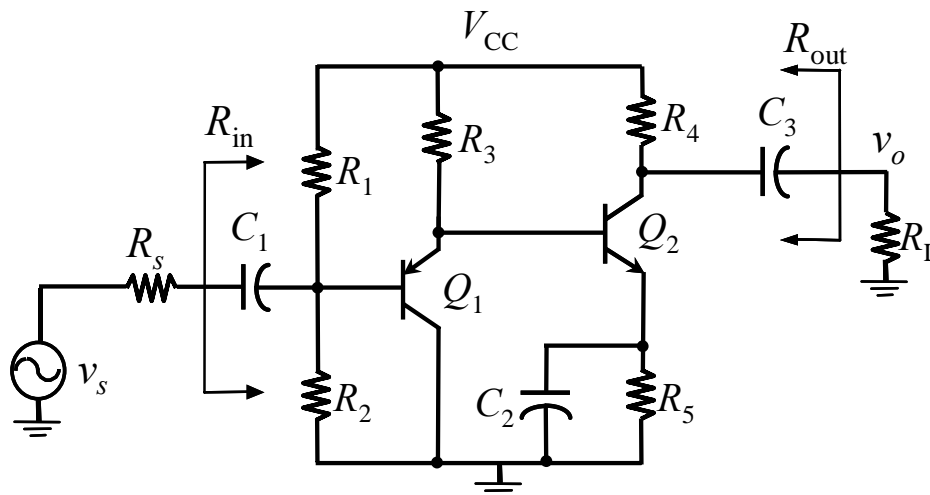


Professor C. Plett

Instructions:

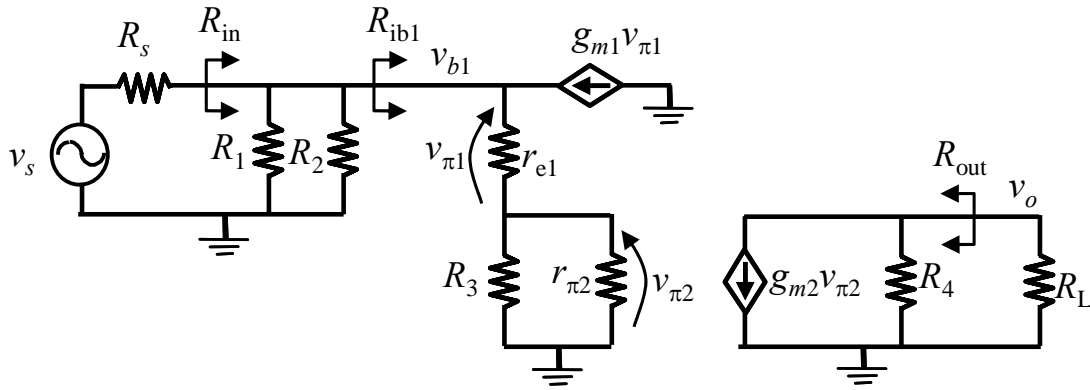
- This is a closed book examination.
- Attempt all questions.
- Assume transistor Q1 is different from Q2 (i.e., β_1 and β_2 are different. $r_{\pi 1}$ and $r_{\pi 2}$ are different).
- Assume simplified hybrid π -model or T-model (i.e., ignore r_{μ} , r_o and r_x) unless stated otherwise.
- Show all analyses and assumptions you make.
- Useful formulas: $r_{\pi} = \frac{\beta}{g_m}$, $r_{\pi} = (1 + \beta)r_e$, $\alpha = \frac{\beta}{1 + \beta}$, $g_m r_e = \alpha$.
- Miller's theorem: $Y_1 = Y(1 - \frac{v_2}{v_1})$, $Y_2 = Y(1 - \frac{v_1}{v_2})$.
- $f_L = f_{L1} + f_{L2} + f_{L3} + \dots$, $1/f_H = 1/f_{H1} + 1/f_{H2} + 1/f_{H3} + \dots$



1. Draw the mid-band small-signal AC equivalent circuit. **(4 marks)**
2. Find the mid-band input resistance R_{in} . **(3 marks)**
3. Find the mid-band output resistance R_{out} , including r_o and r_{μ} in both transistors with the exception that $r_{\mu 2}$ can be ignored. **(2 marks)**
4. Find the mid-band gain v_o/v_s . **(4 marks)**
5. Find the low frequency poles associated with C_1 , C_2 , and C_3 . **(3 marks)**
6. Find the high frequency poles. You may ignore $C_{\pi 1}$. **(4 marks)**
7. DC analysis: Assume that both transistors are active, $|V_{EB1}|$ and $|V_{BE2}|$ are both 0.7V, V_{CC} is 10V, β_1 is 50, and β_2 is 100. Including all base currents, determine values for resistors R_1 , R_2 , R_3 , R_4 , and R_5 such that Q_1 collector current is 0.5 mA, Q_2 collector current is 1 mA, the base of Q_1 is at 5V, current through R_1 is 10 times the base current of Q_1 and the output voltage swing is maximized. **(5 marks)**

Solution:

1.



$$2. R_{in} = R_1 \parallel R_2 \parallel R_{ib1} = R_1 \parallel R_2 \parallel [(r_{e1} + R_3 \parallel r_{\pi 2})(1 + \beta_1)]$$

$$3. R_{out} = R_4 \parallel r_{o2}$$

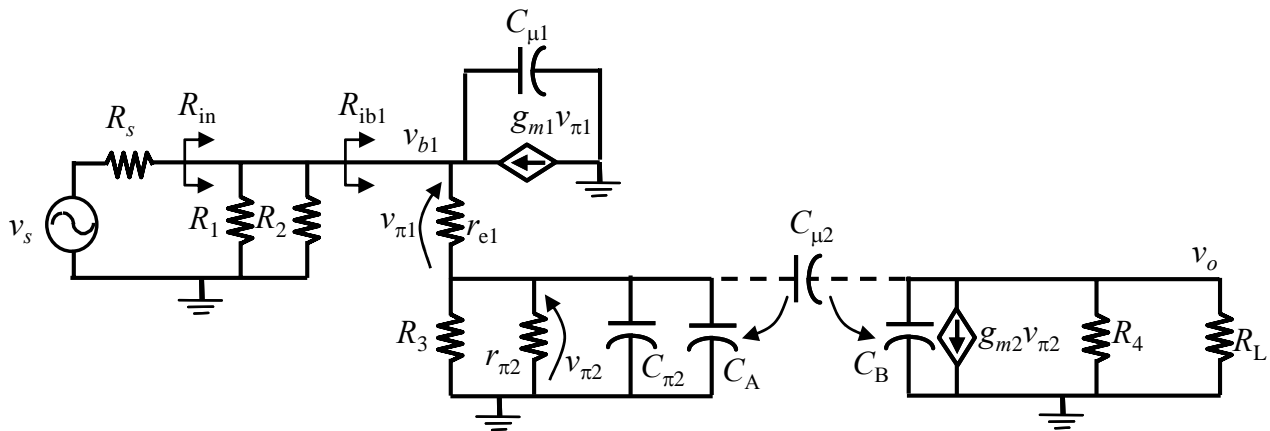
$$4. \frac{v_o}{v_s} = \frac{v_o}{v_{\pi 2}} \frac{v_{\pi 2}}{v_{b1}} \frac{v_{b1}}{v_s}, \quad \text{where the individual terms are: } \frac{v_o}{v_{\pi 2}} = -g_{m1} R_4 \parallel R_L, \quad \frac{v_{\pi 2}}{v_{b1}} = \frac{R_3 \parallel r_{\pi 2}}{r_{e1} + R_3 \parallel r_{\pi 2}},$$

$$\frac{v_{b1}}{v_s} = \frac{R_{in}}{R_s + R_{in}} = \frac{R_1 \parallel R_2 \parallel [(r_{e1} + R_3 \parallel r_{\pi 2})(1 + \beta_1)]}{R_s + R_1 \parallel R_2 \parallel [(r_{e1} + R_3 \parallel r_{\pi 2})(1 + \beta_1)]}, \quad \text{Can leave in terms of } R_{in} \text{ if defined and found in 2.}$$

5. Low frequency pole for each capacitor as: $f_{L1} = 1/(R_{C1}C_1)$, $f_{L2} = 1/(R_{C2}C_2)$, $f_{L3} = 1/(R_{C3}C_3)$,

$$R_{C1} = R_s + R_{in}, \quad R_{C2} = R_3 \left\| \frac{r_{\pi 2} + R_3 \left\| \left(r_{e1} + \frac{R_1 \parallel R_2 \parallel R_s}{1 + \beta_1} \right) \right.}{1 + \beta_2} \right\|, \quad R_{C3} = R_4 + R_L$$

6. High frequency poles are found on nodes with voltages: v_{b1} , $v_{\pi 2}$ and on v_o

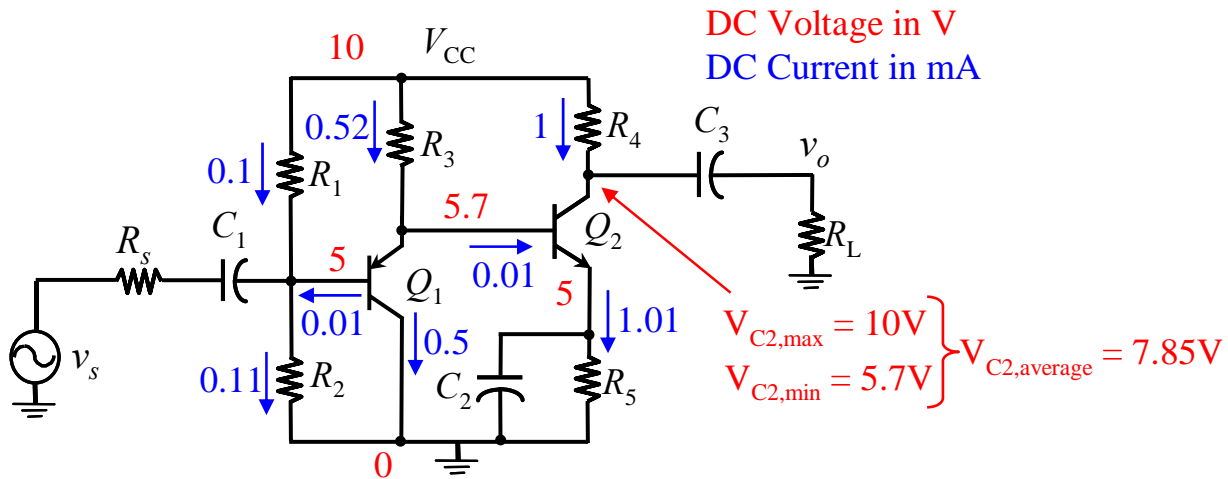


$$f_{H1} = \frac{1}{C_{\mu 1}(R_s \parallel R_{in})}, \quad f_{H2} = \frac{1}{(C_{\pi 2} + C_A) \left[r_{\pi 2} \parallel R_3 \left\| \left(r_{e1} + \frac{R_1 \parallel R_2 \parallel R_s}{1 + \beta_1} \right) \right. \right]}, \quad f_{H3} = \frac{1}{(C_B)(R_4 \parallel R_L)}, \quad \text{where}$$

$$C_A = C_{\mu 2} \left(1 - \frac{v_o}{v_{\pi 2}} \right) = C_{\mu 2} (1 + g_{m2} R_4 \parallel R_L), \quad C_B = C_{\mu 2} \left(1 - \frac{v_{\pi 2}}{v_o} \right) = C_{\mu 2} \left(1 + \frac{1}{g_{m2} R_4 \parallel R_L} \right), \quad \text{OK to refer to 3.}$$

8. Q_{1B} at 5V means that Q_{1E} is at 5.7V and Q_{2E} is at 5V. Minimum value of Q_{2C} is at 5.7V while the maximum is at the power supply rail at 10V, so for maximum swing pick the average at $(10+5.7)/2$, that is 7.85V.

Currents in Q_1 are given as I_{C1} of 0.5 mA, so with $\beta_1 = 50$, $I_{B1} = 0.01$ mA, and $I_{E1} = 0.51$ mA. For Q_2 , I_{C2} is 1 mA, so with $\beta_2 = 100$, I_{B2} is 0.01 mA and $I_{E2} = 1.01$ mA. Thus all voltages and currents are known, as shown on the diagram below, so can calculate resistance as V/I. Note, R_3 has the sum of $I_{E1} + I_{B2}$ flowing in it, or 0.52 mA.



$$R_1 = \frac{10 - 5}{0.1} = 50k, \quad R_2 = \frac{5}{0.11} = 45.45k, \quad R_3 = \frac{10 - 5.7}{0.52} = 8.27k, \quad R_4 = \frac{10 - 7.85}{1} = 2.15k,$$

$$R_5 = \frac{5}{1.01} = 4.95k$$