B1500A Semiconductor Device Parameter Analyzer

Accelerate fundamental current-voltage, capacitance and advanced ultra-fast IV device characterization

KEYSIGHT

Introduction

Keysight B1500A Semiconductor Device Parameter Analyzer of Precision Current-Voltage Analyzer Series is an all-in-one analyzer supporting IV, CV, pulse/dynamic IV and more, which is designed for all-round characterization from basic to cutting-edge applications. It provides a wide range of measurement capabilities to cover the electrical characterization and evaluation of devices, materials, semiconductors, active/passive components, or virtually any other type of electronic device with uncompromised measurement reliability and efficiency. In addition, the B1500A's modular architecture with ten available slots allows you to add or upgrade measurement modules if your measurement needs change over time.

Keysight EasyEXPERT group+ GUI based characterization software is available either on the B1500A's embedded Windows 10 platform with 15-inch touch screen or on your PC to accelerate the characterization tasks. It supports efficient and repeatable device characterization in the entire characterization process from measurement setup and execution to analysis and data management either interactive manual operation or automation across a wafer in conjunction with a semiautomatic wafer prober. EasyEXPERT group+ makes it easy to perform complex device characterization immediately with hundreds of ready-to-use measurements (application tests) furnished and allows you the option of storing test condition and measurement data automatically after each measurement in a unique built-in database (workspace), ensuring that valuable information is not lost and that measurements can be repeated at a later date. Keysight B1500A provides the complete solution for device characterization with these versatile capabilities.

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Basic Features

Measurement capabilities

Current versus voltage (IV) measurement

- Accurate and precise measurement ranges of 0.1 fA - 1 A and 0.5 µV - 200 V
- Spot and sweep measurement
- Time sampling measurements (100 µs minimum sampling rate)
- Pulsed measurement with minimum pulse widths of 50 µs using the MCSMU or 500 µs using the HPSMU, MPSMU, or HRSMU
- The ASU (atto-sense and switch unit) can be used with the MPSMU, or HRSMU to provide 0.1 fA measurement resolution and SMU/AUX path switching
- Two analog-to-digital converter choices (high-resolution ADC or high-speed ADC) available for each SMU type (HPSMU, MPSMU and HRSMU)

Capacitance measurement

- Multi-frequency AC impedance measurement supports CV (capacitance versus voltage), C-t (capacitance versus time) and C-f (capacitance versus frequency) measurement
- Capacitance measurement frequency range of 1 kHz to 5 MHz
- Quasi-Static Capacitance-Voltage (QS-CV) measurement with leakage current compensation
- Automated switching between IV and CV measurements using either the optional SCUU (SMU CMU unify unit) and GSWU (guard switch unit) or a pair of ASUs

Pulsed IV/Fast IV/Transient IV measurement

- Provides high speed and high sensitivity measurement capability for ultra-fast IV (current-voltage), pulsed IV and transient IV measurements, including NBTI/PBTI and RTN (Random Telegraph Signal Noise) measurements
- Arbitrary waveform generation with 10 ns programmable resolution
- Simultaneous high-speed voltage/current measurement (200 MSa/s, 5 ns sampling rate) SMU technology supports pulsed IV measurement without load line effects

Pulse generation

- Up to ±40 V voltage pulsing and arbitrary waveform generation for non-volatile memory evaluation
- Single channel two-level and three level pulsing capability

B1500A platform

- 15-inch touch screen supports all capabilities of the intuitive GUI for convenient device characterization
- Configurable and upgradable measurement modules with 10 slots per mainframe
- GPIB, USB, LAN interfaces, and VGA video output port

EasyEXPERT group+ software

- Characterization environment is available either on mainframe (embedded Windows 10) or on user's PC
- Intuitive GUI based operation with keyboard, mouse operation and touch screen
- Application Test mode provides the furnished hundreds of ready-to-use application tests for quick measurement execution
- Classic test mode provides easy access to the full capability of instrument features
- Graphical display and analysis capabilities facilitate front-end data analysis without additional utilities and support report generation as image data or Excel data
- Individualized built-in database (workspace) records test data automatically, and simplifies the data management without annoying numerous data files
- Tracer test mode enables a curve tracer like knob control of measurement parameters to support interactive real-time device characterization and automatic data recording feature
- Oscilloscope view (available for the MCSMU) supports pulsed voltage and current waveform viewing for quick and easy timing verification
- Quick test mode supports test sequencing without programming
- GUI-based control of the Keysight B2200A, B2201A and E5250A switching matrices GUI-based self-test, self-calibration and diagnostics menu for hardware maintenance
- EasyEXPERT remote control function supports the remote measurement execution of application tests that are created on GUI interactively, via the LAN interface
- Data back capability and various data protection feature for shared usage by multiple users
- EasyEXPERT group+ can be installed on as many PCs as you need without additional charge to take advantage of offline personal analyzer environment among users in your department.

Specification conditions

The measurement and output accuracy are specified at the rear panel connector terminals when referenced to the Zero Check terminal. The B1530A WGFMU measurement and output accuracy are specified at the output terminal of the RSU. Accuracy is specified under the following conditions:

1. Temperature: 23 °C ±5 °C
2. Humidity: 20% to 60%
3. After 40 minutes warm-up followed by self-calibration
4. Ambient temperature changes less than ±1 °C after self-calibration execution, not applicable for MFCMU and WGFMU
5. Measurement made within one hour after self-calibration execution, not applicable for MFCMU and WGFMU
6. Calibration period: 1 year
7. SMU integration time setting:
    - 1 PLC (1 nA to 1A range, voltage range)
    - 20 PLC (100 pA range)
    - 50 PLC (1 pA to 10 pA range)
    - Averaging of high-speed ADC: 128 samples per 1 PLC
8. SMU filter: ON (for HPSMU, MPSMU and HRSMU)
9. SMU measurement terminal connection: Kelvin connection
10. WGFMU load capacitance: 25 pF or less

This document lists specifications and supplemental characteristics for the B1500A and its associated modules.

The specifications are the standards against which the B1500A and its associated modules are tested. When the B1500A and any of its associated modules are shipped from the factory, they meet the specifications.

The “supplemental” characteristics described in the following specifications are not warranted but provide useful information about the functions and performance of the instrument.

Keysight is responsible for removing, installing, and replacing the B1500A modules. Contact your nearest Keysight to install and calibrate the B1500A modules.

B1500A Mainframe Specifications

Supported plug-in modules

The B1500A supports ten slots for plug-in modules.

Module name	Slot occupied	Key features	
B1510A High power source/monitor unit (HPSMU)	2	• Range up to 200 V/1 A with 4-quadrant operation • Minimum measurement resolution 10 fA/2 µV	• Spot, sweep and more measurement capabilities • Sampling (time domain) measurement from 100 µs • Pulse measurement from 500 µs pulse width • Accurate Quasi-Static Capacitance Voltage (QS- CV) measurement with leakage current compensation
B1511B Medium power source/monitor unit (MPSMU)	1	• Range up to 100 V/0.1 A with 4-quadrant operation • Minimum measurement resolution 10 fA/0.5 µV • Optional ASU (atto-sense and switch unit) for 100 aA resolution and IV/CV switching capability	
B1517A High resolution source/monitor unit (HRSMU)	1	• Range up to 100 V/0.1 A with 4-quadrant operation • Minimum measurement resolution 1 fA/0.5 µV • Optional ASU (atto-sense and switch unit) for 100 aA resolution and IV/CV switching capability	
B1514A 50 µs Pulse medium current source/ monitor unit (MCSMU)	1	• Range up to 30 V/1 A pulsed (0.1 A DC) with 4-quadrant operation • Pulse measurement from 50 µs pulse width with 2 µs resolution • Oscilloscope view (voltage/current waveform viewer) is supported • Minimum measurement resolution 10 pA/0.2 µV	
B1520A Multi-frequency capacitance measurement unit (MFCMU)	1	• AC impedance measurement (C-V, C-f, C-t) • 1 kHz to 5 MHz frequency range with minimum 1 mHz frequency resolution • 25 V built-in DC bias and 100 V DC bias with SMU and SCUU (SMU CMU Unify Unit) • Easy and fast yet accurate IV and CV automated connection change by SCUU	
B1525A High voltage semiconductor pulse generator unit (HV-SPGU)	1	• High voltage output up to ±40 V applicable for non-volatile memory testing • Two-level and three-level pulse capability by single channel • Flexible arbitrary waveform generation with 10 ns resolution (arbitrary linear waveform generation function) • Two channels per module	
B1530A Waveform generator/fast measurement unit (WGFMU)	1	• Ultra-fast IV measurement capability for the pulsed IV and transient IV such as NBTI/PBTI, RTN, etc. • Waveform generation with 10 ns programmable resolution • Simultaneous high-speed IV measurement capability (200 MSa/s, 5 ns sampling rate) • 10 V peak-to-peak output • No load line effect accurate pulsed IV measurement by dynamic SMU technology	

Maximum module configuration

The total power consumption of all SMU modules cannot exceed 84 W. Under this rule, the B1500A can contain any combination of the following SMUs:

- Up to 10 MPSMUs
- Up to 10 HRSMUs
- Up to 4 HPSMUs
- Up to 4 MCSMUs

Only one single-slot MFCMU can be installed per B1500A mainframe. Up to five single-slot HV-SPGUs can be installed per mainframe. Up to five single-slot WGFMUs can be installed per mainframe.

When one or more WGFMU modules are installed in the B1500A mainframe, the following table applies. Multiply the values given below by the number of installed modules of that type and add the products together. The sum of the products must be less than or equal to 59 for the configuration to be permissible.

Module	Factor
HPSMU	14
MPSMU	2
HRSMU	2
MCSMU	5
MFCMU	7
HV-SPGU	12
WGFMU	10

Maximum voltage between common and ground

- ≤ ±42 V

Ground unit (GNDU) specification

The GNDU is furnished standard with the B1500A mainframe.

- Output voltage: 0 V ±100 µV
- Maximum sink current: ±4.2 A
- Output terminal/connection: Triaxial connector, Kelvin (remote sensing)

GNDU supplemental characteristics

- Load capacitance: 1 µF
- Cable resistance:
  - For $I_S \leq 1.6$ A: force line R < 1 Ω
  - For 1.6 A < $I_S \leq 2.0$ A: force line R < 0.7 Ω
  - For 2.0 A < $I_S \leq 4.2$ A: force line R < 0.35 Ω
  - For all cases: sense line R ≤ 10 Ω

  Where I_S is the current being sunk by the GNDU.

Peripherals and interface

- Data storage
  - SSD, DVD-R drive[1]
- Interfaces
  - GPIB, Interlock, USB (USB 2.0, front 2, rear 2), LAN (1000BASE-T/100BASE-TX/10BASE-T), Trigger In/Out, Digital I/O, VGA video output
- Remote control capabilities
  - FLEX commands (GPIB)
  - EasyEXPERT remote control function (LAN)
- Trigger I/O
  - Only available using GPIB FLEX commands.
  - Trigger in/out synchronization pulses before and after setting and measuring DC voltage and current. Arbitrary trigger events can be masked or activated independently.

Furnished accessories

- Keyboard
- Mouse
- Stylus pen
- Power cable
- Software entitlement document for EasyEXPERT group+

Furnished software

- EasyEXPERT group+
- MDM file converter
  This tool can convert the EasyEXPERT file (XTR/ZTR) to Keysight IC-CAP MDM file format. The EasyEXPERT file of the following measurements performed in the classic mode is only supported:
  - IV Sweep, Multi-channel IV Sweep, and CV Sweep
- 4155/56 setup file converter tool
  This tool can convert 4155 and 4156 measurement setup files (file extensions MES or DAT) into equivalent EasyEXPERT classic test mode setup files.

1. Mainframe with serial number MY64320101 or later is not equipped with DVD drive.

MPSMU and HRSMU Module Specifications

Voltage range, resolution, and accuracy (High resolution ADC)

Voltage range	Resolution		Accuracy [1]		Maximum current
	Force	Measure	Force	Measure	
±0.5 V	25 µV	0.5 µV	±(0.018% + 150 µV)	±(0.01% + 120 µV)	100 mA
±2 V	100 µV	2 µV	±(0.018% + 400 µV)	±(0.01% + 140 µV)	100 mA
±5 V	250 µV	5 µV	±(0.018% + 750 µV)	±(0.009% + 250 µV)	100 mA
±20 V	1 mV	20 µV	±(0.018% + 3 mV)	±(0.009% + 900 µV)	100 mA
±40 V	2 mV	40 µV	±(0.018% + 6 mV)	±(0.01% + 1 mV)	Note [2]
±100 V	5 mV	100 µV	±(0.018% + 15 mV)	±(0.012% + 2.5 mV)	

Current range, resolution, and accuracy (High resolution ADC)

SMU type	Current range	Resolution			Accuracy [3]		Maximum voltage
		Force	Measure [4,5] (effective)	Measure [1] (display)	Force	Measure	
MPSMU/HR SMU w/ ASU	±1 pA	1 fA	100 aA	1 aA	±(0.9% + 15 fA)	±(0.9% + 12 fA)	100 V
HRSMU	±10 pA	5 fA	400 aA (w/ ASU) 1 fA (w/o ASU)	10 aA	±(0.46% + 30 fA + 10 aA x Vo)	±(0.46% + 15 fA + 10 aA x Vo)	100 V
	±100 pA	5 fA	500 aA (w/ ASU) 2 fA (w/o ASU)	100 aA	±(0.3% + 100 fA + 100 aA x Vo)	±(0.3% + 30 fA + 100 aA x Vo)	100 V
MPSMU/ HRSMU	±1 nA	50 fA	10 fA	1 fA	±(0.1% + 300 fA + 1 fA x Vo)	±(0.1% + 200 fA + 1 fA x Vo)	100 V
	±10 nA	500 fA	10 fA		±(0.1% + 3 pA + 10 fA x Vo)	±(0.1% + 1 pA + 10 fA x Vo)	100 V
	±100 nA	5 pA	100 fA		±(0.05% + 30 pA + 100 fA x Vo)	±(0.05% + 20 pA + 100 fA x Vo)	100 V
	±1 µA	50 pA	1 pA		±(0.05% + 300 pA + 1 pA x Vo)	±(0.05% + 100 pA + 1 pA x Vo)	100 V
	±10 µA	500 pA	10 pA		±(0.05% + 3 nA + 10 pA x Vo)	±(0.04% + 2 nA + 10 pA x Vo)	100 V
	±100 µA	5 nA	100 pA		±(0.035% + 15 nA + 100 pA x Vo)	±(0.03% + 3 nA + 100 pA x Vo)	100 V
	±1 mA	50 nA	1 nA		±(0.04% + 150 nA + 1 nA x Vo)	±(0.03% + 60 nA + 1 nA x Vo)	100 V
	±10 mA	500 nA	10 nA		±(0.04% + 1.5 µA + 10 nA x Vo)	±(0.03% + 200 nA + 10 nA x Vo)	100 V
	±100 mA	5 µA	100 nA		±(0.045% + 15 µA + 100 nA x Vo)	±(0.04% + 6 µA + 100 nA x Vo)	Note [6]

1. ± (% of read value + offset voltage V)
2. 100 mA (Vo ≤ 20 V), 50 mA (20 V < Vo ≤ 40 V), 20 mA (40 V < Vo ≤ 100 V). Vo is the output voltage in Volts.
3. ± (% of read value + offset current (fixed part determined by the output/measurement range + proportional part that is multiplied by Vo))
4. Specified measurement resolution is limited by fundamental noise limits. Minimum displayed resolution is 1 aA at 1 pA range by 6 digits.
5. Measurements made in the lower ranges can be greatly impacted by vibrations and shocks. These specifications assume an environment free of these factors.
6. 100 V (Io ≤ 20 mA), 40 V (20 mA < Io ≤ 50 mA), 20 V (50 mA < Io ≤ 100 mA). Io is the output current in Amps.

Voltage range, resolution, and accuracy (High speed ADC)

Voltage range	Resolution		Accuracy [1]		Maximum current
	Force	Measure	Force	Measure	
±0.5 V	25 µV	25 µV	±(0.018% + 150 µV)	±(0.01% + 250 µV)	100 mA
±2 V	100 µV	100 µV	±(0.018% + 400 µV)	±(0.01% + 700 µV)	100 mA
±5 V	250 µV	250 µV	±(0.018% + 750 µV)	±(0.01% + 2 mV)	100 mA
±20 V	1 mV	1 mV	±(0.018% + 3 mV)	±(0.01% + 4 mV)	100 mA
±40 V	2 mV	2 mV	±(0.018% + 6 mV)	±(0.015% + 8 mV)	Note [2]
±100 V	5 mV	5 mV	±(0.018% + 15 mV)	±(0.02% + 20 mV)	

Current range, resolution, and accuracy (High speed ADC)

SMU type	Current range	Resolution			Accuracy [3]		Maximum voltage
		Force	Measure [4,5] (effective)	Measure [1] (display)	Force	Measure	
MPSMU/HR SMU w/ ASU	±1 pA	1 fA	100 aA	50 aA	±(0.9% + 15 fA)	±(1.8% + 12 fA)	100 V
HRSMU	±10 pA	5 fA	1 fA	500 aA	±(0.46% + 30 fA + 10 aA x Vo)	±(0.5% + 15 fA + 10 aA x Vo)	100 V
	±100 pA	5 fA	5 fA		±(0.3% + 100 fA + 100 aA x Vo)	±(0.5% + 40 fA + 100 aA x Vo)	100 V
MPSMU/ HRSMU	±1 nA	50 fA	50 fA		±(0.1% + 300 fA + 1 fA x Vo)	±(0.25% + 300 fA + 1 fA x Vo)	100 V
	±10 nA	500 fA	500 fA		±(0.1% + 3 pA + 10 fA x Vo)	±(0.25% + 2 pA + 10 fA x Vo)	100 V
	±100 nA	5 pA	5 pA		±(0.05% + 30 pA + 100 fA x Vo)	±(0.1% + 20 pA + 100 fA x Vo)	100 V
	±1 µA	50 pA	50 pA		±(0.05% + 300 pA + 1 pA x Vo)	±(0.1% + 200 pA + 1 pA x Vo)	100 V
	±10 µA	500 pA	500 pA		±(0.05% + 3 nA + 10 pA x Vo)	±(0.05% + 2 nA + 10 pA x Vo)	100 V
	±100 µA	5 nA	5 nA		±(0.035% + 15 nA + 100 pA x Vo)	±(0.05% + 20 nA + 100 pA x Vo)	100 V
	±1 mA	50 nA	50 nA		±(0.04% + 150 nA + 1 nA x Vo)	±(0.04% + 200 nA + 1 nA x Vo)	100 V
	±10 mA	500 nA	500 nA		±(0.04% + 1.5 µA + 10 nA x Vo)	±(0.04% + 2 µA + 10 nA x Vo)	100 V
	±100 mA	5 µA	5 µA		±(0.045% + 15 µA + 100 nA x Vo)	±(0.1% + 20 µA + 100 nA x Vo)	Note [6]

1. ± (% of read value + offset voltage V)
2. 100 mA (Vo ≤ 20 V), 50 mA (20 V < Vo ≤ 40 V), 20 mA (40 V < Vo ≤ 100 V). Vo is the output voltage in Volts.
3. ± (% of read value + offset current (fixed part determined by the output/measurement range + proportional part that is multiplied by Vo))
4. Specified measurement resolution is limited by fundamental noise limits.
5. Measurements made in the lower ranges can be greatly impacted by vibrations and shocks. These specifications assume an environment free of these factors.
6. 100 V (Io ≤ 20 mA), 40 V (20 mA < Io ≤ 50 mA), 20 V (50 mA < Io ≤ 100 mA). Io is the output current in Amps.

Power consumption

Voltage source mode

Voltage range	Power
0.5 V	20 x Ic (W)
2 V	20 x Ic (W)
5 V	20 x Ic (W)
20 V	20 x Ic (W)
40 V	40 x Ic (W)
100 V	100 x Ic (W)

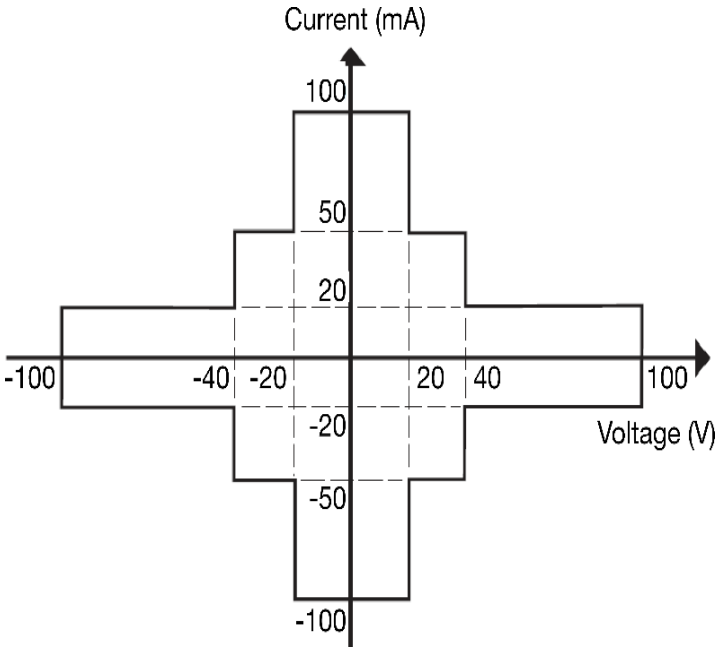
Where Ic is the current compliance setting.

Current source mode

Voltage compliance	Power
Vc ≤ 20	20 x Io (W)
20 < Vc ≤ 40	40 x Io (W)
40 < Vc ≤ 100	100 x Io (W)

Where Vc is the voltage compliance setting and Io is output current.

MPSMU and HRSMU measurement and output range



HPSMU Module Specifications

Voltage range, resolution, and accuracy (High resolution ADC)

Voltage range	Resolution		Accuracy [1]		Maximum current
	Force	Measure	Force	Measure	
±2 V	100 µV	2 µV	±(0.018% + 400 µV)	±(0.01% + 140 µV)	1 A
±20 V	1 mV	20 µV	±(0.018% + 3 mV)	±(0.009% + 900 µV)	1 A
±40 V	2 mV	40 µV	±(0.018% + 6 mV)	±(0.01% + 1 mV)	500 mA
±100 V	5 mV	100 µV	±(0.018% + 15 mV)	±(0.012% + 2.5 mV)	125 mA
±200 V	10 mV	200 µV	±(0.018% + 30 mV)	±(0.014% + 2.8 mV)	50 mA

Current range, resolution, and accuracy (High resolution ADC)

Current range	Resolution			Accuracy [2]		Maximum voltage
	Force	Measure [3] (effective)	Measure (display)	Force	Measure	
±1 nA	50 fA	10 fA	1 fA	±(0.1% + 300 fA + 1 fA x Vo)	±(0.1% + 200 fA + 1 fA x Vo)	200 V
±10 nA	500 fA	10 fA		±(0.1% + 3 pA + 10 fA x Vo)	±(0.1% + 1 pA + 10 fA x Vo)	200 V
±100 nA	5 pA	100 fA		±(0.05% + 30 pA + 100 fA x Vo)	±(0.05% + 20 pA + 100 fA x Vo)	200 V
±1 µA	50 pA	1 pA		±(0.05% + 300 pA + 1 pA x Vo)	±(0.05% + 100 pA + 1 pA x Vo)	200 V
±10 µA	500 pA	10 pA		±(0.05% + 3 nA + 10 pA x Vo)	±(0.04% + 2 nA + 10 pA x Vo)	200 V
±100 µA	5 nA	100 pA		±(0.035% + 15 nA + 100 pA x Vo)	±(0.03% + 3 nA + 100 pA x Vo)	200 V
±1 mA	50 nA	1 nA		±(0.04% + 150 nA + 1 nA x Vo)	±(0.03% + 60 nA + 1 nA x Vo)	200 V
±10 mA	500 nA	10 nA		±(0.04% + 1.5 µA + 10 nA x Vo)	±(0.03% + 200 nA + 10 nA x Vo)	200 V
±100 mA	5 µA	100 nA		±(0.045% + 15 µA + 100 nA x Vo)	±(0.04% + 6 µA + 100 nA x Vo)	Note [4]
±1 A	50 µA	1 µA		±(0.4% + 300 µA + 1 µA x Vo)	±(0.4% + 150 µA + 1 µA x Vo)	

1. ± (% of read value + offset voltage V)
2. ± (% of read value + offset current (fixed part determined by the output/measurement range + proportional part that is multiplied by Vo))
3. Specified measurement resolution is limited by fundamental noise limits.
4. 200 V (Io ≤ 50 mA), 100 V (50 mA < Io ≤ 125 mA), 40 V (125 mA < Io ≤ 500 mA), 20 V (500 mA < Io ≤ 1 A). Io is the output current in Amps.

Voltage range, resolution, and accuracy (High speed ADC)

Voltage range	Resolution		Accuracy [1]		Maximum current
	Force	Measure	Force	Measure	
±2 V	100 µV	100 µV	±(0.018% + 400 µV)	±(0.01% + 700 µV)	1 A
±20 V	1 mV	1 mV	±(0.018% + 3 mV)	±(0.01% + 4 mV)	1 A
±40 V	2 mV	2 mV	±(0.018% + 6 mV)	±(0.015% + 8 mV)	500 mA
±100 V	5 mV	5 mV	±(0.018% + 15 mV)	±(0.02% + 20 mV)	125 mA
±200 V	10 mV	10 mV	±(0.018% + 30 mV)	±(0.035% + 40 mV)	50 mA

Current range, resolution, and accuracy (High speed ADC)

Current range	Resolution			Accuracy [2]		Maximum voltage
	Force	Measure [3] (effective)	Measure (display)	Force	Measure	
±1 nA	50 fA	50 fA		±(0.1% + 300 fA + 1 fA x Vo)	±(0.25% + 300 fA + 1 fA x Vo)	200 V
±10 nA	500 fA	500 fA		±(0.1% + 3 pA + 10 fA x Vo)	±(0.25% + 2 pA + 10 fA x Vo)	200 V
±100 nA	5 pA	5 pA		±(0.05% + 30 pA + 100 fA x Vo)	±(0.1% + 20 pA + 100 fA x Vo)	200 V
±1 µA	50 pA	50 pA		±(0.05% + 300 pA + 1 pA x Vo)	±(0.1% + 200 pA + 1 pA x Vo)	200 V
±10 µA	500 pA	500 pA		±(0.05% + 3 nA + 10 pA x Vo)	±(0.05% + 2 nA + 10 pA x Vo)	200 V
±100 µA	5 nA	5 nA		±(0.035% + 15 nA + 100 pA x Vo)	±(0.05% + 20 nA + 100 pA x Vo)	200 V
±1 mA	50 nA	50 nA		±(0.04% + 150 nA + 1 nA x Vo)	±(0.04% + 200 nA + 1 nA x Vo)	200 V
±10 mA	500 nA	500 nA		±(0.04% + 1.5 µA + 10 nA x Vo)	±(0.04% + 2 µA + 10 nA x Vo)	200 V
±100 mA	5 µA	5 µA		±(0.045% + 15 µA + 100 nA x Vo)	±(0.1% + 20 µA + 100 nA x Vo)	Note [4]
±1 A	50 µA	50 µA		±(0.4% + 300 µA + 1 µA x Vo)	±(0.5% + 300 µA + 1 µA x Vo)	

1. ± (% of read value + offset voltage V)
2. ± (% of read value + offset current (fixed part determined by the output/measurement range + proportional part that is multiplied by Vo))
3. Specified measurement resolution is limited by fundamental noise limits.
4. 200 V (Io ≤ 50 mA), 100 V (50 mA < Io ≤ 125 mA), 40 V (125 mA < Io ≤ 500 mA), 20 V (500 mA < Io ≤ 1 A). Io is the output current in Amps.

Power consumption

Voltage source mode

Voltage range	Power
2 V	20 x Ic (W)
20 V	20 x Ic (W)
40 V	40 x Ic (W)
100 V	100 x Ic (W)
200 V	200 x Ic (W)

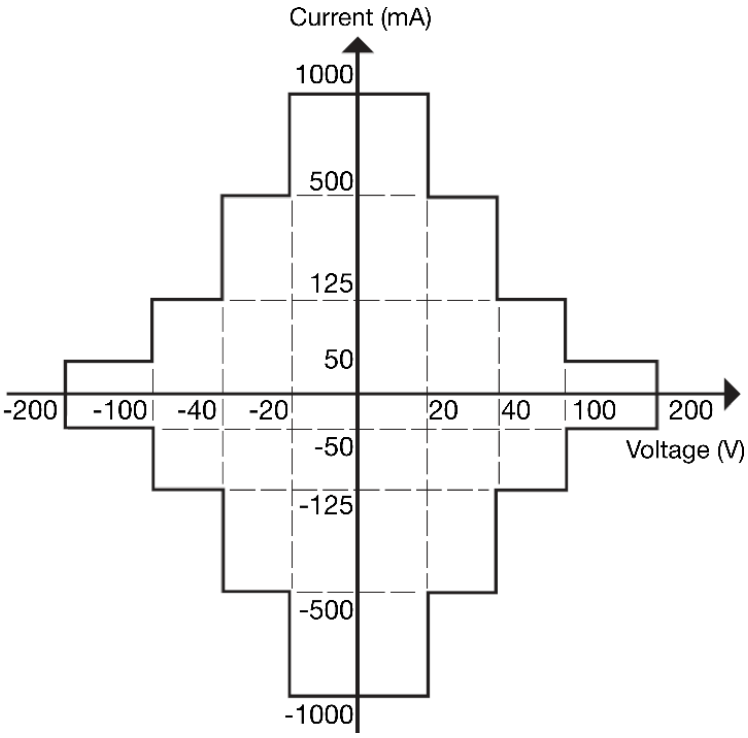
Where Ic is the current compliance setting.

Current source mode

Voltage compliance	Power
Vc ≤ 20	20 x Io (W)
20 < Vc ≤ 40	40 x Io (W)
40 < Vc ≤ 100	100 x Io (W)
100 < Vc ≤ 200	200 x Io (W)

Where Vc is the voltage compliance setting and Io is output current.

HPSMU measurement and output range



MCSMU Module Specifications

Voltage range, resolution, and accuracy

Voltage range	Resolution		Accuracy [1]		Maximum current
	Force	Measure	Force	Measure	
±0.2 V	200 nV	200 nV	±(0.06% + 0.14 mV)	±(0.06% + 0.14 mV)	1 A
±2 V	2 µV	2 µV	±(0.06% + 0.6 mV)	±(0.06% + 0.6 mV)	1 A
±20 V	20 µV	20 µV	±(0.06% + 3 mV)	±(0.06% + 3 mV)	1 A
±40 V [2]	40 µV	40 µV	±(0.06% + 3 mV)	±(0.06% + 3 mV)	1 A

Current range, resolution, and accuracy

Current range	Resolution			Accuracy [3]		Maximum voltage
	Force	Measure (effective)	Measure (display)	Force	Measure	
±10 µA	10 pA	10 pA		±(0.06% + 2 nA + 100 pA x Vo)	±(0.06% + 2 nA + 100 pA x Vo)	30 V
±100 µA	100 pA	100 pA		±(0.06% + 20 nA + 1 nA x Vo)	±(0.06% + 20 nA + 1 nA x Vo)	30 V
±1 mA	1 nA	1 nA		±(0.06% + 200 nA + 10 nA x Vo)	±(0.06% + 200 nA + 10 nA x Vo)	30 V
±10 mA	10 nA	10 nA		±(0.06% + 2 µA + 100 nA x Vo)	±(0.06% + 2 µA + 100 nA x Vo)	30 V
±100 mA	100 nA	100 nA		±(0.06% + 20 µA + 1 µA x Vo)	±(0.06% + 20 µA + 1 µA x Vo)	30 V
±1 A [4]	1 µA	1 µA		±(0.4% + 200 µA + 10 µA x Vo)	±(0.4% + 200 µA + 10 µA x Vo)	30 V

1. ± (% of read value + offset voltage V)
2. Maximum output voltage is 30 V.
3. ± (% of read value + offset current (fixed part determined by the output/measurement range + proportional part that is multiplied by Vo))
4. Pulse mode only. The maximum value of the base current during pulsing is ±50 mA.

Power consumption

Voltage source mode

Voltage range	Power
0.2 V	40 x Ic (W)
2 V	40 x Ic (W)
40 V	40 x Ic (W)

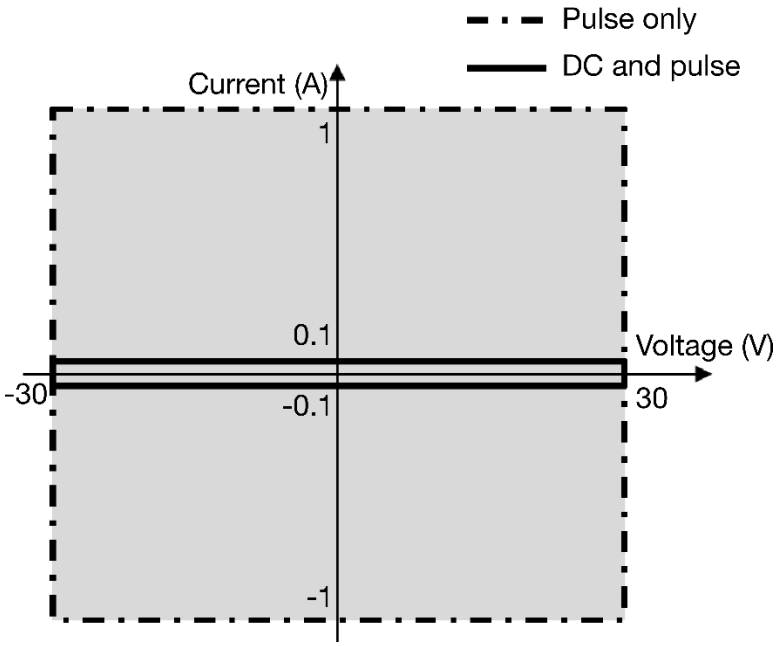
Where Ic is the current compliance setting.

Current source mode

Voltage compliance	Power
Vc ≤ 0.2	40 x Io (W)
0.2 < Vc ≤ 2	40 x Io (W)
2 < Vc ≤ 40	40 x Io (W)

Where Vc is the voltage compliance setting and Io is output current.

MCSMU measurement and output range



Output terminal/connection

- Dual triaxial connector, Kelvin (remote sensing)

Voltage/current compliance (limiting)

The SMU can limit output voltage or current to prevent damaging the device under test.

- Voltage:
  - 0 V to ±100 V (MPSMU, HRSMU)
  - 0 V to ±200 V (HPSMU)
  - 0 V to ±30 V (MCSMU)
- Current:
  - ±10 fA to ±100 mA (HRSMU/MPSMU with ASU)
  - ±100 fA to ±100 mA (HRSMU)
  - ±1 pA to ±100 mA (MPSMU)
  - ±1 pA to ±1 A (HPSMU)
  - ±10 nA to ±1 A (MCSMU)
- Compliance accuracy:
  - Same as the current or voltage set accuracy.

About measurement accuracy

- RF electromagnetic field and SMU measurement accuracy:
  SMU voltage and current measurement accuracy can be affected by RF electro-magnetic field strengths greater than 3 V/m in the frequency range of 80 MHz to 1 GHz. The extent of this effect depends upon how the instrument is positioned and shielded.
- Induced RF field noise and SMU measurement accuracy:
  SMU voltage and current measurement accuracy can be affected by induced RF field noise strengths greater than 3 Vrms in the frequency range of 150 kHz to 80 MHz. The extent of this effect depends upon how the instrument is positioned and shielded.

Pulse measurement

Programmable pulse width, period and delay:

- For HPSMU, MPSMU, and HRSMU:
  - Pulse width: 500 µs to 2 s
  - Pulse width resolution: 100 µs
  - Pulse period: 5 ms to 5 s
    - Period ≥ width + 2 ms (when width ≤ 100 ms)
    - Period ≥ width + 10 ms (when width > 100 ms)
  - Pulse period resolution: 100 µs
  - Pulse delay: 0 s
- For MCSMU:
  - Pulse width:
    - 10 µs [1] to 100 ms (1 A range)
    - 10 µs [1] to 2 s (10 µA to 100 mA range)
  - Pulse width resolution: 2 µs
  - Pulse period: 5 ms to 5 s
  - Pulse period resolution: 100 µs
  - Pulse duty:
    - For 1 A range: ≤ 5%
    - For 10 µA to 100m A range
      - Period ≥ delay + width + 2 ms (when delay + width ≤ 100 ms)
      - Period ≥ delay + width + 10 ms (when delay + width > 100 ms)
  - Pulse delay: 0 s to (Period - width)

1. Recommended pulse width ≥ 50 µs. (Time to reach within 1% of the final value at resistive load > 50 Ω, 10 V step voltage, 1 A compliance. Supplemental characteristics)

SMUs Supplemental Characteristics

Current compliance setting accuracy (for opposite polarity)

- For HPSMU, MPSMU, and HRSMU:
  - For 1 pA to 10 nA ranges: ± (setting accuracy + 12% of range)
  - For 100 nA to 1 A ranges: ± (setting accuracy + 2.5% of range)
- For MCSMU: ± (setting accuracy + 2.5% of range)

SMU pulse setting accuracy (fixed measurement range)

- For HPSMU, MPSMU, and HRSMU:
  - Width: ± (0.5% + 50 µs)
  - Period: ± (0.5% + 100 µs)
- For MCSMU:
  - Width: ± (0.1% + 2 µs)
  - Period: ± (0.1% + 100 µs)

Minimum pulse measurement time

- For HPSMU, MPSMU, and HRSMU: 16 µs
- For MCSMU: 2 µs

Voltage source output resistance (Force line, Non-Kelvin connection)

- For HPSMU: 0.2 Ω
- For MPSMU, HRSMU: 0.3 Ω

Voltage measurement input resistance

- For HPSMU, MPSMU, and HRSMU: ≥ 10^{13} Ω
- For MCSMU (≤ 1 A): ≥ 10^{9} Ω

Current source output resistance

- For HPSMU, MPSMU, and HRSMU: ≥ 10^{13} Ω
- For MCSMU (≤ 1 A): ≥ 10^{9} Ω

Maximum allowable cable resistance (Kelvin connection)

- For HPSMU, MPSMU, and HRSMU:
  - Sense: 10 Ω
  - Force: 10 Ω (≤ 100 mA), 1.5 Ω (>100 mA)
- For MCSMU (between High and Low):
  - Sense: 10 Ω
  - Force: 1 Ω

Maximum allowable inductance

- Force 3 µH with Low Force as shield (MCSMU)

Maximum load capacitance

- For HPSMU, MPSMU, and HRSMU:
  - 1 pA to 10 nA ranges: 1000 pF
  - 100 nA to 10 mA ranges: 10 nF
  - 100 mA and 1 A ranges: 100 µF
- For MCSMU:
  - 10 µA to 10 mA range: 12 nF
  - 100 mA to 1 A range: 100 µF

Maximum guard capacitance

- For HPSMU, MPSMU, and HRSMU: 900 pF
- For HRSMU/MPSMU with ASU: 660 pF

Maximum shield capacitance

- For HPSMU, MPSMU, and HRSMU: 5,000 pF
- For HRSMU/MPSMU with ASU: 3,500 pF

Noise characteristics

- For HPSMU, MPSMU, and HRSMU (Filter ON):
  - Voltage source: 0.01% of V range (rms)
  - Current source: 0.1% of I range (rms)
- For MCSMU:
  - Voltage/Current source: 200 mV (0 to peak) maximum

Overshoot (Filter ON)

- For HPSMU, MPSMU, and HRSMU:
  - Voltage source: 0.03% of V range
  - Current source: 1% of I range
- For MCSMU:
  - Voltage/Current source: 10% of range

Range switching transient noise

- For HPSMU, MPSMU, and HRSMU (Filter ON):
  - Voltage ranging: 250 mV
  - Current ranging: 70 mV
- For MCSMU:
  - Voltage ranging: 250 mV
  - Current ranging: 70 mV

Maximum guard offset voltage

- For HPSMU: ±1 mV
- For MPSMU, HRSMU: ±3 mV
- For HRSMU/MPSMU with ASU (Iout ≤ 100 µA): ±4.2 mV

Maximum slew rate

- For HPSMU, MPSMU, and HRSMU: 0.2 V/µs
- For MCSMU: 1 V/µs

Maximum DC floating voltage

- ±200 V DC between low force and common (MCSMU)

MFCMU (Multi Frequency Capacitance Measurement Unit) Module Specifications

Measurement functions

- Measurement parameters:
  Cp-G, Cp-D, Cp-Q, Cp-Rp, Cs-Rs, Cs-D, Cs-Q, Lp-G, Lp-D, Lp-Q, Lp-Rp, Ls-Rs, Ls-D, Ls-Q, R-X, G-B, Z-q, Y-q
- Ranging: Auto and fixed
- Measurement terminal: Four-terminal pair configuration, four BNC (female) connectors
- Cable length: 1.5 m or 3 m, automatic identification of accessories

Test signal

- Frequency:
  - Range: 1 kHz to 5 MHz
  - Resolution: 1 mHz (minimum)
  - Accuracy: ±0.008%
- Output signal level:
  - Range: 10 mV_{rms} to 250 mV_{rms}
  - Resolution: 1 mV_{rms}
  - Accuracy:
    - ±(10.0% + 1 mV_{rms}) at the measurement port of the MFCMU
    - ±(15.0% + 1 mV_{rms}) at the measurement port of the MFCMU cable (1.5 m or 3.0 m)
- Output impedance: 50 Ω, typical
- Signal level monitor:
  - Range: 10 mV_{rms} to 250 mV_{rms}
  - Accuracy (open load):
    - ±(10.0% of reading + 1 mV_{rms}) at the measurement port of the MFCMU
    - ±(15.0% of reading + 1 mV_{rms}) at the measurement port of the MFCMU cable (1.5 m or 3 m)

DC bias function

- DC bias:
  - Range: 0 to ±25 V
  - Resolution: 1 mV
  - Accuracy: ±(0.5% + 5.0 mV) at the measurement port of the MFCMU or the MFCMU cable (1.5 m or 3.0 m)
- Maximum DC bias current (supplemental characteristics)

Impedance range	Maximum DC bias current
50 Ω	10 mA
100 Ω	10 mA
300 Ω	10 mA
1 kΩ	1 mA
3 kΩ	1 mA
10 kΩ	100 µA
30 kΩ	100 µA
100 kΩ	10 µA
300 kΩ	10 µA

- Output impedance: 50 Ω, typical
- DC bias monitor:
  - Range: 0 to ±25 V
  - Accuracy (open load): ±(0.2% of reading + 10.0 mV) at the measurement port of the MFCMU or the MFCMU cable (1.5 m or 3.0 m)

Sweep characteristics

- Available sweep parameters: Oscillator level, DC bias voltage, frequency
- Sweep type: linear, log
- Sweep mode: single, double
- Sweep direction: up, down
- Number of measurement points: Maximum 1,001 points

Measurement accuracy

The following parameters are used to express the impedance measurement accuracy at the measurement port of the MFCMU or the MFCMU cable (1.5 m or 3.0 m).

- Z_X: Impedance measurement value (Ω)
- D_X: Measurement value of D
- $E = EP' + (Z_S' / |Z_X| + Y_O' \times |Z_X|) \times 100$ (%)
- $E_P' = E_{PL} + E_{POSC} + E_P$ (%)
- $Y_O' = Y_{OL} + Y_{OSC} + Y_O$ (S)
- $Z_S' = Z_{SL} + Z_{OSC} + Z_S$ (Ω)

- |Z| accuracy: ±E (%)
- θ accuracy: ±E / 100 (rad)
- C accuracy:
  - at $D_X \leq 0.1$: ±E (%)
  - at $D_X > 0.1$: $\pm E \times (\sqrt{1 + D_X^2})$ (%)
- D accuracy:
  - at $D_X \leq 0.1$: ±E / 100
  - at $D_X > 0.1$: $\pm E \times (1 + D_X) / 100$
- G accuracy:
  - at $D_X \leq 0.1$: $\pm E / D_X$ (%)
  - at $D_X > 0.1$: $\pm E \times (\sqrt{1 + D_X^2}) / D_X$ (%)

Measurement accuracy is specified under the following conditions:

- Temperature: 23 °C ±5 °C
- Integration time: 1 PLC or 16 PLC

Parameters E_{POSC}, Z_{OSC}

Oscillator level	E_{POSC} (%)	Z_{OSC} (mΩ)
125 mV < V_{OSC} ≤ 250 mV	0.03 x (250 / V_{OSC} - 1)	5 x (250 / V_{OSC} - 1)
64 mV < V_{OSC} ≤ 125 mV	0.03 x (125 / V_{OSC} - 1)	5 x (125 / V_{OSC} - 1)
32 mV < V_{OSC} ≤ 64 mV	0.03 x (64 / V_{OSC} - 1)	5 x (64 / V_{OSC} - 1)
V_{OSC} ≤ 32 mV	0.03 x (32 / V_{OSC} - 1)	5 x (64 / V_{OSC} - 1)

V_{OSC} is oscillator level in mV.

Parameters E_{PL}, Y_{OL}, Z_{SL}

Cable length	E_{PL} (%)	Y_{OL} (nS)	Z_{SL} (mΩ)
1.5 m	0.02 + 3 x f / 100	750 x f / 100	5.0
3 m	0.02 + 5 x f / 100	1,500 x f / 100	5.0

f is frequency in MHz. If measurement cable is extended, open compensation, short compensation, and load compensation must be performed.

Parameters E_P, Y_{OSC}, Y_O, Z_S

Frequency	E_P (%)	Y_{OSC} (nS)	Y_O (nS)	Z_S (mΩ)
1 kHz ≤ f ≤ 200 kHz	0.095	1 x (125 / V_{OSC} - 0.5)	1.5	5.0
200 kHz < f ≤ 1 MHz	0.095	2 x (125 / V_{OSC} - 0.5)	3.0	5.0
1 MHz < f ≤ 2 MHz	0.28	1 x (125 / V_{OSC} - 0.5)	3.0	5.0
2 MHz < f	0.28	20 x (125 / V_{OSC} - 0.5)	30.0	5.0

f is frequency in Hz.

V_{OSC} is oscillator level in mV

Example of calculated C/G measurement accuracy

Frequency	Measured capacitance	C accuracy [1]	Measured conductance	G accuracy [1]
5 MHz	1 pF	±0.61%	≤ 3 µS	±192 nS
	10 pF	±0.32%	≤ 31 µS	±990 nS
	100 pF	±0.29%	≤ 314 µS	±9 µS
	1 nF	±0.32%	≤ 3 mS	±99 µS
1 MHz	1 pF	±0.26%	≤ 628 nS	±16 nS
	10 pF	±0.11%	≤ 6 µS	±71 nS
	100 pF	±0.10%	≤ 63 µS	±624 nS
	1 nF	±0.10%	≤ 628 µS	±7 µS

1. The capacitance and conductance measurement accuracy are specified under the following conditions:
   D_x = 0.1
   Integration time: 1 PLC
   Test signal level: 30 mV_{rms}
   At four-terminal pair port of MFCMU

100 kHz	10 pF	±0.18%	≤ 628 nS	±11 nS
	100 pF	±0.11%	≤ 6 µS	±66 nS
	1 nF	±0.10%	≤ 63 µS	±619 nS
	10 nF	±0.10%	≤ 628 µS	±7 µS
10 kHz	100 pF	±0.18%	≤ 628 nS	±11 nS
	1 nF	±0.11%	≤ 6 µS	±66 nS
	10 nF	±0.10%	≤ 63 µS	±619 nS
	100 nF	±0.10%	≤ 628 µS	±7 µS
1 kHz	100 pF	±0.92%	≤ 63 nS	±6 nS
	1 nF	±0.18%	≤ 628 nS	±11 nS
	10 nF	±0.11%	≤ 6 µS	±66 nS
	100 nF	±0.10%	≤ 63 µS	±619 nS

Atto-Sense and Switch Unit (ASU) Specifications

AUX path specification

- Maximum voltage:
  - 100 V (AUX input to AUX common)
  - 100 V (AUX input to circuit common)
  - 42 V (AUX common to circuit common)
- Maximum current:
  - 0.5 A (AUX input to force output)

ASU supplemental characteristics

- Band width (at -3 dB): 30 MHz (AUX port)

SMU CMU Unify Unit (SCUU) and Guard Switch Unit (GSWU) Specifications

The SCUU multiplexes the outputs from two SMUs (MPSMUs and/or HRSMUs) and the CMU. The SCUU outputs are two sets of Kelvin triaxial ports (Force and Sense). The SCUU also allows the SMUs to act as DC bias sources in conjunction with the CMU. Special cables are available to connect the SMUs and CMU with the SCUU, and an auto-detect feature automatically compensates for the cable length going to the SCUU.

The GSWU contains a relay that automatically opens for IV measurements and closes for CV measurements, forming a guard return path to improve CV measurement accuracy.

Supported SMU

- MPSMU and HRSMU

For SCUU

- Inputs:
  - Triaxial ports: Force1, Sense1, Force2, and Sense2
  - BNC ports: for MFCMU
  - Control port: for MFCMU
- Outputs:
  - Triaxial ports: Force1/CMUH, Sense1, Force2/CMUL, and Sense2
  - Control port: for GSWU
  - LEDs: SMU/CMU output status indicator
- Docking mode: Direct and indirect mode

For GSWU

- Input:
  - Control port: for SCUU
  - Mini pin plug ports: Guard1, Guard2
- Output:
  - LED: Connection status indicator

SCUU supplemental characteristics SMU path

- Offset current: < ±(20 fA + 0.004% of SMU current range) (1 pA to 1 µA range. Offset current is negligible for other current ranges)
- Offset voltage: < 100 µV at 300 sec
- Closed channel residual resistance: < 200 mΩ
- Channel isolation resistance: > 10^{15} Ω

CMU path

- Test signal
  - Signal output level additional errors (CMU bias, open load):
    - ±2% (direct docking)
    - ±7% (indirect docking)
  - Signal output level additional errors (SMU bias, open load):
    - ±5% (direct docking, ≥ 10 kHz)
    - ±10% (indirect docking, ≥ 10 kHz)
- Output impedance: 50 Ω, typical
- Signal level monitor additional errors (open load):
  - ±2% (CMU bias), direct docking
  - ±5% (SMU bias), direct docking
  - ±7% (CMU bias), indirect docking
  - ±10% (SMU bias), indirect docking

DC bias function

- DC voltage bias (CMU bias):
  - Range: 0 to ±25 V
  - Resolution: 1 mV
  - Additional errors (for CMU bias): ±100 µV (open load)
- DC voltage bias (SMU bias):
  - Range: 0 to ±100 V
  - Resolution: 5 mV
  - Additional errors (for SMU voltage output accuracy): ±100 µV (open load)
- DC bias monitor additional errors (open load):
  - ±20 mV, direct docking
  - ±30 mV, indirect docking
- Output impedance: 50 Ω, typical
- DC output resistance: 50 Ω (CMU bias), 130 Ω (SMU bias)

Measurement accuracy

Impedance measurement error is given by adding the following additional error E_e to the MFCMU measurement error [1, 2].

When the measurement terminals are extended by using the measurement cable, the measurement accuracy is applied to the data measured after performing the open/short/load correction at the DUT side cable end.

- $E_e = \pm(A + Z_S / |Z_X| + Y_O \times |Z_X|) \times 100$ (%)
- Z_X: Impedance measurement value (Ω)
- A: 0.05% (direct docking) or 0.1% (indirect docking)
- Z_S: 500 + 500 x f (mΩ)
- Y_O: 1 + 1,000 x f / 100 (nS) (direct docking, x2 for indirect docking)

1. f is frequency in MHz
2. The error is specified under the following conditions:
   Temperature: 23 °C ±5 °C
   Integration time: 1 PLC or 16 PLC

HV-SPGU (High Voltage Semiconductor Pulse Generator Unit) Module Specification

Specifications

- Number of output channels: 2 channels per module
- Modes: pulse, constant, and free run
- Standard pulse mode:
  - Two level pulse
  - Three level pulse per one channel
  - Pulse period: 20 ns to 10 s
- Delay range: 0 s to 9.99 s
- Delay resolution: 2.5 ns (minimum)
- Output count: 1 to 1,000,000
- Voltage monitor minimum sampling period: 5 µs
- Trigger output:
  - Level: TTL
  - Timing: Synchronized with pulse period
  - Trigger width:
    - Pulse period x 1/2 (pulse period ≤ 10 µs)
    - Maximum 5 µs (pulse period > 10 µs)

Pulse/DC output voltage and accuracy

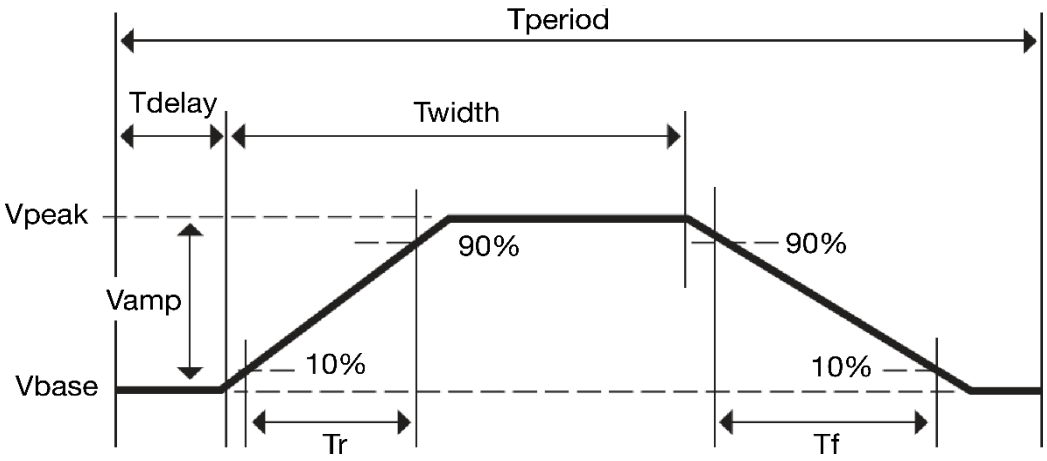
Output voltage (V_{out})	50 Ω load	-20 V to +20 V
	Open load	-40 V to +40 V
Accuracy [1]	Open load	±(0.5% + 50 mV)
Amplitude resolution	50 Ω load	0.2 mV (|Vout| ≤ 5 V)
		0.8 mV (5 V < |Vout| ≤ 20V)
	Open load	0.4 mV (|Vout| ≤ 10 V)
		1.6 mV (10 V < |Vout| ≤ 40V)
Output connectors		SMA
Source impedance		50 Ω [2]
Short circuit current		800 mA peak (400 mA average [3])
Overshoot / Pre-shoot / Ringing [4]	50 Ω load	±(5% + 20 mV)

1. At 1 µs after completing transition.
2. Supplemental characteristics (± 1%)
3. This value is specified under the following condition: [(Number of installed HV- SPGUs) x 0.2 A] + [DC current output by all modules (including HV-SPGUs)] < 3.0 A
4. Follow the specified condition of the transient time.

Pulse range and pulse parameter [1]

Frequency range		0.1 Hz to 33 MHz
Pulse period	Programmable range	20 ns to 10 s
	Resolution	10 ns
	Minimum [2]	100 ns [3]
	Accuracy	±1% (±0.01% + 200 ps) [4]
Width	Programmable range	10 ns to (period - 10 ns)
	Resolution	2.5 ns (Tr and Tf ≤ 8 µs) 10 ns (Tr or Tf > 8 µs)
	Minimum [5]	50 ns (25 ns typical) [6]
	Accuracy	±(3% + 2 ns)
Transition time [5] (Tr and Tf)	Programmable range	8 ns to 400 ms
	Resolution	2 ns (Tr and Tf ≤ 8 µs) 8 ns (Tr or Tf > 8 µs)
	Minimum [5]	15 ns [7] (Vamp ≤ 10 V) 20 ns (Vamp ≤ 10 V) 30 ns (Vamp ≤ 20 V) 60 ns (Vamp > 20 V)
	Accuracy	-5% to 5% + 10 ns (Vamp ≤ 10 V) -5% to 5% + 20 ns (Vamp ≤ 20 V)
Output relay switching time [6]	Open/Close	100 µs [7]

Definition of pulse waveform



1. Unless otherwise stated, all specifications assume a 50 Ω termination.
2. Minimum value in which timing accuracy can be applied.
3. This is specified at Vamp ≤ 10 V.
4. Supplemental characteristics.
5. The time from 10% to 90% of Vamp which is the amplitude of output pulse.
6. Solid state relay for frequent switching applications.

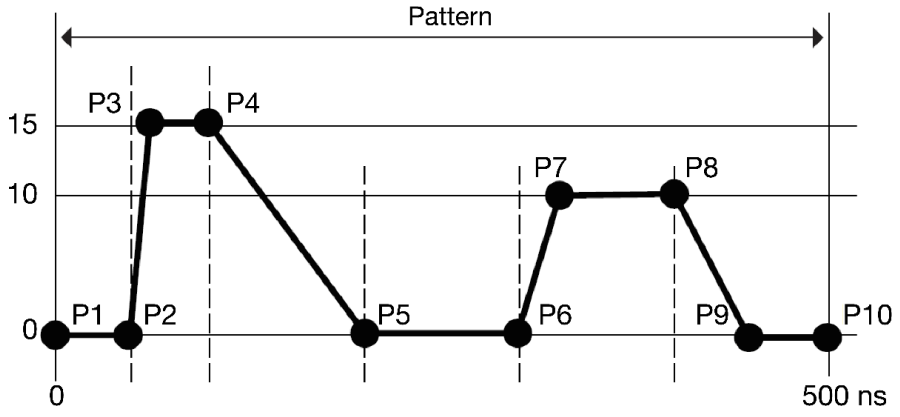
SPGU supplemental characteristics

- Pulse width jitter: 0.001% + 150 ps
- Pulse period jitter: 0.001% + 150 ps
- Maximum slew rate: 1,000 V/µs (50 Ω load)
- Noise: 10 mV_{rms} (at DC output)
- Advanced feature:
  - Voltage monitor: The HV-SPGU has a voltage monitor function to measure the voltage at the DUT terminal.
    - Measurement accuracy [1] (open load): ±(0.1% of reading + 25 mV)
    - Measurement resolution: 50 µV
  - Voltage compensation: The HV-SPGU can measure the impedance of DUT and adjust the output voltage according to the DUT impedance.

ALWG (arbitrary linear waveform generator) function

- Output complex waveform per one channel of HV-SPGU
- Define multi-level pulse and multi-pulse waveform including open state pulse with ALWG GUI editor
- Sequential pulse waveform from user-defined pulse waveform
- 1,024 points per one channel
- Programmable timing range: 10 ns to 671.088630 ms, 10 ns resolution

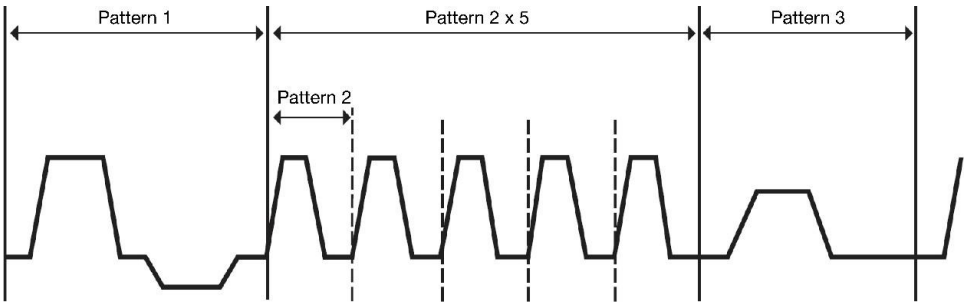
Example 1. ALWG setup table and pattern



Point	Time	Voltage
1	0	0.0 V
2	50 ns	0.0 V
3	70 ns	15.0 V
4	100 ns	15.0 V
5	200 ns	0.0 V
6	300 ns	0.0 V
7	320 ns	10.0 V
8	400 ns	10.0 V
9	450 ns	0.0 V
10	500 ns	0.0 V

1. Specified at 1 PLC (20 ms = (5 µs sample + 5 µs interval) x 2,000 samples)

Example 2. ALWG complex waveform



16440A SMU/pulse generator selector

The Keysight 16440A SMU/pulse generator selector switches either a SMU or PGU to the associated output port. You can expand to four channels by adding an additional 16440A. The PGU port on channel 1 provides a “PGU OPEN” function, which can disconnect the PGU by opening a semiconductor relay. The Keysight B1500A and 16445A are required to use the 16440A.

The following specifications data is specified at 23 °C ±5 °C and 50% relative humidity.

- Channel configuration:2 channels (CH 1 and CH 2)
  Can add an additional 2 channels (CH 3 and CH 4) by adding another 16440A.

Channels	Input	Output
Channel 1 (CH 1)	2 (SMU and PGU [1])	1
Channel 2 (CH 2)	2 (SMU and PGU)	1
Channel 3 (CH 3) [2]	2 (SMU and PGU [1])	1
Channel 4 (CH 4) [2]	2 (SMU and PGU)	1

- Voltage and current range

Input port	Maximum voltage	Maximum current
SMU	200 V	1.0 A
PGU	40 V	0.4 A [3]

16445A SMU/PGU selector connection adaptor

The Keysight 16445A selector adapter is required to control and to supply DC power to the Keysight 16440A SMU/pulse generator selector.

- Power requirement: 100 to 240 V, 50/60 Hz
- Maximum volt-amps (VA): 20 VA

1. PGU channels 1 & 3 have a built-in series semiconductor relay.
2. Available when a second 16440A is installed.
3. This is a peak-to-peak current.

WGFMU (Waveform Generator/Fast Measurement Unit) Module Specification

Overview

The WGFMU is a self-contained module offering the combination of arbitrary linear waveform generation (ALWG) with synchronized fast current or voltage (IV) measurement. The ALWG function allows you to generate not only DC, but also various types of AC waveforms. In addition to this versatile sourcing capability, the WGFMU can also perform measurement in synchronization with the applied waveform, which enables accurate high-speed IV characterization.

Measurement mode, function, and range

WGFMU mode	WGFMU function			Voltage force range	Voltage measurement range	Current measurement range	Source impedance	Maximum output
	VF	VM	IM					
Fast IV mode/ DC mode	Y	Y	Y	-3 V to +3 V -5 V to +5 V -10 V to 0 V 0 V to +10 V	5 V, 10 V	1 µA, 10 µA, 100 µA, 1mA, 10 mA	0 Ω [1]	+10 V, -10 V, ±5 V
PG mode	Y	Y	N	-3 V to +3 V -5 V to +5 V	5 V	-	50 Ω [2]	±5 V (open load) ±2.5 V (50 Ω load)
SMU pass-through	Measurement is performed by an SMU			-	-	-	-	±25 V ±100 mA

- VF: Voltage Force
- VM: Voltage Measurement
- IM: Current Measurement

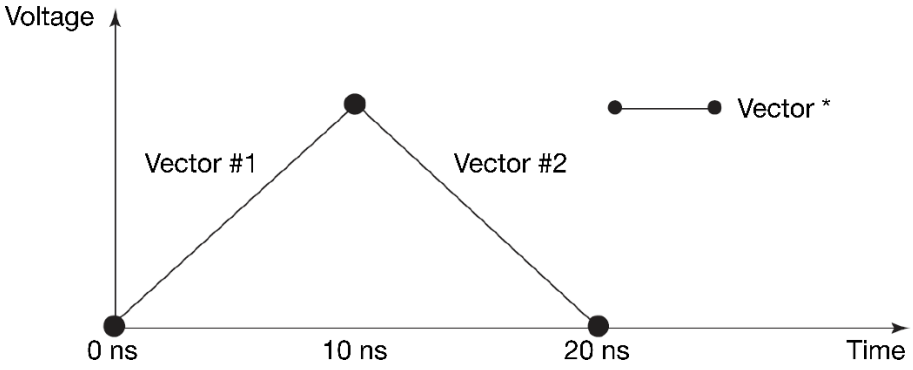
Waveform generation and measurement capabilities

Pulse and any waveform can be generated by using ALWG (Arbitrary Linear Waveform Generation vector data. Measurements can be performed by measurement events embedded on the vectors.

1. Fast IV mode supports active analog feedback loop to keep its output as specified voltage and the output impedance negligible. It can reduce the influence of load line effect by the source impedance and DUT impedance.
2. 50 Ω (nominal) at DC in PG mode.

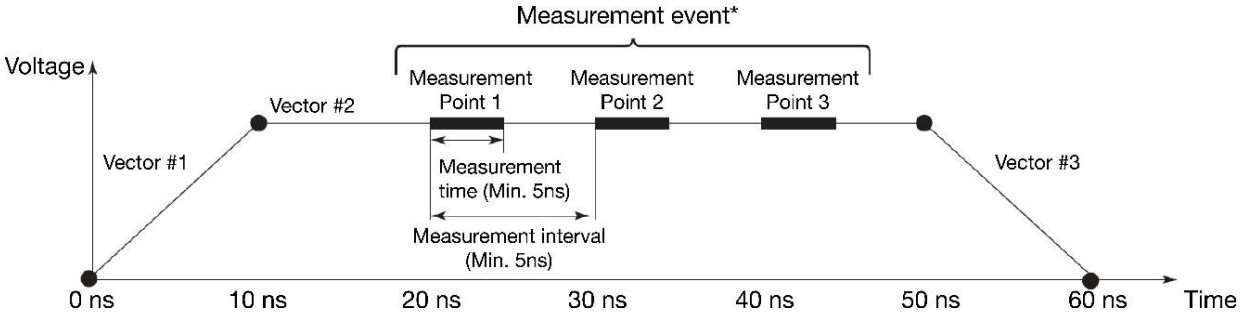
Voltage waveform output	**Waveform programming** Any waveform (including pulse shape) pattern can be programmed by using ALWG vector data within maximum number of vectors.	Minimum timing resolution	10 ns
		Vector length	10 ns to 10,000 s with 10 ns resolution/vector
		Maximum number of vectors	2,048
		Maximum number of sequences	512
		Maximum number of loop counts	10^{12}
Measurement capabilities	**Measurement (event)** Measurement can be performed at any specified points/timing in the waveform by using the measurement event feature. This provides the flexibility to perform the measurement only specific area to reduce the data size and utilize the memory efficiently. Measurement events can be embedded on any ALWG vectors in the waveform with number of measurement points, measurement interval and averaging parameters settings.	Sampling rate	200 MSa/s
		Maximum number of measurement points	About 4 M data points/channel (typical)
		Interval between measurement points	5 ns or 10 ns to 1 s with 10 ns resolution
		Averaging per a measurement point	10 ns to 20 ms with 10 ns resolution
	Range change (Event) Current measurement range can be changed at any specified points/timing in the waveform by using the range change event feature. It enables to use the user specified ranges in a measurement sequence according to the device impedance.		
Trigger capability	**Trigger out (Event)** Output trigger event can be set at any specified points/timing in the waveform by using the trigger out event feature.		

Example 1. Waveform creation by vector data



(*) The waveform is created by specifying multiple vectors (time, voltage). Each vector can be set within the ranges of vector length and voltage.

Example 2. Measurement event on a created waveform



(*) As well as the measurement event, the range change and trigger event can be specified in the vector.

To perform accurate measurement, it is necessary to take the voltage/current settling time into account from the analog performance viewpoint. Refer to the Minimum timing parameters tables as supplemental characteristics of analog performance.

Force, measurement and timing specifications

Voltage force	Accuracy	± (0.1% of setting + 0.1% of range) [1]
	Resolution [2]	96 µV (-3 to 3 V range) 160 µV (all ranges except for -3 V to 3 V range)
	Overshoot / Undershoot	±(5% + 20 mV) [3]
	Noise	Maximum 0.1 mV_{rms} [4]
Voltage measurement	Accuracy	±(0.1% of reading ±0.1% of range) [5]
	Resolution [6]	680 µV (-5 V to +5 V range) 1.4 mV (-10 V to +10 V range)
	Noise [7]	Maximum 4 mV_{rms} (-5 V to +5 V range)
Current measurement	Accuracy	±(0.1% of reading ±0.2% of range) [5]
	Resolution [6]	0.014% of range
	Noise (Effective resolution)	Maximum 0.2% of range [8]
Timing accuracy	Rise time T_{rise} (10 to 90%) / Fall time T_{fall} (90 to 10%)	-5% to (+5% + 10 ns) of setting [9]
	Pulse period	±1% of setting [10]
	Pulse width	±(3% + 2 ns) [11]

Other Specifications

- Number of output channels:
  - 2 channels per module
- RSU:
  - Output Connector: SMA
  - V monitor terminal:
    - Connector: BNC
    - Source Impedance: 50 Ω (nominal) at DC
    - The terminal outputs a buffered signal equal to 1/10 of V_{out} (into a 50 Ω load)

1. Independent of the range or the mode. DC constant voltage output.
   Load impedance must be ≥ 1 MΩ (1 µ A range) or ≥ 200 kΩ (all other current ranges) for Fast IV mode, or ≥ 1 MΩ for PG mode.
2. Can vary at most 5% based on the result of calibration.
3. PG mode, 50 Ω load, T_{rise} and T_{fall} > 16 ns with the 1.5 m cable, > 32 ns with 3 m cable, or > 56 ns with 5 m.
4. Theoretical value for observed time 100 ns to 1 ms, supplemental characteristics.
5. Independent of the range or the mode. DC constant voltage output.
   Applicable condition: 10,000 averaging samples for 10 µA range and above, 100,000 averaging samples for 1 µA range.
6. Display resolution. Can vary at most 5% based on the result of calibration.
7. 0 V output, open load, no averaging. Maximum 1.5 mV_{rms} as supplemental characteristics.
8. Effective value at 0 V output, open load, and no averaging. Supplemental characteristics.
9. PG mode, 50 Ω load, T_{rise} and T_{fall} ≥ 24 ns.
10. PG mode, 50 Ω load, pulse period ≥ 100 ns.
11. PG mode, 50 Ω load, pulse width ≥ 50 ns.

- RSU SMU path:
  - Leak current: < 100 pA (supplemental characteristics)
  - Residual resistance: < 300 mΩ (supplemental characteristics)

- WGFMU to RSU cable length:

  The WGFMU and RSU are connected by a special composite cable. The following configurations are available:

  - 3 m
  - 5 m
  - 1.5 m
  - 2.4 m + connector adapter + 0.6 m
  - 4.4 m + connector adapter + 0.6 m

  Note: The connector adapter is used when routing the cable through the prober's connector panel.

- Trigger output:
  - Level: TTL
  - Trigger width: 10 ns
  - Trigger output skew: < 3 ns (supplemental characteristics)

- Jitter:
  - < 1 ns (supplemental characteristics)

- Skew between channels:
  - < 3 ns, under no electrostatic discharge condition (supplemental characteristics)

- Current range change time:
  - < 150 µs

  Note: The time until the measured current settles within ±0.3% of the final result value after the range change (supplemental characteristics)

Minimum timing parameters for current measurement (supplemental characteristics) [1]

Voltage applied to DUT		10 V					
Current applied to DUT		100 nA	1 µA	10 µA	100 µA	1 mA	10 mA
Applied voltage condition	Recommended minimum pulse width [2]	47 µs	38.7 µs	6.8 µs	950 ns	240 ns	145 ns
Current measurement condition	Measurement Range	1 µA	1 µA	10 µA	100 µA	1 mA	10 mA
	Recommended minimum measurement window	10 µs	1.64 µs	1 µs	130 ns	40 ns	20 ns
	Settling time [3]	37 µs	37 µs	5.8 µs	820 ns	200 ns	125 ns
	Noise (rms) [4]	160 pA	425 pA	2.5 nA	47 nA	280 nA	1.9 µA

Minimum timing parameters for voltage measurement (supplemental characteristics) [5]

Voltage applied to DUT		5 V	10 V
Applied voltage condition	Recommended minimum pulse width [6]	105 ns	130 ns
Voltage measurement condition	Measurement Range	5 V	10 V
	Recommended minimum measurement window	20 ns	20 ns
	Settling time [7]	85 ns	110 ns
	Noise (rms) [8]	1.4 mV	1.4 mV

1. Measurement conditions: The DUT is a resistive load chosen to adjust the flowing current to the specified current in the table above. The capacitance of the cable between the RSU and the DUT is 20 pF. Voltage is applied to the DUT by a channel of WGFMU/RSU in Fast IV mode and in the 10 mA range, and current measurement is performed by another channel at 0 V in Fast IV mode.
2. Recommended minimum pulse width = settling time + recommended minimum measurement window.
3. The time until the measured value settles to within ±0.6% of the final result value after the output voltage is changed from the initial value (0 V). Minimum rise/fall time of 70 ns is recommended for minimizing overshoot.
4. RMS noise measured over the recommended minimum measurement window.
5. Measurement conditions: The DUT is a resistive load between 1 kΩ and 10 MΩ. The capacitance of the cable between the RSU and the DUT is 20 pF. Voltage is applied to the DUT by a channel of WGFMU/RSU, and voltage measurement is performed by the same channel. (PG mode for 5 V, Fast IV mode for 10 V).
6. Recommended minimum pulse width = settling time + recommended minimum measurement window.
7. The time until the measured value settles to within ±0.6% of the final result value after the output voltage is changed from the initial value (0 V). Minimum rise/fall time of 70 ns for 10 V, or 30 ns for 5 V is recommended for minimizing overshoot.
8. RMS noise measured over the recommended minimum measurement window.

WGFMU software

- Application Programming Interface (API):
  - Instrument Library (.DLL/.Lib for .NET)
    Note: Instrument library is available for the following programming environments.
    (Microsoft Visual C++ .NET, Visual C# .NET, Visual Basic .NET, Visual Basic 6.0, VBA, or TransEra HTBasic for Windows (release 8.3 or later)
- Application Tests:
  - BTI (NBTI/PBTI)
  - Sweep/pulsed sweep measurement (using 2ch of WGFMU in fast IV mode)
  - Pattern Editor for general purpose
- Sample application programs:

  Following application programs are available on external Windows PC. The Source code is available for customization.
  - BTI (NBTI/PBTI)
  - Fast IV Sweep
  - Pulsed IV measurement Transient I/V measurement
  - Sampling measurement and RNT data analysis tool

WGFMU supported prober vendors

- Cascade Microtech (Suss MicroTec included)
- Vector Semiconductor

General Specifications

Temperature range

- Operating: +5 °C to +40 °C
- Storage: -20 °C to +60 °C

Humidity range

- Operating: 20% to 70% RH, non-condensing
- Storage: 10% to 90% RH, non-condensing

Altitude

- Operating: 0 m to 2,000 m (6,561 ft)
- Storage: 0 m to 4,600 m (15,092 ft)

Power requirement

- AC voltage: 100 - 240 V (±10%)
- Line frequency: 50/60 Hz

Maximum volt-amps (VA)

- B1500A: 900 VA

Regulatory compliance

- EMC:
  - IEC61326-1/EN61326-1
  - AS/NZS CISPR 11
  - KC: RRA Notification amending Radio
  - Waves Act Article 58-2

- Safety:
  - IEC61010-1/EN61010-1
  - CAN/CSA-C22.2 No. 61010-1-04, C/US

Certification

- CE, cCSAus, C-Tick, KC

Dimensions

- B1500A: 420 mm W x 330 mm H x 575 mm D
- N1301A-100 SMU CMU unify unit (SCUU): 148 mm W x 75 mm H x 70 mm D
- N1301A-200 guard switch unit (GSWU): 33.2 mm W x 41.5 mm H x 32.8 mm D
- E5288A Atto-sense and switch unit (ASU): 132 mm W × 88.5 mm H × 50 mm D
- B1531A RSU: 45.2 mm W x 70 mm H x 82 mm D
- N1255A 2 channel connection box for MCSMU: 184.4 mm W x 61.6 mm H x 169.6 mm D
- 16440A SMU/PGU selector: 250 mm W × 50 mm H × 275 mm D
- 16445A Selector adaptor: 250 mm W × 50 mm H × 260 mm D

Weight

- B1500A mainframe: 20 kg
- B1510A HPSMU: 2.0 kg
- B1511B MPSMU: 1.0 kg
- B1514A MCSMU: 1.3 kg
- B1517A HRSMU: 1.2 kg
- B1520A MFCMU: 1.5 kg
- B1525A HV-SPGU: 1.3 kg
- B1530A WGFMU: 1.3 kg
- B1531A RSU: 0.13 kg
- E5288A ASU: 0.5 kg
- N1301A-100 SCUU: 0.8 kg

- N1301A-200 GSWU: 0.1 kg
- N1255A 2 channel connection box for MCSMU: 0.7 kg
- 16440A SMU/PGU selector: 1.1 kg
- 16445A Selector adapter: 1.0 kg

Keysight EasyEXPERT group+ Software

Keysight EasyEXPERT group+ GUI based characterization software is available either on the B1500A's embedded Windows 10 platform with 15-inch touch screen or on your PC to accelerate the characterization tasks. It supports efficient and repeatable device characterization in the entire characterization process from measurement setup and execution to analysis and data management either interactive manual operation or automation across a wafer in conjunction with a semiautomatic wafer prober. EasyEXPERT group+ makes it easy to perform complex device characterization immediately with the hundreds of ready-to-use measurements (application tests) furnished, and allows you the option of storing test condition and measurement data automatically after each measurement in a unique built-in database (workspace), ensuring that valuable information is not lost and that measurements can be repeated at a later date. Finally, EasyEXPERT group+ has built-in analysis capabilities and a graphical programming environment that facilitate the development of complex testing algorithms.

Key features

- Multiple measurement modes for quick setup and measurement execution (application test, classic test, tracer test, quick test and oscilloscope view)
- Graphical display, automated analysis capabilities and data generation to Excel and image for analysis and reporting.
- Built-in database (workspace) records test data automatically and simplifies the data management without numerous data files.
- GUI-based control of the Keysight B2200A, B2201A and E5250A switching matrices GUI-based self-test, self-calibration and diagnostics menu for hardware maintenance.
- EasyEXPERT remote control function supports the remote measurement execution of application tests that are created on GUI interactively, via the LAN interface.
- Data back capability and various data protection feature for shared usage by multiple users.
- Characterization environment is available either on mainframe (embedded Windows 10) or on user's PC as a personal and portable analyzer environment. EasyEXPERT group+ can be installed on any PC as many as needed without additional charge.

Application library

EasyEXPERT group+ comes with over 300 application tests conveniently organized by device type, application, and technology. You can easily edit and customize the furnished application tests to fit your specific needs. Application tests are provided for the following categories. They are subject to change without notice.

Device type	Application tests
CMOS transistor	Id-Vg, Id-Vd, Vth, breakdown, capacitance, QSCV, etc.
Bipolar transistor	Ic-Vc, diode, Gummel plot, breakdown, hfe, capacitance, etc.
Discrete device	Id-Vg, Id-Vd, Ic-Vc, diode, etc.
Memory	Vth, capacitance, Butterfly Curve, FORM, Set-Reset, endurance test, PUND, etc.
Power device	Pulsed Id-Vg, pulsed Id-Vd, breakdown, SiC JEP183, etc.
Nano device	Resistance, Id-Vg, Id-Vd, Ic-Vc, etc.
Reliability test	NBTI/PBTI, charge pumping, electro migration, hot carrier injection, J-Ramp, TDDB, etc.
And more…	And more…

Measurement modes and functions

- Operation mode
  - Application test mode
    The application test mode provides application oriented point-and-click test setup and execution. An application test can be selected from the library by device type and desired measurement, and then executed after modifying the default input parameters as needed.
  - Classic test mode
    The classic test mode provides function oriented test setup and execution with the same look, feel, and terminology of the 4155/4156 user interface. In addition, it improves the 4155/4156 user interface by taking full advantage of EasyEXPERT's GUI features.
  - Quick test mode
    A GUI-based Quick Test mode enables you to perform test sequencing without programming. You can select, copy, rearrange and cut-and-paste any application tests with a few simple mouse clicks. Once you have selected and arranged your tests, simply click on the measurement button to begin running an automated test sequence.
  - Tracer test mode
    The tracer test mode offers intuitive and interactive sweep control using a rotary knob similar to a curve tracer. Just like an analog curve tracer, you can sweep in only one direction (useful for R&D device analysis) or in both directions (useful in failure analysis applications). Test set ups created in tracer test mode can be seamlessly and instantaneously transferred to classic test mode for further detailed measurement and analysis.
  - Oscilloscope view (available for MCSMU)
    The oscilloscope view (available in tracer test mode) displays measured MCSMU module current or voltage data versus time. The pulsed measurement waveforms appear in a separate window for easy verification of the measurement timings. This function is useful for verifying waveform timings and debugging pulsed measurements. It is available when a tracer test has

one or more MCSMU channels being used in pulsed mode. The oscilloscope view can display the pulsed w waveform timings at any (user specified) sweep step of the sweep output.

- Sampling interval: 2 µs
- Sampling points: 2,000 Sa
- Sampling duration: 22 µs to 24 ms
- Marker function:
  - Read-out for each data channel
  - Resolution: 2 µs
- Data saving:
  - Numeric: Text/CSV/XMLSS
  - Image: EMF/BMP/JPG/PNG

- Measurement mode

  The Keysight B1500A supports the following measurement modes:

  - IV measurement
    - Spot
    - Staircase sweep Pulsed spot Pulsed sweep
    - Staircase sweep with pulsed bias Sampling
    - Multi-channel sweep
    - Multi-channel pulsed sweep List sweep
    - Linear search [1]
    - Binary search [1]
  - C measurement
    - Spot C
    - CV (DC bias) sweep
    - Pulsed spot C
    - Pulsed sweep CV
    - C-t sampling
    - C-f sweep
    - CV (AC level) sweep
    - Quasi-Static CV (QSCV)

- Sweep measurement
  - Number of steps: 1 to 10,001 (SMU), 1 to 1,001 (CMU)
  - Sweep mode: Linear or logarithmic (log)
  - Sweep direction: Single or double sweep

1. They are supported by FLEX command only.

- Hold time: 0 to 655.35 s, 10 ms resolution
- Delay time: 0 to 65.535 s, 100 µs resolution (CV (AC level) sweep, C-f sweep)
- Step delay time: 0 to 1 s, 100 µs resolution
- Step output trigger delay time: 0 to (delay time) s, 100 µs resolution
- Step measurement trigger delay time: 0 to 65.535 s, 100 µs resolution

- Sampling (time domain) measurement
  - Displays the time sampled voltage/current data (by SMU) versus time.
  - Sampling channels: Up to 10
  - Sampling mode: Linear, logarithmic (log)
  - Sampling points:
    - For linear sampling: 1 to 100,001 / (number of channels)
    - For log sampling: 1 to 1 + (number of data for 11 decades)
  - Sampling interval range:
    Note: Sampling interval less than 2ms is only supported in linear mode.
    - 100 µs +20 µs x (number of channels - 1) to 2 ms, 10 µs resolution
    - 2 ms to 65.535 s, 1 ms resolution
  - Hold time, bias hold time:
    - -90 ms to -100 µs, 100 µs resolution
    - 0 to 655.35 s, 10 ms resolution
  - Measurement time resolution: 100 µs

- Other measurement characteristics
  - Measurement control
    Single, repeat, append, and stop
  - SMU setting capabilities
    Limited auto ranging, voltage/current compliance, power compliance, automatic sweep abort functions, self-test, and self-calibration.
  - Standby mode
    SMUs in “Standby” remain programmed to their specified output value even as other units are reset for the next measurement.
  - Bias hold function
    This function allows you to keep a source active between measurements. The source module will apply the specified bias between measurements when running classic tests inside an

application test, in quick test mode, or during a repeated measurement. The function ceases as soon as these conditions end or when a measurement that does not use this function is started.

- Current offset cancel
  This function subtracts the offset current from the current measurement raw data, and returns the result as the measurement data. This function is used to compensate the error factor (offset current) caused by the measurement path such as the measurement cables, manipulators, or probe card.
- Time stamp
  The B1500A supports a time stamp function utilizing an internal quartz clock.
  Resolution: 100 µs

Data display, analysis and arithmetic functions

- Data display
  - X-Y graph plot
    X-axis and up to eight Y-axes, linear and log scale, real time graph plotting.
    - Scale: Auto scale and zoom
    - Marker: Marker to min/max, interpolation, direct marker, and marker skip
    - Cursor: Direct cursor
    - Line: Two lines, normal mode, grad mode, tangent mode, and regression mode
    - Overlay graph comparison: Graphical plots can be overlaid
  - List display
    Measurement data and calculated user function data are listed in conjunction with sweep step number or time domain sampling step number. Up to 20 data sets can be displayed.
  - Data variable display
    Up to 20 user-defined parameters can be displayed on the graphics screen.
  - Automatic analysis function
    On a graphics plot, the markers and lines can be automatically located using the auto analysis setup. Parameters can be automatically determined using automatic analysis, user function, and read out functions.
  - Analysis functions
    Up to 20 user-defined analysis functions can be defined using arithmetic expressions. Measured data, pre-defined variables, and read out functions can be used in the computation, and the result can be displayed.
  - Read out functions
    The read out functions are built-in functions for reading various values related to the marker, cursor, or line.

- Data export
  X-Y graph plot can be printed or stored as image data to clipboard or mass storage device. (File type: bmp, gif, png, emf). Graph and list data can be exported to Excel.

Arithmetic functions

- User functions
  Up to 20 user-defined functions can be defined using arithmetic expressions.
  Measured data and pre-defined variables can be used in the computation. The results can be displayed on the LCD.
- Arithmetic operators
  +, -, *, /, ^, abs (absolute value), at (arc tangent), avg (averaging), cond (conditional evaluation), delta, diff (differential), exp (expo- nent), integ (integration), lgt (logarithm, base 10), log (logarithm, base e), mavg (moving average), max,min, sqrt, trigonometric function, inverse trigonometric function, and so on.
- Physical constants
  Keyboard constants are stored in memory as follows:
  - q: Electron charge, 1.602177E-19 C
  - k: Boltzman's constant, 1.380658E-23
  - e (e): Dielectric constant of vacuum, 8.854188E-12
- Engineering units
  The following unit symbols are also available on the keyboard:
  - a (10^{-18}), f (10^{-15}), p (10^{-12}), n (10^{-9}), u or μ (10^{-6}), m (10^{-3})
  - k (10^{3}), M (10^{6}), G (10^{9}), T (10^{12}), P (10^{15})

Data management

- Workspace (Built-in database)
  EasyEXPERT group+ supports the built-in database called "workspace". Workspaces are created on a SSD, and they enable to manage and access all the measurement related data without handling numerous files. Every workspace supports the following features:
  - Access to measurement capabilities and data stored in the workspace.
  - Save/Import/Export measurement settings and data (application library, measurement settings, my favorite setup, and measurement data)
  - Recall the setup for measurement reproduction and data for analysis
- Data auto record/auto export
  EasyEXPERT group+ has the ability to automatically store the measurement setup and data within a

workspace. It can also export measurement data in real time, in a variety of formats such as Excel (xlsx).

- Import/export files
  File type: Keysight EasyEXPERT format, XML-SS format, CSV format
- Data Protection
  EasyEXPERT group+ has various options to protect important data as follows.
  - Password protection (workspace, test definition and my favorite)
  - User level access control (engineer mode/operator mode)
- Workspace back-up and portability
  EasyEXPERT group+ has the ability to import/export a workspace for back-up and portability.

EasyEXPERT group+ supported instruments and prerequisites

		Advanced device analyzer		Precision IV analyzer		Economic IV analyzer	Discontinued
		B1500A	**B1505A**	**E5270B**	**E5260A E5262/63A**	**B2900A/B Series SMU**	**4155B/C 4156B/C**
Classic Test	I/V Sweep	Yes	Yes	Yes	Yes	Yes	Yes [1]
	Multi-Ch I/V Sweep	Yes	Yes	Yes	Yes	Yes	-
	I/V List Sweep	Yes	Yes	Yes	Yes	Yes	-
	I/V-t Sampling	Yes	Yes	-	-	Yes	Yes
	C-V Sweep	Yes	Yes	-	-	-	-
	SPGU Control	Yes	-	-	-	-	-
	GUI-based Switching Matrix Control	Yes [2]	-	Yes [2]	Yes [2]	Yes [2]	Yes [2]
	Direct Control	Yes	Yes	-	-	-	-
Application Test		Yes	Yes	Yes	Yes	Yes	Yes
Tracer Test		Yes (DC/Pulse)	Yes (DC/Pulse)	Yes (DC)	Yes (DC)	Yes (DC/Pulse)	
Quick Test		Yes	Yes	Yes	Yes	Yes	Yes
Oscilloscope View		Yes [3]	Yes [3]	-	-	-	-
External Instrument Driver Support	LCR Meter (E4980A/4284A)	Yes	Yes	Yes	Yes	Yes	Yes
	Pulse Generator (81110A)	Yes	Yes	Yes	Yes	Yes	Yes
	DVM (3458A)	Yes	Yes	Yes	Yes	Yes	Yes
Prober Control in Quick Test		Yes [4,5]	Yes [4,5]	Yes [4,5]	Yes [4,5]	Yes [4,5]	Yes [4,5]
Firmware Requirement		≥ A.04.00 [6]	≥ A.04.00 [6]	≥ B.01.10	≥ B.01.10	≥ 1.0	HOSTC ≥ 03.08 SMUC ≥ 04.08

1. PGU and VSU/VMU are supported. Differential voltage measurement of VMU is not supported.
2. B2200/01A and E5250A (with E5252A cards) are supported.
3. Only available for supported modules.
4. Cascade Microtech Sumit 12000/S300 (Nucleus), Cascade Microtech (Suss MicroTec) PA 200/PA 300, and Vector Semiconductor VX-2000/VX- 3000
5. MPI SENTIO, SemiProbe PILOT (Contact to the prober vender if the latest driver is available.)
6. The latest firmware version is strongly recommended to take full advantage of measurement capabilities.

Prerequisites

Prerequisites to use the EasyEXPERT group+, WGFMU instrument library, and other furnished software on an external PC are as follows.

Operating system and service pack	Microsoft Windows Vista Business SP2 or later (32 bit)	Microsoft Windows 7 Pro. SP1 or later (32 bit / 64 bit)	Microsoft Windows 8.1 Pro. or later (32 bit /64 bit)	Microsoft Windows 10 Pro. or later (32 bit / 64 bit)	Microsoft Windows 11 Pro.
Processor	Vista certified PC	Windows 7 certified PC	Windows 8.1 certified PC	Windows 10 certified PC	Windows 11 certified PC
Supported language	English (US)	English (US)	English (US)	English (US)	English (US)
Memory	2 GB	2 GB	2 GB	2 GB	2 GB
Display	XGA 1024 x 768 (SXGA 1280 x 1024 recommended)	XGA 1024 x 768 (SXGA 1280 x 1024 recommended)	XGA 1024 x 768 (SXGA 1280 x 1024 recommended)	XGA 1024 x 768 (SXGA 1280 x 1024 recommended)	XGA 1024 x 768 (SXGA 1280 x 1024 recommended)
HDD / SSD	Installation: 1 GB free disk space on the C drive	Installation: 1 GB free disk space on the C drive	Installation: 1 GB free disk space on the C drive	Installation: 1 GB free disk space on the C drive	Installation: 1 GB free disk space on the C drive
	Test setup / result data storage: Free disk space more than 30 GB is recommended	Test setup / result data storage: Free disk space more than 30 GB is recommended	Test setup / result data storage: Free disk space more than 30 GB is recommended	Test setup / result data storage: Free disk space more than 30 GB is recommended	Test setup / result data storage: Free disk space more than 30 GB is recommended
.NET Framework	Microsoft .NET Framework 3.5 SP1	Microsoft .NET Framework 3.5 SP1	Microsoft .NET Framework 3.5 SP1	Microsoft .NET Framework 3.5 SP1	Microsoft .NET Framework 3.5 SP1
IO Libraries	Keysight IO Libraries Suite 16.3, 17.1 update 1 or later (for the Online execution mode)	Keysight IO Libraries Suite 16.3, 17.1 update 1 or later (for the Online execution mode)	Keysight IO Libraries Suite 16.3, 17.1 update 1 or later (for the Online execution mode)	Keysight IO Libraries Suite 17.1 update 1 or later (for the Online execution mode)	Keysight IO Libraries Suite 18.3 update 1 or later

Recommended GPIB I/F

Vendor	Interface		B1500A	4155B/C 4156B/C
Keysight	82350B/C	PCI	X [1]	X
	82351B	PCIe	X [1]	X
	82357A/B	USB	X [2]	X
National Instruments	GPIB-USB-HS	USB	X [2]	X

1. A PCI or PCIe card is highly recommended because of stability and speed.
2. USB GPIB interfaces might cause serial poll error intermittently due to the intrinsic communication scheme differences. It is reported that using an even GPIB address sometimes significantly decreases the chance of the error. The NI GPIB- USB- HS is recommended for stability, and the Keysight 82357x is recommended for speed.

Ordering Information

Mainframe

B1500A	Semiconductor device analyzer mainframe. The following accessories are included	
	16444A-001	Keyboard
	16444A-002	USB mouse
	16444A-003	Stylus pen
	16493J-001/002	Interlock cable (1.5 m or 3.0 m) [1]
	16493L-001/002	GNDU cable (1.5 m or 3.0 m) [1]
	16494A-001/002	Triaxial cable (1.5 m or 3.0 m) [1]
	N1254A-100	GNDU to Kelvin adapter
B1500A-015	1.5 m cable (Cable length is set to 1.5 m for standard and add-on packages)	
B1500A-030	3.0 m cable (Cable length is set to 3.0 m for standard and add-on packages)	
B1500A-050	50 Hz line frequency	
B1500A-060	60 Hz line frequency	
B1500A-A6J [2]	ANSI Z540 compliant calibration	
B1500A-UK6 [2]	Commercial calibration certificate with test data	

Standard packages

B1500A-A00	Empty Package for Custom Solution
B1500A-A01	Standard Package (MPSMU 4ea.& Cables)
B1500A-A02	High Resolution Package (HRSMU 4ea & Cables)
B1500A-A03	High Power Package (HPSMU 2ea, MPSMU 2ea & Cables)
B1500A-A04	Basic Flash Memory Cell Package (MPSMU 2ea, HRSMU 2ea, SPGU, Accessories)

Add-on packages

B1500A-A10	HPSMU Add-on (HPSMU 1ea. & Cables)
B1500A-A11	MPSMU Add-on (MPSMU 1ea. & Cables)
B1500A-A17	HRSMU Add-on (HRSMU 1ea. & Cables)
B1500A-A1A	MCSMU Add-on (MCSMU 1ea. connection box & cables)
B1500A-A1B	MCSMU Add-on (MCSMU 2ea. connection box & cables)
B1500A-A20	MFCMU Add-on (MFCMU, Cable)
B1500A-A25	HV-SPGU Add-on (HV-SPGU 1ea. & Cables)
B1500A-A28	ASU (Atto-Sense and Switch Unit) Add-on for HRSMU (ASU 1ea. & Cables)
B1500A-A29	ASU (Atto-Sense and Switch Unit) Add-on for MPSMU (ASU 1ea. & Cables)
B1500A-A30	WGFMU Add-on (WGFMU 1ea. RSU 2ea. & Cables)
B1500A-A31	WGFMU Add-on with Connector Adapter (WGFMU 1ea, RSU 2ea, Cables & Connector Adapter)
B1500A-A3P	WGFMU probe cable kit (8 probe cables. WGFMU is not included)
B1500A-A5F	Test fixture for packaged device measurement (16442B 1ea)

CMU accessories

N1301A-101	SMU CMU unify unit (SCUU)
N1301A-102	SMU CMU unify unit cable (3 m)
N1301A-110	SMU CMU unify unit magnetic stand
N1301A-200	Guard switch unit (GSWU)
N1301A-201	Guard switch unit cable (1 m)
N1301A-202	Guard switch unit cable (3 m)

1. Select B1500A-015 or B1500A-030 to specify the cable length.
2. The option A6J and UK6 are available ONLY at the initial shipment. Option A6J includes the test data and measurement uncertainties from the calibration and the certificate of calibration stating the instrument has been calibrated using a process in compliance with ANSI Z540 and is operating within the published specifications. Option UK6 includes the test data from the calibration and the certificate of calibration stating the instrument has been calibrated and is operating within the published specifications.

Upgrade options [1]

B1500AU-010	**Addition of B1510A HPSMU module**
B1500AU-11B	Addition of B1511B MPSMU module
B1500AU-141	Addition of B1514A MCSMU 1ea w/ connection box
B1500AU-142	Addition of B1514A MCSMU 1ea w/o connection box
B1500AU-017	Addition of B1517A HRSMU module
B1500AU-088	Addition of E5288A ASU (for HRSMU)
B1500AU-089	Addition of E5288A ASU (for MPSMU)
B1500AU-020	Addition of B1520A MFCMU module
B1500AU-025	Addition of B1525A HV-SPGU module
B1500AU-030	Addition of B1530A WGFMU module with two RSUs
B1500AU-SWS	EasyEXPERT upgrade, extension support and subscription
B1500AU-PC2	Mainframe upgrade (available for S/N starts with JP or less than MY53440000)
B1500AU-PC3	Mainframe upgrade (available for S/N MY53440101 or later)
B1500AU-DR1	Replace DVD-R drive with read-only drive

1. Need to order related test cables separately. For more information, refer to the B1500A Configuration Guide.