Common-Emitter Amplifier Example

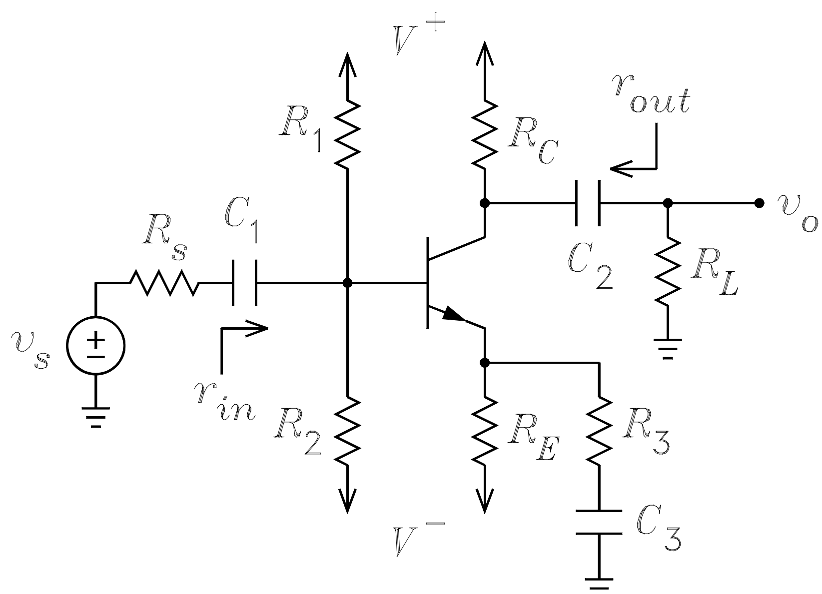
$R_P(x,y) := \frac{x \cdot y}{x+y}$ Function for calculating parallel resistors.

$R_1 := 100000$ $R_2 := 120000$ $R_C := 4300$ $R_E := 5600$ $R_S := 5000$ $R_L := 10000$

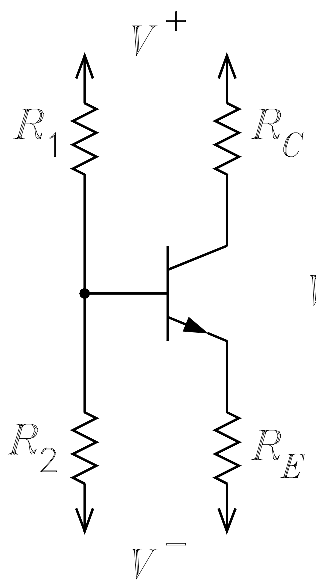
$V_p := 15$ $V_m := -15$ $V_{BE} := 0.65$ $V_T := 0.025$ $\beta := 99$ $\alpha := 0.99$

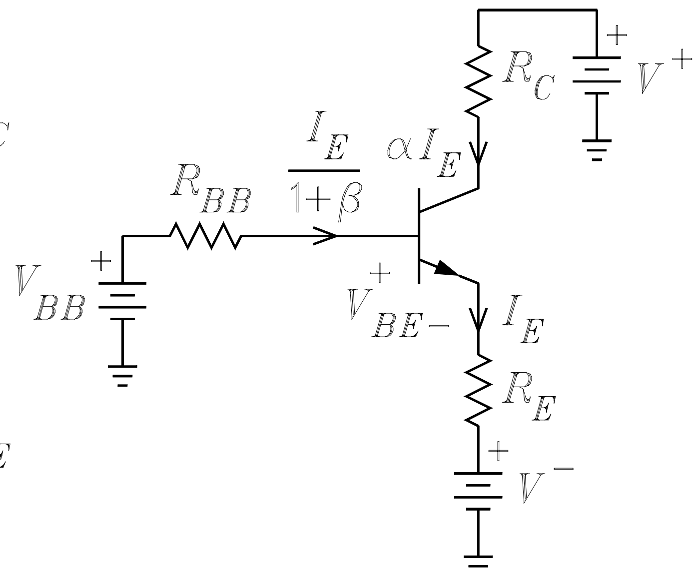
$r_x := 20$ $r_0 := 50000$ $R_3 := 100$

$v_s := 1$ With v_s = 1, the voltage gain is equal to v_o.



DC Bias Solution





$V_{BB} := \frac{V_p \cdot R_2 + V_m \cdot R_1}{R_1 + R_2}$ $\qquad V_{BB} = 1.3636$

$R_{BB} := R_P(R_1, R_2)$ $\qquad R_{BB} = 5.4545 \cdot 10^4$

$I_E := \frac{V_{BB} - V_{BE} - V_m}{\frac{R_{BB}}{1+\beta} + R_E}$ $\qquad I_E = 2.557 \cdot 10^{-3}$

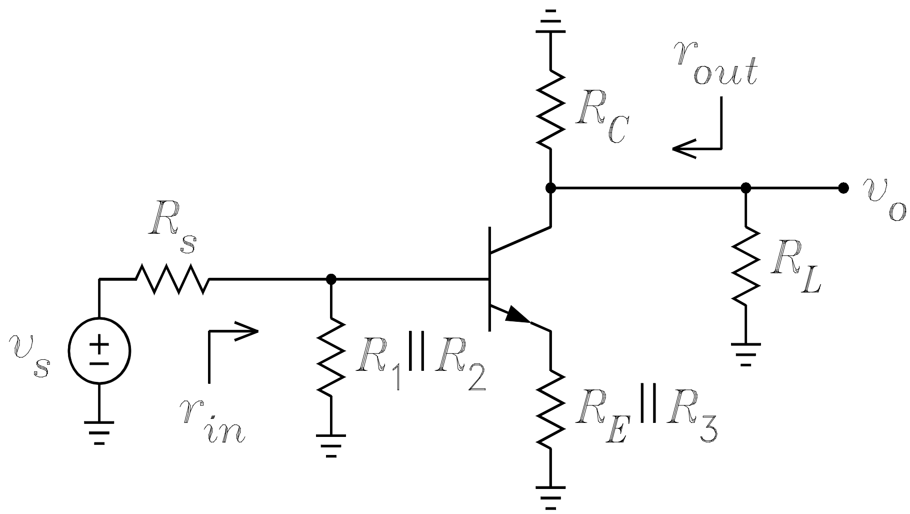
$V_C := V_p - \alpha \cdot I_E \cdot R_C$ $\qquad V_C = 4.1151$

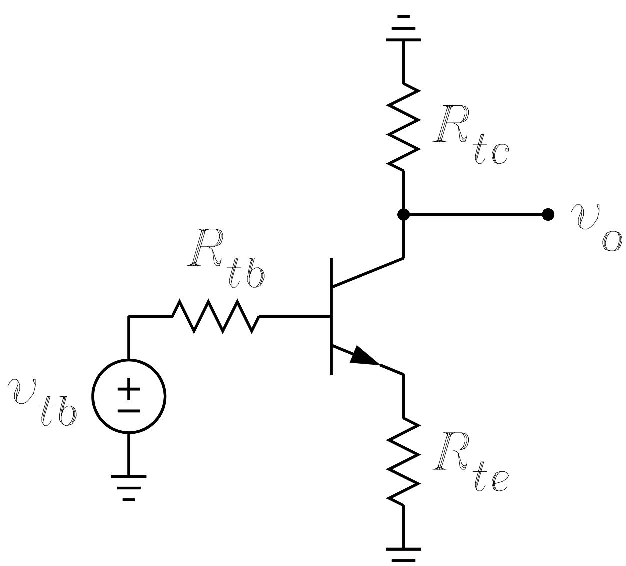
$V_B := V_{BE} + I_E \cdot R_E + V_m$ $\qquad V_B = -0.0311$

$V_C - V_B = 4.1461$ $\qquad$ Thus active mode.

$r_e := \frac{V_T}{I_E}$ $\qquad r_e = 9.7773$

Exact AC Solution





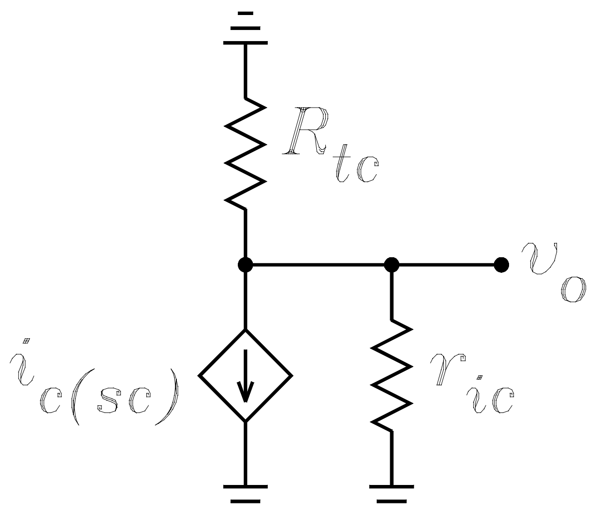
$v_{tb} := v_s \cdot \frac{R_P(R_1, R_2)}{R_S + R_P(R_1, R_2)}$ $v_{tb} = 0.916$

$R_{tb} := R_P(R_S, R_P(R_1, R_2))$ $R_{tb} = 4.5802 \cdot 10^3$

$R_{te} := R_P(R_E, R_3)$ $R_{te} = 98.2456$

$$r'_e := \frac{R_{tb} + r_x}{1 + \beta} + r_e \qquad r'_e = 55.7788$$

$$R_{tc} := R_P(R_C, R_L) \qquad R_{tc} = 3.007 \cdot 10^3$$



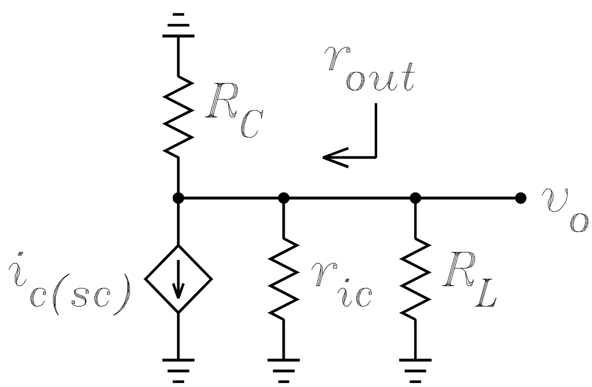
$$r_{ic} := \frac{r_0 + R_P(r'_e, R_{te})}{1 - \frac{\alpha \cdot R_{te}}{r'_e + R_{te}}} \qquad r_{ic} = 1.3577 \cdot 10^5$$

$$i_{csc} := \frac{v_{tb}}{r'_e + R_P(R_{te}, r_0)} \cdot \left(\alpha - \frac{R_{te}}{R_{te} + r_0}\right) \qquad i_{csc} = 5.8835 \cdot 10^{-3}$$

$$v_o := -i_{csc} \cdot R_P(R_C, R_P(r_{ic}, R_L)) \qquad v_o = -17.3084$$

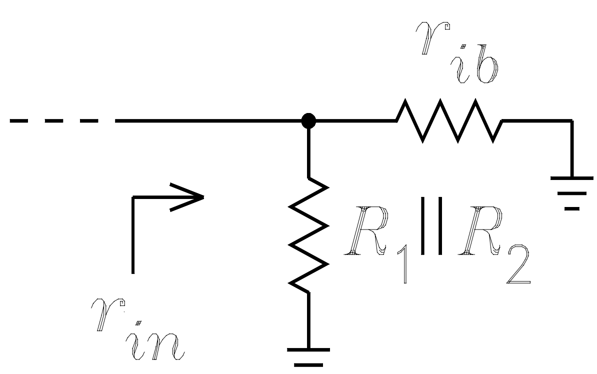
$A_v := v_o$ $\qquad A_v = -17.3084$ This is the voltage gain.

Circuit for r_{out}.



$r_{out} := R_P(R_C, r_{ic})$ $r_{out} = 4.168 \cdot 10^3$

Circuit for r_{in}.



$$r_{ib} := r_x + (1+\beta)\cdot\left(r_e + R_P\left(R_{te}, r_0 + R_{tc}\right)\right) - \frac{\beta \cdot R_{te} \cdot R_{tc}}{R_{tc} + r_0 + R_{te}}$$

$r_{ib} = 1.0253 \cdot 10^4$

$r_{in} := R_P\left(r_{ib}, R_P\left(R_1, R_2\right)\right)$ $r_{in} = 8.6309 \cdot 10^3$

Exact AC solution based on the pi model that is the subject of a homework problem.

$r_\pi := (1+\beta)\cdot r_e \qquad R' := R_{tb} + r_x + r_\pi$

$$A_v := -\frac{\dfrac{\dfrac{\beta}{R'}}{\dfrac{1}{r_0}+\dfrac{\beta}{R'}} - \dfrac{\dfrac{1+\beta}{R'}}{\dfrac{1+\beta}{R'}+\dfrac{1}{R_{te}}+\dfrac{1}{r_0}}}{\dfrac{\dfrac{1}{r_0}+\dfrac{1}{R_{tc}}}{\dfrac{1}{r_0}+\dfrac{\beta}{R'}} - \dfrac{\dfrac{1}{r_0}}{\dfrac{1+\beta}{R'}+\dfrac{1}{R_{te}}+\dfrac{1}{r_0}}} \qquad A_v = -18.895 \qquad \text{This is } v_o/v_{tb}.$$

G_{mb}

$v_o := A_v\cdot\dfrac{R_P(R_1,R_2)}{R_S + R_P(R_1,R_2)}$ $\qquad v_o = -17.3084 \qquad$ Same gain as calculated using G_{mb} and r_{ic} above.

The following solution is based on the r_0 approximations where r_0 is neglected in calculating i_{csc} but not neglected in calculating r_{ic}.

$G_{mb} := \dfrac{\alpha}{r'_e + R_{te}}$

$i_{csc} := v_{tb}\cdot G_{mb} \qquad i_{csc} = 5.8878\cdot 10^{-3}$

$v_o := -i_{csc}\cdot R_P(R_C, R_P(r_{ic}, R_L)) \qquad v_o = -17.3211$

$A_v := v_o \qquad A_v = -17.3211 \qquad$ This is the voltage gain. It is 0.075% lower than the exact solutions found above.

$r_{out} := R_P(r_{ic}, R_C) \qquad r_{out} = 4.168\cdot 10^{3}$

$r_{ib} := r_x + (1+\beta)\cdot(r_e + R_{te}) \qquad r_{ib} = 1.0822\cdot 10^{4}$

$r_{in} := R_P(r_{ib}, R_P(R_1, R_2)) \qquad r_{in} = 9.0305\cdot 10^{3}$

Approximate Solution 1 using the equation $i_c = g_m \cdot (v_b - v_e)$

$i_c = g_m \cdot (v_b - v_e)$

Assume $r_x := 0$ and r_0 is infinity, i.e. an open circuit.

$g_m := \frac{\alpha \cdot I_E}{V_T}$ $g_m = 0.1013$ $r_{ib} := (1+\beta) \cdot (r_e + R_P(R_E, R_3))$ $r_{ib} = 1.0802 \cdot 10^4$

$v_b := v_s \cdot \frac{R_P(r_{ib}, R_P(R_1, R_2))}{R_S + R_P(r_{ib}, R_P(R_1, R_2))}$ $v_b = 0.6433$ $r_\pi := (1+\beta) \cdot r_e$ $r_\pi = 977.7264$

$r_{ib} := r_\pi + (1+\beta) \cdot R_{te}$ $r_{ib} = 1.0802 \cdot 10^4$

$$A_v := \frac{-R_P(R_1, R_2)}{R_S + R_P(R_1, R_2)} \cdot \frac{r_{ib}}{R_{tb} + r_{ib}} \cdot \frac{g_m \cdot R_{tc}}{1 + \frac{g_m \cdot R_{te}}{\alpha}} \qquad A_v = -17.7277$$

$r_{in} := R_P(r_{ib}, R_P(R_1, R_2))$ $r_{in} = 9.0166 \cdot 10^3$

$r_{out} := R_C$ $r_{out} = 4.3 \cdot 10^3$

Approximate Solution 2 using the equation $i_c = \beta \cdot i_b$

Again, assume $r_x := 0$ and r_0 is infinity, i.e. an open circuit.

$$A_v := \frac{-R_P(R_1, R_2)}{R_S + R_P(R_1, R_2)} \cdot \frac{\beta \cdot R_{tc}}{R_{tb} + r_{ib}} \qquad A_v = -17.7277$$

This is the same as in Approximate Solution 1 and is simpler.

$r_{in} := R_P(r_{ib}, R_P(R_1, R_2))$ $r_{in} = 9.0166 \cdot 10^3$

$r_{out} := R_C$ $r_{out} = 4.3 \cdot 10^3$