Lab 6: Models for MOS Devices

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

$$I_G = I_B = 0$$

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

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

With this model, the device is characterized by the process parameters $\{\mu, C_{OX}, V_{TO}, \phi, \lambda, \gamma\}$ 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 {μC_{OX}, V_{TO}, ϕ, λ, γ } from the BSIM model for a device with dimensions W=12µ and L=3µ near an operating point of V_{GS}=2V, V_{DS}=4V, and VBS=0. Note we are only extracting the product μC_{OX}, not the individual parameters µ and C_{OX}.

Hint: One way to extract V_{T0} would be to simulate the following two circuits (with V_{BS}=0V).
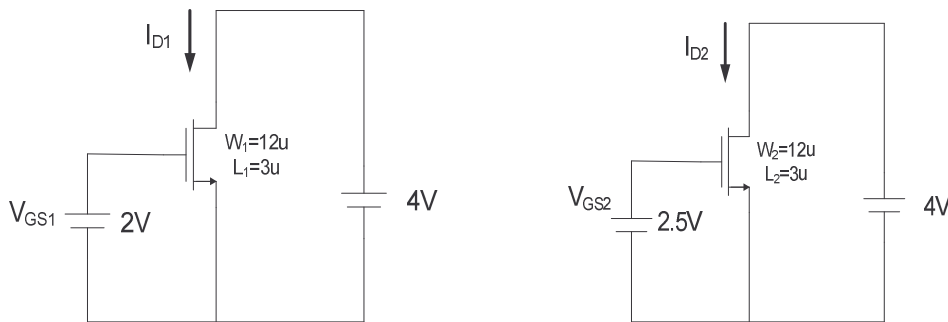
To find the operating point current for a circuit shown above, run a DC analysis and only turn on the option of **Save DC operating point**. After successful completion, click on **Results-Print-DC operating points** in the ADE window. Now click on the transistor in schematic window and you will see the operating point details.

Since both devices are operating in saturation we obtain the expressions from the two circuits

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

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

Since V_{DS} are the same, taking the ratio and then the square root, a single linear expression in V_T is obtained. You may extract the other parameters similarly.

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 again in this lab exercise.

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.

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.
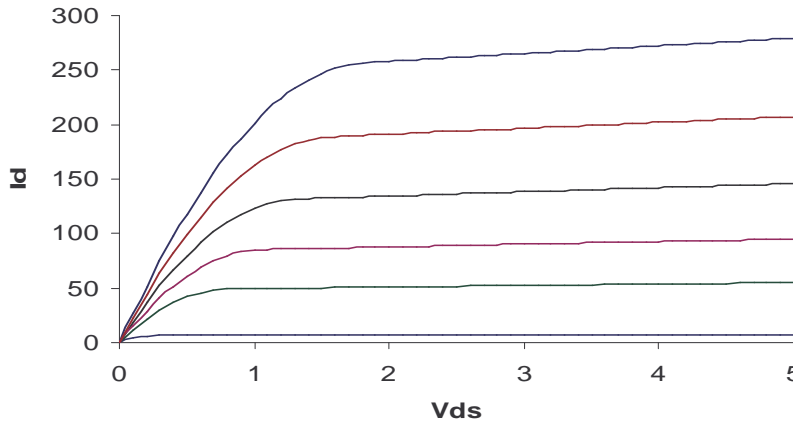
Using the BSIM model, plot the transfer characteristics for a device with dimensions W=12μ and L=3μ near an operating point of V_{GS}=2V, V_{DS}=4V, and V_{BS}=0 and compare with the corresponding square law transfer characteristics using the parameters that you extracted in Part 3. Comment how closely the transfer characteristics compare near the operating point where you extracted your parameters.

> To obtain a family of curves through simulations as shown above, use **Tools-Parametric analysis** in ADE. For example, in schematics window, enter vgs 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.

Now use your extracted model parameters to predict the output characteristics of a device that has dimensions W=50μ, L=1μ operating with a VGS of around 4V and a VDS of around 5V and compare with what the BSIM model predicts for the same device.

Part 5: Output Conductance Extraction

The small signal output conductance, as obtained from the square-law model, is given by the equation

$$g_o = \lambda I_{DQ}$$

Unfortunately the parameter λ is quite device size and operating point dependent. Using a small signal analysis in SPECTRE, develop a table of λ values 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.

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