4200-BTI-A

Ultra-Fast NBTI/PBTI Package for the Model 4200-SCS

- **Best-in-class test speed allows faster, more complete device characterization**
  - **Begin measuring BTI degradation as soon as 30ns after stress is removed**
  - **Measure transistor VT in less than 1μs using I_D–V_G sweep method**
- **Model 4225-RPM Remote Amplifier/Switch**
  - **Switches automatically between low-level precision DC I-V (via standard SMUs) and ultra-fast I-V measurements with no need for re-cabling**
  - **Improves single-pulse source and measurement performance by minimizing cable parasitic effects and increasing low current sensitivity**
- **Best high-speed, low-current measurement sensitivity available in a single-box integrated solution**
  - **Supports sub-microsecond pulse characterization of drain current at reduced drain voltage, minimizing drain-to-source fields that could otherwise skew test results**
  - **Ensures the source/measure instrumentation won't be the limiting factor when making low-level measurements**
  - **Detects degradation trends sooner during the test, reduces the time needed to perform process reliability monitoring**
- **Simple, predictable interconnect scheme prevents measurement problems due to incorrect DUT connections**

The Model 4200-BTI-A Ultra-Fast BTI Package combines Keithley's advanced DC I-V and ultra-fast I-V measurement capabilities with automatic test executive software to provide the most advanced NBTI/PBTI test platform available in the semiconductor test industry. The 4200-BTI-A package, which builds on the Model 4200-SCS semiconductor parameter analyzer's powerful test environment, includes all the instruments, interconnects, and software needed to make the most sophisticated NBTI and PBTI measurements on leading-edge silicon CMOS technology:

- One Model 4225-PMU Ultra-Fast I-V Module
- Two Model 4225-RPM Remote Amplifier/Switches
- Automated Characterization Suite (ACS) Standard Version 4.2 Software
- Ultra-Fast BTI Test Project Module
- Cabling

APPLICATIONS

- **Single-Pulse Charge Trapping/ high-κ dielectric characterization**
- **Silicon-On-Insulator testing**
- **LDMOS/GaAs isothermal characterization**
- **Flash RTS ID**
- **Phase-change random access memory (PCRAM) testing**
- **Ultra-fast NBTI characterization**
- **Charge pumping measurements**
- **Thermal impedance characterization**
- **MEMs capacitor testing**
- **Random telegraph signal (RTS) CMOS**
- **Charge-based capacitance measurement (CBCM) Materials testing for scaled CMOS, such as high-κ dielectrics**
- **NBTI/PBTI reliability tests**

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Ultra-Fast NBTI/PBTI Package for the Model 4200-SCS

- **Optional Multi-Measurement Performance Cables (MMPC) optimize measurement performance of configurations that combine DC I-V, C-V, and ultra-fast I-V capabilities**

- **ACS V4.2 software supports building complex test sequences including up to 20 measurement sequences and full prober integration**

  - **DC I-V and ultra-fast I-V measurements can be easily integrated into a stress-measure sequence**

  - **Degradation and recovery behaviors can be characterized using either AC or DC stress**

  - **Combine spot measurements with precision SMU sweeps in pretesting and posttesting**

  - **Incorporate single pulse charge trapping (SPCT) measurements into longer stress-measure sequences**

- **Support for handling large data sets required in device reliability modeling and process monitoring applications**

- **Support for hot chucks and fully and semi automatic probers, including wafer maps, wafer- and cassette-level sample plans**

Model 4225-PMU Ultra-Fast I-V Module

This module is the hardware core of the ultra-fast I-V measurement capability essential for characterizing NBTI and PBTI degradation in microseconds, allowing for more accurate lifetime measurements for Designed-In Reliability (DIR) that support modeling for device and circuit design. It integrates a sophisticated two-channel waveform generator with high-speed voltage and current measurement capabilities, a deep measurement buffer, and a real-time test execution engine.

Unlike traditional pulse generation solutions, the Model 4225-PMU can be programmed to output the complex waveforms required in ultra-fast BTI testing. And, unlike traditional Arbitrary Waveform Generators (AWGs), the waveforms' duration and complexity aren't limited by bitmap or memory depth. Instead, the 4225-PMU employs a high-level waveform description language that uses the concept of segments, segment libraries, and looping. In addition, the waveform description specifies exactly when measurements must be made during the waveform and the type of measurement to be made.

Spot, step sweep, smooth sweep, and sample measurement types are supported and multiple measurement types can be linked to form a test sequence. The programmable sample period can be set as fast as 5ns, so most measurements will include multiple samples. The system's real-time test execution engine automatically calculates the mathematical mean of the samples, which reduces the volume of data that must be transferred and parsed during the course of the test. The resulting measurements are streamed back to the high-level test module for near-real-time analysis and test termination.

For additional information on this module's capabilities and specifications, consult the Model 4225-PMU data sheet.
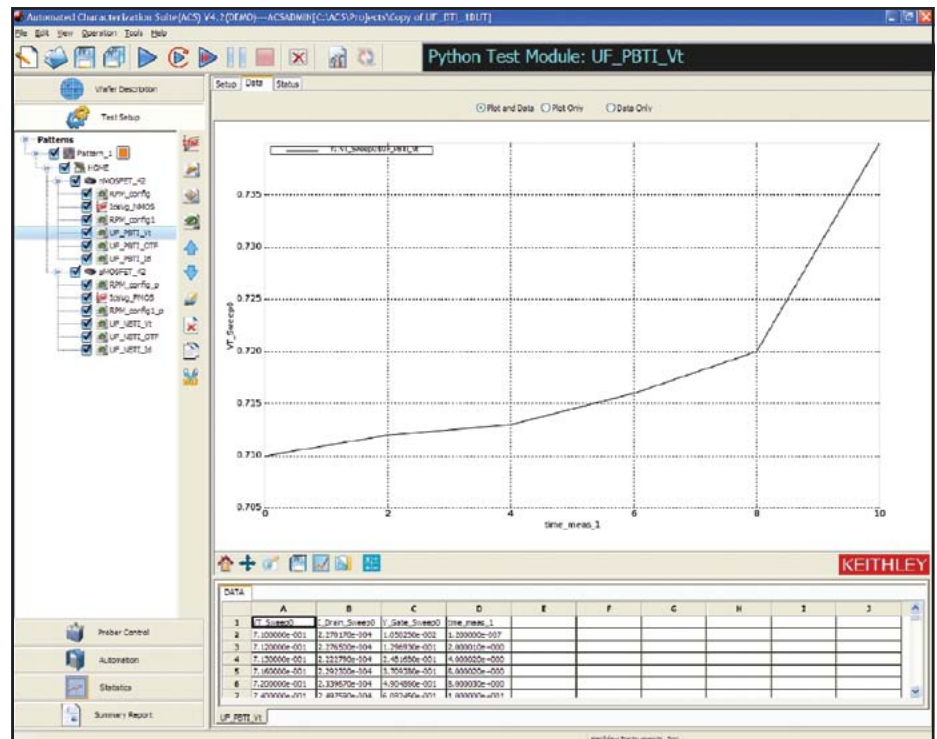
The Model 4225-PMU/4225-RPM's combination of superior speed and sensitivity allow characterizing voltage threshold (V_T) directly with high-speed I_D–V_G sweeps. Measuring V_T directly makes it unnecessary to correlate the single-point I_D measurement to actual V_T levels.

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4200-BTI-A

Ultra-Fast NBTI/PBTI Package for the Model 4200-SCS

Ordering Information

4200-BTI-A

Ultra-Fast BTI Package for the Model 4200-SCS (includes one Model 4225-PMU Ultra-Fast I-V Module, two Model 4225-RPM Remote Amplifier/ Switches, Ultra-Fast BTI Test Project Module, and one copy of the Automated Characterization Suite (ACS) software, V4.2

Accessories Supplied

For the 4225-PMU:

SMA to SMA 50Ω cables, 2m (4 ea.)

SMA to SSMC Y-Cable Assembly, 6 in (2 ea.)

ACCESSORIES AVAILABLE

4210-MMPC-C	Multi Measurement Performance Cables for Cascade probe stations using SSMC probe pin connections.. One kit required per manipulator.
4210-MMPC-S	Multi Measurement Performance Cables for Suss probe stations using SSMC probe pin connections.. One kit required per manipulator.
4225-PMU	Extra Ultra-Fast I-V Module
4225-RPM	Extra Remote Amplifier/Switch. Up to two of these units can be used with a single 4225-PMU module.
4200-PMU-PROBER-KIT	
	General Purpose Cable/Connector Kit. For connecting the 4225-PMU to most triax and coax probe stations. One kit required per 4225-PMU module.

Model 4225-RPM Remote Amplifier/Switch

This module is designed to maximize the Model 4225-PMU's current measurement sensitivity. The 4225-RPM's independent force and sense connections to the DUT maximize its pulse, DC, and C-V performance. Its built-in switching capabilities allow the Model 4200-SCS to switch automatically between making ultra-fast I-V measurements with the 4225-PMU and DC I-V measurements with the system's 4200-SMU and 4210 source-measure units (SMUs).

Model 4225-RPM modules are required for ultra-fast BTI testing; if the 4225-PMU module is used without them, it employs a recursive technique to compensate for cable influences such as load line effects and is typically used for isothermal I-V testing. This recursive technique is inappropriate for use in BTI reliability applications in which measurements must be both as short as possible and highly temporally deterministic in order to minimize the relaxation effects.

By making it possible to locate the pulse source close to the device under test (DUT), the 4225-RPM helps minimize the cable length and corresponding cable parasitic effects. The shorter cables result in reduced cable capacitance, reduced load-line effects, and reduced source overshoot. Placing the pulse source and high speed measurement circuits near the DUT allows the cable length to be reduced so that the round-trip propagation delay is shorter than the rise or fall time of the desired pulse.

For additional details and specifications on the Model 4225-RPM, consult the Model 4225-PMU data sheet.

Speed and Sensitivity

Bias temperature instability is a highly dynamic phenomenon that requires sensitive, high-speed measurements for accurate characterization. Assuming all other factors are constant, measurement physics largely defines the relationship between measurement speed and sensitivity. When making sub-millisecond measurements, all sources of noise must be taken into account; for sub-microsecond applications, quantum effects can't be ignored. The 4200-BTI-A package provides the optimal combination of measurement speed and sensitivity for ultra-fast BTI testing because it's engineered to approach the limits of measurement physics while ensuring high ease of use. The package is optimized to provide optimal ultra-fast results without the use of RF structures and interconnects.

Reduce Unwanted Source-Drain Fields

To eliminate hot carrier injection effects or unwanted charge displacement during BTI testing, minimizing drain-to-source fields is critical. All BTI characterization techniques involve measuring drain current with a voltage applied to the drain. Given that the drain current is proportional to the

Define stress timing and stress conditions easily using familiar parameters like timing – log, linear, custom list; measurements per decade; AC or DC stress; optional recovery test sequence; and test sample rate (speed).

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Disadvantages of BTI systems developed in house

Until now, some researchers have been forced to configure their own ultra-fast BTI test systems. These in-house-developed systems typically combine a pulse generator or arbitrary waveform generator with an oscilloscope equipped with current probes or some type of transimpedance amplifier to help measure low current. Although it is possible to build a BTI system that is suitable for a very specific set of electrical conditions if the instruments and interconnect are carefully selected, several major technical challenges remain:

- **Waveform generation.** Standard pulse generators and arbitrary waveform generators are designed to generate a waveform on a fixed recurring interval, rather than the Log(time) scale required for most reliability tests, including NBTI and PBTI testing.

- **Measurement timing and data storage.** Although oscilloscopes can be configured to trigger based on a waveform feature (such as a falling edge, for example), they are not designed to store samples selectively for specific portions of the waveform. This makes it necessary to store very large data sets for postprocessing. Only the most expensive oscilloscopes or those with costly memory expansion options can store enough data to compensate for these shortcomings.

- **Precision, accuracy, and sensitivity.** Oscilloscopes, current probes, and transimpedance amplifiers all have independently defined performance specifications and they are not necessarily optimized to work together. It is often very difficult to combine these components in a way that provides optimal performance across a wide dynamic range in order to achieve precise and accurate current measurements at high speeds.

- **Interconnect.** Systems built in house typically use splitters and bias tees, which limit the performance of the test setup. For example, a bias tee might limit bandwidth from 100ns to 10μs. Although this is suitable for high speed measurements, it prevents making any meaningful prestress and poststress DC measurements as part of the stress–measure sequence. It also prevents making measurements in the intermediate range of 10μs to DC.

- **Test control and data management.** Traditional oscilloscopes don't support data streaming, so results transfer must wait until the test ends. Once the test is complete, massive amounts of data must be transferred to the control computer for postprocessing, which requires parsing complex waveforms into individual test results, followed by further reduction of the data into actual measurements.

- **Test termination.** Given that the test results can't be analyzed until the data is transferred from the oscilloscope, the test duration must be determined prior to test initiation. This makes it impossible to terminate the test based in parametric shifts or to detect catastrophic failures in real time.

- **Automation.** Wafer- or cassette-level automation requires control of both the test instruments and the wafer probe station, which systems built in house typically wouldn't provide. Also, incorporating sophisticated features like conditional test termination would add considerable complexity to the custom software necessary to run a system of this type.

- **Higher channel count.** Even for an in-house-built system that works well, pressures to increase the channel or test system count may arise. Typical test system maintenance issues such as calibration, operation, and correlation related to these custom setups can easily consume a disproportionate amount of the available resources.

drain-to-source field, the more sensitive the drain current measurement is, the lower the required drain voltage must be. The 4200-BTI-A package's superior low current measurement capability allows the use of lower drain voltages to produce more accurate results.

Reduced Relaxation Time

The 4225-BTI-A package's superior speed and sensitivity allow making degradation measurements faster than any other commercial test system available. Single-point ID spot measurements can be completed in less than 1μs and ten-point ID-VG step sweeps can be made in less than 10μs. A sub-microsecond smooth sweep can be performed in less than 1μs.

Software

The Ultra-Fast BTI test software module brings together the measurement capabilities of the Model 4225-PMU and 4225-RPM through an intuitive interface that doesn't compromise test flexibility. It makes it easy to define stress timing, stress conditions, and a wide range measurement sequences from spot ID, On-The-Fly (OTF), or ID-VG sweeps. The test module allows measuring recovery effects as well as degradation. It also offers prestress and poststress measurement options that incorporate the Model 4200-SCS's DC SMUs for high-precision low-level measurements.

Stress Settings

The Ultra-Fast BTI Test Module employs familiar parameter setting for building stress–measure timing sequences. The stress set-up screen makes defining log or linear timing or building a custom list of time intervals to trigger intra-stress measurements both easy and quick.

Intuitive Test Sequence Development

The Ultra-Fast BTI Test Module makes creating a powerful test sequence as uncomplicated as selecting one or more measurement types, then entering the appropriate values for voltage levels and measurement parameters in the intuitive interface. No coding or script writing is required. Select from four measurement types and chain up to 20 measurements together to form a ready-to-run measurement sequence:

- **Spot.** The spot measurement is a single measurement made while the gate and drain are pulsed. The measurement result is the mean value of the samples taken after the drain settles and before the pulse ends.

- **Step Sweep.** The step sweep is very similar to a conventional DC SMU sweep, in which

each step in the sweep includes a settling period and an integration (or averaging) period.

- **Smooth Sweep.** The smooth sweep does not include settling times, and the signal is sampled continuously throughout the sweep.

- **Sample.** A sample measurement is much like the smooth sweep measurement, except that it is performed at a constant set of voltage conditions on the gate and drain.

Test Automation Speeds Data Sample Acquisition

The ability to acquire large, statistically significant samples of data quickly is key to reliability modeling. Advances in ultra thin film transistors have further increased the required sample size due to the increasingly random nature of the defects in these devices. As a result, it's critical to use a test environment that supports wafer- and cassette-level automation. This environment must also be capable of handling the extremely large data sets associated with reliability testing. The test environment provided with the Automated Characterization Suite software supports full automation capabilities compatible with both semi and fully automatic probe stations.

Interconnect

The 4200-BTI-A package provides all the cabling and connectors required to connect to standard coaxial probe manipulators. For enhanced measurement accuracy, many users add an optional multi-measurement performance cable kit that connects the Model 4200-SCS to a prober manipulator, simplifying switching between DC I-V, C-V, and ultra-fast I-V testing configurations. This kit eliminates the need for re-cabling, as well as maximizing signal fidelity by eliminating the measurement errors that often result from cabling errors. Versions engineered for Cascade Microtech and SUSS MicroTec probers are available. There's also a general-purpose kit for connecting the 4225-PMU to other triaxial and coaxial probe stations.

Additional Applications

The Model 4225-PMU's ultra-fast I-V capabilities are not limited to low-voltage pMOS and nMOS reliability testing. It can drive up to 800mA or 40V with pulse widths from 30ns to several seconds in length. This remarkable dynamic range is suitable for a wide variety of other applications.

Keithley's Model 4200-SCS replaces a variety of electrical test tools with a single, tightly integrated characterization solution that's ideal for a wide variety of applications. To assure customers of the ongoing viability of their systems, Keithley has continually enhanced the system's hardware and software. This ongoing commitment ensures a cost-effective system upgrade path to address new testing needs as they arise. That means Model 4200-SCS users will never have to buy a new parametric analyzer because the old one is obsolete. The Model 4200-SCS is engineered to adapt readily to the industry's changing test needs—making our customers' capital investments stretch further and improving ROI.

Measurement Types

Spot Smooth Sweep

Triangle Step Sweep
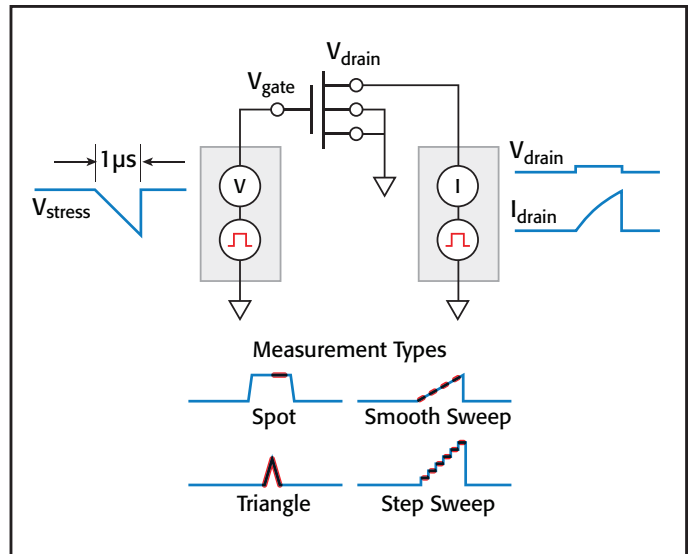
The Ultra-Fast BTI test software module supports spot, step sweep, smooth sweep, and sample measurement types. Each type's timing is defined by the test sample rate and the individual measurement settings. The software module also provides control over the voltage conditions between each element in the test sequence, for maximum flexibility and ease of use, even when defining complex test sequences.
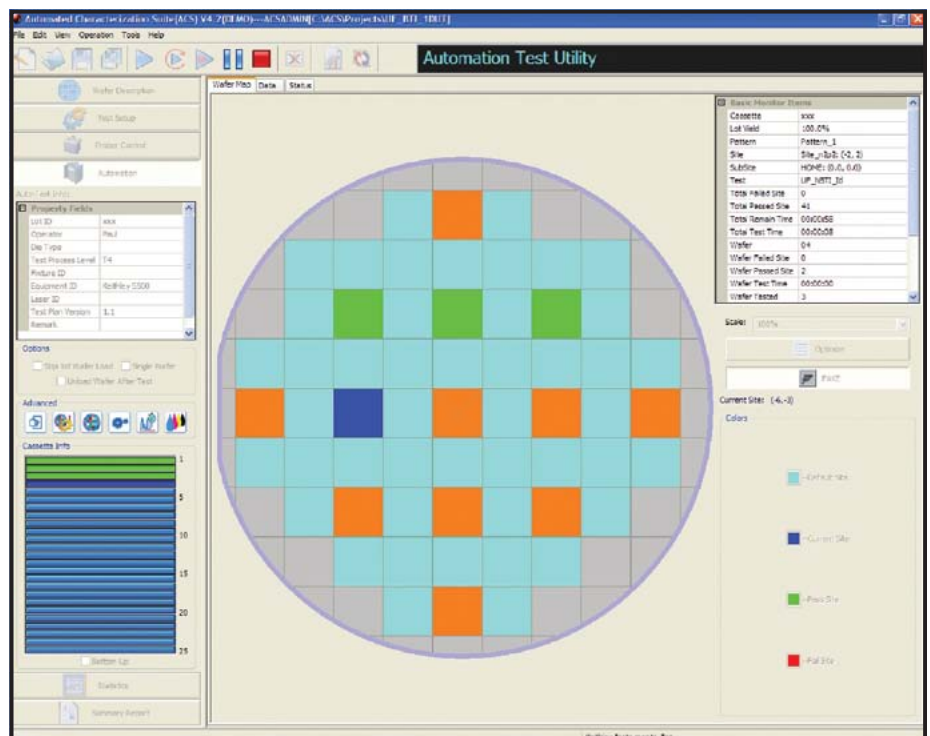
ACS software provides wafer- and cassette-level automation capabilities compatible with semi and fully automatic probe stations.

Hardware and software package optimized for NBTI/PBTI characterization

SEMICONDUCTOR

4200-BTI-A

Ultra-Fast NBTI/PBTI Package for the Model 4200-SCS

Specifications

4225-RPM REMOTE AMPLIFIER/SWITCH Optional Accessory for the 4225-PMU

The 4225-RPM provides lower current measurement ranges to the 4225-PMU.

- Low current measure ranges supports wide range of measurements, from nanotechnology to BTI (Bias Temperature Instability) on leading-edge CMOS devices
- This is a single-channel accessory; order two Model 4225-RPMs to support the two channels of the Model 4225-PMU.
- Supports switching to the Model 4200-SCS's SMUs or 4210-CVU, allowing for a wide range of tests without re-cabling.
- Built-in bypass mode allows access to the Model 4225-PMU's higher current measurement ranges.

PULSE/LEVEL [1]

	4225-PMU with 4225-RPM
V_{OUT}	−10 V to +10 V
Accuracy [2] into open load	±(0.5% ±10 mV)
Resolution	< 0.5 mV
Output Connectors	Triaxes, source and sense
Baseline Noise	±(0.39% + 1 mV) RMS typical
Overshoot/Pre-shoot/Ringing 3	±2% of amplitude ±20 mV

4225-RPM REMOTE AMPLIFIER/SWITCH (must be used in conjunction with 4225-PMU)

TYPICAL MINIMUM TIMING PARAMETER FOR CURRENT MEASUREMENT

Range	100 nA	1 µA	10 µA	100 µA	1 mA	10 mA
Recommended Minimum Pulse Width [4, 5]	134 μs	20.4 μs	8.36 μs	1.04 μs	370 ns	160 ns
Recommended Minimum Measure Window [5]	10 μs	1.64 μs	1 μs	130 ns	40 ns	20 ns
Accuracy (DC)	±(0.5% + 1nA)	±(0.5% + 1nA)	±(0.5% + 30nA)	±(0.5% + 100nA)	±(0.5% + 1µA)	±(0.5% + 10µA)
Recommended Minimum Transition Time [5, 6]	1 μs	360 ns	360 ns	40 ns	30 ns	20 ns
Noise [5, 7]	200 pA	2 nA	5 nA	50 nA	300 nA	1.5 μA
Settling Time [5, 8]	100 μs	15 μs	6 μs	750 ns	250 ns	100 ns

VOLTAGE MEASURE

±10V

RECOMMENDED MINIMUM PULSE WIDTH [4, 5]: 160ns.

RECOMMENDED MINIMUM MEASURE WINDOW [5]: 20ns.

ACCURACY (DC): 0.25% + 10mV.

RECOMMENDED MINIMUM TRANSITION TIME [5, 6]: 20ns.

NOISE [5, 7]: 1mV.

SETTLING TIME [5, 8]: 100ns.

NOTES

1. Performance at the triax output connectors of the 4225-RPM when using a 2m RPM interconnect cable between the 4225-PMU and 4225-RPM Remote Pulse Measure unit.
2. 100mV to 10V.
3. Typical, with transistion time of 100ns (0-100%).
4. Recommended minimum pulse width = (Setting Time)/0.75
5. Typical values, into an open.
6. Recommended rise/fall time to minimize overshoot.
7. RMS noise measured over the Recommended Minimum Measure Window for the given voltage or current range, typical.
8. Time necessary for the signal to settle to the DC accuracy level. (Example: the 10mA measurement range's settling time refers to the period required for the signal to settle to within 0.35% of the final value. Calculated as Accuracy = 0.25% + 10μA = 0.25% + (10μA/10mA) = 0.25% + 0.1% = 0.35%).

All specifications apply at 23° ±5°C, within one year of calibration, RH between 5% and 60%, after 30 minutes of warmup.

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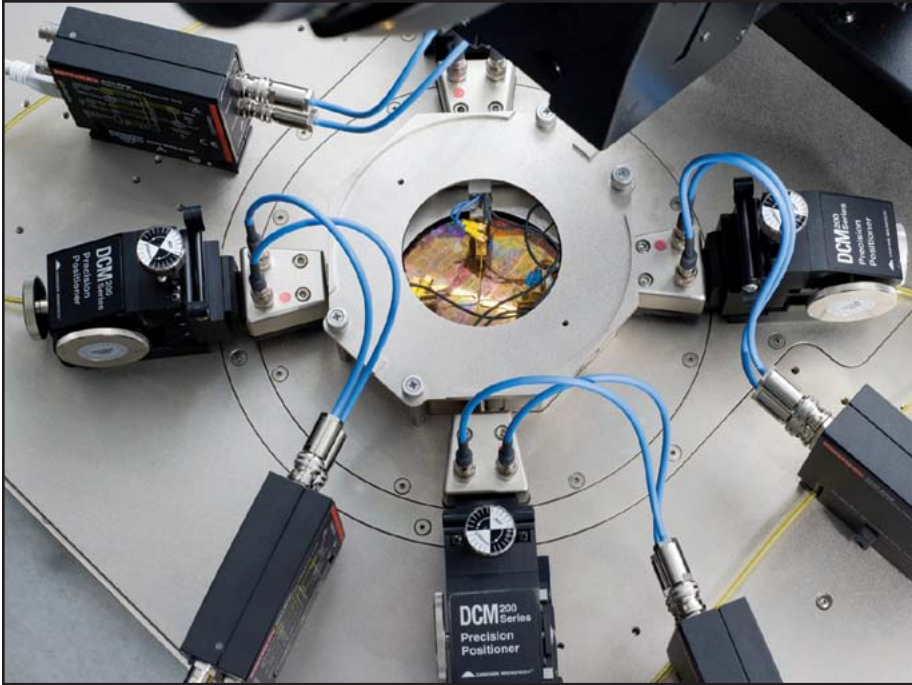
This top-down view of a Cascade Microtech analytical probe station illustrates best practices for interconnecting the Model 4225-RPM Remote Amplifier/Switch to the prober using the blue Multi-Measurement Performance cables.
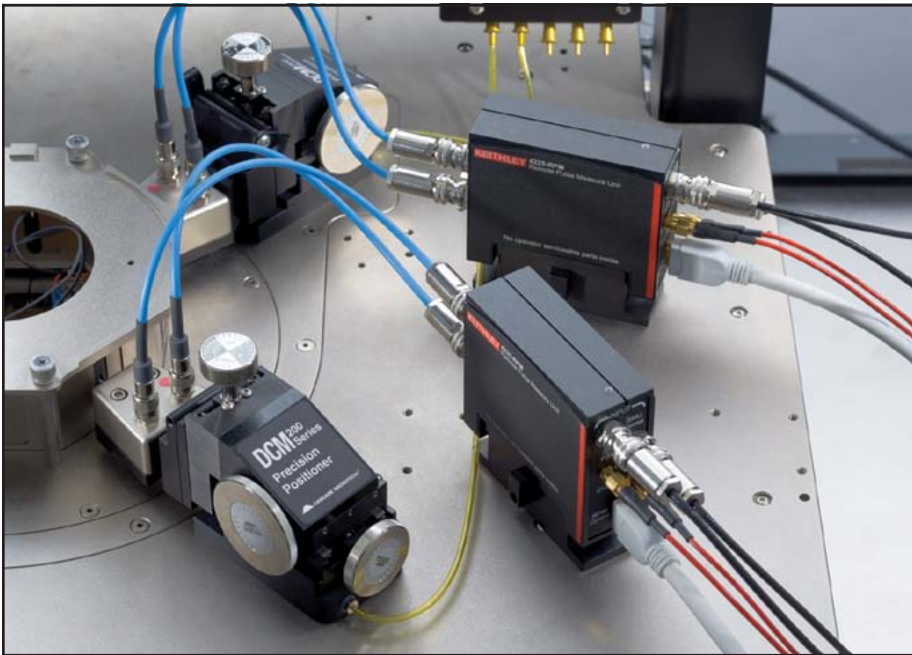
This close-up of two Model 4225-RPMs highlights the DC SMU, C-V, and ultra-fast I-V cable connections.

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