Section 8

Measuring MOSFET characteristics

In this section:

Introduction

These examples demonstrate how to use the Model 2657A High Power System SourceMeter® instrument to measure drain-to-source breakdown and leakage current of a MOSFET.

There are two examples in this section. The first example performs the BV_{dss} measurement, in which a specific current is forced from the drain to the source terminals (I_d) and a voltage measurement is performed (V_{ds}).

The second example performs the I_{dss} measurement in which the Model 2657A sweeps the drain voltage (V_{ds}) and makes drain-current measurements with the FET in the off-state.

In both examples, a second System SourceMeter Instrument is used to apply a voltage from gate to source (V_{gs}). For n-channel, enhancement mode devices, V_{gs} is usually 0 V.

Equipment required

Equipment required:

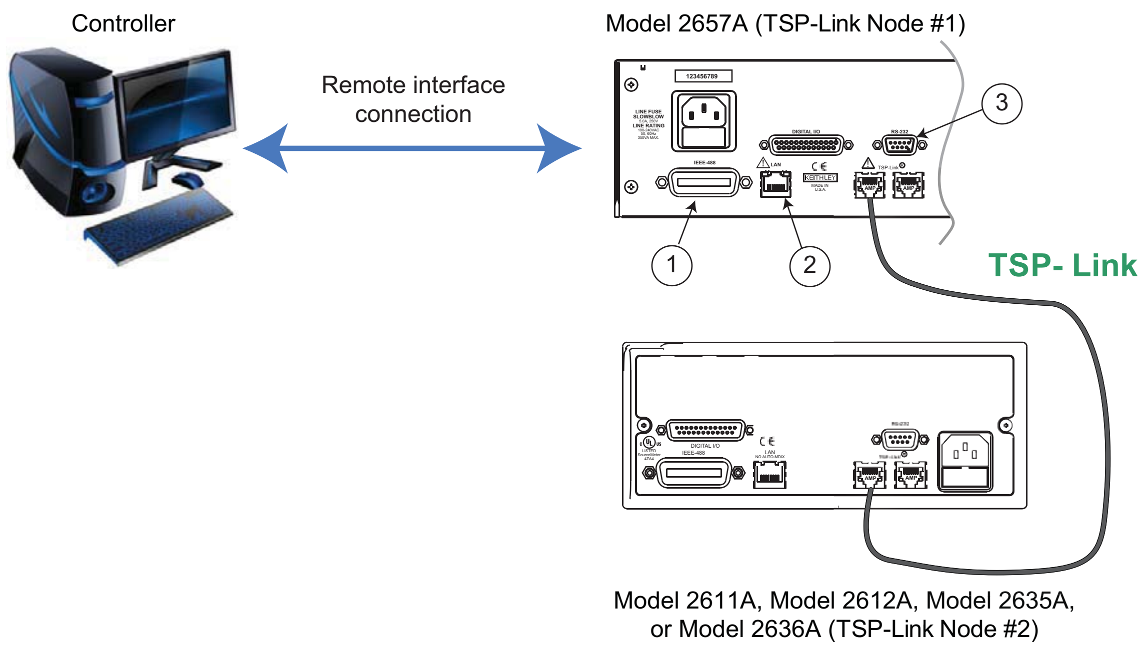
- One Model 2657A High Power System SourceMeter® instrument
- One Series 2600A System SourceMeter Instrument (Model 2611A, Model 2612A, Model 2635A, or Model 2636A)
  - If needed, cables to connect the Series 2600A SourceMeter Instrument to the protection module
  - If needed, cables to connect the protection module to the test fixture
  - If a Model 2611A or Model 2612A is being used, one Model 2600-TRIAX adapter
- If you are not using a Model 8010 High Power Device Test Fixture, you need a Model 2657A-PM-200 Protection Module to ensure that the lower voltage Series 2600A SourceMeter Instrument is protected if the device under test fails
- One GPIB or Ethernet cable to connect the Model 2657A to a computer
- One high voltage MOSFET device enclosed in a safe test fixture, such as the Keithley Instruments Model 8010
- Appropriate cabling to connect the Model 2657A the test fixture

Set up communication

The communication setup is illustrated in the following diagram. This application can be run using any of the supported communication interfaces for the instruments.

For additional detail about remote communications, see "Communications interfaces" in the Model 2657A Reference Manual.

Figure 34: Remote interface and TSP-Link communications setup



Item	Description	Qty	Notes
1	IEEE-488 connection	1	GPIB. Model 2657A is IEEE Std 488.1 compliant.
2	CA-180-3A LAN connection	1	Model 2657A is LXI version 1.4 Core 2011 compliant. It supports TCP/IP and complies with IEEE Std 802.3 (ethernet). 10 or 100 Mbps.
3	RS-232 connection	1	

To set the TSP-Link node number using the front-panel interface:

1. Press the **MENU** key.
2. Select **TSPLink**.
3. Select **NODE**.
4. Use the navigation wheel ◷ to adjust the node number.
5. Press the **ENTER** key to save the TSP-Link node number.

On the Model 2657A SMU #1 (TSP-Link node #1), perform a TSP-Link reset to update it with the linked instruments:

1. Press the **MENU** key.
2. Select **TSPLink**.
3. Select **RESET**.

NOTE

If error 1205 is generated during the TSP-link reset, ensure that the Series Model 2657A has a unique TSP-Link node number.

Quick Tip

You can also perform a TSP-Link reset from the remote command interface by sending `tsplink.reset()` to the Model 2657A. This method is used in the example program.

Device connections

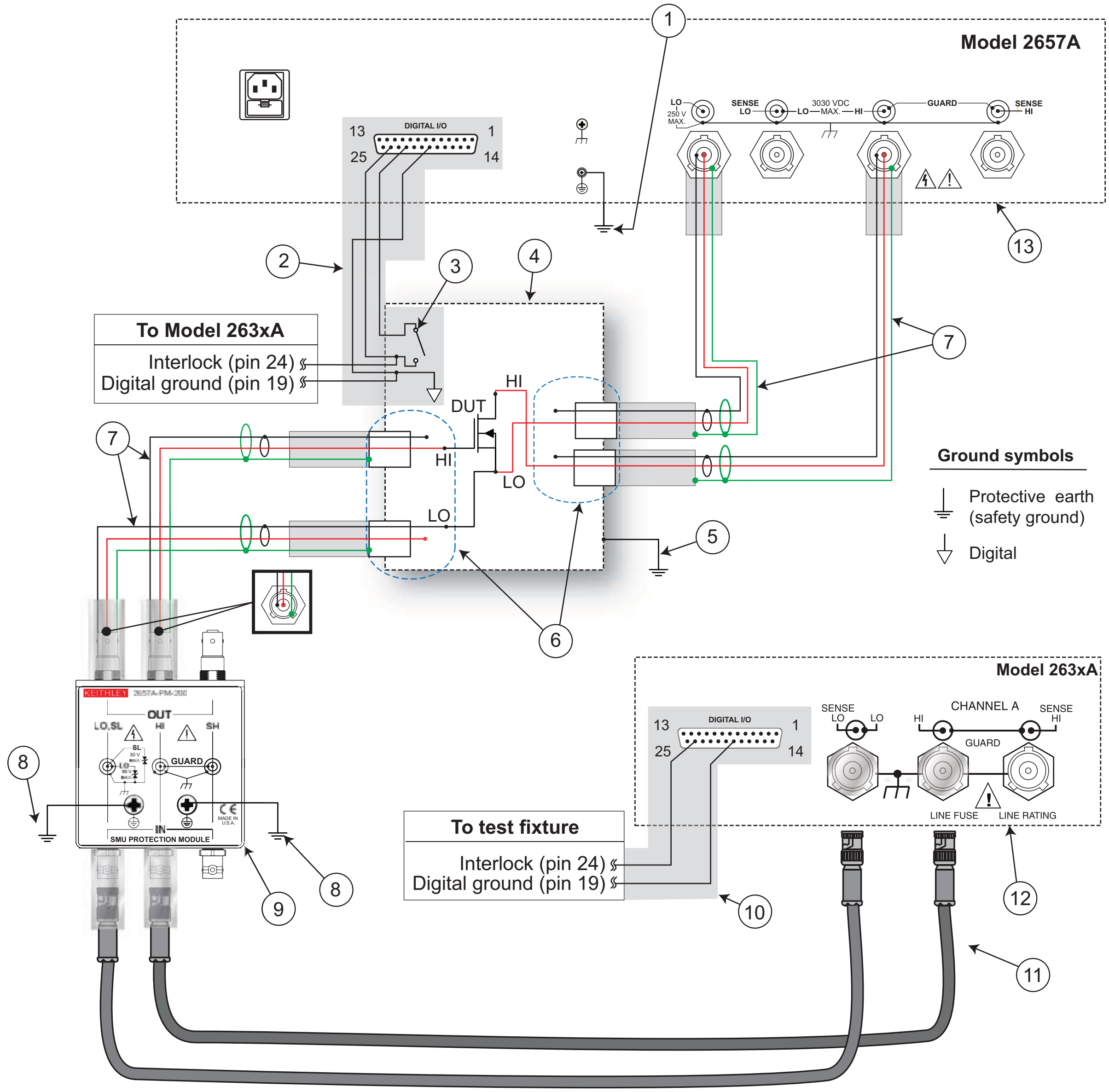
Refer to the following figure to connect the MOSFET in a safe test fixture.

See Safe configuration and test setup (on page 2-1) for information on safely connecting the Model 2657A to a device under test (DUT).

CAUTION

If a device under test fails, high voltage may be present at a terminal to which Series 2600A instruments are connected. This could damage a Series 2600A instrument. To prevent damage to the Series 2600A instrument, use a Model 2657A-PM-200 Protection Module. Failure to use a protection module could result in equipment damage.

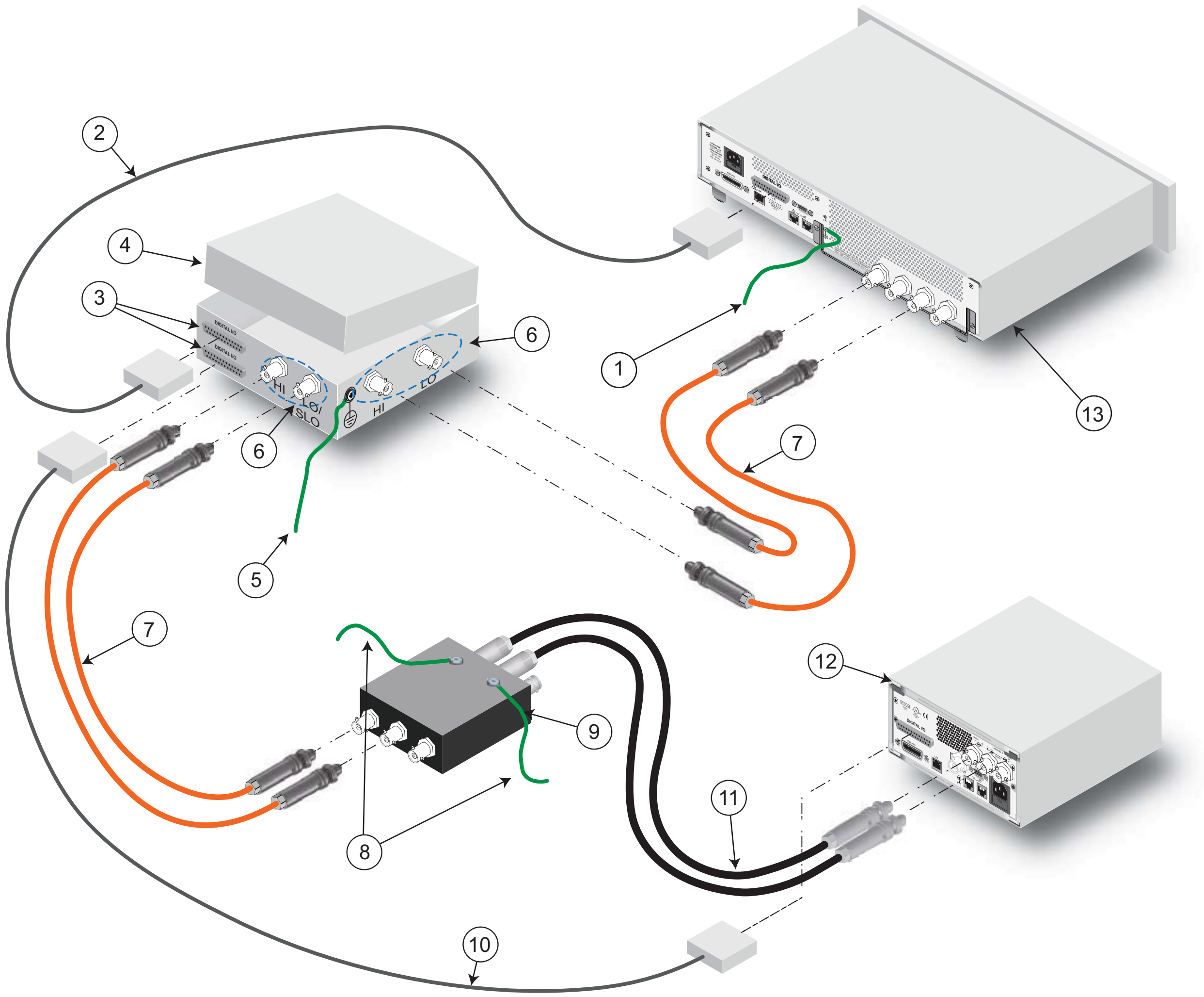
Figure 35: Schematic for measuring MOSFET characteristics application example



Item	Description	Qty	Notes
1	Model 2657A protective earth (safety ground)	1	Additional connections for redundant protective earth may be required. Keithley Instrument's Model CA-568 is a protective earth (safety ground) cable assembly.
2	Model 2657A interlock connection	1	Model 2657A digital I/O; pin 24 (INT) and pin 22 (5 VDC) connected to the test fixture lid switch. Pin 24 and pin 19 are connected to the interlock and digital ground on the Model 263xA. Keithley Instrument's Model 7709-308 is a 25-pin interlock male connector that can be used for custom connections. Interlock switch is shown in the disengaged (lid open) position.
3	Test fixture interlock switch connection	1	
4	Interlocked metal safety enclosure	1	A safety enclosure with an interlock that has a normally-open (NO) switch.
5	Test fixture protective earth (safety ground)	1	Redundant grounds may be required for specific test setups.
6	Model HV-CA-571-3 High-Voltage Triaxial Panel-Mount Cable to Unterminated Cable Assembly	4	See Using high-voltage triaxial connectors (on page 2-7).
7	Model HV-CA-554 HV Triaxial Cable	4	
8	Protective earth (safety ground) for the Model 2657A-PM-200 Protection Module	2	The Model 2657A-PM-200 must be connected to protective earth using the supplied green-yellow ground cables (Model CA-568).
9	Model 2657A-PM-200 Protection Module	1	
10	Model 2611A, 2612A, 2635A or 2636A interlock connection	1	Pin 24 (INT) and pin 19 (5 V DC) are connected to the test fixture lid switch.
11	Model 7078-TRX triaxial cables	2	
12	Series 2600A System SourceMeter Instrument (Model 2611A, Model 2612A, Model 2635A, or Model 2636A)	1	If a Model 2611A or 2612A is used, a Model 2600-TRIAX adapter is also required
13	Model 2657A	1	

If you are using a Model 8010 High Power Test Fixture, see the Interconnect Reference Guide drawing "Three-terminal DUT with a Model 2657A. Also see the Model 8010 User's Manual for information on how to connect the instrument to the fixture.

Figure 36: Measuring MOSFET characteristics application example connections



BVdss measurement

NOTE

The example code is designed to be run from Test Script Builder or TSB Embedded. It can also be run from other programming environments, such as Microsoft® Visual Studio® or National Instruments LabVIEW™. However, you may need to make changes to the example code to use other programming environments.

This example performs the BV_{dss} measurement. The Model 2657A forces a current from the drain to source terminals and measures the resulting V_{ds}. This example uses a TSP script to perform the measurement. The script includes two separate functions for configuring the System SourceMeter Instrument and returning the raw current and voltage readings from the reading buffer.

The script is written using Test Script Processor (TSP) functions rather than as a single block of inline code. TSP functions are similar to functions in other programming languages, such as Microsoft® Visual C® or Visual Basic®. They must be called before the code in them is executed. Because of this, running the script alone will not execute the test. To execute the test, you need to run the script to load the functions into test script memory. You then call the functions.

Refer to the documentation for Test Script Builder or TSB Embedded (on page 4-4) for directions on how to run scripts and enter commands using the instrument console.

Example code

```
 --[[
   Title: FET Drain-Source Breakdown Voltage
   Description: This script measures the drain-source
   breakdown voltage (BVdss) of a FET.
--]]

--[[
   BVdss(gateV, drainI, measDelay, igLimit, vdLimit, numNPLC)

   Description: This function uses the Model 2657A to force a current
   from drain to source. The SMU also measures the resulting voltage (Vds)
   with the FET channel turned off. A second System SourceMeter Instrument
   applies the gate to source voltage (Vgs) to ensure that the gate is
   turned off.

   Parameters:
      gateV: Applied gate voltage (Vgs).
      drainI: Test current applied by the Model 2657A from
       drain to source (Id).
      measDelay: Measurement delay before making the drain voltage
       measurement (Vgs).
      igLimit: Current limit (compliance) for the SMU connected to the
       FET gate terminal.
      vdLimit: Voltage limit (compliance) for the SMU connected to the
       FET drain terminal.
      numNPLC: Integration time for the drain voltage measurement
       (in number of power line cycles).

   Example usage:
   BVdss(0, 0.001, 0.01, 0.01, 2000, 1)
--]]

function BVdss(gateV, drainI, measDelay, igLimit, vdLimit, numNPLC)

   --Initialize SMU.
   reset()
   errorqueue.clear()
   status.reset()
   tsplink.reset()

   --Configure source function.
   node[2].smua.source.func = node[2].smua.OUTPUT_DCVOLTS
   node[2].smua.source.levelv = gateV
   node[2].smua.source.limiti = igLimit

   smua.source.func = smua.OUTPUT_DCAMPS
   smua.source.rangei = drainI
   smua.source.leveli = drainI
   smua.source.limitv = vdLimit
```

```
   --Configure measurement parameters.
   smua.measure.rangev = vdLimit
   smua.measure.nplc = numNPLC
   smua.measure.delay = measDelay

   --Run the test.
   node[2].smua.source.output = 1
   smua.source.output = 1

   I,V = smua.measure.iv()

   smua.source.output = 0
   node[2].smua.source.output = 0

   print("Test current:", I)
   print("Measured voltage:", V)

end
```

Example usage

The function in this script allows updates to the test parameters without rewriting or re-running the script. To run the test, call the `BVdss()` function, passing in the appropriate values for test parameters.

BVdss() parameters		
Parameter	**Units**	**Description**
`gateV`	volts	Gate voltage to apply with Series 2600A System SourceMeter Instrument
`drainI`	amps	Drain current forced by Model 2657A
`measDelay`	seconds	Measurement delay after applying drain current and before measuring BV_{dss}
`igLimit`	amps	Current limit for the Series 2600A SourceMeter Instrument connected to the MOSFET gate terminal
`vdLimit`	volts	Voltage limit (compliance) for the Model 2657A connected to the MOSFET drain terminal; should be greater than or equal to the expected BV_{dss} value
`numNPLC`	not applicable	Integration time, specified as the number of power line cycles

An example of how to call this function is shown here:

```
BVdss(0, 0.001, 0.01, 0.01, 2000, 1)
```

This call applies 0 V to the FET gate terminal and programs the Model 2657A to force 1 mA into the drain terminal. After 10 ms, the drain voltage is measured (up to 2000 V max). The measurement is made at 1 PLC. The actual drain current is also measured. The measurement results are automatically printed at the completion of the test. An example of the measurements results is:

```
Test current:    9.99856e-04
Measured voltage:    1.76940e+03
```

Idss measurement

This example:

- Performs the I_{dss} measurement, where the drain-to-source voltage (V_{ds}) is swept and leakage current measurements are made while the FET is in the off-state.
- Monitors the current measurement to see if the current limit has been reached. When the current limit has been reached, the voltage sweep is aborted.

With this method, a second System SourceMeter is used to apply a voltage from gate to source (V_{gs}). This example uses a TSP script to perform the measurement. The script includes two separate functions for configuring the System SourceMeter Instruments and returning the raw current and voltage readings from the reading buffer.

Example code

```
--[[
   Title: FET Drain-to-Source Leakage Current Measurement Sweep

   Description: This script measures the drain current while the
   drain voltage is sweeping linearly and under a 0 V gate bias.
--]]

--[[
   Idss(gateV, startV, stopV, numSteps, measDelay, measRange, iLimit, numNPLC)

   Description: This function uses the Model 2657A to sweep the voltage
   across the drain up to the drain-source breakdown voltage and measure
   the drain current. A second SourceMeter instrument is used to bias the
   gate. For enhancement-mode power MOSFETs, a typical gate bias is 0 V.

   Parameters:
      gateV: Applied gate voltage bias (Vgs).
      startV: Starting drain voltage (Vds).
      stopV: Final drain voltage (Vds).
      numSteps: Number of points in the drain voltage sweep.
      measDelay: Measurement delay.
      measRange: Current measurement range for the drain current measurements.
      iLimit: Current limit (compliance) for the drain current.
      numNPLC: Integration time in the number of power line cycles.

   Example Usage:
   Idss(0, 10, 1760, 500, 0.05, 100e-9, 500e-6, 1)
--]]
```

```
function Idss(gateV, startV, stopV, numSteps, measDelay, measRange, iLimit,
   numNPLC)

   --Initialize SMU.
   reset()
   errorqueue.clear()
   status.reset()

   --Configure reading buffers.
   smua.nvbuffer1.clear()
   smua.nvbuffer1.appendmode = 1
   smua.nvbuffer1.collecttimestamps = 1

   smua.nvbuffer2.clear()
   smua.nvbuffer2.appendmode = 1
   smua.nvbuffer2.collecttimestamps = 1

   --Configure source parameters for the gate SMU.
   node[2].smua.source.func = node[2].smua.OUTPUT_DCVOLTS
   node[2].smua.source.levelv = gateV
   node[2].smua.source.limiti = 0.001

   --Configure source parameters for the drain SMU.
   smua.source.func = smua.OUTPUT_DCVOLTS
   smua.source.levelv = 0
   smua.source.limiti = iLimit
   if math.abs(startV) > math.abs(stopV) then
      smua.source.rangev = startV
   else
      smua.source.rangev = stopV
   end

   --Configure measurement parameters for the drain SMU.
   smua.measure.rangei = measRange
   smua.measure.nplc   = numNPLC
   smua.measure.delay  = measDelay

   step = (stopV - startV)/(numSteps - 1)
   voltage = startV
   smua.source.levelv = voltage
```

```
   --Run the test.
   node[2].smua.source.output = 1
   smua.source.output = 1
   delay(1)

   for i = 1, numSteps do
      smua.measure.iv(smua.nvbuffer1, smua.nvbuffer2);
      --Remove the following 4 lines if you do not want to monitor
      --for compliance
      testCmpl = smua.source.compliance
      if testCmpl == true then
         break
      end

      smua.source.levelv = voltage + step
      voltage = voltage + step
   end

   --Turn off the SMUs to complete the test.
   smua.source.levelv = 0
   node[2].smua.source.levelv = 0
   node[2].smua.source.output = 0
   smua.source.output = 0

   printData()

end

function printData()

   if  smua.nvbuffer1.n == 0 then
      print("No reading in buffer")
   else
      print("Timestamps\tVoltage\tCurrent")
      for i = 1, smua.nvbuffer1.n do
         print(string.format("%g\t%g\t%g", smua.nvbuffer1.timestamps[i],
          smua.nvbuffer2.readings[i], smua.nvbuffer1.readings[i]))
      end
   end
end
```

Example usage

The functions in this script allow updates to the test parameters without rewriting or re-running the script. To run the test, call the `Idss()` function, passing in the appropriate values for test parameters.

Idss() parameters		
Parameter	**Units**	**Description**
`gateV`	volts	Gate voltage to apply with Series 2600A System SourceMeter Instrument
`startV`	volts	Start voltage for the drain voltage sweep
`stopV`	volts	Final voltage for the drain voltage sweep
`numSteps`	not applicable	Number of voltage steps to perform in the voltage sweep
`measDelay`	seconds	Measurement delay after applying drain voltage and before measuring drain leakage current
`measRange`	amps	Fixed current measurement range used to measure drain leakage current
`iLimit`	amps	Current limit (compliance) for the Model 2657A connected to the MOSFET drain terminal
`numNPLC`	not applicable	Integration time, specified as the number of power line cycles

An example of how to call this function is shown here:

```
Idss(0, 10, 1760, 500, 0.05, 100e-9, 500e-6, 1)
```

This call applies 0 V to the MOSFET gate terminal and programs the Model 2657A to generate a 500 point voltage sweep from 10 V to 1760 V at the drain terminal. After each voltage step, a 50 ms delay occurs before the current is measured. The measurement is made at 1 PLC. The measurements are stored in the instrument's reading buffers and are output from the communication interface immediately after the test is run.

Example output data is shown in the following graphic.

Figure 37: Example output data