CE Amplifier Example

This example makes use of the expressions derived in class for the common-collector amplifier. For the circuits in the figure, it is given that \( V^+ = 10 \text{ V} \), \( V^- = -10 \text{ V} \), \( R_s = 5 \text{ k}\Omega \), \( R_1 = 100 \text{ k}\Omega \), \( R_2 = 120 \text{ k}\Omega \), \( R_E = 2 \text{ k}\Omega \), \( R_3 = 51 \text{ k}\Omega \), \( R_C = 2.4 \text{ k}\Omega \), \( R_L = 10 \text{ k}\Omega \), \( V_{BE_{npn}} = V_{EB_{pnp}} = 0.65 \text{ V} \), \( V_T = 0.025 \text{ V} \), \( \alpha = 0.99 \), \( \beta = 99 \), \( r_x = 20 \Omega \), and \( r_0 = 50 \text{ k}\Omega \). The capacitors are ac short circuits and dc open circuits. The equations below are written for the NPN circuit. By symmetry, the solutions are the same for the PNP circuit.

![NPN and PNP circuits](image)

**DC Solution**

The dc solution is the same as for the CC amplifier and is repeated. To solve for \( I_E \), replace the capacitors with open circuits. Look out the base and emitter and form Thévenin equivalent circuits. We have

\[
V_{BB} = \frac{V^+ R_2 + V^- R_1}{R_1 + R_2} = \frac{10 \times 120 \text{ k}\Omega}{100 \text{ k}\Omega + 120 \text{ k}\Omega} - \frac{10 \times 100 \text{ k}\Omega}{100 \text{ k}\Omega + 120 \text{ k}\Omega} = \frac{10}{11}
\]

\[
R_{BB} = R_1 || R_2 = 100 \text{ k}\Omega || 120 \text{ k}\Omega = 54.55 \text{ k}\Omega
\]

\[
V_{EE} = V^-
\]

\[
R_{EE} = R_E
\]

Write the base-emitter loop bias equation and solve for \( I_E \) to obtain

\[
I_E = \frac{V_{BB} - V_{BE} - V_{EE}}{R_{BB}/(1 + \beta) + R_{EE}} = \frac{10/11 - 0.65 - (-10)}{54.55 \text{ k}\Omega/(1 + 99) + 2 \text{ k}\Omega} = 4.031 \text{ mA}
\]

The ac emitter intrinsic resistance is

\[
r_e = \frac{V_T}{I_E} = \frac{25 \text{ mV}}{4.031 \text{ mA}} = 6.202 \Omega
\]
AC Solution – Method 1

This is based on the “full-blown” or first method given in class. Zero the dc supplies and short the capacitors. Look out the base and make a Thévenin equivalent circuit. We have

\[
v_{tb} = v_s \frac{R_1||R_2}{R_s + R_1||R_2} = v_s \frac{100\, \text{k}\Omega || 120\, \text{k}\Omega}{5\, \text{k}\Omega + 100\, \text{k}\Omega || 120\, \text{k}\Omega} = \frac{v_s}{1.092} = 0.9160v_s
\]

\[
R_{tb} = R_s||R_1||R_2 = 5\, \text{k}\Omega || 100\, \text{k}\Omega || 120\, \text{k}\Omega = 4.580\, \text{k}\Omega
\]

The Thévenin equivalent circuit looking into the \(i'_{e}\) branch is \(v_{tb}\) in series with \(r'_{e}\), where

\[
r'_{e} = \frac{R_{tb} + r_x}{1 + \beta} + r_e = \frac{4.580\, \text{k}\Omega + 20}{1 + 99} + 6.202 = 52.20\, \Omega
\]

The resistance looking out of the emitter is

\[
R_{te} = R_E||R_3 = 2\, \text{k}\Omega || 51 = 49.73
\]

The resistance looking out of the collector is

\[
R_{tc} = R_C||R_L = 2.4\, \text{k}\Omega || 10\, \text{k}\Omega = 1.936\, \text{k}\Omega
\]

The collector output resistance is

\[
r_{ic} = \frac{r_0 + r'_{e}||R_{tc}}{1 - \frac{\alpha R_{te}}{r'_{e} + R_{te}}} = \frac{50\, \text{k}\Omega + 52.20||49.73}{1 - 0.99 \times 49.73/(49.73 + 52.20)} = 97.76\, \text{k}\Omega
\]

The short circuit collector output current is

\[
i_{c(scc)} = G_{mb}v_{tb} = \frac{\alpha}{r'_{e} + R_{tc} + r_{e}}\left(\frac{r_0 - \beta R_{te}}{r_{e} + R_{tc}}\right)v_{tb}
\]

\[
= \frac{0.99}{52.20 + 49.73} \frac{50\, \text{k}\Omega - 49.73/99}{50\, \text{k}\Omega + 52.20||49.73} \frac{v_{tb}}{103.0} = \frac{v_{tb}}{112.4} = \frac{v_s}{97.76\, \text{k}\Omega || 1.936\, \text{k}\Omega = -16.89v_s}
\]

Thus the voltage gain is

\[
\frac{v_o}{v_s} = -16.87
\]

The output resistance is

\[
r_{out} = R_{e}||r_{ic} = 2.4\, \text{k}\Omega || 97.76\, \text{k}\Omega = 2.342\, \text{k}\Omega
\]

The resistance looking into the base is

\[
r_{ib} = r_x + (1 + \beta) r_e + R_{tc} \frac{(1 + \beta) r_0 + R_{tc}}{r_0 + R_{te} + R_{tc}}
\]

\[
= 20 + (1 + 99) 6.202 + 49.73 \frac{(1 + 99) 50\, \text{k}\Omega + 1.936\, \text{k}\Omega}{50\, \text{k}\Omega + 49.73 + 1.936\, \text{k}\Omega}
\]

\[
= 5.425\, \text{k}\Omega
\]

The input resistance is

\[
r_{in} = R_1||R_2||r_{ib} = 100\, \text{k}\Omega || 120\, \text{k}\Omega \frac{5.425\, \text{k}\Omega}{5.425\, \text{k}\Omega = 4.934\, \text{k}\Omega}
\]
AC Solution – Method 2

This is based on the $r_0$ approximations where the current through $r_0$ is neglected in calculating $i_{c(sc)}$ but not in calculating $r_{ic}$. In this case, $i_{c(sc)}$ is

$$i_{c(sc)} = \frac{\alpha}{r_c' + R_{te}} v_{tb} = \frac{0.99}{52.20 + 49.73} v_{tb} = \frac{v_{tb}}{103.0} = \frac{v_s}{111.3}$$

The output voltage is

$$v_o = -i_{c(sc)} r_{ic} R_{tc} = \frac{-v_s}{111.3} \times 97.76 \, \text{k}\Omega \times 1.936 \, \text{k}\Omega = -16.89 v_s$$

Thus the voltage gain is

$$\frac{v_o}{v_s} = -16.89$$

This is 0.12% higher than for the “full-blown” method. This illustrates how accurate the approximate method is.

The solutions for $r_{out}$ and $r_{in}$ are the same as for Method 1.