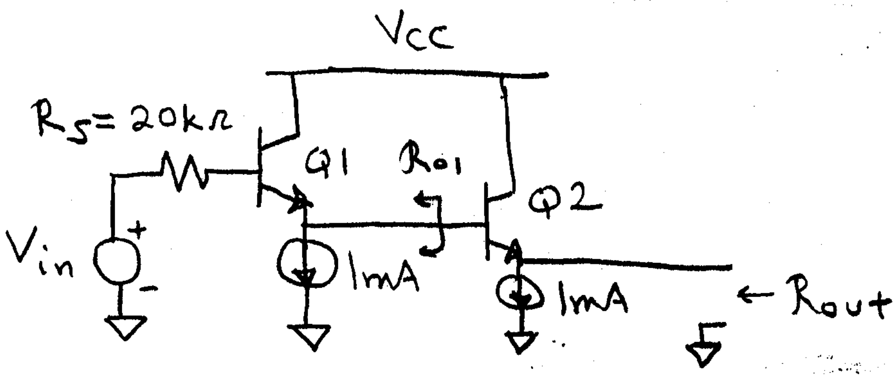
1890 Midterm Sol'n F'09

1: a) Find the small-signal output resistance R_{out} for the amplifier shown below. Assume all the transistors are forward-active with $I_{C1} = I_{C2} = 1$ mA.

7 pts

R_{out} = 26 Ω



$$R_{out} = \frac{r_{\pi_2} + R_{o1}}{\beta + 1} = \frac{5.2k + 124}{201} = 26\,\Omega$$

$$R_{o1} = \frac{r_{\pi_1} + R_S}{\beta + 1} = \frac{5.2k + 20k}{201} = 124\,\Omega$$

$$r_{\pi_1} = r_{\pi_2} = \frac{\beta V_T}{I_C} = 5.2\,k\Omega$$

4 pts

b) How does the small-signal output resistance R_{out} change in each case:

i) if R_s decreases: (circle one) $\Rightarrow R_{o1}\downarrow \Rightarrow R_{out}\downarrow$

R_{out} decreases $\qquad$ R_{out} increases $\qquad$ R_{out} doesn't change

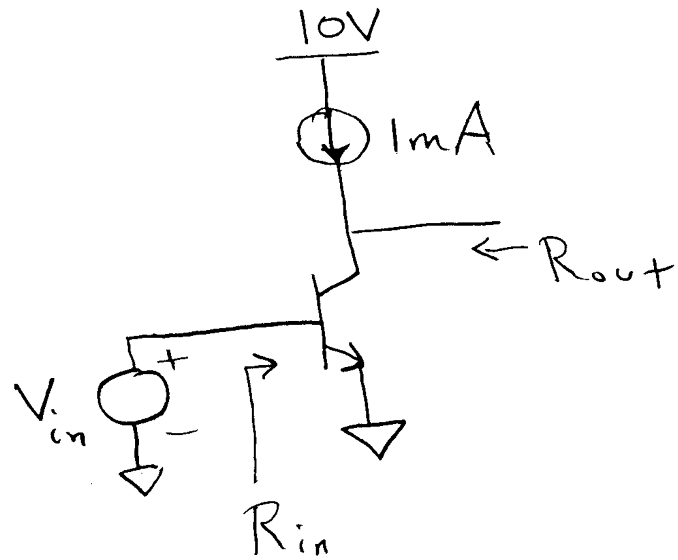
ii) if I_{C1} and I_{C2} both increase to 2 mA : (circle one) $\Rightarrow r_\pi \downarrow \Rightarrow R_{out}\downarrow$

R_{out} decreases $\qquad$ R_{out} increases $\qquad$ R_{out} doesn't change

2. In the circuit below, R_{in} and R_{out} have been measured in the lab: R_{in} = 4k ohms and R_{out} = 112k ohms. Assuming the transistors is forward active and the DC collector current is 1 mA:

What is β for this transistor? β = 154

What is V_A for this transistor? V_A = 112 V



$$R_{in} = r_\pi = \frac{\beta V_T}{I_c} = \frac{\beta(26\text{mV})}{1\text{mA}}$$

$$R_{in} = 4\text{k}\Omega$$

$$\Rightarrow \beta = 154$$

$$R_{OUT} = r_o = \frac{V_A}{I_c} = \frac{V_A}{1\text{mA}}$$

$$R_{OUT} = 112\text{k}\Omega$$

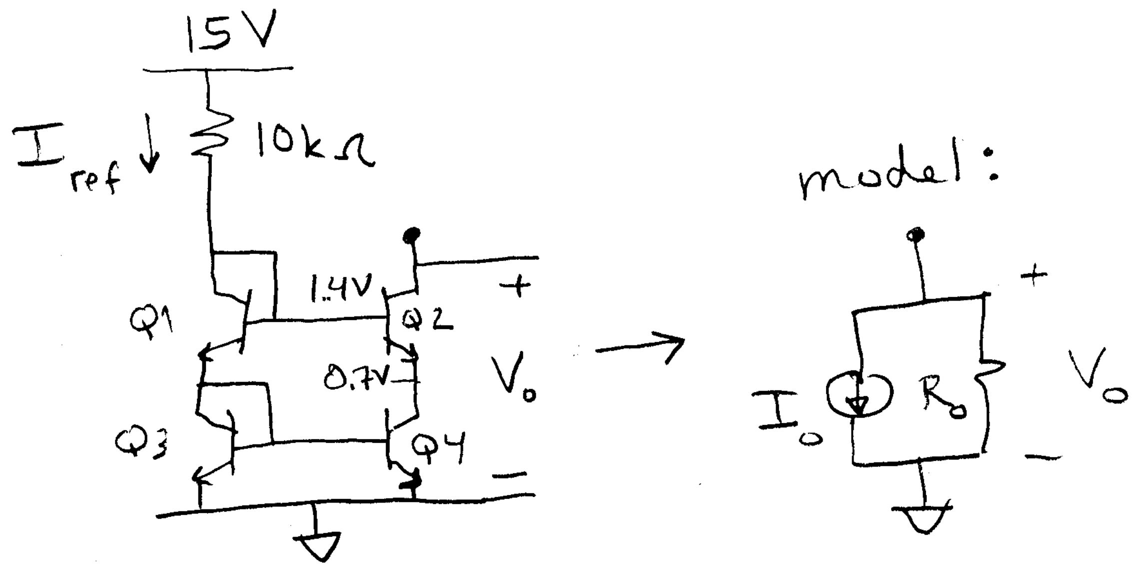
$$\Rightarrow V_A = 112\text{V}$$

3. a) A current source is shown below. All transistors are identical. Assume Q2 is forward active (its collector connects to other circuitry that is not shown). Find the value of I_O in the model shown.

I_O = 1.36m A

b) What is the minimum value of the voltage at the collector of Q2 (V_O) for which Q2 remains forward active?

V_O(min) = 0.8V.



a) Q3 - Q4 = current mirror

$$\Rightarrow I_{C_3} = I_{C_4} = I_{C_2} = I_O \text{ (ignoring } r_o)$$

$$I_{C_3} = I_{ref} = \frac{15V - 2V_{BE}}{10k\Omega}$$

$$\simeq \frac{15V - 2(0.7V)}{10k\Omega}$$

$$= 1.36mA$$

b) $V_E(Q2) = V_{BE_1} + V_{BE_3} - V_{BE_2} \simeq 0.7V$

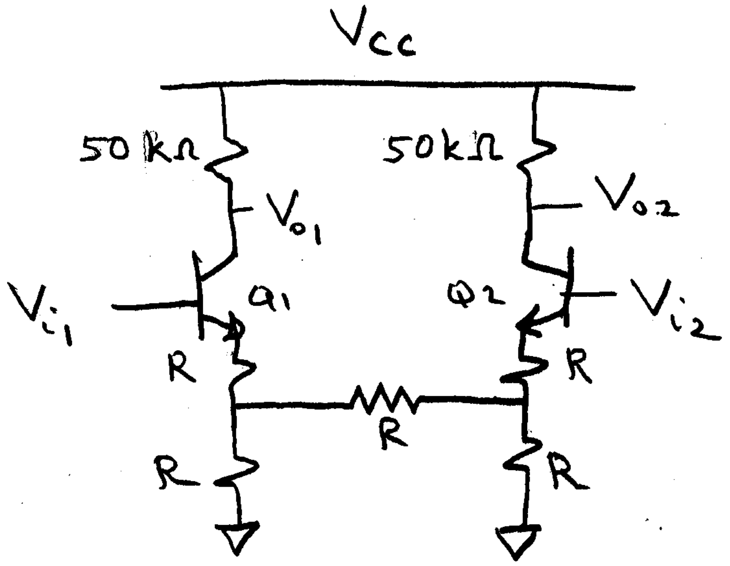
$V_o(\text{min}) \cong 0.7V + V_{CE\,SAT}(Q2) = 0.8V$

12 pts

4. Find the DM and CM gains for the differential amplifier below. Assume all transistors are forward active; Q1 and Q2 are identical; and $I_{C1}(D.C.) = I_{C2}(D.C.) = 1$ mA. FOR THIS PROBLEM ONLY, ignore the transistor's output resistance (that is, take V_A = infinity).

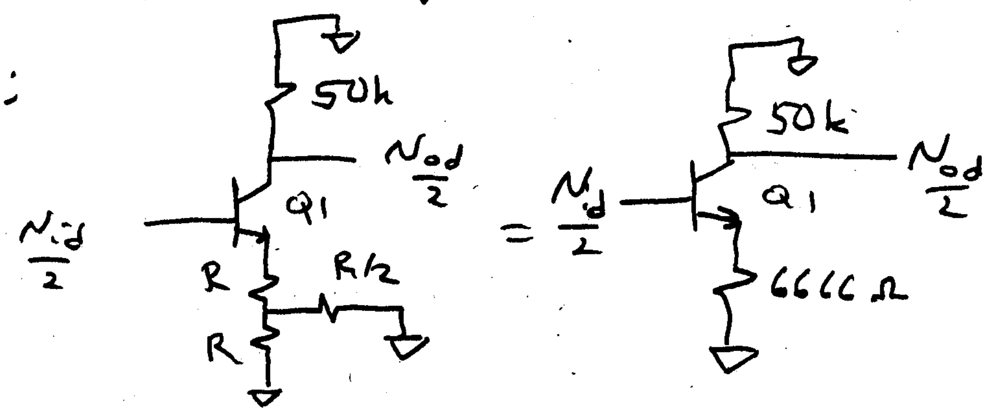
a) What is the Differential Mode (DM) gain? V_{od}/V_{id} = -7.5

b) What is the Common Mode (CM) gain? V_{oc}/V_{ic} = -5.



R=5kΩ

DM ½ ckt:

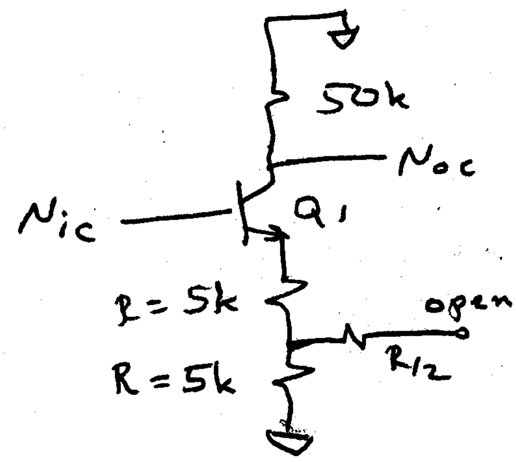


$$\frac{v_{od}}{v_{id}} = a_{DM} \simeq -G_{m_1}(50k) = \frac{-g_{m_1}}{1+g_{m_1}6666} \cdot (50k) \simeq$$

$$= -\frac{\frac{1}{26}}{1+\frac{6666}{26}} 50k = -7.5$$

Extra work space for Problem 4.

cm $\frac{1}{2}$ ckt



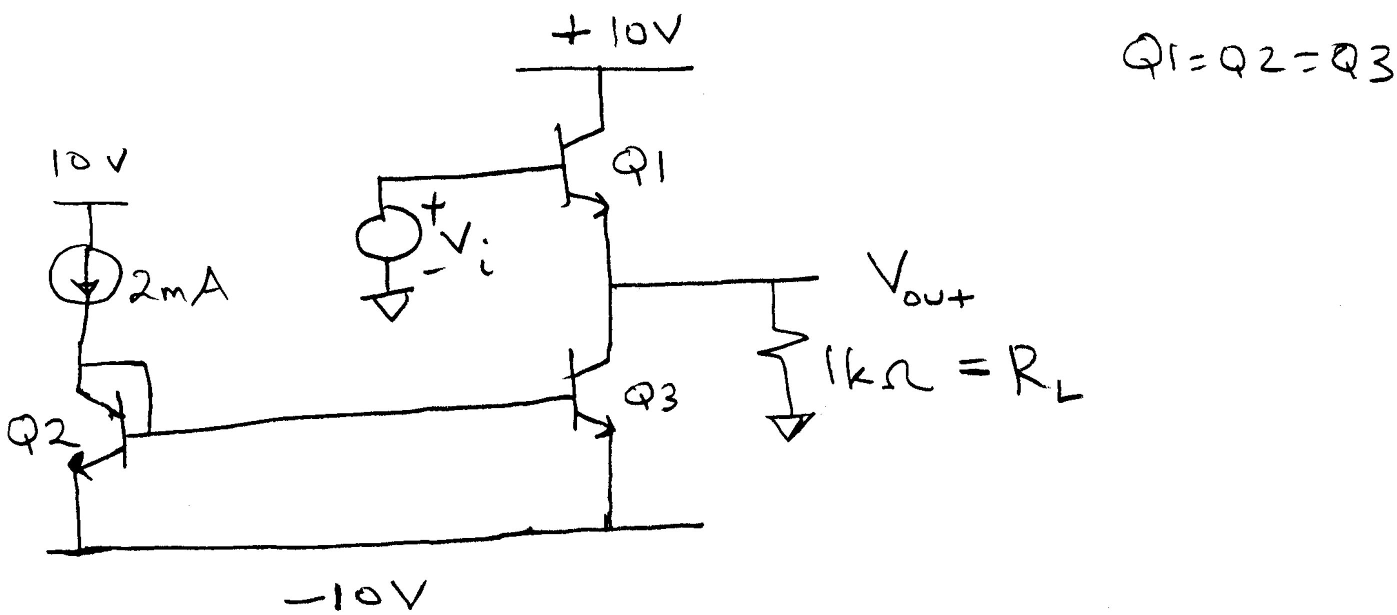
$$a_{cm} = \frac{v_{oc}}{v_{ic}} = -G_{m_1}(50k) = \frac{-g_{m_1}}{1+g_{m_1}(10k)}(50k)$$

$$= -5$$

5. A class A output stage is shown below.

a) What is the positive output swing limit? $V_{out}(max)$ = 9.9 V

b) What is the negative output swing limit? $V_{out}(min)$ = -2.0 V



Q2 - Q3 = current mirror $\Rightarrow I_{C_3} = 2mA$

a) $V_o(max) = 10V - V_{CE_{SAT}}(Q1) = 9.9V$

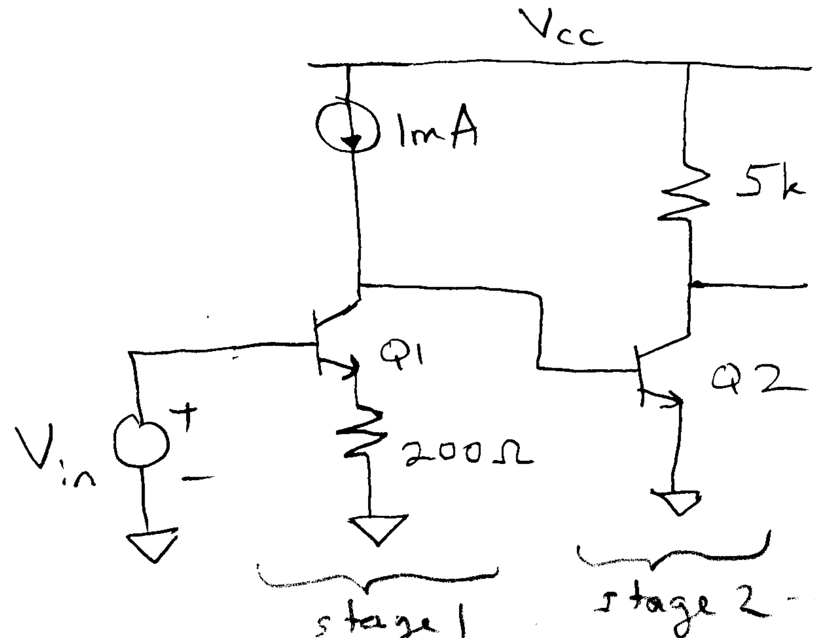
b) $V_o(min) = max\left(\underbrace{-10V + V_{CE_{SAT}}(Q3)}_{-9.9V}, \underbrace{-I_{C_3} R_L}_{-2V}\right)$

$\rightarrow V_o(min) = -2V$

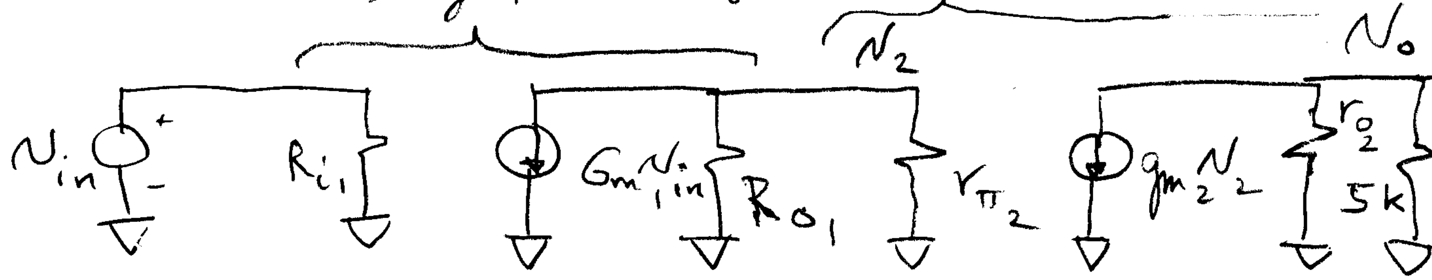
6. A two-transistor amplifier is shown below. For simplicity, the DC sources are not shown. Assume all transistors are forward active with $I_{C1} = I_{C2} = 1$ mA.

same values for Q1 & Q2

Find the small-signal voltage gain v_o/v_{in} = 4230.



$$r_{\pi_2} = \frac{\beta V_T}{I_C} = 5.2k\Omega$$
$$g_{m_2} = \frac{I_C}{V_T} = \frac{1}{26}\frac{A}{V}$$
$$r_{o_2} = \frac{V_A}{I_C} = 130k\Omega$$



$$v_2 = -G_{m_1} v_{in} (R_{o_1} \| r_{\pi_2})$$
$$v_o = -g_{m_2} (r_{o_2} \| 5k\Omega)$$

$$G_{m_1} = \frac{g_{m_1}}{1 + g_{m_1}(200\Omega)} = 4.4 \frac{mA}{V}$$
$$R_{o_1} \simeq r_{o_1}(1 + g_{m_1}(200\Omega)) = 1.1M\Omega$$

so $$v_o = +g_{m_2}(r_{o_2} \| 5k\Omega) G_{m_1} (R_{o_1} \| r_{\pi_2}) =$$
$$= \left(\frac{1}{26}\frac{mA}{V}\right)(130k \| 5k)\left(4.4\frac{mA}{V}\right)(1.1M \| 5k) \simeq 4230$$