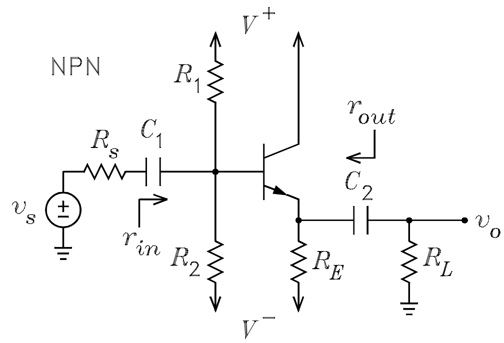
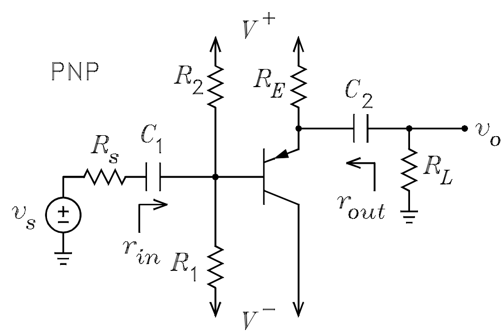
CC Amplifier Example

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 $V^+ = 10\,\text{V}$, $V^- = -10\,\text{V}$, $R_s = 5\,\text{k}\Omega$, $R_1 = 100\,\text{k}\Omega$, $R_2 = 120\,\text{k}\Omega$, $R_E = 2\,\text{k}\Omega$, $R_L = 1\,\text{k}\Omega$, $V_{BE\text{npn}} = V_{EB\text{pnp}} = 0.65\,\text{V}$, $V_T = 0.025\,\text{V}$, $\alpha = 0.99$, $\beta = 99$, $r_x = 20\,\Omega$, and $r_0 = 50\,\Omega$. 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. To understand the solution, you should draw the equivalent circuits for each step.





DC Solution

To solve for I_E, replace the capacitors with open circuits. Look out the base and emitter and form Thévenin equivalent circuits. We have

$$\begin{aligned}
V_{BB} &= \frac{V^+R_2 + V^-R_1}{R_1 + R_2} = \frac{10 \times 120\,\text{k}\Omega - 10 \times 100\,\text{k}\Omega}{100\,\text{k}\Omega + 120\,\text{k}\Omega} = \frac{10}{11} \\
R_{BB} &= R_1 \| R_2 = 100\,\text{k}\Omega \| 120\,\text{k}\Omega = 54.55\,\text{k}\Omega \\
V_{EE} &= V^- = -10 \\
R_{EE} &= R_E = 2\,\text{k}\Omega
\end{aligned}$$

The bias equation for I_E is obtained from a loop equation in the base-emitter loop. The emitter current is given by

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

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

Zero the dc supplies and short the capacitors. Look out of the base and make a Thévenin equivalent circuit. We have

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

Because $R_{tc} = 0$, we can use the simplified T model (rather than the Thévenin emitter circuit) to solve for v_o. The Thévenin equivalent circuit looking into the i_e' branch is v_{tb} in series with r_e' given by

$$r_e' = \frac{R_{tb} + r_x}{1 + \beta} + r_e = \frac{4.580\,\mathrm{k}\Omega + 20}{1 + 99} + 6.202 = 52.20\,\Omega$$

The resistance seen looking out of the emitter is

$$R_{te} = R_E \| R_L = 666.7\,\Omega$$

By voltage division, v_o is given by

$$v_o = v_{tb} \frac{r_0 \| R_{te}}{r_e' + r_0 \| R_{te}} = \frac{v_s}{1.092} \frac{50\,\mathrm{k}\Omega \| 666.7}{52.20 + 50\,\mathrm{k}\Omega \| 666.7} = \frac{v_s}{1.179} = 0.8487 v_s$$

Thus the voltage gain is

$$\frac{v_o}{v_s} = 0.8487$$

The output resistance is

$$r_{\mathrm{out}} = r_e' \| R_E \| r_0 = 52.20 \| 2\,\mathrm{k}\Omega \| 50\,\mathrm{k}\Omega = 50.82\,\Omega$$

The resistance seen looking into the base is

$$\begin{aligned} r_{ib} &= r_x + (1 + \beta)\, r_e + R_{te} \frac{(1 + \beta)\, r_0 + R_{tc}}{r_0 + R_{te} + R_{tc}} \\ &= 20 + (1 + 99)\, 6.202 + 666.7 \frac{(1 + 99)\, 50\,\mathrm{k}\Omega}{50\,\mathrm{k}\Omega + 666.7} = 66.43\,\mathrm{k}\Omega \end{aligned}$$

The input resistance is

$$r_{\mathrm{in}} = R_1 \| R_2 \| r_{ib} = 100\,\mathrm{k}\Omega \| 120\,\mathrm{k}\Omega \| 66.43\,\mathrm{k}\Omega = 29.95\,\mathrm{k}\Omega$$

If the source is connected directly to the load without the common-collector stage, the voltage gain would be

$$\frac{v_o}{v_s} = \frac{1\,\mathrm{k}\Omega}{5\,\mathrm{k}\Omega + 1\,\mathrm{k}\Omega} = \frac{1}{6}$$

This is lower than the gain with the common-collector stage by a factor of 5.1 or 14 dB, despite the fact that the common-collector stage has a gain that is less than 1.