MALVINO & BATES

Electronic PRINCIPLES

SEVENTH EDITION

Chapter 9

AC Models

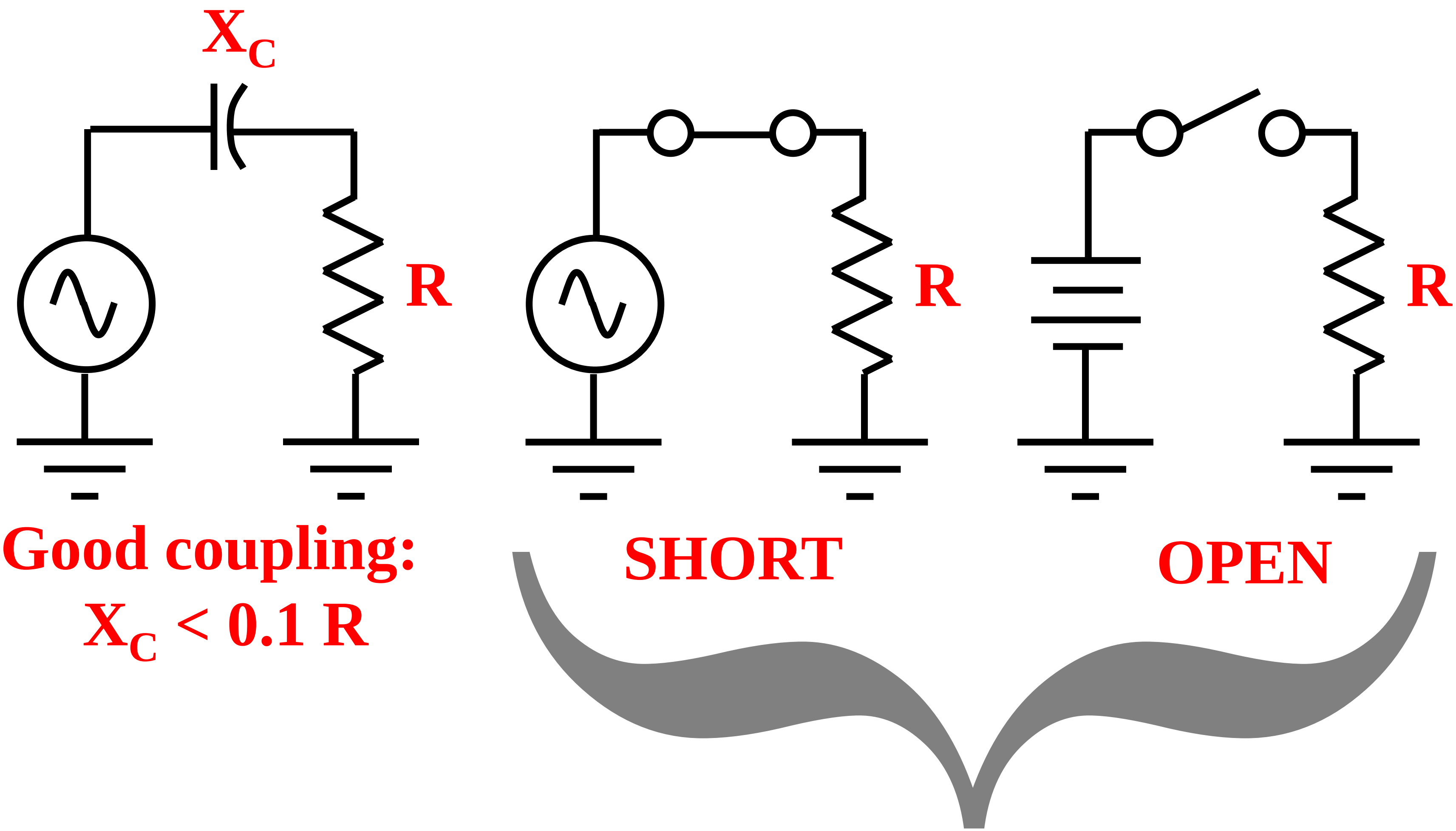
Topics covered in Chapter 9

- **Base-biased amplifier**
- **Emitter-biased amplifier**
- **Small-signal operation**
- **AC beta**
- **AC resistance of the emitter diode**
- **Two transistor models**
- **Analyzing an amplifier**
- **AC quantities on the data sheet**

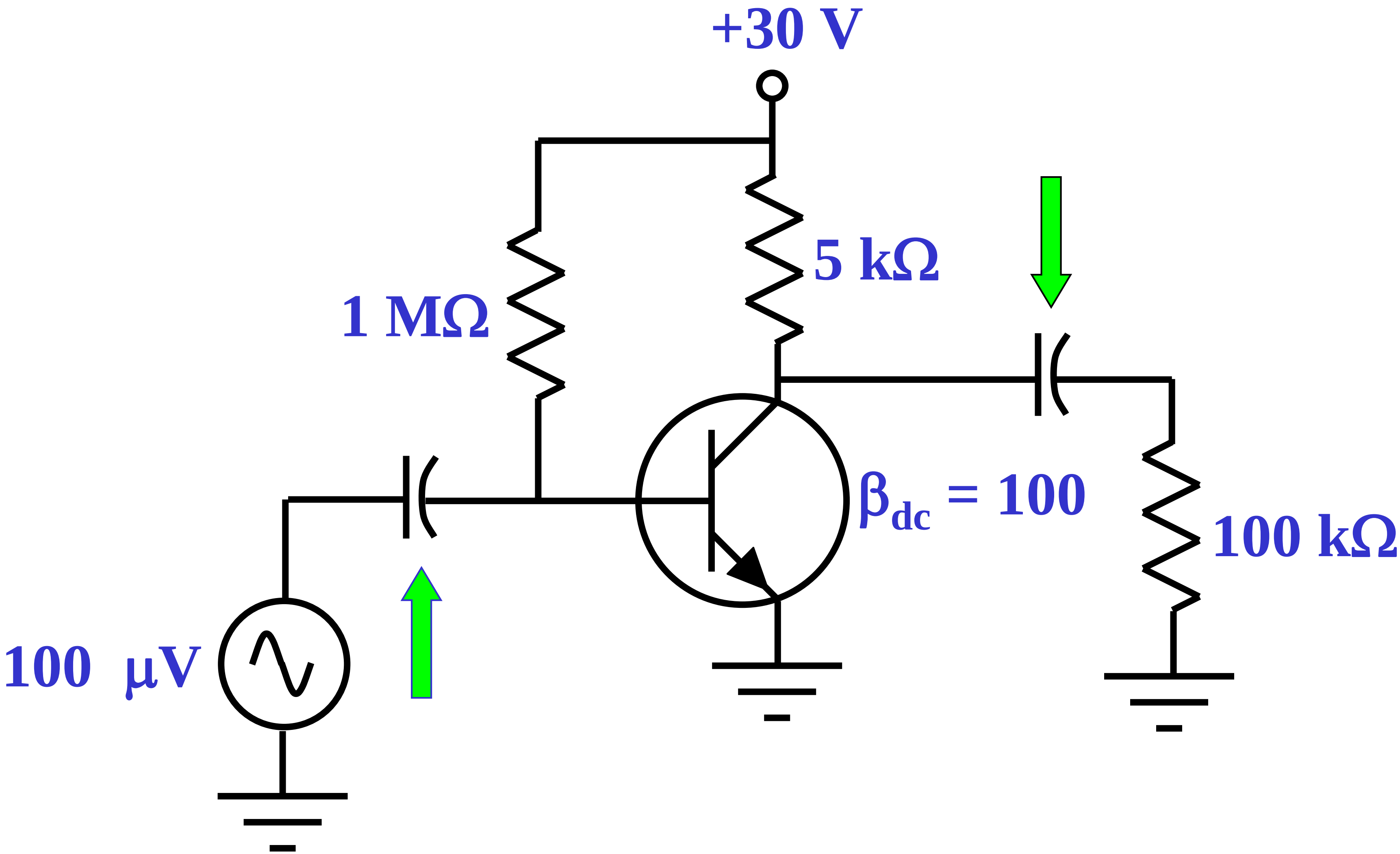
Base-biased amplifier

- The reactance of a coupling capacitor is much smaller than the resistance
- AC input into base
- Amplified and inverted output at the collector
- AC output coupled to the load

The coupling capacitor

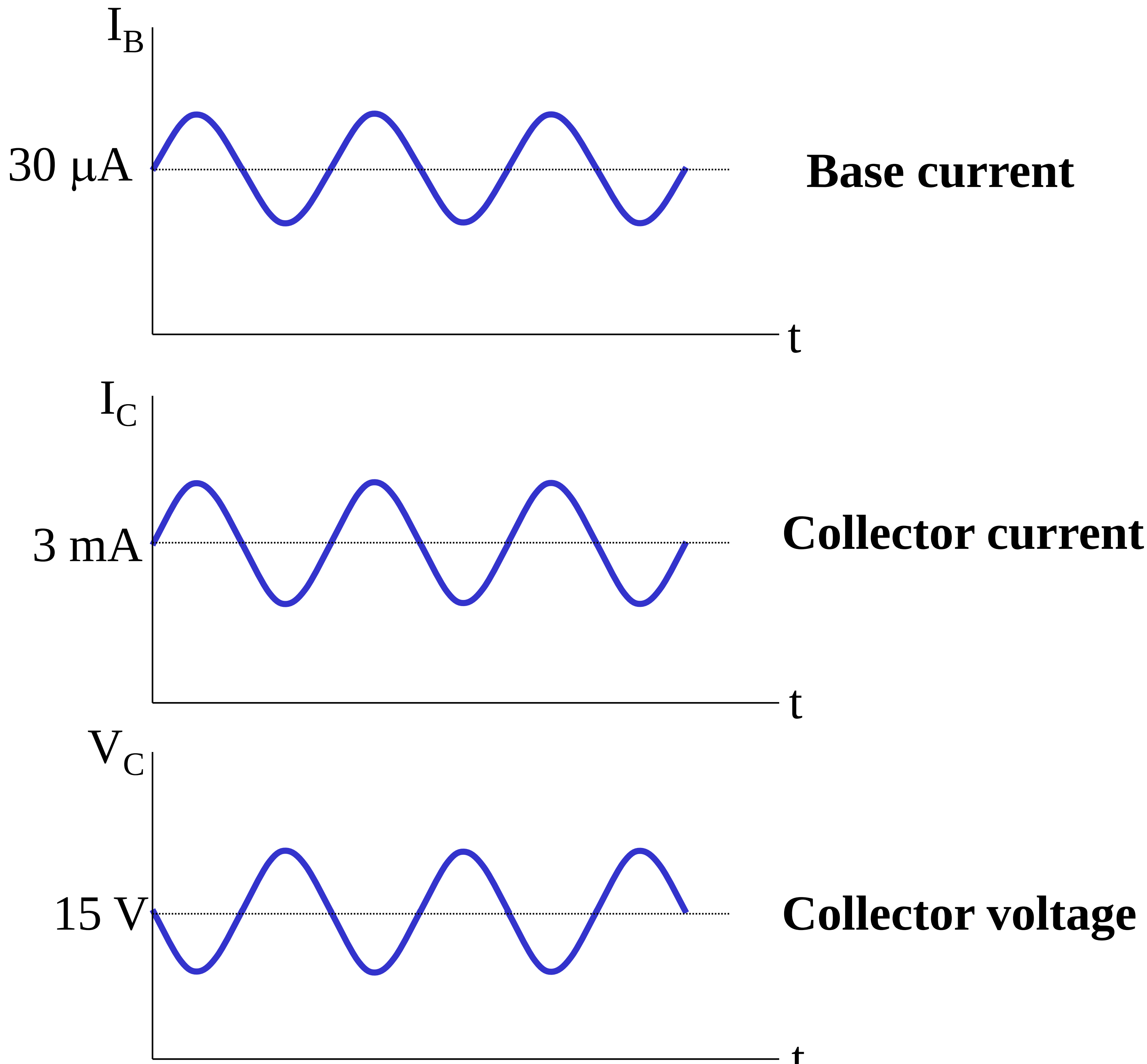


1. For ac analysis, the capacitor is a short.
2. For dc analysis, the capacitor is open.

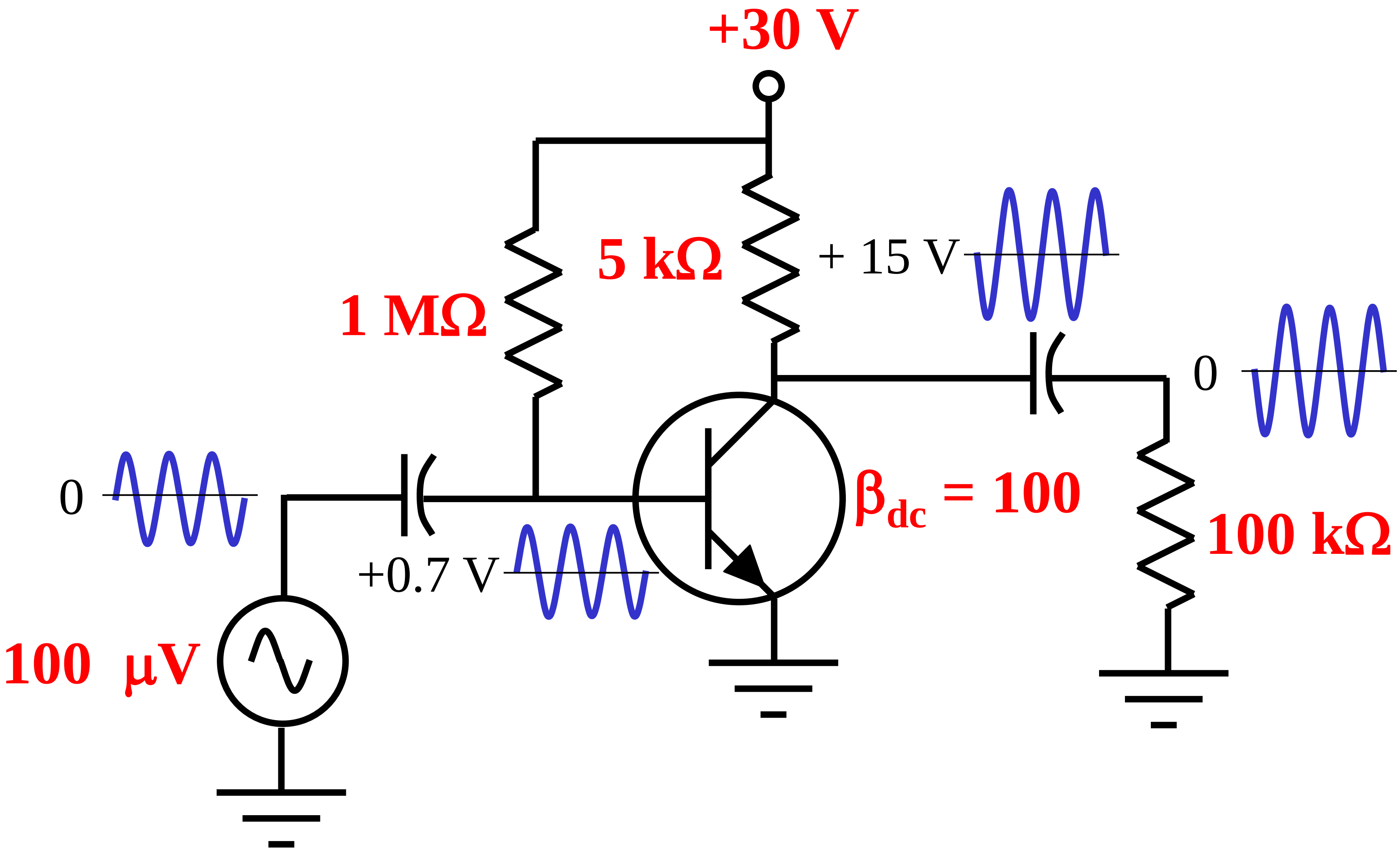


A base-biased amplifier with capacitive coupling

A dc analysis reveals I_B = 30 μA, I_C = 3 mA and V_C = 15 V.

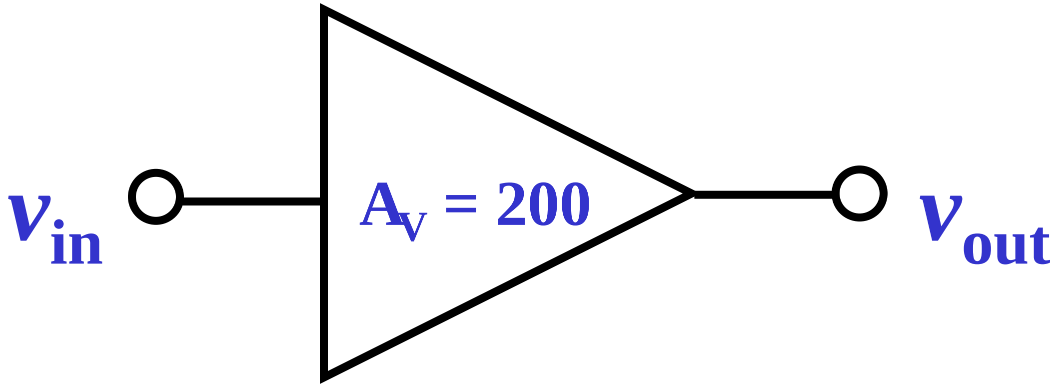


I_B
30 μA
Base current
t
I_C
3 mA
Collector current
t
V_C
15 V
Collector voltage
t



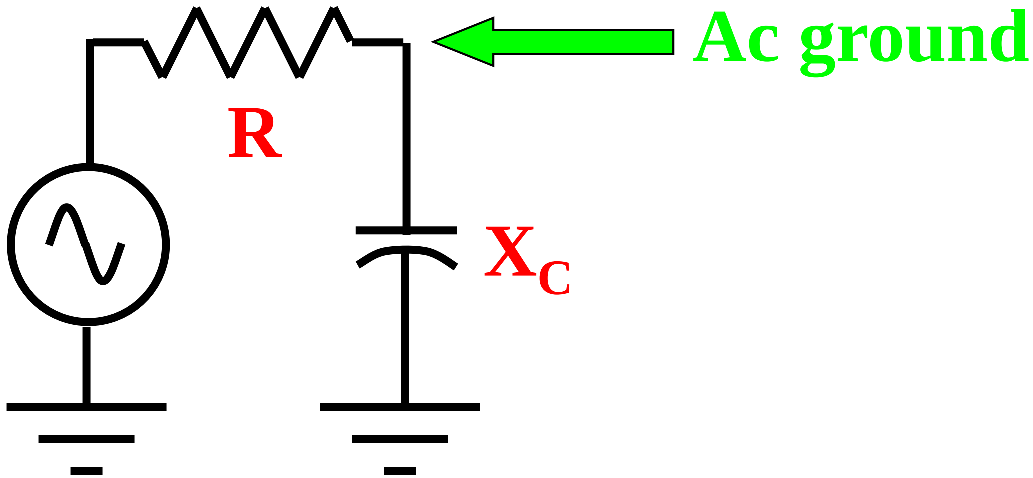
The base-biased amplifier with voltage waveforms

The voltage gain of an amplifier is the ac output divided by the ac input.



$$A_V = \frac{v_{out}}{v_{in}}$$

The bypass capacitor



Good bypassing:

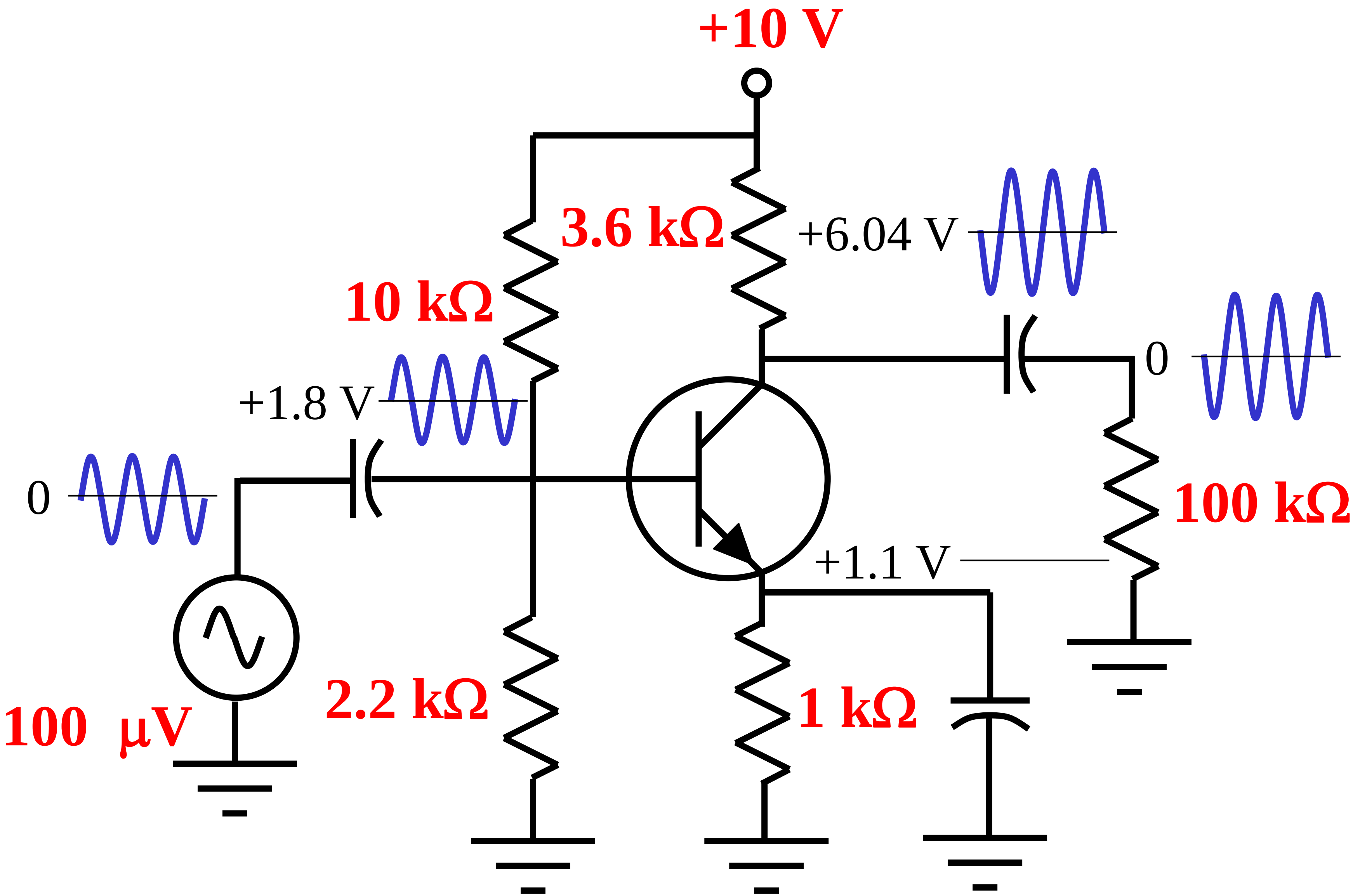
$X_C < 0.1\ R$

Note: The bypass capacitor appears open to dc and shorted to ac

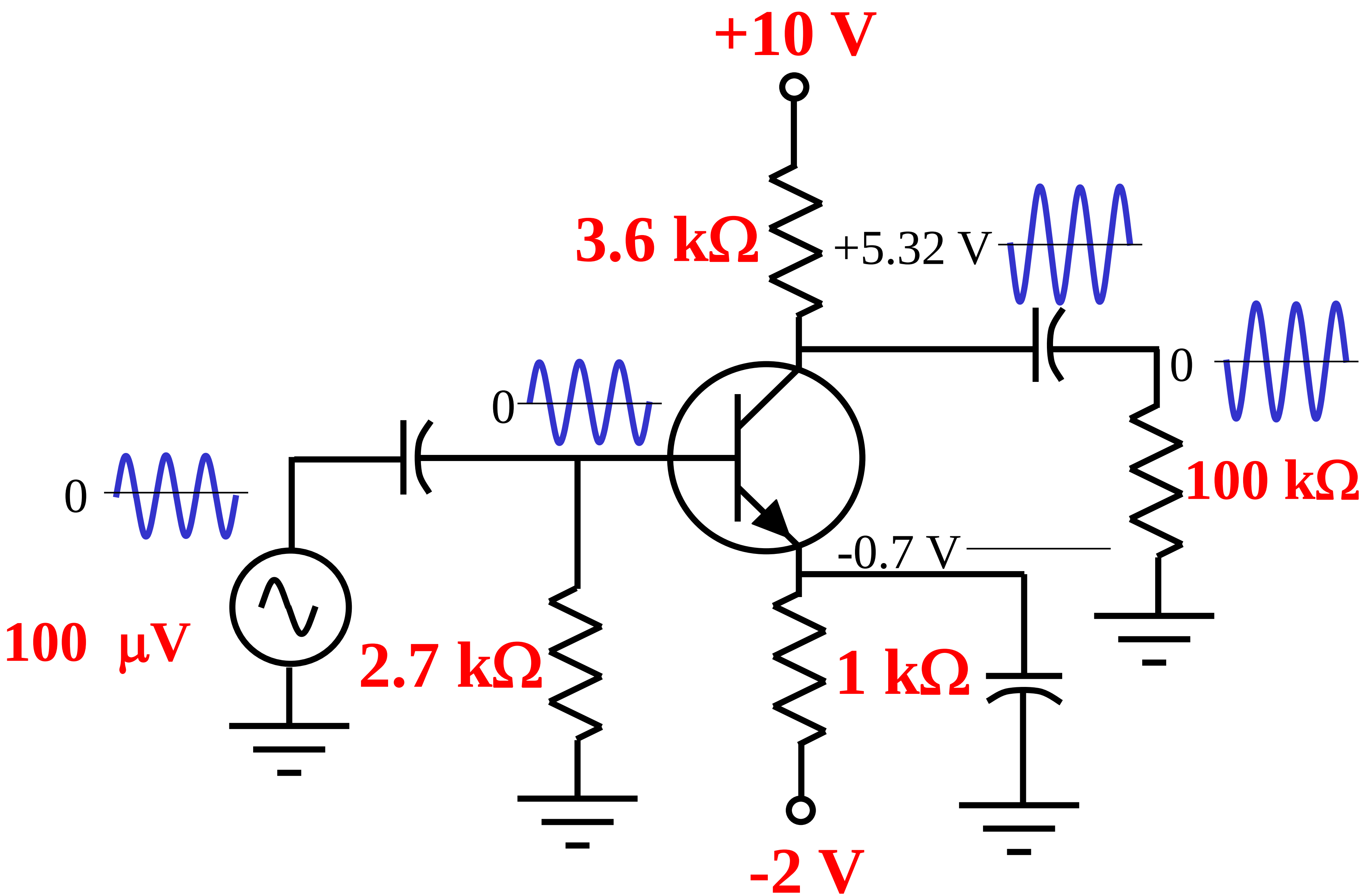
VDB and TSEB amplifiers

- Dc voltages and currents are calculated mentally by <u>opening</u> capacitors
- The ac signal is coupled via a <u>coupling</u> capacitor
- The bypass capacitor causes an <u>ac</u> signal to appear across the base-emitter junction and provides <u>higher</u> gain

A VDB amplifier with voltage waveforms

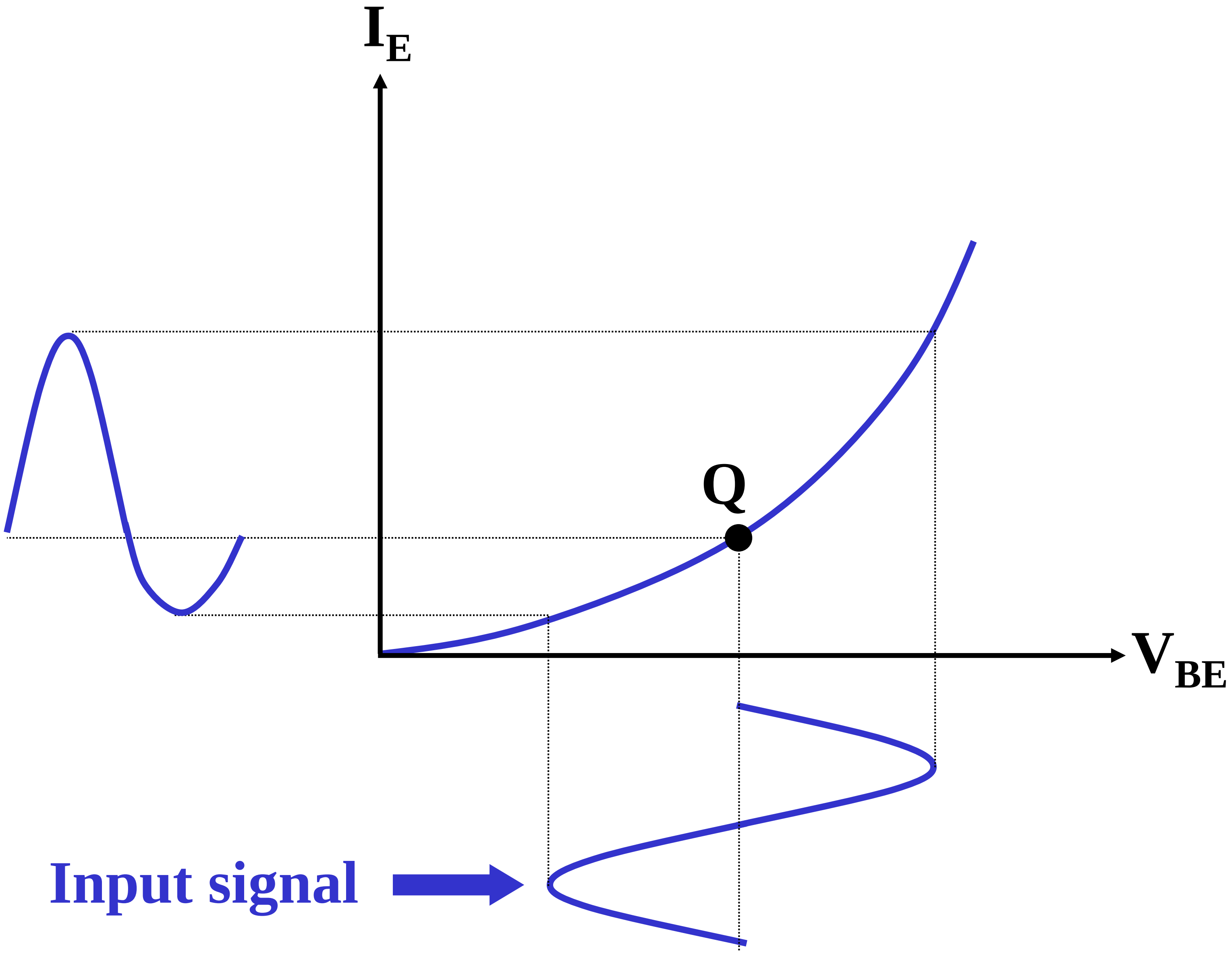


A TSEB amplifier with voltage waveforms



Distortion

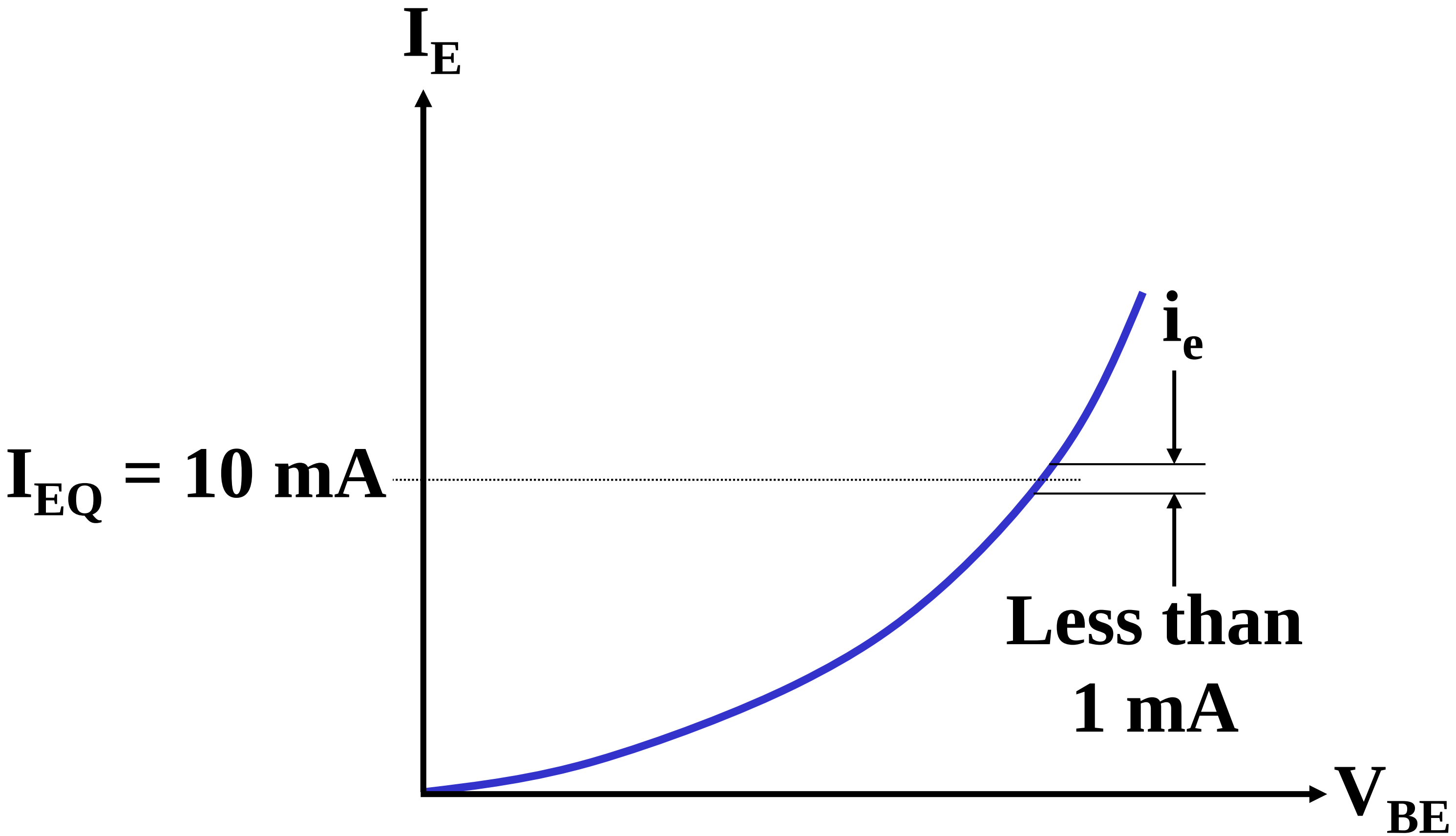
- The stretching and compressing of alternate half cycles
- Undesirable in high-fidelity amplifiers
- Can be minimized by keeping the ac input small



Large-signal operation produces distortion

The 10 percent rule

- Total emitter current consists of dc and ac
- To minimize distortion, i_e must be small compared to I_{EQ}
- The ac signal is small when the peak-to-peak ac emitter current is less than 10 percent of the dc emitter current



Total emitter current: $I_E = I_{EQ} + i_e$

<u>Small-signal</u> operation: $i_{e(PP)} < 0.1I_{EQ}$

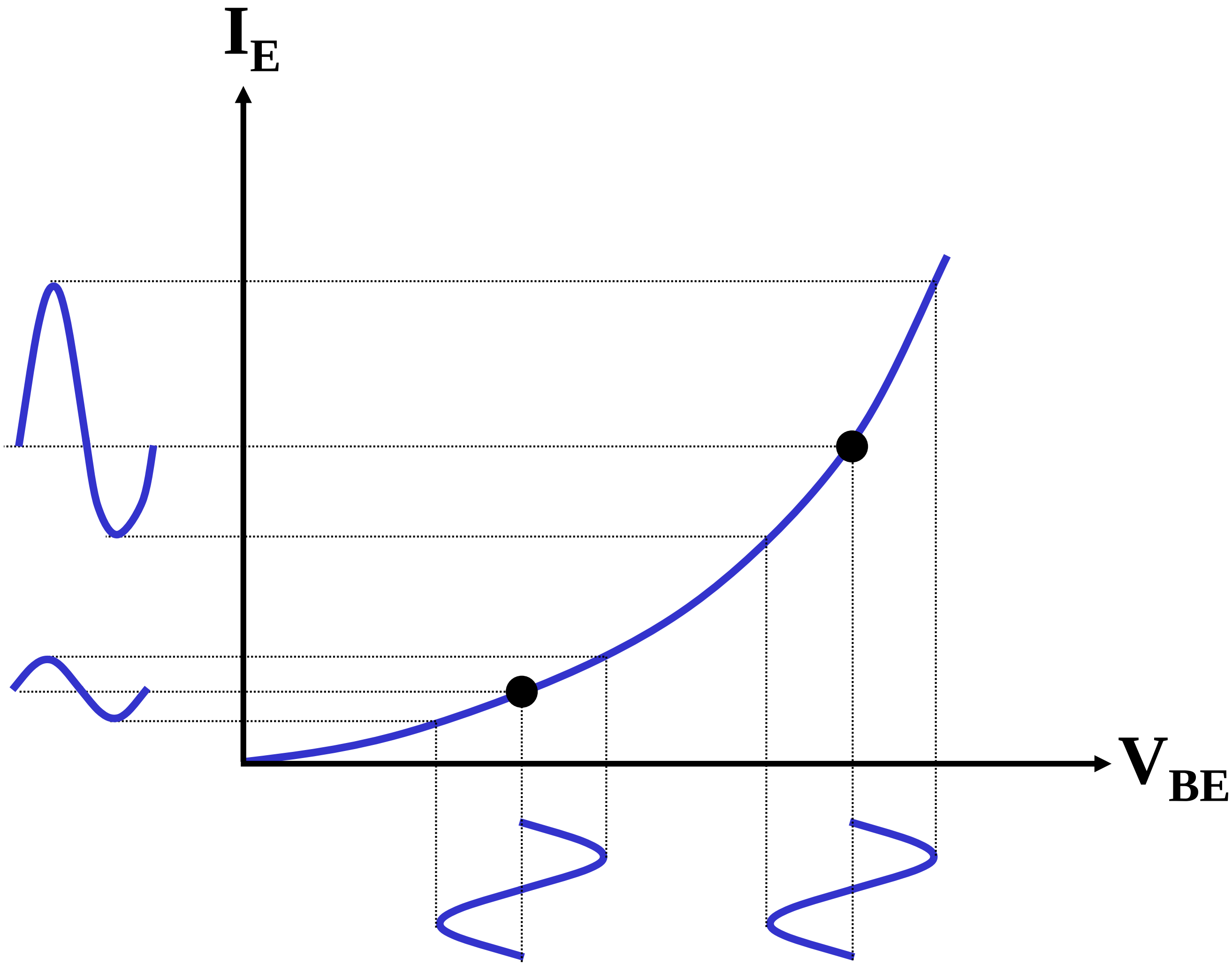
The dc current gain is given as:

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

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.



The size of the ac emitter current depends on the Q point.

Total emitter current: $I_E = I_{EQ} + i_e$

Total base-emitter voltage: $V_{BE} = V_{BEQ} + v_{be}$

The ac resistance of the emitter diode is defined as:

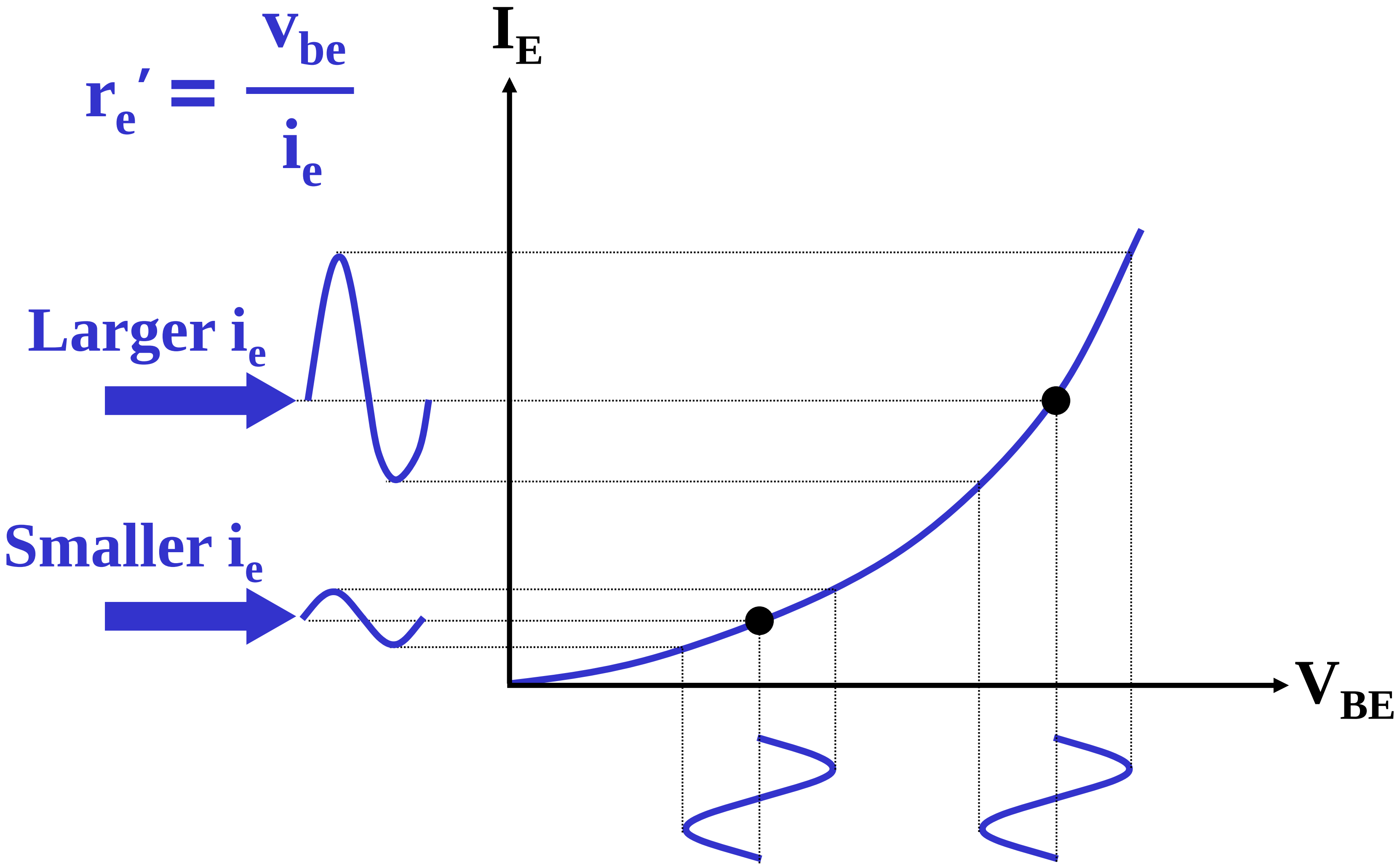
$$r_e' = \frac{v_{be}}{i_e}$$

The ac resistance of the emitter diode decreases when the dc emitter current increases

Ac resistance of the emitter diode

- **Equals the ac base-emitter voltage <u>divided</u> by the ac emitter current**
- **The prime (') in r_e' <u>indicates</u> that the resistance is <u>inside</u> the transistor**

$$r_e' = \frac{v_{be}}{i_e}$$



Note that r_e' <u>varies</u> with the operating point.

This implies that r_e' is a function of the <u>dc emitter</u> current.

Formula for ac emitter resistance

Derived by using solid-state physics and calculus:

$$r_e' = \frac{25\ \text{mV}}{I_E}$$

Widely used in industry because of its simplicity and it applies to almost all commercial transistors

Transistor model

- Ac equivalent circuit for a transistor
- Simulates how a transistor behaves when an ac signal is present
- Ebers-Moll (T model) and π type models are widely used

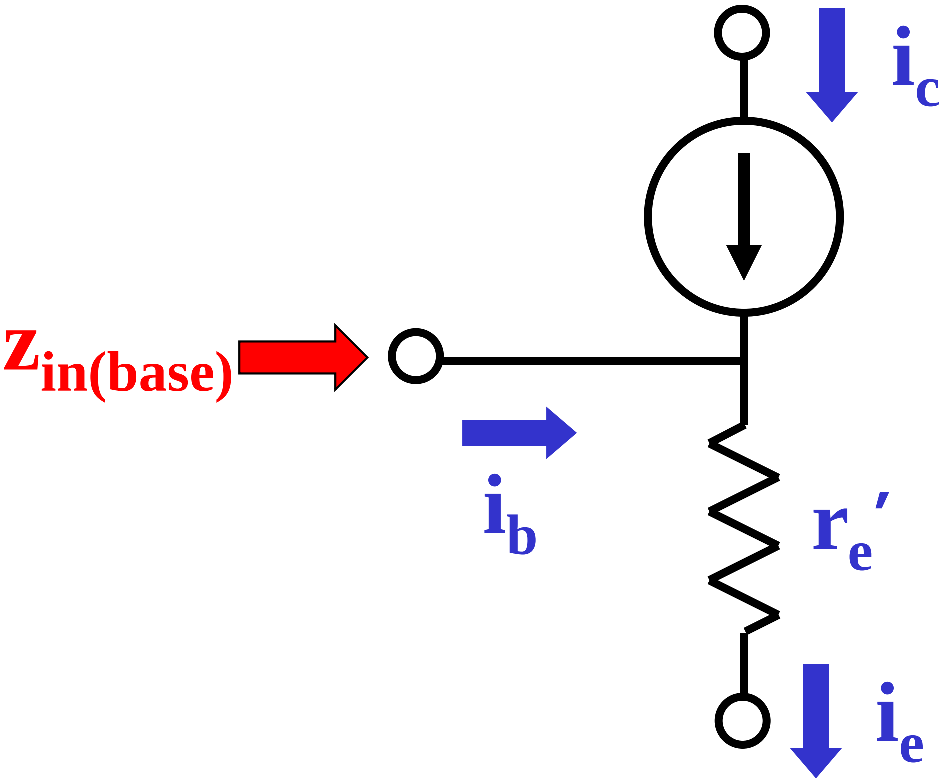
The T model of a transistor:

$$z_{in(base)} = \frac{v_{be}}{i_b}$$

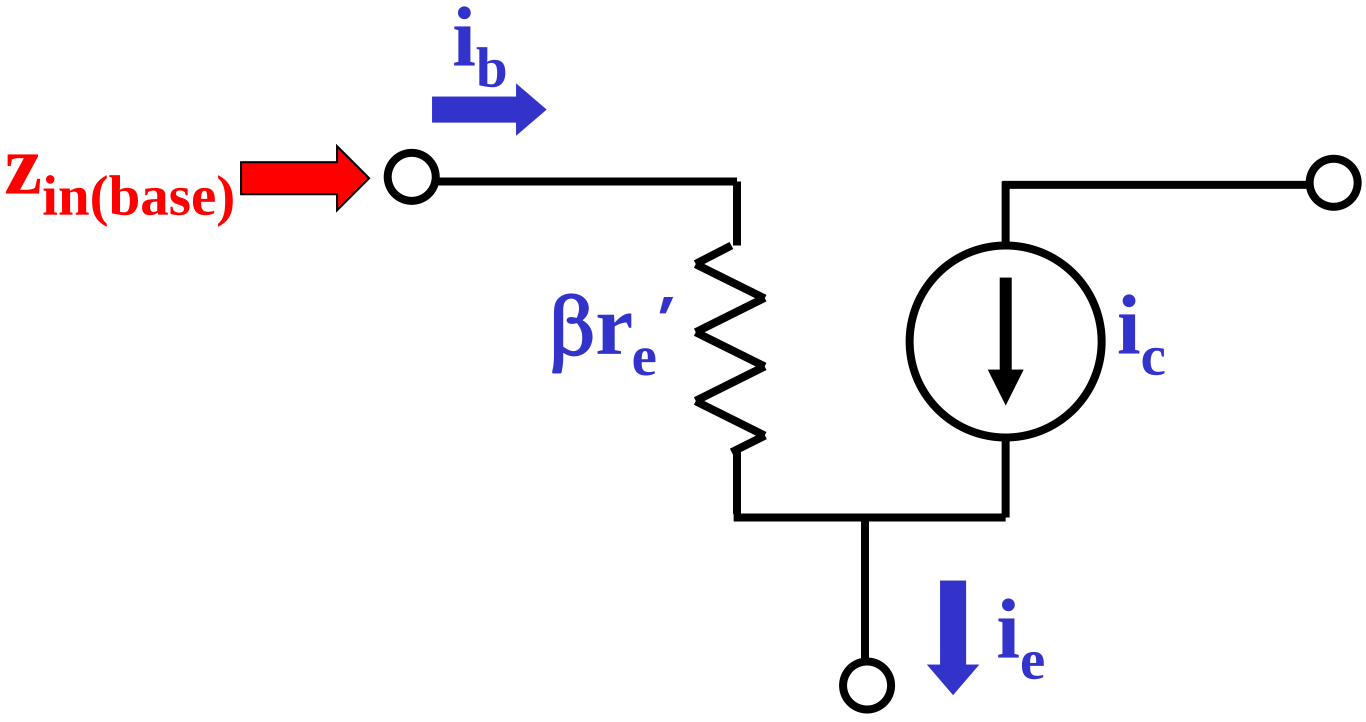
$$v_{be} = i_e r_e'$$

$$z_{in(base)} = \frac{i_e r_e'}{i_b}$$

$$z_{in(base)} = \beta r_e'$$



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

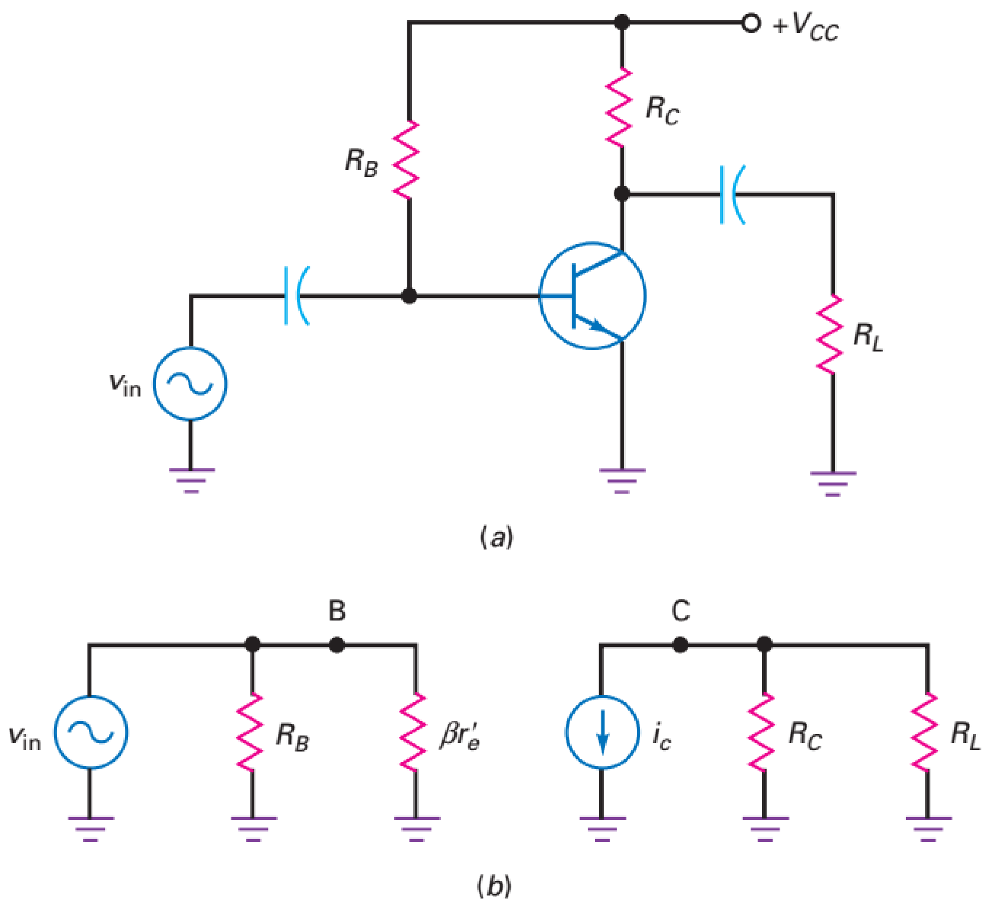


Clearly shows the input impedance of Br_e' will load the ac voltage source driving the base

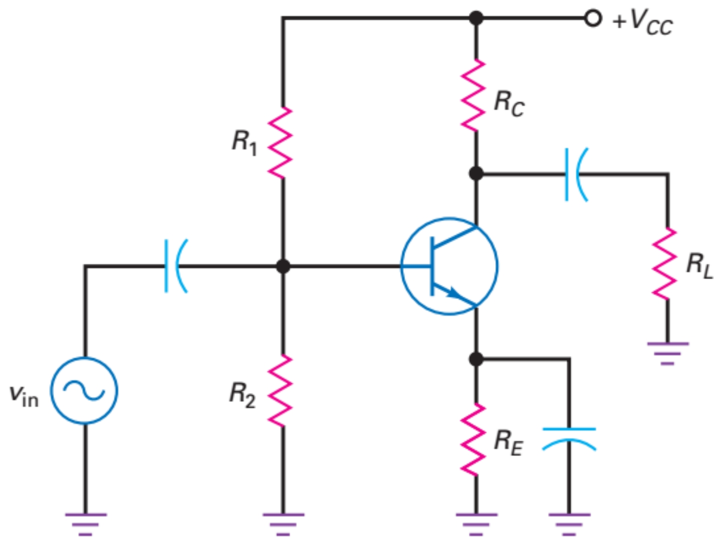
Amplifier analysis

- Perform a complete dc analysis
- Mentally short all coupling and bypass capacitors for ac signals
- Visualize all dc supply voltages as ac grounds
- Replace the transistor by its π or T model
- Draw the ac equivalent circuit

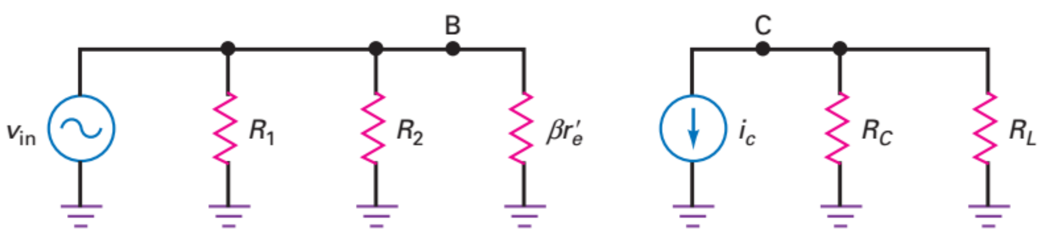
Base-Biased Amplifier and Its ac-Equivalent Circuit



VDB Amplifier and Its ac-Equivalent Circuit

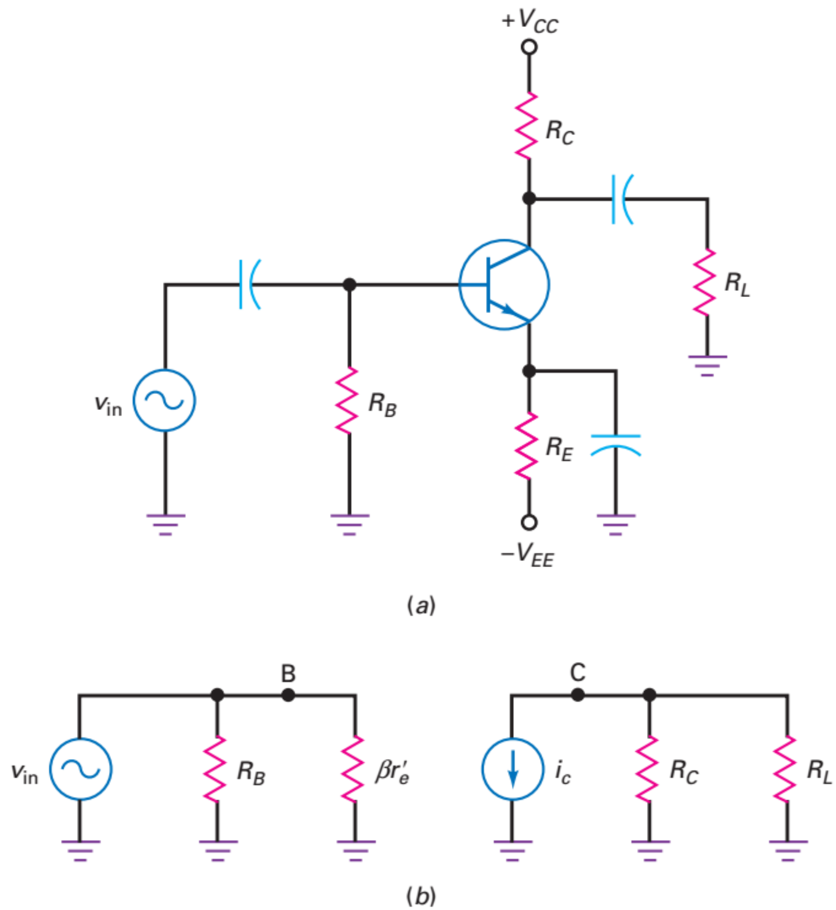


(a)

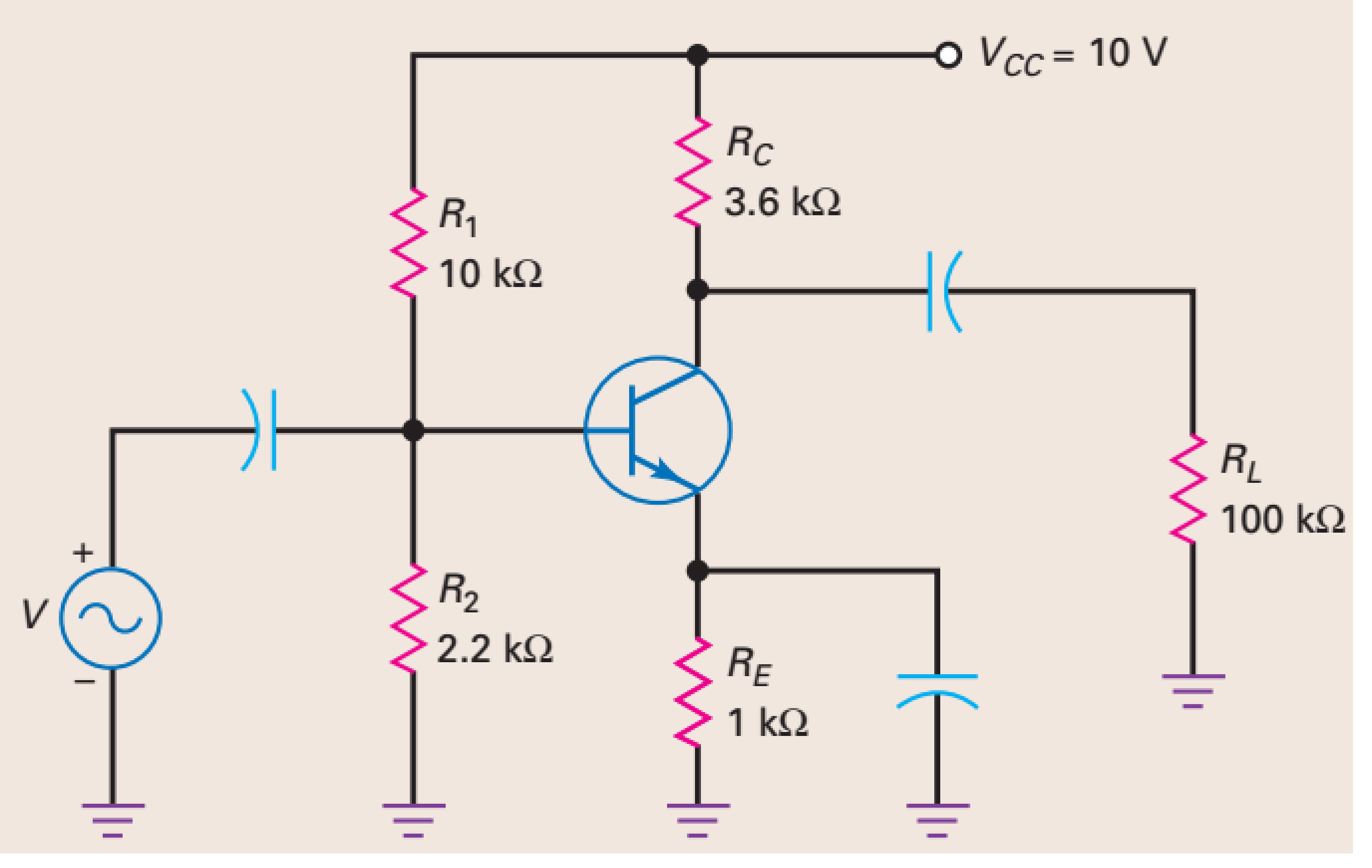


(b)

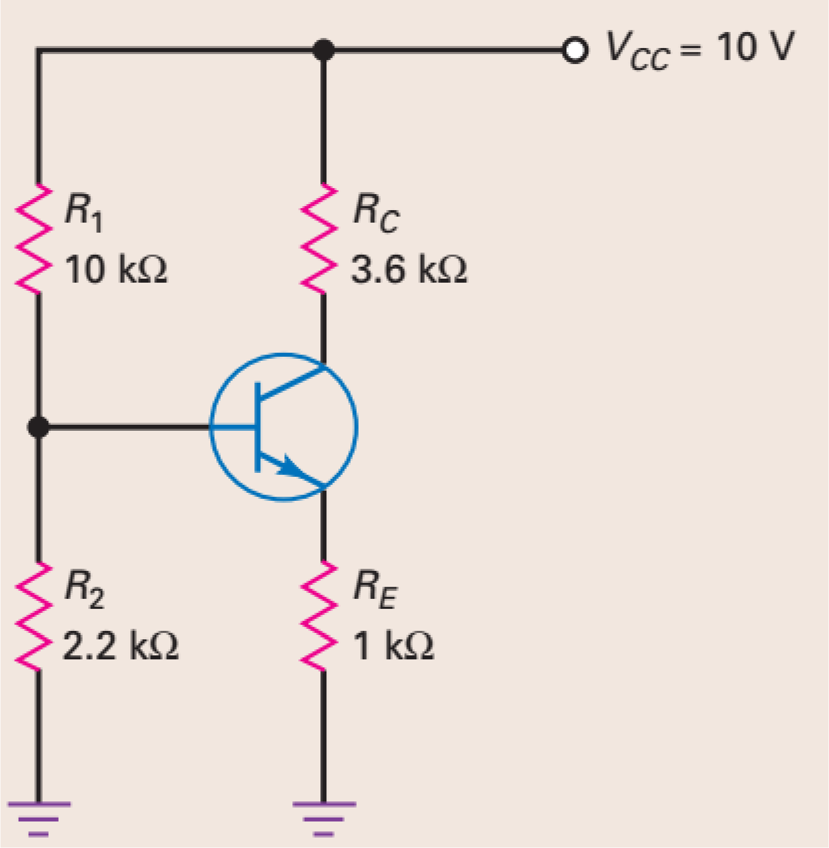
TSEB Amplifier and Its ac-Equivalent Circuit



Example: VDB DC and AC Equivalents



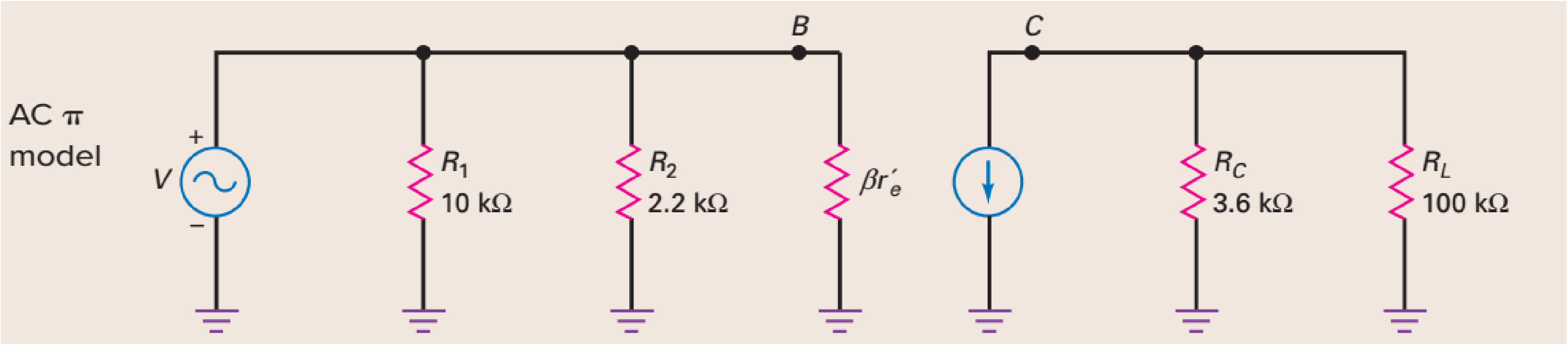
Example: DC Equivalent



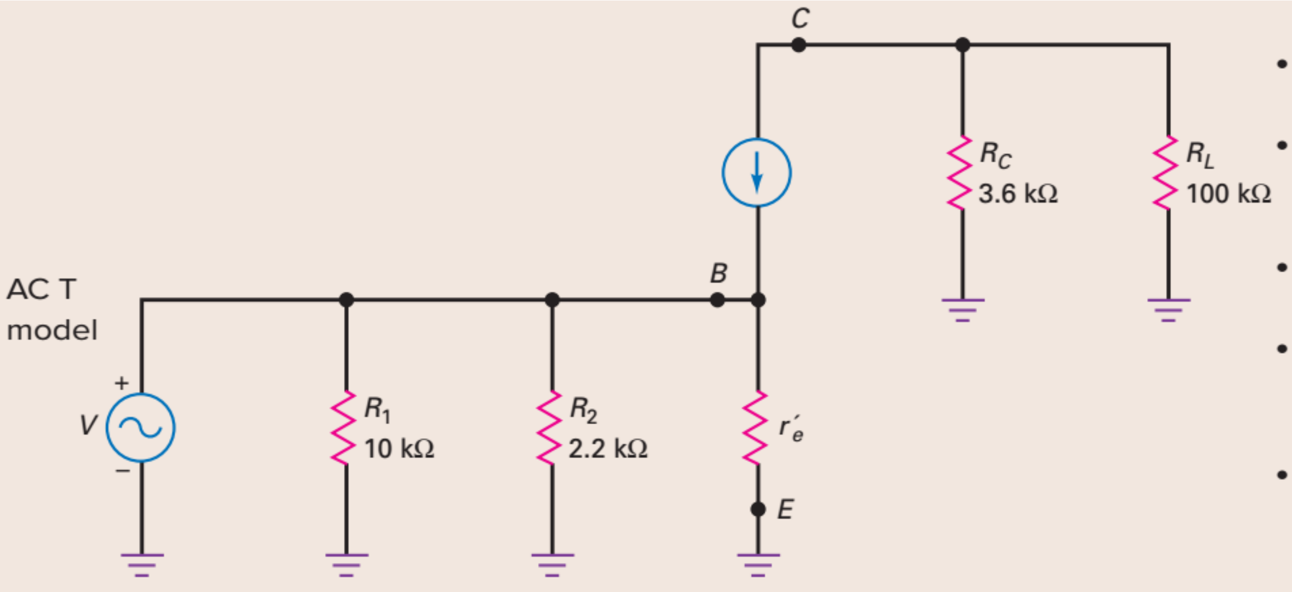
- Open all coupling and bypass capacitors.
- Redraw the circuit.
- Solve the dc circuit's Q point:

$V_B = 1.8$ V
$V_E = 1.1$ V
$I_E = 1.1$ mA
$V_{CE} = 4.94$ V

Example: AC π Model



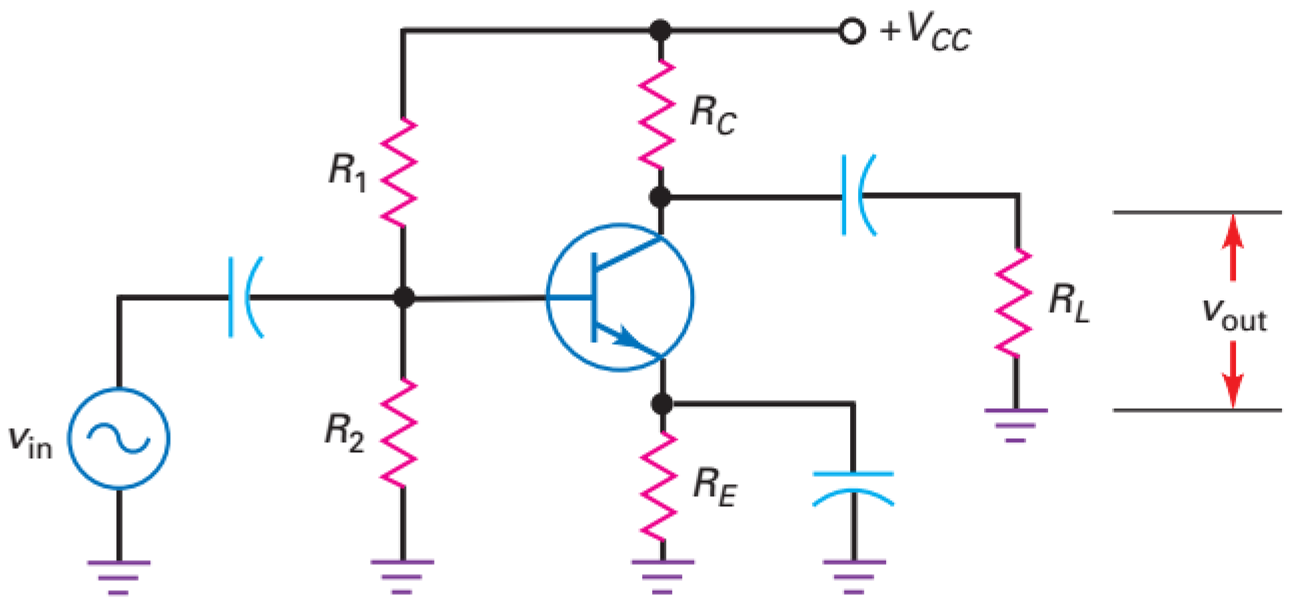
Example: AC T Model



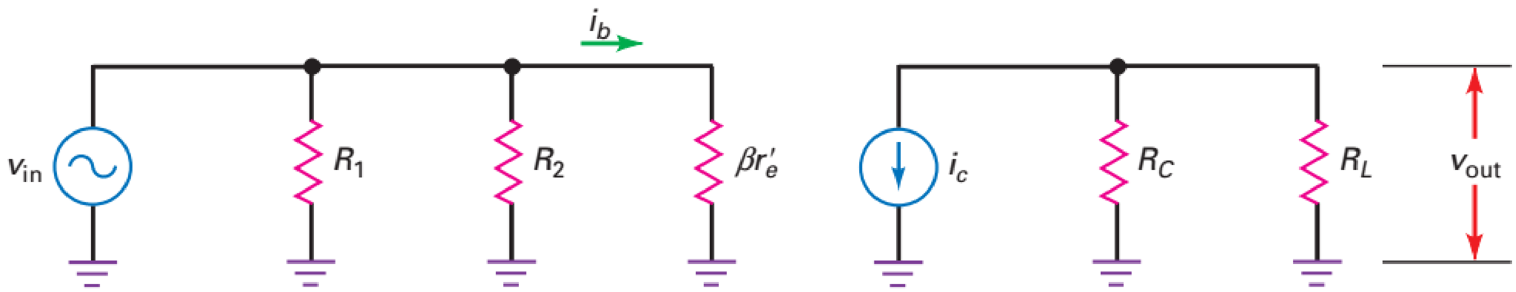
- Short all coupling and bypass capacitors.
- Visualize all dc supply voltages as ac grounds.
- Replace the transistor by its π or T model.
- Draw the ac-equivalent circuit.

- $r'_e = \dfrac{25\text{ mV}}{I_{EQ}} = 22.7\ \Omega$

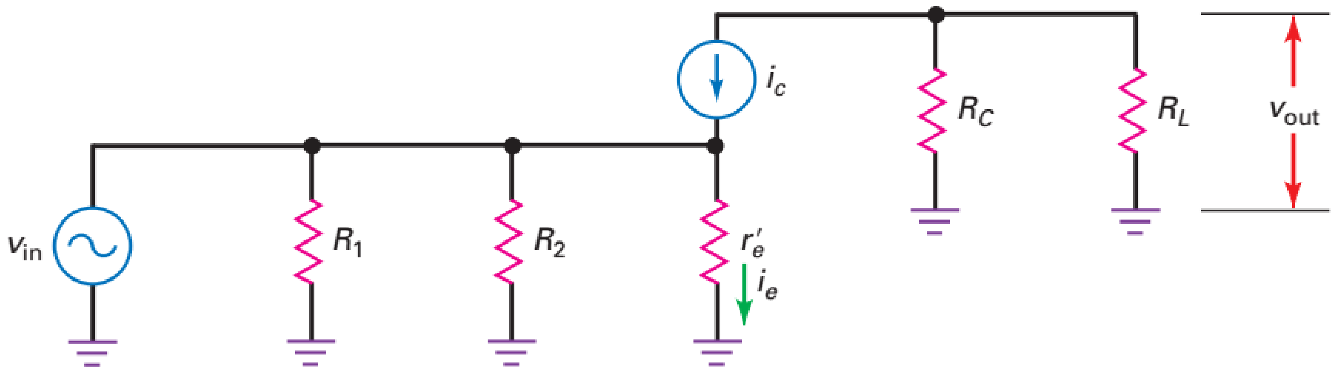
Voltage Gain: VDB Amplifier



AC Equivalent: π and T Models



(b)



(c)

Voltage Gain Calculation

Derived from the π Model

$$v_{\text{in}} = i_b \beta r'_e$$

$$v_{\text{out}} = i_c(R_C \parallel R_L) = \beta i_b (R_C \parallel R_L)$$

$$A_V = \frac{v_{\text{out}}}{v_{\text{in}}} = \frac{\beta i_b (R_C \parallel R_L)}{i_b \beta r'_e}$$

$$\boldsymbol{A_V = \frac{(R_C \parallel R_L)}{r'_e}}$$

Derived from the T Model

$$v_{\text{in}} = i_e r'_e$$

$$v_{\text{out}} = i_c r_c$$

$$\boldsymbol{r_c = R_C \parallel R_L}$$

$$A_V = \frac{v_{\text{out}}}{v_{\text{in}}} = \frac{i_c r_c}{i_e r'_e}$$

Since $i_c \approx i_e$,

$$A_V = \frac{r_c}{r'_e}$$

Data sheets

- The four *h* parameters are a <u>mathematical</u> approach
- h_{fe} is the ac current gain
- h_{ie} is equivalent to input impedance
- $\beta_{ac} = h_{fe}$
- $r_e' = h_{ie}/h_{fe}$
- h_{re} and h_{oe} are <u>not</u> needed for basic design and troubleshooting
- The h parameters give useful information when <u>translated</u> into r' parameters