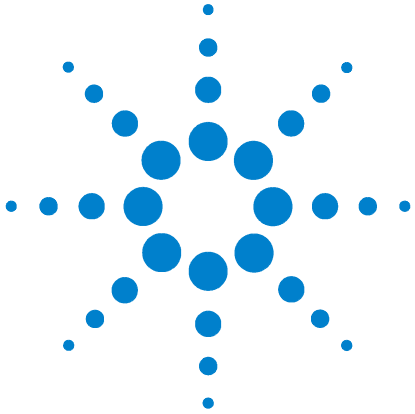

Agilent B1500A Semiconductor Device Analyzer

Self-paced Training Manual

Agilent Technologies

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In This Manual

This document is the self-paced training manual to help you to understand what is Agilent B1500A, what functions the B1500A has, how to use the B1500A, and what applications the B1500A contributes to.

- Module 1. Introduction

  This module explains the product concept and the key features of the B1500A/ EasyEXPERT. You will learn about what is the B1500A.

- Module 2. Basic Measurement

  This module explains the basic I-V sweep measurement function and the cabling and fixturing issues. You will learn how to measure I-V curves in the course exercises.

- Module 3. Low Current Measurement

  This module explains the low current measurement technique. You will learn how to measure the low current in the course exercises.

- Module 4. Capacitance Measurement

  This module explains the capacitance measurement function. You will learn how to measure the capacitance in a course exercise.

- Module 5. SPGU Control and Applications

  This module explains the SPGU Control classic test. You will learn how to create the classic test setup and the applications using SPGU in the course exercises.

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Class Exercises

Class exercises use the test setup listed below. The test setup data are only examples and included in the Demo.xpg file stored in *Agilent B1500 Series Manual CD*.

Module	Exercise	Device	Test setup/definition/data	Page
Module 1	no exercise			
Module 2	Id-Vd measurement	MOSFET	IDVD, Id-Vd	2-7
	Id-Vd measurement	MOSFET	Trace IdVd	2-10
	Id-Vd measurement	MOSFET	Trace IdVd	2-16
	SMU series connection	511 kohm	IRVR	2-28
	SMU parallel connection	1 ohm	Parallel	2-32
	SMU series resistor	511 kohm	IV-res	2-37
	Re measurement, kelvin connection	Bipolar Tr	REKELV	2-50
Module 3	Leak current measurement	-	Zero-check	3-9
	Ultra low current measurement	-	Zero-check-ASU	3-19
	Id-Vg measurement	MOSFET	IDVG	3-20
	Gummel plot	Bipolar Tr	GUMMEL	3-25
Module 4	C-V sweep measurement	MOSFET	CV-1MHz	4-6
Module 5	Charge pumping	MOSFET	Charge Pumping 4T 0.1V step	5-20
	Flash memory	MOSFET	Demo-S-NorFlash Endurance	5-29
	ALWG output	511 kohm	ALWG monitor	5-36

NOTE

Demo.xpg file

Demo.xpg file is required to create the Demo preset group which contains the test setup data used by the class exercises. And it is stored in the \data folder on *Agilent B1500 Series Manual CD*.

The Demo preset group should be created before starting the class exercise. To create the preset group, launch EasyEXPERT and import the file by using the Preset Group Import dialog box opened by clicking My Favorite Setup > Preset Group > Import Preset Group. The test setup data are only examples for the class exercises.

NOTE

.xtd files

The \data folder stores some .xtd files. They are the application test definitions used by some class exercises. To use the definition file, import the file by using the Test Definition Import dialog box opened by clicking Library > Import Test Definition. The test definition data are only examples for the class exercises.

NOTE

.xtr files

The \data folder also stores some .xtr files. They are the sample test results created by executing the test setup which has the same name as the result data. To display these sample test results, import the files by using the Test Result Import dialog box opened by clicking Results > Transport Data > Import.

NOTE

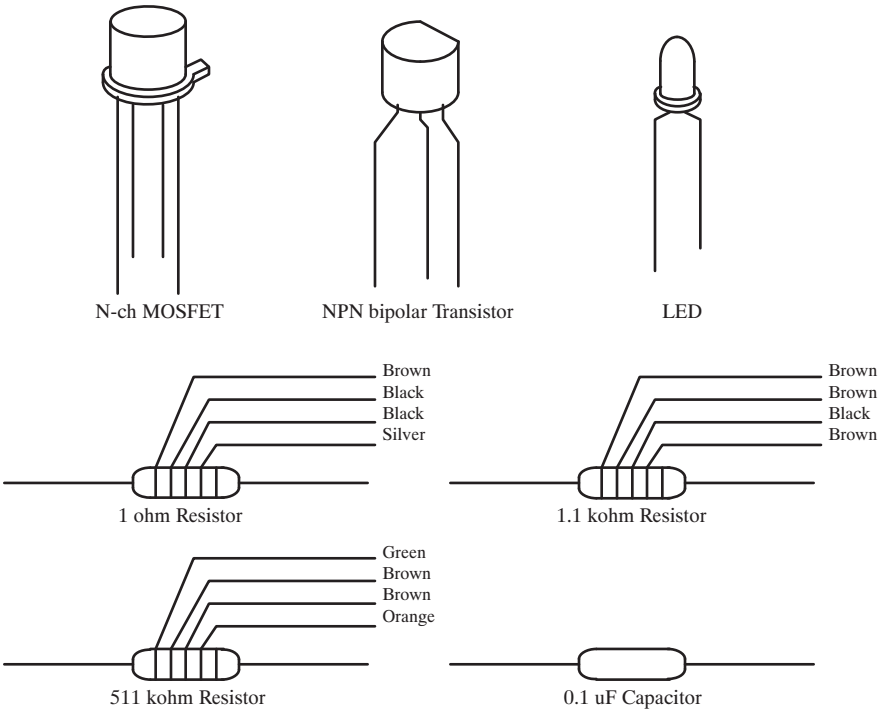
About sample data

The test setup data described in this manual are only examples. If these example data damage your devices, Agilent is *NOT LIABLE* for the damage.

Required Devices for Class Exercises

To perform the class exercises, you need the device set (Agilent part number 04156-87001) which contains the following devices.

Description	Quantity
N-channel MOSFET	2 ea.
NPN Bipolar Transistor	1 ea.
Red Miniature LED	1 ea.
0.1 µF Capacitor 50 V	1 ea.
1.0 Ω Resistor 1/8 W	1 ea.
1.1 kΩ Resistor 1/8 W	1 ea.
511 kΩ Resistor 1/8 W	1 ea.

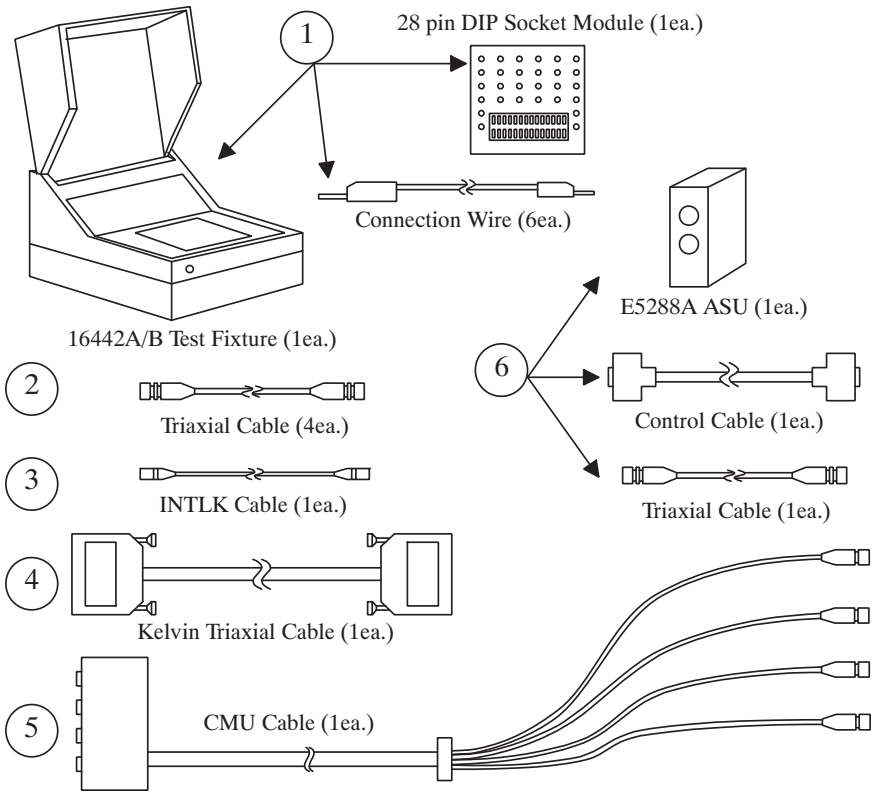


Required Accessories for Class Exercises

To perform the class exercises, you need the following accessories. Prepare the accessories shown below.

Designation	Description	Model No.	Qty.
1	Test Fixture	16442A/B [a]	1 ea.
	28 pin socket module		1 ea.
	Connection wire		6 ea.
2	Triaxial Cable	16494A	4 ea.
3	Interlock Cable	16493J	1 ea.
4	Kelvin Triaxial Cable, for Module 2	16493K	1 ea.
5	CMU Cable, for Module 4	N1300A	1 ea.
6	Atto Sense/Switch Unit, for Module 3	E5288A	1 ea.
	ASU control cable, triax cable, for Module 3	16493M	1 ea.

a. The 16058A Test Fixture for the 4145A/B may be substituted for the 16442A/B Test Fixture. If you use the 16058A, you also need the 16435A Interlock Adapter.



To perform the flash memory class exercise in Module 5 and if you use the ASU, you need the following accessories.

Description	Model No.	Qty.
ASU (Atto Sense/Switch Unit) with control cable	E5288A	Total 3sets
Triaxial Cable	16494A or equivalent	Total 7ea.
BNC-SMA Cable	16493P	3 ea.
SMA-SMA Cable, for synchronization of SPGU	16493Q	2 ea.

To perform the flash memory class exercise in Module 5 and if you use the selector, you need the following accessories.

Description	Model No.	Qty.
SMU/PG selector with control cable [a]	16440A	2 sets
Selector adapter with control cable	16445A	1 set
Triaxial Cable	16494A or equivalent	Total 7ea.
BNC-SMA Cable	16493P	3 ea.
SMA-SMA Cable, for synchronization of SPGU	16493Q	2 ea.

a. One selector can be replaced with one ASU.

Module 1. Introduction

- **New Features**
- **EasyEXPERT**
- **To Perform Easy Application Test**
- **User Interface**
- **Modular Mainframe**
- **SCUU/GSWU**
- **ASU**
- **SMU/Pulse Generator Selector**
- **B2200/E5250 Switch Control**
- **Desktop EasyEXPERT**

Module 2. Basic Measurement

- **SMU Fundamentals**
- **Tracer Test Environment**
- **Classic Test Environment**
- **SMUs Connected in Series or Parallel**
- **SMU Series Resistor**
- **Cabling and Fixture Issues**
- **Kelvin and Driven Guard**
- **Probes and Prober Connections**
- **Triax and Coax Adapters**
- **Safety Interlock Issues**

Module 3. Low Current Measurement

- **Low-Current Measurement Challenges**
- **Calibration and Zero Cancel**
- **Effect of Cable Movement**
- **ASU for Ultra Low-Current Measurement**
- **Low-Current Subthreshold**
- **Trade-Off Speed Vs Accuracy**
- **Low-Current Gummel Plot**
- **Low-Current Gate Oxide Leakage**

Module 4. Capacitance Measurement

- **CMU Fundamentals**
- **Classic Test Environment**
- **CMU Calibration**
- **SCUU for IV/CV Switching**
- **GSWU for Accurate Capacitance Measurement**
- **ASU for IV/CV Switching**

Module 5. SPGU Control and Applications

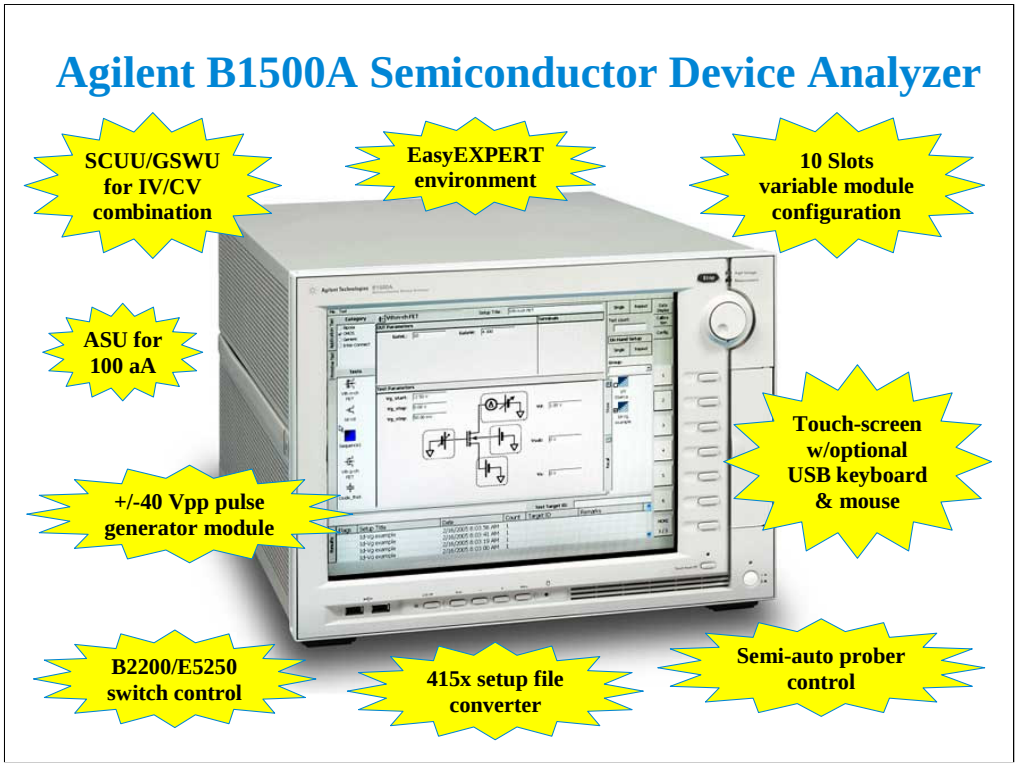
- **High Voltage SPGU**
- **SPGU Control**
- **Pulse Generator Mode**
- **Charge Pumping**
- **Flash Memory Test**
- **ALWG Mode**

1 Introduction

In This Module

- **Key Features**
- **EasyEXPERT**
- **User Interface**
- **Modular Mainframe**
- **Accessories**
- **B2200/E5250 Switch Control**
- **Desktop EasyEXPERT**

Note:

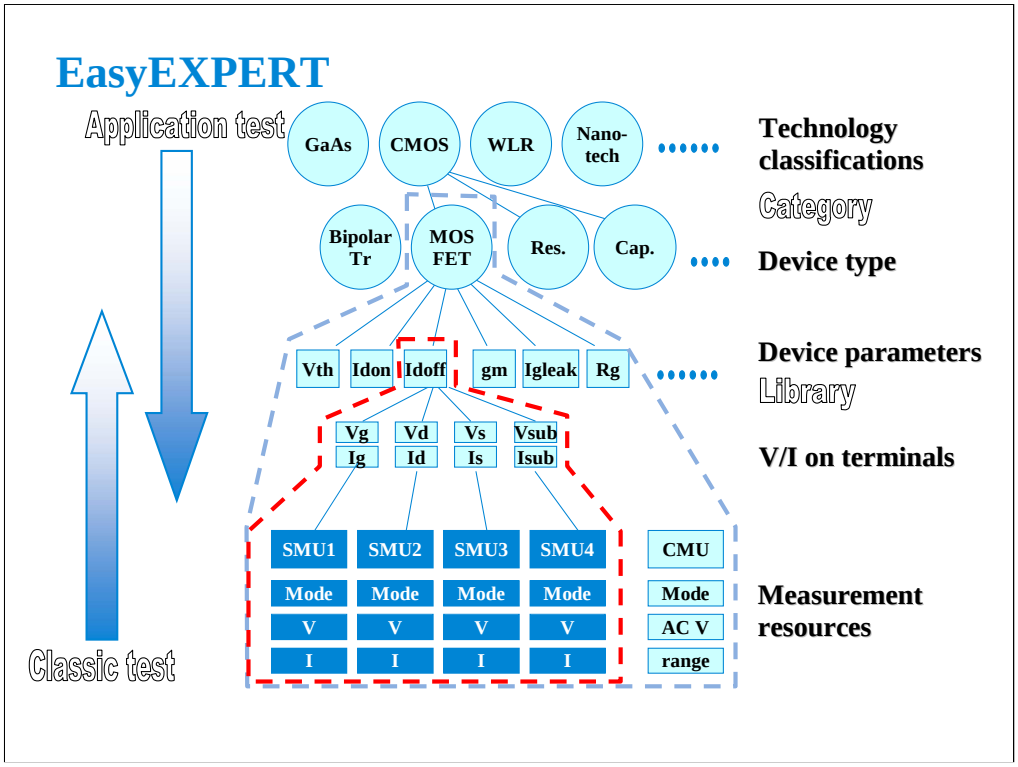

Agilent B1500A Semiconductor Device Analyzer
SCUU/GSWU for IV/CV combination
EasyEXPERT environment
10 Slots variable module configuration
ASU for 100 aA
Touch-screen w/optional USB keyboard & mouse
+/-40 Vpp pulse generator module
B2200/E5250 switch control
415x setup file converter
Semi-auto prober control

Note:

Key Features

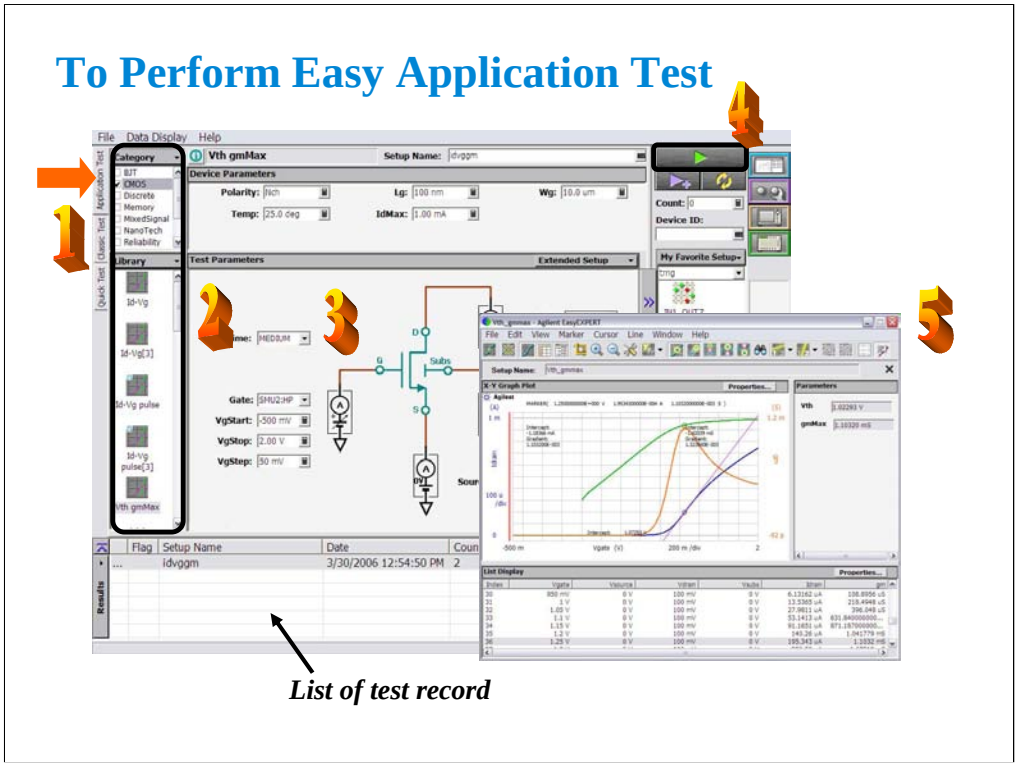
- **EasyEXPERT software**
  - **Application test environment (> 200 algorithms)**
  - **Tracer test environment – new concept curve tracer**
  - **Classic test environment – 415x like setup**
  - **Quick test environment – multiple test execution**
  - **Semi-auto prober control**
- **Modular mainframe**
  - **HPSMU, HRSMU, MPSMU for I/V sweep, multi channel I/V sweep, I/V list sweep, I/V-t sampling**
  - **MFCMU for C-V sweep, C-f sweep**
  - **SPGU for +/-40 Vpp pulse output or arbitrary linear waveform output**
- **SMU CMU Unify Unit (SCUU)/Guard Switch Unit (GSWU)**
  - **switching effortlessly between IV and CV measurement**
- **Atto Sense/Switch Unit (ASU)**
  - **100 aA level low current measurement**
- **Touch-screen, knob, and softkeys**
  - **optional USB keyboard, mouse, and stylus pen**

EasyEXPERT software
•Task-oriented, “top-down” approach to device characterization
•Curve tracer like operation
•415x like operation
•Multiple test execution
•Automatic measurement, auto-analysis functions
•Test sequencing without programming
Versatile Modular Mainframe
•Flexible & expandable (10 slots)
•Multiple SMU types
•Atto-sense and Switch Unit (ASU)
•Multi frequency CMU
•SMU CMU Unify Unit for IV/CV probing
•High voltage SPGU, 2-channel Pulse Generator or Arbitrary Linear Waveform Generator (ALWG)
•SMU/Pulse Generator Selector
•4.2 Amp Ground Unit
Convenient User Interface
•Touch screen operation (with optional stylus pen)
•Contextual softkeys & knob control
•Optional USB keyboard & mouse
Desktop EasyEXPERT software
•Controlling B1500A, B1505A, 4155B/C, or 4156B/C by an external computer
•Offline test development and data analysis
415x Setup File Converter
•Creating the EasyEXPERT test setup file by using the 4155/4156 MES/DAT file



Instead of setting up the instrument hardware, the EasyEXPERT software focuses on the real task at hand for the engineer ---device characterization. All that you need to do is to connect the instrument to the device terminals as shown in the EasyEXPERT test parameters area.

The EasyEXPERT software also provides the classic test mode that allows the 4155/4156 like measurement setup operation and the tracer test mode that suggests the new concept curve tracer operation.



Step 1: Click Application Test tab.

Step 2: Select one or more technology categories, and select a desired test from the list of tests associated with the selected technology categories.

Step 3: Change the setup parameters (Device parameters and Test parameters) if you want.

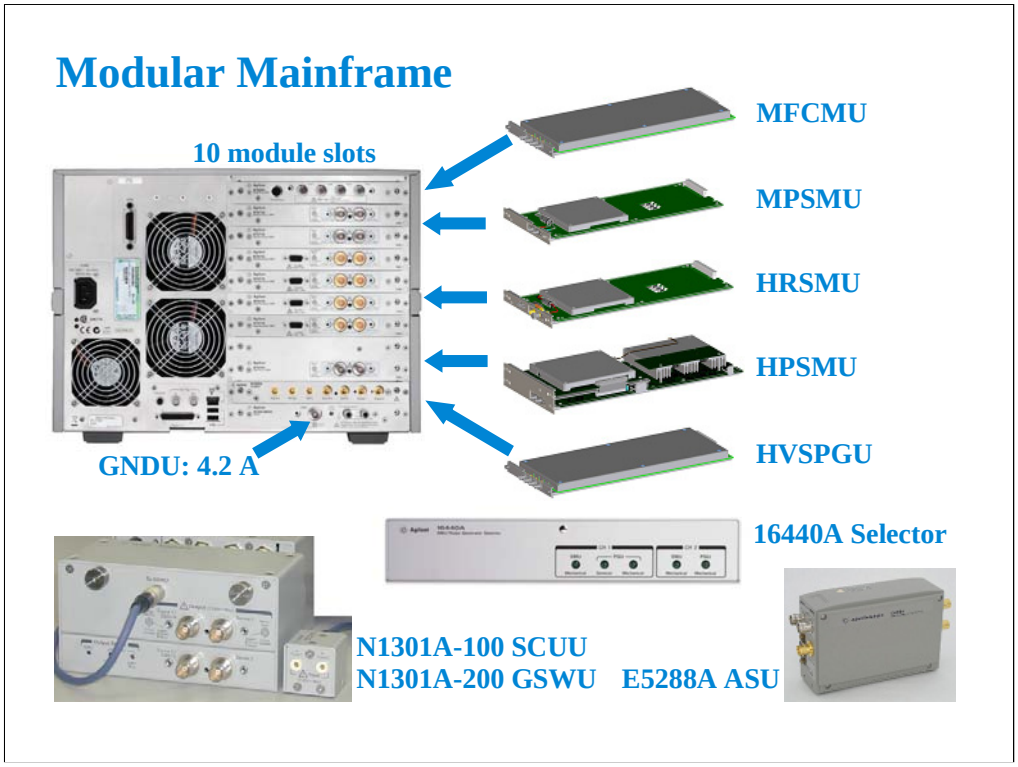
Step 4: Connect DUT, and click the Start button. The B1500A starts the selected test.

Step 5: Analyze the measurement result data displayed on the Data Display window automatically opened after the test.

The measurement result record is automatically stored in the internal hard disk drive when the Auto Recode mode is ON.

User Interface

- **Touch panel**
  - **Stylus pen (option)**
- **Rotary knob**
- **Softkeys**
- **USB keyboard (option)**
- **USB mouse (option)**



The following modules and accessories are available for the B1500A:

•MFCMU: 1 kHz to 5 MHz CV capability (1 slot)

•MPSMU: 100 mA/100 V force capability, 10 fA/0.5 uV measurement resolution (1 slot)

•HRSMU: 100 mA/100 V force capability, 1 fA/0.5 uV measurement resolution (1 slot)

•HPSMU: 1 A/200 V force capability, 10 fA/2 uV measurement resolution (2 slots)

•HVSPGU: 40 V pulse output or arbitrary linear waveform generation (1 slot), up to 5 modules

•Built-in GNDU: 0 V force, maximum 4.2 A sensing

•N1301A-100/102: SMU CMU unify unit (SCUU) & cable assembly

•N1301A-200/201/202: Guard switch unit (GSWU) & cable assembly

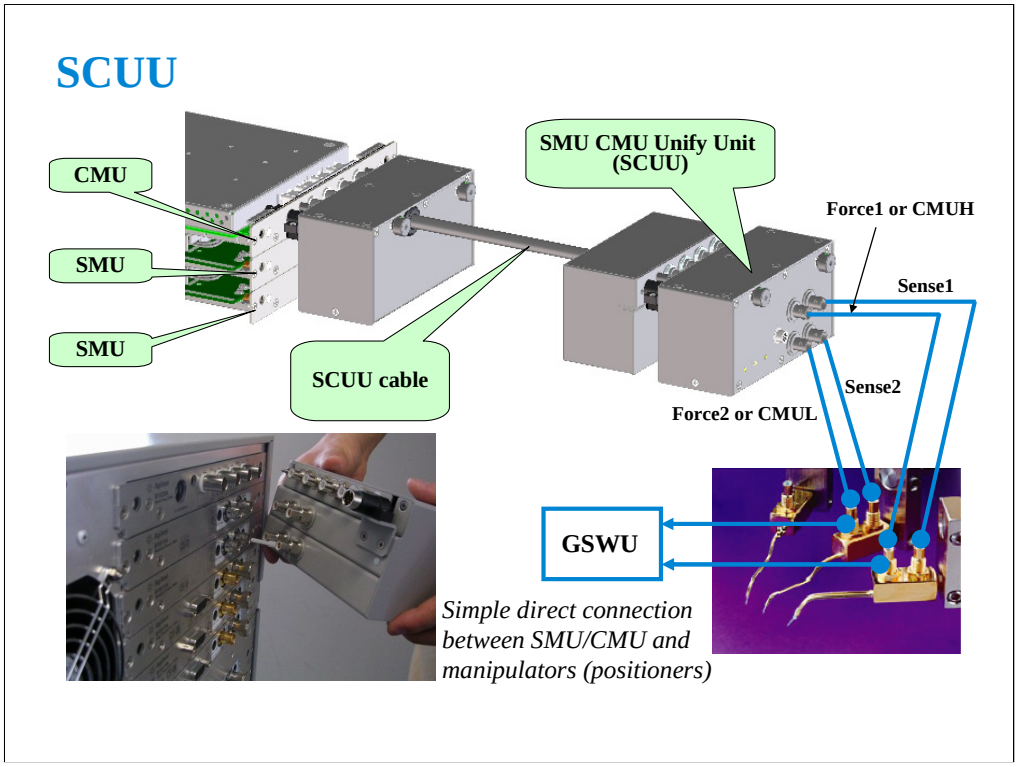
•E5288A ASU: 0.1 fA/0.5 uV measurement resolution with support for IV/CV switching

•16440A Selector for SMU/SPGU switching (2 ports), up to 2 sets

The ASU (Atto sense/switch unit) can be used with the HRSMU calibrated with it.

The SCUU can be used with the CMU (slot N), SMU (slot N-1), and SMU (slot N-2).

The GSWU can be used with the SCUU.



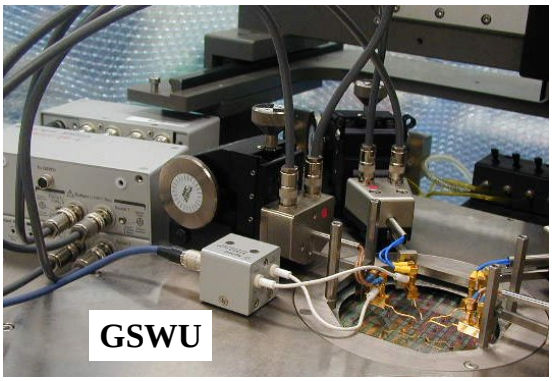
You have a very hard time switching between CV and IV measurements (you may actually devote separate probe stations to CV and IV just to avoid having to change cables). In addition, great care has to be taken when cabling to a capacitance meter to insure that all of the capacitance measurements are properly compensated. The SCUU removes all of these worries and makes connection simple and easy. In addition, the B1500A software automatically takes care of the multiplexing based upon the type of algorithm selected from the front panel.

To install the SCUU near the manipulators/positioners, use the N1301A-102 SCUU cable.

To realize accurate capacitance measurement, use the N1301A-200/201/202 GSWU & cable.

GSWU

SCUU



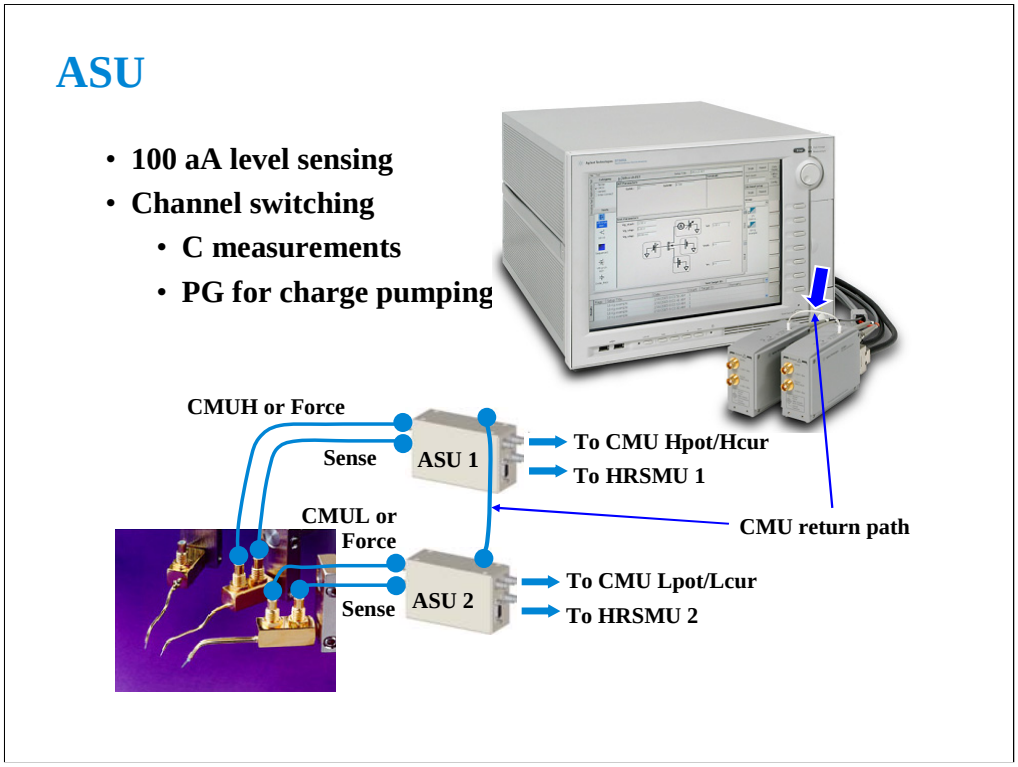
The GSWU must be connected to the outer conductors of the manipulators/positioners connected to the Force1/CMUH and Force2/CMUL connectors of the SCUU. And the GSWU control cable must be connected between the GSWU and the SCUU.

When the SMU paths are available for the manipulators/positioners, the GSWU opens between the outer conductors. However, when the MFCMU paths are available, the GSWU shorts them together to make the return path of measurement current. This will reduce the signal path impedance. And this is effective for the accurate capacitance measurement.

By using the EasyEXPERT software, cable length between the CMU and the SCUU is automatically detected, and the GSWU switch control is automatically performed. Also, capacitance error compensation is also automatically performed if the compensation data are available.

The GSWU is effective for
•reducing the residual inductance of the measurement cable
•stabilizing the residual inductance when measurement cable distance is changed (moved)
It's roughly 1/10 to 1/30 when used with two 80 cm cable.

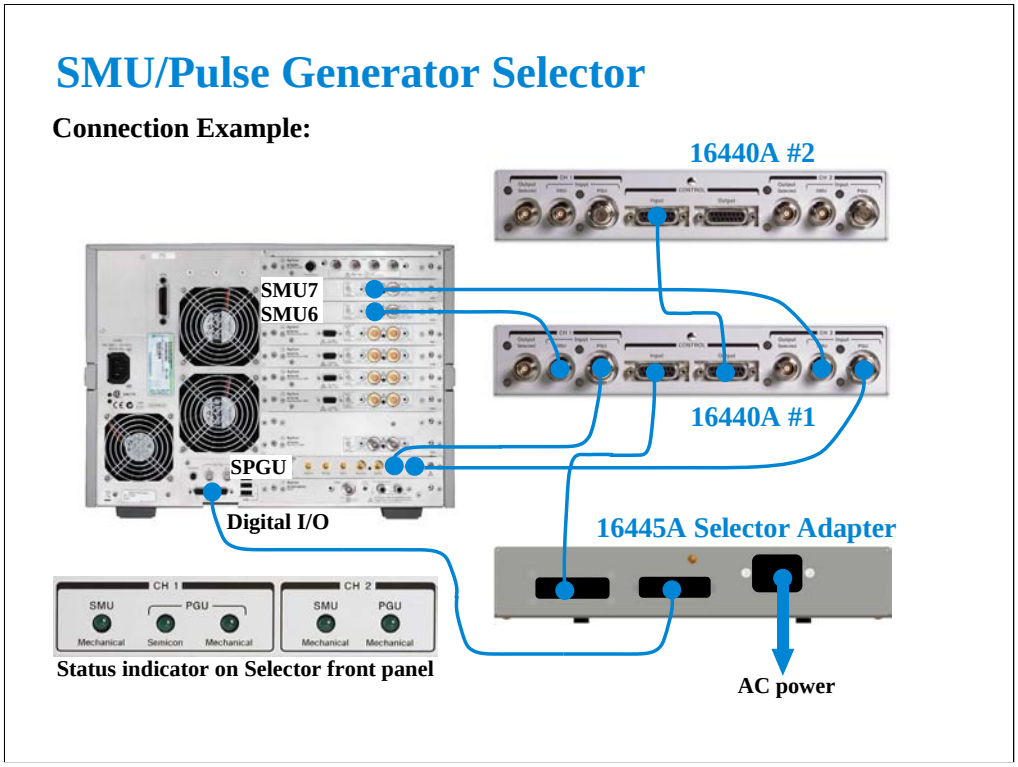
Note:
When the SMU paths are available for the manipulators/positioners, the connection between the outer conductors must be broken because they are connected to the SMU guard terminals separately and the guard terminals must be opened at the end of the extension.



The high-resolution SMU (HRSMU) has an innate 1 fA & 0.5 uV measurement resolution. The optional ASU extends the HRSMU measurement resolution to 0.1 fA.

The ASU has another feature, built-in switching capability. It can switch between the SMU and an auxiliary input (AUX input, two BNC).

If the CMU is connected to the AUX inputs, the ASU can switch between the low current and CV measurements. Then connect a wire between the CMU return terminals of ASUs to make the return path of measurement current. This is effective for accurate capacitance measurement. However, you need to perform capacitance compensation by yourself.



The SMU/Pulse Generator Selector provides the built-in switching capability to select a measurement path to the Output port. The Input ports should be connected to the measurement resources, a SMU and a SPGU channel. And the Output port should be connected to the DUT interface.

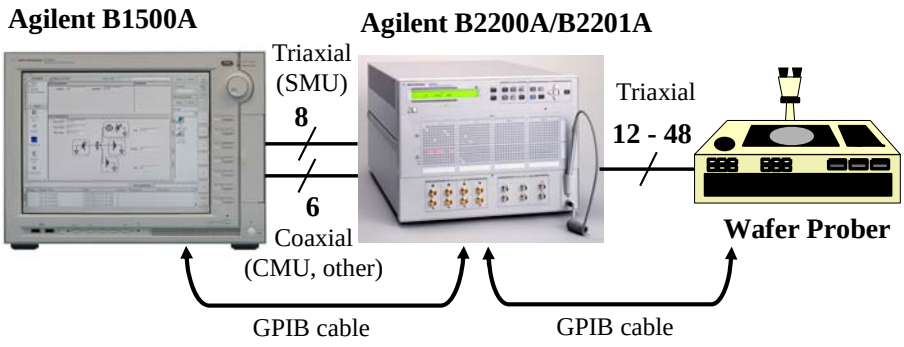
There are two Output ports on one selector. In this example, SMU6 and PG1 are connected to the CH1 Input ports of the selector #1, and SMU7 and PG2 are connected to the CH2 Input ports. For the SMU connection, connect the Force terminal only. The Sense terminal must be opened.

Two 16440As can be used. Connect the dedicated control cable between the CONTROL Output connector of the first selector and the CONTROL Input connector of the second selector.

Switching can be controlled by the B1500A/EasyEXPERT via the 16445A selector adapter. And the switching status is known by the status indicator. When the SMU indicator lights up, the SMU Input to Output path is made. And when the PGU indicator lights up, the PGU Input to Output path is made. If the PGU Semicon indicator goes off, the PGU path is opened by the semiconductor relay. This feature is only for the CH1.

B2200/E5250 Switch Control

- **Allows use of a probe card to facilitate probing of standardized device modules (usually 24-pin configuration)**
- **Enables easy multiplexing between the triaxial outputs of SMUs and the coaxial outputs of other (BNC-based) instruments and modules**



Agilent B2200A/B2201A/E5250A switching matrix can be controlled by B1500A/EasyEXPERT via GPIB. EasyEXPERT provides the Switching Matrix Operation Panel for interactive control of B2200/E5250 independent from the test execution mode of B1500. And switch setup can be saved to a classic test setup data. In the classic test, the switch setup is sent to B2200/E5250 when a measurement start button is clicked.

B1500A/EasyEXPERT also provides the semi-auto prober control script. The semi-auto prober can be controlled without programming. The prober control script supports the die move operation by using the following first three procedures in the repeat measurement setup and adds the subsite move operation by using the Subsite procedure in the quick test setup.

Prober control script:

•Start procedure

•Iteration procedure

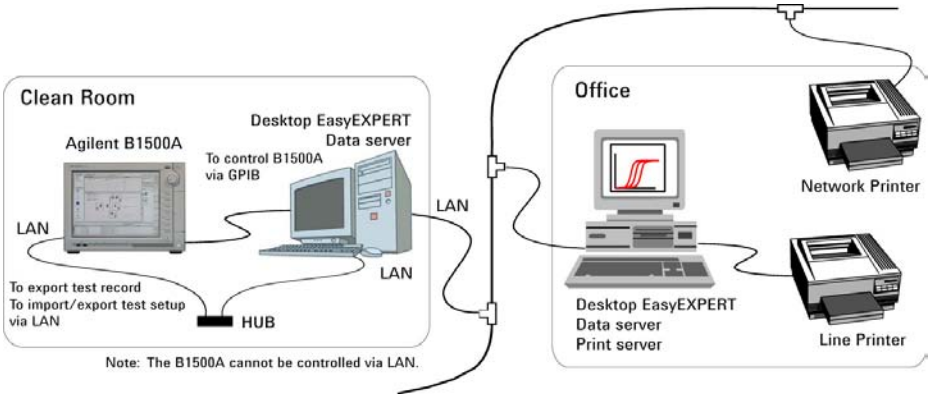
•Final procedure

•Subsite procedure

Note: EasyEXPERT supports the E5250A installed with the E5252A matrix card.

Note: Standard edition of EasyEXPERT cannot support the E5250. The E5250 control is optional and supported by the Plus edition (B1540A-002/B1541A-002).

Desktop EasyEXPERT Software



The Desktop EasyEXPERT software provides the following additional advantages to the B1500A, allowing you to minimize the amount of offline tasks performed on B1500A and increase the working ratio for measurements.

•Allows B1500A/B1505A/4155B/4155C/4156B/4156C to be controlled from an external computer via GPIB while online.

•Allows test setup to be created on an external computer while offline.

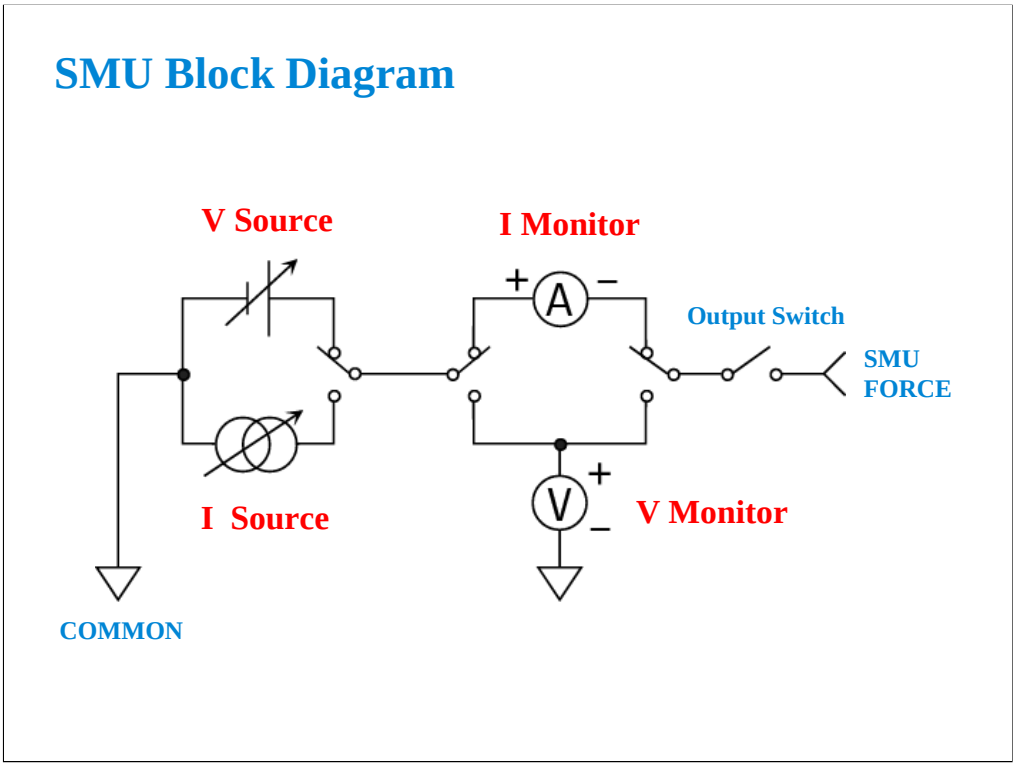
•Allows data analysis to be performed on an external computer while offline.

2 Basic Measurement

In This Module

- **SMU Fundamentals**
- **Tracer Test**
- **Classic Test Environment**
- **SMUs Connected in Series or Parallel**
- **SMU Series Resistor**
- **Cabling and Fixture Issues**
- **Kelvin and Driven Guard**
- **Probes and Prober Connections**
- **Triax and Coax Adapters**
- **Safety Interlock Issues**

Note:



The source monitor unit (SMU) can function in the following modes:

- Voltage source while monitoring current (compliance side measurement)
- Voltage source while monitoring voltage (force side measurement)
- Current source while monitoring current (force side measurement)
- Current source while monitoring voltage (compliance side measurement)

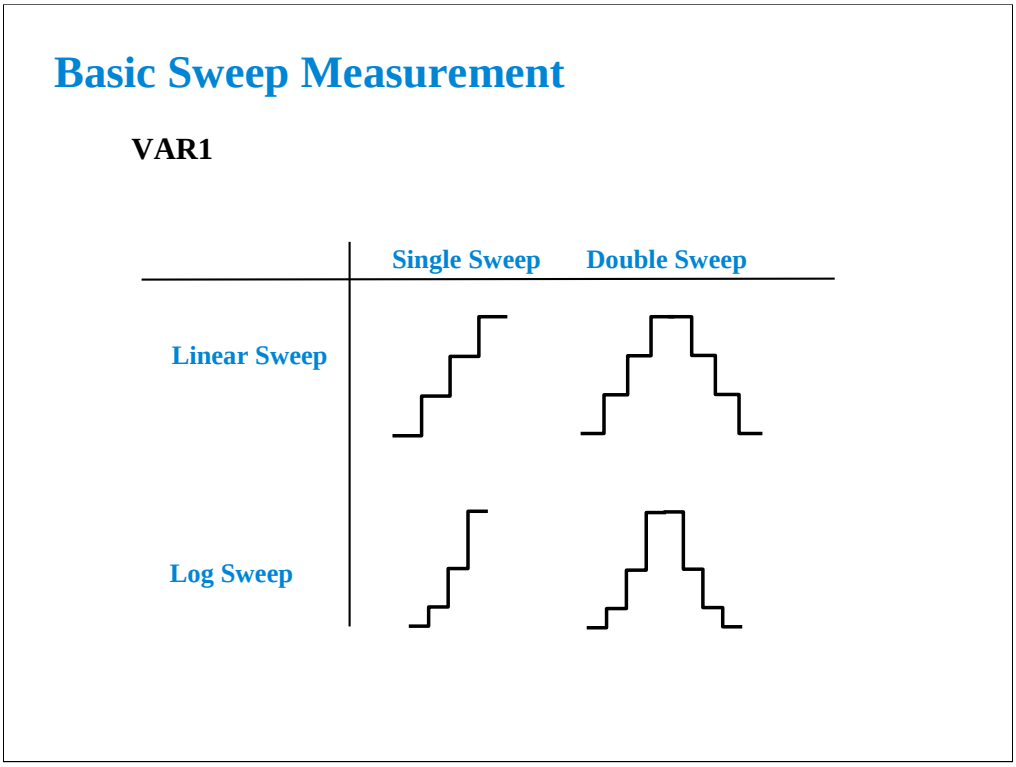
The force side measurement is available when the B1500A is in the GPIB remote mode, and is not available when EasyEXPERT is used.

The SMU can output V or I in constant, linear sweep, logarithmic sweep or pulsed modes.

Constant V or I mode could be used for “spot” measurements or biases.

Swept output is used to trace a curve. A second SMU can be swept subordinately to measure a “family of curves.”

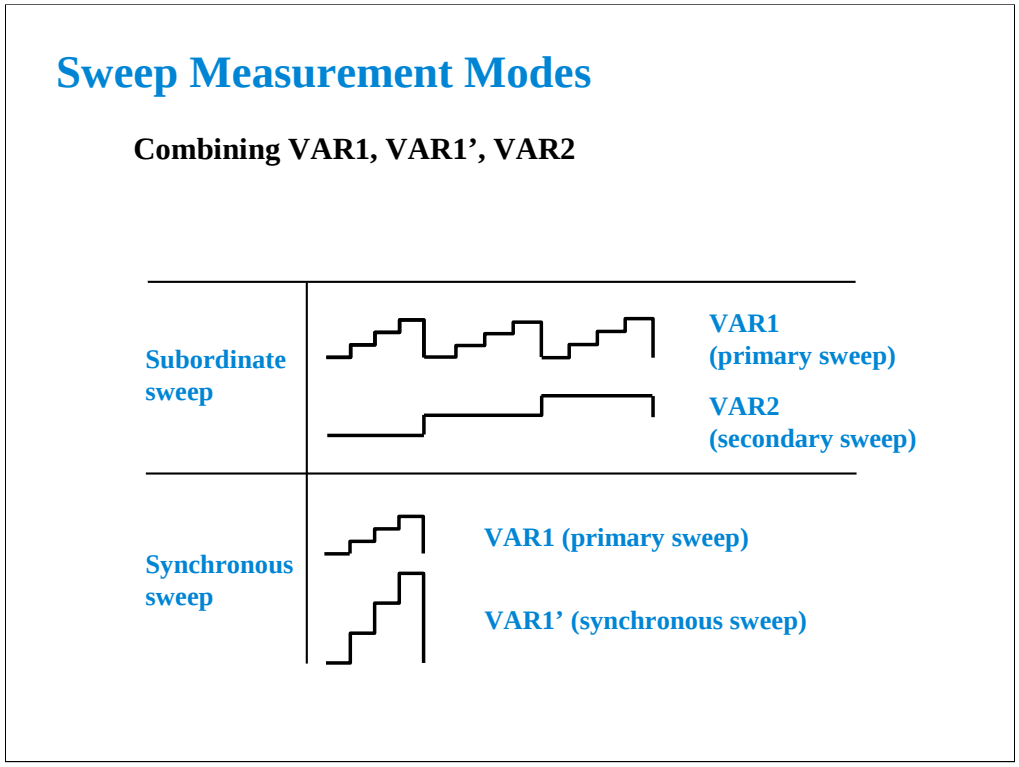
Pulsed mode is used during swept measurements to reduce the effects of thermal stress on the device under test (DUT).



The SMUs can now sweep up to a value and then back down (double sweep). This feature is useful when the device must be tested without abruptly removing the forcing condition.

Log sweeps are required any time the measurement results span many decades, such as a MOS subthreshold curve.

The variable used to set the SMU to a basic sweep is VAR1. It may be called the primary sweep.

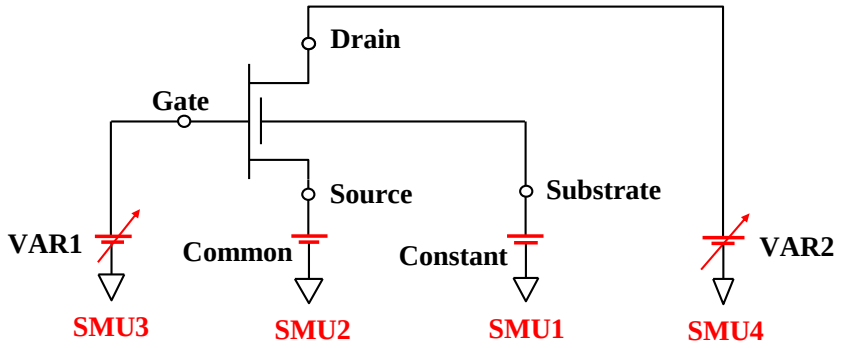


A subordinate sweep variable (VAR2) may be combined with the basic sweep variable (VAR1). This corresponds to the step knob and sweep knob of a curve tracer. This produces a family of curves. VAR2 may be called the secondary sweep.

Another useful combination is a synchronous sweep. Here VAR1 and VAR1' are in-step. VAR1' defaults to a gain of 1, which means it exactly tracks VAR1. You can also vary the initial offset between VAR1 and VAR1'. These features are useful for bipolar gummel plots, op-amp differential input tests, etc.

Why Four SMUs?

- **Four terminal MOS device**
- **Only one configuration required**
- **Speed up testing**



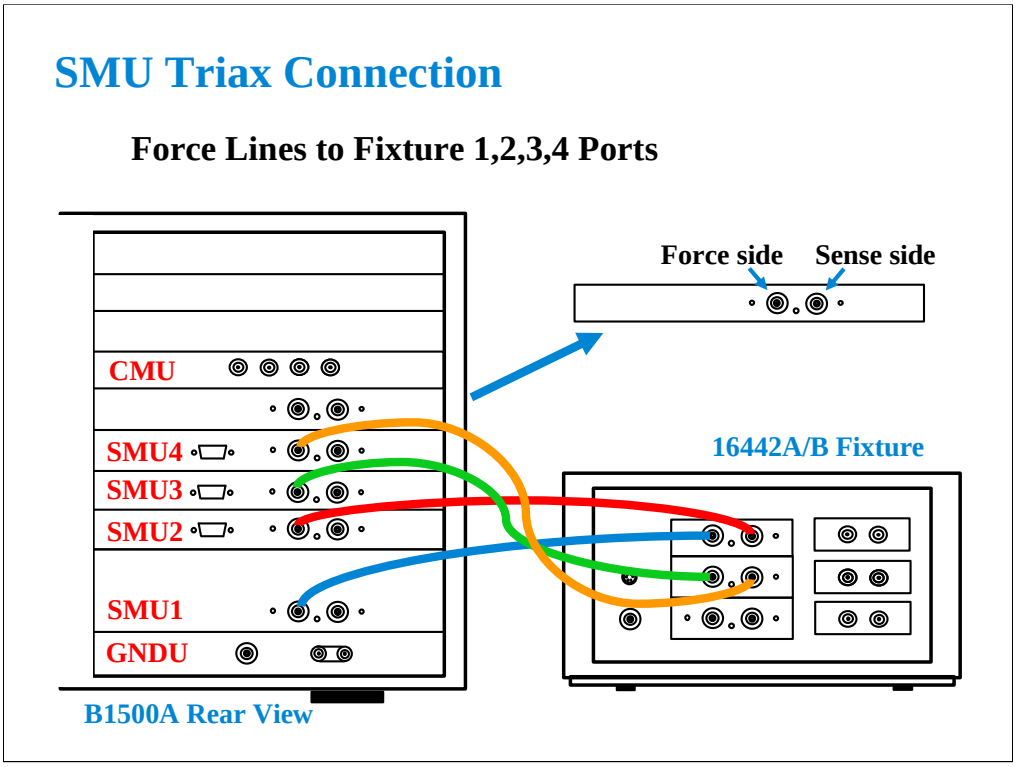
The basic semiconductor device is the 4-terminal MOS transistor. By assigning an SMU to each terminal, you have complete flexibility to make any measurement without having to change the device hookup. No relays are required to switch any connection; this is all done by changing the mode of the SMU from the front panel.

Class Exercise

MOS Id vs Vd Basic Measurement

1. **Connect the B1500A and the test fixture.**
2. **Display Tracer Test screen.**
3. **Set the measurement condition (output value, etc.)**
4. **Create your preset group, and save your setup.**
5. **Connect device (MOSFET).**
6. **Click** **button to start a single measurement, or click** **button to start a repeat measurement.**

Note:



For the non-Kelvin connections, connect only the Force lines, leaving the Sense lines open.

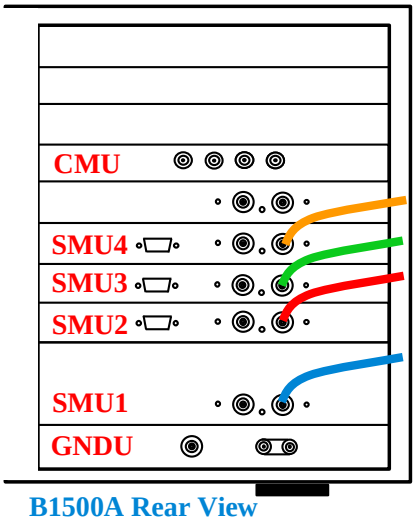
Connect corresponding numbers. On the 16442A/B fixture use the numbers labeled 1 - 6, not 1 - 3.

Your B1500A may not match the SMU configuration shown in this figure. Note that SMU1 is the module top of the GNDU (ground unit). The SMU number become large from bottom to top as shown.

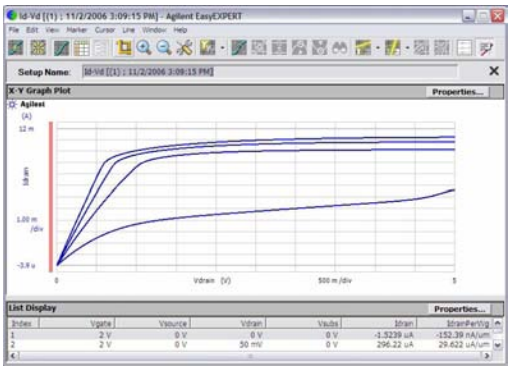
This is the SMU cable setup that will be used in the remainder of the class exercises.

Wrong Triaxial Hookup

If you use the Sense lines …



B1500A Rear View



Curves clamped at 10 mA level

This picture shows the triax cables connected to the right set of connectors which is wrong.

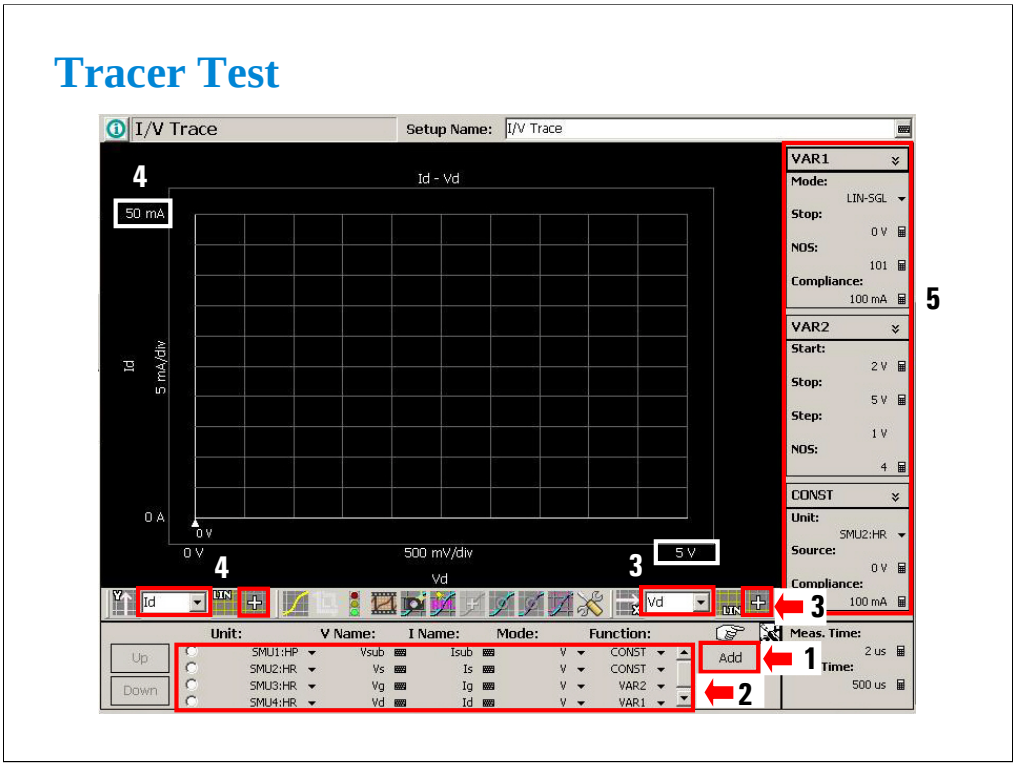
The 4 triax cables must be connected to the left set of connectors (FORCE).

You will likely see this type of erroneous response with clamping at 10 mA (no trace above 10 mA even though compliance is set much higher). Also you may see the response with notches at 10 mA level.

The effect is magnified when the SMU measurement ranging is set to AUTO.

This curve was produced using your training class MOS device and the IDVD setup.

No error was seen until the ranging was changed from FIXED 100 mA to AUTO. Then it was evident that the cables were hooked up improperly.



Tracer Test is the best way for performing I-V measurement easily and quickly.

Display the Tracer Test screen and set the measurement condition.

You can finish the setup by the following five steps.

1. Click Add button and add SMU1, SMU2, SMU3, and SMU4.
2. Set the channel definition. See below.
3. Set the X axis parameter, polarity and maximum value.
4. Set the Y axis parameter, polarity and maximum value.
5. Define the VAR1, VAR2, and CONST setup. See below.

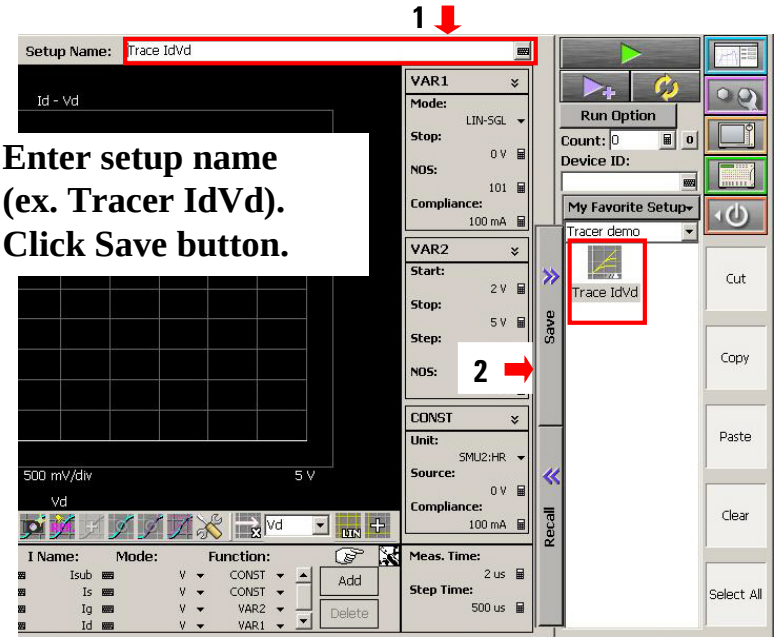
Channel definition:

SMU1: Vsub, Isub, V mode, CONST
SMU2: Vs, Is, V mode, CONST
SMU3: Vg, Ig, V mode, VAR2
SMU4: Vd, Id, V mode, VAR1

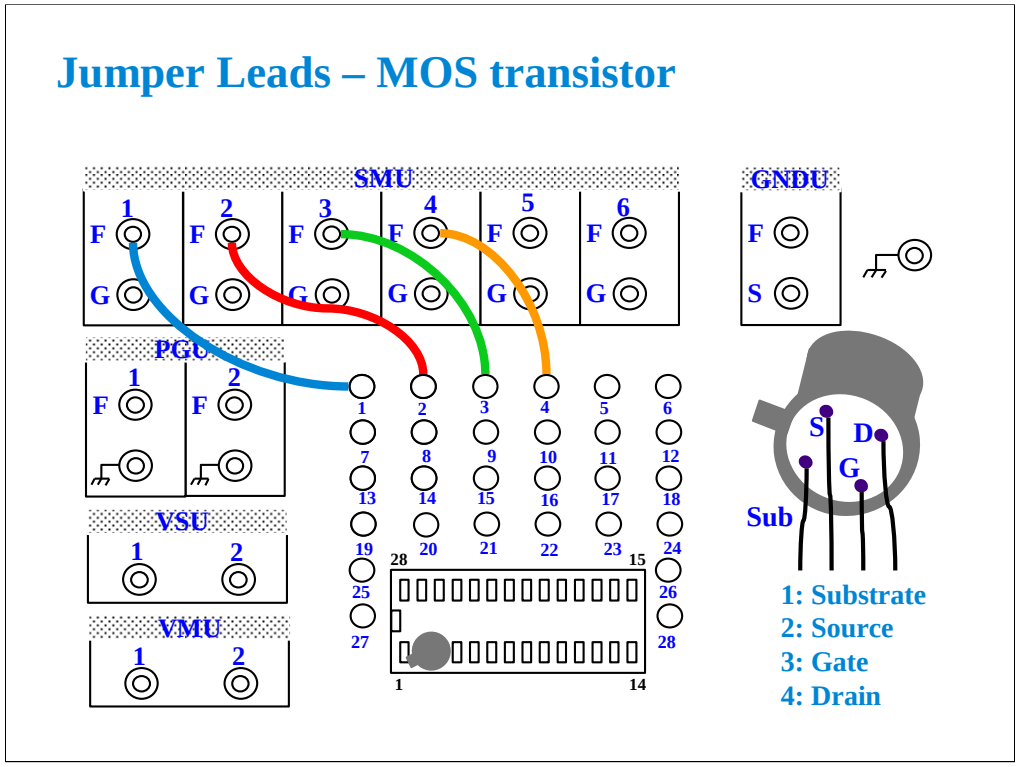
Source setup:

VAR1: Stop 0 V, Compliance 100 mA
VAR2: Start 2 V, Stop 5 V, NOS 4, Compliance 10 mA
CONST: Compliance 100 mA

To Save Setup Data



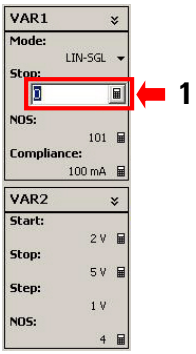
Note:



With the 16442A/B fixture, note that there are two SMU numbering schemes....3 SMUs with force and sense, or six SMUs with force only. For this class example we will use the six (6) SMU scheme. On older fixtures, this scheme is shown in light blue lettering. In newer fixtures, this scheme is shown in white reverse background lettering.

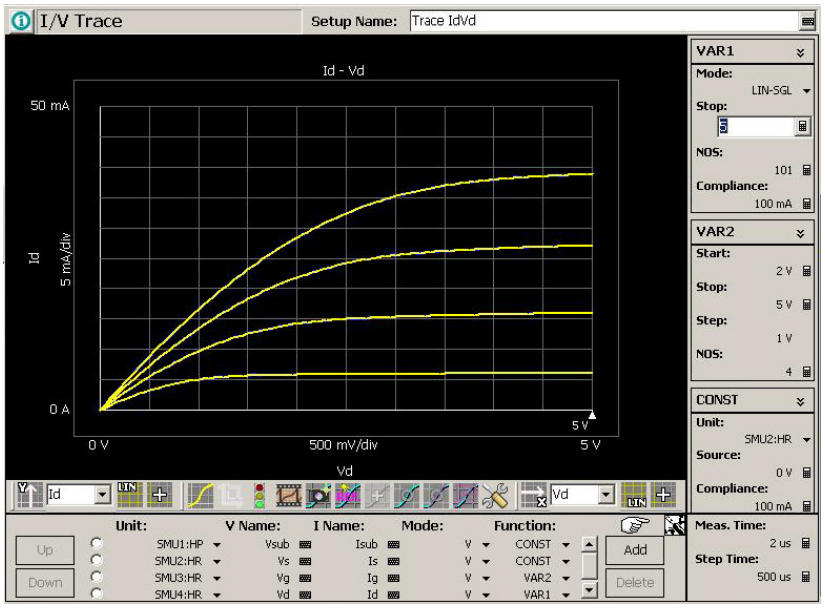
To Perform Repeat Measurement

1. **Highlight the VAR1 Stop entry field and leave it.**
2. **Click** **button to start measurement.**
3. **Rotate the rotary knob to change sweep range.**



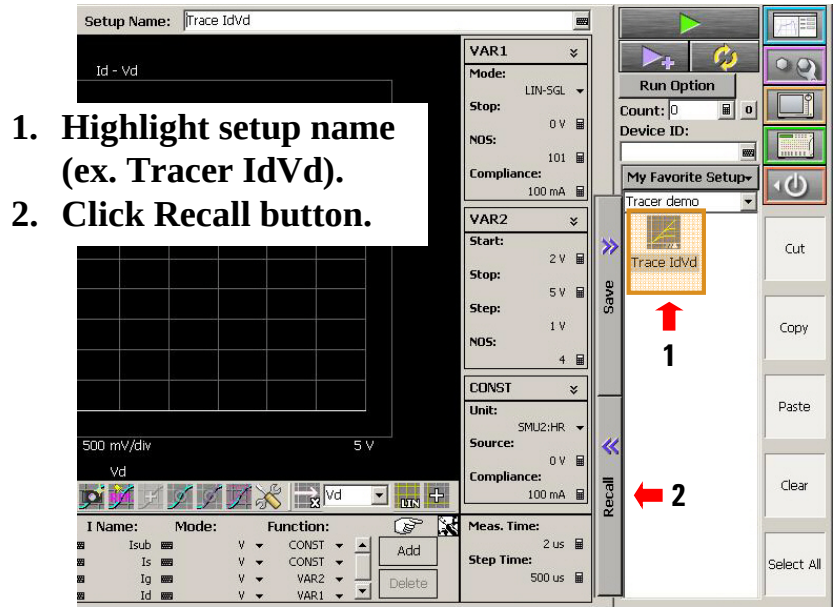
Note:

Result Example



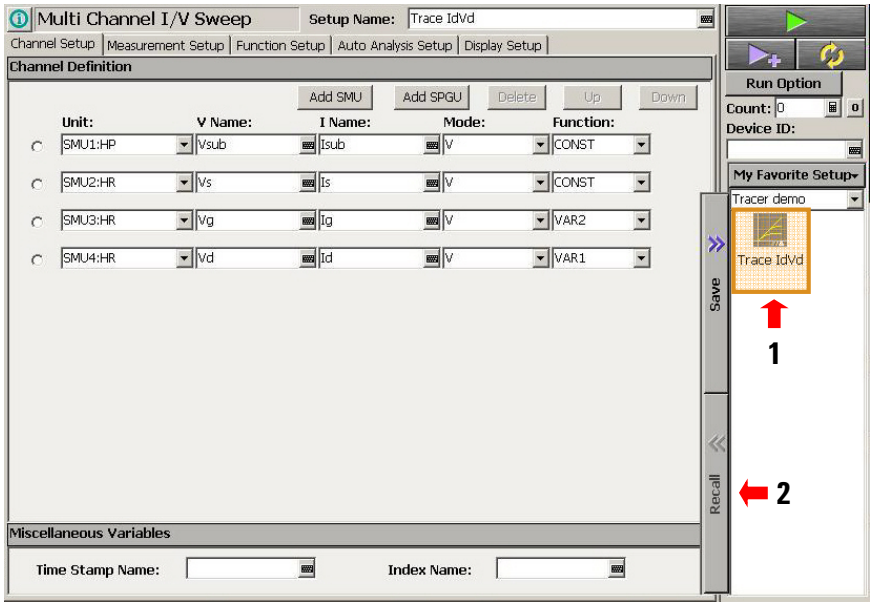
Note:

To Get Setup Data



In the Tracer Test mode, the tracer test setup will be recalled as the tracer test setup. However, the setup will be recalled as the Multi Channel I/V Sweep setup in the Classic Test mode as shown in the next page.

Classic Test – Channel Setup

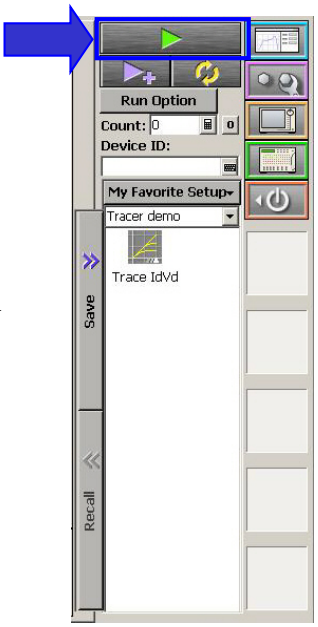


Change the test mode to Classic Test, and perform the procedure as shown.

Display the Measurement Setup, Display Setup, and so on. And check the conversion result of the setup data. Also change the setup as you desire. You can set the details of measurement conditions which are not supported by the Tracer Test mode.

For more information of Tracer Test and Classic Test, see Agilent EasyEXPERT Self-paced Training Manual.

To Start Measurement



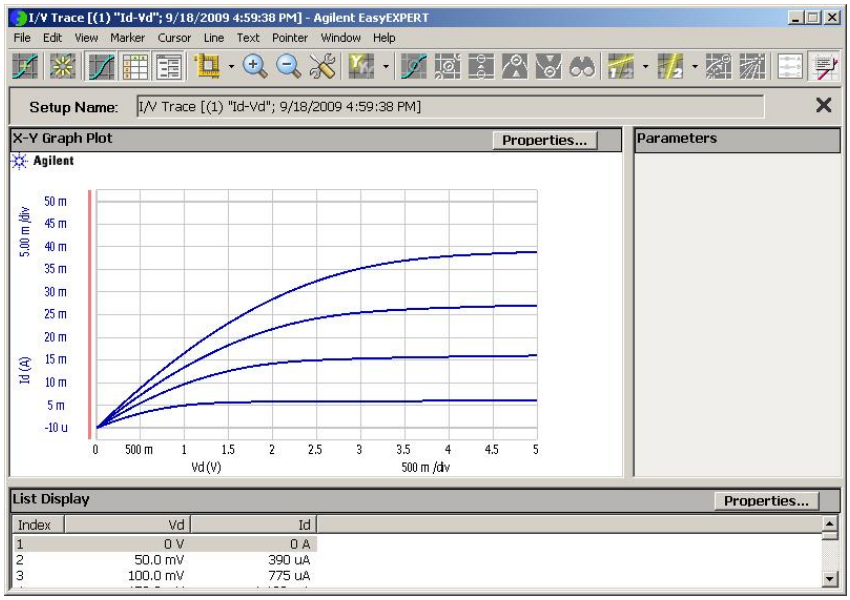
1. Click Single button

This opens the Data Display window and starts measurement.

The Data Display window shows measurement result data graph/list.

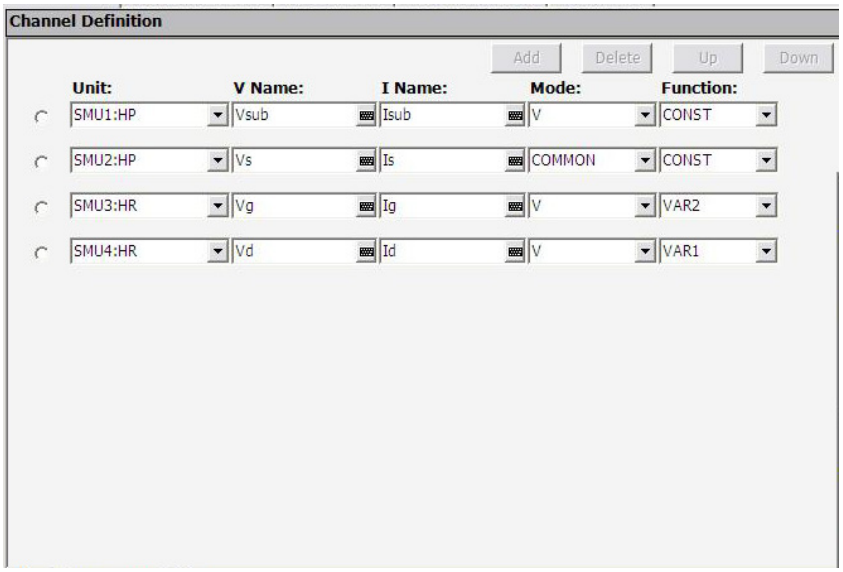
Note:

Data Display Window – Graph



Note:

Classic Test – Channel Setup



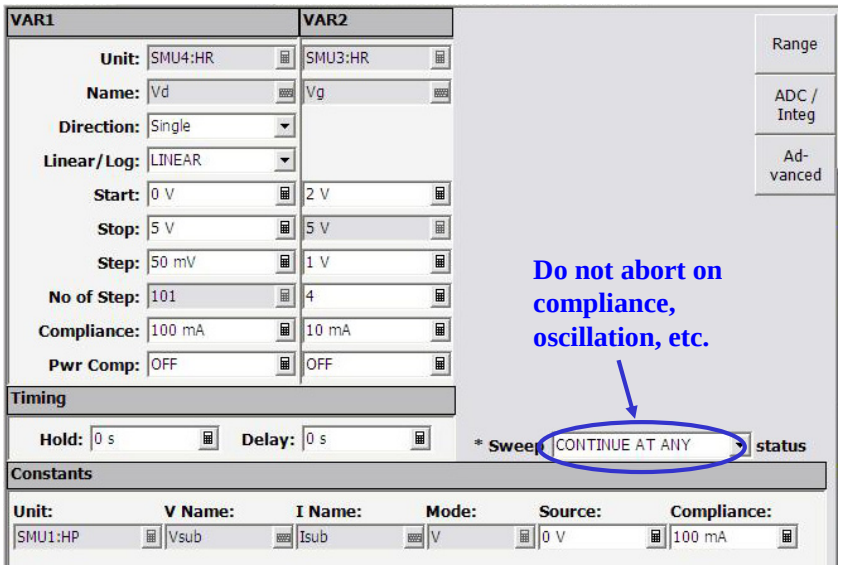
After you get the IDVD setup data, you will see the Classic Test setup screen as shown.

The Channel Setup screen allows the user to assign a meaningful name to the force/meas functions of each SMU. These names may be used in the Function Setup screen to define algebraic expressions.

The Mode column is used to determine whether a particular SMU is to be used to 1) force current and measure voltage (I mode), or 2) force voltage and measure current (V mode). The entry COMMON implies the node is used as "ground."

The Function column defines which SMUs are to be used as swept sources or constant sources. VAR1 is the primary swept source. VAR2 is known as the subordinate swept source, meaning VAR1 will sweep through its range, then VAR2 will step and VAR1 will sweep again. CONST is self- explanatory.

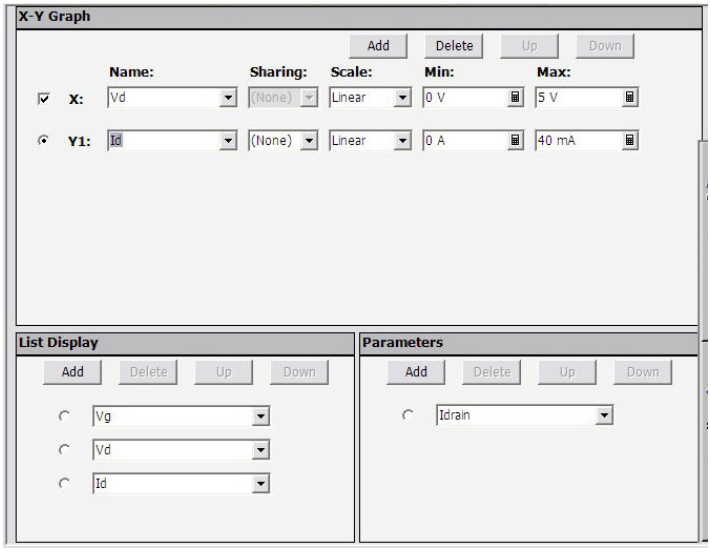
Classic Test – Measurement Setup



The Measurement Setup screen is shown here. The variables VAR1 and VAR2 define the sweep parameters. In a case where two sweep parameters are defined, the second parameter (VAR2) is called the subordinate (secondary) sweep parameter. This means that the primary parameter will be swept once for each discrete value of the subordinate parameter.

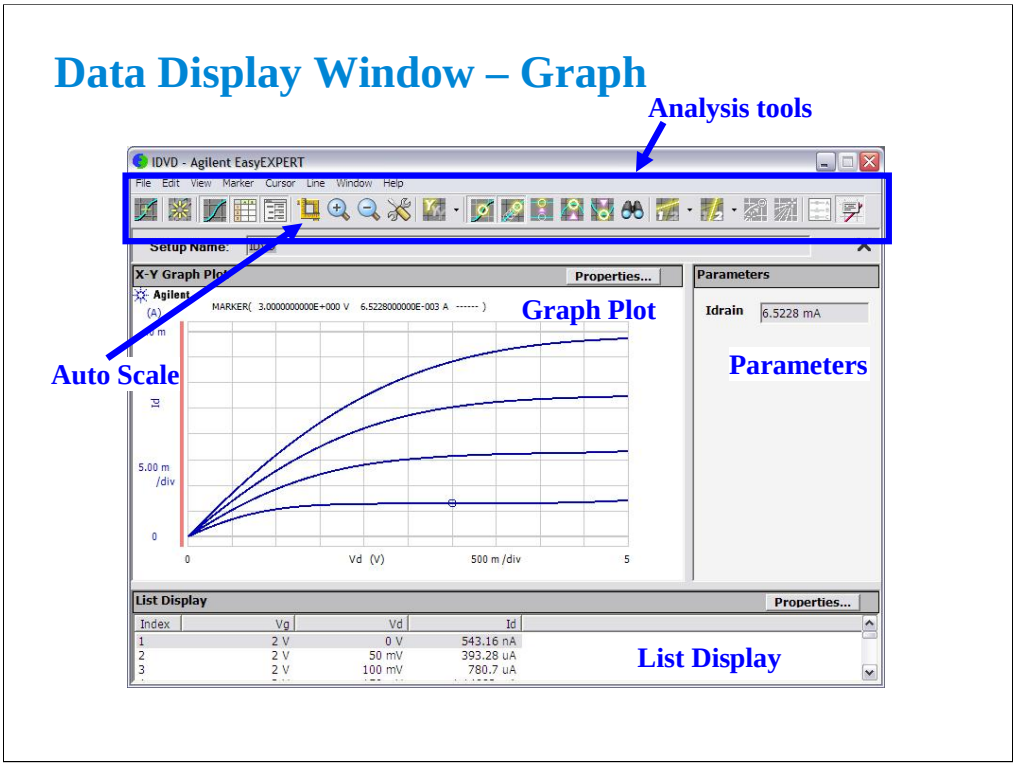
The “Constants” area is used to define non-swept voltage/current sources. This area is used to define ground references (forcing zero volts) as well as constant biases.

Classic Test – Display Setup



The Display Setup screen allows you to set the X-Y graph axes. The display setup is divorced from the measurement setup to allow the user to tailor the view to a particular region of interest.

This screen also allows you to set data variable names to be displayed in the List Display and Parameters areas on the Data Display window which is opened when the measurement is started.



This window displays measurement result graph, list, and parameter values.

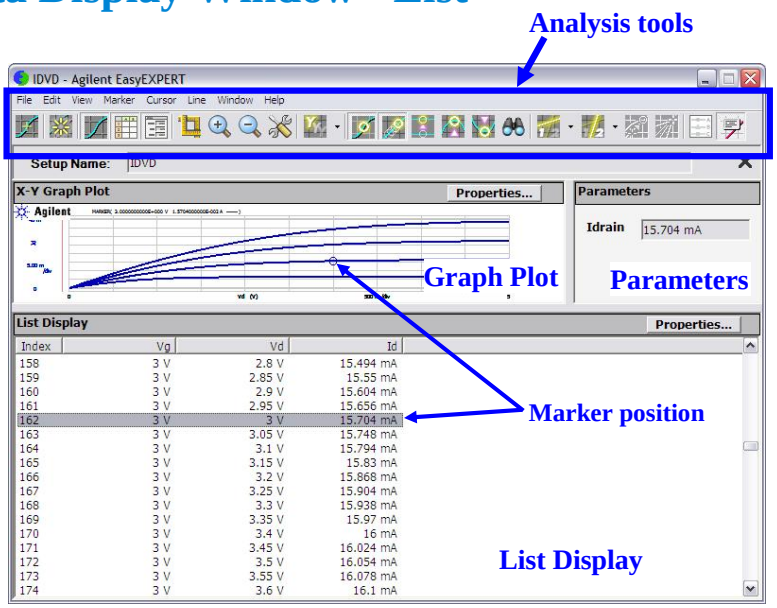
Markers are used to traverse the actual measurement data. Markers cannot be placed anywhere on the screen except on an actual measurement trace. They are denoted with a small circle. One moves the markers with the front panel rotary pulse generator (RPG) knob, mouse, or touch screen.

Cursor may be used anywhere on the screen and are denoted by a small cross. The cursor is moved using mouse, touch screen, or an arrow key.

The line function may be selected to draw one of four types of lines: line between cursors, gradient line, tangent line, regression line.

One of the most used interactive functions on this window is the autoscale feature which is applied by clicking the icon of yardsticks.

Data Display Window - List

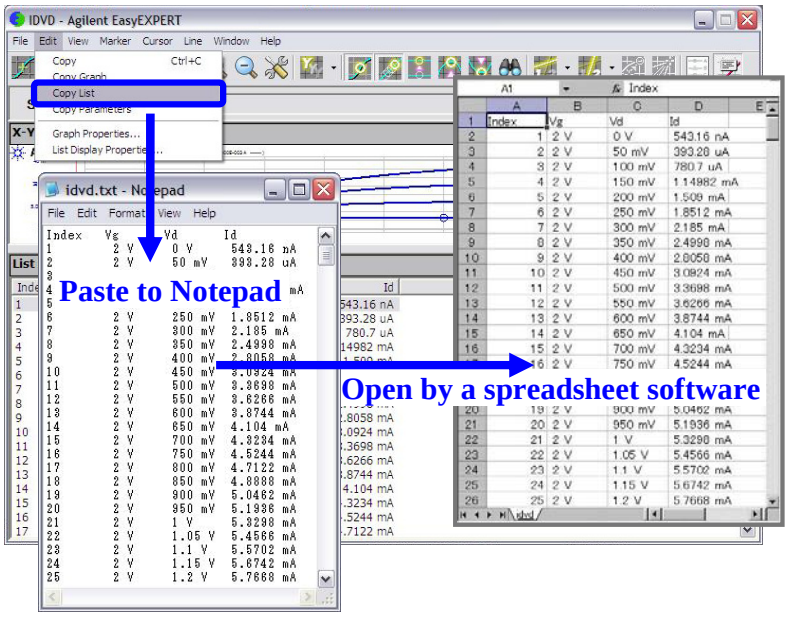


The List Display corresponds exactly with the Graph Plot. Even the highlighted line of data corresponds to the marker position on the Graph Plot.

Up to twenty columns of data can be set on the List Display. Note that the Graph Plot can only plot nine columns (X, Y1 to Y8).

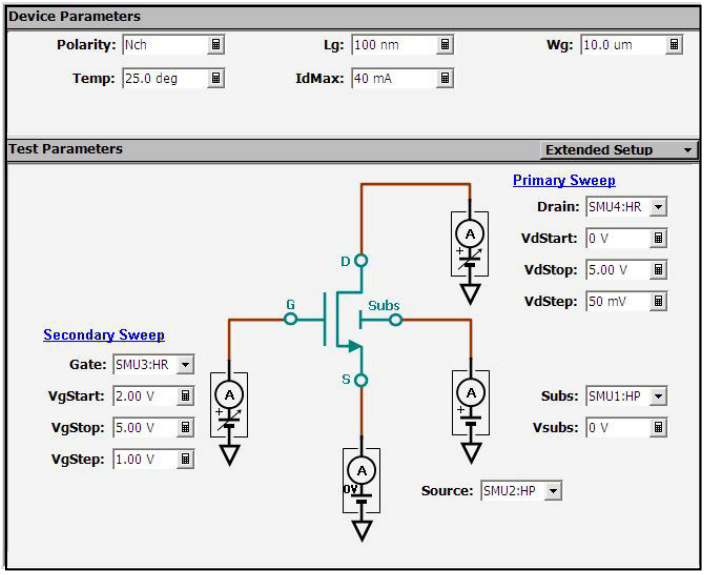
The list data can be copied to a spreadsheet software easily. Click Edit > Copy List. This copies all of the list data into the clipboard.
On the Notepad, paste it and save it as a text file. The file can be opened as a tab separated value data by using a spreadsheet software. See the next page.

To Copy List Data



Note:

Application Test



Recall Id-Vd application test setup data.

After you get the Id-Vd setup data, you will see the Application Test setup screen as shown.

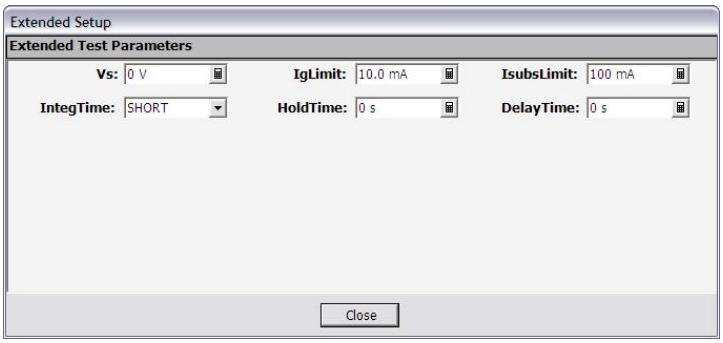
Test Parameters area shows the device connection information and allows the user to set the SMU outputs.

Device Parameters area allows the user to set device parameters. In the Id-Vd setup, the device parameters are polarity, gate length, gate width, temperature, and maximum drain current.

Extended Setup button opens the Extended Setup dialog box shown in the next page.

Application Test – Extended Setup

Clicking the Extended Setup button opens …



The Extended Setup dialog box allows the user to set the additional test setup parameters. In the Id-Vd setup, the additional parameters are source voltage, maximum gate current, maximum substrate current, integration time, hold time, and delay time.

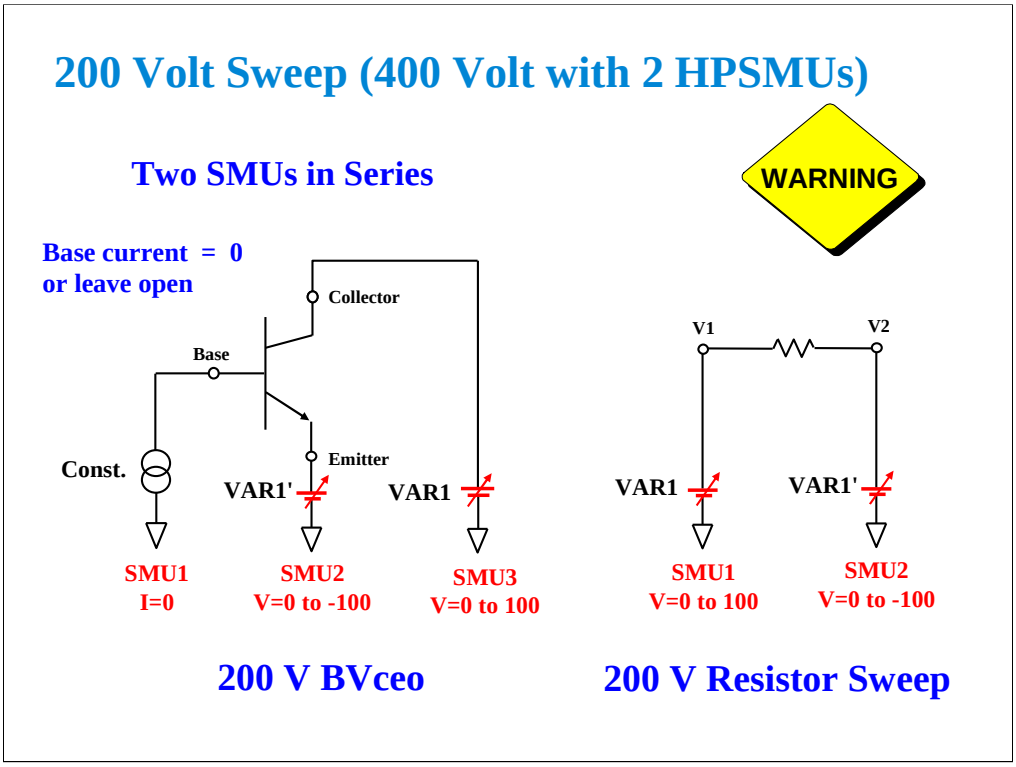
SMUs May Be Connected

In Series or Parallel

- To Double the Output Voltage
  - from 100 V to 200 V for HRSMU and MPSMU
  - from 200 V to 400 V for HPSMU
- To Double the Output Current
  - from 100 mA to 200 mA for HRSMU and MPSMU
  - from 1 A to 2 A for HPSMU
- Use the VAR1’ mode to synchronize two SMUs

You can double the voltage or current output by combining SMUs.

The VAR1’ mode allows a second SMU to be swept in tandem with the first.



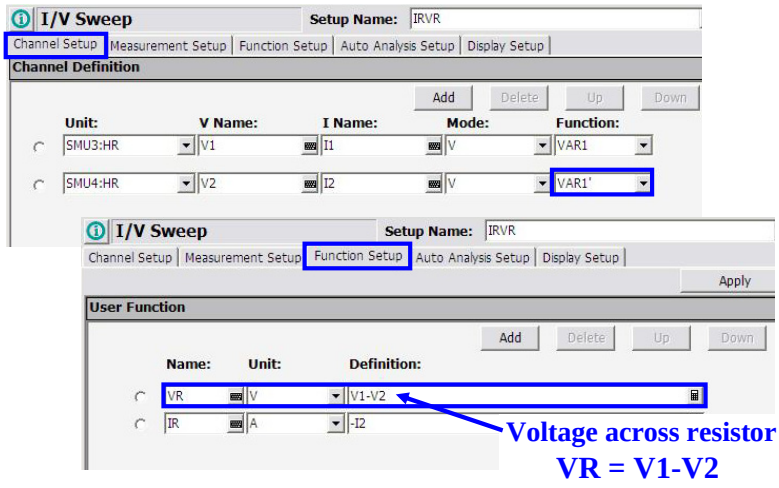
Higher voltages are necessary to observe breakdown conditions, such as BVceo. In the case of BVceo the base must be open (no SMU) or the SMU must be set as a current source with I=0.

One SMU must sweep in a positive direction while the other sweeps in a negative direction. The result is a floating measurement with double the differential voltage. A resistor is used in the next few slides to demonstrate a 200 V sweep.

Note: Using two HPSMUs, it is possible to sweep a total of 400 Volts.

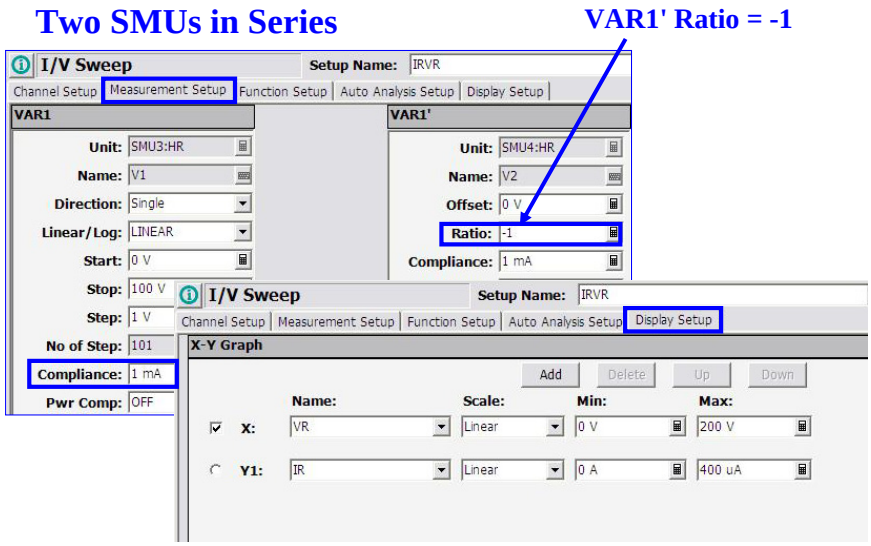
Channel and User Function Pages

Two SMUs in Series



The voltage across the resistor (VR) is the difference between V1 and V2. A simple user function can be used to plot VR.

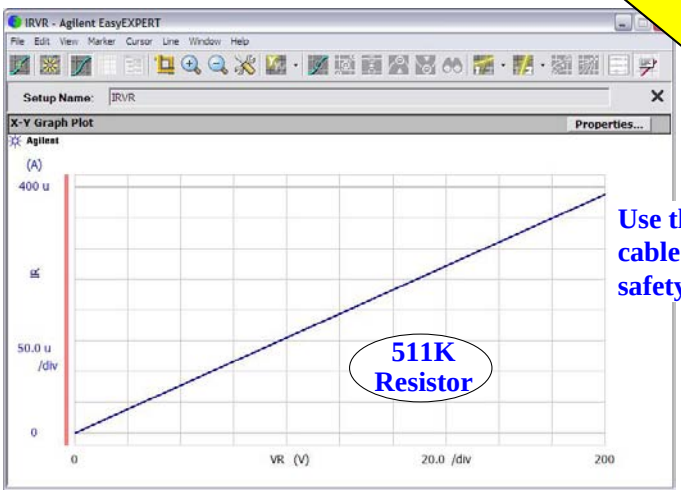
Measurement and Display Pages



The VAR1’ mode is used to synchronously sweep two SMUs. Setting Ratio = -1 forces one SMU to sweep in the opposite direction of the other.

Graphics Page 0 to 200 V

Two SMUs in Series



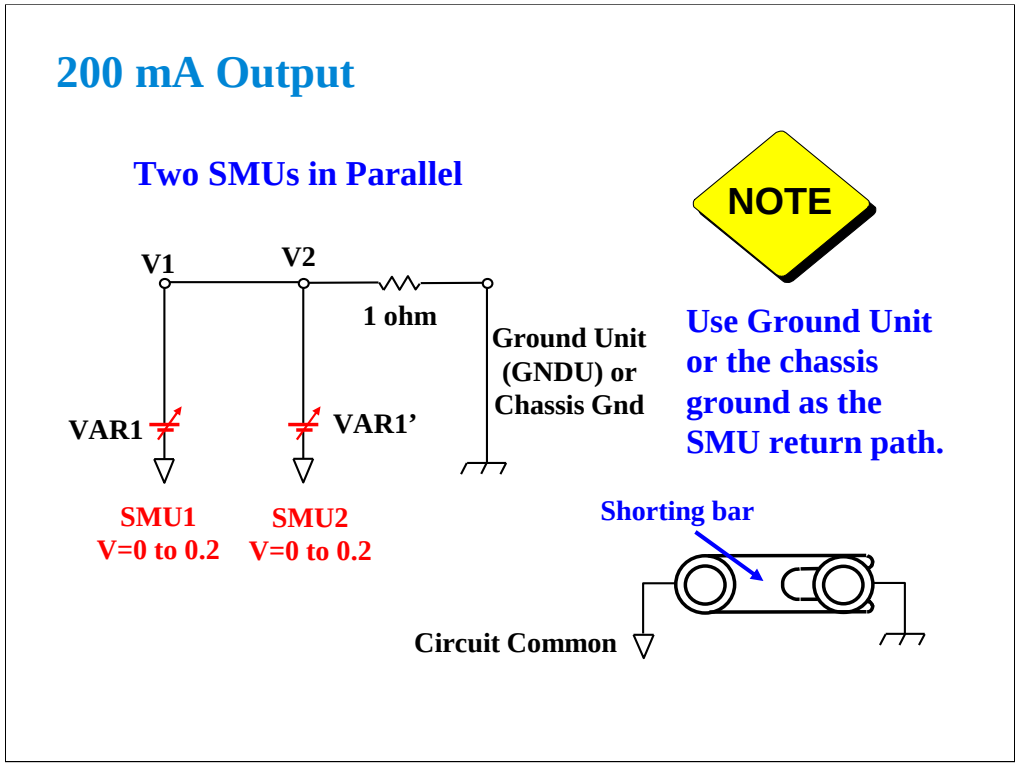
WARNING

Use the interlock cable and observe safety precautions.

The result is a clean 200 V sweep.

Remember that there is a serious shocking hazard.

The interlock cable is necessary for any voltage sweep greater than 42 V.



Two SMUs can be operated in parallel.

The trick is to not use any SMU as COMMON.

HRSMU and MPSMU can only sink 100 mA.
Use GNDU (ground unit) or the chassis to sink the 200 mA of current. Chassis noise level will not affect the measurement. There is a shorting bar in the back of the instrument which connects SMU common to the chassis. The shorting bar must be connected as shown above. Use the connector on the shorting bar to make an easy chassis connection to your circuit. The chassis connection is also provided if you use a packaged part test fixture, such as the 16442A/B.

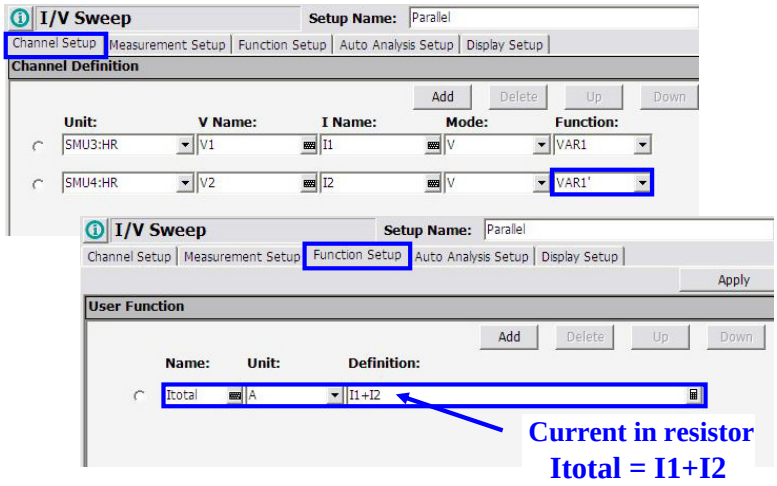
Note
The only time you would ever want to remove the shorting bar, is the case of floating the instrument circuit common when using other instruments. An example might be a connection to a RF Network Analyzer. You may want to remove chassis ground loops by connecting the circuit common directly to the NWA chassis.

Note
Never use the chassis ground for low current measurements. It is noisy. Use the GNDU or an SMU set to 0 volts or COMMON mode.

Note
If the GNDU is used, connect the 16493L GNDU cable between the GNDU and the test fixture. Do not connect the triaxial cable. The GNDU is rated for up to 4.2 A, while the maximum current rating of the triaxial cable is 1 A.

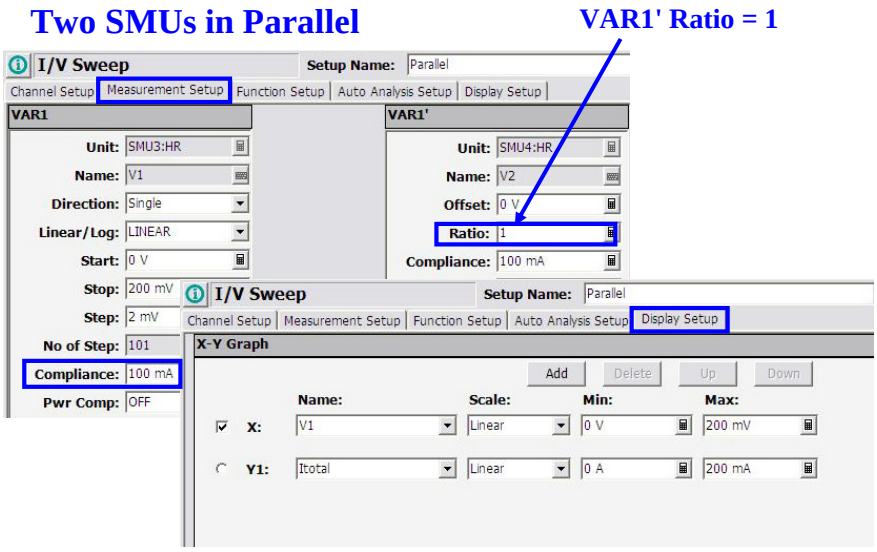
Channel and User Function Pages

Two SMUs in Parallel



A user function totals the current in both SMUs.

Measurement and Display Pages

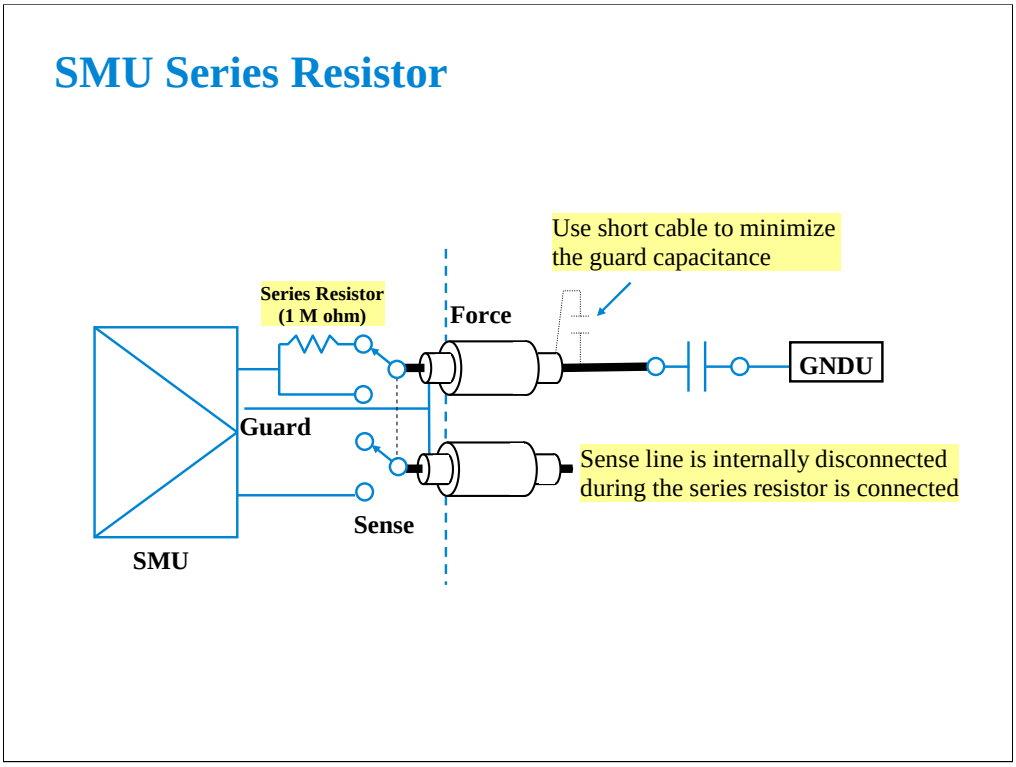


The VAR1’ mode with Ratio = 1 forces two SMUs to sweep the same voltage.

Graphics Page 0 to 200 mA

Two SMUs in Parallel

The result is a clean sweep to 200 mV. It shows the current measurement data near 200 mA.



The series resistor (approx. 1 Mohm) is mounted on each SMU. The series resistor may be used for the device protection, negative resistance measurement, and so on. It depends on the characteristics of test device and measurement environment.

Note that the series resistor may not effective for device protection. For example, the breakdown measurement may damage the device even if the series resistor is used.

If you use a series resistor, the voltage you set is applied to the near side of the series resistor. Thus, the voltage will be divided by the series resistor and the device under test. Then, the measurement data is not compensated.

Restrictions:

The series resistor cannot be used for the measurements that use the HRSMU connected to the ASU or the measurements that use 1 A range of the HPSMU.

Class Exercise
SMU Series Resistor

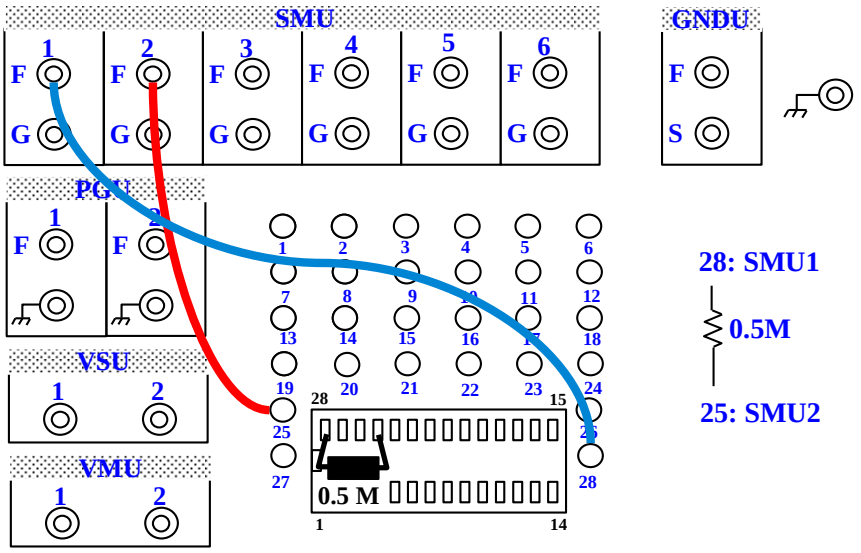
You will:

- Measure 0.5 M ohm without Series Resistor
- Measure the same device with Series Resistor
- Learn how the Series Resistor works

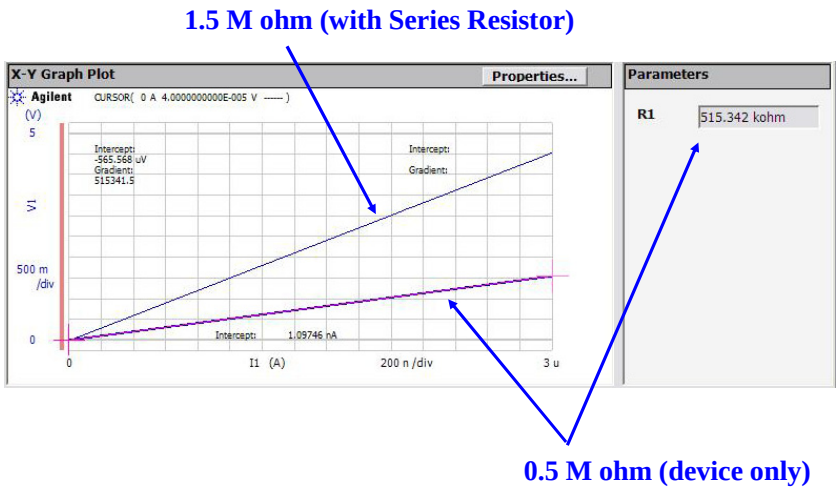
To Get Started:

- Use the instrument setup as same as the SMU pulse exercise
- Connect 0.5 M ohm as shown in the next page
- Get and run the IV-res setup
- Set the Series Resistor and perform Append measurement

Jumper Leads – SMU Series Resistor



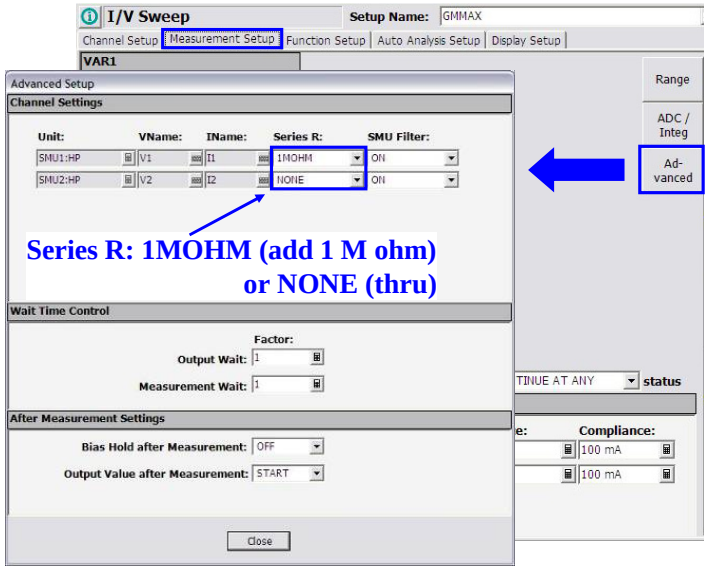
SMU Series Resistor



The measurement result without the SMU series resistor shows about 0.5 M ohm I-V characteristics. By setting the SMU series resistor, the measurement result shows about 1.5 M ohm characteristics.

The IV-res setup uses the analysis function and auto analysis function to draw the regression line and get the slope of the line. For the definition, see the Function Setup screen and the Auto Analysis Setup screen.

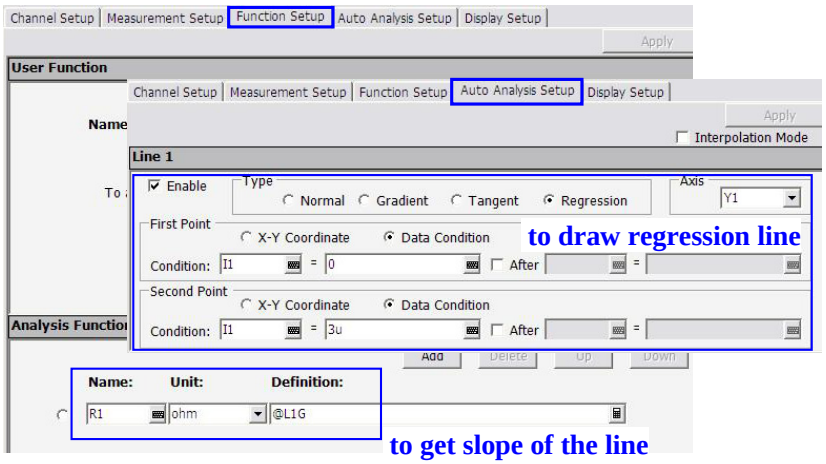
SMU Series Resistor



To change the SMU series resistor setup, open the Advanced Setup window by clicking the Advanced button on the Measurement Setup screen. And specify NONE or 1MOHM by using the Series R pull down menu.

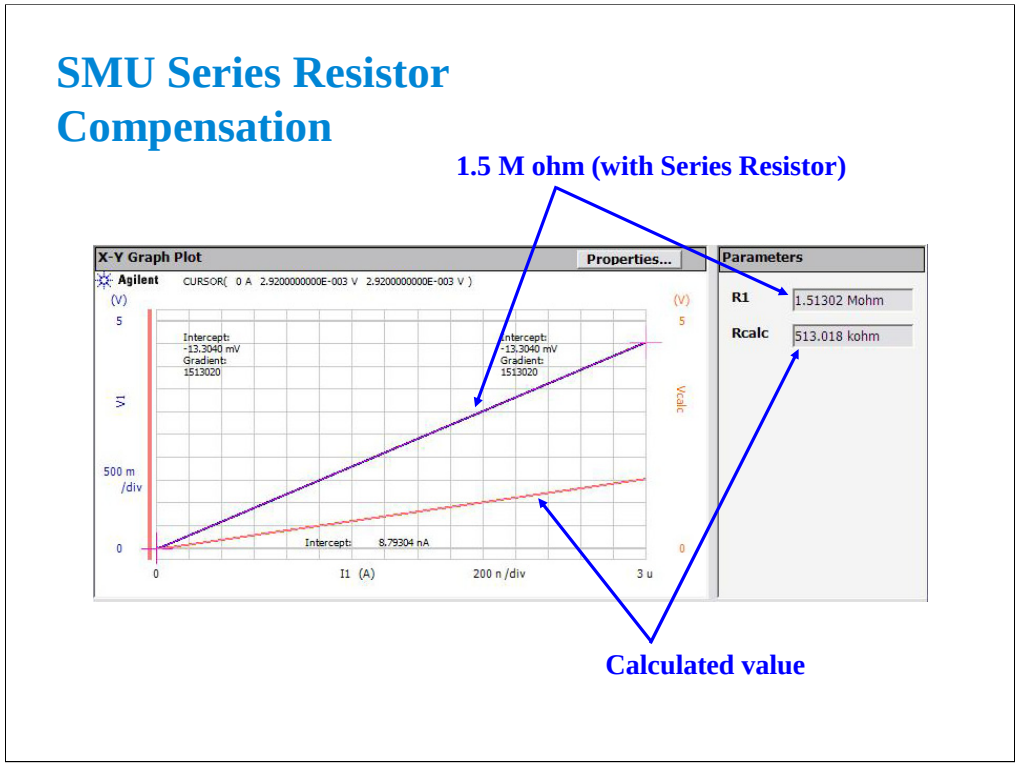
In the power on state, the Classic Test sets the Series R to NONE.

SMU Series Resistor
Function Setup and Auto Analysis Setup



The analysis function and the auto analysis function are used to calculate the resistance value.

This auto analysis setup will draw the regression line for the X-Y1 curve. And the analysis function @L1G is used to pass the slope of the line to the R1 variable.



If you use the SMU series resistor, you will need to compensate the measurement data to eliminate the effects of the series resistor (1 M ohm).

This is a compensation example by using the following user function.

Vcalc = V1 – I1 * 1000000

The Rcalc value is obtained by using the analysis function and the auto analysis function as same as the IV-res setup.

This compensation example is shown in the Rcalc setup.

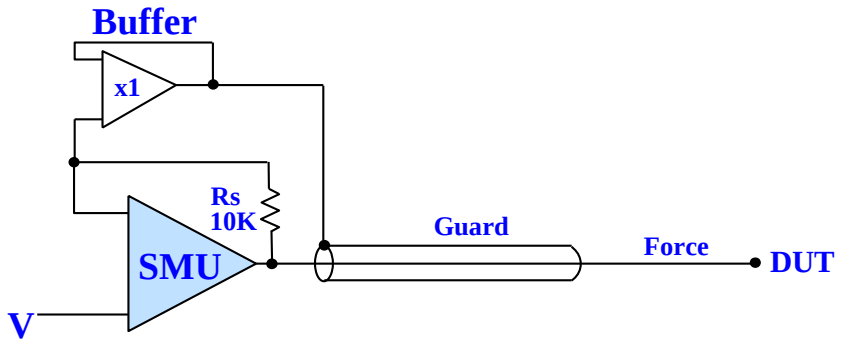
Cabling and Fixturing Issues

- Guard connection
- Kelvin connection
- Prober interface
- Triaxial Probes
- RF Fixturing interface
- Feedthru and triax to coax adapters
- 16442A/B fixture interlock
- 16058A fixture compatibility

The B1500A is a precision instrument. However, the ability to make precise and reliable measurements may be compromised by your fixturing to the device. The following section provides some theory and hints for making sense out of cabling and fixturing issues.

Guard Connection for Non-Kelvin Connection

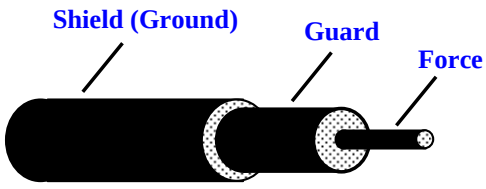
Simplified Diagram



The guard connection is needed for measurement < 1 nA. Below 1 nA a regular coax cable's capacitance dominates over the DUT (device under test) capacitance. What you see is cable charging current. I = C(dv/dt) where dv/dt is the rate of change of SMU voltage from one step to the next of a coax cable with no guard. C is the total capacitance of the cable.

The above diagram shows how the cable capacitance is eliminated with a triaxial cable. The guard is driven at the same voltage as the force center conductor. No current can flow between guard and force when they are held at the same potential. Guard and force are isolated by a buffer amplifier. They can never be shorted together.

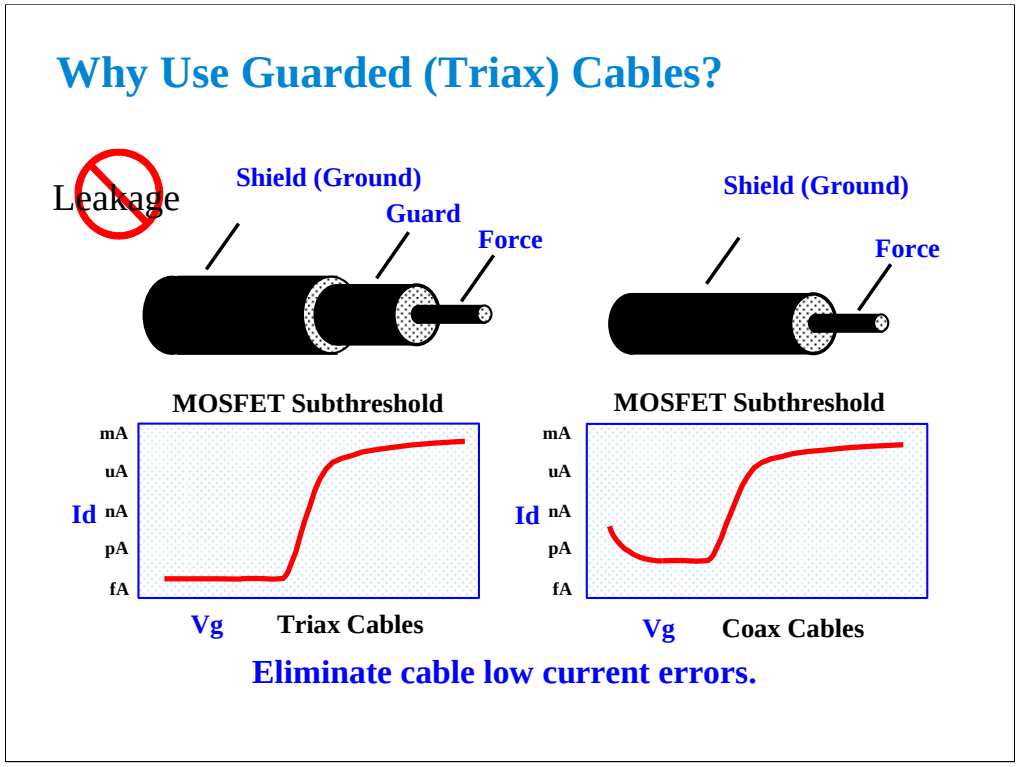
Triaxial Cable for Non-Kelvin connection



	16494A-001 (1.5 m)	16494A-002 (3.0 m)
Shield Capacitance	900 pF	1800 pF
Guard Capacitance	130 pF	240 pF
Force Resistance	160m ohm	320m ohm

Shown above are typical capacitance and series resistance of the force line. If cables are too long, high capacitance may cause the SMU to oscillate. Keep the force-guard cable capacitance less than 600 pF. Similarly, the guard-shield capacitance must be less than 5000 pF.

Note the rather high force resistance. Kelvin connections must be used to eliminate this cable error.



The triax cable is a special low dielectric loss, high impedance cable. This cable may be used down to fA levels when properly used with a guarded probe. The guard voltage tracks the force voltage exactly, so that no voltage drop can exist between guard and force. This eliminates the capacitive loading that would otherwise limit low current measurements.

If low impedance coax cables are used with outer layer at ground potential, two limitations will be immediately apparent. The cable leakage will limit the low current measurement floor. In addition, when the voltage is swept, the sudden change will cause additional cable charging. This distorts the low current portion of a MOS subthreshold curve as shown.

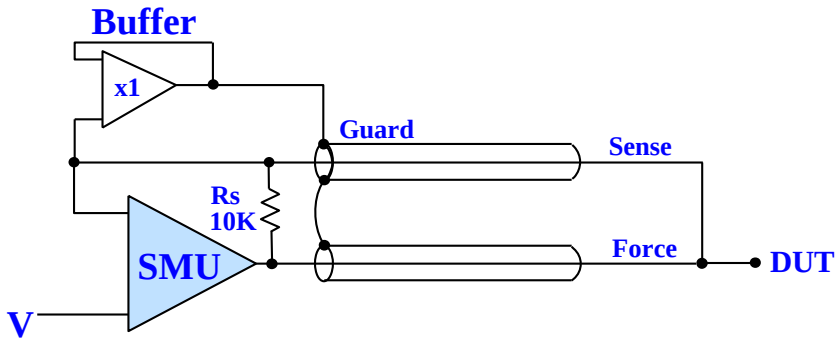
RULES:

Unguarded coax cable is OK for measurements above 1 nA.

Triax cable or coax with outer layer at guard potential should be used for measurements below 1 nA.

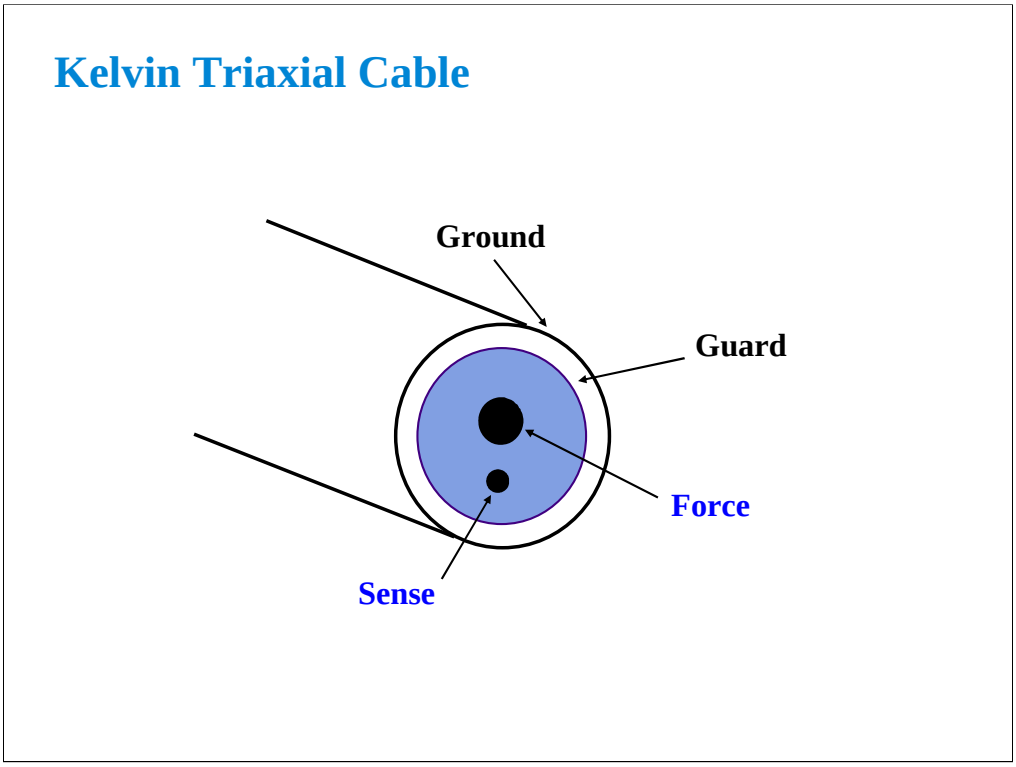
Guard Connection for Kelvin connection

Simplified Diagram



With the Kelvin connection, sensing is done at the DUT, eliminating the fraction of an ohm of cable resistance. The internal sensing resistor Rs is the only feedback path without the Kelvin connection.

Note that the B1500A operates just fine without the sense cable. This is important to know because in general you do not need the sensing Kelvin connection. Most MOS measurements are high impedance and the residual cable loss is insignificant.

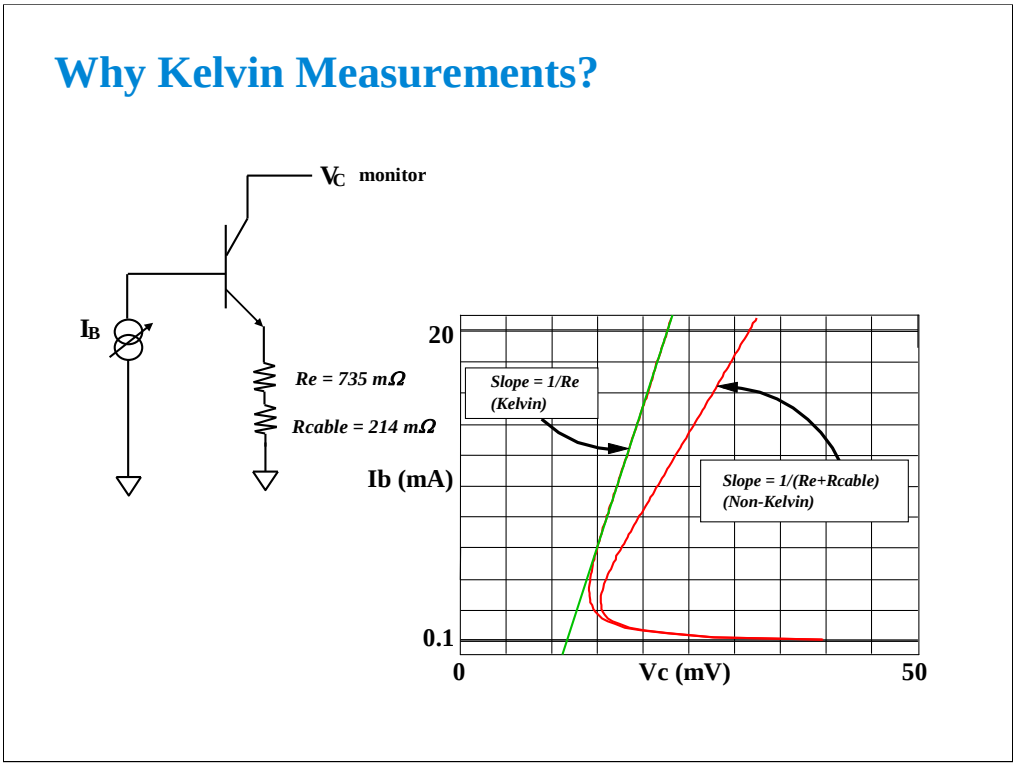


The triaxial cables are good for low current measurements. However, two cables are necessary for low resistance Kelvin measurements.

Agilent Technologies designed a special Kelvin triaxial cable for the precision semiconductor parameter analyzers. This cable is optimized for both low current and low resistance measurement. Both force and sense lines are held rigidly in the same Teflon cable. Friction is reduced and the cable is less sensitive to noise caused by moving the cable.

Kelvin triaxial cable assemblies are available with two connector options:

16494B	B1500/4156 compatible on one end; 4142 compatible on the other end
16493K	B1500/4156 compatible on both ends (standard option)



In the example above, the device is connected with a SMU on the base sweeping current, a voltmeter on the collector, and the emitter is grounded with a Kelvin SMU. The base SMU does not have to be Kelvin since we are only forcing current and do not care about measuring the cable loss in the base. Also, the collector SMU is being used only as a high impedance voltmeter, so there is no cable loss in this lead.

The emitter on the other hand, must be connected to a Kelvin SMU. Because of this, we can compensate for the 0.214 ohm path through the cable and fixture. From the graph we can see the emitter resistance is 0.735 ohm when compensated using the Kelvin connection. Non-Kelvin resistance is 0.949 ohm, due to the extra 0.214 ohm cable and fixture resistance error.

Class Exercise

Bipolar Re Using A Kelvin SMU

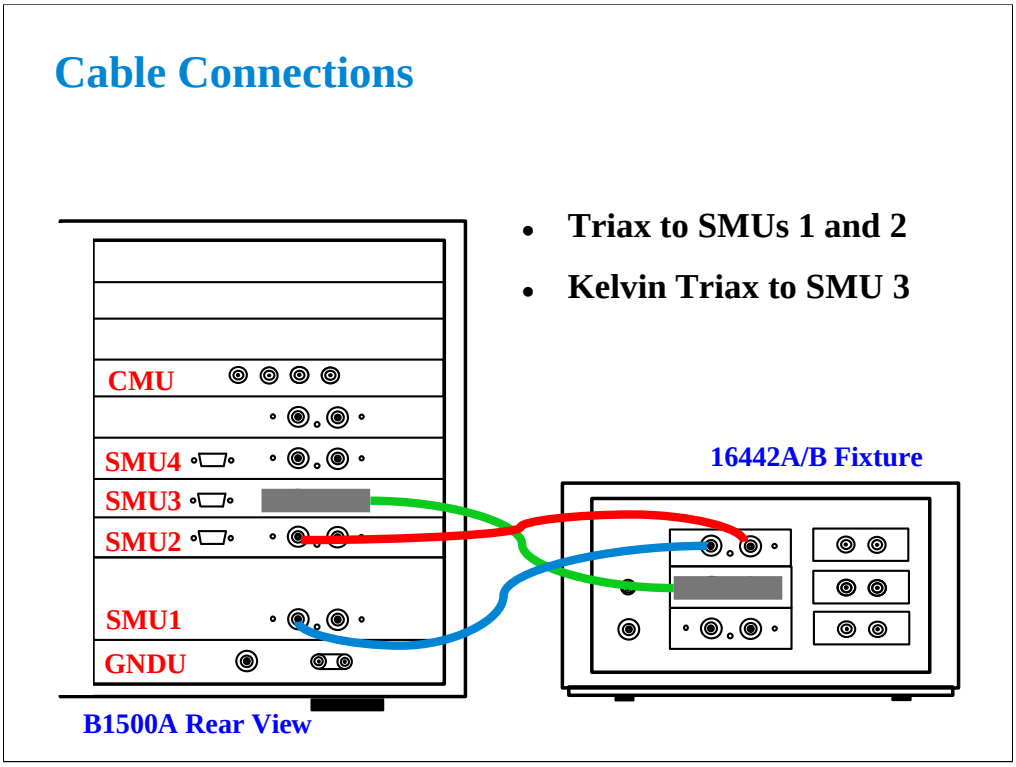
- You will connect a Kelvin triax cable to the B1500A
- You will then connect jumper leads and the bipolar device
- You will get the REKELV setup
- You will observe Re using Kelvin and Non-Kelvin connections. Why is the Non-Kelvin error so large?

To Get Started:

- Use the next several pages as you guide
- Verify that all triax cables are connected properly
- Connect four jumper leads to the 28 pin socket as shown
- Insert the bipolar transistor (not static sensitive)

The purpose of this class exercise is to familiarize yourself with making a Kelvin measurement. Low resistance measurements such as Re, Rc (bipolar) or Rs, Rd (MOS) are excellent examples because the resistances are of the same approximate magnitude as cable resistances. Kelvin techniques must be used, or your error can be as much as 100 %.

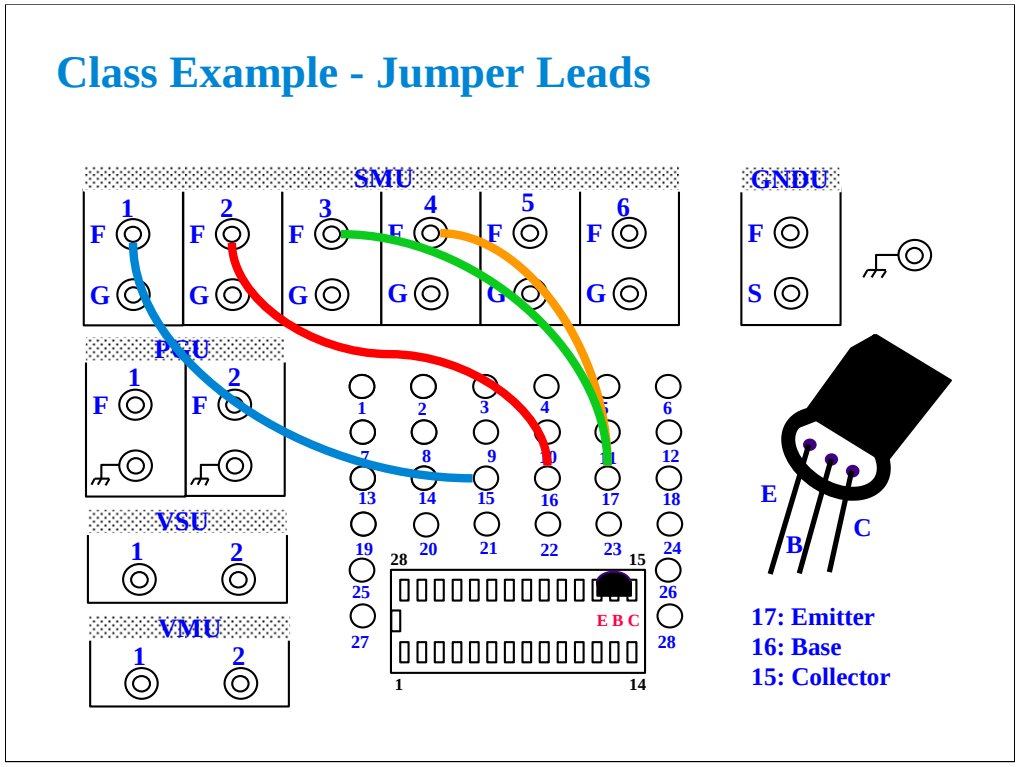
The next several pages lead you through the steps of connecting a Kelvin cable, making the correct Force/Sense jumper lead connections, orienting the device properly in the socket, and getting the REKELV algorithm. The measurement will be Re (emitter resistance) of a bipolar transistor. You will be able to remove the Sense jumper lead on the Emitter terminal of the device to see the gross measurement degradation when the connection is non-Kelvin (no sense connection near the device).



This class example requires a Kelvin triaxial cable. If the Kelvin cable is not available, substitute two standard triax cables.

SMUs 1,2,3 can all be connected with Kelvin triaxial cables, but only SMU3 requires the Kelvin connection.

Note
If you use the 16058A fixture instead of the 16442A/B, connect the triaxial cables as shown below.
SMU1 Force ---> 16058A SMU1
SMU2 Force ---> 16058A SMU2
SMU3 Force ---> 16058A SMU3
SMU3 Sense ---> 16058A SMU4



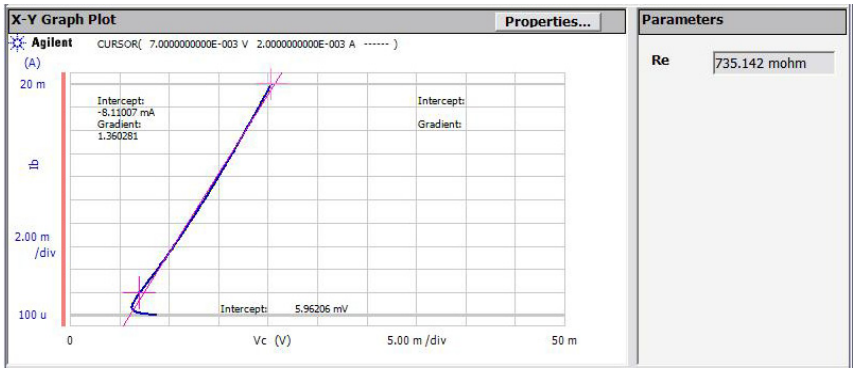
Connect jumper leads as shown. Where, the SMU4 F terminal is connected to the B1500A's SMU3 Sense connector. So the couple of the SMU3 F and SMU4 F terminals makes a Kelvin terminal.

Locate the bipolar transistor in the corner of the socket as shown, with the flat side of the device facing toward you.

Unlike the MOS device, the bipolar transistor is not static sensitive. You may touch the leads without using a ground strap.

Single Kelvin Measurement

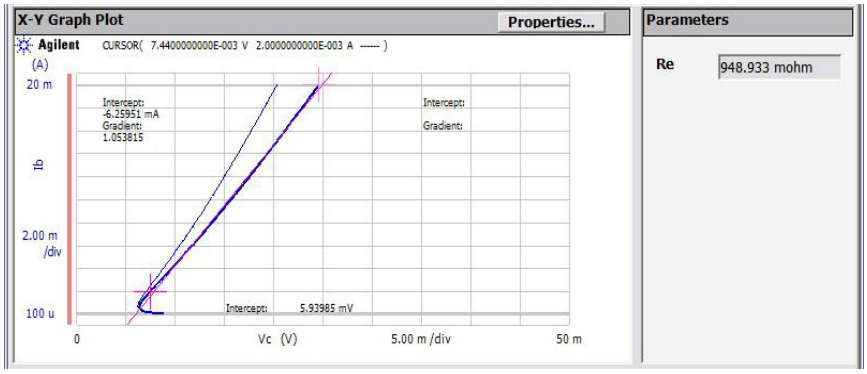
Click button to start measurement



Click the Single button to make a new measurement. You should see a response similar to this, will the analysis line correctly overlaying the curve.

Non-Kelvin Measurement

Click button to start append measurement



Remove the jumper lead connected between the terminal 17 and the SMU4 F terminal. And click the Append button to add another measurement to the graph.

Now you see the very large difference between Kelvin and non-Kelvin measurements when the resistance is low. You can see that Re jumps from about 0.735 ohm in this example, to about 0.949 ohm. The extra resistance is due to cable loss and fixture loss. This resistance is compensated out when you use the Kelvin connection.

Prober Kelvin Cable Connection

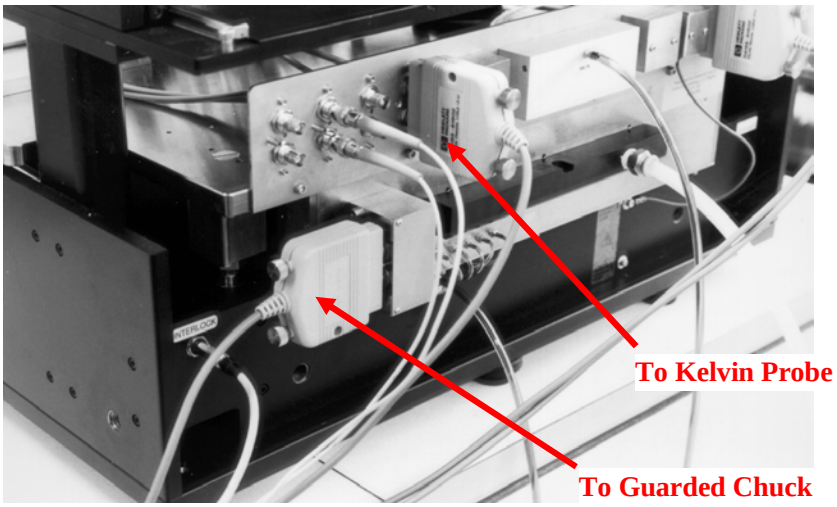
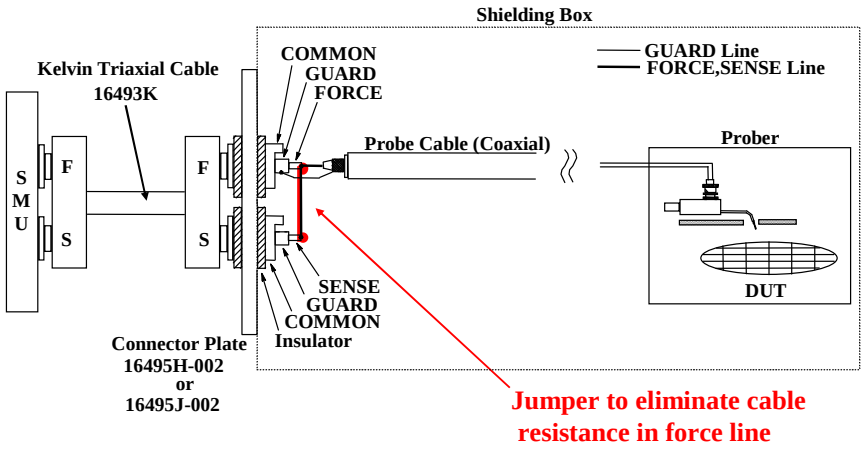


Photo of SMU cable connection to a Cascade Microtech Summit probe station.
The Kelvin triaxial cables mate directly to the probe station.

Connector Plate

Non-Kelvin Connection



This is a "hybrid" Kelvin connection. Cable resistance from SMU is eliminated by shorting FORCE and SENSE lines inside the prober. A short line to the probe makes the non-Kelvin connection, simplifying hookup.

Simplifying the Prober Connection

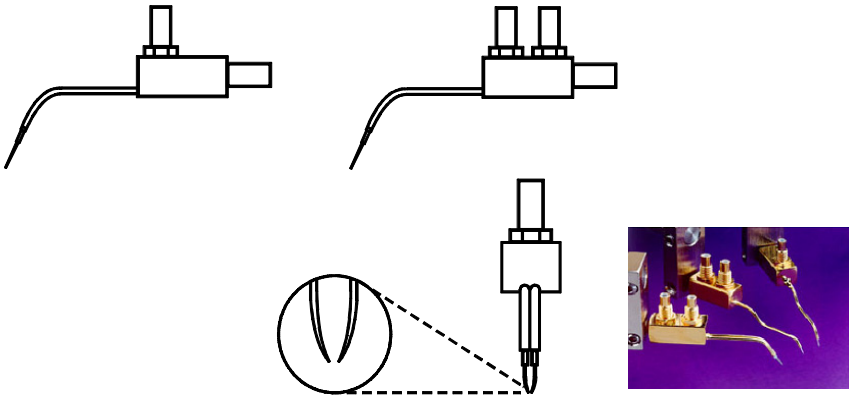
- **Use single triax for basic MOS FET measurements**
- **One triax on each Force line**
- **Leave the Sense lines open...no cable connected**
- **Use triax bulkhead feedthru adapters on the prober**
- **Use a probe holder with a triaxial connector**
- **Use a probe holder than accommodates replaceable probe tips (inexpensive repair)**

The next section sheds light on the confusing topic of connection to the device under test. Without proper considerations, noise, capacitance, sense resistance, or inductance will result in unacceptable measurement error.

Triaxial Probes

Guarded to within 2mm of tip

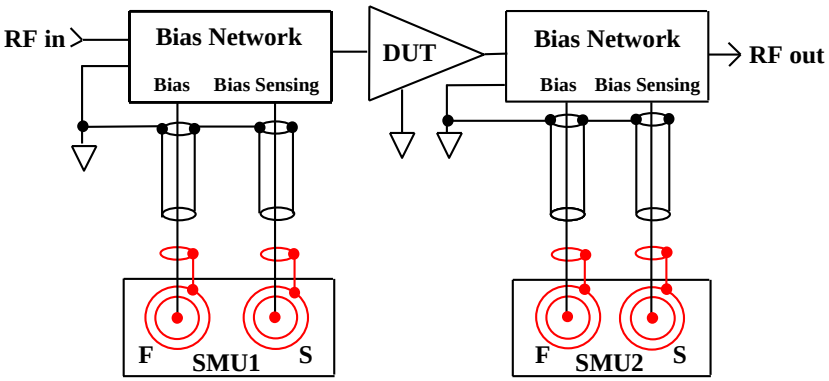
Single Triax **Kelvin Triax**



These probes are guarded within 2mm of the probe tip, ideal for low current applications. The Kelvin triax probe is the ideal mate for the Kelvin triax cable. A third variation of these probes is a Kelvin triax probe with only one probe. The Kelvin connection is made inside the probe holder. This compromise eliminates most cable loss while making a single point contact.

Simplifying RF Connections

- Triax is not necessary...bias currents are > 1 nA.
  Use triax to coax adapters with floating guard.



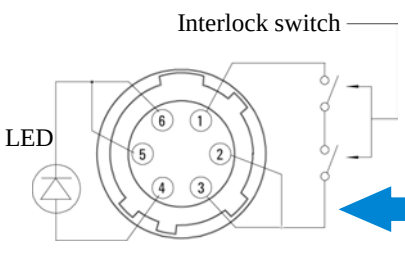
Above 1 nA guarding is of little use. Cable capacitance has a negligible effect on the bias port. Use the floating guard triax(m) to BNC(f) adapter at the B1500A rear panel. Then use standard coax BNC cables. Use sense to minimize series resistance error. 100 mV errors can occur in bias voltages if remote sensing is not used.

Some recent bias tees from Agilent Technologies are specially designed to mate easily to triax SMU ports.

Interlock Connection

- **For measurements above 42 Volts**
- **For program control using program memory**

Interlock circuit



Interlock connector
plug side view

View from B1500A rear panel

To prevent shock hazard, the B1500A will not operate above 42 V, unless you connect the interlock circuit.

The interlock connection is required when the voltage exceeds 42 V or when the program memory is used in a control program.

The 16442A/B test fixture has the interlock circuit internally which makes this short by closing a lid activated switch.

You must make the circuit to your prober to comply with US OSHA safety standards. The switch on the prober should be mounted into the access door of the shield box.

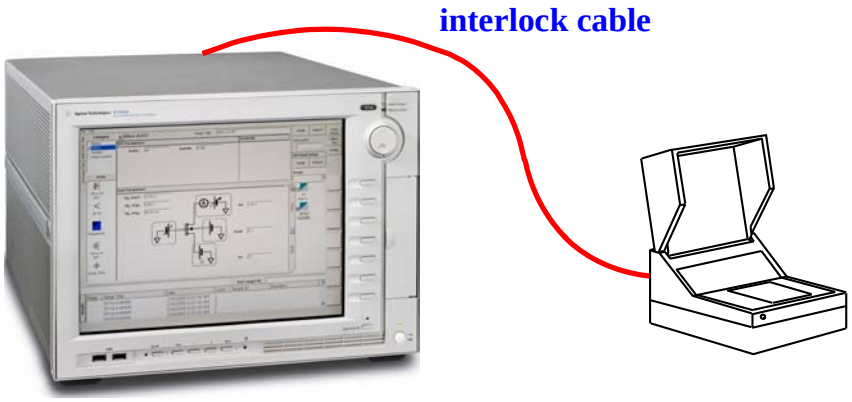
If you want to connect to the BNC type interlock connector on the 16088B, your fixture or prober, use the 16435A Interlock Cable Adapter. The 16435A provides a BNC cable and a small adapter box which is used to join the BNC cable and the interlock cable furnished with the B1500A.

If you want to wire your own cable or fixture, these Agilent part numbers may be used:

1252-1419 Female 6-pin plug connector

1252-1418 Male 6-pin cable connector

16442A/B Fixture



16493J-001 **1.5 m cable**
16493J-002 **3.0 m cable**

The 16493J interlock cable is designed to be connected directly between the B1500A's interlock connector and the 16442A/B. If the fixture lid is closed, internal switch is closed, and then the B1500A can perform measurement up to 100 volts; 200 V with the HPSMU.

16058A Fixture Compatibility

Use the 16058A with the B1500A
- 4 non-Kelvin SMU inputs
- 3 general purpose coaxial inputs

Add the 16493A Adapter Cable
- Interlock connection
- 4 additional coaxial inputs

Add the 16435A Adapter

The 16058A has 4 non-Kelvin SMU inputs and 3 coaxial inputs for the other instrument connection.

By adding the 16493A Adapter Cable, you get access to 5 more coaxial connections. The adapter was designed to bring out the fixture interlock connection and 4 additional connections, such as the 4142/4155/4156's VSU/VMU.

The 16493A cable converts the 16058A fixture interlock connection to a single coaxial connector. This mates directly with the 16435A Interlock Cable Adapter mentioned on the previous page.

Note
You will notice that the socket modules for Agilent Technologies entire DC parametric product line are interchangeable. So socket modules that came with the 4142, 4145, 4155, or 4156 will work with the 16058A, 16088A/B, and 16442A/B fixtures.

3 Low Current Measurement

In This Module

- **Low-Current Measurement Challenges**
- **Calibration and Zero Cancel**
- **Effect of Cable Movement**
- **ASU for Ultra Low-Current Measurement**
- **Low-Current Subthreshold**
- **Trade-Off Speed Vs Accuracy**
- **Low-Current Gummel Plot**
- **Low-Current Gate Oxide Leakage**

This module is primarily written for the B1500A installed with the HRSMU (high resolution SMU) and covers sub pA measurement techniques. Course exercises are included which fully explore speed vs. accuracy issues to the fA level.

Low Current Measurement
What is possible?

- Measurements below 10 fA at the wafer level
- Repeatability within a few fA
- Speeds less than 1 minute for subthreshold sweep

Making wafer level measurements to fA levels is easy and routine using proper measurement procedures on a low noise probe station. This module explains how.

Low Current Measurement Challenges

- NOISE FROM PROBER
  - Faraday enclosure required
  - Eliminate all electrical interference
- STRAY CAPACITANCE
  - Full guarding, including the probe
  - Guarded chuck to measure substrate current
- MEASUREMENT SETUP
  - Hold time, integration, auto ranging
- CALIBRATION & ZERO CANCEL

Measurement below 1pA is not possible without special attention to the prober and cabling. The wafer must be in total darkness and in an electrically isolated metal box. Motors must be turned off or completely shielded.

Stray capacitance kills any hope of making good low current measurements. High cable capacitance which is unguarded can produce pA level currents during voltage steps. The probes themselves must be guarded.

The B1500A defaults at bootup to setup conditions which are not optimized for ultra low current. This is desirable because there is a large trade-off between speed and ultra-low current accuracy. The typical use is moderate current levels where settings can be optimize for speed, not accuracy.

There are some features such as zero cancel, which can eliminate the last 10 or 20 fA of error from your measurement. Before zeroing, you should check that SMU CALIBRATION has been performed. SMU Calibration removes most error and makes the final zero cancel easier.

Clean Probing Environment
What is Required?

- ✓ Low loss triaxial connection (no matrix card)
- ✓ Guard to tip of probe (no bare needle or probe cards)
- ✓ No air flowing near probe tip (including dry nitrogen)
- ✓ No hot chuck
- ✓ Chuck isolated from ground (10^13 ohms)
- ✓ Chuck guarded for substrate measurements
- ✓ Shielded probe station
- ✓ No vibration; cables stationary
- ✓ Microscope light, motors, etc. off

This check list covers most sources of noise or stray capacitance. In a "clean" probing environment the B1500A can be used with short integration time and no delay time between steps.

Debugging A Noisy Probe System Where to Start?

- Sweep 0 to 1 volt with no cables attached to SMU
  - Check that there is a +/- 3 fA base line
- Add prober cables but no prober
  - Wait several minutes
  - Still +/- 3 fA base line?
- Add shielded prober but no probes
- Add probes

This is a systematic strategy for focusing in on the sources of noise and error. You can be very surprised. Some prober cable is not low loss. You may see popping noise due to relaxing of Teflon fiber in the cables, high current level due to poor dielectric loss, etc. You may find improper triax adapters, high levels of stray capacitance, etc., as you add prober and probe connections.

Low Current Calibration & Zero Cancel

- WAIT 30 MINUTES AFTER TURN ON
  - Instrument must stabilize
- CAL & ZERO WITH PROBES UP
  - Prevent device damage
- ZERO EVERY 30 MINUTES
  - To get repeatable fA level measurements

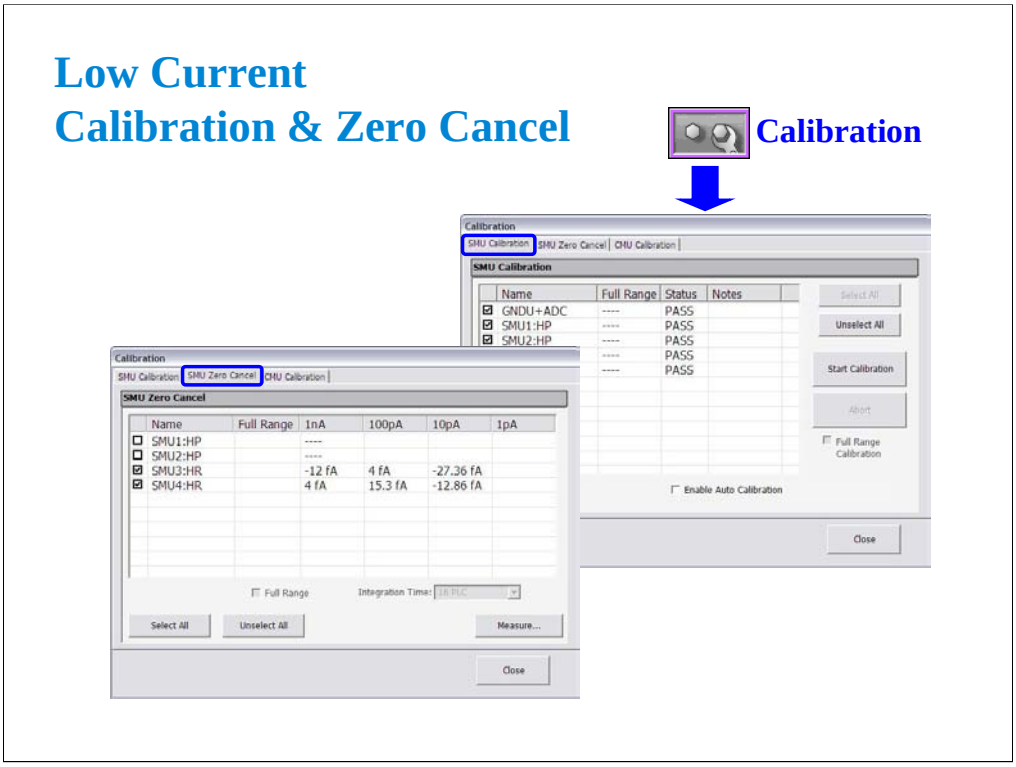
The SMU can be thought of as a sophisticated OP AMP. With any OP AMP there is an associated input offset error. This error is small and varies with ambient temperature shifts and other factors. It can be reduced to a negligible amount with a zero cancel function.

Zeroing is performed with the probes up. If there is a very large error to correct, you may get a warning message. This usually means that SMU CALIBRATION has not been recently performed. SMU calibration eliminates gross. ZEROing only has an effect on the 1 nA range or less.

Use the Calibration window to perform the SMU calibration and zero cancel. See the next page.

NOTE:

The B1500A provides the auto calibration function which automatically starts calibration for all modules every 30 minutes if the output switches of all modules are off for 30 minutes. You can enable or disable this function on the Calibration window. If auto-calibration is enabled, move probes up (open measurement terminals) after measurement to prevent device damage and to perform calibration correctly.



Click Calibration button to open the Calibration window.

SMU calibration is performed on the SMU Calibration tab screen. Specify the modules for calibration by checking the left check box and click Start Calibration button to start calibration. If ASU (atto sense/switch unit) is connected and 1 pA range is used for measurement, check Full Range Calibration check box before clicking Start Calibration button.

SMU zero cancel is performed on the SMU Zero Cancel tab screen. Specify the modules for zero by checking the left check box and click Measure... button to start SMU zero. If ASU is connected and 1 pA range is used for measurement, check Full Range check box before clicking Measure... button.

To enable the auto calibration function, check the Enable Auto Calibration check box on the SMU Calibration tab screen.

Class Exercise
Measurements Near Zero fA

You will be able to answer the following questions:

- What does a sweep into an open SMU port look like?
- What is the time per meas using PLC integration?
- Add a 1.5 m cable during a sweep...how long to settle?
- Move and bend the cable...how much current flows?

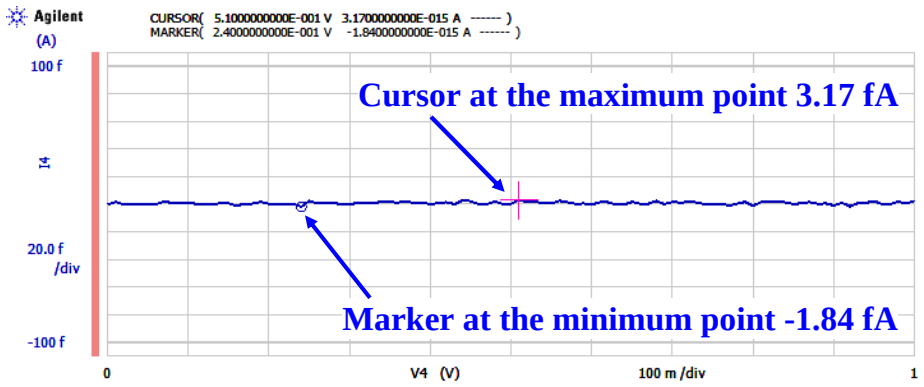
To Get Started:

- Use the next several pages as your guide
- Remove any cable attached to SMU4
- Measure SMU4 noise level using the setup shown

The following pages lead you step-by-step through the "ZERO CHECK" class exercise. This is the logical place to start if you are debugging a "noisy" test environment.

You will create an algorithm to look at the low level measurement capability of a SMU. On the next page you will see the expected curve when looking into an open at the rear panel.

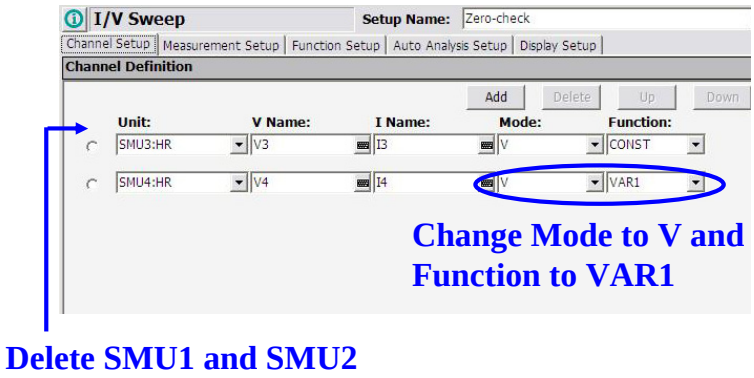
ZERO CHECK - No cable
Using Default SMU Setup



+/- 3 fA variation typical, using 16 PLC integration time

With slight modification of the default SMU settings of Classic Test I/V Sweep, you can check the conditions of your measurement system. This is a typical plot when no cable is attached to the SMU port. You would typically expect no more than a few fAs of deviation from zero using 16 PLC integration time.

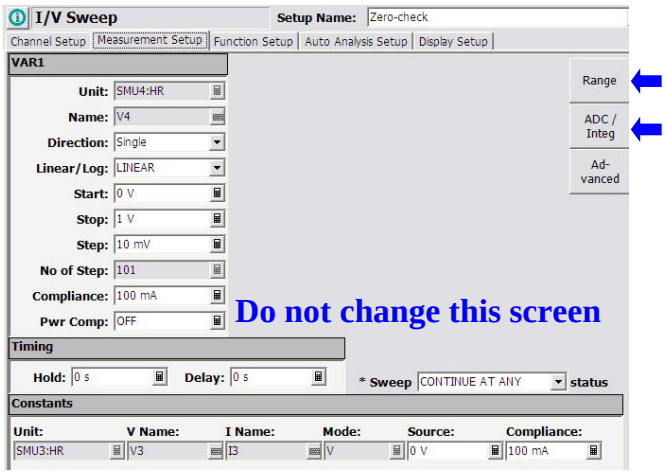
ZERO CHECK
Channel Setup



Click the Classic Test tab, I/V Sweep, and Select to display the Channel Setup screen.
On this display, delete the rows of SMU1 and SMU2.
Change the Mode of SMU4 to V.
Change the Function of SMU4 to VAR1.

This setup will be used for checking the zero measurement on SMU4.

ZERO CHECK
Measurement Setup



This default sweep setup is enough for the Zero Check measurement.

The sweep steps are small (10 mV) and that is ideal for checking current at fA levels.

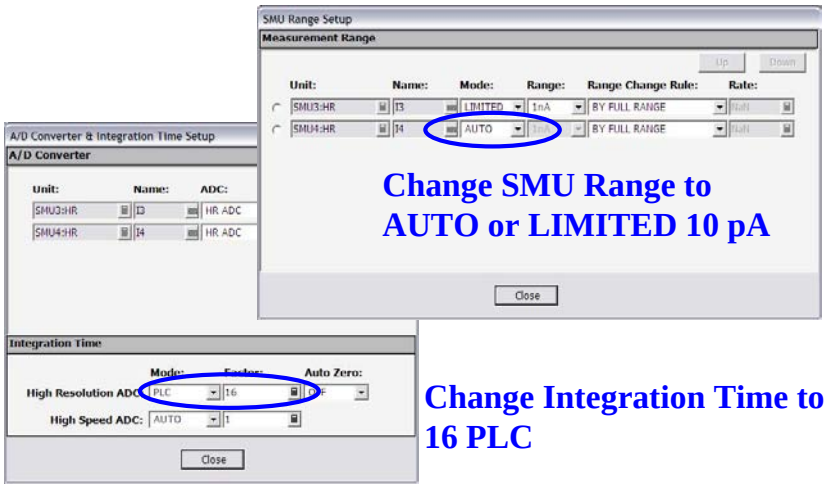
Also the sweep starts at 0, so no big discontinuities on the first step of the sweep.

There is no need to change anything on the Measurement Setup screen. But the ranging mode and the integration time settings must be changed. See the next page.

Click Range button to change the ranging mode.

Click ADC/Integ button to change the integration time setting.

ZERO CHECK
Range and Integration Time



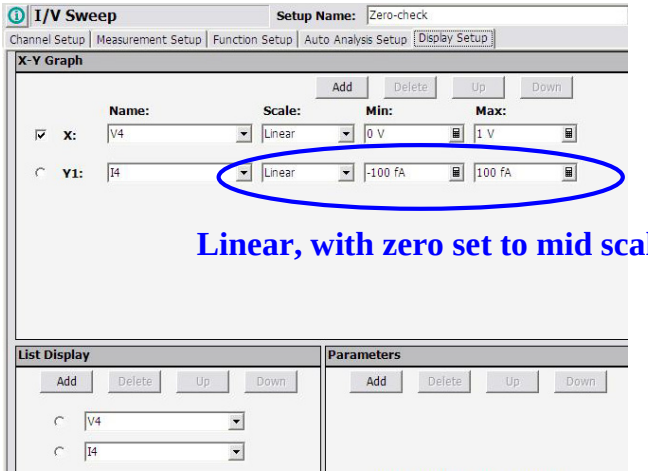
Change SMU Range to AUTO or LIMITED 10 pA

Change Integration Time to 16 PLC

You must change the range setting from the default of LIMITED 1 nA to LIMITED 10 pA or to AUTO. Otherwise you will have 100 fA resolution instead of the best 1 fA resolution possible.

Also change the High Resolution ADC Mode to PLC and Factor to 16. You will see +/- 3 fA variation measurement result as shown in the previous slide.

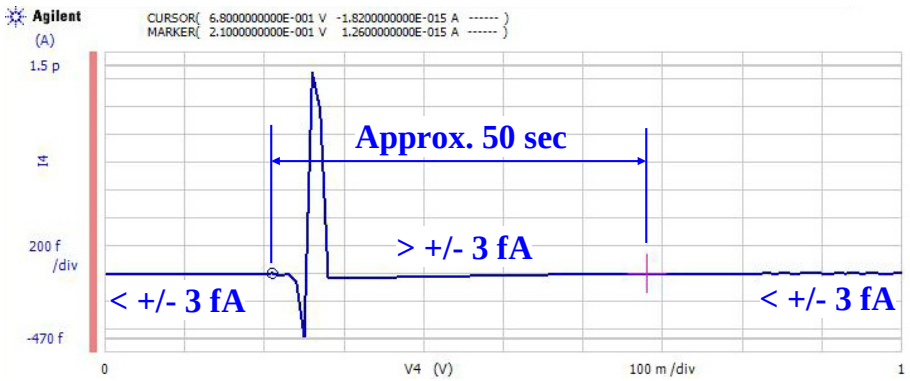
ZERO CHECK
Display Setup



The best check is done with a LINEAR scale which brackets either side of ZERO by 100 fA or less.

A log scale is particularly unacceptable, Log plots of zero are not possible, and all readings of a log plot must be either all positive or all negative.

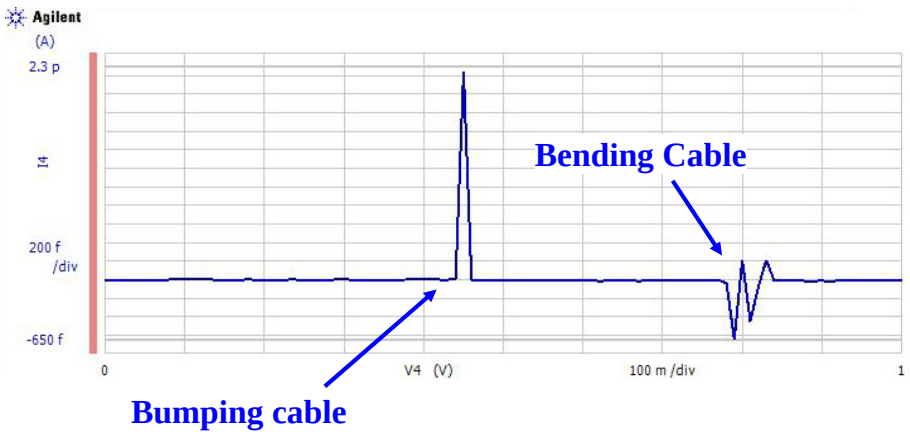
ZERO CHECK
Effect of connecting a triaxial cable



If you change anything in your fixturing or cabling, wait at least 1 minute before making a measurement at low currents.

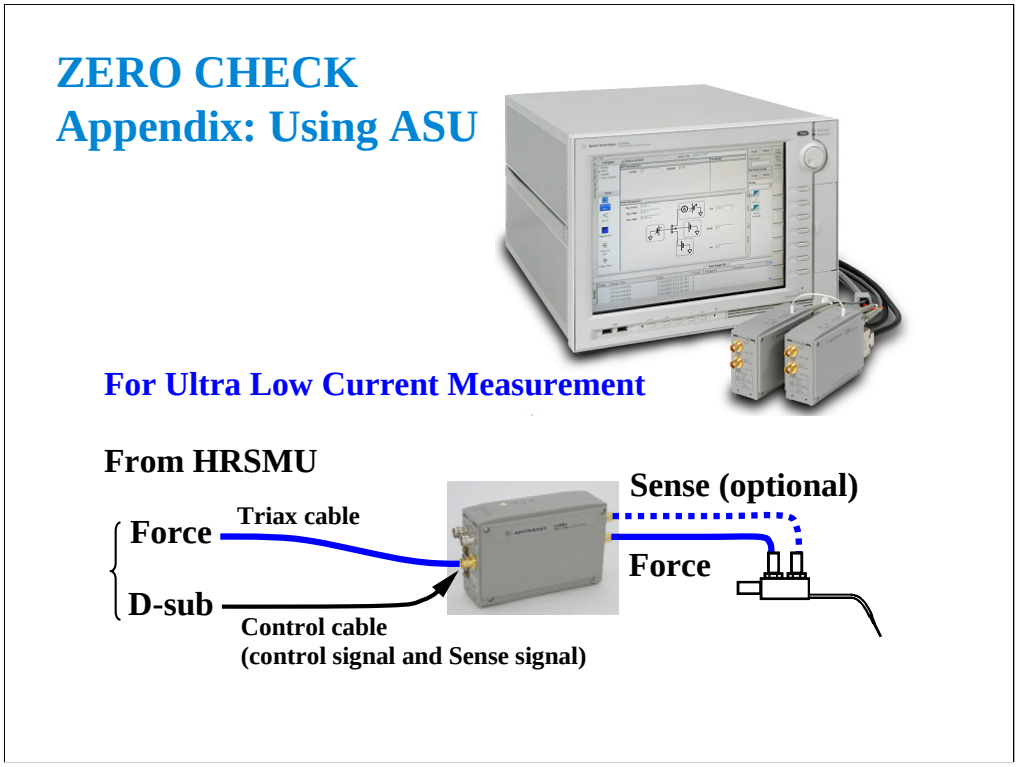
Here we see the effect of connecting a cable to the open SMU port of the B1500A. The discontinuity lasted for 50 seconds of a 2 minute sweep from 0 to 1 volt in 10 mV steps.

ZERO CHECK
Effect of cable movement



As you can see, your fixturing must be free from vibration. Bending cables during a test is another NO NO. The above measurements were made on a single triax cable for classic parameter analyzers. The Kelvin triax cable is less sensitive to movement (triboelectric effects). However, either cable works fine to fA level if the cables are reasonably still...i.e. not swinging, coiled up and moved, etc.

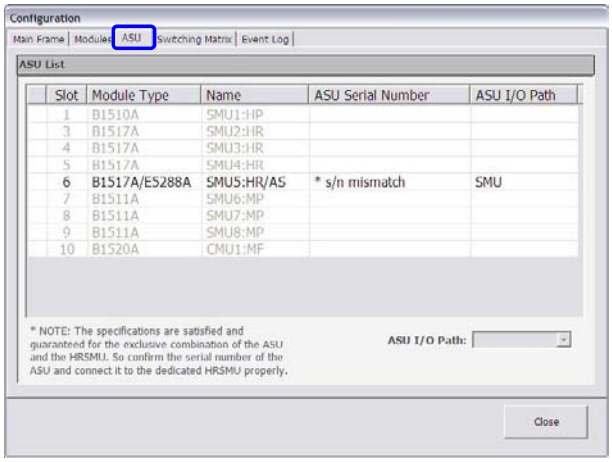
(End Of This Class Exercise)



For ultra low current measurement, use ASU (atto sense/switch unit).
The HRSMU has an innate 1 fA measurement resolution. And the ASU extends it to 0.1 fA.

Note that the ASU must be connected to the HRSMU before turning on the B1500A.

ZERO CHECK
Appendix: Using ASU



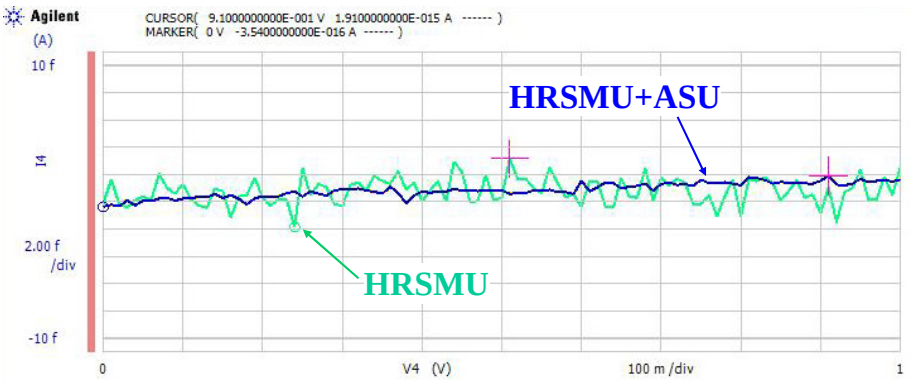
You can check whether the ASU connection is correct or wrong. Open the Configuration window and look at the ASU tab screen.

If the ASU Serial Number field shows its serial number, the HRSMU-ASU combination is correct.

If the ASU Serial Number field shows *s/n mismatch, the combination is wrong.

The B1500A can work with this wrong combination however it cannot satisfy its specifications. The specifications are guaranteed for the correct combination of HRSMU and ASU.

ZERO CHECK
Appendix: Using ASU



This slide shows the open measurement results with ASU and without ASU.

The ASU provides the 1 pA measurement range and the stable measurement results as shown.

The 1 pA range is disabled with the default setting. To enable the 1 pA range, set the ranging mode to LIMITED 1 pA (1 pA limited auto ranging) or FIXED 1 pA (1 pA fixed range).

Class Exercise
Low Current Subthreshold

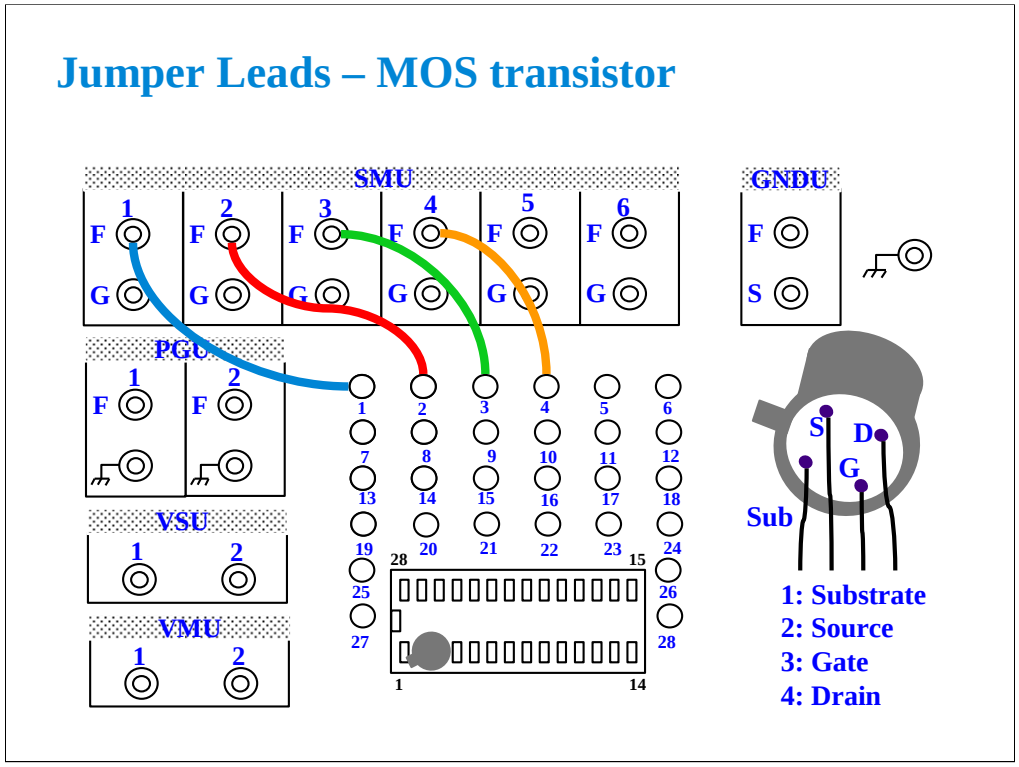
You will:

- Check low level accuracy with fixture lid open/closed
- Observe trade off between resolution and speed
- Change resolution from LIMITED 1 nA to LIMITED 10 pA
- Observe trade off between averaging and speed
- Change integration from AUTO to PLC to MANUAL

To Get Started:

- Use the next pages to setup the MOS FET correctly
- Get the IDVG setup in the Demo preset group

The following pages show a typical plot of the subthreshold curves for this class exercise, device connections, and setup changes with comments.

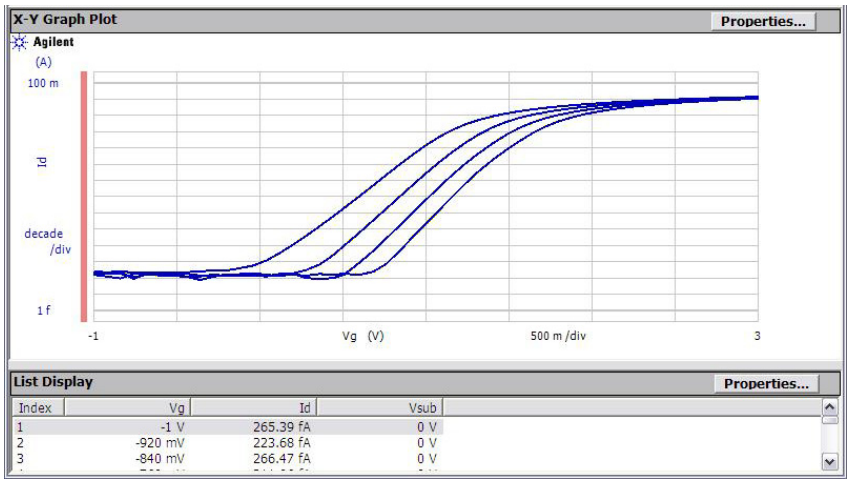


With the 16442A/B fixture, note that there are two SMU numbering schemes....3 SMUs with force and sense, or six SMUs with force only. For this class example we will use the six (6) SMU scheme. On older fixtures, this scheme is shown in light blue lettering. In newer fixtures, this scheme is shown in white reverse background lettering.

Connect the cables between the B1500A and test fixture as follows.
SMU1 : SMU1
SMU2 : SMU2
SMU3 : SMU3
SMU4 : SMU4

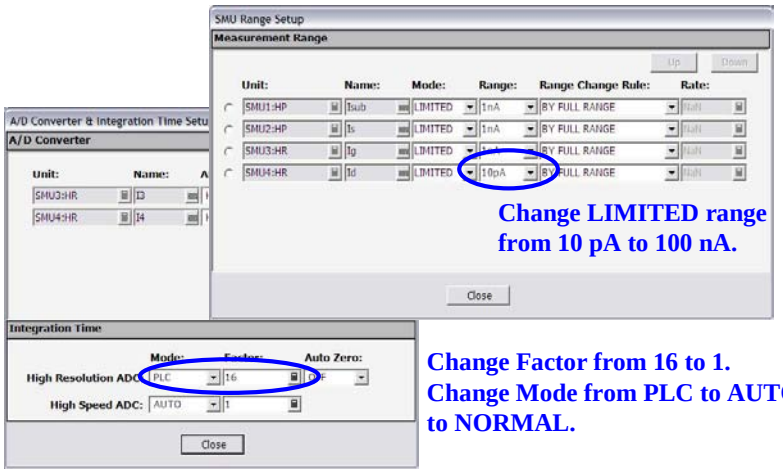
Connect jumper leads as follows.
Terminal 1 : SMU1 F terminal
Terminal 2 : SMU2 F terminal
Terminal 3 : SMU3 F terminal
Terminal 4 : SMU4 F terminal

Class Exercise
SD214DE MOS Subthreshold



With lid closed, you should see this typical response using the IDVG setup data. If the subthreshold region is much higher, at the pA or nA level, the MOS device may be statically damaged. Replace the device using the handling procedure detailed on the previous page.

Class Exercise
Trade Off Speed vs Accuracy



Change LIMITED range from 10 pA to 100 nA.

Change Factor from 16 to 1.
Change Mode from PLC to AUTO to NORMAL.

You can trade off speed vs accuracy by varying the LIMITED range setting or the integration time setting.

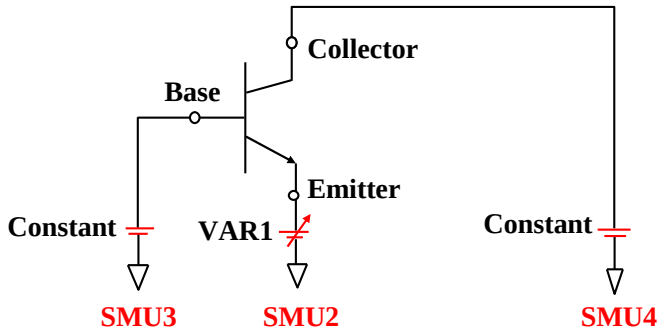
The 100 nA range will speed up the test but you will lose low-end resolution. Try setting LIMITED to 10 pA range or 100 pA range. Accuracy increases but speed slows considerably.

For the integration time, small factor value will speed up but accuracy decreases.

Also measurement speed will be changed by the Mode setting. Set the mode which provides applicable measurement results.

Gummel Plot
What is measured?

- **Ve is swept while Vb and Vc are held at 0 V**
- **Ib and Ic are plotted on log scale**



The "Gummel Plot" is an excellent low current measurement to make on a bipolar transistor. It plots log base current and log collector current against the same bias voltage. A good bipolar device has constant gain over a wide bias range (both curves are linear and parallel). Low level base and collector currents can be measured to the fA level on small signal devices.

Above, we see the simplest channel definition for making a Gummel plot. The emitter is swept from ground to a negative value on a NPN device. Another method would be to hold Ve at 0 V while synchronously sweeping Vb and Vc in a positive direction. In the later case, Vb could be the primary sweep VAR1, and Vc could be the synchronous sweep VAR1'.

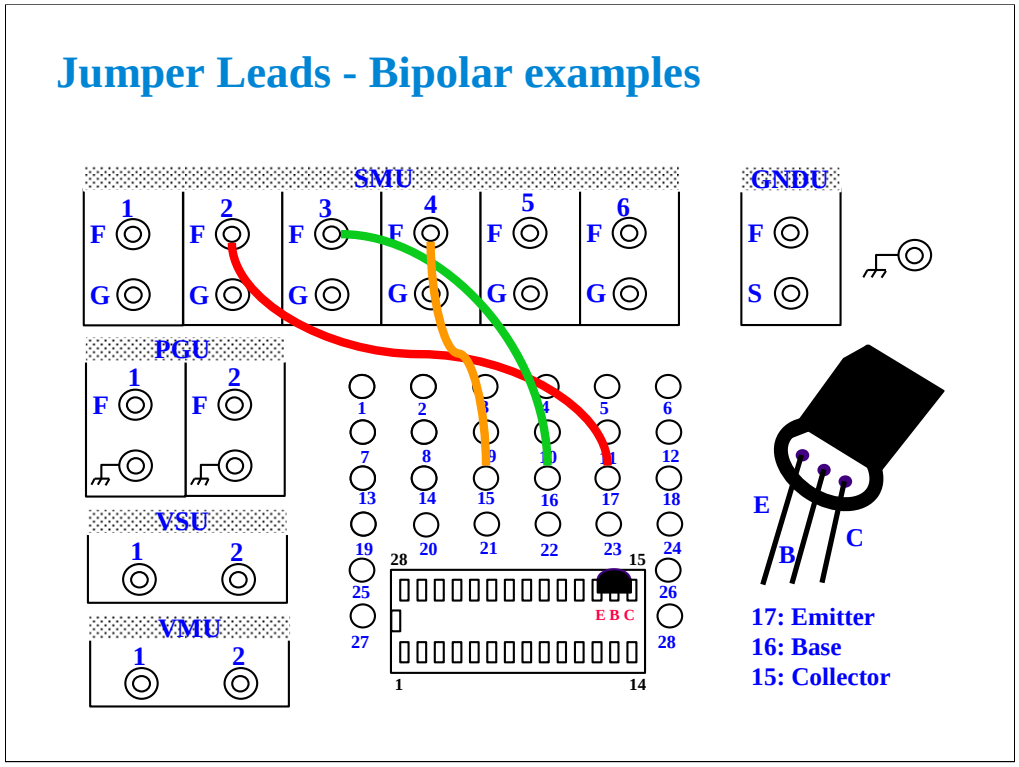
Class Exercise
Low Current Gummel Plot

- You will notice that sub 10 fA measurements are possible

To Get Started:

- Set the jumper leads for the bipolar transistor
- Insert the device and perform a zero cancel offset
- Get the GUMMEL setup in the Demo preset group

The following pages will lead you through the setup and measurement procedure for a low current Gummel measurement. Single triaxial cable connections to the force lines of SMUs 2, 3, and 4 are fine for this test. Kelvin triaxial cables are not necessary.



With the 16442A/B fixture, note that there are two SMU numbering schemes....3 SMUs with force and sense, or six SMUs with force only. For this class example we will use the six (6) SMU scheme.

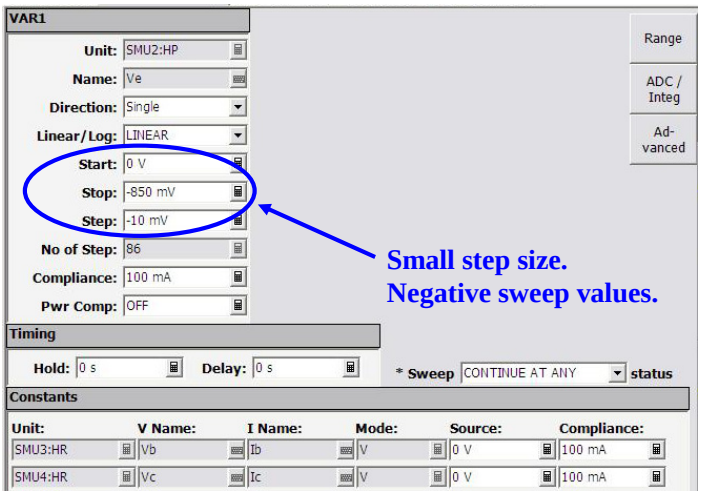
Connect the cables between the B1500A and test fixture as follows.
SMU1 : SMU1
SMU2 : SMU2
SMU3 : SMU3
SMU4 : SMU4

Connect jumper leads as follows.
Terminal 15 : SMU4 F terminal
Terminal 16 : SMU3 F terminal
Terminal 17 : SMU2 F terminal

Locate the bipolar transistor in the corner of the socket as shown, with the flat side of the device facing toward you.

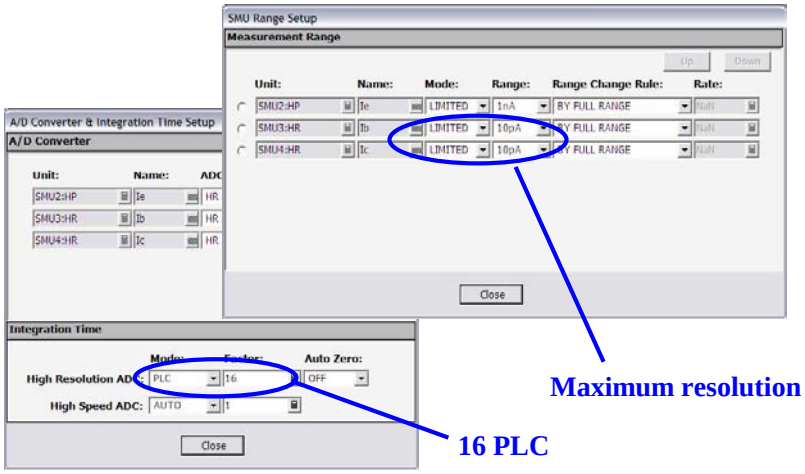
Unlike the MOS device, the bipolar transistor is not static sensitive. You may touch the leads without using a ground strap.

Gummel Plot
Measurement Setup



Ve is swept below ground level to keep positive bias on the NPN device.

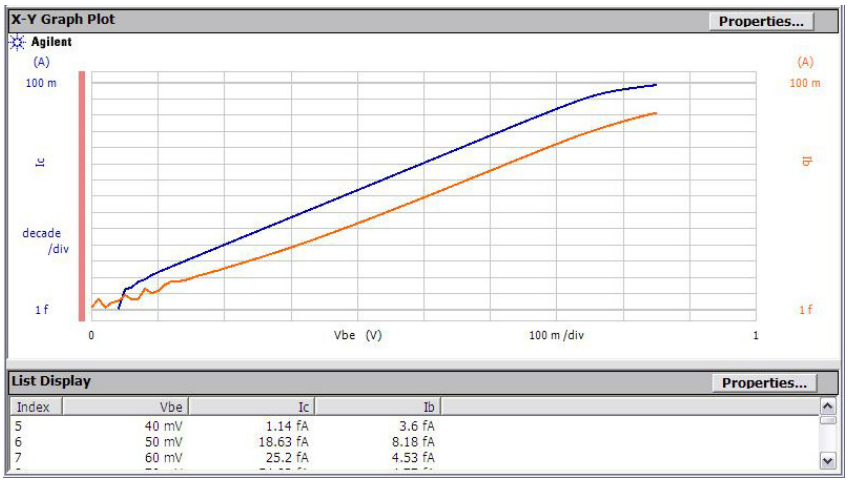
Gummel Plot
Range and Integration Time



Medium integration smoothes the plot at the ultra low levels. Make sure the range is set to AUTO or LIMITED to lowest current range:

HRSMU: 10 pA
MPSMU: 1 nA
HPSMU: 1 nA

LOW CURRENT MEASUREMENT
Gummel Plot

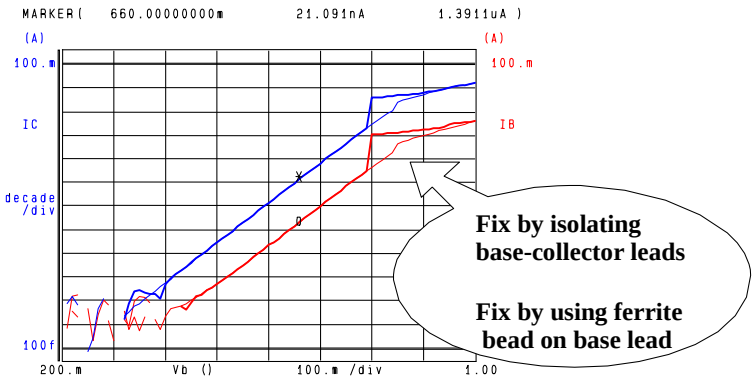


This curve shows a normal gummel characteristic of the bipolar transistor. The collector current is linear when plotted on log scale from 10 mA down to fA levels.

Keep the fixture lid closed and do not bump any part of the setup during the measurement.

(End of This Class Exercise)

Gummel Plot With Base-Collector Self Oscillation

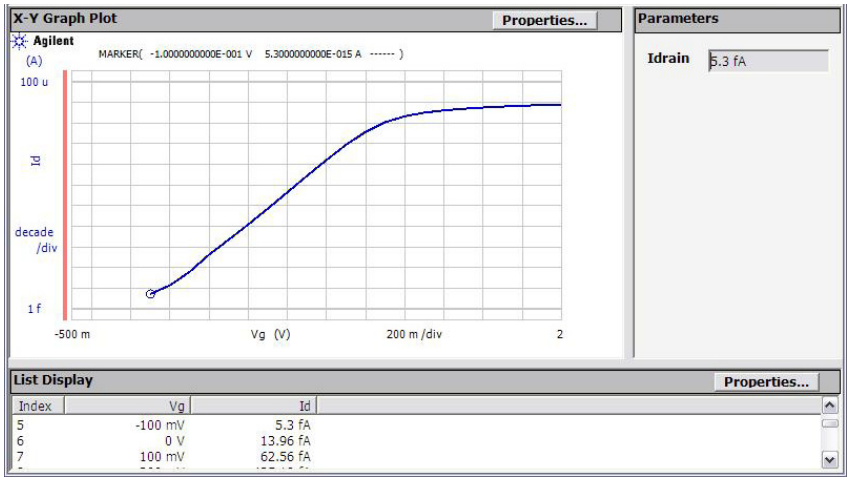


This is a common occurrence when high frequency bipolar transistors are tested with jumper lead connections. When RF couples in the air to the base lead, there can be enough DC rectification to increase the base current bias. This causes positive feedback. At some point along the curve, there will be enough feedback to abruptly turn on the transistor (steep increase in base and collector current).

Separating the leads can help marginally. Threading one or two ferrite beads onto the base jumper lead usually solves the problem. Use ferrite beads with any type of 4145, 4155, 4156 jumper lead. Using the beads on a jumper lead involves prying open one end of the plastic connector. The connector is temporarily unsoldered from the lead to slip on several beads.

For severe oscillation, the RF transistor must be tested in an RF fixtured designed to maintain RF isolation between input (base) and output (collector) ports.

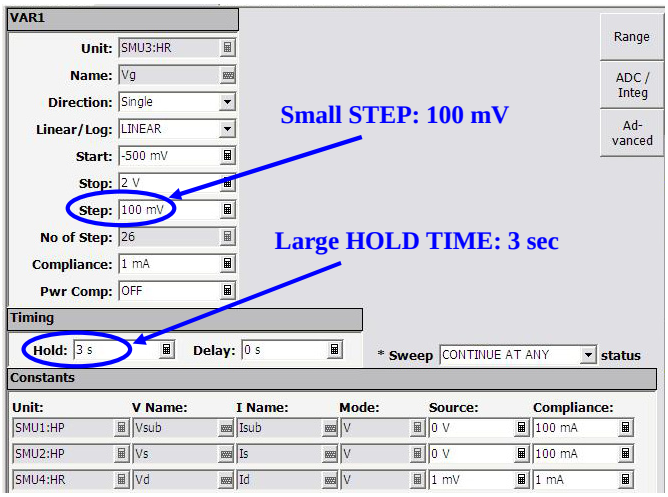
ULTRA LOW CURRENT
Subthreshold Curve



This curve shows the high quality measurement that you would typically expect with the B1500A and a well guarded probe station. The MARKER is sitting at 5.3 fA near the subthreshold region.

To get best ultra low current accuracy, zero the SMU offset error just prior to taking the measurement by using the Calibration window. See beginning of this module, before page 10 in this module. Do the ZEROing procedure with the probes up.

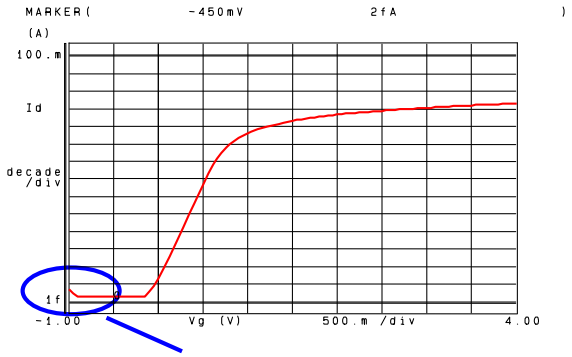
ULTRA LOW CURRENT Measurement Setup



To prevent charging current due to residual cable or probe capacitance, you should limit the STEP size to 100 mV. The B1500A has a built-in delay time on the low current ranges, and you do not need to add extra time.

If the STEP is large, like the -500 mV for the first point in this sweep, simply add an initial hold time. 3 to 5 seconds should work fine. This has the effect of holding off measurement for a specified amount of time, at the beginning point only.

ULTRA LOW CURRENT
Effect of Cable Charging Current

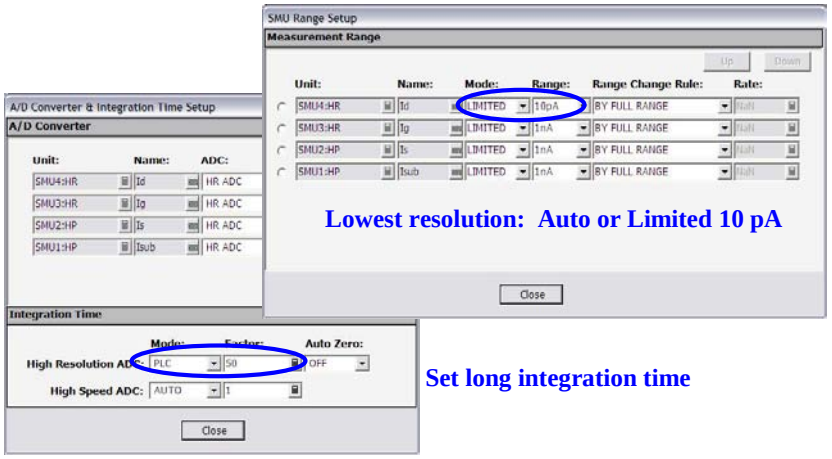


Not part of the subthreshold characteristic

You can see an initial high current that drops off after a few measurements. This is the effect when delay time is set to zero. Any residual capacitance due to un-guarded probes is the cause. This effect is minimal in this case due to the use of fully guarded probes to within 2 mm of the probe tip. With unguarded probes this initial charging current can be orders of magnitude larger, and dominate the low end portion of the subthreshold curve.

The solution is to improve the guarding as much as practical. Then get the last bit of charging out of the curve by using a delay time of at least 3 seconds in the Measurement Setup. This gives the cable time to discharge prior to making the first measurement.

ULTRA LOW CURRENT
Range and Integration Time

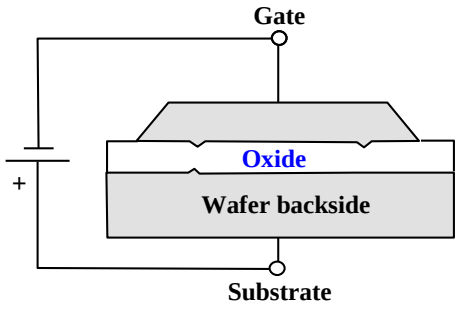


In this example we are measuring Id very accurately. The B1500A autoranges every decade of current down to 1 nA as a factory default. Change this to AUTO or LIMITED 10 pA to get two more ranges of low end resolution (1 fA resolution). The factory default of LIMITED 1 nA gives 100 fA resolution and is adequate for most measurements. Since the B1500A can trade off speed for resolution, you get better speed performance by limiting current ranging.

If your prober environment is not ultra low noise, you can remove some random noise by setting long integration time.

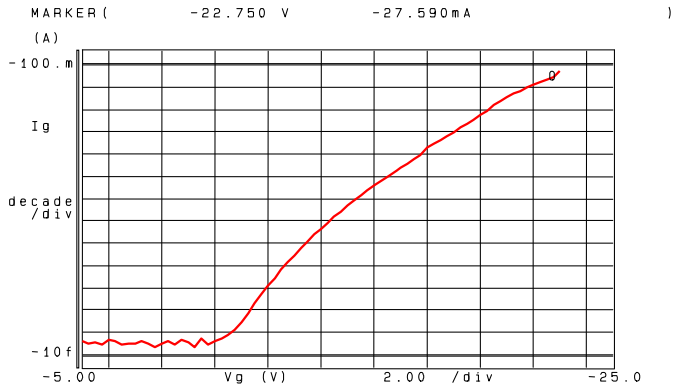
Low Current Leakage
Gate Oxide

- Leakage to fA levels
- Electrical connection to wafer backside
- Chuck must be guarded



Gate oxide leakage tests are complicated by the fact that there is an electrical connection to the back of the wafer. The chuck must be insulated and guarded to get meaningful low current results. The huge capacitance of the chuck surface would cause charging currents which would swamp out the low level currents you are trying to measure through the oxide.

Low Current Gate Oxide Measurement
Fowler-Nordheim (FN) Plot

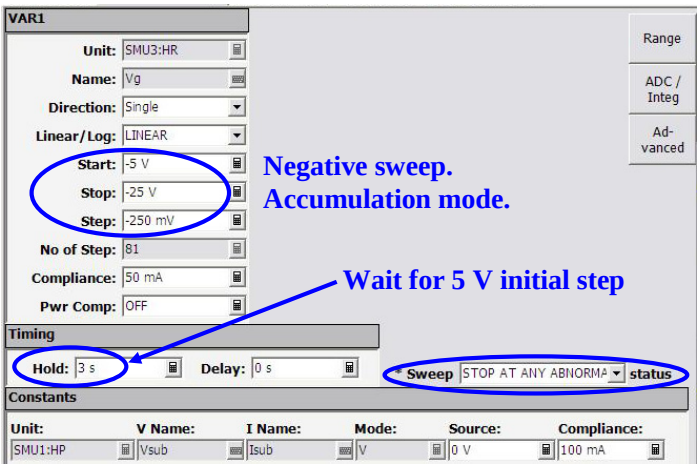


The Fowler-Nordheim (FN) plot is a log plot of oxide leakage in accumulation mode breakdown. The plot shows a characteristic "arc" leading up to the rupture current.

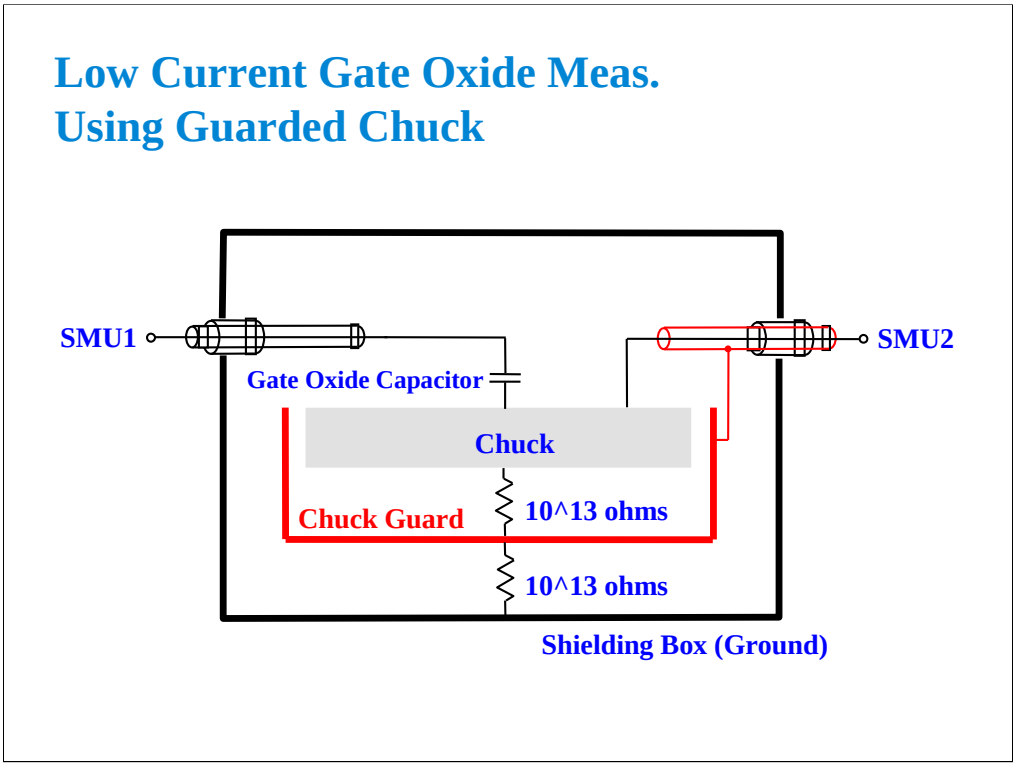
This plot is a measurement result example of a MOS capacitor on a wafer. You cannot get this kind of plot by measuring the class exercise MOS FET.

The MARKER is set to -27.590 mA. This is the point at which rupture of the gate oxide occurred. The B1500A has the sweep abort function which automatically aborts sweep measurement when any abnormal occurs.

FOWLER-NORDHEIM PLOT
Measurement Page



A 3 second delay at the beginning of the measurement will be required. The SMU must initially step from 0 to -5 V, a very large step. Fully guarded probes to within 2 mm of probe tip and fully guarded chuck eliminated the need for delays at every measurement point. The only wait will be the initial 3 second hold time.



This is a simplified block diagram of the prober requirements for a guarded chuck connection. When implemented properly, very fast low level sweeps are possible due to the elimination of stray capacitance at the probes (wafer top side) as well as in the chuck (wafer bottom side).

4 Capacitance Measurement

In This Module

- **CMU Fundamentals**
- **Classic Test Environment**
- **CMU Calibration**
- **SCUU for IV/CV Switching**
- **GSWU for Accurate Capacitance Measurement**
- **ASU for IV/CV Switching**

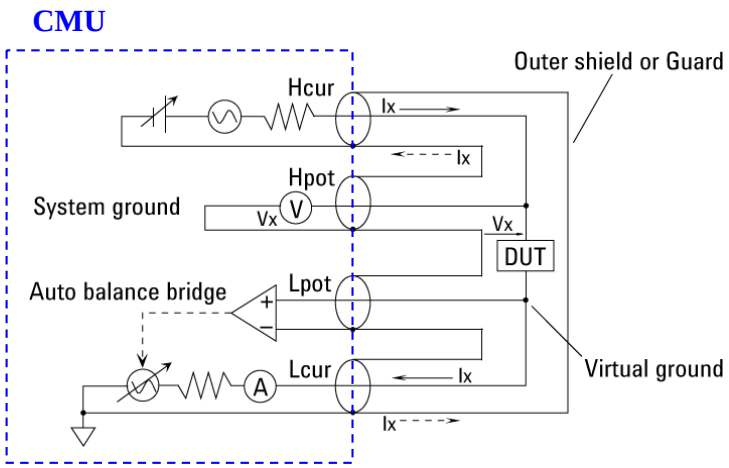
B1500A Multi Frequency CMU

- Occupies 1 slot of B1500A
- Four terminal pair configuration
- Spot & Sweep measurements
- Faster measurement time
- 1 kHz to 5 MHz frequency range
- +/-25 V DC bias
  (+/-100 V with SCUU)
- Cable length auto detection (1.5 or 3 m)
- Higher accuracy below 100 pF

The multi frequency CMU (capacitance measurement unit) adds the CV measurement capability to the B1500A. You can now perform both IV and CV measurements by using the B1500A one box without an external capacitance meter.

Key features of the CMU are listed above.

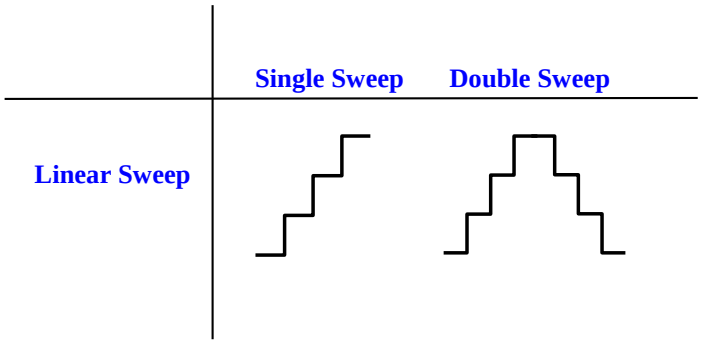
CMU Block Diagram
Four-Terminal Pair Configuration



Generally, any mutual inductance, interference of the measurement signals, and unwanted residual factors in the connection method incidental to ordinary termination methods will have significant effects on the measurements, especially at a high frequency. The CMU employs the four-terminal pair (4TP) measurement configuration which permits easy, stable, and accurate measurements and avoids the measurement limitations inherent to such factors.

The above figure shows the four-terminal pair measurement principle. The measurement terminals consist of the following four coaxial connectors.
-Hcur: High current
-Hpot: High potential
-Lpot: Low potential
-Lcur: Low current

C-V Sweep Source



Up to +/- 25 V, using only CMU
Up to +/- 100 V, using SCUU (Agilent N1301A-100)

CMU supports the linear single sweep and the linear double sweep. The CMU can sweep up to a value and then back down (double sweep). This feature is useful when the device must be tested without abruptly removing the forcing condition.

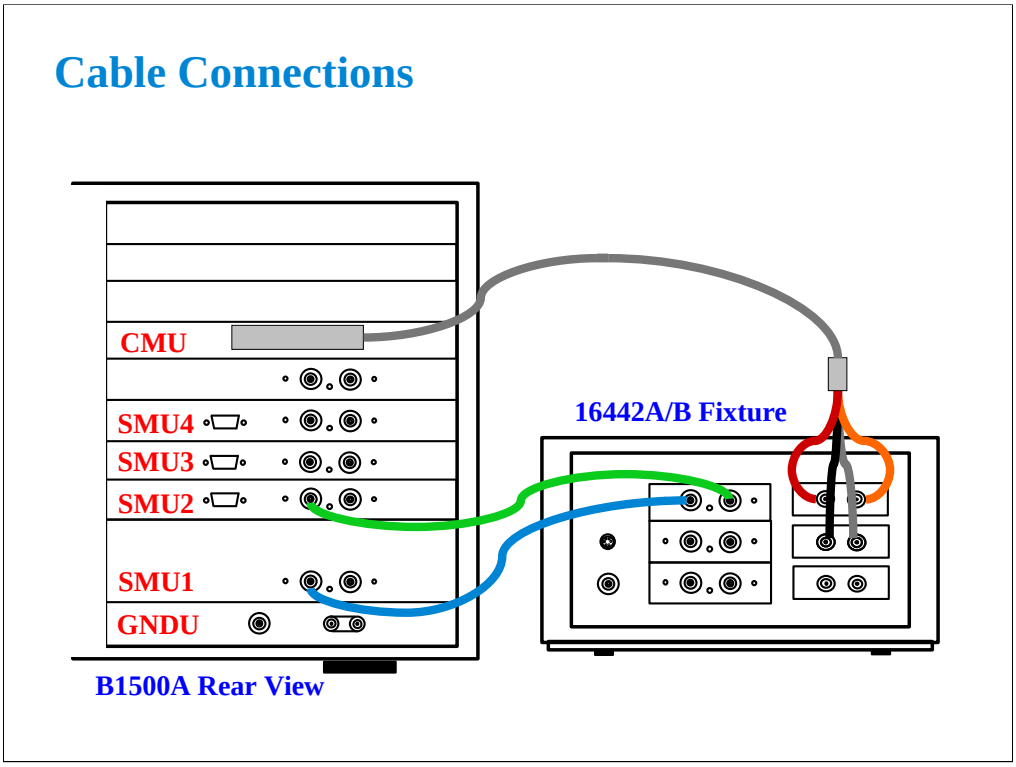
The CMU can force up to 25 V DC bias. The DC bias can be expanded up to 100 V by using the SCUU (SMU CMU unify unit) that is used to switch the IV measurement and the CV measurement automatically. For the SCUU, see the following pages in this module.

Class Exercise
C-V Sweep Measurement

- You will make the MOS FET Cgs-Vg measurement
- You will learn how to properly define a C-V sweep algorithm

To Get Started:

- Use the next several pages as you guide
- Get the CV-1MHz setup
- Follow the instructions on the following pages



The following cables are required to perform this class exercise.

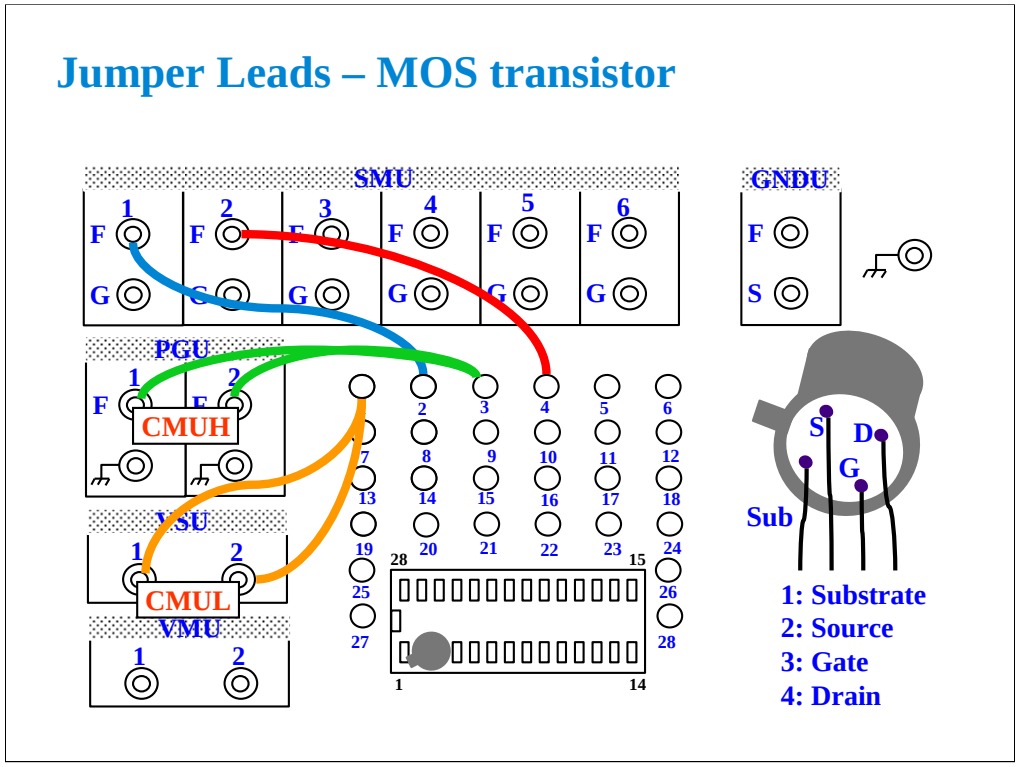
CMU cable (Agilent N1300A-001/002), 1 ea.

Triax cable (Agilent 16494A-001/002), 2 ea.

One side of the CMU cable forms the attachment used to join and fix it to the CMU. And the other side provides four BNC connectors used to connect the fixture as shown.

Connect the cables between the B1500A and the test fixture as follows.

SMU1 : SMU1
SMU2 : SMU2
Hcur : PGU1 (red)
Hpot : PGU2 (orange)
Lcur : VSU1 (black)
Lpot : VSU2 (gray)

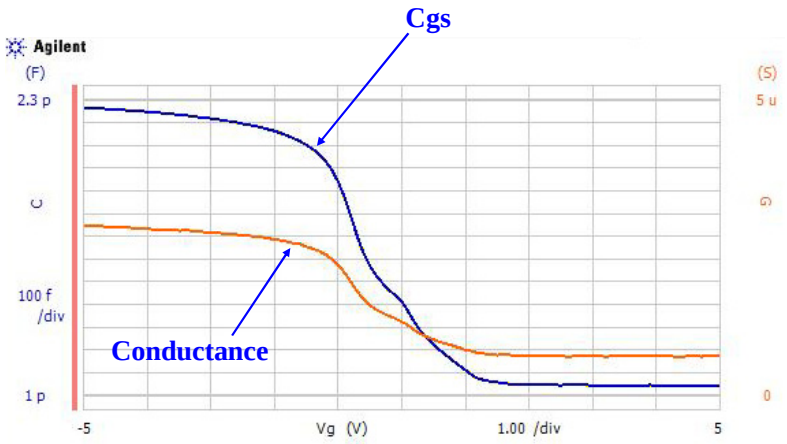


With the 16442A/B fixture, note that there are two SMU numbering schemes....3 SMUs with force and sense, or six SMUs with force only. For this class example we will use the six (6) SMU scheme. On older fixtures, this scheme is shown in light blue lettering. In newer fixtures, this scheme is shown in white reverse background lettering.

This class exercise requires six jumper leads to connect the DUT. Connect the jumper leads between the following terminals.

SMU1 : terminal 2
SMU2 : terminal 4
PGU1 : terminal 1
PGU2 : terminal 1
VSU1 : terminal 3
VSU2 : terminal 3

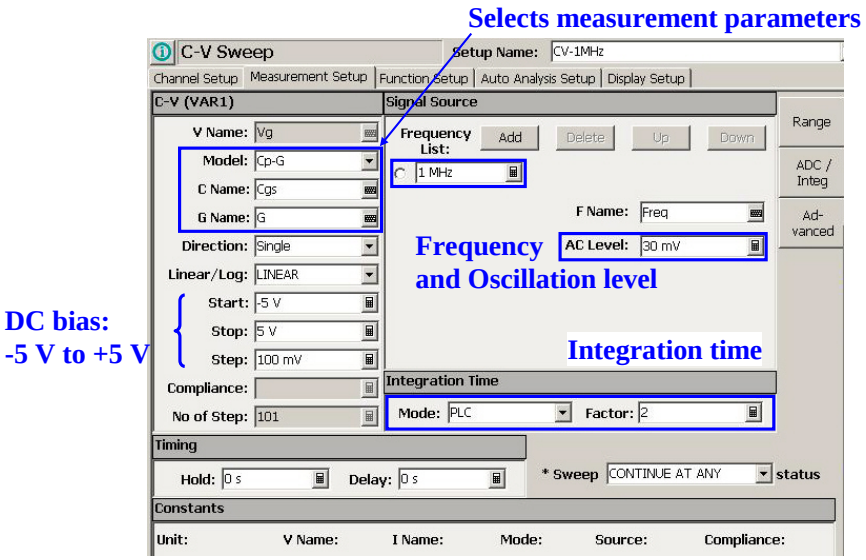
Capacitance Measurement
Measurement Example



This is the measurement example of the MOS FET Cgs-Vg characteristics.

To make the measurement, set SMU1 and SMU2 to COMMON. And set the CMU as shown in the next page.

Capacitance Measurement
Measurement Setup



1. Select the Cp-G mode, and enter the C Name and G Name.
2. Set the Start, Stop, and Step to specify the DC bias sweep condition.
3. Set the Frequency List to specify the measurement frequency.
4. Set the AC Level to specify the AC signal level (oscillation level).
5. Set the Integration Time as you like.

(End of This Class Exercise)

CMU Calibration

Type	Effectiveness	Measurement terminals
Phase Compensation *Perform before measurement*	Corrects phase error caused by extending measurement cables.	Open terminals
Open Correction *Perform before measurement*	Corrects for stray admittance. Effective for high impedance measurement.	Open terminals
Short Correction *Recommended*	Corrects for residual impedance. Effective for low impedance measurement.	Connect terminals together
Load Correction *Recommended*	Corrects any error by using the working standard.	Connect standard

CMU is equipped with the error correction function used to realize accurate impedance measurements. The correction function minimizes the effects of the error elements in the extension cables and the DUT interface such as manipulator and probe card.

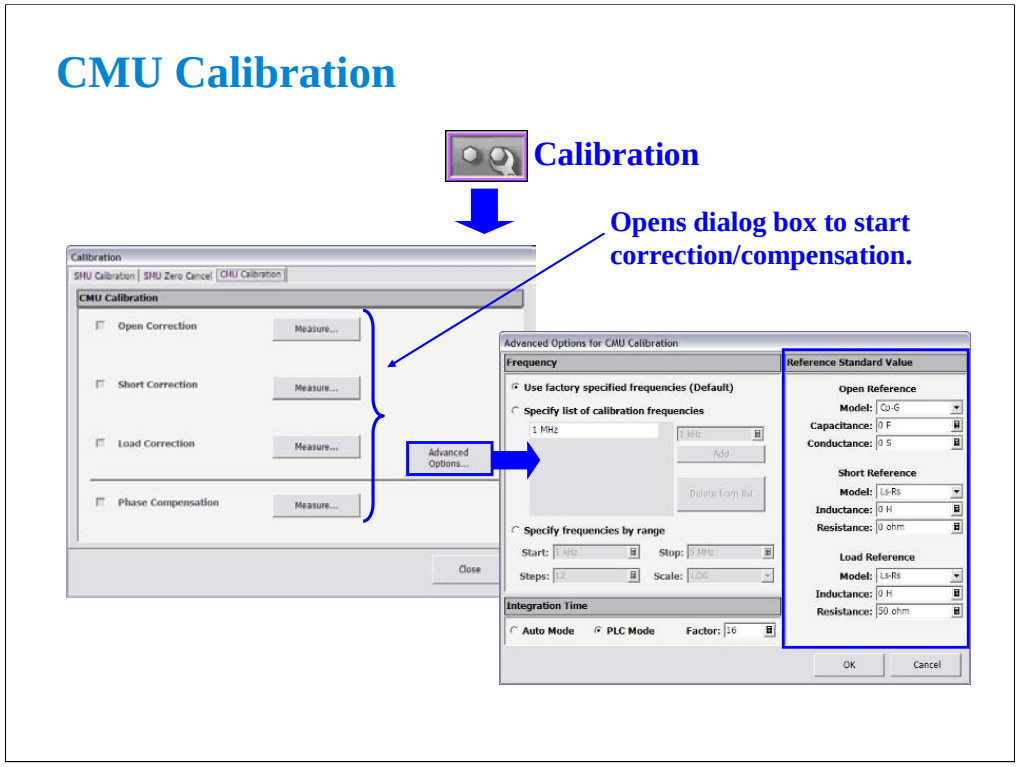
At least perform the phase compensation and the open correction. They only need to open the measurement terminals.

Performing the short correction and the load correction is recommended.

If it is easy to make the short condition in your test environment, perform the short correction.

If you have the load standard, perform the load correction.

The standard must have the reference value. And the reference value must be defined in the Advanced Options for CMU Calibration window. This window is opened by clicking the Advanced Options… button. See the next page.



Open the Calibration window and click the CMU Calibration tab to perform the CMU calibration.

At first, open the measurement terminals for CMUH and CMUL, and perform the Phase Compensation by clicking the Measure… button.

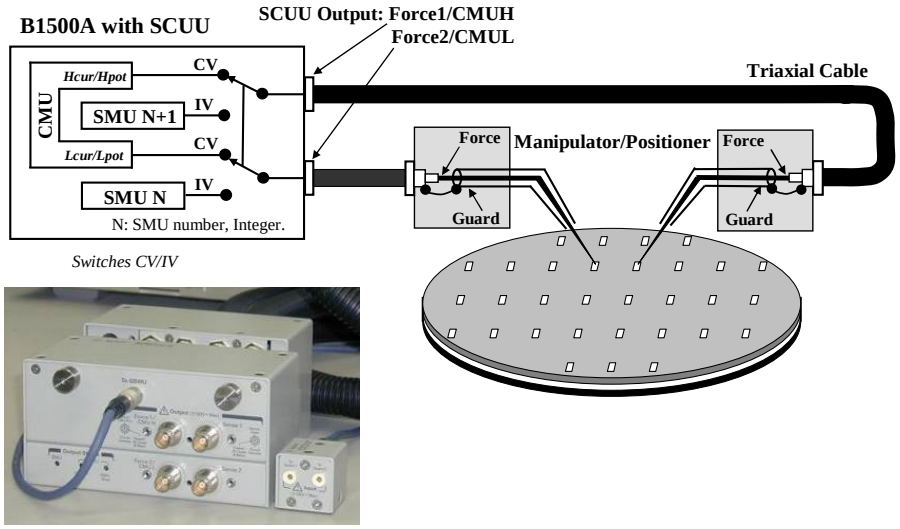
After the phase compensation, perform the Open Correction by clicking the Measure… button.

If you can make the short condition, short the measurement terminals, and perform the Short Correction.

If you have the load standard, connect it, and perform the Load Correction.

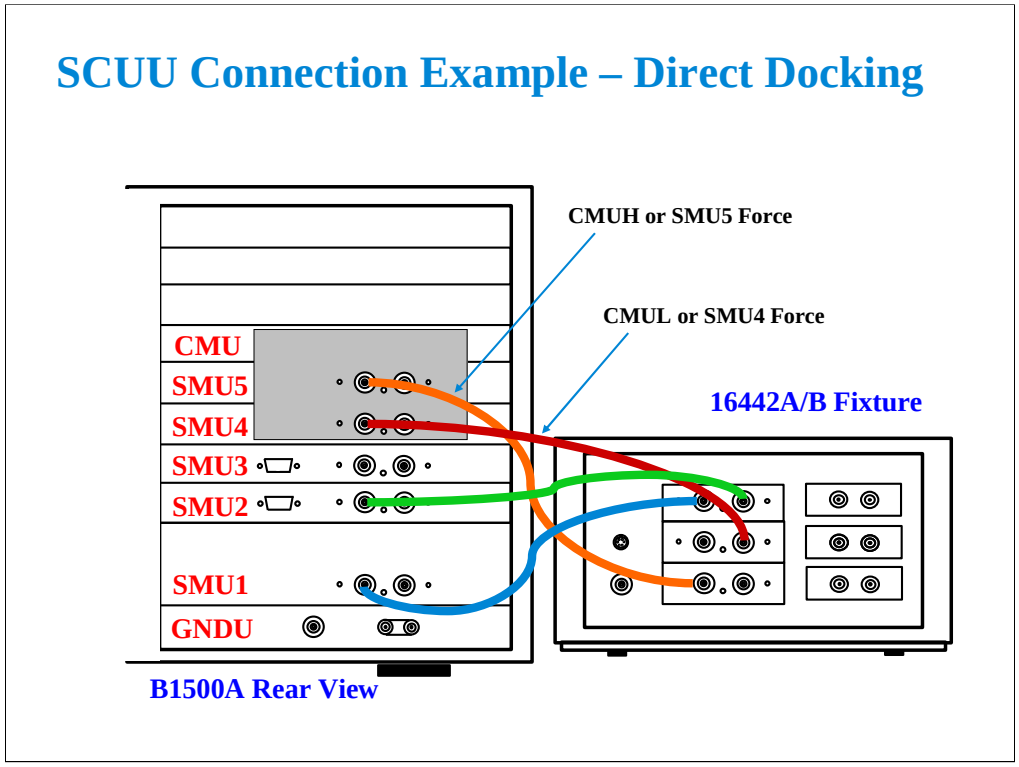
Note:
If you use the calibration standard, define the reference data before starting the calibration. It must be defined in the Reference Standard Value on the Advanced Options for CMU Calibration window.

SCUU – for IV/CV Switching



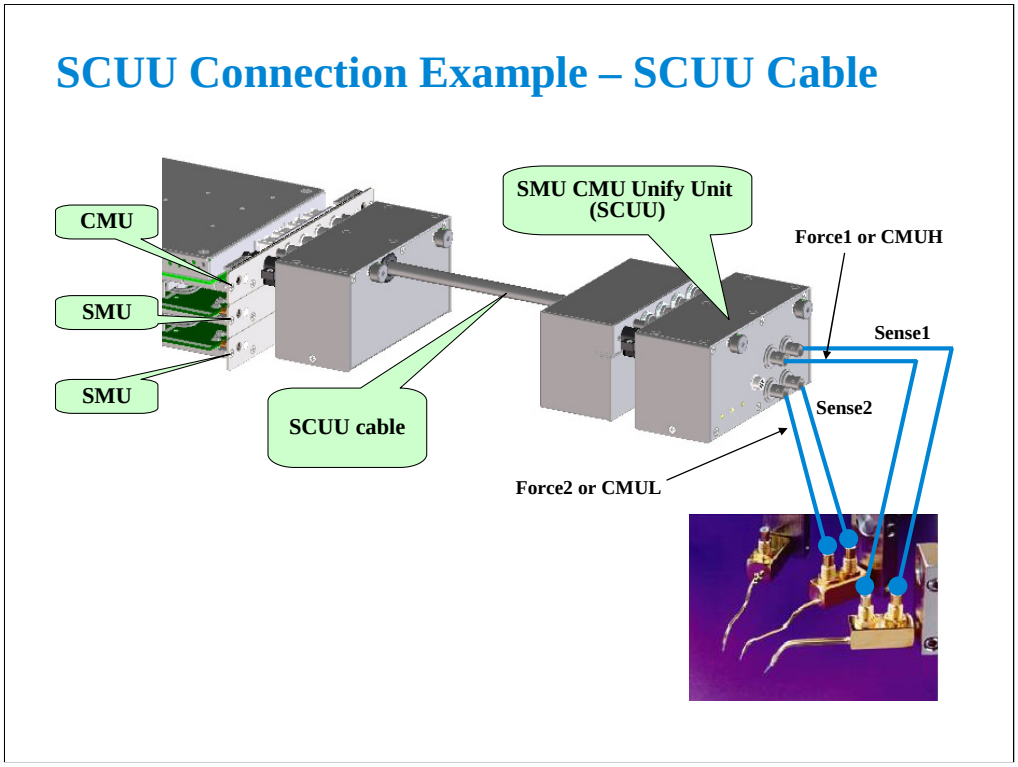
You have a very hard time switching between CV and IV measurements (you may actually devote separate probe stations to CV and IV just to avoid having to change cables). In addition, great care has to be taken when cabling to a capacitance meter to insure that all of the capacitance measurements are properly compensated.

The SCUU removes all of these worries and makes connection simple and easy. In addition, the B1500A software automatically takes care of the multiplexing based upon the type of algorithm selected from the front panel.



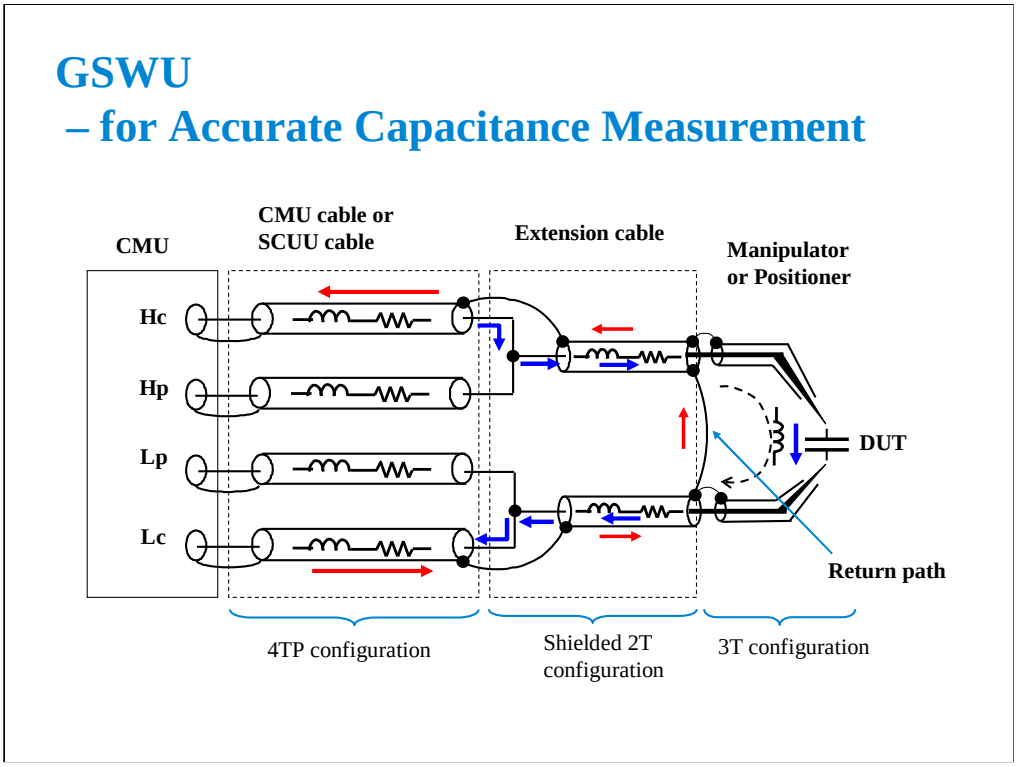
Before connecting the SCUU, turn the B1500A off. And restart the B1500A after connection is completed. The B1500A cannot recognize the SCUU without restart after connection.

Use normal triaxial cables or Kelvin triaxial cables to connect between the SCUU and the test fixture.



To install the SCUU near the manipulators/positioners, use the N1301A-102 SCUU cable.

To realize accurate capacitance measurement, use the N1301A-200/201/202 GSWU & cable. See the next section.



This slide shows the typical cable connections for the capacitance measurement. Note the following tips to perform the measurement accurately.

-Extend the four terminal pair configuration as close as possible to the device side
-Make the return path at the end of the extension cables (coaxial cables)

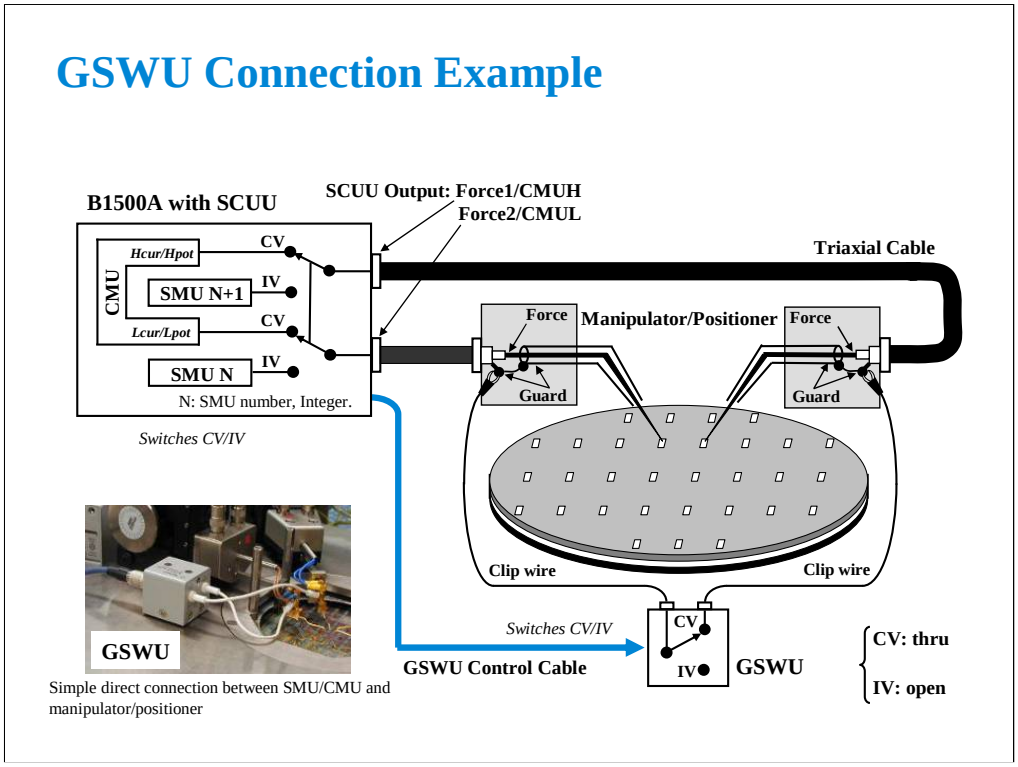
The return path is effective for:

-reducing the residual inductance of the measurement cable
-stabilizing the residual inductance when measurement cable distance is changed (moved)

The residual inductance will be roughly 1/10 to 1/30 compared with no return path.

To make the return path, use the GSWU (Guard Switch Unit) which was developed to make the setup easily. The GSWU is the accessory available only for the B1500A equipped with the CMU and the SCUU.

Note:
For the accurate measurement, it is recommended to make the return path at the point as close as possible to the device side.

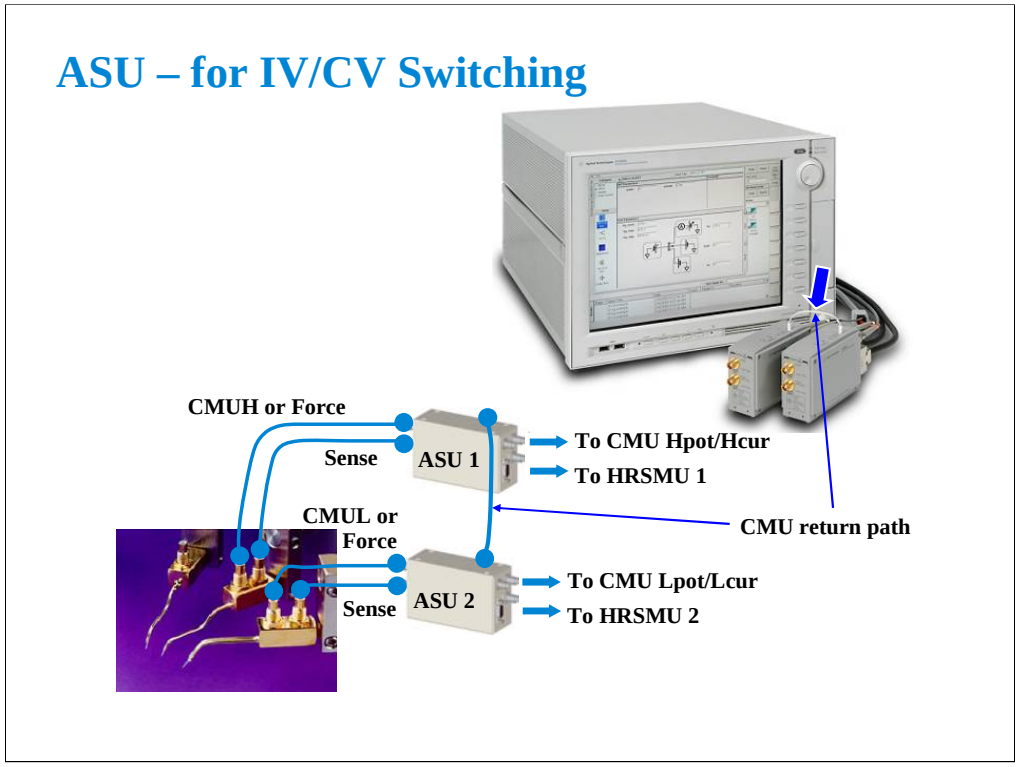


1. Place the GSWU at the appropriate location near the manipulators/positioners.
2. Connect the GSWU control cable between the GSWU and the SCUU.
3. Connect a clip wire between the GSWU and the outer conductor of the manipulator/positioner connected to Force1/CMUH.
4. Connect a clip wire the GSWU and the outer conductor of the manipulator/positioner connected to Force2/CMUL.

When the SMU paths (IV) are available for the manipulators/positioners, the GSWU opens between the outer conductors. However, when the CMU paths (CV) are available, the GSWU connects them together to make the return path of measurement current.

By using the EasyEXPERT software, cable length between the CMU and the SCUU is automatically detected, and the GSWU switch control is automatically performed. Also, capacitance error compensation is also automatically performed if the compensation data are available.

Note:
When the SMU paths are available for the manipulators/positioners, the connection between the outer conductors must be broken because they are connected to the SMU guard terminals separately and the guard terminals must be disconnected from anything at the end of the extension.



The ASU (Atto Sense and Switch Unit) is available for the B1500A installed with the HRSMU. Using the ASU permits use of the 1 pA range. Also the ASU can switch the measurement resources, HRSMU or an instrument connected to the AUX input connectors.

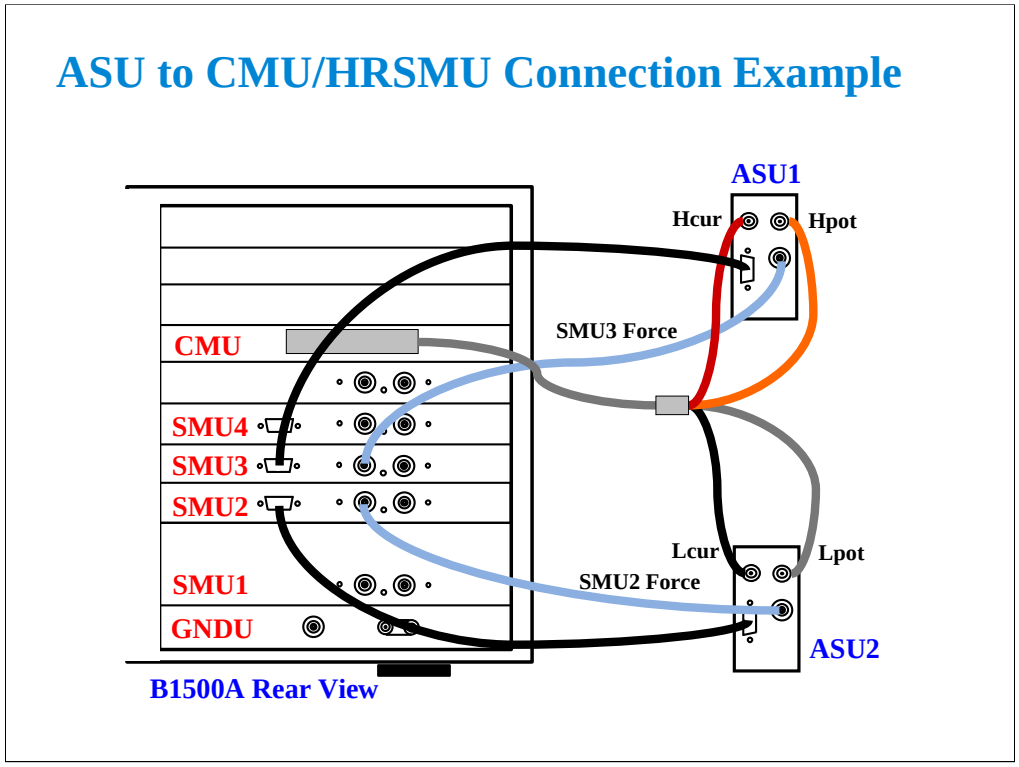
The ASU has input connectors, one triaxial and two coaxial. The triaxial connector must be connected to the HRSMU Force terminal, and the coaxial connectors must be connected to the other resource such as CMU. Also the ASU has the control connector to be connected to the HRSMU by using the ASU cable.

The ASU has output connectors, two triaxial, that must be connected to the DUT interface such as manipulators or probe card. When the measurement resource is the HRSMU, they are the Force/Sense connectors for the Kelvin connection. And when the resource is not the HRSMU, the CMU/AUX is connected to the Force, and the Sense is not used.

If you connect the CMU, two ASUs are required. Then the ASU's CMU-pot/CMU-cur connectors must be connected to the Hpot/Hcur of the CMU. And the other one must be connected to the Lpot/Lcur in like manner.

To realize accurate impedance measurements using the four-terminal pair measurement method, connect the CMU return terminals of ASUs together.

Note:
For the accurate measurement, it is recommended to make the return path at the point as close as possible to the device side.



To connect the ASUs, use the following cables.

CMU cable (Agilent N1300A-001/002), 1 ea.

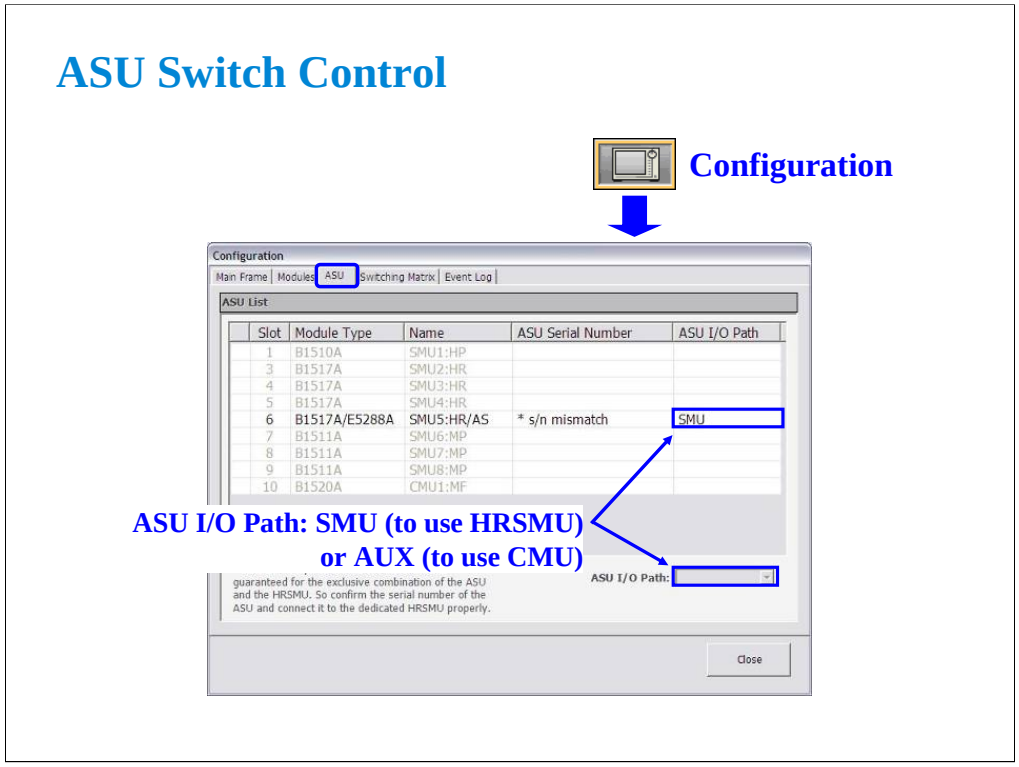
Triax cable (a part of Agilent B5288A-001/002), 2 ea.

D-sub cable (a part of Agilent B5288A-001/002), 2 ea.

One side of the CMU cable forms the attachment used to join and fix it to the CMU. And the other side provides four BNC connectors used to connect two ASUs as shown.

The triax cable and the D-sub cable are connected between ASU and HRSMU.

Before starting the ASU connection, turn the B1500A off. And restart the B1500A after the connection is completed. The B1500A cannot recognize the ASUs without restart after the connection.



To control the ASU switch connection, open the Configuration window and display the ASU tab screen. Then highlight the B1517A/B5288A row and set the ASU I/O Path, SMU or AUX by using the ASU I/O Path pull down menu.

Set SMU when you use the HRSMU.

Set AUX when you use the CMU or the other resource connected to the ASU's AUX In.

If the ASU Serial Number field shows its serial number, the HRSMU-ASU combination is correct.

If the ASU Serial Number field shows *s/n mismatch, the combination is wrong.

The B1500A can work with this wrong combination however it cannot satisfy its specifications. The specifications are guaranteed for the correct combination of HRSMU and ASU.

5 SPGU Control and Applications

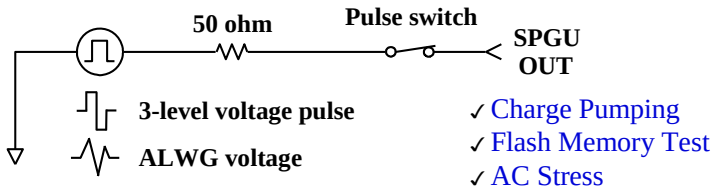
In This Module

- **High Voltage SPGU**
- **SPGU Control**
- **Pulse Generator Mode**
- **Charge Pumping**
- **Flash Memory Test**
- **ALWG Mode**

High Voltage SPGU

High Voltage Semiconductor Pulse Generator Unit

- **2 channels per module**
- **Output impedance: 50 ohm**
- **Amplitude: +/-40 V (open load), +/-20 V (50 ohm load)**
- **PG mode or ALWG mode**
- **Free run, duration, or count**
- **2- or 3-level pulse output for each channel in PG mode**
- **Pulse switch**
- **Automatic voltage level adjustment**



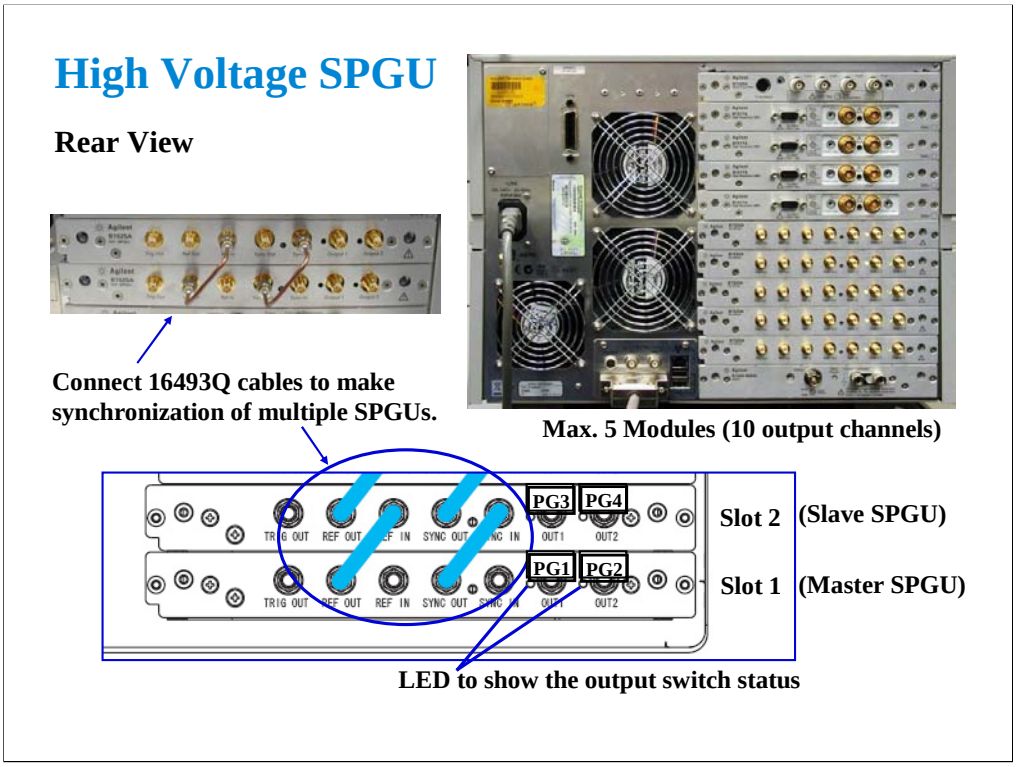
✓ Charge Pumping
✓ Flash Memory Test
✓ AC Stress

High Voltage Semiconductor Pulse Generator Unit (HVSPGU) is specially designed for semiconductor test. Most pulse generators' output voltage is less than 10 V with 50 ohm impedance. However, in semiconductor test (especially reliability test) 30 to 40 V capability is required for the flash memory write/erase cycle test. The HVSPGU output voltage is 40 V at open load.

The HVSPGU provides two output mode, PG mode and ALWG mode. In the PG mode, the HVSPGU can output 2- or 3-level voltage pulse. And in the ALWG mode, it can output an arbitrary linear waveform voltage.

The pulse switch is built into the SPGU channel for performing the endurance test of the NOR type flash memory effectively. The SPGU channel can output the drain pulse for the write operation and make the open status for the erase operation in one pulse period.

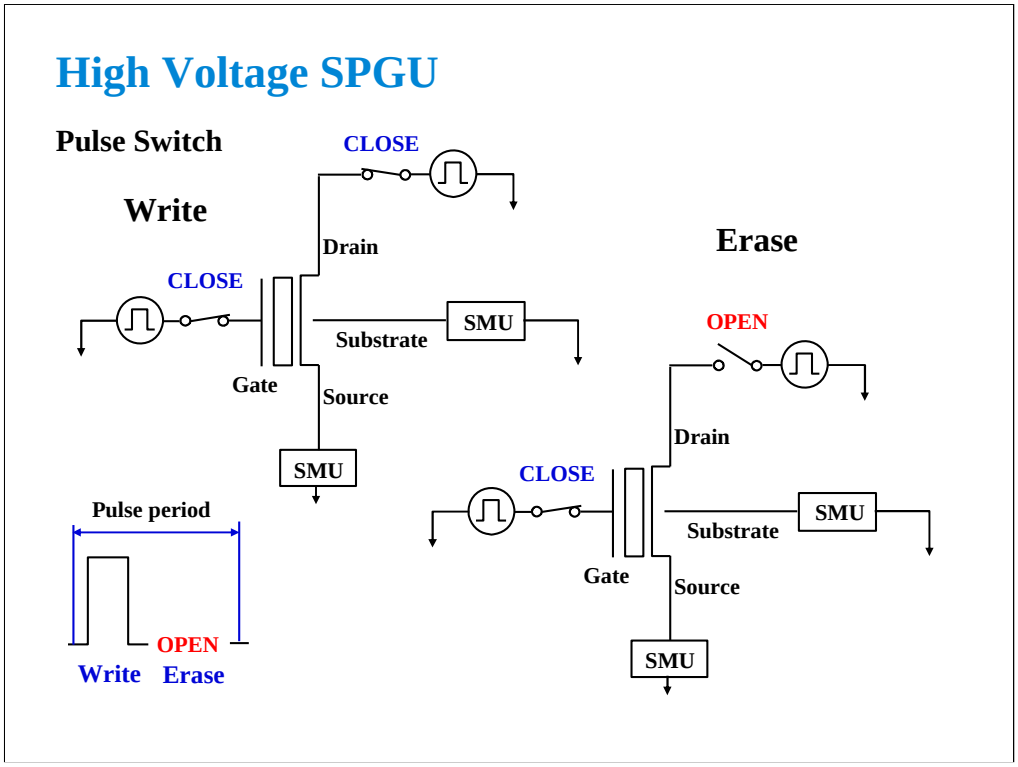
The output impedance of the SPGU is fixed to 50 ohm. However, the SPGU channel can output the voltage close to the setting value if you specify the load impedance of DUT properly. Because the channel automatically adjusts the output level by using the specified load impedance value.



The B1500A can install the maximum of five SPGUs. The SPGUs must be installed in the contiguous slots from the slot 1. Where the SPGU installed in the slot 1 is the master SPGU. The channel number PG1 is assigned for the Output 1 of the master SPGU. And the following numbers are assigned for the subsequent channels.

The SPGU has seven connectors.
The Output connectors are for the SPGU signal output.
The Ref In/Out and Sync In/Out connectors are for making synchronization of multiple modules.
The Trig Out connector outputs the trigger signal used to make synchronization with the external instruments.

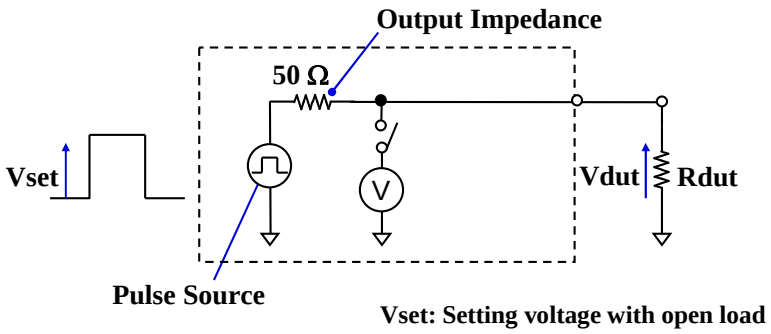
If the multiple SPGU modules are installed, the 16493Q cables must be connected between the Ref Out connector and the Ref In connector and between the Sync Out connector and the Sync In connector as shown above. This is necessary to synchronize the module outputs.



The pulse switch is the built-in high speed analog switch to open/close the SPGU output for each channel. This switch is used in the write/erase cycle of the NOR type flash memory cell test. This dramatically improves throughput of the endurance test (write/erase lifetime reliability test). The SPGU channel can output the drain pulse for the write operation and make the open status for the erase operation in one pulse period.

High Voltage SPGU

Effects of Load Impedance



Vset: Setting voltage with open load

$$Vdut = Vset \times \frac{Rdut}{Rdut + 50}$$

The voltage actually applied to the DUT depends on it's impedance. This behavior is very common among the instrumentations like DC power supply and pulse generators. In this meaning, SMU is very special because the output of SMU is controlled by the feedback loop from the voltage monitored by the sense terminal.

If Rdut is large enough (ex. gate terminal) compared with 50 ohm output impedance, Vdut is almost equal to Vset.

If Rdut is not so large (ex. drain terminal at the ON state), the difference between Vdut and Vset is not negligible. In the case of 1 mA current with 1 V bias (= 1 kohm), the difference will be about 5 %.

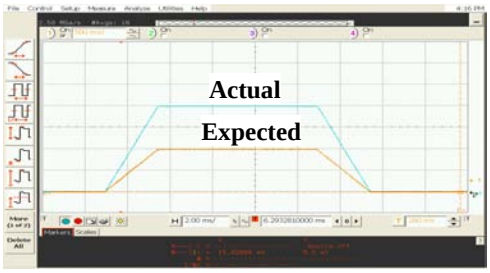
The SPGU provides the function to adjust the output voltage automatically. To use this function properly, the load impedance of DUT must be registered and it must be accurate. Then the SPGU can apply the voltage near the setting value to the DUT.

High Voltage SPGU

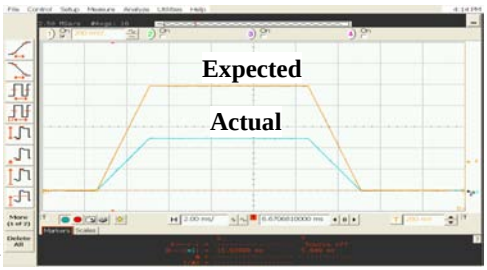
Effects of Load Impedance

Mismatch of load impedance setting may cause the error of applied voltage to the DUT.

Setup: 1V output, 50 Ω load
Actual load: 1 MΩ → 2 V output



Setup: 1 V output, 1 MΩ load
Actual load: 50 Ω → 0.5 V output

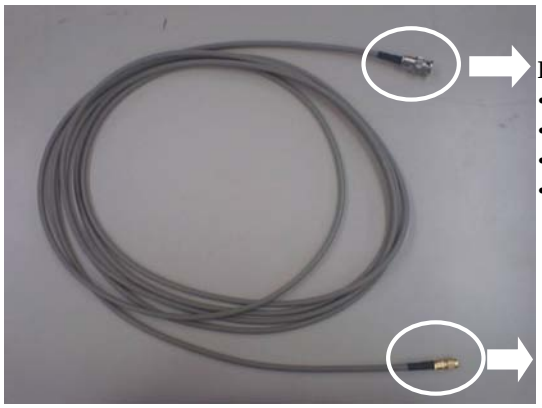


Here is the example of the voltage error due to the mismatch of the load impedance setting.

If the load impedance is set to 50 ohm when the actual load impedance is 1 Mohm, the voltage actually applied to the DUT is about double the setting value. If the load impedance is set to 1 Mohm when the actual load impedance is 50 ohm, the voltage actually applied to the DUT is about half the setting value. So the load impedance value must be accurate to apply the voltage near the setting value to the DUT.

High Voltage SPGU

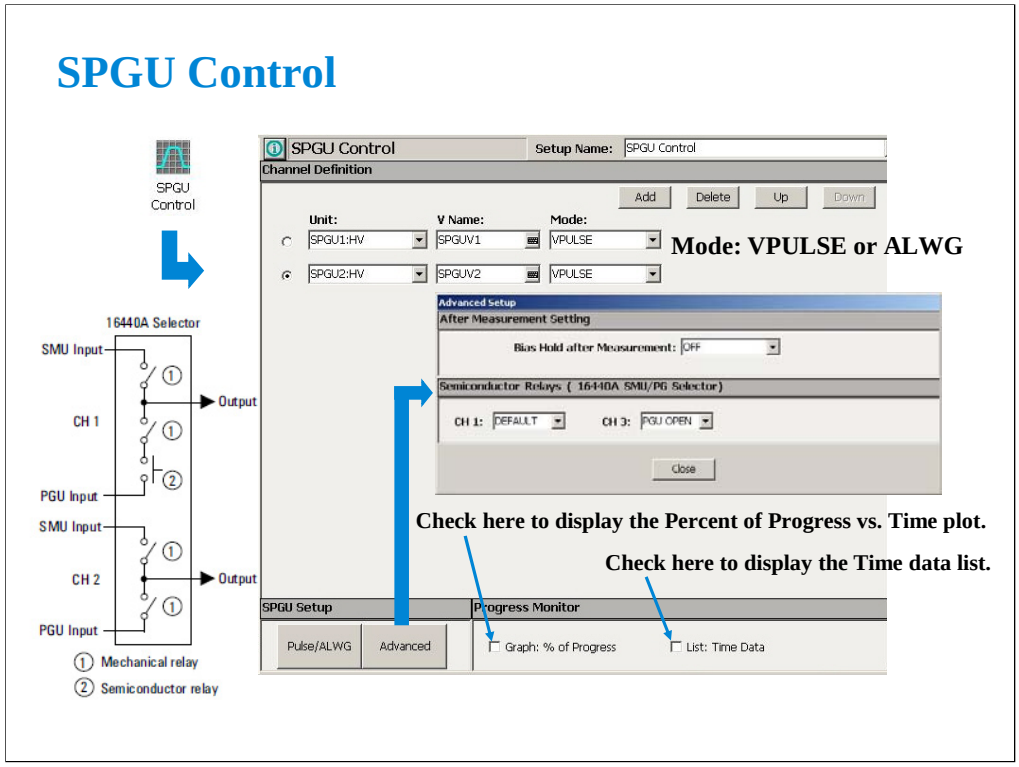
Agilent 16493P BNC (m) - SMA (m) Cable



BNC (m) connector:
- **To connector plate**
- **To 16442A/B test fixture**
- **To 16440A SMU/PGU selector**
- **To E5288A ASU (Atto Sense and Switch Unit)**

SMA (m) connector:
- **To SPGU output**

Agilent 16493P is the connection cable for the SPGU outputs.



The SPGU can be used in the classic test other than the C-V Sweep and the Switching Matrix Control. So you can use the SPGU output while a measurement is performed. If you need the SPGU output only, use the SPGU Control classic test. In this classic test, the single button triggers the SPGU outputs, and the Data Display works as the progress monitor.

The SPGU provides two output mode, VPULSE (pulse generator mode) and ALWG (arbitrary linear waveform generator mode). And the same mode must be set to the all output channels. The B1500A can have the maximum of ten SPGU output channels.

The Advanced button opens the Advanced Setup dialog box. The dialog box is used to set the after measurement settings and the 16440A selector semiconductor relay setting.

After Measurement Setting:

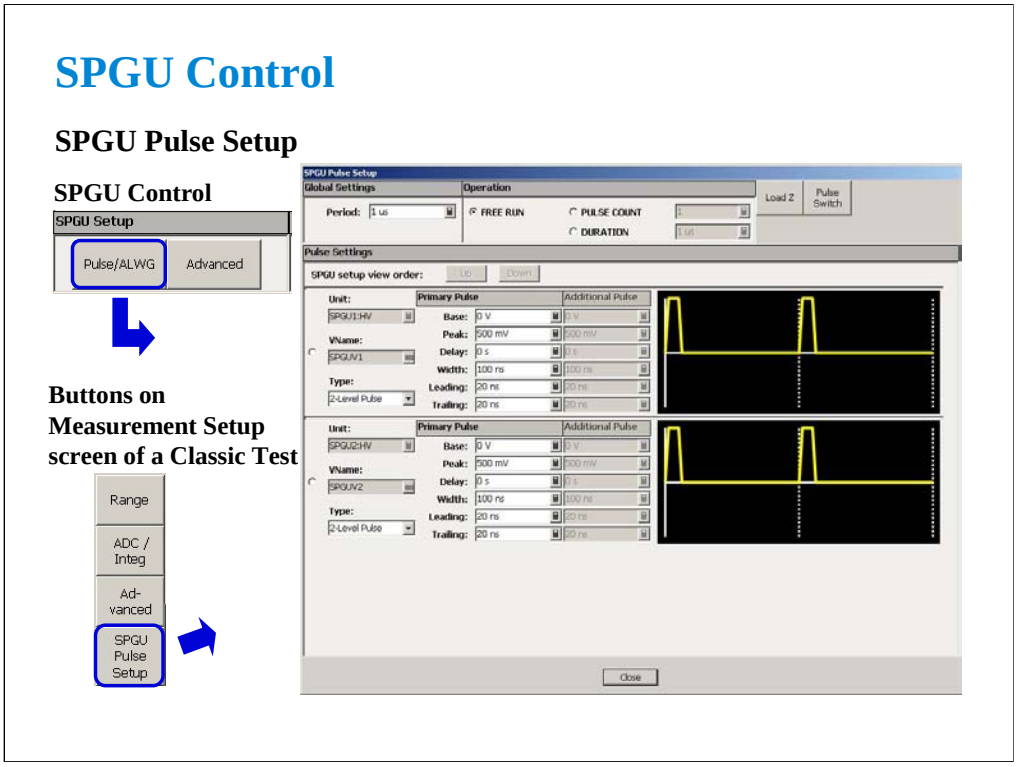
•Bias Hold after Measurement: Bias hold function ON or OFF.

Semiconductor Relays (16440A SMU/PG Selector):

•CH1: Default or PGU OPEN

•CH3: Default or PGU OPEN

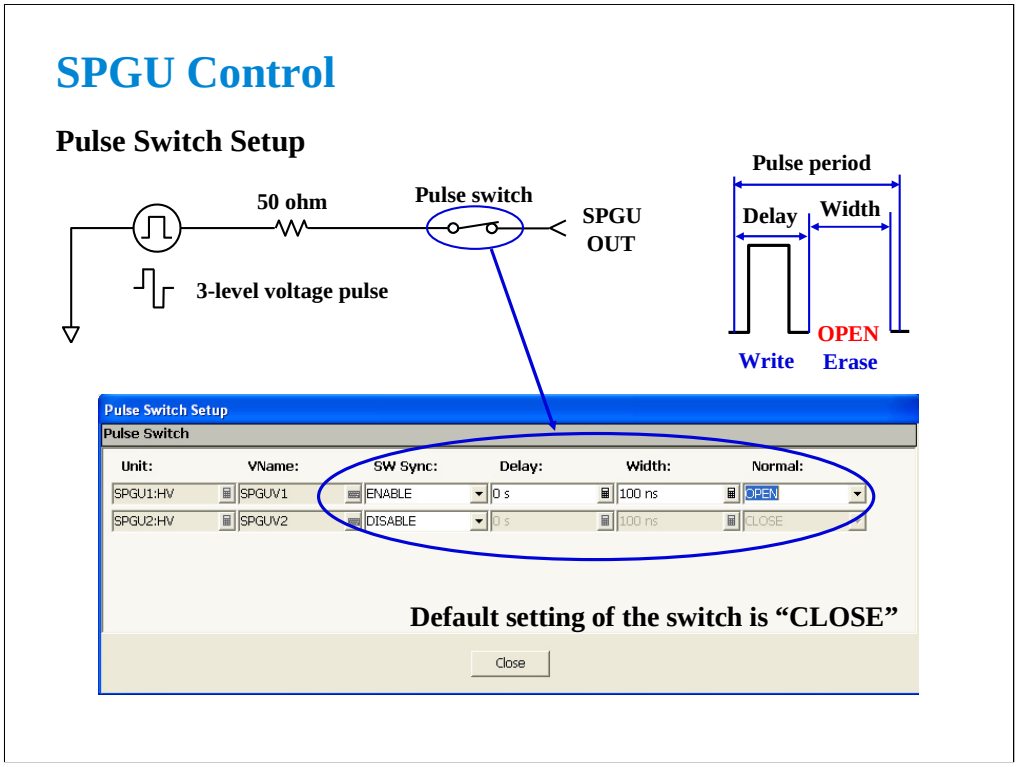
The fields define the selector channel's switch condition during the measurement. Default means the setting defined on the SMU/PG Selector screen of the Configuration window.



If the SPGU output mode is set to VPULSE, the Pulse/ALWG button opens the SPGU Pulse Setup window. This window is used to define the voltage pulses applied by the specified SPGU channels. For the setup parameters, see later page titled Pulse Setup Parameters of Pulse Generator Mode. In the other classic test, this window is opened by the SPGU Pulse Setup button on the Measurement Setup screen.

The Pulse Switch button opens the dialog box used to set the pulse switch operation.

The Load Z button opens the dialog box used to set the load impedance of the DUT.



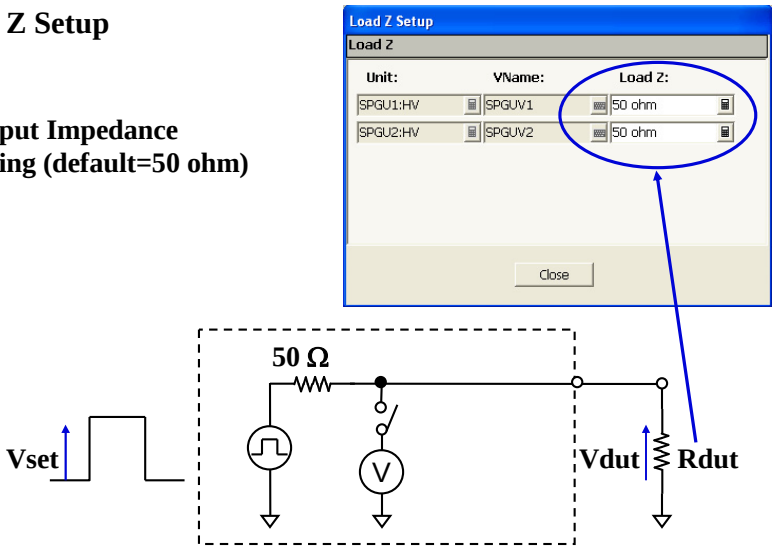
You can set the pulse switch operation on the Pulse Switch Setup dialog box. Set the SW Sync to ENABLE to use the pulse switch. The delay time is the time from start of pulse output to changeover of pulse switch. The width is the duration to hold the switched state of the pulse switch. And the normal field specifies the pulse switch status OPEN or CLOSE at the normal state which is not the switched state.

Recommended width value is more than 100 us because of the time lag for changeover.

SPGU Control

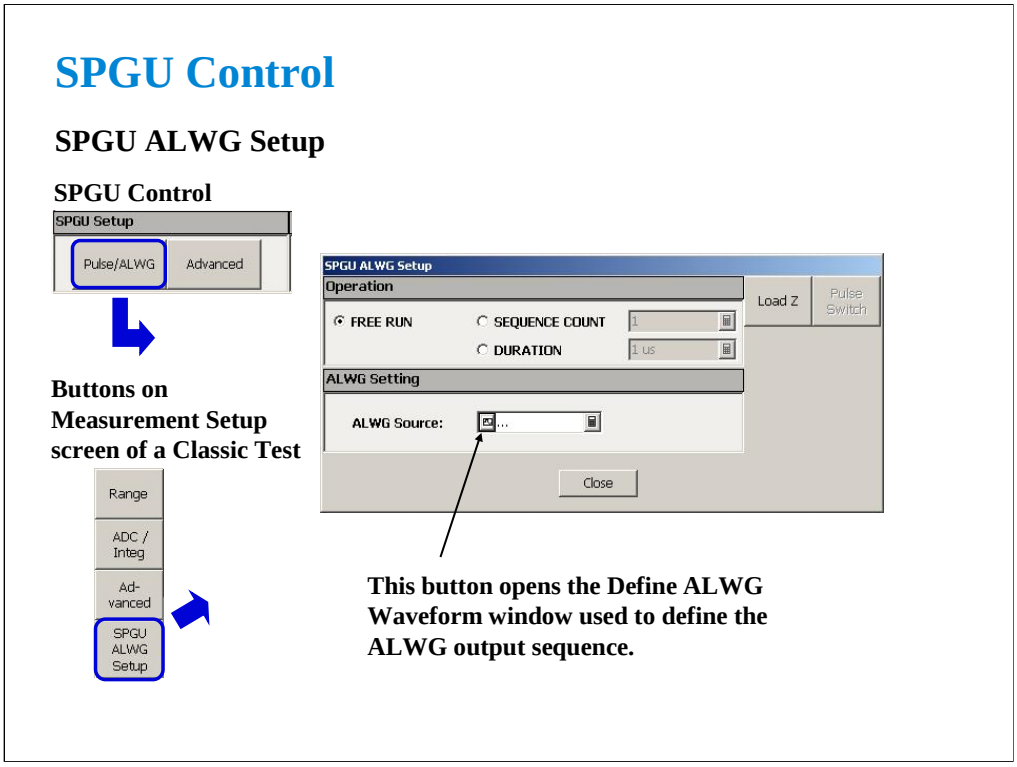
Load Z Setup

Output Impedance Setting (default=50 ohm)



Vset: Setting voltage with open load

You can specify the load impedance of DUT on the Load Z Setup dialog box. By setting the load impedance value accurately, the SPGU can apply the voltage near the setting value to the DUT.

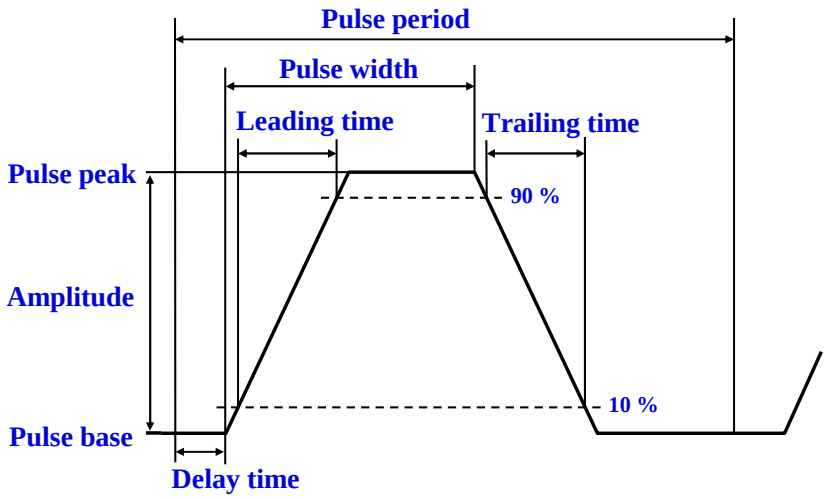


If the SPGU output mode is set to ALWG, the Pulse/ALWG button opens the SPGU ALWG Setup window. This window is used to define the arbitrary linear waveform voltage applied by the specified SPGU channels. In the other classic test, this window is opened by the SPGU ALWG Setup button on the Measurement Setup screen.

The Load Z button opens the dialog box used to set the load impedance of the DUT.

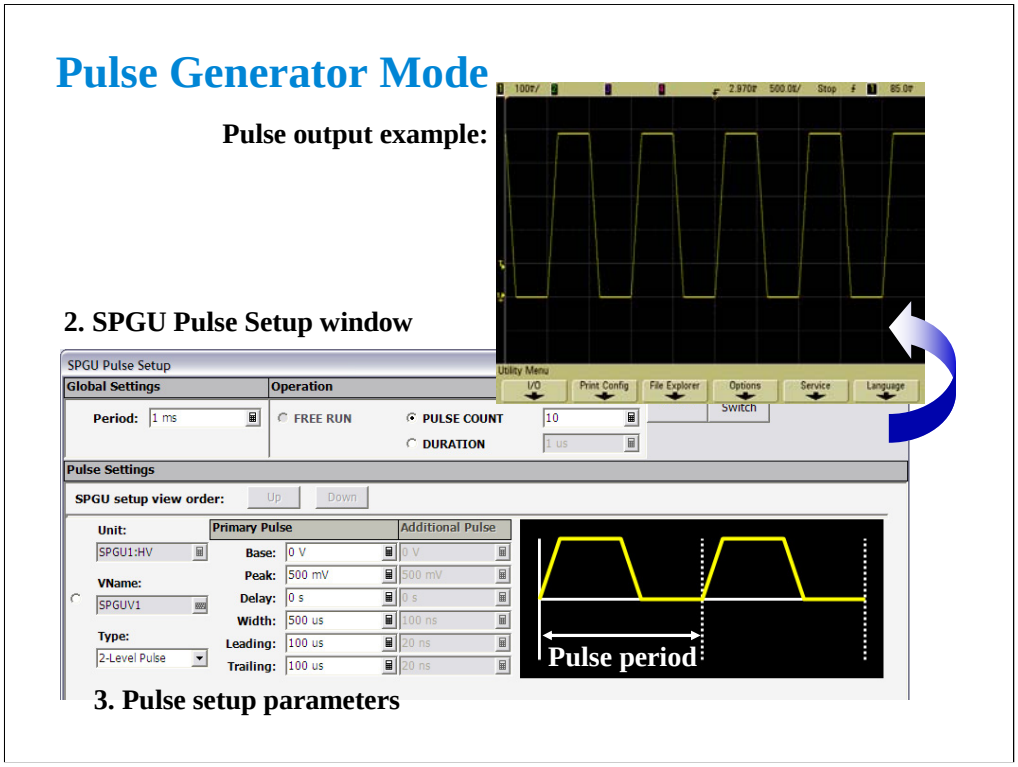
Pulse Generator Mode

Pulse Setup Parameters



The pulse setup parameters are defined as shown above.

The pulse leading time and trailing time are defined as the voltage transition time between 10 % and 90 % of the amplitude. Minimum setting value is 8 ns.



To apply the SPGU pulse output, set the pulse setup parameters, specify the Operation, and click the Single button.

The following operations are available.

PULSE COUNT: SPGU outputs the specified number of pulses. Specify a number within the range of 1 to 1000000.

DURATION: SPGU continues the output until the specified time elapses. Specify a time within the range of 1 us to 31556926 s (1 year).

FREE RUN: SPGU continues the output until the measurement is completed or stopped. This operation is not available for the SPGU Control classic test.

To set the pulse setup parameters,

1. Display the SPGU Control classic test screen or the Measurement Setup screen of the other classic test.

2. Open the SPGU Pulse Setup window by clicking the Pulse/ALWG button on the SPGU Control classic test screen or the SPGU Pulse Setup button on the Measurement Setup screen.

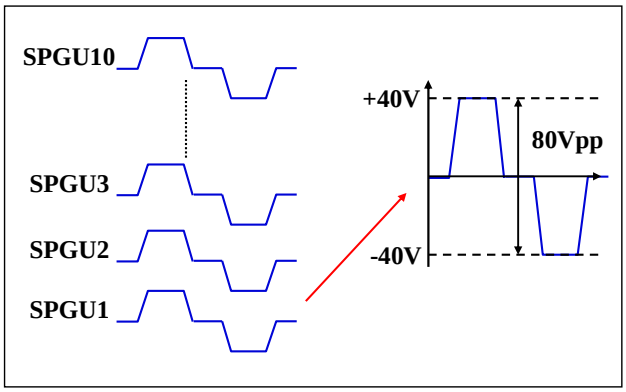
3. Set the Type, Period, and Primary Pulse parameters. For the pulse setup parameters, see the previous page.

For the 3-level pulse, select the 3-Level Pulse type. Then the Additional Pulse fields will be active. The 3-level pulse is defined as sum of two 2-level pulses, Primary Pulse and Additional Pulse.

Pulse Generator Mode

3-Level Pulses

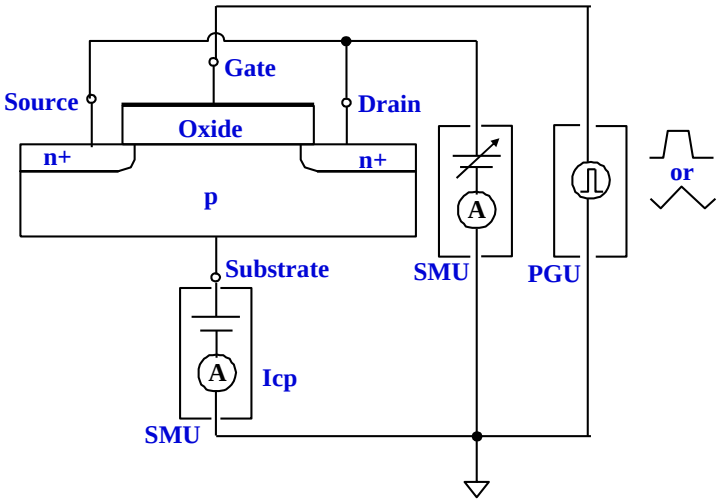
- **Every channel can output 3-level pulse**
  80 Vp-p within +/-40 V window (at open load)
- **Pulse width and level of each channel can be set individually.**



Up to 10 output channels can be installed in one B1500A and each channel can output 3-level pulse with a maximum output voltage.

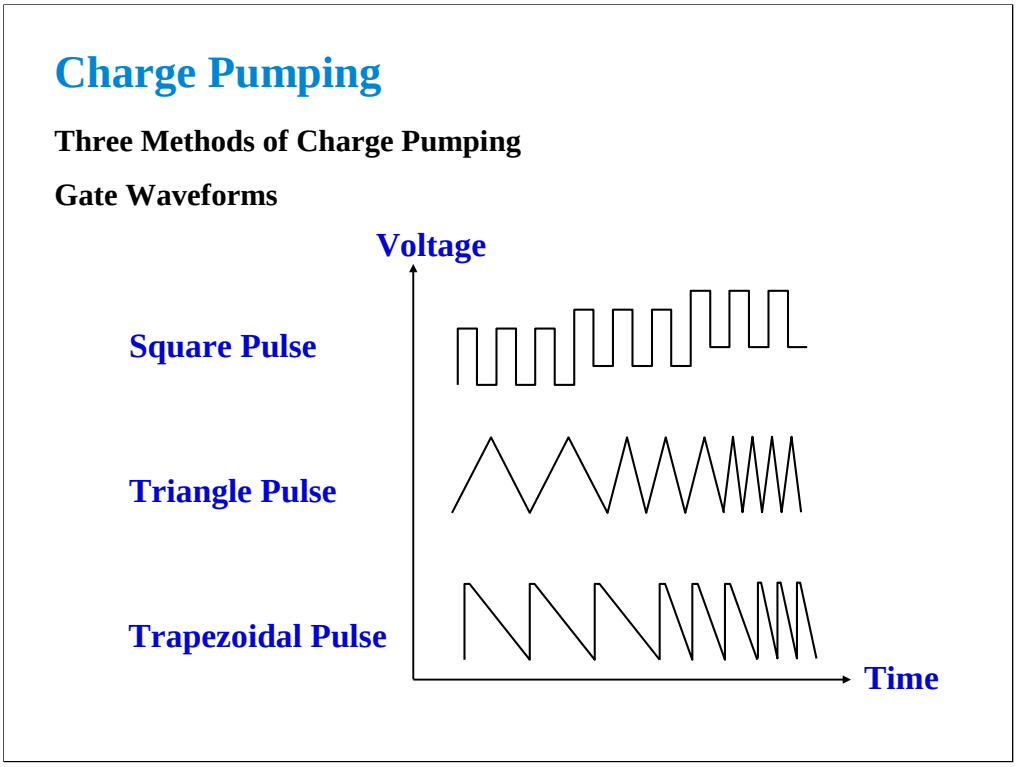
The channels are independent. So the channels can apply the different pulses. However, the pulse period value is common for all channels.

Charge Pumping



Charge pumping is a type of hot carrier measurement. It provides direct measurement of interface states and an indication of electron and hole trapping.

The gate of the MOS transistor is connected to a pulse generator. The current (Icp) is caused by the repetitive recombination of minority carriers with majority carriers at the silicon-silicon oxide interface.



Square Pulse

The base of the pulse is stepped from well below gate threshold to well above. At each step, the substrate leakage current is monitored. The flat part of the resultant curve is proportional to interface-state density.

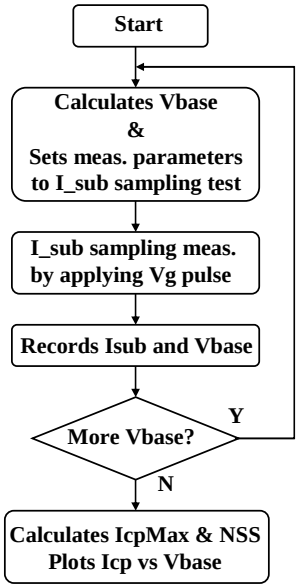
Triangle Pulse

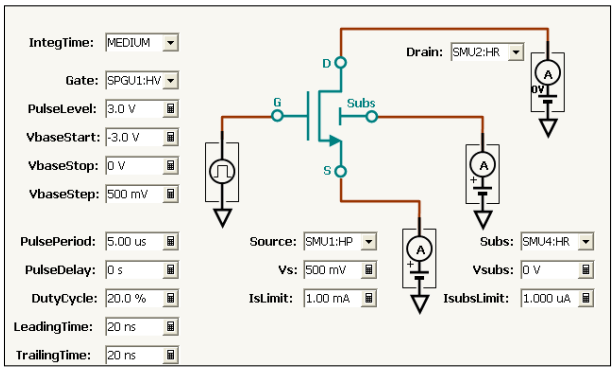
The frequency of a constant height triangle pulse is increased in steps. At each step, substrate leakage is measured. Average interface state density and capture cross-section are measured by this method.

Trapezoidal Pulse

A fixed height pulse is applied to the gate. By varying the leading/trailing edge of the pulse, you can plot interface-state density vs energy.

Charge Pumping





Looping of classic test for each base step of Gate pulse.

Icp is measured after each increment of the gate pulse base value. A curve of Icp vs base value is plotted. The maximum Icp value is noted. At this point:

Icp = f * Qss
= f * Ag * q * Dit

where

f: pulse frequency

Qss: recombined charge per pulse period

Aq: channel area of the transistor

q: electron charge

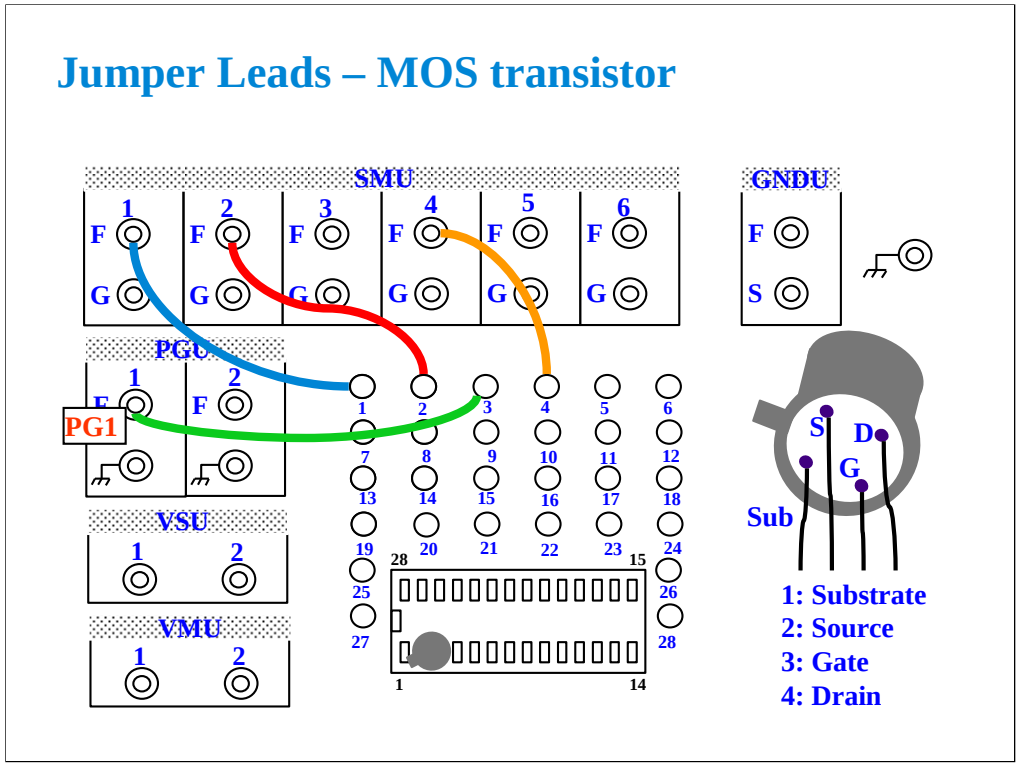
Dit: interface state density

Class Exercise

Square Pulse Charge Pumping

1. **Recall the Charge Pumping 4T 0.1V step test record.**
2. **Connect the DUT (MOS FET) as shown in the next page.**
3. **Specify the module (SMU and PGU) connected to DUT terminal properly.**
4. **Perform the test.**

Note:



This class exercise requires four jumper leads to connect the DUT. Connect the jumper leads between the following terminals.

SMU1 : terminal 1

SMU2 : terminal 2

SMU4 : terminal 4

PGU1 : terminal 3

Then, the modules must be connected to the fixture as shown below.

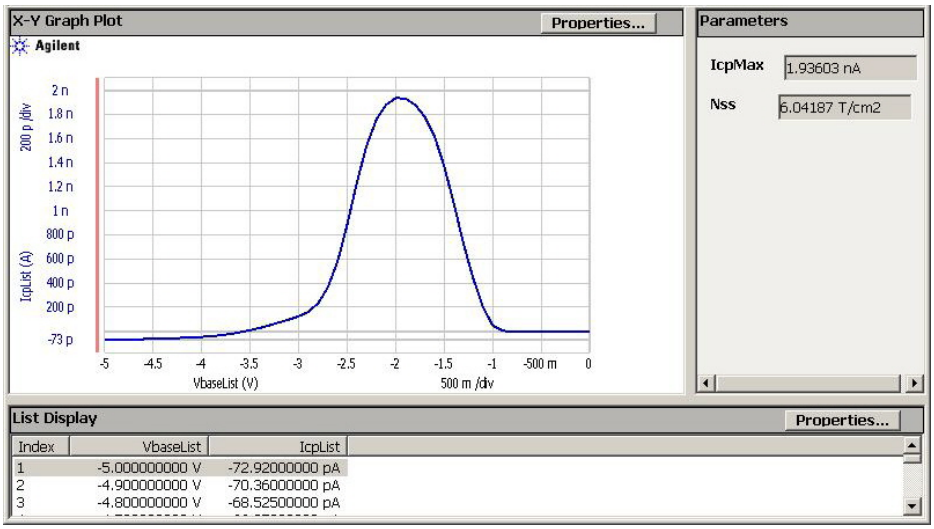
B1500A SMU1 -> Fixture SMU1 connector

B1500A SMU2 -> Fixture SMU2 connector

B1500A SMU4 -> Fixture SMU4 connector

B1500A PG1 -> Fixture PGU1 connector

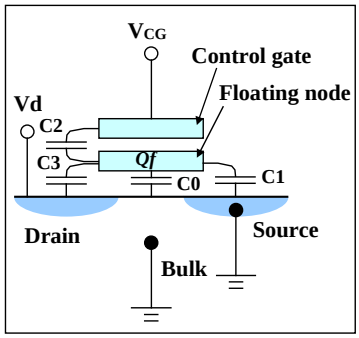
Measurement Result Example

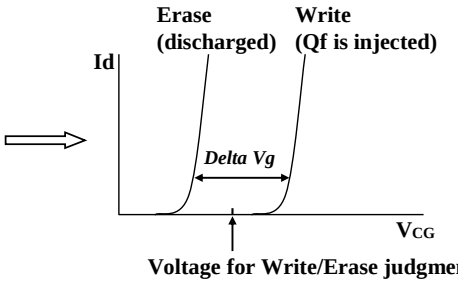


Here we see the result of plotting Icp vs pulse base voltage.

Flash Memory

Basic Flash memory Cell Structure





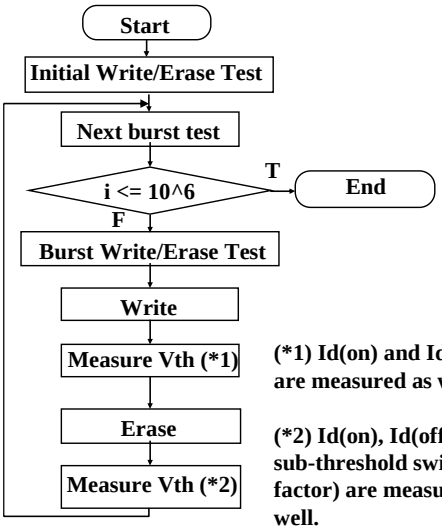
***Qf* is injected (by a pulse) to write the memory**

Effective gate voltage shifts *Delta Vg* = *Qf*/Cf. Cf is effective floating gate capacitance.

Flash memory is one type of floating gate memory. The left figure shows the structure of the floating gate memory cell. There is a metal floating node on the top of transistor channel region. Any stored charge in this floating node shifts its threshold voltage as shown in the right figure.

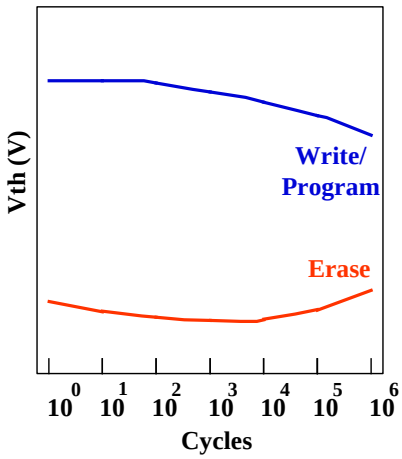
Flash Memory – Endurance Test

1 million Write/Erase cycle test



(*1) Id(on) and Id(off) are measured as well.

(*2) Id(on), Id(off) and sub-threshold swing (S-factor) are measured as well.



Endurance test is a kind of reliability tests. Repetitive write (program) and erase pulses are applied to the cell and the Vth of the cell is monitored after certain number of pulses are applied. This test is important because the flash memory is used for the data and file storage application. Then the failure rate must be less than one percent for one million write/erase cycles. Therefore, for device development, the endurance test is the critical test to make sure that the durability of the cell can meet the target.

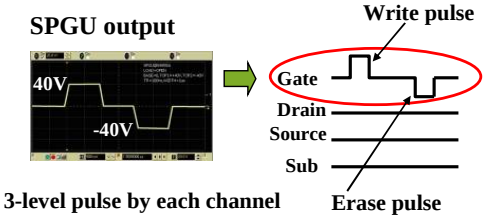
When measuring characteristics after certain number of write-erase cycling, Id(on) and Id(off) are measured besides Vth depending on the cell type. In case of the cell types which use the F-N tunneling between substrate and floating gate, sub-threshold swing is also measured after erasing the cell.

Flash Memory – Endurance Test

NAND Cell Test

- **Burst write/erase reduces test time dramatically**

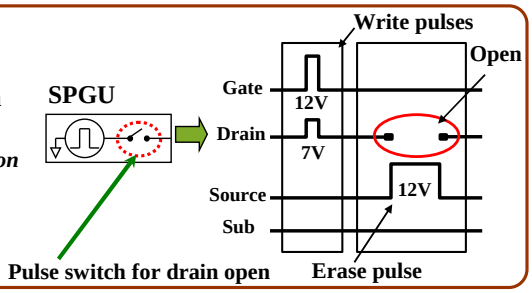
In an example, the test time was less than 2 hours for 1 million cycle test. It will be about 1/70 compared with 4155/4156 solution.



NOR Cell Test

- **Drain open can be made by opening the analog switch in the HVSPGU.**

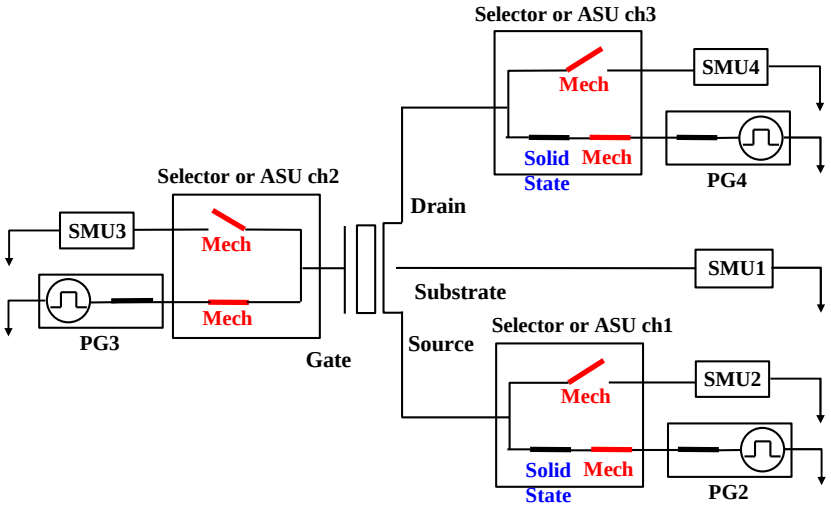
For 1 million cycle test, 2PG solution improves the test time about 1/4 compared with 4155/4156 solution. 3PG solution improves it about 1/4 compared with 2PG solution.



Note:

Flash Memory – Endurance Test

NOR Write Connection



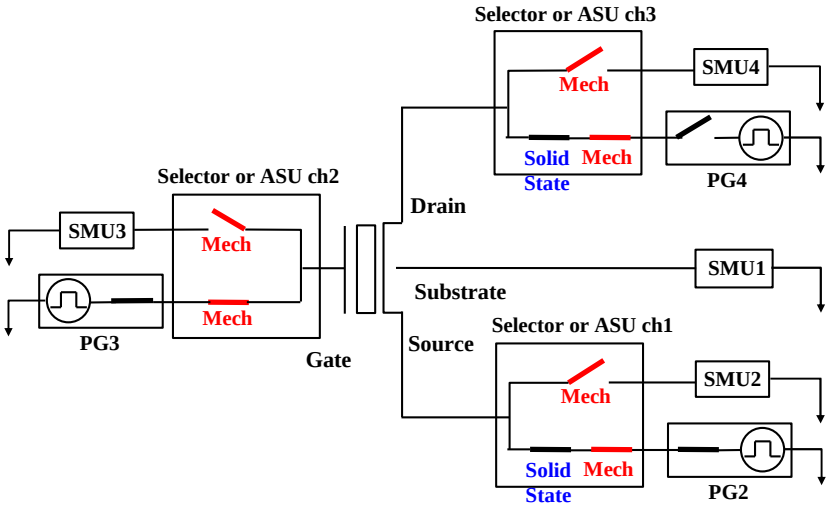
This is an example setup to perform the write operation of the NOR type flash memory cell. This setup uses three sets of the SMU, SPGU, and selector/ASU. This setup is used by the Demo-S-NorFlash Endurance test shown in Class Exercise.

To perform the write operation, all of the selector/ASU channels must make the path to the PG.

Note: The solid state relay is installed in the selector, but not installed in the ASU.

Flash Memory – Endurance Test

NOR Erase Connection

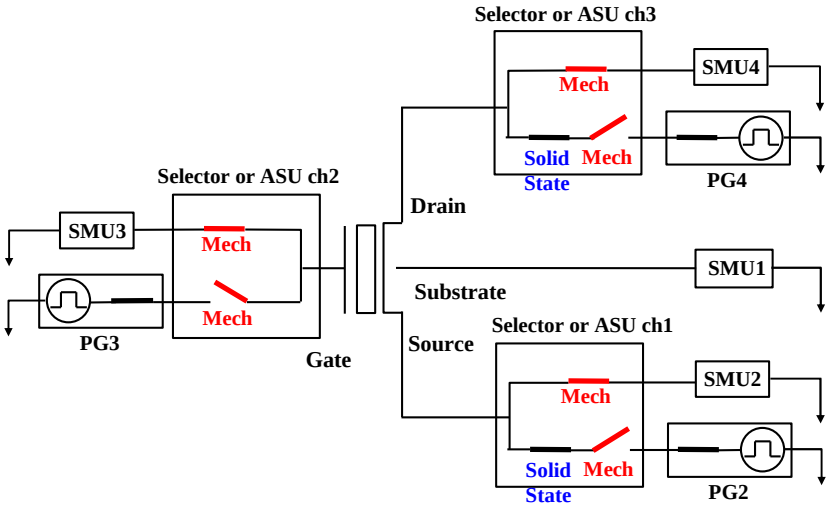


This is an example setup to perform the erase operation of the NOR type flash memory cell. To perform the erase operation, all of the selector/ASU channels must make the path to the PG and the PG3 internal pulse switch must be opened. The pulse switch is also a solid state relay.

Note that the solid state relay in the selector is not used. The relay must be always close.

Flash Memory – Endurance Test

Measure Vth Connection



Vth must be measured after writing or erasing. To perform the Vth measurement, all of the selector/ASU channels must make the path to the SMU. Vth is measured at each decade, so a mechanical relay will be used, not the solid state relay. The mechanical relay has low leakage specifications to better match the capabilities of the SMUs.

Class Exercise

Flash Memory Endurance Test

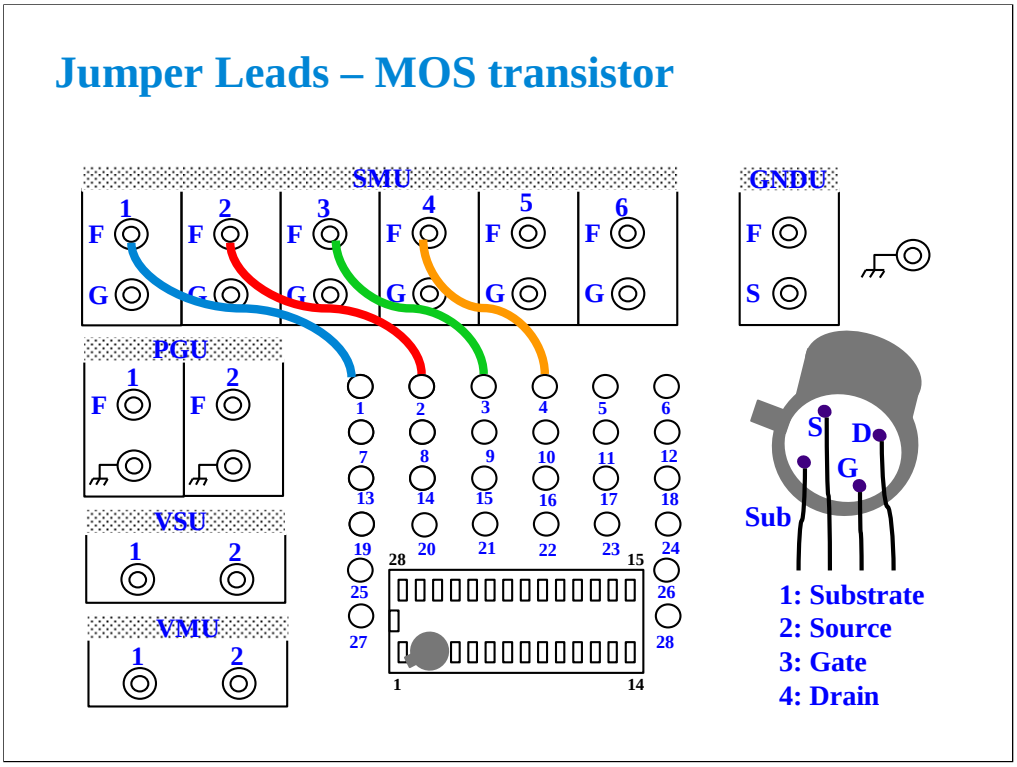
1. **Recall the Demo-S-NorFlash Endurance test record.**
2. **Connect the DUT (MOS FET, not flash memory) as shown in the next page.**
3. **Specify the module (SMU and PGU) connected to DUT terminal properly.**
4. **Perform the test.**

To perform this class exercise, you need the following equipment.

16440A Selector with control cable, 2 sets
16445A Selector adapter with control cable, 1 set
B1500A installed with two SPGU modules and four SMU modules
Test fixture
Triaxial cable, 7 ea.
BNC-SMA cable, 3 ea.

Or,

B1500A installed with two SPGU modules, three pairs of HRSMU and ASU, and a SMU module
Test fixture
Triaxial cable, 7 ea.
BNC-SMA cable, 3 ea.
ASU control cable, 3 ea.



This class exercise requires four jumper leads to connect the DUT. Connect the jumper leads between the following terminals.

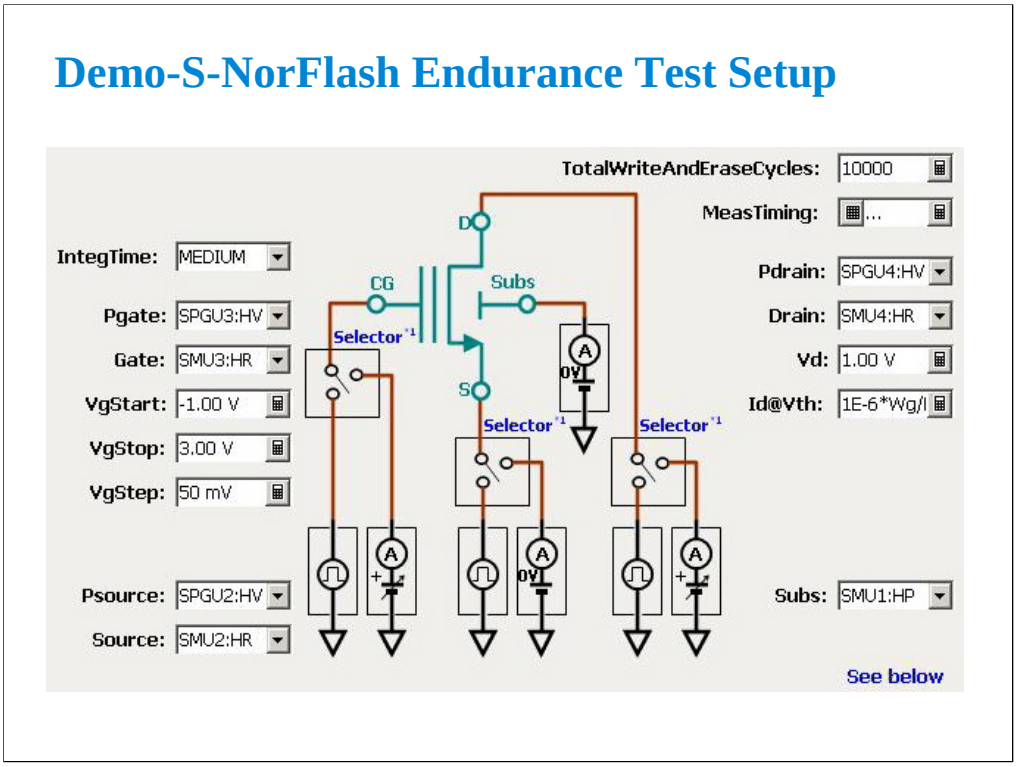
SMU1 : terminal 1
SMU2 : terminal 2
SMU3 : terminal 3
SMU4 : terminal 4

Then, the modules must be connected to the fixture as shown below.

B1500A SMU1 -> Fixture SMU1 connector
B1500A SMU2 -> Selector ch1 SMU input or ASU ch1 Force
B1500A SMU3 -> Selector ch2 SMU input or ASU ch2 Force
B1500A SMU4 -> Selector ch3 SMU input or ASU ch3 Force

B1500A PG2 -> Selector ch1 PGU input or ASU ch1 AUX In
B1500A PG3 -> Selector ch2 PGU input or ASU ch2 AUX In
B1500A PG4 -> Selector ch3 PGU input or ASU ch3 AUX In

Selector/ASU ch1 output -> Fixture SMU2 connector
Selector/ASU ch2 output -> Fixture SMU3 connector
Selector/ASU ch3 output -> Fixture SMU4 connector



For the instrument connection shown in the previous pages, change the value as follows.

Pgate -> SPGU3
Gate -> SMU3

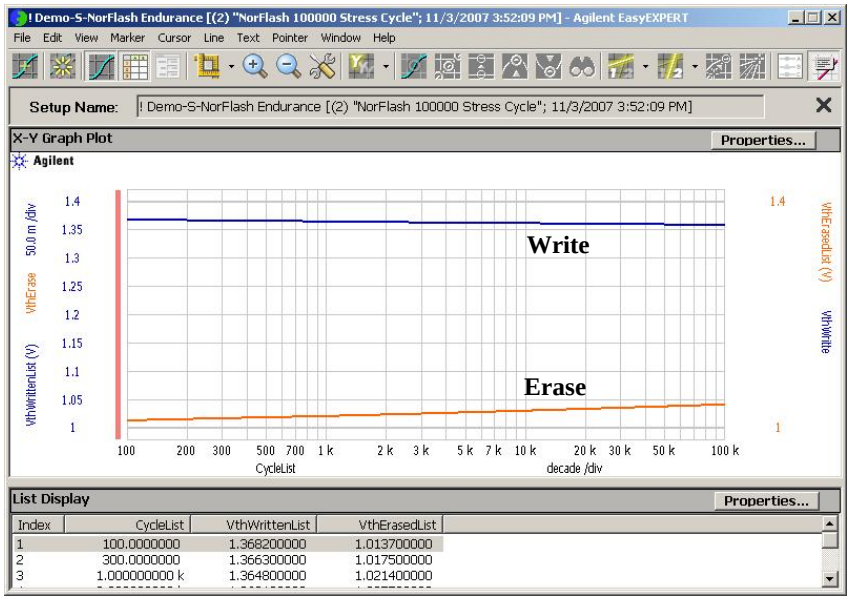
Psource -> SPGU2
Source -> SMU2

Pdrain -> SPGU4
Drain -> SMU4

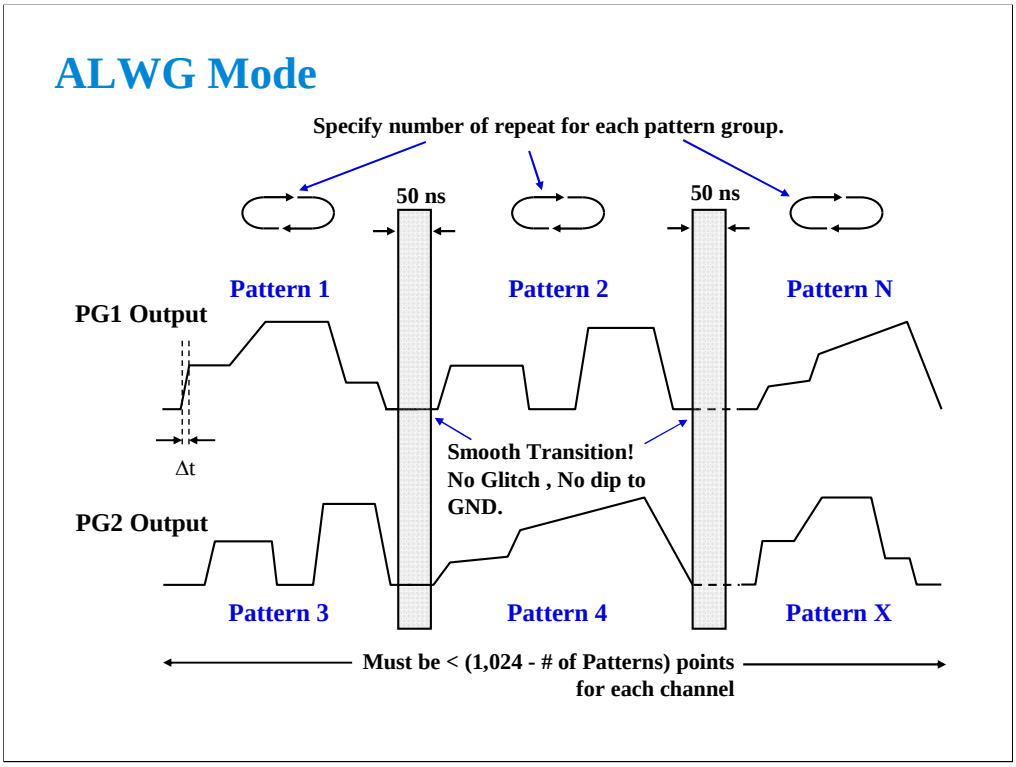
Subs -> SMU1

Also, set a small TotalWriteAndEraseCycles value, for example 1000. If you set one million, you will have to wait long time over several hours until the test is completed.

Measurement Result Example



This is a test result example displayed on the Data Display window.



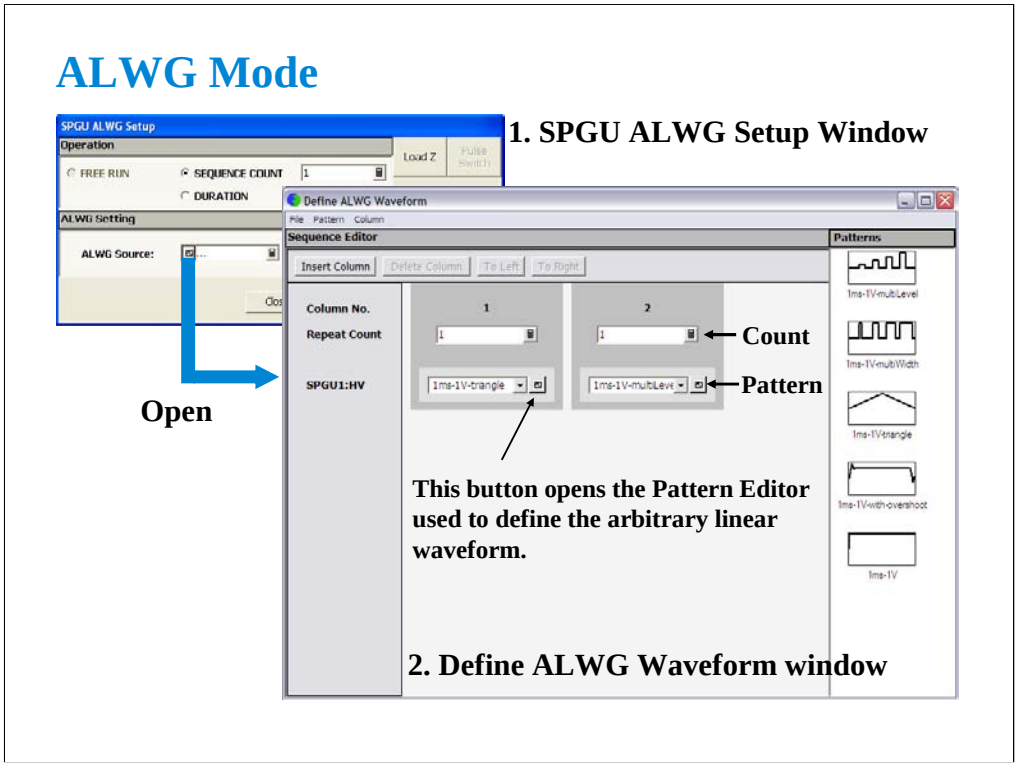
ALWG stands for Arbitrary Linear Waveform Generator. This function is similar to the AWG (Arbitrary Waveform Generator), but specialized for a semiconductor parametric test. The ALWG describes the pulse wave by the combination of the line segment described as the differential time and absolute voltage.

Key features are as follows.

- •Number of patterns in a sequence: maximum 512 for a channel
- •Number of vector data: maximum 1024-N (N: number of patterns) for defining all patterns to a channel
- •Repeat count of a pattern group: maximum 1,048,576
- •Time data (differential time, delta T): 10 ns to 671.088630 ms with 10 ns resolution
- •Extremely short over head, 50 ns to change the pattern. No delay for the repetition of the same pattern.

Of course, +/-40 V and 80 Vpp feature of HVSPGU is available with this ALWG feature.

This function allows you to use more complicated waveform like the multiple level pulse more than 3-level, and step pulse or ramp voltage to characterize the novel flash memory like CTF.



To apply the ALWG output, define the ALWG output sequence, specify the Operation, and click the Single button.

The following operations are available.

PULSE COUNT: SPGU outputs the specified number of sequences. Specify a number within the range of 1 to 1000000.

DURATION: SPGU continues the output until the specified time elapses. Specify a time within the range of 1 us to 31556926 s (1 year).

FREE RUN: SPGU continues the output until the measurement is completed or stopped. This operation is not available for the SPGU Control classic test.

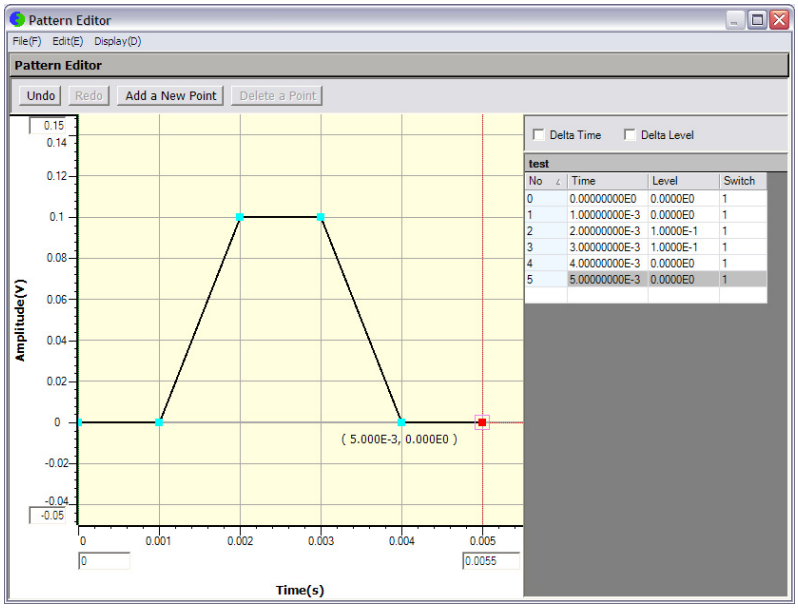
To define the ALWG output sequence,

1. Open the SPGU ALWG Setup window by clicking the Pulse/ALWG button on the SPGU Control classic test screen or the SPGU ALWG Setup button on the Measurement Setup screen of the other classic test.

2. Open the Define ALWG Waveform window by clicking the button of the ALWG Source on the SPGU ALWG Setup window.

The ALWG output sequence can be defined by specifying the waveform pattern and the repeat count on the Define ALWG Waveform window. To create a new waveform pattern, use the Pattern Editor. See the next page.

ALWG Mode



A pattern can be defined by specifying the differential time and the absolute voltage. You can define it by using the left side GUI or the right side table on the window.

Class Exercise

Monitor ALWG output by the sampling measurement.

1. **Click I/V-t Sampling icon and open setup editor.**
2. **Define the measurement setup with the ALWG output.**
3. **Save the test setup.**
4. **Connect a device (511 kohm resistor) as shown in the next page.**
5. **Perform the test.**

Channel Setup:
- SMU1 -> V1, I1, Mode=I
- SMU2 -> V2, I2, Mode=COMMON
- SPGU1 -> SPGUV1, Mode=ALWG

Measurement Setup:
- Interval=2 ms
- No of Samples=201
- SMU1 -> Source=0 A, Compliance=2 V

Range:
- SMU1 -> Mode=FIXED, Range=2 V

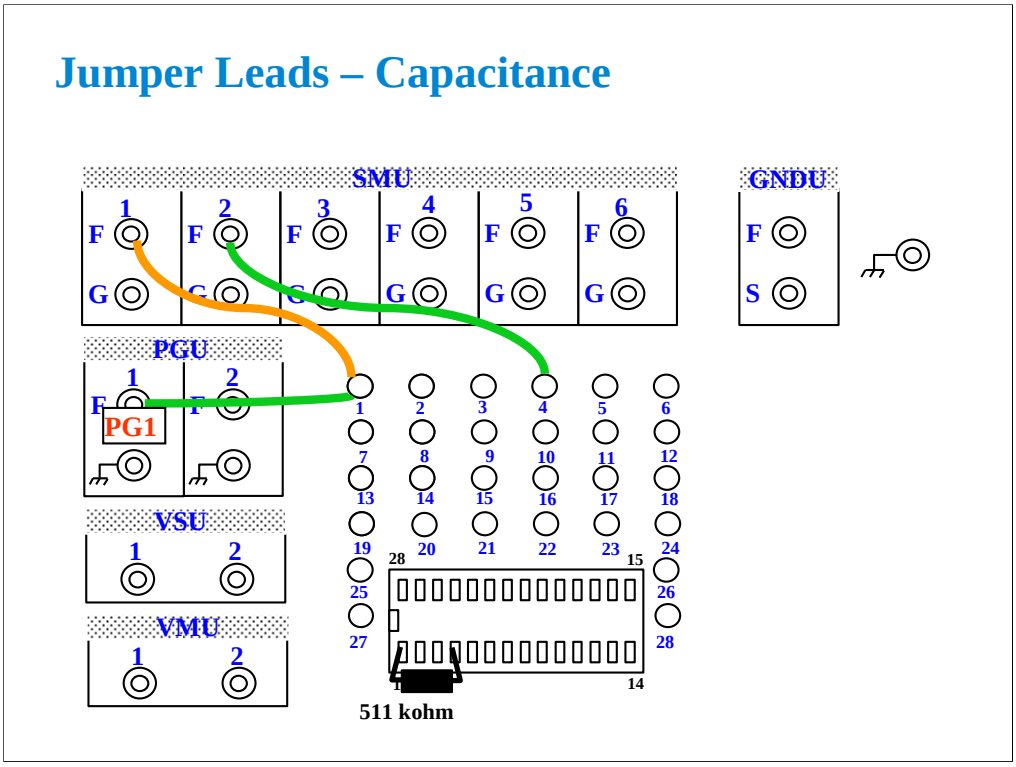
ADC/Integ:
- SMU1 -> ADC=HS ADC

Advanced:
- SMU1 -> SMU Filter=OFF

SPGU ALWG Setup:
- SPGU1 -> LoadZ=511 kohm
- ALWG Source -> Define the waveform as you like.

Display Setup:
- X-axis -> Time
- Y1-axis -> V1

For the example setup, open the “ALWG monitor” test setup.



This class exercise requires three jumper leads to connect the DUT. Connect the jumper leads between the following terminals.

SMU1 : terminal 1

SMU2 : terminal 4

PGU1 : terminal 1

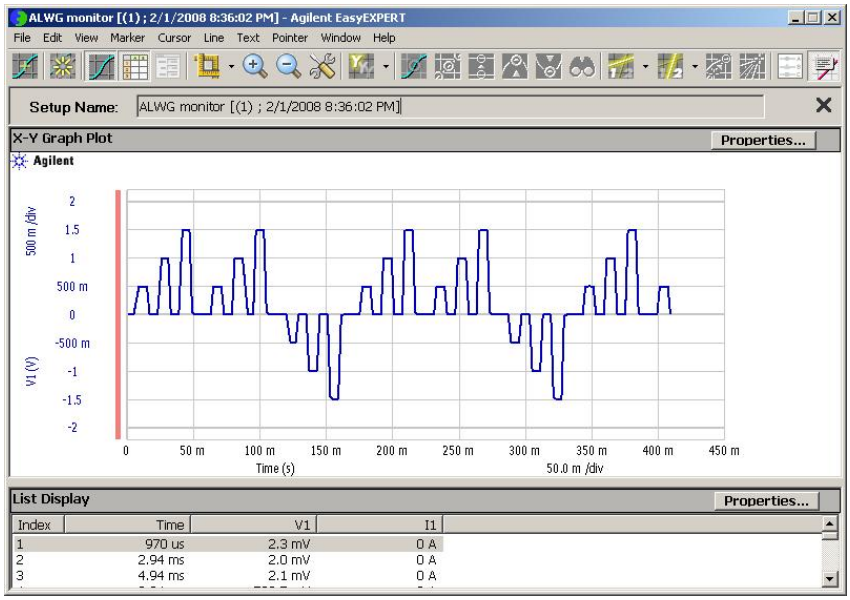
Then, the modules must be connected to the fixture as shown below.

B1500A SMU1 -> Fixture SMU1 connector

B1500A SMU2 -> Fixture SMU2 connector

B1500A PG1 -> Fixture PGU1 connector

Measurement Result Example



This is a test result example displayed on the Data Display window for the “ALWG monitor” test setup.