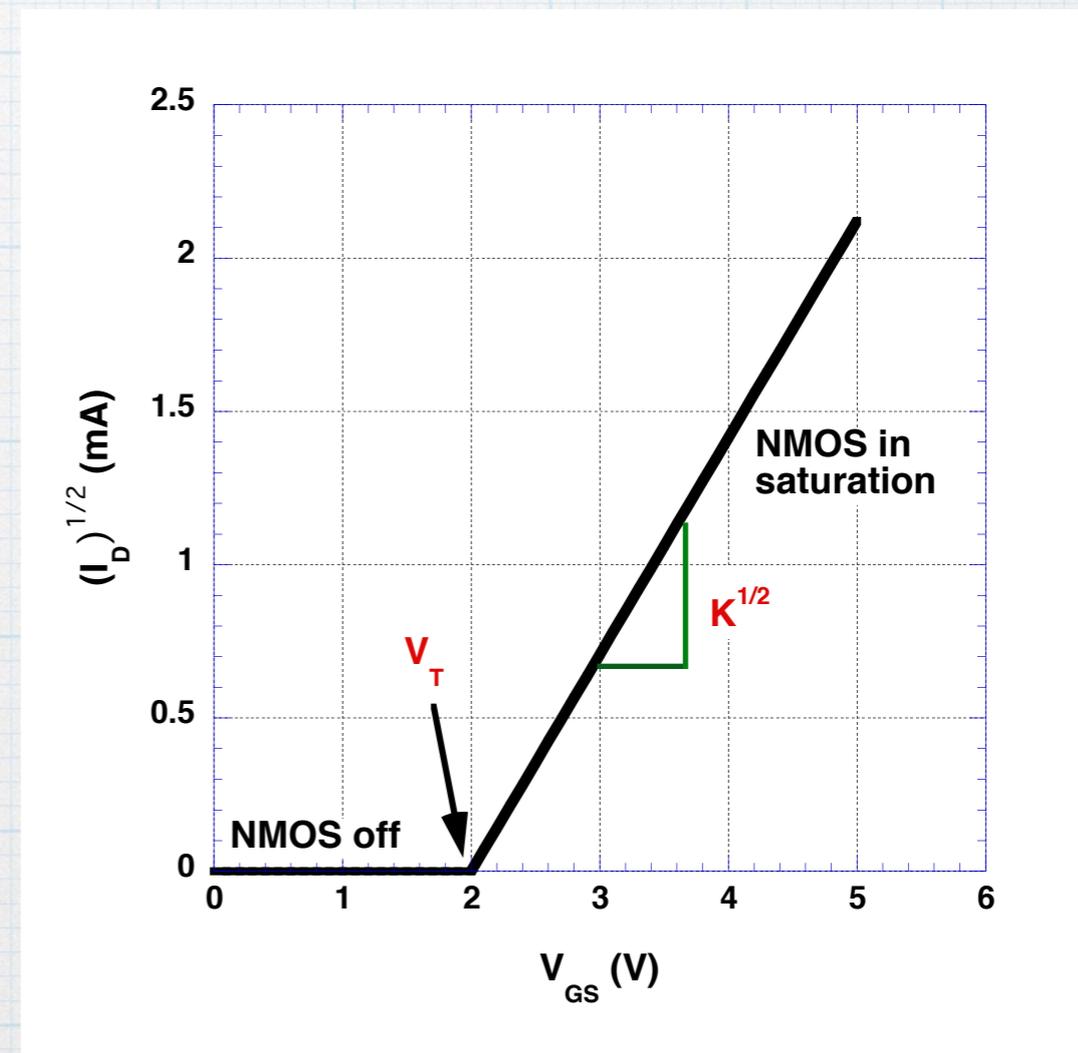
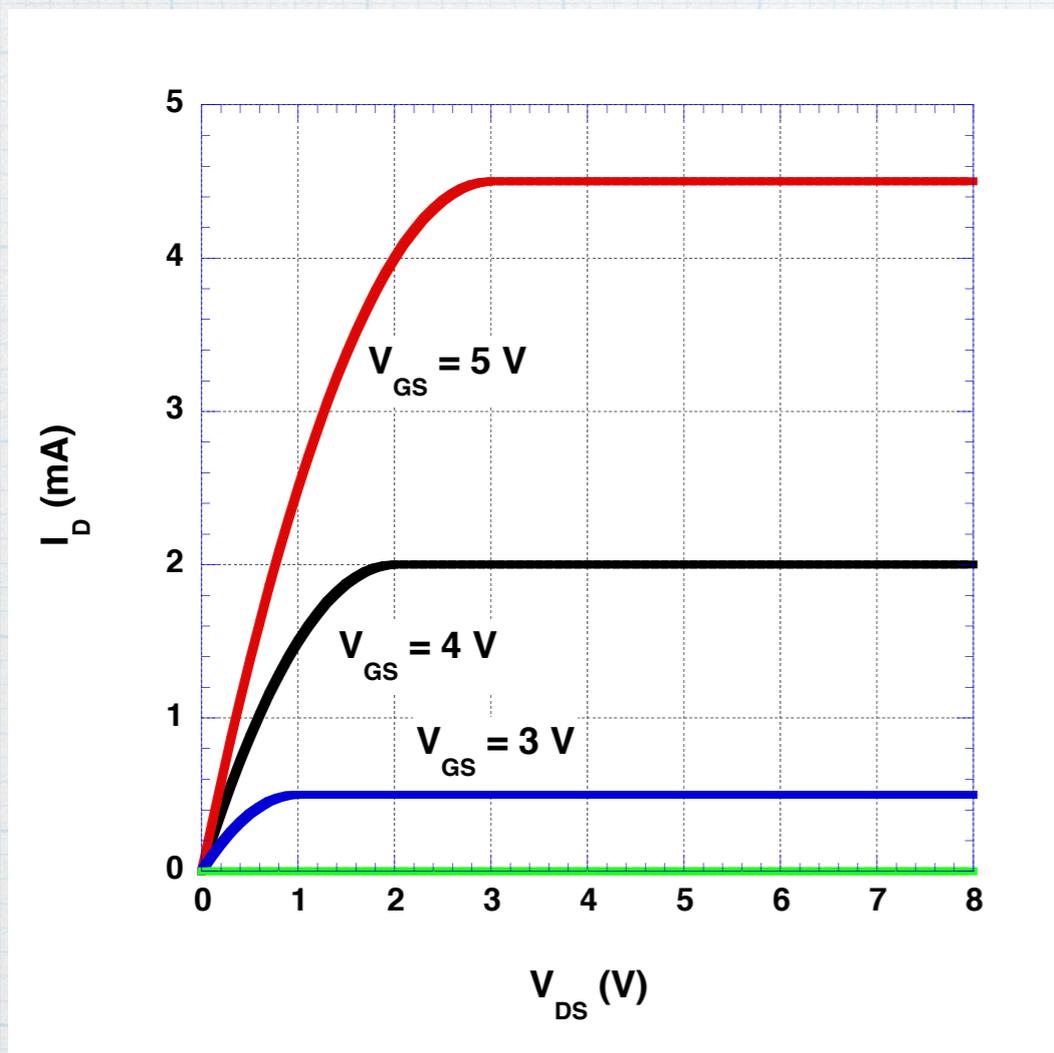


# Measuring MOSFET properties

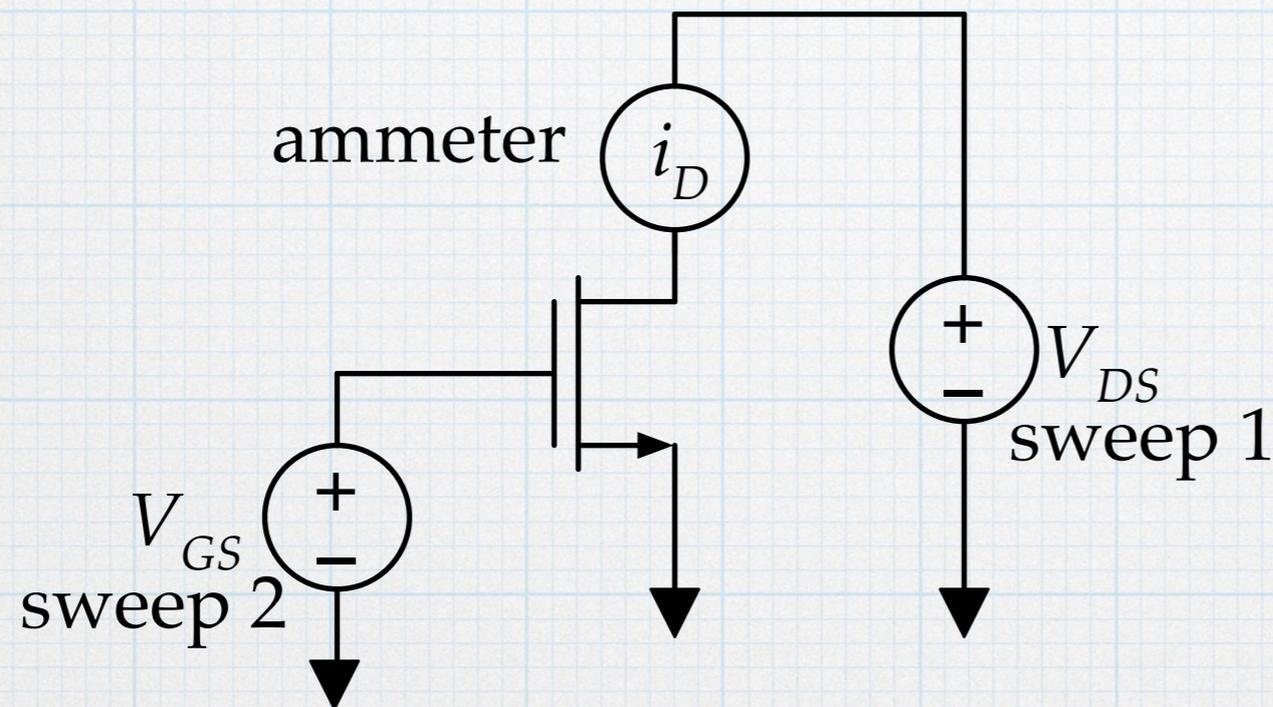
First, we might like to see a set of  $i_D$ - $v_{DS}$  curves, using  $v_{GS}$  as a parameter. This gives a nice “text-book” view of the MOSFET characteristics, but is not helpful for extracting the device parameters.

To obtain device parameters, we need to isolate certain aspects of the device behavior in order to easily extract the parameters that might be used in a SPICE model for the MOSFET. One type of measurement that helps in extracting parameters is the  $\sqrt{i_D} - v_{GS}$  plot.



## Family of $i_D - v_{DS}$ curves.

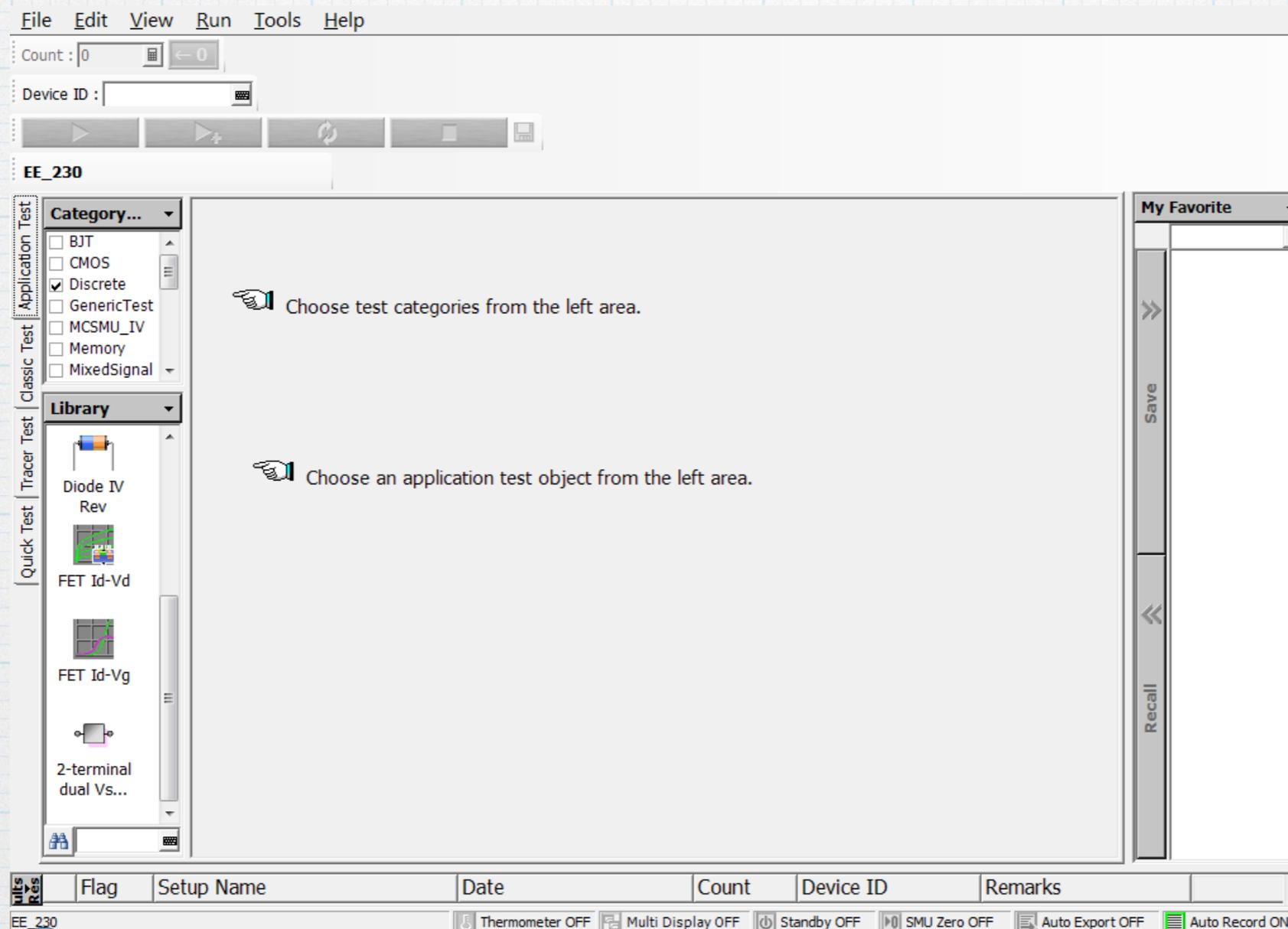
This measurement is conceptually very simple. First set the gate voltage to some value, which sets source-end concentration of the inversion layer. Then sweep through a range of drain voltages, measuring the current at each. Then set a new gate voltage and sweep the drain voltages again. Repeat for as many different gate voltages as desired.



This is easily done with the B1500A semiconductor analyzer. In fact, it is one of the standard, built-in set-ups.

# $i_D - v_{DS}$ measurement

If the analyzer is off, power it up, and, once it is booted, launch the EasyEXPERT software.



Choose the discrete category and then choose the specific “FET Id-Vd” set up.

# $i_D - v_{DS}$ measurement - NMOS

The next page shows the basic measurement set up: SMU1 is the drain, SMU2 is the source, and SMU3 is the gate. We are assuming an  $n$ -channel transistor as indicated by the polarity setting, so all voltages will be positive. Set the drain and gate voltage as desired. (The values shown below are a reasonable starting point.)

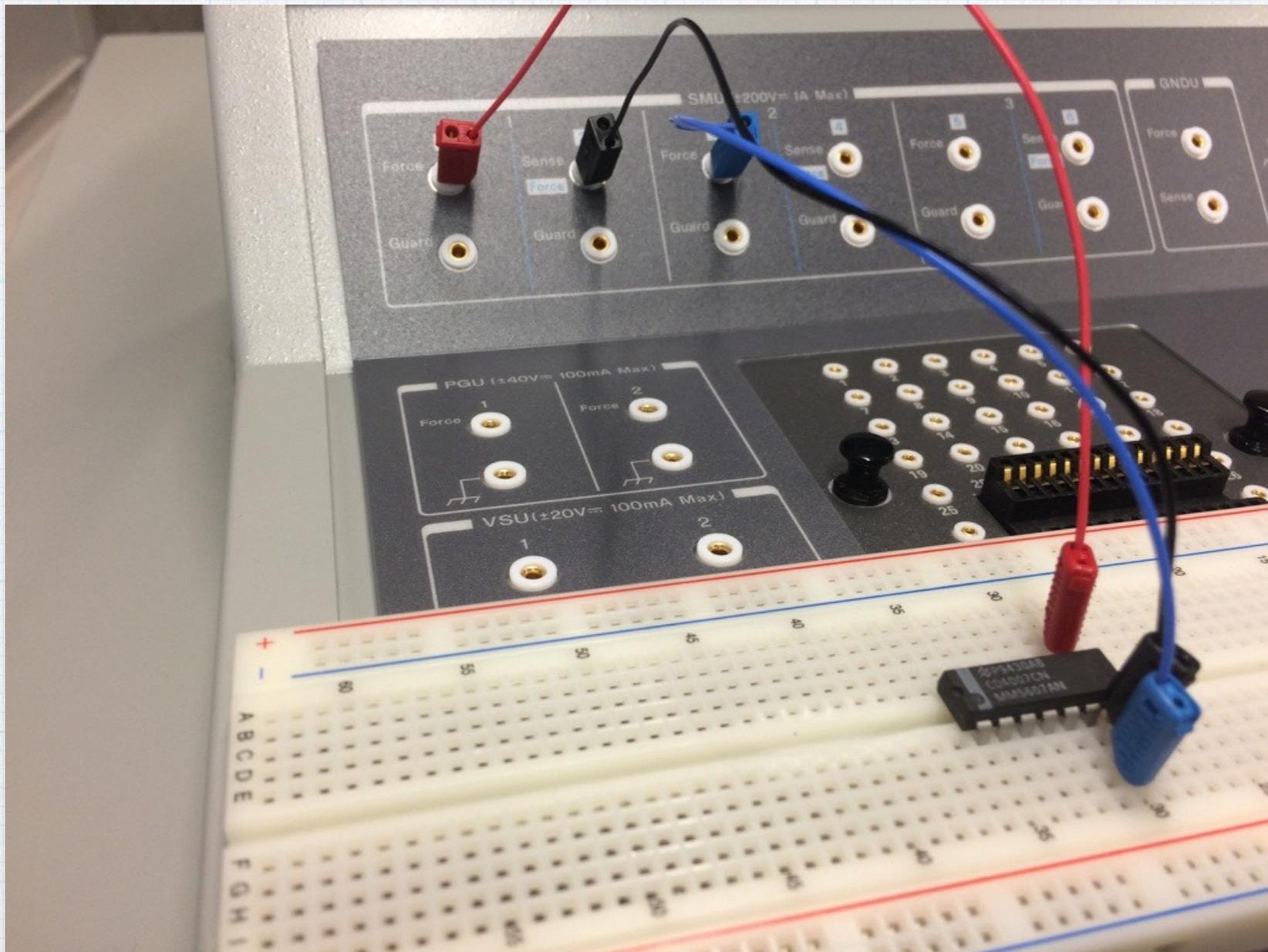
The screenshot displays the software interface for setting up an  $i_D - v_{DS}$  measurement on an n-channel MOSFET. The main window is titled "FET Id-Vd" and shows the following configuration:

- Category:** Discrete (checked)
- Device Parameters:**
  - Polarity: Nch
  - Temp: 25.0 deg
  - IdMax: 10.0 mA
- Test Parameters:**
  - IntegTime: SHORT
  - Primary Sweep:
    - Drain: SMU1:MP
    - VdStart: 0
    - VdStop: 10.0 V
    - VdStep: 100 mV
  - Secondary Sweep:
    - Gate: SMU3:MP
    - VgStart: 0 V
    - VgStop: 6.00 V
    - VgStep: 1.00 V
    - IgLimit: 10.0 mA

The circuit diagram shows an n-channel MOSFET with its Drain (D) connected to SMU1:MP, its Source (S) connected to SMU2:MP, and its Gate (G) connected to SMU3:MP. Each connection point is monitored by an ammeter (A). The SMU2:MP source is set to 0V. The interface also includes a "Library" on the left with options like "Diode IV Rev", "FET Id-Vd", "FET Id-Vg", and "2-terminal dual Vs...". The bottom status bar shows various system settings: Thermometer OFF, Multi Display OFF, Standby OFF, SMU Zero OFF, Auto Export OFF, and Auto Record ON.

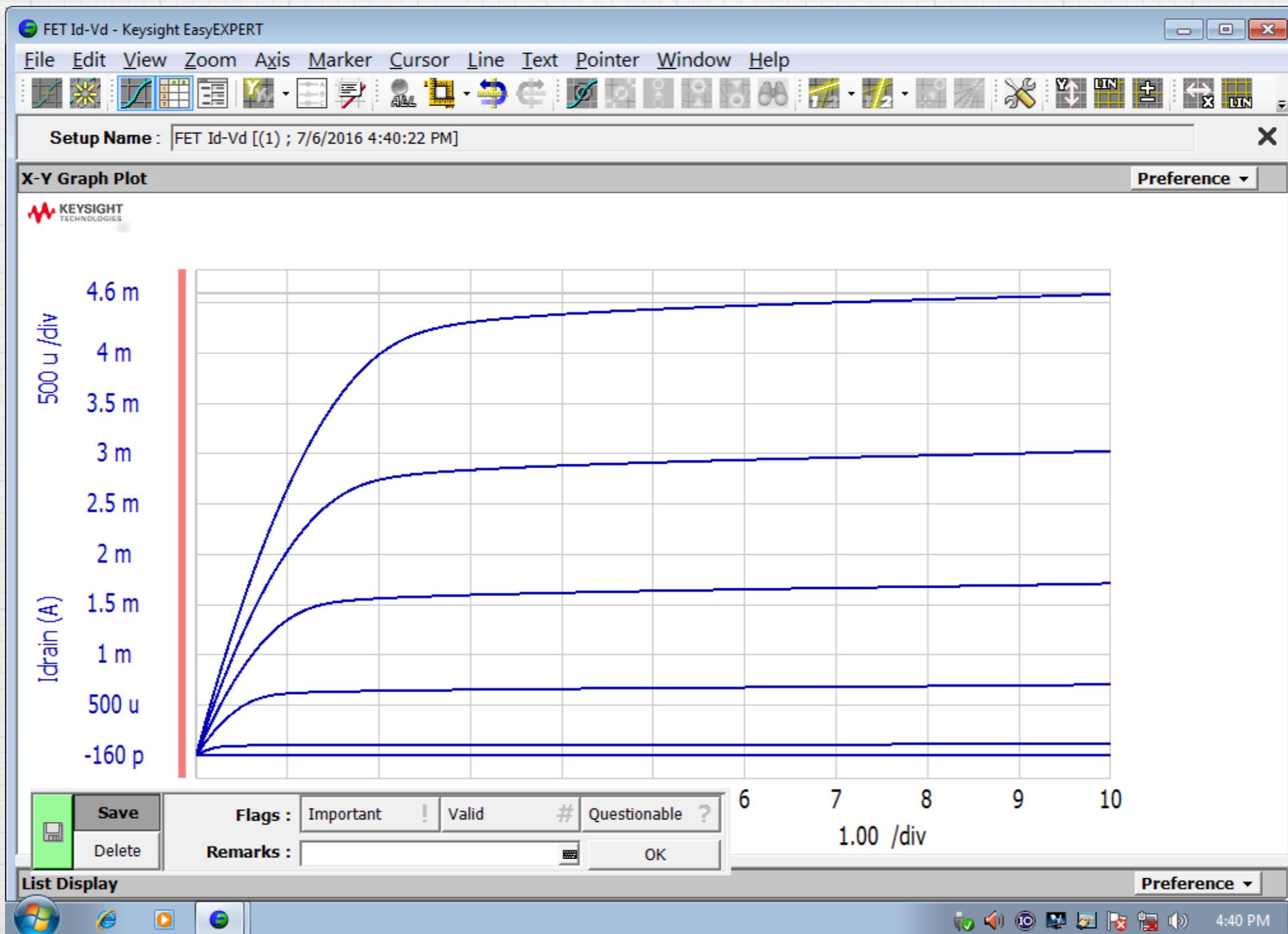
# $i_D - v_{DS}$ measurement - NMOS

Connect the transistor to the SMUs. In this case, we are measuring the body-connected NMOS from the CD4007 MOS array. Drain: pin 8 to SMU 1. Source: pin 7 to SMU 2. Gate: pin 6 to SMU 3. (Check the data sheet.)



# $i_D - v_{DS}$ measurement - NMOS

Hit the run button, and the analyzer should run through the measurement and make a plot. Click the "Autoscale" icon to scale the plot to a nice size. Save the data in whatever form you like - an image of the plot or csv data to plotted in Excel. (Explained in the diode tutorial.)



# $i_D - v_{DS}$ measurement - PMOS

A PMOS measurement is just as easy. The only change that is required is to switch the polarity to "Pch". The analyzer then knows that all of the voltages should be negative. So unless you need a different range for the gate and drain voltages, you can leave everything else the same.

change this

File Edit View Run Tools Help

Count : 1

Device ID :

EE\_230

Category... FET Id-Vd Setup Name : FET Id-Vd

Application Test

Discrete

Device Parameters

Polarity : Pch Temp : 25.0 IdMax : 10.0 mA

Library

Diode IV Rev

FET Id-Vd

FET Id-Vg

2-terminal dual Vs...

Test Parameters Extended Setup...

IntegTime : SHORT

Primary Sweep

Drain : SMU1:MP

VdStart : 0 V

VdStop : 10.0 V

VdStep : 100 mV

Secondary Sweep

Gate : SMU3:MP

VgStart : 0 V

VgStop : 6.00 V

VgStep : 1.00 V

IgLimit : 10.0 mA

Source : SMU2:MP

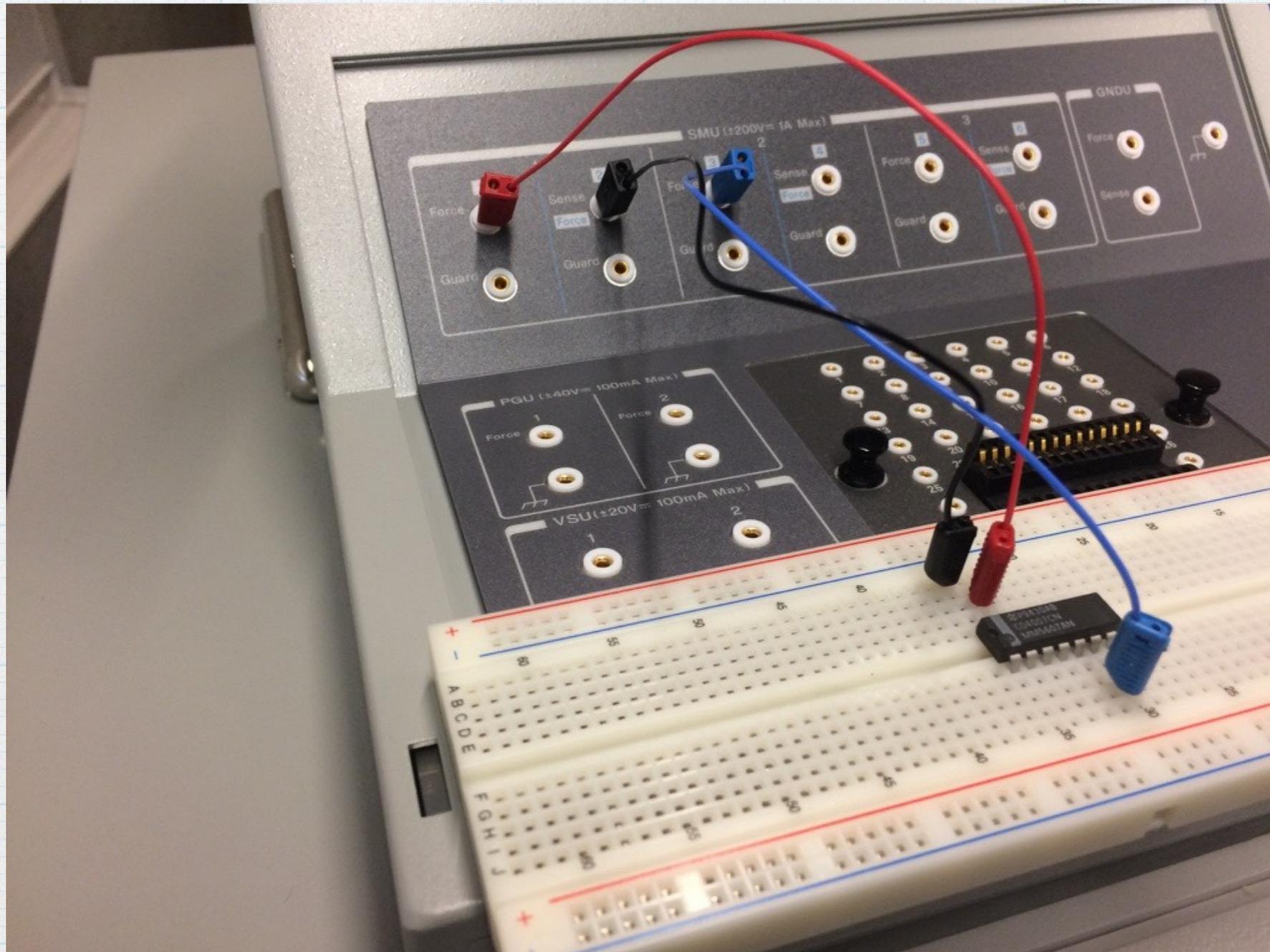
Flag	Setup Name	Date	Count	Device ID	Remarks

EE\_230 Thermometer OFF Multi Display OFF Standby OFF SMU Zero OFF Auto Export OFF Auto Record ON

# $i_D - v_{DS}$ measurement - PMOS

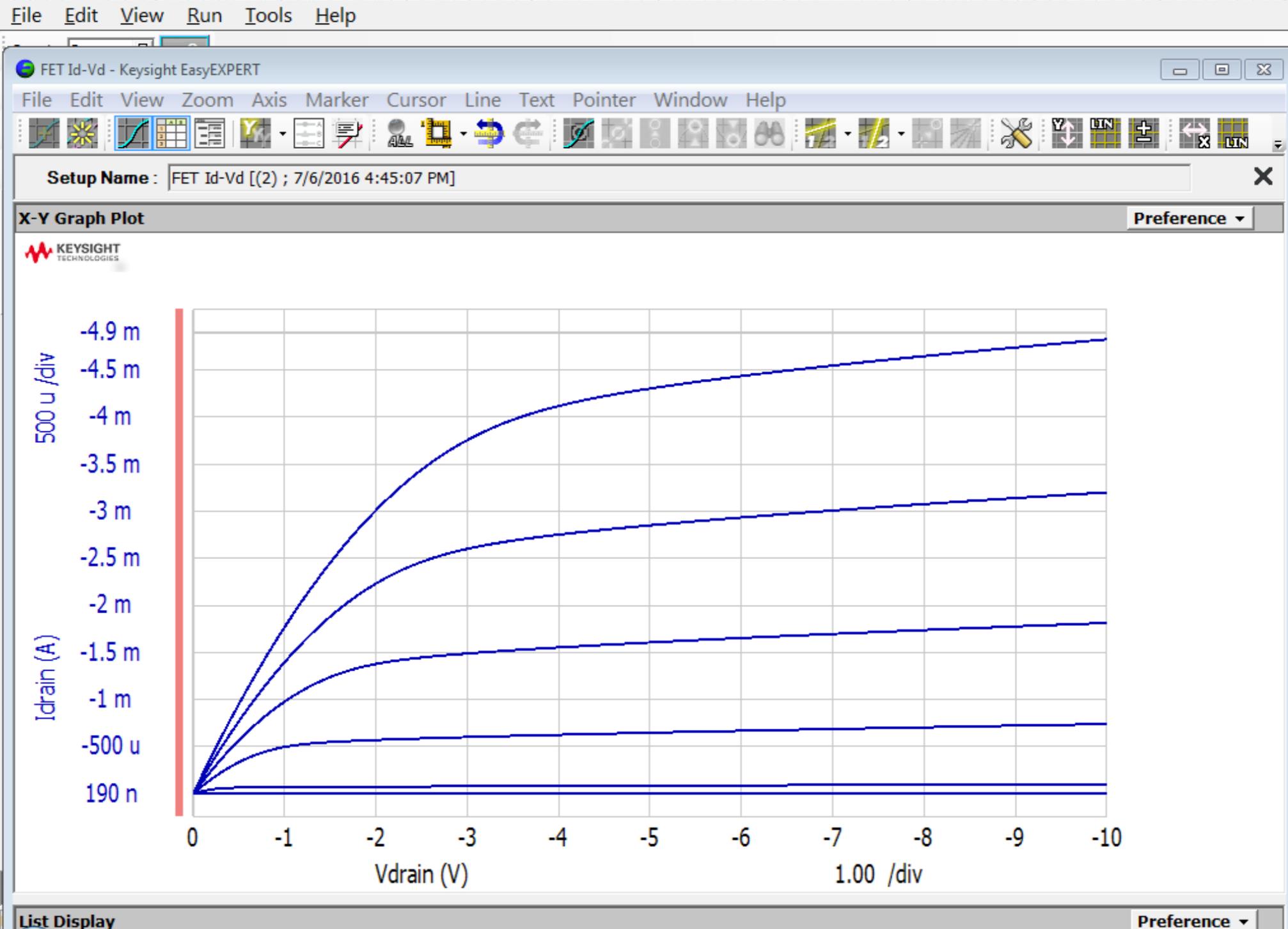
Of course, you must connect the PMOS to the SMUs. In this case, we are measuring the body-connected PMOS from the CD4007 MOS array.

Drain: pin 13 to SMU 1. Source: pin 14 to SMU 2. Gate: pin 6 to SMU 3.



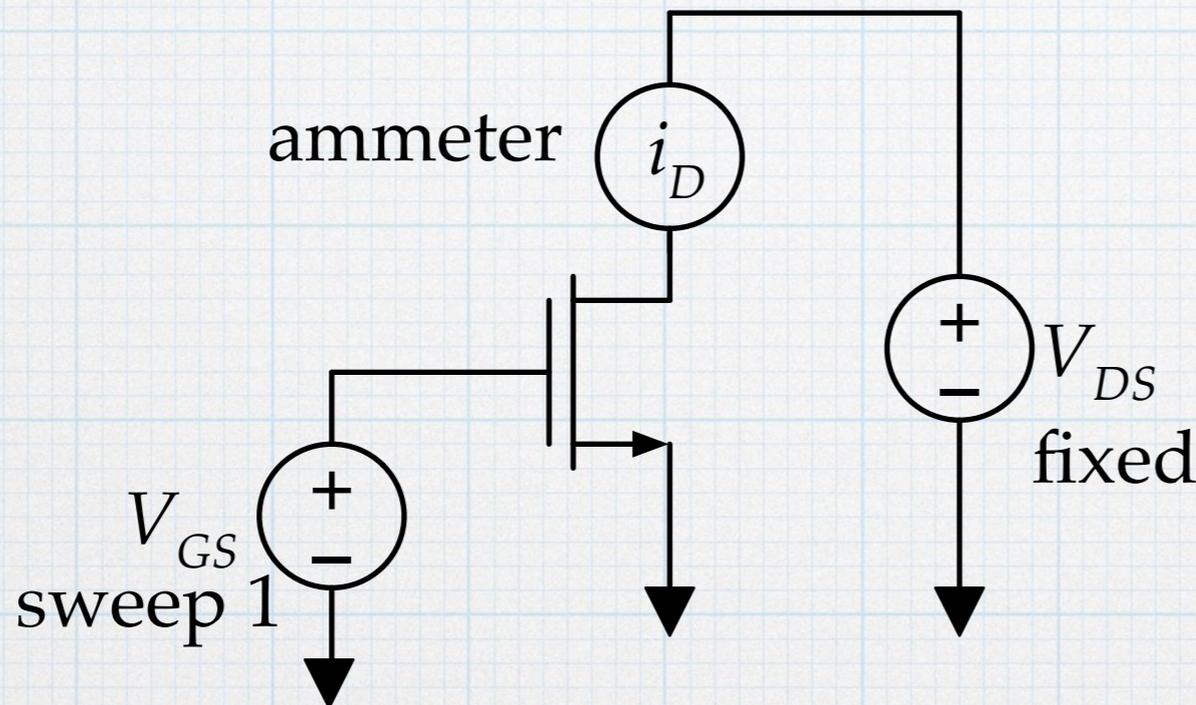
# $i_D - v_{DS}$ measurement - PMOS

Hit the run button, and the PMOS curves should appear. Note the negative voltages and currents on the axes. Autoscale to resize the plot. Save the results in whatever format you like.



## $i_D - v_{GS}$ measurement - NMOS

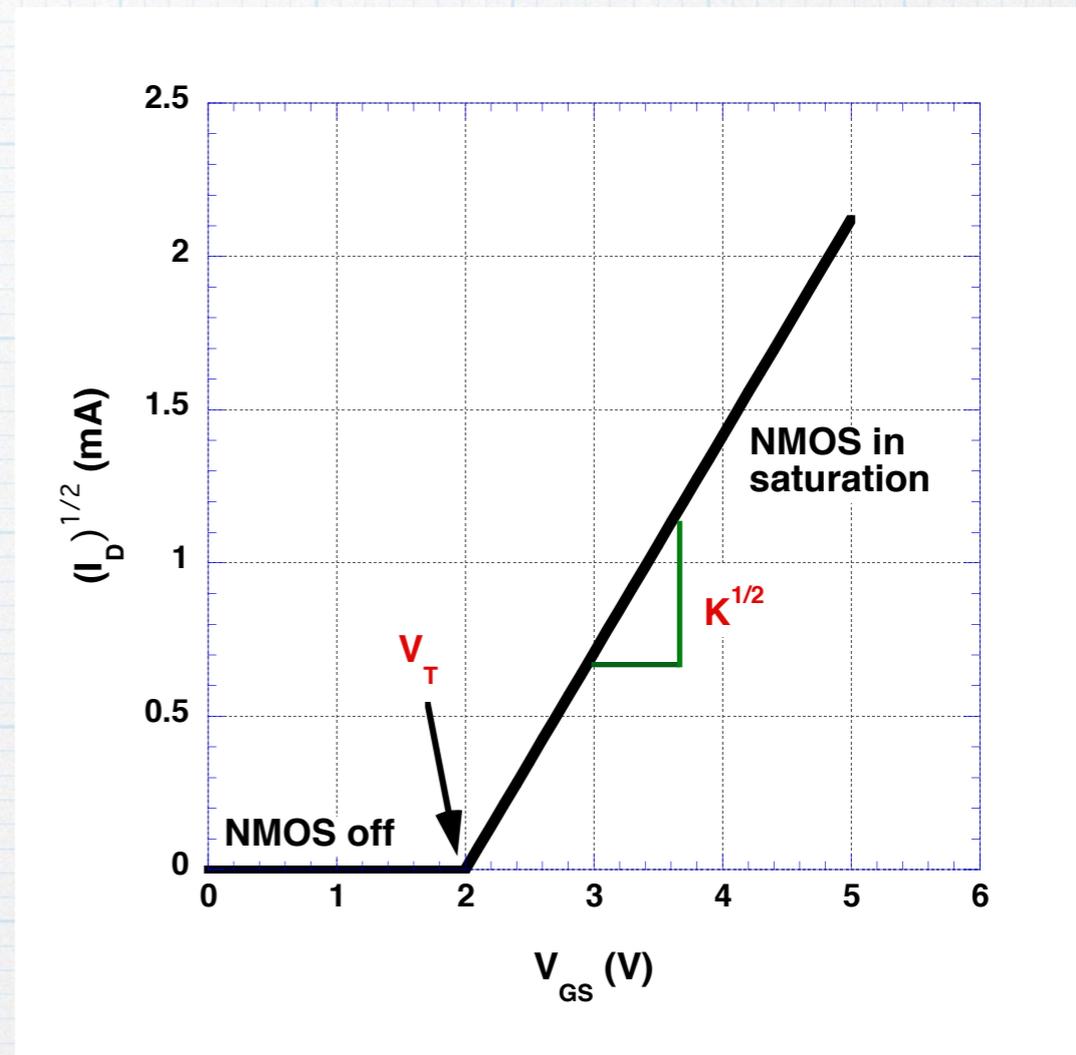
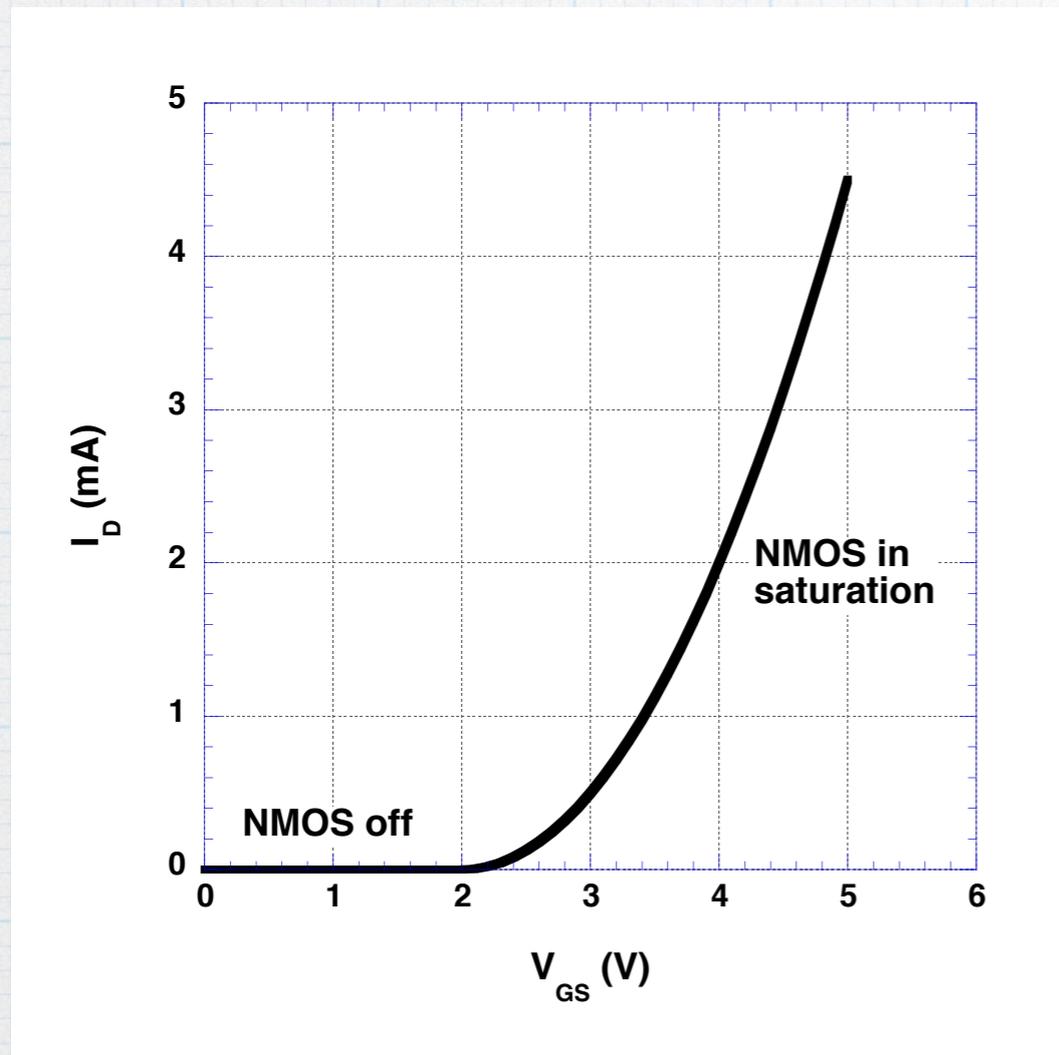
To obtain the curve needed to extract  $V_T$  and  $K$ , we use the same basic measurement set up, with some slight modifications. First, we fix the value of  $V_{DS}$  at a value that will guarantee that the MOS is in saturation. Then we sweep the gate voltage while measuring the drain current.



To make sure that the MOS stays in saturation, the fixed value of  $V_{DS}$  should be bigger than (or at least equal to) any value of  $V_{GS}$  in the sweep. So setting  $V_{DS}$  equal to the maximum of  $V_{GS}$  should work nicely.

# $i_D - v_{GS}$ measurement - NMOS

The basic sweep will give a plot of  $i_D$  versus  $v_{GS}$ . To extract the parameters easily, we prefer to use the square-root of the current.



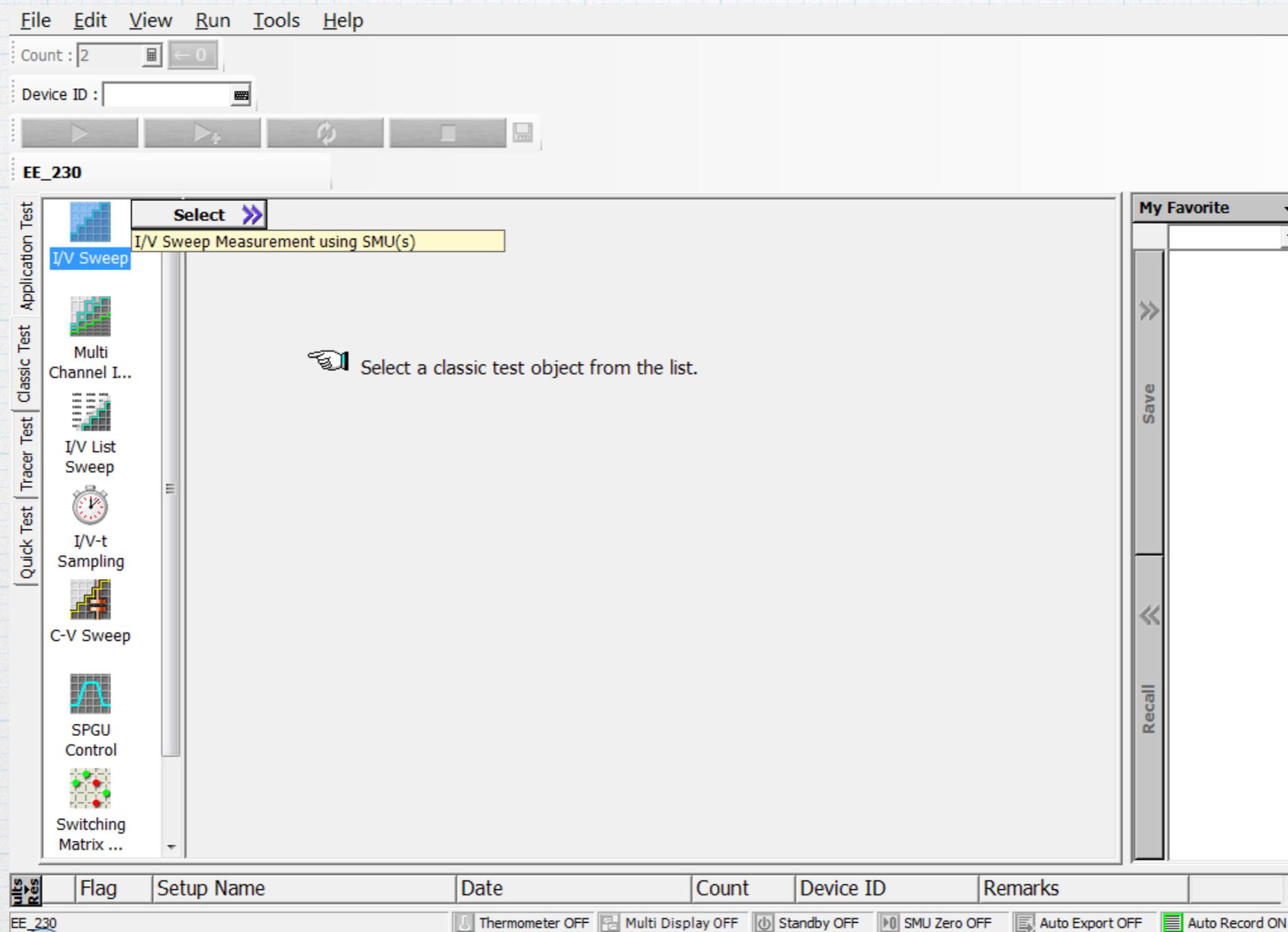
$$i_D = K (v_{GS} - V_T)^2$$

$$\sqrt{i_D} = \sqrt{K} (v_{GS} - V_T)$$

The analyzer will do all of this, but there is no pre-programmed set up. So we will need "roll our own", which is still easy to do. In the process, we will learn how to build our own measurement set ups.

# $i_D - v_{GS}$ measurement - NMOS

To get started, go back to the measurement set up screen. Select the “Classic Test” tab on the left and then choose “I-V Sweep” option.



Start with the “Channel” tab along top of the window. Here, we set up the function of the SMUs. The four SMUs are listed. You can give names to the voltage and current for each. You can also specify the mode of each (voltage source, current source, or common). Finally, you can specify if it will be changing (variable) or constant.

File Edit View Run Tools Help

Count : 0

Device ID :

EE\_230

**Multi Channel I/V Sweep** Setup Name : Multi Channel I/V Sweep

Channel Measurement Function Auto Analysis Display

**Channel Definition**

Unit :	V Name :	I Name :	Mode :	Function :
<input type="radio"/> SMU1:MP	V1	I1	V	VAR1
<input type="radio"/> SMU2:MP	V2	I2	V	CONST
<input type="radio"/> SMU3:MP	V3	I3	V	CONST
<input type="radio"/> SMU4:MP	V4	I4	COMMON	CONST

Miscellaneous Variables

My Favorite

Save Recall

Flag	Setup Name	Date	Count	Device ID	Remarks
EE_230					

Thermometer OFF Multi Display OFF Standby OFF SMU Zero OFF Auto Export OFF Auto Record ON

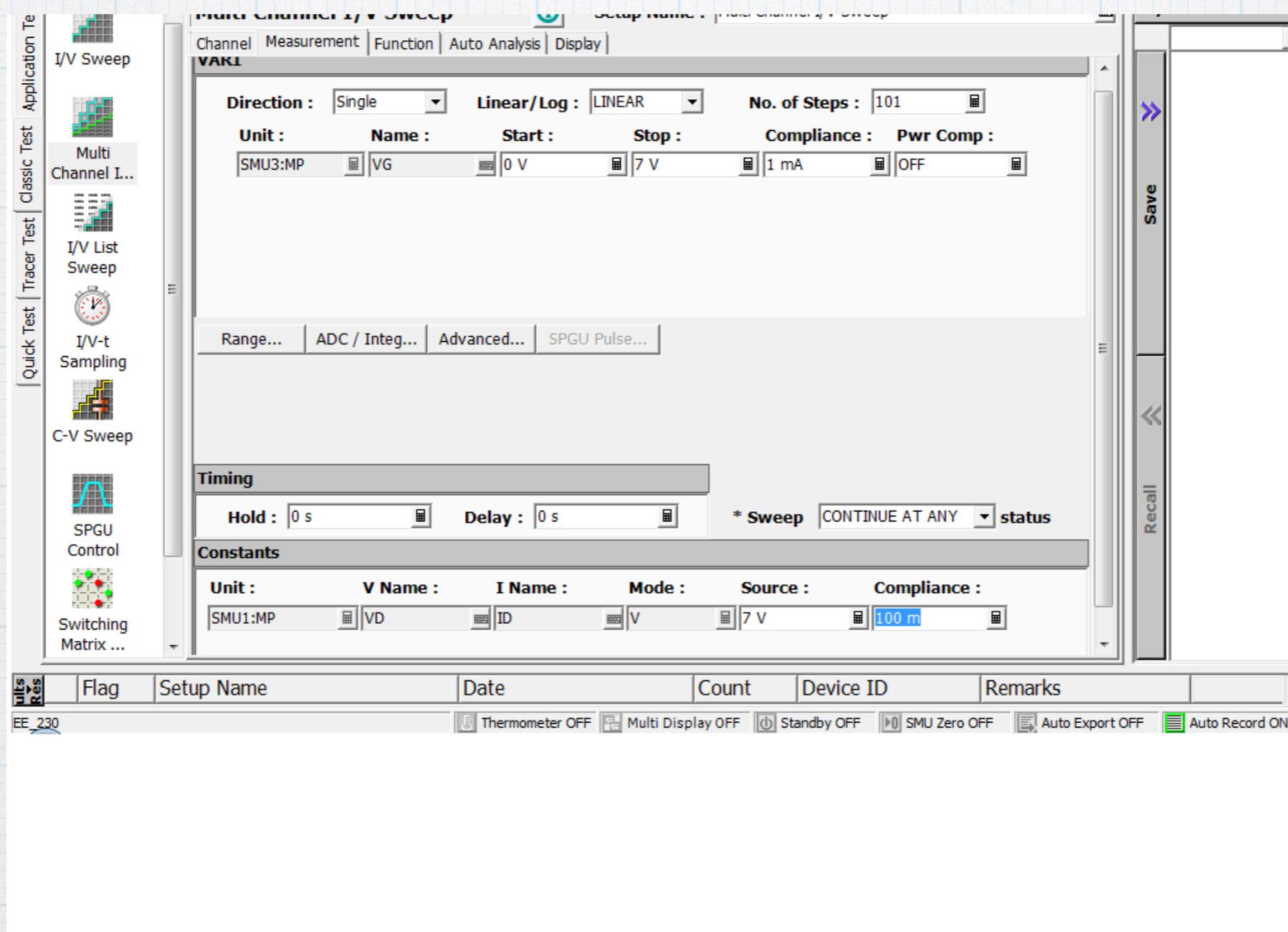
Set up the SMUs as shown below. SMU1 is the drain connection. It will be a voltage source (measuring current) and will have constant value. SMU2 is the MOS source and will serve as ground (common). SMU3 is the gate connection. It will be a swept voltage source, and so it will have the VAR1 function.

The screenshot shows the 'Multi Channel I/V Sweep' configuration window. The 'Channel Definition' table is as follows:

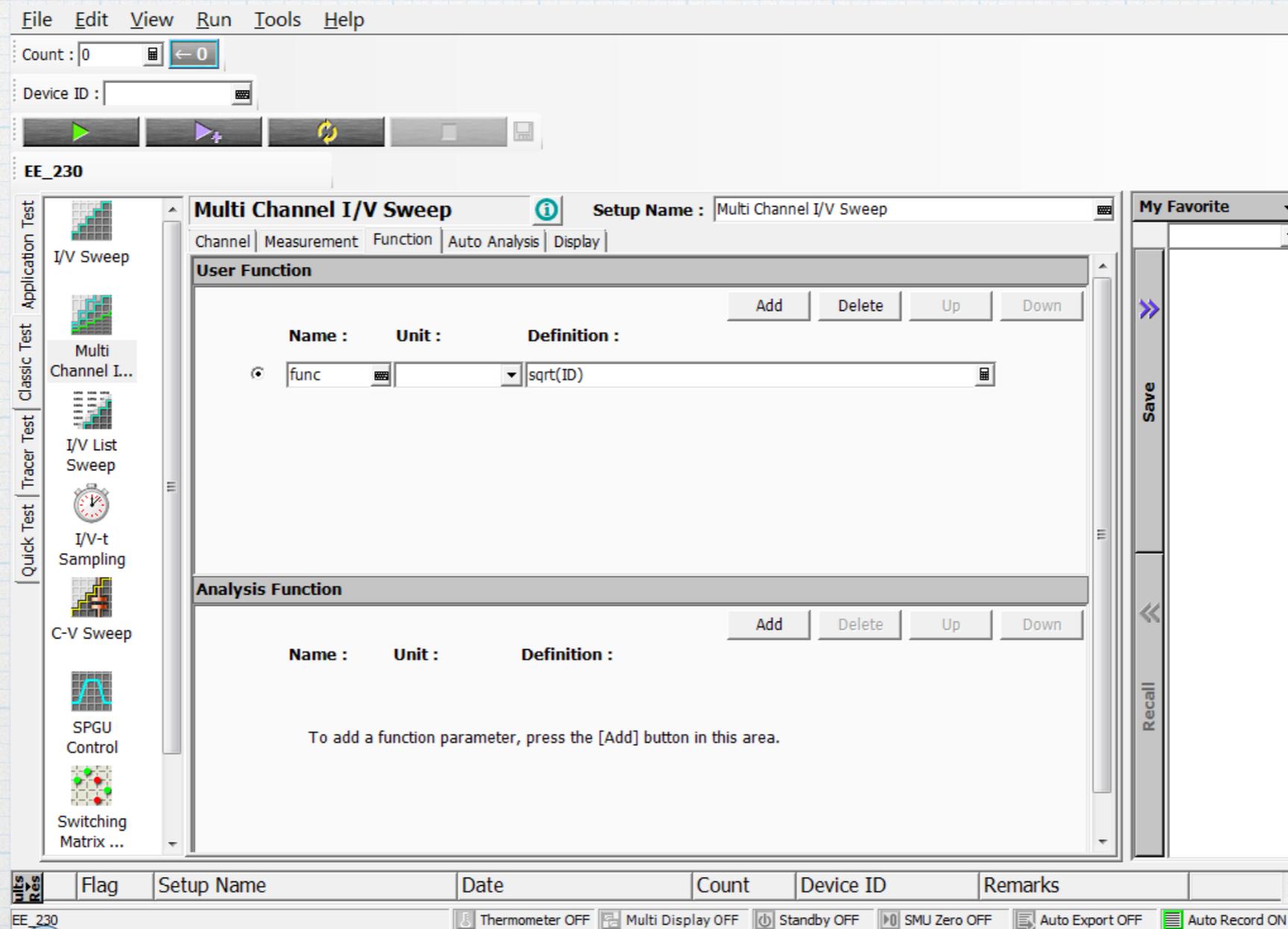
Unit :	V Name :	I Name :	Mode :	Function :
<input type="radio"/> SMU1:MP	VD	ID	V	CONST
<input type="radio"/> SMU2:MP	VS	IS	COMMON	CONST
<input checked="" type="radio"/> SMU3:MP	VG	IG	V	VAR1
<input type="radio"/> SMU4:MP	V4	I4	COMMON	CONST

The status bar at the bottom shows the following settings: Thermometer OFF, Multi Display OFF, Standby OFF, SMU Zero OFF, Auto Export OFF, and Auto Record ON.

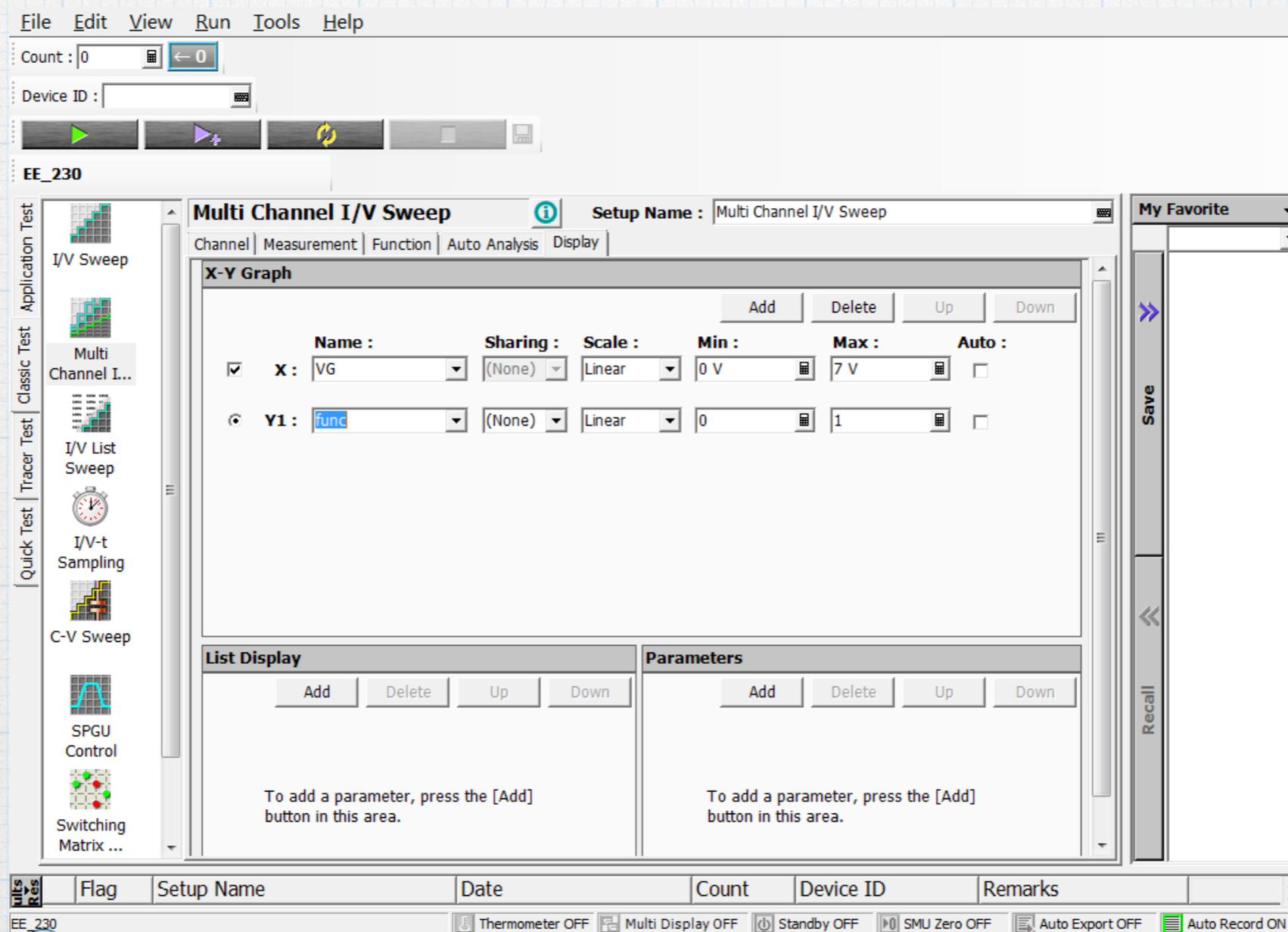
Click the “Measurement” tab. On this page, we can set up the voltages that will be used by the SMUs in the measurement. SMU3 is the gate and will be swept from minimum value to a maximum value (0 V to 7 V in this case). Also, we must set the constant voltage for drain (7 V in this case.) The settings are shown below.



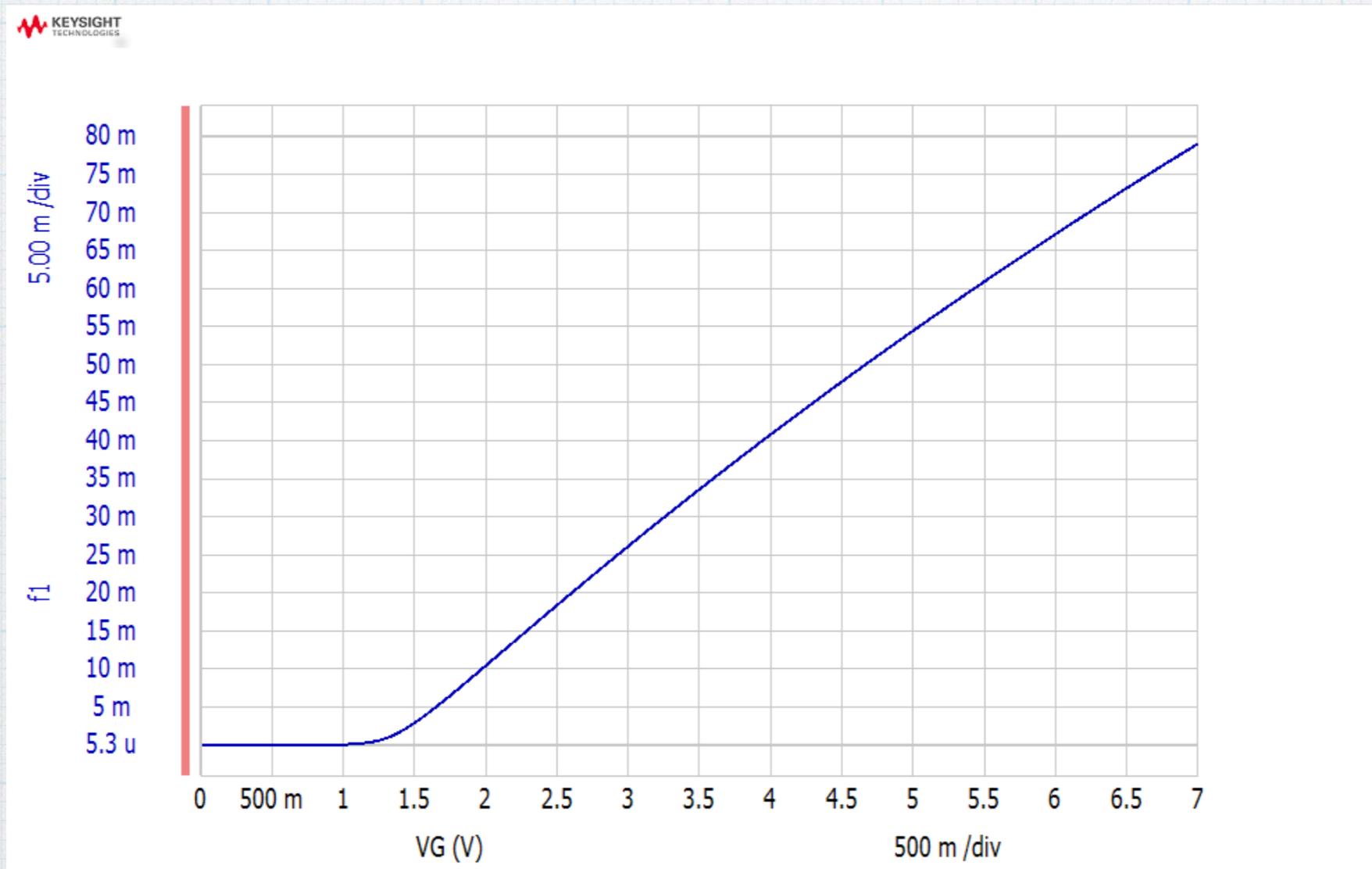
Click the “Function” tab. On this page, we can define a non-standard function that can be used in a plot. We want to use the square-root of  $I_D$  for the y-axis, so define that here. Give the function a name. (The specific name is not important.) The units are also not important, but you can enter something if you want. The most important thing is the definition. Type in  $\text{sqrt}(ID)$ . Note that the variable you enter here must match the name you gave the drain current previously on the channel page.



Almost there. Finally, click the “Display” tab to get the page where the plot can be defined. The  $x$ -axis should be gate voltage, so enter that, along with the limits used in the set up ( 0V to 7V). The  $y$ -axis will be the square-root function that we defined earlier. Click “Add” to add an axis. Choose the “Y1” option, and then select the previously defined function. the limits are not important, since we don’t know what values the measurement will produce. (We can always autoscale after the fact.)

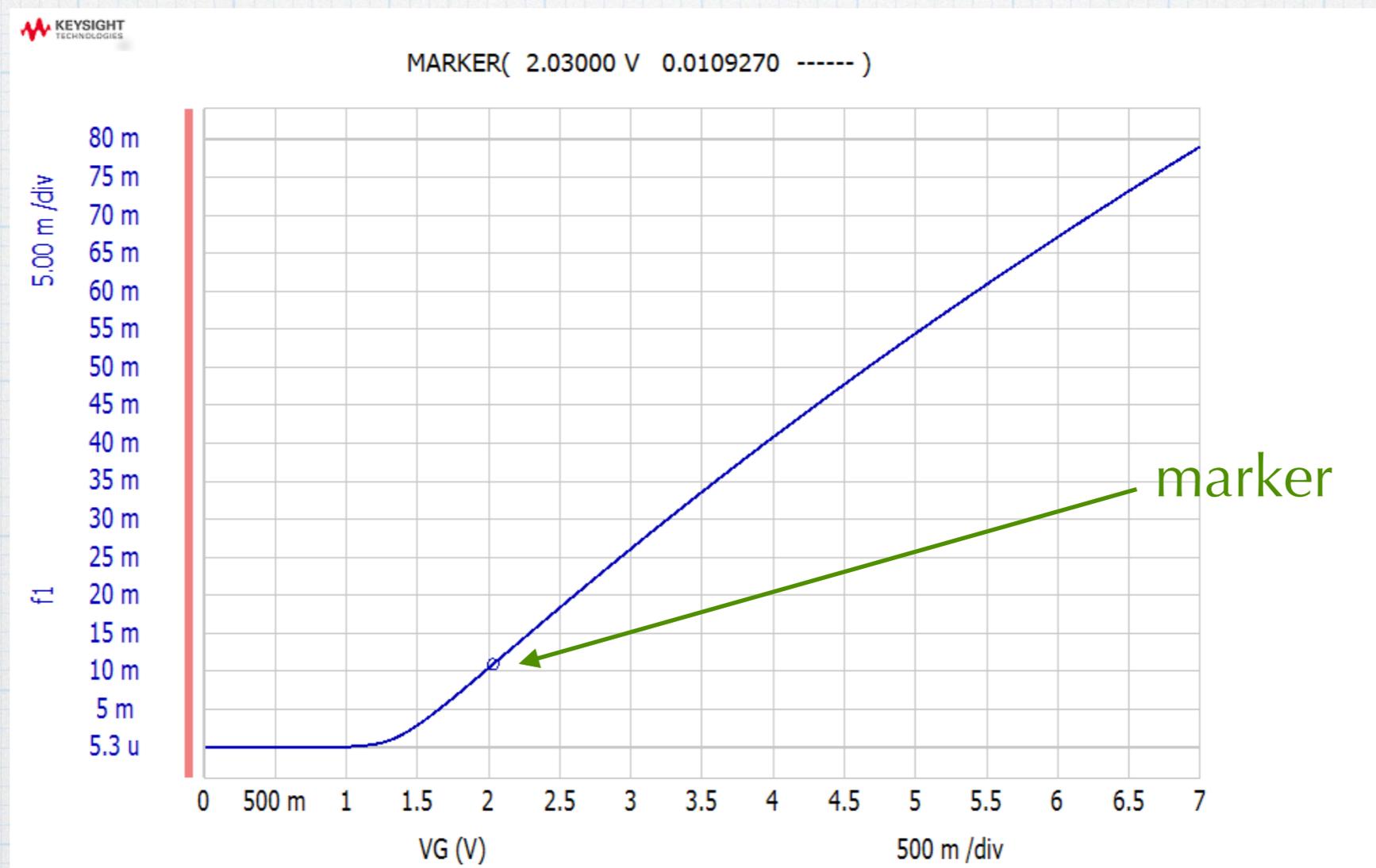


Now that everything is set up for the measurement, we can connect the actual device. (The connections are the same as for the  $i_D$ - $v_{DS}$  measurements done earlier. See slide 5.) Then click the “Run” button. If all is set up properly, you should get a plot of the square-root function versus the swept gate voltage. Click the “Autoscale” icon and you might see something like the graph below.



The first thing we note is that the curve is not ideal. There is not a sharp kink at the threshold voltage – the transition is somewhat gradual. Also the “on” curve is not a perfect line. (Devices are not ideal!)

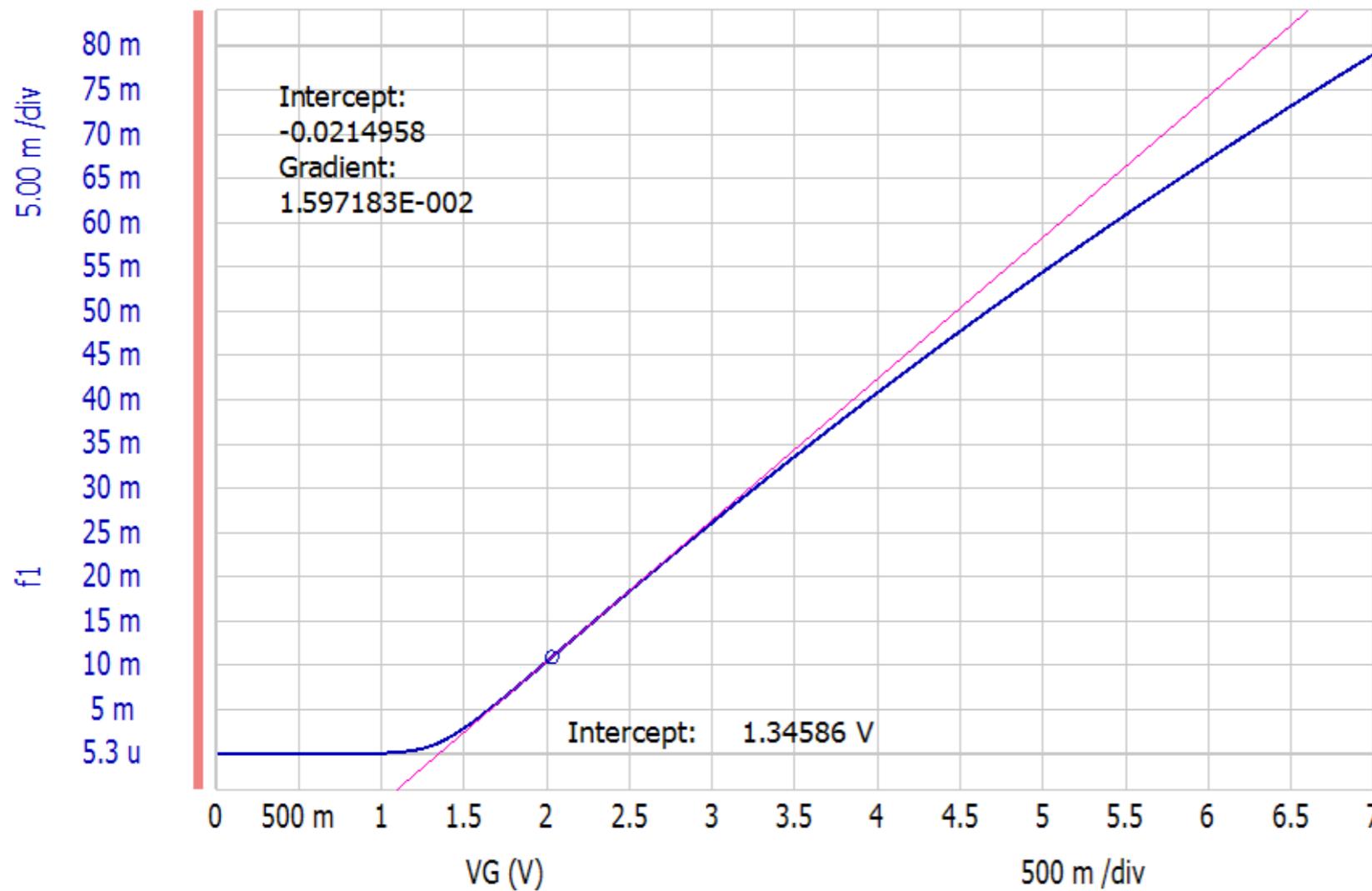
We could just “eyeball” the threshold transition and the slope. However, the analyzer has some tools to help us be more quantitative. First turn on the marker and move it to point on the curve above the threshold, as shown below.



Finally, turn on line 1 and put it into “Tangent” mode. The analyzer plots a straight line tangent to the curve at the point of the marker. It also gives the slope of the line (gradient) and the x- and y-intercepts. Of course, the x-intercept is the threshold voltage and the slope is square-root of K.



MARKER( 2.03000 V 0.0109270 ----- )



For this transistor:

$$V_T = 1.35 \text{ V, and}$$

$$\begin{aligned} K &= (1.597 \times 10^{-2})^2 \\ &= 2.54 \times 10^{-4} \text{ A/V}^2 \\ &= 0.254 \text{ mA/V}^2. \end{aligned}$$

The process for PMOS transistors is similar, with obvious adjustments for negative voltages and currents.