EECS 105 – Microelectronic Devices and Circuits

Spring 2001, **Prof. A. R. Neureuther**
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First Midterm Exam, February 23, 2001 (53 Minutes)

Print Your Name:_____Solutions (see the following pages)

Sign Your Name:_________________________

Use the following parameters for MOS devices.

$$I_{Dn} = \left(\frac{W}{L}\right)_p m_n C_{OXp}\left[V_{GS} - V_{Tn} - (V_{DS}/2)\right](1 + l_n V_{DS})V_{DS}$$

$$I_{Dn} = \frac{1}{2}\left(\frac{W}{L}\right)_n m_n C_{OXn}(V_{GS} - V_{Tn})^2(1 + l_n V_{DS})$$

$$-I_{Dp} = \left(\frac{W}{L}\right)_p m_p C_{OXp}\left[V_{SG} + V_{Tp} - (V_{SD}/2)\right](1 + l_p V_{SD})V_{SD}$$

$$-I_{Dp} = \frac{1}{2}\left(\frac{W}{L}\right)_p m_p C_{OXp}(V_{SG} + V_{Tp})^2(1 + l_p V_{SD})$$

NMOS	PMOS
ì $_n$C$_{ox}$=50ì A/V^2	ì $_p$C$_{ox}$=25ì A/V^2
V_{T0n}=1.0V	V_{T0p}=-1.0V
γ_n=0.6V$^{1/2}$	γ_p=0.6V$^{1/2}$
ë$_n$=(0.1/L)V^{-1} L in ì m	ë$_p$=(0.1/L)V^{-1} L in ì m
ϕ_p=-0.42	ϕ_n=0.42

Assume L = 2 μm

Here are a few fundamental constants and room temperature values.

$e_o = 8.85x10^{-14} F/cm$ $e_{r,ox} = 3.9$ $e_{r,si} = 11.7$

$V_{th} = 0.026eV$ $n_i^2 = 2x10^{20}$ $K = 1.38x10^{-23} J/K$

$q = 1.6x10^{-19} C$

mobility	10^{15}	10^{16}	10^{17}	units
μ_n	1400	1200	750	cm^2 / V-s
μ_p	500	400	350	cm^2 / V-s

Problem	Possible	Score
I	20	
II	30	
III	20	
IV	30	
Total	100	

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Version 2/25/01

I. (20 Points) Threshold Voltage

An NMOS process produces a device with a threshold voltage V_{Tn} = 1V and ϕ_p = - 0.42. Complete the table below that describes the percentage change in the electrical properties listed that is produced by the change shown in the columns for the oxide thickness and doping. You must briefly explain your listed percentages with footnotes 1-6 as indicated.

Electrical Parameter	**Oxide thickness t_{OX}**	**Substrate doping Na**
	doubles	**doubles**
$2\phi_p$	1 0%	4 +4.3%
C_{OX}	2 -50%	5 0%
$Q_{B,MAX}/ C_{OX}$	3 +100%	6 +44%

1) No effect

2) C_{OX} is inverse with t_{OX}

3) C_{OX} decreases causes inverse Q/ C_{OX} increase

4) (2) 26mV ln(2) = 36mV or 4.3% of 840 mv

5) No effect

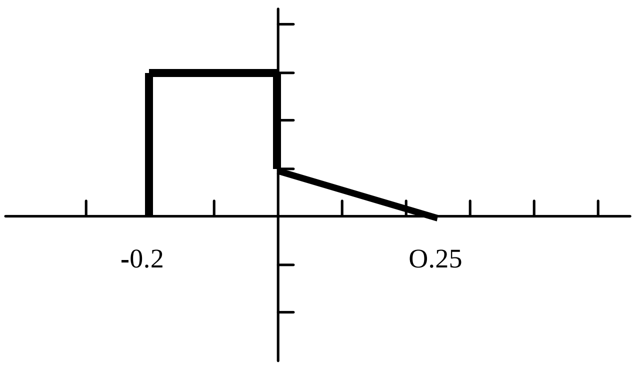
6) Sqrt((2 * (1.043)) = 1.44 or 44%

II. (30 Points) Electrostatic and Mobile Carrier Analysis

An NMOS device is made in a p-type substrate doped $N_a = 10^{+16}$ and an oxide thickness of 0.2 µm. A region 0.25 µm deep under the gate is depleted.

a) (15 Points) Sketch the electric field versus position from the gate electrode. Give the quantitative value of the maximum electric field.

$$E_{MAX} = \frac{qN_a x_d}{e_{OX}} = \frac{1.6x10^{-19} \cdot 1x10^{16} \cdot 0.25x10^{-4}}{3.9 \cdot 8.85x10^{-14}} = 1.16x10^5 V/cm$$



b) (15 Points) Find the local potential and the density of mobile electrons at the silicon-oxide interface.

$$f(x) = A(x - x_p)^2$$

$$E(x) = -\frac{\partial f}{\partial x} = 2A(x - x_p)$$

$$E_{x=0} = 2Ax_p$$

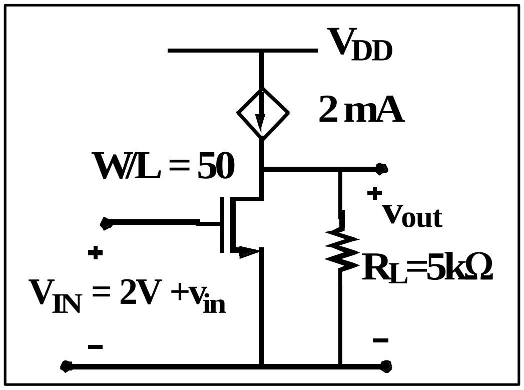
$$f(x) = \frac{E_{x=0}}{2x_p}(x - x_p)^2$$

$$f(0) = \frac{E_{x=0}x_p}{2} = \frac{1.16x10^5 \cdot 10^{16}}{(11.7/3.9) \cdot 2} = 483mV$$

$$n(0) = \frac{2x10^{20}}{10^{16}} \exp\left(\frac{483}{26}\right) = 2x10^4 \cdot 1.16x10^8 = 2.3x10^{12}$$

III. (20 Points) MOS Circuits

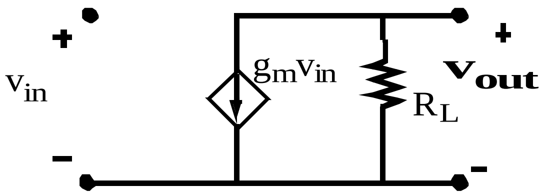
a) (10 Points) Assuming the device is in saturation and $\lambda_n = 0$, find the large-signal quantity V_{OUT}.



$$I_D = 0.5 \cdot 50 \cdot 50 \cdot (2-1)^2 = 1.25mA$$

$$V_{OUT} = (2MA - 1.25mA) \cdot 5k\Omega = 3.75V$$

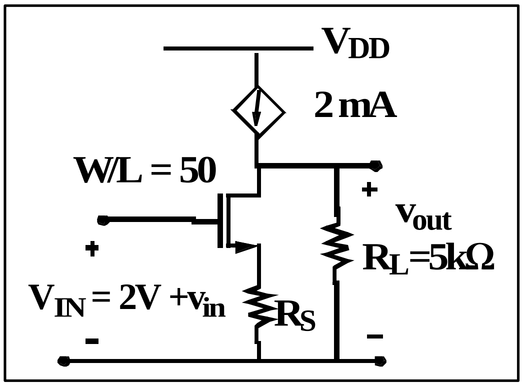
b) (10 Points) Find the small-signal gain v_{OUT}/v_{IN} for the circuit in part a) when $\lambda_n = 0$.



$$g_m = 50 \cdot 50 \cdot (2-1) = 2.5mS$$

$$V_{OUT} = -g_m R_L = -2.5mS \cdot 5k\Omega = -12.5$$

IV. (30 Points) Advanced MOS Circuits



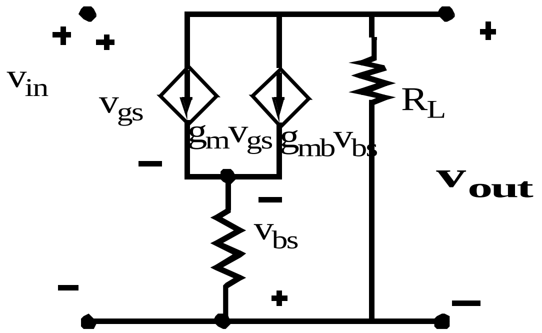
a) (7 Points) A resistor R_S is inserted as shown and has a value such that $V_S = 0.5V$. Find the large-signal quantity V_{OUT} when $\lambda_n = 0$.

$$V_T = 1 + 0.6\left(\sqrt{0.5 + 0.84} - \sqrt{0.84}\right) = 1.145V$$

$$I_D = 0.5 \cdot 50 \cdot 50 \cdot (2 - 0.5 - 1.145)^2 = 0.158mA$$

$$V_{OUT} = (2mA - 0.158mA) \cdot 5k\Omega = 9.21V$$

b) (14 Points) Draw the small-signal equivalent circuit of the circuit in part a) and give quantitative values for each element in the circuit when $\lambda_n = 0$.



$$g_m = 50 \cdot 50(2 - 0.5 - 1.145) = 0.89mS$$

$$g_{mb} = \frac{0.6 \cdot 0.89mS}{2 \cdot \sqrt{0.84 + 0.5}} = 0.23mS$$

$$R_S = \frac{0.5V}{0.158\,mA} = 3.16\,K\Omega$$

c) (9 Points) Write a sufficient set of equations to determine the small-signal gain v_{OUT}/v_{IN} when $\lambda_n = 0$. Solve for the gain if you have completed all other questions on this exam.

$$V_{in} = V_{gs} - V_{bs}$$

$$g_m v_{gs} + g_{mb} v_{bs} + \frac{v_{bs}}{R_s} = 0$$

$$V_{OUT} = -\left(g_m v_{gs} + g_{bs} v_{bs}\right) R_L$$

$$\frac{V_{OUT}}{Vin} = \frac{-(R_L / R_S)}{\left(1 + \frac{g_{mb}}{g_m} + \frac{1}{g_m R_S}\right)}$$

Use the second equation to find v_{gs} in terms of v_{bs} and then substitutes in the first equation to get v_{bs} in terms of v_{in}. Now go backwards and get v_{gs} and then substitute both into the third equation.