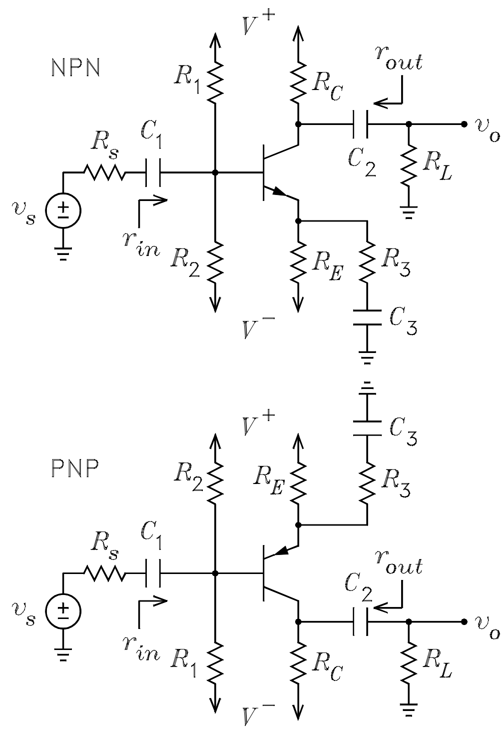
CE Amplifier Example

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 $V^+ = 10\,\mathrm{V}$, $V^- = -10\,\mathrm{V}$, $R_s = 5\,\mathrm{k\Omega}$, $R_1 = 100\,\mathrm{k\Omega}$, $R_2 = 120\,\mathrm{k\Omega}$, $R_E = 2\,\mathrm{k\Omega}$, $R_3 = 51\,\mathrm{k\Omega}$, $R_C = 2.4\,\mathrm{k\Omega}$, $R_L = 10\,\mathrm{k\Omega}$, $V_{BE\mathrm{npn}} = V_{EB\mathrm{pnp}} = 0.65\,\mathrm{V}$, $V_T = 0.025\,\mathrm{V}$, $\alpha = 0.99$, $\beta = 99$, $r_x = 20\,\Omega$, and $r_0 = 50\,\mathrm{k\Omega}$. 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.



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

$$\begin{aligned}
V_{BB} &= \frac{V^+R_2 + V^-R_1}{R_1 + R_2} = 10\frac{120\,\mathrm{k\Omega}}{100\,\mathrm{k\Omega} + 120\,\mathrm{k\Omega}} - 10\frac{100\,\mathrm{k\Omega}}{100\,\mathrm{k\Omega} + 120\,\mathrm{k\Omega}} = \frac{10}{11} \\
R_{BB} &= R_1 \| R_2 = 100\,\mathrm{k\Omega} \| 120\,\mathrm{k\Omega} = 54.55\,\mathrm{k\Omega} \\
V_{EE} &= V^- \\
R_{EE} &= R_E
\end{aligned}$$

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

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

The ac emitter intrinsic resistance is

$$r_e = \frac{V_T}{I_E} = \frac{25\,\mathrm{mV}}{4.031\,\mathrm{mA}} = 6.202\,\Omega$$

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

$$\begin{aligned} v_{tb} &= v_s \frac{R_1 \| R_2}{R_s + R_1 \| R_2} = v_s \frac{100\,\text{k}\Omega \| 120\,\text{k}\Omega}{5\,\text{k}\Omega + 100\,\text{k}\Omega \| 120\,\text{k}\Omega} = \frac{v_s}{1.092} = 0.9160 v_s \\ R_{tb} &= R_s \| R_1 \| R_2 = 5\,\text{k}\Omega \| 100\,\text{k}\Omega \| 120\,\text{k}\Omega = 4.580\,\text{k}\Omega \end{aligned}$$

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

$$r_{ic} = \frac{r_0 + r'_e \| R_{te}}{1 - \alpha R_{te} / \left(r'_e + R_{te}\right)} = \frac{50\,\text{k}\Omega + 52.20 \| 49.73}{1 - 0.99 \times 49.73 / \left(49.73 + 52.20\right)} = 97.76\,\text{k}\Omega$$

The short circuit collector output current is

$$\begin{aligned} i_{c(\text{sc})} &= G_{mb} v_{tb} = \frac{\alpha}{r'_e + R_{te}} \frac{r_0 - R_{te}/\beta}{r_0 + r'_e \| R_{te}} v_{tb} \\ &= \frac{0.99}{52.20 + 49.73} \frac{50\,\text{k}\Omega - 49.73/99}{50\,\text{k}\Omega + 52.20 \| 49.73} v_{tb} = \frac{v_{tb}}{103.0} = \frac{v_s}{112.4} \end{aligned}$$

The output voltage is given by

$$v_o = -i_{c(sc)} r_{ic} \| R_{tc} = \frac{-v_s}{112.4} 97.76\,\text{k}\Omega \| 1.936\,\text{k}\Omega = -16.89 v_s$$

Thus the voltage gain is

$$\frac{v_o}{v_s} = -16.87$$

The output resistance is

$$r_{\text{out}} = R_c \| r_{ic} = 2.4\,\text{k}\Omega \| 97.76\,\text{k}\Omega = 2.342\,\text{k}\Omega$$

The resistance looking into the base is

$$\begin{aligned} r_{ib} &= r_x + (1+\beta) r_e + R_{te} \frac{(1+\beta) r_0 + R_{tc}}{r_0 + R_{te} + R_{tc}} \\ &= 20 + (1+99)\, 6.202 + 49.73 \frac{(1+99)\, 50\,\text{k}\Omega + 1.936\,\text{k}\Omega}{50\,\text{k}\Omega + 49.73 + 1.936\,\text{k}\Omega} \\ &= 5.425\,\text{k}\Omega \end{aligned}$$

The input resistance is

$$r_{\text{in}} = R_1 \| R_2 \| r_{ib} = 100\,\text{k}\Omega \| 120\,\text{k}\Omega \| 5.425\,\text{k}\Omega = 4.934\,\text{k}\Omega$$

AC Solution – Method 2

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

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

The output voltage is

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

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.