

Device Characterization Project

PART III: 0.18 μm MOSFET CHARACTERIZATION - NOVEMBER 8, 2000

Due: November 17, 2000 at lecture

This is a continuation of the 6.720J/3.43J device characterization project. In this third and final part, you will characterize a state-of-the-art deep-submicron MOSFET and compare it with a "long" MOSFET.

The long MOSFET is the same that was characterized in Part II of this project and is still available in the MIT Microelectronics WebLab.

The deep-submicron MOSFET is accessed through a copy of the MIT Microelectronics WebLab that has been set up at the Compaq Alpha Development Group in Shrewsbury (MA). Compaq has graciously offered to host a copy of our weblab system at their site so that students in 6.720J/3.43J can characterize cutting-edge Si hardware that is "too hot" to be allowed out of the plant.

There are some specific considerations regarding the use of weblab at Compaq:

- The web address of weblab at Compaq is: <http://216.126.161.238/>
- At Compaq, we have installed WebLab 3.1 (as opposed to v. 4.1 which is the one deployed on campus). WebLab 3.1 does not have a switching matrix and in consequence only one device is available at any one time.
- The 0.18 μm MOSFET is substantially more fragile than the 1.5 μm MOSFET available on campus. Hence it cannot withstand more than 2 V. Please be careful with your scripts and **do not apply more than 2 V** to the gate or the drain or it will blow. When it blows, the device must be replaced by hand before more measurements are possible.
- If you blow the device or if you think the device is damaged, please send a *polite* e-mail to Norm Leland (norm.leland@compaq.com) asking him to replace it. Please do not just go away and wait for somebody else to request the change.

- The weblab system that we have installed at Compaq seems to have a bug and the device terminal configuration does not show up the first time you log in. Once the applet finishes loading, if you go back to the portal and then go forward again, the terminal configuration will be visible. In any case, the terminal configuration is identical to that of the long MOSFET on campus.
- The weblab system at Compaq is accessed through a phone line. As a result, access is a bit slower than to the system on campus. This is particularly the case for the initial download of the applet to your machine. Please be patient.
- The weblab system at Compaq uses the same user name and password list as the one on Campus.

Part III: 0.18 μm MOSFET characterization (20 points)

This exercise involves two devices: a 0.18 μm n-MOSFET, characteristic of the latest 0.18 μm technology generation (just released in microprocessors with clock rates exceeding 1 GHz), and a 1.5 μm n-MOSFET. You are asked to take the measurements specified below. Once satisfied with the look of the data displayed through the web, you should download the data set for graphing and further analysis using your preferred software tool (typically MATLAB or EXCEL).

In all measurements, hold V_{GS} and V_{DS} between 0 and 2 V for the 0.18 μm device and between 0 and 4 V for the 1.5 μm device. For all measurements on both transistors, the back bias should be $V_{BS} = 0$ V. Refer to Appendix C at end of this document for basic information about short MOSFETs.

Here is your assignment. In the specifications below, V_{DD} refers to 2 V for the 0.18 μm device and 4 V for the 1.5 μm device:

- III-1)** (5 points) Measure and download the *output characteristics* of both devices including the output conductance. Graph I_D/W_G and g_d/W_G for both transistors (**graphs 1 and 2**, linear scales). Extract $I_{on} = I_D(V_{GS} = V_{DS} = V_{DD})/W_G$ for both transistors. Extract V_{DSsat} from the output conductance as shown in Appendix C. Plot V_{DSsat} as a function of $V_{GS} - V_{th}$ for both transistors (**graph 3**, linear scales) (V_{th} is extracted in the next section).
- III-2)** (5 points) Measure and download the *transfer characteristics* of both devices including g_m . Graph I_D/W_G and g_m/W_G for both transistors (**graphs 4 and 5**, linear scales). Extract V_{th} for different values of V_{DS} . Define V_{th} as the value of V_{GS} that yields $I_D/W_G = 1 \mu A/\mu m$. Graph V_{th} as a function of V_{DS} for both transistors (**graph 6**, linear scales).

III-3) (5 points) Measure and download the *transfer characteristics* of both devices, including g_m , for $V_{DS} = 0.1 V$. Graph I_D/W_G and g_m/W_G vs. V_{GS} together for both transistors (**graph 7**, linear scales). Extract V_{th} corresponding to $V_{DS} = 0.1 V$. Calculate *DIBL* (drain-induced barrier lowering), as:

$$DIBL = \frac{|V_{th}(V_{DS} = V_{DD}) - V_{th}(V_{DS} = 0.1 V)|}{V_{DD} - 0.1} \text{ mV/V}$$

III-4) (5 points) Measure and download the *subthreshold characteristics*, that is I_D vs. V_{GS} for $V_{DS} = V_{DD}$. Graph I_D/W_G vs. V_{GS} for both transistors (**graph 8**, log-linear scales). Extract I_{off} (per unit width).

III-5) Summarize in a table I_{on} , I_{off} , $V_{th}(V_{DS} = V_{DD})$, and *DIBL* for both technologies.

The width of the $L_G = 1.5 \mu m$ MOSFET is $W_G = 46.5 \mu m$. For the $L_G = 0.18 \mu m$ MOSFET, $W_G = 8.4 \mu m$.

Additional information and assorted advice:

- This project might take a substantial amount of time. Also, the device at Compaq is rather fragile. Hence, you should carry out the experimental portion as early as possible.
- The MIT WebLab system is being used in a different subject at the same time. Hence there might some traffic through the system. Also, make sure you use the devices that are labeled "6.720 NMOS". There is no *Device* menu at the Compaq weblab since only one device is available at one time.
- The graphs need not be too fancy, just simply correct. They must have proper tickmarks, axis labeling and correct units. If there are several lines, each one should be properly identified (handwriting is OK).
- If you encounter problems with the MIT WebLab, please e-mail the TA, Jorg Scholvin, the instructor, Prof. del Alamo (alamo@mit.edu) or the weblab system manager, Jim Hardison (hardison@mit.edu). For the Compaq WebLab, e-mail Norm Leland (Norm.Leland@compaq.com).
- Both systems keep a record of all logins and all scripts that each user executes.

This exercise is possible thanks to the support, enthusiasm, and hard work of Norm Leland, Larry Bair and Ted Equi of Compaq's Alpha Development Center.

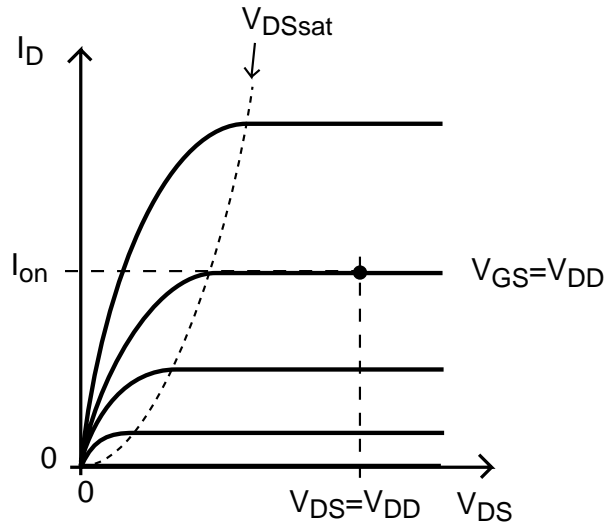
Note on collaboration policy

In carrying out this exercise (as in all exercises in this class), you may collaborate with somebody else that is taking the subject. In fact, collaboration is encouraged. However, this is not a group project to be divided among several participants. Every individual must have carried out the entire exercise, that means, using the web tool, graphing the data off line, and extracting suitable parameters. Everyone of these items contains a substantial educational experience that every individual must be exposed to. If you have questions regarding this policy, please ask the instructor. Prominently shown in your solutions should be the name of the person(s) you have collaborated with in this exercise.

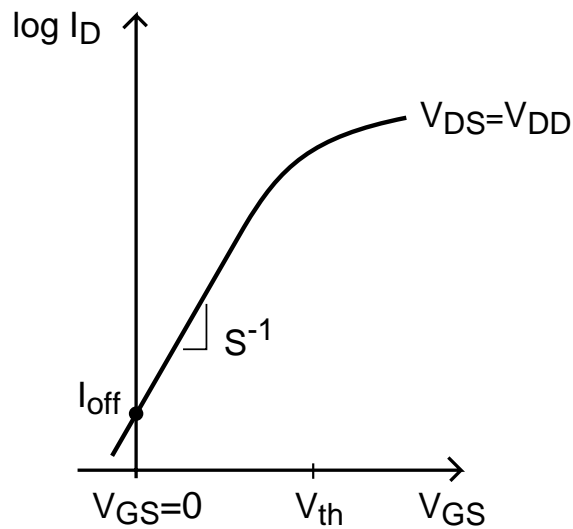
Appendix C: Key figures of merit of "short" MOSFETs for logic applications

In logic MOSFET applications, a *nominal* voltage of operation is defined for each technology. This is referred to as V_{DD} . For a $0.18\ \mu\text{m}$ technology, V_{DD} is typically around $2\ \text{V}$. For a $1.5\ \mu\text{m}$, V_{DD} is typically around $4\ \text{V}$.

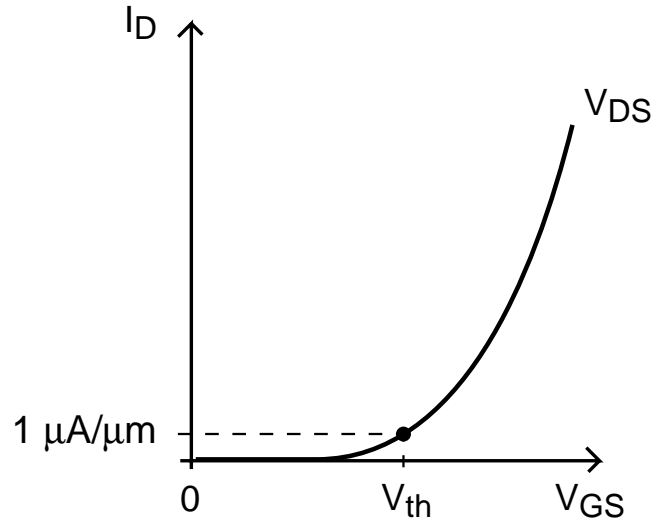
In a MOSFET, I_{on} is defined as the drain current for $V_{GS} = V_{DS} = V_{DD}$, and it is usually normalized by the width of the device. Common units are $\mu\text{A}/\mu\text{m}$.



I_{off} is defined as the drain current for $V_{DS} = V_{DD}$ and $V_{GS} = 0$, and it is usually normalized by the width of the device. Common units are $\mu\text{A}/\mu\text{m}$.



V_{th} is commonly defined as the value of V_{GS} that yields a certain drain current level, typically $I_D = 1 \mu A/\mu m$. V_{th} can be defined for any value of V_{DS} . In this exercise you will extract V_{th} at $V_{DS} = 0.1 V$, $V_{DS} = V_{DD}$ and some values in between. The best way to extract V_{th} is from the transfer characteristics.



There are several ways to extract V_{DSsat} . A simple one involves the output conductance which can be measured at the same time as the output characteristics. In the linear regime, the output conductance is expected to be linear on V_{DS} . The extrapolation of this straight line to $g_d = 0$ yields a reasonable definition of V_{DSsat} . This can be done for any value of V_{GS} .

