MUTHAYAMMAL ENGINEERING COLLEGE

(An Autonomous Institution)

(Approved by AICTE, New Delhi, Accredited by NAAC & Affiliated to Anna University)
Rasipuram - 637 408, Namakkal Dist., Tamil Nadu

L - 1

LECTURE HANDOUTS

ECE | **I / II**

Course Name with Code : 19GES11 - ELECTRONIC DEVICES

Course Teacher : Dr. J.RANGARAJAN

Unit I : SEMICONDUCTOR DIODES **Date of Lecture:**

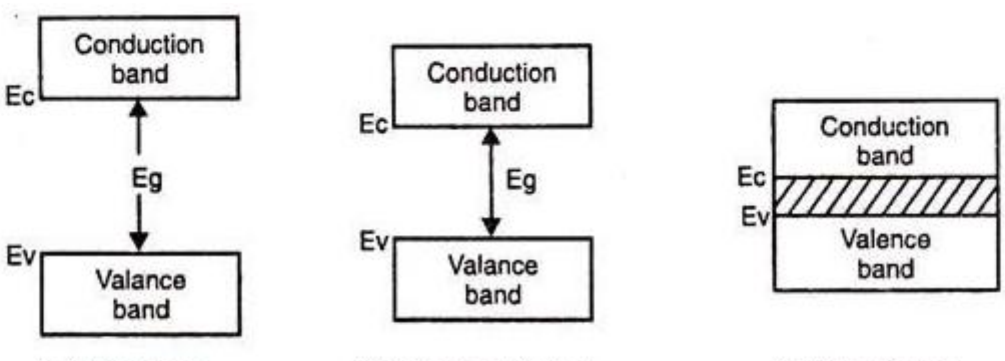
Topic of Lecture: Review of Semiconductor physics

Introduction: Semiconductors are materials which have a conductivity between conductors (generally metals) and nonconductors or insulators (such as most ceramics). Semiconductors can be pure elements, such as silicon or germanium, or compounds such as gallium arsenide or cadmium selenide.

Prerequisite knowledge for Complete understanding and learning of Topic:
Atomic structure, Energy band diagram, conductor and insulator

Detailed content of the Lecture:

- In an atom, electrons in the innermost orbits, which are filled, are called Valence electrons. On the other hand, electrons in the outer orbits that do not fill the shell completely are called Conduction electrons.
- The energy band which includes the energy levels of the valence electrons is called Valence band. Also, the energy band above it is called Conduction band.
- In case of metallic conductors, conduction band overlaps on the electrons in the valence band.
- In insulators, there is a large gap between both these bands. Hence, the electrons in the valence band remain bound and no free electrons are available in the conduction band.
- Semiconductors have a small gap between both these bands. Some valence electrons gain energy from external sources and cross the gap between the valence and conduction bands.



(a) Insulator (b) Semiconductor (c) Conductor

- Solids can be classified as metals, semiconductors or insulators based on conductivity or resistivity and energy bands in electronics.
- Semiconductors are materials which have a conductivity between conductors (generally metals) and nonconductors or insulators (such as most ceramics).

- Semiconductors can be pure elements, such as silicon or germanium, or compounds such as gallium arsenide or cadmium selenide.
- Semiconductors can be broadly classified into Intrinsic and Extrinsic Semiconductors.
- An Intrinsic Semiconductor is the purest form of a semiconductor, elemental, without any impurities.
- Extrinsic Semiconductors are semiconductors which conduct even at room temperature. This is achieved by adding impurities to the pure semiconductor.
- Doping is the process of adding impurities to intrinsic semiconductors to alter their properties.
- Crystals of Silicon and Germanium are doped using two types of dopants:

  Pentavalent (valency 5); like Arsenic (As), Antimony (Sb), Phosphorous (P), etc.

  Trivalent (valency 3); like Indium (In), Boron (B), Aluminium (Al), etc.

- An n-type semiconductor is created when pure semiconductors, like Si and Ge, are doped with pentavalent elements.

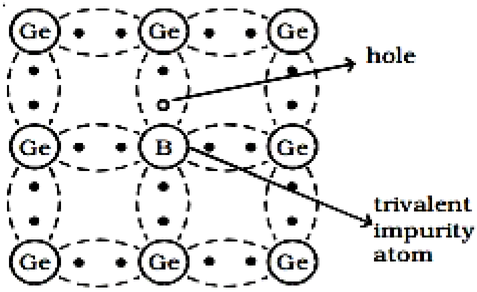


Fig a P-type semiconductor Fig

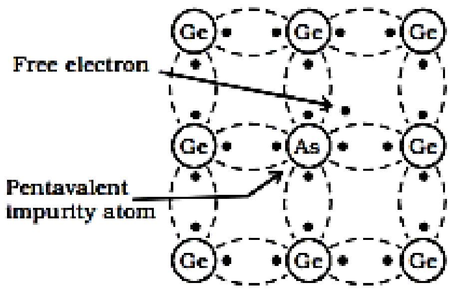


Fig a N-type semiconductor

- A p-type semiconductor is created when trivalent elements are used to dope pure semiconductors, like Si and Ge.

- The P stands for Positive, which means the semiconductor is rich in holes or Positive charged ions. The N stands for Negative, which means the semiconductor is rich in electrons or Negative charged ions.

Video Content / Details of website for further learning (if any):

1. http://community.wvu.edu/~dwgraham/classes/ee551/slides/semiconductor_overview.pdf
2. https://www.toppr.com/guides/physics/semiconductor-electronics-materials-device-and-simple-circuits/extrinsic-semiconductor/
3. https://nptel.ac.in/courses/117103063/

Important Books/Journals for further learning including the page nos.:

1. “Electronic Devices and Circuits”, Jacob Millman, Christos Halkias, McGraw Hill, Third Edition, 2001. (1-7)
2. “Electronic Devices”, Thomas L.Floyd, Prentice Hall, Ninth Edition, 2012. (Unit 1 and 2)

Course Teacher

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Course Name with Code : **19GES11 - ELECTRONIC DEVICES**

Course Teacher : **Dr. J.RANGARAJAN**

Unit I : **SEMICONDUCTOR DIODES** **Date of Lecture:**

Topic of Lecture: Drift and diffusion currents, Continuity Equation

Introduction: Drift current and diffusion current are the two types of currents flowing through the PN junction. Diffusion current flows due to the movement of particles from the region of high concentration towards the region of low concentration. Drift current is the flow of current due to the application of external field.

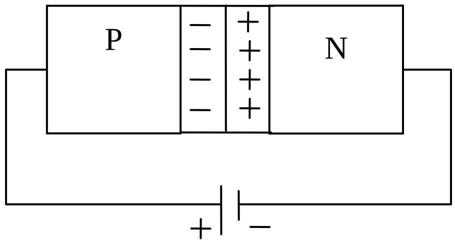
Prerequisite knowledge for Complete understanding and learning of Topic:

Energy band diagram, PN junction, Barrier potential

Detailed content of the Lecture:

Drift Current

- Drift Current: The applied electric field will accelerate the carrier and produce a net movement of charges. This movement of charge carrier due to the applied electric field is called Drift current.



Let P be the charge density and V_d be the drift velocity.
Then, Drift volume current density due to holes is given by

$$J_p\,(drift) = PV_{dp}$$

Where, $P = qp$

q = charge of electron = 1.602×10^{-19} coulomb.

p = Number of holes per cubic cm.

V_{dp} = Average drift velocity of holes = $\mu_p E$,

where μ_p = mobility of hole

Similarly, charge density due to electron is given by,

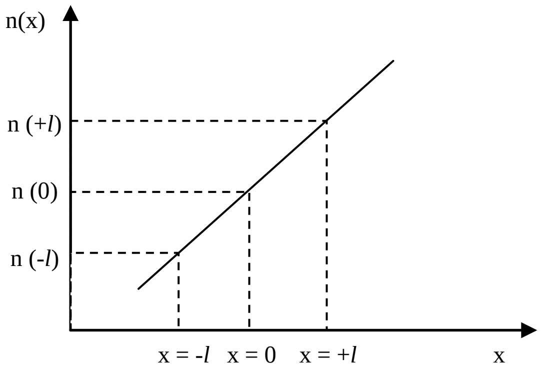
$$J_n\,(drift) = q\,\mu_n nE$$

Therefore,

Total drift current $J\,(drift) = q\,(\mu_n n + \mu_p P)\,E$

Diffusion Current

- Diffusion is the process of flow of particles from the region of high concentration towards the region of low concentration. This movement of charge particles will results in the diffusion current.



- The above graph depicts the variation of electron concentration with respect to distance.

- Diffusion current due to electron and holes are given by,

$$J_n(\text{diffusion}) = +q D_n \frac{dn}{dx}$$

$$J_p(\text{diffusion}) = -q D_p \frac{dp}{dx}$$

- The **total current density** in the semiconductor is due to the sum of the drift and diffusion current density.

For holes, $J_p = q\mu_p PE - qD_p \frac{dp}{dx}$

For electron, $J_n = q\mu_n nE + qD_n \frac{dn}{dx}$

Video Content / Details of website for further learning (if any):

1. http://www.sciencecampus.com/engineering/electronics/semiconductor_theory
2. https://www.tutorialspoint.com/electronic_circuits
3. https://nptel.ac.in/courses/117103063/

Important Books/Journals for further learning including the page nos.:

1. "Electronic Devices and Circuits", S.Salivahanan, N.Sureshkumar and A.Vallavaraj, Tata McGraw Hill, 2nd Edition, 2008. (84-86)
2. "Electronic Devices", Thomas L.Floyd, Prentice Hall, Ninth Edition, 2012. (Unit 1 and 2)

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L - 3

LECTURE HANDOUTS

ECE **I / II**

Course Name with Code : 19GES11 - ELECTRONIC DEVICES
Course Teacher : Dr. J.RANGARAJAN
Unit I : SEMICONDUCTOR DIODES **Date of Lecture:**

Topic of Lecture: Theory of PN Junction Diode, Diode Current Equation

Introduction: Diode is a semiconductor device that allows the current to pass through it in one direction and will not allow in other direction. It is formed by joining the P type and N type semiconductor together. The current that is flowing through the diode is governed by the diode current equation.

knowledge for Complete understanding and learning of Topic:

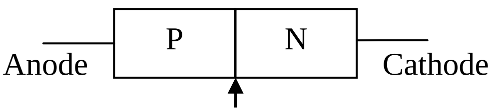
Atomic structure, Energy band diagram, P type and N type semiconductor

Detailed content of the Lecture:

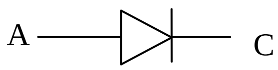
PN junction Diode

- Diode is a semiconductor device that allows the current to pass through it in one direction and will not allow in other direction.
- The diode which is formed by doping one half by P type impurity and other half by N – type impurity is called *PN junction diode*.

Structure of PN junction Diode ***Symbol***

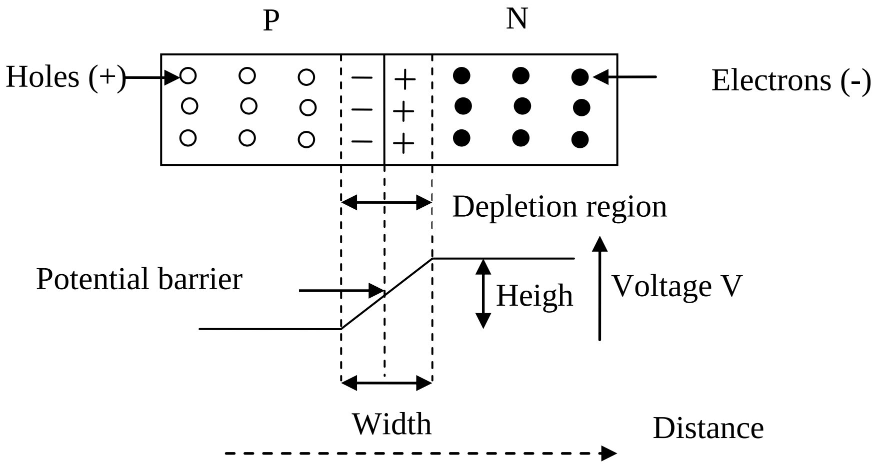


PN junction (or) metallurgical junction



- The interface that separate N and P region is referred to as the PN junction (or) metallurgical junction.
- Electron in the N region will try to move towards P region and holes in the P region will try to move towards N region, which result in the diffuse of electron on P – side and diffuse of holes on N – side. This process is called **Diffusion.**
- Thus, the movement of the mobile charge carriers to the junction due to the difference in the concentration resulting in a region called depletion region.
- The depletion region (or) space region (or) transition region which is formed near the junction will restricts the movement of electrons and holes towards P region and N region
- An electrostatic potential difference is created near the metallurgical junction which is known as potential barrier, junction barrier, diffusion potential (or) contact potential (VB).
- This is due of the diffused oppositely charged ions present on both sides of PN junction.
- Depletion region is of 0.5 µm thickness and the magnitude of contact potential, potential barrier , junction barrier (or) diffusion potential Vo is of 0.3 v for Ge and 0.7 v for Si.

PN junction diode and formation of depletion region



- **Forward biasing:** If the positive terminal of the voltage source is connected to the P type side and negative terminal of the voltage source is connected to the N type of the junction diode. Then the biasing is known as forward biasing.

- **Reverse biasing:** If the positive terminal of the voltage source is connected to the N side and negative terminal of the voltage source is connected to the P – side of the junction diode. Then the biasing is known as Reverse Biasing.

- **Peak inverse voltage:** It is the maximum reverse voltage that can be applied to the PN junction without damage to the junction.

Diode current equation

The diode current equation relating the voltage V and current I is given by

$$I = I_0 * [\exp (qV / n*k*T) - 1]$$

Where,

I – diode current
I_0 – diode reverse saturation current at room temperature
q – charge of electron (1.6x10^-19 C)
V – external voltage applied to the diode
K – Boltzmann's constant (1.38066x10^-23 J/K)
T – temperature of the diode junction
n - n is a junction constant (typically around 2 for diodes, 1 for transistors)

Video Content / Details of website for further learning (if any):

1. https://www.tutorialspoint.com/electronic_circuits
2. https://www.electronicshub.org/characteristics-and-working-of-p-n-junction-diode
3. https://nptel.ac.in/courses/117103063/

Important Books/Journals for further learning including the page nos.:

1. "Electronic Devices and Circuits", S.Salivahanan, N.Sureshkumar and A.Vallavaraj, Tata McGraw Hill, 2nd Edition, 2008. (84-98)
2. "Electronic Devices", Thomas L.Floyd, Prentice Hall, Ninth Edition, 2012. (Unit 1 and 2)

Course Teacher

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Course Name with Code : **19GES11 - ELECTRONIC DEVICES**

Course Teacher : **Dr. J.RANGARAJAN**

Unit I : **SEMICONDUCTOR DIODES** **Date of Lecture:**

Topic of Lecture: Current Voltage Characteristics

Introduction: The current-voltage or VI characteristic of a PN diode is the graphical representation of how the diode behalves in the forward and reverse bias condition.

Prerequisite knowledge for Complete understanding and learning of Topic:

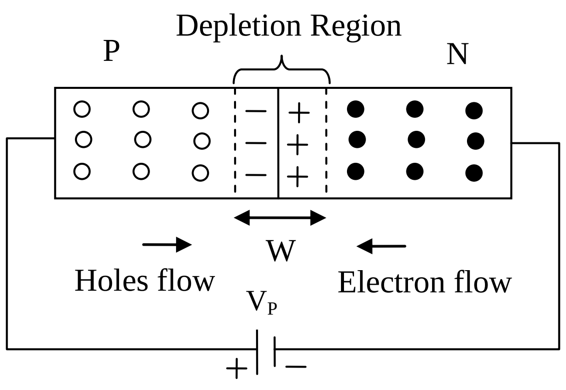
PN Diode, Depletion Region, Biasing

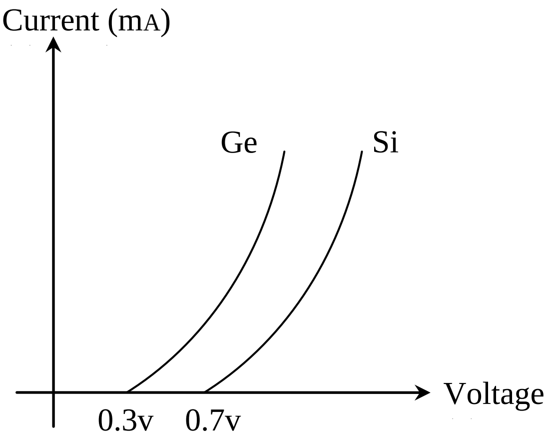
Detailed content of the Lecture:

- Applying external voltage of proper magnitude is known as Biasing.

(i) Forward Bias

- If the positive terminal of the voltage source is connected to the P type side and negative terminal of the voltage source is connected to the N type side of the junction diode. Then the biasing is known as ***forward biasing.***
- Positive potential which is applied to the P type side repels the holes towards the junction.
- Negative potential which is applied to the N type side repels the electrons towards the junction.



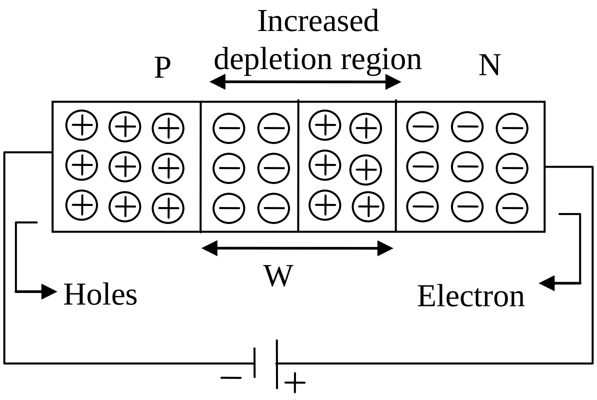


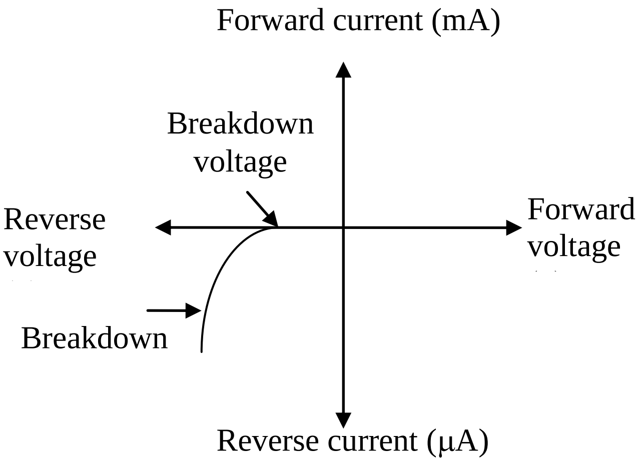
Characteristics of forward bias

- When the applied potential (V_P) is less than Potential Barrier (V_B), the potential barrier prevents the holes and electrons to move on opposite side. Hence there will be no increases in current till threshold voltage.
- When the applied potential (V_P) is greater than Potential Barrier (V_B), the potential barrier disappears completely makes the electron to move towards positive terminal and holes towards negative potential results in large current flow.

(ii) Reverse Bias

- If the positive terminal of the voltage source is connected to the N type side and negative terminal of the voltage source is connected to the P type side of the junction diode. Then the biasing is known as ***Reverse Biasing***.





Characteristics of reverse bias

- Negative potential which is applied to the P- type side attract the holes towards the negative terminal.
- Positive potential which is applied to the N type side attract the electrons towards the positive terminal.
- This results in the increases in the depletion region
- When the Reverse bias is increased. The depletion region increases. Therefore this offers high resistivity in the region.
- Theoretically there is no current flow, but practically a small microampere current flows due to minority carrier this is known as reverse saturation currents.
- The minority carrier obtains enough kinetic energy to break the junction and hence a large reverse current flows after the particular Voltage.
- This is due to the breakdown at the junction and this voltage is known as ***Breakdown Voltage.***

Video Content / Details of website for further learning (if any):

1. https://www.tutorialspoint.com/electronic_circuits
2. https://www.electronicshub.org/characteristics-and-working-of-p-n-junction-diode
3. https://nptel.ac.in/courses/117103063/

Important Books/Journals for further learning including the page nos.:

1. “Electronic Devices and Circuits”, Jacob Millman, Christos Halkias, McGraw Hill, Third Edition, 2001, (124-126)
2. “Electronic Devices”, Thomas L.Floyd, Prentice Hall, Ninth Edition, 2012. (Unit 1 and 2)

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Course Name with Code : 19GES11 - ELECTRONIC DEVICES

Course Teacher : Dr. J.RANGARAJAN

Unit I : SEMICONDUCTOR DIODES **Date of Lecture:**

Topic of Lecture: Effect of Temperature on PN Junction diodes

Introduction: PN junction diode parameters like reverse saturation current, bias current, reverse breakdown voltage and barrier voltage are dependent on temperature. With the increase in temperature, the intrinsic carrier concentration increases. Therefore, the barrier potential is decreased and in turn the current conduction starts at earlier stage.

Prerequisite knowledge for Complete understanding and learning of Topic:
PN diode, Barrier potential, Diode Characteristic

Detailed content of the Lecture:

Forward Bias

- With the increase in temperature, the intrinsic carrier concentration increases.
- This pushes the fermi level closer to the intrinsic fermi level (the middle of the band gap).
- The fermi level in each region moves closer to the middle of the gap, and the built-on potential is decreased.

Reverse Bias

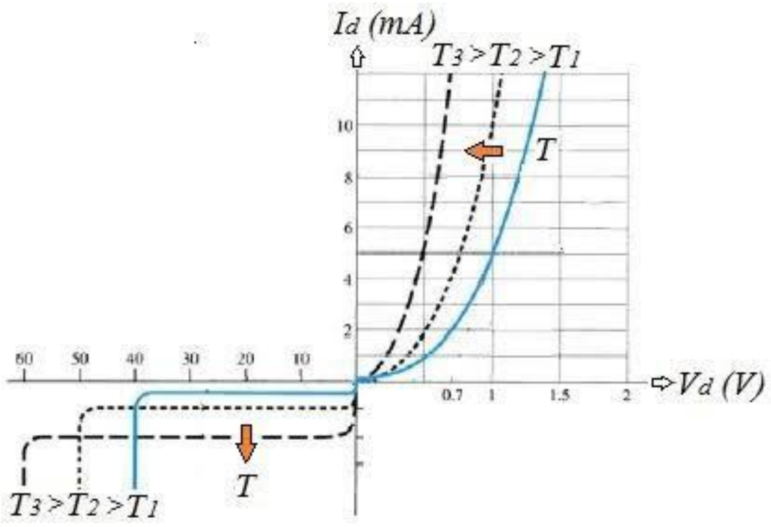
- Intrinsic concentration would increase with increase in temperature and hence minority charges also increase with increase in temperature.
- The reverse current depends on minority carriers. Hence as the number of minority charge carriers increase, the reverse current would also increase with temperature
- PN junction diode parameters like reverse saturation current, bias current, reverse breakdown voltage and barrier voltage are dependent on temperature.
- Mathematically diode current is given by

$$I = I_0 * [\exp(qV / n*k*T) - 1]$$

Where,

I – diode current
I_0 – diode reverse saturation current at room temperature
q – charge of electron (1.6x10^-19 C)
V – external voltage applied to the diode
K – Boltzmann's constant (1.38066x10^-23 J/K)
T – temperature of the diode junction
n - n is a junction constant (typically around 2 for diodes, 1 for transistors)

- Hence, the current should decrease with increase in temperature but exactly opposite occurs. There are two reasons:
  - Rise in temperature generates more electron-hole pair thus conductivity increases and thus increase in current
  - Increase in reverse saturation current with temperature offsets the effect of rise in temperature
- Reverse saturation current (I_S) of diode increases with increase in the temperature. The rise is 7ºC for both germanium and silicon and approximately doubles for every 10ºC rise in temperature.
- Thus if we kept the voltage constant, as we increase temperature the current increases.
- Barrier voltage is also dependent on temperature and it decreases by 2mV/ºC for germanium and silicon.
- Reverse breakdown voltage (V_R) also increases with the increase in temperature.



Video Content / Details of website for further learning (if any):

1. https://www.electronicshub.org/characteristics-and-working-of-p-n-junction-diode/
2. https://www.tutorialspoint.com/electronic_circuits/electronic_positive_clipper_circuits.htm
3. https://nptel.ac.in/courses/117103063/

Important Books/Journals for further learning including the page nos.:

1. "Electronic Devices and Circuits", S.Salivahanan, N.Sureshkumar and A.Vallavaraj, Tata McGraw Hill, 2nd Edition, 2008. (111-112)
2. "Electronic Devices", Thomas L.Floyd, Prentice Hall, Ninth Edition, 2012. (Unit 1 and 2)

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L - 6

LECTURE HANDOUTS

ECE | **I / II**

Course Name with Code : 19GES11 - ELECTRONIC DEVICES

Course Teacher : Dr. J.RANGARAJAN

Unit I : SEMICONDUCTOR DIODES **Date of Lecture:**

Topic of Lecture: Diffusion Capacitance, Applications of diode

Introduction: Diffusion capacitance occurs in a forward biased p-n junction diode. Diffusion capacitance is also referred as storage capacitance. The diffusion capacitance occurs due to stored charge of minority electrons and minority holes near the depletion region. In a forward biased diode, diffusion capacitance is much larger than the transition capacitance.

Prerequisite knowledge for Complete understanding and learning of Topic:

Energy band diagram, Barrier region, PN diode, Biasing

Detailed content of the Lecture:

- In a p-n junction diode, two types of capacitance take place. They are,
  - Transition capacitance (C_T)
  - Diffusion capacitance (C_D)

Transition capacitance (C_T)

- The amount of capacitance changed with increase in voltage is called transition capacitance. The transition capacitance is also known as depletion region capacitance, junction capacitance or barrier capacitance.
- Transition capacitance is denoted as C_T.
- Just like the capacitors, a reverse biased p-n junction diode also stores electric charge at the depletion region.
- The depletion region is made of immobile positive and negative ions.
- In a reverse biased p-n junction diode, the p-type and n-type regions have low resistance.
- Hence, p-type and n-type regions act like the electrodes or conducting plates of the capacitor.
- The depletion region of the p-n junction diode has high resistance.
- Hence, the depletion region acts like the dielectric or insulating material.
- Thus, p-n junction diode can be considered as a parallel plate capacitor.

Diffusion capacitance (C_D)

- Diffusion Capacitance is the capacitance due to transport of charge carriers between two terminals of a device, for example, the diffusion of carriers from anode to cathode in forward bias mode of a diode
- In the forward biased diode, the potential barrier at the junction gets lowered.

- As a result, holes get injected from the P-side to the N-side and electron get injected from the N-side to the P-side.
- These injected charges get stored near the junction just outside the depletion layer, holes in the N-region and electrons in the P-region.
- Due to charge storage, the voltage lags behind the current producing the capacitance effect.
- Such a capacitance is called **diffusion capacitance or storage capacitance** [C_D].
- In a general case, diffusion constant C_D is caused by diffusion of both the holes in the n-regions and electrons in the P-region
- The diffusion capacitance C_D may be defined as the rate of change of injected charge with voltage.

$$C_D = dQ / dV$$

Where,

C_D = Diffusion capacitance
dQ = Change in number of minority carriers stored outside the depletion region
dV = Change in voltage applied across diode

- Diffusion capacitance is always smaller than transition capacitance, both are few tens of pico farads.
- In a forward biased diode, the transition capacitance exist. However, the transition capacitance is very small compared to the diffusion capacitance. Hence, transition capacitance is neglected in forward biased diode.

PN Junction diode application:

1. Switching element in logical circuit.
2. In power supplies, it is used as rectifier and voltage regulator.
3. LED and LASER, a form PN junction diode is commonly used in optical communication.
4. It is used as an oscillator in microwave circuit and tuning element in receiver circuit.

Video Content / Details of website for further learning (if any):

1. https://www.physics-and-radio-electronics.com/electronic-devices-and-circuits/semiconductor-diodes/junctioncapacitance-transitioncapacitance-diffusioncapacitance.html
2. https://bestengineeringprojects.com/transition-capacitance-and-diffusion-capacitance-of-diode/
3. https://nptel.ac.in/courses/117103063/

Important Books/Journals for further learning including the page nos.:

1. “Electronic Devices and Circuits”, S.Salivahanan, N.Sureshkumar and A.Vallavaraj, Tata McGraw Hill, 2nd Edition, 2008. (109-110)
2. “Electronic Devices”, Thomas L.Floyd, Prentice Hall, Ninth Edition, 2012. (Unit 1 and 2)

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LECTURE HANDOUTS

L – 7A

ECE

I / II

Course Name with Code : 19GES11 - ELECTRONIC DEVICES

Course Teacher : Dr. J.RANGARAJAN

Unit I : SEMICONDUCTOR DIODES **Date of Lecture:**

Topic of Lecture: Rectifiers

Introduction: An alternating current has the property to change its state continuously. But during the process of rectification, this alternating current is changed into direct current DC. The wave which flows in both positive and negative direction then will get its direction restricted only to positive direction, when converted to DC.

Prerequisite knowledge for Complete understanding and learning of Topic:
PN Diode, Biasing, Transformer

Detailed content of the Lecture:

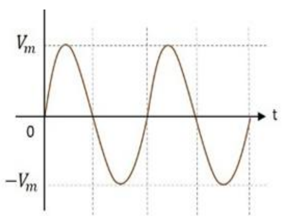
Rectifier

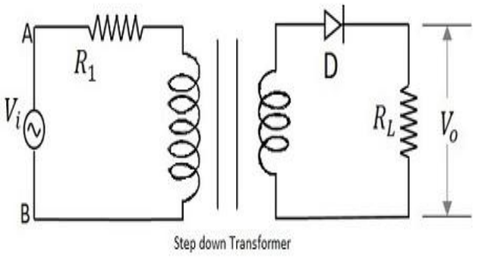
- Rectifier is a circuit which converts an alternating current into a direct current.
- There are two main types of rectifier circuits, depending upon their output. They are
  - **Half-wave Rectifier** and • **Full-wave Rectifier**
- A Half-wave rectifier circuit rectifies only positive half cycles of the input supply whereas a Full-wave rectifier circuit rectifies both positive and negative half cycles of the input supply.

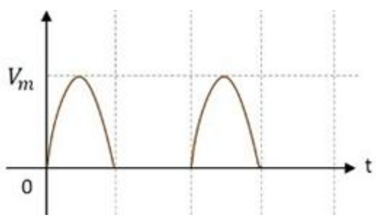
Half-wave Rectifier

- The name half-wave rectifier itself states that the rectification is done only for half of the cycle.
- The AC signal is given through an input transformer which steps up or down according to the usage. Mostly a step down transformer is used in rectifier circuits, so as to reduce the input voltage.

Input Waveform **Rectifier Circuit** **Output Waveform**







- The input signal is given to the transformer which reduces the voltage levels.
- The output from the transformer is given to the diode which acts as a rectifier.
- This diode gets ON and conducts for positive half cycles of input signal.
- Hence a current flows in the circuit and there will be a voltage drop across the load resistor.
- The diode gets OFF and does not conduct for negative half cycles.
- Hence, the output for negative half cycles will be, $i_D = 0$ and Vo = 0.

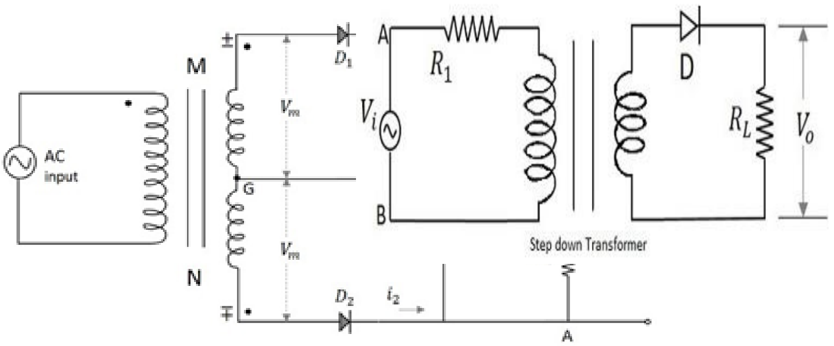
Full-Wave Rectifier

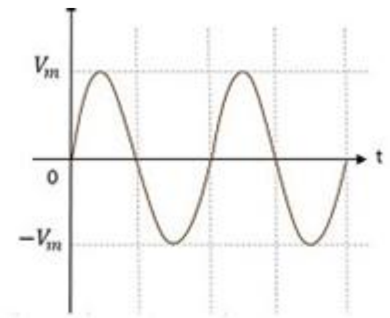
- A Rectifier circuit that rectifies both the positive and negative half cycles can be termed as a full wave rectifier as it rectifies the complete cycle.
- The construction of a full wave rectifier can be made in two types. They are
  - (i) Center-tapped Full wave rectifier
  - (ii) Bridge full wave rectifier

(i) Center-tapped full wave rectifier

- A rectifier circuit whose transformer secondary is tapped to get the desired output voltage, using two diodes alternatively, to rectify the complete cycle is called as a Center-tapped Full wave rectifier circuit.

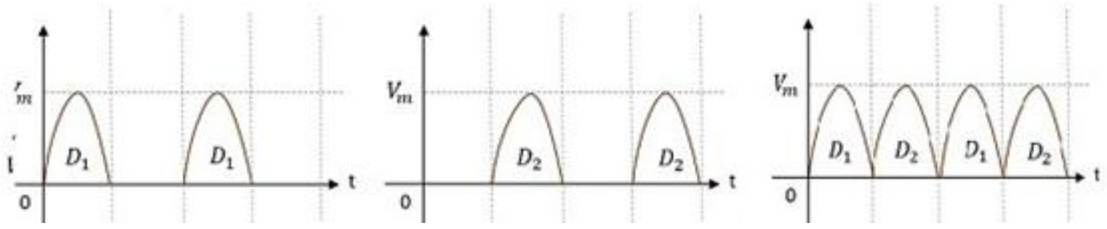
Rectifier Circuit **Input Waveform**





- When the positive half cycle of the input voltage is applied, the point M at the transformer secondary becomes positive with respect to the point N.
- This makes the diode D_1 forward biased. Hence current i_1 flows through the load resistor from A to B. Therefore, positive half cycles flows to the output**.**
- When the negative half cycle of the input voltage is applied, the point M at the transformer secondary becomes negative with respect to the point N.
- This makes the diode D_2 forward biased. Hence current i_2 flows through the load resistor from A to B. Therefore, the positive half cycles flows in the output, even during the negative half cycles of the input.

Output Waveforms

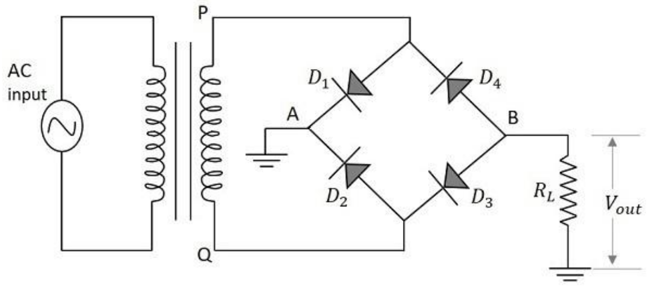


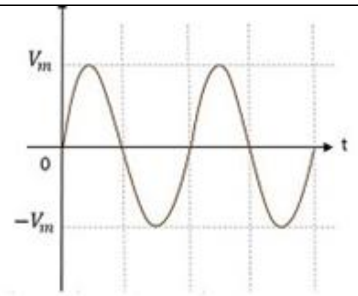
Disadvantages

- Location of center-tapping is difficult
- The dc output voltage is small
- PIV of the diodes should be high

(ii) Bridge Full-Wave Rectifier

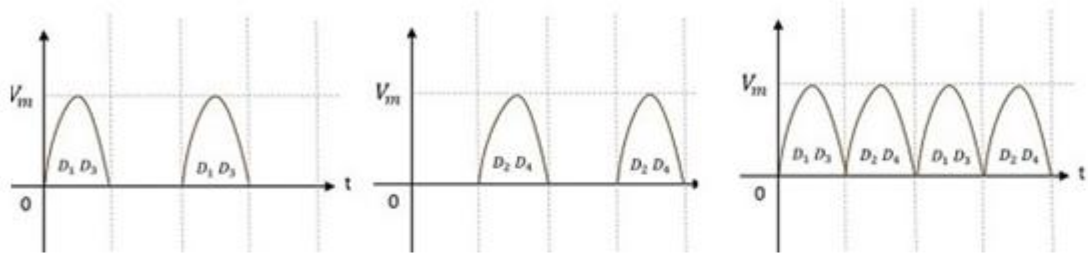
- This is such a full wave rectifier circuit which utilizes four diodes connected in bridge form.
- There is no need of any center-tapping of the transformer in this circuit.
- Four diodes called D_1, D_2, D_3 and D_4 are used in constructing a bridge type network so that two of the diodes conduct for one half cycle and two conduct for the other half cycle of the input supply.





- When the positive half cycle of the input supply is given, point P becomes positive with respect to the point Q.
- This makes the diode D_1 and D_3 forward biased while D_2 and D_4 reverse biased.
- Hence the diodes $_{D1}$ and $_{D3}$ conduct during the positive half cycle of the input supply to produce the output along the load resistor.
- As two diodes work in order to produce the output, the voltage will be twice the output voltage of the center tapped full wave rectifier.
- When the negative half cycle of the input supply is given, point P becomes negative with respect to the point Q.
- This makes the diode D_1 and D_3 reverse biased while D_2 and D_4 forward biased.
- The current flows through the load in the same direction as during the positive half cycle of the input.

Output Waveforms



Advantages

- No need of center-tapping.
- The dc output voltage is twice that of the center-tapper FWR.
- PIV of the diodes is of the half value that of the center-tapper FWR.
- The design of the circuit is easier with better output.

Video Content / Details of website for further learning (if any):

1. https://www.tutorialspoint.com/electronic_circuits
2. https://www.electronicshub.org
3. https://nptel.ac.in/courses/117103063

Important Books/Journals for further learning including the page nos.:

1. "Electronic Devices and Circuits", S.Salivahanan, N.Sureshkumar and A.Vallavaraj, Tata McGraw Hill, 2nd Edition, 2008. (619-628)
2. "Electronic Devices", Thomas L.Floyd, Prentice Hall, Ninth Edition, 2012. (Unit 1 and 2)

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LECTURE HANDOUTS

ECE | **I / II**

Course Name with Code : 19GES11 - ELECTRONIC DEVICES

Course Teacher : Dr. J.RANGARAJAN

Unit I : SEMICONDUCTOR DIODES **Date of Lecture:**

Topic of Lecture: Clippers

Introduction: A Clipper circuit is a circuit that rejects the part of the input wave specified while allowing the remaining portion. The portion of the wave above or below the cut off voltage determined is clipped off or cut off. The clipping circuits consist of linear and non-linear elements like resistors and diodes but not energy storage elements like capacitors.

Prerequisite knowledge for Complete understanding and learning of Topic:
PN Diode, Biasing

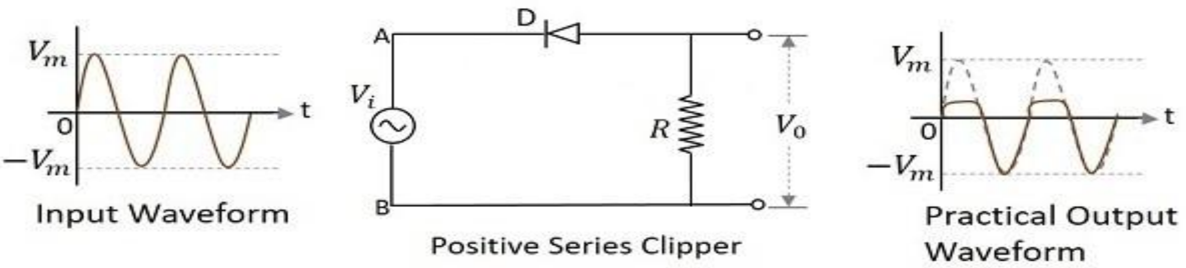
Detailed content of the Lecture:

Clipper Circuits

- A Clipper circuit is a circuit that rejects the part of the input wave specified while allowing the remaining portion.
- The main advantage of clipping circuits is to eliminate the unwanted noise present in the amplitudes.
- These can work as square wave converters, as they can convert sine waves into square waves by clipping.
- The amplitude of the desired wave can be maintained at a constant leve

(i) Positive Series Clipper

- A Clipper circuit in which the diode is connected in series to the input signal and that attenuates the positive portions of the waveform, is termed as **Positive Series Clipper**.



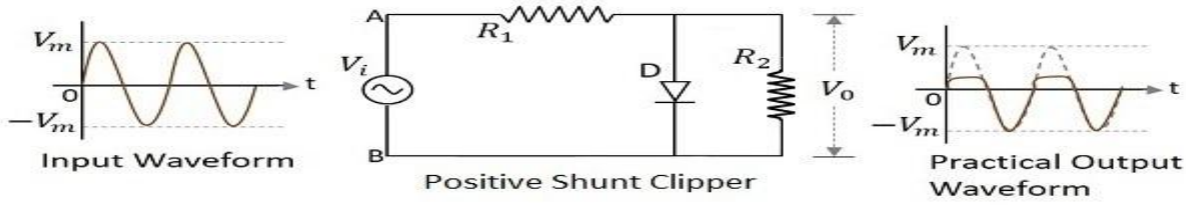
Positive Cycle of the Input

- When the input voltage is applied, the positive cycle of the input makes the point A in the circuit positive with respect to the point B.
- This makes the diode reverse biased and hence it behaves like an open switch.
- Thus the voltage across the load resistor becomes zero as no current flows through it and hence V_0 will be zero.

Negative Cycle of the Input

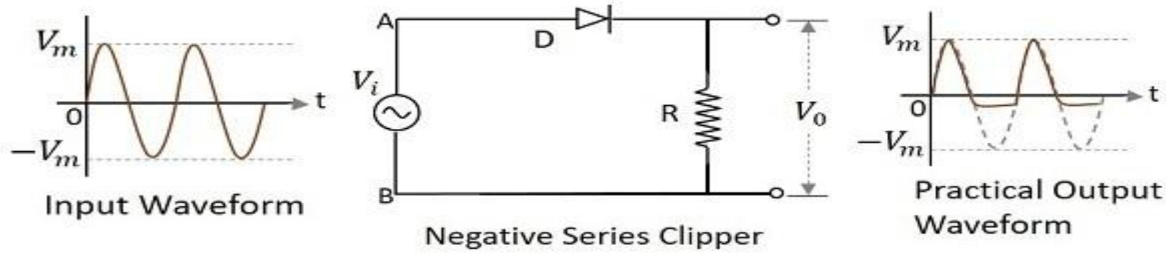
- The negative cycle of the input makes the point A in the circuit negative with respect to the point B. This makes the diode forward biased and hence it conducts like a closed switch.
- Thus the voltage across the load resistor will be equal to the applied input voltage as it completely appears at the output V_0.

(ii)Positive Shunt Clipper



(iii)Negative Series Clipper

- The Clipper circuit that is intended to attenuate negative portions of the input signal can be termed as a Negative Clipper.
- A Clipper circuit in which the diode is connected in series to the input signal and that attenuates the negative portions of the waveform, is termed as Negative Series Clipper.



Positive Cycle of the Input

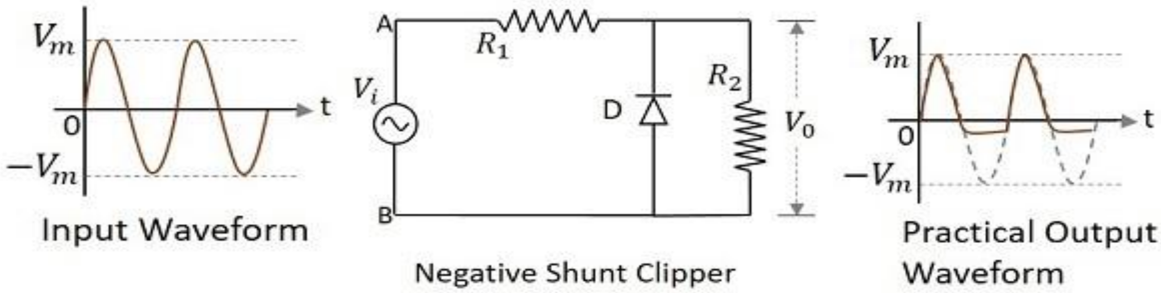
- When the input voltage is applied, the positive cycle of the input makes the point A in the circuit positive with respect to the point B.
- This makes the diode forward biased and hence it acts like a closed switch. Thus the input voltage completely appears across the load resistor to produce the output V_0.

Negative Cycle of the Input

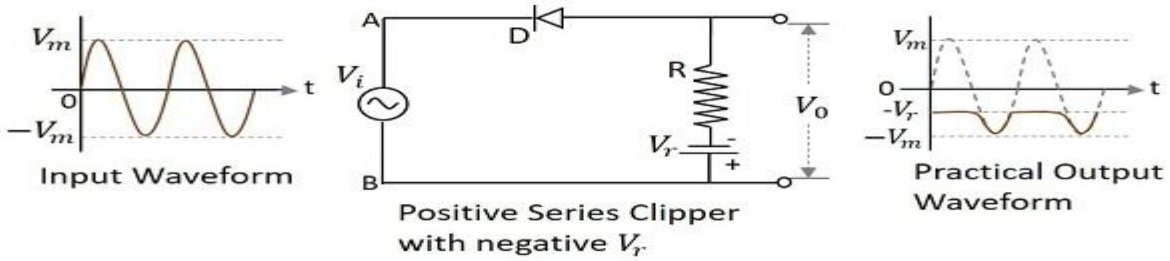
- The negative cycle of the input makes the point A in the circuit negative with respect to the point B.
- This makes the diode reverse biased and hence it acts like an open switch. Thus the voltage across the load resistor will be zero making V_0 zero.

(iv)Negative Shunt Clipper

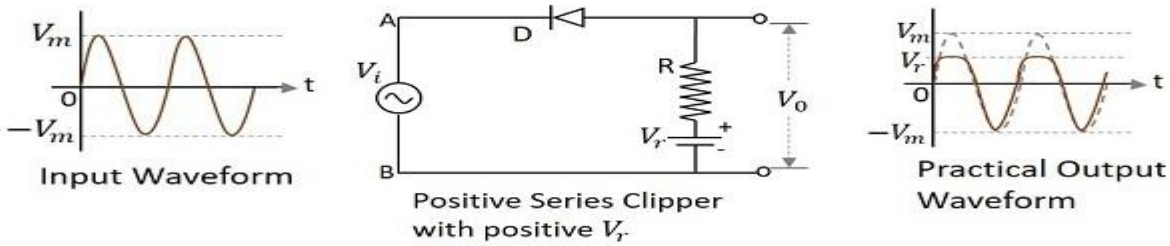
- A Clipper circuit in which the diode is connected in shunt to the input signal and that attenuates the negative portions of the waveform, is termed as Negative Shunt Clipper.



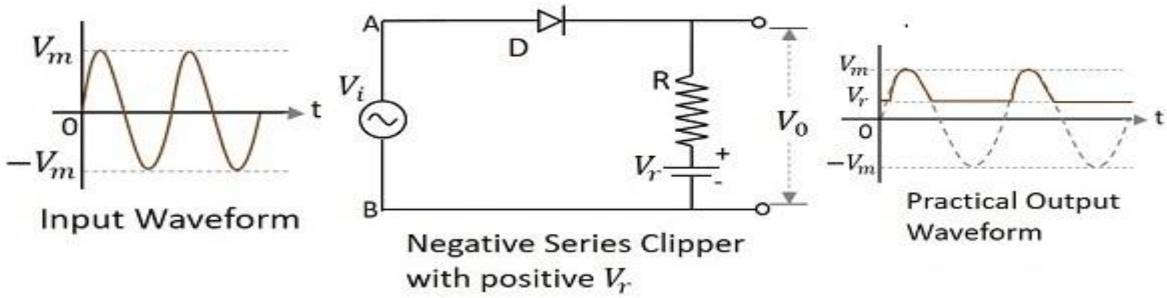
(v)Biased Clipper : Positive Clipper with negative Vr



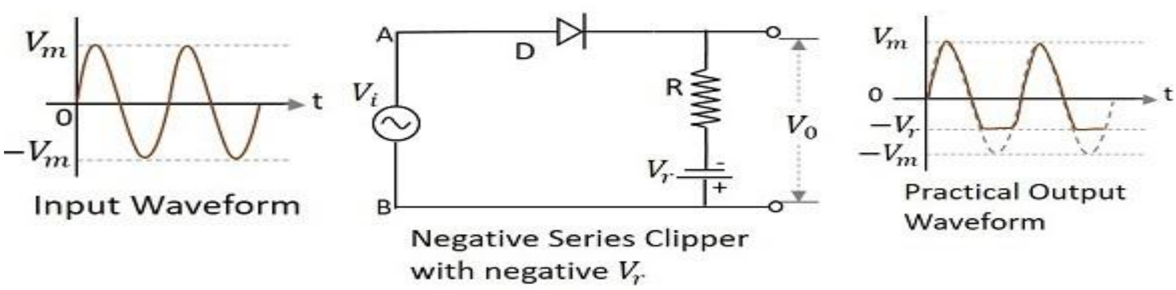
(vi)Biased Clipper : Positive Clipper with positive Vr



(vii)Negative Series Clipper with positive Vr



(viii)Negative Series Clipper with negative Vr



Video Content / Details of website for further learning (if any):

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Rasipuram - 637 408, Namakkal Dist., Tamil Nadu

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L - 8

LECTURE HANDOUTS

ECE | **I / II**

Course Name with Code : 19GES11 - ELECTRONIC DEVICES

Course Teacher : Dr. J.RANGARAJAN

Unit I : SEMICONDUCTOR DIODES **Date of Lecture:**

Topic of Lecture: Clampers, Avalanche Breakdown Mechanism

Introduction: A Clamper Circuit is a circuit that adds a DC level to an AC signal. Actually, the positive and negative peaks of the signals can be placed at desired levels using the clamping circuits. As the DC level gets shifted, a clamper circuit is called as a Level Shifter.

Prerequisite knowledge for Complete understanding and learning of Topic:
PN diode, Capacitor, Biasing

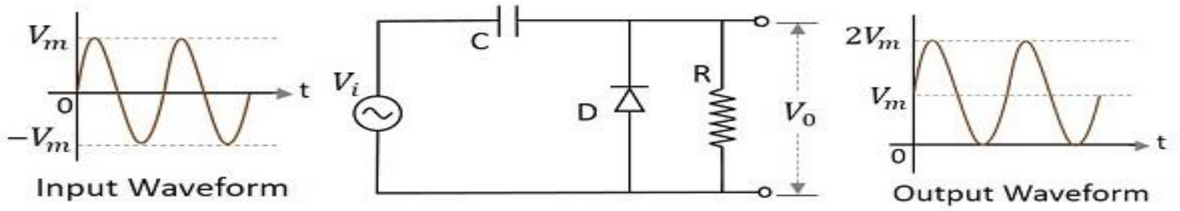
Detailed content of the Lecture:

Clamper circuit

- Clamper circuits consist of energy storage elements like capacitors.
- A simple clamper circuit comprises of a capacitor, a diode, a resistor and a dc battery if required.
- A Clamper circuit can be defined as the circuit that shifts the waveform to a desired DC level without changing the actual appearance of the applied signal.
- In order to maintain the time period of the wave form, the Ʈ must be greater than, half the time period of the capacitor. [Ʈ = RC]
- The time constant of charge and discharge of the capacitor determines the output of a clamper circuit.
- The DC component present in the input is rejected when a capacitor coupled network is used as a capacitor blocks dc as a capacitor blocks dc. Hence when **dc** needs to be **restored**, clamping circuit is used.

Positive Clamper Circuit

- When a negative peak of the signal is raised above to the zero level, then the signal is said to be **positively clamped**.
- A Positive Clamper circuit is one that consists of a diode, a resistor and a capacitor and that shifts the output signal to the positive portion of the input signal.

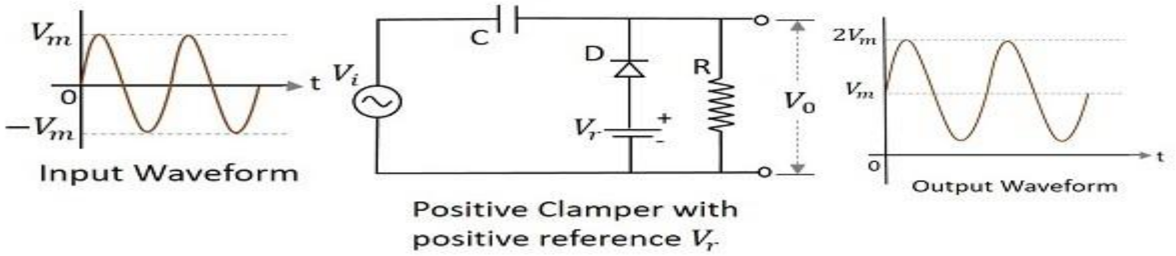


Positive Clamper circuit

- Initially when the input is given, the capacitor is not yet charged and the diode is reverse biased.
- During the negative half cycle, at the peak value, the capacitor gets charged with negative on one plate and positive on the other.
- The capacitor is now charged to its peak value Vm. The diode is forward biased and conducts heavily.
- During the next positive half cycle, the capacitor is charged to positive Vm while the diode gets reverse biased and gets open circuited.
- The output of the circuit at this moment will be V_0 = Vi + Vm
- Hence the signal is positively clamped as shown in the figure.
- The output signal changes according to the changes in the input, but shifts the level according to the charge on the capacitor, as it adds the input voltage.

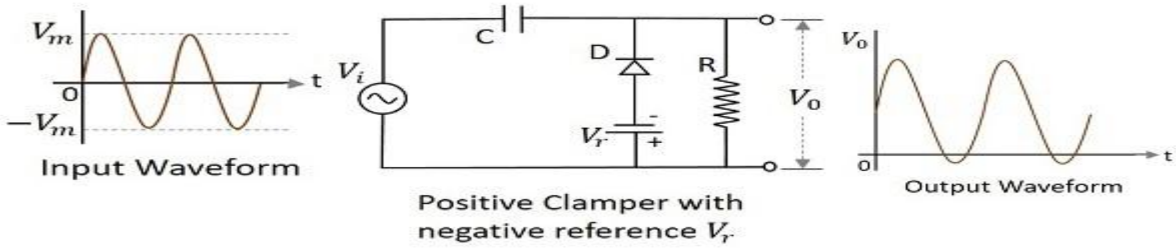
Positive Clamper with Positive V_r

- A Positive clamper circuit if biased with some positive reference voltage, that voltage will be added to the output to raise the clamped level.



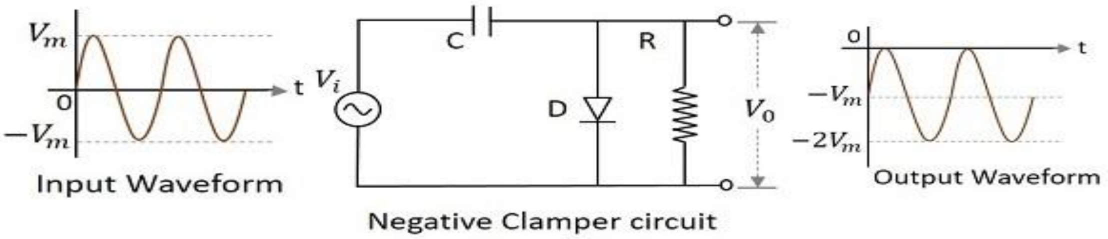
Positive Clamper with Negative Vr

- A Positive clamper circuit if biased with some negative reference voltage, that voltage will be added to the output to raise the clamped level.



Negative Clamper

- A Negative Clamper circuit is one that consists of a diode, a resistor and a capacitor and that shifts the output signal to the negative portion of the input signal.
- During the positive half cycle, the capacitor gets charged to its peak value Vm. The diode is forward biased and conducts.



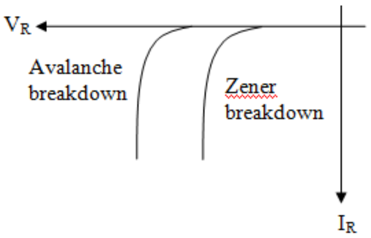
- During the negative half cycle, the diode gets reverse biased and gets open circuited. The output of the circuit at this moment will be V_0 =Vi + Vm
- Hence the signal is negatively clamped as shown in the figure.

Avalanche Breakdown

- Avalanche Breakdown occurs due to avalanche multiplication.
- It occurs when the doping concentration is less of order 1 to 10^{8}.
- Under Reverse bias, the thermally generated carrier crosses the depletion region and acquires Kinetic energy from the applied voltage. This carrier collides with the crystal and disrupts the covalent band. This is known as ***Impact Ionization.***
- The new electron hole pair will be created apart from original carrier. The new carrier in turn collide with another crystal by acquiring enough energy from applied field will create electron hole pair.
- This process continues result in avalanche multiplication. This causes Breakdown known as ***avalanche Breakdown***.

Zener Breakdown

- This breakdown occurs in the heavily doped P and N region.
- When the strong electric field is applied, the direct rupture of covalent bond takes place produce new electron hale pair.
- The new electron hale pair so created will increases the reverse current.
- This reverse current increase at almost 6 volts for heavily doped diode at the field of order 2×107 v/m.
- This kind of breakdown occurs in heavily doped PN region is known as zener breakdown.
- Zener Breakdown occur less than 6 V where as Avalanche Breakdown occur greater than 6V.



Video Content / Details of website for further learning (if any):

1. https://www.tutorialspoint.com/electronic_circuits
2. https://www.physics-and-radio-electronics.com/electronic-devices-and-circuits
3. https://nptel.ac.in/courses/117103063/

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2. "Electronic Devices", Thomas L.Floyd, Prentice Hall, Ninth Edition, 2012. (Unit 1 and 2)

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LECTURE HANDOUTS

ECE | **I / II**

Course Name with Code : 19GES11 - ELECTRONIC DEVICES

Course Teacher : Dr. J.RANGARAJAN

Unit I : SEMICONDUCTOR DIODES **Date of Lecture:**

Topic of Lecture: Zener Diode as a Voltage Regulator

Introduction: Zener diode is a special purpose semiconductor PN junction device made of silicon, which is designed to operate in reverse biased condition by varying the doping concentration.

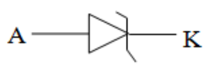
Prerequisite knowledge for Complete understanding and learning of Topic:
PN junction, Diode, Doping , Biasing

Detailed content of the Lecture:

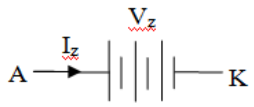
Zener Diode:

- ✓ The doping concentration of the Zener diode is high than the ordinary diode.
- ✓ The silicon high power dissipation characteristic and doping concentration of the zener diode makes the diode to prefer for Reverse bias condition.
- ✓ When the breakdown occur, the current increases whereas the voltage remain Constant (very small change). This phenomenon makes the Zener diode to work as voltage Regulator.
- ✓ The forward bias characteristics of the zener diode will be similar to the PN junction diode when the cut in voltage reaches, the current starts to increases with respect to the voltage.
- ✓ In the Reverse bias condition, because of high doping concentration the breakdown occurs very quickly and once the breakdown occur the current rises sharply whereas the voltage remains more (or) less constant.

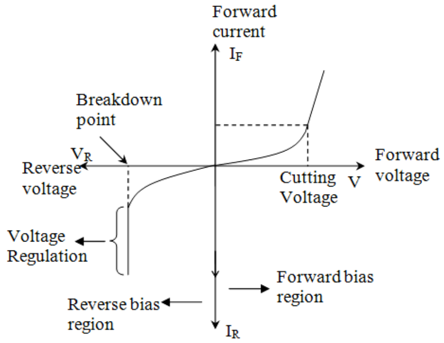
Symbol



Equivalent Circuit Diagram



Characteristics of Zener Diode

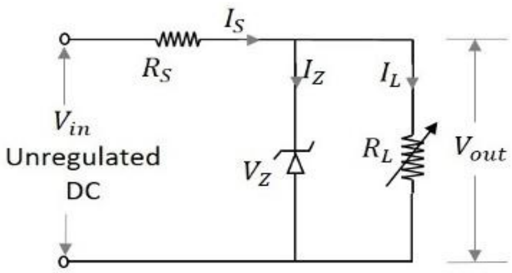


Applications: Zener Diode is used as Voltage Regulator, Waveform clipper, Voltage shifter and Reference voltage in electronic circuits.

Voltage Regulator: Voltage Regulator is an electronic circuit which provides constant voltage level independent of the current in the load.

- **Line Regulator** − A regulator which regulates the output voltage to be constant, in spite of input line variations, it is called as **Line regulator**.
- **Load Regulator** − A regulator which regulates the output voltage to be constant, in spite of the variations in load at the output, it is called as **Load regulator**.

Zener Regulator - Working of Zener Voltage Regulator



- If the applied input voltage Vi is increased beyond the Zener voltage Vz, then the Zener diode operates in the breakdown region and maintains constant voltage across the load.
- The series limiting resistor Rs limits the input current.

Case 1 − If the load current I_L increases, then the current through the Zener diode I_Z decreases in order to maintain the current through the series resistor R_S constant. The output voltage Vo depends upon the input voltage Vi and voltage across the series resistor R_S.

$$Vo = Vin - Is\ Rs$$

Where Is is constant. Therefore, Vo also remains constant.

Case 2 − If the load current I_L decreases, then the current through the Zener diode I_Z increases, as the current IS through R_S series resistor remains constant. Though the current I_Z through Zener diode increases it maintains a constant output voltage V_Z, which maintains the load voltage constant.

Case 3 − If the input voltage Vi increases, then the current I_S through the series resistor RS increases. This increases the voltage drop across the resistor, i.e. V_S increases. Though the current through Zener diode I_Z increases with this, the voltage across Zener diode V_Z remains constant, keeping the output load voltage constant.

Case 4 − If the input voltage decreases, the current through the series resistor decreases which makes the current through Zener diode I_Z decreases. But the Zener diode maintains output voltage constant due to its property.

Limitations of Zener Voltage Regulator

- It is less efficient for heavy load currents.
- The Zener impedance slightly affects the output voltage.

Video Content / Details of website for further learning (if any):

1. https://www.tutorialspoint.com/electronic_circuits
2. https://www.physics-and-radio-electronics.com/electronic-devices-and-circuits
3. https://nptel.ac.in/courses/117103063/

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LECTURE HANDOUTS

ECE

I / II

Course Name with Code : 19GES11 - ELECTRONIC DEVICES

Course Faculty : Dr. J.Rangarajan

Unit : II - Bipolar Junction Transistors **Date of Lecture:**

Topic of Lecture: Bipolar Junction Transistor Operation

Introduction: Transistor is a three terminal semiconductor devices (Base, emitter and collector) that can be used to switch and amplify electronic signals such as radio and television signals. The amplification in the transistor is achieved by passing input current from a region of low resistance to a region of high resistance, hence it is known as Transfer – resistor (Transistor)

Prerequisite knowledge for Complete understanding and learning of Topic:

- Atomic structure
- Energy band diagram
- Diode

Bipolar Junction Transistor Operation

TYPES OF TRANSISTORS

There are two basic types of transistors

(i) Unipolar Junction Transistor:

In this type, the current conduction is due to one type of carrier that is majority carrier.

(ii) Bipolar junction Transistor:

In this type, the current conduction is due to both types of charge carriers that is majority as well as minority carrier.

The Bipolar junction transistors are of two types

(a) PNP transistor

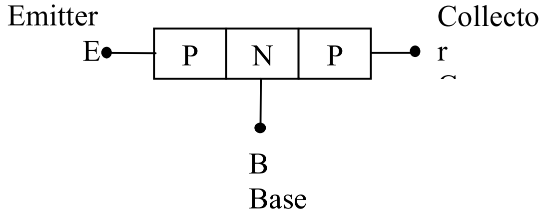
(b) NPN transistor

CONSTRUCTION OF PNP AND NPN TRANSISTOR

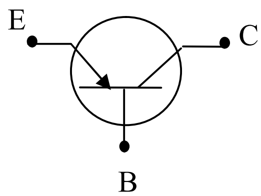
(a) PNP Transistor:

When the transistor is formed by sandwiching a single n-region between two p - region, then it is known as PNP transistor.

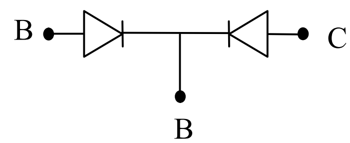
PNP transistor



Symbol



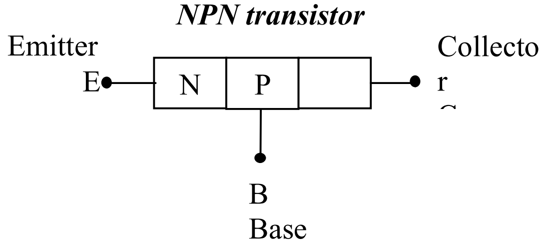
Two diode transistor



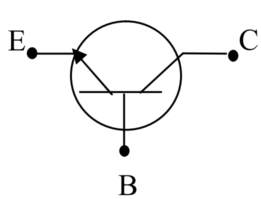
(b) NPN Transistor:

When the transistor is formed by sandwiching a single p – region between two n – region then it is known as NPN transistor.

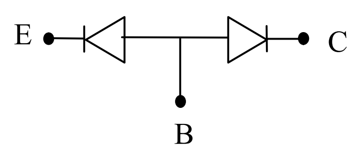
NPN transistor



Symbol



Two diode transistor version



From the above figures, we can understand that the

- Transistor has two junctions

One junction is formed between Emitter and base, and it is called ***Emitter – Base junction.***
Other junction is formed between Base and Collector, and it is called ***Collector – Base junction.***

- It has three terminals.

Emitter:

The emitter is *heavily doped*. The main function of the emitter is to *inject* a *large number of charge carriers* into the base. The arrow head is always at the collector which indicates the conventional direction of current flow.

Base:

The Base is *lightly doped* middle region and very thin. The main function of the base is to *pass* most of the *injected charge carriers into the collector*.

Collector:

The collector is *moderately doped*. The main function of the collector is to *collect* the *charge carriers*. Since it dissipate more power, it is physically larger than emitter region.

BIASING

Applying external voltage of correct polarity and magnitude to the two junction of the transistor is called Biasing

Transistor Biasing

Based on the external voltage polarity, the transistor will be operated in three different regions.

That is

(i) Active region

(ii) Cutoff region and

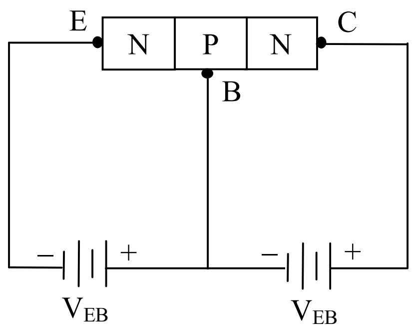
(iii) Saturation region

Region	Emitter Base junction	Collector Base junction	Application
Active Cut off Suration	Forward biased Reverse biased Forward biased	Reverse biased Reverse biased Forward biased	Amplifier Open switch closed switch

OPERATION OF AN NPN TRANSISTOR

Normally the transistor will be biased in active region. Hence Emitter base is forward biased and collector base is reverse biased.

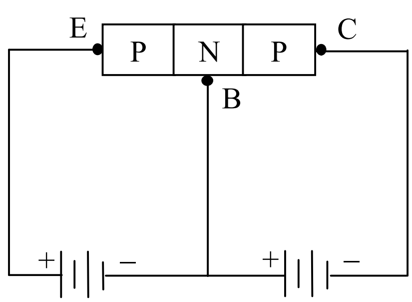
Biasing the NPN Transistor



- The applied forward bias causes the lot of electrons from the emitter region to enter into the base region and this causes the forward current flow due to majority carrier electrons.
- Since the base is lightly doped with P – type impurity, the *injected electron* from the emitter Combines with the *holes* in the P – type region to Constitute a **base current (I_B)**
- Few electron combines with holes and the remaining electrons (more than 95%) crossover the base region into collector region to Contribute Collector Current*(I_C)*
- Collector is reverse biased and hence they collects the diffused electrons which enters the collector junction.
- The magnitude of emitter current $I_E = I_B + I_C$

OPERATION OF AN PNP TRANSISTOR

Biasing the PNP Transistor



- The applied forward bias causes lot of holes from the emitter region to enter into the base region and this causes the forward current flow due to majority carrier holes.
- Since the base is lightly doped with n type impurity, the injected holes from the emitter

combines with the electrons in the n type region to constitute a base current(I_B)

- Few holes combines with electron and the remaining holes (more than 95%) cross over the base region into collector region to Contribute Collector Current
- Collector is reverse biased and hence they collects the diffused holes which enters the collector junction(I_C)
- The magnitude of emitter Current $I_E = I_B + I$

Video Content / Details of website for further learning (if any):

1. https://www.elprocus.com/using-transistor-as-a-switch/
2. httphttps://circuitglobe.com/transistor-as-an-amplifier.html
3. https://nptel.ac.in/courses/117103063/
4. httphttps://circuitglobe.com/transistor-as-an-amplifier.htmls://www.electronics-tutorials.ws/amplifier/amp_2.htmlbuild-electronic-cir

Important Books/Journals for further learning including the page nos.:

1. "Electronic Devices and Circuits", S.Salivahanan, N.Sureshkumar, &A.Vallavaraj Tata McGraw Hill, Second Edition, 2008. (151-152)
2. "Electronic Devices", Thomas L.Floyd, Prentice Hall, Ninth Edition, 2012. (Unit 1 and 2)

Course Faculty

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Course Name with Code : 19GES11 - ELECTRONIC DEVICES

Course Faculty : Dr. J.Rangarajan

Unit : II - Bipolar Junction Transistors **Date of Lecture:**

Topic of Lecture: Common Base Configuration

Introduction:

- In this configuration, the input is given between emitter and base and output is taken between collector and base
- The emitter base junction is forward biased and collector base junction is reversed biased.
- Hence I_E (Emitter Current) flows in the input circuit and I_C (collector Current) flows in the output circuit.

Prerequisite knowledge for Complete understanding and learning of Topic:

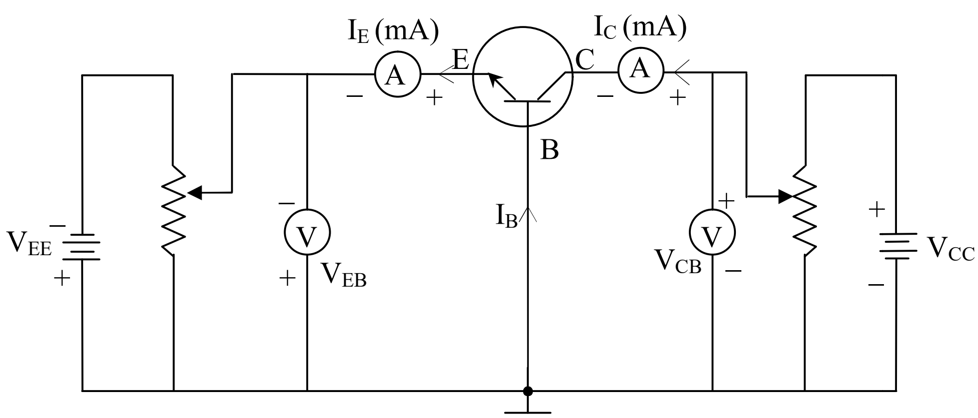
- Diode operation
- Transistor Operation

Common Base Configuration

Characteristics of CB Configuration:

The performance of the transistor Configuration can be determined from the static characteristics curves, which relates the different dc currents and voltage of the transistor.

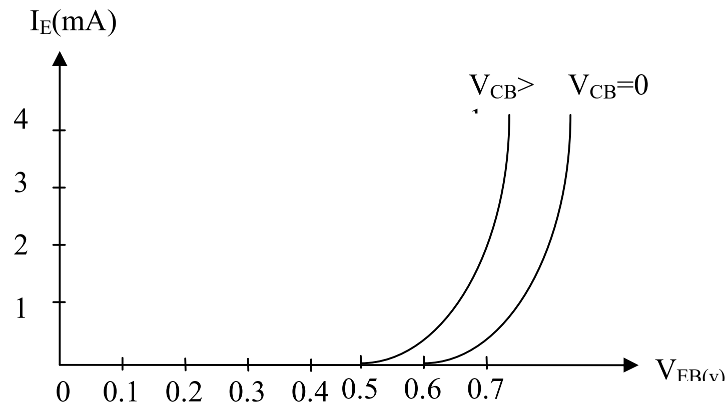
Circuit to determine CB static characteristics (Input and Output characteristics)



Input Characteristics:

The input characteristics of the CB configuration is determined by increasing the emitter current I_E from zero by increasing V_{EB}, keeping V_{CB} constant. The input curve is obtained are shown

Input characteristics curve

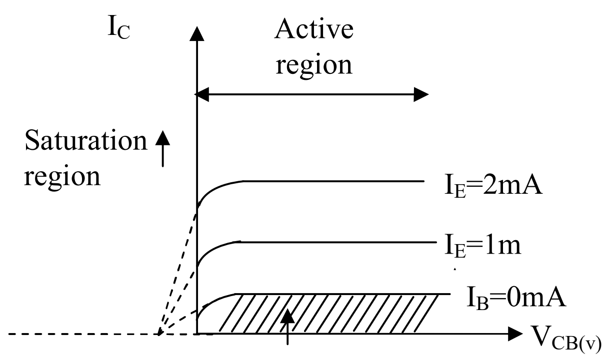


- For the given value of V_{CB} and increase in the V_{EB}, the emitter base junction is forward biased. The value of IE increases when the values of V_{EB} increase similar to forward biased diode.
- When V_{CB} increased, the width of the base region will decrease which result in increases in the value of I_E much earlier for increases in V_{EB}. This makes the curve to shift left.

Output characteristics:

The output characteristics of the CB configuration is determined by increasing the collector current I_C by increasing V_{CB}, keeping I_E constant at a suitable value by adjusting V_{EB}. This step is repeated for various fixed values of I_E. The curves obtained are shown below.

Output characteristics curve



Two important characteristics can be observed from the output graph.

(i) For a constant value of I_E, Ic is independent of V_{CB} and the curves are parallel to the axis of the V_{CB}.

(ii) IC flows even when V_{CB} = 0, the majority carrier electron from the emitter base forward biased junction will injected into the collector base junction due to internal potential barrier at the reversed biased collector base junction.

Early effect (or) Base width Modulation

When the collector voltage is increased, the width of the depletion region increases as the reverse bias voltage increases. This increase in the depletion region decreases the width of the Base. This phenomenon of variation in the Base width with respect to the variation of collector voltage is known as Base width modulation (or) Early effect. *The value of α increases for large value of V_{CC} (or) early effect.*

Punch Through

When the value of collector voltage is extremely large, the effective base width will reduces to zero leads to the voltage breakdown in the transistor. This phenomenon is known as Punch through.

Transistor equation

If there is no ac signal, then the ratio of I_C to I_E is known as dc amplification factor

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

(Since I_C flows into transistor & I_E flows out of transistor)

The ratio of charge in collector current to the change in emitter current is known as current amplification factor (α).

$$\alpha_{ac} = \frac{-\Delta I_C}{\Delta I_E}, V_{CB} \text{ Constant}$$

The collector current depends upon two factors

(i) amplified emitter current (αI_E)

(ii) leakage current due to movement of minority carrier across output (I_{CBO})

Hence Collector Current $\boxed{I_C = \alpha I_E + I_{CBO}}$

We know that $I_E = I_B + I_C$

Hence $I_B = I_E - I_C$ ----------- (1)

Sub I_C in (1) $I_B = I_E - (\alpha I_E + I_{CBO})$

$I_B = I_E - \alpha I_E - I_{CBO}$

$\boxed{I_B = I_E (1-\alpha) - I_{CBO}}$

Transistor Parameters:

Four transistor parameters can be determined from CB characteristics curve, they are known as common base hybrid parameters (or) h parameters.

(a) Input Impedance (h_{ib}):

It is the ratio of the change in emitter voltage to the change in emitter current, keeping V_{CB} constant.

$$hib = \frac{\Delta V_{EB}}{\Delta I_E}, V_{CB} \text{ Constant}$$

(b) Output admittance (h_{ob}):

It is the ratio of the change in collector current to the change in the collector voltage, keeping I_E constant.

$$hob = \frac{\Delta I_C}{\Delta V_{CB}}, I_E \text{ Constant}$$

(c) Forward current gain (hfb):

It is the ratio of the change in the collector current to the change in the Emitter Current keeping V_{CB} constant

$$hfb = \frac{\Delta I_C}{\Delta I_E}, V_{CB} \text{ Constant}$$

(d) Reverse Voltage gain (hrb):

If is the ratio of the change in the Emitter voltage to the change in the collector voltage, keeping I_E constant.

$$hrb = \frac{\Delta V_{EB}}{\Delta V_{CB}}, I_E \text{ Constant}$$

Video Content / Details of website for further learning (if any):

1. https://www.elprocus.com/using-transistor-as-a-switch/
2. https://circuitglobe.com/transistor-as-an-amplifier.html
3. https://nptel.ac.in/courses/117103063/
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Course Faculty **Verified by HOD**

MUTHAYAMMAL ENGINEERING COLLEGE

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Rasipuram - 637 408, Namakkal Dist., Tamil Nadu

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L 12

LECTURE HANDOUTS

ECE

I / II

Course Name with Code : 19GES11 - ELECTRONIC DEVICES

Course Faculty : Dr. J.Rangarajan

Unit : II - Bipolar Junction Transistors **Date of Lecture:**

Topic of Lecture: Common Emitter Configuration

Introduction

- Hence I_B (Base In this configuration, the input is given between emitter and base and output is taken between collector and emitter.
- Emitter base junction is forward biased, whereas the emitter collector junction is reversed biased
- current) flows in the input circuit and I_C (Collector current) flows in the output circuit.

Prerequisite knowledge for Complete understanding and learning of Topic:

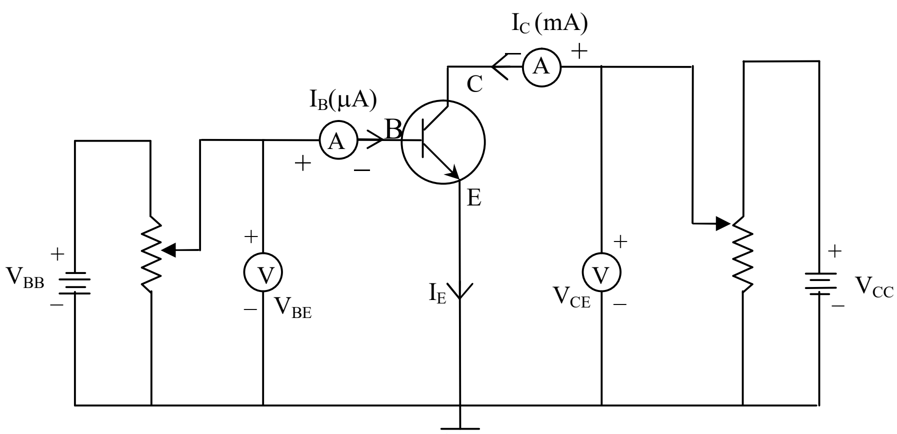
- Diode operation
- Transistor Operation

Common Emitter Configuration

Characteristics of CE Configuration

The circuit diagram for CE configuration is given below

Circuit to determine CE static characteristics (Input and Output characteristics)

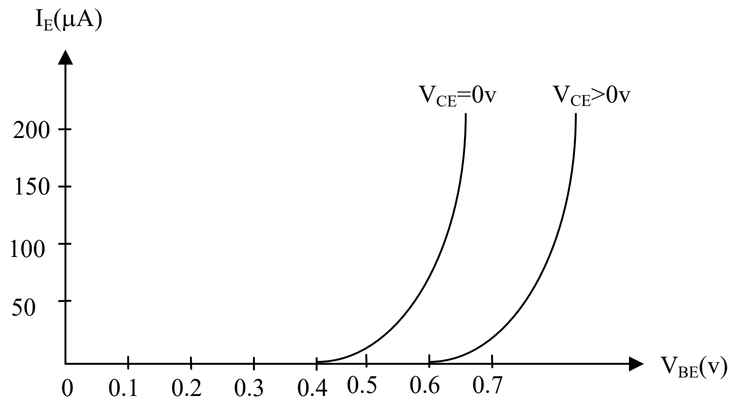


The performance of the CE configuration can be determined from the static characteristic curve.

Input characteristics:-

The input characteristics of CE configuration are determined by increasing the base current I_B from zero by increasing V_{EB}, keeping V_{CE} constant. This step is repeated for various fixed values of V_{CE} .The input curve obtained are shown below

Input characteristics curve

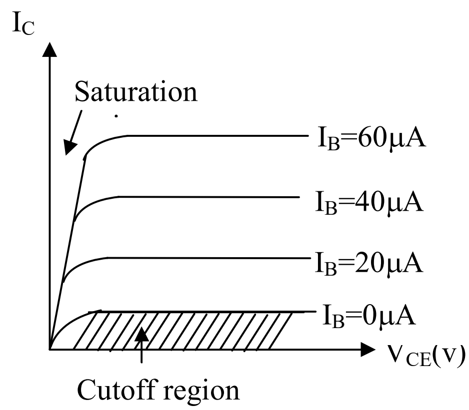


- For the given value of V_{CE} and increasing the value of V_{BE}, the base current I_B increased, Input characteristics of the CE configuration is similar to CB configuration, where the Emitter base is forward biased . Hence increases in V_{BE} increases I_B.
- But when V_{CE} is increased, the width of the depletion region increases due to reverse bias which makes the effective width of the base to decreases which in turn decreases I_E. Therefore the curve shifts to the right.

Output characteristics:

The output characteristics of the CE configuration is determined by increasing the collector current I_C by increasing V_{CE}, keeping I_B constant at a suitable value by adjusting V_{CB}. This step is repeated for various fixed values of I_B. The curves obtained are shown below.

Output characteristics curve



The output characteristics have three regions namely

(i) Active region:

In this region, curves are uniform in spacing increases in the collector voltage increases I_C here for large value of I_B, I_C is larger than I_B. Thus current gain is greater than unity makes the transistor to be uses as an amplifier.

(ii) Saturation region:

For low values of V_{CE}, the transistor operates in this region. Increase in the base current I_B does not cause a corresponding change in I_C.

(iii)Cutoff Region:

In this region, the collector current becomes almost zero and small amount of collector current flows even when I_B=0. This is called I_{CEO}.

Transistor equation

The ratio of change in collector current to change in base current is known as current amplification factor β.

$$\beta = \frac{\Delta I_C}{\Delta I_B}, V_{CE} \text{ Constant}$$

We know that $I_E = I_B + I_C$

$I_C = \alpha I_E + I_{CBO}$ ------------ (1)

Sub I_E in eqn (1) $\Rightarrow I_C = \alpha(I_B + I_C) + I_{CBO}$

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

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

$I_C (1- \alpha) = \alpha I_B + I_{CBO}$

÷ 1-αon both sides

$$I_C = \frac{\alpha}{1-\alpha} I_B + \frac{I_{CBO}}{1-\alpha} \qquad \text{------------ (2)}$$

We already know

$$I_C = \beta I_B + I_{CEO} \qquad \text{----------- (3)}$$

Hence comparing (2) & (3)

$$\beta = \frac{\alpha}{1-\alpha} \text{ and } I_{CEO} = \frac{I_{CBO}}{1-\alpha}$$

$\therefore \quad I_C = \beta I_B + (\beta + 1) I_{CBO}$

Transistor Parameters

Four transistor parameters can be determined from CE configuration curve. They are known as common emitter hybrid parameters (or) h parameters.

(a) Input Impedance (hie)

It is the ratio of the change in base voltage to the change in Base current, keeping V_{CE} constant.

$$h_{ie} = \frac{\Delta V_{BE}}{\Delta I_B}, V_{CE} \text{ Constant}$$

(b) Output admittance (hoe)

It is the ratio of the change in collector current to the change in collector voltage keeping base current constant.

$$h_{oe} = \frac{\Delta I_C}{\Delta V_{CE}}, I_B \text{ Constant}$$

(c) Forward current gain (hfe)

It is the ratio of the change in collector current to the change in the base current, keeping V_{CE} constant.

$$h_{fe} = \frac{\Delta I_C}{\Delta I_B}, V_{CE} \ \textbf{Constant}$$

(d) Reverse Voltage gain (hre)

It is the ratio of the change in the base voltage to the change in the collector Voltage, keeping I_B constant.

$$h_{re} = \frac{\Delta V_{BE}}{\Delta V_{CE}}, I_B \text{ Constant}$$

Video Content / Details of website for further learning (if any):

1. https://www.elprocus.com/using-transistor-as-a-switch/
2. httphttps://circuitglobe.com/transistor-as-an-amplifier.html
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2 "Electronic Devices", Thomas L.Floyd, Prentice Hall, Ninth Edition, 2012. (Unit 1 and 2)

Course Faculty **Verified by HOD**

L 13

LECTURE HANDOUTS

ECE

I / II

Course Name with Code : 19GES11 - ELECTRONIC DEVICES

Course Faculty : Dr. J.Rangarajan

Unit : II - Bipolar Junction Transistors **Date of Lecture:**

Topic of Lecture: Common Collector Configuration, Current components

Introduction

- In this configuration, the input is given between base and collector and output is taken between collector and emitter.
- The base – Collector is forward biased, whereas the emitter collector junction is reversed biased
- Hence I_B (Base current) flows in the input circuit and I_E (Emitter current) flows in the output circuit.

Prerequisite knowledge for Complete understanding and learning of Topic:

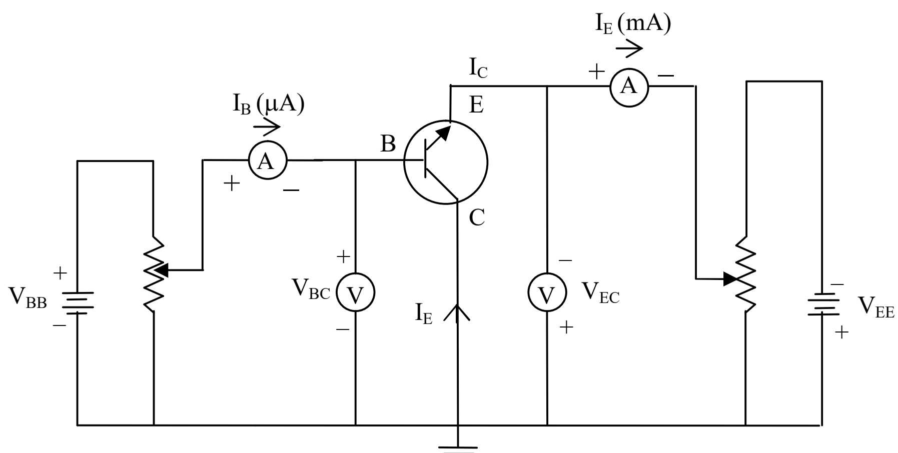
- Diode operation
- Transistor Operation

Common Collector Configuration

Characteristics of CC configuration

The circuit diagram for CC Configuration is given below

Circuit to determine CC static characteristics (Input and Output characteristics)



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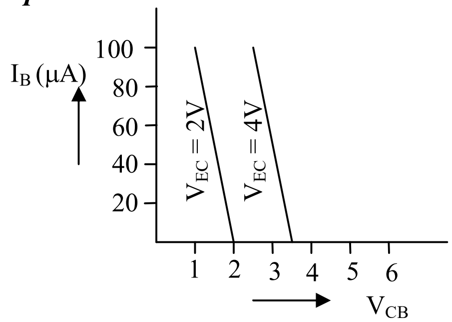
The performance of CC configuration can be determined from the static characteristic curve.

Input characteristics:

The input characteristics of CC configuration are determined by increasing the base current I_B from zero by increasing V_{BC} keeping V_{EC} constant. This step is repeated for various fixed values of V_{EC}. The curves obtained are shown below.

Input characteristics curve

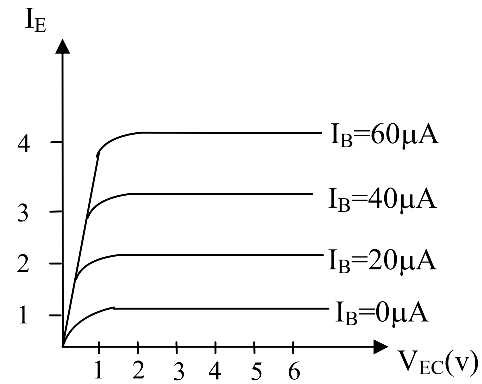


The characteristics curve of CC is similar to the CE configuration except the V_{BC} in increased instead of V_{BE}.

Output Characteristics:

The output characteristics of the CC configuration is determined by increasing the Emitter current (I_E) by increasing V_{EC}, keeping I_B constant at a suitable value by adjusting V_{BC}. This step is repeated for various fixed values of I_B. The curves obtained are shown below.

Output Characteristics curve



Transistor equation

The ratio of change in Emitter Current to the change in Base current is known as Current amplification factor (γ)

$$\gamma_{dc} = \frac{\Delta I_E}{\Delta I_B}, \text{ Keeping } V_{CE} \text{ constant}$$

The Collector Current $I_C = \alpha I_E + I_{CBO}$

Here, $I_E = I_B + I_C$ -------- (1)

sub I_C in (1) $I_E = I_B + \alpha I_E + I_{CBO}$

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

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

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

(a) Relationship between α and β:

WKT, $\alpha = \frac{\Delta I_C}{\Delta I_E} = \frac{\Delta I_C}{\Delta I_C + \Delta I_B}$ [since $I_E = I_B + I_C$]

$$\& \ \beta = \frac{\Delta I_C}{\Delta I_B}$$

Hence $\frac{1}{\alpha} = \frac{\Delta I_C + \Delta I_B}{\Delta I_C} = 1 + \frac{1}{\beta} = \frac{1+\beta}{\beta}$

$$\alpha = \frac{\beta}{1+\beta}$$

(b)Relationship betweenα, β and γ :-

Current gain $\gamma = \frac{\Delta I_E}{\Delta I_B} = \frac{\Delta I_E}{\Delta I_E - \Delta I_C}$ (since $I_E = I_B + I_C$)

Dividing numerator & Denominator by ΔI_C

$$\gamma = \frac{\Delta I_E / \Delta I_C}{\Delta I_E / \Delta I_C - 1}$$

$$\text{WKT } \alpha = \frac{\Delta I_C}{\Delta I_E} \Rightarrow \gamma = \frac{1/\alpha}{1/\alpha - 1} = \frac{\frac{1}{\alpha}}{\frac{1-\alpha}{\alpha}}$$

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

COMPARISON OF TRANSISTOR CONFIGURATIONS

Characteristic	Common Base	Common emitter	Common Collector
Input Resistance	Very low (20Ω)	Low (1 k Ω)	High (400 k Ω)
Output Resistance	Very high (400kΩ)	High (45 k Ω)	Low (30Ω)
Input Current	IE	IB	IB
Output Current	IC	IC	IE
Input voltage applied	Emitter Base	Base Emitter	Base collector
output voltage taken	Collector Base	Collector emitter	Emitter collector
voltage gain	About 150	About 500	Less than 1
Current gain	Unity Current gain	High	Very high
Current amplification factor	$\alpha_{dc} = \frac{I_C}{I_E}$	$\beta_{dc} = \frac{I_C}{I_B}$	$\gamma_{dc} = \frac{I_E}{I_B}$
Application	high frequency circuit	Audio frequency circuits	Impedance matching circuit

Video Content / Details of website for further learning (if any):

1. https://www.elprocus.com/using-transistor-as-a-switch/
2. httphttps://circuitglobe.com/transistor-as-an-amplifier.html
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Course Faculty

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Rasipuram - 637 408, Namakkal Dist., Tamil Nadu

L 14

LECTURE HANDOUTS

ECE | **I / II**

Course Name with Code : 19GES11 - ELECTRONIC DEVICES

Course Faculty : Dr. J.Rangarajan

Unit : II - Bipolar Junction Transistors **Date of Lecture:**

Topic of Lecture: Ebermoll's model

Introduction

- When the collector voltage is increased, the width of the depletion region increases as the reverse bias voltage increases.
- This increase in the depletion region decreases the width of the Brase. This phenomenon of variation in the Base width with respect to the variation of collector voltage is known as Base width modulation (or) early effect.
- The value of α increases for large value of VCC (or) early effect.

Prerequisite knowledge for Complete understanding and learning of Topic:

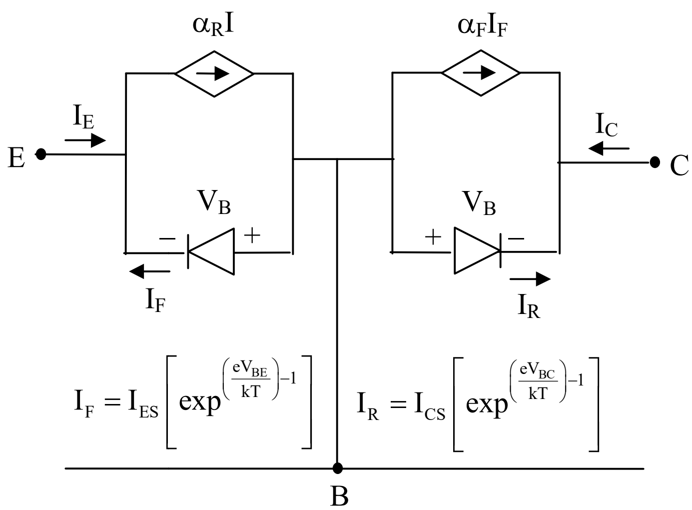
- Transistor Operation
- Configuration

Eber's moll model

Eber's moll model is commonly used for large signal analysis and switching application
It is the steady state model helps to analyze the conduction of the various model of the transistor

Current direction and Voltage polarity direction for Ebers moll model

E ***Basic Eber's moll equivalent circuit:-*** C



According to the current equation referred by Kirchhoff's current law

$I_E + I_B + I_C = 0$ ------- (1)

The collector current is given as

$$I_C = \alpha_F I_F - I_R \qquad \text{------- (2)}$$

Where $I_f = I_{ES}\,[\,e^{qV_{BE}/kT} - 1]$

and $\quad I_R = I_{CS}\,[\,e^{qV_{BC}/kT} - 1]$

Hence sub I_F & I_R in eqn (2), we get

$$I_C = \alpha_F I_{ES}\left[e^{qV_{BE}/kT} - 1\right] - I_{CS}\left[e^{qV_{BC}/kT} - 1\right] \qquad \text{------- (3)}$$

|||^{ly} The Emitter Current is given as

$$I_E = \alpha_R I_R - I_F \qquad \text{------- (4)}$$

α_R = Common base current in Reverse active mode

Sub I_F & I_R in equ (4), we get

$$I_E = \alpha_R I_{CS}\left[e^{qV_{BC}/kT} - 1\right] - I_{ES}\left[e^{qV_{BE}/kT} - 1\right] \qquad \text{------- (5)}$$

Equation (3) & (5) are classic Ebers moll – equations

Eber's moll model has four parameters: α_F, α_R, I_{ES} & I_{CS}

$$\boxed{a_F I_{ES} = a_R I_{CS}} \qquad \text{------- (6)}$$

In this model, Let us determine the Ebers moll equation for the transistor in saturation mode.

We know that, saturation Voltage as

$$\boxed{V_{CE}(sat) = V_{BE} - V_{BC}} \qquad \text{------- (7)}$$

In the saturation mode, $V_{BE} > 0$, & $V_{BC} > 0$ since both BE & BC junction are forward bias.

V_{BE} Expression

From equation (5)

$$I_E = \alpha_R I_{CS}\left[e^{qV_{BC}/kT} - 1\right] - I_{ES}\left[e^{qV_{BE}/kT} - 1\right]$$

We know that $I_E = -(I_B + I_C)$, hence sub this in above equation

$$-(I_B + I_C) = \alpha_R I_{CS}\left[e^{qV_{BC}/kT} - 1\right] - I_{ES}\left[e^{qV_{BE}/kT} - 1\right]$$

$$\Rightarrow \alpha_R I_{CS}\left[e^{qV_{BC}/kT} - 1\right] = -I_B - I_C + I_{ES}\left[e^{qV_{BE}/kT} - 1\right]$$

$$\Rightarrow e^{qV_{BC}/kT} - 1 = \frac{-I_B - I_C + I_{ES}\left[e^{qV_{BE}/kT} - 1\right]}{\alpha_R I_{CS}} \qquad \text{------- (8)}$$

Sub eqn (8) in eqn (3), we get

$$I_C = \alpha_F I_{ES}\left[e^{qV_{BE}/kT} - 1\right] - I_{CS}\left[\frac{-I_B - I_C + I_{ES}\left[e^{qV_{BE}/kT} - 1\right]}{\alpha_R I_{CS}}\right]$$

$$I_C \alpha_R = \alpha_F I_{ES} \alpha_R \left[e^{qV_{BE}/kT}\right] - \alpha_F I_{ES} \alpha_R + I_B + I_C - I_{ES}\left[e^{qV_{BE}/kT}\right] + I_{ES}$$

$$\left[e^{qV_{BE}/kT}\right]\left[I_{ES} - \alpha_F \alpha_R I_{ES}\right] = I_C(1 - \alpha_R) + I_B + I_{ES}\left[1 - \alpha_F \alpha_R\right]$$

$$e^{qV_{BE}/kT} = \frac{I_C(1 - \alpha_R) + I_B + I_{ES}\left[1 - \alpha_F \alpha_R\right]}{I_{ES}(1 - \alpha_F \alpha_R)}$$

Taking ln on both sides, we get

$$\frac{qV_{BE}}{KT} = \ln \frac{I_C(1 - \alpha_R) + I_B + I_{ES}\left[1 - \alpha_F \alpha_R\right]}{I_{ES}(1 - \alpha_F \alpha_R)}$$

Hence $V_{BE} = V_t \ln \dfrac{I_C(1-\alpha_R) + I_B + I_{ES}[1-\alpha_F\alpha_R]}{I_{ES}(1-\alpha_F\alpha_R)}$ ------- (9)

$V_t = \dfrac{KT}{q}$ =Thermal voltage

V_{BC} Expression:

From equation (3)

$$I_C = \alpha_F I_{ES}\left[e^{qV_{BE}/kT} - 1\right] - I_{CS}\left[e^{qV_{BC}/kT} - 1\right]$$

$$\left[e^{qV_{BE}/kT} - 1\right] = \frac{I_C + I_{CS}\left[e^{qV_{BC}/kT} - 1\right]}{\alpha_F I_{ES}} \quad \text{------- (10)}$$

Sub eqn (10) in (5) and also substituting $I_E = -I_B - I_C$, we get

$$-I_B - I_C = \alpha_R I_{CS}\left[e^{qV_{BC}/kT} - 1\right] - \frac{I_{ES}\left(I_C + I_{CS}\left[e^{qV_{BC}/kT} - 1\right]\right)}{\alpha_F I_{ES}}$$

$$(-I_B - I_C)\alpha_F = \alpha_F\alpha_R I_{CS}\left[e^{qV_{BC}/kT}\right] - \alpha_R I_{CS}\alpha_F - I_C - I_{CS}\left(e^{qV_{BC}/kT}\right) + I_{CS}$$

Taking $e^{qV_{BC}/kT}$ term on left side we get

$$e^{qV_{BC}/kT}\left[-\alpha_R\alpha_F I_{CS} + I_{CS}\right] = I_B\alpha_F + I_C(\alpha_F - 1) + I_{CS}(1-\alpha_R\alpha_F)$$

$$e^{qV_{BC}/kT} = \frac{I_B\alpha_F + I_C(\alpha_F - 1) + I_{CS}(1-\alpha_R\alpha_F)}{I_{CS}(1-\alpha_F\alpha_R)}$$

Taking ln on both sides

$$\frac{qV_{BC}}{KT} = \ln\frac{I_B\alpha_F + I_C(\alpha_F - 1) + I_{CS}(1-\alpha_F\alpha_R)}{I_{CS}(1-\alpha_F\alpha_R)}$$

$$V_{BC} = \frac{KT}{q}\ln\frac{I_B\alpha_F + I_C(\alpha_F - 1) + I_{CS}(1-\alpha_F\alpha_R)}{I_{CS}(1-\alpha_F\alpha_R)}$$

$$V_{BC} = V_T \ln\frac{I_B\alpha_F + I_C(\alpha_F - 1) + I_{CS}(1-\alpha_F\alpha_R)}{I_{CS}(1-\alpha_F\alpha_R)} \quad \text{------ (11)}$$

Now $\boxed{V_{CE}\,(Sat) = V_{BE} - V_{BC}}$

Sub eqn (9) & (11) by neglecting I_{ES} & I_{CS} term we get

$$V_{CE}(sat) = V_t \ln\frac{I_C(1-\alpha_R) + I_B}{I_{ES}(1-\alpha_F\alpha_R)} - V_t \ln\frac{I_B\alpha_F + I_C(\alpha_F - 1)}{I_{CS}(1-\alpha_F\alpha_R)}$$

$$V_{CE}(sat) = V_t \ln\frac{I_C(1-\alpha_R) + I_B}{I_{ES}(1-\alpha_F\alpha_R)} X \frac{I_{CS}(1-\alpha_F\alpha_R)}{I_B\alpha_F + I_C(\alpha_F - 1)}$$

$$V_{CE}(sat) = V_t \ln\left\{\frac{I_C(1-\alpha_R) + I_B}{I_B\alpha_F + I_C(\alpha_F - 1)} X \frac{I_{CS}}{I_{ES}}\right\}$$

Sub $\dfrac{\alpha_F}{\alpha_R} = \dfrac{I_{CS}}{I_{ES}}$, we get

$$V_{CE}(sat) = V_t \ln\left\{\frac{I_C(1-\alpha_R) + I_B}{I_B\alpha_F + I_C(\alpha_F - 1)} X \frac{\alpha_F}{\alpha_R}\right\}$$

Video Content / Details of website for further learning (if any):

1. https://www.elprocus.com/using-transistor-as-a-switch/
2. httphttps://circuitglobe.com/transistor-as-an-amplifier.html
3. https://nptel.ac.in/courses/117103063/

4. httphttps://circuitglobe.com/transistor-as-an-amplifier.htmls://www.electronics-tutorials.ws/amplifier/amp_2.htmlbuild-electronic-cir/
Important Books/Journals for further learning including the page nos.: 1. "Electronic Devices and Circuits", S.Salivahanan, N.Sureshkumar, &A.Vallavaraj Tata McGraw Hill, Second Edition, 2008. (161-164) 2. "Electronic Devices", Thomas L.Floyd, Prentice Hall, Ninth Edition, 2012. (Unit 1 and 2)

Course Faculty

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Course Name with Code : 19GES11 - ELECTRONIC DEVICES

Course Faculty : Dr. J.Rangarajan

Unit : II - Bipolar Junction Transistors **Date of Lecture:**

Topic of Lecture: Small Signal Low Frequency Model

Introduction

- h- parameter is used to analysis the behavior of the device. Commonly h parameter is used to analyze the small signal frequency of the transistor and mid band analysis of the transistor.
- It is a set of four transistor equivalent circuit parameters that conveniently used to specify transistor performance for small voltage and current.

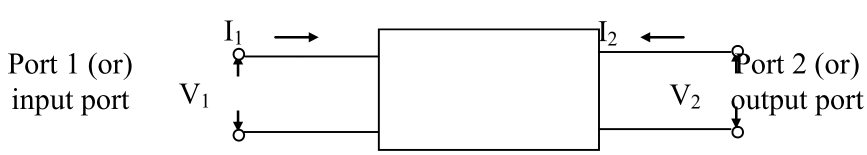
Prerequisite knowledge for Complete understanding and learning of Topic:

- Transistor Operation
- Configuration

Small Signal Low frequency Model

- h-parameter is used to analysis the behavior of the device. commonly h parameter is used to analyze the small signal frequency of the transistor and midband analysis of the transistor.
- It is a set of four transistor equivalent circuit parameters that conveniently used to specify transistor performance for small voltage and current.
- This model consider transistor as two port Network with V_1 & I_1 as input Voltage and input current and V_2 & I_2 as output voltage and output current.
- Two parameters are considered as dependent parameter and other two parameters as independent parameter.

Two port Network



The input voltage and output current can be written as

$$V_1 = h_{11}I_1 + h_{12}V_2$$

$$I_2 = h_{21}I_1 + h_{22}V_2$$

When $V_2 = 0$ that is output port short circuited

$V_1 = h_{11} i_1 \Rightarrow h_{11} = \frac{V_1}{i_1}$, it is known as input impedance

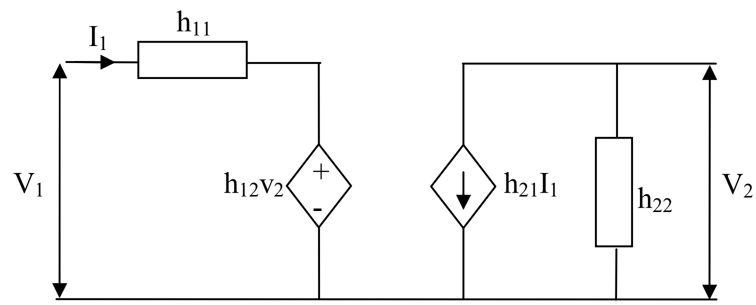
$I_2 = h_{21} I_1 ==> h_{21} = \frac{I_2}{I_1}$, it is known as *forward current gain (or) forward transfer ratio.*

When I_1=0 that is input port open circuited

$I_2 = V_2 h_{22} \Rightarrow h_{22} = \frac{I_2}{V_2}$, it is known as *output admittance*

$V_1 = h_{12} V_2 \Rightarrow h_{12} = \frac{V_1}{V_2}$, it is known as *Reverse Voltage gain (or) reverse transfer ratio*

Equivalent Circuit of the h – parameter



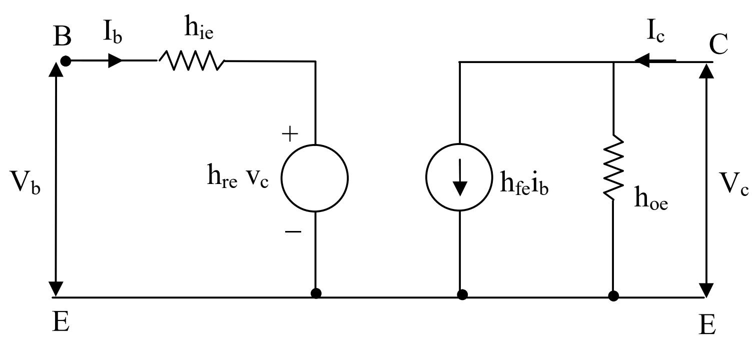
From the above circuit, the unit for various h parameters are h_{11}=Ω, h_{22} =℧ and h_{12}, h_{21}→ dimensionless all the h parameters units are unique and they are hybrid in nature. Hence these parameters are referred to as hybrid parameters.

- Based upon the type of configuration the various hybrid parameters are expressed by adding the configuration type to the second subscript.

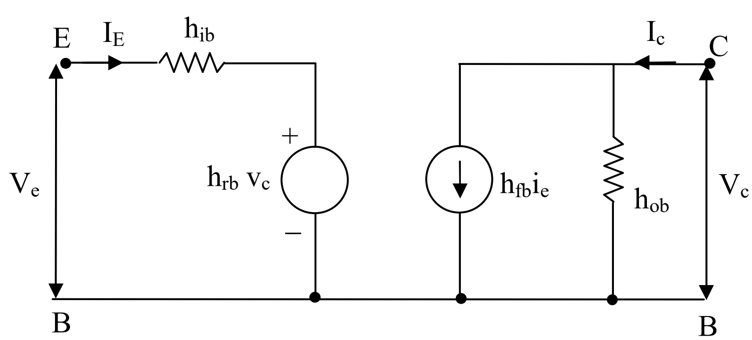
(e.g.) h_{11}e = short circuit input impedance for CE Configuration.

h parameter model for various configurations

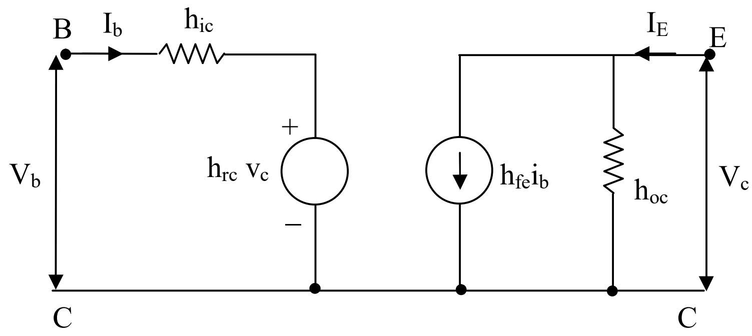
CE configuration:-



CB Configuration:-



CC Configuration:-



The h parameter model can be applied to any kind of biasing and load.

Video Content / Details of website for further learning (if any):

1. https://www.elprocus.com/using-transistor-as-a-switch/
2. httphttps://circuitglobe.com/transistor-as-an-amplifier.html
3. https://nptel.ac.in/courses/117103063/
4. httphttps://circuitglobe.com/transistor-as-an-amplifier.htmls://www.electronics-tutorials.ws/amplifier/amp_2.htmlbuild-electronic-cir

Important Books/Journals for further learning including the page nos.:

1. "Electronic Devices and Circuits", Jacob Millman, Christos Halkias, McGraw Hill, Third Edition, 2001. (317-320)
2. "Electronic Devices", Thomas L.Floyd, Prentice Hall, Ninth Edition, 2012. (Unit 1 and 2)

Course Faculty

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L 16

LECTURE HANDOUTS

ECE

I / II

Course Name with Code : 19GES11 - ELECTRONIC DEVICES

Course Faculty : Dr. J.Rangarajan

Unit : II - Bipolar Junction Transistors **Date of Lecture:**

Topic of Lecture: Hybrid High frequency effects

Introduction

- At high frequencies, the capacitive effects of the transistor junctions and the delay in response of the transistor caused by the process of diffusion of carriers should be taken into account in determining the high frequency model of a transistor.

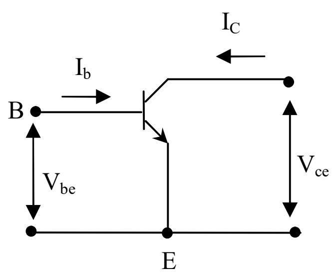
Prerequisite knowledge for Complete understanding and learning of Topic:

- Transistor Operation
- Transistor Configuration

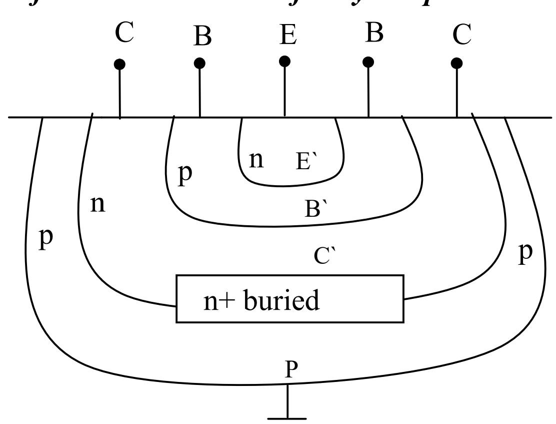
Hybrid High frequency effects (Hybrid- Pi Model)

The capacitive effects of the transistor junctions and analysis of the transistor can be done at high frequency by means of high frequency model of a transistor.

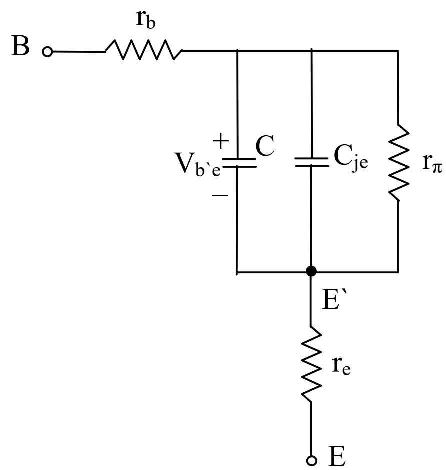
Common emitter NPN transistor with input V_{be} and output V_{ce}



Cross section of the NPN transistor for hybrid pi-model

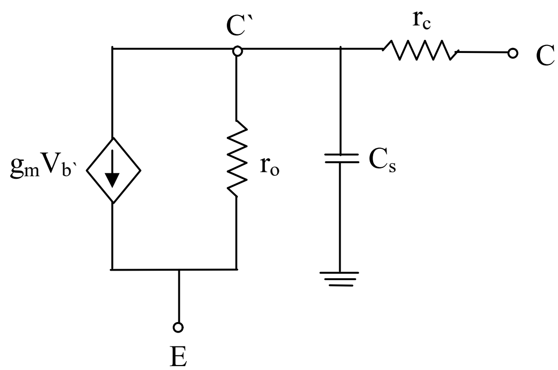


here C, B, E are the external Connections to the transistor and C’, B’, E’ are the idealized internal collector base and emitter regions. Equivalent circuit between various two terminals of the



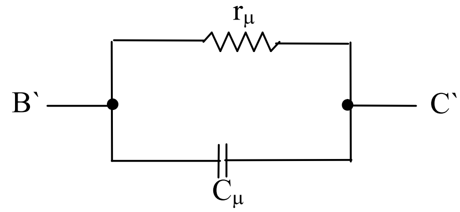
- The resistance r_b is the series resistance in the base between external base terminal B and internal Base region B'.
- The resistance r_e is the series resistance between external emitter terminal and internal emitter region. This resistance is small of order 1 to 2Ω.
- Since B'E' junction is forward biased, C_π is the junction diffusion Capacitance and r_π is the junction diffusion resistance. These two parameters are functions of junction current.
- There two elements are in parallel with the junction capacitance, C_{je}.

Hybrid pi-equivalent Circuit between collector and emitter



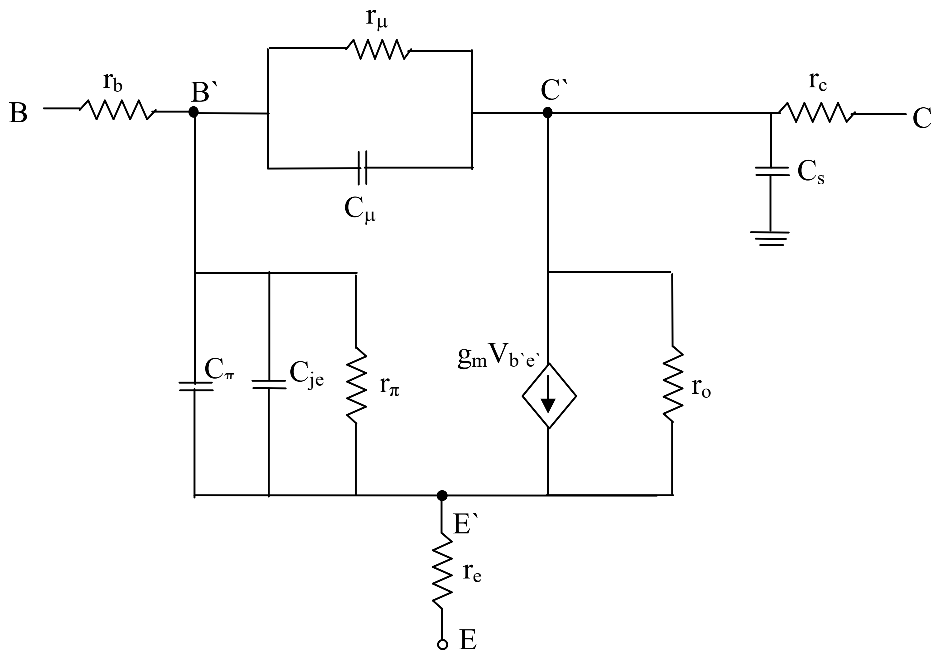
- The r_c resistance is the series resistance between external and internal collector connections
- C_s is the junction capacitance of the collector substrate junction
- r_o is the inverse of output conductance g_o primarily due to early effect.
- $g_m V_{b'e'}$ is the dependent current source which is controlled by internal base – emitter voltage

Hybrid pi-equivalent circuit between base and collector:



- The C is the reverse biased junction capacitance and r_μ is the reverse bias biased resistance. The value of C_μ is much smaller than C_π but due to the miller capacitance effect, C_μ cannot be ignored. Miller capacitance is the equivalent capacitance between B_1 and E_1 due to C_μ and feedback effect (gain) of transistor.

Hybrid pi-equivalent circuit



The above circuit helps to analyze the effect of input signal frequency on the transistor.

Video Content / Details of website for further learning (if any):

1. https://www.elprocus.com/using-transistor-as-a-switch/
2. httphttps://circuitglobe.com/transistor-as-an-amplifier.html
3. https://nptel.ac.in/courses/117103063/
4. httphttps://circuitglobe.com/transistor-as-an-amplifier.htmls://www.electronics-tutorials.ws/amplifier/amp_2.htmlbuild-electronic-cir

Important Books/Journals for further learning including the page nos.:

1. "Electronic Devices and Circuits", Jacob Millman, Christos Halkias, McGraw Hill, Third Edition, 2001. (381-383)
2. "Electronic Devices", Thomas L.Floyd, Prentice Hall, Ninth Edition, 2012. (Unit 1 and 2)

Course Faculty

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L 17

LECTURE HANDOUTS

ECE **I / II**

Course Name with Code : 19GES11 - ELECTRONIC DEVICES

Course Faculty : Dr. J.Rangarajan

Unit : II - Bipolar Junction Transistors **Date of Lecture:**

Topic of Lecture: Transistor as an Amplifier

Introduction

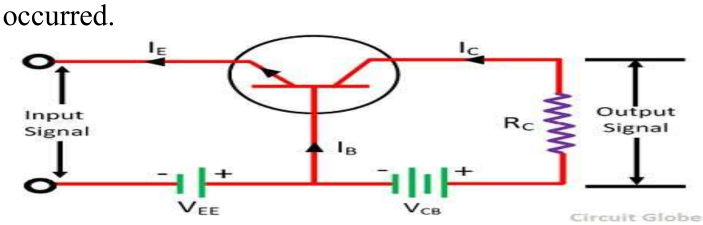
- It is used to magnify the given input signal.
- It has finite gain
- In an amplifier the frequency waveform and magnitude of AC output signal are controlled by the AC input signal applied at the input.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Transistor Operation
- Configuration

Transistor Amplifier Circuit

- The transistor raises the strength of a weak signal and hence acts an amplifier. The transistor amplifier circuit is shown in the figure below.
- The transistor has three terminals namely emitter, base and collector. The emitter and base of the transistor are connected in forward biased and the collector base region is in reverse bias.
- The forward bias means the P-region of the transistor is connected to the positive terminal of the supply and the negative region is connected to the N-terminal and in reverse bias just opposite of it has occurred.



- The input signal or weak signal is applied across the emitter base and the output is obtained to the load resistor RC which is connected in the collector circuit.
- The DC voltage VEE is applied to the input circuit along with the input signal to achieve the amplification.
- The DC voltage VEE keeps the emitter-base junction under the forward biased condition regardless of the polarity of the input signal and is known as a bias voltage.
- When a weak signal is applied to the input, a small change in signal voltage causes a change in emitter current (or we can say a change of 0.1V in signal voltage causes a change of 1mA in the emitter current) because the input circuit has very low resistance. This change is almost the same in collector current because of the transmitter action.

- In the collector circuit, a load resistor RC of high value is connected. When collector current flows through such a high resistance, it produces a large voltage drop across it. Thus, a weak signal (0.1V) applied to the input circuit appears in the amplified form (10V) in the collector circuit.

Video Content / Details of website for further learning (if any):

1. https://www.elprocus.com/using-transistor-as-a-switch/
2. httphttps://circuitglobe.com/transistor-as-an-amplifier.html
3. https://nptel.ac.in/courses/117103063/
4. httphttps://circuitglobe.com/transistor-as-an-amplifier.htmls://www.electronics-tutorials.ws/amplifier/amp_2.htmlbuild-electronic-cir

Important Books/Journals for further learning including the page nos.:

1. "Electronic Devices and Circuits", Jacob Millman, Christos Halkias, McGraw Hill, Third Edition, 2001. (251)
2. "Electronic Devices", Thomas L.Floyd, Prentice Hall, Ninth Edition, 2012. (Unit 1 and 2)

Course Faculty

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L 18

LECTURE HANDOUTS

ECE

I / II

Course Name with Code : 19GES11 - ELECTRONIC DEVICES

Course Faculty : Dr. J.Rangarajan

Unit : II - Bipolar Junction Transistors **Date of Lecture:**

Topic of Lecture: Transistor as a Switch

Introduction

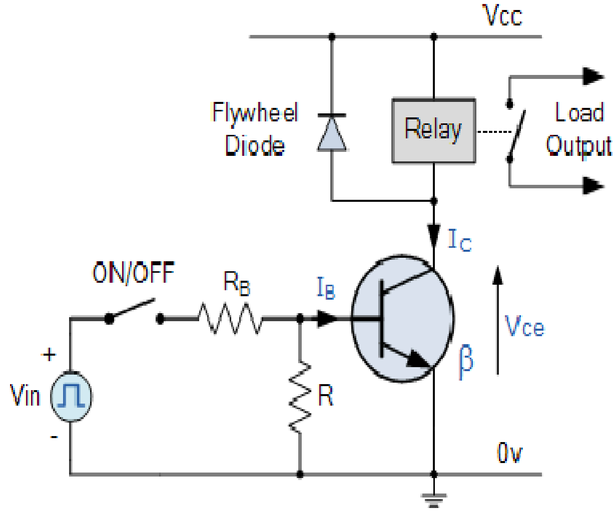
- Transistor acts a switch when it is operated at either cutoff region or saturation region.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Transistor Operation
- Configuration

Transistor as a Switch

- To operate the transistor as a switch the transistor needs to be turned either fully “OFF” (cut-off) or fully “ON” (saturated).
- An ideal transistor switch would have infinite circuit resistance between the Collector and Emitter when turned “fully-OFF” resulting in zero current flowing through it and zero resistance between the Collector and Emitter when turned “fully-ON”, resulting in maximum current flow.
- In practice when the transistor is turned “OFF”, small leakage currents flow through the transistor and when fully “ON” the device has a low resistance value causing a small saturation voltage (VCE) across it.
- Even though the transistor is not a perfect switch, in both the cut-off and saturation regions the power dissipated by the transistor is at its minimum.
- The figure shows the circuit diagram of transistor switching arrangement.
- In order for the Base current to flow, the Base input terminal must be made more positive than the Emitter by increasing it above the 0.7 volts needed for a silicon device.
- By varying this Base-Emitter voltage VBE, the Base current is also altered and which in turn controls the amount of Collector current flowing through the transistor.



- When maximum Collector current flows the transistor is said to be Saturated. The value of the Base resistor determines how much input voltage is required and corresponding Base current to switch the transistor fully "ON".

Video Content / Details of website for further learning (if any):

1. https://www.elprocus.com/using-transistor-as-a-switch/
2. httphttps://circuitglobe.com/transistor-as-an-amplifier.html
3. https://nptel.ac.in/courses/117103063/
4. httphttps://circuitglobe.com/transistor-as-an-amplifier.htmls://www.electronics-tutorials.ws/amplifier/amp_2.html

Important Books/Journals for further learning including the page nos.:

1. "Electronic Devices and Circuits", Jacob Millman, Christos Halkias, McGraw Hill, Third Edition, 2001. (276-277)
2. "Electronic Devices", Thomas L.Floyd, Prentice Hall, Ninth Edition, 2012. (Unit 1 and 2)

Course Faculty

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MUTHAYAMMAL ENGINEERING COLLEGE

(An Autonomous Institution)

(Approved by AICTE, New Delhi, Accredited by NAAC & Affiliated to Anna University)
Rasipuram - 637 408, Namakkal Dist., Tamil Nadu

L-19

LECTURE HANDOUTS

ECE | I/II

Course Name with Code : 16GES11 - ELECTRONIC DEVICES
Course Teacher : Dr. J.RANGARAJAN

Unit III : FIELD EFFECT TRANSISTORS **Date of Lecture:**

Topic of Lecture: Operation and Characteristics of JFET

Introduction: The JFET is abbreviated as **Junction Field Effect Transistor**. The types of JFET are n-channel FET and P-channel FET. A p-type material is added to the n-type substrate in n-channel FET, whereas an n-type material is added to the p-type substrate in p-channel FET. Hence it is enough to discuss one type of FET to understand both.

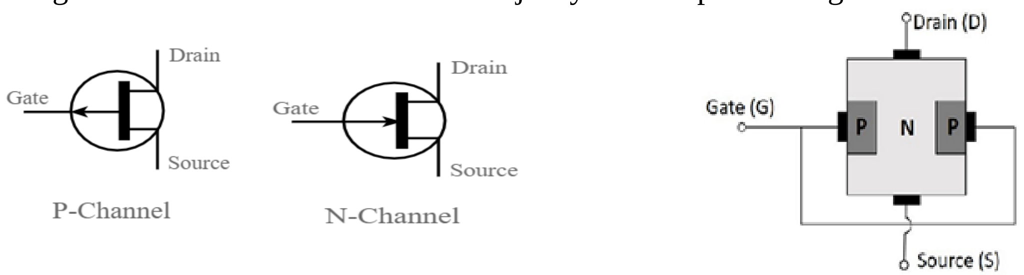
Prerequisite knowledge for Complete understanding and learning of Topic:

PN junction, Diode, Transistor

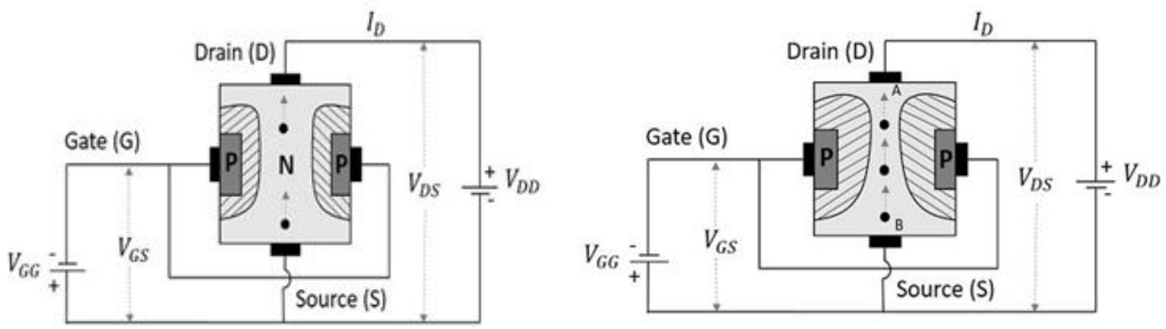
Detailed content of the Lecture:

N-channel JFET

- For the fabrication of N channel FET, a narrow bar of N-type semiconductor is taken on which P-type material is formed by diffusion on the opposite sides.
- These two sides are joined to draw a single connection for gate terminal. The area between gates is called as a **channel**. The majority carriers pass through this channel.



- When $\mathbf{V_{GG}}$ is reverse biased and $\mathbf{V_{DD}}$ is not applied, the depletion regions between P and N layers tend to expand.
- When $\mathbf{V_{DD}}$ is applied (positive terminal to drain and negative terminal to source) and $\mathbf{V_{GG}}$ is not applied, the electrons flows from source to drain which constitute the drain current I_D.



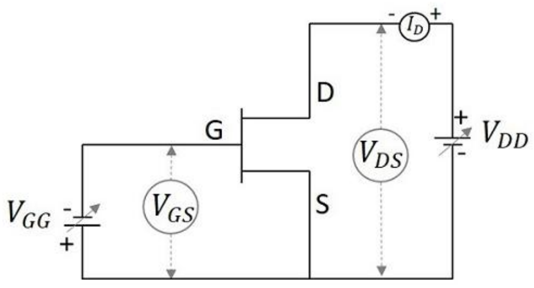
- The supply at gate terminal makes the depletion layer grow and the voltage at drain terminal allows the drain current from source to drain terminal.

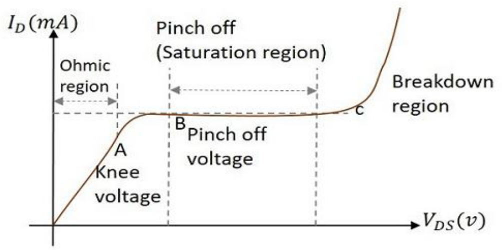
- The resistance of the channel will be such that the voltage drop at the drain terminal is greater than the voltage drop at the source terminal.
- So, the reverse biasing effect is stronger at drain terminal than at the source terminal. This is why the depletion layer tends to penetrate more into the channel near drain than at source.

Operation of FET

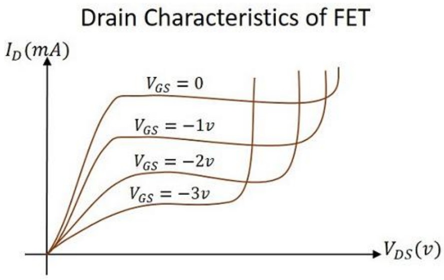
- Let us consider that there is no potential applied between gate and source terminals and a potential $\mathbf{V_{DD}}$ is applied between drain and source.
- Now, a current $\mathbf{I_D}$ flows from drain to source terminal, at its maximum as the channel width is more. Let the voltage applied between gate and source terminal $\mathbf{V_{GG}}$ is reverse biased.
- This increases the depletion width, as discussed above. As the layers grow, the cross-section of the channel decreases and hence the drain current $\mathbf{I_D}$ also decreases.
- When this drain current is further increased, a stage occurs where both the depletion layers touch each other, and prevent the current $\mathbf{I_D}$ flow.
- The voltage at which both these depletion layers literally "touch" is called as "**Pinch off voltage**". It is indicated as VP.
- The drain current is literally nil at this point. Hence the drain current is a function of reverse bias voltage at gate.
- Since gate voltage controls the drain current, FET is called as the **voltage controlled device**.

Drain Characteristics of JFET





- The circuit of FET to obtain these characteristics is given above.
- When the voltage between gate and source $\mathbf{V_{GS}}$ is zero, or they are shorted, the current $\mathbf{I_D}$ from source to drain is also nil as there is no $\mathbf{V_{DS}}$ applied.
- As the voltage between drain and source $\mathbf{V_{DS}}$ is increased, the current flow $\mathbf{I_D}$ from source to drain increases. This increase in current is linear up to a certain point **A**, known as **Knee Voltage**.
- The gate terminals will be under reverse biased condition and as $\mathbf{I_D}$ increases, the depletion regions tend to constrict.
- This constriction is unequal in length making these regions come closer at drain and farther at drain, which leads to **pinch off** voltage.
- The point at which this pinch off voltage occurs is called as **Pinch off point**, denoted as **B**.
- As $\mathbf{V_{DS}}$ is further increased, the channel resistance also increases in such a way that $\mathbf{I_D}$ practically remains constant.
- The region **BC** is known as **saturation region** or amplifier region. All these along with the points A, B and C are plotted in the graph.
- The drain characteristics are plotted for drain current $\mathbf{I_D}$ against drain source voltage $\mathbf{V_{DS}}$ for different values of gate source voltage VGS.
- The overall drain characteristics for such various input voltages are as given in the next figure.



- As the negative gate voltage controls the drain current, FET is called as a Voltage controlled device. The drain characteristics indicate the performance of a FET.

Video Content / Details of website for further learning (if any):

- https://nptel.ac.in/content/storage2/courses/113106065/Week%206/Lesson13.pdf
- https://www.ee.iitb.ac.in/~sequel/ee101/ee101_ jfet_1.pdf
- https://www.tutorialspoint.com/basic_electronics/basic_electronics_jfet.htm
-

Important Books/Journals for further learning including the page no's:

- "Electronic Devices and Circuits", S.Salivahanan, N.Sureshkumar and A.Vallavaraj,TataMicgraw Hill, 2nd Edition, 2008 (197-205)

Course Teacher

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L-20

LECTURE HANDOUTS

ECE **I/II**

Course Name with Code : 16GES11 - ELECTRONIC DEVICES
Course Teacher : Dr. J.RANGARAJAN

Unit III : FIELD EFFECT TRANSISTORS **Date of Lecture:**

Topic of Lecture:Configuration of JFET - JFET as Amplifier

Introduction :

- In this chapter, we will discuss about a Configuration of JFET and how JFET act as Amplifier.

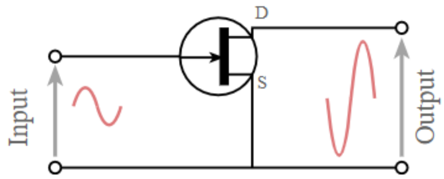
Prerequisite knowledge for Complete understanding and learning of Topic:

- BJT Configuration, Concept of JFET

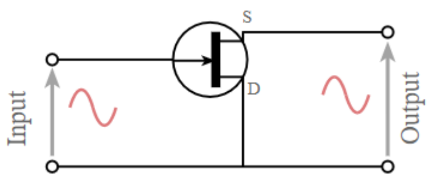
Detailed content of the Lecture:

- Three different configurations of FET are shown in the following figure.
- Their important characteristics are shown in the table.

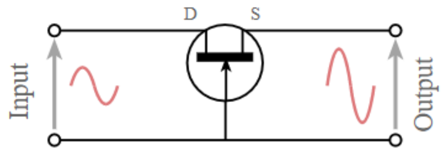
Common Source Configuration



Common Drain Configuration



Common Gate Configuration

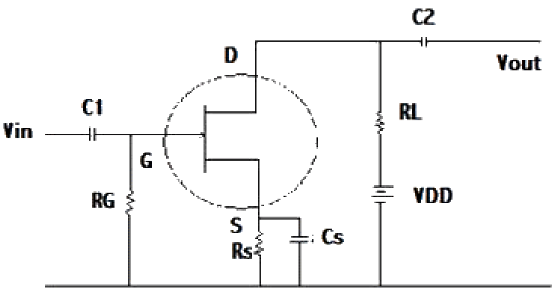


Performance parameters

FET CONFIGURATION	COMMON GATE	COMMON DRAIN (SOURCE FOLLOWER)	COMMON SOURCE
Voltage gain	High	Low	Medium
Current gain	Low	High	Medium
Power gain	Low	Medium	High
Input resistance	Low	High	Medium
Output resistance	High	Low	Medium
Input / output phase relationship	0°	0°	180°

JFET as Amplifier

One of the application of the JFET is an Amplifier, it amplified the weak signal connected in the Gate terminal , the input is always reversed biased, a small change in the reverse bias on the gate produce large change in the drain current, this fact make JFET capable of amplifing the weak signals



Working / Operation

When negative signal is applied at in put of the amplifier, the gate bias is increase, duplication layer is decrease, Channel resistance is increase, ID is decreased, Drop across Load Resistor is decreases, and the positive signal is present at output through C2.

When the positive signal is applied at the input the action will be the wise versa

This seen that there is phase inveration between the input signal at the gate and the output signal at the drain.

Video Content / Details of website for further learning (if any):

- https://nptel.ac.in/content/storage2/courses/113106065/Week%206/Lesson13.pdf
- https://www.ee.iitb.ac.in/~sequel/ee101/ee101_ jfet_1.pdf
- https://www.tutorialspoint.com/basic_electronics/basic_electronics_jfet.htm
- https://www.electronics-notes.com/articles/analogue_circuits/fet-field-effect-transistor/fet-circuit-configurations.php

Important Books/Journals for further learning including the page no's:

- "Electronic Devices and Circuits", S.Salivahanan, N.Sureshkumar and A.Vallavaraj, Tata Micgraw Hill, 2nd Edition, 2008 (197-205)

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L-21

LECTURE HANDOUTS

ECE **I/II**

Course Name with Code : 16GES11 - ELECTRONIC DEVICES
Course Teacher : Dr. J.RANGARAJAN

Unit III : FIELD EFFECT TRANSISTORS **Date of Lecture:**

Topic of Lecture: JFET as Switch

Introduction :

- In this chapter, we will discuss about a how JFET act as Switch. By providing proper biasing to the Gate terminal of the FET, it can work as an ON and OFF switch. Fast switching operation can be achieved than the junction transistor.

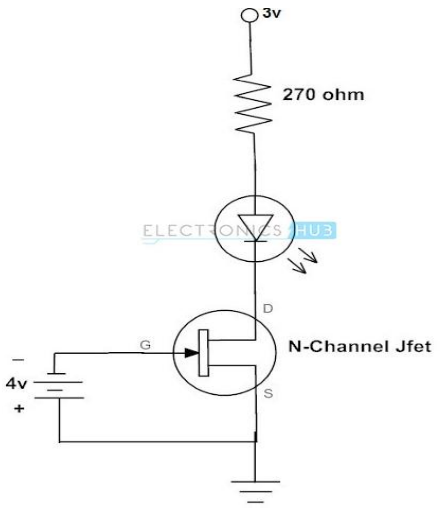
Prerequisite knowledge for Complete understanding and learning of Topic:

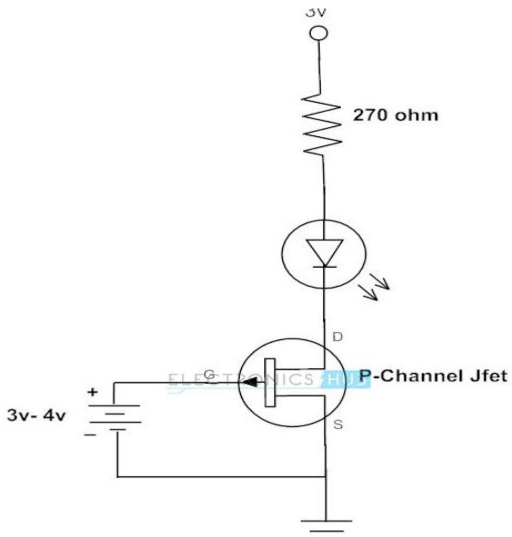
- Concept of JFET

Detailed content of the Lecture:

N-Channel JFET as a Switch

- The N-channel JFET used to switch the LED.
- The LED is connected between supply and source terminal through a resistor. Here resistor is used to limit the current through the LED.
- Gate terminal of the transistor connected to the negative supply.
- From the JFET discussion, zero voltage on the gate terminal makes current to flow through the LED because FET is in saturation mode. Therefore, the LED becomes ON.
- With a sufficient negative voltage on the gate terminal (about 3-4 volts), JFET drives into cutoff mode so the LED becomes turned OFF.





P-Channel JFET as a Switch

- Similar to the N-channel JFET driven LED, P-channel JFET switched LED circuit is given below. The difference between the two circuits is the supply source at the gate terminal.
- Turn ON condition remains same for both circuits that is zero voltage at the gate terminal causes the LED to glow as the FET is active.
- For switching the FET into cutoff, a sufficient positive voltage (about 3 to 4 volts in this case) stops the current flow through the circuit.
- Therefore the LED is turned OFF.
- We can also use FETs for turning the relay circuits, motor drivers, and other electronic controlling circuits.

Video Content / Details of website for further learning (if any):

- https://nptel.ac.in/content/storage2/courses/113106065/Week%206/Lesson13.pdf
- https://www.ee.iitb.ac.in/~sequel/ee101/ee101_ jfet_1.pdf
- https://www.tutorialspoint.com/basic_electronics/basic_electronics_jfet.htm
- https://www.electronicshub.org/fet-as-a-switch/

Important Books/Journals for further learning including the page no's:

- "Electronic Devices and Circuits", S.Salivahanan, N.Sureshkumar and A.Vallavaraj, TataMicgraw Hill, 2nd Edition, 2008 (202-205)

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L-22

LECTURE HANDOUTS

ECE

I/II

Course Name with Code : 16GES11 - ELECTRONIC DEVICES
Course Teacher : Dr. J.RANGARAJAN

Unit III : FIELD EFFECT TRANSISTORS **Date of Lecture:**

Topic of Lecture: JFET as Voltage Variable Resistor

Introduction :

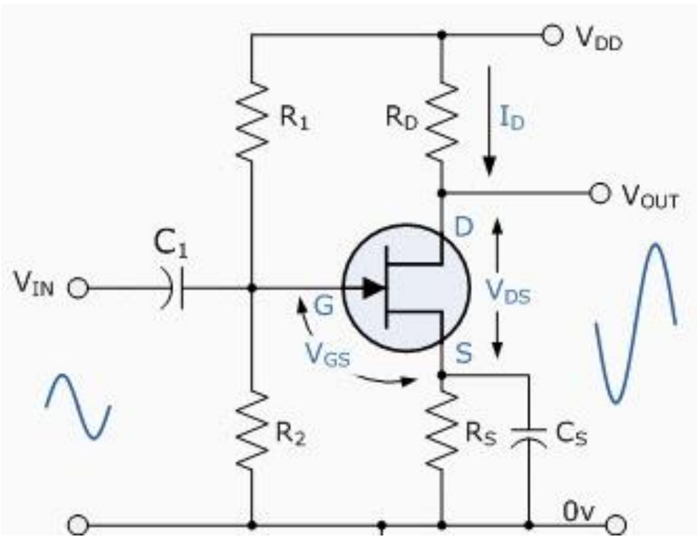
- In addition to working as a switch, the JFET can also act as Voltage Variable Resistor.

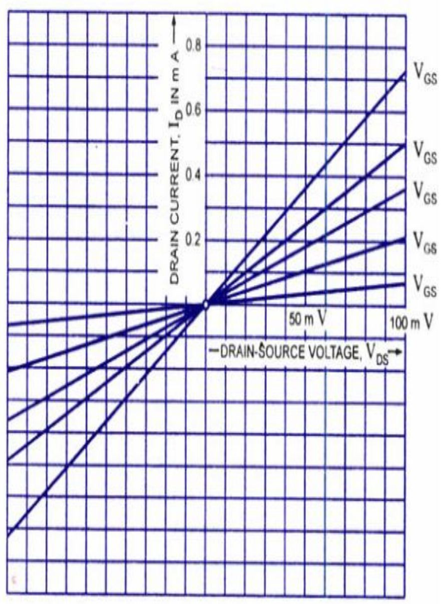
Prerequisite knowledge for Complete understanding and learning of Topic:

- Concept of JFET

Detailed content of the Lecture:

- FET is a device that is usually operated in the constant-current portion of its output characteristics.
- But if it is operated on the region prior to pinch-off (that is where V_{DS} is small, say below 100 mV), it will behave as a voltage-variable resistor (VVR).
- It is due to the fact that in this region drain-to-source resistance R_{DS} can be controlled by varying the bias voltage V_{GS}.
- In such applications the FET is also referred to as a voltage-variable resistor or volatile dependent resistor.





- Note that the drain curves shown in figure, extend on both sides of the origin.

- This means that a JFET can be employed as a voltage-variable resistor for small ac signals, typically those less than 100mV.
- When it is employed in this way, it does not require a dc drain voltage from the supply. All that is required is an ac input signal.

Video Content / Details of website for further learning (if any):

- https://nptel.ac.in/content/storage2/courses/113106065/Week%206/Lesson13.pdf
- https://www.ee.iitb.ac.in/~sequel/ee101/ee101_ jfet_1.pdf
- https://www.tutorialspoint.com/basic_electronics/bsic_electronics_jfet.htm
- http://www.circuitstoday.com/fet-as-a-vvr-voltage-variable-resistor

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LECTURE HANDOUTS

ECE **I/II**

Course Name with Code : 16GES11 - ELECTRONIC DEVICES
Course Teacher : Dr. J.RANGARAJAN

Unit III : FIELD EFFECT TRANSISTORS **Date of Lecture:**

Topic of Lecture: MOSFET

Introduction :

FETs have a few disadvantages like high drain resistance, moderate input impedance and slower operation. To overcome these disadvantages, the MOSFET(Metal Oxide Silicon Field Effect Transistor) which is an advanced FET is invented.

Prerequisite knowledge for Complete understanding and learning of Topic:

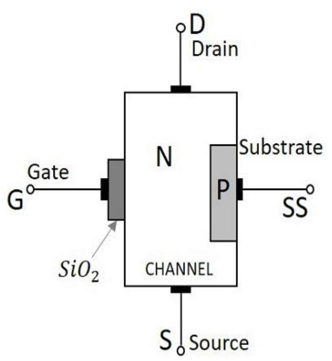
- JFET

Detailed content of the Lecture:

- MOSFET stands for Metal Oxide Silicon Field Effect Transistor or Metal Oxide Semiconductor Field Effect Transistor.
- This is also called as IGFET meaning Insulated Gate Field Effect Transistor. The FET is operated in both depletion and enhancement modes of operation.

Construction of a MOSFET

- The construction of a MOSFET is a bit similar to the FET. An oxide layer is deposited on the substrate to which the gate terminal is connected.
- This oxide layer acts as an insulator (sio_2 insulates from the substrate), and hence the MOSFET has another name as IGFET.
- In the construction of MOSFET, a lightly doped substrate, is diffused with a heavily doped region.
- Depending upon the substrate used, they are called as **P-type** and **N-type** MOSFETs.

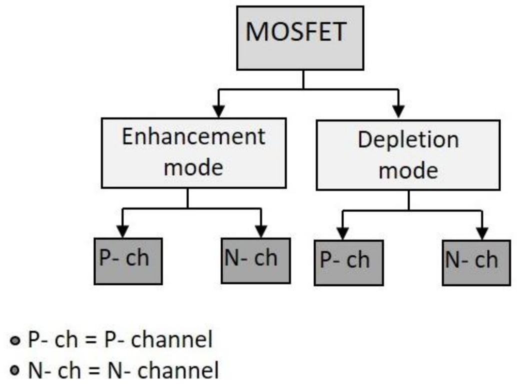


- The voltage at gate controls the operation of the MOSFET. In this case, both positive and negative voltages can be applied on the gate as it is insulated from the channel.
- With negative gate bias voltage, it acts as **depletion MOSFET** while with positivegate bias

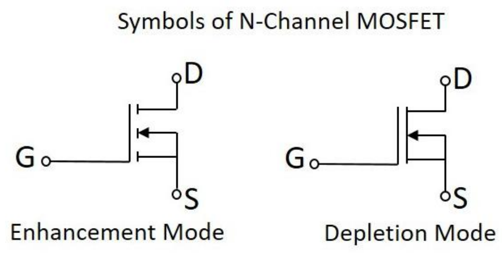
voltage it acts as an **Enhancement MOSFET**.

Classification of MOSFETs

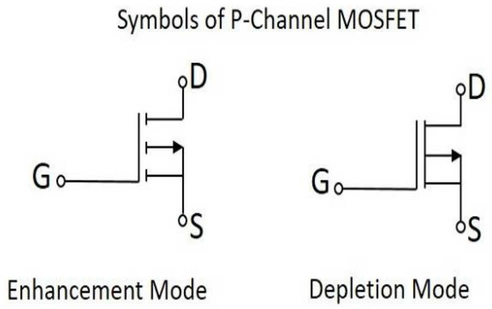
- Depending upon the type of materials used in the construction, and the type of operation, the MOSFETs are classified as follows:



The **N-channel MOSFETs** are simply called as **NMOS**. The symbols for N-channel MOSFET are as given below.



- The **P-channel MOSFETs** are simply called as **PMOS**. The symbols for P-channel MOSFET are as given below



Video Content / Details of website for further learning (if any):

- https://nptel.ac.in/content/storage2/courses/108105066/PDF/L-6(DK)(PE)%20((EE)NPTEL).pdf
- http://home.iitk.ac.in/~imon/Teaching.html
- https://www.tutorialspoint.com/basic_electronics/basic_electronics_mosfet.htm

Important Books/Journals for further learning including the page no's:

- "Electronic Devices and Circuits", S.Salivahanan , N.Sureshkumar and A.Vallavaraj, TataMicgraw Hill, 2^{nd} Edition, 2008.

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LECTURE HANDOUTS

ECE **I/II**

Course Name with Code : 16GES11 - ELECTRONIC DEVICES
Course Teacher : Dr. J.RANGARAJAN

Unit III : FIELD EFFECT TRANSISTORS **Date of Lecture:**

Topic of Lecture: Enhancement and Depletion mode MOSFET

Introduction :

Like FET, the MOSFETs are three terminal devices with a Gate, Drain and Source and both P-channel (PMOS) and N-channel (NMOS) MOSFETs are available. The main difference this time is that MOSFETs are available in two basic forms:

- Depletion Type – the transistor requires the Gate-Source voltage, (V_{GS}) to switch the device "OFF". The depletion mode MOSFET is equivalent to a "Normally Closed" switch.
- Enhancement Type – the transistor requires a Gate-Source voltage, (V_{GS}) to switch the device "ON". The enhancement mode MOSFET is equivalent to a "Normally Open" switch.

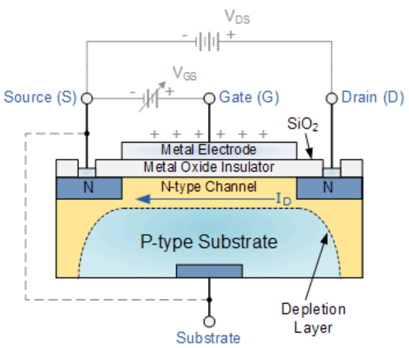
Prerequisite knowledge for Complete understanding and learning of Topic:

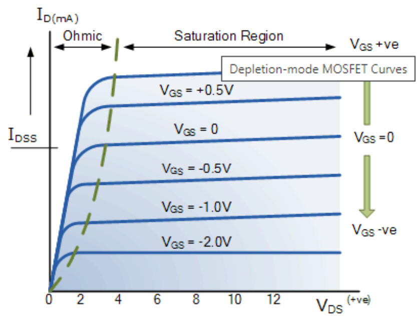
- JFET

Detailed content of the Lecture:

Depletion-mode MOSFET

- The Depletion-mode MOSFET, which is less common than the enhancement mode types is normally switched "ON" (conducting) without the application of a gate bias voltage.
- That is the channel conducts when V_{GS} = 0 making it a "normally-closed" device.
- The circuit symbol shown above for a depletion MOS transistor uses a solid channel line to signify a normally closed conductive channel.
- For the n-channel depletion MOS transistor, a negative gate-source voltage, -V_{GS} will deplete (hence its name) the conductive channel of its free electrons switching the transistor "OFF".
- Likewise for a p-channel depletion MOS transistor a positive gate-source voltage, +V_{GS} will deplete the channel of its free holes turning it "OFF".





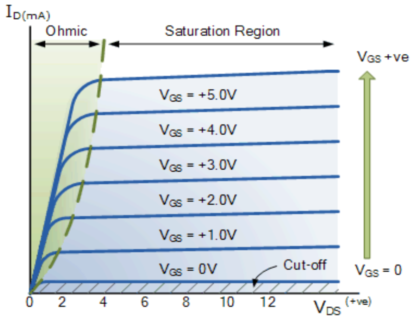
- In other words, for an n-channel depletion mode MOSFET: +V_{GS} means more electrons and more current.
- While a -V_{GS} means less electrons and less current. The opposite is also true for the p-channel types. Then the depletion mode MOSFET is equivalent to a "normally-closed" switch.
- The depletion-mode MOSFET is constructed in a similar way to their JFET transistor

counterparts were the drain-source channel is inherently conductive with the electrons and holes already present within the n-type or p-type channel.

- This doping of the channel produces a conducting path of low resistance between the Drain and Source with zero Gate bias.

Enhancement-mode MOSFET

- The more common **Enhancement-mode MOSFET** or eMOSFET, is the reverse of the depletion-mode type.
- Here the conducting channel is lightly doped or even undoped making it non-conductive. This results in the device being normally "OFF" (non-conducting) when the gate bias voltage, V_{GS} is equal to zero. The circuit symbol shown above for an enhancement MOS transistor uses a broken channel line to signify a normally open non-conducting channel.
- For the n-channel enhancement MOS transistor a drain current will only flow when a gate voltage (V_{GS}) is applied to the gate terminal greater than the threshold voltage (V_{TH}) .
- The application of a positive (+ve) gate voltage to a n-type eMOSFET attracts more electrons towards the oxide layer around the gate thereby increasing or enhancing (hence its name) the thickness of the channel allowing more current to flow.
- This is why this kind of transistor is called an enhancement mode device as the application of a gate voltage enhances the channel.
- Increasing this positive gate voltage will cause the channel resistance to decrease further causing an increase in the drain current, I_D through the channel.
- In other words, for an n-channel enhancement mode MOSFET: $+V_{GS}$ turns the transistor "ON", while a zero or $-V_{GS}$ turns the transistor "OFF".
- Thus the enhancement-mode MOSFET is equivalent to a "normally-open" switch.



Video Content / Details of website for further learning (if any):

- https://nptel.ac.in/content/storage2/courses/108105066/PDF/L-6(DK)(PE)%20((EE)NPTEL).pdf
- http://www.iitg.ac.in/apvajpeyi/ph218/Lec-27.pdf
- https://www.electronics-tutorials.ws/transistor/tran_6.html

Important Books/Journals for further learning including the page no's:

- "Electronic Devices and Circuits", S.Salivahanan , N.Sureshkumar and A.Vallavaraj, TataMicgraw Hill, 2nd Edition, 2008 (206-214)

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LECTURE HANDOUTS

ECE

I/II

Course Name with Code : 16GES11 - ELECTRONIC DEVICES
Course Teacher : Dr. J.RANGARAJAN

Unit III : FIELD EFFECT TRANSISTORS **Date of Lecture:**

Topic of Lecture: Characteristics of NMOS

Introduction :

- The metal–oxide–semiconductor field-effect transistor (MOSFET) is a transistor used for amplifying or switching electronic signals. In MOSFETs, a voltage on the oxide-insulated gate electrode can induce a conducting channel between the two other contacts called source and drain. The channel can be of n-type or p-type, and is accordingly called an NMOS or a PMOS

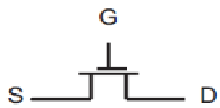
Prerequisite knowledge for Complete understanding and learning of Topic:

JFET , MOSFET

Detailed content of the Lecture:

N-channel

- As the voltage on the top electrode increases further, electrons are attracted to the surface.
- At a particular voltage level, which we will shortly define as the threshold voltage, the electron density at the surface exceeds the hole density.
- At this voltage, the surface has inverted from the p-type polarity of the original substrate to an n-type inversion layer, or inversion region, directly underneath the top plate.
- This inversion region is an extremely shallow layer, existing as a charge sheet directly below the gate.
- In the MOS capacitor, the high density of electrons in the inversion layer is supplied by the electron–hole generation process within the depletion layer.
- The positive charge on the gate is balanced by the combination of negative charge in the inversion layer plus negative ionic acceptor charge in the depletion layer.
- The voltage at which the surface inversion layer just forms plays an extremely important role in field-effect transistors and is called the threshold voltage V_{tn}.

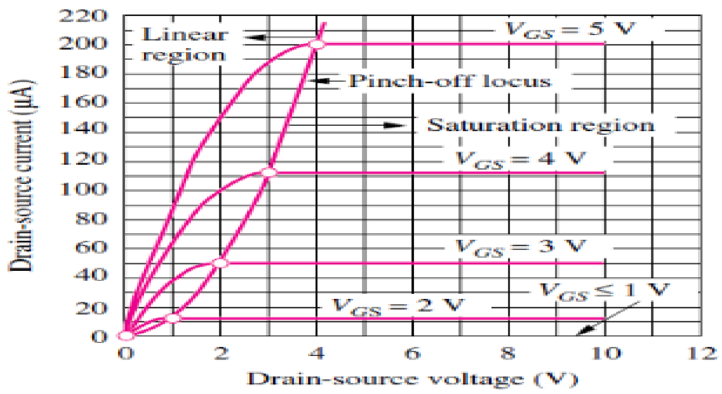


*n*MOS

- When the channel forms in the nMOS (pMOS) transistor, a positive (negative) drain voltage with respect to the source creates a horizontal electric field moving the electrons (holes) toward the drain forming a positive (negative) drain current coming into the transistor.
- The positive current convention is used for electron and hole current, but in both cases electrons are the actual charge carriers.
- If the channel horizontal electric field is of the same order or smaller than the vertical thin oxide

field, then the inversion channel remains almost uniform along the device length.

- This continuous carrier profile from drain to source puts the transistor in a bias state that is equivalently called either the **non-saturated, linear, or ohmic bias state**.
- The drain and source are effectively short-circuited. This happens when $V_{GS} > V_{DS} + V_{tn}$ for nMOS transistor and $V_{GS} < V_{DS} + V_{tp}$ for pMOS transistor.
- Drain current is linearly related to drain-source voltage over small intervals in the linear bias state.
- But if the nMOS drain voltage increases beyond the limit, so that $VGS < VDS + Vtn$, then the horizontal electric field becomes stronger than the vertical field at the drain end.



Video Content / Details of website for further learning (if any):

- https://www.ee.iitb.ac.in/course/~dghosh/mosfetSlides.pdfhttps://www.iitg.ac.in/cseweb/vlab/vlsi/MOSFET_theory.html
- http://vlab.amrita.edu/index.php?sub=59&brch=16&sim=270&cnt=1

Important Books/Journals for further learning including the page no's:

- "Electronic Devices and Circuits", S.Salivahanan , N.Sureshkumar and A.Vallavaraj,TataMicgraw Hill, 2nd Edition, 2008 (212-214)

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LECTURE HANDOUTS

ECE | I/II

Course Name with Code : 16GES11 - ELECTRONIC DEVICES
Course Teacher : Dr. J.RANGARAJAN
Unit III : FIELD EFFECT TRANSISTORS **Date of Lecture:**

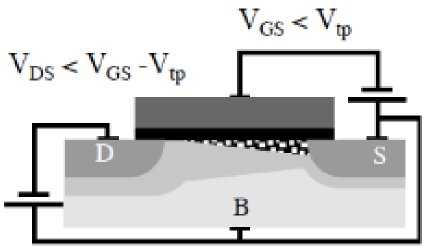
Topic of Lecture: Characteristics of PMOS

Introduction :

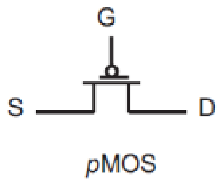
- The metal–oxide–semiconductor field-effect transistor (MOSFET) is a transistor used for amplifying or switching electronic signals. In MOSFETs, a voltage on the oxide-insulated gate electrode can induce a conducting channel between the two other contacts called source and drain. The channel can be of n-type or p-type, and is accordingly called an NMOS or a PMOS

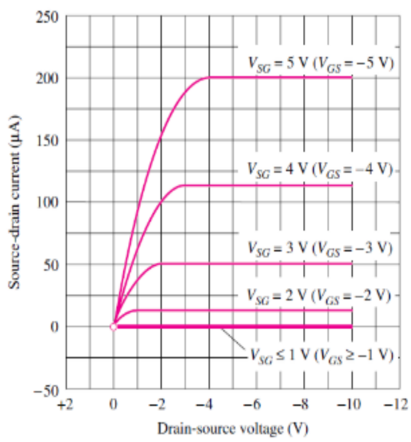
Prerequisite knowledge for Complete understanding and learning of Topic:
FET, Channel, MOSFET

Detailed content of the Lecture: The biasing arrangement and the characteristic curve of PMOS is shown in the figure.



(b) *p*MOS





Video Content / Details of website for further learning (if any):

- https://www.ee.iitb.ac.in/course/~dghosh/mosfetSlides.pdfhttps://www.iitg.ac.in/cseweb/vlab/vlsi/MOSFET_theory.html
- http://vlab.amrita.edu/index.php?sub=59&brch=165&sim=270&cnt=1

Important Books/Journals for further learning including the page no's:

- "Electronic Devices and Circuits", S.Salivahanan , N.Sureshkumar and A.Vallavaraj, TataMicgraw Hill, 2nd Edition, 2008 (212-214)

Course Teacher **Verified by HOD**

Course Name with Code : 16GES11 - ELECTRONIC DEVICES
Course Teacher : Dr. J.RANGARAJAN

Unit III : FIELD EFFECT TRANSISTORS **Date of Lecture:**

Topic of Lecture: Characteristics of CMOS

Introduction :

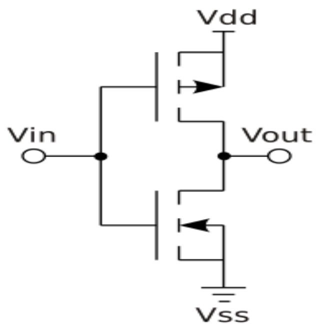
- Two important characteristics of CMOS devices are high noise immunity and low static **power** consumption. Since one transistor of the MOSFET pair is always off, the series combination draws significant **power** only momentarily during switching between on and off states.

Prerequisite knowledge for Complete understanding and learning of Topic:

- NMOS, PMOS

Detailed content of the Lecture:

- CMOS circuits are constructed in such a way that all P-type metal–oxide–semiconductor (PMOS) transistors must have either an input from the voltage source or from another PMOS transistor.
- Similarly, all NMOS transistors must have either an input from ground or from another NMOS transistor.
- The composition of a PMOS transistor creates low resistance between its source and drain contacts when a low gate voltage is applied and high resistance when a high gate voltage is applied.



- On the other hand, the composition of an NMOS transistor creates high resistance between source and drain when a low gate voltage is applied and low resistance when a high gate voltage is applied.
- CMOS accomplishes current reduction by complementing every nMOSFET with a pMOSFET and connecting both gates and both drains together.
- A high voltage on the gates will cause the nMOSFET to conduct and the pMOSFET not to conduct, while a low voltage on the gates causes the reverse.
- This arrangement greatly reduces power consumption and heat generation.

- However, during the switching time, both MOSFETs conduct briefly as the gate voltage goes from one state to another. This induces a brief spike in power consumption and becomes a serious issue at high frequencies.
- The input is connected to both a PMOS transistor (top of diagram) and an NMOS transistor (bottom of diagram).
- When the voltage of input is low, the NMOS transistor's channel is in a high resistance state. This limits the current that can flow from to ground.
- The PMOS transistor's channel is in a low resistance state and much more current can flow from the supply to the output. Because the resistance between the supply voltage and output is low, the voltage drop between the supply voltage and output due to a current drawn from output is small. The output, therefore, registers a high voltage
- On the other hand, when the voltage of input is high, the PMOS transistor is in an OFF (high resistance) state so it would limit the current flowing from the positive supply to the output, while the NMOS transistor is in an ON (low resistance) state, allowing the output from drain to ground.
- Because the resistance between output and ground is low, the voltage drop due to a current drawn into output placing output above ground is small. This low drop results in the output registering a low voltage.

In short, the outputs of the PMOS and NMOS transistors are complementary such that when the input is low, the output is high, and when the input is high, the output is low. Because of this behavior of input and output, the CMOS circuit's output is the inverse of the input.

Video Content / Details of website for further learning (if any):

- https://www.ee.iitb.ac.in/~smdp/DKStutorials/logic-notes.pdf
- https://nptel.ac.in/content/storage2/courses/117101058/downloads/Lec-15.pdf

Important Books/Journals for further learning including the page no's:

- "Electronic Devices and Circuits", S.Salivahanan, N.Sureshkumar and A.Vallavaraj,TataMicgraw Hill, 2nd Edition, 2008 (212-214)

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LECTURE HANDOUTS

L - 28

ECE

I/II

Course Name with Code : 16GES11 - ELECTRONIC DEVICES

Course Teacher : Dr. J.RANGARAJAN

Unit IV : BIASING OF BJT AND FET **Date of Lecture:**

Topic of Lecture: DC operating point and Load line

Introduction:

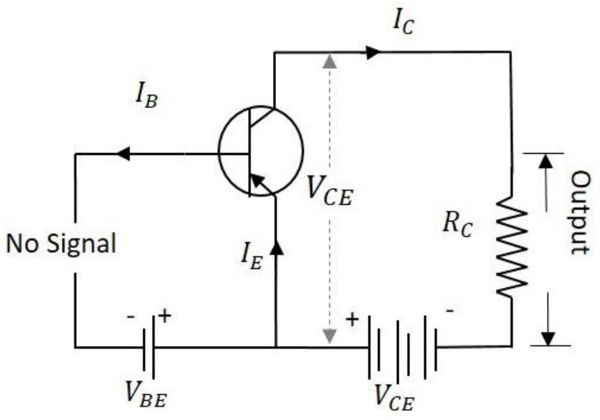
The DC load line is the load line of the DC equivalent circuit, defined by reducing the reactive components to zero (replacing capacitors by open circuits and inductors by short circuits). ... Once a DC operating point is defined by the DC load line, an AC load line can be drawn through the Q point.

Prerequisite knowledge for Complete understanding and learning of Topic:

Transistors, Types of Transistors, Operation of Transistor

DC operating point and Load line:

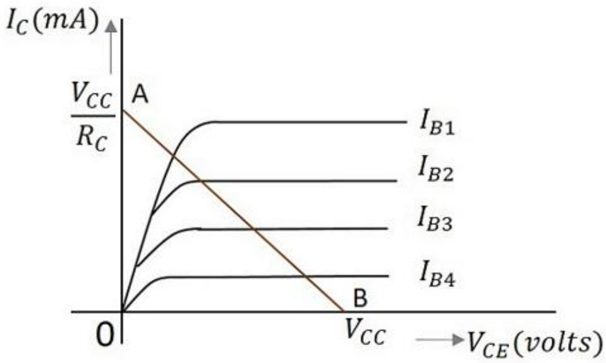
- When the transistor is given the bias and no signal is applied at its input, the load line drawn at such condition can be understood as DC condition.
- Here there will be no amplification as the signal is absent. The circuit will be as shown below.



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

VCE=VCC−ICRC

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



- To obtain the load line, the two end points of the straight line are to be determined. Let those two points be A and B.

To obtain A

- When collector emitter voltage V_{CE} = 0, the collector current is maximum and is equal to V_{CC}/R_C. This gives the maximum value of V_{CE}. This is shown as

$$V_{CE}=V_{CC}-I_CR_C$$
$$0 = V_{CC}-I_CR_C$$
$$V_{CE}=V_{CC}-I_CR_C$$
$$I_C = (V_{CE} - V_{CC}) / R_C$$

- This gives the point A (OA = V_{CC}/R_C) on collector current axis, shown in the above figure.

To obtain B

- When the collector current IC = 0, then collector emitter voltage is maximum and will be equal to the VCC. This gives the maximum value of I_C. This is shown as

$$V_{CE}=V_{CC}-I_CR_C$$
$$=V_{CC} \qquad\qquad (\text{As } I_C = 0)$$

- This gives the point B, which means (OB = V_{CC}) on the collector emitter voltage axis shown in the above figure.
- Hence we got both the saturation and cutoff point determined and learnt that the load line is a straight line. So, a DC load line can be drawn.

Video Content / Details of website for further learning (if any):

- https://www.tutorialspoint.com/amplifiers/operating_point.htm

Important Books/Journals for further learning including the page nos.:

1. "Electronic Devices and Circuits", S.Salivahanan, N.Sureshkumar, &A.Vallavaraj Tata McGraw Hill, Second Edition, 2008. (172-174)
2. "Electronic Devices", Thomas L.Floyd, Prentice Hall, Ninth Edition, 2012.

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LECTURE HANDOUTS

L - 29

ECE

I/II

Course Name with Code : 16GES11 - ELECTRONIC DEVICES

Course Teacher : Dr. J.RANGARAJAN

Unit IV : BIASING OF BJT AND FET **Date of Lecture:**

Topic of Lecture: Q Point, Bias Stability

Introduction :

- **Q-point** is the operating **point** of the transistor (I_{CQ},V_{CEQ}) at which it is biased. The concept of **Q-point** is used when transistor act as an amplifying device and hence is operated in active region of input output characteristics.
- **Bias Stability** (also known as **Bias Instability**) can be defined as how much deviation or drift the sensor has from its mean value of the output rate. ... Lower **Bias Instability** is advantageous, as it results in a gyro producing fewer deviations from the mean rate over time.

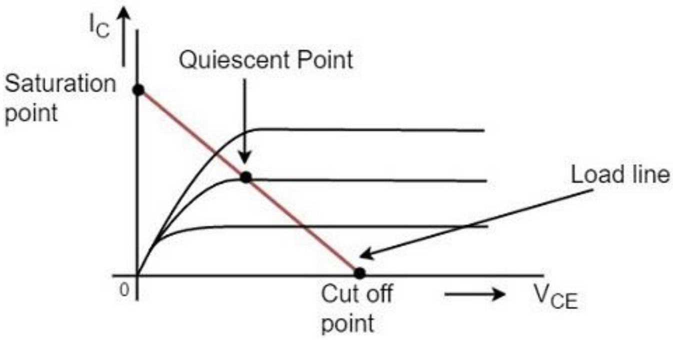
Prerequisite knowledge for Complete understanding and learning of Topic:

Transistors, Types of Transistors, Operation of Transistors

Q Point:

- When a line is drawn joining the saturation and cut off points, such a line can be called as Load line. This line, when drawn over the output characteristic curve, makes contact at a point called as Operating point.
- This operating point is also called as quiescent point or simply Q-point. There can be many such intersecting points, but the Q-point is selected in such a way that irrespective of AC signal swing, the transistor remains in the active region.

The following graph shows how to represent the operating point.



- The operating point should not get disturbed as it should remain stable to achieve faithful amplification. Hence the quiescent point or Q-point is the value where the Faithful Amplification is achieved.

- Biasing is the process of providing DC voltage which helps in the functioning of the circuit. A transistor is based in order to make the emitter base junction forward biased and collector base junction reverse biased, so that it maintains in active region, to work as an amplifier.

Transistor Biasing

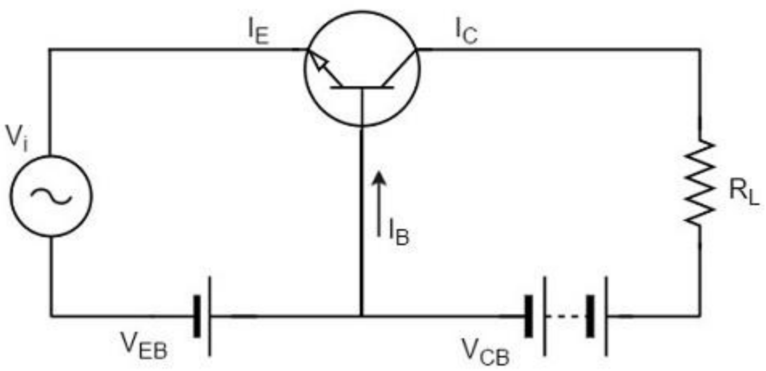
- The proper flow of zero signal collector current and the maintenance of proper collectoremitter voltage during the passage of signal is known as **Transistor Biasing**. The circuit which provides transistor biasing is called as **Biasing Circuit**.

Need for DC biasing

If a signal of very small voltage is given to the input of BJT, it cannot be amplified. Because, for a BJT, to amplify a signal, two conditions have to be met.

- The input voltage should exceed **cut-in voltage** for the transistor to be **ON**.
- The BJT should be in the **active region**, to be operated as an **amplifier**.
- If appropriate DC voltages and currents are given through BJT by external sources, so that BJT operates in active region and superimpose the AC signals to be amplified, then this problem can be avoided.
- The given DC voltage and currents are so chosen that the transistor remains in active region for entire input AC cycle. Hence DC biasing is needed.

The below figure shows a transistor amplifier that is provided with DC biasing on both input and output circuits.



- For a transistor to be operated as a faithful amplifier, the operating point should be stabilized. Let us have a look at the factors that affect the stabilization of operating point.

Factors affecting the operating point

- The main factor that affect the operating point is the temperature. The operating point shifts due to change in temperature.
- As temperature increases, the values of I_{CE}, β, V_{BE} gets affected.
- I_{CBO} gets doubled (for every 10^o rise)
- V_{BE} decreases by 2.5mv (for every 1^o rise)
- So the main problem which affects the operating point is temperature. Hence operating point should be made independent of the temperature so as to achieve stability.
- To achieve this, biasing circuits are introduced.

Stabilization

- The process of making the operating point independent of temperature changes or variations in transistor parameters is known as **Stabilization**.
- Once the stabilization is achieved, the values of I_C and V_{CE} become independent of temperature variations or replacement of transistor. A good biasing circuit helps in the stabilization of operating point.

Need for Stabilization

Stabilization of the operating point has to be achieved due to the following reasons.

- Temperature dependence of I_C
- Individual variations
- Thermal runaway

As the expression for collector current I_C is

$$IC = \beta\, Ib + ICEO$$
$$= \beta\, IB + (\beta+1)\, ICBO$$

- The collector leakage current I_{CBO} is greatly influenced by temperature variations. To come out of this, the biasing conditions are set so that zero signal collector current I_C = 1 mA. Therefore, the operating point needs to be stabilized i.e. it is necessary to keep I_C constant.

Individual Variations

- As the value of β and the value of V_{BE} are not same for every transistor, whenever a transistor is replaced, the operating point tends to change.
- Hence it is necessary to stabilize the operating point.

Video Content / Details of website for further learning (if any):

1. https://www.tutorialspoint.com/amplifiers/operating_point.htm

Important Books/Journals for further learning including the page nos.:

1. "Electronic Devices and Circuits", S.Salivahanan, N.Sureshkumar, &A.Vallavaraj Tata McGraw Hill, Second Edition, 2008. (172-174)
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LECTURE HANDOUTS **L - 30**

ECE **I/II**

Course Name with Code : 16GES11 - ELECTRONIC DEVICES

Course Teacher : Dr. J.RANGARAJAN

Unit IV : BIASING OF BJT AND FET **Date of Lecture:**

Topic of Lecture: Transistor Biasing Methods

Introduction :
The **biasing** in **transistor** circuits is done by using two DC sources V_{BB} and V_{CC}. It is economical to minimize the DC source to one supply instead of two which also makes the circuit simple.

Prerequisite knowledge for Complete understanding and learning of Topic:

- FET
- Types of FET
- Operation of JFET
- Charecteristics of JFET

Transistor Biasing Methods:

- The biasing in transistor circuits is done by using two DC sources V_{BB} and V_{CC}.
- It is economical to minimize the DC source to one supply instead of two which also makes the circuit simple.

The commonly used methods of transistor biasing are

- Base Resistor method
- Collector to Base bias
- Biasing with Collector feedback resistor
- Voltage-divider bias

All of these methods have the same basic principle of obtaining the required value of I_B and I_C from V_{CC} in the zero signal conditions.

Base Resistor method:

- In this method, a resistor R_B of high resistance is connected in base, as the name implies.
- The required zero signal base current is provided by V_{CC} which flows through R_B.
- The base emitter junction is forward biased, as base is positive with respect to emitter.

Collector to Base bias:

The collector to base bias circuit is same as base bias circuit except that the base resistor R_B is returned to collector, rather than to V_{CC} supply.

Biasing with Collector feedback resistor:

In this method, the base resistor R_B has its one end connected to base and the other to the collector as its name implies. In this circuit, the zero signal base current is determined by V_{CB} but not by V_{CC}.

Voltage-divider bias:

- Among all the methods of providing biasing and stabilization, the **voltage divider bias method** is the most prominent one.
- Here, two resistors R_1 and R_2 are employed, which are connected to V_{CC} and provide biasing. The resistor R_E employed in the emitter provides stabilization.

Video Content / Details of website for further learning (if any):

1. https://www.tutorialspoint.com/amplifiers/operating_point.htm

Important Books/Journals for further learning including the page nos.:

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2. "Electronic Devices", Thomas L.Floyd, Prentice Hall, Ninth Edition, 2012.

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Course Name with Code : 16GES11 - ELECTRONIC DEVICES

Course Teacher : Dr. J.RANGARAJAN

Unit IV : BIASING OF BJT AND FET **Date of Lecture:**

Topic of Lecture: Fixed Bias

Introduction :

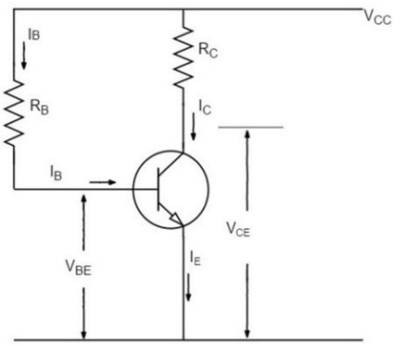
Fixed biasing is a type of bias where base current is maintained constant for given Vcc by using fixed resistor. So operating point must remain fixed. Using this two resistors and fixed current, initial operating point has to be found.

Prerequisite knowledge for Complete understanding and learning of Topic:

FET, Types of FET, Operation of JFET, Characteristics of JFET

Fixed Bias:

- In this method, a resistor R_B of high resistance is connected in base, as the name implies.
- The required zero signal base current is provided by V_{CC} which flows through R_B.
- The base emitter junction is forward biased, as base is positive with respect to emitter.
- The required value of zero signal base current and hence the collector current (as $I_C = \beta I_B$) can be made to flow by selecting the proper value of base resistor R_B.
- Hence the value of R_B is to be known. The figure below shows how a base resistor method of biasing circuit looks like.



- Let I_C be the required zero signal collector current. Therefore,

$$I_B = IC/\beta$$

- Considering the closed circuit from V_{CC}, base, emitter and ground, while applying the Kirchhoff's voltage law, we get,

$$V_{CC} = I_B R_B + V_{BE}$$

Or

$$I_B R_B = V_{CC} - V_{BE}$$

- Therefore,

$$R_B = V_{CC} - V_{BE} / I_B$$

- Since V_{BE} is generally quite small as compared to V_{CC}, the former can be neglected with little error. Then,

$$R_B = V_{CC} / I_B$$

- We know that V_{CC} is a fixed known quantity and I_B is chosen at some suitable value. As R_B can be found directly, this method is called as **fixed bias method**.
- Stability factor S is given by,

$$S = (\beta+1) / 1-\beta(dI_B dI_C)$$

- In fixed-bias method of biasing, I_B is independent of I_C so that,

$$dI_B/dI_C=0$$

- Substituting the above value in the previous equation,

$$\text{Stability factor } (S) = \beta+1$$

- Thus the stability factor in a fixed bias is **(β+1)** which means that I_C changes (β+1) times as much as any change in I_{CO}.

Advantages

- The circuit is simple.
- Only one resistor R_E is required.
- Biasing conditions are set easily.
- No loading effect as no resistor is present at base-emitter junction.

Disadvantages

- The stabilization is poor as heat development can't be stopped.
- The stability factor is very high. So, there are strong chances of thermal run away.

Hence, this method is rarely employed.

Video Content / Details of website for further learning (if any):
https://www.tutorialspoint.com/amplifiers/operating_point.htm

Important Books/Journals for further learning including the page nos.:

1. "Electronic Devices and Circuits", S.Salivahanan, N.Sureshkumar, &A.Vallavaraj Tata McGraw Hill, Second Edition, 2008. (172-174)
2. "Electronic Devices", Thomas L.Floyd, Prentice Hall, Ninth Edition, 2012.

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LECTURE HANDOUTS | **L - 32**

ECE | **I/II**

Course Name with Code : 16GES11 - ELECTRONIC DEVICES

Course Teacher : Dr. J.RANGARAJAN

Unit IV : BIASING OF BJT AND FET **Date of Lecture:**

Topic of Lecture: Collector to Base Bias

Introduction :

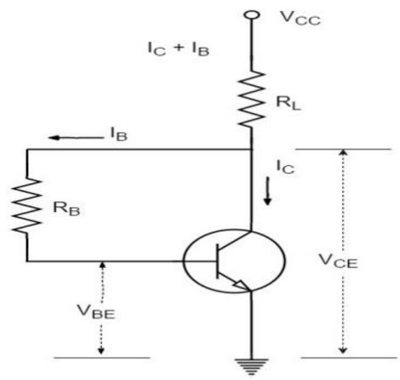
It is an improvement over fixed bias method. In this, biasing resistor is connected between collector and base of the transistor to provide feedback path.

Prerequisite knowledge for Complete understanding and learning of Topic:

FET, Types of FET, Operation of JFET and Characteristics of JFET

Collector to Base Bias:

- The collector to base bias circuit is same as base bias circuit except that the base resistor R_B is returned to collector, rather than to V_{CC} supply as shown in the figure below.



- This circuit helps in improving the stability considerably. If the value of I_C increases, the voltage across R_L increases and hence the V_{CE} also increases.
- This in turn reduces the base current I_B. This action somewhat compensates the original increase.
- The required value of R_B needed to give the zero signal collector current I_C can be calculated as follows:
- Voltage drop across R_L will be

$$R_L = (I_C+I_B)R_L \cong I_CR_L$$

- From the figure,

$$I_CR_L+I_BR_B+V_{BE}=V_{CC}$$

Or

$$I_B R_B = V_{CC} - V_{BE} - I_C R_L$$

- Therefore,

$$R_B = (V_{CC} - V_{BE} - I_C R_L) / I_B$$

Or

$$R_B = (V_{CC} - V_{BE} - I_C R_L)\ \beta / I_C$$

- On applying KVL,

$$(I_B + I_C) R_L + I_B R_B + V_{BE} = V_{CC}$$

Or

$$I_B (R_L + R_B) + I_C R_L + V_{BE} = V_{CC}$$

- Therefore,

$$I_B = (V_{CC} - I_C R_L - V_{BE}) / (R_L + R_B)$$

- Since V_{BE} is almost independent of collector current, we get

$$dI_B / dI_C = - R_L / R_L + R_B$$

- We know that

$$S = 1+\beta / 1-\beta\ (dI_B / dI_C)$$

- Therefore

$$S = (1+\beta) / (1+\beta\ (R_L / (R_L + R_B))$$

- This value is smaller than (1+β) which is obtained for fixed bias circuit.
- Thus there is an improvement in the stability.
- This circuit provides a negative feedback which reduces the gain of the amplifier.
- So the increased stability of the collector to base bias circuit is obtained at the cost of AC voltage gain.

Video Content / Details of website for further learning (if any):

1. https://www.tutorialspoint.com/amplifiers/operating_point.htm

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L - 33

LECTURE

ECE

I/II

Course Name with Code : 16GES11 - ELECTRONIC DEVICES

Course Teacher : Dr. J.RANGARAJAN

Unit IV : BIASING OF BJT AND FET **Date of Lecture:**

Topic of Lecture: Self biasing, Thermal Runaway, Thermal Stability

Introduction :

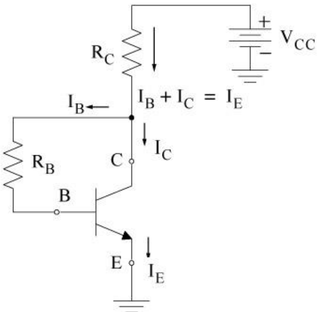
The regenerative heating cycle produced is called thermal runaway. In a self-biased CE amplifier a d.c power $P_C = V_{CE}I_C$ is developed at the collector junction of the transistor. With no signal present, this d.c power is completely dissipated in the form of heat. Thermal stability of polymer is defined as the ability of the polymeric material to resist the action of heat and to maintain its properties, such as strength, toughness, or elasticity at given temperature.

Prerequisite knowledge for Complete understanding and learning of Topic:

- FET, Types of FET, Operation of JFET and Characteristics of JFET

Self Biasing:

- The fixed bias arrangement discussed in the previous section is thermally unstable.
- If the temperature of the transistor rises for any reason (due to a rise in ambient temperature or due to current flow through it), the collector current will increase.
- This increase in current also causes the DC quiescent point to move away from its desired position (level).



NPN transistor amplifier with self-bias

- This reaction to temperature is undesirable because it affects amplifier gain (the number of times of amplification) and could result in distortion.
- A better method of biasing, known as *self-bias* is obtained by inserting the bias resistor directly between the base and collector.
- By tying the collector to the base in this manner, feedback voltage can be fed from the collector to the base to develop forward bias.
- Now, if an increase of temperature causes an increase in collector current, the collector voltage V_C will fall because of the increase of voltage produced across the collector resistor R_L.
- This drop in V_C will be fed back to the base and will result in a decrease in the base current. The decrease in base current will oppose the original increase in collector current and tend to stabilize it.

- The exact opposite effect is produced when the collector current decreases.

$$R_C I_E + R_B I_B + V_{BE} = V_{CC}$$

$$R_C I_E + R_B \frac{1}{\beta + 1} I_E + V_{BE} = V_{CC}$$

$$I_E = \frac{V_{CC} - V_{BE}}{R_C + R_B/(\beta + 1)}$$

Thermal Runaway:

- As the expression for collector current I_C is

$$I_C = \beta I_B + I_{CEO}$$
$$= \beta I_B + (\beta+1) I_{CBO}$$

- The flow of collector current and also the collector leakage current causes heat dissipation.
- If the operating point is not stabilized, there occurs a cumulative effect which increases this heat dissipation.
- The self-destruction of such an unstabilized transistor is known as **Thermal run away**.
- In order to avoid **thermal runaway** and the destruction of transistor, it is necessary to stabilize the operating point, i.e., to keep I_C constant.

Stability Factor

- It is understood that I_C should be kept constant in spite of variations of I_{CBO} or I_{CO}.
- The extent to which a biasing circuit is successful in maintaining this is measured by **Stability factor**. It denoted by **S**.
- By definition, the rate of change of collector current I_C with respect to the collector leakage current I_{CO} at constant β and I_B is called **Stability factor**.

$$S = dI_C / dI_{CO} \text{ at constant } I_B \text{ and } \beta$$

- Hence we can understand that any change in collector leakage current changes the collector current to a great extent.
- The stability factor should be as low as possible so that the collector current doesn't get affected. S=1 is the ideal value.
- The general expression of stability factor for a CE configuration can be obtained as,

$$I_C = \beta I_B + (\beta+1) I_{CO}$$

- Differentiating above expression with respect to I_C, we get

$$1 = \beta \, dI_B / dI_C + (\beta+1) \, dI_{CO}/dI_C$$

Or

$$1 = \beta (dI_B / dI_C) + (\beta+1) S \quad [\text{Since } dI_{CO}/dI_C = S]$$
$$S = (\beta+1) / 1 - \beta (dI_B c / dI_C)$$

- Hence the stability factor S depends on β, I_B and I_C.

Thermal Stability:

- **Thermal** instability occurs when junction temperature and collector current increase in regenerative and uncontrollable fashion.
- The limit depends on factors both within and external to the **transistor**.

Video Content / Details of website for further learning (if any):
https://www.tutorialspoint.com/amplifiers/operating_point.htm

Important Books/Journals for further learning including the page nos.:

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LECTURE

L - 34

ECE

I/II

Course Name with Code : 16GES11 - ELECTRONIC DEVICES

Course Teacher : Dr. J.RANGARAJAN

Unit IV : BIASING OF BJT AND FET **Date of Lecture:**

Topic of Lecture: FET Biasing Methods :Self Bias and Source Bias

Introduction :
In JFET, the drain current is limited by drain to saturation current Ids. The FET has high input impedance and there are no gate current flows. The dc voltage of gate is set by voltage divider is not affected by FET.

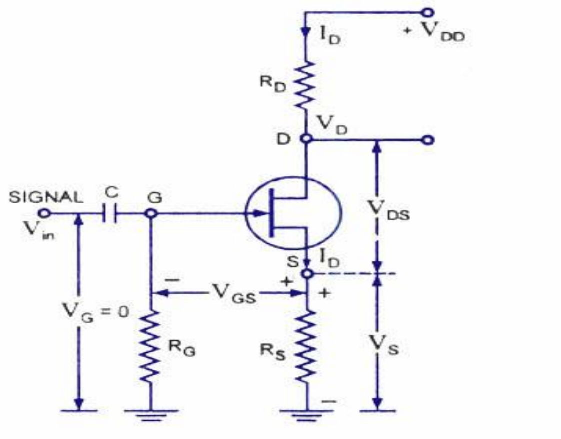
Prerequisite knowledge for Complete understanding and learning of Topic:

- FET
- Types of FET
- Operation of JFET
- Charecteristics of JFET

FET Biasing Methods:

- Unlike BJTs, thermal runaway does not occur with FETs.
- However, the wide differences in maximum and minimum **transfer characteristics** make I_D levels unpredictable with simple fixed-gate bias voltage.
- To obtain reasonable limits on quiescent drain currents I_D and drain-source voltage V_{DS}, source resistor and potential divider bias techniques must be used.
- With few exceptions, MOSFET bias circuits are similar to those used for **JFET**s. Various FET biasing circuits are discussed below:

Self-Bias:



Self-Bias Circuit For N-Channel JFET

- This is the most common method for biasing a JFET. Self-bias circuit for N-channel JFET is shown in figure.
- Since no gate current flows through the reverse-biased gate-source, the gate current IG = 0 and, therefore, $V_G = i_G R_G = 0$
- With a drain current I_D the voltage at the S is

$$Vs = I_D Rs$$

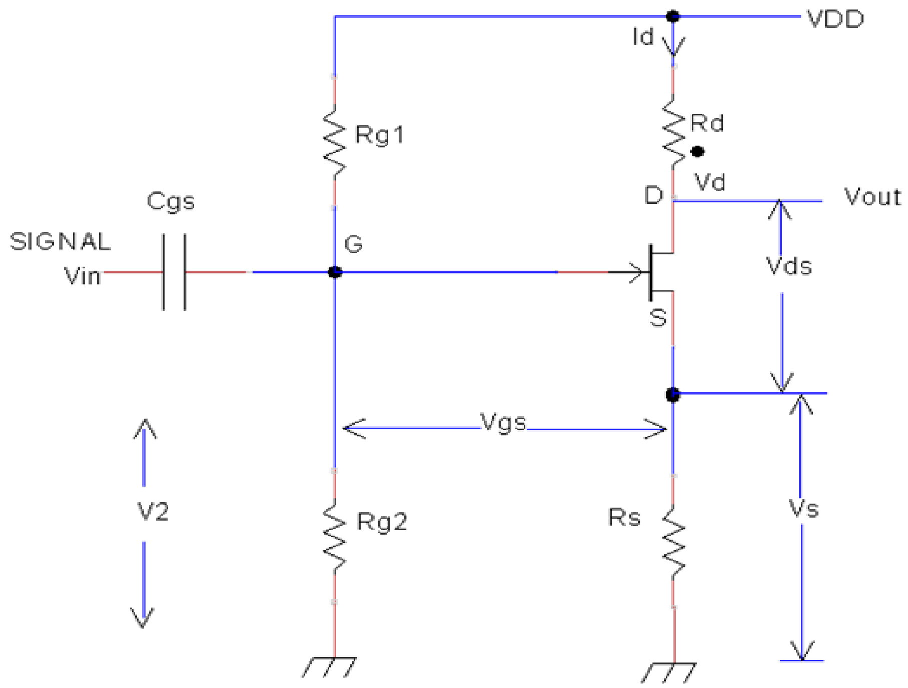
- The gate-source voltage is then
- $$V_G s = V_G – Vs = 0 – I_D Rs = – I_D Rs$$
- So voltage drop across resistance Rs provides the biasing voltage VGg and no external source is required for biasing and this is the reason that it is called self-biasing.
- The operating point (that is zero signal I_D and V_{DS}) can easily be determined from equation and equation given below :

$$V_{DS} = V_{DD} – I_D (R_D + R_S)$$

- Thus dc conditions of JFET amplifier are fully specified. Self biasing of a JFET stabilizes its quiescent operating point against any change in its parameters like transconductance. .

Source Bias:

- The resistors Rg1 and Rg2 formed the potential divider across V_{DD}.
- The necessary bias is provided by the voltage V2 across Rg2.
- For the adjustment of dc bias point RG1 is used. The gate is reverse biased and so there is no current flow through Rg. i.e, Ig = 0.



The gate voltage, $V_g = V2 = (V_{DD}/(Rg1+Rg2))*Rg2$

$V_{gS} = Vg-Vs$

$= Vg-Id$

For negative the gate to source voltage, the circuit is designed that IdRs must be greater than Vg. It provides the correct bias voltage. The operating point can be determined by : $Id = (V2 – V_{GS})/Rs$

$V_{DS} = V_{DD}- I_D(R_D+R_S)$.

Video Content / Details of website for further learning (if any):

1. https://www.tutorialspoint.com/amplifiers/operating_point.htm

Important Books/Journals for further learning including the page nos.:

1. "Electronic Devices and Circuits", S.Salivahanan, N.Sureshkumar, &A.Vallavaraj Tata McGraw Hill, Second Edition, 2008. (172-174)
2. "Electronic Devices", Thomas L.Floyd, Prentice Hall, Ninth Edition, 2012.

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LECTURE HANDOUTS

L - 35

ECE

I/II

Course Name with Code : 16GES11 - ELECTRONIC DEVICES

Course Teacher : Dr. J.RANGARAJAN

Unit IV : BIASING OF BJT AND FET **Date of Lecture:**

Topic of Lecture: Voltage Divider Bias Method

Introduction :

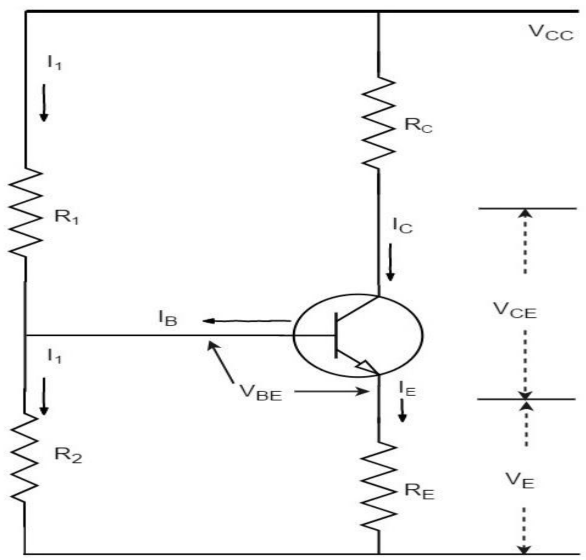
Bias voltage is the amount of **voltage** that an electronic device needs in order to power on and function. Without **bias voltage**, an electronic device wouldn't have the power to turn on and be operated. A microphone is one such device which needs **bias voltage** in order to operate.

Prerequisite knowledge for Complete understanding and learning of Topic:

- FET
- Types of FET
- Operation of JFET
- Charecteristics of JFET

Voltage Divider Bias Method:

- Among all the methods of providing biasing and stabilization, the **voltage divider bias method** is the most prominent one.
- Here, two resistors R_1 and R_2 are employed, which are connected to V_{CC} and provide biasing. The resistor R_E employed in the emitter provides stabilization.
- The name voltage divider comes from the voltage divider formed by R1 and R2. The voltage drop across R2 forward biases the base-emitter junction.
- This causes the base current and hence collector current flow in the zero signal conditions. The figure below shows the circuit of voltage divider bias method
.



- Suppose that the current flowing through resistance R_1 is I_1. As base current I_B is very small, therefore, it can be assumed with reasonable accuracy that current flowing through R_2 is also I_1.

Now let us try to derive the expressions for collector current and collector voltage.

Collector Current, I_C

From the circuit, it is evident that,

$$I_1=V_{CC}/R_1+R_2$$

Therefore, the voltage across resistance R_2 is

$$V_2 =(V_{CC}R_1+R_2)/R_2$$

Applying Kirchhoff's voltage law to the base circuit,

$$V_2 =V_{BE}+V_E$$
$$V_2 =V_{BE}+I_ER_E$$
$$I_E =V_2-V_{BE}/R_E$$

Since $I_E \approx I_C$,

$$I_C = V_2-V_{BE}/R_E$$

- From the above expression, it is evident that I_C doesn't depend upon β. V_{BE} is very small that I_C doesn't get affected by V_{BE} at all.

- Thus I_C in this circuit is almost independent of transistor parameters and hence good stabilization is achieved.

Collector-Emitter Voltage, V_{CE}

Applying Kirchhoff's voltage law to the collector side,

$$V_{CC} =I_CR_C+V_{CE}+I_ER_E$$

Since $I_E \cong I_C$

$$= I_CR_C+V_{CE}+I_CR_E$$
$$= I_C(R_C+R_E)+V_{CE}$$

Therefore,

$$V_{CE}=V_{CC}-I_C(R_C+R_E)$$

R_E provides excellent stabilization in this circuit.

$$V_2=V_{BE}+I_CR_E$$

- Suppose there is a rise in temperature, then the collector current I_C decreases, which causes the voltage drop across R_E to increase.

- As the voltage drop across R_2 is V_2, which is independent of I_C, the value of V_{BE} decreases. The reduced value of I_B tends to restore I_C to the original value.

-

Stability Factor

The equation for **Stability factor** of this circuit is obtained as

$$\text{Stability Factor} = S=(\beta+1)(R_0+R_3)/R_0+R_E+\beta R_E$$

$$= (\beta+1)\times(1+R_0R_E/\beta+1+R_0R_E)$$

Where

$$R_0 = R_1 R_2 / R_1 + R_2$$

- If the ratio R_0/R_E is very small, then R_0/R_E can be neglected as compared to 1 and the stability factor becomes

$$\text{Stability Factor} = S = (\beta+1)\times 1/\beta+1 = 1$$

- This is the smallest possible value of S and leads to the maximum possible thermal stability.

Video Content / Details of website for further learning (if any):

1. https://www.tutorialspoint.com/amplifiers/operating_point.htm

Important Books/Journals for further learning including the page nos.:

1. "Electronic Devices and Circuits", S.Salivahanan, N.Sureshkumar, &A.Vallavaraj Tata McGraw Hill, Second Edition, 2008. (172-174)

2. "Electronic Devices", Thomas L.Floyd, Prentice Hall, Ninth Edition, 2012.

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LECTURE HANDOUTS

L - 36

ECE

I/II

Course Name with Code : 16GES11 - ELECTRONIC DEVICES

Course Teacher : Dr. J.RANGARAJAN

Unit IV : BIASING OF BJT AND FET **Date of Lecture:**

Topic of Lecture: Biasing of MOSFET

Introduction :

Biasing in MOSFET Amplifiers is similar to biasing of the FET and transistor . Biasing: Creating the circuit to establish the desired. DC voltages and currents for the operation of the amplifier.

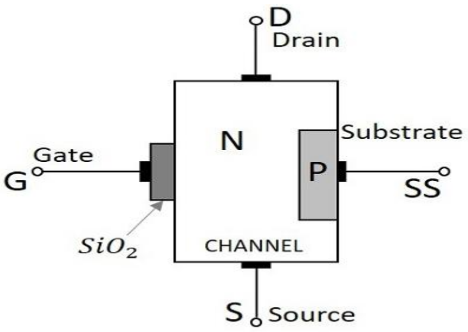
Prerequisite knowledge for Complete understanding and learning of Topic:

- FET
- Types of FET
- Operation of JFET
- Characteristics of JFET

Biasing MOSFET:

- MOSFET is a bit similar to the FET. An oxide layer is deposited on the substrate to which the gate terminal is connected. This oxide layer acts as an insulator (sio_2 insulates from the substrate), and hence the MOSFET has another name as IGFET.
- In the construction of MOSFET, a lightly doped substrate, is diffused with a heavily doped region. Depending upon the substrate used, they are called as **P-type** and **N-type** MOSFETs.
-

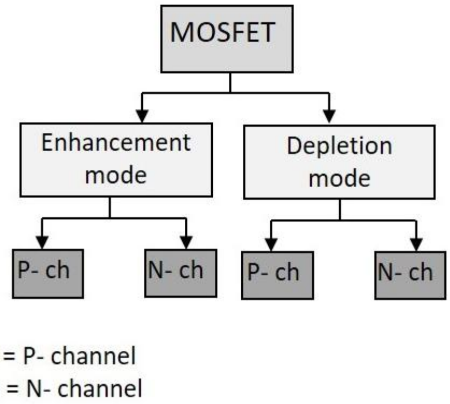
The following figure shows the construction of a MOSFET.



The voltage at gate controls the operation of the MOSFET. In this case, both positive and negative voltages can be applied on the gate as it is insulated from the channel. With negative gate bias voltage, it acts as **depletion MOSFET** while with positive gate bias voltage it acts as an **Enhancement MOSFET**.

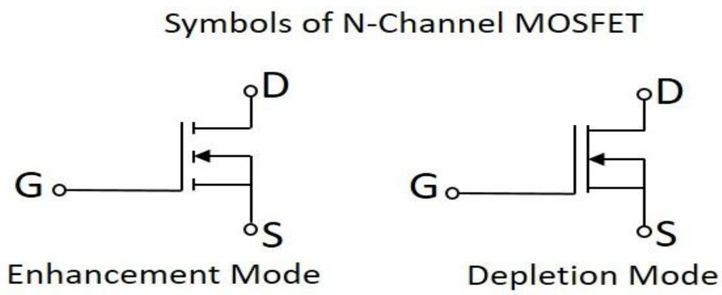
Classification of MOSFETs

Depending upon the type of materials used in the construction, and the type of operation, the MOSFETs are classified as in the following figure.

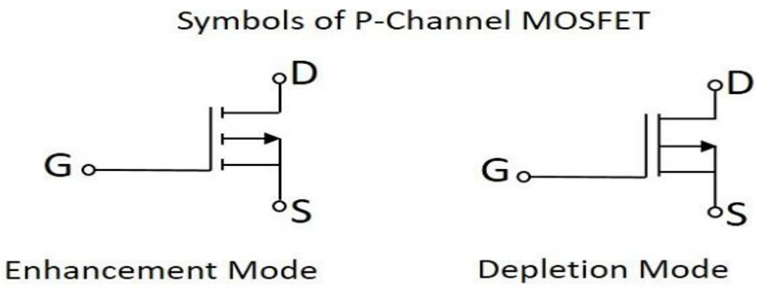


After the classification, let us go through the symbols of MOSFET.

The **N-channel MOSFETs** are simply called as **NMOS**. The symbols for N-channel MOSFET are as given below.



The **P-channel MOSFETs** are simply called as **PMOS**. The symbols for P-channel MOSFET are as given below.



Video Content / Details of website for further learning (if any):

1. https://www.tutorialspoint.com/amplifiers/operating_point.htm

Important Books/Journals for further learning including the page nos.:

1. "Electronic Devices and Circuits", S.Salivahanan, N.Sureshkumar, &A.Vallavaraj Tata McGraw Hill, Second Edition, 2008. (172-174)
2. "Electronic Devices", Thomas L.Floyd, Prentice Hall, Ninth Edition, 2012.

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LECTURE HANDOUTS

L 37

ECE

I / II

Course Name with Code : 19GES11 - ELECTRONIC DEVICES

Course Faculty : Dr. J. Rangarajan

Unit :V - Special Diodes and Opto Electronic Devices Date of Lecture:

Topic of Lecture: Theory and Characteristics of Schottky Diode

Introduction: A Schottky diode is a majority carrier device, where electron-hole recombination is usually not important. Hence, Schottky diodes have a much faster response under forward bias conditions than p-n junction diodes. Schottky diodes are specially manufactured to solve the problem of fast switching which consists of a metal to semiconductor junction.

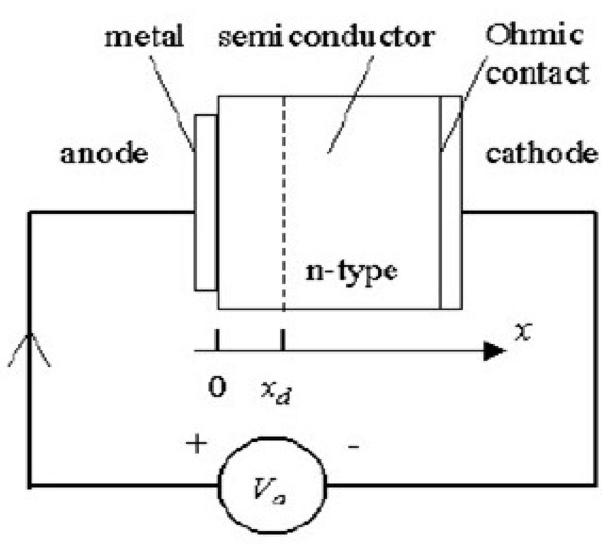
Prerequisite knowledge for Complete understanding and learning of Topic:

- Barrier region
- Barrier potential
- Operation of diode

Theory and Characteristics of Schottky Diode

Structure

The structure of a metal-semiconductor junction is shown in figure. It consists of a metal contacting a piece of semiconductor. An ideal Ohmic contact, a contact such that no potential exists between the metal and the semiconductor, is made to the other side of the semiconductor.

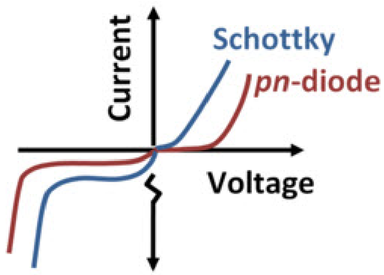


Principle of Operation:

Due to minority carrier free region, schottky diode cannot store the charge. Hence due to lack of charge storage,it can switch off very fast than a conventional diode.

It can be easily switched off for the frequencies above 300MHz. The barrier at the junction for a schottky diode is less than that of normal p-n diode in both forward and reverse bias region. The barrier potential and breakdown voltage in forward bias and reverse bias region respectively are also less than p-n junction diode. The barrier potential is 0.25V as compared to 0.7V for normal diode.

Characteristics of Schottky Diode:



Applications:

Due to fast switching characteristics this diode is very useful for high frequency, high speed applications such as:

- ✓ digital computer
- ✓ high speed TTL
- ✓ radar systems
- ✓ mixers and detectors in communication equipments and
- ✓ analog to digital converters

Video Content / Details of website for further learning (if any):

1. https://www.elprocus.com/using- schottky-diode /
2. https://www.elprocus.com/schottky-diode-working-and-applications/https://nptel.ac.in/courses/117103063/
3. httphttps://circuitglobe.com/ schottky-diode -as-an-amplifier.htmls://www.electronics- build-electronic-cir

Important Books/Journals for further learning including the page nos.:

1. "Electronic Devices and Circuits", S.Salivahanan, N.Sureshkumar, & A.Vallavaraj, Tata McGraw Hill, Second Edition, 2008. (151-152)
2. "Electronic Devices", Thomas L.Floyd, Prentice Hall, Ninth Edition, 2012. (Unit 4 and Unit 5)

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L 38

LECTURE HANDOUTS

ECE | I / II

Course Name with Code : 19GES11 - ELECTRONIC DEVICES

Course Faculty : Dr. J. Rangarajan

Unit : V - Special Diodes and Opto Electronic Devices Date of Lecture:

Topic of Lecture: Tunnel Diode

Introduction: *Tunneling* is the phenomenon in which the electron from the N side of the PN diode penetrates into the P side of the PN diode through the junction. The Diode which utilizes this tunneling phenomenon to exhibit negative resistance under forward bias condition is known as *Tunnel Diode*.

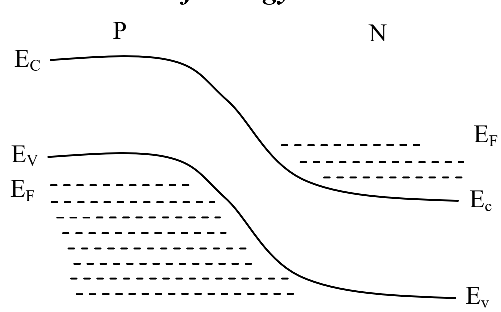
Prerequisite knowledge for Complete understanding and learning of Topic:

- Barrier potential
- PN junction
- Diode Operation

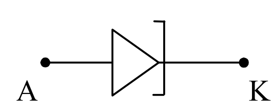
Tunnel Diode

Construction:-

Structure of Energy level



Symbol



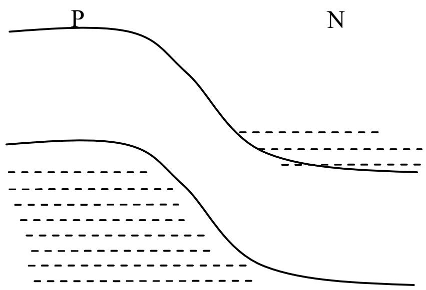
- The Tunneling property is achieved by increasing the doping concentration of 1 part of 10^3.
- It consist of thin junction that is of 100 A˚ which is achieved by increasing the doping concentration, since width of the junction barrier is inversely proportional to square root of Impurity concentration.
- The Anode is connected to the P type material and Cathode is connected to the N type material.

Operation

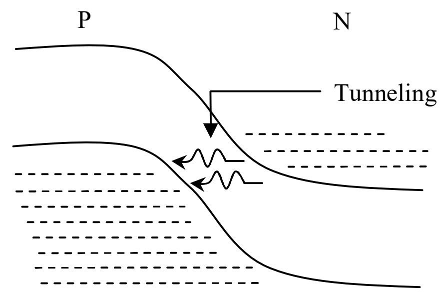
(i) Under zero bias, the electron will not have sufficient energy to move into P side through the junction. Hence the forward current is zero and the energy level will be same throughout the material.

(ii) When forward bias increases with small applied potential, energy level of the N side increases. The electron in the conduction band of the N side will see empty energy level on the P side. This makes the tunneling to happen from the N side to the P side.

Zero - Bias condition

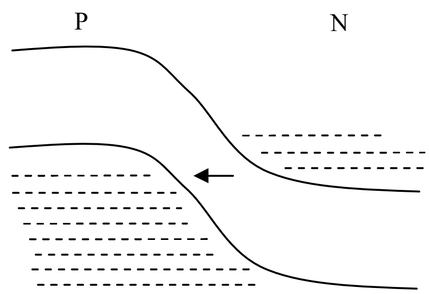


Forward bias – Peak voltage



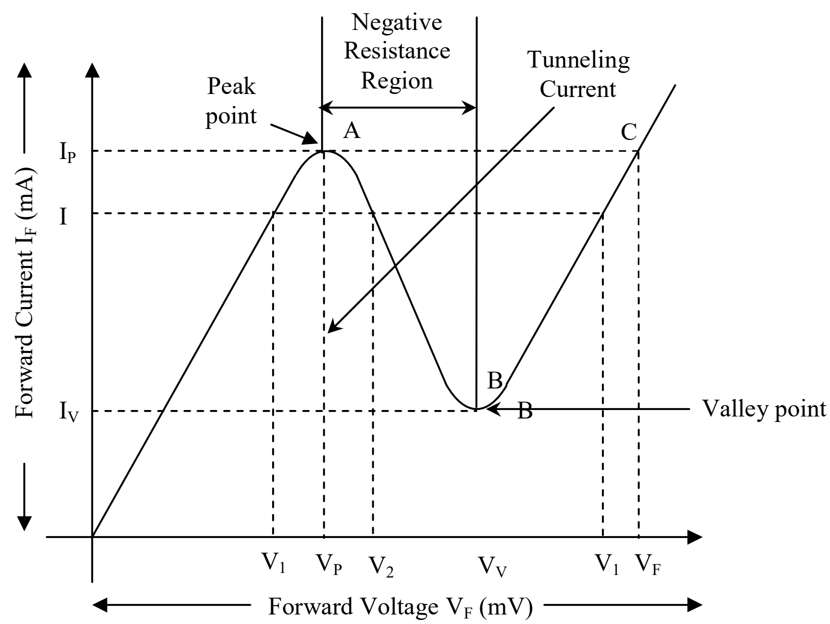
(iii) When the forward bias is further increased the tunneling will decreases. At particular voltage there will be no empty state and few electrons in the N side are opposite to the P side energy level. Hence current drops to zero. This phenomenon of decreases in current due to increases in voltage is known as negative resistance characteristics. The diode will behave as a normal PN junction diode after some particular voltage

Forward bias valley voltage



VI characteristic

VI characteristic of Tunnel Diode



- When the voltage increases, the current increases till the peak point is reached. The voltage & current at this particular peak point is known as peak voltage (V_P) and peak current (I_P)
- After this point current decreases with increases in applied voltage. This phenomenon of decreases in the current when the voltage increases takes place till the point known as valley point. This Region from the peak point to the valley point is known as Negative resistance Region.

- The voltage and current at valley point is known as valley voltage (V_v) and valley current (I_V)
- After this point, the tunnel diode will behave as a normal PN junction diode.

4.6.4 Applications: -Tunnel diode is used as

(i) Relaxation oscillation due to the negative resistance characteristics.
(ii) High speed switch circuits using hysteresis.
(iii) An amplifier and microwave oscillator due to the negative Resistance characteristics (which Requires a few mw of power).
(iv) Memory element.

4.6.5 Advantages:-
(i) Low cost.
(ii) Simple to operate and maintain.
(iii) Need low power and less noise.
(iv) Exhibit high speed due to the fact that tunneling takes place at the speed of light.
Immune to environment.

Video Content / Details of website for further learning (if any):

1. https://www.elprocus.com/using-transistor-as-a-switch/
2. httphttps://circuitglobe.com/transistor-as-an-amplifier.html
3. https://nptel.ac.in/courses/117103063/
4. httphttps://circuitglobe.com/transistor-as-an-amplifier.htmls://www.electronics-tutorials.ws/amplifier/amp_2.htmlbuild-electronic-cir

Important Books/Journals for further learning including the page nos.:

1. "Electronic Devices and Circuits", S.Salivahanan, N.Sureshkumar, &A.Vallavaraj Tata McGraw Hill, Second Edition, 2008. (172-174)
2. "Electronic Devices", Thomas L.Floyd, Prentice Hall, Ninth Edition, 2012. (Unit 5)

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LECTURE HANDOUTS

ECE

I / II

Course Name with Code : **19GES11 - ELECTRONIC DEVICES**

Course Faculty : **Dr. J. Rangarajan**

Unit : **V - Special Diodes and Opto Electronic Devices** **Date of Lecture:**

Topic of Lecture: Varactor diode

Introduction: Varactor diode is the specially designed Reverse bias PN junction diode in which the junction (or) transition capacitance can be varied by suitable variation of Impurity concentration. Varactor diode is also known as varicap, tuning (or) voltage capacitor diode (or) voltacap.

Prerequisite knowledge for Complete understanding and learning of Topic:

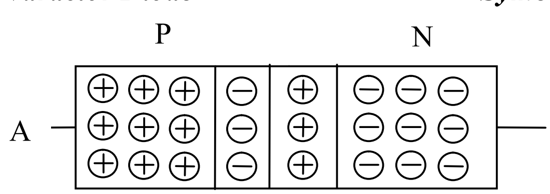
- Capacitor
- Diode Operation

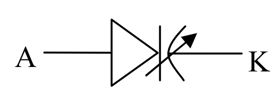
Varactor diode

Construction:

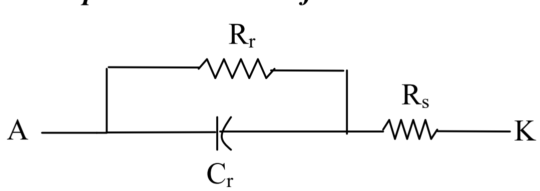
Varactor diode is the specially designed semiconductor diode to operate in Reverse biased condition. The capacitor is formed when the P and N type material is in contact. The junction will be filled with immobile positive and negative charge which contributes to capacitor.

Structure of varactor Diode ***Symbol***





Equivalent circuit of varactor Diode



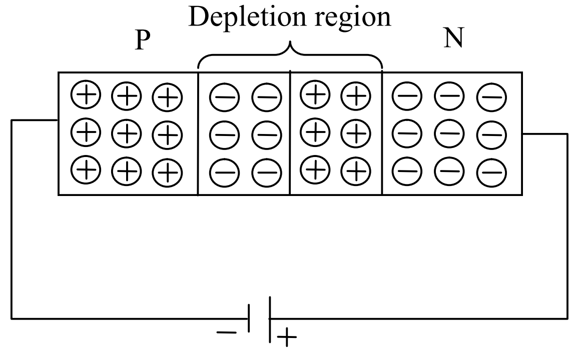
A = Anode.
K = Cathode.
R_r = Reverse diode Resistance.
C_r = Reverse capacitance (or) barrier capacitance.
R_s = Body Resistance.

Operation

We know that capacitance $C = \varepsilon A / W$

Where ε = permittivity of semiconductor material

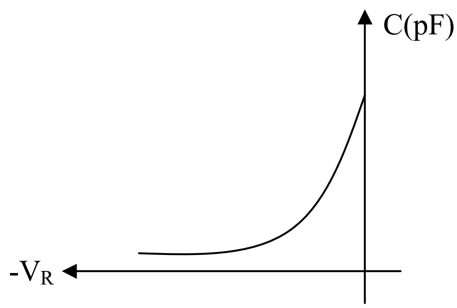
Hence capacitance is inversely proportional to depletion region width which is given by $C \alpha 1/W$. When the reverse bias is increased the depletion Region increases hence width of the Depletion Region increases which in turn decreases the capacitance. Since capacitance and depletion width is inversely proportional, the Depletion Region acts as conduction plate to vary the capacitance.



Characteristic of Varactor Diode

The characteristic curve of the varactor diode is obtained by plotting the curve between Reverse voltage and capacitance. The capacitance decreases with the increases in the voltage of Reverse bias.

Characteristic of varactor Diode



Applications: - Varactor diode can be used as

(i) Frequency modulator.
(ii) Frequency multiplier in microwave receiver.
(iii) Automatic frequency control devices due to its tuning phenomenon.
(iv) RF phase shifter.
(v) Filters and amplifiers.

Video Content / Details of website for further learning (if any):

1. https://www.elprocus.com/using-transistor-as-a-switch/
2. https://www.electronicshub.org/varactor-diode/
3. https://nptel.ac.in/courses/117103063/
4. https://www.electronics-notes.com/articles/electronic_components/diode/varactor-varicap-diode.php

Important Books/Journals for further learning including the page nos.:

1. "Electronic Devices and Circuits", S.Salivahanan, N.Sureshkumar, &A.Vallavaraj Tata McGraw Hill, Second Edition, 2008. (172-174)
2. "Electronic Devices", Thomas L.Floyd, Prentice Hall, Ninth Edition,2012. (Unit 5)

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L 40

LECTURE HANDOUTS

ECE | **I/ II**

Course Name with Code : 19GES11 - ELECTRONIC DEVICES

Course Faculty : Dr. J. Rangarajan

Unit :V - Special Diodes and Opto Electronic Devices Date of Lecture:

Topic of Lecture: Silicon Controlled Rectifier, TRIAC

Introduction: Silicon Controlled Rectifier also known as SCR is three terminal, four layered semiconductor device which is the modified version of thyristor by adding the terminal Gate (G). TRIAC is a three terminal, four layered switch. In this device two SCR are connected in parallel but in opposite direction.

Prerequisite knowledge for Complete understanding and learning of Topic:

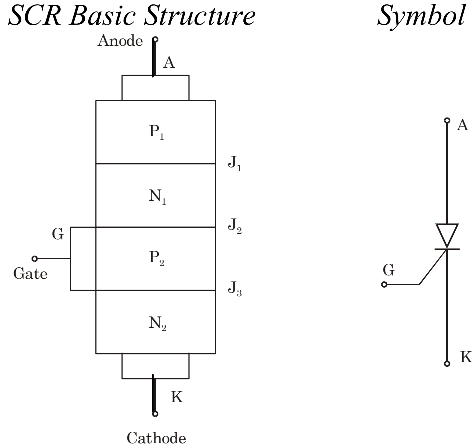
- PN junction
- Barrier potential
- Diode
- Transistor

Silicon Controlled Rectifier, TRIAC

<u>Silicon Controlled Rectifier</u>

Construction

SCR Basic Structure *Symbol*



The basic structure and symbol of the SCR is shown above. It is the four layered semiconductor device formed by consecutive placement of two PN layers. It is a three terminal (Gate, anode and cathode) and three junctions (J_1, J_2 and J_3) device in which Gate terminal is connected to lower P_2 layer to trigger the device. The Anode and Cathode is connected to the P_1 and N_2 layer

Operation of SCR:-

The operation of the SCR is based on two biasing characteristics, that is forward and Reverse Biasing.

Forward Bias:-

(I) When the forward bias is applied to the Anode and the Cathode as well as Gatecurrent

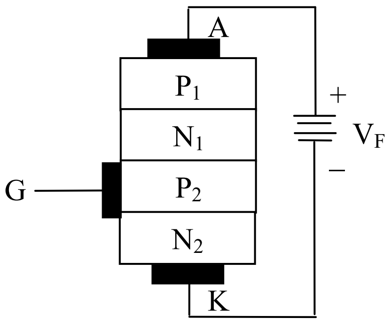
(II) When the Gate current is negative that is $I_G < 0$, J_1 and J_3 is forward biased and J_2 is reverse biased. The SCR will conduct after large breakover voltage V_{B0}.

(III) When the Gate current is increased that is $I_G > 0$, J_1 and J_3 is forward biased and J_2 is reversed biased. The SCR will conduct quickly due to decrease in breakover voltage.

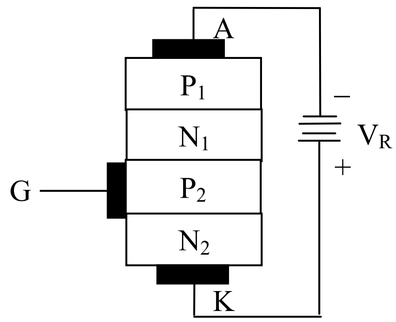
Hence by Gate Current I_G the switching Characteristics can be is controlled. This makes the device to function as controlled switch. But once the device is ON, the gate cannot be used to switch off the device. The only way to switch off the device is by reducing the value of anode current below I_H (Holding Current) by reducing V_H.

In the Reverse bias, J_1 and J_3 are reverse bias and J_2 is forward bias. This makes the SCR to switch off due to no flow of current.

Forward bias



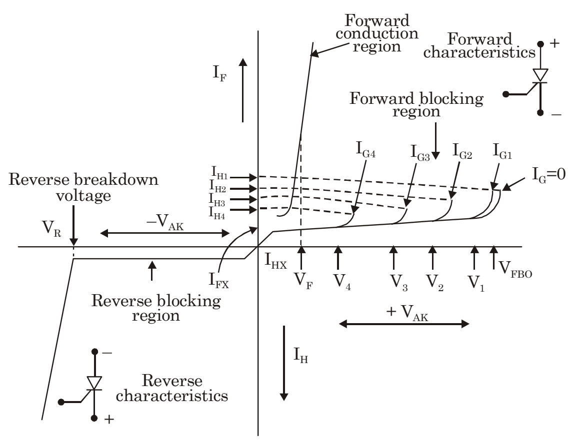
Reverse bias



Characteristics:-

The characteristic of the SCR is the graph drawn between the anode current and the anode to cathode voltage by adjusting the values of I_G.

The Breakover voltage (V_{BO}) is defined as the voltage at which SCR starts to conduct hence, when IG increases V_{BO} decreases and the device conduct soon. Once the device attains holding point the device will perform as normal diode. The minimum value of current which is required to hold the device in on-state is known as Holding Current (I_H). The voltage correspond to IH is known as Holding Voltage (V_H)



In the Reverse bias condition the device will breakdown due to avalanche breakdown Mechanism.

Turning ON (Triggering)

Turning ON the SCR is known as Triggering

1. Forward Break over Voltage

When the voltage applied across the SCR is greater than the forward break over voltage. Then the SCR will start to conduct.

2. Gate triggering

The SCR can be triggered to ON state by applying the gate voltage > 0 which makes the device to ON state but once the device is ON, the gate will not have any control over the device.

3. Light triggering

.

4. Rate effect triggering

By rapidly increasing the anode to cathode voltage $\frac{dV_A}{dt}$, the SCR will turn ON from off state. This produce the charges to flow, makes the device to conduct.

Turning OFF

Normally two methods are available to turn OFF the SCR.

(i) Anode Current Interruption Method

The anode current of the SCR is reduced to zero by reducing the value of Current Less than Holding I_G. This is done by switching arrangement.

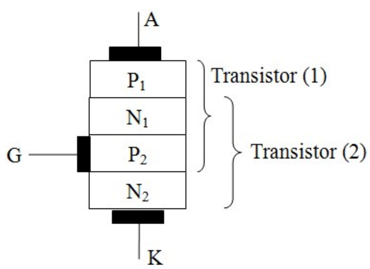
(ii) Forced commutation method

In this method, the current through SCR is reduced below the holding current by reversing the polarity of anode to cathode voltage.

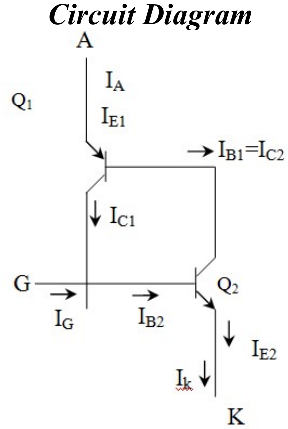
Two transistor version of SCR

The operation of the SCR can be analyzed by considering the SCR of two transistor ($P_1N_1P_2$) and ($N_1P_2N_2$) connected back to back.

Structure of SCR



Circuit Diagram



Applications:-

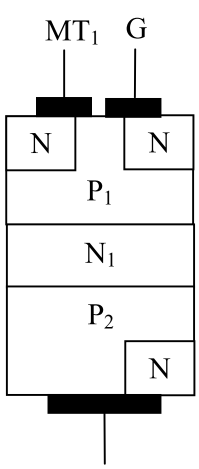
SCR is commonly used in

(i) Battery charger and Inverter
(ii) Rectifier circuit in various electronic equipment
(iii) Switches and power supplying unit
(iv) Control element such as motor, power, phase ,etc

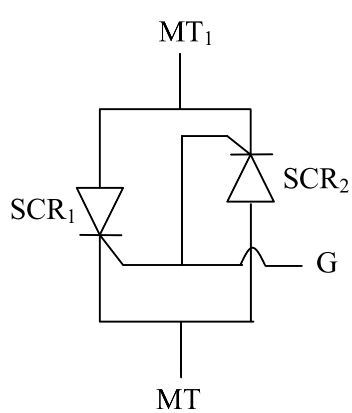
TRIAC

Construction:-

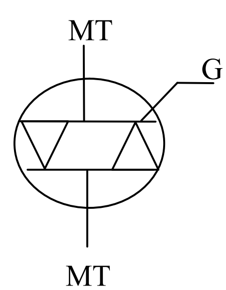
Structure of TRIAC



Equivalent circuit



Symbol



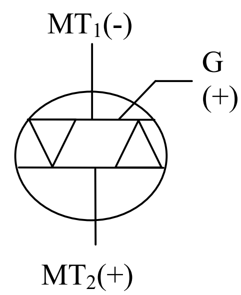
The structure of TRIAC consist of three terminal, four layered switch of $P_1N_1P_2N_2$ and $P_2N_1P_1N_3$. The two SCR are connected in parallel but in opposite direction. It is seen that anode of one SCR is connected to cathode of another SCR. The gate is connected near terminal MT_1. The gate is applied with positive (or) negative voltage with respect to terminal MT_2 to control the devices.

Operation:-

TRIAC exhibit four modes of operation based on the polarity of the voltage applied across the main terminal MT_2 and Gate.

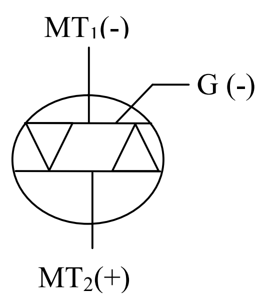
Mode 1:-

In this mode, the terminal 2 (MT_2) is positive with respect to the terminal 1 (MT_1) and Gate is positive. The TRIAC will be forward biased and the TRIAC is said to operate in the first quadrant. This mode is also known as (I+) mode of operation.



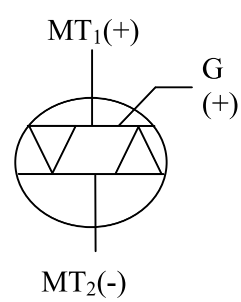
Mode 2:-

In this mode, the terminal 2 (MT_2) is positive with respect to the terminal 1(MT_1) and Gate is made negative. The TRIAC will be forward biased and the TRIAC is said to operate in the first quadrant. This mode is also known as (I-) mode of operation. It is less efficient.



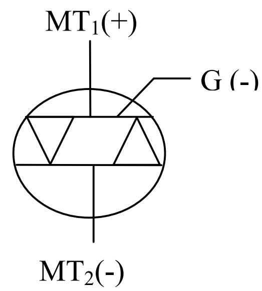
Mode 3:-

In this mode, the terminal 2 (MT_2) is negative with respect to the terminal 1 (MT_1) and the Gate is made positive. The TRIAC current reverses and function in the third quadrant. This mode is also known as (III+) mode of operation. It is inefficient mode.



Mode 4:-

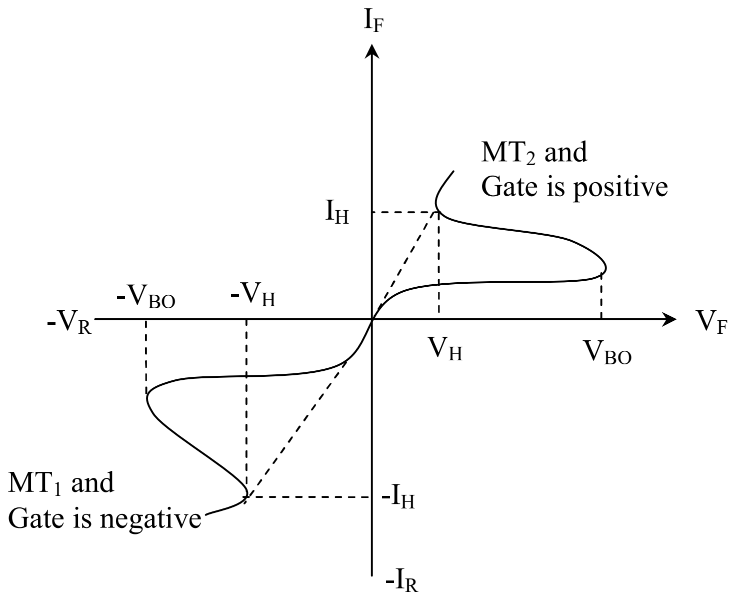
In this mode, the terminal 2 (MT_2) and gate is made negative with respect to terminal 1 (MT_1). The TRIAC current reverses and function in the third quadrant. This made is also known as (III-) mode of operation. It is more efficient and sensitive than III+ mode



VI characteristics of TRIAC

The VI characteristics of the TRIAC is the relationship between voltage and current across the two main terminals.

VI characteristics curve



The characteristics of the TRIAC when MT_2 is made positive and negative with respect to MT_1 are shown above. When Gate and MT_2 is positive, the TRIAC is efficient in the quadrant 1 and when MT_2 and Gate is negative, the TRIAC is efficient in quadrant III.

Applications:-

It is

(i) Used as a switch to ON and OFF the AC supply.

(ii) Used as a light dimmer.

(iii) Used to control motor speed, heat and phase of the circuit.

Video Content / Details of website for further learning (if any):
1. https://www.physics-and-radio-electronics.com/electronic-devices-and-circuits/semiconductor-diodes/silicon-controlled-rectifier.html 2. https://www.tutorialspoint.com/power_electronics/power_electronics_silicon_controlled_rectifier.htm 3. httphttps://circuitglobe.com/schottky-diode -as-an-amplifier.htmls://www.electronics-build-electronic-cir
Important Books/Journals for further learning including the page nos.: 1. “Electronic Devices and Circuits”, S.Salivahanan, N.Sureshkumar, &A.Vallavaraj Tata McGraw Hill, Second Edition, 2008. (151-152) 2. “Electronic Devices”, Thomas L.Floyd, Prentice Hall, Ninth Edition,2012. (Unit 4 and Unit 5)

Course Faculty

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Rasipuram - 637 408, Namakkal Dist., Tamil Nadu

L 41

LECTURE HANDOUTS

ECE **I / II**

Course Name with Code : **19GES11 - ELECTRONIC DEVICES**

Course Faculty : **Dr. J. Rangarajan**

Unit : **V - Special Diodes and Opto Electronic Devices** **Date of Lecture:**

Topic of Lecture: Light Dependent Resistor (LDR), Unijunction Transistor (UJT)

Introduction: Light Dependent Resistor also known as photo resistor (or) photo conductive cell (or) photocell is the two terminal semiconductor device. It is a light controlled variable resistor in which the resistance of the photo resistor decreases with incident light intensity. Unijunction transistor commonly known as UJT is the three terminal semiconductor device with single junction which is extensively used in an electronic switching operation.UJT has no ability to amplify and hence it is not used as an amplifier.

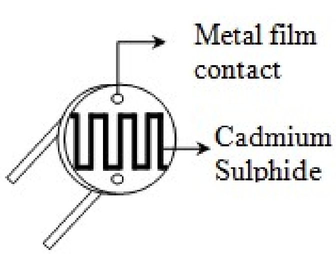
Prerequisite knowledge for Complete understanding and learning of Topic:

- Transistor operation
- Photo resistance
- Photo conduction

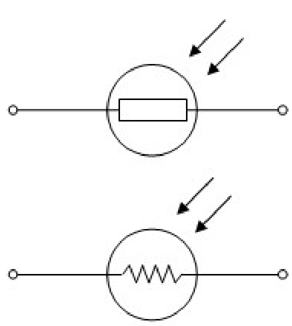
Light Dependent Resistor:

Construction:

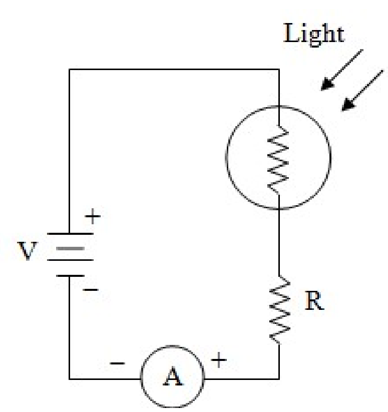
Structure of LDR



Symbol



Circuit Diagram



- LDR consist of thin layer of semiconductor material which is made of either Cadmium sulphide(CdS), Cadmium selenide(CdSe) (or) Lead sulphide(PbS).
- The coating of this material is made over top of the surface.
- It is placed over the ceramic substance. Two metal electrodes are taken out which is connected to positive and negative terminal of the battery.

OPERATION

When the light is allowed to pass through the glass window over the LDR. It exhibit photo conductivity.

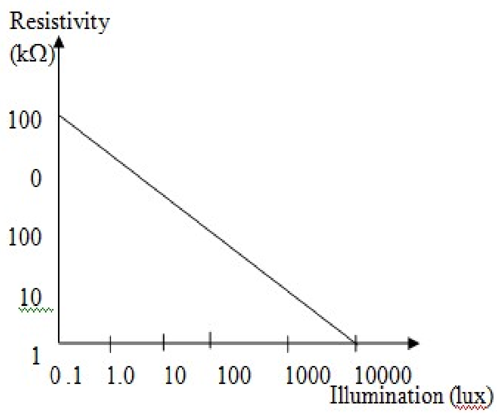
(i) When no light falls on the cell, the Resistance of the device is very high. Hence the current (I) is very low.

(ii) When light falls on the cell, the Resistance of the device will decrease. Hence the current I increase with Respect to the light intensity.

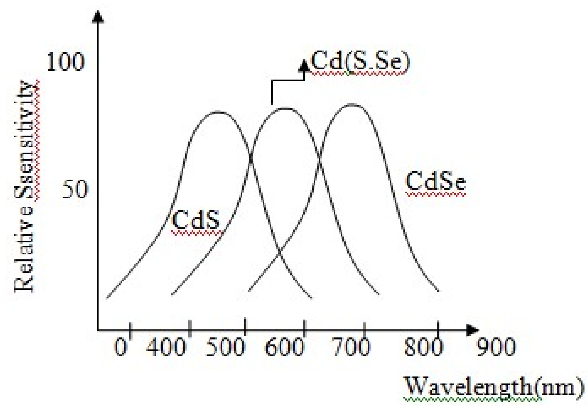
(iii) Therefore the value of the current will be controlled by light.

CHARACTERISTICS

Resistivity Vs illumination



Spectral Response



The resistivity of the device decreases with increases with illumination. For the illumination of 10000 lux, the resistivity will be around zero

The spectral response of the LDR shows that the responsivity of the Cds is superior for short wavelength and Cdse shows superior result for longer wavelength.

APPLICATIONS

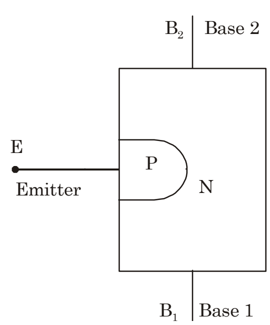
LDR is used as:

(i) Photo switch and Photo electric control element.
(ii) Industrial control and counting system.
(iii) An autoflash in camera.
(iv) Street light triggering circuit.

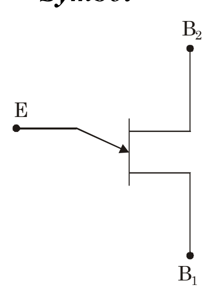
Unijunction Transistor (UJT):

Construction:-

UJT Basic structure

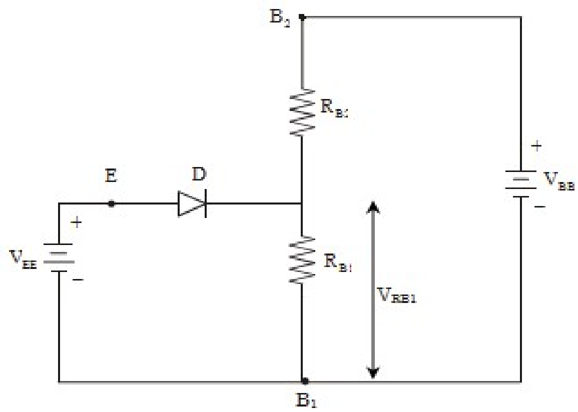


Symbol



- Emitter is connected to the heavily doped P type material. Base B_1 and B_2 is connected to both end of the n type substrate.

Equivalent Circuit



- The equivalent circuit of the UJT consists of PN junction diode which is connected to the inter base resistance (or) internal bulk resistance between terminal B_1 and B_2.
- Hence the total resistance between the base terminal $R_{BB}=RB_1 + RB_2$.

  R_{B1} and R_{B2}- Internalbase resistance across Base 1 and Base 2
  R_{BB} = Interbase Resistance
  V_{RB1} is the voltage drop across R_{B1}, when V_{BB} is applied
- Hence,V_{RB1} (voltage drop across R_{B1}) = $V_{BB} = \frac{R_{B_1}}{R_{B_1}+R_{B_2}}$

$$\text{(or)}\ V_{BB} = \frac{R_{B_1}}{R_{BB}}$$

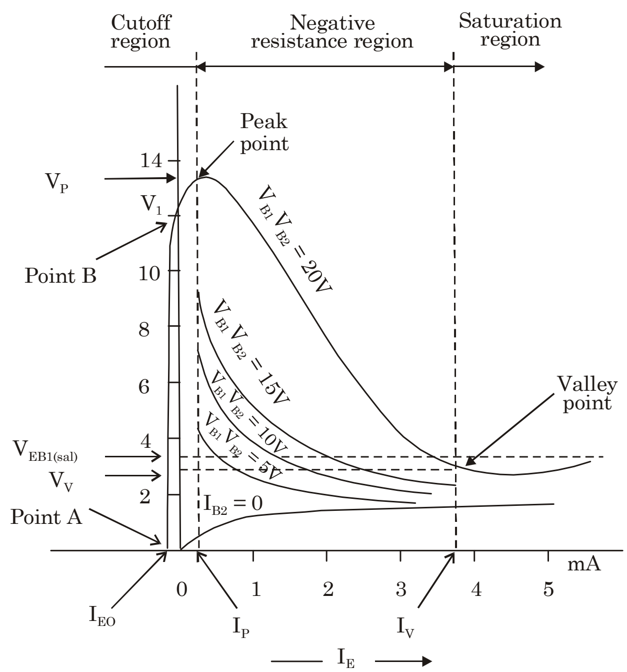
  - In the above equation $V_{BB} = \frac{R_{B_1}}{R_{BB}}$, which is the ratio of the internal Base Resistance across Base 1 (R_{B1}) to the interbase across B_1.
  - Resistance is known as Intrinsic standoff Ratio (η). Its value ranges from 0.5 to 0.8

Operation

- When V_{EE} is applied, the emitter current will be cutoff due to the voltage drop across the Internal Base Resistance R_{B1} and diode potential barrier.
- This is known as Reverse bias voltage which is given by $V_R = \eta V_{BB} + V_D$. When the value of V_{EE} is greater than V_R, the diode is forward bias and will start to conduct.
- This value of emitter voltage which makes the diode to conduct is known as peak point voltage(V_P) which is given by $V_P = \eta V_{BB} + V_D$.
- The emitter current starts to flow after the peak point voltage.

Characteristics

VI characteristics of UJT



It is shown from the characteristics curve that the UJT functions in three Regions.

Cutoff Region:-

Till point A, the device is in cutoff where the diode will be in reverse bias. Hence the emitter current is almost zero.

Negative Resistance Region:-

- In this region the UJT is said to be fired (or) turned on at peak point (P), where the peak point Voltage is greater that $\eta V_{BB} + V_{D.}$
- In this region, the holes are injected into the N region and which is swept by the base electric field. This makes the resistance R_{B1} to reduce thereby the value of ηV_{BB} is reduced.
- This phenomenon is known as *Conductivity Modulation.*
- When more holes are injected into n region, it further reduces ηV_{BB}. As a result, the emitter current increases but V_E decreases.
- This is known as Negative resistance characteristics. This phenomenon makes the UJT to operate as an oscillator.

Saturation Region:-

- The Region of curve beyond the valley point is the saturation region. In this region UJT is in ON position.
- The device will behave as a PN junction diode. V_E increases gradually with increases in I_E.

Applications:

(i) The Negative resistance characteristics make the device to function as Relaxation oscillator, non sinusoidal oscillator and sawtooth generator.

(ii) It is used as a switching circuit.

(iii) It functions as a triggering device for Thyristor based devices.

(iv) It is also used in the timing circuit.

Video Content / Details of website for further learning (if any):
1. https://www.kitronik.co.uk/blog/how-an-ldr-light-dependent-resistor-works/ 2. https://www.electronics-notes.com/articles/electronic_components/resistors/light-dependent-resistor-ldr.php 3. https://www.electroschematics.com/ldr-light-dependent-resistor-photoresistor/ 4. http://www.circuitstoday.com/ujt-uni-junction-transistors
Important Books/Journals for further learning including the page nos.:
1. "Electronic Devices and Circuits", S.Salivahanan, N.Sureshkumar, &A.Vallavaraj Tata McGraw Hill, Second Edition, 2008. (151-152) 2. "Electronic Devices", Thomas L.Floyd, Prentice Hall, Ninth Edition,2012. (Unit 4 and Unit 5)

Course Faculty

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LECTURE HANDOUTS

ECE | **I / II**

Course Name with Code : 19GES11 - ELECTRONIC DEVICES

Course Faculty : Dr. J. Rangarajan

Unit :V - Special Diodes and Opto Electronic Devices Date of Lecture:

Topic of Lecture: Photoemissivity and Photoconductivity

Introduction:

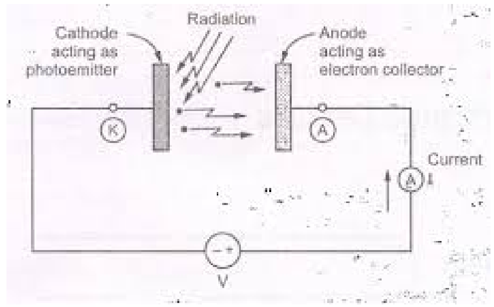
Photoconductivity is an optical and electrical phenomenon in which a material becomes more electrically conductive due to the absorption of electromagnetic radiation such as visible light, ultraviolet light, infrared light, or gamma radiation.

Prerequisite knowledge for Complete understanding and learning of Topic:

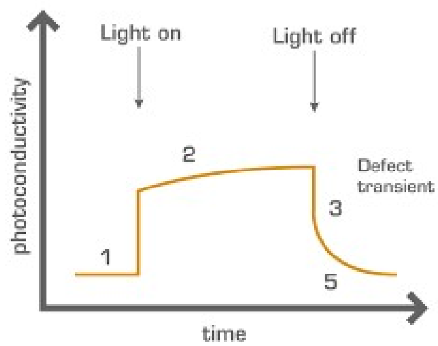
- Photon
- Light energy
- Electromagnetic radiation

Photoemissivity and Photoconductivity

- The increase in the electrical conductivity of certain materials when they are exposed to light of sufficient energy.
- Photoconductivity serves as a tool to understand the internal processes in these materials, and it is also widely used to detect the presence of light and measure its intensity in light-sensitive devices.Certain crystalline semiconductors, such as silicon, germanium, lead sulfide, and cadmium sulfide, and the related semimetal selenium, are strongly photoconductive. Normally, semiconductors are relatively poor electrical conductors because they have only a small number of electrons that are free to move under a voltage.
- Most of the electrons are bound to their atomic lattice in the set of energy states called the valence band. But if external energy is provided, some electrons are raised to the conduction band, where they can move and carry current.
- Photoconductivity ensues when the material is bombarded with photons of sufficient energy to raise electrons across the band gap, a forbidden region between the valence and conduction bands.



In cadmium sulfide this energy is 2.42 electron volts (eV), corresponding to a photon of wavelength 512 nanometres (1 nm = 10^{-9} metre), which is visible green light. In lead sulfide the gap energy is 0.41 eV, making this material sensitive to infrared light.



Video Content / Details of website for further learning (if any):

1. https://whatis.techtarget.com/definition/photoconductivity
2. https://en.wikipedia.org/wiki/Photoconductivity
3. http://bgsptech.ac.in/ecedept%5C2-sem%5CSemiconductor%20Devices.pdf
4.

Important Books/Journals for further learning including the page nos.:

1. "Electronic Devices and Circuits", S.Salivahanan, N.Sureshkumar, &A.Vallavaraj Tata McGraw Hill, Second Edition, 2008. (151-152)
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LECTURE HANDOUTS

L 43

ECE

I / II

Course Name with Code : 19GES11 - ELECTRONIC DEVICES

Course Faculty : Dr. J. Rangarajan

Unit :V - Special Diodes and Opto Electronic Devices Date of Lecture:

Topic of Lecture: Photoconductive cells, Photo voltaic cells

Introduction: The photoconductive cell is a two terminal semiconductor device whose terminal resistance will vary (linearly) with the intensity of the incident light. Both materials respond rather slowly to changes in light intensity. The solar cell is the device that converts the light energy into electrical energy when the light (sunlight) is passed into it. It is also known as solar battery (or) photovoltaic cell.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Photo resistance
- Photoconduction
- Photoemission

Photoconductive cells:

Photo-conductive-cell-circuit-symbol

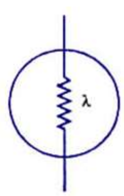
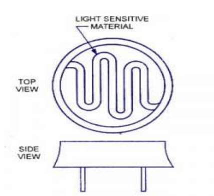
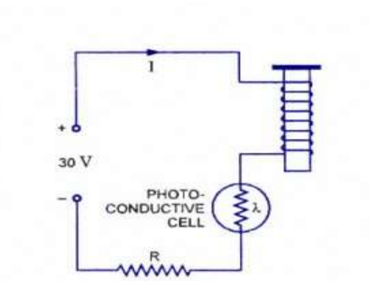


photo-conductive-cell-construction

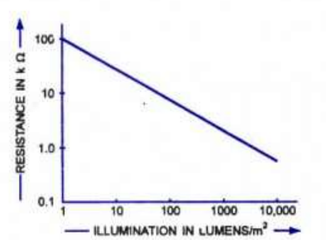


- Light sensitive material is arranged in the form of a long strip, zigzagged across a disc shaped base with protective sides.
- For added protection, a glass or plastic cover may be included. The two ends of the strip are brought out to connecting pins below the base.

Photoconductive cell circuit:



Characteristics of a Photoconductive cell:



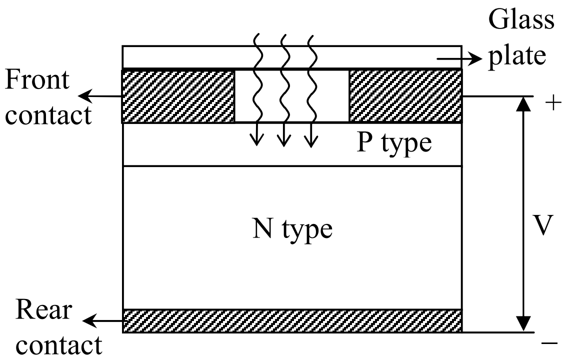
Illumination Characteristic of a Typical Photoconductive Cell

Characteristics of a Photoconductive cell:

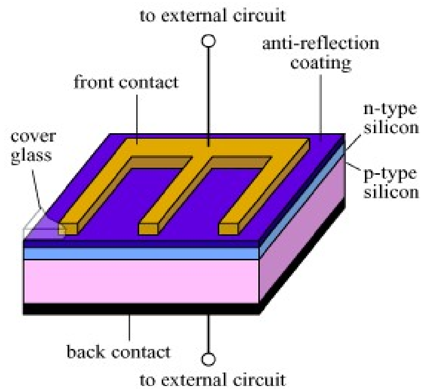
- The illumination characteristics of a typical photoconductive cell are shown from which it is obvious that when the cell is not illuminated its resistance may be more than 1 00 kilo ohms.
- This resistance is called the *dark resistance*. When the cell is illuminated, the resistance may fall to a few hundred ohms.
- Note that the scales on the illumination characteristic are logarithmic to cover a wide ranges of resistance and illumination that are possible.
- Cell sensitivity may be expressed in terms of the cell current for a given voltage and given level of illumination.

Photo voltaic cells:

Construction



Cell basic Structure



- The basic structure of the solar cell consist of P type silicon material doped with P type impurity and also N type silicon material doped with N type impurity.
- Hence PN junction is formed between the P and N type material. The sunlight is allowed to falls on the junction through the glass plate.

OPERATION

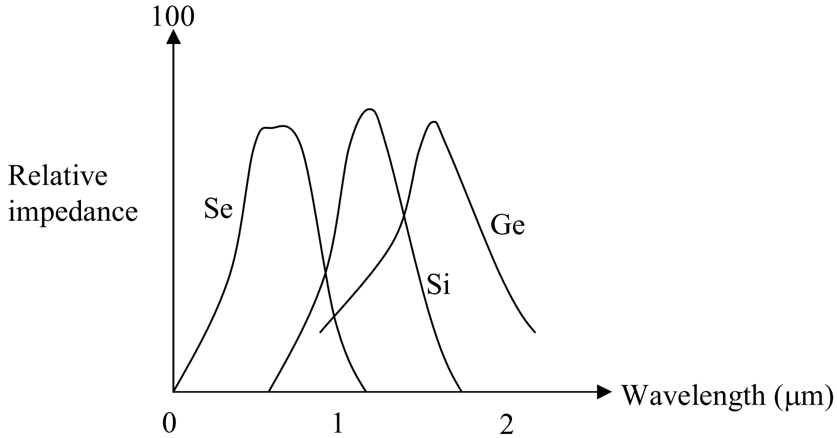
- When the incident photon in the form of light falls on the junction.
- The valence electron will gain enough energy from the incident photons and move toward the conduction band, which in turn will creates electron hole pairs.
- The flow of electrons and holes across the junction will leads to the accumulation of carriersin the junction.
- Hence this phenomenon gives rise to photovoltaic voltage across the junction.

The increase in the photovoltaic voltage depends upon the intensity of the light falls on the device.

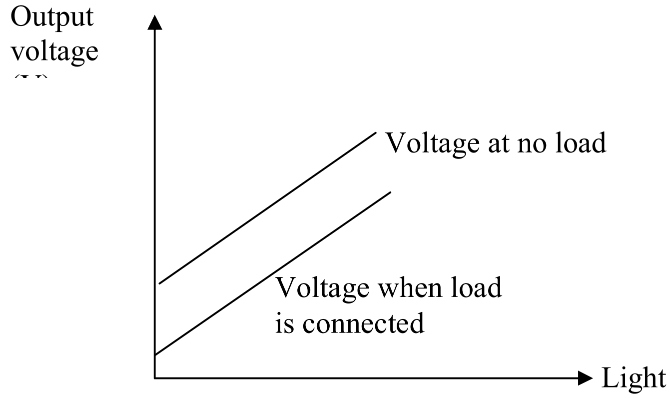
CHARACTERISTICS

- The spectral Response of the various semiconductor materials (Selenium, silicon and Germanium) is given in the figure below.
- The silicon and Germanium shows an efficient Response in the infrared region.
- The selenium provides superior advantage than silicon by its spectral response and environmental radiation tolerance (1000 times than silicon).

Spectral Response of Semiconductor material



Output voltage versus high intensity



- The output voltage increases with increases in the light intensity falls on the cell. The single solar cell can produce 0.6v for the incident sunlight. The average cell will produce about 30 mw per square inch of cell. The efficiency of the solar cell can be obtained upto 40%.

APPLICATION

They are used in:

(i) Satellite to provide required power.

(ii) Power plants, as renewable energy source.

(iii) Home to provide required power.

(iv) Various commercial applications such as solar cars, Remote applications, etc.

Video Content / Details of website for further learning (if any):

1. http://www.ladyada.net/media/sensors/APP_PhotocellIntroduction.pdf
2. https://www.electronicdesign.com/markets/lighting/article/21769406/photoconductive-cells-for-industrial-use
3. https://electronicslesson.com/transducer/photoconductive-cell/

Important Books/Journals for further learning including the page nos.:

1. "Electronic Devices and Circuits", S.Salivahanan, N.Sureshkumar, &A.Vallavaraj Tata McGraw Hill, Second Edition, 2008. (151-152)
2. "Electronic Devices", Thomas L.Floyd, Prentice Hall, Ninth Edition,2012. (Unit 4 and Unit 5)

Course Faculty

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LECTURE HANDOUTS | **L 44**

ECE | **I / II**

Course Name with Code : 19GES11 - ELECTRONIC DEVICES

Course Faculty : Dr. J. Rangarajan

Unit :V - Special Diodes and Opto Electronic Devices Date of Lecture:

Topic of Lecture: Photodiode, Phototransistors, LCD and LED

Introduction: The function of the photodiode is to convert light signal into electrical signal hence it is known as Light sensitive device. Phototransistor is the light sensitive semiconductor device which is not only used to convert electrical energy from light energy but also used to amplify. LCD uses a liquid crystal to produce a visible image. A light-emitting diode (*LED*) is a semiconductor light source that emits light when current flows through it.

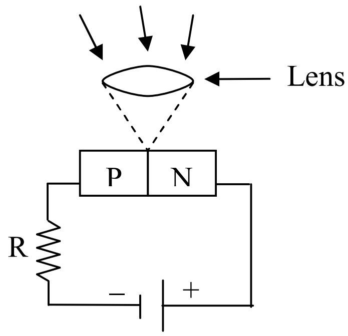
Prerequisite knowledge for Complete understanding and learning of Topic:

- Photoconduction,
- PN junction
- Diode and Transistor operation

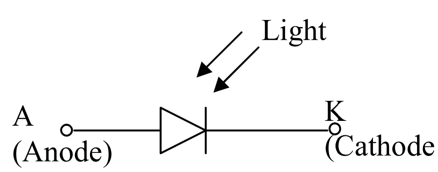
Photodiode, Phototransistors, LCD and LED

Photodiode
Construction

Structure of photodiode



Symbol



Photodiode consist of P and N region which is kept inside a glass casing. The arrangement is made in such a way that the light ray is accumulate and passed into the junction of the PN diode. The sides of the casing are painted to prevent the scattering of light.

Operation:-

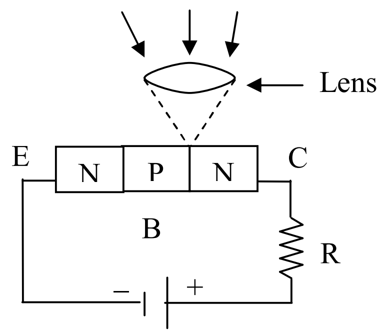
When the light ray is passed into the junction of the Reverse biased PN – photo diode. The electron hole pairs are created in the depletion region result in the generation of charge carrier which depends upon the intensity of light falling on the depletion region. The magnitude of current produced is $I = I_S + I_o\,(1\text{-}e^{-v/\eta vT})$.

Where I_S = Current proportion to light intensity Diode

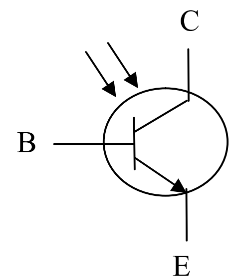
Phototransistors:

Construction

Structure of Phototransistor



Symbol



The Emitter and collector of the phototransistor is connected to the negative and positive terminal of the voltage. The base terminal left unused. Instead the base is supplied with external biasing, the light is made to fall on the base collector junction.

Operation

When no light falls on the transistor, the reverse saturation current is generated due to minority carrier I_{CO} (Reverse Saturation Current).

When the light falls on the junction, electron hole pair created result in the photo carrier result in the generation of collector current.

The collector current

$$I_C = (1 + \beta)\,(I_{CO} + I_L)$$

B = amplification factor

I_{CO} = Reverse saturation current

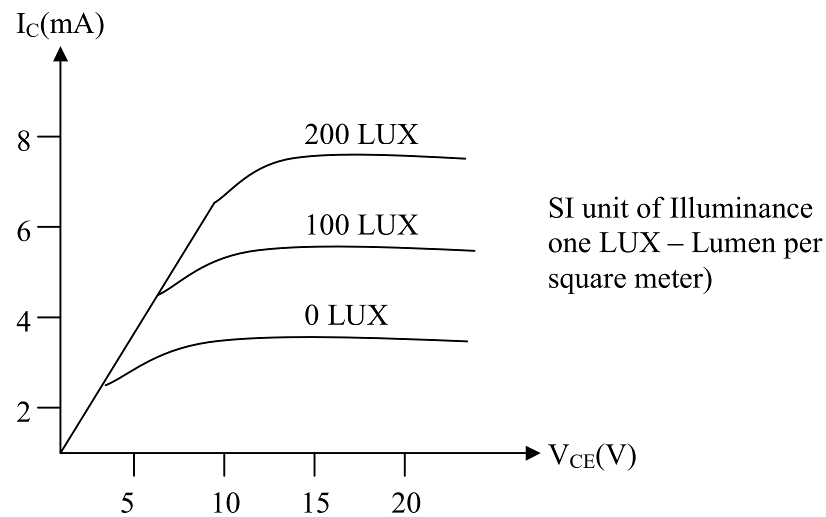
I_L = current due to Light

Hence the collector current depends upon the applied voltage and intensity of light falling on the junction.

Characteristics

The characteristic of the photo transistor is the graph drawn between collector current and the emitter to collector voltage. The value of IC increases when the light intensity increases.

VI characteristics of Phototransistor



Applications

The phototransistor is commonly used in

(i) Light detection circuit.

(ii) Light dependent switches.

(iii) Counting of objects in production unit.

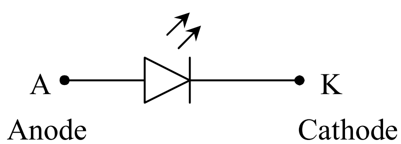
Reading equipments such as taps, sound track etc.,

Light Emitting Diode:

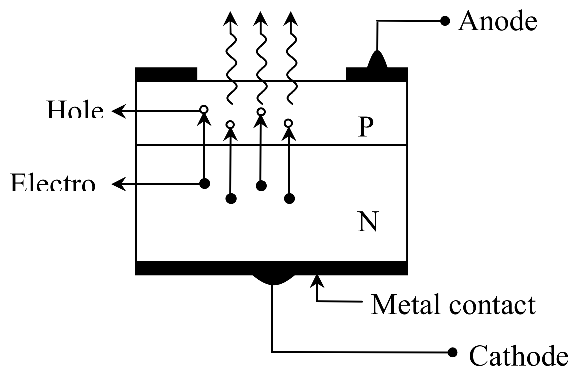
Construction

LED consist of PN junction device in which the basic component is made of Gallium phosphide (Gap) (or) Gallium arsenide phosphide (GaAsP) instead of silicon (or) Germanium. This is because Gap (or) GaAsP emits light when Recombination takes place.

Symbol



Basic Structure of LED



The two end of the P and N region is connected to positive anode and negative cathode through which the forward bias voltage is applied. LED emit different colour based on the wavelength.

Gallium Arsenide – Infrared radiation
Gallium phosphide – Red (or) green
Gallium Arsenide phosphide – Red (or) yellow

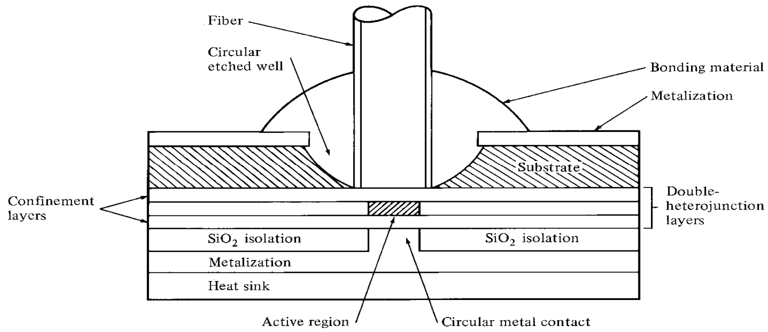
Operation:-

- The electroluminescence is the basic principle of the LED. When the forward bias is applied to the two lead, the electrons in the conduction band of N region cross the junction and recombine with the holes in the valance band of P region.
- The energy emitted during recombination will be in the form of light energy (photon).
- Hence the emitted light depends upon the forward bias and Rate of Recombination.

(i) Surface emitter (burrus (or) Front emitter):-

- Surface emitting LED consists of P and N region of GaAlAS placed one above the another.
- The well is etched through the surface of the deviceinto which the fiber is inserted and the emitted light due to recombination will be collected by the fiber place on the surface of the material.
- The double heterojunction layer helps for optical and carrier confinement.

Surface emitting LED



Applications:-

LED is commonly used in

(i) Display devices such as calculator phones, watches etc.,

(ii) Optical communication as a source to transmit information in the form of light.

(iii) Image sensor circuits.

(iv) Burglar alarm unit and memory unit (optical).

TYPES OF LCD

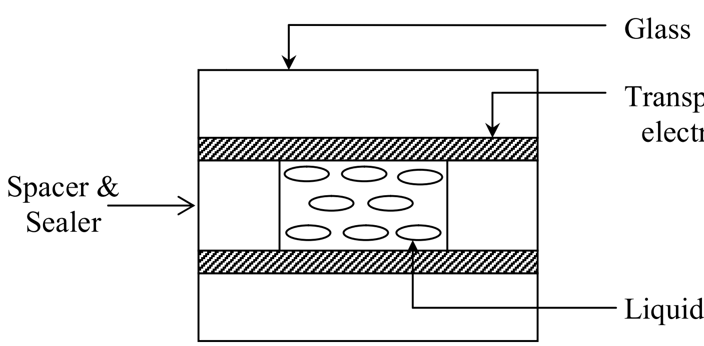
There are two types of LCD which is available for Display is

(i) Dynamic Scattering Display.

(ii) Twisted Nematic (or) field effect Display.

(i) Dynamic Scattering Display:-
Construction:-

Without field ***Dynamic Scattering Display***



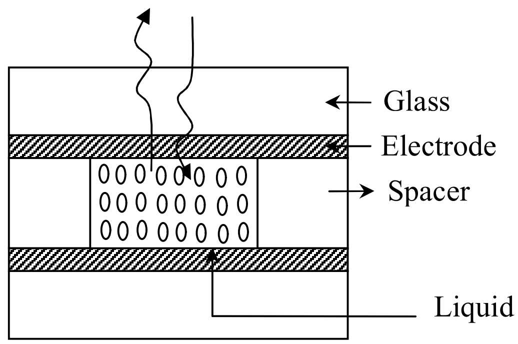
The structure of the Dynamic scattering display consists of two glass plate in which the inner wall is coated with transparent electrode of tinoxide. The two glass plates are separated by 5 to 50μm thickness of filled Liquid crystal layer. The spacer on both side is used to fill the liquid crystal and adjust the level.

Working:-

(i) When no electric field is applied, all the molecules in the nematic liquid crystal are properly aligned and hence they are transparent.

(ii) When the electric field is applied, the molecules will align perpendicular to the field direction. When the electric field increases, flow becomes turbulent. This causes crest due to negative charge and trough due to positive charge. The disorder state makes the

With field *Dynamic scattering Display*



Hence the cells appear to be bright due to scattering of light. This phenomenon is known as Dynamic Scattering.

Advantages of LCD:-

The various advantages of LCD are

(i) It is of Low cost.
(ii) It consumes less voltage and power.
(iii) It produces very bright image.

Disadvantages of LCD:-

The various disadvantages of LCD are

(i) The Life time of LCD is low which is limited to 50,000hours.
(ii) The Space occupied by LCD is large.
(iii) It exhibit slow speed of operation due to high response time.

Applications:-

Some of the applications of LCD are

(i) It is usedfor Numerical display in calculator.

(ii) It is usedin wrist watches, clocks ,etc.

(iii) It is widely usedin the video Display.

(iv) It is used as a monitoring unit for various applications.

Video Content / Details of website for further learning (if any):

1. https://en.wikipedia.org/wiki/Photodiode
2. https://www.elprocus.com/photodiode-working-principle-applications/
3. https://www.electronics-notes.com/articles/electronic_components/transistor/what-is-a-phototransistor-tutorial.php

Important Books/Journals for further learning including the page nos.:

1. "Electronic Devices and Circuits", S.Salivahanan, N.Sureshkumar, &A.Vallavaraj Tata McGraw Hill, Second Edition, 2008. (151-152)
2. "Electronic Devices", Thomas L.Floyd, Prentice Hall, Ninth Edition,2012. (Unit 4 and Unit 5)

Course Faculty

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MUTHAYAMMAL ENGINEERING COLLEGE

(An Autonomous Institution)

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Rasipuram - 637 408, Namakkal Dist., Tamil Nadu

Estd. 2000

LECTURE HANDOUTS | **L 45**

ECE | **I / II**

Course Name with Code : 19GES11 - ELECTRONIC DEVICES

Course Faculty : Dr. J. Rangarajan

Unit :V - Special Diodes and Opto Electronic Devices Date of Lecture:

Topic of Lecture: Laser diode, Opto Couplers, Fin field-effect Transistor(FINFET)

Introduction: Laser Diode is the semiconductor device which is used to convert electrical energy into light signal. It is the acronym for Light amplification for stimulated emission of Radiation. Opto-coupler also known as optical isolator, photo-coupler (or) optically coupler Isolator is a electronic component that is used to transfer electrical signals between two isolated circuits by using light. A fin field-effect transistor (FinFET) is a multigate device, a MOSFET (metal-oxide-semiconductor field-effect transistor) built on a substrate where the gate is placed on two, three, or four sides of the channel or wrapped around the channel, forming a double gate structure

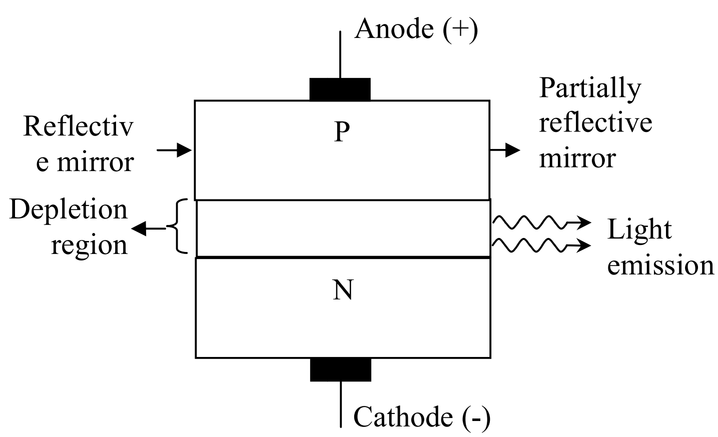
Prerequisite knowledge for Complete understanding and learning of Topic:

- LASER
- LED
- Photo diode
- FET

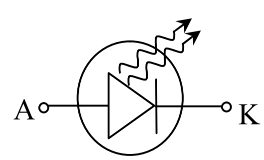
Laser diode:

Construction

Structure of Laser Diode



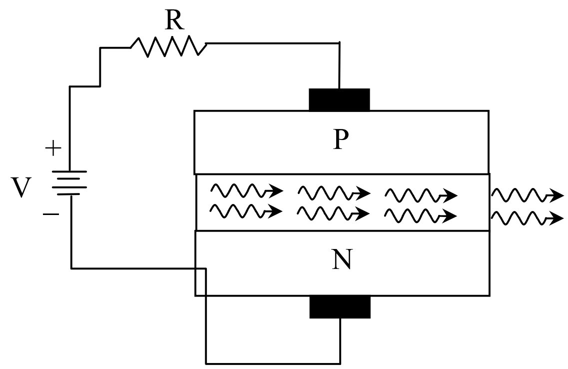
Symbol



- The Laser consists of PN junction which is formed by the P type gallium arsenide and N type gallium arsenide material.
- The depletion region will be formed between the two regions which act as the active region. The opposite end of the junction consists of the partially and fully reflective mirror.
- The light which is emitted as photon will be reflected back and forth between these mirror

Operation:-*Biasing of LASER diode*

- When the PN junction is forward biased, by means of absorption followed by emission or Light radiation, photons will be emitted. These photons will be reflected back and forth between two faces of the mirror.
- During this process the emitted photon will in turn produce multiple photons and hence avalanche effect takes which leads to the release of generated photon of same phase from the transparent side.
- Hence the emitted Laser light will be of same frequency and phase.



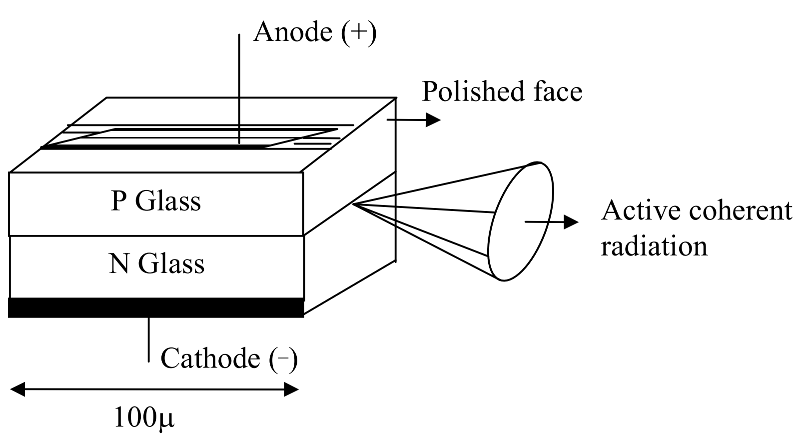
Types of Laser Diode:-

Commonly two types of Laser Diodes are available

(i) Homojunction Laser:-

Homojunction Laser is the semiconductor Laser formed by Layers of similar semiconductor material of equal band gap but different doping.

Structure of Homojunction structure



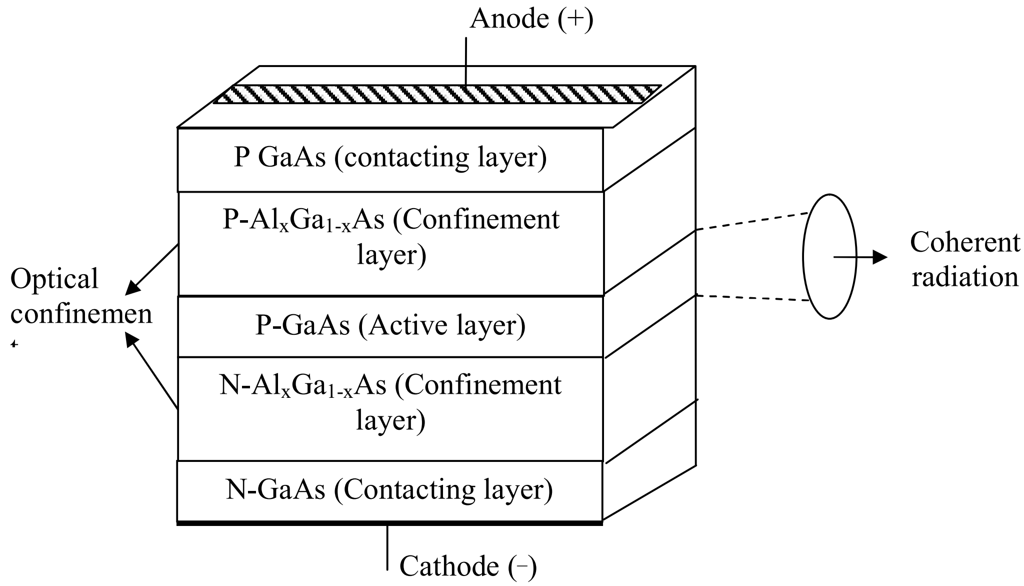
(ii) Heterojunction Laser:-

- Heterojunction Laser is formed by Layers of dissimilar semiconductor material of different Bandgap.

- The commonly used Heterojunction Laser will be double heterojunction structure formed by sandwiching GaAs between GaAlAs.

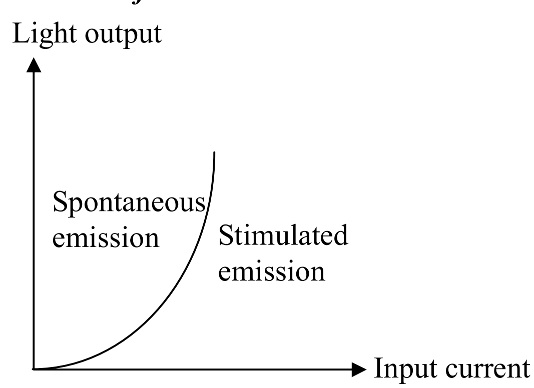
- Optical confinement is better in this Laser compared to homojunction Laser and it is preferred for continuous operation.

Structure of Double Heterojunction structure



4.8.5 Characteristics:-

Characteristics of Laser Diode

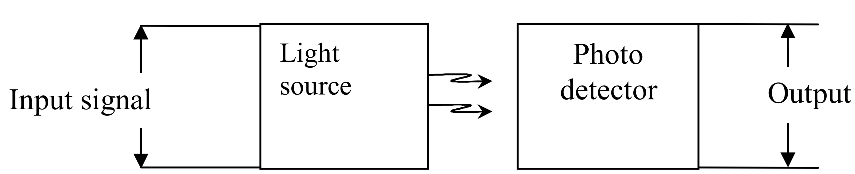


- The graph drawn between Light output and Input current gives the characteristics of the Laser.
- The Laser will produce Low light output with respect to input current till threshold level.
- Once the threshold level is reached, the light output increases for small increases in current.

Opto Couplers

Construction:-

Structure of Optocoupler



- The structure of the optocoupler consists of light source (LED) and the photo detector with the transparent isolation cap between them to allow the light transfer.

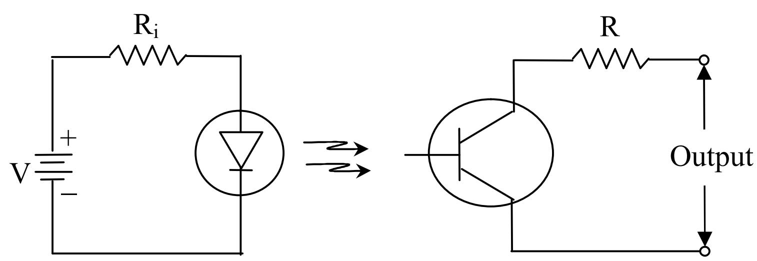
- The LED made of GaAs material is used to provide proper matching with the output circuit. The photo detector may be photodiode, phototransistor (or) photo SCR. Commonly photo diode is preferred for its fast Response.

Operation:-

- When the input signal is applied to the LED, the LED emits light signal in which the intensity of light emitted depends on the input signal.

- The photo detector provides the output signal based on the intensity of light falling on the detector. Hence external current is obtained in the output.

Circuit connection of optoisolator



- The basic characteristics of the optocoupler are

  (i) The light signal is transmitted with respect to input signal in the range of MHZ.

  (ii) The optocoupler provide isolation voltage of 500v to 2500v and isolation resistance of order $10^{11}\Omega$.

  (iii) The output current will be stable for the temperature variation up to 75°C.

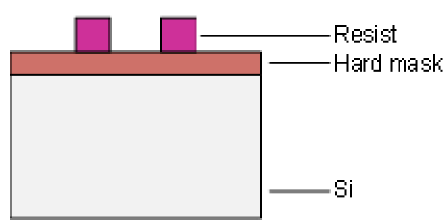
The switching time of the optoisolator varies based on the input current and the load Resistance in the range of µs.

Fin Field-Effect transistor (FinFET)

Construction of a bulk silicon-based FinFET

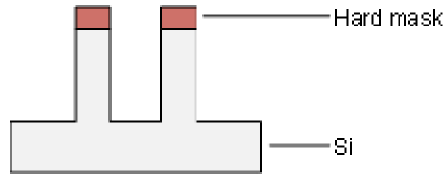
1. Substrate

Basis for a FinFET is a lightly p-doped substrate with a hard mask on top (e.g. silicon nitride) as well as a patterned resist layer.



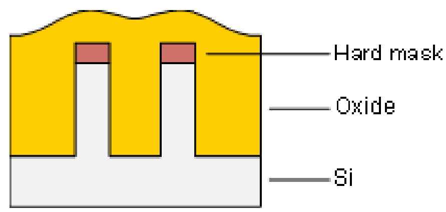
2. Fin etch

The fins are formed in a highly anisotropic etch process. Since there is no stop layer on a bulk wafer as it is in SOI, the etch process has to be time based. In a 22 nm process the width of the fins might be 10 to 15 nm, the height would ideally be twice that or more.



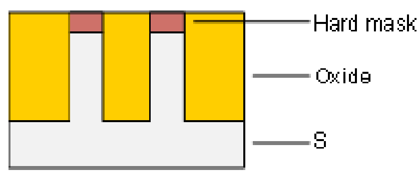
3. Oxide deposition

To isolate the fins from each other a oxide deposition with a high aspect ratio filling behavior is needed.



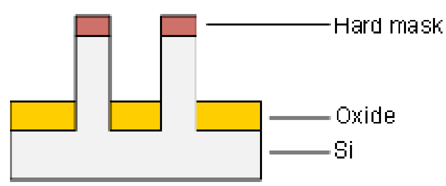
4. Planarization

The oxide is planarized by chemical mechanical polishing. The hard mask acts as a stop layer.



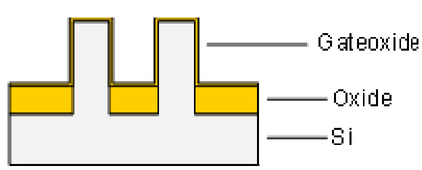
5. Recess etch

Another etch process is needed to recess the oxide film to form a lateral isolation of the fins.



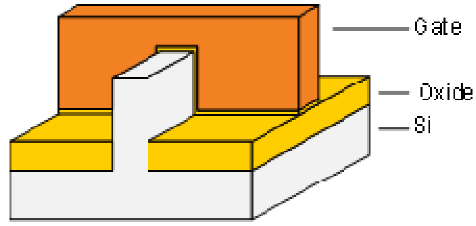
6. Gate oxide

On top of the fins the gate oxide is deposited via thermal oxidation to isolate the channel from the gate elctrode. Since the fins are still connected underneath the oxide, a high-dose angled implant at the base of the fin creates a dopant junction and completes the isolation (not illstrated).



7. Deposition of the gate

Finally a highly n^+-doped poly silicon layer is deposited on top of the fins, thus up to three gates are wrapped around the channel: one on each side of the fin, and - depending on the thickness of the gate oxide on top - a third gate above.



The influence of the top gate can also be inhibited by the deposition of a nitride layer on top of the channel.Since there is an oxide layer on an SOI wafer, the channels are isolated from each other anyway. In addition the etch process of the fins is simplified as the process can be stopped on the oxide easily.

Video Content / Details of website for further learning (if any):

1. https://www.elprocus.com/laser-diode-construction-working-applications/
2. https://circuitglobe.com/laser-diode.html
3. https://electronicscoach.com/laser-diode.html
4. https://www.electronics-notes.com/articles/electronic_components/transistor/what-is-a-photocoupler-optocoupler-optoisolator.php
5. https://www.quora.com/What-is-a-FinFET-transistor

Important Books/Journals for further learning including the page nos.:

1. "Electronic Devices and Circuits", S.Salivahanan, N.Sureshkumar, &A.Vallavaraj Tata McGraw Hill, Second Edition, 2008. (151-152)
2. "Electronic Devices", Thomas L.Floyd, Prentice Hall, Ninth Edition,2012. (Unit 4 and Unit 5)

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