The Common-Base Amplifier

Basic Circuit

Fig. 1 shows the circuit diagram of a single stage common-base amplifier. The object is to solve for the small-signal voltage gain, input resistance, and output resistance.

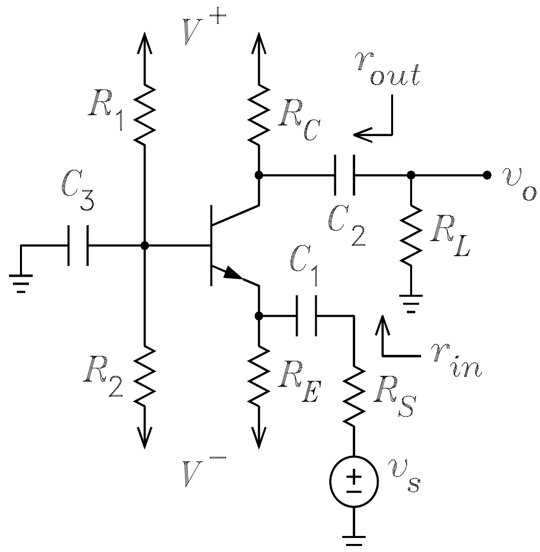

Figure 1: Common-base amplifier.

DC Solution

(a) Replace the capacitors with open circuits. Look out of the 3 BJT terminals and make Thévenin equivalent circuits as shown in Fig. 2.

$$V_{BB} = \frac{V^+ R_2 + V^- R_1}{R_1 + R_2} \qquad R_{BB} = R_1 \| R_2$$

$$V_{EE} = V^- \qquad R_{EE} = R_E \qquad V_{CC} = V^+ \qquad R_{CC} = R_C$$

(b) Make an "educated guess" for V_{BE}. Write the loop equation between the V_{BB} and the V_{EE} nodes. To solve for I_C, this equation is

$$V_{BB} - V_{EE} = I_B R_{BB} + V_{BE} + I_E R_{EE} = \frac{I_C}{\beta} R_{BB} + V_{BE} + \frac{I_C}{\alpha} R_{EE}$$

(c) Solve the loop equation for the currents.

$$I_C = \alpha I_E = \beta I_B = \frac{V_{BB} - V_{EE} - V_{BE}}{R_{BB}/\beta + R_{EE}/\alpha}$$

(d) Verify that $V_{CB} > 0$ for the active mode.

$$V_{CB} = V_C - V_B = (V_{CC} - I_C R_{CC}) - (V_{BB} - I_B R_{BB}) = V_{CC} - V_{BB} - I_C \left(R_{CC} - R_{BB}/\beta\right)$$

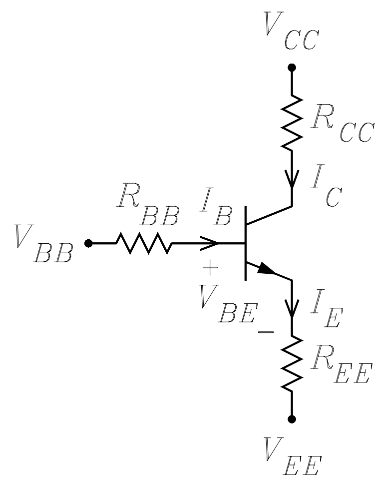

Figure 2: DC bias circuit.

Small-Signal or AC Solutions

It will be assumed that the base spreading resistance r_x is non zero. This is a resistance in series with the base lead in the small signal models.

(a) Redraw the circuit with $V^+ = V^- = 0$ and all capacitors replaced with short circuits as shown in Fig. 3.

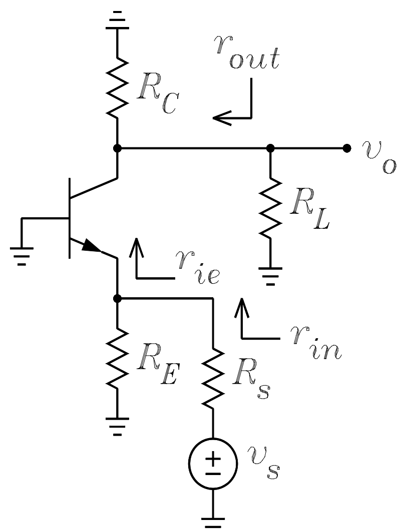

Figure 3: Signal circuit.

(b) Calculate g_m, r_π, r_e, and r_0 from the DC solution.

$$g_m = \frac{I_C}{V_T} \qquad r_\pi = \frac{V_T}{I_B} \qquad r_e = \frac{V_T}{I_E} \qquad r_0 = \frac{V_A + V_{CE}}{I_C}$$

(c) Solve for r_{in} and r_{out}.

$$r_{in} = R_1 \| R_2 \| r_{ie} \qquad r_{ie} = \frac{r_\pi}{1+\beta} \overset{\text{or}}{=} r_e$$

$$r_{out} = r_{ic} \| R_C \qquad r_{ic} = r_0 \left(1 + \frac{\beta \times R_s \| R_E}{r_\pi + R_s \| R_E}\right) + r_\pi \| R_s \| R_E$$

(d) Replace the circuits looking out of the base and emitter with Thévenin equivalent circuits as shown in Fig. 4.

$$v_{tb} = 0 \qquad R_{tb} = 0 \qquad v_{te} = v_s \frac{R_E}{R_s + R_E} \qquad R_{te} = R_s \| R_E$$

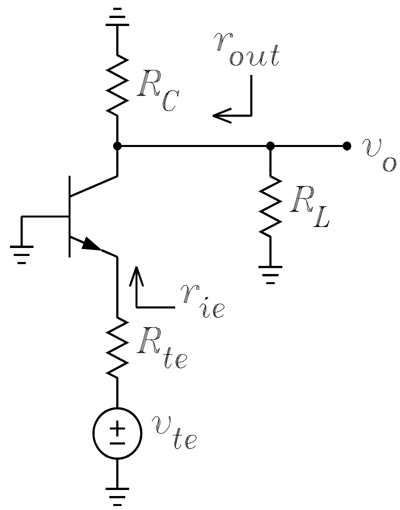

Figure 4: Signal circuit with Thévenin emitter circuit.

(e) Replace the BJT in Fig. 4 with the Thévenin emitter circuit and the Norton collector circuit as shown in Fig. 5.

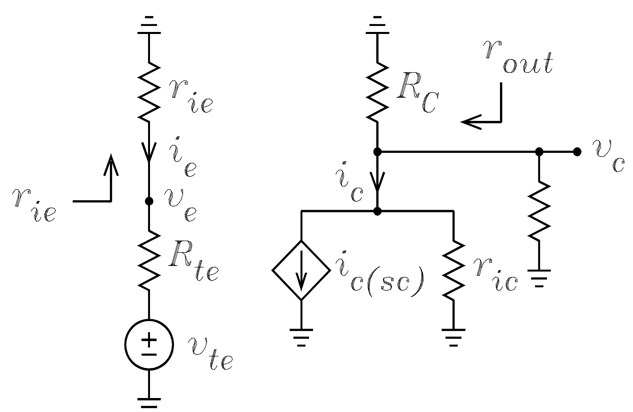

Figure 5: Emitter and collector equivalent circuits.

(e) Solve for $i_{c(sc)}$.

$$i_{c(sc)} = i'_c = -G_m v_{te} \qquad G_m = \frac{1}{\dfrac{r_\pi}{\beta} + R_{te}} \overset{\text{or}}{=} \frac{1}{\dfrac{1}{g_m} + R_{te}}$$

(f) Solve for v_o.

$$v_o = -i_{c(sc)} \times -\left(r_{ic} \| R_C \| R_L\right)$$

(g) The flow graph is show in Figure 6. The voltage gain is given by

$$A_v = \frac{v_o}{v_s} = \frac{R_E}{R_s + R_E} \times -G_m \times -\left(r_{ic} \| R_C \| R_L\right)$$

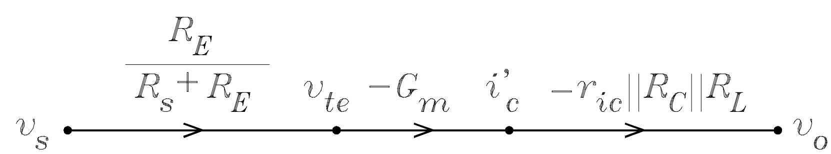

Figure 6: Flow graph for the voltage gain.

Example 1 *For the CB amplifier in Fig. 1, it is given that* $R_s = 100\,\Omega$, $R_1 = 120\,\mathrm{k}\Omega$, $R_2 = 100\,\mathrm{k}\Omega$, $R_C = 4.3\,\mathrm{k}\Omega$, $R_E = 5.6\,\mathrm{k}\Omega$, $R_L = 20\,\mathrm{k}\Omega$, $V^+ = 15\,\mathrm{V}$, $V^- = -15\,\mathrm{V}$, $V_{BE} = 0.65\,\mathrm{V}$, $\beta = 99$, $\alpha = 0.99$, $V_A = 100\,\mathrm{V}$, *and* $V_T = 0.025\,\mathrm{V}$. *Solve for* A_v, r_{in}, *and* r_{out}.

Solution. Because the dc bias circuit is the same as for the common-emitter amplifier example, the dc bias values, r_e, g_m, r_π, and r_0 are the same. They are

$$I_C = 2.092\,\mathrm{mA} \qquad I_E = 2.113\,\mathrm{mA} \qquad I_B = 21.13\,\mu\mathrm{A}$$

$$r_0 = \frac{V_A + V_{CE}}{\alpha I_E} = 52.18\,\mathrm{k}\Omega \qquad g_m = \frac{I_C}{V_T} = \frac{2.092}{25} = \frac{1}{11.95}\,\mathrm{S}$$

$$r_\pi = \frac{V_T}{I_B} = \frac{\beta V_T}{I_C} = \frac{99 \times 25}{2.113} = 1.183\,\mathrm{k}\Omega \qquad r_e = \frac{V_T}{I_E} = 11.83\,\Omega$$

In the signal circuit, the Thévenin voltage and resistance seen looking out of the emitter are given by

$$v_{te} = \frac{R_E}{R_s + R_E} v_s = 0.9825 v_s \qquad R_{te} = R_s \| R_E = 98.25\,\Omega$$

The Thévenin resistances seen looking out of the collector is

$$R_{tc} = R_C \| R_L = 3.539\,\mathrm{k}\Omega$$

Next, we calculate G_m, r_{ic}, and r_{ie}.

$$G_m = \frac{1}{\dfrac{r_x + r_\pi}{\beta} + \dfrac{R_{te}}{\alpha}} = \frac{1}{111.4}\,\mathrm{S}$$

$$r_{ic} = r_0 \left(1 + \frac{\beta \times R_{te}}{r_x + r_\pi + R_{te}}\right) + \left(r_x + r_\pi\right) \| R_{te} = 442.3\,\mathrm{k}\Omega \qquad r_{ie} = r_e = 12.03\,\Omega$$

The voltage gain is given by

$$A_v = \frac{v_o}{v_s} = \frac{v_{te}}{v_s} \times \frac{i'_c}{v_{te}} \times \frac{v_o}{i'_c} = \frac{R_E}{R_s + R_E} \times -G_m \times -\left(r_{ic} \| R_{tc}\right) = 30.97$$

The input and output resistances are

$$r_{in} = R_1 \| R_2 \| r_{ib} = 11.81\,\Omega \qquad r_{out} = r_{ic} \| R_C = 4.259\,\mathrm{k}\Omega$$