Tektronix

吉时利经典测试测量和行业解决方案

$$R = \frac{V}{I}$$

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测试测量行业先锋

- 领先的测试测量公司，为工程和技术专业人士服务
- 成立于1946年，2007年加入丹纳赫集团
- 总部位于美国俄勒冈州毕佛顿市
- 在多个主要产品和市场中居于领导地位
- 知名品牌，提供优质创新产品、杰出的工程设计及全球服务和支持
- 屡获大奖：
  - 示波器
  - 信号源
  - 逻辑分析仪
  - 频谱分析仪
  - 视频测试

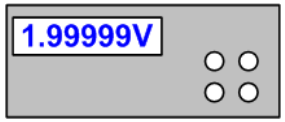
KEITHLEY
A Tektronix Company

- 吉时利是精密电气测试领域的领导者
- 成立于1946年，2010年被泰克收购
- 总部位于美国俄亥俄州索伦
- 提供各种仪器和系统，满足从纳伏到千兆赫兹的任何测量要求
- 21项R&D 100大奖，多次荣获Semiconductor International、Solid State Technology、Electronic Products、Test & Measurement World杂志颁发的荣誉

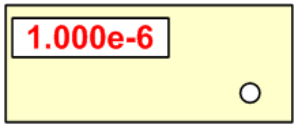
Keithley SMU Simplifies I-V Testing

Precision Power Supply (source)

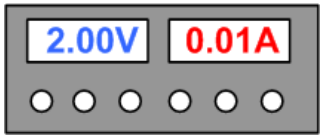
DMM (measure I, V, and R)



Current Source



Electronic Load



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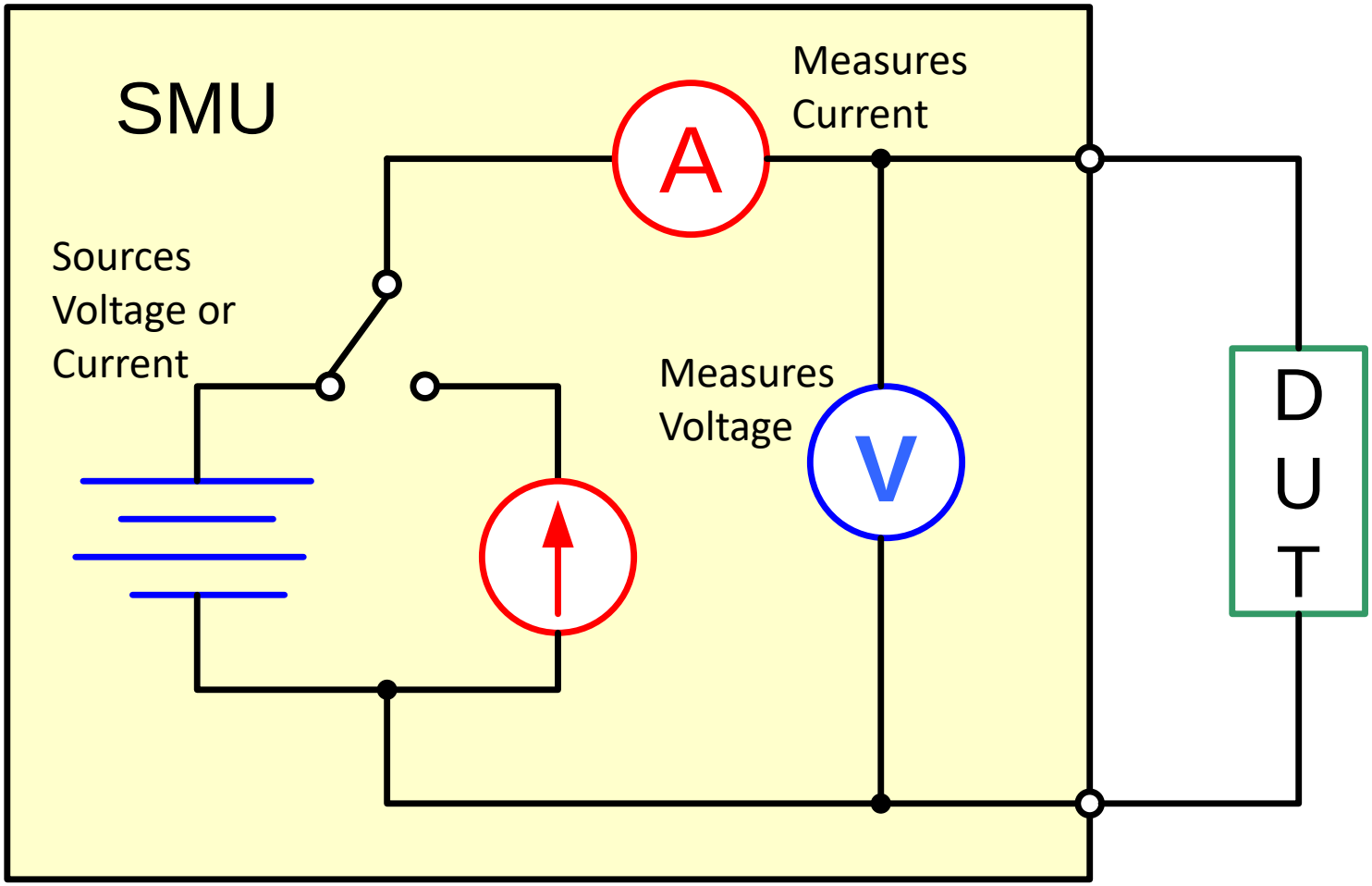
Keithley Model 2636A

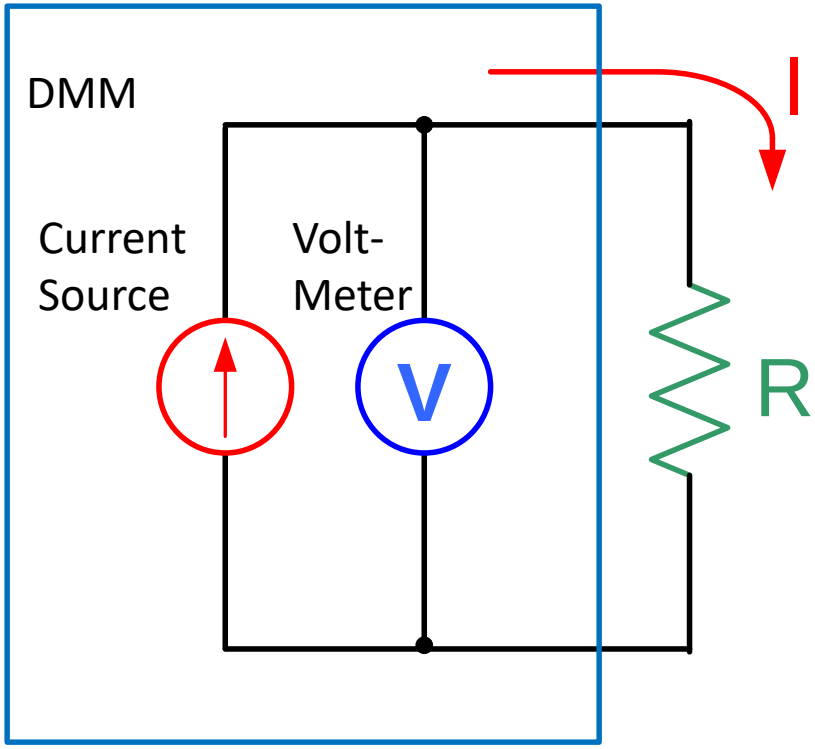
Source Measure Unit (SMU)

Simplified SMU Circuit

One SMU can replace entire rack of equipment!



SMU vs. DMM: Measuring Resistance



Measuring Resistance as a function of Current

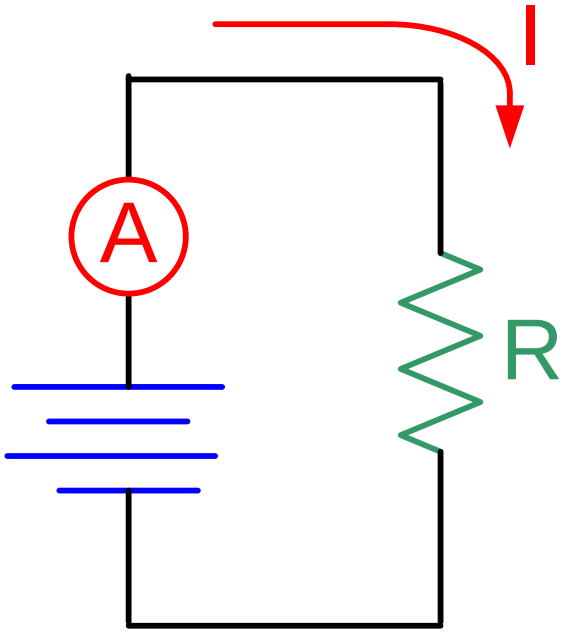
DMMs usually measure resistance by sourcing a fixed current and measuring the voltage drop across the resistor:

$$R = \frac{V}{I}$$

The user has no control over the test current.

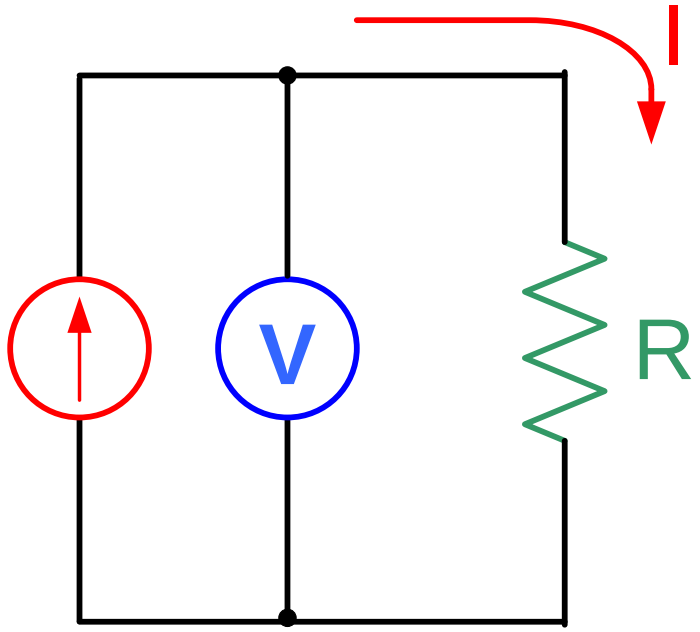
SMU for Measuring Resistance

Here are the two most common ways to measure resistance:



Source Voltage
Measure Current

Method for
High Resistances



Source Current
Measure Voltage

Method for
Low Resistances

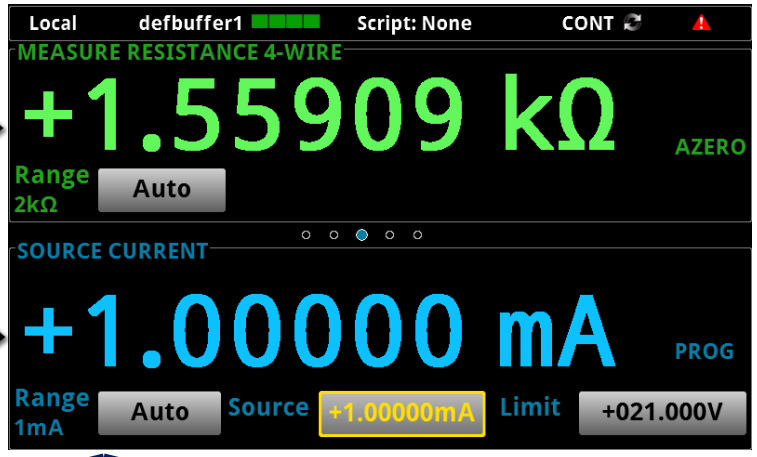
Model 2450 versus 2400

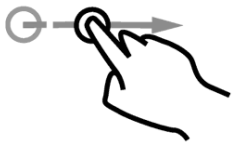
5-inch Touchscreen Graphical Interface

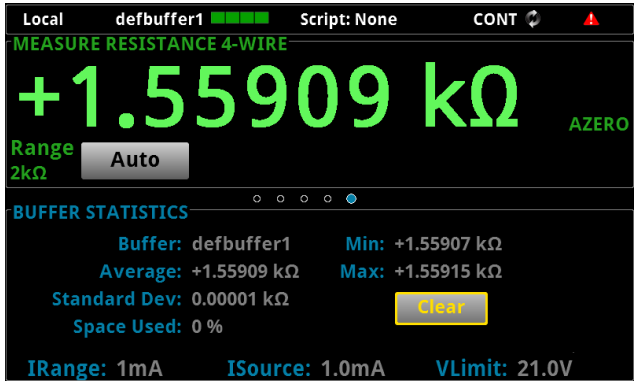
- *Multi-point Gestural Operation*

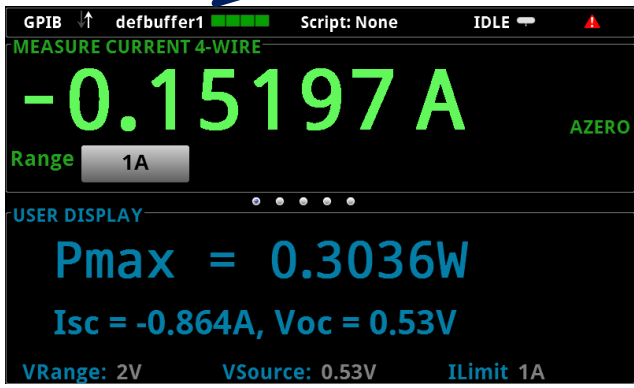
Measurement Row

Source row offers swipe capability for multiple screens





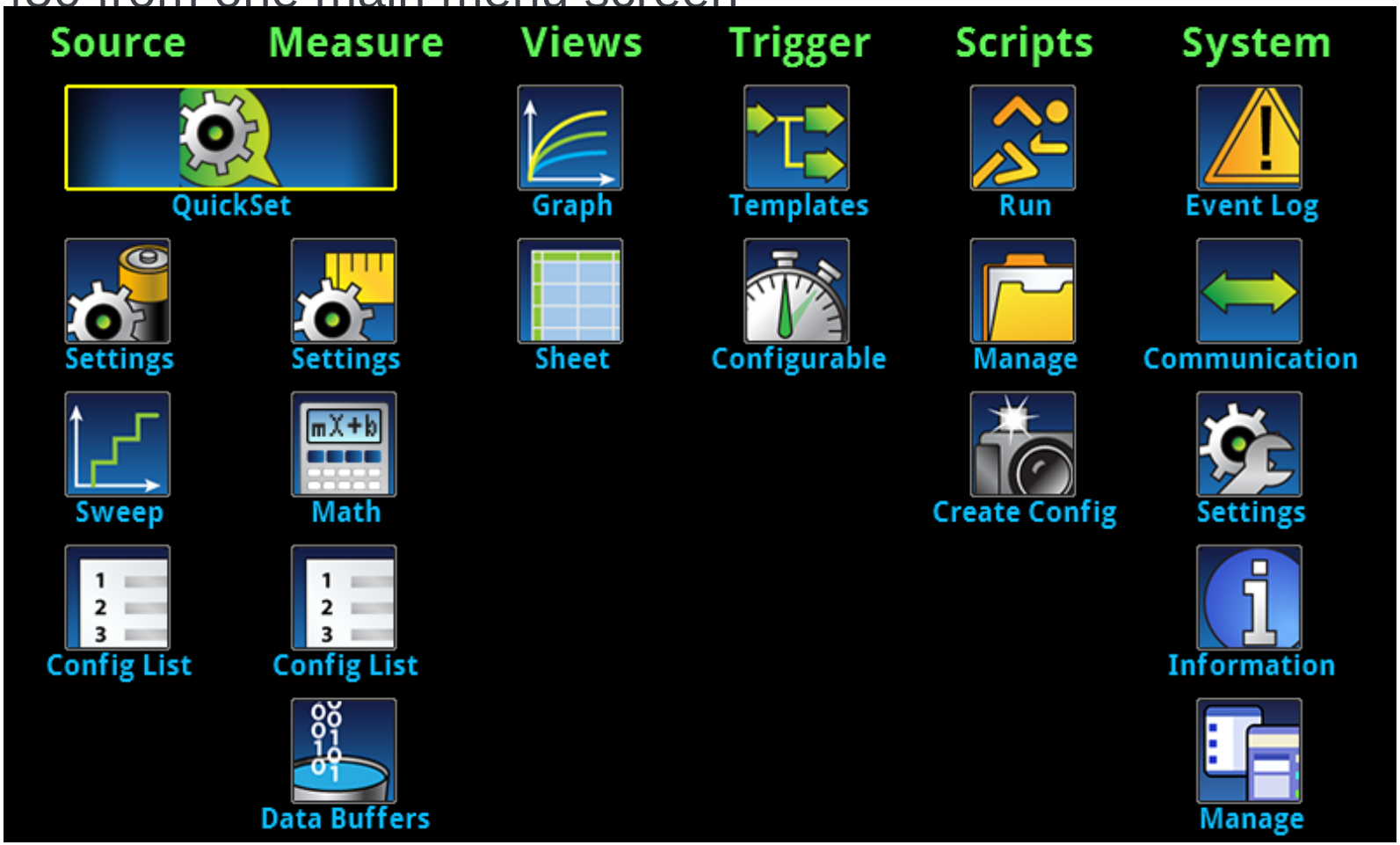




Icon-based Menu System

Fewer configuration steps – faster speed to answer

- Everything you need to quickly configure the Model 2450 from one main menu screen



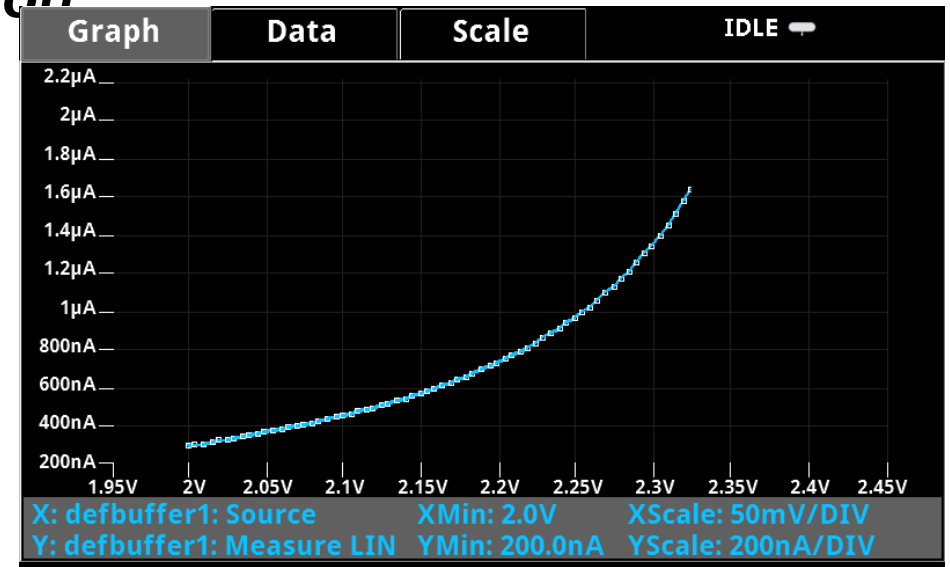
Graphing and Data Display

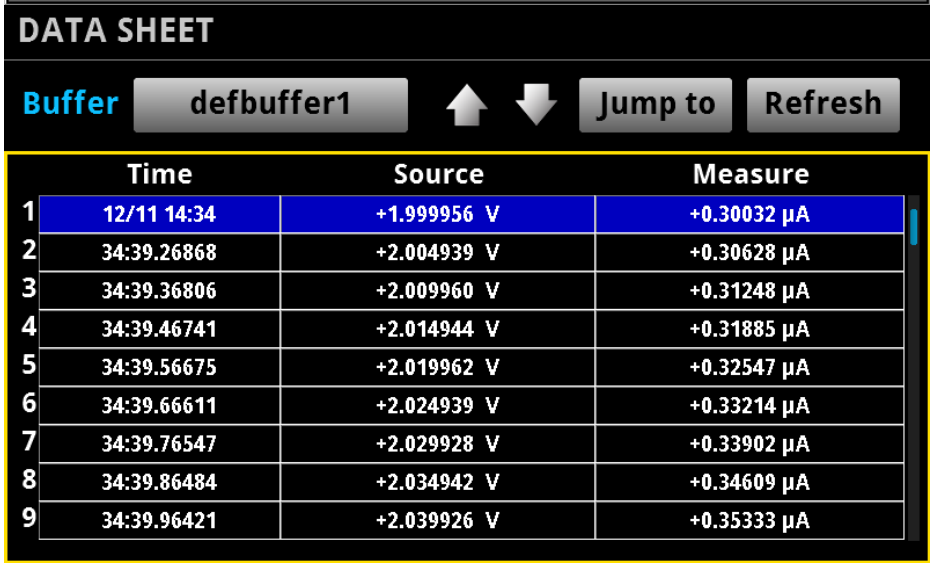
Convert raw data to information

- Graph Plot
  - X-axis: Source, Time, or Points

    versus
  - Y-axis: Measure or Source

- Display Data Sheet
  - Swipe through table
  - Use Navigation knob to scroll through data
  - Click on a data point to get full details

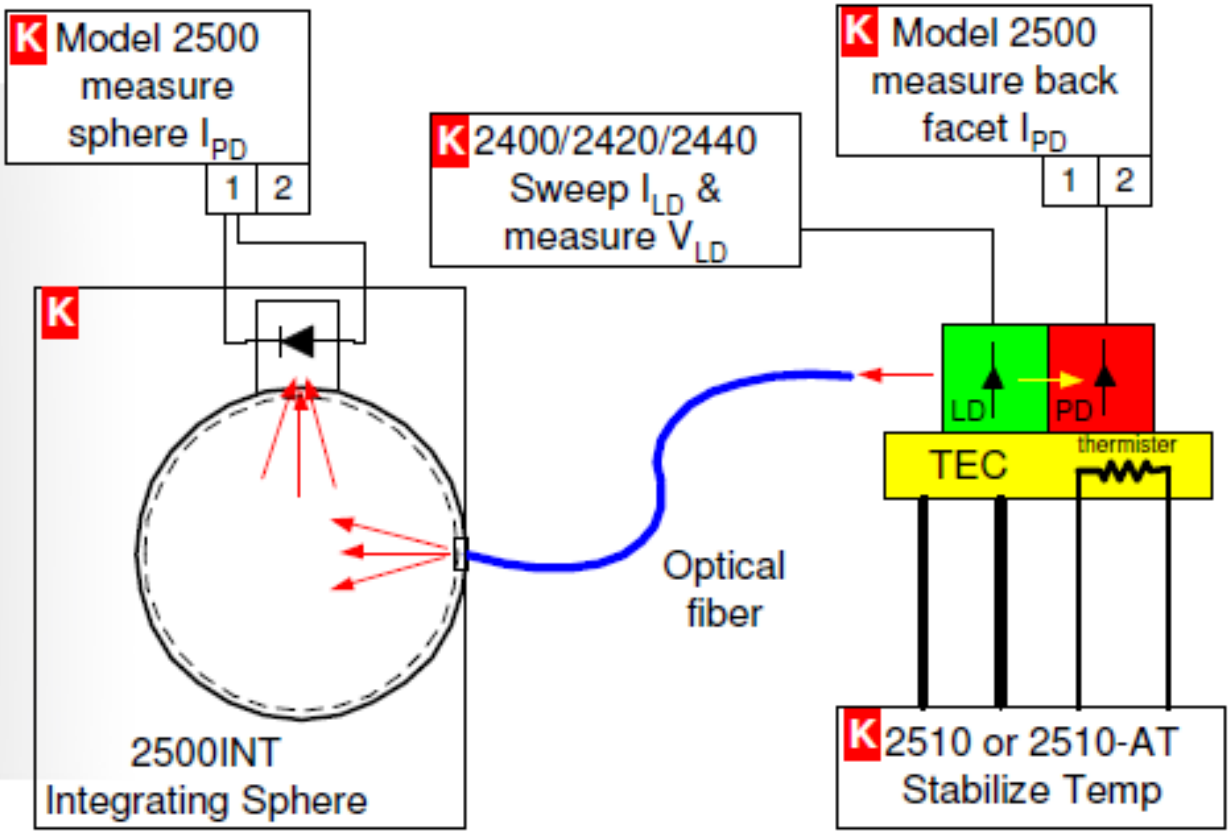


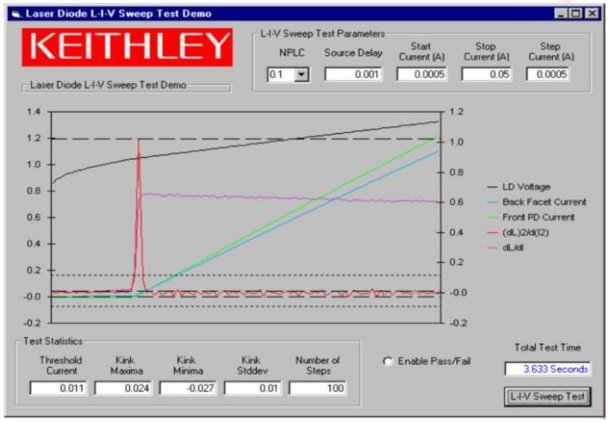


	Time	Source	Measure
1	12/11 14:34	+1.999956 V	+0.30032 µA
2	34:39.26868	+2.004939 V	+0.30628 µA
3	34:39.36806	+2.009960 V	+0.31248 µA
4	34:39.46741	+2.014944 V	+0.31885 µA
5	34:39.56675	+2.019962 V	+0.32547 µA
6	34:39.66611	+2.024939 V	+0.33214 µA
7	34:39.76547	+2.029928 V	+0.33902 µA
8	34:39.86484	+2.034942 V	+0.34609 µA
9	34:39.96421	+2.039926 V	+0.35333 µA

--光电材料及器件测试(Laser Diode)

- LIV系统测LD的应用





Tektronix

低压 Low V 、低阻 Low R

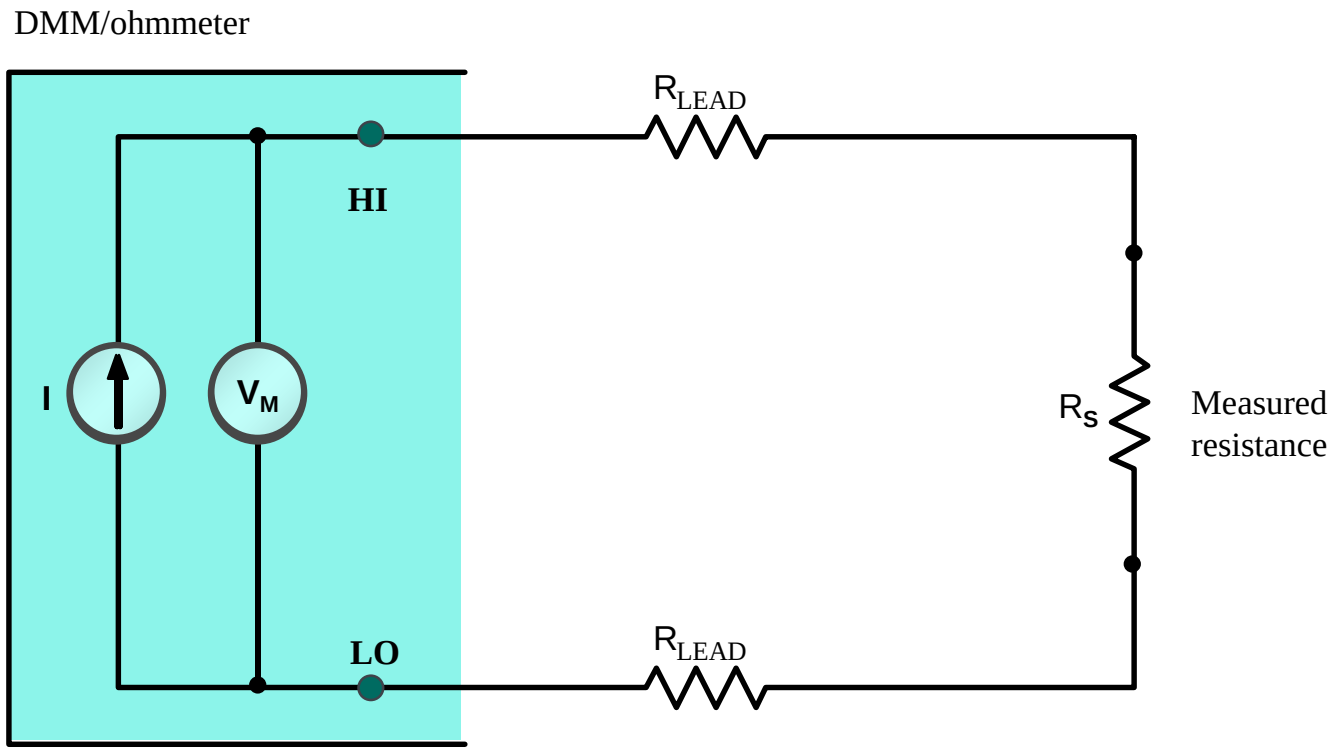
$$r = \frac{V}{I}$$

Low Resistance Measurement Challenges & Solutions

低阻测试挑战与解决方案

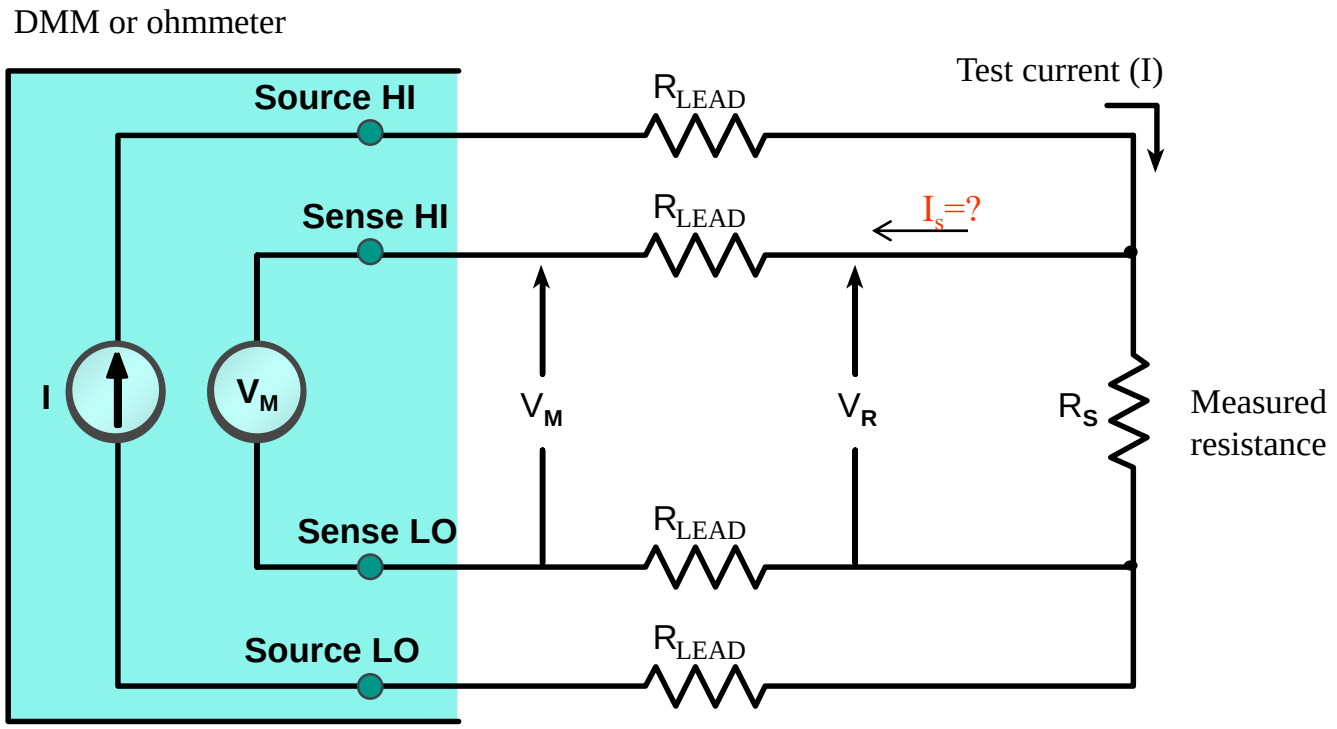
挑战	*解决方案/技术*
Lead Resistance errors 导线电阻误差	**4 wire (Kelvin) Technique** 4线法技术
Thermal EMFs 热电动势	**Offset Compensation or Delta Mode** 偏置补偿/Delta模式
Oxide Breakdown Prevention (applies to circuits that are opened and closed often – connectors, switches, relays)氧化层击穿防护	**Dry Circuit Protection (Voltage Clamp)** 干电路保护

Lead Resistance in 2 Wire Ohms Circuit
2线法电阻测试电路中的导线电阻



$$R_{measured} = R_S + R_{LEAD} + R_{LEAD}$$

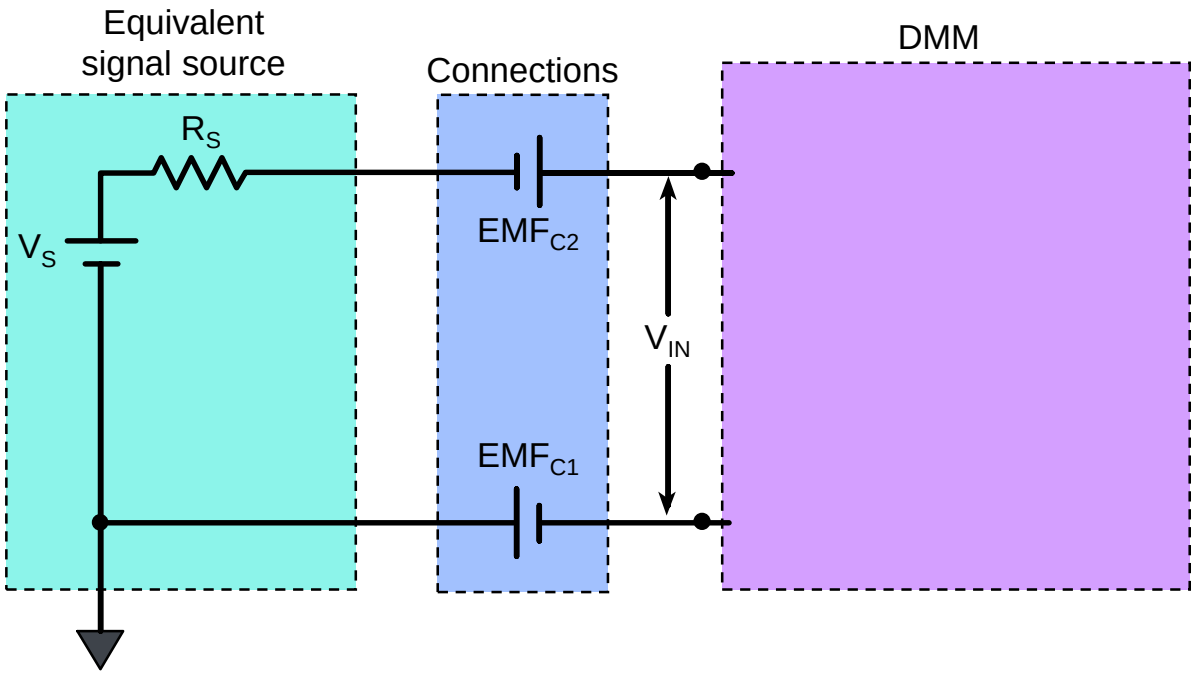
4-wire Ohms – to minimize Lead Resistance Errors
4线法测电阻—最小化导线电阻误差



V_M = Voltage measured by meter
V_R = Voltage across resistor
Because sense current is negligible, $V_M = V_R$

and measured resistance = $\frac{V_M}{I} = \frac{V_R}{I}$

Thermal EMF errors
热电动势误差

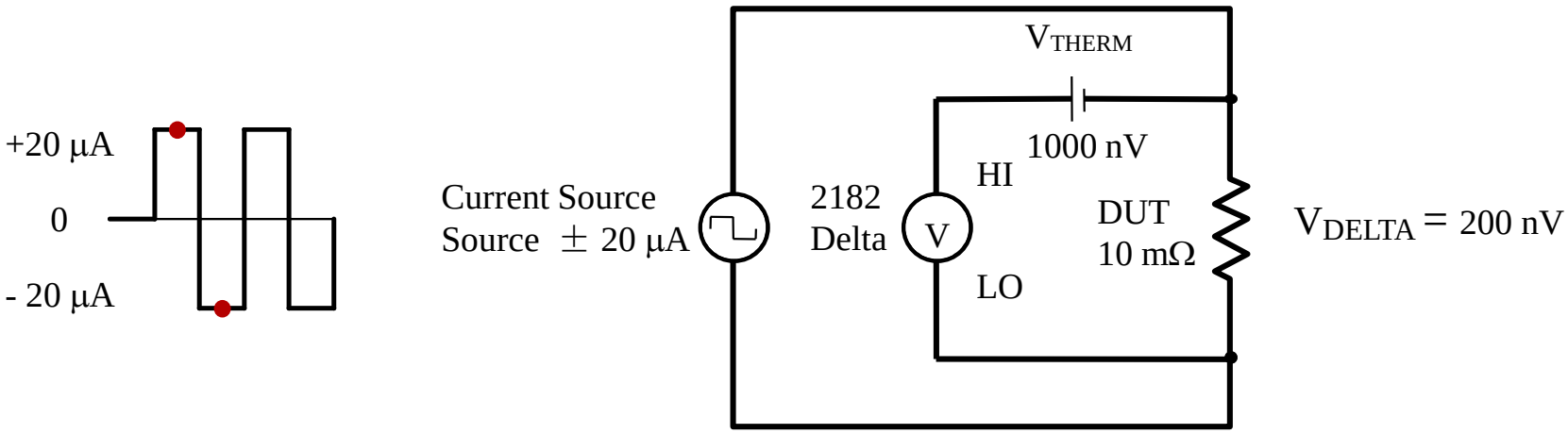


Unwanted Thermocouples are created when

- Dissimilar metal are connected together
- Temperature gradients exist in the circuit

Delta Mode (Current Reversal Method)
Delta模式（电流反向方法）

Note: This Method is used with 2400 & 2182



At + 20 µA :

$V_1 = 200\ nV + 1000\ nV$
$= 1200\ nV$

At - 20 µA :

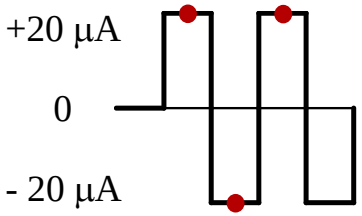
$V_2 = -200\ nV + 1000\ nV$
$= 800\ nV$

$$V_{DELTA} = \frac{V_1 - V_2}{2} = \frac{1200\ nV - 800\ nV}{2} = 200\ nV$$

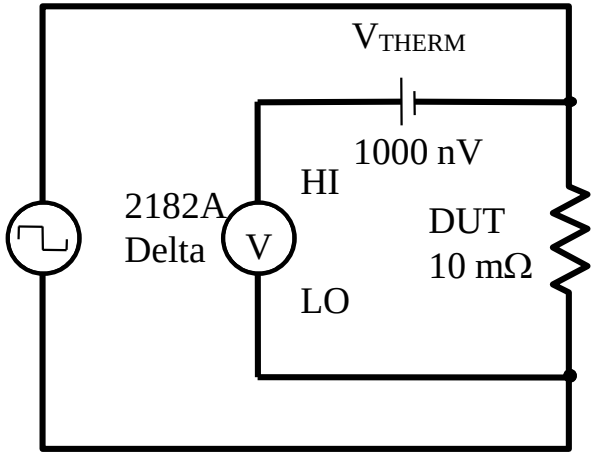
By reversing current, Delta Mode significantly reduces effects from thermal voltages.

Improved Delta Mode
改进的Delta模式

Note: This new Method is used with 6220 or 6221 & 2182A



622X
Current Source
Source ± 20
µA



V_{DELTA} = 200 nV

At + 20 µA :

V_1 = 200 nV + 1000 nV
= 1200 nV

At - 20 µA :

V_2 = - 200 nV + 1010 nV
= 810 nV

At + 20 µA :

V_3 = 200 nV + 1020 nV
= 1220 nV

$$V_{DELTA} = \frac{\frac{V_1 - V_2}{2} + \frac{V_3 - V_2}{2}}{2} = \frac{195\text{ nV} + 205\text{ nV}}{2} = 200\text{ nV}$$

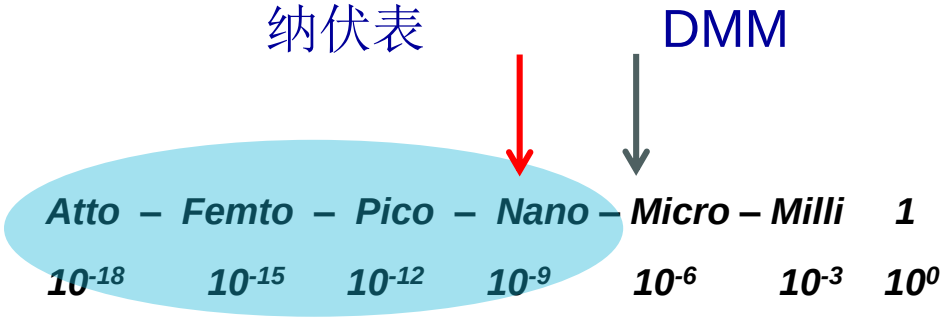
Improved Delta Mode eliminates effects from thermal voltage drift

高传导率 (低电阻): 纳伏表和低电流源

Model 2182A纳伏表

- 1nV灵敏度
- 双通道
- Delta模式测量 (反向电流) 模式

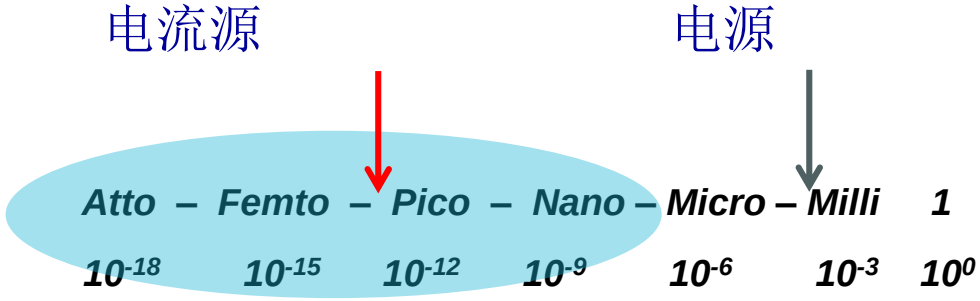
电压灵敏度



Models 6220/21电流源

- 100fA源分辨率
- AC / 任意波形发生(6221)

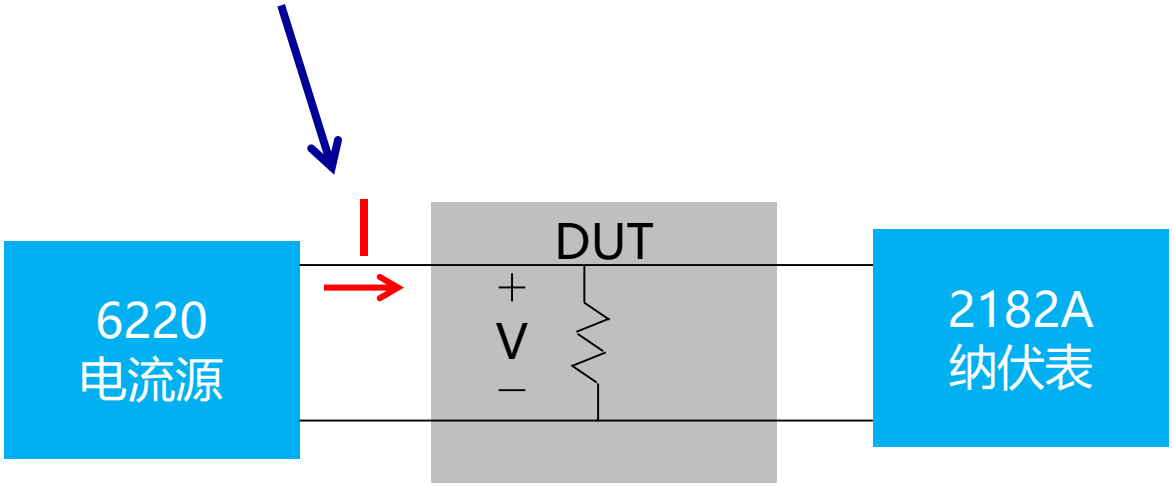
电流灵敏度

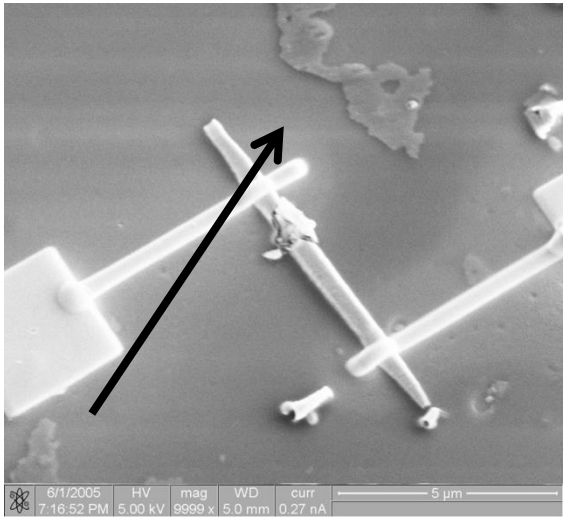


最大低电阻测量精度 – 消除自热

我们较其他低电阻测量解决方案的主要优势:

- 只向器件施加非常非常小的电流, 100fA

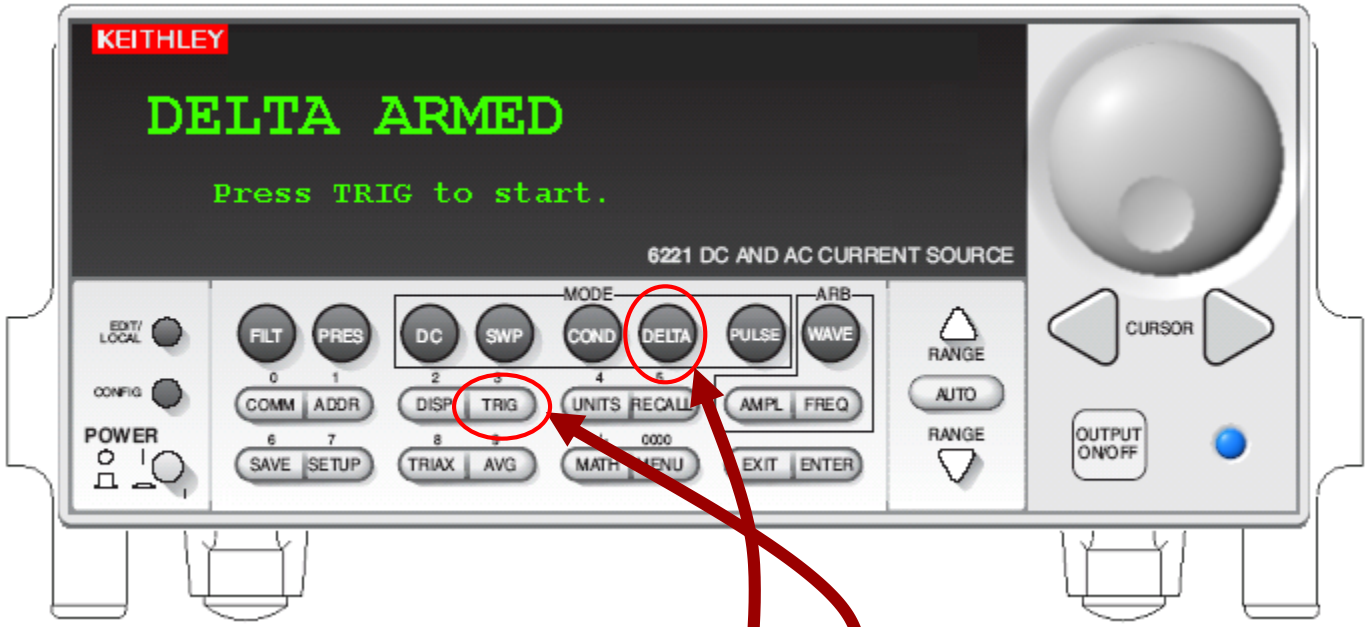




纳米线由于自热熔化

Improved Delta Mode is EASY to USE!
改进的Delta模式非常易于使用！

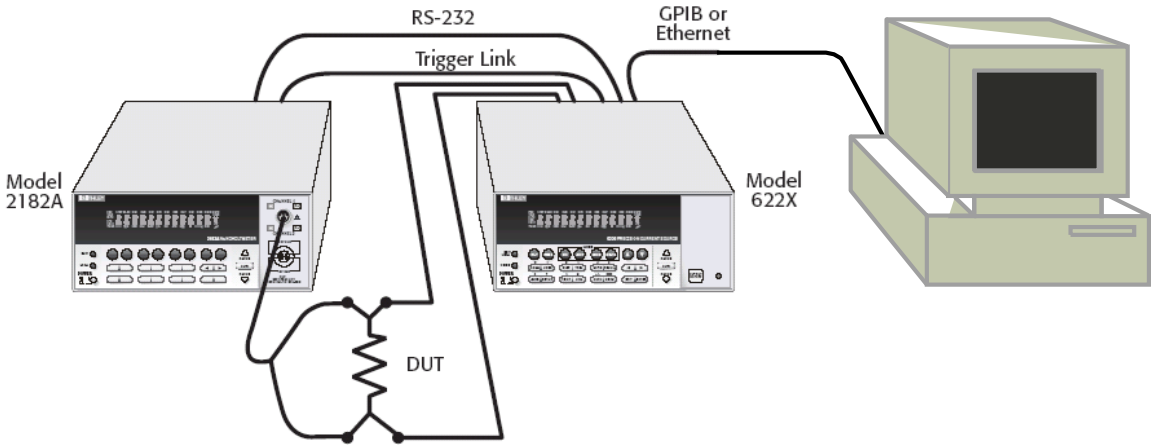
6220 or 6221 & 2182A



- First Press DELTA to arm
- Then Press TRIG to execute
- 6220 or 6221& 2182A also can be used with free software

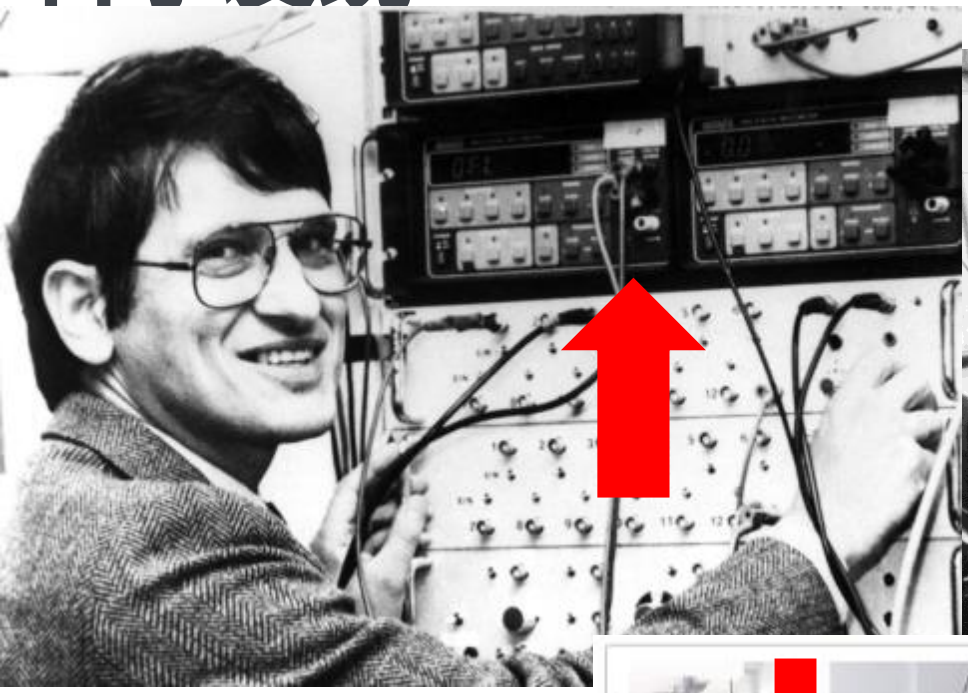
The BEST Low Resistance Solution EVER!
目前为止最好的低阻测试解决方案！

6220 or 6221/ 2182A Delta Mode



622X controls the 2182A. The pair act as a single instrument for trouble-free programming and operation.

研究人员使用我们的灵敏仪器，获得伟大的科学发现



Dr. Klaus von Klitzing
1985年诺贝尔物理学奖
量子化霍尔效应

Dr. K. Alexander Muller和
Dr. J. Georg Bednorz
1987年诺贝尔物理学奖
陶瓷材料超导

Dr. Konstantin Novoselov
2010年诺贝尔物理学奖
石墨烯 (二维材料)

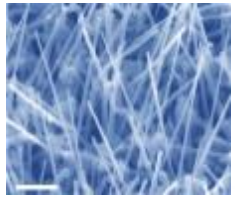
Tektronix

高阻Hi R、低流 Low I

$$R = \frac{V}{I}$$

高电阻或低电流测量应用

常见应用	测量
纳米材料研究 电化学测量	绝缘电阻 表面电阻系数 体积电阻系数
纸、橡胶制品、塑料的电阻系数	表面电阻系数 体积电阻系数
继电器、电缆或连接器的绝缘电阻	绝缘电阻 电压系数
材料特性分析	波束电流 霍尔效应
半导体特性分析	泄漏电流 暗电流 击穿电压



Electrometer Overview
静电计概览

Electrometers measure volts, ohms and amps - - just like a DMM (plus charge)

- Low-current measurement低电流测试
- High-input impedance on volts高输入阻抗电压测试
- High-resistance measurements高阻测试

NOTE: An electrometer is **not** a good choice for low-voltage measurements.

注：静电计不是低压测试的理想选择

吉时利灵敏仪器旗舰产品：静电计

测量超高电阻和超低电流

Model 6517B静电计/高电阻仪表

多功能(电压, 电流, 电阻)
- ❑测量超高电阻 – $10^{18}\Omega$
- ❑测量超低电流 - 10aA ($10x10^{-18}A$) 分辨率
- ❑DC电压及超高输入阻抗 – 200TΩ
- ❑±1000V源 (仅6517B)
- ❑测量电荷

电流灵敏度

电表 DMM

Atto – Femto – Pico – Nano – Micro – Milli 1 Kilo – Mega – Giga – Tera – Peta – Exa

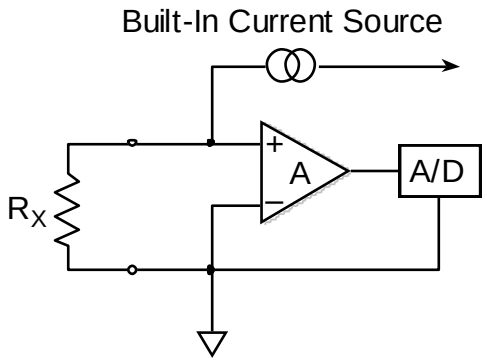
10^{-18} 10^{-15} 10^{-12} 10^{-9} 10^{-6} 10^{-3} 10^{0} 10^{3} 10^{6} 10^{9} 10^{12} 10^{15} 10^{18}

最大电阻

DMM 电表

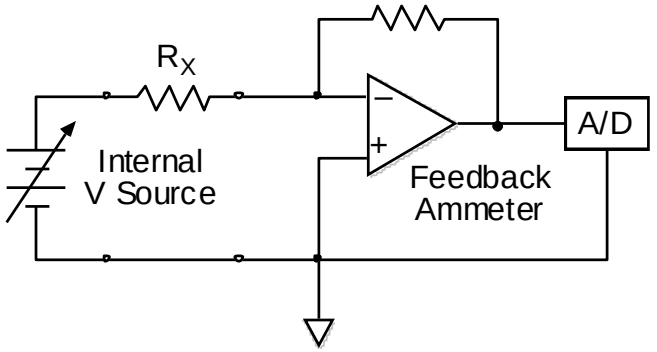
High-Resistance Measurements
高阻测试

High-Resistance Measurements - - 200GΩ to 200TΩ



Model 6514

(apply constant I, measure V)

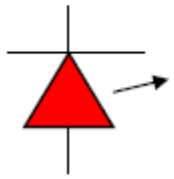


Model 6517B, 6487

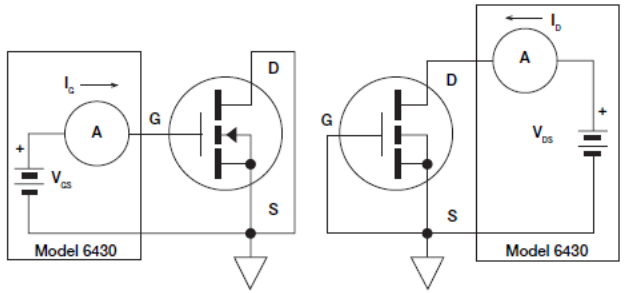
(apply constant V, measure I)

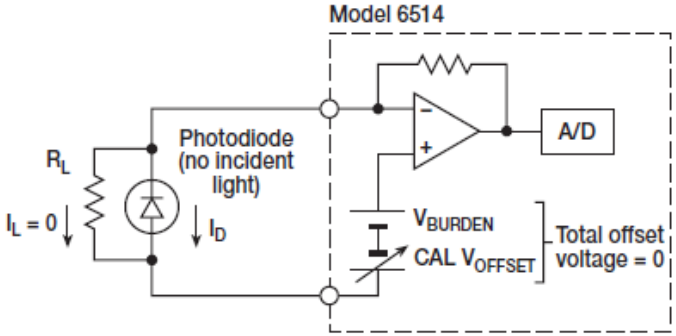
Low current measurement applications
低电流测试应用

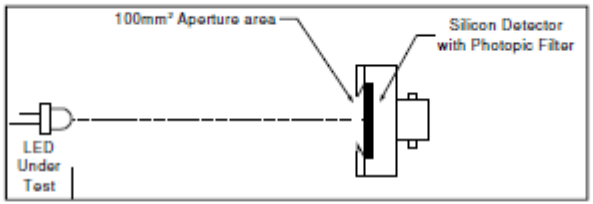
- 热释光发光电流测试
- 荧光计与光谱仪测试
- 光电倍增管电流测试
- 扫描电子显微镜电流测试
-
-



Measuring FET Gate Leakage & Channel Currents







Spectrometer

6485 Picoammeter

Low Current Measurement Capability
低电流测试能力

- Current is most used function of electrometers

  测电流是静电计使用最多的功能

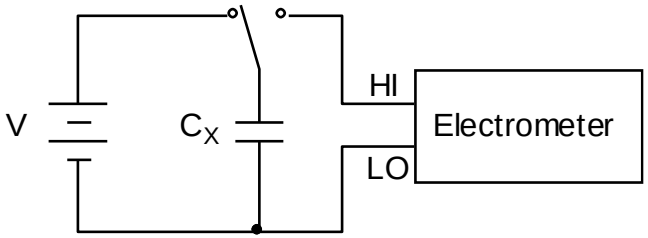
- Low range – to fA and aA (1E-15 and 1E-18)
  低量程—可到fA & aA

- Low offset current (<5fA vs. 100pA for DMM)
  低偏置电流

- Low voltage burden
  低输入分压

  - Feedback ammeter not a shunt ammeter反馈式安培表而不是分流安培表
  - <1mV vs. 200mV for DMM

High-Input Impedance, >200TΩ
高输入阻抗，＞200TΩ



Example:

Electrometer used to measure voltage on a capacitor

NOTE: An electrometer is **NOT** a good choice for low voltage measurements. A nanovoltmeter, like a 2182, should be used.

注：静电计不是低压测试的理想选择。应选择纳伏表，如2182.

High impedance Voltage measurement applications
高阻抗电压测试应用

- Resistivity measurements of semiconductors

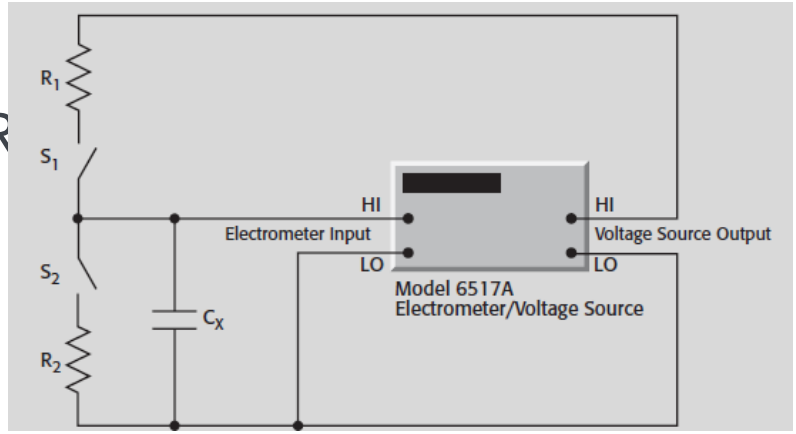
  半导体的电阻率测试

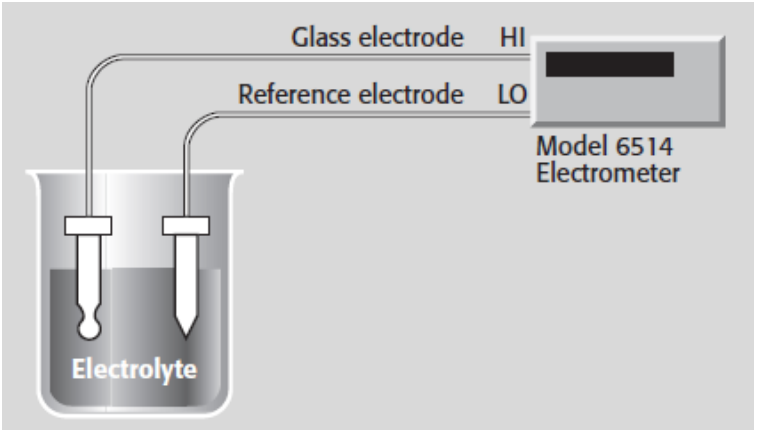
- PH electrode measurements

  PH电极测量

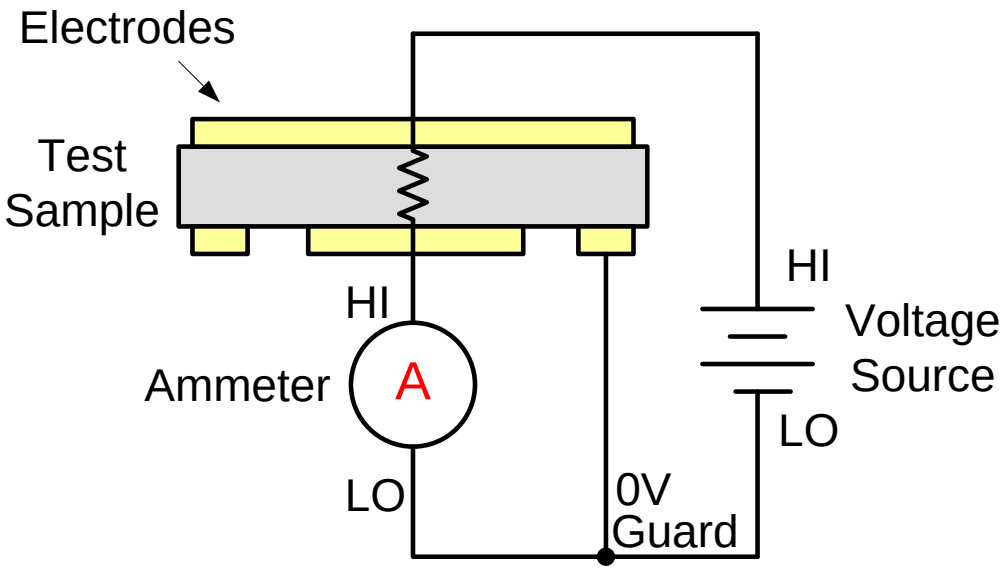
- Dielectric absorption of capacitors

- R

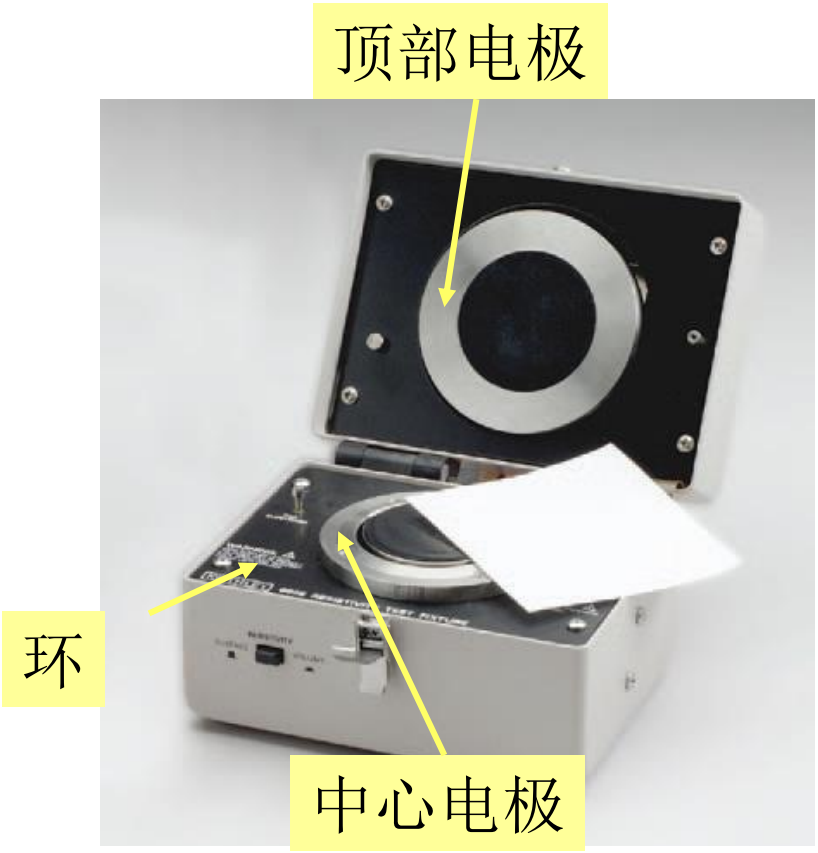




使用Model 8009电阻系数测试夹具测量体积或表面电阻



体积电阻系数用来衡量经过材料的泄漏电流。



Model 8009
夹具盒

感谢！