DDP report

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Contents

1 MOSFET Model

Constants

$$n_i = 10^{10}/cm^3 \tag{1}$$
$$\epsilon_{ox} = 3.9 \times 8.854 \times 10^{-14} F/cm \tag{2}$$
$$\epsilon_s = 11.9 \times 8.854 \times 1e - 14 F/cm \tag{3}$$

Variable Parameters

$$N_A = 10^{15}/cm^3 \tag{4}$$
$$t_{ox} = 2 \times 10^{-5} cm \tag{5}$$
$$V_{FB} = 1.035 V \tag{6}$$
$$q = 1.60217663 \times 10^{-19} C \tag{7}$$
$$W = 0.22 \times 10^{-4} cm \tag{8}$$
$$L = 4 \times 10^{-4} cm \tag{9}$$
$$V_{BS} = -10 V \tag{10}$$
$$\mu_n = 1340 cm^2/(V.s) \tag{11}$$

Calculations

$$C_{ox} = \frac{\epsilon_{ox}}{t_{ox}} \tag{12}$$
$$\phi_B = 0.0258 \log(N_A/n_i) \tag{13}$$
$$V_{th} = V_{FB} + 2\phi_B + \frac{\sqrt{2qN_A\epsilon_s 2\phi_B}}{C_{ox}} V \tag{14}$$
$$\gamma = \frac{\sqrt{2 \times \epsilon_s q N_A}}{C_{ox}} \tag{15}$$
$$\alpha = 1 + \gamma/(2\sqrt{2\phi_B - V_{BS}}) \tag{16}$$

Level-3 Model

$$V_{DSat} = (V_{GS} - V_{th})/\alpha \tag{17}$$
$$I_{DS} = \begin{cases} \frac{\mu_n C_{ox} W}{2L}(V_{GS} - V_{th}) \left[2V_{DS} - \frac{V_{DS}^2}{V_{DSat}}\right], & \text{if } V_{DS} \leq V_{DSat} \\ \frac{\mu_n C_{ox} W}{2L}(V_{GS} - V_{th}) V_{DSat}, & \text{if } V_{DS} \geq V_{DSat} \end{cases} \tag{18}$$

Simulations

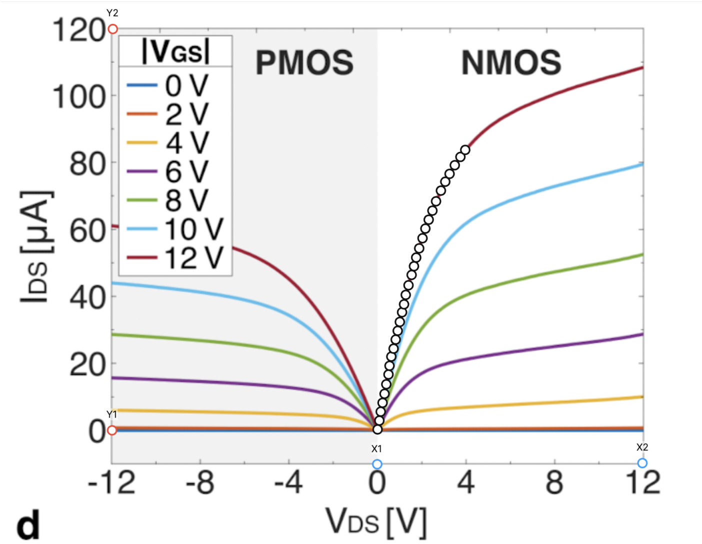
$$V_{DSeff} = V_{DS} - \frac{1}{2}(V_{DS} - V_{DSat} + \sqrt{(V_{DS} - V_{DSat})^2 + \Delta^2}) \tag{19}$$

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

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

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.

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

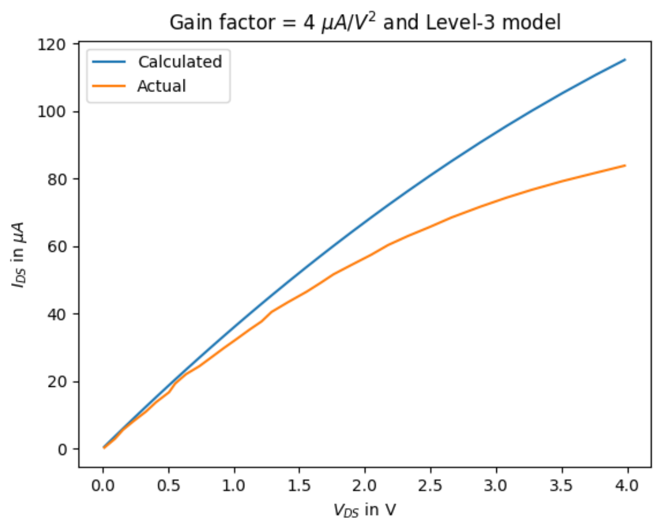
$$\mu C_{ox}\frac{W}{L} = \frac{1}{12 - 2.45} \times \frac{57.44 - 00.28}{2.05 - 0.01}\mu A/V^2 \tag{23}$$

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

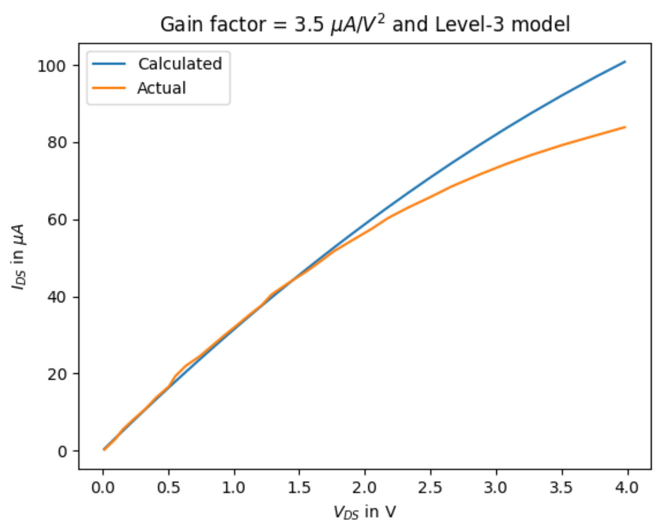
The gain factor given in the reference is $4\mu A/V^2$ the difference may be due to the fact that the Current through channel is not a linear function of V_{DS}.

Comparing acquired data with level-3 model

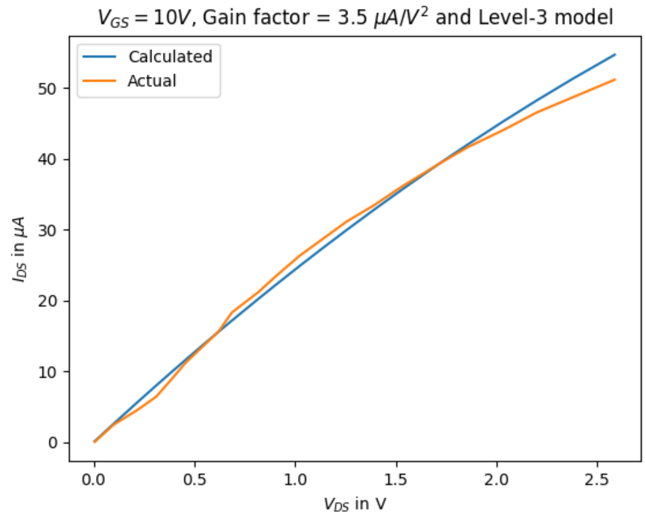
The Drain current (I_{DS}) is calculated using the level-3 model given by equation 21, the gain factor is fixed at the value $4\mu A/V^2$ as described in the paper. The comparison of calculated drain current and acquired drain current is shown in figure (1).



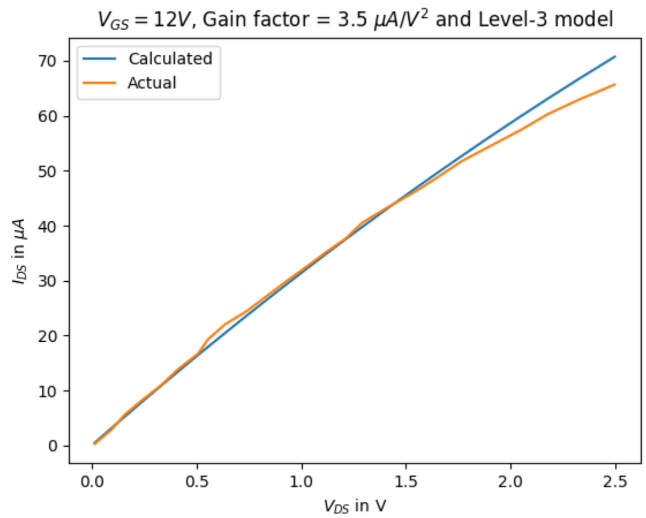
If the gain factor is reduced to $3.5\mu A/V^2$ the Comparison graph is as shown below in figure (1).



The plot of $V_{GS} = 10V$ is digitized and compared with the model with gain factor $= 3.5$ V the comparison is shown in figure (1). The range of V_{DS} considered is $0V \rightarrow 2.5V$ because the plot is linear in that region.



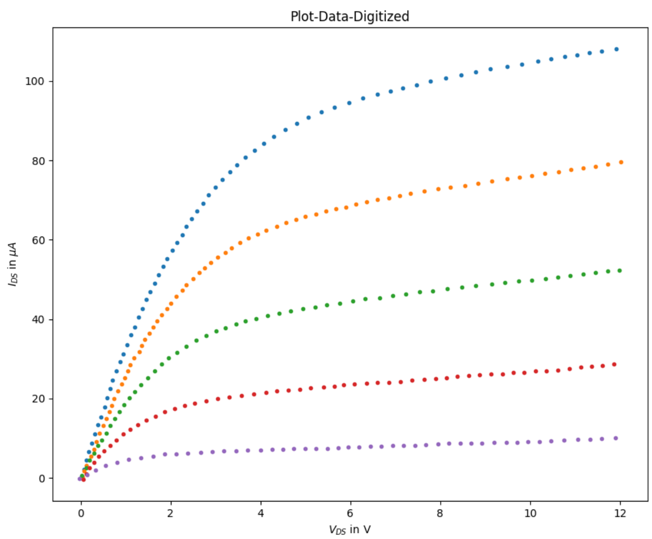
The comparison of Calculated and acquired data for $V_{GS} = 12V$ and for V_{DS} in range of $0V \rightarrow 2.5V$ is shown in figure (1).



Four MOS-CAPs in parallel

Model

The data from the plot is extracted for the gate voltage values of $4V$, $6V$, $8V$, $10V$, $12V$ and plotted in figure 1.



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

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

where,

$$\alpha = \text{ Level - 3 model Parameter} \tag{26}$$

$$\text{Gain } = \frac{\mu C_{ox} W}{L} \tag{27}$$

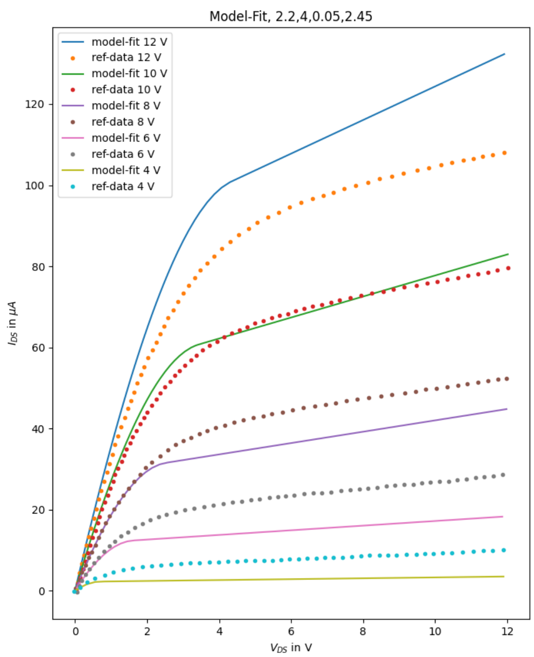
$$V_{DSat} = \frac{V_{GS} - V_{th}}{\alpha} \tag{28}$$

$$\tag{29}$$

Fit - 1

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

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

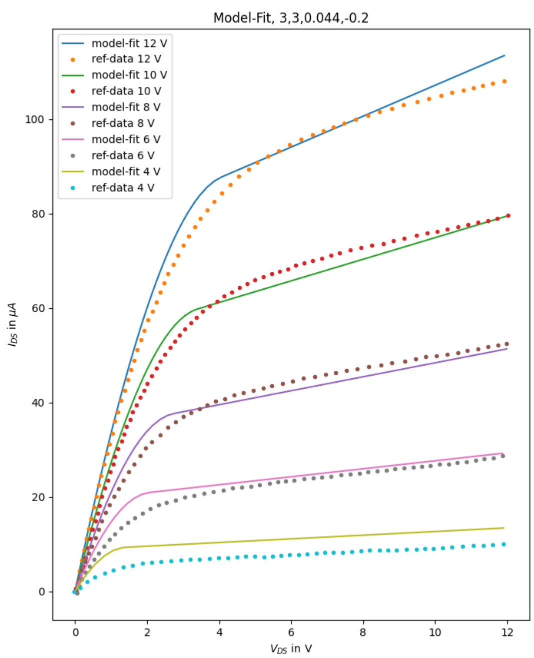


Fit - 2

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

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

With the parameters set the model is fit and shown in the figure 1.



Analysis of the Fit

$V_{DS} < V_{DSat}$

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

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

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

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 (32).

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

The model used to simulate is as shown in the figure 1. I_D is given by equation 33.

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

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

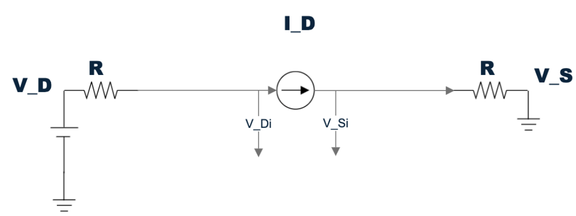
$$V_{GSi} = V_{GS} - V_{Si} \tag{34}$$

$$V_{DSi} = V_{DS} - V_{Si} \tag{35}$$

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

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

The parameters are α, gain, V_{th}, λ



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2.1 Above threshold and sub-threshold currents

Current equation for above threshold is given by equation (38)

$$I_{at} = \text{ gain } (\frac{V_{gt}}{\alpha}V_{dseff} - \frac{V_{dseff}^2}{2}) \tag{38}$$

where,

$$V_{gt} = \begin{cases} V_{gs} - V_{th} & \text{if } V_{gs} - V_{th} > 0 \\ 0 & \text{otherwise} \end{cases}$$

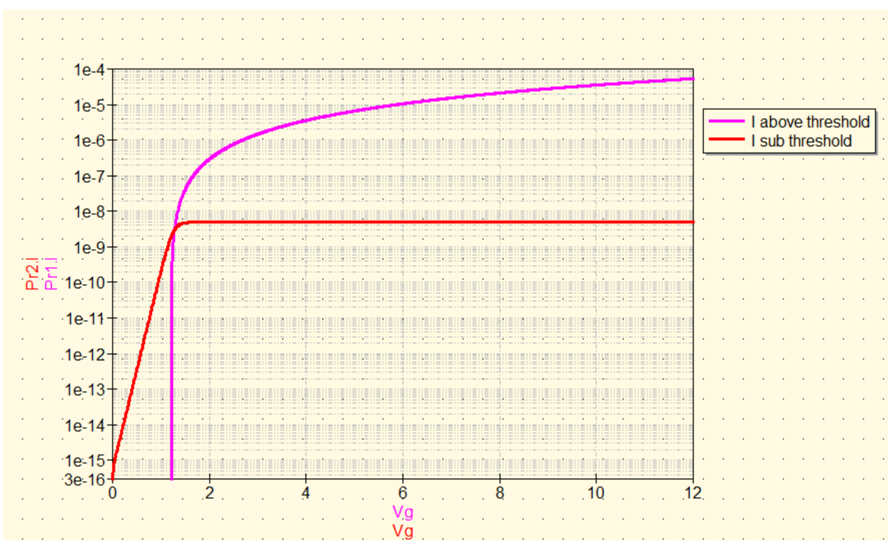
Current equation for sub-threshold region is given by equation (39)

$$I_{st} = \frac{I_s I_p}{I_s + I_p} \tag{39}$$

The equation of I_s is given by equation (40)

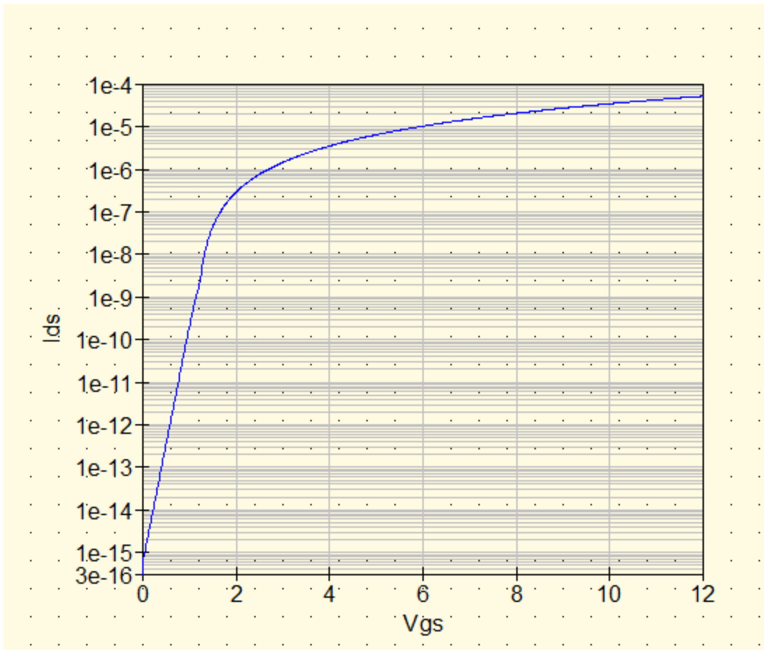
$$I_s = I_o \exp\frac{V_{gs} - V_{th}}{mV_T} \tag{40}$$

where, $I_o = I_{at}(V_{gs} = V_{th} + 3V_T)$ and $I_p = I_{at}(V_{gs} = V_{th} + 4V_T)$ The figure (2.1) shows the above threshold and sub-threshold currents.



2.2 Total current

Total current I_{DS} is given by addition of sub-threshold and above-threshold currents as shown in figure(2.2)



The sub-threshold and above threshold currents are added at a point $V_{gs} = V_{th} + 3V_T$ therefore, the slopes are not matched at that point. The gradient of the sub-threshold curve from the plot in the reference is found to be around 6.57 which should be equal to our $\frac{1}{mV_T}$ and that gives the value of $m = 5.85$.

To match the slope we need to find the gradients of each point on I_{at} curve and find the point of V_{gs} at which slope of I_{at} is equal to slope of $I_{st} = 6.57$.

Currently, I am figuring out how to find the gradients at every point and check if the slope is equal to 6.57 using verilog A. I have found a python interfacing for qucs at https://github.com/zonca/python-qucs.git and trying to send find gradients using it.

3 03-08-2024

3.1 Slope matching

Slope of sub-threshold current in log-scale is given by equation (41).

$$\frac{1}{mV_T} \tag{41}$$

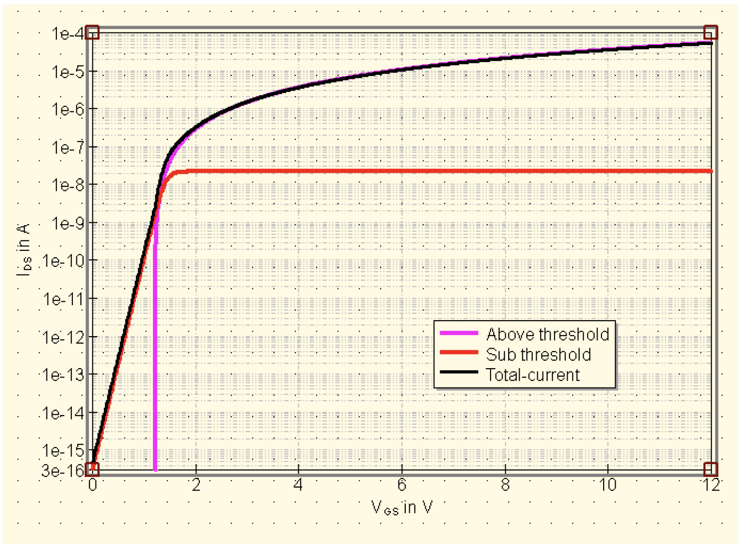
Slope of above-threshold current in log-scale when V_{gs} is just greater than V_{th} is given by equation (42).

$$\frac{2}{V_{gs} - V_{th}} \tag{42}$$

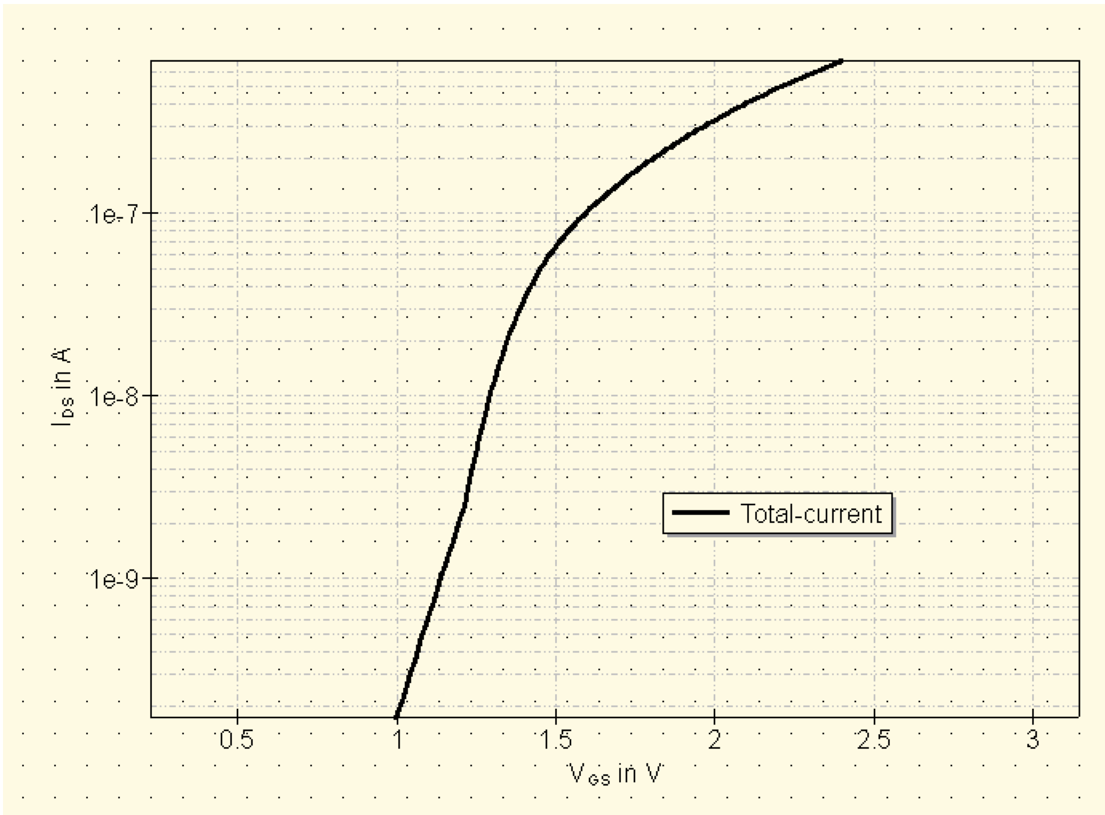
When slopes are equated, $V_{gs} = V_{th} + 2mV_T$. At this point if we equate currents, we get $I_o = I_{at}(V_{gs} = V_{th} + 2mV_T)$ by equation (43).

$$I_o = \text{ gain } \frac{2m^2V_T^2}{\alpha} \tag{43}$$

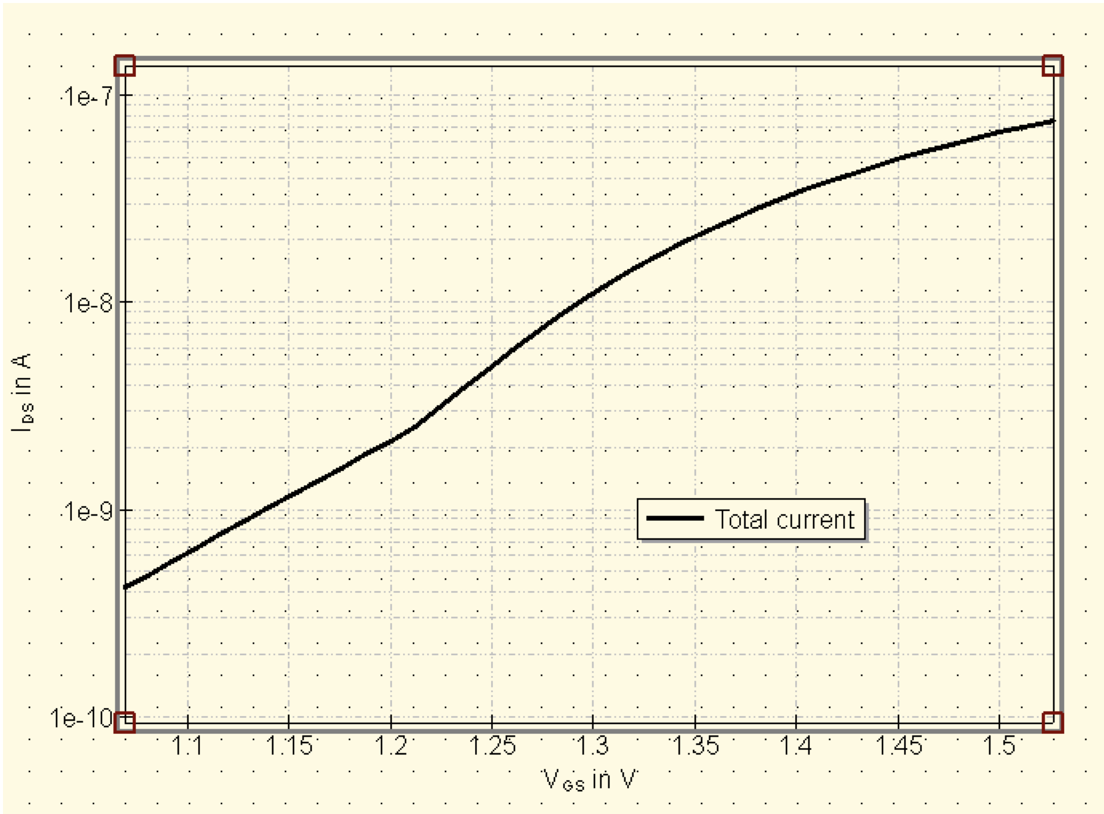
The figure (3.1) shows the above threshold, sub-threshold and total currents after matching the slope.



The figure (3.1) shows the total current curve in the region V_{gs} from 0.5 V to 3 V.



It can be seen that the total current is having a sharp point where slope changes abruptly. Is this because $I_o = I_{at}(V_{gs} = V_{th} + 2mV_T)$ by equation (43) rather than considering $I_st(V_{gs} = V_{th} + 2mV_T) = I_{at}(V_{gs} = V_{th} + 2mV_T)$ that results in $I_o = \text{ gain } \frac{2m^2V_T^2}{\alpha}\exp(-2)$. After fixing I_o to this new value when plotted we get the total current as shown in figure (3.1).



Even after this the slope is changing abruptly.