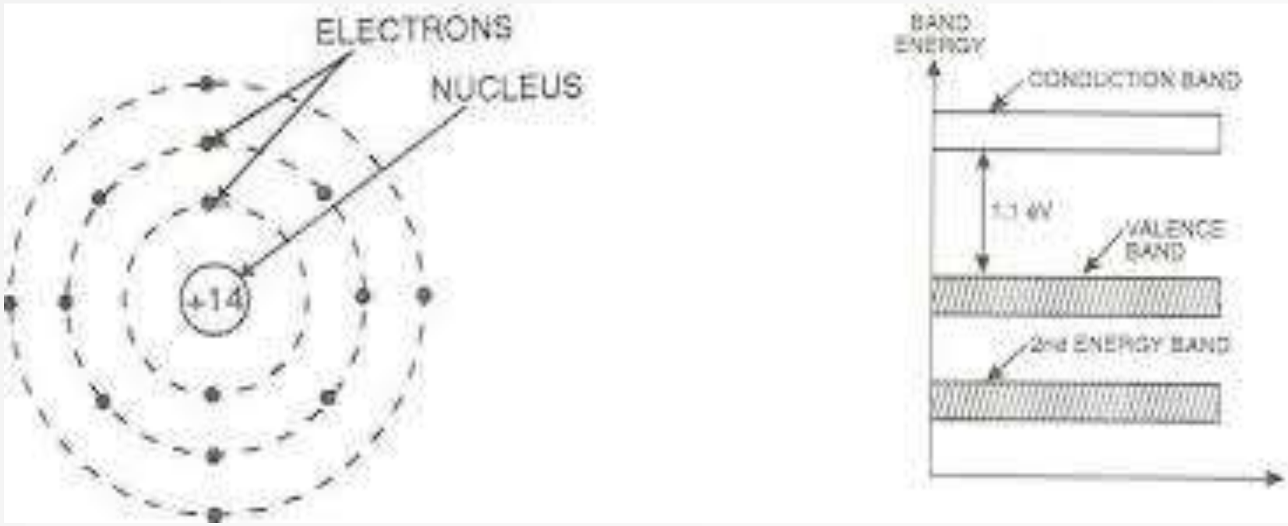
Energy level & Energy band

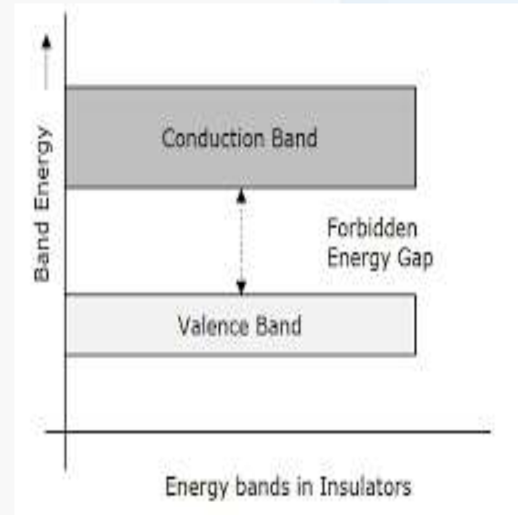
- Energy possesed by electrons in an orbit for an isolated atom is fixed and represented by energy level.

- The range of energies possesed by electrons in an orbit in solids is known as energy band.



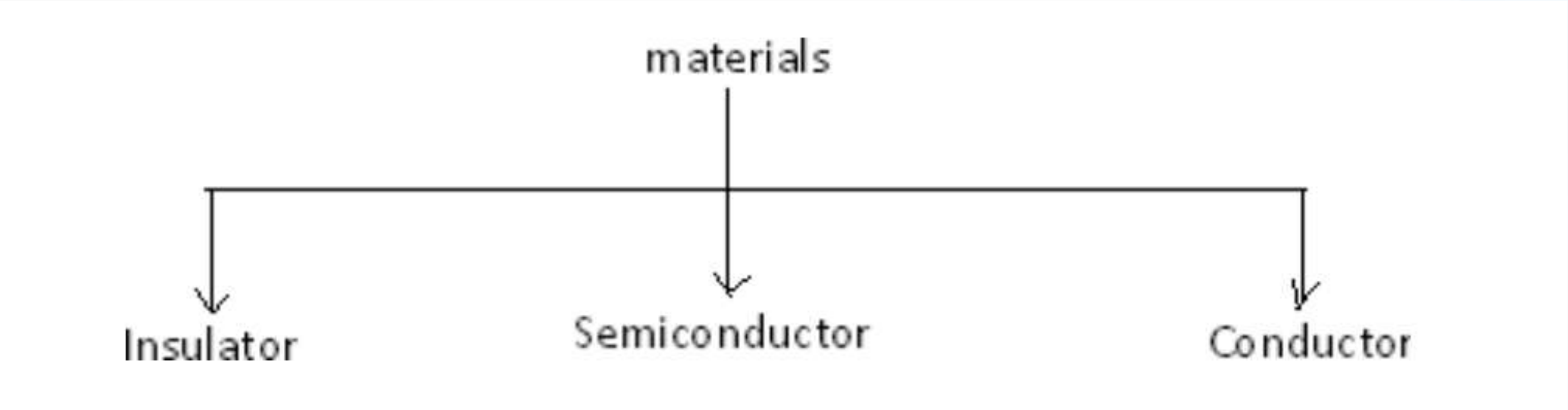
Energy Band





- The range of energies possesed by valance electrons are known as Valance energy band (V.B).
- The range of energy possesed by free/conduction electrons are known as conduction energy band (C.B).
- The separation between conduction energy band and valance energy band is known as forbiden energy band gap (Eg).

Classification of Solids



- Insulator:Those materials which do not allow the flow of current through them.
- Example:Glass,wood,paper etc
- In this type of materials V.B are full and C.B is empty.
- Energy gap is very large (nearly 15 eV)

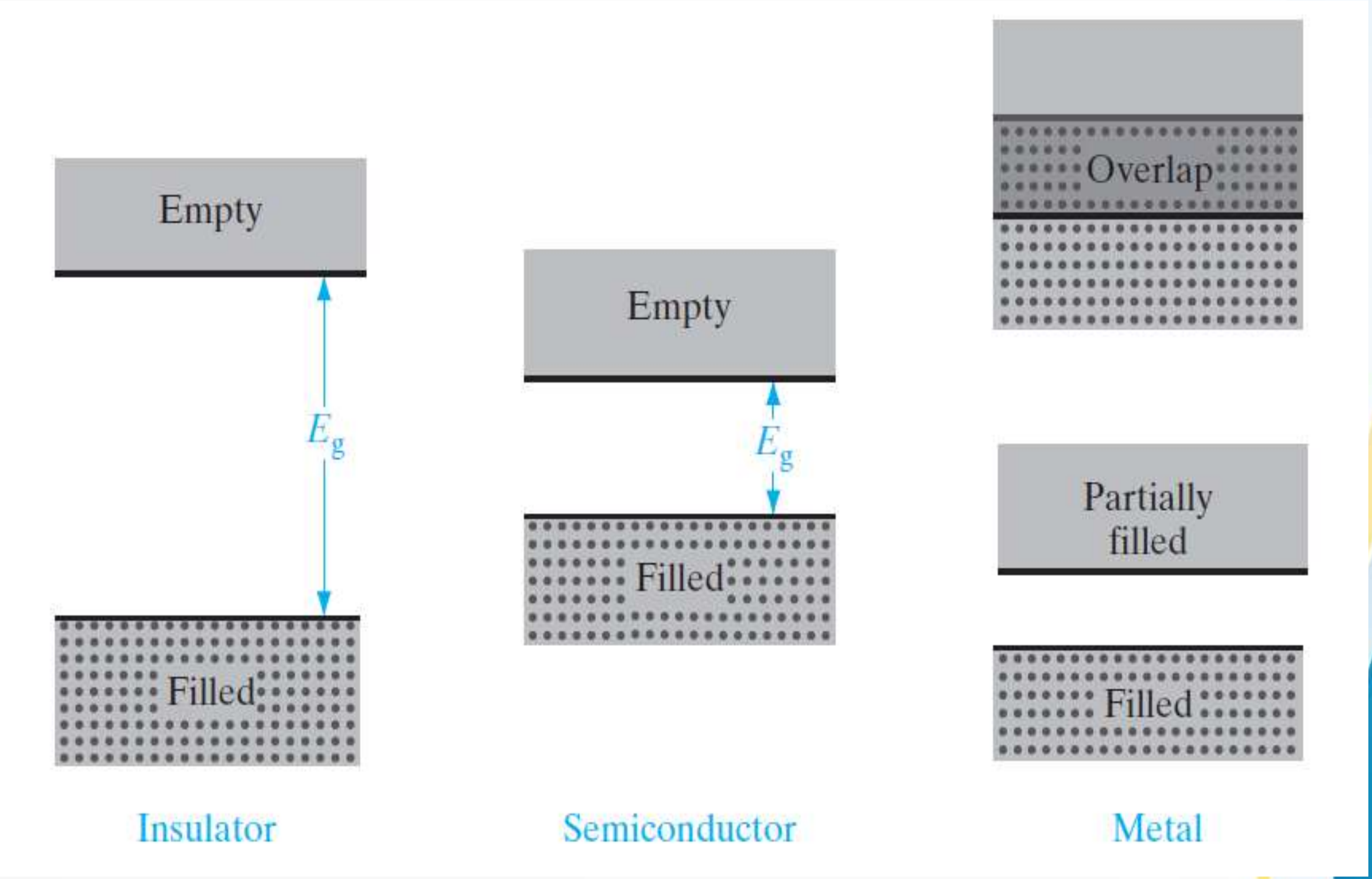
- Unit of Energy:An electron moving through 1Volt potential difference will gain some kinetic energy which is expressed in eV.

- $1eV=1.6\times10^{-19}\times1V=1.6\times10^{-19}$ Joule

Contd...

- Conductor:Those substances which easily allow the flow of current through them.
- Example:copper,gold etc
- A large number of free electrons are available in conduction band.
- Conduction band and valance band are overllaped.
- A slight potential difference across material cause the flow of carrier to constitute current in it.
- Conductor shows positive temperature coefficient of resistance.
- Semiconductor:Those substances which which have conductivity lies between conductor and insulator.
- Example:Silicon,Germanium,GaAs,GaP
- The energy gap between C.B and V.B are very less.
- Very small energy is required to move electrons from V.B to C.B.
- Semiconductor shows negative temperature coefficient of resistance.

Band Diagram



Why semiconductor device ?

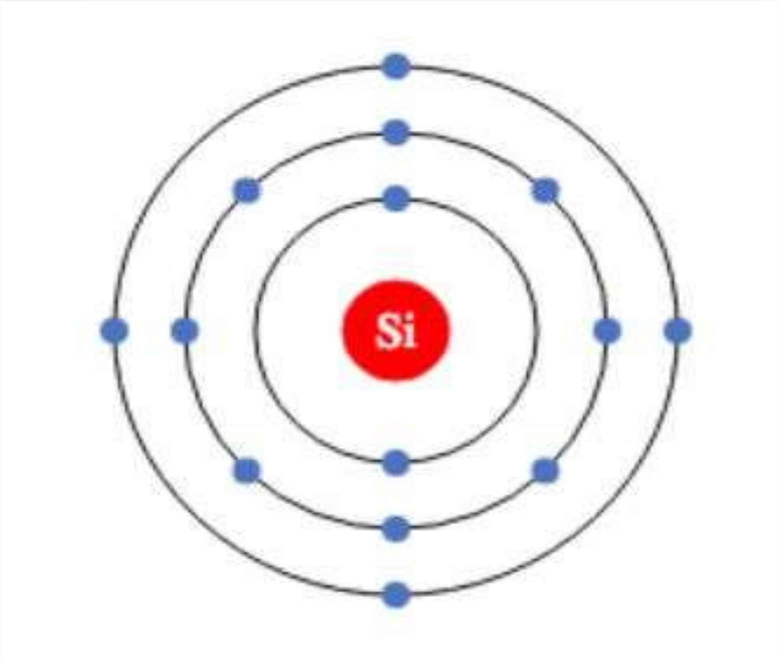
- Semiconductor devices such as diodes, transistors and integrated circuits can be found everywhere in our daily lives like in televisions, automobiles, washing machines and computers.

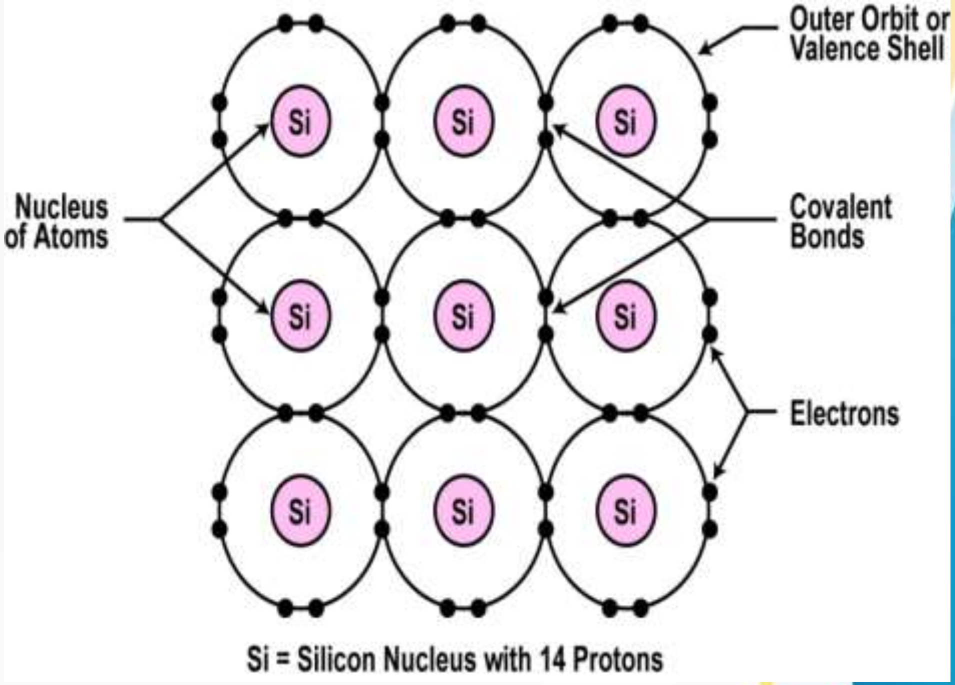
- Semiconductor conductivity can be varied/controlled.

- Semiconductor is easily available.

Semiconductor

- Silicon : It's a Group 4 element which means it has 4 electrons in outer shell.
- However, like all other elements it would prefer to have 8 electrons in its outer shell.
- The unique capability of semiconductor atoms is their ability to link together to form a physical structure called a crystal lattice.
- The atoms link together with one another sharing their outer electrons.
- These links are called covalent bonds.





Basic Electronics

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Types of semiconductor

- Semiconductors are classified into 2 types.
  - Intrinsic semiconductor
  - Extrinsic Semiconductor

- Extrinsic semiconductora are again divided into 2 types.
  - P type extrinsic semiconductor
  - N type extrinsic semiconductor

Intrinsic Material

A pure semiconductor crystal with no impurities or lattice defects is called an ***intrinsic*** semiconductor.

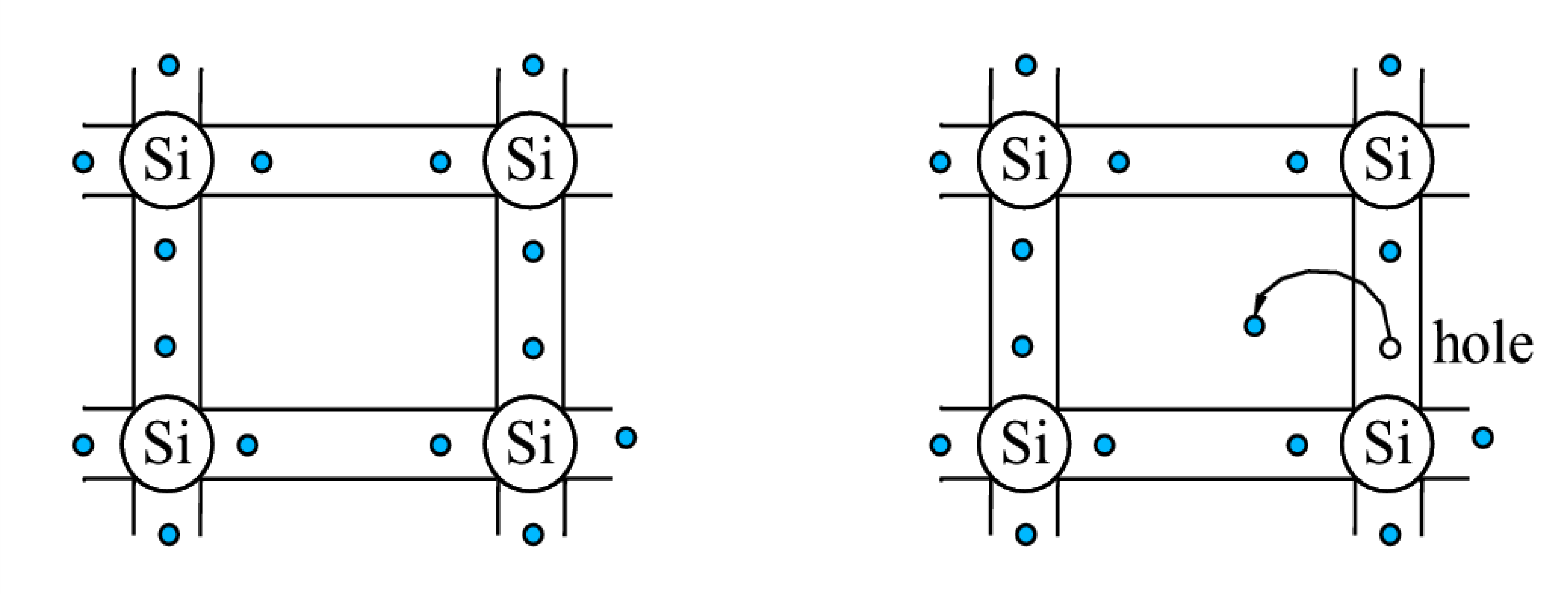
At T=0 K
Valence band is full with electrons
Conduction band is empty

So no carriers available for conduction.

At T>0 thermal fluctuations break electrons to free creating electron-hole pairs.

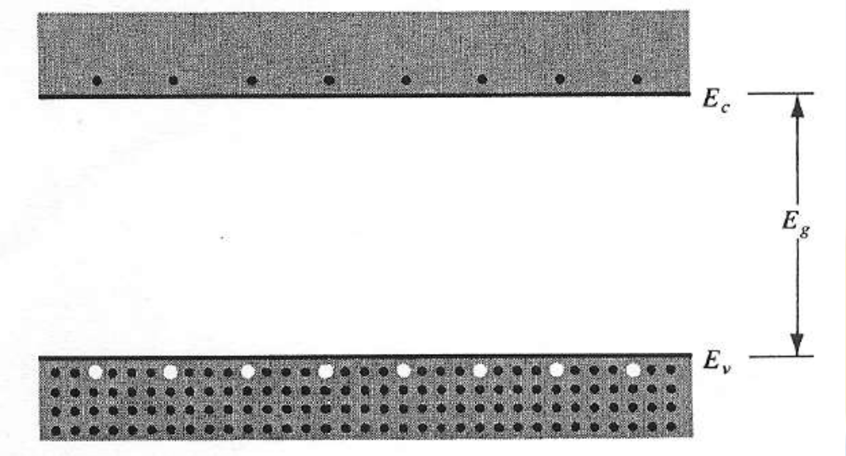
Electron-hole pairs (EHP) are generated.

Number of electrons=No. of holes



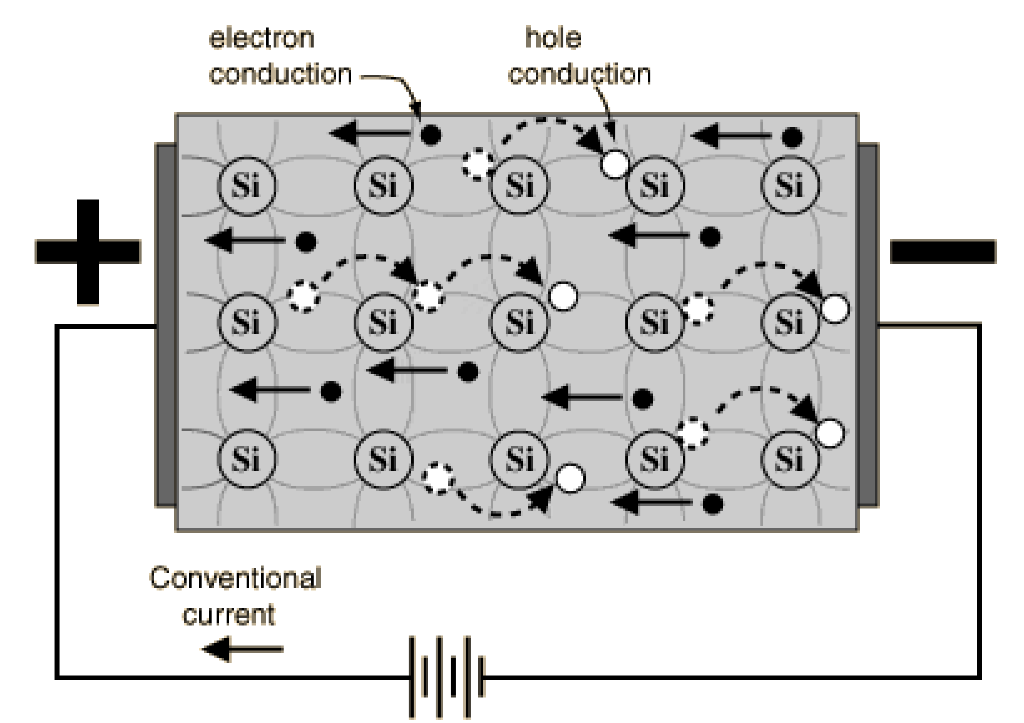
Concept of Electron and hole

- At temperature T>0,some electrons in the valence band receive enough thermal energy to be excited across the band gap to the conduction band.
- The result is a material with some **electrons** in an empty conduction band and some unoccupied states in an filled valence band.
- An empty state in the valence band is referred to as a ***hole***.
- If the conduction band electron and the hole are created by the excitation of a valence band electron to the conduction band, they are called an ***electron-hole pair*** (EHP).



Electron-hole pairs in a semiconductor. The bottom of the conduction band denotes as E_c and the top of the valence band denotes as E_v.

current carrying mechanisim of hole



- If a voltage is applied, then both the electron and the hole can contribute to a small current flow.
- Current carried by valence electrons in valance band is called as hole current.
- Current carried by free electrons in conuction band is called as electron current.

How to Increase conductivity

- **Case-1**
- The conductivity of the semiconductor material increases when the temperature increases.
- This is because the application of heat makes it possible for some electrons in the valence band to move to the conduction band.
- Obviously the more heat applied the higher the number of electrons that can gain the required energy to make the conduction band transition and become available as charge carriers.
- This is how temperature affects the carrier concentration.
- **Case-2**
- Another way to increase the number of charge carriers is to add them in from an external source.
- Doping or implant is the term given to a process whereby one element is injected with atoms of another element in order to change its properties.
- Semiconductors (Si or Ge) are typically doped with elements such as Boron, Arsenic and Phosphorous to change and enhance their electrical properties.

Extrinsic semiconductor

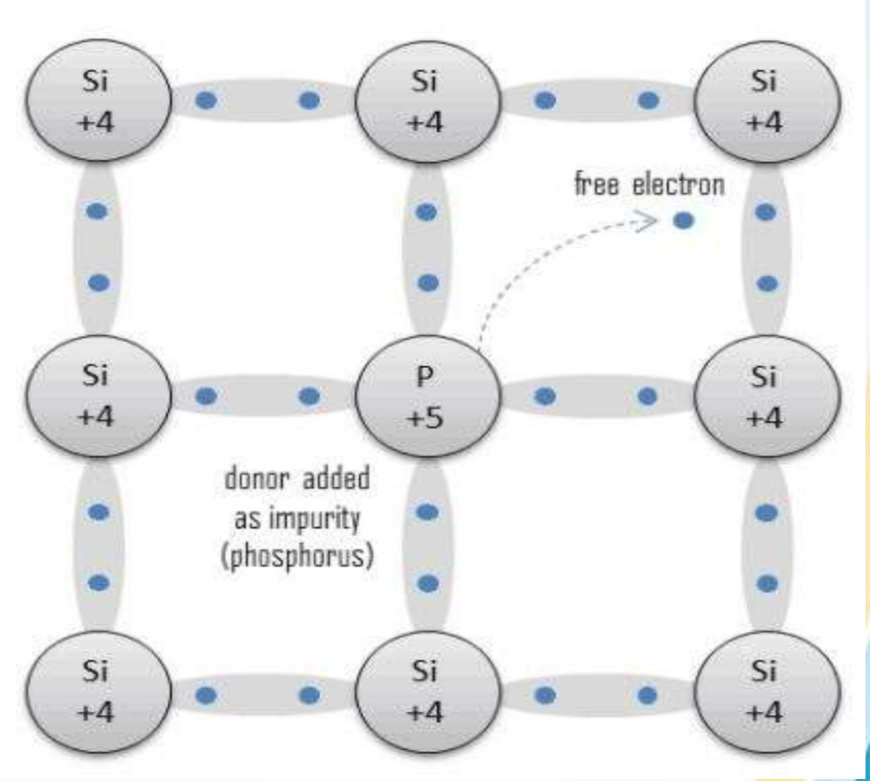
- Doping or implant is the term given to a process whereby one element is injected with atoms of another element in order to change its properties.

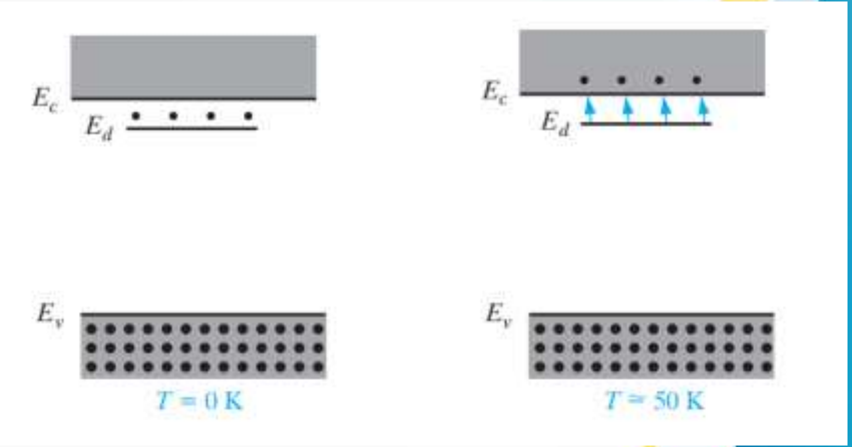
- Semiconductors (Si or Ge) are typically doped with elements such as Boron, Arsenic and Phosphorous, etc. to change and enhance their electrical properties.
- Doping (adding an impurity) can produce 2 types of semi-conductors depending upon the element added.

- When a crystal is doped such that the equilibrium carrier concentrations n_0 and p_o are different from the intrinsic carrier concentration n_i, the material is said to be *extrinsic.*
- When trivalent impurities(B,Al) are added to intrinsic semiconductor, then it is called as p-type extrinsic semiconductor.
- When pentavalent impurities(P,As) are added to intrinsic semiconductor, then it is called as n-type extrinsic semiconductor.

N-type extrinsic semiconductor

- An impurity from column V introduces an energy level very near the conduction band in Ge or Si.
- This level is filled with electrons at 0 K, and very little thermal energy is required to excite these electrons to the conduction band.
- Thus, at about 50-100 K nearly all of the electrons in the impurity level are "donated" to the conduction band.
- Such an impurity level is called a donor level, and the column V impurities in Ge or Si are called donor impurities.
- So the material doped with donor impurities can have a considerable concentration of electrons in the conduction band.





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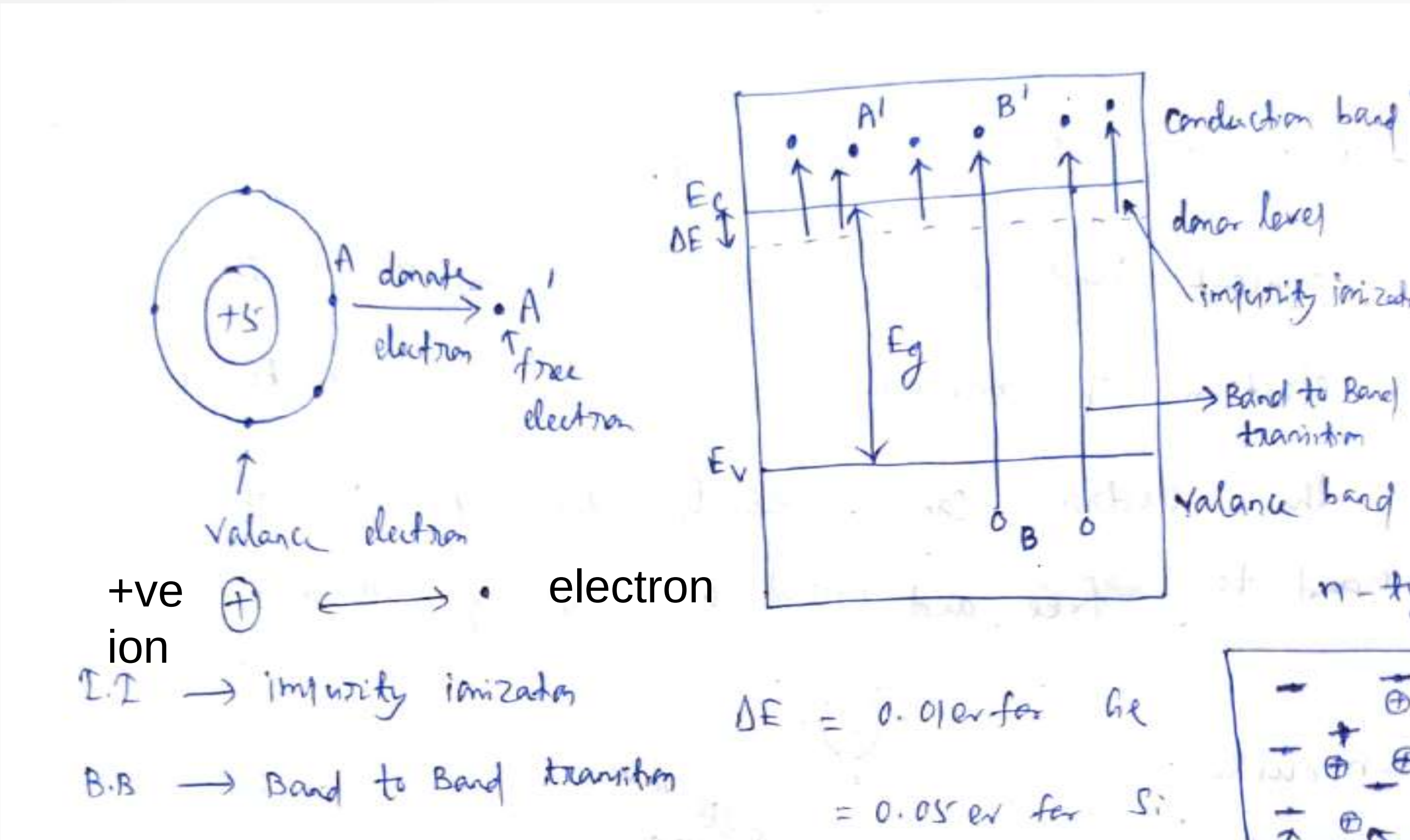
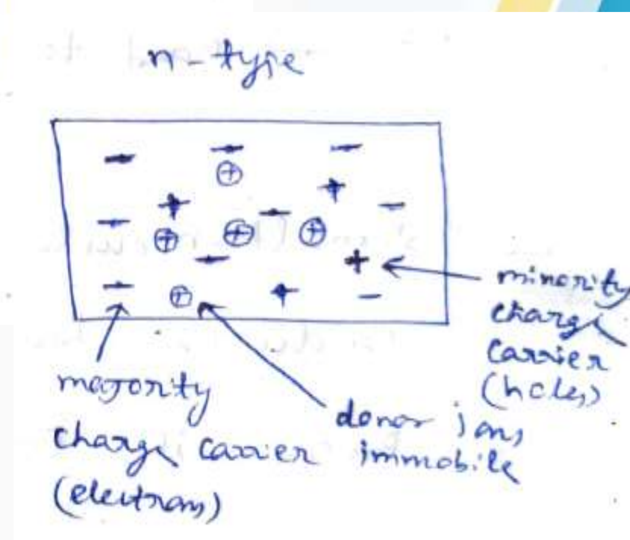
- Thus semiconductors doped with a significant number of donor atoms will have n>>p at room temperature. This is n-type material.

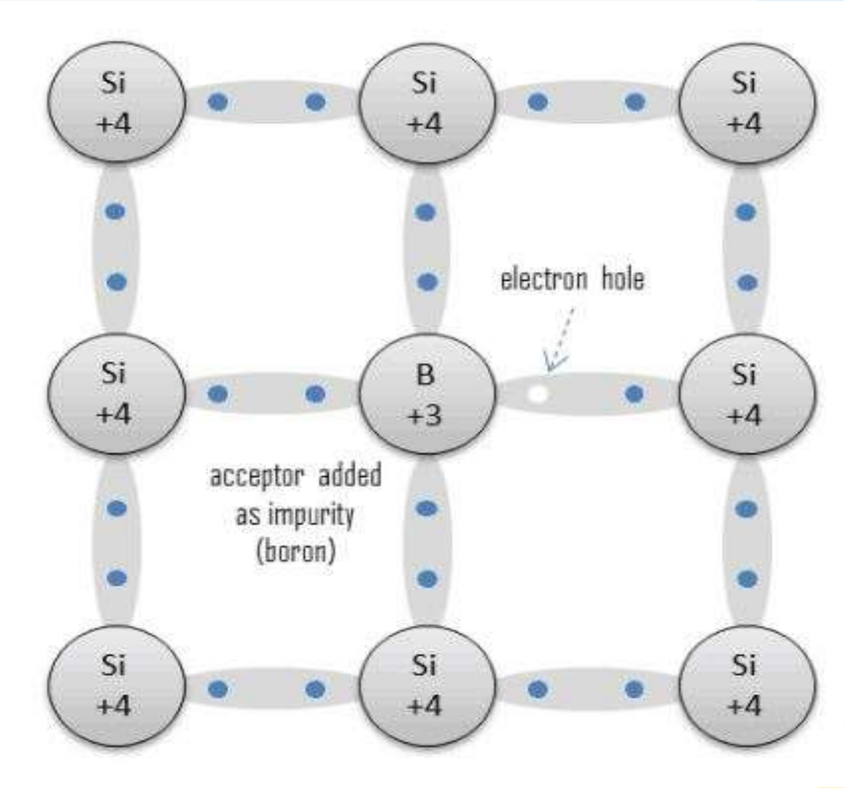


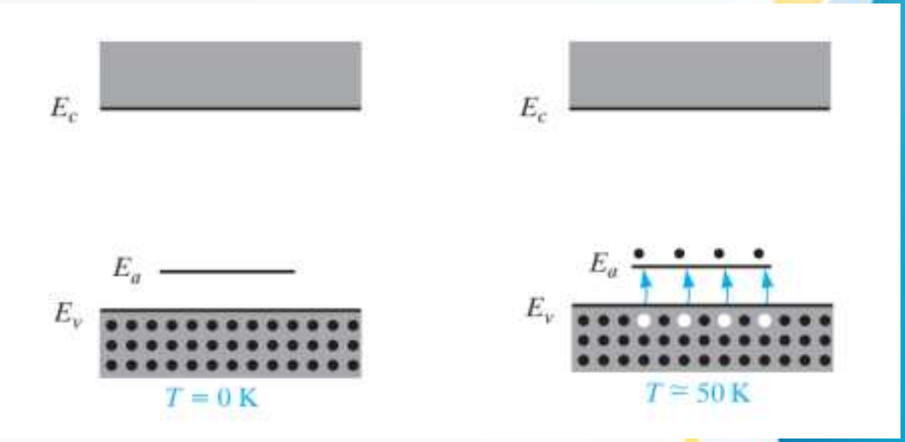


+ve ion + hole = electrons
no. of electrons > no. of holes (n-type)

P-type extrinsic semiconductor

- Atoms from group III (B, Al, Ga, and In) introduce impurity levels in Ge or Si near the valence band.
- These levels are empty of electrons at 0 K.
- At low temperatures, enough thermal energy is available to excite electrons from the valence band into the impurity level, leaving behind holes in the valence band.
- Since this type of impurity level "accepts" electrons from the valence band, it is called an *acceptor* level, and the column III impurities are acceptor impurities in Ge and Si.





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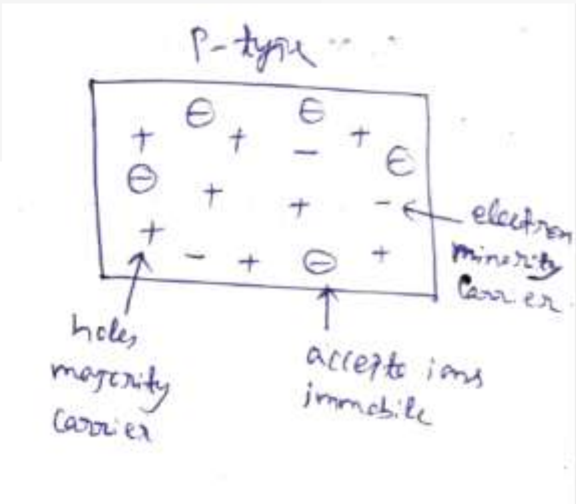
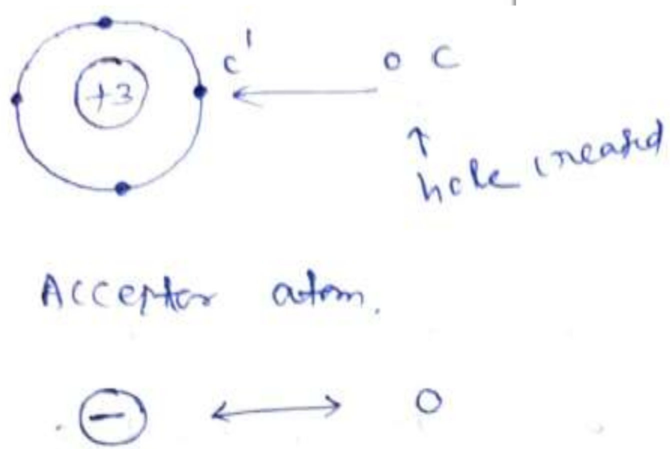
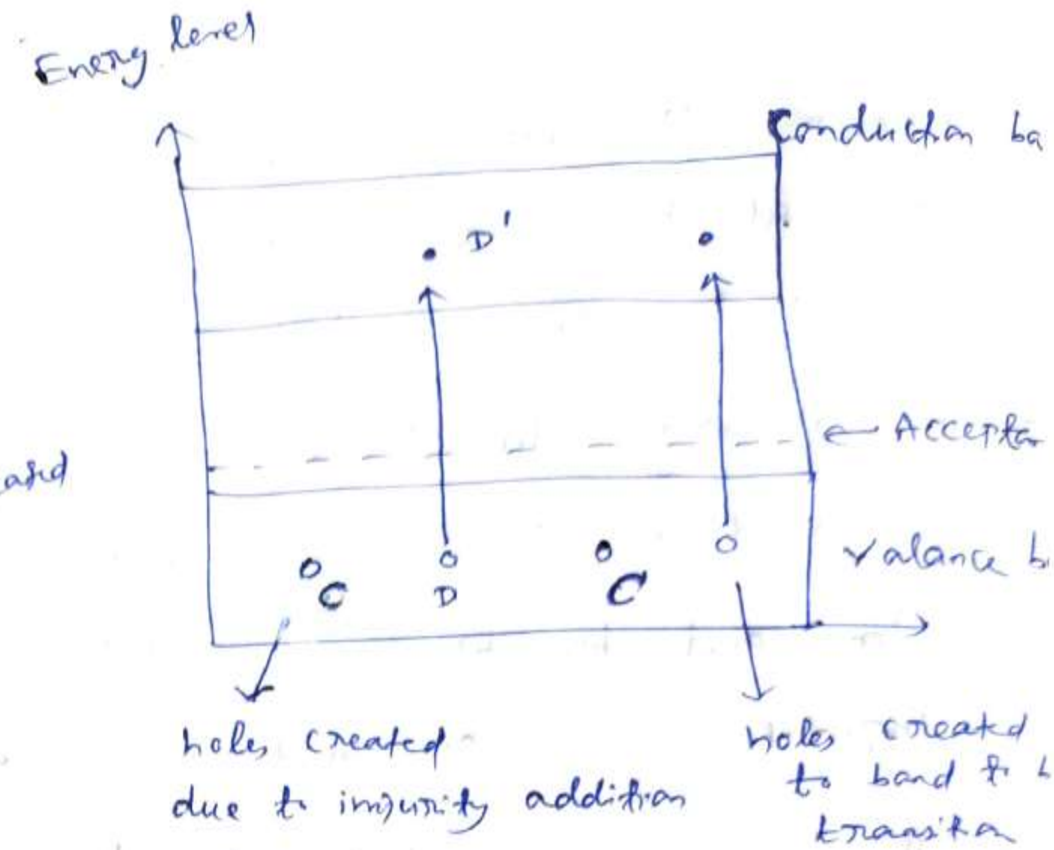
- As figure indicates, doping with acceptor impurities can create a semiconductor with a hole concentration *p* much greater than the conduction band electron concentration *n* (*this is p-type material*).



-ve ion +electron = hole

no. of holes < no. of electrons (p-type)



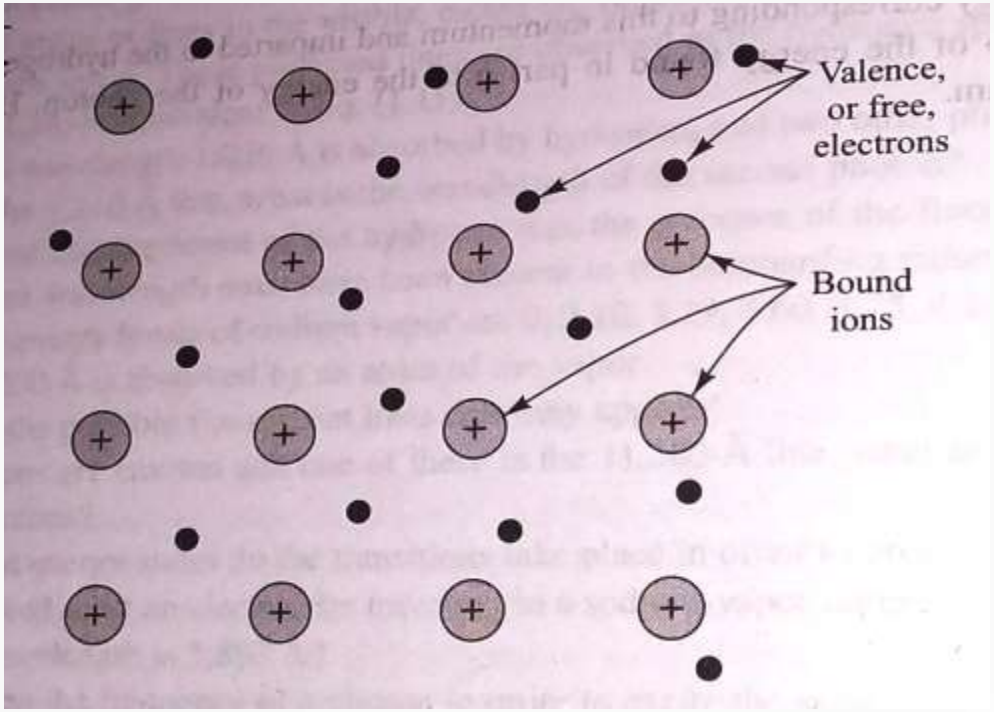


-ve ion

hole

Mobility and conductivity

- In a crystal lattice large number of free electrons moves in random fashion at room temperature.
- The number of electrons crossing the area of crystal in any direction will be same as number of electrons moving in opposite direction.
- So net current due to electron is 0.
- Under the influence of electric field, charge carriers are accelerated parallel to direction of applied electric field.
- In their path, free electrons collide with other electrons or with ions, hence energy is lost.



Mobility

- After sometime steady state is reached and electrons move with finite steady velocity. It iscalled as drift velocity.
- Drift velocity is directly proportional to applied electric field.
- The constant of proportionality is called as mobility(μ).
- Mobility:The average drift velocity per unit electric field is called mobility.

$$v_{d(hole)} = \mu_p E \Rightarrow \mu_p = \frac{v_d}{E}$$

$$v_{d(electron)} = -\mu_n E \Rightarrow \mu_n = -\left(\frac{v_d}{E}\right)$$

Here -ve sign indicate electric field and movement of electron are in opposite direction

$$\text{Mobility} = \frac{\text{drift velocity}}{\text{electric field}} \qquad \left[\frac{m/s}{V/m}\right] = \left[m^2/V.s\right]$$

- As temperature increases mobility decreases.
- μ_n ≈ 1350 ($cm^2/V\cdot s$), μ_p ≈ 500 ($cm^2/V\cdot s$)

Mass Action Law

- Under thermal equilibrium, the product of concentration of electrons and concentration of holes is square of intrinsic carrier concentration (constant) and independent of amount of donor and acceptor doping level.
- n p = n_i^2 , where

n_i = intrinsic carrier concentration

n = no. of free electrons per unit volume

p = no. of holes per unit volume

$$n_i^2 = A_0 T^3 \exp(-E_{Go}/KT)$$

E_{Go} : energy band gap at 0^0 K in eV

k : Boltzmann’s constant in eV / ^{0}K

T : Absolute temperature in K (Kelvin)

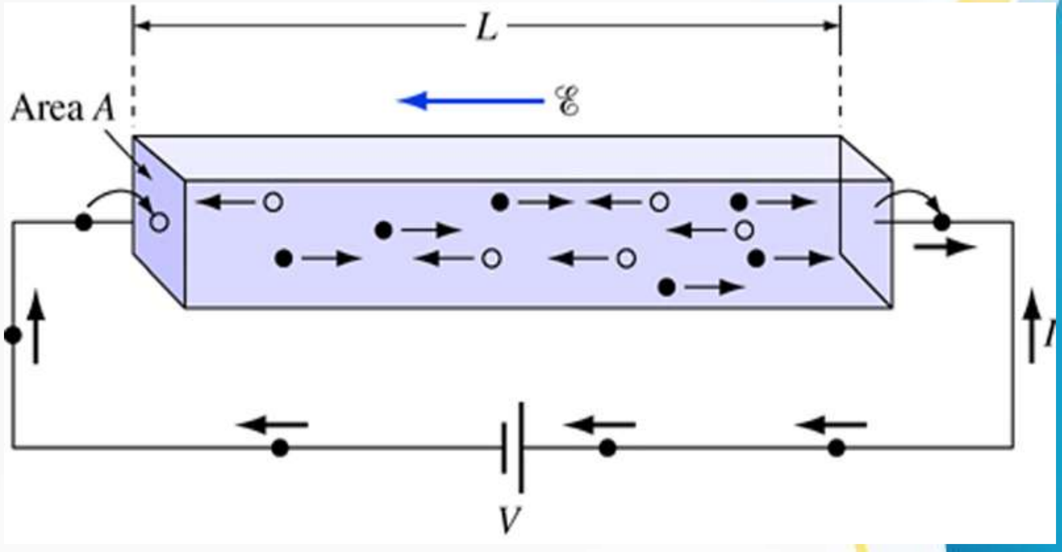
A_0 : constant independent of temperature

Current in semiconductor

- Current in semiconductor are of two types.
  - Drift current
  - Diffusion current

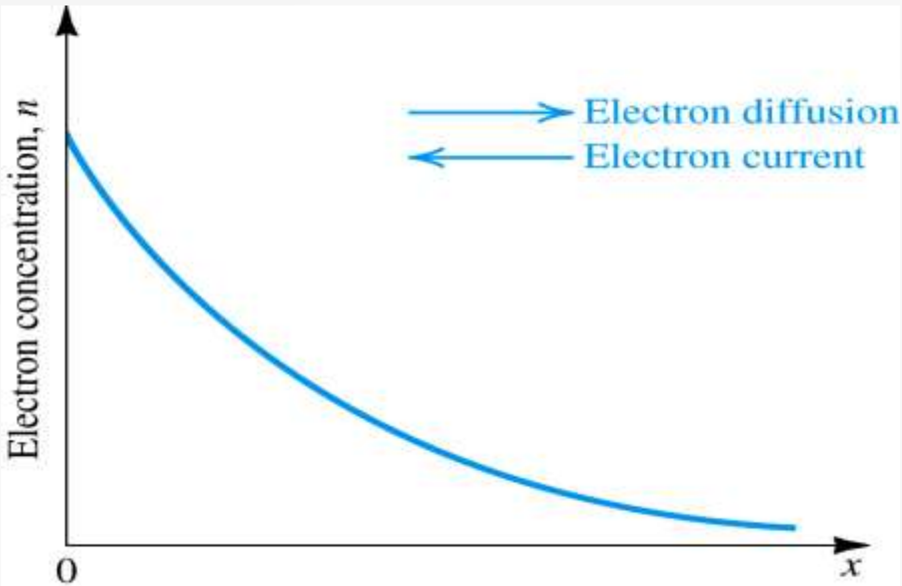
Drift Current

- Charged particles move or drift under the influence of the applied field.
- Drift current:The current due to the drifting movement of charge carries by the appliction of elecric field is called drift current.
- Electrical resistivity ρ and its reciprocal, conductivity σ, characterize current flow in a material when an electric field is applied.
- Drift current density due to electron = $J_n = n\,q\,\mu_n\,E$ A/cm^2
- Drift current density due to hole = $J_p = p\,q\,\mu_p\,E$ A/cm^2
- Total drift current density is denoted by J.
- $J = \sigma E = q(n\,\mu_n + p\,\mu_p)E$



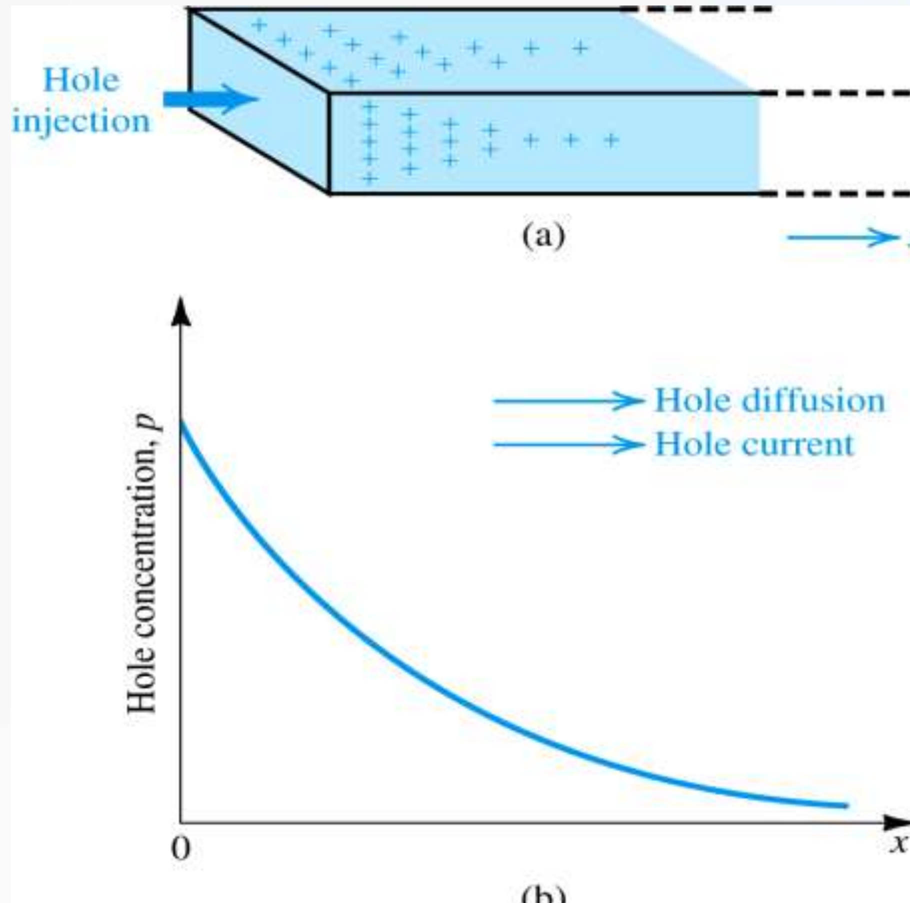
Diffusion Current

- In practical semiconductors, it is quite useful to create carrier concentration gradients by varying the dopant concentration and/or the dopant type across a region of semiconductor.
- Diffusion current:The current due to movement of charge carriers by the concentration gridient is called diffusion current.



$$J_n(\text{diff.}) = -(-q)D_n\frac{dn(x)}{dx} = +qD_n\frac{dn(x)}{dx}$$

$$J_p(\text{diff.}) = -(+q)D_p\frac{dp(x)}{dx} = -qD_p\frac{dp(x)}{dx}$$



Einestine's Relation

$$\boxed{\frac{D_p}{\mu_p} = \frac{KT}{q} = v_t}$$

This is called as Einestine's relation where V_t is called as thermal voltage and is given as 0.0259v.

Analog Electronics Circuit

S.N.Mishra

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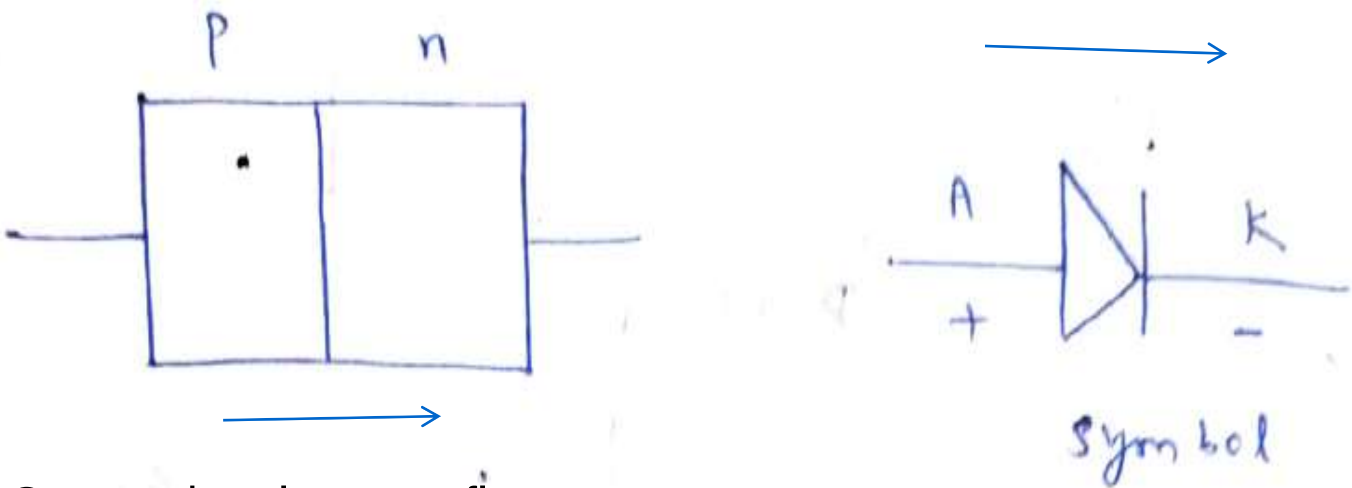
Introduction

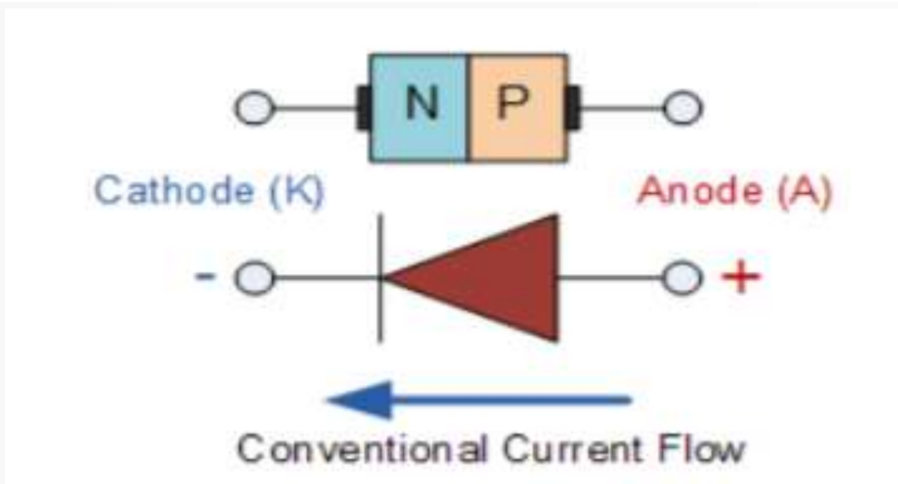
- Symbol
- Construction
- Operation
- Charecteristics
- Equivalent circuit
- Applications

PN Junction Diode

A PN diode is formed by doping one side of crystal with acceptor and other side donor atoms.



Conventional current flow



Contd...

- There are three possibilities depend upon the application of voltage across the two terminals.

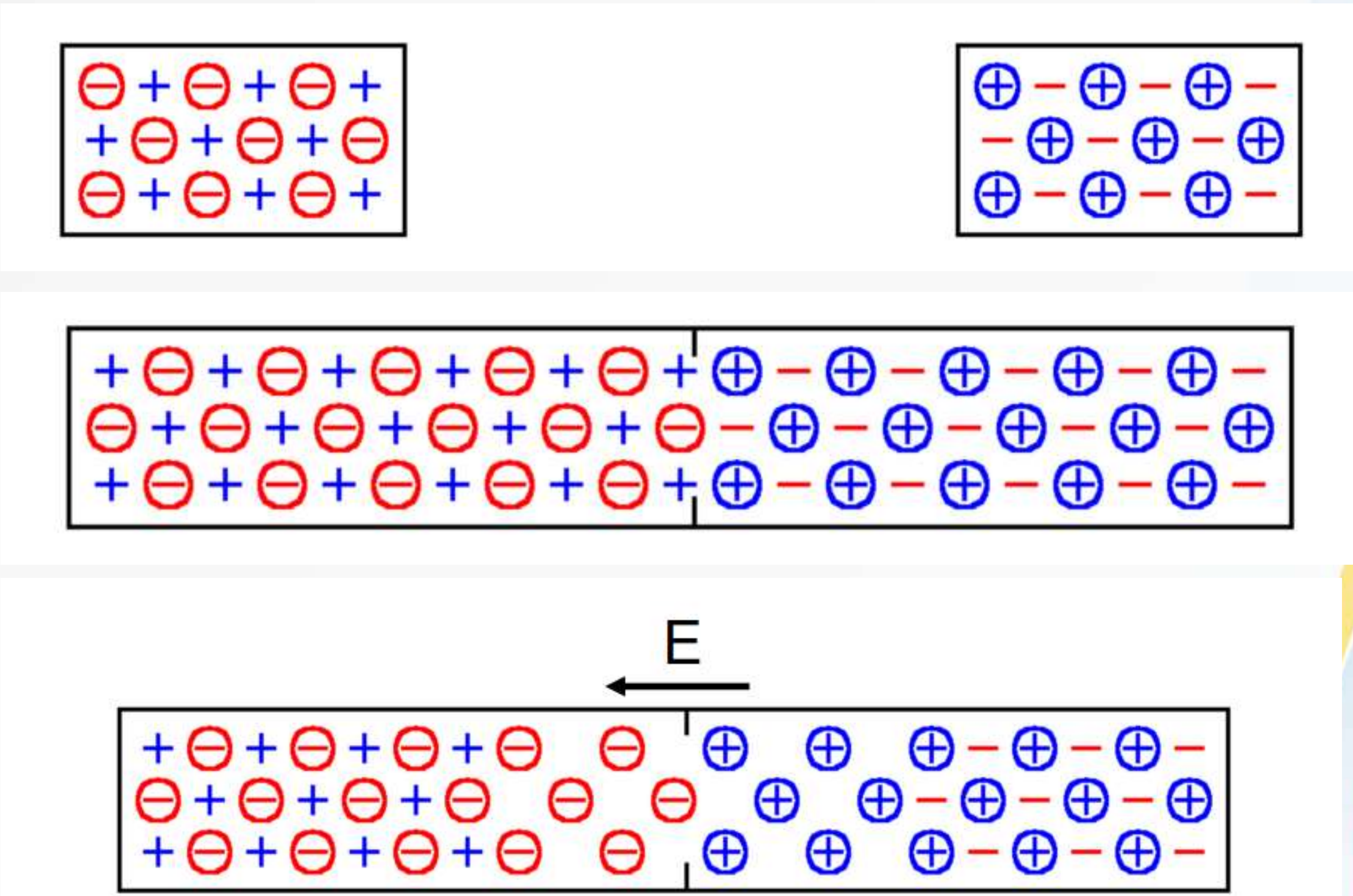
➢ 1.No Bias (V=0)

➢ 2.Forward Bias (V>0)

➢ 3.Reverse Bias (V<0)

No Bias (V=0)

When diode is not connected with bias voltage are claaed no bias condition.



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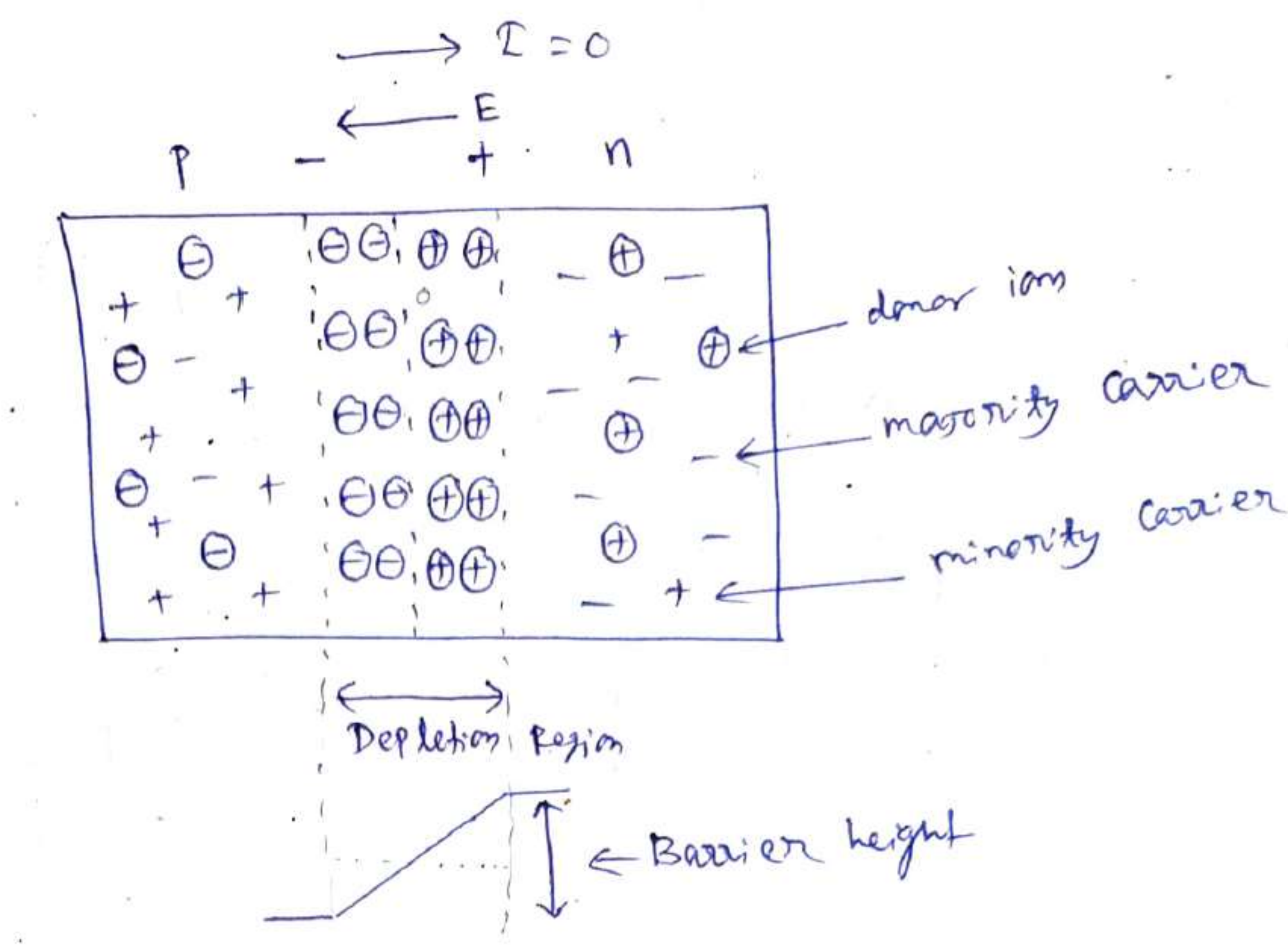
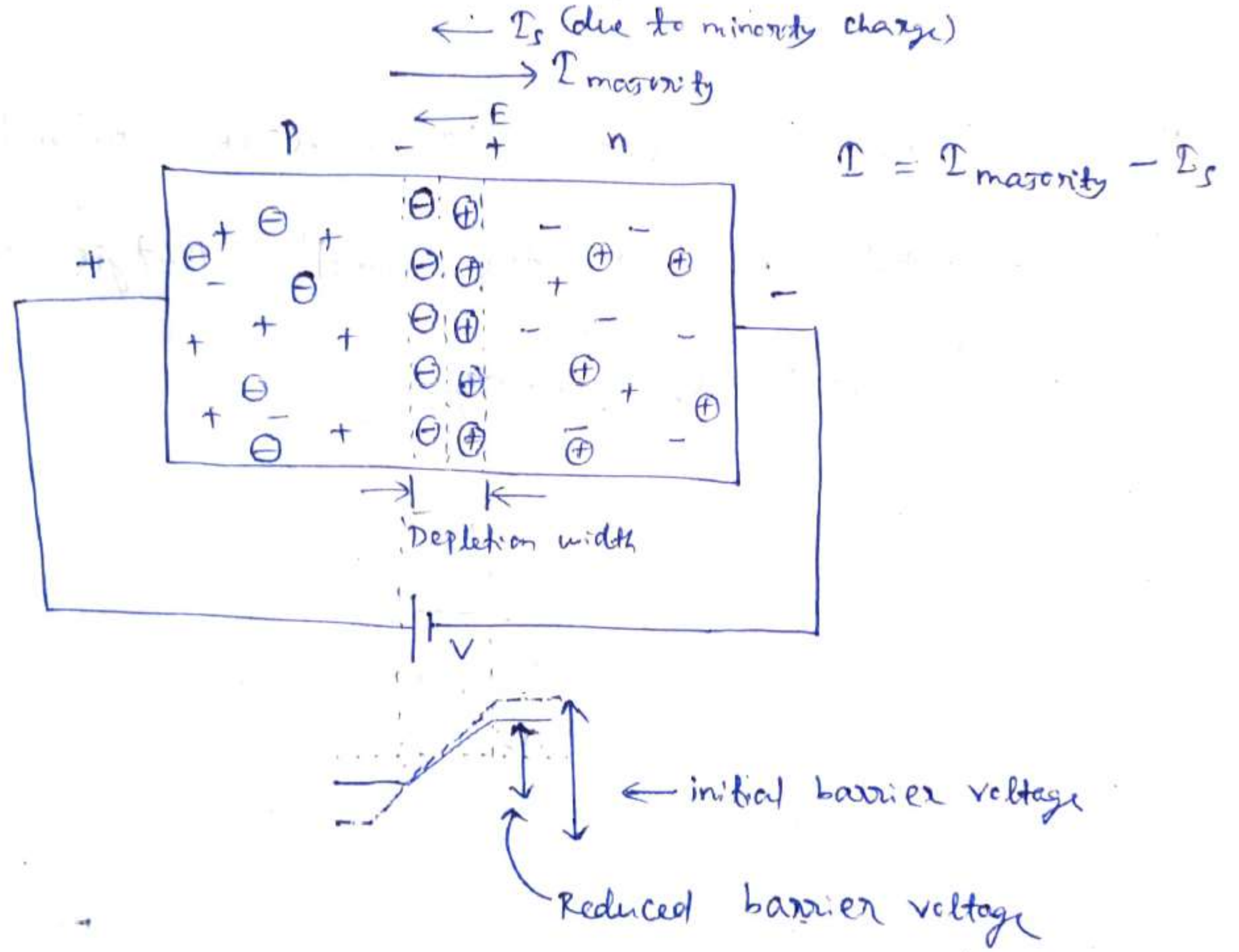


I = 0
E
p
n
donor ion
majority carrier
minority carrier
Depletion Region
← Barrier height

Contd...

- When P-type and N-type are joined,due to diffusion carreir movement starts.
- Electrons from N-side flows to P-side leaving behind +ve ions and holes from P-side flow to N-side leaving behind -ve ions near the edge of junction.
- The region across the junction where only ions are found are called depletion region due to depleted of charge carriers in this region.
- Due to this a dipole is created and the direction of electric field is from N-side to P-side and a built in potential (contact potential) is developed.
- Further movement of carriers are stopped by the developed electric field and contact potential in the depletion region.
- So, at equlibrium the net current across the junction is zero.

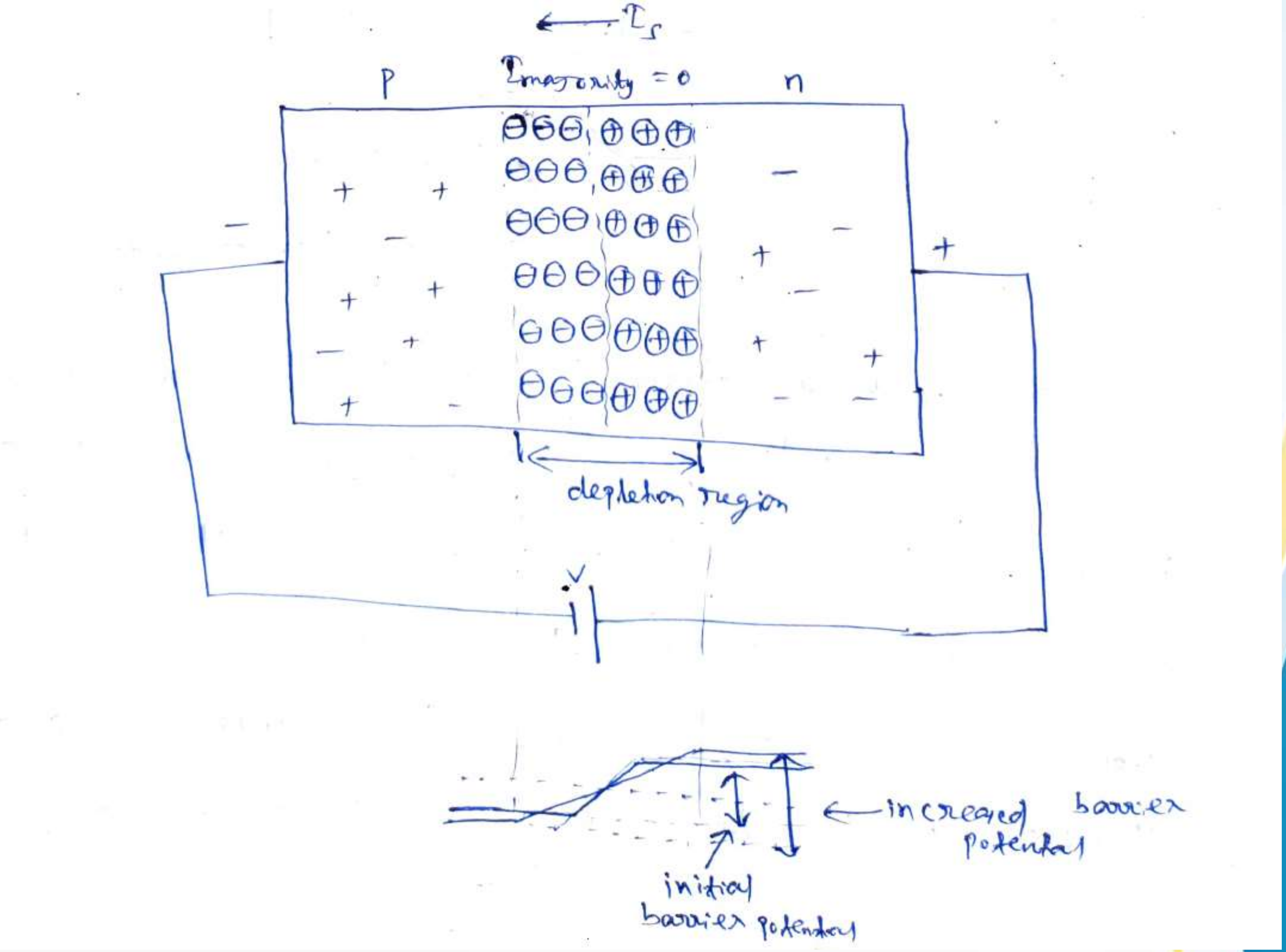
Forward Bias (V>0)



Contd...

- If the diode's P-side is connected to higher potential and N-side to lower potential then the diode is forward biased.
- Whe the diode forward biased (F.B),the -ve potential force the electrons to combine with +ve ions and +ve potential force the holes to combine with -ve ions.
- In response to that the depletion region width decreases so as contact potential.
- As we increase the applied voltage between diode,the majority carreir starts flowing and current appears across junction.
- The minimum voltage from which the current starts increaing in diode is called threshold voltage or knee voltage.

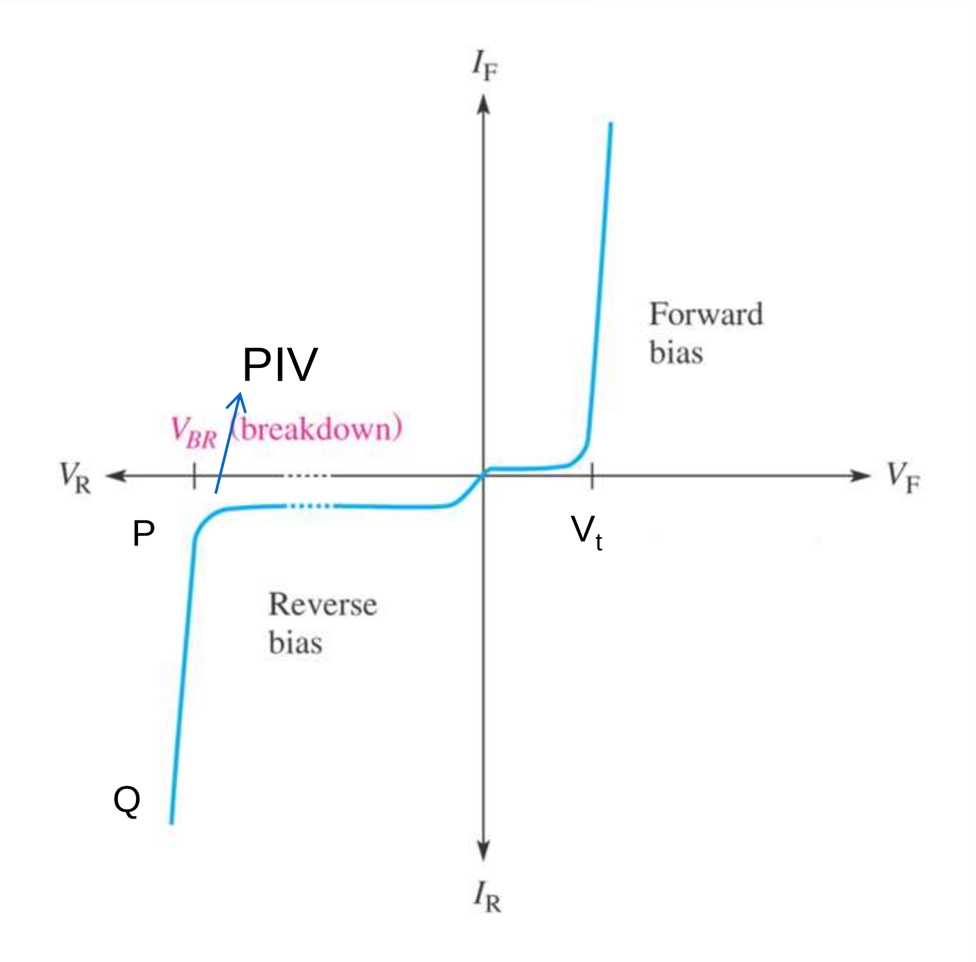
Reverse Bias (V<0)



Contd...

- If the diode's P-side is connected to lower potential and N-side to higher potential then the diode is reverse biased.
- Whe the diode reverse biased (R.B),the -ve potential force the electrons to create more +ve ions and +ve potential force the holes to create more -ve ions.
- In response to that the depletion region width increases so as contact potential.
- As we increase the applied voltage between diode,the majority carreir movement stops and current appears across junction is zero due to majority carriers.
- But due to the depletion region,the generated electric field drives the minoity carriers to flow.
- The minority carriers flow gives current opsite to conventional current i.e N-side to P-side.
- This current is called leakge current Is.

I-V Charecteristics of Diode



The maximum reverse voltage that can be applied to the PN junction without damage to the diode is called peak inverse voltage (PIV).

The plot between current and voltage is called I-V charecteristics of diode.

In F.B condition, $V_F < V_t$ current is very small.

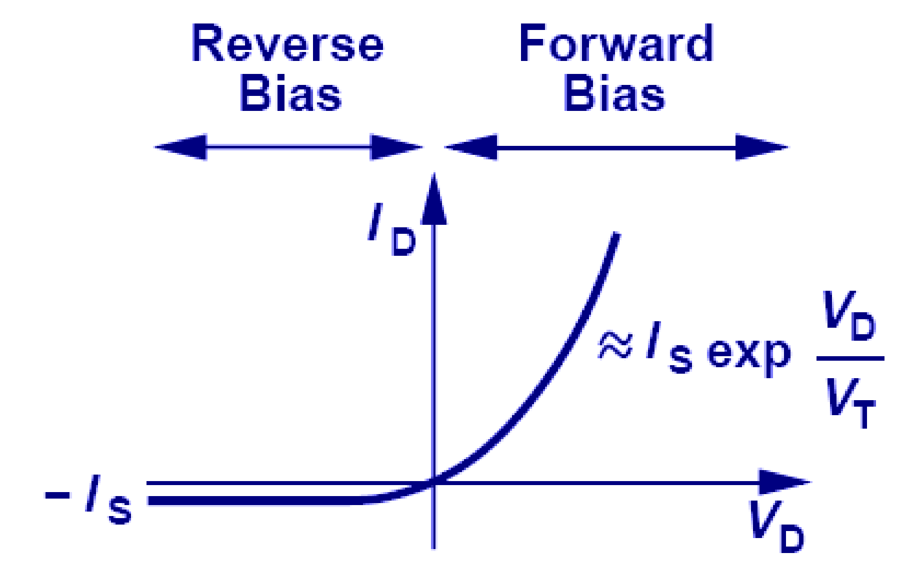
when , $V_F > V_t$ current increases sharply.

Generally the thresold voltage for Silicon is 0.7V and for Germanium is 0.3V.

At reverse bias voltage, after point 'P' shown in figure,reverse current increases suddenly a almost parallen to y-axis.

This region 'PQ' shown in figure is called breakdown region and diode may damage in this region.

I-V Characteristic of PN Junction



$$I_D = I_S(\exp\frac{V_D}{V_T} - 1)$$

- The current and voltage relationship of a PN junction is exponential in forward bias region, and relatively constant in reverse bias region.

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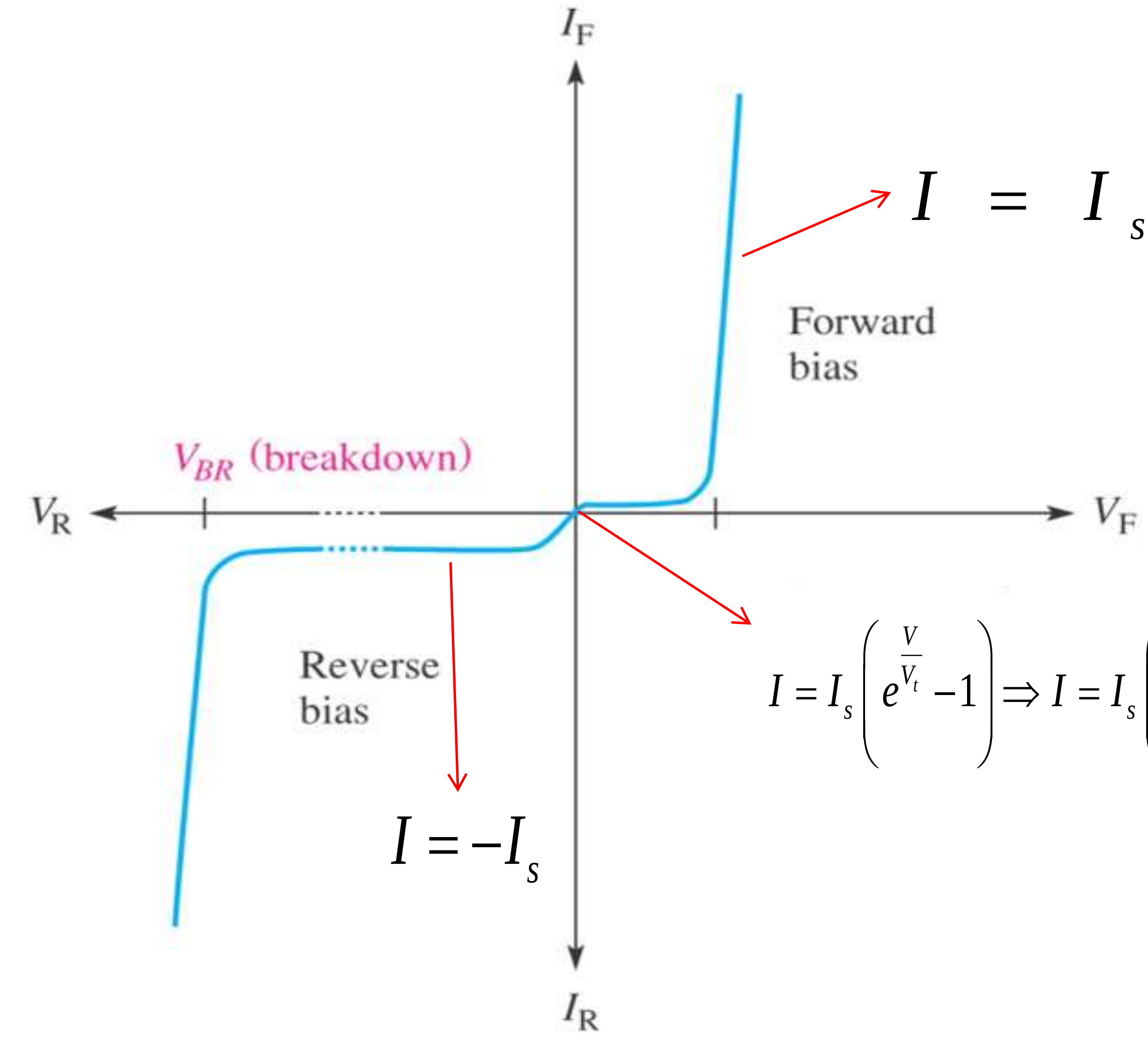

$$I = I_s e^{\frac{V}{V_t}}$$

$$I = I_s\left(e^{\frac{V}{V_t}} - 1\right) \Rightarrow I = I_s\left(e^{\frac{0}{V_t}} - 1\right) \Rightarrow 0$$

$$I = -I_s$$

Contd...

$$I = I_s\left(e^{\frac{V}{V_t}} - 1\right)$$

$$\Rightarrow \frac{I}{I_s} = e^{\frac{V}{V_t}}$$

$$\Rightarrow \ln\frac{I}{I_s} = \ln e^{\frac{V}{V_t}}$$

$$\Rightarrow \ln\frac{I}{I_s} = \frac{V}{V_t}$$

$$\Rightarrow V = V_t \ln\left(\frac{I}{I_s}\right)$$

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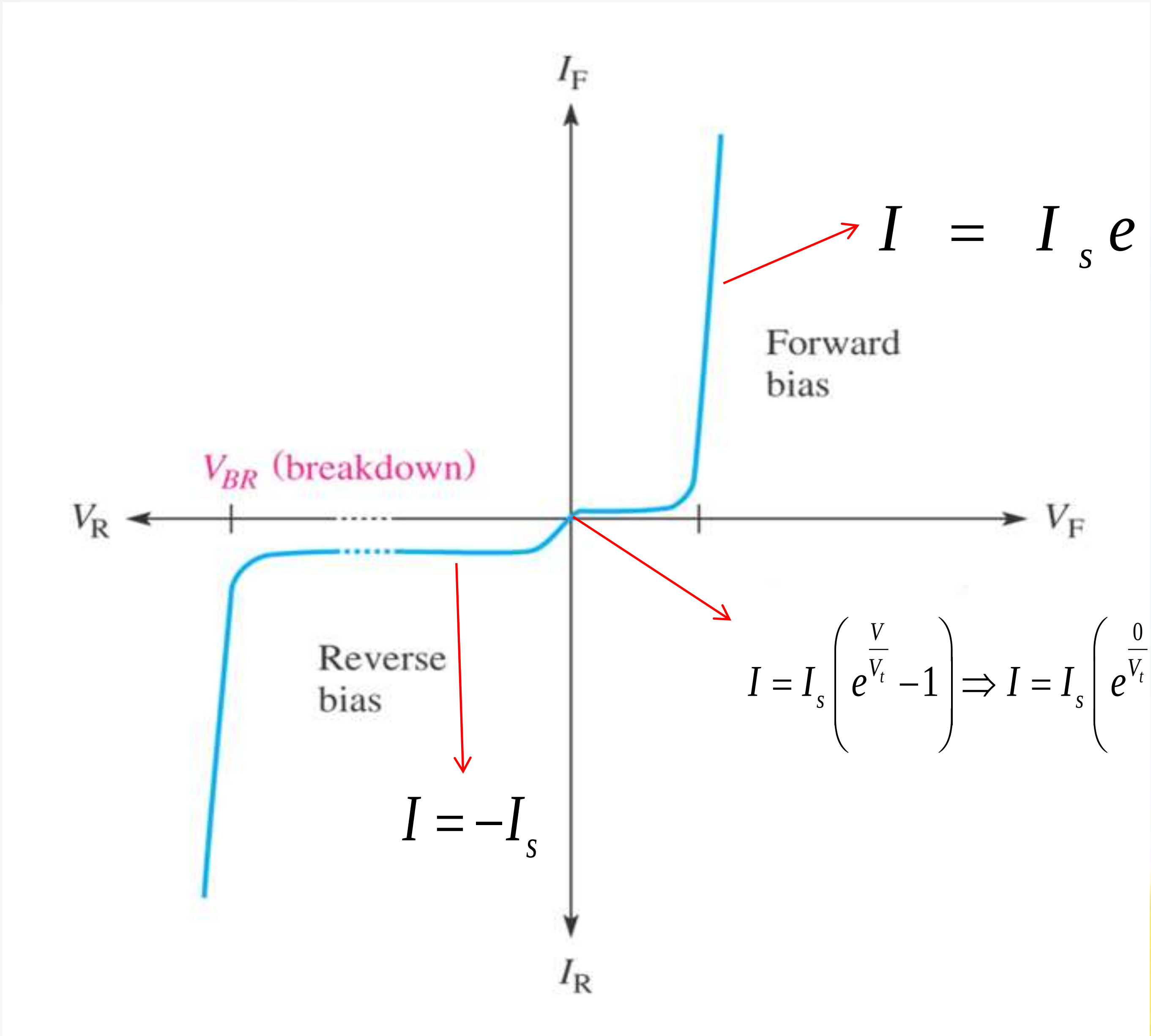


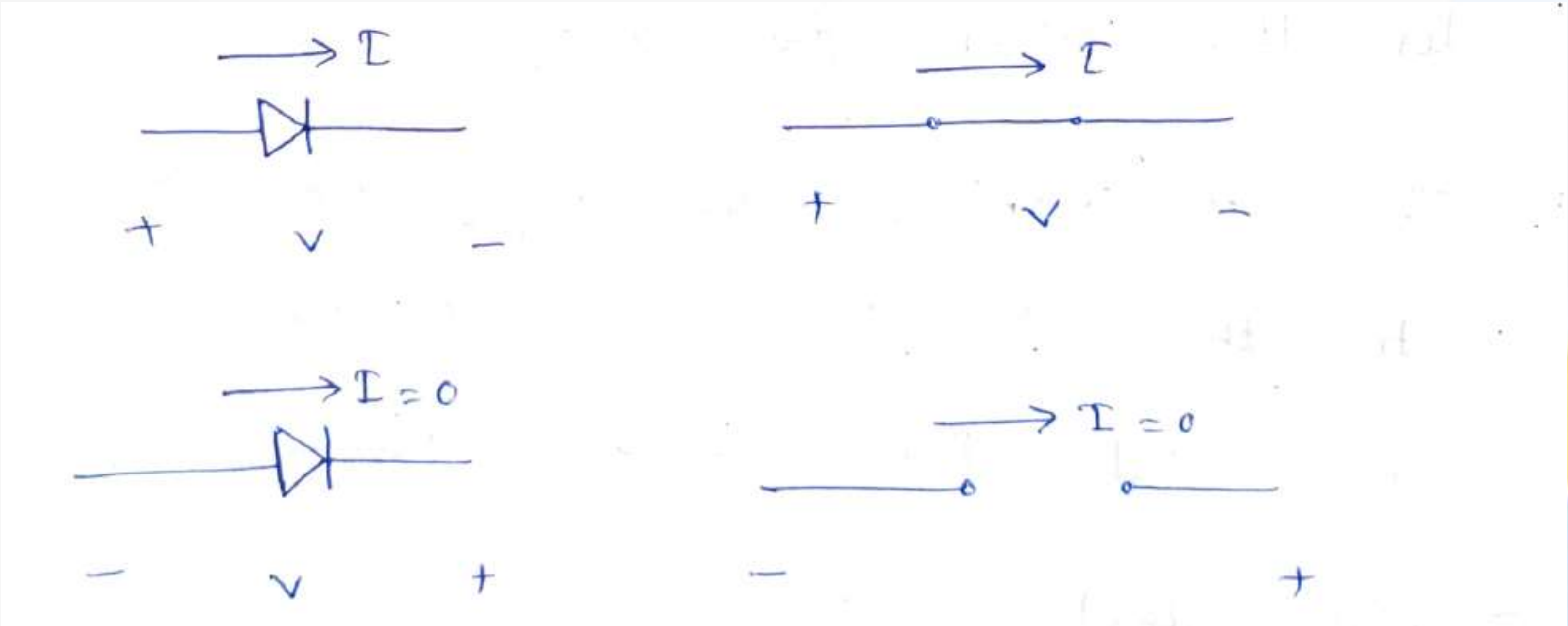
$$I = I_s e^{\frac{V}{V_t}}$$

$$I = I_s\left(e^{\frac{V}{V_t}} - 1\right) \Rightarrow I = I_s\left(e^{\frac{0}{V_t}} - 1\right) \Rightarrow 0$$

$$I = -I_s$$

Diode as switch

- When diode forward biased current flows and when reverse biased the current doesnot flows.
- This can be use as a switch application as shown below.

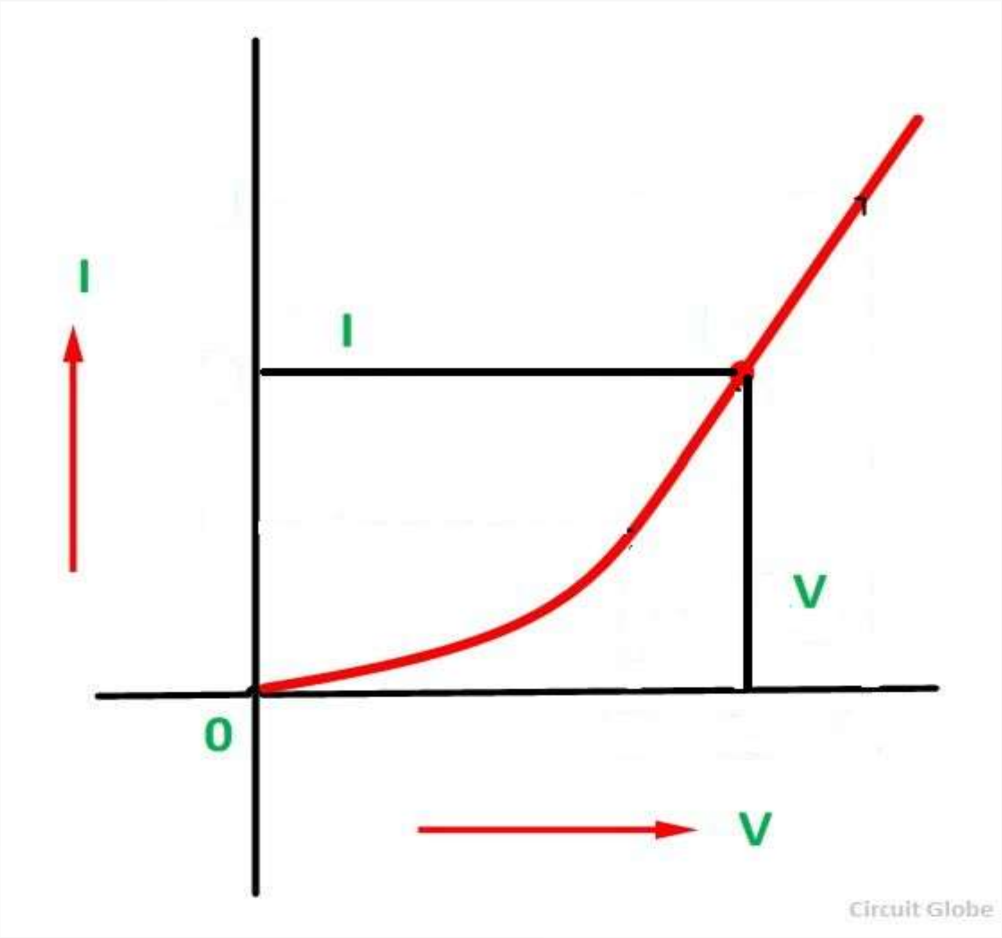


Diode resistance

- Resistance is the opposition offered to the flow of current through the device.
- Diode resistance can be defined as the effective opposition offered by the diode to the flow of current through it.
- Diode offers a small resistance when forward biased, which is called as forward resistance.
- Diode offers a considerable resistance when it is reverse biased, which is called as reverse resistance.
- Diode resistance is classified into two types, static or dynamic depending on whether the current flowing through the device is DC (Direct Current) or AC (Alternating Current), respectively.

Static Resistance

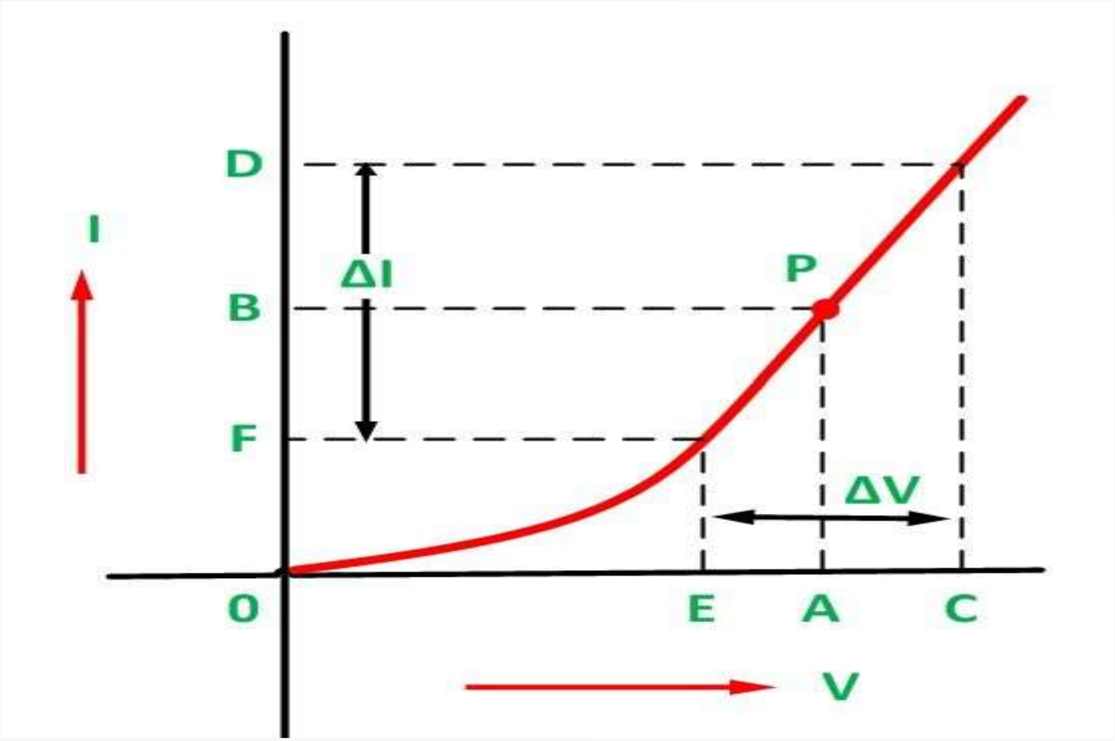
- Static resistance or DC resistance of a PN junction diode defines the ratio of voltage to current at any point. It will not follow ohm's law.



$$R_{DC} = \frac{V}{I}$$

Dynamic Resistance

- Dynamic resistance is the resistance offered by the diode to the flow of AC current through it when it is connected it in a circuit which has an AC voltage source.
- It is the ratio of change in voltage to change in current.
- It is also calculated from the inverse of slope.



$$r_{ac} = dV/dI$$

Effect of temperature on reverse current

- The reverse saturation current Is nearly doubles for every 10C rise in temperature.

$$I_{s(T_2)} = I_{s(T_1)} 2^{\left(\frac{T_2 - T_1}{10}\right)}$$

- When temperature increases by 1C, the junction voltage drops by -2.5mV.

$$\frac{dV}{dT} = -2.5mV / {}^{0}C$$

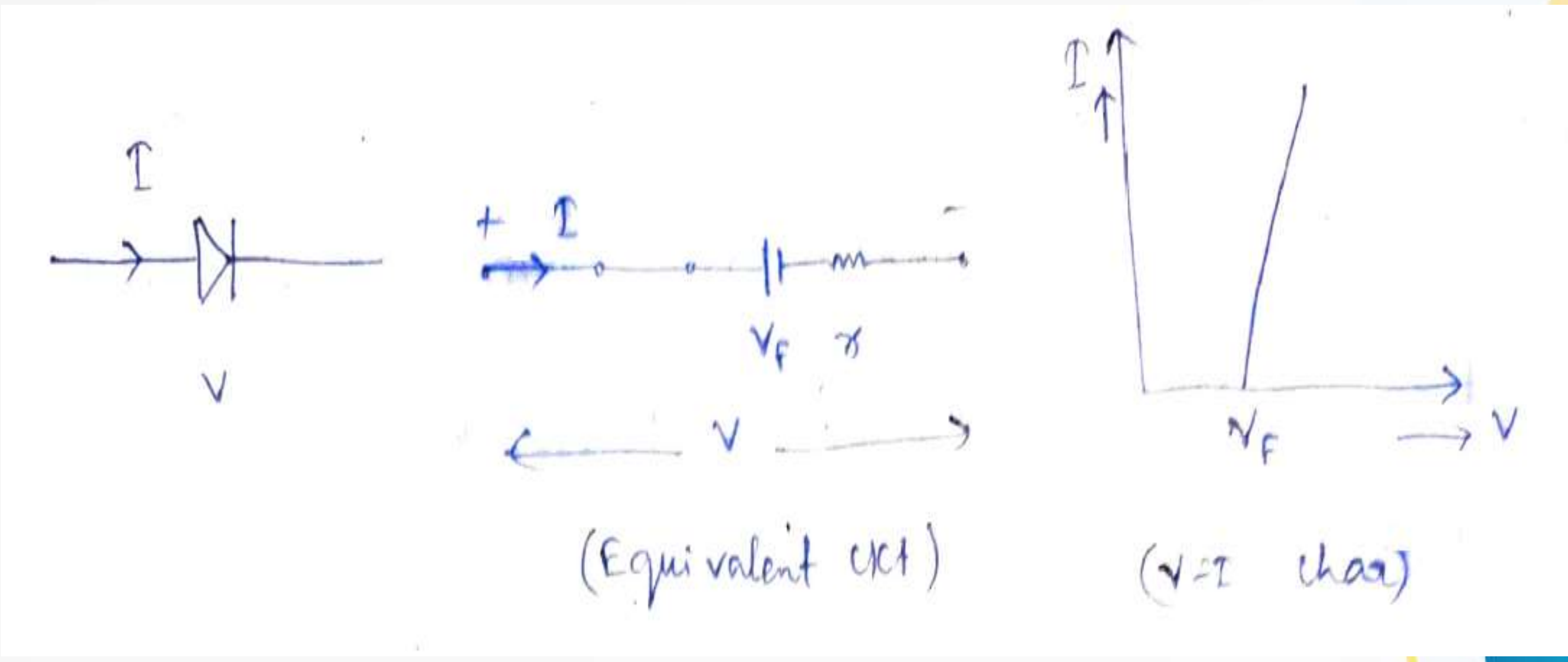
Equivalent circuit of Diode

- An equivalent circuit is a combination of electrical elements,which when connected in a circuit act exactly same as the device connected in the circuit.
- Equivalent circuit makes the network/complex circuit analysis simpler.

1.Approximate model:This model approximate the actual charecteristics and series combination of threshod voltage and voltage drop across the diode.

$$\boxed{V=V_f+I.r}$$

Where 'V_f ' is threshold voltage and 'r' is internal resistance.



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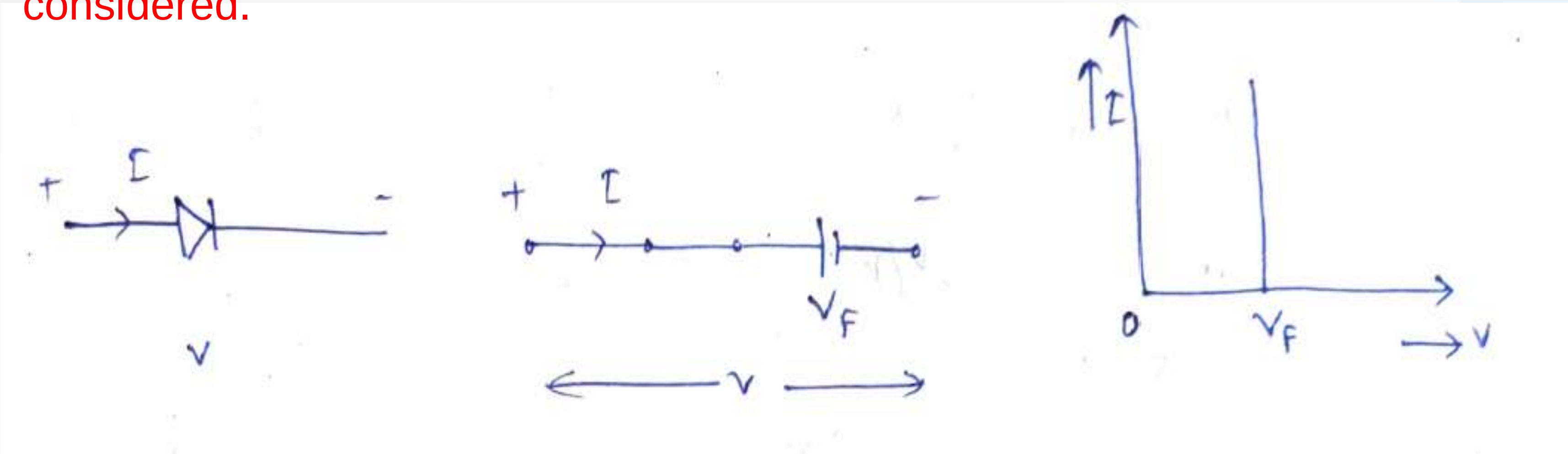
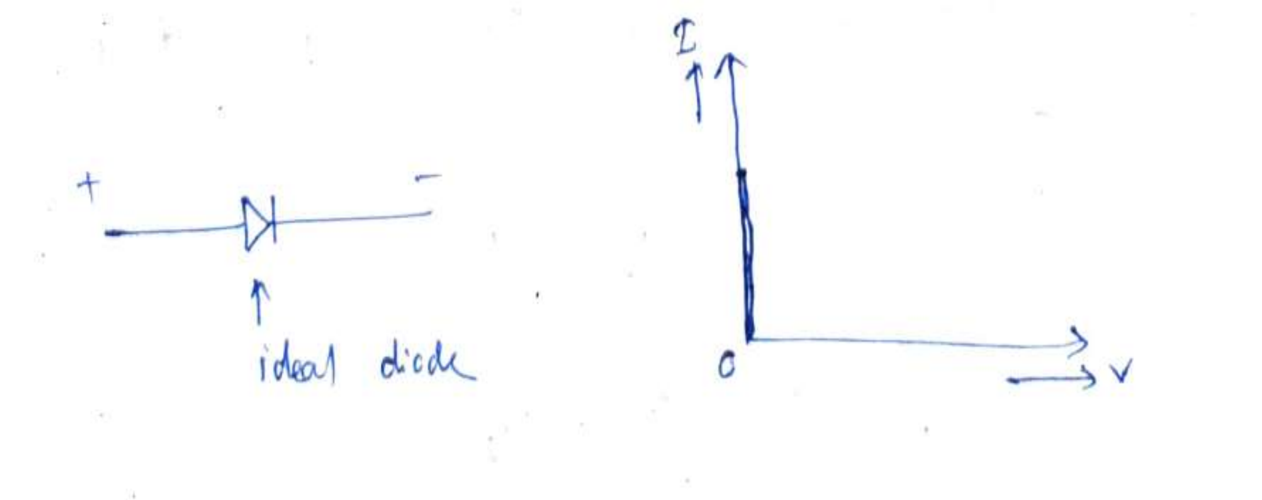
2.Simpplified Model:For most of application internal resistance is not considered.



3.Ideal Model:This model behaves perfect conductor in F.B and perfect insulator in R.B. so in this hypothetical case 'r'=0 and V_t=0.



Diode Problem

- A Silicon diode is biased with 0.75V so that leakage current is 0.5pA measured.Find the doide current across the junction ?
- Ans-1.685A
- A silicon diode is connected in F.B so that 90mA current flows across the junction and 10pA leakage current flows.Find the applied voltage across the junction ? Ans-0.595V
- In a circuit the ratio of forward current and reverse current is measured as 10^{10}.Find the applied bias across the junction ? Ans-0.598V

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Half Wave Rectifier

A haif wave rectifier is a circuit which is converting alternating signal (A.C) to direct signal (D.C).Input is generally given through transformer and circuit have single diode with a load resistor connected in series.Finally output is taken across the load resistor.

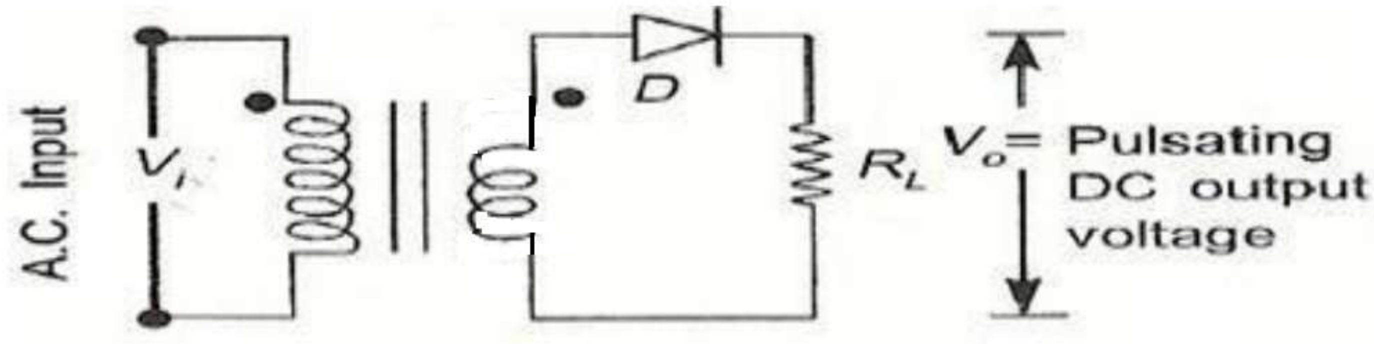
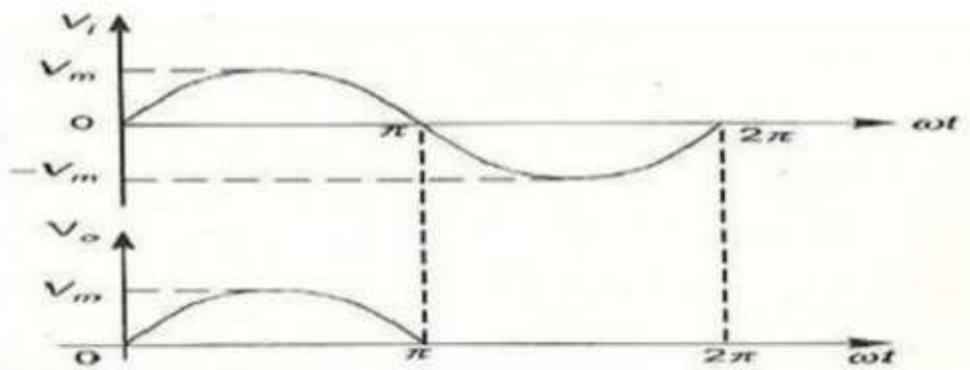


Fig 1 : Basic structure of Half-Wave Rectifier



Input and output waveforms of a Half wave rectifier

Contd...

For the positive half-cycle of input a.c. voltage, the diode D is forward biased and hence it conducts.

Now a current flows in the circuit and there is a voltage drop across R_L.

For the negative half-cycle of input, the diode D is reverse biased and hence it does not Conduct.

Now no current flows in the circuit i.e., i=0 and Vo=0. Thus for the negative half- cycle no power is delivered to the load.

The out put of H.W.R is pulsatinin nature.

The output frequency is equals to input frequency. $f_{out}=f_{in}$

Parameter of H.W.Rectifier

Efficiency:The efficiency of rectifier is defined as the ratio of d.c output power (Pdc) to a.c input power (Pa.c) or (Pi) and denoted as η and expressed in percentage.

$$\eta = \frac{\text{o/p d.c power}}{\text{i/p a.c power}} = \frac{P_{dc}}{P_i} \times 100 \text{ Per cent.}$$

Let $V=V_m \sin \omega t$ is the input signal and R_f and R_L are the internal resistance of diode and load resistance of diode respectvely.

$$\boxed{P_{dc} = I_{d.c}^2 R_L}$$

$$\boxed{I_{d.c} = \frac{I_m}{\pi}}$$

$$\boxed{V_{d.c} = \frac{V_m}{\pi}}$$

$$\boxed{P_{dc} = I_{d.c}^2 R_L = \left(\frac{I_m}{\pi}\right)^2 R_L = \left(\frac{\left(\frac{V_m}{\pi}\right)^2}{R_L}\right)}$$

A.C power

$$\boxed{P_i = P_{a.c} = I^2_{r.m.s}\left(R_L + R_f\right)}$$

$$\boxed{I_{r.m.s} = \frac{I_m}{2}}$$

$$\boxed{V_{r.m.s} = \frac{V_m}{2}}$$

$$\boxed{P_i = I^2_{r.m.s}\left(R_L + R_f\right) = \left(\frac{I_m}{2}\right)^2\left(R_L + R_f\right)}$$

Efficiency

Now Efficiency $(\eta) = \dfrac{P_{dc}}{P_i} \times 100$

$$= \frac{\left(\frac{I_m}{\pi}\right)^2 \cdot R_L}{\left(\frac{I_m}{2}\right)^2 \cdot (R_f + R_L)} \times 100 = \frac{\frac{I_m^2 \cdot R_L}{\pi^2}}{\frac{I_m^2 (R_f + R_L)}{4}} \times 100 = \frac{4 R_L}{\pi^2 (R_L + R_f)} \times 100$$

$$= \frac{4}{\pi^2 \left(1 + \frac{R_f}{R_L}\right)} \times 100 = 0.406 \times 100 = 40.6\ \%$$

(As $R_f << R_L$ so $\frac{R_f}{R_L}$ neglect

So maximum efficiency $\boxed{\eta = 40.6\ \%}$

Ripple Factor

Ripple Factor :- The output of rectifier consist of d.c component and a.c component (ripple). The a.c component is undesirable and accounts for pulsating nature at output.

- Smaller is the a.c component, the more effective is the rectifier

- Ripple Factor is defined as the ratio of r.m.s value of a.c component to the d.c component in the rectifier output.

$$\text{Ripple Factor} = \gamma = \frac{\text{R.m.s value of a.c component of load voltage or current}}{\text{d.c value of load voltage or current}}$$

$$= \frac{I_{ac}}{I_{dc}} \text{ or } \frac{I'_{rms}}{I_{dc}} = \frac{V'_{rms}}{V_{dc}}$$

Effective Rms value of total load current or voltage is

$$I_{rms} = \sqrt{I_{dc}^2 + I_{ac}^2} \text{ or } I_{rms} = \sqrt{I_{dc}^2 + I_{rms}'^2}$$

$$\Rightarrow I'_{rms} = \sqrt{I_{rms}^2 - I_{dc}^2}$$

Alternate Definition

Defined also for current

- I_{ac} = effective value of ac harmonic component
- I_{dc} = average of dc component

$$I_{rms} = \sqrt{I_{dc}^2 + I_{ac}^2} \quad so,$$

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

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

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

Contd...

$$\gamma = \frac{I'_{rms}}{I_{dc}} = \frac{1}{I_{dc}}\sqrt{I_{rms}^2 - I_{dc}^2}$$

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

For Half wave Rectifier: $I_{rms} = \frac{I_m}{2}$, $I_{dc} = \frac{I_m}{\pi}$

$$\therefore \gamma = \text{Ripple factor} = \sqrt{\left(\frac{I_m/2}{I_m/\pi}\right)^2 - 1} = 1.21$$

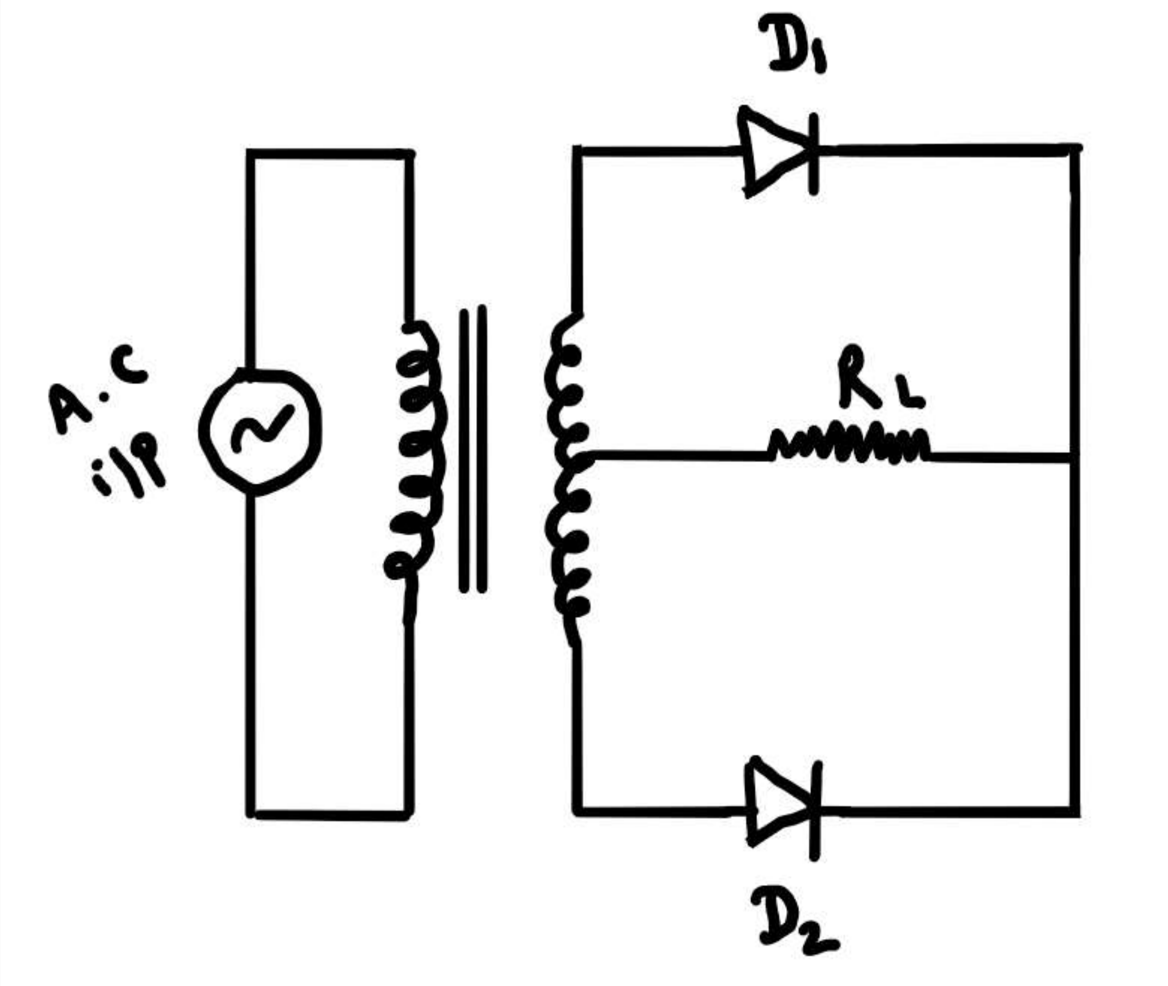
Full Wave Rectifier

Full wave rectifiers are of two types.

1.Center tap Rectifier

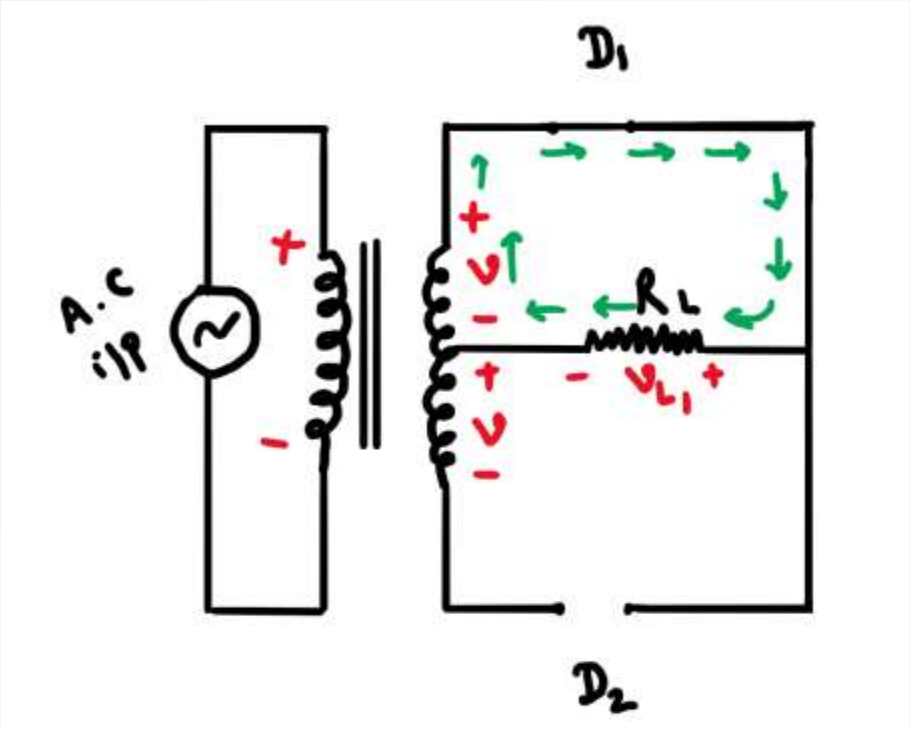
2.Bridge type rectifier

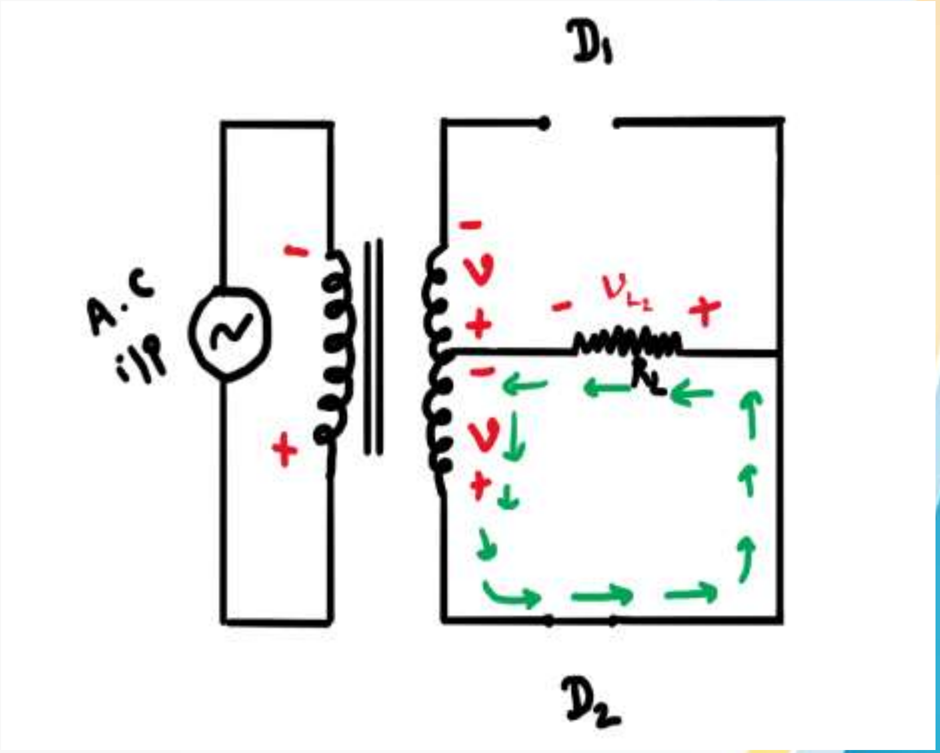
Center-tap F.W.Rectifier :It consist of Center tap transformer and two diode and a load resistor.



C.T Full wave rectifier circuit

Operation



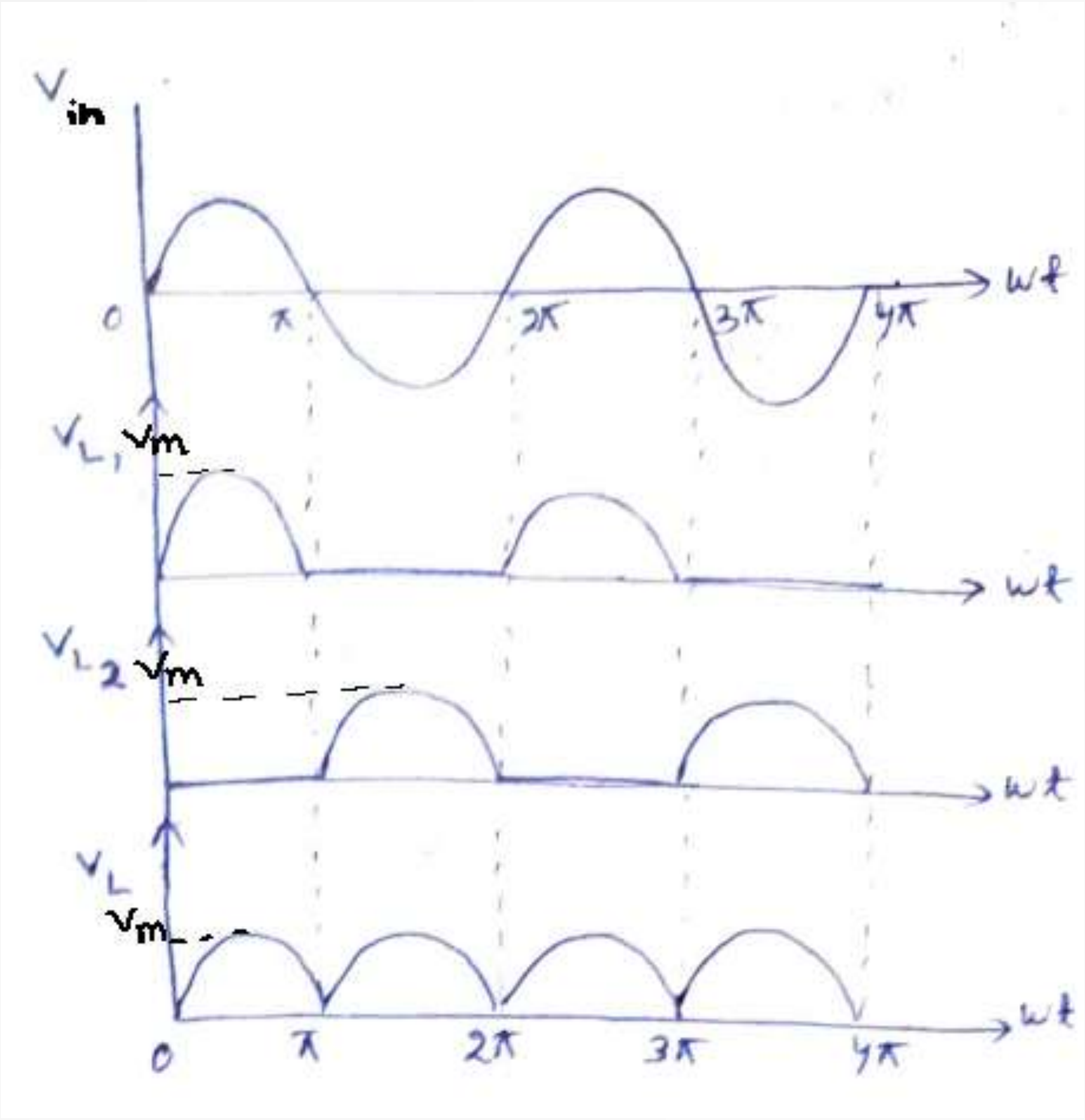


For +ve half cycle

For -ve half cycle

NOTE:Current flowing in both half cycle in the same direction.

Output Waveform of C.T.F.W.R



Contd...

- During positive half of the input signal, anode of diode D1 becomes positive and at the same time the anode of diode D2 becomes negative. Hence D1 conducts and D2 does not conduct.
- The load current flows through D1 and the voltage drop across RL will be equal to the input voltage.
- During the negative half cycle of the input, the anode of D1 becomes negative and the anode of D2 becomes positive. Hence, D1 does not conduct and D2 conducts.
- The load current flows through D2 and the voltage drop across RL will be equal to the input voltage.
- It is noted that the load current flows in the both the half cycles of ac voltage and in the same direction through the load resistance.

A.C Power Calcuation for C.T.F.W.R

$$P_i = P_{a.c} = I^2_{r.m.s}\left(R_L + R_f\right)$$

$$I_{r.m.s} = \frac{I_m}{\sqrt{2}}$$

$$V_{r.m.s} = \frac{V_m}{\sqrt{2}}$$

$$P_i = I^2_{r.m.s}\left(R_L + R_f\right) = \left(\frac{I_m}{\sqrt{2}}\right)^2\left(R_L + R_f\right) = \left(\frac{\left(\frac{V_m}{\sqrt{2}}\right)^2}{\left(R_L + R_f\right)}\right)$$

D.C Power Calculation

$$P_{d.c} = I_{d.c}^2 R_L$$

$$I_{d.c} = \frac{2I_m}{\pi}$$

$$V_{d.c} = \frac{2V_m}{\pi}$$

$$P_{d.c} = I_{d.c}^2 (R_L) = \left(\frac{2I_m}{\pi}\right)^2 (R_L) = \left(\frac{\left(\frac{2V_m}{\pi}\right)^2}{(R_L)}\right)$$

Efficency and R.F of C.T.F.W.R

$$P_i = (R_f + R_L)\left(\frac{I_m}{\sqrt{2}}\right)^2$$

$$\eta = \frac{P_{dc}}{P_i} \times 100 = \frac{\left(\frac{2I_m}{\pi}\right)^2 \cdot R_L}{\left(\frac{I_m}{\sqrt{2}}\right)^2 (R_f + R_L)} \times 100 = \frac{8}{\pi^2} \cdot \frac{R_L}{R_f + R_L} \times 100$$

$$\eta = \frac{0.812}{1 + \frac{R_f}{R_L}} \times 100 = 81.2\,\% \quad (\because R_f << R_L)$$

Max efficiency is 81.2 %. (double than half wave rectifier

<u>Ripple Factor for Full wave Rectifier</u> :-

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

$$= \sqrt{\left(\frac{I_m/\sqrt{2}}{2I_m/\pi}\right)^2 - 1} = 0.48$$

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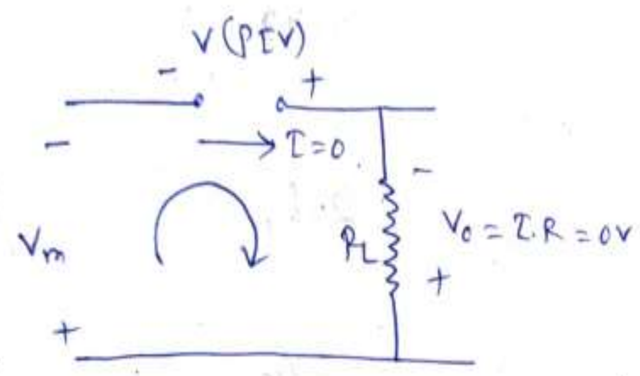
PIV of Rectifier

- PIV is the maximum reverse voltage that can be applied to the diode which will not damage the diode.
- PIV rating of diode is very much important to design the circuit.
- PIV of rectifier can be forund as below.

Half wave Rectifier



Apply KVL in the loop

$$-V_m + PIV = 0$$

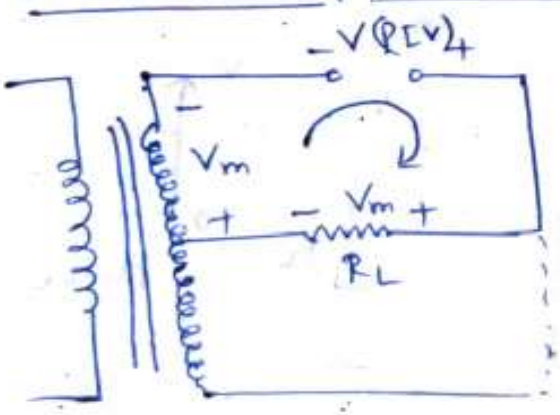
$$PIV = V_m$$

So PIV rating of half wave rectifier is greater or equal to V_m.

$$\boxed{PIV \geq V_m}$$

Contd...

centre-tap Rectifier



Apply KVL in the loop shown

$$-V_m + PIV - V_m = 0$$

$$PIV = 2V_m$$

So $\boxed{PIV \text{ Rating} \geq 2V_m}$

Comparison of Rectifiers

Particulars	W.H.R	C.T.F.W.R
No. of Diode	1	2
Transformer Requirement	No	Yes
Max. Efficiency	40.6%	81.2%
R.F	1.21	0.48
Output frequency	fin	2fin
PIV	Vm	2Vm

Filters

- We have now used diodes to produced a pulsed dc signal.
- Most equipment requires “regulated” dc
  - We must remove the “ripple”
  - Ripple is departure of waveform from pure dc (flat, constant voltage level)
    - Frequency – so far we have seen pulsed dc at the same frequency as the input (½ wave) or twice the line frequency (full wave rectifier)
    - Amplitude – a measure of the effectiveness of the filter

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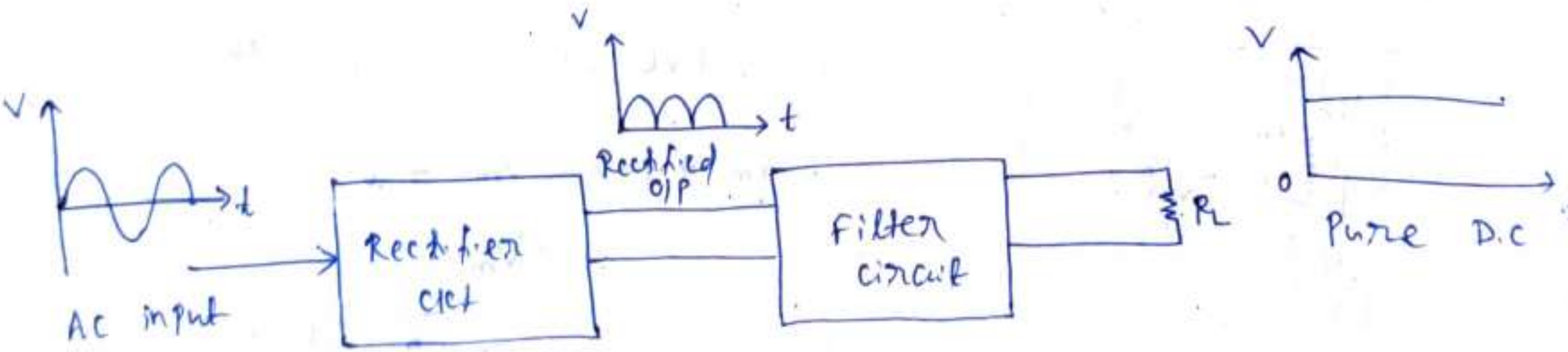


- The output of a rectifier circuit is not a pure d.c but it has pulsating in nature that contains both a.c & d.c component.

- The a.c component is undesirable. and must be kept away from load.

Contd...

To do this filter circuit is used which filter out the a.c component and allow only d.c component to reach the load.

A filter circuit is generally a combination of inductors (L) and capacitors.

- Like Resistance, capacitor have some opposition force which is called capacitive reactance and for inductor it is inductive reactance.

Principle of C and L

– Capacitive Reactance $X_C = \frac{1}{2\pi f C}$

where f is freq. of signal, 'C' is the capacitance

For d.c signal $X_C = \frac{1}{2\pi \cdot f \cdot c} = \frac{1}{2 \cdot \pi \cdot 0 \cdot c} = \infty$ ($\because f = 0$ for d.c)

That means a capacitor doesn't allow d.c to pass through them but allow a.c to pass.

– Inductive Reactance $X_L = 2\pi f L$

For d.c signal, $f = 0 \Rightarrow X_L = 0$

Inductor passes d.c quite easily but for a.c it offer opposition.

*** NOTE →** A capacitor passes a.c but don't allow d.c

A inductor passes d.c but dont allow or oppose a.c

Type of Filter circuit

(i) Capacitor Filter

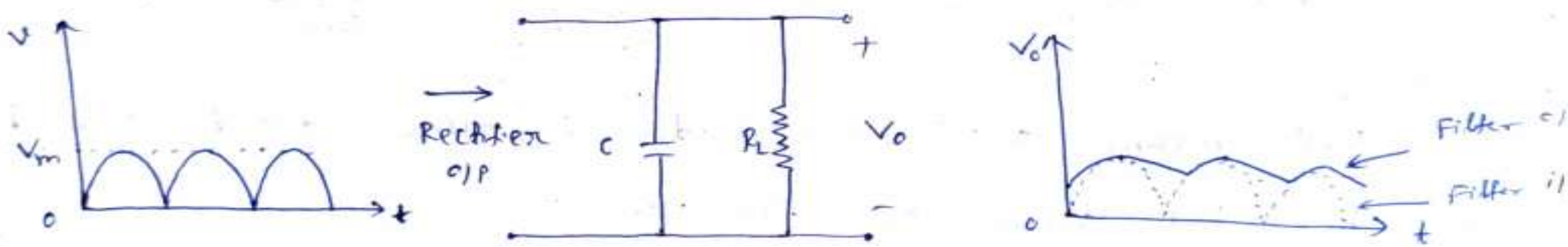
(ii) Inductive Filter

(iii) LC Filter

(iv) LC π Filter

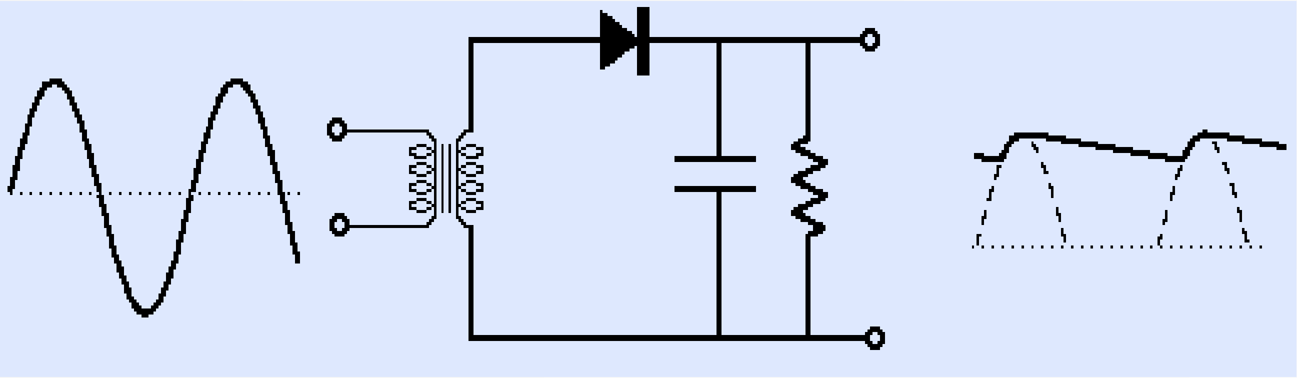
(i) Capacitor Filter :-

- A capacitor filter circuit consist of a capacitor placed across the rectifier output in parallel with Load R_L.

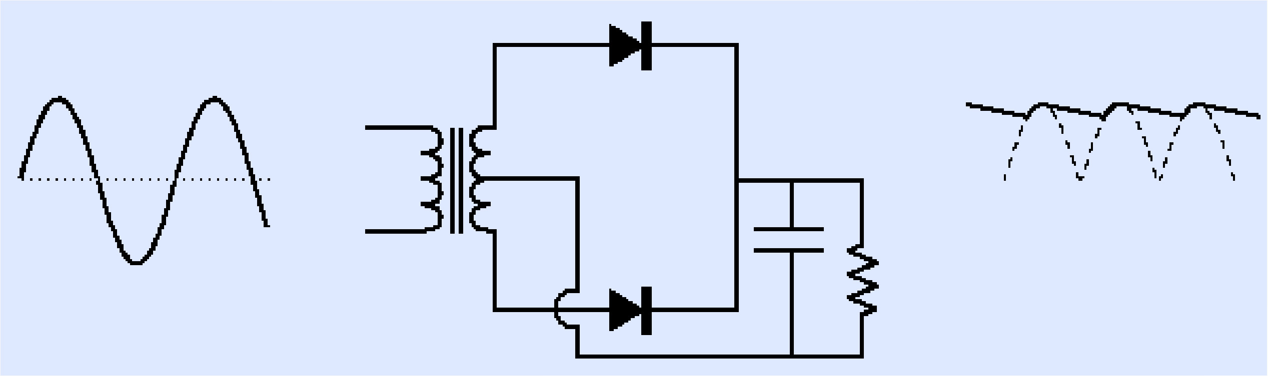


Half Wave Capacitive Filter & Full Wave Capacitive Filter

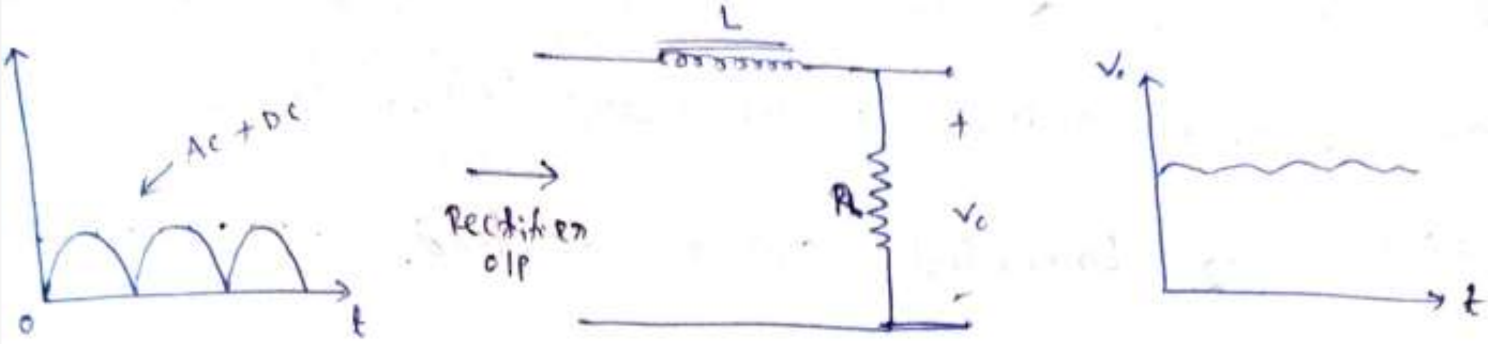
- Improving the ripple factor



  - During forward bias half-cycle, capacitor is charging
  - During the reverse bias half-cycle, the capacitor discharges through the output resistor



Inductive Filter

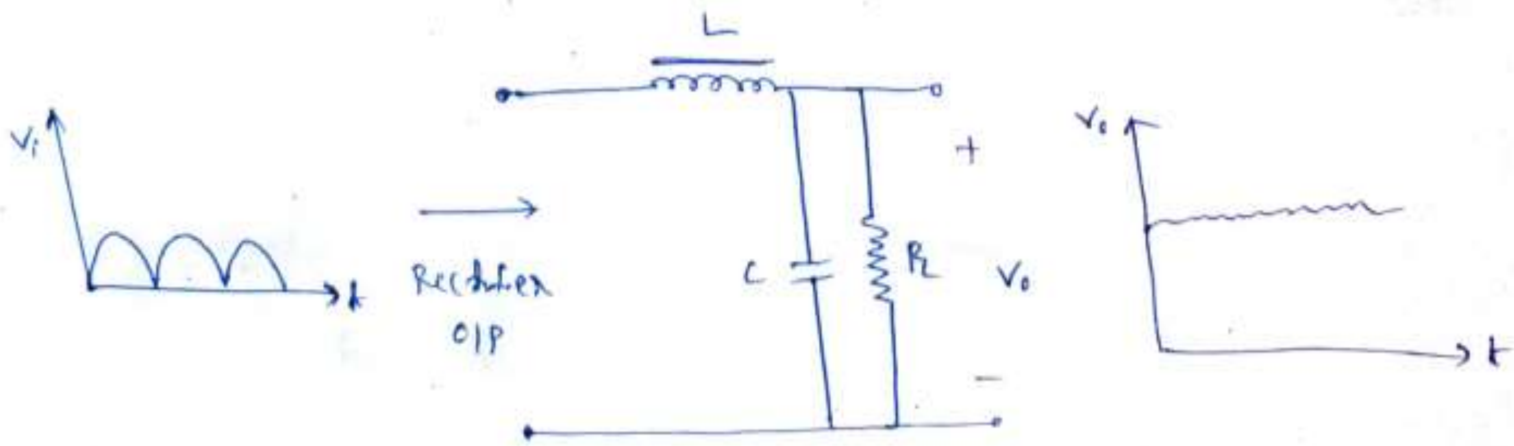


- It consist of a inductor 'L' connected in series with the rectifier output.
- The pulsating output of the rectifier is applied to the filter which contains ac and d.c.
- As inductor offer high opposition to a.c and allow only dc to pass to load, only dc component are appear in the load.

(iii) <u>LC Filter</u> :

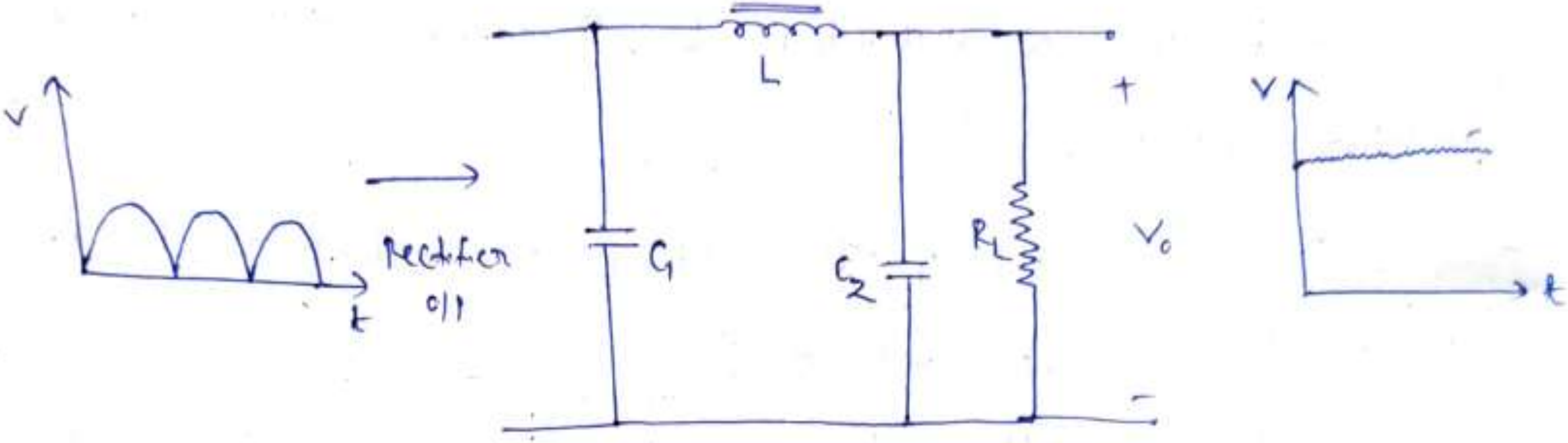
- It consist of a inductor 'L' connected in series with the rectifier output and a capacitor 'c' across the load.

- The pulsating o/p is applied to filter, inductor offer high opposition to ac and pass d.c component to capacitor which appear across the load.



(iv) <u>LC π type Filter</u>

- It consist of a filter capacitor C_1 connected across the rectifier output, a inductor in series and another capacitor C_2 connected across the load.



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Break down Diodes

The PN junction diodes which are operated in the breakdown region of reverse voltage are called breakdown diodes.

The diodes are designed with sufficient power dissipation capacity to work in the breakdown region.

The breakdown of diode in reverse bias are of two types.

1. Avalanche breakdown
2. Zener breakdown

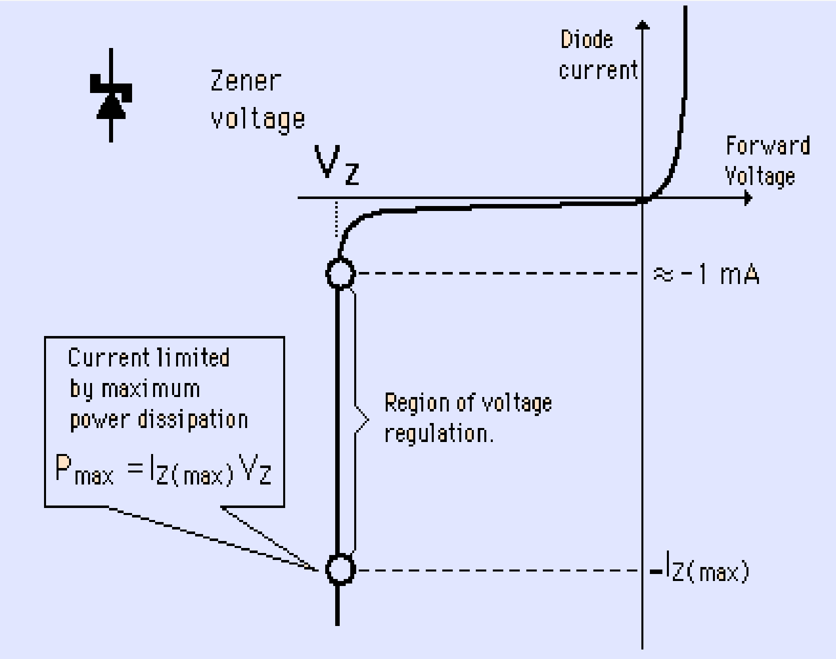
Avalanche breakdown:-

- With increasing R.B voltage, the electric field across the junction increases.
- At certain R.B,the electric field imparts sufficient high energy to thermally generated carriers crossing the junction.
- These carriers collide with with anather atom,break covalent bond and produce more free electrons.
- The newly generated carriers produce more free crriers and this is a cumulitive process to generate high current.
- This is called impact ionization and causes avalanche breakdown.
- Avalanche breakdown occures in lightly doped diode with wide depletion region and generally occures at greater than 6V.

Contd...

Zener breakdown:-

- With narrow depletion region,the electric field strength (Volt/width) produced by reverse voltage can be very high.
- The electric field exerts a large force on bound electrons to tear out from the atom and this increase the reverse current.
- This is called field ionization and causes zener breakdown.
- Zener breakdown occures in highly doped diode with narrow depletion region and generally occures at less than 6V.
- Despite the two types of breakdown mechanism,zener diode are commonly used in all breakdown diodes.



For a large change of current, voltage remains at V_Z

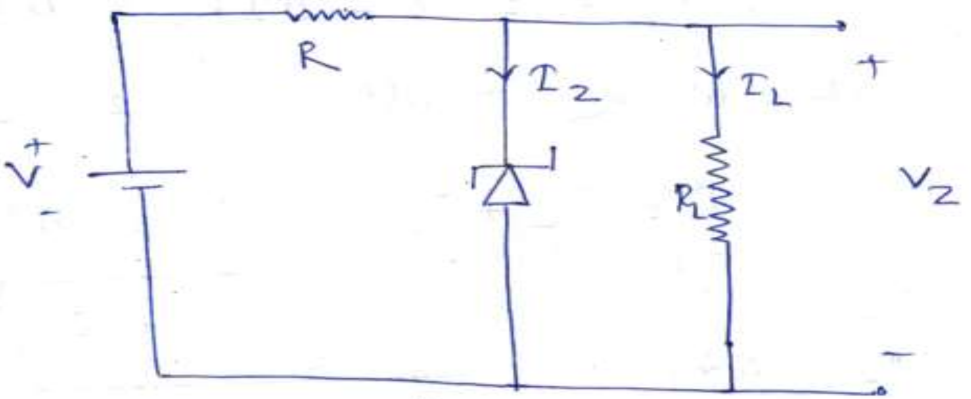
Zener diode as voltage Regulator

As in the reverse bias, the zener voltage remains almost constant for increase in reverse current, this zener diode can act as ~~zener~~ voltage Regulator.

- If 'w' is the power rating of zener diode then maximum allowable current across zener diode is $I_{zm} = \frac{W}{V_z}$.

- The voltage regulator circuit is shown below.

Contd...



The output voltage V_Z remains constant. we can vary supply voltage or load resistance to see how zener diode makes constant output voltage

Apply KVL and KCL in the circuit we get

$$I = I_Z + I_L \quad \text{——— (I)}$$

$$V_Z = V - IR \quad \text{——— (II)}$$

$$V_Z = I_L R_L \quad \text{——— (III)}.$$

Contd...

Case -1

Input voltage V is constant

Load current I_L vary by varying R_L.

since change in o/p voltage $\Delta V_Z = 0$ and

change in i/p voltage $\Delta V = 0$

From eqn (1) $V_Z = V - IR$

$$\Delta V_Z = \Delta V - \Delta I R$$

$$\Rightarrow 0 = 0 - \Delta I R \Rightarrow \Delta I = 0.$$

Put the above result in eqn (1)

$$I = I_Z + I_L \Rightarrow \Delta I = \Delta I_Z + \Delta I_L = 0$$

$R_L \downarrow \Rightarrow I_L \uparrow$ $I = \downarrow I_Z + I_L \uparrow$	$R_L \uparrow \Rightarrow I_L \downarrow$ $I = \uparrow I_Z + I_L \downarrow$

$$\Rightarrow \boxed{\Delta I_Z = -\Delta I_L}$$

Contd...

- When the load resistance is decreased but the supply voltage remains constant the the load current I_L increas and zener current I_Z decrease equally such that the supply current I remains constant.
- If R_L increase the I_L decrease so that I_Z increases to mantain constant supply current.

Case-II

Load resistance R_L keep constant and input voltage V vary.

since $\Delta V_Z = 0$, from eqn (II)

$$V_Z = I_L R_L$$

$$\Rightarrow \Delta V_Z = \Delta I_L R_L \Rightarrow \Delta I_L = 0$$

Contd...

put the above result in eqn ①

$$I = I_L + I_Z$$

$$\Delta I = \Delta I_L + \Delta I_Z$$

$$\boxed{\Delta I = \Delta I_Z} \quad (\because \Delta I_L = 0)$$

$V \uparrow \Rightarrow I \uparrow = I_Z \uparrow + I_L$

$V \downarrow \Rightarrow I \downarrow = I_Z \downarrow + I_L$

when the supply voltage is changed and load resistance is kept constant, the supply current and zener current changes equally to mantain load current I_L at constant value

Basic Electronics

Module-2

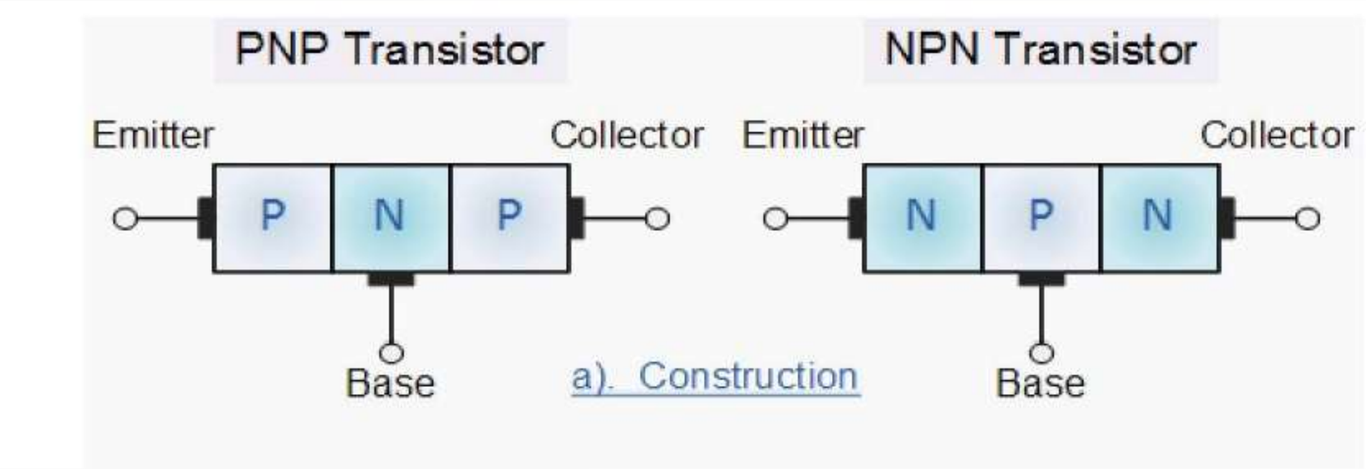
S.N.Mishra

Introduction

- Basics structure
- Current components in BJT
- Current Equation
- Different configurations
- I/P & O/P characteristics
- Load line & Biasing

Introduction

- The transistor was successfully demonstrated on December 23, 1947 at Bell Laboratories is the research arm of American Telephone and Telegraph (AT&T).
- The three individuals credited with the invention of the transistor were William Shockley, John Bardeen and Walter Brattain.
- A bipolar junction transistor (BJT) is a three terminal device consisting of either two n-type and one p-type or two p-type and one n-type sandwitched between them.



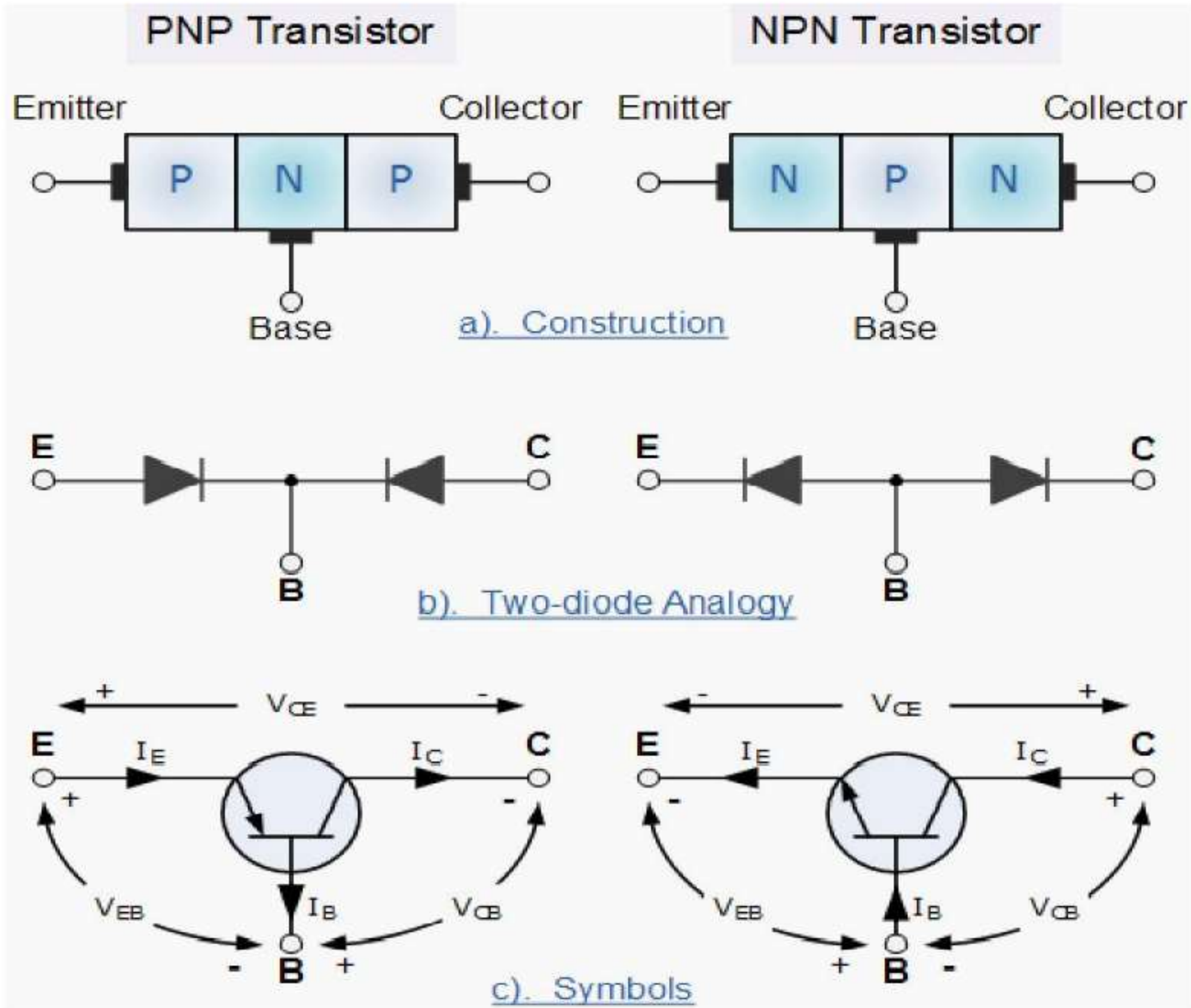
Contd...

- These three terminals are known and labelled as the Emitter (E), the Base (B) and the Collector (C) respectively.
- Emitter is heavely doped,base is lightly doped and collector is very lightly doped.
- The ratio of total width to that center layer (base) is 150:1.
- The middle layer is lightly doped compared to outer layer typically (10:1) or low, to reduce conductivity in base.
- In BJT current depends on the both majority and minority carriers and hence the name bipolar.
- The Bipolar Transistor basic construction consists of two PN-junctions producing three connecting terminals with each terminal being given a name to identify it from the other two.

Construction

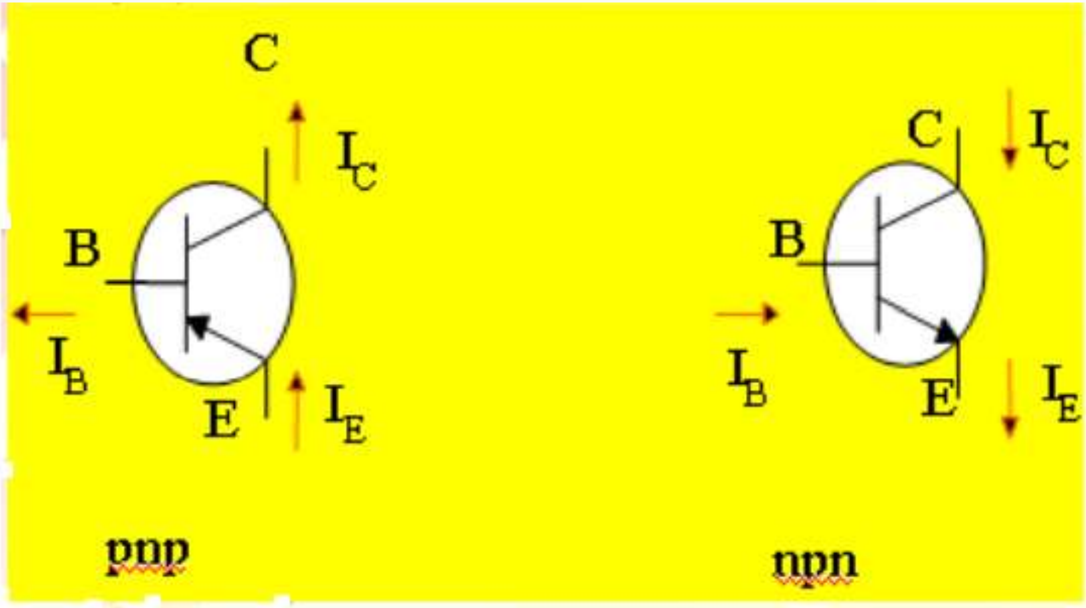
- There are two basic types of bipolar transistor construction, PNP and NPN, which basically describes the physical arrangement of the P-type and N-type semiconductor materials from which they are made.
- It is used as amplifier and oscillator circuits and as a switch in digital circuits.
- It has wide applications in computers, satellites and other modern communication systems.
- The transistor's ability to change between these two states enables it to have two basic functions: "switching" (digital electronics) or "amplification" (analogue electronics).
- Bipolar Transistors are current regulating devices that control the amount of current flowing through them in proportion to the amount of biasing voltage applied to their base terminal acting like a current-controlled switch.

Contd...


PNP Transistor
NPN Transistor
Emitter
Collector
P
N
P
Emitter
Collector
N
P
N
Base
a). Construction
Base
E
C
B
b). Two-diode Analogy
E
C
B
+
V_{CE}
-
E
I_E
I_C
C
+
-
V_{EB}
I_B
V_{CB}
-
B
+
c). Symbols
-
V_{CE}
+
E
I_E
I_C
C
-
+
V_{EB}
I_B
V_{CB}
+
B
-

Contd...

- The principle of operation of the two transistor types PNP and NPN, is exactly the same the only difference being in their biasing and the polarity of the power supply for each type.
- The construction and circuit symbols for both the PNP and NPN bipolar transistor are given above with the arrow in the circuit symbol always showing the direction of "conventional current flow" between the base terminal and its emitter terminal.



Basic Electronics

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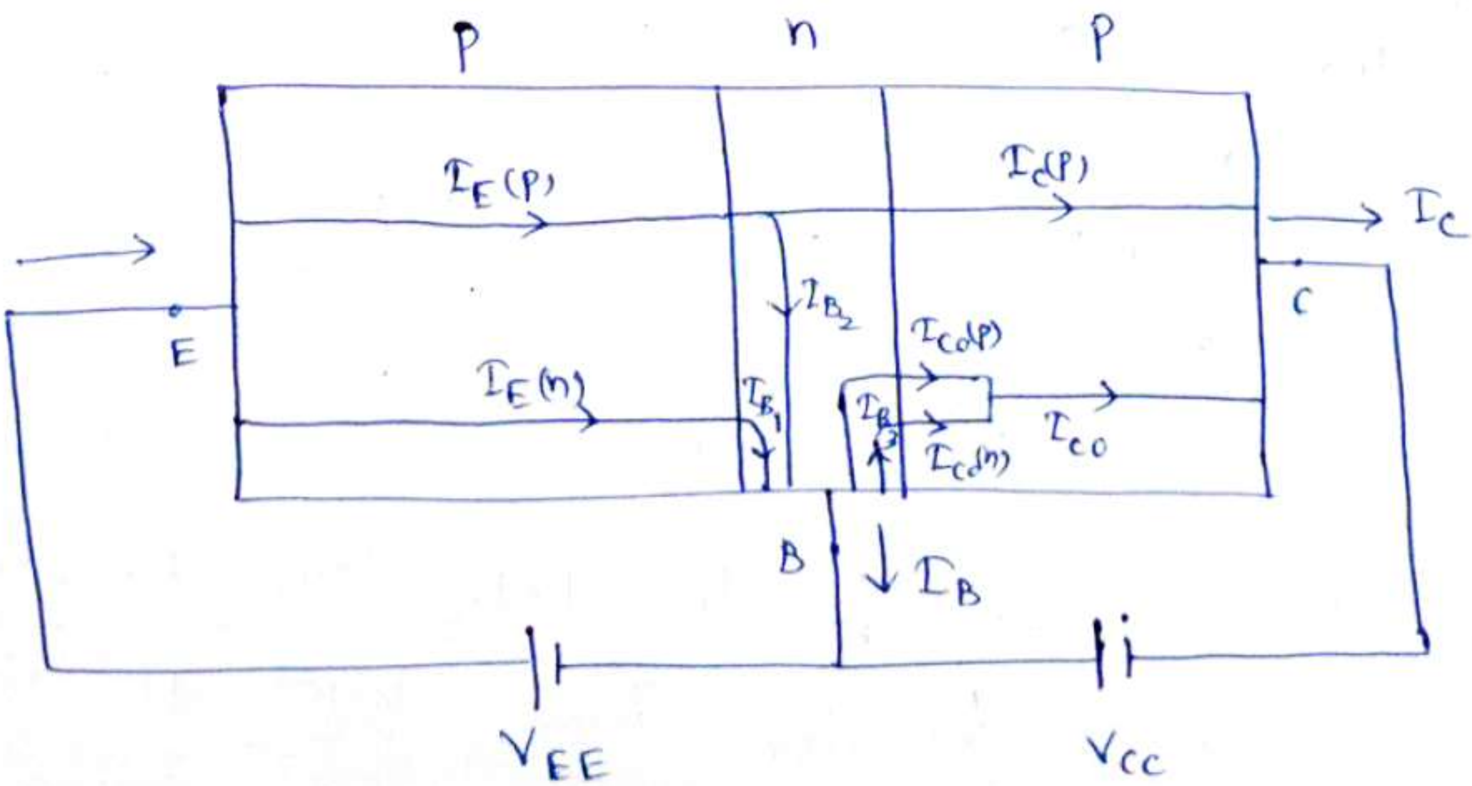
Current components



$$I_E = I_{E(p)} + I_{E(n)}$$

$$I_C = I_{C(p)} + I_{C0}$$

$I_E = I_C + I_B$

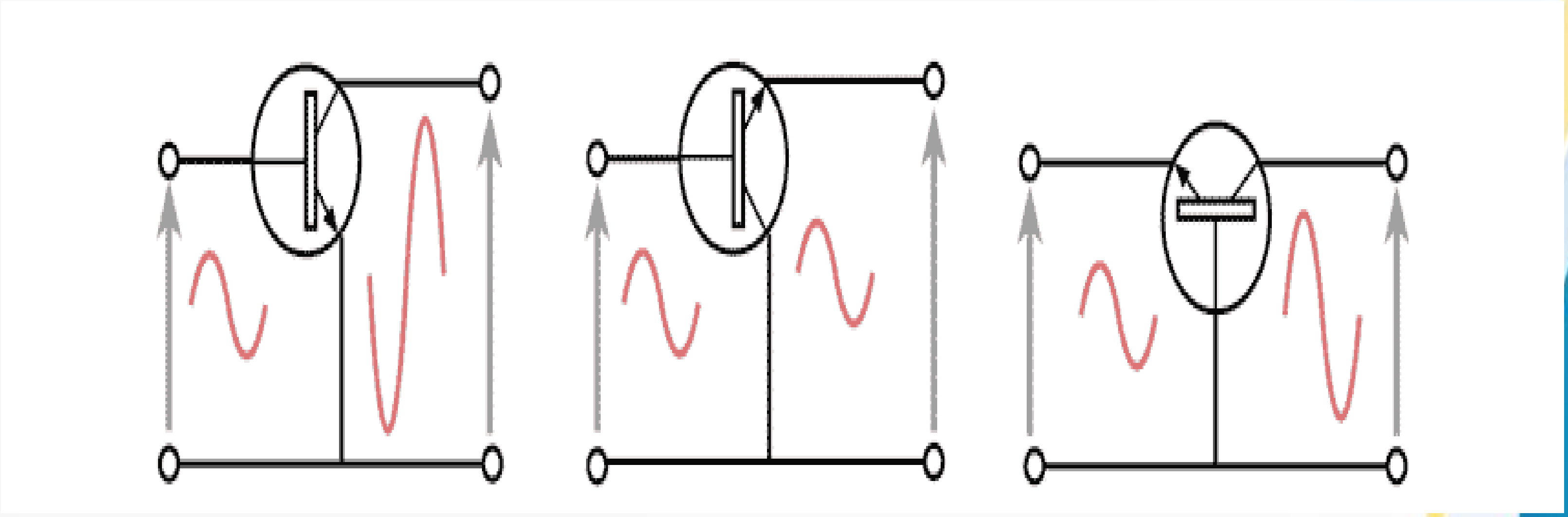
$I_C = \alpha\, I_E$

Contd...

- Trannsistor amplyfing action is due to it's capacity of transfer it's signal current from low resistance path to high resistance path.
- TRANSFER+RESISTOR=TRANSISTOR
- <u>Configuration of Transistors</u>
- As the Bipolar Transistor is a three terminal device, there are basically three possible ways to connect it within an electronic circuit with one terminal being common to both the input and output.
- Each method of connection responding differently to its input signal within a circuit as the static characteristics of the transistor vary with each circuit arrangement.

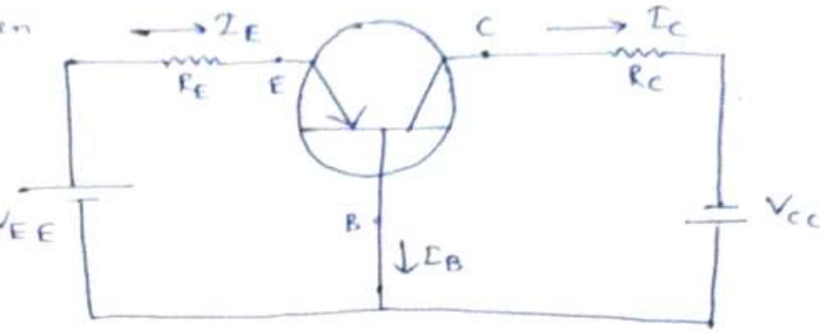
Configuration of Transistors

- 1. Common Base Configuration (CB) - has Voltage Gain but no Current Gain.
- 2 Common Emitter Configuration (CE) - has both Current and Voltage Gain.
- 3. Common Collector Configuration (CC) - has Current Gain but no Voltage Gain.



CB Confuguration

- Here i/p is applied between Emitter and Base while o/p is taken between Collector and Base



- So Base is common to both i/p and o/p and named as CB config

Current amplification factor (α)

- when there is no i/p a.c signal applied, the ratio of o/p collector current to the i/p emitter current is called as dc alpha (α_{dc}) of transistor.

$$\boxed{\alpha_{dc} = \frac{I_C}{I_E}}$$

'α' measures the quality of transistor.

'α' lies between (0.96 – 0.995)

Contd...

$$\Rightarrow \quad I_C = \alpha I_E$$

we know $\quad I_E = I_C + I_B$

$$\Rightarrow \quad I_E = \alpha I_E + I_B$$

$$\Rightarrow \quad \boxed{I_B = (1-\alpha) I_E}$$

If we consider leakage current

$$I_C = \alpha I_E + I_{CBO} = \alpha (I_C + I_B) + I_{CBO}$$

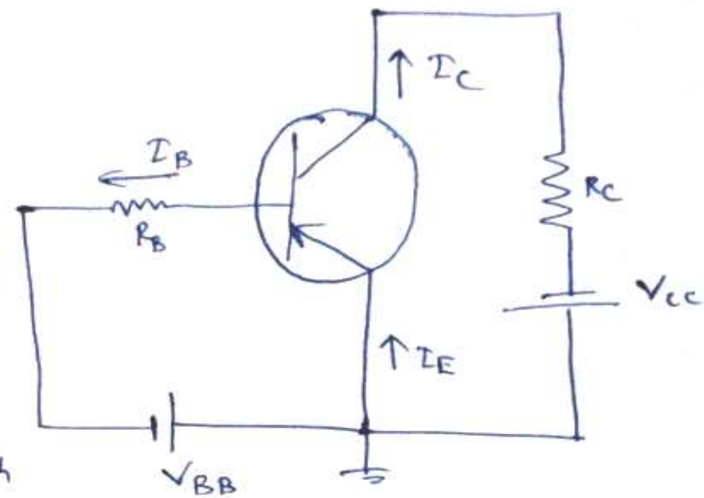
$$I_C - \alpha I_C = \alpha I_B + I_{CBO}$$

$$\Rightarrow \boxed{I_C = \frac{\alpha}{1-\alpha} I_B + \frac{1}{1-\alpha} I_{CBO}}$$

$\because$ ($I_{CO} = I_{CBO}$ for CB configuration

CE Configuration

- Here i/p is applied between Emitter and base while o/p is taken between collector and emitter.



- So emitter is common to both i/p and o/p and named as CE Configuration

<u>Current Amplification factor (β)</u>

- when no ac signal is applied, then the ratio of collector current (o/p) to base current (i/p) is called as β_{dc}.

$$\boxed{\beta = \frac{I_C}{I_B}}$$

β lies between 25-300

$$I_C = \beta I_B$$

Contd...

If leakage current considered then $I_C = \beta I_B + I_{CEO}$

$$I_C = \beta I_B + \frac{1}{1-\alpha} I_{CBO}$$

$I_{CEO} \longrightarrow$ Leakage current in CE configuration

$I_{CBO} \longrightarrow$ leakage current in CB configuration

$$\boxed{I_{CEO} = \frac{1}{1-\alpha} I_{CBO}}$$

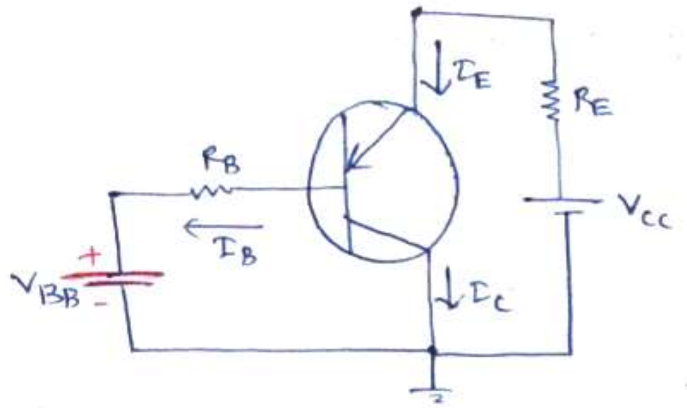
CC Configuration :-

- Here i/p is applied between collector and Base while o/p is taken between emitter and collector.
- So collector is common between both i/p and o/p & named as CC configuration.

CC Configuration

Current Amplification factor (γ)

- when no ac signal applied, the ratio of emitter current to base current is called γ_{dc}.



$$\boxed{\gamma = \frac{I_E}{I_B}}$$

we know $\quad I_E = I_C + I_B$

$$I_C = \alpha I_E + I_{CBO}$$

$$\Rightarrow I_E = \alpha I_E + I_{CBO} + I_B$$

$$\Rightarrow I_E(1-\alpha) = I_B + I_{CBO} \Rightarrow I_E = \frac{1}{1-\alpha} I_B + \frac{1}{1-\alpha} I_{CBO}$$

$$\Rightarrow \boxed{I_E = (1+\beta) I_B + (1+\beta) I_{CBO}}$$

Relation Between α, β, γ :-

$$\alpha = \frac{I_C}{I_E}, \quad \beta = \frac{I_C}{I_B}, \quad I_E = I_C + I_B \Rightarrow I_B = I_E - I_C$$

$$\beta = \frac{I_C}{I_B} = \frac{I_C}{I_E - I_C} = \frac{I_C / I_E}{1 - \frac{I_C}{I_E}} = \boxed{\frac{\alpha}{1-\alpha} = \beta}$$

$$\Rightarrow \beta = \frac{\alpha}{1-\alpha} \Rightarrow \beta(1-\alpha) = \alpha$$

$$\Rightarrow \beta - \alpha\beta = \alpha$$

$$\Rightarrow \alpha(1+\beta) = \beta \Rightarrow \boxed{\alpha = \frac{\beta}{1+\beta}}$$

$$\gamma = \frac{I_E}{I_B}, \quad \alpha = \frac{I_C}{I_E} \Rightarrow I_B = I_E - I_C$$

$$\gamma = \frac{I_E}{I_B} = \frac{I_E}{I_E - I_C} = \frac{1}{1 - \frac{I_C}{I_E}} = \boxed{\frac{1}{1-\alpha} = \gamma}$$

$$\Rightarrow \gamma(1-\alpha) = 1 \Rightarrow \gamma - \gamma\alpha = 1 \Rightarrow \boxed{\alpha = \frac{\gamma - 1}{\gamma}}$$

$$\boxed{\alpha = \frac{\beta}{1+\beta} = \frac{\gamma - 1}{\gamma}}$$

Basic Electronics

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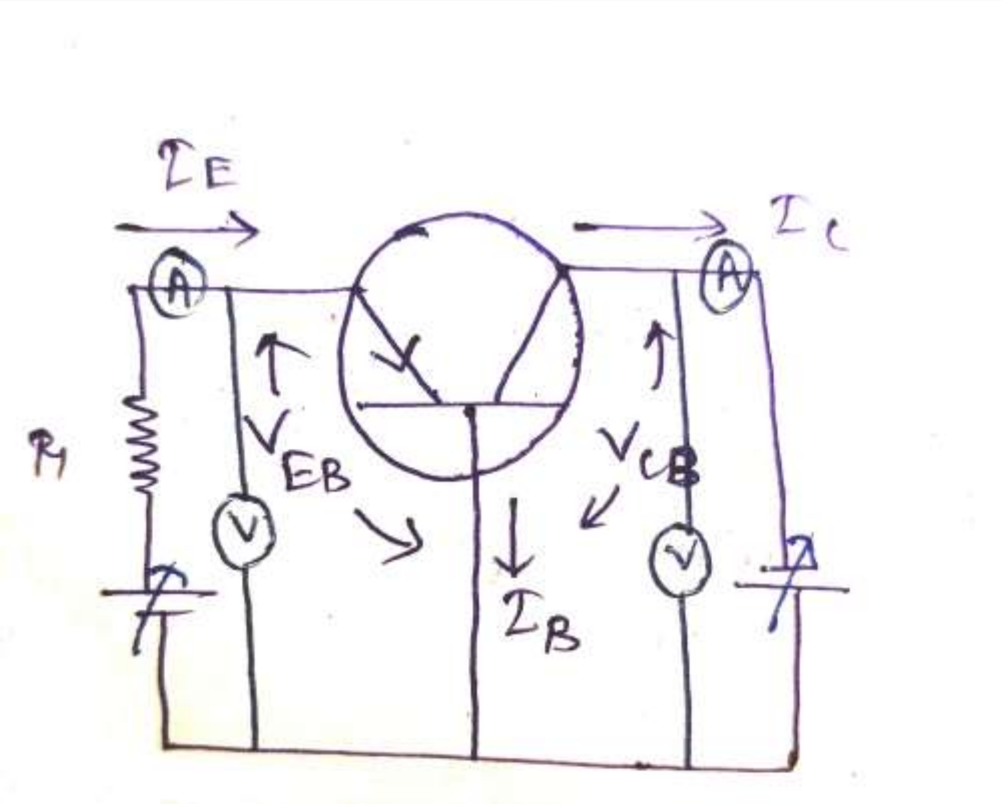
CB Conf.



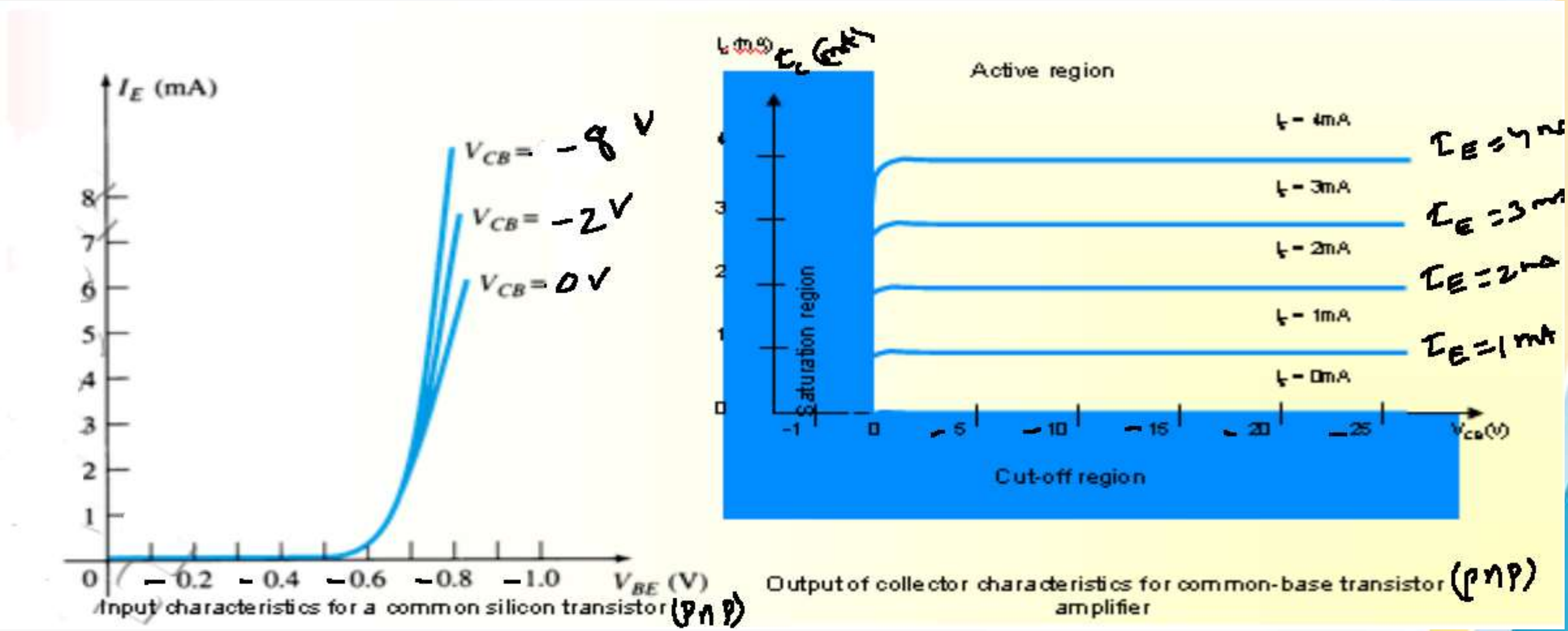
- The plot between i/p current (I_E) and i/p voltage (V_{EB}) for different o/p voltage (V_{CB}) is caled i/p char. of CB configuration.

- As i/p side emitter base junction is forward biased like PN junction,the char. look like diode charecteristics i.e for constant V_{CB} when V_{EB} increases,I_B also increases exponentially.

- When V_{CB} increases,depletion layer of CB junction increase which will decrease the effective base width and the process is called as base width modulation/Early effect.

- Due to decrease in effective base width for increase in $V_{CB,}I_B$ decreases which is shown in Figure.

CB i/p & o/p Char.



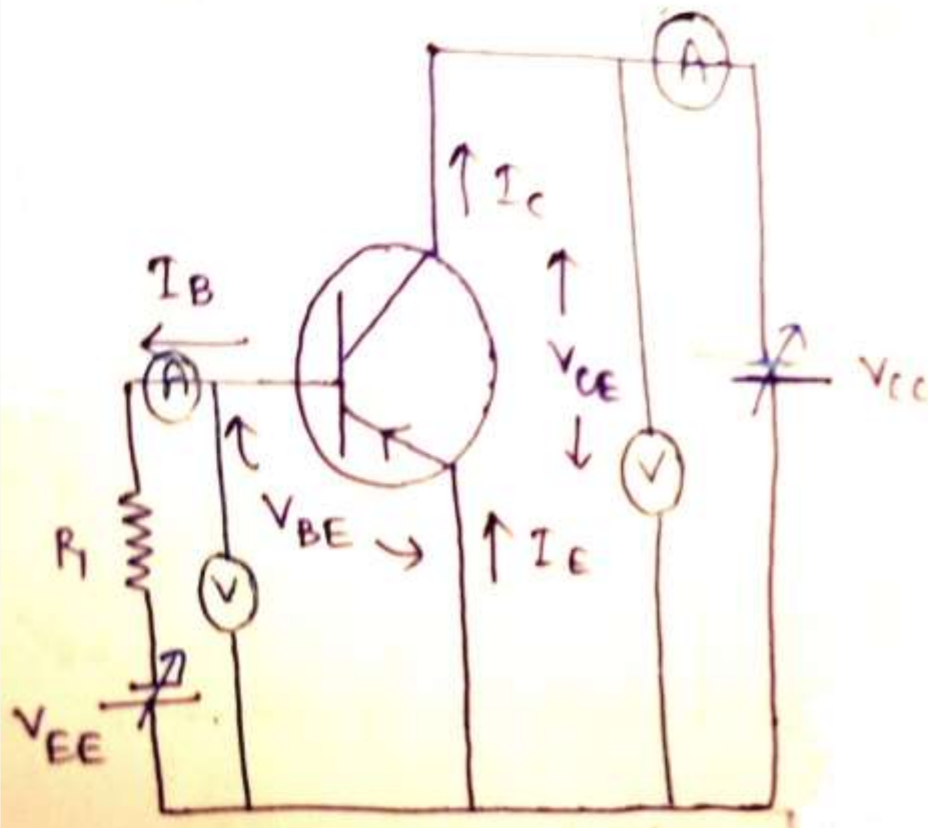
- The plot between o/p current (I_C) and o/p voltage (V_{CB}) for different i/p current (I_E) is called o/p charecteristics.

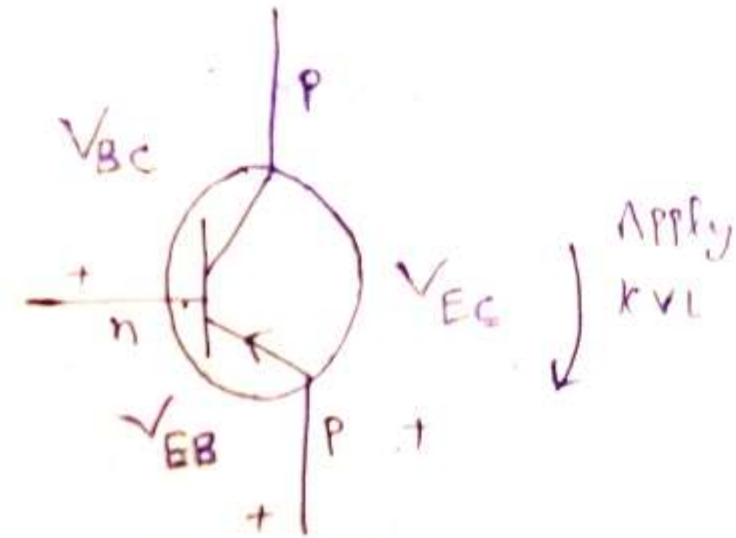
- The o/p char. is divided into three regions.
- Active Region
- Saturation Region
- Cutoff Region

Contd...

- Active Region:The transistor used as an amplifier should operate in active region.In this region EB junction forward biased and CB junction reverse biased.
- If emitter current (I_E=0) then I_C=I_{CO}(reverse saturation current).
- As EB junction is forward biased,I_E flows and I_B current is very less so almost all the currents reach to collector from emitter and I_C almost equal to I_E.
- I_C is nearly constant and almost parallel to I_E.
- Saturation Region:In this region both the junctions are forward biased.
- Saturation region is located to left of the ordinate (V_{CB}=0) and above I_E=0.
- As the CB junction is forward biased,holes will flow from collector to emitter so that we will get zero collector current when we increse V_{CB} in forward biased.
- Cutoff Region:On this region,both the junction are reverse biased.
- This region is located below I_E=0 i.e leakage current.
- Breakdown Region:If VCB increase beyond limit then IE increase and goes to breakdown condition.This must be avoided.

CE Conf.





$V_{EC}-V_{EB}-V_{BC}=0$

$V_{BC}=V_{EC}-V_{EB} \rightarrow V_{CB}=V_{CE}-V_{BE}$

$V_{CE}\uparrow \rightarrow V_{CB}\uparrow$

- The plot between V_{BE} and I_B for different V_{CE} is called i/p char. of CE configuration.
- Here also when V_{BE} increse, I_B increase as in case of diode char.
- As V_{CE} increases for constant V_{BE},V_{CB} increases hence effective base width decreases so that base current decreases as shown in figure.

CE i/p & o/p Char.

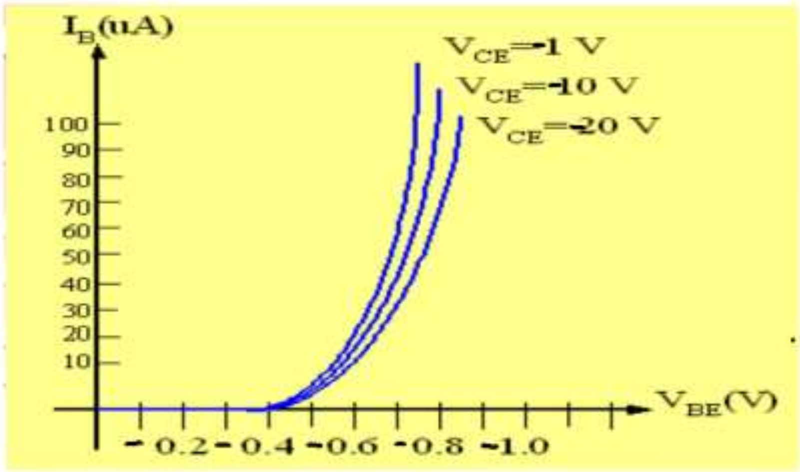


Fig Input characteristics for common-emitter pnp transistor

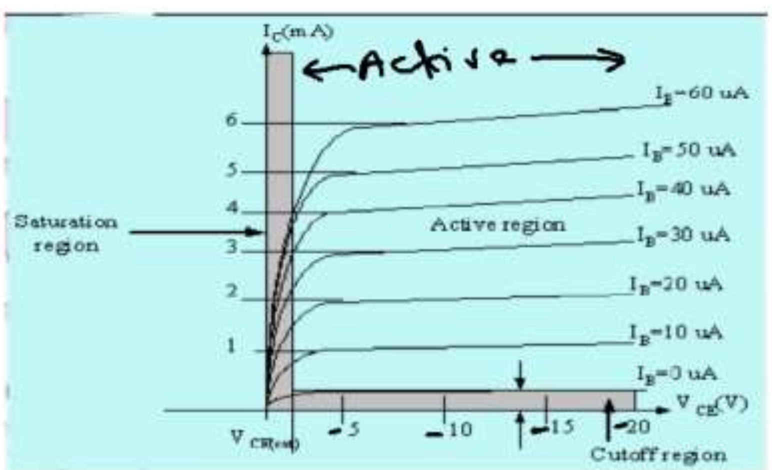
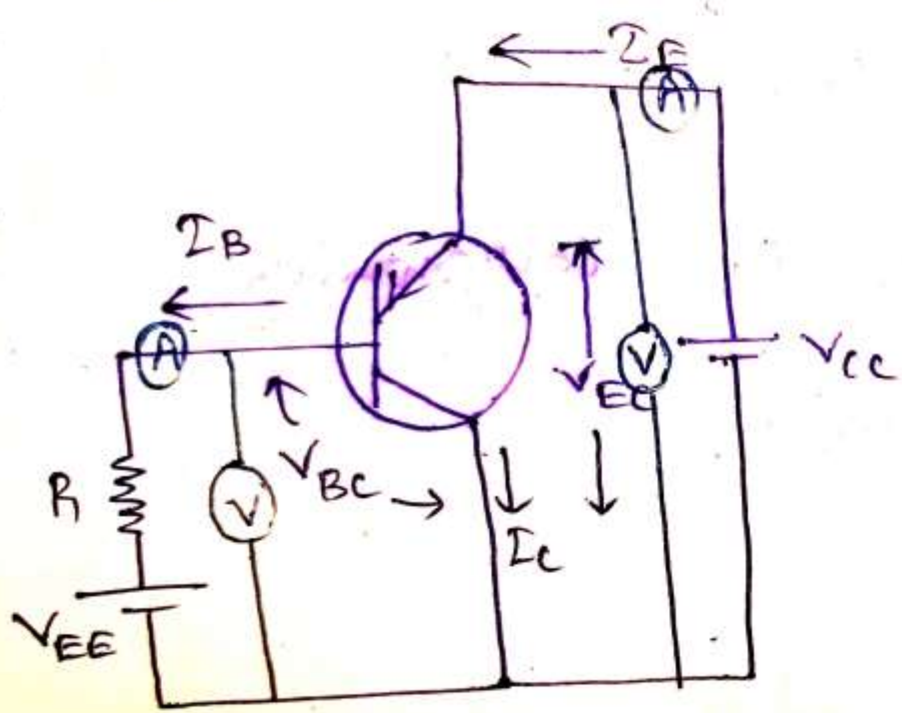
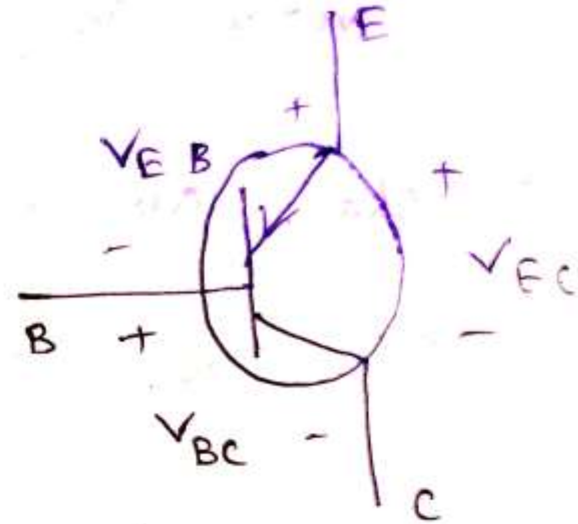


Fig Output characteristics for common-emitter pnp transistor

- The plot between V_{CE} and I_C for different value of I_B is called o/p char. of CE configuration.
- The o/p char. is divided into three regions.
- Active region:where EB junction is FB and CB junction is RB.
- The curve in this region is not horizontal as in CB char. for fixed IB.Here IC increases with VCE increase due to base width modulation.
- Cutoff Region:In this region both junctions are reverse biased.
- Saturation Region:In this region both the junctions are forward biased.

CC Conf.

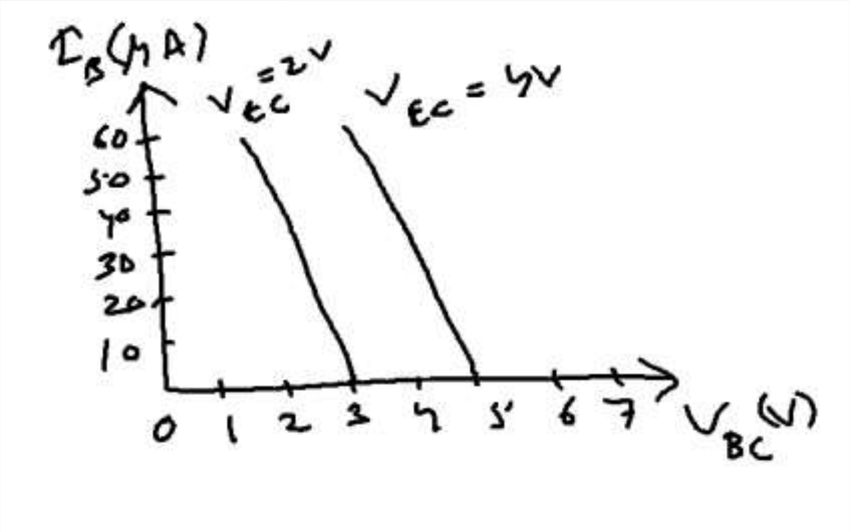




$-V_{EC}+V_{BC}+V_{EB}=0$
$V_{EB}=V_{EC}-V_{BC}$
if $V_{BC}\uparrow\rightarrow V_{EB}\downarrow\rightarrow I_B\downarrow$

- The plot between V_{BC} and I_B for different V_{EC} is called i/p char. of CC configuration.
- As V_{BC} increases,V_{EB} decreases which leads to decrease in I_B as shown in figure.
- The plot between V_{EC} vs I_E for different I_B is called o/p char. of CC configuration.
- The o/p char. is same as CE configuration becouse I is nearly equal to I

CC O/P char.



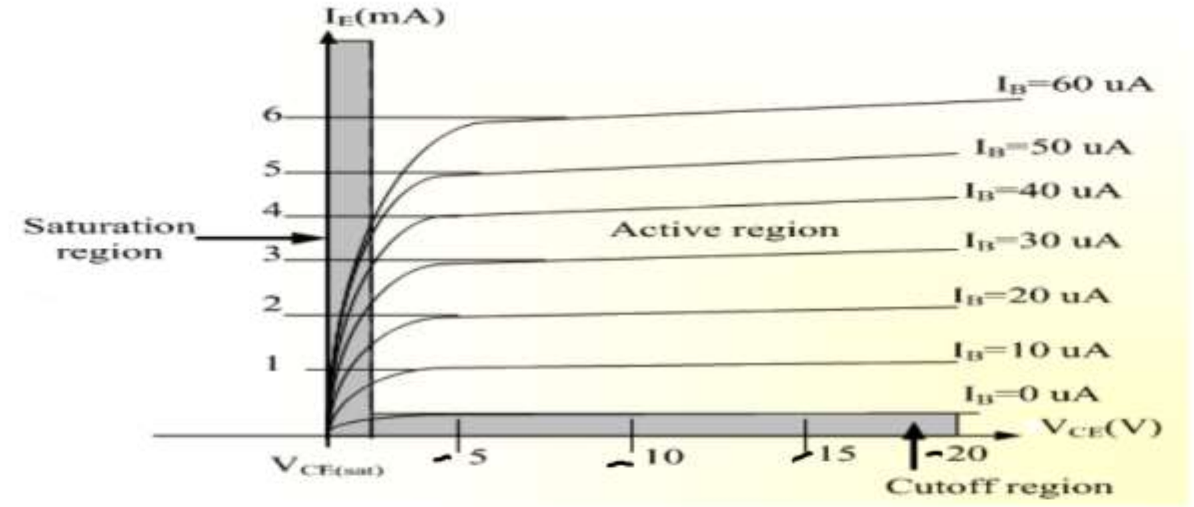


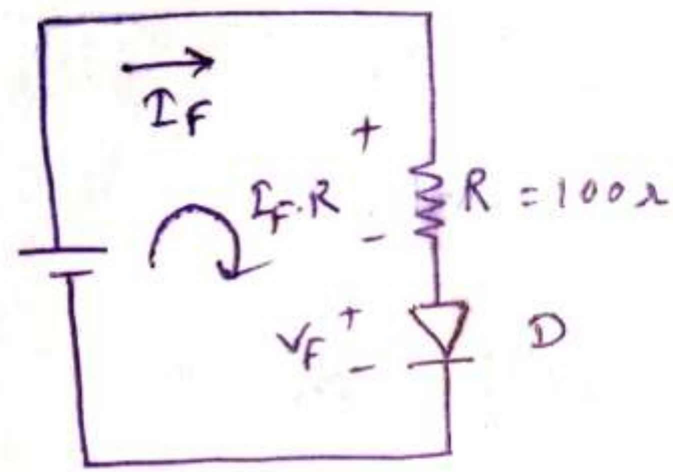
Fig Output Characteristics of CC Configuration for pnp Transistor

Basic Electronics

S.N.Mishra

Load line and Biasing

E=5V



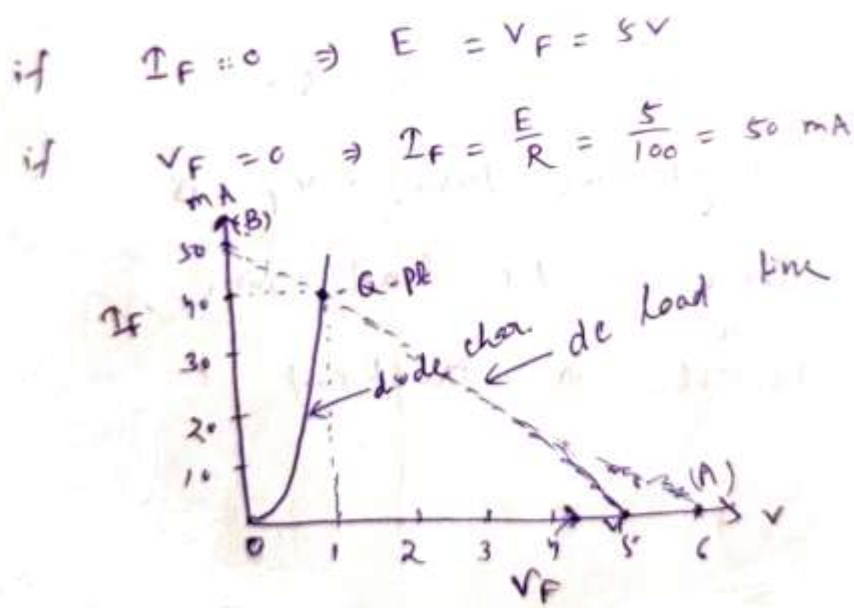
$E - I_F.R - V_F = 0$

$E = I_F.R + V_F$

If $I_F = 0, E = V_F = 5V$

If $V_F = 0, I_F = E/R = 5/100 = 50mA$

DC load line is a line that gives all d.c conditions that could exist with in the circuit.



Quescent Point (Q-point)

- The intersection point between d.c load line and device char. is known as quescent point (Q-point).

- This is the only point on the d.c load line where diode voltage and current are compatable with circuit condition.

- From the graph I_F=40mA,V_F=1V

- We know

  $E=V_F-I_F.R=1+(40mA*100ohm)=5V$

Note:Though we take V_F is 0-5V for plotting load line,it will not possible in practical cases.

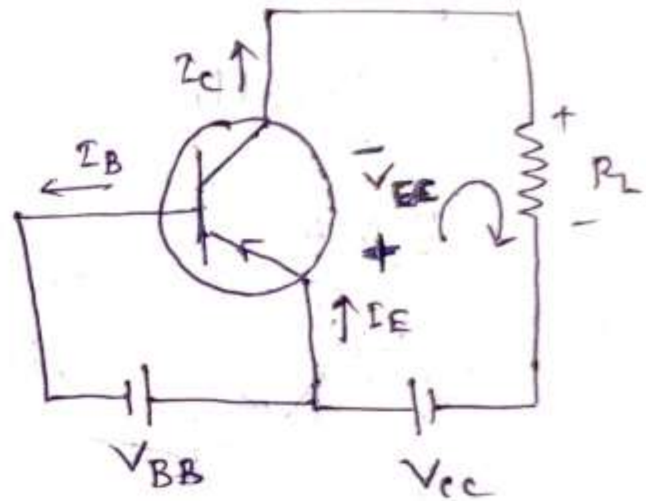
Transistor Biasing

Apply KVL in collector ckt

$$-V_{EC} - I_C R_L + V_{CC} = 0$$

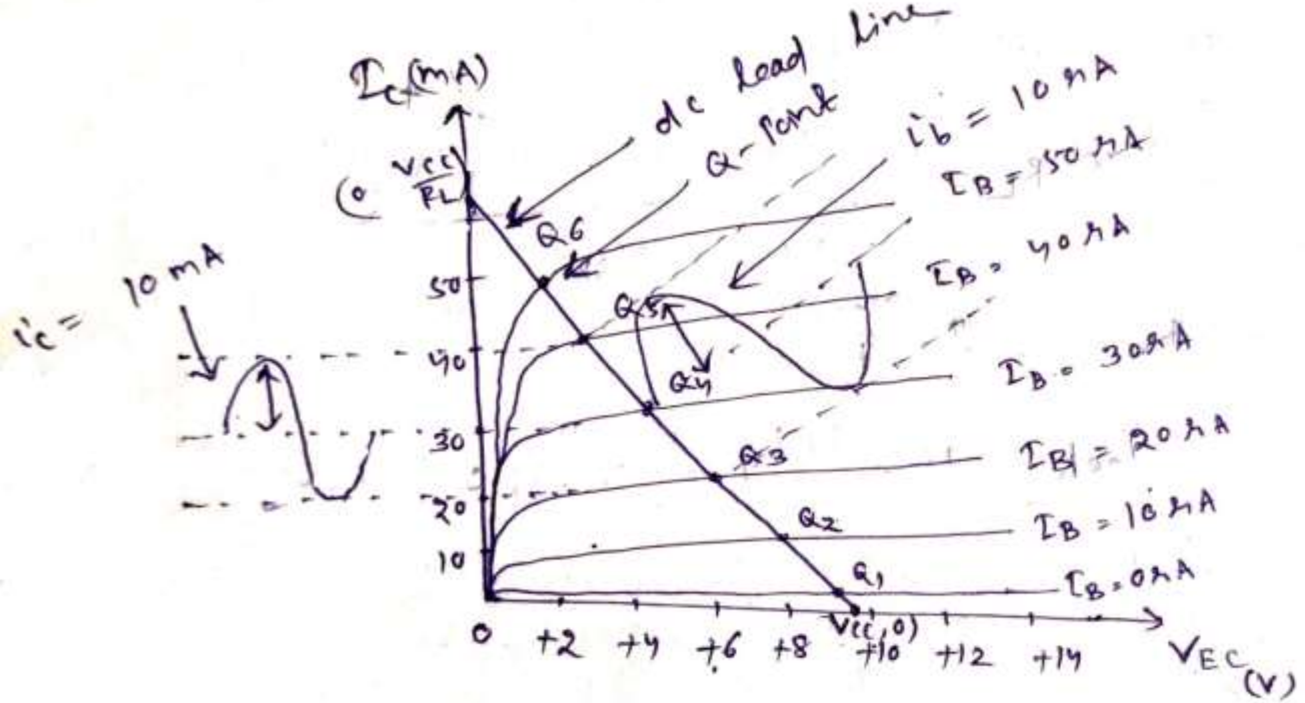
$$V_{EC} = +V_{CC} - I_C R_L$$

$$I_C = \left(-\frac{1}{R_L}\right) V_{EC} + \frac{V_{CC}}{R_L}$$



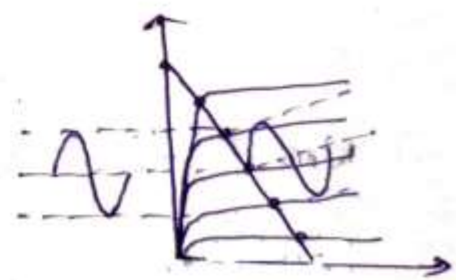
If $I_c=0, V_{EC}=V_{CC}$
If $V_{EC}=0, I_C=V_{CC}/R_C$

Plotting these points in VI char. we get load line.



portion
+ve clipped

-ve portion clipped



No distortion

Contd...

- If the o/p signal must be a faithful reproduction(shape of signal must not change) of the i/p signal, the transistor must be operated in active region.
- To establish an operating point (proper values of collector current Ic and collector to emitter voltage V_{CE}) appropriate supply voltages and resistances must be suitably chosen in the ckt.
- This process of selecting proper supply voltages and resistance for obtaining desired operating point or Q point is called as biasing and the ckt used for transistor biasing is called as biasing ckt.
- In this example we have six Q-points,out of which if we take top or bottom one then we will not get faithful amplified output as shown in above figure.
- Hence for proper amplification,always choose Q-point in the middle of load line.

Contd...

- As shown in the figure, the optimum POINT IS LOCATED AT THE MID POINT OF THE LOAD LINE in order to get faithful amplification, the Q point must be well within the active region of the transistor.

- Even though the Q point is fixed properly, it is very important to ensure that the operating point remains stable where it is originally fixed.

- If the Q point shifts nearer to either up or down side, the output voltage and current get clipped, thereby o/p signal is distorted.

- In practice, the Q-point tends to shift its position due to any or all of the following three main factors.

- 1) Reverse saturation current, Ico, which doubles for every 10° C raise in temperature.
- 2) Base emitter Voltage ,V_{BE}, which decreases by 2.5 mV/° C
- 3) Transistor current gain, h_{FE} or β which increases with temperature.

Contd...

- We know $I_c = \beta I_B + (\beta+1) I_{CBO}$
- As temperature increases,leakage current (I_{CBO}) increases which leads to increase in collector current and power dissipation increase.The increse heat again increase tenperature and whole process repeats and this is a cumulative process which may damage the transistor. This is called thermal runway.
- The change in collector current with respect to I_{CO},V_{BE} and β determine stability factor and denoted as S,S',S".
- The rate of change of Ic w.r.t I_{CO},keeping V_{BE},β constant is denoted by 'S'.

$$S = \frac{\partial I_c}{\partial I_{co}} \approx \frac{dI_c}{dI_{co}} \approx \frac{\Delta I_c}{\Delta I_{co}}, \beta \text{ and } I_B \text{ constant}$$

Stability factor S' and S'':

S' is defined as the rate of change of I_C with V_{BE}, keeping I_C and V_{BE} constant.

$$S' = \frac{\partial I_c}{\partial V_{BE}}$$

S'' is defined as the rate of change of I_C with β, keeping I_{CO} and V_{BE} constant.

$$S'' = \frac{\partial I_c}{\partial \beta}$$

Fixed Bias Circuit

Fixed bias (base bias)

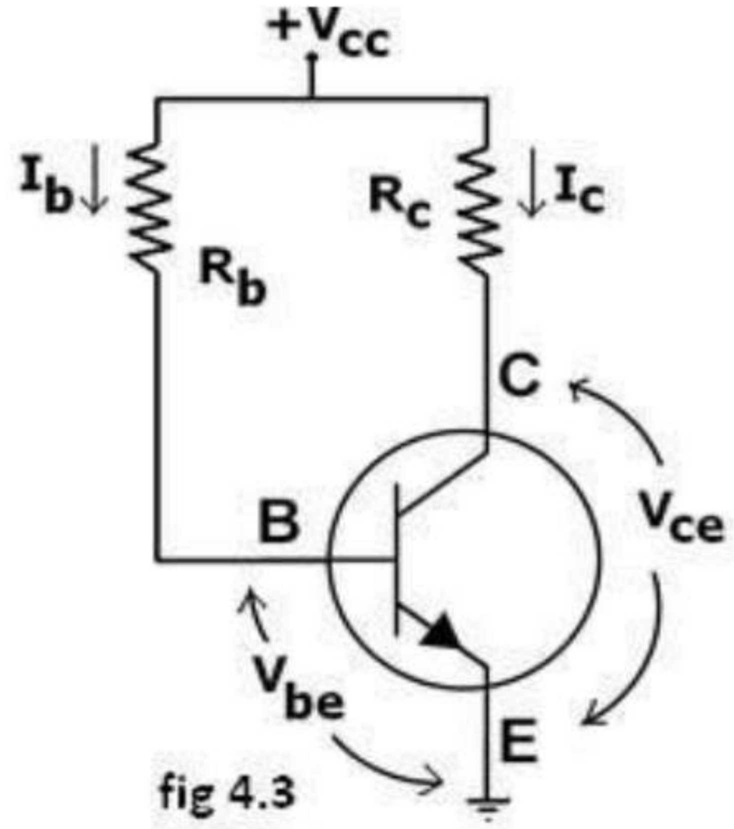


Fig Fixed Biasing Circuit

Contd...

- This form of biasing is also called base bias. In the figure shown, the single power source (for example, battery) is used for both collector and base of a
- transistor, although separate batteries can also be used.
- In the given circuit, $Vcc = I_B R_B + Vbe$
- Therefore, $I_B = (Vcc - Vbe)/R_B$
- We know $I_c = \beta I_B + (\beta+1) I_{CBO}$
- The stability factor is given by the equation $I_c = \beta I_B + (\beta+1) I_{CBO}$ reduces to $S = 1 + \beta$
- Since β is a large quantity, this is very poor biasing circuit. Therefore in practice the circuit is not used fo biasing.
- For a given transistor, Vbe does not vary significantly during use. As Vcc is of fixed value, on selection of R the base current I_B is fixed. Therefore this type is called fixed bias type of circuit.
- Also for given circuit, $Vcc = I_C R_C + Vce$
- Therefore, $Vce = Vcc - I_C R_C$

Contd...

- Merits:
- It is simple to shift the operating point anywhere in the active region by merely changing the base resistor (R_B).
- A very small number of components are required.
- Demerits:
- The collector current does not remain constant with variation in temperature or power supply voltage. Therefore the operating point is unstable.
- When the transistor is replaced with another one, considerable change in the value of β can be expected. Due to this change the operating point will shift.

FETs vs. BJTs

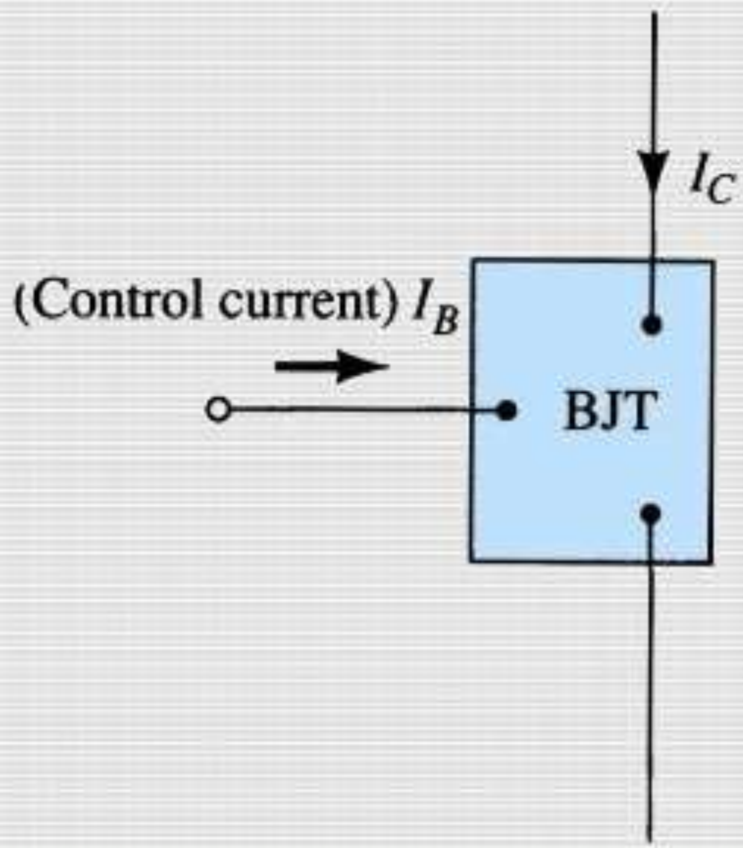
Similarities:

- Amplifiers
- Switching devices
- Impedance matching circuits

Differences:

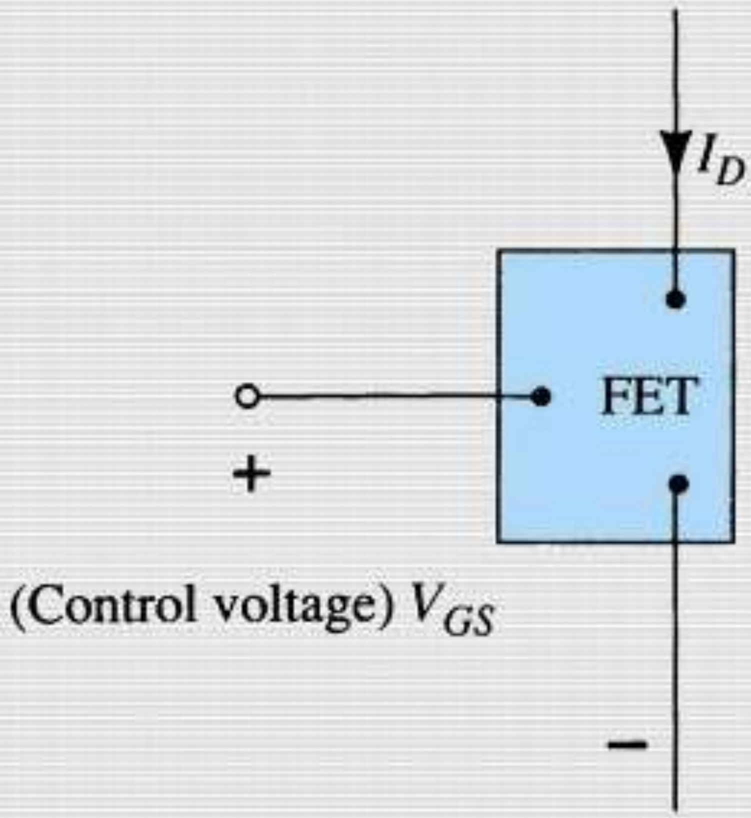
- FETs are voltage controlled devices. BJTs are current controlled devices.
- FETs have higher input impedance.
- Noise is less in FET
- FETs are less sensitive to temperature variations and are better suited for integrated circuits
- FETs are generally more static sensitive than BJTs.
- NO thermal runway.
- FET is unipolar but BJT is bipolar device.

BJT is Current-controlled



(a)

FET is Voltage-controlled



(b)

FET Types

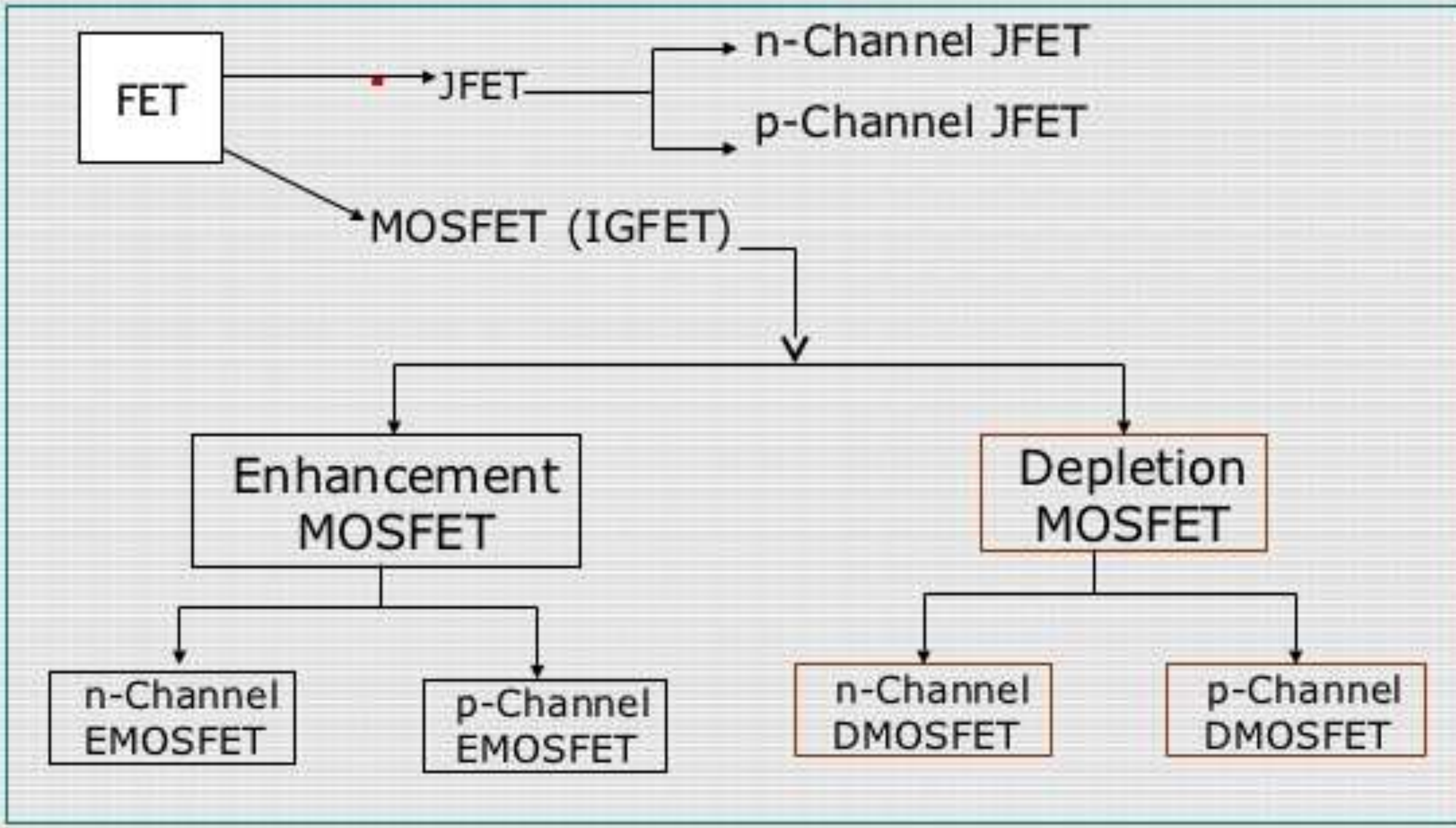
JFET: Junction FET

MOSFET: Metal–Oxide–Semiconductor FET

D-MOSFET: Depletion MOSFET

E-MOSFET: Enhancement MOSFET

Types of Field Effect Transistors
(The Classification)



Junction Field effect Transistor(JFET)

There are two types of JFETs:

- ***n*-channel**
- ***p*-channel**

The n-channel is the more widely used of the two.

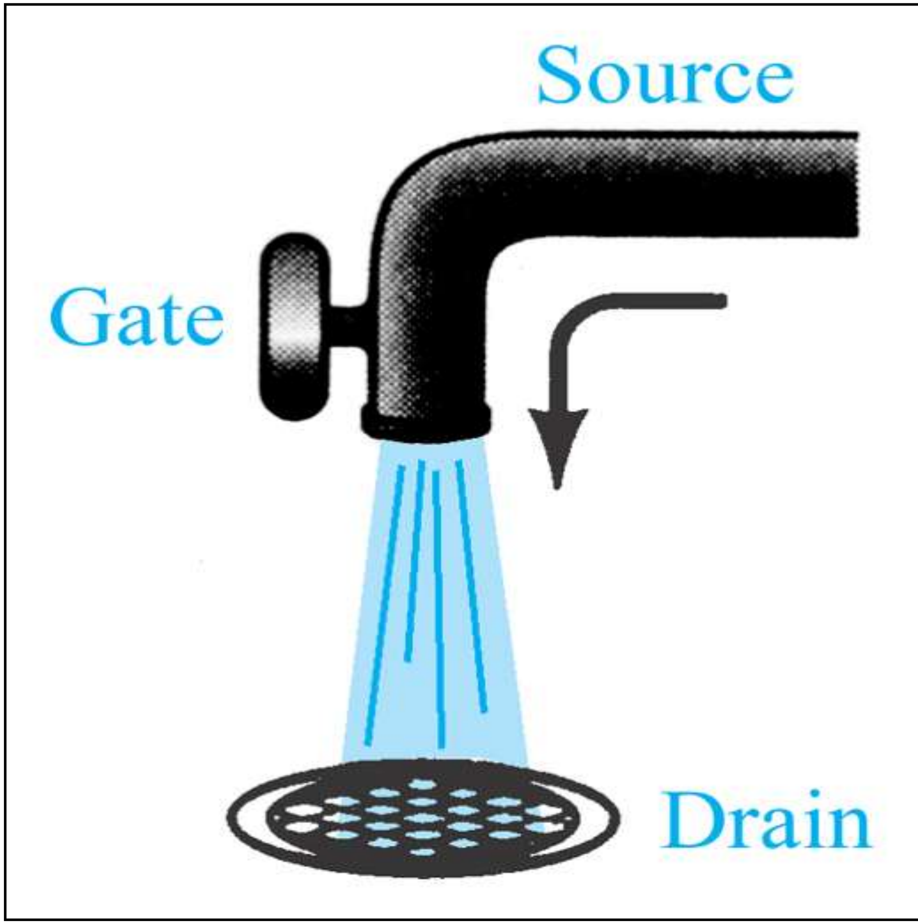
JFETs have three terminals:

- The **Drain** (D) and **Source** **(S)** are connected to the *n*-channel

- The **Gate** **(G)** is connected to the *p*-type material

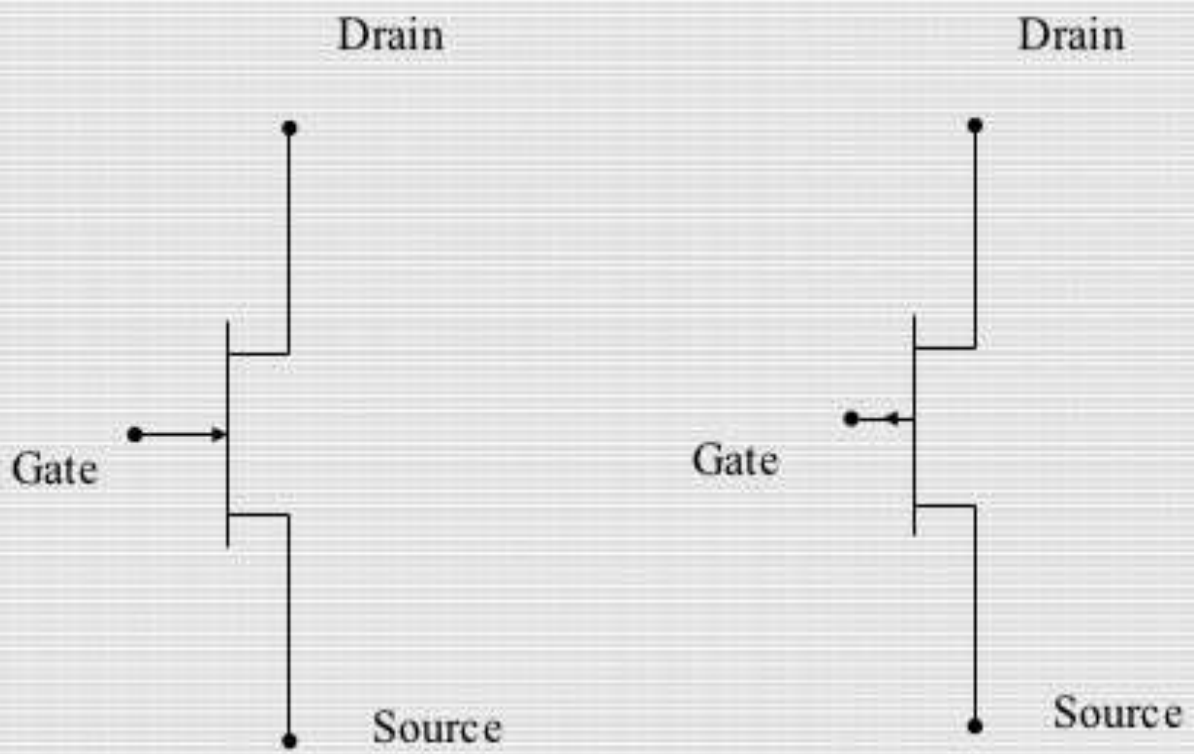
JFET Operation: The Basic Idea

JFET operation can be compared to that of a water spigot.



- **The source is the accumulation of electrons at the negative pole of the drain-source voltage.**
- **The drain is the electron deficiency (or holes) at the positive pole of the applied voltage.**
- **The gate controls the width of the n-channel and, therefore, the flow of charges from source to drain.**

SYMBOLS



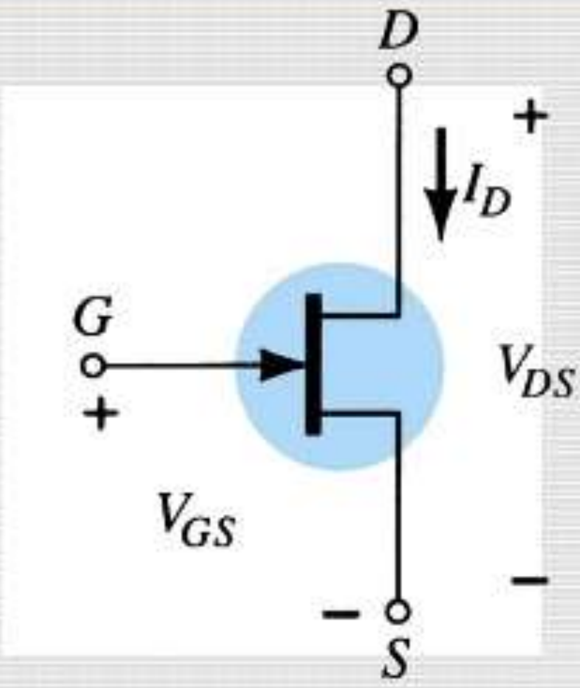
n-channel JFET

p-channel JFET

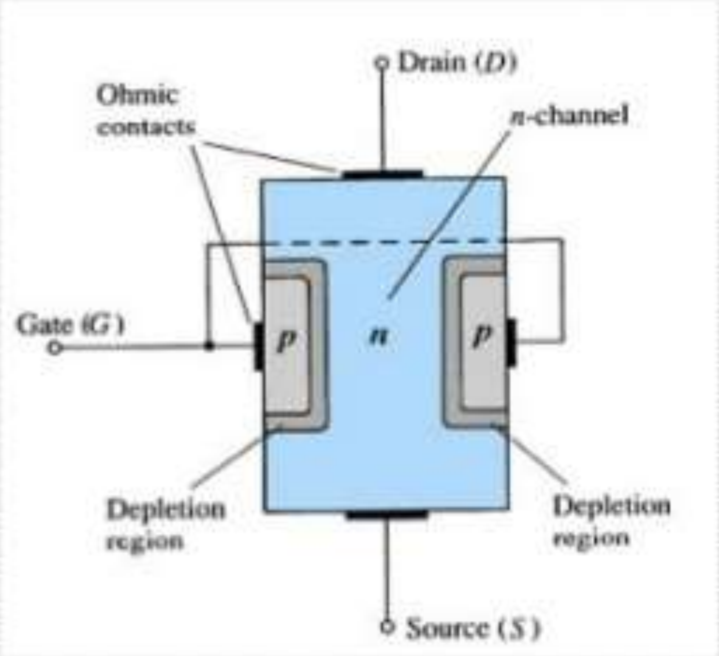
N-channel JFET

- N channel JFET:
  - Major structure is n-type material (channel) between embedded p-type material to form 2 p-n junction.
  - In the normal operation of an n-channel device, the Drain (D) is positive with respect to the Source (S). Current flows into the Drain (D), through the channel, and out of the Source (S)
  - Because the resistance of the channel depends on the gate-to-source voltage (V_{GS}), the drain current (I_D) is controlled by that voltage

N-channel JFET..



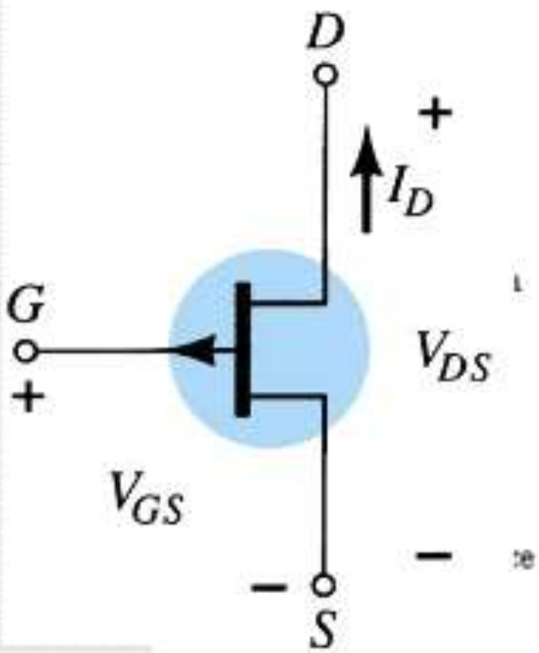
(a)



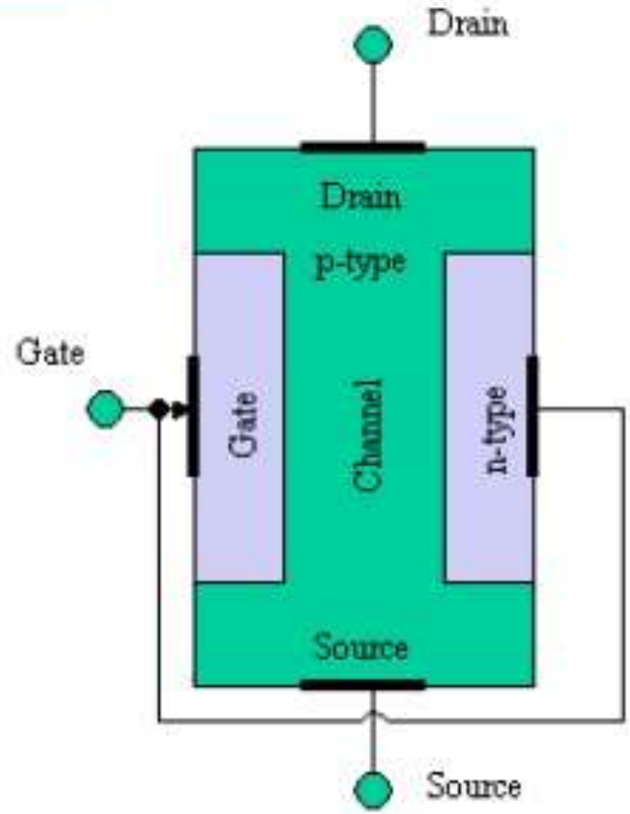
P-channel JFET

- P channel JFET:
  - Major structure is p-type material (channel) between embedded n-type material to form 2 p-n junction.
  - Current flow : from Source (S) to Drain (D)
  - Holes injected to Source (S) through p-type channel and flowed to Drain (D)

P-channel JFET..



(b)



JFET Operating Characteristics

There are three basic operating conditions for a JFET:

- $V_{GS} = 0$ V, V_{DS} **increasing to some positive value**
- $V_{GS} < 0$ V, V_{DS} **at some positive value**
- **Voltage-controlled resistor**

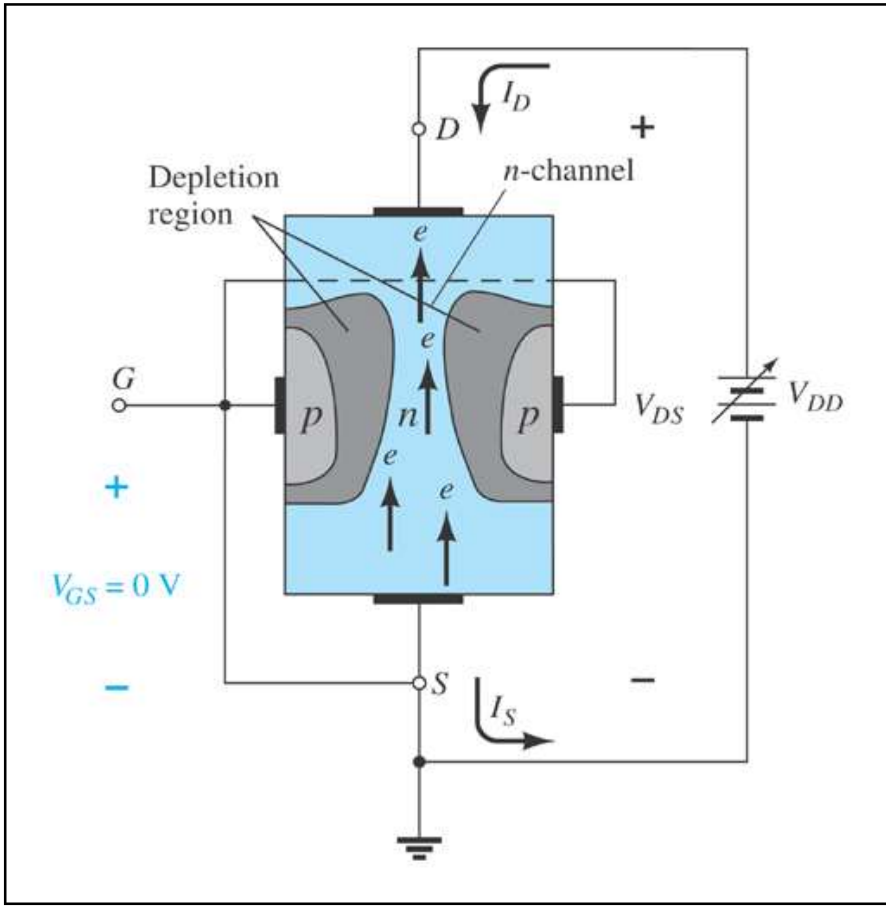
JFET Characteristic for $V_{GS} = 0$ V and $0 < V_{DS} < |V_p|$

- To start, suppose $V_{GS}=0$
- Then, when V_{DS} is increased, I_D increases. Therefore, I_D is proportional to V_{DS} for small values of V_{DS}
- For larger value of V_{DS}, as V_{DS} increases, the depletion layer become wider, causing the resistance of channel increases.
- After the pinch-off voltage (V_p) is reached, the I_D becomes nearly constant (called as I_D maximum, I_{DSS}-Drain to Source current with Gate Shorted)

JFET Characteristics: V_{GS}=0V

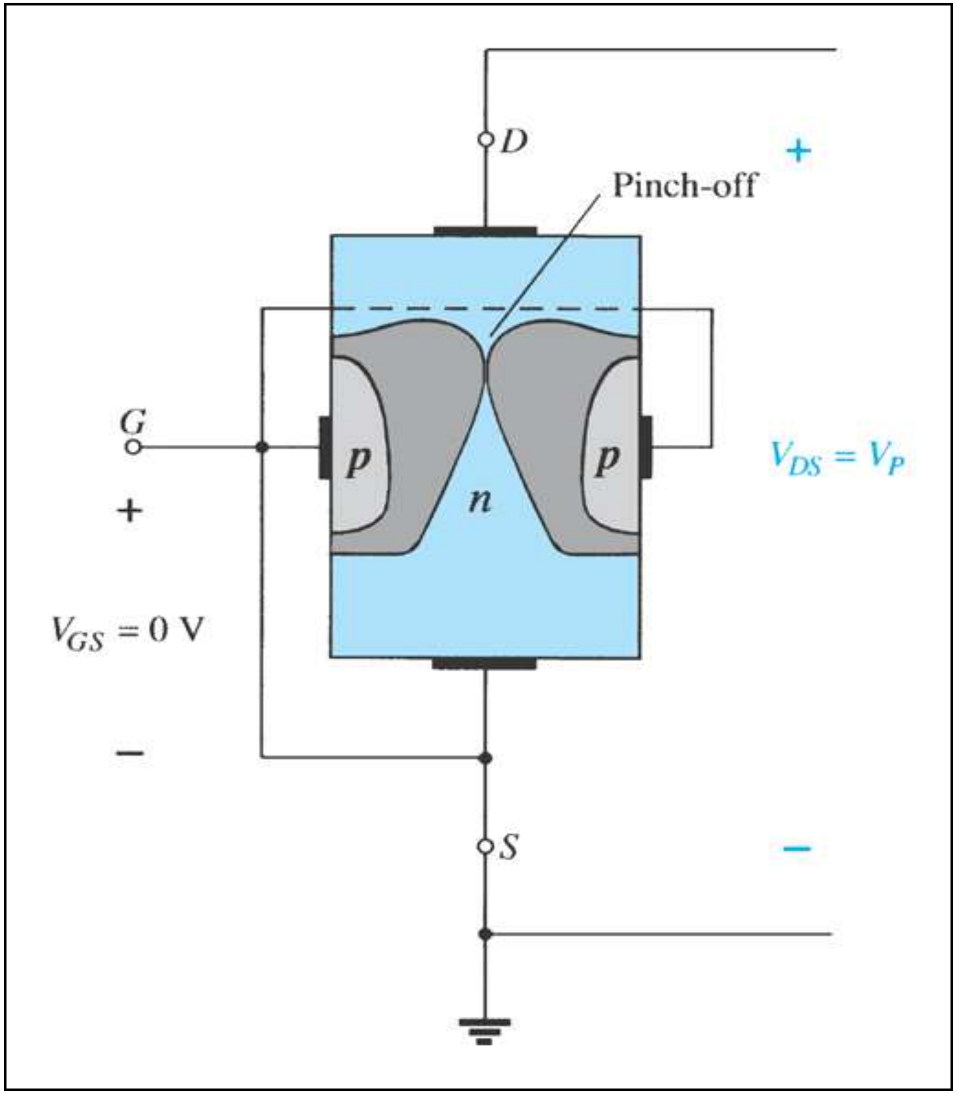
Three things happen when V_{GS} = 0 V and V_{DS} increases from 0 V to a more positive voltage:

- **The size of the depletion region between *p*- type gate and *n*-channel increases.**
- **Increasing the size of the depletion region decreases the width of the *n*-channel, which increases its resistance.**
- **Even though the *n*-channel resistance is increasing, the current from source to drain (I_D) through the *n*-channel is increasing because V_{DS} is increasing.**



JFET Characteristics: Pinch Off

- If V_{GS} = 0 V and V_{DS} continually increases to a more positive voltage, a point is reached where the depletion region gets so large that it **pinches off** the channel.
- This suggests that the current in channel (I_D) drops to 0 A, but it does not: As V_{DS} increases, so does I_D. However, once pinch off occurs, further increases in V_{DS} do not cause I_D to increase.

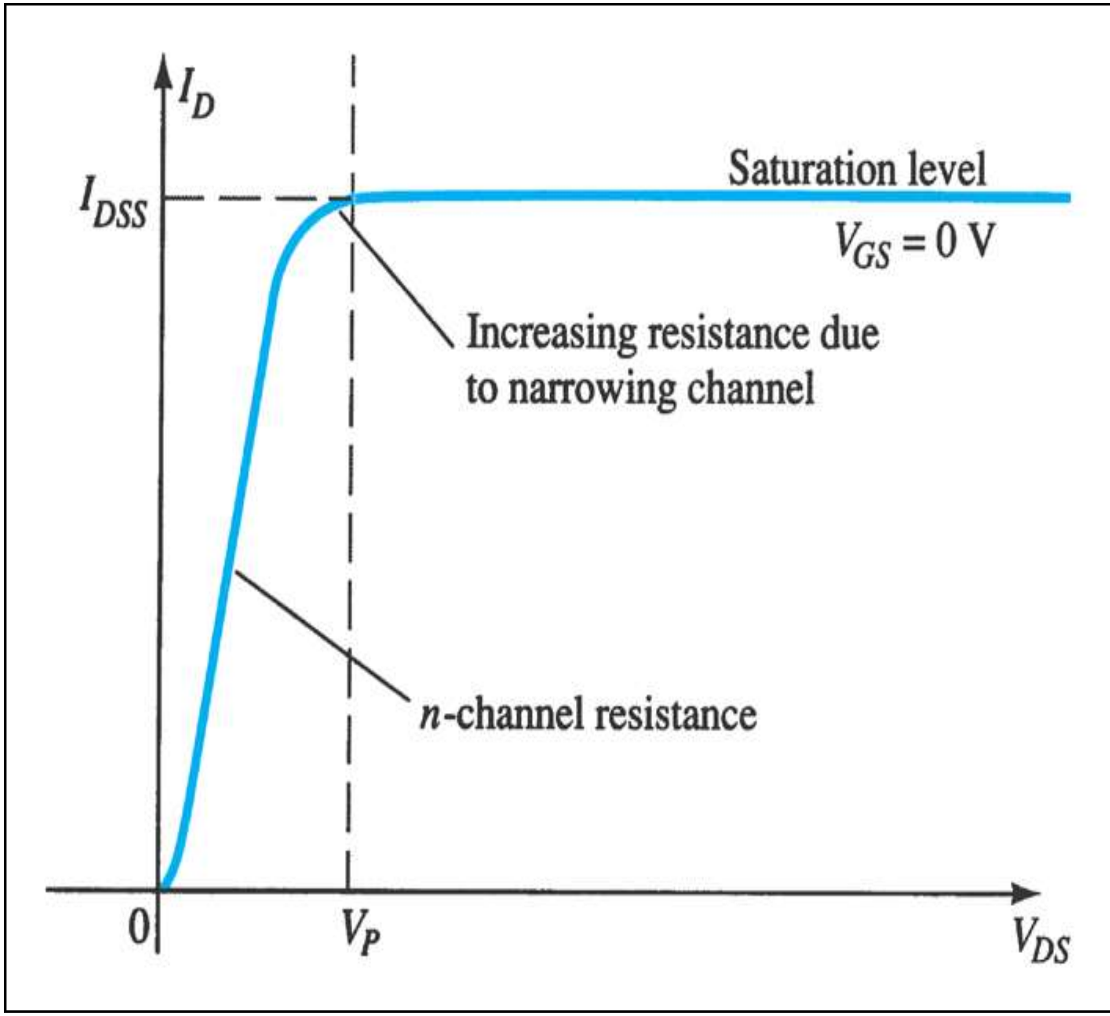


JFET Characteristics: Saturation

At the pinch-off point:

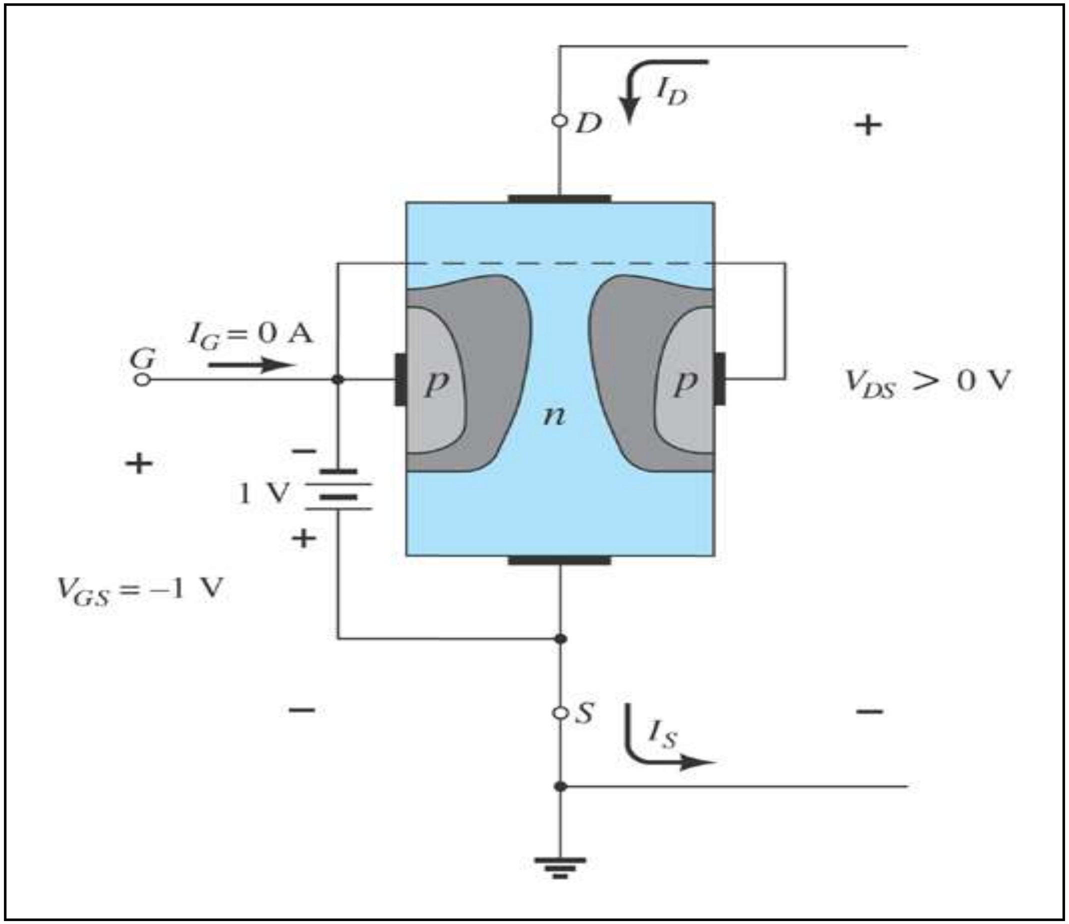
- Any further increase in V_{DS} does not produce any increase in I_D. V_{DS} at pinch-off is denoted as $\boldsymbol{V_p}$

- I_D is at saturation or maximum, and is referred to as $\boldsymbol{I_{DSS}}$.



JFET Operating Characteristics(V_{GS}<0, V_{DS} at some positive value

- **Application of a negative voltage to the gate of a JFET.**
- **As V_{GS} becomes more negative, the depletion region increases.**



$V_{GS} < 0$, V_{DS} at some positive value

JFET Characteristic Curve..

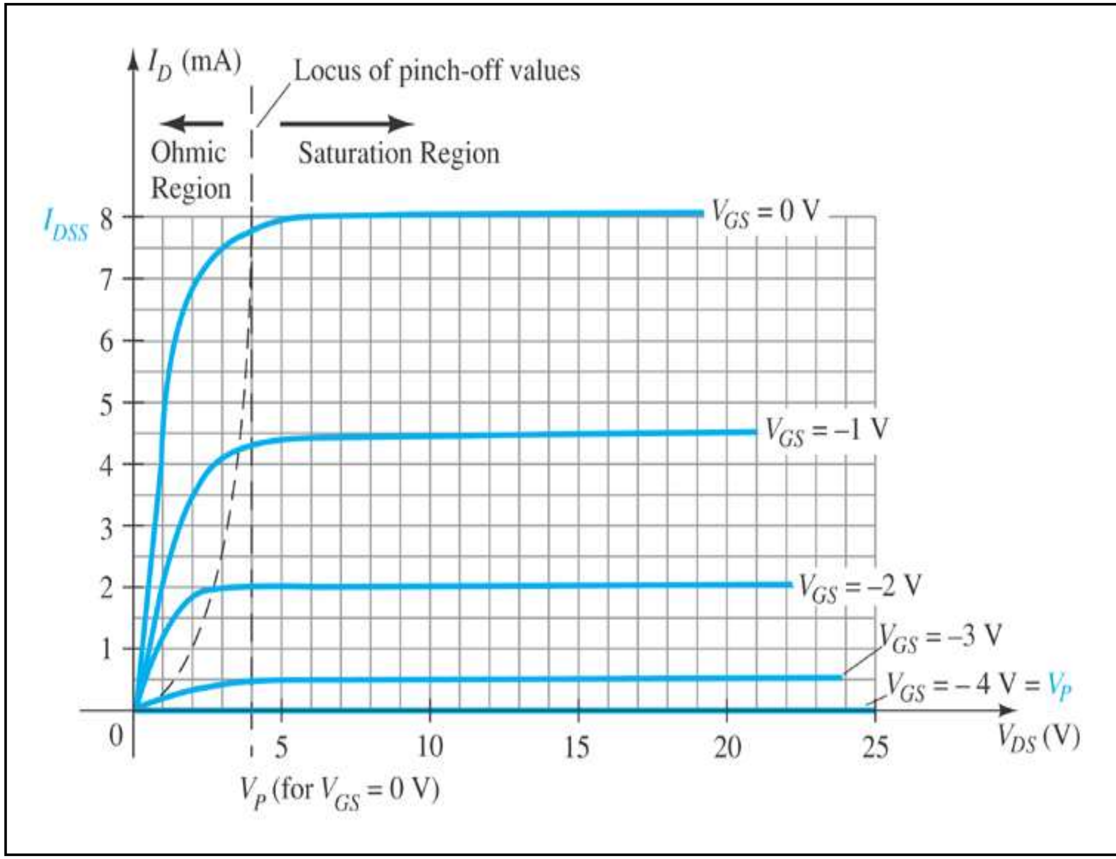
- For negative values of V_{GS}, the gate-to-channel junction is reverse biased even with $V_{DS}=0$
- Thus, the initial channel resistance of channel is higher.
- The resistance value is under the control of V_{GS}
- If V_{GS} = pinch-off voltage(V_P)

  The device is in cutoff ($V_{GS}=V_{GS(off)} = V_P$)
- The region where I_D constant – The saturation/pinch-off region
- The region where I_D depends on V_{DS} is called the linear/ohmic region

JFET Operating Characteristics

As V_{GS} becomes more negative:

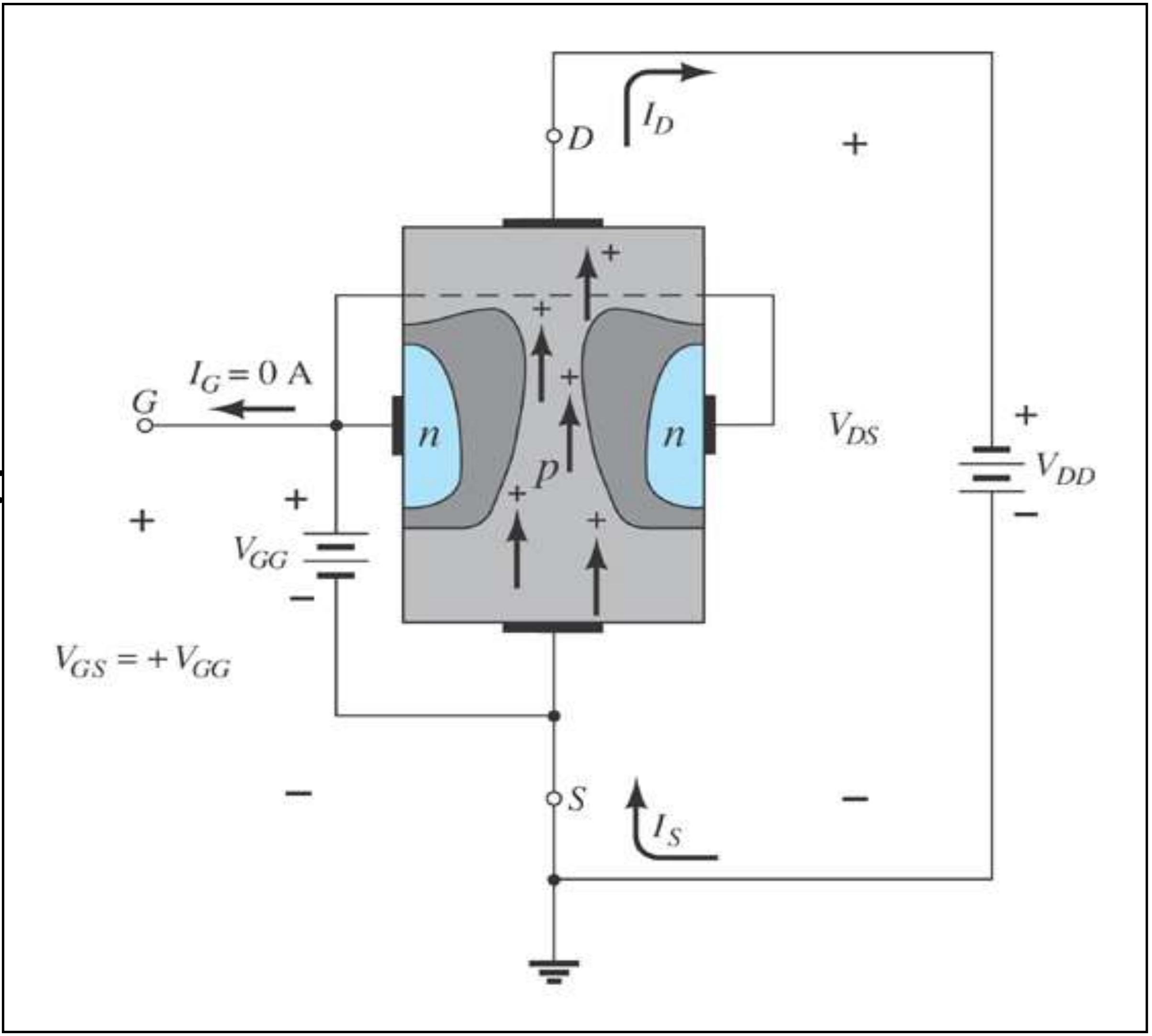
- **The JFET experiences pinch-off at a lower voltage (V_P).**
- **I_D decreases ($I_D < I_{DSS}$) even when V_{DS} increases**
- **I_D eventually drops to 0 A. The value of V_{GS} that causes this to occur is designated $V_{GS(off)}$.**



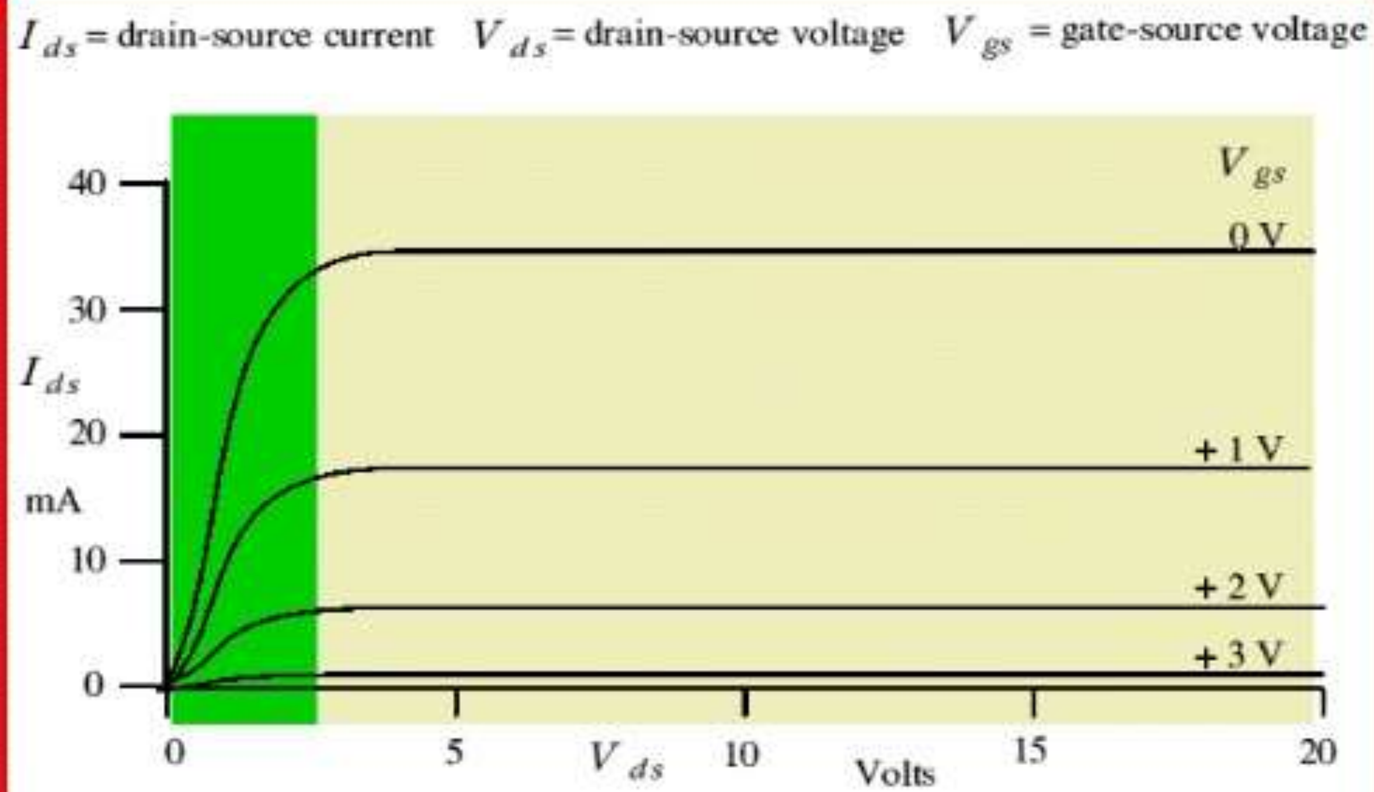
Note that at high levels of V_{DS} the JFET reaches a breakdown situation. I_D increases uncontrollably if $V_{DS} > V_{DSmax}$, and the JFET is likely destroyed.

P-Channel JFETs

- The *p*-channel JFET behaves the same as the *n*-channel JFET. The only differences are that the voltage polarities and current directions are reversed.



Characteristics for p-channel JFET



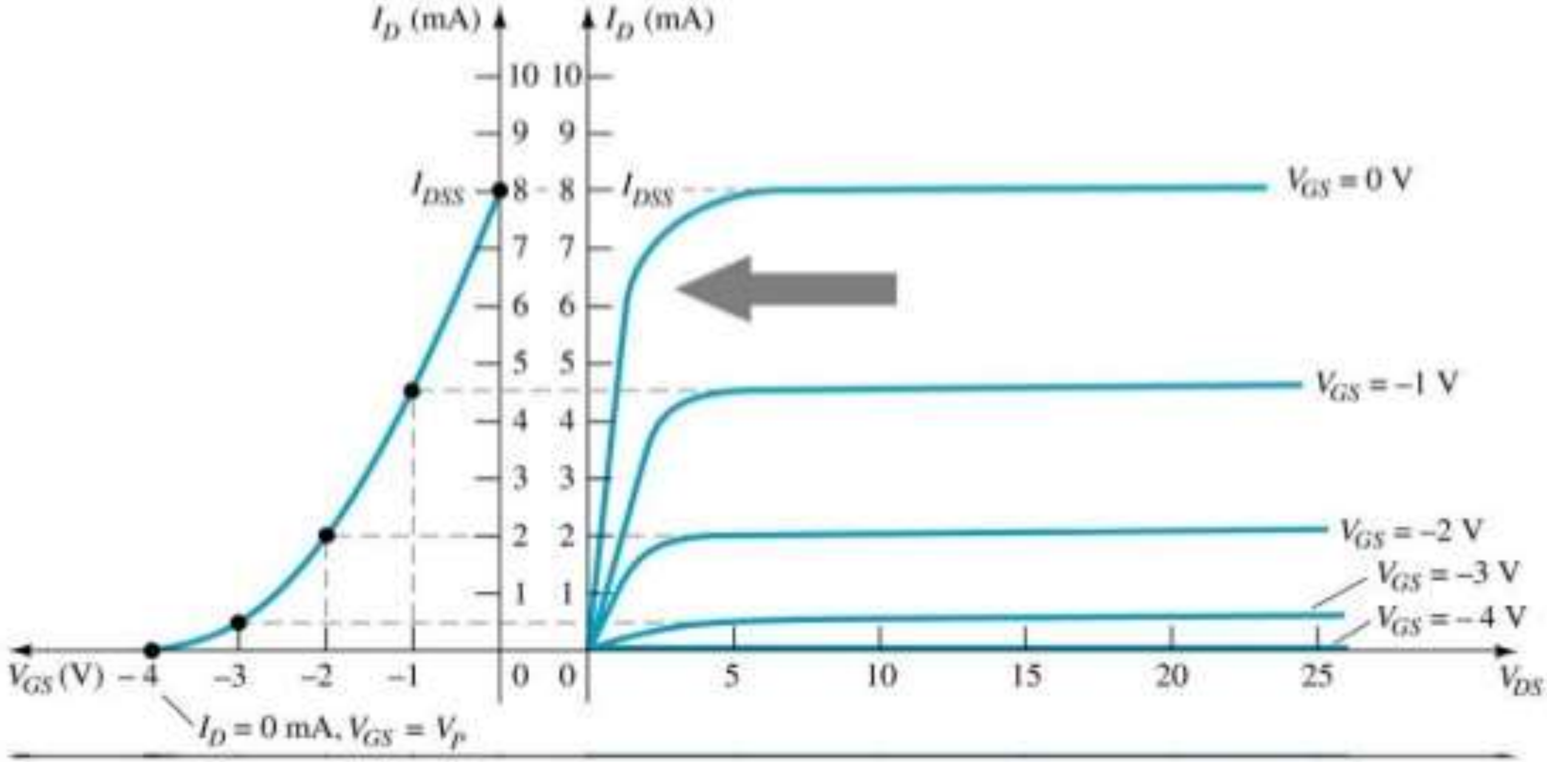
'Characteristic curves for a typical P -channel JFET.

Transfer Characteristics…

- Defined by Shockley's equation:

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_{GS(off)}}\right)^2 \qquad V_P = V_{GS(off)}$$

- Relationship between I_D and V_{GS}.
- Obtaining transfer characteristic curve axis point from Shockley:
  - When $V_{GS} = 0$ V, $I_D = I_{DSS}$
  - When $V_{GS} = V_{GS(off)}$ or V_p, $I_D = 0$ mA



JFET Transfer Characteristic Curve

JFET Characteristic Curve

JFET Parameters

- Dynamic Resistance (r_d):The ratio of change in V_{DS} to I_D for constant V_{GS} is called dynamic resistance.

$$r_d = \frac{\delta V_{DS}}{\delta I_D} \quad at\ constant\ \ V_{GS}$$

- Transconductance or mutual conductance (g_m): The ratio of change in I_D to V_{GS} for constant V_{DS} is called dynamic resistance.

$$g_m = \frac{\delta I_D}{\delta V_{GS}} \quad at\ constant\ \ V_{DS}$$

- Amplification factor (μ): The ratio of change in V_{DS} to V_{GS} for constant I_D is called dynamic resistance.

$$\mu = \frac{\delta V_{DS}}{\delta V_{GS}} \quad at\ constant\ \ I_D$$

$$\mu = \frac{\delta V_{DS}}{\delta V_{GS}} = \frac{\delta V_{DS}}{\delta I_D} \times \frac{\delta I_D}{\delta V_{GS}}$$

$$\Rightarrow \mu = r_d \times g_m$$

MOSFETs

MOSFETs have characteristics similar to those of JFETs and additional characteristics that make then very useful.

There are two types of MOSFETs:

Depletion-Type

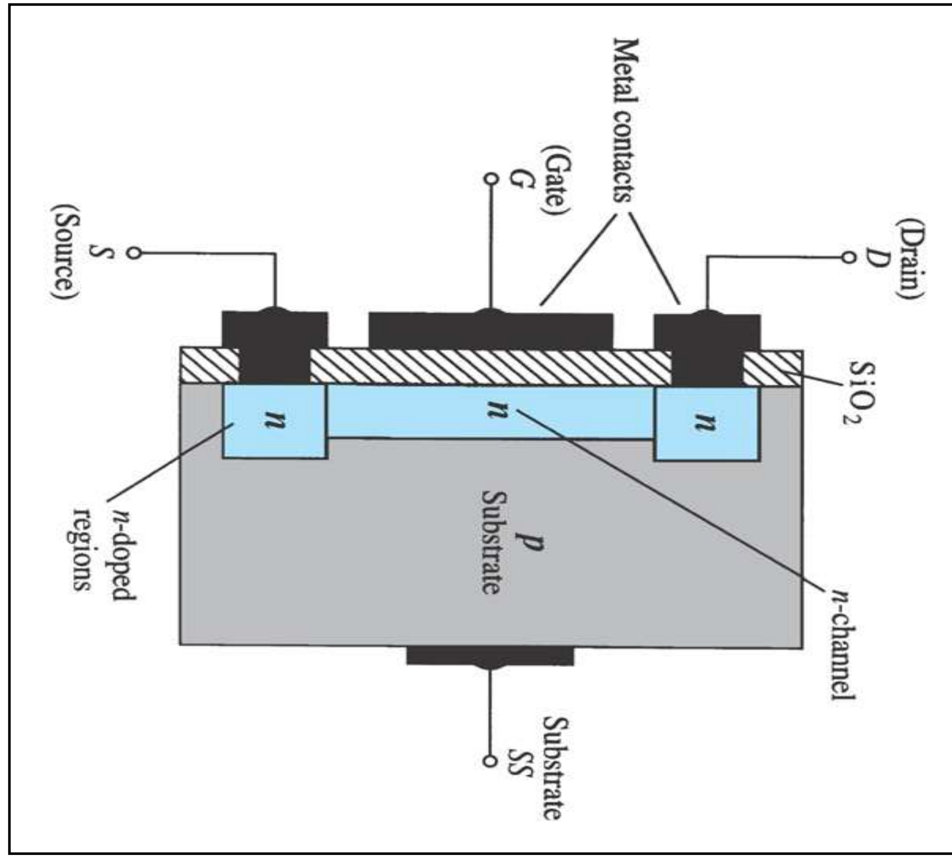
Enhancement-Type

Depletion-Type MOSFET Construction

The Drain (D) and Source (S) connect to the to *n*-type regions.
These *n*-typed regions are connected via an *n*-channel. This *n*-channel is connected to the Gate (G) via a thin insulating layer of silicon dioxide (SiO_2).

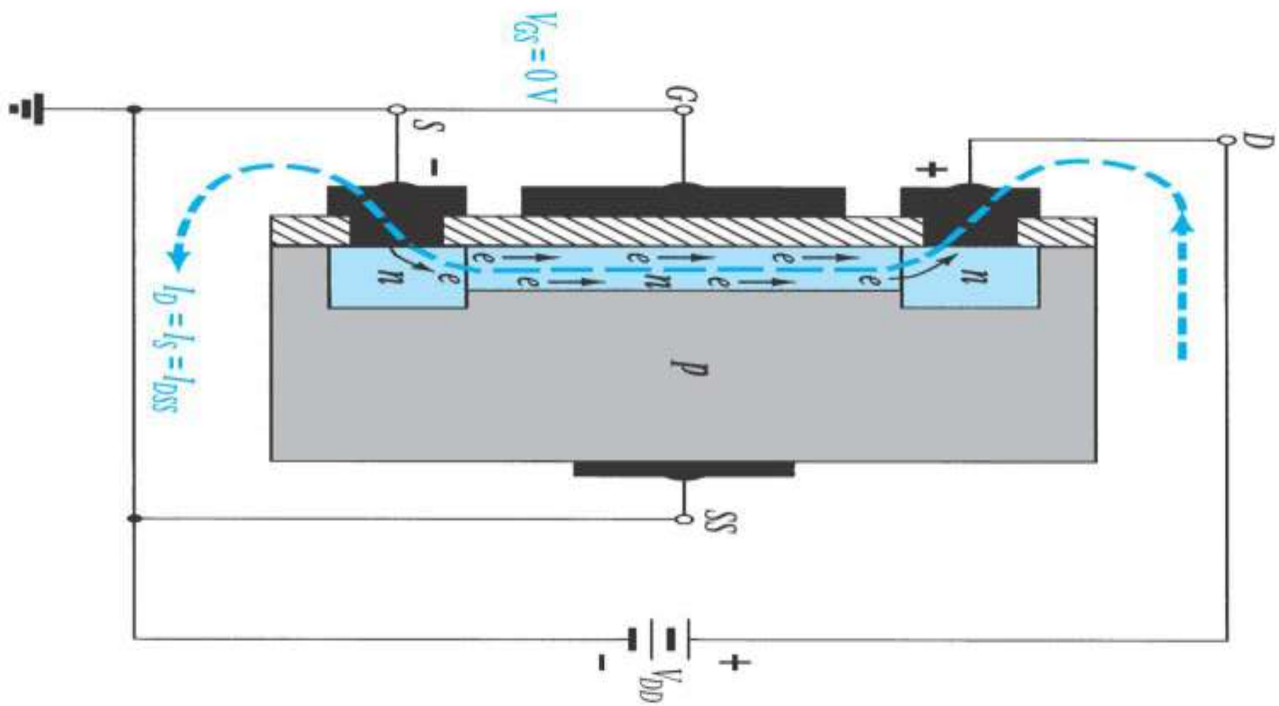
The *n*-type material lies on a *p*-type substrate that may have an additional terminal connection called the Substrate (SS).

MOSFET are also called as IGFET.

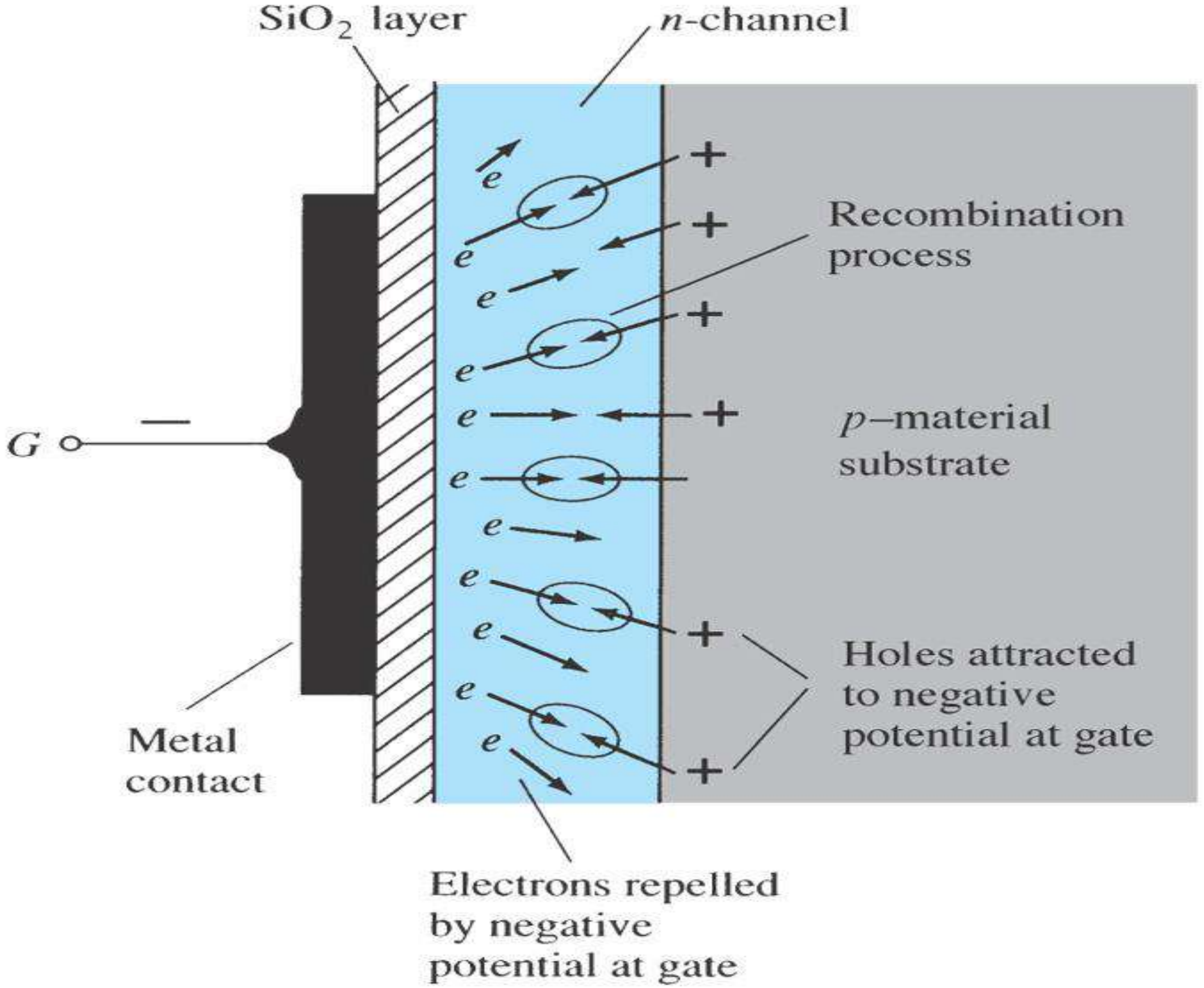


Depletion-Type MOSFET :Basic Operation and Characteristics

- **V_{GS}=0** and **V_{DS}** is applied across the drain to source terminals.
- This results to attraction of free electrons of the n-channel to the drain, and hence current flows.
- n-Channel depletion-type MOSFET with **V_{GS} = 0 V** and applied voltage **V_{DD}**



- V**GS** is set at a negative voltage such as -1 V.
- The negative potential at the gate pressures electrons toward the p-type substrate and attract holes from the p-type substrate.
- This will reduce the number of free electrons in the n-channel available for conduction.
- The more negative the V_{GS}, the resulting level of drain current I_D is reduced.
- When $V_{\mathbf{GS}}$ is reduced to V_P (Pinch-off voltage), then I_D=0 mA.

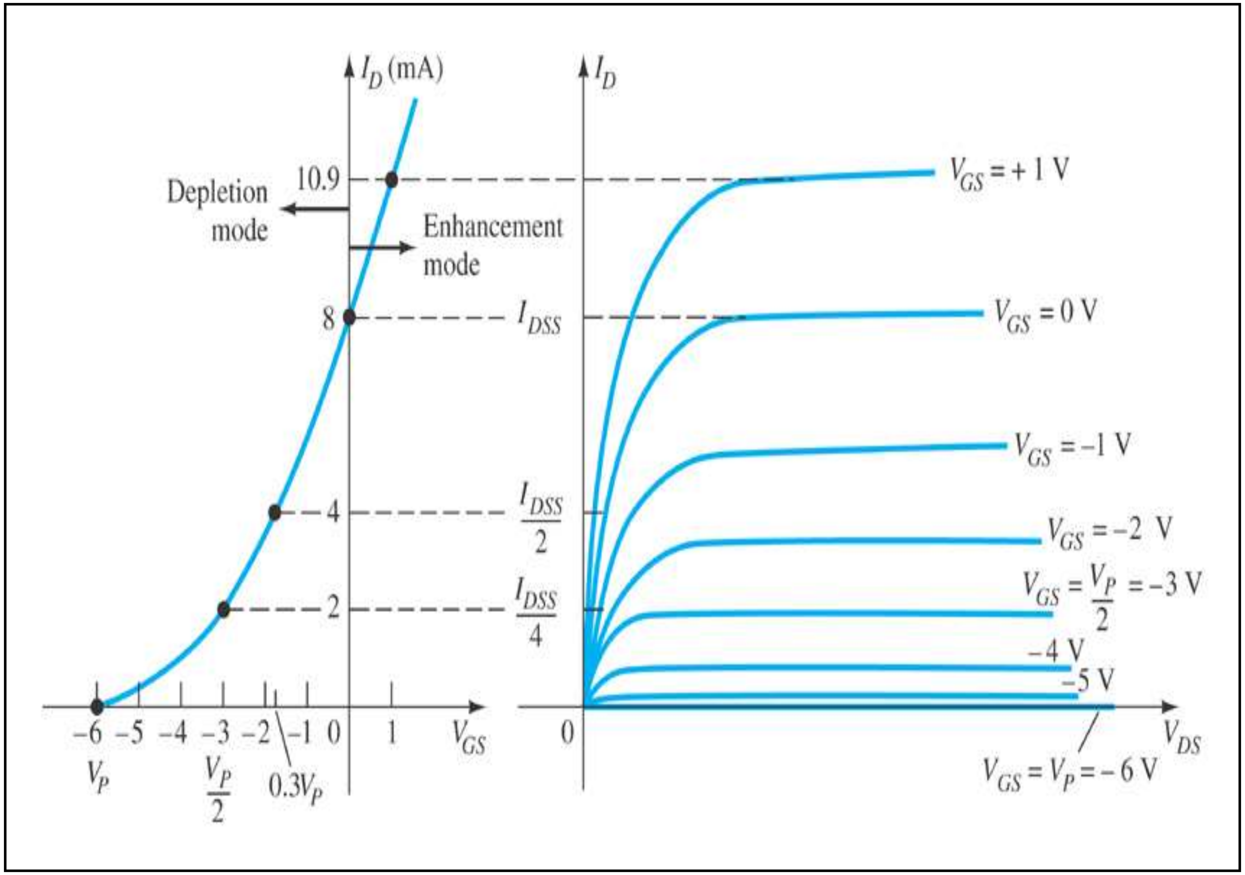

SiO2 layer
n-channel
Recombination process
p–material substrate
Holes attracted to negative potential at gate
Metal contact
Electrons repelled by negative potential at gate
G
e
+
−

Basic MOSFET Operation

A depletion-type MOSFET can operate in two modes:

Depletion mode

Enhancement mode

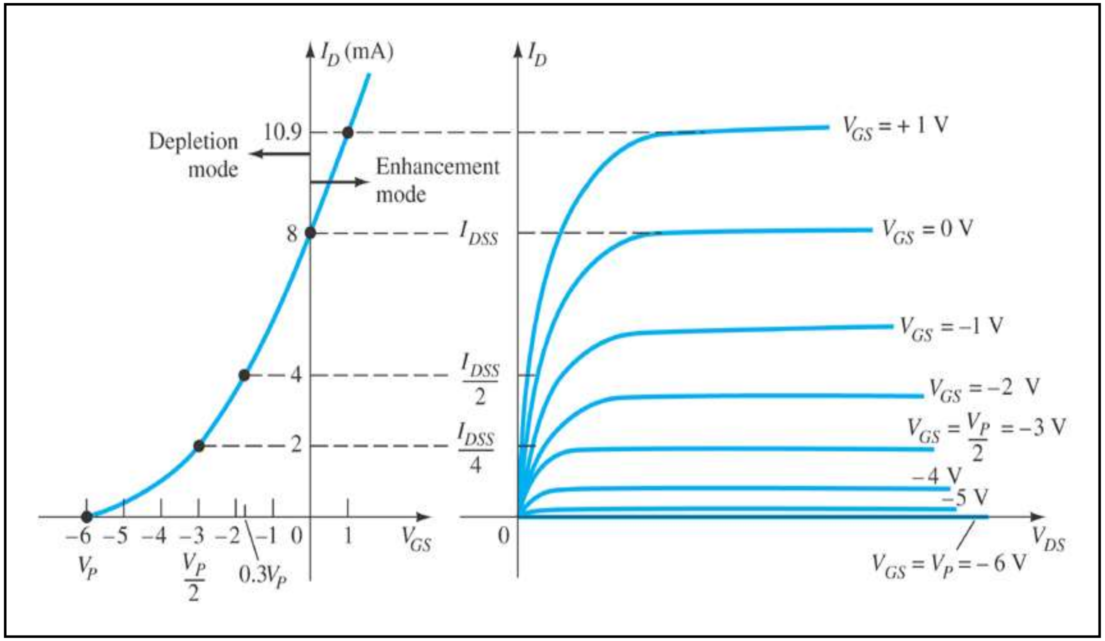


Depletion Mode Operation (D-MOSFET)

The characteristics are similar to a JFET.

When V_{GS} = 0 V, $I_D = I_{DSS}$

When V_{GS} < 0 V, $I_D < I_{DSS}$



The formula used to plot the transfer curve for a JFET applies to a D-MOSFET **as** well:

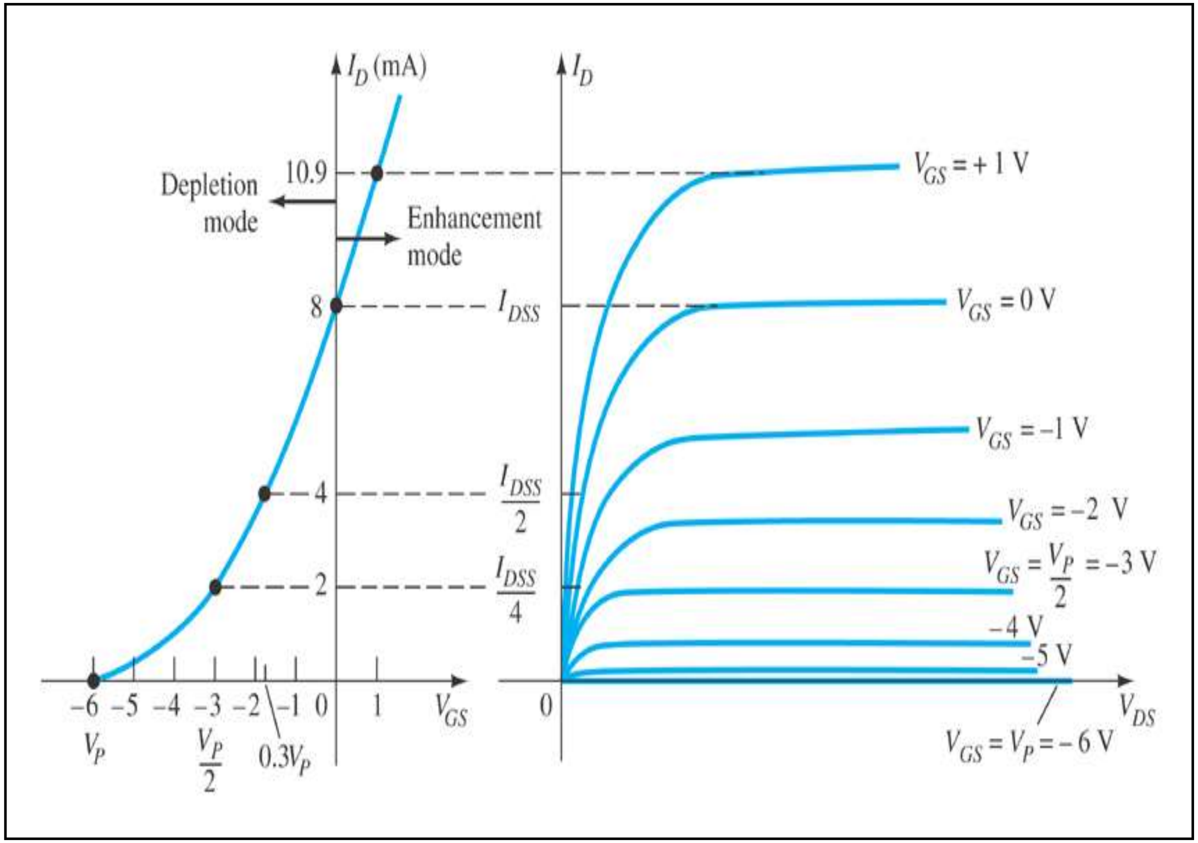
$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$$

Enhancement Mode Operation (D-MOSFET)

V_{GS} > 0 V, I_D increases above I_{DSS} ($I_D > I_{DSS}$)

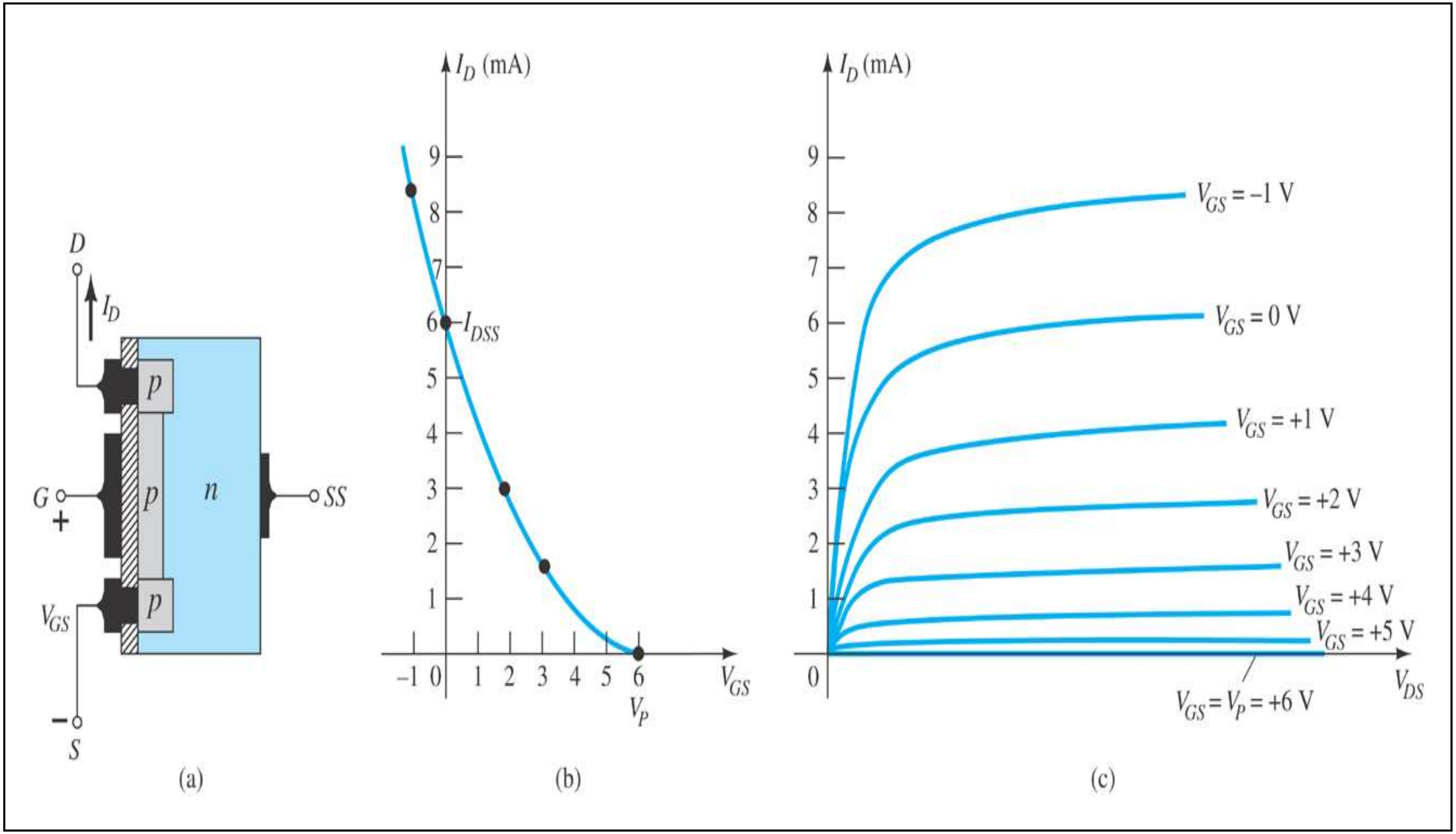
The formula used to plot the transfer curve still applies:

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$$

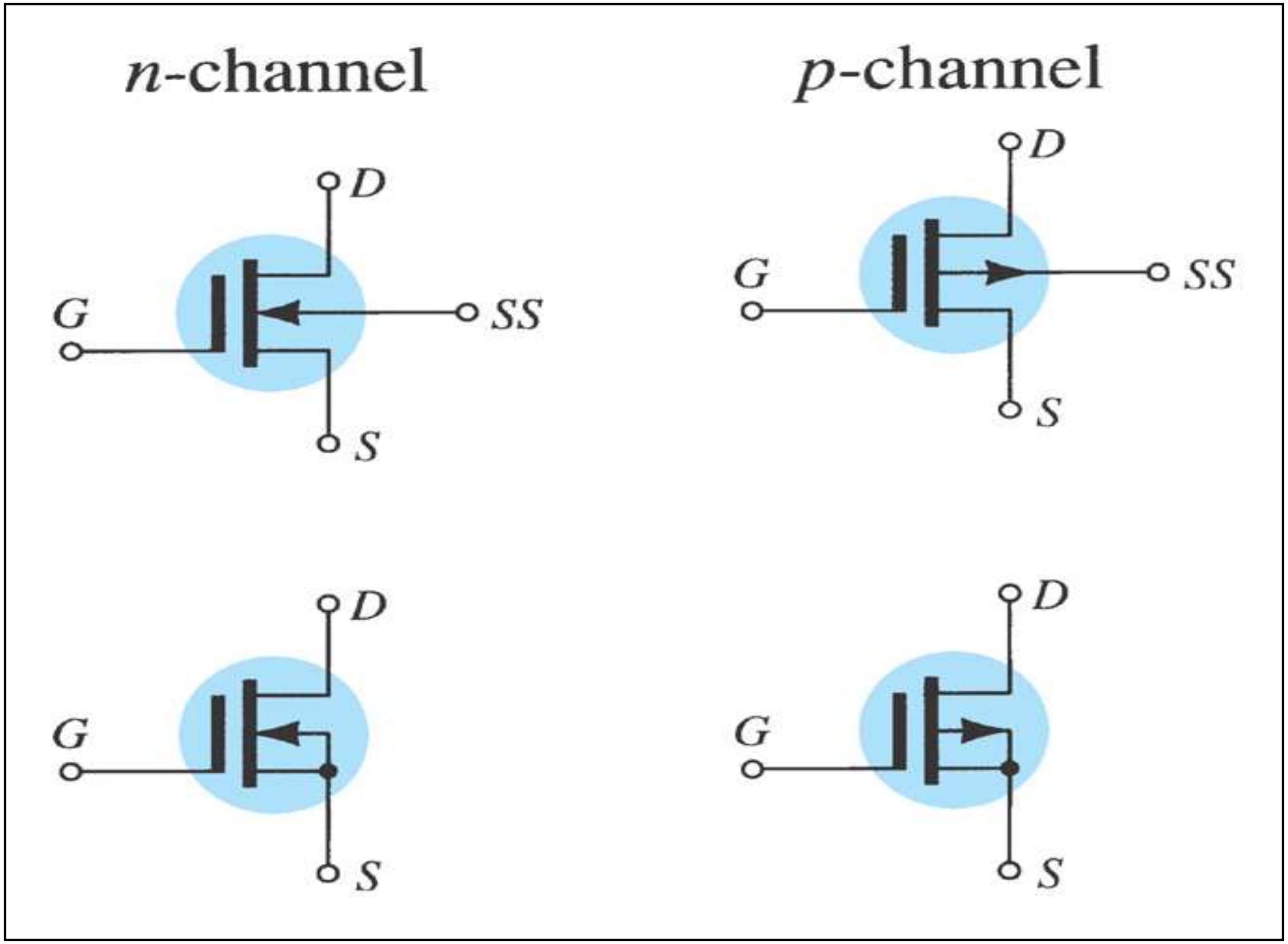


Note that V_{GS} is now positive

p-Channel D-Type MOSFET

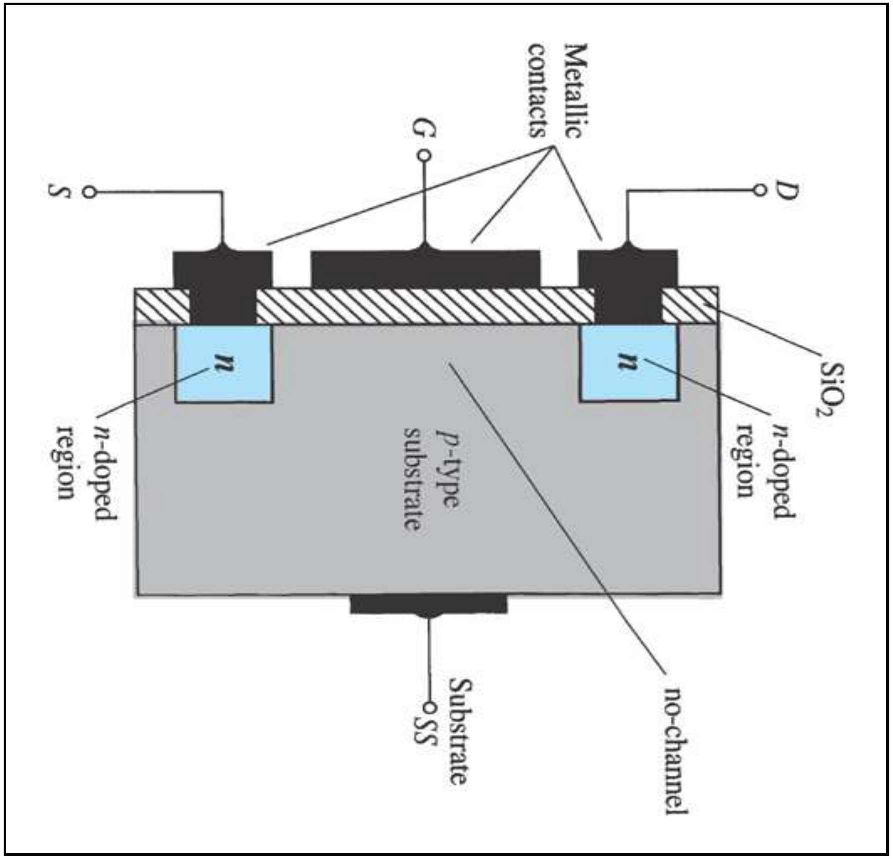


D-Type MOSFET Symbols



E-Type MOSFET Construction

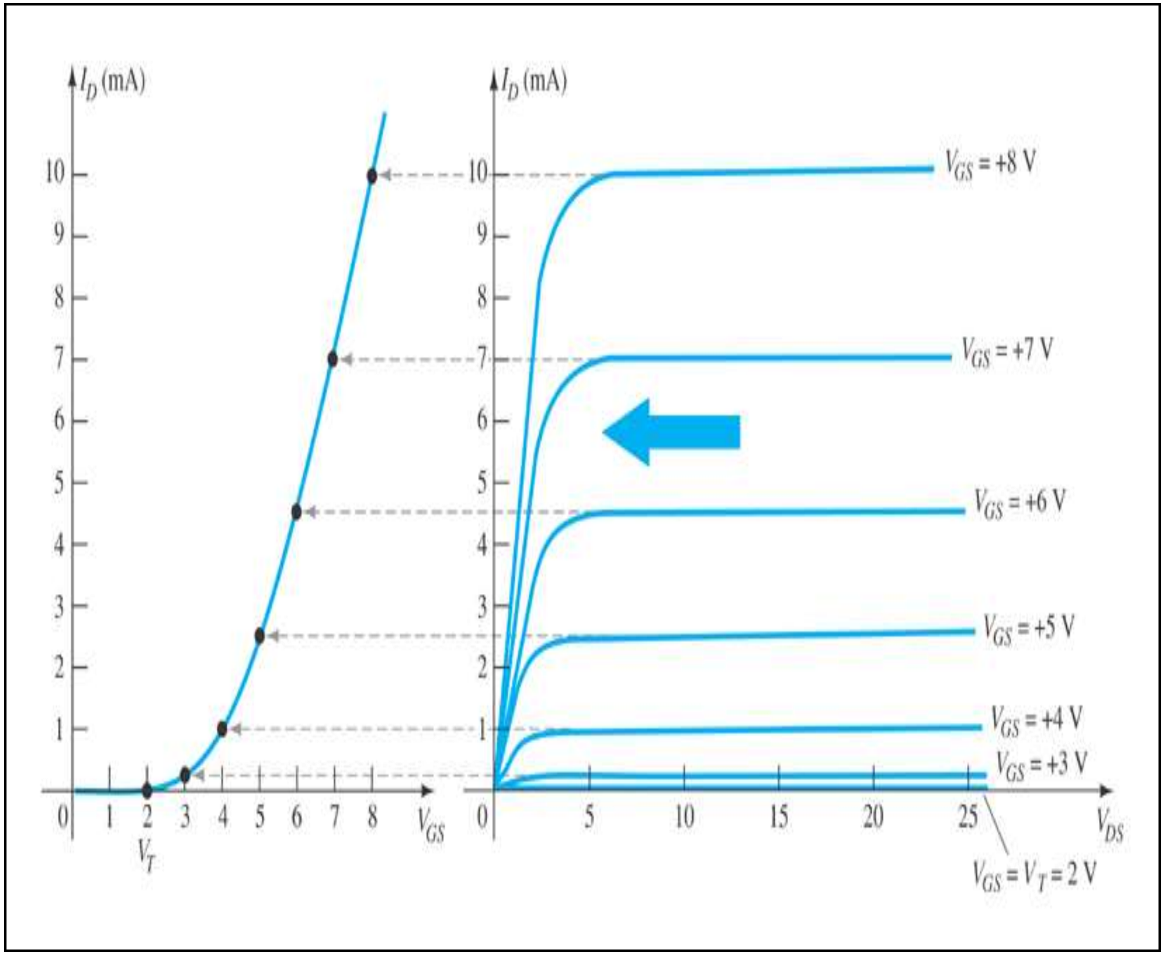
- The Drain (D) and Source (S) connect to the to *n*-type regions. These *n*-type regions are connected via an *n*-channel
- The Gate (G) connects to the *p*-type substrate via a thin insulating layer of silicon dioxide (SiO_2)
- There is no channel
- The *n*-type material lies on a *p*-type substrate that may have an additional terminal connection called the Substrate (SS)



E-Type MOSFET Operation

The enhancement-type MOSFET (E-MOSFET) operates only in the enhancement mode.

- **V_{GS} is always positive**
- **As V_{GS} increases, I_D increases**
- **As V_{GS} is kept constant and V_{DS} is increased, then I_D saturates (I_{DSS}) and the saturation level (V_{DSsat}) is reached**



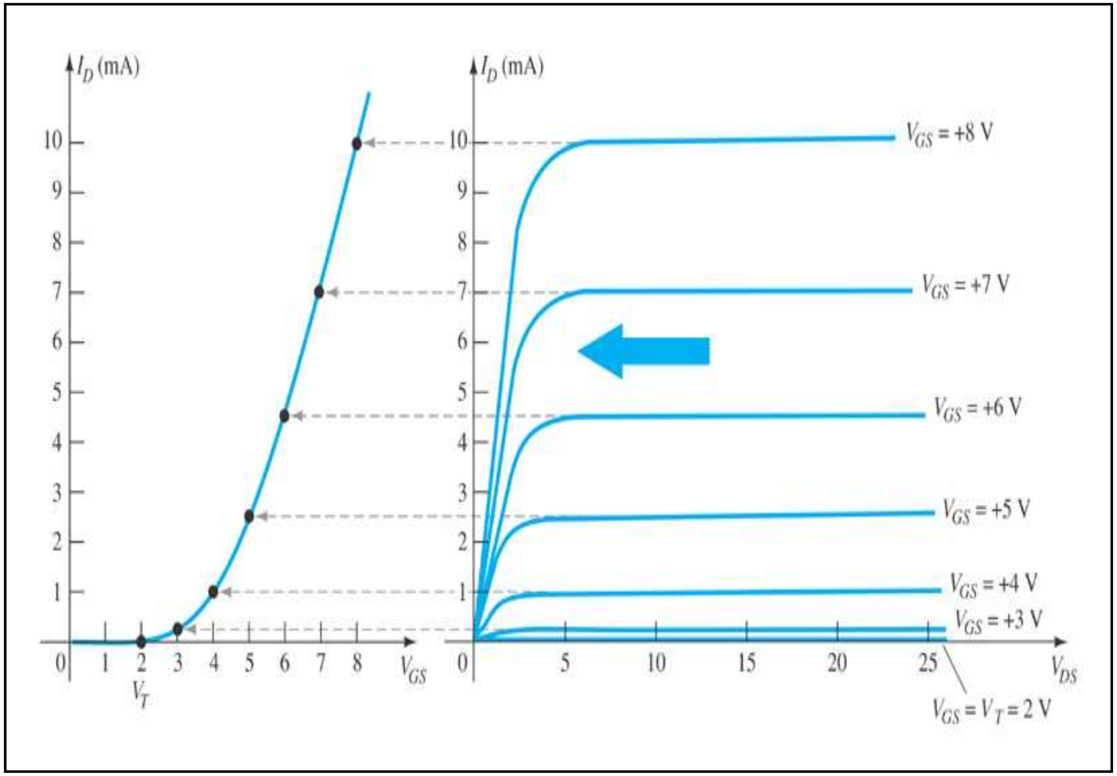
E-Type MOSFET Transfer Curve

To determine I_D given V_{GS}:

$$I_D = k(V_{GS} - V_T)^2$$

where:

V_T = the E-MOSFET threshold voltage



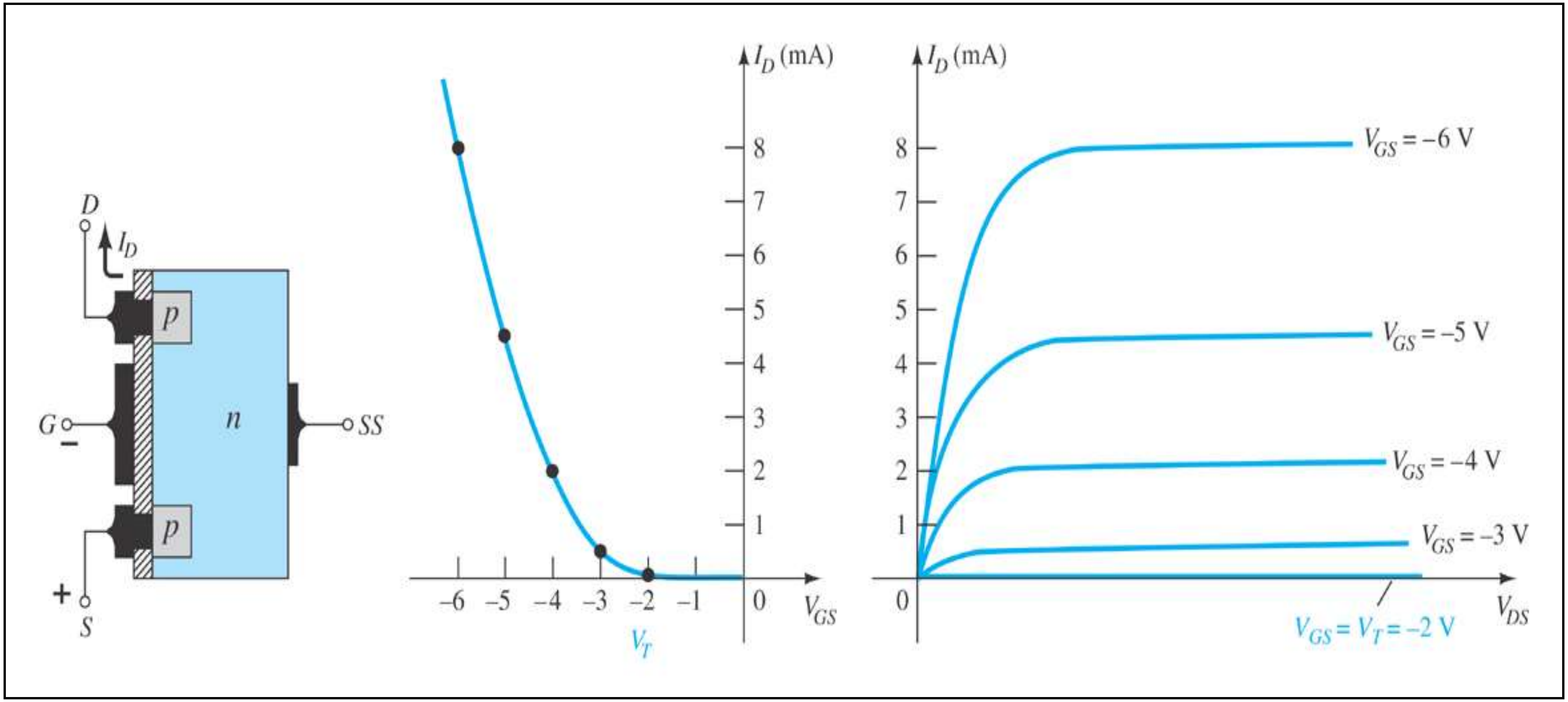
***k*, a constant, can be determined by using values at a specific point and the formula:**

$$k = \frac{I_{D(ON)}}{(V_{GS(ON)} - V_T)^2}$$

V_{DSsat} can be calculated using:

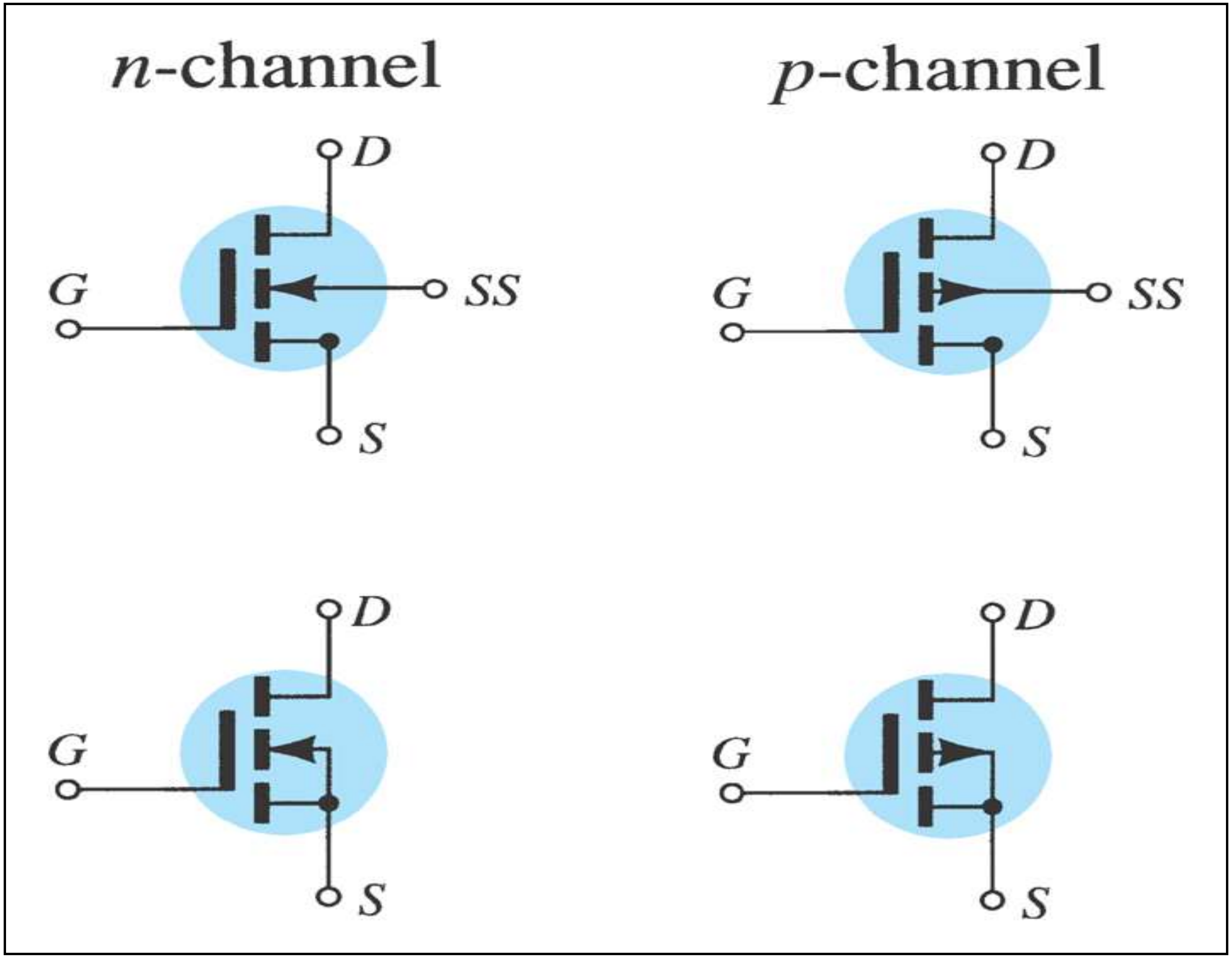
$$V_{DSsat} = V_{GS} - V_T$$

p-Channel E-Type MOSFETs



The *p*-channel enhancement-type MOSFET is similar to its *n*-channel counterpart, except that the voltage polarities and current directions are reversed.

MOSFET Symbols



MOSFET Advantages

- Small Size
- Low Power
- High power
- High input impedance
- Use in VLSI Circuit

Operational Amplifier (OP-AMP)

EC-10001

Topics to be covered

- Introduction
- Symbol & IC diagram
- Characteristics of Op Amp
- CMRR
- Virtual Ground
- Types of Op Amps
- Conclusion

Introduction

- It is a general purpose IC developed by Robert Widlar in 1964.

- 'Operational' term in operational amplifier signifies that it can perform different mathematical operations like summation, subtraction, integration, differentiation etc.

- Op-Amp is used in signal amplification, oscillators, filters, voltage regulators, ADC, DAC, calculators etc.

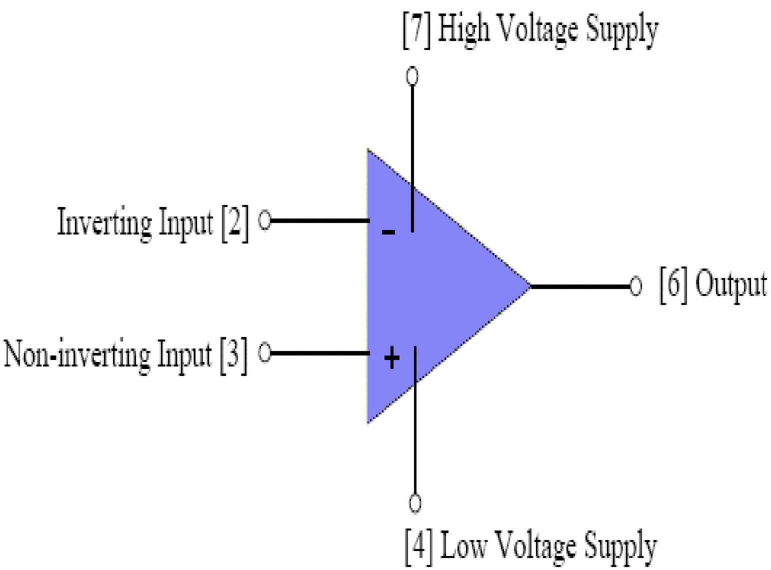
Contd..

- Feedback is used in Op-Amp and performance is controlled by feedback element.

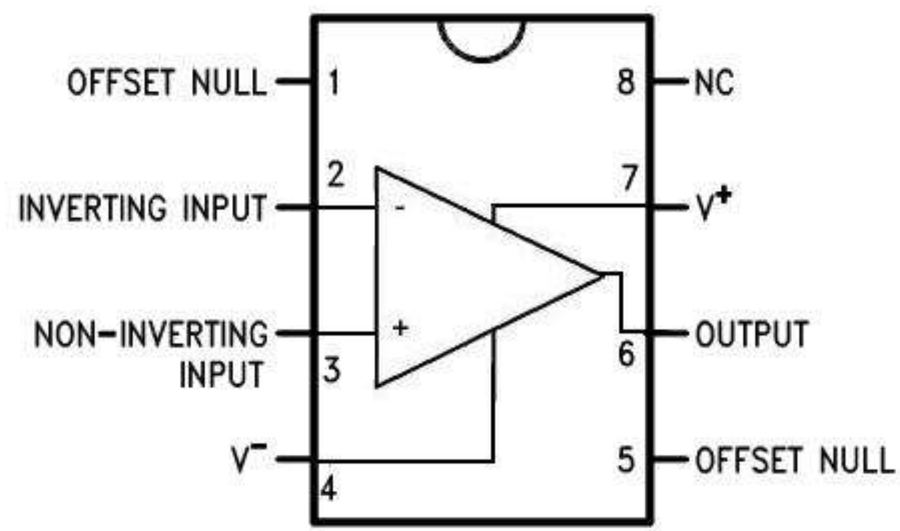
- The internal circuit of the Op-Amp is not required to operate,i.e only terminal properties is sufficient for external circuit connection.

- Op-Amp is low cost, easy to use and temperature stable.

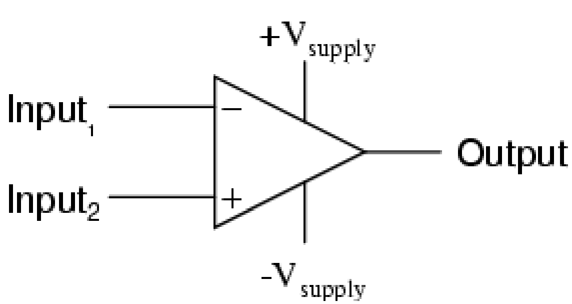
Symbol & IC diagram



LM741 Pinout Diagram



Differential amplifier



Ideal OP-AMP Char.

- Input impedance (Z_{in}) is infinite.
- Output impedance Z_{out} is zero
- Voltage Gain(Av) V_{out} / $V_{in} = \infty$
- Bandwidth is infinite
- Characteristics not drifting with temperature
- Finite common mode rejection ratio (CMRR)
- Perfect balanced i.e $V_{out} = 0$ when Voltage inputs = 0

Non-ideal OP-AMP Char.

- Finite input impedance (150k Ω - Hundreds of MΩ)
- Finite output resistance (Less than 100 Ω range)
- Finite voltage gain ($\sim 10^5$)
- Finite Bandwidth
- Characteristics drifting with temperature
  Input bias currents
- Finite common mode rejection ratio (CMRR)
- Not perfectly balanced

Comparison

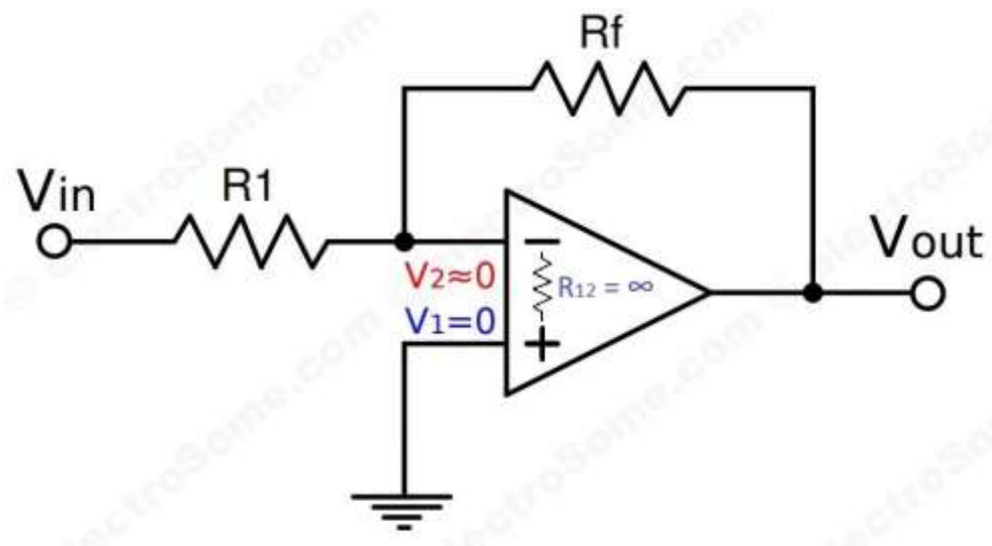
	Ideal Op-Amp	Typical Op-Amp
Input Resistance	infinity	$10^6\ \Omega$ (bipolar) $10^9\ \Omega$ - $10^{12}\ \Omega$ (FET)
Input Current	0	10^{-12} – 10^{-8} A
Output Resistance	0	100 – 1000 Ω
Operational Gain	infinity	10^5 - 10^9
Common Mode Gain	0	10^5
Bandwidth	infinity	finite
Temperature	independent	dependent

Common mode rejection ratio (CMRR)

- Op-Amp is basically a differential amplifier with signal V_1 and V_2 measured with respect to ground.
- The difference signal is $V_d = V_1 - V_2$
- The common signal/Average signal $V_c = (V_1 + V_2)/2$
- Similiarly difference signal gain and Common gain and is A_d and A_c .
- $CMRR = A_d/A_c$
- Generally CMRR is expressed in dB i.e $CMRR = 20 \log (A_d/A_c)$ dB.
- Ideally CMRR is infinite but practically very high.

Virtual Ground

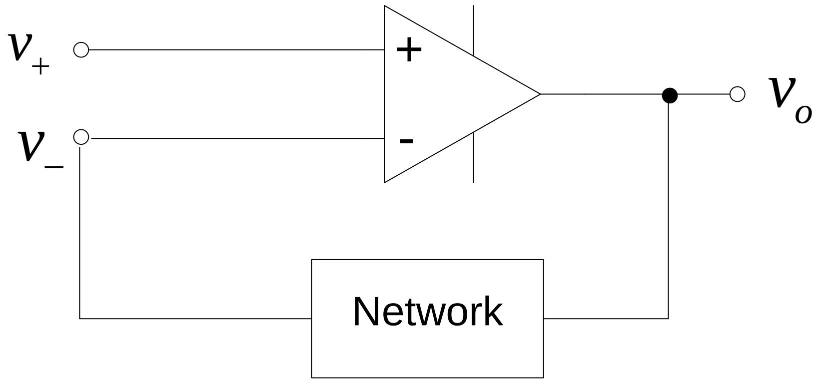
- Terminal is not actual grounded but act as grounded so it is called as virtual ground.



Applications

- Inverting Amplifier
- Non-inverting Amplifier
- Unity-Gain Buffer
- Summing Amplifier
- Differential Amplifier
- Integrator
- Differentiator

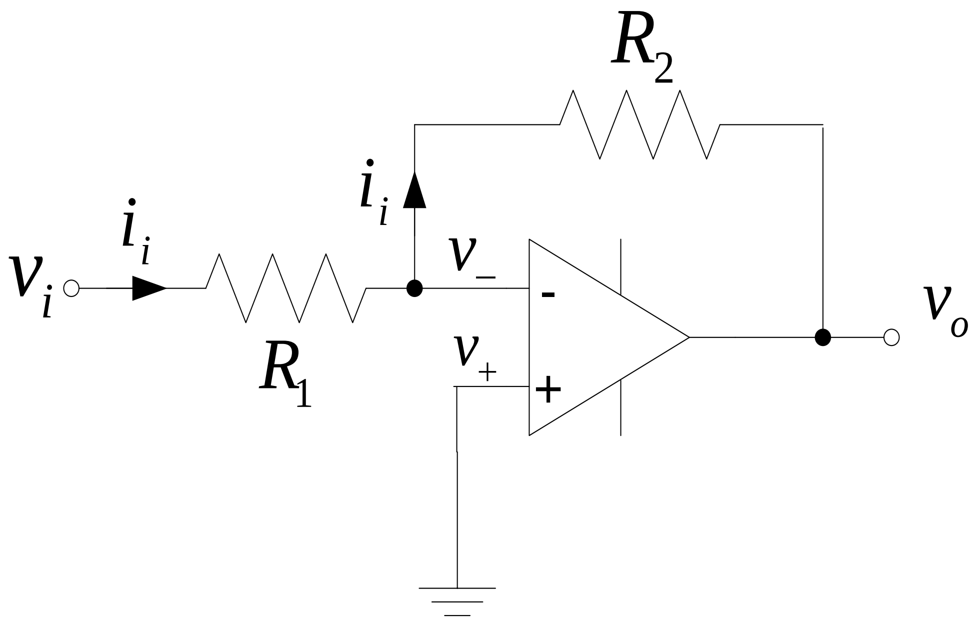
Basic Structure



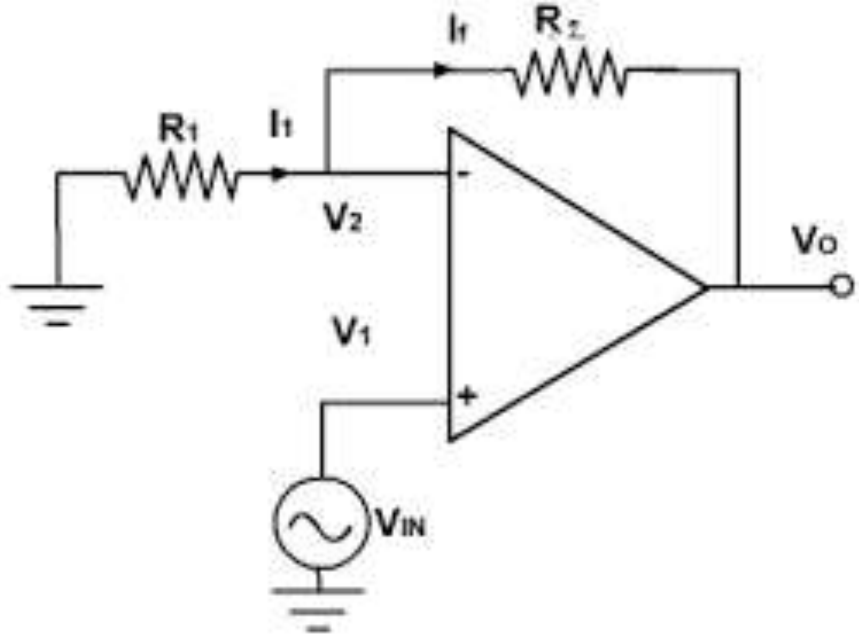
1. The output attempts to do whatever is necessary to make the voltage difference between the inputs zero.

2. The inputs draw no current.

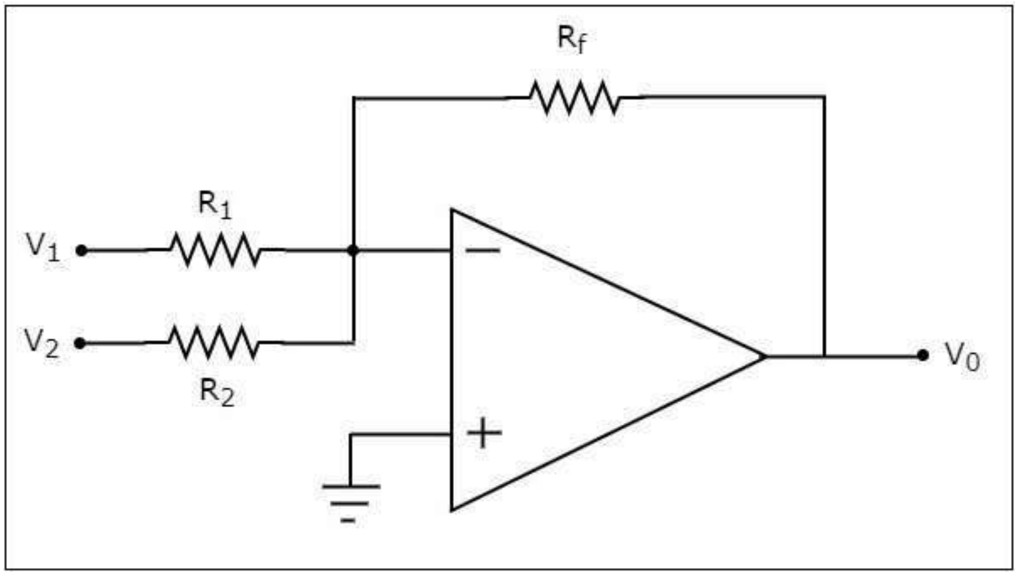
Inverting Amplifier



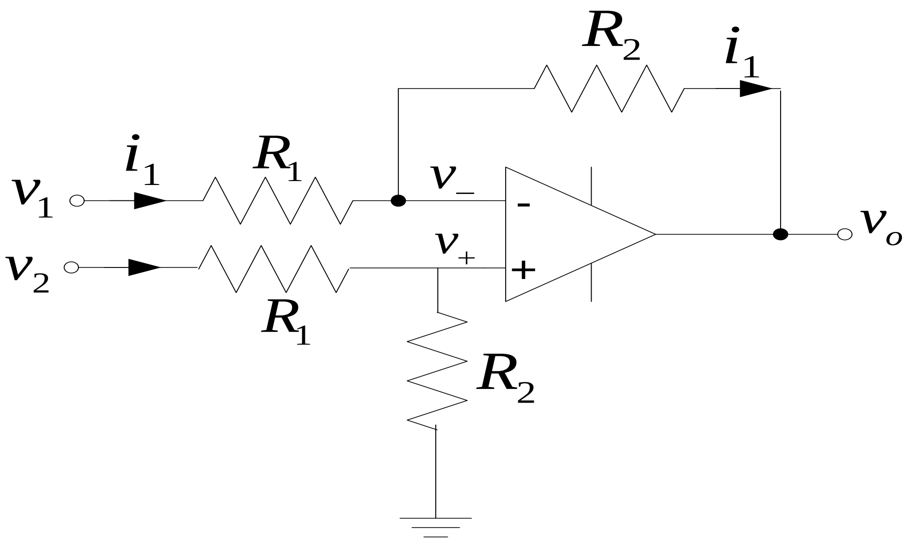
Non inverting Amp



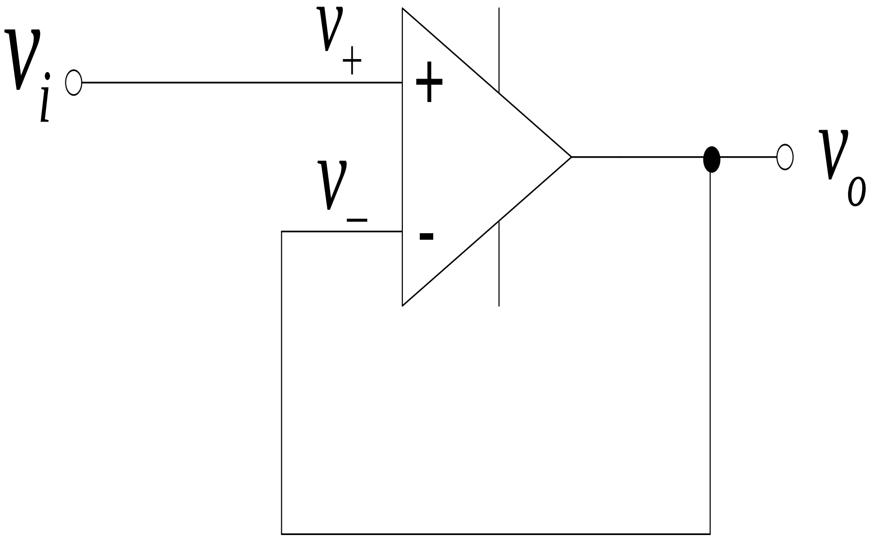
Summing Amp.



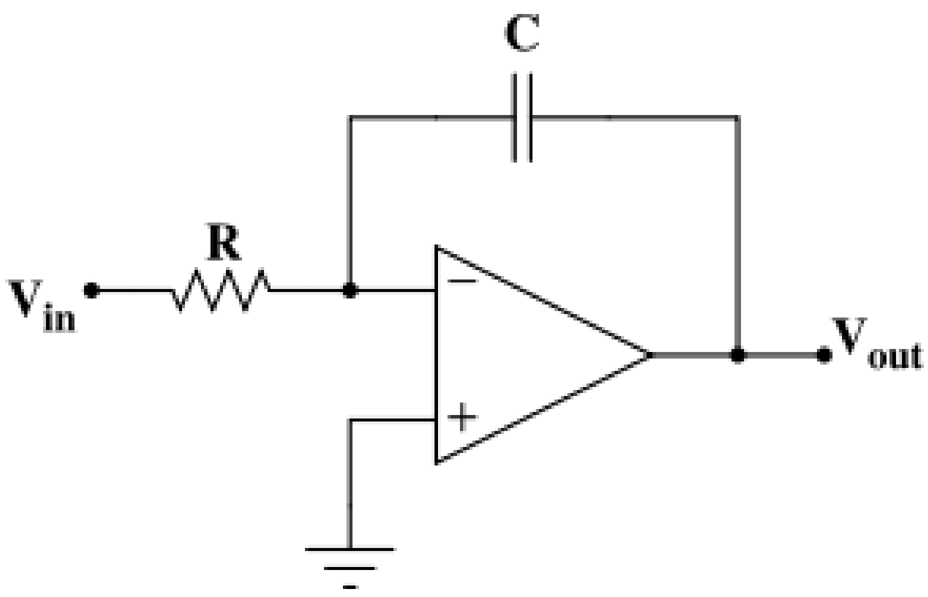
Differential Amplifier



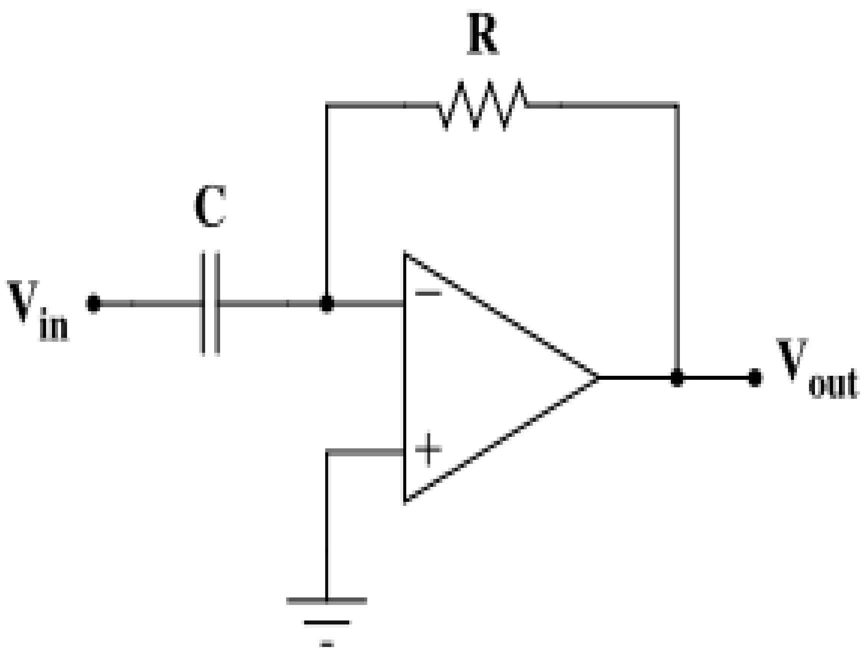
Unit gain buffer



Integrator



Differentiator



INTRODUCTION TO DIGITAL

Why Binary System?

- Computers are made of a series of switches
- Each switch has two states: ON or OFF
- Each state can be represented by a number – 1 for “ON” and 0 for “OFF”

Number System

- Number systems include decimal, binary, octal and hexadecimal
- Each system have four number base

Number System	**Base**	**Symbol**
Binary	**Base** 2	**B**
Octal	**Base** 8	**O**
Decimal	**Base** 10	**D**
Hexadecimal	**Base** 16	**H**

Number System

- Binary numbers
  - Digits = {0, 1}
  - $(11010.11)_2 = 1 \times 2^4 + 1 \times 2^3 + 0 \times 2^2 + 1 \times 2^1 + 0 \times 2^0 + 1 \times 2^{-1} + 1 \times 2^{-2} = (26.75)_{10}$
- Octal numbers
  - Digits = {0, 1, 2, 3, 4, 5, 6, 7}
  - $(127.4)_8 = 1 \times 8^2 + 2 \times 8^1 + 7 \times 8^0 + 4 \times 8^{-1} = (87.5)_{10}$
- Hexadecimal numbers
  - Digits = {0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, F}
  - $(B65F)_{16} = 11 \times 16^3 + 6 \times 16^2 + 5 \times 16^1 + 15 \times 16^0 = (46687)_{10}$

Number System

Binary

	Quotient	Remainder
$56 \div 2 =$	28	0
$28 \div 2 =$	14	0
$14 \div 2 =$	7	0
$7 \div 2 =$	3	1
$3 \div 2 =$	1	1
$1 \div 2 =$	0	1

Octal

	Quotient	Remainder
$56 \div 8 =$	7	0
$7 \div 8 =$	0	7

$56_{10} = 111000_2$

$56_{10} = 70_8$

Hexadecimal

$$
\begin{array}{r|l}
16 & \underline{315} \quad B \quad \text{LSD} \\
16 & \underline{19} \quad 3 \\
16 & \underline{1} \quad 1 \quad \text{MSD} \\
 & 0
\end{array}
$$

$(315)_{10} = (13B)_{16}$

Number System

- $(0.479)_{10} = (0.0111...)_2$

  MSD $0.9580 \leftarrow 0.479 * 2$

  $1.9160 \leftarrow 0.9580 * 2$

  $1.8320 \leftarrow 0.9160 * 2$

  LSD $1.6640 \leftarrow 0.8320 * 2$

- $(0.479)_{10} = (0.3651...)_8$

  MSD $3.832 \leftarrow 0.479 * 8$

  $6.656 \leftarrow 0.832 * 8$

  $5.248 \leftarrow 0.656 * 8$

  LSD $1.984 \leftarrow 0.248 * 8$

Binary to Octal & Hexadecimal

- $(001\ 010\ 111.\ 100)_2 = (127.4)_8$ (group bits by 3)
- $(1011\ 0110\ 0101\ 1111)_2 = (B65F)_{16}$ (group bits by 4)

- $(\ 1\ 001\ 010\ 111.\ 01)_2 = (1127.2)_8$ (group bits by 3)
- $(\ 11\ 0110\ 0101\ .\ 111\ )_2 = (365.E)_{16}$ (group bits by 4)

Number System

Decimal	Binary	Octal	Hexadecimal
0	0	0	0
1	1	1	1
2	10	2	2
3	11	3	3
	100	4	4
5	101	5	5
6	110	6	6
7	111	7	7
8	1000	10	8
9	1001	11	9
10	1010	12	A
11	1011	13	B
12	1100	14	C
13	1101	15	D
14	1110	16	E
15	1111	1	F
16	10000	20	10

Binary coded decimal(8421 code)

- In digital we use binary numbers, but in real life we use decimal numbers.
- It is difficult to convert any decimal number to binary & vice-versa.
- So to solve this problem, BCD codes are used.
- 0 → 0000 7 → 0111
- 1 → 0001 8 → 1000
- 2 → 0010 9 → 1001
- 3 → 0011 10 → 0001 0000
- 4 → 0100 1579 → 0001 0101 0111 1001
- 5 → 0101
- 6 → 0110

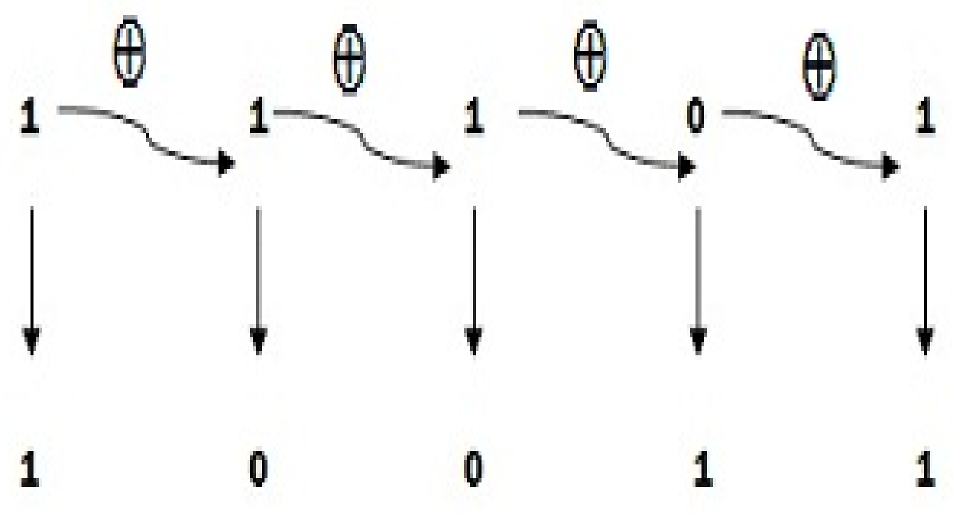
EXCESS-3 CODE

- Excess-3 code is obtained by adding 0011 to 8421 code.

Decimal	BCD 8 4 2 1	Excess-3 BCD + 0011
0	0 0 0 0	0 0 1 1
1	0 0 0 1	0 1 0 0
2	0 0 1 0	0 1 0 1
3	0 0 1 1	0 1 1 0
4	0 1 0 0	0 1 1 1
5	0 1 0 1	1 0 0 0
6	0 1 1 0	1 0 0 1
7	0 1 1 1	1 0 1 0
8	1 0 0 0	1 0 1 1
9	1 0 0 1	1 1 0 0

Gray Code

- When you count up or down in binary, the number of bit that change with each digit change varies.
  - From 0 to 1 in binary,just have a single bit change but
  - From 1 to 2 have 2 bits chages.
  - From 7 to 8 have 3 bits changes.
- For some applications multiple bit changes cause significant problems.
- Binary: BnBn-1........Bo
- Gray: GnGn-1........Go
- Gn= Bn
- Gn-1= Bn⊕Bn-1
- Go= B1⊕Bo



Gray Code

Decimal Number	4 bit Binary Number ABCD	4 bit Gray Code $G_1G_2G_3G_4$
0	0 0 0 0	0 0 0 0
1	0 0 0 1	0 0 0 1
2	0 0 1 0	0 0 1 1
3	0 0 1 1	0 0 1 0
4	0 1 0 0	0 1 1 0
5	0 1 0 1	0 1 1 1
6	0 1 1 0	0 1 0 1
7	0 1 1 1	0 1 0 0
8	1 0 0 0	1 1 0 0
9	1 0 0 1	1 1 0 1
10	1 0 1 0	1 1 1 1
11	1 0 1 1	1 1 1 0
12	1 1 0 0	1 0 1 0
13	1 1 0 1	1 0 1 1
14	1 1 1 0	1 0 0 1
15	1 1 1 1	1 0 0 0

Boolean Algebra

- Boolean algebra is a mathematical system for the manipulation of variables that can have one of two values.
  - In formal logic, these values are "true" and "false."
  - In digital systems, these values are "on" and "off," 1 and 0, or "high" and "low."
- Variables and their complements are sometimes called literals
- Boolean expressions are created by performing operations on Boolean variables.
- A Boolean operator can be completely described using a truth table.
- A Boolean algebra comprises...
  - A set of elements (A, X, etc)
  - Binary operators {+ , •} Boolean sum and product
  - A unary operation { ' } (or { }) example: A' or A

Boolean Algebra

- Axioms & laws of Boolean Algebra

0.0 = 0	**0 + 0 = 0**	**0’ = 1**	**A . 0 = 0**	**A + 0 = A**
0 . 1 = 0	0 + 1 = 1	1’ = 0	A . 1 = A	A + 1 = 1
1 . 0 = 0	1 + 0 = 1	A= 0=> A’=1	A . A = A	A + A = A
1 . 1 = 1	1 + 1 = 1	A= 1=> A’=0	A . A’ = 0	A + A’ = 1

Logic Gates

- Logic gates are fundamental building block of any digital system.
- It is called so because of its ability to make decisions.
- There are 3 type of basic gate.

  1) And 2) Or 3) Not
- There are 2 type of universal gate.

  1) Nand 2) Nor

Logic Gates

- Input & output of logic gates can occur in two level.

a) High or Low

b) True or False

c) On or Off

d) 1 or 0

- **Positive logic System**

  Higher of two voltage levels treated as 1 & lower level is treated as 0.

Eg: 5V → logic 1   0V→ logic 0

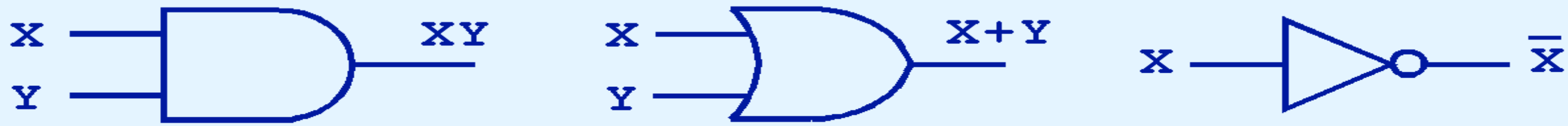
- **Negative logic System**

  Higher of two voltage levels treated as 0 & lower level is treated as 1.

Eg: 5V → logic 0   0V→ logic 1

Logic Gates

- The three simplest gates are the AND, OR, and NOT gates.



X AND Y

X	Y	XY
0	0	0
0	1	0
1	0	0
1	1	1

X OR Y

X	Y	X+Y
0	0	0
0	1	1
1	0	1
1	1	1

NOT X

X	$\overline{X}$
0	1
1	0

- They correspond directly to their respective Boolean operations, as you can see by their truth tables.

Logic Gates

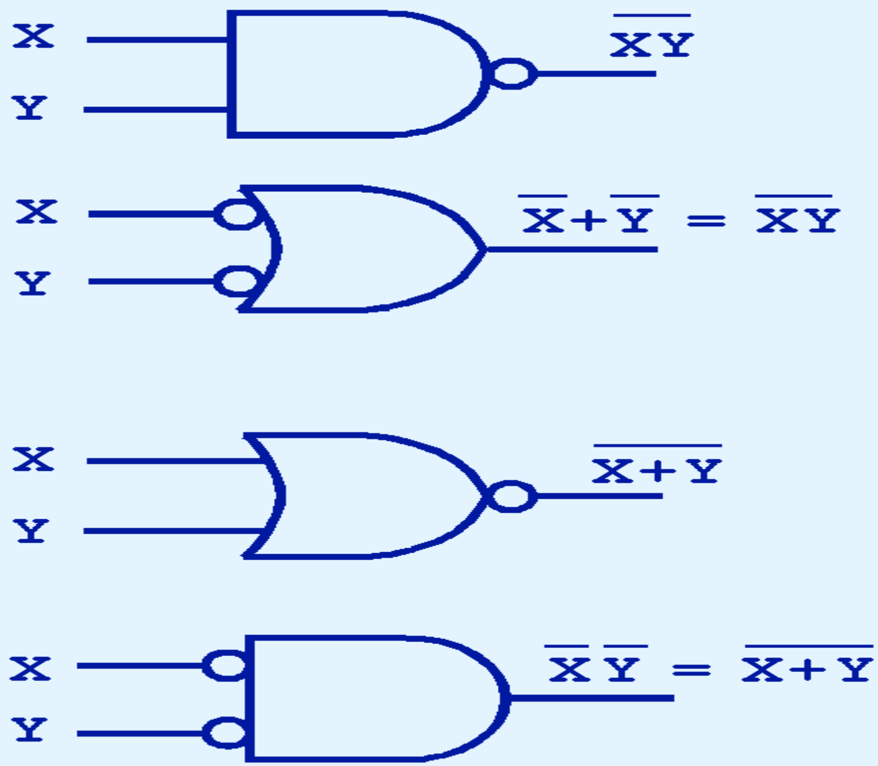
- NAND and NOR are two very important gates. Their symbols and truth tables are shown below.

X NAND Y

X	Y	X NAND Y
0	0	1
0	1	1
1	0	1
1	1	0

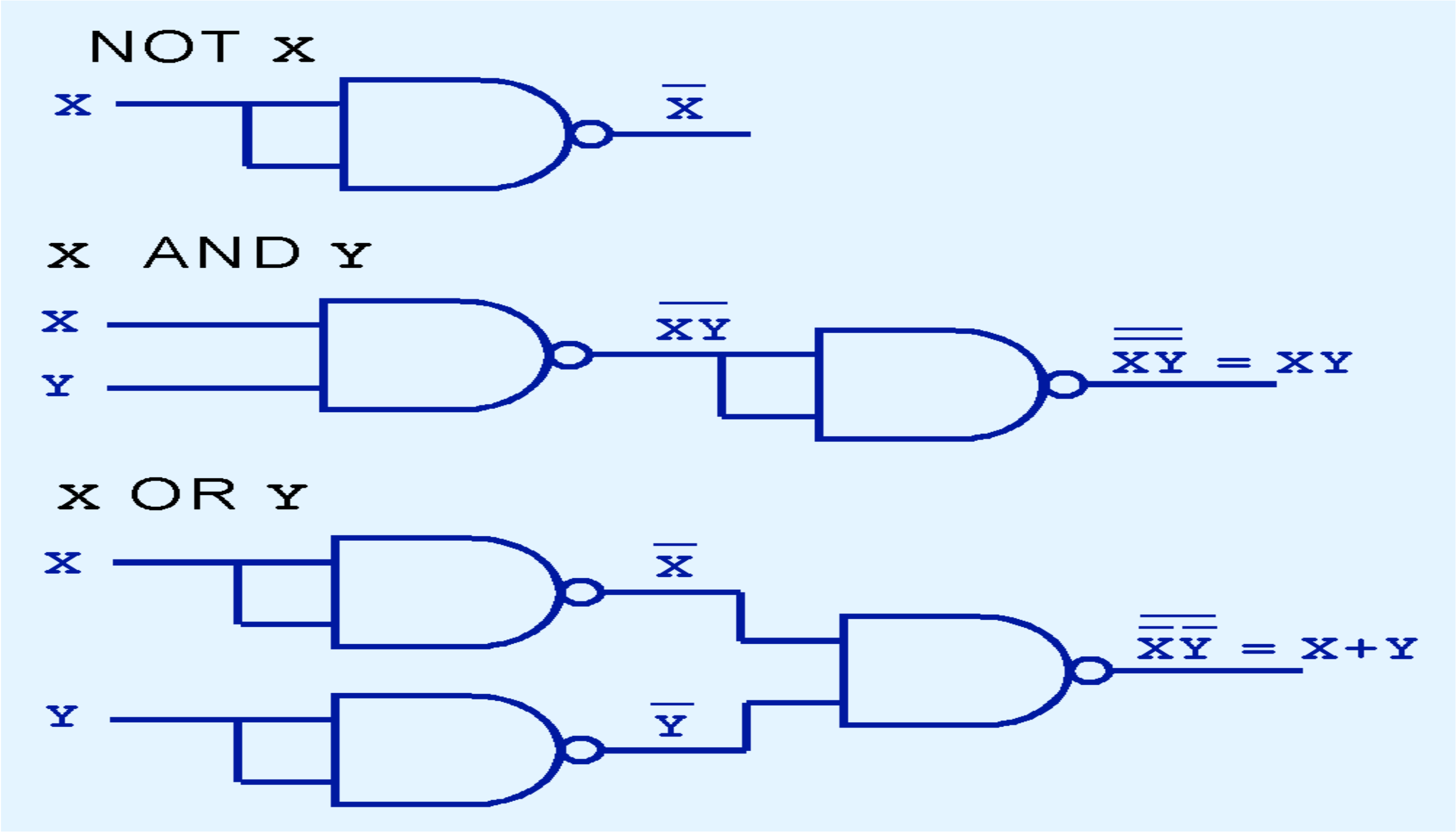
X NOR Y

X	Y	X NOR Y
0	0	1
0	1	0
1	0	0
1	1	0



Logic Gates

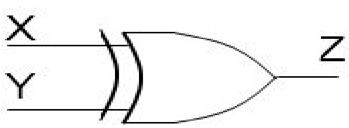
- NAND and NOR are known as *universal gates* because they are inexpensive to manufacture and any Boolean function can be constructed using only NAND or only NOR gates.
- XOR & XNOR using minimum number of NAND & NOR gates.



Logic Gates

- Another very useful gate is the exclusive OR (XOR) & XNOR.
- The output of the XOR operation is true only when the values of the inputs differ.
- The output of the XNOR operation is true only when the values of the inputs are same.
- Problem : XOR & XNOR as buffer & inverter??

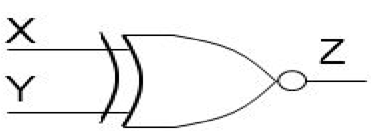
Exclusive OR (XOR)



$F = X'Y + XY'$
$= X \oplus Y$

X	Y	$Z=X\oplus Y$
0	0	0
0	1	1
1	0	1
1	1	0

Exclusive NOR (XNOR)



$F = XY + X'Y'$
$= (X \oplus Y)'$
$= X \otimes Y$
$= X \odot Y$

Different symbols for XNOR

X	Y	$Z=(X\ominus Y)'$
0	0	1
0	1	0
1	0	0
1	1	1

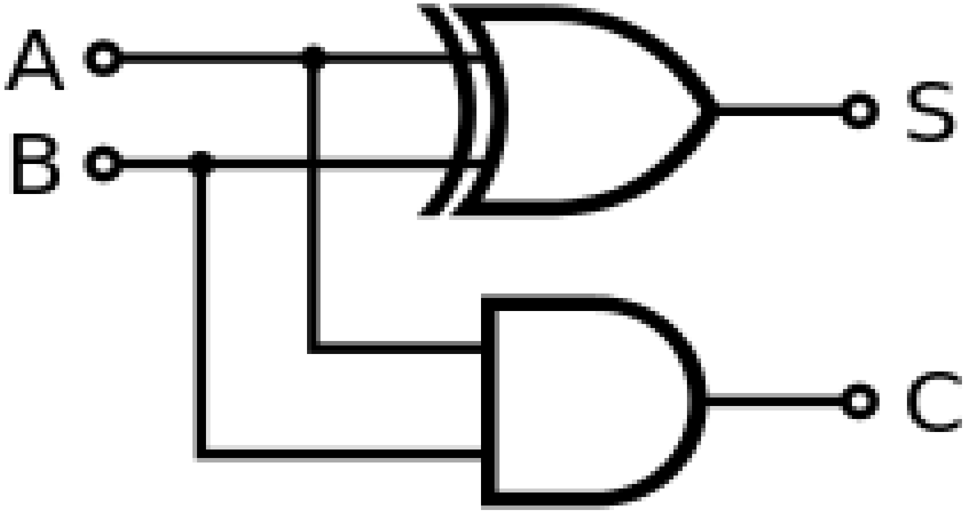
Half Adder

TRUTH TABLE

A	B	S	C
0	0	0	0
0	1	1	0
1	0	1	0
1	1	0	1

$$S = A'B + AB'$$

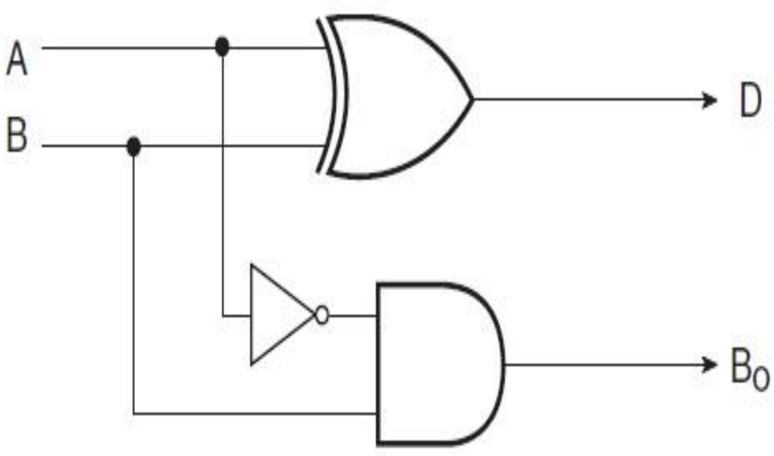
$$C = AB$$



HALF SUBTRACTOR

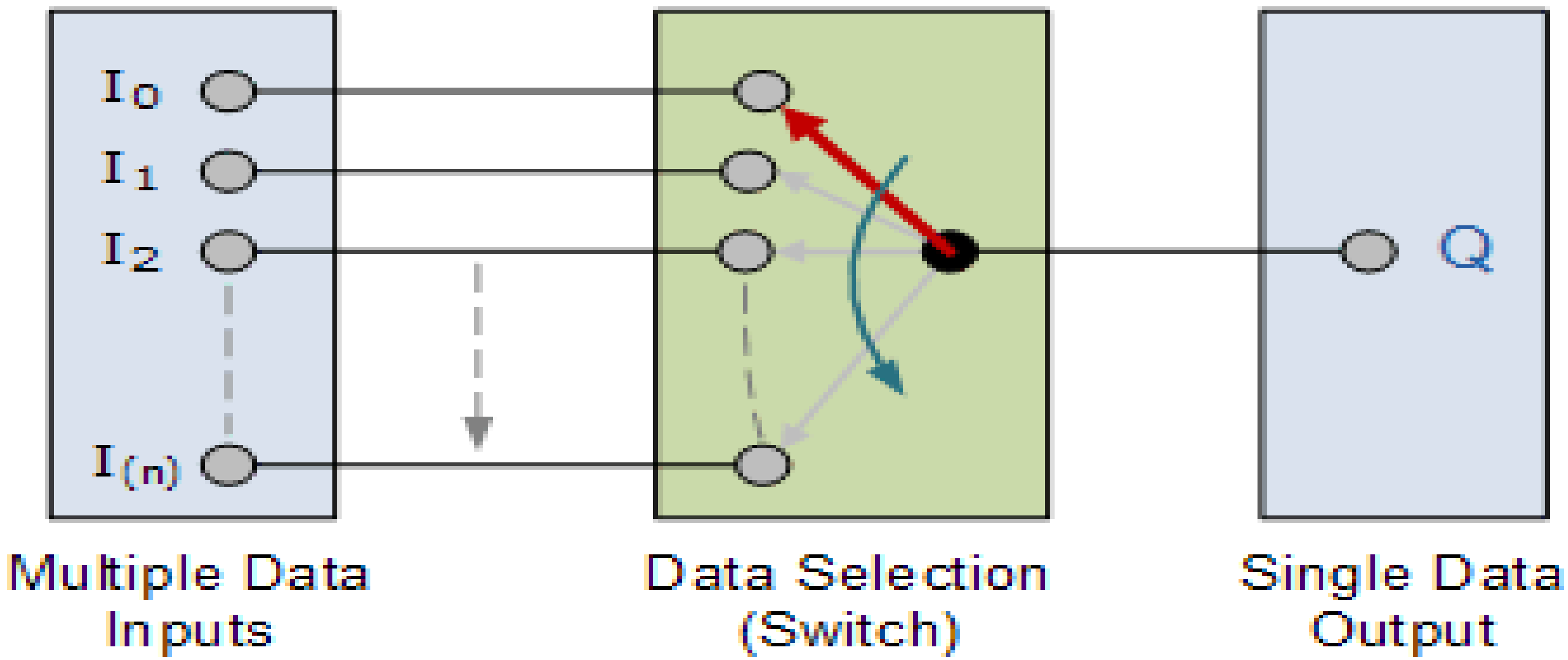
A	B	D	Bo
0	0	0	0
0	1	1	1
1	0	1	0
1	1	0	0

- D = A’B + AB’
- Bo = A’B



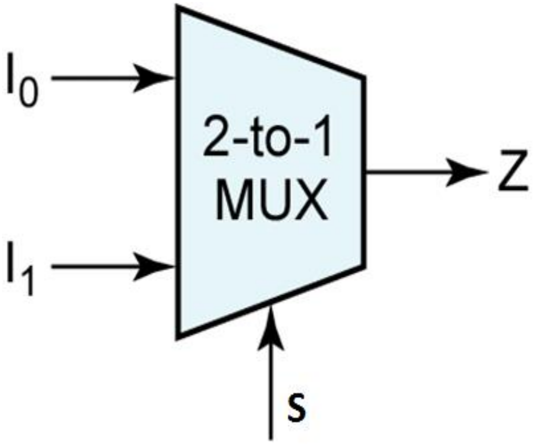
Multiplexer

- A multiplexer switches (or routes) data from 2^N inputs to one output, where N is the number of select (or control) inputs.
- A multiplexer (mux) is a digital switch.



2 x 1 MUX

S	Z
0	Io
1	I1

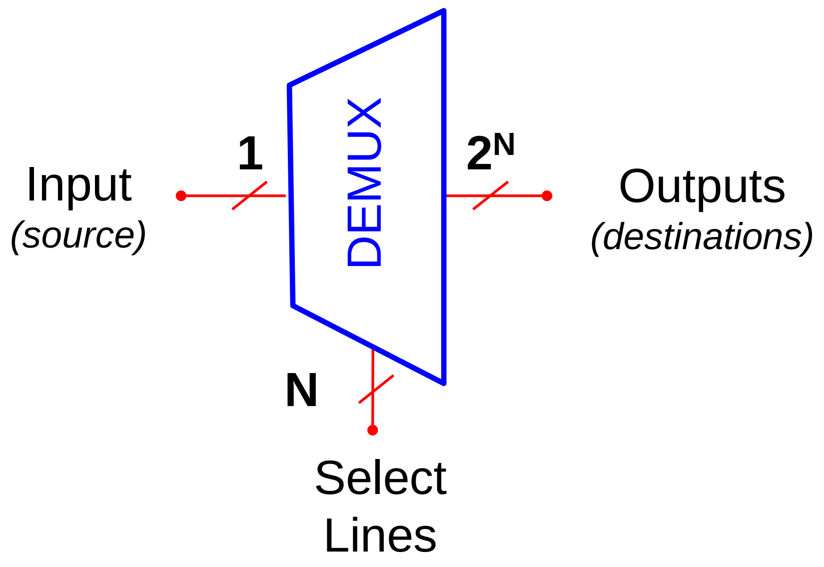


$$Z = S'I_0 + S\,I_1$$

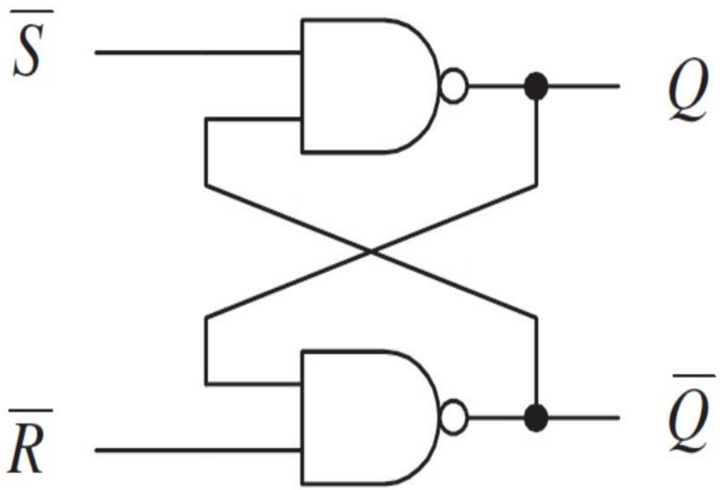
S	Io	I1	Z
0	0	0	0
0	0	1	0
0	1	0	1
0	1	1	1
1	0	0	0
1	0	1	1
1	1	0	0
1	1	1	1

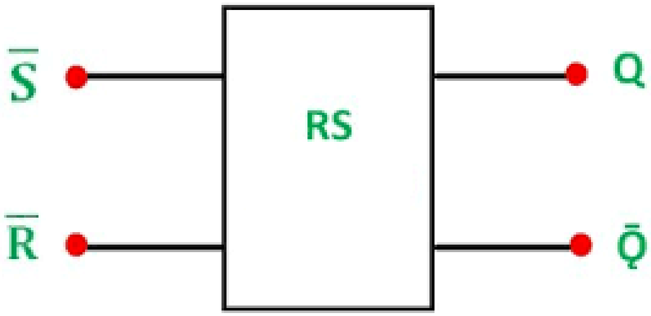
DEMULTIPLEXER

- A DEMUX is a digital switch with a single input (source) and a multiple outputs (destinations).
- The select lines determine which output the input is connected to.
- DEMUX Types
  - → 1-to-2 (1 select line)
  - → 1-to-4 (2 select lines)
  - → 1-to-8 (3 select lines)
  - → 1-to-16 (4 select lines)



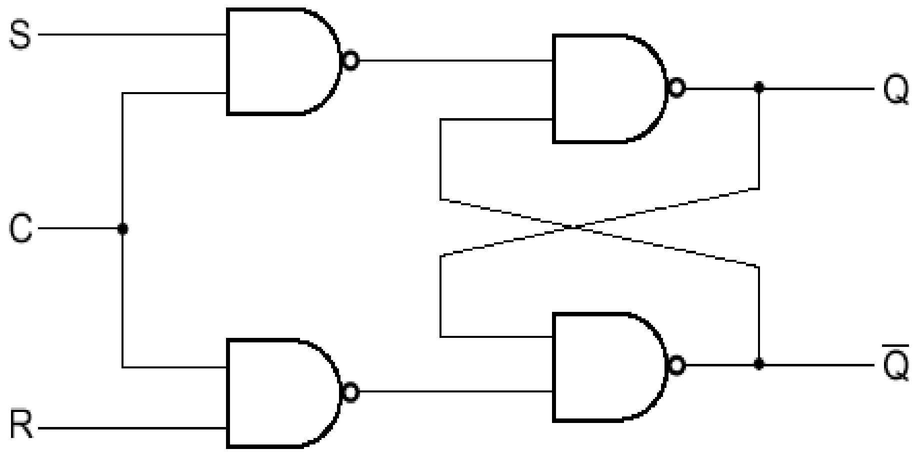
S-R Latch





S	R	Q_n	Q_{n+1}	State
0	0	0	0	NC
0	0	1	1	
0	1	0	0	Reset
0	1	1	0	
1	0	0	1	Set
1	0	1	1	
1	1	0	x	Invalid
1	1	1	x	

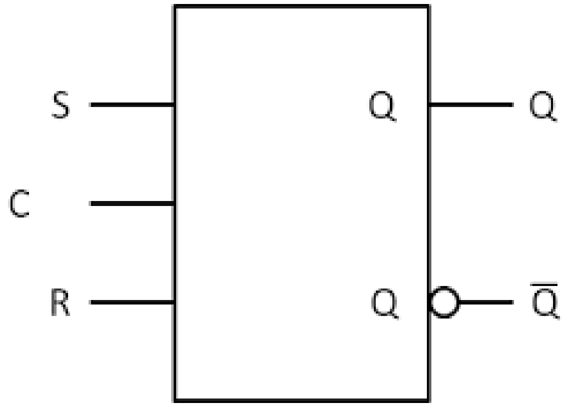
SR Flipflop



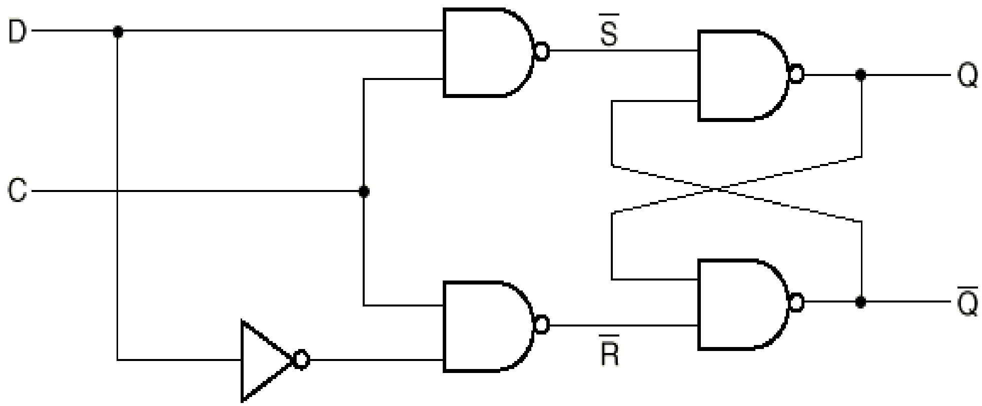
(a) Logic diagram

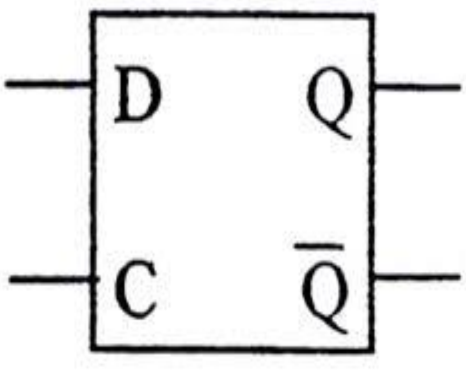
C	S	R	Next state of Q
0	X	X	No change
1	0	0	No change
1	0	1	Q = 0; Reset state
1	1	0	Q = 1; Set state
1	1	1	Undefined

(b) Function table



D Flipflop

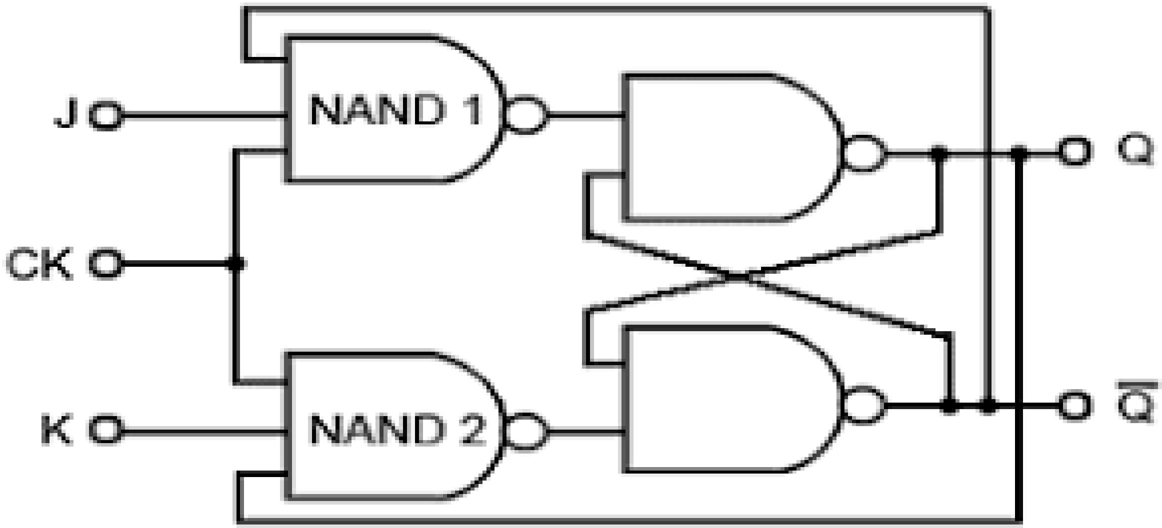


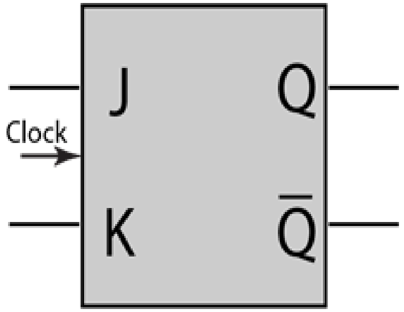


C	D	Q_{n+1}
0	x	Q_n
1	0	0
1	1	1

$Q_{n+1} = D$

JK Flipflop





J-K Type

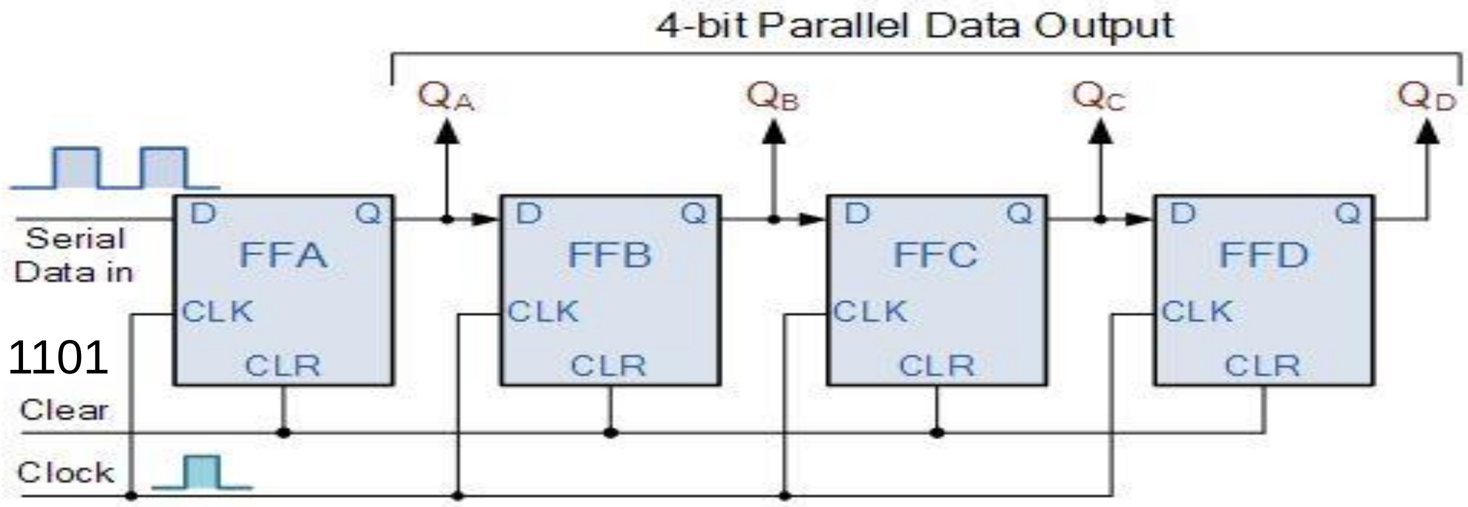
Clk	J	K	Q	Q’	State
1	0	0	Q	Q’	No change in state
1	0	1	0	1	Resets Q to 0
1	1	0	1	0	Sets Q to 1
1	1	1	-	-	Toggles

$Q_{n+1} = J\,Q_n' + K'\,Q_n$

Shift Register

- A Flip flops can be used to store a single bit of binary data (1or 0)
- In order to store multiple bits of data we need multiple flip flops.
- Shift Register is a group of flip flops used to store multiple bits of data.
- The bits stored in such registers can be made to move within the registers and in/out of the registers by applying clock pulses.
- An n-bit shift register can be formed by connecting n flip-flops where each flip flop stores a single bit of data.
- Shift registers are basically of 4 types. These are:
    - Serial In Serial Out shift register
    - Serial In parallel Out shift register
    - Parallel In Serial Out shift register
    - Parallel In parallel Out shift register

SIPO Shift Register

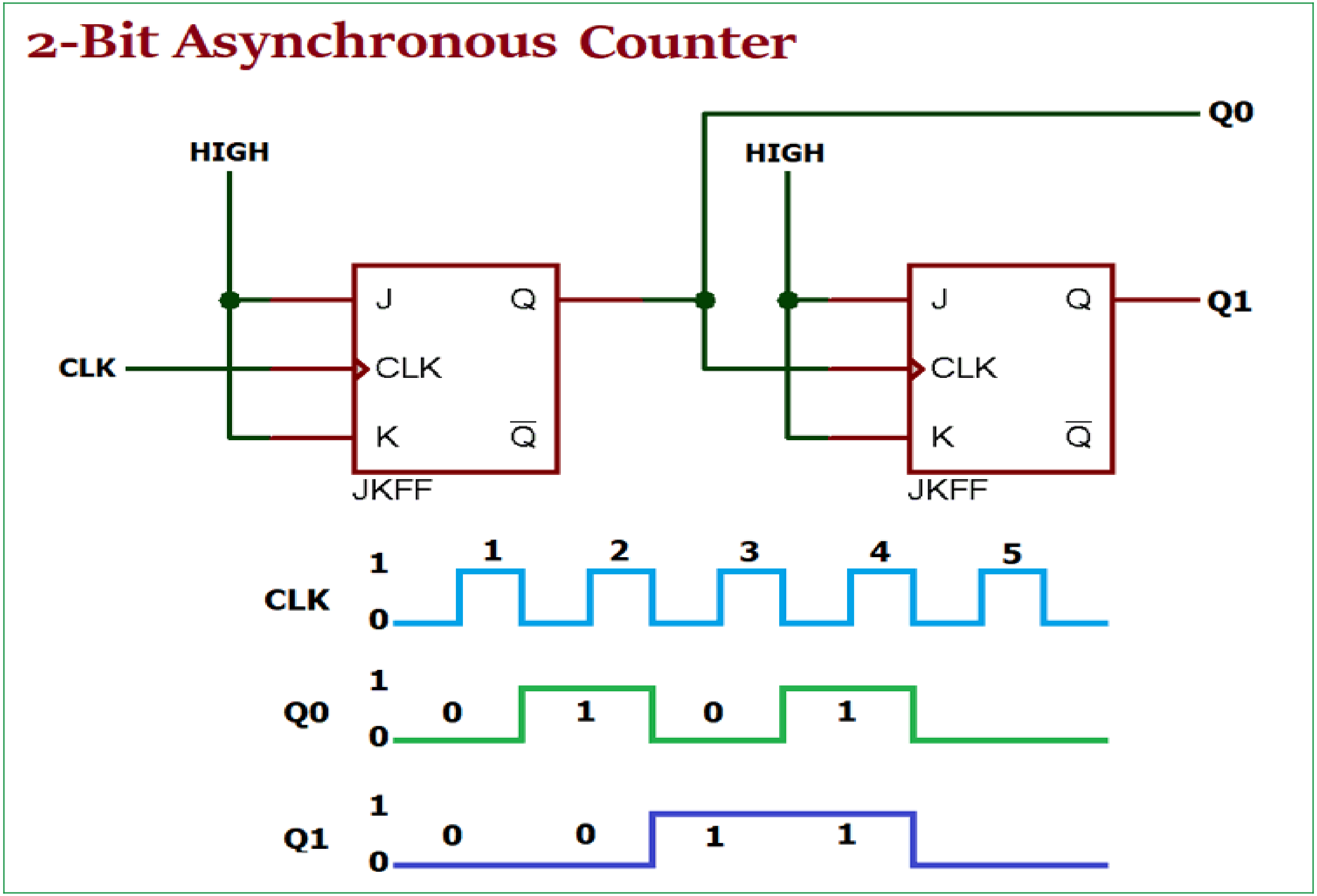


Clock	In	Q_A	Q_B	Q_C	Q_D
0	-	0	0	0	0
1	1	1	0	0	0
2	0	0	1	0	0
3	1	1	0	1	0
4	1	1	1	0	1

Counter

- Counter is a sequential circuit.
- A digital circuit which is used for a counting pulses is known counter.
- It is a group of flip-flops with a clock signal applied.
- Counters are of two types.
  - Asynchronous or ripple counters.
    - If the different clock pulses are applied to all the flip-flops in a counter simultaneously, then such a counter is called as asynchronous counter.
  - Synchronous counters.
    - If the same clock pulses are applied to all the flip-flops in a counter simultaneously, then such a counter is called as synchronous counter.

Asynchronous Counter



Module-6

Basic Electronics

EC-10001

Table of content

Opto-electronics device

- LED
- Photo Diode
- Photo transistor

Optical Fiber Technique

- Law of Reflection and Refraction
- Snell’s Law
- Total internal Reflection
- Optical Fiber

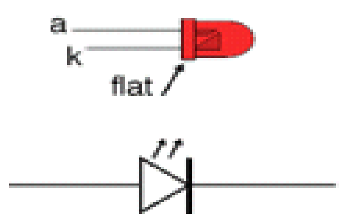
Opto electonic devices

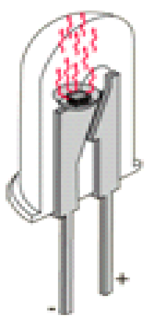
- Optoelectronics is the communication between optics and electronics which includes the study, design and manufacture of a hardware device that converts electrical energy into light and light into energy through semiconductors.
- This device is made from semiconductor materials basically an electronic device involving light.
- This device can be found in many optoelectronics applications like military services, telecommunications, automatic access control systems and medical equipments.

Light Emitting Diodes

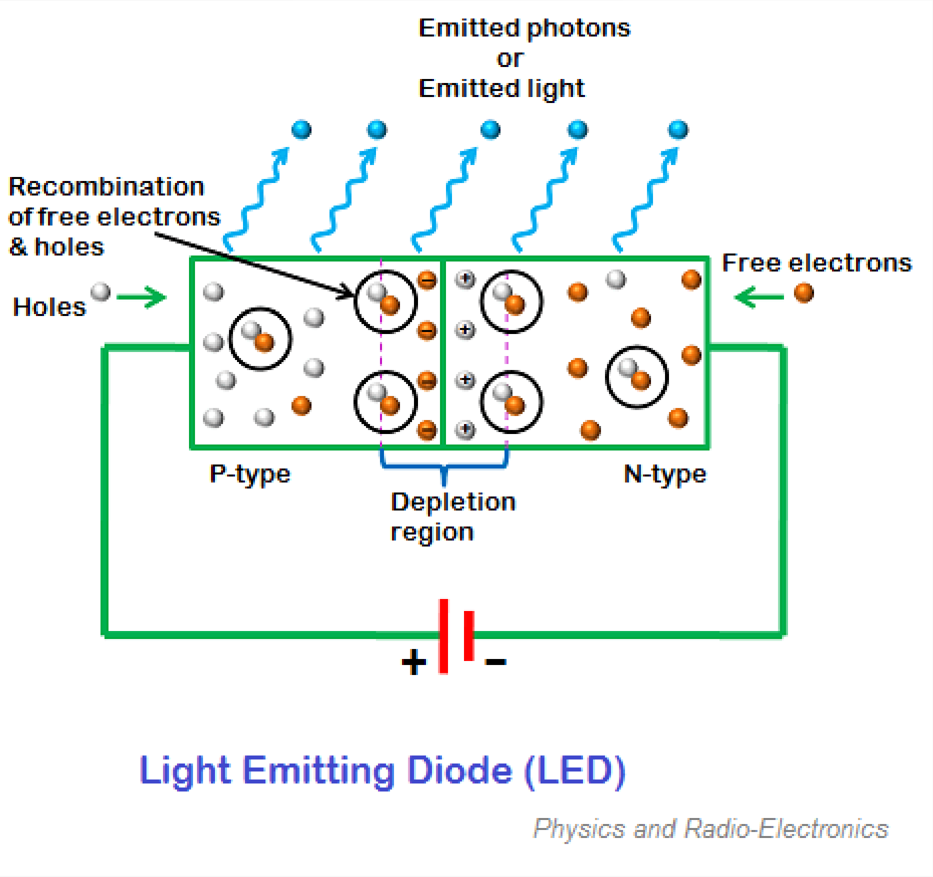
A light emitting diode (LED) is essentially a PN junction opto-semiconductor that emits a monochromatic (single color) light when operated in a forward biased direction.

LEDs convert electrical energy into light energy. They are frequently used as "pilot" lights in electronic appliances to indicate whether the circuit is closed or not.





Construction and operation



When sufficient voltage is applied to the leads of the LED, electrons can move easily in only one direction across the *junction* between the *p* and *n* regions,the electrons recombine with the holes within the device and release energy in the form of photons.

- This effect is called as electroluminescence. It is the conversion of electrical energy into light.

The color of the light is decided by the energy band gap of the material.

$\lambda = hc/E_g$ μm= 1.24/Eg(in ev)

Advantages of LED

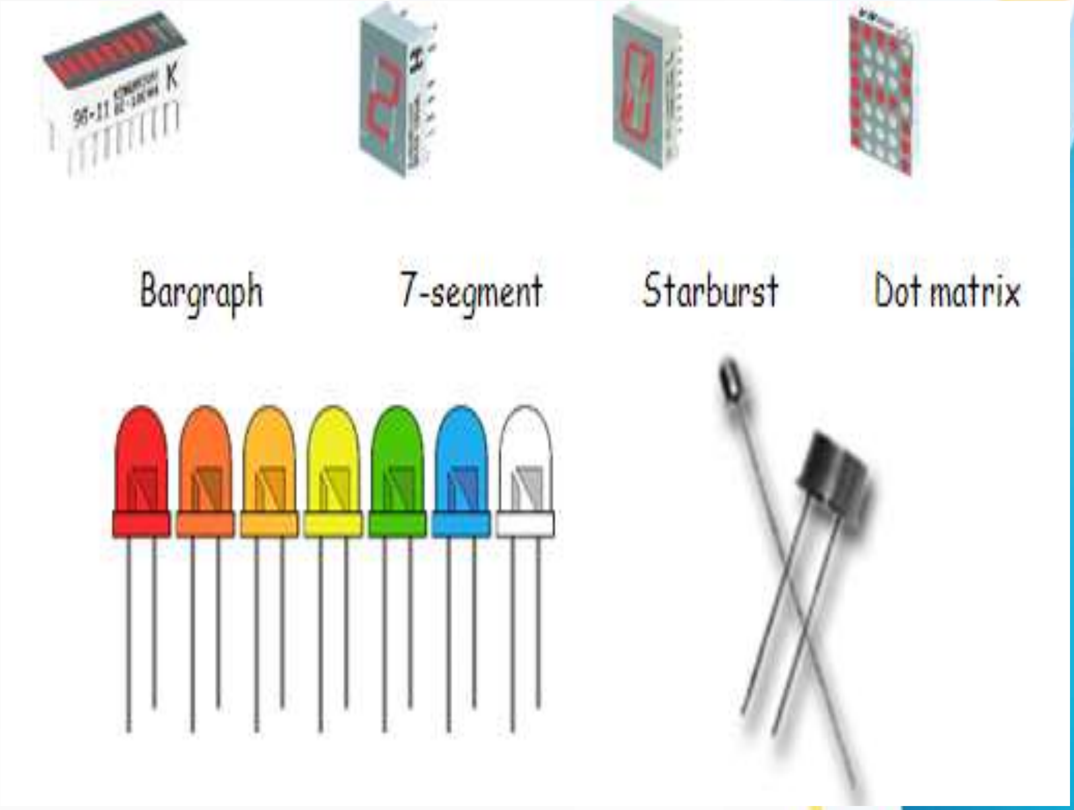
- The usage of LED is advantageous as it consumes less power and produces less heat.

- LEDs last longer than incandescent lamps.

- LEDs could become the next generation of lighting and used anywhere like in indication lights, computer components, medical devices, watches, instrument panels, switches, fiber-optic communication, consumer electronics, household appliances, etc.

Applications

- Sensor Applications
- Mobile Applications
- Sign Applications
- Automative Uses
- LED Signals
- Illuminations
- Indicators



Photodiodes

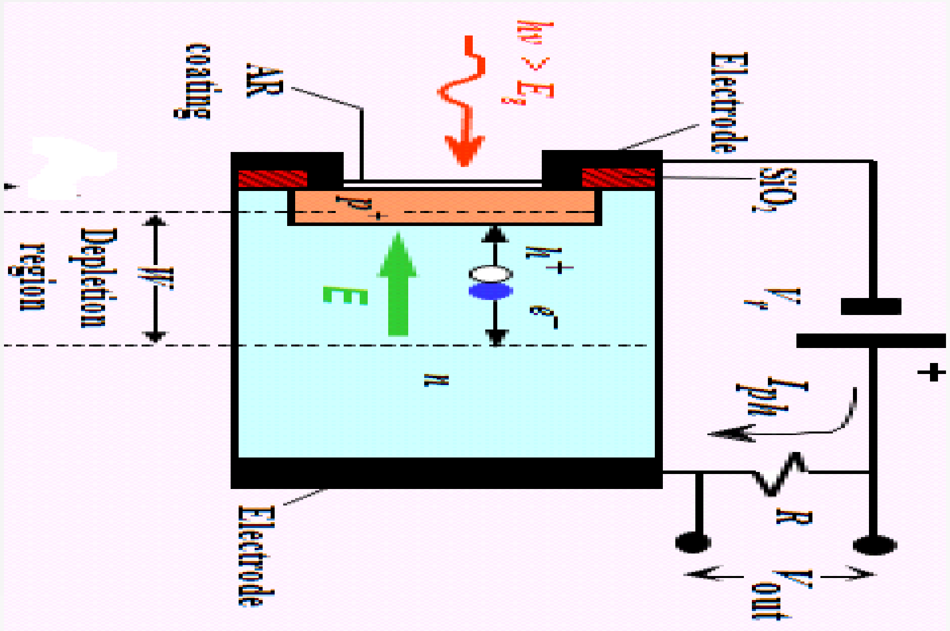
- A photo diode is a semiconductor light sensor that generates a voltage or current when light falls on the junction.

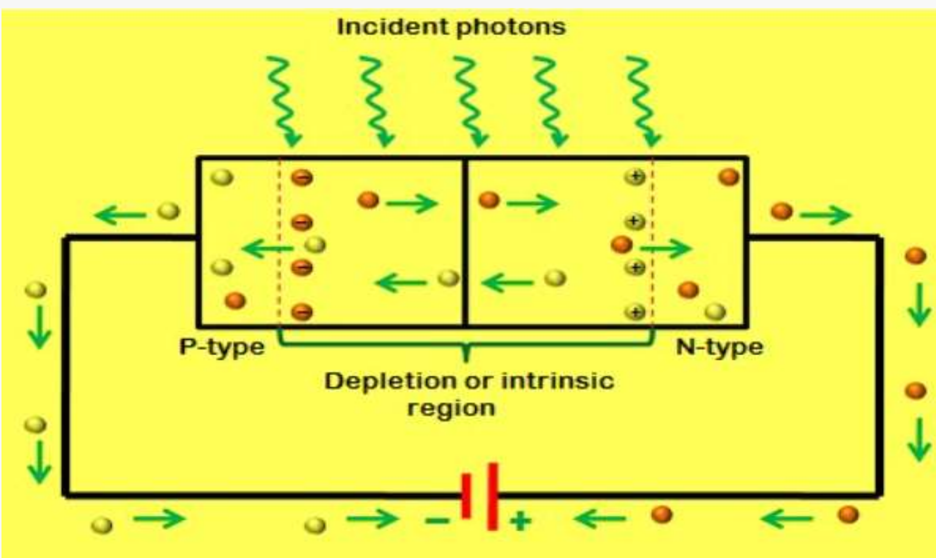
- It consists of an active P-N junction, which is operated in reverse bias.

- When a light (photon) with plenty of energy strikes the semiconductor, photogeneration happens where electron-hole pairs generated through band-to-band optical absorption.

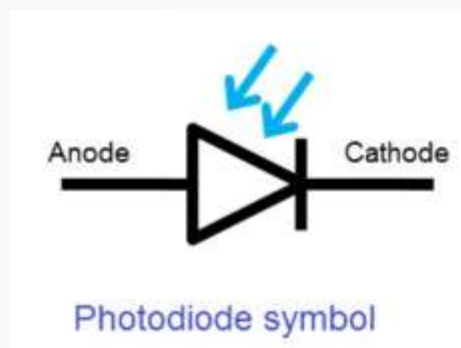
- The electrons diffuse to the junction to form an electric field.
- This electric field across the depletion region is equal to a negative voltage across the unbiased diode. This method is also known as the inner photoelectric effect.

Construction and operation

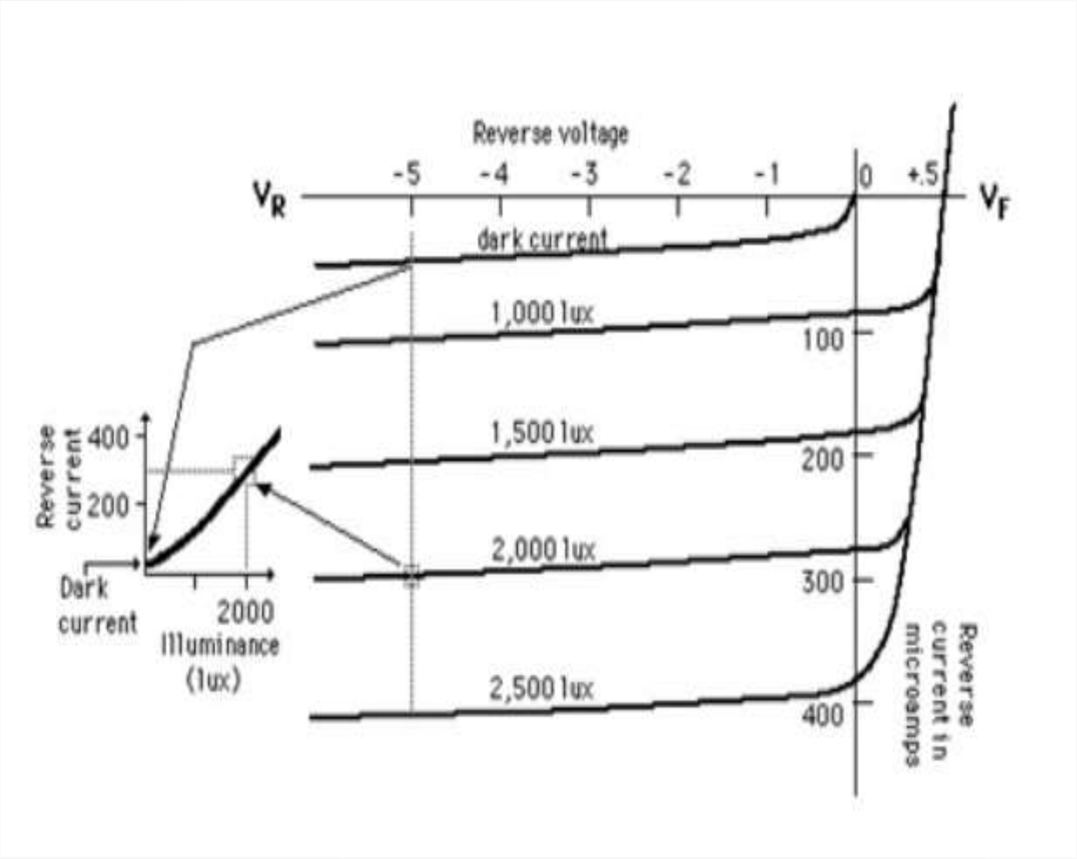




- Optical receivers convert optical signal (light) to electrical signal (current/voltage).
- Hence referred 'O/E Converter'
- Photodetector is the fundamental element of optical receiver



I-V characteristics of photo diodes



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

- 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.

Photo transistors

- A phototransistor is similar to a regular BJT except that the base current is produced and controlled by light instead of a voltage source.
- The phototransistor effectively converts light energy to an electrical signal.
- A transistor which is sensitive to the input light intensity.
- Operation similar to traditional transistors; Have collector, emitter, and base.
- Phototransistor base is a light-sensitive collector-base junction
- Dark Current: Small collector can emit leakage current when transistor is switched off.
- Photocurrent: The electrons are amplified by the transistor and appear as a current in the collector/emitter circuit.
- The base is internally left open and is at the focus of a plastic lens.

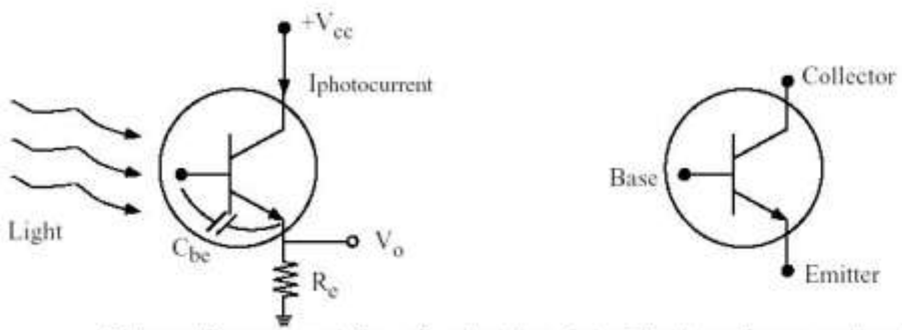
Phototransistor Operation

- The collector current is given by the equation: $I_c=(1+\beta)I_{co}$

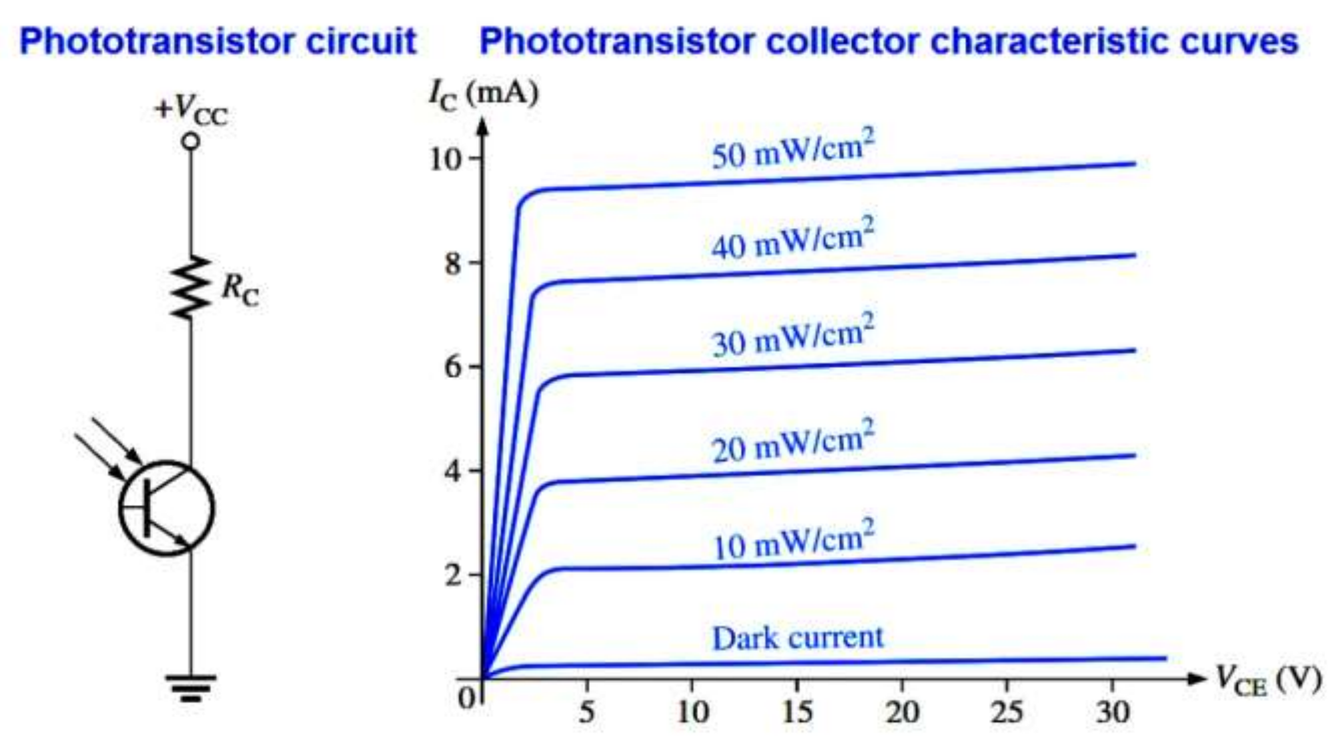
  Due to Transistor action the current caused by the radiation is multiplied by the large factor ($\beta+1$).

- The phototransistor must be properly biased.
- A light sensitive collector base p-n junction controls current flow between the emitter and collector.
- As light intensity increases, resistance decreases, creating more emitter-base current.
- The small base current controls the larger emitter-collector current.
- Collector current depends on the light intensity and the DC current gain of the phototransistor.

Symbol & Charecteristics



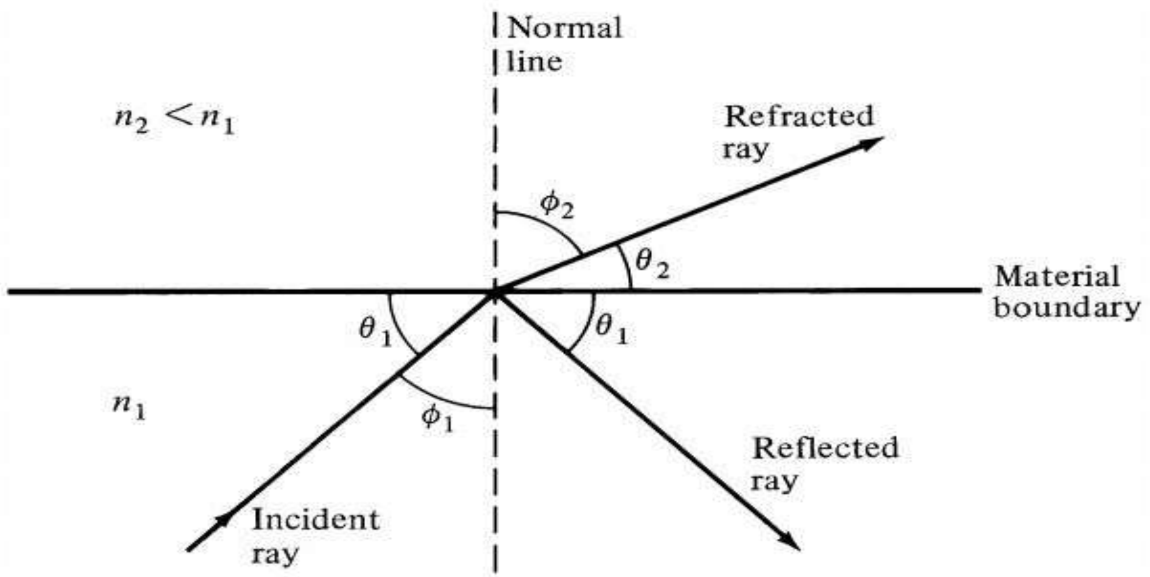
Schematic representation of a phototransistor. The base is generally not connected to the outside world.



Why Use Phototransistors

- More sensitive than photodiodes of comparably sized area and produce a higher current than photodiodes.
- Available with gains form 100 to over 1500
- Moderately fast response times,relatively inexpensive, simple, and small enough to fit several of them onto a single integrated computer chip.
- **Applications**
- Punch-card readers.
- Security systems
- Encoders – measure speed and direction
- IR detectors photo
- electric controls
- Computer logic circuitry.
- Relays
- Lighting control (highways etc)
- Level indication
- Counting systems

Laws of Reflection & Refraction



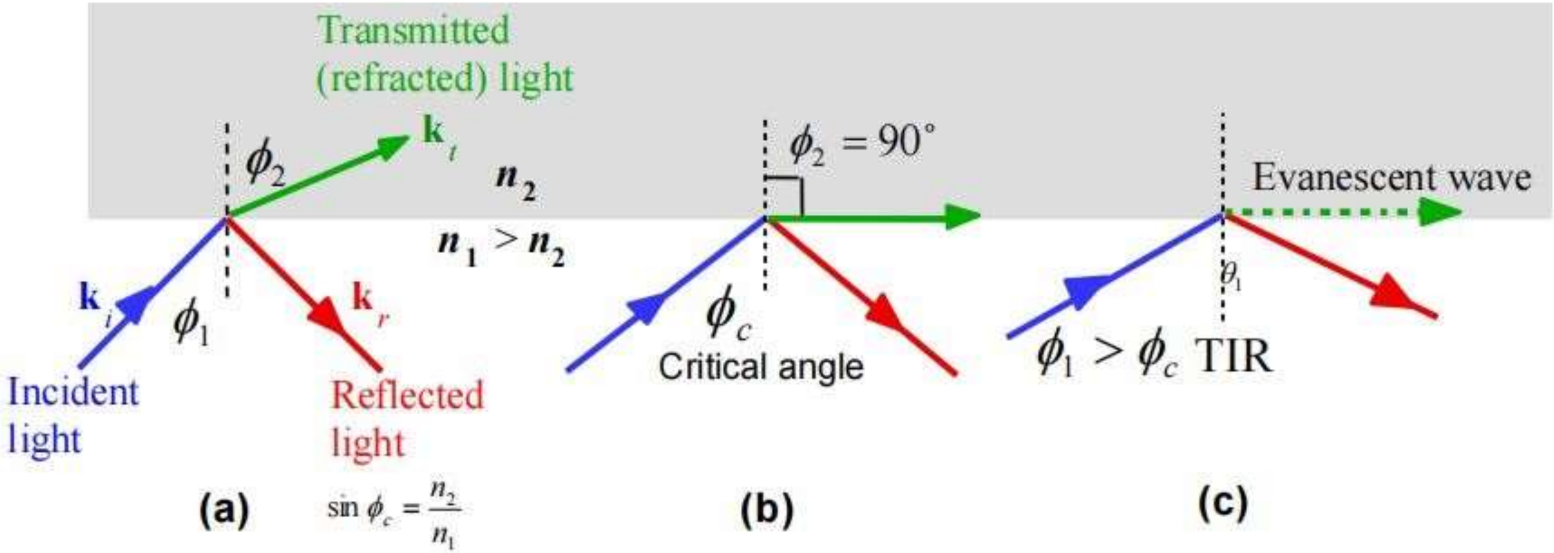
Reflection law: angle of incidence=angle of reflection

Snell's law of refraction:

$$n_1 \sin \phi_1 = n_2 \sin \phi_2$$

Snell's law states that, for a given pair of media, the ratio of the sines of angle of incidence (ϕ_1) and angle of refraction (ϕ_2) is equal to ratio of the refractive indices (n_2/n_1) of the two media.

Total internal reflection, Critical angle



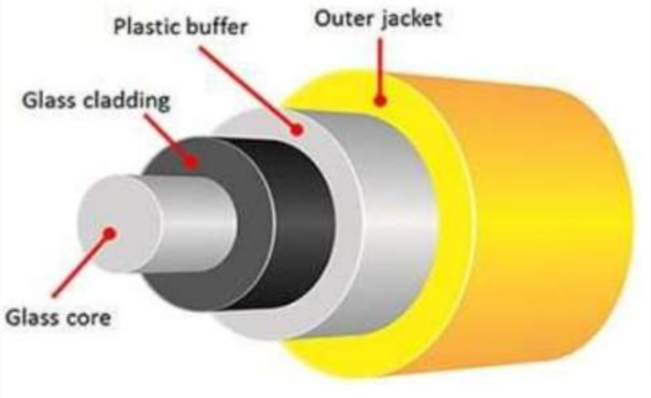
Light wave travelling in a more dense medium strikes a less dense medium. Depending on the incidence anglewrt to ϕ_c, which is determined by the ratio of the refractive indices, the wave may be transmitted (refracted) or reflected. (a) $\phi_1 < \phi_c$ (b) $\phi_1 = \phi_c$ (c) $\phi_1 > \phi_c$ and total internal reflection (TIR).

$$\sin\phi_c = \frac{n_2}{n_1}$$

Optical Fiber Cable Construction

The three basic elements of a fiber optic cable are the core, the cladding and the coating.

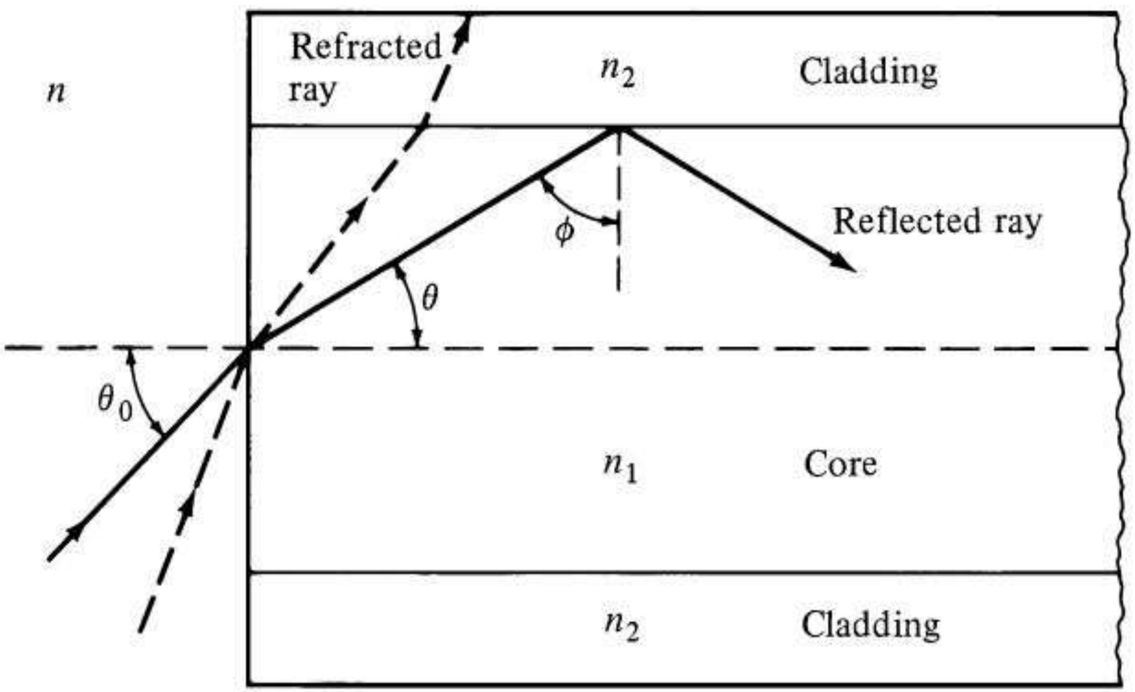
- Core: This is the light transmission area of the fiber, either glass or plastic. The larger the core, the more light that will be transmitted into the fiber.
- Cladding: The function of the cladding is to provide a lower refractive index at the core interface in order to cause reflection within the core so that light waves are transmitted through the fiber.
- Coating: Coatings are usually multi-layers of plastics applied to preserve fiber strength, absorb shock and provide extra fiber protection. These buffer coatings are available from 250 microns to 900 microns.



Optical fiber uses the optical principle of "total internal reflection" to capture the light transmitted in an optical fiber and confine the light to the core of the fiber.

An optical fiber is comprised of a light-carrying core in the center, surrounded by a cladding that acts to traps light in the core.

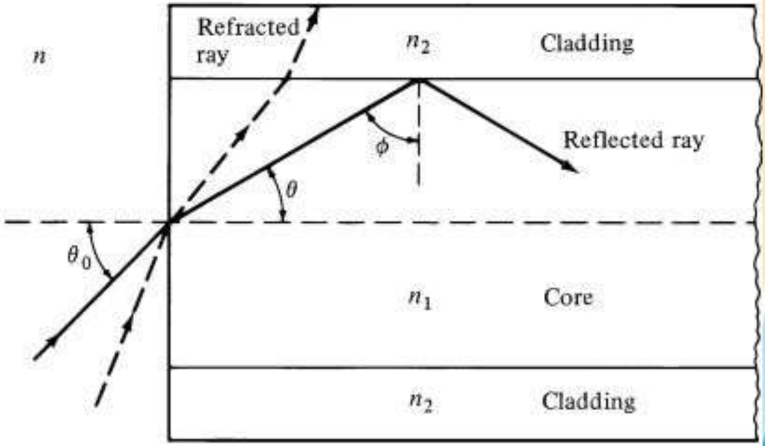
Optical waveguiding by TIR: Dielectric Slab Waveguide



Propagation mechanism in an ideal step-index optical waveguide.

Launching optical rays to slab waveguide

$\sin\phi_{\min} = \frac{n_2}{n_1}$; minimum angle that supports TIR



Maximum entrance angle, $\theta_{0\max}$ is found from the Snell's relation written at the fiber end face.

$$n\sin\theta_{0\max} = n_1\sin\theta_c = \sqrt{n_1^{\,2} - n_2^{\,2}}$$

Numerical aperture:

$$\mathrm{NA} = n\sin\theta_{0\max} = \sqrt{n_1^{\,2} - n_2^{\,2}} \approx n_1\sqrt{2\Delta}$$

$$\Delta = \frac{n_1 - n_2}{n_1}$$

Advantages of Optical Fiber Cable

- Fibre optic cables are designed to **carry signals** over much **longer distances** than traditional cabling as they offer **low power loss**.

- **Thin and Light weight** : Optical fibres are much thinner and lighter than copper wires, allowing them to be drawn into smaller diameters, making them more suitable for places where space is restricted.
- Unlike electrical signals, light signals from one fibre **don’t interfere** with those of other fibres.
- Fibre transmission offers a level of security that simply cannot be matched by other materials. As they don’t radiate electromagnetic energy, it is extremely **difficult to ‘listen’ in or tap**. This makes it the most secure medium available for carrying sensitive data.
- Optic fibres possess greater tensile strength and are sturdier than metal fibres of the same diameter, which means **they’re less likely to suffer damage**. Fibre also isn’t as affected anywhere near as much by weather, moisture or corrosive elements as metal wiring can be.

Disadvantages of Optical Fiber Cable

- The **cost** to produce optic fibre cabling is **higher** than that of copper. Installation is also more expensive as special test equipment is usually required.

- As they are made of glass, fibre optic cables are **more fragil**e than electrical wires like copper cabling. If you bend them too much, they will break.

- When deploying a new fibre optic network or expanding an existing one, the fibres need to be properly sliced in order to avoid network disruptions. This is **a very delicate process** – if the fibres aren't properly connected, the signal will suffer.

- Due to how small and compact the fibre optic cable is, it is highly **susceptible** to becoming **cut or damaged** during installation or any construction/renovation activities. It is therefore necessary to consider restoration, backup and survivability.

Communication
Module-7
EC-10001

Modulation

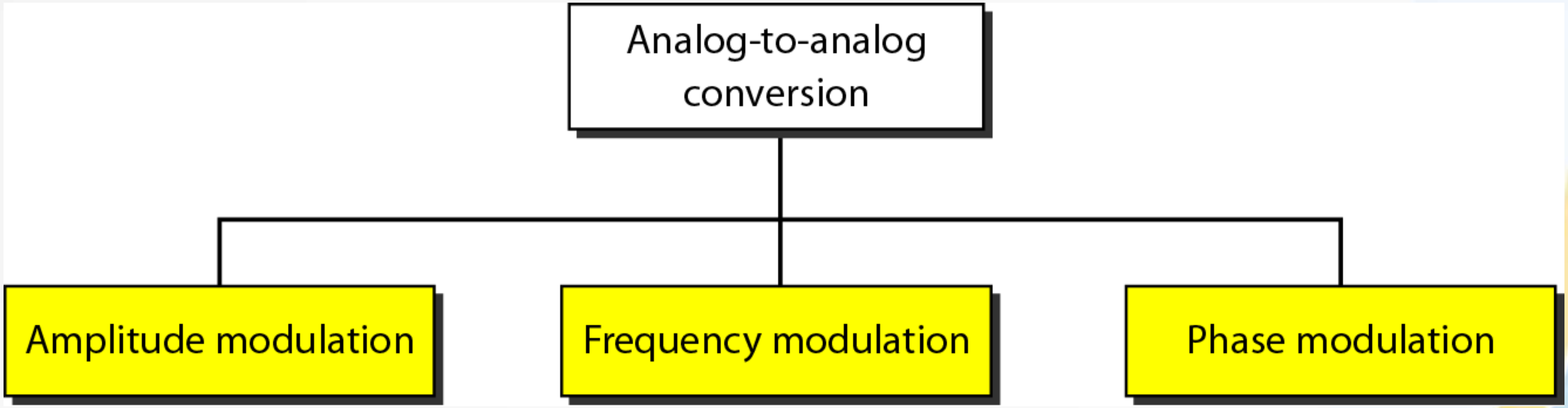
- **In electronics and telecommunications, modulation is the process of varying one or more properties of a periodic waveform, called the carrier signal, with a separate signal called the modulation signal that typically contains information to be transmitted.**

- **A carrier signal is one with a steady waveform having constant height, or amplitude, and frequency.**

Topics discussed in this section:

- **Amplitude Modulation**
- **Frequency Modulation**
- **Phase Modulation**

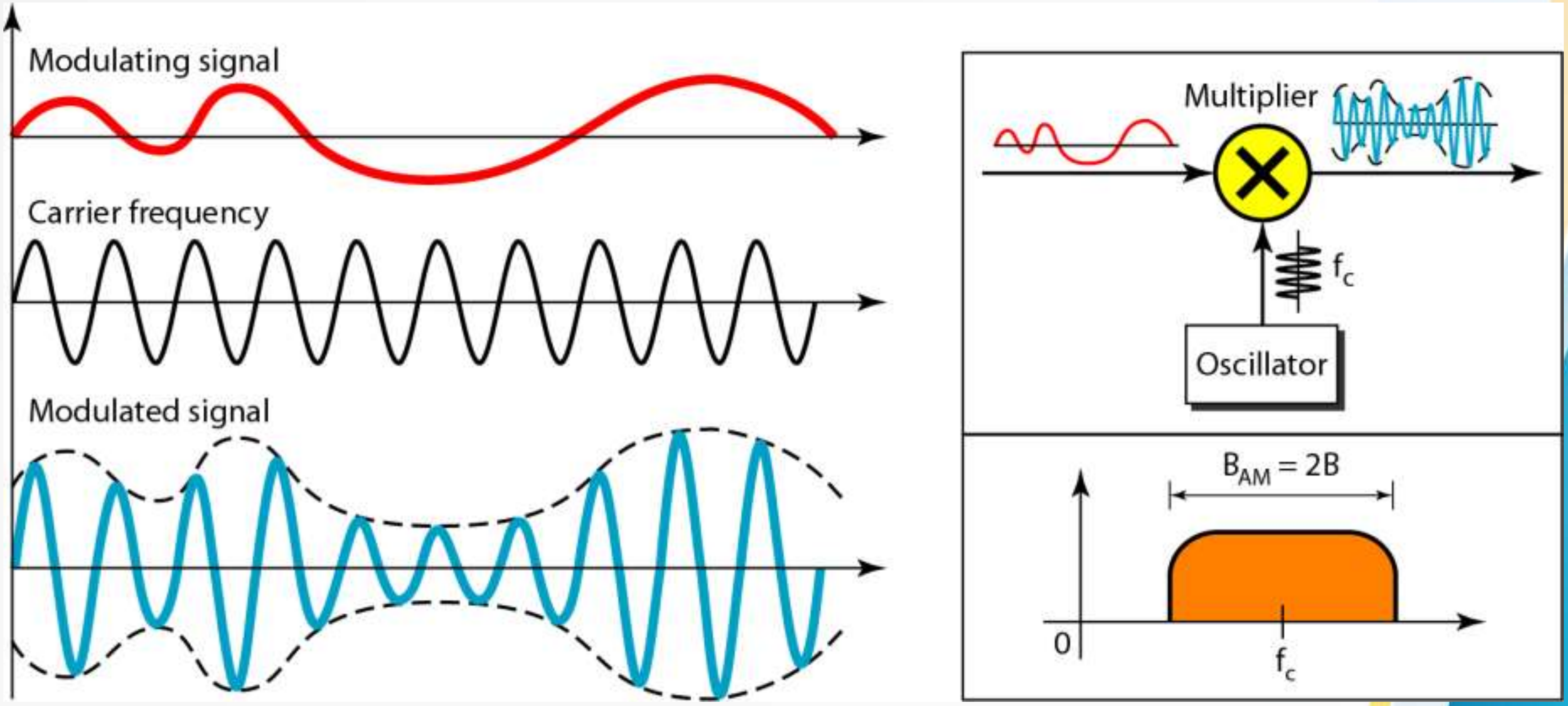
Types of analog-to-analog modulation



Amplitude Modulation

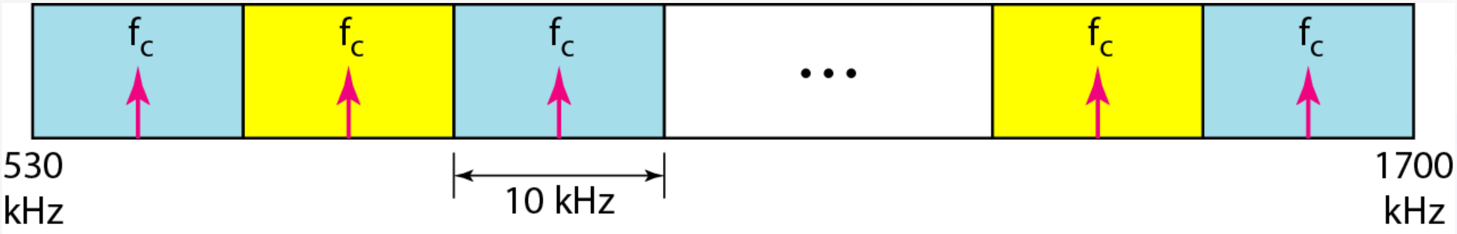
- AM is defined as the process of changing the amplitude of the carrier signal w.r.t. the instantaneous values of the message or modulating signal.
- The required bandwidth is 2B, where B is the bandwidth of the modulating signal.
- Since on both sides of the carrier freq. f_c, the spectrum is identical, we can discard one half, thus requiring a smaller bandwidth for transmission.

Amplitude modulation



The total bandwidth required for AM can be determined from the bandwidth of the audio signal: $B_{AM} = 2B$.

AM band allocation



Application

AM Radio

Frequency Modulation

- The modulating signal changes the frequency ‘fc’ of the carrier signal.

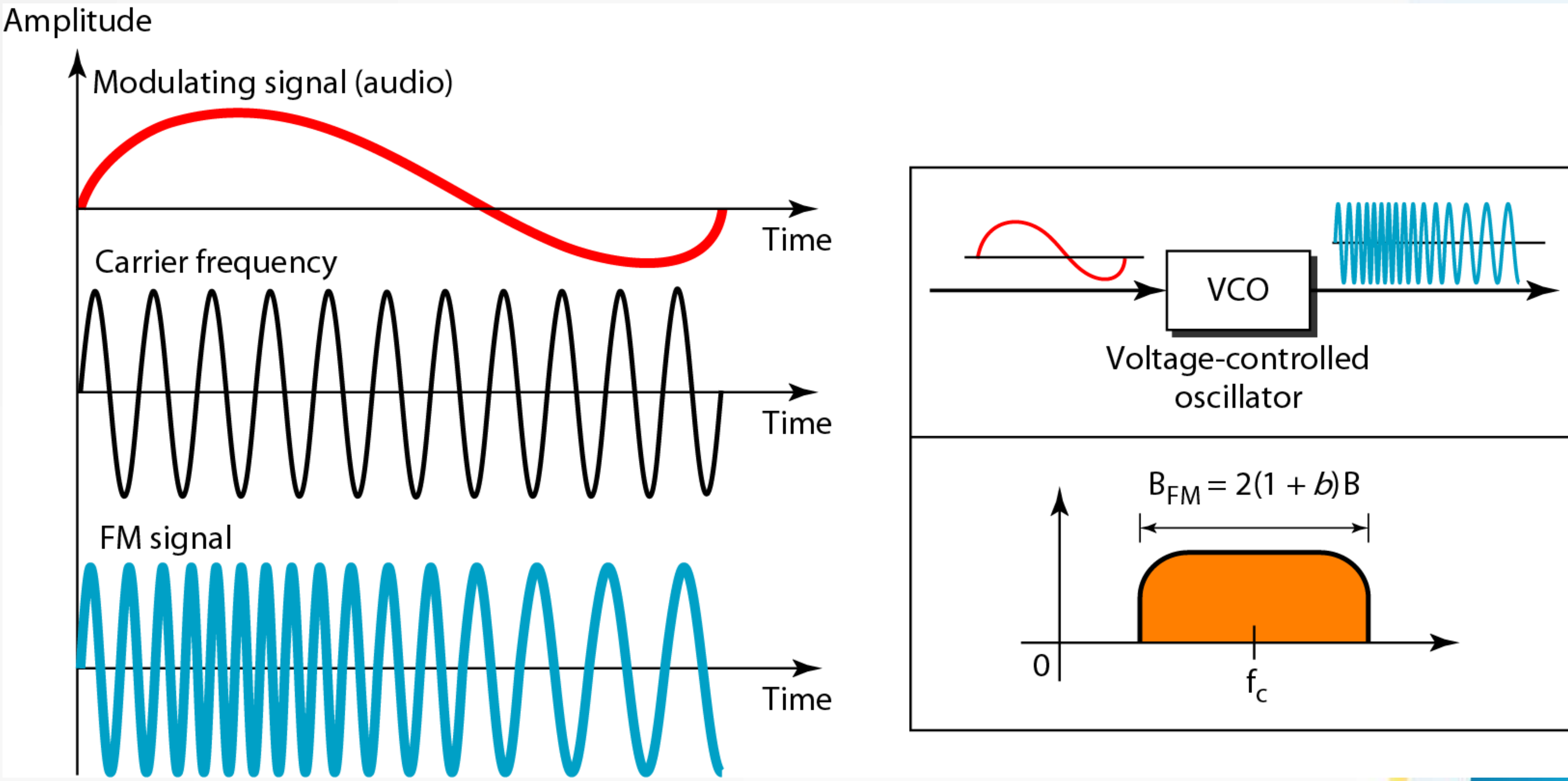
- FM is defined as the process of changing the frequency of the carrier signal w.r.t. the instantaneous values of the message or modulating signal.

- The bandwidth for FM is high

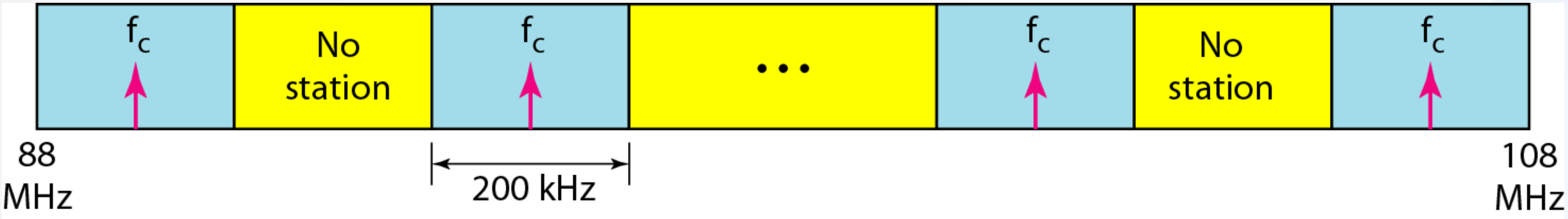
- It is approxmately 10x the signal frequency

The total bandwidth required for FM can be determined from the bandwidth of the audio signal: $B_{FM} = 2(1 + \beta)B$. Where modulation index, β is usually 4.

Frequency modulation



FM band allocation



Application

FM Radio

Comparison

Amplitude Modulation (AM)	Frequency Modulation (FM)
Frequency and phase remain the same	Amplitude and phase remain the same
Can be transmitted over a long distance but has poor sound quality.	Better sound quality with higher bandwidth.
The frequency range varies between 535 to 1705 kHz	For FM it is from88 to 108 MHz mainly in the higher spectrum
Signal distortion can occur in AM	Less instances of signal distortion
Consists of two sidebands	An infinite number of sidebands
Circuit design is simple and less expensive	Circuit design is intricate and more expensive
Easily susceptible to noise	Less susceptible to noise

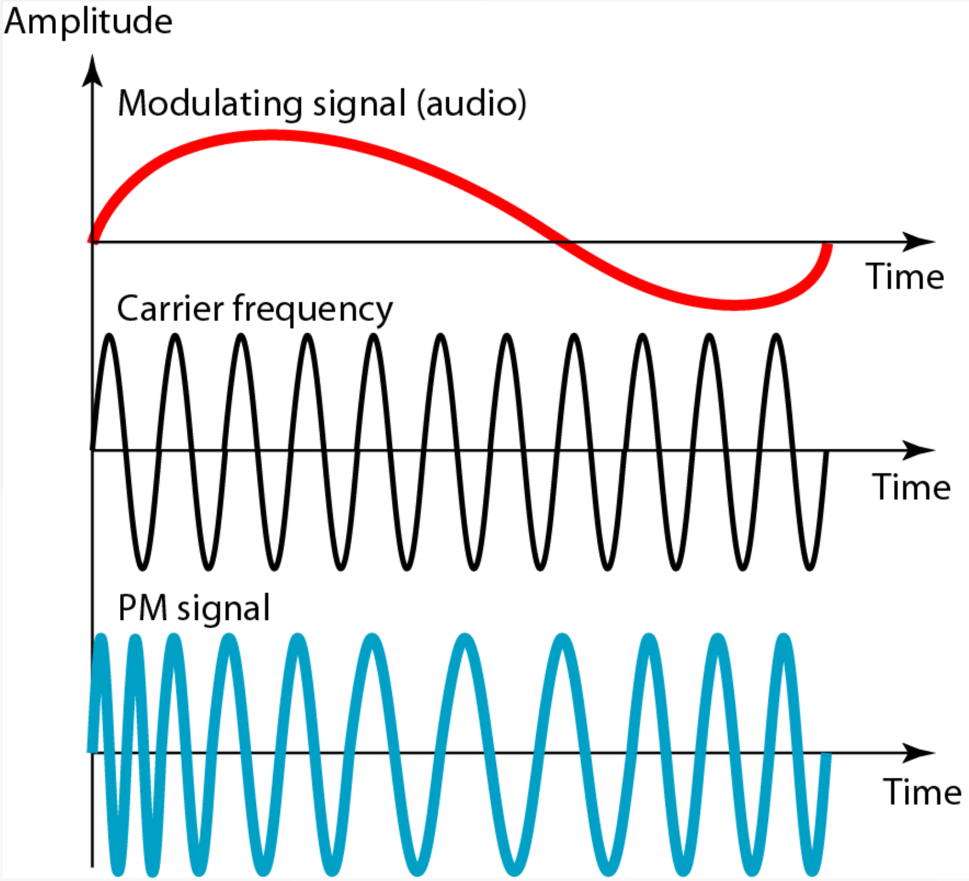
Phase Modulation (PM)

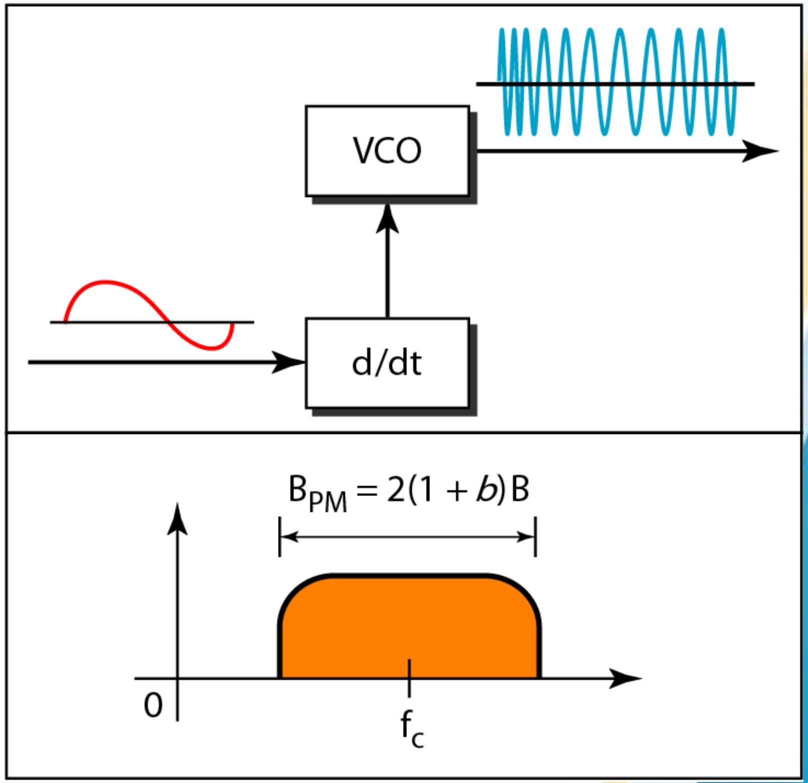
- The modulating signal only changes the phase of the carrier signal.

- The phase change manifests itself as a frequency change but the instantaneous frequency change is proportional to the derivative of the amplitude.

- The bandwidth is higher than for AM.

Phase modulation





The total bandwidth required for PM can be determined from the bandwidth and maximum amplitude of the modulating signal:

$$B_{PM} = 2(1 + \beta)B.$$

Where $\beta = 2$ most often.