UNIVERSITY OF CALIFORNIA AT BERKELEY
College of Engineering
Dept. of Electrical Engineering and Computer Sciences

EECS 40 **Spring 2004**

Homework Assignment #9
Issued: 3/25/04 Due: 2pm in 240 Cory on Friday, 4/2/04
Be sure to put your **Discussion Section** on your paper.

Problem 1: MOSFET subthreshold leakage

For a MOSFET operating in the subthreshold regime ($V_{GS} < V_T$), the reduction in gate voltage needed to reduce the drain current by one decade is defined as the "subthreshold swing":

$$\boldsymbol{S = n(kT/q)(\ln 10)}$$

The units of S are mV/decade. A small value of S is desirable, because it allows a low OFF current (I_{DS} at V_{GS} = 0 V) to be achieved with a low threshold voltage (desirable for high ON current I_{DSAT}). Note that the smallest value of S attainable at room temperature (300K) is 60 mV/decade.

Consider an n-channel MOSFET for which the factor $n = 1.5$. The threshold voltage for this device is defined to V_{GS} at which the normalized drain current $I_D/(W/L)$ reaches 100 nA, with V_{DS} = 100 mV.

- **a)** Find S
- **b)** Suppose the leakage current must be less than 100 pA when V_{GS} = 0 V and V_{DS} = 100 mV, for $W = L$. What is the minimum threshold voltage this device can have?
- **c)** For ultralow-power technology (such as that used for memory chips used in portable electronic devices, *e.g.* cell phones) the leakage current requirement is much more stringent, typically less than 0.1 pA. Qualitatively, how would the transistor drive current (I_{DSAT}) for such a technology compare with that of the technology described in part (b)?

Problem 2: The MOSFET as a resistive switch

For digital circuit applications, the MOSFET can be modeled simply as a resistor in the ON state ($V_{GS} = V_{DD}$, the power-supply voltage). Its equivalent resistance in the ON state is

$$R_{eq} \cong \frac{3}{4}\frac{V_{DD}}{I_{DSAT}}\left(1 - \frac{5}{6}\lambda V_{DD}\right)$$

where I_{DSAT} is the drain saturation current and λ is the channel-length modulation parameter.

- **a)** Consider a long n-channel MOSFET (refer to Eq. 3.29 on p. 93 of the Rabaey et al text for the appropriate I_{DSAT} equation) of dimensions W = 100 μm and L = 10 μm, for which k_n'=100 μA/V^2, V_T = 0.7 V, and $\lambda = 0$. Calculate its equivalent resistance in the ON state, for V_{DD} = 2.5 V.
- **b)** In general, a lower ON-state resistance (R_{eq}) is desirable for achieving faster circuit speed (*i.e.* lower propagation delay). Describe at least two approaches to lowering R_{eq}.
- **c)** Consider a very-short n-channel MOSFET (refer to Eq. 3.38 on p. 97 of the Rabaey et al text for the appropriate I_{DSAT} equation) of dimensions W = 1 μm and L = 0.1 μm, for which C_{ox} = 2 μF/cm^2, V_T = 0.4 V, and λ = 0.1. Calculate its equivalent resistance in the ON state, for V_{DD} = 1 V. Assume that the saturation velocity $v_{sat} = 10^7$ cm/s, and that the electron mobility μ_n = 300 cm^2/Vs.

<u>Problem 3</u>: Hambley text prob. 12.14. For each of the three values of V_{DD} , draw the appropriate small signal model, and estimate the voltage gain $A_v = v_{out}/v_{in}$ for the operating point. Here, the output voltage is the drain voltage.