EE 330 Pre-Lab 7

Spring 2024

The square-law model is frequently used to model MOSFETs for quick hand calculations and for gaining insight into circuits. This model, for an n-channel transistor, is described by the equations:

$$I_G = I_B = 0$$

$$I_{DS} = \begin{cases} 0 & \mathrm{V_{GS}} \le \mathrm{V_{TH}} & \mathit{Cutoff} \\ \mu\mathrm{C_{ox}}\frac{\mathrm{W}}{\mathrm{L}}\left(\mathrm{V_{GS}} - \mathrm{V_{TH}} - \frac{\mathrm{V_{DS}}}{2}\right)\mathrm{V_{DS}} & \mathrm{V_{GS}} \ge \mathrm{V_{TH}}, \mathrm{V_{DS}} < (\mathrm{V_{GS}} - \mathrm{V_{TH}}) & \mathit{Triode/Linear} \\ \mu\mathrm{C_{ox}}\frac{\mathrm{W}}{2\mathrm{L}}(\mathrm{V_{GS}} - \mathrm{V_{TH}})^2(1 + \lambda\mathrm{V_{DS}}) & \mathrm{V_{GS}} \ge \mathrm{V_{TH}}, \mathrm{V_{DS}} \ge (\mathrm{V_{GS}} - \mathrm{V_{TH}}) & \mathit{Saturation} \end{cases}$$

where,

$$V_{TH} = V_{TH0} + \gamma(\sqrt{\phi - V_{BS}} - \sqrt{\phi})$$

In these equations, $\boldsymbol{V_{GS}}$, $\boldsymbol{V_{BS}}$, $\boldsymbol{V_{DS}}$, $\boldsymbol{W}$, and $\boldsymbol{L}$ are parameters that can be determined by the designer (design variables). The variables $\boldsymbol{\mu C_{ox}}$, $\boldsymbol{\lambda}$, $\boldsymbol{\gamma}$, $\boldsymbol{\phi}$, and $\boldsymbol{V_{T0}}$ are process parameters that are unique to the process and cannot be selected by the designer. For analytical calculations, the process parameters must known.

If the process parameters in these models are not known, they can be extracted by making specific measurements on test devices. In this experiment, emphasis will be placed on determining the process parameters from test devices. Though the most likely scenario for extracting process parameters would be to make measurements of test devices in the laboratory, simulated device performance obtained using an accurate BSIM model of test devices will be used instead in this experiment to reduce the time required to make electrical measurements from test devices.

Though it can be measured, for this lab it will be assumed that $\phi \approx 0.6V$.

Determining $\mathrm{V_{TH0}}$: Suppose a transistor is biased to operate in the saturation region and the current through an n-channel MOSFET is measured twice. The first time, $\mathrm{V_{DS1}}$ is fixed and the gate-source voltage is V_{GS1}. The second time, $\mathrm{V_{DS2}}$=$\mathrm{V_{DS1}}$ but the gate-source voltage is V_{GS2} where $\mathrm{V_{GS2}}$ is different than $\mathrm{V_{GS1}}$. In both measurements, $V_{BS} = 0$. Derive the following expression for the zero-bias threshold voltage, V_{TH0}.

$$V_{TH0} = \frac{V_{GS1} - V_{GS2}\sqrt{\frac{I_{DS1}}{I_{DS2}}}}{1 - \sqrt{\frac{I_{DS1}}{I_{DS2}}}}$$

Hint: Write two independent equations and solve these two equations for V_{TH0}.

Determining λ : Suppose a transistor is biased to operate in the saturation region and the current through an n-channel MOSFET is measured twice. The first time, $\mathrm{V_{GS1}}$ is fixed and the drain-source voltage is V_{DS1} . The second time, $\mathrm{V_{GS2}}$=$\mathrm{V_{GS1}}$ but the drain-source voltage is set to V_{DS2} where $\mathrm{V_{DS1}}$ and $\mathrm{V_{DS2}}$ are not equal. In both measurements, set $V_{BS} = 0$. Derive the below expression for λ.

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

Determining γ: Suppose the threshold voltage, following an approach similar to that used to extract V_{TH0} ,is extracted the threshold voltage for V_{BS} =0 and again for a value of V_{BS} that is not 0. Derive an expression for γ in terms of the two drain currents and the values of V_{GS}.

Determining μCOX: Suppose V_{TH0}, λ, and γ have been extracted using the techniques described above. Set up a test procedure for deriving μC_{ox} and give the mathematical expression you have for extracting μC_{OX}.

Create an Excel table that implements the expressions you derived for extracting model parameters based upon measured or simulated data. The inputs in the table should be measured or simulated drain currents for specific biasing conditions (i.e. specific values for V_{GS}, V_{DS}, and V_{BS}) as relevant for specific parameter extractions. Keep the table organized. You will use it heavily in the next two labs.

Use the data given below which was derived from a device with model parameters $\mu C_{ox} = 81\mu A/V^2$, $\lambda = 0.025V^{-1}$, γ of $0.44V^{-0.5}$, ϕ=0.6V, and $V_{TH0} = 0.71V$ to validate that your Excel table correctly extracts these model parameters.

Data Point	I_{DS}	V_{GS}	V_{DS}	V_{BS}	W/L
1	$6.011\mu A$	$0.9V$	$1.6V$	$0V$	4
2	$14.07\mu A$	$1V$	$1.6V$	$0V$	4
3	$17.56\mu A$	$1V$	$1.6V$	$0.1V$	4
4	$8.273\mu A$	$0.9V$	$1.6V$	$0.1V$	4
5	$14.14\mu A$	$1V$	$1.8V$	$0V$	4