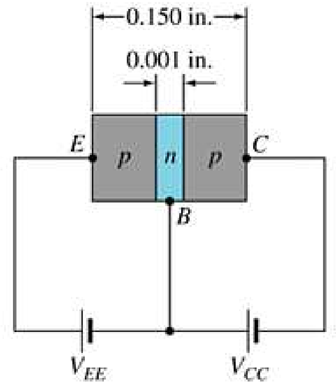
Module III

- Bipolar Junction Transistors:
  - Construction, Working and VI Characteristics of BJT
  - Input and Output Characteristics of CE configuration
  - Comparison of CE, CB and CC Configuration
  - Concept of Biasing and Load line
  - Transistor as a Switch
  - Transistor as an Amplifier (Circuit Diagram and Working)
  - RC Coupled Amplifier - Circuit Diagram and Frequency Response

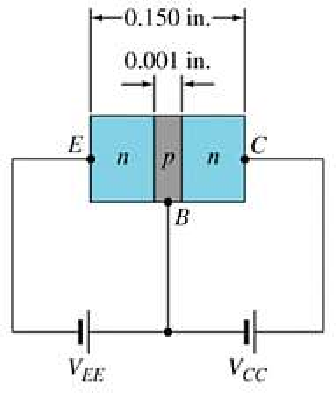
Transistor Construction

- There are two types of transistors:
  - *pnp*
  - *npn*
- The terminals are labeled:
  - E - Emitter
  - B - Base
  - C - Collector

pnp

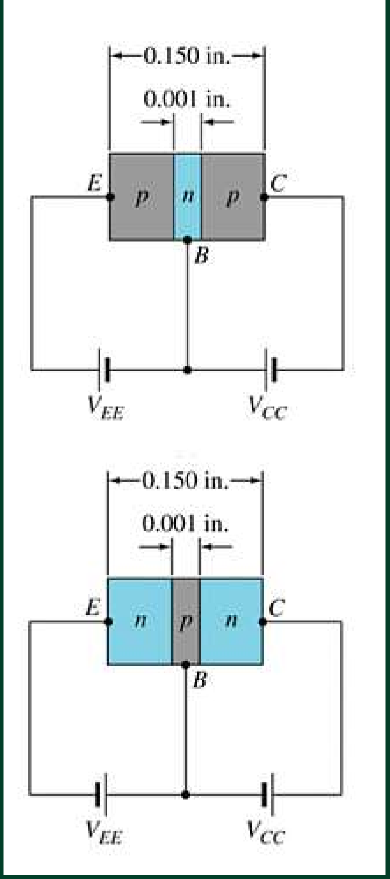


npn



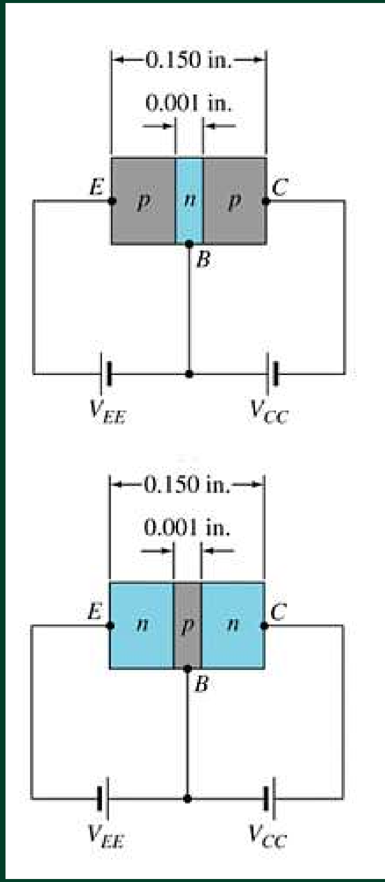
Transistor Construction

- A **Bipolar Junction Transistor (BJT)** is a semiconductor device composed of three regions of doped materials: the **Emitter (E)**, **Base (B)**, and **Collector (C)**.
- Its construction and operation are based on the interaction of two **PN junctions**, allowing it to amplify or switch electrical signals.
- **1. Basic Structure**
  - **Emitter (E):** Heavily doped to provide a large number of charge carriers. It emits carriers into the base.
  - **Base (B):** Thin and lightly doped. It controls the flow of carriers between the emitter and collector.
  - **Collector (C):** Moderately doped and larger in size compared to the emitter. It collects carriers from the emitter.



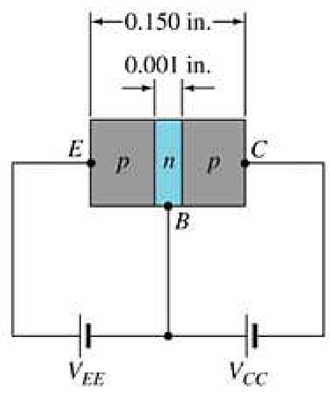
Transistor Construction

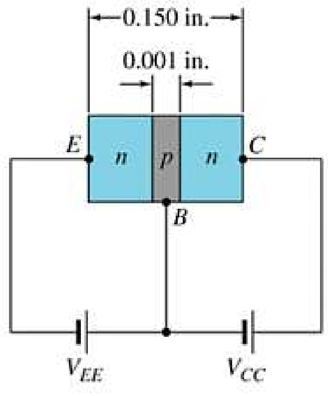
- **2. Types of BJT**
  - There are two types of BJTs, depending on the arrangement of the P-type and N-type regions:
  - **NPN Transistor:**
    - Layers: N-type (Emitter), P-type (Base), N-type (Collector)
    - Current flows from the collector to the emitter when the base is forward-biased.
  - **PNP Transistor:**
    - Layers: P-type (Emitter), N-type (Base), P-type (Collector)
    - Current flows from the emitter to the collector when the base is forward-biased.



Transistor Construction

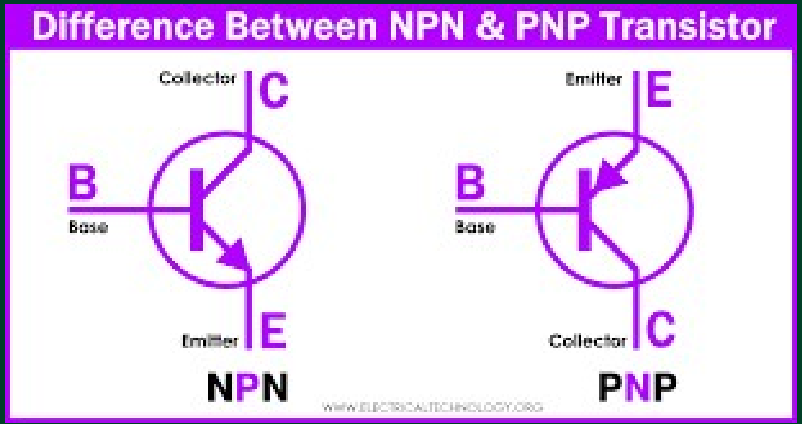
- **3. Layer Arrangement**
  - **Emitter:** The most heavily doped region to inject charge carriers efficiently.
  - **Base:** A very thin region to ensure most carriers from the emitter pass through to the collector.
  - **Collector:** A larger and moderately doped region to dissipate heat and handle high voltage.
- **4. Physical Representation**
  - **Semiconductor Material:** Typically made of silicon or, less commonly, gallium arsenide.
  - **Contacts:** Metal contacts are attached to each region (Emitter, Base, and Collector) for external circuit connections.
  - **Isolation:** The regions are isolated with insulation to prevent undesired current flow.

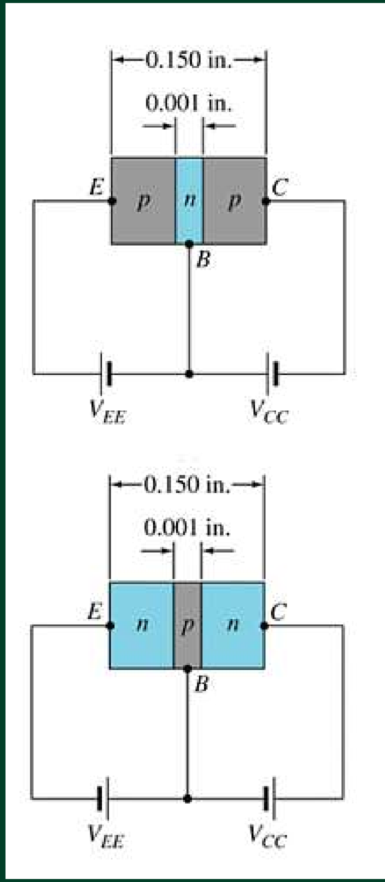




Transistor Construction

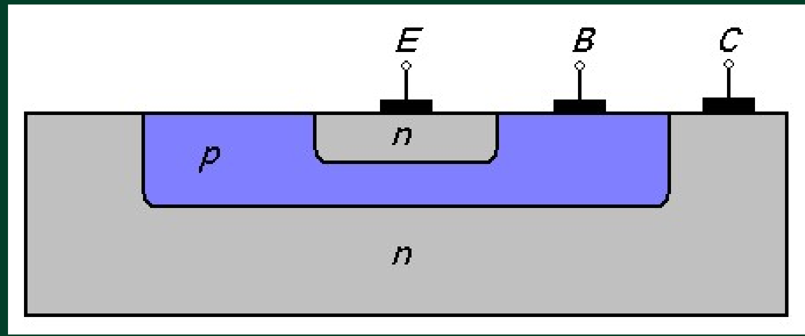
- **5. Symbol and Circuit Representation**
  - **NPN BJT Symbol:** The arrow on the emitter points outwards (indicating conventional current flow).
  - **PNP BJT Symbol:** The arrow on the emitter points inwards (indicating conventional current flow).

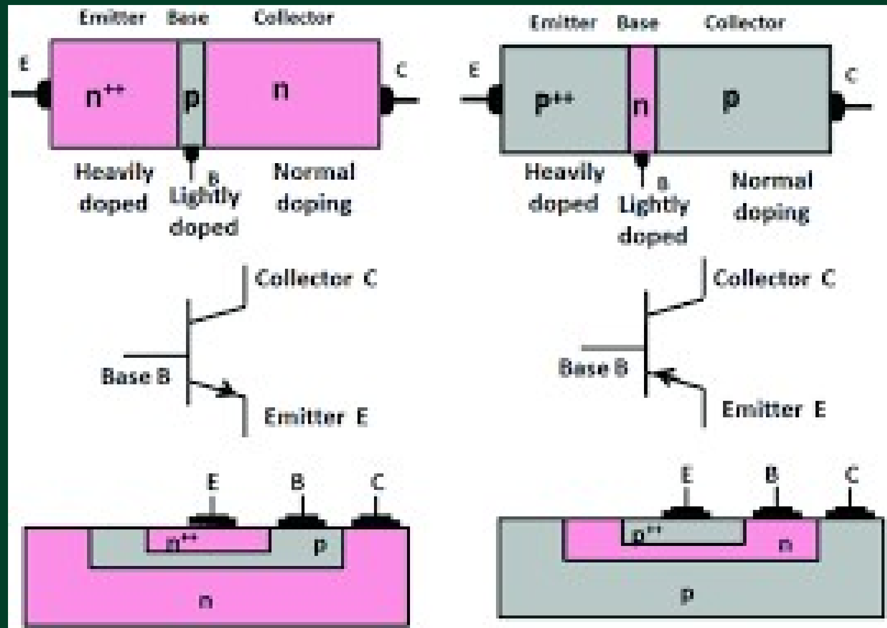




Transistor Construction

- **6. Cross-Section Diagram**
  - A cross-section diagram illustrates:
  - Two PN junctions: Emitter-Base and Base-Collector.
  - Thin base sandwiched between the emitter and collector.
  - Relative doping levels: $N_E > N_C > N_B$



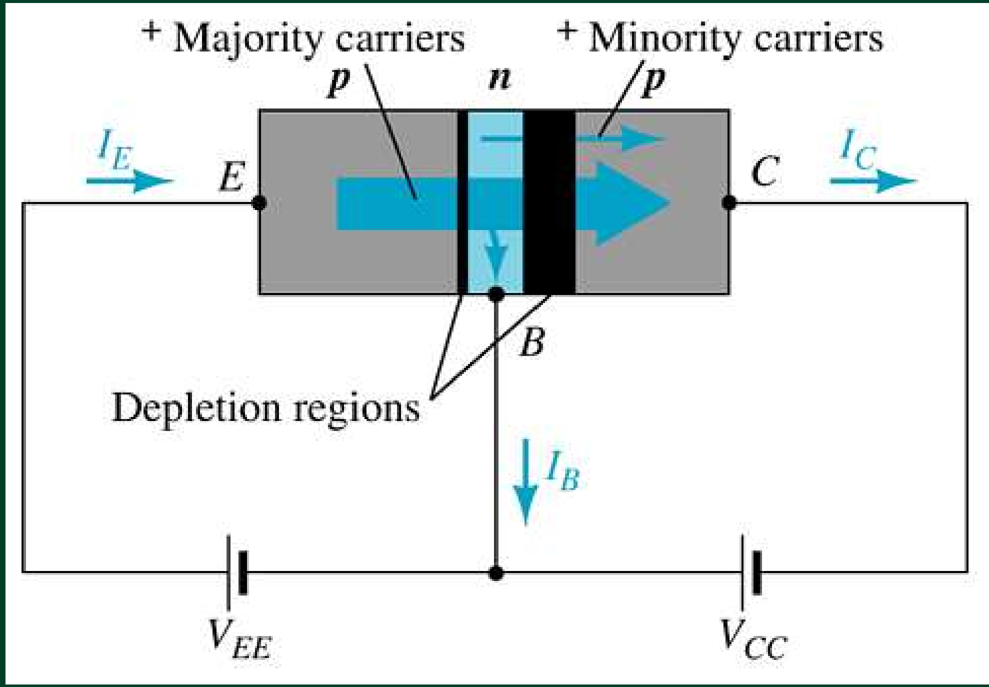


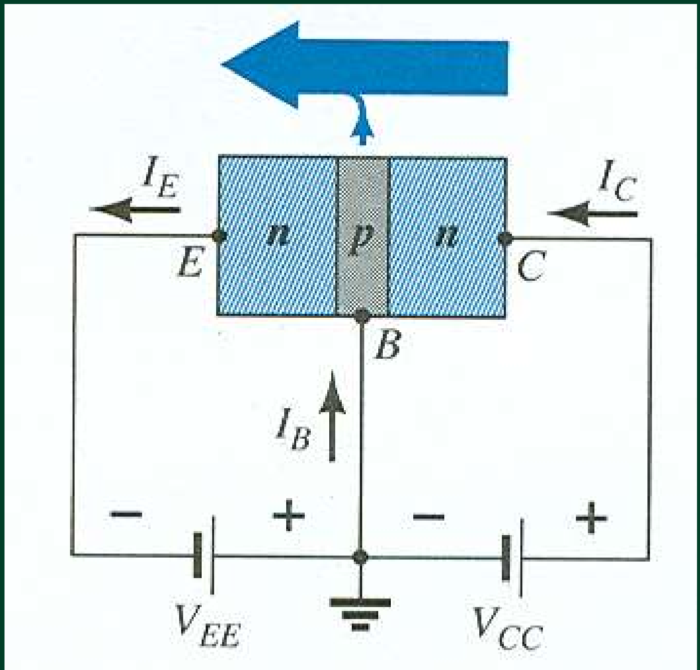
Modes of Operation

- The BJT can operate in four modes, depending on the biasing of the **Emitter-Base (EB)** and **Collector-Base (CB)** junctions:
  - Active Mode (Amplification):
    - EB junction: Forward-biased.
    - CB junction: Reverse-biased.
    - Used for amplification.
  - Saturation Mode (Switch ON):
    - Both EB and CB junctions: Forward-biased.
    - Used for switching.
  - Cutoff Mode (Switch OFF):
    - Both EB and CB junctions: Reverse-biased.
    - No current flows; acts as an open circuit.
  - Reverse Active Mode:
    - EB junction: Reverse-biased.
    - CB junction: Forward-biased.
    - Rarely used.

Transistor Operation

- With the external sources, V_{EE} and V_{CC}, connected as shown:
  - The emitter-base junction is forward biased
  - The base-collector junction is reverse biased

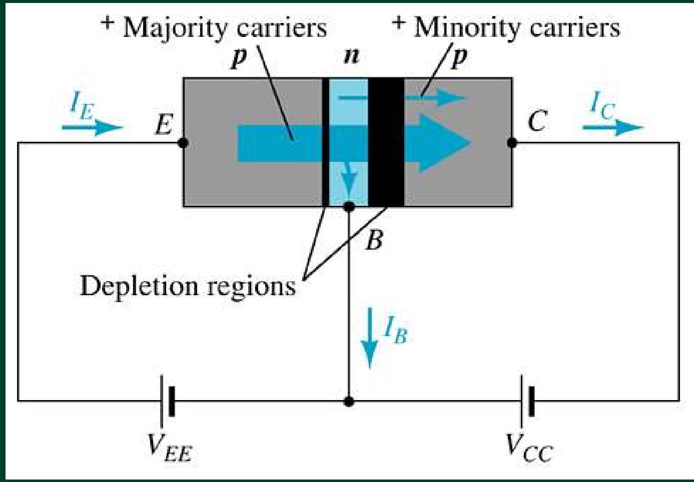


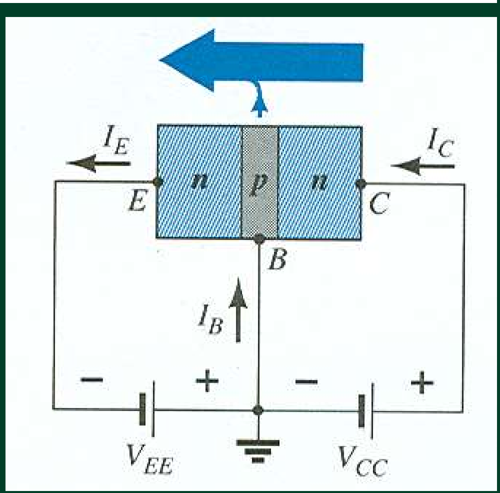


382 Transistor Operation

- In **active mode**, the BJT functions as a current amplifier. Here's how it works for an **NPN transistor** (the process is similar but reversed for a PNP transistor):

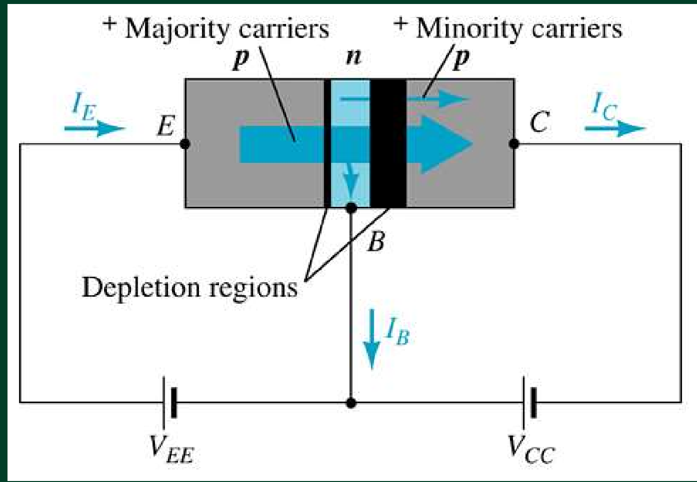
1. **Forward Biasing of Emitter-Base Junction:**
    1. A small forward voltage (V_{BE}) is applied between the base and emitter.
    2. This reduces the depletion region at the **EB junction**, allowing majority carriers (electrons in NPN) to flow from the emitter into the base.
2. **Base as a Thin Region:**
    1. The base is very thin and lightly doped, so only a small fraction of the carriers recombine in the base.
    2. Most electrons pass through the base and reach the collector.

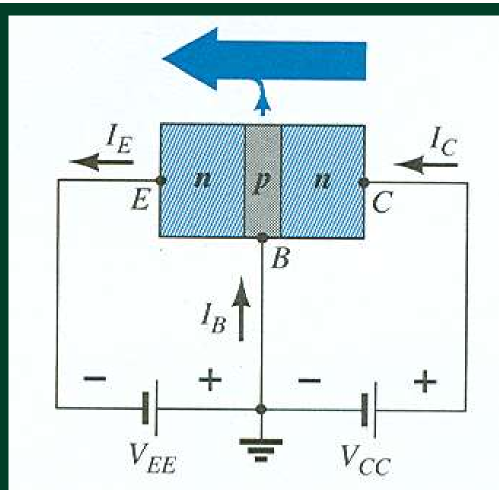




383 Transistor Operation

- Reverse Biasing of Collector-Base Junction:
  - A reverse voltage (V_{CE}) is applied between the collector and base.
  - This widens the CB junction depletion region, pulling electrons from the base into the collector.
- Current Flow:
  - The emitter injects a large number of electrons into the base.
  - A small fraction of electrons (I_B) recombine in the base.
  - The majority are collected by the collector, resulting in a large collector current (I_C).
  - The emitter current (I_E) is the sum of I_C and I_B:
  - $I_E = I_B + I_C$

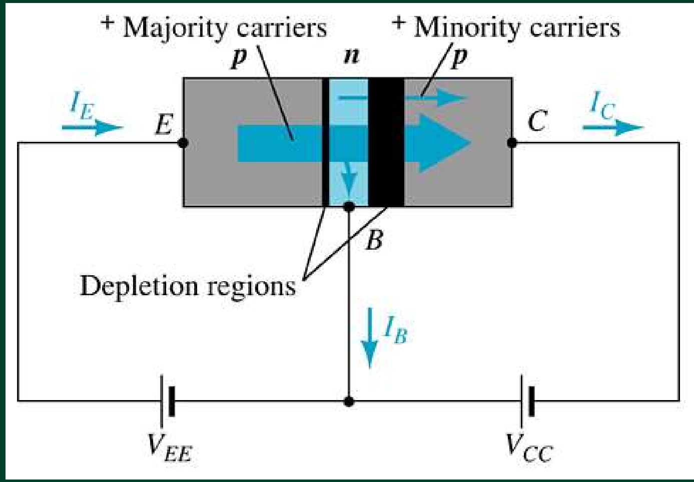




Transistor Operation

- **Amplification:**
  - A small base current (I_B) controls a much larger collector current (I_C).
  - Current gain (β) is the ratio of I_C to I_B:

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

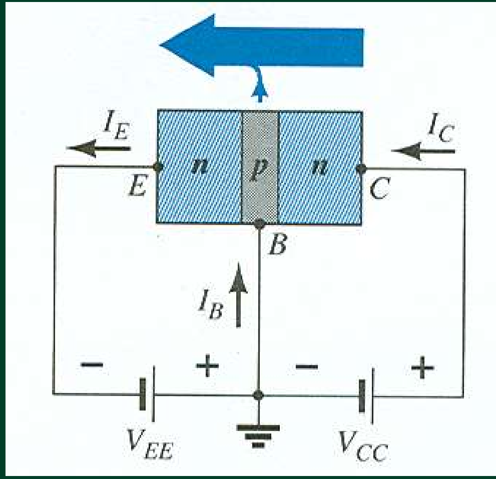


The **CB current gain** (α) is given by:

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

Where:

- I_C = Collector current (output current in CB configuration)
- I_E = Emitter current (input current in CB configuration)



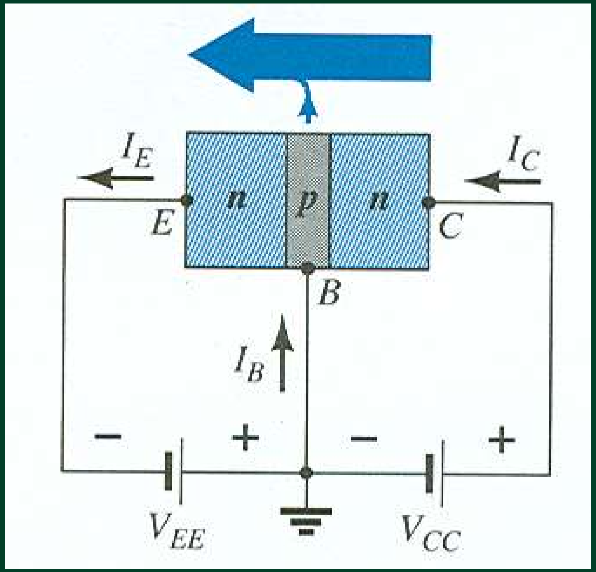
Currents in a Transistor

- **Emitter current is the sum of the collector and base currents:**

$$I_E = I_C + I_B$$

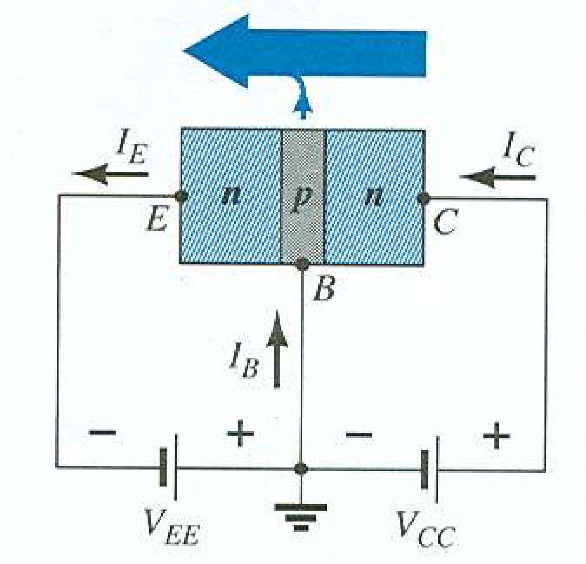
- **The collector current is comprised of two currents:**

$$I_C = I_{C_{majority}} + I_{CO_{minority}}$$



Currents in a Transistor

- **What is I_{CO} in an NPN Transistor?**
- In an NPN transistor, the collector-base junction is typically reverse-biased. A small reverse saturation current flows across this junction due to thermally generated minority carriers.
- **Minority carriers**:
  - In the **collector region**: Holes are the minority carriers in the N-type collector material.
  - In the **base region**: Electrons are the minority carriers in the P-type base material.
- I_{CO} is primarily influenced by:
  - The **quality of the material** (impurities and doping levels).
  - The **temperature** (it increases exponentially with temperature).



Currents in a Transistor

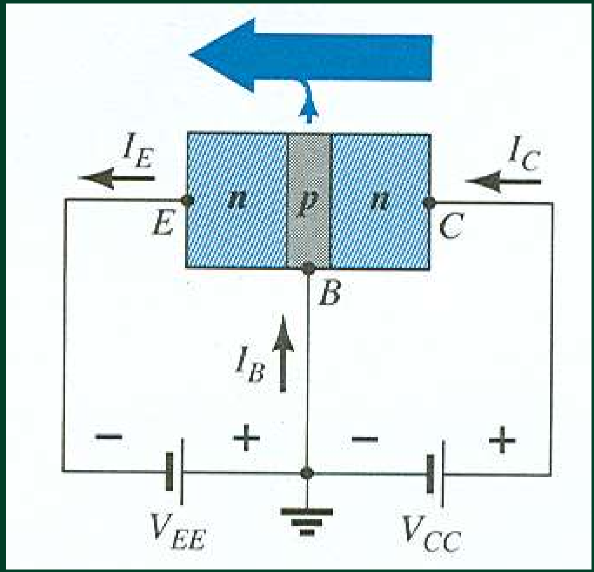
The total collector current in a transistor is given by:

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

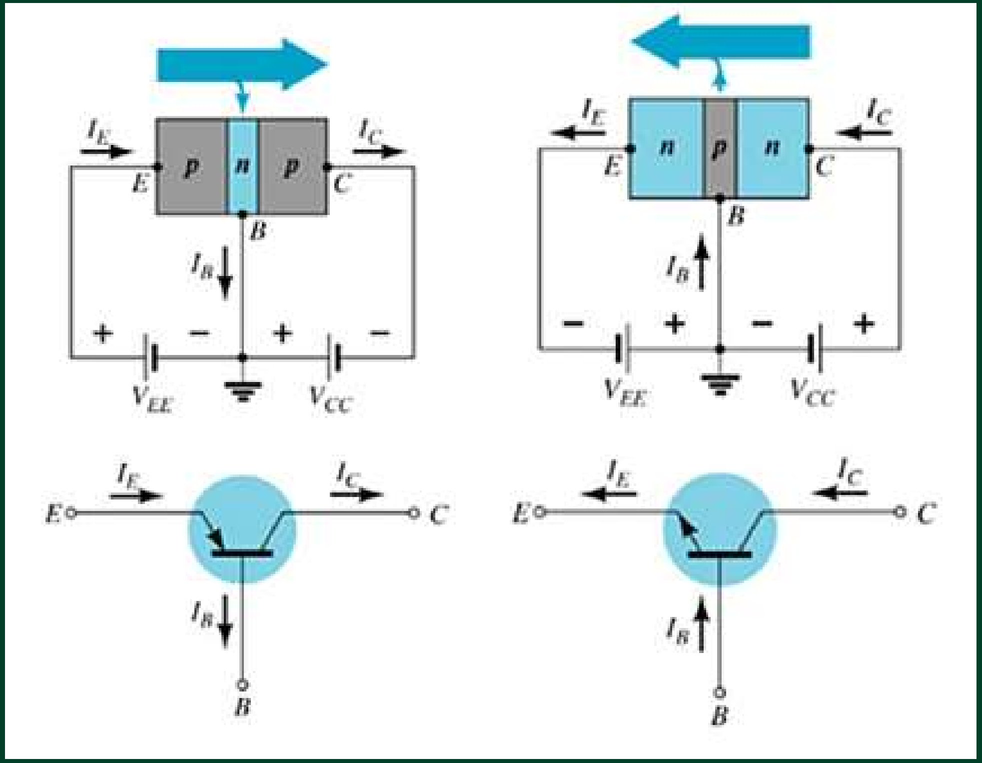
Where:

- β: Common-emitter current gain.
- I_B: Base current.

At low base currents, I_{CO} might become a significant portion of I_C.



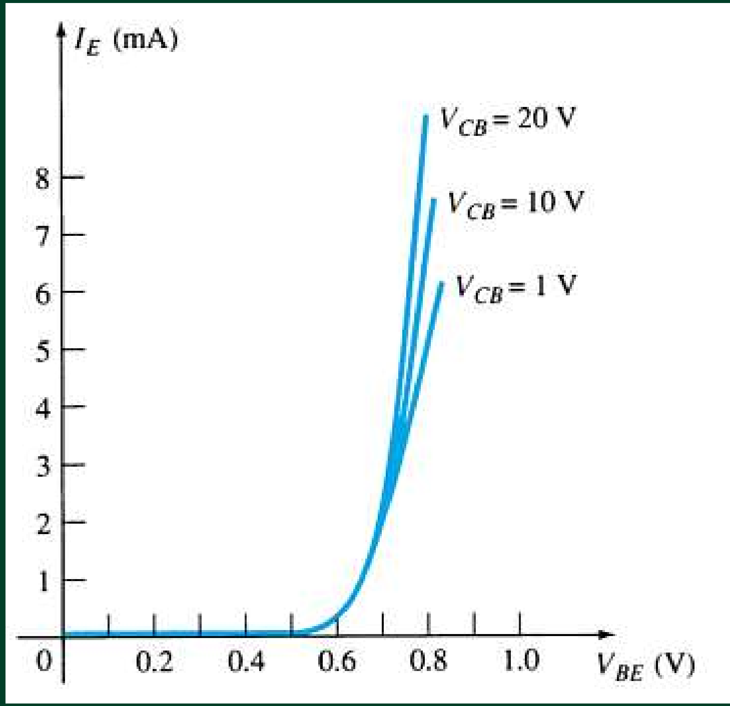
Common-Base Configuration



- **The base is common to both input (emitter–base) and output (collector–base) of the transistor.**

Common-Base Amplifier

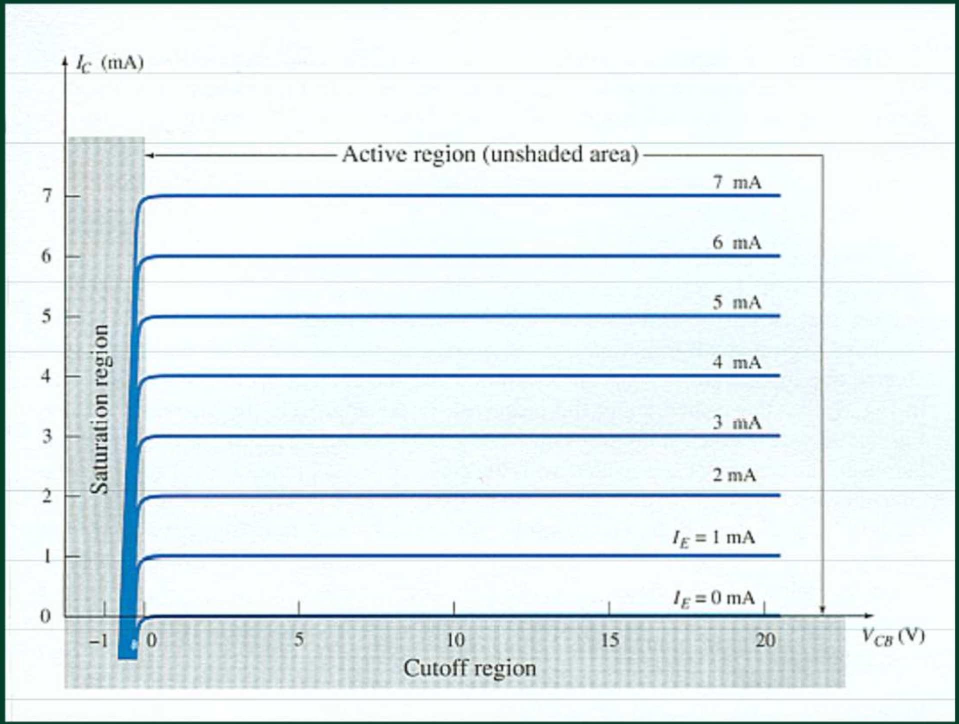
- Input Characteristics



- **This curve shows the relationship between of input current (I_E) to input voltage (V_{BE}) for three output voltage (V_{CB}) levels.**

Common-Base Amplifier

- Output Characteristics



- **This graph demonstrates the output current (I_C) to an output voltage (V_{CB}) for various levels of input current (I_E).**

Operating Regions

- **Active – Operating range of the amplifier.**
- **Cutoff – The amplifier is basically off. There is voltage, but little current.**
- **Saturation – The amplifier is full on. There is current, but little voltage.**

Approximations

- **Emitter and collector currents:**

$$I_C \cong I_E$$

- **Base-emitter voltage:**

$$V_{BE} = 0.7\ \mathrm{V}\ \ (\text{for Silicon})$$

Alpha (α)

Alpha (α) is the ratio of I_C to I_E :

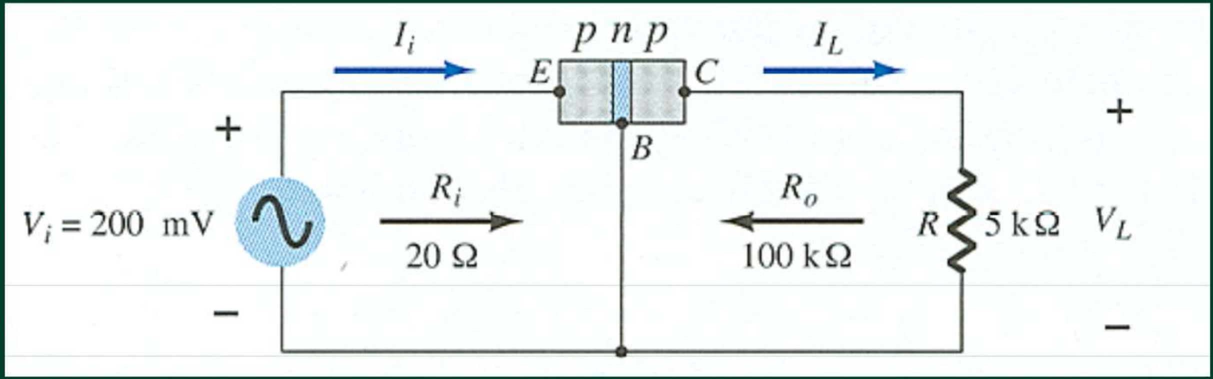
$$\alpha_{dc} = \frac{I_C}{I_E}$$

Ideally: $\alpha = 1$
In reality: α is between 0.9 and 0.998

Alpha (α) in the AC mode:

$$\alpha_{ac} = \frac{\Delta I_C}{\Delta I_E}$$

Transistor Amplification



Currents and Voltages:

$$I_E = I_i = \frac{V_i}{R_i} = \frac{200\text{mV}}{20\Omega} = 10\text{mA}$$

$$I_C \cong I_E$$

$$I_L \cong I_i = 10\text{ mA}$$

$$V_L = I_L R = (10\text{ ma})(5\text{ k}\Omega) = 50\text{ V}$$

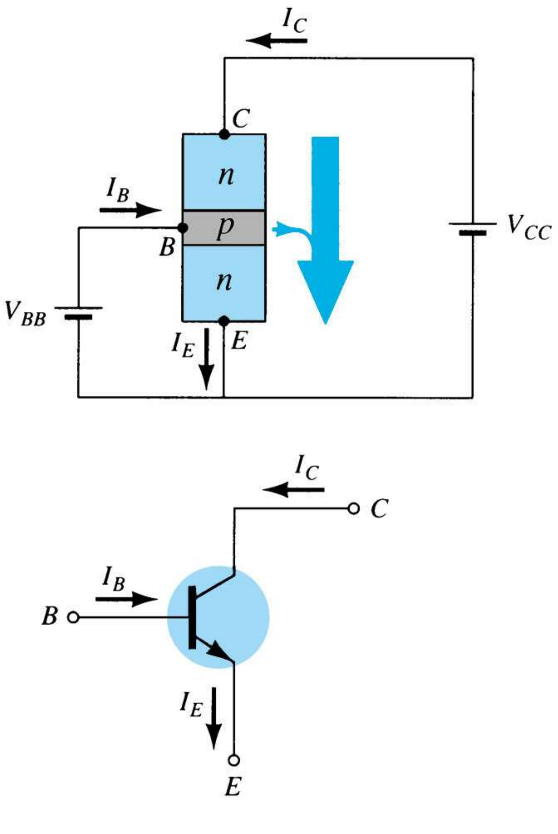
Voltage Gain:

$$A_v = \frac{V_L}{V_i} = \frac{50\text{V}}{200\text{mV}} = 250$$

Common–Emitter Configuration

- The emitter is common to both input (base-emitter) and output (collector-emitter).

- The input is on the base and the output is on the collector.



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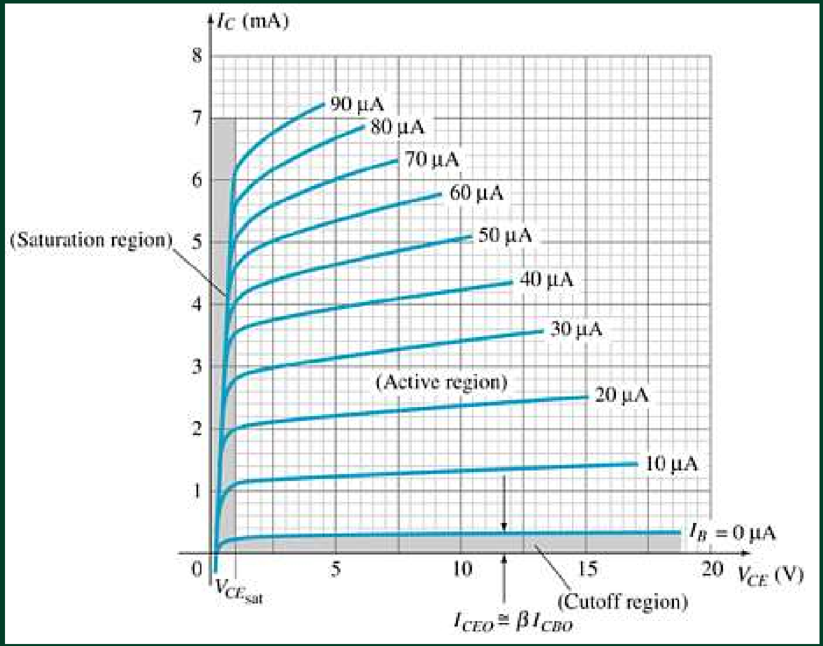
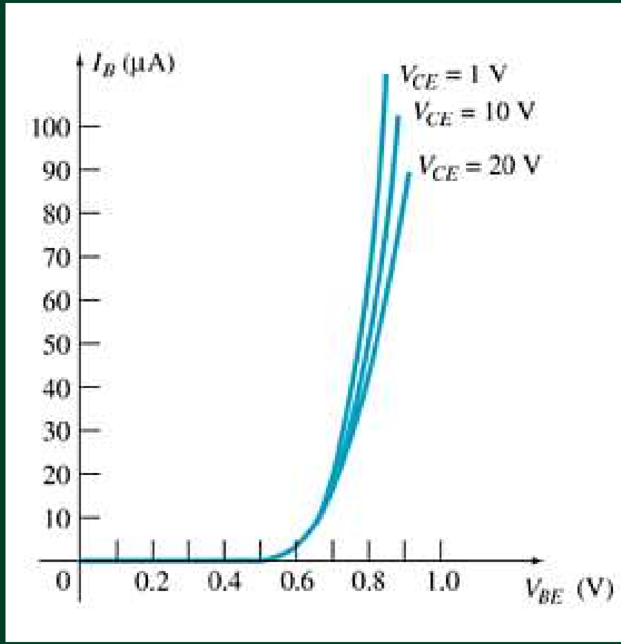
Common-Emitter Characteristics



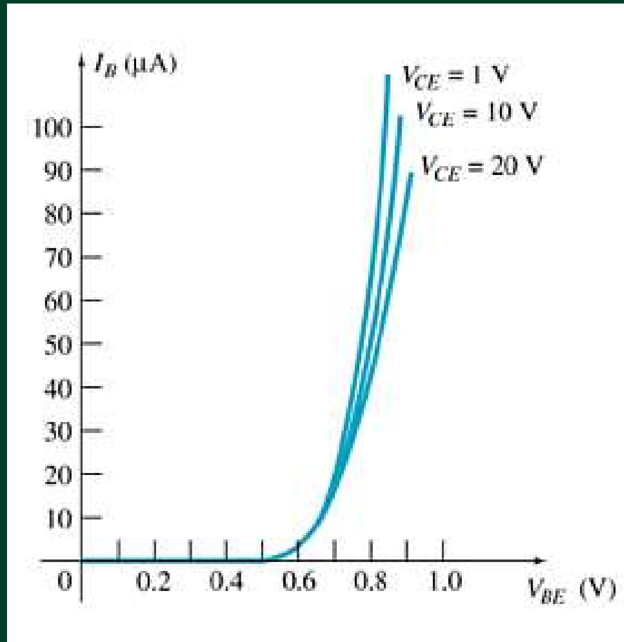
Output / Collector Characteristics



Input / Base Characteristics

Common-Emitter Characteristics

- In the common-base configuration, the emitter current directly controls the collector current, and with I_E=0, there's no driving current for the collector.
- In the common-emitter configuration, the base current serves as the controlling input, and even a small base current can lead to a nonzero collector current.



Output / Collector Characteristics

Input / Base Characteristics

Common-Emitter Amplifier Currents

Ideal Currents

$$I_E = I_C + I_B \qquad I_C = \alpha I_E$$

Actual Currents

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

where I_{CBO} = minority collector current

I_{CBO} is usually so small that it can be ignored, except in high power transistors and in high temperature environments.

When $I_B = 0\ \mu A$ the transistor is in cutoff, but there is some minority current flowing called I_{CEO}.

$$I_{CEO} = \left.\frac{I_{CBO}}{1-\alpha}\right|_{I_B = 0\,\mu A}$$

Beta (β)

- β represents the amplification factor of a transistor. (β is sometimes referred to as h_{fe}, a term used in transistor modeling calculations)

In DC mode:

$$\beta_{\mathrm{dc}} = \frac{I_C}{I_B}$$

In AC mode:

$$\beta_{\mathrm{ac}} = \left.\frac{\Delta I_C}{\Delta I_B}\right|_{V_{CE}=\mathrm{constant}}$$

Beta (β)

Determining β from a Graph

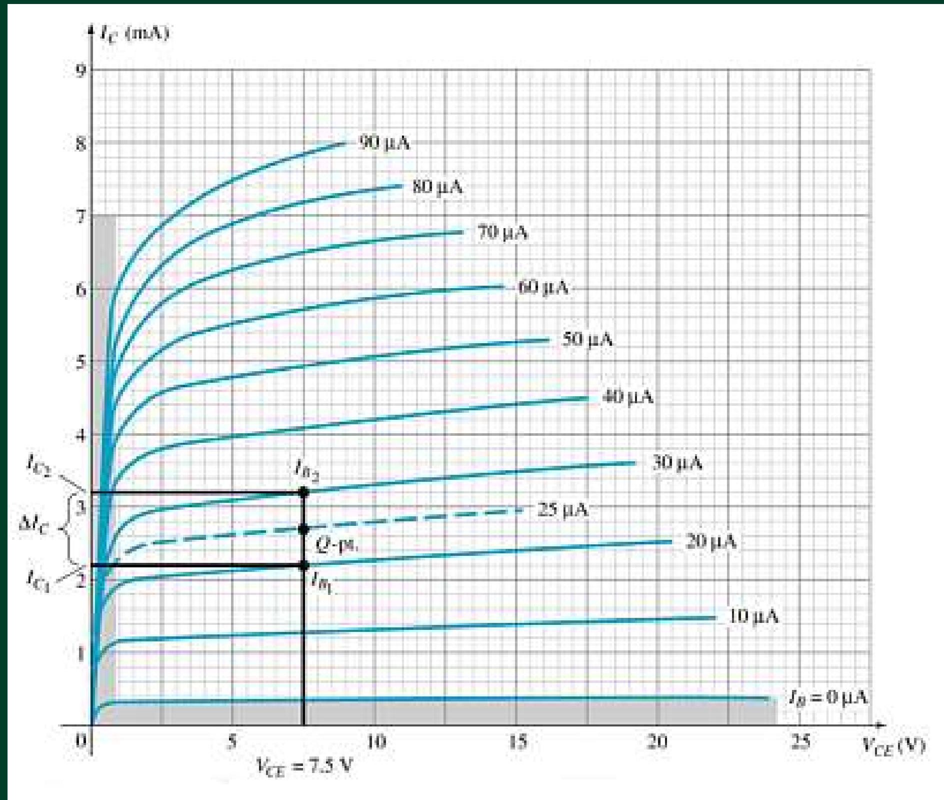
$$\beta_{AC} = \frac{(3.2\,\mathrm{mA} - 2.2\,\mathrm{mA})}{(30\,\mu\mathrm{A} - 20\,\mu\mathrm{A})}$$

$$= \frac{1\,\mathrm{mA}}{10\,\mu\mathrm{A}}\bigg|_{V_{CE}=7.5}$$

$$= 100$$

$$\beta_{DC} = \frac{2.7\ \mathrm{mA}}{25\ \mu\mathrm{A}}\bigg|_{V_{CE}=7.5}$$

$$= 108$$



Beta (β)

Relationship between amplification factors β and α

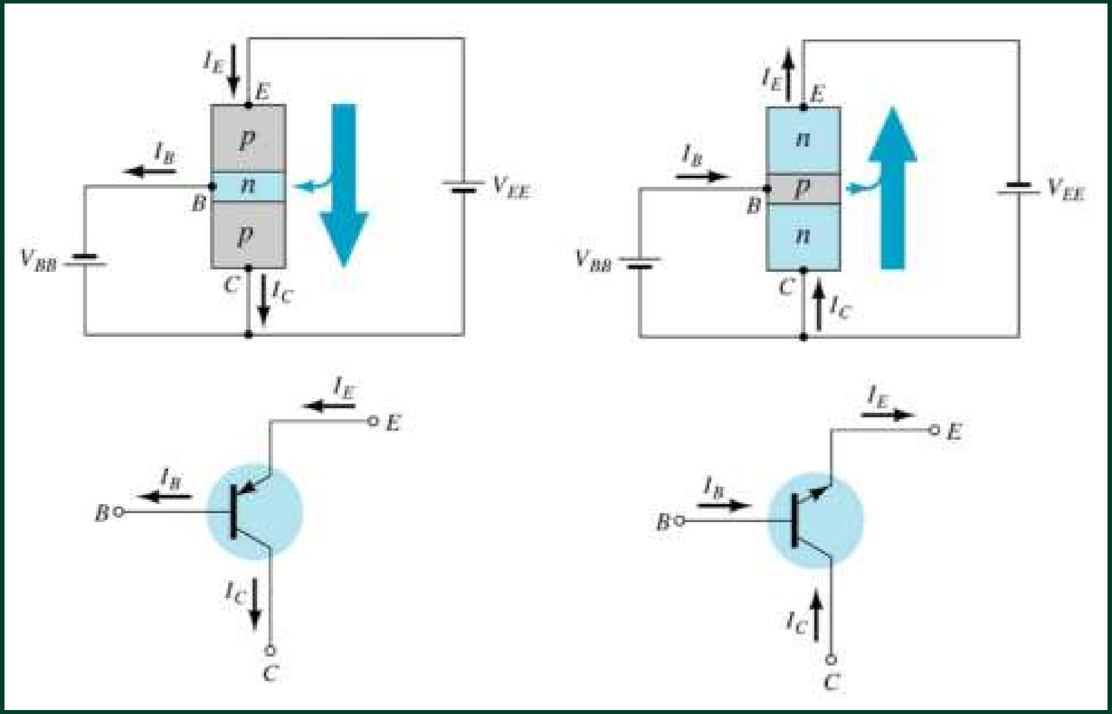
$$\alpha = \frac{\beta}{\beta + 1} \qquad \beta = \frac{\alpha}{\alpha - 1}$$

Relationship Between Currents

$$I_C = \beta I_B \qquad I_E = (\beta + 1) I_B$$

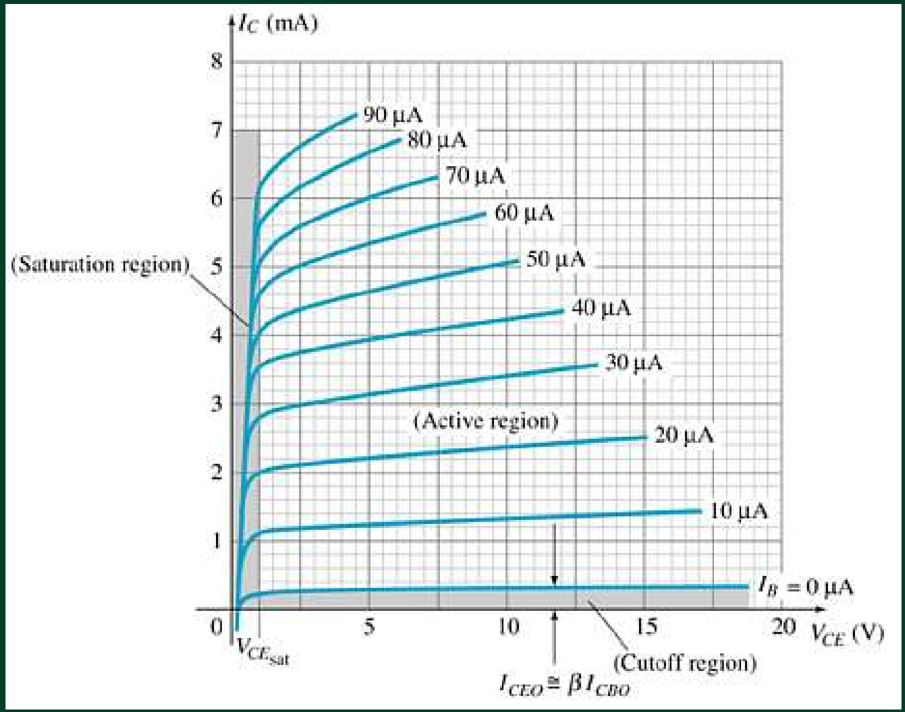
Common–Collector Configuration

- The input is on the base and the output is on the emitter.



Common–Collector Configuration

- The characteristics are
- similar to those of the
- common-emitter configuration,
- except the vertical axis is I_E.



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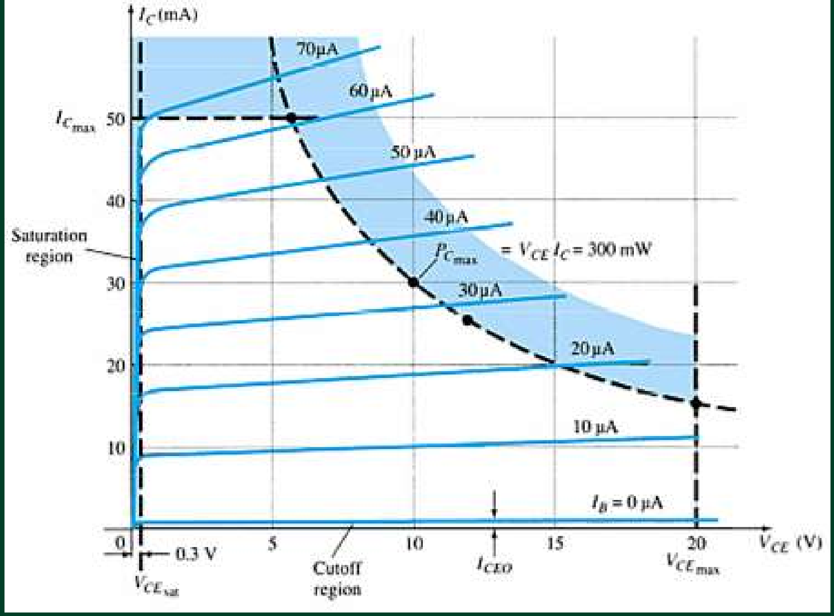
Operating Limits for Each Configuration

- V_{CE} is at maximum and I_C is at minimum ($I_{Cmax} = I_{CEO}$) in the cutoff region.
- I_C is at maximum and V_{CE} is at minimum ($V_{CE\,max} = V_{CEsat} = V_{CEO}$) in the saturation region.
- The transistor operates in the active region between saturation and cutoff.



Power Dissipation

Common-base:

$$P_{Cmax} = V_{CB} I_C$$

Common-emitter:

$$P_{Cmax} = V_{CE} I_C$$

Common-collector:

$$P_{Cmax} = V_{CE} I_E$$

Comparison between CE, CB and CC Configuration

Parameter	Common Emitter (CE)	Common Base (CB)	Common Collector (CC)
Common Terminal	Emitter	Base	Collector
Input Terminal	Base	Emitter	Base
Output Terminal	Collector	Collector	Emitter
Voltage Gain (A_v)	High	Very High	Less than 1
Current Gain (A_i)	Moderate (β)	Less than 1	High ($1+\beta$)
Power Gain	High	Moderate	Moderate
Input Impedance	Moderate (~1kΩ)	Low (~50Ω)	High (~100kΩ)
Output Impedance	High (~50kΩ)	Very High (~500kΩ)	Low (~100Ω)
Phase Relationship	180° phase shift (inverted output)	No phase shift	No phase shift
Applications	Amplifiers (general purpose)	RF amplifiers, impedance matching	Voltage buffers
Signal Handling	Good balance of voltage & current	Voltage amplification only	Current amplification only