EE215A

Midterm Exam

Fall 2014

Time Limit: 1 hour and 50 minutes

Open Book, Open Notes

Calculators are allowed.

Your Name:

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Name of Person to Your Left: ____________________________

Name of Person to Your Right: ____________________________

1.

2.

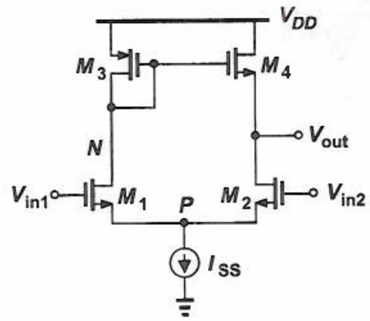
3.

4.

1. In the circuit shown below, an NMOS device has been mistakenly used in the active load. Assume $\lambda = \gamma = 0$. Also, assume that M_1 and M_2 are identical and all transistors are in saturation.

(a) Determine the dc value of the output voltage in terms of the transistor parameters and I_{SS}. 10

(b) Compute the small-signal voltage gain $V_{out}/(V_{in1} - V_{in2})$. 10



(a) $\because$ $\lambda = \gamma = 0$ & all devices are in saturation the tail current will split equally b/w M_1 & M_2

$\Rightarrow I_3 = I_4 = \frac{I_{SS}}{2}$

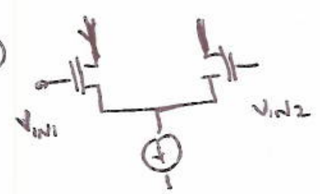
$\Rightarrow V_N = V_{DD} - \left[|V_{thp}| + \sqrt{\frac{2 \cdot I_{SS}/2}{\beta_p}} \right]$ $\quad \beta_p = \mu_n C_{ox} (W/L)_{M3}$

$\beta_n = \mu_p C_{ox} (W/L)_{M4}$

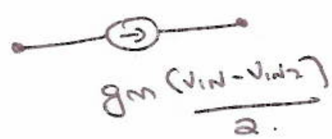
$\Rightarrow V_{out} = V_N - \left[V_{thN} + \sqrt{\frac{2 I_{SS}/2}{\beta_n}} \right]$

$= V_{DD} - |V_{thp}| - V_{thN} - \sqrt{I_{SS}/\beta_p} - \sqrt{I_{SS}/\beta_N}$.

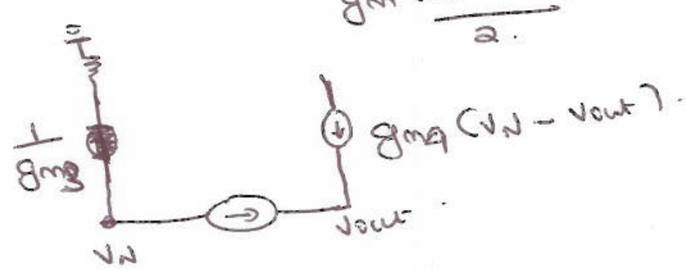
(b)



Norton equivalent $\Rightarrow$



So ckt equivalent $\Rightarrow$



$V_N = -\frac{g_{m1}(V_{IN1} - V_{IN2})}{2} * \frac{1}{g_{m3}}$

$g_{m4}(V_N - V_{out}) + g_{m1}\frac{(V_{IN1} - V_{IN2})}{2} = 0$.

$$g_{m4} V_{out} = -\frac{g_{m4}}{g_{m3}} \cdot \frac{g_{m1}}{2}(V_{IN1} - V_{IN2}) + \frac{g_{m1}}{2}(V_{IN1} - V_{IN2})$$

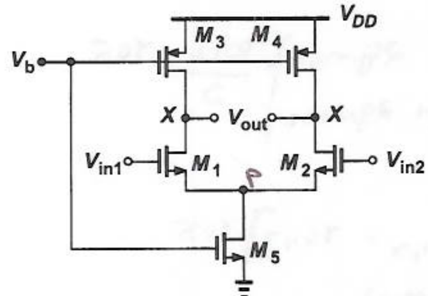
$$= \left(1 - \frac{g_{m4}}{g_{m3}}\right) \cdot \frac{g_{m1}}{2}(V_{IN1} - V_{IN2})$$

$$\frac{V_{out}}{V_{IN1} - V_{I2}} = \cancel{g_{m3}}\ \frac{g_{m1}}{2 g_{m4}} \cdot \left(1 - \frac{g_{m4}}{g_{m3}}\right).$$

2. In the circuit shown below, the gates of the tail and PMOS current sources are mistakenly shorted.

(a) Is it possible to choose V_b, the input CM level, the output CM level, and the tail current such that all transistors are in saturation? Explain in detail why or why not. 10

(b) Assuming all transistors are in saturation, compute the small-signal gain from V_{DD} to the output CM level. You can neglect body effect. 10



$$V_P = V_{INcm} - V_{thN} - \sqrt{\frac{I_5}{\beta_1}}$$

For a given V_b

For M_5 to be in sat-

$$V_P > V_b - V_{thN}$$

$$\Rightarrow V_{INcm} - \sqrt{\frac{I_5}{\beta_1}} > V_b$$

$$\Rightarrow V_{INcm} > V_b + \sqrt{\frac{I_5}{\beta_1}}$$

; $I_5 = I_{M5}$, $\beta_1 = \mu_n C_{ox} (W/L)_{M_{1,2}}$

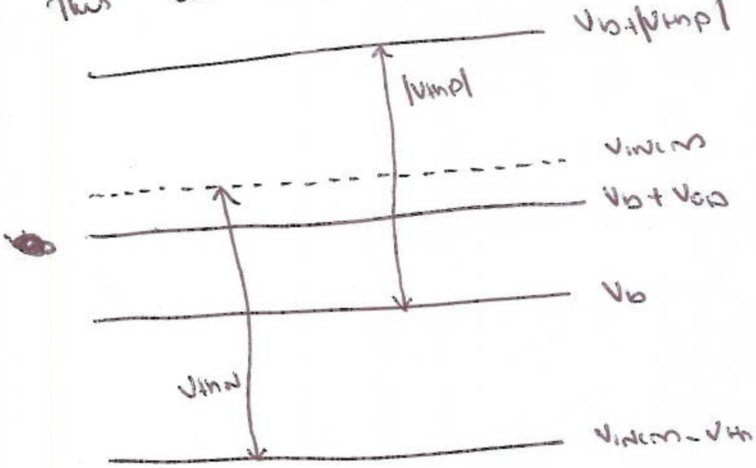
IIly For $M_{1,2}$ to be in saturation

$$V_{outcm} > V_{INcm} - V_{thN}.$$

& For $M_{3,4}$ to be in saturation

$$V_{outcm} < V_b + |V_{thP}|.$$

This is shown below



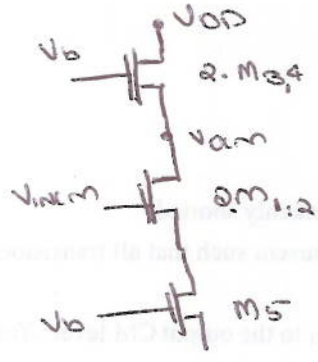
$\Rightarrow$ (a) $V_b + \sqrt{\frac{I_5}{\beta_1}} \le V_{INcm} \le V_b + |V_{thP}| + V_{thN}$

(b) $V_{INcm} - V_{thn} \le V_{outcm} \le V_b + |V_{thP}|$

there exist such a solution.

(c) $V_b > V_{thN}$ & $V_b < V_{DD} - |V_{thP}|$.

(b)



⇐ common mode equivalent

gain is like that of a cascode with load impedance

$$R_D = \frac{r_{o12}}{2} + r_{o5} + \left(2g_{m1,2} + 2g_{mb1,2}\right)\cdot\frac{r_{o12}}{2}\cdot r_{o5}$$

$$= \frac{r_{o12}}{2} + r_{o5} + \left[(g_{m1,2} + g_{mb1,2})\cdot r_{o1,2}\right] r_{o5}$$

⇒ gain from VDD to output common mode

$$= \frac{\left[1 + (g_{m3,4} + g_{mb3,4})(r_{o3,4})\right]\cdot R_D}{\frac{r_{o3,4}}{2} + R_D}$$

3. The circuit shown below is called the "Cherry-Hooper" amplifier. Neglecting channel-length modulation and all other capacitances,

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(a) Determine the low-frequency voltage gain of the circuit.

(b) Without using Miller's theorem, compute the transfer function of the circuit. Verify that it reduces to the result obtained in (a) if $s = 0$.

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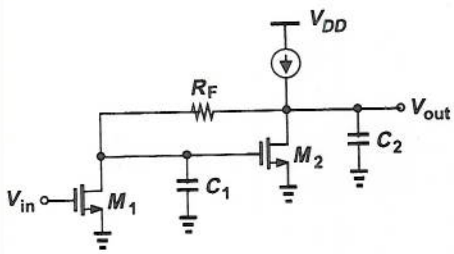
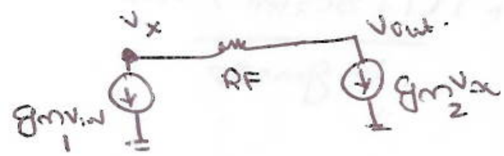


(a) small signal equivalent at low frequency.



$$g_{m1}V_{in} + g_{m2}V_x = 0$$

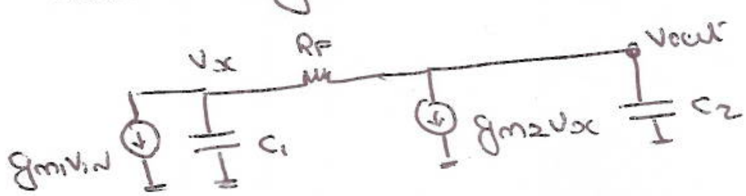
$$V_x = -\frac{g_{m1}V_{in}}{g_{m2}}$$

Also $$\frac{(V_x - V_{out})}{R_F} = g_{m2}V_x.$$

$$V_{out} = V_x(1 - g_{m2}R_F)$$

$$= -\frac{g_{m1}}{g_{m2}}(1 - g_{m2}R_F)V_{in}. \Rightarrow \frac{V_{out}}{V_{in}} = -\frac{g_{m1}(1 - g_{m2}R_F)}{g_{m2}}$$

(b) Small signal model



$$g_{m1}V_{IN} + V_x sC_1 + \frac{(V_x - V_{out})}{R_F} = 0 \qquad — ①$$

$$g_{m2}V_x + V_{out}sC_2 + \frac{(V_{out} - V_x)}{R_F} = 0 \qquad — ②$$

$$② \Rightarrow V_{out}\frac{(1 + sC_2R_F)}{\cancel{R_F}} = V_x\frac{(1 - g_{m2}R_F)}{\cancel{R_F}}.$$

$$\cancel{V_x} = \frac{\cancel{(1 - g_{m2}R_F)V_{out}}}{\cancel{1 + sC_2R_F}}.$$

$$V_x = \frac{V_{out}(1 + sC_2R_F)}{1 - g_{m2}R_F}.$$

$$① \Rightarrow R_F g_{m1}V_{IN} + \frac{(1 + sC_1R_F)(1 + sC_2R_F)V_{out}}{1 - g_{m2}R_F} - V_{out} = 0.$$

$$\cancel{V_{out}} = \cancel{g_{m}V_{IN}R_F}$$

$$R_F g_{m1}V_{IN}(1 - g_{m2}R_F) + V_{out}\left[(1 + sC_1R_F)(1 + sC_2R_F) - (1 - g_{m2}R_F)\right] = 0$$

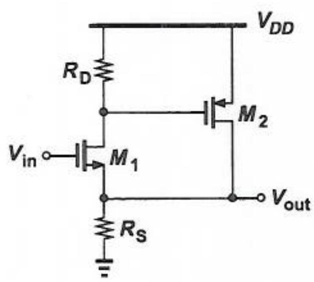
$$\frac{V_{out}}{V_{IN}} = \frac{-g_{m1}R_F(1 - g_{m2}R_F)}{g_{m2}R_F + s(C_1 + C_2)R_F + s^2C_1C_2R_F^2}$$

$s = 0$

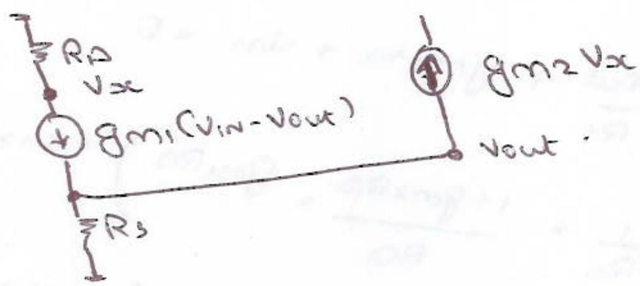
$$\Rightarrow \frac{V_{out}}{V_{IN}} = -\frac{g_{m1}(1 - g_{m2}R_F)}{g_{m2}} = \text{Solution A part a.}$$

4. Consider the circuit shown below. Assume channel-length modulation and body effect are negligible. Also, neglect the noise contributed by the resistors.
(a) Determine the voltage gain. 8
(b) Compute the total output noise voltage. 5+5
(c) Determine the input-referred noise voltage. 2

$\lambda = 0 \quad \gamma = 0$



(a) small signal equivalent:



$$\frac{V_x}{R_D} + g_{m2}V_x + \frac{V_{out}}{R_S} = 0$$

$$\Rightarrow V_x\frac{(1+g_{m2}R_D)}{R_D} + \frac{V_{out}}{R_S} = 0$$

$$\Rightarrow V_x = -V_{out}\cdot\frac{R_D}{R_S}\cdot\frac{1}{1+g_{m2}R_D}$$

Also

$$g_{m1}(V_{IN}-V_{out}) = -\frac{V_x}{R_D} = \frac{V_{out}}{R_S(1+g_{m2}R_D)}$$

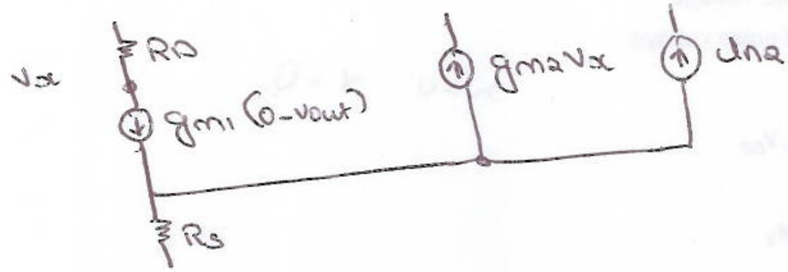
$$g_{m1}V_{IN} = \left[g_{m1} + \frac{1}{R_S + g_{m2}R_DR_S}\right]V_{out}$$

$$\frac{V_{out}}{V_{IN}} = \frac{g_{m1}R_S + g_{m1}g_{m2}R_DR_S}{1 + g_{m1}R_S + g_{m1}g_{m2}R_DR_S}$$

(b) Noise due to M_1 at output

$$\overline{V_{nout1}^2} = \frac{4KT\gamma}{g_{m1}} \cdot \left[\frac{g_{m1}R_S + g_{m1}g_{m2}R_SR_D}{1 + g_{m1}R_S + g_{m1}g_{m2}R_SR_D} \right]^2$$

Noise due to M_2 at output



$$g_{m1}(0 - V_{out}) + \frac{V_x}{R_D} = 0$$

$$V_x = g_{m1}R_DV_{out}$$

Also

$$\frac{V_x}{R_D} + \frac{V_{out}}{R_S} + g_{m2}V_x + i_{n2} = 0$$

$$V_{out}\left(\frac{1}{R_S} + \frac{1 + g_{m2}R_D}{R_D} \cdot g_{m1}R_D\right) + i_{n2} = 0$$

$$V_{out}\left(\frac{1}{R_S} + g_{m1}(1 + g_{m2}R_D)\right) + i_{n2} = 0$$

$$V_{out} = \frac{i_{n2}R_S}{1 + g_{m1}R_S + g_{m1}g_{m2}R_SR_D}$$

$$\overline{V_{nout2}^2} = 4KT\gamma g_{m2} \frac{R_S^2}{(1 + g_{m1}R_S + g_{m1}g_{m2}R_SR_D)^2}$$

Total Nois $= \overline{V_{nout2}^2} + \overline{V_{nout1}^2}$

(c) I/P referred Noise $= \dfrac{4KT\gamma}{g_{m1}} + 4KT\gamma g_{m2} \dfrac{R_S^2}{(g_{m1}R_S + g_{m1}R_Sg_{m2}R_D)^2}$

$$= \frac{4KT\gamma}{g_{m1}} + 4KT\gamma \frac{g_{m2}}{g_{m1}^2} \cdot \frac{1}{(1 + g_{m2}R_D)^2}$$