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Electronics for Information Technology

(Điện tử cho Công nghệ Thông tin)

IT3420E

Đỗ Công Thuần

Department of Computer Engineering

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General Information

- Course: **Electronics for Information Technology**
- ID Number: IT3420
- Credits: 2 (2-1-0-4)
- Lecture/Exercise: 32/16 hours (48 hours, 16 weeks)
- Evaluation:
  - Midterm examination and weekly assignment: **50%**
  - Final examination: **50%**
- Learning Materials:
  - Lecture slides
  - Textbooks
    - ***Introductory Circuit Analysis*** (2015), 10^{th} – 13^{th} ed., Robert L. Boylestad
    - ***Electronic Device and Circuit Theory*** (2013), 11^{th} ed., Robert L. Boylestad, Louis Nashelsky
    - ***Microelectronics Circuit Analysis and Design*** (2006), 4^{th} ed., Donald A. Neamen
    - ***Digital Electronics: Principles, Devices and Applications*** (2007), Anil K. Maini

Contact Your Instructor

- You can reach me through office in **<u>Room 802, B1 Building</u>**, HUST.
  - You should make an appointment by email before coming.
  - If you have urgent things, just come and meet me!
- You can also reach me at the following **<u>email</u>** any time. This is the best way to reach me!
  - thuandc@soict.hust.edu.vn

Course Contents

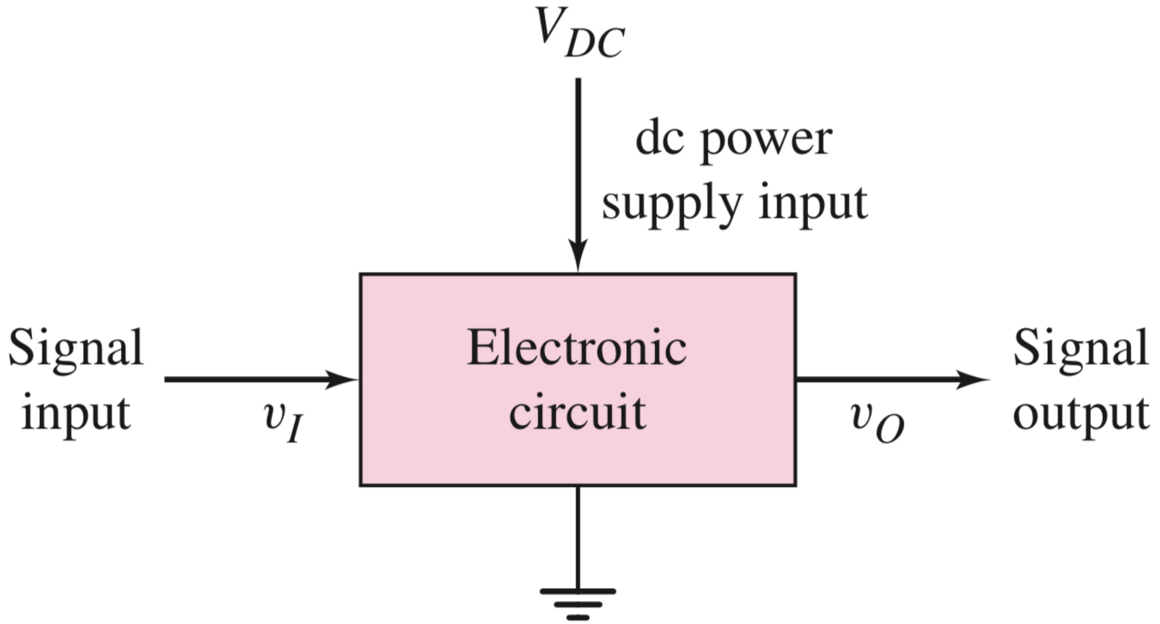
- The Concepts of Electronics for IT
- **Chapter 1**: Passive Electronic Components and Applications
- **Chapter 2**: Semiconductor Components and Applications
- **Chapter 3**: Operational Amplifiers
- **Chapter 4**: Fundamentals of Digital Circuits
- **Chapter 5**: Logic Gates
- **Chapter 6**: Combinational Logic
- **Chapter 7**: Sequential Logic

Chapter 2: **Semiconductor Components and Applications**

- Semiconductor Materials
- Diodes and Applications
- Transistors and Applications

Analog Circuits

- A signal contains some type of information.
  - Ex: a sound wave produced by a speaking human
- Electronic circuits that process analog signals are called analog circuits.
  - Ex: a linear amplifier

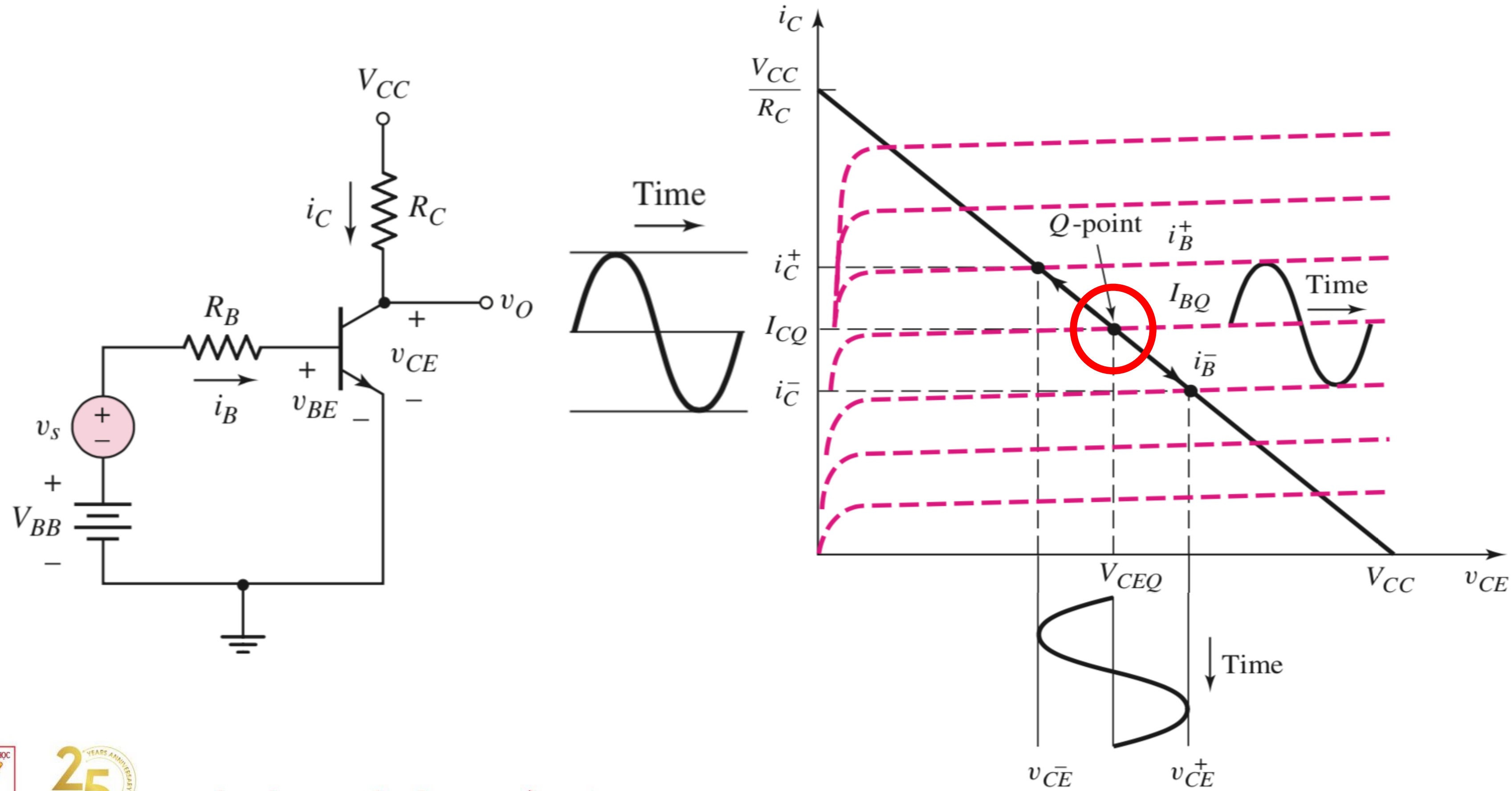


Analysis Method

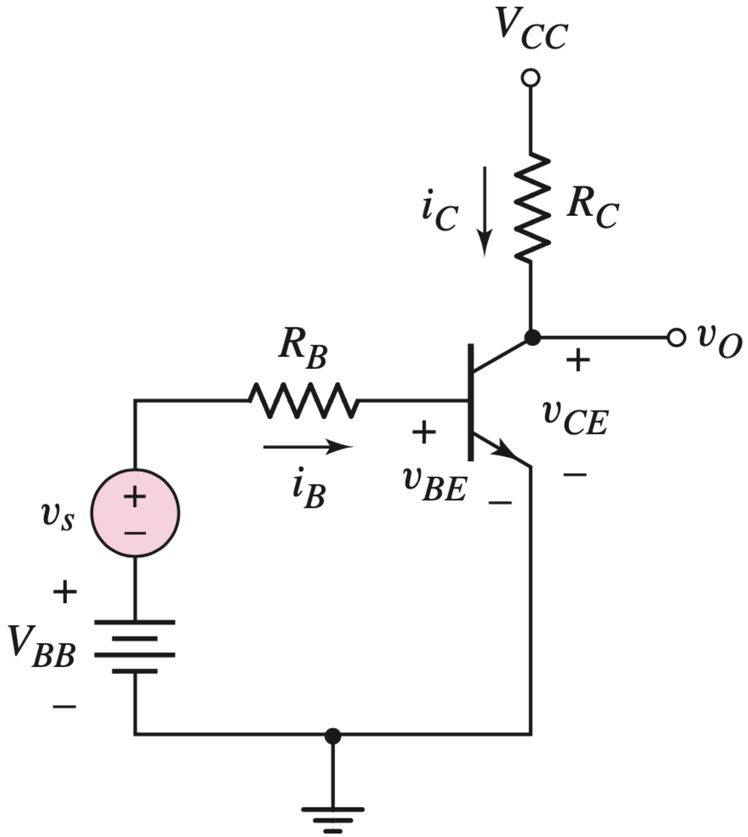
- **Using a small-signal analysis → a linear model**
  - Doing the DC analysis to establish the Q-point of the transistor in the linear amplifier
  - Doing the AC analysis to determine the relationships between the time-varying output and input signals
  - Applying the superposition principle (thanks to the linear model)
    - "*The response of a linear circuit excited by multiple independent input signals is the sum of the responses of the circuit to each of the input signals alone.*"

Graphical Analysis

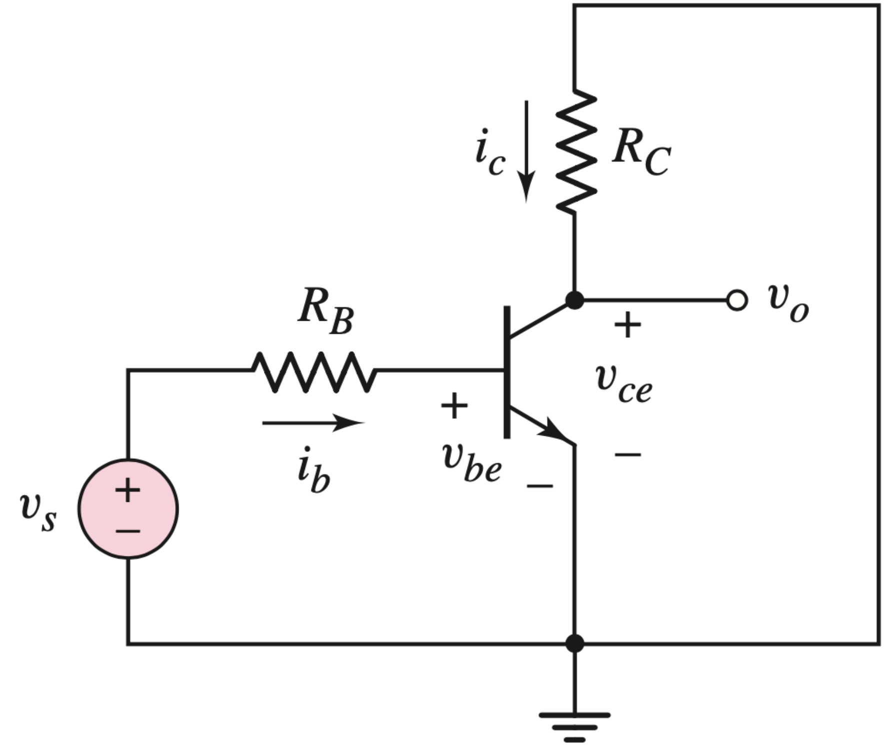
- **DC Analysis**: to find the desired Q-point
- **AC Analysis**: to determine the relationships between the time-varying output and input signals



AC Equivalent Circuit

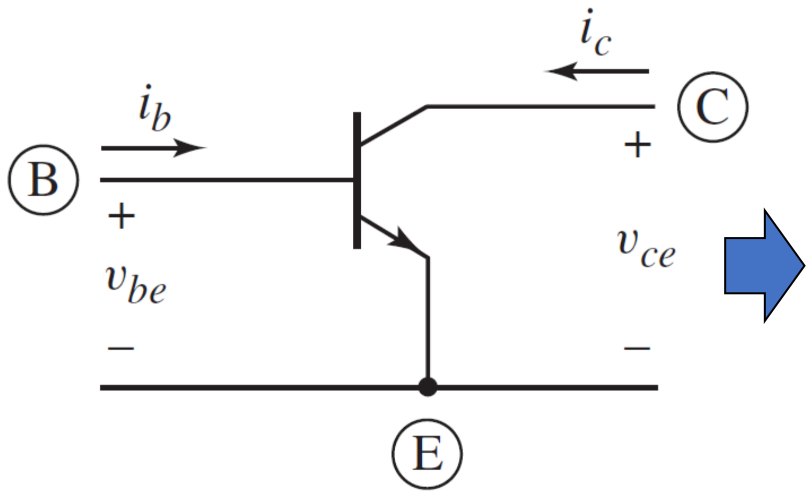


Common-Emitter Circuit

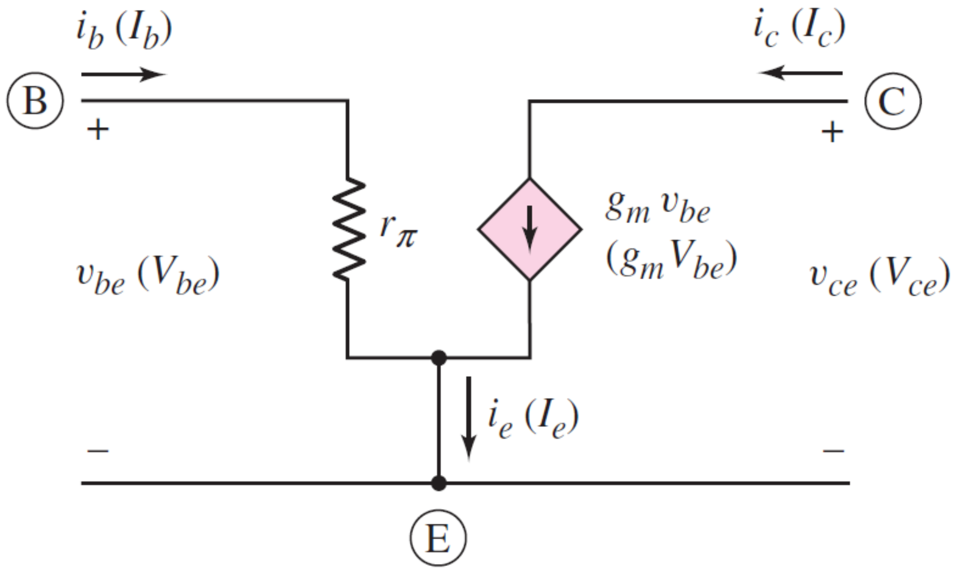


AC equivalent circuit

Small-Signal Hybrid-π Equivalent Circuit



Can treat the bipolar transistor as a two-port network

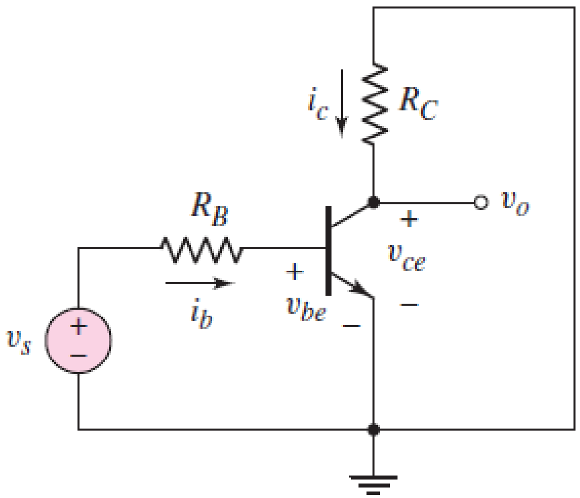


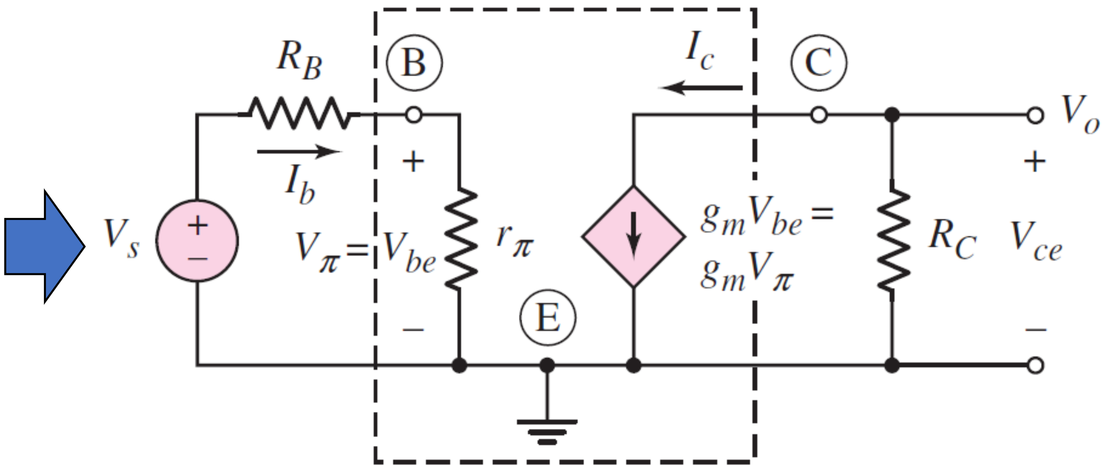
Hybrid-π equivalent circuit with small time-varying signals

$$r_\pi = \frac{V_T}{I_{BQ}}$$ **Diffusion resistance or B–E input resistance**

$$g_m = \frac{I_{CQ}}{V_T}$$ **Transconductance**

Hybrid-π Equivalent Circuit





Output signal voltage

$$V_o = V_{ce} = -(g_m V_\pi) R_C$$

Small-signal B-E voltage

$$V_\pi = \left(\frac{r_\pi}{r_\pi + R_B}\right) \cdot V_s$$

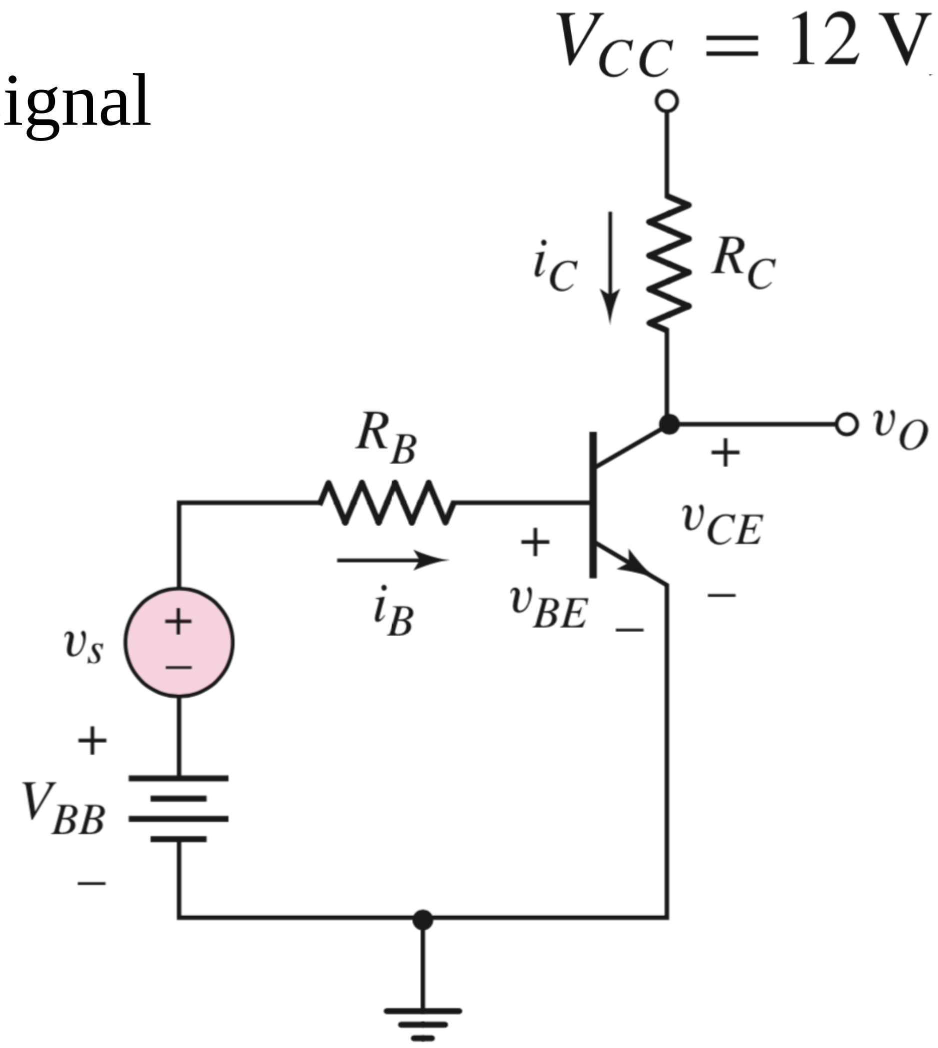
Small-signal voltage gain

$$A_v = \frac{V_o}{V_s} = -(g_m R_C) \cdot \left(\frac{r_\pi}{r_\pi + R_B}\right)$$

Example 2.13

- Calculate the small-signal voltage gain.
- Assume:

$$\beta = 100$$
$$V_{BE} = 0.7\text{ V}$$
$$R_C = 6\text{ k}\Omega$$
$$R_B = 50\text{ k}\Omega$$
$$V_{BB} = 1.2\text{ V}$$



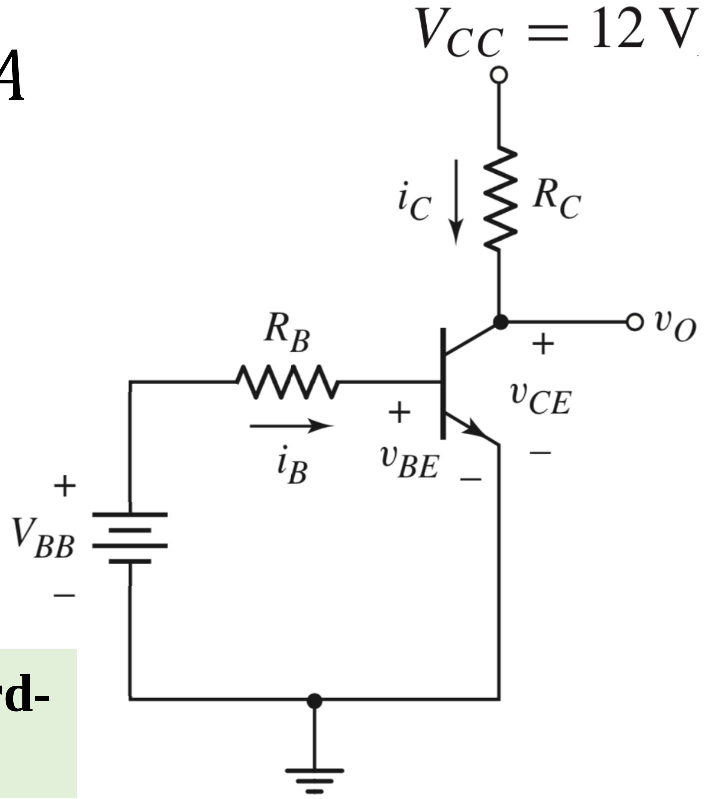
Example 2.13: DC Analysis

- DC equivalent circuit:

$$I_{BQ} = \frac{V_{BB} - V_{BE}(on)}{R_B} = \frac{1.2 - 0.7}{50} = 10\ \mu A$$

$$I_{CQ} = \beta I_B = 100 * 0.01 = 1mA$$

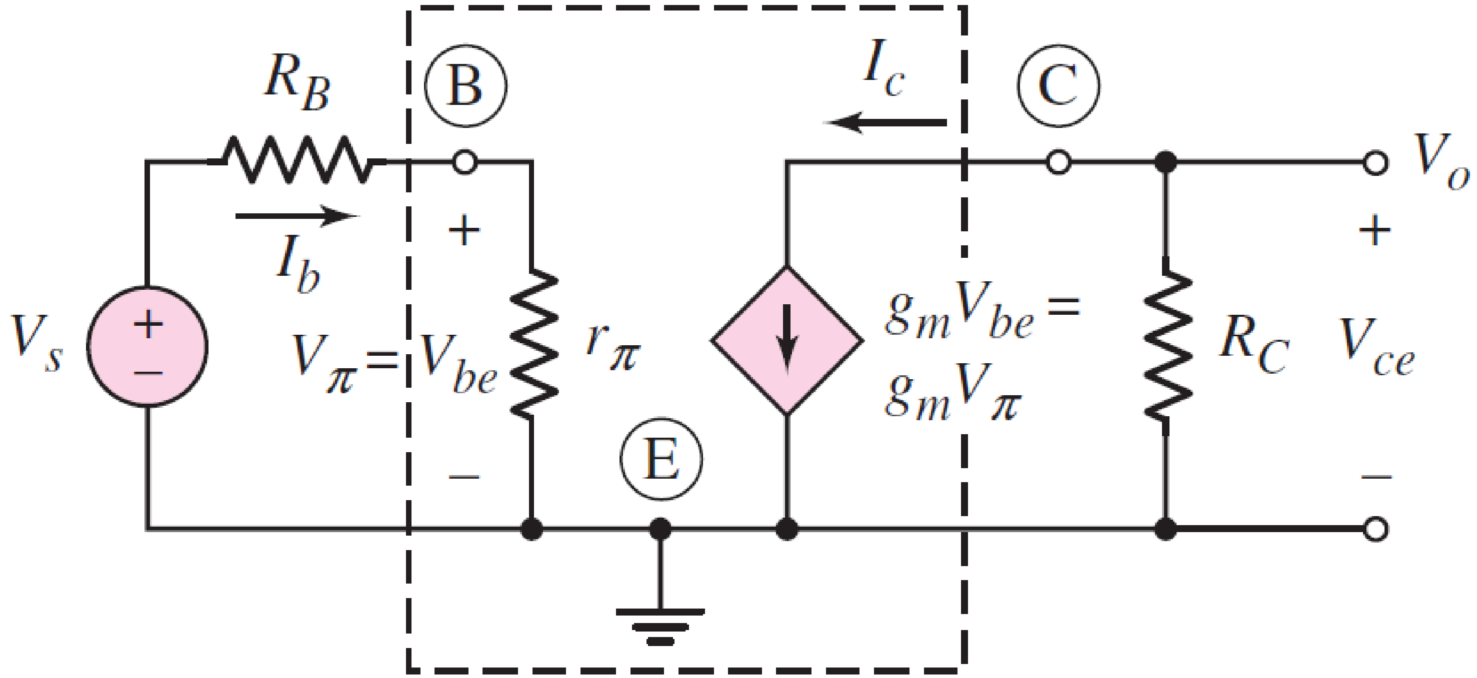
$$V_{CEQ} = V_{CC} - I_C R_C$$
$$= 12 - 1 * 6 = 6V$$



$$\Rightarrow \begin{cases} I_{BQ} = 10\ \mu A \\ I_{CQ} = 1mA \\ V_{CEQ} = 6V \end{cases}$$

$\Rightarrow$ **The transistor is biased in the forward-active mode**

Example 2.13: Hybrid-π Equivalent Circuit



Small-signal voltage gain

$$A_v = \frac{V_o}{V_s} = -(g_m R_C) \cdot \left(\frac{r_\pi}{r_\pi + R_B} \right)$$

Example 2.13: AC Analysis

- The small-signal hybrid-π parameters are:

$$r_\pi = \frac{\beta V_T}{I_{CQ}} = \frac{(100)(0.026)}{1} = 2.6\ \mathrm{k\Omega}$$

$$g_m = \frac{I_{CQ}}{V_T} = \frac{1}{0.026} = 38.5\ \mathrm{mA/V}$$

$$A_v = \frac{V_o}{V_s} = -(g_m R_C) \cdot \left(\frac{r_\pi}{r_\pi + R_B}\right)$$

$$= -(38.5)(6)\left(\frac{2.6}{2.6 + 50}\right)$$

$$= -11.4$$

Example 2.13: Sinusoidal Input Voltage

- Considering a specific sinusoidal input voltage:

$$v_s = 0.25 \sin \omega t \text{ V}$$

- The sinusoidal base current is given by:

$$i_b = \frac{v_s}{R_B + r_\pi} = \frac{0.25 \sin \omega t}{50 + 2.6} \rightarrow 4.75 \sin \omega t \ \mu\text{A}$$

- The sinusoidal base current is given by:

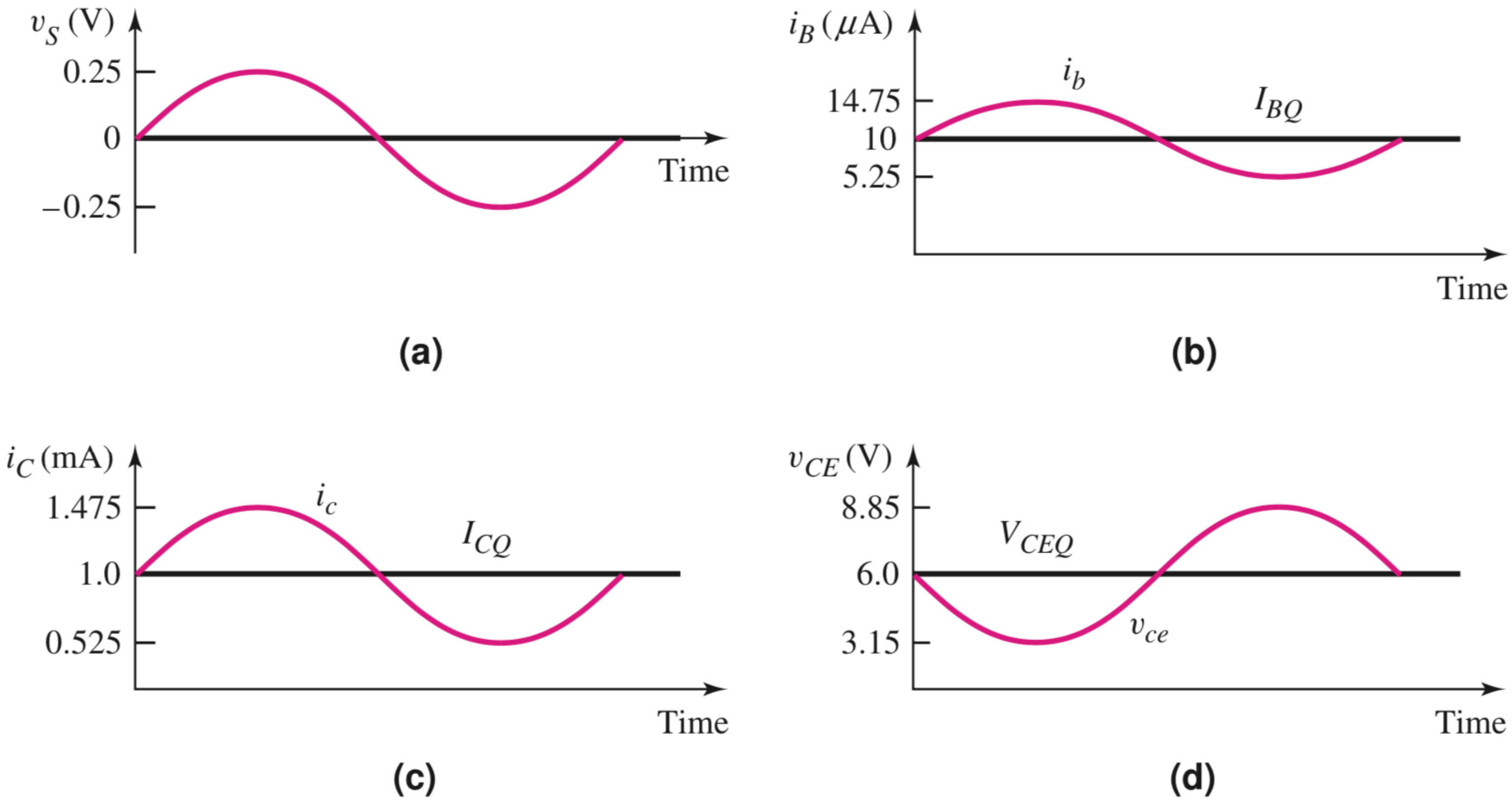
$$i_c = \beta i_b = (100)(4.75 \sin \omega t) \rightarrow 0.475 \sin \omega t \text{ mA}$$

- The sinusoidal C-E voltage is:

$$v_{ce} = -i_c R_C = -(0.475)(6) \sin \omega t = -2.85 \sin \omega t \text{ V}$$

Example 2.13: Sinusoidal Input Voltage

- The DC and AC signals in the common-emitter circuit:



Problem-Solving Technique: AC Analysis

- **Step 1:** Analyze the circuit with only the dc sources present → Q-point. The transistor must be biased in the forward-active region to produce a linear amplifier.
- **Step 2:** Replace each element in the circuit with its small-signal model. Apply the small-signal hybrid-π model to the transistor.
- **Step 3:** Analyze the small-signal equivalent circuit, setting the dc source components equal to zero, to produce the response of the circuit to the time-varying input signals only.
- **Step 4:** Apply the principle of superposition.

Transformation of Elements in DC and Small-Signal Analysis

Element	I–V relationship	DC model	AC model
Resistor	$I_R = \dfrac{V}{R}$	R	R
Capacitor	$I_C = sCV$	Open	C
Inductor	$I_L = \dfrac{V}{sL}$	Short	L
Diode	$I_D = I_S(e^{v_D/V_T} - 1)$	$+V_\gamma - r_f$	$r_d = V_T / I_D$
Independent voltage source	$V_S = \text{constant}$	$+V_S-$	Short
Independent current source	$I_S = \text{constant}$	I_S	Open

Superposition Principle

- The time-varying signals are superimposed on dc values:

$$i_B = I_{BQ} + i_b$$

$$i_C = I_{CQ} + i_c$$

$$v_{CE} = V_{CEQ} + v_{ce}$$

$$v_{BE} = V_{BEQ} + v_{be}$$

Variable	Meaning
i_B, v_{BE}	Total instantaneous values
I_B, V_{BE}	DC values
i_b, v_{be}	Instantaneous ac values
I_b, V_{be}	Phasor values

Example 2.13: Superposition Principle

- The total instantaneous base current is given by:

$$i_B = I_{BQ} + i_b$$
$$= 10 + 4.75 sin\omega t \ \mu A$$

- The total instantaneous collector current is given by:

$$i_C = I_{CQ} + i_c$$
$$= 1 + 0.475 sin\omega t \ mA$$

- The total instantaneous C-E voltage is given by:

$$v_{CE} = V_{CEQ} + v_{ce}$$
$$= 6 - 2.85 sin\omega t \ V$$

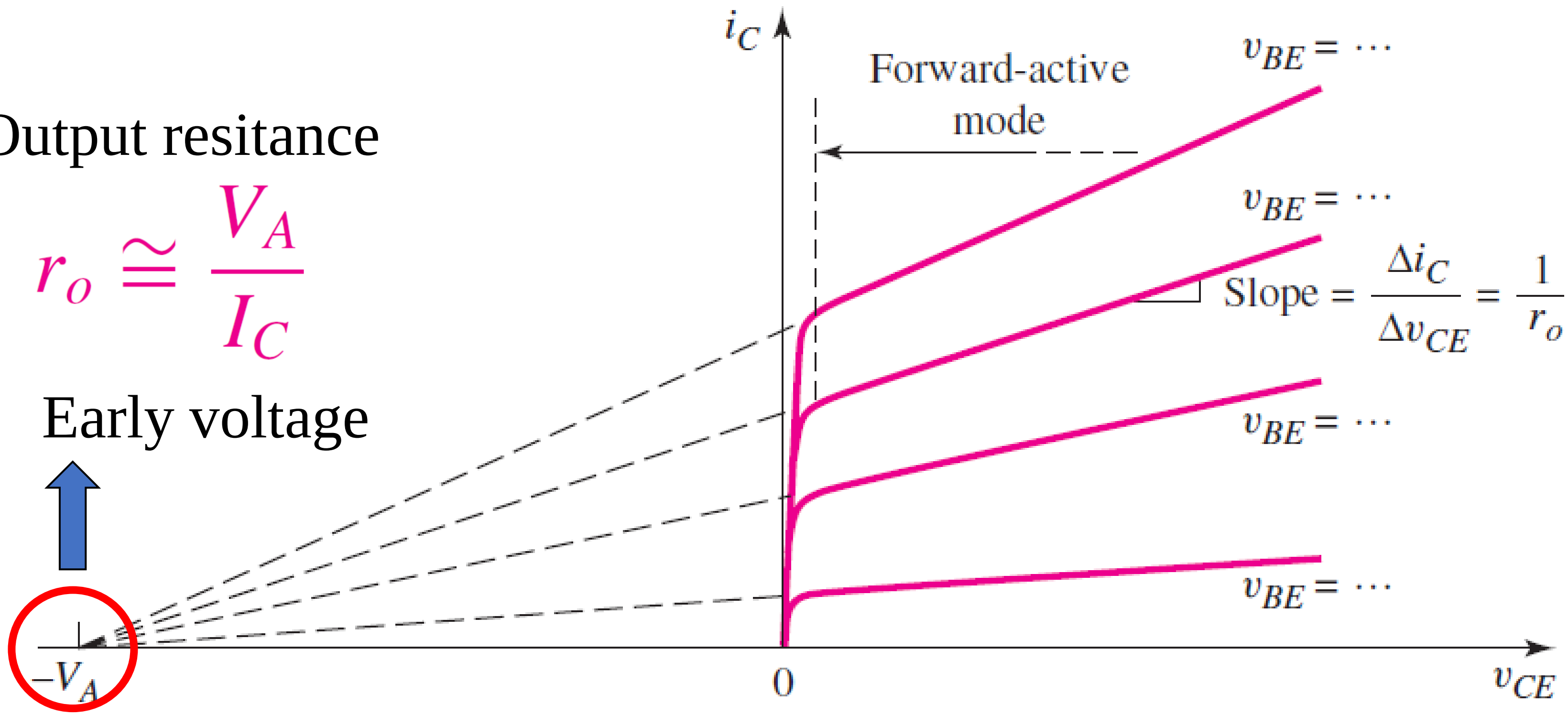
Hybrid-π Equivalent Circuit, Including the Early Effect

- When the curves are extrapolated to zero current, they meet at a point on the negative voltage axis, at $v_{CE} = -V_A$.

Output resitance

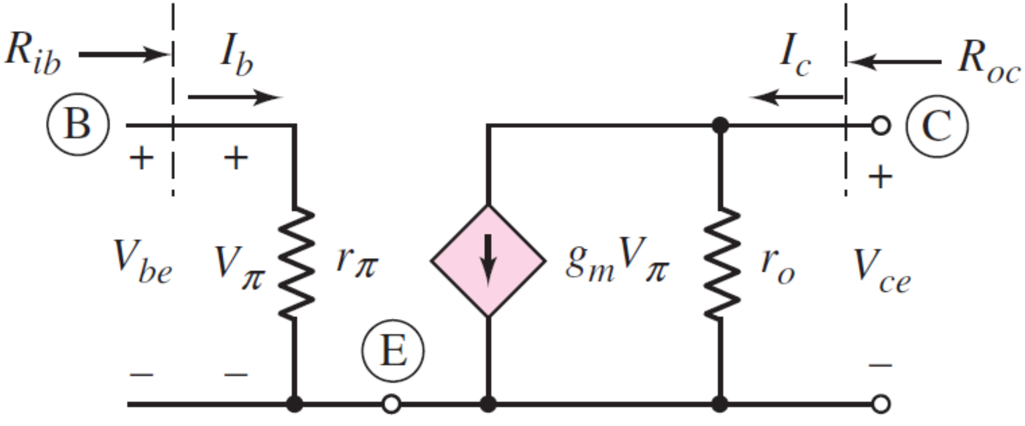
$$r_o \cong \frac{V_A}{I_C}$$

Early voltage



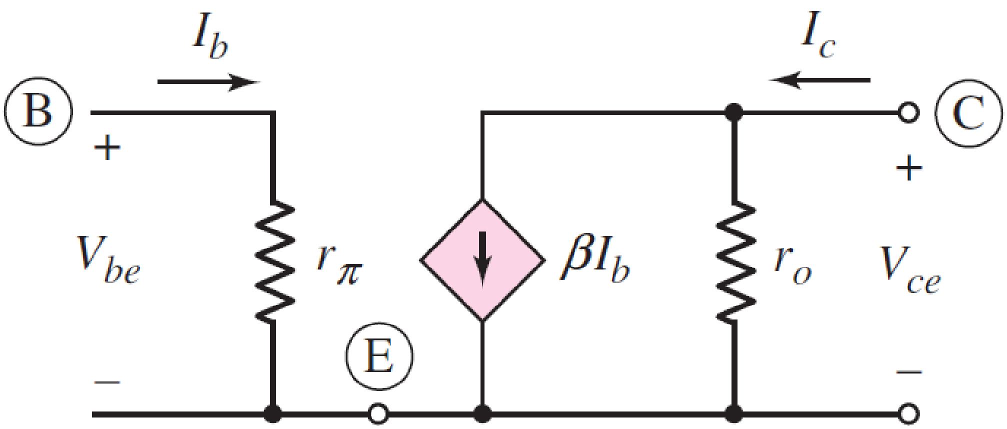
- Typical values of V_A: $50 < V_A < 300$ V

Hybrid-π Equivalent Circuit, Including the Early Effect



The small-signal equivalent circuit, including the output resistance when the circuit contains the transconductance parameter.

The small-signal equivalent circuit, including the output resistance when the circuit contains the current gain parameter.

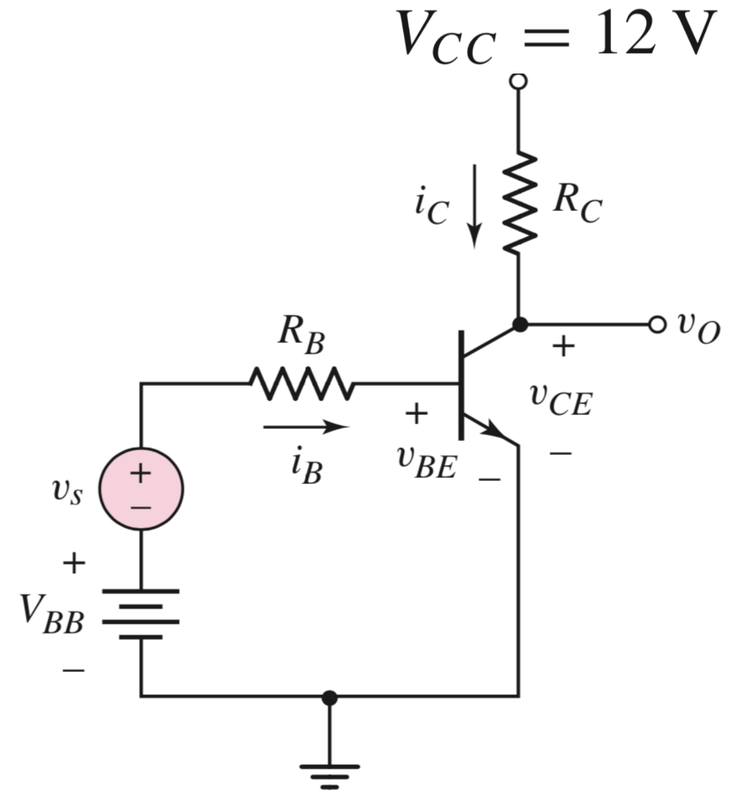


$$r_o = \frac{V_A}{I_{CQ}}$$ **Small-signal transistor output resistance**

Example 2.14

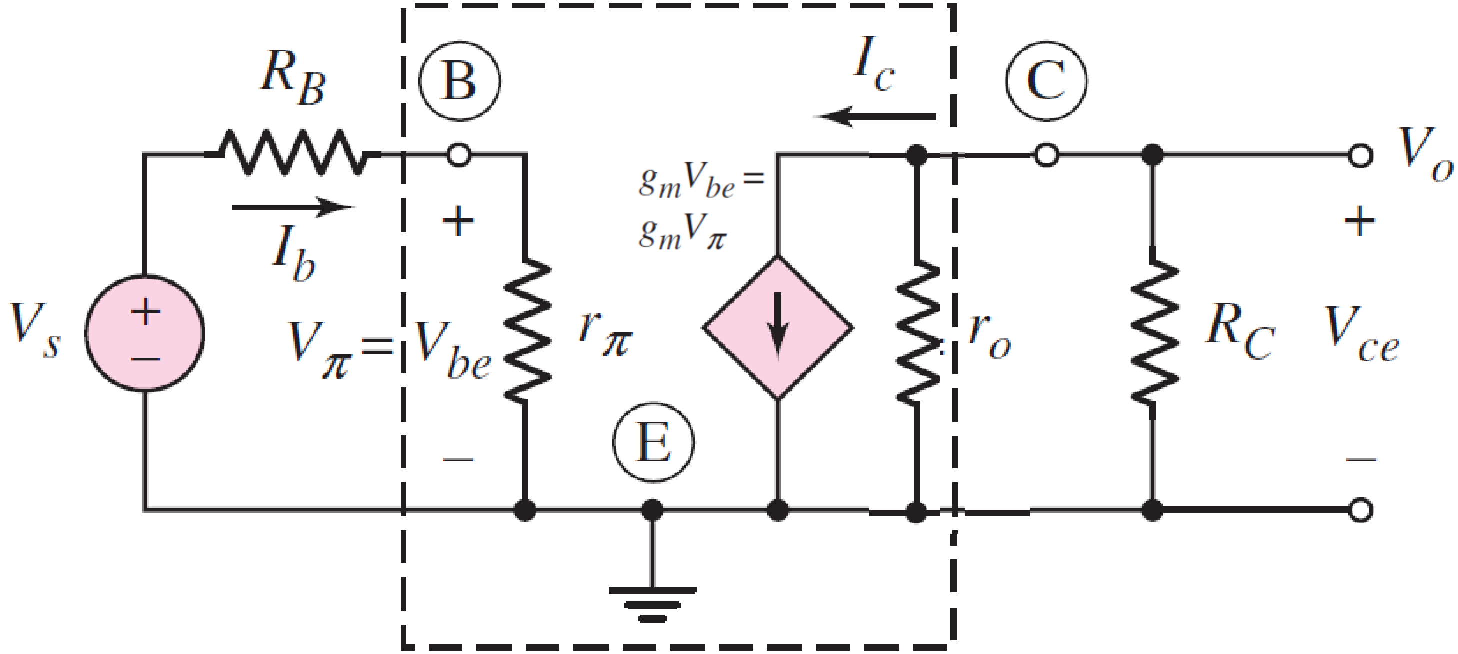
- Determine the small-signal voltage gain, including the effect of the transistor output resistance r_o, with the parameters:

$$\beta = 100$$
$$V_{BE} = 0.7\ \text{V}$$
$$R_C = 6\ \text{k}\Omega$$
$$R_B = 50\ \text{k}\Omega$$
$$V_{BB} = 1.2\ \text{V}$$
$$V_A = 50\ \text{V}$$



Example 2.14

- The small-signal equivalent circuit, including the output resistance r_o:



$$A_v = \frac{V_o}{V_s} = -g_m(R_C \| r_o)\left(\frac{r_\pi}{r_\pi + R_B}\right)$$

Example 2.14

- The output resistance is given by:

$$r_o = \frac{V_A}{I_{CQ}} = \frac{50}{1\text{ mA}} = 50\,\text{k}\Omega$$

- The small-signal voltage gain is therefore:

$$A_v = \frac{V_o}{V_s} = -g_m(R_C \| r_o)\left(\frac{r_\pi}{r_\pi + R_B}\right)$$

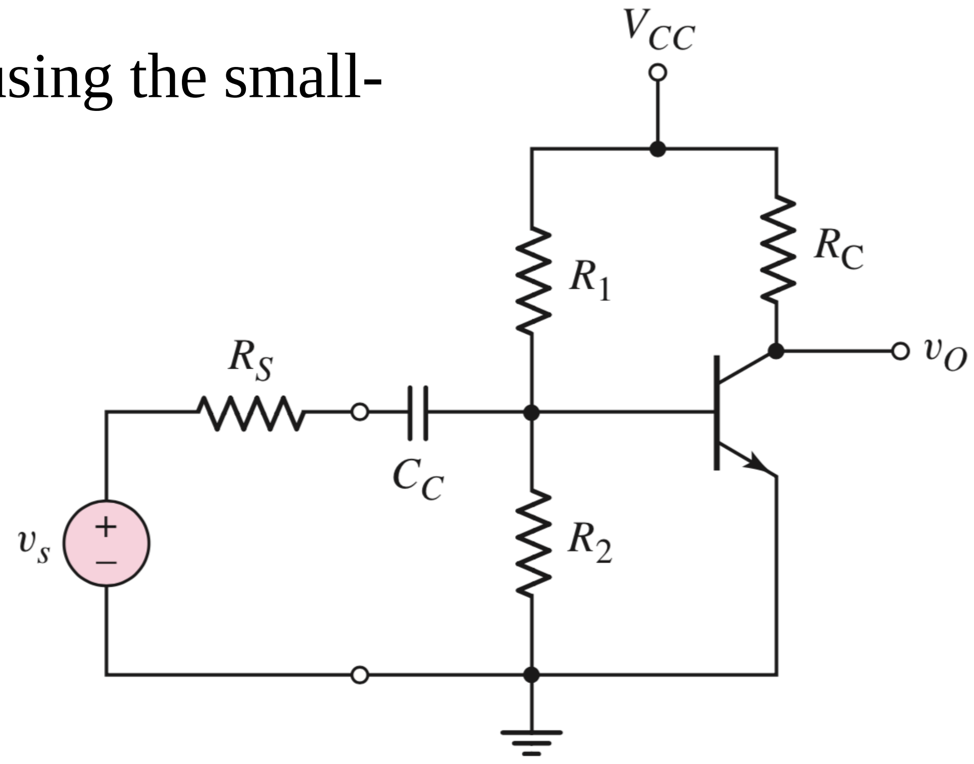
$$= -(38.5)(6\|50)\left(\frac{2.6}{2.6+50}\right)$$

$$= -10.2$$

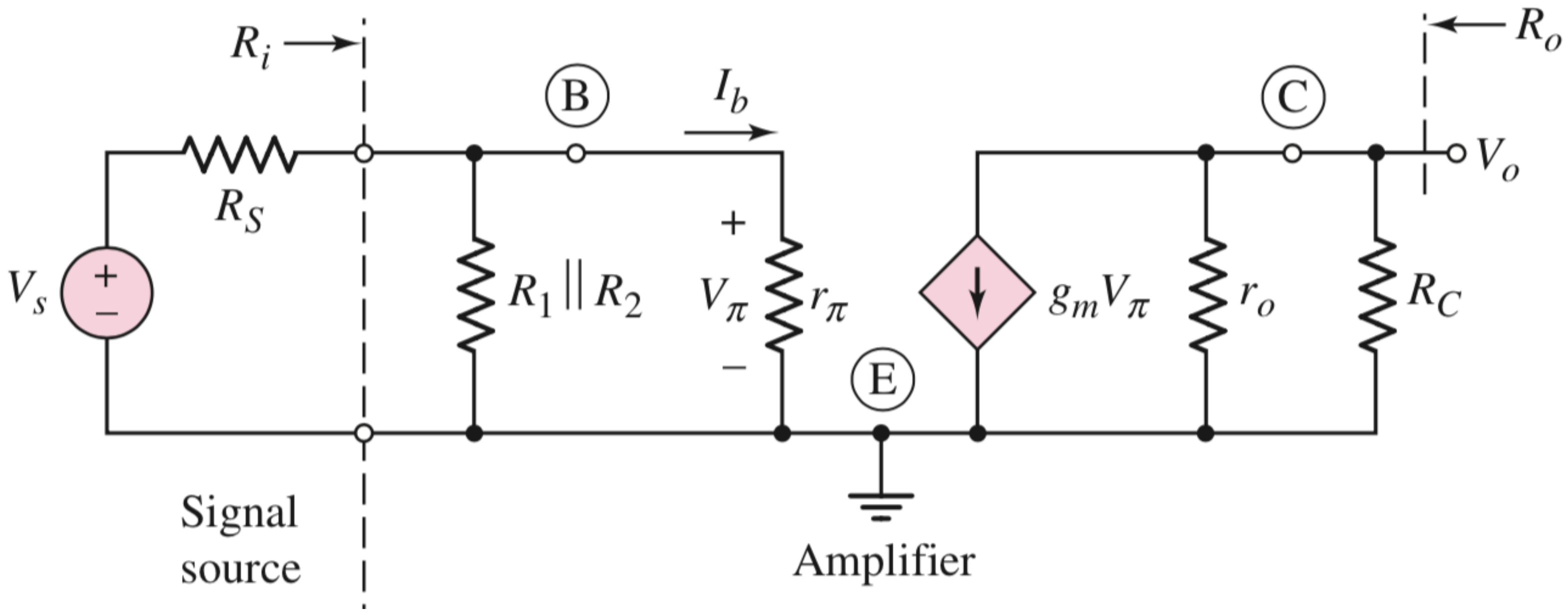
r_o reduces the magnitude of the small-signal voltage gain

Basic Common-Emitter Amplifier Circuit

- Basic common-emitter circuit with voltage-divider biasing:
  - Do the dc analysis (to find the Q-point).
  - Do the ac analysis using the small-signal model.



Basic Common-Emitter Amplifier Circuit



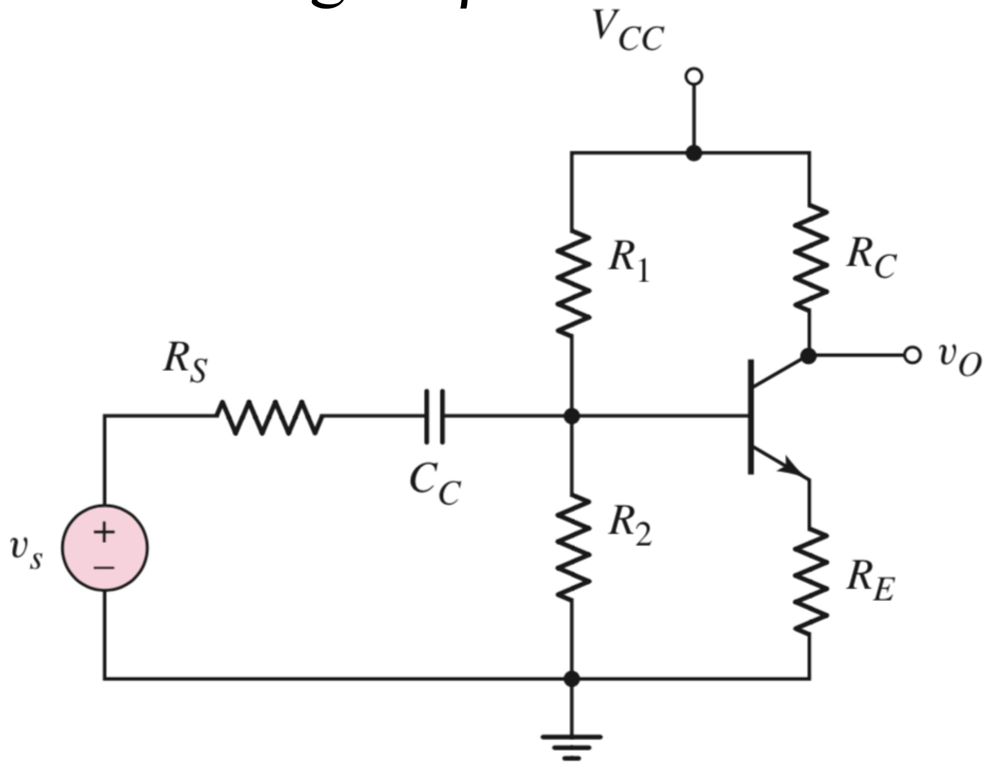
Output voltage: $$V_o = -g_m V_\pi \, (r_o \| R_C)$$

Control voltage: $$V_\pi = \frac{R_1 \| R_2 \| r_\pi}{R_1 \| R_2 \| r_\pi + R_S} \cdot V_s$$

Voltage gain: $$A_v = \frac{V_o}{V_s} = -g_m (r_o \| R_C) \left(\frac{R_1 \| R_2 \| r_\pi}{R_1 \| R_2 \| r_\pi + R_S} \right)$$

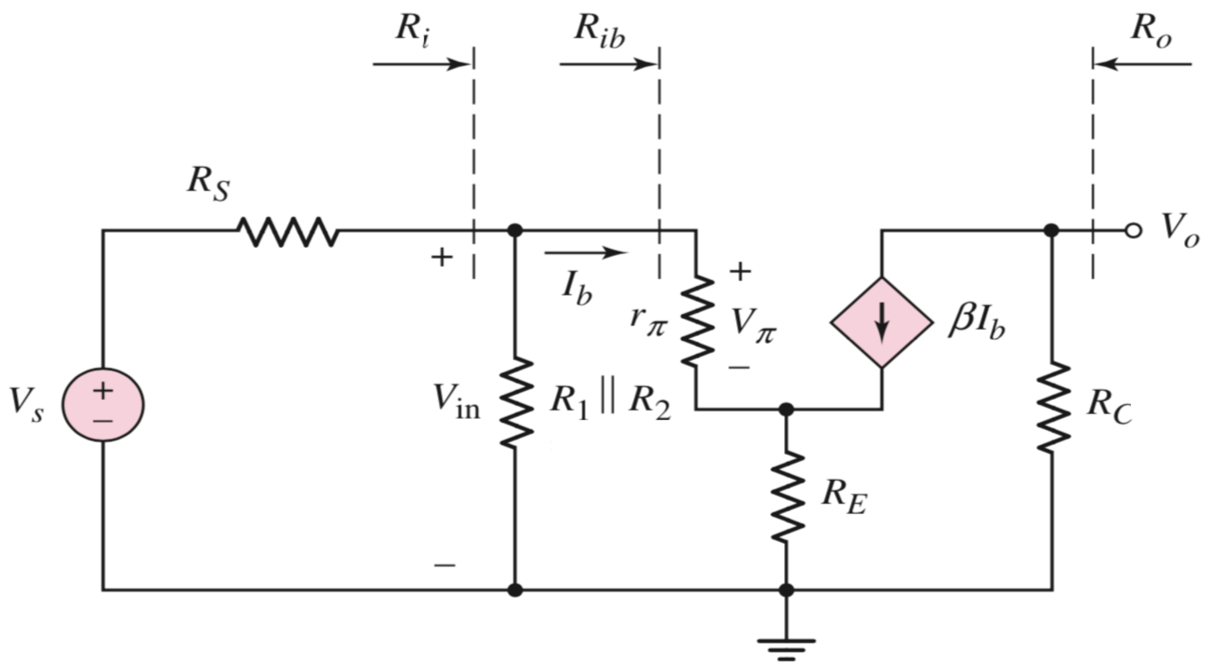
Basic Common-Emitter Amplifier Circuit

- Using the Emitter resistor (R_E) so that the voltage gain of the amplifier circuit will be less dependent on the transistor current gain β.



Basic Common-Emitter Amplifier Circuit

- The small-signal equivalent circuit:



Output voltage: $V_o = -(\beta I_b)R_C$

Input resistance: $R_{ib} = \dfrac{V_{in}}{I_b} = r_\pi + (1+\beta)R_E$

Basic Common-Emitter Amplifier Circuit

- Input resistance to the amplifier: $R_i = R_1 \| R_2 \| R_{ib}$
- Input voltage: $V_{\text{in}} = \left(\dfrac{R_i}{R_i + R_S}\right) \cdot V_s$

- The small-signal voltage gain is:

$$A_v = \frac{V_o}{V_s} = \frac{-(\beta I_b) R_C}{V_s} = -\beta R_C \left(\frac{V_{\text{in}}}{R_{ib}}\right) \cdot \left(\frac{1}{V_s}\right)$$

or:

$$A_v = \frac{-\beta R_C}{r_\pi + (1+\beta) R_E} \left(\frac{R_i}{R_i + R_S}\right)$$

Basic Common-Emitter Amplifier Circuit

- Voltage gain is:

$$A_v = \frac{-\beta R_C}{r_\pi + (1+\beta)R_E}\left(\frac{R_i}{R_i + R_S}\right)$$

- If:

$$\begin{cases} R_i \gg R_S \\ (1+\beta)R_E \gg r_\pi \end{cases}$$

- Voltage gain is approximately:

$$A_v \cong \frac{-\beta R_C}{(1+\beta)R_E} \cong \frac{-R_C}{R_E}$$

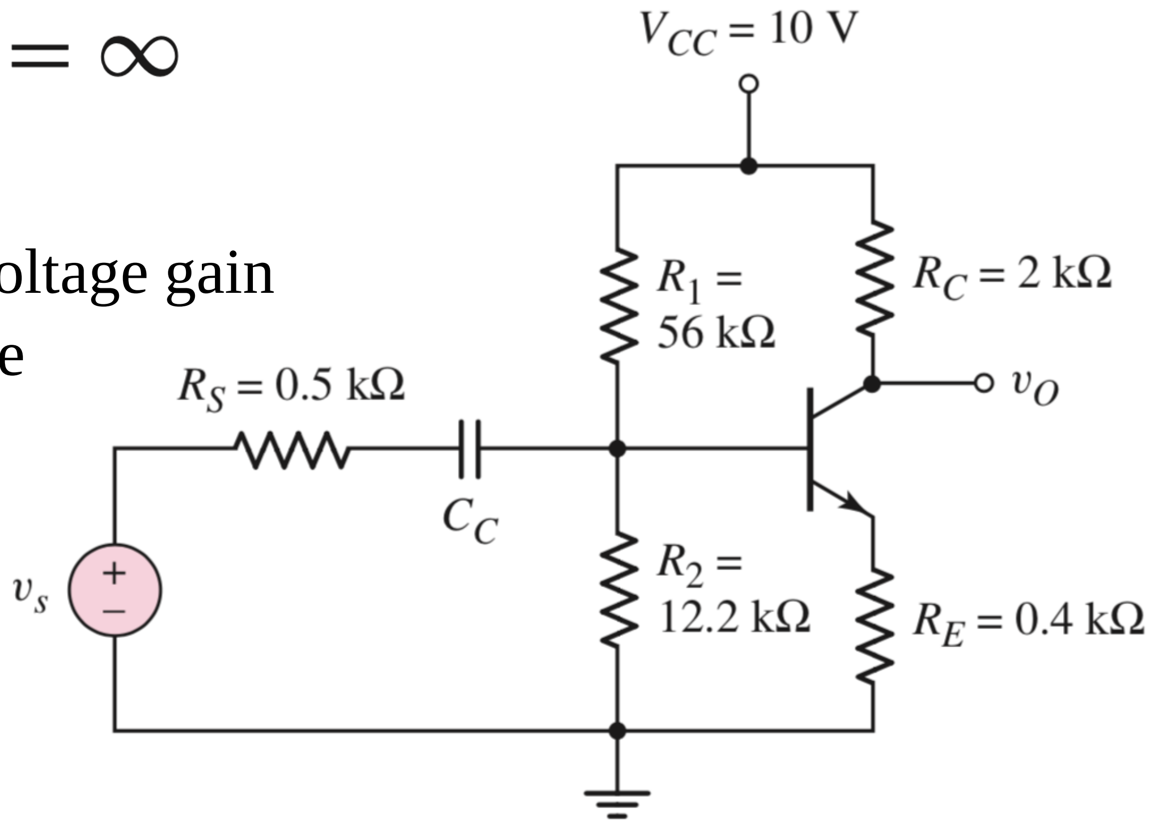
Example 2.15

- For the circuit in the figure:

$$V_{BE}(\text{on}) = 0.7 \text{ V}$$

$$\beta = 100 \quad V_A = \infty$$

- Determine:
  - Small-signal voltage gain
  - Input resistance



Example 2.15: DC Analysis

- DC solution:

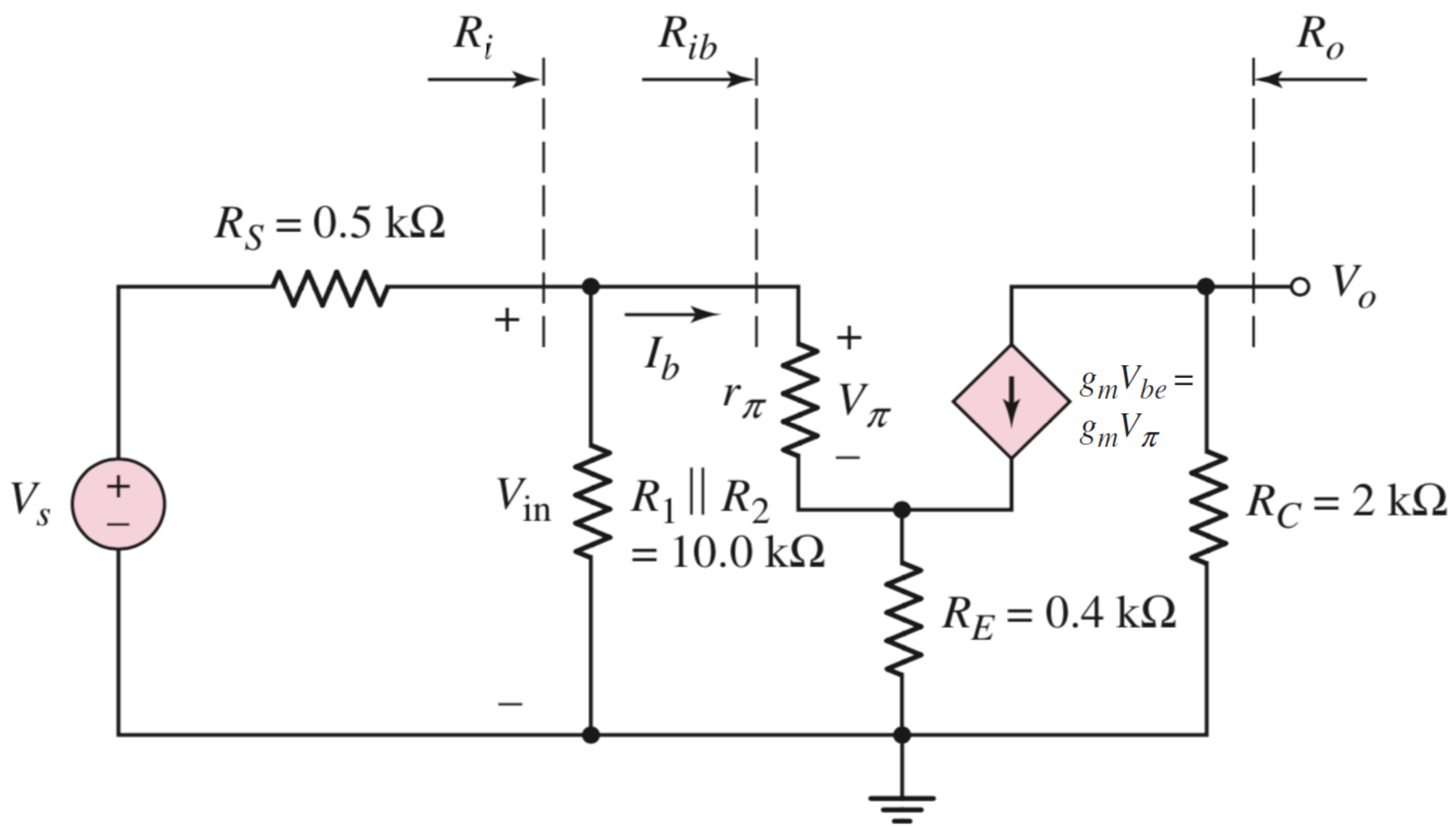
$$V_{CEQ} = 4.81 \text{ V}$$

$$I_{CQ} = 2.16 \text{ mA}$$

⇨ The transistor is biased in the forward-active mode

Example 2.15: AC Analysis

- The small-signal equivalent circuit:



Example 2.15: AC Analysis

- The small-signal hybrid-π parameters:

$$r_\pi = \frac{V_T\beta}{I_{CQ}} = \frac{(0.026)(100)}{(2.16)} = 1.20\,\text{k}\Omega$$

$$g_m = \frac{I_{CQ}}{V_T} = \frac{2.16}{0.026} = 83.1\,\text{mA/V}$$

- The input resistance to the base:

$$R_{ib} = r_\pi + (1+\beta)R_E = 1.20 + (101)(0.4) = 41.6\,\text{k}\Omega$$

- The input resistance to the amplifier :

$$R_i = R_1 \| R_2 \| R_{ib} = 10\|41.6 = 8.06\,\text{k}\Omega$$

Example 2.15: AC Analysis

- Voltage gain:

$$A_v = \frac{-(100)(2)}{1.20 + (101)(0.4)} \left(\frac{8.06}{8.06 + 0.5} \right)$$

$$= -4.53$$

- Approximate voltage gain:

$$A_v \cong \frac{-\beta R_C}{(1+\beta)R_E} \cong \frac{-R_C}{R_E}$$

- Obtain:

$$A_v = \frac{-R_C}{R_E} = \frac{-2}{0.4} = -5.0$$

Example 2.15: Comment

- The magnitude of the voltage gain is substantially reduced when an emitter resistor (R_E) is included.
  - Because of the $(1 + \beta)R_E$ term in the denominator
- $-R_C/R_E$ can be used in the initial design of a common-emitter circuit with an emitter resistor.
- The amplifier gain is nearly independent of changes in the current gain parameter β.

β	A_v
50	–4.41
100	–4.53
150	–4.57