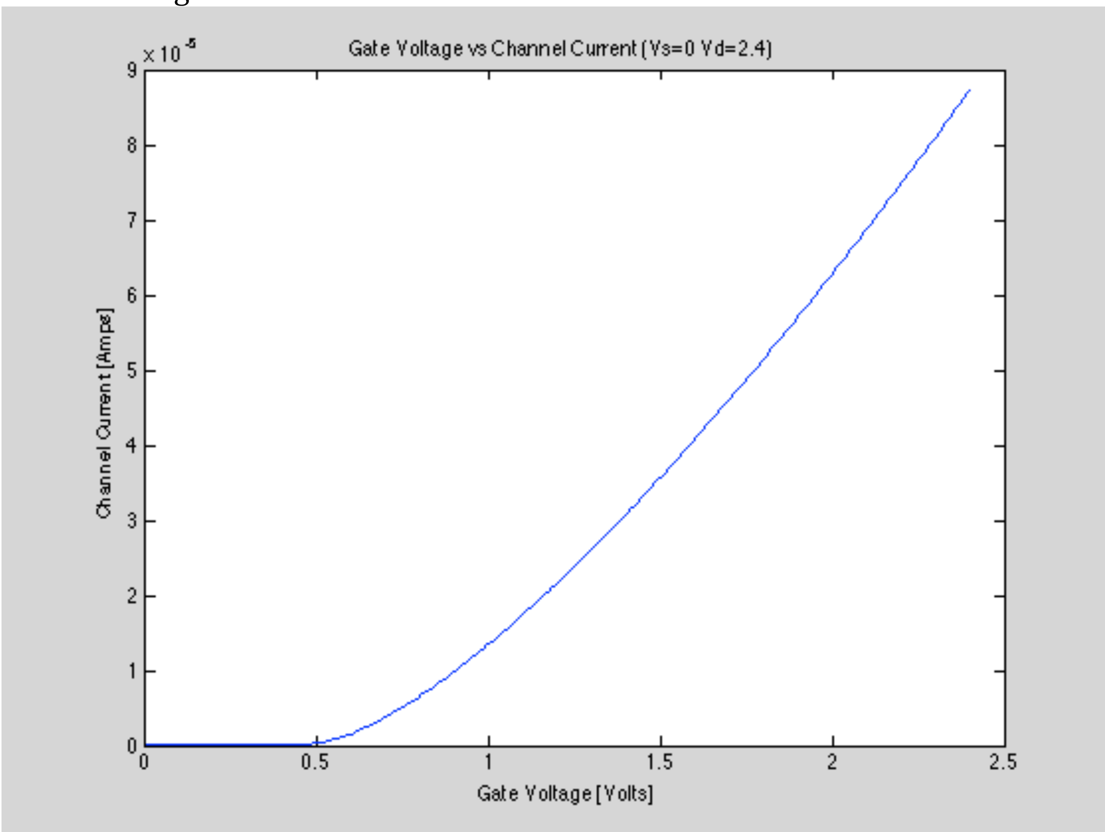
Analog 3050 Mosfet Project 1

nFET

Gate Voltage and Channel Current

Static measurements of channel current versus gate voltage. The source was held to 0V, and the drain was held to 2.4V so that the device would stay in the saturation regime.



Above Threshold Region

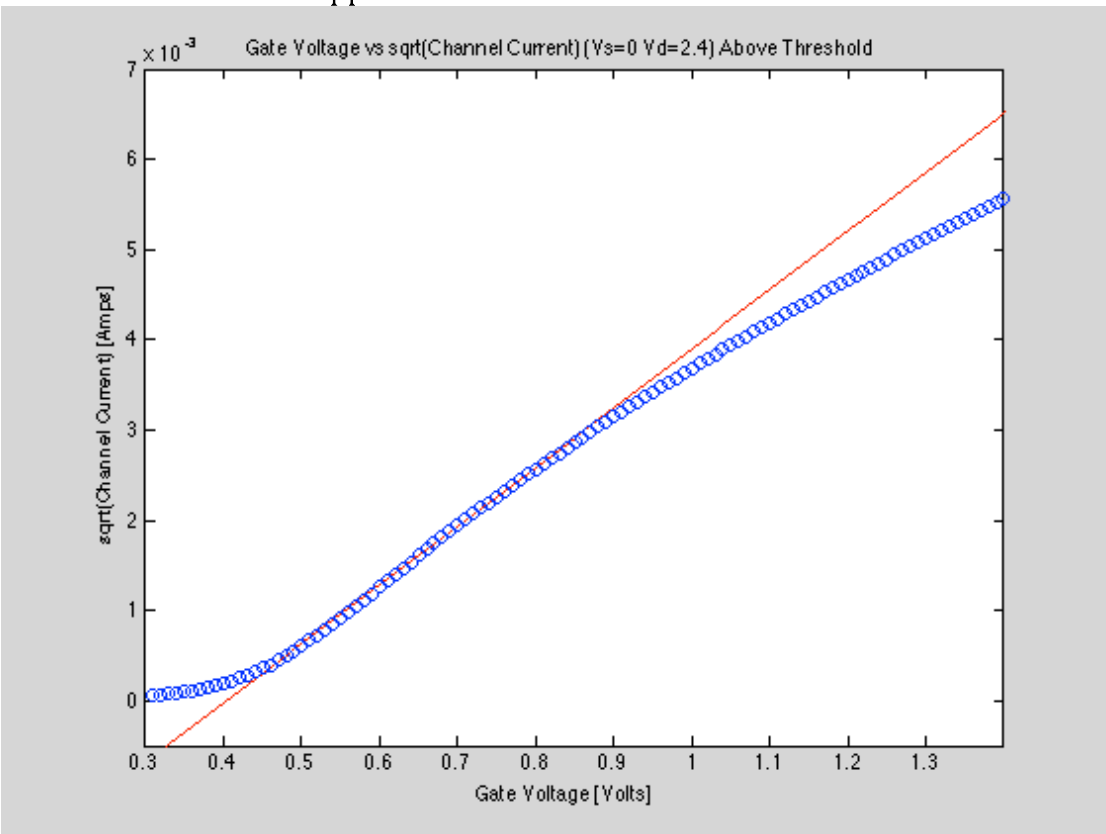
To perform a curve fit in the above threshold region it is convenient to take the square root of the current and plot it against the gate voltage. This leads to the curve fit being linear instead of quadratic as seen below. Assume that V_D/V_A is negligible.

$$I = \frac{K}{2k}(k(V_G - V_{To}) - V_S)^2\left(1 + \frac{V_D}{V_A}\right)$$

$$I = \frac{K}{2k}(k(V_G - V_{To}))^2$$

$$\sqrt{I} = \sqrt{\frac{Kk}{2}}V_G - \sqrt{\frac{Kk}{2}}V_{To}$$

This is the equation of a line, so by finding the slope and intersection, V_{TO} can be found as a function of kappa and K.



$$m = 0.0065 = \sqrt{\frac{Kk}{2}}$$

$$c = -0.0026 = -\sqrt{\frac{Kk}{2}}V_{TO}$$

$$\frac{-c}{m} = \frac{\sqrt{\frac{Kk}{2}}V_{TO}}{\sqrt{\frac{Kk}{2}}} = V_{TO} = \frac{0.0026}{0.0065} = 0.4044\ V$$

Identify the Channel Current Level when the device is biased with a gate voltage equal to threshold Voltage, i.e. the threshold current, I_{th}.

From the data given, when the gate voltage is 0.4 volts, then the channel current is 3.6093×10^{-8} Amps.

Sub-Threshold Region

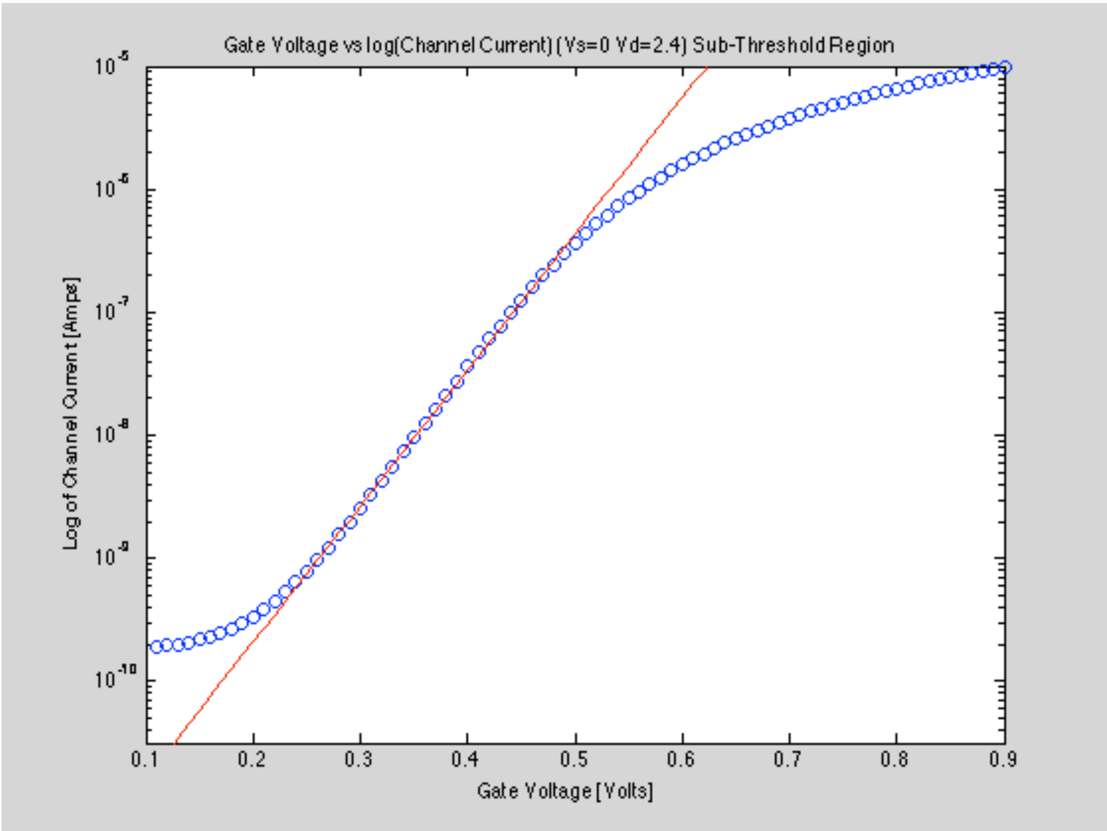
$$I = I_{th}\exp(\frac{k(V_G - V_{To}) - V_s + \sigma V_D}{U_T})$$

Next perform a curve fit in the sub-threshold region. The current and gate voltage are exponentially related in the sub threshold region. By taking the natural log of the equation above, it is possible to perform a linear curve fit between the log (I) and Vg. Assume sigma is negligible.

$$I = I_{th}\exp(\frac{k(V_G - V_{TO})}{U_T})$$

$$\log(I) = \frac{kV_G}{U_T} + \log(I_{th}) - \frac{kV_{TO}}{U_T}$$

Again this is the equation of a line and by solving for the slope we can find kappa in the sub-threshold region. (Take U_T to be 25.8mV) As well as I_0, which is the current when there is no gate voltage.



$$m = \frac{k}{U_T} = 25.6651$$

$$k = 25.6651 U_T = 25.6651(25 \times 10^{-3}) = 0.6570$$

$$c = -27.3791 = \log(I_{th}) - \frac{kV_{TO}}{U_T}$$

$$\exp(-27.3791) = I_{th}\exp(-\frac{kV_{TO}}{U_T}) = I_0$$

$$I_0 = 1.2865 \times 10^{-12}\ A$$

Compute gm/I for all values of current and make a figure of gm/I vs. Log(I).
Taking the threshold voltage to be 0.4044

Sub-threshold

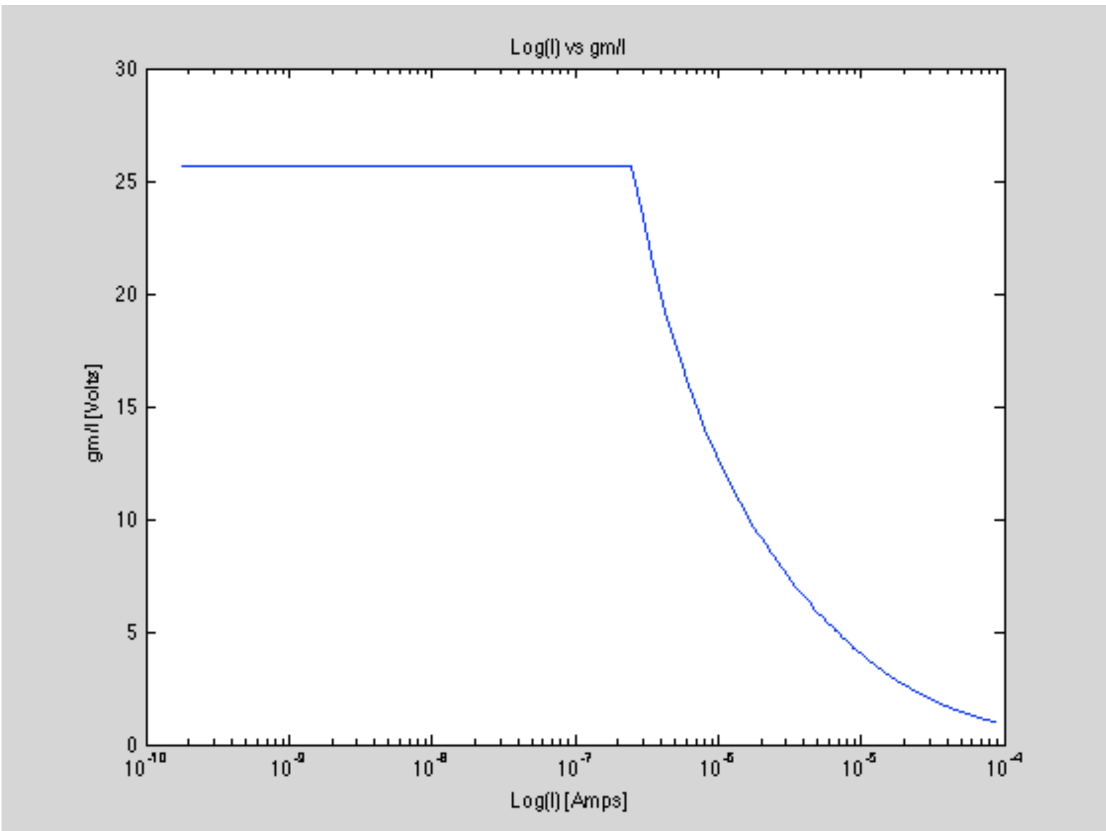
$$g_m = \frac{dI}{dV_G} = \frac{kI}{U_T}$$

$$\frac{g_m}{I} = \frac{k}{U_T} = 25.6651$$

Above Threshold

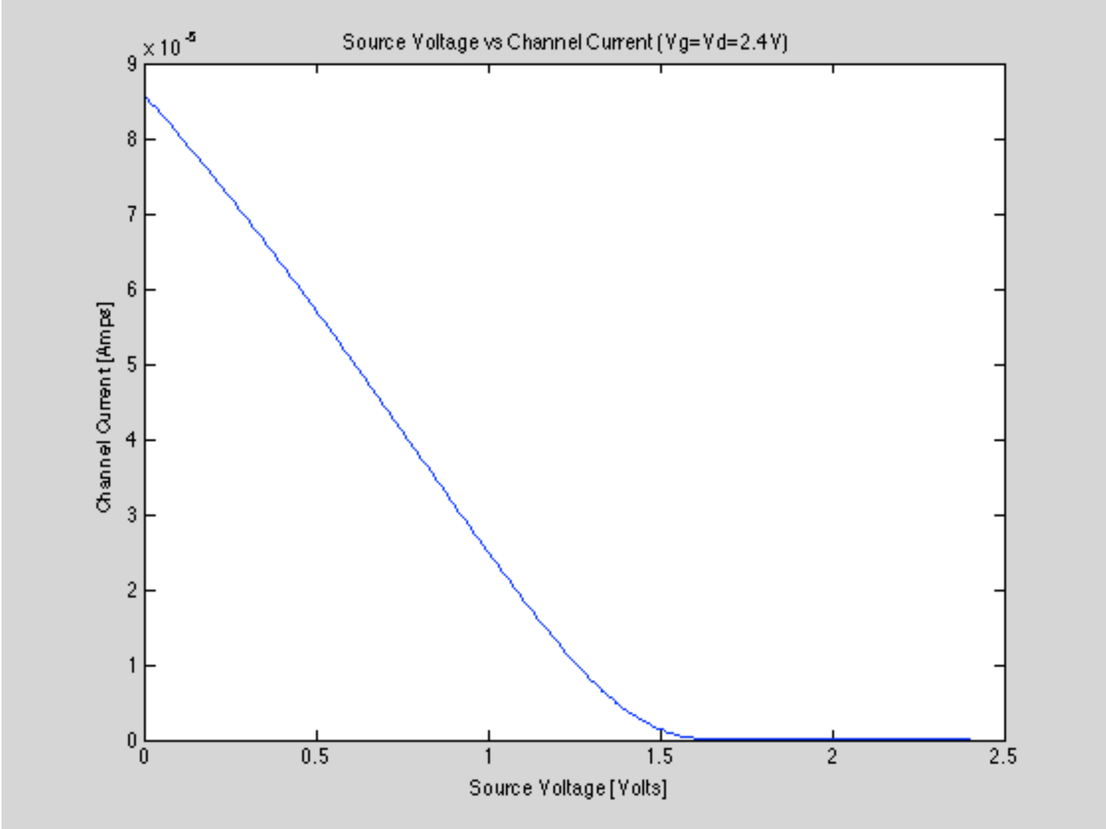
$$gm = \frac{dI}{dV_G} = \frac{2kI}{V_{on}} = \frac{2kI}{k(V_G - V_{TO}) - V_S}$$

$$\frac{gm}{I} = \frac{2}{(V_G - V_{TO})} = \frac{2}{(V_G - 0.4044)}$$



Source Voltage and Channel Current

Static measurements of channel current versus source voltage. The gate and drain voltages were held constant at 2.4V and the bulk voltage was held constant at 0V. The transistor was in saturation for the entire source sweep.



Above Threshold Region

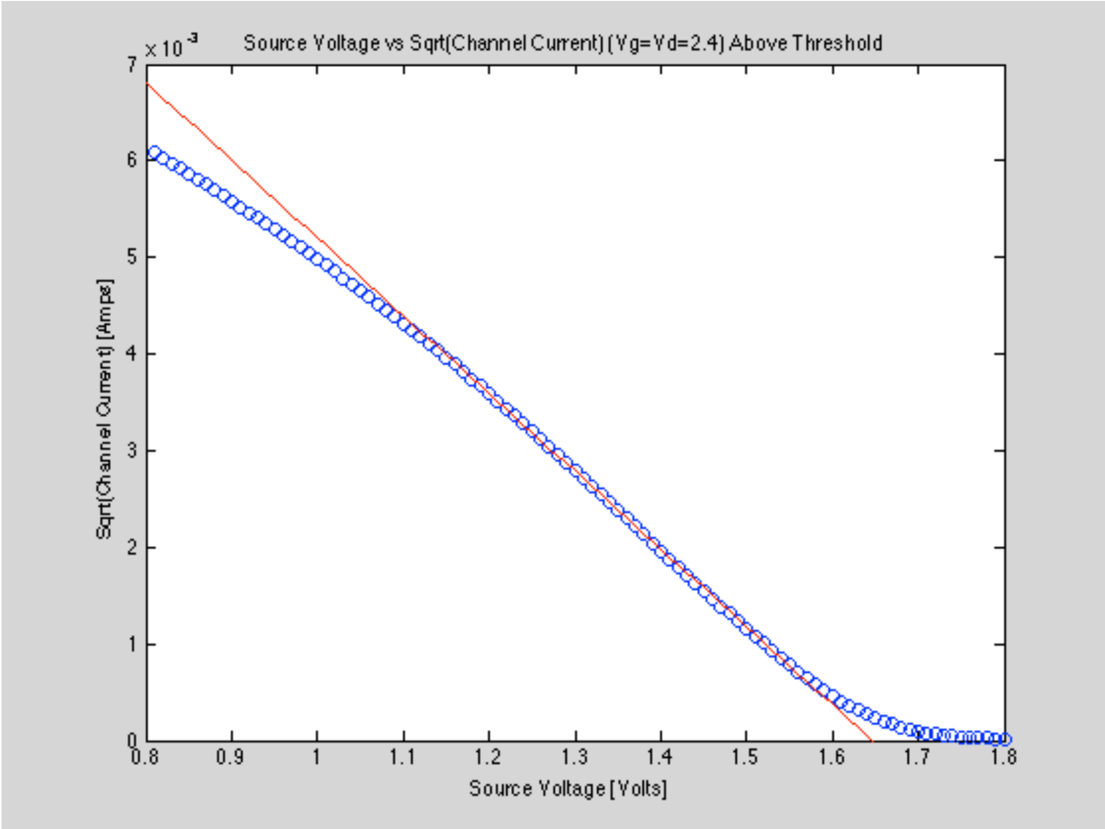
To perform a curve fit in the above threshold region it is convenient to take the square root of the current and plot it against the source voltage. This leads to the curve fit being linear instead of quadratic as seen below. Assume that V_D/V_A is negligible.

$$I = \frac{K}{2k}(k(V_G - V_{To}) - V_s)^2$$

$$\sqrt{I} = \sqrt{\frac{K}{2k}}(k(V_G - V_{To}) - V_s)$$

$$\sqrt{I} = -V_s\sqrt{\frac{K}{2k}} + \sqrt{\frac{Kk}{2}}(V_G - V_{To})$$

This is the equation of a line, and the slope and intercept can be found by finding a linear fit to the data.



$$m = -\sqrt{\frac{K}{2k}} = -0.0080$$

$$\sqrt{\frac{K}{2k}} = 0.0080$$

$$c = \sqrt{\frac{Kk}{2}}(V_G - V_{To}) = 0.0132$$

$$V_{To} = V_G - 0.0132\sqrt{\frac{2}{Kk}}$$

$$V_{To} = 2.4 - 0.0132\sqrt{\frac{2}{Kk}}$$

From this we have obtained a different equation for the threshold voltage in terms of K and kappa.

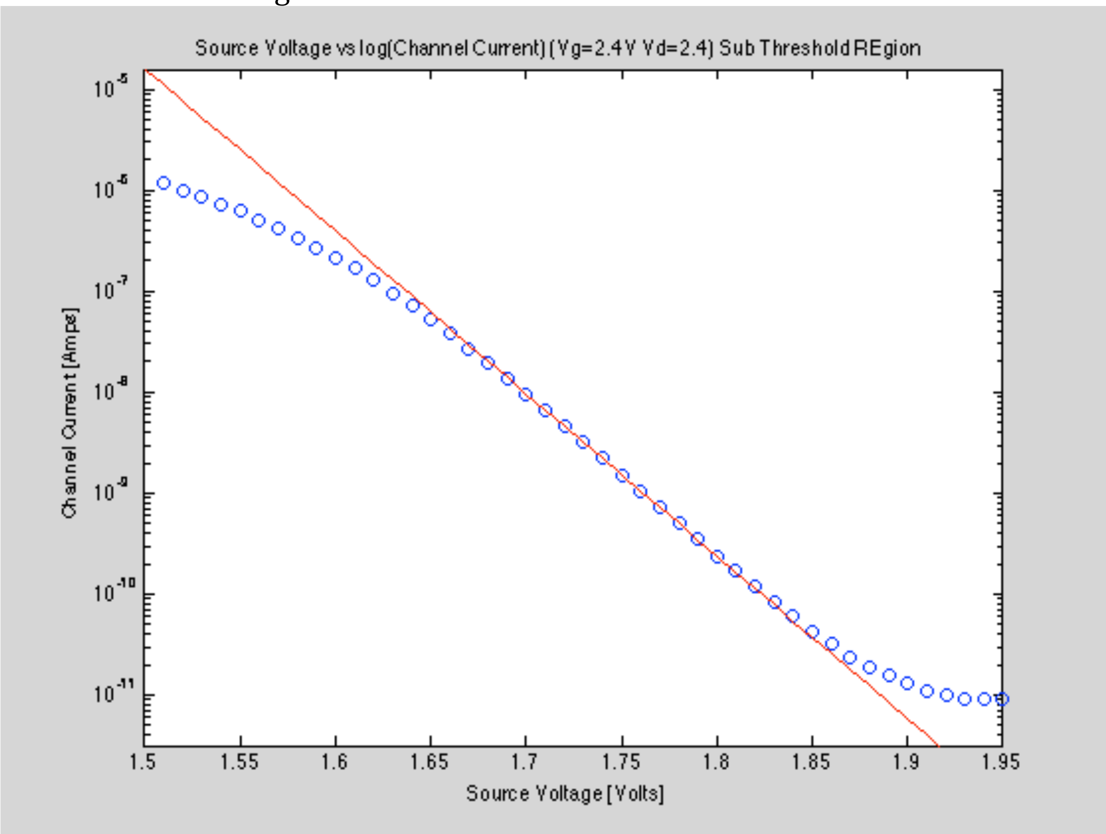
Sub-Threshold Region

By performing a curve fit in the sub-threshold region, a value for U_T can be calculated.
The current and gate voltage are exponentially related in the sub threshold region. By taking the natural log of either side, it is possible to perform a linear curve fit between the log (I) and Vg. (Assume sigma is negligible.)

$$I = I_{th} \exp(\frac{k(V_G - V_{TO}) - V_S}{U_T})$$

$$\log(I) = \frac{-V_S}{U_T} + \log(I_{th}) + \frac{k(V_G - V_{TO})}{U_T}$$

Again this is the equation of a line and by solving for the slope we can find U_T in the sub-threshold region.



$$m = \frac{-1}{U_T} = -37.0803$$

$$\frac{1}{37.0803} = U_T = 0.027\ mV$$

$$c = \log(I_{th}) + \frac{k(V_G - V_{TO})}{U_T} = 44.5845$$

The value for U_T is higher than expected. At 300K ,U_T is around 25.8 mV.

Solve for K and kappa

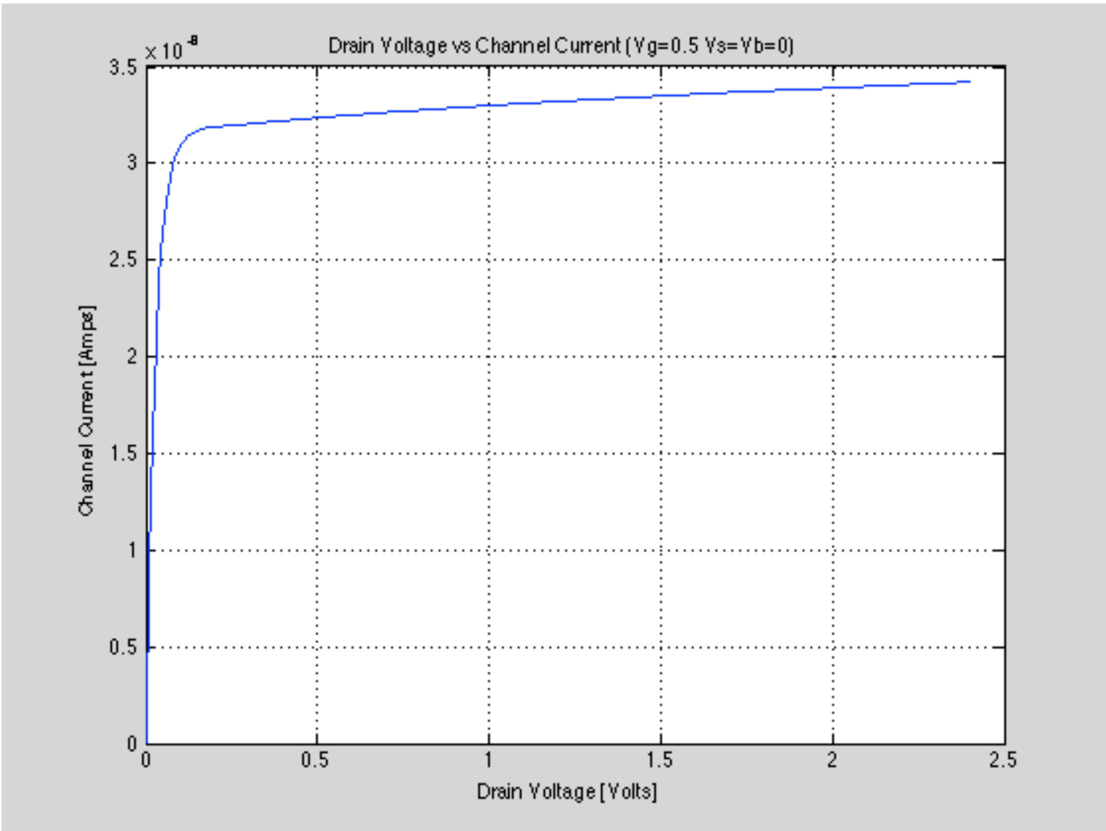
Gate Sweep: $\sqrt{\frac{Kk}{2}} = 0.0065$

Source Sweep: $\sqrt{\frac{K}{2k}} = 0.008$

Solving these equations gives k=0.8125 and K=1.04 x 10^{-4} A/V^2

Drain Voltage and Channel Current

Static measurements of channel current versus drain voltage. The gate voltage is held constant at 0.4 Volts and the gate, bulk and source voltages was held constant at 0V.



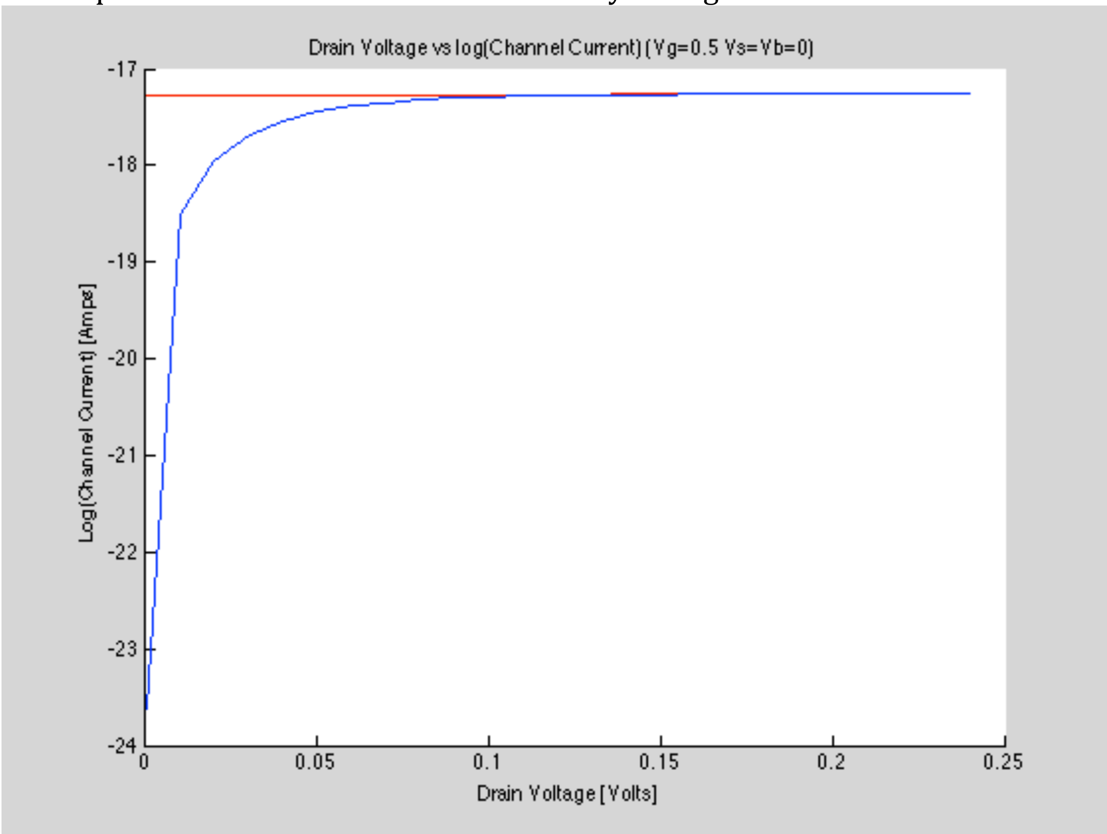
The current at which the curve saturates is below the threshold current, therefore the curve is taken in the sub threshold operation of the MOSFET. It is possible to tell this from the way the curve saturates at greater than 100 mV ($4U_T$)

$$I = I_{th}\exp(\frac{k(V_G - V_{To}) - V_S + \sigma V_D}{U_T})$$

$$\log(I) = \frac{\sigma V_D}{U_T} + \log(I_{th}) + \frac{k(V_G - V_{To})}{U_T}$$

$$\log(I) = \frac{V_D}{V_A} + \log(I_{th}) + \frac{k(V_G - V_{To})}{U_T}$$

The slope of the line is the inverse of the Early Voltage.



$$m = 0.0596$$

$$V_A = 1/m = 16.78\ Volts$$

For the Spice–simulation, the following values are needed:

K=1.04 x 10-4 A/V^2 $\quad$ V_A=16.8 Volts

Above Threshold Kappa=0.8125 $\quad$ Sub Threshold Kappa=0.6570

Average Kappa=0.7348 $\quad$ V_{TO}=0.4044

To input kappa, two parameters are used, gamma and phi, such that the following equation is satisfied: $\gamma = 2\sqrt{2\varphi}\left(\frac{1}{k} - 1\right)$

Take φ=0.5 and γ=0.7218.

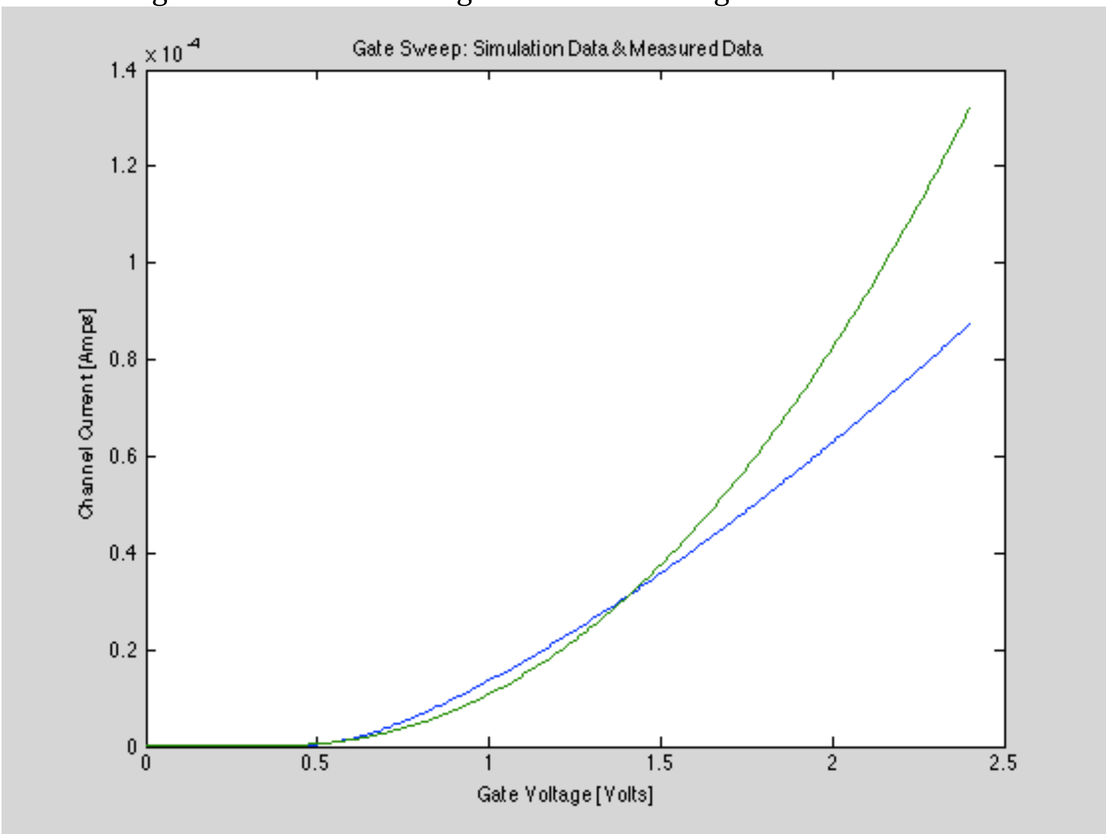
Results of Simulation (Multi-Sim) nFET

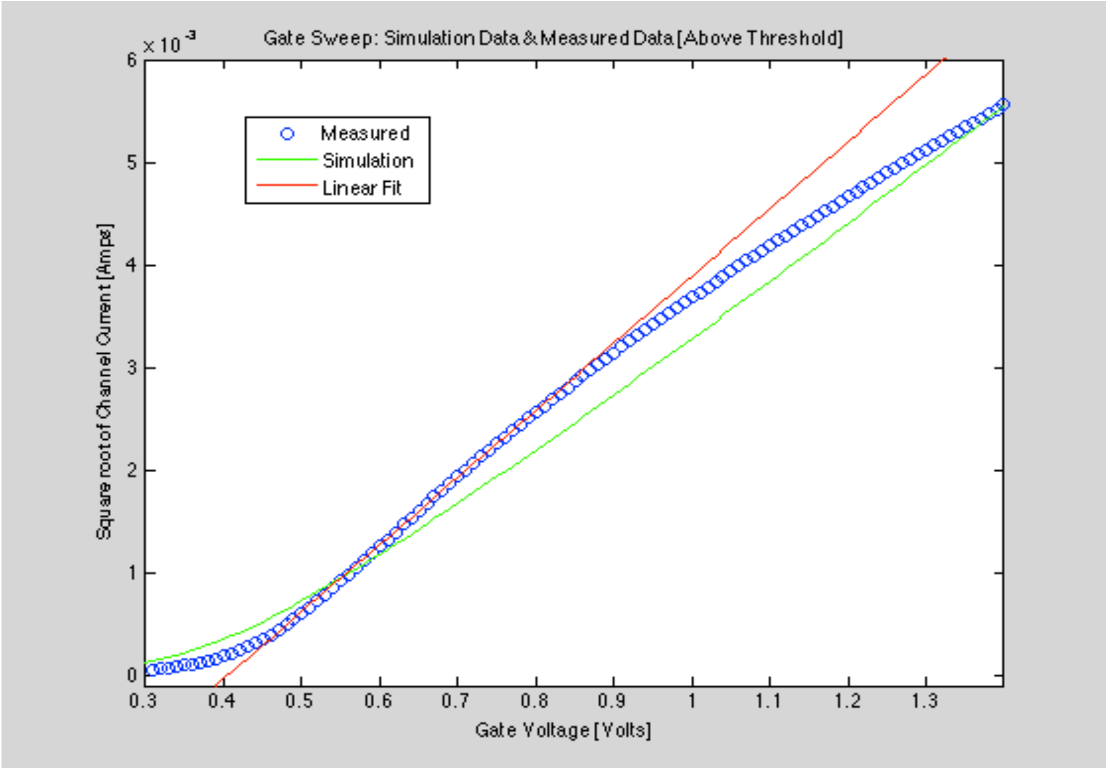
For all simulations the following parameter in and EKV model were used:

- K=1.04 x 10-4 A/V2
- Lambda=0.0596 Volts
- Average Kappa=0.7348
- VTO=0.4044
- Take φ=0.5
- γ=0.7218.

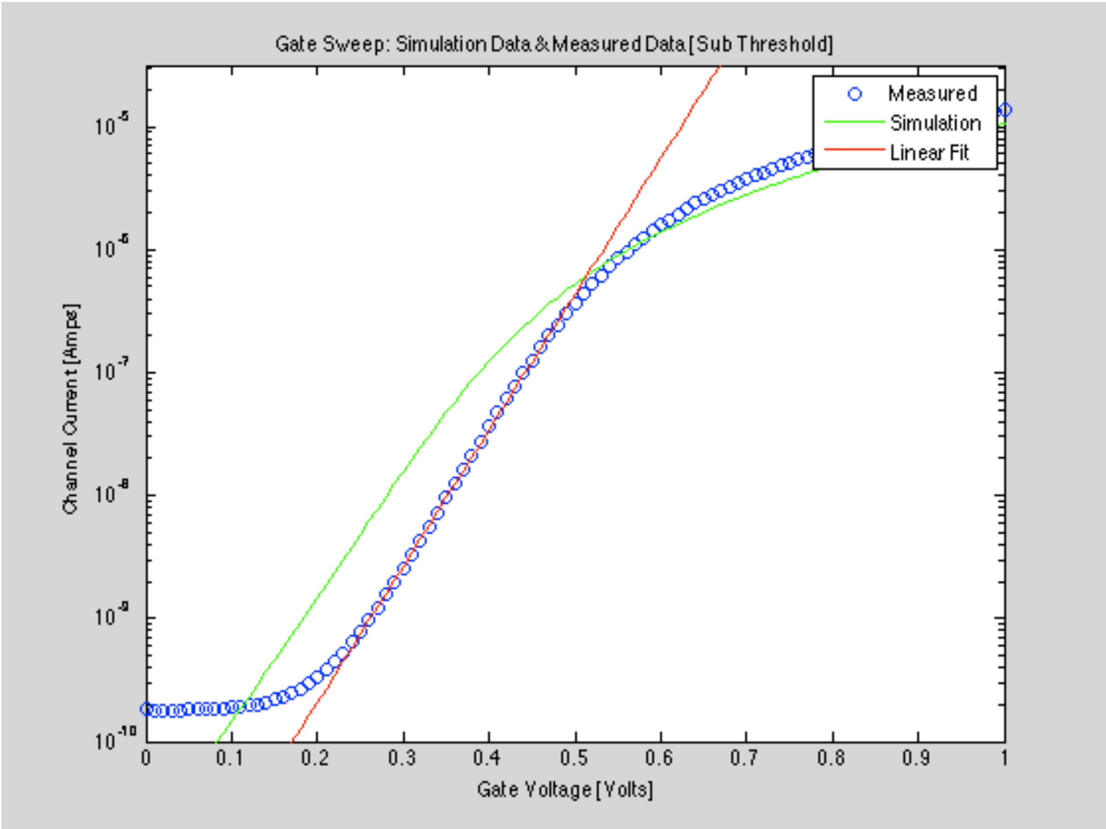
Gate Sweep

Drain Voltage=2.4V   Source Voltage= 0V   Bulk Voltage=0V





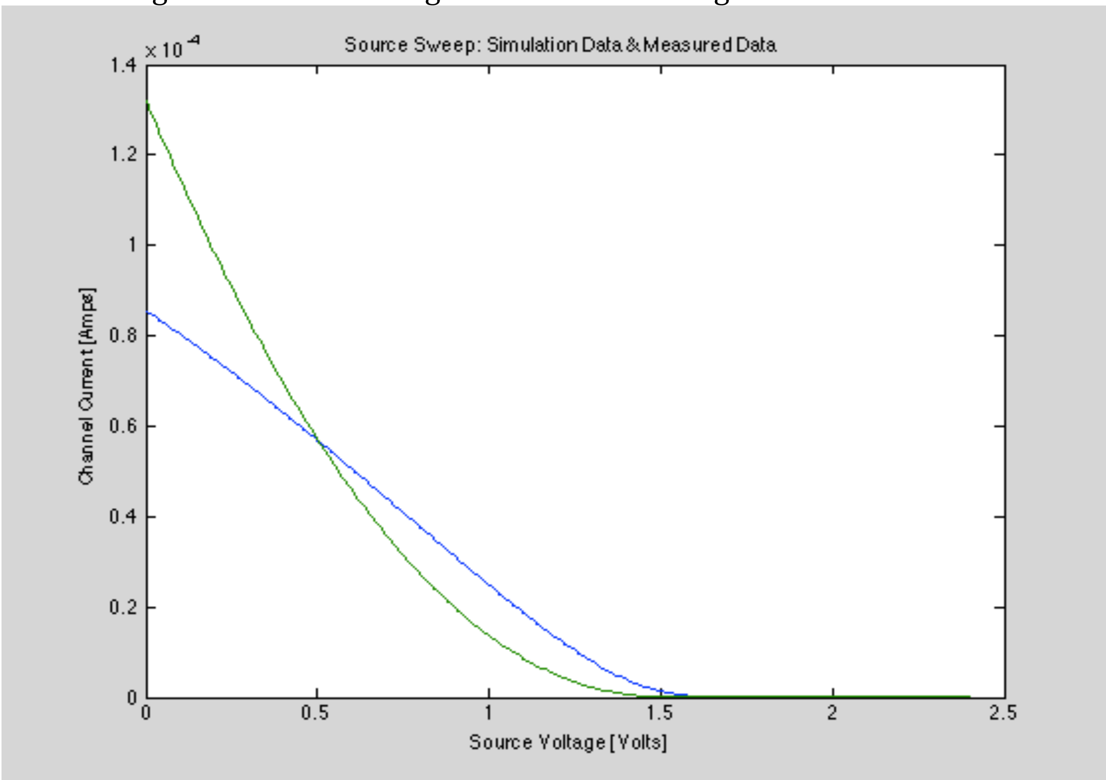
The simulation data gives a reasonably good approximation to the measured data.

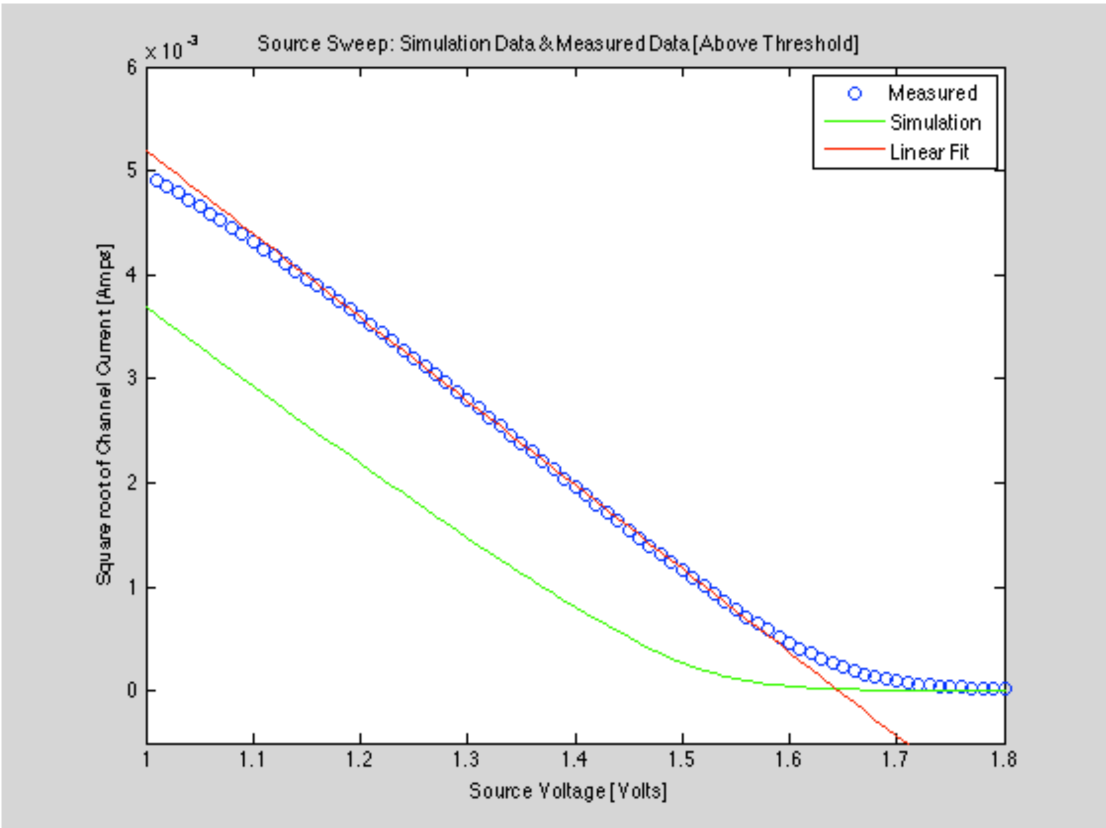


The simulation data deviates from the measured data below the threshold voltage, after the threshold voltage is reached the error of the simulation decreases.

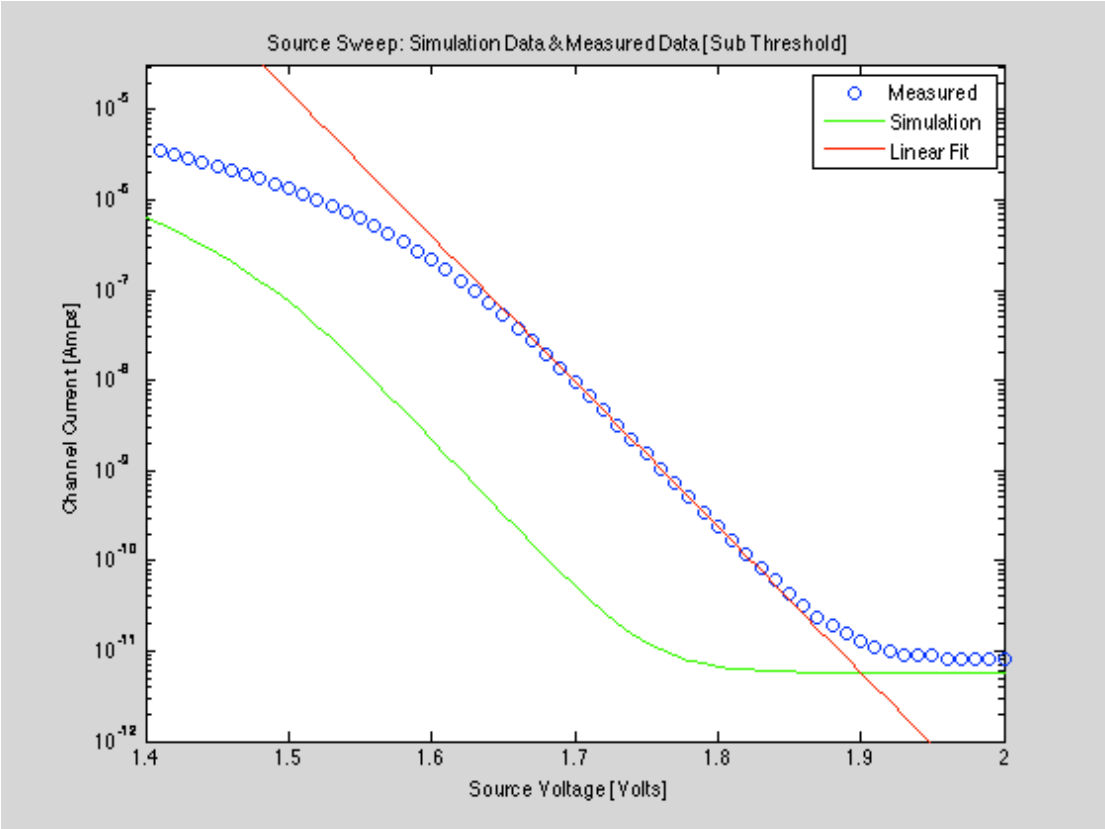
Source Sweep

Drain Voltage=2.4V   Gate Voltage= 2.4V   Bulk Voltage=0V





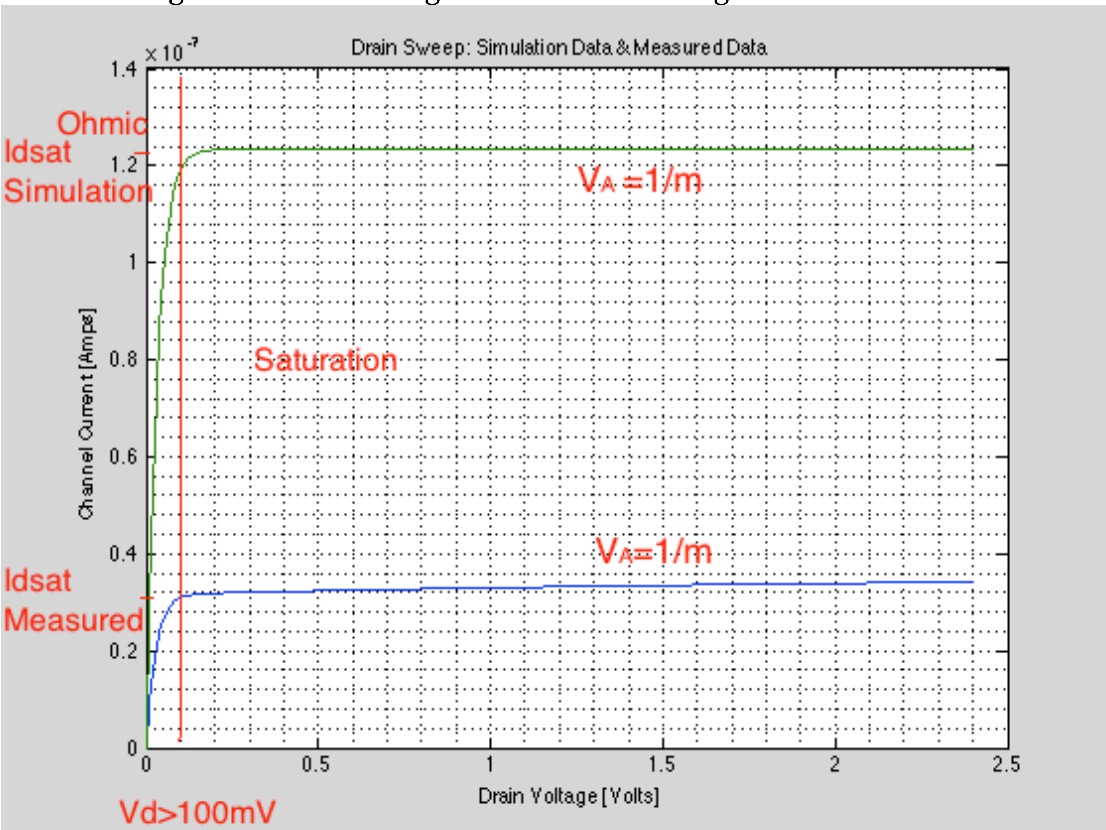
The simulation data deviates from the measured data by approximately 0.1 Volts, however it does follow the same shape.



The simulation data deviates from the measured data by approximately 0.1 Volts, however it does follow the same shape.

Drain Sweep

Source Voltage=0V   Gate Voltage= 0.4V   Bulk Voltage=0V

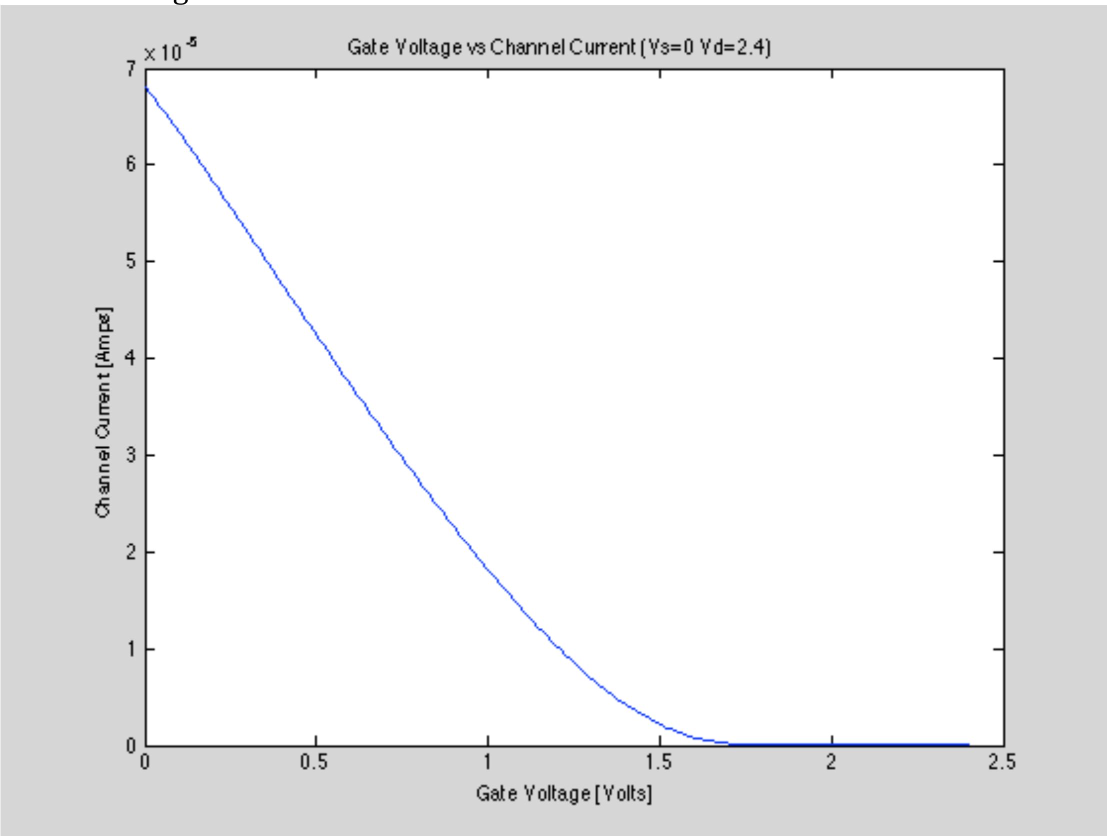


Clearly the simulation data (green) and the measured data (blue) are different. It appears as though the measured data was taken at a lower gate voltage.
The measured data is sub-threshold, because the curve saturates at 100 mV.

pFET

Gate Voltage and Channel Current

Static measurements of channel current versus gate voltage. The source was held to 0V, and the drain was held to 2.4V so that the device would stay in the saturation regime.



Above Threshold Region

To perform a curve fit in the above threshold region it is convenient to take the square root of the current and plot it against the gate voltage. This leads to the curve fit being linear instead of quadratic as seen below. Assume that V_D/V_A is negligible.

$$I = \frac{K}{2k}(k(V_{DD} - V_G - V_{TO}) - (V_{DD} - Vs))^2$$

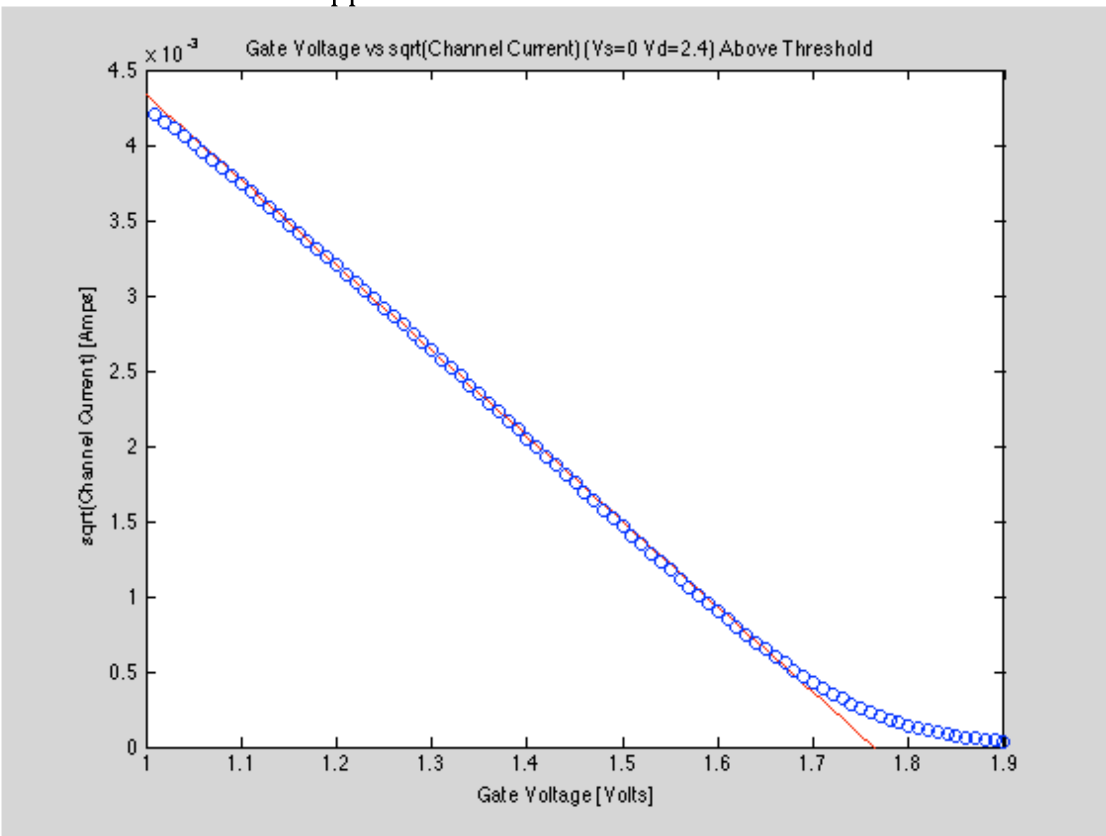
$$\sqrt{I} = \sqrt{\frac{K}{2k}}(k(V_{DD} - V_G - V_{TO}))$$

$$\sqrt{I} = -V_G\sqrt{\frac{Kk}{2}} + \sqrt{\frac{Kk}{2}}(V_{DD} - V_{TO})$$

$$\sqrt{I} = -V_G\sqrt{\frac{Kk}{2}} + \sqrt{\frac{Kk}{2}}(2.4 - V_{TO})$$

V_{DD} is the highest voltage in the circuit, which in this case is 2.4 V

This is the equation of a line, so by finding the slope and intersection, V_{TO} can be found as a function of kappa and K.



$$m = -0.0057 = -\sqrt{\frac{Kk}{2}}$$

$$c = 0.01 = \sqrt{\frac{Kk}{2}}((2.4 - V_{TO}))$$

$$V_{TO} = 0.645$$

From the graph it can be seen that the threshold voltage is 2.4-1.75= 0.65 Volts

Identify the Channel Current Level when the device is biased with a gate voltage equal to threshold Voltage, i.e. the threshold current, I_{th}.
From the data given, when the gate voltage is 1.75 volts, then the channel current is 6.7075x 10-8 Amps.

Sub-Threshold Region

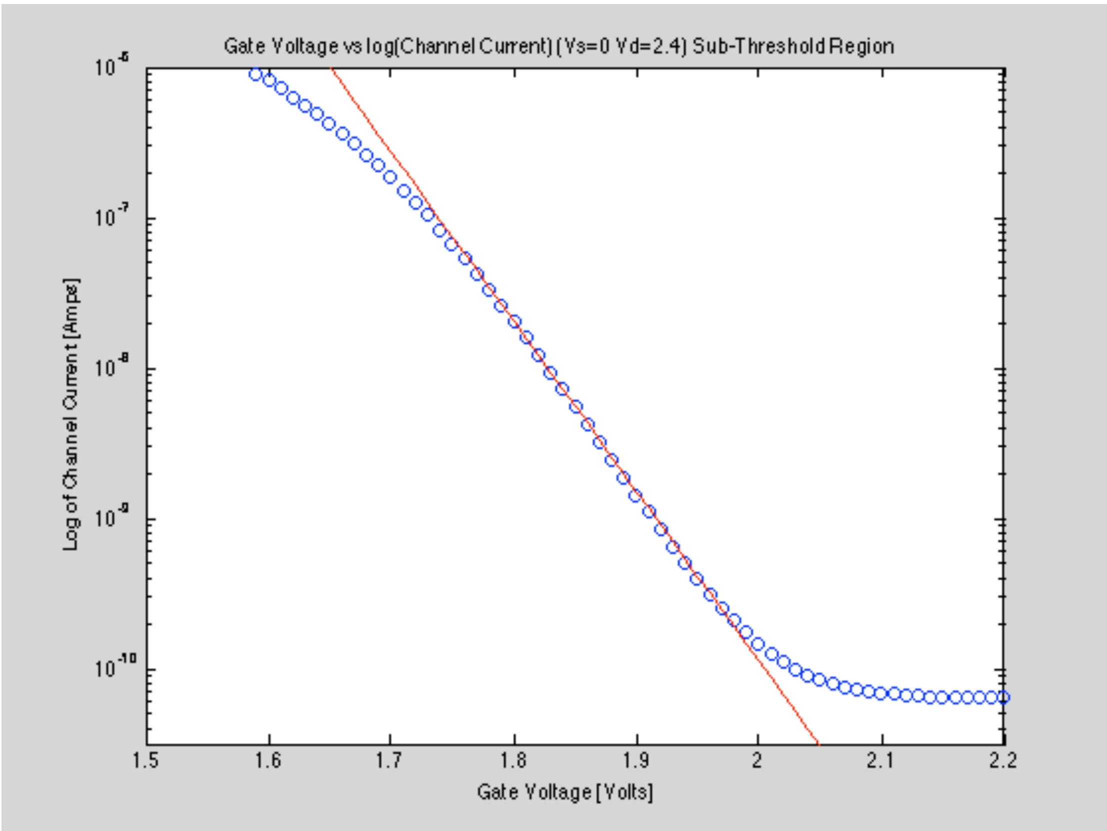
$$I = I_{th}\exp\left(\frac{k((V_{DD} - V_G - V_{TO})}{U_T}\right)$$

Next perform a curve fit in the sub-threshold region. The current and gate voltage are exponentially related in the sub threshold region. By taking the natural log of the equation above, it is possible to perform a linear curve fit between the log (I) and Vg. Assume sigma is negligible.

$$\log(I) = \log(I_{th}) + \left(\frac{k((V_{DD} - V_G - V_{TO})}{U_T}\right)$$

$$\log(I) = -\frac{kV_G}{U_T} + \log(I_{th}) + \frac{k(V_{DD} - V_{TO})}{U_T}$$

Again this is the equation of a line and by solving for the slope we can find kappa in the sub-threshold region. (Take U_T to be 25.8mV) As well as I_0, which is the current when there is no gate voltage.



$$m = \frac{-k}{U_T} = -25.9621$$

$$k = 0.6698$$

$$c = 29.0233$$

$$\exp(c) = I_0 = 4.0141 \times 10^{-12}$$

Compute gm/I for all values of current and make a figure of gm/I vs. Log(I).
Taking the threshold voltage to be 0.4044

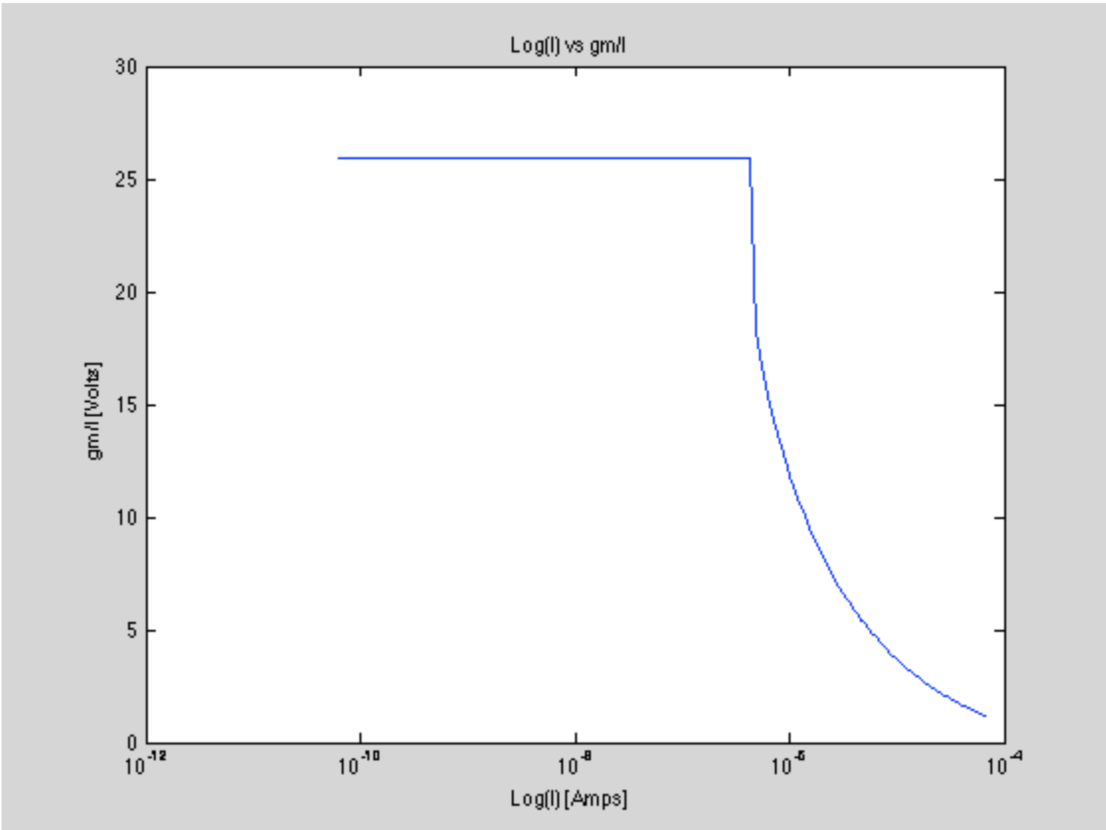
Sub-threshold

$$g_m = \frac{dI}{dV_G} = \frac{kI}{U_T}$$

$$\frac{g_m}{I} = \frac{k}{U_T} = 25.9621$$

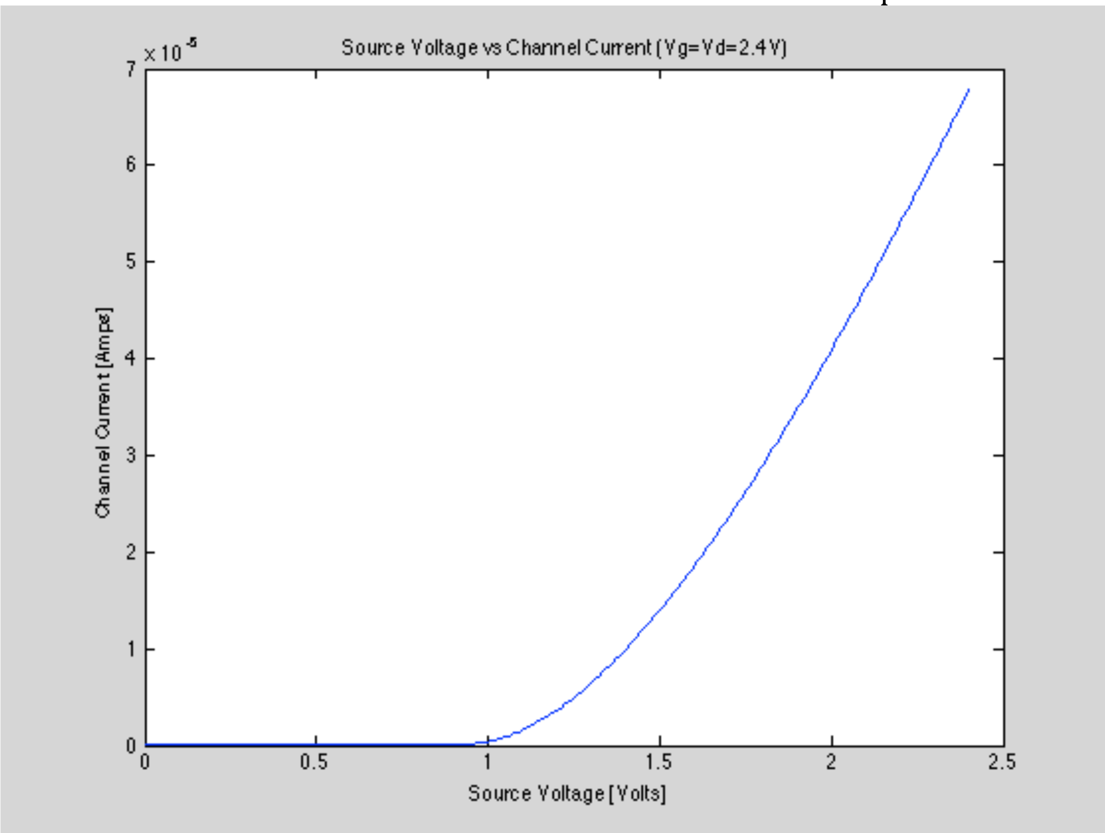
Above Threshold

$$g_m = \frac{dI}{dV_G} = \frac{2kI}{V_{on}} = \frac{2kI}{k(V_{dd} - V_g - V_{To}) - V_s}$$



Source Voltage and Channel Current

Static measurements of channel current versus source voltage. The gate and drain voltages were held constant at 2.4V and the bulk voltage was held constant at 0V. The transistor was in saturation for the entire source sweep.



Above Threshold Region

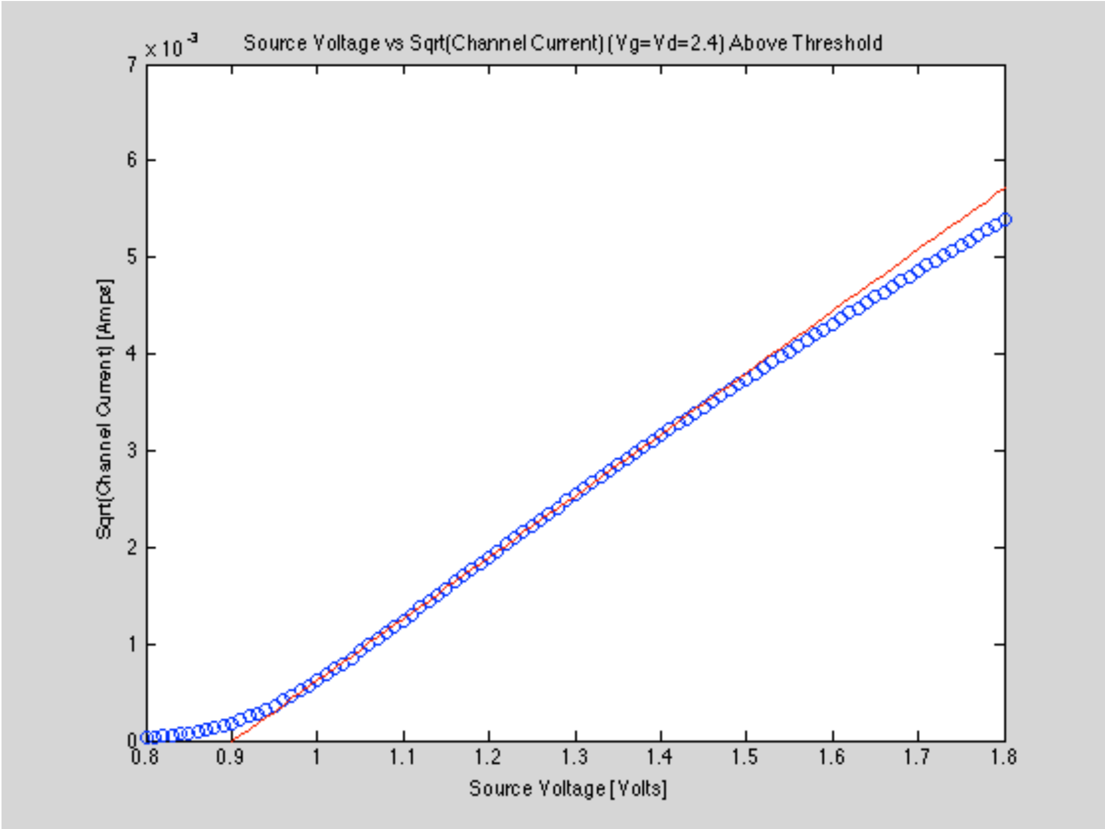
To perform a curve fit in the above threshold region it is convenient to take the square root of the current and plot it against the source voltage. This leads to the curve fit being linear instead of quadratic as seen below. Assume that V_D/V_A is negligible.

$$I = \frac{K}{2k}(k(V_{DD} - V_G - V_{To}) - V_s)^2$$

$$\sqrt{I} = \sqrt{\frac{K}{2k}}(k(V_{DD} - V_G - V_{To}) - (V_{DD} - V_S))$$

$$\sqrt{I} = V_s\sqrt{\frac{K}{2k}} + \sqrt{\frac{Kk}{2}}(V_{DD} - V_G - V_{To}) - \sqrt{\frac{K}{2k}}V_{DD}$$

This is the equation of a line, and the slope and intercept can be found by finding a linear fit to the data.



$$m = \sqrt{\frac{K}{2k}} = 0.0064$$

$$c = \sqrt{\frac{Kk}{2}}(V_{DD} - V_G - V_{To}) - \sqrt{\frac{K}{2k}}V_{DD} = -0.0057$$

$$\sqrt{\frac{Kk}{2}}(V_{DD} - V_G - V_{To}) = \sqrt{\frac{K}{2k}}V_{DD} - 0.0057$$

$$\sqrt{\frac{Kk}{2}}(2.4 - 2.4 - V_{To}) = 0.0064(2.4) - 0.0057$$

$$-\sqrt{\frac{Kk}{2}}V_{To} = 0.00966$$

From this we have obtained a different equation for the threshold voltage in terms of K and kappa.

Sub-Threshold Region

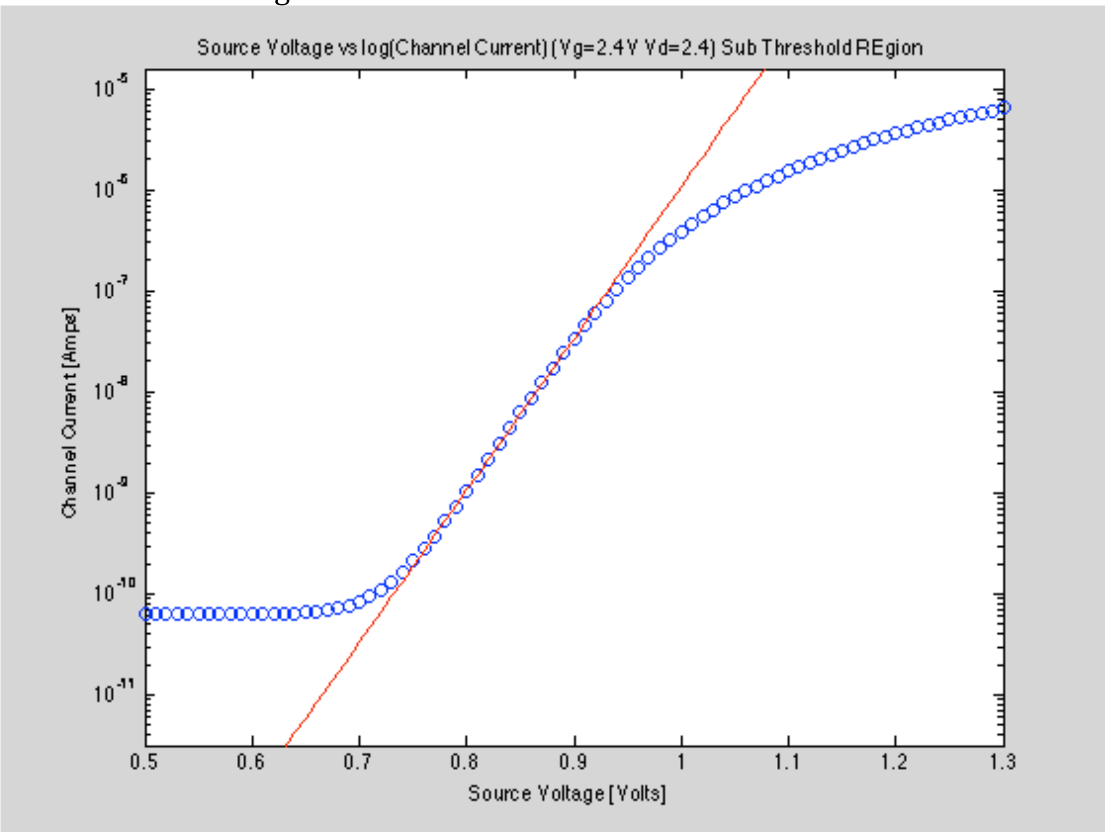
By performing a curve fit in the sub-threshold region, a value for U_T can be calculated.

The current and gate voltage are exponentially related in the sub threshold region. By taking the natural log of either side, it is possible to perform a linear curve fit between the log (I) and Vg. (Assume sigma is negligible.)

$$I = I_{th} \exp(\frac{k(V_G - V_{TO}) - V_S}{U_T})$$

$$\log(I) = \frac{-V_S}{U_T} + \log(I_{th}) + \frac{k(V_G - V_{TO})}{U_T}$$

Again this is the equation of a line and by solving for the slope we can find U_T in the sub-threshold region.



$$m = \frac{1}{U_T} = 35.8410$$

$$U_T = 0.0279\ Volts$$

$$c = \log(I_{th}) + \frac{k(V_{DD} - V_G - V_{TO}) - V_{DD}}{U_T}$$

$$c = -49.3580$$

The value for U_T is higher than expected. At 300K , U_T is around 25.8 mV.

Solve for K and kappa

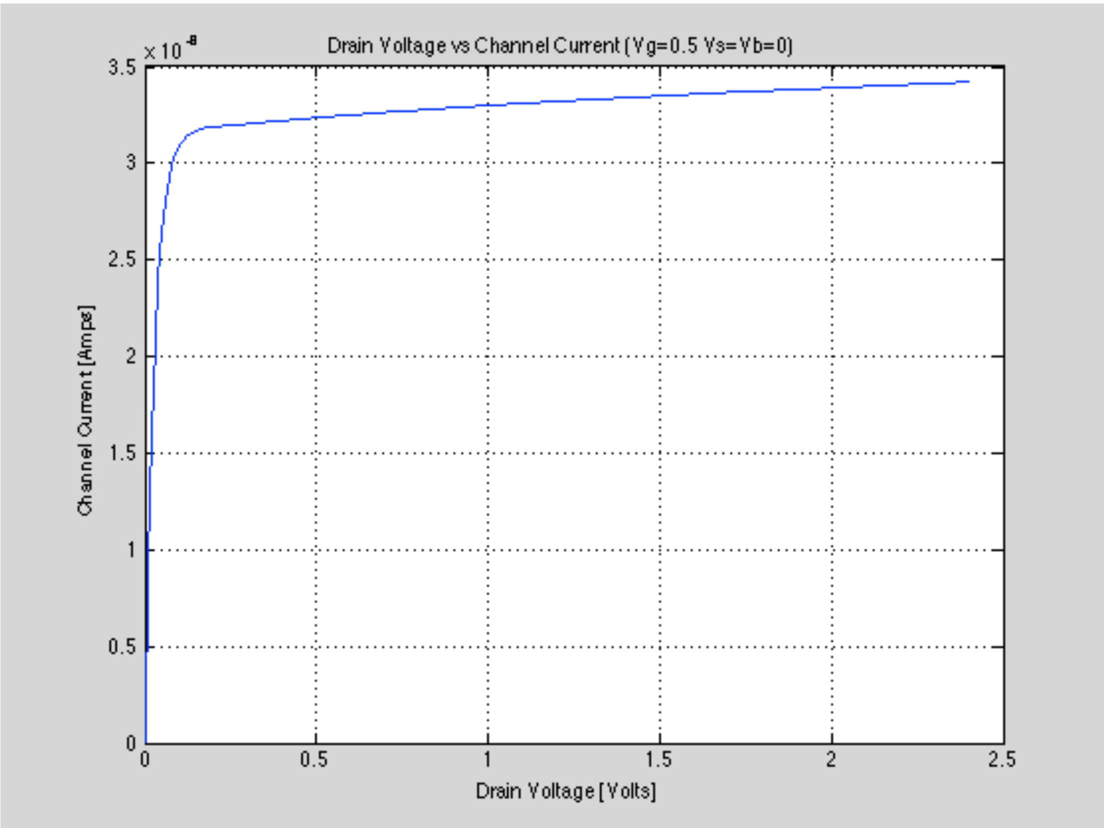
Gate Sweep: $\sqrt{\frac{Kk}{2}} = 0.0057$

Source Sweep: $\sqrt{\frac{K}{2k}} = 0.0064$

Solving these equations gives k=0.891 and K=72.9 x 10^{-6} A/V^2

Drain Voltage and Channel Current

Static measurements of channel current versus drain voltage. The gate voltage is held constant at 0.4 Volts and the gate, bulk and source voltages was held constant at 0V.



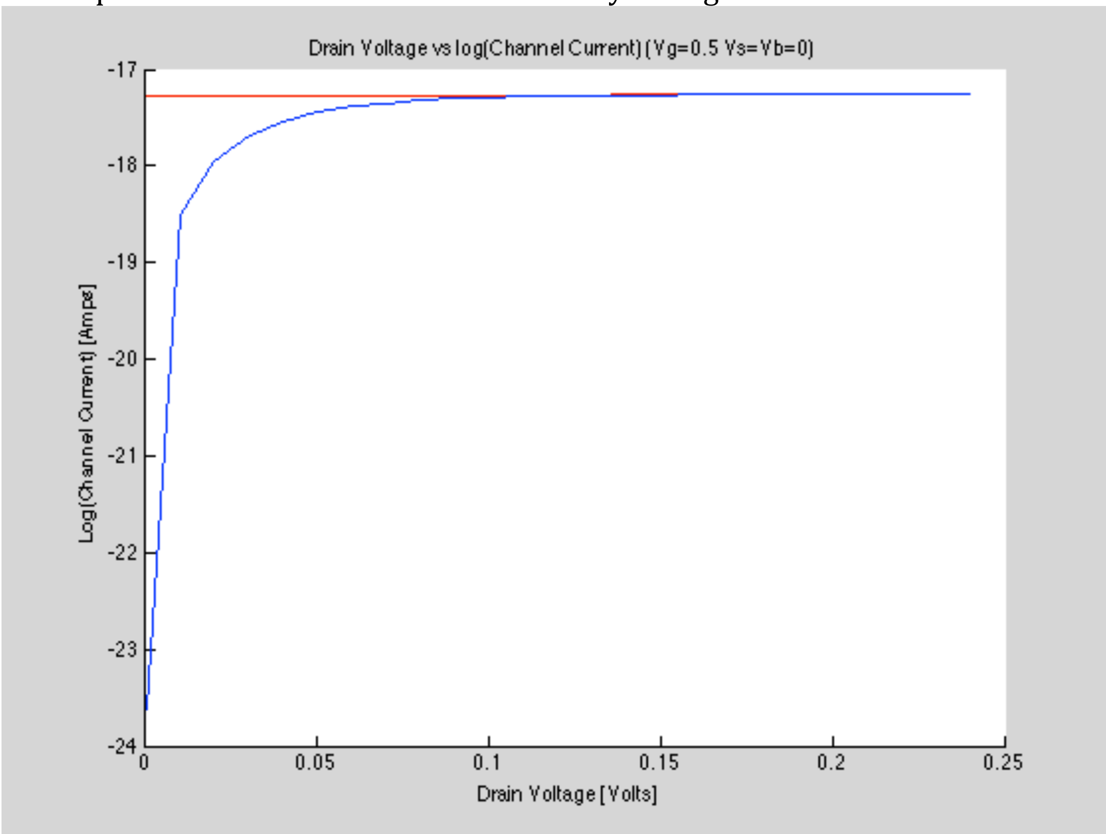
The current at which the curve saturates is below the threshold current, therefore the curve is taken in the sub threshold operation of the MOSFET. It is possible to tell this from the way the curve saturates at greater than 100 mV ($4U_T$)

$$I = I_{th} \exp\left(\frac{k(V_G - V_{To}) - V_S + \sigma V_D}{U_T}\right)$$

$$\log(I) = \frac{\sigma V_D}{U_T} + \log(I_{th}) + \frac{k(V_G - V_{To})}{U_T}$$

$$\log(I) = \frac{V_D}{V_A} + \log(I_{th}) + \frac{k(V_G - V_{To})}{U_T}$$

The slope of the line is the inverse of the Early Voltage.



$$m = 0.0596$$

$$V_A = 1/m = 16.78 \; Volts$$

For the Spice–simulation, the following values are needed:

K=72.9 x 10^{-6} A/V^2 V_A=16.8 Volts (Lambda= 0.0596)

Above Threshold Kappa=0.891 Below Threshold Kappa=0.67

Average Kappa=0.78 V_{T0}=0.65

To input kappa, two parameters are used, gamma and phi, such that the following equation is satisfied: $\gamma = 2\sqrt{2\varphi}\left(\frac{1}{k} - 1\right)$

Take φ=0.5 and γ=0.564.

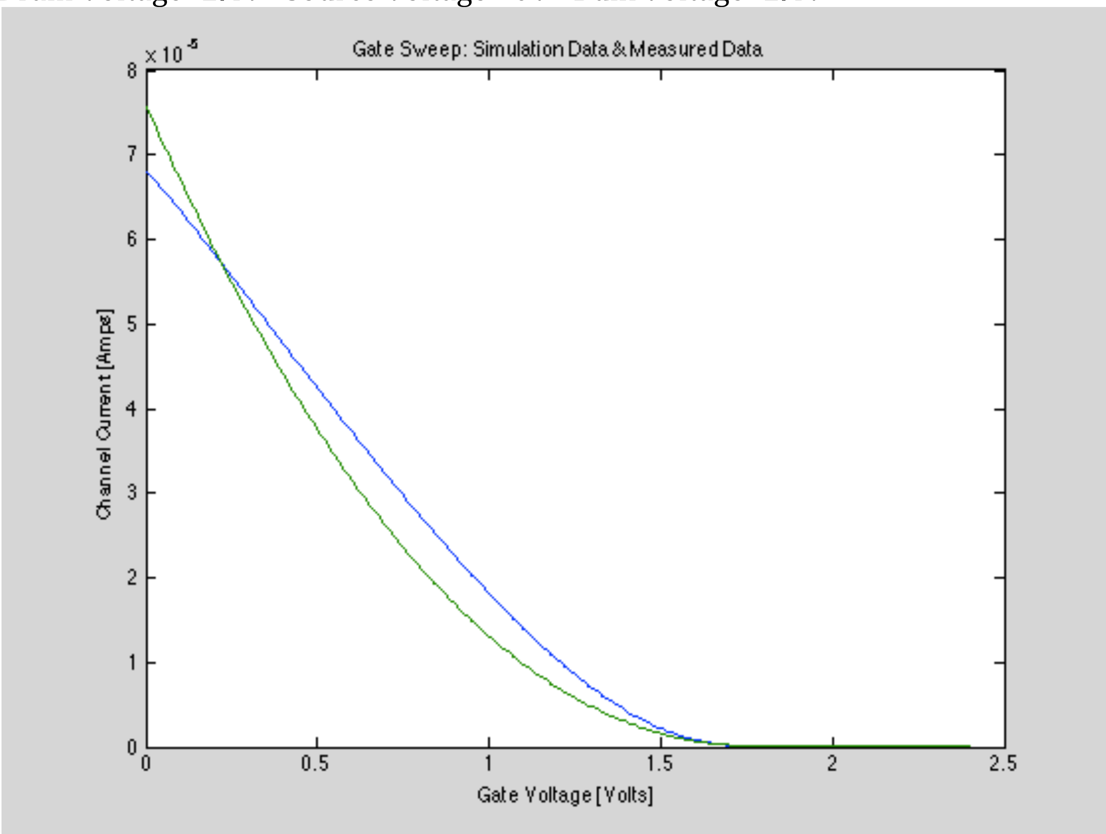
Results of Simulation (Multi-Sim) pFET

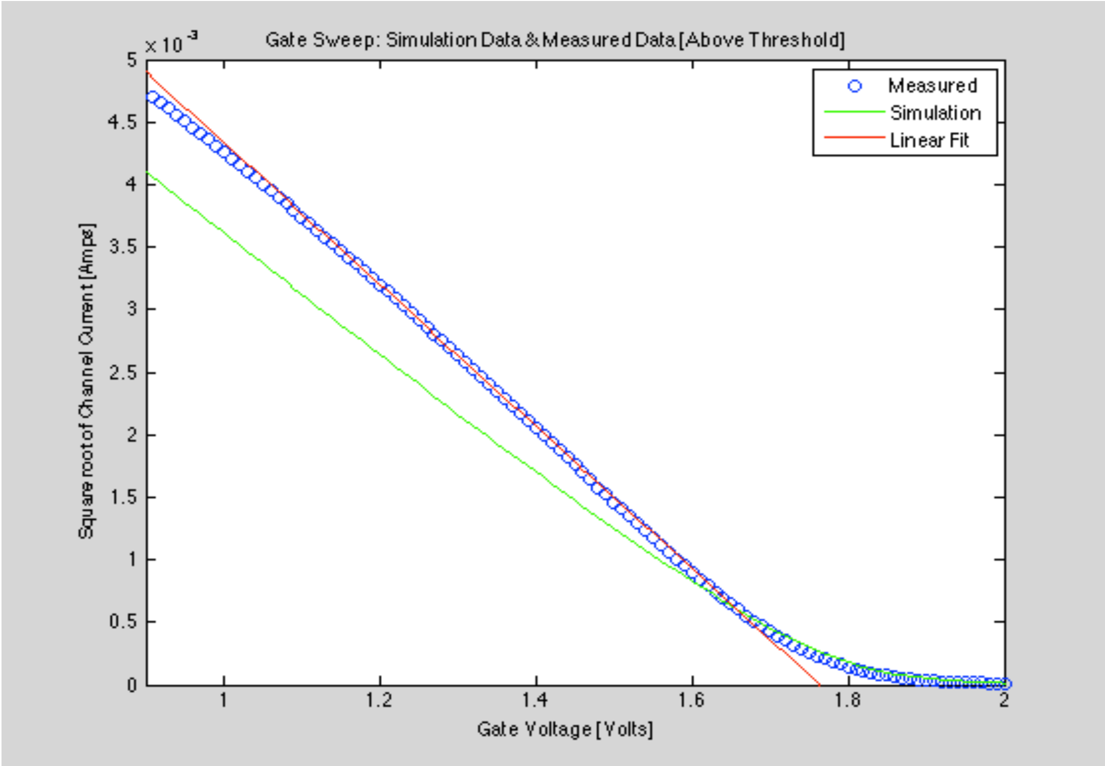
For all simulations the following parameter in and EKV model were used:

- $K=72.9 \times 10^{-6}\ A/V^2$
- Lambda=0.0596 Volts
- Average Kappa=0.78
- VTO=0.65
- Take φ=0.5
- γ=0.564

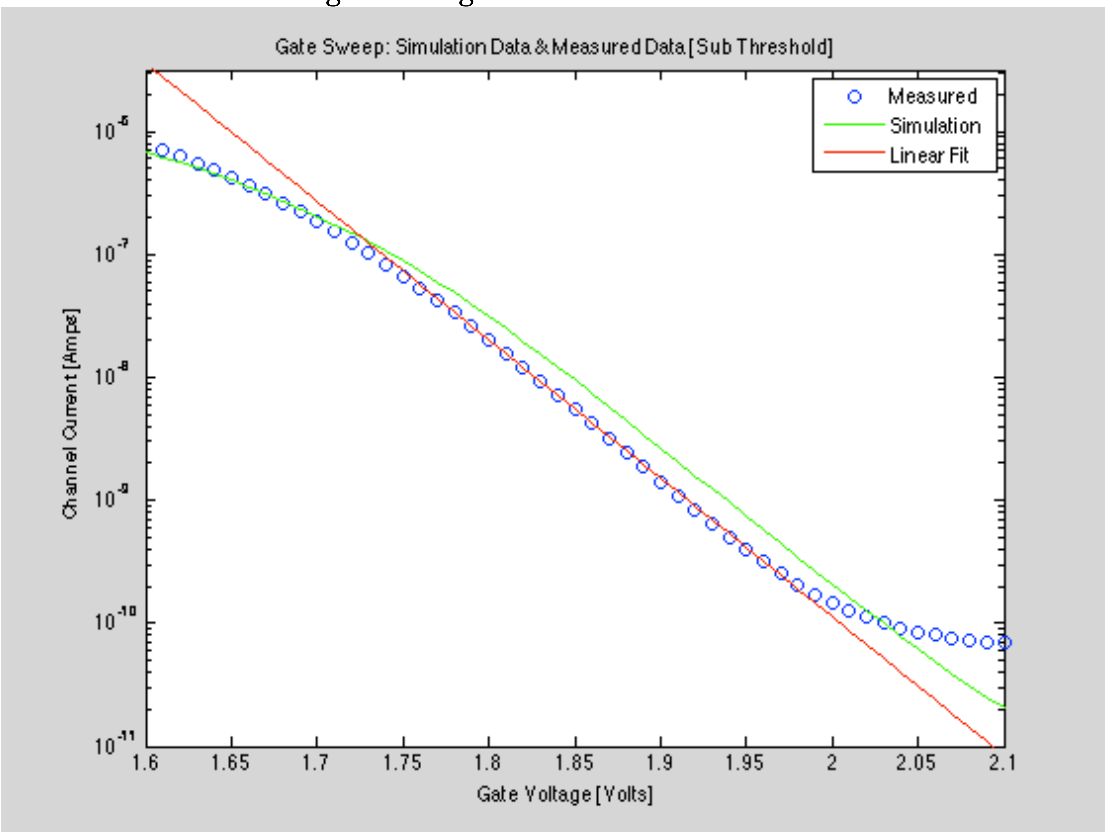
Gate Sweep

Drain Voltage=2.4V   Source Voltage= 0V   Bulk Voltage=2.4V

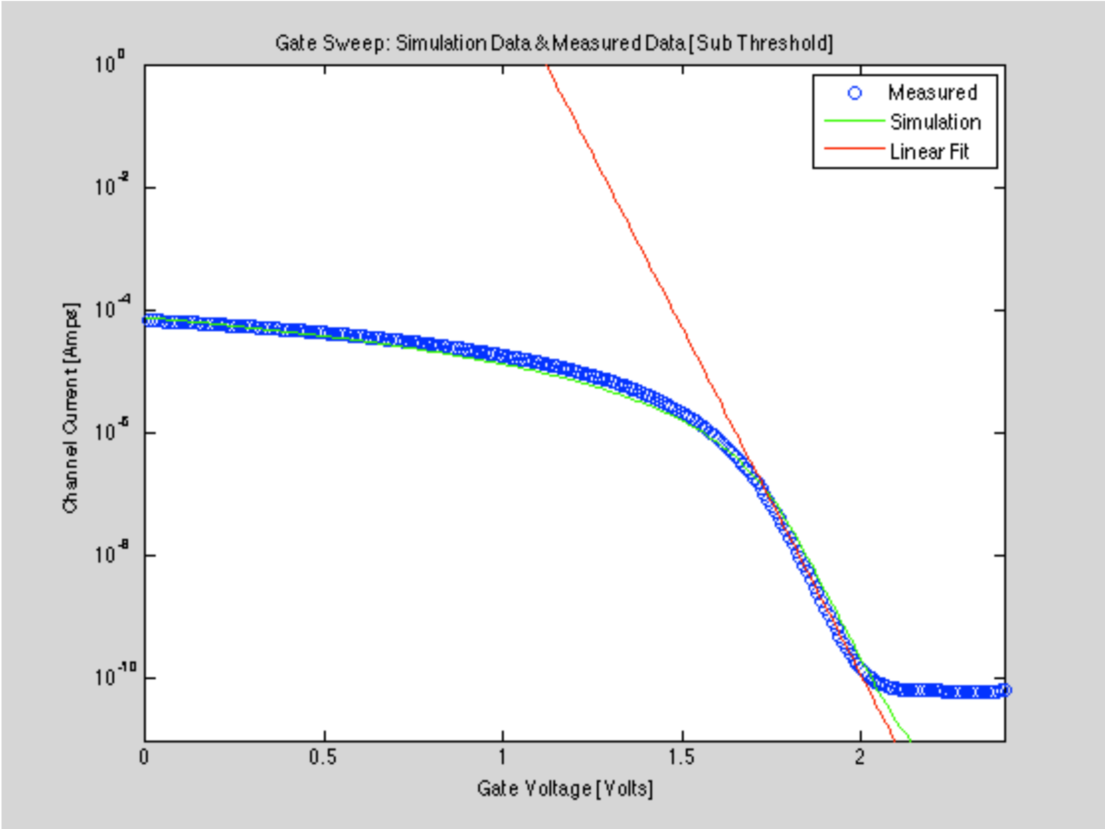




The simulation data gives a reasonably good approximation to the measured data but deviates as the gate voltage decreases.



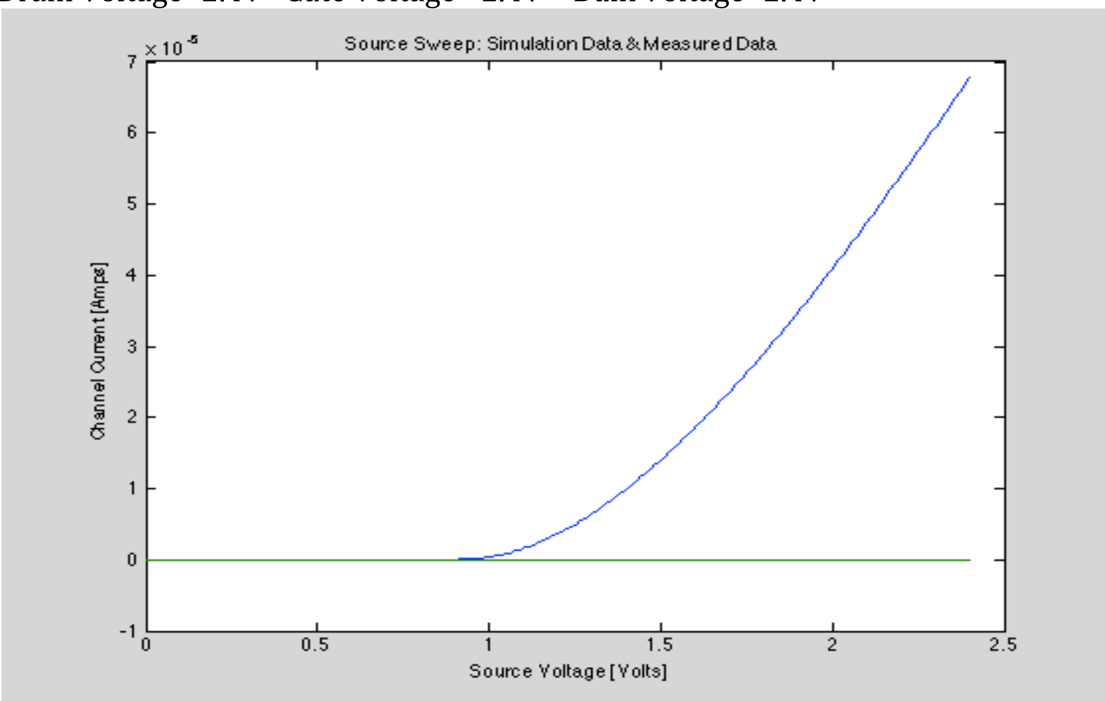
The simulation data gives a good approximation to the measured data, however at higher gate voltages, this approximation is not as good.



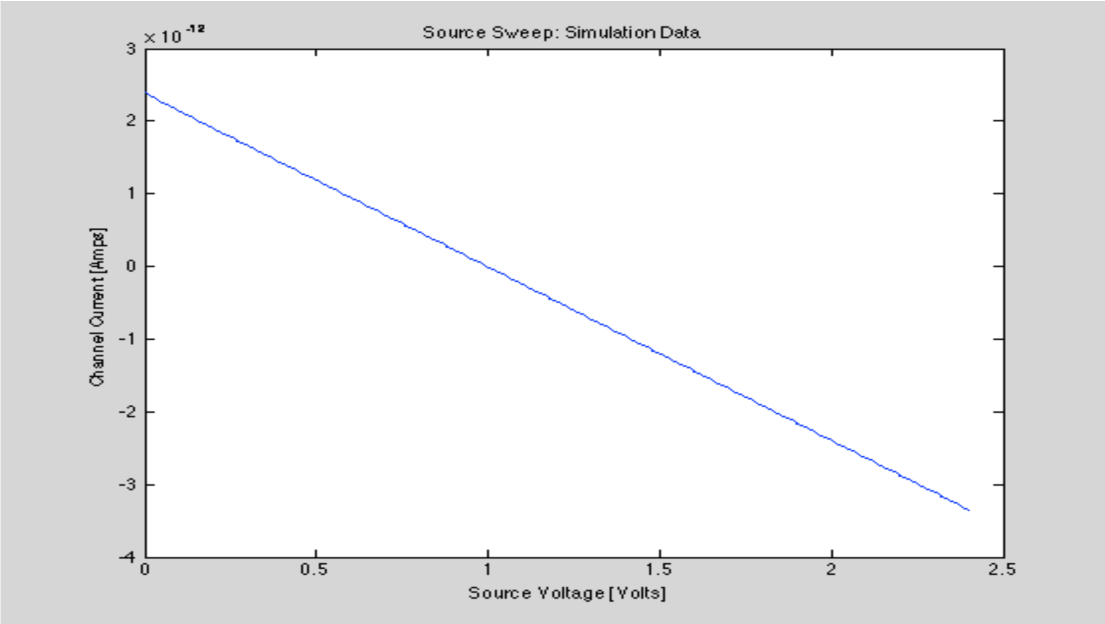
This figure shows how the simulation is a good approximation of the measured data at lower gate voltages.

Source Sweep

Drain Voltage=2.4V Gate Voltage= 2.4V Bulk Voltage=2.4V



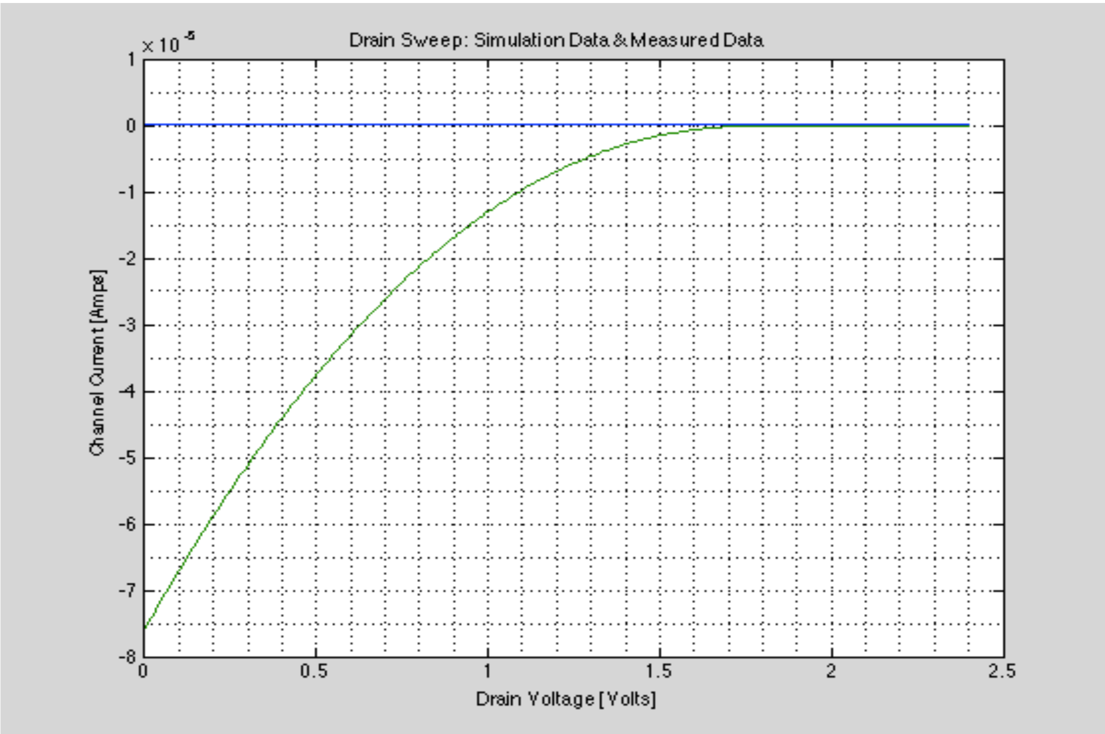
The simulation for the Source sweep did not work, possibly because the biasing voltages were wrong.



The source sweep gave results that suggested a linear relationship but on the wrong scale.

Drain Source Sweep

Source Voltage=0V   Gate Voltage= 0.4V   Bulk Voltage=2.4V



Again the pFET simulation gave results that did not match the measured results. In this case it appears that the simulation pFET was in the above threshold region, while the measured results was identical to the nFET results and was in sub threshold.