BJT AC Analysis

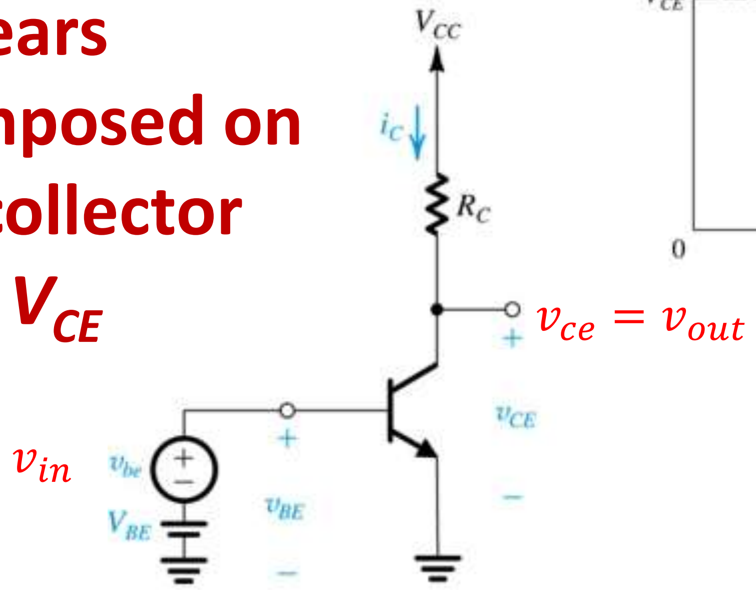
Topic 5 (Chapter 5)

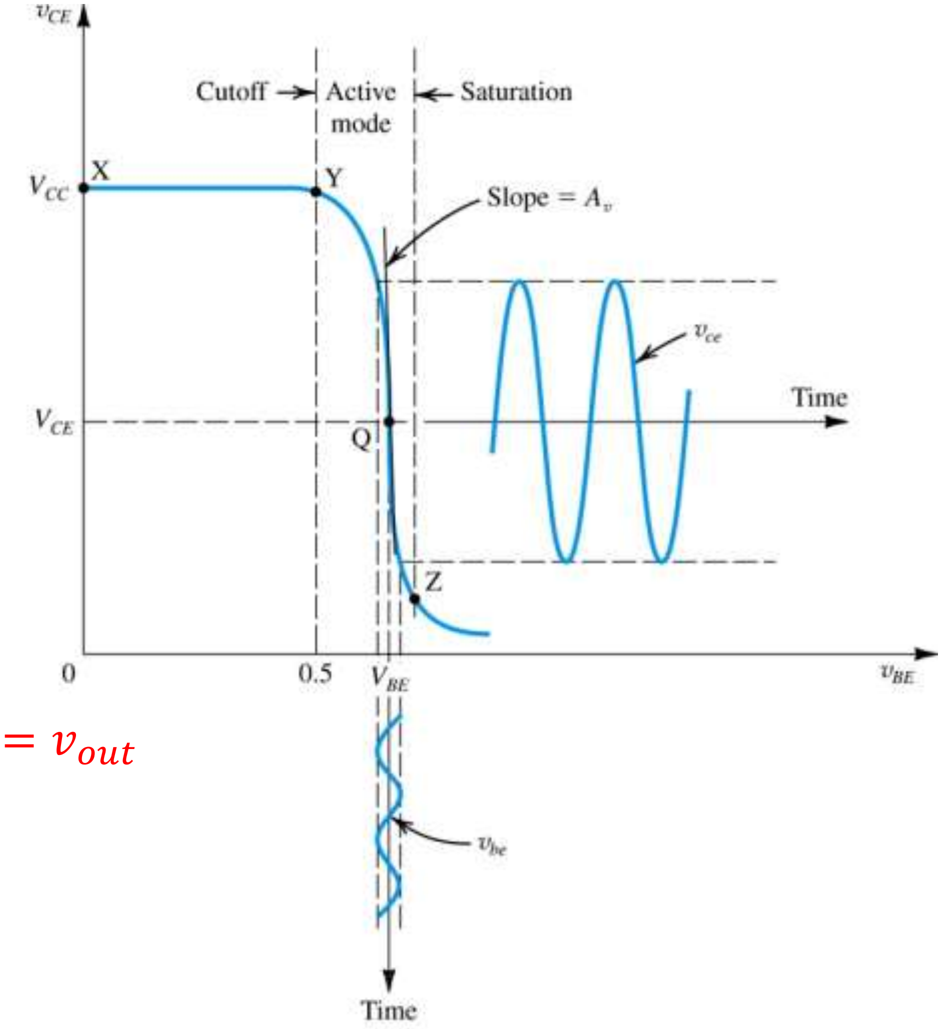
5.2 AC Amplification

- After a transistor has been biased with the Q point near the middle of the load line, we can couple a small ac voltage into the base (input).
  - This will produce an ac collector voltage (output).
  - The ac collector voltage looks like the ac base voltage, except that it's a lot bigger.
    - In other words, the ac collector voltage is an *amplified* version of the ac base voltage.
- The invention of amplifying devices, first vacuum tubes and later transistors, was crucial to the evolution of electronics.
  - Without amplification, there would be no radio, no television, and no computers.

BJT amplifier biased at a point Q

- A small signal voltage v_{be} is applied
- The output signal v_{ce} appears superimposed on the dc collector voltage V_{CE}





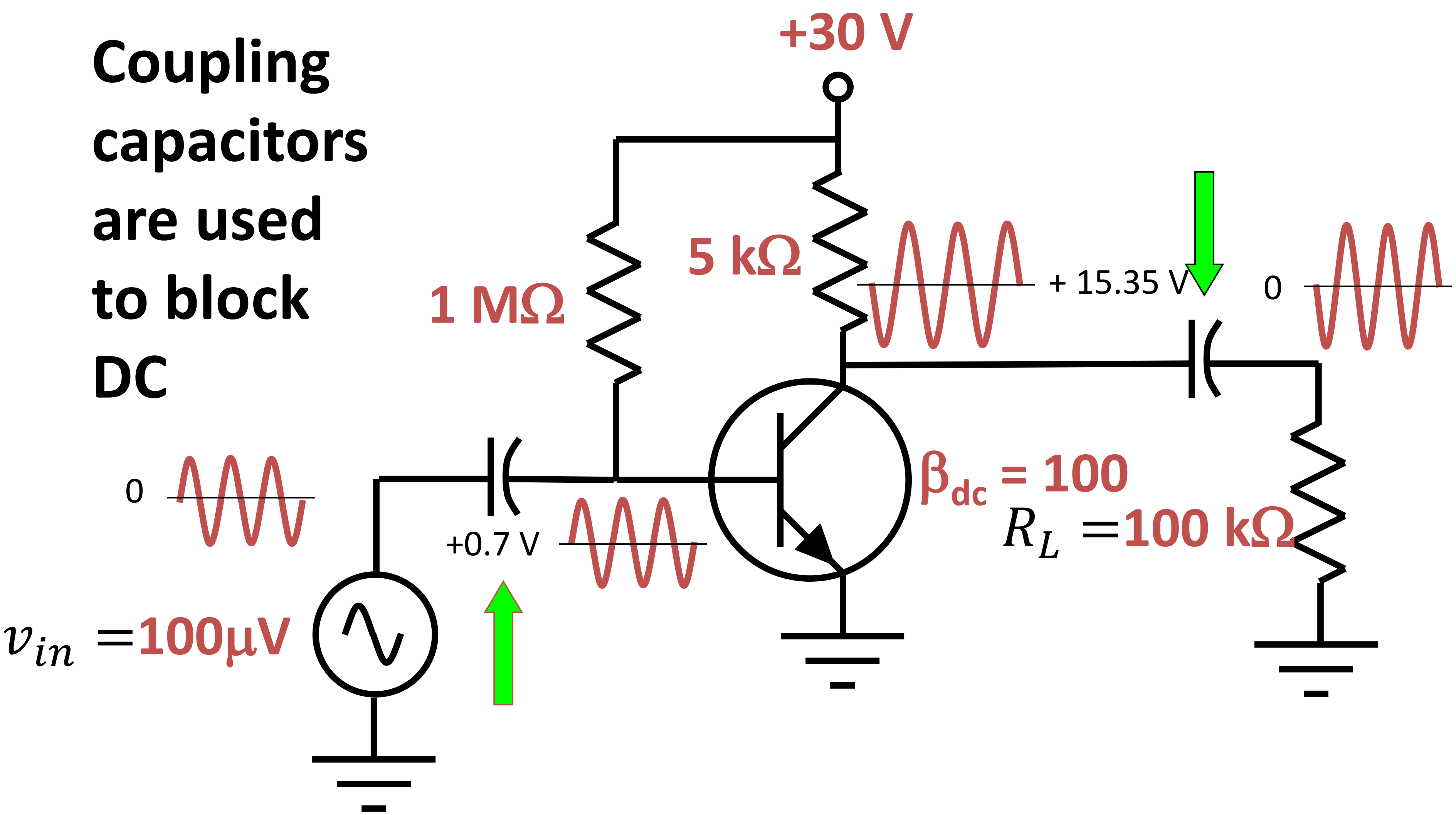
- The amplitude of v_{ce} is larger than that of v_{be} by the voltage gain A_v

Base-biased amplifier

- **AC** input is applied into <u>base</u>
- $v_{be} = v_{in}$
- Coupling capacitors are used to block DC
  - The **reactance** of a coupling capacitor is <u>small</u> for AC signal
- Amplified and inverted **output** at the <u>collector.</u> $v_{ce} = v_{out}$
- **AC** output coupled to the <u>load (R_L)</u>
- Voltage Gain: $A_v = -\frac{v_{out}}{v_{in}} = -\frac{v_{ce}}{v_{be}}$

A base-biased amplifier with capacitive coupling

Coupling capacitors are used to block DC



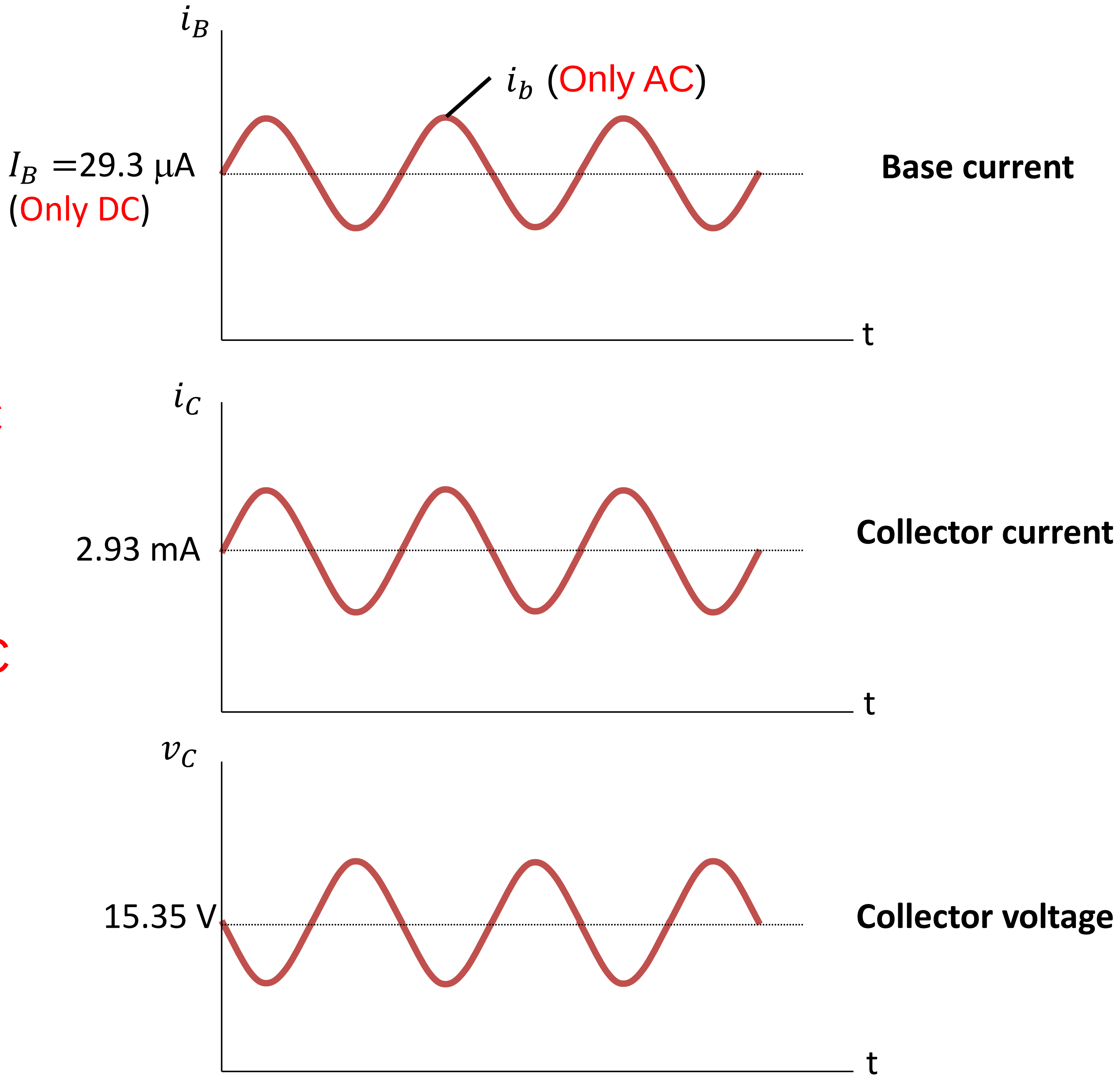
DC analysis gives: I_B = 29.3 μA, I_C = 2.93 mA and V_C = 15.35 V

Waveforms

I_B: Only DC

i_b: Only AC

i_B: DC + AC



The coupling capacitor

Capacitor current,

$$i_c = C\frac{dv}{dt}.$$

DC Analysis: v is fixed. $\frac{dv}{dt} = 0$

$i_c = 0$. **Open**

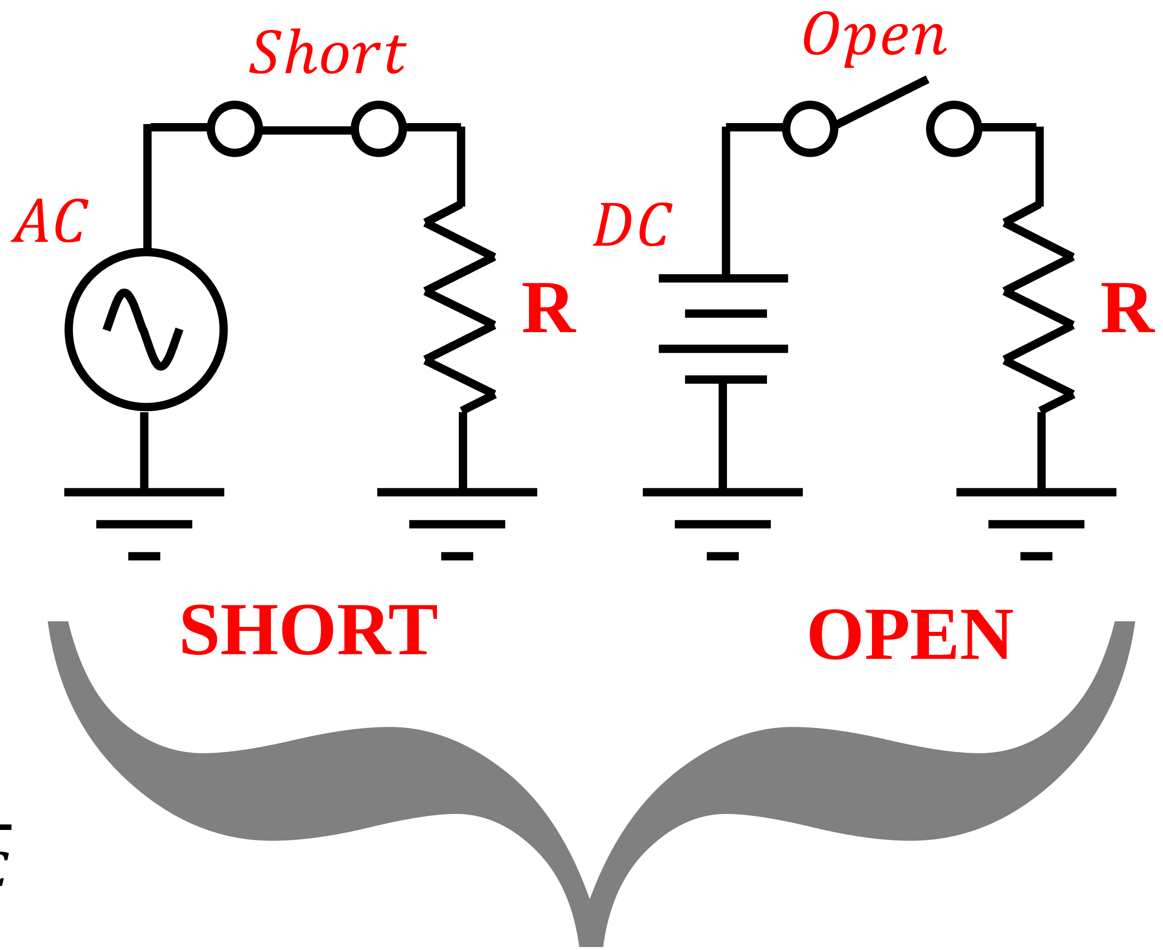
AC Analysis:

Reactance $X = \frac{1}{2\,\pi f C}$

$C = Large$

$X = 0$. **Short**

$i_c = C\frac{dv}{dt} =$ **Large**

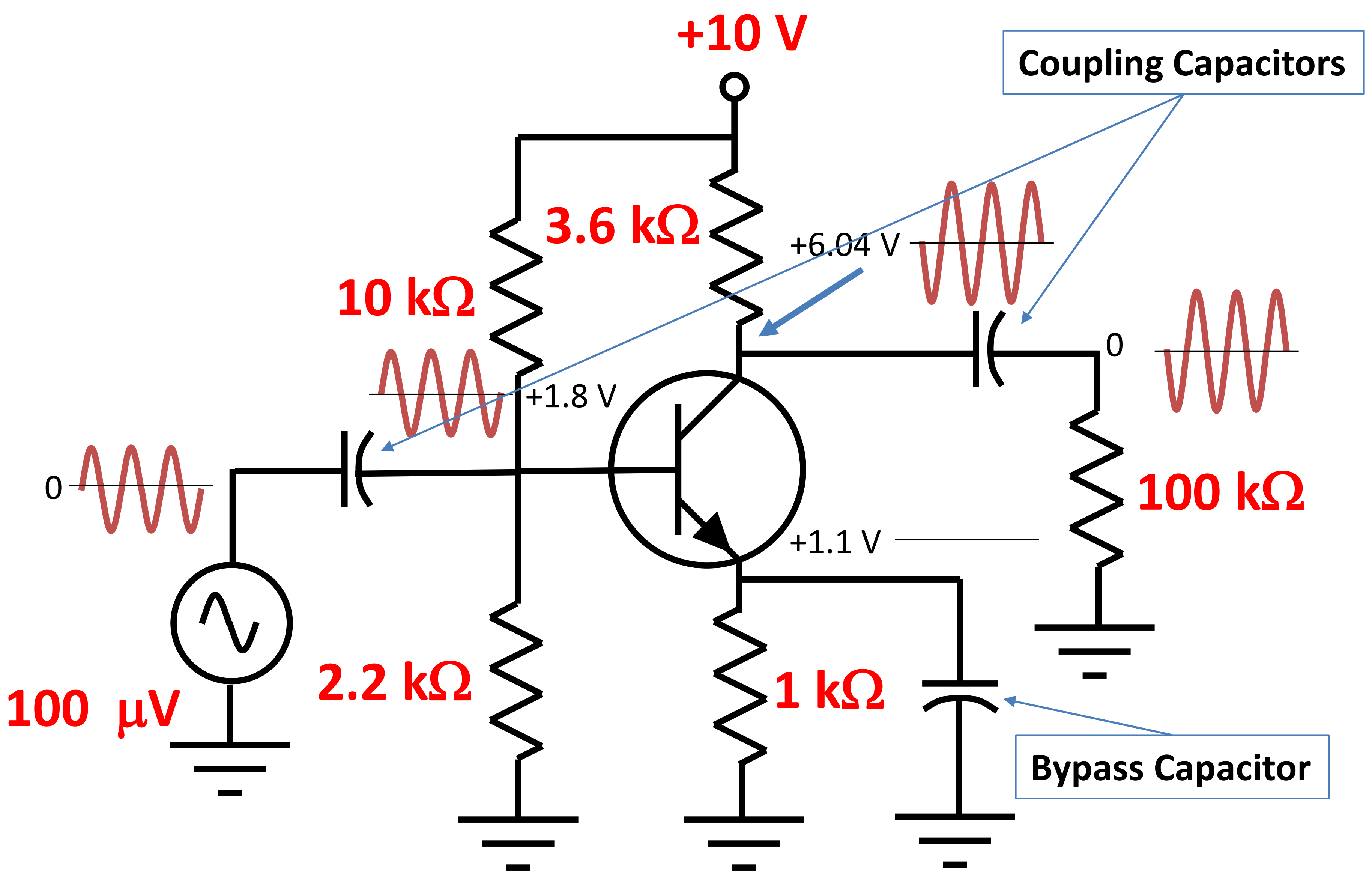


1. **For ac analysis, the capacitor is a short.**
2. **For dc analysis, the capacitor is open.**

BJT Amplifier Analysis

- **Superposition Theorem (DC + AC analysis)**
- **DC voltages and currents are calculated mentally by opening capacitors: DC Analysis (Chapter 4)**
- **The AC signal is coupled via a coupling capacitor**
- **Coupling capacitor: couples between BJT & input AND BJT & output**
- **The bypass capacitor causes an AC signal to appear across the base-emitter junction and provides higher gain**
- **Bypass capacitor: Need in DC. Not need in AC.**

VDB Amplifier



The dc current gain is given as:

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

The ac current gain is given as:

$$\beta_{ac} = \frac{i_c}{i_b}$$

Use CAPITAL letters for dc quantities and lowercase letters for ac.

Formula for ac emitter resistance

Derived by using solid-state physics and calculus:

Diode AC Resistance, $r_{ac} = \frac{nV_T}{I_D}$ Chapter 1

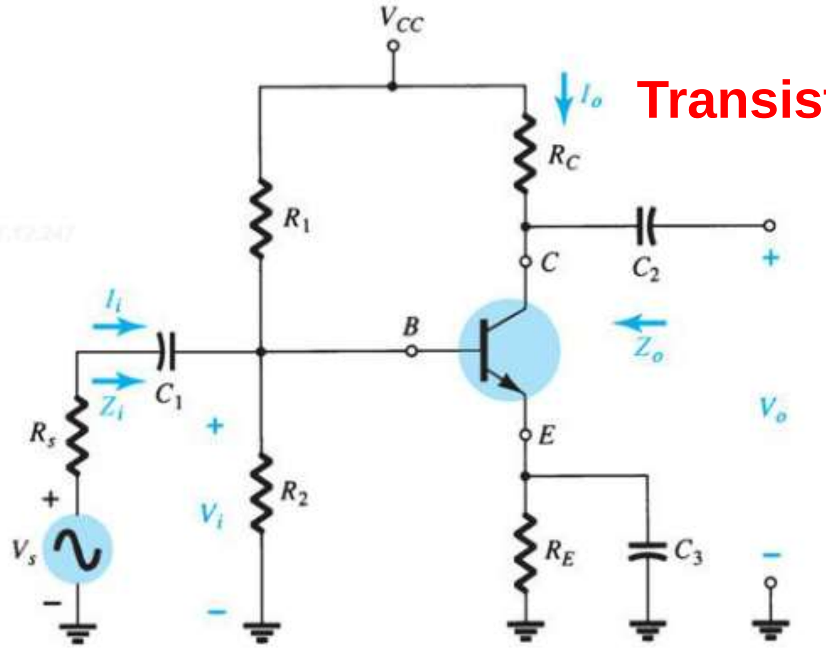
$$\mathrm{r_e}' = \frac{nV_T = 26\ \mathrm{mV}}{\mathrm{I_E}}$$

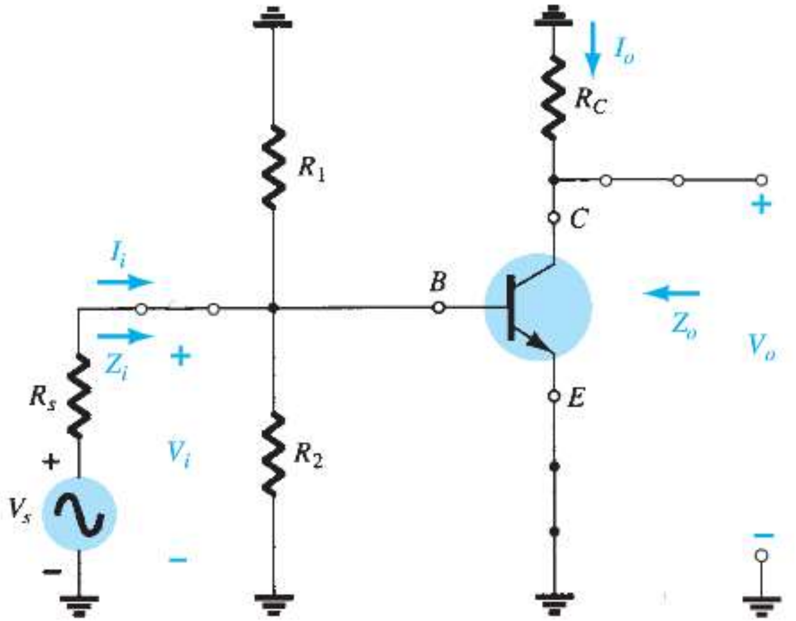
r_e **is AC emitter resistance**

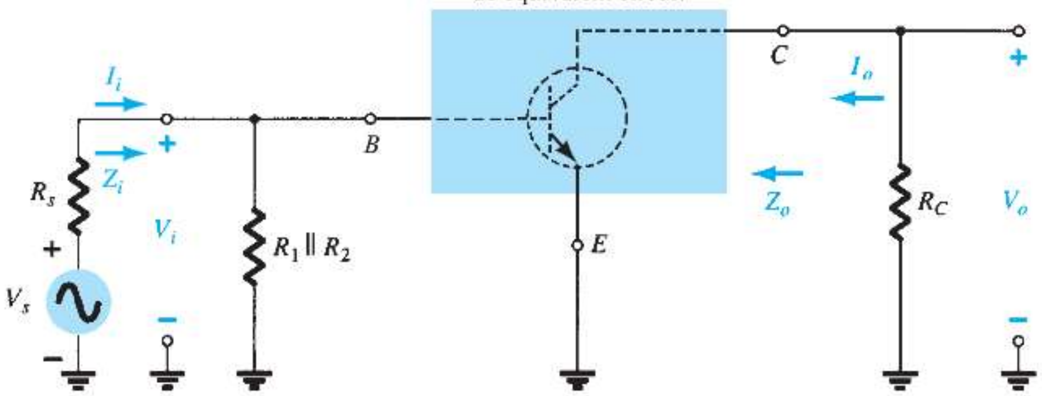
I_E **is DC emitter current**

5.3 BJT TRANSISTOR MODELING

Transistor Circuit







Redrawn for small-signal ac analysis

AC Equivalent Circuit:
After the removal of the dc supply and insertion of the short-circuit equivalent for the capacitors.

Transistor AC models

- **AC equivalent circuit** for a transistor
- **Simulates** how a transistor behaves when an ac signal is present
- There are two models commonly used in **small signal AC** analysis of a transistor:
    - **r_e model**
        - T model and π type models are widely used
    - **Hybrid equivalent model (*h* parameter model)**

5.4 The r_e Transistor Model

(The Input Equivalent Circuit)

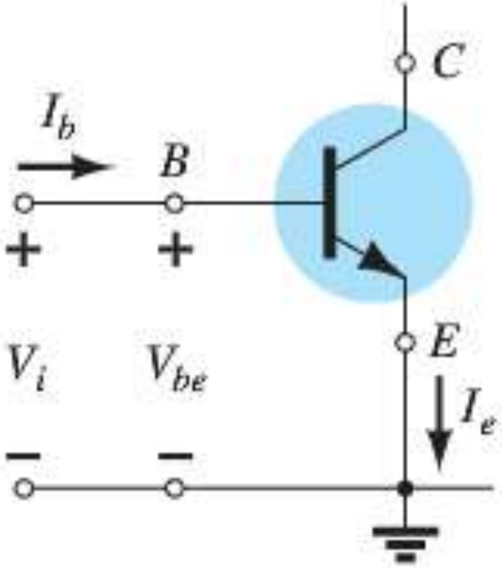
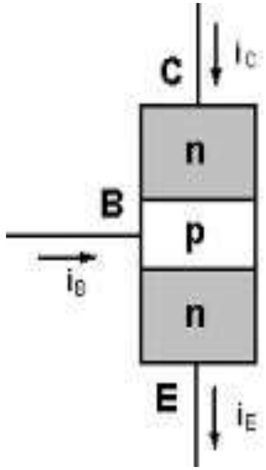


FIG. 5.8
Finding the input equivalent circuit for a BJT transistor.



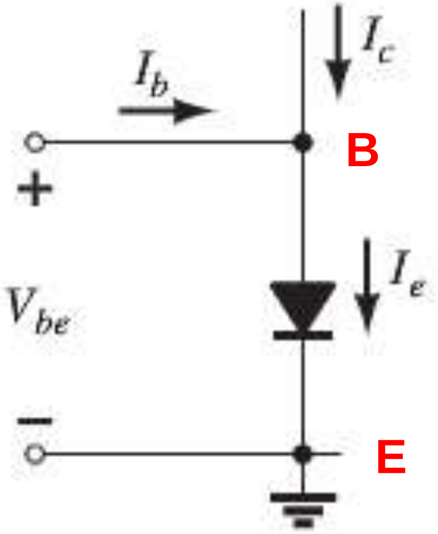


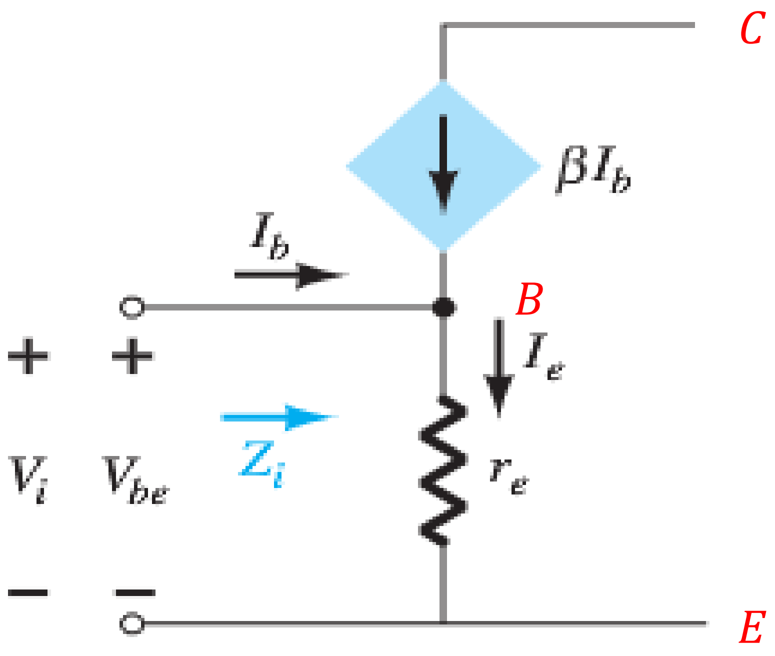
FIG. 5.10
Equivalent circuit for the input side of a BJT transistor.

BJT similar to two diodes, emitter-base (FB) and collector-base (RB)

r_e Transistor Model: Diode between Emitter and Base

The r_e Transistor Model

(The BJT Equivalent Circuit – T Model)



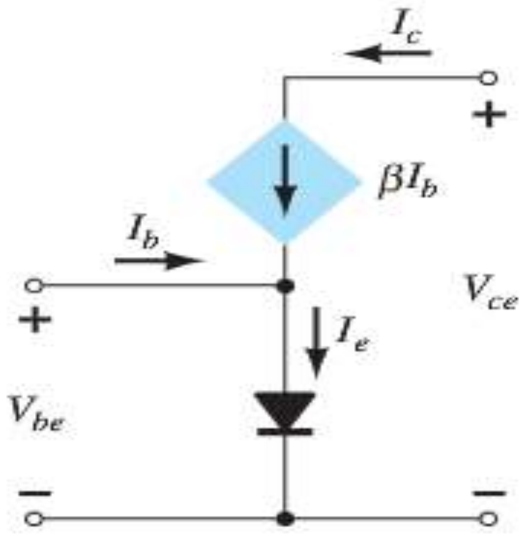


FIG. 5.12
BJT equivalent circuit.

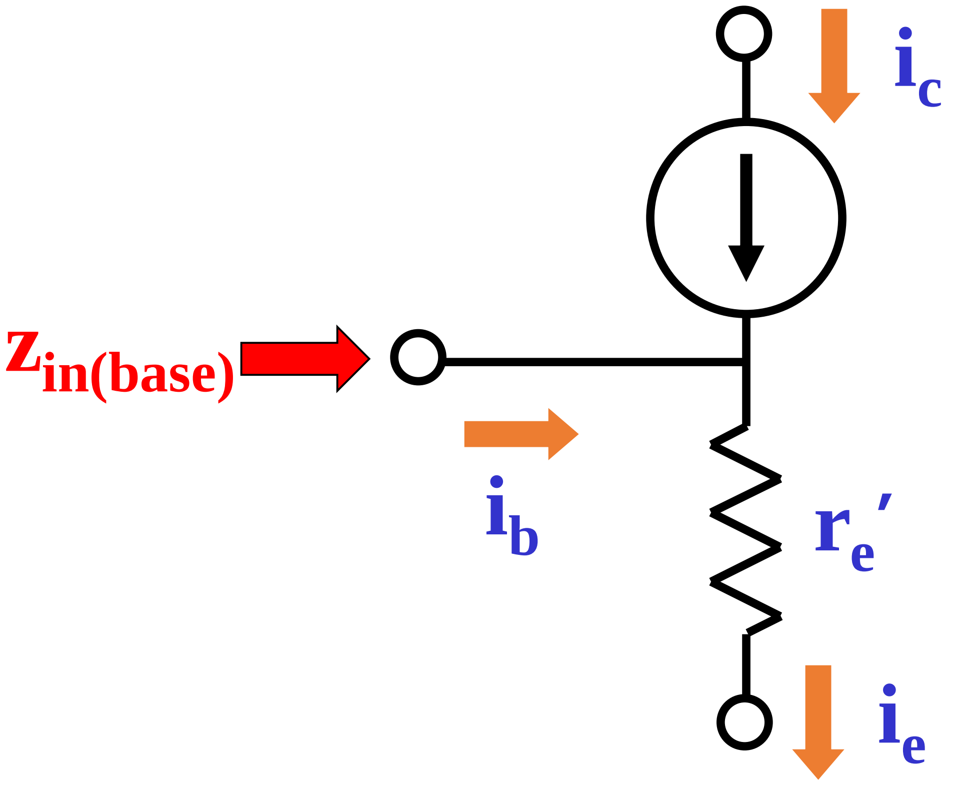
- BJT similar to two diodes, emitter-base (FB) and collector-base (RB)
- r_e Transistor Model: AC resistance (r_e) between Emitter and Base (input/ base side)
- Output/ collector side: $i_c = \beta i_b$; output current = $\beta \times$ input current
- Output side: Current dependent current source (diamond shape)

Deriving π model from T model

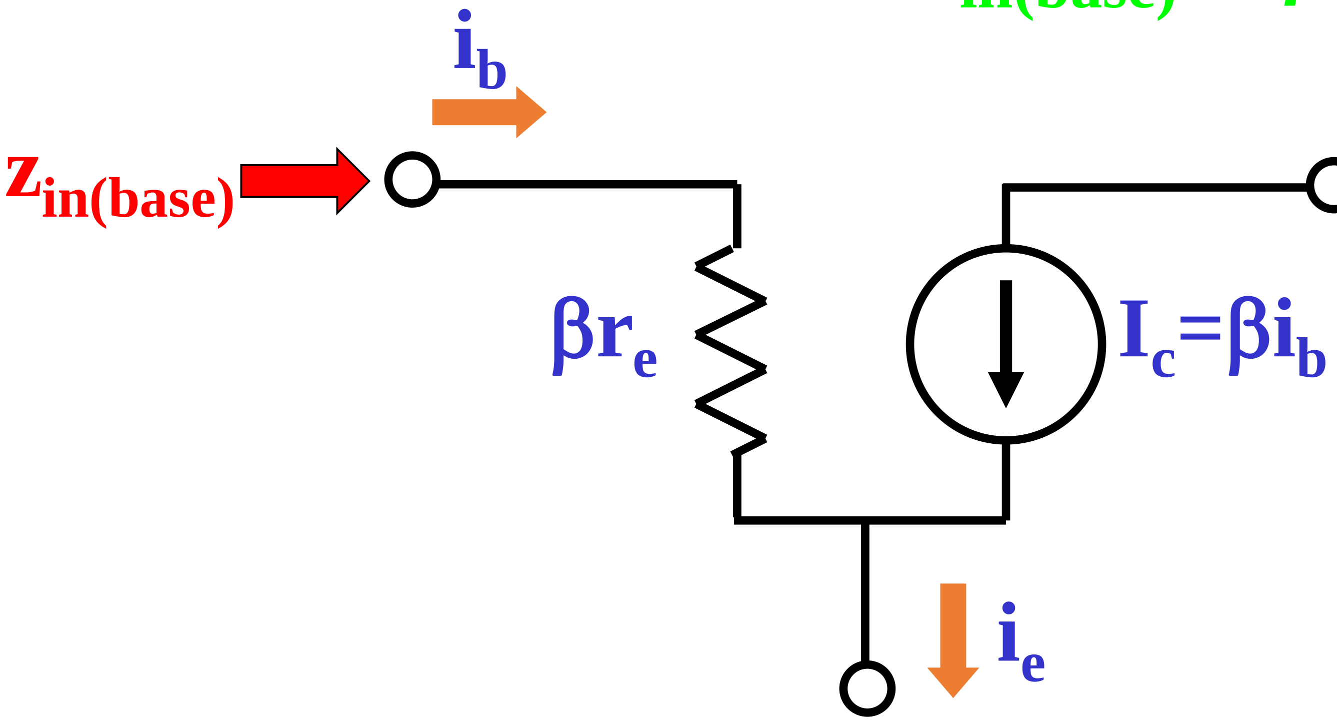
$$v_{be} = i_e \times r_e$$

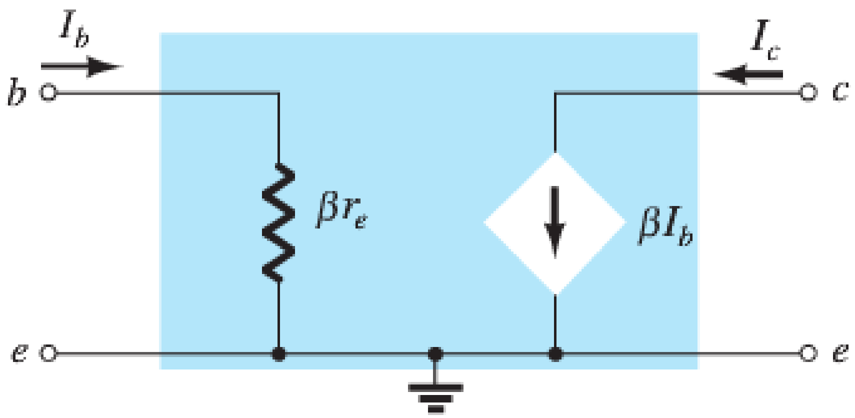
$$= (\beta+1)\, i_b r_e$$

$$\cong i_b \times \beta\, r_e$$



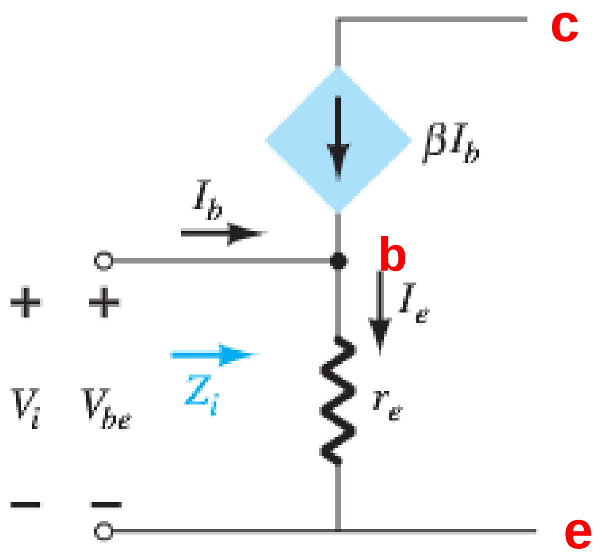
The π model of a transistor is based on $z_{in(base)} = \beta r_e$:



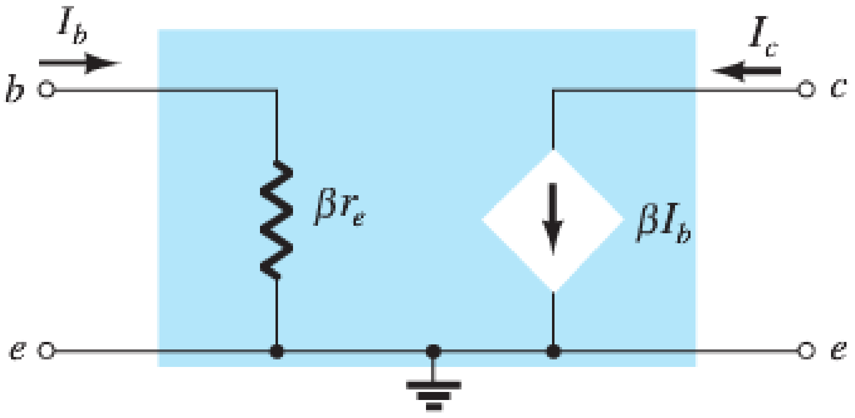


Overview of r_e Transistor Models

(T and π Model)



T Model

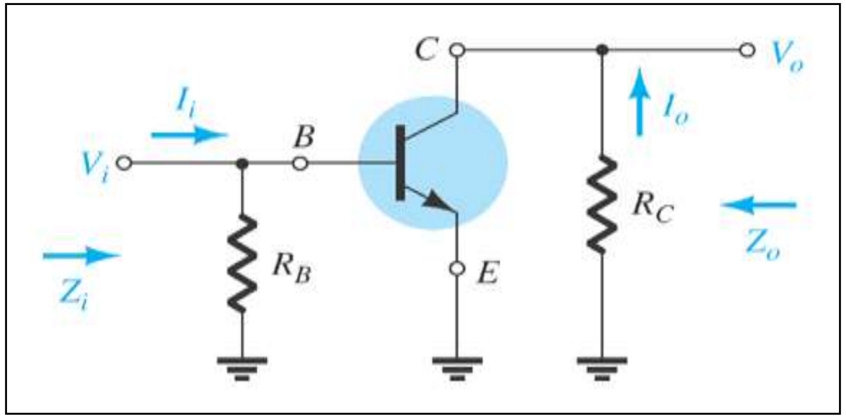


π Model

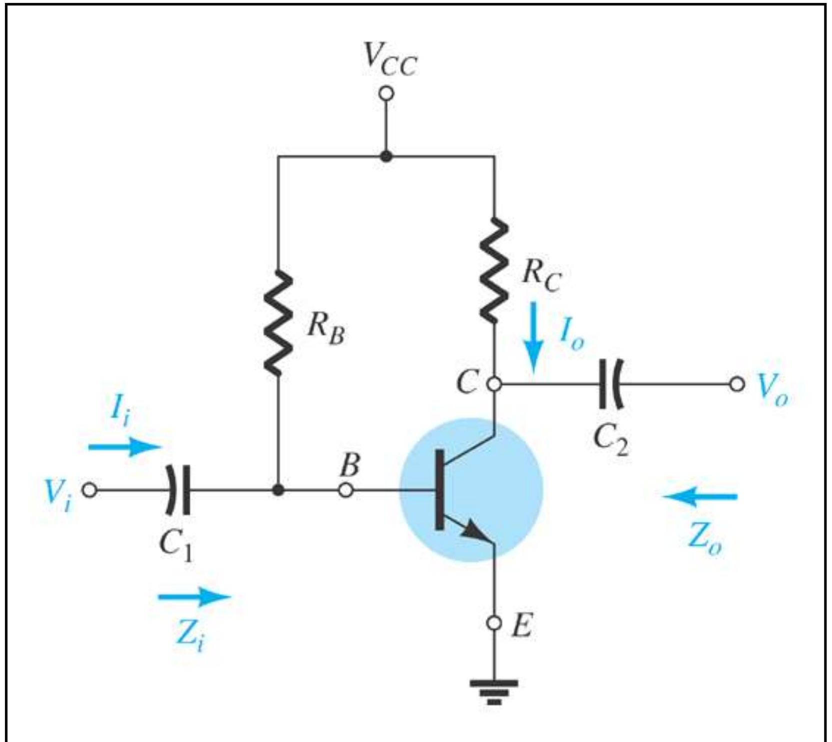
BJT Amplifier AC analysis

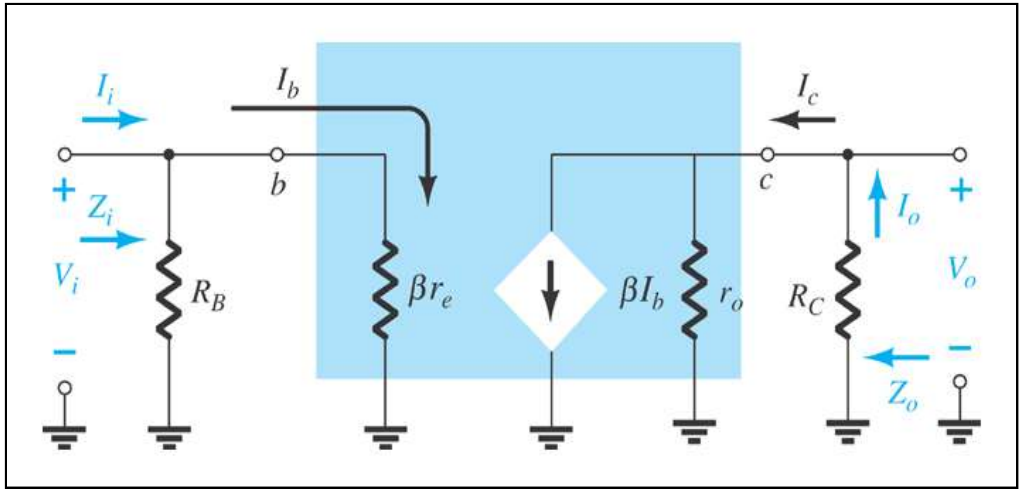
- **Superposition theorem (DC + AC analysis)**
- **Perform a complete DC analysis (Chapter 4)**
- **Short all coupling and bypass capacitors for ac signals**
- **Visualize all DC supply voltages as grounds**
- **Replace the transistor by its π or T model**
- **Draw the AC equivalent circuit**

5.5 Common-Emitter Fixed-Bias Configuration



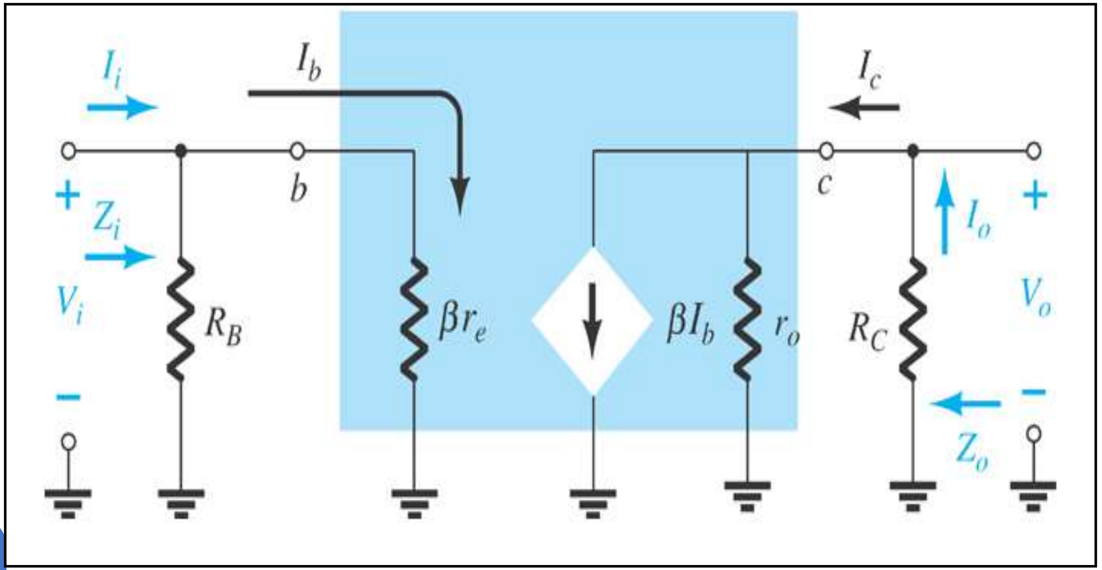
AC equivalent





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:

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

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

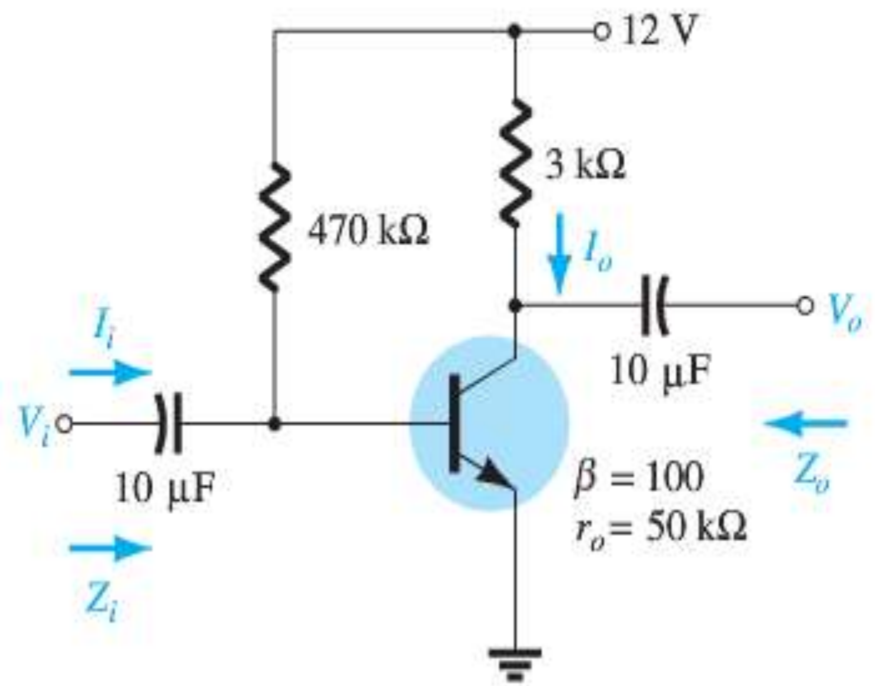
Current gain:

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

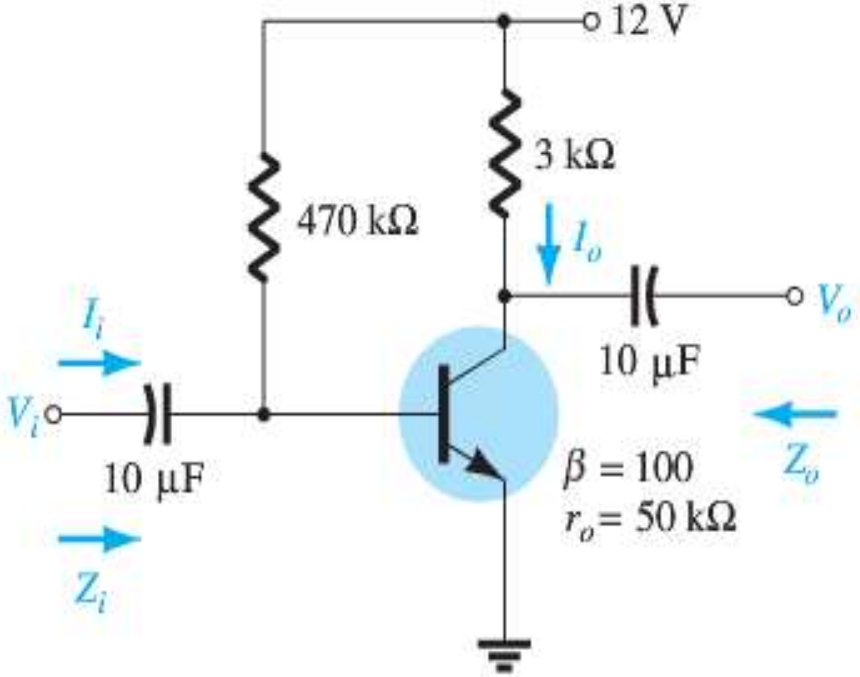
$$A_i \cong \beta \Big|_{r_o \geq 10 R_C,\ R_B \geq 10\beta r_e}$$

EXAMPLE 5.1 For the network of Fig. 5.25:

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 $r_o = \infty\,\Omega$).

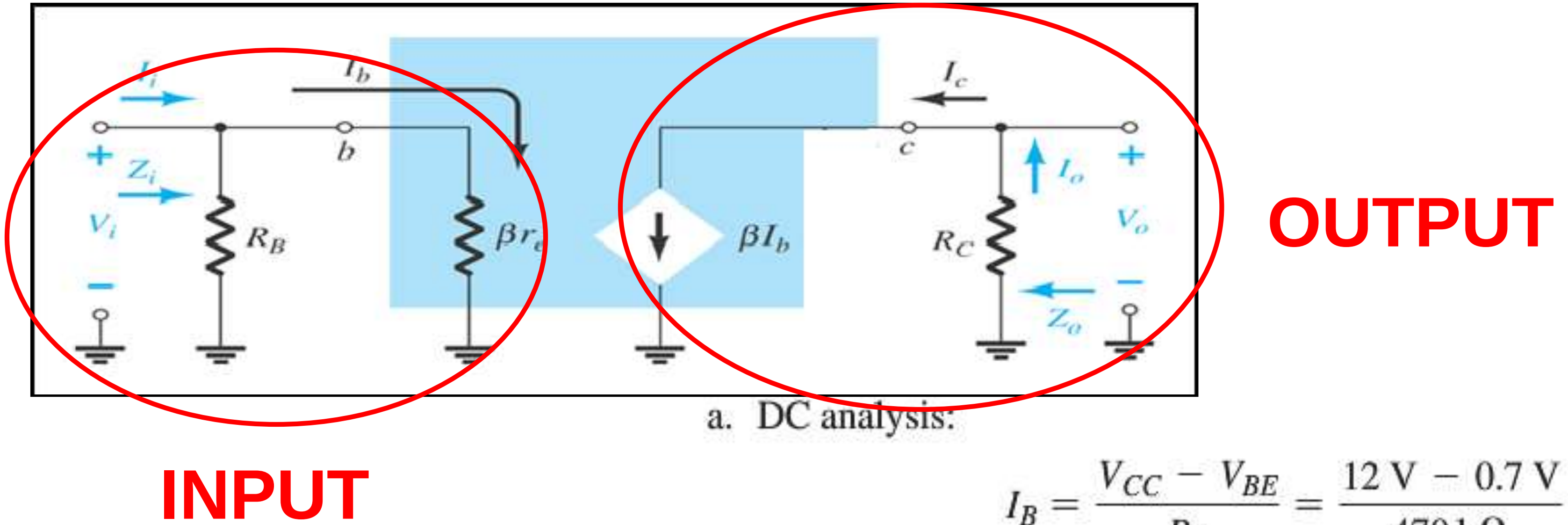


1. Short all coupling and bypass capacitors for ac signals
2. DC supply voltages as grounds
3. Replace the transistor by its π or T model
π Model: CE
T model: CB
4. Draw the AC equivalent circuit



12 V
3 kΩ
470 kΩ
I_o
V_o
10 μF
I_i
V_i
10 μF
β = 100
r_o = 50 kΩ
Z_o
Z_i

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 $r_o = \infty\,\Omega$).



a. DC analysis:

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

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

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

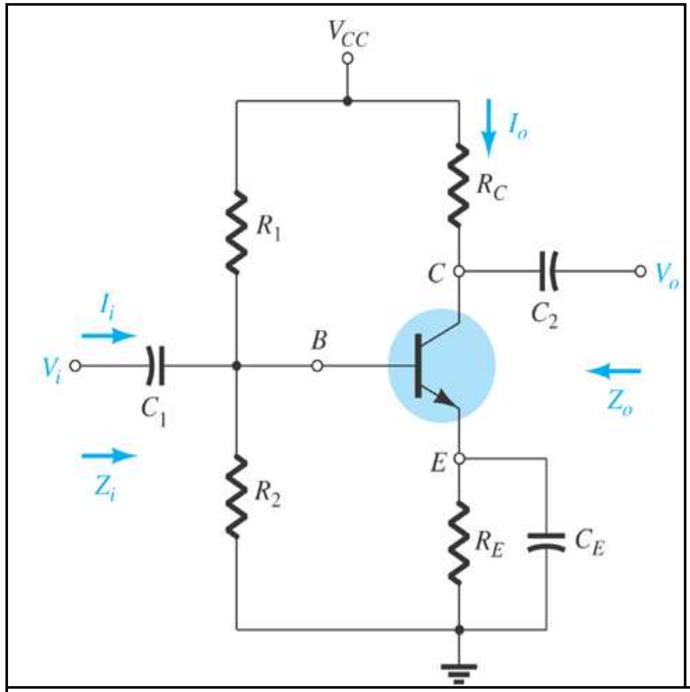
b. $\beta r_e = (100)(10.71\ \Omega) = 1.071\text{ k}\Omega$

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

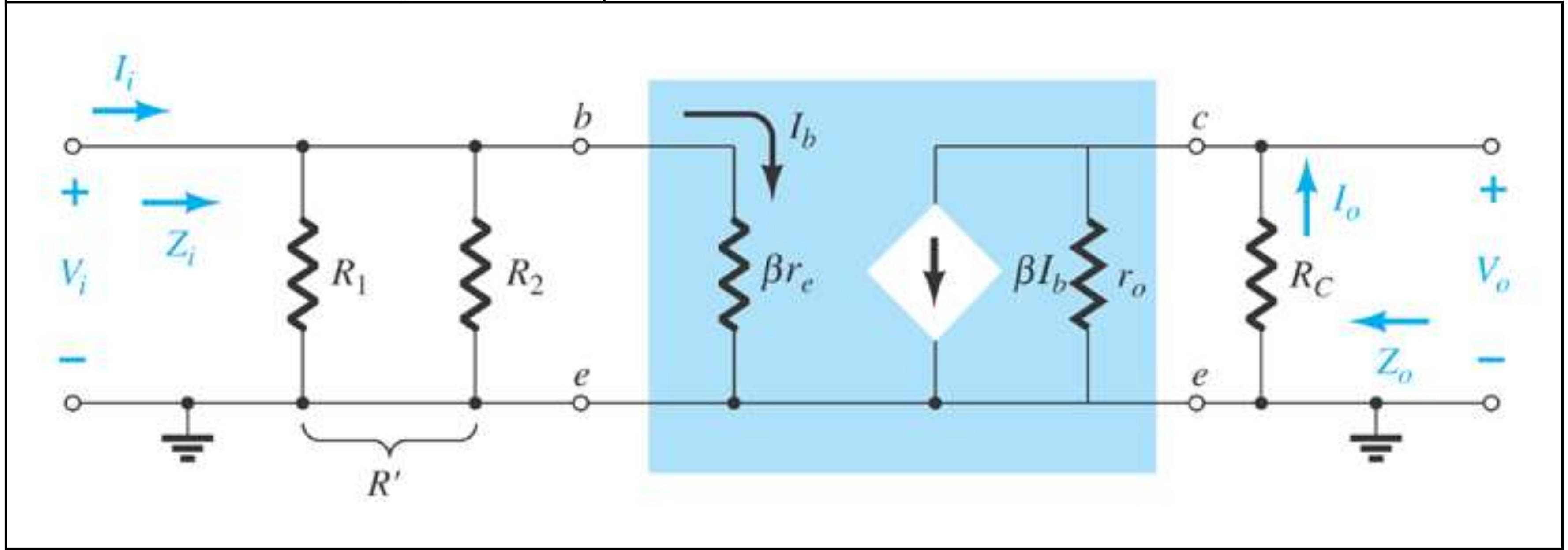
c. $Z_o = R_C = \mathbf{3\text{ k}\Omega}$

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

5.6 Common-Emitter Voltage-Divider Bias



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



5.6 Common-Emitter Voltage-Divider Bias

Input impedance

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

Output impedance

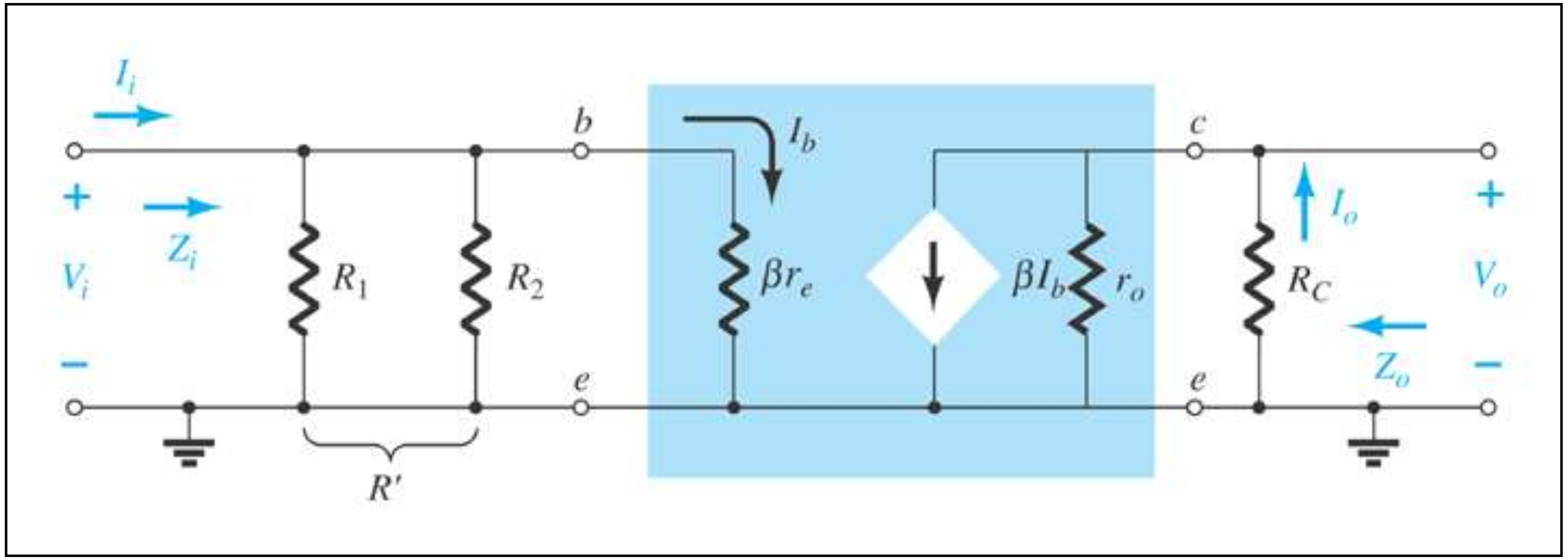
$$Z_o = R_C \| r_o$$
$$Z_o \cong R_C \Big|_{r_o \geq 10R_C}$$

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

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



EXAMPLE 5.2 For the network of Fig. 5.28, determine:

a. r_e.
b. Z_i.
c. Z_o ($r_o = \infty\,\Omega$).
d. A_v ($r_o = \infty\,\Omega$).

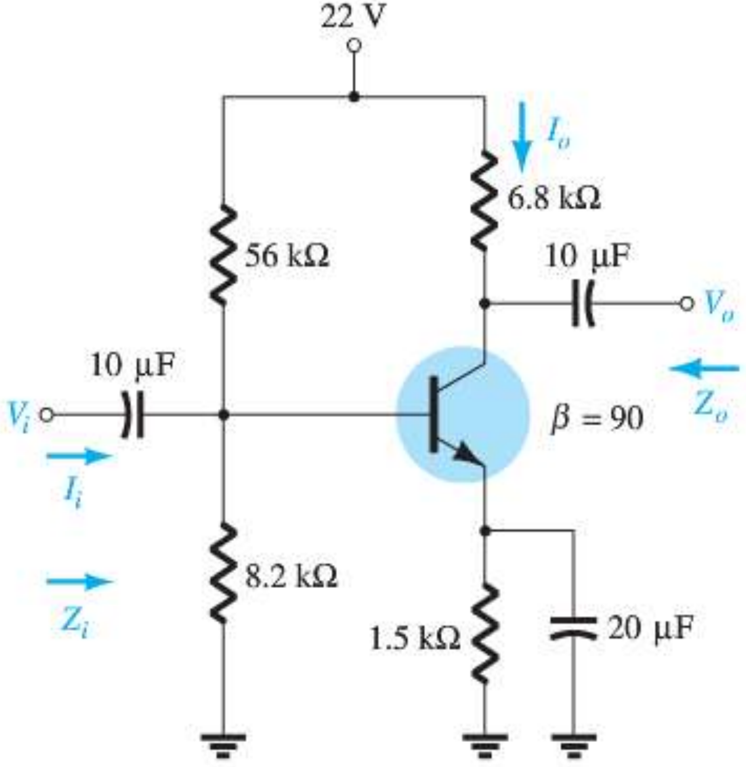


FIG. 5.28
Example 5.2.

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

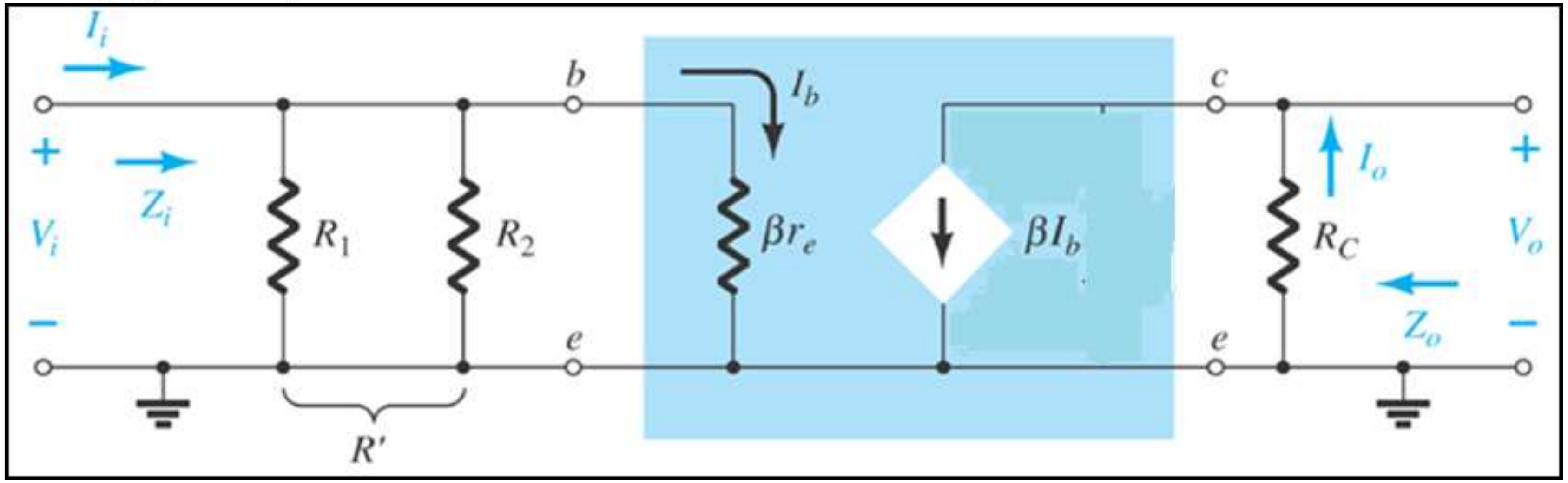
$$V_E = V_B - V_{BE} = 2.81\,\text{V} - 0.7\,\text{V} = 2.11\,\text{V}$$

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

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

EXAMPLE 5.2 For the network of Fig. 5.28, determine:

a. r_e.
b. Z_i.
c. Z_o ($r_o = \infty\,\Omega$).
d. A_v ($r_o = \infty\,\Omega$).



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

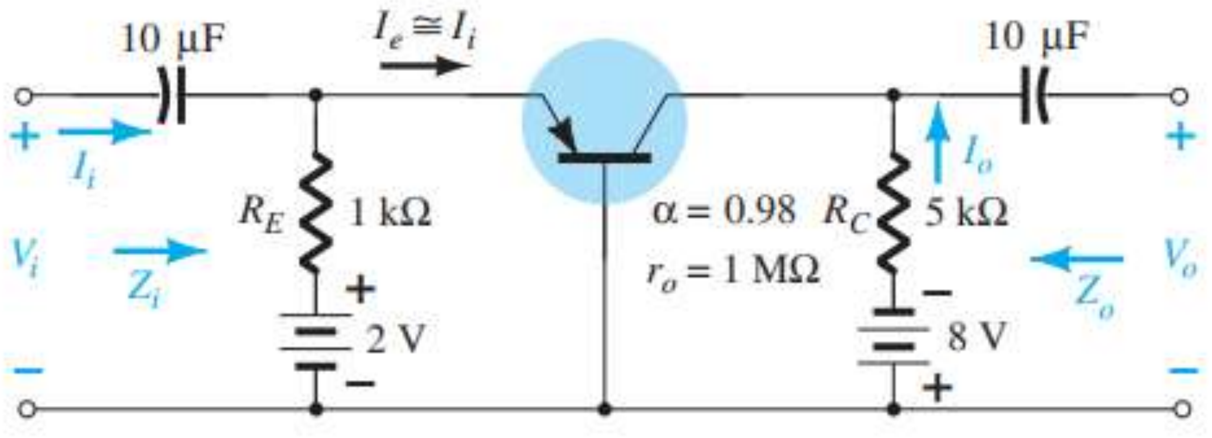
$$Z_i = R' \| \beta r_e = 7.15\,\text{k}\Omega \| (90)(18.44\,\Omega) = 7.15\,\text{k}\Omega \| 1.66\,\text{k}\Omega$$
$$= \mathbf{1.35\,k\Omega}$$

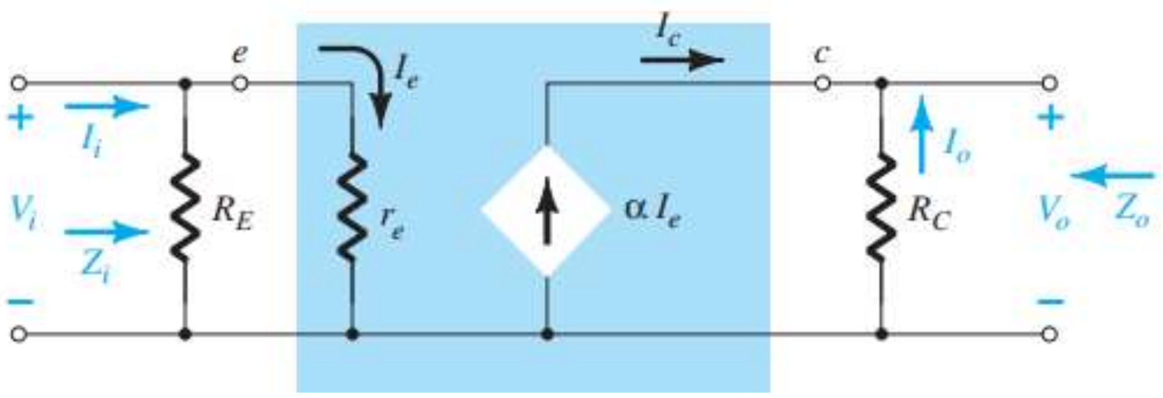
c. $Z_o = R_C = \mathbf{6.8\,k\Omega}$

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

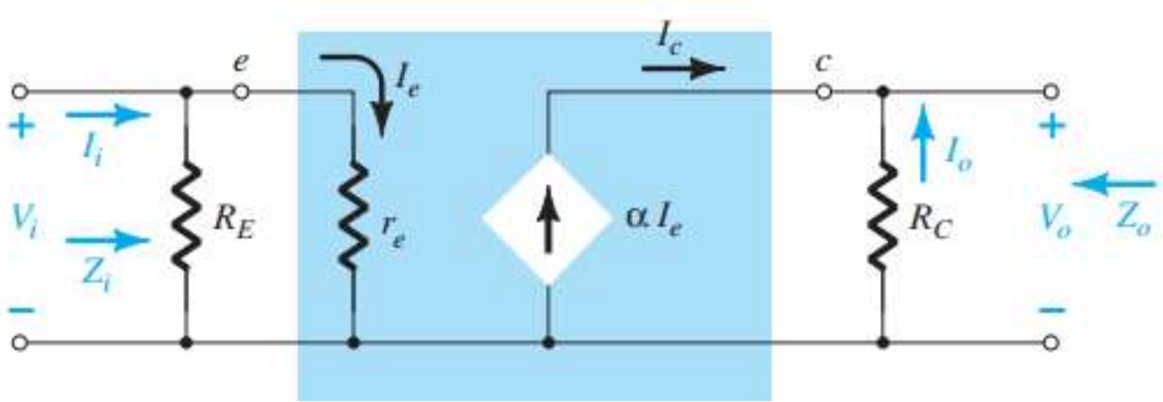
Example 5.8: Common Base BJT Amplifier

- Common base PNP: r_e T model
- Input: emitter; output: collector
- Output Current: $I_C = \beta I_B = \alpha I_E = \alpha \times$ input current





Example 5.8: Common Base BJT Amplifier



$$I_E = \frac{V_{EE} - V_{BE}}{R_E} = \frac{2\text{ V} - 0.7\text{ V}}{1\text{ k}\Omega} = \frac{1.3\text{ V}}{1\text{ k}\Omega} = 1.3\text{ mA}$$

$$r_e = \frac{26\text{ mV}}{I_E} = \frac{26\text{ mV}}{1.3\text{ mA}} = \mathbf{20\ \Omega}$$

$$Z_i = R_E \| r_e = 1\text{ k}\Omega \| 20\ \Omega$$
$$= \mathbf{19.61\ \Omega} \cong r_e$$

$$Z_o = R_C = \mathbf{5\text{ k}\Omega}$$

$$A_v \cong \frac{R_C}{r_e} = \frac{5\text{ k}\Omega}{20\ \Omega} = \mathbf{250}$$