REPORT

on

"VLSI Circuits Design Laboratory"

Experiment-VII: "Verification of nMOS and pMOS DC-Characteristics."

Course Code: CSE-406

Submitted by

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Experiment-7:

Verification of nMOS and pMOS DC-charactericistics

Objectives:

- To find the MOS model parameters for the transistors and then by "paper and pencil" manually calculate the DC characteristics of I_{DS} current vs V_{DS} voltage, using simple current equations for MOS model Level 1 to determine a number of corresponding value pairs of (I_{DS}; V_{DS}) with gatesource voltage V_{gs} = a constant > V_{Th} .
- Use circuit simulator of Microwind to do a DC simulation of the I_{DS} current vs V_{DS} voltage and the result of the two methods compared.
- Calculation of the threshold voltage.

Theory:

The nMOS transistor I_{DS} current versus V_{DS} voltage equations are as follows:

Cut-off mode: $I_{DS} = 0$ when $V_{GS} < 0$

Triod/Linear region: $I_{DS} = k_n\left\{(V_{GS} - V_{Tn})V_{DS} - \frac{1}{2}V_{DS}^{2}\right\} when \quad V_{DS} < V_{GS} - V_{Tn}$ ....(1)

In Level 1 SPICE model, $I_{DS} = UO \cdot \frac{\varepsilon_0 \varepsilon_{SiO_2}}{TOX} \frac{W}{L}\left\{(V_{GS} - V_{Tn})V_{DS} - \frac{1}{2}V_{DS}^{2}\right\}$

Saturation region: $I_{DS} = \frac{1}{2}k_n\left\{(V_{GS} - V_{Tn})^2(1 + \lambda V_{DS})\right\} when \quad V_{DS} > V_{GS} - V_{Tn}$ ......(2)

In Level 1 SPICE model, $I_{DS} = \frac{1}{2}UO \cdot \frac{\varepsilon_0 \varepsilon_{SiO_2}}{TOX} \frac{W}{L}(V_{GS} - V_{TN})^2$

When the channel modulation effect is neglected the drain current equation (2) can be simplified as $I_{DS} = \frac{1}{2}k_n\left\{(V_{GS} - V_{Tn})^2\right\} when \quad V_{DS} > V_{GS} - V_{Tn}$ ....(3)

Procedure:

a) Level 1 MOS model equations to calculate DC values for the drain current I_{DS} vs drain-source voltage V_{DS} (paper & pencil)

Values $V_{GS} = +2.0v$ is taken. for the following values of $V_{DS} = 0.5V, 1.0V, 1.5V, 2.0V, 2.5V$ and to determine the region $V_{DS} - (V_{GS} - V_{Tn})$ is calculated then whatever the region it follows either cut off or (1) or (2) equation must be followed. Here we should consider $V_{th} = 0.45V$, $\mu_0 = \mu_n = 0.06$, $r = 0.4$.

Calculations:

(i) $V_{DS} - (V_{GS} - V_{th}) < 0$

$\Rightarrow 0.5 - (2 - 0.45) < 0$

$\Rightarrow -1.05 < 0$; it satisfies the linear region.

$$I_{DS} = k_n \left\{ (V_{GS} - V_{Tn}) V_{DS} - \frac{1}{2} V_{DS}^2 \right\}$$

$$= 8.424 \times 10^{-4} \left[(2 - 0.45) \times 0.5 - \frac{1}{2} \times (0.5)^2 \right]$$

$$= 8.424 \times 10^{-4} \times 0.65$$

$$= 5.4756 \times 10^{-4} A$$

$$= 5.4756 \times 10^{-4} \times 10^{6} \mu A$$

$$= 547.56 \mu A$$

$K_n = K_n' * (W_n / L_n)$

$= K_n * 2$

$K_n' = \mu_n * C_{ox}$

$\mu_n = 0.60 m^2/V\text{-}sec$

$C_{ox} = \varepsilon_{ox} / t_{ox} = 7.02 \times 10^{-3}$

$\varepsilon_{ox} = 3.51 \times 10^{-11}$ [F/m]

$t_{ox} = 5.000 nm = 5 \times 10^{-9} m$

$K_n = 0.060 \times 7.02 \times 10^{-3} = 4.212 \times 10^{-4}$

(ii) $V_{DS} - (V_{GS} - V_{TH}) < 0$

$= 1 - (2 - 0.45) < 0$

$= -0.55 < 0$; it satisfies linear region.

$I_{DS} = k_n \{ (V_{GS} - V_{th}) V_{DS} - \frac{1}{2} V_{DS}^2 \}$

$= 8.424 \times 10^{-4} [(2 - 0.45) \times 1 - \frac{1}{2}(1)^2]$

$= 8.424 \times 10^{-4} \times 1.05$

$= 8.8452 \times 10^{-4} A$

$= 8.8452 \times 10^{-4} \times 10^6 \mu A$

$= 884.52 \mu A$

iii) $V_{DS} - (V_{GS} - V_{tn}) < 0$

$\Rightarrow 1.5 - (2 - 0.45) < 0$

$\Rightarrow -0.05 < 0$; it satisfies linear region.

$I_{DS} = K_n \{ (V_{GS} - V_{Tn}) V_{DS} - \frac{1}{2} V_{DS}^2 \}$

$= 8.424 \times 10^{-4} \{ (2 - 0.45) \times 1.5 - \frac{1}{2} (1.5)^2 \}$

$= 8.424 \times 10^{-4} \times 1.2$

$= 1.01088 \times 10^{-3} A$

$= 1.01088 \times 10^{-3} \times 10^{-6} \mu A$

$= 1010.88 \mu A$

iv) $V_{DS} - (V_{GS} - V_{th}) > 0$

$\Rightarrow 2 - (2 - 0.45) > 0$

$\Rightarrow 0.45 > 0$; it satisfies saturation region.

$I_{DS} = \frac{1}{2} K_n \{ (V_{GS} - V_{Tn})^2 \}$

$= \frac{1}{2} \times 8.424 \times 10^{-4} \{ (2 - 0.45)^2 \}$

$= \frac{1}{2} \times 8.424 \times 10^{-4} \times 2.4025$

$= 1.011933 \times 10^{-3} A = 1011.933 \mu A$

v) $V_{DS} - (V_{GS} - V_{th}) > 0$

$\Rightarrow 2.5 - (2 - 0.45) > 0$

$\Rightarrow 0.95 > 0$; it satisfies saturation region

$I_{DS} = \frac{1}{2} K_n \{(V_{GS} - V_{th})^2\}$

$= \frac{1}{2} \times 8.424 \times 10^{-4} \times (2 - 0.45)^2$

$= 1.011933 \times 10^{-3} A$

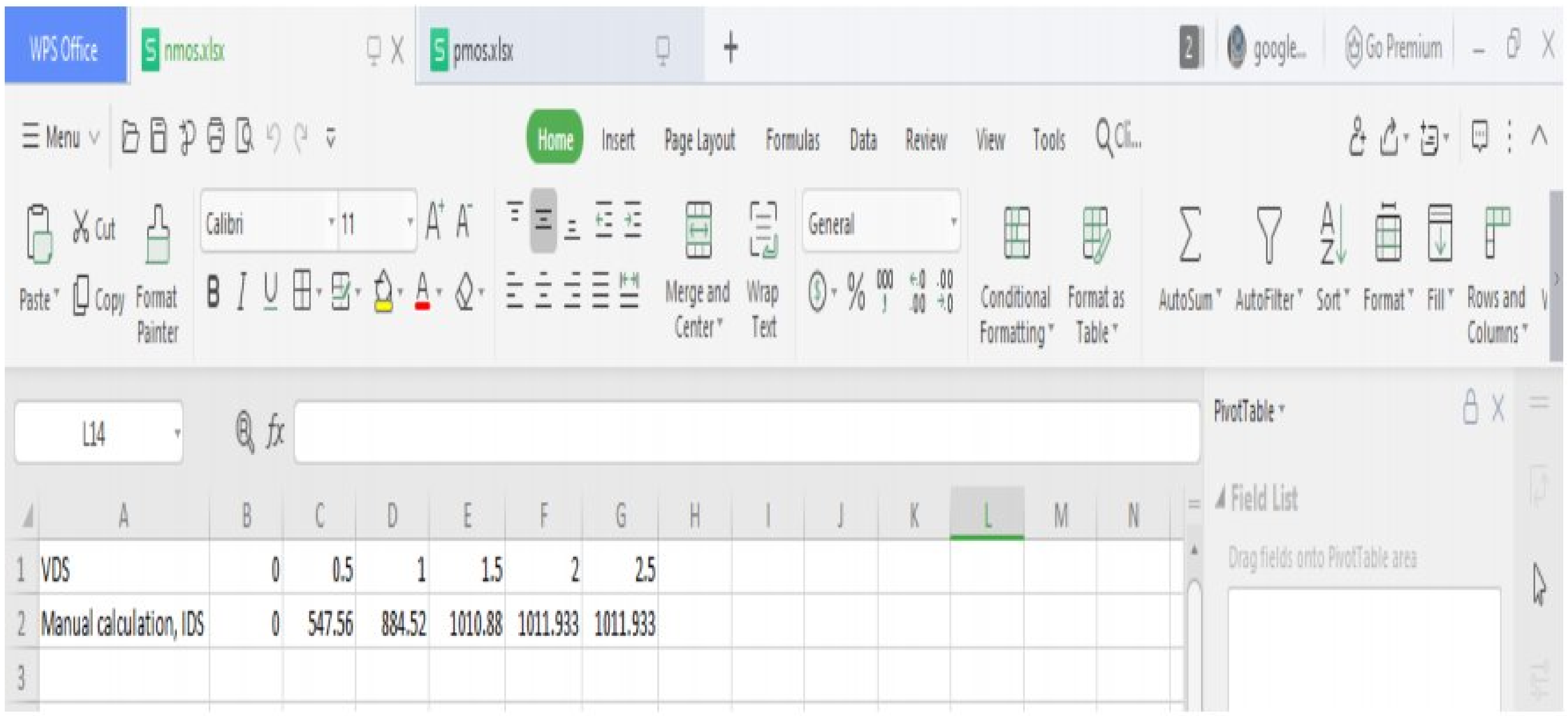
$= 1011.933 \mu A$

Table of values: $V_{GS} = +2.0V$ and $W_n/L_n = 2$

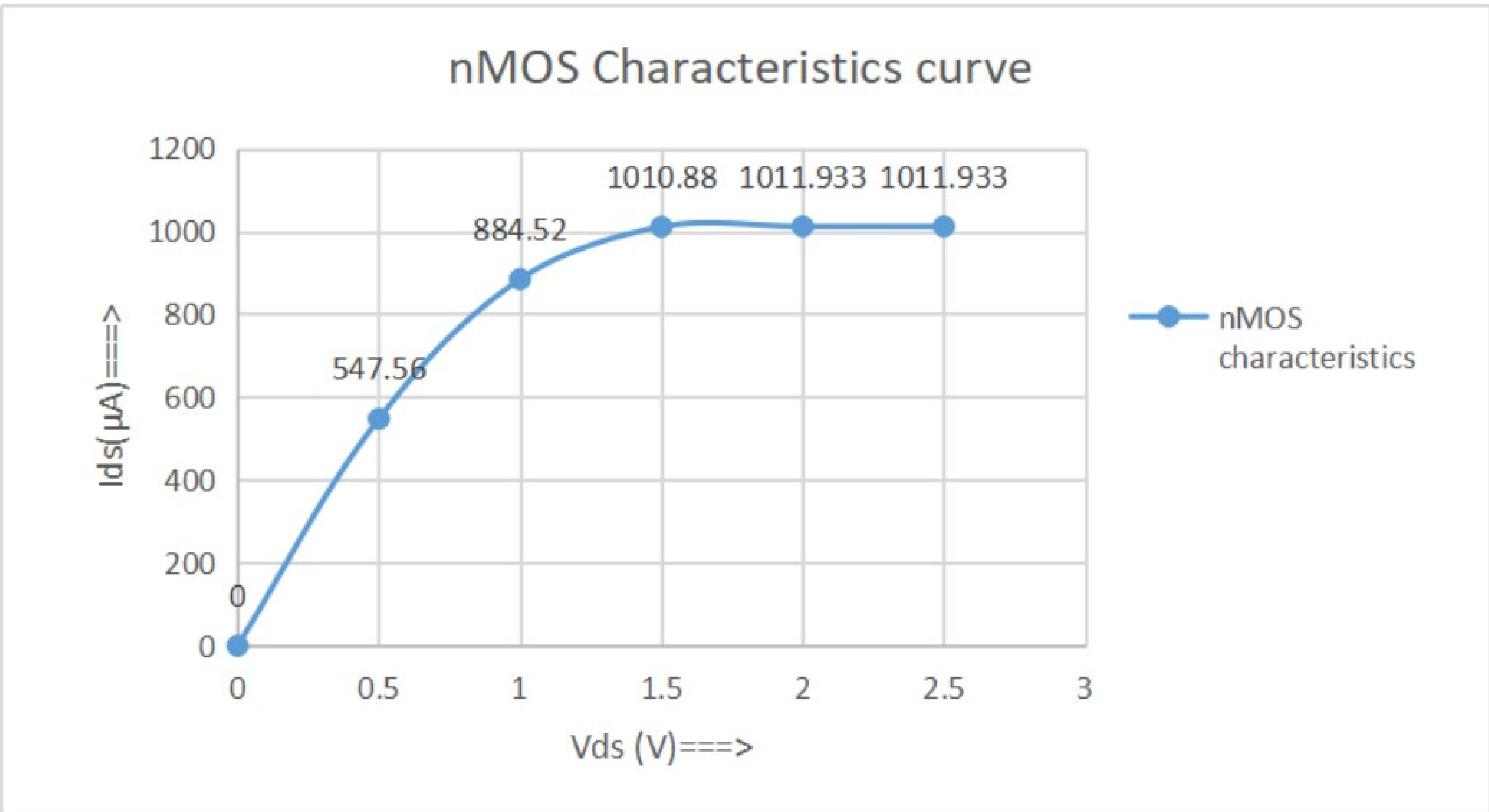
V_{DS} (V)	0.5	1.0	1.5	2.0	2.5
$V_{DS} - (V_{GS} - V_{th})$	-1.05	-0.55	-0.05	0.45	0.95
	(1)	(1)	(1)	(3)	(3)
	Linear	Linear	Linear	Saturation	Saturation
Manual Calculation, I_{DS} (μA)	547.56	884.52	1010.88	1011.933	1011.933

Excel Calculations & Plotting:

after plotting we will see the graph to be compared further.



In picture, excel table for nmos.



b) Use of "Simulate > MOS characteristic" to generate the DC characteristics I_{DS} for the NMOS transistor in microwind.

⊞ After selecting the foundry → cmos025.rul
. Use level1 MOS transistor model.

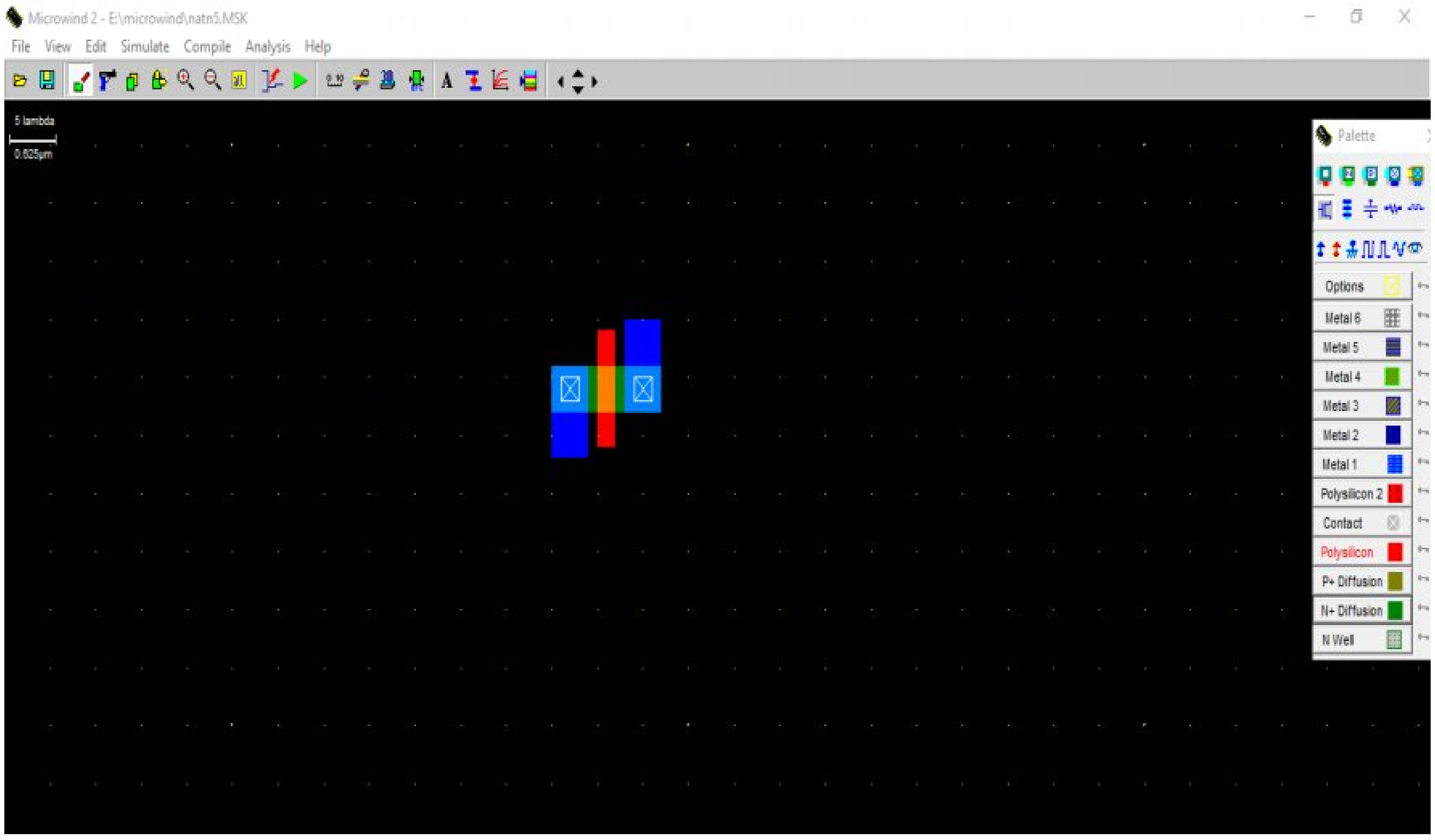
⊞ We will take width & length ratio 4γ×2γ.

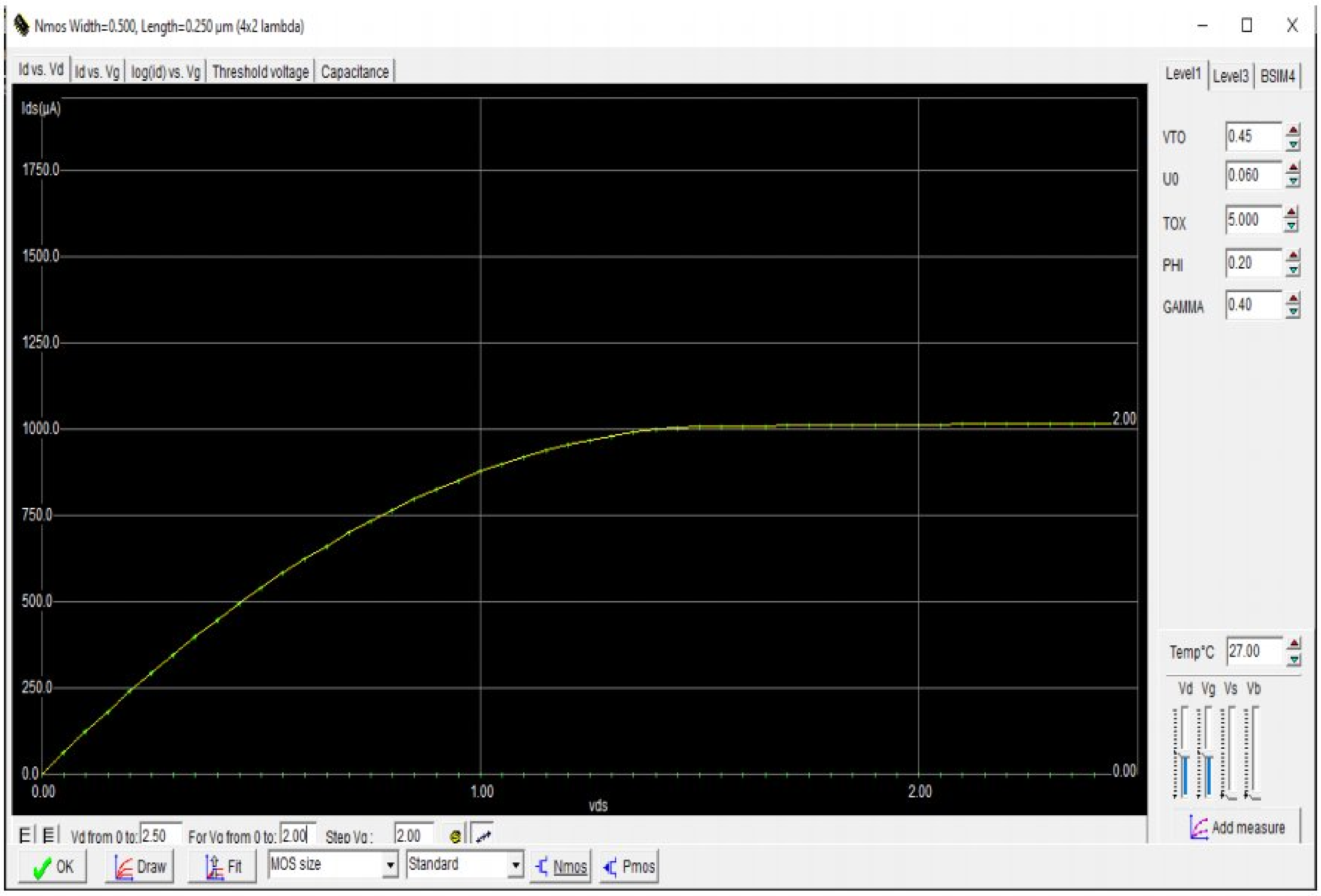
⊞ Simulate → MOS characteristics and then point to the NMOS transistor. Here, choose V_{gs} = +2.0V then V_{ds} = upto 2.50 and steps 2.0. Then click on the draw button.

From Microwind:

V_{DS} (V)	0.5	1.0	1.5	2.0	2.5
Manual Calculation I_{DS} (μA)	547.56	884.52	1010.88	1011.933	1011.93

We compared, the microwind and pen-pencil I_{DS} and then we ought for the calculation of theshold voltage factor.


Microwind 2 - E:\microwind\natn5.MSK
File View Edit Simulate Compile Analysis Help
5 lambda
0.625µm
Palette
Options
Metal 6
Metal 5
Metal 4
Metal 3
Metal 2
Metal 1
Polysilicon 2
Contact
Polysilicon
P+ Diffusion
N+ Diffusion
N Well


Nmos Width=0.500, Length=0.250 µm (4x2 lambda)
Id vs. Vd
Id vs. Vg
log(Id) vs. Vg
Threshold voltage
Capacitance
Level1
Level3
BSIM4
Ids(µA)
1750.0
1500.0
1250.0
1000.0
750.0
500.0
250.0
0.0
0.00
1.00
2.00
vds
2.00
0.00
VTO 0.45
U0 0.060
TOX 5.000
PHI 0.20
GAMMA 0.40
Temp°C 27.00
Vd Vg Vs Vb
Add measure
Vd from 0 to: 2.50
For Vg from 0 to: 2.00
Step Vg: 2.00
OK
Draw
Fit
MOS size
Standard
Nmos
Pmos

c) Calculation of the threshold voltage factor(γ)

We have considered that the threshold voltage factor gamma $\gamma = 0$. We have found that

$U_{TO} = 0.45V$.

Result: The lab objectives are successfully observed and verified with theoretical calculation.

PMOS

Theory: The following regions will be used for the calculations. The regions are 3 as follows.

cut-off region : $vgs > vt$, $Ids = 0$

Linear Region : $Vgs < vt$ and

$Vds > Vgs - V_t$

$Ids = -kp\left[(Vgs - V_t)Vds - \frac{1}{2}(Vds)^2\right]$

Saturation Region: $Vds < Vgs - V_t$

$Ids = -kp/2\,(Vgs - V_t)^2$

Procedure:

a) Level 1 MOS model equations to calculate DC values for the IDS:

We will first calculate the values of Ids manually by paper & pencil method. Then we will plot it in excel for further calculations & comparisons.

(i) $V_{ds} = 0.5$

$V_{ds} - (V_{gs} - V_t) < 0$

$\Rightarrow 0.5 - (2 + 0.45) < 0$

$\Rightarrow 0.5 - 2.45 < 0$

$\Rightarrow -1.95 < 0$; it satisfies saturation region

$I_{ds} = -K_p/2 \, (V_{gs} - V_t)^2$

$= -\frac{1}{2} \times 8.424 \times 10^{-4} (2 + 0.45)^2$

$= -2.528253 \times 10^{-3} A$

$= -2528.253 \, \mu A$

$K_p = \mu_p C_{ox} \frac{W}{L}$

$= 0.06 \times \frac{3.9 \times 10^{-11}}{5 \times 10^{-9}} \times 2$

$= 8.424 \times 10^{-4}$

(ii) $V_{ds} = 1 < 0$

$V_{ds} - (V_{gs} - V_t) < 0$

$\Rightarrow 1 - (2 + 0.45) < 0$

$\Rightarrow 1 - 2.45 < 0$

$\Rightarrow -1.45$; it satisfies saturation region.

$I_{ds} = -\beta/2 \, (V_{gs} - V_t)^2$

$= -\frac{1}{2} \times 8.424 \times 10^{-4} (2 + 0.45)^2$

$= -2528.253 \, \mu A$

(iii) $V_{ds} = 1.5$

$V_{ds} - (V_{gs} - V_t) < 0$

$\Rightarrow 1.5 - (2+0.45) < 0$

$\Rightarrow 1.5 - 2.45 < 0$

$\Rightarrow -0.95 < 0$; it satisfies the saturation region

$I_{ds} = -\frac{1}{2} K_p (V_{gs} - V_t)^2$

$= -\frac{1}{2} \times 8.424 \times 10^{-4} (2+0.45)^2$

$= -2528.253 \mu A$

iv) $V_{ds} = 2$

$V_{ds} - (V_{gs} - V_t) < 0$

$\Rightarrow 2.5 - (2+0.45) < 0$

$\Rightarrow 2.5 - 2.45 < 0$

$\Rightarrow 0.95$; it satisfies saturation region

$I_{ds} = -\frac{1}{2} K_p (V_{gs} - V_t)^2$

$= -\frac{1}{2} \times 8.424 \times 10^{-4} (2+0.45)^2$

$= -2528.253 \mu A$

v) $V_{ds} = 2.5$

$V_{ds} - (V_{gs} - V_t) > 0$

$\Rightarrow 2.5 - (2 + 0.45) > 0$

$\Rightarrow 2.5 - 2.45 > 0$

$\Rightarrow 0.05$; it satisfies the linear Region.

$$I_{ds} = -K_p \left[(V_{gs} - V_t) V_{ds} - \frac{1}{2} V_{ds}^2 \right]$$

$$= -8.424 \times 10^{-4} \left[(2 + 0.45) \times 2.5 - \frac{1}{2} (2.5)^2 \right]$$

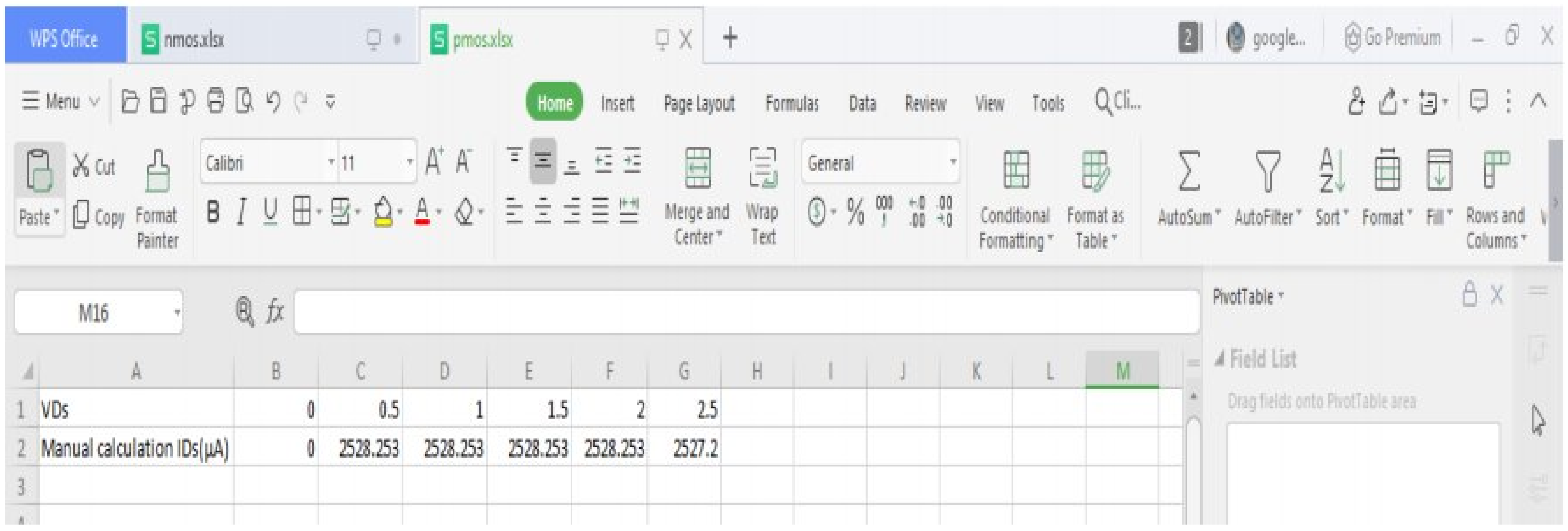
$$= -8.424 \times 10^{-4} \times 3$$

$$= -2.5272 \times 10^{-3} A$$

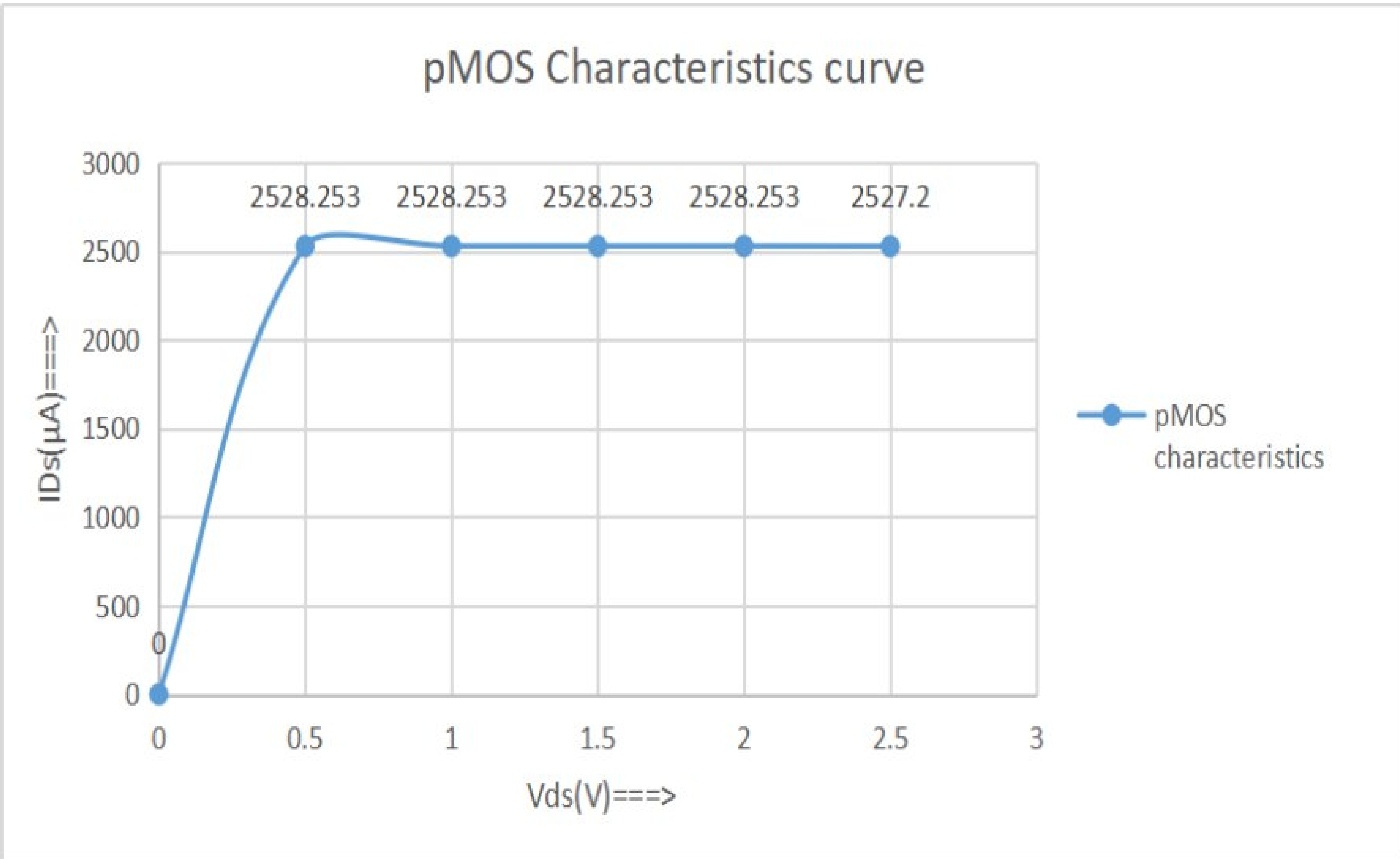
$$= -2527.2 \mu A$$

for the values of these we can put it in this table:

V_{DS} (V)	0.5	1.0	1.5	2.0	2.5
$V_{DS} - (V_{GS} - V_{TP})$	-1.95 saturation	-1.45 saturation	-0.95 saturation	0.45 saturation	0.05 Linear
Manual calculation I_{DS} (μA)	-2528.253 μA	-2528.253 μA	-2528.253 μA	-2528.253 μA	-2527.2 μA

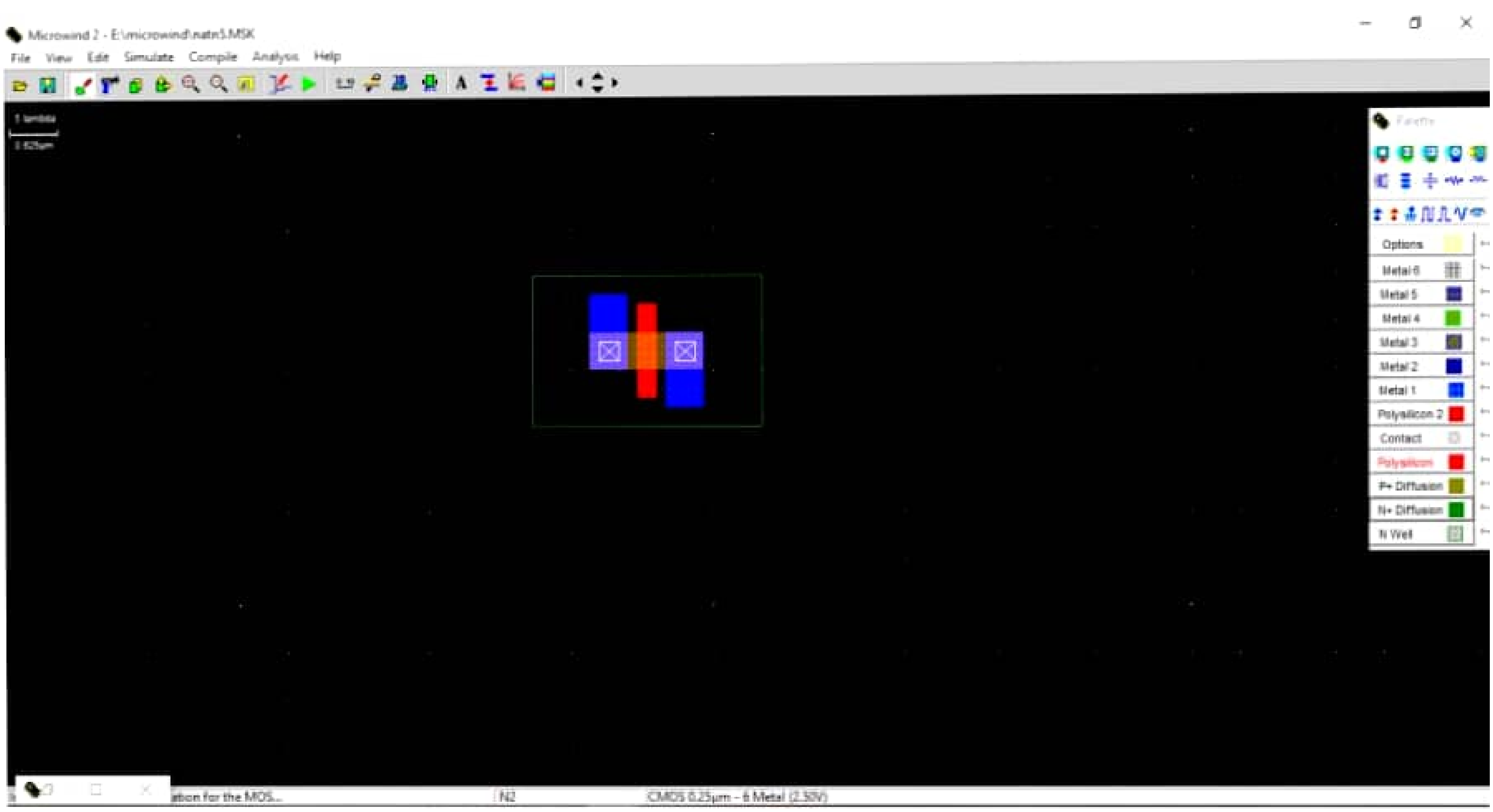


	A	B	C	D	E	F	G
1	VDs	0	0.5	1	1.5	2	2.5
2	Manual calculation IDs(µA)	0	2528.253	2528.253	2528.253	2528.253	2527.2

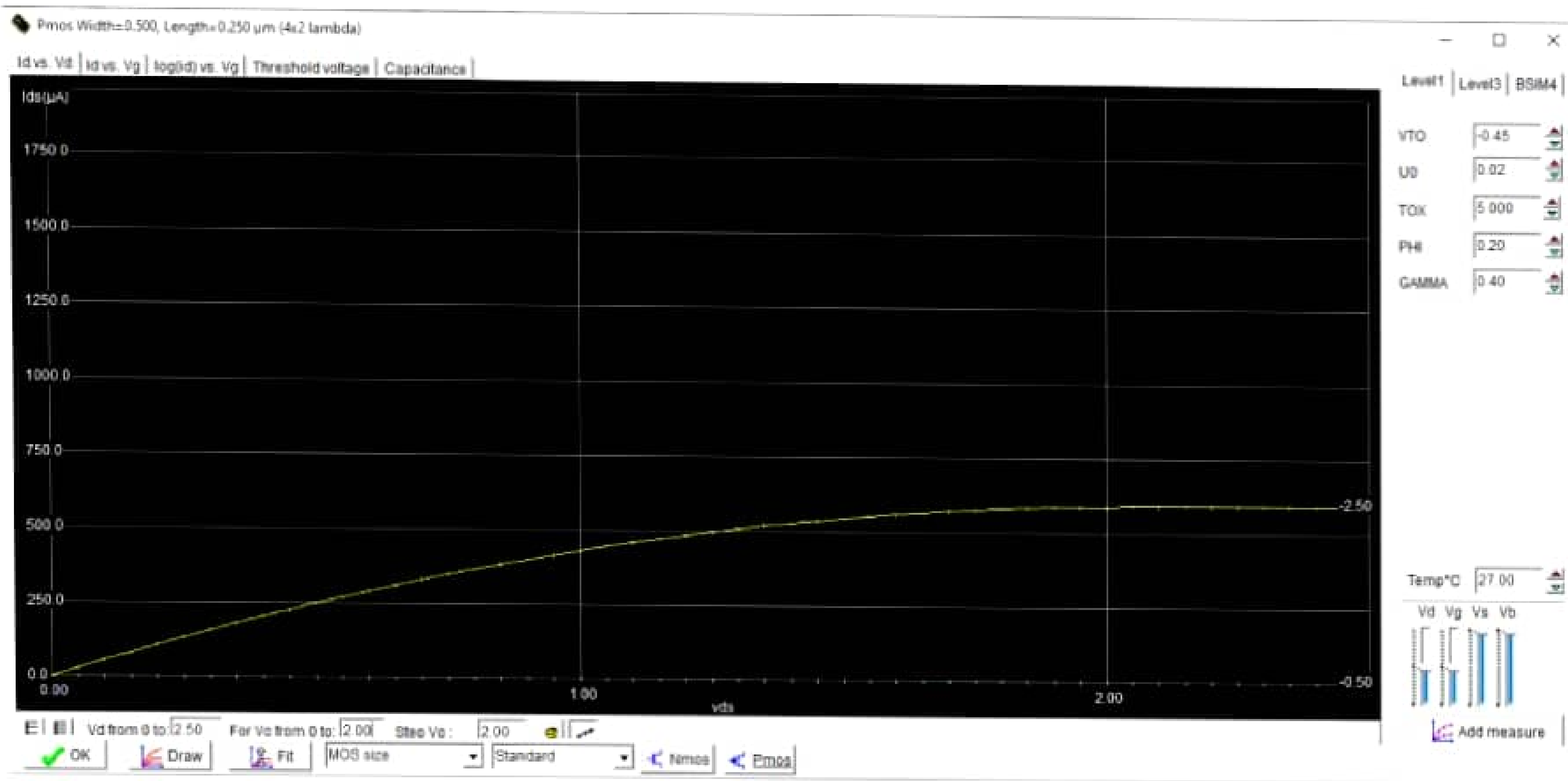


b) Use of " simulate > MOS characteristics" to generate the DC characteristics I_{DSP} Vs V_{DSP} for the PMOS transistor in microwind.

- selecting the foundary → cmos 025.rul . Using level1 MOS transistor Model.
- Now generating nMOS transistor of width and length ratio is $4\lambda \times 2\lambda$ from palette.
- Now clicking simulate → MOS characteristics.
- Now steps should be 2.0 and others accordingly.



In picture, PMOS transistor.



Result:

The lab objectives are successfully observed and verified with theoretical calculation.