**ELE339, Electronics I Laboratory**

**LAB 9 - MOS Transistor Modeling**

# Introduction

**Objective:**
In this lab, we investigate an n-channel enhancement mode MOS transistor. This device, and its complement, the p-channel enhancement mode MOS transistor, represent the work horses of today's semiconductor industry. Thanks to the comparatively simple geometry, the channel length of a state-of-the-art MOS transistor can be as short as 40nm. These ultra short channel length devices support switching frequencies in the GHz range.

**Device Characteristics**
Figure 1 shows the cross section, the top view and the symbol used for an n-channel MOS transistor.

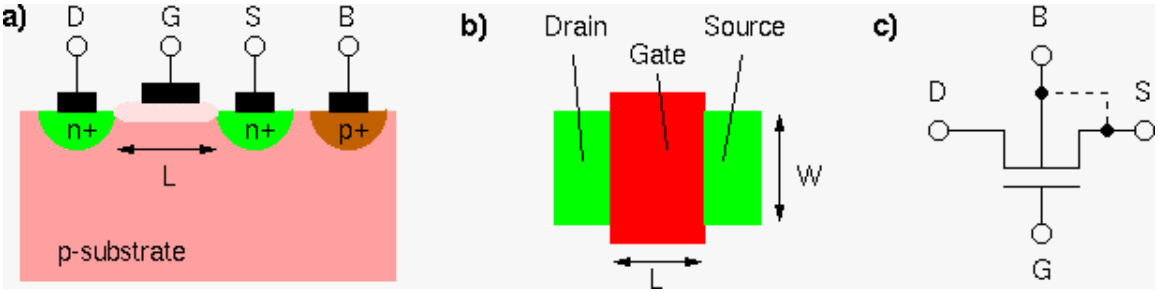


Figure1: a) Cross section, b) top view and c) symbol on an enhancement mode n-channel MOS transistor.

If we apply a minimum positive voltage (*threshold voltage*) between the gate and the body B of the transistor, we create a thin sheet of electrons at the very surface of the semiconductor underneath the gate. This *inversion layer* forms a *resistive* connection between the drain and the source contacts and thus acts similar to a resistor. As long as the drain voltage remains small, we can approximate the drain-source current to drain-source voltage characteristic by the following equation

$$I_{D_{triode}} = \mu C_{ox} \frac{W}{L}[(V_{GS} - V_{th})V_{DS} - \frac{1}{2}V_{DS}{}^{2}] \qquad (1)$$

where W and L are the channel width and length, respectively, μ the carrier mobility and $C_{ox}=\varepsilon_{ox}/t_{ox}$ the oxide capacitance. This operating mode of the device is referred to as *ohmic* or *triode* operation. If we continue to increase the drain potential, we progressively reduce the inversion layer on the drain side until we end up with a small region, which features no mobile charge carriers at all (*depletion region*). If the drain potential is further increased beyond this *saturation voltage*, the drain-source current remains approximately constant (*saturated*). The corresponding device equation for this region is

$$I_{D_{sat}} = \frac{1}{2}\mu C_{ox}\frac{W}{L}[V_{GS} - V_{th}]^2 \qquad (2)$$

The minimum drain-source voltage for *saturation* is

$$V_{D_{sat}} = V_{GS} - V_{th} \qquad (3)$$

## Pre-Lab

**Tasks:**

1. Set up a circuit that allows you to simulate, using Pspice, the input characteristics, i.e., $I_D$ vs. $V_{GS}$, of the 2N7000 MOS transistor. To do so, keep the drain of the device at a constant potential while the source remains grounded. Note: the source and body of this device are shorted.
2. From the plot of the input characteristics find a way to graphically deduce the threshold voltage of your transistor and the value of the product $K=\mu C_{ox}W/L=k_pW/L$. Hint, if the drain voltage is very small, the I-V characteristic becomes linear.
3. Consider the circuit in figure 2 and find an expression for the current $I_{ref}$. Hint: Transistor M1 is operated in the saturation region.
4. Find a numerical value for $I_{ref}$ if $V_{DD}$=10V and $R_{ref}$=10kΩ. To do so, use the values for K and $V_{th}$ you deduced from your plots in task 2. How is the current through M2 related to $I_{ref}$?
5. Use Pspice to plot the current $I_{d2}$ of M2 in the circuit of Fig. 2 as a function of $V_d$ as $V_d$ is in the range of 0 – 10V (Set $V_{DD}$=10V and select $R_{ref}$=10kΩ).
6. From the output characteristic of M2 deduce an approximate value for the output resistance $r_o$ of M2.
7. Repeat task 5 with $R_{ref}$=4.7kΩ. By considering both output characteristics (of tasks 5 and 7) find an approximate value for the transconductance $g_m$ of the MOS device?

## Experimental

8. Set up a circuit that allows you to measure the input characteristics of task 1 and compare the measured to the simulated results.
9. Build the circuit depicted in figure 2 on your Protoboard and record the drain current $I_{d2}$ of M2 while you raise $V_d$ from 0 – 10V in steps of 0.5V (Set $V_{DD}$=10V and select $R_{ref}$=10kΩ). Compare your results to the simulated ones in task 5.

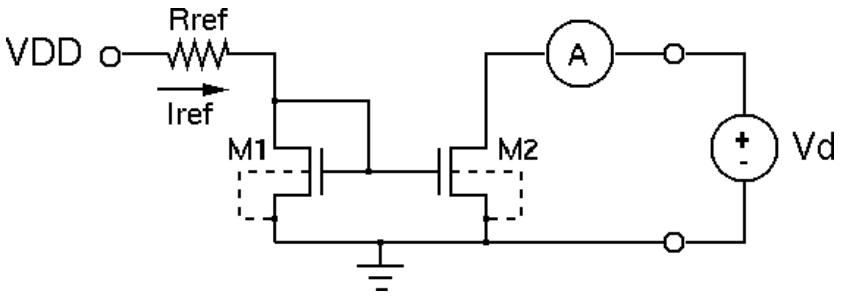


Figure 2: MOS transistor with current source biasing.