EE 330 Pre-Lab 7

Spring 2022

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:

$$I_G = I_B = 0$$

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

Equation 1

where,

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

Equation 2

In these equations, $\boldsymbol{V_{GS}}$, $\boldsymbol{V_{BS}}$, $\boldsymbol{V_{DS}}$, $\boldsymbol{W}$, and $\boldsymbol{L}$ are parameters that can be selected by the designer (design variables). The variables $\boldsymbol{\mu C_{ox}}$, $\boldsymbol{\lambda}$, $\boldsymbol{\gamma}$, and $\boldsymbol{V_{T0}}$ are process parameters that are unique to the process and cannot be selected by the designer. To do any quick hand calculations for a circuit, these process parameters must be found.

For this lab, assume $\phi \approx 0.6V$.

Question 1: Suppose the current through an n-channel MOSFET is measured twice. The first time, the gate-source voltage is V_{GS1}. The second time, the gate-source voltage is V_{GS2}. All other design variables remain the same across both measurements. In both measurements, the device is saturated and $V_{BS} = 0$. You do not know the values of μC_{ox}, λ, or γ. Derive the below expression for the device's no-bias threshold voltage (V_{TH0}). <u>You must show your work.</u>

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

Hint: Two equations, two unknowns

Question 2: Suppose the current through an n-channel MOSFET is measured twice. The first time, the drain-source voltage is V_{DS1}. The second time, the drain-source voltage is V_{DS2}. All other design variables remain the same across both measurements. In both measurements, the device is saturated and $V_{BS} = 0$. You do not know the values of μC_{ox}, λ, or γ. Derive the below expression for λ. <u>You must show your work.</u>

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

Question 3: Suppose the situation from Question 1 is repeated, but this time V_{BS} is some non-zero value for both measurements. You know V_{TH0}. Could you use this data to find γ? Derive an expression for γ that is in terms of only currents, gate-source voltages, and V_{BS}. You must show your work.

Question 4: Suppose you know V_{TH0}, λ, and γ, as well as all your design variables. Derive an expression for μC_{ox}.

Question 5: Create an Excel table that implements the expressions you derived in Questions 1 through 4. Keep the table organized and clean. You will use it heavily in the next two labs.

Use the below data to test your Excel table. You should calculate a μC_{ox} of $81\mu A/V^2$, a λ of $0.025V^{-1}$, a γ of 0.44, and a V_{TH0} of $0.71V$.

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