LOW CURRENT SMU MODELS OPEN THE DOOR TO MORE SEMI APPLICATIONS AND LOWER COST OF TESTING

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New SourceMeter® Instruments combine 1fa (10^{-15} amp) measurement integrity with fast test speeds, easy scalability, and lower cost of ownership.

Researchers and manufacturing managers are continually looking for ways to improve testing by increasing throughput and measurement integrity. This is particularly true in semiconductor and other component testing. While large mainframe test systems can be customized for these purposes, their cost is often prohibitive. So, there is an acute need for an instrument architecture that allows easy, low-cost customization and expandability without a cumbersome mainframe. Keithley designed its SourceMeter® instruments for just this purpose, and the new Models 2635 and 2636 extend source-measure resolution down to the one femtoamp level, which is often required for many semiconductor, optoelectronic, and nanotechnology devices. This allows accurate high-speed measurements of leakage and quiescent currents, plus other critical and sensitive I-V characterizations. Moreover, their instrument-based, multi-channel architecture results in a 50 percent lower cost than most mainframe-based source-measure solutions.

With their Test Script Processor (TSP™) and TSP-Link™ intercommunications bus, the Models 2635 and 2636 enable engineers to quickly create fast test systems that are ideal for research, characterization, wafer sort, reliability, production monitoring, and a multitude of other test applications. Their low cost and high resolution supply economical DC and pulse testing from femtoamps and microvolts up to 200V/1.5A. They operate with or without a PC, providing test speeds up to four times faster than typical mainframe-based source-measure solutions.

Each SourceMeter instrument includes a PC-like microprocessor to enable easy programming and independent execution of test programs (scripts) ranging from simple to complex, including sourcing, measuring, test sequence flow control, and decisions with conditional program branching. A back panel port on every Series 2600 instrument provides 14 bits of universal digital I/O to link the instrument to a variety of popular handlers for sorting and binning components after

testing. Since they can be easily integrated with other instruments in automated systems, they will be very attractive to component manufacturers and semiconductor fabricators for wafer level testing and packaged device testing. At the same time, their low cost makes them attractive to researchers and academics in a wide variety of disciplines that require fast and easy I-V characterization of devices and materials.

Typical applications include:

- I-V functional test and characterization of a wide range of devices, including:
    - Discrete and passive components
    - Two-leaded resistors, disk drive heads, metal oxide varistors (MOVs), diodes, zener diodes, sensors, capacitors, and thermistors
    - Three-leaded small signal BJTs, field-effect transistors (FETs), etc.
    - Parallel testing of two- and three-leaded component arrays
    - Simple ICs such as opto types, drivers, switches, and sensors
- Wafer level reliability testing, including NBTI, TDDB, HCI, and electromigration
- Integrated devices – Small Scale Integrated (SSI) and Large Scale Integrated (LSI) types:
    - Analog ICs
    - Radio frequency integrated circuits (RFICs)
    - Application specific integrated circuits (ASICs)
    - System on a chip (SOC) devices
    - Optoelectronic devices such as light-emitting diodes (LEDs), laser diodes, high brightness LEDs (HBLEDs), vertical cavity surface-emitting lasers (VCSELs), and displays
- New materials testing

Easy Scalability for Lowest Cost of Ownership

The Models 2635 and 2636 enable users to significantly reduce their cost of test for low and medium pin count devices or multiple devices and material samples. They operate as five precision instruments in a single box: SMU (source-measure unit), DMM (digital multimeter), bias source, low frequency pulse generator, and arbitrary waveform generator. These functions are controlled by TSP, which enables fully programmable sequences to be downloaded and executed within the

instrument. This eliminates communications and PC overhead for critical throughput gains, while allowing complete flexibility in controlling and adapting to different test situations.

In addition to TSP, Keithley's TSP-Link master/slave connection provides a high-speed, low-latency interface to other TSP-based instruments, enabling simple multi-box and multi-instrument software control. A major benefit is easy scalability of Series 2600 test systems according to present and future needs. Multiple single-channel (Model 2635) units, and dual-channel (Model 2636) units, can be integrated seamlessly without a host mainframe. This mainframeless scalability allows system sizes up to 32 channels per GPIB address, while minimizing cost, rack space, and time required when adding future channels. By using selected products in the Series 2600, users can standardize on two or three SMU models to cover tests up to 10A pulse or 3A DC in a wide range of applications. The SMUs can then be re-purposed by simply changing the test scripts they execute.

Figure 1. Mainframeless 36-channel semiconductor test system.

Figure 1 illustrates a 36-channel I-V measurement system consisting of eighteen dual channel Series 2600 instruments. By combining Model 2636 units with other Series 2600 instruments, measurements can cover a dynamic range from 1fA to 10A, and 1μV to 200V. The TSP-Link

master/slave connection allows seamlessly integration of multiple Series 2600 SourceMeters into a multi-channel system that can be programmed and controlled as a single instrument. Furthermore, by eliminating the need for a mainframe chassis, they allow ATE (automated test equipment) engineers to configure a readily scalable system at significantly lower cost per channel than other solutions, with the industry's highest SMU rack density.

Shorter Test Times

All of Keithley's TSP-based systems are capable of storing and running thousands of lines of code for predefined device tests that include limit comparisons, pass/fail decisions, parts binning, etc., and they all work with or without a PC controller during test execution. In contrast with existing embedded test sequencers for instrumentation, TSP scripts offer far greater programming flexibility, including support for:

- Instrument command queuing
- Modular subroutines with passable parameters
- Pass/fail testing
- A wide range of math operations
- Flexible branching and looping capability
- Flexible external triggering
- Intelligent digital I/O read and write capability
- RS-232 communication

The digital I/O of the Series 2600 can directly control probers, handlers, and other instruments, while TSP-Link allows users to execute high-speed automated tests across multiple channels and instruments without GPIB traffic. TSP-Link is optimized for small message transfer in test and measurement applications, and allows a single TSP program to control up to 16 or more SMU channels, with a theoretical maximum of 128 channels. Each SourceMeter Instrument has two TSP-Link connectors to facilitate chaining instruments together. When SourceMeter Instruments are interconnected via TSP-Link, a computer can access all of the resources of each instrument via its host interface.

With very little network overhead and a 100Mbit/sec data rate, TSP-Link is significantly faster than GPIB and 100BaseT Ethernet in actual applications. The net result is test time reductions as large as 10X compared to older sequencing instruments; 2X to 4X test time reductions are common in component testing.

When the Models 2635 and 2636 are combined with Keithley's new Series 3700 System Switch/Multimeter instruments, which also incorporate TSP and TSP-Link, an even broader range of high-speed applications can be served. Together, these two product series provide the fundamental building blocks that enable tightly integrated high-performance switching and multi-channel I-V measurements. Test engineers can use them to easily create low-cost ATE systems optimized for high throughput in applications such as semiconductor stress testing and functional packaged device tests.

Easy System Development

Historically, it has been a challenge to develop multi-instrument characterization or ATE systems for basic R&D and high-speed production testing. Keithley solves this problem with two free software tools that greatly simplify systemization of the Series 2600 SourceMeter Instruments. For R&D and curve tracing applications, Keithley's LabTracer™ 2.0 software controls up to eight SourceMeter Instrument channels to perform device characterization with no programming whatsoever. This software allows the user to fully configure each channel, run device parameter tests, and plot test data – simply and easily. Data can also be viewed in spreadsheet or graphical formats and is easily exported to Excel.

For high-speed production applications, the Test Script Processor is programmed with an uncomplicated BASIC-style programming language that runs in real time on the instrument. The intuitive, easy-to-use interface is compatible with all the popular programming languages. Keithley provides built-in test scripts for sweeping, pulsing, waveform generation, and common component tests. A number of test scripts are included in the instrument, while others can be downloaded at no charge from http://www.keithley.com/products/tsbscripts/tsprocessor These pre-written factory test scripts can be used as supplied or easily customized, allowing production users to get their systems up and running faster than ever.

Users can develop custom test scripts in other ways, including a free programming tool called Test Script Builder that helps users create, modify, debug, and store TSP scripts using its simple command language. The user's scripts can be downloaded from the PC to the master SourceMeter Instrument and saved in its non-volatile memory. Sixteen megabytes of total storage allows up to 50,000 lines of TSP code and more than 100,000 readings. Test scripts are called with a single GPIB command from any test executive software (VB, C/C++, Test Point, LabVIEW, etc.).

The non-volatile reading buffers that are reserved for measurement data have been arranged in element arrays. Each element can hold the:

- Measurement
- Measurement status
- Timestamp
- Source setting (at the time the measurement was taken)
- Range information

Test Script Builder includes a project/file manager window to store and organize test scripts, a text-sensitive program editor (like Visual Basic) to create and modify TSP code, and an Instrument Console for communicating with any TSP enabled instrument in an interactive manner. The console's *immediate instrument control* window can be used to view the output of a given test script for simplified debugging, send GPIB commands to the instrument, and receive test data back. Studies have shown that by using TSP and its associated software, users can cut system development time by 50 to 75 percent compared to previous generations of test sequencing instruments.

Application Flexibility

The pulse generator and low frequency arbitrary waveform generator capability of the Series 2600 can be applied to each SMU channel. This greatly simplifies complex testing requirements by providing a universal analog I/O pin for a wide range of applications involving active and

passive components. When coupled with TSP-Link scalability, the result is unmatched accuracy and low noise data in high-speed multi-channel testing for almost any I-V test application.

Keithley can also deliver the advantages of Series 2600 instruments within turnkey integrated test systems driven by its Automated Characterization Suite (ACS). Series 2600 instruments enable scalable source-measure channel counts and high-speed testing for a variety of semiconductor test applications including wafer level reliability, on-wafer parametric die sort, and automated characterization. For example, measurements requiring unprecedented measurement speeds such as on-the-fly NBTI can be made sequentially or in parallel with test plans at the device, wafer, or cassette level. The flexibility and user-friendliness of ACS enables full control of the system instruments, provides a powerful wafer description utility, allows semiautomatic and fully automatic prober control, permits test plan automation, and gives in-depth results analysis. ACS takes advantage of the Series 2600 flexibility, resulting in automated systems that only Keithley can deliver.

Hardware Refinements

The Models 2635 and 2636 represent the third generation design of Keithley's SMUs. In addition to features described earlier, the latest design has enhanced test speed in other ways. For example, while earlier designs used a parallel current ranging topology, the Series 2600 uses a series ranging topology (patent pending), which provides faster and smoother range changes and outputs that settle more quickly. It also allows the current output limit to be programmed independently of the measurement current range for fast charging of capacitive loads and more intuitive operation during bench use.

Each Series 2600 channel offers highly flexible, four-quadrant source coupled operation with precision voltage and current meters/limiters. Each channel can be configured as a:

- Precision power supply (up to 200V/3A DC (10A pulsed) with 1pA readback resolution)
- True current source
- DMM (DCV, DCI, ohms, power, with 5½-digit resolution)
- Power V or I pulse generator (Pulse width: 200µs and longer—source and measure)
- Power V or I waveform generator (20-point sine wave up to 400Hz in a TSP test script)

- Electronic load (with sink mode capability)

All Series 2600 instruments can be connected in series or in parallel to extend their dynamic range. In the first and third quadrants, they operate as a source, delivering power to a load. In the second and fourth quadrants, they operate as a sink, dissipating power internally. They measure voltage and current simultaneously with up to 5½-digit resolution, and they display voltage, current, resistance, or power readings.

Two analog-to-digital converters per channel (one for I, one for V) can run simultaneously, providing precise source-readback without sacrificing test throughput. These A/D converters offer the flexibility of programmable integration rates, allowing the user to optimize for either high speed (>10,000 rdgs/s at 0.001 NPLC setting) or for high resolution (up to 24 bits at 10 NPLC setting) to make high accuracy measurements. Each SourceMeter channel is electrically isolated for high integrity measurements and wiring flexibility. The Common Mode Voltage is 250vdc; Common Mode Isolation is greater than 1GΩ up to 4500pf.

To enable optimum low current measurement integrity, plus maximum flexibility and compatibility with a user's existing solution, the Models 2635 and 2636 are fitted with separate triax connectors for Hi, Lo, Sense Hi, and Sense Lo. In addition, the Lo connections can either float or be grounded – depending on the user's requirement. An advantage of this approach is that users can change their grounding scheme on the fly by using the digital I/O to drive a relay to short or open this connection. This can save test time in photodiode test applications, for example, where 2- and 4-wire ohms measurements are typically done in addition to the current and voltage tests.

About the Author

Mark Cejer is a Business Manager for Keithley Instruments, where he is responsible for developing Precision Electronic Test applications, markets, and products. Mark has been with Keithley for over 10 years and during that time has led the launch of the Keithley SourceMeter® Line, the Integra Series DMM/Data Acquisition System line, DMMs, and other precision

instruments. He has a BSEE from the University of Akron and a MBA from Case Western Reserve University.

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