SAWA UNIVERSITY

# عنوان المحاضرة:BJT


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كلية التقنية الهندسية

القسم الاجهرة الطبية


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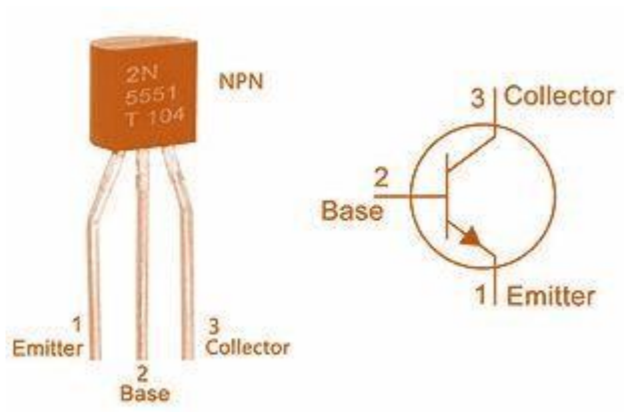
رقم المحاضرة السابعة

# Electronic Circuit

## Lecture 7

# Bipolar Junction Transistor (BJT)



### 1.16. Bipolar Junction Transistor

A **Bipolar Junction Transistor (BJT)** is a type of transistor that uses both electron and hole charge carriers in its operation as shown in Fig. (1). BJTs are essential components in many electronic circuits and are widely used for amplification and switching purposes.

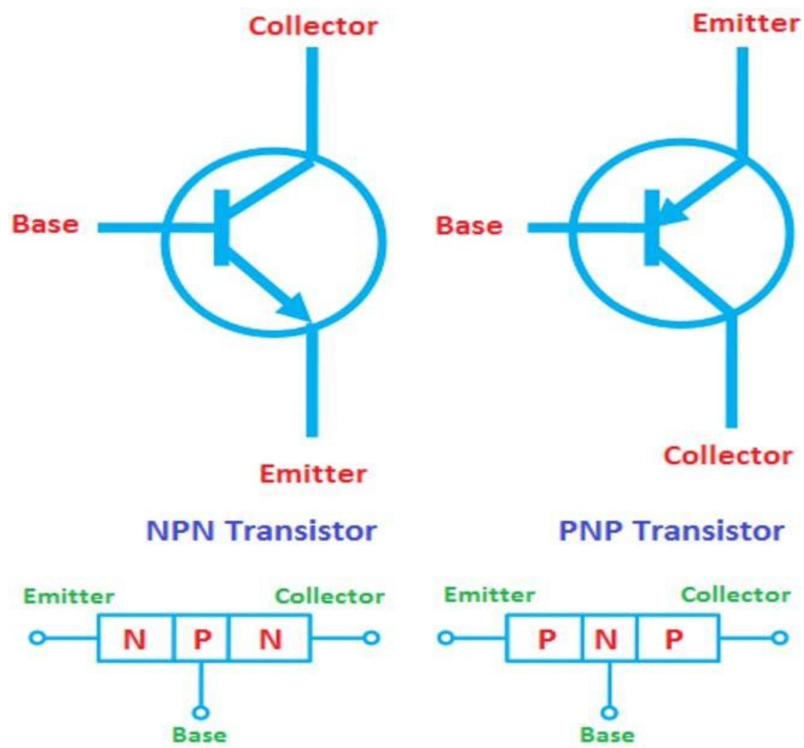



**Fig. (1). Notation and symbols used with the transistor configuration: (a) NPN transistor (b) PNP transistor**

A BJT has three terminals:

- **Emitter (E)**: Emits charge carriers (electrons for NPN, holes for PNP).
- **Base (B)**: Controls the number of charge carriers flowing between the emitter and collector.
- **Collector (C)**: Collects the charge carriers from the emitter.

### 1.16.1. Common-Emitter Configuration

The most commonly used transistor configuration, shown in Fig. (2). for npn transistors, is known as the common-emitter configuration. This name comes from the fact that the emitter is shared between both the input and output terminals, meaning it is common to both the base and collector terminals.

To fully describe the behavior of the common-emitter configuration, two sets of characteristics are required: one for the input (base-emitter circuit) and another for the output (collector-emitter circuit).

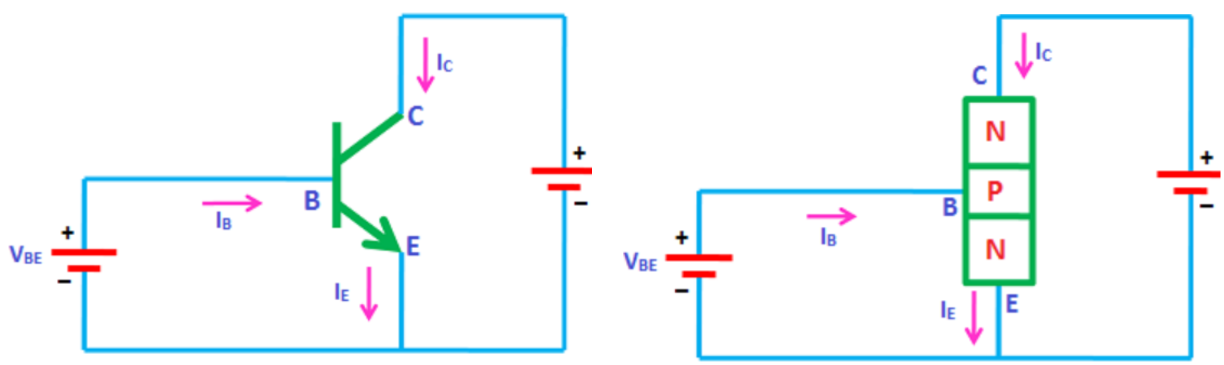



**Fig. (2). Notation and symbols used with the CE configuration NPN transistor**

**Characteristics Common-Emitter Configuration**

**Input Characteristics:**

Plot of Input Current $I_B$ versus Input Voltage $V_{BE}$: This plot is generated for various values of the output voltage $V_{CE}$, showing the relationship between the base current $I_B$ and the base-emitter voltage $V_{BE}$. As shown in Fig. (3).

- $I_B$ is plotted on the vertical axis (Y-axis).
- $V_{BE}$ is plotted on the horizontal axis (X-axis).
- Each curve corresponds to a different, constant value of $V_{CE}$.

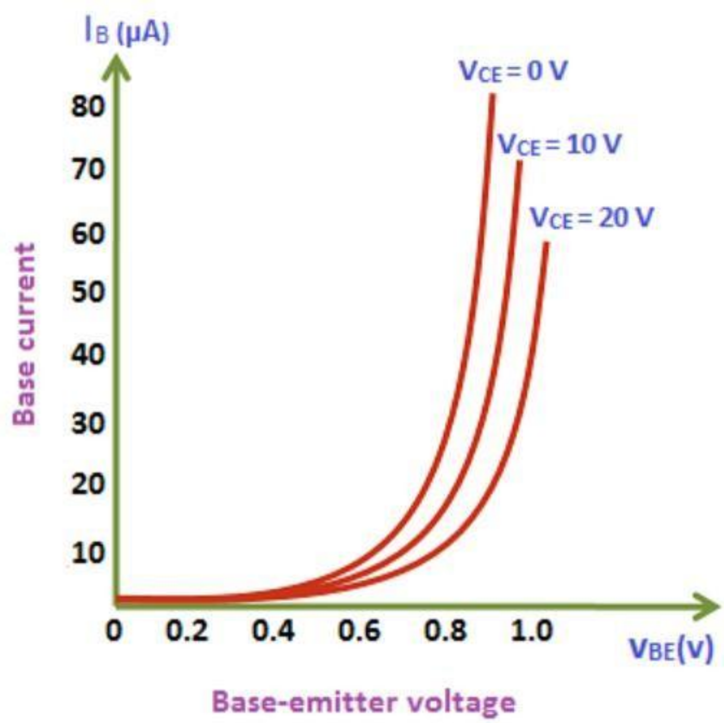



**Fig. (3). I/P characteristics CE configuration**

## Output Characteristics:

Plot of Output Current $I_C$ versus Output Voltage $V_{CE}$: This plot is typically drawn for various values of the input current $I_B$, meaning that for different base current values, the collector current $I_C$ is measured as the collector-emitter voltage $V_{CE}$: is varied. As shown in Fig. (4).

- $I_C$ is plotted on the vertical axis (Y-axis).
- $V_{CE}$ is plotted on the horizontal axis (X-axis).
- Each curve on the graph corresponds to a different, constant value of the base current $I_B$.
- At higher values of $V_{CE}$, $I_C$ becomes nearly independent of $V_{CE}$, and the transistor enters the saturation region.

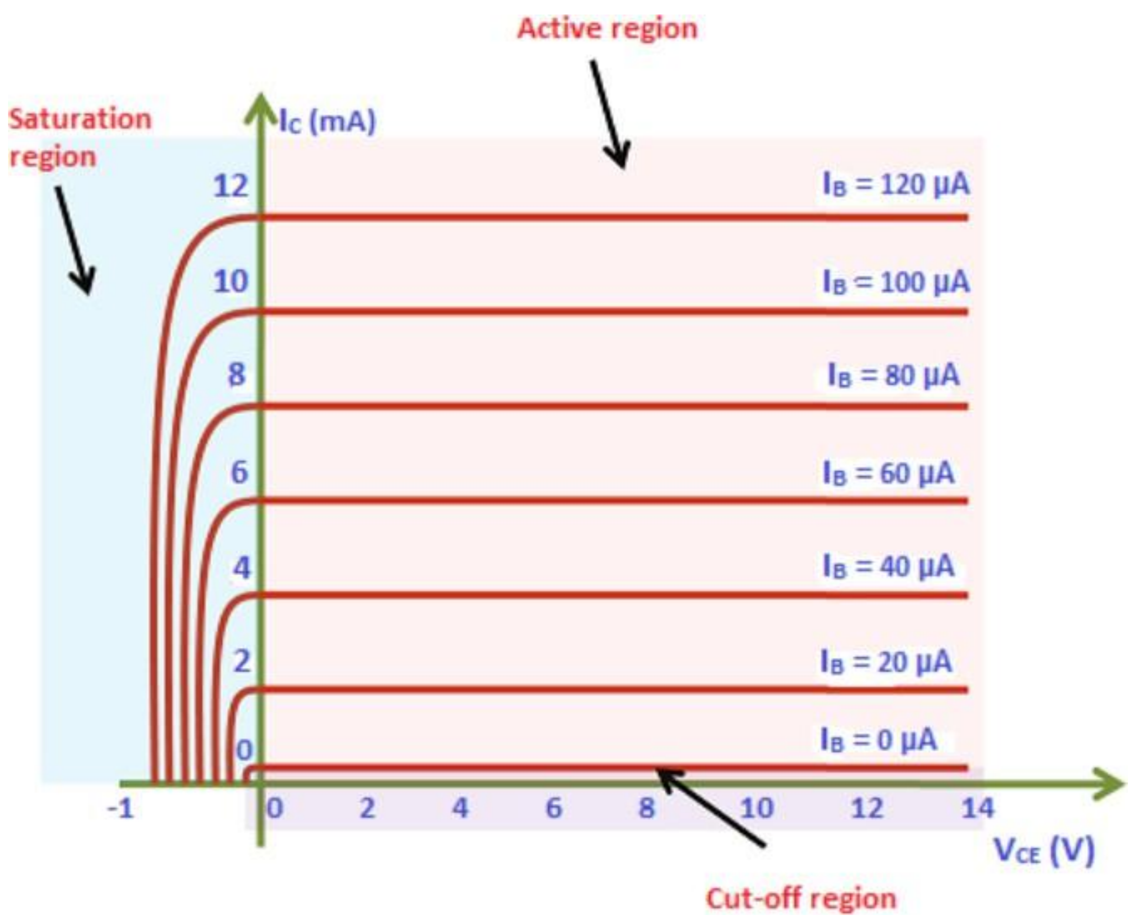



**Fig. (4). O/P characteristics CE configuration**

In the context of a common-emitter (CE) transistor configuration, the terms **active**, **saturation**, and **cutoff** refer to the different regions of operation of a transistor based on the applied voltages and currents. Each region affects how the transistor behaves, whether as a switch or an amplifier:

**Active Region (Amplification Mode):**

- In the active region, the transistor operates as an amplifier.
- **Condition**: The base-emitter junction is forward biased, and the base-collector junction is reverse biased.
- **Voltages**:
  - $V_{BE}$ (Base-Emitter Voltage): Positive and typically around 0.7V for silicon transistors.
  - $V_{CE}$ (Collector-Emitter Voltage): Positive and higher than $V_{BE}$, but not too high to push it into saturation.
- **Current Relationships**: In this region, the collector current $I_C$ is proportional to the base current $I_B$ following the relation $I_C = \beta I_B$ where $\beta$ is the current gain of the transistor.

In the DC mode the levels of $I_C$ and $I_B$ are related by a quantity called beta $\beta$ and defined by the following equation:

$$\beta_{DC} = \frac{I_C}{I_B}$$

A relationship can be developed between $\beta$ and $\alpha$ using the basic relationships introduced thus far. Using $\beta = I_C/I_B$, we have $I_B = I_C/\beta$, and from $\alpha = I_C/I_E$ we have $I_E = I_C/\alpha$ . Substituting into:

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

and dividing both sides of the equation by $I_C$ results in:

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

$$\beta = \alpha\beta + \alpha = (\beta + 1)\alpha$$

So,

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

## Cutoff Region (Fully OFF, Switch Mode):

- In the cutoff region, the transistor is fully off and behaves like an open switch, with no current flowing between the collector and the emitter.
- **Condition**: Both the base-emitter and base-collector junctions are reverse biased.
- **Voltages**:
  - $V_{BE}$ is zero or negative (less than the threshold to turn the transistor on).
  - $V_{CE}$ is high.
- **Current Relationships**: Both $I_B$ and $I_C$ are approximately zero.

## Saturation Region (Fully ON, Switch Mode):

In the saturation region, the transistor is fully on and behaves like a closed switch, allowing maximum current to flow from the collector to the emitter.

### 1.16.2. Charactersitics Common-Base Configuration

In a common-base (CB) configuration, the base terminal of a BJT is common to both the input and output sidesas shown in Fig.(5). This configuration is less commonly used compared to the common-emitter configuration, but it has specific characteristics that make it useful in certain applications, such as high-frequency amplification.

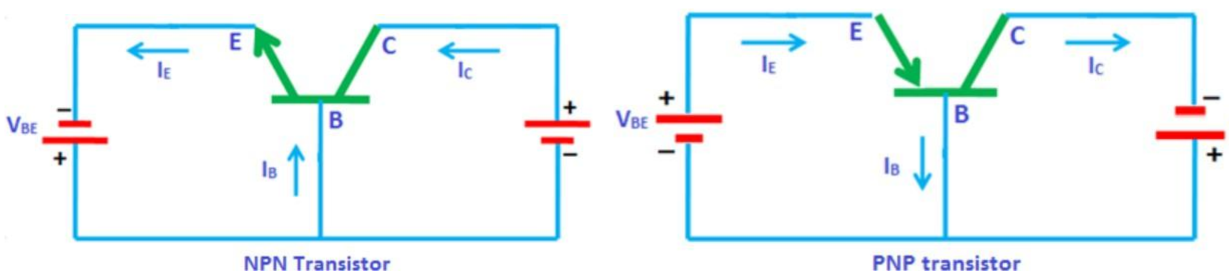



**Fig. (5). Notation and symbols used with the CB configuration NPN and PNP transistor**

**Characteristics of a Common-Base Configuration:**

**Input Characteristics:**

The input characteristics of a common-base configuration represent the relationship between the **input current** (emitter current, $I_E$) and the **input voltage** (emitter-base voltage, $V_{BE}$) for different values of **output voltage** (collector-base voltage, $V_{CB}$).as shown in Fig.(6)

- **Input current** $I_E$ is plotted on the vertical axis (Y-axis).
- **Input voltage** $V_{BE}$ is plotted on the horizontal axis (X-axis).
- **Key Points**:
  - The input characteristics resemble a diode forward bias characteristic since the emitter-base junction behaves like a forward-biased diode.
  - As $V_{BE}$ increases, $I_E$ increases exponentially.

- The curves for different values of $V_{CB}$ are nearly identical because the emitter current is largely independent of the collector voltage in the input region.

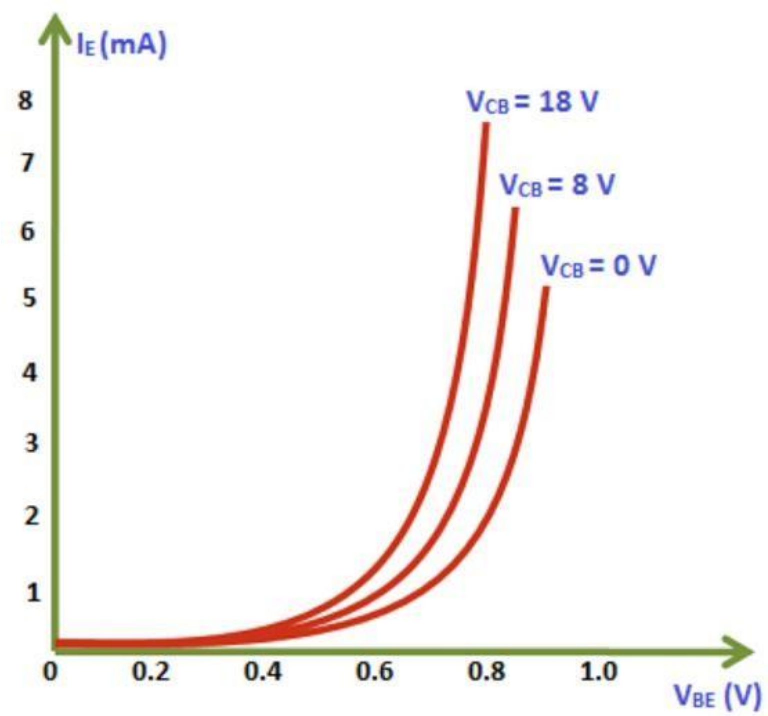



**Fig. (6). I/P characteristics CB configuration**

## Output Characteristics:

The output characteristics describe the relationship between the **output current** (collector current, $I_C$) and the **output voltage** (collector-base voltage, $V_{CB}$) for different values of **input current** (emitter current, $I_E$).as shown Fig.(7).

- **Output current** $I_C$ is plotted on the vertical axis (Y-axis).
- **Output voltage** $V_{CB}$ is plotted on the horizontal axis (X-axis).

- **Key Points**:
    - For a given value of emitter current $I_{E,}$the collector current $I_C$, remains almost constant as $V_{CB}$ is increased, showing a flat, horizontal line in the active region.
    - There is a slight increase in $I_C$ with $V_{CB}$, known as the **Early effect**.
    - At low values of $V_{CB}$, the transistor enters the **saturation region**, where $I_C$ decreases rapidly.
    - For negative values of $V_{CB}$, the transistor enters the **cutoff region**, where both $I_C$ and $I_E$approach zero.

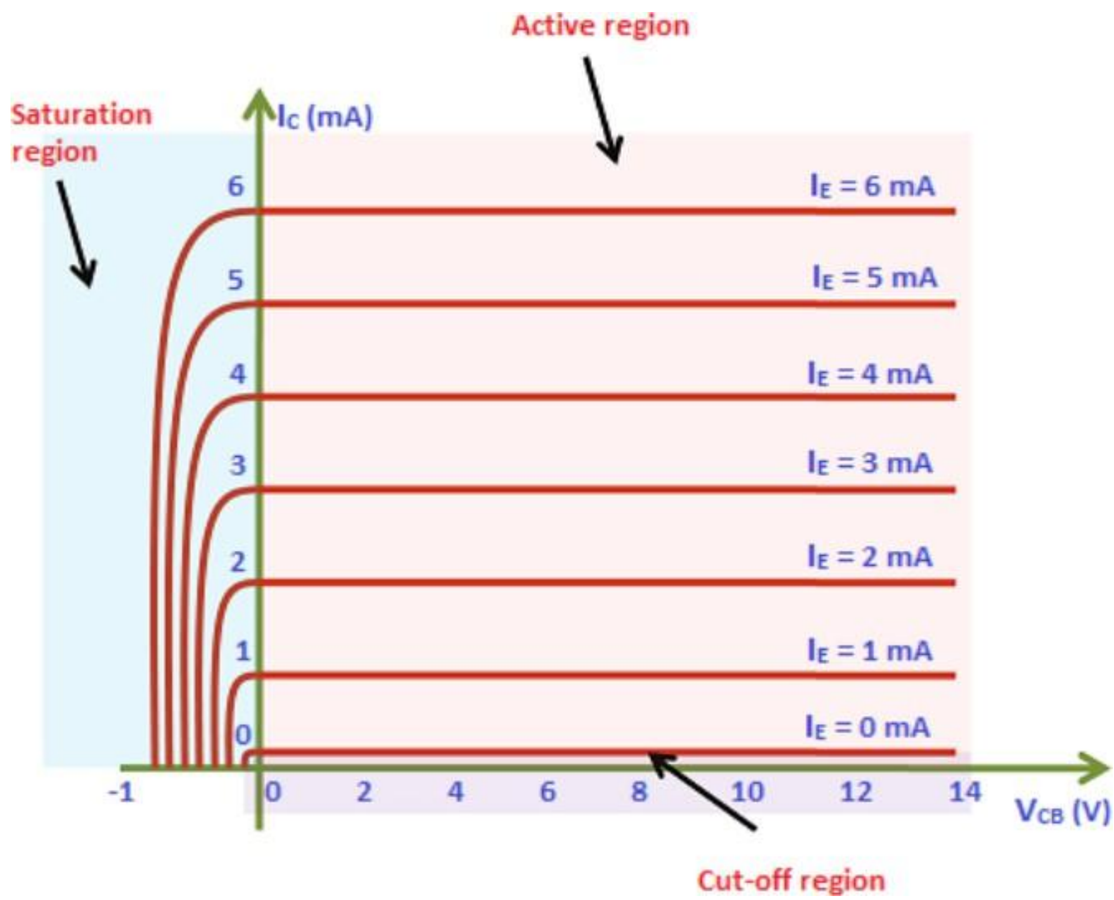



**Fig. (7). O/P characteristics CB configuration**

**Regions of Operation in Common-Base Configuration:**

**Active Region:**

- The **collector-base junction** is reverse biased, and the **emitter-base junction** is forward biased.
- The transistor amplifies signals.
- **Condition**: $V_{CB}$ is positive, and $V_{BE}$ is forward biased.
- **Current Relation**: $I_C = \alpha I_E$, where α\alphaα is the current gain in a common-base configuration (slightly less than 1, typically 0.95–0.99).

**Saturation Region:**

- Both the **emitter-base** and **collector-base** junctions are forward biased.
- The transistor is fully on, acting like a closed switch.
- **Condition**: $V_{CB}$ is close to zero or slightly negative.
- **Current Relation**: Increasing $I_E$ no longer results in significant increases in $I_C$.

**Cutoff Region:**

- Both the **emitter-base** and **collector-base** junctions are reverse biased.
- The transistor is off, and there is no current flowing.
- **Condition**: $V_{BE}$ is less than the forward voltage threshold.
- **Current Relation**: Both $I_C$ and $I_E$ are approximately zero.

since it has a high input impedance and low output impedance, opposite to that of the common-base and common-emitter configurations.

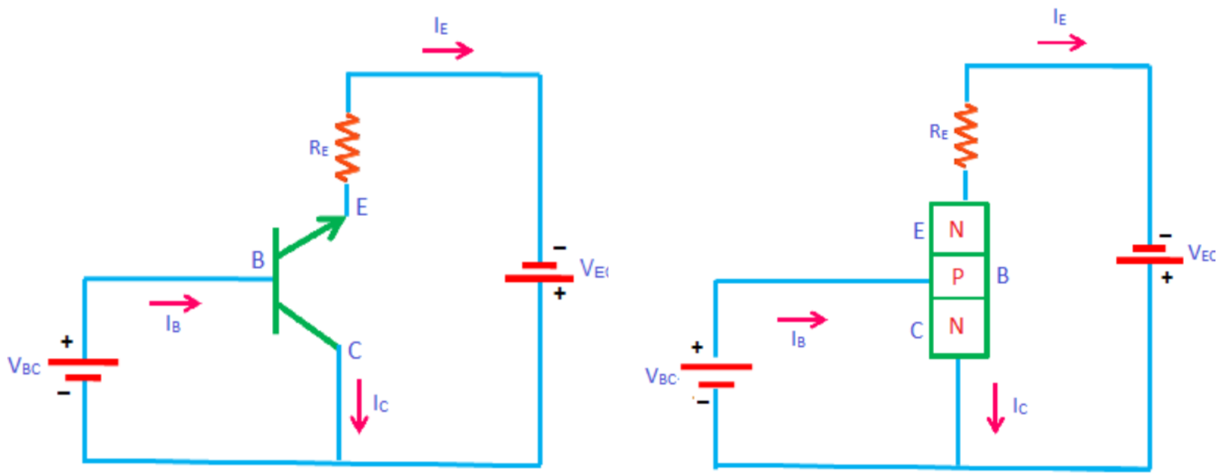



**Fig. (8). Notation and symbols used with the CC configuration NPN transistor**

## Characteristics of a Common-Collector Configuration:

### Input Characteristics:

The input characteristics represent the relationship between the **input current** (base current, $I_B$ ) and the **input voltage** (base-emitter voltage, $V_{BE}$) for different values of **output current** (emitter current, $I_E$). As shown in Fig.(9).

- **Input current** $I_B$ is plotted on the vertical axis (Y-axis).
- **Input voltage** $V_{BE}$ is plotted on the horizontal axis (X-axis).
- **Key Points**:
  - Similar to other transistor configurations, the base-emitter junction behaves like a forward-biased diode, so the relationship between $I_B$ and $V_{BE}$ is exponential.
  - As $V_{BE}$ increases (typically reaching about 0.7V for silicon transistors), $I_B$ starts to rise sharply.

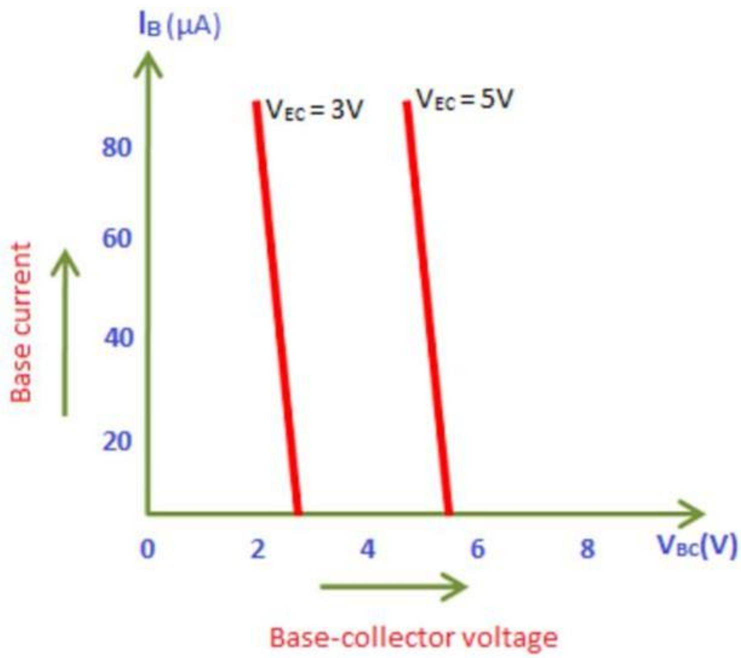



**Fig. (9). I/P characteristics CC configuration**

## Output Characteristics:

The output characteristics describe the relationship between the **output current** (emitter current, $I_E$ ) and the **output voltage** (emitter voltage, $V_E$) for different values of **input current** (base current,$I_B$). As shown Fig.(10).

- **Output current** $I_E$ is plotted on the vertical axis (Y-axis).
- **Output voltage** $V_E$ is plotted on the horizontal axis (X-axis).
- **Key Points**:
  - $I_E$ is almost equal to the collector current $I_C$ because $I_E = I_C + I_B$, and $I_B$ is small compared to $I_C$.
  - The emitter voltage $V_E$ follows the base voltage $V_B$ closely, hence the term "emitter follower."

- For different base currents $I_B$, the emitter current $I_E$ changes accordingly, but the voltage gain remains approximately 1, meaning $V_E \approx V_B - V_{BE}$.

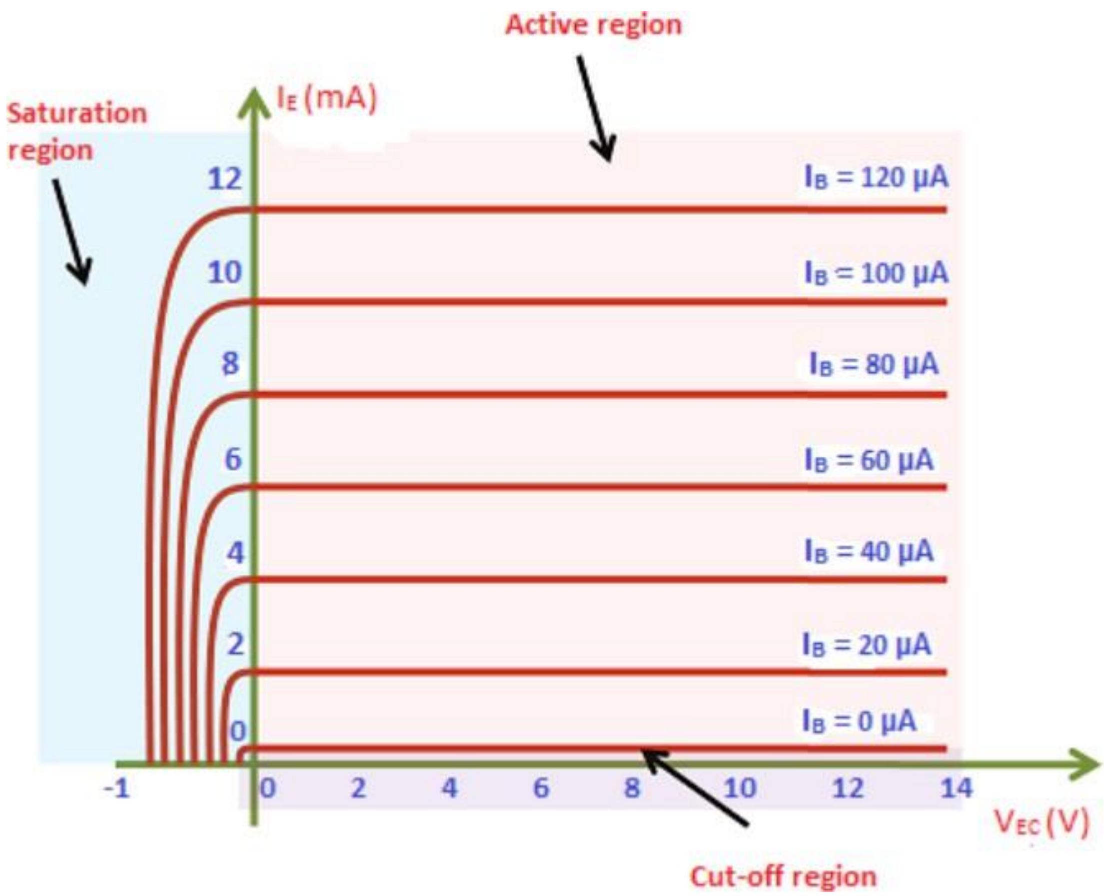



**Fig. (10). O/P characteristics CC configuration**

**Regions of Operation in Common-Collector Configuration:**

**Active Region:**

In the active region, the transistor operates as a voltage buffer.

- **Condition**: The base-emitter junction is forward biased, and the collector-base junction is reverse biased.

- **Voltages**:
    - $V_{BE} \approx 0.7$ (for silicon BJTs).
    - The output voltage $V_E$ follows the input voltage $V_B$ , with a small voltage drop of $V_{BE}$ between them.
- **Current Relations**:
    - The emitter current $I_E \approx \beta I_B$, where $\beta$ is the current gain of the transistor.
    - $I_E \approx I_C$ because $I_B$ is very small.

**Saturation Region:**

In the saturation region, the transistor is fully on, and both the base-emitter and base-collector junctions are forward biased.

- **Condition**: The collector-emitter voltage $V_{CE}$ is small, and the transistor behaves like a closed switch.
- **Current Relations**:
    - $I_E$ reaches its maximum, and increasing $I_B$ does not significantly increase $I_E$ anymore.

**Cutoff Region:**

In the cutoff region, the transistor is fully off, and there is no current flow between the emitter and the collector.

- **Condition**: Both the base-emitter and base-collector junctions are reverse biased.
- **Current Relations**:
    - Both $I_B$ and $I_E$ are approximately zero.

## Example:

BJT in Common-Emitter Configuration Given:

- Supply Voltage $V_{CC}$ = 10V
- Collector Resistor $R_C$ = 1kΩ
- Base Resistor $R_B$ = 100kΩ
- Base Current $I_B$ = 20μA
- Current Gain $\beta$ = 100

**Calculate $I_C$, $V_{CE}$, $V_B$.**

**Sol:**

The collector current can be calculated using the formula:

$$I_C = \beta I_B$$

$$I_C = 100 \times 20 \times 10^{-6} = 2\ mA$$

Using Kirchhoff's Voltage Law (KVL) around the collector loop:

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

Rearranging gives:

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

$$V_{CE} = 10 - (2 \times 10^{-3} \times 1000) = 8\ Volt$$

Using Ohm's law to find the voltage at the base due to the base current:

$$V_B = I_B R_B$$

$$V_B = 20 \times 10^{-6} \times 100 \times 10^{3} = 2\ V$$

## Summary

1. BJT: An electronic device used for amplification or switching, Composed of three regions: Base, Collector, and Emitter.

2. Types of BJT: NPN: Uses N-type materials for Collector and Emitter, and P-type for Base. And PNP: Uses P-type materials for Collector and Emitter, and N-type for Base.

3. Active Region:
   - Acts as an amplifier.
   - Collector current depends on Base current.

4. Saturation Region:
   - Functions as a closed switch.
   - Collector-Emitter voltage is low.

5. Cutoff Region:
   - Functions as an open switch.
   - No current flows from Collector to Emitter.

6. Applications of BJT:
   - Amplifying electrical signals.
   - Used in digital switching circuits.
   - Building oscillators and amplifiers.

7. Considered a fundamental component in most electronic circuits due to its diverse properties.