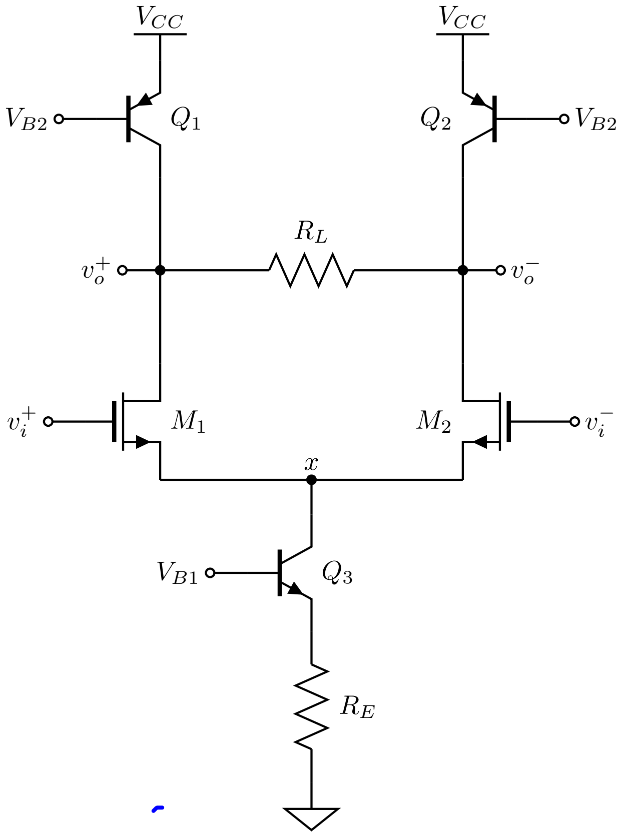
Name: Solutions

Student No.:

Part III:

(19 points) The differential amplifier below, with $V_{CC} = 5\,\text{V}$, $R_E = 50\,\Omega$, and $R_L = 800\,\text{k}\Omega$, has the following quiescent state: $I_{C3} = 1\,\text{mA}$, $I_{C1} = I_{C2} = 500\,\mu\text{A}$, $V_{GS1} = V_{GS2} = 1.5\,\text{V}$, and $V_x = 0.5\,\text{V}$. All the BJTs have $|V_{CE,sat}| = 0.2\,\text{V}$, with $r_{o,Q1} = r_{o,Q2} = 200\,\text{k}\Omega$, and $r_{o,Q3} = 100\,\text{k}\Omega$. The MOSFETs are identical, with $V_{TH} = 1\,\text{V}$, and $\lambda = 0$. The bias voltage V_{B1} is a constant, while an external circuit (not shown) automatically adjusts V_{B2} to maintain $V_o^+ = V_o^- = 2.5\,\text{V}$. Assume $V_T = \frac{kT}{q} = 26\,\text{mV}$.



1. Determine the minimum input common mode voltage, $V_{IC,\min}$. *(3 points)*

$V_{IC,min} = V_{GS_1} + V_{CE,sat,Q_1} + V_{R_E} = V_{x,min}$

$= 1.5V + 0.2V + (1mA \cdot 50\Omega)$

$= 1.5V + 0.2V + 50mV$

$= 1.75V$

$V_{IC,\min} =$ 1.75V

2. Determine the maximum input common mode voltage, $V_{IC,\max}$. *(2 points)*

$V_{DS1,min} = V_o^+ - V_{x,max}$ but $V_{x,max} = V_{ic,max} - V_{GS1}$

$V_{Dsat} = V_o^+ - V_{ic,max} + V_{GS1}$

$V_{GS1} - V_{TH} = V_o^+ - V_{ic,max} + V_{GS1}$

$V_{IC,\max} =$ 3.5V

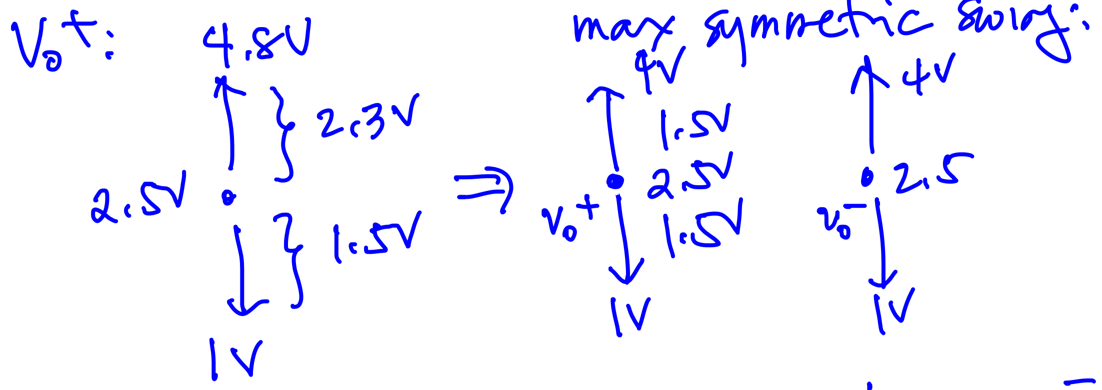
$\therefore V_{ic,max} = V_o^+ + V_{TH}$
$= 2.5V + 1V = 3.5V$

3. What is the maximum symmetric differential output voltage swing? *(4 points)*

If $V_o^+ = V_o^- = 2.5V$, the max. swing of V_o^+ is $V_{DD} - V_{CE,sat,Q_1} = 5V - 0.2V = 4.8V$.

The min. swing is set by $V^+_{o,min} - V_x > V_{Dsat1}$

$\therefore V^+_{o,min} = V_{Dsat1} + V_x = V_{GS1} - V_{TH} + V_x$
$= 1.5V - 1V + 0.5V$
$= 1V$



$V_{od} = V_o^+ - V_o^-$

$V_{od,max} = V^+_{o,max} - V^-_{o,min}$
$= 4V - 1V = 3V$

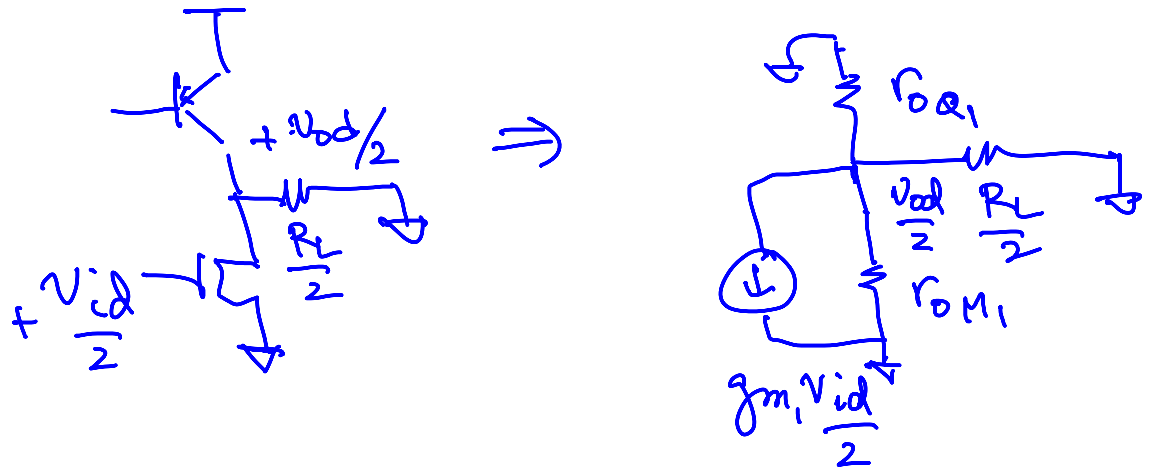
$V_{od,min} = V^+_{o,min} - V^-_{o,max}$
$= 1V - 4V = -3V$

$v_{od,swing,\max} =$ 6V

4. Determine the maximum differential input voltage swing such that there is no clipping at the output. *(5 points)*

To get the input swing, we need the diff. voltage gain.

Diff. half circuit:



$$A_{dm} = \frac{v_{od}}{v_{id}} = -g_{m_{M_1}} \left(r_{oQ_1} \parallel r_{oM_1} \parallel \frac{R_L}{2} \right)$$

$$= -\frac{2 I_{DM_1}}{V_{GS_1} - V_{TH}} \left(r_{oQ_1} \parallel r_{oM_1} \parallel \frac{R_L}{2} \right)$$

$$= -\frac{(2) 500\,\mu A}{1.5V - 1V} \left(200k\Omega \parallel \infty \parallel 400k\Omega \right)$$

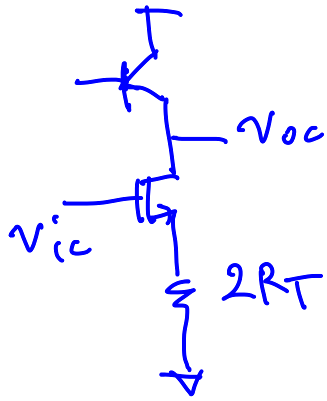
$$= -133.3\,(2) = -266.6$$

$$\therefore\ v_{id_{swing}} = \frac{v_{od,swing}}{|A_{dm}|} = \frac{6}{266.6} = 22.5\,mV$$

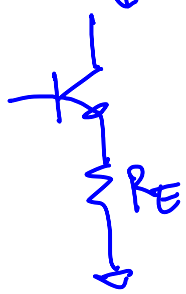
$v_{id,swing,\max} =$ 22.5 mV

5. Determine the common-mode rejection ratio (CMRR) of the amplifier. *(5 points)*

CM Half circuit:



R_T:

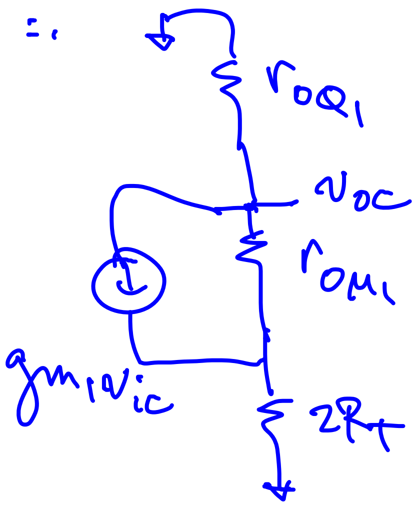


$$R_T = r_{oQ_3}(1+g_{mQ_3}R_E)$$

$$= 100k\left(1+\frac{1mA}{26mV}\cdot 50\Omega\right)$$

$$= 292\,k\Omega$$

∴



$$A_{cm} = \frac{-g_{m1}}{1+g_{m1}(2R_T)} \cdot r_{oQ_1}$$

$$= \frac{-\frac{2(500\mu A)}{1.5V-1V}\cdot(200k\Omega)}{1+\frac{2(500\mu A)}{1.5V-1V}\cdot 2\cdot 292k\Omega}$$

$$= \frac{-400}{1+1168} = -0.171$$

$$\therefore CMRR = \left|\frac{A_{dm}}{A_{cm}}\right| = \frac{266.6}{0.171} = 1559$$

$$\approx 1560$$

$CMRR =$ 1560