Unit-II BIPOLAR JUNCTION TRANSISTOR

INTRODUCTION

- The transistor was developed by Dr.Shockley along with Bell Laboratories team in 1951
- The transistor is a main building block of all modern electronic systems
- It is a three terminal device whose output current, voltage and power are controlled by its input current
- In communication systems it is the primary component in the amplifier
- An amplifier is a circuit that is used to increase the strength of an ac signal
- Basically there are two types of transistors
    - Bipolar junction transistor
    - Field effect transistor
- The important property of the transistor is that it can raise the strength of a weak signal
- This property is called amplification
- Transistors are used in digital computers, satellites, mobile phones and other communication systems, control systems etc.,
- A transistor consists of two P-N junction
- The junction are formed by sand witching either p-type or n-type semiconductor layers between a pair of opposite types which is shown below

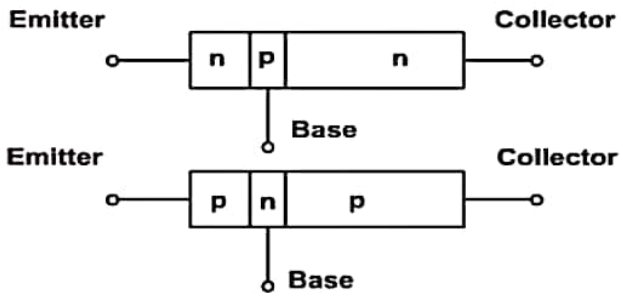


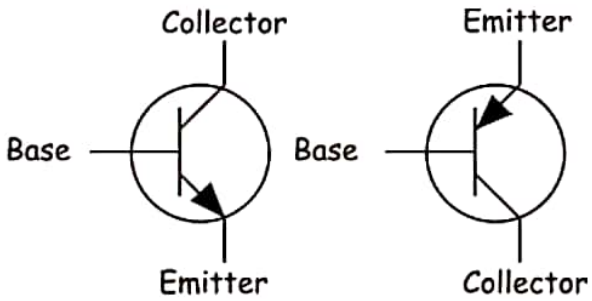
Fig: transistor

TRANSISTOR CONSTRUCTION

- A transistor has three regions known as emitter, base and collector

- **Emitter:** it is aregion situated in one side of a transistor, which supplies charge carriers (ie., electrons and holes) to the other two regions
- Emitter is heavily doped region
- **Base:** It is the middle region that forms two P-N junction in the transistor
- The base of the transistor is thin as compared to the emitter and is alightly doped region
- **Collector:** It is aregion situated in the other side of a transistor (ie., side opposite to the emitter) which collects the charge carrirs
- The collector of the transistor is always larger than the emitter and base of a transistor
- The doping level of the collector is intermediate between the heavy doping of emitter and the light doping of the base

TRANSISTOR SYMBOLS



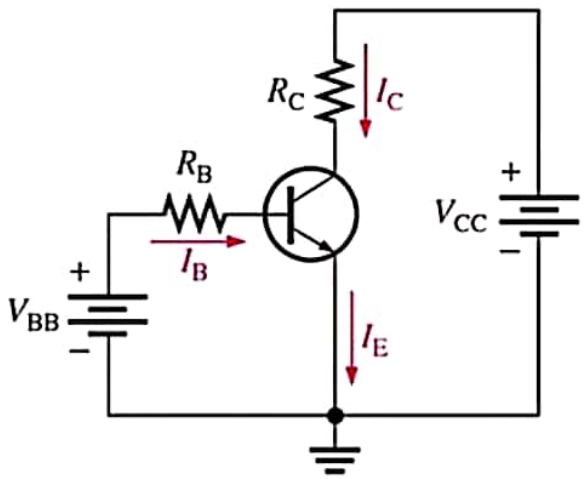
- The transistor symbol carries an arrow head in the emitter pointing from the P- region towards the N- region
- The arrow head indicates the direction of a conventional current flow in a transistor
- The direction of arrow heads at the emitter in NPN and PNP transistor is opposite to each other
- The PNP transistor is a complement of the NPN transistor
- In NPN transistor the majority carriers are free electrons, while in PNP

transistor these are the holes

UNBIASED TRANSISTORS

- A transistor with three terminals (Emitter, Base, Collector) left open is called an unbiased transistor or an open – circuited transistor
- The diffusion of free electrons across the junction produces two depletion layers
- The barrier potential of three layers is approximately 0.7v for silicon transistor and 0.3v for germanium transistor
- Since the regions have different doping levels therefore the layers do not have the same width
- The emitter base depletion layer penetrates slightly into the emitter as it is a heavily doped region where as it penetrates deeply into the base as it is a lightly doped region
- Similarly the collector- base depletion layer penetrates more into the base region and less into the collector region
- The emitter- base depletion layer width is smaller than the that of collector base depletion layer
- The unbiased transistor is never used in actual practice. Because of this we went for transistor biasing

OPERATION OF NPN TRANSISTOR



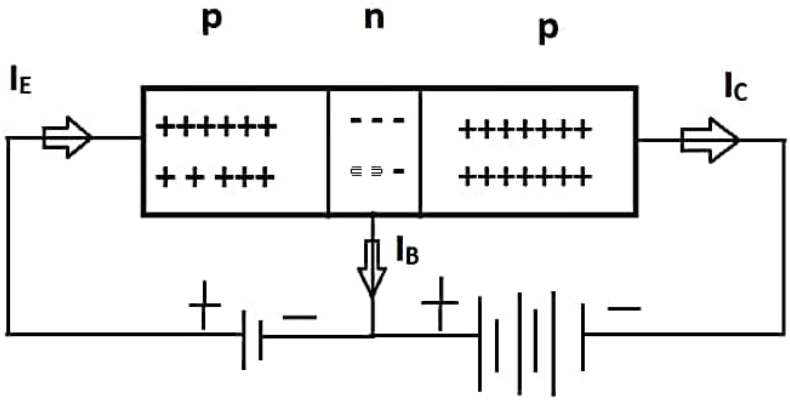
(a) *npn*

- The NPN transistor is biased in forward active mode ie., emitter – base of

transistor is forward biased and collector base junction is reverse biased

- The emitter – base junction is forward biased only if V is greater than barrier potential which is 0.7v for silicon and 0.3v for germanium transistor
- The forward bias on the emitter- base junction causes the free electrons in the N –type emitter to flow towards the base region. This constitutes the emitter current . Direction of conventional current is opposite to the flow of electrons
- Electrons after reaching the base region tend to combine with the holes
- If these free electron combine with holes in the base, they constitute base current ().
- Most of the free electrons do not combine with the holes in the base
- This is because of the fact that the base and the width is made extremely small and electrons do not get sufficient holes for recombination
- Thus most of the electrons will diffuse to the collector region and constitutes collector current . This collector current is also called injected current, because of this current is produced due to electrons injected from the emitter region
- There is another component of collector current due to the thermal generated carriers.
- This is called as reverse saturation current and is quite small

OPERATION OF PNP TRANSISTOR



p-n-p transistor

- Operation of a PNP transistor is similar to npn transistor
- The current within the PNP transistor is due to the movement of holes where as, in an NPN transistor it is due to the movement of free electrons
- In PNP transistor, its emitter – base junction is forward biased and collector base junction is reverse biased.
- The forward bias on the emitter – base junction causes the holes in the emitter region to flow towards the base region
- This constitutes the emitter current ( ).
- The holes after reaching the base region, combine with the electrons in the base and constitutes base current.
- Most of the holes do not combine with the electrons in the base region
- This is due to the fact that base width is made extremely small, and holes does not get sufficient electrons for recombination.
- Thus most of the holes diffuse to the collector region and constitutes collector region
- This current is called injected current, because it is produced due to the holes injected from the emitter region
- There is small component of collector current due to the thermally generated carriers
- This is called reverse saturation current.

TRANSISTOR CURRENTS

- We know that direction of conventional current is always opposite to the electron current in any electronic device.
- However, the direction of a conventional current is same as that of a hole current in a PNP transistor
- Emitter current
- Base current
- Collector current

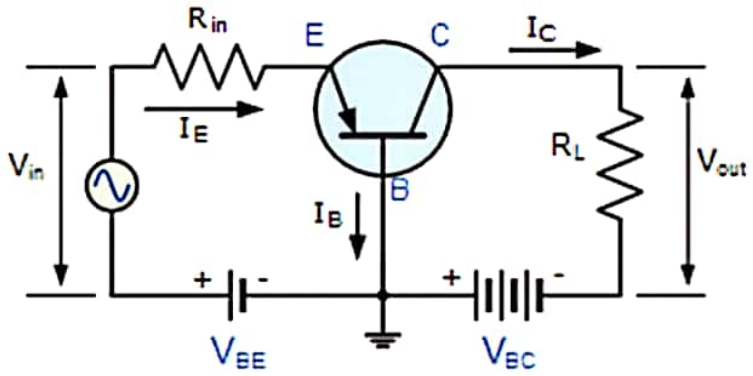
- Since the base current is very small

TRANSISTOR CONFIGURATIONS

- A transistor is a three terminal device, but we require four terminals (two for input and two for output) for connecting it in a circuit.
- Hence one of the terminal is made common to the input and output circuits.
- The common terminal is grounded
- There are three types of configuration for the operation of a transistor

- **Common base configuration**
  - This is also called grounded base configuration
  - In this configuration emitter is the input terminal, collector is the output terminal and base is the common terminal
- **Common emitter configuration(CE)**
  - This is also called grounded emitter configuration
  - In this configuration base is the input terminal, collector is the output terminal and emitter is the common terminal
- **Common collector configuration(CC)**
  - This is also called grounded collector configuration
  - In this configuration, base is the input terminal, emitter is the output terminal and collector is the common terminal.

- **Common base configuration (CB)**



- The input is connected between emitter and base and output is connected across collector and base
- The emitter – base junction is forward biased and collector – base junction is reverse biased.
- The emitter current, flows in the input circuit and the collector current flows in the output circuit.
- The ratio of the collector current to the emitter current is called current amplification factor.
- If there is no input ac signal, then the ratio of collector current to emitter current is called dc alpha
- The ratio of change in the collector current to change in the emitter current is known as ac alpha
- = Common-emitter current gain = Common-base current gain

$$= \frac{I_C}{I_B} \qquad = \frac{I_C}{I_E}$$

- The input characteristics look like the characteristics of a forward-biased diode. Note that V_{BE} varies only slightly, so we often ignore these characteristics and assume:

- Common approximation: $V_{BE} = V_o = 0.65$ to $0.7V$

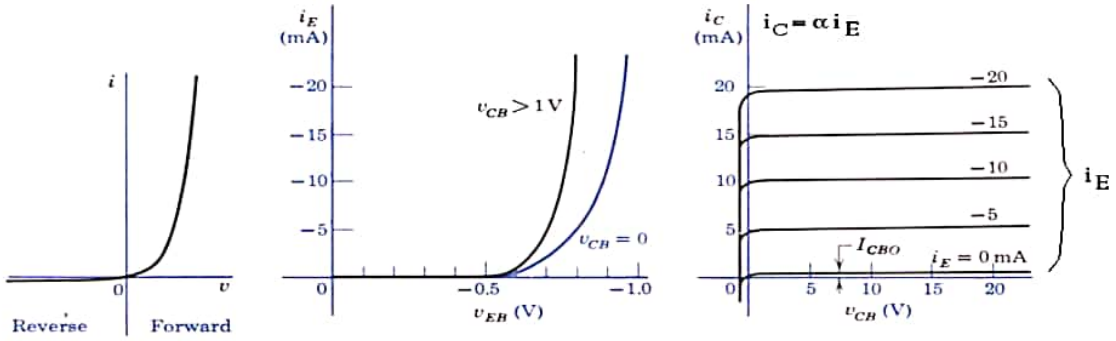
- The higher the value of better the transistor. It can be increased by making the base thin and lightly doped

- The collector current consists of two parts transistor action. Ie., component dependind upon the emitter current , which is produced by majority carriers

- The leakage current due to the movement of the minority carriers across base collector junction

CHARACTERISTICS OF CB CONFIGURATION

- The performance of transistors determined from their characteristic curves that relate different d.c currents and voltages of a transistor
- Such curves are known as static characteristics curves
- There are two important characteristics of a transistor
  - Input characteristics
  - Output characteristics



(a) Diode characteristic (b) Emitter characteristics (c) Collector characteristics

INPUT CHARACTERISTICS

- The curve drawn between emitter current and emitter – base voltage for a given value of collector – base voltage is known as input characteristics

Base width modulation (or) Early effect

- In a transistor, since the emitter – base junction is forward biased there is no effect on the width of the depletion region
- However, since collector – base junction is reverse biased as the reverse bias voltage across the collector – base junction

increase the width of the depletion region also increases
    - Since the base is lightly doped the depletion region penetrates deeper into the base region
    - This reduces the effective width of the base region
    - This variation or modulation of the effective base width by the collector voltage is known as base width modulation or early effect
    - The decrease in base width by the collector voltage has the following three effects
- It reduces the chances of recombination of electrons with the holes in the base region
  Hence current gain increases with increase in collector – base voltage

- The concentration gradient of minority carriers within the base increases. This increases the emitter current
- For extremely collector voltage , the effective base width may be reduced to zero, resulting in voltage breakdown of a transistor
- This phenomenon is known as punch through
    - The emitter current increases rapidly with small increase in which means low input resistance
    - Because input resistance of a transistor is the reciprocal of the slope of the input characteristics

Output characteristics

- The curve drawn between collector current and collector – base voltage, for a given value of emitter current is known as output characteristics

ACTIVE REGION

- There is a very small increase in with increase in
- This is because the increase in expands the collector – base depletion region and shorten the distance between two depletion region
- Hence due to the early effect does not increase very much with increase in
- Although, the collector current is independent of if is increased beyond a certain value, eventually increases rapidly because of avalanche effects
- This condition is called punch – through or reach – through
- When it occurs large current can flow destroying the device

CUT - OFF REGION

- small collector current flows even when emitter current
- this is the collector leakage current

SATURATION REGION

- collector current flows even when the external applied voltage is reduced to zero. There is a low barrier potential existing at the collector – base junction and this assists in the flow of collector current

(II) COMMON – EMITTER CONFIGURATION

- The input is connected between base and emitter, while output is connected between collector and emitter
- Emitter us common to both input and output circuits.

- The bias voltage applied are Vce and Vbe.
- The emitter-base junction is forward biased and collector-emitter junction is reverse biased.
- The base current Ib flows in the input circuit and collector current Ic flows sin the output circuit.
- CE is commonly used because its current, Voltage, Power gain are quite high nd output to input impedance ratio is moderate
- The rate of change in collector current to change in base current is called amplification factor B.
- The current gain in the common-emitter circuit is called BETA (b). Beta is the relationship of collector current (output current) to base current (input current).

- Two voltages are applied respectively to the base B and collector C with respect to the common emitter E.

- Same as the CB configuration, here in the CE configuration, the BE junction is forward biased while the CB junction is reverse biased. The voltages of CB and CE configurations are related by:

$$V_{CE} = V_{CB} + V_{BE}, \quad \text{or} \quad V_{CB} = V_{CE} - V_{BE}$$

- The base current is treated as the input current, and the collector current is treated as the output current:

$$I_C = \alpha I_E + I_{CB0} = \alpha(I_C + I_B) + I_{CB0} \approx \alpha(I_C + I_B)$$

- Solving this equation for collector current, we get the relationship between the output collector current and the input base current:

$$I_C = \frac{\alpha}{1-\alpha} I_B + \frac{1}{1-\alpha} I_{CB0} = \beta I_B + (\beta+1) I_{CB0} = \beta I_B + I_{ce0} \approx \beta I_B$$

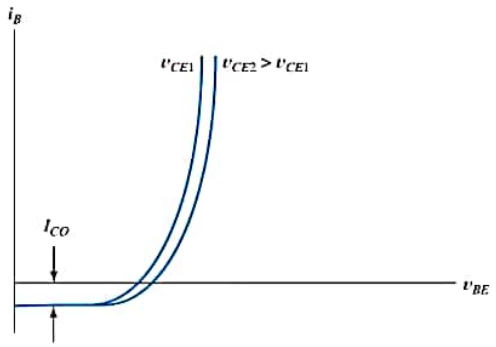
- Here we have also defined the CE *current gain* or *current transfer ratio*

$$\beta = \frac{\alpha}{1-\alpha} \approx \frac{I_C}{I_B}$$

- which is approximately the ratio of the output current and the input current . The two parameters α and β are related by:

$$\beta = \frac{\alpha}{1-\alpha}, \qquad \alpha = \frac{\beta}{1+\beta}, \qquad 1+\beta = \frac{1}{1-\alpha}, \qquad 1-\alpha = \frac{1}{1+\beta}$$

Characteristics of CE configuration



(a) Input characteristics

i) Input Characteristics

- Same as in the case of common-base configuration, the junction of the common-emitter configuration can also be considered as a forward biased diode, the current-voltage characteristics is similar to that of a diode:

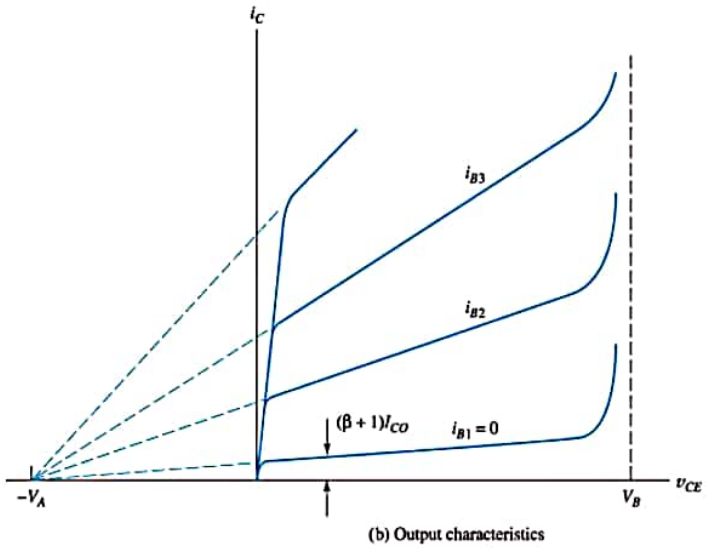
$$I_B = f(V_{BE}, V_{CE}) \approx f(V_{BE}) = I_0(e^{V_{BE}/V_T} - 1)$$

- The Curve drawn between base current and base-emitter voltage for a given value of collector-emitter voltage is known as input characteristics.
- The input characteristics of CE transistors are similar to those of a forward biased diode because the base-emitter region of the transistor is forward-biased.
- Input Resistance is larger in CE configuration than in CB configuration.

This is because the I/P current increases less rapidly with increase in Vbe.

- An increment in value of Vce causes the input current to be lower for a given level of Vbe.
- This is explained on the basis of early effect.
- As a result of early effect, more charge carriers from the emitter flows across the collector-base junction and flow out through the based lead.

ii) Output Characteristics



(b) Output characteristics

$$I_C = f(I_B, V_{CE}) \approx f(I_B) = \beta I_B \qquad \text{(in linear region)}$$

- It is the curve drawn between collector current Ic and collector-emitter voltage Vce for a given value of base current Ib.

- The collector current Ic varies with Vce and becomes a constant.
- Output characteristics in CE configuration has some slope while CB configuration has almost horizontal characteristics.
- This indicates that output resistance incase of CE configuration is less than that in CB configuration.

Active Region

- For small values of base current, the effect of collector voltage Vc over Ic is small but for large values of Ib, this effect increases.
- The shape of the characteristic is same as CB configuration
- The difference that Ic is larger than input current

- Thus, the current gain is greater than unity.

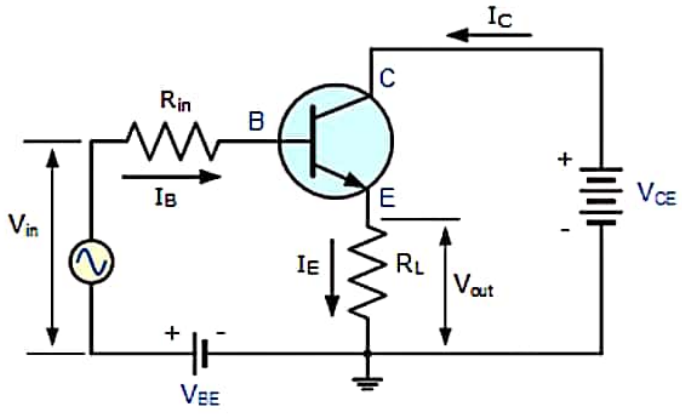
Saturation Region

- With low values of Vce, the transistor is said to be operated in saturation region and in this region, base current Ib does not correspond to Ic,

Cut off Region

- A small amount of collector current Ic flows even when Ib=0, This is called emitter leakage current.

iii) Common Collector Configuration:



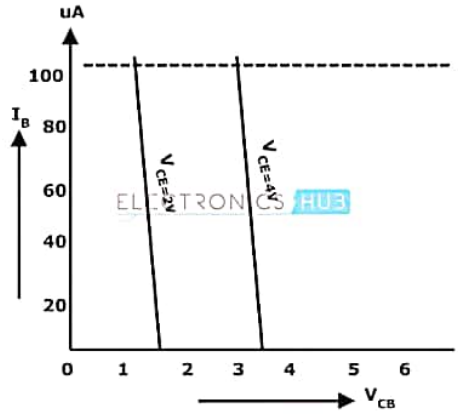
- Input is applied between base and collector while output is applied between emitter and collector.
- The collector forms the terminal common to both the input and output.
  GAIN is a term used to describe the amplification capabilities of an amplifier. It is basically a ratio of output to input. The current gain for the three transistor configurations (CB, CE, and CC) are ALPHA(a), BETA (b), and GAMMA (g), respectively.

$$\alpha = \frac{\Delta I_C}{\Delta I_E}$$

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

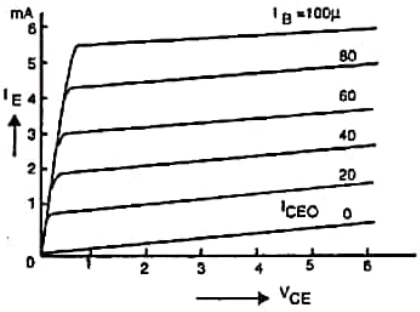
$$\gamma = \frac{\Delta I_E}{\Delta I_B}$$

i) Input Characteristics



- To determine the i/p characteristics Vce is kept at a suitable fixed value.
- The base collector voltage Vbc is increased in equal steps and the corresponding increase in Ib is noted.
- This is repeated for different fixed values of Vce.

ii) Output Characteristics



Current components in a Transistor

- As a result of biasing the active region current flows to drift and diffusion in various parts of transition.
- Due to forward bias across input junction, there across three phenomena.
  a) The generation and Recombination of electrons and holes
  Let,
  n -> Electron concentration
  P -> Hole concentration
  Tn -> Life time of electron
  Tp -> Life time of Holes
  no -> Equilibrium density of electrons
  po -> Equilibrium density of Holes