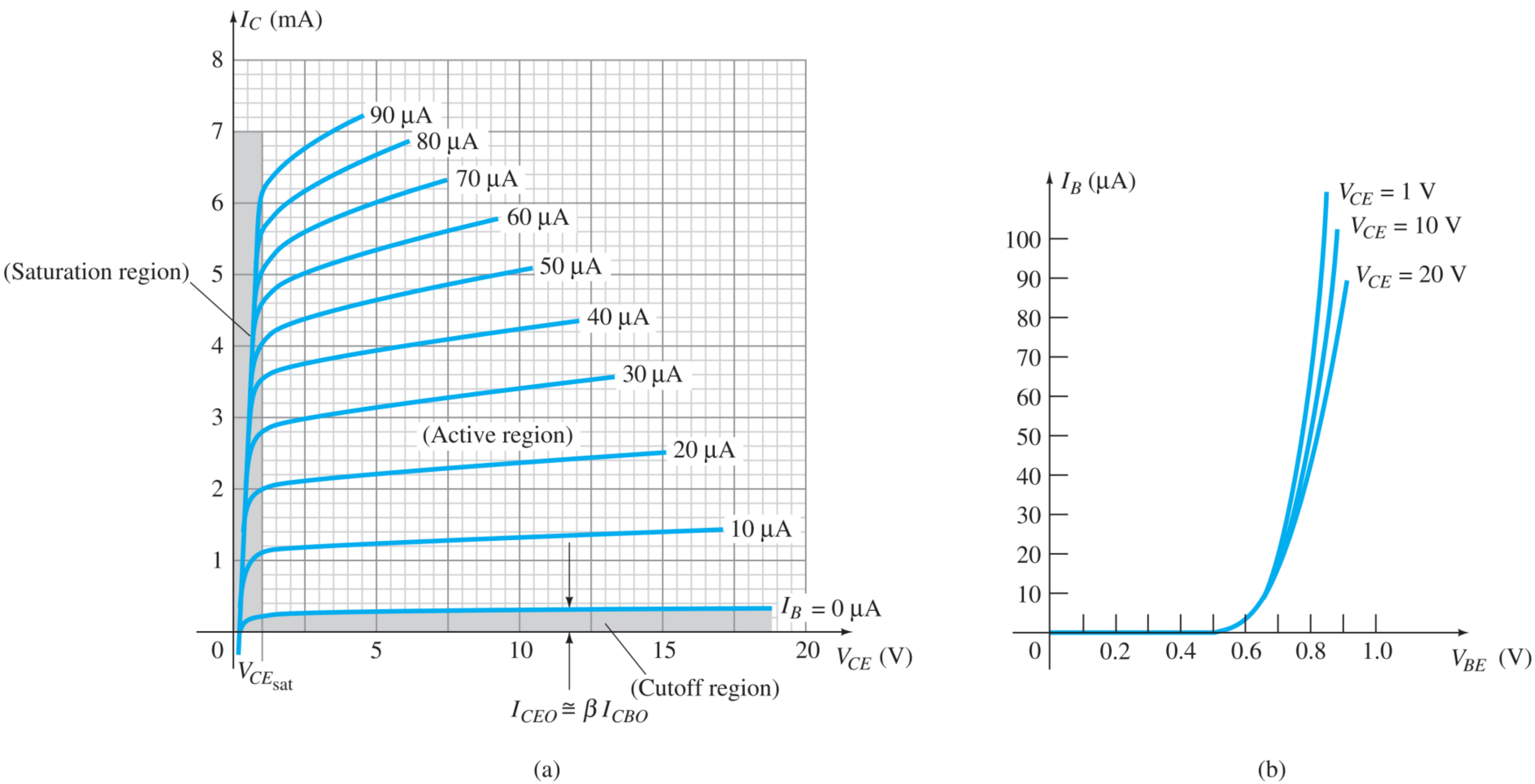
Supplementation

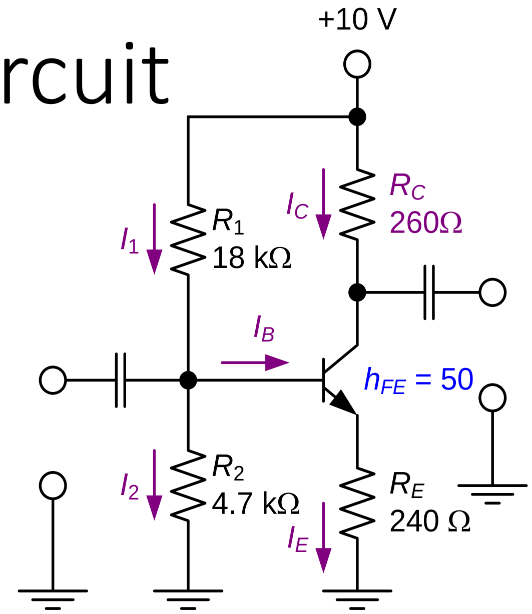
Week 8

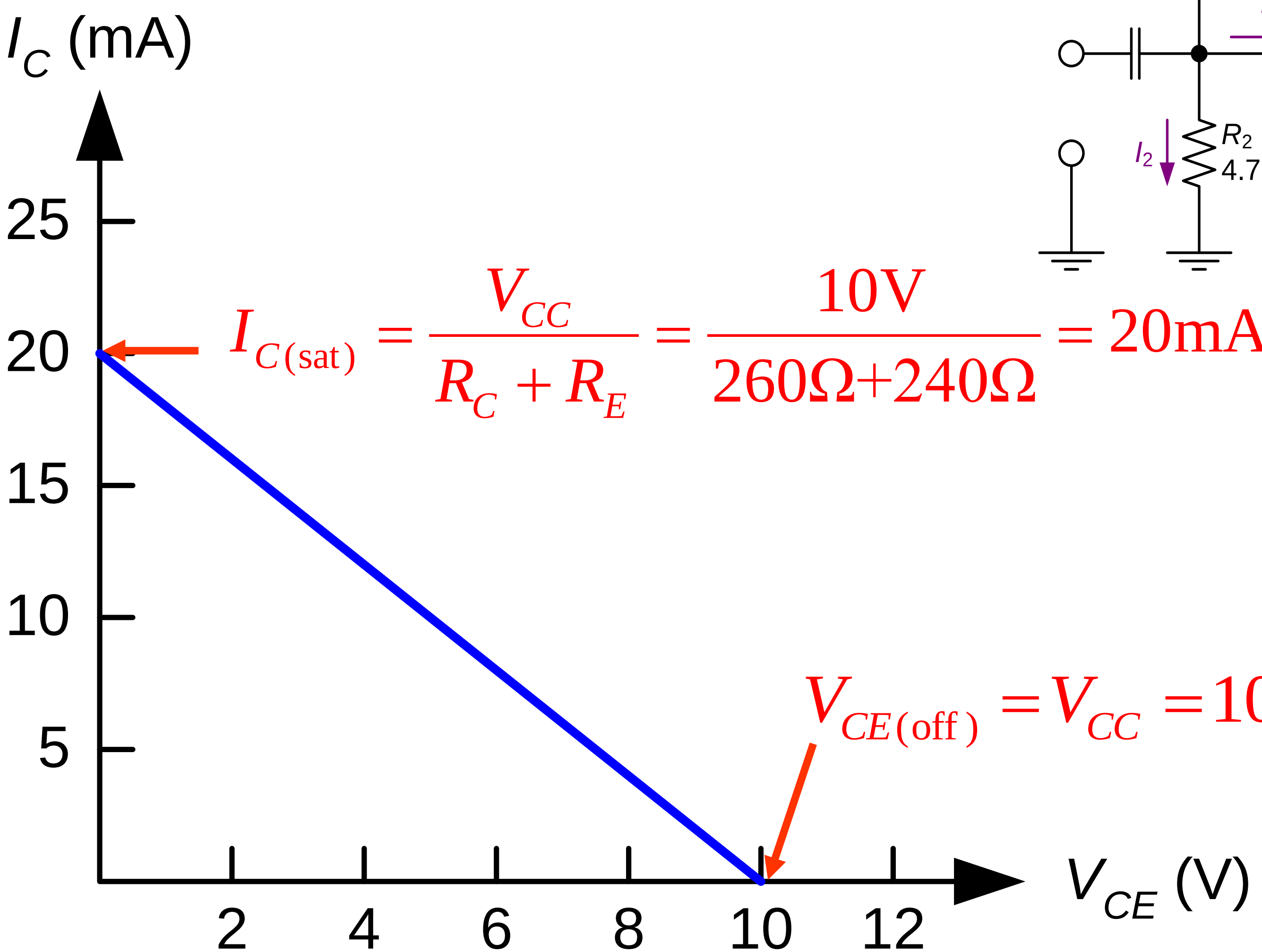
Operating regions



Note : $I_C = I_{C_{majority}} + I_{CO_{minority}}$

Load line for voltage divider bias circuit

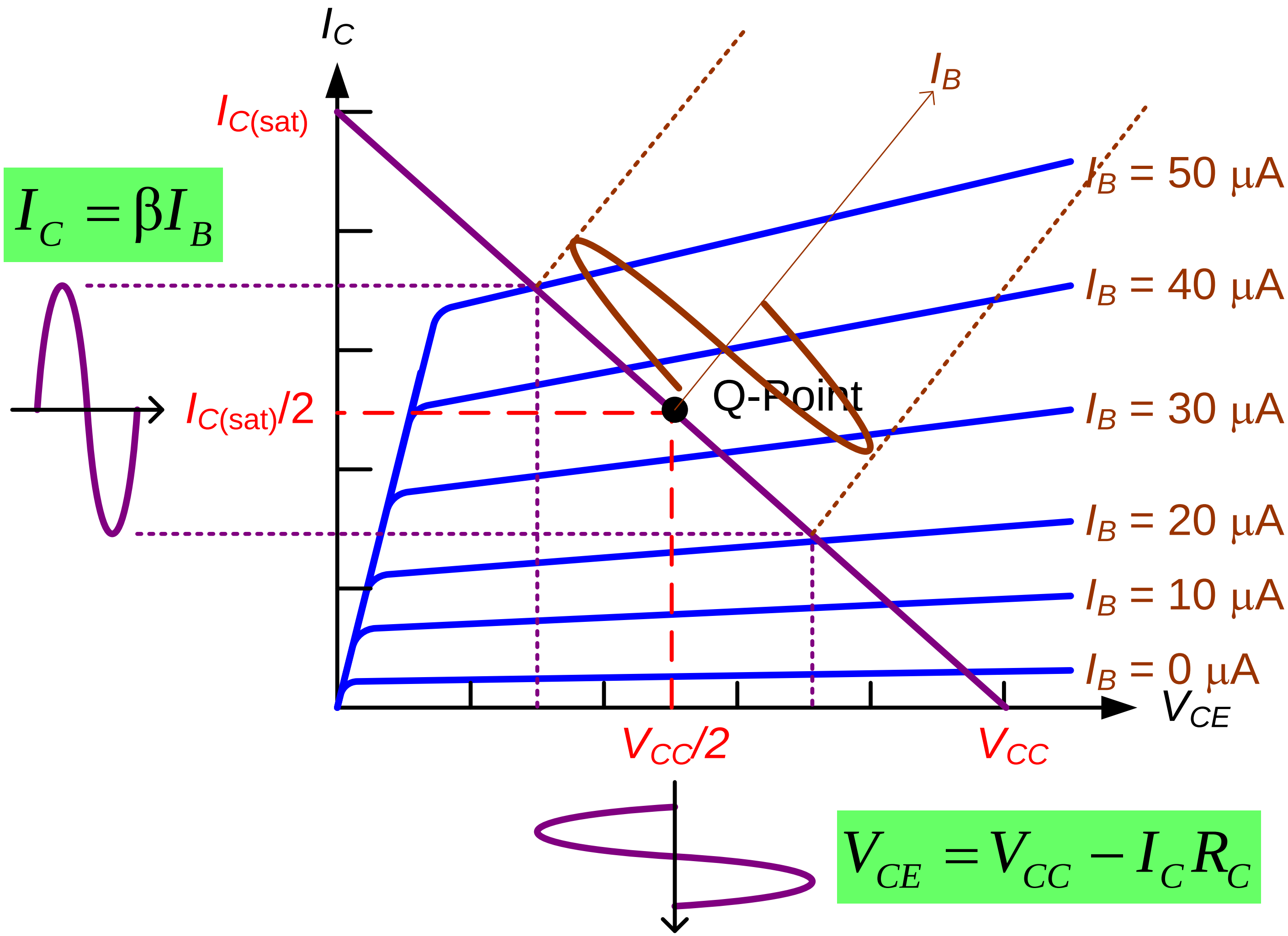




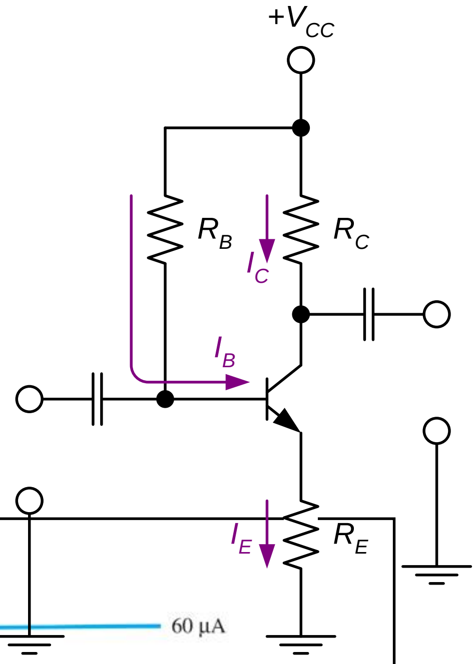
$$I_{C(\text{sat})} = \frac{V_{CC}}{R_C + R_E} = \frac{10\text{V}}{260\Omega + 240\Omega} = 20\text{mA}$$

$$V_{CE(\text{off})} = V_{CC} = 10\text{V}$$

Q-point with amplifier operation, Where?



Switching Circuit Calculations

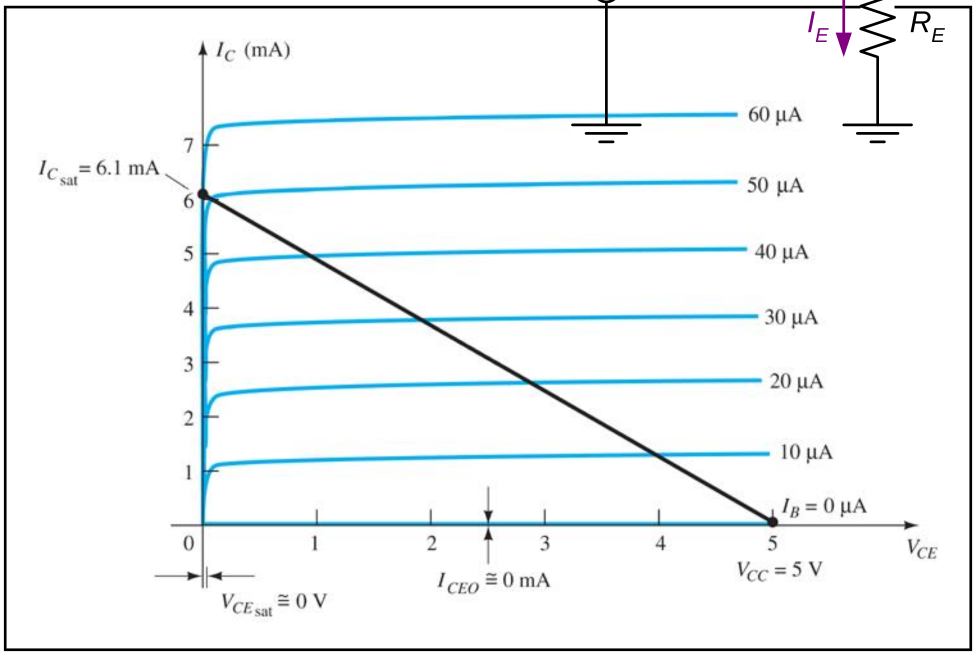


Saturation current:

$$I_{Csat} = \frac{V_{CC}}{R_C}$$

To ensure saturation:

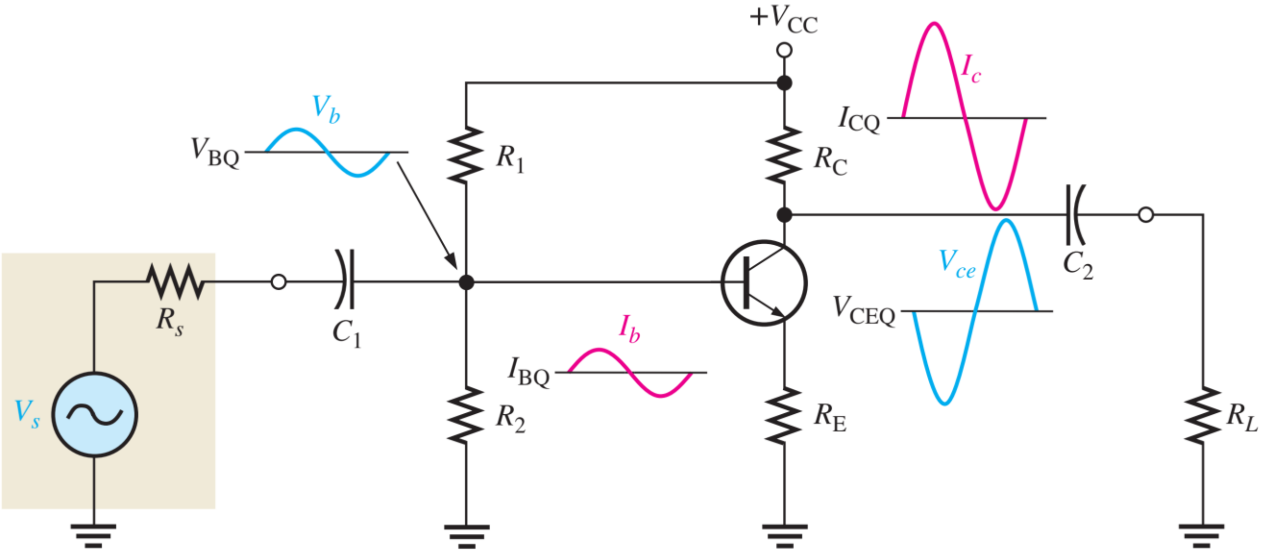
$$I_B > \frac{I_{Csat}}{\beta_{dc}}$$



Emitter-collector resistance at saturation and cutoff:

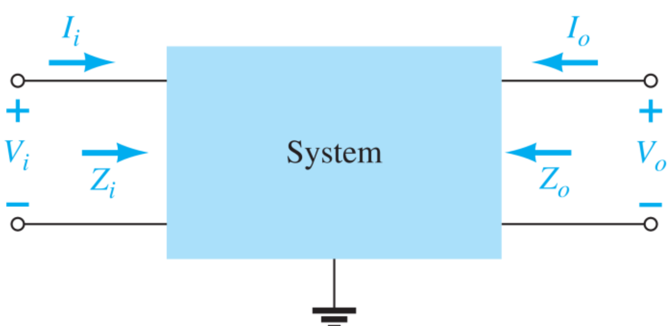
$$R_{sat} = \frac{V_{CEsat}}{I_{Csat}}$$

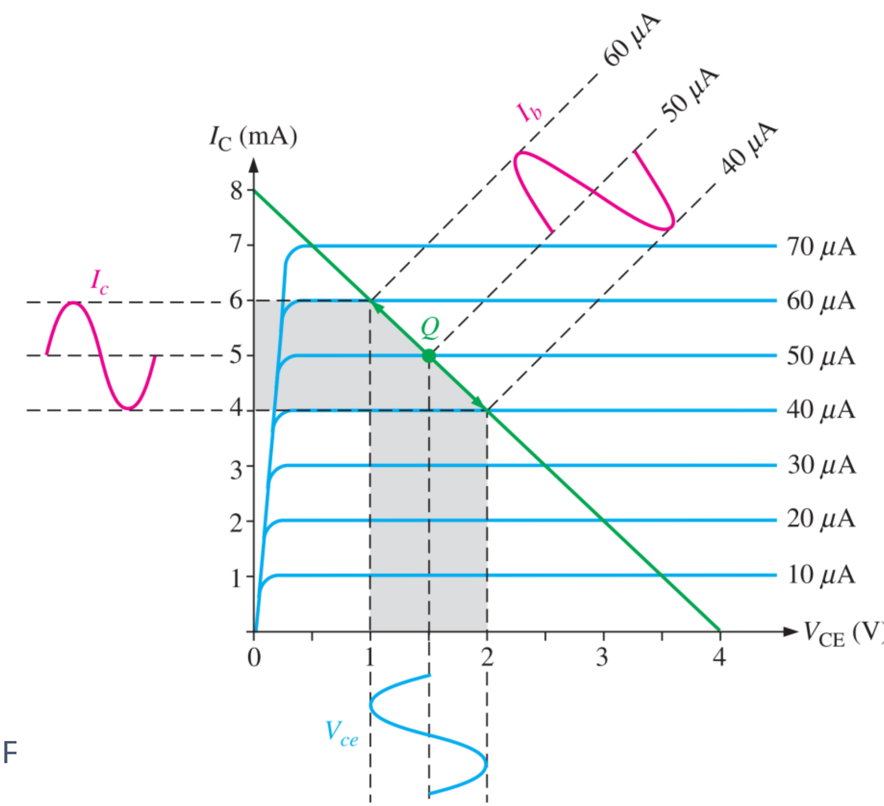
$$R_{cutoff} = \frac{V_{CC}}{I_{CEO}}$$

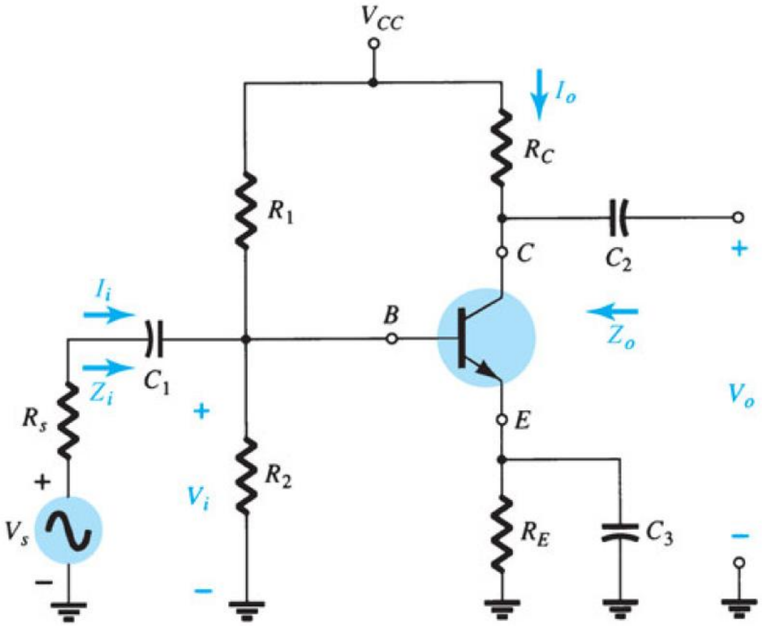


The important circuit parameters:

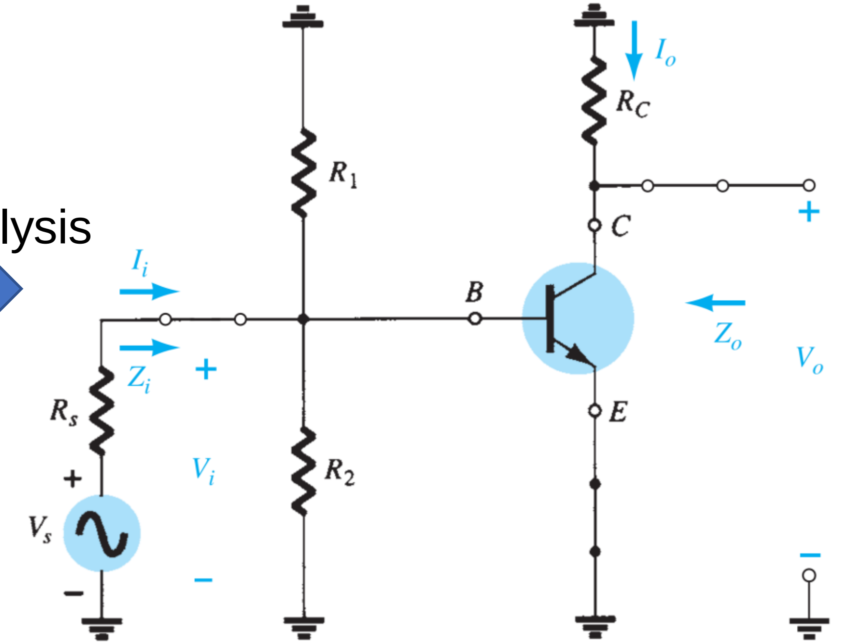
1. $Z_i = V_i/I_i$ input impedance
2. $Z_o = V_o/I_o$ output impedance
3. $A_v = V_o/V_i$ voltage gain
4. $A_i = I_o/I_i$ current gain







ac analysis



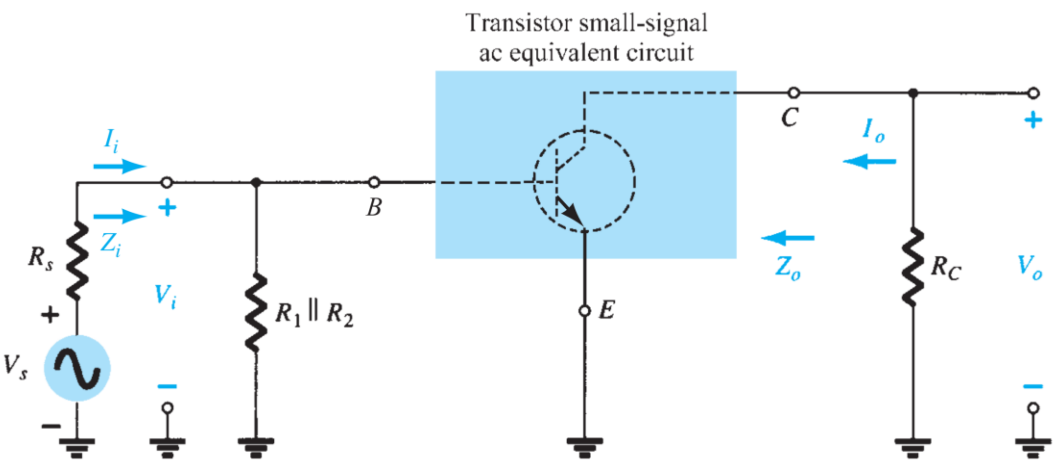
In summary, therefore, the ac equivalent of a transistor network is obtained by:

1. Setting all dc sources to zero and replacing them by a short-circuit equivalent

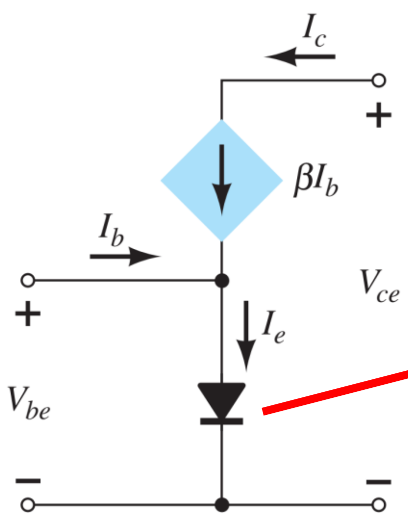
2. Replacing all capacitors by a short-circuit equivalent

3. Removing all elements bypassed by the short-circuit equivalents introduced by steps 1 and 2

4. Redrawing the network in a more convenient and logical form



The r_e Transistor Model



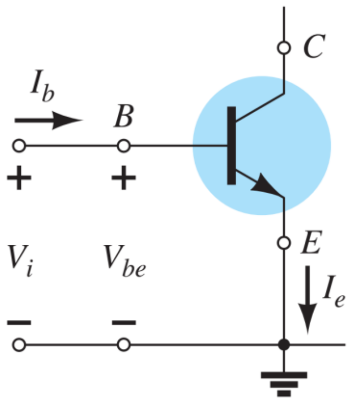
ac resistance of the diode

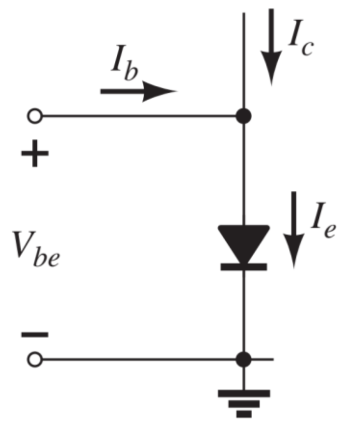
$$r_e = \frac{dI_D}{dV} = \frac{d}{dV}[I_S(e^{V/\eta kT} - 1)]$$

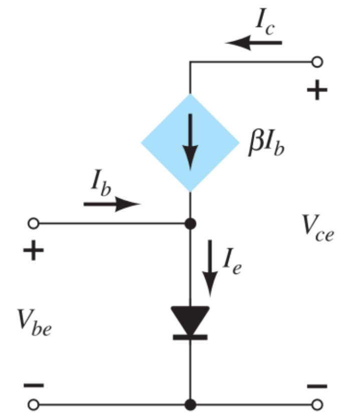
for Si and T = 25 ^oC, $r_e = \frac{26mV}{I_e}$ For $I_D = I_e >> I_S$

(a few ohms)

Common-Emitter Configuration







The diode r_e model can be replaced by the resistor r_e.

$$r_e = \frac{26\ mV}{I_e}$$

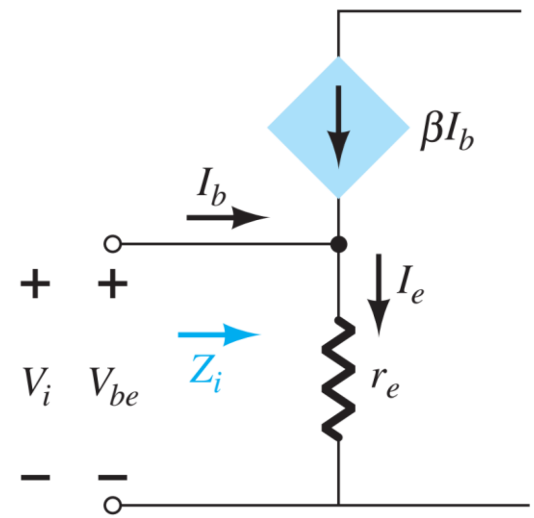
Current through diode:

$$I_e = I_c + I_b = \beta I_b + I_b = (\beta + 1) I_b \cong \beta I_b$$

(generally β>>1)

Input impedance: $$Z_i = \frac{V_i}{I_i} = \frac{V_{be}}{I_b} = \frac{I_e r_e}{I_b} \cong \frac{\beta I_b r_e}{I_b}$$

⇨ $$Z_i \cong \beta r_e$$



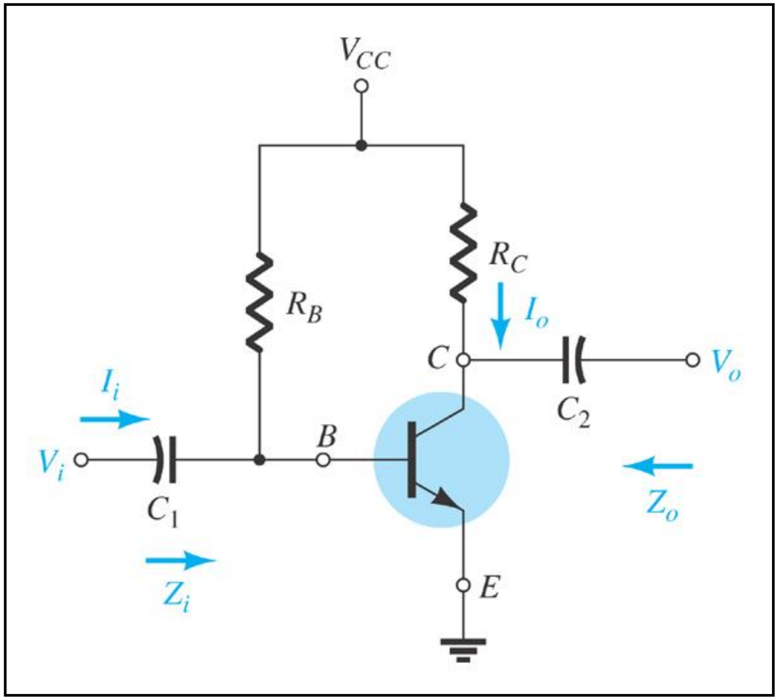
Common-Emitter Fixed-Bias Configuration

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

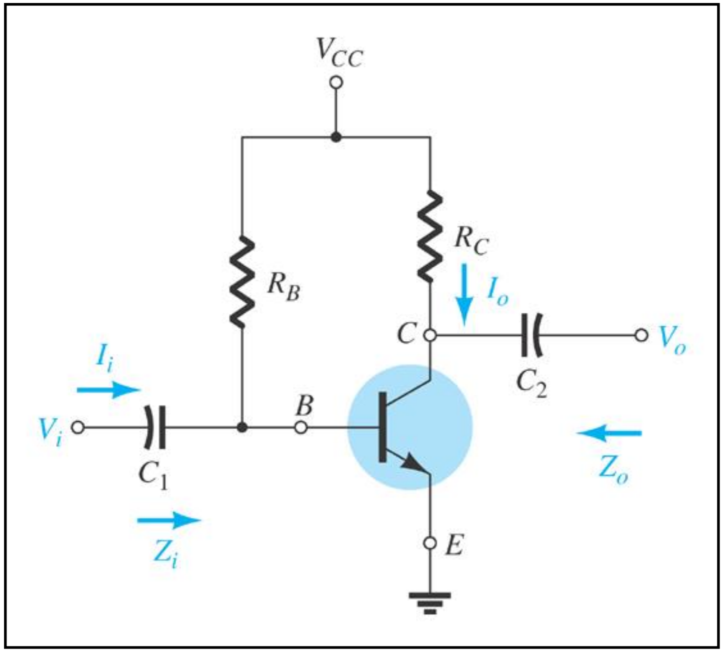
High input impedance
Low output impedance

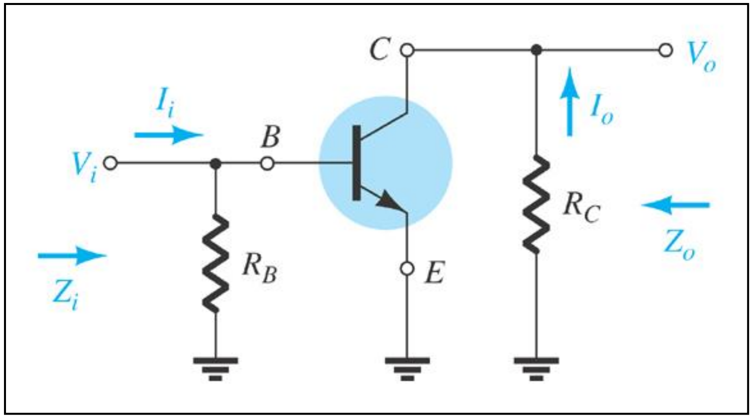
High voltage and current gain

Phase shift between input and output is 180°

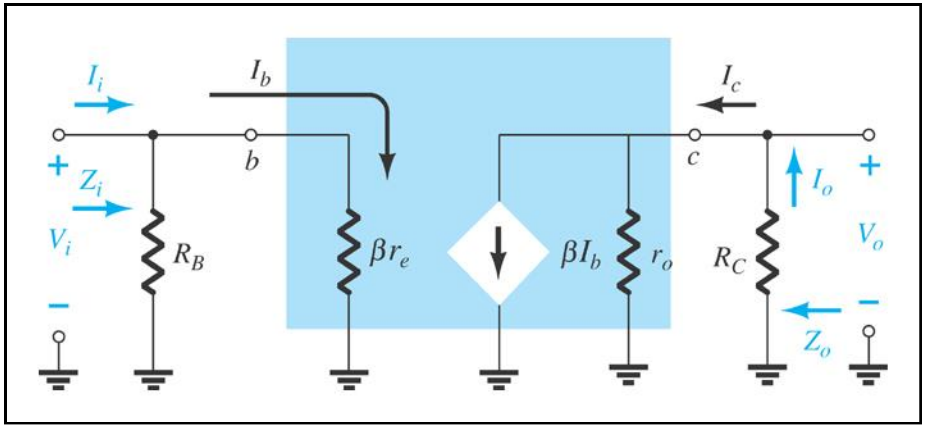


Common-Emitter Fixed-Bias Configuration



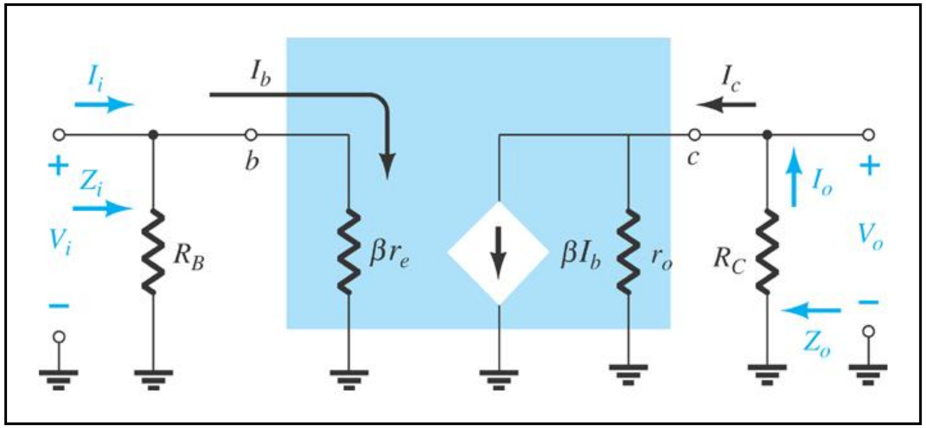


AC equivalent



r_e model

Common-Emitter Fixed-Bias Calculations



Input impedance:

$$Z_i = R_B||\beta|_e$$

$$Z_i \cong \beta r_e \Big|_{R_E \geq 10\beta r_e}$$

Output impedance:

$$Z_o = R_C||r_o$$

$$Z_o \cong R_C \Big|_{r_o \geq 10 R_C}$$

Voltage gain:

$$A_v = \frac{V_o}{V_i} = -\frac{(R_C||r_o)}{r_e}$$

$$A_v = -\frac{R_C}{r_e}\Big|_{r_o \geq 10 R_C}$$

Current gain:

$$A_i = \frac{I_o}{I_i} = \frac{\beta R_B r_o}{(r_o + R_C)(R_B + \beta r_e)}$$

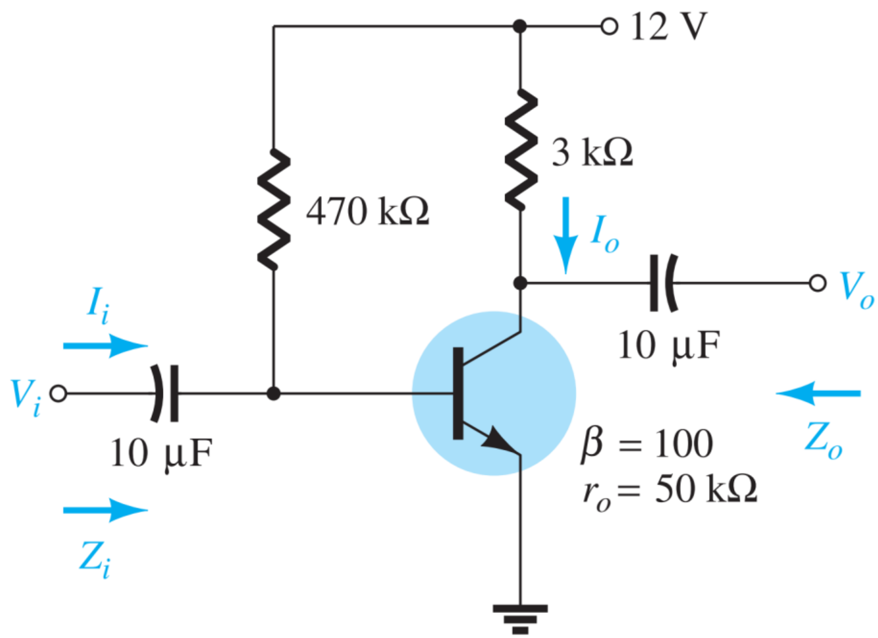
$$A_i \cong \beta \Big|_{r_o \geq 10 R_C,\, R_B \geq 10\beta r_e}$$

Current gain from voltage gain:

$$A_i = -A_V \frac{Z_i}{R_C}$$

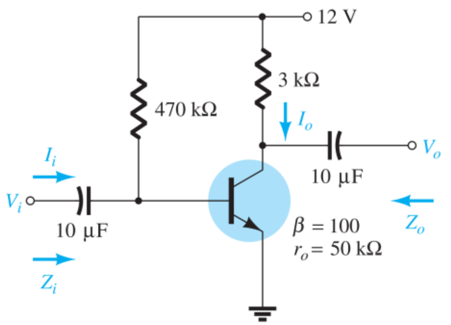
Example

a. Determine r_e.
b. Find Z_i (with $r_o = \infty\,\Omega$).
c. Calculate Z_o (with $r_o = \infty\,\Omega$).
d. Determine A_v (with $r_o = \infty\,\Omega$).
e. Repeat parts (c) and (d) including $r_o = 50\text{ k}\Omega$ in all calculations and compare results.



Solution:

a. DC analysis:



$$I_B = \frac{V_{CC} - V_{BE}}{R_B} = \frac{12\text{ V} - 0.7\text{ V}}{470\text{ k}\Omega} = 24.04\ \mu\text{A}$$

$$I_E = (\beta + 1)I_B = (101)(24.04\ \mu\text{A}) = 2.428\text{ mA}$$

$$r_e = \frac{26\text{ mV}}{I_E} = \frac{26\text{ mV}}{2.428\text{ mA}} = \mathbf{10.71\ \Omega}$$

b. $\beta r_e = (100)(10.71\ \Omega) = 1.071\text{ k}\Omega$

$$Z_i = R_B \| \beta r_e = 470\text{ k}\Omega \| 1.071\text{ k}\Omega = \mathbf{1.07\text{ k}\Omega}$$

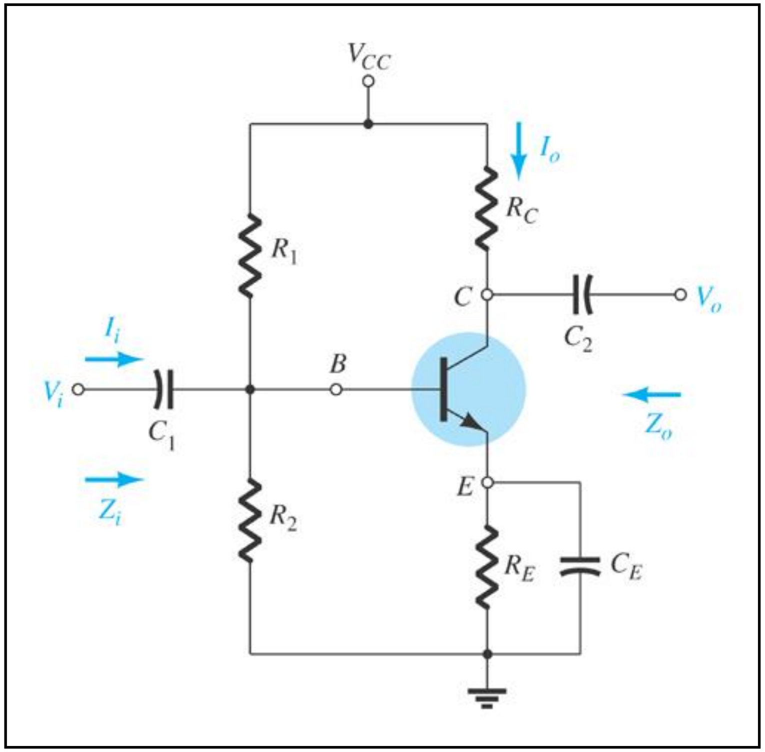
c. $Z_o = R_C = \mathbf{3\text{ k}\Omega}$

d. $A_v = -\frac{R_C}{r_e} = -\frac{3\text{ k}\Omega}{10.71\ \Omega} = \mathbf{-280.11}$

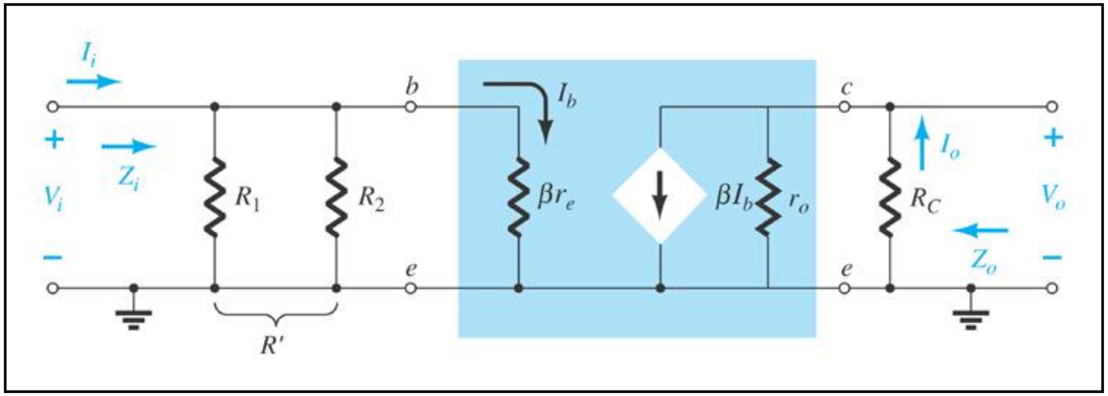
e. $Z_o = r_o \| R_C = 50\text{ k}\Omega \| 3\text{ k}\Omega = \mathbf{2.83\text{ k}\Omega}$ vs. $3\text{ k}\Omega$

$$A_v = -\frac{r_o \| R_C}{r_e} = \frac{2.83\text{ k}\Omega}{10.71\ \Omega} = \mathbf{-264.24} \text{ vs. } -280.11$$

Common-Emitter Voltage-Divider Bias



r_e model requires you to determine β, r_e, and r_o.



Common-Emitter Voltage-Divider Bias Calculations

Input impedance

$$R' = R_1 \,||\, R_2$$
$$Z_i = R' \,||\, \beta r_e$$

Output impedance

$$Z_o = R_C \,||\, r_o$$
$$Z_o \cong R_C \Big|_{r_o \geq 10R_C}$$

Current gain

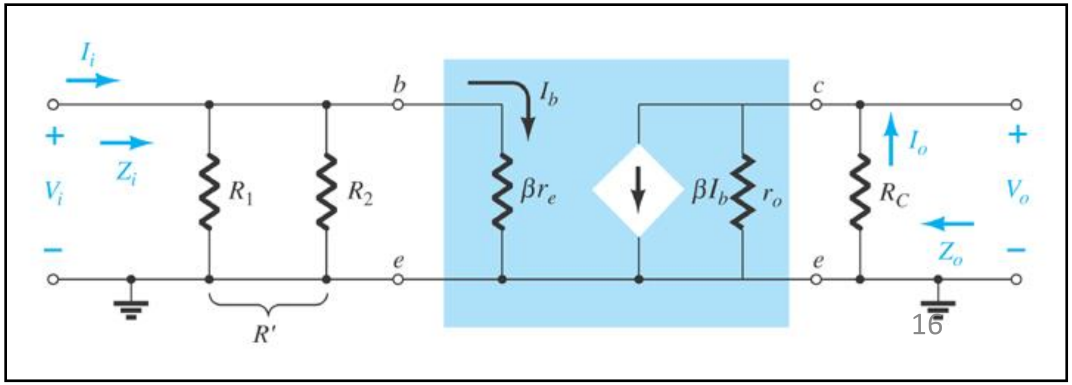
$$A_i = \frac{I_o}{I_i} = \frac{\beta R' r_o}{(r_o + R_C)(R' + \beta r_e)}$$
$$A_i = \frac{I_o}{I_i} \cong \frac{\beta R'}{R' + \beta r_e}\Big|_{r_o \geq 10R_C}$$
$$A_i = \frac{I_o}{I_i} \cong \beta \Big|_{r_o \geq 10R_C,\, R' \geq 10\beta r_e}$$

Voltage gain

$$A_v = \frac{V_o}{V_i} = \frac{-R_C \,||\, r_o}{r_e}$$
$$A_v = \frac{V_o}{V_i} \cong -\frac{R_C}{r_e}\Big|_{r_o \geq 10R_C}$$

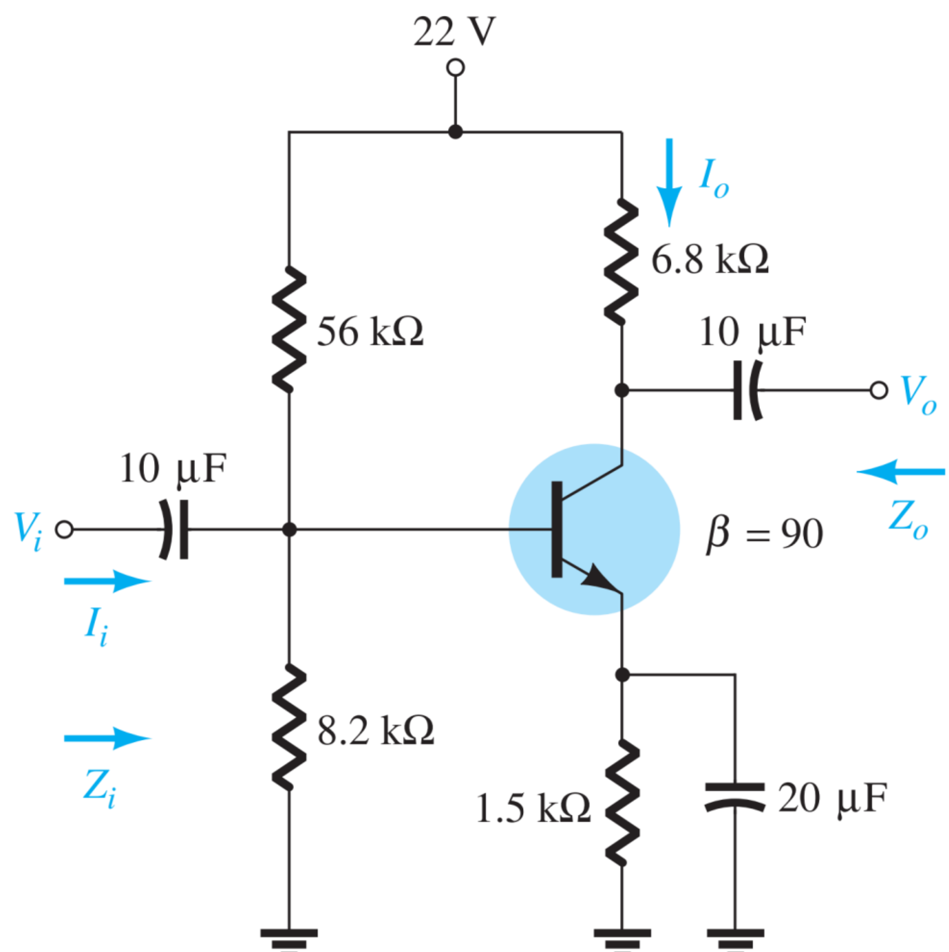
Current gain from A_v

$$A_i = -A_v \frac{Z_i}{R_C}$$



Example

a. r_e.
b. Z_i.
c. Z_o ($r_o = \infty\,\Omega$).
d. A_v ($r_o = \infty\,\Omega$).
e. The parameters of parts (b) through (d) if $r_o = 50\ \text{k}\Omega$ and compare results.



Solution:

a. DC: Testing $\beta R_E > 10R_2$,

$$(90)(1.5\text{ k}\Omega) > 10(8.2\text{ k}\Omega)$$
$$135\text{ k}\Omega > 82\text{ k}\Omega\ (\textit{satisfied})$$

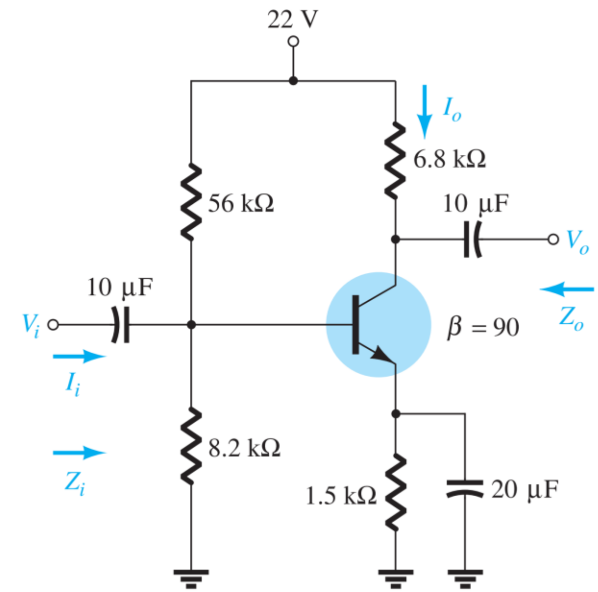
Using the approximate approach, we obtain

$$V_B = \frac{R_2}{R_1 + R_2}V_{CC} = \frac{(8.2\text{ k}\Omega)(22\text{ V})}{56\text{ k}\Omega + 8.2\text{ k}\Omega} = 2.81\text{ V}$$

$$V_E = V_B - V_{BE} = 2.81\text{ V} - 0.7\text{ V} = 2.11$$

$$I_E = \frac{V_E}{R_E} = \frac{2.11\text{ V}}{1.5\text{ k}\Omega} = 1.41\text{ mA}$$

$$r_e = \frac{26\text{ mV}}{I_E} = \frac{26\text{ mV}}{1.41\text{ mA}} = \mathbf{18.44\ \Omega}$$



b. $R' = R_1 \| R_2 = (56\text{ k}\Omega)\|(8.2\text{ k}\Omega) = 7.15\text{ k}\Omega$

$Z_i = R' \| \beta r_e = 7.15\text{ k}\Omega \| (90)(18.44\ \Omega) = 7.15\text{ k}\Omega \| 1.66\text{ k}$

$= \mathbf{1.35\text{ k}\Omega}$

c. $Z_o = R_C = \mathbf{6.8\text{ k}\Omega}$

d. $A_v = -\frac{R_C}{r_e} = -\frac{6.8\text{ k}\Omega}{18.44\ \Omega} = \mathbf{-368.76}$

e. $Z_i = \mathbf{1.35\text{ k}\Omega}$

$Z_o = R_C \| r_o = 6.8\text{ k}\Omega \| 50\text{ k}\Omega = \mathbf{5.98\text{ k}\Omega}$ vs. $6.8\text{ k}\Omega$

$A_v = -\frac{R_C \| r_o}{r_e} = -\frac{5.98\text{ k}\Omega}{18.44\ \Omega} = \mathbf{-324.3}$ vs. -368.76

There was a measurable difference in the results for Z_o and A_v, because the condition $r_o \geq 10R_C$ was *not* satisfied.