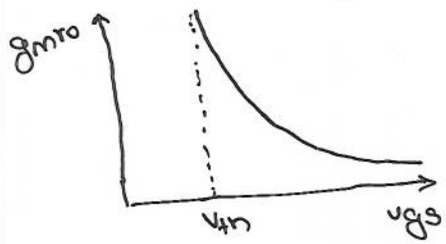
$\boxed{\beta = \mu_n C_{ox} \frac{W}{L}}$ $\Rightarrow$ Total = 33

(3.6) (a) $g_m = \dfrac{2 I_D}{V_{gs} - V_{th}}$ $\qquad r_o = \dfrac{1}{\lambda I_d}$

Eqn — 1 mark

$g_m r_o = \dfrac{2}{\lambda [V_{gs} - V_{th}]}$



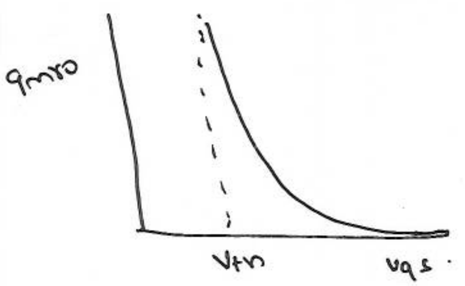
plot — 1 mark

total (2.)

(b) $g_m = \mu_n C_{ox} \dfrac{W}{L} (V_{gs} - V_{th})$ $\qquad r_o = \dfrac{1}{\lambda I_D} = \dfrac{1}{\frac{\lambda}{2} \mu_n C_{ox} \frac{W}{L} (V_{gs} - V_{th})^2}$

Eqn — 1 mark

$g_m r_o = \dfrac{2}{\lambda (V_{gs} - V_{th})}$



plot — 1 mark

total (2)

(3.7) $\cancel{g_m = \sqrt{2\mu_n C_{ox} \frac{W}{L}}}$

(a) $g_m = \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_{th})$ $\quad r_o = \frac{1}{\lambda I_D} = \frac{1}{\frac{\lambda}{2} \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_{th})^2}$

$g_m r_o = \frac{2}{\lambda (V_{GS} - V_{th})}$

Assuming L is constant.

Ean - 1

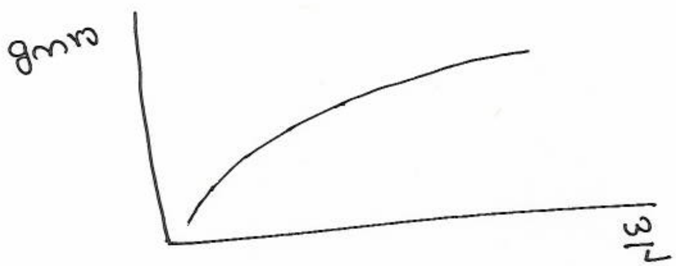
plot - 1

2

(b) $g_m = \sqrt{2 \mu_n C_{ox} \frac{W}{L} I}$ $\quad r_o = \frac{1}{\lambda I}$.

Assuming L is contant.

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



Ean - 1

plot - 1

2

(3.9) $g_m = \beta(v_{gs} - v_{th})$

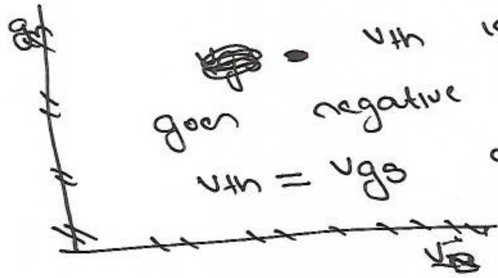
$$= \beta\left(v_{gs} - \left[v_{th0} + \gamma\left[\sqrt{2\phi_F + V_{SB}} - \sqrt{2\phi_F}\right]\right]\right). \quad — \ 1$$

$$r_o = \frac{1}{\lambda I_D} = \frac{1}{\lambda \frac{\beta}{2}(v_{gs} - v_{th})^2}$$

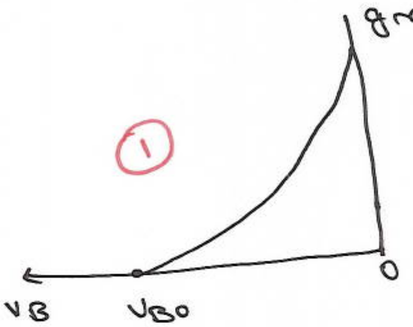
$$= \frac{1}{\lambda \frac{\beta}{2}\left(v_{gs} - \left[v_{th0} + \gamma\left\{\sqrt{2\phi_F + V_{SB}} - \sqrt{2\phi_F}\right]\right\}\right)^2}. \quad — \ 1$$

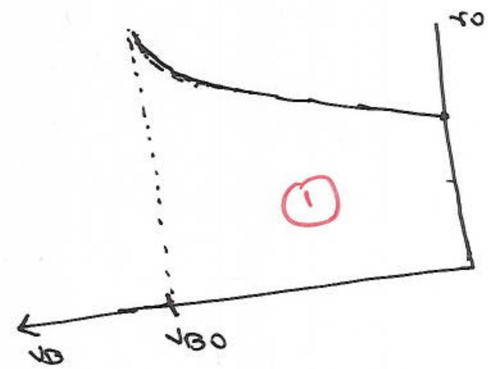
$$g_m r_o = \frac{2}{\lambda(v_{gs} - v_{th})} = \frac{2}{\lambda\left(v_{gs} - \left[v_{th0} + \gamma\left\{\sqrt{2\phi_F + V_{SB}} - \sqrt{2\phi_F}\right\}\right]\right)}.$$

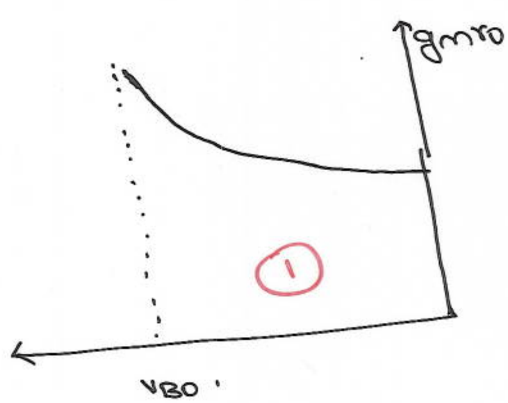
1 —



• V_{th} increases as bulk potential goes negative and at a voltage V_{BO} $V_{th} = V_{gs}$ and device ~~gets~~ will go off.





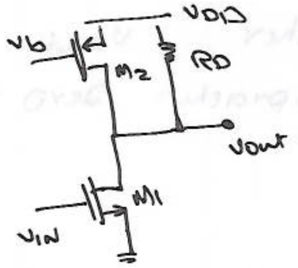


$V_{BO} \Rightarrow$

$$-\left[\frac{v_{gs} - v_{th0} + \sqrt{2\phi_F}}{\gamma}\right]^2 + 2\phi_F + V_g.$$

total 6.

(3.16a)



(i) $V_{IN} = 0$ M_1 is off $V_{out} = V_{DD}$ & M_2 is in ~~saturation~~ linear region
this stays like this till $V_{IN} = V_{th}$ when M_1 turn on

(ii) $V_{in} > V_{th}$ current through M_1 ~~decrease~~ increases & V_{out} drops.
M_2 stays in linear region

$$\frac{\beta_n}{2}(V_{IN}-V_{th})^2 = \beta_p\left((V_{DD}-V_b-|V_{thp}|)(V_D-V_{out}) - \frac{(V_D-V_{out})^2}{2}\right) + \frac{V_{DD}-V_{out}}{R_D}$$

(iii) when $V_{out} = V_b + |V_{thp}|$ M_2 enters saturation. the assuming M_1 is in saturatio ~~linear~~ at this point.
corresponding $V_{IN} = V_{IN1}$ is given by.

$$\frac{\beta_n}{2}(V_{IN}-V_{th})^2 = \frac{\beta_p}{2}(V_{DD}-V_b-|V_{thp}|)^2 + \frac{V_{DD}-V_b-|V_{thp}|}{R_D}$$

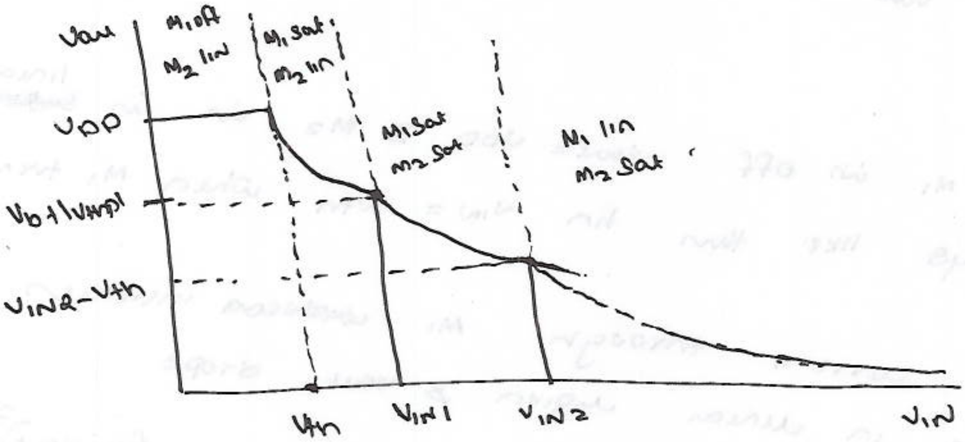
(iv) ~~when~~ ~~Beyond~~ For $V_{in} > V_{IN1}$ M_2 stays in saturation & V_{out} drops conducting constant current.
as per equation

$$\frac{\beta_n}{2}(V_{in}-V_{th})^2 = \frac{\beta_p}{2}(V_{DD}-V_b-|V_{thp}|)^2 + \frac{V_{DD}-V_{out}}{R_D}$$

(v) when V_{out} drops to $V_{IN} - V_{th}$ M_1 will enter into linear region. & corresponding $V_{IN} = V_{in2}$ is given by

$$\frac{\beta_n}{2}(V_{in2}-V_{th})^2 = \frac{\beta_p}{2}(V_{DD}-V_b-|V_{thp}|)^2 + \frac{V_{DD}-(V_{in2}-V_{th})}{R_D}$$

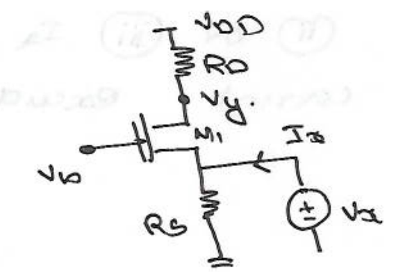
(vi) as V_{IN} increases still further V_{out} continues to drop an asymptotically approaches zero.



Each region 1 mark total (4)

Each region
1 = 1/2 for boundary condition & trend.
1/2 for relevant equation

3.18C



Starting from $V_x = V_{DD}$ for convenience $V_y = V_{DD}$

(i) $V_x = V_{DD}$ M_1 is off at which point

This continues until $V_x = V_b - V_{th}$. Till then M_1 will turn on in saturation.

$I_x = \frac{V_x}{R_S}$.

(ii) $V_x < V_b - V_{th}$ M_1 is in saturation & V_y starts dropping. M_1 will enter saturation when V_y reaches $V_b - V_{th}$ at $V_x = V_{x1}$

$$\Rightarrow V_{DD} - \frac{\beta_n}{2}(V_b - V_{x1} - V_{th})^2 R_D = V_b - V_{th}.$$

$$\Rightarrow \cancel{V_{x1}} = \cancel{V_{DD} - (V_b - V_{th}) \cdot \frac{2}{\beta_n R_D}}$$

$$(V_b - V_{x1} - V_{th})^2 = (V_{DD} - V_b + V_{th})\frac{2}{\beta_n R_D}.$$

$$V_b - V_{x1} - V_{th} = \sqrt{(V_{DD} - V_b + V_{th})\frac{2}{\beta_n R_D}}$$

$$V_{x1} = V_b - V_{th} - \sqrt{(V_{DD} - V_b + V_{th})2/\beta_n R_D}.$$

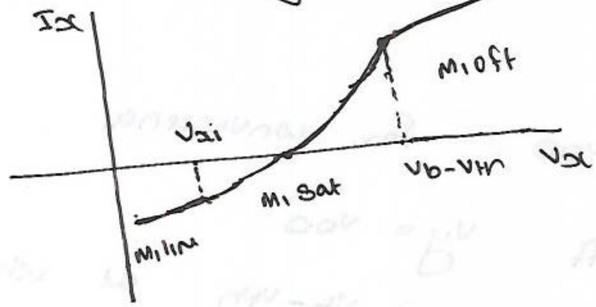
till then current $= \frac{V_x}{R_S} - \frac{\beta_n}{2}(V_b - V_x - V_{th})^2$

(iii) $V_x < V_{x1}$ M_1 is in linear region.

$\cancel{I_x} = \cancel{\frac{V_x}{R_S}}$ $\cancel{\frac{\beta_n}{2}}$ $V_y = V_{DD} - \left(\frac{V_x}{R_S} - I_x\right)R_D.$

$$I_x = \frac{V_x}{R_S} - \frac{\beta_n}{2}\left[(V_b - V_x - V_{th})(V_y - V_x) - \frac{(V_y - V_x)^2}{2}\right]$$

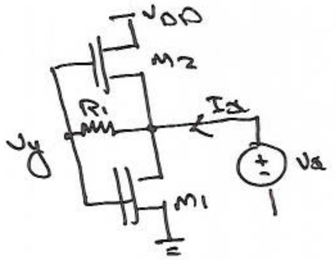
(iv) At some point in region (ii) or (iii) I_x will change polarity when drain current exceeds $\frac{V_x}{R_S}$



Each region - 1

total 3

(3.19d)



Since there is no current flow through R_1, $V_y = V_x$.

(i) At $V_x = 0$, M_1 is off & M_2 is on in saturation.

This is the state till M_1 turns on at $V_x = V_{thn}$.

So for $0 \le V_x \le V_{thn}$

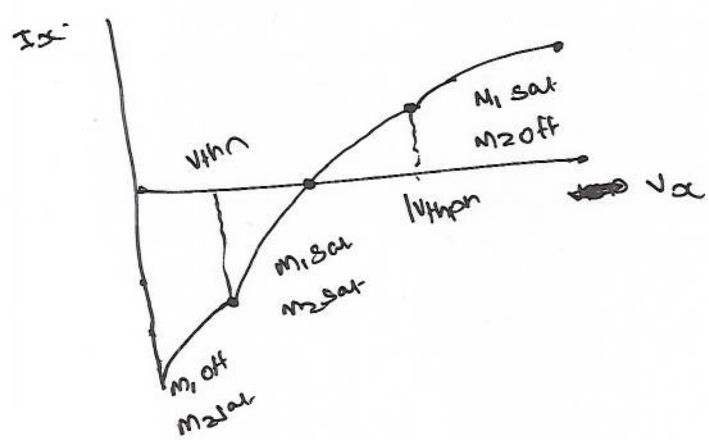
$$I_x = -\frac{\beta_p}{2}\left(V_{DD} - V_x - |V_{thp}|\right)^2$$

(ii) For $V_{thn} \le V_x \le |V_{thp}|$ both M_1 and M_2 are in saturation

$$I_x + \frac{\beta_p}{2}\left(V_{DD} - V_x - |V_{thp}|\right)^2 = \frac{\beta_n}{2}\left(V_x - V_{thn}\right)^2$$

(iii) $V_x \ge |V_{thp}|$ M_2 is off.

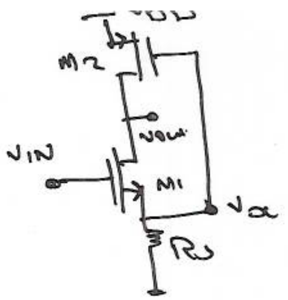
$$I_x = \frac{\beta_n}{2}\left(V_x - V_{thn}\right)^2$$

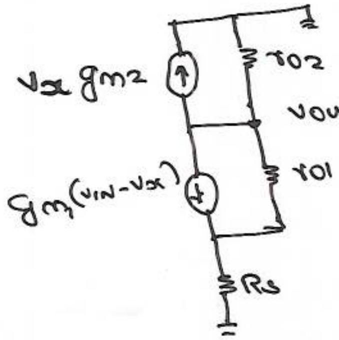


Each region 1

total 3.

(3.20 e)





Small signal model - 1

Analysis - 2 } 1 mark if approach is correct & final answer is wrong.

total 3

$$g_{m2}v_x + \frac{V_{out}}{r_{o2}} + \frac{v_x}{R_s} = 0$$

$$\Rightarrow \frac{1+g_{m2}R_s}{R_s}\, v_x = \frac{-V_{out}}{r_{o2}}$$

$$v_x = -V_{out}\cdot\frac{R_s}{r_{o2}}\cdot\frac{1}{1+g_{m2}R_s}$$

Also

$$g_{m1}(v_{IN}-v_x) + \frac{v_{out}-v_x}{r_{o1}} = \frac{v_x}{R_s}$$

$$g_{m1}v_{IN} = g_{m1}v_x + \frac{v_x}{r_{o1}} + \frac{v_x}{R_s} - \frac{V_{out}}{r_{o1}}$$

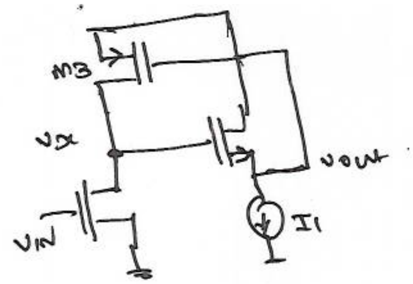
$$\cancel{\Rightarrow g_{m1} + \frac{1}{r_{o1}} + \frac{1}{R_s}}$$

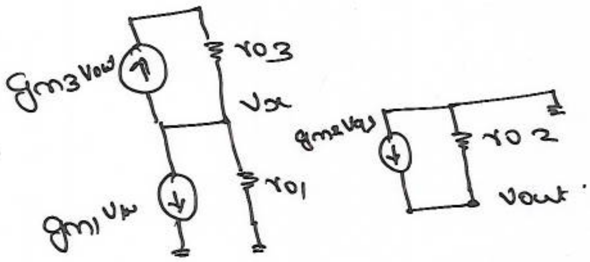
$$= \left[\frac{1}{r_{o1}} + \frac{r_{o1}+R_s+g_{m1}r_{o1}R_s}{r_{o1}R_s}\cdot\frac{R_s}{r_{o2}}\cdot\frac{1}{(g_{m2}R_s+1)}\right] \cdot -V_{out}$$

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

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

3Q1h





Small signal model - 1
Analysis 2 { 1 mark for correct approach },
Total (5)

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

$$g_{m2}V_x = \left[\frac{1 + g_m r_{o2}}{r_{o2}}\right]V_{out}$$

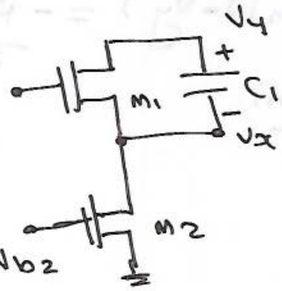
$$V_x = \frac{1 + g_m r_{o2}}{g_{m2} r_{o2}} V_{out}.$$

$$g_{m1}V_{IN} + \frac{V_x}{r_{o1}} + \frac{V_x}{r_{o3}} + g_{m3}V_{out} = 0$$

$$g_{m1}V_{IN} + \left[\left(\frac{1}{r_{o1}} + \frac{1}{r_{o3}}\right)\frac{1 + g_{m2} r_{o2}}{g_{m2} r_{o2}} + g_{m3}\right]V_{out} = 0.$$

$$\frac{V_{out}}{V_{IN}} = \frac{-g_{m1}}{g_{m3} + \left[\frac{1 + g_{m2} r_{o2}}{g_{m2} r_{o2}}\right]\left[\frac{1}{r_{o1}} + \frac{1}{r_{o3}}\right]}.$$

3.22b



current through $M_2 = 0 \Rightarrow V_x = 0$

M_1 starts in saturation at $t=0$

(i) $V_y(0^-) = V_{DD} \Rightarrow$

$$\frac{\beta}{2}(V_{b1} - V_{th})^2 + C\frac{dV_y}{dt} = 0$$

$$dV_y = -\frac{\beta}{2C}(V_{b1}-V_{th})^2\, dt.$$

$$V_y = V_{DD} - \frac{\beta}{2C}(V_{b1}-V_{th})^2 t$$

(ii) when $V_y(t=t_1) = V_{b1} - V_{th}$ M_1 enters linear region

$$\Rightarrow V_{DD} - \frac{\beta}{2C}(V_{b1}-V_{th})^2 t_1 = (V_{b1}-V_{th}).$$

$$\Rightarrow t_1 = \frac{(V_{DD} - V_{b1} + V_{th})}{\frac{\beta}{2C}(V_{b1}-V_{th})^2}.$$

(iii) $t > t_1$ M_1 is in linear region

$$\frac{\beta}{2}\left[(V_{b1}-V_{th})V_y - \frac{V_y^2}{2}\right] + C\frac{dV_y}{dt} = 0.$$

$$\frac{dV_y}{V_y[2(V_{b1}-V_{th}) - V_y]} = \frac{-\beta\, dt}{2C}.$$

$$\frac{1}{2(V_{b1}-V_{th})} \cdot dV_y\left[\frac{1}{V_y} + \frac{1}{2(V_{b1}-V_{th}) - V_y}\right] = \frac{-\beta}{2C}dt.$$

$$\ln(v_y) - \ln((v_{b1} - v_{tn})2 - v_y) = -\frac{\beta t (v_{b1} - v_{tn})}{c}$$

unk

$$\frac{K v_y}{2(v_{b1} - v_{tn}) - v_y} = e^{-\frac{\beta t (v_{b1} - v_{tn})}{c}}$$

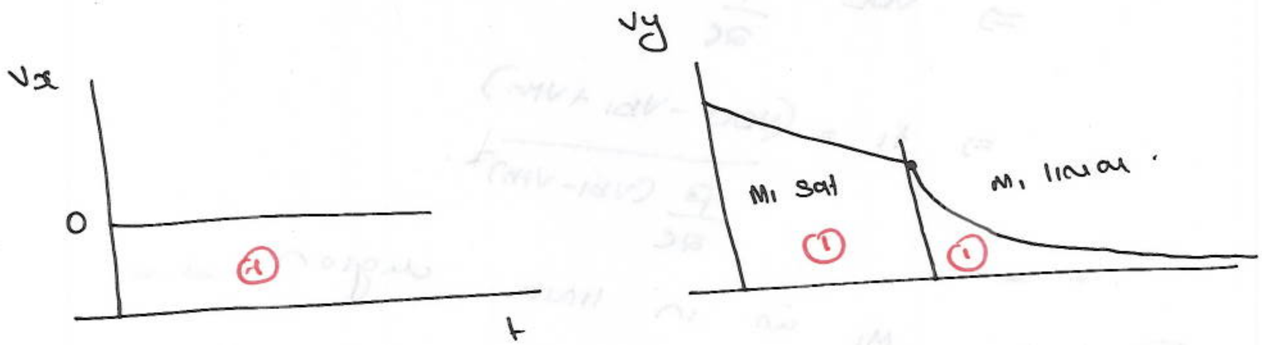
$t = t_1 \quad v_y = v_b - v_{tn}.$

$$\frac{K(v_{b1} - v_{tn})}{v_{b1} - v_{tn}} = e^{-\frac{\beta t_1 (v_{b1} - v_{tn})}{c}}$$

$$\frac{v_y}{2(v_{b1} - v_{tn}) - v_y} = e^{-\frac{\beta (t - t_1)(v_{b1} - v_{tn})}{c}}$$

$$\frac{2(v_{b1} - v_{tn})}{v_y} - 1 = e^{\frac{\beta (t - t_1)(v_{b1} - v_{tn})}{c}}$$

$$v_y = \frac{2(v_{b1} - v_{tn})}{1 + e^{\frac{\beta (t - t_1)(v_{b1} - v_{tn})}{c}}}$$



1 mark for vx.

1 mark for each region

total 3

(a) MOS param

NMOS

$V_{th} = 476.7m$ $\quad \mu_n C_{ox} = 248\ \mu A/V^2$ $\quad g_{ds}@400\mu A = 167\mu S$

PMOS

$|V_{th}| = 488m$ $\quad \mu_n C_{ox} = 102\ \mu A/V^2$ $\quad g_{ds} @ 400\mu A = 153\mu S$

(a) To keep M_4 in saturation

$$V_{b2} = V_{gs4} - V_{th4} + V_{gs3}$$

ignoring body effect.

$$= \sqrt{\frac{2I}{\beta_n}} + V_{thn} + \sqrt{\frac{2I}{\beta_n}}$$

$$= 0.754V$$

(a) 1/2 approximately close & if expression in correct

(b) To keep M_1 in saturation

~~$V_{b1} = V_{sg1} - |V_{thn}| + V_{sg2}$~~

$$V_{b1} = V_{DD} - ((V_{sg1} - |V_{thn}|) + V_{sg2})$$

$$= 3 - |V_{thp}| + 2\sqrt{\frac{2I}{\beta_p}}$$

$$= 2.0781V$$

1/2 approximately close. & if expression in correct.

(b) V_{out} (max) $= V_{DD} - 2\times V_{ODP}$

$$= 2.5662$$

V_{out} min $= 2\times V_{ODn}$

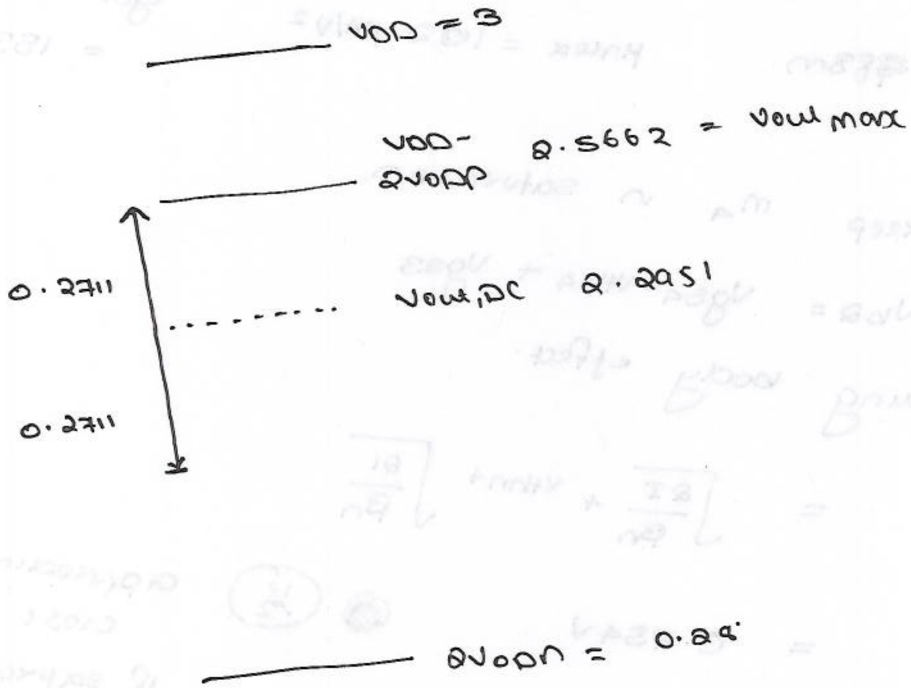
$$= 0.28.$$

V_{out} DC $= V_{DD} - V_{sg1}$

$$= 2.2951$$

So even though the bias points $\{V_{o1}, V_{o2}\}$ are such that it allows $V_{DD} - 4V_{OD}$ swing, the output DC point prevents the swing to

$\pm$ 0.2711V



1

1 .

ⓒ $A \cong g_{m1} * (g_{m2} r_{o2} r_{o1} \| g_{m3} r_{o3} r_{o4})$

$g_{m1} = \sqrt{2\beta_p I} = 3.7mS = g_{m2}$

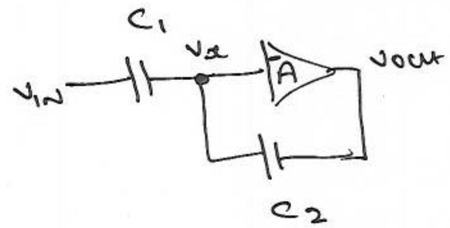
$g_{m3} = \sqrt{\beta_n 2I} = 5.8mS = g_{m4}$

$$A \cong 3.7m * \left[\left(3.7m * \frac{1}{(153H)^2} \right) \| \left(5.8m * \left(\frac{1}{167H} \right)^2 \right). \right]$$

$= 3.7m * (158k \| 208k)$

$= 330.$

Adjustment may be required to keep M_1 & M_4 in saturation due to body effects of M_2 & M_3



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

$$C_1 V_{IN} = V_x (C_1 + C_2) - V_{out} C_2$$

$$= \frac{-V_{out}}{A} (C_1 + C_2) - V_{out} C_2$$

$$\frac{V_{out}}{V_{in}} = \frac{C_1}{C_2 + \frac{C_1 + C_2}{A}}$$

$$\text{is } \frac{C_1}{C_2} = \underline{\underline{2}}.$$

1

d 4 ⇒ a 1 ⇒ Netlist / present SCH

b 2 ⇒ Bias currents & DC gain

A reasonable. {I ±50%}

{A ≥ 50}.

c 1 ⇒ mid Band gain = 2 ± 10%.