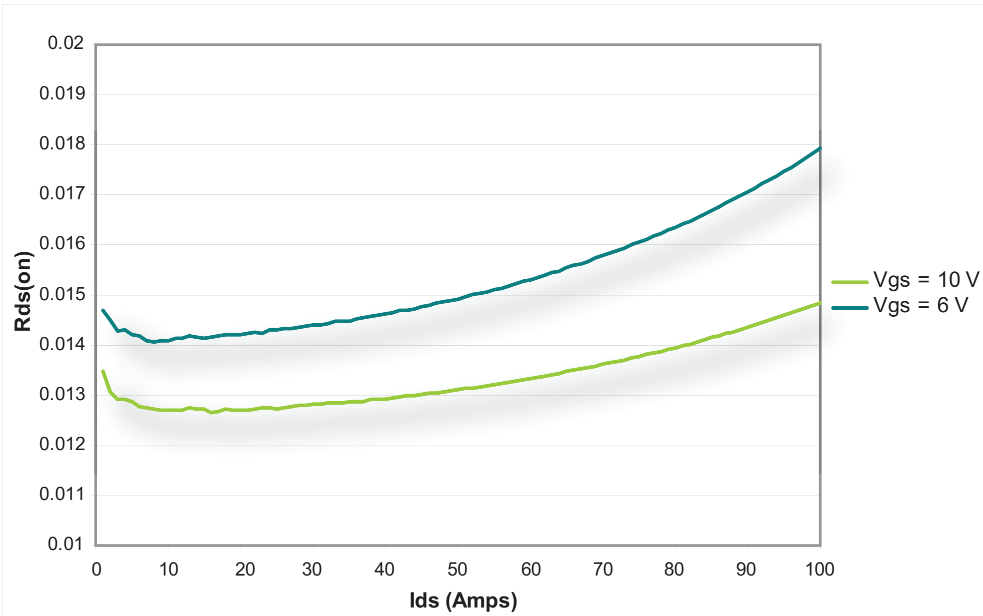
Introduction to combining SMUs

A common test performed on power MOSFETs characterizes the resistance of the device under test (DUT). In this test, the gate of the device is held at a constant voltage (representing the on-state of the device) while a current is swept through the drain and the voltage is measured. The resulting data can be plotted to show drain current versus Rds(on) for the device. The following figure illustrates an example of this plot.

Figure 1: Example Rds(on) curves for a power MOSFET device



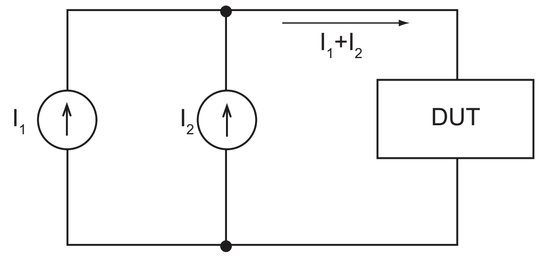
In order to avoid device self-heating, this test is usually performed using pulsed measurements. This method pulses current across the device for a short duration. During this pulse, after the pulse has settled, the voltage is measured. The duration of the pulse and the duty cycle in which the pulses are applied to the device are controlled, minimizing self-heating. A single Model 2651A High Power System SourceMeter® Instrument can pulse-measurement test with precision timing at currents up to 50 A and pulse widths as low as 100 µs.

To increase the pulse output, you can combine two Model 2651A High Power System SourceMeter® Instruments to output a pulse that is greater than that of a single Model 2651A. This example demonstrates how to perform an Rds(on) sweep up to 100 A using two Model 2651A High Power System SourceMeter® Instruments.

Combining SMUs

To combine two Model 2651A High Power System SourceMeter® Instruments to output a pulse that is greater than that of a single instrument, the current sources are connected in parallel so that the sum of the currents is delivered to the DUT, which allows us to sweep the DUT up to 100 A. The following figure illustrates this principle of combining current sources.

Figure 2: Sum of parallel current sources



Since each Model 2651A can produce up to 50 A, placing the instruments in parallel can deliver up to 100 A. In this example, we will sweep the DUT using each Model 2651A to source exactly half of the desired total current level for each point in the sweep.

Equipment needed for this example

To run this test you will need the following equipment:

- Two Model 2651A High Power System SourceMeter® Instruments.
- One Series 26xxA System SourceMeter® Instrument (see Note).
- Two TSP-Link® Cable (Keithley Instruments part number CA-180-3A).
- One GPIB cable or Ethernet cable to connect one Model 2651A to a computer.
- Additional cable and connector assemblies as required to make connections to the DUT (for example, Model 2651A-KIT and Model 2600-KIT). See Device connections (on page 5) for a schematic of required connections.

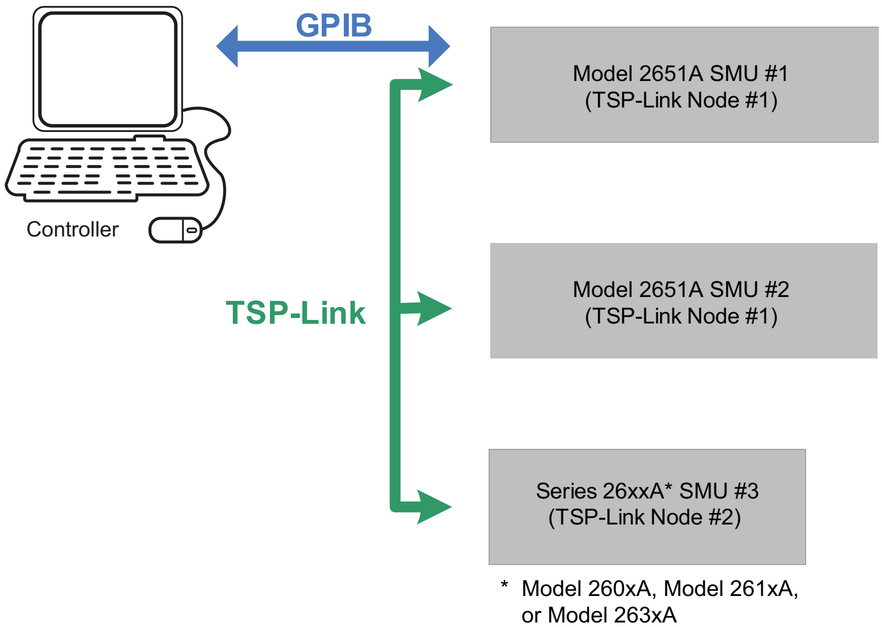
NOTE

For this application, Series 26xxA System SourceMeter® Instrument refers to any of the following instrument models: Model 260xA, Model 261xA, or Model 263xA.

Set up communication

The communication setup is illustrated in the following diagram. GPIB is used as an example, but this application can be run using any of the supported communication interfaces for the instruments. A TSP-Link connection enables communication between the two instruments. Commands for the Model 2651A SMU #2 (node #2) and the Series 26xxA SMU #3 (node #3) are sent over the TSP-link interface.

Figure 3: GPIB communication example for Rds(on) sweep



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

Press the **MENU** key.

Select **TSPLink**.

Select **NODE**.

Use the navigation wheel ◷ to adjust the node number.

Press the **ENTER** key to save the TSP-Link node number.

On the Model 2651A SMU #1 (TSP-Link node #1), perform a TSP-Link reset to update it with the linked instruments:

Press the **MENU** key.

Select **TSPLink**.

Select **RESET**.

NOTE

If error 1205 is generated during the TSP-link reset, ensure that the Series 26xxA has a unique TSP-Link node number.

Quick Tip

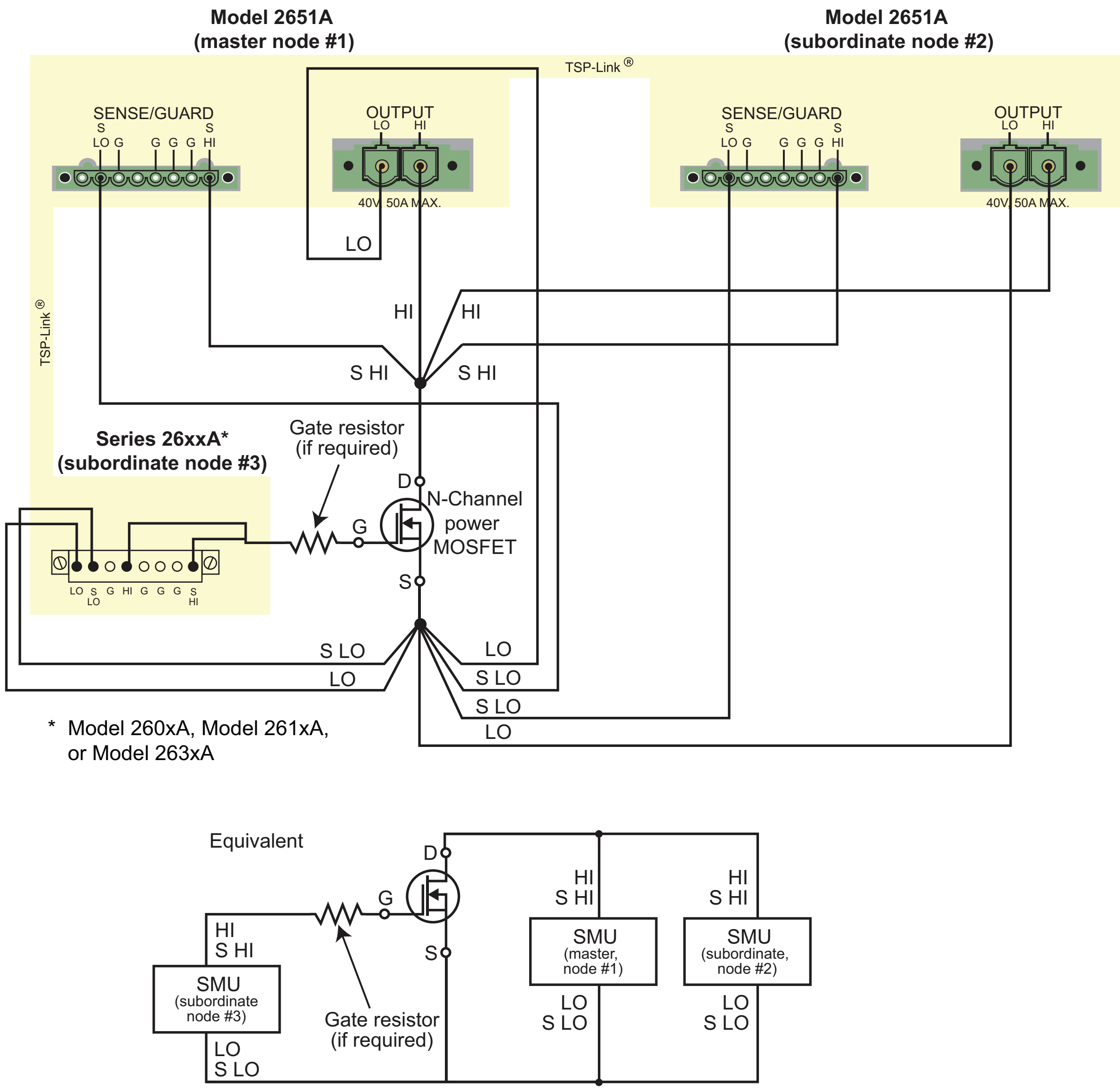
You can also perform a TSP-Link reset from the remote command interface by sending `tsplink.reset()` to the Model 2651A. This command is also included in the example program code below for completion.

Device connections

To run the test, make the connections as illustrated in the following figure. To ensure good contact, use care when making connections.

> **NOTE**
>
> For best results, all connections should be left floating (no connections should be tied to ground).

Figure 4: Connections for Rds(on) sweep



NOTE

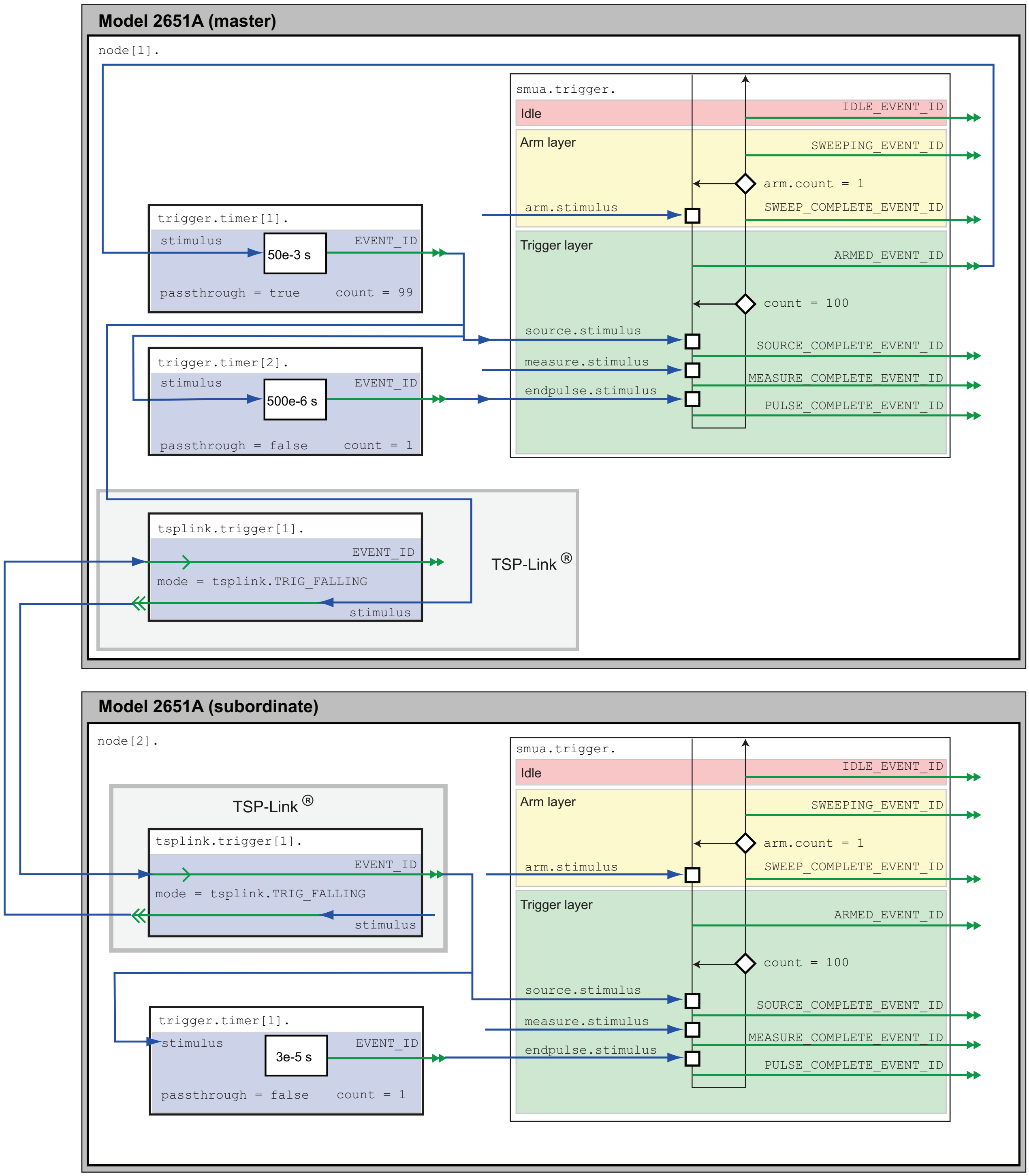
During high-current pulsing through the channel of the device, the gate may begin to oscillate. This oscillation creates an unstable voltage on the gate, which may cause unstable measurements through the device channel. You can install a resistor to dampen this oscillation and stabilize the gate. Install the resistor between the gate of the device and the force and sense HI of the Model 2651A. If the gate still remains unstable, enable High-C mode on the Model 2651A source-measure unit (SMU).

Configuring the trigger model

Correctly configuring the trigger model allows us to achieve the pulsed measurements with precise timing and current levels up to 100 A for the combined Model 2651A instruments. Refer to the Example program code for an implementation of this trigger model.

In this trigger model, the master Model 2651A node[1] is configured to control the overall timing of the sweep. Subordinate Model 2651A node[2] is configured to wait for signals from the master Model 2651A node[1] as to when it should pulse. In this example, the Series 26xxA is controlled by script so its trigger model is not used. The following figure illustrates this test's overall trigger model configuration that synchronizes the two Model 2651A High Power System SourceMeter® Instruments to within 1 µs to provide a single 100 A pulse.

Figure 5: Trigger model configuration for Rds(on) sweep



Master Model 2651A node[1] trigger model operation

In the master Model 2651A (`node[1]`) trigger model, Timer 1 is used to control the period of the pulse while Timer 2 is used to control the pulse width. TSP-Link Trigger 1 is used to tell Model 2651A (subordinate, `node[2]`) to output its pulse.

When the trigger model of the master Model 2651A (`node[1]`) is initialized, the following occurs:

The SMU's trigger model leaves the idle state, flows through the Arm Layer, enters the Trigger Layer, outputs the ARMED event trigger and then reaches the Source Event where it waits for an event trigger.

The ARMED event trigger is received by Timer 1 which begins its countdown and passes the trigger through to be received by TSP-Link Trigger 1, Timer 2, and the SMU's Source Event.

TSP-Link Trigger 1 receives the event trigger from Timer 1 and sends a trigger through the TSP-Link to Model 2651A (subordinate, `node[2]`) to instruct it to output the pulse.

The SMU's Source Event receives the event trigger from Timer 1, begins to output the pulse and then waits the programmed source delay (if any), outputs the SOURCE_COMPLETE event to timer 2, and then lets the SMU's trigger model continue.

Timer 2 receives the SOURCE_COMPLETE event trigger from Timer 1 and begins to countdown.

The SMU's trigger model continues to the Measure Event where it waits a programmed measure delay (if any), takes a measurement and then continues until it hits the End Pulse Event where it waits for an event trigger.

Timer 2's countdown expires and Timer 2 outputs an event trigger to the SMU's End Pulse Event.

The SMU's End Pulse Event receives the event trigger from Timer 2 and outputs the falling edge of the pulse and then lets the SMU's trigger model continue.

The SMU's trigger model then compares the current Trigger Layer loop iteration with the trigger count.

- If the current iteration is less than the trigger count, then the trigger layer repeats and the SMU's trigger model reaches Source Event where it waits for another trigger from Timer 1. Because Timer 1 had its count set to one less than the trigger count, Timer 1 will continue to output a trigger for each iteration of the Trigger Layer loop. The trigger model then repeats from Step 3.
- If the current iteration is equal to the trigger count, then the SMU's trigger model exits the Trigger Layer, passes through the Arm Layer and returns to Idle.

Model 2651A node[2] trigger model operation

In the Model 2651A (subordinate, node[2]) instrument's trigger model, Timer 1 is used to control the pulse width and is programmed with the same delay as Timer 2 in the Model 2651A (master, node[1]). The pulse period is controlled by TSP-Link Trigger 1 which gets its triggers from Model 2651A (master, node[1]) instrument's Timer 1 thus the pulse period is controlled by the same Timer in the system.

When the trigger model of Model 2651A (subordinate, node[2]) is initialized, the following occurs:

The SMU's trigger model leaves the idle state, flows through the Arm Layer, enters the Trigger layer, and then reaches the Source Event where it waits for an event trigger.

TSP-Link Trigger 1 receives a trigger from the TSP-Link and outputs an event trigger to the SMU's Source Event.

The SMU's Source Event receives the event trigger from TSP-Link Trigger 1, begins to output the pulse and then waits the programmed source delay (if any), outputs the SOURCE_COMPLETE event to Timer 1 before letting the SMU's trigger model continue.

Timer 1 receives the SOURCE_COMPLETE event trigger from TSP-Link Trigger 1 and begins its countdown.

The SMU's trigger model continues to the Measure Event where it waits for a programmed measure delay (if any), takes a measurement, and then continues until it stopping at the End Pulse Event where it waits for an event trigger.

Timer 1's countdown expires and Timer 1 outputs an event trigger to the SMU's End Pulse Event.

The SMU's End Pulse Event receives the event trigger from Timer 1, outputs the falling edge of the pulse, and then lets the SMU's trigger model continue.

The SMU's trigger model then compares the current trigger layer loop iteration with the trigger count.

- If the current iteration is less than the trigger count, then the trigger layer repeats and the SMU's trigger model reaches Source Event where it waits for another trigger from TSP-Link Trigger 1. The trigger model then repeats from Step 2.
- If the current iteration is equal to the trigger count, then the SMU's trigger model exits the Trigger layer, passing through the Arm Layer and returns to Idle.

Series 26xxA trigger model operation

In this example, the Series 26xxA is controlled by script so its trigger model is not used.

Example program usage

This script's functions allow the sweep parameters of the test to be adjusted without having to rewrite and re-run the script. A test can be executed by calling the function `DualSmuRdson()` with the appropriate values passed to it in its parameters.

DualSmuRdson() parameters

Parameter	Units	Description
gateLevel	V	The voltage level to hold the gate
dstart	A	The level of the first step in the drain sweep.
dstop	A	The level of the last step in the drain sweep.
dsteps	Not applicable	The number of steps in the drain sweep
pulseWidth	Seconds	The width of the pulse in the drain sweep
pulsePeriod	Seconds	The time between the start of consecutive pulses in the drain sweep
pulseLimit	V	The voltage limit of the pulses in the drain sweep.

An example call to this function is as follows:

```
DualSmuRdson(10, 1, 100, 100, 500e-6, 50e-3, 10)
```

This call will set the gate SMU output to 10 V and then sweep the drain of the device from 1 A to 100 A in 100 points. The points of this sweep will be gathered using pulsed measurements with a pulse width of 500 µs and a pulse period of 50 ms for a 1% duty cycle. These pulses will be limited to a maximum of 10 V. At the end of the sweep, all SMU outputs will be turned off. The resulting data from this test will be returned in an Excel compatible format (you can cut and paste the output from the console) that can be used for graphing and analysis.