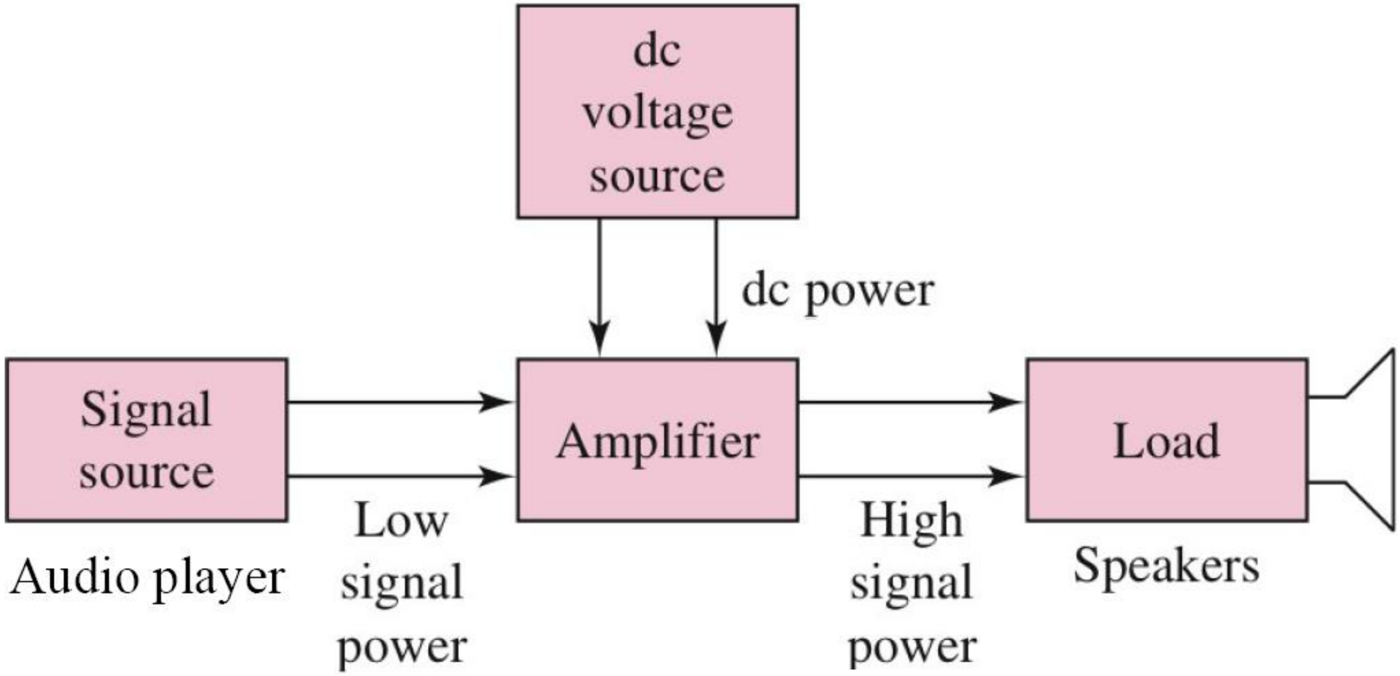
Basic Electronic Circuits
(IEC-103)

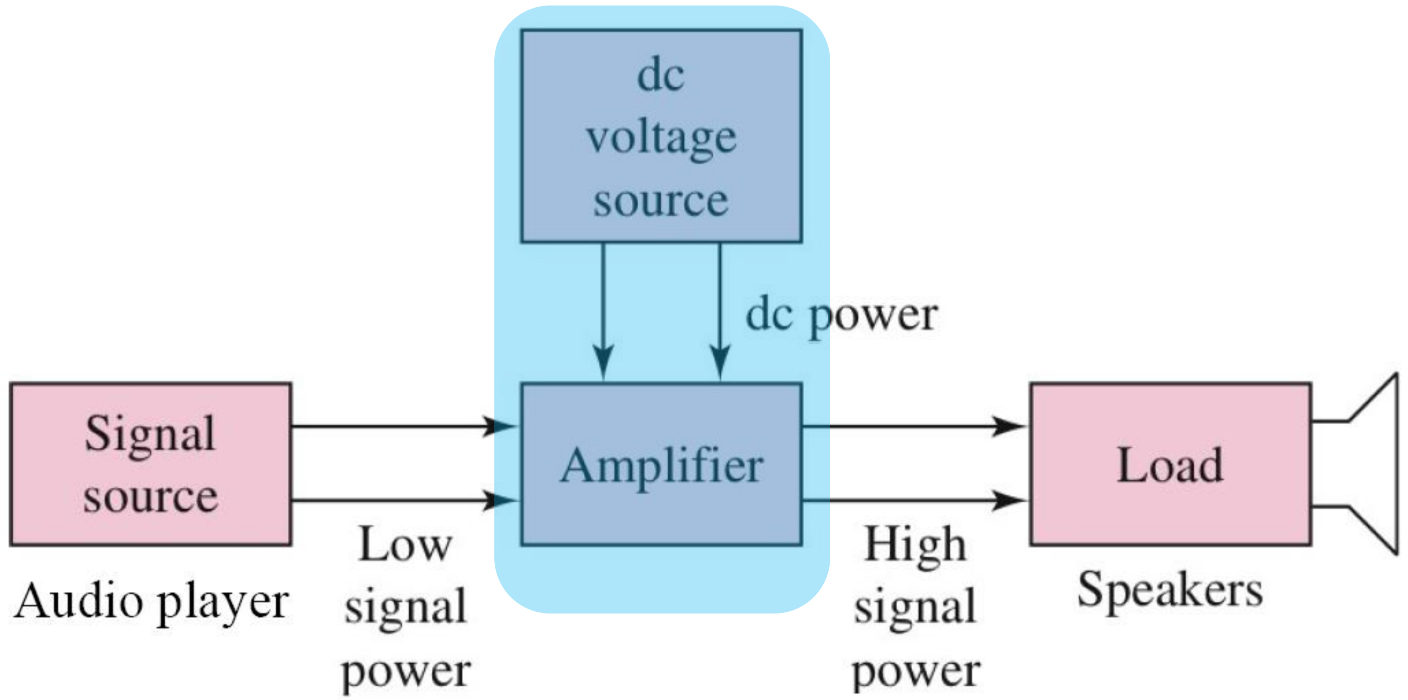
Lecture-18

Small Signal Analysis

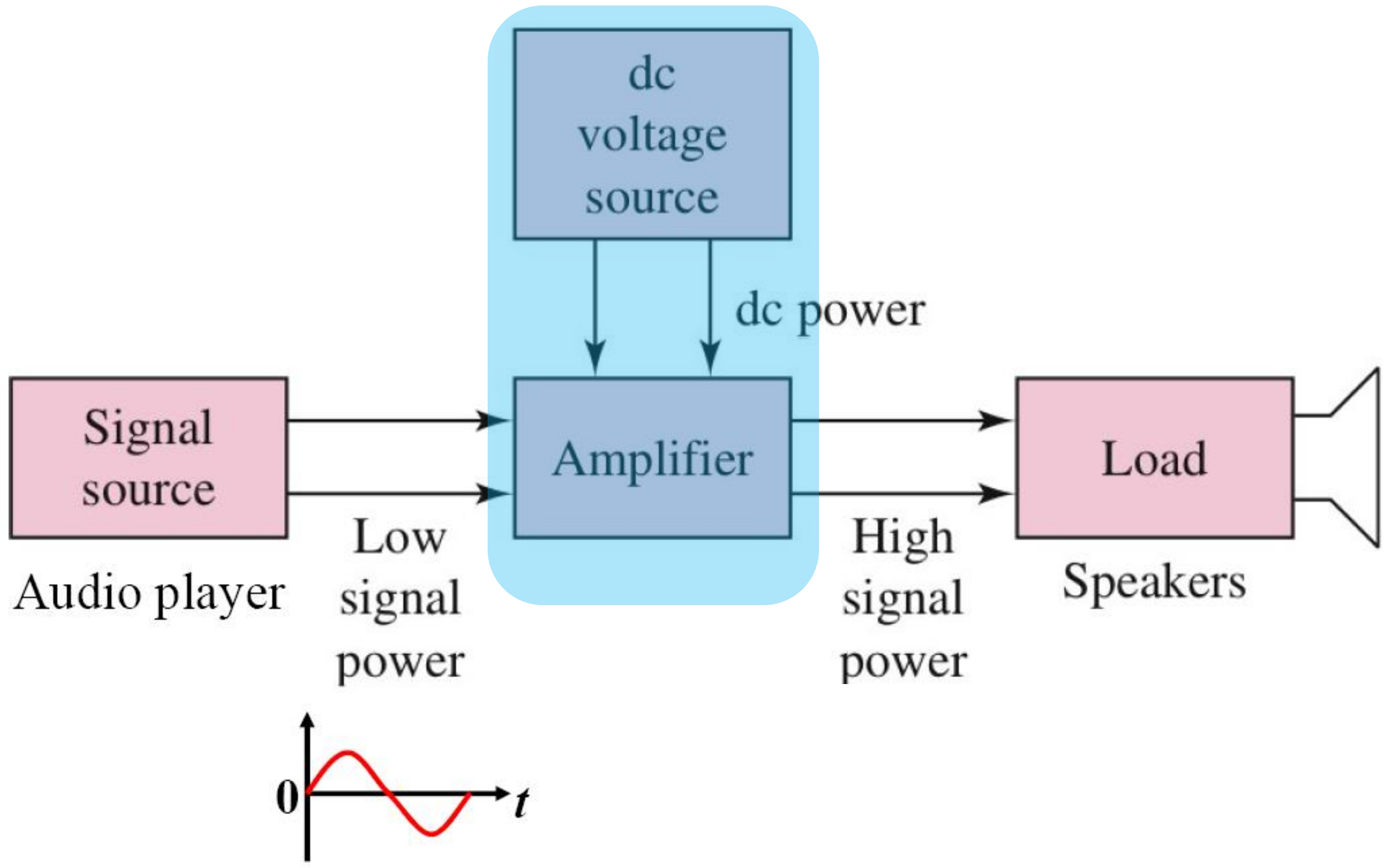
Analog Audio Amplifier



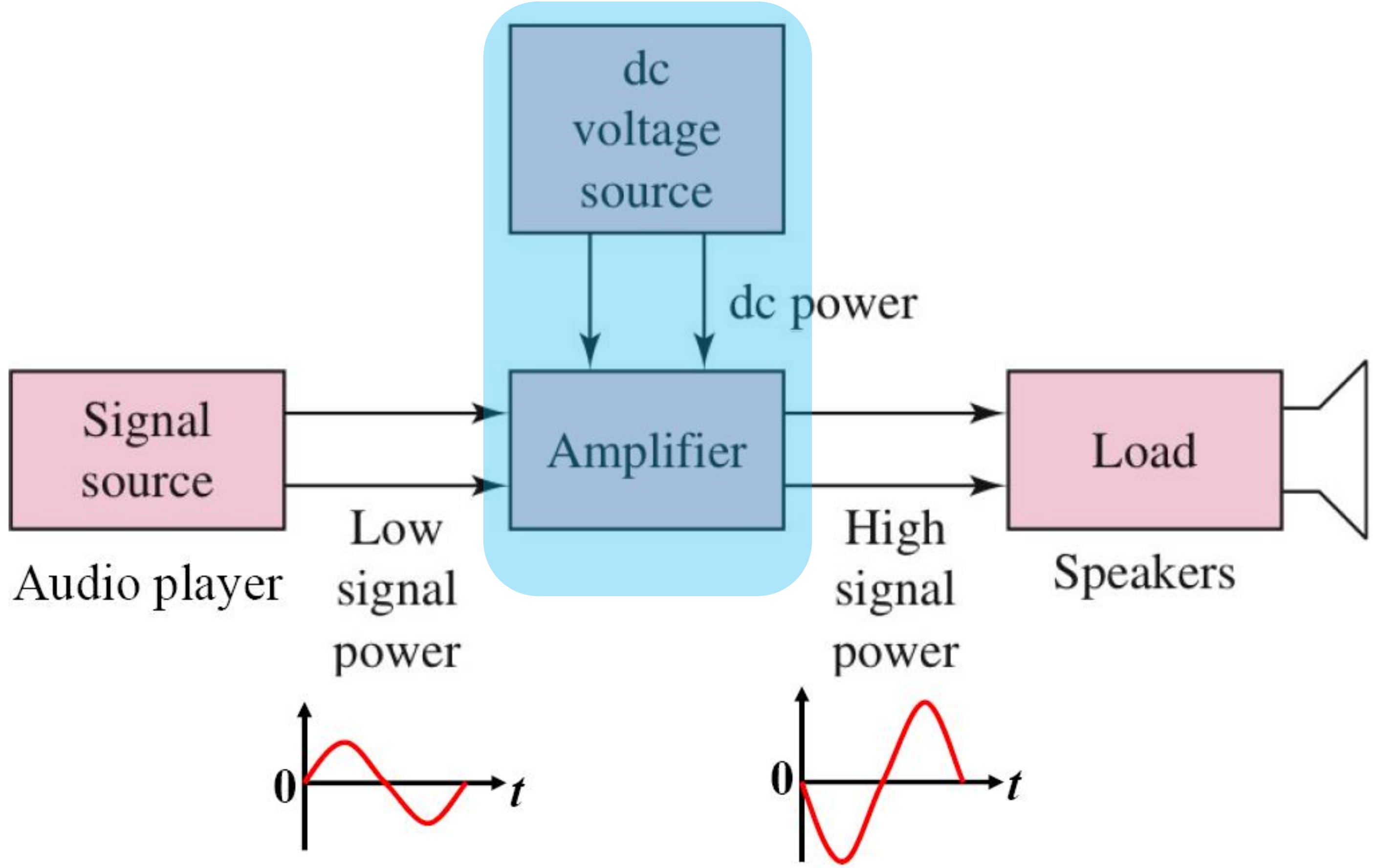
Analog Audio Amplifier



Analog Audio Amplifier



Analog Audio Amplifier



BJT Circuit Analysis

- **DC Analysis: To fix DC operating point (Q point). Also called biasing of transistor.**

BJT Circuit Analysis

- DC Analysis: To fix DC operating point (Q point). Also called biasing of transistor.

- Small Signal Analysis: Analyze BJT circuits for signals being amplified. Small signal model is used for analysis.

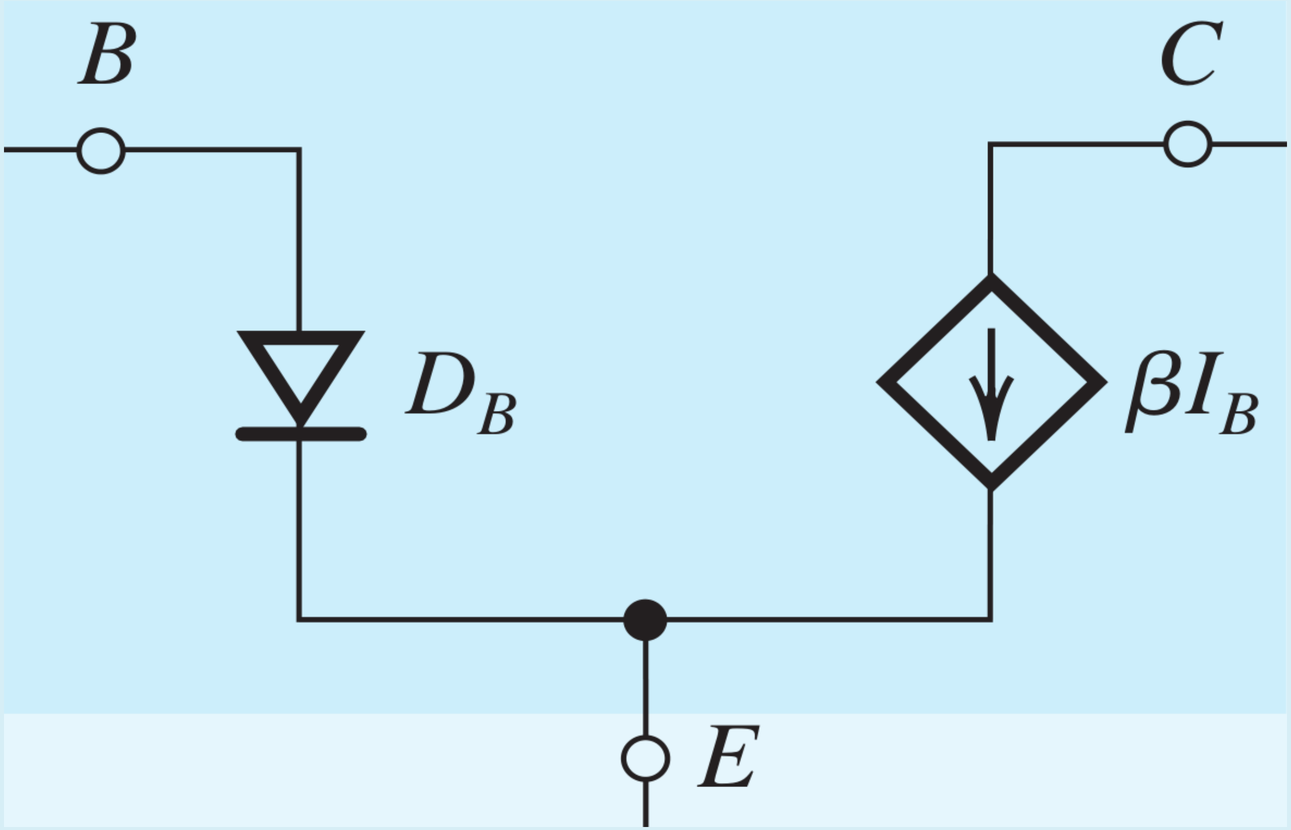
BJT Circuit Analysis

- DC Analysis: To fix DC operating point (Q point). Also called biasing of transistor.

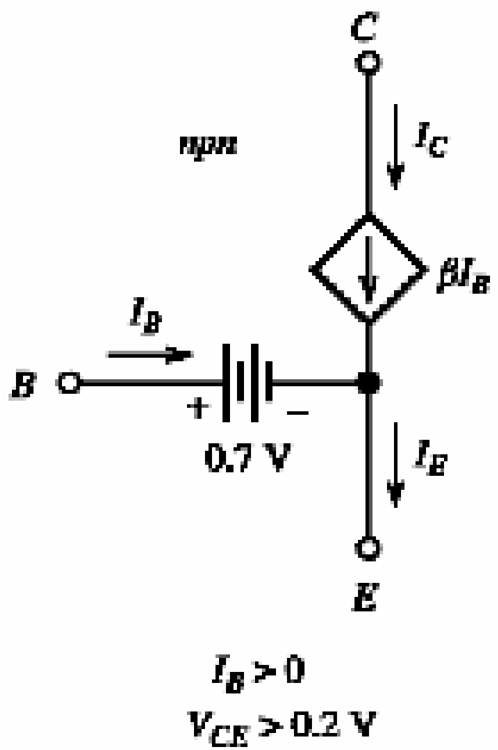
- Small Signal Analysis: Analyze BJT circuits for signals being amplified. Small signal model is used for analysis.

- The transistor is biased such a way to operate it in active region if used in amplifier circuit.

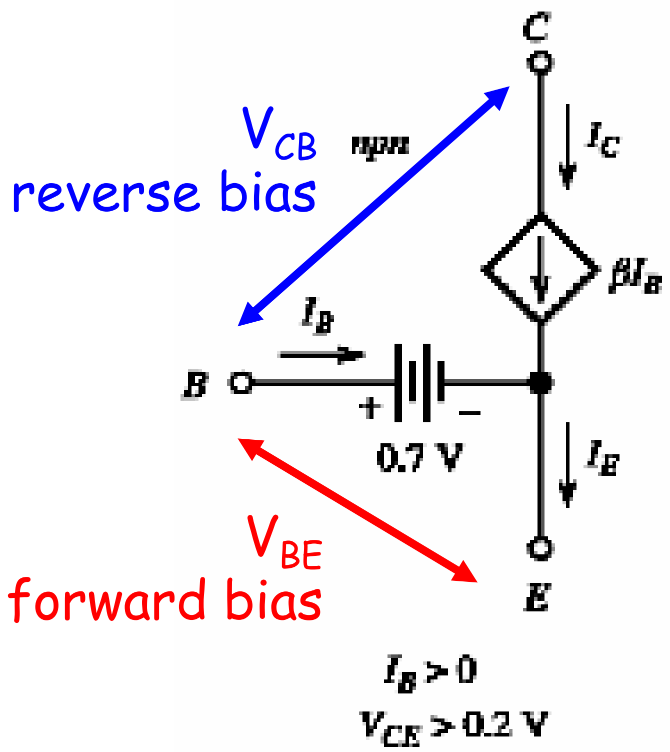
Large Signal Model (BJT) (Active Region)



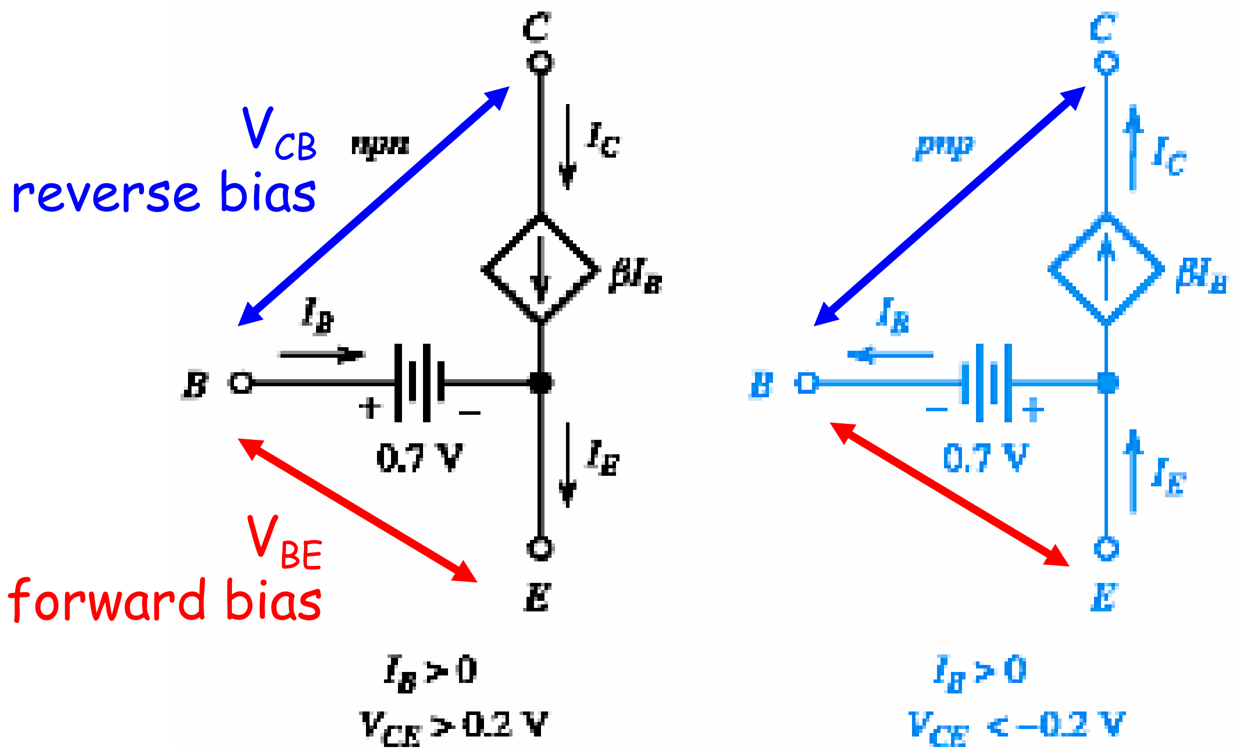
Large Signal DC Analysis (Active Region)



Large Signal DC Analysis (Active Region)

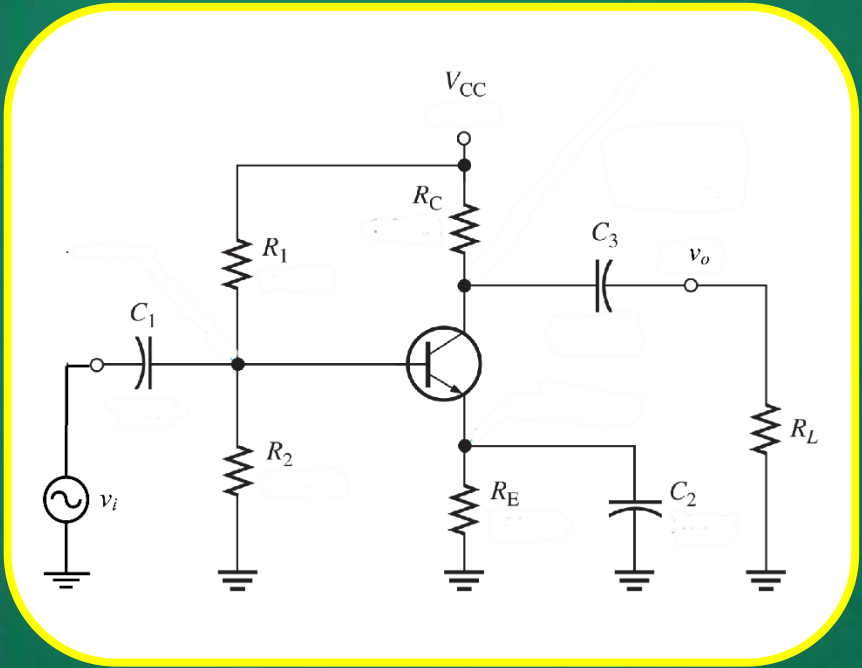


Large Signal DC Analysis (Active Region)

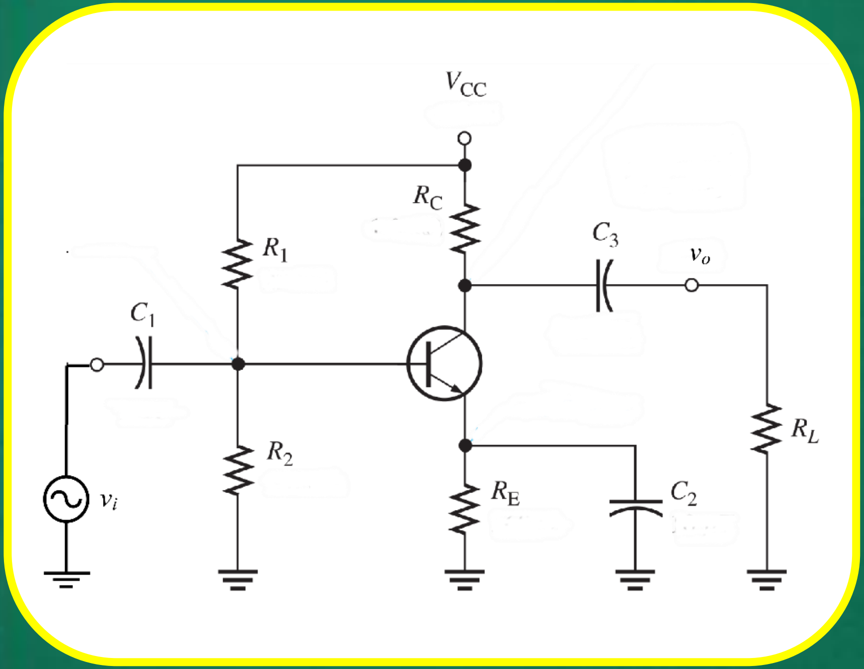


Analysis of BJT Amplifiers

Function of each component



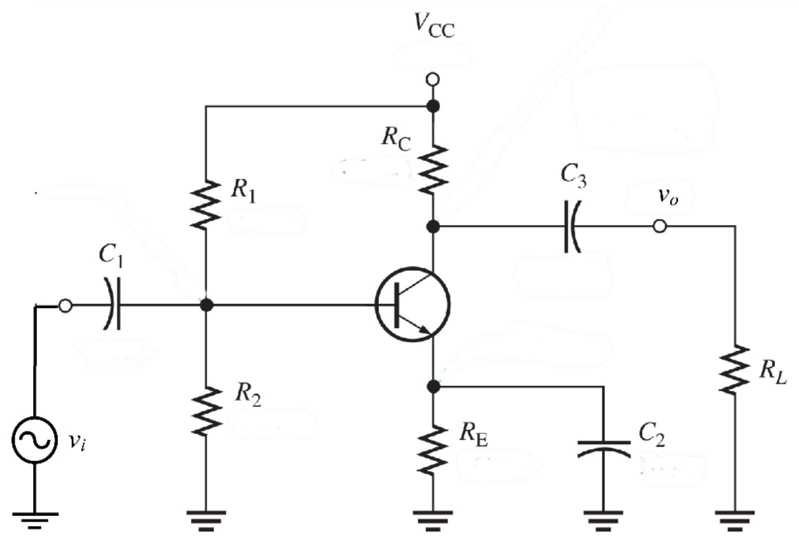
Analysis of BJT Amplifiers



Function of each component

- Capacitors: Act as an open circuit DC operation and short circuits to AC.

Analysis of BJT Amplifiers

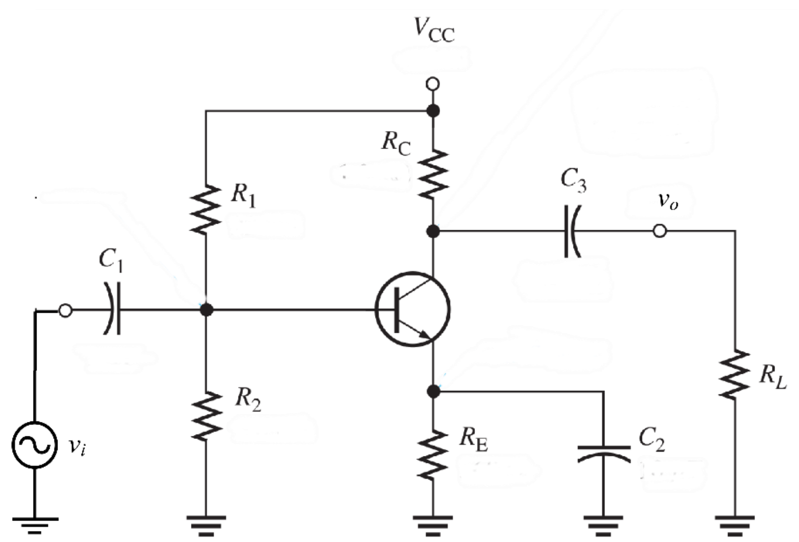


Function of each component

- **Capacitors: Act as an open circuit DC operation and short circuits to AC.**

(If f = 10 kHz & C = 10 μF, then $|Zc| = (2\pi fC)^{-1} = 8\ \Omega$ which is usually smaller than $R_{TH} = R_1 \| R_2$).

Analysis of BJT Amplifiers



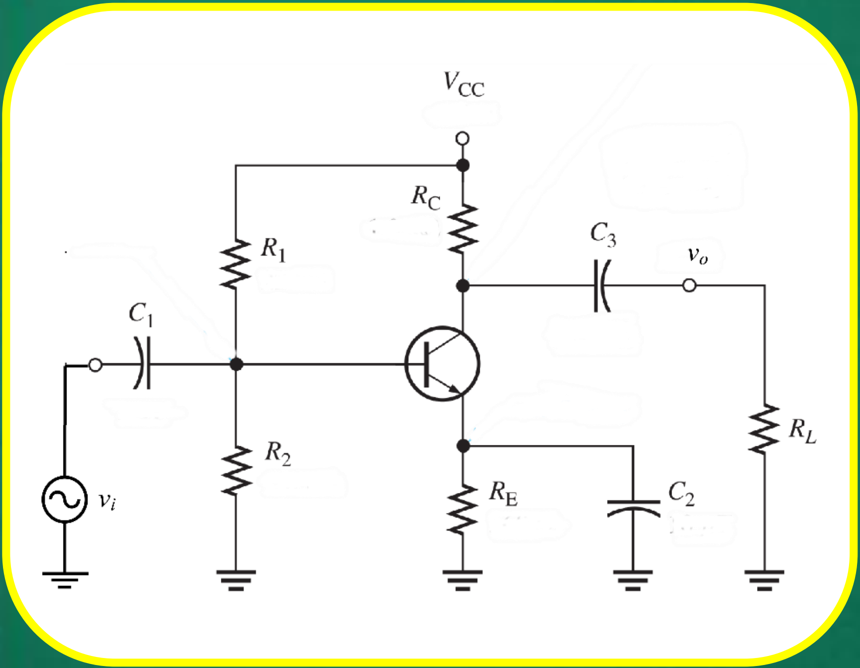
Function of each component

- **Capacitors: Act as an open circuit DC operation and short circuits to AC.**

  (If f = 10 kHz & C = 10 µF, then $|Z_c| = (2\pi fC)^{-1} = 8\ \Omega$ which is usually smaller than $R_{TH} = R_1 \| R_2$).

- **R_1, R_2, R_C, and R_E: Setting DC biasing Q-Opoint.**

Analysis of BJT Amplifiers



Function of each component

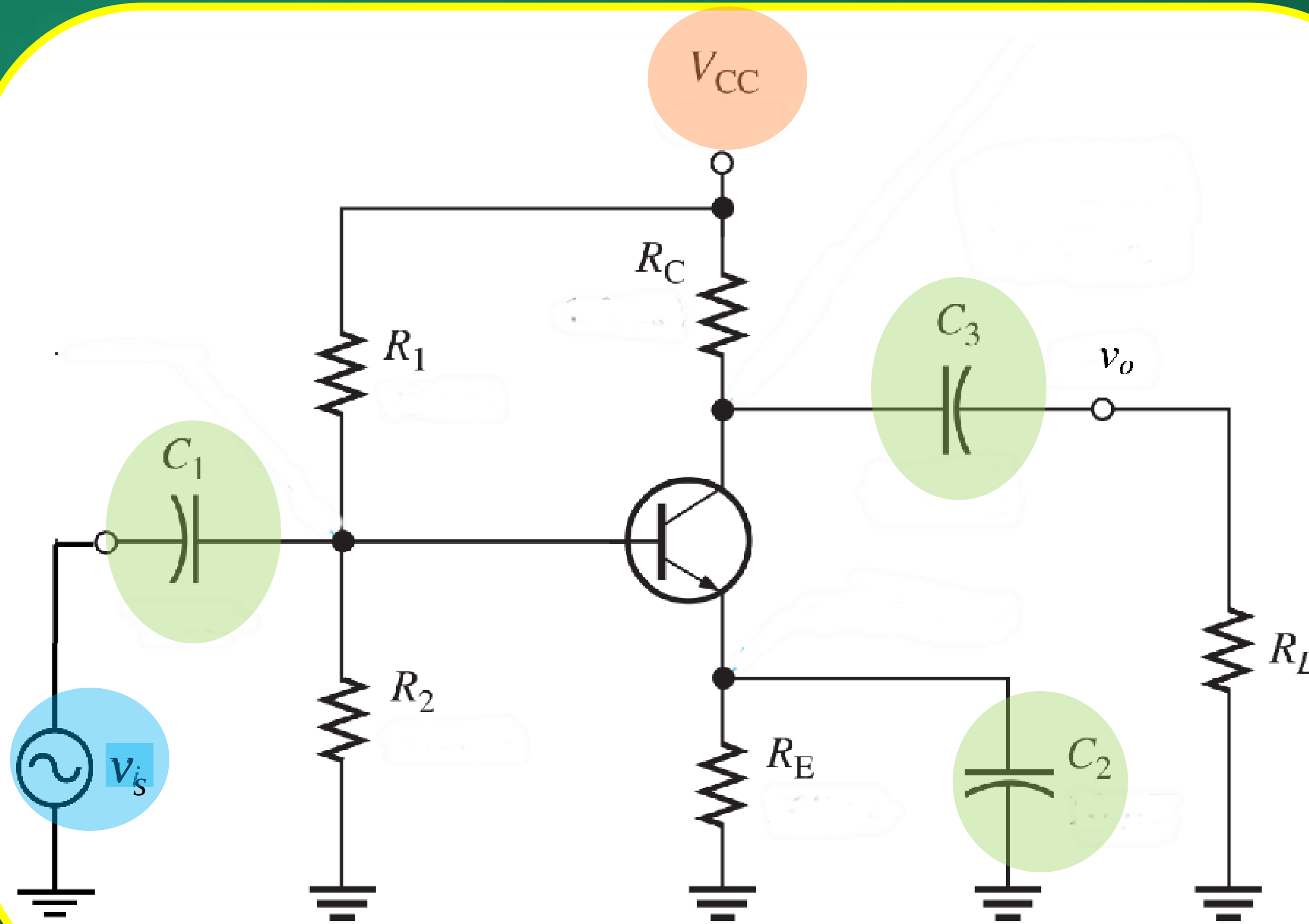
- **Capacitors: Act as an open circuit DC operation and short circuits to AC.**

  (If f = 10 kHz & C = 10 μF, then $|Zc| = (2\pi fC)^{-1} = 8\ \Omega$ which is usually smaller than $R_{TH} = R_1 \| R_2$).

- **R_1, R_2, R_C, and R_E: Setting DC biasing Q-Opoint.**

- **R_C : Converting i_c variation into v_{ce} (or v_o) variation (signal conversion).**

DC & AC Analysis of Amplifiers



DC Equiv. Circuit & Analysis

To determine DC operating point (or Q-point)

DC Equiv. Circuit & Analysis

To determine DC operating point (or Q-point)

- **Reduce all signal sources to zero.**

DC Equiv. Circuit & Analysis

To determine DC operating point (or Q-point)

- **Reduce all signal sources to zero.**
- **Open all the capacitors**

DC Equiv. Circuit & Analysis

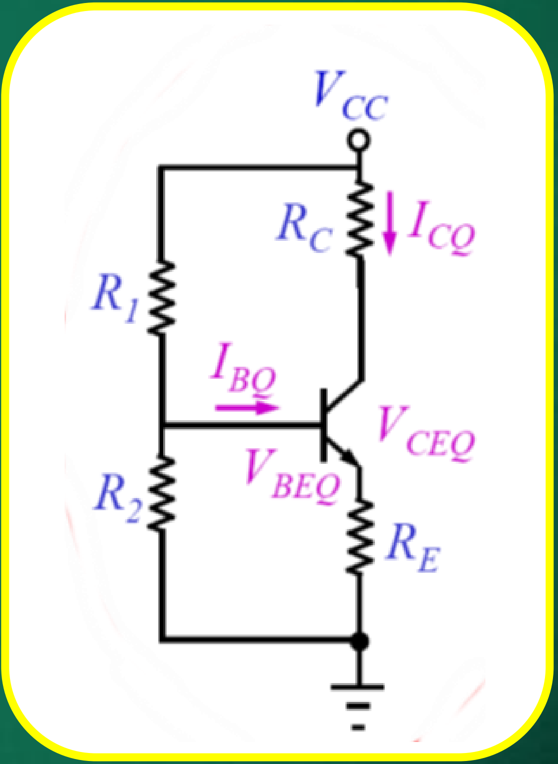
To determine DC operating point (or Q-point)

- Reduce all signal sources to zero.
- Open all the capacitors
- Draw and analyze the DC equivalent.

DC Equiv. Circuit & Analysis

To determine DC operating point (or Q-point)

- Reduce all signal sources to zero.
- Open all the capacitors
- Draw and analyze the DC equivalent.



AC Equiv. Circuit & Analysis

To determine ac characteristics (e.g., small signal voltage gain, input impedance, output impedance, frequency response etc.

AC Equiv. Circuit & Analysis

To determine ac characteristics (e.g., small signal voltage gain, input impedance, output impedance, frequency response etc.

- **Reduce all DC sources to zero.**

AC Equiv. Circuit & Analysis

To determine ac characteristics (e.g., small signal voltage gain, input impedance, output impedance, frequency response etc.

- Reduce all DC sources to zero.

- Short all the capacitors

AC Equiv. Circuit & Analysis

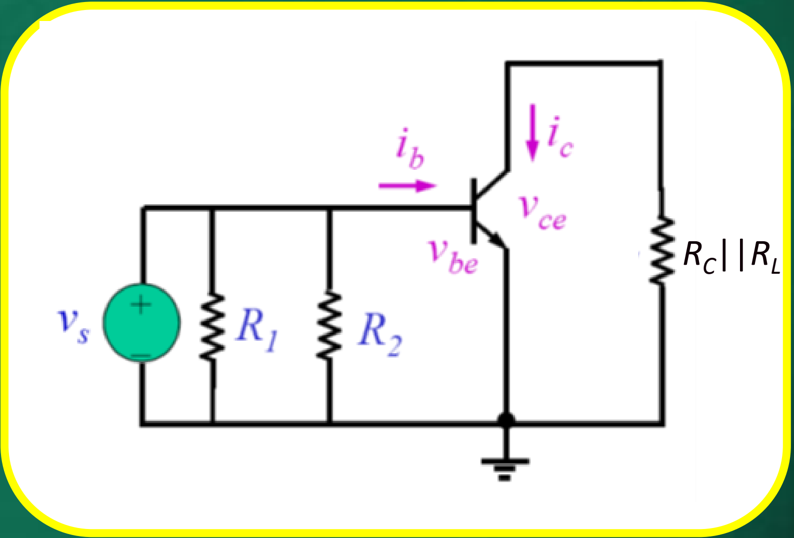
To determine ac characteristics (e.g., small signal voltage gain, input impedance, output impedance, frequency response etc.

- **Reduce all DC sources to zero.**
- **Short all the capacitors**
- **Draw and analyze the AC equivalent.**

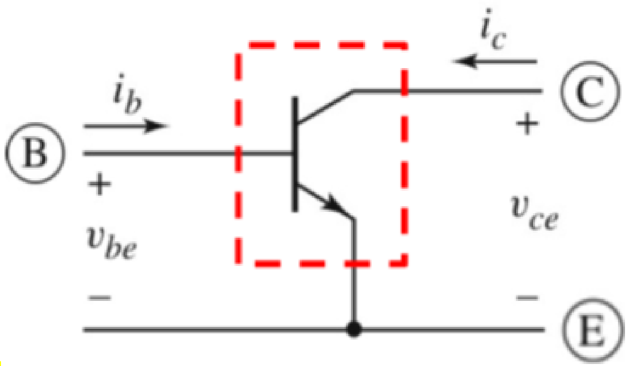
AC Equiv. Circuit & Analysis

To determine ac characteristics (e.g., small signal voltage gain, input impedance, output impedance, frequency response etc.

- **Reduce all DC sources to zero.**
- **Short all the capacitors**
- **Draw and analyze the AC equivalent.**

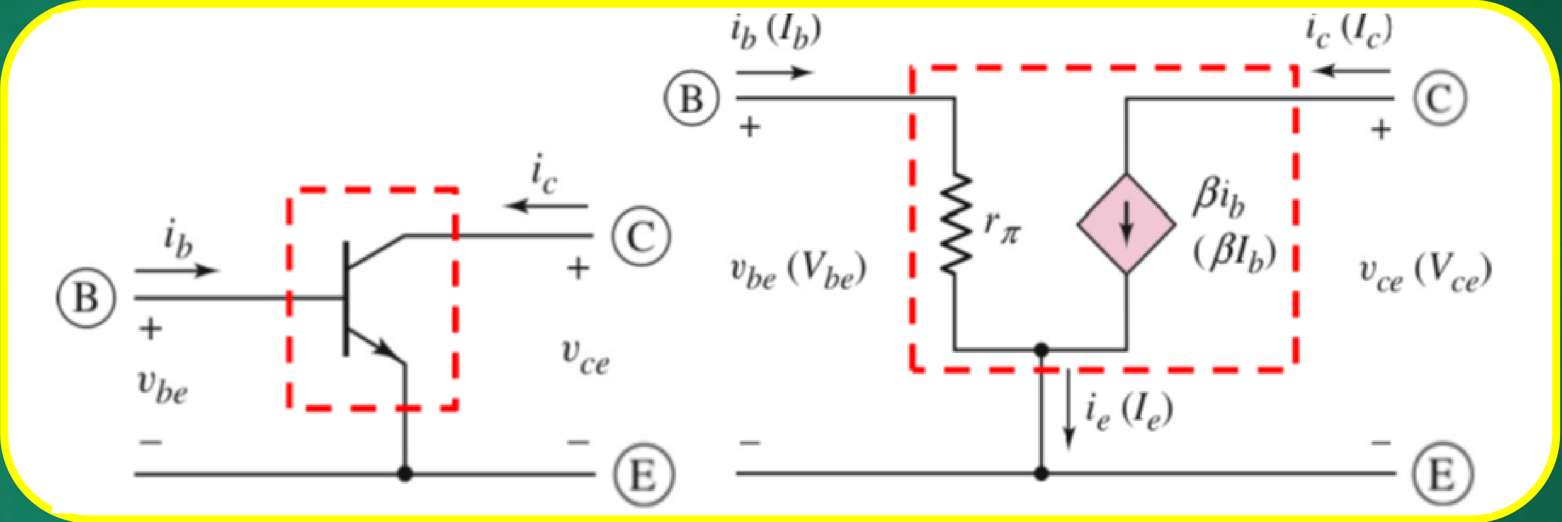


Small Signal Hybrid-π Equiv. Circuit



BJT as a 2 port network

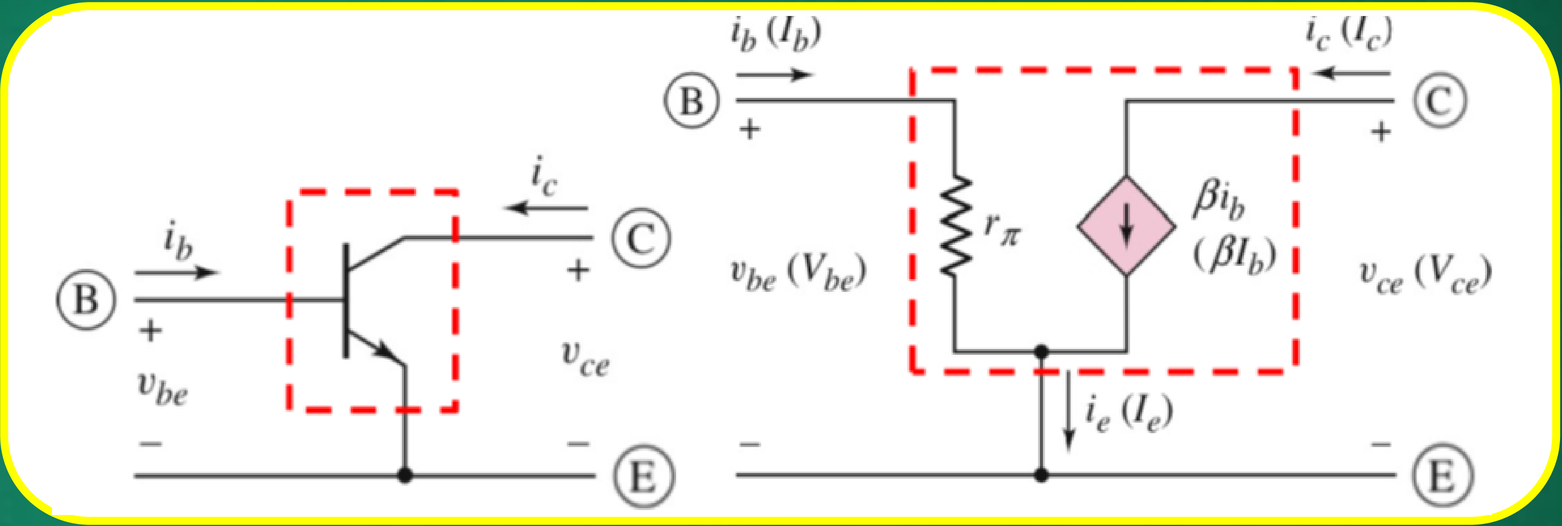
Small Signal Hybrid-π Equiv. Circuit



BJT as a 2 port network

Small signal hybrid π equivalent circuit

Small Signal Hybrid-π Equiv. Circuit

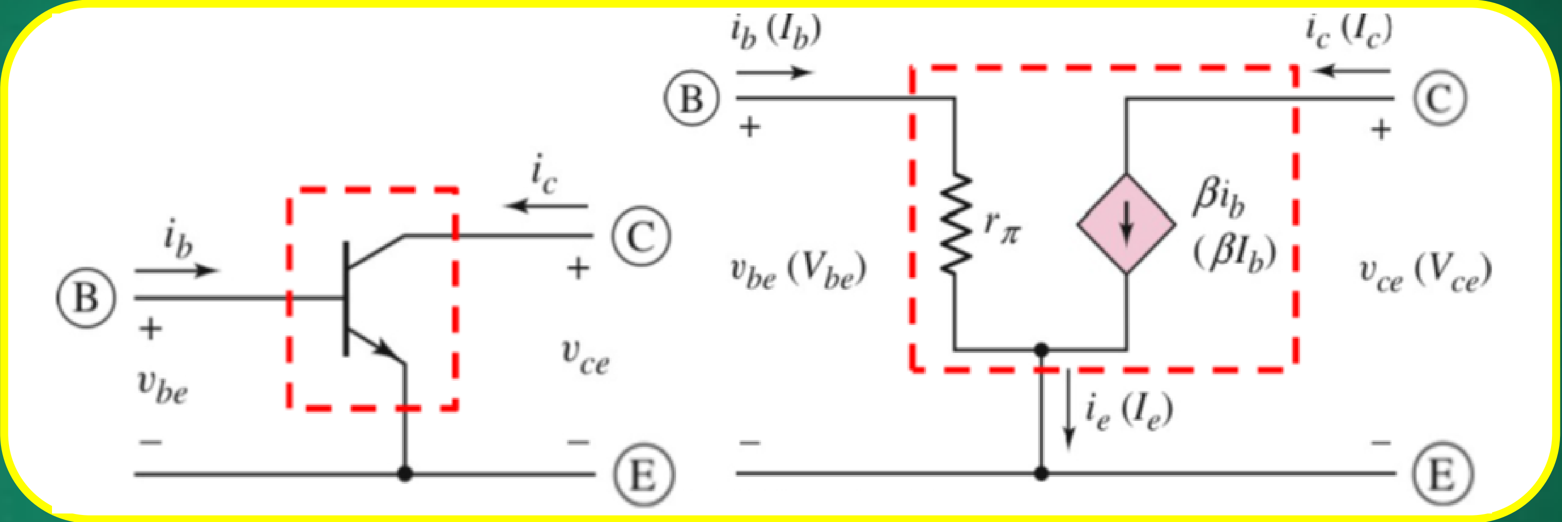


BJT as a 2 port network

Small signal hybrid π equivalent circuit

$$\beta = Common\ emitter\ current\ gain = \ i_c/i_b$$

Small Signal Hybrid-π Equiv. Circuit



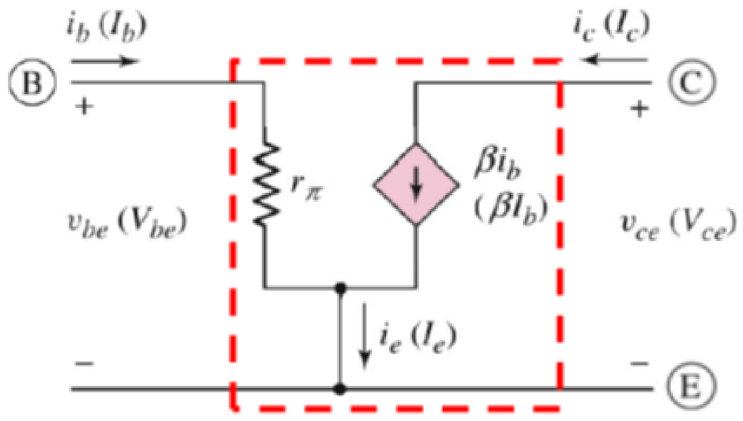
BJT as a 2 port network

Small signal hybrid π equivalent circuit

$\beta = Common\ emitter\ current\ gain = \ i_c/i_b$

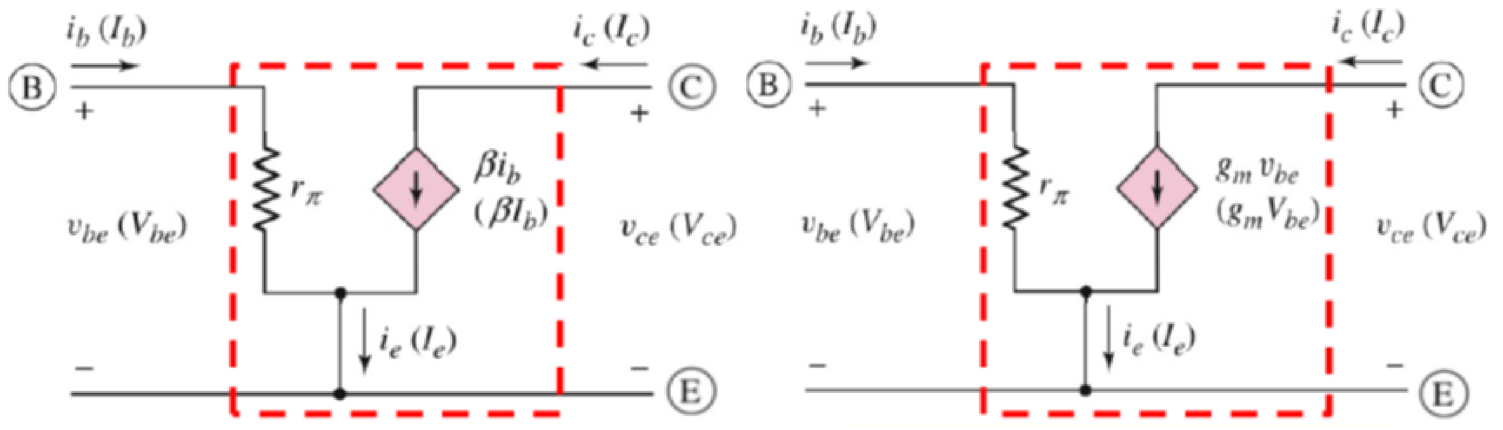
$$\boldsymbol{r}_\pi = v_{be}/i_b = V_T/I_{BQ}$$
$$= \beta V_T/I_{CQ} = small\ signal\ resistance, where\ \ V_T\ is\ the\ thermal\ voltage$$

Small Signal Hybrid-π Equiv. Circuit



With current gain parameter

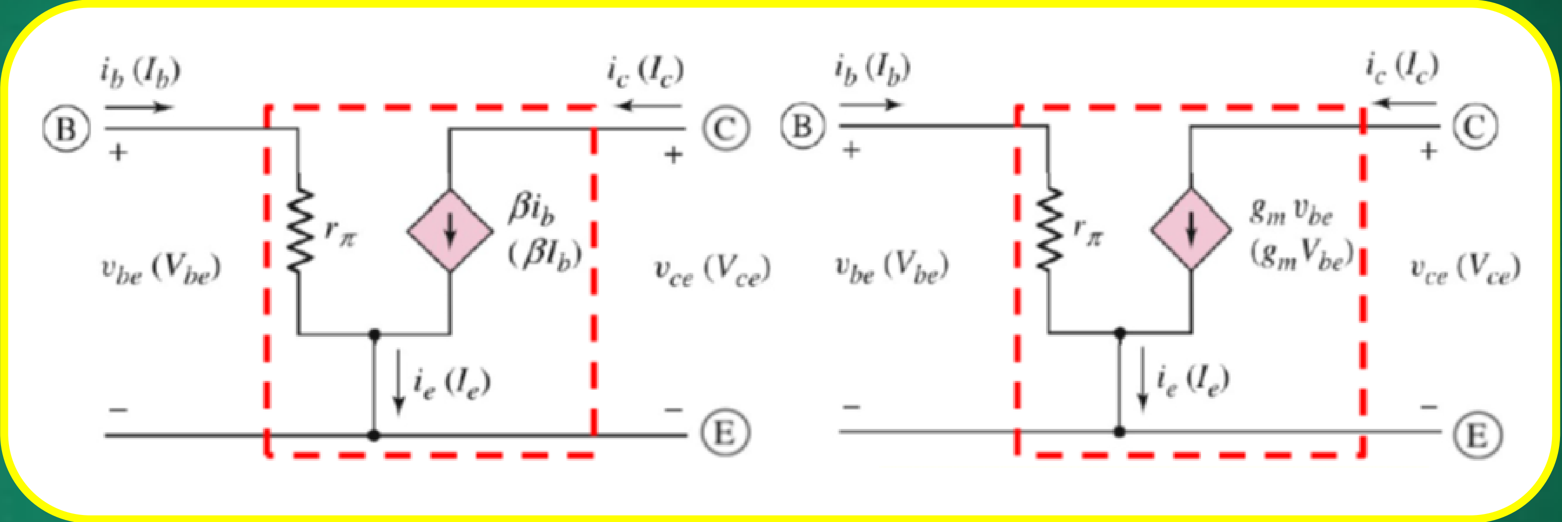
Small Signal Hybrid-π Equiv. Circuit



With current gain parameter

With transconductance parameter

Small Signal Hybrid-π Equiv. Circuit

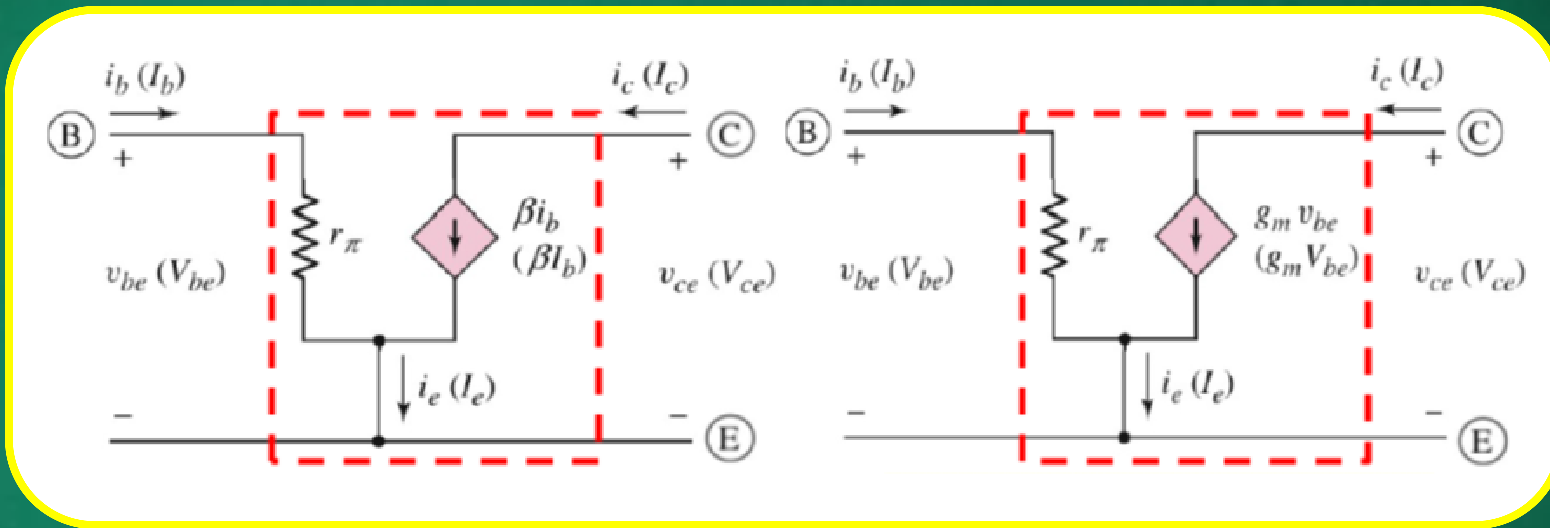


With current gain parameter

With transconductance parameter

$$g_m = \beta / r_\pi = I_{CQ}/V_T \ = transconductance$$

Small Signal Hybrid-π Equiv. Circuit



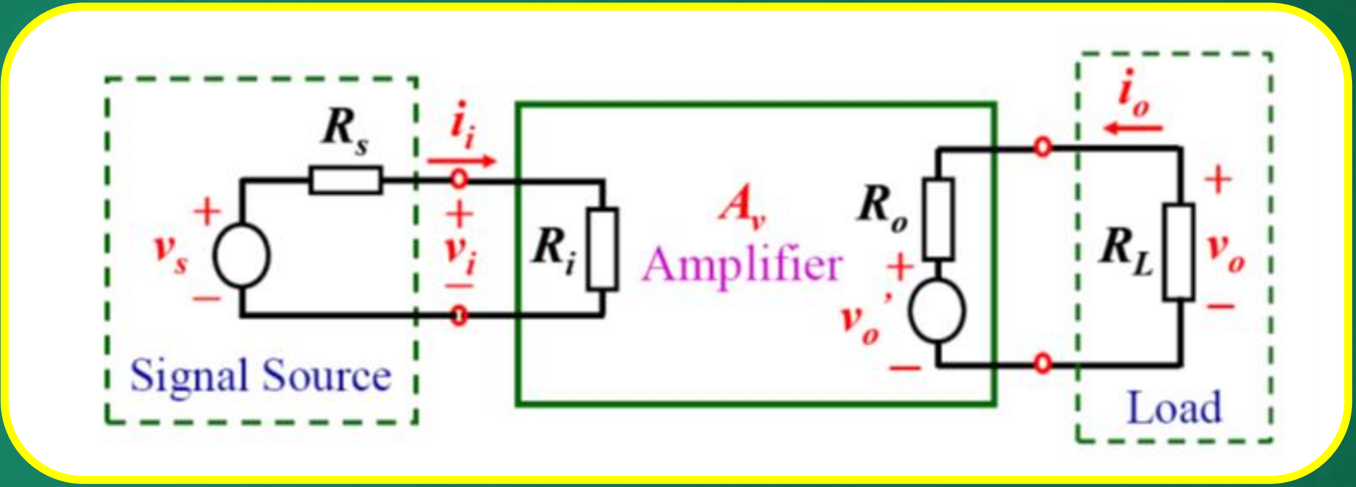
With current gain parameter

With transconductance parameter

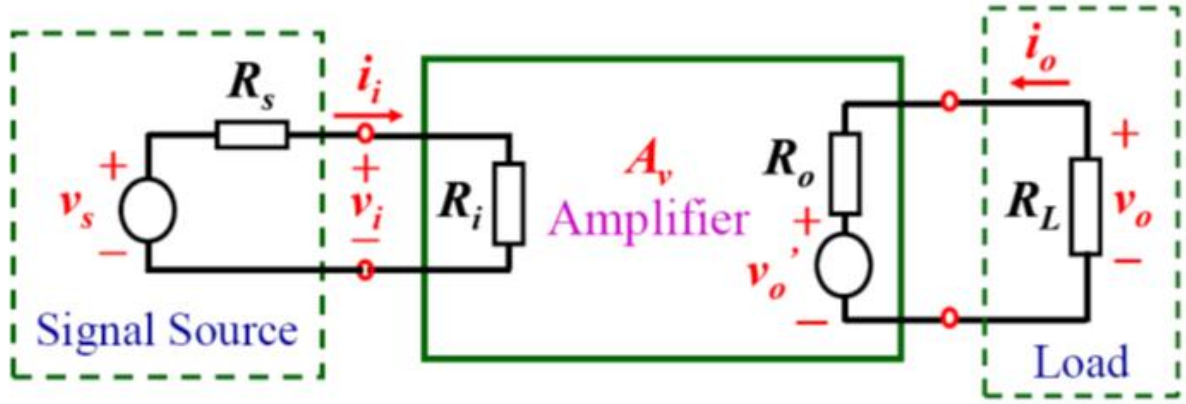
$$g_m = \beta / r_\pi = I_{CQ}/V_T = transconductance$$

i_c is assumed to be independent of v_{ce} which is not the case in practice and the assumption will be released later to include the "Early effect"

Basic Characteristics of an Amplifier

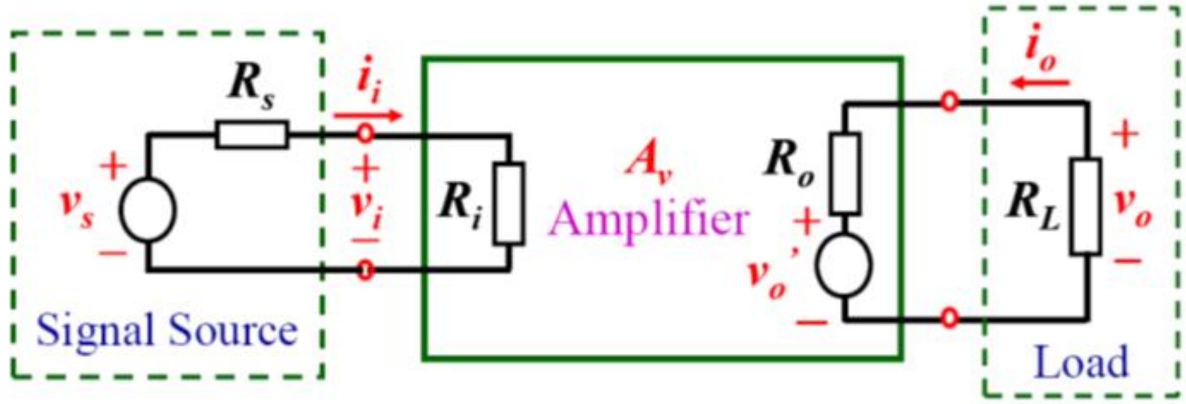


Basic Characteristics of an Amplifier



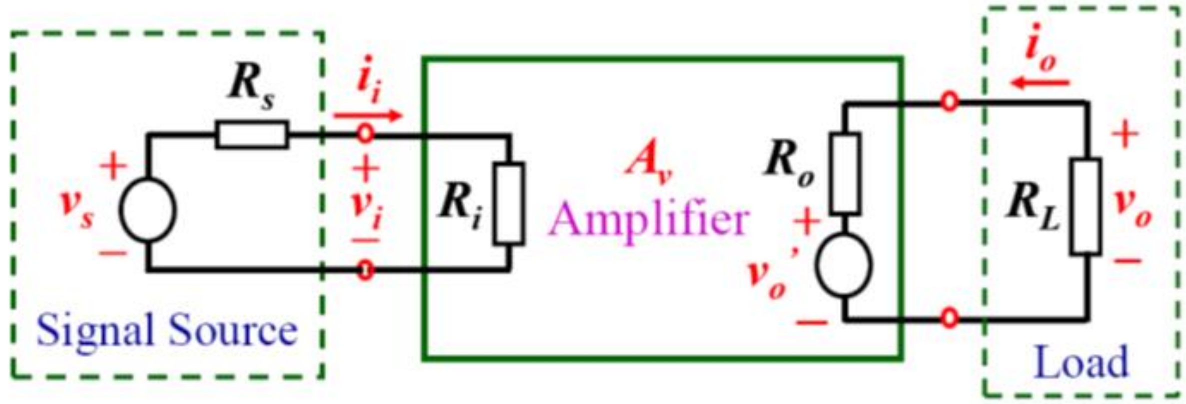
- **Overall Amplifier Gain** $$A_v = \frac{v_o}{v_s}$$

Basic Characteristics of an Amplifier



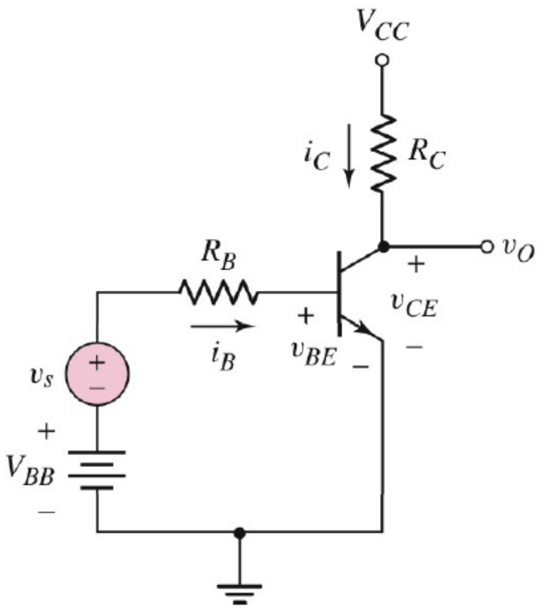
- **Overall Amplifier Gain** $$A_v = \frac{v_o}{v_s}$$
- **Input Resistance** $$R_i = \frac{v_i}{i_i}$$

Basic Characteristics of an Amplifier

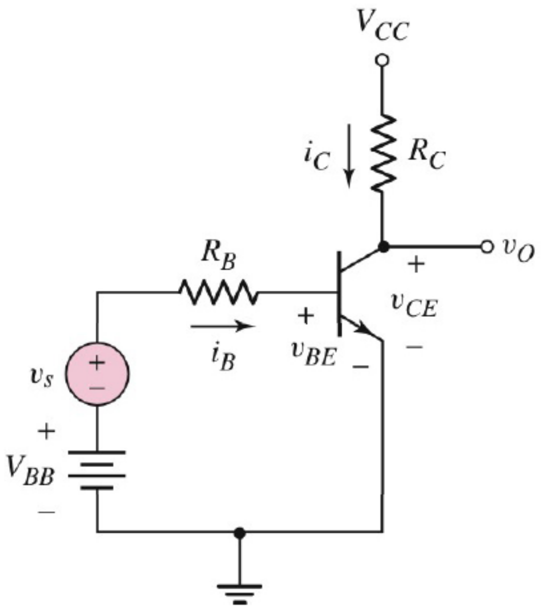


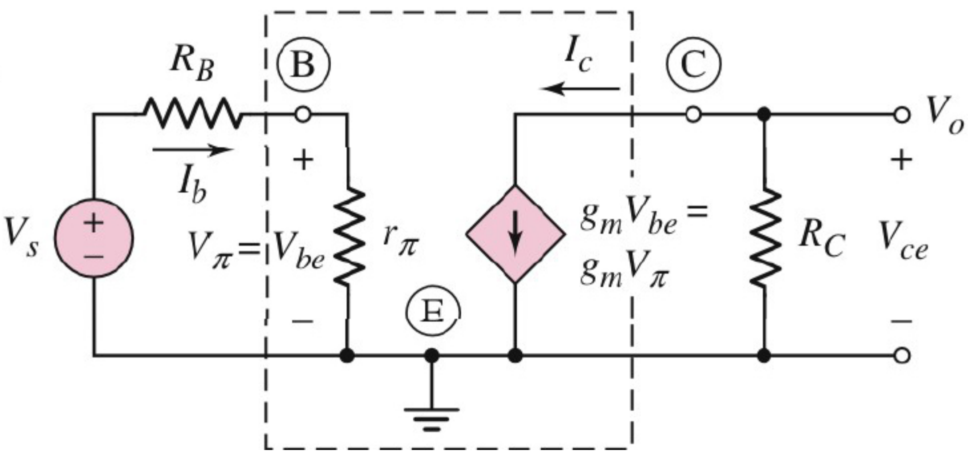
- **Overall Amplifier Gain** $$A_v = \frac{v_o}{v_s}$$
- **Input Resistance** $$R_i = \frac{v_i}{i_i}$$
- **Output Resistance** $$R_o = \frac{v_o}{i_o}\Big|_{v_s=0}$$

Small Signal Voltage Gain

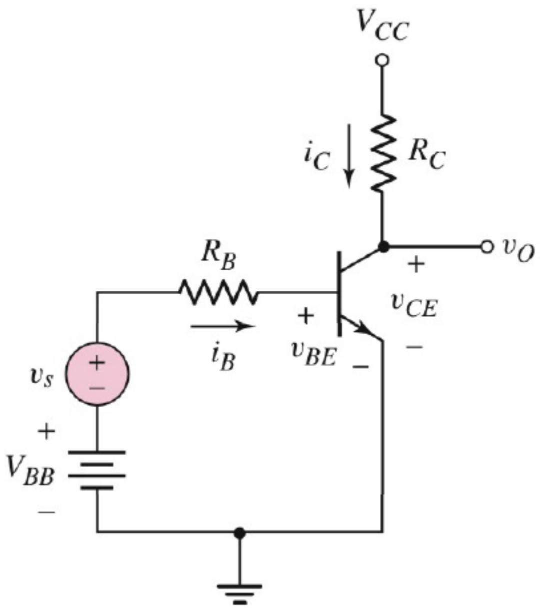


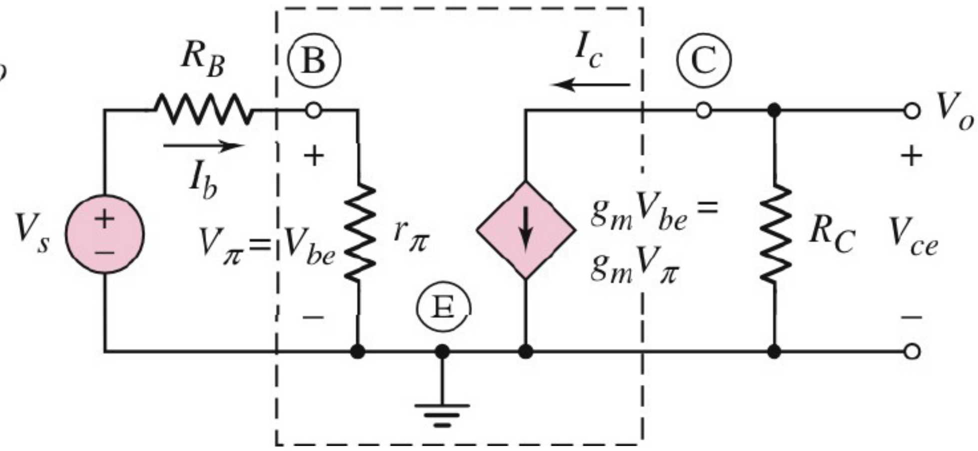
Small Signal Voltage Gain





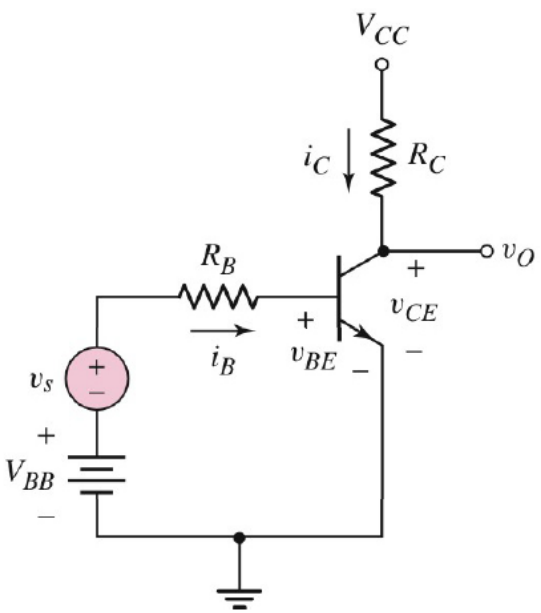
Small Signal Voltage Gain

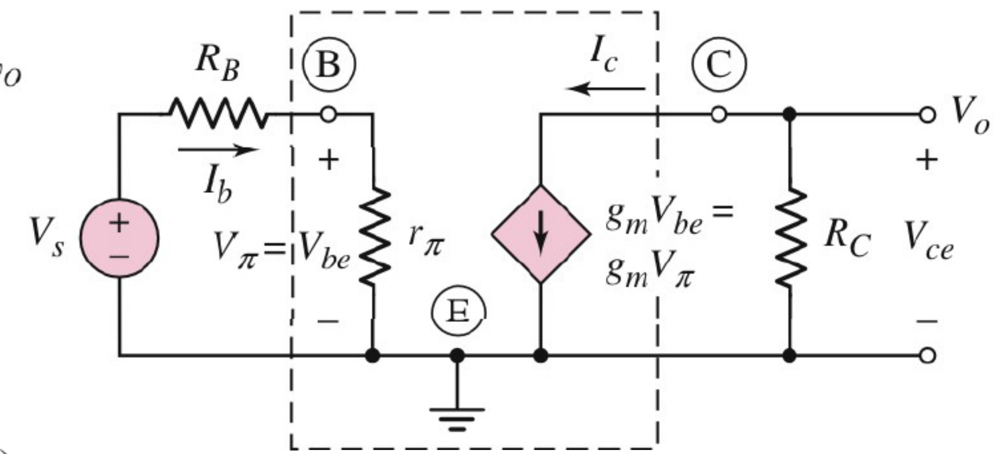




$$V_\pi = V_{be} = V_s \left(\frac{r_\pi}{r_\pi + R_B} \right)$$

Small Signal Voltage Gain

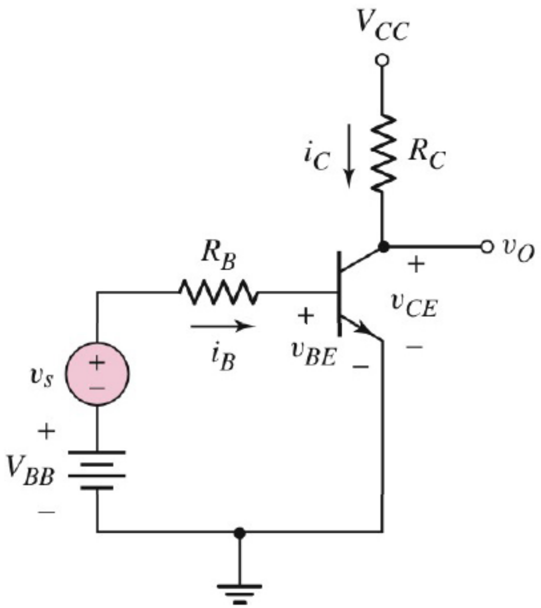


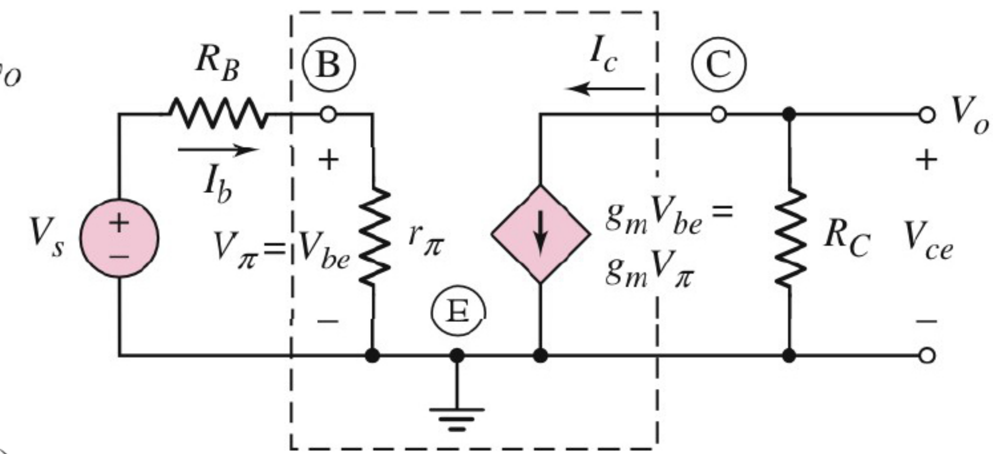


$$V_\pi = V_{be} = V_s\left(\frac{r_\pi}{r_\pi + R_B}\right)$$

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

Small Signal Voltage Gain





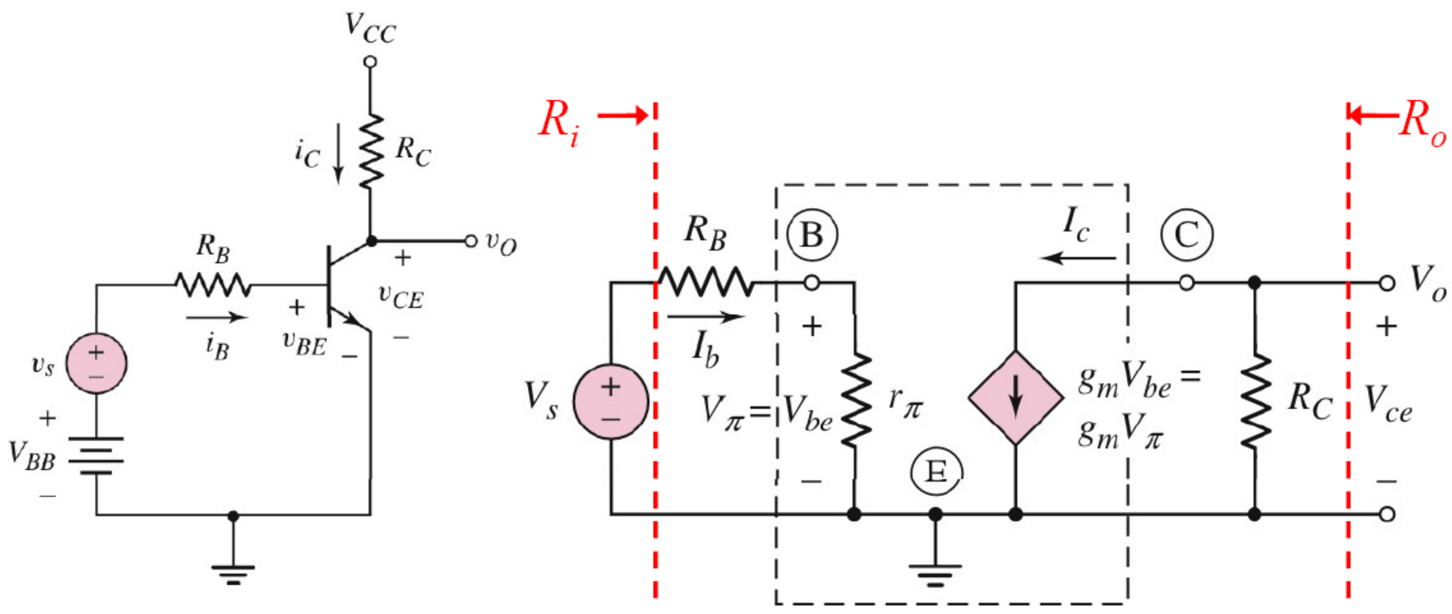
$$V_\pi = V_{be} = V_s \left(\frac{r_\pi}{r_\pi + R_B} \right)$$

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

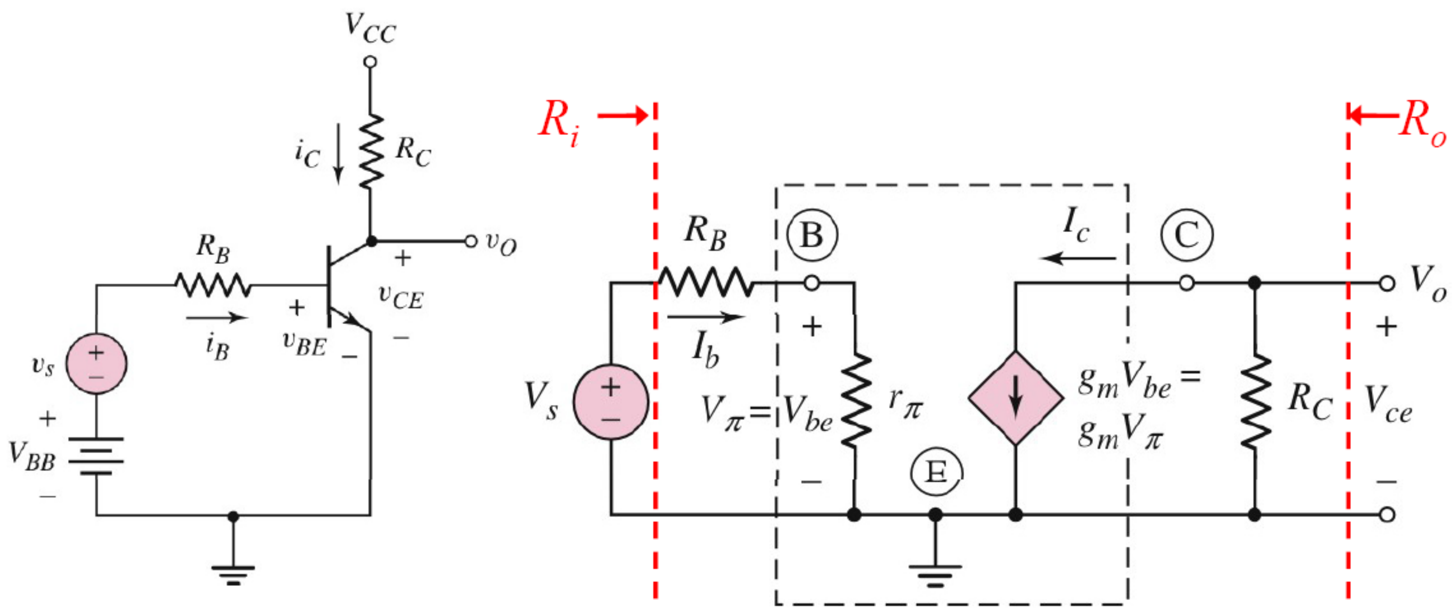
Small-signal voltage gain:

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

Input and Output Resistances

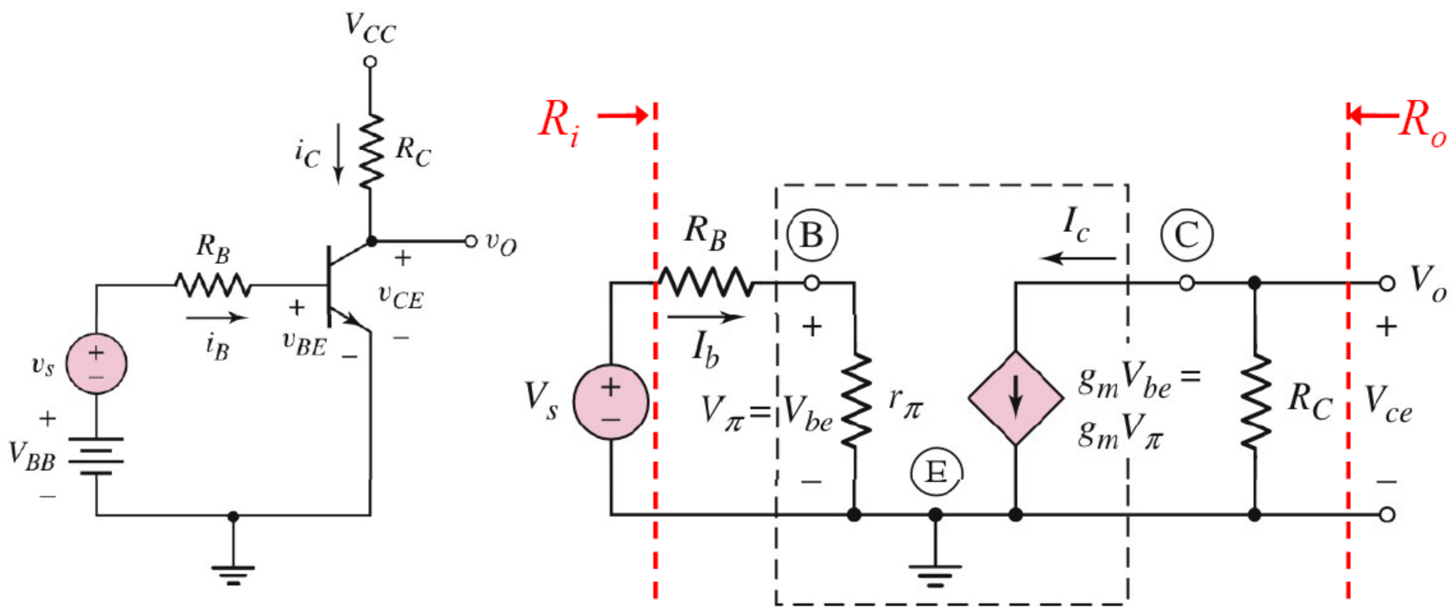


Input and Output Resistances



Input resistance: $R_i = R_B + r_\pi$

Input and Output Resistances



Input resistance: $R_i = R_B + r_\pi$

Output resistance: $R_o = R_C$

[Setting $V_s = 0$ (short), then $V_\pi = 0$ & $g_m V_\pi = 0$ (open)]

Example

- Calculate the small-signal voltage gain, input resistance & output resistance of the BJT amplifier circuit at 300 K. Assume that the BJT & circuit parameters are: $\beta = 100$, $V_{CC} = 12$ V, $V_{BE} = 0.7$ V, $R_C = 6$ kΩ, $R_B = 50$ kΩ & $V_{BB} = 1.2$ V.