Keithley Solutions for HB-LED

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Keithley Brand, Tektronix Technology

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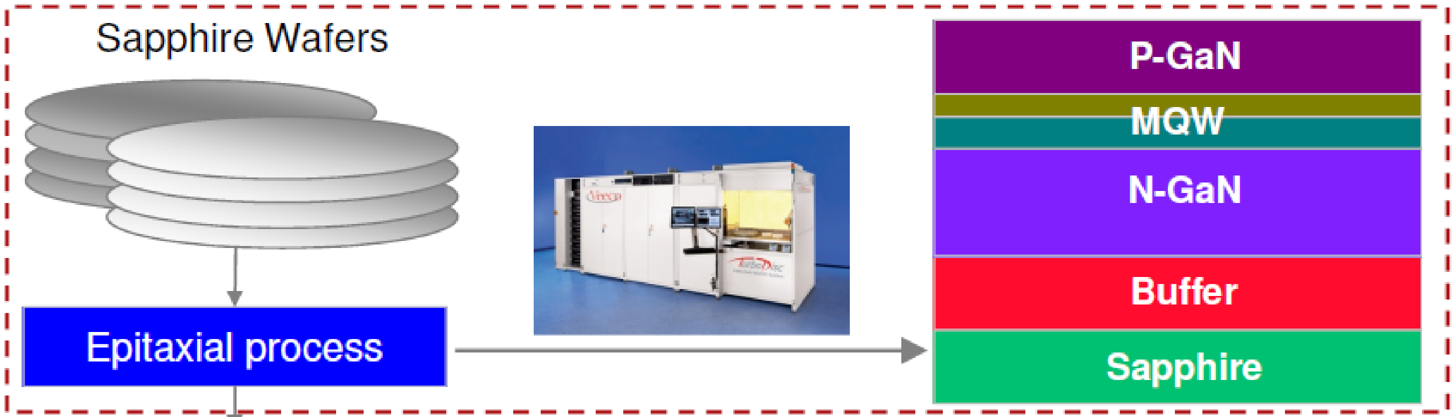
KEITHLEY

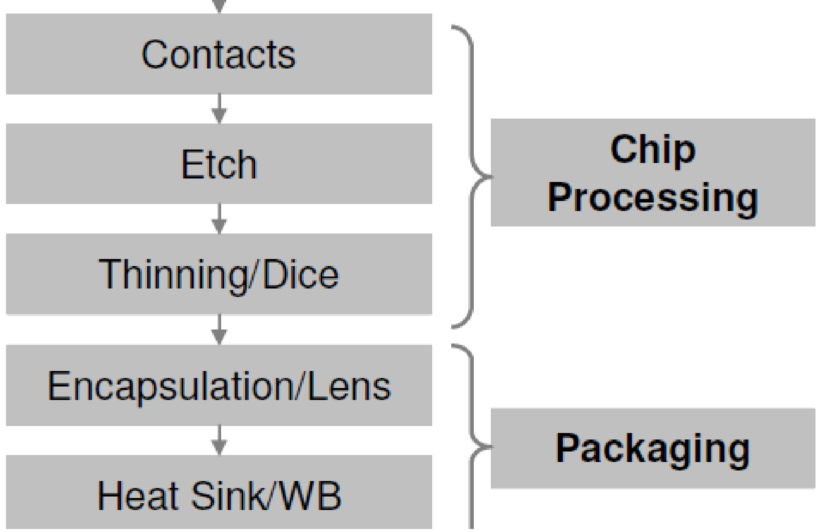
A GREATER MEASURE OF CONFIDENCE

Agenda

1. LED Optoelectronic Testing Intro.
2. Keithley SMU Technology Intro.
3. High Power LED Module Testing Requirements
4. Cabling Considerations
5. Keithley Solutions for LED Applications

MOCVD is the Critical Process in LED Manufacturing





- Color, brightness, electrical properties and cost are determined by MOCVD
- MOCVD is > 50% of the LED fab capital expenditure

Source: Veeco

The Process of LED Manufacturing

Wafer +	Gas →	MOCVD →	Laser Dicers
Kyocera, Monochrystal, Rubicon, Sumitomo	Sumitomo, Dow Chemical	Aixtron Veeco	Disco

Test →	Packaging →	Final Test →	End Product
MPI (Keithley) Fittech (Keithley) Innobiz (Keithley)	Stanley Electric, Everlight	Towa, ASM Pacific **MPI Corporation**	Sharp, GE, Osram Gree, Philips Toshiba, Panasonic

Source: Deutsche Bank + Personal Experience

Typical HB Visible LED LIV Testing Parameters

For a typical 300 μm x 300 μm LED

項目	符號	測試條件*	單位
順向電壓	V_F	20 mA	V
逆向電流	I_R	-5V	uA
主波長	λ_d	20mA	nm
峰值波長	λ_p	20mA	nm
光譜輻射帶寬 (半高寬)	$\Delta\lambda$	20mA	nm
光通量	Φ_V	20mA	mlm
發光強度	I_v	20mA	mcd
色度範圍	x , y	20mA	--
發光效率	η_V	20mA	lm/W

Source: Prof. Wei-I Lee, http://ocw.nctu.edu.tw/

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Instrument Systems
- Lab Application

Instrument Systems
light measurement

Instrument Systems
- Production Application

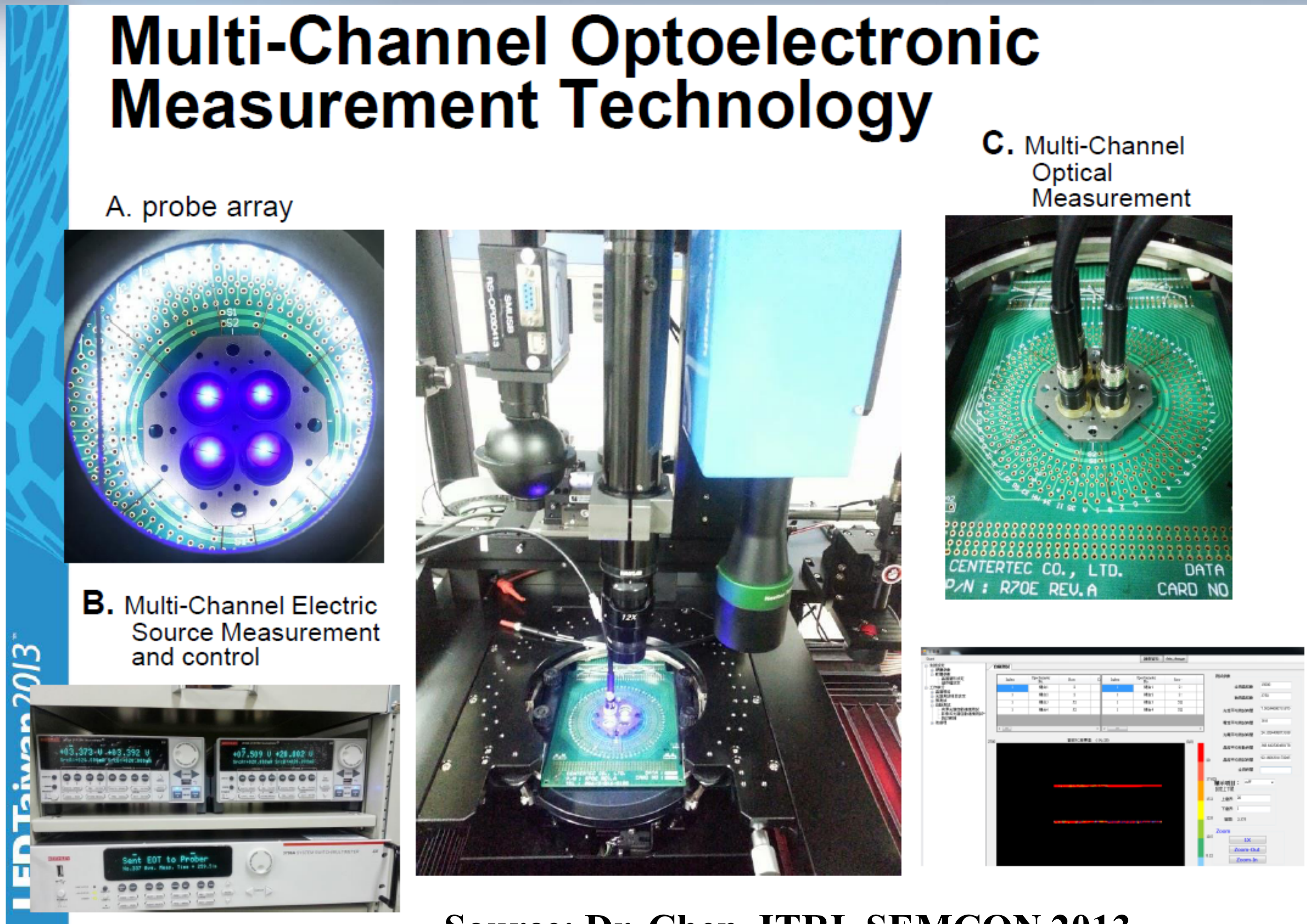
LED檢測儀 – 產線專用的完整檢測系統

藉由 LED-Tester 檢測系統的輔助，在生產線上也能實現實驗室等級的量測精準度。這款完整的檢測系統以 CCD 陣列式光譜儀 CAS 140CT 為核心，搭配吉時利(Keithley)2400/2600 電源供應器，以及專用的監控電腦與 Instrument Systems 自行研發之檢測軟體。CAS 140CT 準確優秀的量測能力，加上其他高精度儀器的組合，正是有效提高生產線效率以及品質穩定度的最佳保證。

Keithley SMU

Instrument Systems
light measurement

LIV Parallel Production System, ITRI, 2013



Source: Dr. Chen, ITRI, SEMCON 2013

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Keithley's Leadership in SMU Technology

Series 23x SMUs

Series 2400 SourceMeter Instruments

Series 2600 System SourceMeter Instruments

Series 2600A System SourceMeter Instruments

1989 — 1995 — 2000 — 2005 — 2012

- **20 patents issued for SMU-specific technology**
- **Numerous industry awards, including *R&D*100, *T&MW*, and more**
- **Thousands and thousands of customers**
- **Serving Semiconductor, Electronic Components, Optoelectronics, Automotive, Mil/Aero, Medical, Research & Education, and many more industries**

S500 and S530 Parametric Test Systems

Common Instruments for Semiconductor Device Testing?

Picoammeter

Power Supply

Current Source

Digital Multimeter

Electronic Load

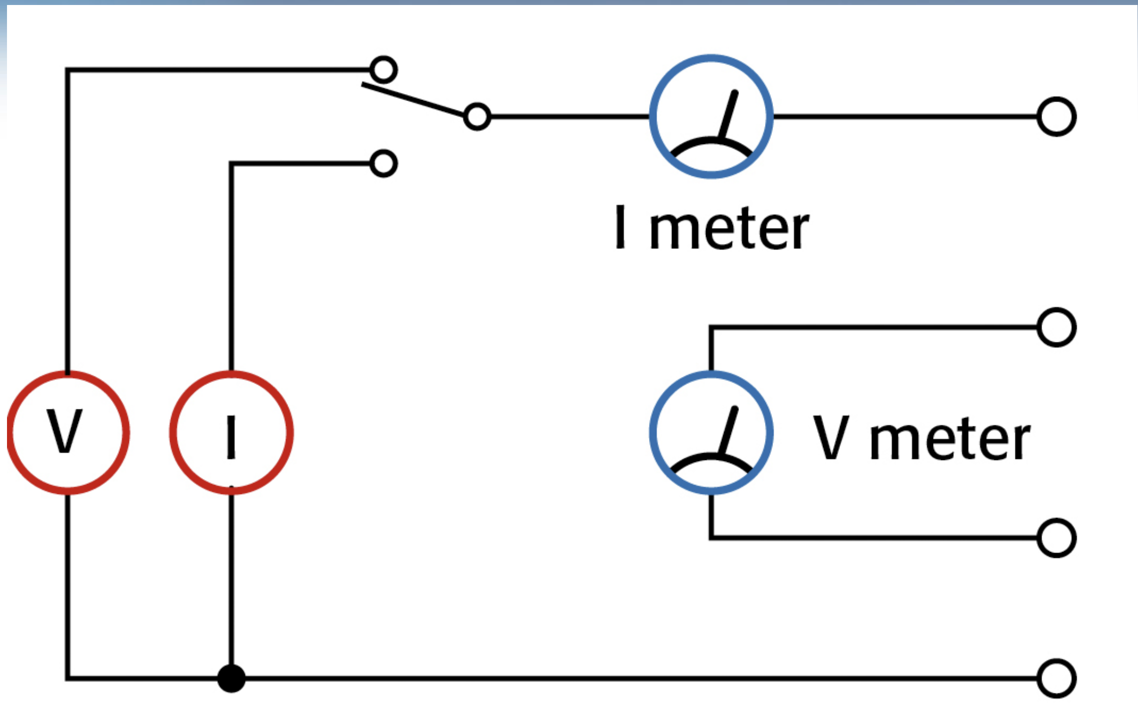
Typical Equipment Rack for Device Testing

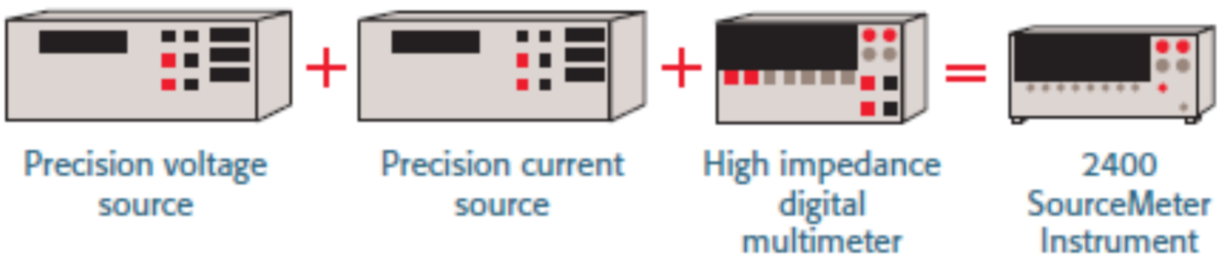
Which One Do You Want?

Well, it works.

It works well.

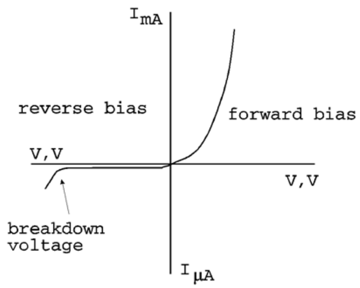
Basic SMU Topology





SMUs compared to Power Supplies - Speed, Precision, Resolution

	2602A SourceMeter Instrument	Typical Power Supply
Speed	0 1 2 3 4 5 6 7 ms	0 1 2 3 4 5 6 7 ms
Source/ Measure Precision	10µA measurement uncertainty = 5nA	10µA measurement uncertainty = 2500nA
Voltage and Current Resolution	**Voltage** 1µV 40V **Current** 1pA 3A	**Voltage** 1µV 1mV 40V **Current** 1pA 1mA 3A
4 Quadrant Operation	**Source + Sink** +I, II, I, –V, +V, III, IV, –I	**Source Only** +I, II, I, –V, +V, III, IV, –I



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SMUs compared to Power Supplies - Rising Time Comparison

K2636B

K2260

K2200

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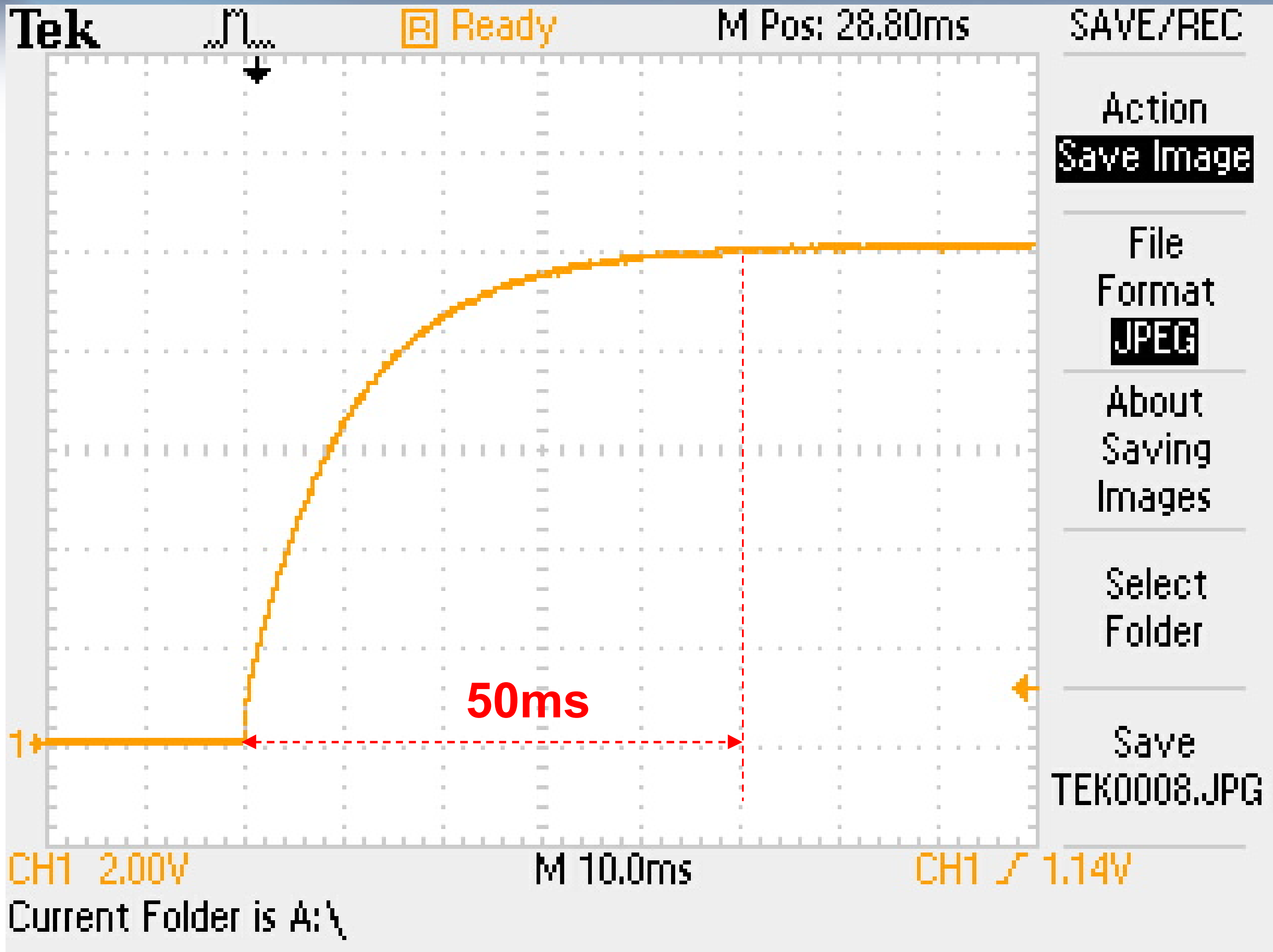
Vsrc = 10V, K2260 → Tr = 50ms



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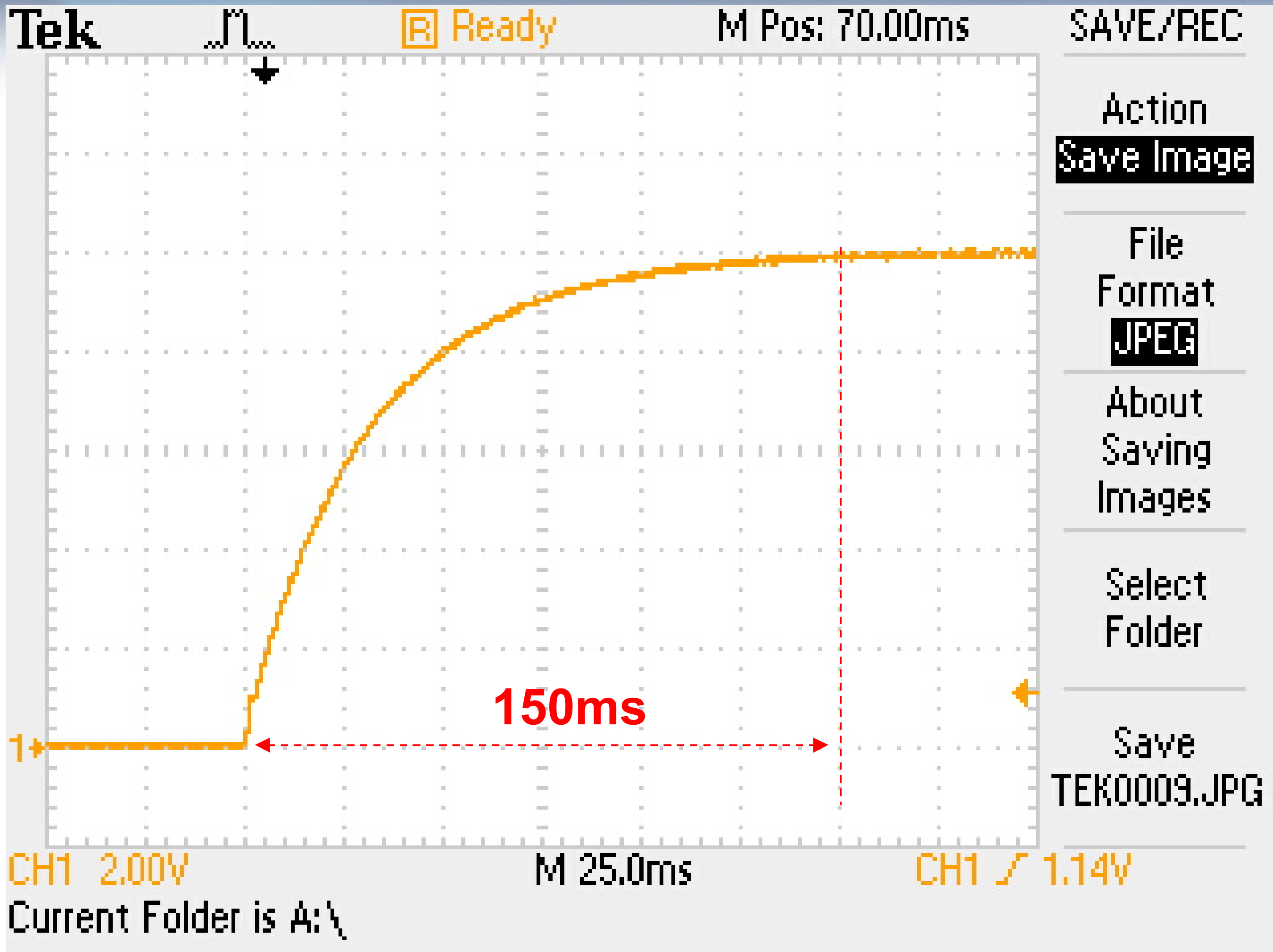
Vsrc = 10V, K2200 → Tr = 100ms



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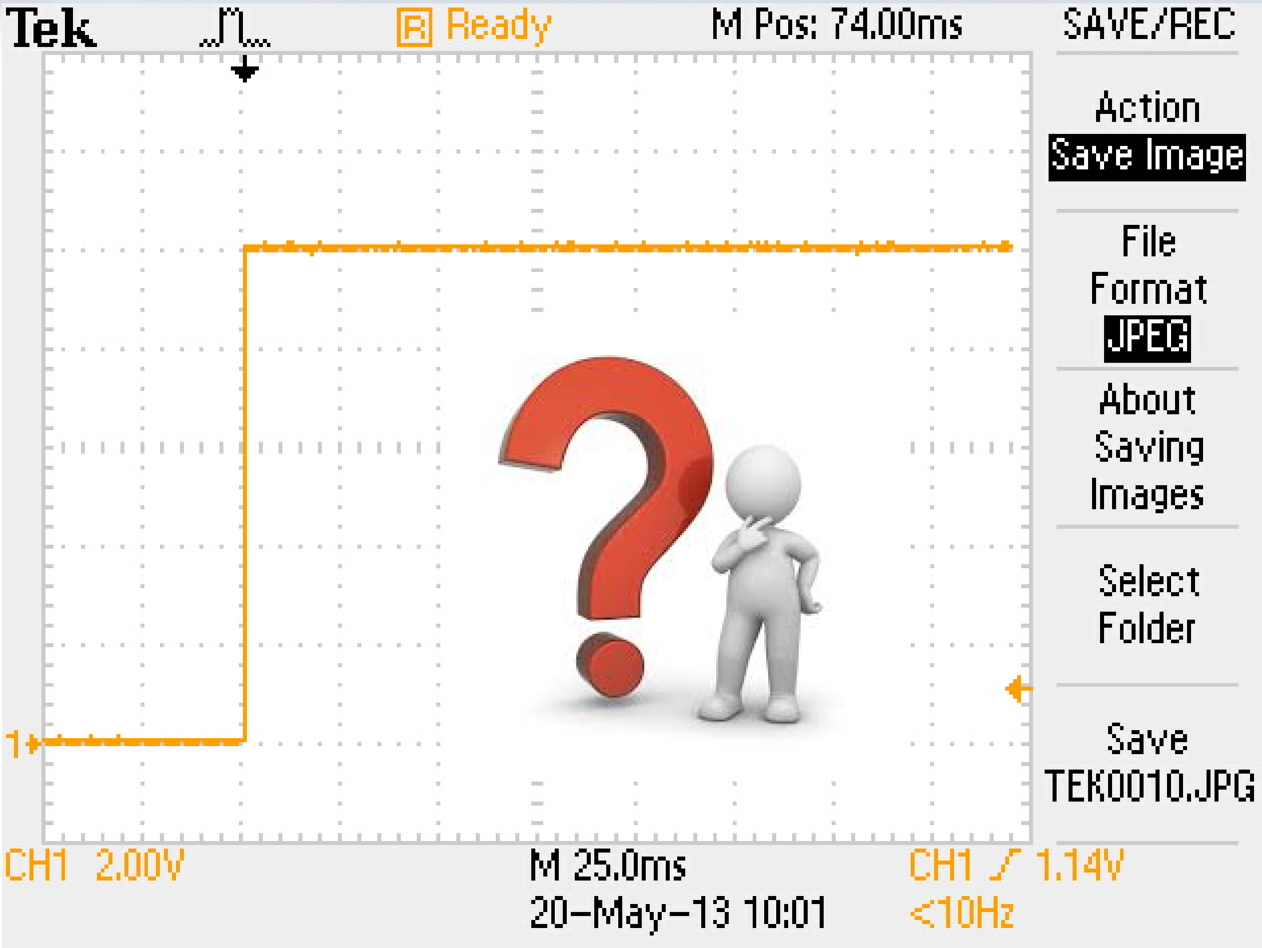
Vsrc = 10V, K2636B, Tr = → ?? (M:25ms)



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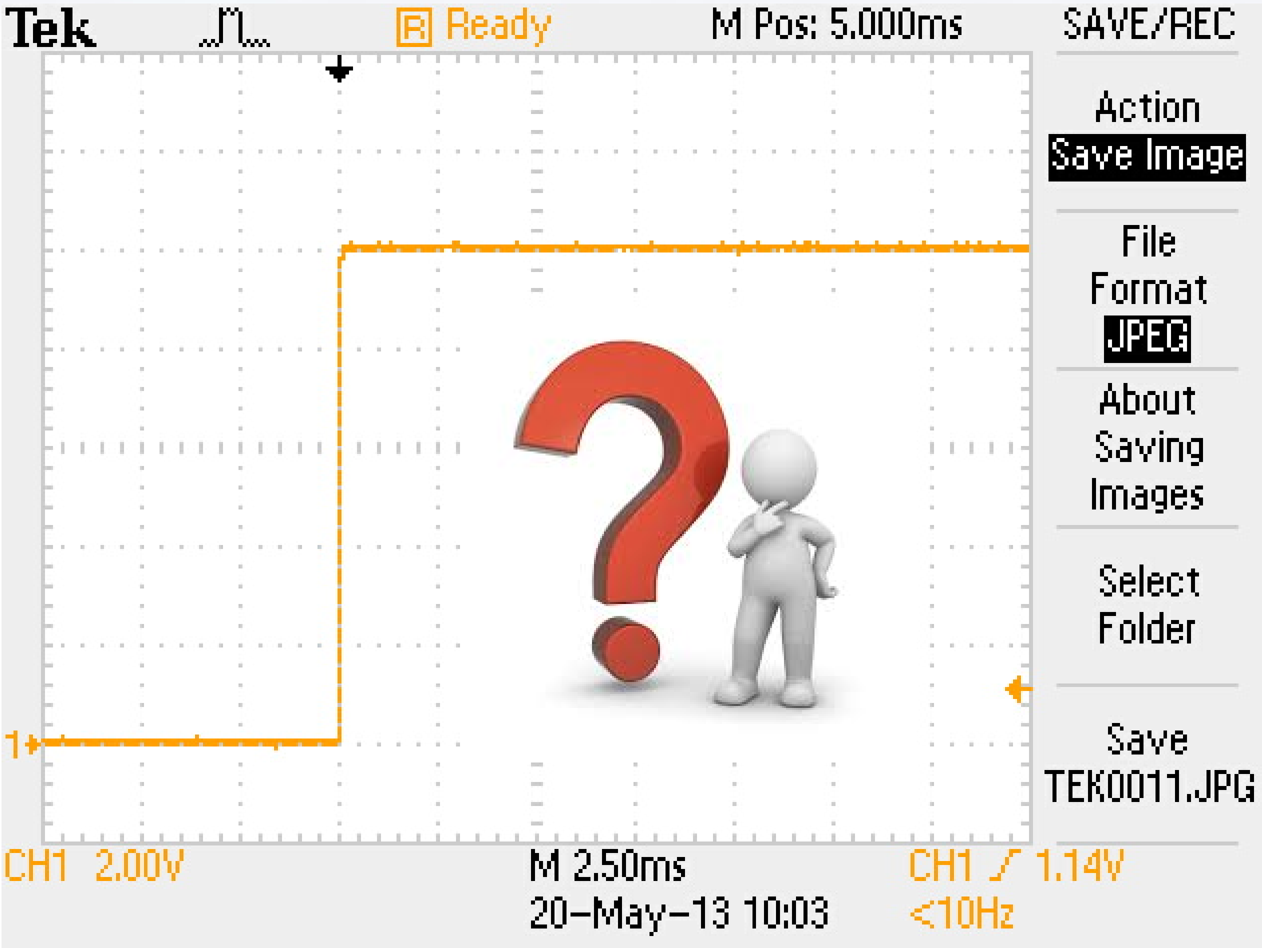

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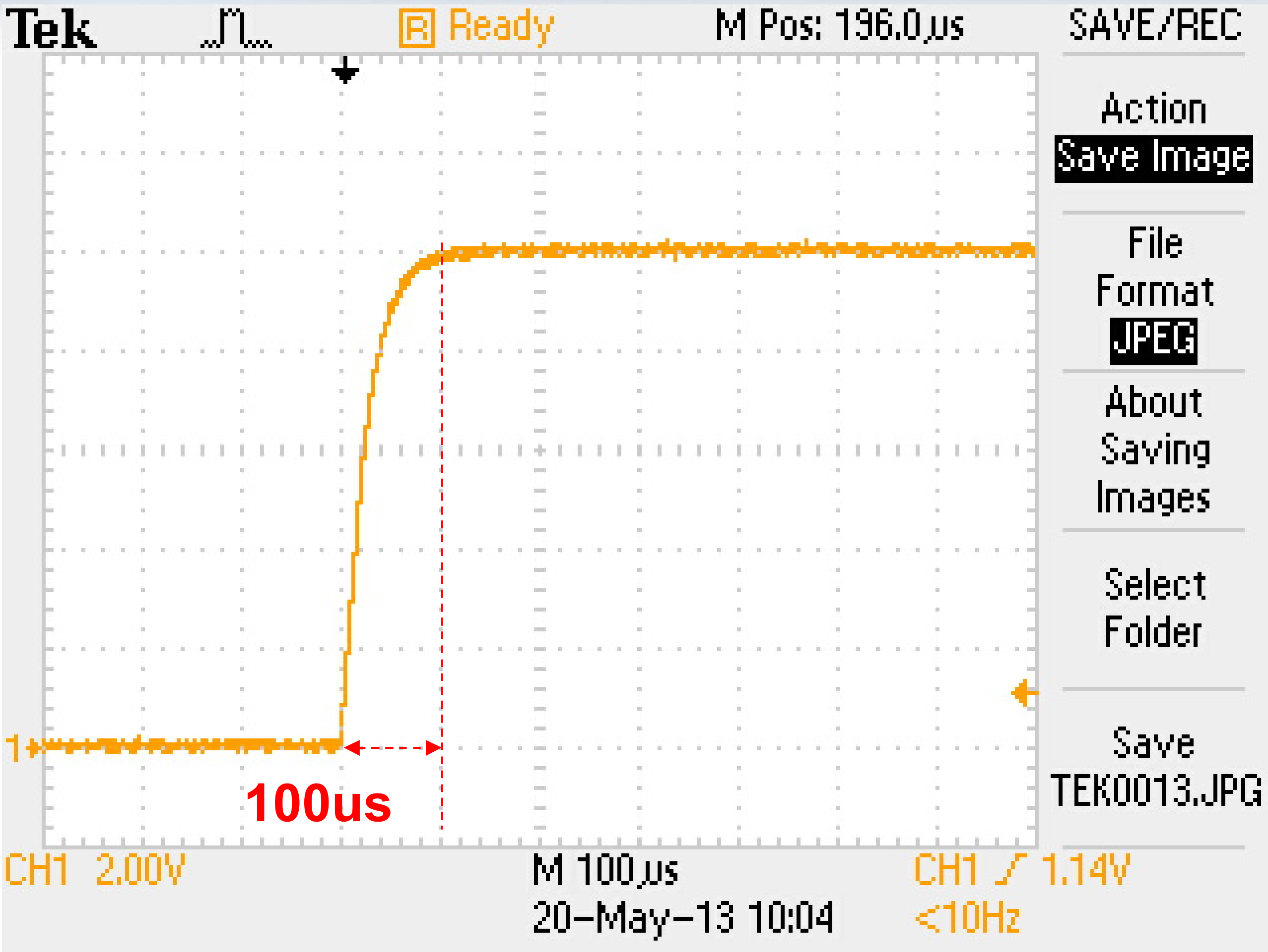
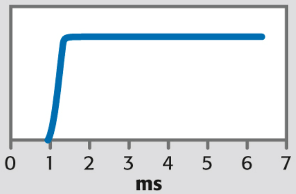
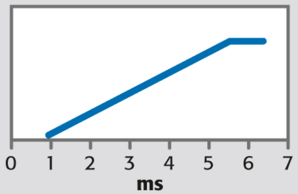
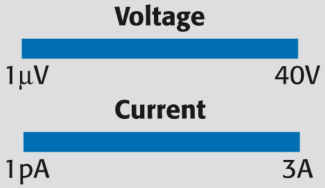
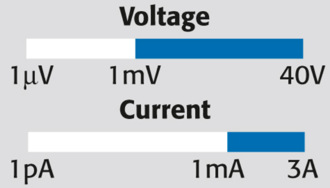
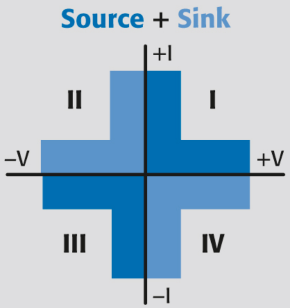
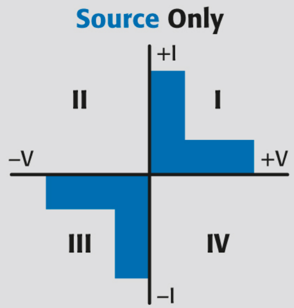
A GREATER MEASURE OF CONFIDENCE

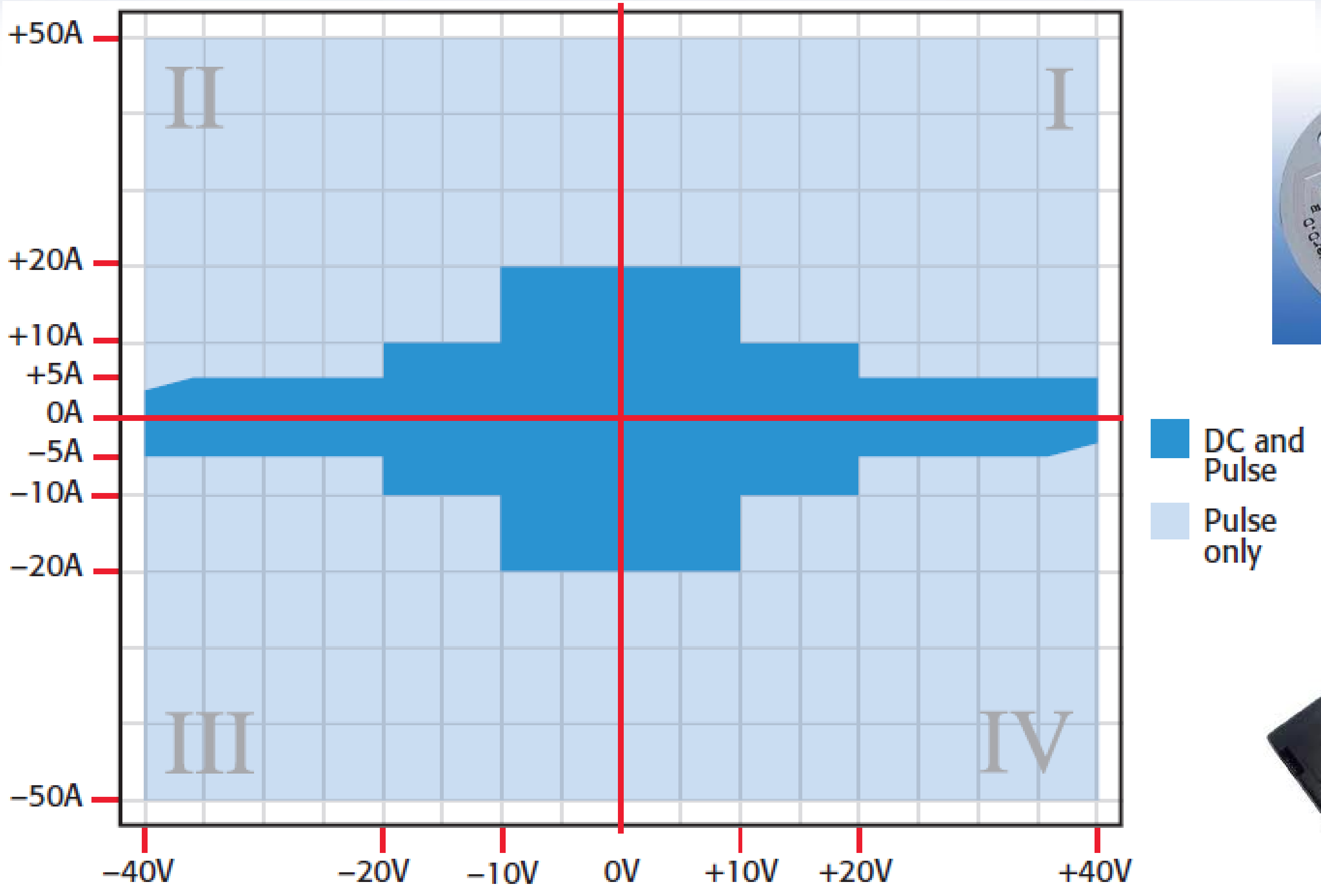
Vsrc = 10V, K2636B, Tr = → ?? (M:100us)



SMUs compared to Power Supplies - 4 Quadrant Operation

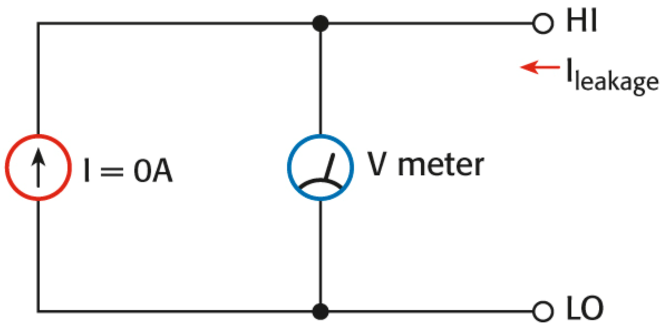
	2602A SourceMeter Instrument	Typical Power Supply
Speed		
Source/ Measure Precision	10μA measurement uncertainty = 5nA	10μA measurement uncertainty = 2500nA
Voltage and Current Resolution		
4 Quadrant Operation		

SMUs compared to Power Supplies - 4 Quadrant Operation (Ex. K2651A)



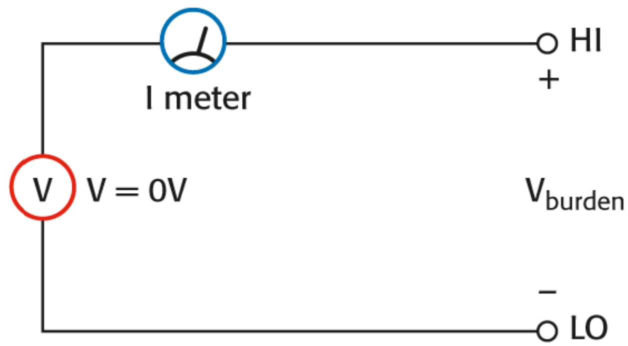
SMUs compared to DMMs

Voltmeter Configuration



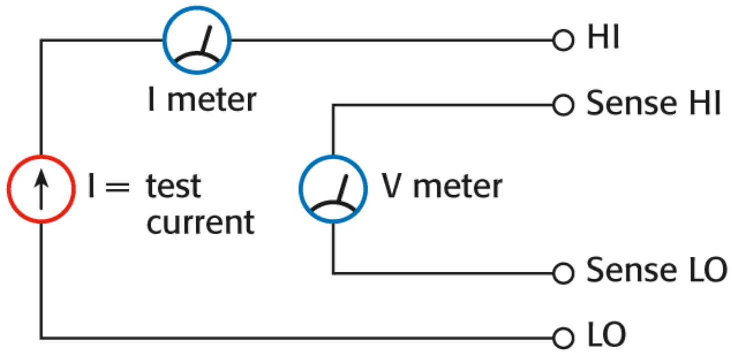
Source I = 0A, Measure V

Ammeter Configuration

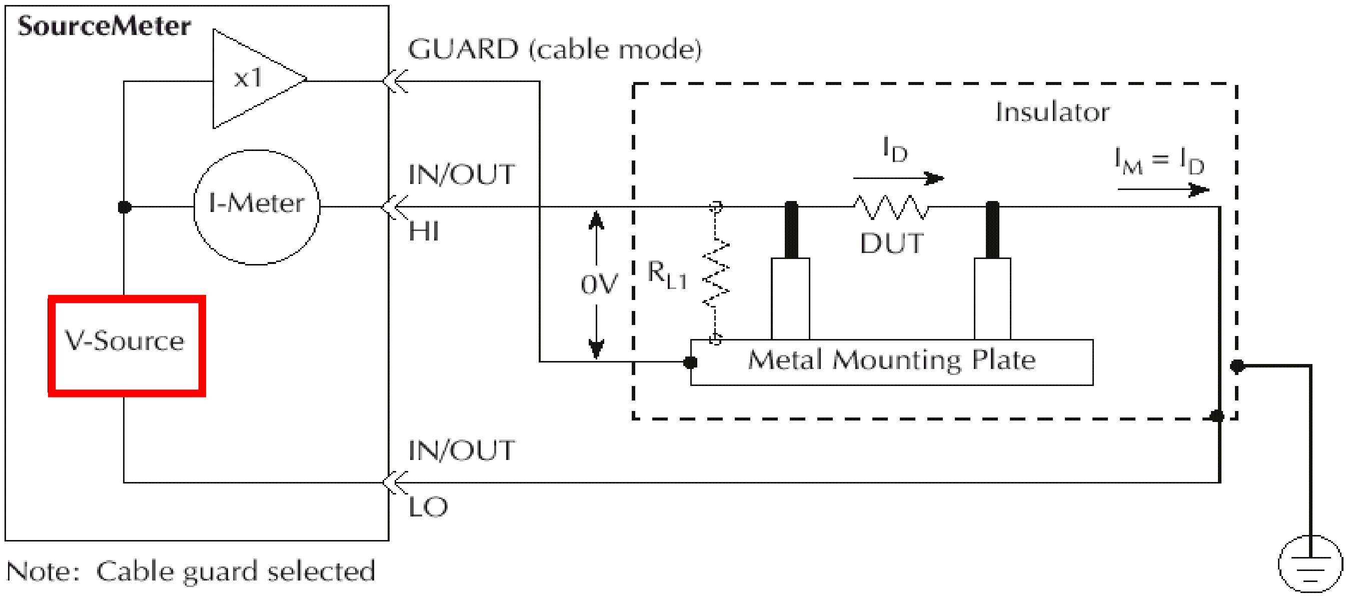


Source V = 0V, Measure I

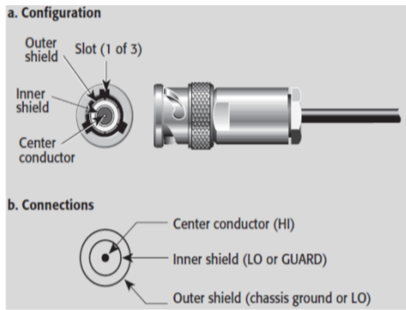
Ohmmeter Configuration



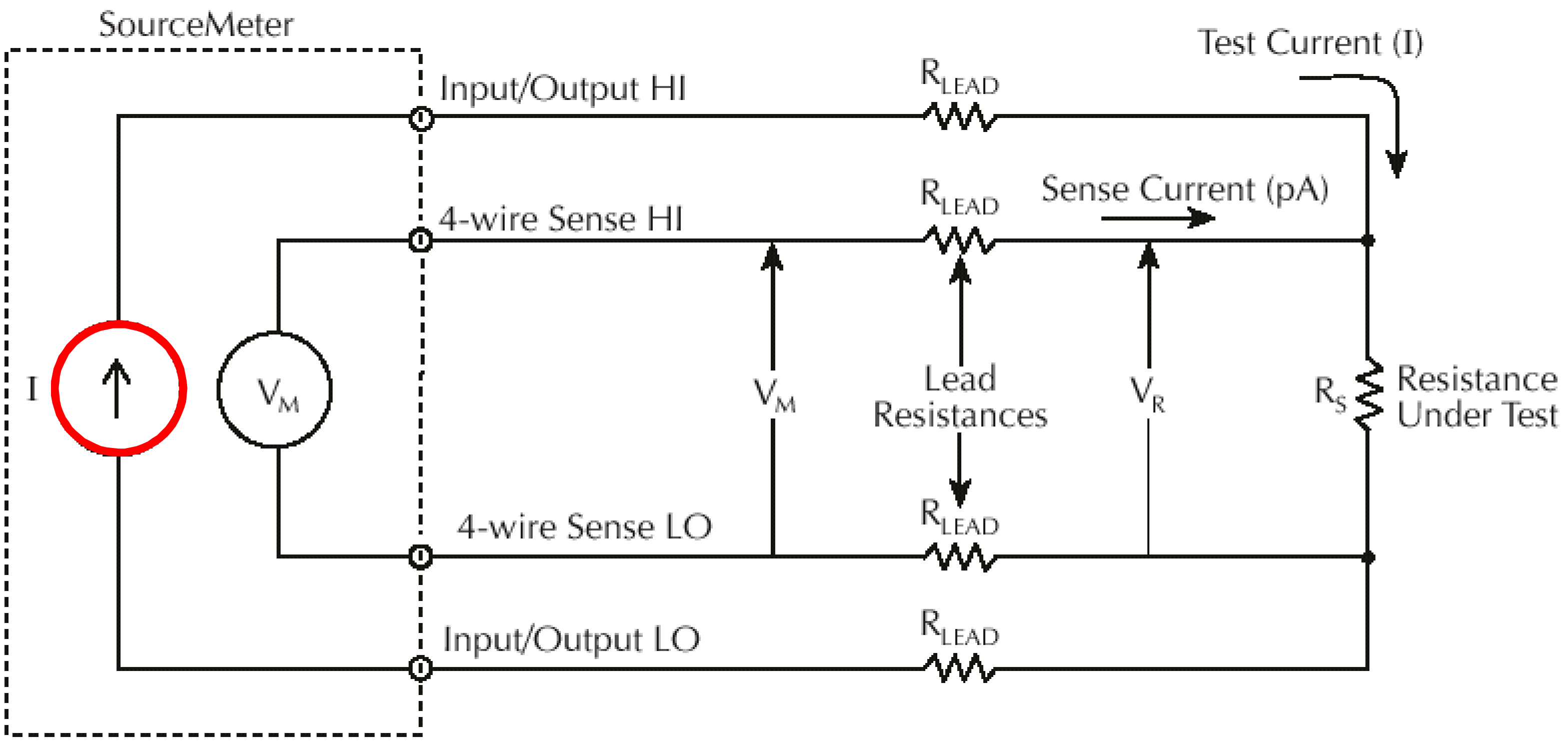
SMU Instrument Basics
- For High Resistance Meas. (Guard)



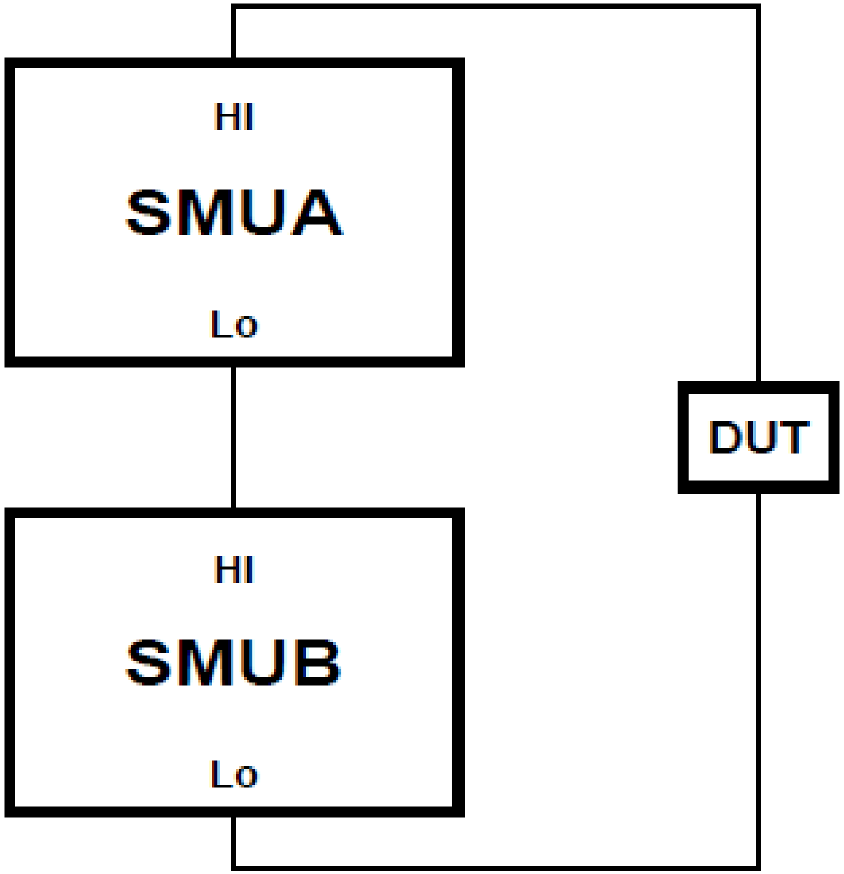
Note: Cable guard selected



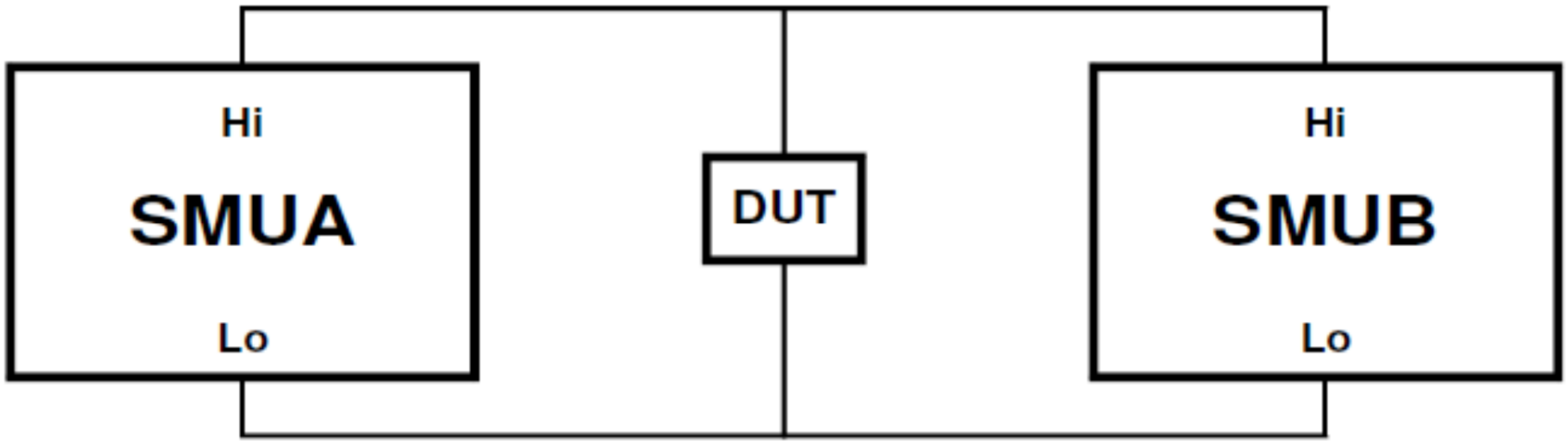
SMU Instrument Basics - For Low Resistance Meas. (4W)



SMU Instrument Basics
- Higher Voltage Applications



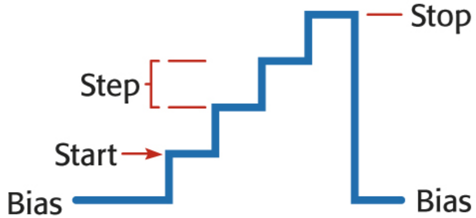
SMU Instrument Basics
- Higher Current Applications



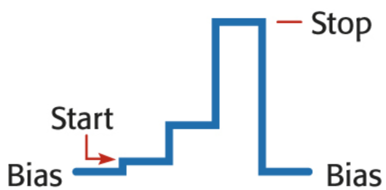
SMU Instrument Basics - Built-in Sweeps

DC

Fixed Level

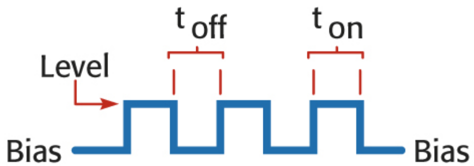


Linear Stair

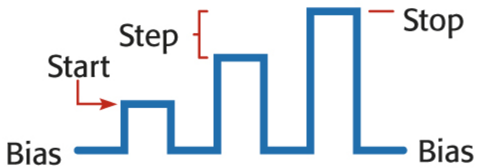


Logarithmic Stair

Pulse



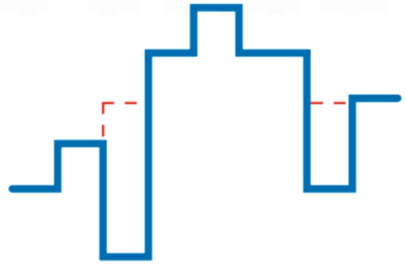
Pulse



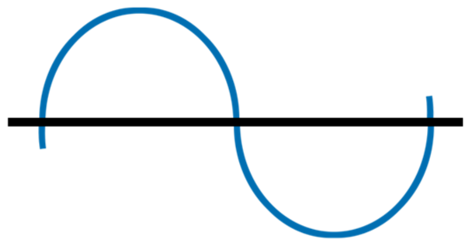
Linear Stair Pulse

Logarithmic Stair Pulse

Custom



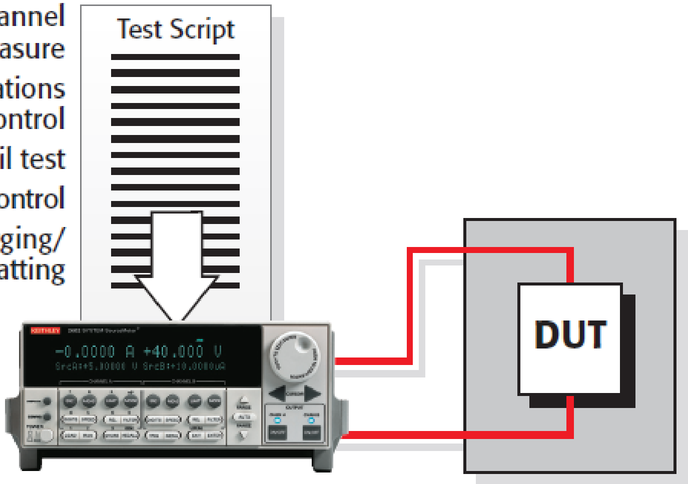
Arbitrary

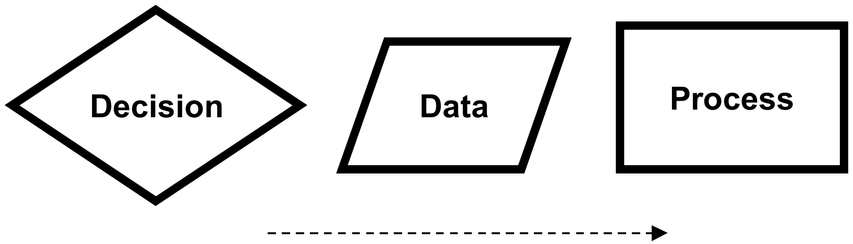


Sine Wave

Keithley TSP® Technology - Smart SourceMeter

- Multi-channel Source-Measure
- Advanced calculations and flow control
- Pass/Fail test
- Prober/Handler control
- Datalogging/ Formatting





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1. **LED Optoelectronic Testing Intro.**
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4. **Cabling Considerations**
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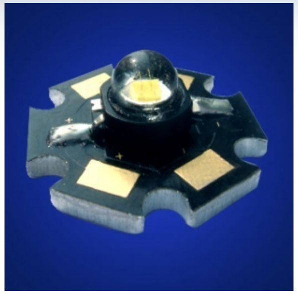
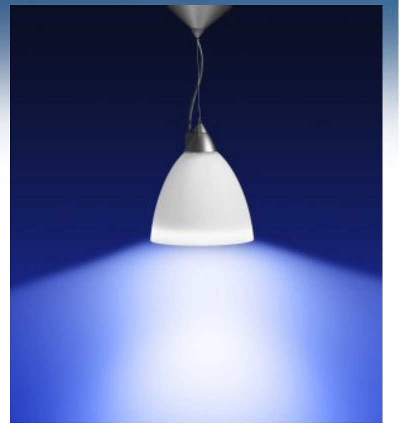
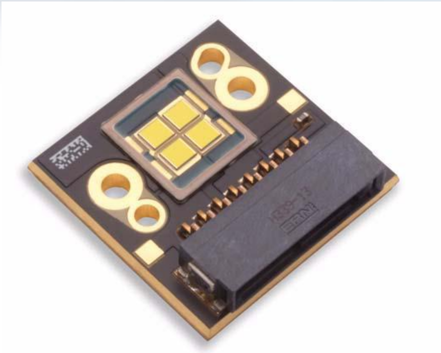
High Brightness LEDs





- **High Brightness LEDs are commonly defined as LEDs that operate at 1W of power or higher**
- **Often multiple High Brightness LEDs are put together to create luminaires for lighting applications**

High Power LED Modules



- **Demand for more light from a smaller physical package has lead to the development of High Power LED Modules**
- **High Power LED Modules contain large die LEDs and/or multiple LED die in a single package**
  - Multiple LEDs are wired in parallel or in series

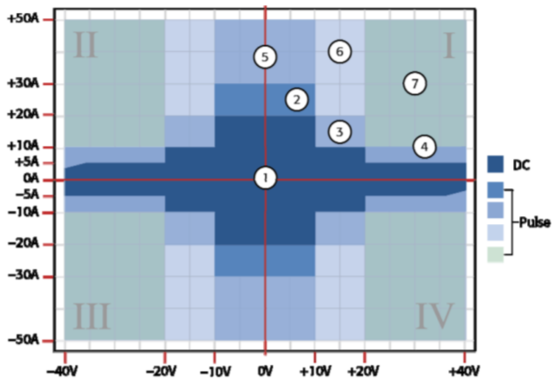
High Power LED Module Test Requirements

Testing High Power LED Modules requires test equipment with:

1. **More Power**

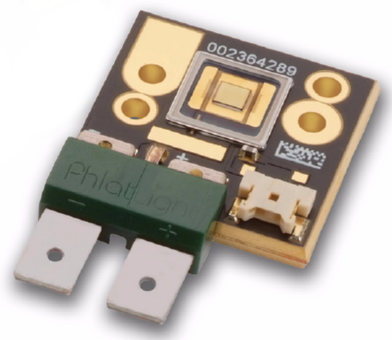
2. **Pulse Width Modulation**

3. **Precise Timing & Consistent Pulse Width**



1. More Power

- **DC power approaching 100 Watts**
  - Example: Luminus Devices CSM-360 Phlatlight
    - Operates at **6.3A DC** with a V_F of **14.15V** for nearly **90 Watts**

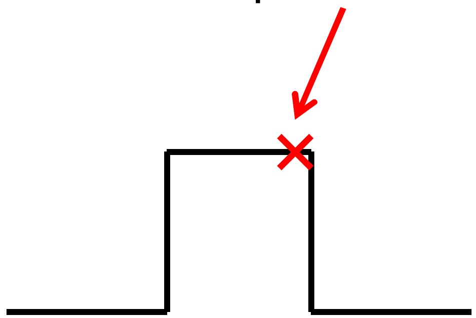


- **Pulsed power exceeding 100 Watts**

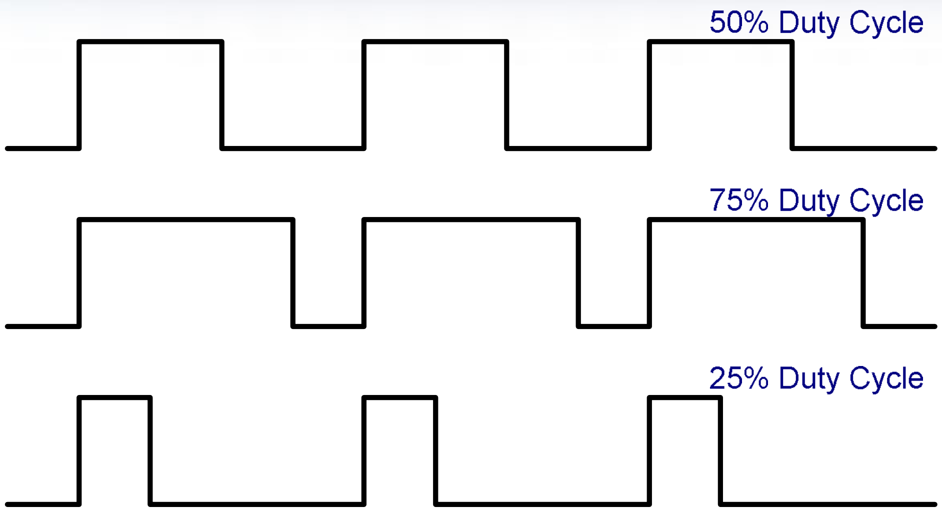
- **High power at duty cycles up to 50%**
  - Example: Luminus Devices CBT-90 Green Phlatlight
    - Operates at **22.5A**, 50% Duty cycle with a V_F of **4.9V** for **110 Watts** Pulsed

Pulse Testing

- **Heating can be minimized by pulse testing LEDs**
- **Pulse widths of 1ms or less can greatly reduce device heating**
  - Requires a current source that can be pulsed consistently
  - Requires precisely timed measurements
- **On wafer requires smaller pulse widths**

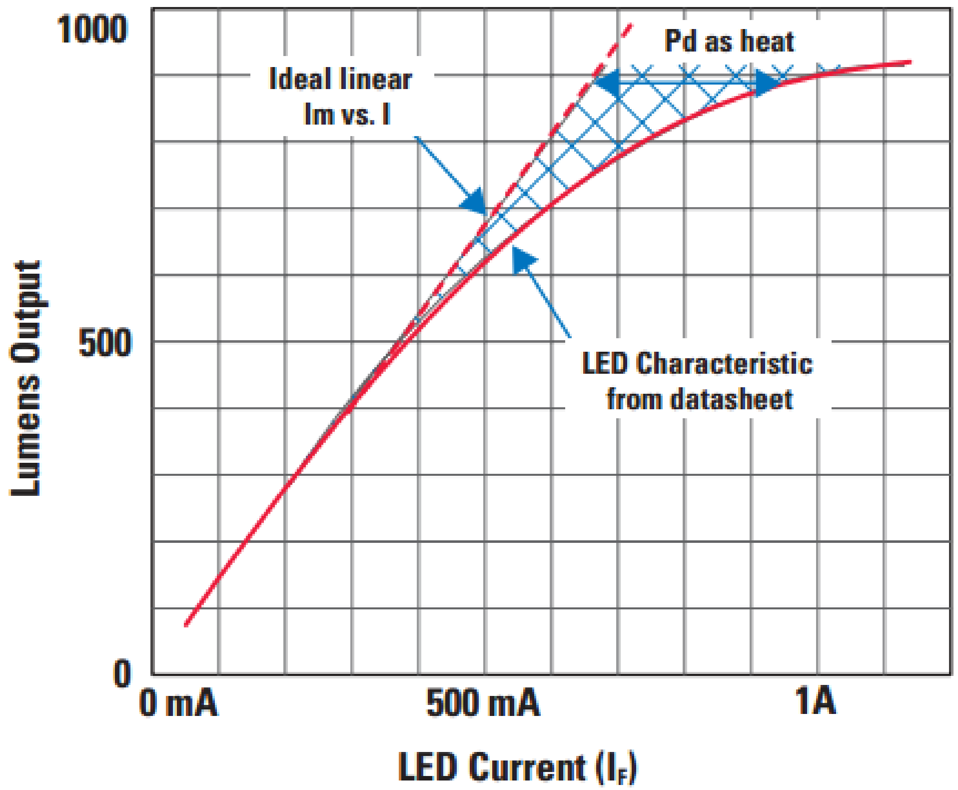


2. Pulse Width Modulation



- **Used as a method to control brightness**
  1. **Current to LED is pulsed while pulse level is kept constant**
  2. **Pulse width is modulated to increase/decrease the on time and therefore increase/decrease LED brightness**

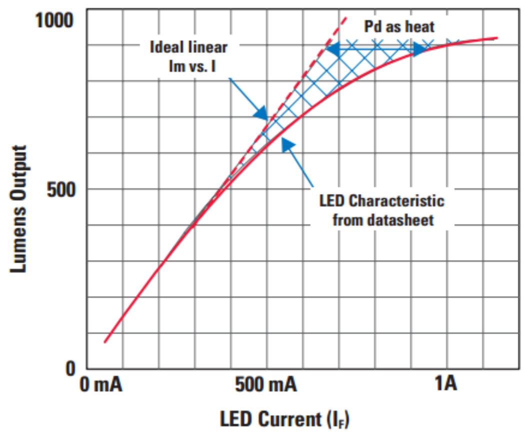
LED Output vs. LED Current - Current Drop by Self Heating



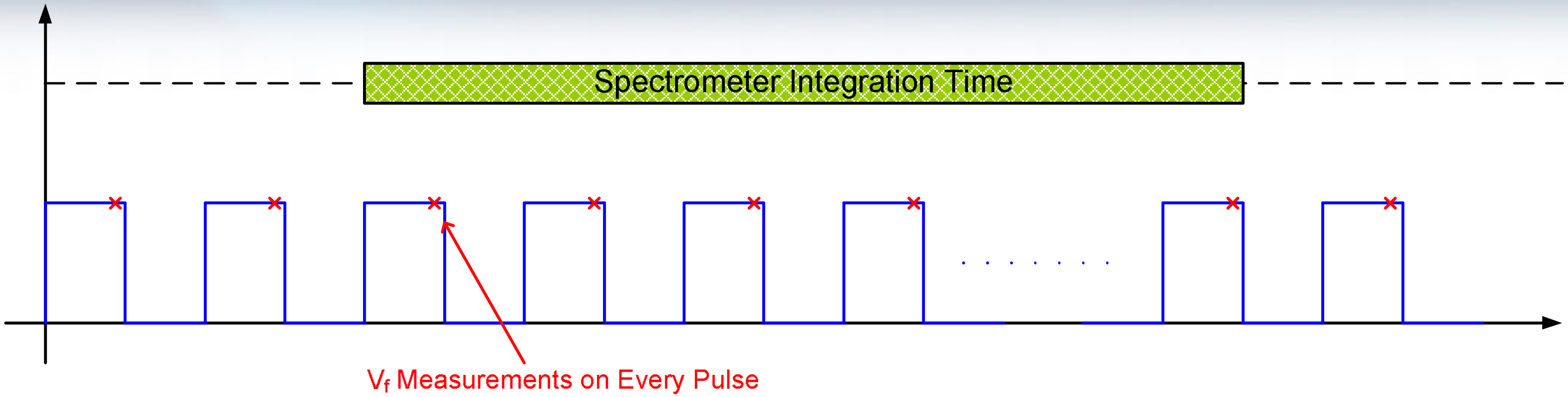
Refer to the LED driver spec of National Semiconductor

PWM Advantages

- **Consistent LED color as LED is dimmed**
- **Brightness control linearity**
- **Power Efficiency**
  - LED can be operated at its most efficient current level for all brightness levels (Maximum Lumens/Watt!)
  - LEDs often produce more Lumens/Watt when pulsed
  - Switching circuitry uses little power
- **Simple to implement and control with inexpensive digital circuitry**



Pulse Width Modulation
Test Equipment Requirements



- Pulse frequencies from up to 10KHz
- Duty Cycles as high as 50%
- Ability to measure V_F at every pulse
- Ability to trigger and respond to a spectrometer
- Precise timing and consistent pulse shape

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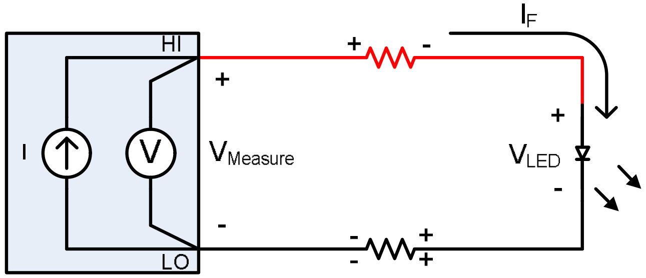
Cabling Considerations

1. **Two-Wire (2W) vs. Four-Wire (4W, Kelvin) Connections**
2. **The Effects of Excessive Lead Resistance**
3. **The Effects of Excessive Lead Inductance**

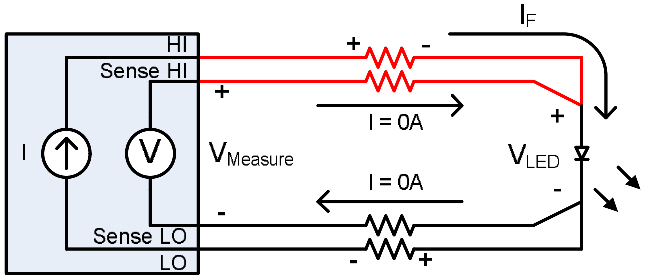
2-Wire vs. 4-Wire Connections

- **2-Wire Connections**
  - Same leads that are used to source the current are used to sense the voltage
  - Voltage drops across the test leads will cause the measured voltage to be greater than the voltage at the device
- **4-Wire (Kelvin) Connections**
  - A separate set of test leads is used to sense the voltage at the device
  - The volt meter is high impedance so nearly zero current flows through its leads thus there is no voltage drop
  - $V_{Measure} = V_{LED}$

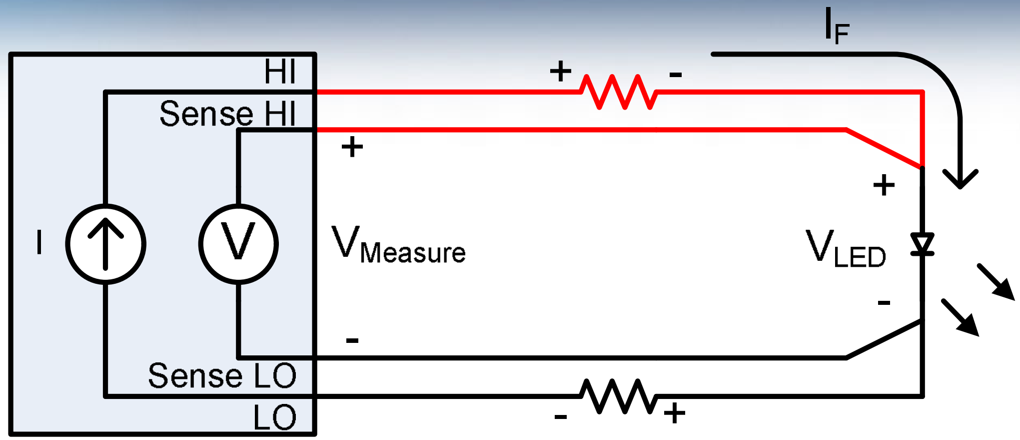
2-Wire Connections



4-Wire Connections

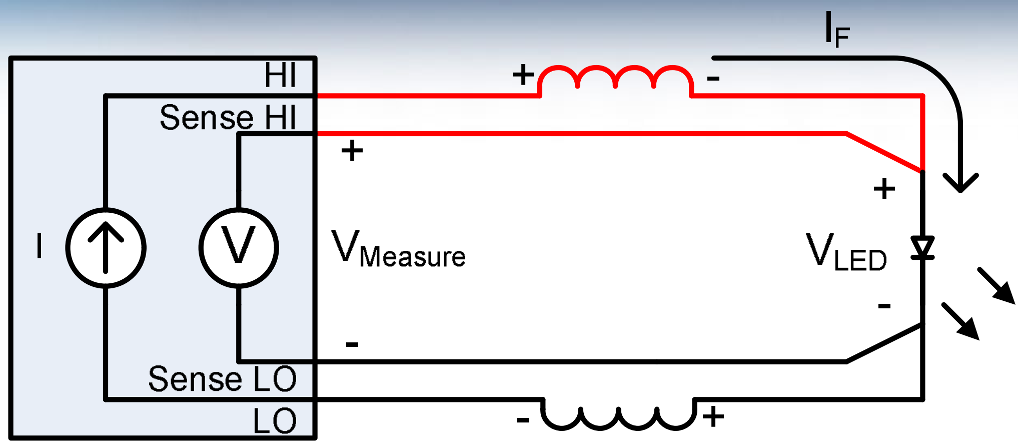


Effects of Excessive Lead Resistance



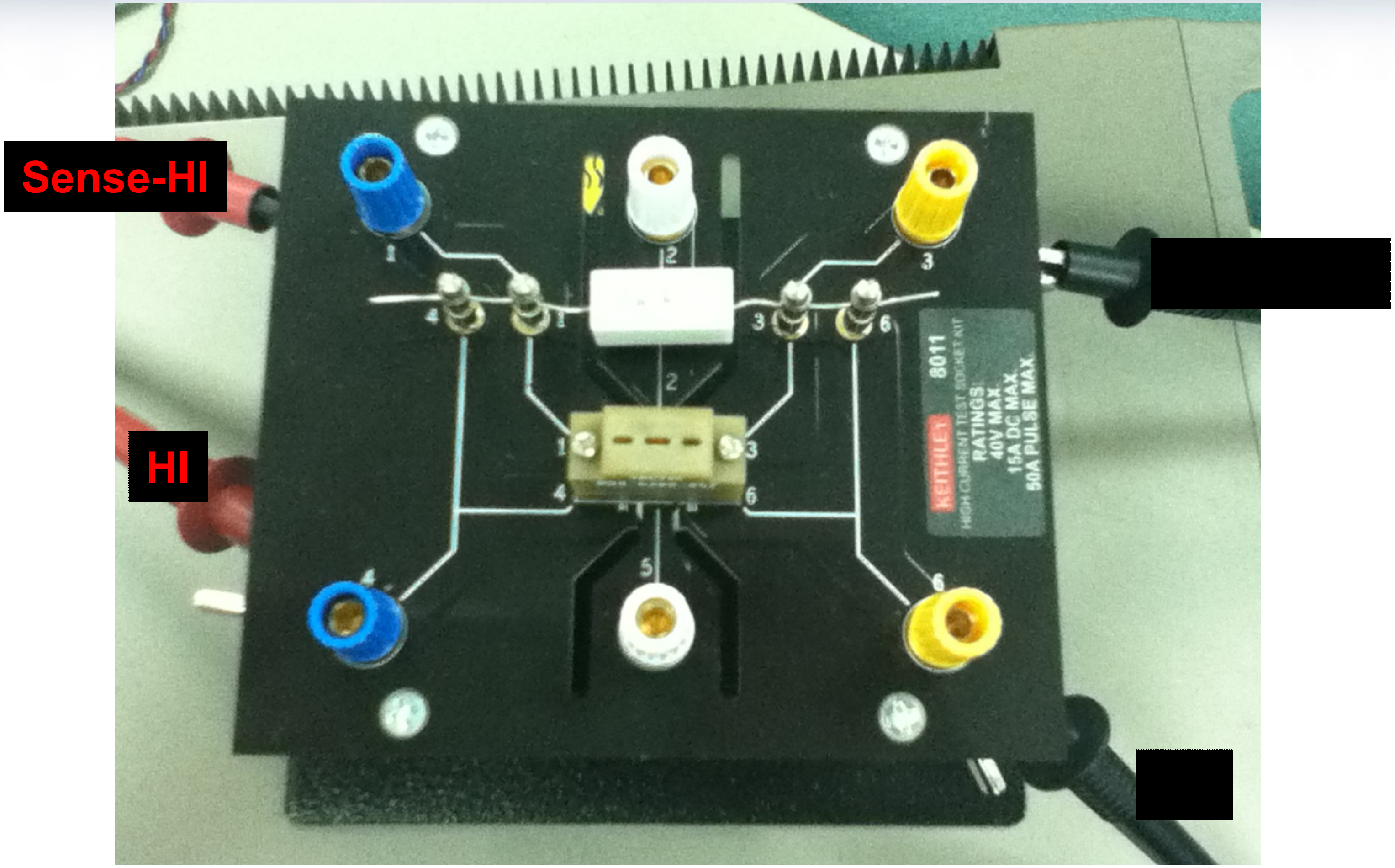
- **Excessive cable wastes a lot of power**
  - Voltage drop can be calculated: $V_{Drop} = I_F * R_{Cable}$
  - At 20A, only 200mΩ of lead resistance will cause a 4V drop. That's 80 Watts of power lost in the test leads! Fire hazard!
- **There is a limit to how much voltage drop an SMU can compensate for in 4-wire mode**
  - Exceeding this limit will cause measurements to be incorrect
- **Lead resistance slows the rise time of the pulse**

Effects of Excessive Lead Inductance



- **Cable inductance resists changes in current**
  - Causes voltage drops across the test leads during the rising and falling edges of the pulse
  - Voltage drop created by inductance is determined by **V = L * di/dt**
  - Cable inductance does not have an affect when the current is constant
  - Example: 20A pulse with a 20μs rise time and 2μH cable inductance. V = 2μH * 20A/20μs = 2 Volts
- **An SMU will try to compensate for cable inductance but if excessive, the rise and fall times of the pulse will slow down**
- **SMUs have a limit to how much cable inductance they can handle**
  - Ensure cable inductance is kept below the maximum specification for your SMU

Isrc=1A @ Resistor = 0.1 ohm → Vmeas = ?
DUT Setup on Test Fixture (Module 8001)



Isrc=1A @ Resistor = 0.1 ohm → Vmeas = ?
Theory: V = I*R = 1A * 0.1 ohm = 0.1V

2-wire method

→ Rm = **0.21** ohm

4-wire method

→ Rm = 0.099 ohm ≈ **0.1** ohm

Tips for Optimal Cabling

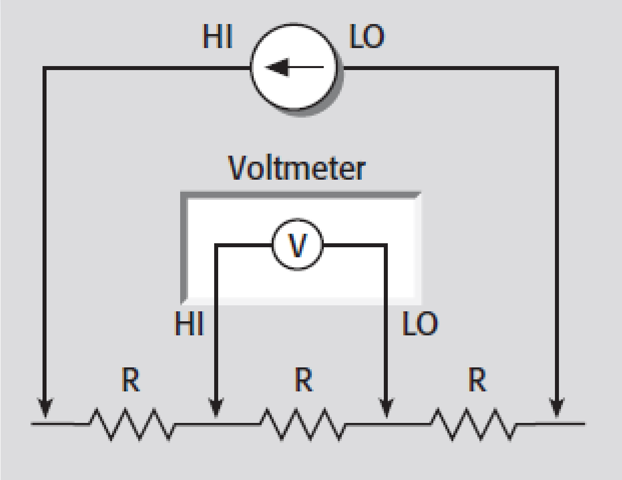
- **Minimizing Resistance**
  - Always use wire of the appropriate gauge for required level of current
    - Example: 20A DC requires 12 AWG or lower
  - Minimize contact resistance
    - Ensure contacts are clean, connections are secure, good solder joints
  - Minimize the number of connection adapters between the instrument and the device
- **Minimizing Inductance**
  - Minimize loop area by twisting test leads together to form a twisted pair
  - Use coaxial cable

- **The Keithley Model 2651A High Power SourceMeter instrument includes a low resistance, low inductance coaxial cable**
  - Cable is rated **3mΩ** and **85nH** per meter

Agenda

1. LED Optoelectronic Testing Intro.
2. Keithley SMU Technology Intro.
3. High Power LED Module Testing Requirements
4. Cabling Considerations
5. Keithley Solutions for LED Applications

LED Application
- 1. Four-Point Probe Method for Resistivity



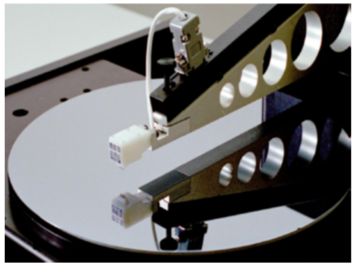
$$\rho = \frac{\pi}{\ln 2} \times \frac{V}{I} \times t \times k$$

where: V = the measured voltage (volts)

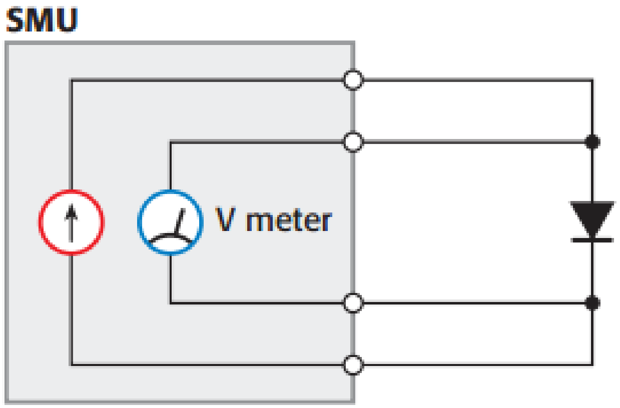
I = the source current (amps)

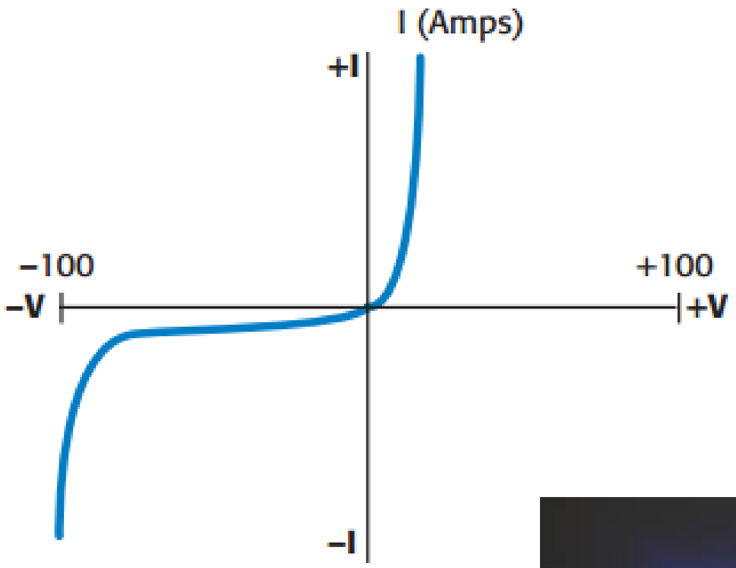
t = the wafer thickness (cm)

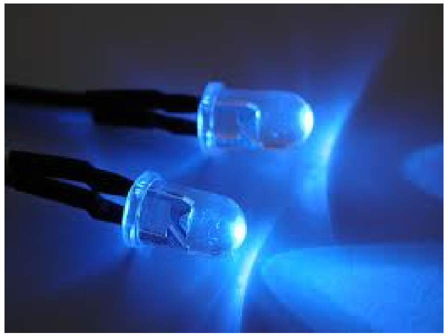
k = a correction factor based on the ratio of the probe to wafer diameter and on the ratio of wafer thickness to probe separation



LED Application
- 2. Sweep Current Measure Voltage

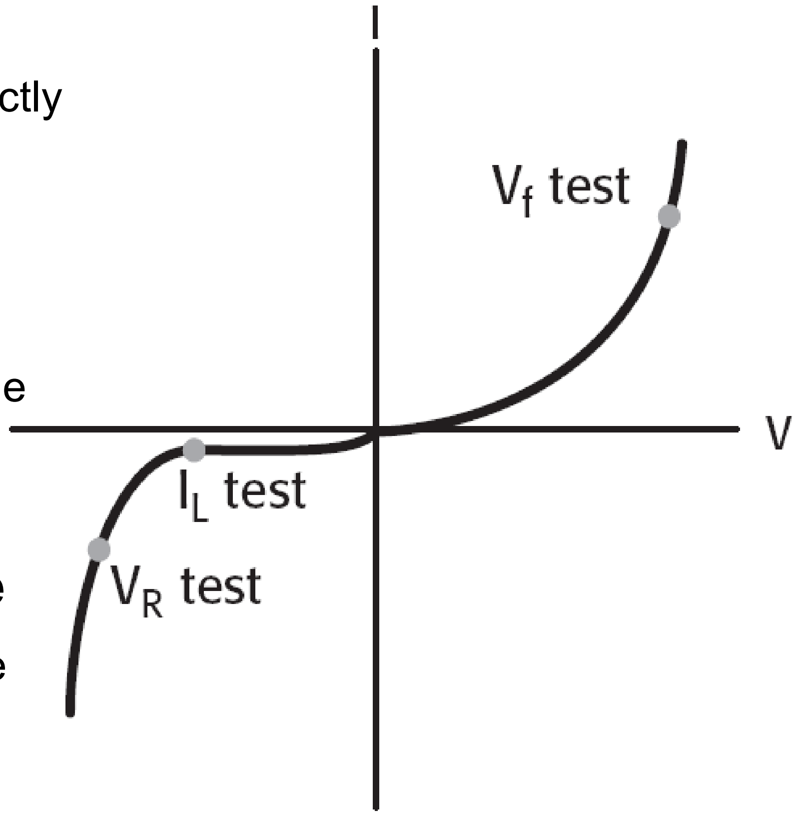




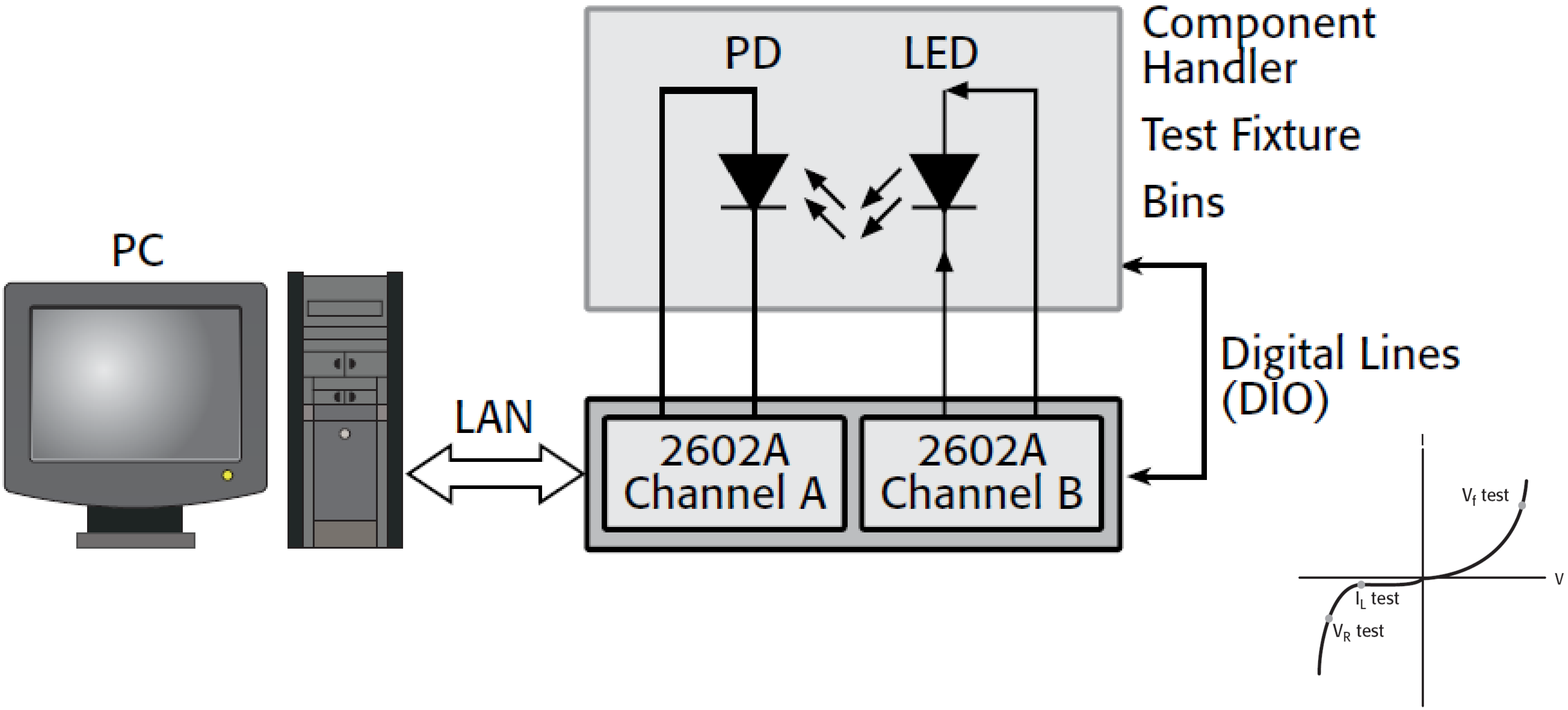


LED Application
- 3. Common Electrical Measurements for LEDs

- **V_f – Forward Voltage**
  - **Chromaticity (color)** of the LED is directly related to V_f
  - Ex. If = 700mA, Vm = 3.7V
- **I_L – Reverse Leakage Current**
  - to a specified minimum limit to determine pass or fail
  - Ex. I_L = -5 µA, if Vm >= 20V → Pass
- **V_R – Reverse Breakdown Voltage**
  - a specified maximum to determine if the LED passes or fails.
  - Ex. V_R = -10V, if Im > -10mA → Pass



LED Application
- 4. Common Electrical Measurements for LEDs



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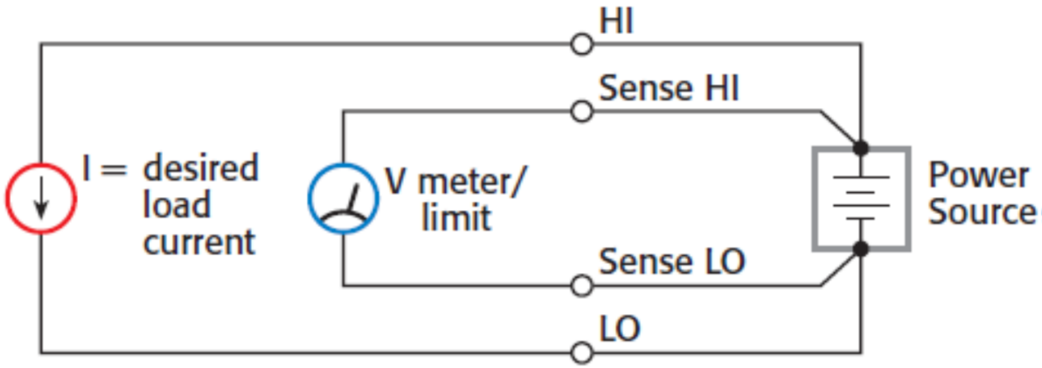
LED Application
- 5. Sink Current (Electrical Load)

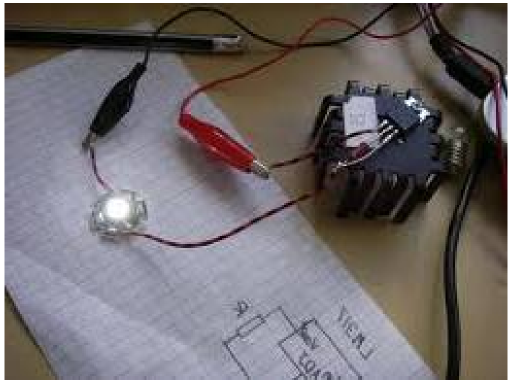
Power Load Configuration



Sink I = Desired load current, Measure V, Remote Sense ON

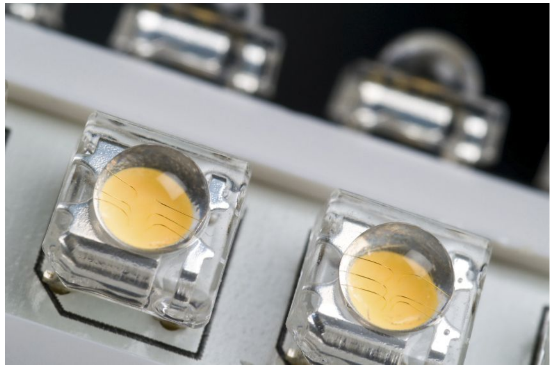
Note:

SMU can perform e-load which means you can verify the characteristics of LED driver.

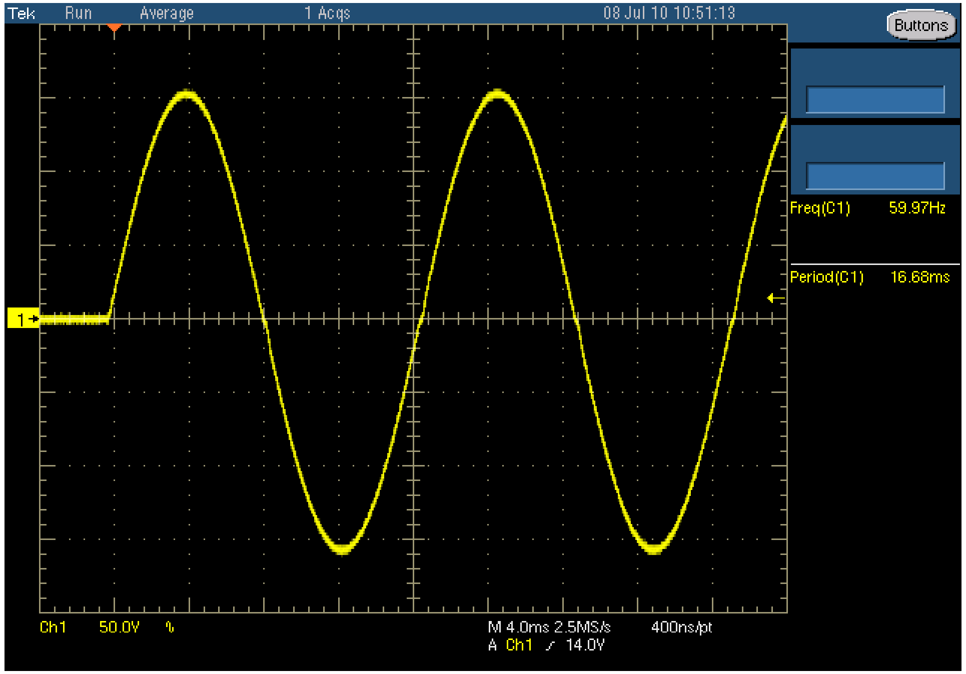


LED Application - 6. AC LED Challenges

- AC LEDs run off of an AC voltage rather than a DC current
- Thorough testing requires an AC voltage source in combination with synchronized current and voltage measurements
- Can be performed with high speed SMUs

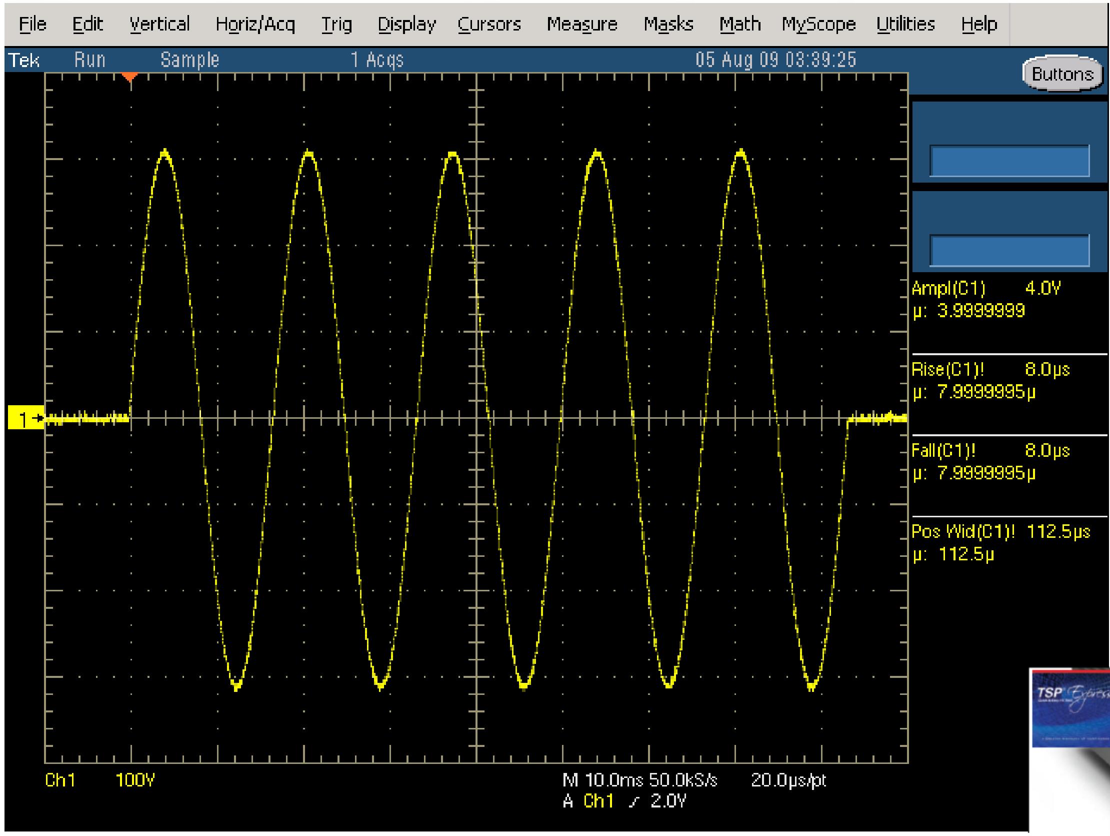


LED Application
- Output Signal Verification for AC110V$_{rms}$ Driving



60 Hz sine wave generated using a Model 2612A

LED Application
- Output Signal Verification for AC220V$_{rms}$ Driving (Cont.)



60 Hz sine wave generated using a Model 2612A

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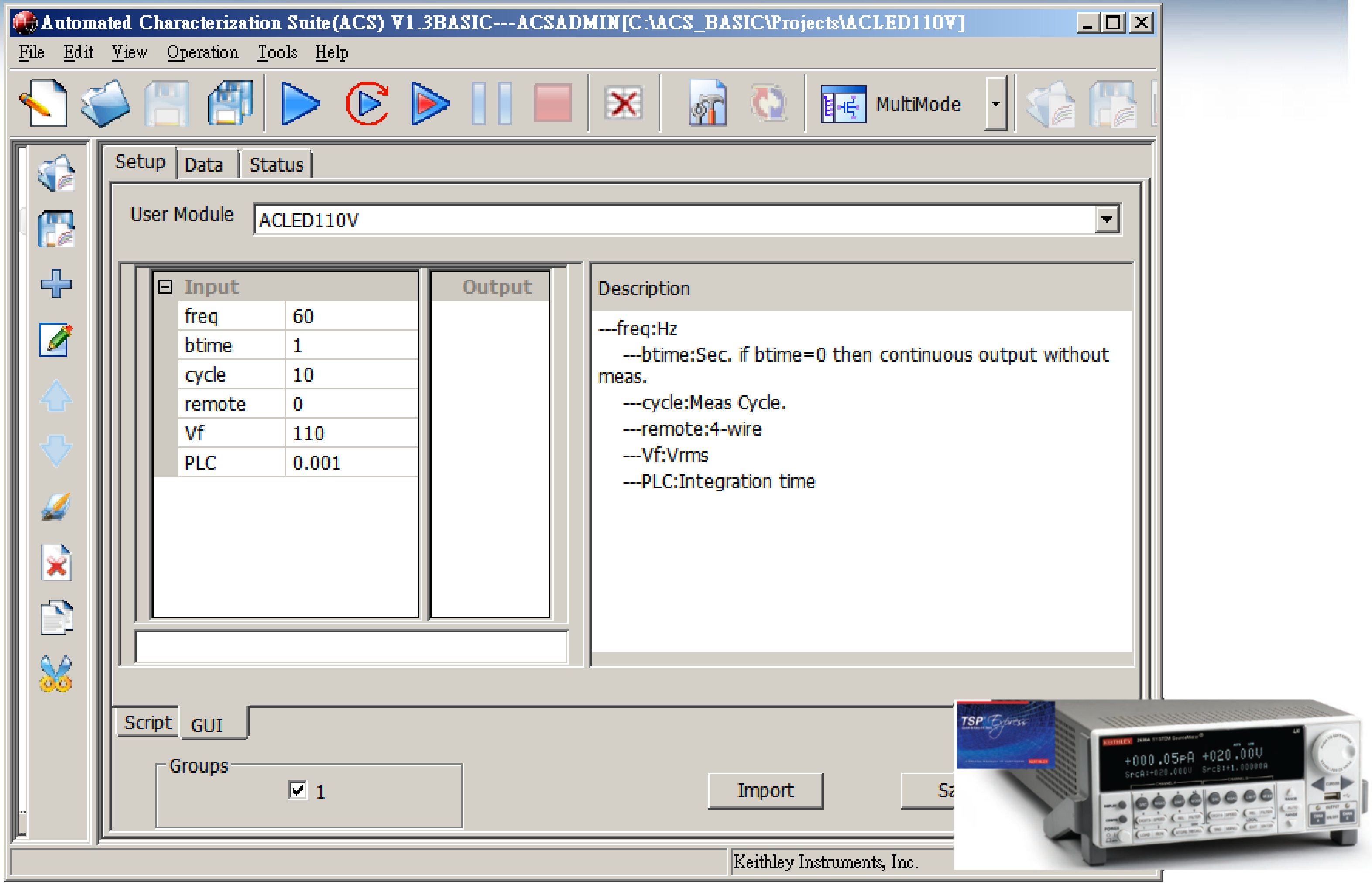
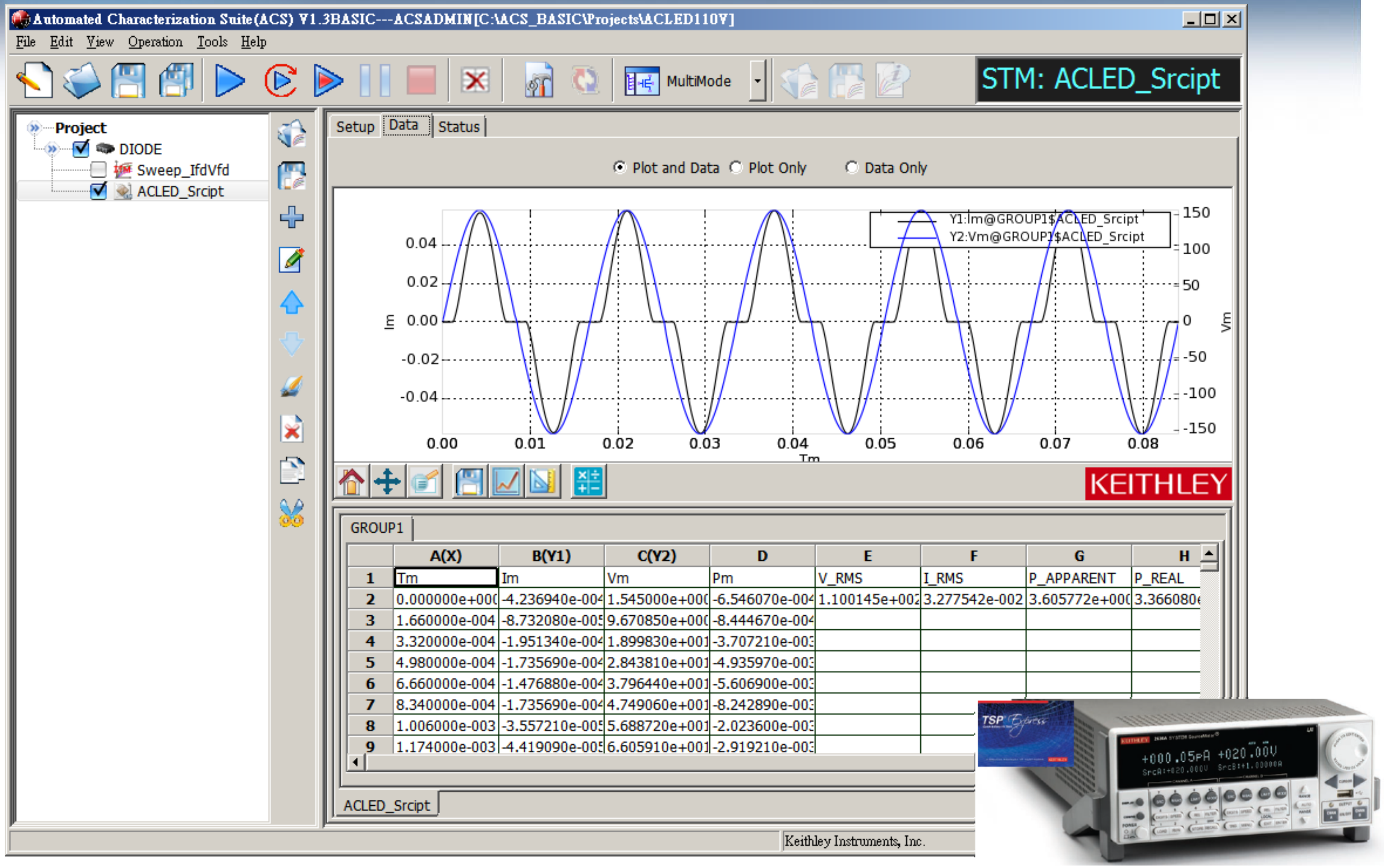
LED Application
- ACS BASIC GUI for ACLED Measurement (Cont.)



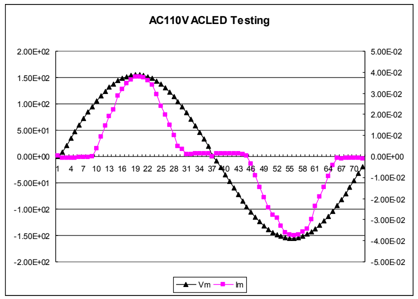
LED Application
- ACLED IV Measurement with ACS BASIC (Cont.)



LED Application
Electrical Parameters Calculation (Cont.)

- Meas RMS Voltage (Vm.rms)
- Meas RMS Current (Im.rms)
- Peak Forward Current (Ipf)
- Peak Reverse Current (Ipr)
- Real Power (P) = Sum of Pm / pts
- Apparent Power (S) = Vm.rms X Im.rms
- Power Factor (PF) = P / S

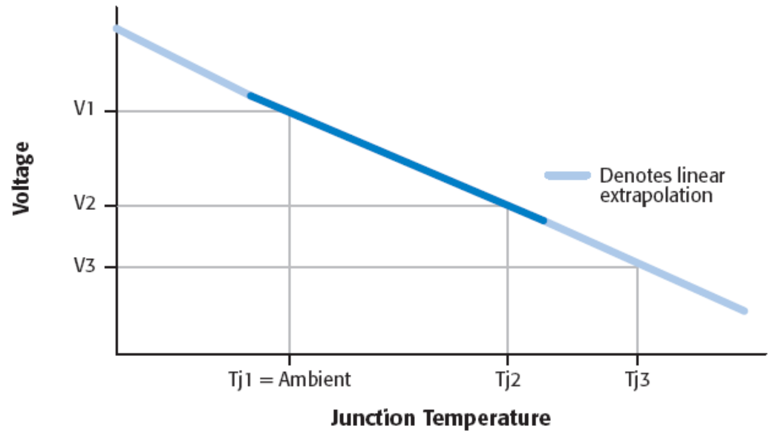
Parameter	Value
Vs_RMS	110.76
Vm_RMS	110.61
Im_RMS	0.02
Ipf	0.04
Ipr	-0.04
S (Apparent P)	2.22
P (Real P)	1.94E+00
PF	87.53%



Note: Refer to ACLED Measurement Draft, ITRI

LED Application
- 7. T_j Measurement vs. Device Self Heating

- **An LED's junction heats as current is sourced through it**
- **An LED's forward voltage drops as its junction heats**
- **Problematic at all levels but most problematic on wafer.**



Temp ↑ V_f ↓

LED Application - T_j Measurement

- **The junction temperature (T_j) of a diode can be measured by measuring V_f and calculating T_j**

$$T_j = m * V_f + T_0$$

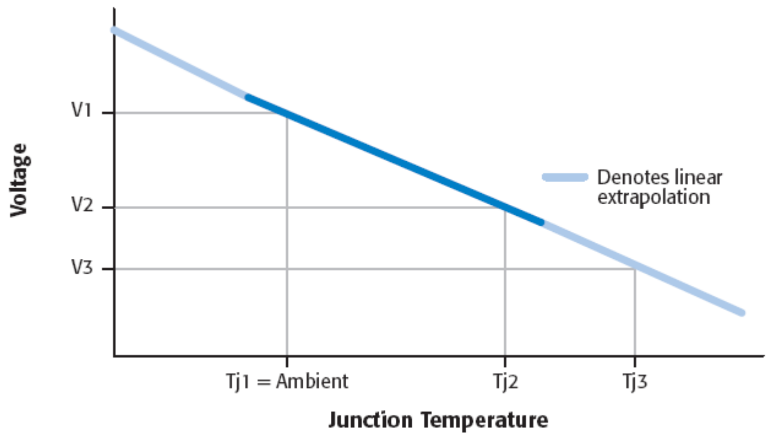
T_j = Junction Temperature in ˚C

***m = slope in ˚C/Volt**

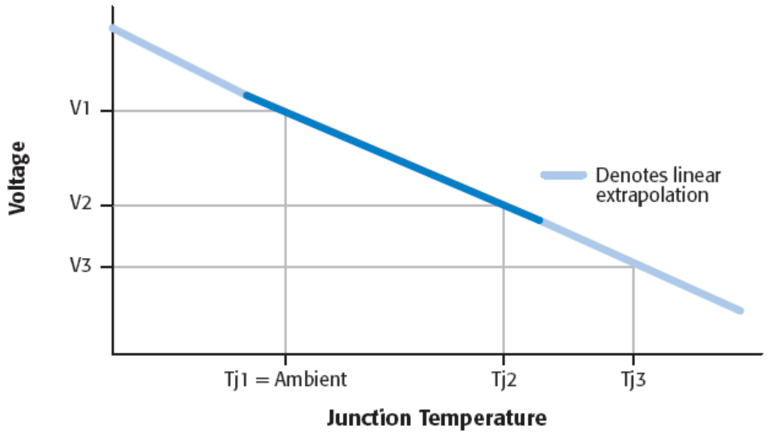
Vf = forward voltage drop

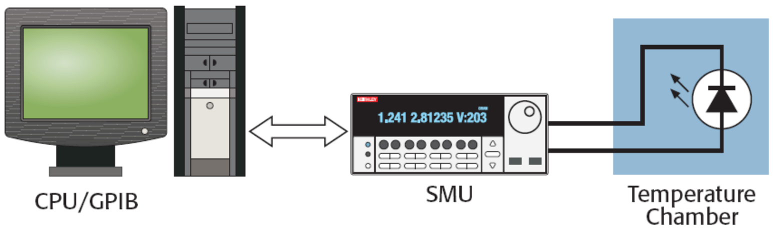
***T_0 = intercept in ˚C**

* Device specific parameters



T_j Measurement - Finding m and T_0

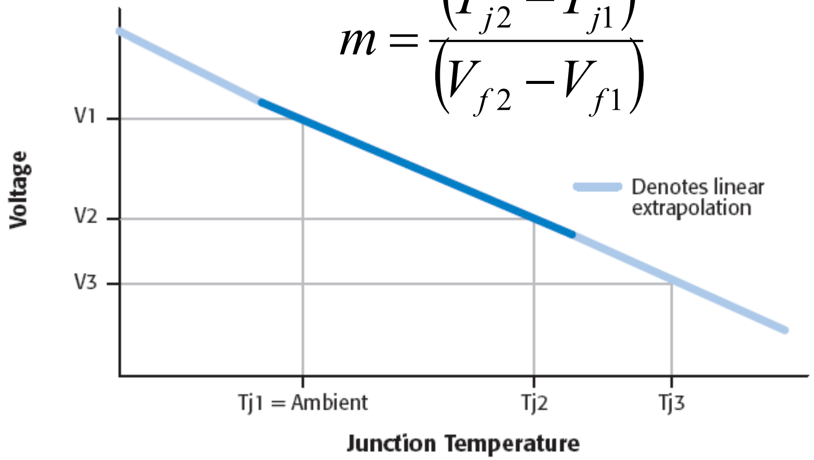




- To find m and T_0 we must first collect some known points on the Tj vs Vf curve
  - T_{j1}, V_{f1} and T_{j2}, V_{f2}
- Equipment needed
  - LED device under test
  - Precision SourceMeter instrument
  - Temperature chamber
  - Computer for control

T_j Measurement - Calculating Slope m and T_0

$$m = \frac{(T_{j2} - T_{j1})}{(V_{f2} - V_{f1})}$$



- **T_0 can be calculated by extrapolating the curve to the junction temperature axis.**

Equation 1

$$T_j = m * V_f + T_0$$

Point-slope form of equation 1

$$T_{j2} - T_{j1} = m(V_{f2} - V_{f1})$$

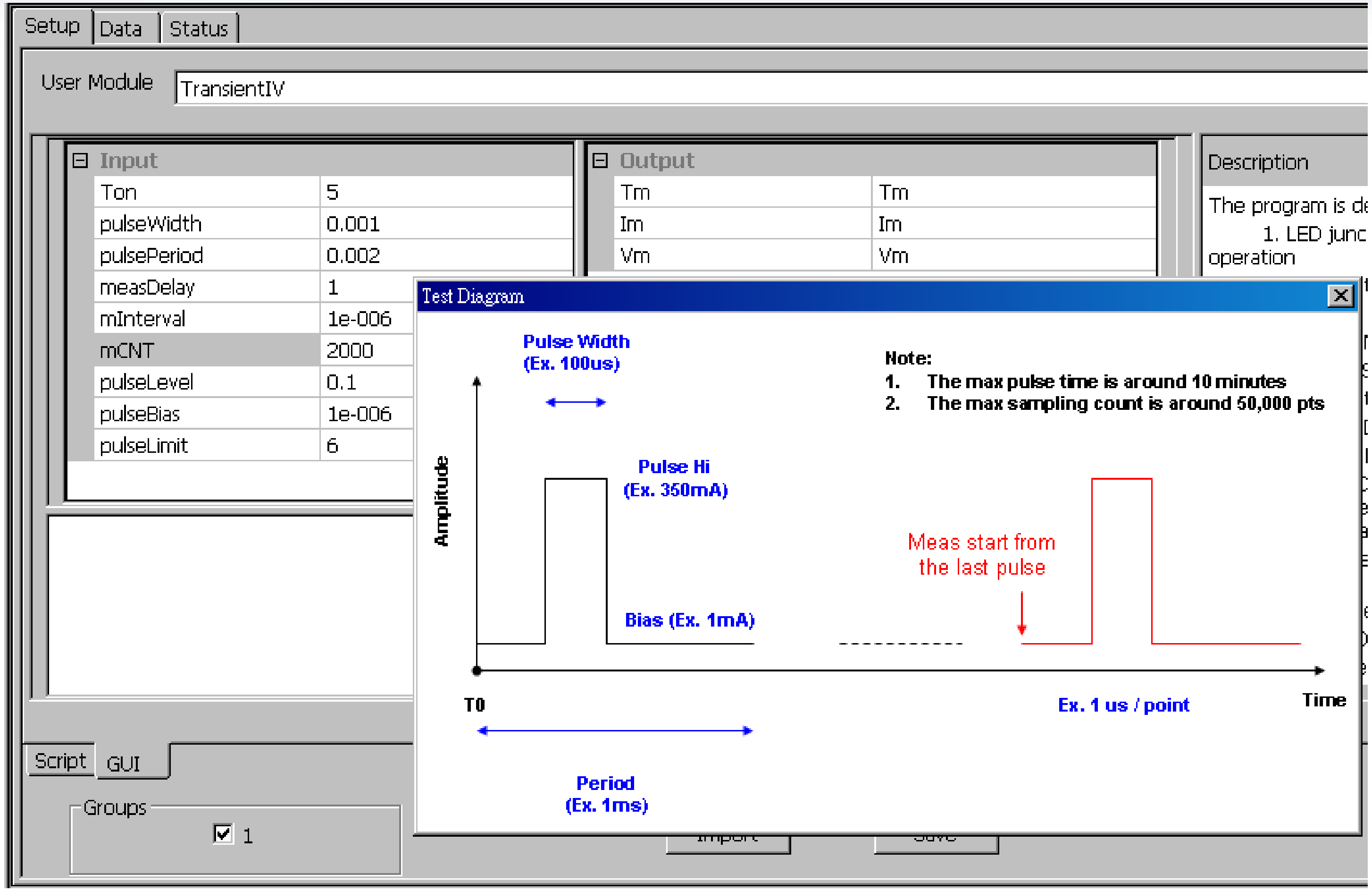
By setting V_{f2} to 0, equation 2 becomes

$$T_{j2} = T_{j1} - mV_{f1}$$

T_{j2} in this case is equal to the intercept, or T_0

$$T_0 = T_{j2} = T_{j1} - mV_{f1}$$

T_j Measurement with Pulse Operation → Setting for Transient Pulse IV Measurement



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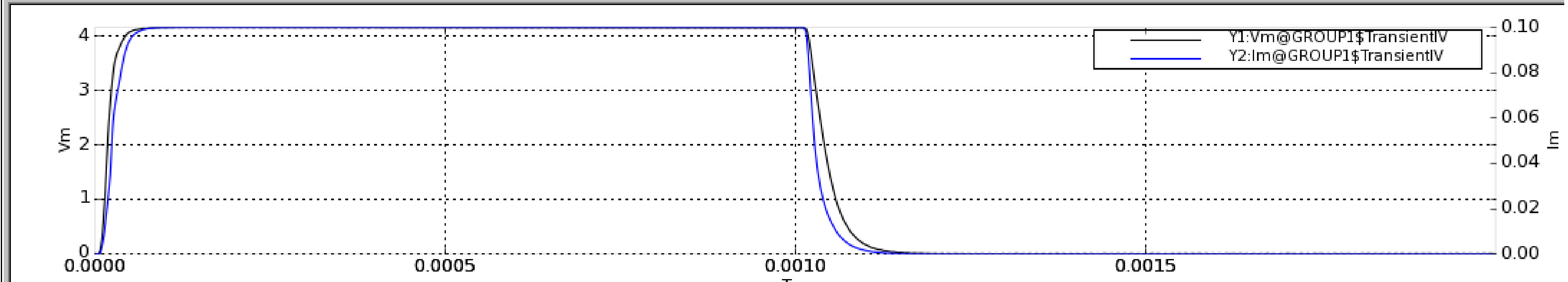
T_j Measurement with Pulse Operation → PW = 1ms, PRD = 2ms @ I.pulse = 0.1A

Setup | Data | Status

Plot and Data / Plot Only / Data Only



GROUP1

	A(X)	B(Y2)	C(Y1)	D	E	F	G	H	
1	Tm	Im	Vm	pulsePeriod	pulseLimit	Ton	pulseBias	pulseLevel	pulseW
2	0	2.603e-5	1.694e-3	2e-3	6	5	1e-6	1e-1	1e-3
3	1e-6	2.603e-5	2.494e-3						
4	2e-6	2.462e-5	6.926e-4						
5	3e-6	2.462e-5	-2.911e-3						
6	4e-6	1.755e-5	-5.313e-3						
7	5e-6	-5.083e-6	-5.313e-3						
8	[illegible]	[illegible]	[illegible]						

Input	
Ton	5
pulseWidth	0.001
pulsePeriod	0.002
measDelay	1
mInterval	1e-006
mCNT	2000
pulseLevel	0.1
pulseBias	1e-006
pulseLimit	6

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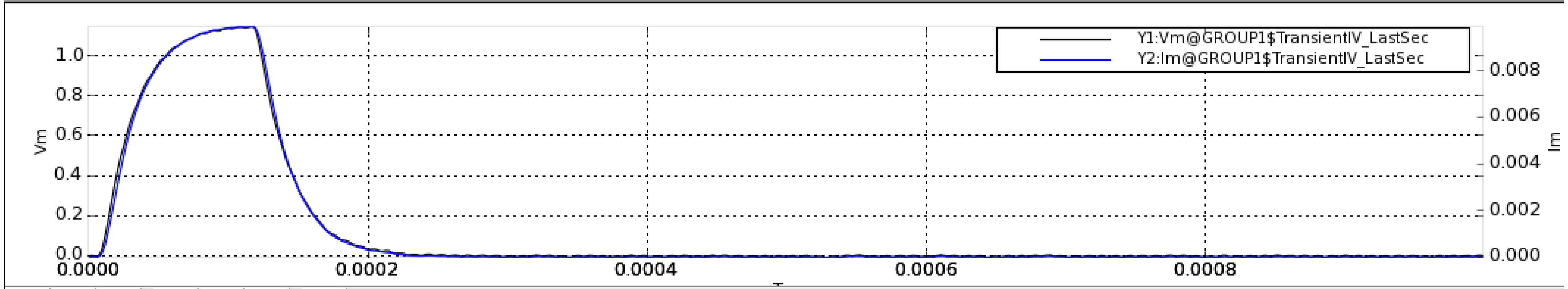
T_j Measurement with Pulse Operation → PW = 100us, PRD = 1ms @ I.pulse = 0.1A

Setup | Data | Status

Plot and Data · Plot Only · Data Only



GROUP1

	A(X)	B(Y2)	C(Y1)	D	E	F	G	H	I
1	Tm	Im	Vm	pulsePeriod	pulseLimit	Ton	pulseBias	pulseLevel	pulseWidth
2	0	-4.775e-6	-1.51e-3	1e-3	1e+1	5	1e-6	1e-2	1e-4
3	1e-6	-3.48e-6	2.922e-4						
4	2e-6	5.471e-7	6.926e-4						
5	3e-6	5.006e-6	8.928e-4						
6	4e-6	1.062e-5	-9.09e-4						
7	5e-6	1.306e-5	-3.912e-3						
8	[illegible]	[illegible]	[illegible]						

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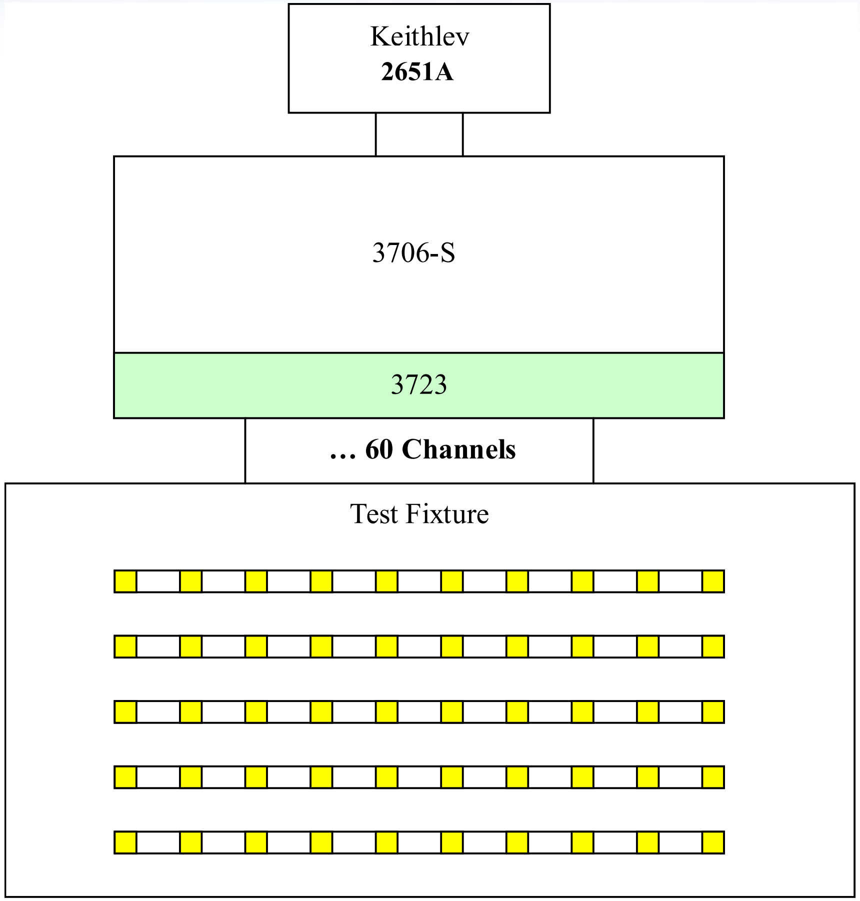
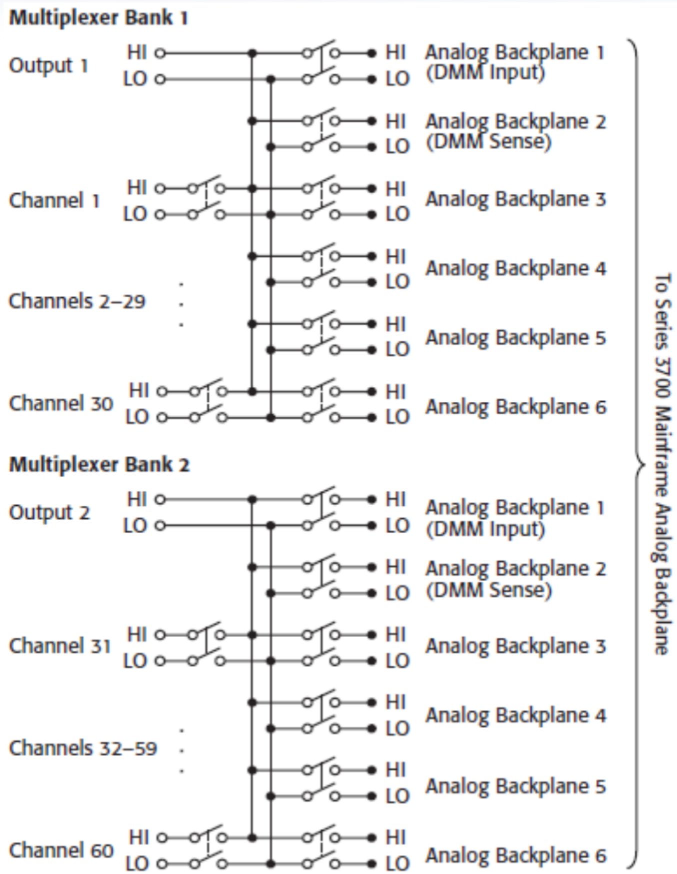
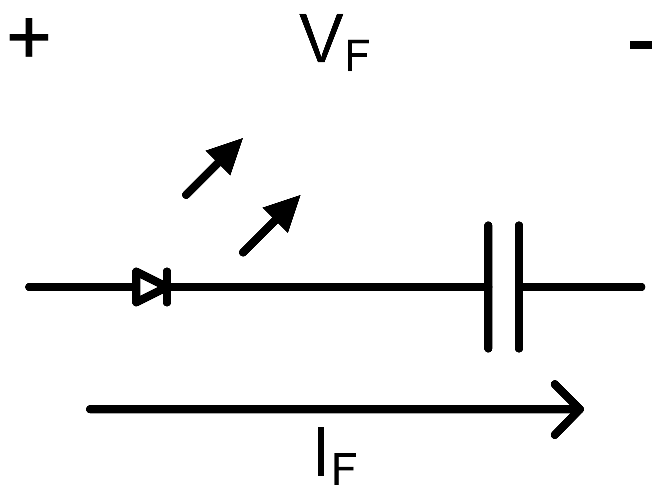
Input	
Ton	5
pulseWidth	0.0001
pulsePeriod	0.001
measDelay	1
mInterval	1e-006
mCNT	1000
pulseLevel	1e-2
pulseBias	1e-006
pulseLimit	10

LED Application
- 8. LED Light Bar





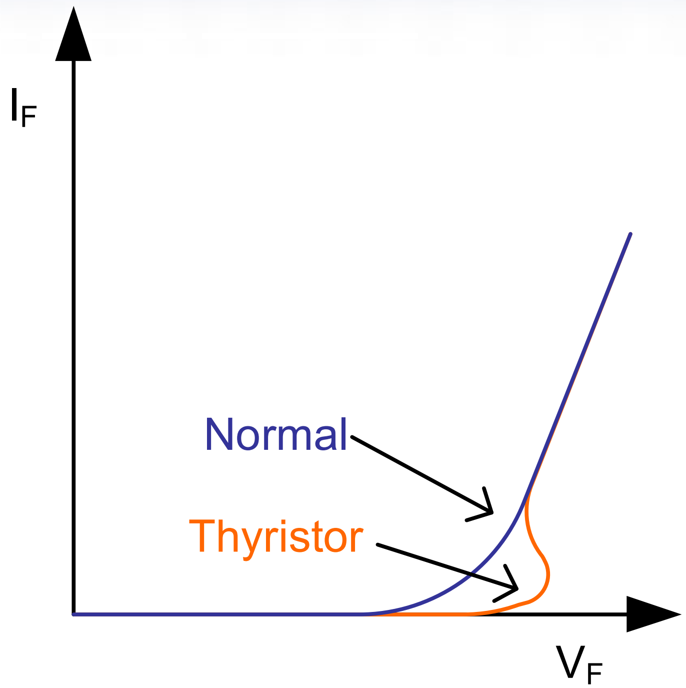
LED Application
- 9. What is a Thyristor?



- **A thyristor is an unwanted capacitance in series with the LEDs junction**
- **$V_F = V_{LED} + V_{Capacitor}$**

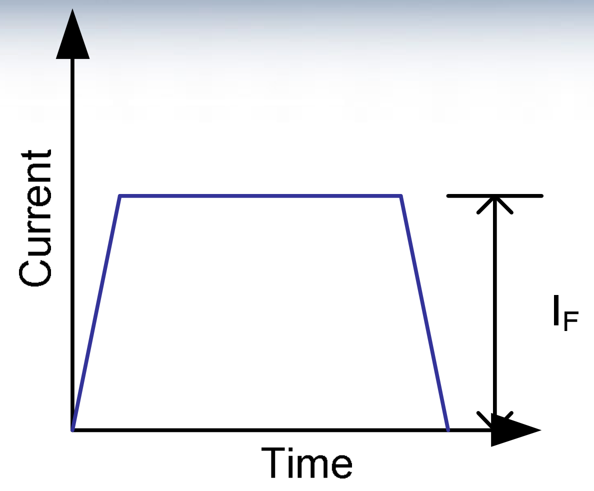
The Thyristor Effect

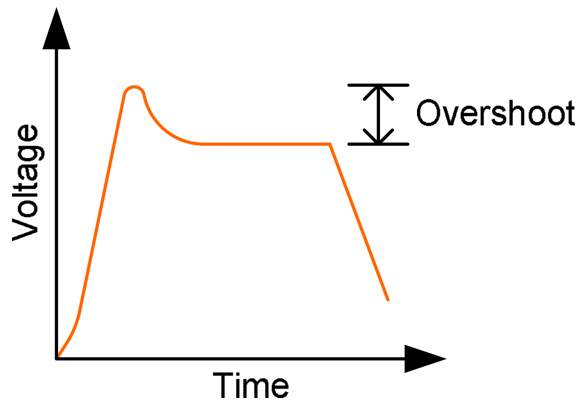
- **A thyristor shows up as a "Kink" in the V_F-I_F curve**
- **LED will exhibit a higher V_F than expected for a given I_F**
- **Causes a delayed turn on of the LED**



Detecting a Thyristor

- **A thyristor will cause an overshoot in the voltage waveform before it breaks down**
- **Pulse current into the LED and capture the voltage waveform**
- **Adjust the pulsed forward current IF to adjust for thyristor sensitivity**
  - A thyristor will be most sensitive at certain current levels
- **The Keithley Model 2651A High Power SourceMeter Instrument features a fast 18-bit digitizing ADC that can capture the waveform.**
  - Waveform analysis can be performed on the instrument in script.





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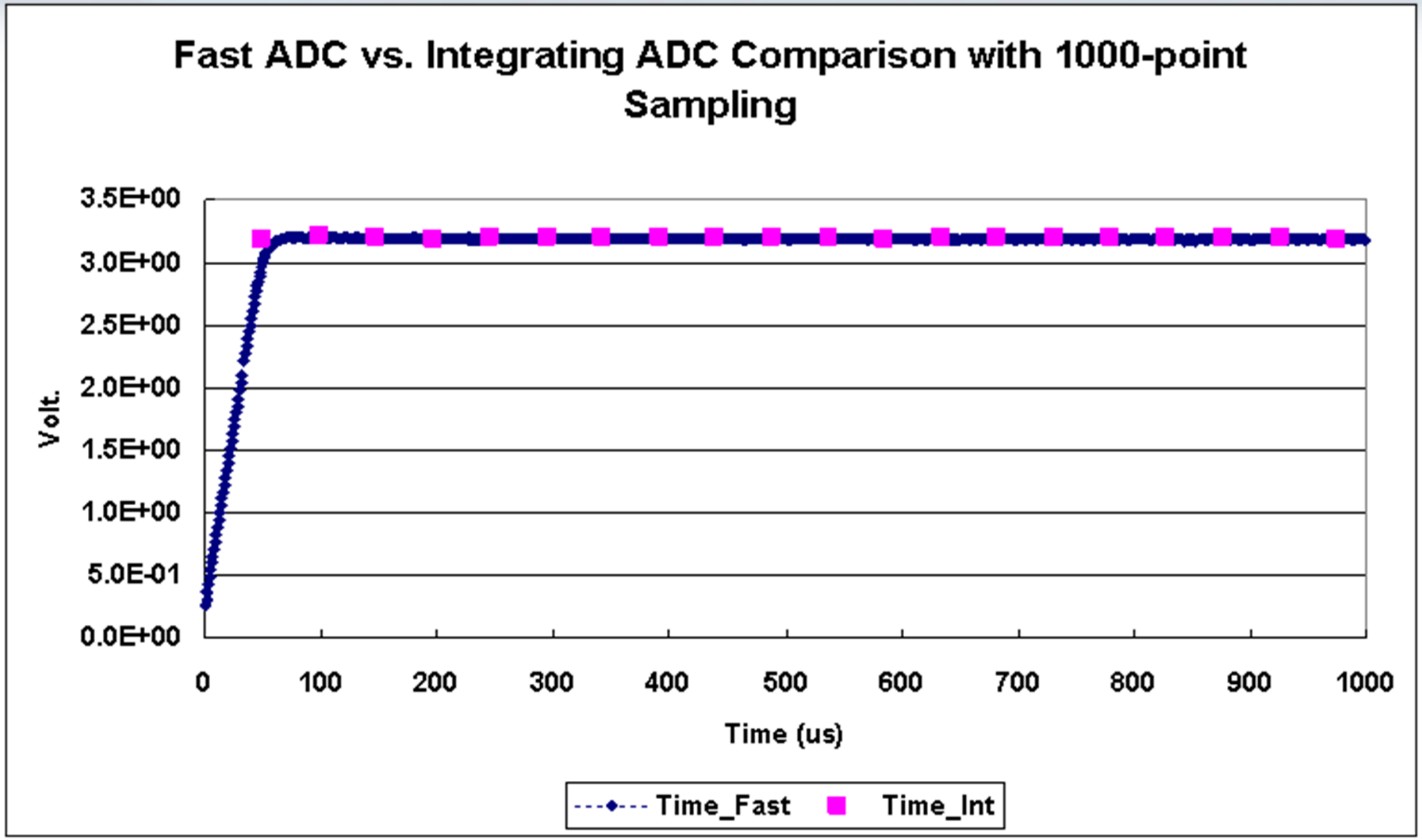
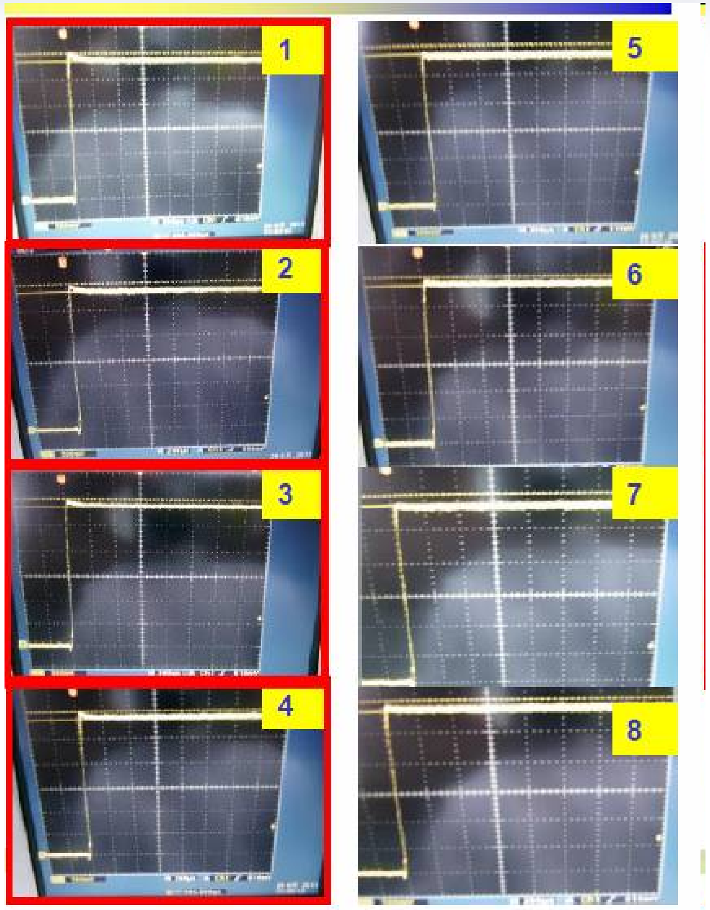
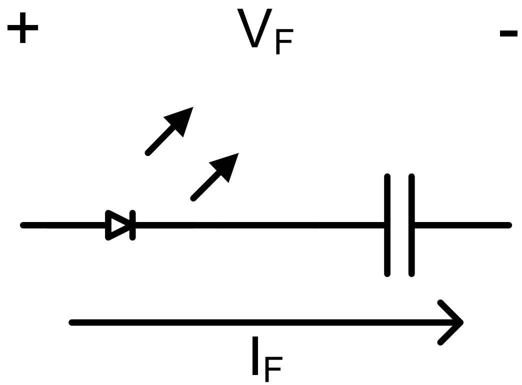
Sampling Speed Comparison with K2651A - Integrating ADC (50us/pt) vs. Fast ADC (1us/pt)

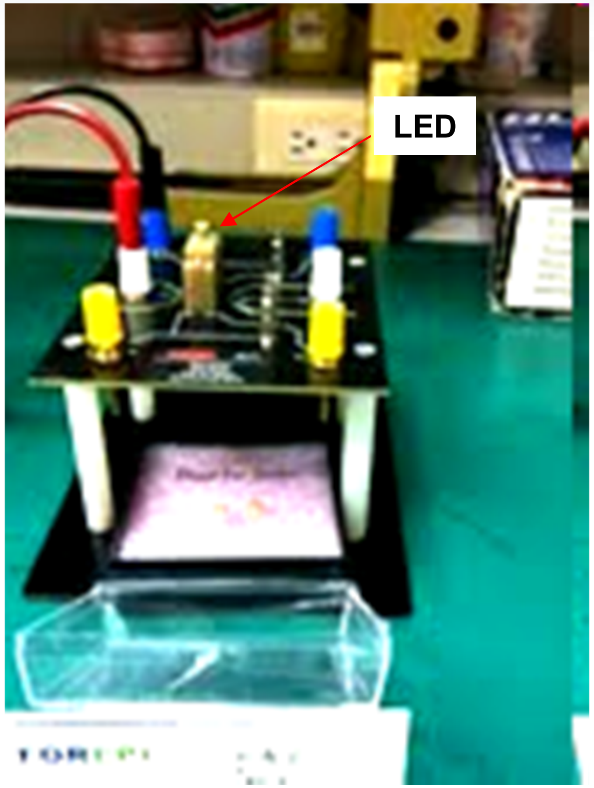


Oscilloscope Verification, Thyristor LED

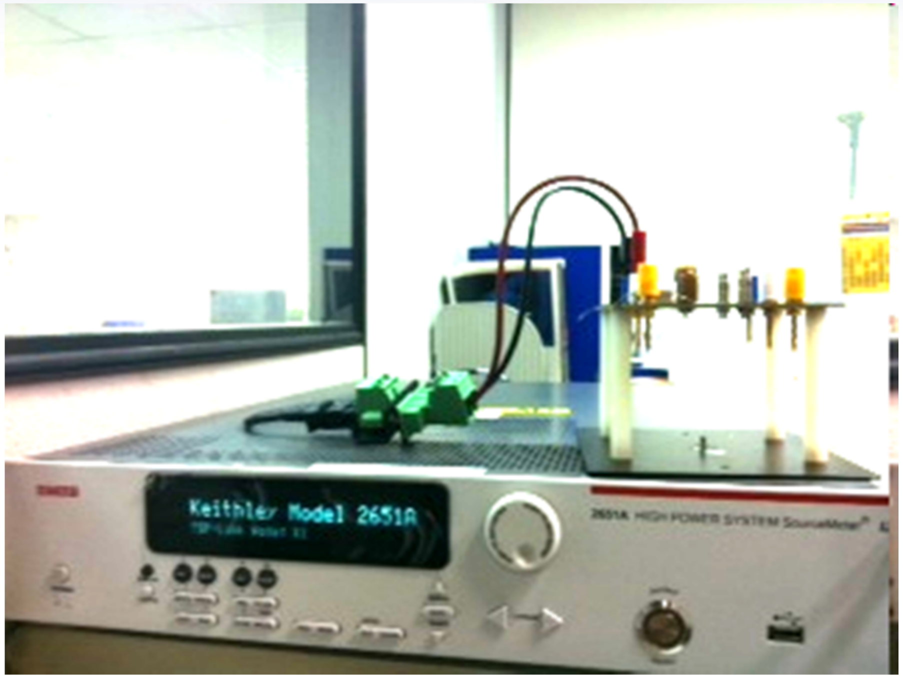




K2651A Setup and Verification



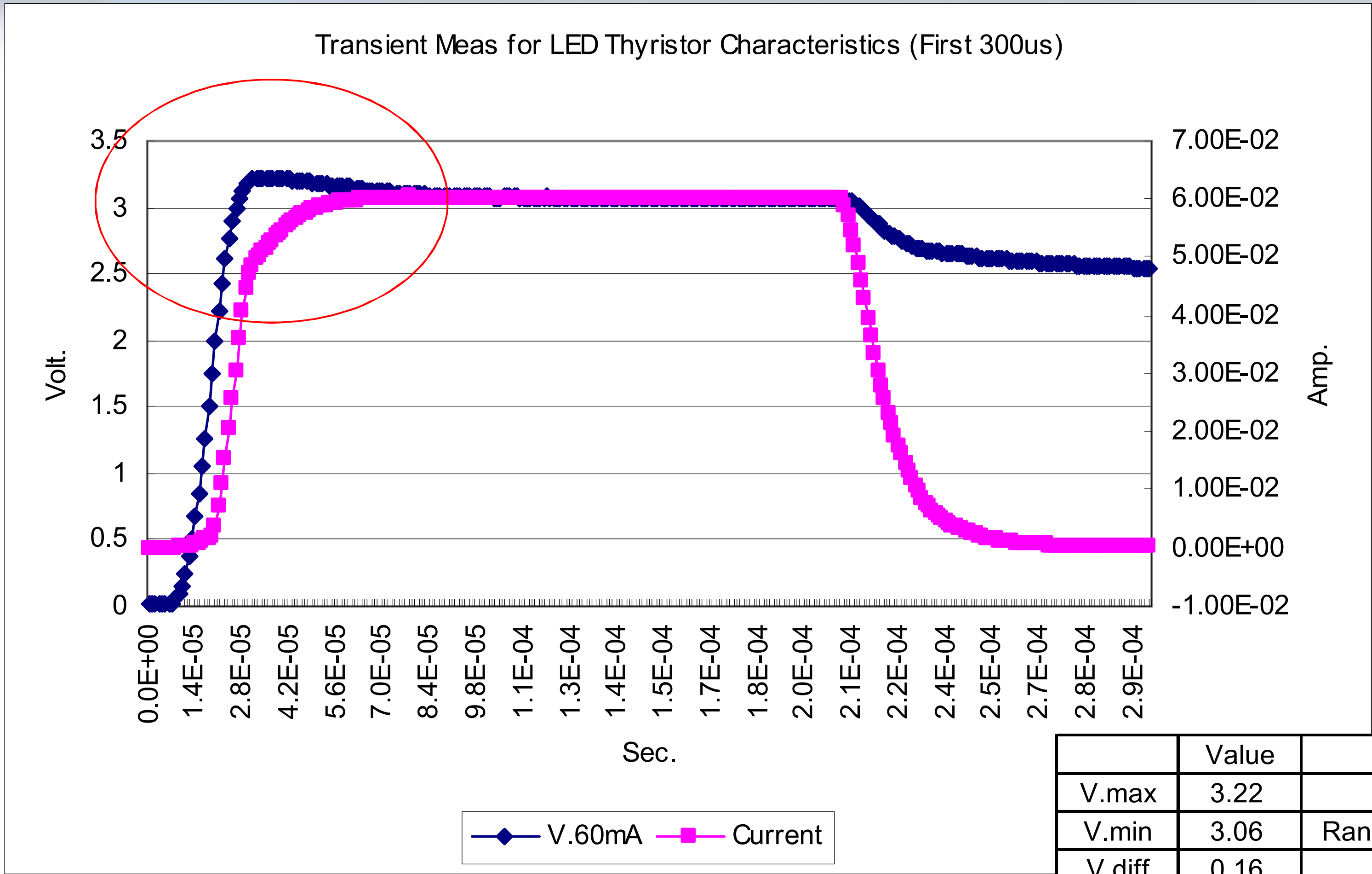
Keithley Test Fixture



New Features: 18-bit Fast ADC → 1us / point

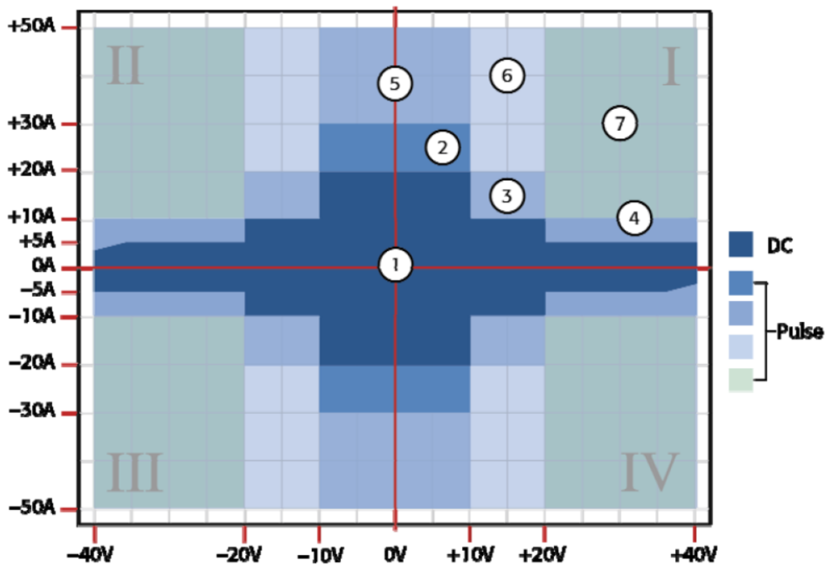
Keithley 2651A

Transient IV Measurement for Thyristor Investigation



	Value	Remark
V.max	3.22	
V.min	3.06	Range 100~200us
V.diff	0.16	

The Keithley Model 2651A High Power SourceMeter® Instrument



- 200 Watts of DC Power
- Up to 2000 Watts of pulsed power
- Pulse Width Modulation capability
- Programmable duty cycle from 0-100% in the standard DC operating areas
- Up to 50% duty cycle at 30A
- Precision timing and synchronization to 500ns
- High speed vs. accuracy A/D
  - **True 1 us/point with 18-bit digitizing A/D**
  - **Full line-cycle integration with 22-bit integrating A/D**

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SourceMeter® Source Measurement Unit

2651A High Current 50A model

- **Power: 200W DC, 2KW Pulse**
  - 20A @ 10V (DC) / 50A @ 40V (pulse)
  - Easily expand to 80V @ 50A pulse or 40V @ 100A pulse (with 2 units)
  - 100uSec minimum pulse with ~30uSec rise time
  - Pulse from 1% to 100% duty cycle

  "Easily capture important parametric data that other equipment cannot"

- **High Speed and High Accuracy A/D Converters (same as 2657A)**
  - True 1 uSec per point sampling with 18-bit digitizing A/D
  - Full line-cycle integration with 22-bit integrating A/D

  "Precisely characterize transient and steady-state behavior, as well as thermal effects"

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SourceMeter® Source Measurement Unit
2657A High Voltage 3KV model

- **180W of Power**
  - 120mA @ 1.5kV / 20mA @ 3kV

  "Easily capture important parametric data that other equipment cannot"

- **Scalable, Flexible, High Speed Architecture**
  - Part of 26xx Family with TSP / TSP-Link
  - Fully floating, independent channels support SMU-per-pin testing

  "Improve productivity in many applications across R&D, Reliability, and Production"

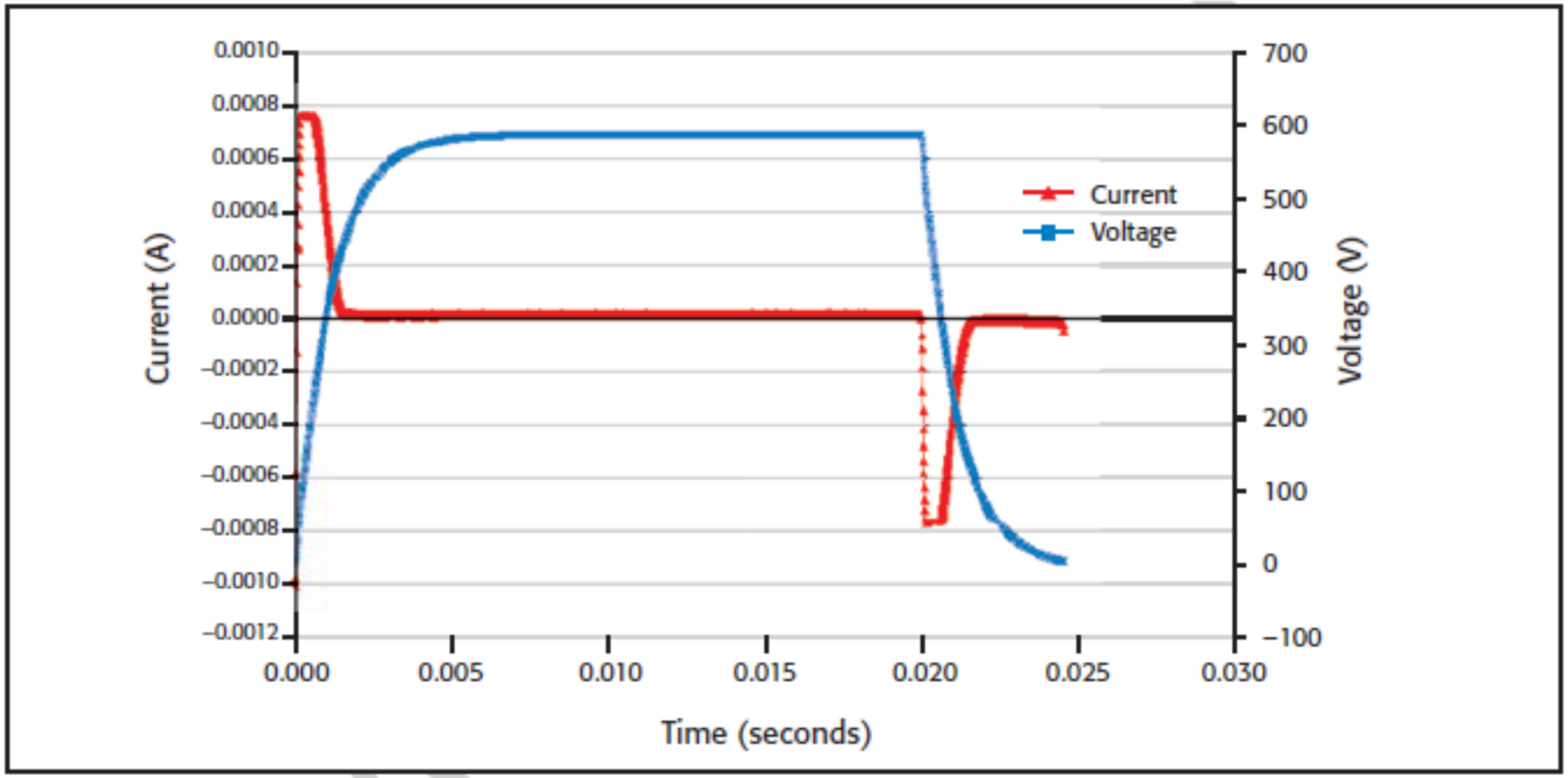
- **High Speed and High Accuracy A/D Converters**
  - 1 uSec per point sampling with 18-bit digitizing A/D
  - Full line-cycle integration with 22-bit integrating A/D

  "Precisely characterize transient and steady-state behavior"

- **Sub pA Resolution**
  - 1nA range with 10fA resolution

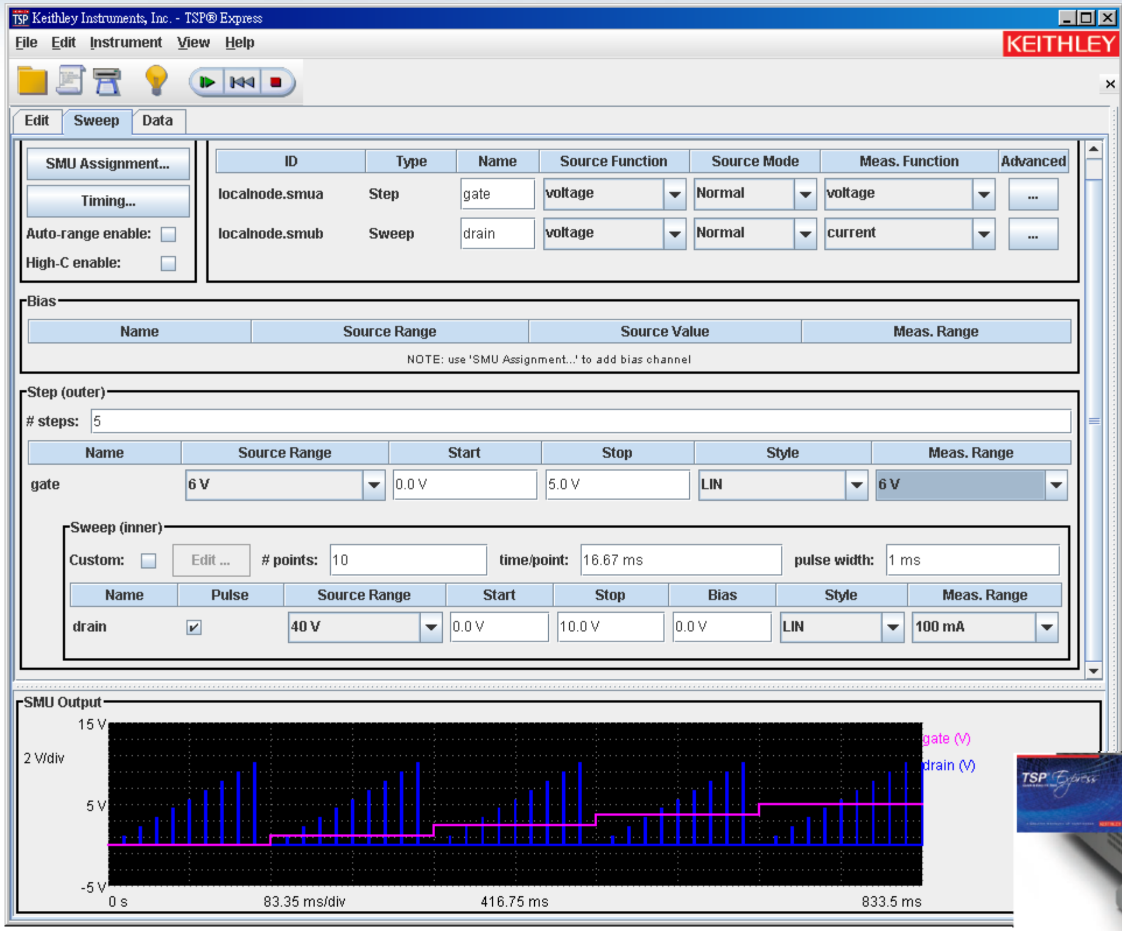
  "Support low-leakage requiren

SourceMeter® Source Measurement Unit Ex. Fast ADC Function (sync IV meas.)



The dual high speed A/D converters will sample as fast as 1μs per point, enabling full simultaneous characterization of both voltage and current.

TSP Express, Powerful Built-IN Software - Sweep Setting GUI



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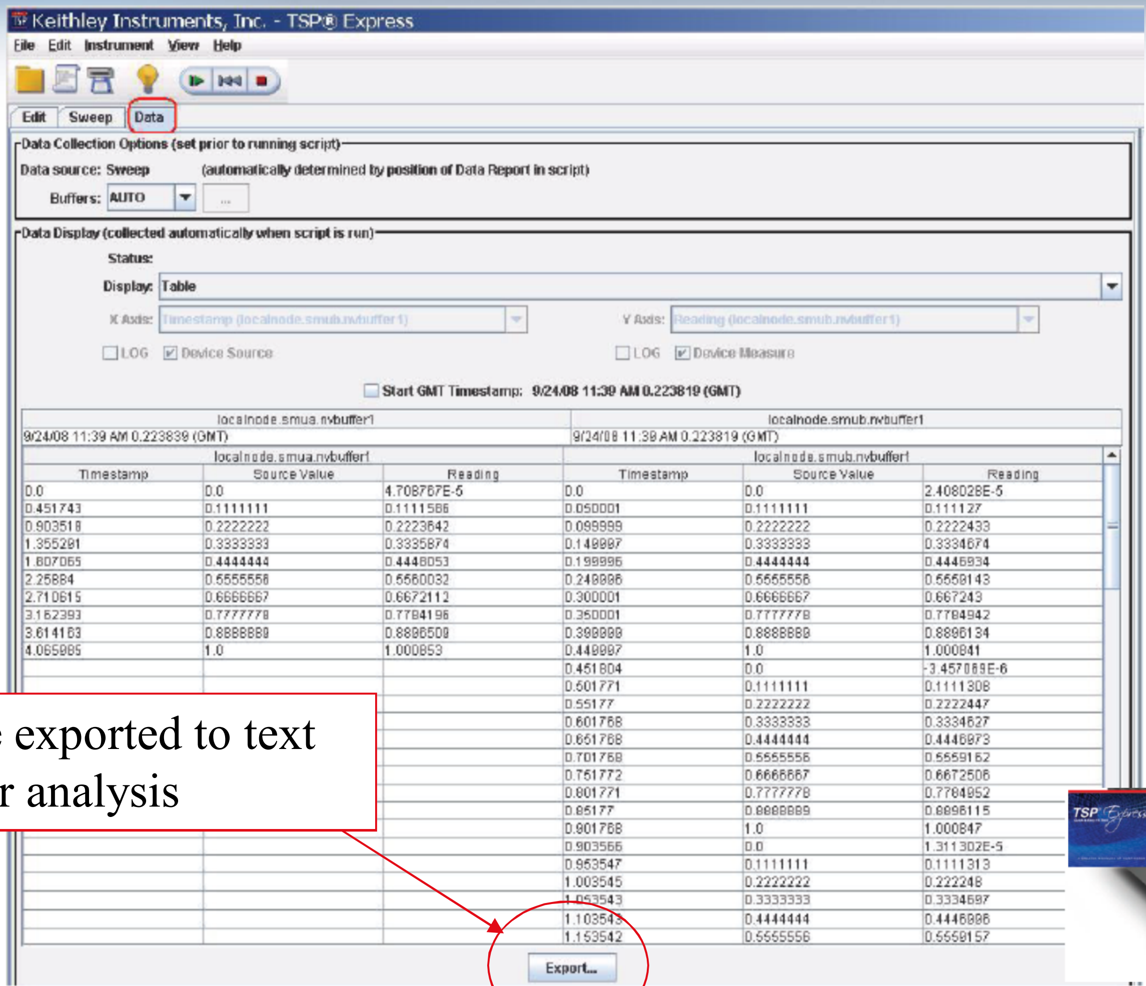
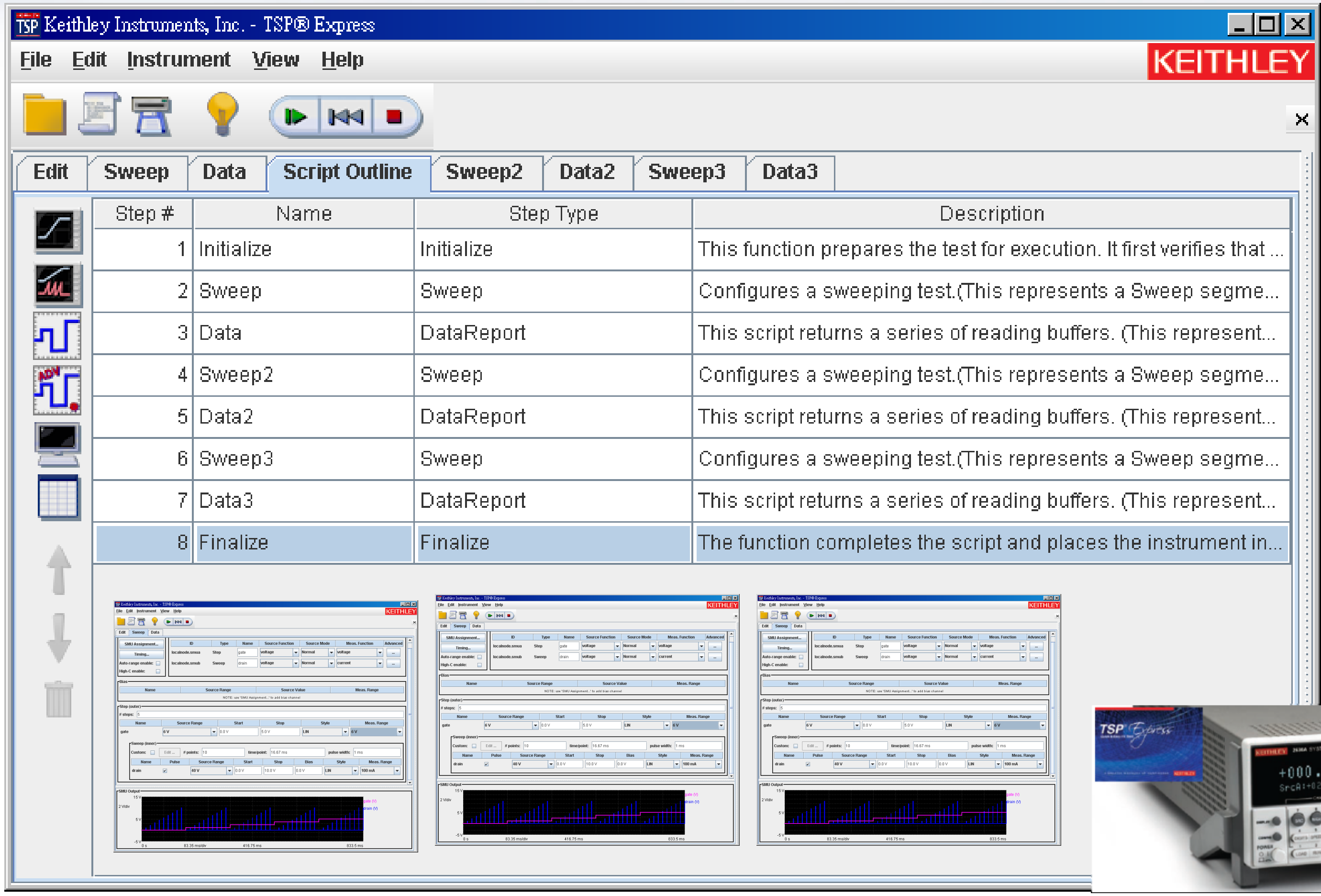
TSP Express, Powerful Built-IN Software - Output Data GUI



* Data can be exported to text file for further analysis

TSP Express, Powerful Built-IN Software - Multi-Sweep with One Click



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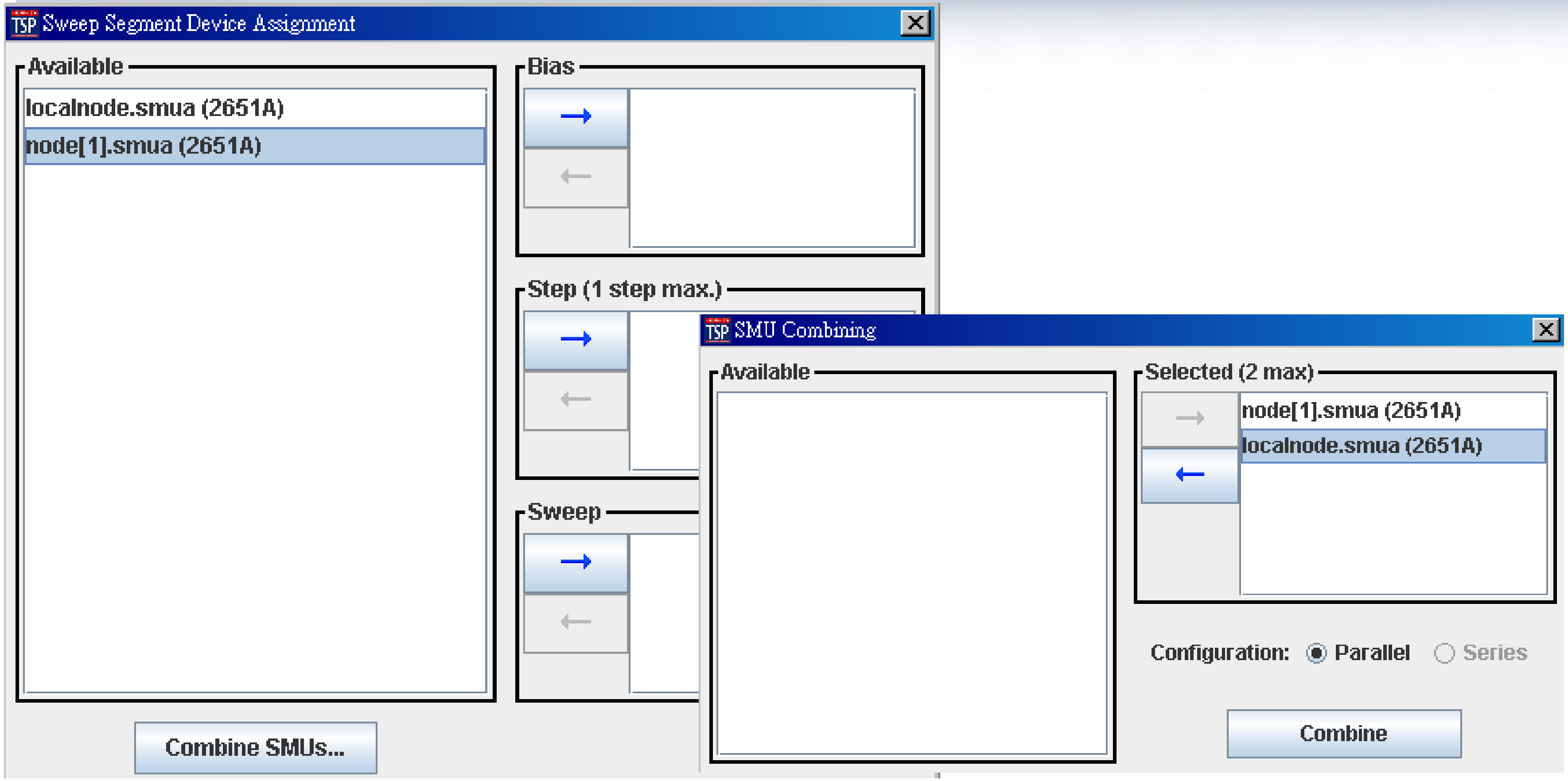
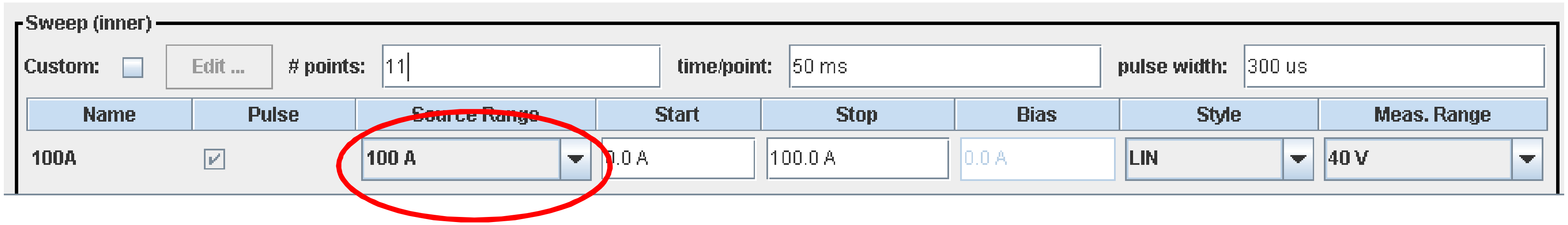
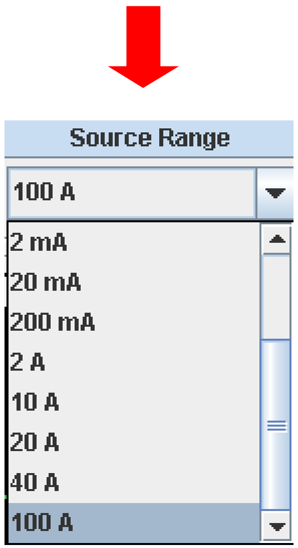
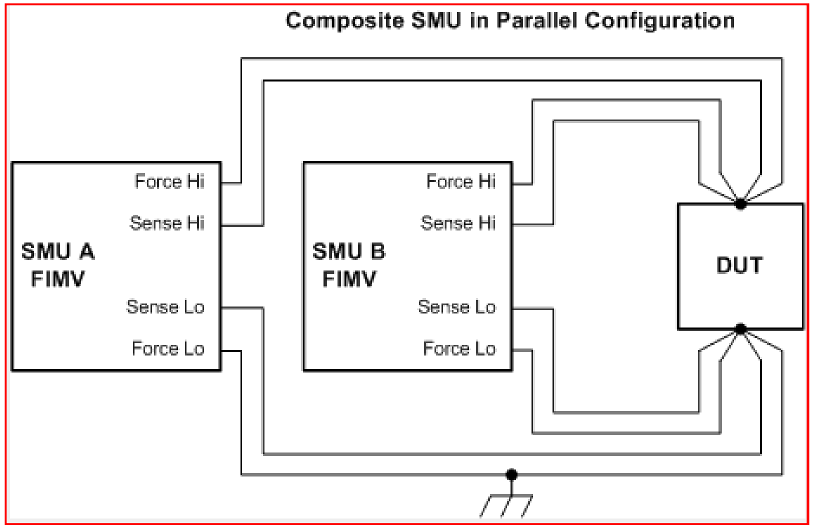
TSP Express, Powerful Built-IN Software - Higher Current (50AX2, Parallel)



TSP Express, Powerful Built-IN Software - Higher Current (100A, Parallel)





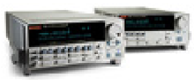


Conclusion
- Your Superior Partner in Precision IV Measurement

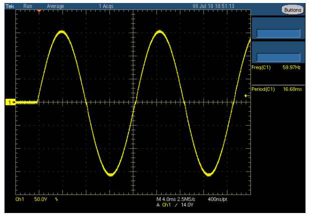
Home / Products

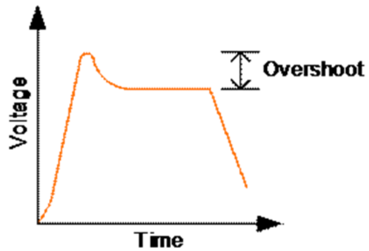
Current/Voltage Source and Measure Products

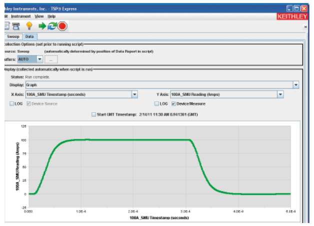
Multi-Channel I-V Test Solutions, Source Measure Units (SMU), Curve Tracer, and Precision Power Supplies for current/voltage source/measure capability.

	Multi-Channel I-V Test Solutions Series 2600 with embedded Test Script Processors			**Sub-Femtoamp**	**Source Measure Unit (SMU)**	**Multi-Channel I-V Characterization (Parameter Analyzer)**
						 4200-SCS C-V Option Pulse IV option Pulse IV w/ Q Point 2 Ch Pulse Gen 2 Ch Oscilloscope FLASH memory test
Model	2602(Dual Ch) 2601(Single Ch)	2612(Dual Ch) 2611(Single Ch)	2636(Dual Ch) 2635(Single Ch)	6430	2651A (50A) 2657A (3KV)	4200-SCS
Description	Scalable, High Throughput	High voltage and pulsed output	Low current and pulsed output	Ultra-Low Current	High Power	Multi-Channel I-V Characterization
Programming	IEEE-488, RS-232 communication with embedded Test Script Processor (TSP) capability			IEEE-488, RS-232	IEEE-488, RS232, TSP	Embedded GUI

	I-V Test Solutions - Series 2400 SourceMeter Instruments					
						
Model	2400	2410	2420	2425	2430	2440
Description	General Purpose	High Voltage	3 A	High Power	Pulse	5 A
Programming	IEEE-488, RS-232					
Contact Check and Other	2400-C 2400-LV	2410-C	2420-C	2425-C	2430-C	2440-C







Thanks for your time ~

Keithley Brand,
Tektronix Technology

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