

report

Siddhartha

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## 1 MOSFET Model

### 1.1 Constants

$$n_i = 10^{10}/cm^3 \quad (1)$$

$$\epsilon_{ox} = 3.9 \times 8.854 \times 10^{-14} F/cm \quad (2)$$

$$\epsilon_s = 11.9 \times 8.854 \times 10^{-14} F/cm \quad (3)$$

### 1.2 Variable Parameters

$$N_A = 10^{15}/cm^3 \quad (4)$$

$$t_{ox} = 2 \times 10^{-5} cm \quad (5)$$

$$V_{FB} = 1.035V \quad (6)$$

$$q = 1.60217663 \times 10^{-19} C \quad (7)$$

$$W = 0.22 \times 10^{-4} cm \quad (8)$$

$$L = 4 \times 10^{-4} cm \quad (9)$$

$$V_{BS} = -10V \quad (10)$$

$$\mu_n = 1340 cm^2/(V.s) \quad (11)$$

### 1.3 Calculations

$$C_{ox} = \frac{\epsilon_{ox}}{t_{ox}} \quad (12)$$

$$\phi_B = 0.0258 \log(N_A/n_i) \quad (13)$$

$$V_{th} = V_{FB} + 2\phi_B + \frac{\sqrt{2qN_A\epsilon_s 2\phi_B}}{C_{ox}} V \quad (14)$$

$$\gamma = \frac{\sqrt{2 \times \epsilon_s q N_A}}{C_{ox}} \quad (15)$$

$$\alpha = 1 + \gamma / (2\sqrt{2\phi_B - V_{BS}}) \quad (16)$$

### 1.4 Level-3 Model

$$V_{DSat} = (V_{GS} - V_{th})/\alpha \quad (17)$$

$$I_{DS} = \begin{cases} \frac{\mu_n C_{ox} W}{2L} (V_{GS} - V_{th}) \left[ 2V_{DS} - \frac{V_{DS}^2}{V_{DSat}} \right], & \text{if } V_{DS} \leq V_{DSat} \\ \frac{\mu_n C_{ox} W}{2L} (V_{GS} - V_{th}) V_{DSat}, & \text{if } V_{DS} \geq V_{DSat} \end{cases} \quad (18)$$

### 1.5 Simulations

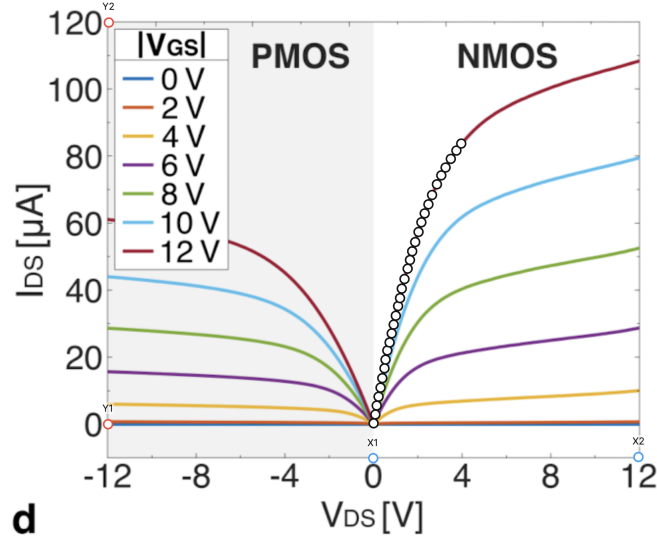
$$V_{DSeff} = V_{DS} - \frac{1}{2}(V_{DS} - V_{DSat} + \sqrt{(V_{DS} - V_{DSat})^2 + \Delta^2}) \quad (19)$$

$$V_{DSeff} = \begin{cases} V_{DS}, & \text{if } V_{DS} \leq V_{DSat} \\ V_{DSat}, & \text{if } V_{DS} \geq V_{DSat} \end{cases} \quad (20)$$

$$I_{DS} = \frac{\mu_n C_{ox} W}{2L} (V_{GS} - V_{th}) \left( 2V_{DSeff} - \frac{V_{DSeff}^2}{V_{DSat}} \right) \quad (21)$$

## 1.6 Plot-digitizer

Plot digitizer app is used to digitize the plot given in the paper and the data obtained is used to calculate the gain factor.



$$I_{DS}(2.05V) = 57.44\mu A$$

$$I_{DS}(0.01V) = 00.28\mu A$$

In equation 21 if we assume linearity with  $V_{DS}$  and neglecting the term  $\frac{V_{DS}^2}{2V_{DSat}}$  the gain factor is given by the equation 22.

$$\mu C_{ox} \frac{W}{L} = \frac{1}{V_{GS} - V_{th}} \times \frac{I_{DS}(2.05V) - I_{DS}(0.01V)}{2.05 - 0.01} \quad (22)$$

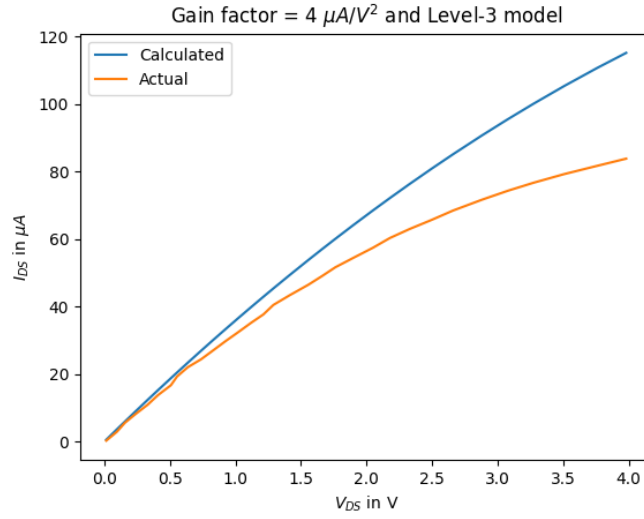
$$\mu C_{ox} \frac{W}{L} = \frac{1}{12 - 2.45} \times \frac{57.44 - 00.28}{2.05 - 0.01} \mu A/V^2 \quad (23)$$

$$\mu C_{ox} \frac{W}{L} = 2.93 \mu A/V^2 \quad (24)$$

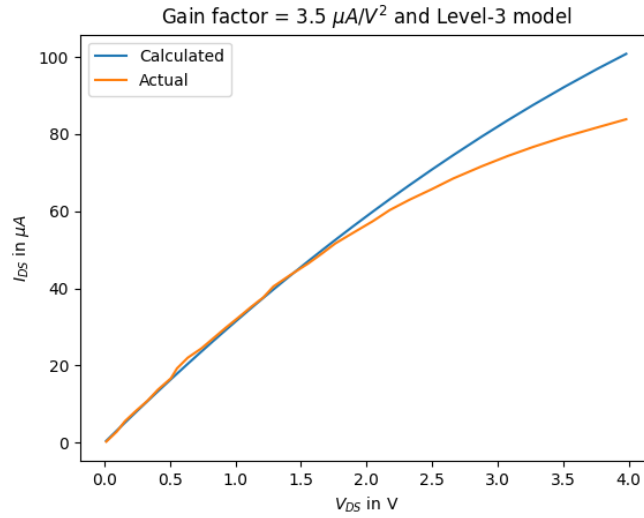
The gain factor given in the reference is  $4\mu A/V^2$  the difference may be due to the fact that the Current through channel is not a linear function of  $V_{DS}$ .

## 1.7 Comparing acquired data with level-3 model

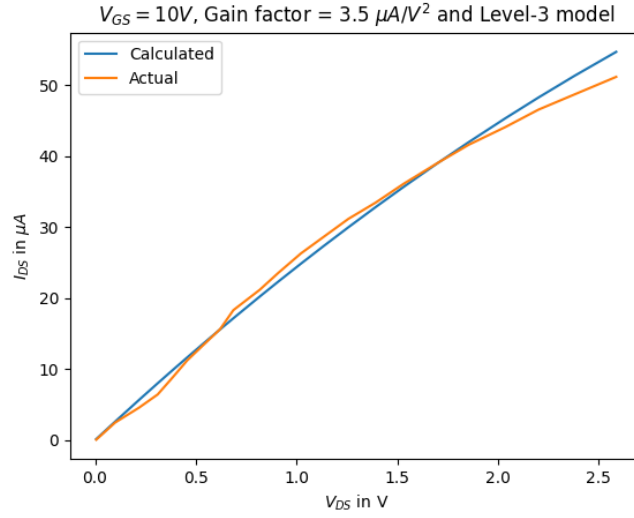
The Drain current ( $I_{DS}$ ) is calculated using the level-3 model given by equation 21, the gain factor is fixed at the value  $4\mu A/V^2$  as described in the paper. The comparison of calculated drain current and acquired drain current is shown in figure (1.7).



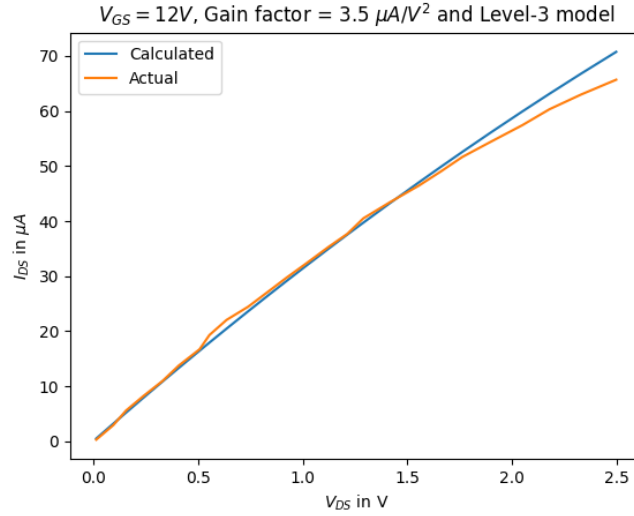
If the gain factor is reduced to  $3.5\mu A/V^2$  the Comparison graph is as shown below in figure (1.7).



The plot of  $V_{GS} = 10V$  is digitized and compared with the model with gain factor =  $3.5 \text{ V}$  the comparison is shown in figure (1.7). The range of  $V_{DS}$  considered is  $0V \rightarrow 2.5V$  because the plot is linear in that region.



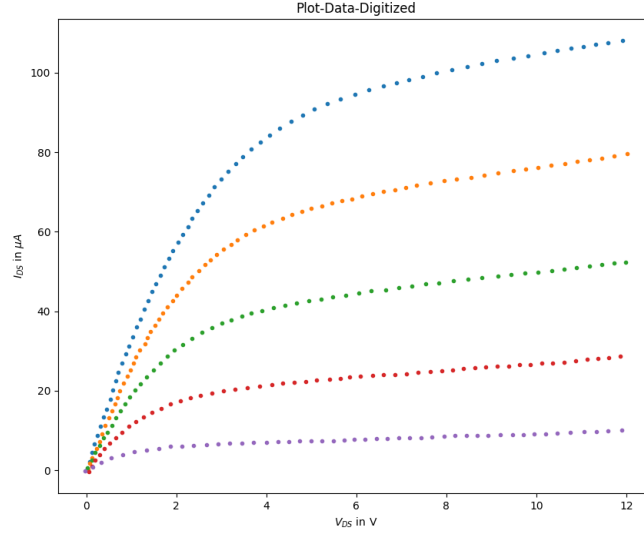
The comparison of Calculated and acquired data for  $V_{GS} = 12V$  and for  $V_{DS}$  in range of  $0V \rightarrow 2.5V$  is shown in figure (1.7).



## 1.8 Four MOS-CAPs in parallel

### 1.9 Model

The data from the plot is extracted for the gate voltage values of 4V, 6V, 8V, 10V, 12V and plotted in figure 1.9.



Since, there is a small slope in saturation region the previous model is modified and the new modified model contains a new parameter  $\lambda$ . The new model is given by the equation 25.

$$I_{DS} = \text{gain} \times \alpha \left( V_{DSeff} V_{DSat} - \frac{V_{DSeff}^2}{2} \right) (1 + \lambda V_{DS}) \quad (25)$$

where,

$$\alpha = \text{Level - 3 model Parameter} \quad (26)$$

$$\text{Gain} = \frac{\mu C_{ox} W}{L} \quad (27)$$

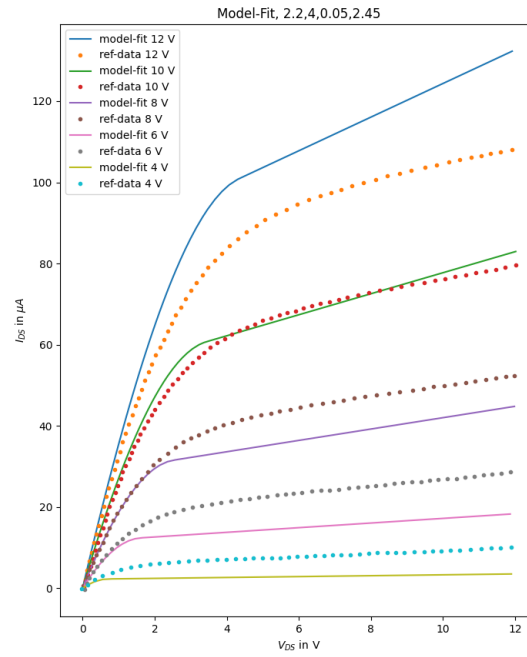
$$V_{DSat} = \frac{V_{GS} - V_{th}}{\alpha} \quad (28)$$

$$(29)$$

## 1.10 Fit - 1

Variable parameters to fit the model for different values of  $V_{GS}$  and  $V_{DS}$ .

- $\alpha = 2.2$
- $\text{gain} = 4$
- $\lambda = 0.05$
- $V_{th} = 2.45$

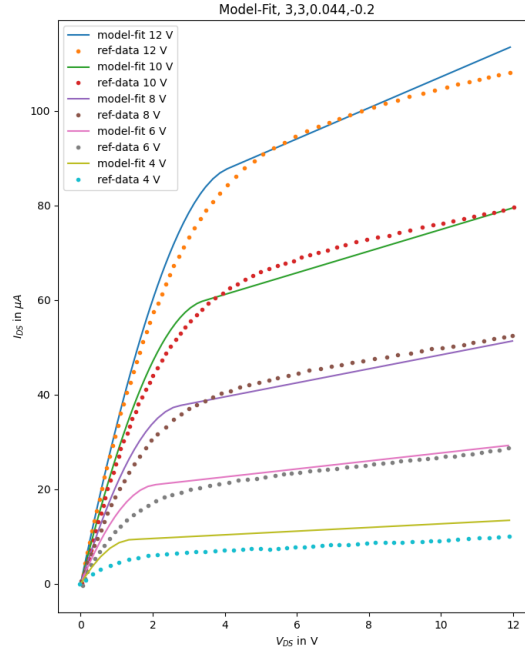


## 1.11 Fit - 2

Variable parameters to fit the model for different values of  $V_{GS}$  and  $V_{DS}$ .

- $\alpha = 3$
- $\text{gain} = 3$
- $\lambda = 0.044$
- $V_{th} = -0.2$

With the parameters set the model is fit and shown in the figure 1.11.



### 1.11.1 Analysis of the Fit

$$V_{DS} < V_{DSat}$$

$$I_{DS} = \text{gain} \times \left[ (V_{DS}(V_{GS} - V_{th})) - \frac{(V_{GS} - V_{th})^2}{2\alpha} \right] (1 + \lambda V_{DS}) \quad (30)$$

$$V_{DS} \geq V_{DSat}$$

$$I_{DS} = \text{gain} \times \frac{(V_{GS} - V_{th})^2}{2\alpha} (1 + \lambda V_{DS}) \quad (31)$$



## 1.12 QUCS simulations

There is some resistance in between source contact pad and source terminal in transistor therefore, we model a resistor in between them and similarly a resistance between drain contact pad drain terminal at transistor. The resistance is calculated as shown in equation (??eq:resistance]).

$$R = \frac{\rho L}{A} = \frac{0.085 \times 6}{2 * 0.22 \times 10^{-4}} = 11590\Omega \quad (32)$$

The model used to simulate is as shown in the figure 1.12.  $I_D$  is given by equation 33.

$$I_D = \alpha * \text{gain} * (V_{DSeff} V_{DSat} - \frac{V_{DSeff}^2}{2})(1 + \lambda V_{DSi}) \quad (33)$$

the equations of  $V_{DSeff}$ ,  $V_{DSat}$  and  $V_{DSi}$  are given by equation 34

$$V_{GSi} = V_{GS} - V_{Si} \quad (34)$$

$$V_{DSi} = V_{DS} - V_{Si} \quad (35)$$

$$V_{DSat} = (V_{GSi} - V_{th})/\alpha \quad (36)$$

$$V_{DSeff} = V_{DSi} - \frac{1}{2}(V_{DSi} - V_{DSat} + \sqrt{(V_{DSi} - V_{DSat})^2 + \Delta^2}) \quad (37)$$

The parameters are  $\alpha$ , gain,  $V_{th}$ ,  $\lambda$

