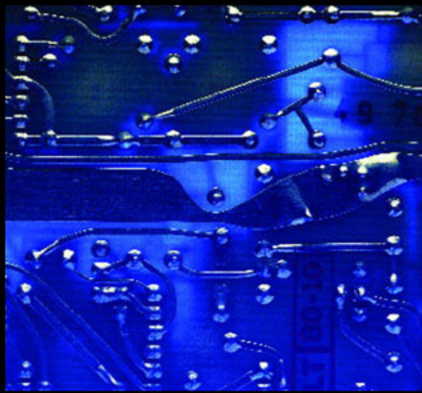
Electronic Devices and Circuit Theory

Tenth Edition

Boylestad



Pearson

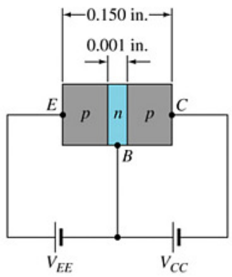
Chapter 3:
Bipolar Junction Transistors

Transistor Construction

There are two types of transistors:

- *pnp*
- *npn*

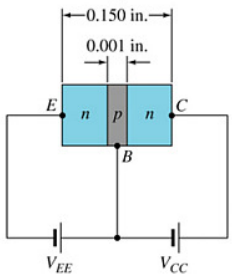
pnp



The terminals are labeled:

- E - Emitter
- B - Base
- C - Collector

npn



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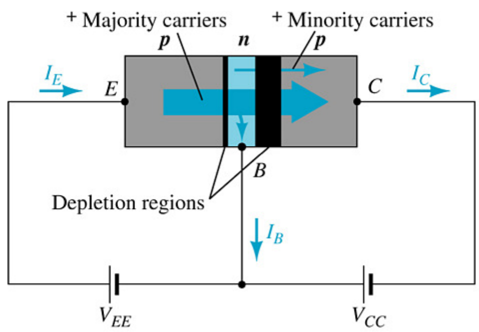
Transistor Operation

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



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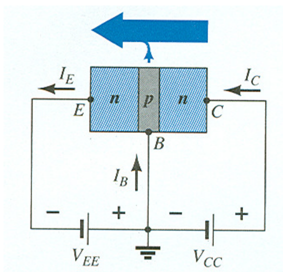
Currents in a Transistor

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:

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



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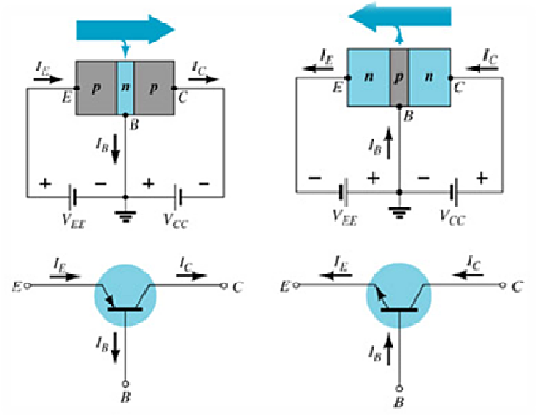
Common-Base Configuration



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

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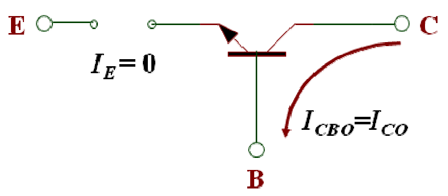
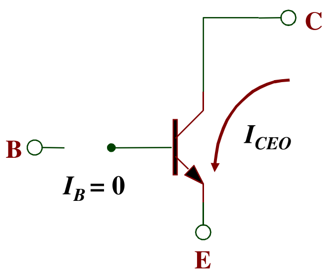


Reverse saturation current

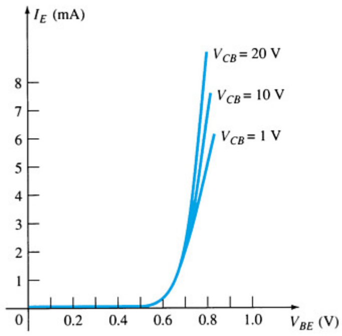


Circuit conditions related to I_{CEO} .

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.



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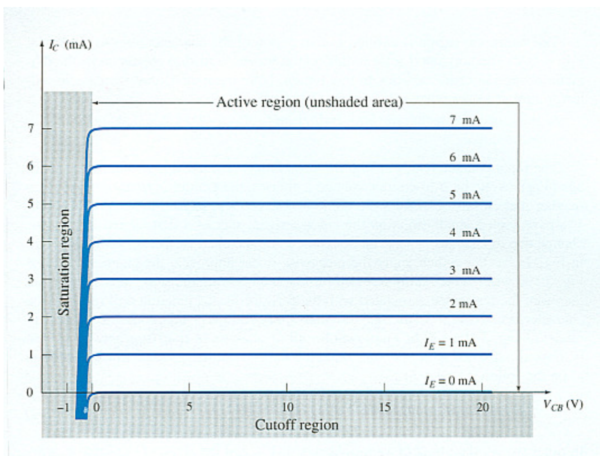
Common-Base Amplifier

Output Characteristics

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



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Operating Regions

- **Active – Operating range of the amplifier.** ***In the active-region the base-emitter junction is forward-biased, whereas the collector-base junction is reverse-biased.***

- **Cutoff – The amplifier is basically off. There is voltage, but little current.** ***In the cutoff region the base-emitter and collector-base junctions of a transistor are both reverse-biased.***

- **Saturation – The amplifier is full on. There is current, but little voltage.** ***In the saturation region the base-emitter and collector-base junctions are forward-biased.***

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Approximations

Emitter and collector currents:

$$I_C \cong I_E \quad \text{(in the active region)}$$

Base-emitter voltage:

$$V_{BE} = 0.7\ \text{V} \quad \text{(for Silicon)} \quad \text{(also transistor "on" state voltage)}$$

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

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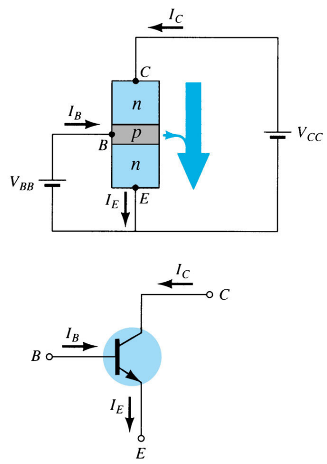
Common–Emitter Configuration

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.



(a)

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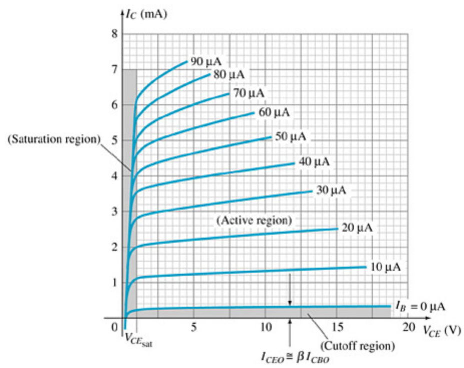
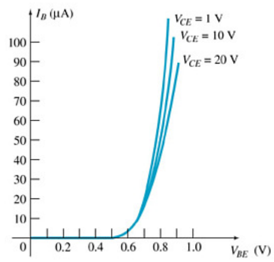
Common-Emitter Characteristics



Collector Characteristics



Base Characteristics

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Operating Regions

- Active – **Operating range of the amplifier.** *In the active-region of a common-emitter amplifier, the base-emitter junction is forward-biased, whereas the collector-base junction is reverse-biased.*
- Cutoff – **The cutoff region for the common-emitter configuration is not well defined as for the common-base configuration. Note on the collector characteristics of the figure on the previous slide that I_C is not equal to zero when I_B is zero.** *For linear amplification purposes, cutoff for the common-emitter configuration will be defined by $I_C = I_{CEO}$.*
- **When employed as a switch in the logic circuitry, a transistor will have two points of operation of interest: one in the cutoff and one in the saturation region. The cutoff condition should ideally be I_C = 0mA for the chosen V_{CE} voltage. Since I_{CEO} is typically low in magnitude for silicon materials,** *cutoff will exist for switching purposes when $I_B = 0\mu A$ or $I_C = I_{CEO}$ for silicon transistors only. For germanium transistors, however, cutoff for switching purposes will be defined as those conditions that exist when $I_C = I_{CBO}$.* **This condition can be obtained for germanium transistors by reverse-biasing the base-to-emitter junction a few tenths of a volt.**

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Common-Emitter Amplifier Currents

Ideal Currents

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

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 µA the transistor is in cutoff, but there is some minority current flowing called I_{CEO}.

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

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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:

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

Relationship between amplification factors β and α

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

Relationship Between Currents

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

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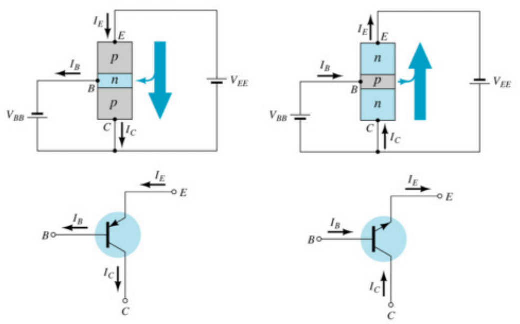
Common–Collector Configuration

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



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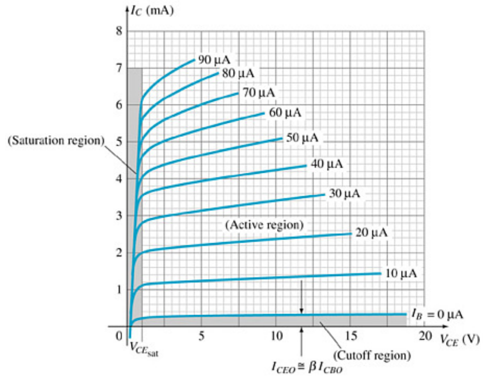
Common–Collector Configuration

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

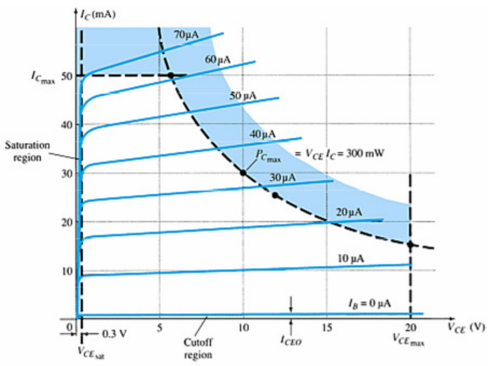


Operating Limits for Each Configuration

The *cutoff* region is defined as that region below $I_C = I_{CEO}$. V_{CE} is at maximum and I_C is at minimum ($I_{Cmax} = I_{CEO}$) in the cutoff region.

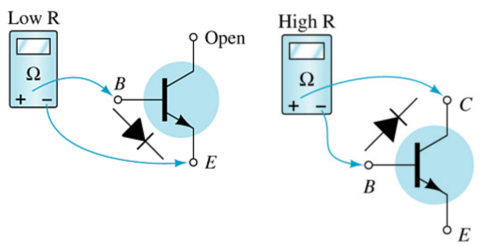
I_C is at maximum and V_{CE} is at minimum ($V_{CE\,max} = V_{CEsat} = V_{CEO}$) in the saturation region.

The transistor operates in the active region between saturation and cutoff.



Transistor Testing

- **Curve Tracer**
  Provides a graph of the characteristic curves.
- **DMM**
  Some DMMs measure β_{DC} or h_{FE}.
- **Ohmmeter**



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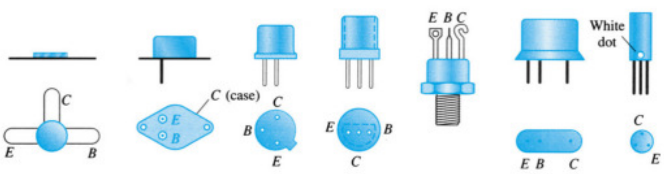
Transistor Terminal Identification



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