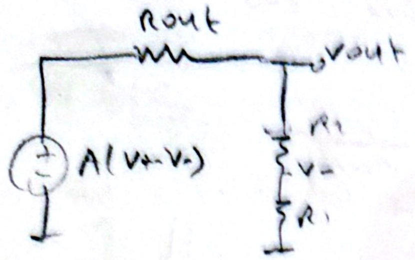
1) Orhan, İbrahim [illegible]

a)



$$V_- = \left(\frac{R_1}{R_1+R_2}\right)V_{out} \qquad \boxed{\frac{V_{out}}{V_+} = ?}$$

KCL

$$0 = \frac{V_{out} - \left(\frac{R_1}{R_1+R_2}\right)V_{out}}{R_2} + \frac{V_{out} - A\left(V_+ - \frac{R_1}{R_1+R_2}V_{out}\right)}{R_{out}}$$

Let $\frac{R_1}{R_1+R_2} = B$ then,

$$V_{out}(R_{out} - B\cdot R_{out}) = V_{out}(R_2 + ABR_2) - AV_+R_2$$

$$V_{out}\left[(1-B)R_{out} - (1+AB)R_2\right] = -(A\cdot R_2)V_+$$

$$\frac{V_{out}}{V_+} = \frac{A\cdot R_2}{(1+AB)R_2 + (1-B)R_{out}}$$

if $R_{out} = 0$

$$\frac{A}{1-AB} = \boxed{\frac{A}{1+A\cdot\frac{R_1}{R_1+R_2}}}$$ ✓ holds

$$\boxed{\frac{V_{out}}{V_+} = \frac{AR_2}{\left(1+A\cdot\frac{R_1}{R_1+R_2}\right)R_2 - \left(1-\frac{R_1}{R_1+R_2}\right)R_{out}}}$$

b)

$$A_v = \frac{A}{1 - A\cdot\frac{R_1}{R_1+R_2}}$$, if $A = 1000 \gg 1$ this equation becomes as follows:

$$A_v = \frac{\cancel{A}}{\cancel{A}\cdot\frac{R_1}{R_1+R_2}} = \boxed{\frac{R_1+R_2}{R_1} = 5}$$

c) with Rout

$$A_v = \frac{1000\cdot 1k}{\left(1+1000\cdot\frac{1}{5}\right)4k - \left(1-\frac{1}{5}\right)100k} = \boxed{1.38}$$

without Rout

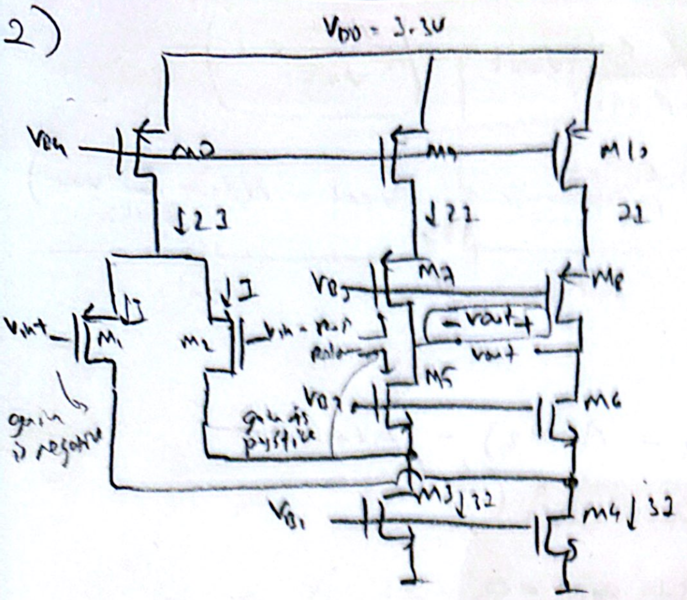
$$\boxed{A_v \cong 5}$$

so without Rout, OPAMP gain is large compared to with Rout case. the feedback wants to correct this value but OPAMP couldn't. However, as seen in the without Rout case, due to feedback we get 5 gain.

$$\frac{1}{4}\left[\frac{2A^2 + 2A^2 + 4A^2}{[illegible]}\right]$$

$2A^2 = E_s$

2)



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

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

$\left(\frac{W}{L}\right)_5 = \left(\frac{W}{L}\right)_6 = \frac{10\mu m}{1\mu m}$

a) − Vout +

b) $\frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_{5,6}(V_{GS}-V_{th})^2 = 2I$

$\frac{1}{2}\underbrace{\mu_p C_{ox}}_{\frac{\mu_n C_{ox}}{4}}\left(\frac{W}{L}\right)_{7,8}(V_{GS}-V_{th})^2 = 2I$

$$\boxed{\Rightarrow \left(\frac{W}{L}\right)_{7,8} = 4\left(\frac{W}{L}\right)_{5,6} = \left(\frac{W}{L}\right)_{9,10} = \left(\frac{W}{L}\right)_0}$$

$\frac{1}{2}\frac{\mu_n C_{ox}}{4}\left(\frac{W}{L}\right)_{1,2}(V_{GS}-V_{th})^2 = I$

$$\boxed{\left(\frac{W}{L}\right)_{1,2} = 2\left(\frac{W}{L}\right)_{5,6}}$$

$\frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_{3,4}(V_{GS}-V_{th})^2 = 3I$

$$\boxed{\left(\frac{W}{L}\right)_{3,4} = \frac{3}{2}\left(\frac{W}{L}\right)_{5,6}}$$

c) $A_v = -G_m R_{out}$

$\boxed{G_m \simeq -g_{m1}} = -g_m$

$r_{out} = R_{up} \,//\, R_{down}$ $\quad (g_m r_o \gg 1)$

$R_{up} = g_{m7} r_{o7} r_{o9} = g_m r_o^2$

$R_{down} = \underbrace{g_{m5} r_{o5}}_{g_m r_o}\underbrace{(r_{o3} // r_{o1})}_{\frac{r_o}{2}} = \frac{g_m r_o^2}{2}$

$$R_{out} = \frac{g_m r_o^2 \cdot \frac{g_m r_o^2}{2}}{\frac{2 g_m r_o^2}{2} + \frac{g_m r_o^2}{2}} = \frac{1}{3} g_m r_o^2 \Rightarrow \boxed{A_v = -\frac{(g_m r_o)^2}{3}}$$

e) Total noise contributors: M1, M9, and M3. Due to source degeneration, noise is not amplified, so that I can ignore the contribution coming from the transistors M0, M7, and M5. (Same ones for the other branch of course)

M1: $\frac{4kT\gamma g_{m1}}{g_{m1}^2}$

M9 (current to voltage conversion): $\frac{4kT\gamma g_{m9} \cdot R_{out}^2}{\underbrace{g_{m1}^2 \cdot R_{out}^2}_{\text{gain of the opamp}}} = \frac{4kT\gamma g_{m9}}{g_{m1}^2}$

M3: $\frac{4kT\gamma g_{m3}}{g_{m1}^2}$

Total noise

$$2 \times 4kT\gamma\left[\frac{1}{g_{m1}} + \frac{g_{m9}}{g_{m1}^2} + \frac{g_{m3}}{g_{m1}^2}\right]$$

d) $V_{out,max} = V_{in,max} = V_{DD} - 2V_{ov}$

$V_{out,min} = V_{in,min} = V_{ov} + V_{th}$

3) $\Delta V_{BE} = V_T \ln(n)$

Nature of the OPAMP $= V_y - V_x$

$V_{EB} = V_T \ln\left(\frac{I_C}{I_1}\right)$ normally

$V_{EB_1} - V_{EB_2} = V_T \ln(n)$ what we want

$\underbrace{A I_s \quad B I_s}_{\text{assume}} \Rightarrow V_T \ln\left(\frac{I_C}{A I_s}\right) - V_T \ln\left(\frac{I_C}{B I_s}\right) = V_T\left[\ln I_C - \ln A I_s - \ln I_C + \ln B I_s\right]$

$= V_T \ln\left(\frac{B I_s}{A I_s}\right)$

B = n
A = 1

a) $A_2 = nA$, $A_1 = A$

b) $\beta_n = \frac{R_{down}}{R_{down} + R_{up}} = \boxed{\frac{\overset{BJT}{1/g_{m1}} \,//\, R_o}{1/g_{m1} \,//\, R_o + r_{o1}}}$

$\beta_p = \boxed{\frac{(\overset{BJT}{1/g_{m2}} + R_1) \,//\, R_o}{(1/g_{m2} + R_1) \,//\, R_o + r_{o2}}}$

In Bandgap reference, we want $\beta_n > \beta_p$ for stability purpose

when $V_x \uparrow$ $A_v(V_x - V_y) \uparrow$ so output of the OPAMP $\uparrow$. Gate voltage of $M_2 \uparrow$. PMOS current decreases. $\rightarrow$ Negative feedback.

c) $\Delta V_{BE} = V_T \ln(n)$

$V_x = V_y \Rightarrow \Delta V_{BE} = I \cdot R_1 \Rightarrow \boxed{I = \frac{V_T \ln(n)}{R_1}}$

Because M1, M2, M3 are identical, current passing thru each branch is I

so $V_{out} = I \cdot R_2$

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

4) a) Single pole OPAMPs are unconditionally stable due to only 90° phase shift

Two pole OPAMPs are conditionally stable, phase margin may or may not satisfy enough phase margin (depends on the amplitude)

b) In order to ensure OPAMP is stable and do not produce any oscillation at its output

pole splitting: $w_{p1,new}$ moved towards low freq, and $w_{pout,new}$ moved towards high freq, so poles became far apart from each other.

c) w_{p1}

$\boxed{\frac{1}{R_{out1} \cdot C_1} = w_{p1}}$

w_{pout}

$R_{out} = r_{o2} // r_{o1}$

$C_{total} = C_L$ assumed transistor capacitances are inside C_L

$\boxed{w_{pout} = \frac{1}{(r_{o2} // r_{o1}) C_L}}$

d) $w_{p1,new}$

$\boxed{\frac{1}{R_{out1} \cdot (C_1 + (1 - A_v) C_c)}}$

$A_v = -g_{m1}(r_{o1} // r_{o2})$

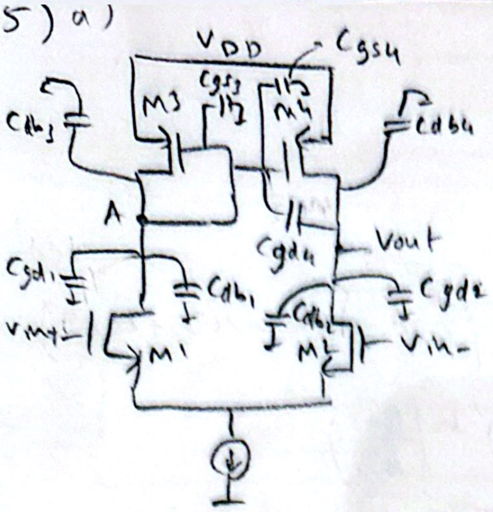
$w_{pout,new}$

$C_{total} = C_L + \left(1 - \frac{1}{A_v}\right) C_c$

$R_{out} = \frac{1}{g_m}$

$\boxed{w_{pout,new} = \frac{g_{m1}}{C_L + \left(1 - \frac{1}{A_v}\right) C_c}}$

5) a)



gain from A to vout

$A_v = -g_{m4}(r_{o4} // r_{o2})$

$C_A = C_{gd1} + C_{db1} + C_{db3} + C_{gs3} + C_{gs4} + C_{gd4}(1 - A_v)$

$C_{out} = C_{db2} + C_{gd2} + C_{gd4}\left(1 - \frac{1}{A_v}\right) + C_{db4}$

b) gain from vin+ to A $= -g_{m1}\, \overbrace{r_{o1} // \left(\frac{1}{g_{m3}} // r_{o3}\right)}^{1/g_{m3}} = \frac{-g_{m1}}{g_{m3}} = -1$

A to Vout $= -g_{m4}\underbrace{(r_{o4} // r_{o2})}_{\frac{r_o}{2}} = \frac{-g_m r_o}{2}$

gain from vin+ to vout $= \boxed{\frac{v_{out}}{v_{in+}} = \frac{g_m r_o}{2}}$

gain from vin- to vout $= \boxed{\frac{-g_m r_o}{2} = \frac{v_{out}}{v_{in-}}}$

$$\frac{V_{out}}{v_{in+}}(s) = \underbrace{(-1)\left(\frac{1}{1+\frac{s}{w_{pA}}}\right)}_{\text{vin+ to A}} \cdot \underbrace{\left(\frac{-g_m r_o}{2}\right)\left(\frac{1}{1+\frac{s}{w_{pout}}}\right)}_{\text{A to Vout}} = \boxed{\frac{g_m r_o}{2}\left(\frac{1}{1+\frac{s}{w_{pA}}}\right)\left(\frac{1}{1+\frac{s}{w_{pout}}}\right)}$$

$$\boxed{\frac{v_{out}}{v_{in-}}(s) = \frac{-g_m r_o}{2} \cdot \left(\frac{1}{1+\frac{s}{w_{pout}}}\right)}$$

+

$$\boxed{\frac{v_{out}}{v_{in}}(s) = \frac{g_m r_o}{2}\left(\frac{1}{1+\frac{s}{w_{pout}}}\right)\left[\frac{1}{1+\frac{s}{w_{pA}}} + 1\right]}$$

$$\boxed{w_{pA} = \frac{1}{C_A \cdot \frac{1}{g_{m3}}}} \quad \boxed{w_{pout} = \frac{1}{C_{out} \cdot (r_{o4} // r_{o2})}}$$

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

$$\boxed{\text{Zero at } s = w_{pA} = 2\frac{g_m}{C_A}}$$