Bipolar Junction Transistor

Text Book

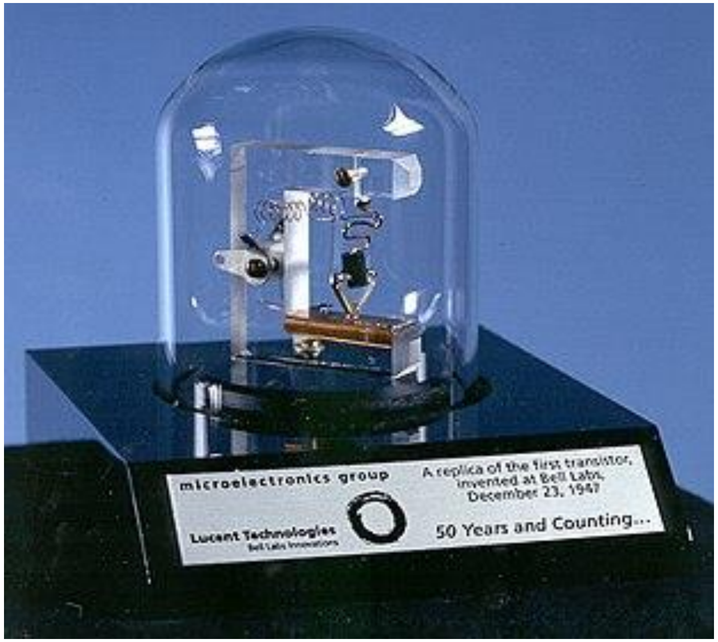
Electronic Devices and Circuit Theory

By R. Boylestad and L. Nashelsky

History in brief

- 1904-1947: Vacuum tubes
- 23 December 1947: The amplifying action of the first transistor was demonstrated at Bell Tel Lab.
- It was a point-contact transistor
- It was smaller and lightweight,
- no heater requirement, hence, no heater loss
- It had a rugged construction
- It was more efficient due to less absorbed power
- Requiring no warm-up period
- The advantages of solid state devices

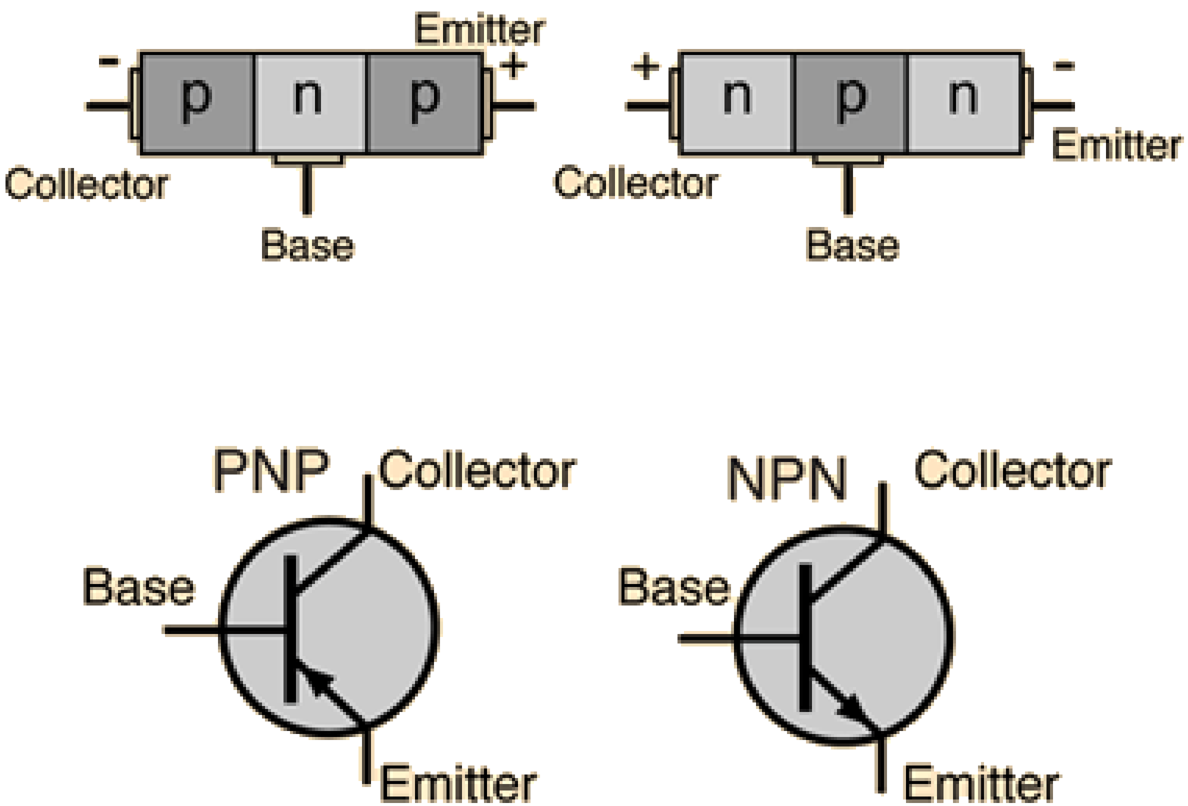
The first transistor

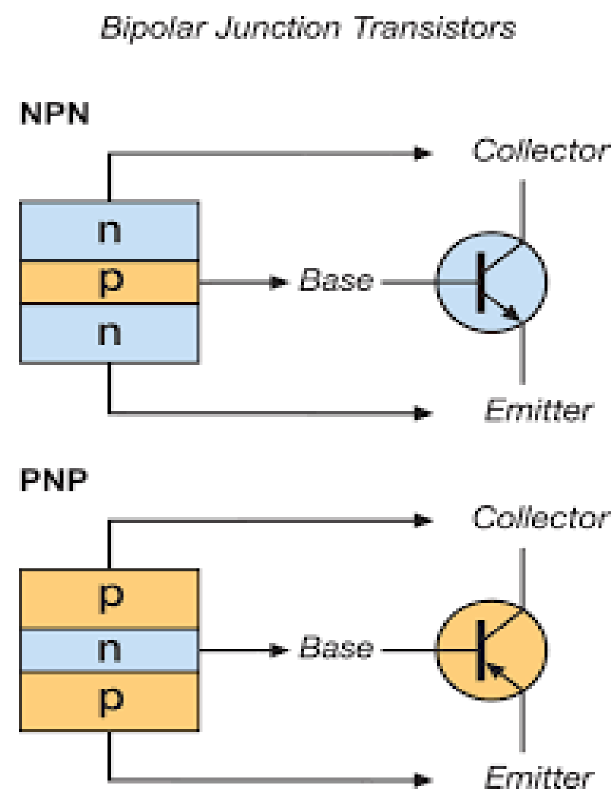


Present day Transistor Characteristics

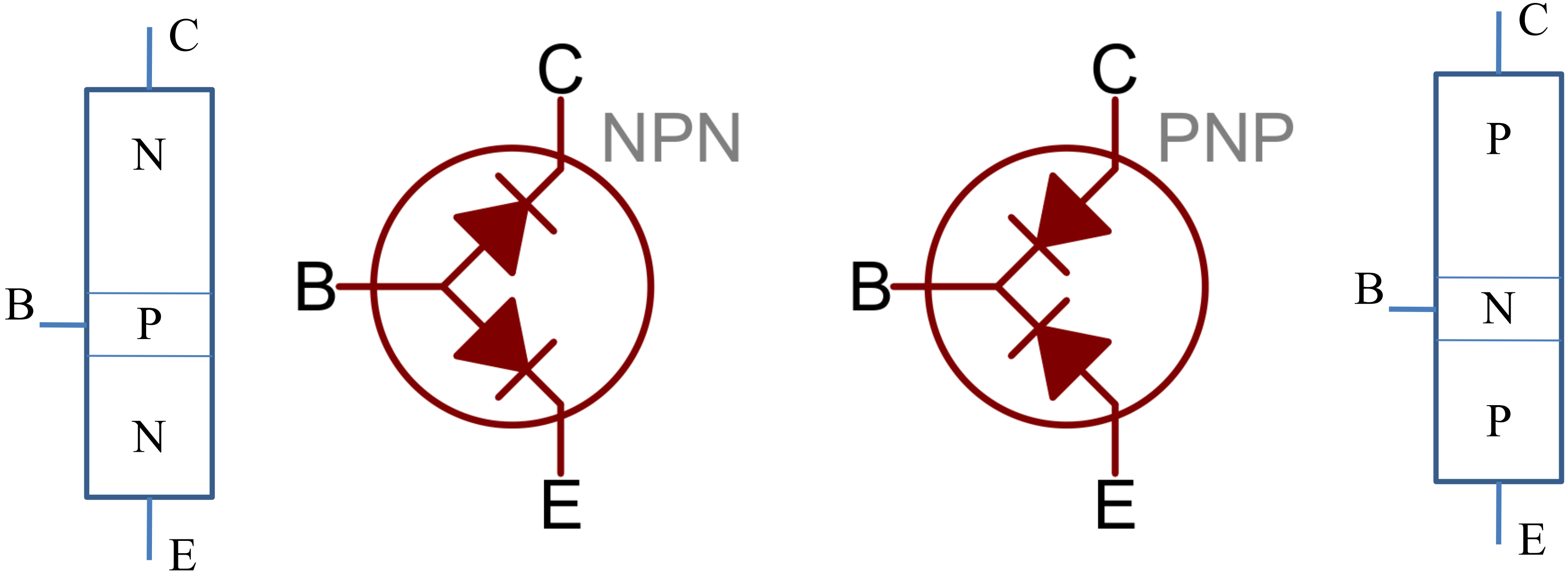
- BJT abbreviates bipolar junction transistor
- Three terminals semiconductor device
- Bipolar device: bipolar reflects the fact that holes and electrons participate in injection process
- Current controlled device
- Types: PNP and NPN transistors
- Terminals are- emitter, base, and collector.
- Higher voltage gain
- Applications: amplification and switching

PNP and NPN Transistor





Transistor equivalence diodes



Junction biasing

BE Junction	BC Junction	State of Operation
RB	RB	Cut-off
FB	RB	Active
RB	FB	Reverse-active
FB	FB	Saturation

Biasing for amplification and switching

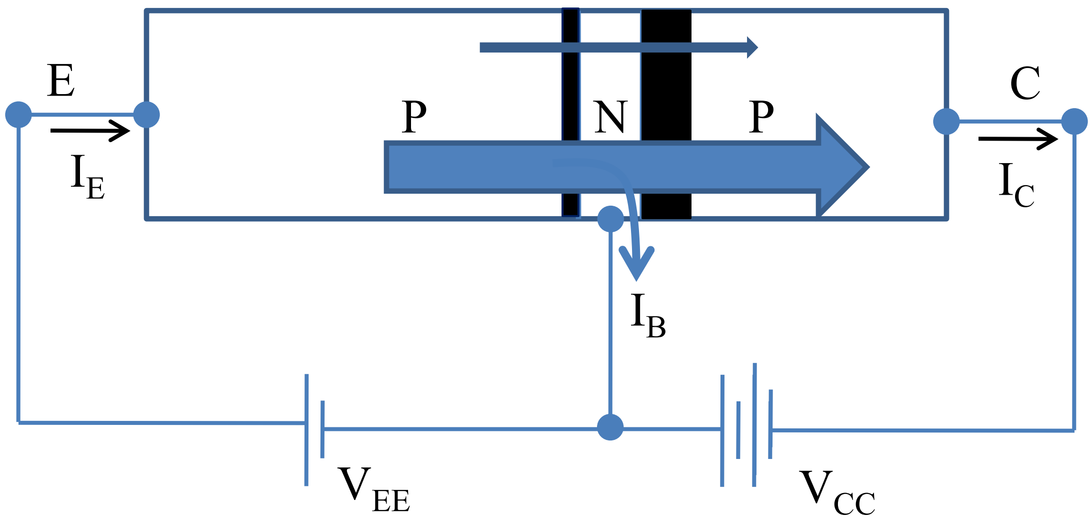
BJT as a switch

1. Cut-off: BE and BC Junctions are reverse biased
2. Saturation: BE and BC Junctions are forward biased.

Amplification (active mode)

- BE junction forward bias, BC reverse bias

Operation in the active mode



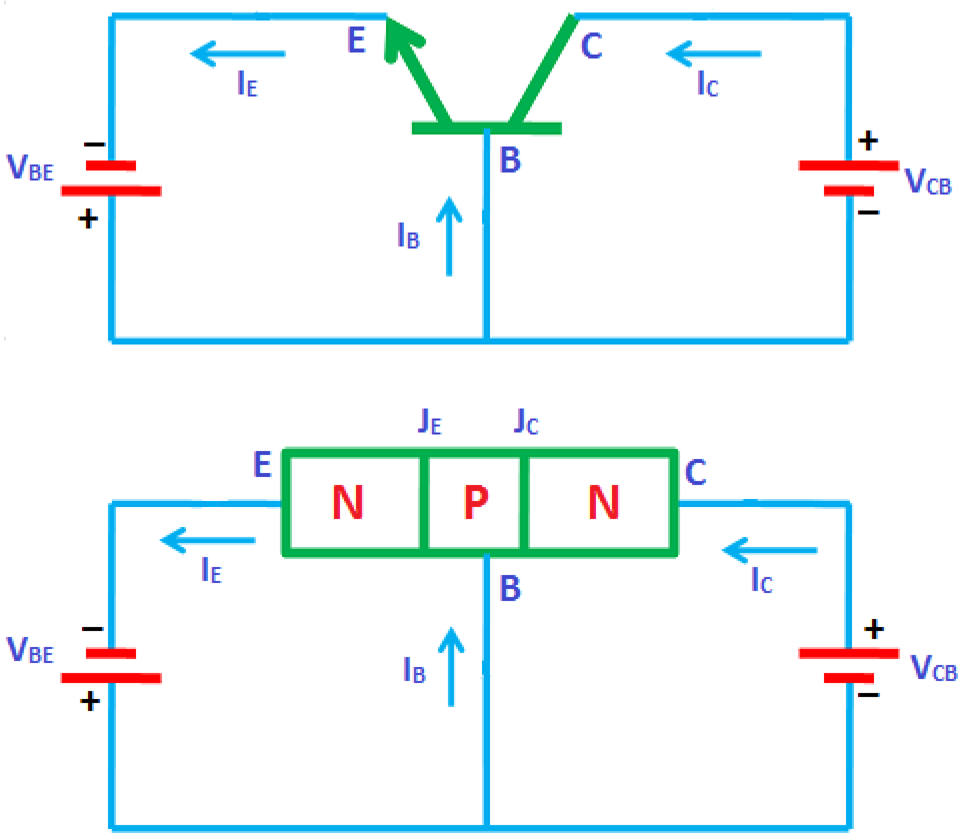
$$I_E = I_C + I_B \qquad\qquad I_E = I_{C_{majority}} + I_{CO_{minority}}$$

BJT configurations

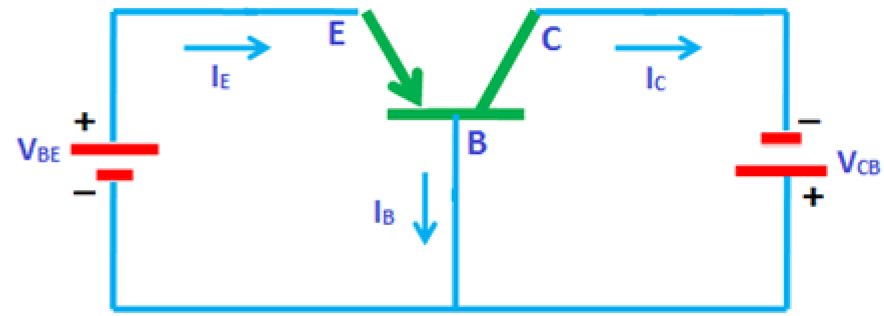
- Common base (CB) configuration
- Common emitter (CE) configuration
- Common collector (CC) configuration

CB Configuration

Sometimes common base configuration is referred to as common base amplifier, CB amplifier, or CB configuration.



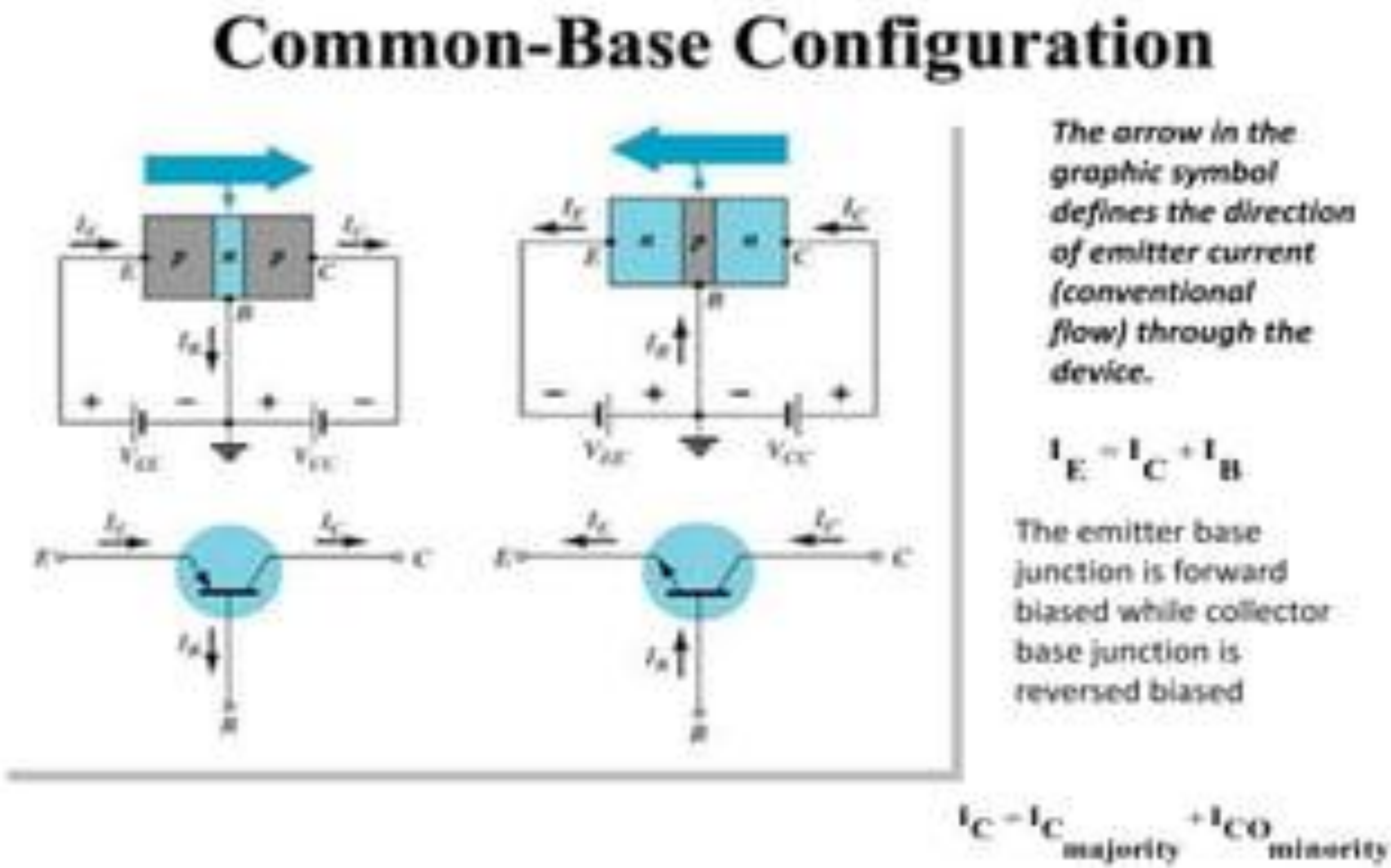
Common base configuration



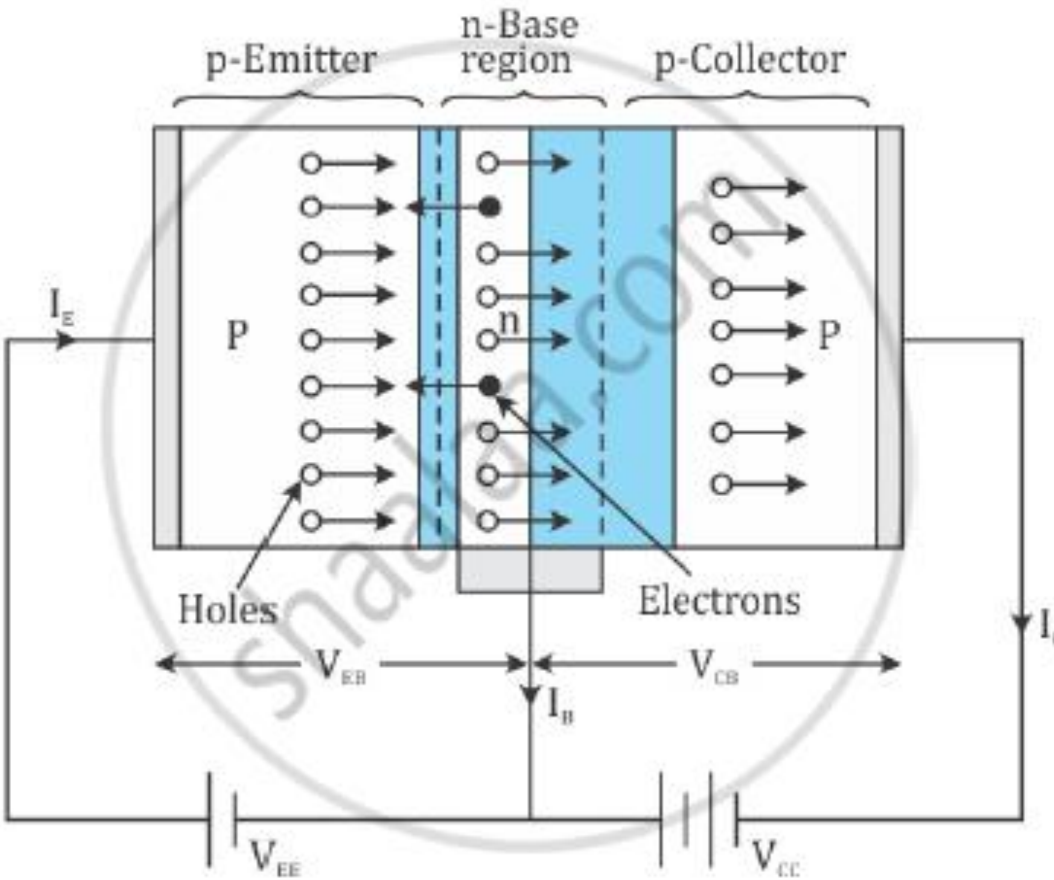
PNP transistor

Common base configuration

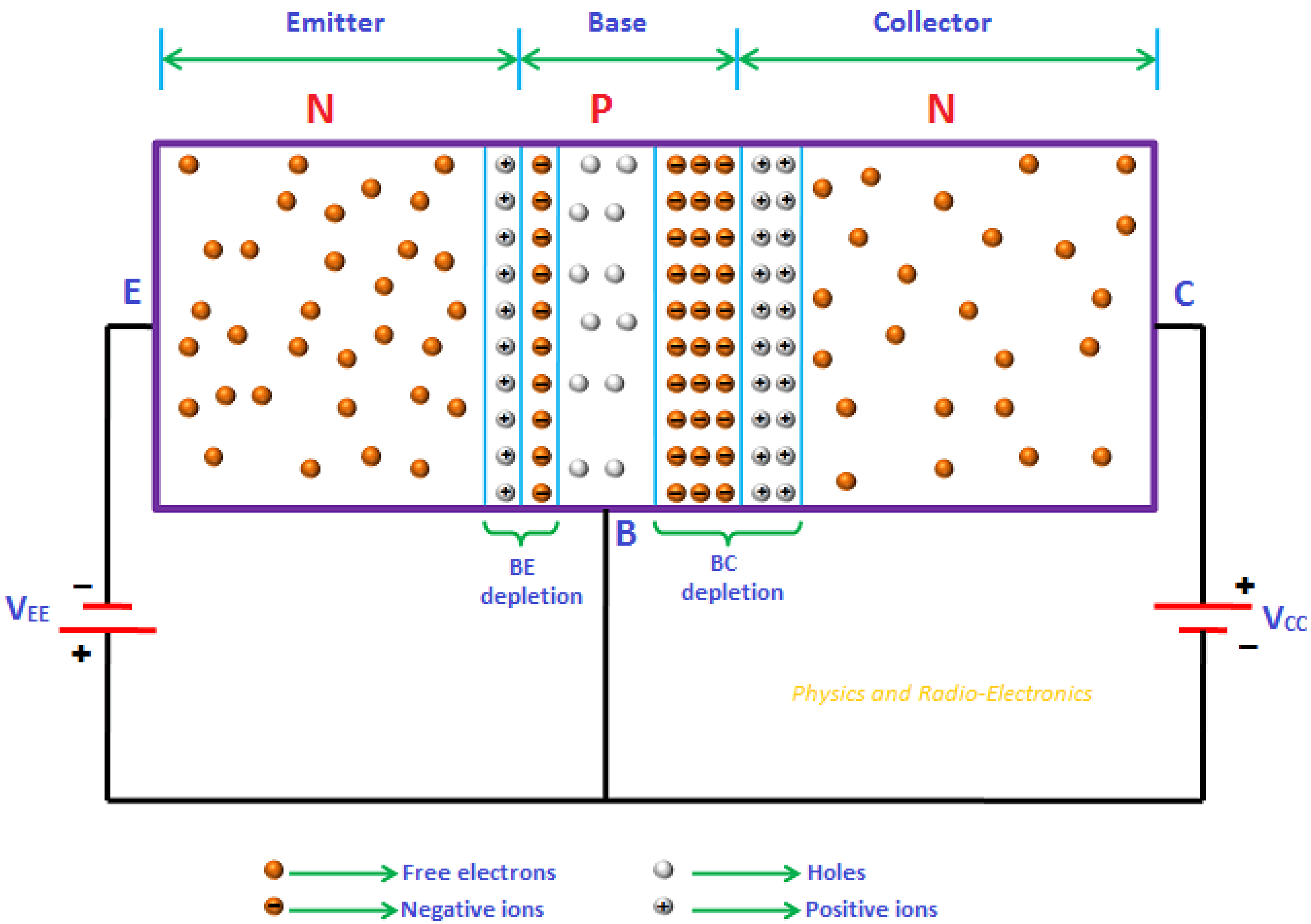
CB Configuration



CB Configuration



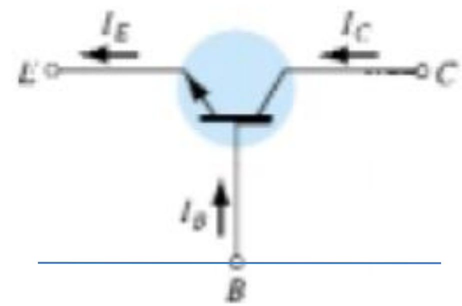
CB Configuration

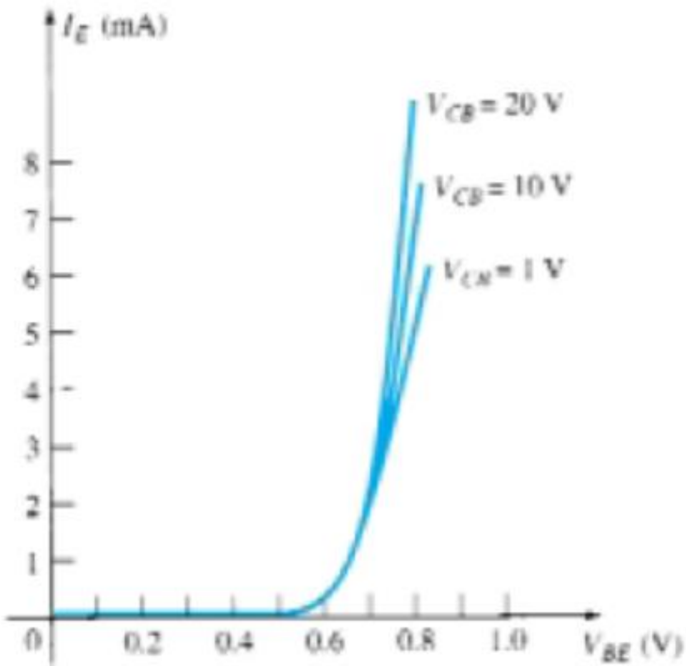


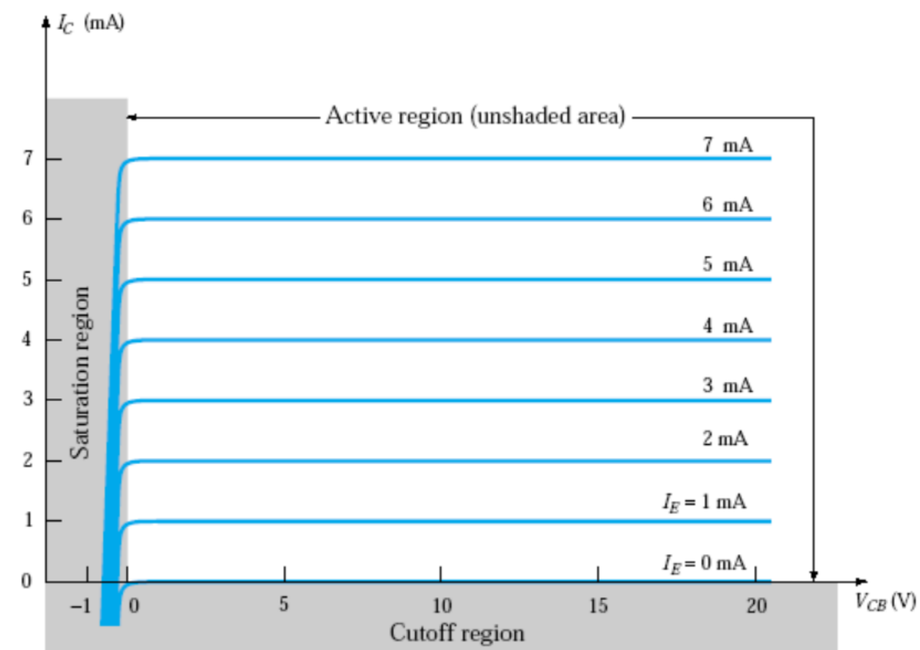
CB Configuration

The emitter current is the sum of base current and collector current.

$$I_E = I_B + I_C$$







$$R_{in} = \frac{\Delta V_{BE}}{\Delta I_E}$$

Low input impedence

BE Voltage

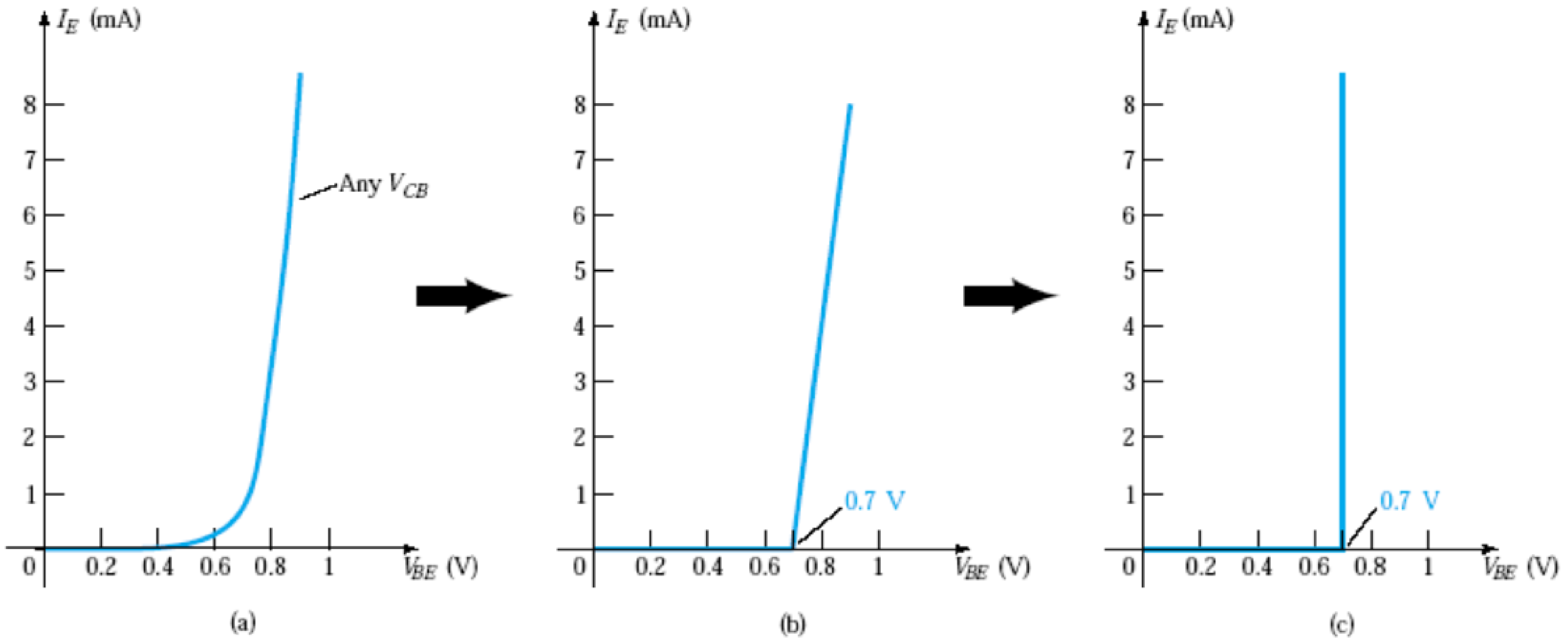


Figure 3.10 Developing the equivalent model to be employed for the base-to emitter region of an amplifier in the dc mode.

CB Configuration

Dynamic input resistance (r_i)

$$r_i = \frac{\Delta V_{BE}}{\Delta I_E}, \qquad V_{CB} = \text{constant}$$

The input resistance of common base amplifier is very low.

Dynamic output resistance (r_o)

$$r_o = \frac{\Delta V_{CB}}{\Delta I_C}, \qquad I_E = \text{constant}$$

The output resistance of common base amplifier is very high.

Alpha (α)

DC mode,

In the dc mode the levels of I_C and I_E due to the majority carriers are related by a quantity called *alpha* and defined by the following equation:

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

Generally assume 1 but practically 0.90 to 0.998

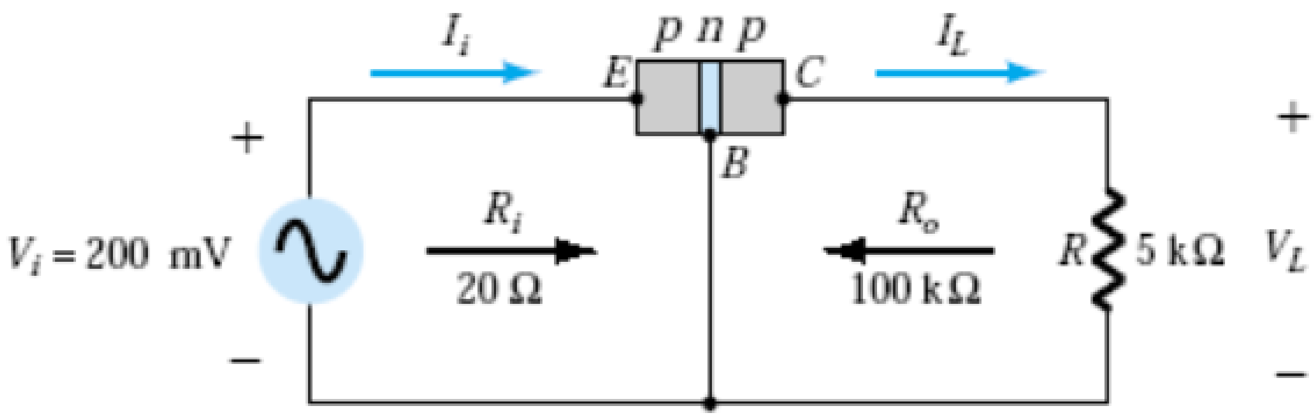
$$\boxed{I_C = \alpha I_E + I_{CBO}}$$

AC mode,

$$\boxed{\alpha_{ac} = \left.\frac{\Delta I_C}{\Delta I_E}\right|_{V_{CB} = \text{constant}}}$$

The ac alpha is formally called the *common-base, short-circuit, amplification factor*

Basic amplification action



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

If we assume for the moment that $\alpha_{ac} = 1$ ($I_c = I_e$),

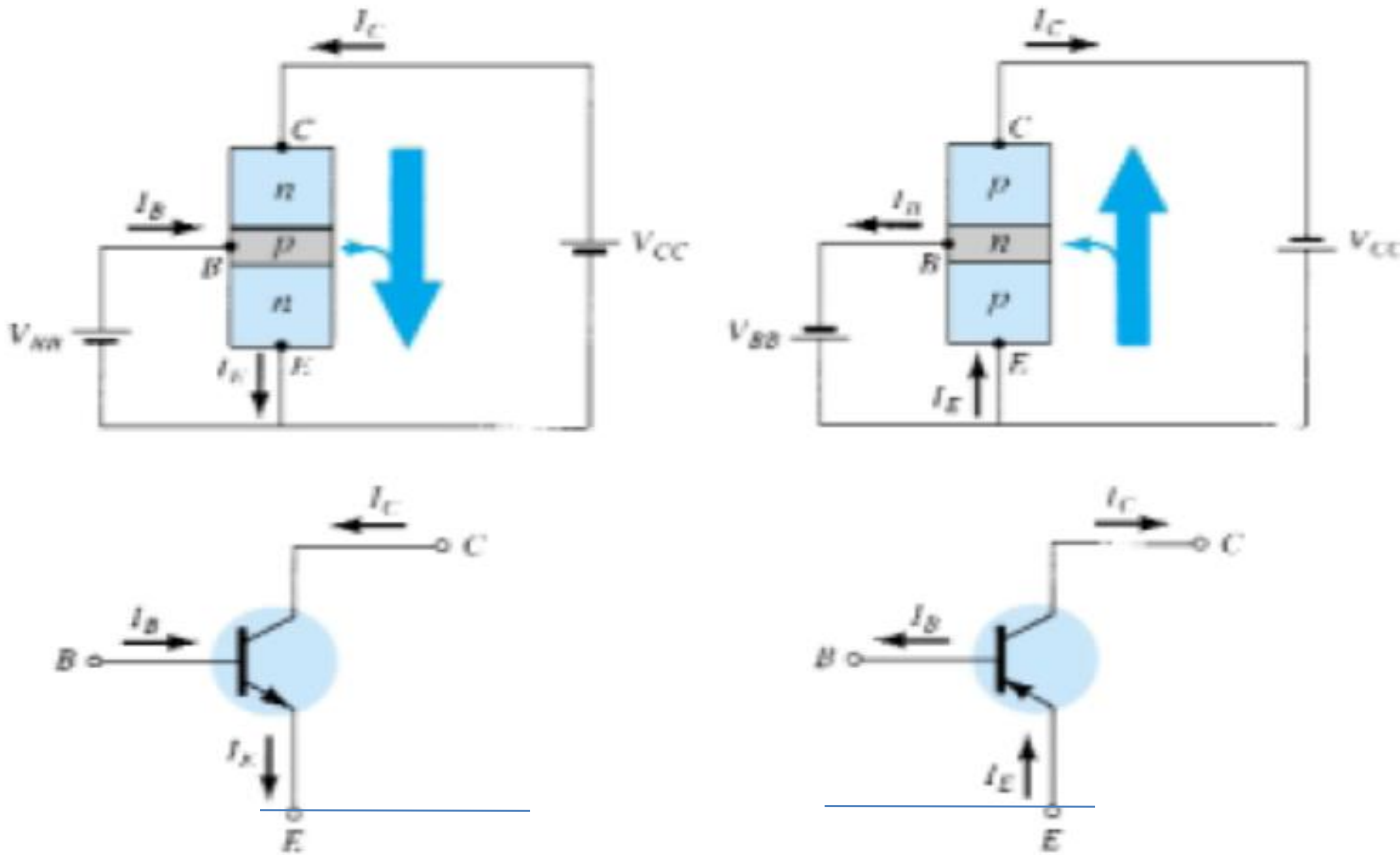
$$I_L = I_i = 10\text{ mA}$$

and

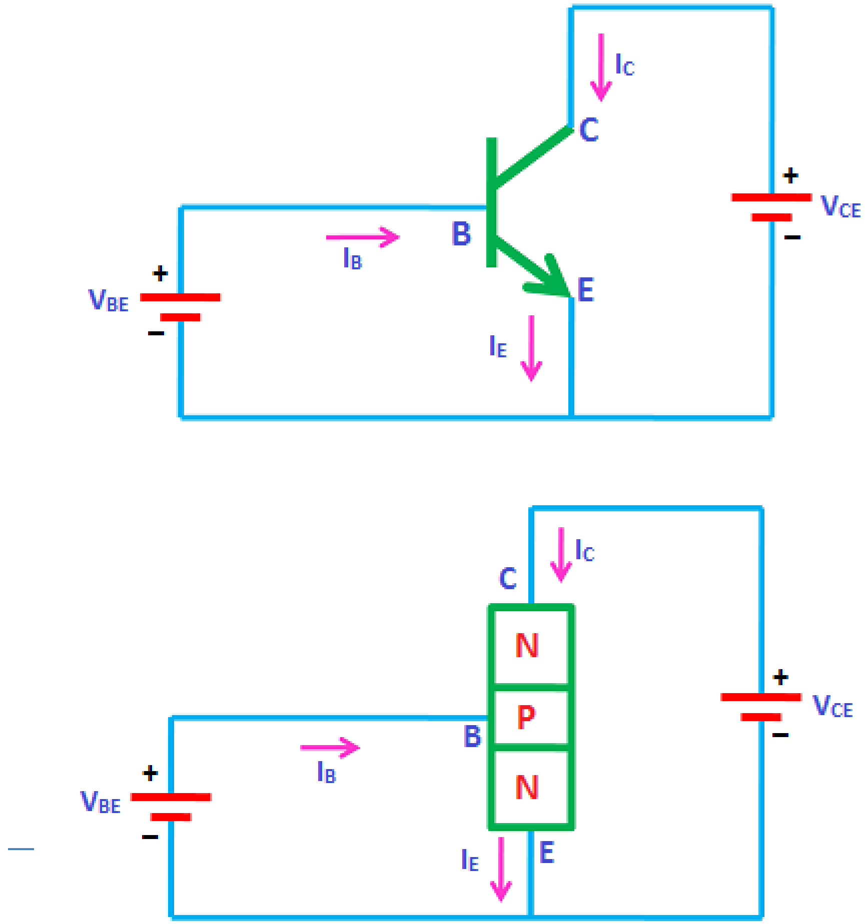
$$\begin{aligned} V_L &= I_L R \\ &= (10\text{ mA})(5\text{ k}\Omega) \\ &= \mathbf{50\ V} \end{aligned}$$

Transfer+Resistor → Transistor

CE Configuration

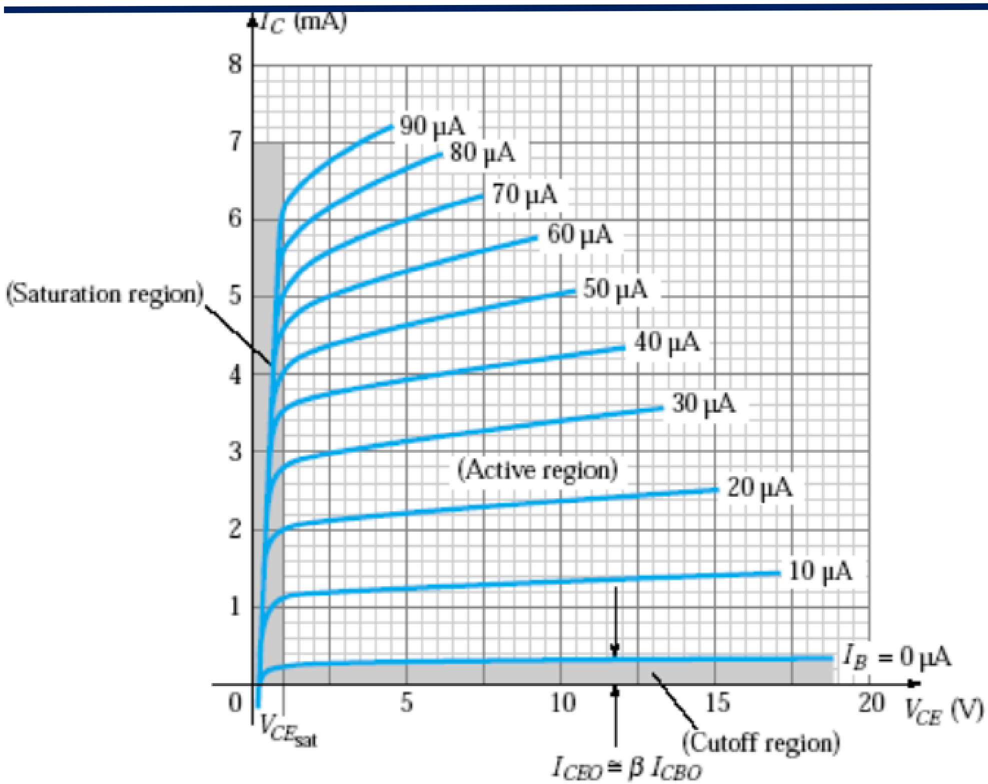


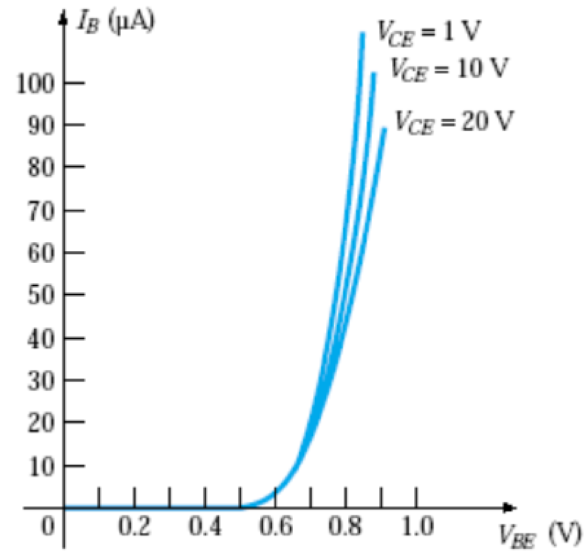
CE Configuration



Common emitter configuration

Input and output characteristics





How Ic is high when I_B=0 :

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

$$\Rightarrow I_C = \alpha (I_C + I_B) + I_{CBO}$$

$$\Rightarrow (1-\alpha) I_C = \alpha I_B + I_{CBO}$$

$$\Rightarrow I_C = \frac{\alpha}{1-\alpha} I_B + \frac{1}{1-\alpha} I_{CBO}$$

$$\Rightarrow I_C = \beta I_B + \frac{1}{1-\alpha} I_{CBO}$$

$$= \frac{1}{1-\alpha} I_{CBO}$$

$$= (\beta+1) I_{CBO}$$

$$0.95 \rightarrow 0.99$$

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

$$I_{CEO} = (\beta+1) I_{CBO}$$

$$\Rightarrow I_{CEO} = 100 \mu A$$

$$\beta = 99$$

$$I_{CBO} = 1 \mu A$$

Transistor Parameters

Moderate Current Gain

Moderate Voltage Gain

High Power Gain

Moderate Input Impedance

Moderate Output Impedance

Dynamic input resistance (r_i)

$$r_i = \frac{\Delta V_{BE}}{\Delta I_B}, \qquad V_{CE} = \text{constant}$$

In CE configuration, the input resistance is very low.

Dynamic output resistance (r_o)

$$r_o = \frac{\Delta V_{CE}}{\Delta I_C}, \qquad I_B = \text{constant}$$

In CE configuration, the output resistance is high.

Beta (β)

DC mode,

In the dc mode the levels of I_C and I_B are related by a quantity called *beta* and defined by the following equation:

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

Range: 50 to 200

AC mode,

For ac situations an ac beta has been defined as follows:

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

The formal name for β_{ac} is *common-emitter, forward-current, amplification factor.*

Relationship between α and β

$$\alpha = \frac{I_C}{I_E} \qquad \beta = \frac{I_C}{I_B}$$

$$I_E = I_C + I_B$$

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

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

$$\beta = \alpha\beta + \alpha = (\beta + 1)\alpha$$

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

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

Collector and emitter current in terms of base current

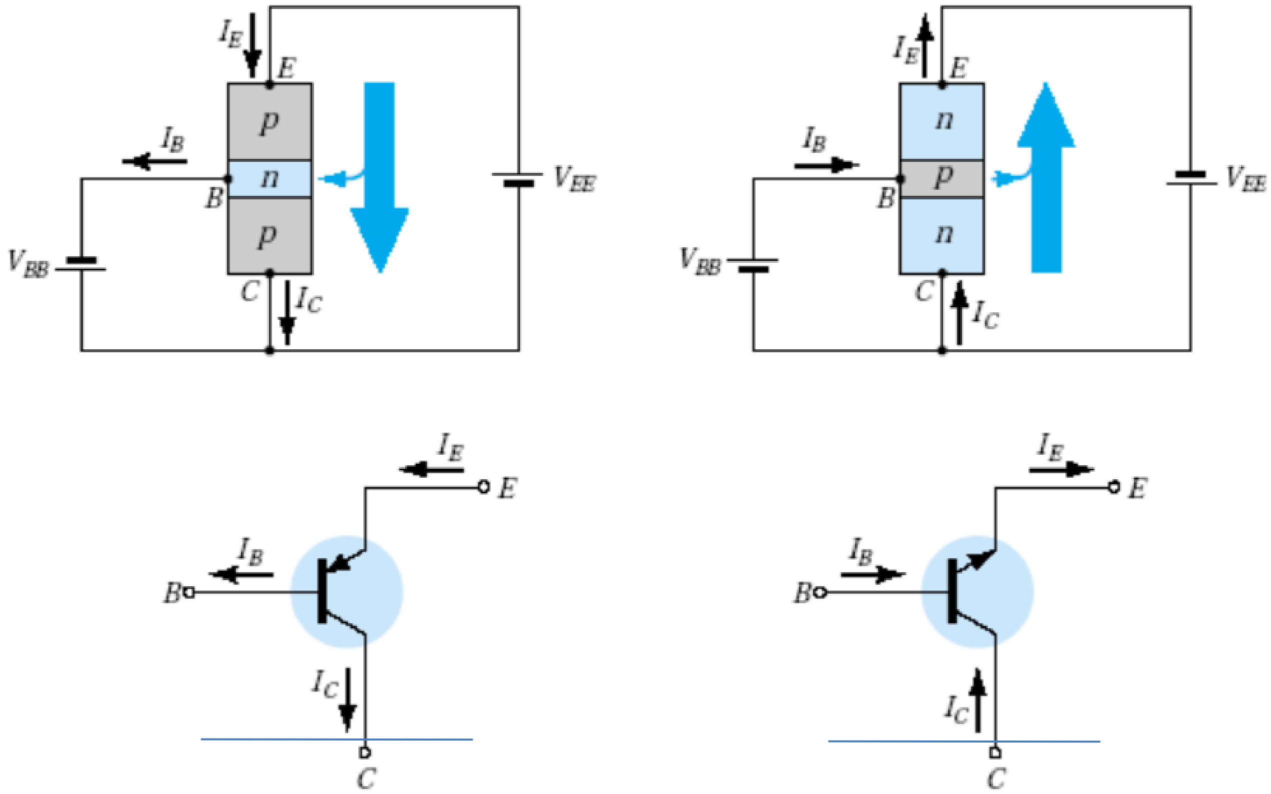
$$\boxed{I_C = \beta I_B}$$

$$I_E = I_C + I_B$$

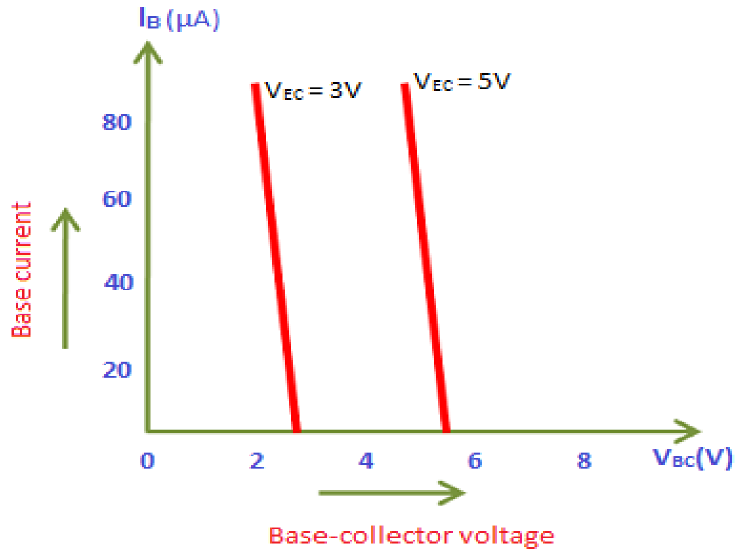
$$= \beta I_B + I_B$$

$$\boxed{I_E = (\beta + 1) I_B}$$

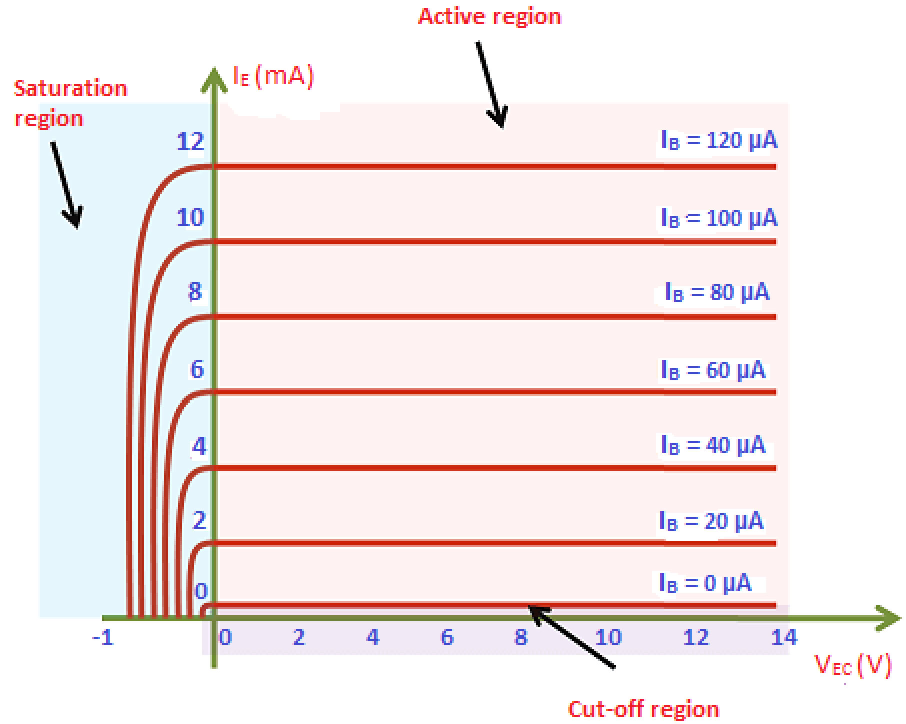
CC Configuration



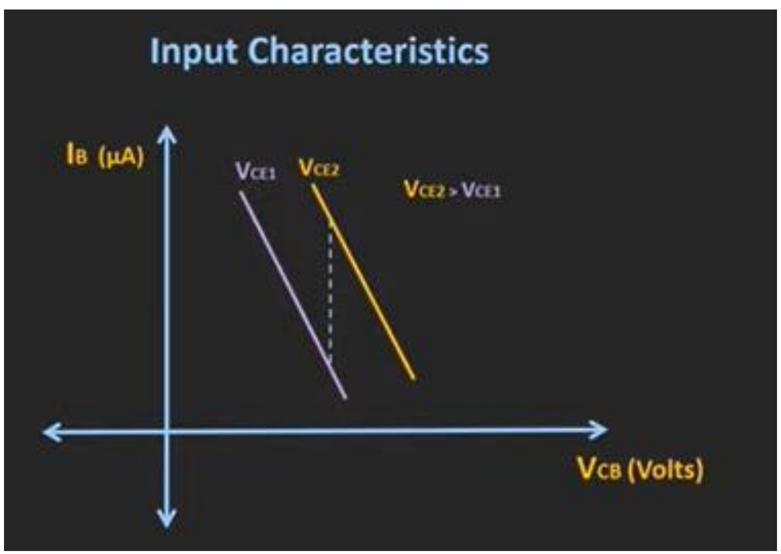
CC Configuration



Input characteristics



Output characteristics



Output characteristics is similar to CE Conf.

High Input Impedance

Low Output Impedance

High Current Gain

Low Voltage Gain

Low Power Gain

Because :

$I_E = \alpha I_C$

$I_E \simeq I_C$

CC Configuration

Dynamic input resistance (r_i)

$$r_i = \frac{\Delta V_{BC}}{\Delta I_B}, \qquad V_{EC} = \text{constant}$$

The input resistance of common collector amplifier is high.

Dynamic output resistance (r_o)

$$r_o = \frac{\Delta V_{EC}}{\Delta I_E}, \qquad I_B = \text{constant}$$

The output resistance of common collector amplifier is low.

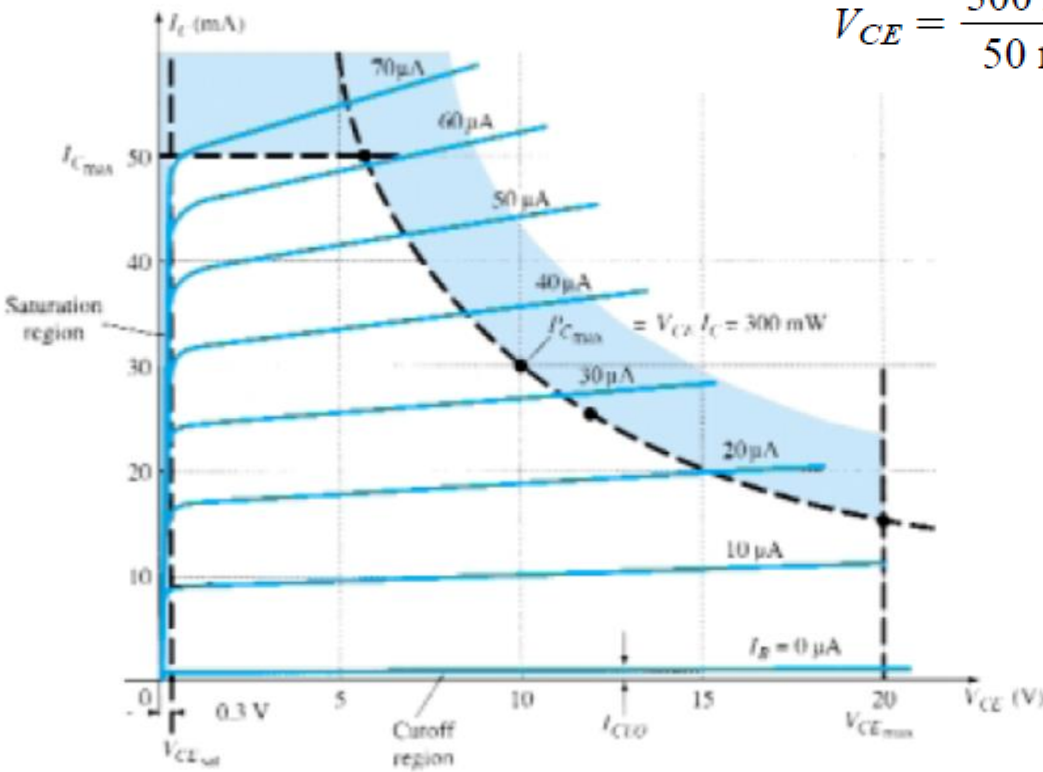
Current amplification factor (γ)

$$\gamma = \frac{\Delta I_E}{\Delta I_B}$$

The current gain of a common collector amplifier is high.

Derive the relationship among three current gain for three types of configurations

Limits of operation



$$V_{CE}I_C = 300 \text{ mW}$$

$$V_{CE}(50 \text{ mA}) = 300 \text{ mW}$$

$$V_{CE} = \frac{300 \text{ mW}}{50 \text{ mA}} = \mathbf{6\ V}$$

$$(20 \text{ V})I_C = 300 \text{ mW}$$

$$I_C = \frac{300 \text{ mW}}{20 \text{ V}} = \mathbf{15\ mA}$$

$$V_{CE}(25 \text{ mA}) = 300 \text{ mW}$$

$$V_{CE} = \frac{300 \text{ mW}}{25 \text{ mA}} = \mathbf{12\ V}$$

$$I_{CEO} \leqq \boldsymbol{I_C} \leqq I_{C_{max}}$$

$$V_{CE_{sat}} \leqq \boldsymbol{V_{CE}} \leqq V_{CE_{max}}$$

$$\boldsymbol{V_{CE}I_C} \leqq P_{C_{max}}$$

Terminal Identification

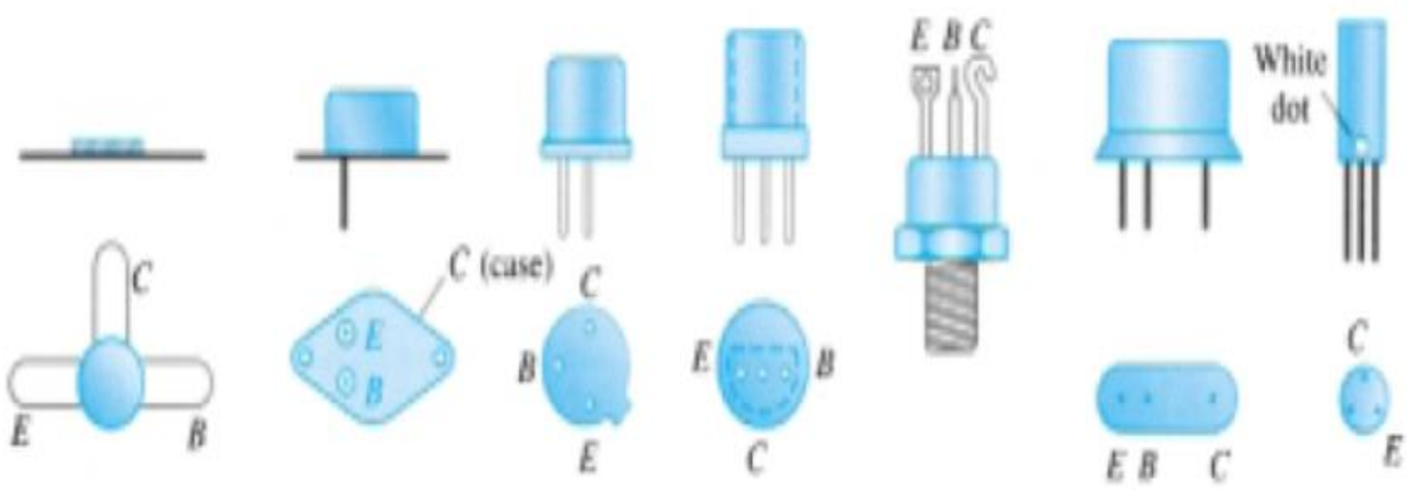
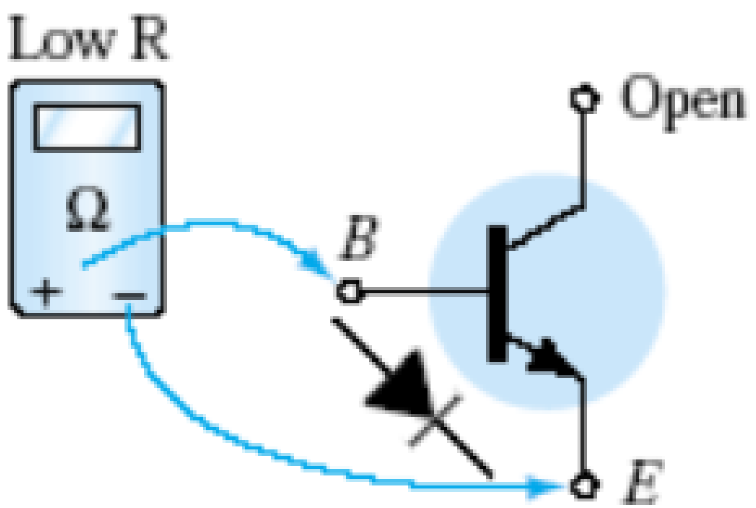
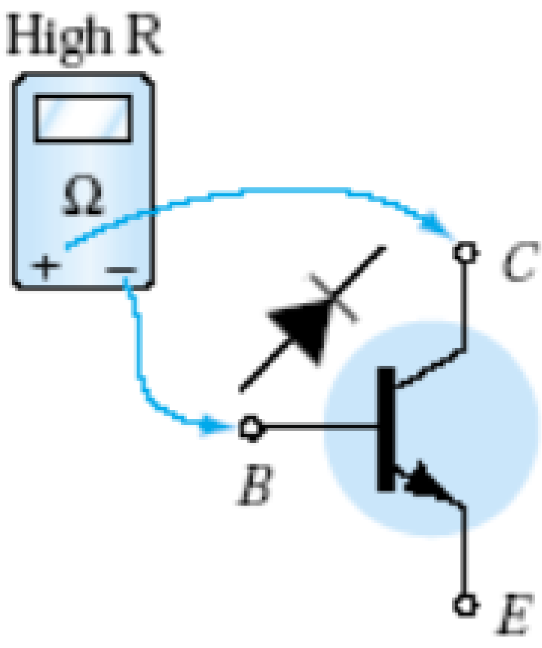


Figure 3.30 Transistor terminal identification.

Transistor tester: Use of Ohmmeter





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