EE330 Lab 8
MOSFET Device Experimental Characterization and Basic Applications

Spring 2022

Objective

The objective of this lab is to develop methods for extracting key model parameters for MOS devices. This parallels what was done in the previous laboratory experiment where these parameters were extracted from computer simulations using device models that are embedded in sophisticated model files.

Discussion

So far, you have used Cadence to build, simulate, and layout circuits. Moving forward, you'll begin to build your circuits on breadboards to obtain experimental verification of performance. Though experimental performance of large integrated structures is preferred, it is not practical to fabricate structures for experimental verification within both the time and financial constraints of a 15-week course. Fortunately Texas Instruments agreed to fabricate a test chip, designated as the EDU1000, which contains several transistors that were fabricated in a 5V 0.5μm CMOS process. The EDU 1000 will be used to investigate experimentally the properties of individual transistors. It can also be used to create small circuits by interconnecting these basic devices. But since the EDU 1000 was fabricated for the use of a general-purpose test structure, the designer has no control of the dimensions of the individual transistors but rather must work with devices that have pre-determined dimensions. The data sheet for the EDU 1000 is linked on the class WEB site.

Checkpoints

1. I_D vs. V_{DS} Curves for the EDU1000 array, obtained from the B1500A Parameter Analyzer
2. Extracted parameters
3. Measurements vs. Calculations
4. Inverter Measurement Results

Background

Although MOS transistors are widely used in the design of very large and complex systems that incorporate thousands or millions of transistors or even several billion transistors today, discrete MOS transistors are seldom used at such a scale and, as such, it is difficult to do experimental work with

MOS transistors in the laboratory with state-of-the-art transistors since there are few commercial components available that provide access to the terminals of individual transistors.

Part 1: I_D vs V_{DS} Using the B1500A Semiconductor Parameter Analyzer

In the previous lab, you obtained the I_D vs V_{DS} characteristics (termed the output characteristics) of an n-channel device available in the ON 0.5μm CMOS process. You did this by instructing Cadence Virtuoso to simulate the drain current I_D at a fixed V_GS by sweep V_{DS} from a starting voltage to an ending voltage, with a sufficient number of intermediary points so the curve looked smooth. This was repeated for several V_{GS} values and the resulting outputs were displayed on a single I_D:V_DS graph.

In this part of the lab, we will do something similar, except this time with a transistor with W=60μm and L=3μm in the EDU1000 array.   This is designated as a "Long Channel Transistor" in the EDU 1000 datasheet. Instead of manually setting the transistor's voltages and performing current measurements, we will use the Semiconductor Parameter Analyzer to perform automated measurements at hundreds of points.

Use the Semiconductor Parameter Analyzer to obtain the output characteristics (I_D vs. V_{DS} plots) for the long-channel n-channel device in the MOSFET array. Instructions on using the B1500A Semiconductor Parameter Analyzer can be found in the Appendix of this document or by asking your TA. The plot should have at least four curves on it, each curve being for a different value of V_{GS}. An example output is shown below:
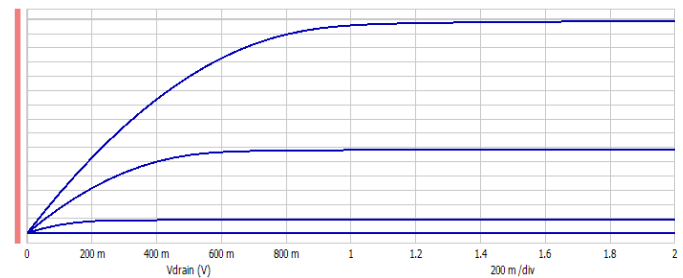

Figure 1

Do this twice: once with $V_{BS} = 0V$, and once with $V_{BS} = -1V$. Save both datasets to your computer for the next part of the lab.

Part 2: Extracting Key Parameters

Using the data collected in Part 1, and the Excel table you created last week, extract γ, λ, V_{T0}, and μC_{ox} for the long-channel NMOS device with dimensions W=60μm and L=3μm that is in the

EDU1000 MOS array. When choosing data points to enter into Excel, make sure the transistor is operating in the saturation region.

As a reminder, recall the following equations. These equations describe the square-law model of a MOS device.

$$I_D = \begin{cases} 0 & V_{GS} < V_T \\ \mu C_{OX} \dfrac{W}{L} \left(V_{GS} - V_T - \dfrac{V_{DS}}{2} \right) V_{DS} & V_{GS} > V_T \text{ and } V_{DS} < V_{GS} - V_T \\ \mu C_{OX} \dfrac{W}{2L} \left(V_{GS} - V_T \right)^2 \left(1 + \lambda V_{DS} \right) & V_{GS} > V_T \text{ and } V_{DS} > V_{GS} - V_T \end{cases}$$

where

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

Part 3: Comparison of analytical and measured results

Using the model parameters for the process extracted in the previous part of this experiment, analytically calculate the output voltage for the following circuit. Using the appropriate long channel device in the EDU1000 MOSFET array, construct the following circuit and measure the output voltage. Compare this with the output voltage predicted from the device models. You should see close agreement between the calculated output voltage and the measured output voltage.
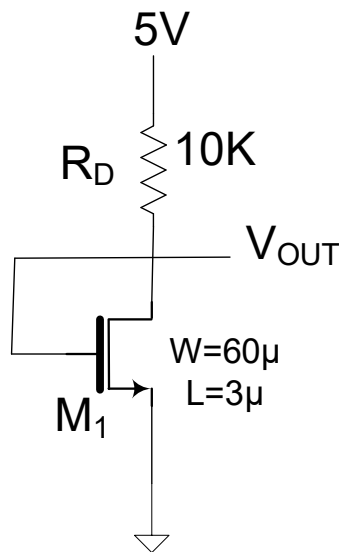
Part 4: CMOS Inverter

A CMOS inverter is shown below. This circuit is widely used in digital applications but can also serve as an analog amplifier if biased properly.
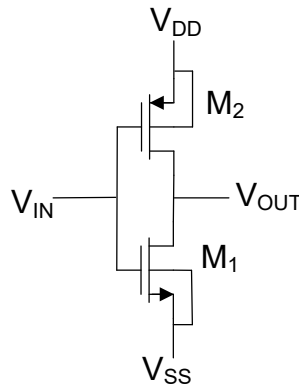
Create this circuit using devices available in the EDU 1000.   Let M_1 be a short-channel NMOS transistor with W=12μ and L = 0.6μ. For M_2 use the short-channel PMOS device with W=24μ and L = 0.6μ.   Let $V_{DD} = 2.5V$ and $V_{SS} = 0V$. Measure the output voltage when $V_{IN} = 0V$ and when $V_{IN} = 2.5V$. Apply a $1kHz$ square wave at the input that goes between $0V$ and 2.5V. Display both the input and output on the oscilloscope at the same time. Comment on the performance.

Re-create the circuit. This time, let M_1 be a long-channel NMOS transistor with W = 60μ and L = 3 μ.   Realize M2 as before.   Repeat the same measurements. Comment on how the performance has changed.

Part 5: Extra Credit

Devise a method for measure V_{TH} and uC_{OX} for the long-channel n=channel transistor with W=60u and L=3u using only two voltage measurements (i.e. no current measurements) and use this method to measure these two parameters. Compare with the results obtained with use of the Semiconductor Parameter Analyzer. You may assume λ=0 in these measurements.

Appendix

## Sweeping V_{DS} and V_{GS} while measuring I_D with the parameter analyzer

To turn on the B1500A parameter analyzer, hit the large power button located on the bottom-right corner of the device's front panel. In most cases, the parameter analyzer should already be on. If it is not, be aware that it will take a few minutes to boot.

Once turned on, the analyzer's software will launch automatically. If it is not open yet, wait a few minutes. If it continues to not open, click on the shortcut located on the Desktop.

Depending on who used the B1500A last, when the software launches, you may see the screen below. We want to open an already-existing workspace, in this case the EE330_F21 workspace, so select that and hit "Continue".
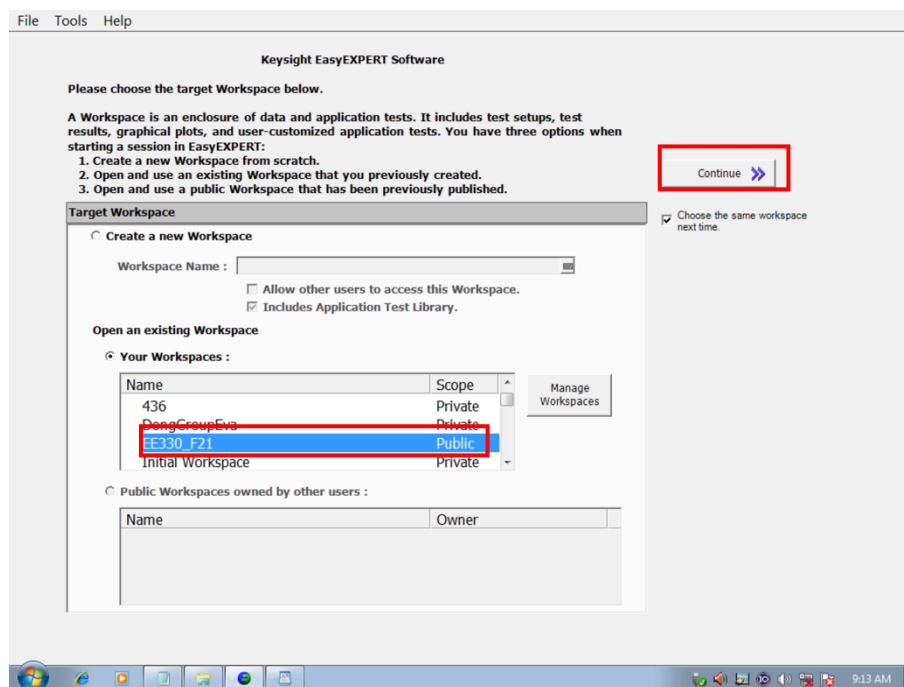

You will now see the program's primary interface, shown below. The B1500A has a large set of already-existing measurements built into it. We can define new measurements using its built-in editor, however that is out of the scope of this class.
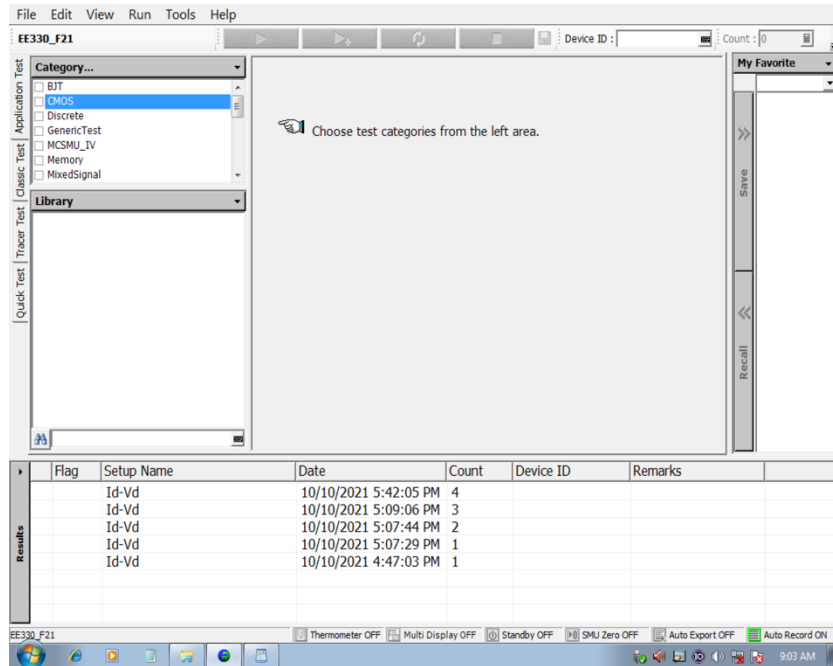
We want to perform an I_D vs. V_{DS} sweep across one of the devices in the EDU1000 MOS array. To do that, first select "CMOS" under the category section to see all measurements made for CMOS devices. Then, select "Id-Vd" to select the pre-made I_D vs. V_{DS} measurement tool.
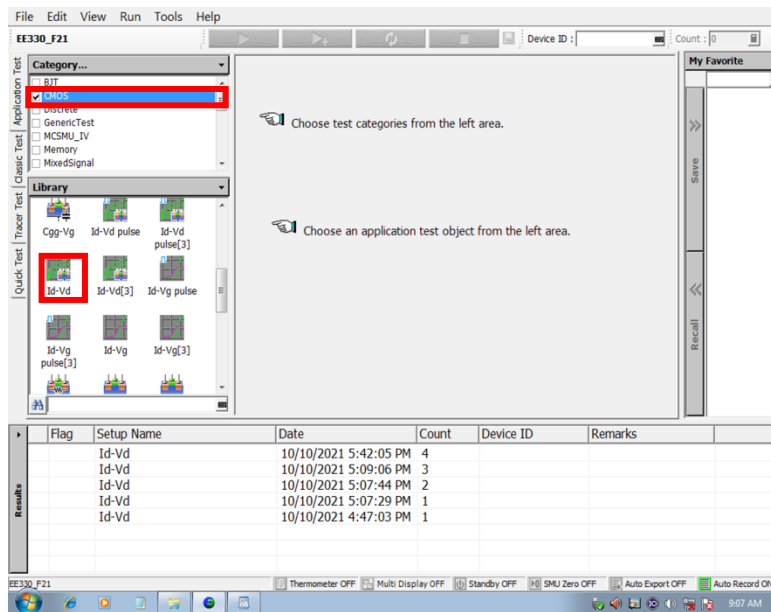
This will open a new screen, like the one seen below. This interface allows you to set some device information (such as whether the device is NMOS or PMOS, the length and width of the gate, etc) as well as control the sweep you want to perform.
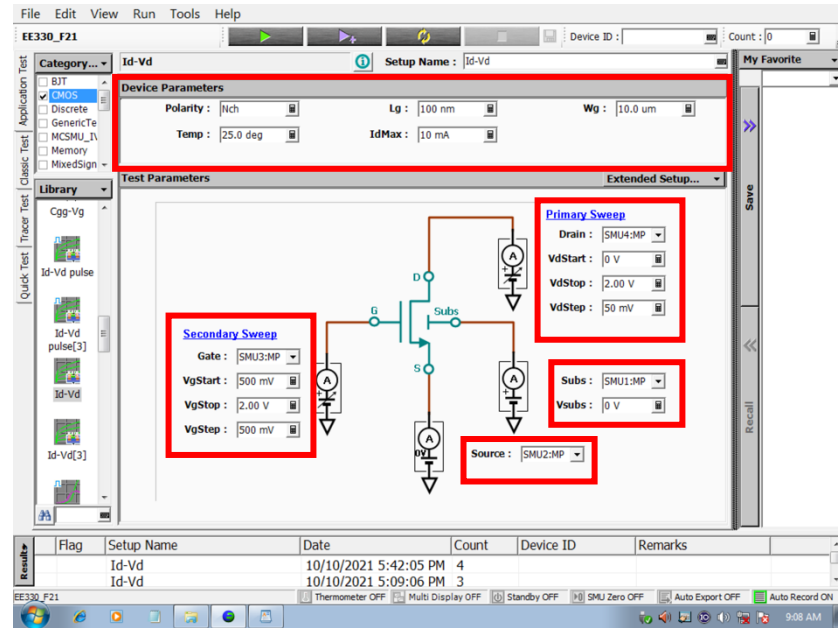
When satisfied with the settings, connect the EDU1000 array to the device SMUs and click the green play button at the top of the screen. This will run the measurement. If done properly, you should see results similar to below.
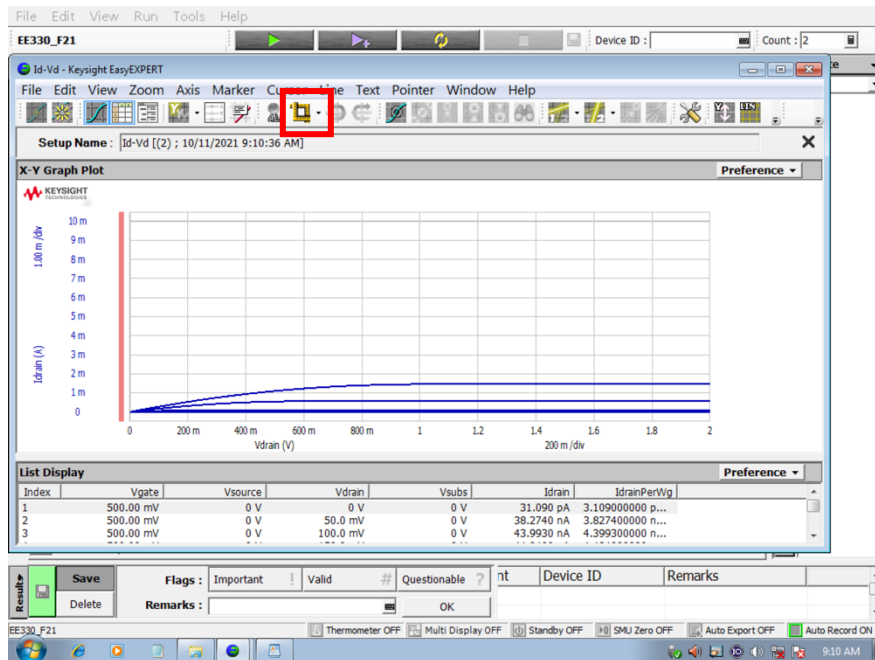
We can auto-scale the y-axis of the plot using the button highlighted in the image. There are many other useful buttons available from this screen, and you're encouraged to explore them briefly.

When you're ready to save the plot and data, go to Edit > Copy Image and paste the resulting image in a Notepad file. Go to Edit > Copy List and paste the data into a new Notepad file. Using a thumb drive, move these files to your computer.