Unit-3: Bipolar Junction Transistors

❖ Syllabus

Unit– III Bipolar Junction Transistor	3a. Describe with sketches the construction and working of the given type of device. 3b. Explain with sketches the working principle of the given transistor configuration 3c. Determine the current gain of the given transistor configuration. 3d. Explain with sketches the specified transistor parameter. 3e. Explain with sketches the concept of the specified transistor biasing.	3.1 Unipolar and Bipolar devices 3.2 Symbol, construction and working principle of NPN transistor. 3.3 Transistor as switch and amplifier. 3.4 CE, CB and CC configurations. 3.5 Regions – Cut-off, saturation and Active region. 3.6 Transistor parameters- alpha, beta, input and output resistance and relation between alpha and beta 3.7 Transistor biasing- DC load line, Q-point and Fix bias and voltage divider biasing. 3.8 RC coupled amplifier.

❖ Introduction

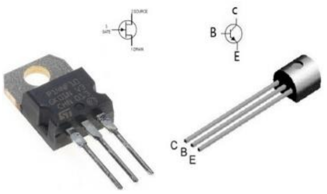
Transistor

The semiconductor device which can transfer a signal current from a low resistance to a high resistance is called a transistor.

[transistor = transfer + resistor]

OR

Transistor is a solid-state electronic device which can amplify the weak electrical signal by transferring the signal current from a low resistance P-N junction to a high resistance P-N junction is called a transistor.



Types of Transistors:

- **BJT**
- **FET**

Advantages of transistor:

- **small size, lightweight**
- **operates at low voltage**
- **long life**
- **higher efficiency**

❖ Bipolar Junction Transistors

BJT

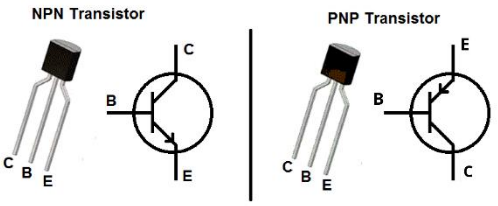
A bipolar junction transistor is basically a silicon or germanium crystal having two P-N junctions formed by sandwiching either P-type or N-type semiconductors between a pair of opposite types.

Applications:

- **It is used as an amplifier**
- **It is used in switching circuits**
- **It is used as an electronic switch**
- **It is used as a modulator**

Types of BJT:

- **NPN**
- **PNP**

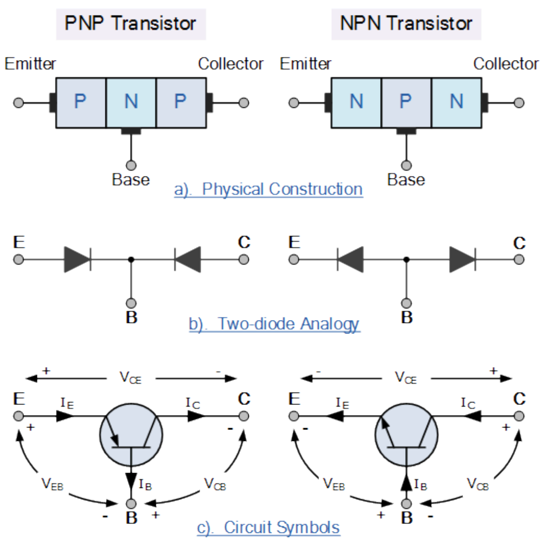


3 terminals:

- **Base**
- **Emitter**
- **Collector**

Construction:

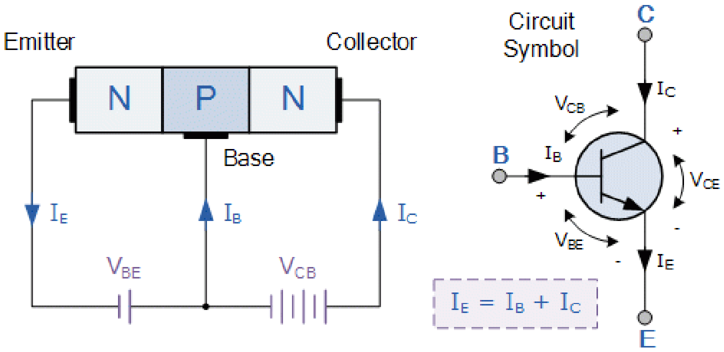
The Bipolar junction transistor consists of two P-N junctions. The junctions are formed by sandwiching either P-type or N-type semiconductor layers between a pair of opposite types.



❖ NPN Transistor

NPN Transistor

When a thin layer of P-type semiconductor is sandwiched between two layers of N-type semiconductors, it is known as NPN transistor



- **The NPN transistor has two P-N junctions namely the base-to-emitter (B-E) junction and collector-to-base (C-B) junction**
- **The arrowhead on the emitter E indicates the direction of conventional current in an N-P-N transistor and the conventional emitter current will flow from base to emitter, that's why the direction is outward.**

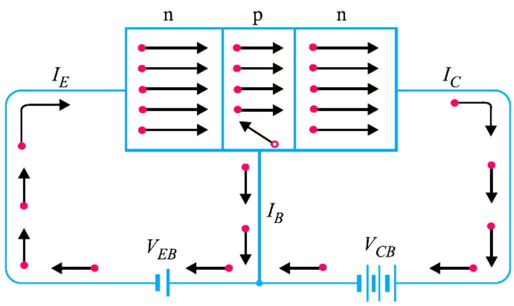
Construction:

- **In an NP-N transistor the majority charge carriers are electrons (e^-)**
- **The middle P-region is very thin and lightly doped, this region is called the base, and is one of the most important factors in the function of a transistor.**
- **Out of the two outer N-regions, one is called the emitter and the other is called the collector, they have different physical and electrical properties.**
- **The collector is made larger in surface area than that of emitter, as it is required to collect the charges and dissipate more heat.**
- **The doping concentration of emitter is higher than that of collector and base; collector has doping concentration between heavy doping of emitter and light doping of base.**

Biasing Conditions:

Modes	Emitter-Base junction	Collector- Base junction
Cutoff	Reverse	Reverse
Active	Forward	Reverse
Saturation	Forward	Forward
Reverse active	Reverse	Forward

Working principle:



Basic connection of *npn* transistor

- **The figure shows an NPN transistor biased in forward-active mode. i.e the emitter base junction V_{EB} is in forward bias and collector base junction V_{CB} is in reverse bias.**
- **The forward bias emitter base junction V_{EB} causes majority charge carriers (electrons) in the N-type emitter to flow towards the P-type base. This constitutes the emitter current I_E.**
- **The free electrons after reaching the base region tend to combine with the holes in the base. These free electrons combine with the holes in the base region; this constitutes the base current I_B.**
- **Most of the electrons do not combine with the holes in the base because, the base is lightly doped and very thin & free electrons do not get sufficient holes in the base for recombination.**
- **Thus most of the free electrons will diffuse in the collector region and constitute the collector current I_C.**
- **The small component of collector current is called reverse saturation current I_{CO} and is quite small.**
- **It may be noted that the current conduction in NPN transistor is by free electrons.**
- **It can be stated that emitter current is the sum total of collector current and base current i.e**

  $$I_E = I_B + I_C$$
- **Since, the base current is very small compared to the collector current, therefore:**

  $$I_E \approx I_C$$

BJT CIRCUIT CONFIGURATIONS

Concept of Biasing

The application of a suitable DC voltage across the terminals of solid state (i.e. semiconductor) device is called a biasing.

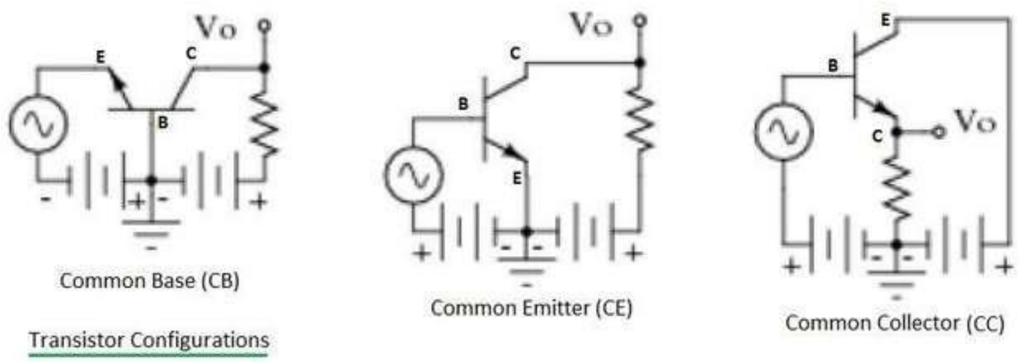
BJT Biasing:

The application of a suitable DC voltage across the terminals of a BJT is called a BJT biasing.

To bring the BJT in the normal operating condition, the biasing is provided to the P-N junctions of a BJT.

❖ Types of BJT Configurations:

- **Common Base (CB) Configuration: no current gain but voltage gain**
- **Common Collector (CC) Configuration: current gain but no voltage gain**
- **Common Emitter (CE) Configuration: current gain and voltage gain**



Advantages of CE Configuration:

1. **It has moderate input impedance of about 1Ω**
2. **It has moderate output impedance of about 40kΩ**
3. **It has high current gain β and hence power gain**
4. **It has higher voltage gain**
5. **As it offers high current and voltage gain so power gain is high.**

Why CE Configuration widely used?
The common-emitter (CE) configuration has high input impedance and low output impedance which is very useful for impedance matching in the power amplifiers. Also it has very high current gain and power gain, which is also very useful property for power amplifiers. Therefore CE configuration of BITS is best suited and hence it is widely used for amplification purposes.

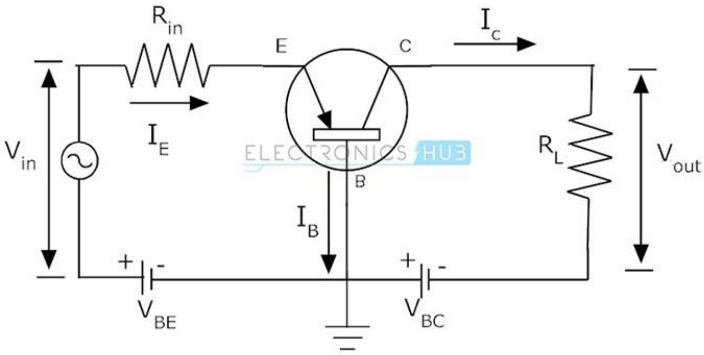
V-I Characteristics of BJT
The characteristic curves which relate the steady (DC) values of BUT currents and voltages are known as the static characteristics of BJT.

Types
1 Input characteristics. 2. Output characteristics 3 Transfer characteristics.

Input characteristics:
The curves giving the relationship between the input current and input voltage of BJT for a given constant output voltage are called input characteristics of a BJT.

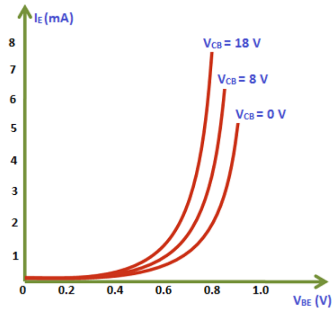
Output characteristics:
The curves giving the relationship between the output current and the output voltage of a BJT for a given constant input current are known as output characteristics of a BJT.

❖ Characteristics of BJT in CB mode:



Input Characteristics

The input characteristic curves give the relationship between the emitter current I_E and the emitter-to-base voltage V_{EB} for a constant collector-to-base voltage V_{CB}.



I/p characteristics CB configuration

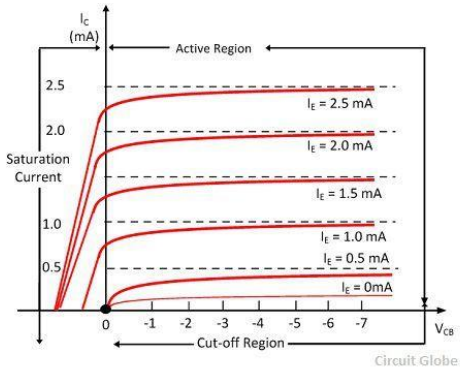
AC Input resistance

It is defined as the ratio of a small change in emitter-to-base voltage (ΔV_{EB}) to the resulting change in emitter current (ΔI_E) for a constant collector-to-base voltage (V_{CB}) . It is also known as dynamic input resistance.

$r_i = \Delta V_{EB} / \Delta I_E$ [V_{CB} = constant]

Output Characteristics

The output characteristic curves give the relationship between the collector current I_C and the collector-to-base voltage V_{CB} for a constant emitter current I_E.



AC Output resistance

It is defined as the ratio of a small change in collector to-base voltage (ΔV_{CB}) to the resulting change in collector current (ΔI_C) for a constant emitter current (I_E). It is also known as dynamic output resistance.

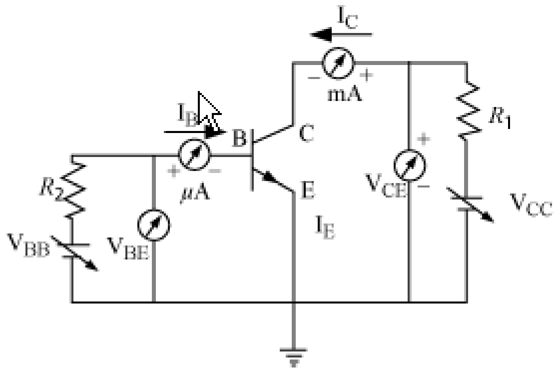
$r_o = \Delta V_{CB} / \Delta I_C$ [I_E = constant]

AC current gain (α_o)

The AC current gain of a transistor can be determined by selecting two points X and Y on the characteristics and noting down the corresponding values of ΔI_C & ΔI_E

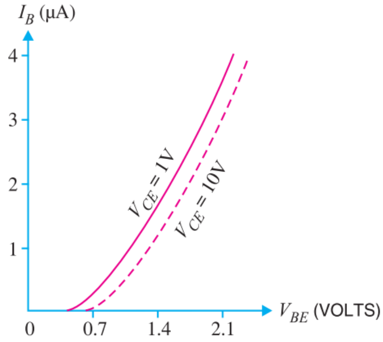
$\alpha_o = \Delta I_C / \Delta I_E$

❖ Characteristics of BJT in CE mode:



Input Characteristics

The input characteristic curves give the relationship between the base current I_B and the base-to-emitter voltage V_{BE} for a constant collector-to-emitter voltage V_{CE}.



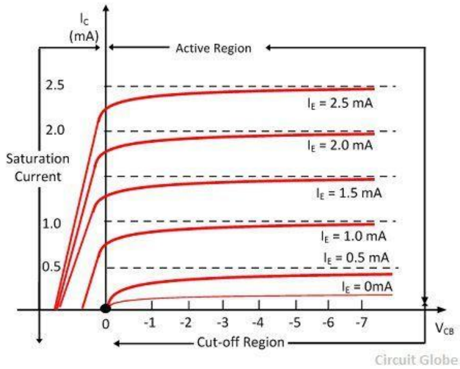
AC Input resistance

It is defined as the ratio of a small change in base-to-emitter voltage (ΔV_{BE}) to the resulting change in base current (ΔI_B) for a constant collector-to-emitter voltage (V_{CE}) . It is also known as dynamic input resistance.

$r_i = \Delta V_{BE} / \Delta I_B$ [V_{CE} = constant]

Output Characteristics

The output characteristic curves give the relationship between the collector current I_C and the collector-to-emitter voltage V_{CE} for a constant base current I_B.



AC Output resistance

It is defined as the ratio of a small change in collector to-emitter voltage (ΔV_{CE}) to the resulting change in collector current (ΔI_C) for a constant base current (I_B). It is also known as dynamic output resistance.

$r_o = \Delta V_{CE} / \Delta I_C$ [I_B = constant]

AC current gain (β_o)

The AC current gain of a transistor can be determined by selecting two points X and Y on the characteristics and noting down the corresponding values of ΔI_C & ΔI_B

$\beta_o = \Delta I_C / \Delta I_B$

Relation between the current gains α & β

We know, $I_E = I_B + I_C$

Dividing the equation on both sides by I_C

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

Since, $\alpha_o = \Delta I_C \ / \ \Delta I_E$

& $\beta_o = \Delta I_C \ / \ \Delta I_B$

So, $\Delta I_E \ / \ \Delta I_C = 1/\alpha_o$

$\Delta I_B \ / \ \Delta I_C = 1/\beta_o$

$$\frac{1}{\alpha_o} = \frac{1}{\beta_o} + 1$$

$$\text{So,} \quad \frac{1}{\alpha_o} = \frac{1+\beta_o}{\beta_o}$$

$$\text{So,} \quad \alpha_o = \frac{\beta_o}{1+\beta_o}$$

$\alpha_o(1+\beta_o) = \beta_o$

$\alpha_o + \alpha_o\beta_o = \beta_o$

$\alpha_o = \beta_o - \alpha_o\beta_o$

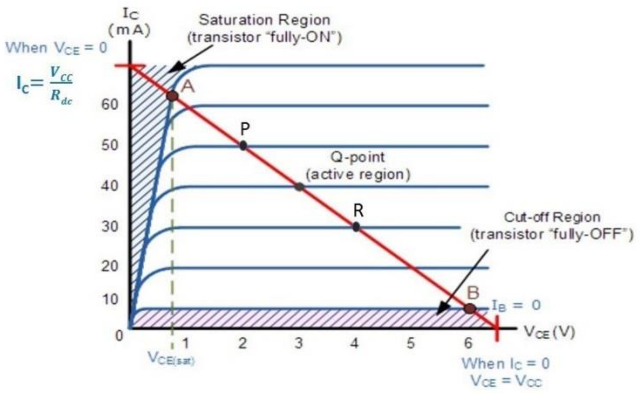
$\alpha_o = \beta_o(1-\alpha_o)$

$\beta_o = \dfrac{\alpha_o}{(1-\alpha_o)}$ Similarly, $\alpha_o = \dfrac{\beta_o}{(1+\beta_o)}$

❖ Transistor Biasing

The biasing of transistor (BJT) in which there is proper flow of zero signal collector current and maintenance of proper collector-emitter voltage during the passage of A.C input signal is known as transistor biasing.

❖ DC Load Line

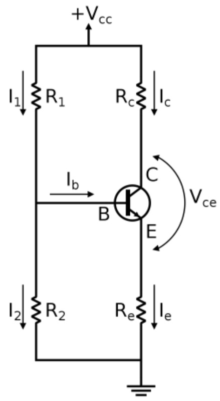


The straight line drawn on the output characteristics of a BJT amplifier which give the DC values of collector current I_C and collector to emitter voltage V_{CE} corresponding to zero signal (Le. DC conditions) is called a D.C. load line.
Since the slope of this load line is decided by the value of D.C. collector load resistance of the BJT amplifier, it is called a DC load line.

❖ Q-point

For the operation of a BJT for any application we have to set a fixed level of certain currents and voltages of a These values of currents and voltages define the point at which the BJT operates. This point is called the operating point
The point decided by the zero signal (or DC) values of I_C and V_{CE} lying on the DC load line is known as the D.C. operating point. The operating point is also known as quiescent point or simply point.

❖ Voltage-Divider Bias



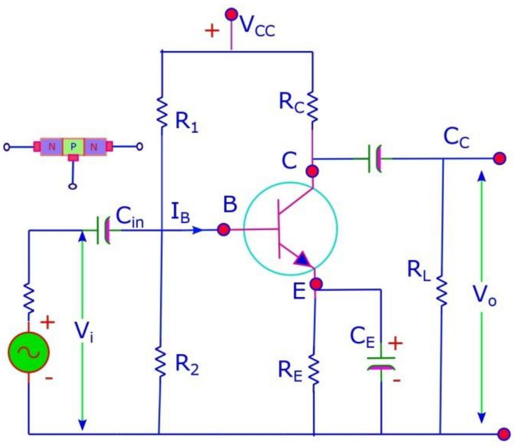
One way to bias a BJT transistor is a method called voltage divider bias.
This voltage divider configuration is the most widely used transistor biasing method, as the emitter diode of the transistor is forward biased by the voltage dropped across resistor R_2. Also, voltage divider network biasing makes the transistor circuit independent of changes in beta as the voltages at the transistors base, emitter, and collector are dependent on external circuit values.

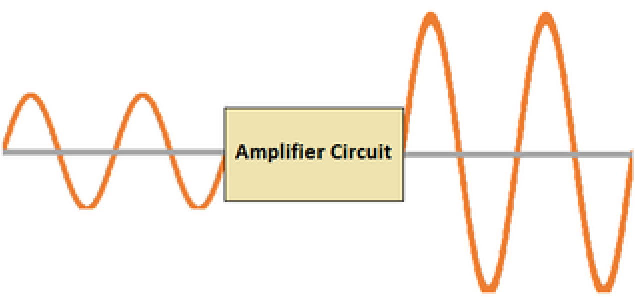
Operating principle:
A potential divider bias, also known as voltage divider bias, is commonly used in transistors so as to produce faithful amplification. It is a method used for the dc biasing of bipolar junction transistors (BJT) in a simple amplifier circuit. When we consider amplifier circuits in transistors, the main thing that we should concentrate on is to provide a constant current output. The circuit usually consists of biasing resistors in a voltage divider network whose values are determined through circuit analysis.

Advantages
1. It is very simple method of transistor biasing
2. The biasing conditions can be very easily set
3. There is no loading of source
4. It provides better bias stabilization as stability factor is very low.

Disadvantages
1 The ratio R_B/R_B needs to be low for better Q-point stabilization. So the base resistor R_B should be small and the emitter resistor R_E high. But this reduces the input resistance
2. It reduces the gain due to negative feedback if the resistor R_E is un-bypassed.

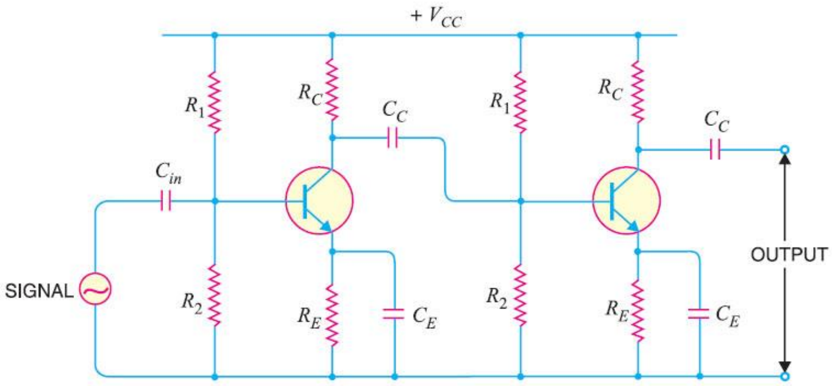
❖ Single – Stage RC Coupled CE Amplifier



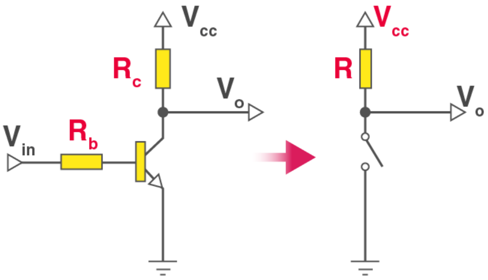


- **The BJT is the heart of an amplifier. When a BJT is in the active region, it can work as an amplifier.**
- **When the input AC signal is so weak as to produce small fluctuations in the collector current compared to its quiescent value, the amplifier is called small signal amplifier. It is also known as <u>RC coupled amplifier</u> or <u>single transistor amplifier.</u>**
- **In order to amplify the input signal faithfully (.e without introducing any distortion), the amplifier should operate in the linear portion of the transfer characteristic of a BJT.**
- **To achieve this the amplitude of the input signal has to be sufficiently small. Hence the name of the amplifier is small signal or linear amplifier.**
- **Basically, it provides the voltage amplification in CE configuration, it is also known as a voltage amplifier.**

❖ <u>Two –Stage RC Coupled CE Amplifier</u>



❖ <u>Transistor as a Switch</u>



Using a transistor as a switch is the simplest application of the device. A transistor can be extensively used for switching operation either for opening or closing of a circuit.
Both PNP and NPN transistors can be utilized as switches. A basic terminal transistor can be handled differently from a signal amplifier by biasing both NPN and PNP bipolar transistors by an "ON / OFF" static switch. One of the main uses of the transistor to transform a DC signal "On" or "OFF" is solid-state switches.
Some devices, including LEDs, only require several mill amperes of DC voltages at the logical level and can be directly controlled via the logical gate output. High-power devices such as generators, solenoids or lamps usually need more power to use transistor switches than the usual logic gate.