Large-signal and small-signal analysis

Large-signal DC analysis

⇒ suitable for non-linear circuits

⇒ DC values I_B I_E I_C V_{BE} V_{CE}

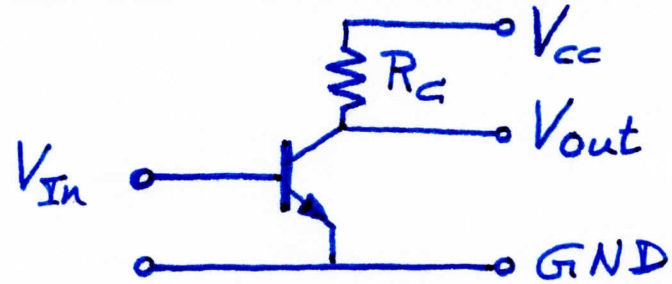
Small-signal AC analysis

⇒ we can linearize any circuit and make it suitable for small-signal AC analysis.

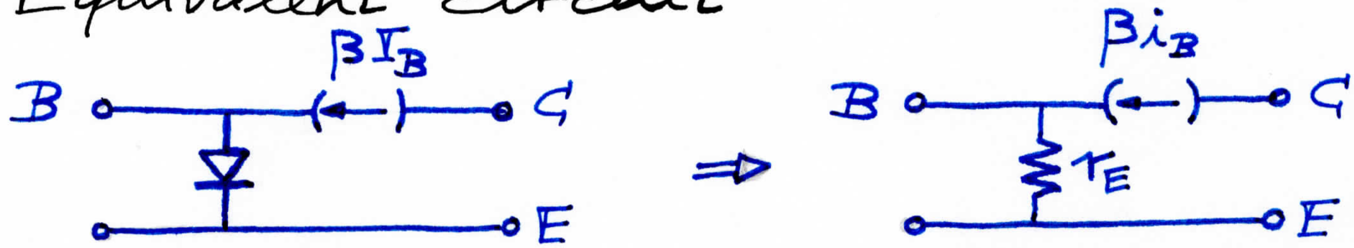
⇒ Superposition principle applies

⇒ AC values i_B i_E i_C v_{BE} v_{CE}

Primitive common-E BJT circuit

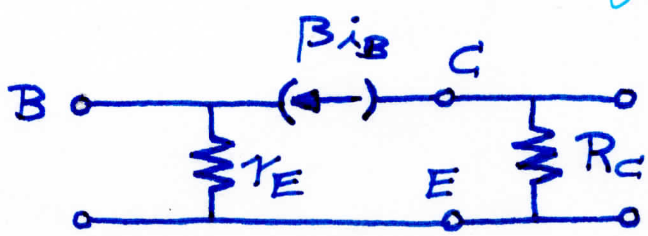


Equivalent circuit



Large signal   Small signal

Include R_C



Voltage amplification

$$A_{VOC} = \frac{V_{out}}{V_{in}} = \frac{-\beta\, i_B\, R_C}{i_E\, r_E} = \frac{-\beta\, i_B\, R_C}{(\beta+1)\, i_B\, r_E}$$

$$\approx \underline{-R_C/r_E}$$

Input impedance

$$Z_{in} = \frac{V_{in}}{i_{in}} = \frac{r_E\, i_E}{i_B} = r_E\,\frac{(\beta+1)\, i_B}{i_B} \approx \underline{\beta\, r_E}$$

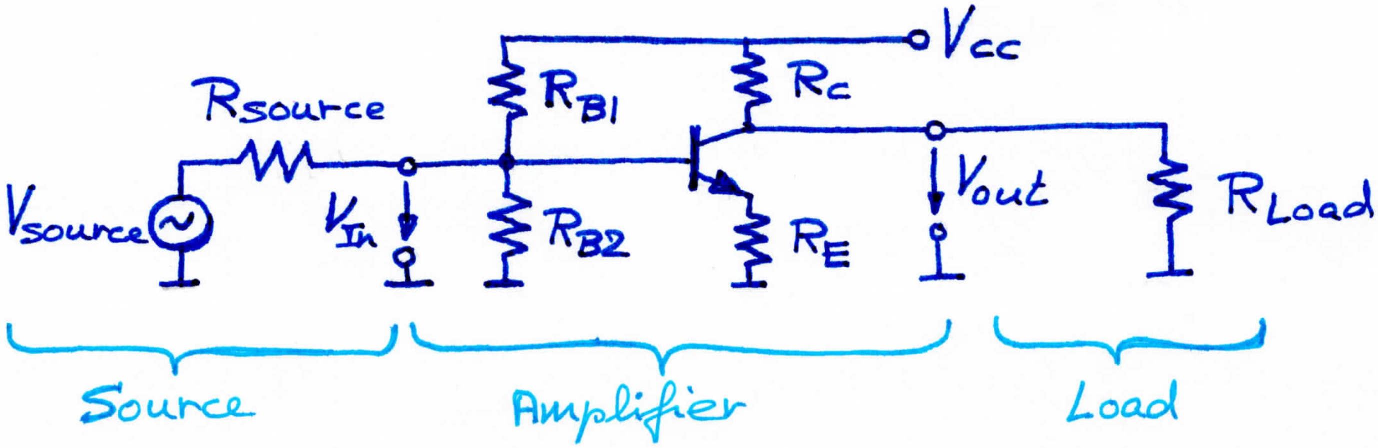
Output impedance

$$z_{out} = \frac{v_{out}}{i_{out}} = \frac{R_C\, i_C}{i_C} = R_C$$

Q: What is a disadvantage of the primitive common-E circuit?

Q: Where is the quiescent point (Q-point) of the primitive common-E circuit?

Small-signal analysis of common-E amplifier



Strictly speaking, this is not a common-E amplifier.

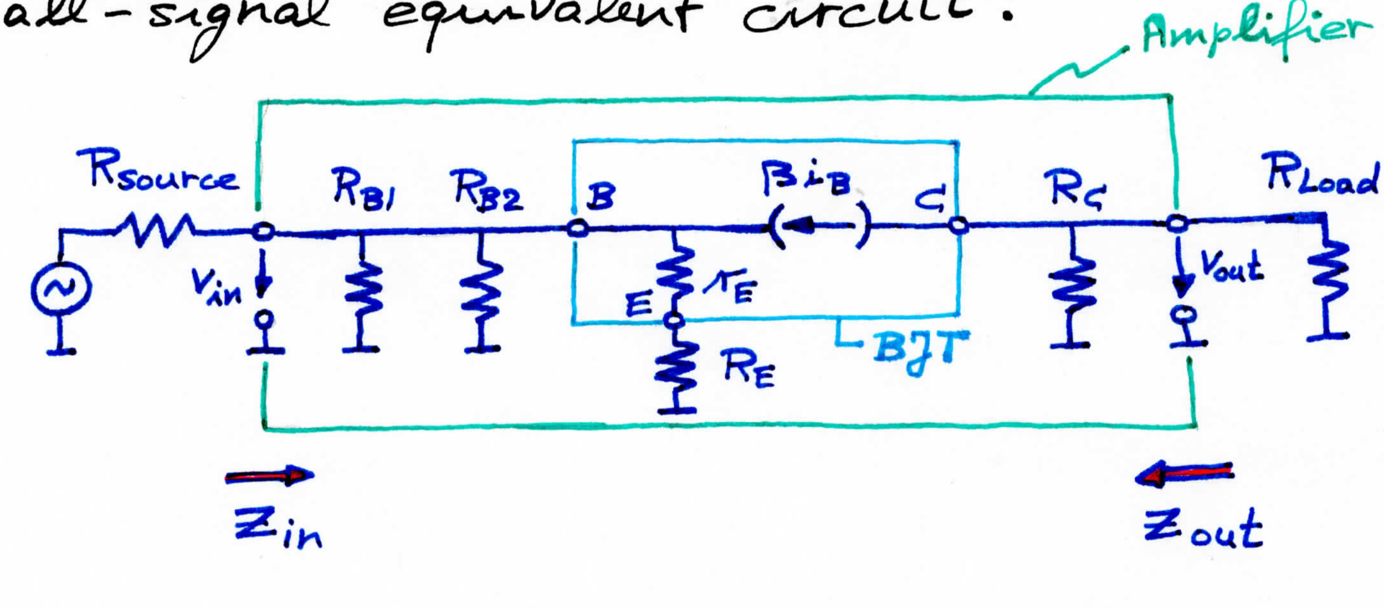
But for $R_E = 0$, it would be a common-E amp.

Previously, we determined the Q-point. $\Rightarrow r_E = \frac{V_t}{I_E}$.

$V_{cc} \Rightarrow$ Ideal voltage source $\Rightarrow$ Internal resistance?

$\Rightarrow$ zero.

Small-signal equivalent circuit:



Voltage amplification $= A_{voc} = \dfrac{V_{out}}{V_{in}}$

$\hookrightarrow$ voc = open circuit voltage
$\Rightarrow$ No load

$$V_{in} = (i_B + \beta i_B)(r_E + R_E) = i_B(\beta+1)(r_E+R_E)$$

$$\approx \beta i_B (r_E + R_E)$$

$$V_{out} = -\beta i_B R_C$$

$$\Rightarrow \boxed{A_{voc} = \frac{V_{out}}{V_{in}} = \frac{-\beta i_B R_C}{\beta i_B (r_E + R_E)} = \frac{-R_C}{r_E + R_E}}$$

Input impedance

Input impedance without considering R_{B1} & R_{B2}

$$z_{in} = \frac{V_{in}}{i_{in}} = \frac{(r_E + R_E)\, \overbrace{i_E}^{= i_B(\beta+1)}}{i_B} = (r_E + R_E)(\beta+1)$$

$$\approx (r_E + R_E)\beta$$

Input impedance considering R_{B1} & R_{B2}

$$z_{in} = \frac{V_{in}}{i_{in}} = (r_E + R_E)\beta \parallel \underbrace{(R_{B1} \parallel R_{B2})}_{R_B}$$

$$= \beta(r_E + R_E) \parallel R_B$$

Output impedance

Applying a voltage to the output terminals, which impedance would we "see"?

Recall: Resistance of $\bullet\!-\!(\leftarrow)\!-\!\circ = \infty$

$$z_{out} = \frac{V_{out}}{i_{out}} = \underline{\underline{R_C}}$$

Current amplification $= A_{ISC} = \dfrac{i_{out}}{i_{in}}$

↳ ISC = Short circuit current

$\Rightarrow R_L = 0$

$$A_{ISC} = \frac{i_{out}}{i_{in}} = \frac{\beta\, i_B}{\underbrace{i_{RB} + i_B}} \approx \beta\, \frac{i_B}{i_{RB}}$$

↳ Note: $i_{RB} \gg i_B$. Why?

$$i_B = \frac{V_{in}}{(r_E + R_E)\beta}$$

$$i_{RB} = \frac{V_{in}}{R_B} \qquad (R_B = R_{B1} \parallel R_{B2})$$

$$\Rightarrow A_{ISC} = \beta\, \frac{V_{in}}{(r_E + R_E)\beta}\, \frac{R_B}{V_{in}} = \underline{\underline{\frac{R_B}{r_E + R_E}}}$$

Q: How to obtain a high current amplification?

Capacitive coupling in amplifiers

Recall: $Z_C = \frac{1}{j\omega C}$

DC $\Rightarrow \omega = 0 \Rightarrow Z_C = \infty$

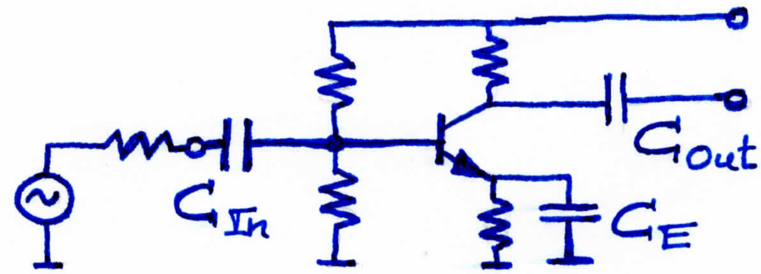
$\Rightarrow$ For DC, the C is an OC

AC $\Rightarrow \omega$ = finite, e.g. 1 kHz

$\Rightarrow$ Assume that C is large $\Rightarrow Z_C = 0$

$\Rightarrow$ For AC, the C is a SC

Consider the following circuit:



Q: What is purpose of C_{In}, C_{out}, and C_E?

$\Rightarrow C_{In}$ decouples input from DC bias

$\Rightarrow C_{out}$ decouples output from DC bias

$\Rightarrow R_E$ provides operational stability but reduces A_{voc}. Bypassing R_E increases A_{voc}.