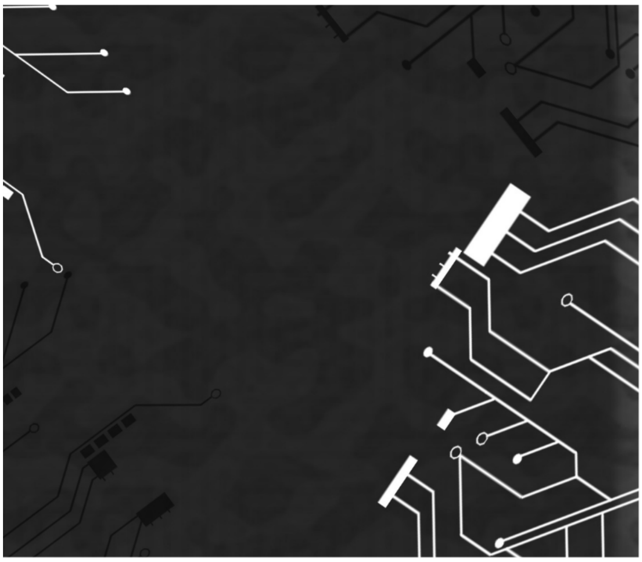

VLSI LAB
CODE: CSE-406
Experiment No: 5

Submission Date:10.10.2020

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Dept. of CSE,JU.

Experiment No: 5

Experiment Name: Verification of nMOS and pMOS DC-Chara cteristics.

Objectives:

① 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 gate-source voltage V_{gs} = a constant $> V_{Th}$.

② 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.

③ Calculation of the threshold voltage.

NMOS

Theory:

There are 3 regions and for calculation of the value I_{DS}. The nMOS transistor I_{DS} current versus V_{DS} voltage equations are stated below for level 1 stimulation and other calculations.

- Cut-off mode: $I_{DS} = 0$ when $V_{GS} < 0$
- Triod/Linear Region: $I_{DS} = K_n\{(V_{GS} - V_{Th})V_{DS} - \frac{1}{2}V_{DS}^2\}$ when, $V_{DS} < V_{GS} - V_{Th}$ ......(1)
- Saturation region: $I_{DS} = \frac{1}{2}K_n\{(V_{GS} - V_{Tn})^2(1+\lambda V_{DS})\}$ when, $V_{DS} > V_{GS} - V_{Tn}$ ......(2)

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 $V_{Tn} = 0.45V$, $\mu_0 = \mu_n = 0.06$, $r = 0.4$.

Calculations:

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

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

$\Rightarrow -1.05 < 0$; 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.

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

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

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

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

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

$= 884.52 \mu A$

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) $V_{DS} - (V_{GS} - V_{tn}) > 0$

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

$\Rightarrow 0.45 > 0$; 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

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

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

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

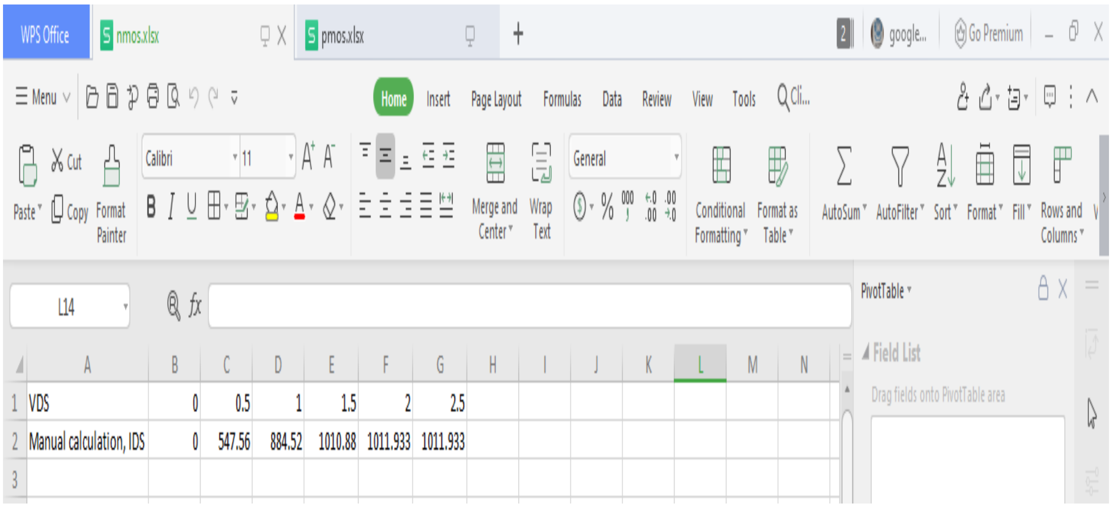
$= 1011.933 \mu A$

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

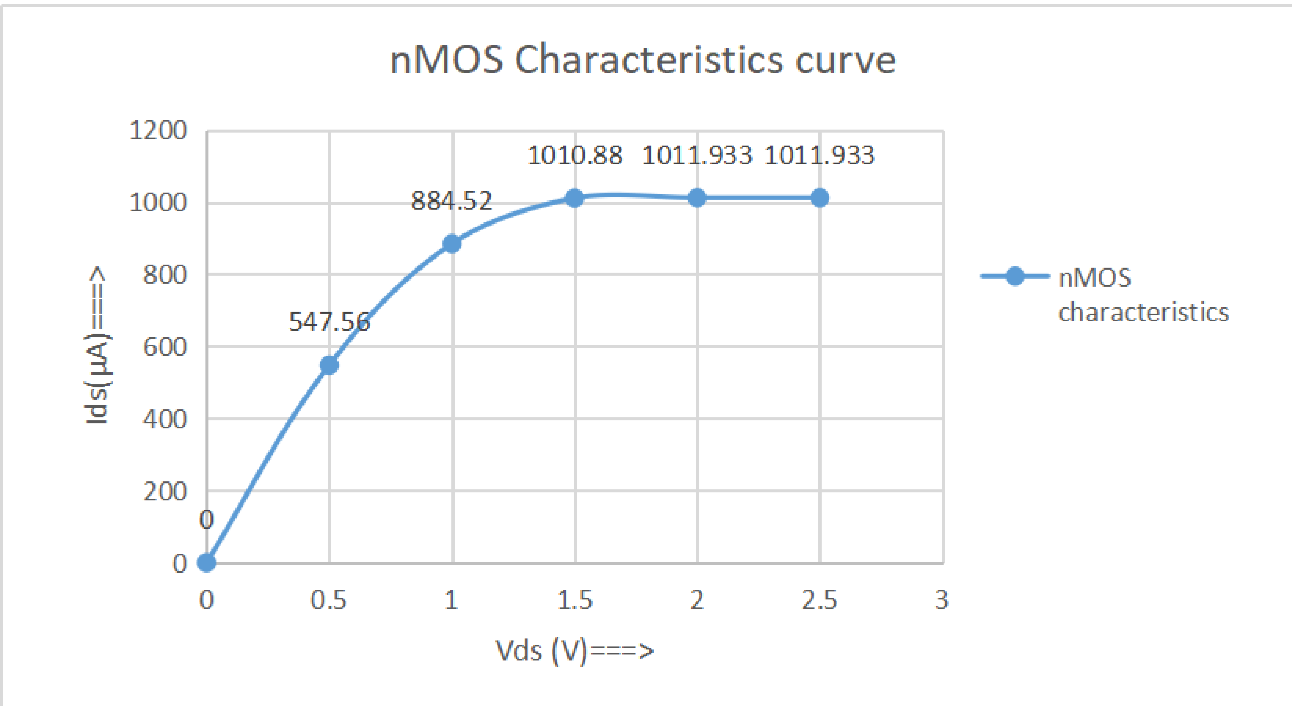
Excel Calculation & Plotting:

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



	A	B	C	D	E	F	G
1	VDS	0	0.5	1	1.5	2	2.5
2	Manual calculation, IDS	0	547.56	884.52	1010.88	1011.933	1011.933

In picture, excel table for nmos.



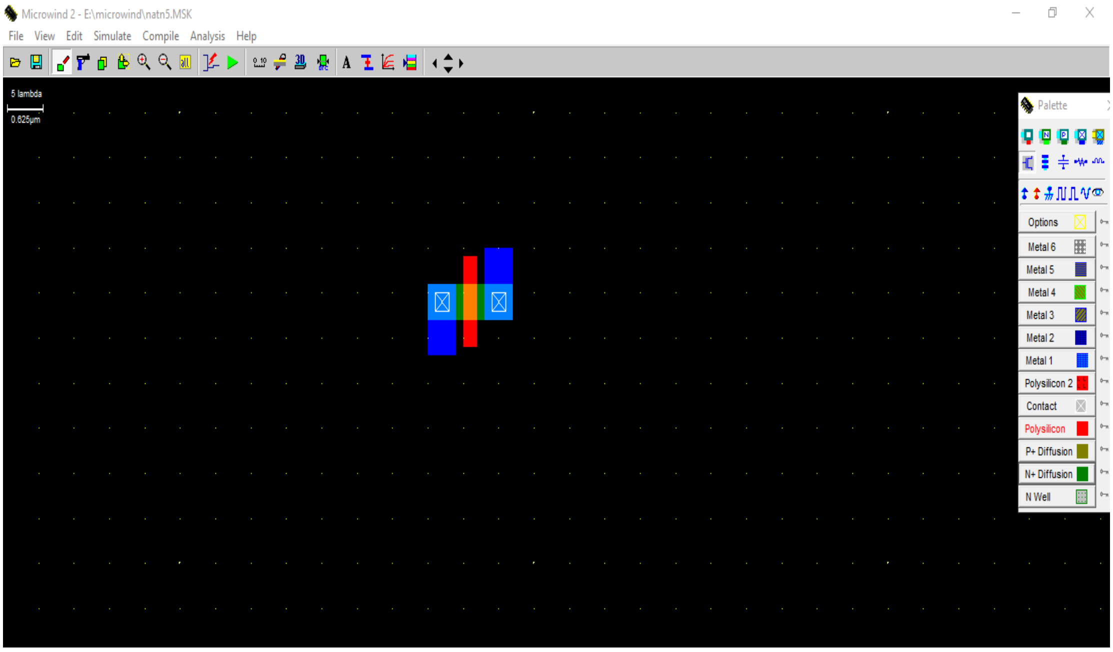
b) Use of "Simulate > MOS characteristic" to generate the DC characteristics I_{DS} for the NMOS transistor in microwind.

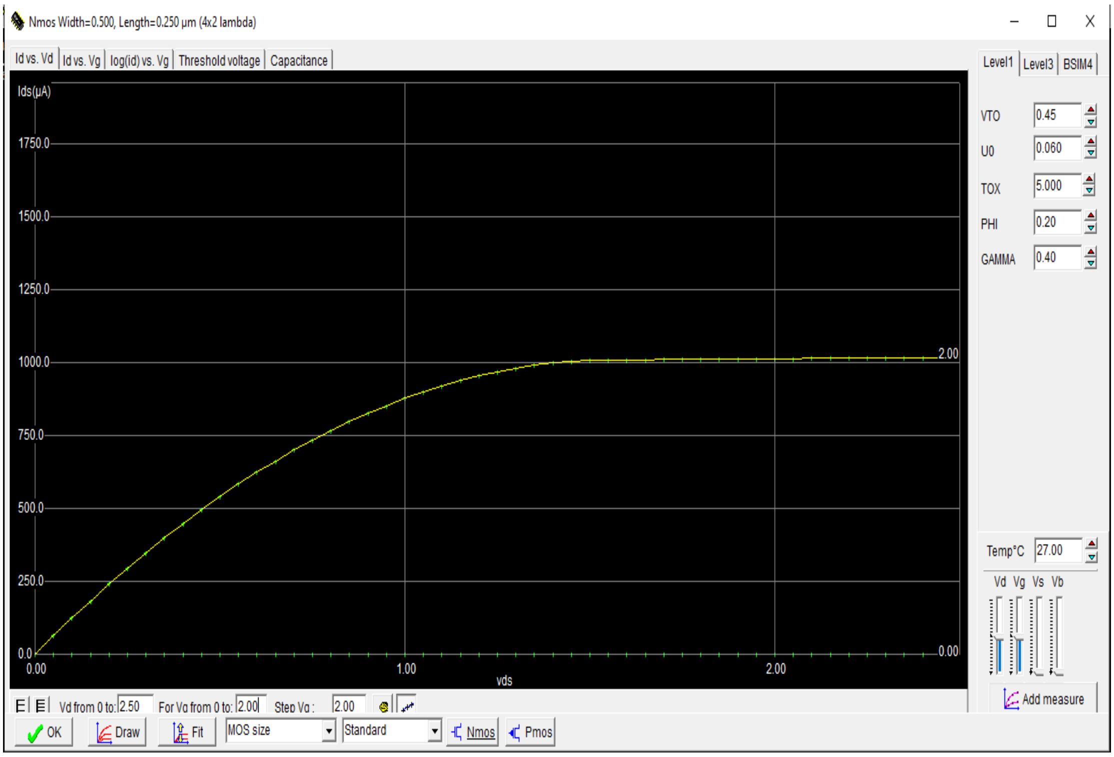
- After selecting the foundary → cmos025.rul
  . Use level1 MOS transistor model.
- We will take width & length ratio $4\gamma \times 2\gamma$.
- Simulate → MOS characteristics and then point to the NMOS transistor. Here, choose V_{GS} = +2.0V then V_{ds} = upto 2.50 and steps 2.0. Then click on the 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

$V_{TO} = 0.45V$.

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

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

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

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

$= -2528.253 \mu A$

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

$= 0.06 \times \frac{3.51 \times 10^{-11}}{5 \times 10^{-9}} \times 2$

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

(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) $V_{ds} = 2$

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

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

$\Rightarrow 2.5 - 2.45 < 0$

$\Rightarrow 0.05$; 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.

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

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

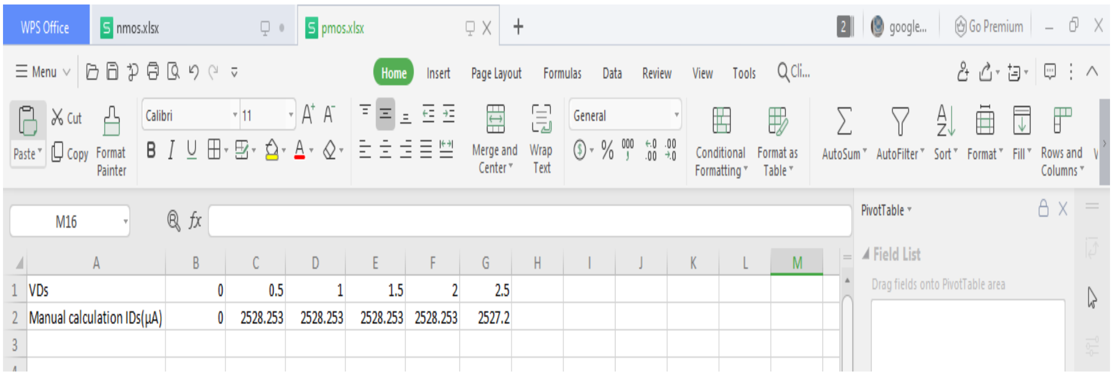
$= -8.424 \times 10^{-4} \times 3$

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

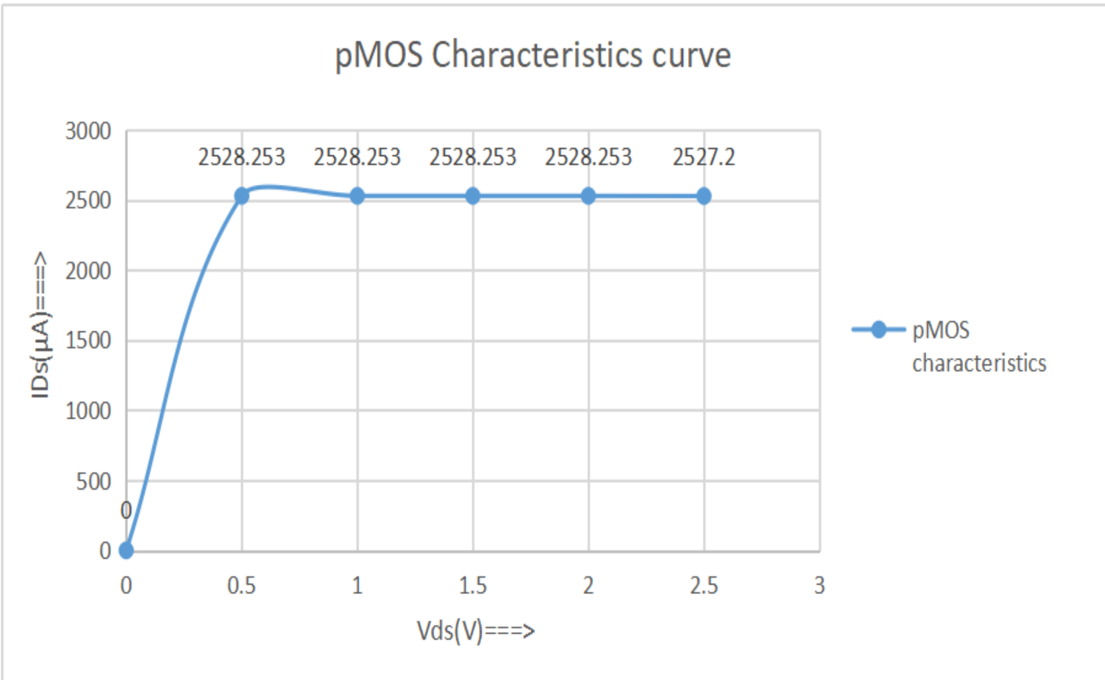
$= -2527.2 \mu A$

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	-1.45	-0.95	0.45	0.05
	saturation	saturation	saturation	saturation	Linear
Manual calculation I_{DS} (μA)	-2528.253 μA	-2528.253 μA	-2528.253 μA	-2528.253 μA	-2527.2 μA



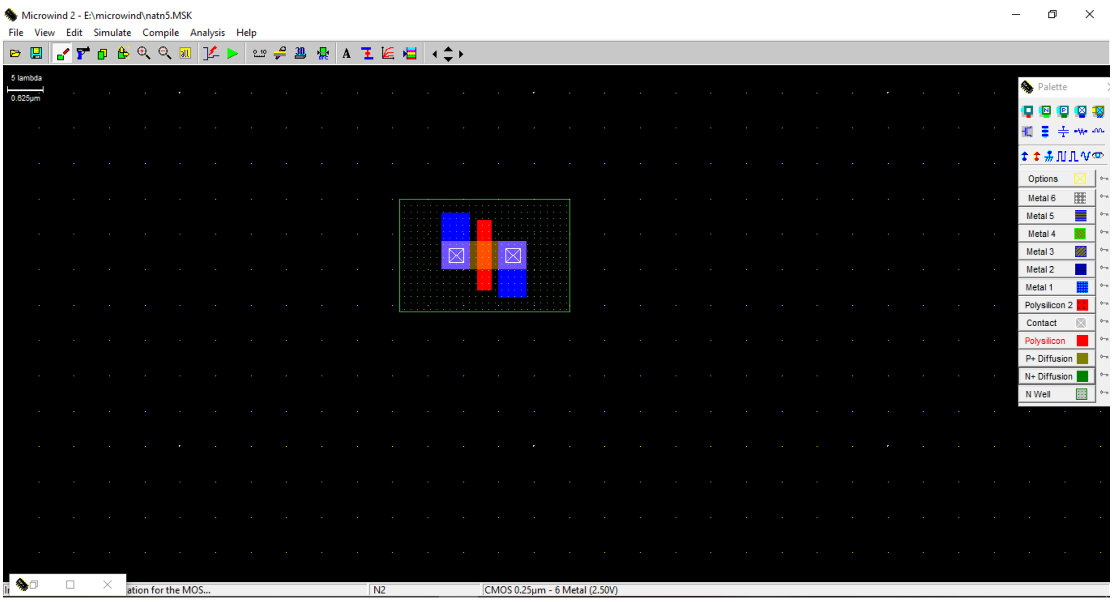
M16
VDs 0 0.5 1 1.5 2 2.5
Manual calculation IDs(μA) 0 2528.253 2528.253 2528.253 2528.253 2527.2



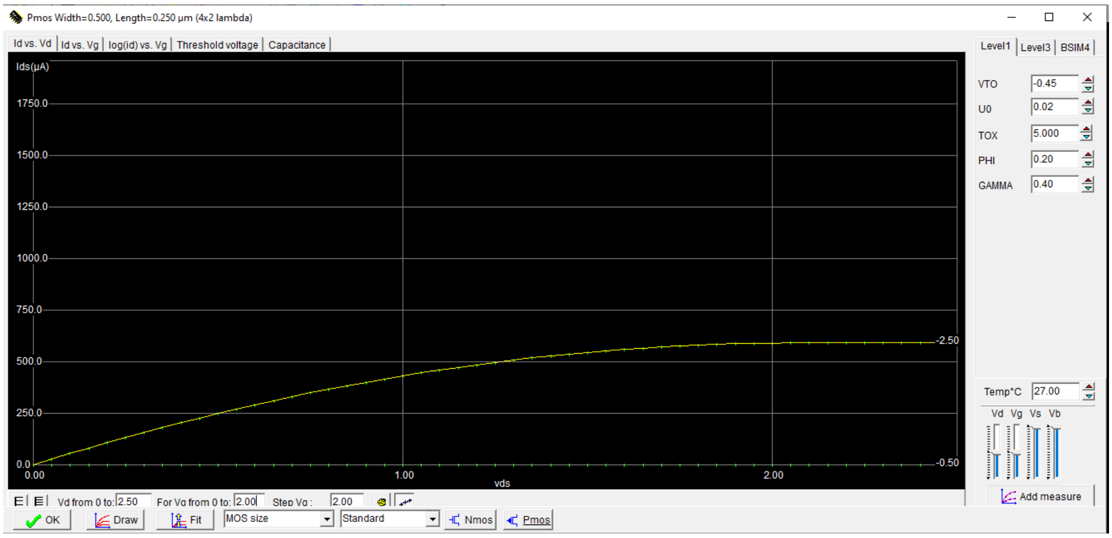
pMOS Characteristics curve
3000
2500
2000
1500
1000
500
0
0 0.5 1 1.5 2 2.5 3
IDs(µA)===>
Vds(V)===>
0
2528.253
2528.253
2528.253
2528.253
2527.2
pMOS characteristics

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.