Lecture 4 BJT Small Signal Analysis

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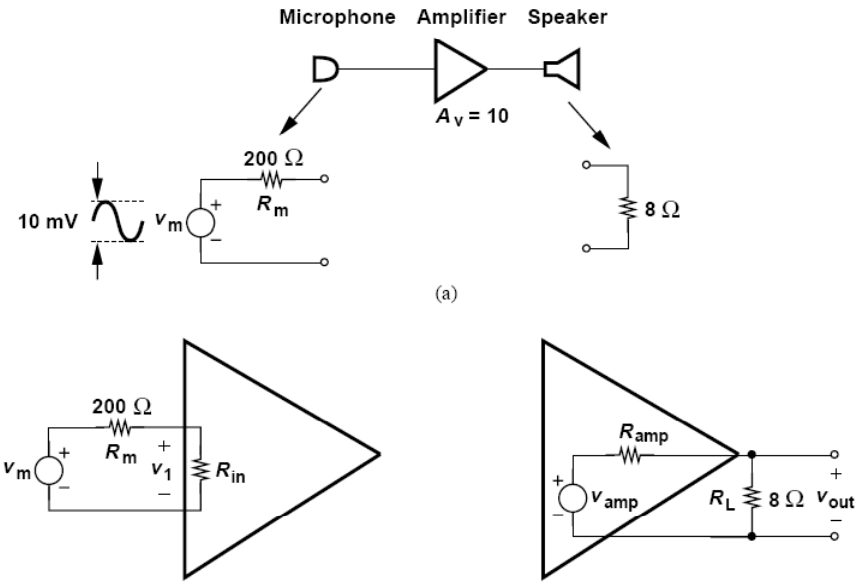
BJT Small Signal Analysis

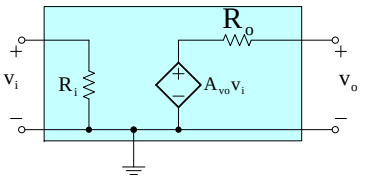
- Outline
  - BJT as Amplifier
  - Small Signal Model
    - The π-Model
    - The T-Model
  - Small Signal Analysis
  - Common Emitter (CE) Amplifier
  - Common Base (CB) Amplifier
  - Common Collector or Emitter Follower
  - BJT Digital Logic

Introduction



Amplifier types

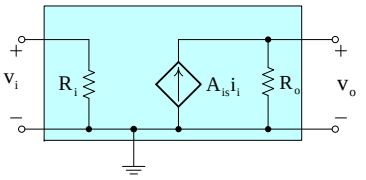
- Voltage Amplifiers



  - High input resistance
  - Low output resistance

$$A_v = \frac{v_o}{v_i}$$

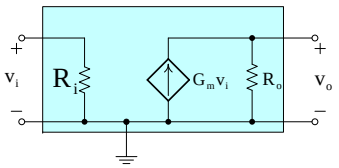
- Current Amplifiers



  - Low input resistance
  - High output resistance

$$A_i = \frac{i_o}{i_i}$$

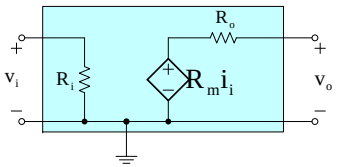
- Transconductance Amplifiers



  - High input resistance
  - High output resistance

$$A_G = \frac{i_o}{v_i}$$

- Transresistance Amplifiers

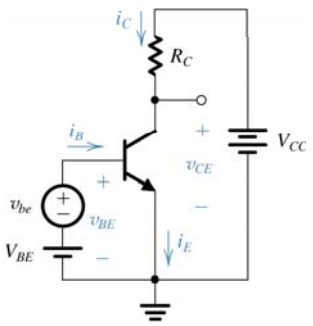


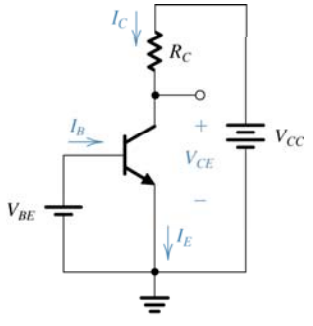
  - Low input resistance
  - Low output resistance

$$A_R = \frac{v_o}{i_i}$$

Introduction

- ใช้วิธีการ superposition วิเคราะห์วงจรขยาย
- วิเคราะห์การไบอัสแรงดันกระแสตรง

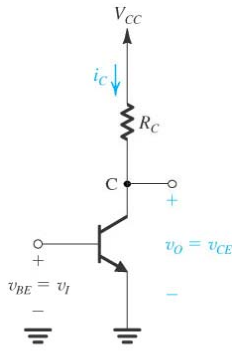


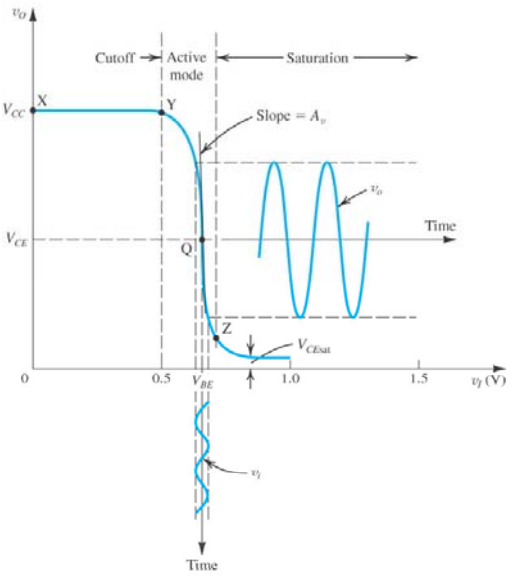


Transistor as an amplifier. (b) The circuit of (a) with the signal source v_{be} eliminated for dc (bias) analysis.

Transfer characteristic of amplifier circuit

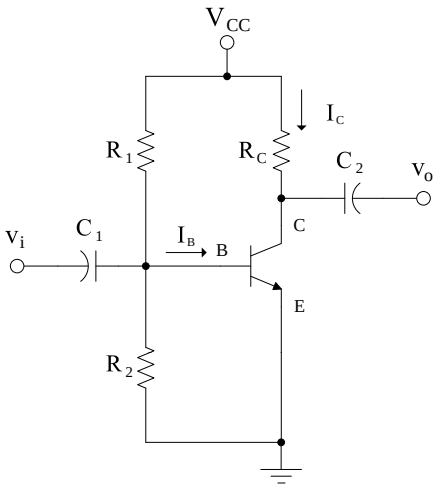
- การไบอัสแรงดันกระแสตรงหมายถึงออกแบบแรงดันกระแสตรงที่เหมาะสมให้กับวงจรขยายเพื่อขยายสัญญาณโดยไม่ผิดเพี้ยน





ภาพที่ 4.26 **(a)** Basic common-emitter amplifier circuit. **(b)** Transfer characteristic of the circuit in (a).

Equivalence amplifier circuit



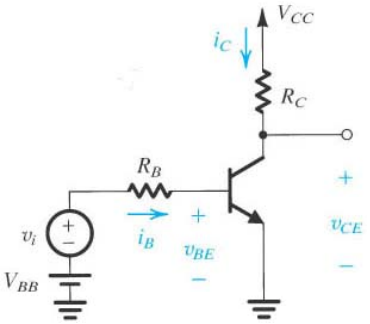
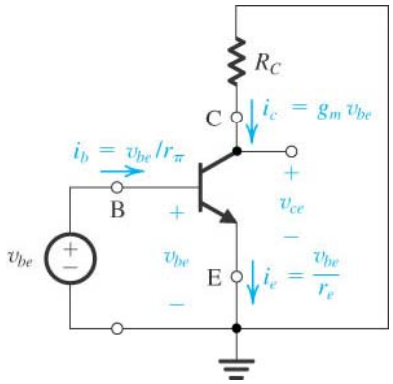


Figure 5.27 Circuit whose operation is to be analyzed graphically.

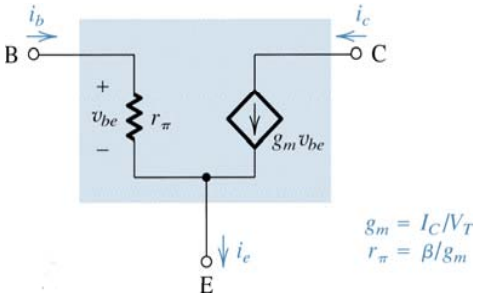
Small Signal Model of the BJT

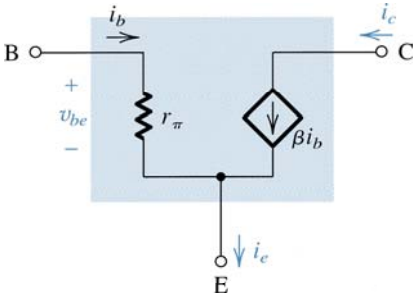


ภาพที่ 4.50

The amplifier circuit of Fig. 5.48(a) with the dc sources (*VBE* and *VCC*) 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.

The Hybrid- π Model $r_o = \infty$

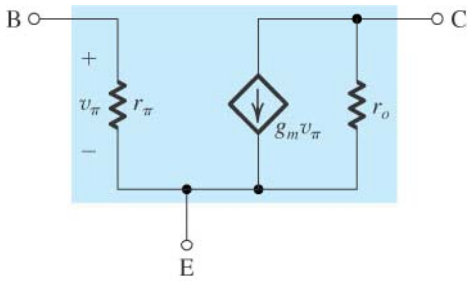


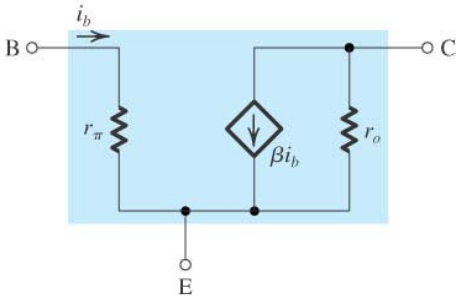


BJT as a voltage-controlled current source (a transconductance amplifier)

BJT as a current-controlled current source (a current amplifier).

The Hybrid- π Model $r_o \neq \infty$





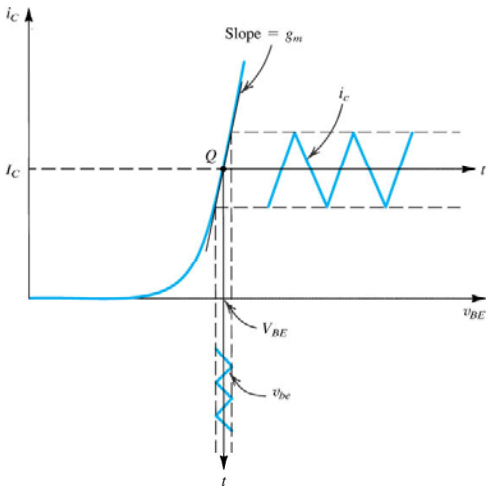
BJT as a voltage-controlled current source (a transconductance amplifier)

BJT as a current-controlled current source (a current amplifier).

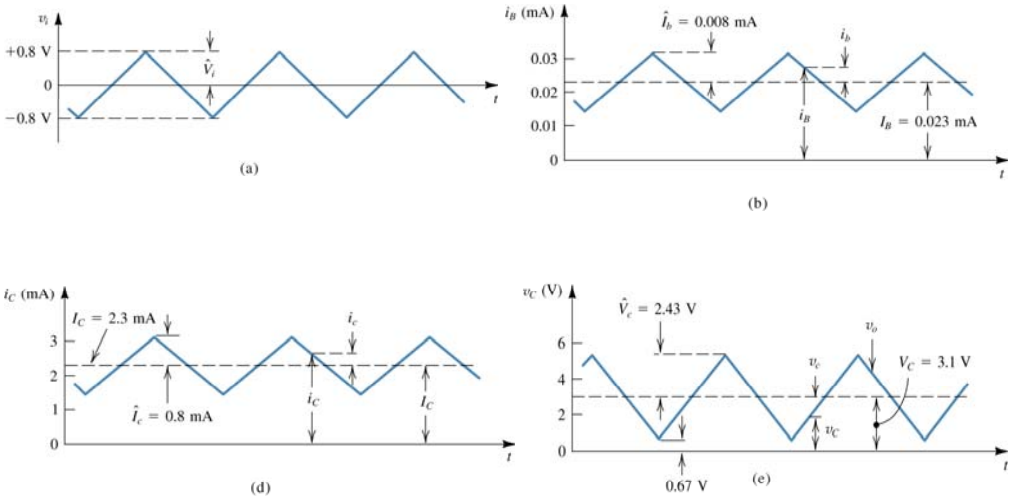
Small Signal Analysis

Linear operation of the transistor: small-signal

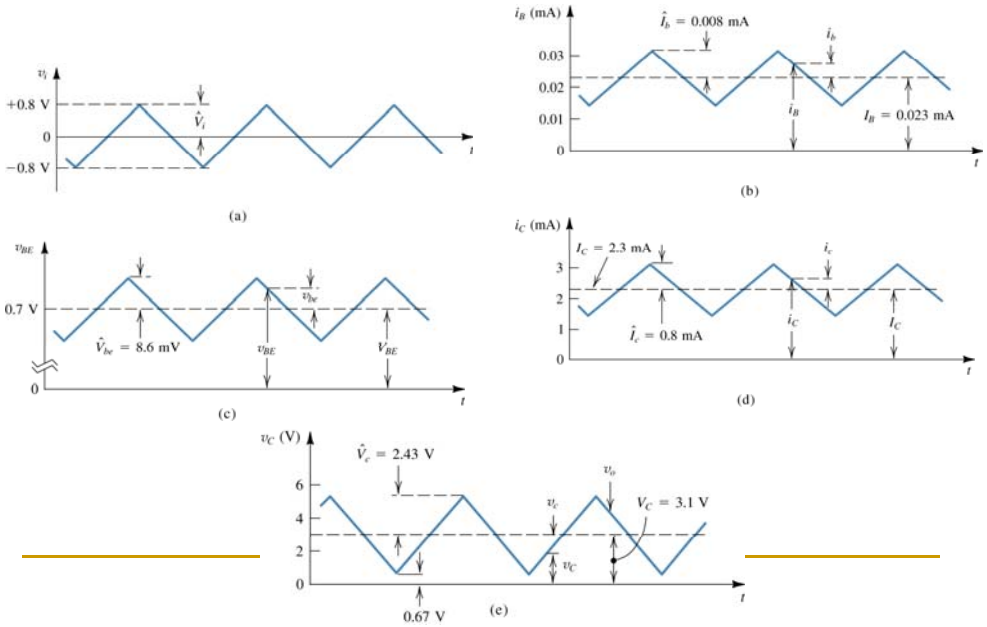
- v_{be} triangular waveform is superimposed on dc voltage V_{BE}.
- Collector signal current i_c, also of triangular waveform, superimposed on the dc current I_C.
- $I_c = g_m v_{be}$, where g_m is the slope of the i_c - v_{BE} curve at the bias point Q.



Small Signal Analysis



Signal Waveforms

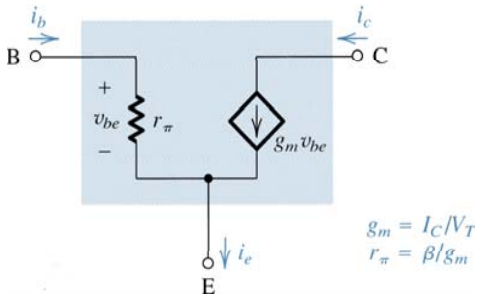


Small Signal Analysis

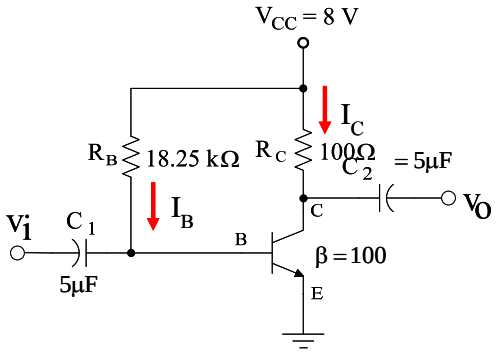
$$r_e = \frac{V_T}{I_E} = \frac{25mV}{(2.3/0.99)mA} = 10.8\Omega$$

$$g_m = \frac{I_C}{V_T} = \frac{2.3mA}{25\,mV} = 92\,mA/V$$

$$r_\pi = \frac{\beta}{g_m} = \frac{100}{92} = 1.09\,k\Omega$$



Ex 4.1 ให้เขียนวงจรเทียบเคียงของทรานซิสเตอร์และหาค่า g_m , r_o และ r_π ของวงจรในรูปที่ 4. $V_A = 100$



Single Stage BJT Amplifiers

- Common Emitter (CE) Amplifier
- Common Base (CB) Amplifier
- Common Collector or Emitter Follower

Measurement of input and output impedances.

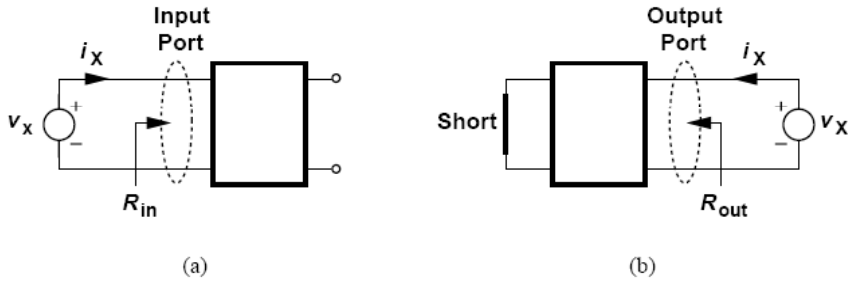


Figure Measurement of (a) input and (b) output impedances.

BJT small signal characteristic

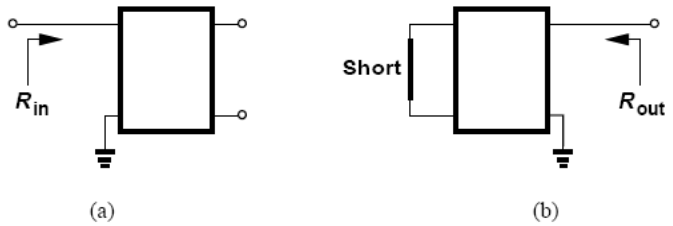
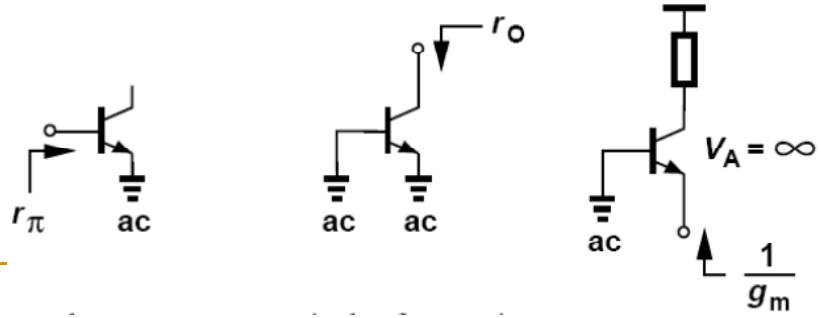
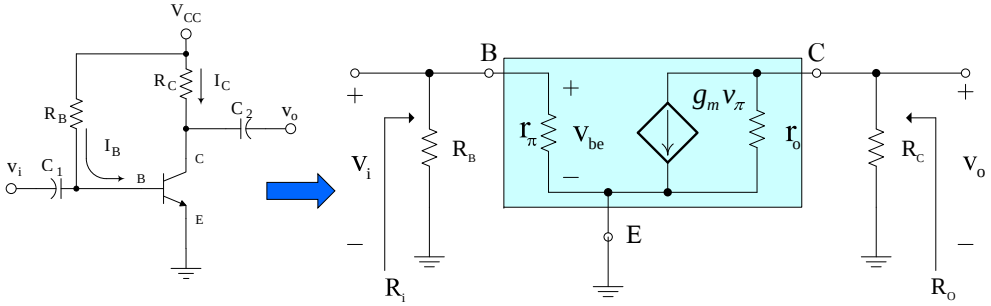


Figure Concept of impedance seen at a node.



Common Emitter (CE) Amplifier



Find A_v

$$A_v = \frac{V_{in}}{V_{out}} = -G_m R_{out}$$

$$G_m = \frac{I_{short}}{V_{in}}$$

$$v_i = v_\pi \quad (1)$$

$$v_o = -g_m v_\pi (r_o \,//\, R_C) \quad (2)$$

CE

$$A_v = \frac{v_o}{v_i} = -g_m(r_o \,//\, R_C) \quad (3)$$

Assume $r_o \cong \infty$

$$A_v \equiv \frac{v_o}{v_i} = -g_m R_C \quad (5)$$

$$R_o = R_C \,//\, r_o \quad (6)$$

thus

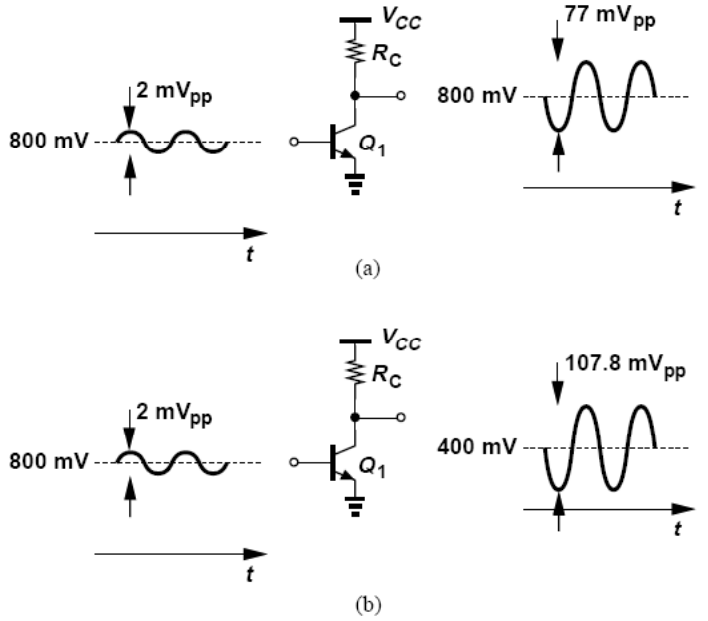
$$R_o \cong R_C \quad (7)$$

Thus R_i

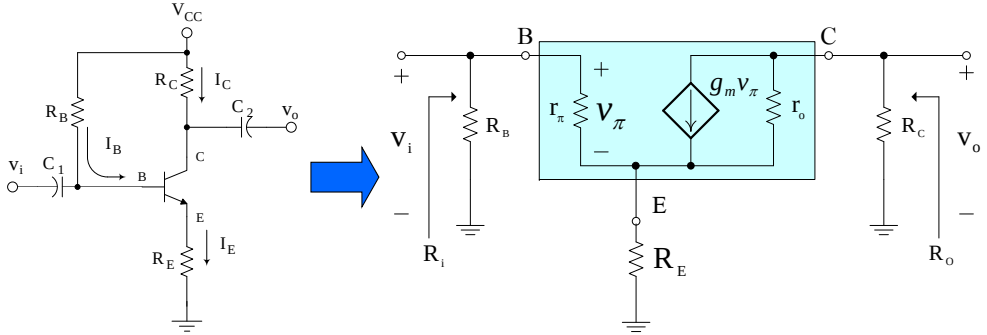
$$R_i = R_B \,//\, r_\pi$$

$$R_i \cong r_\pi \quad (8)$$

แรงดันเอาต์พุตของวงจรขยายแบบอิมิเตอร์ร่วมกลับเฟสกับแรงดันอินพุต 180 องศา



Common Emitter (CE) Amplifier with R_E

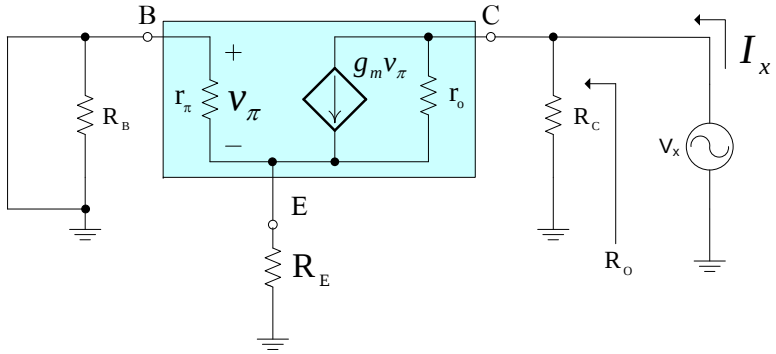


$$A_v = \frac{V_{in}}{V_{out}} = -G_m R_{out} \quad (1)$$

$$G_m = \frac{I_{short}}{V_{in}} \quad (2)$$

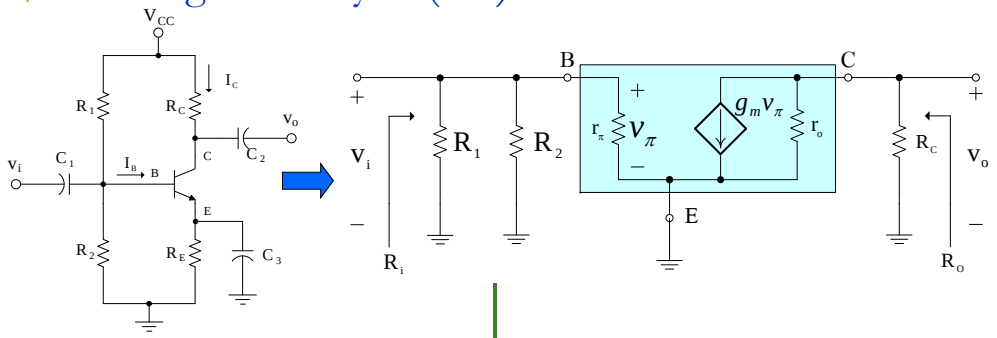
$$A_v = \frac{v_o}{v_i} = -\frac{g_m v_{be} R_C}{I_b\left(r_\pi + (\beta+1)R_E\right)} \quad (3)$$

- Find R_o
- Short v_i and open $g_m v_{be}$



$$R_o \cong R_C$$

Small Signal Analysis (CE)



Find A_v

$$v_i = v_\pi \quad (1)$$

$$v_o = -g_m v_\pi (r_o \,//\, R_C) \quad (2)$$

thus

$$A_v = \frac{v_o}{v_i} = -g_m (r_o \,//\, R_C) \quad (3)$$

Small Signal Analysis (CE)

$$R_o = R_C \,//\, r_o \quad (4)$$

Assume $r_o \cong \infty$

$$R_o \cong R_C \quad (5)$$

thus

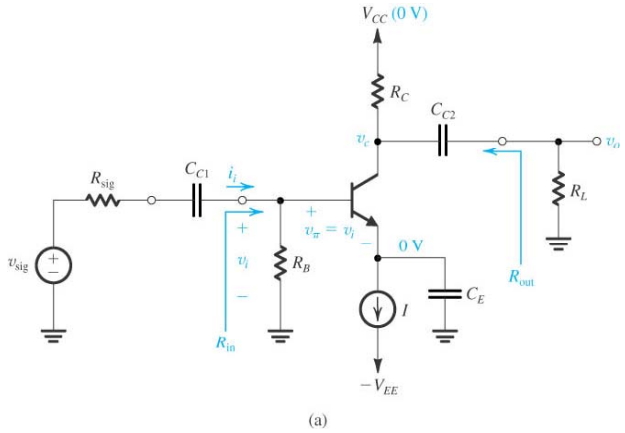
$$A_v \equiv \frac{v_o}{v_i} = -g_m R_C \quad (6)$$

Thus R_i

$$R_i = R_1 \,//\, R_2 \,//\, r_\pi \quad (7)$$

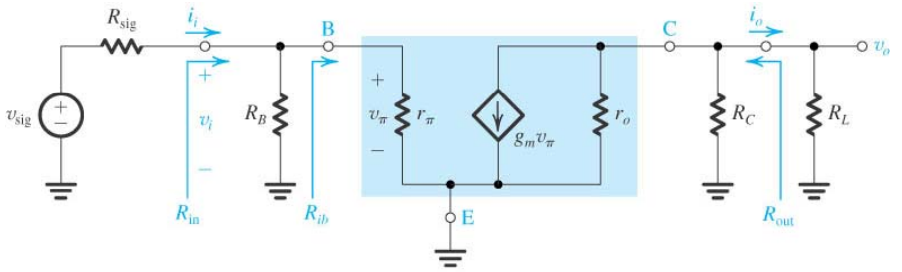
Common Emitter (CE) Amplifier

C_E grounds emitter, also called "bypass" capacitor



Small Signal Analysis

- Replace BJT with hybrid π equivalent.



$$A_v = G_m R_{out}$$

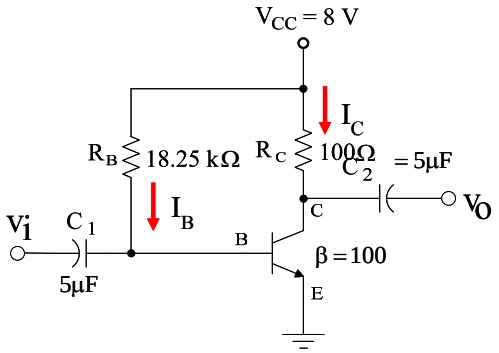
$$G_m = -g_m$$

$$R_{out} = r_o \,//\, R_C$$

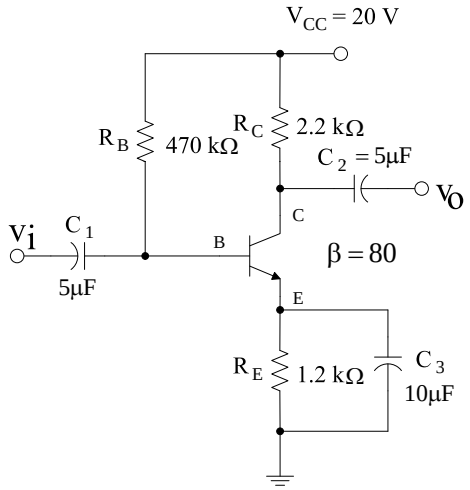
$$A_v = \frac{v_o}{v_i} = -g_m (r_o \,//\, R_C)$$

$$R_{in} = \frac{v_i}{i_i} = r_\pi \,//\, R_B$$

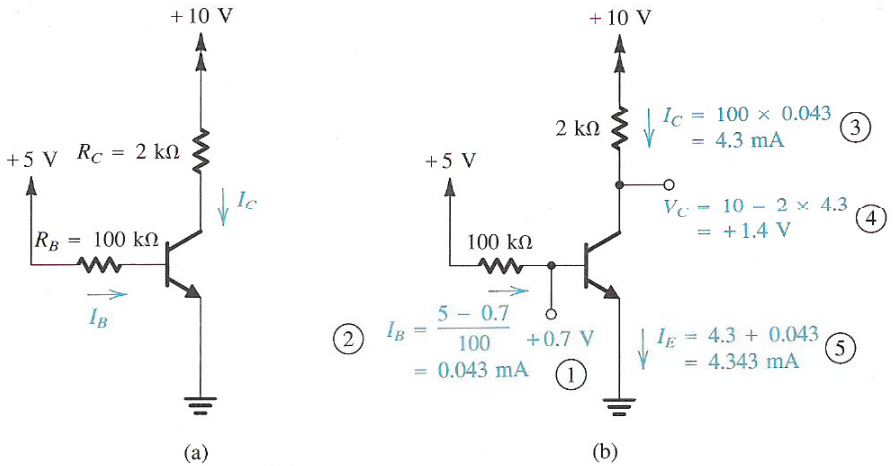
Ex4.3 Find A_v, R_i and R_o on amplifier circuit $V_A = 100$



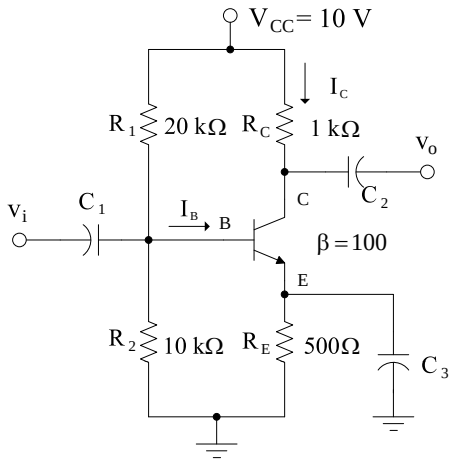
Ex4.4 Find A_v, R_i and R_o on amplifier circuit $V_A = 100$



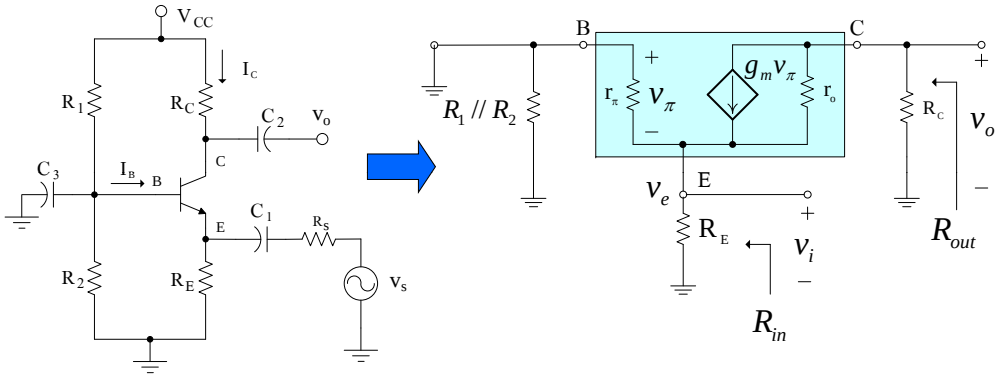
Ex4.5 Find A_v, R_i and R_o on amplifier circuit at $V_{BE} = 0.7$ and $\beta = 100$ $V_A = 100$



Ex4.6 Find A_v, R_i and R_o on amplifier circuit $V_A = 100$



Common Base (CB) Amplifier



Small Signal Analysis (CB)

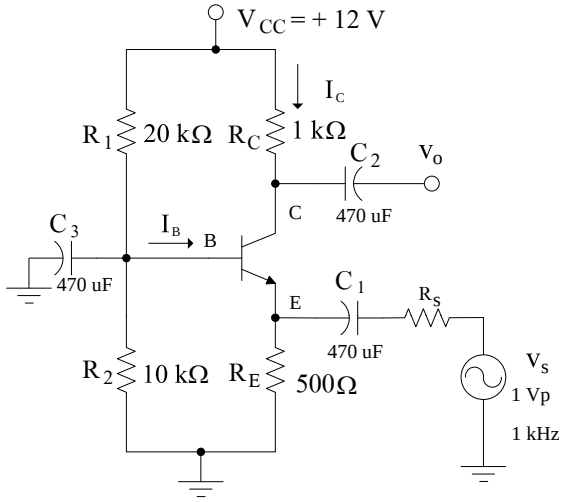
Thus R_i and R_o

$$R_{in} = \frac{1}{g_m} // R_E \qquad (7)$$

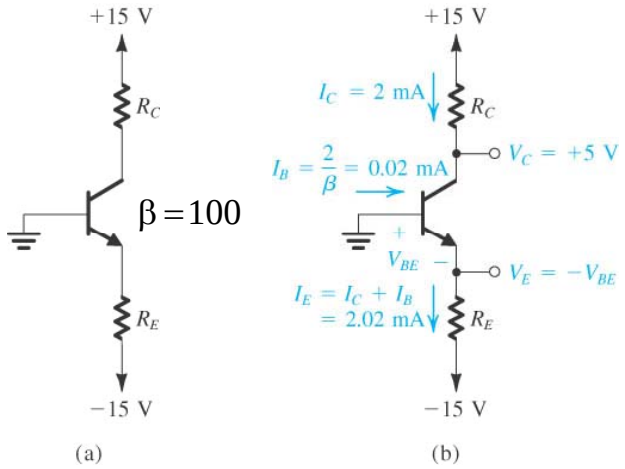
$$R_{out} = R_C \qquad (8)$$

แรงดันเอาต์พุตของวงจรขยายแบบเบสร่วมมีเฟสเดียวกับแรงดันอินพุต

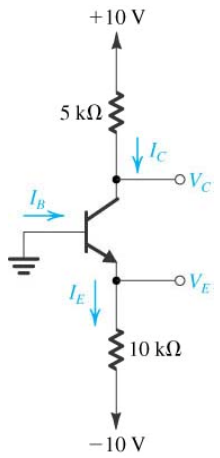
Ex4.7 Amplifier circuit at $I_C = 2$ mA and $V_C = +5$ V $V_A = 100$ Find R_C , R_E , A_v, R_i and R_o



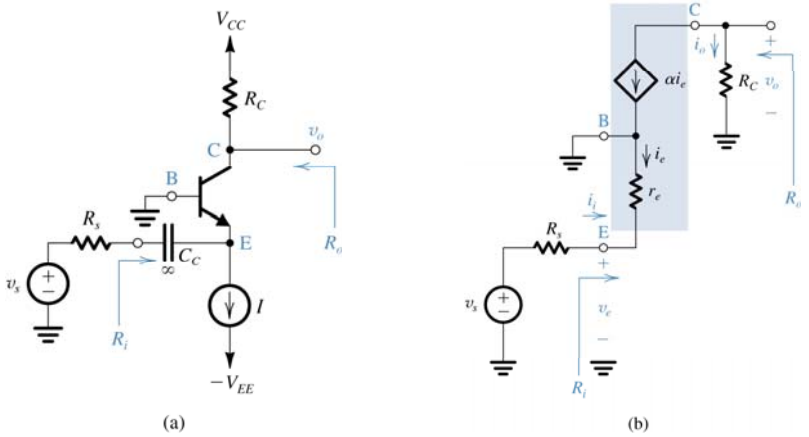
Ex4.8 Amplifier circuit at $I_C = 2$ mA and $V_C = +5$ V $V_A = 100$ Find R_C , R_E , A_v, R_i and R_o



Ex4.9 Find A_v, R_i and R_o on amplifier circuit at V_E = -0.7 and β=50 V_A = 100

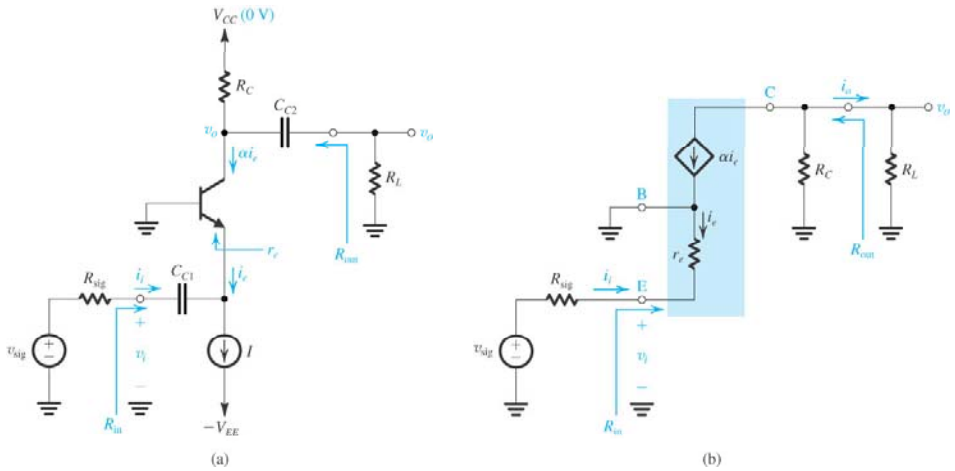


Common Base (CB) Amplifier

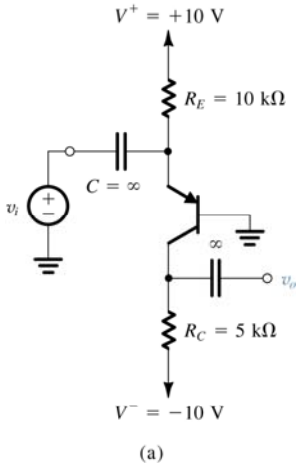


The common-base amplifier. **(a)** Circuit. **(b)** Equivalent circuit obtained by replacing the BJT with its T model.

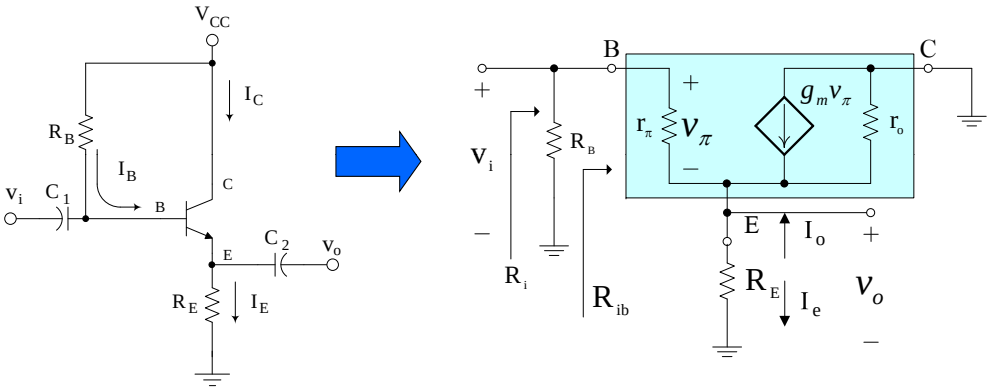
Small Signal Analysis (CB)



Ex 4.10 จากวงจรขยายเบสร่วมโดยใช้ทรานซิสเตอร์ชนิด PNP มี β = 50 ให้หาอัตราขยายของวงจร V_A = 100

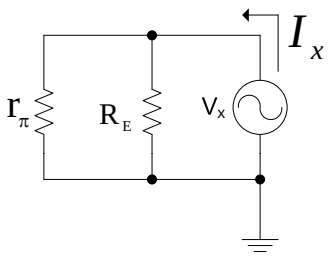


Common Collector Amplifier or Voltage Follower



$$A_v \cong 1$$

Find R_o with short v_i



Thus R_o

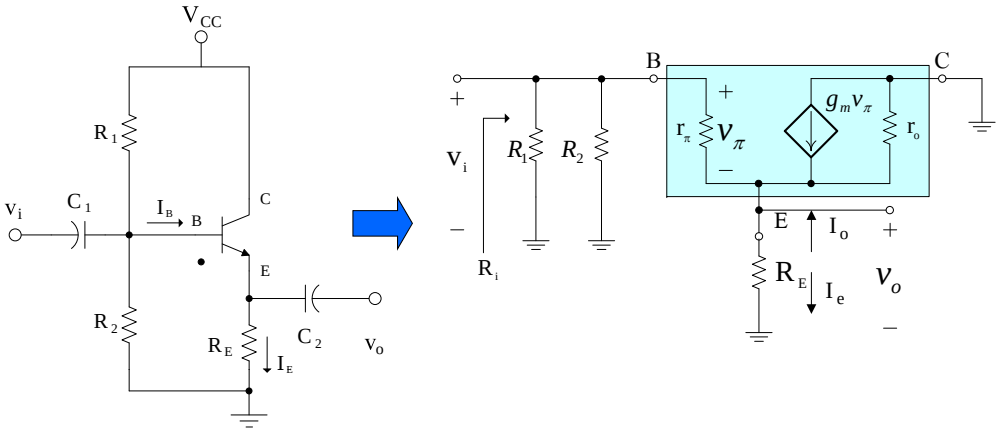
$$R_o = R_E \,//\, r_\pi$$

Thus R_i

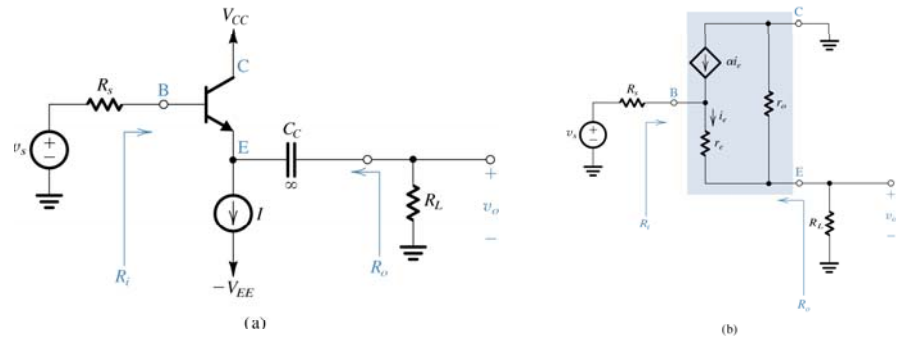
$$R_i = R_{ib} \,//\, R_B$$

วงจร Emitter-Follower ถูกนำไปใช้เป็นวงจรภาคเอาต์พุตของวงจรขยายที่ต้องการขับโหลดที่มีค่าความต้านทานต่ำมาก

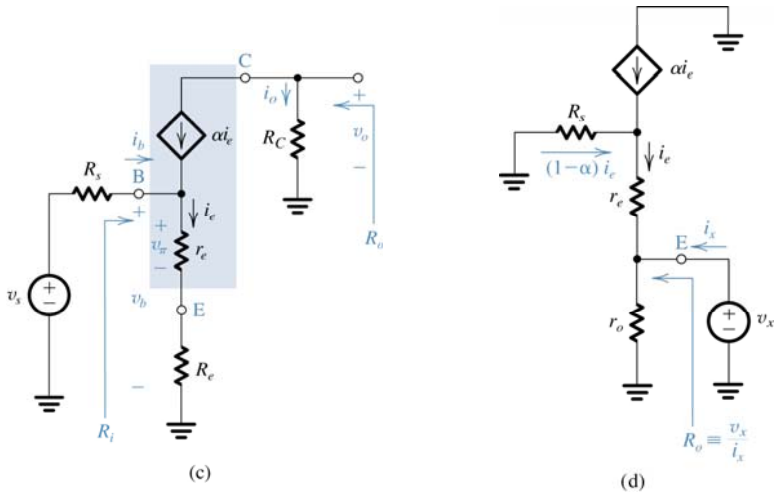
Common Collector Amplifier or Voltage Follower



Emitter-Follower



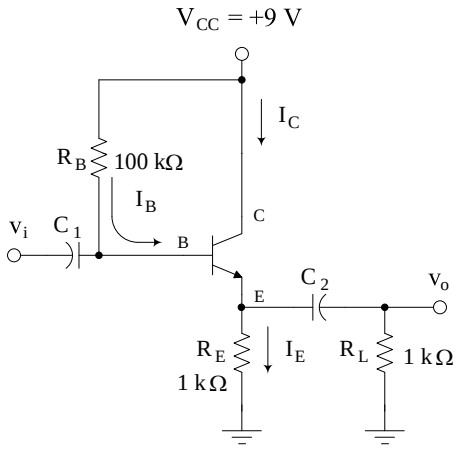
The common-collector or emitter-follower amplifier. **(a)** Circuit. **(b)** Equivalent circuit obtained by replacing the BJT with its T model.



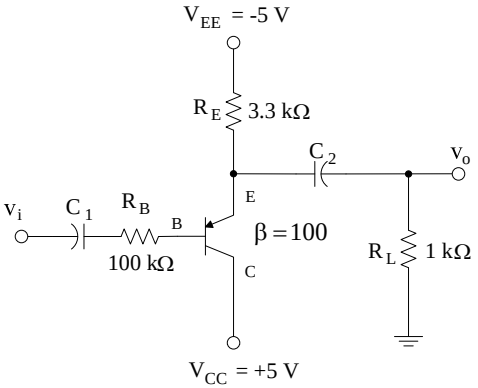
(c) The circuit redrawn to show that r_o is in parallel with R_L.

(d) Circuit for determining R_o.

Ex4.11 Find A_v, R_i and R_o on amplifier circuit $V_A = 100$



Ex4.12 Find A_v, R_i and R_o on amplifier circuit $V_A = 100$



Ex4.13 Find A_v, R_i and R_o on amplifier circuit $V_A = 100$

Example 5.49

Assuming $V_A = \infty$, compute the voltage gain of the circuit shown in Fig. 5.98(a).

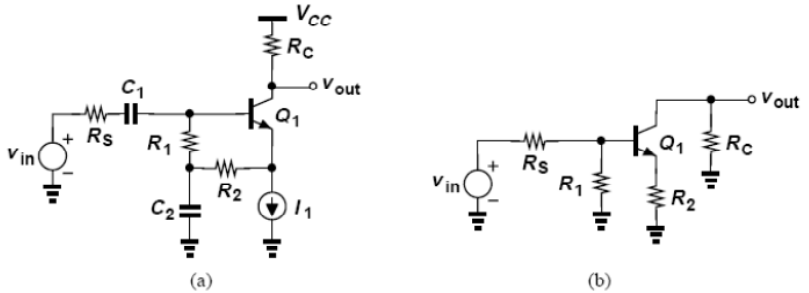


Figure 5.98 (a) Example of CE stage, (b) simplified circuit.

Ex4.14 Find A_v, R_i and R_o on amplifier circuit $V_A = 100$

Example 5.53

Compute the voltage gain and the output impedance of the circuit depicted in Fig. 5.102(a) with $V_A < \infty$.

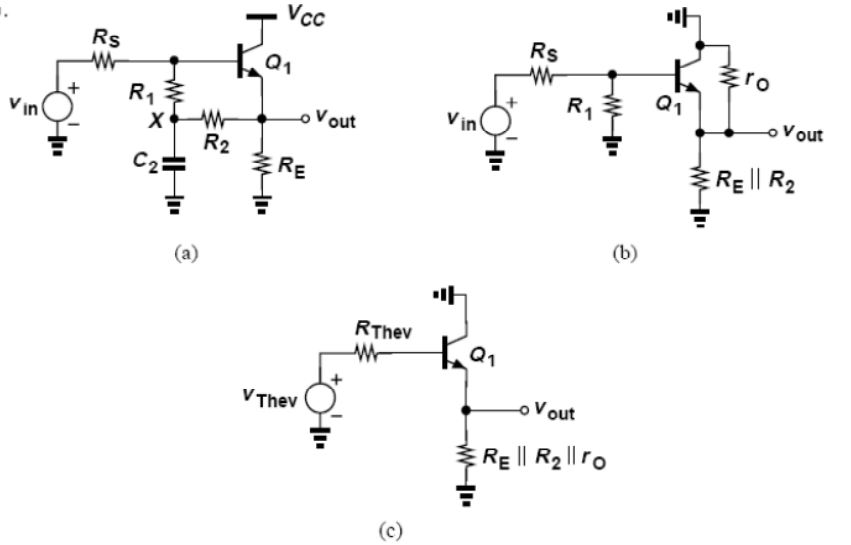


Figure 5.102 (a) Example of emitter follower, (b) circuit with C_1 shorted, (c) simplified circuit.

Ex4.15 Find A_v, R_i and R_o on amplifier circuit

Example 5.54

Determine the voltage gain and I/O impedances of the topology shown in Fig. 5.103(a). Assume $V_A = \infty$ and equal β's for *npn* and *pnp* transistors.

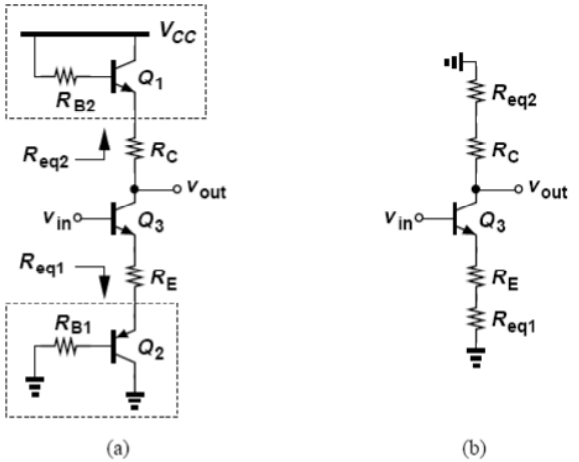


Figure 5.103 (a) Example of CE stage, (b) simplified circuit.

เอกสารอ้างอิง (Reference)

1. Adel S. Sedra, Kenneth C. Smith "Microelectronic Circuit"
2. Pual R. Gray and Robert G. Mayer "Analysis and Design of Integrated Circuit"
3. Behzad Razavi "Fundamentals of Microelectronics"
4. รศ.สักรียา ชิตวงศ์ "วิศวกรรมอิเล็กทรอนิกส์"

Thank you