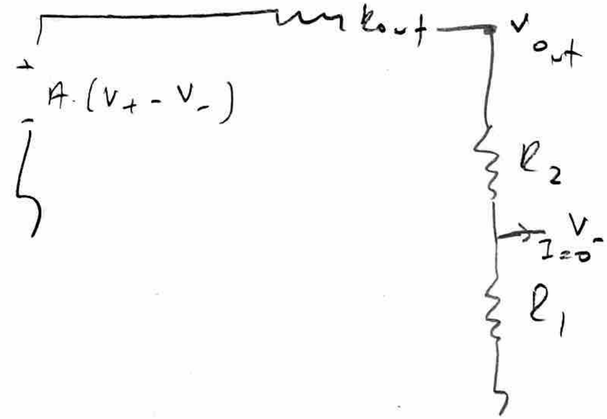
Q.1)



$$V_- = \underbrace{\frac{R_1}{R_1+R_2}}_{\beta} \cdot V_{out}$$

$$\frac{A.(V_{in} - \beta . V_{out})}{R_{out}} = \frac{V_{out} - \beta . V_{out}}{R_2}$$

$$\frac{A.V_{in}}{R_{out}} = \frac{A.\beta.V_{out}}{R_{out}} + \frac{V_{out}}{R_2} - \frac{\beta.V_{out}}{R_2}$$

$$\frac{A.V_{in}}{R_{out}} = V_{out}\left(\frac{A.\beta}{R_{out}} + \frac{1}{R_2} - \frac{\beta}{R_2}\right)$$

$$A.V_{in} = V_{out}\left(A\beta + \frac{(1-\beta)R_{out}}{R_2}\right)$$

(a) $$\frac{V_{out}}{V_{in}} = \frac{A.R_2}{A.\beta.R_2 + (1-\beta)R_{out}} = \frac{4.1000}{4.1000.\frac{1}{5} + (0.8)100} = 4.54$$

(b) $R_{out} = 0$, A is very large, $\frac{V_{out}}{V_{in}} \approx \frac{1}{\beta} = 5$

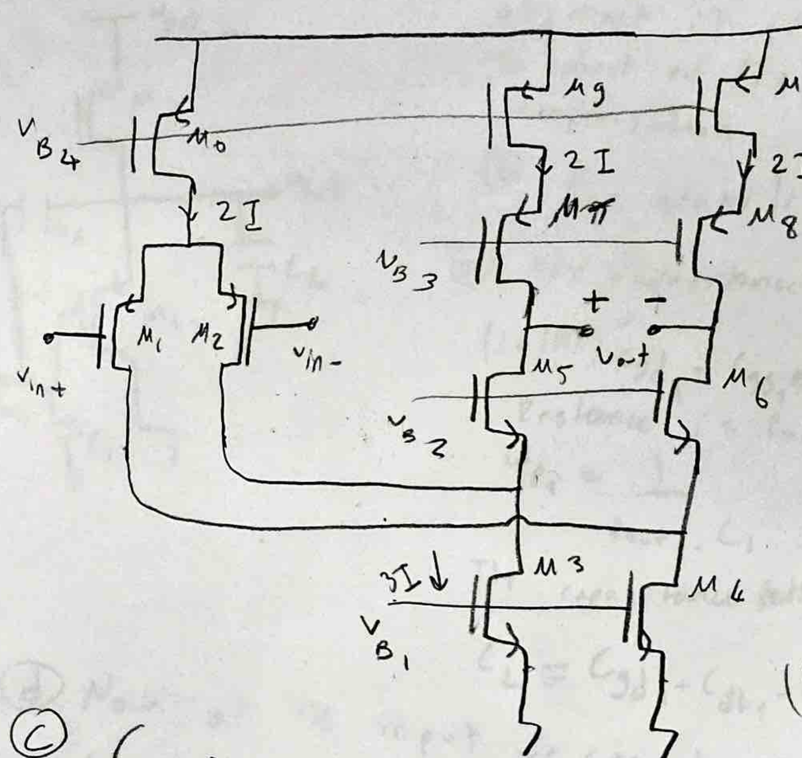
(c) As it can be see from the equation in part (a) Rout has a significant role in determining the closed loop gain hence with comparable Rout ~~to~~ with R_L the loading does not occur and OPAMP (or small) operates as desired.

Question 2

$\mu_n C_{ox} = 4\mu_p C_{ox}$, $\gamma = 0$

$r_{o5} = r_o$ $g_{m5} = g_m$ $\lambda_n = \lambda_p$

$(W/L)_5 = (W/L)_6$



(a) CS inverts Common gate does not

(b) $\left(\frac{W}{L}\right)_0 = \left(\frac{W}{L}\right)_9 = \left(\frac{W}{L}\right)_{10}$

$\left(\frac{W}{L}\right)_9 \frac{1}{2}\mu_p C_{ox} (V_{ov})^2 = 2I$ $= \left(\frac{W}{L}\right)_8 = \left(\frac{W}{L}\right)_7$

$\left(\frac{W}{L}\right)_5 \frac{1}{2}\mu_n C_{ox} (V_{ov})^2 = 2I$

$4 \cdot \left(\frac{W}{L}\right)_5 = \left(\frac{W}{L}\right)_9$

$\left(\frac{W}{L}\right)_5 = \left(\frac{W}{L}\right)_6 = \frac{2}{3}\left(\frac{W}{L}\right)_3 = \frac{2}{3}\left(\frac{W}{L}\right)_4$

$\left(\frac{W}{L}\right)_1 = \left(\frac{W}{L}\right)_2 = 2 \cdot \left(\frac{W}{L}\right)_0$

(c) $G_m \approx g_{m2}$, $R_{out} = \underbrace{g_{m7} r_{o9} r_{o7}}_{\text{simplification of } R_S + r_o(1+g_m R_S)} \parallel g_{m5} r_{o5} (r_{o3} \parallel r_{o1})$

$A_v = \left|\frac{V_{out}}{V_{in}}\right| = g_{m2} \cdot R_{out}$,

$g_{m5} = \sqrt{2I_D \cdot \left(\frac{W}{L}\right)_5 \mu_n C_{ox}}$

$g_{m7} = \sqrt{2I_D \cdot \left(\frac{W}{L}\right)_7 \mu_p C_{ox}}$

$g_{m7} = g_{m5} = g_m$

$g_{m2} = \sqrt{I_D \cdot \left(\frac{W}{L}\right)_2 \mu_p C_{ox}}$

$g_{m2} = g_{m7} = g_m$

$A_v = g_m \cdot (g_m r_o^2 \parallel g_m \frac{r_o^2}{2})$

$A_v = g_m \cdot \frac{2 g_m r_o^2}{3} = \frac{2 g_m^2 r_o^2}{3}$

(d) Short V_{in-} and V_{out}, (1) $V_{B3} > V_{out} - V_{th}$,

(2) $V_{out} > V_{B2} - V_{th}$, $V_{B2} - V_{GS} + V_{th} < V_{in}$

(3) greater than (2)

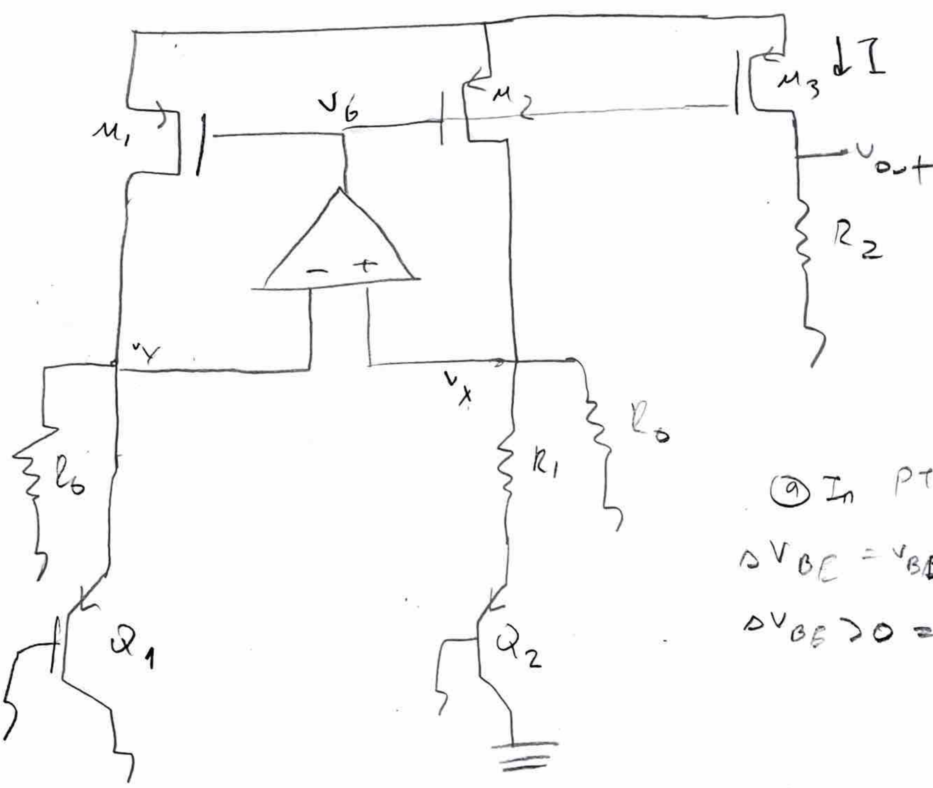
$V_{B3} + V_{th} > V_{in} > V_{B2} - V_{ov1} - 2V_{th}$

(e) From M_2, $\frac{4kT\gamma}{g_{m2}}$, From M_3, $\frac{4kT\gamma g_{m3} \cdot \cancel{(R_{out})^2}}{g_{m2}^2 \cdot \cancel{(R_{out})^2}}$

From M_9, $\frac{4kT\gamma g_{m9} \cdot \cancel{(R_{out})^2}}{g_{m2}^2 \cdot \cancel{(R_{out})^2}}$, $V_{nin}^2 = \left(\frac{4kT\gamma}{g_{m2}} + \frac{4kT\gamma g_{m3}}{g_{m2}^2} + \frac{4kT\gamma g_{m9}}{g_{m2}^2}\right)^2$

Middle transistors do not contribute to noise due to source degeneration noise is not amplified.

Question 3



ⓐ In PTAT behaviour $\Delta V_{BE} > 0$

$\Delta V_{BE} = V_{BE_1} - V_{BE_2} = V_T \ln(n)$ $\rightarrow \frac{A_2}{A_1}$

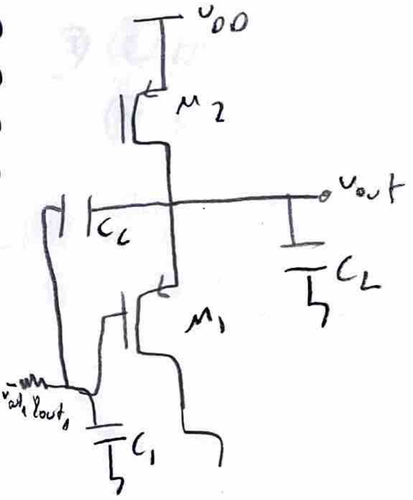
$\Delta V_{BE} > 0 \Rightarrow n \cdot A_1 = A_2$

ⓑ We need to verify that when $V_X \uparrow$ $V_{out} \downarrow$.
when $V_X \uparrow$, $A.(V_X - V_Y) = V_G \uparrow$, As $V_G \uparrow$ $V_{SG} \downarrow$ hence $I \downarrow$
$V_{out} = R_2 . I$, $V_{out} \downarrow$. Therefore negative feedback is avaliable.

ⓒ $V_X = V_Y$, $I . R_1 + V_{EB_2} = V_{EB_1}$, $I . R_1 = V_T . \ln(n)$, $I . R_2 = V_{out}$

$$\boxed{V_{out} = \frac{R_2}{R_1} . V_T \ln(n)}$$

Question 4



(a) 2 poles does not ~~cross~~ exceed -180° degrees at most it will reach -180° and oscillate So most of the cases it does not require compensation

(b) For stability

(c) The capacitance from M_1

$(1+|A|)\,C_{gd_1} + C_{gs_1}$ Total cap at the gate of M_1 → $\underbrace{C_1 = (1+|A|)\,C_{gd_1} + C_{gs_1}}_{C_1}$

Resistance is R_{out_1}

$$\omega_{p_1} = \frac{1}{R_{out_1} \cdot C_1}$$

The capacitance ~~at~~ at the output is

$$C_L = C_{gd_1} + C_{db_1} + C_{gs_2} + C_{sb_2} = C_L \qquad \omega_{p_2} = \frac{1}{(r_{o_2} \| r_{o_1}) \cdot C_L}$$

(d) Now at the input we see $(1+|A|)\,C_c + C_1$ as the cap.

At the output we see $C_L + C_c$ as the cap

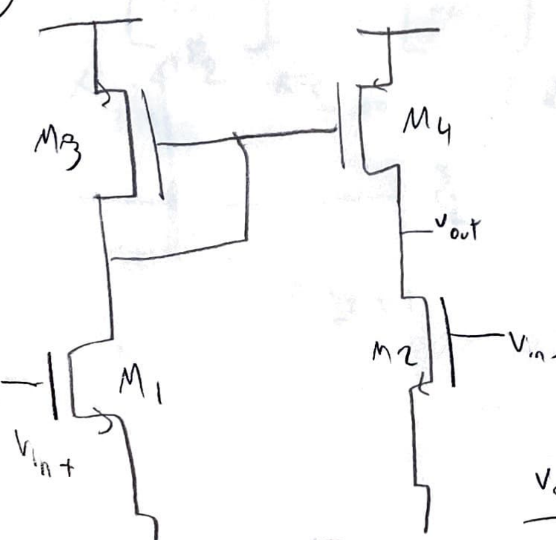
$$\omega_{p_1,new} = \frac{1}{R_{out_1}\underbrace{\left(C_1 + (1+A)\,C_c\right)}_{\text{moves to lower freq}}} \qquad \omega_{p_2,new} \approx \underbrace{\frac{g_m}{C_c}}_{\text{moves to higher freq}}$$

Question 5

(a) @ A → $R_A = \frac{1}{g_m} \| r_o = \frac{1}{g_m}$, $\omega_{pA} = \frac{g_m}{C_A}$, $C_A = C_{gs3} + C_{gd3} + C_{db1} + C_{gd1} + C_{gs4} + C_{gd4}(1-\underset{-g_m \frac{r_o}{2}}{A})$

@ out → $R_{out} = r_o \| r_o = \frac{r_o}{2}$, $\omega_{p_{out}} = \frac{2}{r_o \cdot C_{out}}$, $C_{out} = C_{db4} + C_{gd4} + C_{db2} + C_{gd2}$

(b)



$V_{in+} \to V_{out}$ gain is $\overset{g_m \frac{1}{g_m}}{1} \cdot g_m \frac{r_o}{2}$

$V_{in-} \to V_{out}$ gain is $-g_m \frac{r_o}{2}$

$$\frac{V_{out}(s)}{V_{in+}} = \frac{g_m r_o}{2} \cdot \frac{1}{\left(1+\frac{s}{\omega_{pA}}\right)} \cdot \left(\frac{1}{1+\frac{s}{\omega_{po}}}\right)$$

$$\frac{V_{out}(s)}{V_{in-}} = -\frac{g_m r_o}{2} \cdot \frac{1}{\left(1+\frac{s}{\omega_{po}}\right)}$$

$$\frac{V_{out}(s)}{V_{in}} = \frac{g_m r_o}{2} \left(\frac{1}{1+\frac{s}{\omega_{pout}}}\right) \cdot \left(1 + \frac{1}{1+\frac{s}{\omega_{pA}}}\right)$$

$$\frac{V_{out}(s)}{V_{in}} = \frac{g_m r_o}{2} \cdot \frac{\left(2+\frac{s}{\omega_A}\right)}{\left(1+\frac{s}{\omega_{pout}}\right)\left(1+\frac{s}{\omega_A}\right)}$$

(c) $\boxed{\text{zero at } 2\omega_{pA} = 2\frac{g_m}{C_A}}$