Cascode Amplifier Example - Spring 2002

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

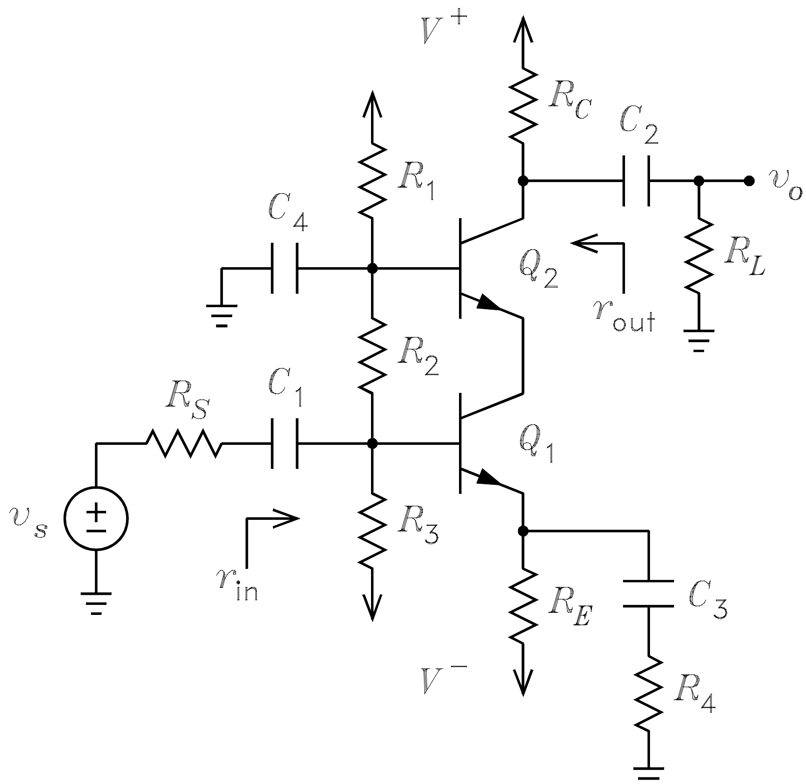
$R_1 := 390000$ $R_2 := 200000$ $R_3 := 56000$ $R_4 := 100$

$R_C := 20000$ $R_E := 4300$ $R_S := 1000$ $R_L := 10000$

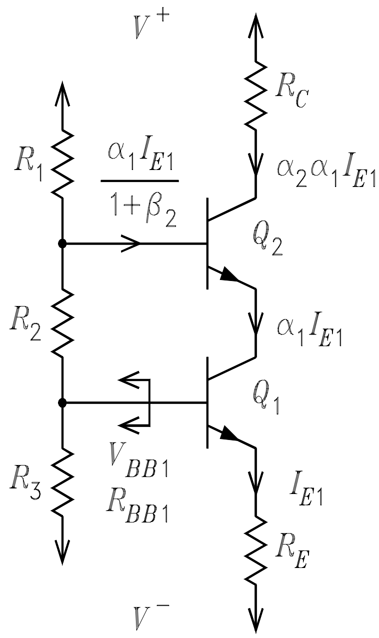
$V_{plus} := 35$ $V_{minus} := -30$ $V_{BE} := 0.65$ $V_T := 0.025$ $\beta := 199$ $\alpha := 0.995$

$r_x := 20$ $r_0 := 50000$

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



First, the dc bias solution



Solve for the Thevenin equivalent circuit looking out of the base of Q1

$$V_{BB1} = \frac{V_{plus}\cdot R_3 + V_{minus}\cdot\left(R_1 + R_2\right)}{R_1 + R_2 + R_3} - \frac{\alpha\cdot I_{E1}}{1+\beta}\cdot\frac{R_1}{R_1 + R_2 + R_3}\cdot R_3$$

$$R_{BB1} := R_P\left(R_1 + R_2, R_3\right)$$

The bias loop equation is

$$V_{BB1} - V_{minus} = \frac{I_{E1}}{1+\beta} R_{BB1} + V_{BE} + I_{E1}\cdot R_E$$

It follows that the solution for I_{E1} is

$$I_{E1} := \frac{\frac{V_{plus}\cdot R_3 + V_{minus}\cdot\left(R_1 + R_2\right)}{R_1 + R_2 + R_3} - V_{minus} - V_{BE}}{\frac{R_{BB1}}{1+\beta} + R_E + \frac{\alpha}{1+\beta}\cdot\frac{R_1\cdot R_3}{R_1 + R_2 + R_3}} \qquad I_{E1} = 1.0552\bullet 10^{-3}$$

$r_{e1} := \frac{V_T}{I_{E1}}$ $\quad r_{e1} = 23.6922$

$I_{E2} := \alpha \cdot I_{E1}$ $\quad I_{E2} = 1.0499 \cdot 10^{-3}$

$r_{e2} := \frac{V_T}{I_{E2}}$ $\quad r_{e2} = 23.8113$

Now, check to see that Q1 and Q2 are in the active mode

$V_{B1} := V_{BE} + I_{E1} \cdot R_E + V_{minus}$ $\quad V_{B1} = -24.8126$

$V_{B2} := \frac{V_{plus} \cdot (R_2 + R_3) + V_{minus} \cdot R_1}{R_1 + R_2 + R_3} - \frac{I_{E2}}{1+\beta} \cdot R_P(R_1, R_2 + R_3)$ $\quad V_{B2} = -5.0528$

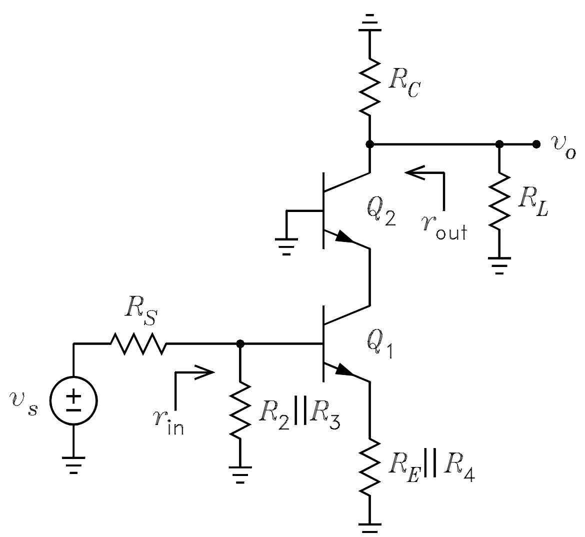
$V_{C1} := V_{B2} - V_{BE}$ $\quad V_{C1} = -5.7028$

$V_{CB1} := V_{C1} - V_{B1}$ $\quad V_{CB1} = 19.1098$ Thus active mode for Q1.

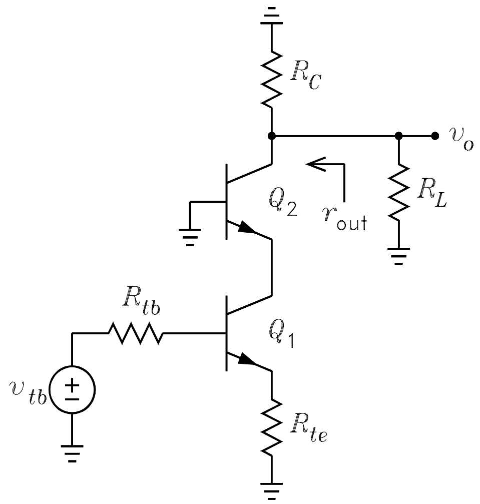
$V_{C2} := V_{plus} - \alpha \cdot I_{E2} \cdot R_C$ $\quad V_{C2} = 14.1065$

$V_{CB2} := V_{C2} - V_{B2}$ $\quad V_{CB2} = 19.1594$ Thus active mode for Q2.

Now for the ac solution



Make a Thevenin equivalent circuit looking out of the base of Q1



$$v_{tb1} := v_S \cdot \frac{R_P(R_2, R_3)}{R_S + R_P(R_2, R_3)} \qquad v_{tb1} = 0.9777$$

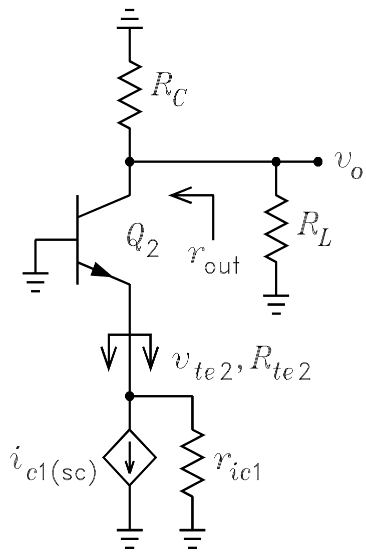
$$R_{tb1} := R_P(R_S, R_P(R_2, R_3)) \qquad R_{tb1} = 977.6536$$

$$R_{te1} := R_P(R_E, R_4) \qquad R_{te1} = 97.7273$$

$$r'_{e1} := \frac{R_{tb1} + r_x}{1 + \beta} + r_{e1} \qquad r'_{e1} = 28.6805$$

$$r'_{e2} := \frac{r_x}{1 + \beta} + r_{e2} \qquad r'_{e2} = 23.9113$$

Next make a Thevenin equivalent circuit looking out of the emitter of Q2



$$r_{ic1} := \frac{r_0 + R_P(r'_{e1}, R_{te1})}{1 - \frac{\alpha \cdot R_{te1}}{r'_{e1} + R_{te1}}} \qquad r_{ic1} = 2.1678 \bullet 10^5$$

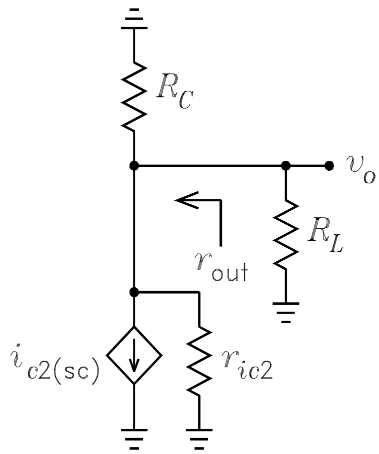
$$G_{mb1} := \frac{\alpha}{r'_{e1} + R_{te1}} \cdot \frac{r_0 - \frac{R_{te1}}{\beta}}{r_0 + R_P(r'_{e1}, R_{te1})}$$

$$i_{c1sc} := v_{tb1} \cdot G_{mb1} \qquad i_{c1sc} = 7.692 \bullet 10^{-3}$$

$$v_{te2} := -i_{c1sc} \cdot r_{ic1} \qquad v_{te2} = -1.6674 \bullet 10^3$$

$$R_{te2} := r_{ic1} \qquad R_{te2} = 2.1678 \bullet 10^5$$

Now make a Norton equivalent circuit looking into the collector of Q1.It follows that the circuit for the output voltage and output resistance is



$R_{tc2} := R_P(R_C, R_L)$ $\qquad R_{tc2} = 6.6667 \cdot 10^{3}$

$$G_{me2} := \frac{\alpha}{r'_{e2} + R_{te2}} \cdot \frac{r_0 + \frac{r'_{e2}}{\alpha}}{r_0 + R_P(r'_{e2}, R_{te2})}$$

$i_{c2sc} := -G_{me2} \cdot v_{te2}$ $\qquad i_{c2sc} = 7.6527 \cdot 10^{-3}$

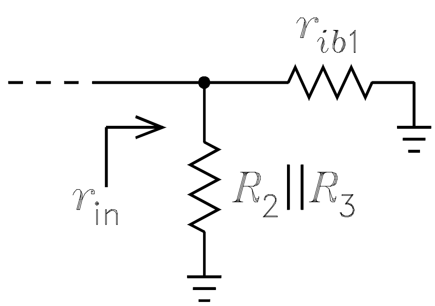
$$r_{ic2} := \frac{r_0 + R_P(r'_{e2}, R_{te2})}{1 - \frac{\alpha \cdot R_{te2}}{r'_{e2} + R_{te2}}} \qquad r_{ic2} = 9.7899 \cdot 10^{6}$$

$v_o := -i_{c2sc} \cdot R_P(r_{ic2}, R_{tc2})$

$A_v := v_o$ $\qquad A_v = -50.9832$ $\qquad$ This is the voltage gain.

$r_{out} := R_P(R_C, r_{ic2})$ $\qquad r_{out} = 1.9959 \cdot 10^{4}$

The circuit for the input resistance is



$$r_{ie2} := r'_{e2} \cdot \frac{r_0 + R_{tc2}}{r'_{e2} + r_0 + \frac{R_{tc2}}{1+\beta}}$$ $r_{ie2} = 27.0685$

$R_{tc1} := r_{ie2}$ $R_{tc1} = 27.0685$

$$r_{ib1} := r_x + (1+\beta) \cdot \left(r_{e1} + R_P\left(R_{te1}, r_0 + R_{tc1}\right)\right) - \frac{\beta \cdot R_{te1} \cdot R_{tc1}}{R_{tc1} + r_0 + R_{te1}}$$

$r_{ib1} = 2.4255 \bullet 10^4$

$r_{in} := R_P\left(r_{ib1}, R_P\left(R_2, R_3\right)\right)$ $r_{in} = 1.5604 \bullet 10^4$

The following simpler solution is based on the r_0 approximations for Q2 .

$i_{c2sc} := \alpha \cdot i_{c1sc} \cdot \frac{r_{ic1}}{r_{ie2} + r_{ic1}}$ $\quad i_{c2sc} = 7.6526 \cdot 10^{-3}$ $\quad$ The $\frac{r_{ic1}}{r_{ie2} + r_{ic1}}$ is a current divider.

$v_o := -i_{c2sc} \cdot R_P(R_{tc2}, r_{ic2})$

$A_v := v_o$ $\quad A_v = -50.9823$ $\quad$ This is the voltage gain.

$r_{out} := R_P(r_{ic2}, R_C)$ $\quad r_{out} = 1.9959 \cdot 10^4$

$r_{ib1} := r_x + (1+\beta) \cdot (r_{e1} + R_{te1})$ $\quad r_{ib1} = 2.4304 \cdot 10^4$

$r_{in} := R_P(r_{ib1}, R_P(R_2, R_3))$ $\quad r_{in} = 1.5624 \cdot 10^4$