

Device Characterization Project #2 - March 14, 2003

N-CHANNEL MOSFET CHARACTERIZATION

Due: March 21, 2003 at recitation (Rm. 26-310, 1 PM)
(late project reports not accepted)

Please write your recitation session time on your project report.

In this project, you will characterize the current-voltage characteristics of an n-channel MOSFET. To do this, you will use the *MIT Microelectronics WebLab*. Refer to the User Manual for instructions on how to use the system.

Several identical $1.5 \times 46.5 \mu\text{m}$ n-channel MOSFETs are available through WebLab. The terminal connection configuration is identical for all of them and is available on line. This exercise involves three separate phases: measurement, graphing, and analysis. Take the measurements specified below. When you are happy with the results (as judged by the characteristics displayed through the web), download the data to your local machine for more graphing and further analysis. You might find useful to refer to the contents of *Appendix A* which describes the ideal model for the I-V characteristics of a MOSFET as studied in class.

Important note: For all measurements, hold V_{GS} between 0 and 3 V, and V_{DS} between 0 and 4 V. When relevant, examine V_{BS} between 0 and -2.5 V. As inputs to this exercise, you need the dimensions of the MOSFET: $L = 1.5 \mu\text{m}$ and $W = 46.5 \mu\text{m}$.

Here is your assignment.

1. Obtain the *output characteristics* of the MOSFET. This is a plot of I_D vs. V_{DS} with V_{GS} as parameter. Use $\Delta V_{GS} = 0.5$ V and $V_{BS} = 0$ V. You might want to take a screen shot of these characteristics for later use. Download the data to your local machine.
2. Obtain the *transfer characteristics* of the MOSFET. This is a plot of I_D vs. V_{GS} with V_{DS} as parameter. Use $\Delta V_{DS} = 1$ V and $V_{BS} = 0$ V. You might want to take a screen shot of these characteristics for later use. Download the data to your local machine.

3. Obtain the *backgate characteristics* of the MOSFET in the saturation regime. This is a plot of I_D vs. V_{GS} with V_{BS} as parameter. Use $\Delta V_{BS} = -0.5 V$ and $V_{DS} = 4 V$. You might want to take a screen shot of these characteristics for later use. Download the data to your local machine.
4. (10 points) On your local machine, using Matlab or your favorite spreadsheet program, graph the *output characteristics* of the MOSFET. This is a plot of I_D vs. V_{DS} with V_{GS} as parameter. Do this for $V_{BS} = 0 V$.

Graph 1: Linear plot of output characteristics (V_{DS} in x axis in linear scale, I_D in y axis in linear scale). Print this graph.

5. (10 points) On your local machine, graph the *transfer characteristics* of the MOSFET. This is a plot of I_D vs. V_{GS} with V_{DS} as parameter. Do this for $V_{BS} = 0 V$.

Graph 2: Linear plot of transfer characteristics (V_{GS} in x axis in linear scale, I_D in y axis in linear scale). Print this graph.

6. (10 points) On your local machine, graph the *backgate characteristics* of the MOSFET in the saturation regime. This is a plot of I_D vs. V_{GS} with V_{BS} as parameter. Do this for $V_{DS} = 4 V$.

Graph 3: Linear plot of backgate characteristics (V_{GS} in x axis in linear scale, I_D in y axis in linear scale). Print this graph.

7. (10 points) From the transfer characteristics and using the model described in Appendix A, extract $\mu_n C_{ox}$ and the threshold voltage, V_{T0} , for this MOSFET [*Suggestions: use the transfer characteristics in saturation, say for $V_{DS} = 4 V$, to determine V_T . You can define V_T as the gate-source voltage that results in a drain current of $50 \mu A$. Then scale the $\mu_n C_{ox}$ product to get the best possible match to the transfer characteristics. Don't be disappointed if the match is not great. These MOSFETs do not perfectly follow the behavior of the ideal MOSFET model*].
8. (10 points) From the backgate characteristics, and using the model described in Appendix A, extract the values of γ , and ϕ_p that best describe this MOSFET [*Suggestion: use the procedure mentioned above to extract V_T as a function of V_{BS} ; then try values of ϕ_p in the -0.3 to $-0.5 V$ range and extract the value of γ that is most consistent among the entire data set.*]
9. (40 points) Using the parameter that you have extracted, "play back" the I-V characteristics of the transistors and compare them with the measurement data. The most effective way to do this is to program the model in matlab or your favorite spreadsheet program and construct graphs that depict the measured data as individual dots and the model as continuous lines.

Graph 4: Graph together the measured *output characteristics* of the MOSFET and those predicted from the model. Print this graph. Comment on the accuracy of the model.

Graph 5: Graph together the measured *transfer characteristics* of the MOSFET and those predicted by the model. Print this graph. Comment on the accuracy of the model.

Graph 6: Graph together the measured *backgate characteristics* of the MOSFET in the saturation regime and those predicted by the model. Print this graph. Comment on the accuracy of the model.

Graph 7: Graph together the experimentally extracted threshold voltage of the MOSFET in the saturation regime *vs.* V_{BS} . Plot in this same graph the predictions of the model using the extracted values of γ and ϕ_p . Print this graph. Comment on the accuracy of the model.

10. (10 points) *Post-mortem* and evaluation. On a separate page, give us feedback on this assignment and on the use of WebLab in this device characterization project. You can be candid. This page will be separated from the rest of your work before the assignment is graded. It will only be studied by the WebLab team.

Additional information and assorted advice

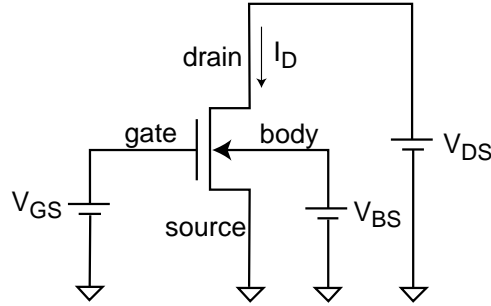
- The required graphs need not be too fancy, just simply correct. They must have proper tickmarks, axis labeling and correct units. When there are several lines, each one should be properly identified (handwriting is OK).
- Your lab report should only include the required graphs, the values of the extracted parameters, and brief discussions on the accuracy of the models, as requested. We do not need the raw data nor any screen shots. Please put two graphs per page.
- For the parameter extraction portion of the exercise, there is no need to use an optimizer or any other fancy software. The ideal model does not match the experimental characteristics all that well. Simple extraction algorithms that you can devise should do an adequate job. Make sure the resulting values of the extracted parameters make physical sense.
- If you encounter problems with weblab or the MOSFETs, please e-mail the weblab TA, Niamh Waldron, Prof. del Alamo, or the weblab system manager, David Zych.
- You have to exercise care with these devices. Please do not apply a higher voltage than suggested. The MOSFETs are real and they can be damaged. If the characteristics look funny, try a different device and let us know.
- It will be to your advantage to make good use of the *Set-up* management functions that are built into the tool under the *File* menu (see manual).
- For research purposes, the system keeps a record of all logins and all scripts that each user executes.

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 homework.

Appendix A: MOSFET I-V characteristics

The conventions for terminal naming, and voltage and current notations for an n-channel MOSFET are all shown below:



The ideal I-V characteristics of a MOSFET are given by the following set of equations:

- *Linear regime*, $V_{GS} > V_T$, $V_{DS} < V_{DSsat}$:

$$I_D = \frac{W}{L} \mu_n C_{ox} \left(V_{GS} - \frac{V_{DS}}{2} - V_T \right) V_{DS}$$

- *Saturation regime*, $V_{GS} > V_T$, $V_{DS} > V_{DSsat}$:

$$I_D = \frac{W}{2L} \mu_n C_{ox} (V_{GS} - V_T)^2$$

In these equations, L and W are the gate dimensions, μ_n is the electron mobility, C_{ox} is the capacitance per unit area of the gate, and V_T is the threshold voltage.

V_{DSsat} is the drain-source voltage that "saturates" the transistor. In the simplest model:

$$V_{DSsat} = V_{GS} - V_T$$

- The effect of applying a *back bias* is to shift the threshold voltage according to the following relation:

$$V_T = V_{T0} + \gamma \left(\sqrt{-2\phi_p - V_{BS}} - \sqrt{-2\phi_p} \right)$$

where γ and ϕ_p are two parameters that describe the electrostatics of the MOSFET, as we will see in class. V_{T0} is the value of threshold voltage that corresponds to $V_{BS} = 0$.

The *output characteristics* of the MOSFET refer to a graph that shows the drain current, I_D , vs. the drain-source voltage, V_{DS} , with the gate-source voltage V_{GS} as parameter.

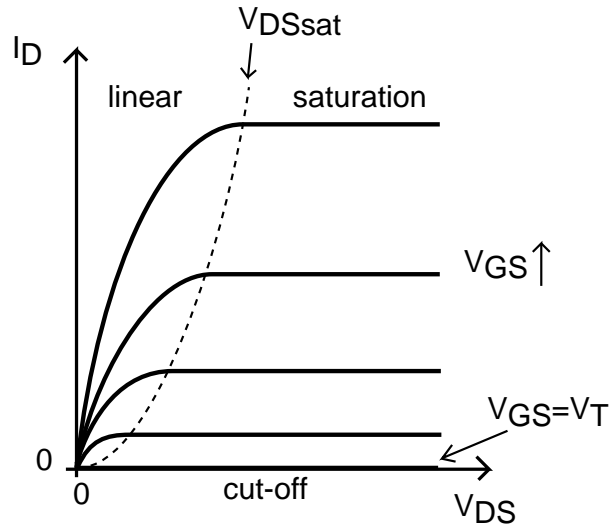


Figure 1: Sketch of ideal output characteristics of an n-channel MOSFET.

The *transfer characteristics* refer to a graph of I_D vs. V_{GS} with V_{DS} as parameter.

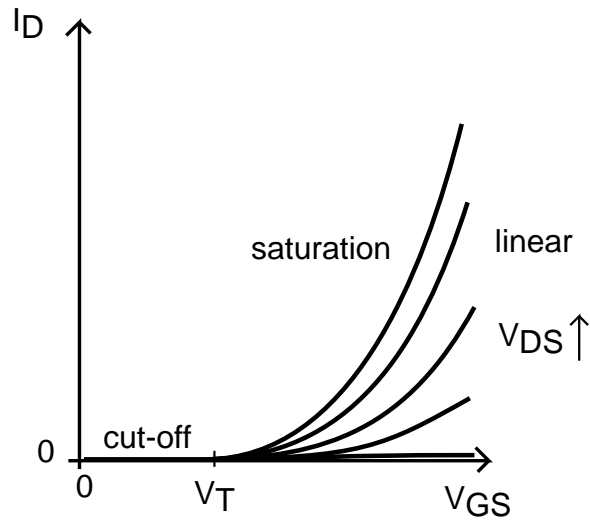


Figure 2: Sketch of ideal transfer characteristics of an n-channel MOSFET.

The *backgate characteristics* refer to a graph that plots the drain current in saturation as a function of V_{GS} for several values of V_{BS} .

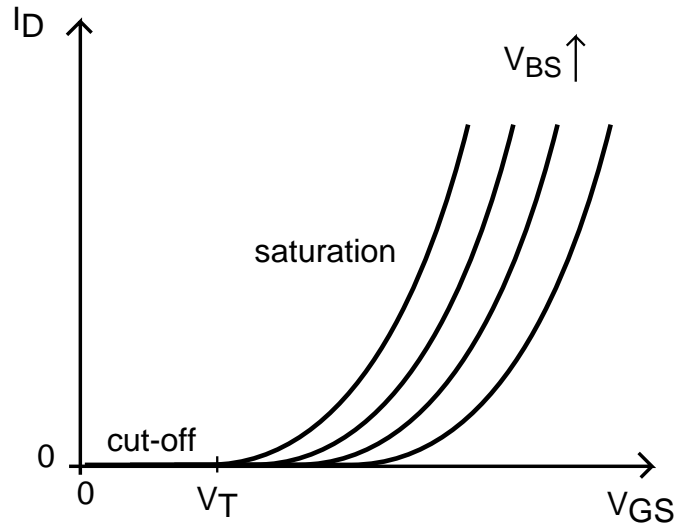


Figure 3: Sketch of ideal backgate characteristics of an n-channel MOSFET in saturation.