

EE 330 Laboratory 7

MOSFET Device Experimental Characterization and Basic Applications

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Contents

Prelab:.....	2
Objective:	2
Background:	2
Part 1. Set up Signal Express.....	3
Part 2. Measurement of MOSFET output characteristics.....	4
Part 3. Measurement of MOSFET parameters	4
Part 4. Measurement of parameters using B1500a Parameter Analyzer	6
Part 5. CMOS Inverter (Extra Credit)	7
Deliverables.....	7

Caution: You would be using MOS chips in this lab. MOS chips are very sensitive to electrostatic discharge (ESD) and can be destroyed by improper handling. Never store these parts in Styrofoam or other non-conducting containers unless the leads are covered with a conducting medium. Always use a protective grounding strap (sometimes termed “wrist bracelet”) when touching these devices or the circuit to which they are connected.

Remember to go through the deliverables as you do the lab.

Prelab:

Lab 7 will require you to use Signal Express and the Semiconductor Parameter Analyzer. This Pre-Lab will ensure you are familiar with them before you start the lab.

- a) Using Signal Express: Read through the instructions in the handout then use signal express to measure the resistance of a 1k resistor and calculate the accuracy of your measurement. (if you cannot measure resistance directly, you can measure resistance from a plot of voltage against current) You can get the handout at the following link. http://class.ece.iastate.edu/ee330/miscHandouts/ee_330_signal_express.pdf
- b) Using the Parameter Analyzer: Read through the instructions in the handout and draw a block diagram describing the process of plotting I_d against V_{gs} for a transistor (Assume that the transistor is on a chip (8 pins) and has pin 4,5,6 and 7 connected to the drain, source, gate and substrate). Here is a link to the handout. <http://class.ece.iastate.edu/ee330/miscHandouts/Partial%20B1500%20Parameter%20Analyzer%20Manual.pdf>

Objective:

The objective of this laboratory experiment is to become more familiar with the operation of the MOS transistor, to develop methods for measuring key parameters of the transistor, and to investigate some basic applications of the device.

Components Needed:

MOSFET transistor (TI XEDU1000)

Breadboard

Test Equipment Needed:

B1500a Semiconductor Parameter Analyzer, DC power supply, Oscilloscope, Digital Multimeter.

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 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. In this experiment we will work with a set of MOS transistors available in the transistor array. Although these devices are large and fabricated in a process with a metal gate rather than a polysilicon gate, the low frequency properties are indicative of that seen in smaller feature size transistors but some of the parameter values are considerably different than what is common in smaller feature size processes.

Part 1. Set up Signal Express

Signal Express is a program that automates testing by controlling the multimeters, power sources, and other equipment. It is assumed that you have successfully completed the prelab and know how to set up and use signal express.

If you have not, you will need to go through the instructions here:

http://class.ece.iastate.edu/ee330/miscHandouts/ee_330_signal_express.pdf

First turn on the multimeters, and power supplies. Start Signal Express and click on **Empty LabVIEW SignalExpress Project**. In the next screen go to **Add Step** in the tool bar and add the **IVI DMM Acquire, IVI Power Suply, and Sweep**. In the project panel on the left drag the Power Supply and Multimeter (DMM Acquire) in the sweep.

Connect the Power Supply to the specific devices. This is done in their configuration tab in the IVI session name drop down box. If the device is not turned on you will get a 'configuration error'. In the power supply configuration make sure **ALL channels are turned ON**. Make sure unused channels are set to 0V, set the Voltage to 1V. Use the unconnected multimeter to verify the output is working.

If you are having 'configuration' errors while using Signal Express, refer to the instruction manual for Signal Express. If you are still having errors, you can call on the TA to help you out.

Connect the multimeter to Signal Express. This is done in the **DMM Signal Acquire** configuration. Set the multimeter to measure DC Volts and edit the Sweep. In Sweep Configuration click **Add** and add a sweep parameter,

- 1: Voltage level (V) if using the 6V output
 - 2: Voltage Level (V) if using the 25V output
 - 3: Voltage Level (V) if using the -25V output
- We advise not using the 25V or -25V source.

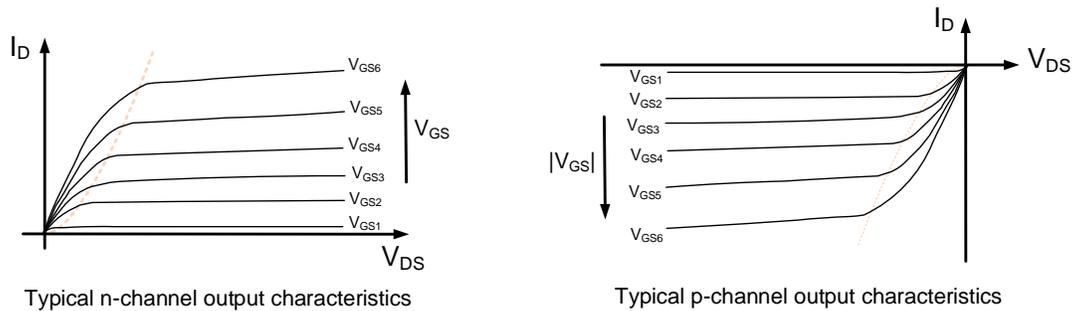
In the Configuration on the bottom left of the Sweep Configuration tab set a linear voltage between 0 and 3 V with 5 steps. Click the Sweep Output tab, select MyIViDmm0 as the Y-Axis and # – Voltage Level (V) as the X-axis.

When you run the simulation, there are two power sources hence t may be confusing. When you sweep, watch the one that changes so you can be sure you are using the right source.

Test across a resistor to make sure the sweep is working. Do this by clicking the arrow next to Run and click Run Once (or **Ctrl+Shift+R**). Once it has run right click on myIviDmm0 vs # - Voltage and select the output you want to see (often Excel).

Part 2. Measurement of MOSFET output characteristics

The output characteristics of a MOS transistor refers to the relationship between the drain current and the port voltage variables V_{GS} and V_{DS} . These are often represented graphically on a plot of the I_D vs V_{DS} for several different values of V_{GS} as shown in the following figure. From the output characteristics, several of the key model parameters of the MOS transistor can be obtained.



Measure the output characteristics of one of the n-channel MOS transistors in the array using Signal Express. Use 6 values of V_{GS} in these measurements, specifically, $V_{GS} = 0.5V, 1.0V, 1.5V, 2.0V,$ and $2.5V$ for $0 < V_{DS} < 2.5V$. **Compare** with those predicted in the datasheet

Part 3. Measurement of MOSFET parameters

The parameters μC_{ox} , V_{T0} , λ and γ are key parameters that characterize the MOS transistor along with the physical parameters W and L . Most of these parameters can be measured with standard test equipment or can be obtained from a semiconductor parameter analyzer which is a piece of equipment especially designed for extracting such parameters. You will be asked to extract these parameters using both techniques in this experiment.

a) **Extraction of μC_{ox} and V_{T0} :** In the saturation region, the drain current is given by the expression

$$I_D = \mu C_{ox} \frac{W}{2L} (V_{GS} - V_T)^2 (1 + \lambda V_{DS}) \quad (1)$$

where

$$V_T = V_{T0} + \gamma (\sqrt{\phi - V_{BS}} - \sqrt{\phi}) \quad (2)$$

Note some authors define the product of μ and C_{ox} by the parameter $k' = \mu C_{ox}$. For the purpose of model extraction in this experiment, we will not be concerned in separating these parameters and hence will only be interested in the product μC_{ox} . If the substrate (bulk) is connected to the source (to make $V_{BS} = 0$) and we estimate $\lambda = 0$, it follows that .

$$I_D = \mu C_{ox} \frac{W}{2L} (V_{GS} - V_{T0})^2 \quad (3)$$

If we connect the gate of the MOSFET to the drain, forcing the device into the saturation region (provided $V_{GS} > V_T$), and plot $\sqrt{I_D}$ versus V_{GS} , we find that the slope of the curve becomes

$\sqrt{\frac{\mu C_{ox} W}{2L}}$ and the V_{GS} axis intercept is V_{T0} . If W and L are known, the parameter product μC_{ox} can thus be obtained from the slope.

b) Extraction of γ : If the bulk to source voltage is set to another value, e.g. $-1V$, the method used in (a) above can be used to measure the new value of V_T . As before, the value of V_T will be the intercept of the $\sqrt{I_D}$ plot with the V_{GS} axis. Since Φ is assumed known and is about $0.6V$, and since V_{T0} was extracted above, equation (2) can be solved for γ .

c) Extraction of λ : From equation (1), it follows that if I_D is measured at two different V_{DS} values while maintaining V_{GS} constant, the lambda is given by the expression

$$\lambda = \frac{I_{D2} - I_{D1}}{I_{D1} V_{DS2} - I_{D2} V_{DS1}} \quad (4)$$

Using appropriate circuits **measure** the parameters μC_{ox} , V_{T0} , λ and γ for the NMOS transistor in the array using the techniques listed above and **compare** μC_{ox} , V_{T0} , and λ with the parameters in the datasheet. Make appropriate connections to the bulk for these measurements.

Part 4. Measurement of parameters using B1500a Parameter Analyzer

The parameters μC_{ox} , V_{T0} , λ and γ are key parameters that characterize the MOS transistor along with the physical parameters W and L . Most of these parameters can be measured with standard test equipment or can be obtained from a semiconductor parameter analyzer which is a piece of equipment especially designed for extracting such parameters.

In a previous experiment you extracted these parameters from special test circuits that you built. In this experiment, these same parameters will be obtained using a semiconductor parameter analyzer. The parameters obtained with the semiconductor parameter analyzer will be compared with the results obtained in the previous experiment and with the parameters predicted by the manufacturer on the datasheet for the part. These parameters are the parameters that appear in the device model equations which, for the purpose of this experiment, is assumed to be the square law model

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

where

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

Measure the parameters μC_{ox} , V_{T0} , λ and γ for the NMOS transistor (the one with the gate on pin 3) in the array using the B1500A Semiconductor Parameter Analyzer. **Compare** the results obtained with those measured in a previous experiment and with what is given on the datasheet. It is assumed that you have successfully completed the prelab and know how to use the parameter analyzer. If you have not, you may find help in the instruction manual.

<http://class.ece.iastate.edu/ee330/miscHandouts/Partial%20B1500%20Parameter%20Analyzer%20Manual.pdf>

Part 5. CMOS Inverter (Extra Credit)

A CMOS inverter is shown. This circuit is widely used in digital applications but can also serve as an analog amplifier if biased properly.

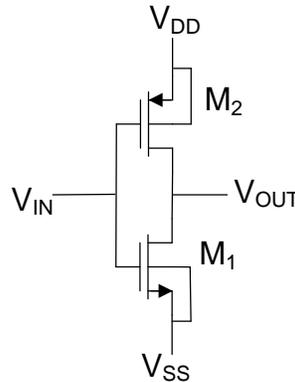


Figure 1 CMOS Inverter

Two implementations of this inverter will be considered.

- In Case 1, M₁ will be an NMOS(Short Channel), and M₂ will be a PMOS(Short Channel)
- In Case 2, M₁ will be an NMOS(Long Channel) , and M₂ will be a PMOS(Short Channel)

For digital logic applications, the CMOS inverter is typically operated from a single power supply with $V_{DD} = 2.5V$ and $V_{SS} = 0V$. **Note** the output voltage when $V_{in} = 0V$ and when $V_{in} = 2.5V$.

Apply a 1 KHz 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.

Deliverables

- Verification sheet
- Prelab
- Introduction
 - Summarize what was done in the lab
 - Why do you think this Lab is useful?
 - Why do you think discrete MOS transistors is seldom used?
- Part 1
 - Screenshot of the plot on signal express
 - Screenshot of the same plot in Excel

- Part 2
 - Screenshot of the output characteristics curve from signal express
 - Compare the results with those predicted in the data sheet and explain your observation
- Part 3
 - Explain how you extracted μC_{OX} and V_{TO} and attach the necessary plots
 - Explain how you extracted γ and attach the necessary plots
 - Explain how you extracted λ and attach the necessary plots
 - Compare the value of μC_{OX} , V_{TO} and λ with the parameters in the data sheet and explain your observations
- Part 4
 - Explain how you extracted μC_{OX} , V_{TO} , γ and λ
 - Compare the results obtained with those measured in the previous experiment and explain your observations
- Part 5 (Extra Credit)
 - A screenshot of your connections on the breadboard
 - Output voltage when $V_{in} = 0V$ and when $V_{in} = 2.5V$
 - A screenshot of the oscilloscope display
 - Comment and explain your observation
- Conclusion
 - Discuss what you learned in the Lab
 - Add any comments on what you liked or what you would want see changed against next lab