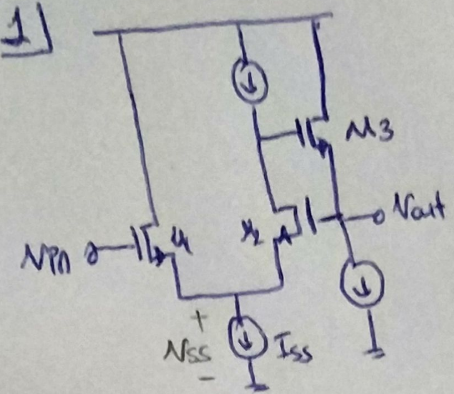
EHB 335E HW#5

1)



- Assume $V_{in}\uparrow$, Since I_{d,M_2} and hence I_{d,M_1} cannot change. To accomodate the increase in V_{in}, V_{ss} should increase
- As $V_{ss}\uparrow$, $V_{out}\uparrow$ ($V_{gs,2} = V_{out} - V_{ss}$), I_{d,M_2} is fixed.
- As $V_{out}\uparrow$, $V_{G3}\uparrow$ ($V_{gs,3} = V_{G,3} - V_{out}$), I_{d,M_3} is fixed.
- As $V_{G,3}\uparrow$, drain-to-source voltage of M_2 increases and I_{d,M_2} tends to increase but since I_{d,M_2} cannot increase $V_{gs,2}$ has to decrease to hold I_{d,M_2} constant. Therefore V_{out} has to decrease. Therefore this circuit employs negative feedback.

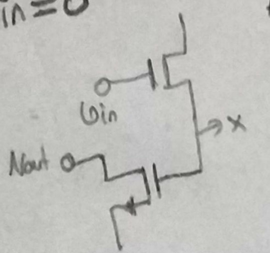
In Summary,

$$V_{in}\uparrow \Rightarrow V_{ss}\uparrow \Rightarrow V_{out}\uparrow \Rightarrow V_{G,3}\uparrow \Rightarrow V_{out}\downarrow$$

negative Feedback

Second Method

$V_{in}=0$



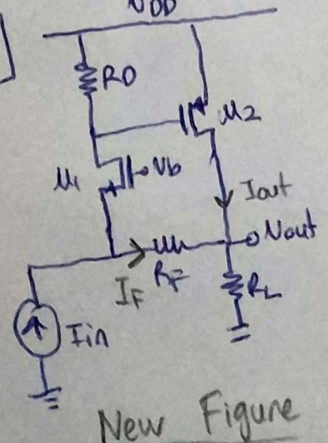
$$A_V = \frac{V_{out}}{V_{in}} = \frac{V_x}{V_{in}} \cdot \frac{V_{out}}{V_x}$$

$\frac{V_{out}}{V_x}$ → CS stage (<0)

$\frac{V_x}{V_{in}}$ → SF stage (>0)

$(<0) \times (>0) = (<0) \Rightarrow$ Negative Feedback.

2)

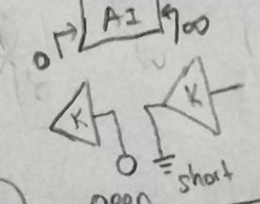


Sensed : current

Returned : current

$\Rightarrow$ Current-Current Amplifier (Shunt-Series)

How to Break the loop $\Rightarrow$



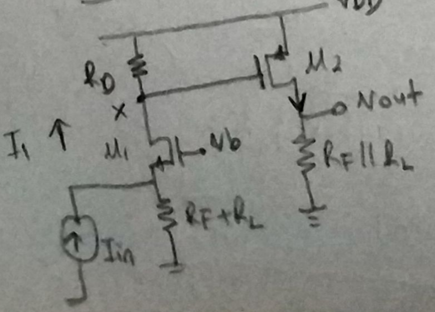
Open-loop Gain Calculation

$$I_1 = \frac{R_F+R_L}{\frac{1}{g_{m_2}} + R_F+R_L} I_{in} \quad \text{(Current Divider)}$$

$$V_x = R_D I_1 = \frac{R_D(R_F+R_L)}{\frac{1}{g_{m_1}} + R_F+R_L} I_{in} \; ;$$

$$\boxed{\begin{aligned} R_{in} &= \frac{1}{g_{m_1}} \parallel (R_F+R_L) \\ R_{out} &= R_F \parallel R_L \end{aligned}}$$

New Figure

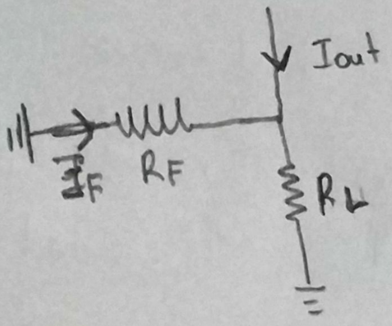


$$V_{out} = -g_{m_2}(R_F \parallel R_L) V_x$$

$$I_{out} = \frac{V_{out}}{I_{out}} = -g_{m_2} V_x = -\frac{g_{m_2} R_D (R_F+R_L)}{\frac{1}{g_{m_1}} + R_F + R_L} I_{in}$$

$$A_I = \frac{I_{out}}{I_{in}} = -\frac{g_{m_2} R_D (R_F+R_L)}{\frac{1}{g_{m_1}} + R_F + R_L}$$

Now, Let us determine the Feedback Factor (K)



$\Rightarrow$ By Current Division

$$I_F = -\frac{R_L}{R_F+R_L} I_{out}$$

$$\Rightarrow K = \frac{I_{out}}{I_F} = -\frac{R_L}{R_F+R_L}$$

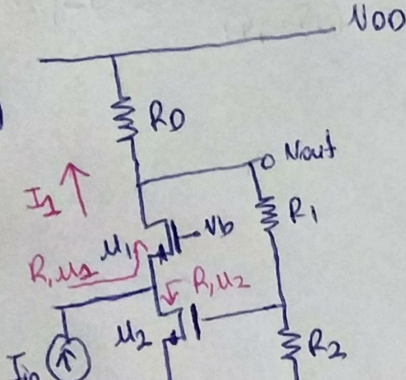
$$\Rightarrow A_{I,CL} = \frac{A_I}{1+KA_I} = \frac{-\frac{g_{m_2}R_O(R_F+R_L)}{\frac{1}{g_{m_1}}+R_F+R_L}}{1+\left(-\frac{R_L}{R_F+R_L}\right)\left(-\frac{g_{m_2}R_O(R_F+R_L)}{\frac{1}{g_{m_1}}+R_F+R_L}\right)}$$

$$\Rightarrow A_{I,CL} = -\frac{g_{m_2}R_O(R_F+R_L)}{\left(\frac{1}{g_{m_1}}+R_F+R_L\right)\left(1+g_{m_2}R_OR_L\right)}$$

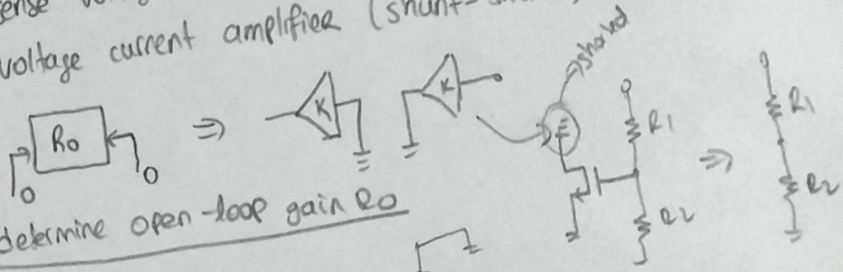
; $R_{out,CL} = R_{out}(1+KA_I)$
$= (R_F \| R_L)\left[1+\frac{g_{m_2}R_OR_L}{\frac{1}{g_{m_1}}+R_F+R_L}\right]$

$$R_{in,CL} = \frac{R_{in}}{1+KA_I} = \frac{\frac{1}{g_{m_1}} \| (R_F+R_L)}{1+\frac{g_{m_2}R_OR_L}{\frac{1}{g_{m_1}}+R_F+R_L}}$$

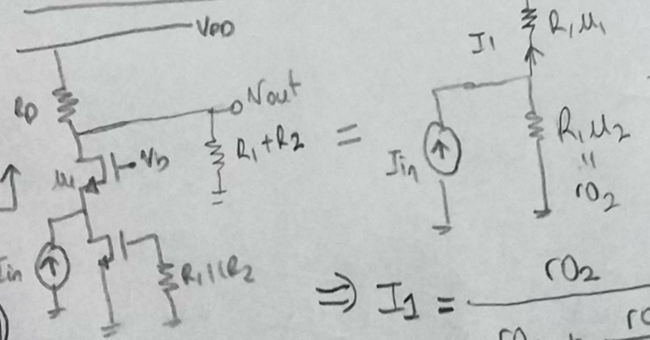
Q3)



We sense voltage and return current.
$\Rightarrow$ voltage current amplifier (shunt-shunt)



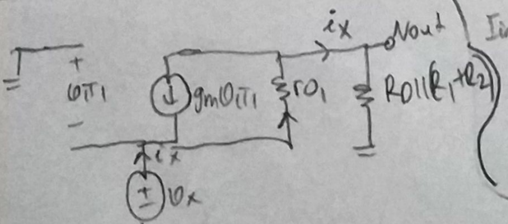
First determine open-loop gain Ro



$$\Rightarrow I_1 = \frac{R_{,M_2}}{R_{,M_2}+R_{,M_1}}$$

$$\Rightarrow I_1 = \frac{r_{O2}}{r_{O2}+\frac{r_{O1}+R_D\|(R_1+R_2)}{1+g_{m_1}r_{O1}}} I_{in}$$

In order to find $R_{,M_1}$



$$V_{out} = (R_D \| (R_1+R_2))\, I_1$$

$$V_{out} = \frac{(R_D\|(R_1+R_2))\, r_{O2}\, I_{in}}{r_{O2}+\frac{r_{O1}+R_D\|(R_1+R_2)}{1+g_{m_1}r_{O1}}}$$

open-loop gain of the circuit

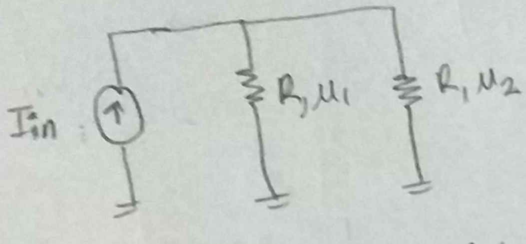
$v_{out} = v_x - (i_x + g_{m_1}v_{\pi_1})r_{O1}$; $(v_\pi = -v_x)$

$i_x(R_D\|(R_1+R_2)) = v_x - i_x r_{O1} + g_{m_1} r_{O1} v_x$

$$\frac{v_x}{i_x} = R_{,M_1} = \frac{r_{O1}+R_D\|(R_1+R_2)}{1+g_{m_1}r_{O1}}$$

$$\Rightarrow \boxed{R_O = \frac{V_{out}}{I_{in}} = \frac{(R_D\|(R_1+R_2))\,r_{O2}}{r_{O2}+\frac{r_{O1}+(R_D\|(R_1+R_2))}{1+g_{m_1}r_{O1}}}}$$

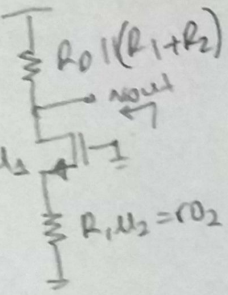
we draw



$\Rightarrow R_{in} = R, M_1 \parallel R, M_2$

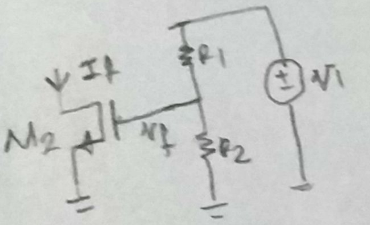
$$R_{in} = \left[\frac{r_{o1} + (R_o \parallel (R_1+R_2))}{1 + g_{m1} r_{o1}} \right] \parallel r_{o2}$$

and Rout can be calculated as



$$R_{out} = R_o \parallel (R_1+R_2) \parallel \left[(1 + g_{m1} r_{o1}) r_{o2} + r_{o1} \right]$$

Let's calculate the feedback factor K



$$\Rightarrow K = \frac{I_f}{V_1} = \frac{V_f}{V_1} \cdot \frac{I_f}{V_f} = \frac{R_2}{R_1+R_2} \cdot g_{m2}$$

Now, we can calculate the closed-loop parameters

$$R_{o,CL} = \frac{R_o}{1+KR_o} = \frac{\dfrac{(R_o \parallel (R_1+R_2)) r_{o2}}{r_{o2} + \dfrac{r_{o1} + (R_o \parallel (R_1+R_2))}{1 + g_{m1} r_{o1}}}}{1 + \dfrac{g_{m2} R_2}{R_1+R_2} \cdot \dfrac{(R_o \parallel (R_1+R_2)) r_{o2}}{r_{o2} + \dfrac{r_{o1} + (R_o \parallel (R_1+R_2))}{1 + g_{m1} r_{o1}}}}$$

$\Rightarrow$ closed-loop gain of transimpedance amplifier

$$R_{in,CL} = \frac{R_{in}}{1+KR_o} = \frac{\left[\dfrac{r_{o1} + (R_o \parallel (R_1+R_2))}{1 + g_{m1} r_{o1}}\right] \parallel r_{o2}}{1 + \dfrac{g_{m2} R_2}{R_1+R_2} \cdot \dfrac{(R_o \parallel (R_1+R_2)) r_{o2}}{r_{o2} + \dfrac{r_{o1} + (R_o \parallel (R_1+R_2))}{1 + g_{m1} r_{o1}}}}$$

$\Rightarrow$ closed-loop input impedance of transimpedance amplifier

$$R_{out,CL} = \frac{R_{out}}{1+KR_o} = \frac{R_o \parallel (R_1+R_2) \parallel \left[(1 + g_{m1} r_{o1}) r_{o2} + r_{o1} \right]}{1 + \dfrac{g_{m2} R_2}{R_1+R_2} \cdot \dfrac{(R_o \parallel (R_1+R_2))}{r_{o2} + \dfrac{r_{o1} + (R_o \parallel (R_1+R_2))}{1 + g_{m1} r_{o1}}}}$$

$\Rightarrow$ closed-loop output impedance of transimpedance amplifier

$\Rightarrow$ Negative feedback makes the amplifier close to the ideal by reducing Rout and Rin at the cost of reducing the gain.