Chapter 3:
Bipolar Junction Transistors

3.2 Transistor Construction

There are two types of transistors:

- ***pnp***
- ***npn***

The terminals are labeled:

- **E – Emitter**
- **B – Base**
- **C – Collector**

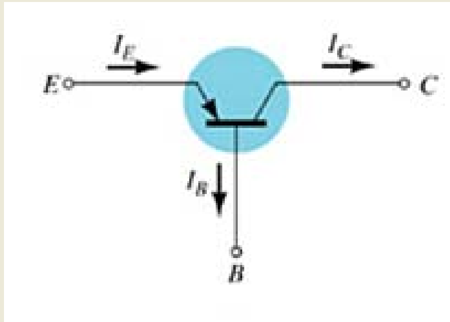
Features of each doped region:

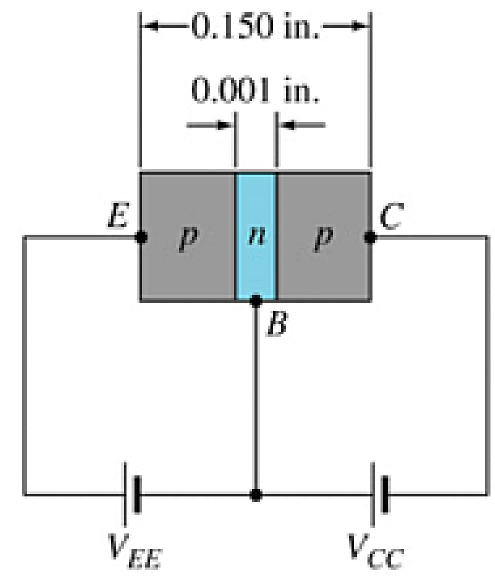
- **E – Highly doped**
- **B – Very narrow, lowest doped**
- **C – lower doped, large surface**

There are two pn junctions:

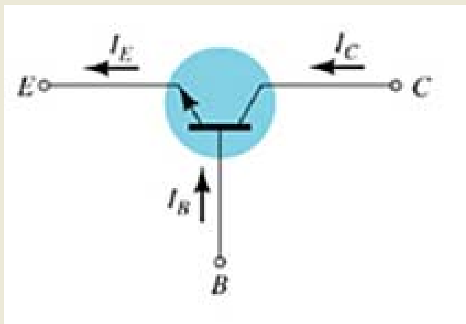
- **Base-Emitter junction**
- **Base-Collector junction**

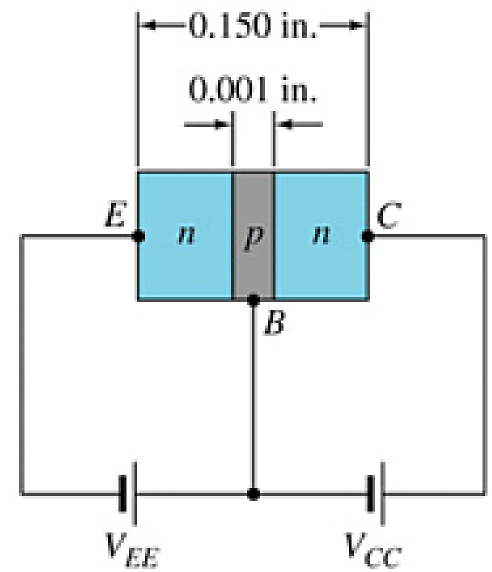
pnp





npn





3.3 Transistor Operation

There four operation modes depending on the bias condition of each pn junction:

	Emitter-Base junction	Base-Collector junction
Active operation (linear amplification)	Forward bias	Reverse bias
Saturation region	Forward bias	Forward bias
Cutoff region	Reverse bias	Reverse bias
Reverse operation	Reverse bias	Forward bias

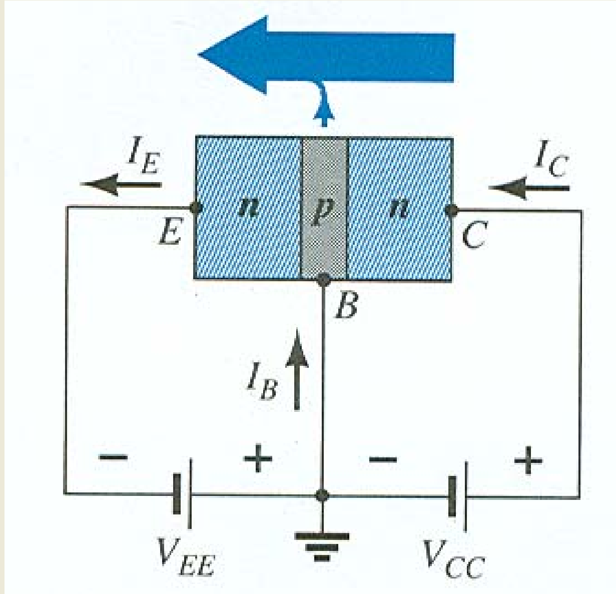
The active operation region is normally employed for linear (undistorted) amplifiers.

Currents in a Transistor

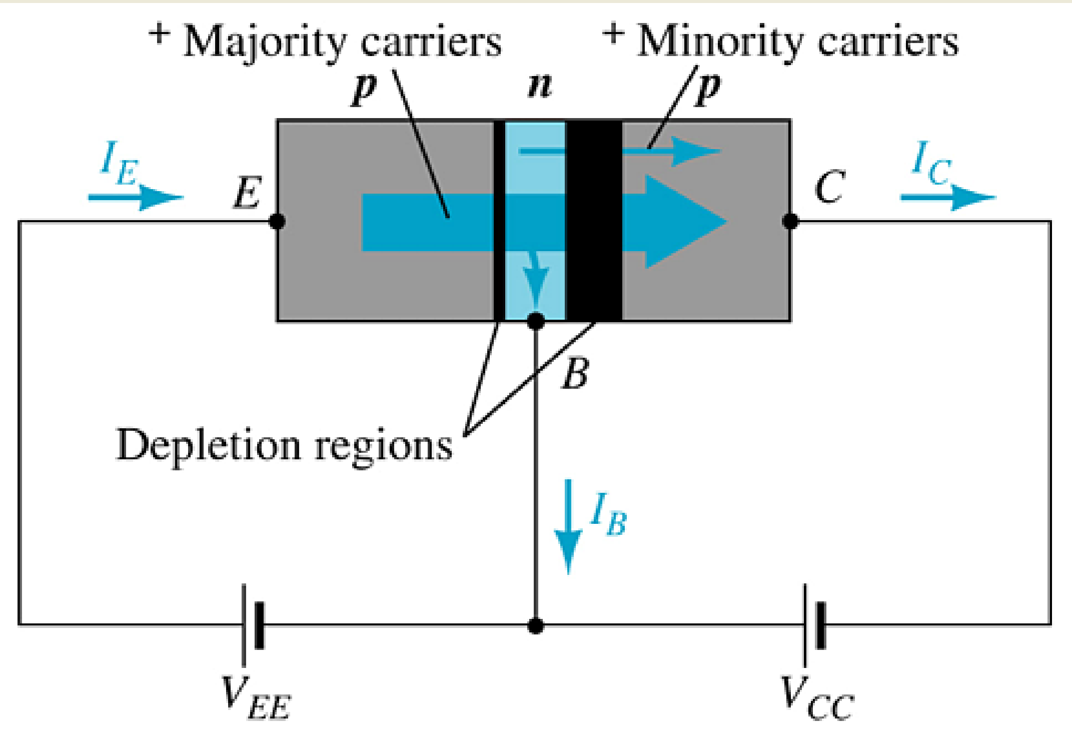
With the external sources, V_{EE} and V_{CC}, connected as shown below:

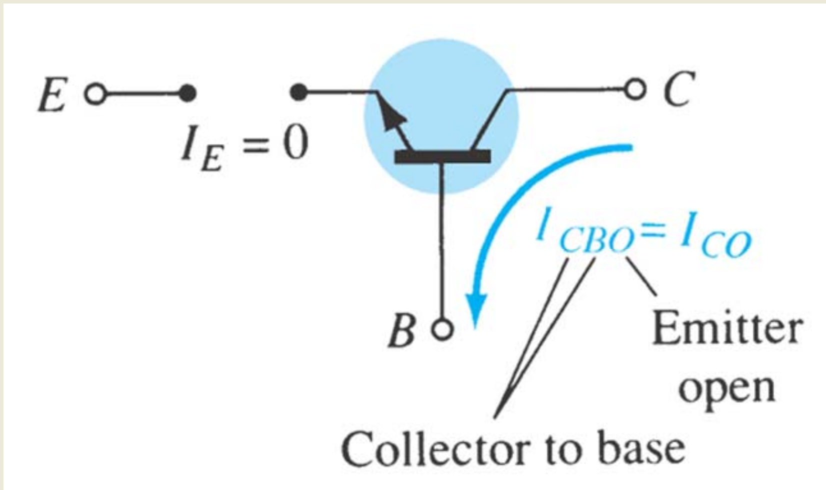
- **The emitter-base junction is forward biased**
- **The base-collector junction is reverse biased**

NPN



PNP





$$I_C = I_{C\,majority} + I_{CO\,minority}$$

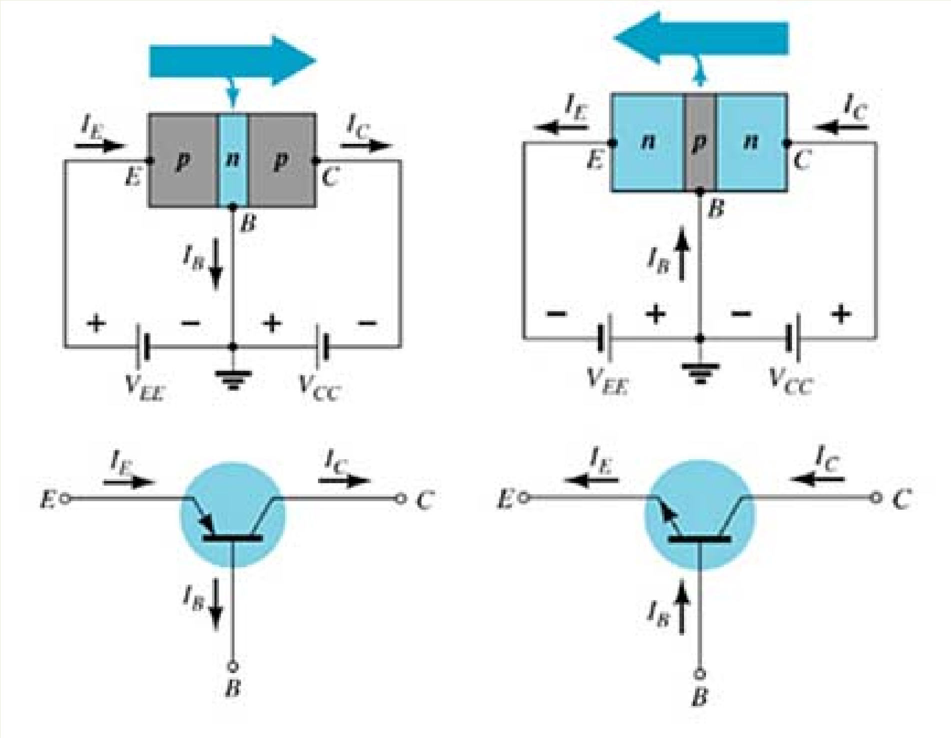
$$I_{CO\,minority} = I_{CBO}$$

3.4 Common-Base Configuration

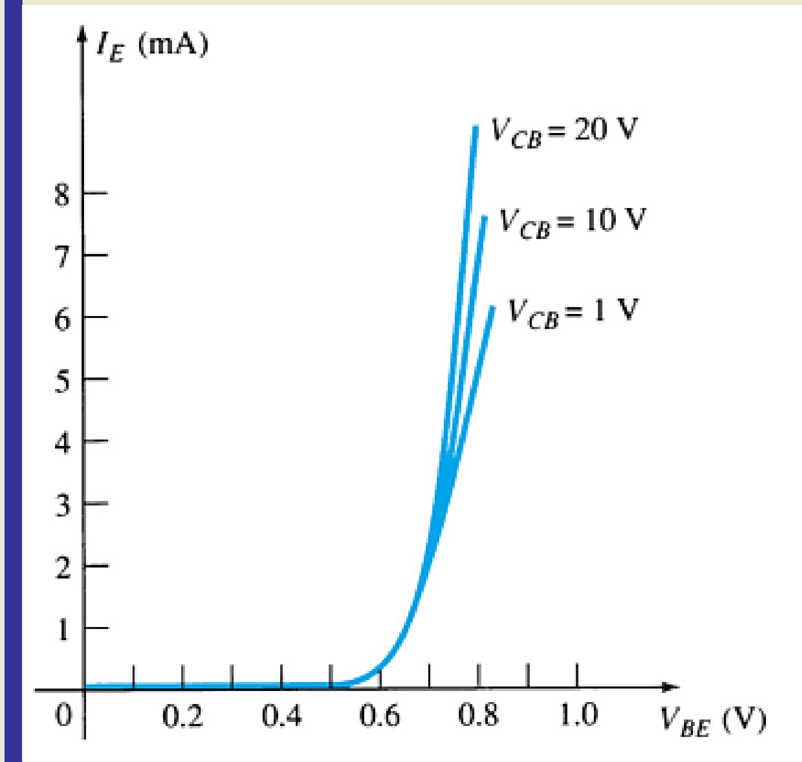
Three basic configurations of a BJT according to the common terminal:

	Input terminal	Common terminal	Output terminal
Common-Base (CB)	Emitter	Base	Collector
Common-Emitter (CE)	Base	Emitter	Collector
Common-Collector (CC)	Base	Collector	Emitter

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



Common-Base Amplifier

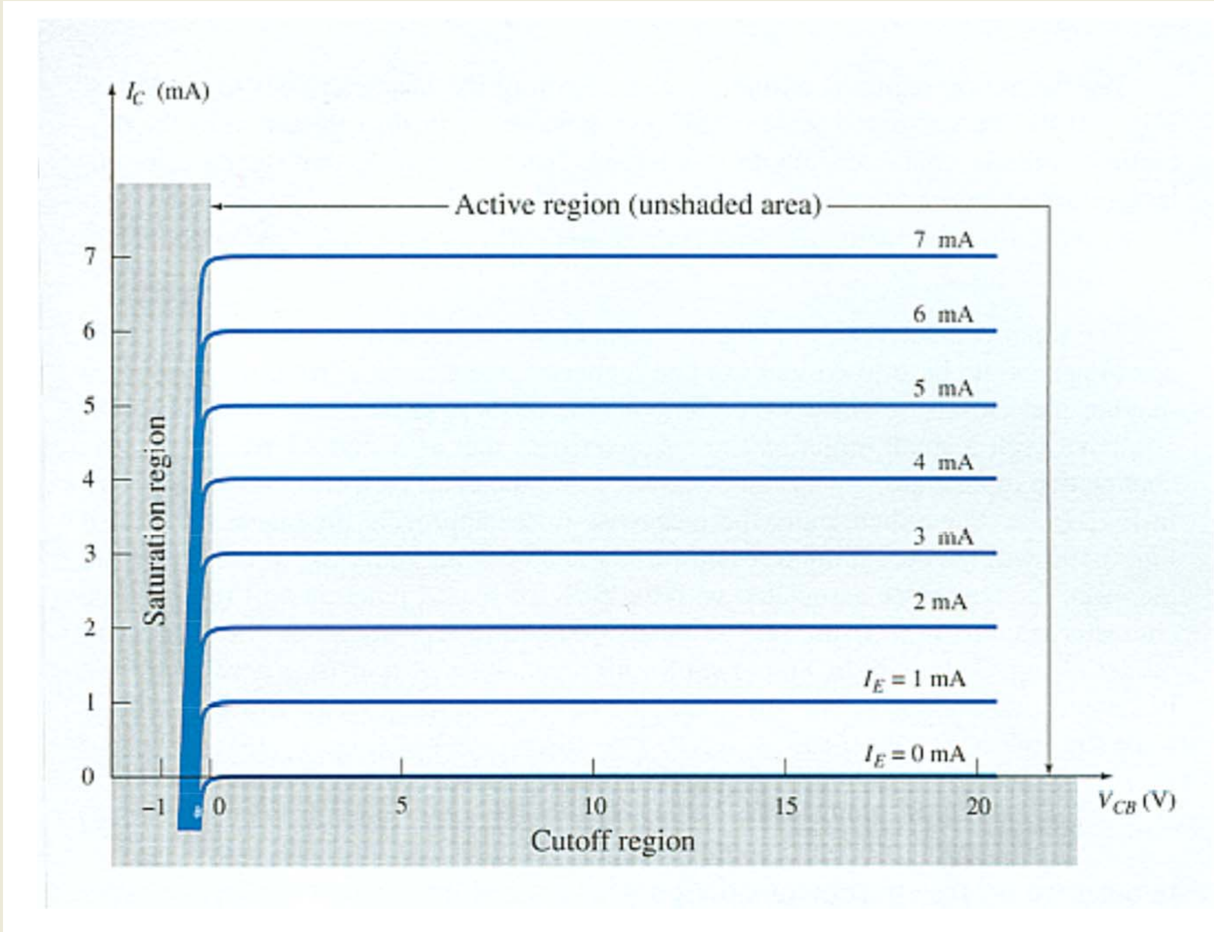


Input Characteristics

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

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

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

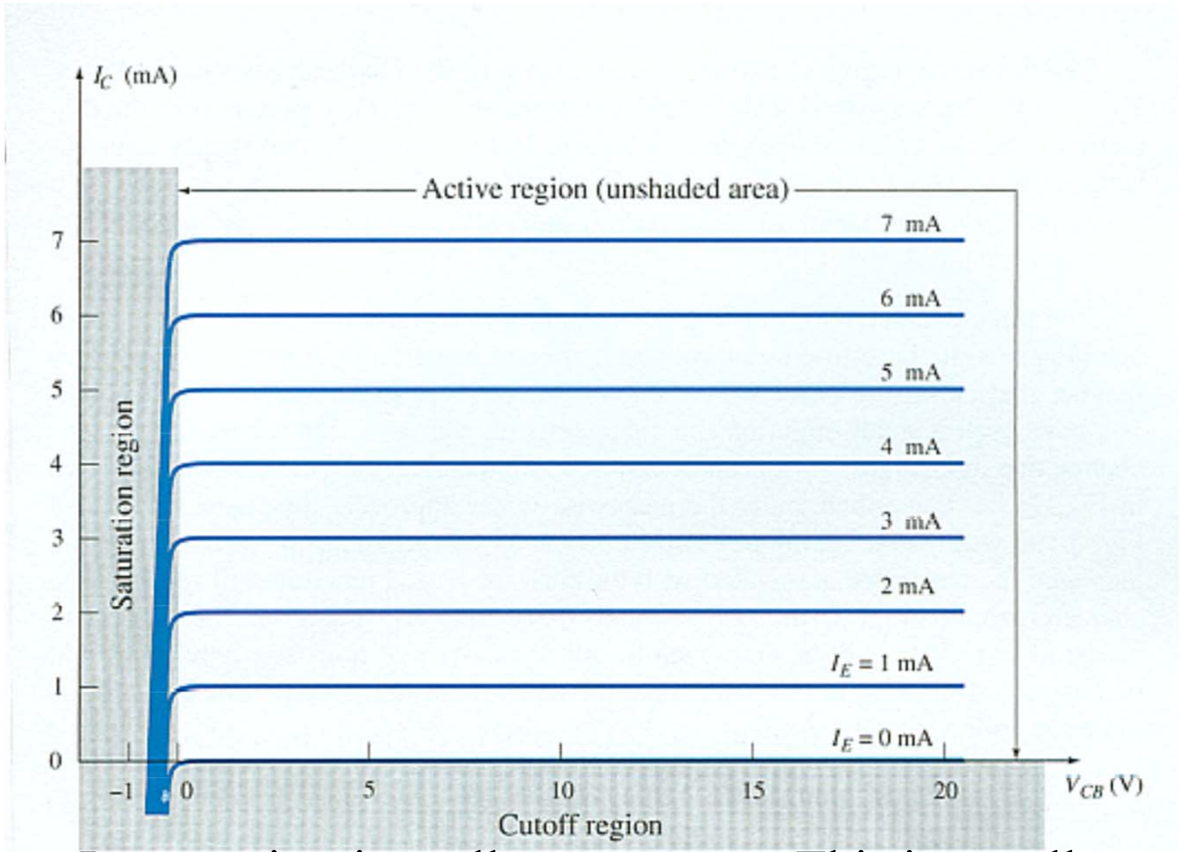
In active region:

Emitter and collector currents:

$$I_C \cong I_E$$

Base-emitter voltage:

$$V_{BE} = 0.7V$$



I_{CBO} = minority collector current. This is usually so small that it can be ignored

Alpha (α)

Alpha (α) relates the DC currents I_C and I_E :

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

Ideally: $\alpha = 1$

In reality: α is between 0.9 and 0.998

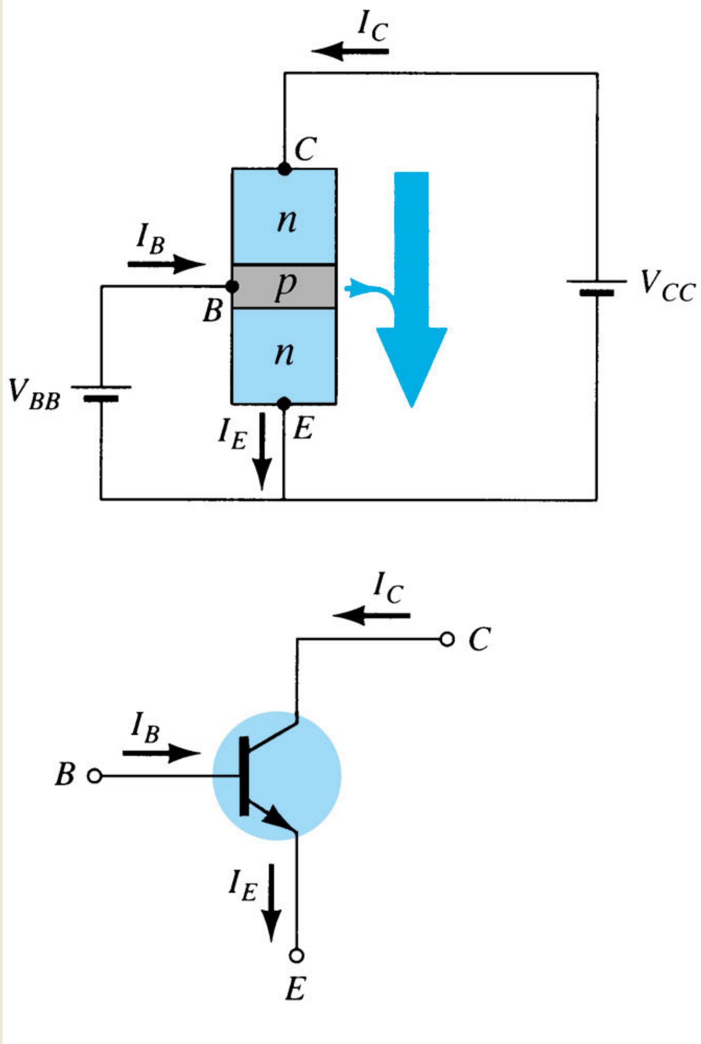
Alpha (α) in the AC mode:

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

3.6 Common–Emitter Configuration

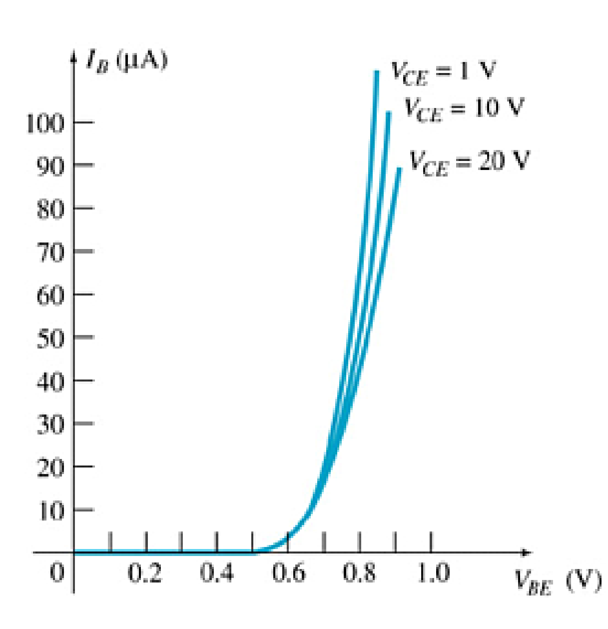
CE: The emitter is common to both input (base-emitter) and output (collector-emitter).

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

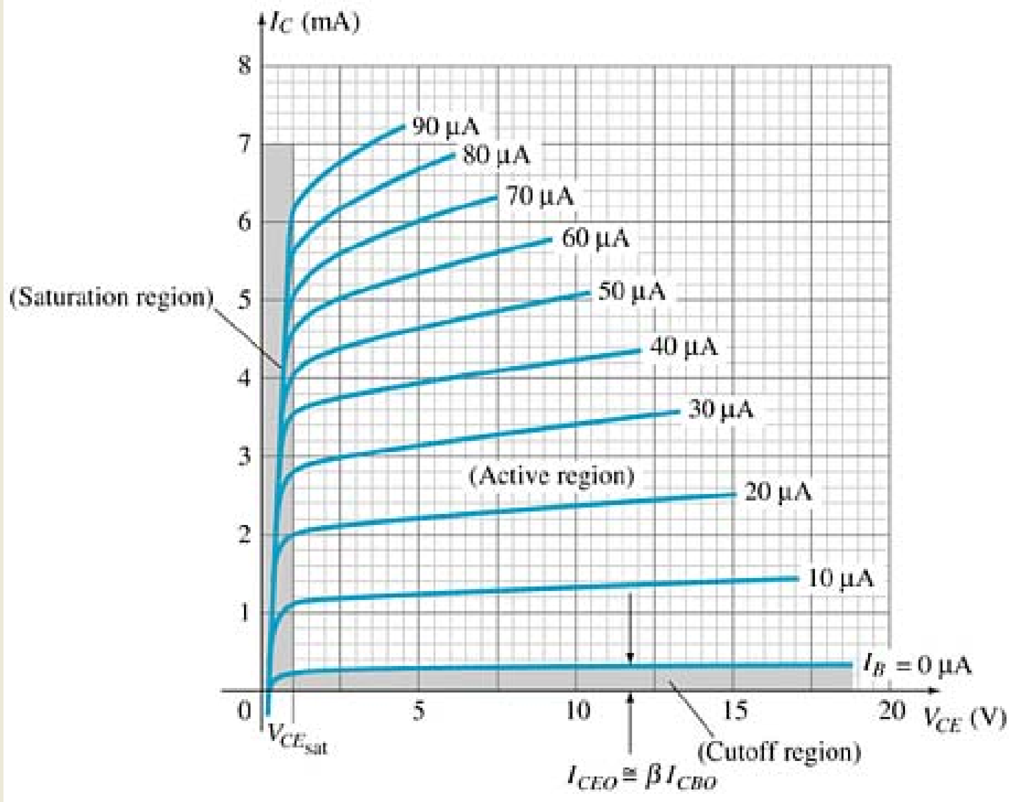


(a)

Common-Emitter Characteristics



Base Characteristics



Collector Characteristics

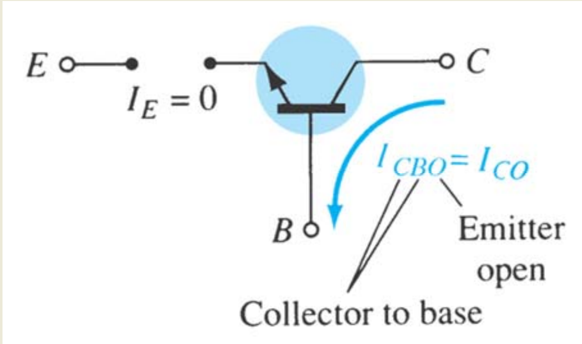
Input Characteristics

This curve shows the relationship between of input current (I_B) to input voltage (V_{BE}) for various levels of output voltage (V_{CE}).

Output Characteristics

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

Common-Emitter Amplifier Currents



Ideal Currents

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

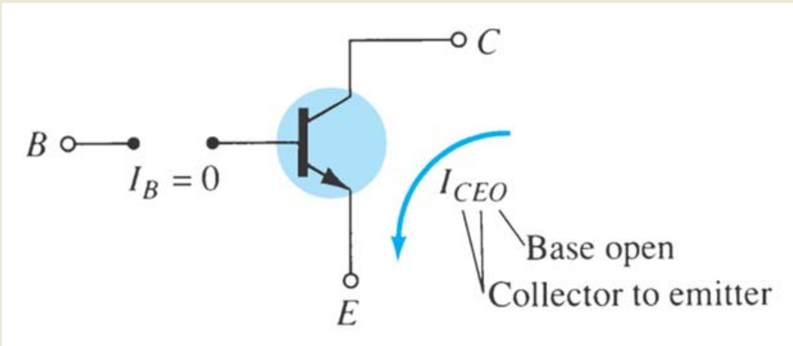
Actual Currents

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

where I_{CBO} = minority collector current. This 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}.

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



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:

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

In AC mode:

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

Beta (β)

Determining β from a Graph

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

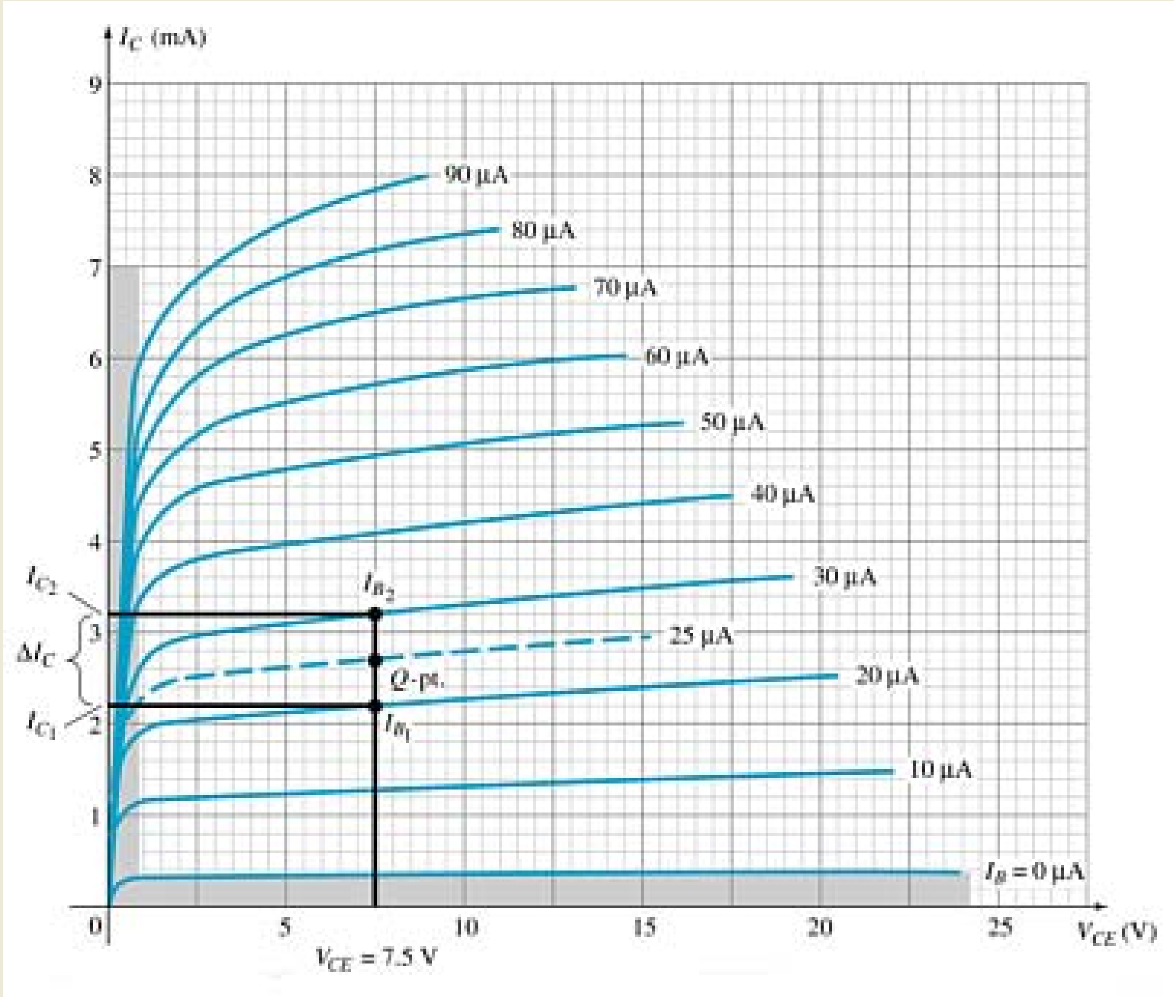
$$= \left.\frac{1\,\text{mA}}{10\,\mu\text{A}}\right|_{V_{CE}=7.5}$$

$$= 100$$

$$\beta_{dc} = \left.\frac{2.7\ \text{mA}}{25\ \mu\text{A}}\right|_{V_{CE}=7.5}$$

$$= 108$$

Note: $\beta_{AC} \approx \beta_{DC}$



Beta (β)

Relationship between amplification factors β and α

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

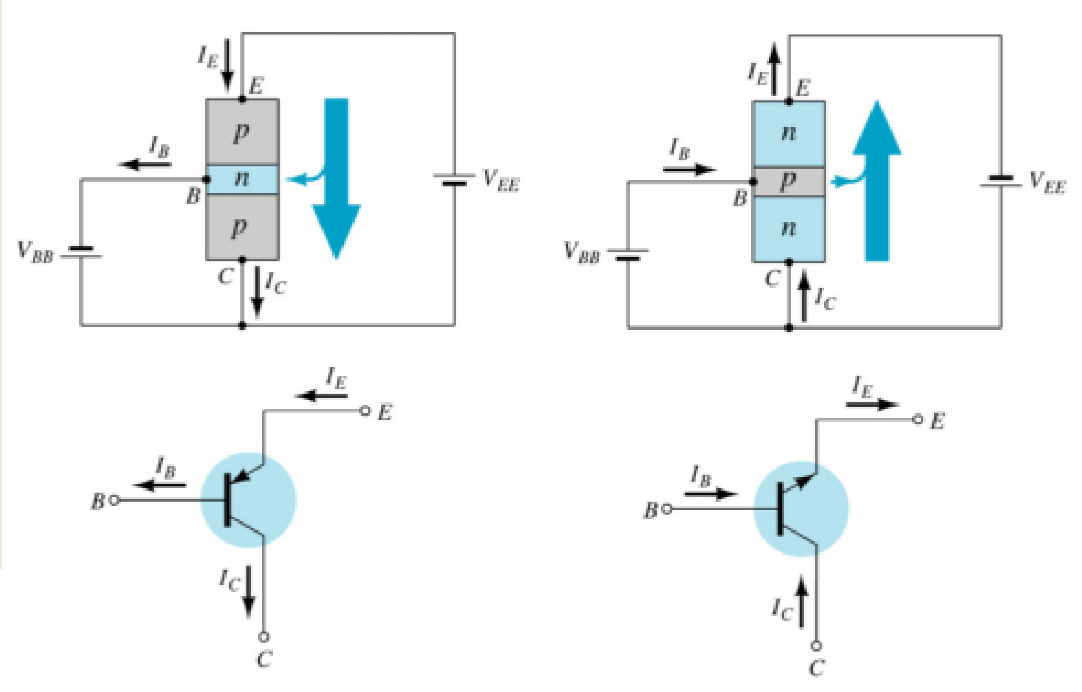
Relationship Between Currents

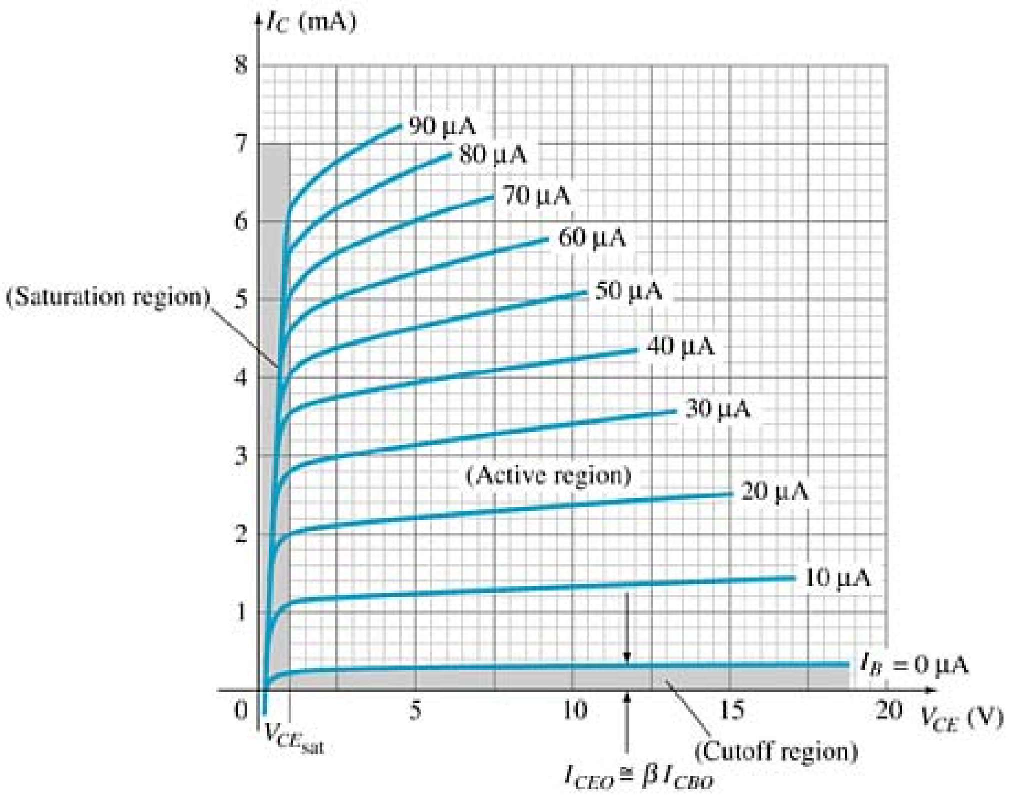
$$I_C = \beta I_B \qquad I_E = (\beta + 1) I_B$$

3.7 Common–Collector Configuration

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

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





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

3.8 Limitations of Operation

V_{CE} is at maximum and I_C is at minimum ($I_{Cmin} = I_{CEO}$) in the cutoff region.

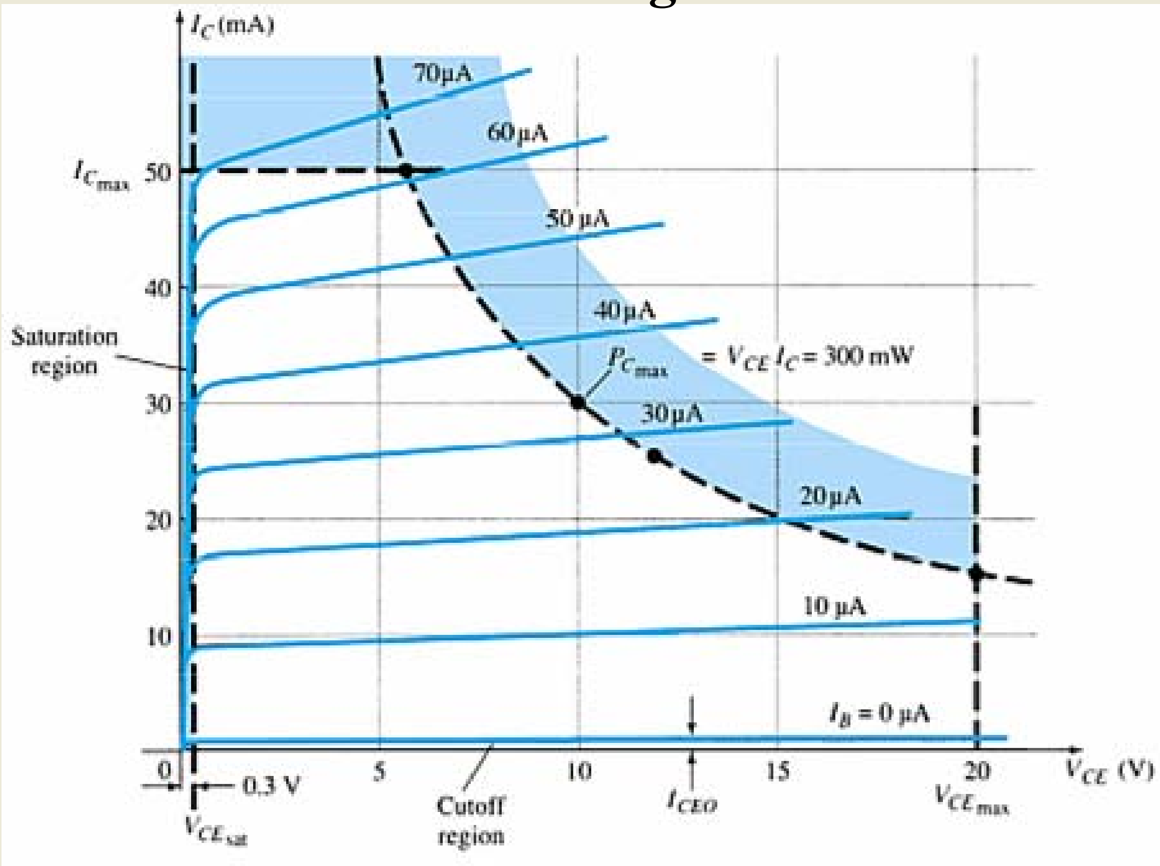
I_C is at maximum and V_{CE} is at minimum ($V_{CE\ min} = V_{CEsat} = V_{CEO}$) in the saturation region.

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

Common-emitter:

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

CE Configuration



3.9 Transistor Specification Sheet

ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic	Symbol	Min	Max	Unit
OFF CHARACTERISTICS				
Collector-Emitter Breakdown Voltage (1) (I_C = 1.0 mAdc, I_B = 0)	$V_{(BR)CEO}$	30		Vdc
Collector-Base Breakdown Voltage (I_C = 10 μAdc, I_E = 0)	$V_{(BR)CBO}$	40		Vdc

MAXIMUM RATINGS

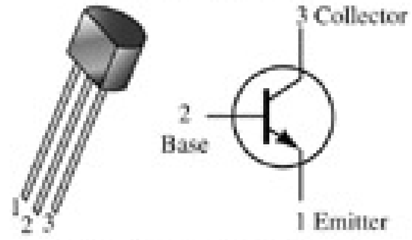
Rating	Symbol	2N4123	Unit
Collector-Emitter Voltage	V_{CEO}	30	Vdc
Collector-Base Voltage	V_{CBO}	40	Vdc
Emitter-Base Voltage	V_{EBO}	5.0	Vdc
Collector Current – Continuous	I_C	200	mAdc
Total Device Dissipation @ T_A = 25°C Derate above 25°C	P_D	625 5.0	mW mW/°C
Operating and Storage Junction Temperature Range	T_J, T_{stg}	−55 to +150	°C

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	83.3	°C/W
Thermal Resistance, Junction to Ambient	$R_{\theta JA}$	200	°C/W

2N4123

CASE 29-04, STYLE 1
TO-92 (TO-226AA)



GENERAL PURPOSE TRANSISTOR
NPN SILICON

Characteristic	Symbol	Min	Max	Unit
Current-Gain – Bandwidth Product (I_C = 10 mAdc, V_{CE} = 20 Vdc, f = 100 MHz)	f_T	250		MHz
Output Capacitance (V_{CB} = 5.0 Vdc, I_E = 0, f = 100 MHz)	C_{obo}	–	4.0	pF
Input Capacitance (V_{BE} = 0.5 Vdc, I_C = 0, f = 100 kHz)	C_{ibo}	–	8.0	pF
Collector-Base Capacitance (I_E = 0, V_{CB} = 5.0 V, f = 100 kHz)	C_{cb}	–	4.0	pF
Small-Signal Current Gain (I_C = 2.0 mAdc, V_{CE} = 10 Vdc, f = 1.0 kHz)	h_{fe}	50	200	–
Current Gain – High Frequency (I_C = 10 mAdc, V_{CE} = 20 Vdc, f = 100 MHz) (I_C = 2.0 mAdc, V_{CE} = 10 V, f = 1.0 kHz)	h_{fe}	2.5 50	– 200	–
Noise Figure (I_C = 100 μAdc, V_{CE} = 5.0 Vdc, R_S = 1.0 k ohm, f = 1.0 kHz)	NF	–	6.0	dB

(1) Pulse Test: Pulse Width = 300 μs, Duty Cycle = 2.0%

more…

Summary of Chapter 3

- **Key Information**
  - **Transistor construction and operation**
    - **Current relationship**
  - **Three Basic Configurations:**
    - **CE**
    - **CB**
    - **CC**
  - **Characteristics of CE, CB and CC configuration**
  - **Transistor Operation Regions**
    - **Active region**
    - **Cutoff region**
    - **Saturation region**

- **Application Key Notes**
  - **Limits of Operation**