EEE381 Tech Memo

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To: Colin Bussert
Date: Performed: 10/04/18; Due: 10/11/18
Subject: Lab #02

1 Abstract

The purpose of this lab exercise was to observe the DC and small AC signal charactaristics of MOSFET devices. This includes extracting various parameters that determine specific characteristics of MOSFETs. Theses parameters were extracted from both NMOS and PMOS devices.

2 Theory

DC behavior of MOSFETs can be modeled like a simple transconductance amplifier, where the current through the device is a function of the properties of the transistor, the voltage across the gate and source, and the voltage across the drain and source. This relationship changes based on what operating mode the transistor is in, either linear or saturation. Both of these relationships can be seen in Equations 1 and 2.

$$I_d = k_n\prime \frac{W}{L}[(V_{GS} - V_t)V_{DS} - \frac{1}{2}V_{DS}^2](1 + \lambda V_{DS}), \qquad V_{DS} \geq V_{GS} - V_t \quad (Linear) \tag{1}$$

$$I_d = k_n\prime \frac{W}{L}(V_{GS} - V_t)^2(1 + \lambda V_{DS}), \qquad V_{DS} < V_{GS} - V_t \quad (Saturation) \tag{2}$$

Where $k_n\prime = \mu_n C_{ox}$, μ_n is the electron mobility, C_{ox} is oxide capacitance per unit area, W is channel width, L is channel length, λ is the channel length modulation parameter, and V_t is the threshold voltage. V_t can be calculated when there is a voltage between the source and body with Equation 3.

$$V_t = V_{t0} + \gamma\Big[\sqrt{2\phi_f + V_{SB}} - \sqrt{2\phi_f}\,\Big] \tag{3}$$

Where V_{t0} is the threshold voltage when $V_{SB} = 0$, ϕ_f is a physical parameter of the device and γ is the body-effect parameter, which can be expressed as seen in Equation 4.

$$\gamma = \frac{\sqrt{2q\varepsilon_s N_{sub}}}{C_{ox}} \tag{4}$$

The body-effect parameter γ can be found by ploting $\sqrt{I_D}$ vs. V_{GS} and finding the slope, which is γ. Using this same graph, the threshold voltages can be found by looking at the x-intercept for each of the different V_{SB} values.

These equations apply both to NMOS and PMOS but when calculating values for PMOS, the absolute value of the voltages need to be used, due to the opposite polarity of the device.

The channel length modulation effect causes an increase in current by a factor of $1 + \lambda V_{DS}$ due to the shortening of the channel length. For small signal AC modeling, this can effectvly be modeled by a resistance between the drain and source, r_0. The value can be found using Equation 5.

$$r_0 = \frac{1}{|\lambda| I_D} = \frac{|V_A|}{I_D} \tag{5}$$

Where V_A is the early voltage, which can be found by extrapolating the line created by the I_d vs. V_{DS} curve when the MOSFET is in saturation, to the x-intercept and taking the absolute value.

3 Results and Discussion

For the first part of the experiment, five different V_{DS} values were applied and I_D was measured for three V_{SB} values, with $V_{GS} = V_{DS}$for a total of 24 data points. This data was then used to create the $sqrtI_D$ vs. V_{DS} graphs (Figures 1 and 2 and Tables 1 and 2).

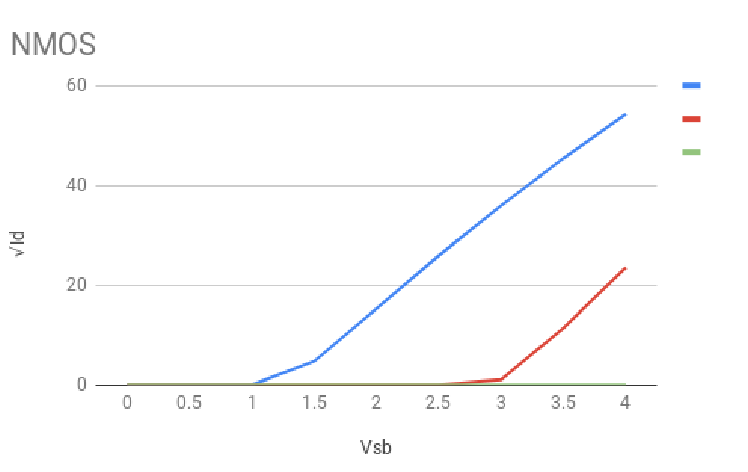

Figure 1: NMOS $\sqrt{I_D}$ vs. V_{DS}

Table 1: NMOS I_D vs. V_{DS} data

$\mathbf{V_{DS}}$ (V)	$\mathbf{I_D}$ (µA)		
V_{SB}	0V	2V	5V
0	0	0	0
0.5	0	0	0
1	0	0	0
1.5	22.2	0	0
2	234.1	0	0
2.5	673.2	0	0
3	1294.4	1.2	0
3.5	2062.8	131.3	0
4	2950.5	555.9	0

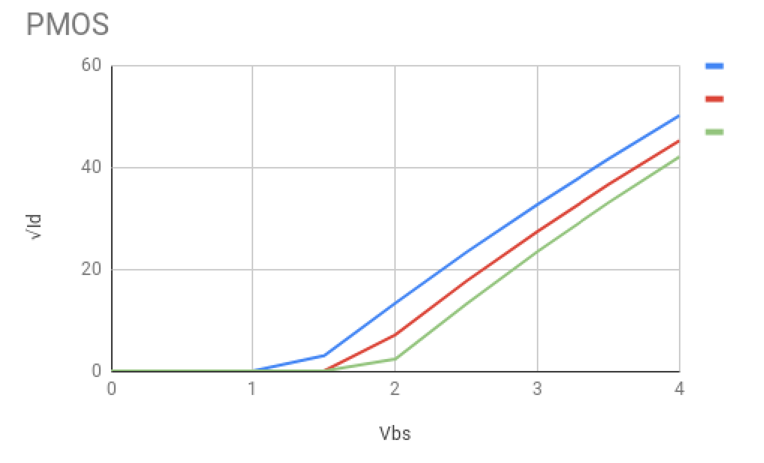

Figure 2: PMOS $\sqrt{I_D}$ vs. V_{DS}

Table 2: PMOS I_D vs. V_{SD} data

$\mathbf{V_{SD}}$ (V)	$\mathbf{I_D}$ (µA)		
V_{BS}	0V	2V	5V
0	0	0	0
0.5	0	0	0
1	0	0	0
1.5	9.1	0	0
2	177.9	50.6	5.5
2.5	546.8	313.4	174.7
3	1076	756	553.6
3.5	1741.4	1346	1097.2
4	2525	2053	1780.1

A linear regression was used to find a line of best fit for the extraction of the body-effect parameter (γ) and the threshold voltage (V_t). The experimental values for V_t that were found can be seen in Table 3 and the experimental value for γ can be seen in Table 4.

Table 3: MOSFET V_t parameter extraction

$\lvert\mathbf{V_{SB}}\rvert$ (V)	$\mathbf{V_t}$ (V)	
	NMOS	PMOS
0	0.644	0.669
2	1.08	0.77
5	4.8	0.839

Table 4: MOSFET γ parameter extraction

MOSFET	γ
NMOS	9.6265
PMOS	12.2729

Tables, graphs, equations, and prose should be used to convey all of the results in an easy-to-follow format. Details should be provided to explain how the experimental results were obtained. The text should explain any knowledge and/or information gained by performing the experiment. All questions posed in the labratory handout and/or by the TAs in lab should be answered.

All plots must be created using a software package (e.g. EXCEL or MATLAB). Tables and equations must not be hand drawn. Be sure to include comparisions between theoretical, simulation, and hardware results, as well as comparison to design specifications where appropriate.

4 Conclusion

A breif section contaning one or two paragraphs that concisely states the nature/objective of the assignment, the approch taken to complete the assignment, and general observations about the outcome(s). Breif commentary on agreement – or lack thereof – between theory and experiment would be appropriate, but specific results that were already reported and discussed at length in the *Results and Discussion* section should not be repeated.