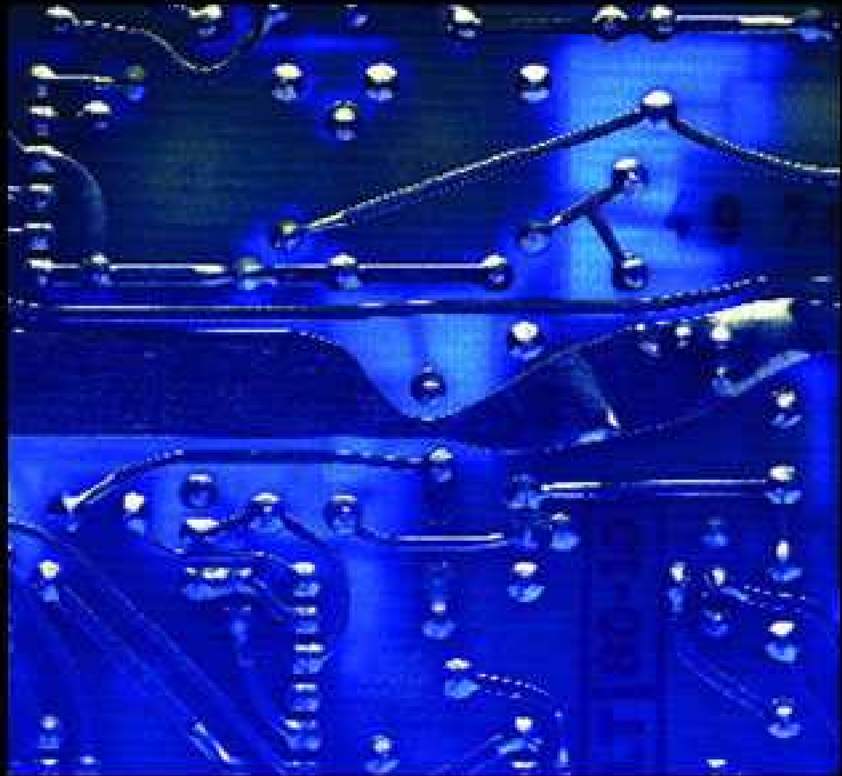
ELECTRONIC DEVICES AND CIRCUIT THEORY

TENTH EDITION

BOYLESTAD



PEARSON

Chapter 3: Bipolar Junction Transistors

Transistor Construction

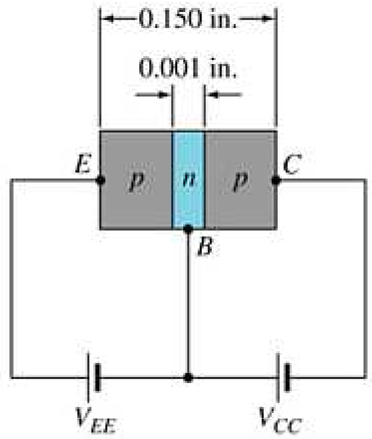
There are two types of transistors:

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

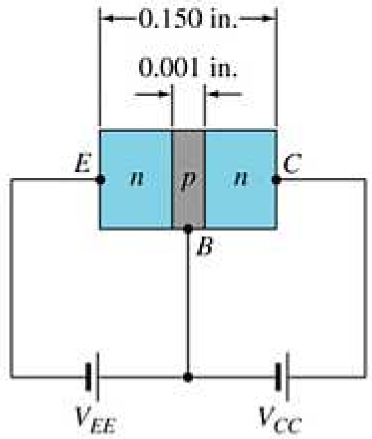
The terminals are labeled:

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

pnp



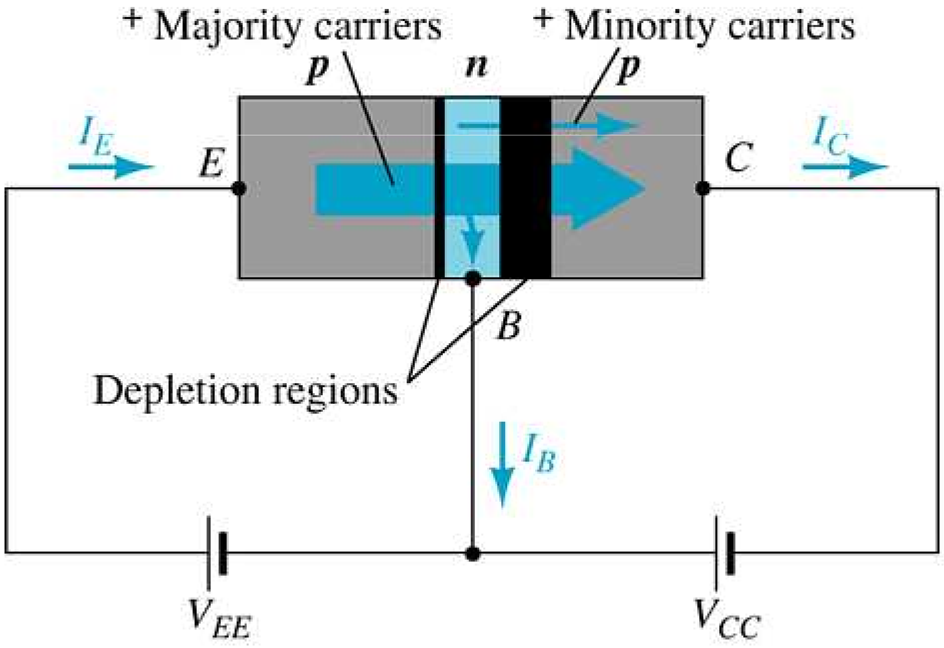
npn



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**



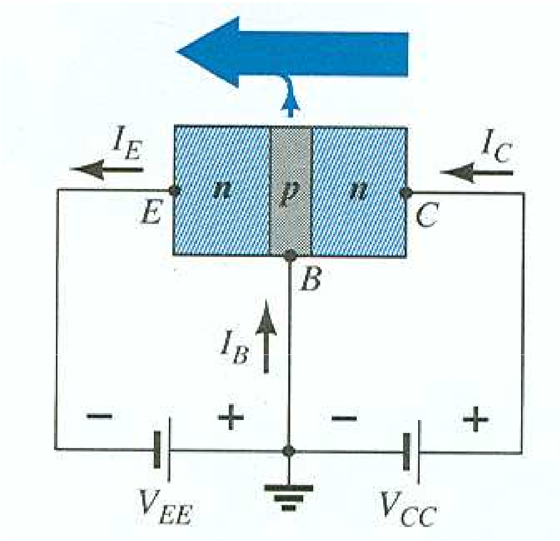
Currents in a Transistor

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

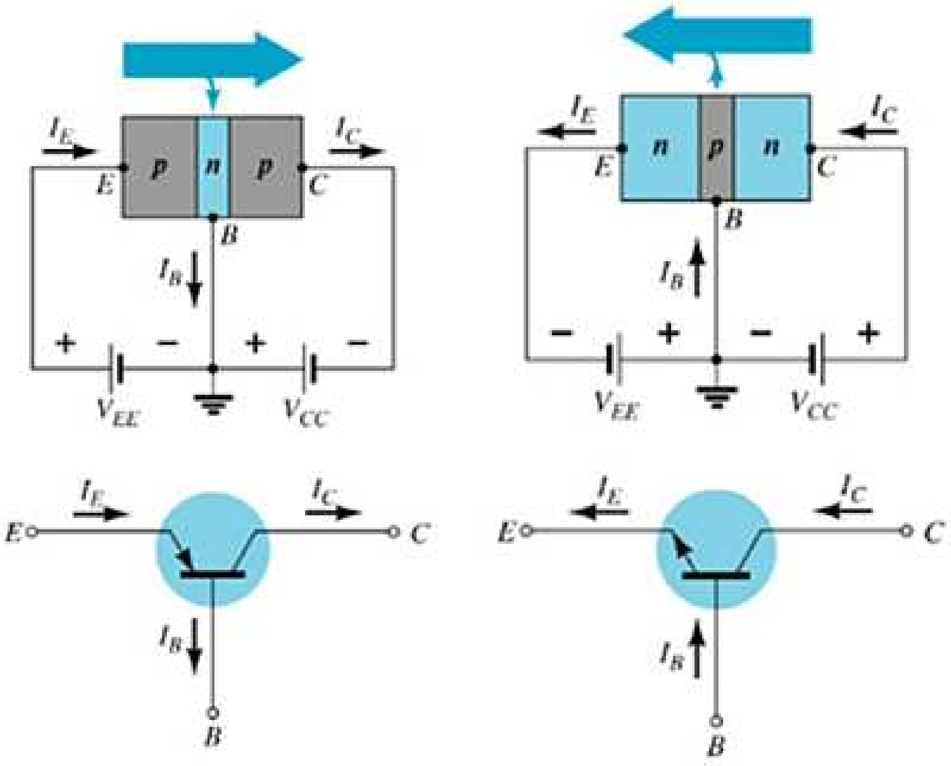
$$I_E = I_C + I_B$$

The collector current is comprised of two currents:

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



Common-Base Configuration

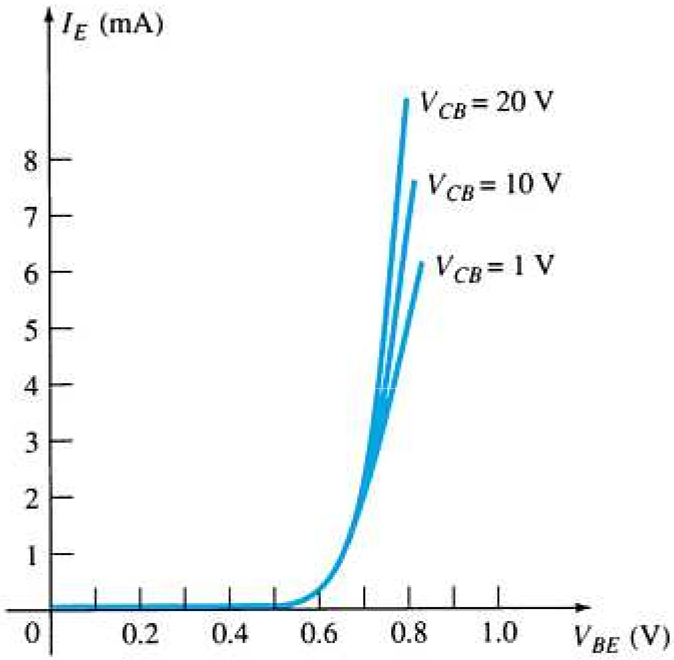


The base is common to both input (emitter–base) and output (collector–base) of the transistor.

Common-Base Amplifier

Input Characteristics

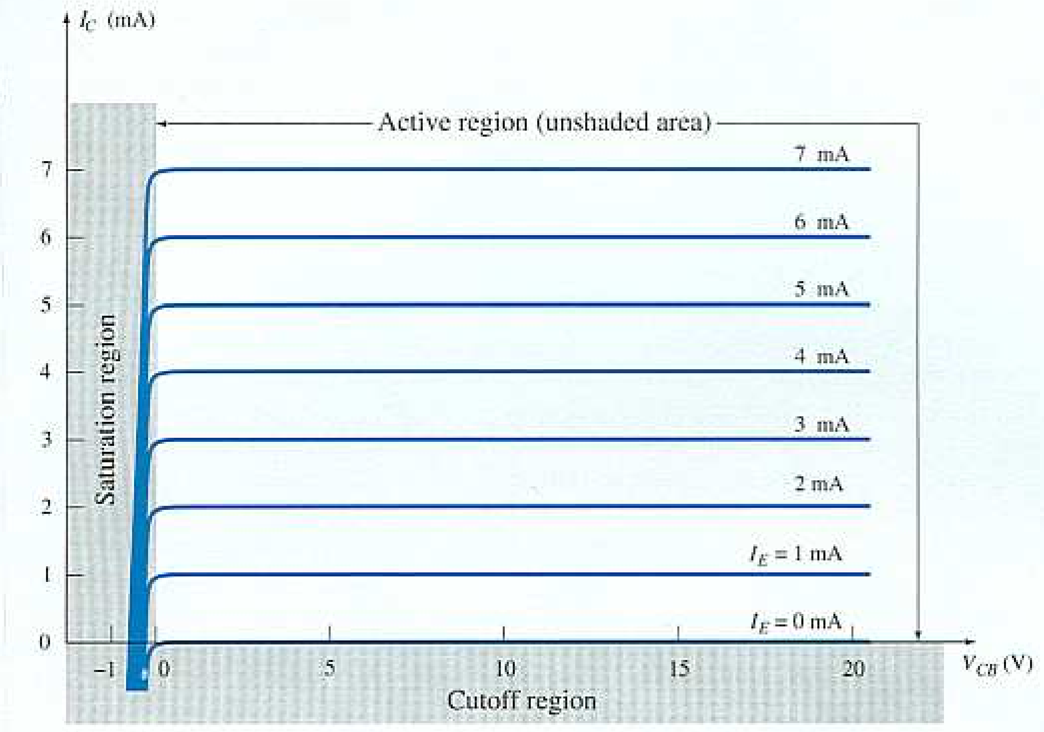
This curve shows the relationship between of input current (I_E) to input voltage (V_{BE}) for three output voltage (V_{CB}) levels.



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:

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

Alpha (α)

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

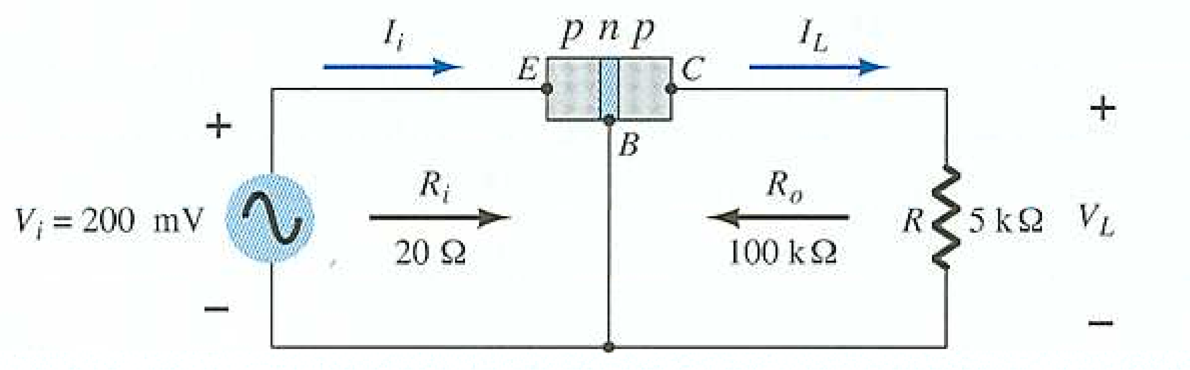
$$\alpha_{dc} = \frac{I_C}{I_E}$$

Ideally: α = 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:

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

$$I_C \cong I_E$$

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

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

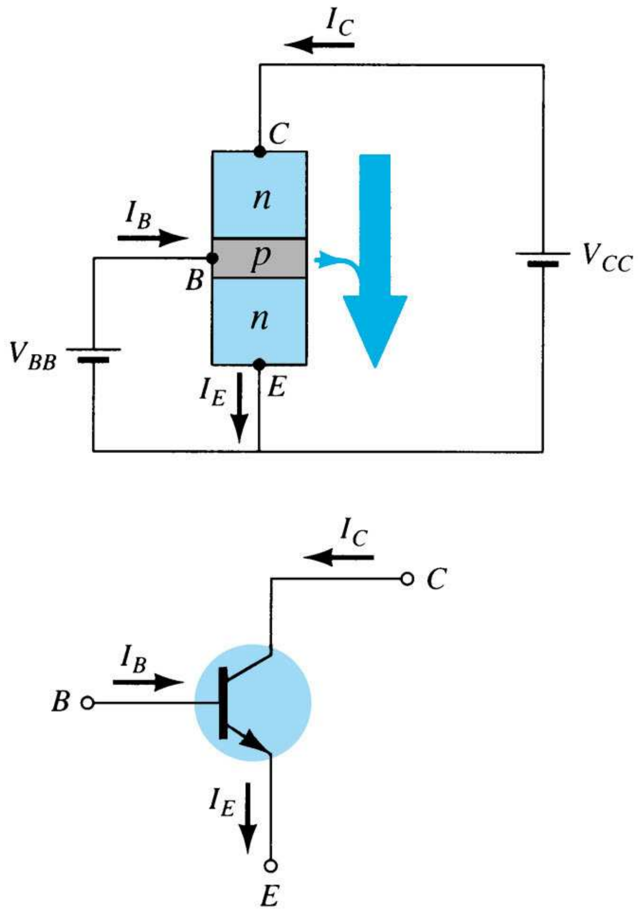
Voltage Gain:

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

Common–Emitter Configuration

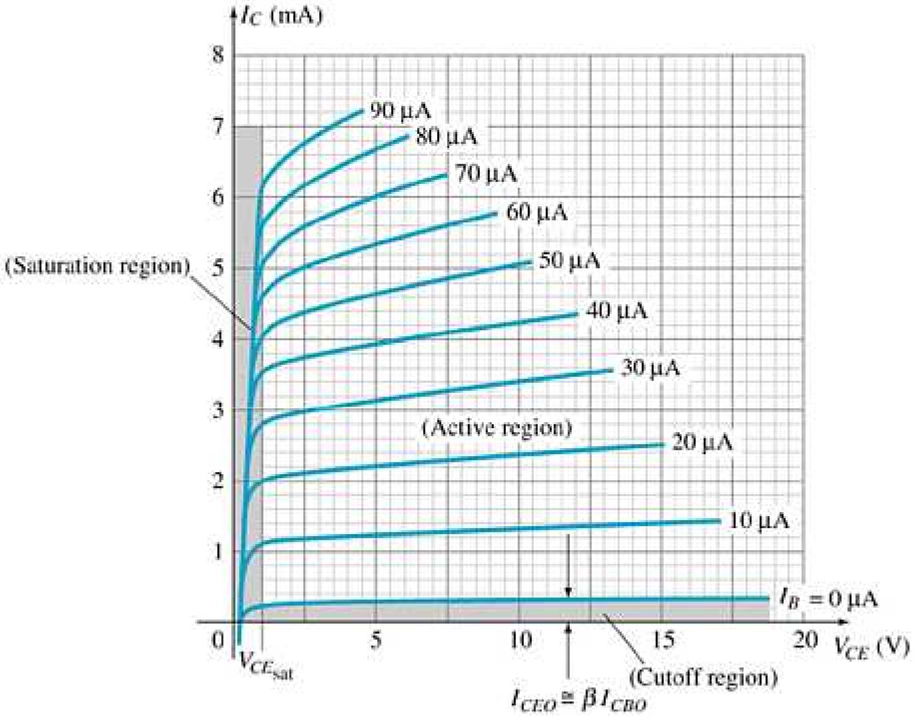
The emitter is common to both input (base-emitter) and output (collector-emitter).

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

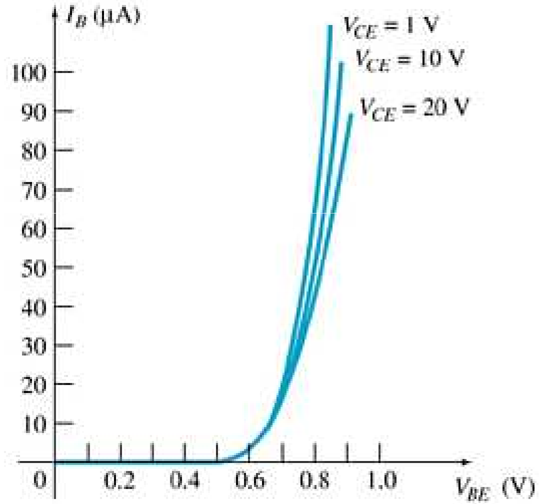


(a)

Common-Emitter Characteristics



Collector Characteristics



Base Characteristics

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}.

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

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:

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

In AC mode:

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

Beta (β)

Determining β from a Graph

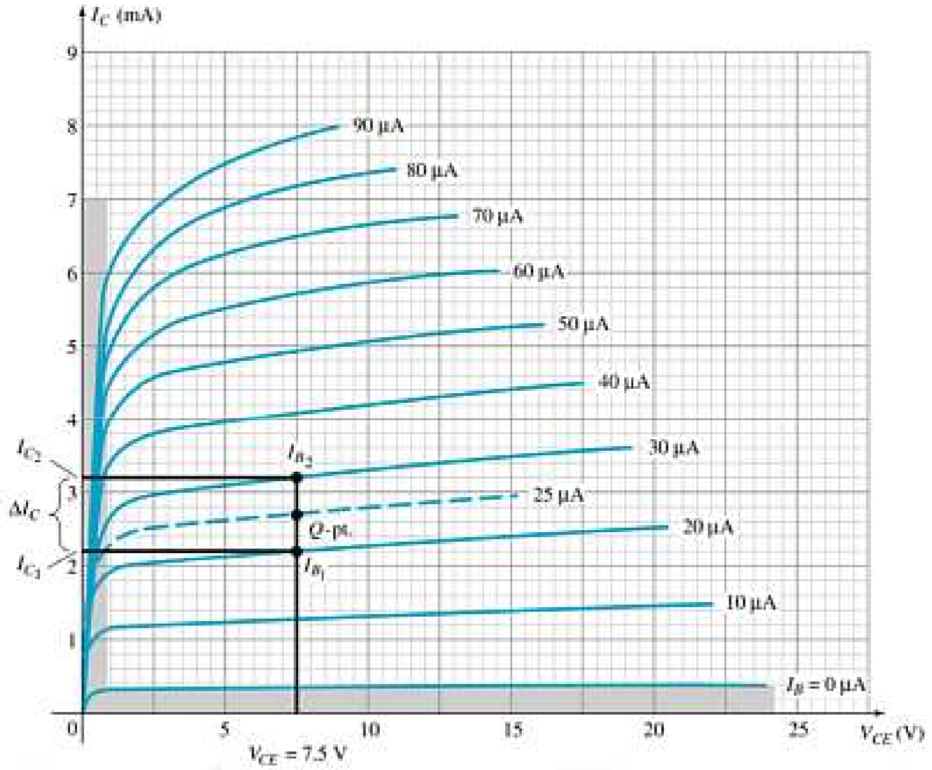
$$\beta_{AC} = \frac{(3.2\,\text{mA} - 2.2\,\text{mA})}{(30\,\mu\text{A} - 20\,\mu\text{A})}$$

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

$$= 100$$

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

$$= 108$$



Beta (β)

Relationship between amplification factors β and α

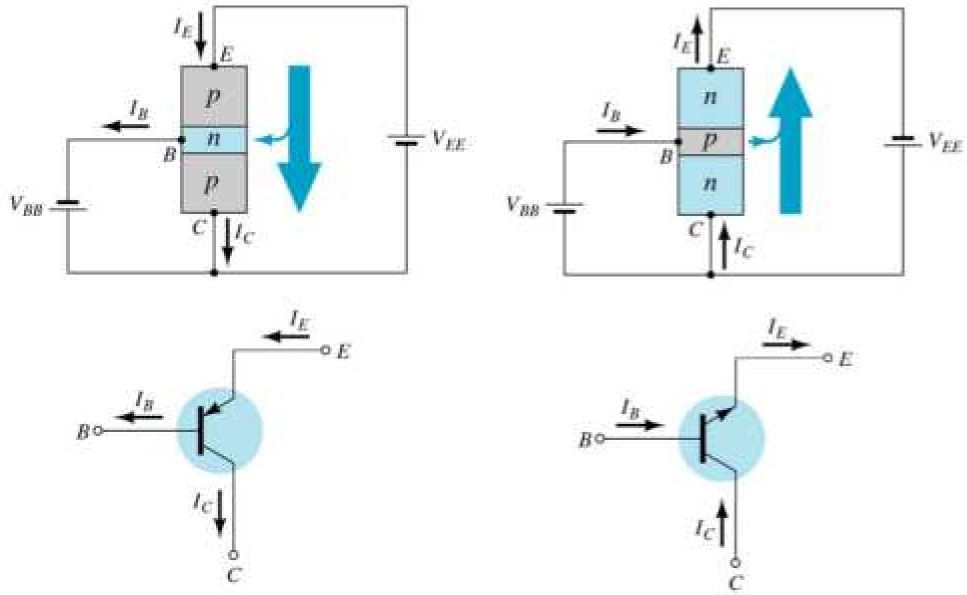
$$\alpha = \frac{\beta}{\beta + 1} \qquad \beta = \frac{\alpha}{\alpha - 1}$$

Relationship Between Currents

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

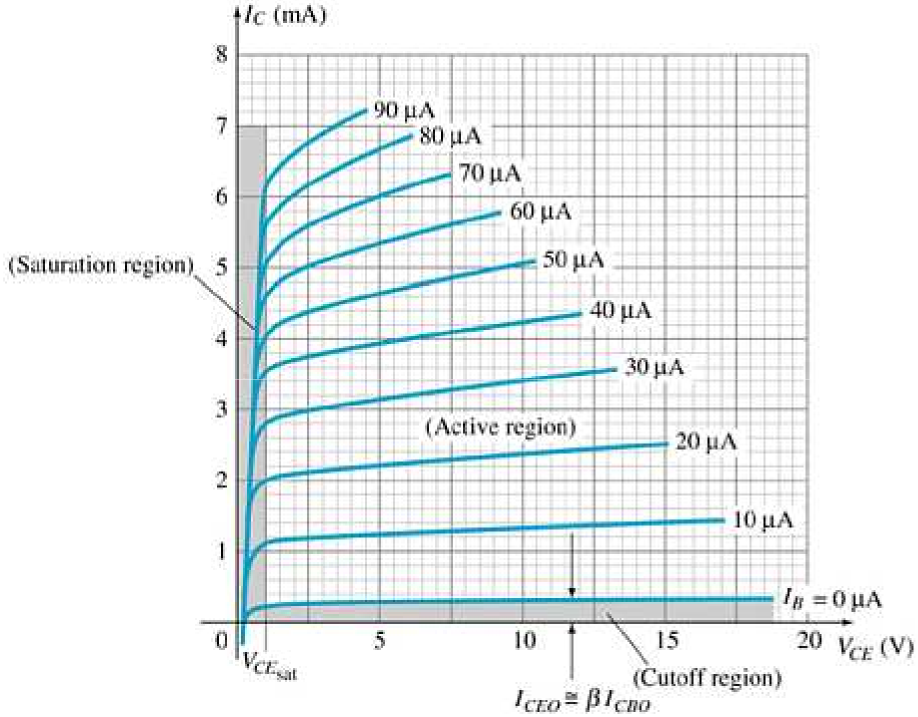
Common–Collector Configuration

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.

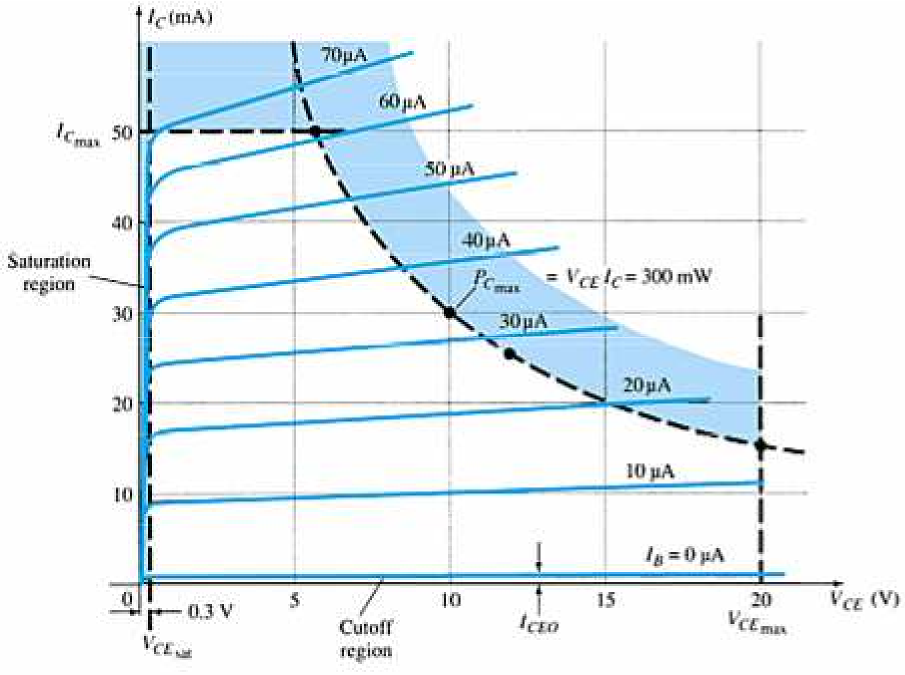


Operating Limits for Each Configuration

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:

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

Transistor Specification Sheet

MAXIMUM RATINGS

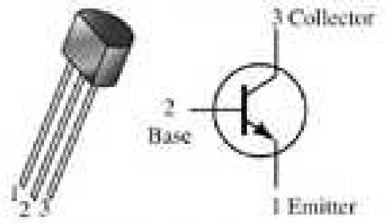
Rating	Symbol	2N4123	Unit
Collector-Emitter Voltage	V_{CEO}	30	Vdc
Collector-Base Voltage	V_{CBO}	40	Vdc
Emitter-Base Voltage	V_{EBO}	5.0	Vdc
Collector Current – Continuous	I_C	200	mAdc
Total Device Dissipation @ $T_A = 25°C$ Derate above 25°C	P_D	625 5.0	mW mW/°C
Operating and Storage Junction Temperature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

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Case	$R_{θJC}$	83.3	°C/W
Thermal Resistance, Junction to Ambient	$R_{θJA}$	200	°C/W

2N4123

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



GENERAL PURPOSE
TRANSISTOR
NPN SILICON

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
Emitter-Base Breakdown Voltage (I_E = 10 μAdc, I_C = 0)	$V_{(BR)EBO}$	5.0	–	Vdc
Collector Cutoff Current (V_{CB} = 20 Vdc, I_E = 0)	I_{CBO}	–	50	nAdc
Emitter Cutoff Current (V_{BE} = 3.0 Vdc, I_C = 0)	I_{EBO}	–	50	nAdc
ON CHARACTERISTICS				
DC Current Gain(1) (I_C = 2.0 mAdc, V_{CE} = 1.0 Vdc) (I_C = 50 mAdc, V_{CE} = 1.0 Vdc)	h_{FE}	50 25	150 –	–
Collector-Emitter Saturation Voltage(1) (I_C = 50 mAdc, I_B = 5.0 mAdc)	$V_{CE(sat)}$	–	0.3	Vdc
Base-Emitter Saturation Voltage(1) (I_C = 50 mAdc, I_B = 5.0 mAdc)	$V_{BE(sat)}$	–	0.95	Vdc
SMALL-SIGNAL CHARACTERISTICS				
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

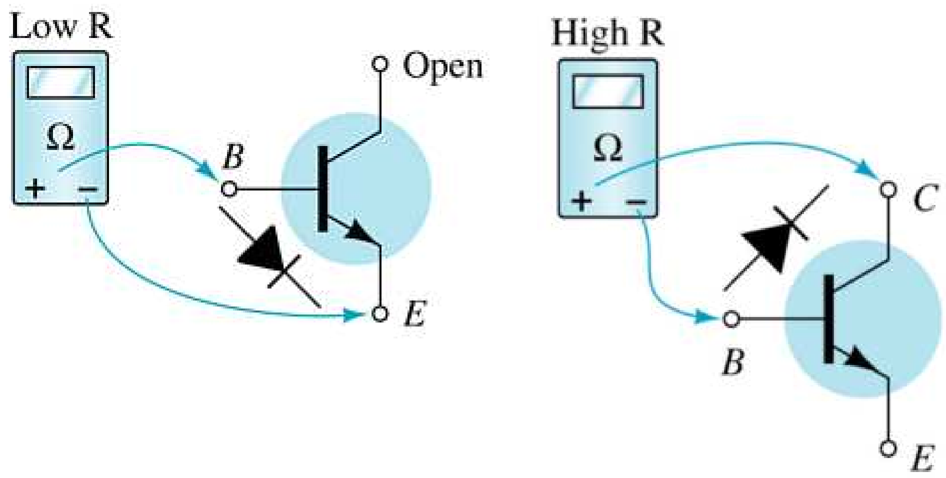
(1) Pulse Test: Pulse Width = 300 μs, Duty Cycle = 2.0%

Transistor Testing

- **Curve Tracer**
  Provides a graph of the characteristic curves.

- **DMM**
  Some DMMs measure β_{DC} or h_{FE}.

- **Ohmmeter**



Transistor Terminal Identification