

### PROBLEM SET 4

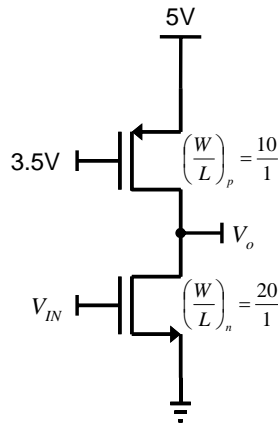
Issued: Tuesday, March 20, 2007

Due (at the beginning of class): Tuesday, March 27, 2007

1. Show that the output resistance of a MOSFET in saturation, when  $(V_D - V_{Dsat})/l \gg E_{sat}$ , is approximately given by:

$$r_o = \frac{\partial V_D}{\partial I_D} = \left( L_{eff} + \frac{V'_G}{E_{sat}} \right) \frac{E_m}{I_{Dsat}}$$

2. A simple single-stage CMOS analog amplifier is shown below. For the devices,  $V_{th}=700\text{mV}$  and  $V_{tp}=-700\text{mV}$ . Assume that the  $(W/L)$  ratios are effective values, post-fabrication, and that this is an n+ gate technology.
- Estimate the DC input bias voltage  $V_{IN}$  necessary to establish a DC output voltage,  $V_o$ , of 2.5V. [Hint: The  $V_D$  dependence is in  $\Delta L$ .]
  - Calculate the small-signal gain of the amplifier at the bias point of part (a). Use the expression in problem 1 above for the device output resistance.



3. The ratio  $(I_{sub}/I_D)$  at hot-carrier induced breakdown usually falls within the range of 0.05 to 0.2. For this problem, assume that it is equal to 0.05 and is device independent. A  $1\mu\text{m}$  CMOS technology has the following device and process parameters:  $t_{ox}=20\text{nm}$ ,  $x_j=0.3\mu\text{m}$ ,  $\alpha=0$ ,  $V_{th}=700\text{mV}$ .
- Derive an expression for the hot-carrier induced breakdown voltage,  $V_{BD}$ , of the nMOS devices as a function of  $L_{eff}$  and  $V_G'$ .
  - Plot (or sketch)  $\log(V_{BD})$  as a function of  $\log(L_{eff})$  for  $L_{eff}=0.1\mu\text{m}$  to  $100\mu\text{m}$  for  $V_G'=2\text{V}$ .
4. Use the following parameters for an nMOSFET:  $t_{ox}=20\text{nm}$ ,  $x_j=0.3\mu\text{m}$ ,  $\alpha=0$ ,  $V_{th}=700\text{mV}$ ,  $L_{eff}=1\mu\text{m}$ . Based on device degradation results, it is recommended that this nMOS device should not be operated with  $E_m > 2 \times 10^5 \text{V/cm}$ .
- What is the ratio of  $I_{sub}/I_D$  at this value of  $E_m$ ? Determine the recommended maximum supply voltage  $V_{DD}$ . Assume  $V_G=3\text{V}$  and that this value of  $V_G$  produces the maximum  $I_{sub}$ .
  - What is the breakdown voltage of the device with  $V_G=3\text{V}$ , assuming that the device breaks down at  $E_m=4 \times 10^5 \text{V/cm}$ ?