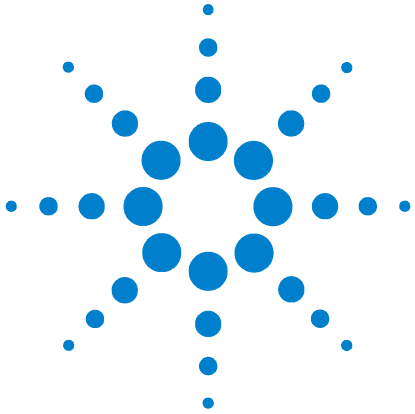

Agilent B1500A Semiconductor Device Analyzer

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.

CAUTION

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.

- 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. Getting Started

  This module explains the basic operations of the B1500A. You will learn about how to launch B1500A/EasyEXPERT and how to perform application test and quick test.

- Module 3. Data Display and Management

  This module explains the data display and analysis capabilities of the EasyEXPERT software. You will learn how to use analysis tools, how to change display setup, and how to print/export test result data.

- Module 4. Classic Test Environment

  This module explains the classic test mode of the EasyEXPERT. You will learn how to create the classic test setup in the course exercises.

- Module 5. 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 6. 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 7. Measurement Functions

  This module explains the measurement functions available with the B1500A. You will learn how to use various measurement functions in the course exercises.

- Module 8. Capacitance Measurement

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

- Module 9. Modifying Application Test Definitions

  This module explains a modification example of an application test definition. You will learn how to modify the definition in a course exercise.

- Module 10. Creating Your Test Definitions

  This module explains about the application test definition. You will learn how to create your application test definition in a course exercise.

- Module 11. Advanced Definitions and Operations

  This module explains how to control external GPIB devices, how to call an execution file, how to perform a repeat measurement, and how to use the prober control script.

- Module 12. Miscellaneous Operations

  This module explains what is the status indicator, what is the automatic data export function and the automatic data record function, how to perform selftest and calibration, how to perform SMU zero offset cancel, and such.

- Module 13. 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 the Manual CD-ROM.

Module	Exercise	Device	Test setup/definition/data	Page
Module 1	no exercise			
Module 2	Id-Vd measurement	MOSFET	CMOS: Id-Vd	2-19, 27
	Id-Vg, gm-Vg measurement	MOSFET	CMOS: Vth gmMax	2-19, 27
	B2200/E5250 switch control	-	-	2-32
Module 3	Id-Vg, gm-Vg measurement	MOSFET	GMMAX.xtr	3-28
	Using Preview window	-	-	3-31
Module 4	Id-Vd measurement	MOSFET	Trng Id-Vd	4-25
	Multi Channel I/V Sweep Measurement	Bipolar Tr LED	Trng Multi	4-37
	I/V List Sweep Measurement	MOSFET	Trng List	4-51
	I/V-t sampling measurement	0.1 µF	Trng Sampling	4-64
	C-V sweep measurement	MOSFET	Trng CV	4-76
	B2200/E5250 switch control	-	Trng Switch	4-81
	Direct Control (C-f measurement)	0.1 µF	Trng C-f	4-88
Module 5	Id-Vd measurement	MOSFET	IDVD, Id-Vd	5-7
	SMU series connection	511 kohm	IRVR	5-24
	SMU parallel connection	1 ohm	Parallel	5-28
	Re measurement, kelvin connection	Bipolar Tr	REKELV	5-38
Module 6	Leak current measurement	-	Zero-check	6-9
	Ultra low current measurement	-	Zero-check-ASU	6-19
	Id-Vg measurement	MOSFET	IDVG	6-20
	Gummel plot	Bipolar Tr	GUMMEL	6-25
Module 7	SMU pulse mode	MOSFET	IDVD-Pulse	7-8
	RC measurement	0.1 µF and 511 kohm	RC-sampling-log	7-16
	Negative hold time	511 kohm	R-sampl-neg-hold	7-22
	Auto analysis	MOSFET	GMMAX	7-28
	Bias hold function	LED	LED	7-35
	SMU series resistor	511 kohm	IV-res	7-43

Module	Exercise	Device	Test setup/definition/data	Page
Module 8	C-V sweep measurement	MOSFET	CV-1MHz	8-6
Module 9	Modifying application test definition	MOSFET	Trng IdVd Vth.xtd	9-14
			Trng idvd idvg2.xtd	9-29
			Trng idvd idvg3.xtd	9-32
	Using auto analysys twice	MOSFET	Vth gmMax and Id	9-34
	Using vector data	MOSFET	Trng Cgg-Vg	9-42
Module 10	Creating application test definition	MOSFET	Trng idvd idvg.xtd	10-17
Module 11	no exercise			
Module 12	no exercise			
Module 13	Charge pumping	MOSFET	Charge Pumping 4T 0.1V step	13-20
	Flash memory	MOSFET	Demo-S-NorFlash Endurance	13-29
	ALWG output	511 kohm	ALWG monitor	13-36

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 the Agilent B1500A Manual CD-ROM, Edition 4 or later.

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 on the Manual CD-ROM 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 on the Manual CD-ROM 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.

Test Setup for Class Exercises

The Demo preset group contains the following test setup. The setup data are only examples for the class exercises. The following table lists the test setup name in alphabetical order.

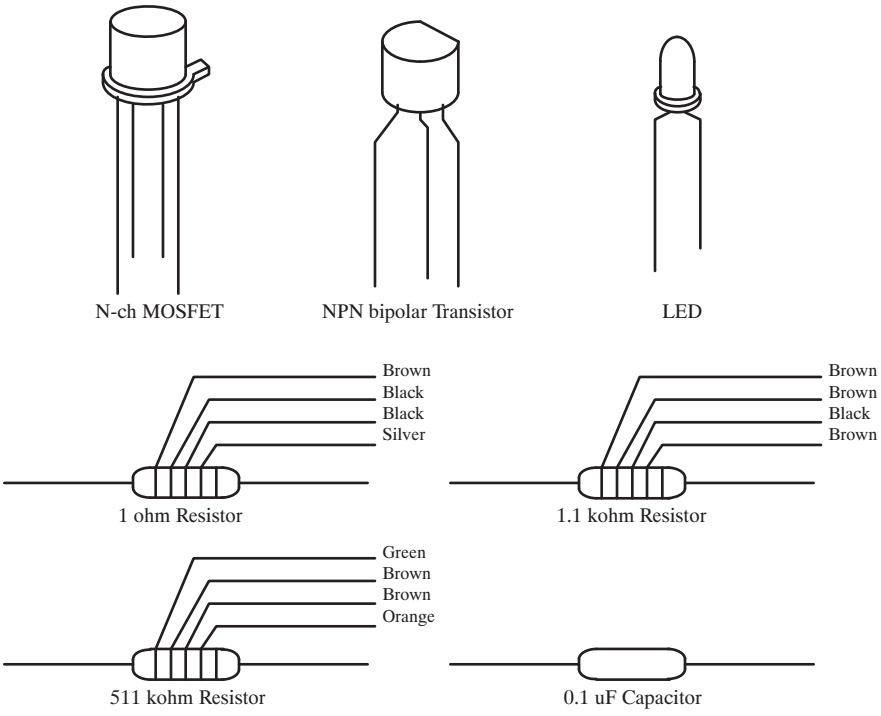
Test Setup Name	Description
ALWG monitor	511 kohm sampling measurement with SPGU ALWG output
Charge Pumping 4T 0.1V step	MOSFET Icp-Vbase measurement
CV-1MHz	MOSFET Cgs-Vg measurement
Demo-S-NorFlash Endurance	MOSFET Endurance test
Fowler-Nordheim	Fowler-Nordheim (FN) plot
GMMAX	MOSFET sqrt_Id-Vg, PEAK-Vg measurement
GUMMEL	Bipolar transistor gummel plot
IDVD	MOSFET Id-Vd measurement
IDVD-Pulse	MOSFET pulsed Id-Vd measurement
Id-Vd	MOSFET Id-Vd measurement, Application Test
IDVG	MOSFET Id-Vg measurement
IRVR	511 kohm I-V measurement
IV-res	511 kohm I-V measurement with SMU series resistor
LED	LED I-V measurement
Parallel	1 ohm I-V measurement, voltage force and current measurement
PG monitor	511 kohm sampling measurement with SPGU VPULSE output
RC-sampling-log	RC sampling measurement, log sampling
REKELV	Bipolar transistor Re measurement
R-sampl-neg-hold	511 kohm sampling measurement with negative hold time
Subthreshold	MOSFET subthreshold measurement
Trng C-f	Direct Control (C-f measurement)
Trng Cgg-Vg	Cgg-Vg modification example for multi-frequency
Trng CV	MOSFET C-V measurement
Trng Id-Vd	MOSFET Id-Vd measurement

Test Setup Name	Description
Trng List	MOSFET Vth-gmmax measurement using I/V List Sweep
Trng Multi	Multi Channel I/V Sweep (Bipolar transistor and LED)
Trng Sampling	0.1 μF sampling measurement
Trng Switch	B2200/E5250 switch setup, Input 1-3-5-7 to Output 1-3-5-7
Vth gmMax and Id	Vth gmMax modification example to use auto analysis twice
Zero-check	SMU open measurement
Zero-check-ASU	SMU open measurement with ASU

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.

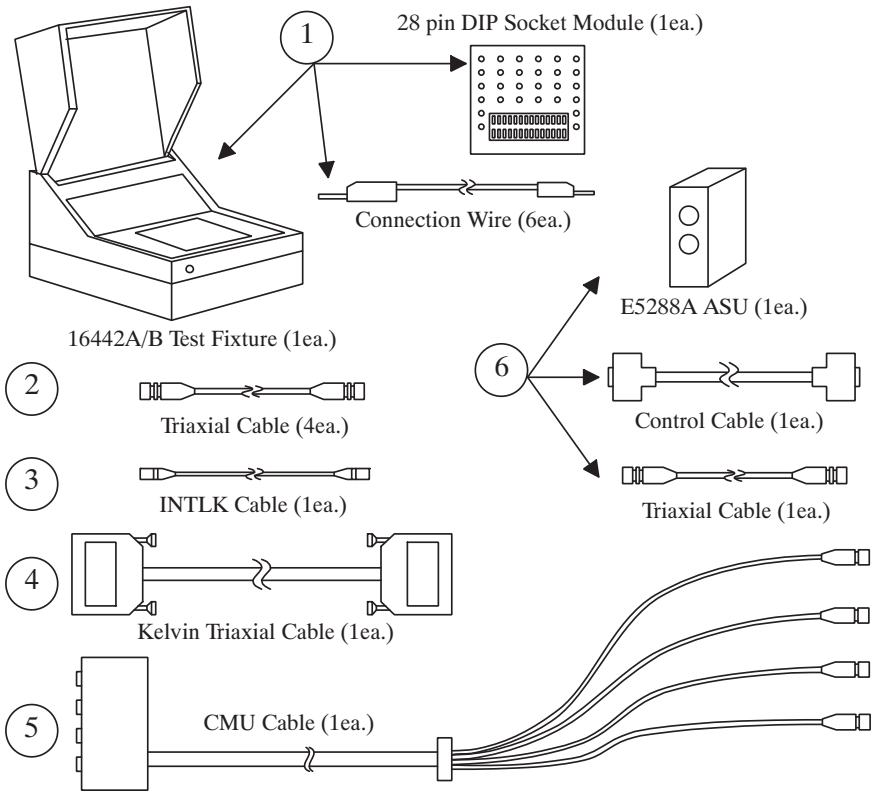


Required Accessories for Class Exercises

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 5	16493K	1 ea.
5	CMU Cable, for Module 8	N1300A	1 ea.
6	Atto Sense/Switch Unit, for Module 6	E5288A	1 ea.
	ASU control cable, triax cable, for Module 6	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 13 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 13 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. Getting Started

- **To Turn on/off B1500A**
- **To Launch EasyEXPERT**
- **To Specify/Create Workspace**
- **To Perform Application Test**
- **To Save/Recall Your Test Setup**
- **To Export/Import Your Preset Group**
- **To Export/Import Test Record**
- **To Perform Quick Test**
- **To Control Switching Matrix**
- **To Manage Data Display Window**

Module 3. Data Display and Management

- **Data Display window**
- **Graph Analysis Tools**
- **Data Status**
- **To Change Graph/List/Display Setup**
- **To See Print Preview**
- **To Print Display Data**
- **To Copy Graph Plot/List Data**
- **To Save Analysis Result**
- **To Use Preview Window**

Module 4. Classic Test Environment

- **Classic Test Execution Mode**
- **I/V Sweep Measurement**
- **Multi Channel I/V Sweep Measurement**
- **I/V List Sweep Measurement**
- **I/V-t Sampling Measurement**
- **C-V Sweep Measurement**
- **Switching Matrix Control**
- **Direct Control**

Module 5. Basic Measurement

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

Module 6. 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 7. Measurement Functions

- **SMU Pulsed Sweep Measurement**
- **I/V-t Sampling Measurement**
- **Negative Hold Time for High Speed Sampling**
- **Auto Analysis**
- **SMU Filter**
- **SMU Series Resistor**
- **Standby Function**
- **Bias Hold Function**

Module 8. 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 9. Modifying Application Test Definitions

- **To Open Application Test Definition**
- **To Modify Test Definition**
- **To Use Debug Tools**
- **To Use Built-in Functions**
- **To Add Data Display**
- **To Use Auto Analysis**
- **To Use Test Setup Internal Variables**
- **To Use Auto Analysis twice (as Class Exercise)**
- **To Use Vector Data (as Class Exercise)**

Module 10. Creating Your Test Definitions

- **What is Test Definition**
- **What is Test Contents**
- **To Open Test Definition Editor**
- **To Define Test Specification**
- **To Define Test Contents**
- **Available Elements**
- **Available Variables**
- **To Define Test Output**

Module 11. Advanced Definitions and Operations

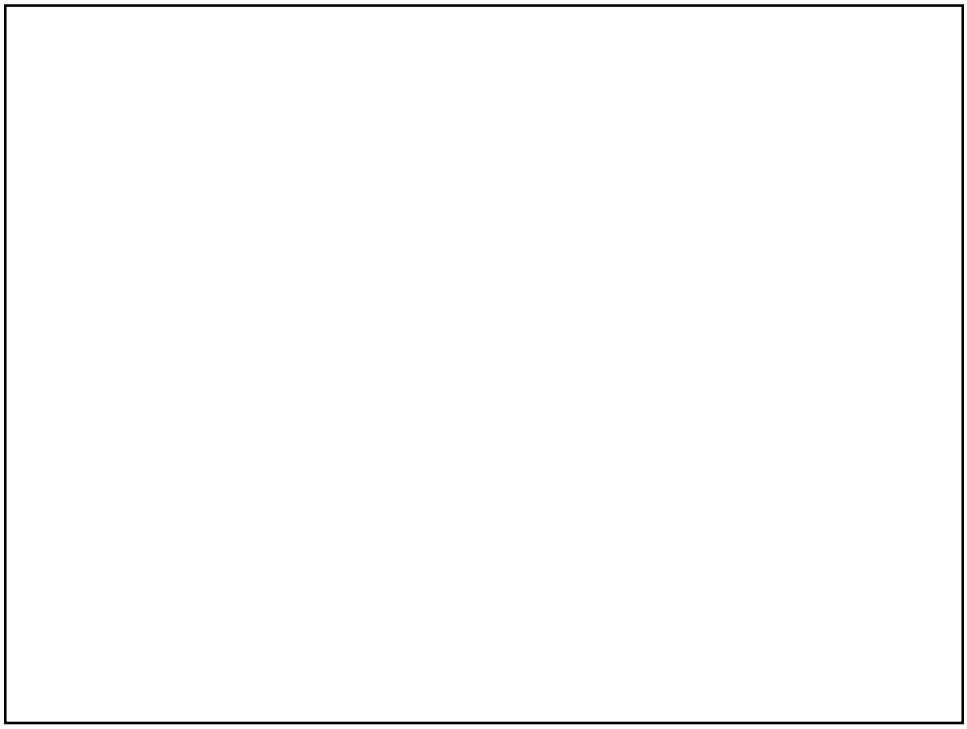
- **To Control External GPIB Devices**
- **To Call Execution Files**
- **To Perform Repeat Measurements**
- **Prober Control Script**

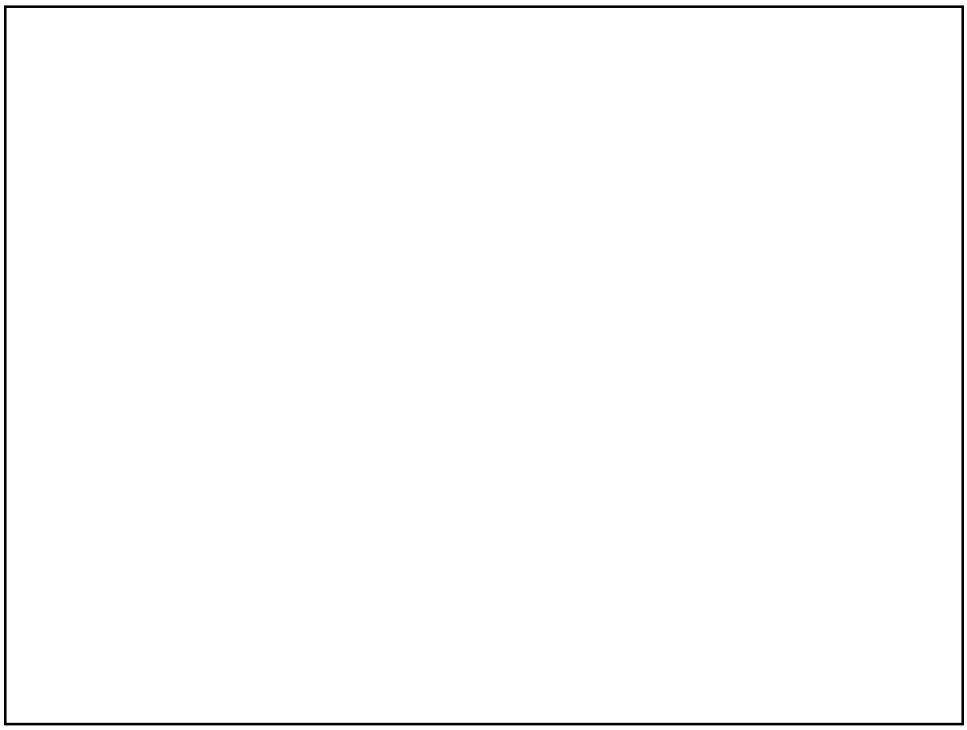
Module 12. Miscellaneous Operations

- **Function Status Indicator**
- **Run Option**
- **Automatic Data Export and Data Record**
- **Calibration**
- **Configuration**
- **XSLT Samples**
- **To Enable System Controller**
- **To Start Desktop EasyEXPERT**
- **To Use 415x Setup File Converter**

Module 13. SPGU Control and Applications

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

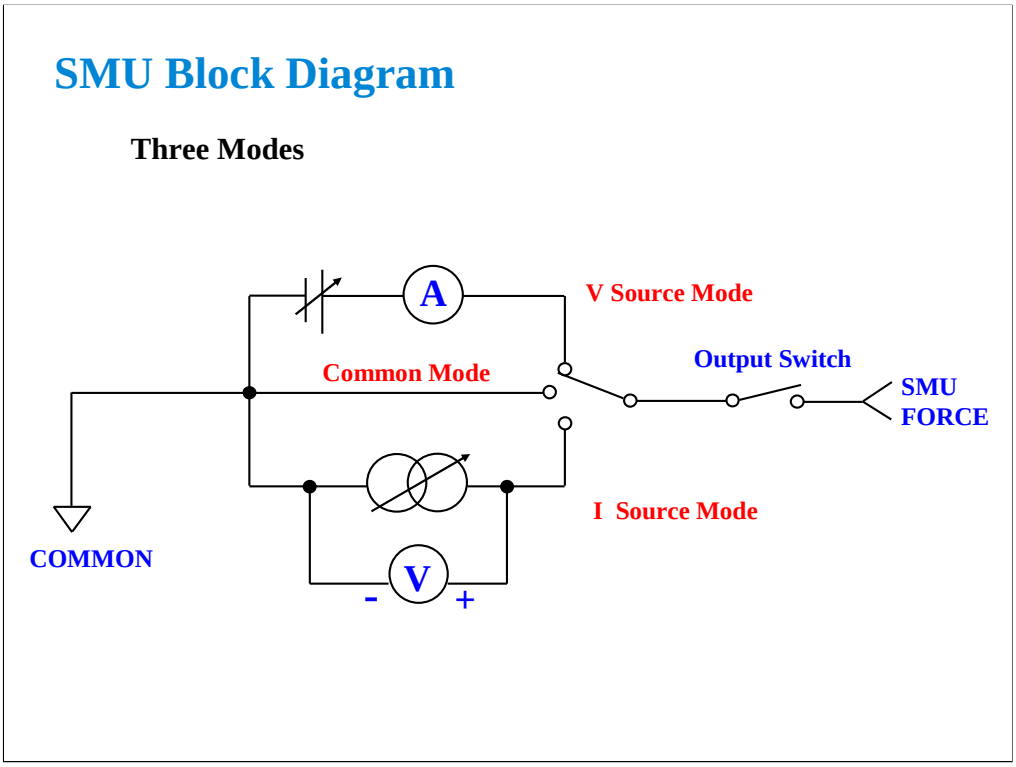




5 Basic Measurement

In This Module

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



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

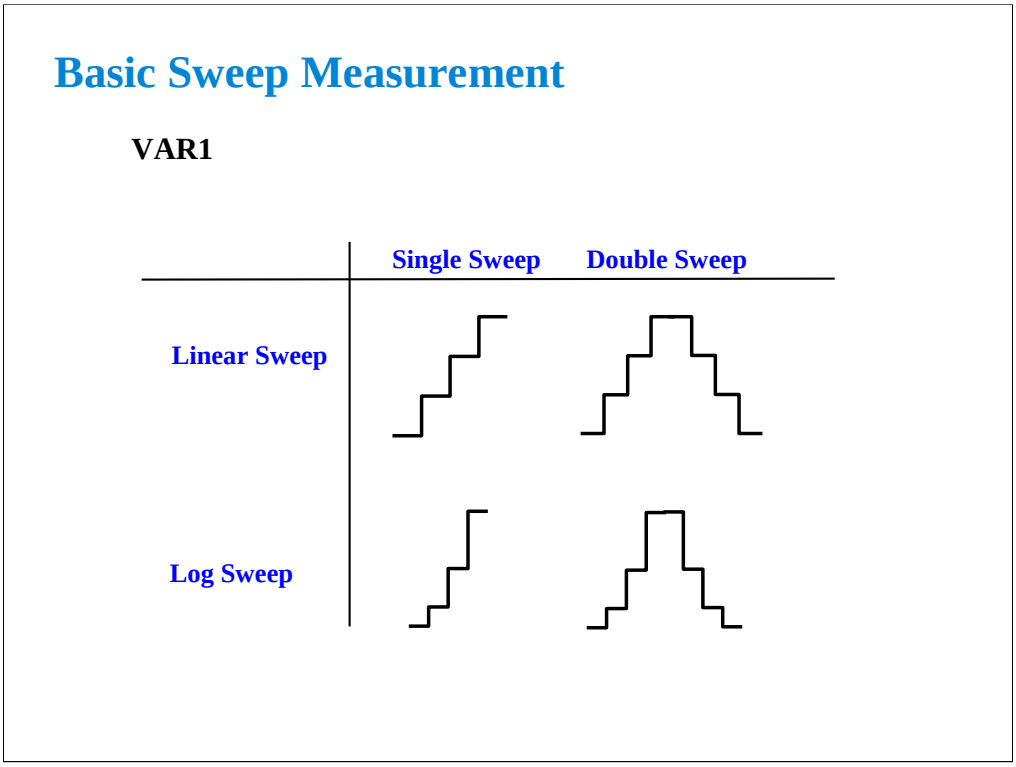
- Voltage source while monitoring current
- Current source while monitoring voltage
- Source common with no monitor

The SMUs on the B1500A 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.”

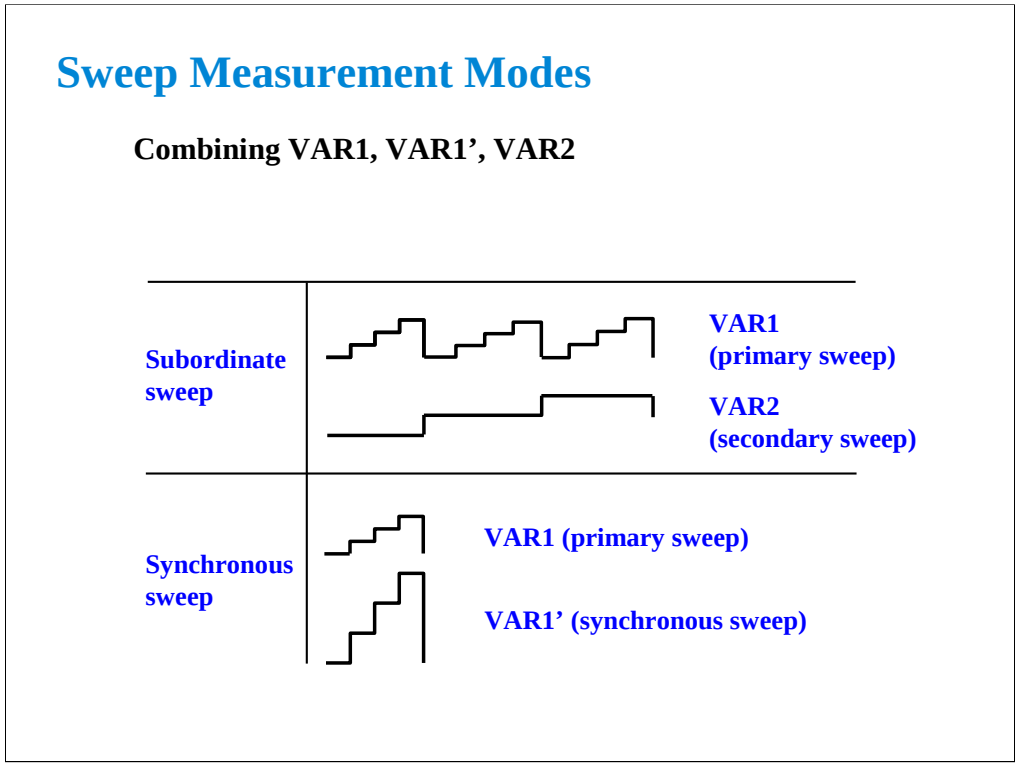
Pulsed mode is used during swept measurements to reduce the effects of thermal stress on the device under test (DUT).



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.

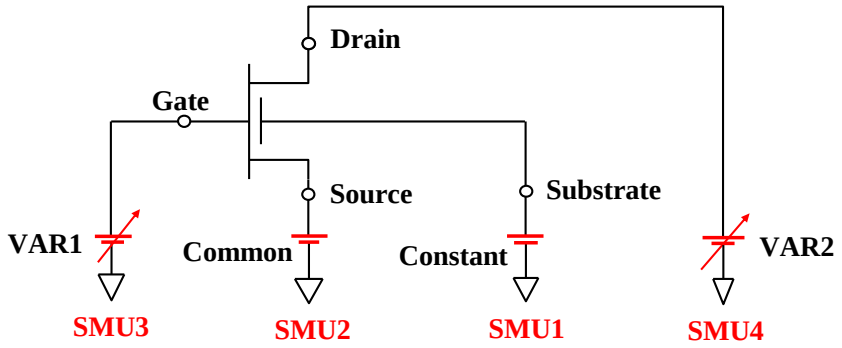


A subordinate sweep variable (VAR2) may be combined with the basic sweep variable (VAR1). This corresponds to the step knob and sweep knob of a curve tracer. This produces a family of curves. VAR2 may be called the secondary sweep.

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

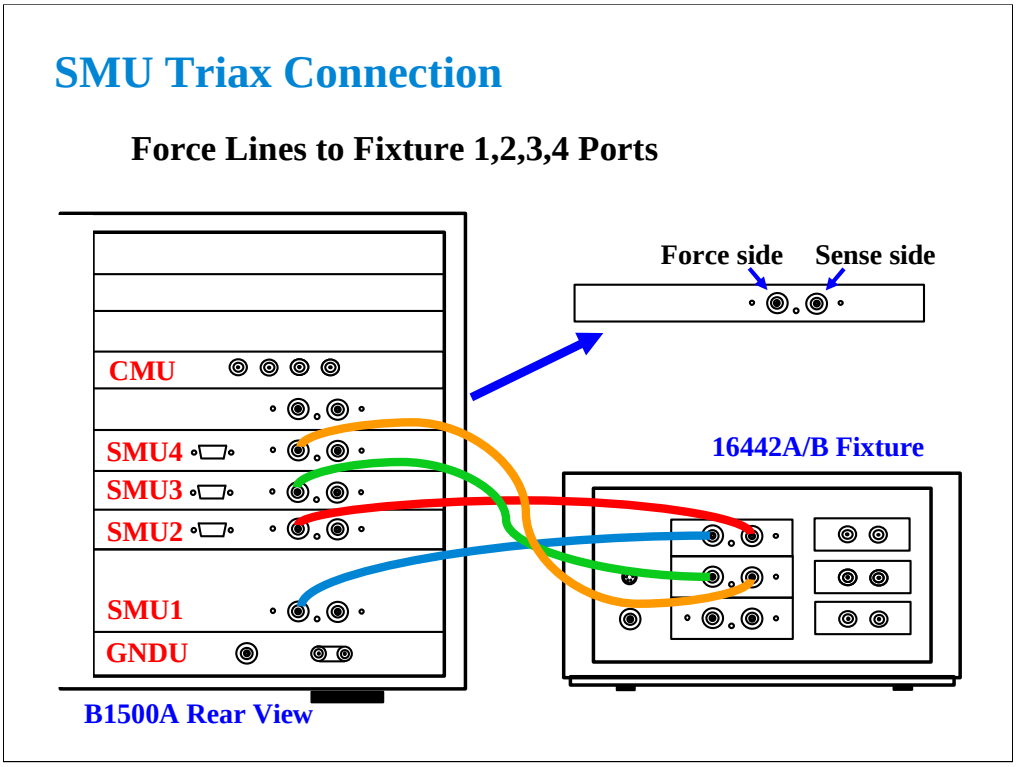
- You will connect the SMU cables and jumper leads
- You will then "properly" insert the MOS transistor
- You will learn how to load a setup data
- Observe Classic Test setup screen
- Click button to make a new measurement
- Observe Application Test setup screen

To Get Started:

- Use the next several pages as you guide
- Verify that four triax cables are connected as shown
- Connect four jumper leads to the 28 pin socket as shown
- Insert the MOS transistor using the "anti-static" procedure

The purpose of this class exercise is to familiarize yourself with how to connect a MOS FET device, and make a basic IDVD family of curves measurement. You will observe the Application Test setup screen and the Classic Test setup screen (interrelationship between the Channel Setup, Measurement Setup, Display Setup screen).

The next several pages show how to connect the 4-terminal MOS FET used in this course. The device for this exercise includes a separate substrate pin. This corresponds to the back gate connection. We can observe all characteristics of the device as if we were probing it at the wafer level.



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

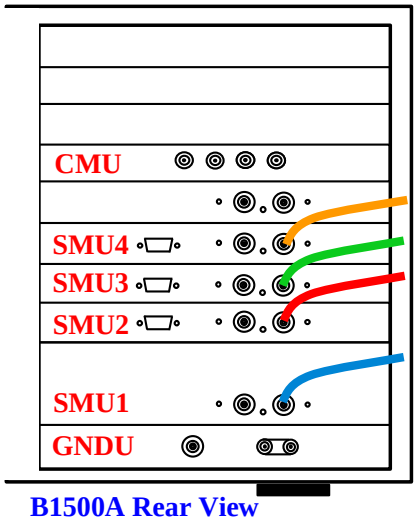
Connect corresponding numbers. On the 16442A/B fixture use the numbers labeled 1 - 6, not 1 - 3.

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.

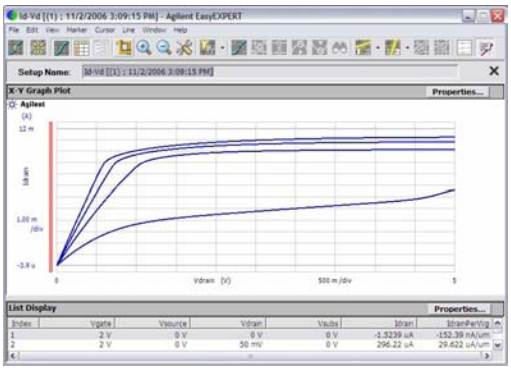
This is the SMU cable setup that will be used in the remainder of the class exercises.

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.

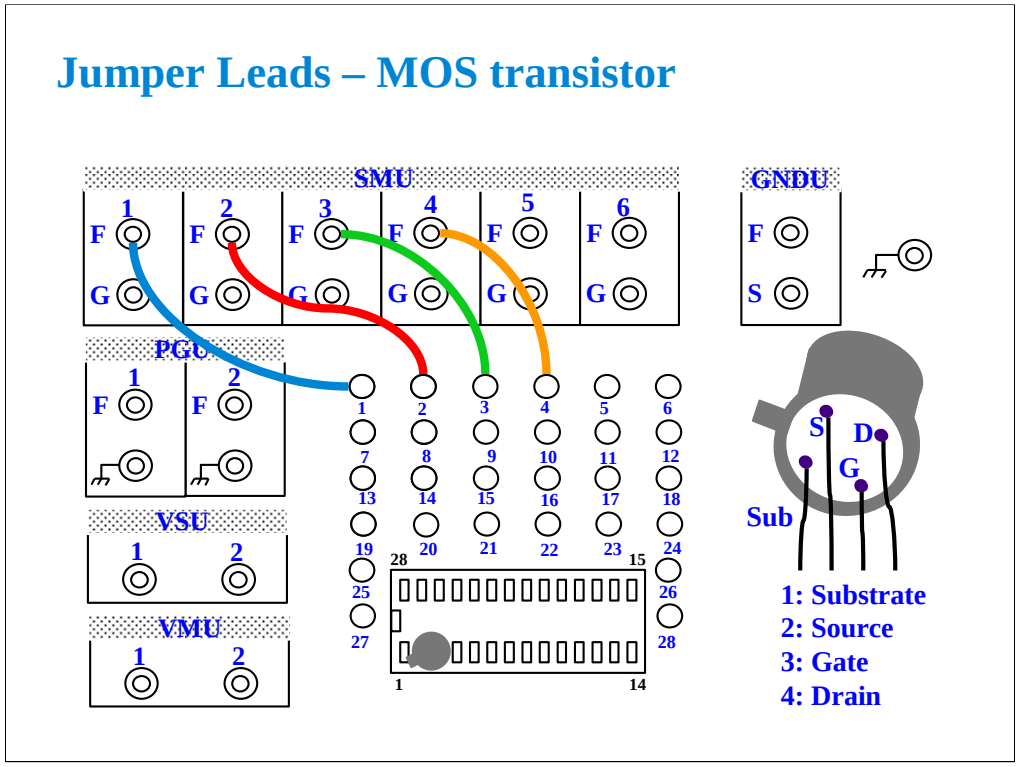
The 4 triax cables must be connected to the left set of connectors (FORCE).

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.

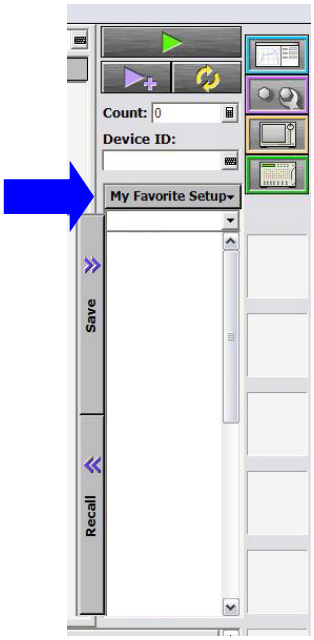


For all class exercises, you need the 28-pin dual in line socket which comes standard with the 4145 fixture (16058A) or the newer fixture (16442A/B). Either fixture works fine.

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 Import Demo Data

1. Prepare the Agilent B1500A Manual CD-ROM Edition 4 or later
2. Insert the CD-ROM into the B1500A built-in CD-ROM drive
3. Click My Favorite Setup button
4. Click Preset Group > Import Preset Group …
5. Import \data\Demo.xpg on the Manual CD-ROM



The Agilent B1500A Manual CD-ROM stores demo data used for performing this class exercise. Insert the CD-ROM and import the demo data to the EasyEXPERT database. The demo.xpg file contains the test setup data used in this class exercise.

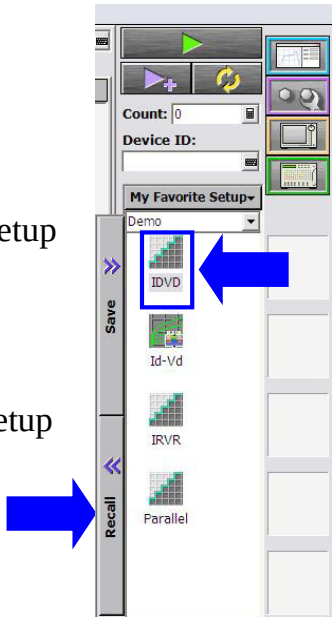
To Get Setup Data

To Get Classic Test Setup:

1. Highlight IDVD in My Favorite Setup
2. Click Recall button

To Get Application Test Setup:

1. Highlight Id-Vd in My Favorite Setup
2. Click Recall button

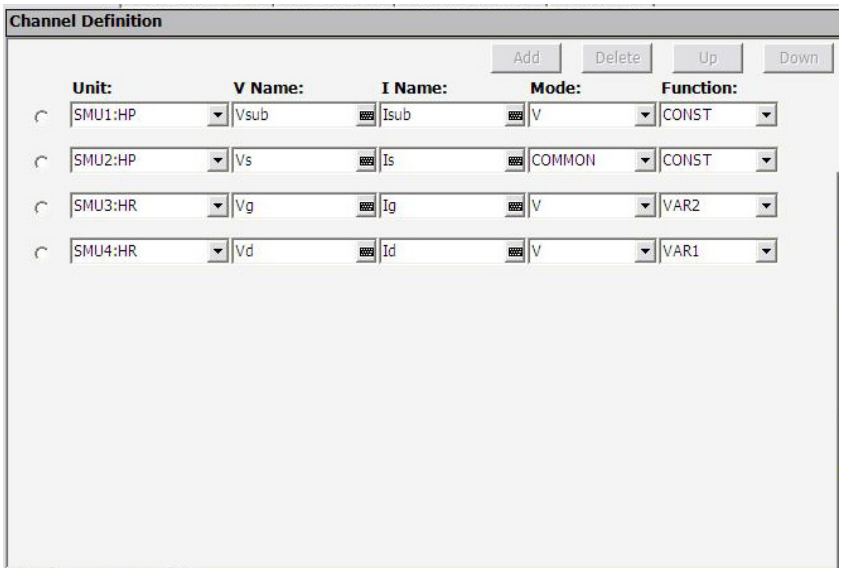


You can get the test setup data as shown.

IDVD is a sample setup data for Classic Test.

Id-Vd is a sample setup data for Application Test.

Classic Test – Channel Setup



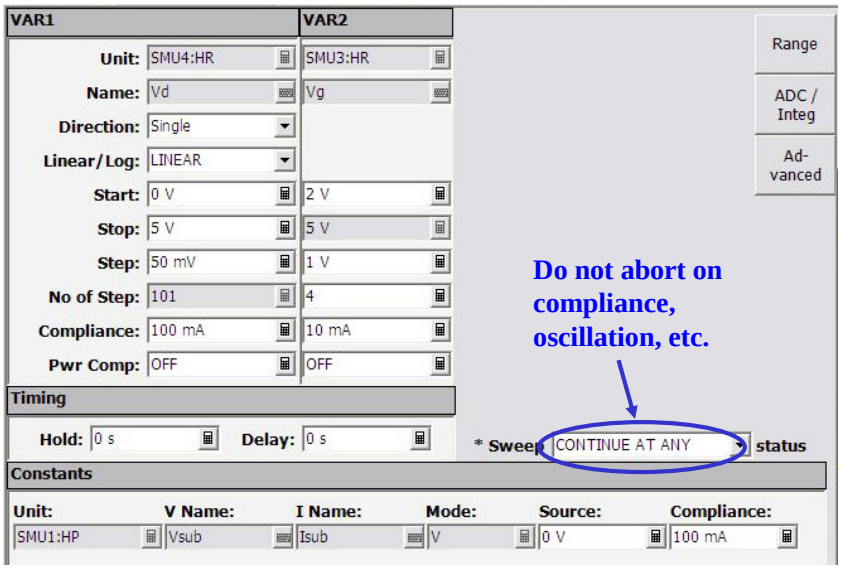
After you get the IDVD setup data, you will see the Classic Test setup screen as shown.

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.

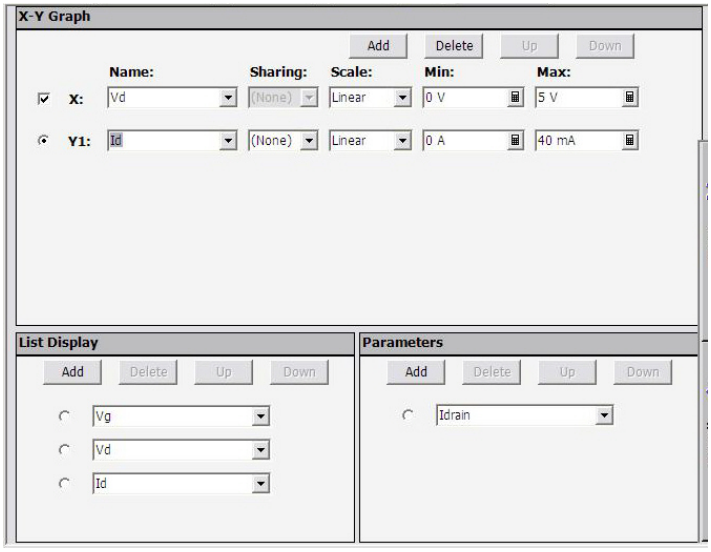
Classic Test – Measurement Setup



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.

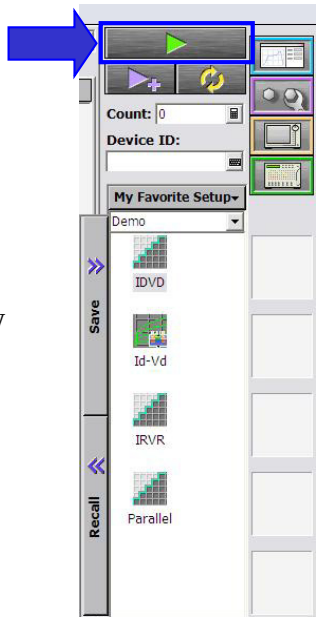
Classic Test – Display Setup



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.

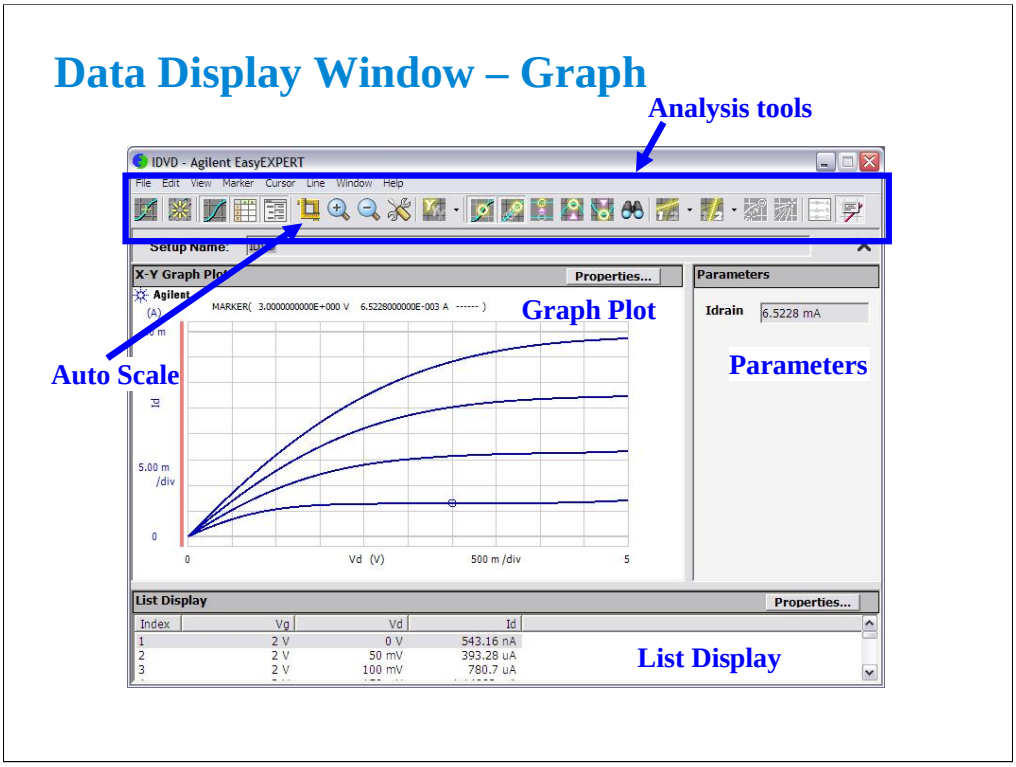
To Start Measurement



1. Click Single button

This opens the Data Display window and starts measurement.

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



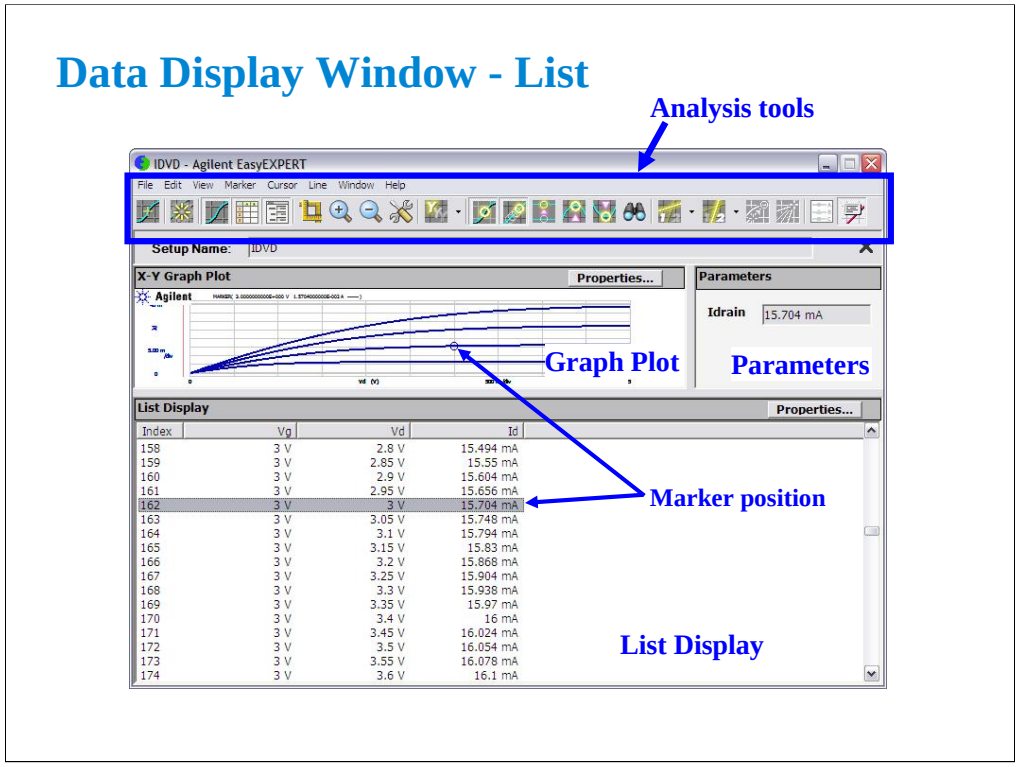
This window displays measurement result graph, list, and parameter values.

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.



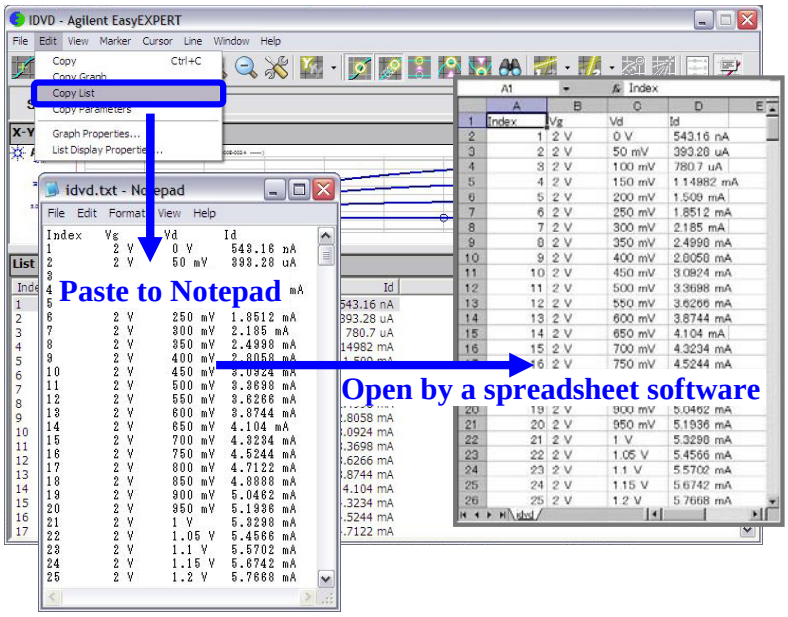
The List Display corresponds exactly with the Graph Plot. Even the highlighted line of data corresponds to the marker position on the Graph Plot.

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).

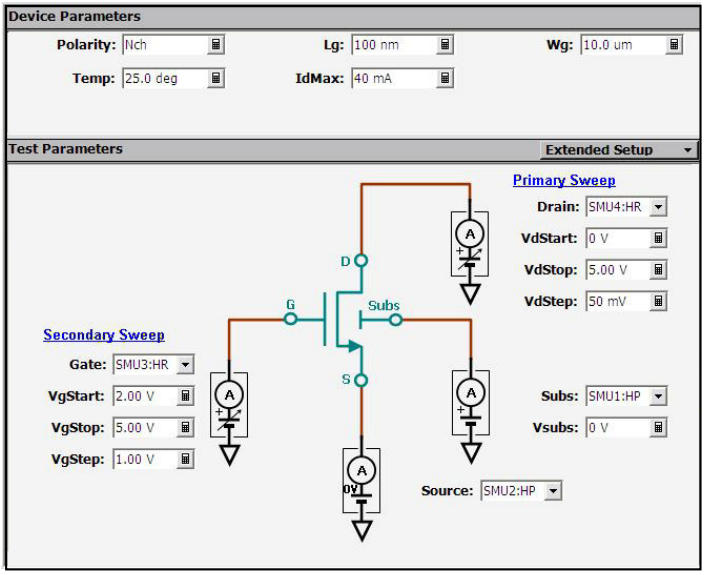
The list data can be copied to a spreadsheet software easily. Click Edit > Copy List. This copies all of the list data into the clipboard.
On the Notepad, paste it and save it as a text file. The file can be opened as a tab separated value data by using a spreadsheet software. See the next page.

The details of the analysis tools function are discussed in Module3.

To Copy List Data



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.

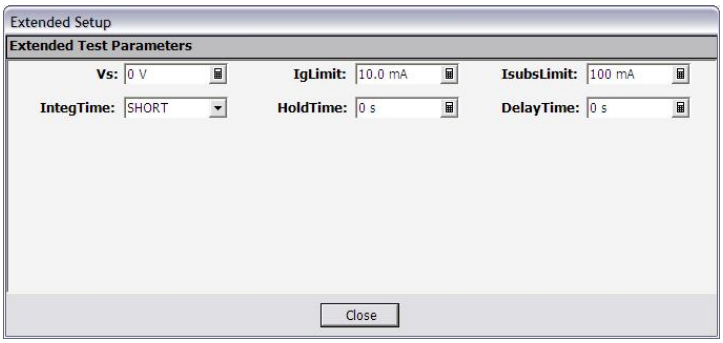
Test Parameters area shows the device connection information and allows the user to set the SMU outputs.

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.

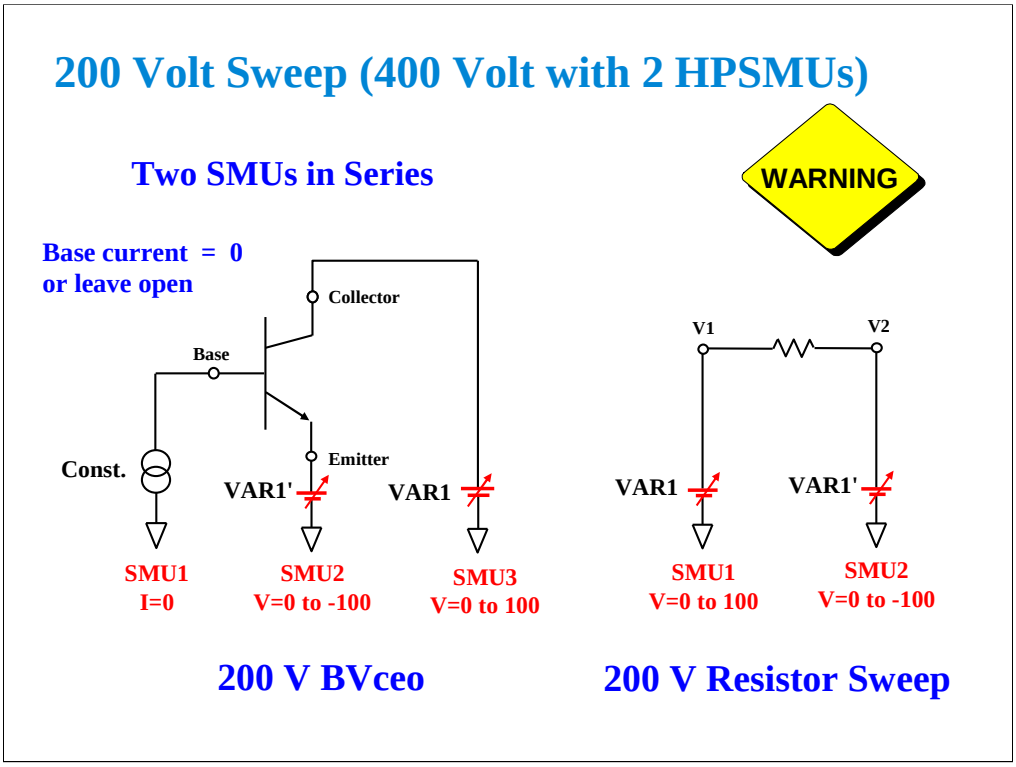
SMUs May Be Connected

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.



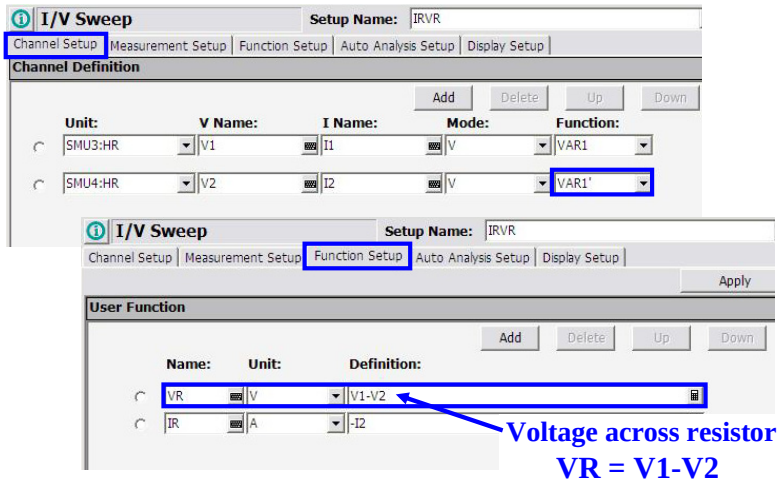
Higher voltages are necessary to observe breakdown conditions, such as BVceo. In the case of BVceo the base must be open (no SMU) or the SMU must be set as a current source with I=0.

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.

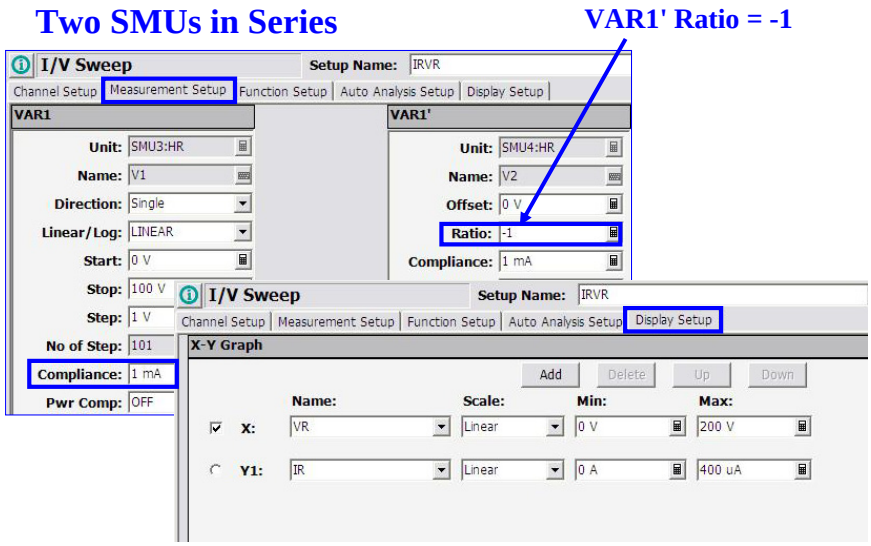
Channel and User Function Pages

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.

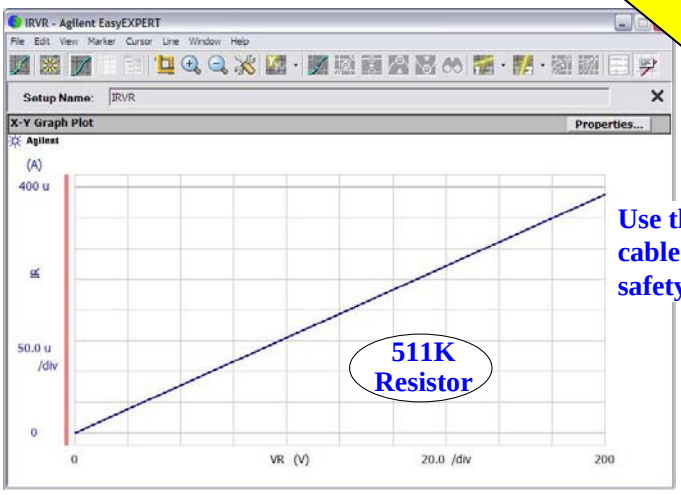
Measurement and Display Pages



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



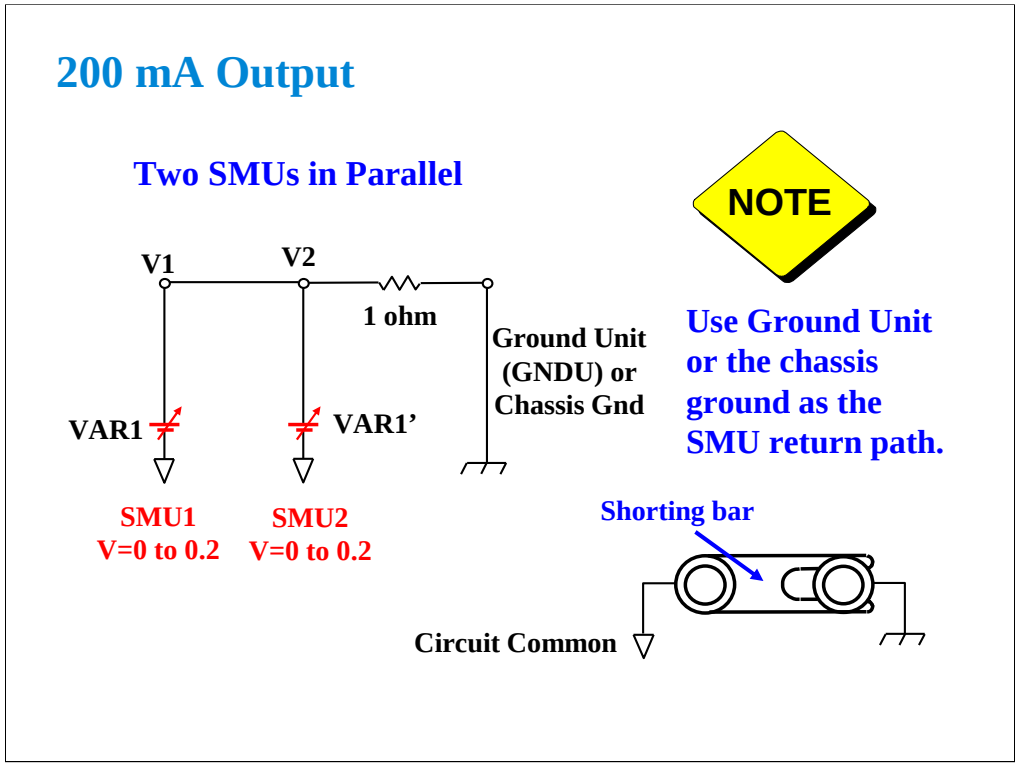
WARNING

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 16058A or 16442A/B.

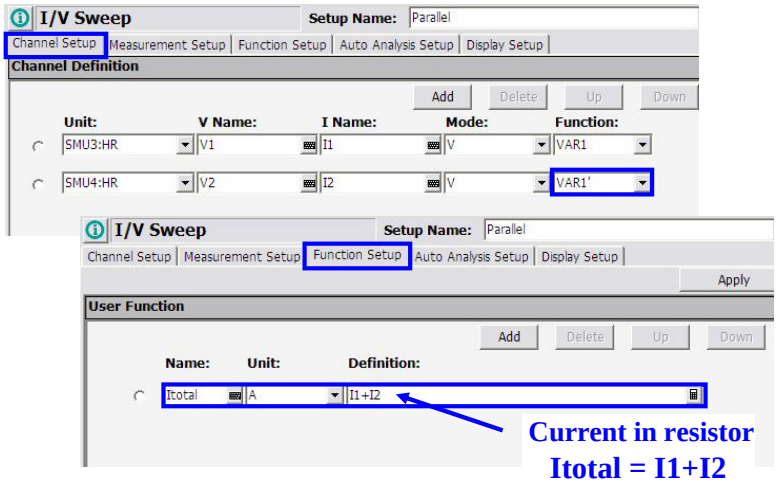
Note
The only time you would ever want to remove the shorting bar, is the case of floating the instrument circuit common when using other instruments. An example might be a connection to a RF Network Analyzer. You may want to remove chassis ground loops by connecting the circuit common directly to the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

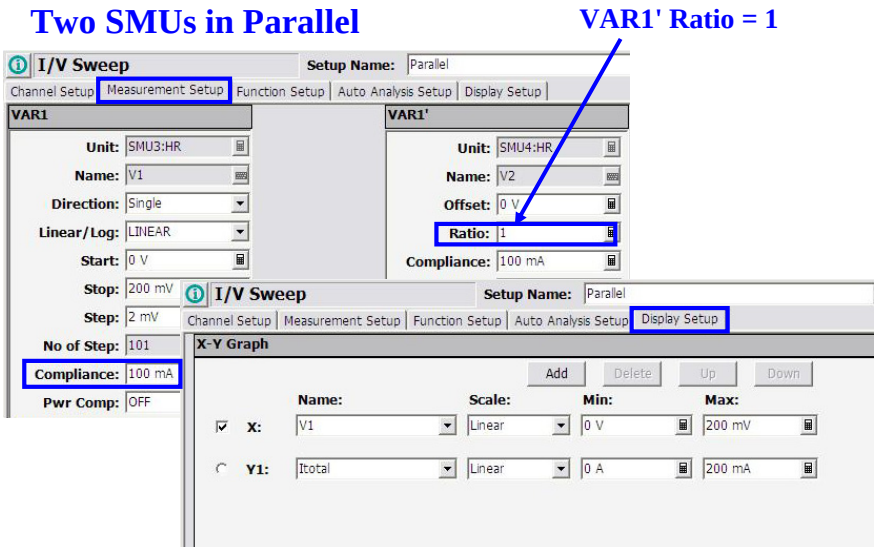
Channel and User Function Pages

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.

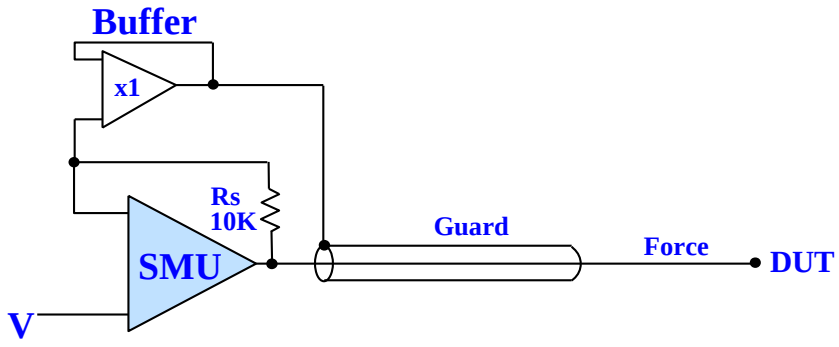
Cabling and Fixturing Issues

- 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

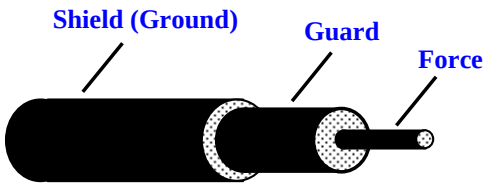
Simplified Diagram



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.

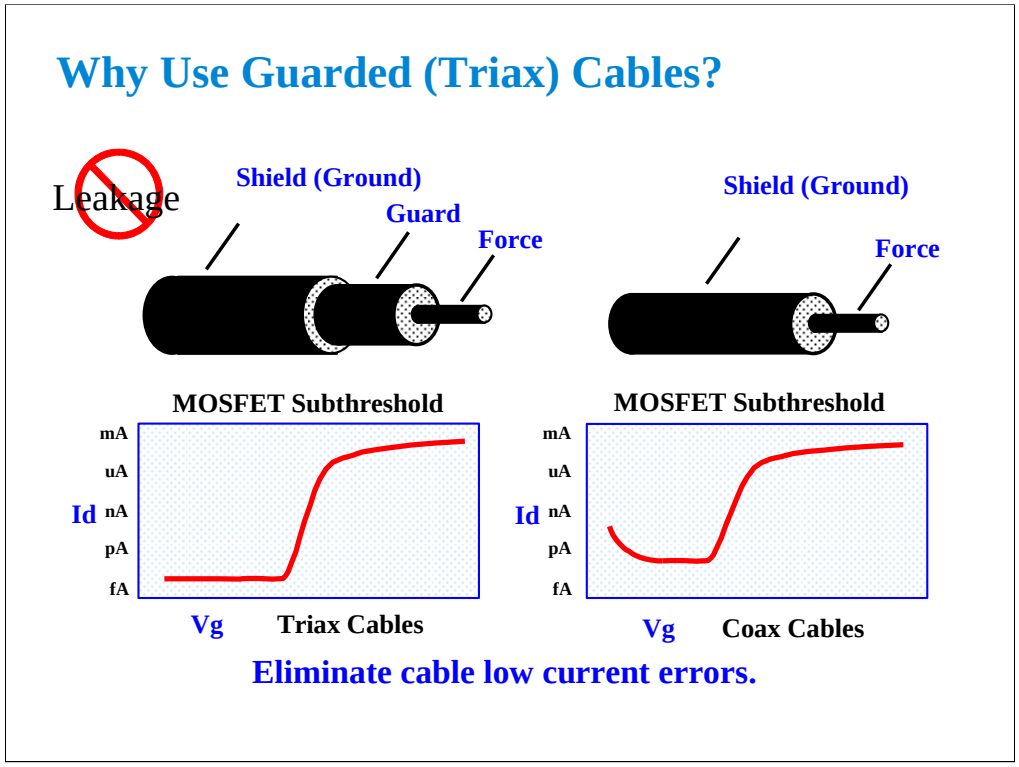
Triaxial Cable for Non-Kelvin connection



	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.

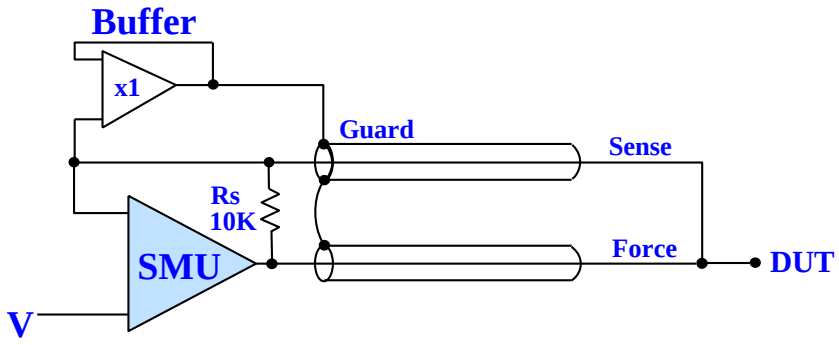
RULES:

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.

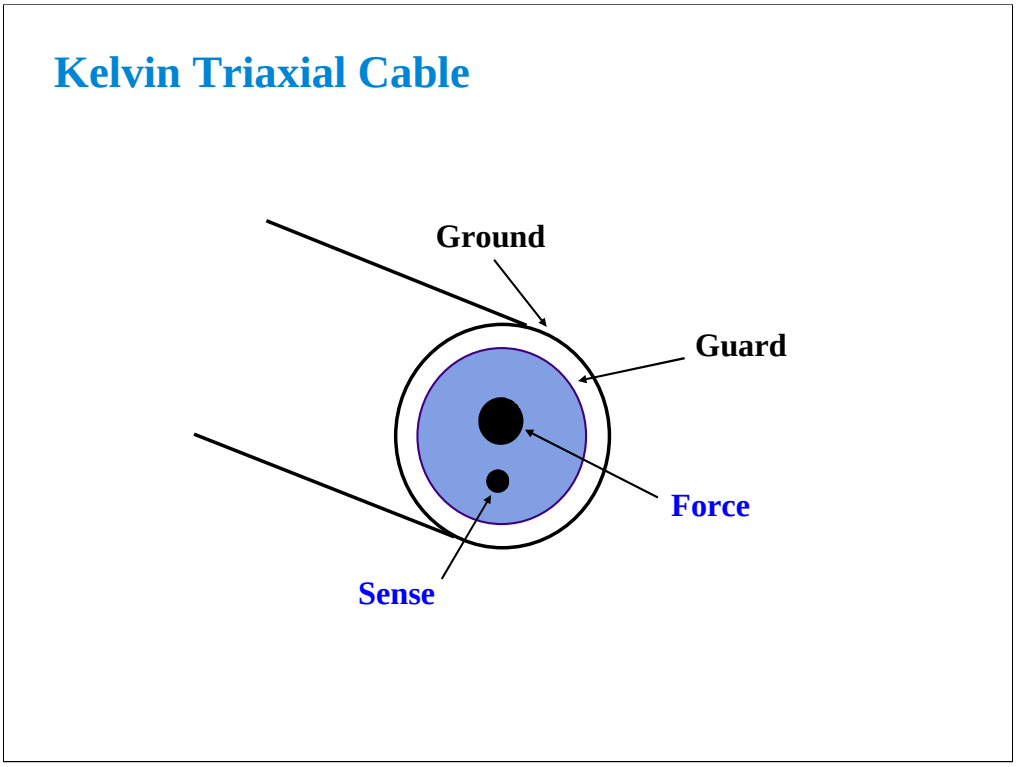
Guard Connection for Kelvin connection

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.

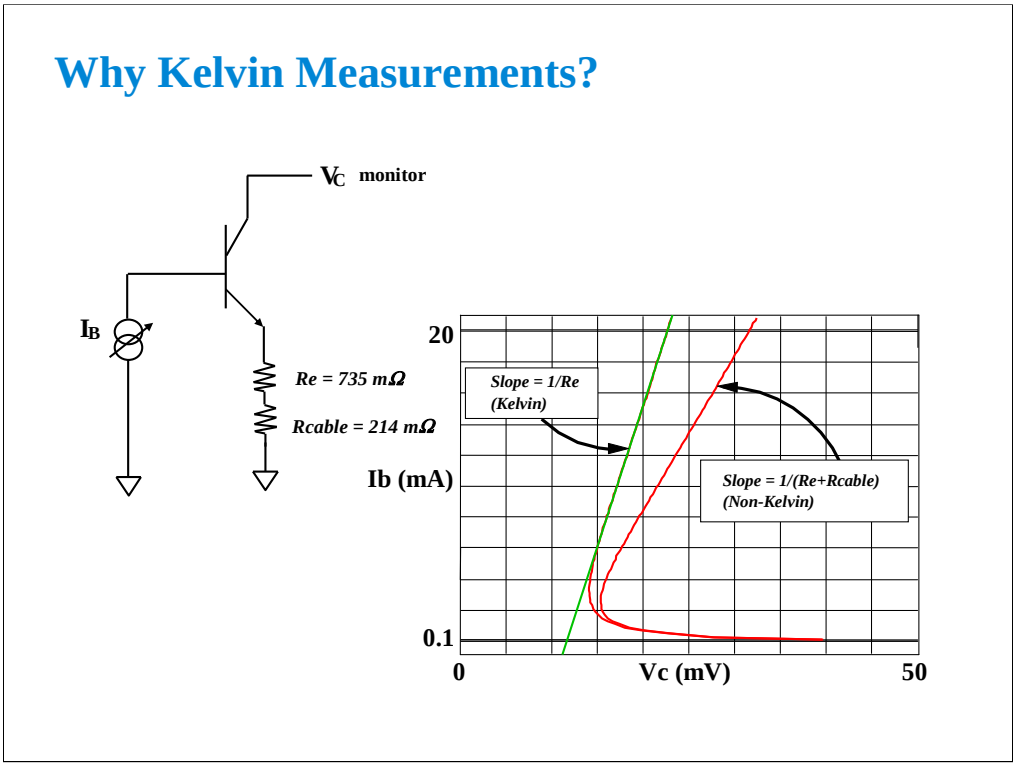


The triaxial cables are good for low current measurements. However, two cables are necessary for low resistance Kelvin measurements.

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

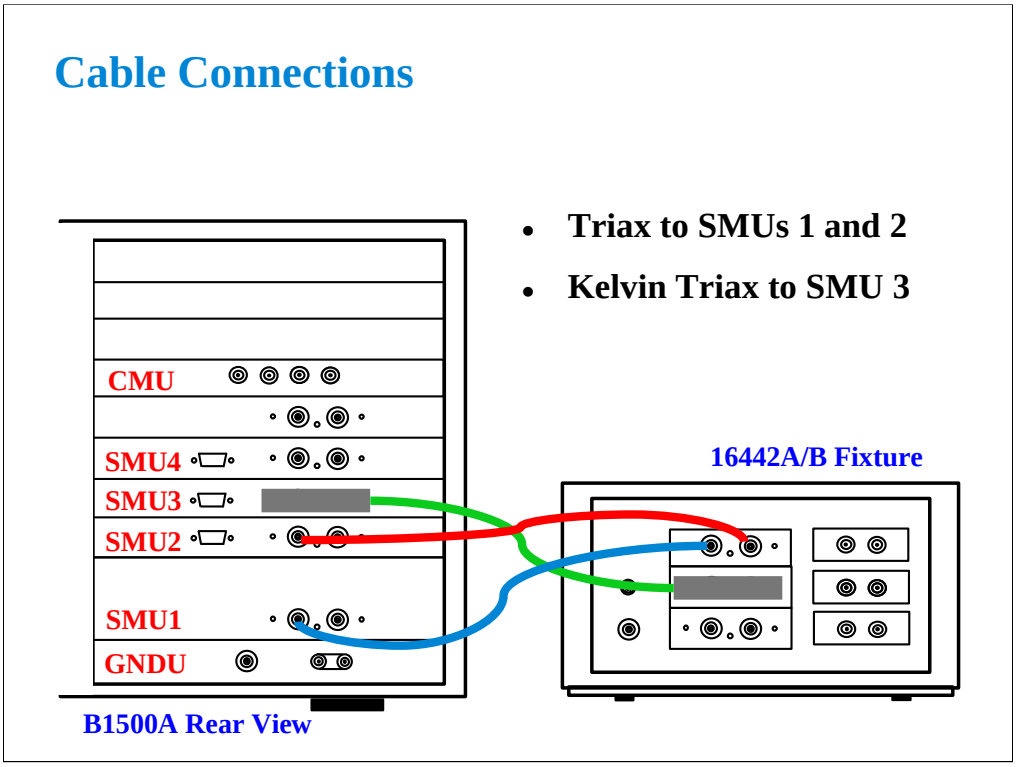
- You will connect a Kelvin triax cable to the B1500A
- You will then connect jumper leads and the bipolar device
- You will get the REKELV setup
- You will observe Re using Kelvin and Non-Kelvin connections. Why is the Non-Kelvin error so large?

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 %.

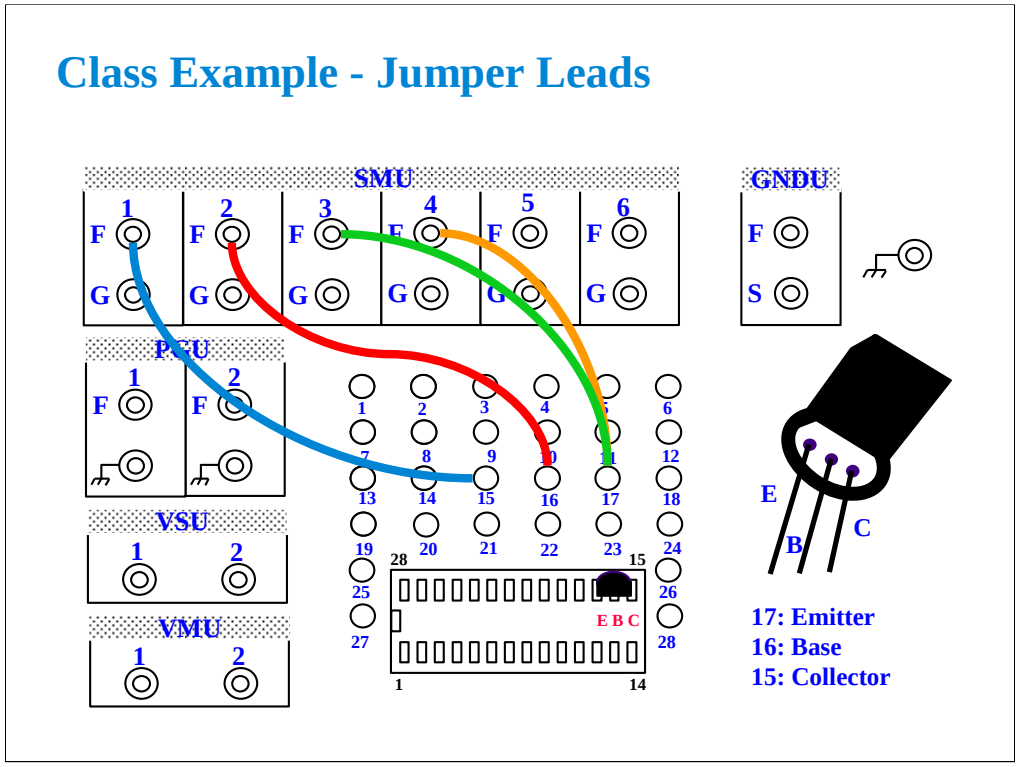
The next several pages lead you through the steps of connecting a Kelvin cable, making the correct Force/Sense jumper lead connections, orienting the device properly in the socket, and getting the REKELV algorithm. The measurement will be Re (emitter resistance) of a bipolar transistor. You will be able 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.

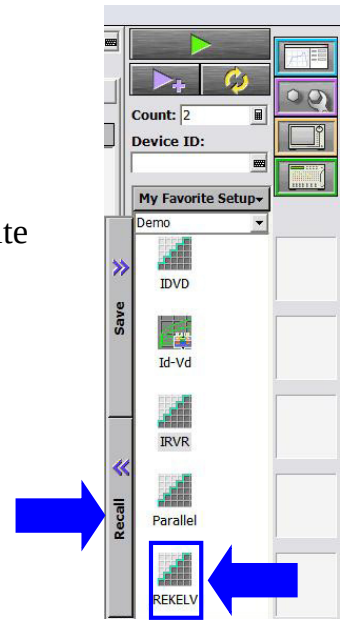
Locate the bipolar transistor in the corner of the socket as shown, with the flat side of the device facing toward you.

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

To Get Setup Data

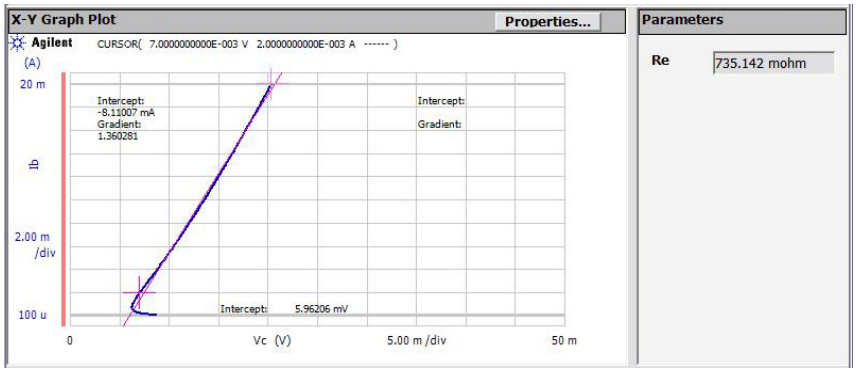
To Get REKELV Test Setup:

1. Highlight REKELV in My Favorite Setup
2. Click Recall button



Single Kelvin Measurement

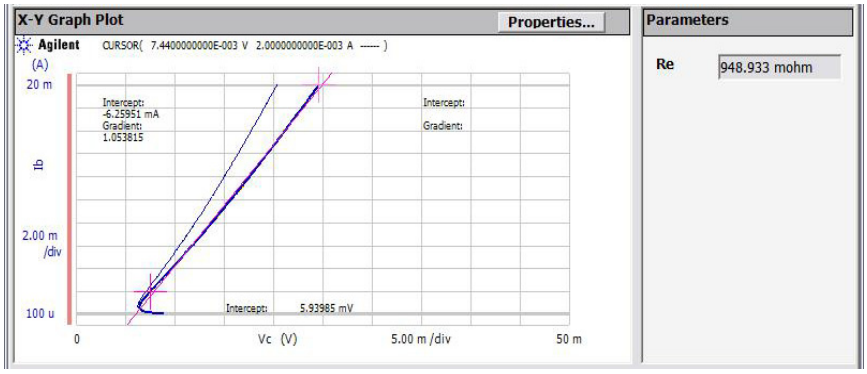
Click button to start measurement



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

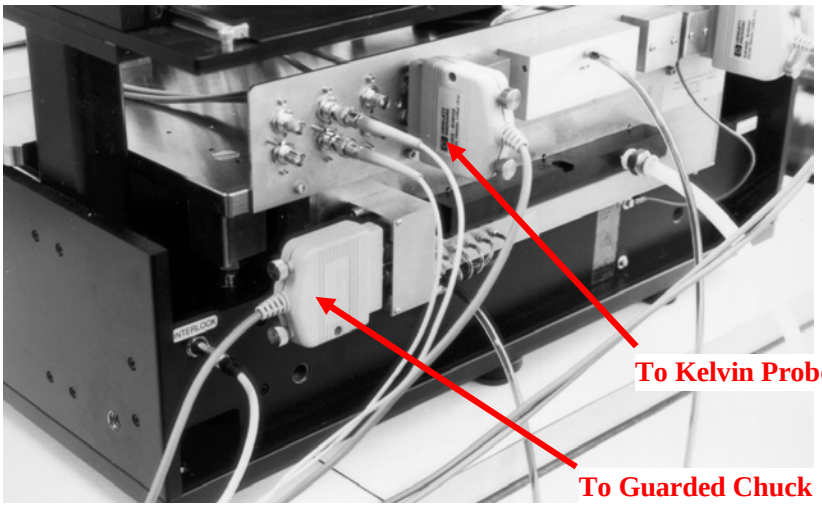
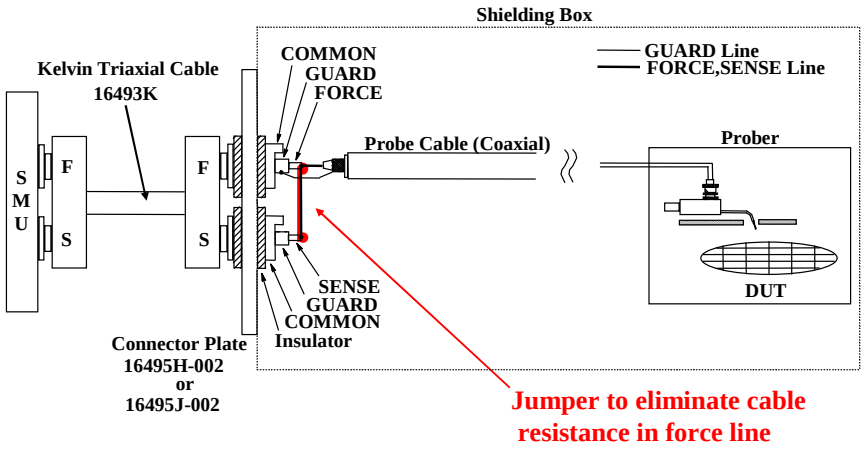


Photo of SMU cable connection to a Cascade Microtech Summit probe station.
The Kelvin triaxial cables mate directly to the probe station.

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

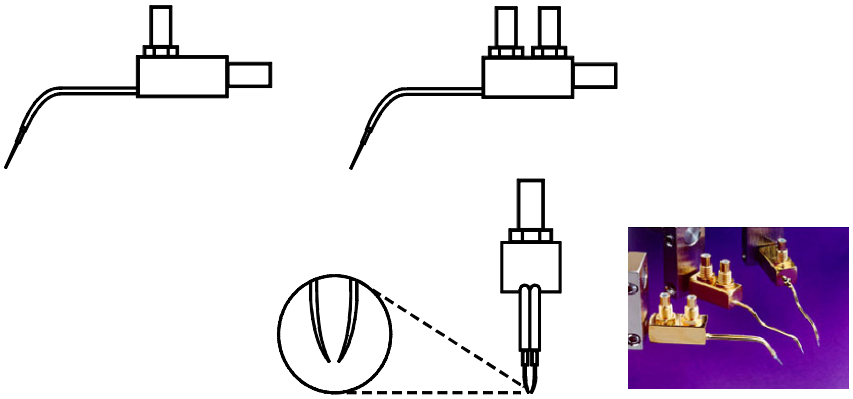
- **Use single triax for basic MOS FET measurements**
- **One triax on each Force line**
- **Leave the Sense lines open...no cable connected**
- **Use triax bulkhead feedthru adapters on the prober**
- **Use a probe holder with a triaxial connector**
- **Use a probe holder than accommodates replaceable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

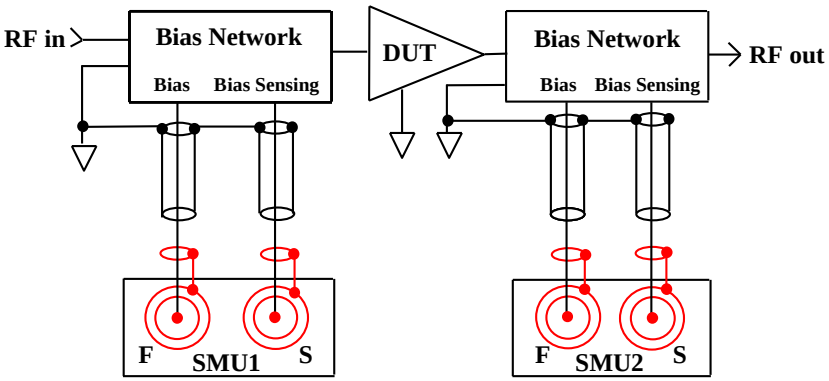
Single Triax **Kelvin Triax**



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**

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.

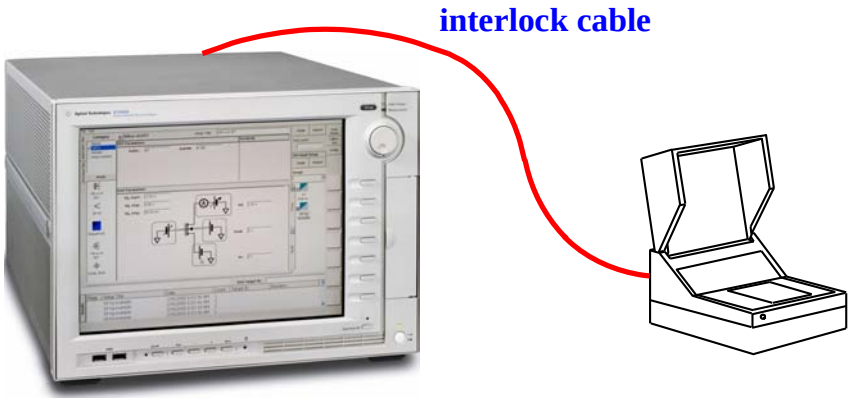
If you want to connect to the BNC type interlock connector on the 16088B, your fixture or prober, use the 16435A Interlock Cable Adapter. The 16435A provides a BNC cable and a small adapter box which is used to join the BNC cable and the interlock cable furnished with the B1500A.

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

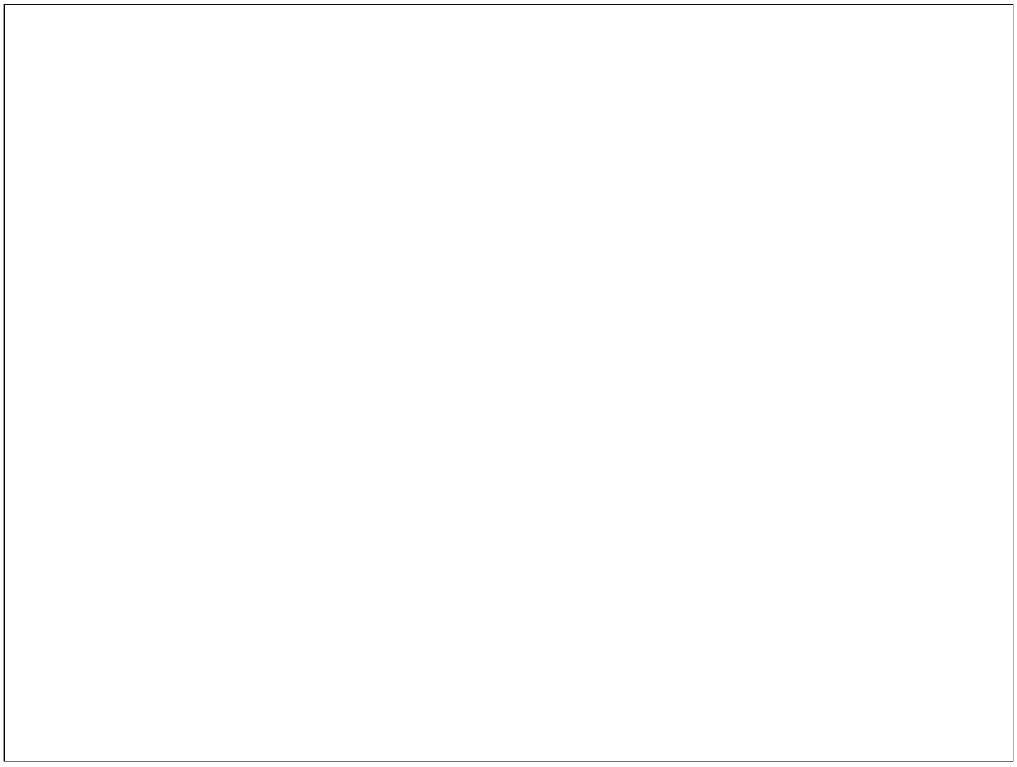
Add the 16435A Adapter

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.



6 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

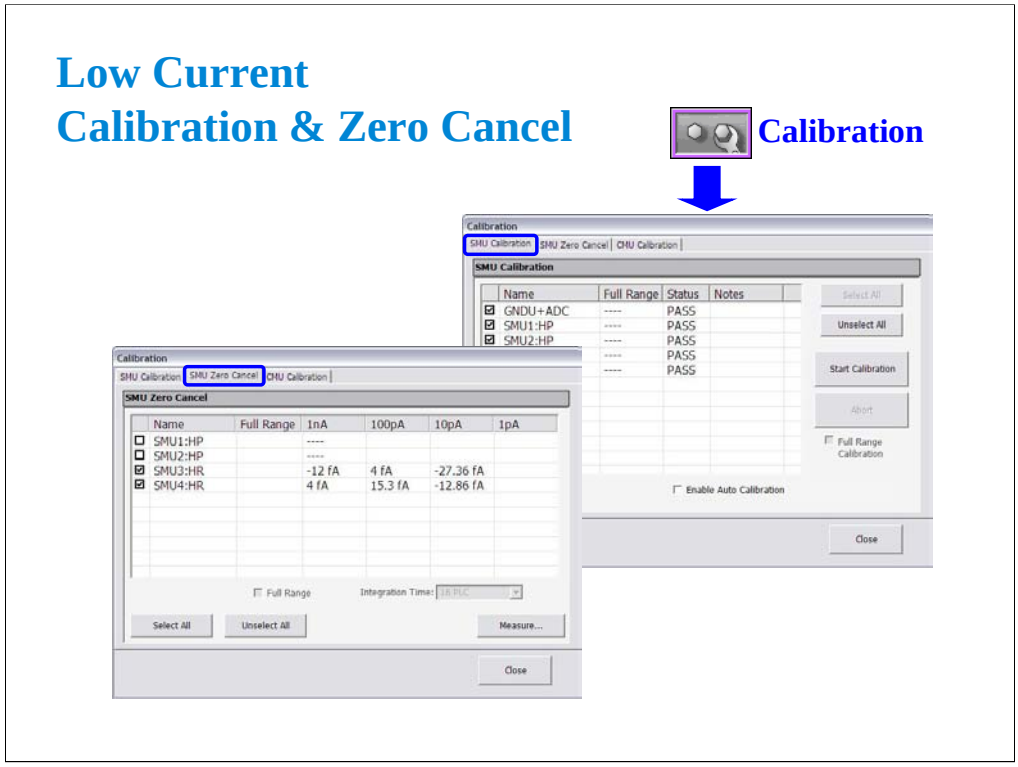
The SMU can be thought of as a sophisticated OP AMP. With any OP AMP there is an associated input offset error. This error is small and varies with ambient temperature shifts and other factors. It can be reduced to a negligible amount with a zero cancel function.

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?

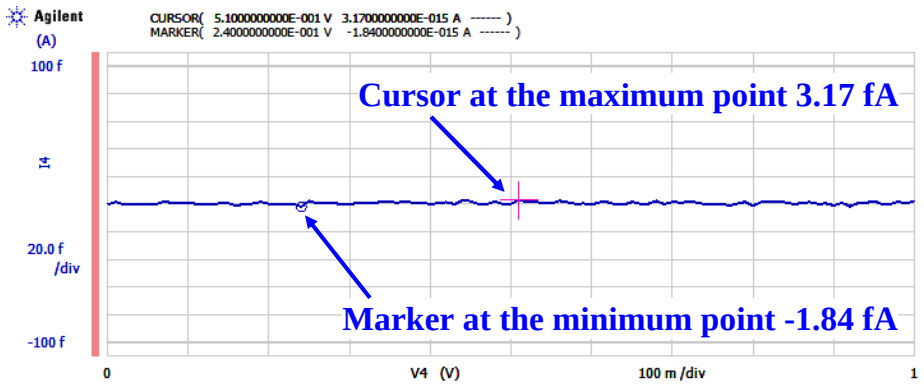
To Get Started:

- 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.

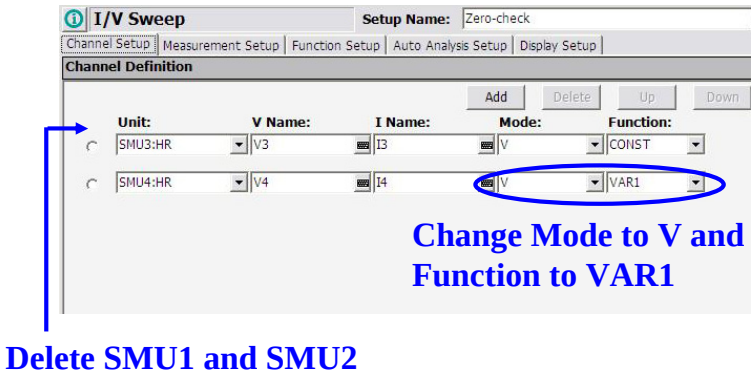
ZERO CHECK - No cable
Using Default SMU Setup



+/- 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.

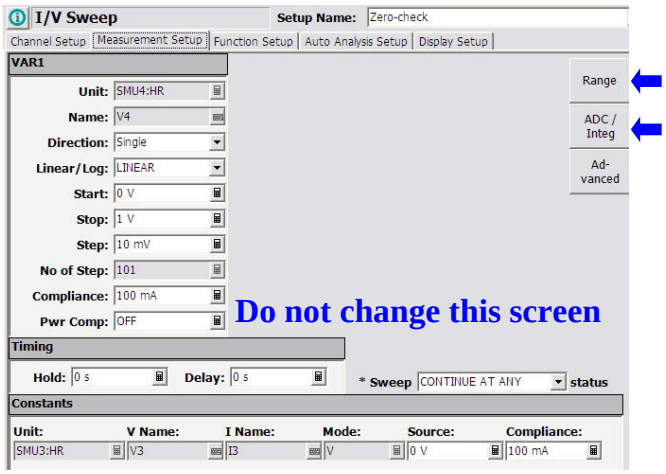
ZERO CHECK
Channel Setup



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.

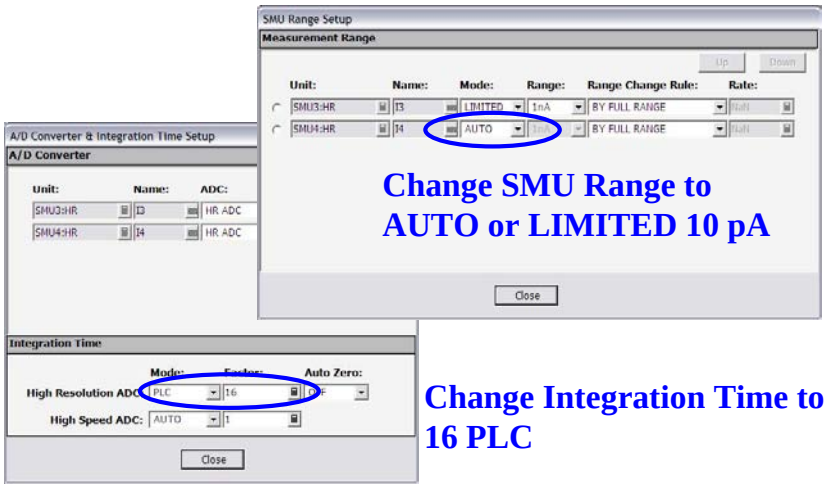
Also the sweep starts at 0, so no big discontinuities on the first step of the sweep.

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



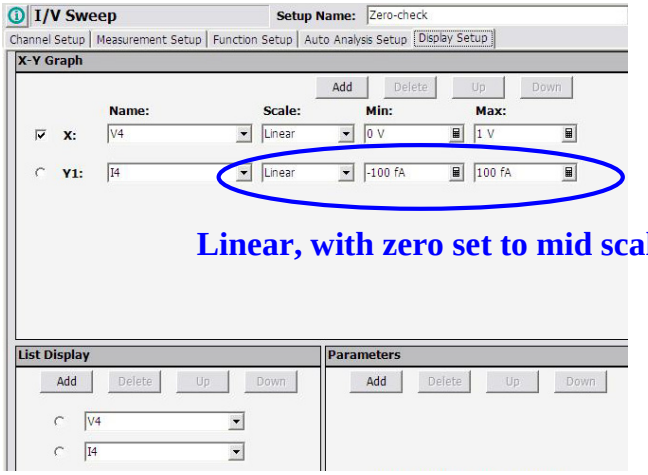
Change SMU Range to AUTO or LIMITED 10 pA

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.

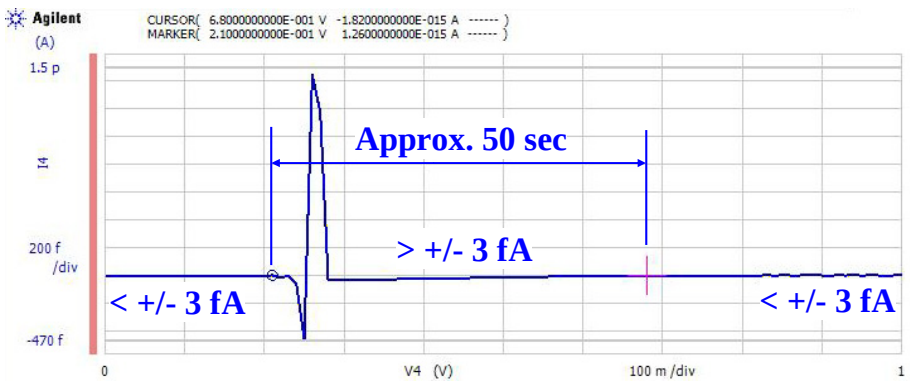
ZERO CHECK
Display Setup



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.

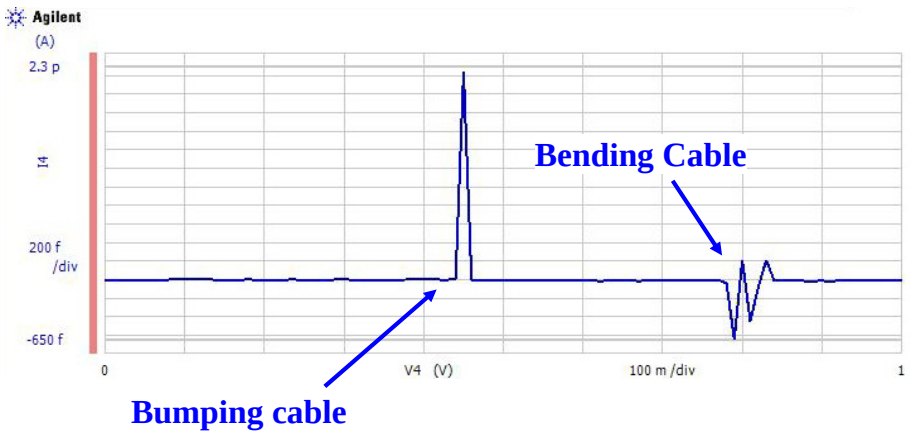
ZERO CHECK
Effect of connecting a triaxial cable



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

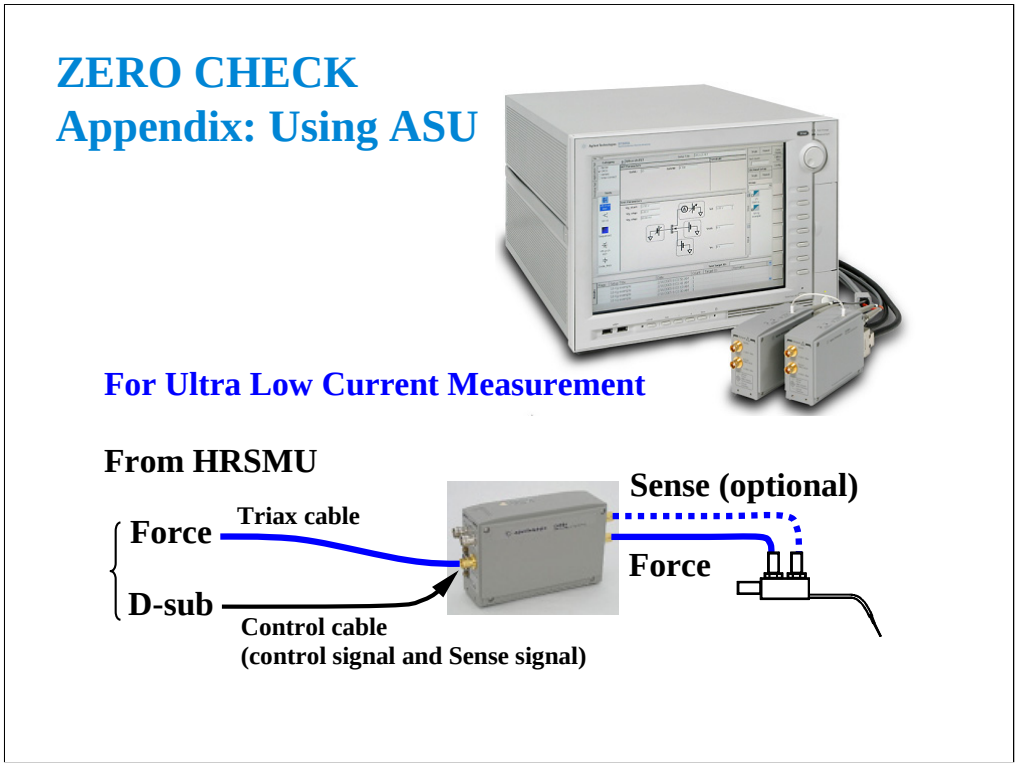
Here we see the effect of connecting a cable to the open SMU port of the B1500A. The discontinuity lasted for 50 seconds of a 2 minute sweep from 0 to 1 volt in 10 mV steps.

ZERO CHECK
Effect of cable movement



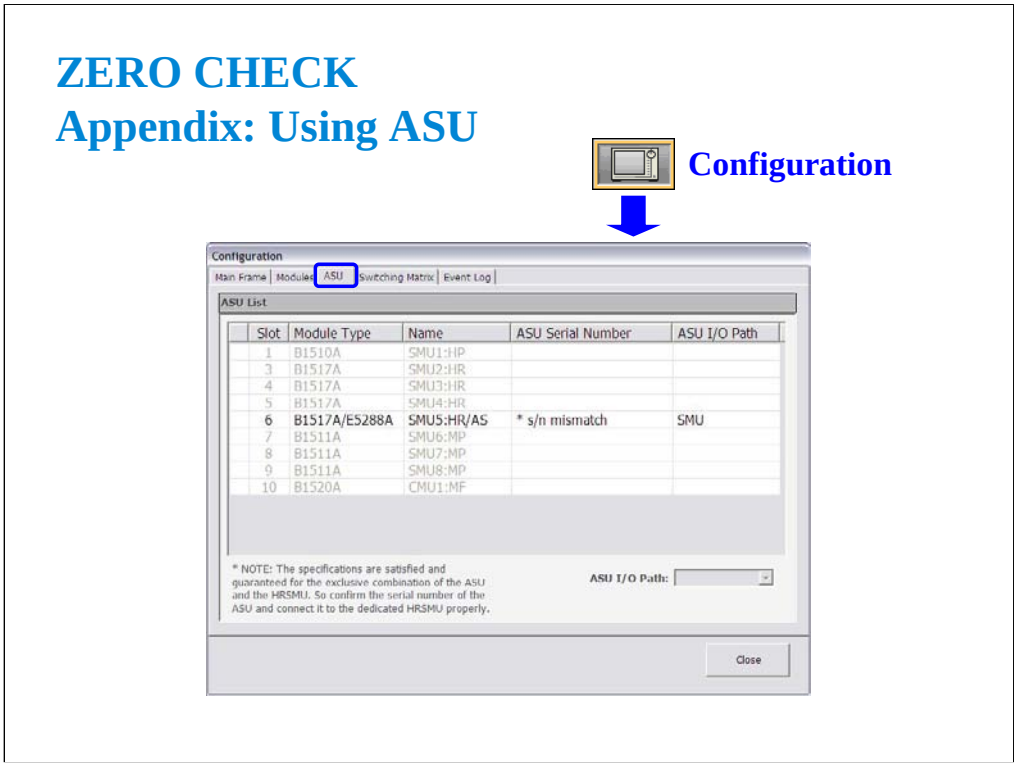
As you can see, your fixturing must be free from vibration. Bending cables during a test is another NO NO. The above measurements were made on a single triax cable for classic parameter analyzers. The Kelvin triax cable is less sensitive to movement (triboelectric effects). However, either cable works 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.



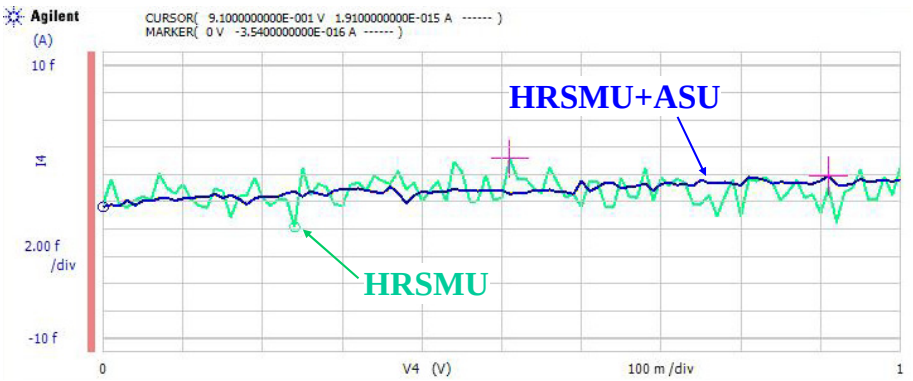
You can check whether the ASU connection is correct or wrong. Open the Configuration window and look at the ASU tab screen.

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

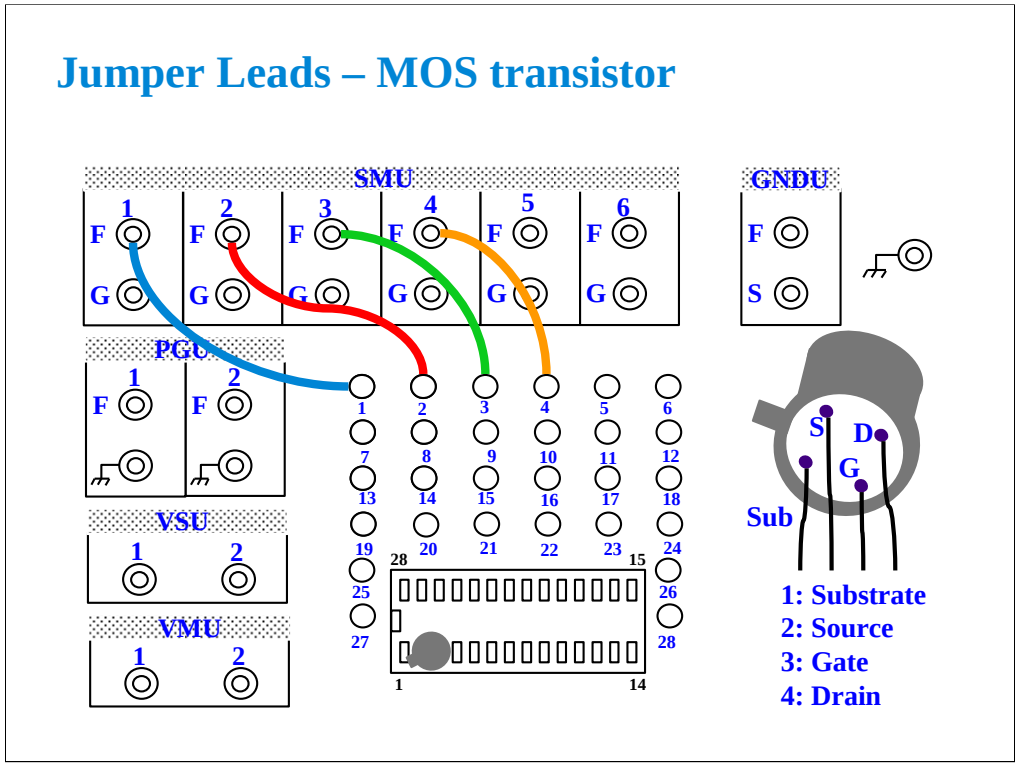
You will:

- 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.



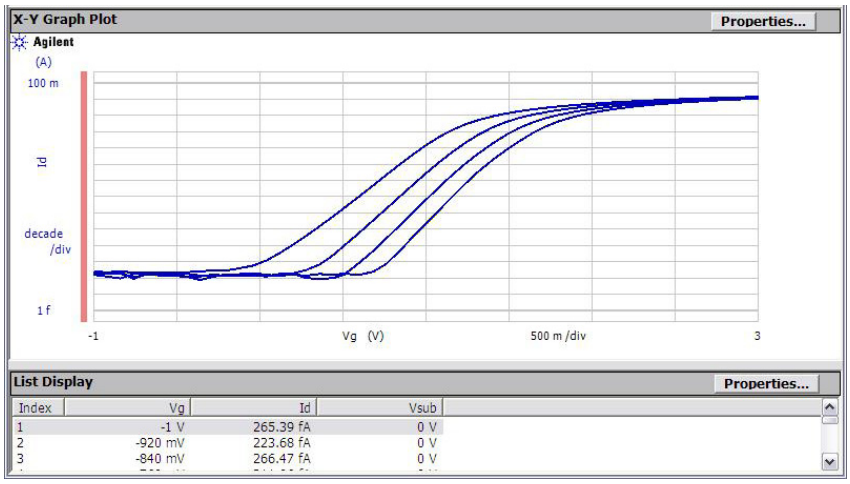
For all class exercises, you need the 28-pin dual in line socket which comes standard with the 4145 fixture (16058A) or the newer fixture (16442A/B). Either fixture works fine.

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

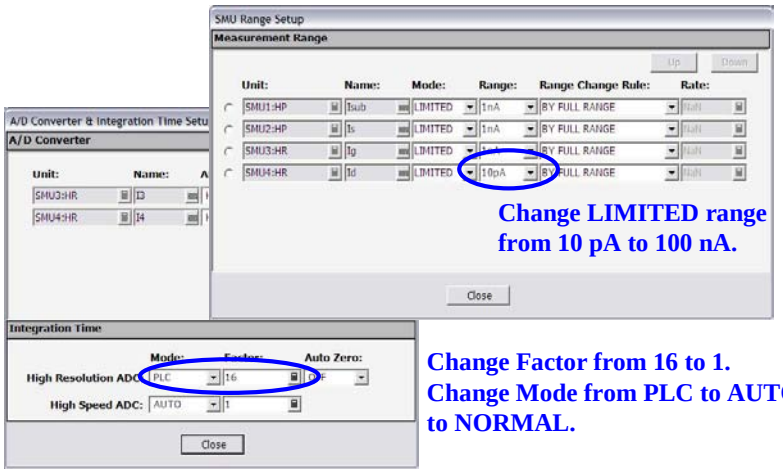
Connect jumper leads as follows.
Terminal 1 : SMU1 F terminal
Terminal 2 : SMU2 F terminal
Terminal 3 : SMU3 F terminal
Terminal 4 : SMU4 F terminal

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



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

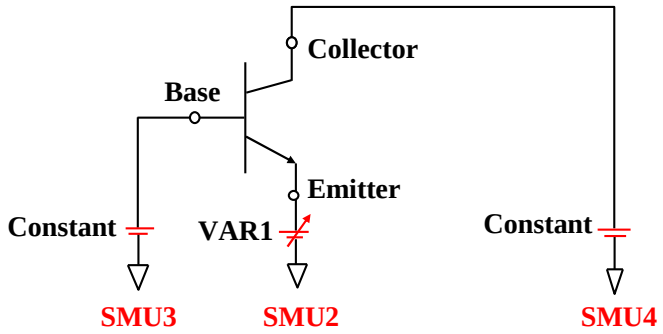
The 100 nA range will speed up the test but you will lose low-end resolution. Try setting LIMITED to 10 pA range or 100 pA range. Accuracy increases but speed slows considerably.

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'.

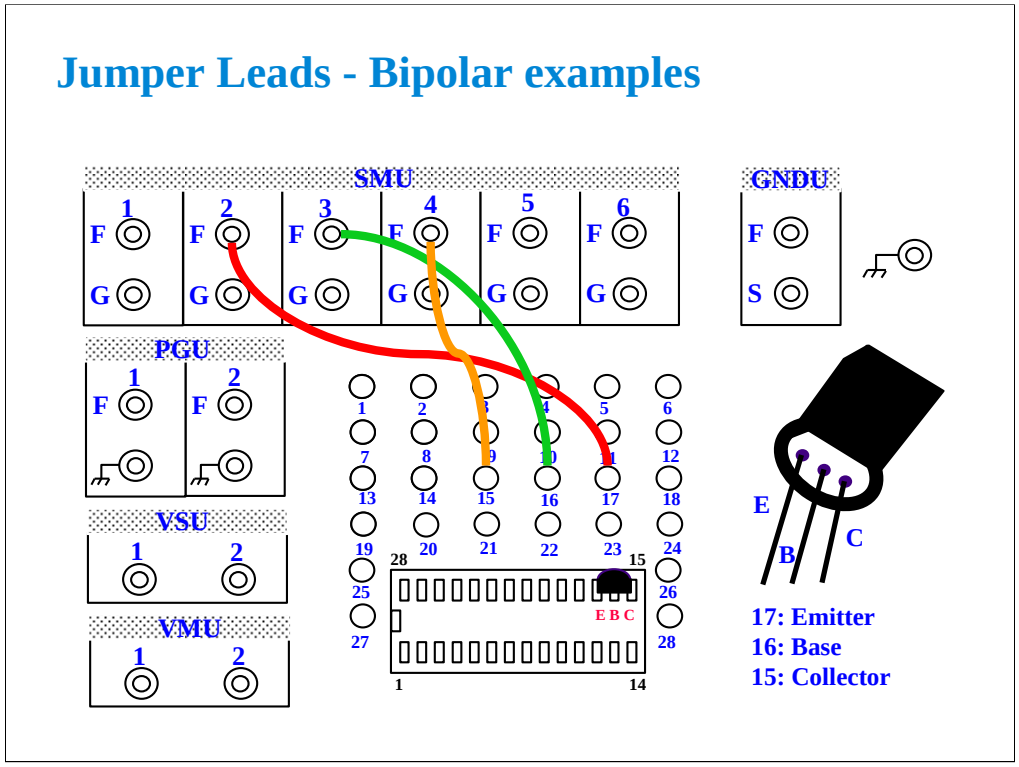
Class Exercise
Low Current Gummel Plot

- 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.



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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.

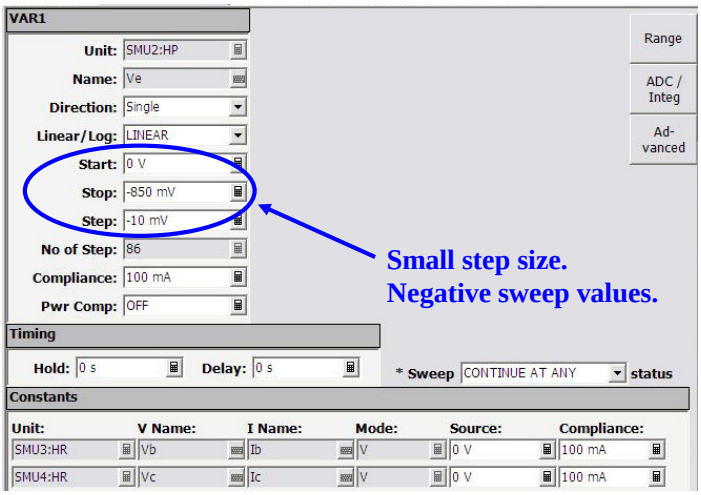
Connect the cables between the B1500A and test fixture as follows.
SMU1 : SMU1
SMU2 : SMU2
SMU3 : SMU3
SMU4 : SMU4

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.

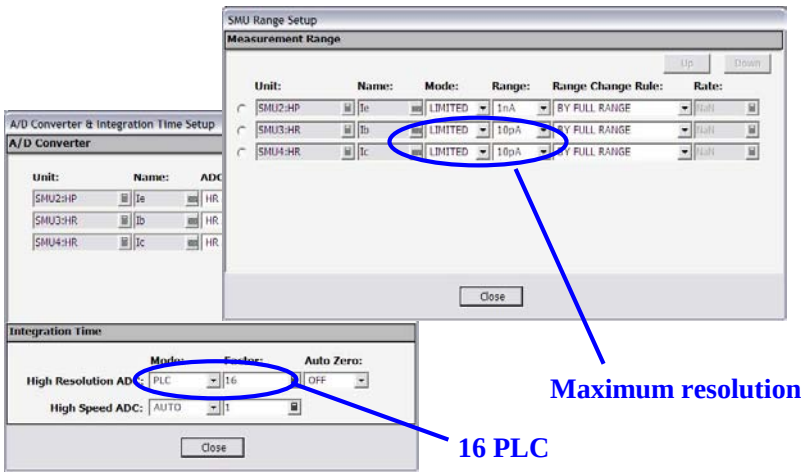
Unlike the MOS device, the bipolar transistor is not static sensitive. You may touch the leads without using a ground strap.

Gummel Plot
Measurement Setup



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

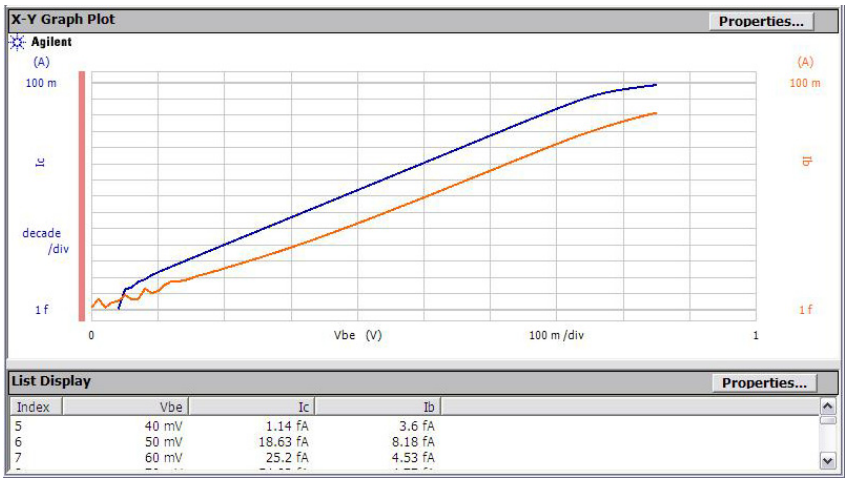
Gummel Plot
Range and Integration Time



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

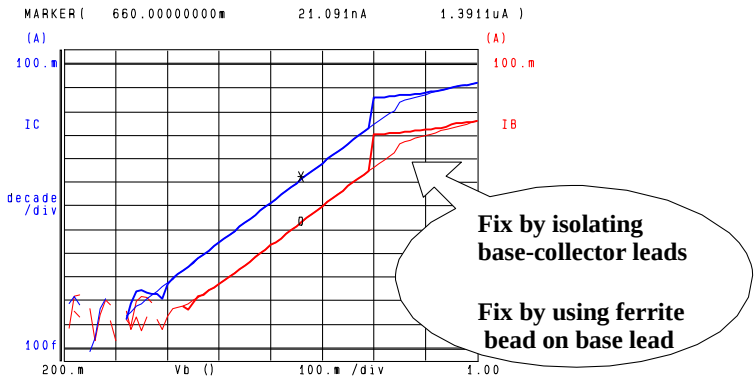


This curve shows a normal gummel characteristic of the bipolar transistor. The collector current is linear when plotted on log scale from 10 mA down to fA levels.

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

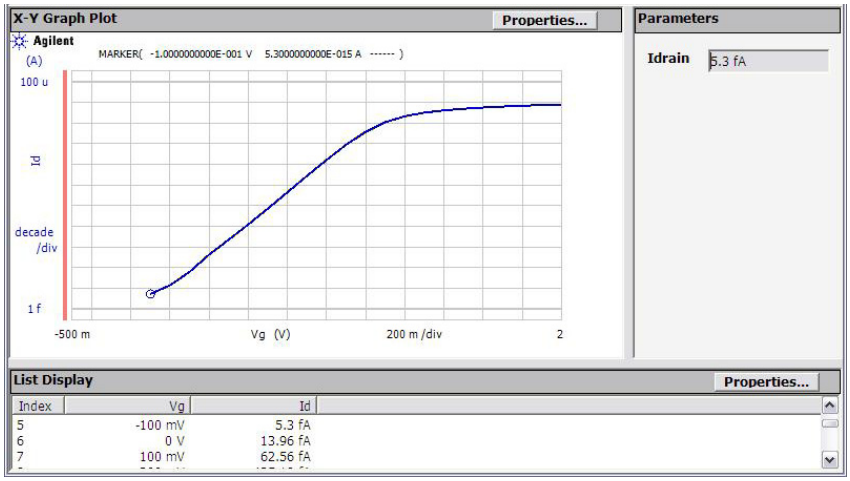


This is a common occurrence when high frequency bipolar transistors are tested with jumper lead connections. When RF couples in the air to the base lead, there can be enough DC rectification to increase the base current bias. This causes positive feedback. At some point along the curve, there will be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

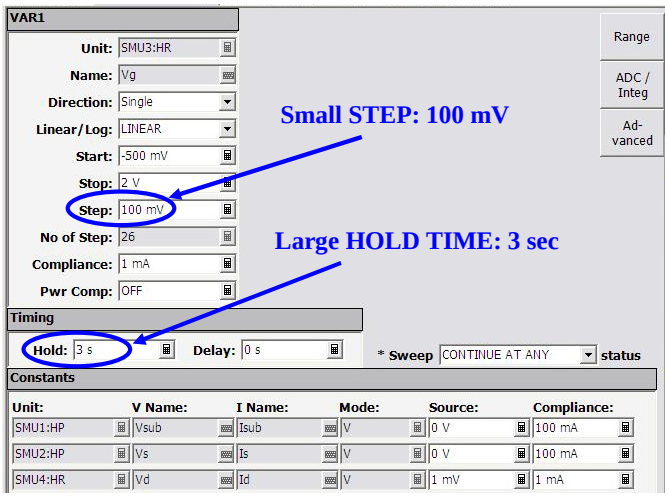
ULTRA LOW CURRENT
Subthreshold Curve



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.

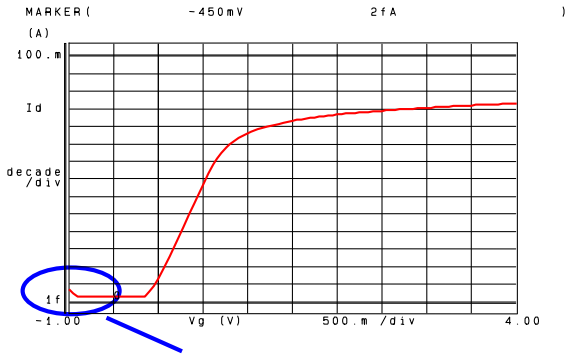
ULTRA LOW CURRENT Measurement Setup



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

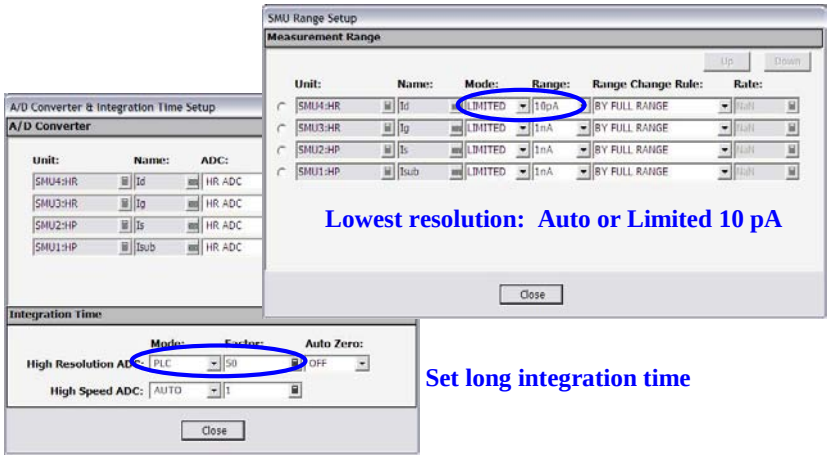


Not part of the subthreshold characteristic

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



Lowest resolution: Auto or Limited 10 pA

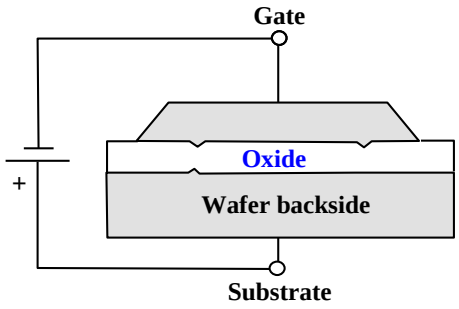
Set long integration time

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.

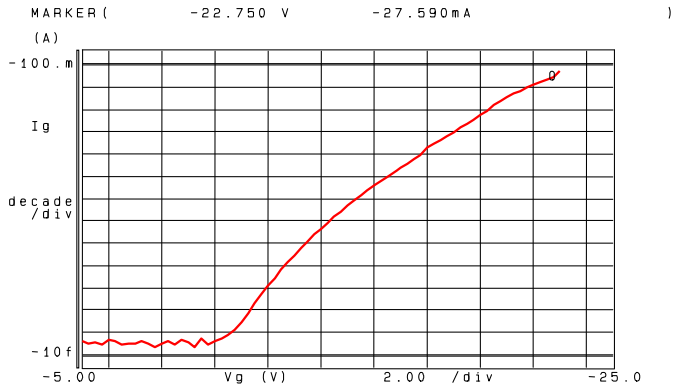
Low Current Leakage
Gate Oxide

- 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

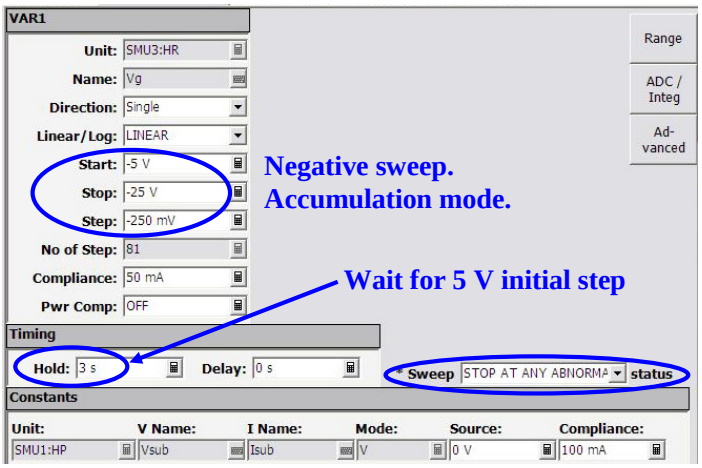


The Fowler-Nordheim (FN) plot is a log plot of oxide leakage in accumulation mode breakdown. The plot shows a characteristic "arc" leading up to the rupture current.

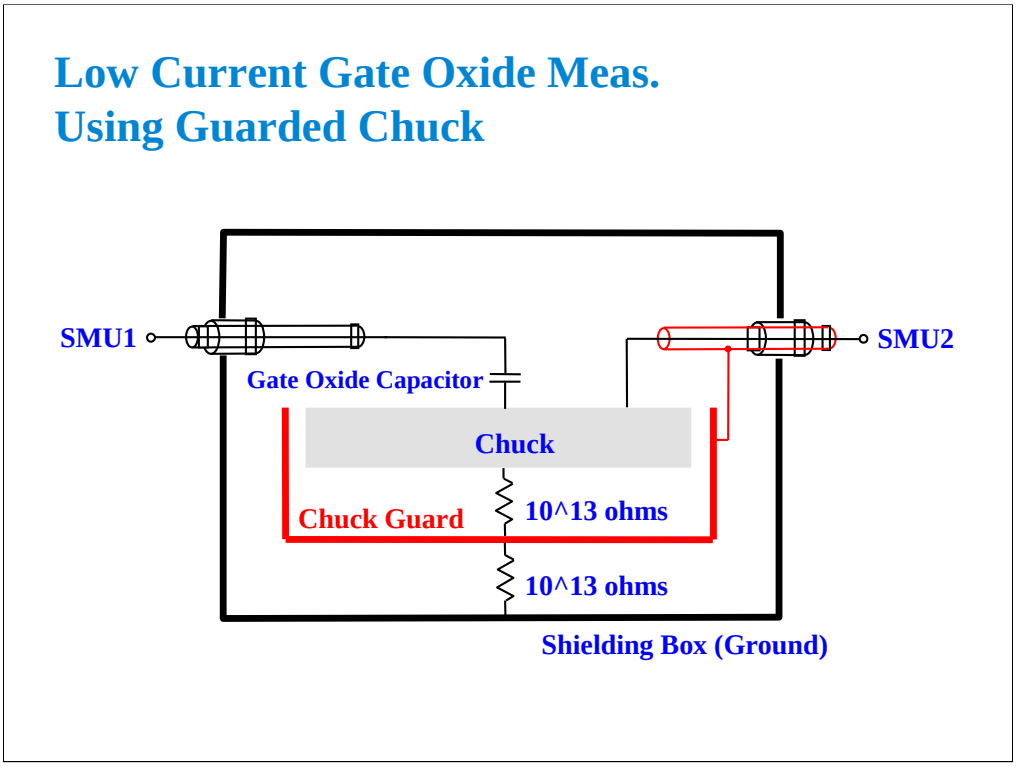
This plot is a measurement result example of a MOS capacitor on a wafer. You cannot get this kind of plot by measuring the class exercise MOS FET.

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).