Electronic Devices and Circuit Theory

Boylestad

Bipolar Junction Transistors

Chapter 3

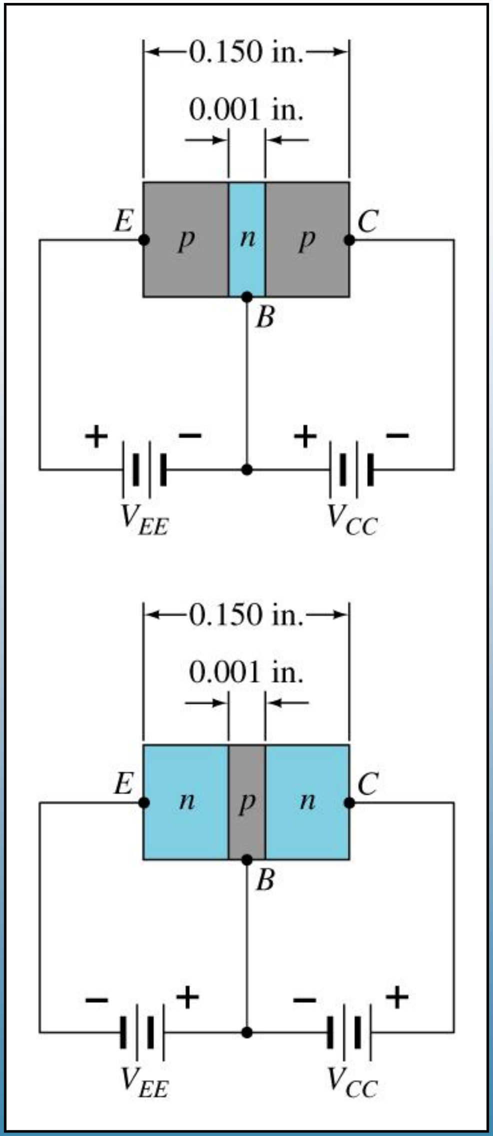
Transistor Construction

There are two types of transistors:

pnp and ***npn***

The terminals are labeled:

E - Emitter
B - Base
C - Collector



pnp

npn

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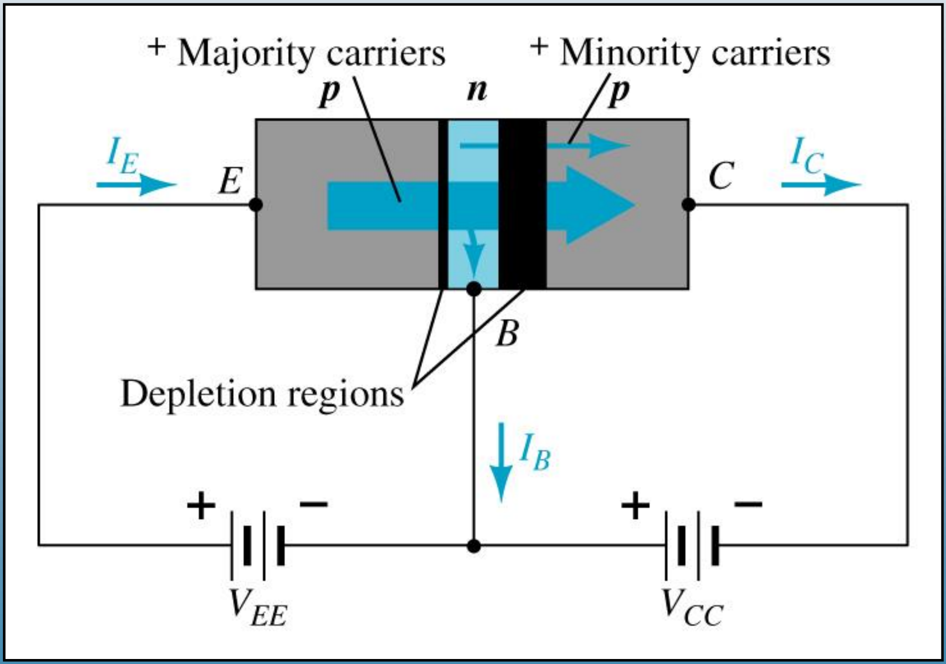
Transistor Operation

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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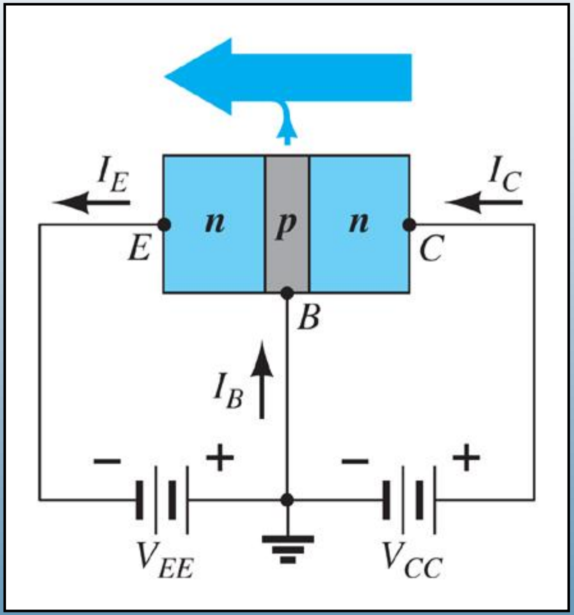
Currents in a Transistor

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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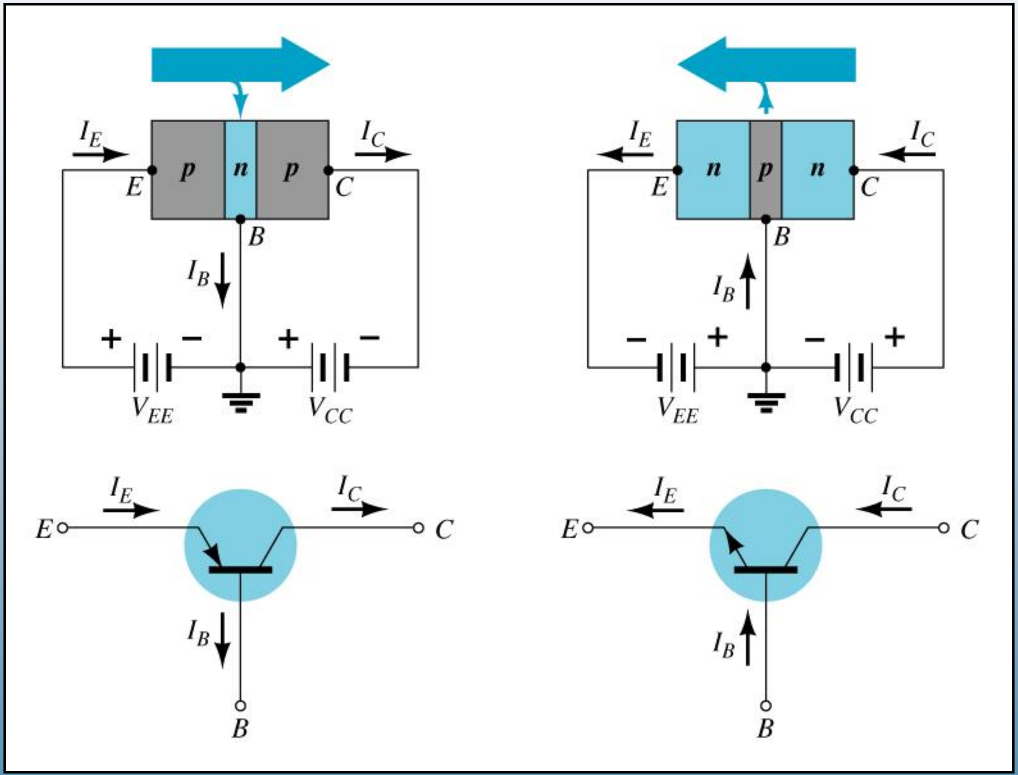
Common-Base Configuration



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

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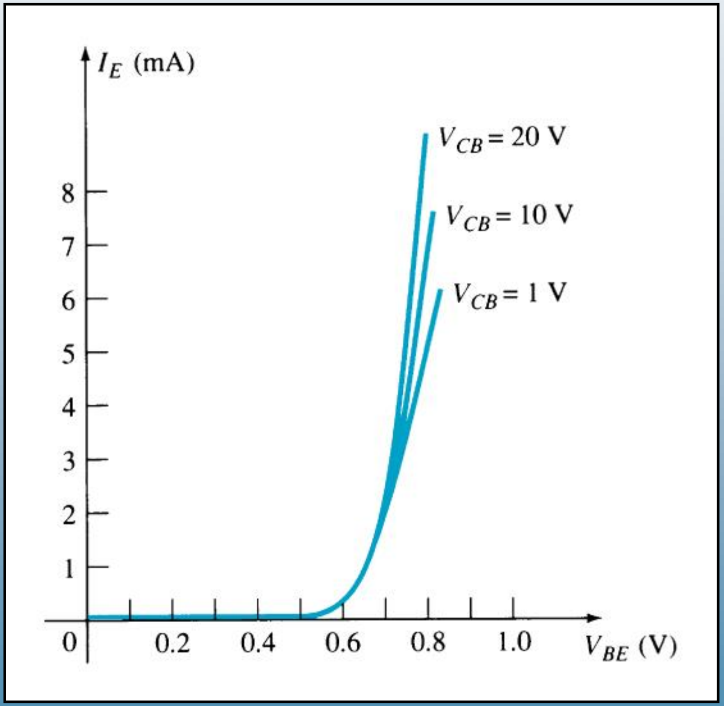
Common-Base Amplifier

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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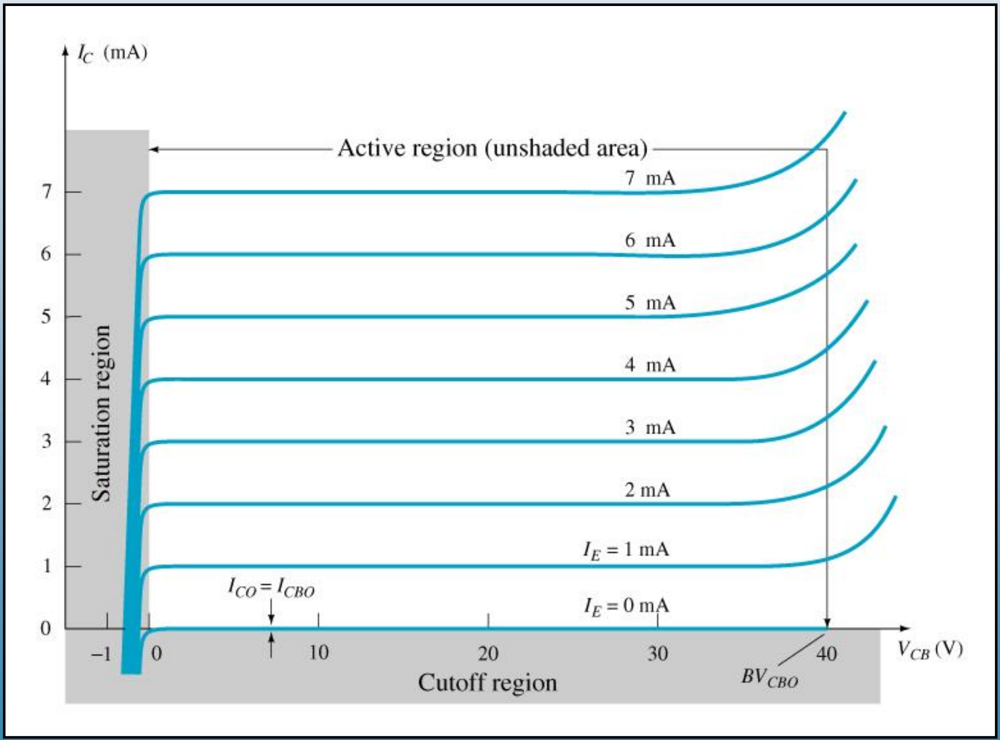
Common-Base Amplifier

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.

Cutoff

The amplifier is basically off. There is voltage, but little current.

Saturation

The amplifier is fully on. There is current, but little voltage.

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Approximations

Emitter and collector currents:

$$I_C \cong I_E$$

Base-emitter voltage:

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

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Alpha (α)

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

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

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

Ideally: α = 1

In reality: α falls somewhere between 0.9 and 0.998

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

Alpha (α) in the AC mode:

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

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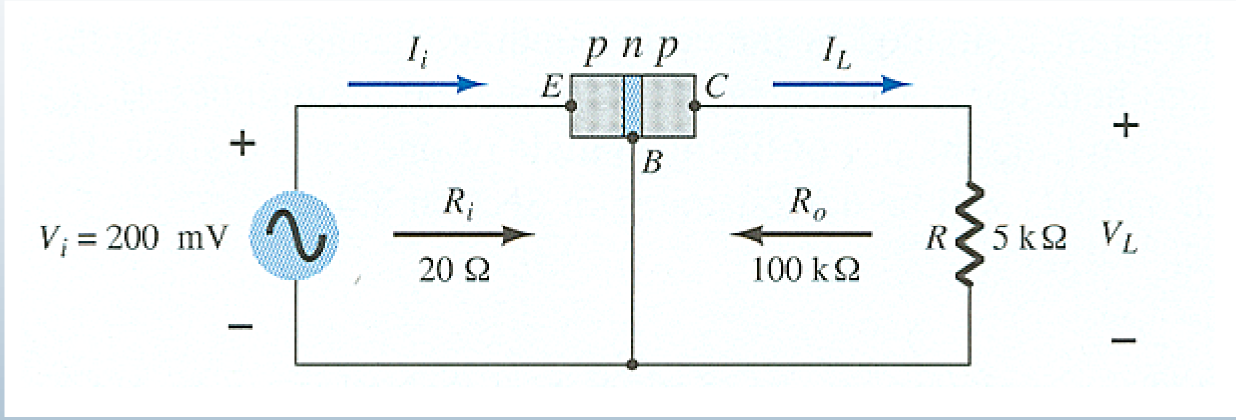
Transistor Amplifier



Currents and Voltages:

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

$$I_C \cong I_E$$

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

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

Voltage Gain:

$$A_V = \frac{V_L}{V_i} = \frac{50V}{200\,mV} = 250$$

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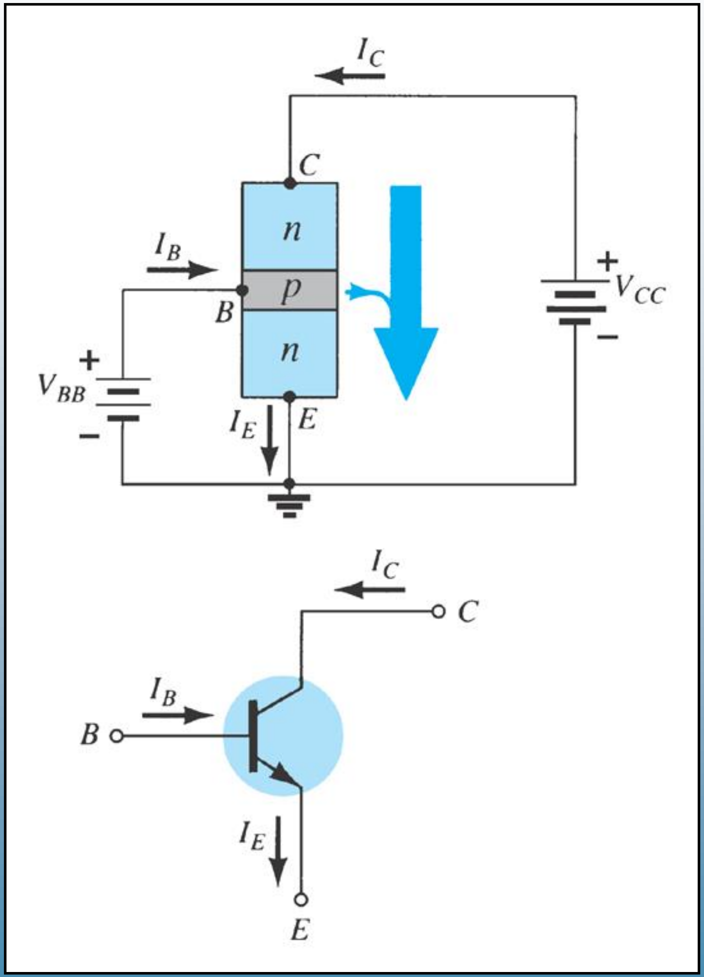
Common-Emitter Configuration

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

The input is applied to the base and the output is taken from the collector.



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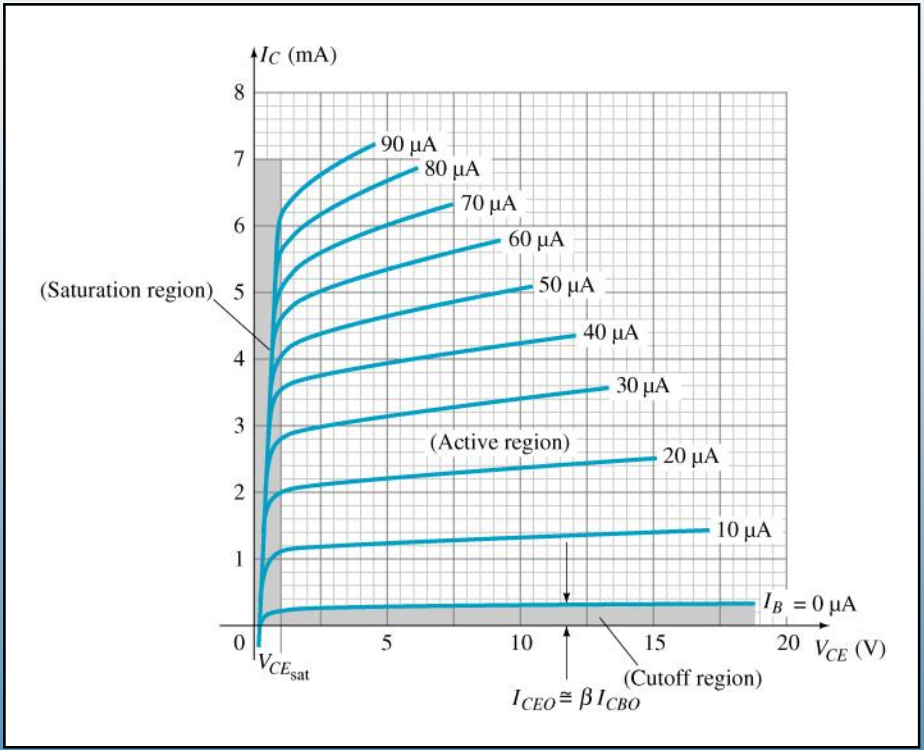
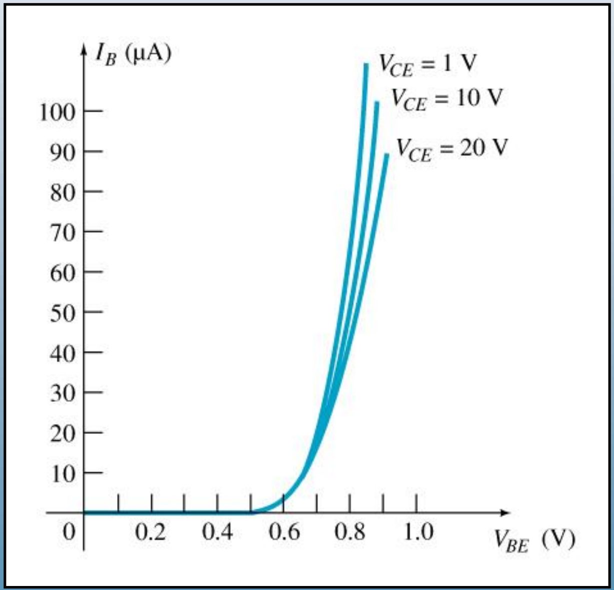
Common-Emitter Characteristics



Collector Characteristics



Base (input) Characteristics

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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 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.

In DC mode:

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

In AC mode:

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

β_{ac} is sometimes referred to as h_{fe}, a term used in transistor modeling calculations

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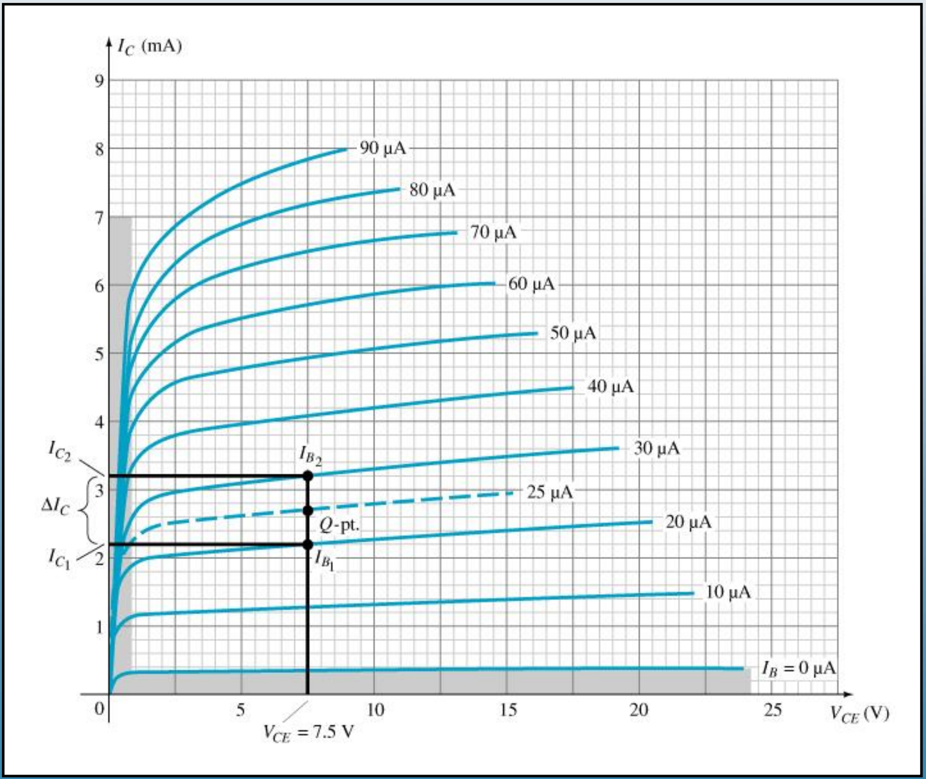
Beta (β)

Determining β from a Graph

$$\beta_{AC} = \frac{(3.2\ mA - 2.2\ mA)}{(30\ \mu A\ -\ 20\ \mu A)} = \frac{1\ mA}{10\ \mu A}\Big|_{V_{CE}=7.5V} = 100$$

$$\beta_{DC} = \frac{2.7\ mA}{25\ \mu A}\Big|_{V_{CE}=7.5V} = 108$$



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Beta (β)

Relationship between amplification factors β and α:

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

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

Relationship Between Currents:

$$I_C = \beta I_B$$

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

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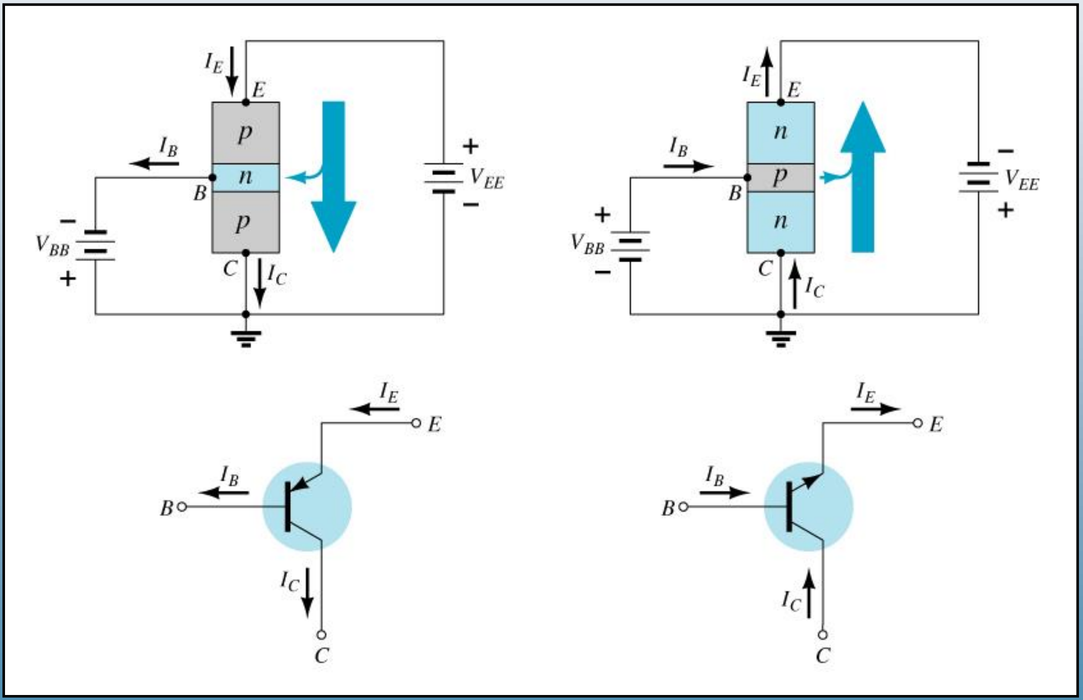
Common-Collector Configuration

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



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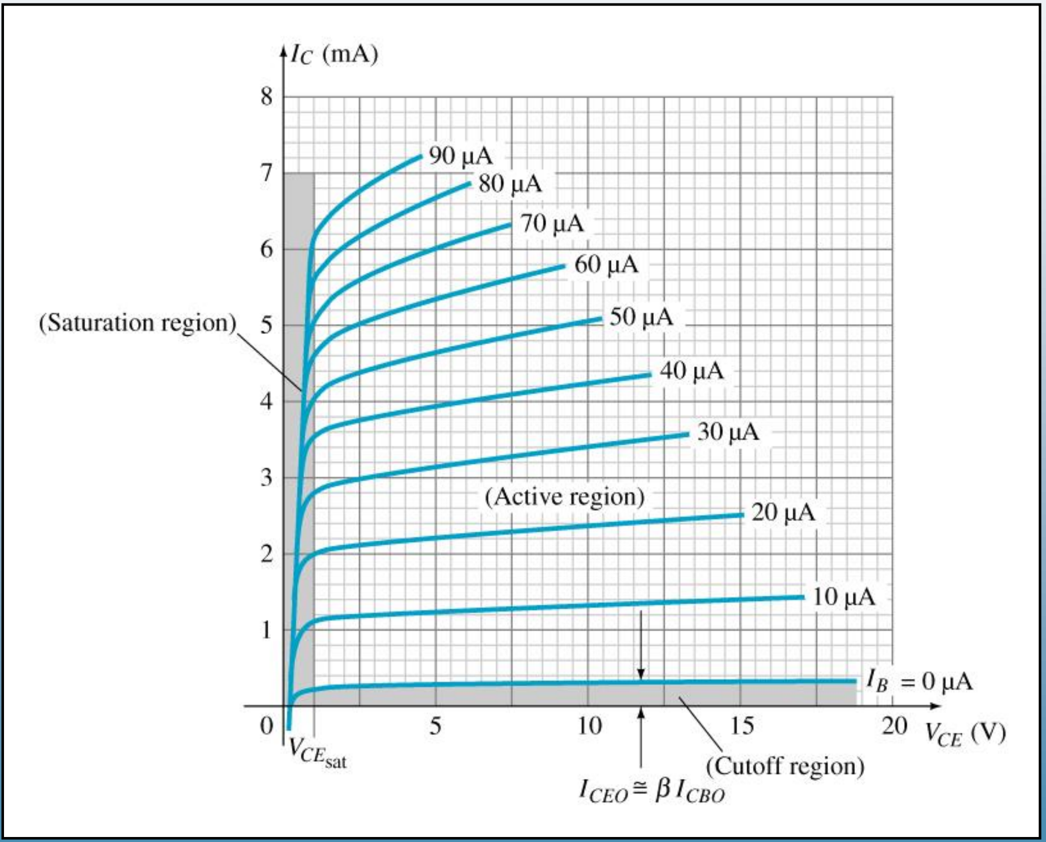
Common-Collector Configuration

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



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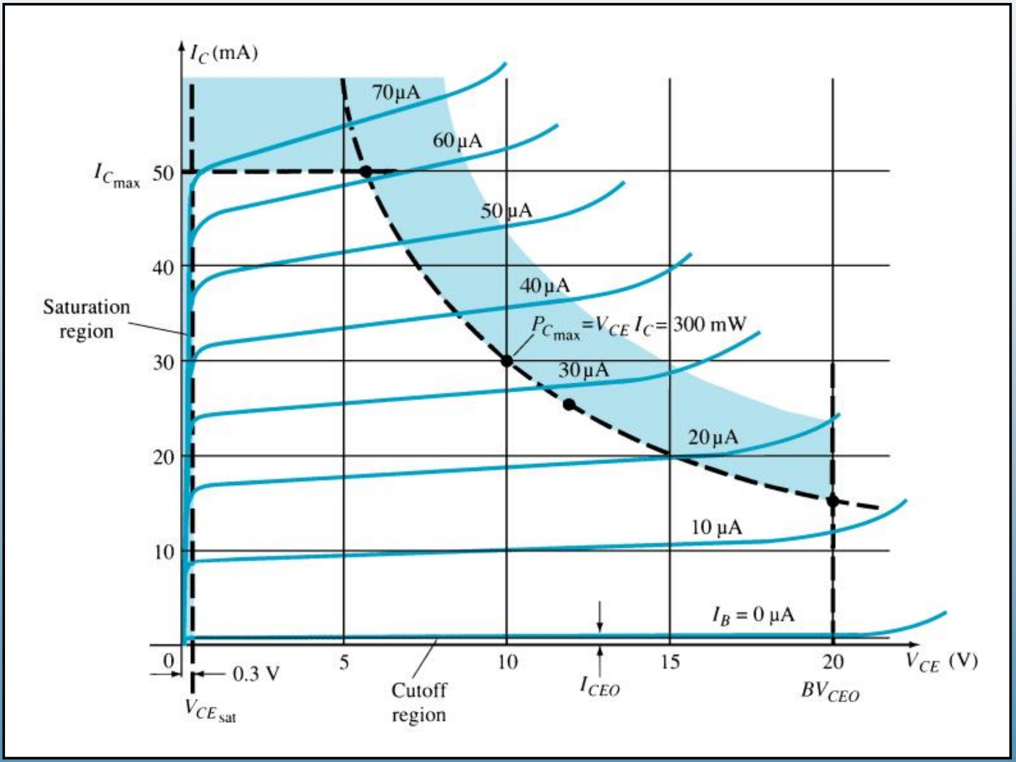
Operating Limits

V_{CE} is maximum and I_C is minimum in the cutoff region.

$$I_{C(max)} = I_{CEO}$$

I_C is maximum and V_{CE} is minimum in the saturation region.

$$V_{CE(max)} = V_{CE(sat)} = V_{CEO}$$



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

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Power Dissipation

Common-base:

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

Common-emitter:

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

Common-collector:

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

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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

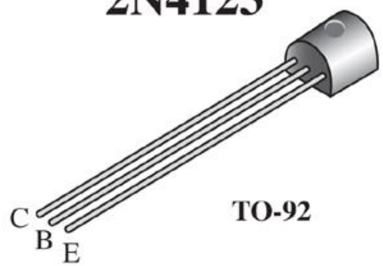
THERMAL CHARACTERISTICS

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

FAIRCHILD

SEMICONDUCTOR TM

2N4123



General Purpose
Transistor
NPN Silicon

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Ch.3 Summary

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_E = 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

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Transistor Specification Sheet

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%

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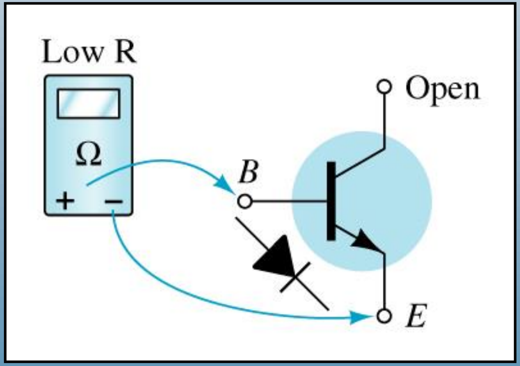
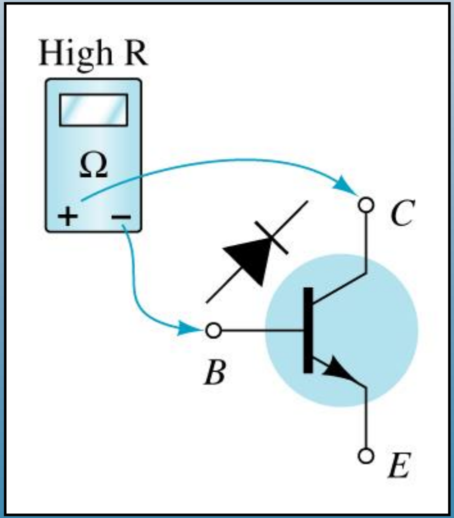
Transistor Testing

Curve Tracer Provides a graph of the characteristic curves.

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

Ohmmeter:





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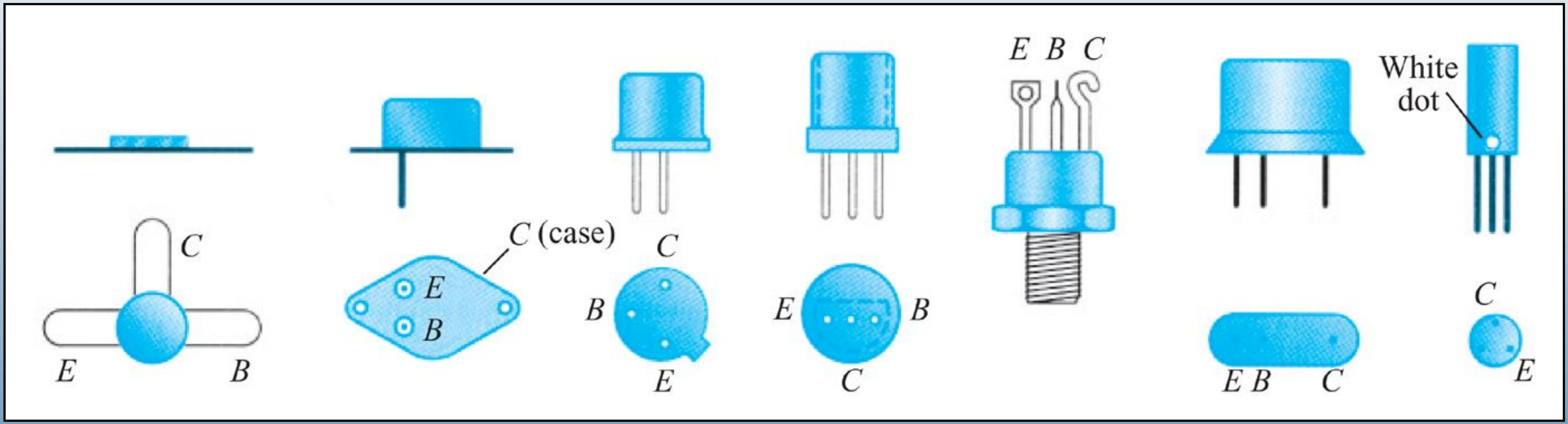
Transistor Terminal Identification



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