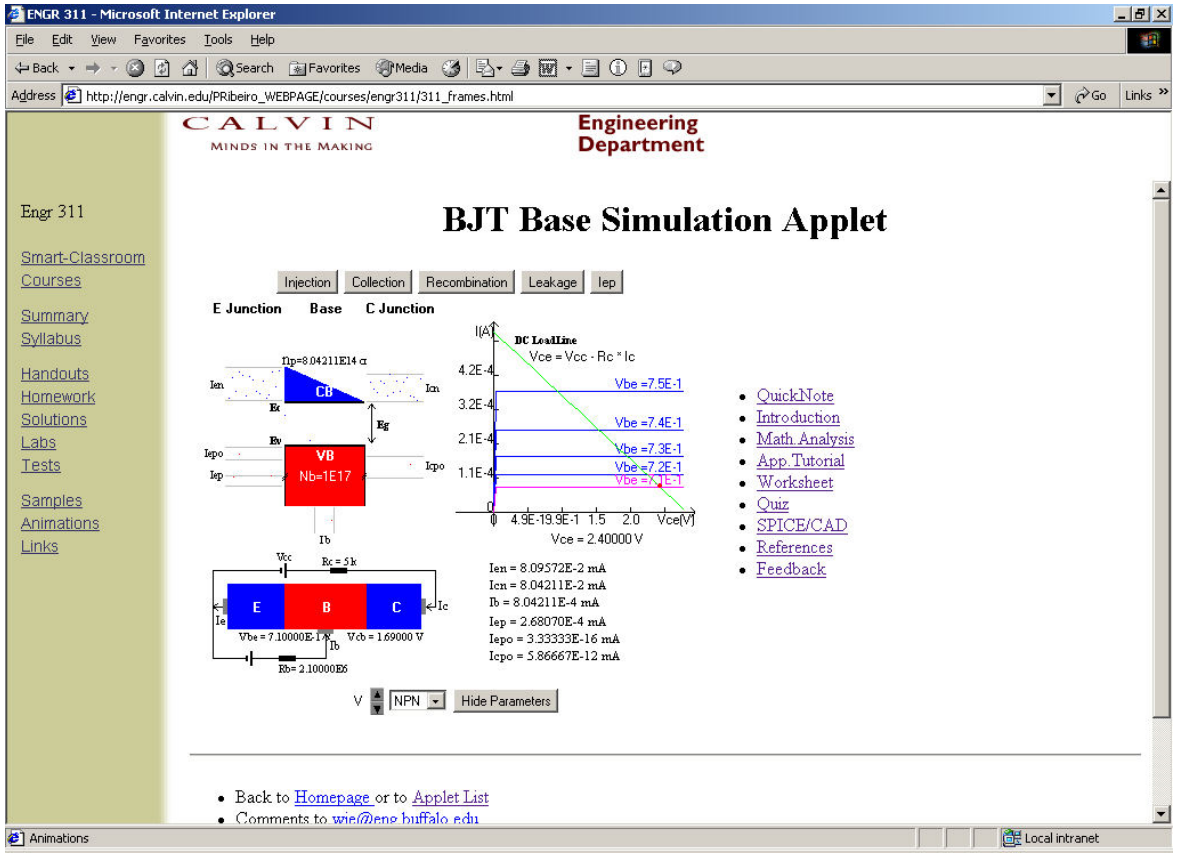
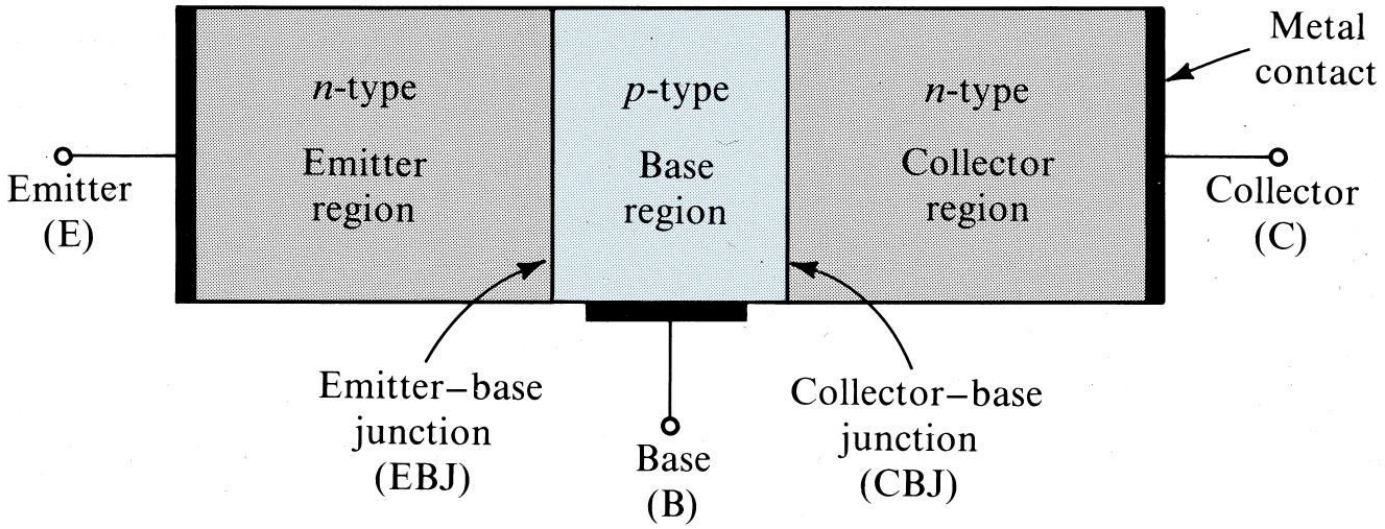
Chapter 4 – Bipolar Junction Transistors (BJTs)

Introduction

http://engr.calvin.edu/PRibeiro_WEBPAGE/courses/engr311/311_frames.html

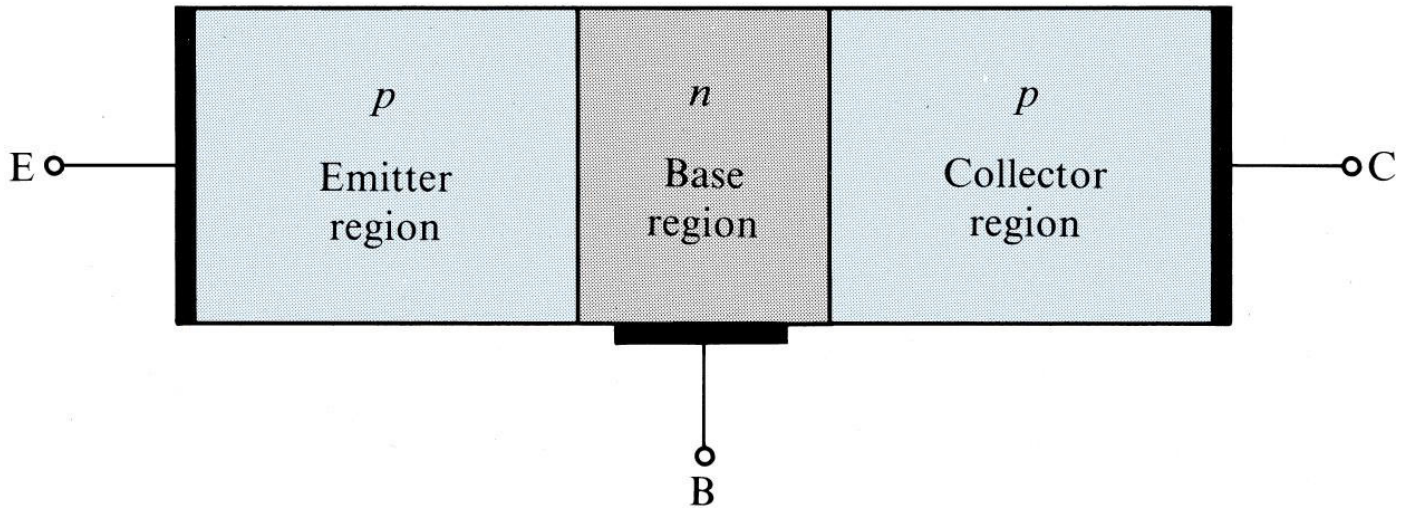


Physical Structure and Modes of Operation



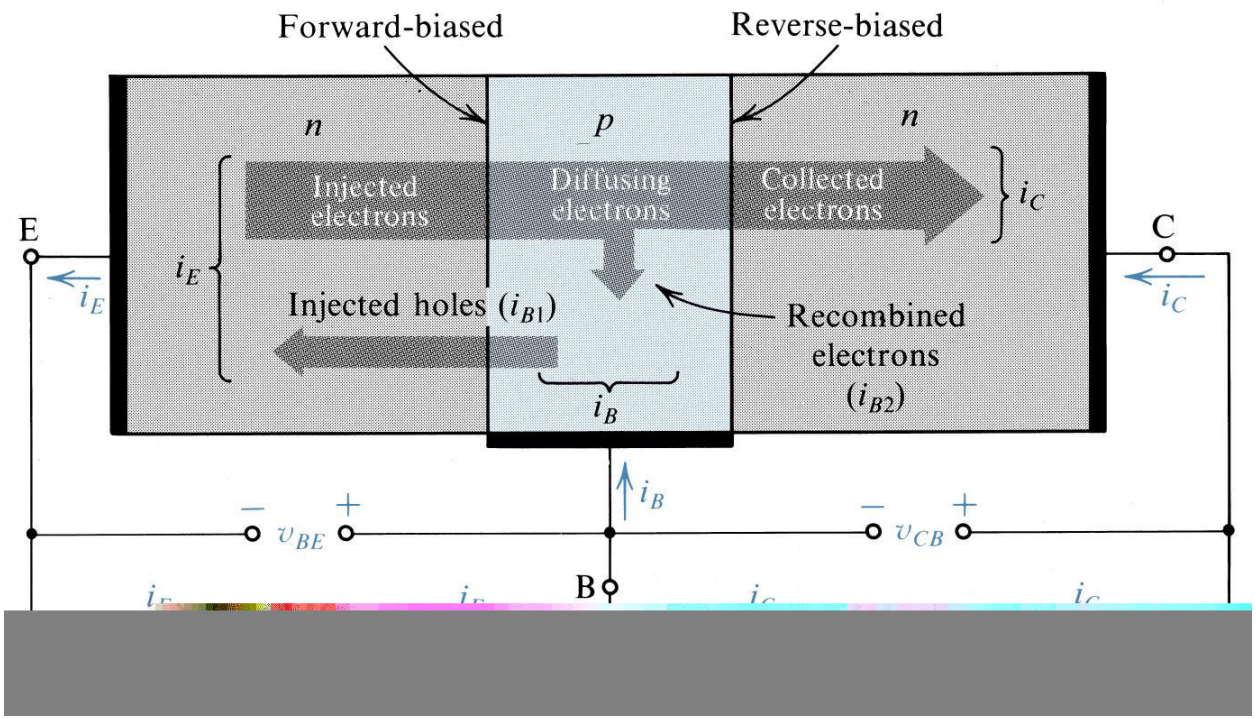
A simplified structure of the *npn* transistor.

Physical Structure and Modes of Operation



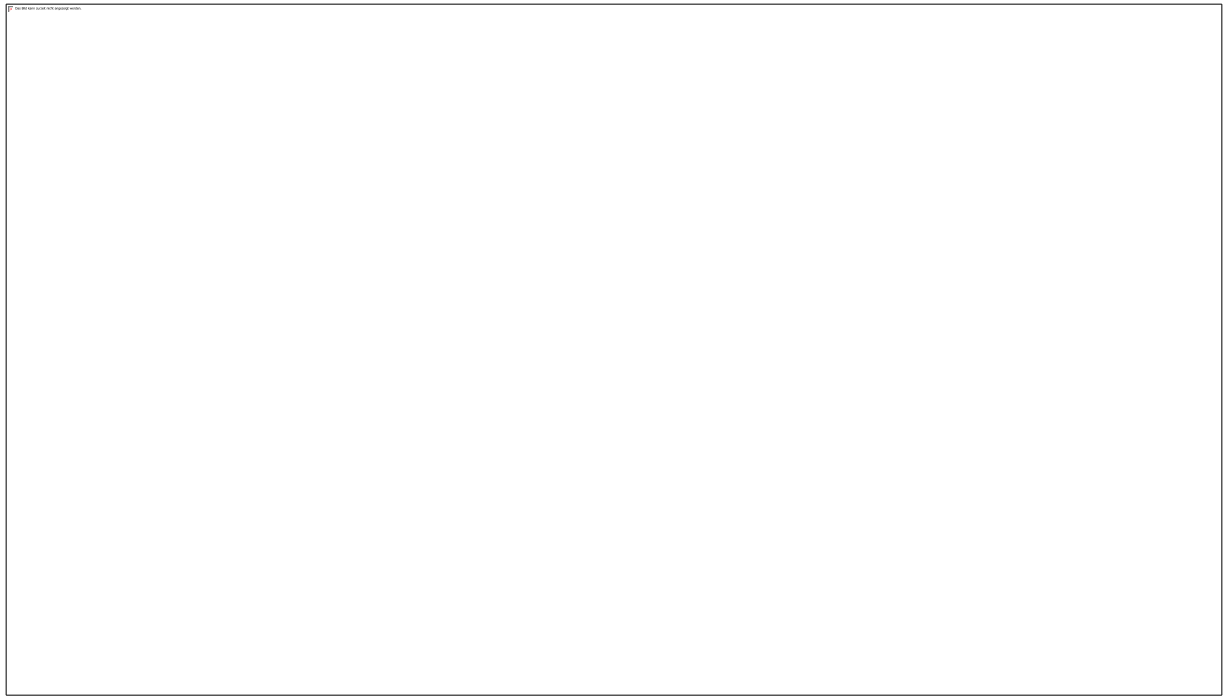
A simplified structure of the *pnp* transistor.

Operation of The npn Transistor Active Mode



Current flow in an *npn* transistor biased to operate in the active mode, (Reverse current components due to drift of thermally generated minority carriers are not shown.)

Operation of The npn Transistor Active Mode



Profiles of minority-carrier concentrations in the base and in the emitter of an *npn* transistor operating in the active mode; $v_{BE} > 0$ and $v_{CB} \geq 0$.

Operation of The npn Transistor Active Mode

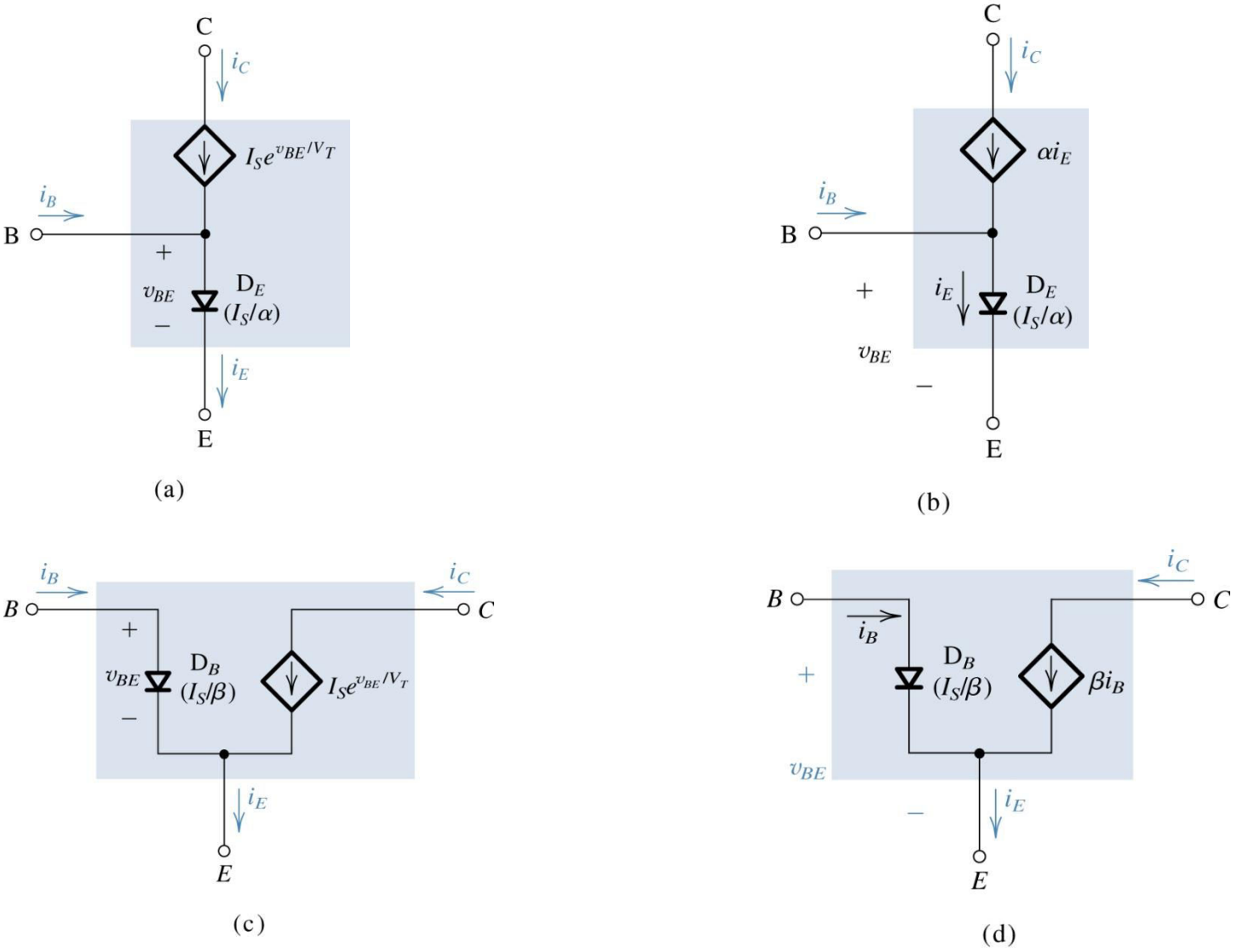
Current Flow

The Collector Current

The Base Current

The Emitter Current

Equivalent Circuit Models



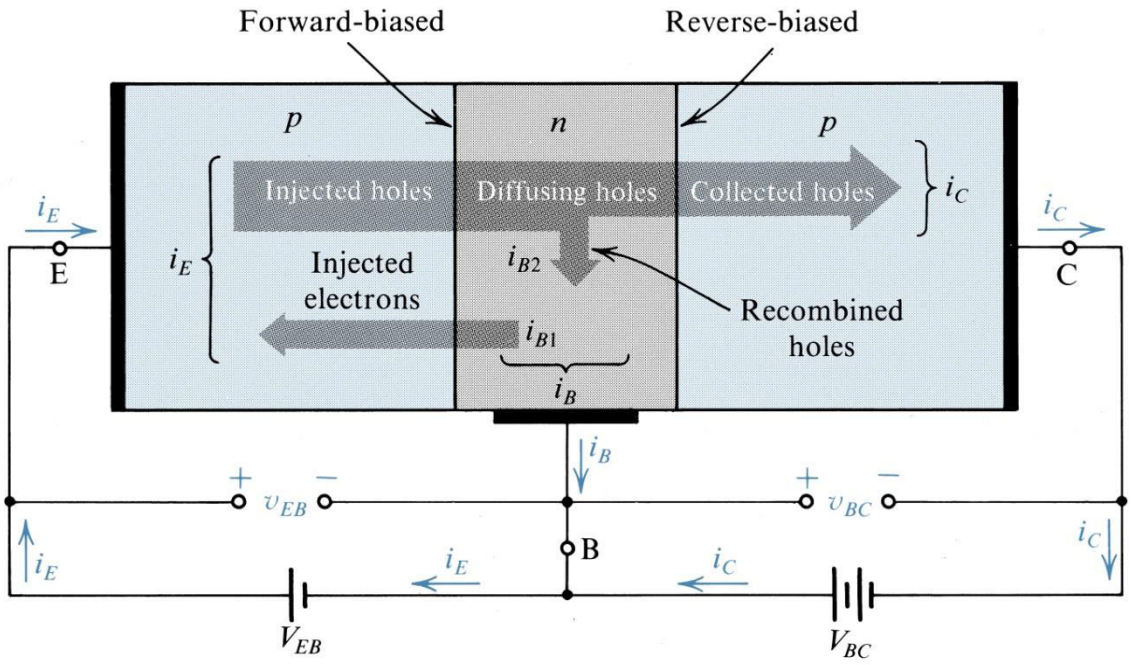
Large-signal equivalent-circuit models of the *npn* BJT operating in the active mode.

The Constant n

The Collector-Base Reverse Current

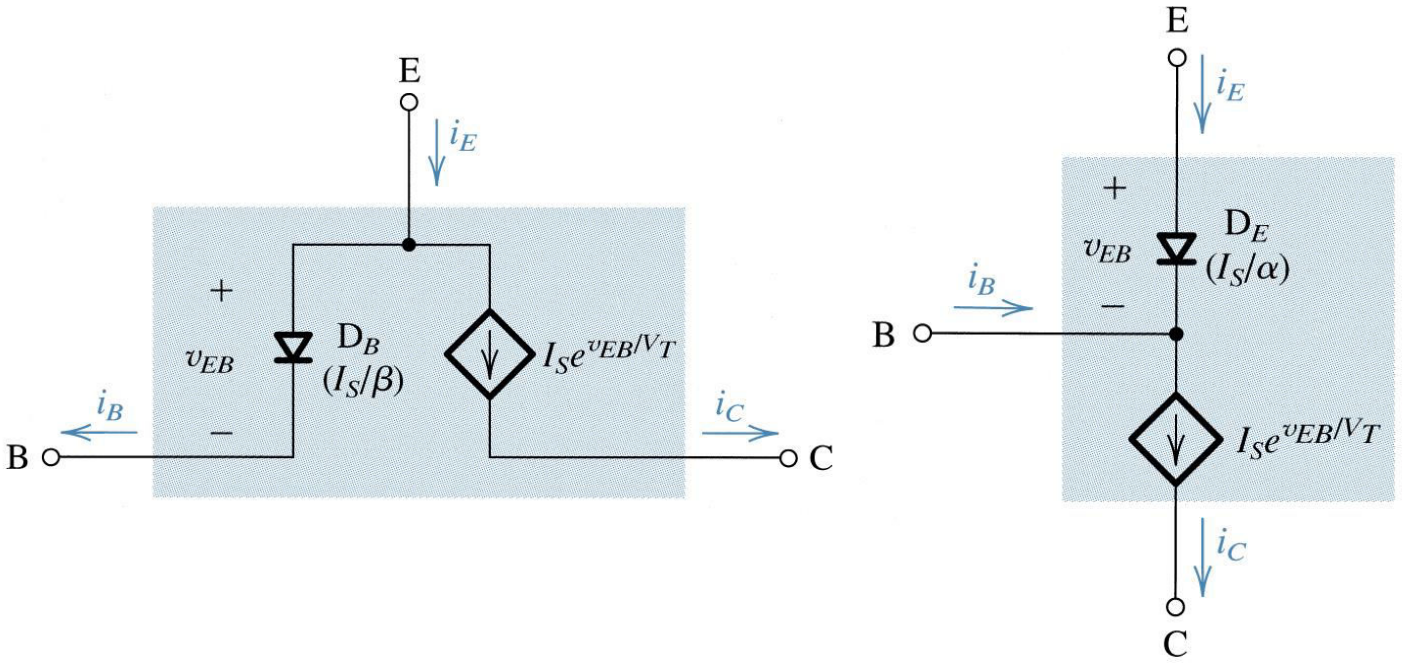
The Structure of Actual Transistors

The pnp Transistor



Current flow in an pnp transistor biased to operate in the active mode.

The pnp Transistor



Two large-signal models for the pnp transistor operating in the active mode.

Circuit Symbols and Conventions

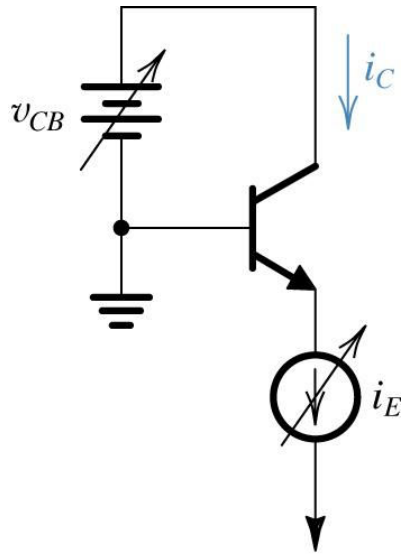
Summary of the BJT Current-Voltage Relationships In Active Mode

Example 4.1

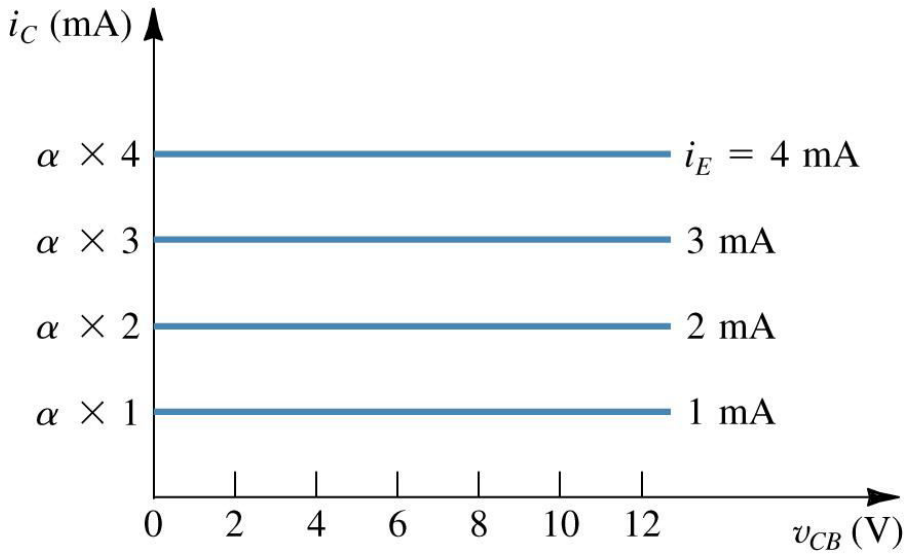
Exercise 4.8 and 4.9

The Graphical Representation of the Transistor Characteristics

Dependence of ic on the Collector Voltage – Early Effect



(a)



(b)

The i_C-v_{CB} characteristics for an npn transistor in the active mode.

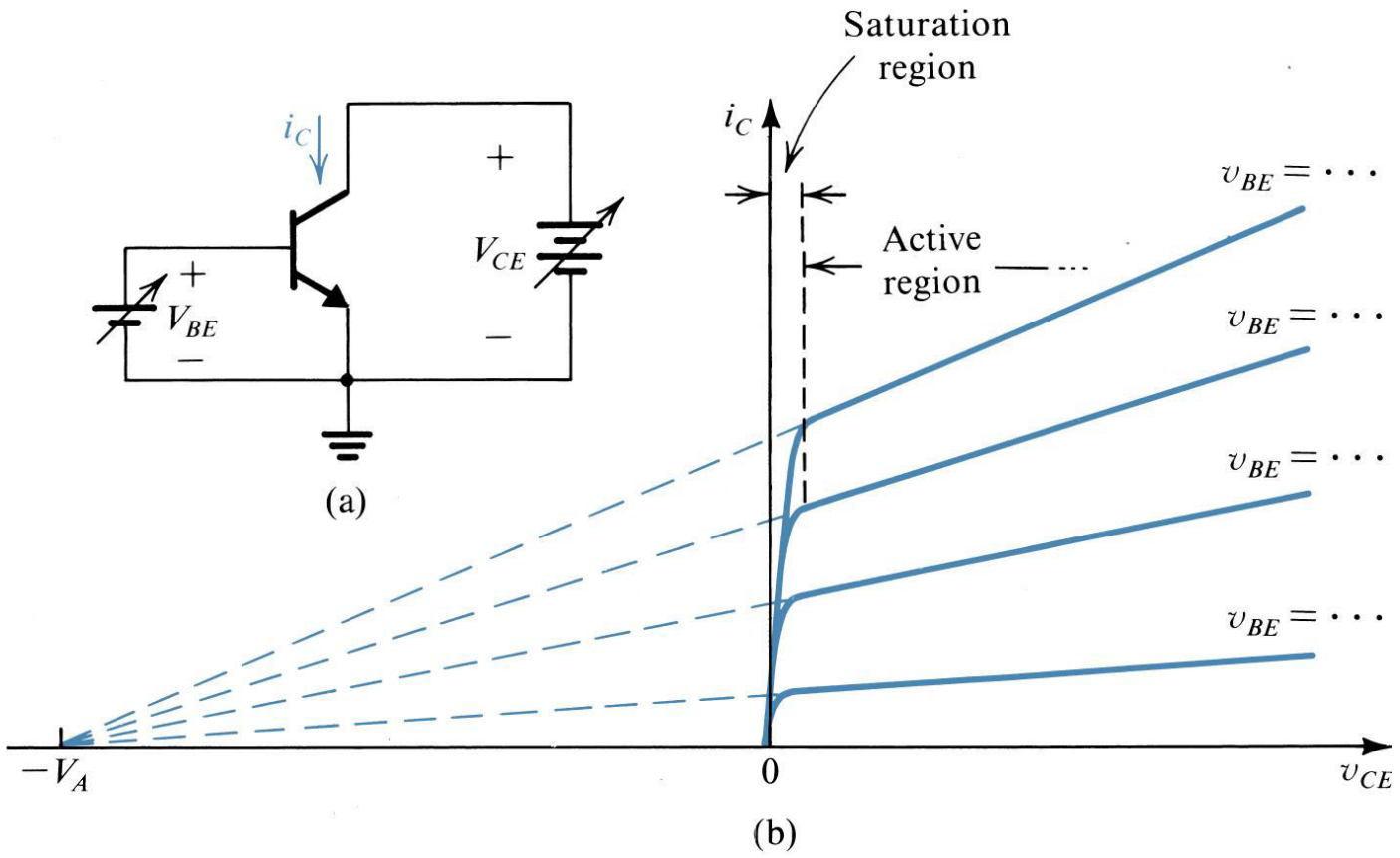


Fig. 4.15 **(a)** Conceptual circuit for measuring the i_C-v_{CE} characteristics of the BJT. **(b)** The i_C-v_{CE} characteristics of a practical BJT.

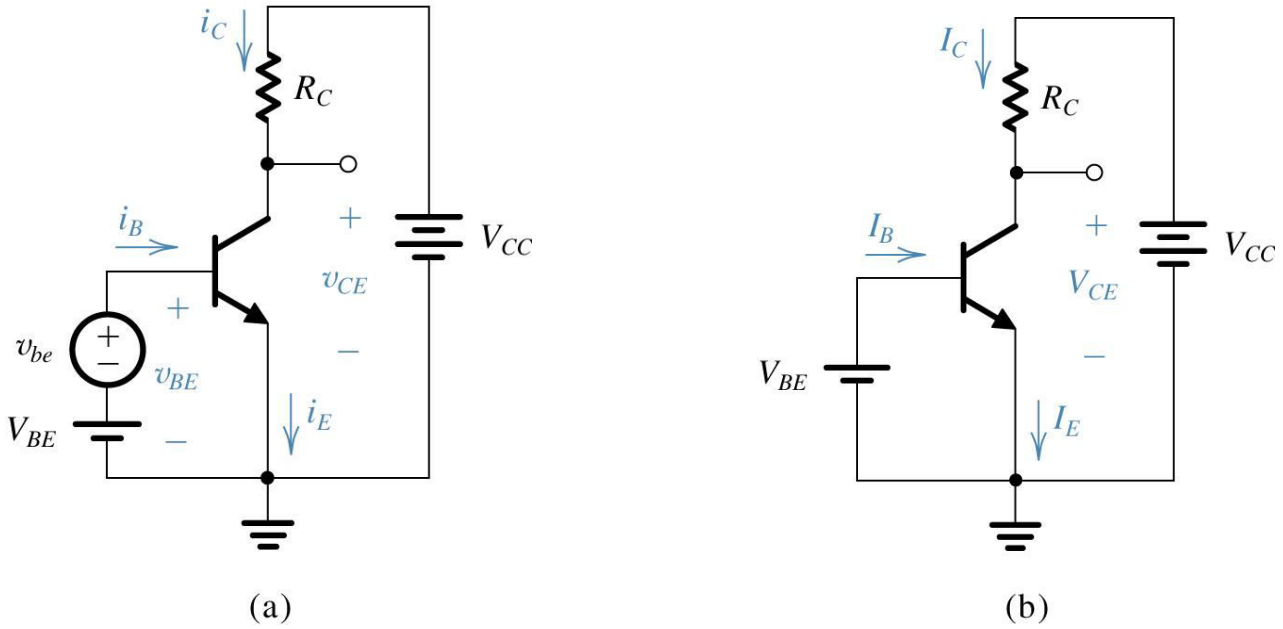


Fig. 4.23 **(a)** Conceptual circuit to illustrate the operation of the transistor of an amplifier. **(b)** The circuit of (a) with the signal source v_{be} eliminated for dc (bias) analysis.

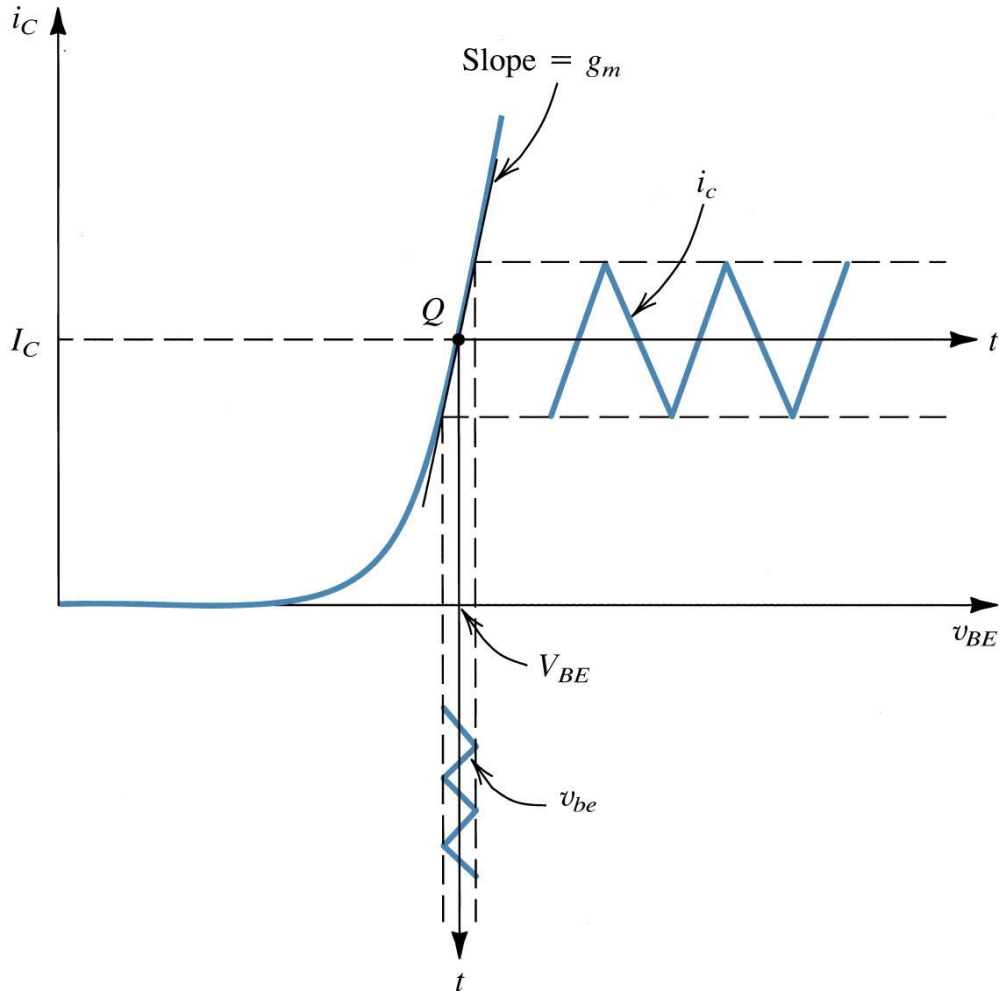


Fig. 4.24 Linear operation of the transistor under the small-signal condition: A small signal v_{be} with a triangular waveform is superimpose din the dc voltage V_{BE}. It gives rise to a collector signal current i_c, also of triangular waveform, superimposed on the dc current I_C. $I_c = g_m v_{be}$, where g_m is the slope of the i_c - v_{BE} curve at the bias point Q.

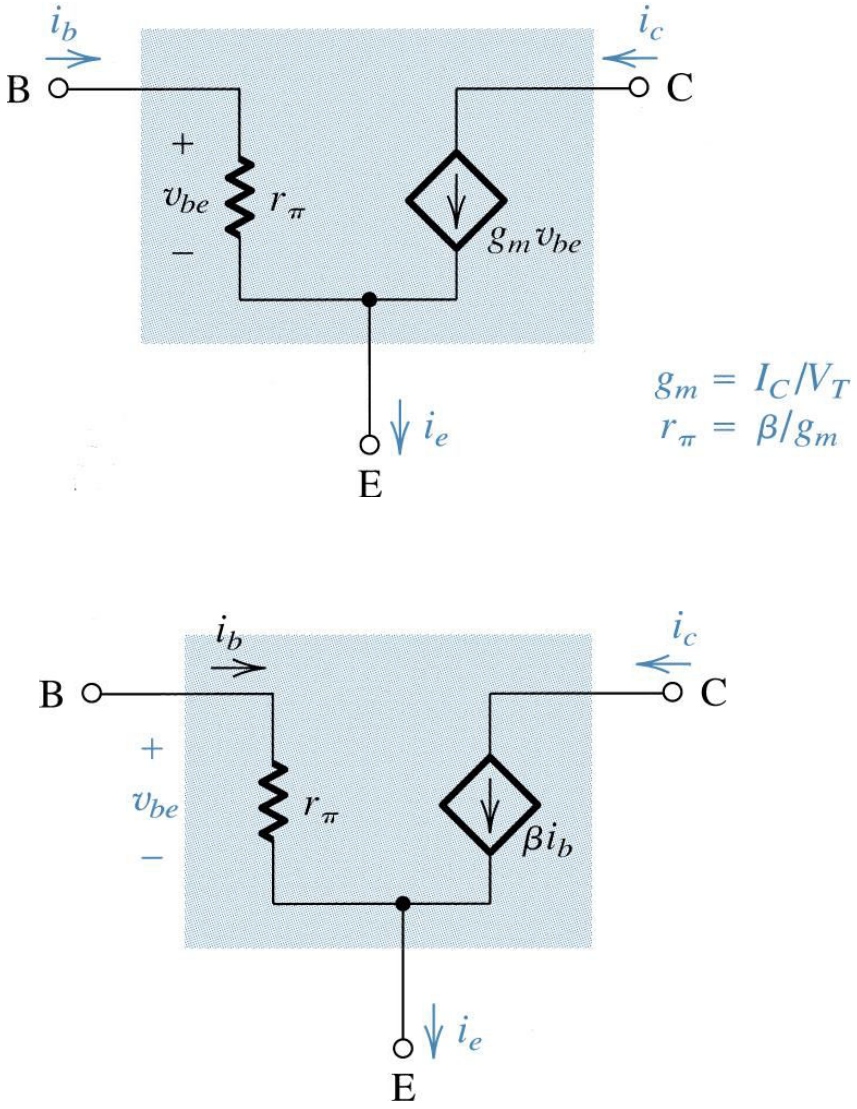


Fig. 4.26 Two slightly different versions of the simplified hybrid-Π model for the small-signal operation of the BJT. The equivalent circuit in **(a)** represents the BJT as a voltage-controlled current source (a transconductance amplifier) and that in **(b)** represents the BJT as a current-controlled current source (a current amplifier).

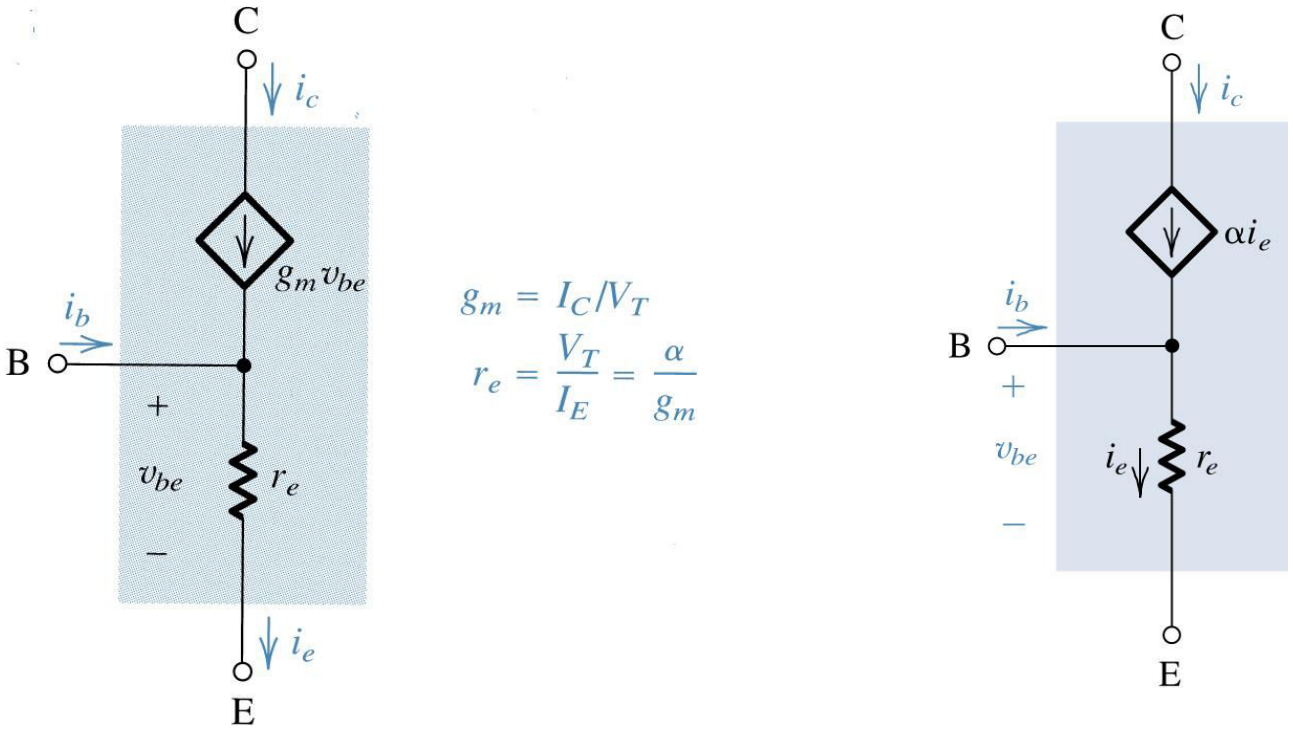


Fig. 4.27 Two slightly different versions of what is known as the *T model* of the BJT. The circuit in **(a)** is a voltage-controlled current source representation and that in **(b)** is a current-controlled current source representation. These models explicitly show the emitter resistance r_e rather than the base resistance r_{Π} featured in the hybrid-π model.

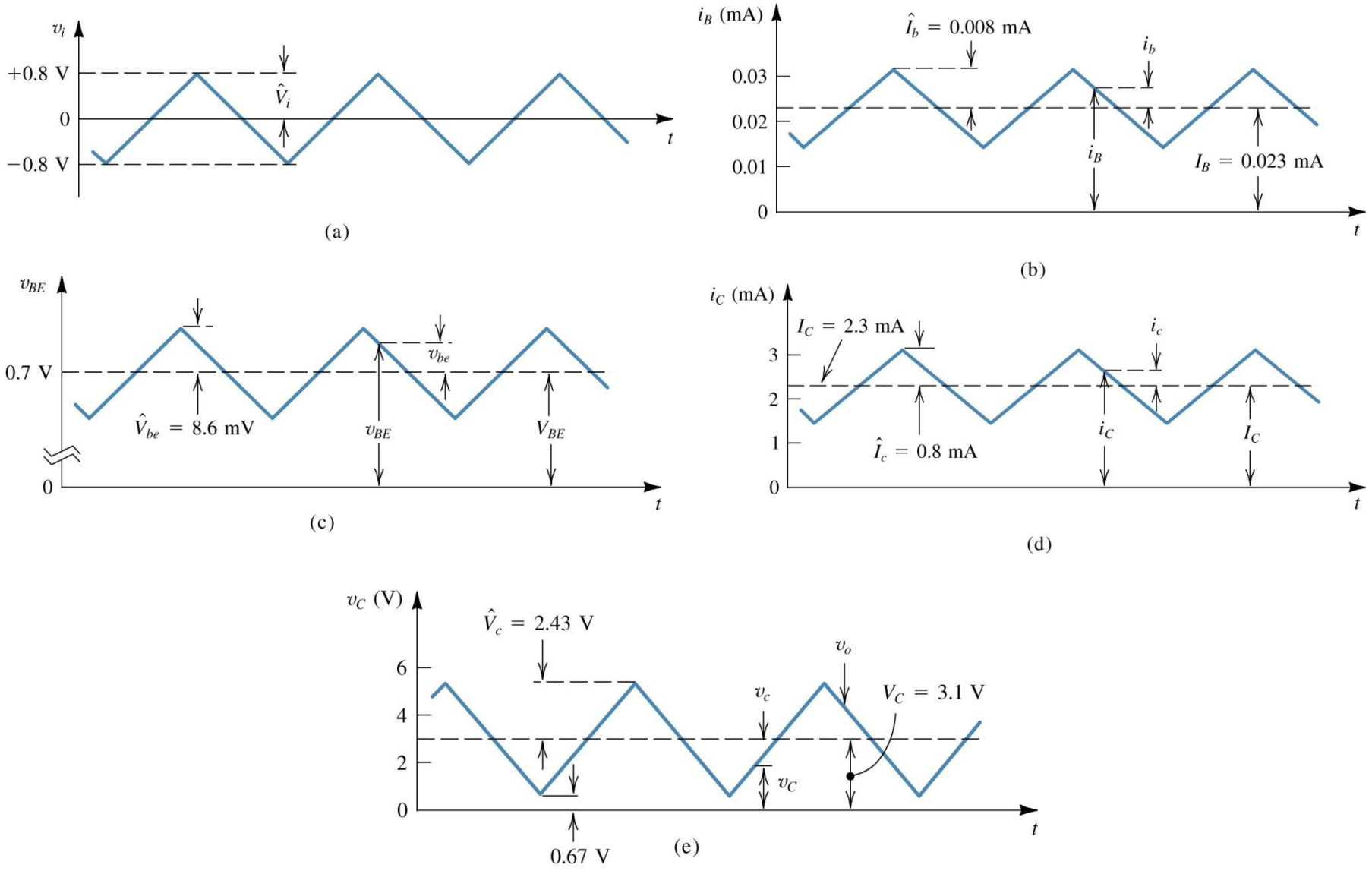


Fig. 4.29 Signal waveforms in the circuit of **Fig. 4.28**.

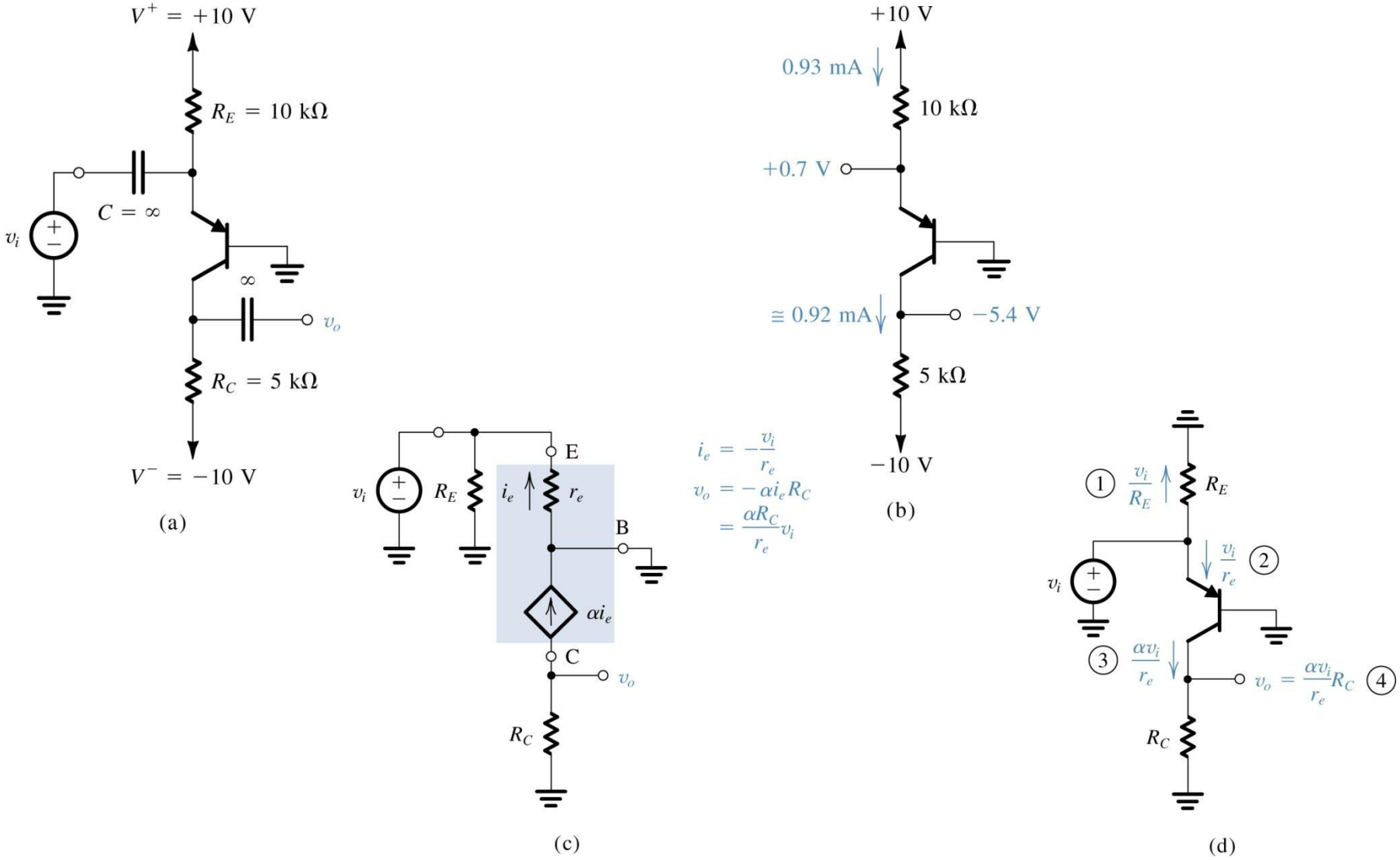


Fig. 4.30 Example 4.11: **(a)** circuit; **(b)** dc analysis; **(c)** small-signal model; **(d)** small-signal analysis performed directly on the circuit.

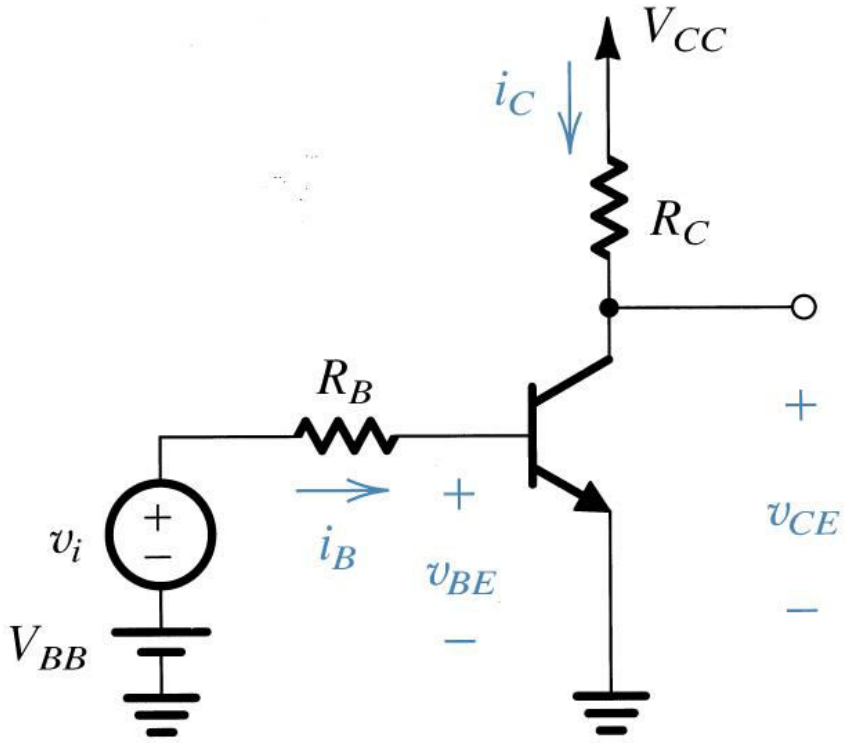


Fig. 4.34 Circuit whose operation is to be analyzed graphically.

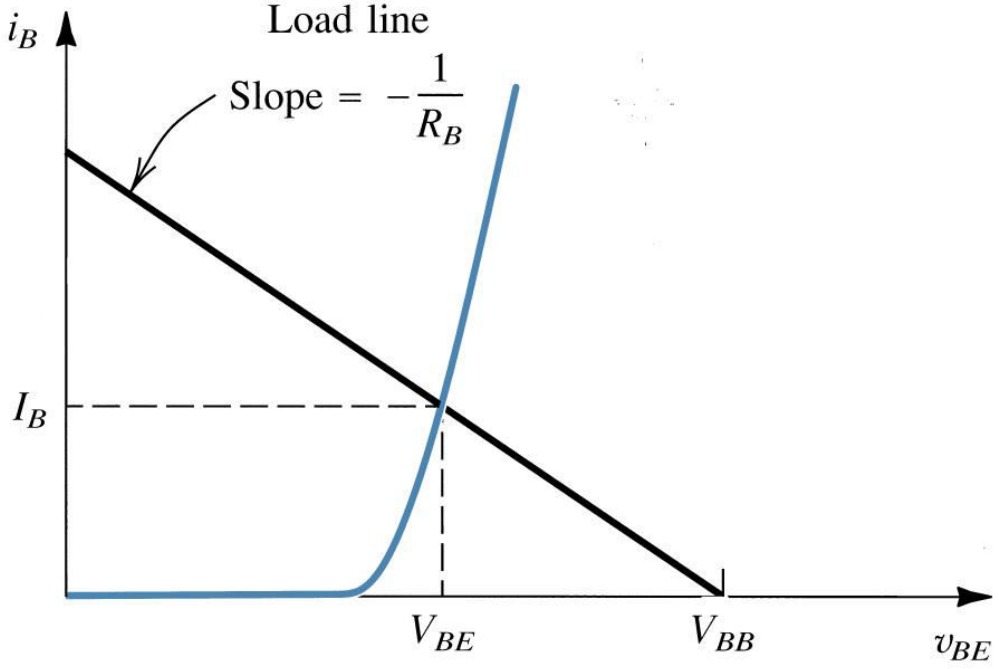


Fig. 4.35 Graphical construction for the determination of the dc base current in the circuit of **Fig. 4.34**.

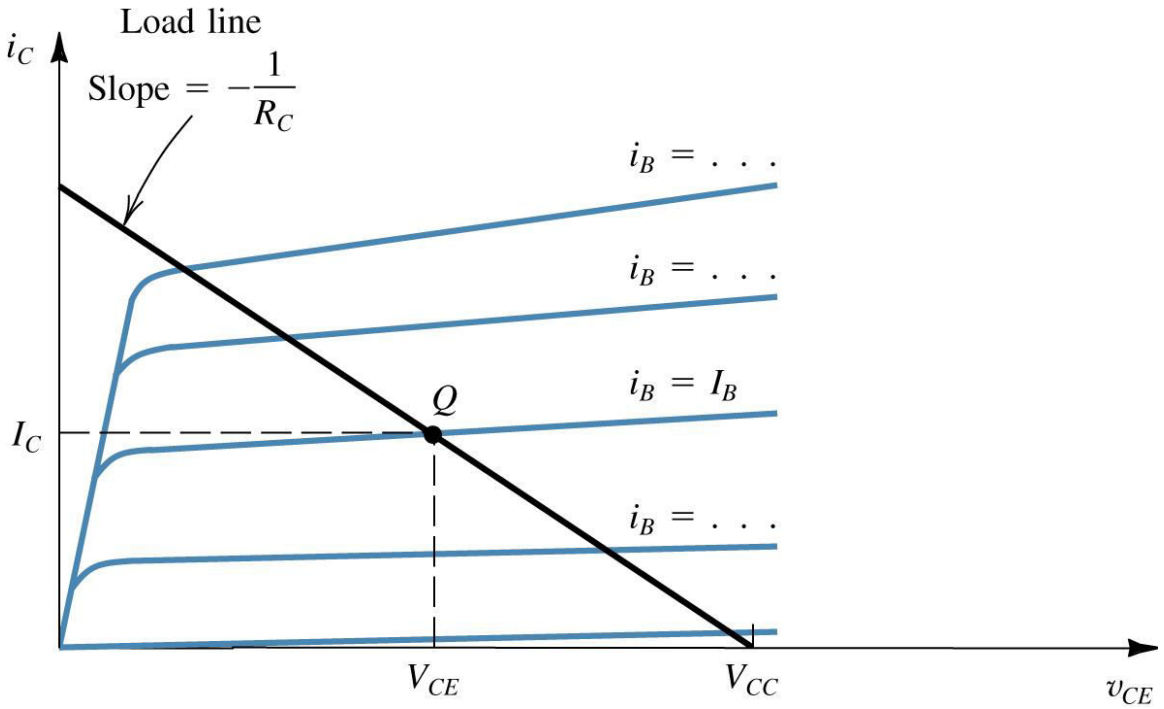


Fig. 4.36 Graphical construction for determining the dc collector current I_C and the collector-to-emmiter voltage V_{CE} in the circuit of Fig. 4.34.

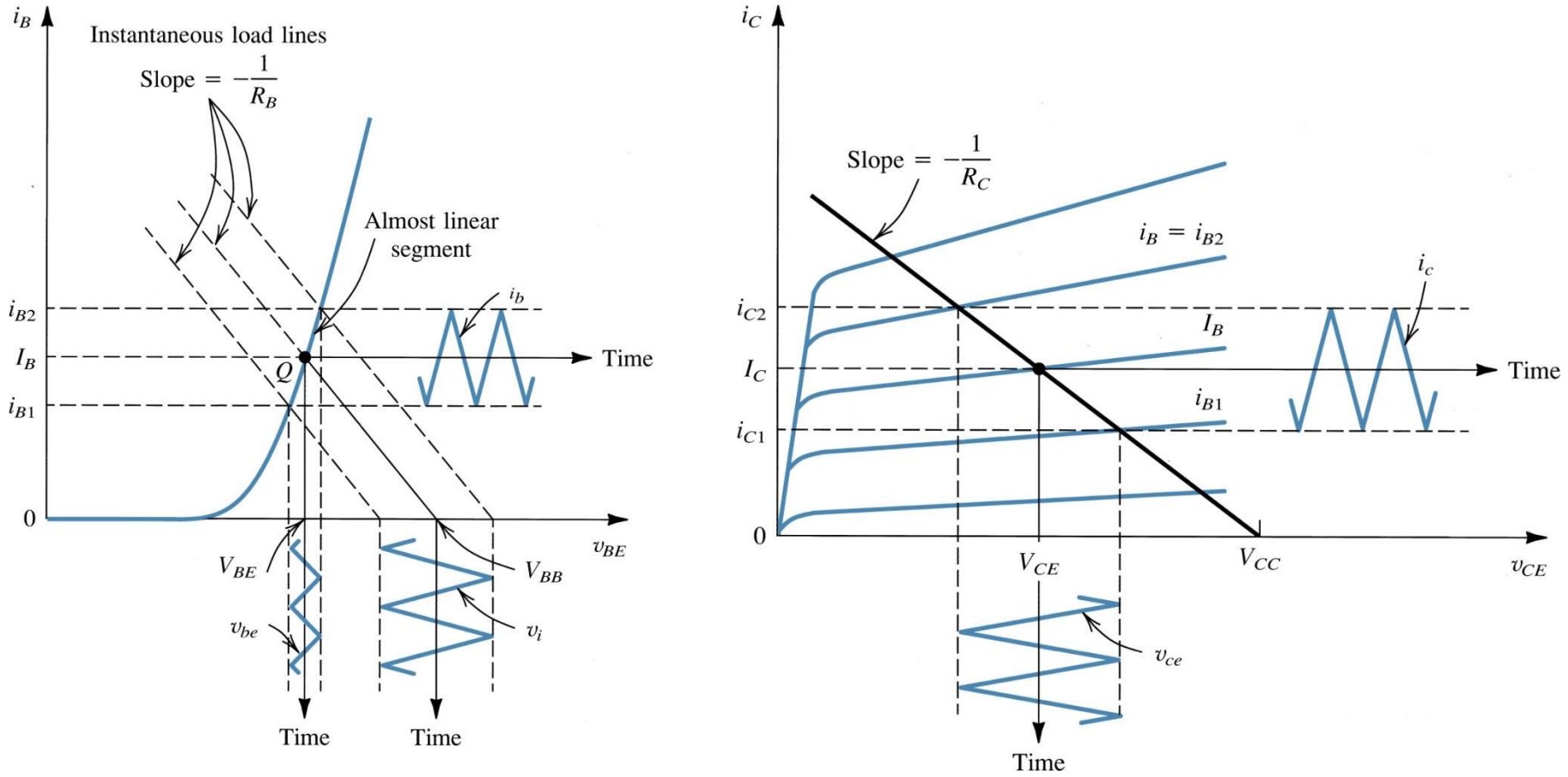


Fig. 4.37 Graphical determination of the signal components v_{be}, i_b, i_c, and v_{ce} when a signal component v_i is superimposed on the dc voltage V_{BB} (see **Fig. 4.34**).

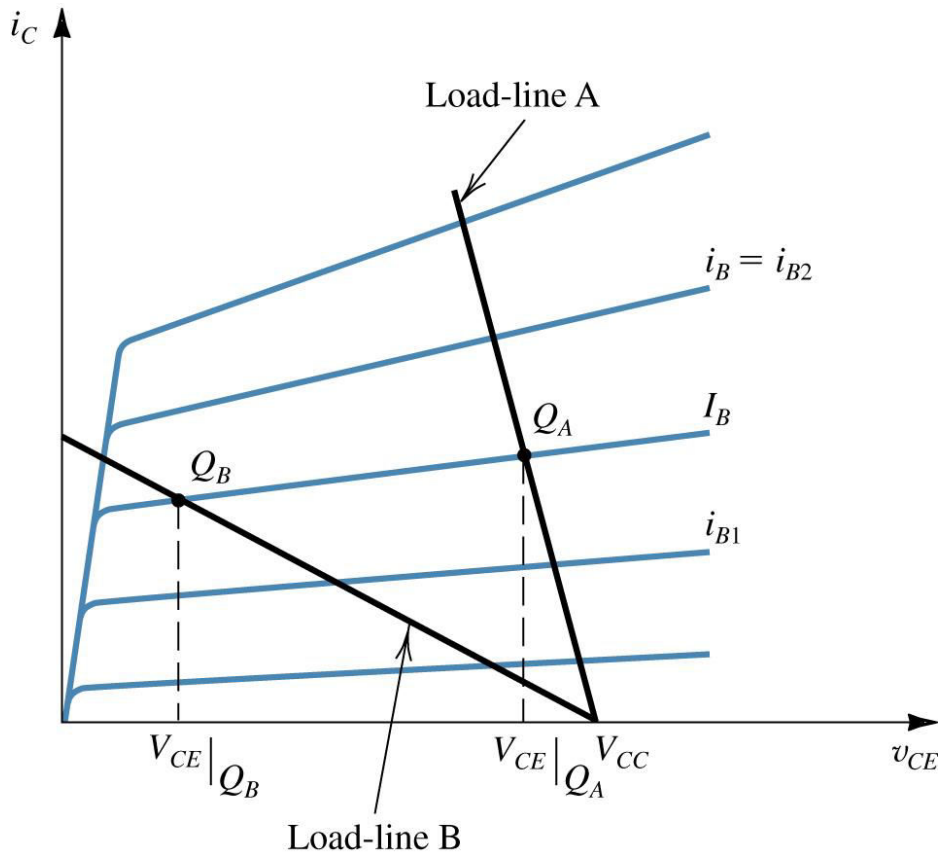


Fig. 4.38 Effect of bias-point location on allowable signal swing: Load-line A results in bias point Q_A with a corresponding V_{CE} which is too close to V_{CC} and thus limits the positive swing of v_{CE}. At the other extreme, load-line B results in an operating point too close to the saturation region, thus limiting the negative swing of v_{CE}.

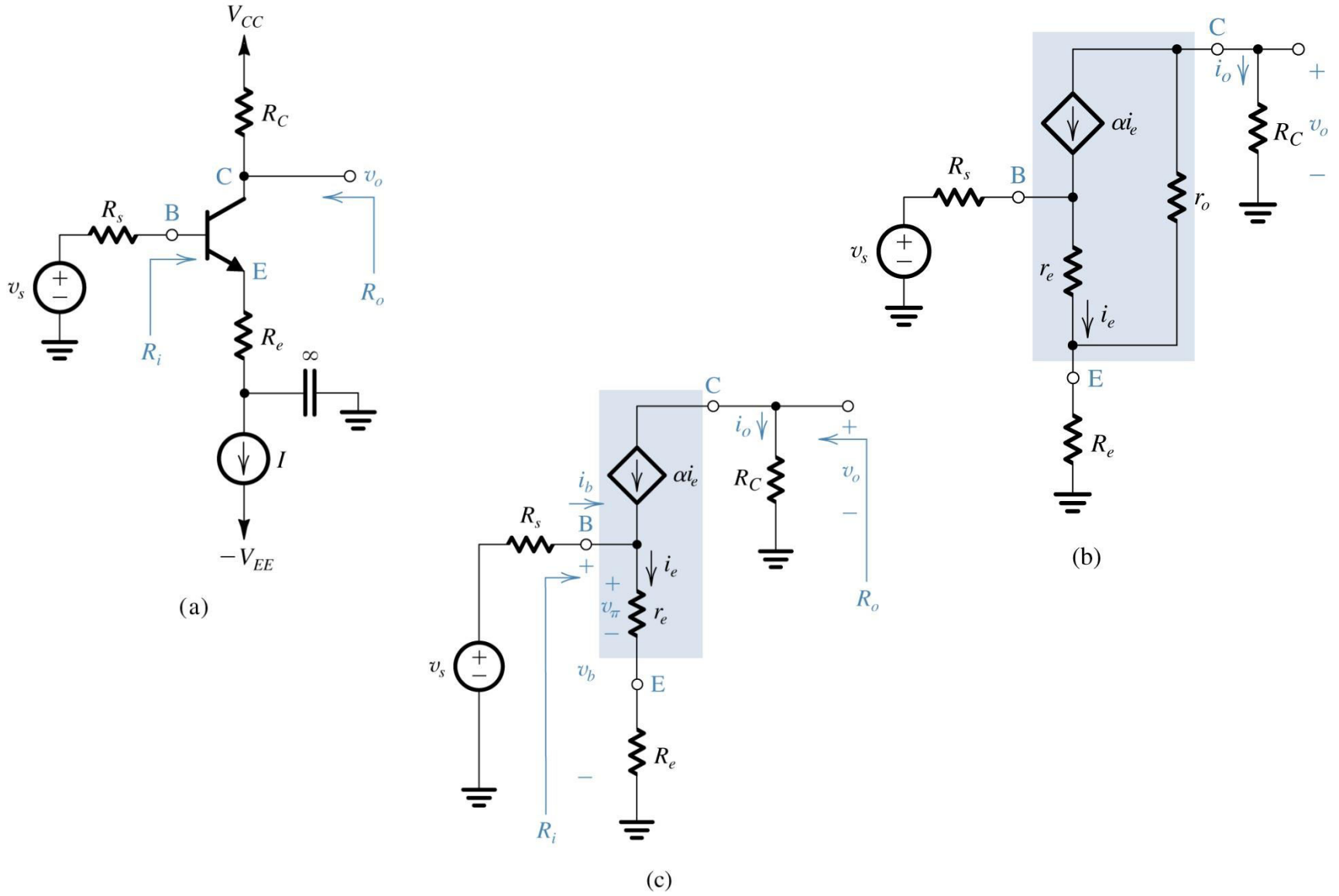


Fig. 4.44 The common-emitter amplifier with a resistance R_e in the emitter. **(a)** Circuit. **(b)** Equivalent circuit with the BJT replaced with its T model **(c)** The circuit in (b) with r_o eliminated.

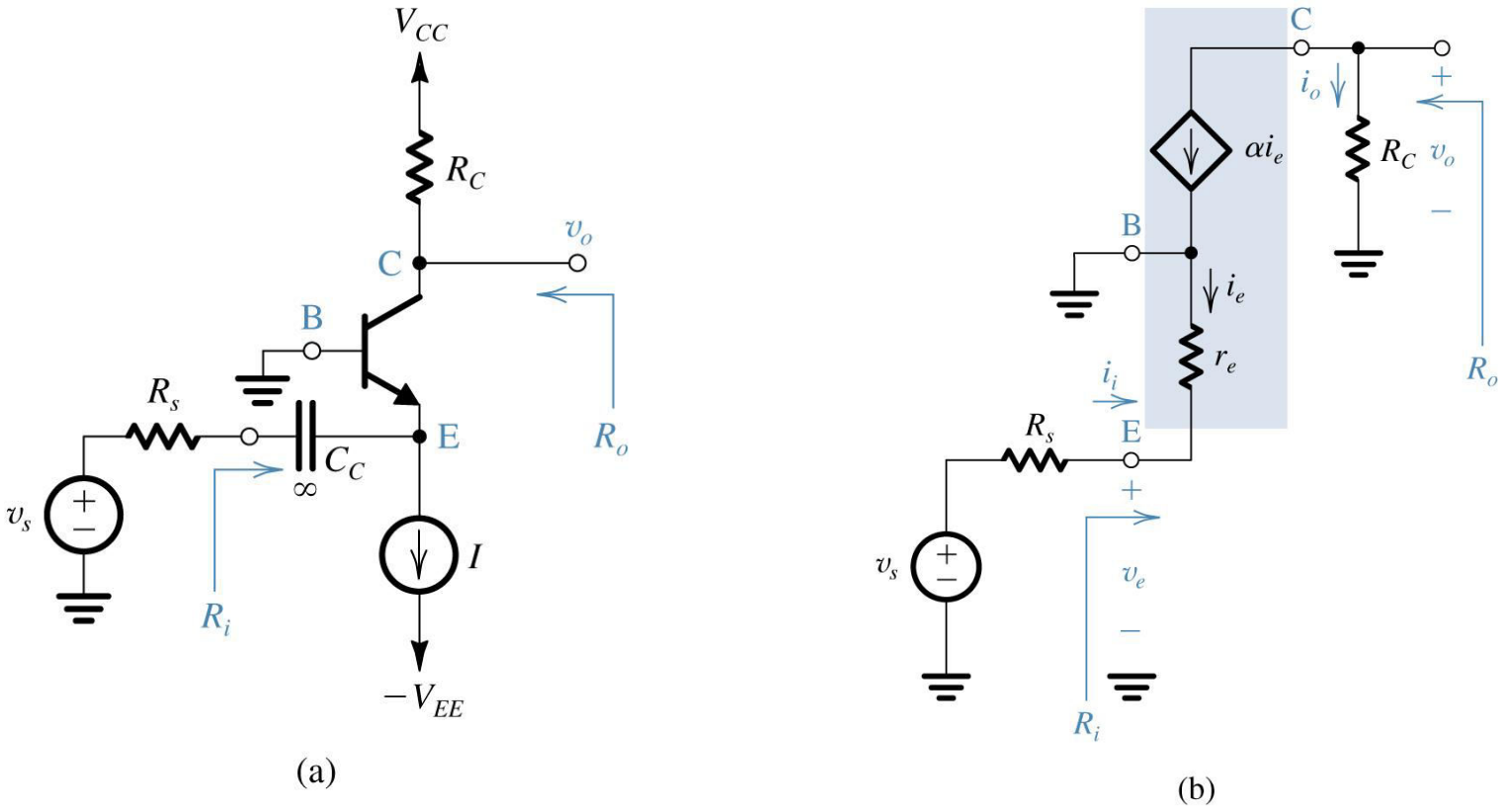


Fig. 4.45 The common-base amplifier. **(a)** Circuit. **(b)** Equivalent circuit obtained by replacing the BJT with its T model.

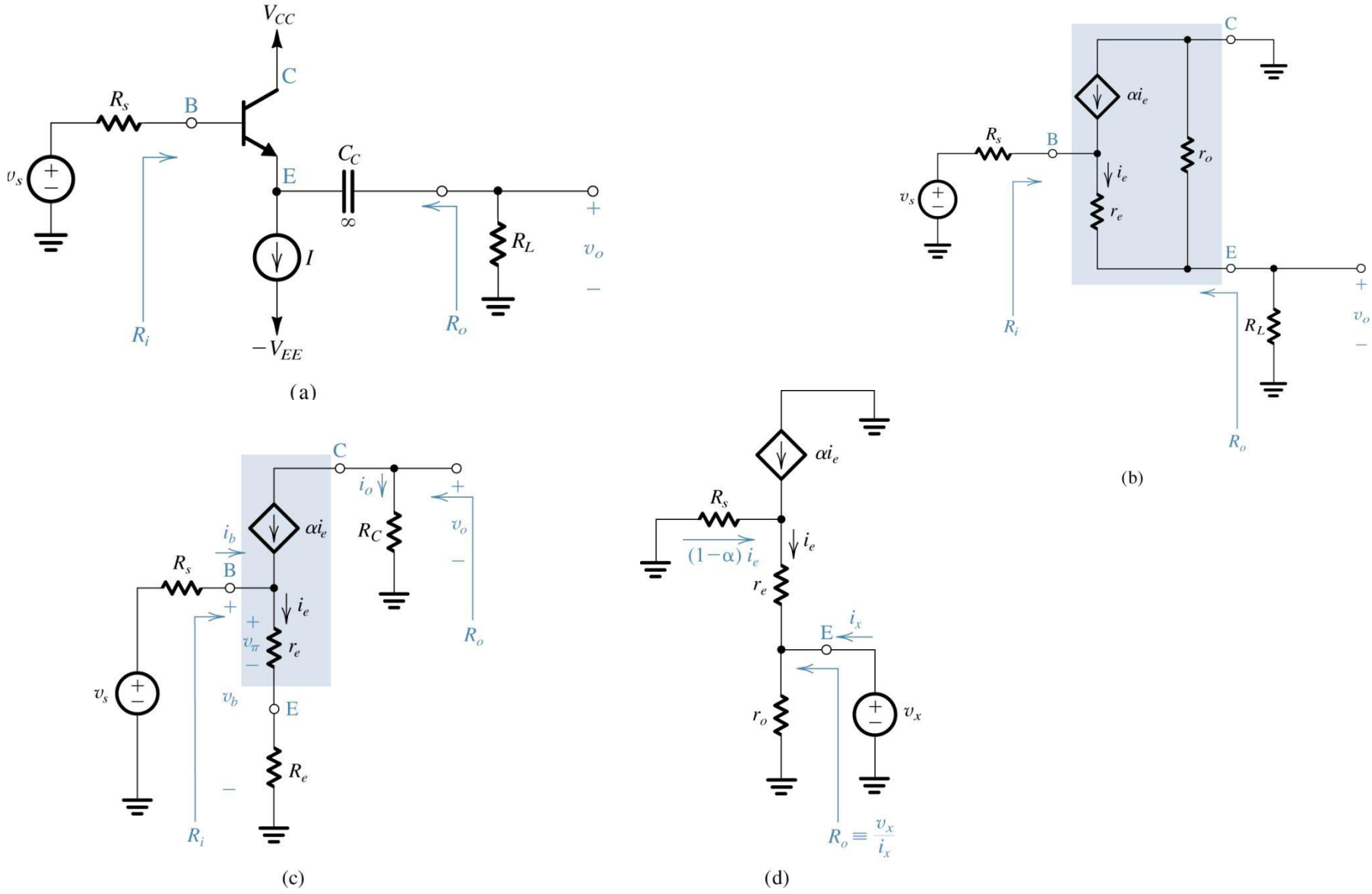


Fig. 4.46 The common-collector or emitter-follower amplifier. **(a)** Circuit. **(b)** Equivalent circuit obtained by replacing the BJT with its T model. **(c)** The circuit in (b) redrawn to show that r_o is in parallel with R_L. **(d)** Circuit for determining R_o.

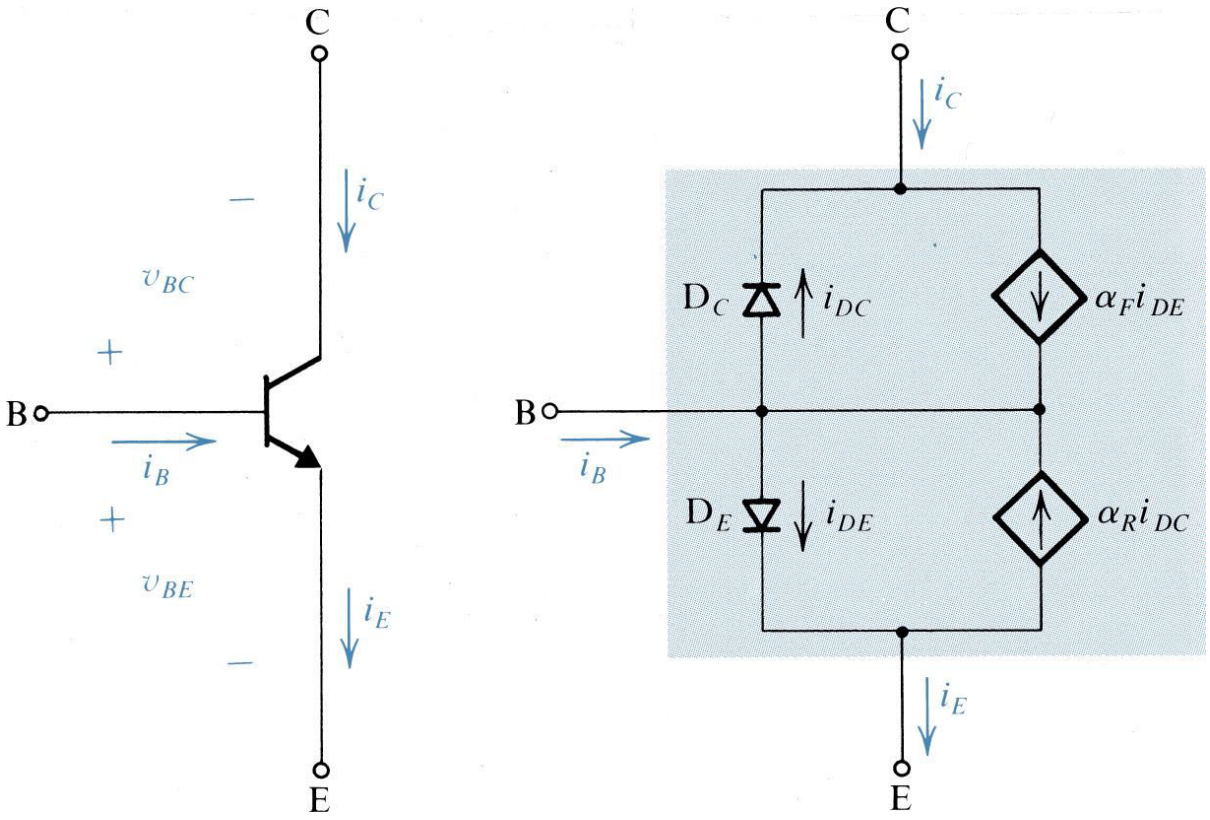


Fig. 4.55 An *npn* resistor and its Ebers-Moll (EM) model. The scale or saturation currents of diodes D_E (EBJ) and D_C (CBJ) are indicated in parentheses.

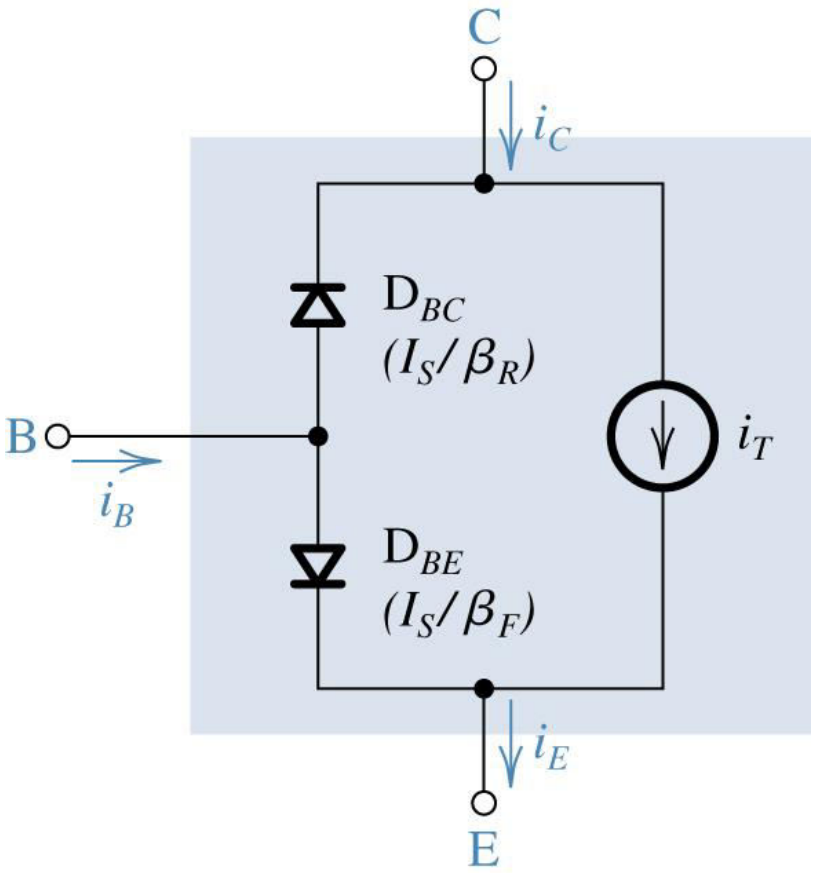


Fig. 4.59 The transport model of the *npn* BJT. This model is exactly equivalent to the Ebers-Moll model of **Fig. 4.55**. Note that the saturation currents of the diodes are given in parentheses and i_T is defined by Eq. (4.117).

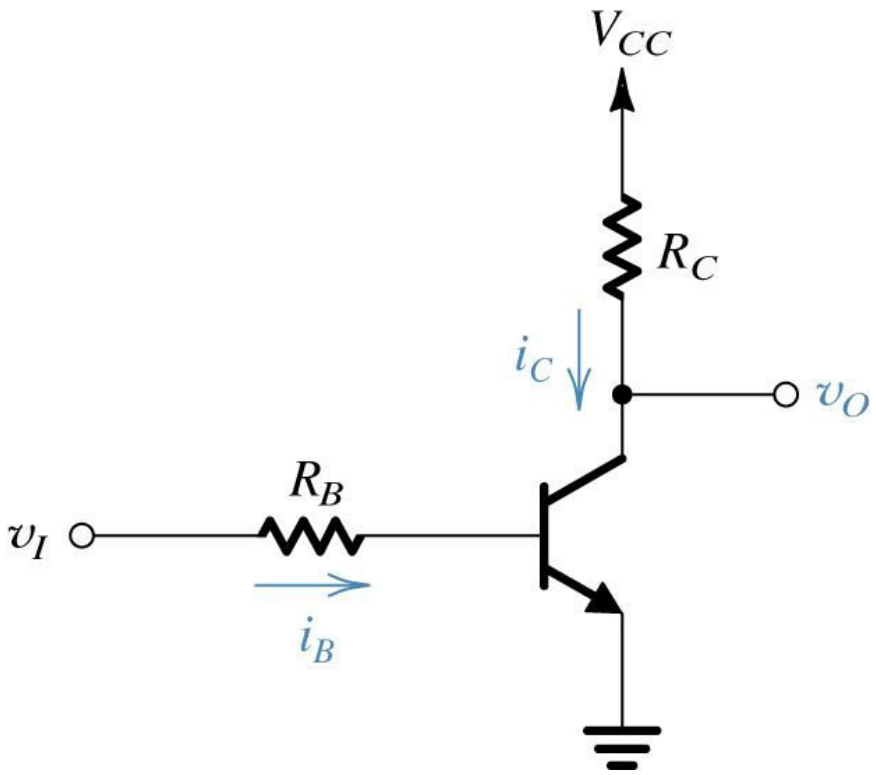


Fig. 4.60 Basic BJT digital logic inverter.

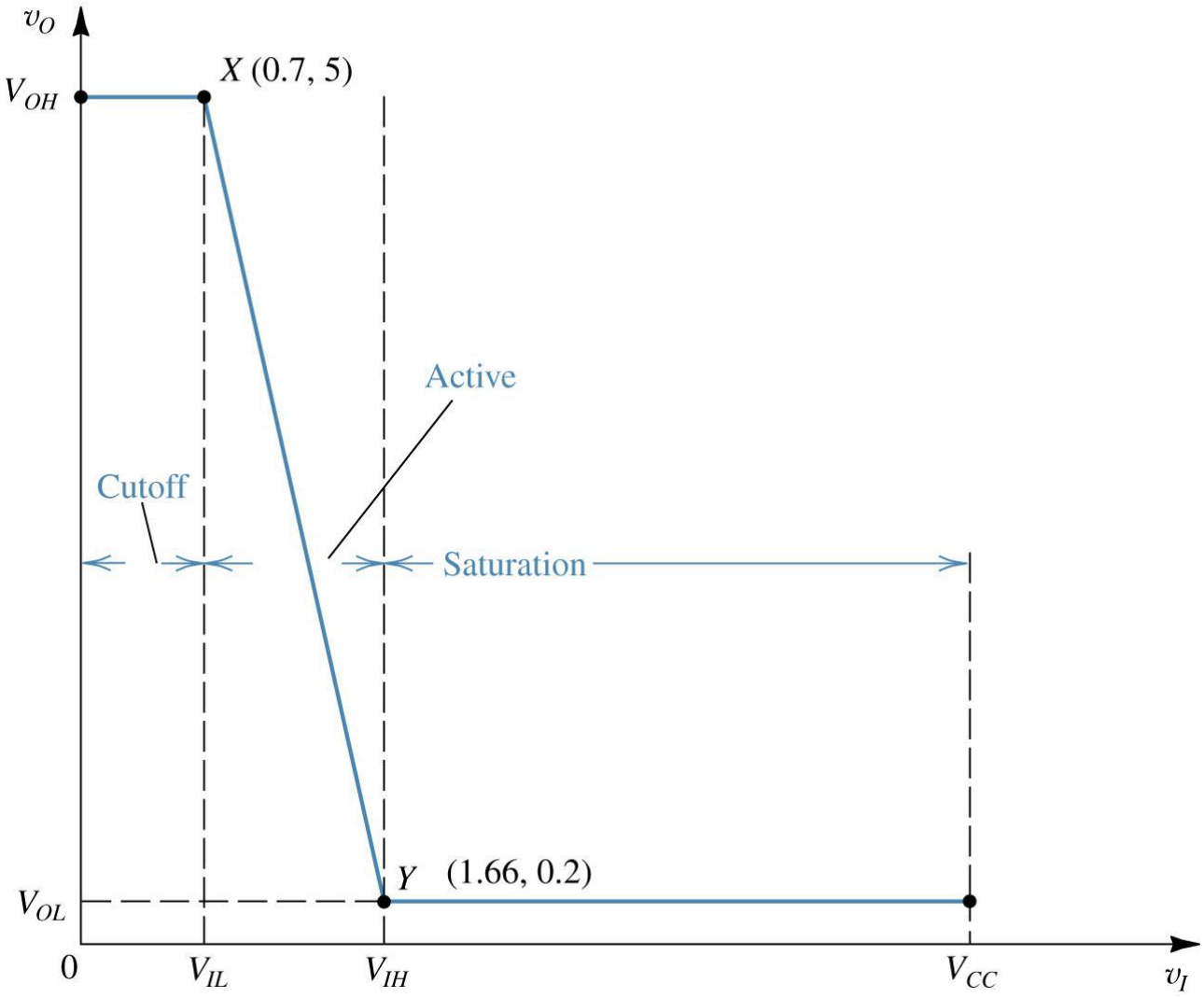


Fig. 4.61 Sketch of the voltage transfer characteristic of the inverter circuit of **Fig. 4.60** for the case R_B = 10 kΩ, R_C = 1 kΩ, β = 50, and V_{CC} = 5V. For the calculation of the coordinates of X and Y refer to the text.

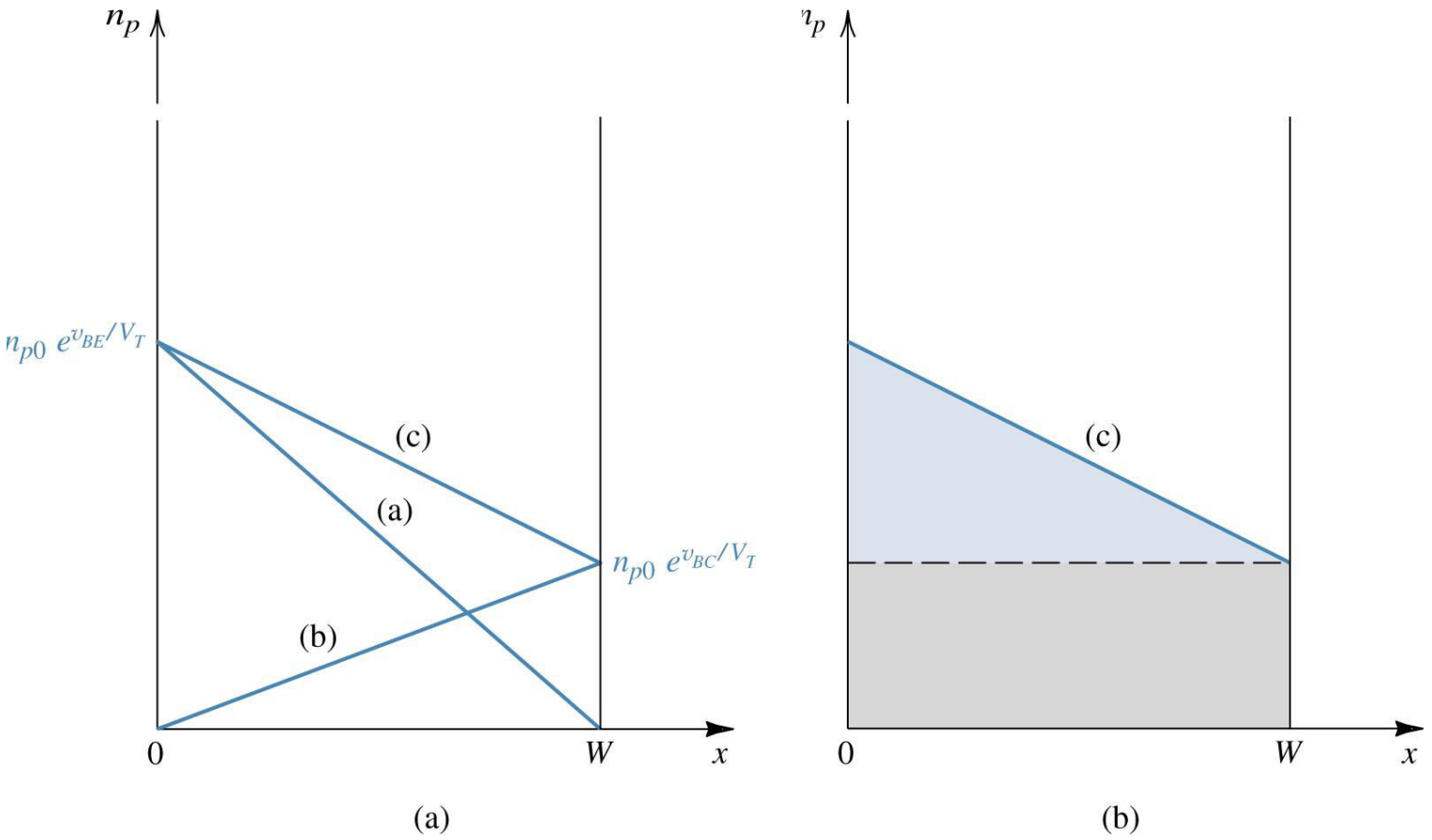


Fig. 4.62 **(a)** The minority-carrier concentration in the base of a saturated transistor is represented by line (c). **(b)** The minority-carrier charge stored in the base can de divided into two components: That in blue produces the gradient that gives rise to the diffusion current across the base, and that in gray results in driving the transistor deeper into saturation.

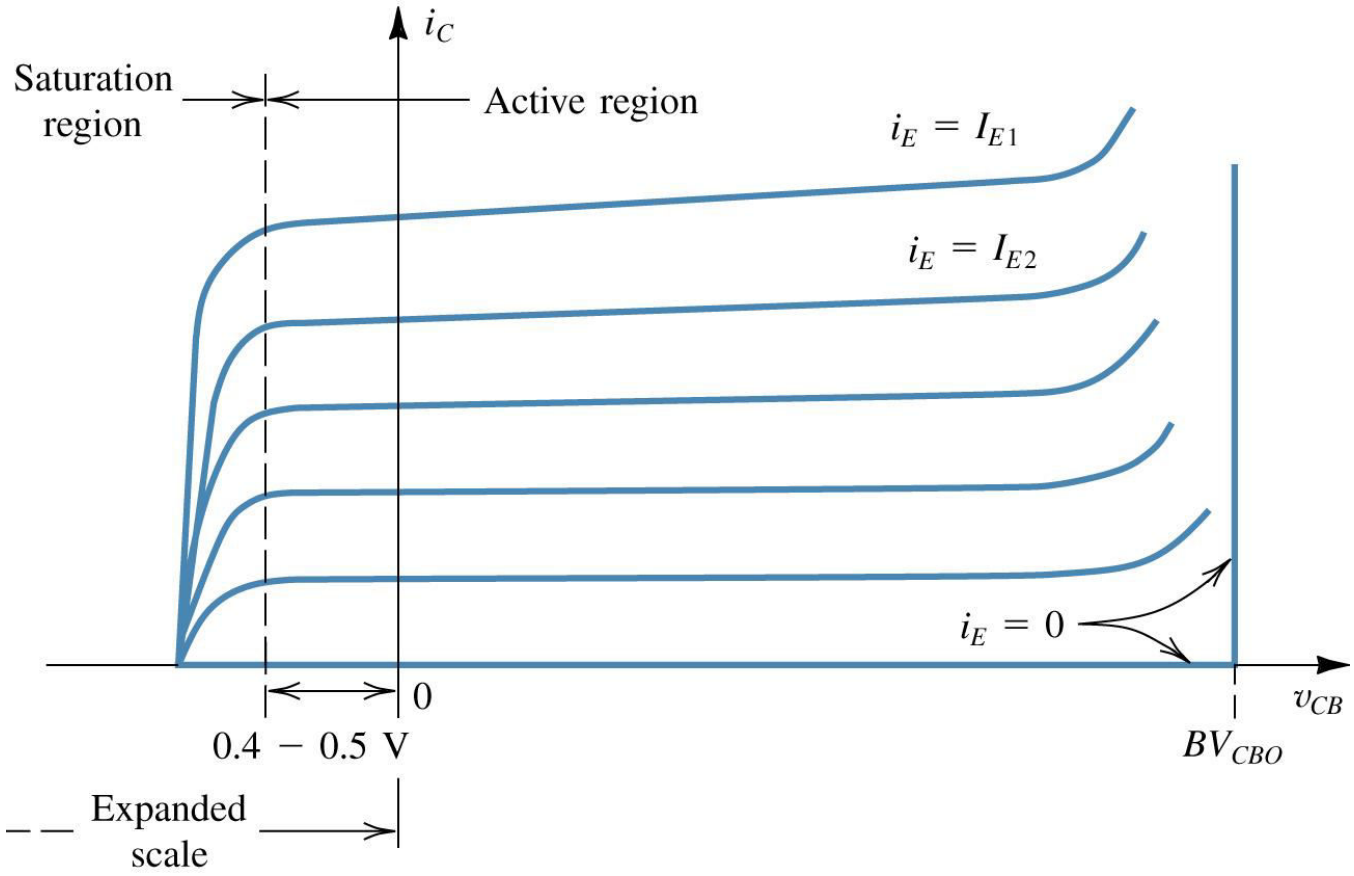


Fig. 4.63 The i_c-v_{cb} or common-base characteristics of an *npn* transistor. Note that in the active region there is a slight dependence of i_C on the value of v_{CB}. The result is a finite output resistance that decreases as the current level in the device is increased.

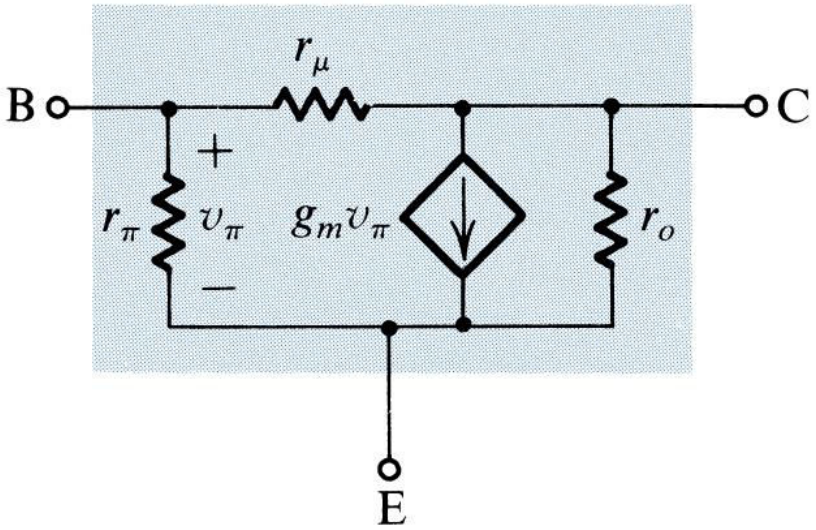


Fig. 4.64 The hybrid-π model, including the resistance r_μ, which models the effect of v_c on i_b.

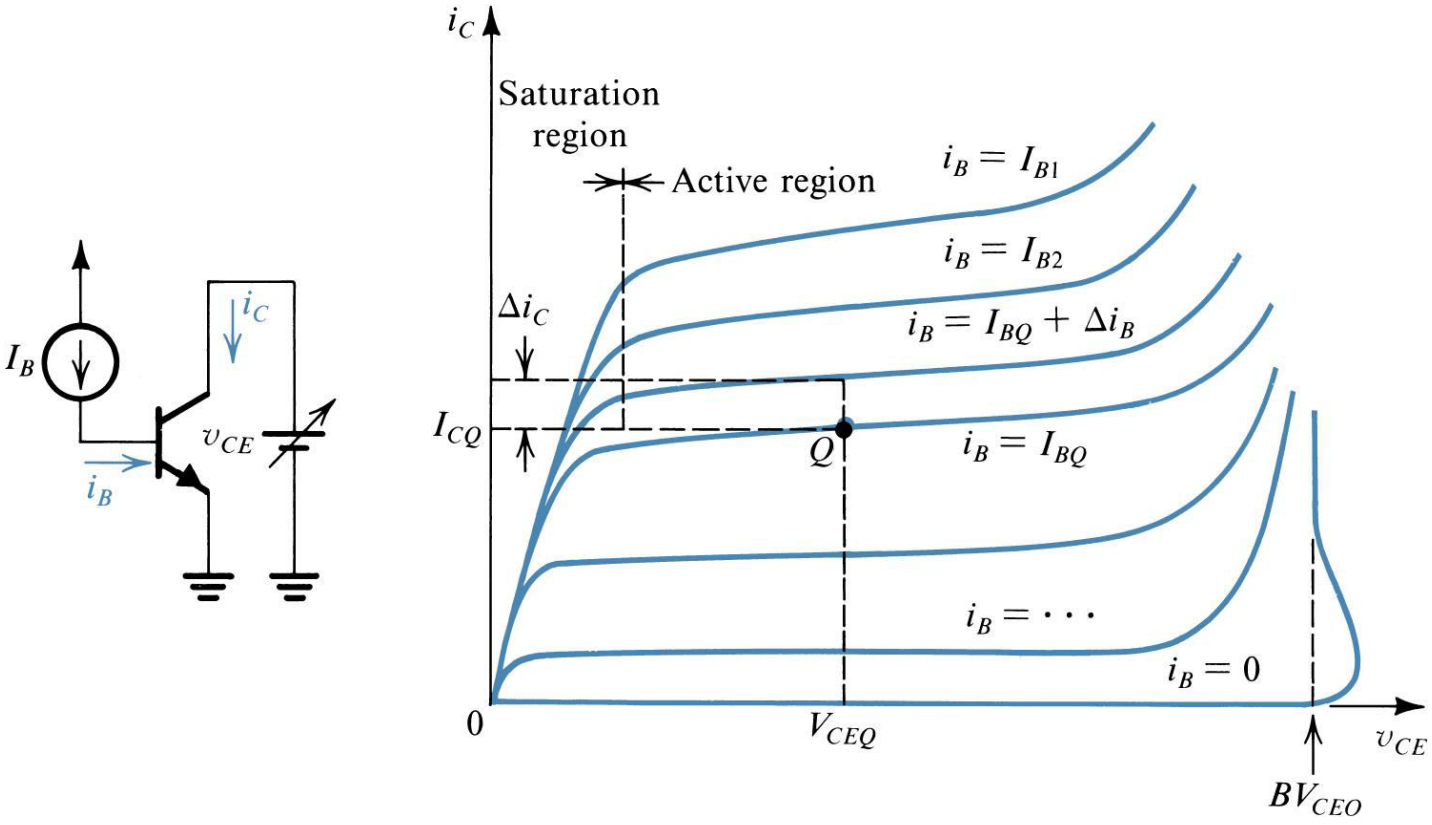


Fig. 4.65 Common-emitter characteristics. Note that the horizontal scale is expanded around the origin to show the saturation region in some detail.

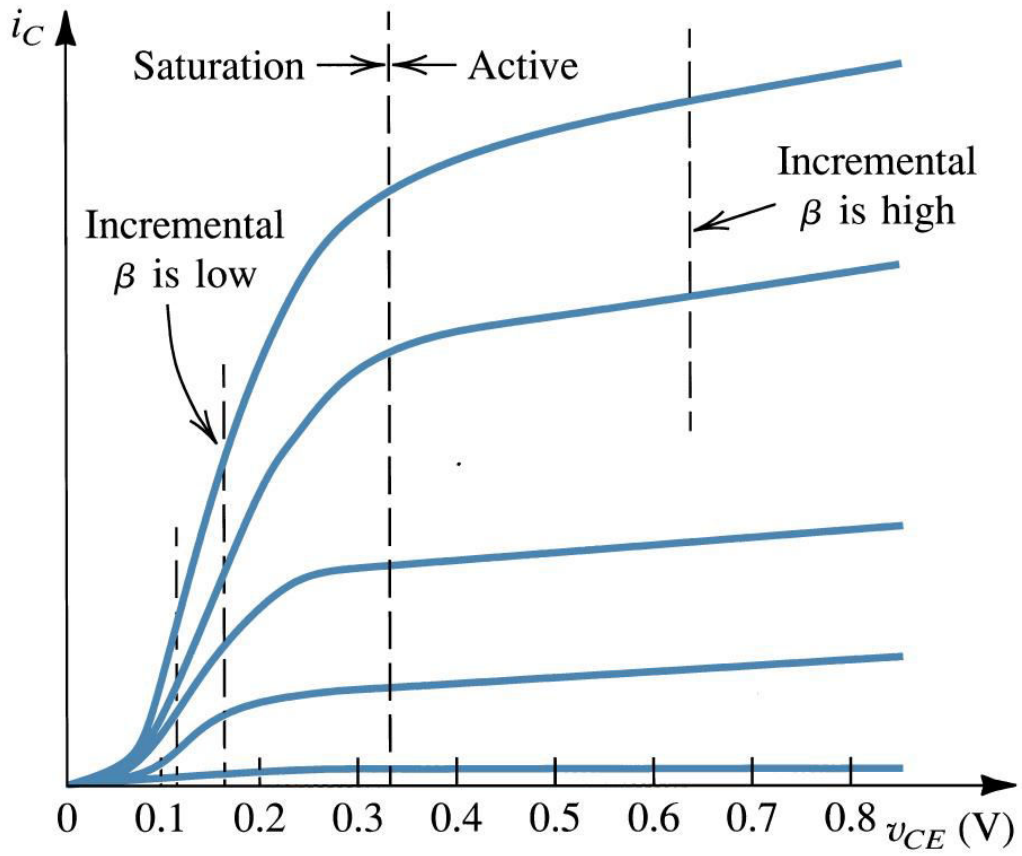


Fig. 4.66 An expanded view of the common-emitter characteristics in the saturation region.