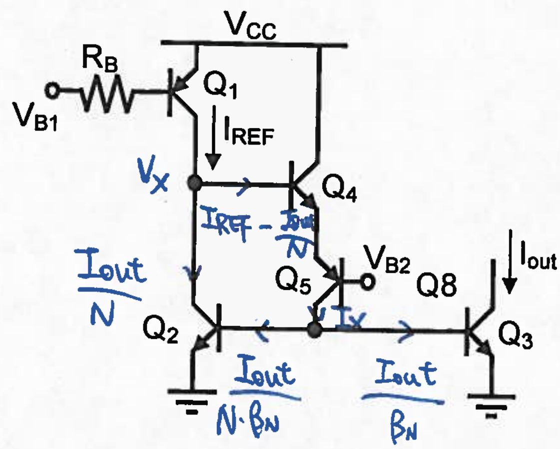
Name: Solution Student ID:

1- A) Find an exact expression for I_{out} in terms of I_{REF}, β_N, and β_P. Q_3 is matched but N times larger than Q_2. B) Find the minimum and maximum value of V_{B2} for all the transistors to stay in the active region. Assume a piece-wise linear model for the transistors with a turn-on voltage of V_{BEon} and saturation voltage of V_{CEsat}.



(10+15=25 points)

(A)

$$I_X = \frac{(\beta_N+1)\beta_P}{\beta_P+1}\left[I_{REF} - \frac{I_{out}}{N}\right] = I_{out}\left(\frac{1}{\beta_N} + \frac{1}{N\cdot\beta_N}\right)$$

$$\Rightarrow \quad I_{out} = \frac{N\cdot I_{REF}}{1+\dfrac{(N+1)(\beta_P+1)}{(\beta_N+1)\beta_N\beta_P}}$$

(B)

Make Q_1 active:

$$|V_{CE,Q1}| > V_{CEsat}$$

$$\Rightarrow V_{CC} - V_X > V_{CEsat} \Rightarrow V_{CC} - (V_{B2} + 2V_{BEON}) > V_{CEsat}$$

$$\Rightarrow V_{B2} < V_{CC} - V_{CEsat} - 2V_{BEON}$$

Make Q_5 active:

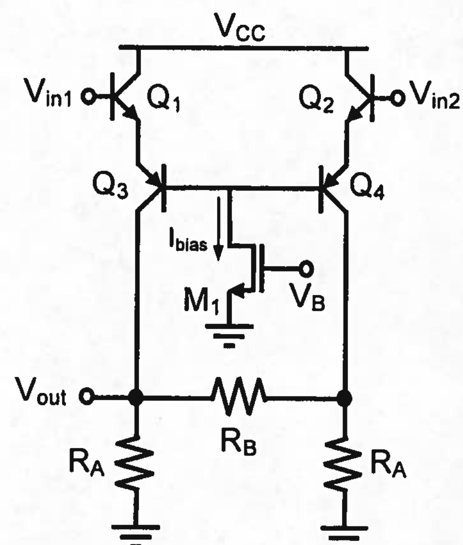
$$|V_{CE,Q5}| > V_{CE,sat} \Rightarrow (V_{B2} + V_{BEON}) - V_{BEON} > V_{CEsat}$$

$$\Rightarrow V_{B2} > V_{CEsat}$$

2- Assuming that V_T=25mV, $|V_{BEon}|$=0.7V, $|V_{CEsat}|$=0.2V, $V_A=\infty$, β=100, V_{TH}=0.3V, $\lambda=0.1V^{-1}$, V_{CC}=10V, V_B=0.5V, R_A=5KΩ, R_B=10KΩ, and I_{bias}=20μA: A) Find the bounds for the input common mode level for all the transistors to stay in the active region. B) If the input common mode level is set at V_{CC} find maximum differential swing at the input for all the transistors to stay in the active region. C) Find $A_{Vd}=V_{out}/(V_{in1}-V_{in2})$. D) Find CMRR.

Note: Anything can be ignored compared to something 100 times larger. Also $\beta/(\beta+1)\approx 1$

(10+10+5+10=35 points)



(A) $I_{bias} = 20\mu A \Rightarrow I_{B3} = I_{B4} = 10\mu A \Rightarrow I_{C1} = I_{C2} = I_{C3} = I_{C4} = 1mA$

$\Rightarrow V_{out,DC} = 5V$

Make M_1 sat. :

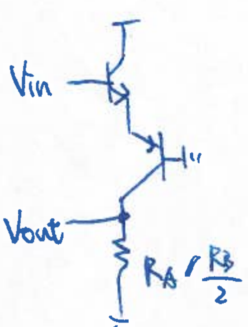
$V_{CM} > 2V_{BE} + (V_{GS} - V_{TH}) = 2 \times 0.7 + 0.2 = 1.6$

Make Q_1 act :

$V_{EC,Q1} = V_{CC} - (V_{CM} - V_{BEON}) > V_{CEsat}$

$\Rightarrow V_{CM} < V_{CC} + V_{BEON} - V_{CEsat} = 10.5$

(B) Find differential gain :



$G_m = -\frac{1}{\frac{1}{g_{m1}} + \frac{1}{g_{m3}}} = -20mS$

$R_{out} = R_A // \frac{R_B}{2} = 2.5k \Rightarrow A_V = 50 = \frac{V_{out}}{V_{in}}$

However $A_{vd} = \frac{V_{out}}{V_{in1} - V_{in2}} = \frac{1}{2} \times A_V = 25$

The output can swing lower without affecting the transistors but if it swings higher, Q_3 may go into saturation.

That means

$$V_{EC,Q_3} \geq V_{CEsat} \Rightarrow \left(V_{CM} + \frac{V_{id}}{2} - V_{EB,ON}\right) - \left(V_{out,DC} + 25 \times V_{id}\right) \geq 0.2$$

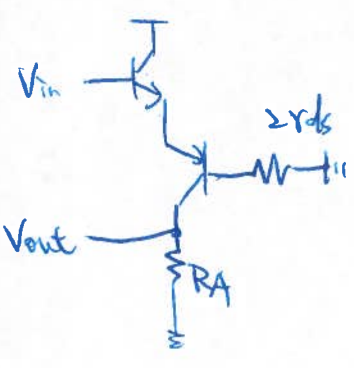
($V_{CM} + \frac{V_{id}}{2} - V_{EB,ON}$ = V_{E,Q_3})

$$\Rightarrow \quad 10 + \frac{V_{id}}{2} - 0.7 - 5 - 25\,V_{id} \geq 0.2$$

$$\Rightarrow \quad V_{id} \leq 0.167\ V$$

(c) $A_{vd} = 25$

(D) Find common-mode gain:



$$G_m = -\frac{1}{\frac{1}{g_{m1}} + \frac{r_{\pi 3} + 2r_{ds}}{\beta}}$$

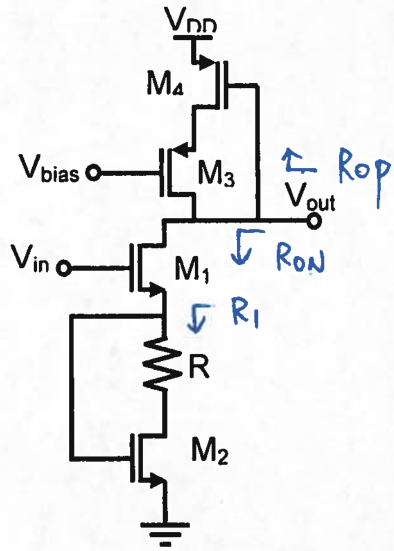
$$= -100\,\mu S$$

$R_{out} = 5k$

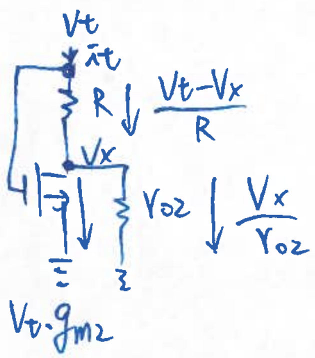
$$\Rightarrow A_{CM} = 0.5 \Rightarrow CMRR = \frac{25}{0.5} = 50$$

3- In this amplifier, without making any simplifying assumption: A) Find the output impedance. B) Find the voltage gain.

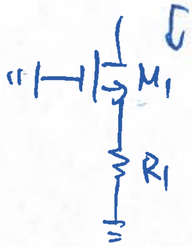
(20+20=40 points)



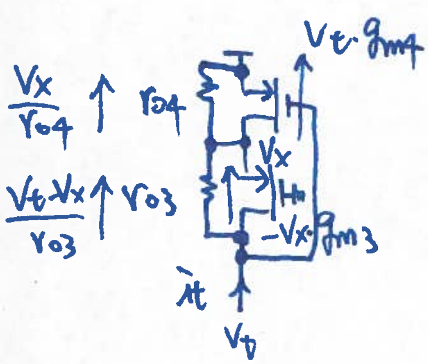
(A)



$$\Rightarrow \frac{V_t}{i_t} = \frac{R + r_{o2}}{1 + g_{m2} r_{o2}} = R_1$$



$R_{ON} = g_{m1} r_{o1} R_1 + r_{o1} + R_1$

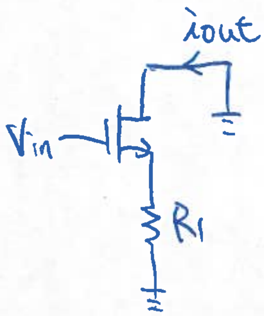


$$\Rightarrow \frac{V_t}{i_t} = \frac{r_{o4} + r_{o3} + g_{m3} r_{o3} r_{o4}}{1 + g_{m4} r_{o4} + g_{m3} g_{m4} r_{o3} r_{o4}} = R_{op}$$

$$\Rightarrow R_{out} = R_{op} \parallel R_{ON}$$

(B)

$$G_m = \frac{g_{m1}}{1 + g_{m1}R_1 + \frac{R_1}{r_{o1}}}$$



$$A_V = -G_m \cdot R_{out}$$