EE 215A

Fall 2011

50/50
+ 70/70
120/120.

Analog Integrated Circuit Design

Homework #2.

Date: 2011.10.12.

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⑩

$r_o = \frac{1+\lambda V_{DS}}{\lambda I_D}$

2.6 In Saturated devize,

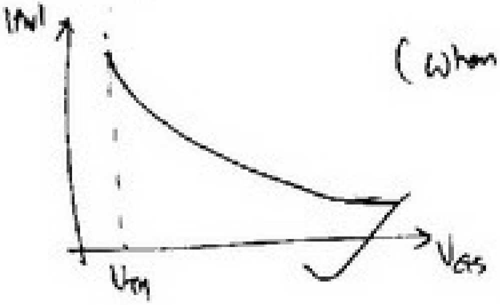
(a) Intrinsiz gain $|A_v| = g_m \cdot r_o = \frac{2I_D}{(V_{GS}-V_{TH})} \cdot \frac{1}{\lambda I_D} = \frac{2}{V_{GS}-V_{TH}} \cdot \frac{1}{\lambda}$ ✓ , where λ is function of L

⑤

Under Drain current (I_D) is constant,

[redacted]

(when : λ is constant → L is constant)

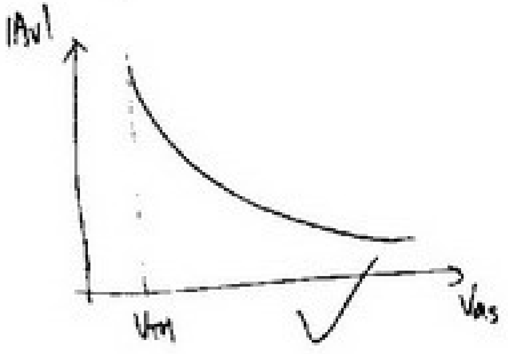


(b) Intrinsiz gain $|A_v| = g_m r_o = \mu_n C_{ox}\frac{W}{L}(V_{GS}-V_{TH}) \cdot \frac{1}{\lambda I_D}$

⑤

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

W & L = const $= \frac{2}{\lambda(V_{GS}-V_{TH})}$ ✓ (λ is function of L)



3.7 [illegible].

Intrinsic gain of saturated devices vs W/L
$|A_v|$

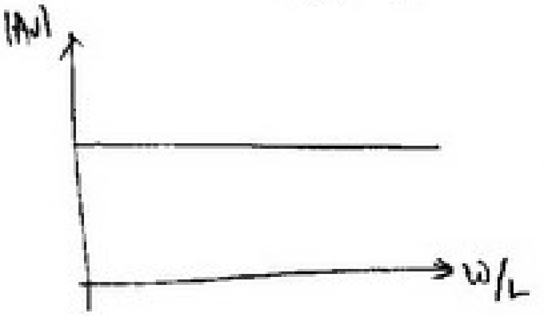
(a) V_{GS} = const.

⑤

$|A_v| = g_m r_o = \frac{2}{(V_{GS}-V_{TH})\cdot\lambda}$

[redacted].

λ is funtion of L



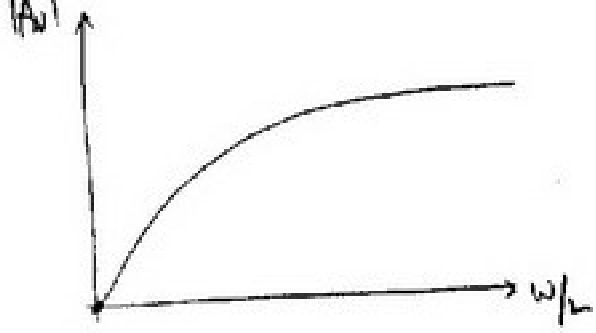
when λ is constant.

(b) I_D = const

⑤

$|A_v| = g_m r_o = \sqrt{2\mu_n C_{ox}\frac{W}{L}\cdot I_D}\cdot\frac{1}{\lambda I_D} =$

$= \frac{\sqrt{2\mu_n C_{ox}\frac{W}{L}}}{\lambda\sqrt{I_D}} = \frac{\sqrt{2\mu_n C_{ox}}}{\lambda I_D}\cdot\sqrt{W/L}$, λ is funtion of L



when λ is constant

3.9 g_m, r_O, $g_m r_O$ in saturated device (NMOS)

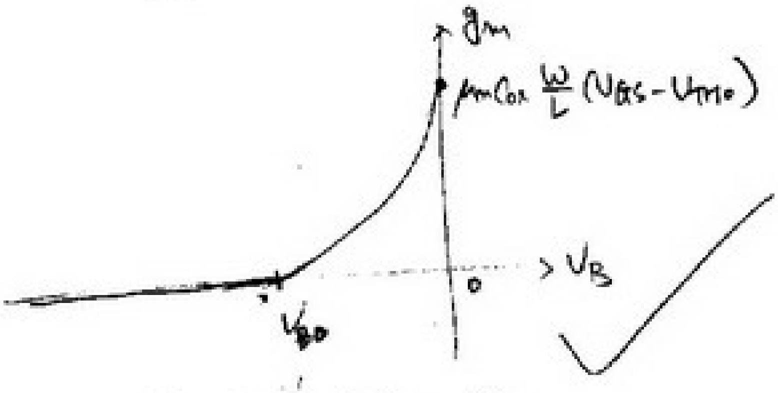
① $g_m = \mu_n C_{ox}\frac{W}{L}(V_{GS}-V_{TH})$

(10). $V_{TH} = V_{TH0} + \gamma\left(\sqrt{|2\Phi_F + V_{SB}|} - \sqrt{|2\Phi_F|}\right)$

Let's assume $V_S=0$

$V_B=0 \to V_{SB}=0$: $V_{TH}=V_{TH0}$

$V_B=-\infty \to V_{SB}=\infty$: $V_{TH}=\infty$



turned off below V_{B0}

V_{B0}: $V_{GS} = V_{TH}$

$= V_{TH0} + \gamma\left(\sqrt{|2\Phi_F - V_{B0}|} - \sqrt{|2\Phi_F|}\right)$

$$\Rightarrow \frac{(V_{GS}-V_{TH0})}{\gamma} + \sqrt{|2\Phi_F|} = \sqrt{|2\Phi_F - V_{B0}|}$$

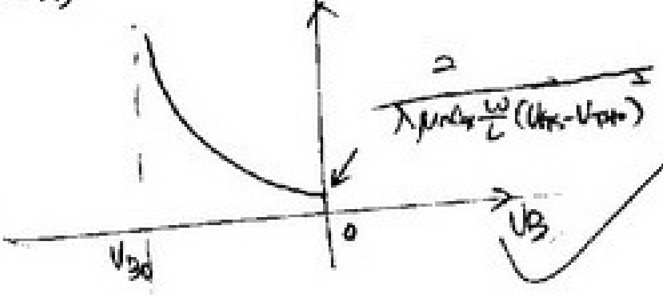
$$\therefore V_{B0} = 2\Phi_F - \left\{\frac{(V_{GS}-V_{TH0})}{\gamma} + \sqrt{|2\Phi_F|}\right\}^2$$

② r_O

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

$V_S=0$:

$$r_O = \frac{2}{\lambda\cdot\mu_n C_{ox}\frac{W}{L}(V_{GS}-V_{TH0})}$$

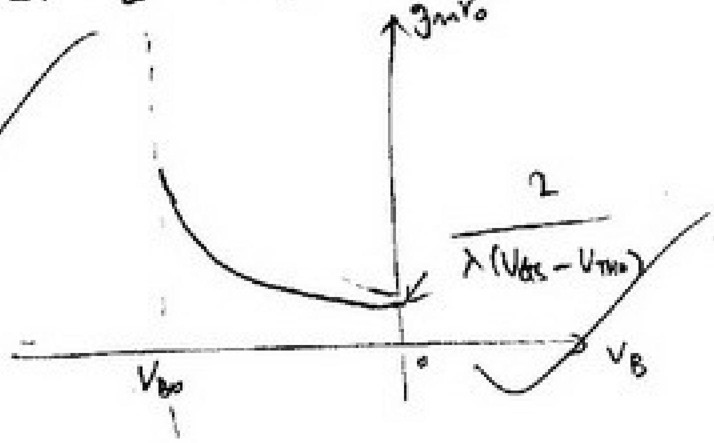


3.9 - cont'd

③ $g_m r_o$

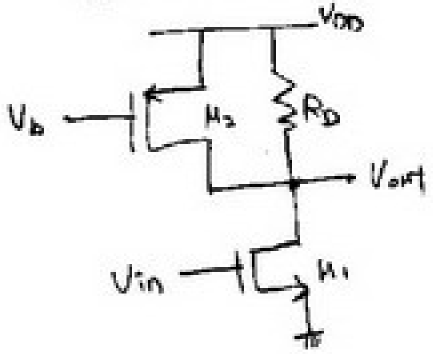
$$g_m r_o = \mu_n C_{ox}\frac{W}{L}(V_{GS}-V_{TH}) \cdot \frac{1}{\lambda \cdot \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS}-V_{TH})^2}$$

$$= \frac{2}{\lambda \cdot (V_{GS}-V_{TH})}$$



3.16 (a) V_{out} vs. V_{in} , $V_{in}: 0 \rightarrow V_{DD}$

⑩



i) $V_{in} < V_{TH}$: M_1 off , $V_{out} = V_{DD}$

ii) $V_{TH} \le V_{in} < V_1$: M_1 saturation , M_2 triode

iii) $V_1 \le V_{in} < V_2$: M_1 saturation , M_2 saturation

iv) $V_2 \le V_{in} \le V_{DD}$: M_1 triode , M_2 saturation ✓

- $V_{in} = V_1$,

M_2 enters in saturation region.

$$|V_{out} - V_{DD}| = |V_b - V_{DD}| - |V_{TH2}|$$

$$\rightarrow \cancel{V_{DD}} - V_{out} = \cancel{V_{DD}} - V_b - |V_{TH2}| \qquad \therefore V_{out} = V_b + |V_{TH2}|$$

$$\rightarrow I_D = \frac{V_{DD} - V_{out}}{R_D} + \frac{1}{2}\mu_p C_{ox}\left(\frac{W}{L}\right)_2 (V_{DD} - V_b - |V_{TH2}|)^2 = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_1 (V_1 - V_{TH1})^2$$

$$\therefore V_1 = V_{TH1} + \left\{\left[\frac{V_{DD} + V_b + |V_{TH2}|}{R_D} + \frac{1}{2}\mu_p C_{ox}\left(\frac{W}{L}\right)_2 (V_{DD} - V_b - |V_{TH2}|)^2\right]\frac{2}{\mu_n C_{ox}\left(\frac{W}{L}\right)_1}\right\}^{\frac{1}{2}}$$ ✓

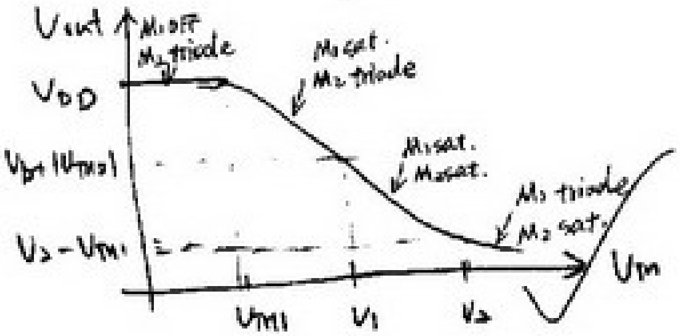
- $V_{in} = V_2$

M_1 is in the edge of saturation region

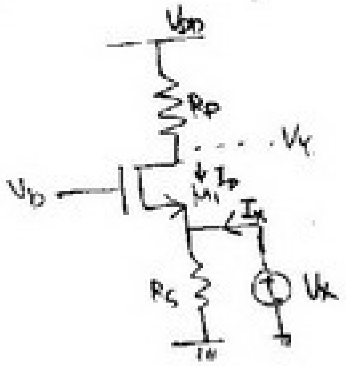
$$V_{out} = V_{in} - V_{TH1} = V_2 - V_{TH1}$$

$$I_D = \frac{V_{DD} - (V_2 - V_{TH1})}{R_D} + \frac{1}{2}\mu_p C_{ox}\left(\frac{W}{L}\right)_2 (V_{DD} - V_b - |V_{TH2}|)^2 = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_1 (V_2 - V_{TH1})^2$$ ✓

∴ V_2 value can be solved from the above equation



3.18 (c) ⑩ I_x vs. V_x V_x $0 \to V_{DD}$



$$V_Y = V_{DD} - I_D R_D = V_{DD} - \left(\frac{V_x}{R_S} - I_x\right) R_D$$

$$I_D = \frac{V_x}{R_S} - I_x \quad , \quad I_x = \frac{V_x}{R_S} - I_D$$

i) $0 < V_x < V_1$. M_1 is in triode

ii) $V_1 \le V_x < V_2$ M_1 is in saturation and $I_x < 0$

iii) $V_b - V_{TH} \le V_x < V_{DD}$ M_1 is turned off and $I_x = \frac{V_x}{R_S}$ ✓

@ V_1 point.

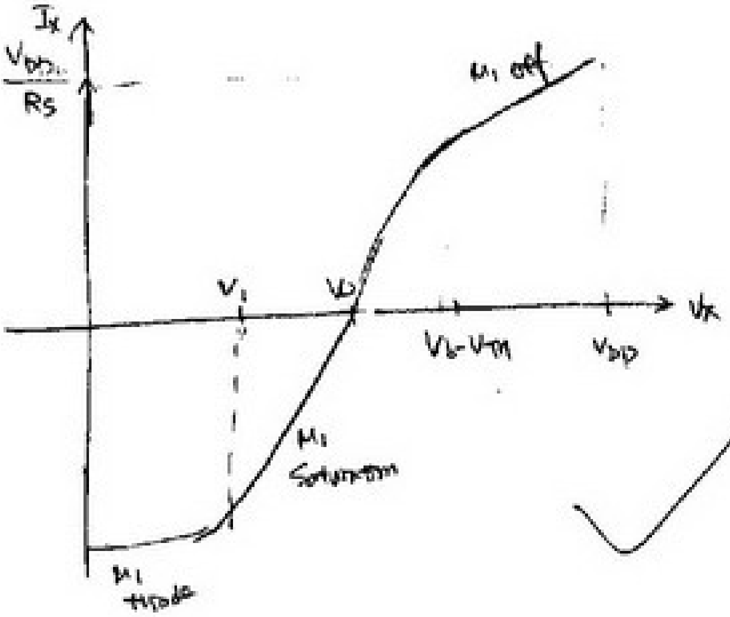
$$V_Y = V_b - V_{TH} \quad . \quad I_D = \frac{V_{DD} - (V_b - V_{TH})}{R_D} = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_b - V_1 - V_{TH})^2$$

$$V_1 = V_b - V_{TH} - \sqrt{\frac{2(V_{DD} - V_b + V_{TH})}{R_D \mu_n C_{ox}\frac{W}{L}}}$$ ✓

If $V_1 < 0$, M_1 won't be in triode.

@ V_2 point.

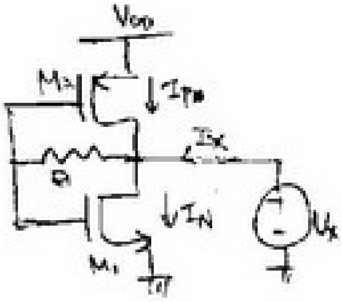
$$I_D = \frac{V_2}{R_S} = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_b - V_2 - V_{TH})^2$$ ✓



✓

⑩

3.19 (d) I_x vs. V_x



$V_x : 0 \rightarrow V_{DD}$

M_1, M_2 are in saturation in all V_x

i) $0 \leq V_x < V_{THN}$, $I_N = 0$ ✓ (∵ M_1 is off)

$$I_x = -I_P = -\frac{1}{2}\mu_p C_{ox}\left(\frac{W}{L}\right)_2 (V_{DD} - V_x - V_{THP})^2$$ ✓

ii) $V_{THN} \leq V_x \leq V_{DD} - V_{THP}$

$I_x = I_N - I_P$ ✓

$$= \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_1 (V_x - V_{THN})^2 - \frac{1}{2}\mu_p C_{ox}\left(\frac{W}{L}\right)_2 (V_{DD} - V_x - |V_{THP}|)^2$$ ✓

iii) $V_{DD} - V_{THP} < V_x \leq V_{DD}$.

M_2 off : $I_P = 0$ ✓

$$I_x = I_N = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_1 (V_x - V_{THN})^2$$ ✓

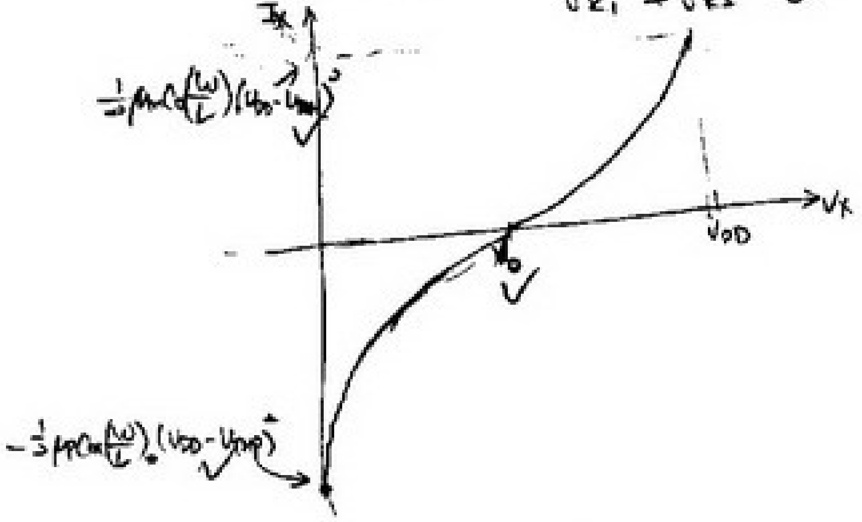
@ $V_x = V_0$, $I_x = 0$. when $I_N = I_P$

$$\frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_1 (V_0 - V_{THN})^2 = \frac{1}{2}\mu_p C_{ox}\left(\frac{W}{L}\right)_2 (V_{DD} - V_0 - |V_{THP}|)^2$$

$$K_1 (V_0 - V_{THN})^2 = K_2 (V_{DD} - V_0 - |V_{THP}|)^2$$

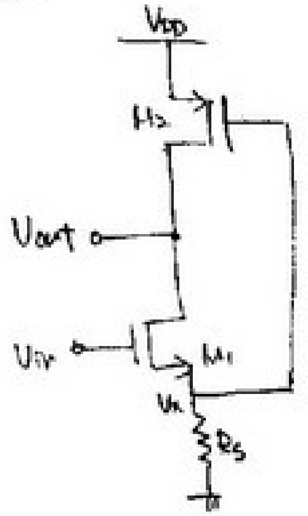
$$V_0 (\sqrt{K_1} + \sqrt{K_2}) = V_{THN} \cdot \sqrt{K_1} + (V_{DD} - |V_{THP}|)\sqrt{K_2}$$

$$\therefore V_x = \frac{\sqrt{K_1} \cdot V_{THN} + \sqrt{K_2} \cdot (V_{DD} - |V_{THP}|)}{\sqrt{K_1} + \sqrt{K_2}}$$ ✓



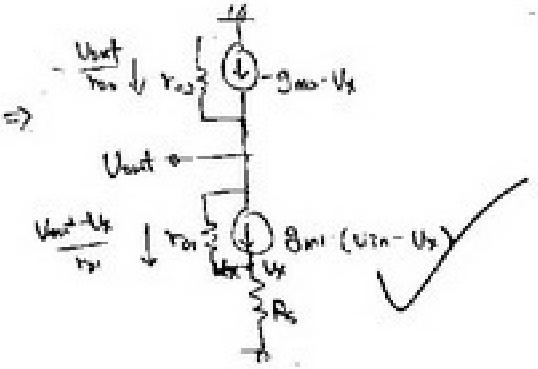
3.20 (e) all MOSFETs are in saturation. $\lambda \neq 0$, $\gamma = 0$

⑩ Small signal voltage gain?



Small sig. equivalent ckt.

⇒



$$\begin{cases} -g_{m2}\cdot V_x - \frac{V_{out}}{r_{o2}} = g_{m1}\cdot(V_{in}-V_x) + \frac{V_{out}-V_x}{r_{o1}} = \frac{V_x}{R_S} & ① \\ V_x\left(\frac{1}{R_S}+g_{m2}\right) = -\frac{V_{out}}{r_{o2}} & ② \end{cases}$$

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

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

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

$$= -g_{m1}\cdot V_{in}$$

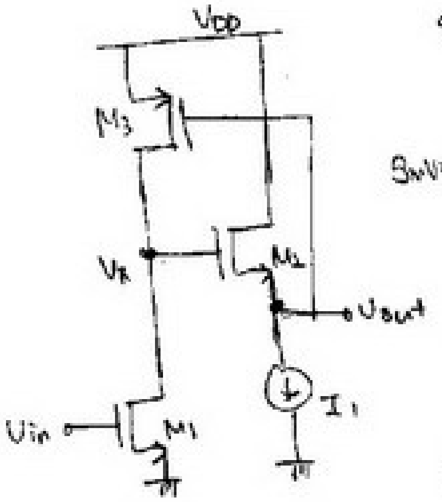
$$\therefore \frac{V_{out}}{V_{in}} = \frac{-g_{m1}}{\frac{g_{m1}}{r_{o2}\left(\frac{1}{R_S}+g_{m2}\right)} + \frac{1}{r_{o1}} + \frac{1}{r_{o1}\cdot r_{o2}\left(\frac{1}{R_S}+g_{m2}\right)} + \frac{1}{R_S\cdot r_{o2}\left(\frac{1}{R_S}+g_{m2}\right)}}$$

$$= \frac{-g_{m1}\cdot r_{o2}\left(g_{m2}+\frac{1}{R_S}\right)}{g_{m1} + \frac{r_{o2}}{r_{o1}}\left(g_{m2}+\frac{1}{R_S}\right) + \frac{1}{r_o} + \frac{1}{R_S}}$$

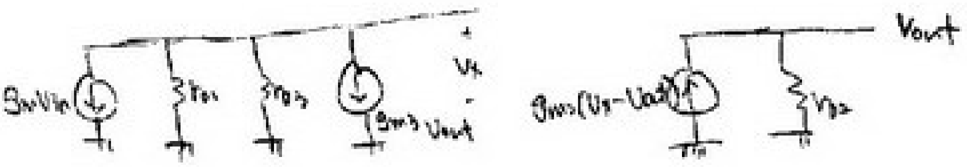
⑩

3.21 (h) Assuming all MOSFETs are in saturation $\lambda \neq 0,\ \gamma = 0$

Find small signal gain.



Small sig. equivalent ckt



$$\begin{cases} V_x = -(g_{m1} \cdot V_{in} + g_{m3} \cdot V_{out}) \cdot (r_{o1} \| r_{o3}) \checkmark \\ V_{out} = g_{m2}(V_x - V_{out}) \cdot r_{o2} \checkmark \end{cases}$$

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

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

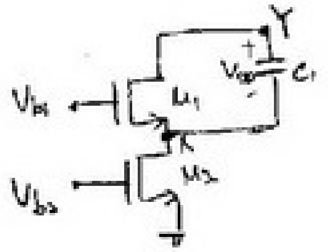
$$\frac{V_{out}}{V_{in}} = \frac{-g_{m1} \cdot g_{m2} \cdot (r_{o1} \| r_{o3}) r_{o2}}{1 + g_{m2} \cdot r_{o2} + g_{m2} \cdot g_{m3} (r_{o1} \| r_{o3}) r_{o2}}$$

$$= \frac{-g_{m1} \cdot g_{m2} \cdot \dfrac{r_{o1} \cdot r_{o2} \cdot r_{o3}}{r_{o1} + r_{o3}}}{1 + g_{m2} r_{o2} + g_{m2} \cdot g_{m3} \cdot \dfrac{r_{o1} \cdot r_{o2} \cdot r_{o3}}{r_{o1} + r_{o3}}}$$

$$= \frac{-g_{m1} \cdot g_{m2} \cdot r_{o1} r_{o2} \cdot r_{o3}}{r_{o1} + r_{o3} + g_{m2} \cdot r_{o2}(r_{o1} + r_{o3}) + g_{m2} \cdot g_{m3} \cdot r_{o1} \cdot r_{o2} \cdot r_{o3}}$$

⑩

3.22(b) V_X, V_Y vs time. $V_{C_1}(0^-) = V_{DD}$



assume $V_Y(0^-) = V_{DD}$, $V_X(0^-) = 0$

$I_{D2}(0^-) : 0.$

$I_{D1}(0^-) = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_1 (V_{b1} - V_{TH})^2$

when $V_X \uparrow_{,} V_Y \downarrow, \rightarrow I_D \uparrow \rightarrow V_X \downarrow$: V_X returns to zero

: V_Y goes from V_{DD} to zero.

M_1 is saturated until $V_Y = V_{b1} - V_{TH}$ ✓

$I_{D1} = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_1 (V_{b1} - V_{TH})^2$

$C\Delta V = I\Delta t \rightarrow C_1 \cdot (V_{DD} - (V_{b1} - V_{TH})) = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_1 (V_{b1} - V_{TH})^2 \cdot \Delta t$

$$\therefore \Delta t = \frac{C_1 \cdot (V_{DD} - V_{b1} + V_{TH})}{\frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_1 (V_{b1} - V_{TH})^2} = t_1$$

after t_1, M_1 enters to triode region

$$I_C = -C\frac{dV_C}{dt} \rightarrow -C_1\frac{dV_Y}{dt} = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_1 \left[2(V_{b1} - V_{TH})V_Y - V_Y^2\right] ✓$$

$$\frac{dV_Y}{2(V_{b1} - V_{TH})V_Y - V_Y^2} = -\frac{\mu_n C_{ox}}{2C_1}\frac{W}{L}dt$$

$$\left[\frac{1}{V_Y} + \frac{1}{2(V_{b1} - V_{TH}) - V_Y}\right] \cdot \frac{dV_Y}{2(V_{b1} - V_{TH})} = -\frac{\mu_n C_{ox}\frac{W}{L}}{✓2C_1}dt$$

$$\int \Rightarrow \ln(V_Y) - \ln[2(V_{b1} - V_{TH}) - V_Y] = -\frac{\mu_n C_{ox}\frac{W}{L}}{C_1}(V_{b1} - V_{TH})t + K$$

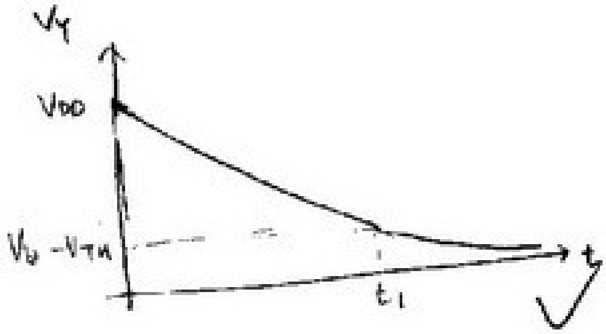
at $t = t_1$, $V_Y = V_{b1} - V_{TH}$

$$\ln(V_{b1} - V_{TH}) - \ln[2(V_{b1} - V_{TH}) - (V_{b1} - V_{TH})] = \frac{-\mu_n C_{ox}\frac{W}{L}}{C_1}(V_{b1} - V_{TH}) \frac{C_1(V_{DD} - V_{b1} + V_{TH})}{\frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{b1} - V_{TH})^2} + K$$

3.22 (b) cont'd

$$0 = -\frac{2(V_{DD} - V_{b1} + V_{TH})}{(V_{b1} - V_{TH})} + K \qquad \therefore K = \frac{2(V_{DD} - V_{b1} + V_{TH})}{V_{b1} - V_{TH}}$$

$$\therefore \ln\left[\frac{V_Y}{2(V_{b1} - V_{TH}) - V_Y}\right] = -\frac{\mu_n C_{ox}\frac{W}{L}}{C_1}(V_{b1} - V_{TH})t + \frac{2(V_{DD} - V_{b1} + V_{TH})}{V_{b1} - V_{TH}}$$



2. $W/L = 30/0.18$ $\quad V_{DD} = 1.8V$

(a)

⑤

$V_{b1} = V_{DD} - |V_{DS1}| - |V_{GS2}|$

$V_{b2} = V_{DS4} + V_{GS3}$

M1: $I_D = \frac{1}{2}\mu_p C_{ox}\frac{W}{L}(|V_{GS1}| - |V_{THP}|)^2$ $\quad |V_{DS1}| = |V_{GS1}| - |V_{THP}|$ at the edge of saturation

$\Rightarrow |V_{DS1}| = |V_{GS1}| - |V_{THP}| = \sqrt{\frac{2I_D}{\mu_p C_{ox}\frac{W}{L}}}$

M2: $I_D = \frac{1}{2}\mu_p C_{ox}\frac{W}{L}(|V_{GS2}| - |V_{THP}|)^2$

$\Rightarrow |V_{GS2}| = |V_{THP}| + \sqrt{\frac{2I_D}{\mu_p C_{ox}\frac{W}{L}}}$

$\therefore \underline{V_{b1} = V_{DD} - |V_{DS1}| - |V_{GS2}|}$ ✓

$= V_{DD} - \sqrt{\frac{2I_D}{\mu_p C_{ox}\frac{W}{L}}} - |V_{THP}| - \sqrt{\frac{2I_D}{\mu_p C_{ox}\frac{W}{L}}} = V_{DD} - |V_{THP}| - 2\sqrt{\frac{2I_D}{\mu_p C_{ox}\frac{W}{L}}}$

$\underline{= 0.793V}$ ✓

M3: $I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS3} - V_{THN})^2$

$\Rightarrow V_{GS3} = V_{THN} + \sqrt{\frac{2I_D}{\mu_n C_{ox}\frac{W}{L}}}$

M4: $I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS4} - V_{TH})^2$ $\quad V_{GS4} - V_{TH} = V_{DS4}$ at the edge of saturation

$\Rightarrow V_{DS4} = \sqrt{\frac{2I_D}{\mu_n C_{ox}\frac{W}{L}}}$

$\therefore V_{b2} = \underline{V_{DS4} + V_{GS3}} = \sqrt{\frac{2I_D}{\mu_n C_{ox}\frac{W}{L}}} + V_{THN} + \sqrt{\frac{2I_D}{\mu_n C_{ox}\frac{W}{L}}} = V_{THN} + 2\sqrt{\frac{2I_D}{\mu_n C_{ox}\frac{W}{L}}}$ ✓ ✓

$= 0.803V$ ✓

(b) · PMOS side

· $|V_{DS2}| \geq |V_{GS2}| - |V_{THP}|$

⑧

$-V_{out} \geq -V_{b1} - |V_{THP}|$

$\therefore V_{out} \leq V_{b1} + |V_{THP}| = V_{DD} - \cancel{|V_{THP}|} - 2\sqrt{\frac{2I_D}{\mu_p C_{ox}\frac{W}{L}}} + \cancel{|V_{THP}|} = V_{DD} - 2\sqrt{\frac{2I_D}{\mu_p C_{ox}\frac{W}{L}}} = 1.284V$ ✓

· NMOS side

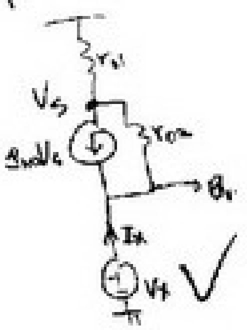
$V_{out} \geq V_{b2} - V_{THN} = V_{THN} + 2\sqrt{\frac{2I_D}{\mu_n C_{ox}\frac{W}{L}}} - \cancel{V_{THN}} = 2\sqrt{\frac{2I_D}{\mu_n C_{ox}\frac{W}{L}}} = 0.332V$ ✓

$\therefore \text{Swing} = V_{DD} - 2\sqrt{\frac{2I_D}{\mu_p C_{ox}\frac{W}{L}}} - 2\sqrt{\frac{2I_D}{\mu_n C_{ox}\frac{W}{L}}} = 0.952\ V$ ✓

(C) $\frac{V_{out}}{A} = -g_{m1}(r_{up} \| r_{dn})$

⑩

r_{up}



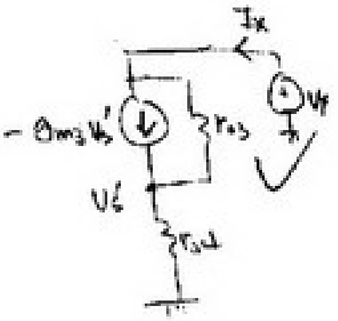
$$\begin{cases} I_x = \frac{V_s}{r_{o1}} = \frac{V_x - V_s}{r_{o2}} - g_{m2} \cdot V_s \\ V_s = r_{o1} \cdot I_x \end{cases}$$

$\therefore I_x = \frac{V_x - I_x \cdot r_{o1}}{r_{o2}} - g_{m2} \cdot I_x r_{o1}$

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

$\therefore \frac{V_x}{I_x} = r_{up} = \underline{r_{o1} + r_{o2} + g_{m2} r_{o1} \cdot r_{o2}}$ ✓

r_{dn}



$$\begin{cases} I_x = \frac{V_s'}{r_{o4}} = \frac{V_x - V_s'}{r_{o3}} - g_{m3} \cdot V_s' \\ V_s' = I_x \cdot r_{o4} \end{cases}$$

$I_x = \frac{V_x - I_x \cdot r_{o4}}{r_{o3}} - g_{m3} \cdot I_x \cdot r_{o4}$

$I_x \left(1 + \frac{r_{o4}}{r_{o3}} + g_{m3} \cdot r_{o4}\right) = \frac{V_x}{r_{o3}}$

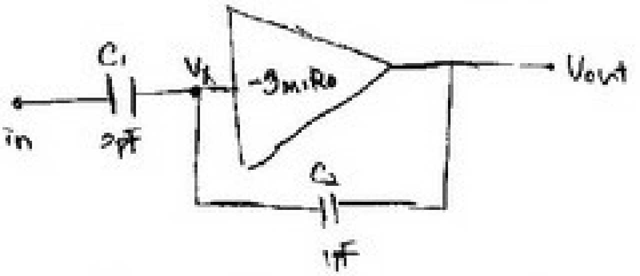
$\therefore \frac{V_x}{I_x} = r_{dn} = \underline{r_{o3} + r_{o4} + g_{m3} \cdot r_{o3} \cdot r_{o4}}$

$$\therefore \frac{V_{out}}{A} \approx -g_{m1}\cdot\left[(r_{o1}+r_{o2}+g_{m5}\cdot r_{o1}\cdot r_{o2}) \parallel (r_{o3}+r_{o4}+g_{m3}\cdot r_{o3}\cdot r_{o4})\right] = -g_{m1}\cdot R_o$$ ✓

$$= -275$$ ✓

$\frac{V_{out}}{V_{in}}$: closed loop

(resistor can be viewed as open circuit in midband) ✓



$$V_{out} = -g_{m1}\cdot R_o\cdot V_x$$

$$(V_{in}-V_x)sC_1 = (V_x-V_{out})sC_2$$

$$V_x(sC_2+sC_1) = V_{in}\cdot sC_1 + V_{out}\cdot sC_2 \qquad \therefore V_x = \frac{C_1\cdot V_{in}+C_2\cdot V_{out}}{C_1+C_2}$$

$$\Rightarrow V_{out} = -g_{m1}\cdot R_o\cdot\frac{C_1\cdot V_{in}+C_2\cdot V_{out}}{C_1+C_2}$$

$$V_{out}\left(1+\frac{g_{m1}\cdot R_o\cdot C_2}{C_1+C_2}\right) = \frac{-g_{m1}\cdot R_o\cdot C_1}{C_1+C_2}V_{in}$$

$$\therefore \frac{V_{out}}{V_{in}} = \frac{-g_{m1}\cdot R_o\cdot C_1}{C_1+C_2+g_{m1}\cdot R_o\cdot C_2} \cong \frac{-g_{m1}\cdot R_o C_1}{g_{m1}\cdot R_o\cdot C_2} = -\frac{C_1}{C_2} = -2$$ ✓

C_1 = 2pF, C_2 = 1pF

$$\left.\begin{aligned} r_{o1}+r_{o2}+g_{m5}\cdot r_{o1}\cdot r_{o2} &\simeq g_{m5}\cdot r_{o1}\cdot r_{o2} = 157.6K \\ r_{o3}+r_{o4}+g_{m3}\cdot r_{o3}\cdot r_{o4} &\simeq g_{m3}\cdot r_{o3}\cdot r_{o4} = 188.8K \end{aligned}\right\} R_o = \frac{1}{\frac{1}{157.6k}\ \frac{1}{188.8k}} = 86.9k\Omega$$ ✓

Coefficient Values.

$I_D = 600\mu A$

Simul.

$V_{THN0} = 0.343V$, $V_{THP0} = -0.418V$ $\gamma = 0$ | $V_{THN} = 0.471V$, $V_{THP} = -0.491$

$\mu_n = 310.24\ cm^2/V.sec$, $\mu_p = 128.28\ cm^2/V.sec$

$t_{ox} = 4.1\times10^{-9}\ m$

$$C_{ox} = \frac{\epsilon_{SiO_2}}{t_{ox}} = \frac{3.9\times8.854\times10^{-12}}{4.1\times10^{-9}} = 8.422\times10^{-3}\ F/m^2 = 0.8422\mu\ A\cdot s/_{V\cdot cm^2}$$

$$\frac{W}{L} = \frac{30\mu m}{0.18\mu m}$$

$V_{DD} = 1.8V$

$$2\sqrt{\frac{2I_D}{\mu_p C_{ox}\frac{W}{L}}} = 2\sqrt{\frac{2\times600}{128.28\times0.8422\times\frac{30}{0.18}}} = 0.258$$

$$g_{m1} = \sqrt{2\mu_p C_{ox}\frac{W}{L}I_D} = \sqrt{2\times128.28\times0.8422\times\frac{30}{0.18}\times600} = 4.684\,mA/V$$

$$g_{m3} = \sqrt{2\mu_n C_{ox}\frac{W}{L}I_D} = \sqrt{2\times310.24\times0.8422\times\frac{30}{0.18}\times600} = 7.229\,mA/V$$

@ [illegible] V

Let $r_{o1} = r_{o2} = 5.8\,k\Omega$

$r_{o3} = r_{o4} = 5.11\,k\Omega$

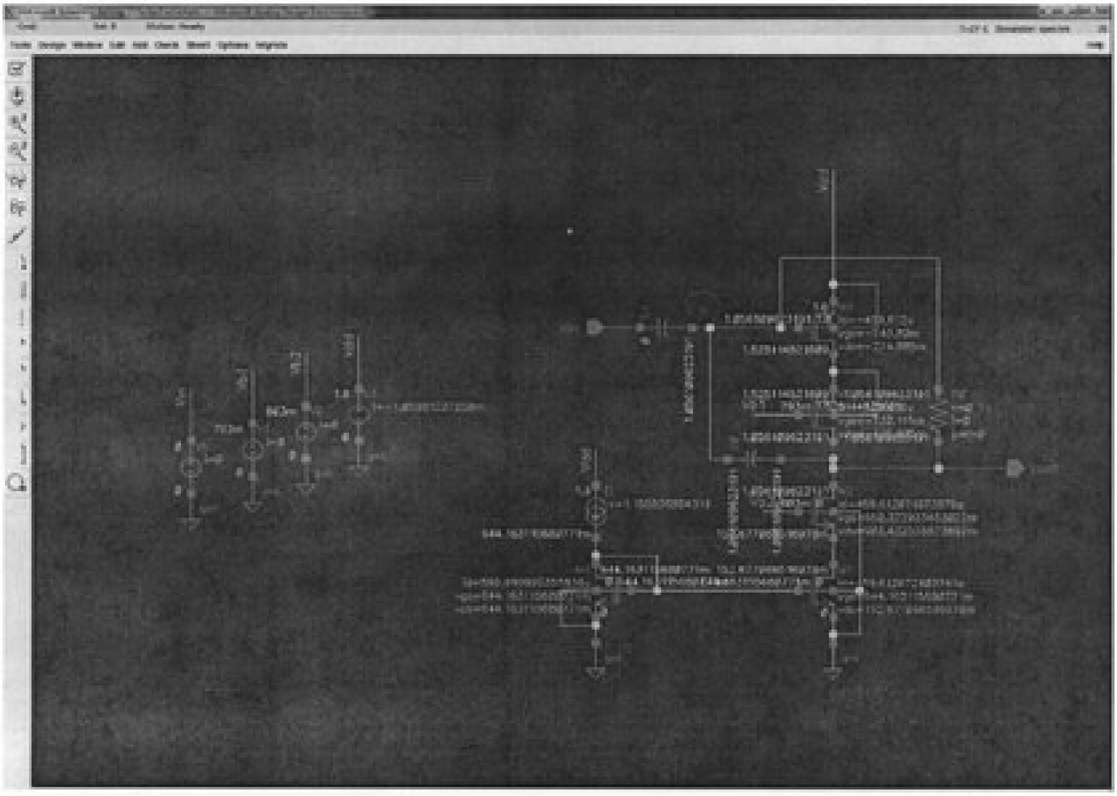
$g_{m1} \simeq g_{m2}$

$g_{m3} \simeq g_{m4}$ at saturation region

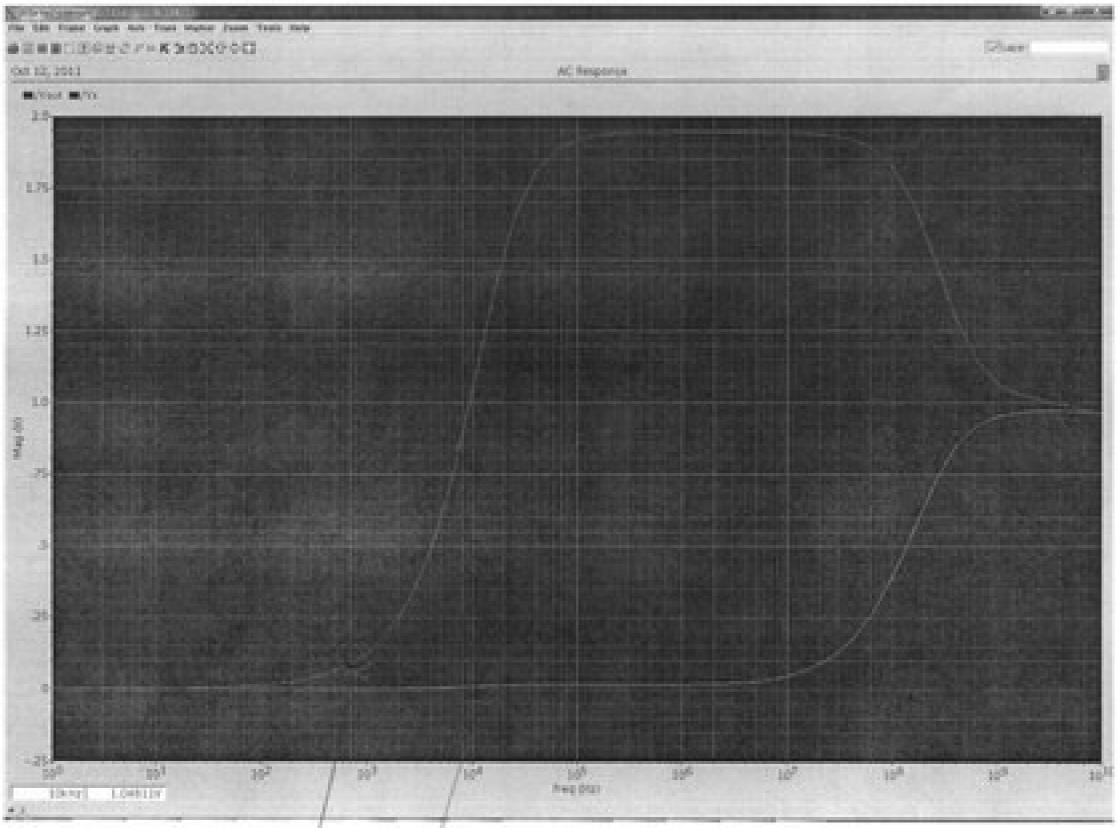
$r_{o1} + r_{o2} + g_{m1}\cdot r_{o1}\cdot r_{o2} \simeq g_{m1}\cdot r_{o1}\cdot r_{o2} = 157.6k$ ✓

$r_{o3} + r_{o4}\ g_{m3}\cdot r_{o3}\cdot r_{o4} \simeq g_{m3}\cdot r_{o4}\cdot r_{o4} = 188.8k$

10



$I_D = 46\mu m$ due to channel length modulation on M4

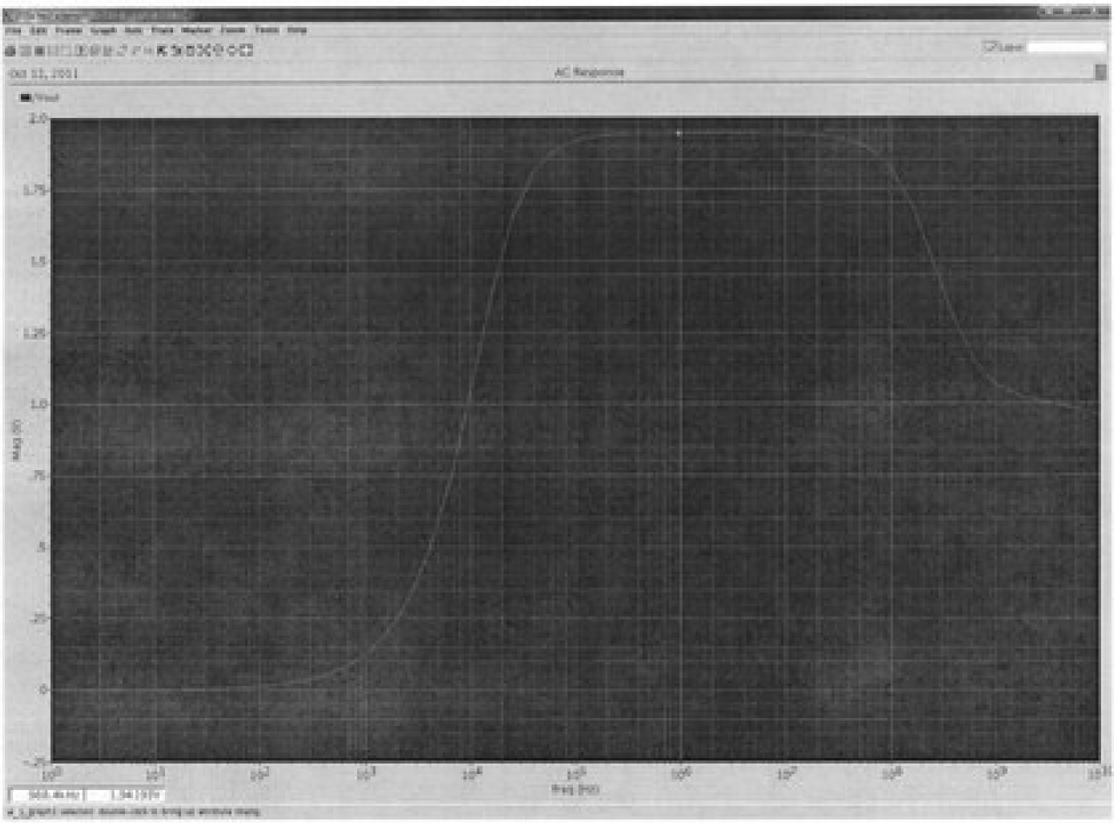


VA : AC Ground

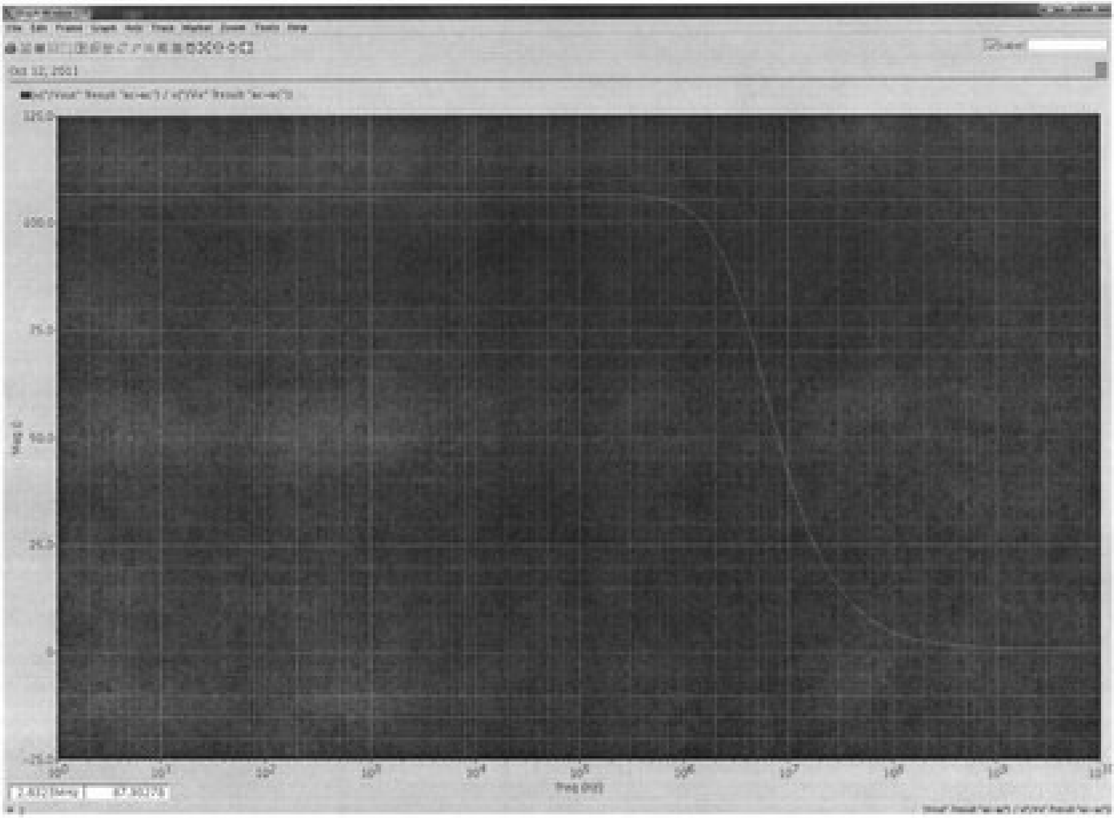
Vout

Closed loop gain is below 2.

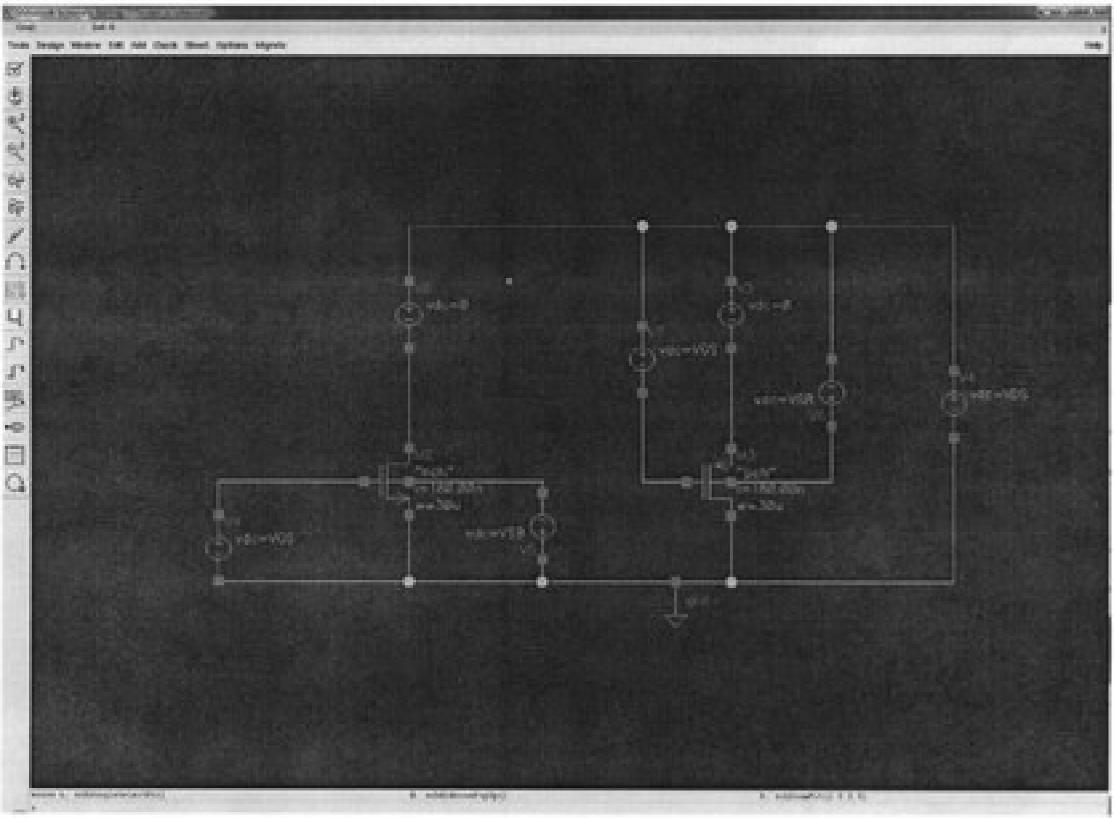
Also, amplifier is loaded by transistor caps which manifest themselves in high frequency.



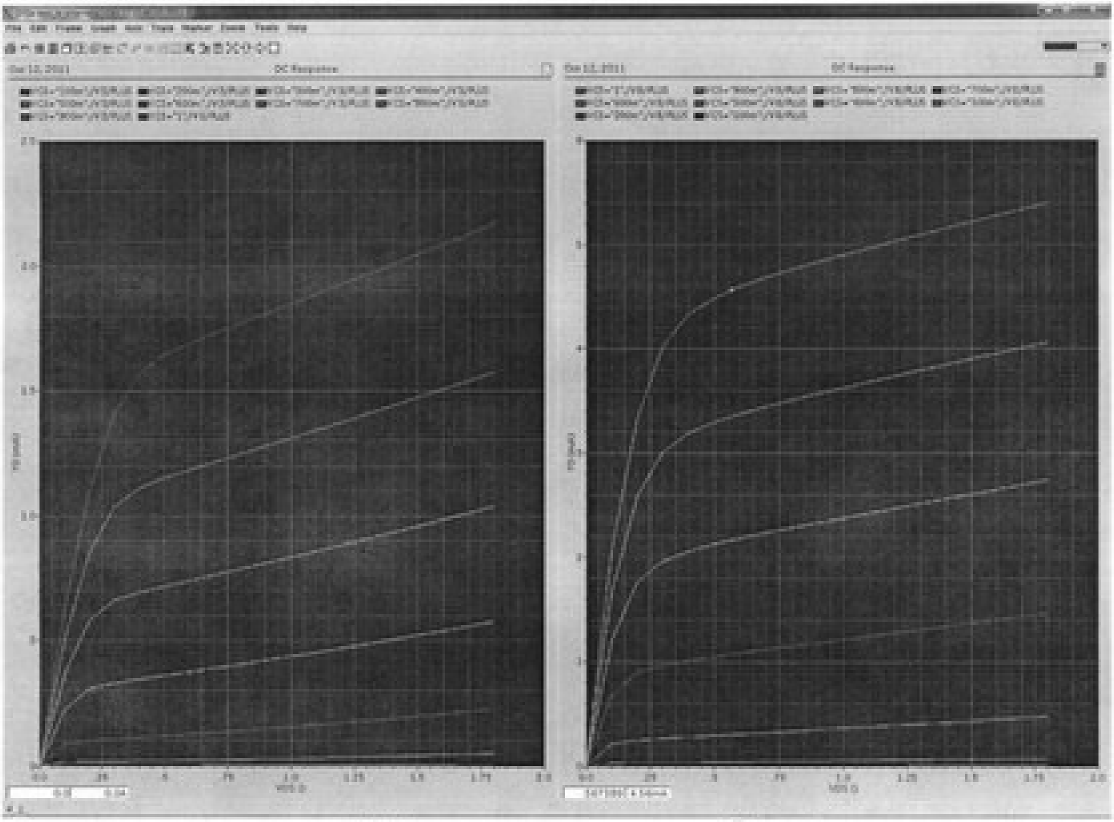
Closed Loop Gain



OPen loop gain = $\frac{V_{out}}{V_A}$



Schematic to find I-V characteristics of NMOS & PMOS



NMOS PMOS

I-V Characteristic Curve of NMOS & PMOS