CHAPTER 7

Transistor Amplifiers
BJT

Disclaimer: Most of the slides are skeletons that will be filled/modified in the lecture. Please do not assume that you can know the material just by reading the slides.

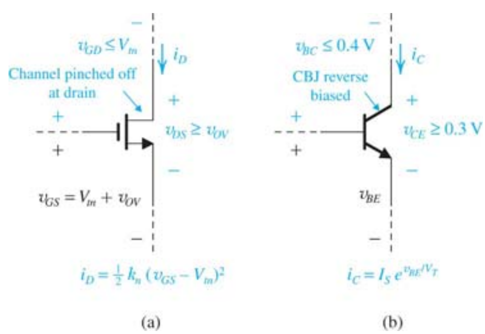


Figure 7.1 Operating (**a**) an NMOS transistor and (**b**) a n *npn* transistor in the active mode. Note that $v_{GS} = V_{tn} + v_{OV}$ and $v_{DS} \ge v_{OV}$; thus $v_{GD} \le V_{tn}$, which ensures channel pinch-off at the drain end. Similarly, $v_{BE} \simeq 0.7$ V, and $v_{CE} \ge 0.3$ V results in $v_{BC} \le 0.4$ V, which is sufficient to keep the CBJ from conducting.

Microelectronic Circuits, Seventh Edition Sedra/Smith Copyright © 2015 by Oxford University Press

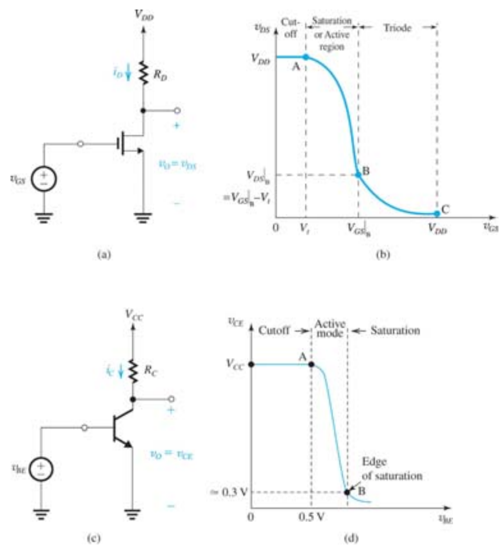


Figure 7.2 (**a**) An NMOS amplifier and (**b**) its VTC; and (**c**) a n*npn* amplifier and (**d**) its VTC.

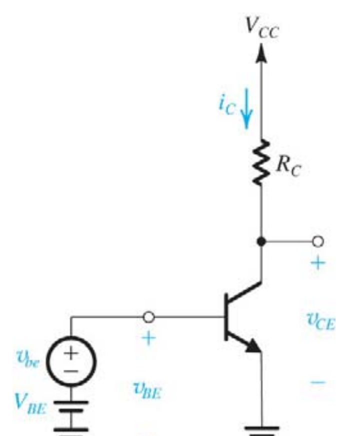
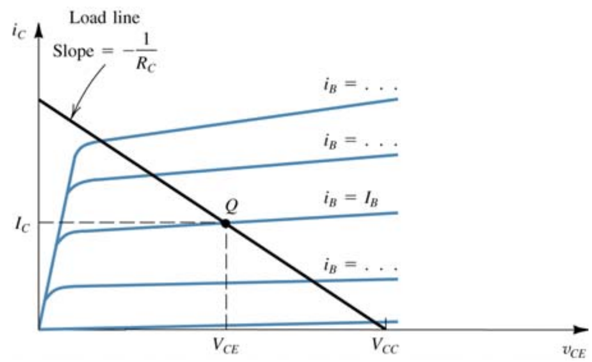


Figure 7.6 BJT amplifier biased at a point Q, with a small voltage signal v_{be} superimposed on the dc bias voltage V_{BE}. The resulting output signal v_{ce} appears superimposed on the dc collector voltage V_{CE}. The amplitude of v_{ce} is larger than that of v_{be} by the voltage gain A_v.



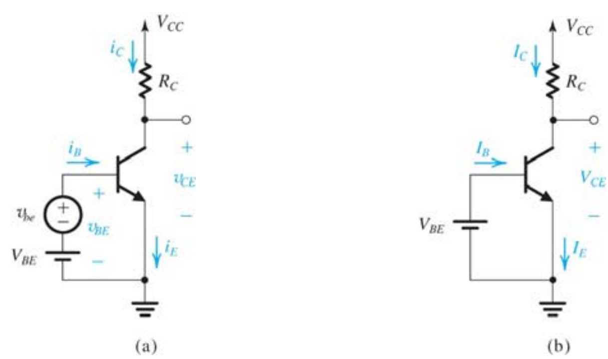
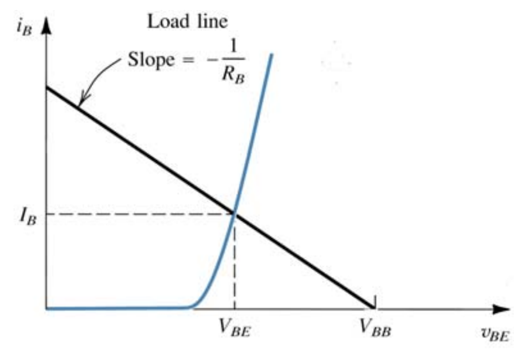


Figure 7.20 (**a**) Conceptual circuit to illustrate the operation of the transistor as an amplifier. (**b**) The circuit of (**a**) with the signal source v_{be} eliminated for dc (bias) analysis.



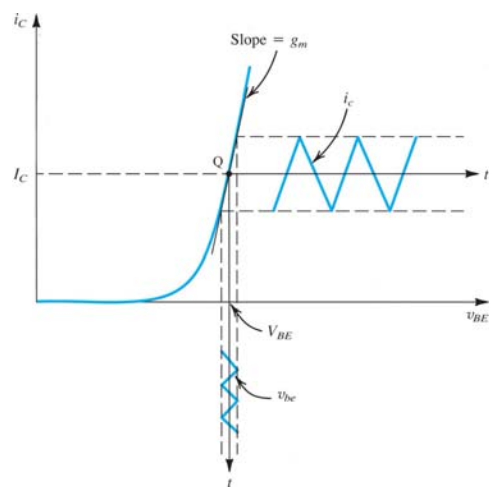
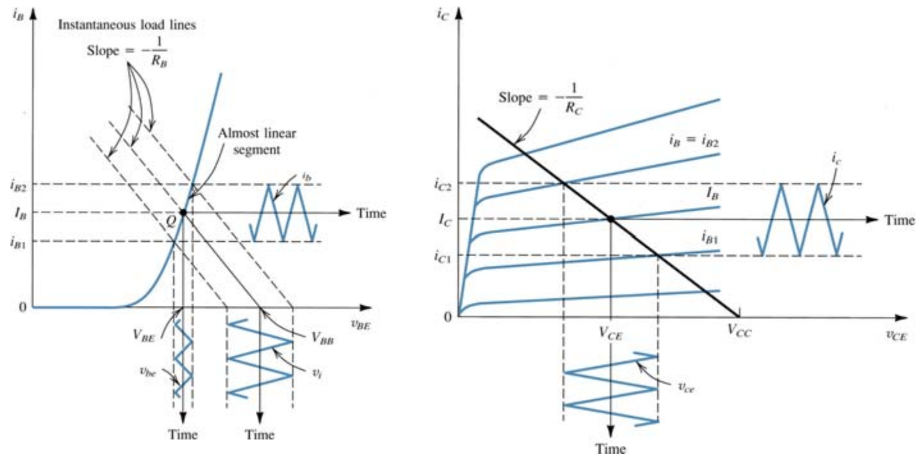


Figure 7.21 Linear operation of the transistor under the small-signal condition: A small-signal v_{be} with a triangular waveform is superimposed on the dc voltage V_{BE}. It gives rise to a collector-signal current i_c, also of triangular waveform, superimposed on the dc current I_C. Here, $i_c = g_m v_{be}$, where g_m is the slope of the i_C–v_{BE} curve at the bias point Q.



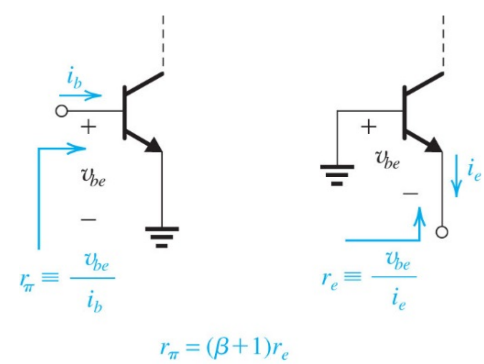


Figure 7.22 Illustrating the definition of r_π and r_e.

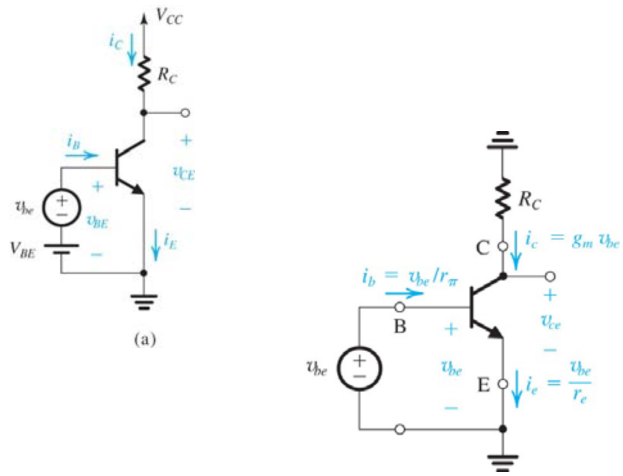


Figure 7.23 The amplifier circuit of Fig. 7.20(a) with the dc sources (V_{BE} and V_{CC}) eliminated (short-circuited). Thus only the signal components are present. Note that this is a representation of the signal operation of the BJT and not an actual amplifier circuit.

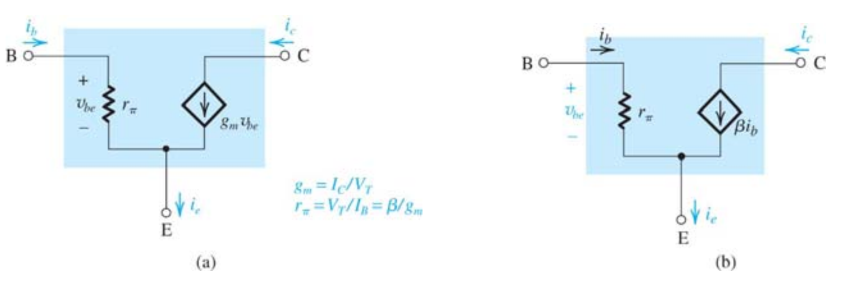


Figure 7.24 Two slightly different versions of the hybrid-π model for the small-signal operation of the BJT. The equivalent circuit in (**a**) represents the BJT as a voltage-controlled current source (a transconductance amplifier), and that in (**b**) represents the BJT as a current-controlled current source (a current amplifier).

$$g_m = I_C / V_T$$
$$r_\pi = V_T / I_B = \beta / g_m$$
$$r_o = V_A / I_C$$

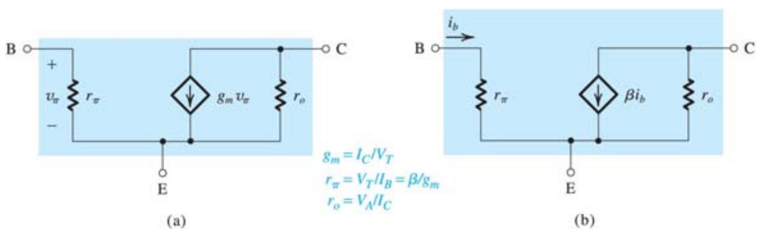
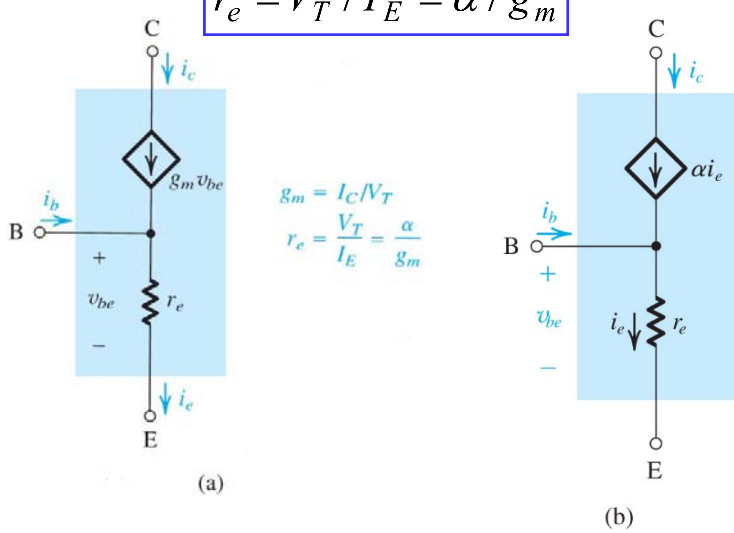


Figure 7.25 The hybrid-π small-signal model, in its two versions, with the resistance r_o included.

$$g_m = I_C / V_T$$
$$r_e = V_T / I_E = \alpha / g_m$$



$$g_m = I_C / V_T$$
$$r_e = V_T / I_E = \alpha / g_m$$
$$r_o = V_A / I_C$$

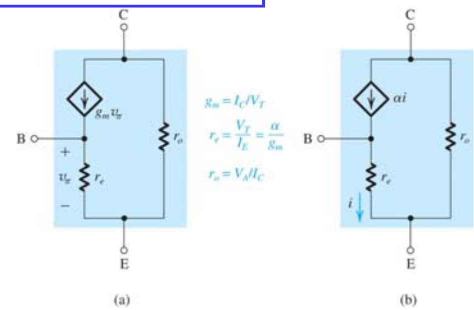
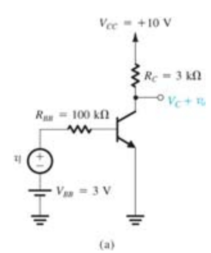
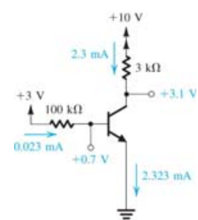


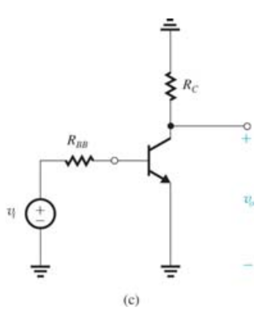
Figure 7.27 The T models of the BJT.

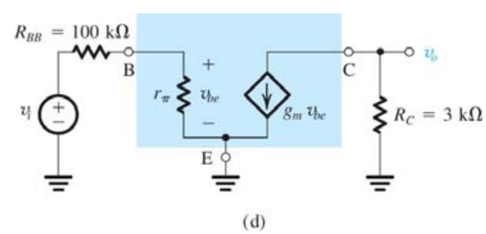


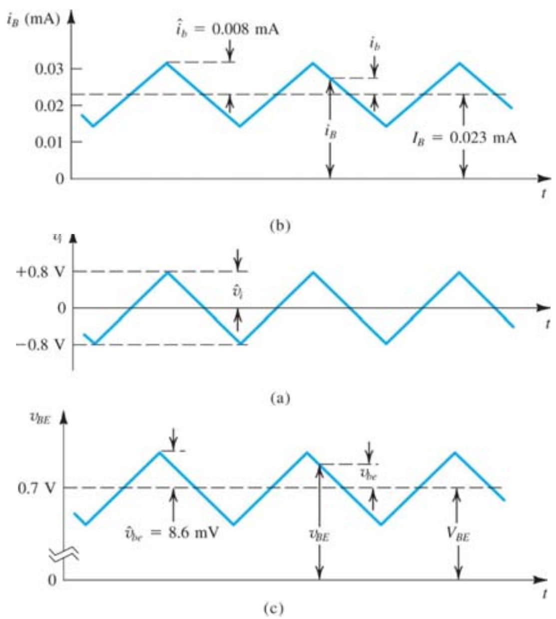
$$\beta = 100$$



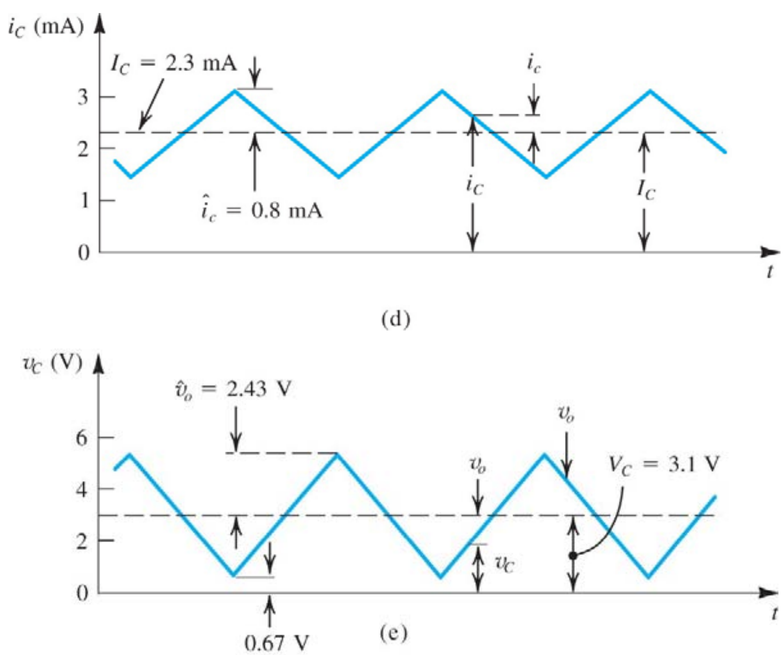
$$g_m = I_C / V_T = 2.3/25 = 92mA/V$$
$$r_\pi = \beta / g_m = 100/92 = 1.09K\Omega$$
$$r_e = V_T / I_E = 25/(2.3/99) = 10.8\Omega$$



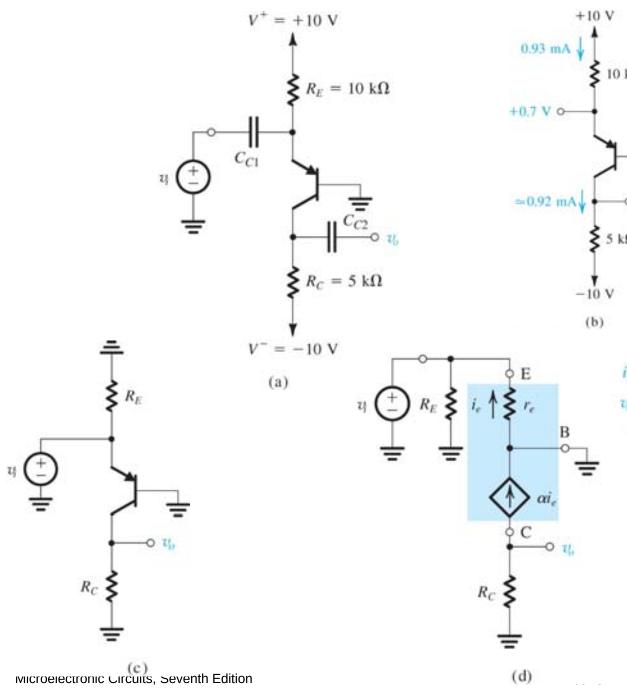




i_B (mA)
$\hat{i}_b$ = 0.008 mA
i_b
0.03
0.02
0.01
0
i_B
I_B = 0.023 mA
t
(b)
v_i
+0.8 V
$\hat{v}_i$
0
−0.8 V
t
(a)
v_{BE}
0.7 V
v_{be}
$\hat{v}_{be}$ = 8.6 mV
v_{BE}
V_{BE}
0
t
(c)



i_C (mA)
I_C = 2.3 mA
i_c
3
2
1
0
$\hat{i}_c$ = 0.8 mA
i_C
I_C
t
(d)
v_C (V)
$\hat{v}_o$ = 2.43 V
6
4
2
0
v_o
v_o
V_C = 3.1 V
v_C
0.67 V
(e)
t



$$i_e = -v_i / r_e$$

$$v_o = -\alpha\, i_e\, R_C$$

$$= \frac{\alpha\, i_e\, R_C}{r_e} v_i$$

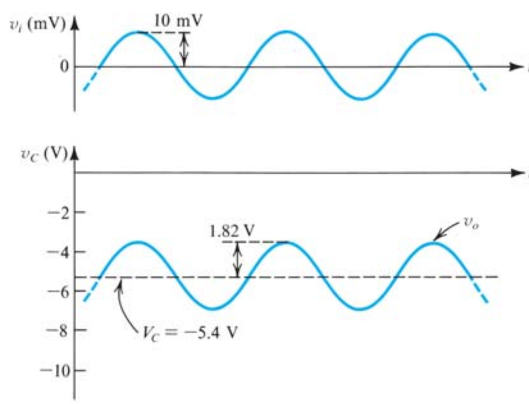
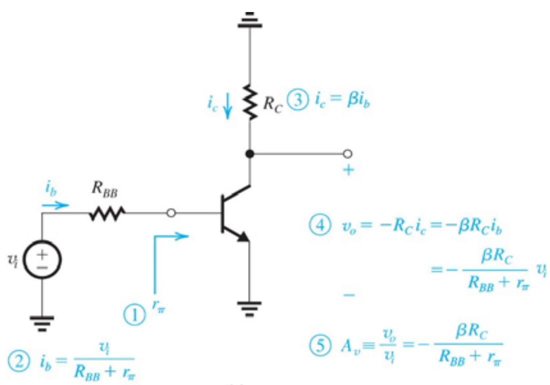
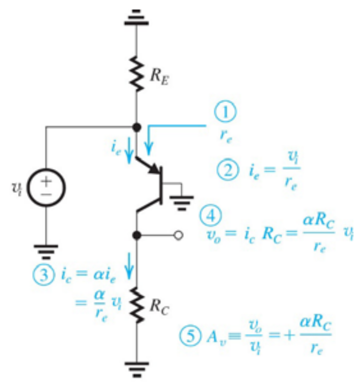


Figure 7.31 Input and output waveforms for the circuit of Fig. 7.30. Observe that this amplifier is noninverting, a property of the grounded-base configuration.

Performing Small Signal Analysis Directly on the Circuit



(a)



(b)

β=100 V_A=100V

a) Find V_A, V_B, and V_C ignoring Early Effect
b) Find g_m, r_π, r_o
c) Z is grounded and v_{sig} is connected to X (with 2K internal R, and 8K load resistance connected to Y find A_v with or without the Early effect

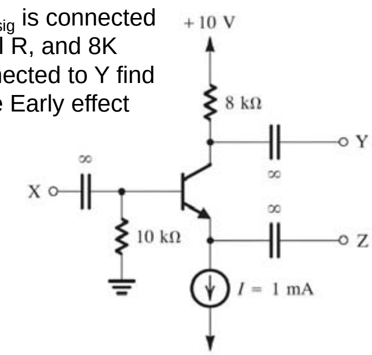


Figure E7.20

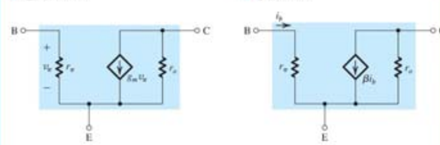
Table 7.1 Systematic Procedure for the Analysis of Transistor Amplifier Circuits

1. Eliminate the signal source and determine the dc operating point of the transistor.
2. Calculate the values of the parameters of the small-signal model.
3. Eliminate the dc sources by replacing each dc voltage source by a short circuit and each dc current source by an open circuit.
4. Replace the transistor with one of its small-signal, equivalent-circuit models. Although any of the models can be used, one might be more convenient than the others for the particular circuit being analyzed. This point will be made clearer in the next section.
5. Analyze the resulting circuit to determine the required quantities (e.g., voltage gain, input resistance).

Table 7.3 Small-Signal Models of the BJT

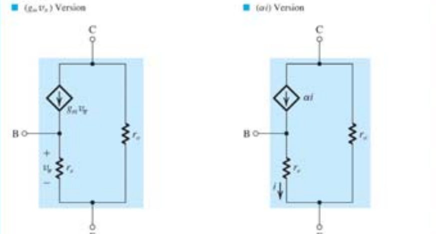
Hybrid-π Model

■ ($g_m v_\pi$) Version ■ (βi_b) Version



T Model

■ ($g_m v_\pi$) Version ■ (αi) Version



Model Parameters in Terms of DC Bias Currents

$g_m = \frac{I_C}{V_T}$ $r_e = \frac{V_T}{I_E} = \alpha \frac{V_T}{I_C}$ $r_\pi = \frac{V_T}{I_B} = \beta \frac{V_T}{I_C}$ $r_o = \frac{|V_A|}{I_C}$

In Terms of g_m

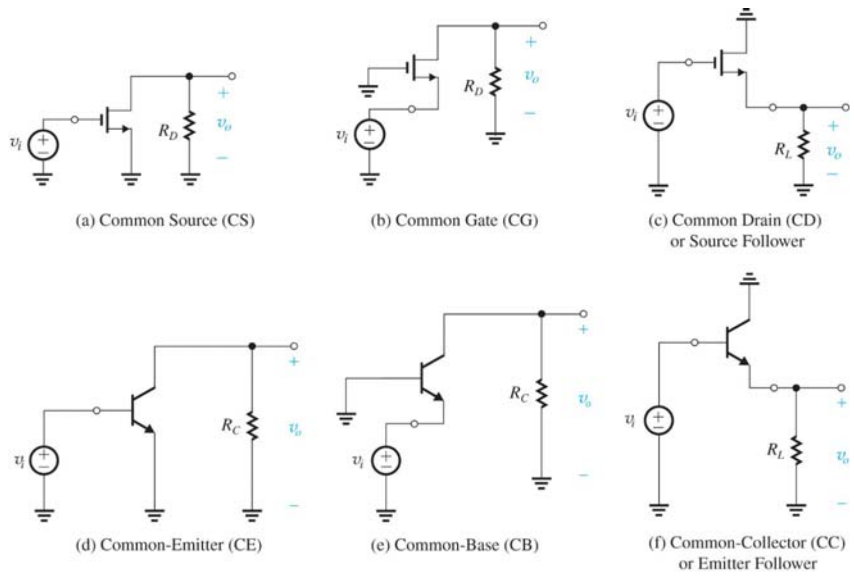
$r_e = \frac{\alpha}{g_m}$ $r_\pi = \frac{\beta}{g_m}$

In Terms of r_e

$g_m = \frac{\alpha}{r_e}$ $r_\pi = (\beta + 1) r_e$ $g_m + \frac{1}{r_\pi} = \frac{1}{r_e}$

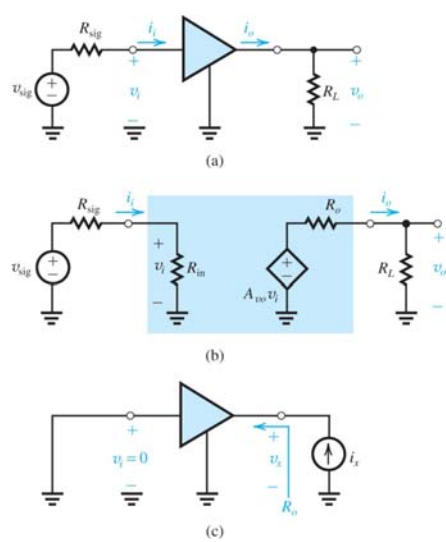
Relationships between α and β

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



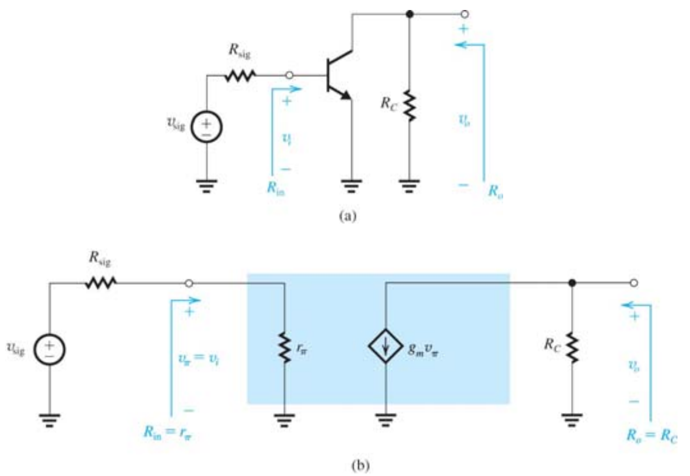
(a) Common Source (CS)
(b) Common Gate (CG)
(c) Common Drain (CD) or Source Follower
(d) Common-Emitter (CE)
(e) Common-Base (CB)
(f) Common-Collector (CC) or Emitter Follower

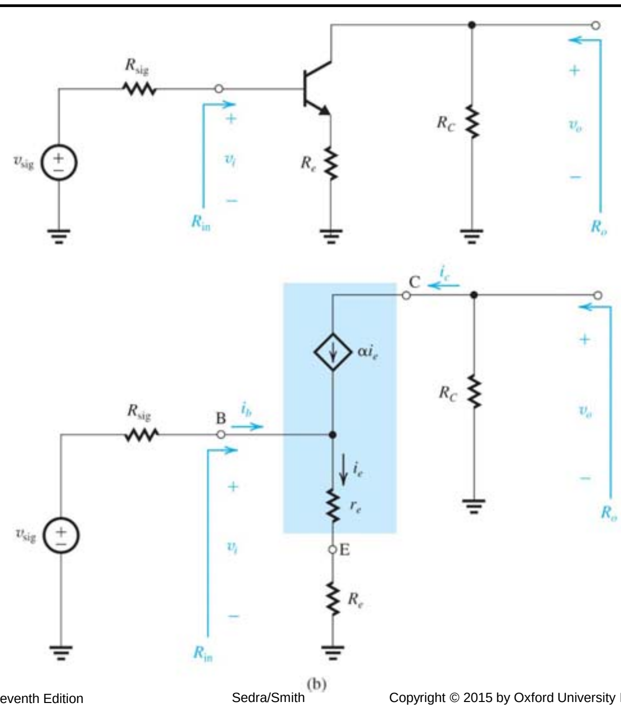
Amplifiers



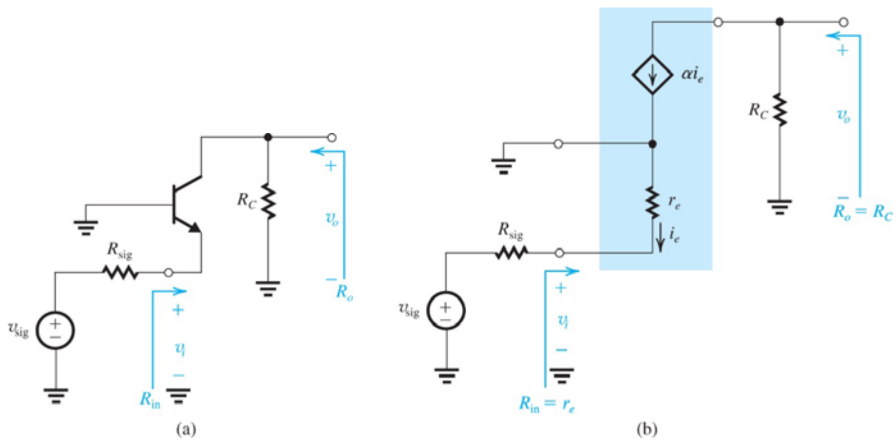
(a)
(b)
(c)

Common Emitter





Common Base



Common Collector – Emitter Follower