EE330 Lab 6
Models for MOS Devices

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Contents

Part 0: Prelab

In this lab we will use 2 new functions of Cadence: The parametric analysis and the calculator. To help you learn how to use them, we have uploaded 2 reading materials on the website called "reading material 1" (which talks about parametric analysis) and "reading material 2" (which talks about using the calculator". Read through these 2 documents and perform the exercises in them. Provide screenshots of your parametric analysis and calculator set ups and 2 output waveforms – one for each of the papers.

Part 1: Introduction

The mathematical relationship between the terminal currents and voltages for a device is termed the device model. Although the basic operation of the MOS transistor is quite straightforward, the task of obtaining a mathematical model for the device that accurately predicts characteristics that can be measured in the laboratory is quite challenging. A large number of models for the MOS transistor have been developed and the research community continues to work on developing even better models.

Although there is considerable ongoing activity on modeling of the MOS transistor, a simple analytical model is widely used for hand calculations and most circuit design activities use the same simple analytical model. This model is often termed the square-law model and is characterized by the equations

$$I_G = I_B = 0$$

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

where $V_T = V_{T_0} + \gamma\left(\sqrt{\Phi - V_{BS}} - \sqrt{\Phi}\right)$

For this experiment you can assume $\Phi \approx 0.6V$

With this model, the device is characterized by the process parameters $\{V_{T_0}, \lambda, \mu C_{ox}, \gamma\}$ and design parameters $\{W, L\}$; the rest are electrical port variables. A more accurate model is the BSIM model used in programs such as SPICE and SPECTRE. The basic BSIM 3 model has 97 parameters but extreme values for the BSIM model parameters (often termed corner models) are often included resulting in a several-fold increase in the total number of parameters. Even this model, however, is often not considered good enough so the concept of "binning models" is incorporated into existing simulators. A binning BSIM model would be a set of BSIM models that are optimized for given range of device sizes and operating conditions. The simulator would then select a BSIM model from a model library that has device sizes and operating point close to that of a device in a circuit. The bottom line is that a good BSIM model will typically have several hundred or maybe even a few thousand parameters to characterize a MOS transistor.

Part 2: Purpose

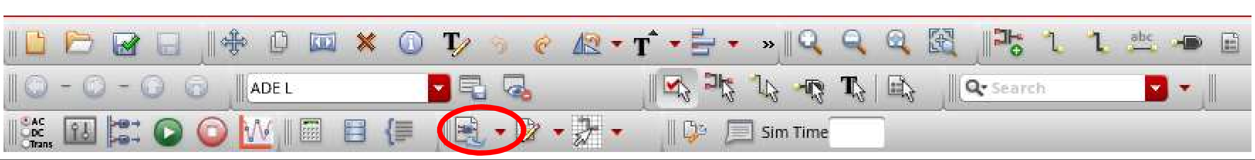
The purpose of this laboratory is to investigate the relationship between the square law model of a MOS transistor and the BSIM model. Specifically, square-law model parameters will be extracted from the BSIM model and a comparison of the performance of a device with the simpler square-law model and the more complicated BSIM models will be made.

Since the square-law model is less accurate, one would expect that there will be close agreement between the square-law model and the BSIM model when the device is operating close to the point where the model parameters are extracted. Additionally, the deviation between the square law model and the BSIM model will become significant when the square law model parameters are used to predict performance of a device with dimensions or operating conditions that differ considerably from the conditions under which the parameters were extracted.

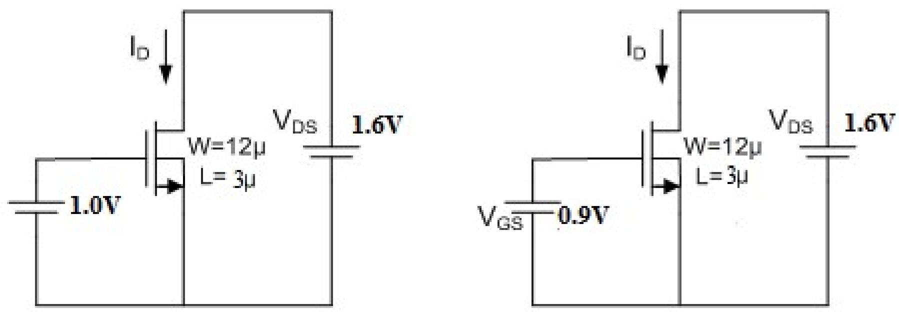
Part 3: Square-Law Parameter Extraction

Extract the process parameters $\{\mu C_{ox}, V_{T_0}, \lambda, \gamma\}$ from the BSIM model for a device with dimensions W=12μ and L=3μ near an operating point of V_{GS}=1V, V_{DS}=1.6V, and V_{BS}=0. Note we are only extracting the product μC_{ox}, not the individual parameters μ and C_{ox}

Note: to find the operating point current for a circuit shown below, run a DC analysis and only turn on the option of **Save DC operating point.** After successful completion, click on **Results-Print-DC operating points** in the ADE window. Now click on the transistor in schematic window and you will see the operating point details. Another useful tool is using the "Annotation" to view a few selected operating points on schematic. Press on the icon in the red circle below and pick "DC operating points".



Hint: One way to extract V_{T0} would be to simulate the following two circuits (with V_{BS}=0V).



Both devices are operating in saturation. We obtain the expressions from the two circuits

$$I_{D1} = \mu C_{OX}\left(\frac{W_1}{2L_1}\right)(V_{GS1} - V_T)^2(1 + \lambda V_{DS})$$
$$I_{D2} = \mu C_{OX}\left(\frac{W_2}{2L_2}\right)(V_{GS2} - V_T)^2(1 + \lambda V_{DS})$$

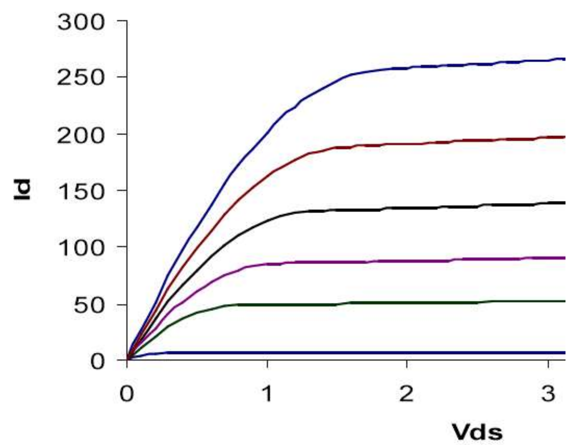
Since V_{DS} are the same, taking the ratio and then the square root, a single linear expression in V_T is obtained. A similar approach can be used to extract the remaining parameters. Obtain values for μC_{OX}, V_{T0}, λ, and γ.

Extract the same parameters for a device with dimensions W=1.5µ, L=0.6µ near an operating point of V_{GS} =1.2V and V_{DS} = 0.8V. **Compare the extracted model parameters from the 2 different operating conditions you just simulated.**

Note: When you derive equations to extract these parameters, it would be useful later to enter them in a spreadsheet for re-use. You will need to extract the same parameters for slightly different set of transistors.

Part 4: Comparison with BSIM Model

The output characteristics of a MOS transistor are often used to graphically display the transfer characteristics of a device. Typical transfer characteristics of a device are shown below. The different color curves refer to different V_{GS} values.



To obtain a family of curves through simulations as shown above, use Tools-Parametric analysis (SPECTRE) in ADE. For example, in schematics window, enter v_{gs} as value of your DC voltage source at the gate. In the Parametric analysis tool window, enter how you want to sweep vgs and then click on Analysis-Start in the same form. If you saved and plotted Id, you will see the family of curves.

Using the BSIM model, plot the transfer characteristics for a device with dimensions W=12μ and L=3μ near an operating point of V_{GS}=1.6V, V_{DS}=1V, and V_{BS}=0 and compare with the corresponding square law transfer characteristics using the parameters that you extracted in Part 3. Comment how closely the transfer characteristics compare near the operating point where you extracted your parameters.

Now use your extracted model parameters to predict the output characteristics of a device that has dimensions W=60μ, L=3μ operating with a V_{GS} of around 1V and a V_{DS} of around 1.6V and compare with what the BSIM model predicts for the same device.

Comment on how closely model parameters predict performance when operating near the operating point and with device dimensions close to those used to extract the parameters and when operating at distant operating points with device dimensions that are substantially different than those used to extract the model parameters.

In other words, choose a few points around $V_{GS} = 1V, V_{DS} = 1.6V$ and calculate with your extracted parameters what you expect the value of I_D would be. Compare this to what the simulation says I_D is. Use Marker(m) feature to view points' coordinates on your output plots.

Part 5: Output Conductance Extraction

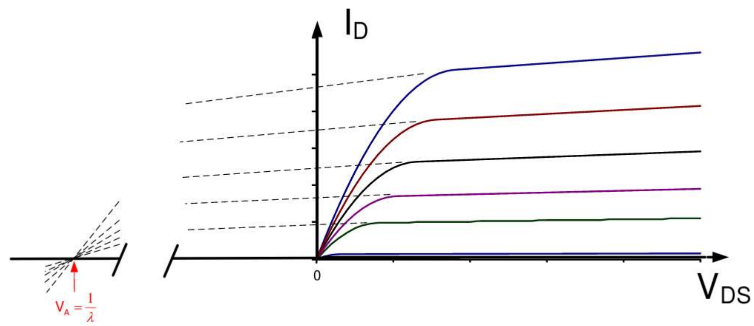
The small signal output conductance, as obtained from the square-law model, is given by the equation, $g_0 = \lambda I_{DQ}$

Unfortunately, the parameter λ is quite device size and operating point dependent. Using a small signal analysis in SPECTRE (parametric analysis) and the calculator feature to plot λ for a wide range of L values and a wide range of operating conditions (small, medium, and large V_{DS} values). Comment on how λ varies with L and with V_{DS}. Support your comments with graphical comparisons.

Part 6: (Extra Credit) Early Voltage

The parameter λ obtained in Part 3 and used again in Part 5 is related to a parameter called the Early Voltage. In the saturation region, at constant V_{GS} voltages, the drain current I_D varies nearly linearly with V_{DS}. If a line is fit to this drain current, the x-axis intercept of the line is called the Early voltage. Determine the Early Voltage for several I_D-V_{DS} curves. How is the Early Voltage related for the different I_D-V_{DS} curves you obtained? What is the relationship between the Early Voltage and the parameter λ?

Curve shown below should help you extract early voltage V_A.



Deliverables:

- Verification sheet
- Prelab
- Introduction:
  - Discuss what is done in lab
  - Discuss why is it useful
- Part 3 - Square-Law Parameter Extraction:
  - Screenshot of circuit you used to extract parameters
  - Screenshot of how you extracted 1 parameter
  - Derivation of formulas you used to extract each parameter (you should have 4 in total, one for each parameter)
  - Table showing the 4 different parameters for 2 different operating conditions
  - Comparison between the 2 sets of parameters
- Part 4 - Comparison with BSIM Model:
  - Screenshot of 2 simulation waveforms
  - Comparison between calculated and simulated I_D
  - Comparison between I_D at 2 different operating conditions
- Part 5 - Output Conductance Extraction:
  - Plots of λ vs V_{DS} and λ vs L (you can do them on 1 plot if you want)
  - Analyze how λ varies with L and V_{DS}
- Part 6 – (Extra Credit) Early Voltage:
  - Plot of how you extracted V_A
  - Discuss the relationship between V_A and λ
- Conclusion:
  - Discuss what you learned in lab
  - Add any comments on what you liked or what would you want to see changed