Name: ______________________________

SID: ______________________________

Name of student at your left:
____________________________ (1 point)

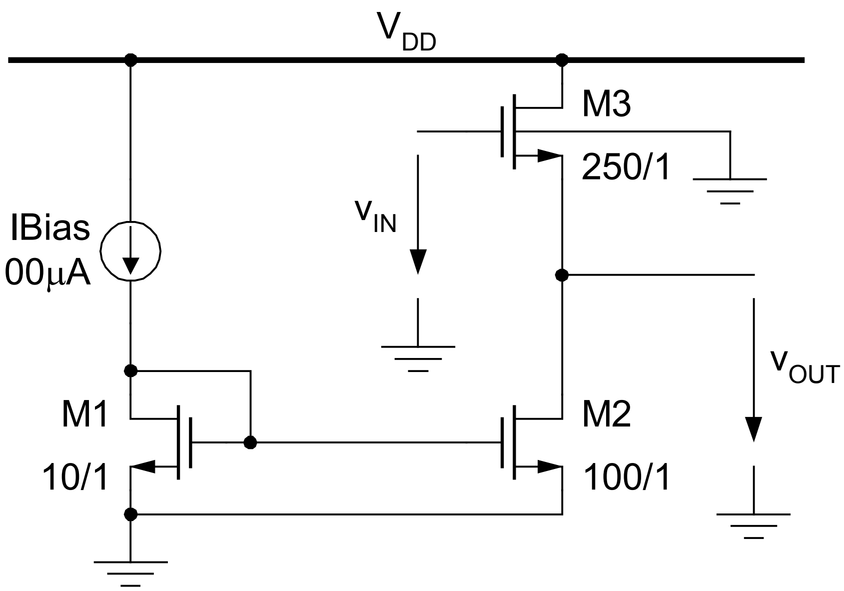
Name of student at your right:
____________________________ (1 point)

UNIVERSITY OF CALIFORNIA
College of Engineering
Department of Electrical Engineering
and Computer Sciences

	Midterm 2	**EECS 105**
B. E. BOSER	**October 26, 2004**	**FALL 2004**

- *Closed book, closed notes.*
- *No calculators.*
- *Copy your answers into marked boxes on exam sheets.*
- *Simplify numerical and algebraic results as much as possible.*
  Up to 5 points penalty for results that are not reasonably simplified.
- *Mark your name and SID at the top of the exam and all extra sheets.*
- *Be kind to the graders and write legibly. No credit for illegible results.*

Problem 1 [25 points]



Given: $\mu_n C_{ox} = 200\mu A/V^2$, $V_{TN}=1V$, $\lambda_n=0.01V^{-1}$ @ $L=1\mu m$
$g_m r_o >> 1$
The circuit is biased such that all transistors are in saturation.

a) [10 points] Find *numerical* values (not expressions) for:

I_{D3} = **1000**	µA

g_{m3} = **10000**	µS

$$I_{DS3} = I_{DS2} = \frac{(\frac{W}{L})_2}{(\frac{W}{L})_1} \cdot I_{DS1} = \frac{(\frac{100}{1})}{(\frac{10}{1})} \cdot 100\mu A = 1000\mu A$$

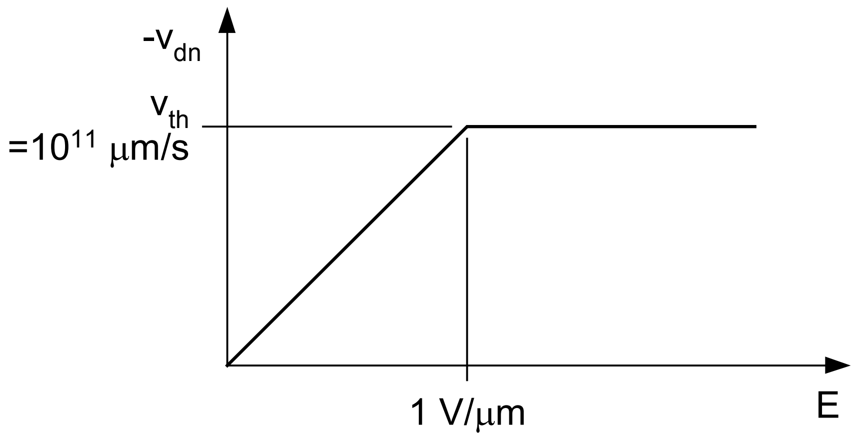
$$g_{m3} \approx \sqrt{\mu_n C_{ox} \cdot (\frac{W}{L})_3 \cdot 2 \cdot I_{DS3}} = \sqrt{(200\,{}^{\mu A}\!/_{V^2}) \cdot (\frac{250}{1}) \cdot 2 \cdot 1000\mu A} = 10mS = 10000\mu S$$

b) [15 points] Find an *algebraic* expression for the small signal output resistance (at terminal v_{OUT}) of the circuit as a function of transistor small-signal parameters. Use $g_m r_o >> 1$ to simplify your result as much as possible:

r_{out} = **$1/(g_{m3} + g_{mb3})$**

$$r_{out} = r_{o2} \ // \ \frac{r_{o3}}{1+(g_{m3}+g_{mb3})\cdot r_{o3}} \approx r_{o2} \ // \ \frac{1}{(g_{m3}+g_{mb3})} \approx \frac{1}{(g_{m3}+g_{mb3})}$$

Problem 2 [25 points]



The above sketch shows a rough approximation of the electron drift velocity versus the electrical field in Silicon. For an NMOS transistor with L=0.1μm, W=10μm, and C_{ox}=5fF/μm^2 calculate the following:

a) [10 points] What is the minimum V_{DS} (*numerical* value) for which current flow is limited by the thermal carrier drift velocity? Assume that the field in the channel is uniform.

V_{DS} = **0.1**	V

$$E_{critical} = \frac{1V}{1\mu m} = \frac{V_{DS}}{L} = \frac{V_{DS}}{0.1\mu m} \Rightarrow V_{DS} = 0.1V$$

b) [15 points] Find the *numerical* value of the maximum drain current I_D for $V_{GS}-V_{TH}=1V$. Hint: get the current from the channel charge and its velocity.

I_D = **4.75**	mA

$$Average\ \ channel\ \ charge = \frac{(Charge@source) + (Charge@drain)}{2}$$

$$= \frac{C_{ox}\cdot W\cdot L\cdot[(V_{GS}-V_{TH})+(V_{GD}-V_{TH})]}{2} = \frac{C_{ox}\cdot W\cdot L\cdot[(V_{GS}-V_{TH})+(V_{GS}-V_{DS}-V_{TH})]}{2}$$

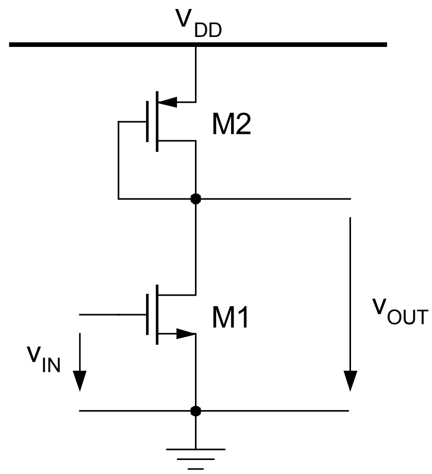
$$= \frac{5\, {fF}/{\mu m^2}\cdot 10\mu m\cdot 0.1\mu m\cdot[1V+0.9V]}{2} = 4.75 fC$$

$$\therefore Average\ \ channel\ \ charge\ \ per\ \ unit\ \ length = \frac{Average\ \ channel\ \ charge}{L} = 47.5\, {fC}/{\mu m}$$

$$I_D = (Average\ \ channel\ \ charge\ \ per\ \ unit\ \ length)\cdot(velocity)$$

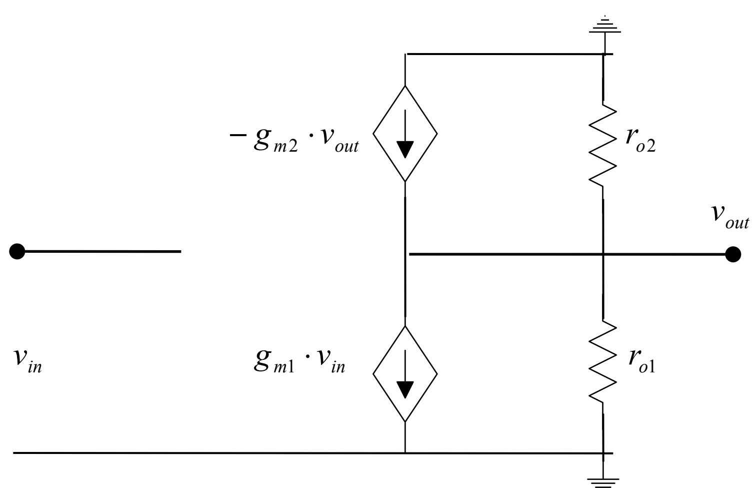
$$\therefore I_D = 47.5\, {fC}/{\mu m}\cdot 10^{11}\, {\mu m}/{s} = 4.75 mA$$

Problem 3 [25 points]



The circuit shown above is biased so that all transistors are in saturation. Draw a small signal model (label all elements with appropriate symbols, e.g. g_{m1}, r_{o2}) and find an *algebraic* expression for the small-signal voltage gain $a_v=v_{out}/v_{in}$ as a function of small-signal parameters (g_m's and r_o's). Use $g_m r_o >> 1$ to simplify your result.

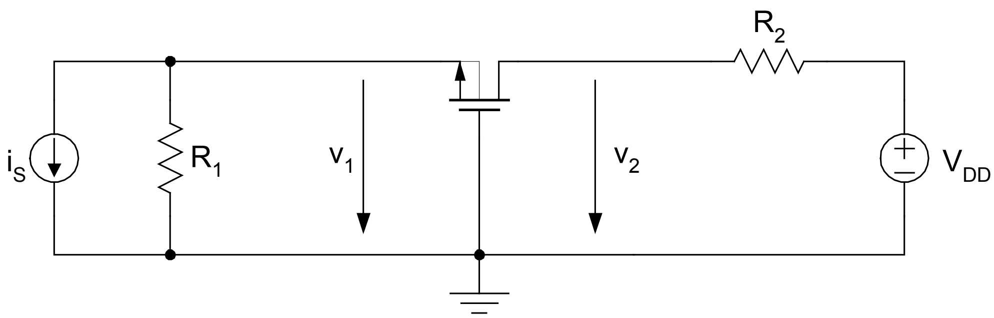
Small-signal model (neatness counts) [13 points]:



$$a_v = -\mathbf{g_{m1}/g_{m2}}$$

$$a_v = -g_{m1} \cdot (r_{o1} \ // \ r_{o2} \ // \ \frac{1}{g_{m2}}) \approx \frac{-g_{m1}}{g_{m2}}$$

Problem 4 [23 points]



The circuit shown above is biased so that the transistor is in saturation.

a) [8 points] What is the type of this amplifier?

Common **Gate**

b) [15 points] Find an *algebraic* expression for the small-signal voltage ratio v_2/v_1 for $i_s=0$ as a function of R_1, R_2, and transistor small-signal parameters.
Hint: you may find small-signal model very helpful to answer this question.

$$v_2/v_1 = \frac{(1+g_m r_o)}{r_o + R_2} \cdot R_2$$