BIPOLAR JUNCTION TRANSISTOR (BJT)

Chapter 3

Reference book: Electronic Devices and Circuit Theory

(11th Edition) Robert F. Boylestad

Revised by Dr. Md. Rifat Hazari

Desk # D Building (5th Floor)

E-mail: rifat@aiub.edu

OBJECTIVES

- Become familiar with the basic construction and operation of the Bipolar Junction Transistor.
- Be able to apply the proper biasing to insure operation in the active region.
- Recognize and be able to explain the characteristics of an npn or pnp transistor.
- Become familiar with the important parameters that define the response of a transistor.
- Be able to test a transistor and identify the three terminals.

INTRODUCTION

- The basic of electronic system nowadays is semiconductor device.
- The famous and commonly use of this device is BJTs (Bipolar Junction Transistors).
- It can be used as amplifier and logic switches.
- BJT consists of three terminal:
  - collector : C (Lightly Doped)
  - base : B (Very lightly doped)
  - emitter : E (Heavily doped)

- Two types of BJT : p-n-p and n-p-n

TRANSISTOR CONSTRUCTION

- 3 layer semiconductor device consisting:
    - 2 n- and 1 p-type layers of material = n-p-n transistor
    - 2 p- and 1 n-type layers of material = p-n-p transistor

- The term bipolar reflects the fact that ***holes and electrons participate*** in the injection process into the oppositely polarized material.

- A single p-n junction has two different types of bias:
    - forward bias
    - reverse bias

- Thus, a two-p-n-junction device has four types of bias.

POSITION OF THE TERMINALS AND SYMBOL OF BJT

- Base is located at the middle and more thin from the level of collector and emitter.

- The emitter and collector terminals are made of the same type of semiconductor material, while the base of the other type of material.

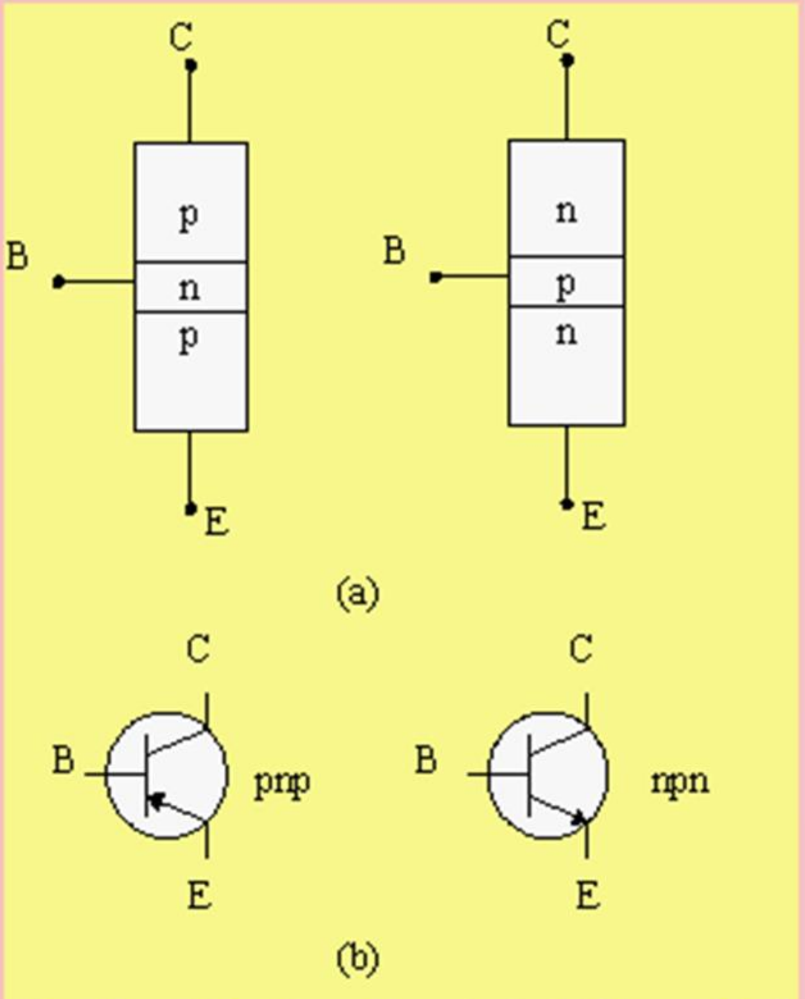


Fig. 4.1: (a) Position of terminals (b) Type of BJT

TRANSISTOR OPERATION

- The basic operation will be described using the p-n-p transistor. The operation of the n-p-n transistor is exactly the same if the roles played by the electron and hole are interchanged.
- One p-n junction of a transistor is reverse-biased, whereas the other is forward-biased.

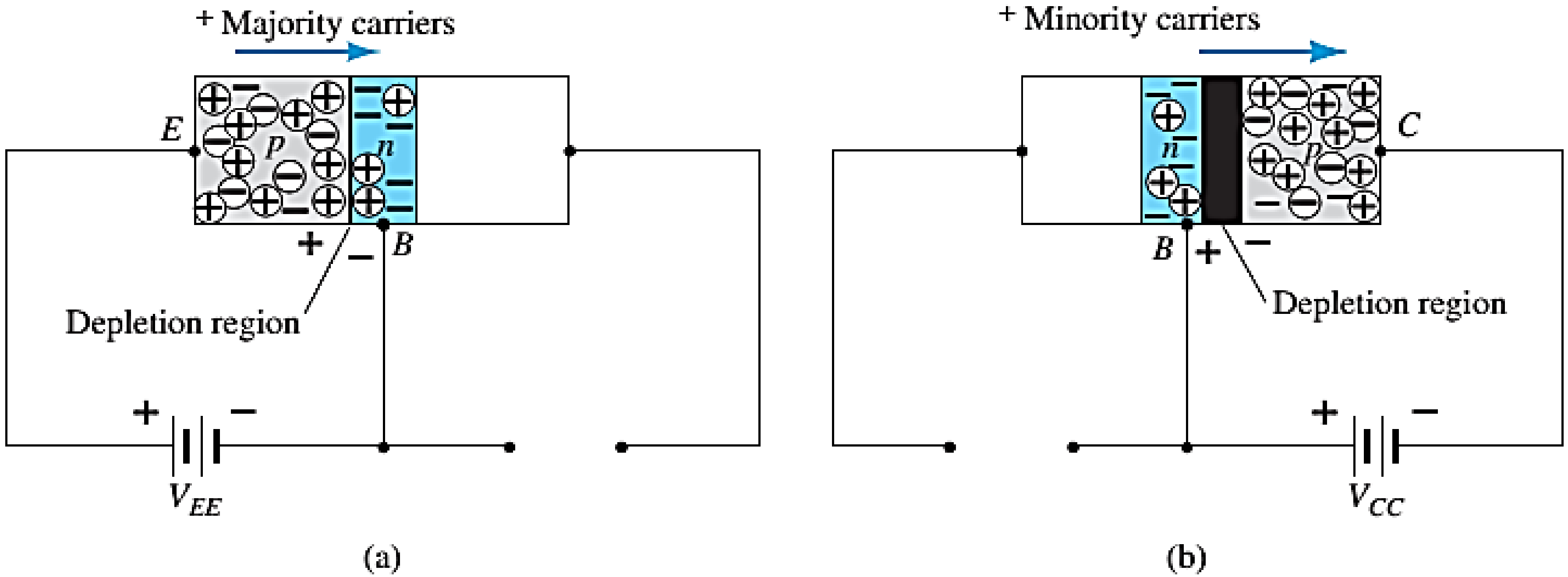


FIG. 3.4

Biasing a transistor: (a) forward-bias; (b) reverse-bias.

TRANSISTOR OPERATION CONTD.

- Both biasing potentials have been applied to a p-n-p transistor and resulting majority and minority carrier flows indicated.
- Majority carriers (+) will diffuse across the forward-biased p-n junction into the n-type material.
- A very small number of carriers (+) will go through n-type material to the base terminal. Resulting IB is typically in order of microamperes.
- The large number of majority carriers will diffuse across the reverse-biased junction into the p-type material connected to the collector terminal.

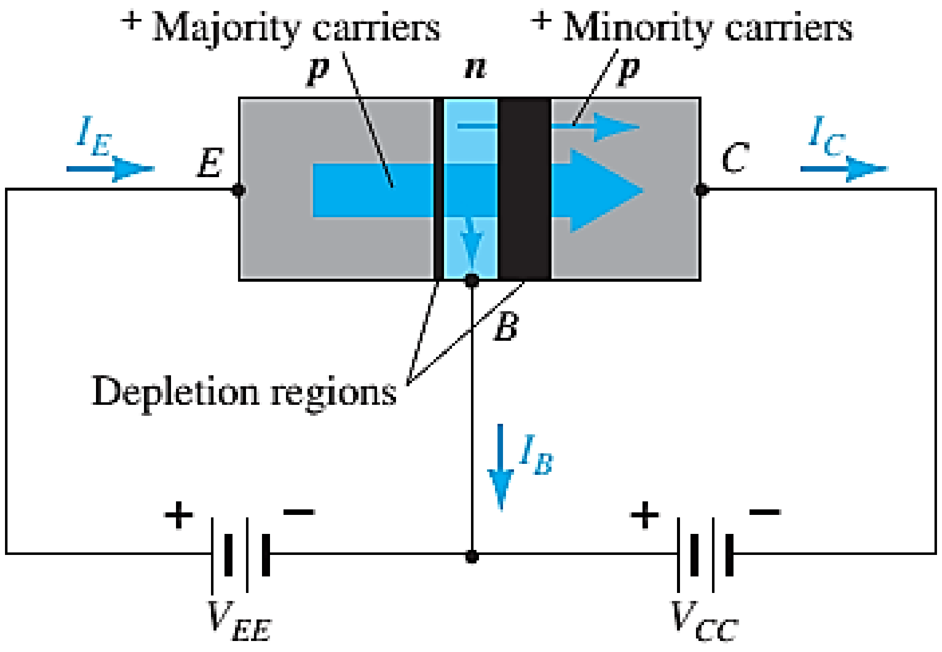


FIG. 3.5
Majority and minority carrier flow of a pnp transistor.

TRANSISTOR OPERATION CONTD.

- Majority carriers can cross the reverse-biased junction because the injected majority carriers will appear as minority carriers in the n-type material.

- Applying KCL to the transistor :

$$\boxed{I_E = I_C + I_B}$$

- The collector current comprises of two components – the majority and minority carriers

$$\boxed{I_C = I_{C_{\text{majority}}} + I_{CO_{\text{minority}}}}$$

- I_{CO} = I_C current with emitter terminal open and is called ***leakage current.***

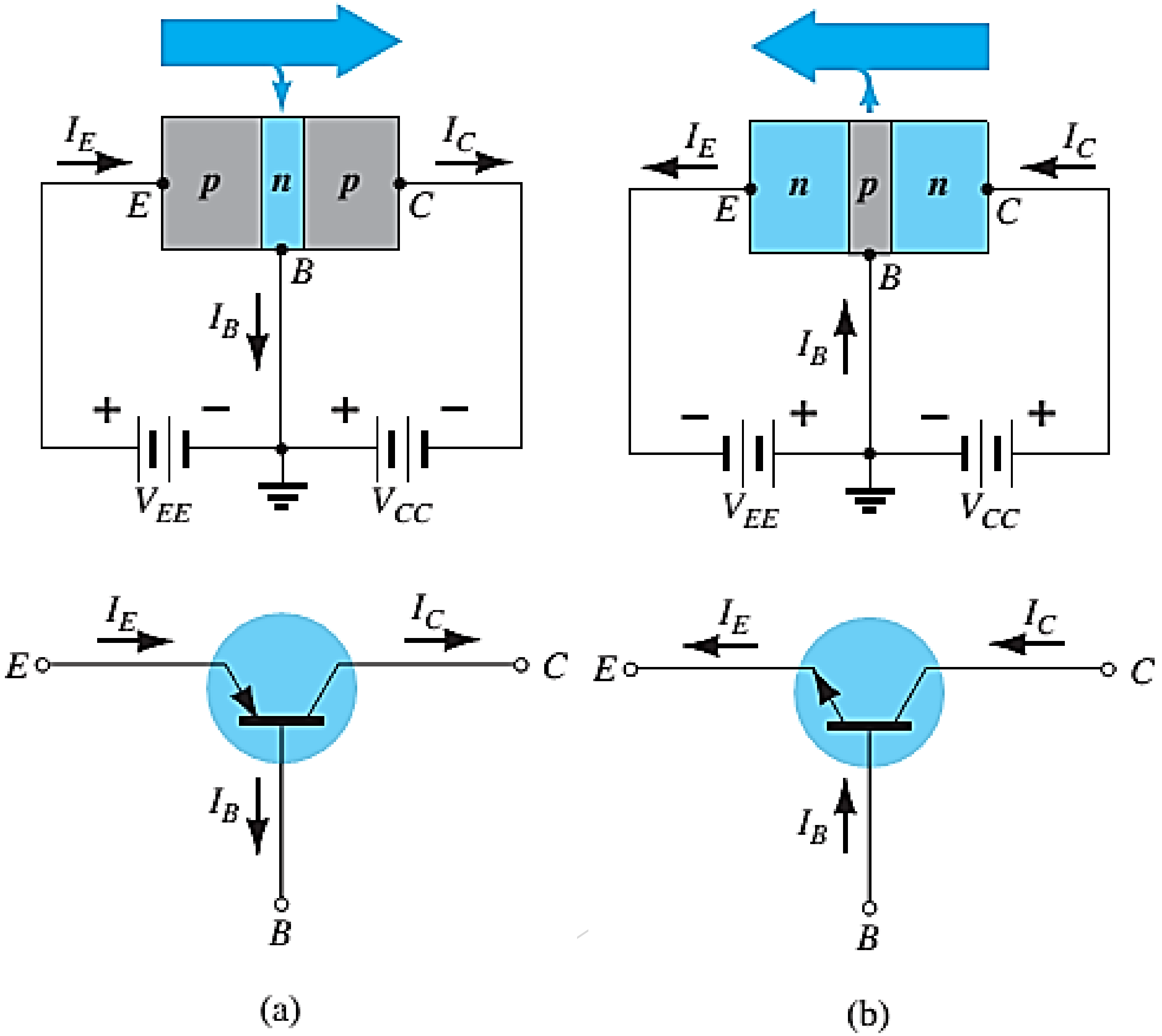
COMMON-BASE CONFIGURATION

- Common-base terminology is derived from the fact that the :

  - base is common to both input and output of the configuration.

  - base is usually the terminal closest to or at ground potential.

- All current directions will refer to conventional (hole) flow and the arrows in all electronic symbols have a direction defined by this convention.
- Note that the applied biasing (voltage sources) are such as to establish current in the direction indicated for each branch.



Notation and symbols used with the common-base configuration: (a) pnp transistor; (b) npn transistor.

COMMON-BASE CONFIGURATION CONTD.

- To describe the behavior of common-base amplifiers requires two set of characteristics:
  - Input or driving point characteristics.
  - Output or collector characteristics

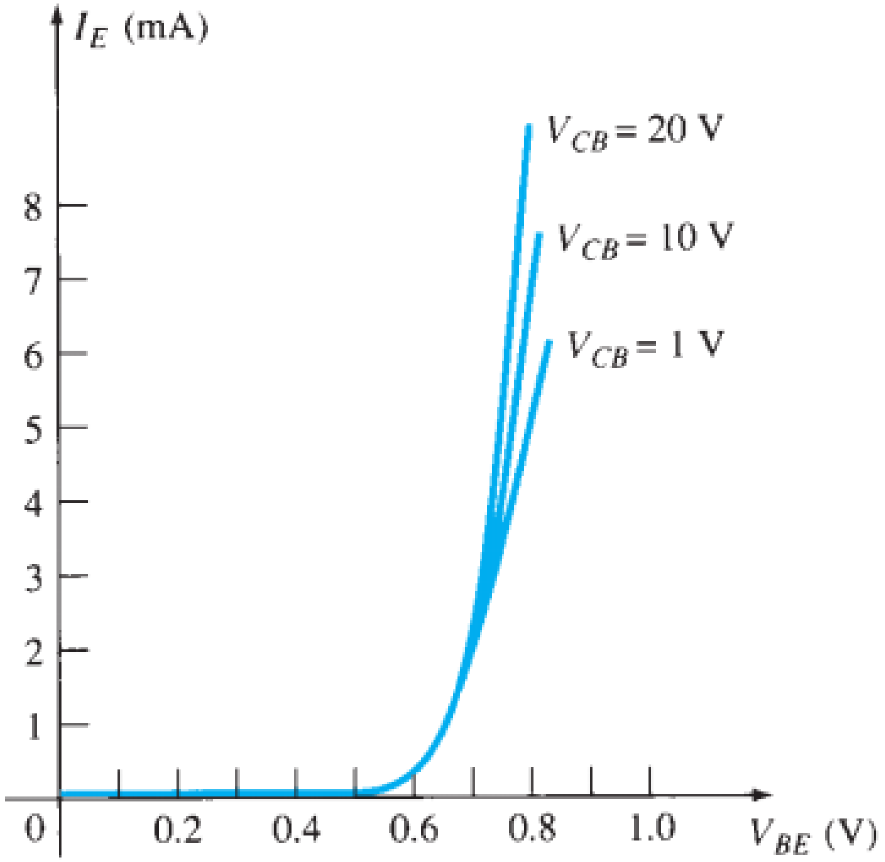


FIG. 3.7

Input or driving point characteristics for a common-base silicon transistor amplifier.

COMMON-BASE CONFIGURATION CONTD.

- The output characteristics has 3 basic regions:
  - Active region – defined by the biasing arrangements
  - Cutoff region – region where the collector current is 0A
  - Saturation region- region of the characteristics to the left of V_{CB} = 0V

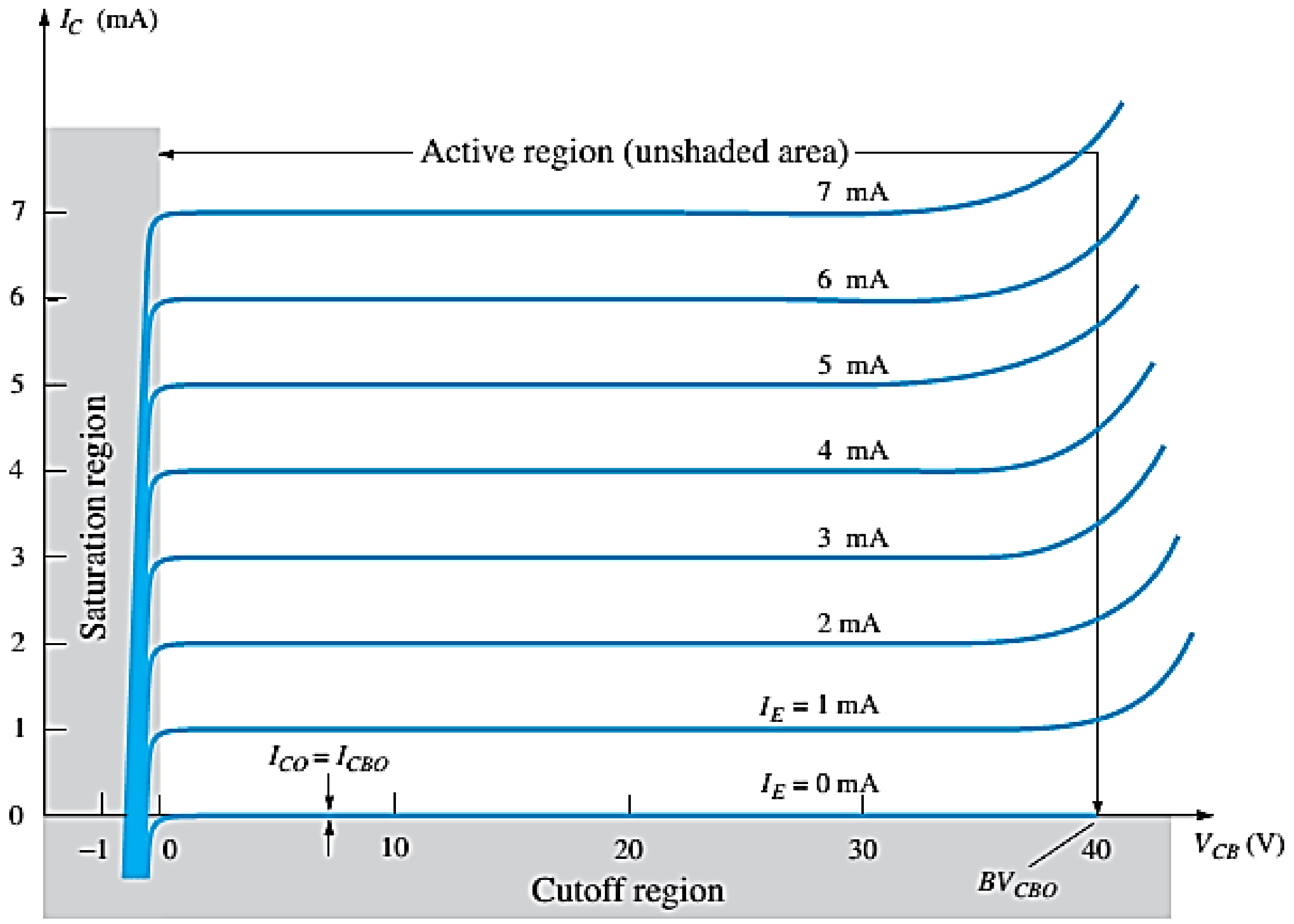


FIG. 3.8
Output or collector characteristics for a common-base transistor amplifier.

COMMON-BASE CONFIGURATION CONTD.

ACTIVE REGION	SATURATION REGION	CUTOFF REGION
I_E increased, I_C increased		
BE junction forward biased and CB junction reverse biased	BE and CB junctions are forward biased	BE and CB junction are reverse biased
$I_C \approx I_E$		No current flow at collector, only leakage current
I_C does not depend on V_{CB}	Small change in V_{CB} will cause big difference in I_C	
Suitable region for the transistor to work as an amplifier	The allocation for this region is to the left of the V_{CB} = 0 V	Region below the line of $I_E = 0$

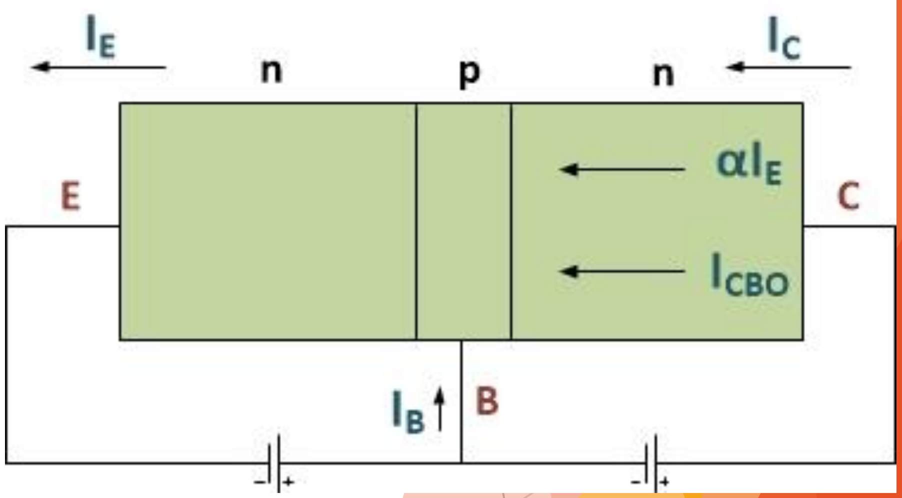
COMMON-BASE CONFIGURATION CONTD.

- The curves (output characteristics) clearly indicate that a first approximation to the relationship between I_E and I_C in the active region is given by

$$I_C \approx I_E$$

- Once a transistor is in the 'on' state, the base-emitter voltage will be assumed to be

$$V_{BE} = 0.7V$$



- In the dc mode the level of I_C and I_E due to the majority carriers are related by a quantity called alpha

$$\alpha = \frac{I_C}{I_E}$$

$$I_E = I_C + I_B$$

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

COMMON-BASE CONFIGURATION CONTD.

- It can then be summarize to $I_C = \alpha I_E$(ignore I_{CBO} due to small value)

- For ac situations where the point of operation moves on the characteristics curve, an ac alpha defined by

$$\alpha = \frac{\Delta I_C}{\Delta I_E}$$

- Alpha a common base current gain factor that shows the efficiency by calculating the current percent from current flow from emitter to collector. The value of α is typical from 0.9 ~ 0.998.

BIASING

- The proper biasing of the common-base configuration in the active region can be determined quickly using the approximation $I_C \cong I_E$ and assuming for the moment that $I_B \cong 0$ mA.
- The result is the configuration of Fig. 3.11 for the pnp transistor.
- For the npn transistor the polarities will be reversed.

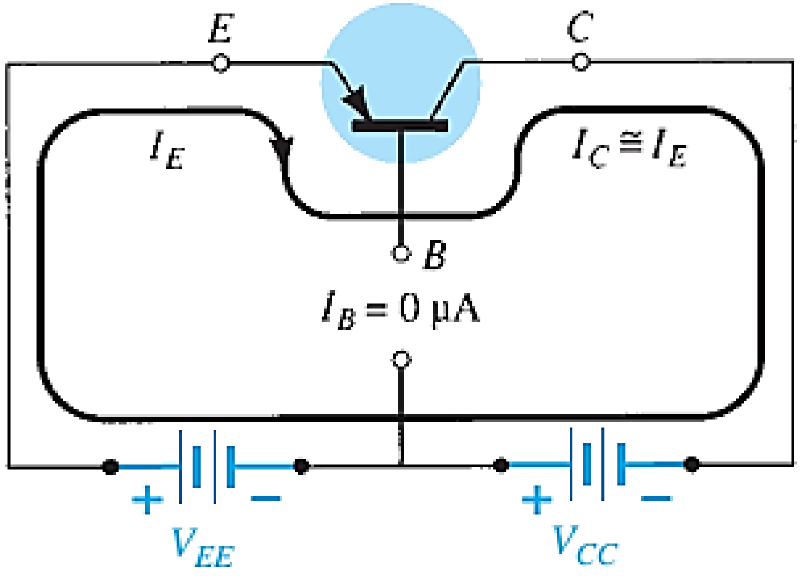


FIG. 3.11
Establishing the proper biasing management for a common-base pnp transistor in the active region.

COMMON-EMITTER CONFIGURATION

- It is called common-emitter configuration since :
  - emitter is common or reference to both input and output terminals.
  - emitter is usually the terminal closest to or at ground potential.

- Almost all amplifier design is using connection of CE due to the high gain for current and voltage.

- Two set of characteristics are necessary to describe the behavior for CE:
  - input (base terminal) and
  - output (collector terminal) parameters.

COMMON-EMITTER CONFIGURATION CONTD.

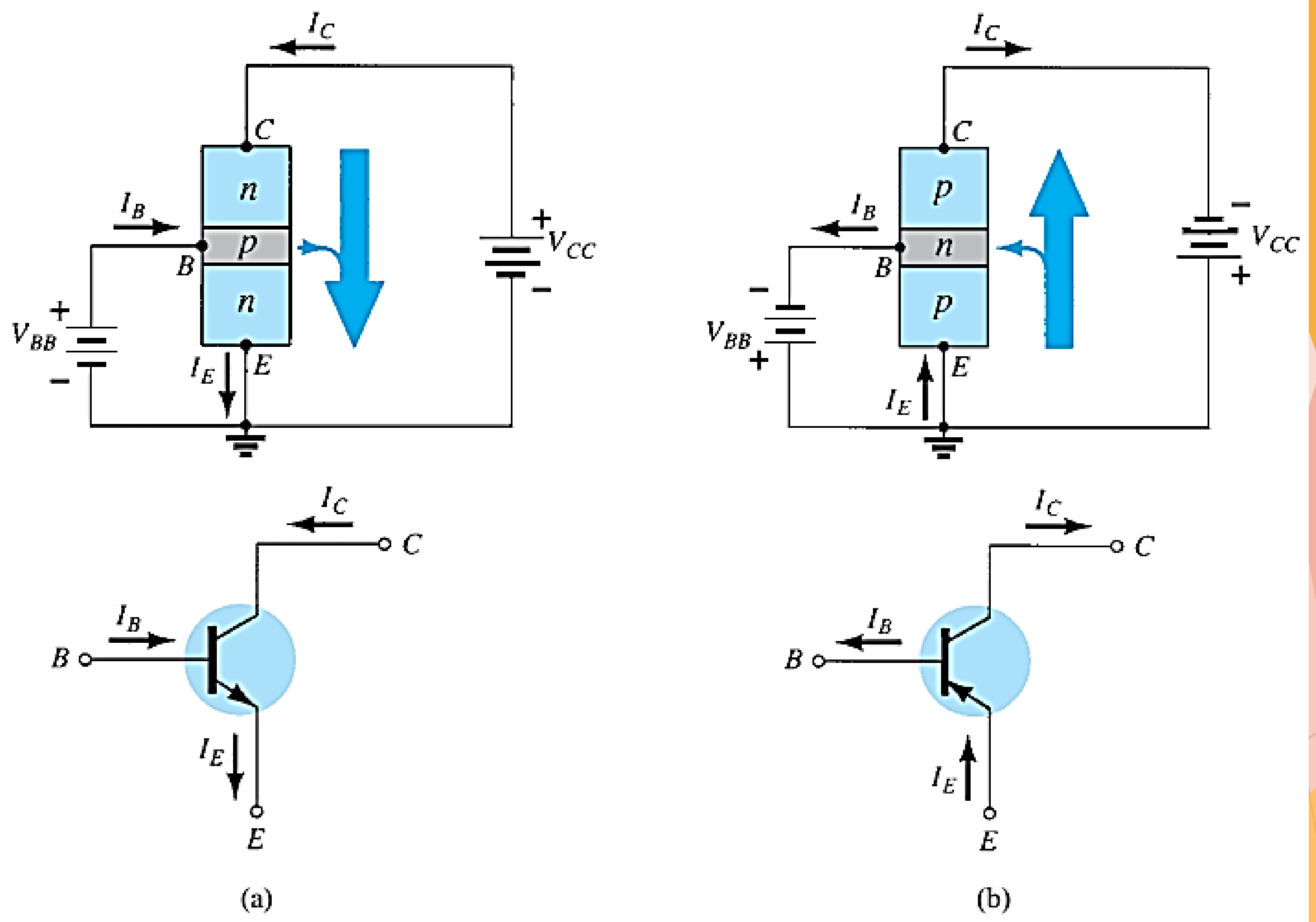
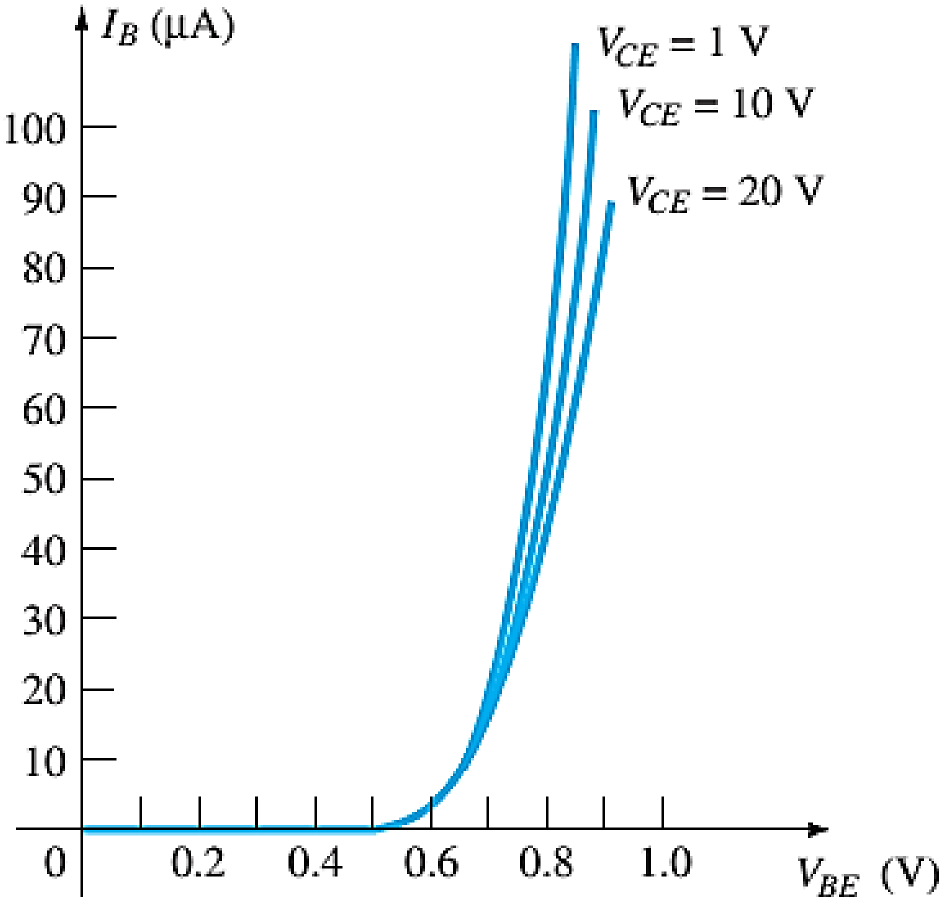


FIG. 3.12

Notation and symbols used with the common-emitter configuration: (a) npn transistor; (b) pnp transistor.

COMMON-EMITTER CONFIGURATION CONTD.

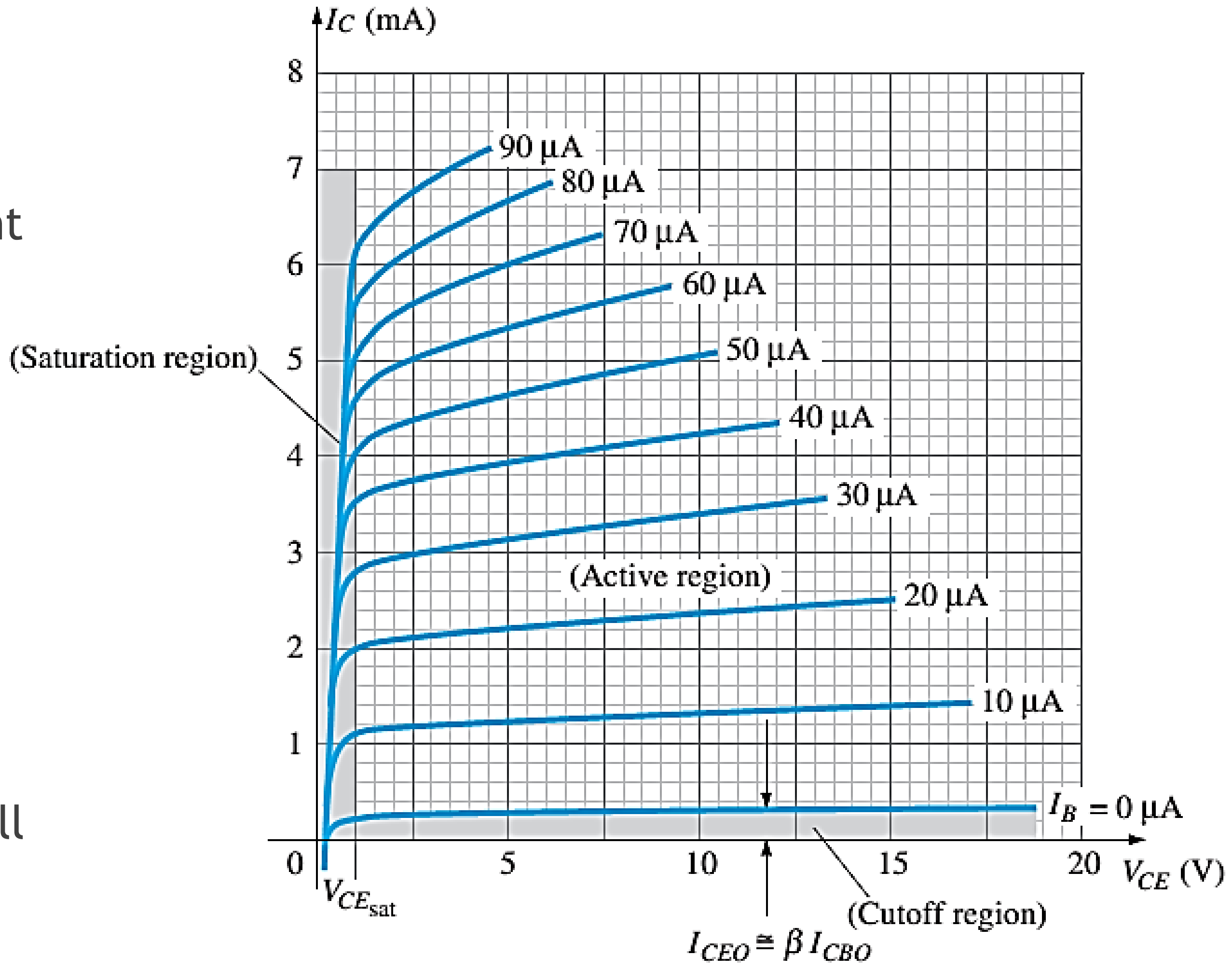
- I_B is microamperes compared to milliamperes of I_C.
- I_B will flow when V_{BE} > 0.7V for silicon and 0.3V for germanium
- Before this value I_B is very small.
- Base-emitter junction is forward bias
- Increasing V_{CE} will reduce I_B for different values.



Input characteristics for a common-emitter n-p-n transistor

COMMON-EMITTER CONFIGURATION CONTD.

- For small V_{CE} ($V_{CE} < V_{CESAT}$, I_C increase linearly with increasing of V_{CE}
- $V_{CE} > V_{CESAT,}$ Independent of V_{CE} → constant I_C
- I_B(uA) is very small compare to I_C (mA). Small increase in I_B cause big increase in I_C
- I_B=0 A → I_{CEO} occur.
- Noticing the value when I_B=0A. There is still some value of current flows.



Output characteristics for a common-emitter n-p-n transistor

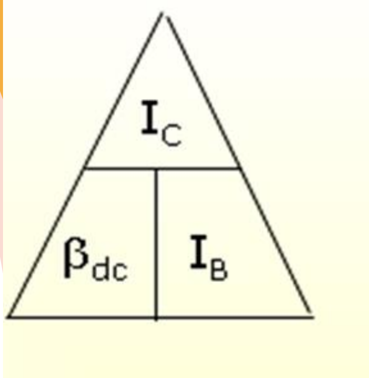
COMMON-EMITTER CONFIGURATION CONTD.

ACTIVE REGION	SATURATION REGION	CUTOFF REGION
BE junction is forward biased	BE and CB junctions are forward biased, thus the values of I_B and I_C is too big	Region below I_B = 0 μA is to be avoided if an undistorted output signal is required
CB junction is reverse biased	The value of V_{CE} is too small	BE junction and CB junctions are reverse biased
Can e employed for voltage, current and power amplification	Suitable region when the transistor is used a logic switch	$I_B = 0$, I_C not zero, during this condition $I_C = I_{CEO}$ where this is the current flow when BE is reverse biased
	NOT and avoid this region when the transistor as an amplifier	

BETA (Β) OR AMPLIFICATION FACTOR

- The ratio of dc collector current (I_C) to the dc base current (I_B) is dc beta (β_{dc}) which is dc current gain where I_C and I_B are determined at a particular operating point, Q-point (quiescent point).
- It's define by the following equation:

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



- On data sheet, $\beta_{dc}=h_{FE}$ with h is derived from ac hybrid equivalent cct. FE are derived from forward-current amplification and common-emitter configuration respectively.
- For ac conditions an ac beta has been defined as the changes of collector current (I_C) compared to the changes of base current (I_B) where I_C and I_B are determined at operating point.
- It can defined by the following equation:

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

RELATIONSHIP ANALYSIS BETWEEN α AND β

A relationship can be developed between β and α using the basic relationships introduced thus far. Using $\beta = I_C/I_B$, we have $I_B = I_C/\beta$, and from $\alpha = I_C/I_E$ we have $I_E = I_C/\alpha$. Substituting into

$$I_E = I_C + I_B$$

we have

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

and dividing both sides of the equation by I_C results in

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

or

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

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

COMMON-COLLECTOR CONFIGURATION

- Also called emitter-follower (EF).
- It is called common-collector configuration since both the signal source and the load share the collector terminal as a common connection point.
- The output voltage is obtained at emitter terminal.
- The input characteristic of common-collector configuration is similar with common-emitter configuration.
- Common-collector circuit configuration is provided with the load resistor connected from emitter to ground.
- It is used primarily for impedance-matching purpose since it has high input impedance and low output impedance.

COMMON-COLLECTOR CONFIGURATION CONTD.

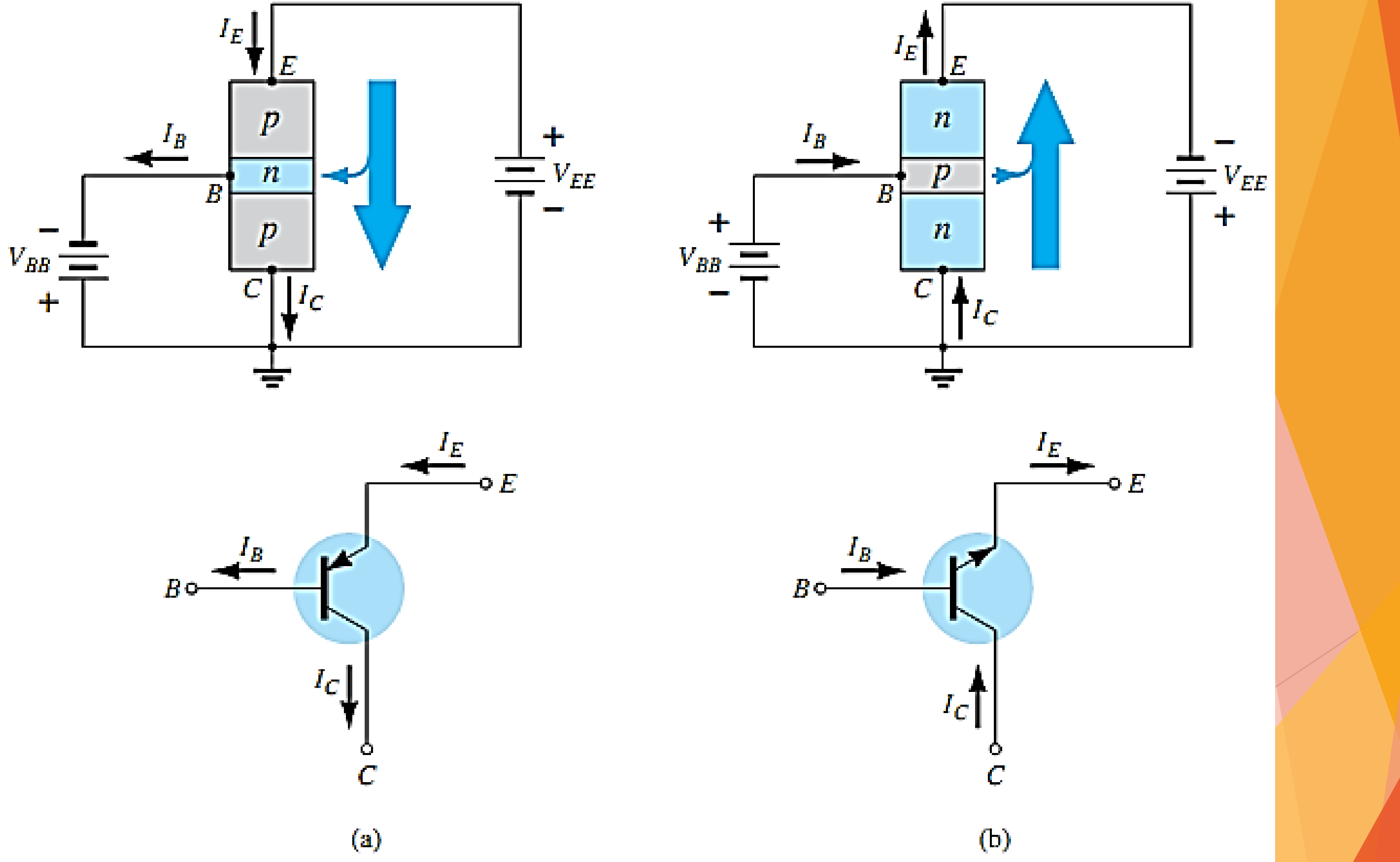


FIG. 3.20

Notation and symbols used with the common-collector configuration: (a) pnp transistor; (b) npn transistor.

LIMITS OF OPERATION

- Many BJT transistor used as an amplifier. Thus it is important to notice the limits of operations.
- At least 3 maximum values is mentioned in data sheet.
- There are:
  a) Maximum power dissipation at collector: P_{Cmax} or P_D
  b) Maximum collector-emitter voltage: V_{CEmax} ;sometimes named as $V_{(BR)CEO}$ or V_{CEO}.
  c) Maximum collector current: I_{cmax}
- There are few rules that need to be followed for BJT transistor used as an amplifier. The rules are:
  i. transistors need to operate in active region!
  ii. $I_C < I_{cmax}$
  iii. $P_C < P_{Cmax}$

LIMITS OF OPERATION

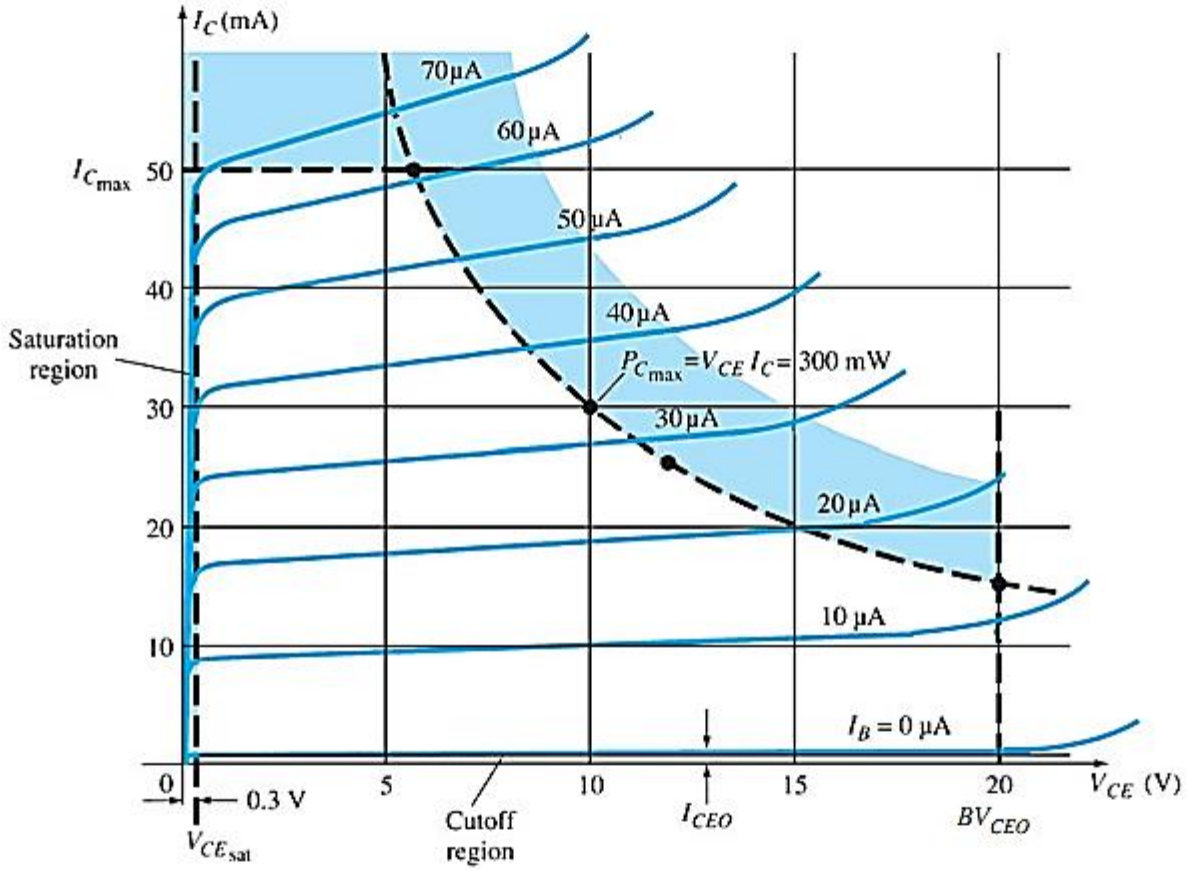


FIG. 3.22
Defining the linear (undistorted) region of operation for a transistor.

Note: 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.

END OF CHAPTER 3