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The Common-Collector Amplifier

Basic Circuit

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

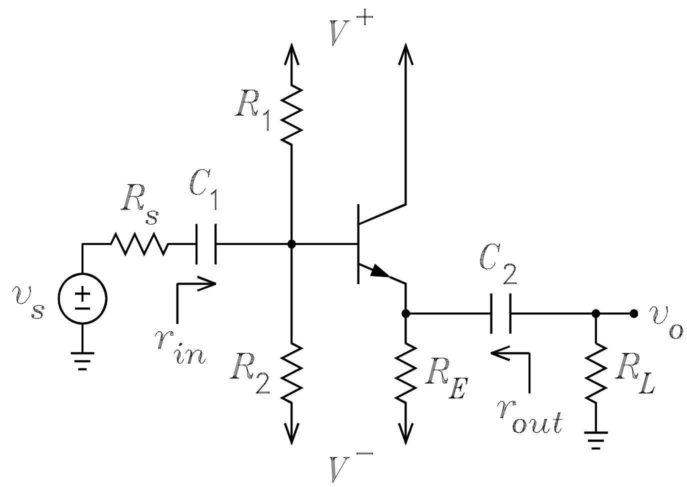

Figure 1: Common-collector amplifier.

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.

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

(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.

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

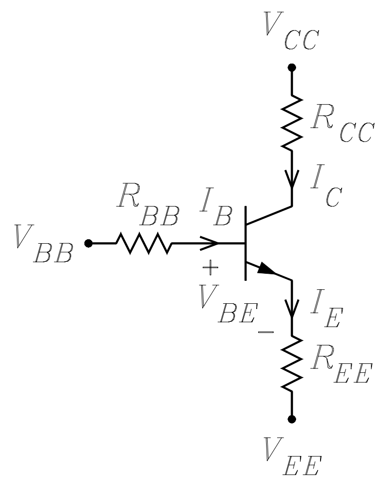

Figure 2: Bias circuit.

Small-Signal or AC Solutions

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

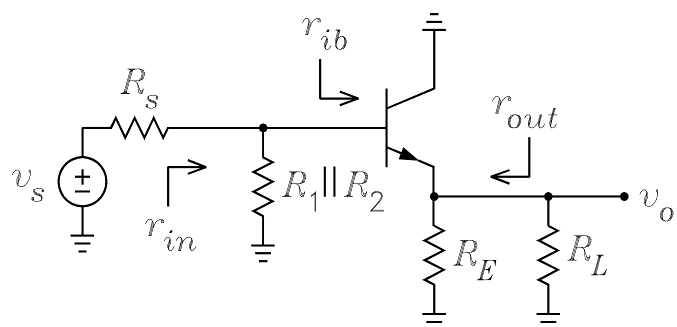

Figure 3: Signal circuit.

(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) Replace the circuits looking out of the base with a Thévenin equivalent circuit as shown in Fig. 4.

$$v_{tb} = v_s \frac{R_1 \| R_2}{R_s + R_1 \| R_2} \qquad R_{tb} = R_1 \| R_2$$

Exact Solution

(a) Replace the BJT in Fig. 4 with the Thévenin base emitter circuits as shown in Fig. 5.

$$v_{e(oc)} = v_{tb}$$

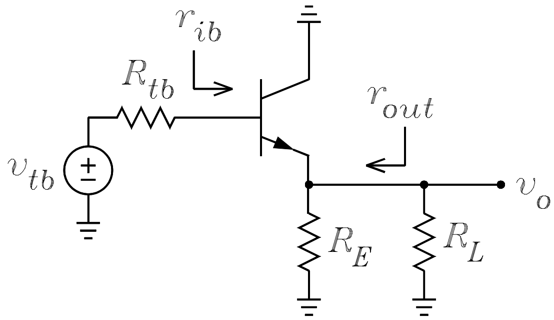

Figure 4: Signal circuit with Thévenin base circuit.

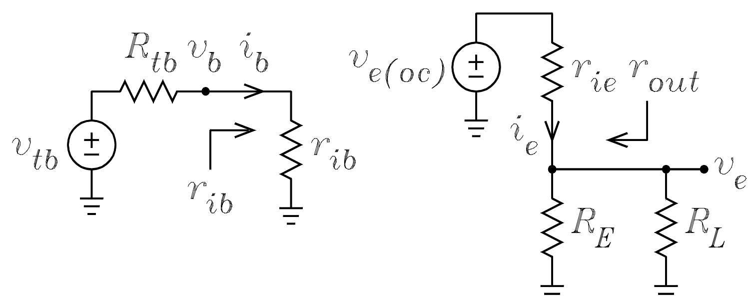

Figure 5: Base and emitter equivalent circuits.

(b) Solve for the voltage gain. The flow graph is shown in Figure 6. It is given by

$$A_v = \frac{v_e}{v_s} = \frac{v_{tb}}{v_s} \times \frac{v_e}{v_{tb}} = \frac{R_1 \| R_2}{R_s + R_1 \| R_2} \times \frac{R_E \| R_L}{r_{ie} + R_E \| R_L}$$

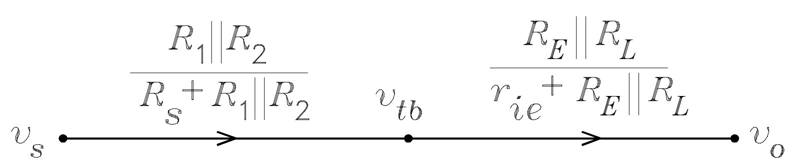

Figure 6: Flow graph for the voltage gain.

(c) Solve for r_{in}.

$$r_{in} = R_1 \| R_2 \| r_{ib} \qquad r_{ib} = r_\pi + (1+\beta)\, R_{te}$$

(d) Solve for r_{out}.

$$r_{out} = r_{ie} \| R_E$$

Example 1 *For the CC amplifier in Fig. 1, it is given that* $R_S = 5\,\mathrm{k}\Omega$, $R_1 = 120\,\mathrm{k}\Omega$, $R_2 = 100\,\mathrm{k}\Omega$, $R_E = 5.6\,\mathrm{k}\Omega$, $R_L = 20\,\mathrm{k}\Omega$, $V^+ = 15\,\mathrm{V}$, $V^- = -15\,\mathrm{V}$, $V_{BE} = 0.65\,\mathrm{V}$, $\beta = 99$, $\alpha = 0.99$, $r_x = 20\,\Omega$, $V_A = 100\,\mathrm{V}$ *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

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

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

Note that the base spreading resistance r_x is non zero.

The Thévenin voltage and resistance seen looking out of the base are given by

$$v_{tb} = \frac{R_1 \| R_2}{R_S + R_1 \| R_2} v_s = 0.916 v_s \qquad R_{tb} = R_S \| R_1 \| R_2 = 4.58\,\mathrm{k}\Omega$$

The Thévenin resistance seen looking out of the emitter is

$$R_{te} = R_E \| R_L = 4.375\,\mathrm{k}\Omega$$

Next, we calculate r_{ie} and r_{ib}.

$$r_{ie} = \frac{R_{tb} + r_x}{1 + \beta} + r_e = 57.83\,\Omega$$

$$r_{ib} = r_x + r_\pi + (1 + \beta) R_{te} = 407\,\mathrm{k}\Omega$$

The voltage gain is given by

$$A_v = \frac{v_{tb}}{v_s} \times \frac{v_e}{v_{tb}} = \frac{R_1 \| R_2}{R_S + R_1 \| R_2} \times \frac{R_{te}}{r \times_{ie} + R_{te}} = 0.916 \times \frac{4.375\mathrm{k}}{57.83 + 4.375\mathrm{k}} = 0.904$$

The input and output resistances are given by

$$r_{in} = R_1 \| R_2 \| r_{ib} = 48.8\,\mathrm{k}\Omega \qquad r_{out} = r_{ie} \| R_E = 57.2\,\Omega$$