University of California at Berkeley
College of Engineering
Dept. of Electrical Engineering and Computer Sciences

EE 105 Midterm 2

Spring 2006 Prof. Ming C. Wu April 6, 2006

Guidelines

- Closed book and notes.
- Two pages of information sheets allowed.
- Total time = 90 minutes

(1) For the circuit shown in Fig. 1, W/L = 2 for both M_1 and M_2, $\mu_n C_{ox}$ = 100 μA/V^2, λ = 0.05 V^{-1}, V_{Tn} = 1V, V_{DD} = 5V.

a) [5 pt] Find the DC drain current at M_2 when V_{OUT} = 3V. Use λ = 0 for this part.
b) [5 pt] Find the DC gate bias (V_G) of M_2 such that the DC output voltage V_{OUT} = 3V. Use λ = 0 for this part.
c) [5 pt] Draw the small-signal equivalent circuit. Find the values of all circuit elements in the small signal circuit (e.g., g_m, r_0, …).
d) [5 pt] Find the voltage gain, $A_V = v_{out}/v_s$.
e) [5 pt] Find the output resistance of the circuit (both expression and numeric value).
f) [5 pt] Find the input resistance, and construct the two-port model of this voltage amplifier.

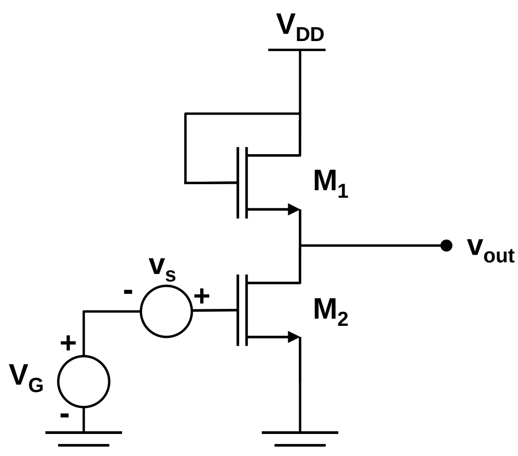

Fig. 1

(2) Consider the following circuit with $(W/L)_1 = 2$, $(W/L)_2 = 1$, $\mu_p C_{ox}$ = 50 μA/V^2, $\mu_n C_{ox}$ = 100 μA/V^2, $\lambda_n = \lambda_p$ = 0.05 V^{-1}, V_{Tn} = 1V and V_{Tp} = -1V, V_{DD} = 5V :

a) [10 pt] The gate is biased at 2.5V DC. Show that both transistors are in saturation regime. Find the expression and numeric value of small-signal voltage gain, $A_V = v_{out}/v_s$
b) [10 pt] Find the maximum and the minimum voltage at the output of this circuit when both transistors stay in saturation regime.

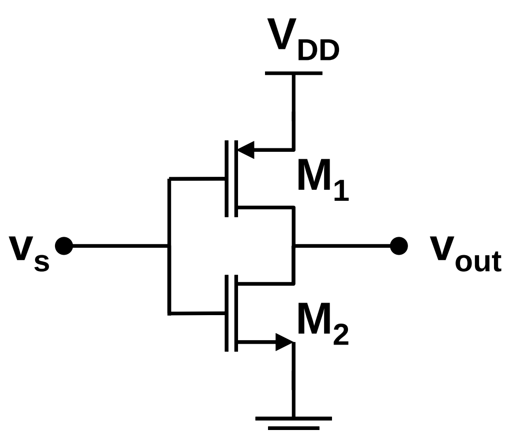

Fig. 2

(3) Consider the following circuit with 3 PMOS transistors: $(W/L)_1 = 10$, $(W/L)_2 = 20$, $(W/L)_3 = 100$, $\mu_p C_{ox} = 50\ \mu A/V^2$, $\lambda = 0.05\ V^{-1}$, $V_{Tp} = -1$ V, $I_{REF} = 10\ \mu A$, $V_+ = 3$ V, $V_- = -3$V, $R_L = 100$ KΩ.

a) [5 pt] Can you identify any functional block in this circuit (i.e., any portion of the circuit that performs a known function)? Replace that functional block, and draw a simplified circuit of the amplifier.

b) [10 pt] Find the expression of the voltage gain, $A_V = v_{out} / v_s$, and then find its numerical value.

c) [10 pt] Find both the expression and the numeric value of the output resistance of the amplifier.

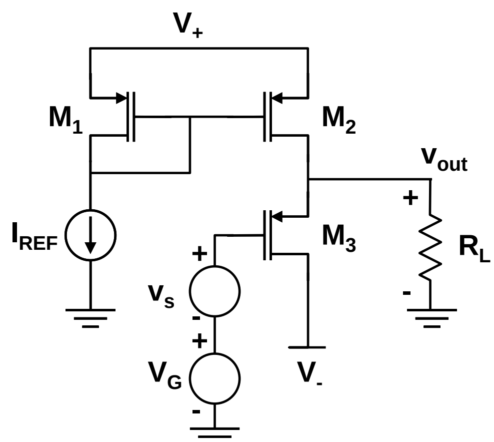

Fig. 3

(4) The frequency response of an amplifier is shown in the figure below.

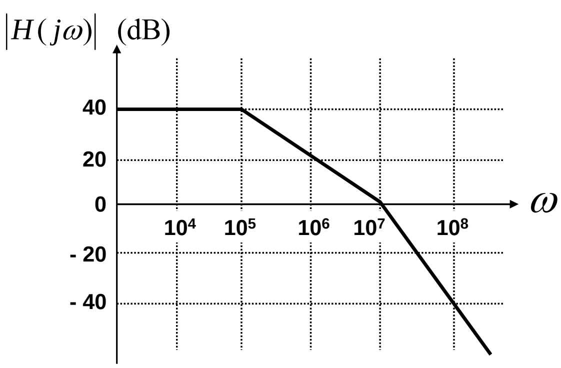

Fig. 4A

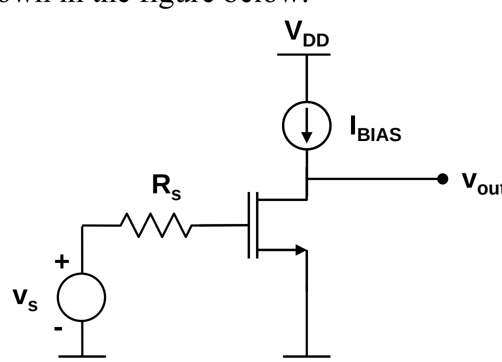

Fig. 4B

a) [8 pt] Find the transfer function of the frequency response shown in Fig. 4A.

b) [7 pt] This transfer function can be realized by the circuit in Fig. 4B. Draw the small-signal circuit that includes C_{gd}. For simplicity, we will neglect C_{gs}. Analysis of this circuit can be simplified by Miller approximation. Draw the simplified small-signal equivalent circuit. Show the Miller capacitances explicitly in terms of other circuit parameters.

c) [10 pt] The following parameters of the circuit are given:
$I_{BIAS} = 10\ \mu A$, $\lambda = 0.1\ V^{-1}$, $r_{oc} = \infty$ (ideal current source).
If the frequency response of the amplifier matches the transfer function shown in Fig. 4A, find the numeric values of the transistor parameters: C_{gd}, r_0, g_m, and the circuit parameter, R_s.

Some equations

Threshold voltage (NMOS)

$$V_{Tn} = V_{FB} - 2\phi_p + \frac{1}{C_{ox}}\sqrt{2q\varepsilon_s N_a\left(-2\phi_p\right)} \qquad \phi_p = -\frac{kT}{q}\ln\frac{N_a}{n_i}$$

$$V_{Tn} = V_{Tn0} + \gamma\left(\sqrt{V_{SB} - 2\phi_p} - \sqrt{-2\phi_p}\right)$$

NMOS equations:

$$I_D = 0, \quad V_{GS} < V_{Tn}$$

$$i_D = \frac{W}{L}\mu C_{ox}\left(v_{GS} - V_{Tn} - \frac{v_{DS}}{2}\right)v_{DS}\left(1+\lambda V_{DS}\right), \quad V_{GS} > V_{Tn},\, V_{DS} < V_{GS} - V_{Tn}$$

$$i_D = \frac{W}{L}\frac{\mu C_{ox}}{2}\left(v_{GS} - V_{Tn}\right)^2\left(1+\lambda V_{DS}\right), \quad V_{GS} > V_{Tn},\, V_{DS} > V_{GS} - V_{Tn}$$

MOS capacitances in saturation $C_{gs} = (2/3)WLC_{ox} + C_{ov}$ $\quad C_{ov} = L_D W C_{ox}$

MOS signal parameters:

$$g_m = \left.\frac{\partial i_D}{\partial v_{GS}}\right|_{V_{GS},V_{DS}} = \mu C_{ox}\frac{W}{L}\left(V_{GS} - V_{Tn}\right)\left(1+\lambda V_{DS}\right)$$

$$\approx \mu C_{ox}\frac{W}{L}\left(V_{GS} - V_{Tn}\right)$$

$$= \sqrt{2 i_D\left(\frac{W}{L}\right)\mu C_{ox}}$$

$$r_o = \left(\left.\frac{\partial i_D}{\partial v_{DS}}\right|_{V_{GS},V_{DS}}\right)^{-1} \approx \frac{1}{\lambda I_{DS}}$$

$$g_{mb} = \left.\frac{\partial i_D}{\partial v_{BS}}\right|_Q = \frac{\gamma g_m}{2\sqrt{-V_{BS} - 2\phi_p}}$$