Simple MOSFET measurements with the 4145 parameter analyzer

In a first attempt at measuring a MOSFET, you probably would like to see a family of drain current vs. drain voltage curves, and then would like to extract the parameters V_T, K, and lambda that could be used in a level 1 MOSFET model. Of course, there are a variety of ways to extract parameters. The tutorial below describes one relatively simple approach. You will have to make two separate measurements in order to get all three parameters. The first measurement obtains a conventional family of i_D vs V_{DS} curves, and from these you can easily find lambda. The second measurement involves plotting the square-root of the drain current vs. the gate voltage in the saturation region. If you assume the MOSFET has text-book square-law behavior, the drain current is given by

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

Taking the square-root of both sides gives

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

so that a plot of the square-root of i_D vs. v_{GS} will look like Fig. 1 below.

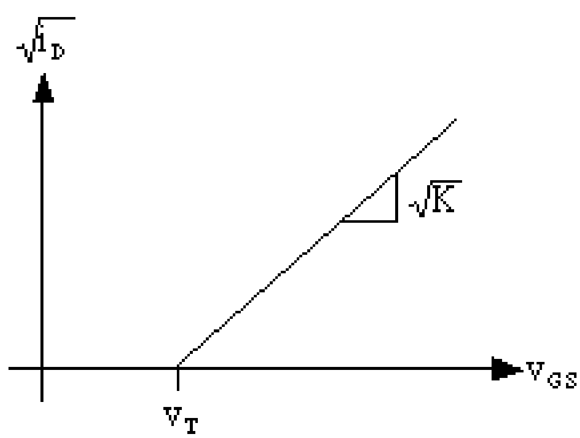

Figure 1.

With this type of plot, you can easily extract the threshold voltage (x-intercept) and the K-parameter (square of the slope).

The instructions below describe the details of setting the 4145 to do MOSFET measurements and extracting parameters from the measured data. The instructions assume that you are measuring an n-channel enhancement-mode MOSFET. The numbers used must be adjusted if you are measuring a PMOS or an depletion-mode device.
Source: Dr.Tuttle Iowa State University

Step 1 - Obtaining i_D vs v_{DS} curves and extracting lambda

1. **Getting the data**.
    a. Go to the CHANNEL DEFINITION page. Push the soft key (FET VDS-ID) that brings up the standard setup for a FET. This puts the 4145 into a configuration for measuring i_D vs. v_{DS} for FETs. Connect the drain, source, and gate of your MOSFET to the prescribed SMUs.

    2. Next, go to the SOURCE SETUP page to define the voltage and current ranges to be used. As a reasonable starting point, you might have the drain voltage range from 0 to 10V in 0.1V increments. The current compliance on the drain can be set to 25mA. Let the gate voltage step in 0.5V increment from 0 to 5V. The current compliance for the gate can be set to something small, like 1 μA.

    3. Now advance to the MEAS & DISP SETUP page. Set up the graphics plot so that v_{DS} ranges from 0 to 10V and i_D ranges from 0 to 10 mA. (You may have to come back to this page to resize the graph.

    4. Advance to the GRAPHICS PLOT page, and push the measurement button to get some data. If everything is hooked up correctly, you should see the familiar family of MOSFET curves. It may be necessary to AUTO SCALE the graph in order to see the curves clearly.

    5. You might want to make a plot of the graph or save the data to disk before proceeding.

2. **Extracting lambda**
    You can determine lambda for the MOSFET using the line features of the 4145. The sequence of steps is as follows:
    a. Turn on the marker using the MARKER soft key and move the marker to a point in that saturation region for one of the curves.
    2. Push the EXTN soft key to advance to the next set of soft keys and turn on the SHORT CURSOR. The cursor cross-hairs should appear in the middle of the screen.
    3. Push EXTN soft key again and hit the "cursor to marker" soft key. (This one has the word "cursor" followed by arrow pointing to a small dot.) This moves the cursor to the marker.
    4. Push EXTN again and then hit the LINE 1 soft key. This draws a vertical line through the cursor.
    5. Now hit the CHANGE POINT soft key, and use the marker dial to move the marker to a new point - *in the saturation region of the same curve.*
    6. Push the "cursor to marker" key again. A second cursor is placed at the new marker

location, and the line is redrawn so that it passes through the both the old cursor location and the new cursor location.

The line that you have drawn should be right on top of the saturation region portion of the i_D vs v_{DS} curve. The table at the bottom of the screen tells the slope and intercepts of the line. The x-axis intercept is equal to the inverse of lambda for the transistor.

You should measure lambda on at least two different curves, i.e. for different at least two different values of gate voltage.

Step 2 - extracting V_T and K

- **Setting up and obtaining the data**

1. Use the PREV key to step back to the CHANNEL DEFINITION page. You do not need to change the connections to the MOSFET terminals or the names or the modes, but you do need to make changes to the SMU FCTNs. Make the following changes:

   a. Change the function of SMU2 (VDS) to CONST.
   2. Change the function of SMU3 (VG) to VAR1.
   3. Enter a user function at the bottom of the page. You can call it SQRTID (or some such thing - the name is irrelevant), skip the units (also irrelevant), and enter the "the square root of ID" using the square root symbol from the key pad.

   The CHANNEL DEFINITION page should now look something like the table below.

	NAME		SOURCE	
CHAN	V	I	MODE	FCTN
SMU1	VS	IS	COM	CONST
SMU2	VDS	ID	V	CONST
SMU3	VG	IG	V	VAR1
SMU4				
Vs 1		-----	V	
Vs 2		-----	V	
Vm 1		-----	-----	-----

Vm 2		-----	-----	-----

USER FCTN	NAME(UNIT) = EXPRESSION
1	SQRTID() = $\sqrt{ID}$
2	_______( ) =

2. Push the NEXT button to go on to the SOURCE SET UP page. Set up the page to look something like the table below.

[hp] ****** SOURCE SET UP ******

	VAR 1	
NAME	VG	
SWEEP MODE	LINER	
START	.0000V	
STOP	5.0000V	
STEP	.05V	
NO. OF STEP	101	
COMPLIANCE	1.0mA	
CONSTANT	SOURCE	
VS COM	.0000V	
VDS V	8.0000	10.0mA
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		- - - - - - -

You are programming the 4145 to sweep through a range of gate voltages while keeping the drain voltage constant. Using the numbers from the above table as an example, the gate voltage would sweep from 0 to 5V, while the drain voltage is held constant at 8V. Remember to set the compliances at reasonable values.

Important measurement note: The values used above are purely for illustration. The numbers you use in your measurement will depend on the particular device your are measuring. The gate must sweep through a range that includes the threshold voltage. For instance, if you were measuring an *depletion-mode* NMOS transistor, where the threshold voltage is negative, the gate voltage range would have to start at value more negative than the threshold. Or, if measuring a PMOS transistor, *all* the voltages would have to be negative. Also, in setting the constant drain voltage, you must make certain that the MOSFET will stay in saturation. You will be safe as long as you choose the constant drain voltage to be bigger than any applied gate voltage. After taking a measurement, you might find it necessary to return to this page to adjust the settings, and then measure again.

3. Move to the MEAS & DISP MODE SET UP page. This is where you set up how the plot will look.

   DISPLAY MODE: GRAPHICS

	X axis	Y1 axis	Y2 axis
NAME	VG	SQRTID	
SCL	LINEAR	LINEAR	
MIN	.0000V	.000	
MAX	5.0000V	1.00	

   Set up the graph so that the gate voltage will be on the x-axis and your user-defined function, SQRTID (or whatever), will be on the Y1 axis. These are entered using the soft keys. To find the user function, you must push EXTN to go to the next menu of soft keys. SQRTID will show up there.

4. Advance to the GRAPHICS PLOT page and push the SINGLE measurement button to take the measurement. If necessary, push AUTO SCALE to make the graph fit the data. You should see something like Fig. 1 above.

- **Extracting V_T and K**

  Once you the graph in hand, determining the parameters is simply a matter of fitting a line to the sloping portion of the curve. Follow the procedure described above for creating a line and fitting it to a portion of the curve. The x-interecept and slope of the fitted line are given in the table at the bottom of the display.

  At this point you might want to make a hard copy of your graph.

  Measurement note: For some MOSFETs the plot of the square-root of i_D is sublinear (meaning that it is not a straight line, but bends down at higher gate voltages). This is an indicator that the simple level 1 model for the MOSFET will probably not provide a very good description of the real MOSFET's behavior. When trying to find the threshold voltage for a MOSFET that displays this type of behavior, try to fit the straight line at lower gate voltages - just slightly above threshold. If you use higher gate voltages - in the region where the curve is bending - the extracted threshold voltage will be unreasonably low and perhaps even negative.

Source: Dr.Tuttle Iowa State University