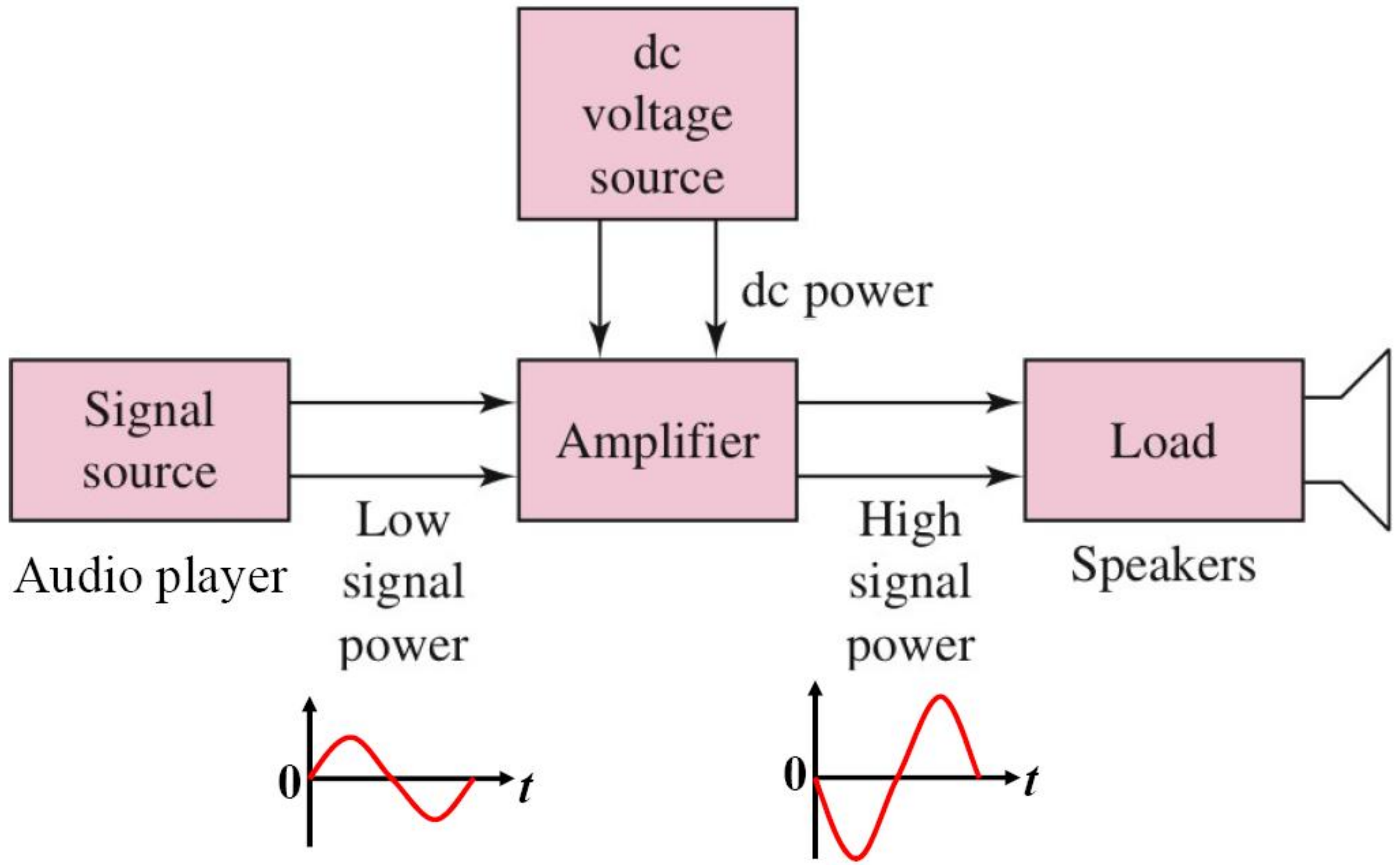
# Basic Electronic Circuits (IEC-103)

## Lecture-17

# Small Signal Analysis

# Linear Analog Amplifier



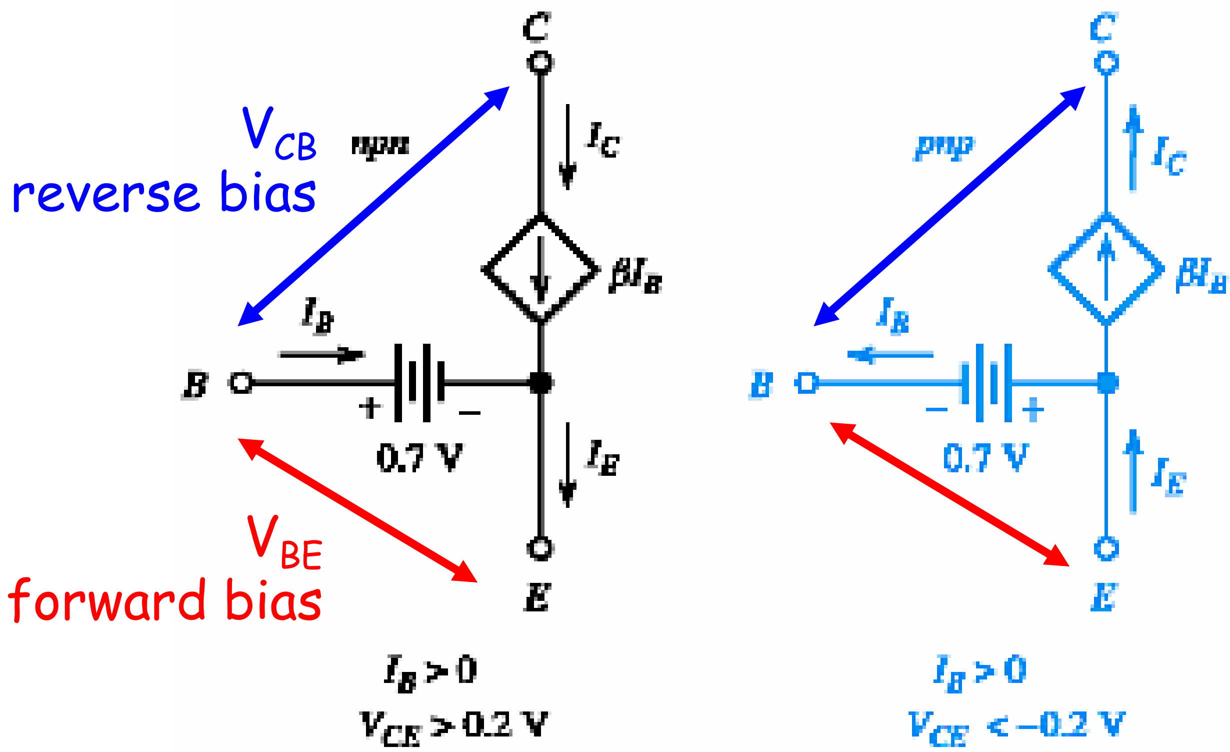
# BJT Circuit Analysis

- 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.

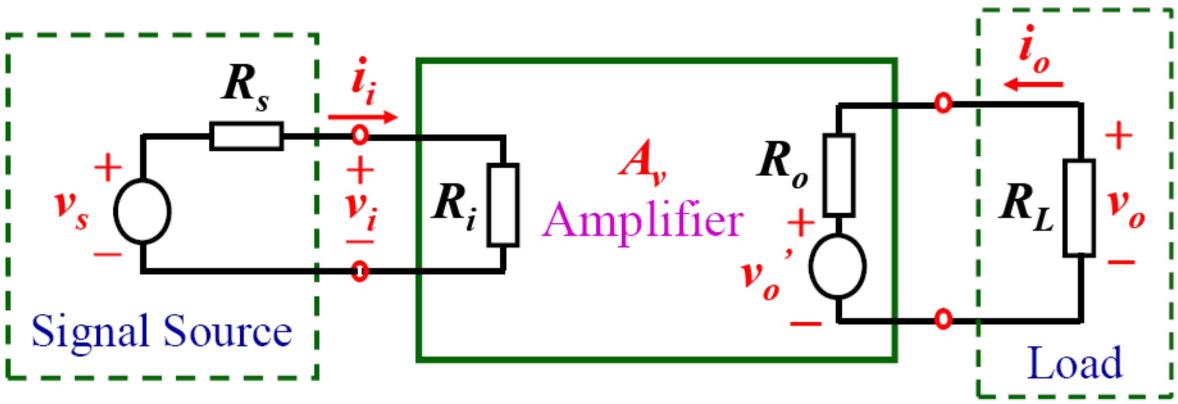
# Large Signal DC Analysis (Active Region)



# Notation in Transistor Analysis

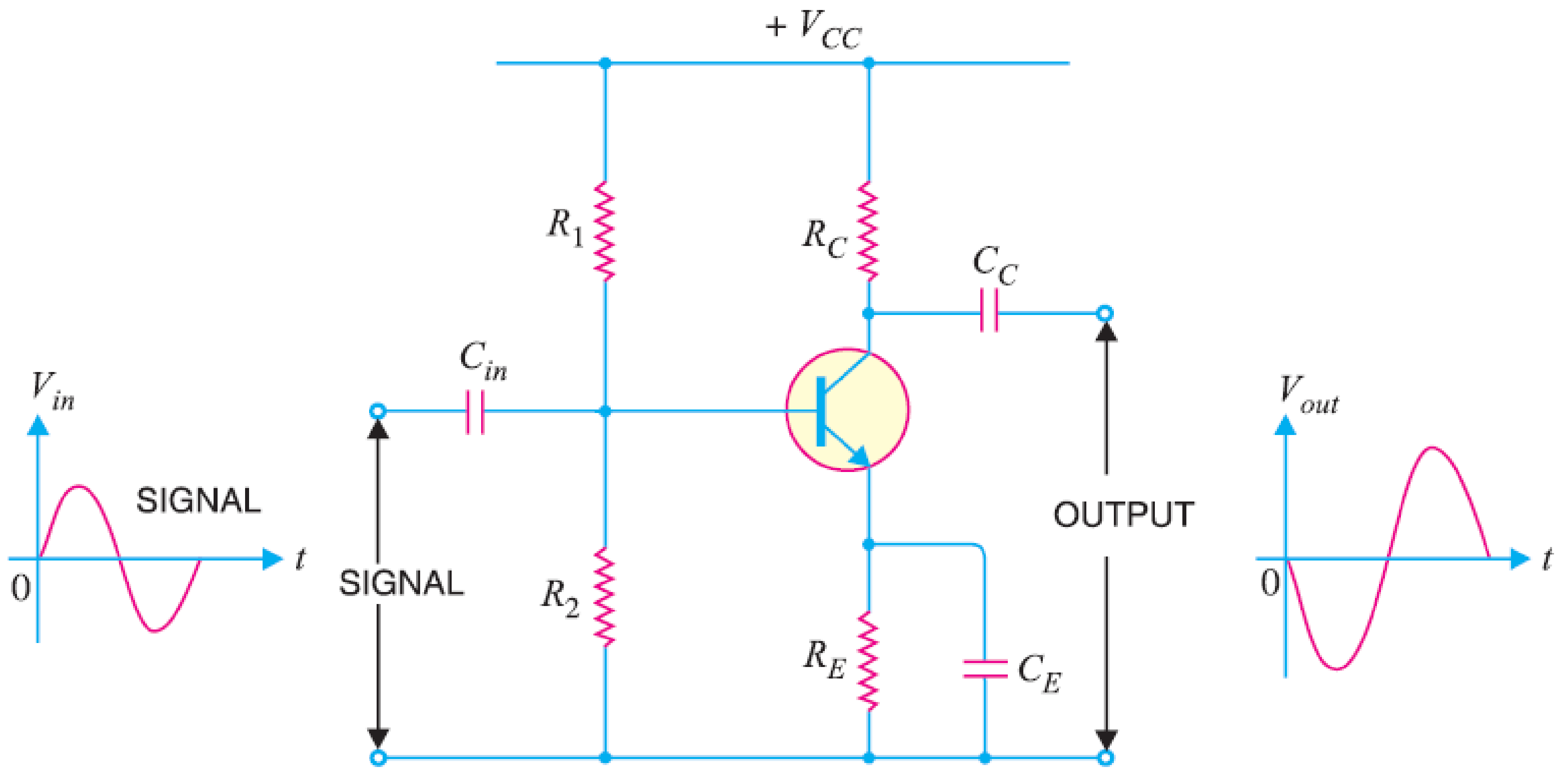
| S. No | Variable | Instantaneous AC | DC | Total |
|---|---|---|---|---|
| 1 | Emitter Current | $i_e$ | $I_E$ | $i_E$ |
| 2 | Collector Current | $i_c$ | $I_C$ | $i_C$ |
| 3 | Base Current | $i_b$ | $I_B$ | $i_B$ |
| 4 | Collector-emitter Voltage | $v_{ce}$ | $V_{CE}$ | $v_{CE}$ |
| 5 | Emitter-base Voltage | $v_{eb}$ | $V_{EB}$ | $v_{EB}$ |

# Basic Characteristics of an Amplifier

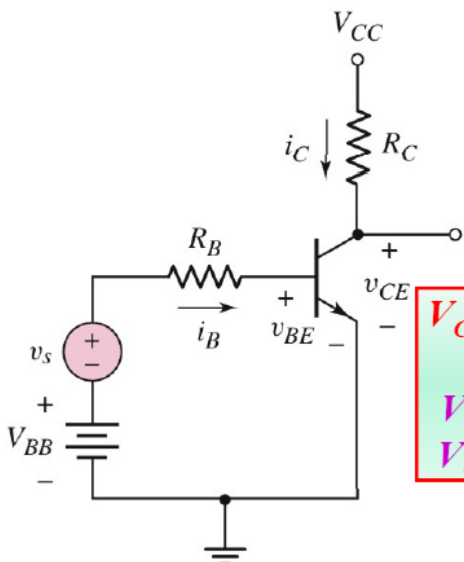



- **Amplifier Gain:** $A_v = \dfrac{v_o}{v_s}$
- **Input Resistance:** $R_i = \dfrac{v_i}{i_i}$
- **Output Resistance:** $R_o = \left.\dfrac{v_o}{i_o}\right|_{v_s = 0 \text{ (a short circuit)},\ R_L = \infty \text{ (an open circuit)}}$

# Basic Common Emitter Amplifier

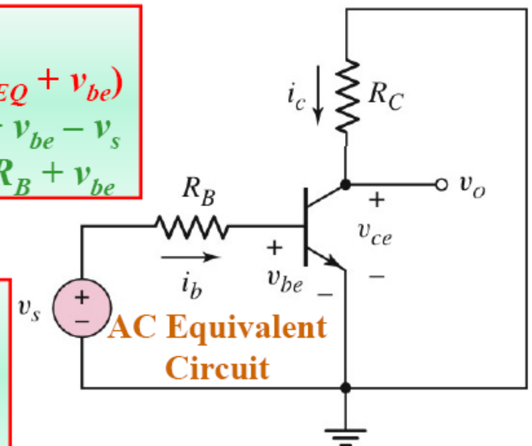


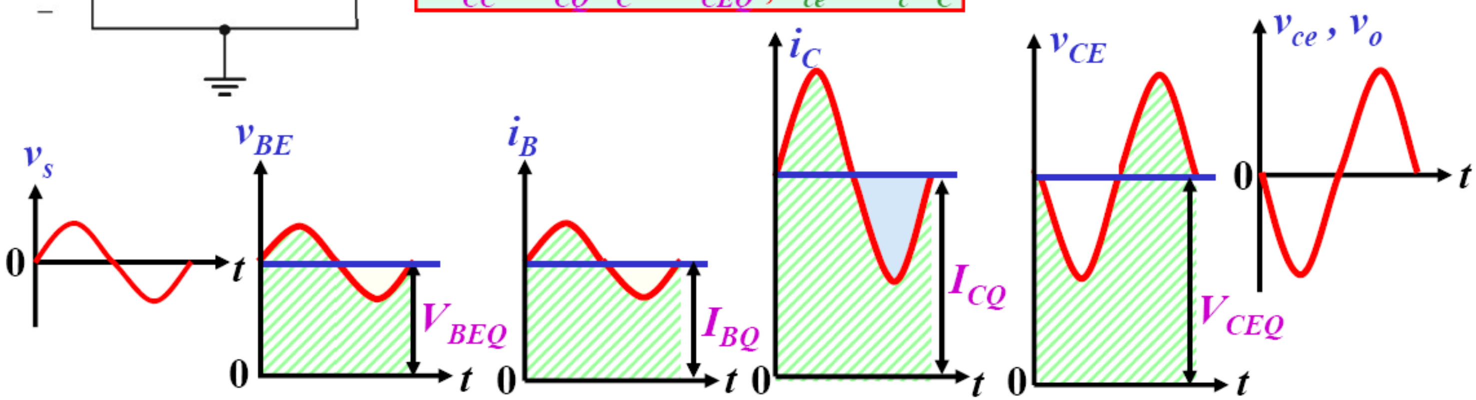
# Graphical Analysis of BJT Amplifier




$$
\begin{aligned}
V_{BB} + v_s &= i_B R_B + v_{BE} \\
&= (I_{BQ} + i_b) R_B + (V_{BEQ} + v_{be}) \\
V_{BB} - I_{BQ} R_B - V_{BEQ} &= i_b R_B + v_{be} - v_s \\
V_{BB} = I_{BQ} R_B + V_{BEQ} \;&;\; v_s = i_b R_B + v_{be}
\end{aligned}
$$

$$
\begin{aligned}
V_{CC} &= i_C R_C + v_{CE} \\
&= (I_{CQ} + i_c) R_C + (V_{CEQ} + v_{ce}) \\
V_{CC} - I_{CQ} R_C - V_{CEQ} &= i_c R_C + v_{ce} \\
V_{CC} = I_{CQ} R_C + V_{CEQ} \;&;\; v_{ce} = -i_c R_C
\end{aligned}
$$



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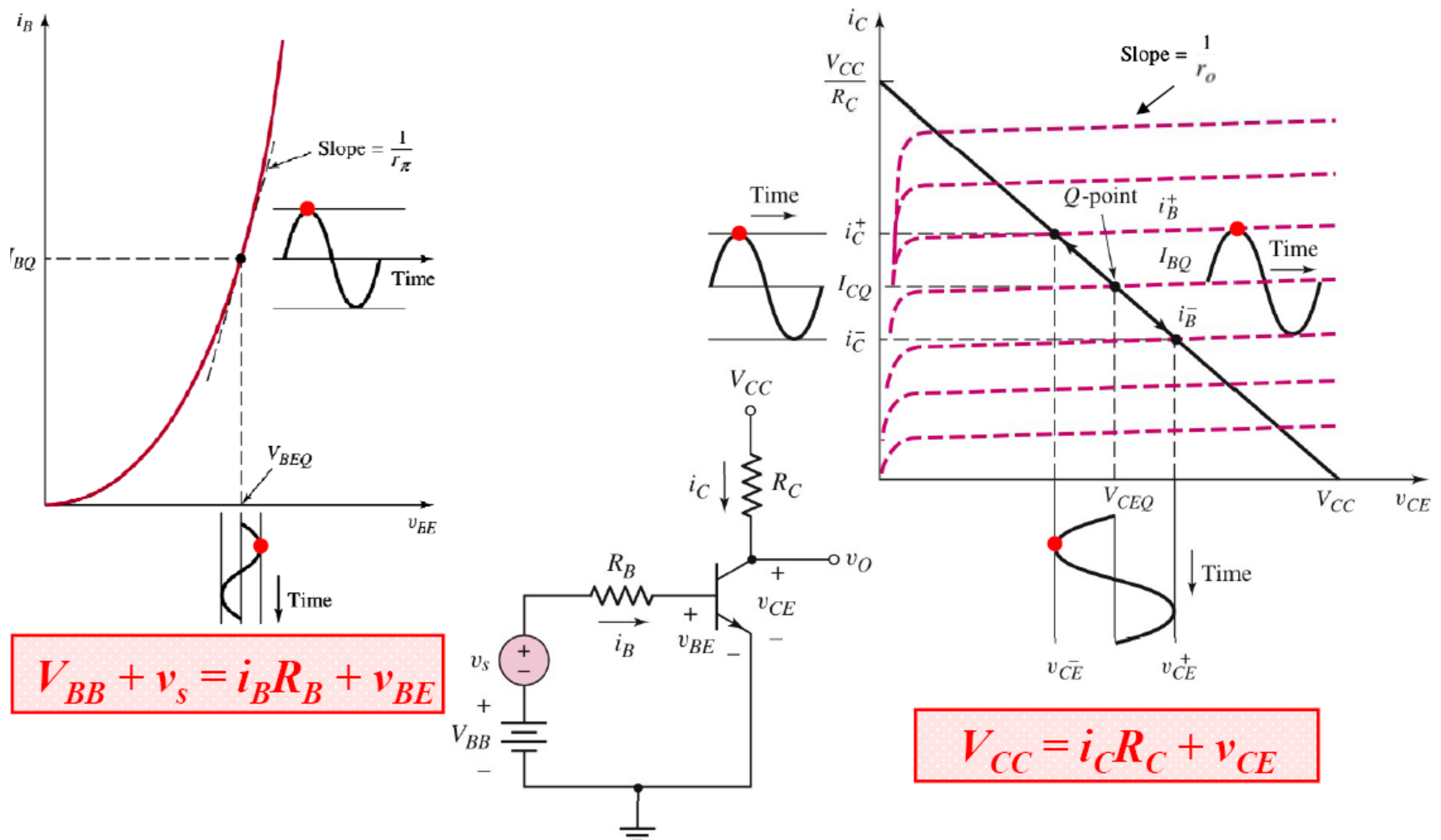
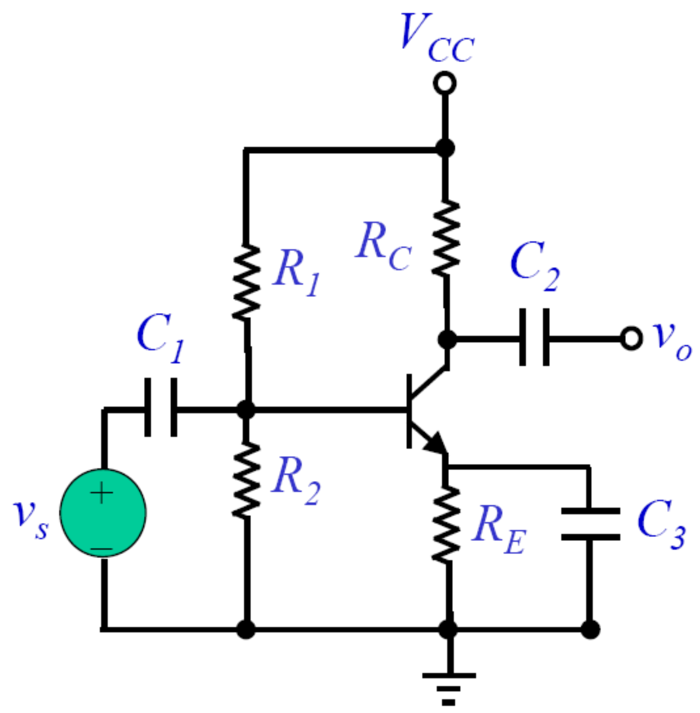



$$V_{BB} + v_s = i_B R_B + v_{BE}$$

$$V_{CC} = i_C R_C + v_{CE}$$

# Analysis of BJT Amplifiers

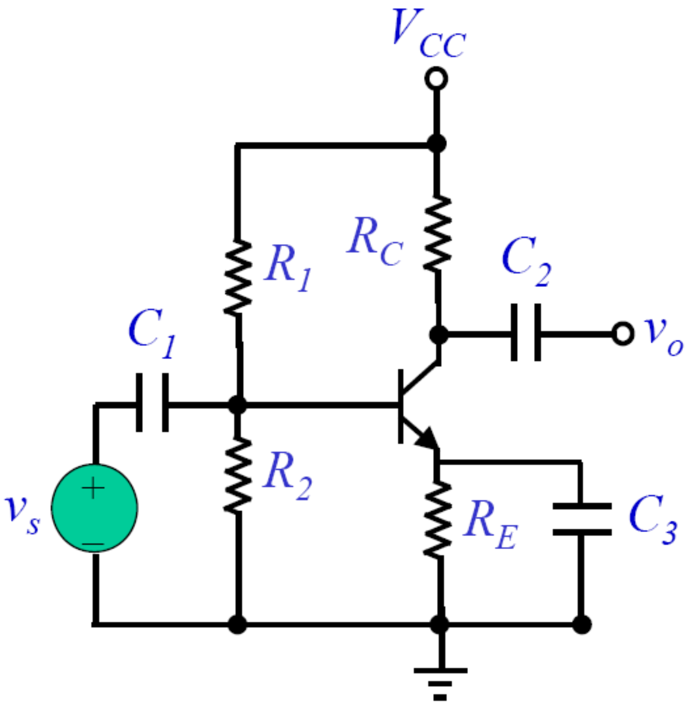
**Function of each component:**



# Analysis of BJT Amplifiers

**Function of each component:**

- Capacitors: Acting as an open circuit for a dc operation but a short circuit for an ac operation (If $f = 10$ kHz & $C = 10\ \mu$F, then $|Z_C| = (2\pi f C)^{-1} = 8\ \Omega$, which is usually smaller than $R_{TH} = R_1 // R_2$)



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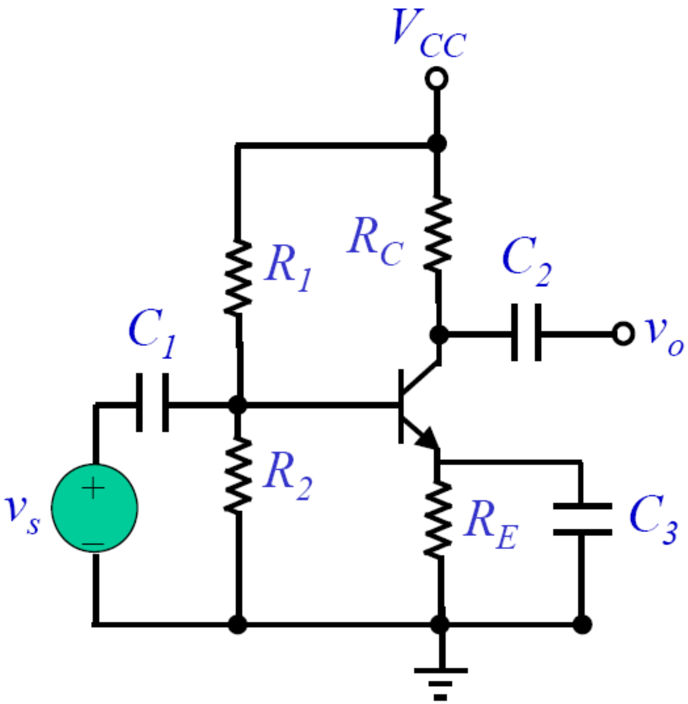
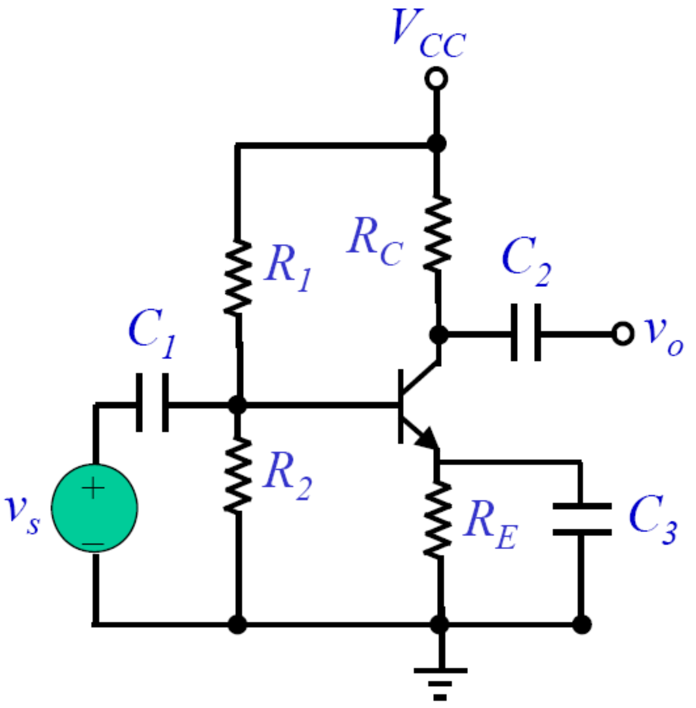
- $R_1$, $R_2$, $R_C$ & $R_E$: Setting dc biasing Q-point



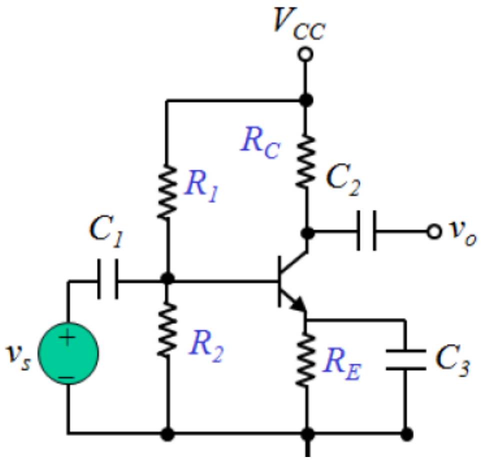
# Analysis of BJT Amplifiers

**Function of each component:**

- Capacitors: Acting as an open circuit for a dc operation but a short circuit for an ac operation (If $f = 10$ kHz & $C = 10\ \mu$F, then $|Z_C| = (2\pi f C)^{-1} = 8\ \Omega$, which is usually smaller than $R_{TH} = R_1//R_2$)
- $R_1$, $R_2$, $R_C$ & $R_E$: Setting dc biasing Q-point
- $R_C$: Converting $i_c$ variation into $v_{ce}$ (or $v_o$) variation (signal conversion)



# DC Analysis and Equivalent Circuits



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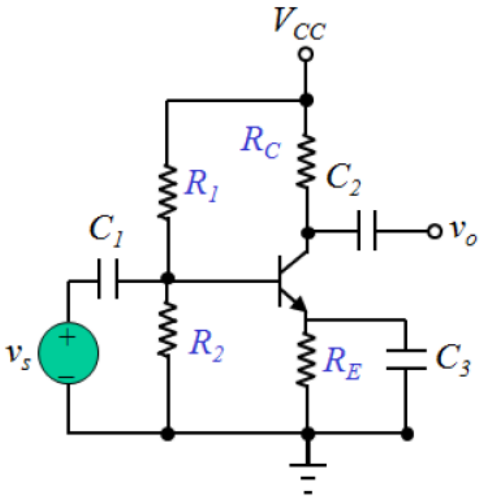
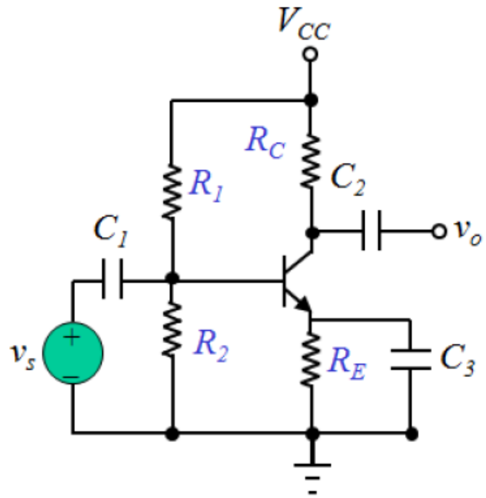
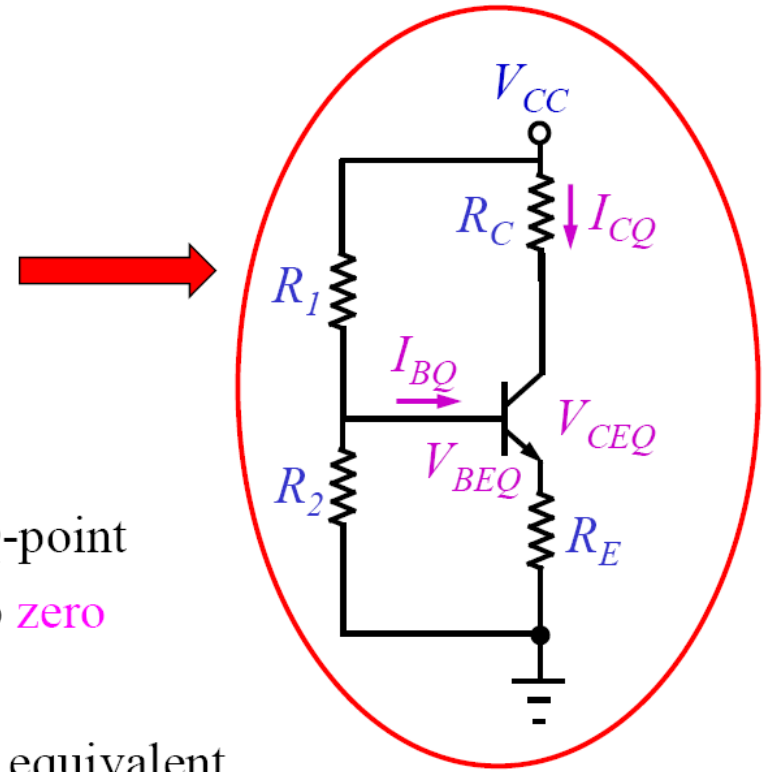



- To determine the dc biasing Q-point
  - Reduce all signal sources to zero
  - Open all capacitors
  - Draw & analyze the dc equivalent circuit

# DC Analysis and Equivalent Circuits

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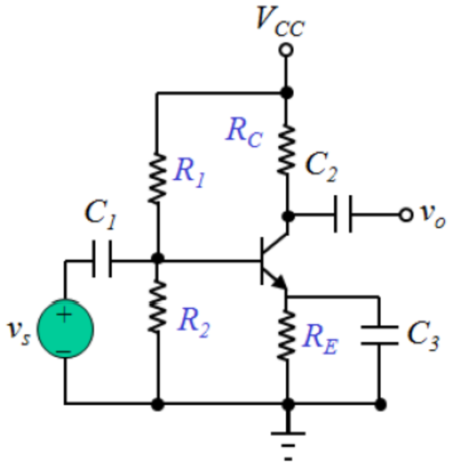
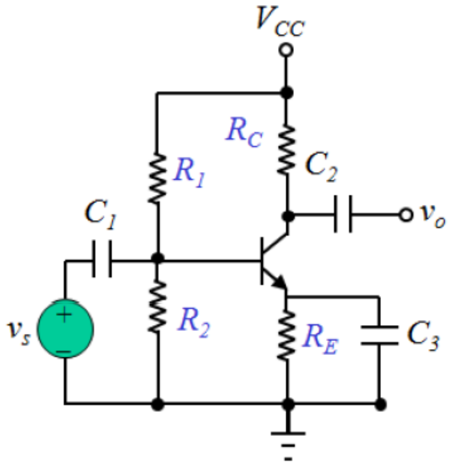
# AC Analysis and Equivalent Circuits

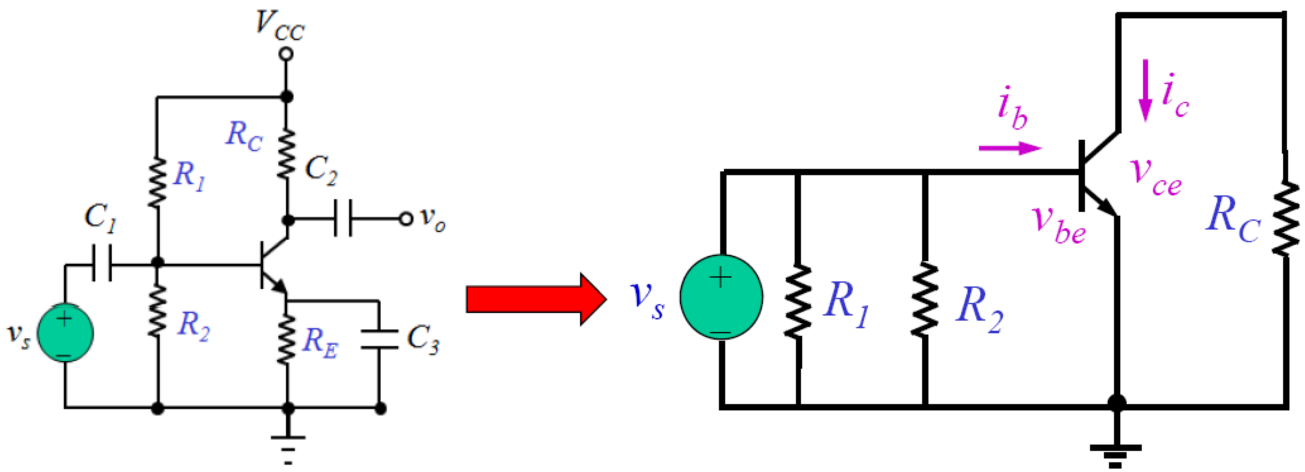


# AC Analysis and Equivalent Circuits




- To determine the ac characteristics (e.g., small-signal voltage gain, input & output impedances, frequency response, etc.)
  - Reduce all dc voltage sources to zero
  - Short all capacitors
  - Draw & analyze the ac equivalent circuit

# AC Analysis and Equivalent Circuits

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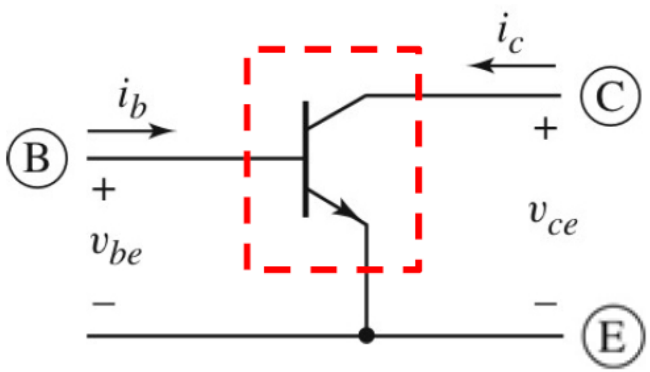
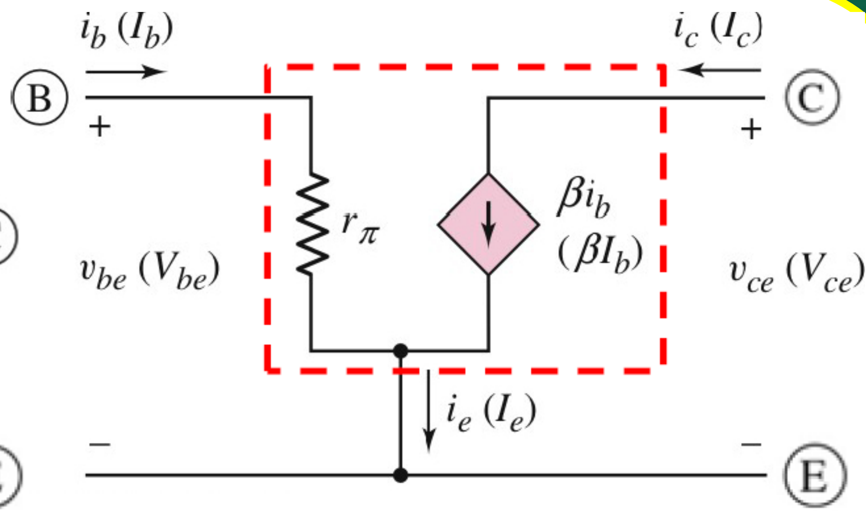
  - Draw & analyze the ac equivalent circuit

# Small Signal Hybrid-π Equivalent Circuit

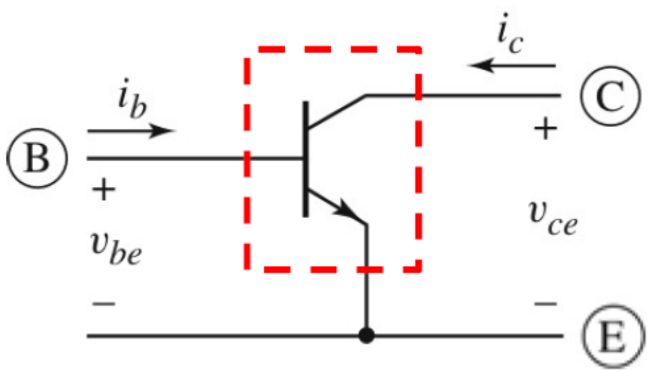



BJT as a small-signal, two-port network




Small-signal hybrid-$\pi$ equivalent circuit

# Small Signal Hybrid-π Equivalent Circuit

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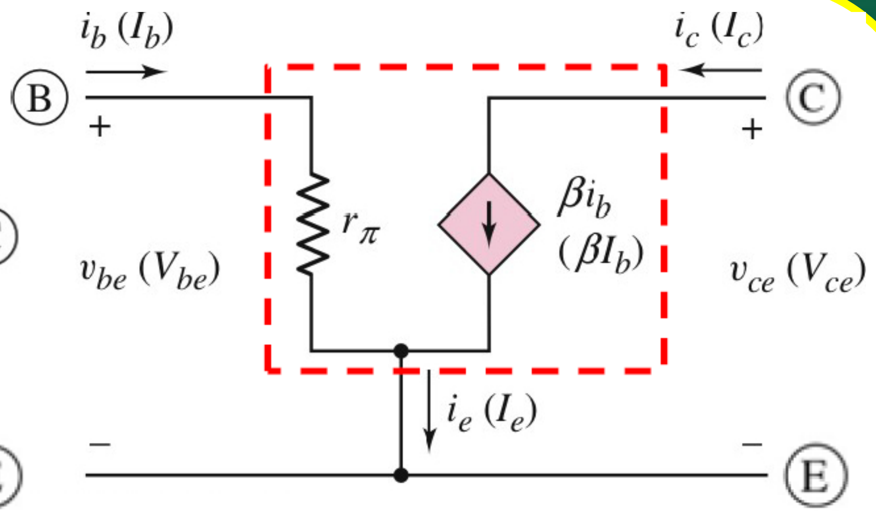
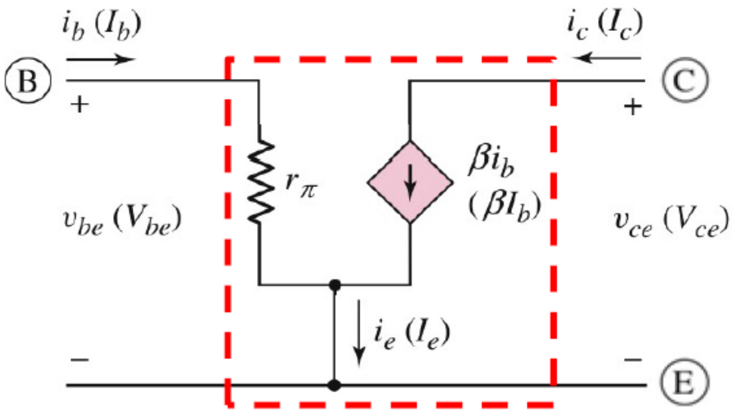


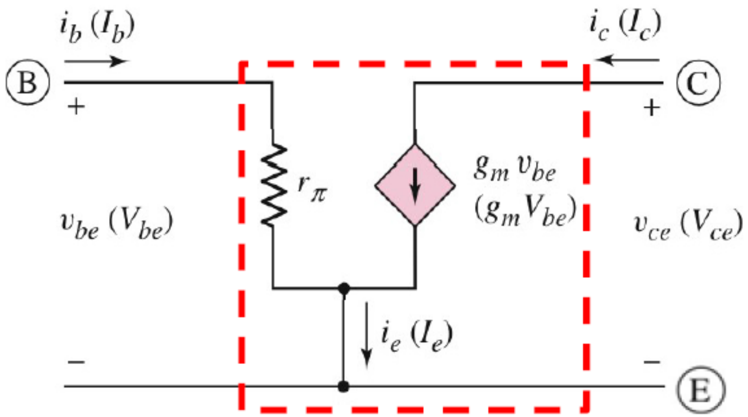

Small-signal hybrid-π equivalent circuit

- $\beta = i_c / i_b = I_c / I_b$ = common-emitter current gain
- $r_\pi = v_{be} / i_b = V_{be} / I_b = V_T / I_{BQ} = \beta V_T / I_{CQ}$ = small-signal resistance, where $V_T = kT / e$ = thermal voltage

# Small Signal Hybrid-π Equivalent Circuit

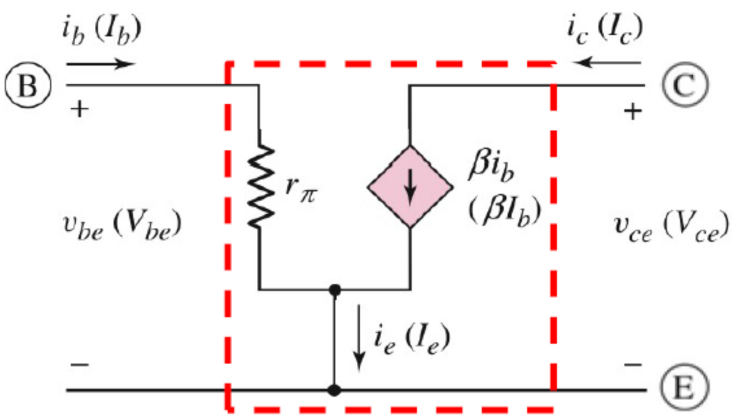


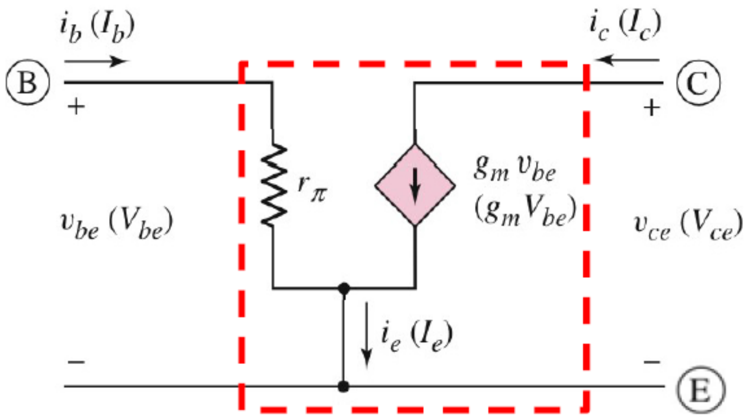

**With current gain parameter**




**With transconductance parameter**

# Small Signal Hybrid-π Equivalent Circuit



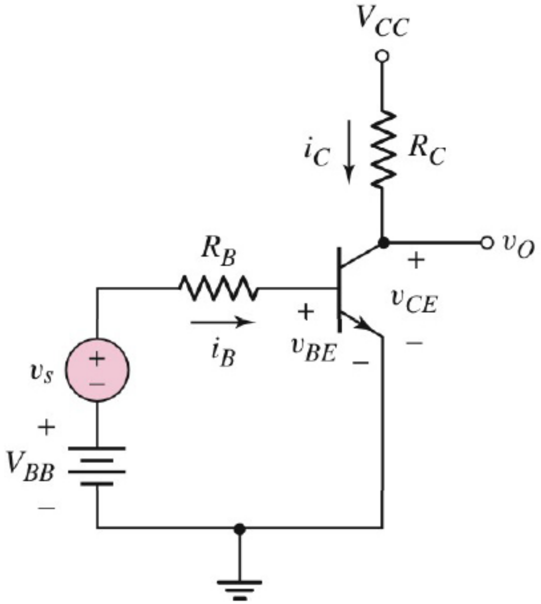




**With current gain parameter**

**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 & the assumption will be released later to include the "Early Effect".

# Small Signal Voltage Gain



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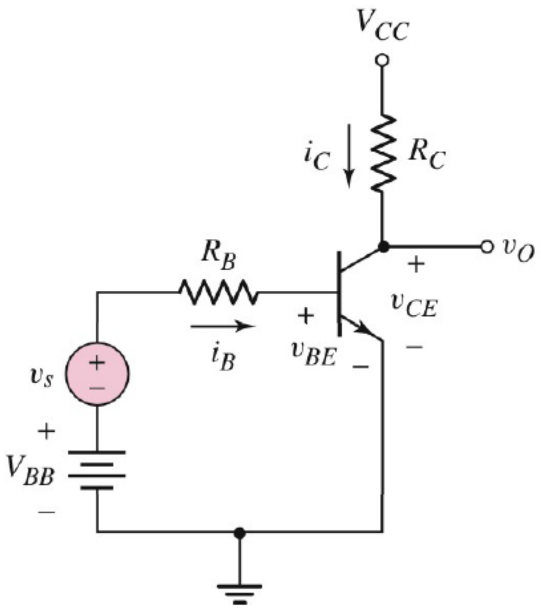


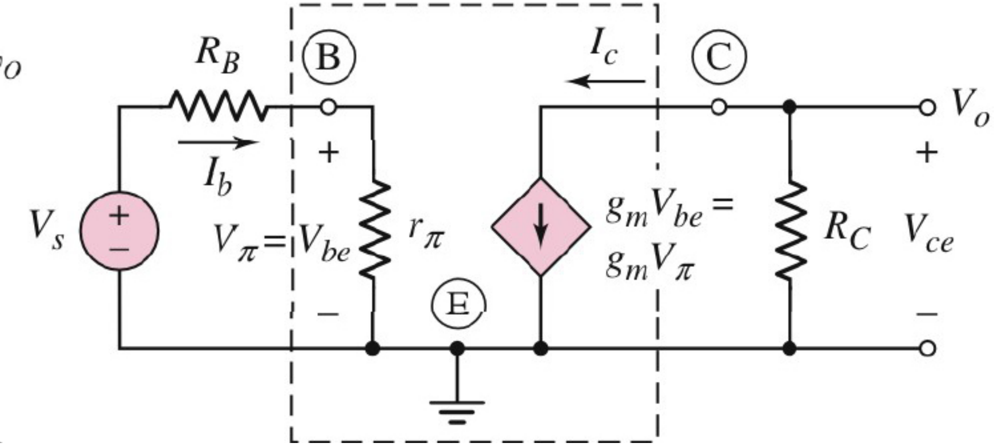

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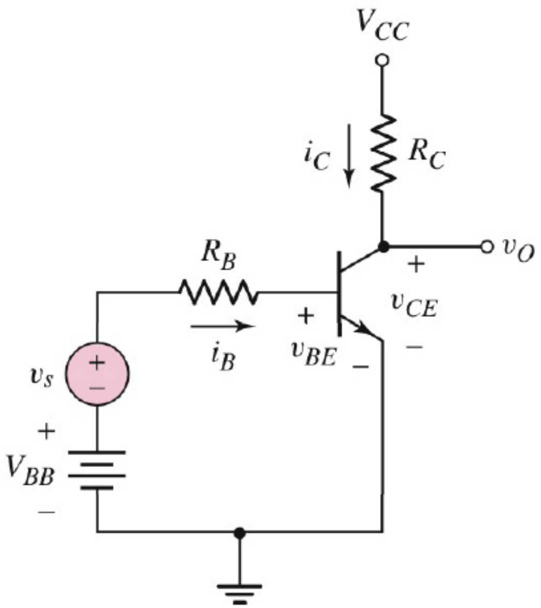
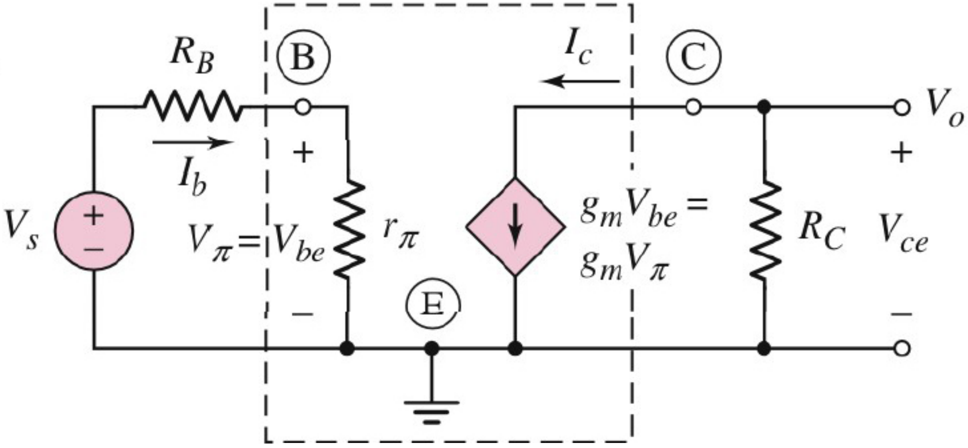
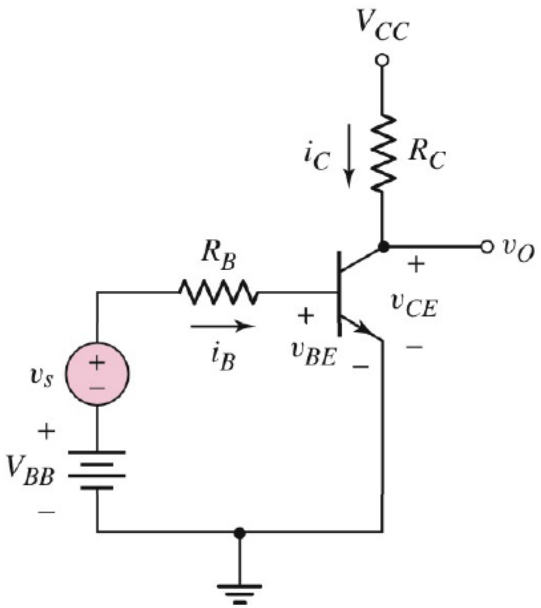


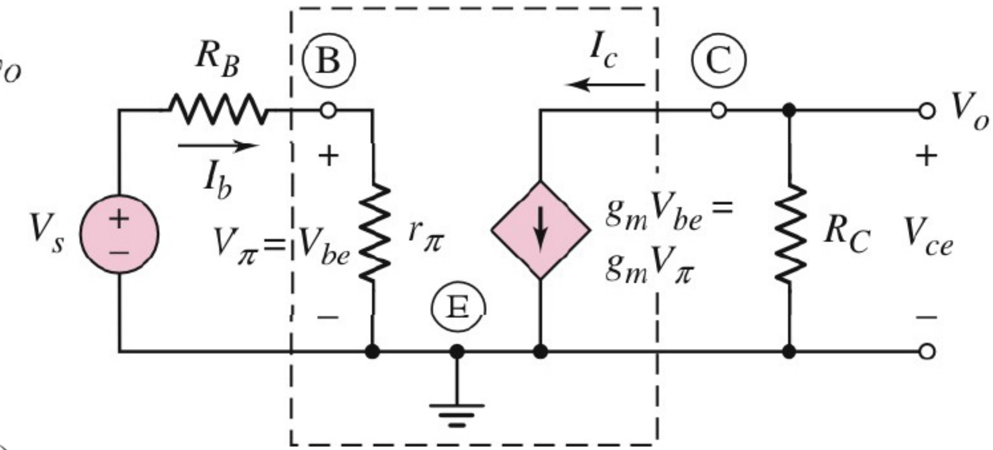




$$V_\pi = V_{be} = V_s \left( \frac{r_\pi}{r_\pi + R_B} \right)$$

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

# Small Signal Voltage Gain

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

Small-signal voltage gain:

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