ECE 311 – Microelectronics I - Lab

Department of Electrical and Computer Engineering
University of Idaho

Lab #7: MOSFET Characterization and Biasing

Goals: This lab is designed for you;

- To measure fundamental characteristics of a MOSFET including (I_{DS}/V_{GS}) and (I_{DS}/V_{DS}) curves.
- To extract fundamental parameters of a MOSFET including threshold voltage (V_{TH}), lambda (λ), β, and input capacitance (C_{in}).

Background:

MOSFET transistors are ideally have infinite output impedance and as a result applied V_{DS} voltage do not have any effect on the I_{DS} current in saturation region of operation (λ=0). However I_{DS} current in real devices depends on the V_{DS} voltage slightly. This is modeled as lambda (λ) parameter in saturation equation as given in equation (1).

$$I_{DS} = \frac{1}{2} KP\left(\frac{W}{L}\right) \cdot \left(V_{GS}\text{-}V_{TH}\right)^2 \cdot \left(1+\lambda \cdot V_{DS}\right) = \beta \cdot \left(V_{GS}\text{-}V_{TH}\right)^2 \cdot \left(1+\lambda \cdot V_{DS}\right) \tag{1}$$

There are three parameter in equation (1) that are unique to different MOSFET devices and even they are manufactured by same company. They are the parameter β, V_{TH}, and λ.

The threshold voltage (V_{TH}) of the transistor could be determined by measuring I_{DSi} currents for applied V_{GSi} voltages when the transistor is biased in ON region. The I_{DS} current ideally becomes zero when V_{GS} is less than V_{TH}, and transistor becomes OFF. However, to eliminate quadratic relation between V_{GS} voltage and I_{DS} current, it is better to work with the square root (sqrt) of the measured I_{DS} current. Thus, the extrapolated V_{GS} voltage for sqrt(I_{DS})=0 for the linear curve fitted data would be considered as the threshold voltage of the MOSFET. Here it is necessary for transistor to work in saturation (SAT) region. It is done by making sure that V_{DS}>V_{GS}-V_{TH}, and the measurement setup shown in Figure 1, makes sure that the MOSFET is always in SAT as long as it in ON.

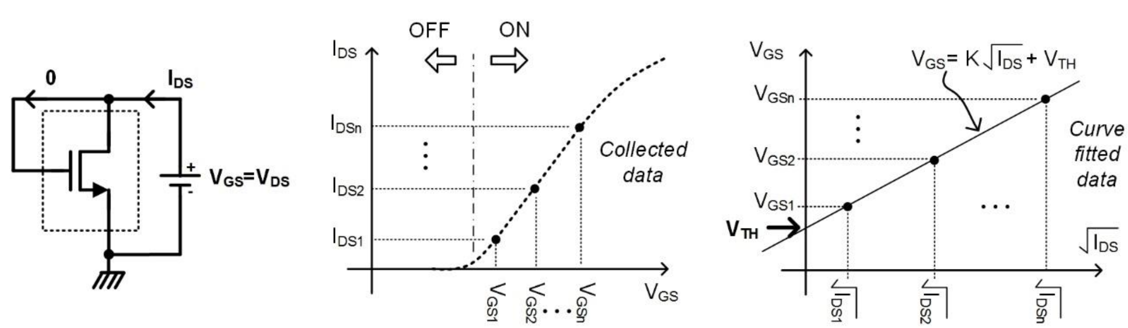

Figure 1. Setup for measuring threshold voltage (V_{TH}) of a MOSFET.

Lambda (λ) parameter typically changes for applied V_{GS} voltage and could be calculated when transistor is in saturation region by measuring I_{DS} for given V_{DS} voltages as shown in Figure 2 and by using equation (2).

$$\lambda = \frac{I_{DS2} - I_{DS1}}{I_{DS1}V_{DS2} - I_{DS2}V_{DS1}} \tag{2}$$

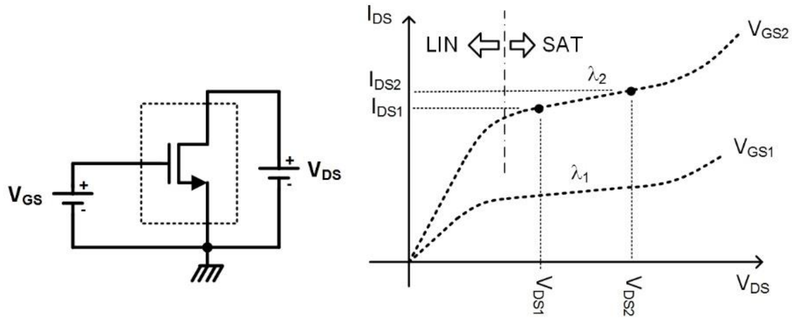

Figure 2. Setup for measuring lambda (λ) of a MOSFET for given V_{GS} voltage.

If both V_{TH} and λ is known, β could easily be determined by using equation (1) and the measured I_{DS}, V_{DS} data. If λ is very small (λ<0.01) than, β could be approximated to be about $1/K^2$, where K is a constant in the curve fit function shown in Figure 1.

Almost all systems has certain amount of input impedance. MOSFETs are fundamentally capacitive devices at the input or gate side that is characterized as input capacitance of the MOSFET transistors. A simple RC circuit could be constructed with the MOSFET as shown in Figure 3. The unknown capacitor value (C) could be determined by applying a step input voltage ($\Delta V_{step} = V_{stop} - V_{start}$) through a known resistor (R) and measuring the capacitor voltage (V_C) in the linear region (i.e. 40-60% of ΔV_{step}). Then, the unknown capacitor value could be calculated using equation (3).

$$V_C = V_S\left(1 - \frac{1}{\exp\left(\frac{t}{RC}\right)}\right) \quad \Rightarrow \quad C = \frac{\Delta t}{R \cdot \ln\left(\frac{1}{1 - \frac{\Delta V}{\Delta V_{Step}}}\right)} \tag{3}$$

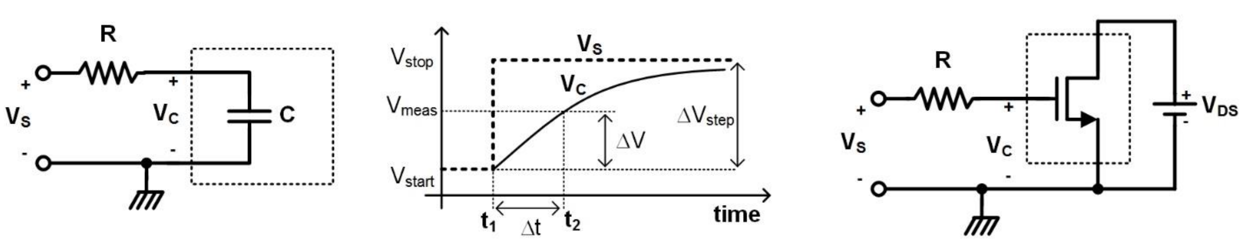

Figure 3. Measuring capacitance of an unknown capacitor.

Preliminary:

1. STUDY: In this lab, you will use ZVN2106A, an NMOS transistor.
   a. Study the datasheet of the transistor and extract as much of data as possible to know expected values of the MOSFET parameters that you will be measured.
   b. Study the background information of this lab document. Understand, and derive equations (2) and (3) by yourself.
2. SIMULATE:
   a. Construct the circuit shown in Figure 1 in Cadence and simulate it. Change the V_{GS} voltage between 0V and 3.0V (or more to see when it turn nonlinear) and record I_{DS} and V_{GS} data (at least 20 points starting 1μA up to 500mA of I_{DS} current levels) on Excel worksheet.
   b. Using the recorded data, determine the threshold voltage using linear curve fit function of Excel in linear region. Also estimate V_{GS} voltage range that is linear enough to extract the threshold voltage. Compare your finding with the datasheet number(s).
   c. Construct the circuit shown in Figure 2 in Cadence and simulate it. Set the V_{GS} voltage such that the MOSFET is biased 0.5V and 1V in the ON region (meaning set the overdrive voltage, V_{OD1}=0.5V and V_{OD2}=1V). Change V_{DS} voltage between 0.01V and 3V with reasonable steps and have enough data point (>10) to extract λ parameter in SAT region of operation.
   d. Using the recorded data, determine the lambda (λ) parameter for the two biasing conditions using equation (2). Also estimate V_{DS} voltage range to keep the transistor in SAT region where the lambda is measured.
   e. Construct the circuit shown in Figure 3 in Cadence and simulate it. Apply a steep V_{GS} voltage through a 10MOhm resistor to the MOSFET. You can apply V_{start}=0V to V_{stop}=5V square wave pulse with 100ms period, 50ms pulse width, 1ns rise/fall time.
   f. Select different Vmeas levels and determine Cin capacitance of the MOSFET for V_{stop}=2V, 3.3V and 5.0V. Compare your findings with the datasheet.

Laboratory Procedure:

It is required to take notes while working on the lab steps. These notes has to be check marked by TA and be included in the lab report. See reporting requirements section. Use standard, blank, white US letter (8.5"x11") pages for taking your notes.

1. <u>Measurement of the threshold voltage (V_{TH})</u>
   a. Construct the circuit in Figure 1 on a prototype board using ZVN2106A. Make sure that you do not applied more than maximum rated V_{GS} or V_{DS} voltages the transistor anytime during measurement.
   b. Measure and plot I_{DS} versus applied V_{GS} voltage and record your data in Excel worksheet. Following the same procedure you used in preliminary study, and extract the threshold voltage of the device you have.
   c. Show your work to TA and get a mark on your notes. Answer any questions, and/or implement any suggestions he may have.
2. <u>Measurement of the lambda (λ) value</u>
   a. Construct the circuit in Figure 2 on a prototype board using ZVN2106A. Make sure that you do not applied more than maximum rated V_{GS} or V_{DS} voltages the transistor anytime during measurement.
   b. Set V_{GS} such that transistor work 0.5V in the ON region or transistor having 0.5V overdrive voltage. Use the V_{TH} you measured to determine the appropriate V_{GS} voltage.

c. Change V_{DS} voltage from 0V to 3V and measure I_{DS} current and record them in Excel sheet. Collect as many data points as possible in saturation region to determine the lambda value. Also plot I_{DS} versus V_{DS} voltage in Excel sheet.
d. Show your work to TA and get a mark on your notes. Answer any questions, and/or implement any suggestions he may have.
e. Repeat steps 2.b and 2.c for 1V overdrive voltage, and determine the lambda value.
f. Show your work to TA and get a mark on your notes. Answer any questions, and/or implement any suggestions he may have.

3. Measurement of the input capacitance (C_{in}) of the MOSFET
   a. Construct the circuit in Figure 3 on a prototype board using ZVN2106A and 10MOhm resistor. Measure the resistor value before connecting it in the circuit. Make sure that you do not applied more that maximum rated V_{GS} or V_{DS} voltages the transistor anytime during measurement.
   b. Apply a square wave to the circuit and measure the gate voltage using oscilloscope. Determine C_{in} capacitance deducting the probe and oscilloscope capacitances, as modelled in Figure 4. Read the information on the probe and check oscilloscope manual for input impedance. To eliminate the probe/oscilloscope parasitic capacitances, make 2 or 3 measurements applying different V_{stop} voltages as you did during preliminaries.
   c. Try measuring the C_{in} with a meter too.
   d. Show your work to TA and get a mark on your notes. Answer any questions, and/or implement any suggestions he may have.

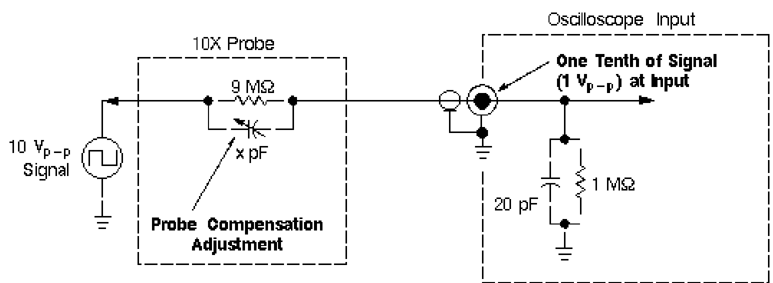

Figure 4. Typical Probe/Oscilloscope 10-to-1 Divider Network.

4. Determine the β value
   a. Determine the β value using your measurement results. Compare your value with the datasheet. Show your work to TA and get a mark on your notes. Answer any questions, and/or implement any suggestions he may have.

Reporting Requirement

1. Follow the required lab report guidelines outlined in the syllabus.
2. Attached to your report also:
   a. Notes and/or printouts of your preliminary works.
   b. Check marked notes you took during lab.
   c. Include printout of your simulation and Excel sheet plots and Tables that you build in step 5 (if not presented in the lab report, section d).