EEE 108L MICRO-ELECTRONICS 1
LAB 6

Lab Session: Tuesday 3PM - 5:40PM

Student Name: Andrew Robertson

TABLE OF CONTENTS

PRE-LAB CALCULATIONS

STEP 1.

Step 1)

$V_{DS} > V_{GS} - V_{TH}$ ← start

$V_D - V_S > V_G - V_S - V_{TH}$

$V_D > V_G - V_{TH}$

$V_D - V_G > -V_{TH}$

$V_{GD} < V_{TH}$ ← finish

Other condition: $\boxed{V_{GS} \geq V_{TH}}$

STEP 2.

V_{GS}	V_{DS}	I_D	State
1V	3.6125	295.2m	cutoff
2V	4.38336	.31.2m	triode
4V	-17.199	4.72m	saturation

$V_{th} = 1.6V$

$K = 0.00082$

Showing process for $V_{GS} = 1V$. (2V & 4V share same process)

$$V_{DS} = V_{DD} - I_D R_D = V_{DD} - R_D\left(K(V_{GS} - V_{TH})\right)^2$$

for V_{GS} = 1 : $3.612 > 1 - 1.6$ ✓ & $1 \geq 1.6$ ✗

" " 2 : $4.38336 > 2 - 1.6$ ✓ & $2 \geq 1.6$ ✓

" " 4 : $-17.199 > 4 - 1.6$ ✗ & $4 \geq 1.6$ ✓

STEP 3.

Step 3

$$I_D = \frac{\mu C'_{ox}}{2} \cdot \frac{W}{L} (V_{GS} - V_{TH})^2$$

$$\sqrt{I_D} = \sqrt{\frac{\mu C'_{ox}}{2} \cdot \frac{W}{L} (V_{GS} - V_{TH})^2}$$

$$\sqrt{I_D} = \left(\sqrt{\frac{\mu C'_{ox}}{2} \cdot \frac{W}{L}}\right)(V_{GS} - V_{TH})$$

$$5.9161m = \left(\sqrt{\frac{\mu C'_{ox}}{2} \cdot \frac{W}{L}}\right)(1.46 - V_{TH}) \qquad (\text{case } 1)$$

$$\frac{5.9161m}{1.46 - V_{TH}} = \left(\sqrt{\frac{\mu C'_{ox}}{2} \cdot \frac{W}{L}}\right), \quad \frac{1.46}{5.9161m} - \frac{V_{TH}}{5.9161m} = \left(\sqrt{\frac{\mu C'_{ox}}{2} \cdot \frac{W}{L}}\right)^{-1}$$

$$\frac{V_{TH}}{5.9161m} = \frac{1.46}{5.9161m} - \left(\sqrt{\frac{\mu C'_{ox}}{2} \cdot \frac{W}{L}}\right)^{-1}, \quad \boxed{V_{TH} = 1.46 - 5.9161m\left(\sqrt{\frac{\mu C'_{ox}}{2} \cdot \frac{W}{L}}\right)^{-1}}$$

$$20.7364m = \left(\sqrt{\frac{\mu C'_{ox}}{2} \cdot \frac{W}{L}}\right)(2.18 - V_{TH}) \qquad (\text{case } 2)$$

$$\frac{20.7364m}{2.18 - V_{TH}} = \left(\sqrt{\frac{\mu C'_{ox}}{2} \cdot \frac{W}{L}}\right), \quad \frac{2.18}{20.7364m} - \frac{V_{TH}}{20.7364m} = \left(\sqrt{\frac{\mu C'_{ox}}{2} \cdot \frac{W}{L}}\right)^{-1}$$

$$\frac{V_{TH}}{20.7364m} = \frac{2.18}{20.7364m} - \left(\sqrt{\frac{\mu C'_{ox}}{2} \cdot \frac{W}{L}}\right)^{-1}, \quad \boxed{V_{TH} = 2.18 - 20.7364m\left(\ldots \right)^{-1}}$$

$$\text{let } \left(\sqrt{\frac{\mu C'_{ox}}{2} \cdot \frac{W}{L}}\right)^{-1} = \alpha . \quad 1.46 - 5.9161m\,\alpha = 2.18 - 20.7364m\,\alpha$$

$$\left(\sqrt{\frac{\mu C'_{ox}}{2} \cdot \frac{W}{L}}\right) = \frac{1}{\alpha} = 20.58375m \qquad 14.8203m\,\alpha = .720, \ \alpha = 48.58201251$$

or

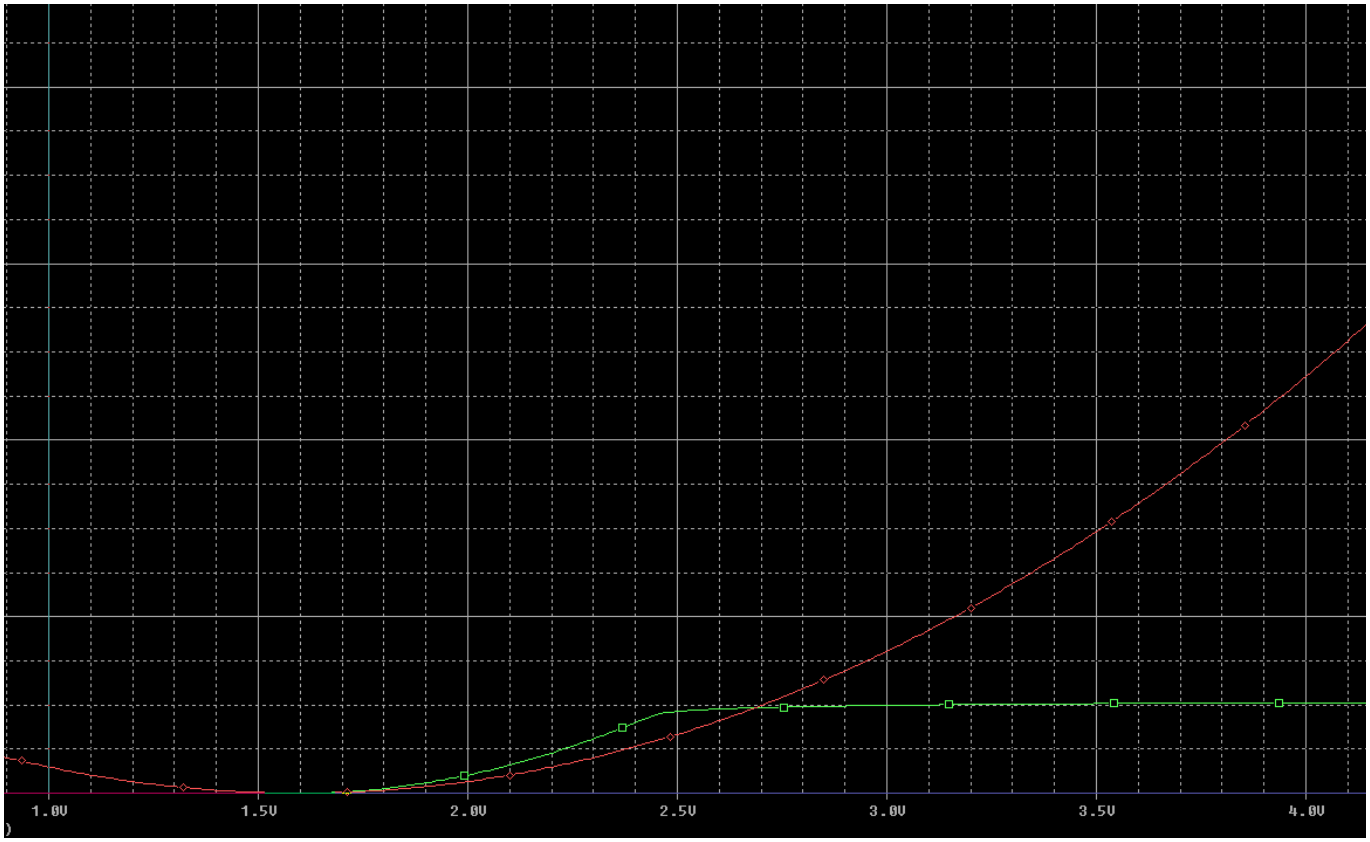
$$\boxed{\frac{\mu C'_{ox}}{2} \cdot \frac{W}{L} = (20.58375m)^2 = 423.6908\mu = 4.236908 \cdot 10^{-4}}$$

$$\boxed{V_{TH} = 2.18 - 20.7364m(48.58201251) = 1.172583956}$$

SPICE SIMULATION

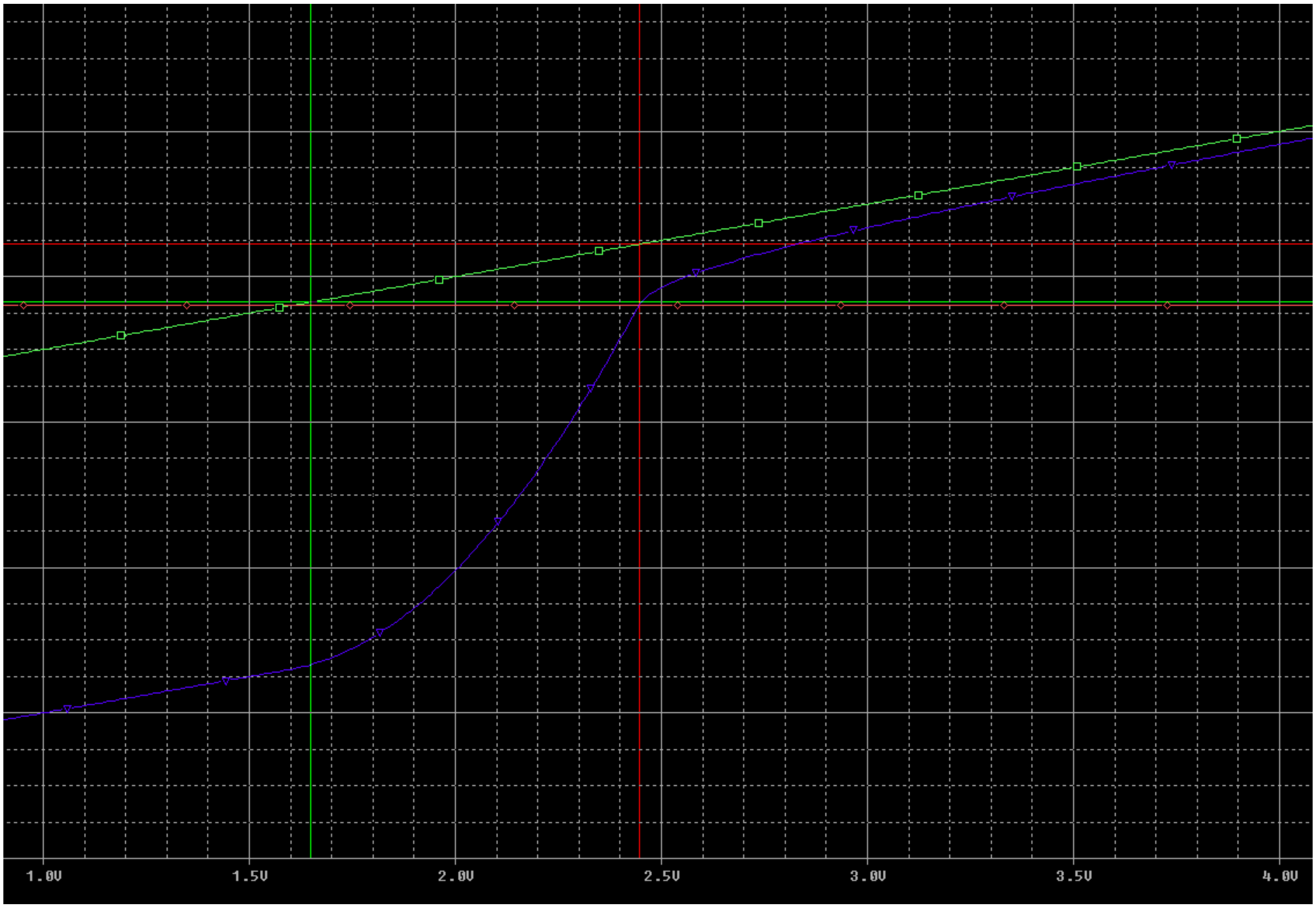
STEP 4.

Plot of ID



$I_D = K\left(V_{GS} - V_{th}\right)^2$ Is accurate for the saturation region of operation when lambda is 0.

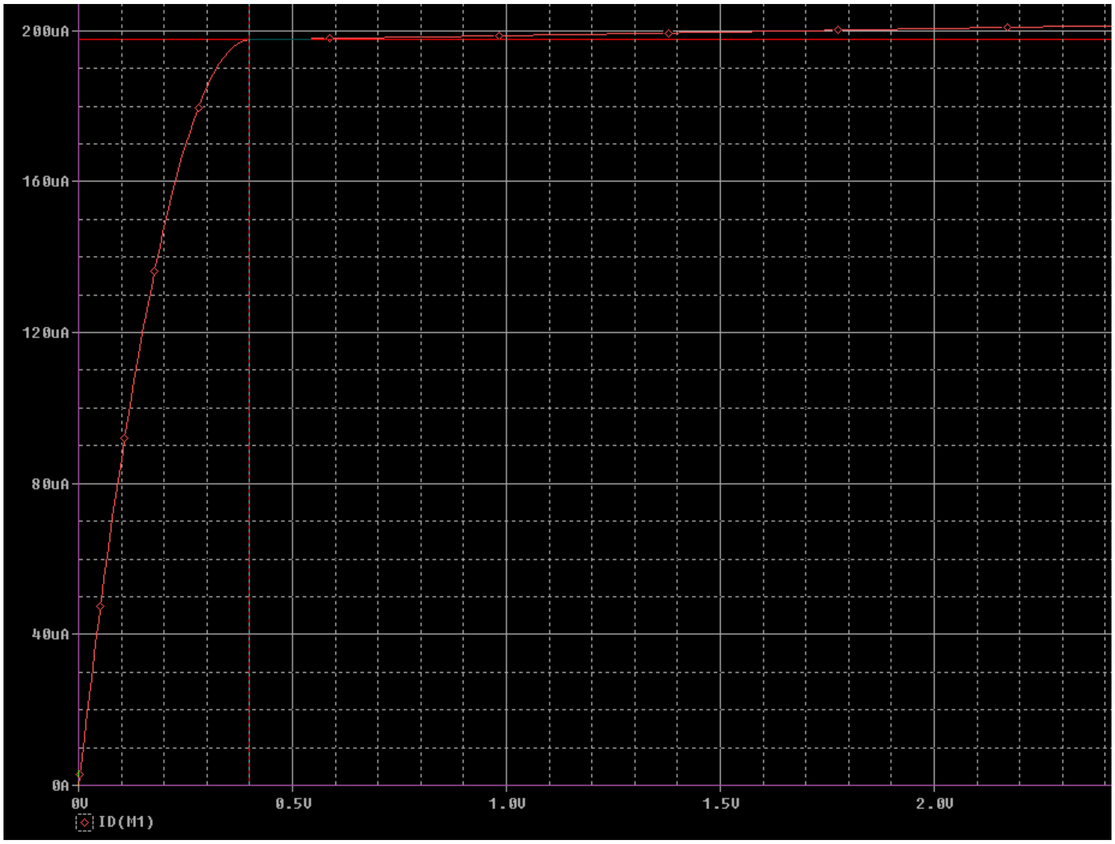
Plot of VGS(Green), VGD(Blue), and VTH(Red)



Cutoff occurs to the left of the green cursor, linear between red and green cursors, and forward active to the right of the red cursor.

STEP 5.

Plot of ID



Saturation occurs when VDD becomes and exceeds .4V

Linear : $\frac{\Delta VDS}{\Delta ID} \approx \frac{344.446m}{193.611\mu} \approx 1.779K$

compare to : $R_{DS} = \left[\mu C'_{ox} \frac{W}{L} (V_{GS} - V_{tn})\right]^{-1}$

$= \left[2 \times .00082 (2V - 1.6)\right]^{-1}$ $\qquad \frac{50m}{28.421\mu} \approx$

$R_{DS} = 1.5244K \ldots$

Saturation : $\frac{\Delta VDS}{\Delta ID} \approx \frac{1.7275}{3.2297\mu} \approx 534.879K$

$r_0 = \frac{1}{\lambda I_D}$

$r_0 = \frac{1}{(.004482) K (V_{GS} - V_{tn})^2}$

$\rightarrow r_0 = \frac{1}{(.004482)(.00082)(2 - 1.6)^2}$

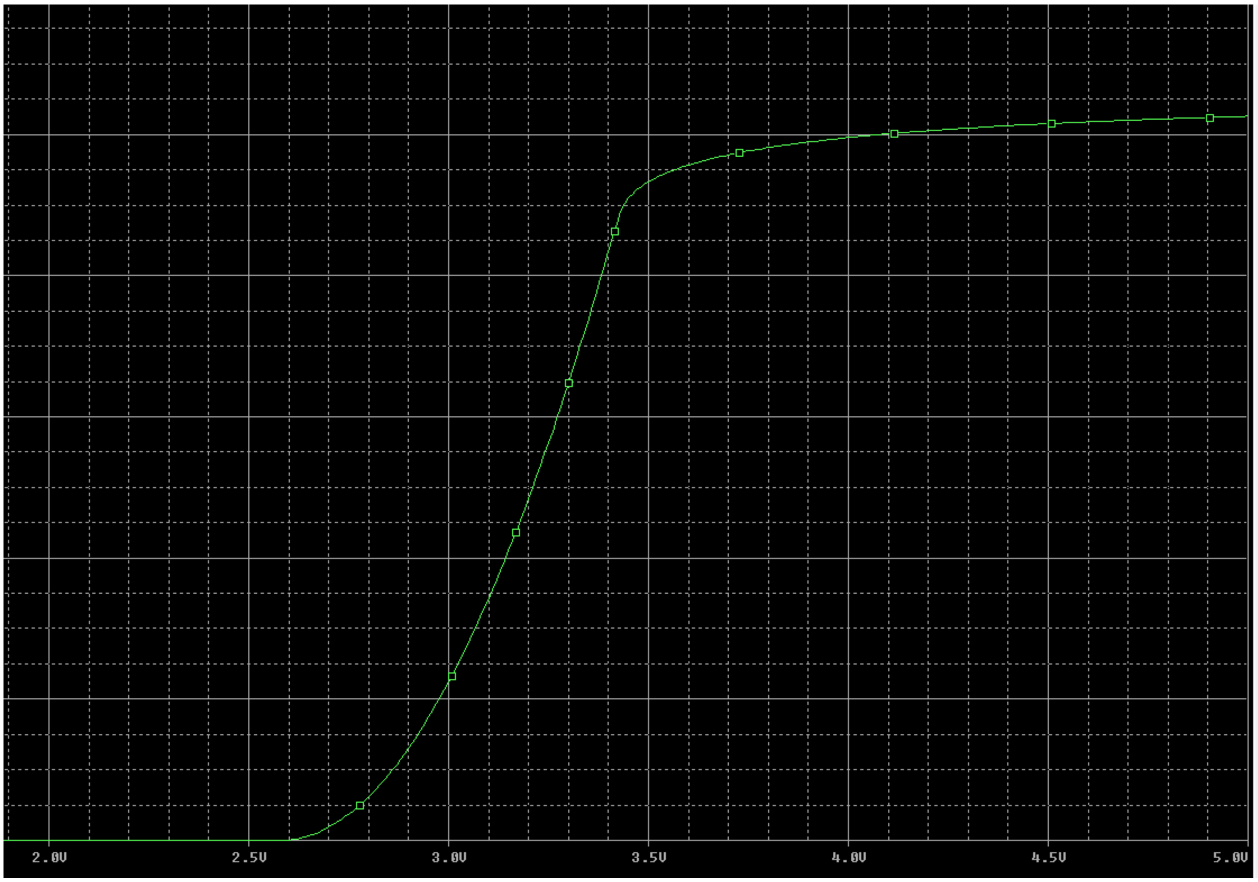
$r_0 = 803.834K$

STEP 6.

There is no step 6

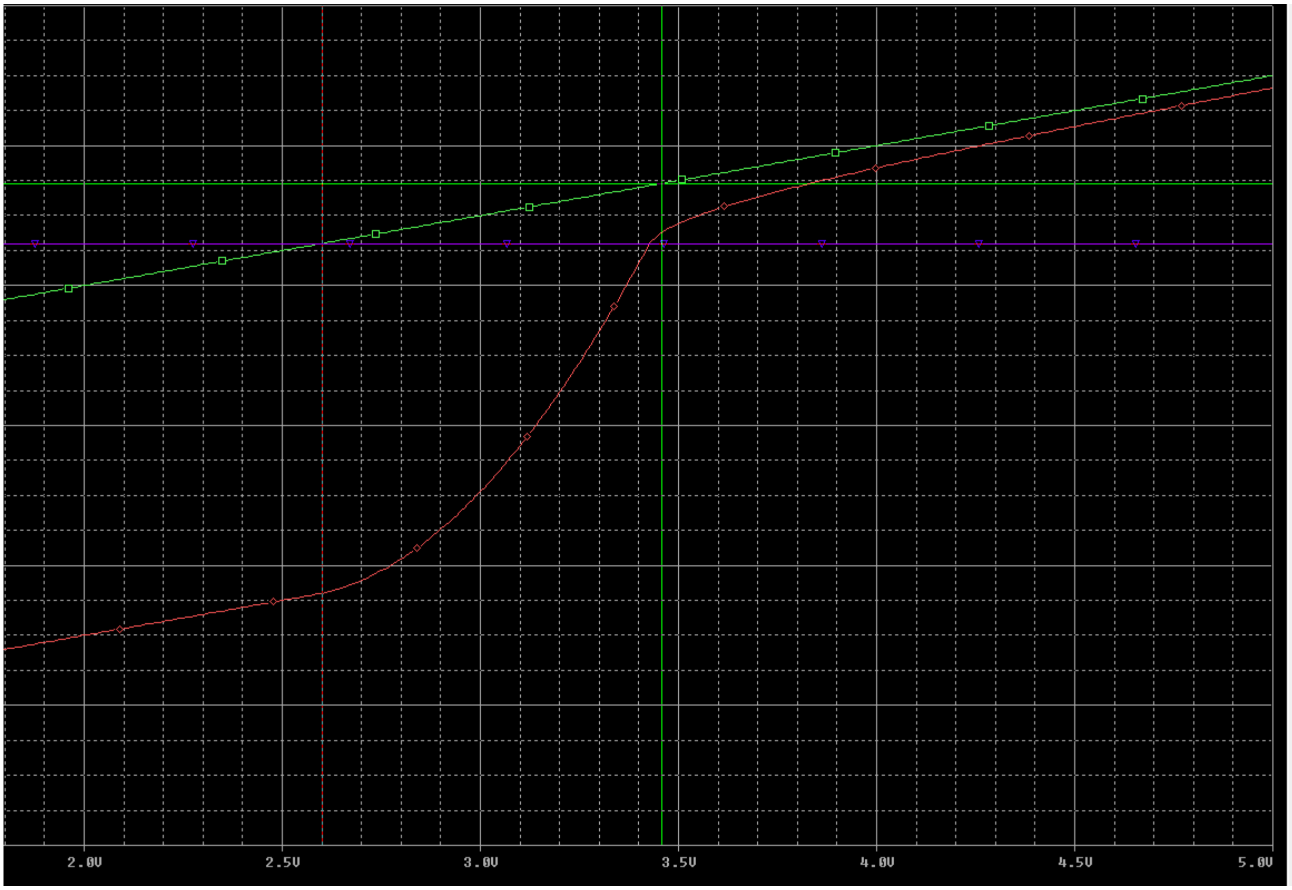
Put R_D back in the circuit

STEP 7.
Plot of ID



Step 7 New $V_{TH} = 2.6V$ ✓

$I_D = K(V_{GS} - V_{th})^2$ Is accurate for the saturation region of operation when lambda is 0.



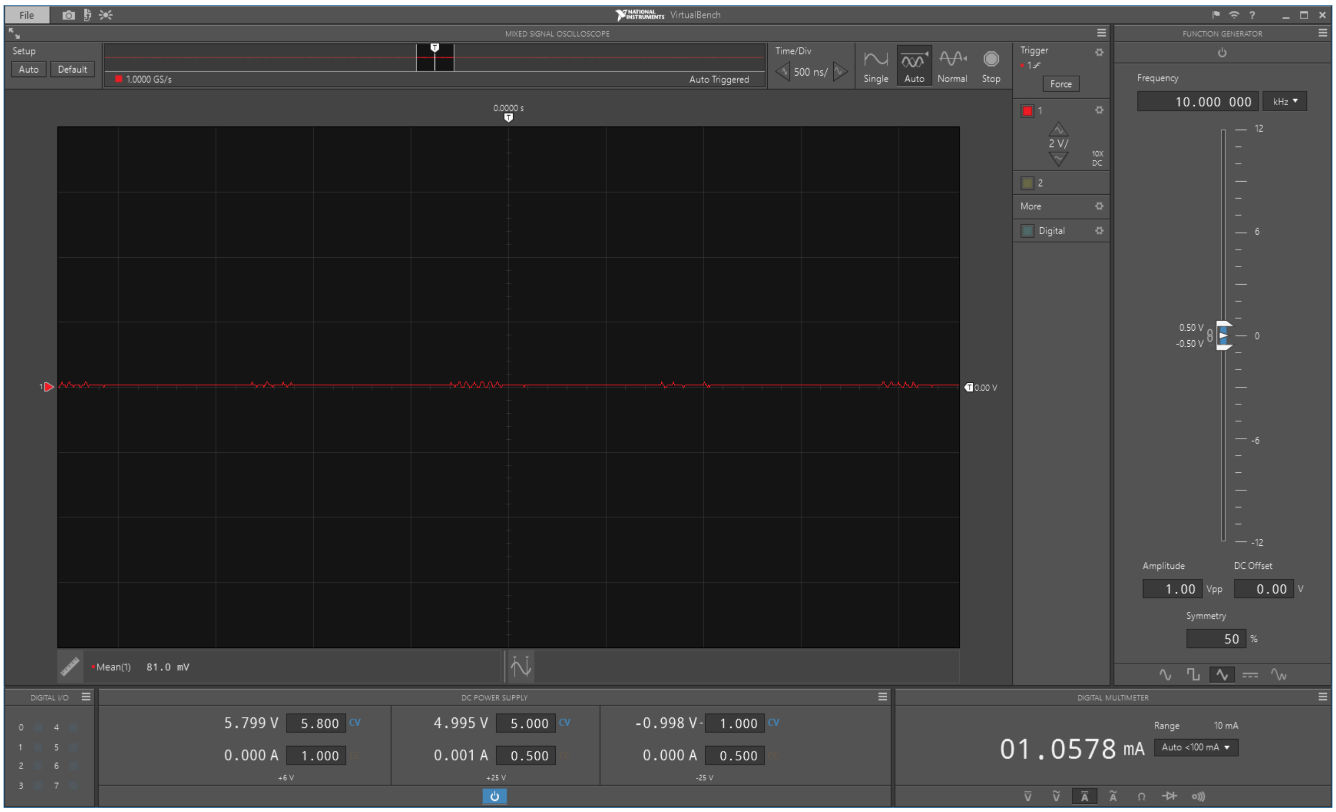
Cutoff occurs to the left of the red cursor, linear between red and green cursors, and forward active to the right of the green cursor.

EXPERIMENT PART 1

STEP 8.

(VDS shown on O scope and ID recorded through the DMM on bottom right corner)

This is pretty much all that was seen for steps 8 – 11 so I'll avoid clutter by only using one plot



Step 8

$R \approx 4.612k\Omega$

VDD stays 5V

did not calculate ID, put DMM in series instead

VGS	VDS	ID mA
1.8	3.38	.338
2.0	2.32	.566
2.5	.330	1.002
3.0	.180	1.033
4.0	.090	1.051
4.25	.085	1.054
4.50	.082	1.056
4.80	.081	1.058

STEP 10.

Step 10 VGS = 2.06V VDS ≈ 2.0V

VGS	VDD	I_D mA	VDS
2.06V	0	.0002	-32mV
	1	.1973	56mV
	2	.390	172mV
	3	.584	370
	4	.633	1.05
	5	.644	2.0
	6	.651	2.98
	7	.657	3.94

STEP 11.

Step 11

	VDS	ID
2.8	2.37	.557 mA
3.0	1.04	.850 mA
3.5	.255	1.015 mA
4.0	.167	1.036 mA
5.0	.090	1.051 mA
5.25	.088	1.054 mA
5.5	.083	1.055 mA
5.8	.079	1.058 mA

CONCLUSIONS

Item 1.

Discuss the variation of the parameter V_{th}
What were the low and high values?
What is the average?
What is the value of the SPICE model parameter?

This question asks whether you understand the "milestone" role the V_{th} plays in solving MOSFET operation – so show understanding.

Item 2.

Discuss the variation of the parameter $K = \frac{\mu C'_{ox}}{2}\frac{W}{L}$
What were the low and high values?
What is the average?
What is the value of the SPICE model parameter?

This question asks whether you understand the physical composition and layout of the MOSFET and then the effects on MOSFET operation – so show understanding.

Item 3.

Discuss on how well your measured values of I_D conform to the equation

$$I_D = \frac{\mu C'_{ox}}{2}\frac{W}{L}\left(V_{GS} - V_{th}\right)^2.$$

Editing the SPICE model so it has the same V_{th} and KP – compare to the value you calculated for your device under the test of Step 9.
Show simulation results from editing the SPICE model versus your measured raw data from Step 8.

Item 4.

Compare $\frac{\Delta V_{DS}}{\Delta I_D}$ obtained from the simulations of Step 5 to the same value obtained from the laboratory measurements of Step 10

What value of λ is indicated by the measured data?

Item 5.

How does V_{th} change when $V_{SB} = 0\text{V}$ is changed to $V_{SB} = -1\text{V}$

Vth is shifted up by 1V

APPENDIX A

FIGURE 1

Lab 6 Pre-lab (mbreakN4)

Step 1) $V_{DS} > V_{GS} - V_{TH}$ ← start

$V_D - V_S > V_G - V_S - V_{TH}$

$V_D > V_G - V_{TH}$

$V_D - V_G > -V_{TH}$

$V_{GD} < V_{TH}$ ← finish

Other condition : $\boxed{V_{GS} \geq V_{TH}}$

Step 2)

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FIGURE 2

Step 3 $$I_D = \frac{\mu_n C'_{ox}}{2} \cdot \frac{W}{L} (V_{GS} - V_{TH})^2$$

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FIGURE 3

Step 5) Linear : $\frac{\Delta V_{DS}}{\Delta I_D} \cong \frac{344.446m}{193.611\mu m} \cong 1.779K$

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