Characterizing Transistors and Field Effect Transistors using two SMUs
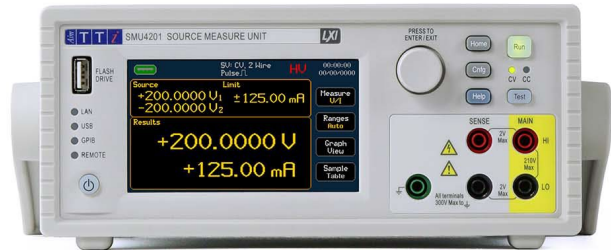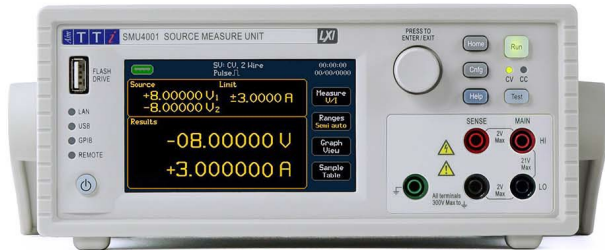
Application Note

82110-0120-1

Products:

SMU4001
SMU4201
SMU Link Adaptor
Test Bridge SMU Software

Introduction

This document describes a test and measurement method for characterizing Field Effect Transistors using Aim-TTi SMU4000 Series instruments, accessories and software.

The characterization of three leaded components (such as a field effect transistor) requires two SMU output channels; one to stimulate the Gate of the FET, and the other provides a drain to source voltage (Vds) for which current measurements can be made.

SMU4000 Series instruments provide a single output; however, a fully functioning two-channel SMU can be achieved with the addition of a second SMU connected via the DIO terminals. Simply adding an additional SMU to the test setup can result in a slow and arduous test; therefore, the following accessories are available to make this type of test quick and simple to set up and perform:

SMU Link Adaptor- Page 3

Linking two SMUs via the DIO terminals enables them to perform simultaneously via a handshake triggering system, effectively creating the fully functioning two channel SMU.

The 'SMU LINK' adaptor accessory is available to make this 'link' far simpler and convenient to use, the link adaptor connects to both DIO terminal ports to synchronise the two SMUs together, without the need to wire each DIO terminal individually.
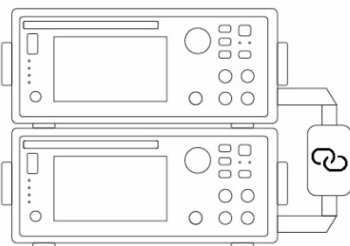
Test Bridge SMU- Page 6

The entire process can be made far simpler via the use of the free 'Test Bridge SMU' PC software. This software allows for complete control of both instruments and provides powerful intuitive graphing features for plotting I/V curves with measurement data provided by both SMUs.
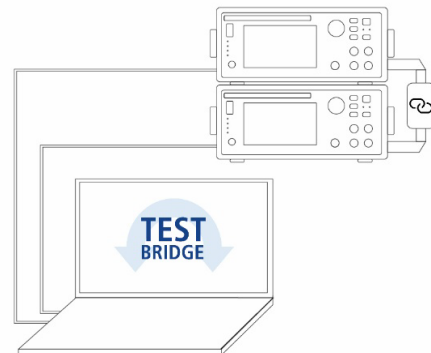
Using the Link Adaptor

This SMU Link Adaptor is designed to connect two Aim-TTi SMUs together via the DIO terminal ports on the rear panel.

Figure 1- Two Aim-TTi SMUs and a Link Adaptor, connected via the DIO terminals.

It can also be used as a DIO Expander for one or two instruments, removing the need to wire each DIO terminal individually. See the *SMU Link Adaptor Instruction Manual* for more details on using the link as a DIO expander.

Figure 2- SMU Link Adaptor from Aim-TTi.

A fully functioning two-channel SMU can be created with two SMUs via a handshake-triggering system using the Link Adaptor to connect the trigger DIO lines.

When using the Link adaptor to connect two SMUs, the adaptor **internally** connects the 'Trigger In' of each SMU to the 'Trigger Out' of the other. 'Trigger Out' will be set once all measurements associated with the level/shape are complete.

This combination of 'Trigger In' and 'Trigger Out' allows for the handshaking of multiple instruments without further wiring.

For full synchronization of two SMUs, consider the following settings with the 'Manual Setup' of the SMU:

- To initialize the test, both SMUs must be 'RUN'.

- The DIO must all be set to either active high or active low on both instruments. CNFG > [System] Interfaces > [DIO] Pin Action

- A trigger (either level or shape) must be set on both instruments, A shape other than steady must be selected to set the trigger. CNFG > [Source Measure Action] Manual Setup > [Timing] Trigger

- If both sets of results are intended to be plotted on one graph, the total number of measurements on both SMUs must match.

- To maintain synchronisation, set the same number of levels/ shapes on both SMUs.

The time for Trigger In/ Trigger Out to respond will typically take:

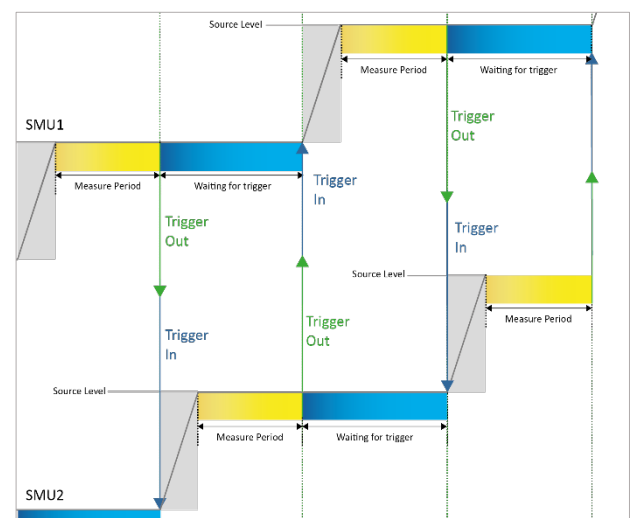| Trigger Out	≤ 50ms
Trigger In	≤ 1ms

Figure 3- Trigger Out / In typical timings

Figure 4- Example setup - Using level triggering to synchronise two SMUs.
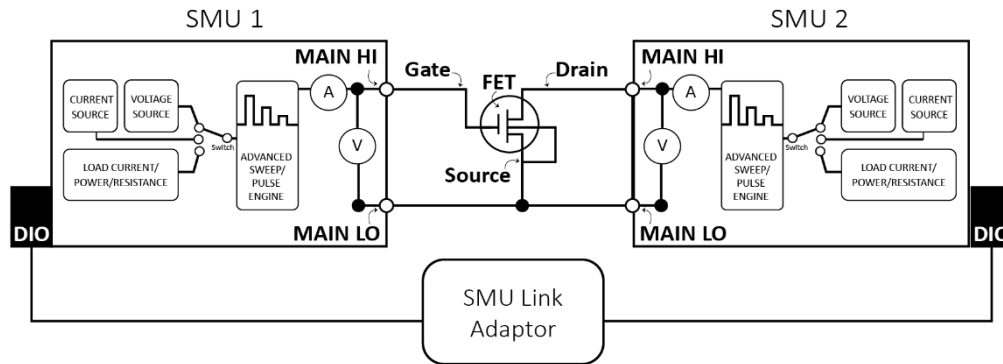
Test Setup

Figure 5 – FET test setup example, using two Aim-TTi SMUs and a Link Adaptor

Equipment Required

- Two Aim-TTi SMUs
- Aim-TTi SMU Link adaptor (ribbon cables included)
- Test cables and clips, at least two per SMU. Additional cables are required for 4-wire measurement or for utilizing 2-wire plus guard.
- FET for characterization.

Characterization Test Concept

To perform an IV characterization measurement of a Field Effect Transistor requires one SMU to stimulate the Gate of the FET by providing a gate to source voltage (Vgs) whilst the other SMU provides a drain to source voltage (Vds) for which current measurements can be made.

The gate-source voltage is swept from a start voltage to an end voltage in discrete voltage steps; at each of these steps, a drain current measurement is performed. The gate voltage can then be plotted against the drain current as an IV curve. This can then be repeated at different drain to source voltages. If instability or ringing occurs, it is recommended that a small amount of gate resistance is added.

There is a huge abundance of different FETs, in various forms and sizes; therefore, no one setup configuration suits all. As such, the set levels and limits in this document are very specific to the device under test. However, there are key settings required for the synchronised test to work as intended.

Example Settings

SMU 1		SMU 2	
Connection	Vgs	Connection	Vds
Mode	SV	Mode	SV
Shape	Sweep	Shape	Sweep
Start Level	0V	Start Level	3V
End Level	2V	End Level	3V
Points	101	Points	101
Trigger	Level	Trigger	Level

Figure 6- Example Settings table.
[Voltage and Current settings are FET specific]

Firstly, and most importantly, is the 'Trigger' setting within the manual setup. This must be set to 'Level'. This essentially controls the state of the global trigger; setting it to 'Level' means that a global input trigger is required prior to setting the next level, once all measurements are complete for the set level, the global output trigger is set. Without this, no synchronisation handshaking between the units takes place.

In order for both the SMUs to remain in synchronization, requires that both source the same number of levels to ensure that there is a measurement of drain current for each gate voltage step. This effectively means that the start and end level will likely remain the same for the Vds sourcing SMU (i.e., the Vds voltage remains the same for the whole test. However, there is a triggered measurement on each step level).

In most applications the Measurement Count should be set to one, this ensures that for each gate level voltage measurement there is a single drain current measurement.

The DIO must all be set to either 'Active High' or 'Active Low' on both instruments.

Running the Test

Once the test setup and configuration are complete, the IV characterisation can be performed.
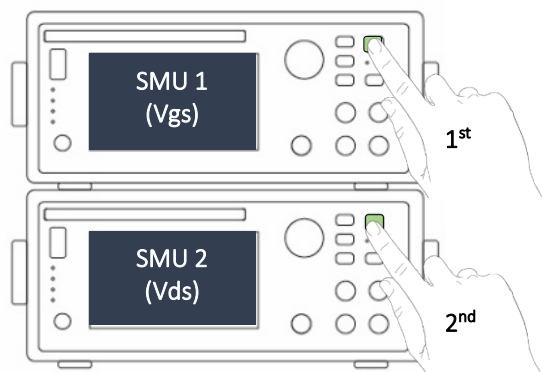

Figure 7- Running the FET test setup.

To perform the test, enable SMU 1 (Vgs), wait for the first measurement to be made, then enable SMU 2 (Vds). The two SMUs will then perform the test and synchronise themselves together via the SMU link.

Once the test is complete, the results from each SMU can be exported via the USB flash drive or over remote to a PC to combine the results.
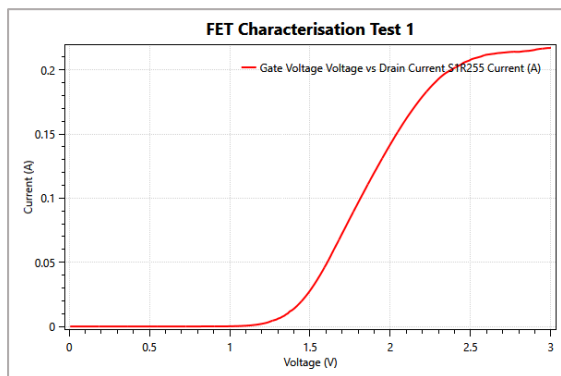

Figure 8- FET test results, exported from Aim-TTi Test Bridge SMU.

This is an example of how to characterize a FET with one I/V curve at a single constant drain to source voltage. However, the test can be repeated, and the Vds sweep voltage of SMU 2 changed to build up a series of results at different drain-to-source voltages. This can be done as individual tests or can be combined into a test sequence by importing multiple test setups into the sequence mode.
For more information on test sequence setups, see the SMU4000 Series Instruction Manual.

When performing this type of test, the first measurement of SMU 1 and the last measurement of SMU 2 may be 'unexpected' for each step or setup, causing a similar result to that shown:
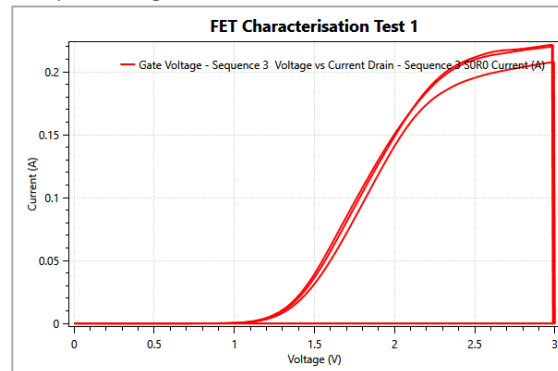
Figure 9- FET test results, exported from Aim-TTI Test Bridge SMU.

The first and last measurement results are created during the initiation of the handshaking process.
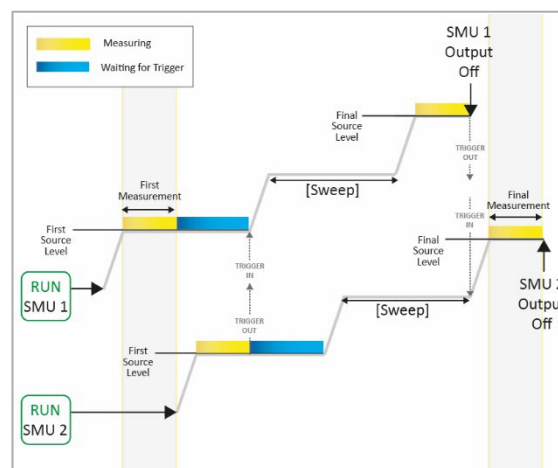
Figure 10- Handshaking process using two AIm-TTi SMUs and a Link Adaptor.

Some solutions can alleviate the impact of this:

Add an additional point to the setup of SMU 1, allowing SMU 2 to take the final measurement before the SMU 1 sweep finishes.

Increase the total number of points to allow for these results- if 100 measurements are required, select 101 points. The measurement results can be exported, and the unwanted measurements removed as needed.

Set Measurement control to 'Constant Level'; the final measured level will be recorded with the output of SMU 1 still running. The output of SMU 1 will need to be disabled manually.

Using Test Bridge SMU

The entire process of Characterizing a FET using two SMUs can be made far simpler and quicker via the free 'Test Bridge SMU' PC software. This package is available as a free download from: www.aimtti.com/support

This software allows complete control of both instruments and provides powerful but intuitive graphing features for plotting IV curves with measurement data supplied by both SMUs.

Test Bridge SMU setup features

Figure 11- Aim-TTi Test Bridge SMU setup.

When initialising the connection, each SMU can be given an individual name for ease of identification- for example, 'Gate Voltage' and 'Current Drain'; this name is associated with all exported results from that instrument. Allowing the results to be quickly and efficiently organised for analysis.

Once identified, the setup for each SMU can be shown together on one screen, allowing all settings to be shown at once and edited for each instrument.

From this window, setups can also be saved and loaded from one SMU to another, allowing identical setups to run simultaneously without further configuration.

Test Bridge SMU sequence features

Test Bridge also allows sequences to be created from one place instead of the multiple screens on the front panel by simply changing the mode to sequence using the 'Mode' drop-down box.

Figure 12- Aim-TTi Test Bridge SMU sequence setup.

Once a step has been added, setups can be loaded into a sequence or created directly like the setup using expanders below the step.
This allows the same setup to be repeated at different drain-to-source voltages.

Up to 25 steps can be added to a sequence. In addition, each sequence step can be named and reordered as needed.

Once the test is complete, a results window will appear with the options to save/analyse the data.

Analysing Results with Test Bridge

Test Bridge provides powerful features to simplify the extraction and analysis of results from one or two SMUs.

After running a test, Test Bridge will extract the results from the SMUs and load them into the 'Results' tab (if 'analyse data' is checked in the pop-up window).

Figure 13- Aim-TTi Test Bridge SMU results analysis.

This data can be selected in the 'Graph' tab for further analysis or compared in a table format.

When characterising a FET, Test Bridge can plot the gate voltage results from SMU 1 against the drain current results of SMU 2 as an IV curve on the graph, using the 'Two Datasets' feature.
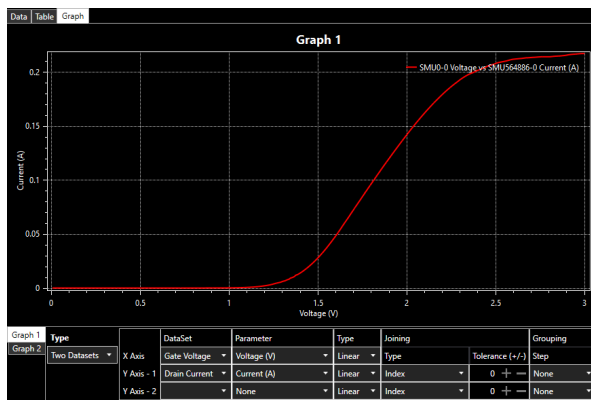

Figure 14- Aim-TTi Test Bridge SMU I/V graph using two datasets.

The selected data combined in the graph can be directly exported to a .csv file to further analyse in an external program, creating a concise new set of results from the two tests.

Image files can also be saved directly from the graph, as shown in Figures 8 & 9.

If the results are part of a sequence, Test bridge provides a feature called 'Grouping'. Grouping is designed to be used with measurement data collected from the SMU when in Sequence Mode. The recorded measurement data must have steps and/or repeats for grouping to work.
Each step within the dataset can be shown as a new series on the X-Axis.

Grouping also allows a dataset to be split when a step repeats or changes. For example, figure 15 shows each step and repeat within the dataset as a new series on the X-Axis.
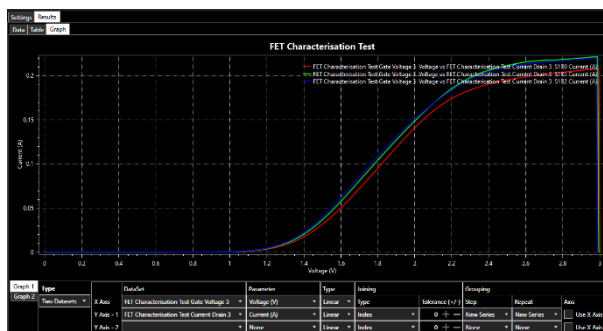

Figure 15- Aim-TTi Test Bridge SMU I/V graph using two sequenced datasets.

Advanced zooming and panning functions, alongside many other features, are also available to analyse the results further. For more information, see the 'Test Bridge SMU Instruction Manual'.

All documentation referenced in this document and further information are available on the Aim-TTi website:
www.aimtti.com/support