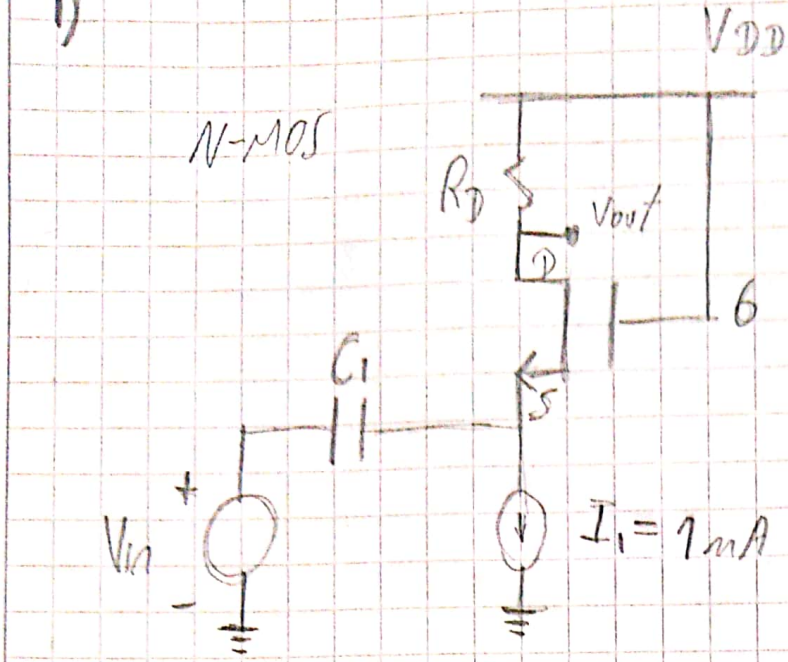
1)



$\mu_n C_{ox} = 200 \mu A/V^2$

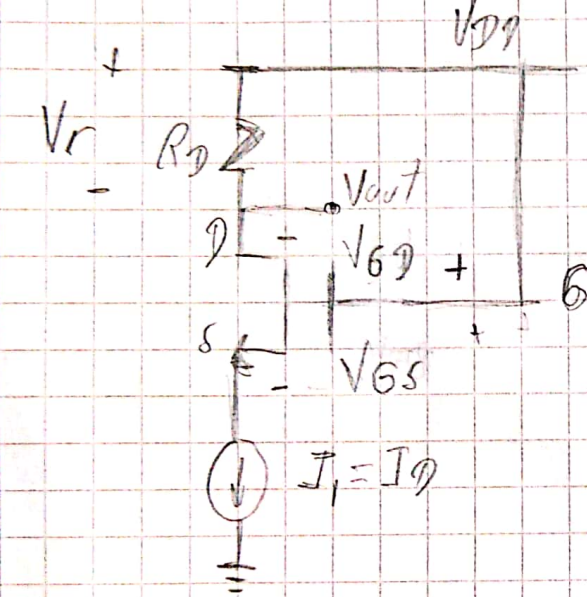
$\mu_p C_{ox} = 100 \mu A/V^2$

$\lambda = 0$

$V_{TH} = 0,4 V \rightarrow NMOS$

$V_{TH} = -0,4V \rightarrow PMOS$

A) En DC



$V_{DS} = V_{GS} - V_{TH} + 0,1$

$V_{DS} = 1,8 - 0,4 + 0,1 = 1,5 V$

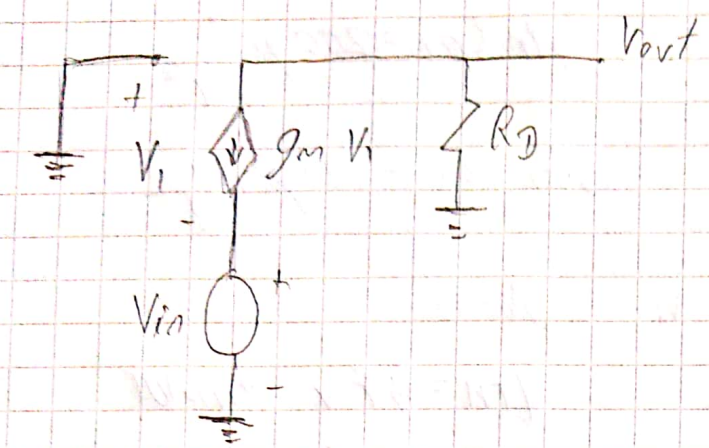
$V_{out} = V_{DS} = 1,5 V$

$R_D = \frac{V_{DD} - V_{out}}{1 \cdot 10^{-3}} =$

$= \frac{1,8 - 1,5}{1 \cdot 10^{-3}} = \frac{0,3}{1.10^{-3}} = 300 \ \Omega$

b)

en AC



$$V_{out} = -g_m(-V_{in})R_D$$

$$\frac{V_{out}}{V_{in}} = g_m \cdot R_D$$

$$5 = g_m \cdot 300$$

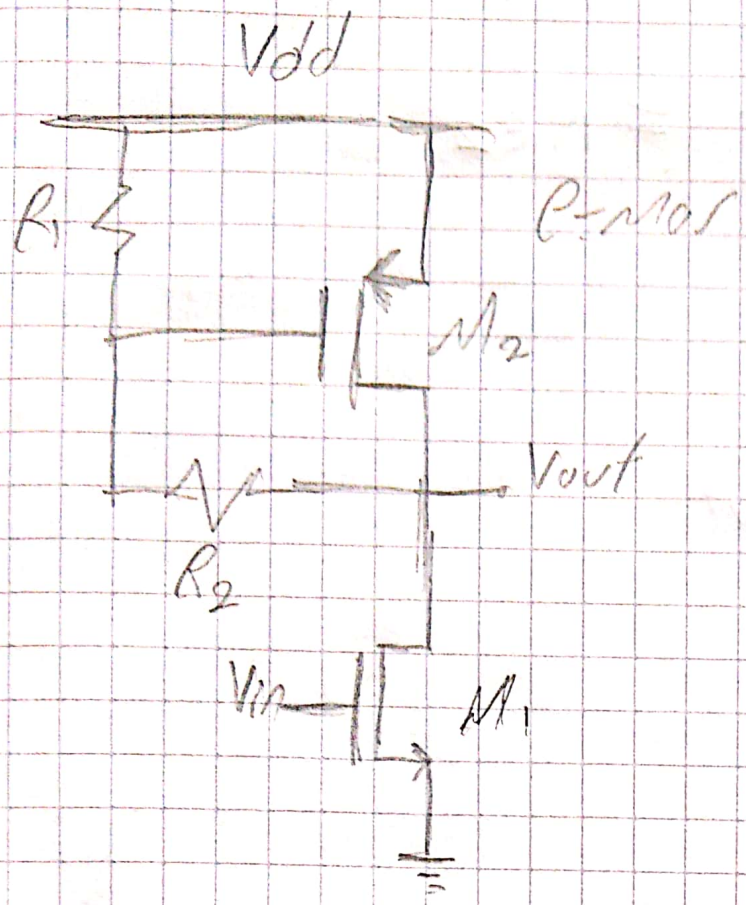
$$g_m = \frac{5}{300} =$$

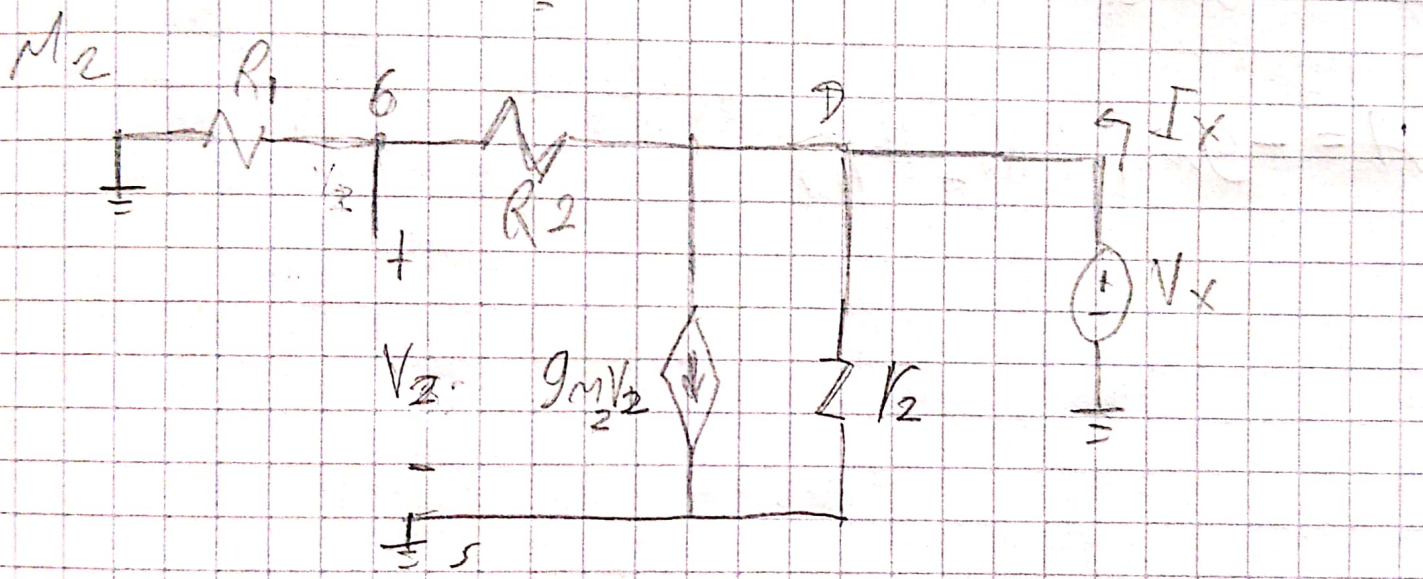
$$\left(\frac{5}{300}\right)^2 = 2\mu_n C_{ox}\frac{W}{L} I_D$$

$$\sqrt{2\mu_n C_{ox}\frac{W}{L} I_D} = \frac{5}{300}$$

$$\frac{W}{L} = \frac{\left(\frac{5}{300}\right)^2}{2 \cdot 200 \cdot 10^{-6} \cdot 1 \cdot 10^{-3}} = 694{,}4$$

2





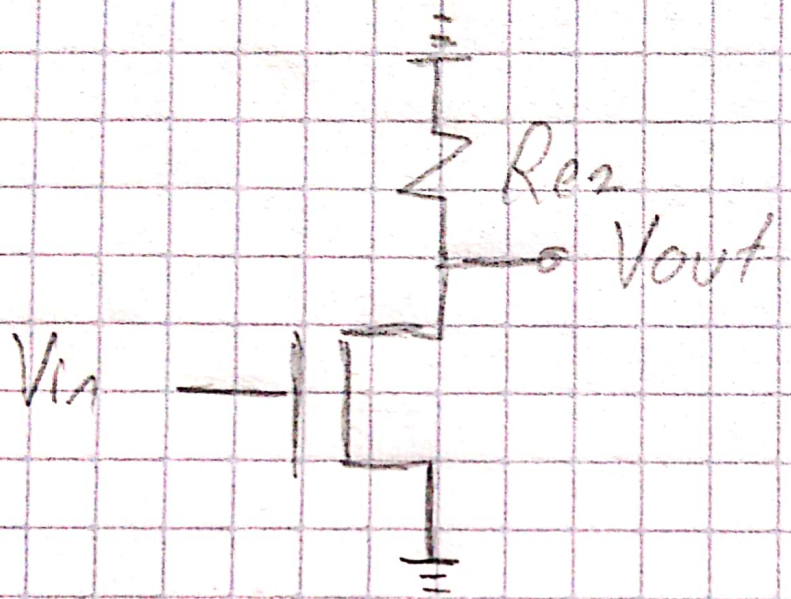
$$V_2 = \frac{V_X R_1}{R_1 + R_2}$$

$$I_X = g_{m2} V_2 + \frac{V_X}{r_2}$$

$$I_X = g_{m2} \frac{V_X R_1}{R_1 + R_2} + \frac{V_X}{r_2} = V_X \left(\frac{(g_{m2} * R_1) r_2 + R_1 + R_2}{(R_1 + R_2) r_2} \right)$$

$$\frac{V_x}{I_x} \simeq \frac{(R_1+R_2)\,r_2}{(g_{m2}*R_1)r_2 + R_1 + R_2} = R_{e2}$$

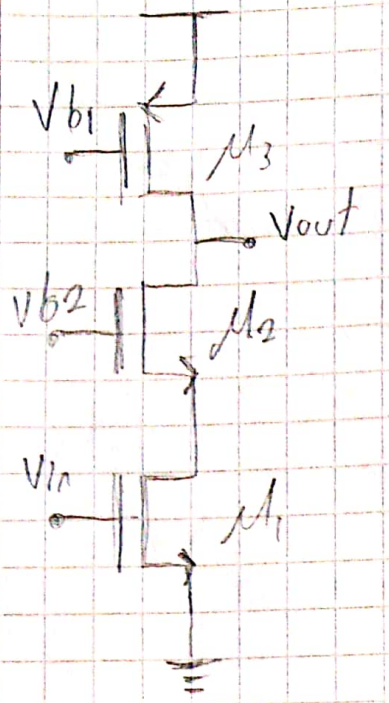
M_1

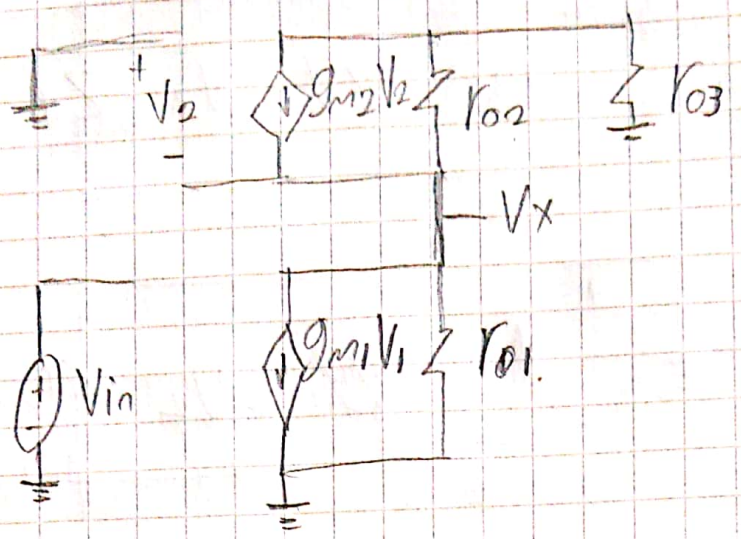


Comun Source

$$A = -g_{m1}(R_{e2} \parallel R_1)$$

3)





① $V_x = -g_{m1} V_{in} \cdot r_{o1}$

$$g_{m2}(-V_x) + \frac{V_{out} - V_x}{r_{o2}} + \frac{V_{out}}{r_{o3}} = 0$$

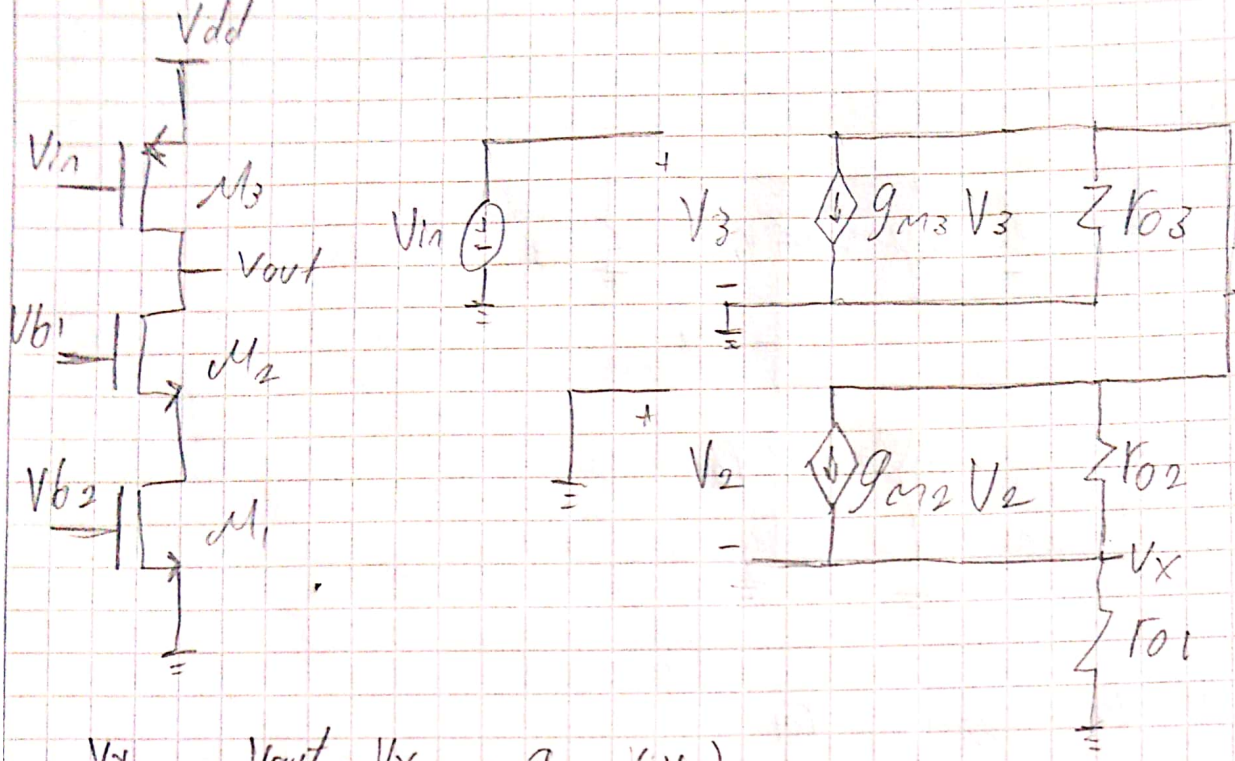
$$-V_x\left(g_{m2} + \frac{1}{r_{o2}}\right) + V_{out}\left(\frac{1}{r_{o2}} + \frac{1}{r_{o3}}\right) = 0$$

② $$V_x = V_{out}\left(\frac{\frac{1}{r_{o2}} + \frac{1}{r_{o3}}}{g_{m2} + \frac{1}{r_{o2}}}\right)$$

① = ②

$$-g_{m1} V_{in} \cdot r_{o1} = V_{out}\left(\frac{\frac{1}{r_{o2}} + \frac{1}{r_{o3}}}{g_{m2} + \frac{1}{r_{o2}}}\right)$$

$$\frac{V_{out}}{V_{in}} = \frac{(-g_{m1} \cdot r_{o1})(g_{m2} + \frac{1}{r_{o2}})}{\frac{1}{r_{o2}} + \frac{1}{r_{o3}}}$$



$$\frac{V_x}{r_{o1}} = \frac{V_{out} - V_x}{r_{o2}} + g_{m2}(-V_x)$$

$$V_x\left(\frac{1}{r_{o1}} + \frac{1}{r_{o2}} + g_{m2}\right) = \frac{V_{out}}{r_{o2}}$$

$$\frac{V_x}{V_{out}} = \frac{1}{r_{o2}\left(\frac{1}{r_{o1}} + \frac{1}{r_{o2}} + g_{m2}\right)} \quad (1)$$

$$\frac{V_{out}}{r_{o3}} + g_{m3}V_{in} + \frac{V_{out} - V_x}{r_{o2}} + g_{m2}(-V_x) = 0$$

$$V_{out}\left(\frac{1}{r_{o3}} + \frac{1}{r_{o2}}\right) + g_{m3}V_{in} = V_x\left(g_{m2} + \frac{1}{r_{o2}}\right)$$

$$\frac{1}{r_{o3}} + \frac{1}{r_{o2}} + \frac{g_{m3}V_{in}}{V_{out}} = \frac{V_x}{V_{out}}\left(g_{m2} + \frac{1}{r_{o2}}\right)$$

$$\frac{V_x}{V_{out}} = \frac{\frac{1}{r_{o3}} + \frac{1}{r_{o2}} + \frac{g_{m3}V_{in}}{V_{out}}}{g_{m2} + \frac{1}{r_{o2}}} \quad (2)$$

$$① = ②$$

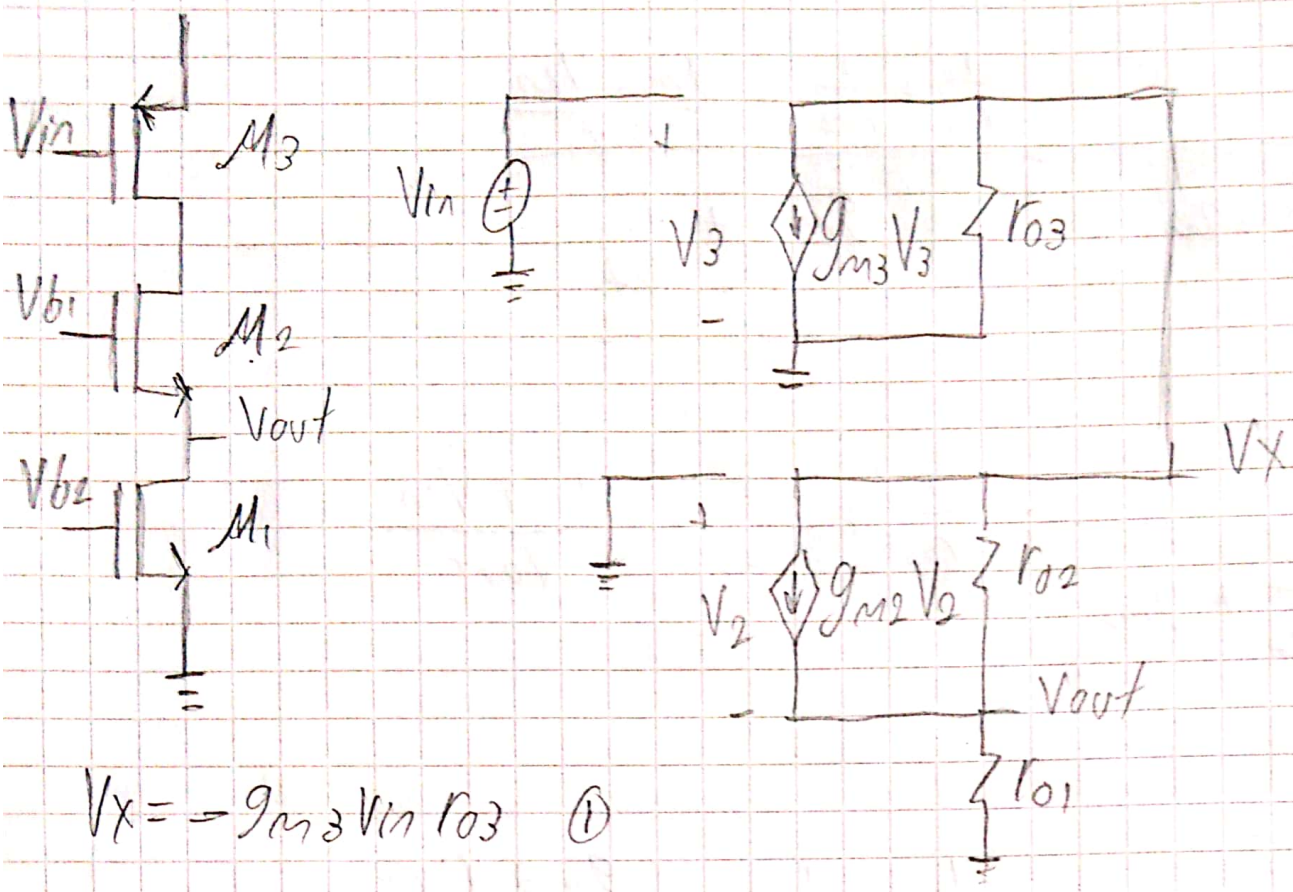
$$\frac{1}{r_{o2}\left(\frac{1}{r_{o1}} + \frac{1}{r_{o2}} + g_{m2}\right)} = \frac{\frac{1}{r_{o3}} + \frac{1}{r_{o2}} + \frac{g_{m3} V_{in}}{V_{out}}}{g_{m2} + \frac{1}{r_{o2}}}$$

$$\frac{\frac{1}{r_{o2}} + g_{m2}}{r_{o2}\left(\frac{1}{r_{o1}} + \frac{1}{r_{o2}} + g_{m2}\right)} = \frac{1}{r_{o3}} + \frac{1}{r_{o2}} + \frac{g_{m3} V_{in}}{V_{out}}$$

$$\frac{\frac{1}{r_{o2}} + g_{m2}}{r_{o2}\left(\frac{1}{r_{o1}} + \frac{1}{r_{o2}} + g_{m2}\right)} - \frac{1}{r_{o3}} - \frac{1}{r_{o2}} = \frac{g_{m3} V_{in}}{V_{out}}$$

$$\frac{\frac{\frac{1}{r_{o2}} + g_{m2}}{r_{o2}\left(\frac{1}{r_{o1}} + \frac{1}{r_{o2}} + g_{m2}\right)} - \frac{1}{r_{o3}} - \frac{1}{r_{o2}}}{g_{m3}} = \frac{V_{in}}{V_{out}}$$

$$\frac{V_{out}}{V_{in}} \frac{g_{m3}}{\frac{\frac{1}{r_{o2}} + g_{m2}}{r_{o2}\left(\frac{1}{r_{o1}} + \frac{1}{r_{o2}} + g_{m2}\right)} - \frac{1}{r_{o3}} - \frac{1}{r_{o2}}}$$



$$V_x = -g_{m3} V_{in} r_{o3} \quad (1)$$

$$\frac{V_{out}}{r_{o1}} = \frac{V_x - V_{out}}{r_{o2}} + g_{m2}(-V_{out})$$

$$\frac{V_x}{r_{o2}} = V_{out}\left(\frac{1}{r_{o1}} + \frac{1}{r_{o2}} + g_{m2}\right)$$

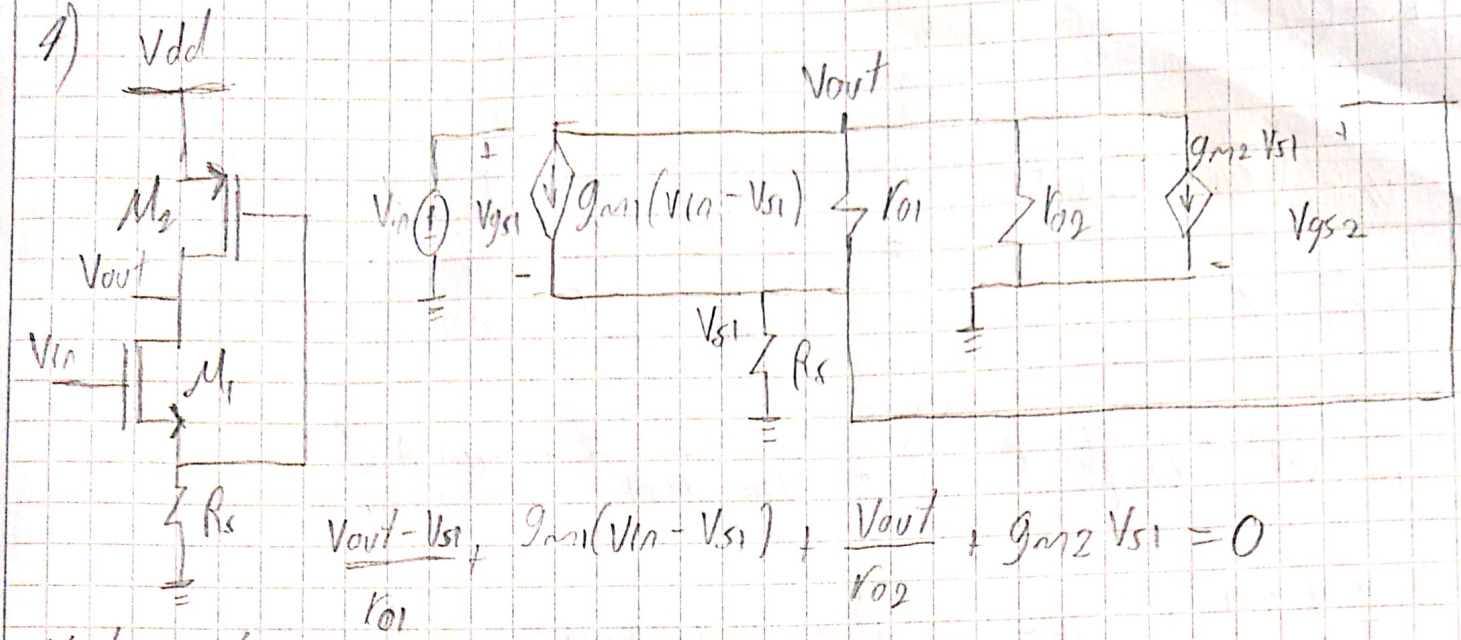
$$V_x = V_{out} r_{o2}\left(\frac{1}{r_{o1}} + \frac{1}{r_{o2}} + g_{m2}\right) \quad (2)$$

$(1) = (2)$

$$-g_{m3} V_{in} r_{o3} = V_{out} r_{o2}\left(\frac{1}{r_{o1}} + \frac{1}{r_{o2}} + g_{m2}\right)$$

$$\frac{V_{out}}{V_{in}} = \frac{-g_{m3} r_{o3}}{r_{o2}\left(\frac{1}{r_{o1}} + \frac{1}{r_{o2}} + g_{m2}\right)}$$

4)



$$\frac{V_{out}-V_{s1}}{r_{o1}} + g_{m1}(V_{in}-V_{s1}) + \frac{V_{out}}{r_{o2}} + g_{m2}V_{s1} = 0$$

Nodo vout

$$V_{s1}\left(\frac{1}{r_{o1}} + g_{m1} - g_{m2}\right) = V_{out}\left(\frac{1}{r_{o1}} + \frac{1}{r_{o2}}\right) + V_{in}g_{m1}$$

$$V_{s1} = \frac{V_{out}\left(\frac{1}{r_{o1}} + \frac{1}{r_{o2}}\right) + V_{in}g_{m1}}{\frac{1}{r_{o1}} + g_{m1} - g_{m2}} \Rightarrow \frac{V_{s1}}{V_{in}} = \frac{\frac{V_{out}\left(\frac{1}{r_{o1}} + \frac{1}{r_{o2}}\right)}{V_{in}} + g_{m1}}{\underbrace{\frac{1}{r_{o1}} + g_{m1} - g_{m2}}_{A}} \quad (1)$$

Nodo Vs1

$$\frac{V_{s1}}{R_s} = g_{m1}(V_{in}-V_{s1}) + \frac{V_{out}-V_{s1}}{r_{o1}}$$

$$V_{s1}\left(\frac{1}{R_s} + \frac{1}{r_{o1}} + g_{m1}\right) = \frac{V_{out}}{r_{o1}} + g_{m1}V_{in}$$

$$V_{s1} = \frac{\frac{V_{out}}{r_{o1}} + g_{m1}V_{in}}{\frac{1}{R_s} + \frac{1}{r_{o1}} + g_{m1}}$$

$$\frac{V_{s1}}{V_{in}} = \frac{\frac{V_{out}}{V_{in}r_{o1}} + g_{m1}}{\underbrace{\frac{1}{R_s} + \frac{1}{r_{o1}} + g_{m1}}_{B}} \quad (2)$$

(1) = (2)

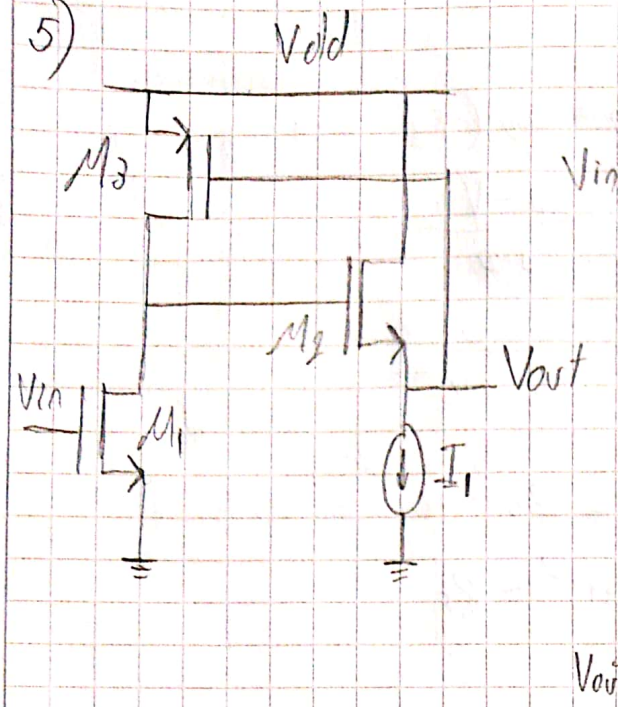
$$\frac{\frac{V_{out}}{V_{in}}\left(\frac{1}{r_{o1}}+\frac{1}{r_{o2}}\right)+g_{m1}}{A} = \frac{\frac{V_{out}}{V_{in}}\left(\frac{1}{r_{o1}}\right)+g_{m1}}{B}$$

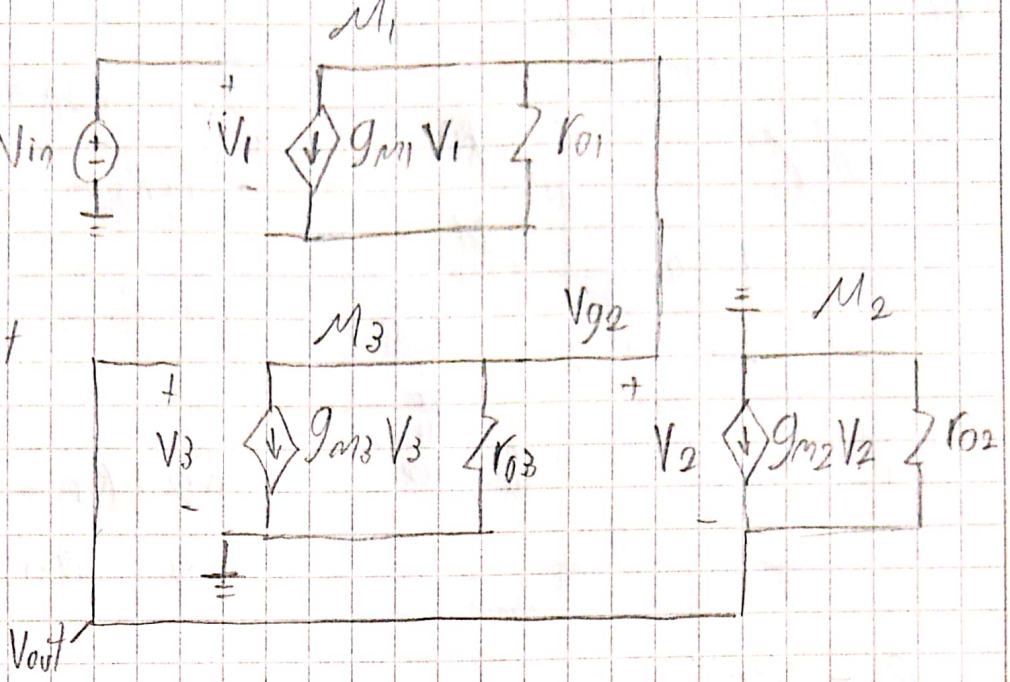
$$\frac{V_{out}}{V_{in}}\left(\frac{1}{r_{o1}}+\frac{1}{r_{o2}}\right)B + g_{m1}B = \frac{V_{out}}{V_{in}}\left(\frac{1}{r_{o1}}\right)A + g_{m1}A$$

$$\frac{V_{out}}{V_{in}}\left(\left(\frac{1}{r_{o1}}+\frac{1}{r_{o2}}\right)B-\left(\frac{1}{r_{o1}}\right)A\right) = g_{m1}(A-B)$$

$$\frac{V_{out}}{V_{in}} = \frac{g_{m1}(A-B)}{\left(\frac{1}{r_{o1}}+\frac{1}{r_{o2}}\right)B-\left(\frac{1}{r_{o1}}\right)A} \;//$$

5)





$V_3 = V_{out} \qquad V_1 = V_{in} \qquad V_2 = V_{g2} - V_{out}$

Para V_{g2}

$$\frac{V_{g2}}{r_{o1}} + \frac{V_{g2}}{r_{o3}} + g_{m1} V_{in} + g_{m3} V_{out} = 0 \quad (1)$$

Para V_{out}

$$\frac{V_{out}}{r_{o2}} - g_{m2}(V_{g2} - V_{out}) = 0$$

$$V_{g2} = \frac{V_{out}}{g_{m2}} \left(\frac{g_{m2} r_{o2} + 1}{r_{o2}} \right) \quad (2)$$

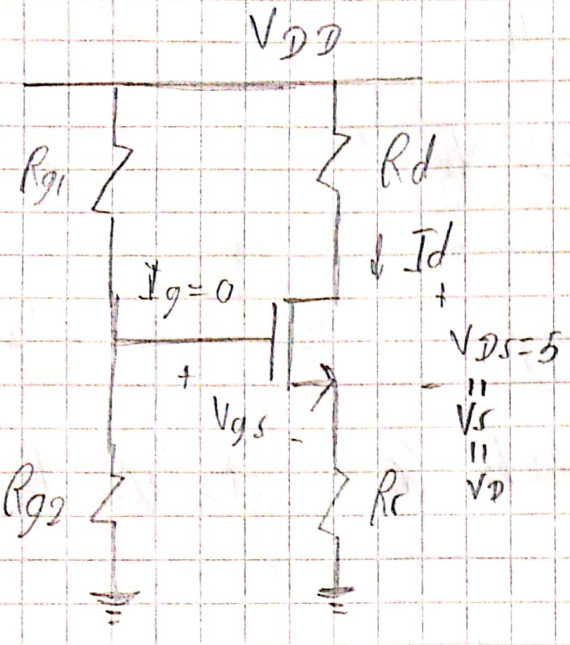
(2) en (1)

$$\frac{V_{out}}{g_{m2}} \left(\frac{g_{m2} r_{o2} + 1}{r_{o2}} \right) \left(\frac{r_{o3} + r_{o1}}{r_{o1} \cdot r_{o3}} \right) + g_{m1} V_{in} + g_{m3} V_{out} = 0$$

$$V_{out} \underbrace{\left(\left(\frac{1}{g_{m2}} \right) \left(\frac{g_{m2} r_{o2} + 1}{r_{o2}} \right) \left(\frac{r_{o3} + r_{o1}}{r_{o1} \cdot r_{o3}} \right) + g_{m3} \right)}_{A} = - g_{m1} V_{in}$$

$$\frac{V_{out}}{V_{in}} \doteq - \frac{g_{m1}}{A}$$

6)



$$V_{DS} - V_{DD} = I_D (R_d + R_s)$$

$$R_d + R_s = \frac{V_{DD} - V_{DS}}{I_D}$$

$$R_d + R_s = \frac{15 - 5}{0{,}5 \times 10^{-3}}$$

$$R_D + R_s = 20 \cdot 10^3$$

$$R_D = 20 \cdot 10^3 - R_s$$

$$R_s = \frac{V_{DS}}{Id} = \frac{5}{0{,}5 \cdot 10^{-3}} = 10 \cdot 10^3 = 10\,k\Omega$$

$$R_D = 20 \cdot 10^3 - 10 \cdot 10^3 = 10\,K\Omega$$

N-Mos en saturacion

$$I_D = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_{TH})^2$$

$$0{,}5 \times 10^{-3} = \frac{1}{2} \cdot 1 \cdot 10^{-3} (V_{GS} - V_{TH})^2$$

$$0{,}5 \cdot 10^{-3} = 0{,}5 \cdot 10^{-3} (V_{GS} - V_{TH})^2$$

$$\sqrt{1} = (V_{GS} - V_{TH})$$

$$1 = V_{GS} - V_{TH}$$

$$1 = V_{GS} - 1$$

$$V_{GS} = 2$$

$$V_{GS} = V_G - V_S$$

$$V_G = V_{GS} + V_S$$

$$V_G = 2 + 5$$

$$V_G = 7v$$

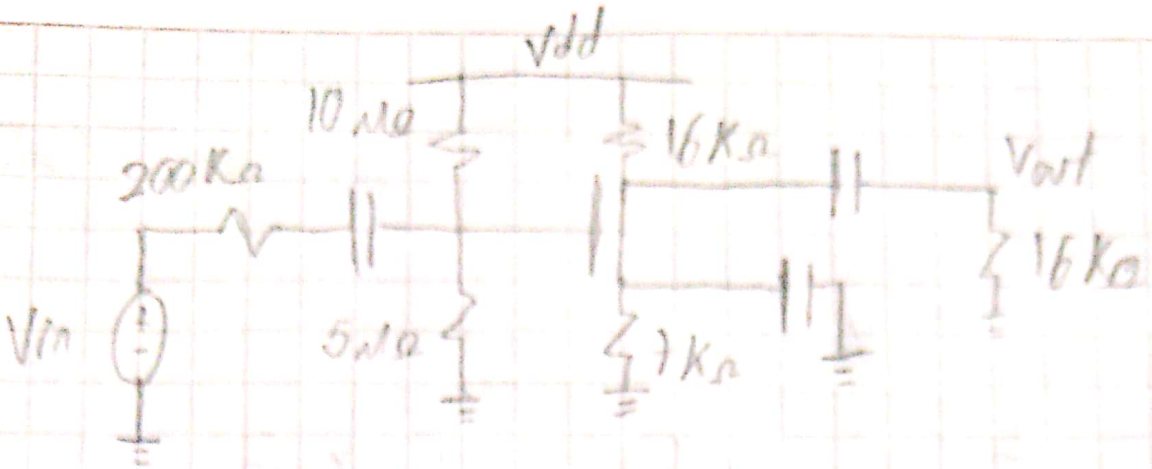
$$R_{G1} = \frac{V_{DD}}{V_G} R_{GT}$$

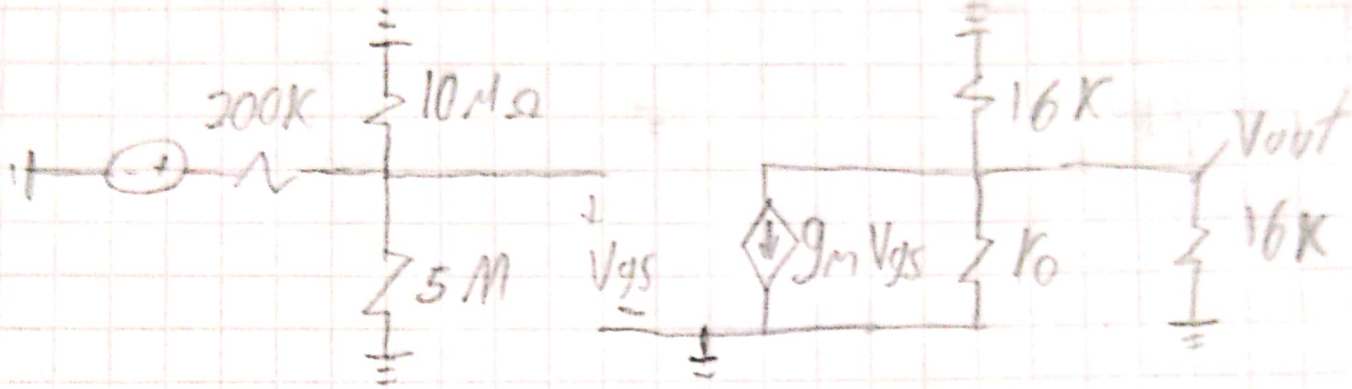
$$R_{G2} = \frac{V_{DD}}{V_{DD} - V_G} R_{GT}$$

$$R_{G1} = 8\,M\Omega$$

$$R_{G2} = 7\,M\Omega$$

8)



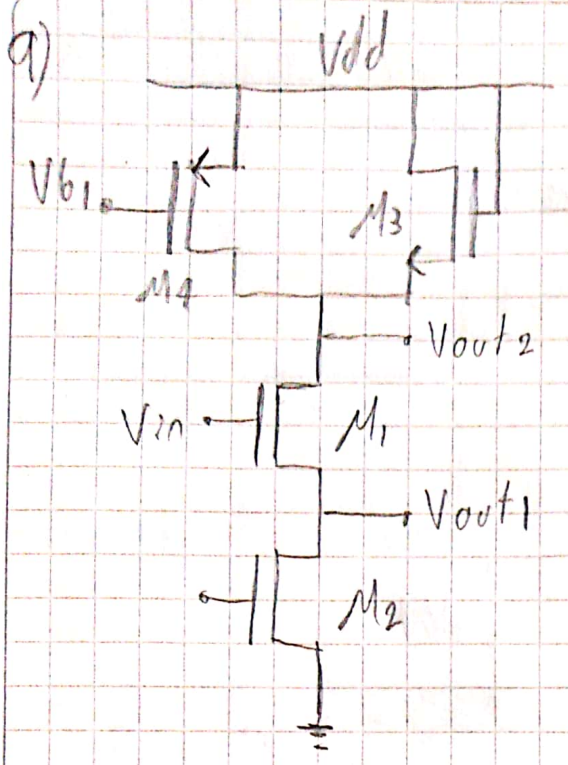


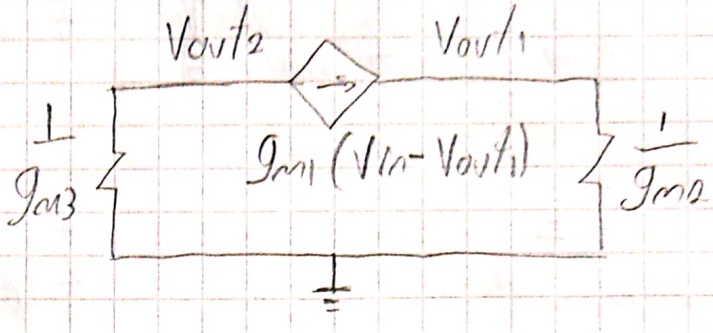
$$V_{gs} = \frac{V_{in}\,(10M \parallel 5M)}{200K + (10M \parallel 5M)} = V_{in}\,\frac{50}{53}$$

$$V_{out} = -g_m\left(V_{in}\,\frac{50}{53}\right)\cdot(r_o \parallel 16K \parallel 16K)$$

$$\frac{V_{out}}{V_{in}} = -g_m\left(\frac{50}{53}\right)\cdot(r_o \parallel 16K \parallel 16K)$$

a)





$$\frac{V_{out1}}{\frac{1}{g_{m2}}} = g_{m1}(V_{in} - V_{out1})$$

$$\frac{V_{out2}}{\frac{1}{g_{m3}}} = -g_{m1}(V_{in} - V_{out1})$$

$$V_{out1} g_{m2} = g_{m1} V_{in} - g_{m1} V_{out1}$$

$$V_{out2} g_{m3} = -g_{m1} V_{in} + V_{out1} g_{m1}$$

$$V_{out1}(g_{m2} + g_{m1}) = g_{m1} V_{in}$$

$$V_{out1} = \frac{V_{out2} g_{m3} + V_{in} g_{m1}}{g_{m1}}$$

$$V_{out1} = \frac{g_{m1} V_{in}}{g_{m1} + g_{m2}} \quad (1)$$

$$V_{out1} = \frac{V_{out2} g_{m3}}{g_{m1}} + V_{in} \quad (2)$$

$$\frac{V_{out1}}{V_{in}} = \frac{g_{m1}}{g_{m1} + g_{m2}} \;//$$

$$(1) = (2)$$

$$\frac{g_{m1} V_{in}}{g_{m2} + g_{m1}} = \frac{V_{out2} g_{m3}}{g_{m1}} + V_{in}$$

$$\frac{V_{out2} g_{m3}}{g_{m1}} = \frac{g_{m1} V_{in}}{g_{m2} + g_{m1}} - V_{in}$$

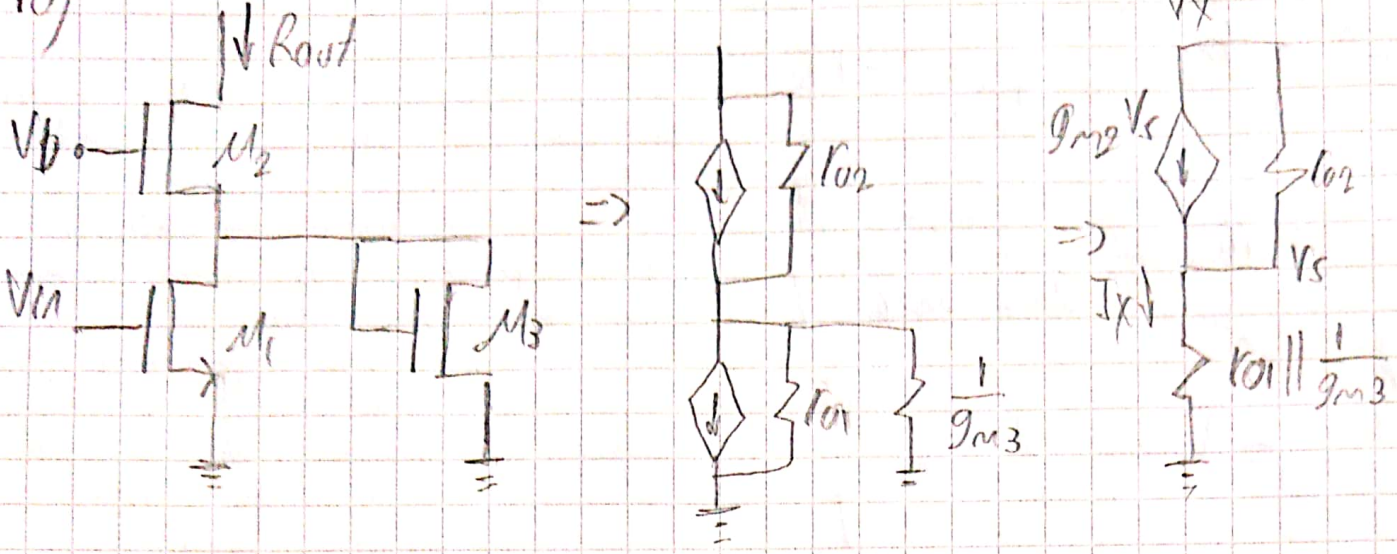
$$\frac{V_{out2}\, g_{m3}}{g_{m1}} = V_{in}\left(\frac{g_{m1}}{g_{m2}+g_{m1}} - 1\right)$$

$$\frac{V_{out2}\, g_{m3}}{g_{m1}} = V_{in}\left(\frac{g_{m1} - g_{m2} - g_{m1}}{g_{m2}+g_{m1}}\right)$$

$$\frac{V_{out2}\, g_{m3}}{g_{m1}} = V_{in}\left(\frac{-g_{m2}}{g_{m2}+g_{m1}}\right)$$

$$\frac{V_{out2}}{V_{in}} = \frac{-g_{m2}g_{m1}}{g_{m2}g_{m3} + g_{m1}g_{m3}}$$

10)



$$I_X = \frac{V_S}{r_{o1} \parallel \frac{1}{g_{m3}}} = g_{m2}(-V_S) + \frac{V_X - V_S}{r_{o2}} \quad (1)$$

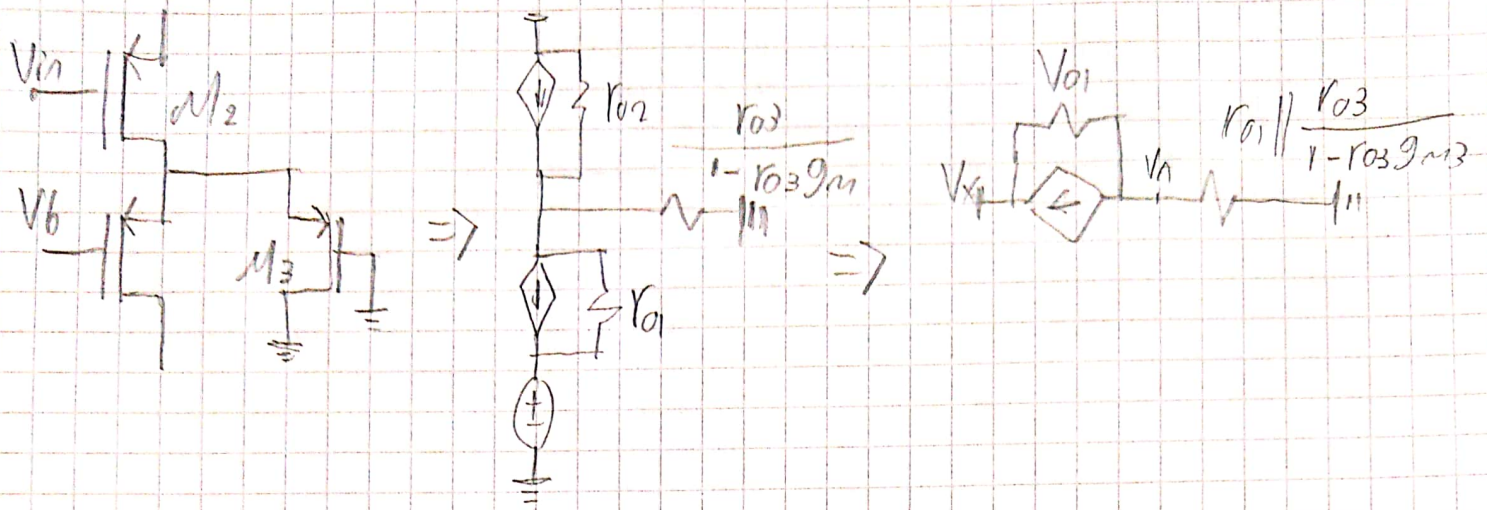
$$V_S = I_X \left(r_{o1} \parallel \frac{1}{g_{m3}}\right) \quad (2)$$

(1) en (2)

$$I_X = -g_{m2}\left(I_X \left(r_{o1} \parallel \frac{1}{g_{m3}}\right)\right) + \frac{V_X - \left(I_X \left(r_{o1} \parallel \frac{1}{g_{m3}}\right)\right.}{r_{o2}}$$

$$I_X \left(1 + g_{m2}\left(r_{o1} \parallel \frac{1}{g_{m3}}\right) + \frac{r_{o1} \parallel \frac{1}{g_{m3}}}{r_{o2}}\right) = \frac{V_X}{r_{o2}}$$

$$\frac{V_X}{I_X} = r_{o2} + g_{m2} r_{o2}\left(r_{o1} \parallel \frac{1}{g_{m3}}\right) + r_o \parallel \frac{1}{g_{m3}}$$



$$I_x = \frac{V_A}{r_{o2} \parallel \frac{r_{o2}}{1 - r_{o3} g_{m3}}} = I_x \left(r_{o2} \parallel \frac{r_{o3}}{1 - r_{o2} g_{m3}} \right)$$

$$I_x = \frac{V_x - V_A}{r_{o2}} - g_{m1} V_a$$

$$I_x \left(1 + \frac{r_{o2} \parallel \frac{r_{o3}}{1 - r_{o2} g_{m3}}}{r_{o1}} + g_{m1} \left(r_{o2} \parallel \frac{r_{o3}}{1 - r_{o2} g_{m3}} \right) \right)$$

$$\frac{V_x}{I_x} = r_{o1} + \frac{r_{o2} \parallel \frac{r_{o3}}{1 - r_{o3} g_{m3}}}{r_{o3}} + \frac{g_{m1} \; r_{o2} \parallel \frac{r_{o3}}{1 - r_{o3} g_{m3}}}{r_{o1}}$$

(12)

Orden del ejercicio

① ② ③

④ ⑤ ⑥

1) off → $V_{GS} = 0$

2) Triodo → $V_{GS} > V_{TH}$ $V_{DS} << 2(V_{GS} - V_{TH})$

3) Triodo → $V_{GS} > V_{TH}$ $V_{DS} < (V_{GS} - V_{TH})$

4) saturación → $V_{GS} > V_{TH}$ $V_{DS} > (V_{GS} - V_{TH})$

5) saturación → $V_{GS} > V_{TH}$ $V_{DS} > (V_{GS} - V_{TH})$

6) off → $V_{GS} = 0$