The Common Emitter (CE) Amplifier

For the CE amplifier, the signal is applied to the base and the output is taken from the collector. A typical capacitively coupled CE amplifier is shown.

The dc bias currents and voltages are solved for assuming the capacitors are open circuits. For the ac small-signal solution, set $V^+ = V^- = 0$ and assume the capacitors are ac short circuits. The circuit reduces to
The input and output resistances are given by

\[ R_{\text{in}} = R_1 \parallel R_2 \parallel R_{ib} \]
\[ R_{\text{out}} = R_c \parallel R_{ic} \]

where

\[ R_{ib} = R_x + R_{\pi} + R_{te} \frac{(1+\beta) R_0 + R_{te}}{R_0 + R_{te} + R_{tc}} \]
\[ R_{te} = R_E \parallel R_3 \quad R_{tc} = R_c \parallel R_L \]
\[ R_{ic} = \frac{\frac{1}{R_{ic} + R_{te}}}{1 - \frac{\alpha R_{te}}{R_x + R_{te}}} \]
\[ R'_e = \frac{R_{tb} + R_x}{1+\beta} + R_e \quad R_{tb} = R_3 \parallel R_1 \parallel R_2 \]
Looking out of the base, the Thévenin equivalent circuit has the values

\[ V_{tb} = V_C - \frac{R_{11}R_2}{R_S + R_{11}R_2} \]

\[ R_{tb} = R_S || R_{11} || R_2 \]

To solve for \( V_0 \), we replace the BJT with the Norton collector circuit.

\[ i_c(sc) \] is given by

\[ i_c(sc) = G_{mb} V_{tb} \]

where

\[ G_{mb} = \frac{\alpha}{r_e + R_{te} || R_o} \]

\[ \frac{P_0 - R_{te}/\beta}{R_o + R_{te}} \]
The output voltage is given by

\[ V_o = -i_c(\infty) \frac{R_{ic} \parallel R_c \parallel R_L}{R_{s} + R_{1} \parallel R_L} \]

\[ = -G_m V_t \frac{R_{1} \parallel R_L}{R_s + R_{1} \parallel R_L} \frac{R_{1} \parallel R_L}{R_{s} + R_{1} \parallel R_L} \]

Thus the voltage gain is given by

\[ A_v = \frac{V_o}{V_t} \]

\[ = -\frac{R_{1} \parallel R_L}{R_s + R_{1} \parallel R_L} G_m \frac{R_{1} \parallel R_L}{R_{s} + R_{1} \parallel R_L} \]

The above solution is exact. Often, an approximate solution is made for rough calculations. Assume that \( R_x = 0 \) and \( R_0 = \infty \) for the approximations. In this case

\[ R_{ic} = (1+\beta) (R_e + R_{te}) \]

\[ = R_{\pi} + (1+\beta) R_{te} \]

\[ i_c = \alpha i_e = g_m V_{be} = g_m (V_b - V_e) \]
The signal equivalent circuit is

\[ V_b = V_{tb} \frac{R_{ib}}{R_{tb} + R_{ib}} \]

\[ V_e = \frac{I_c}{\alpha} R_{te} \]

\[ I_c = g_m (V_b - V_e) = g_m (V_b - \frac{I_c}{\alpha} R_{te}) \]

\[ \Rightarrow I_c = \frac{g_m V_b}{1 + \frac{g_m R_{te}}{\alpha}} \]

\[ V_o = -I_c R_{tc} = -\frac{g_m V_b}{1 + \frac{g_m R_{te}}{\alpha}} R_{tc} \]

\[ = -V_{tb} \frac{R_{ib}}{R_{tb} + R_{ib}} \frac{g_m R_{tc}}{1 + \frac{g_m R_{te}}{\alpha}} \]

\[ = \frac{R_{11} R_2}{R_s + R_{11} R_2} \frac{R_{ib}}{R_{tb} + R_{ib}} \frac{g_m R_{tc}}{1 + \frac{g_m R_{te}}{\alpha}} \]

\[ \Rightarrow A_v = \frac{V_o}{V_b} \]

\[ = -\frac{R_{11} R_2}{R_s + R_{11} R_2} \frac{R_{ib}}{R_{tb} + R_{ib}} \frac{g_m R_{tc}}{1 + \frac{g_m R_{te}}{\alpha}} \]
An Alternate Approximate Solution

If $r_x = 0$ and $r_0 = \infty$, $R_{ab}$ is given by

$$R_{ab} = (1+\beta) (r_e + R_{te}) = r_e + (1+\beta) R_{te}$$

$$i_b = \frac{v_{tb}}{R_{tb} + R_{ab}}$$

$$i_c = \beta i_b$$

$$v_o = -i_c R_{tc} = -v_{tb} \frac{\beta R_{tc}}{R_{tb} + R_{ab}}$$

$$= -v_i \frac{R_{11} R_2}{R_s + R_{11} R_2} \frac{\beta R_{tc}}{R_{tb} + R_{ab}}$$

$$\Rightarrow \text{Av} = \frac{v_o}{v_i} = -\frac{R_{11} R_2}{R_s + R_{11} R_2} \frac{\beta R_{tc}}{R_{tb} + R_{ab}}$$