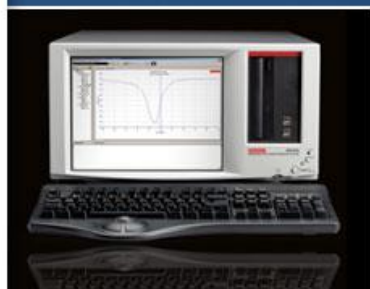


# Implementation of a nanovoltmeter as an alternate detector in the MI 6000B Automatic Resistance Bridge



**Nick Zallar · Slavik Moskalets**

**Keithley Instruments, Inc**

**NCSLI Workshop and Symposium · National Harbor · MD  
August 2011**

**KEITHLEY**

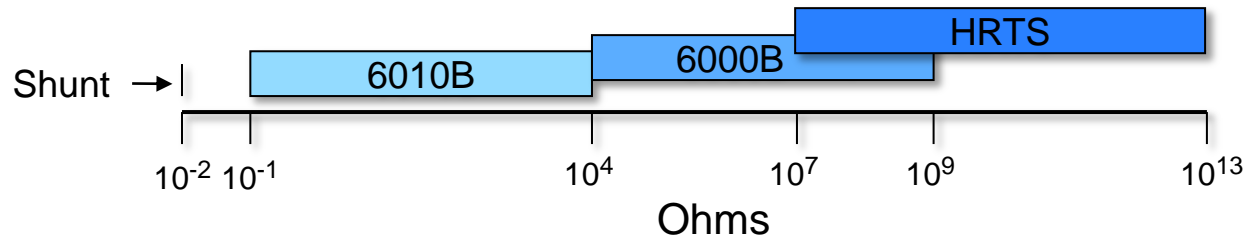
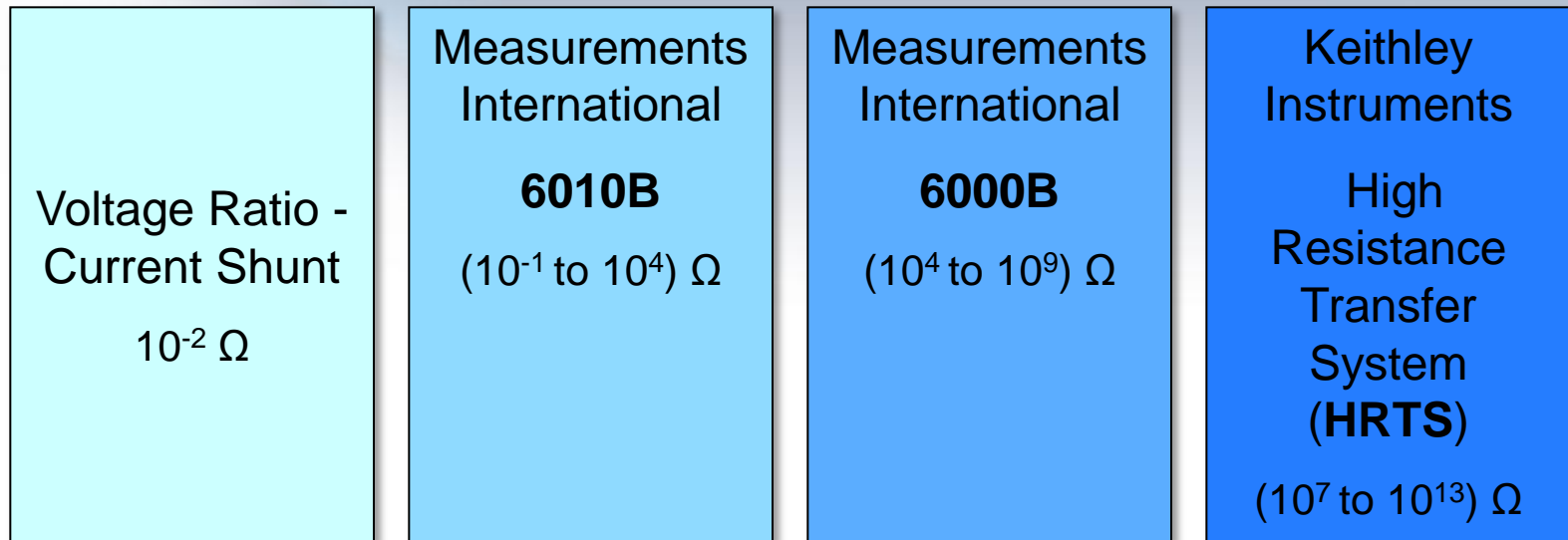
A GREATER MEASURE OF CONFIDENCE

## Goals

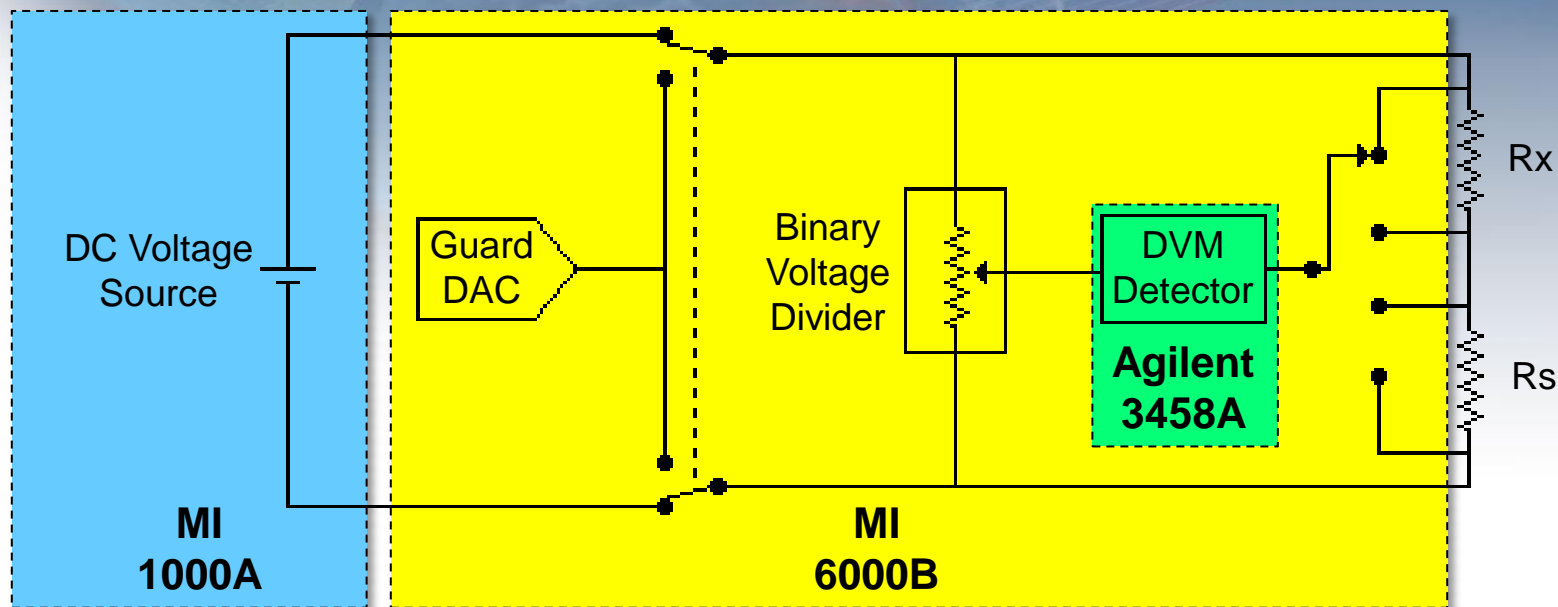
- **Show 6000B Configuration Settings To Enable 2182A Usage**
- **Demonstrate Validation Of Changes**
- **Describe Software Written To Increase 6000B Automation**

# Keithley Instruments Resistance Measurement Systems

ISO/IEC 17025:2005 DC Resistance Generate/Measure



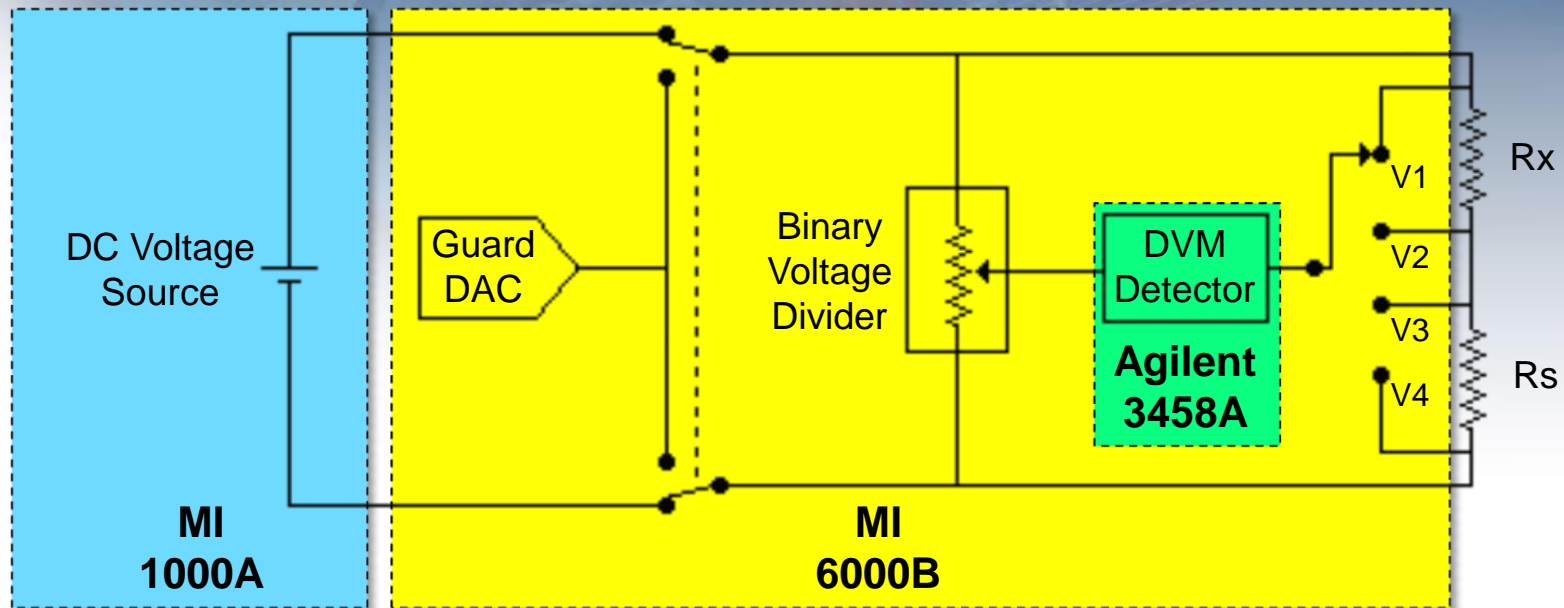
# Original MI 6000B Configuration



## System Components

- MI 6000B Bridge
- MI 1000A Precision DC Voltage Source
- Agilent 3458A Used As A Voltage Detector
- MI 4220A Low-Thermal Matrix Scanner (not shown)

# Original MI 6000B Configuration



## 6000B Operation

- 13-Bit Binary Voltage Divider (Resolution = 1 / 8192)
- BVD Programmed For Minimum Detector Reading For V1, V2, V3, And V4

- Final Ratio  $R = \frac{R_x}{R_s} = \frac{V_1 - V_2}{V_3 - V_4}$



# 6000B Software



## 6000B System Software

- Controls/Communicates With System Instruments
- Customizable Resistor Database And Measurement Programs
- Provision For Manual DVM Detector Configuration

# DMM Features

## Agilent 3458A



- DC Voltage
- DC Current
- 2W/4W Resistance
- AC Voltage
- AC Current
- Frequency & Period
- Digitizing Mode

## Keithley 2182A



- DC Voltage

# DMM Features

## Agilent 3458A



### DC Voltage

- 100mV Lowest Range
- 10nV Resolution
- Guarded

## Keithley 2182A

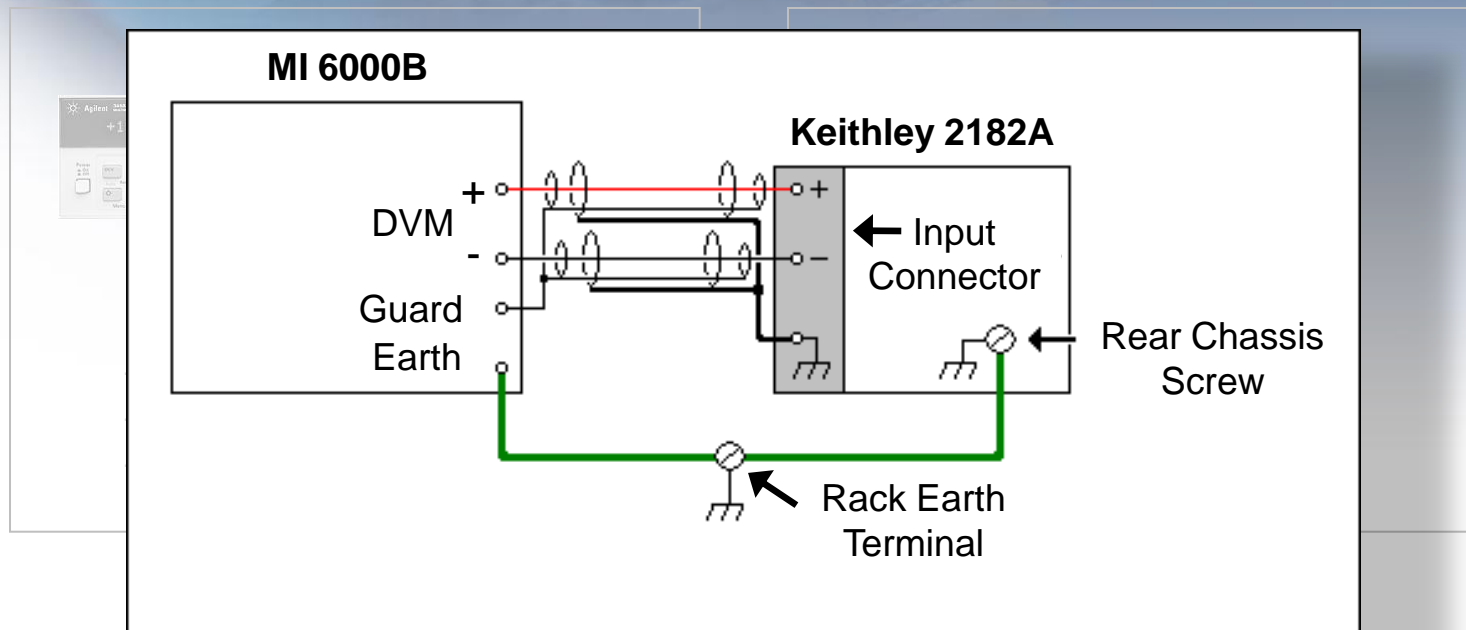


### DC Voltage

- 10mV Lowest Range
- 1nV Resolution
- Un-Guarded

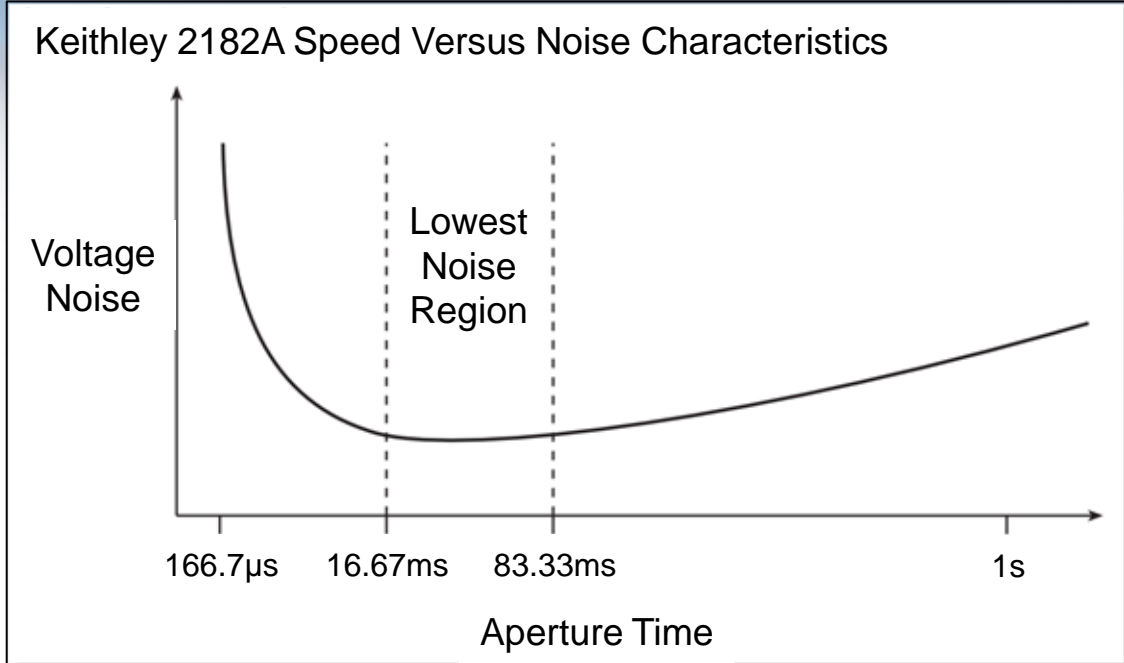


# DMM Features



## DVM Guard Configuration

- 2182A – No Provision For Guarding
- Custom Cabling/Fixturing
  - Guards Measurement to Front Terminals Of 2182A
  - Two 12-Inch Lengths Of Triax Cable



2182A Is Optimized For Measurements Between 1 And 5 NPLC's

## Resistance Standards Used

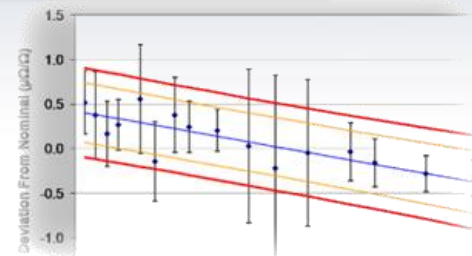
- 10k $\Omega$  Through 1G $\Omega$  Standards Were Used To Verify System Operation
- All Resistance Standards In Use Have An Associated Control Chart
- Existing Control Charts Aid In Optimizing 6000B Configuration Settings For 2182A
- Historical Data For 10k $\Omega$  Resistors Provided By NIST
- Historical Data For Resistors In The 100k $\Omega$  to 1G $\Omega$  Range Based On 6000B/3458A

# 6000B / 2182A Configuration Strings

Modify 2182A Configuration Strings

Characterize a Resistor on the 6000B / 2182A

Plot Value on Control Chart



# 6000B Resistance Measurement Program Parameters

Resistance Low – Hi	Voltage	Interchange	Settle Time	# of DVM Readings	# of Measurements	# of Stats
$10^4 - 10^4$	<b>20</b> (10)	<b>Yes</b> (No)	<b>8</b>	<b>15</b>	<b>6</b>	<b>5</b>
$10^4 - 10^5$	<b>20</b> (10)	<b>Yes</b> (No)	<b>12</b>	<b>15</b>	<b>6</b>	<b>5</b>
$10^5 - 10^6$	<b>50</b> (10)	<b>Yes</b> (No)	<b>16</b>	<b>20</b>	<b>6</b>	<b>5</b>
$10^6 - 10^7$	<b>100</b> (10)	<b>Yes</b> (No)	<b>20</b>	<b>25</b>	<b>6</b>	<b>5</b>
$10^7 - 10^8$	<b>100</b> (10)	<b>Yes</b> (No)	<b>45</b>	<b>30</b>	<b>6</b>	<b>5</b>
$10^8 - 10^9$	<b>100</b>	<b>No</b>	<b>60</b>	<b>30</b>	<b>6</b>	<b>5</b>

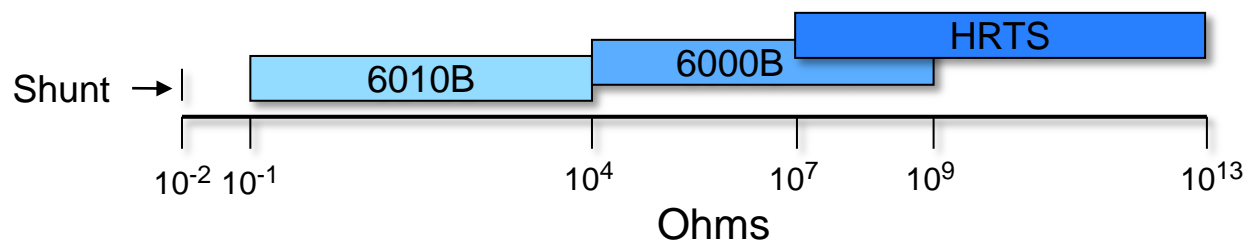
Parameter Values In Parentheses ( ) Indicate Where Our Existing Program Values Differed From MI-Recommended Values.



# 6000B Resistance Measurement Program Parameters

Resistance Low – Hi	Voltage	Interchange	Settle Time	# of DVM Readings	# of Measurements	# of Stats
$10^4 - 10^4$	20 (10)	Yes (No)	8	15	6	5
$10^4 - 10^5$	20 (10)	Yes (No)	12	15	6	5
$10^5 - 10^6$	50 (10)	Yes (No)	16	20	6	5
$10^6 - 10^7$	100 (10)	Yes (No)	20	25	6	5
$10^7 - 10^8$	100 (10)	Yes (No)	45	30	6	5
$10^8 - 10^9$	100	No	60	30	6	5

Parameter Values In Parentheses () Indicate Where Our Existing Program Values Differed From MI-Recommended Values.



# 6000B Software Settings for DVM

Parameter	Value
Microvolt Range	: SENS : VOLT : RANG : <b>AUTO ON</b>
Auto Range	: SENS : VOLT : RANG : AUTO ON
Termination Char	<i>[Leave Blank]</i>
Reading Trigger	: READ?
Reading Rate	<i>[Leave Blank]</i>
Setup Function	*RST ; : SYST : <b>LSYN : STAT ON</b> ; : SENS : VOLT : <b>NPLC 5</b> ; : SENS : VOLT : DFIL : STAT ON ; : SENS : VOLT : <b>DFIL : COUN 2</b> ; : SENS : VOLT : DFIL : WIND 1 ; : SENS : VOLT : DFIL : <b>TCON MOV</b> ; : SENS : VOLT : <b>LPAS ON</b>

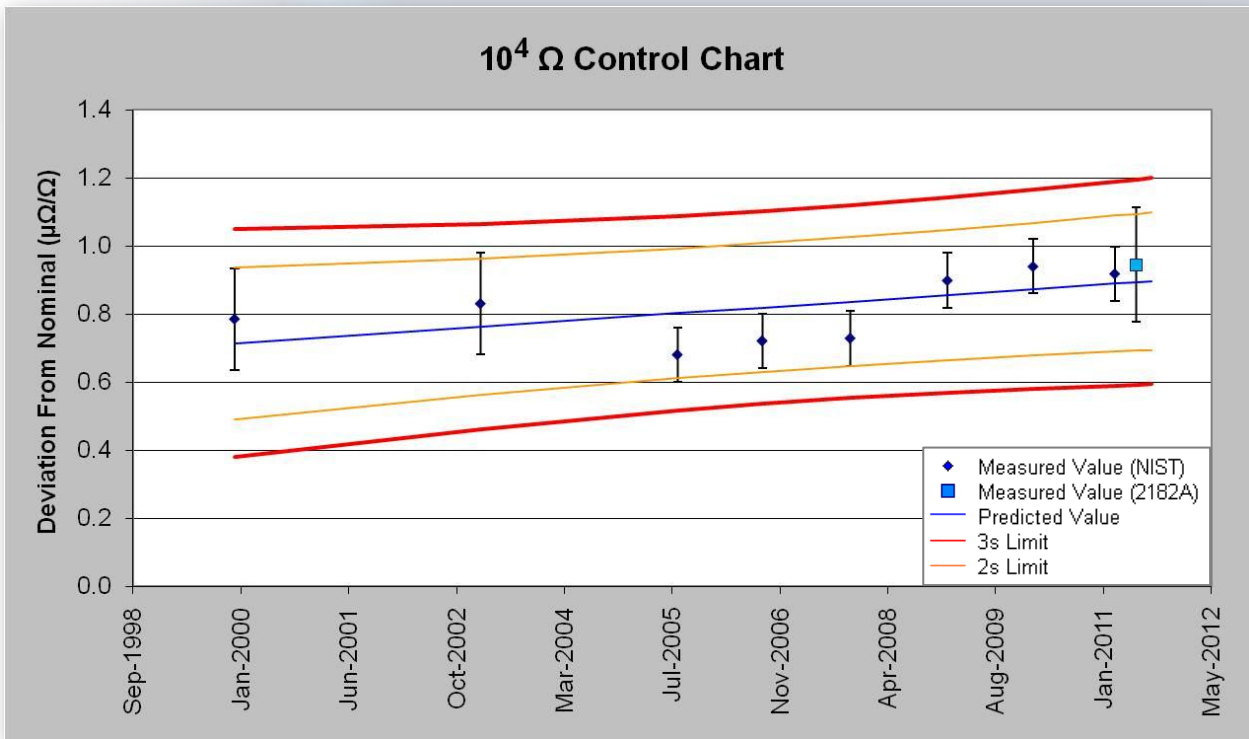
## DVM Settings Configuration

- Settings Yielded Results Equivalent To Historical 6000B Data
- Microvolt Range -> 'AUTO'
  - Recall 13-Bit BVD Resolution Is  $1 / 8192 = \sim 0.000122$
  - Max Voltage At DVM When Running System At 100V Is  $\sim 12.2$  mV

# 10 kΩ Measurement Results

## Measurement Details 1:1 Ladder

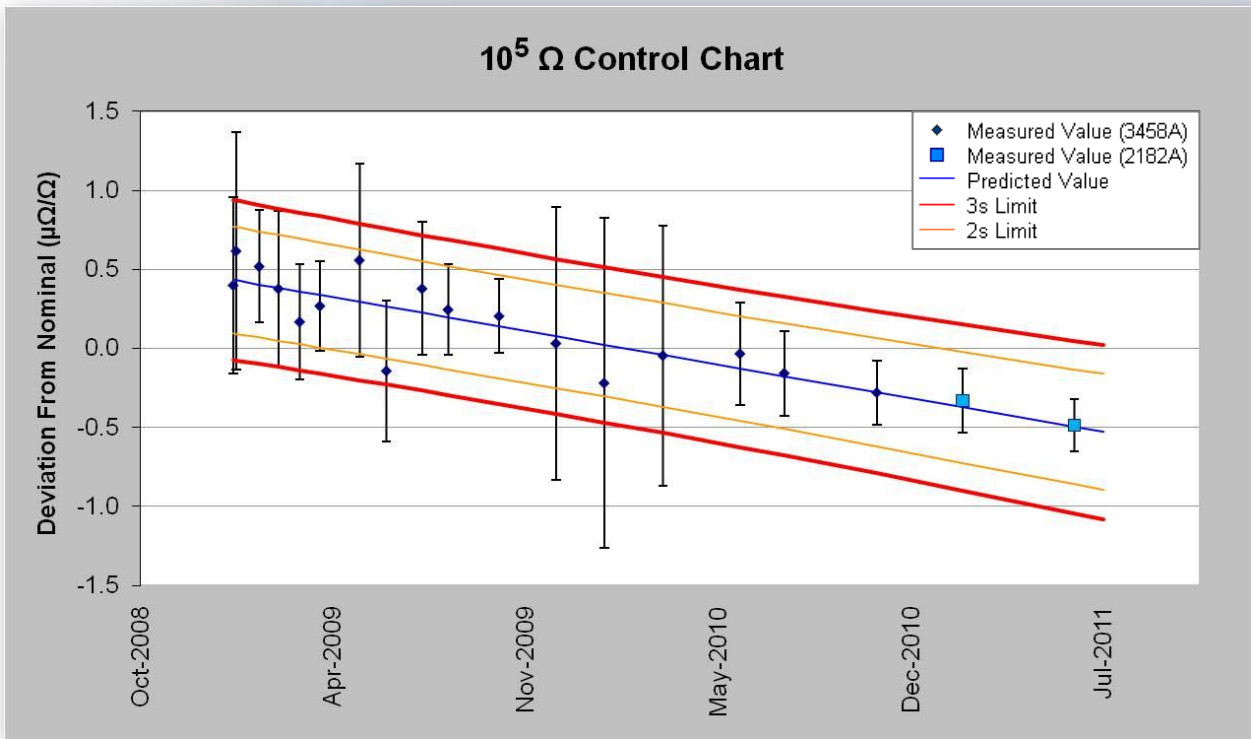
	Model Number	Historical Data Source
<b>Rs</b>	ESI SR-104	NIST
<b>Rx</b>	ESI SR-104	NIST



# 100 kΩ Measurement Results

## Measurement Details 1:10 Ladder

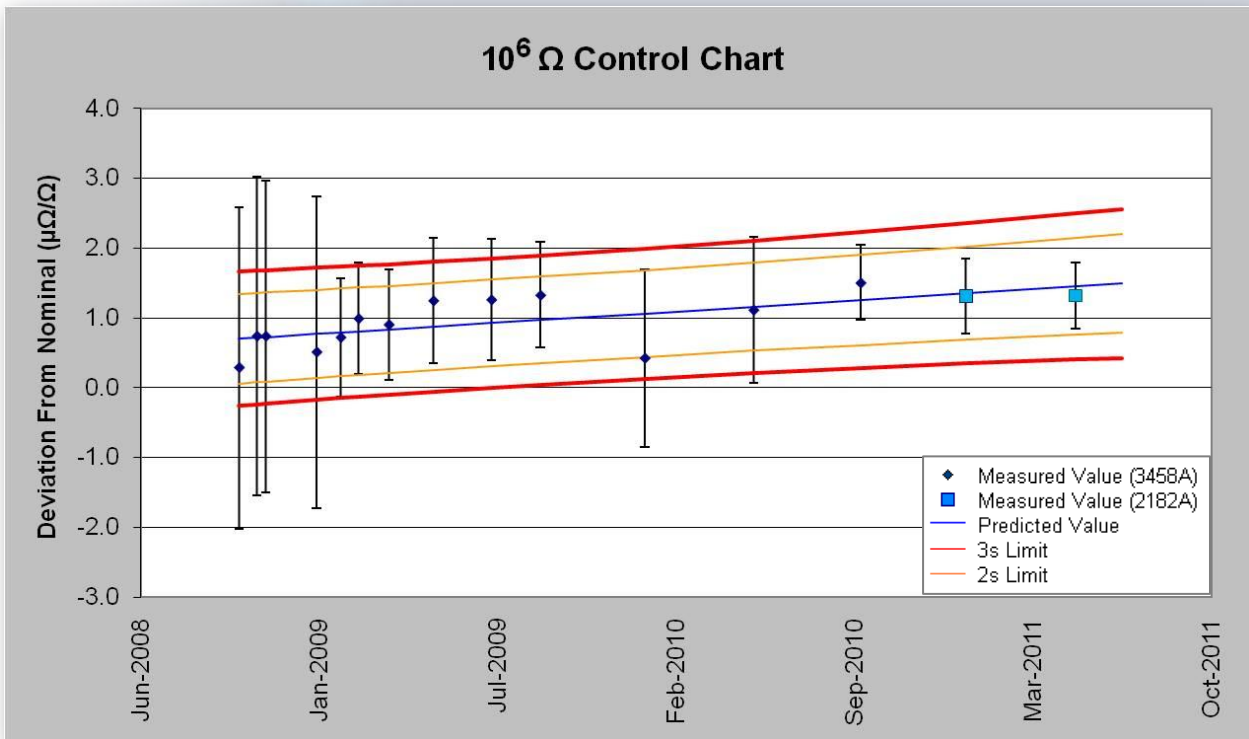
	Model Number	Historical Data Source
<b>Rs</b>	ESI SR-104	NIST
<b>Rx</b>	MI 9331/100k	6000B / 3458A



# 1 MΩ Measurement Results

## Measurement Details 1:10 Ladder

	Model Number	Historical Data Source
<b>Rs</b>	MI 9331/100k	6000B / 3458A
<b>Rx</b>	Fluke 742A-1M	6000B / 3458A

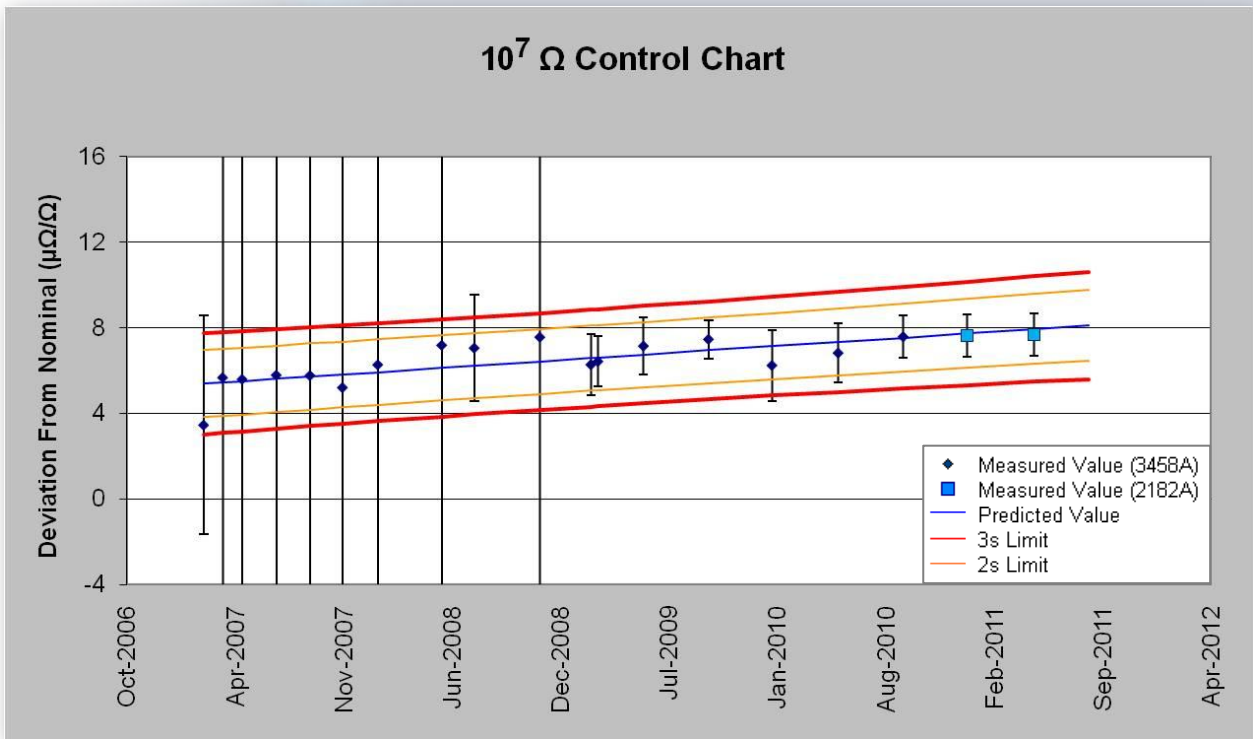




# 10 MΩ Measurement Results

## Measurement Details 1:10 Ladder

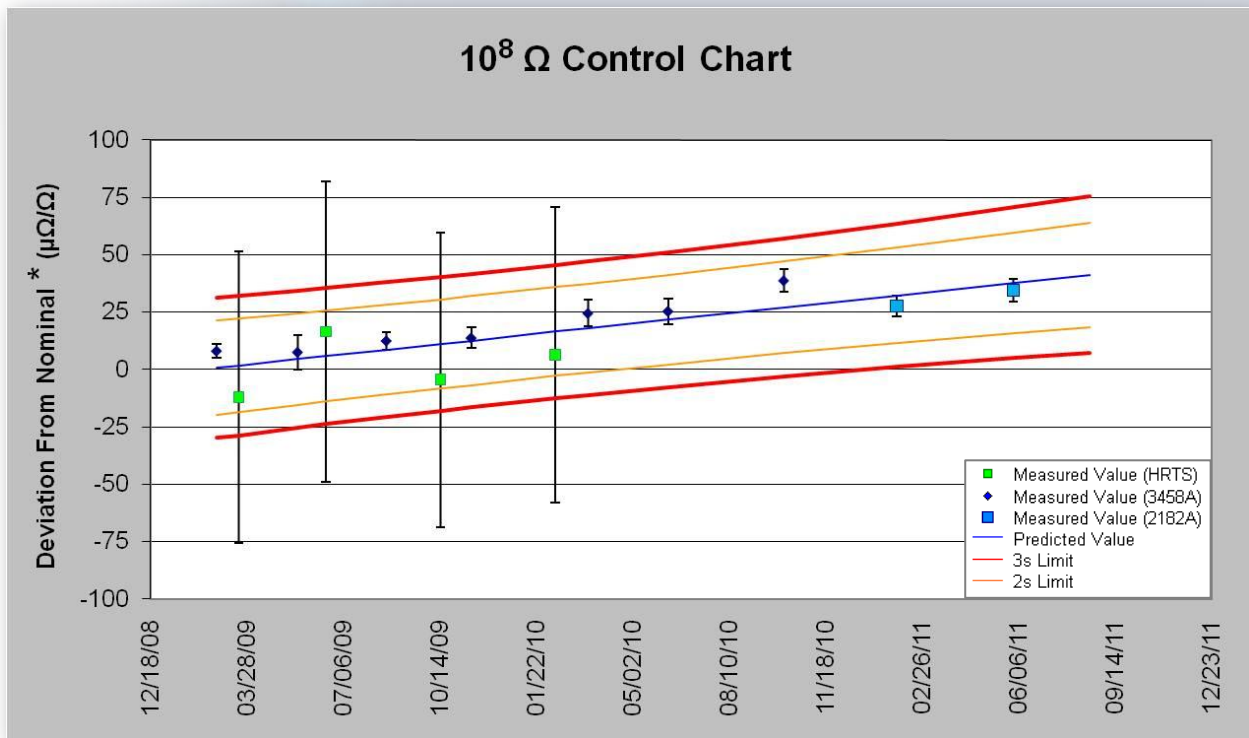
	Model Number	Historical Data Source
<b>Rs</b>	Fluke 742A-1M	6000B / 3458A
<b>Rx</b>	Fluke 742A-10M	6000B / 3458A



# 100 MΩ Measurement Results

## Measurement Details 1:10 Ladder

Model Number	Historical Data Source
Rs Fluke 742A-10M	6000B / 3458A
Rx Keithley 5155-8	HRTS + 6000B / 3458A

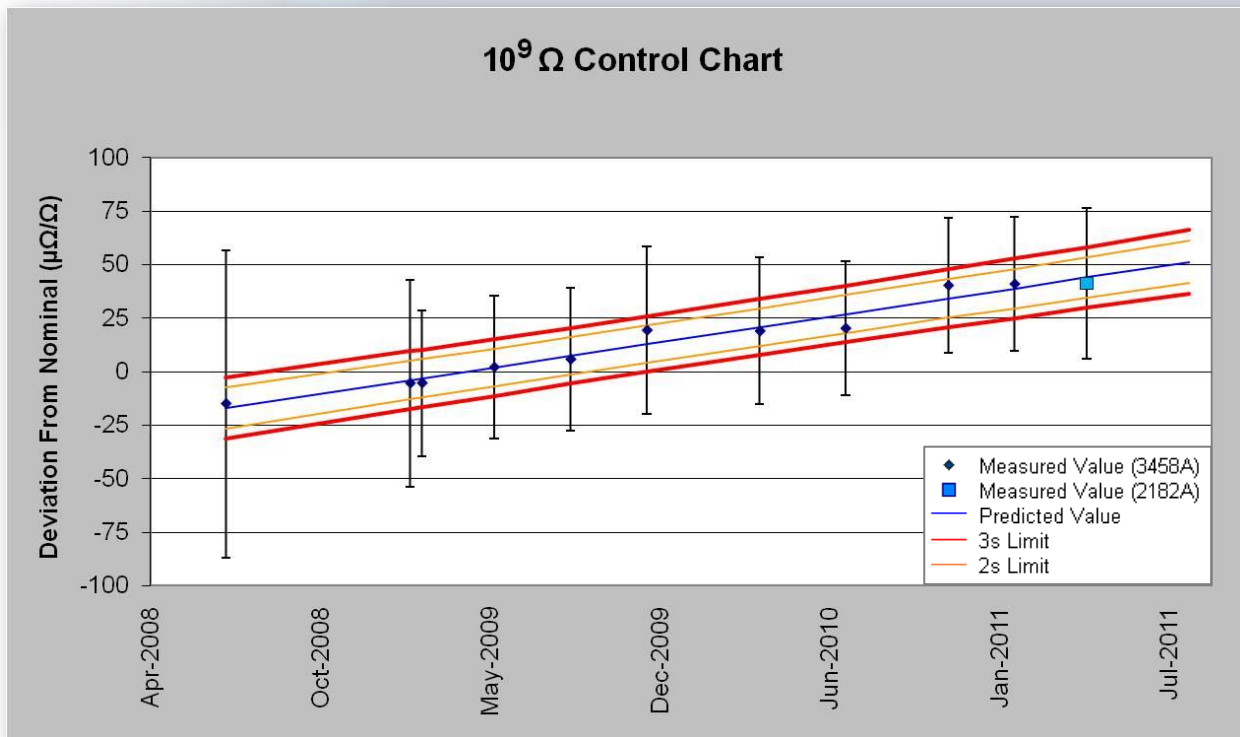


\* Nominal Value is 1.0037 x 10<sup>8</sup> Ω

# 1 GΩ Measurement Results

## Measurement Details 1:10 Ladder

	Model Number	Historical Data Source
<b>Rs</b>	Keithley 5155-8	HRTS + 6000B / 3458A
<b>Rx</b>	MI 9331G/1G	6000B / 3458A



# Measurement Results Overview

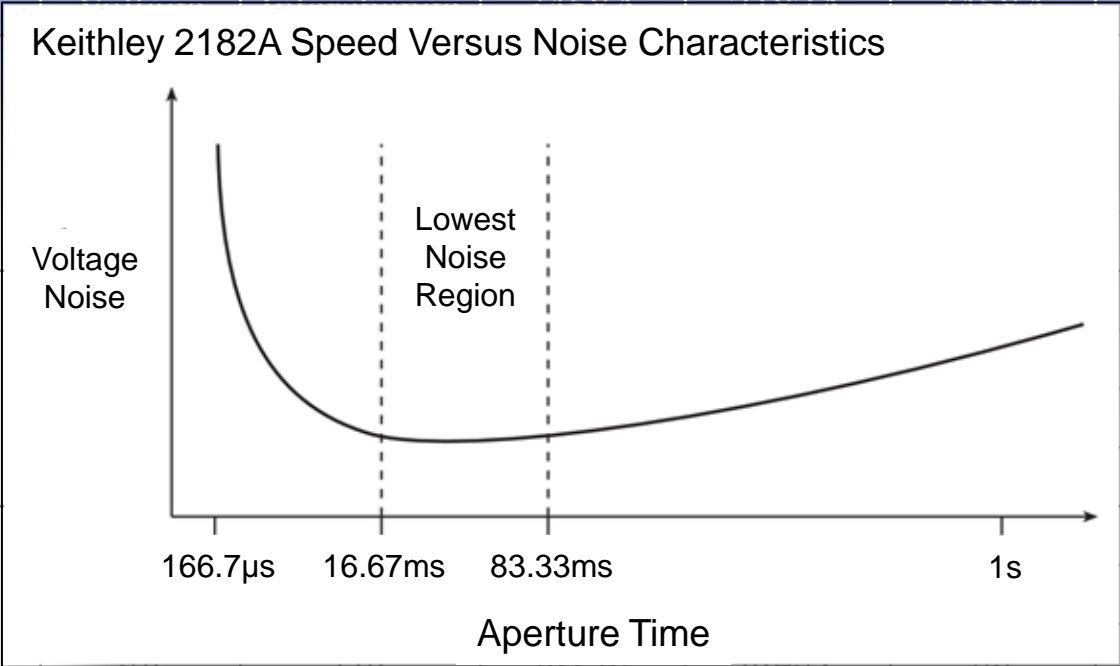
Resistance Low – Hi	Voltage	Interchange	Ratio Uncertainty ( $\mu\Omega/\Omega$ )		Execution Time (minutes)	
			3458A	2182A	3458A	2182A
$10^4 - 10^4$	<b>10</b>	<b>No</b>	<b>0.127</b>	<b>0.047</b>	<b>27</b>	<b>22</b>
	10	Yes	0.093	0.015	22	18
	20	No	0.027	0.014	27	22
	20	Yes	0.067	0.015	22	18
$10^4 - 10^5$	<b>10</b>	<b>No</b>	<b>0.427</b>	<b>0.222</b>	<b>28</b>	<b>24</b>
	10	Yes	0.313	0.158	23	20
	20	No	0.260	0.095	28	24
	20	Yes	0.150	0.039	23	20
$10^5 - 10^6$	<b>10</b>	<b>No</b>	<b>0.443</b>	<b>0.364</b>	<b>35</b>	<b>28</b>
	10	Yes	0.319	0.643	28	24
	50	No	0.143	0.231	35	28
	50	Yes	0.073	0.121	28	24

- **Using MI-Recommended Values For Settle Time, Number Of DVM Readings, Number Of Measurements, And Number Of Statistics**
- Similar Ratio Uncertainties Reported By The System
- Execution Time Benefit With 2182A



# Measurement Results Overview

Resistance	Ratio Uncertainty	Execution Time
Low – Hi	( $\mu\Omega/\Omega$ )	(minutes)
$10^4 - 10^4$	0.073	22
$10^4 - 10^5$	0.121	18
$10^5 - 10^6$	0.073	22
	0.121	18
	0.121	24
	0.121	20
	0.121	24
	0.121	20
	0.121	28
	0.121	24
	0.121	28
	0.121	24



- **Using MI-Recommended Values For Settle Time, Number Of DVM Readings, Number Of Measurements, And Number Of Statistics**
- **Similar Ratio Uncertainties Reported By The System**
- **Execution Time Benefit With 2182A**



# Measurement Results Overview

Resistance Low – Hi	Voltage	Interchange	Ratio Uncertainty ( $\mu\Omega/\Omega$ )		Execution Time (minutes)	
			3458A	2182A	3458A	2182A
$10^6 - 10^7$	<b>10</b>	<b>No</b>	<b>0.332</b>	<b>0.379</b>	<b>41</b>	<b>33</b>
	10	Yes	0.224	0.166	34	27
	100	No	0.017	0.036	41	33
	100	Yes	0.029	0.028	34	27
$10^7 - 10^8$	<b>10</b>	<b>No</b>	<b>3.02</b>	<b>2.78</b>	<b>60</b>	<b>49</b>
	10	Yes	1.02	1.79	51	43
	100	No	3.34	1.43	60	49
	100	Yes	0.722	0.676	51	43
$10^8 - 10^9$	20	No	3.34	3.21	66	55
	<b>100</b>	<b>No</b>	<b>2.17</b>	<b>3.07</b>	<b>66</b>	<b>55</b>

- **Using MI-Recommended Values For Settle Time, Number Of DVM Readings, Number Of Measurements, And Number Of Statistics**
- Similar Ratio Uncertainties Reported By The System
- Execution Time Benefit With 2182A

# Independent Measurement Results

- 1 G $\Omega$  Inter-laboratory Comparison Conducted Between Measurements International (OEM) And Keithley With Passing Results
- 1 G $\Omega$  Proficiency Test Performed With Accredited PT Provider With Passing Results

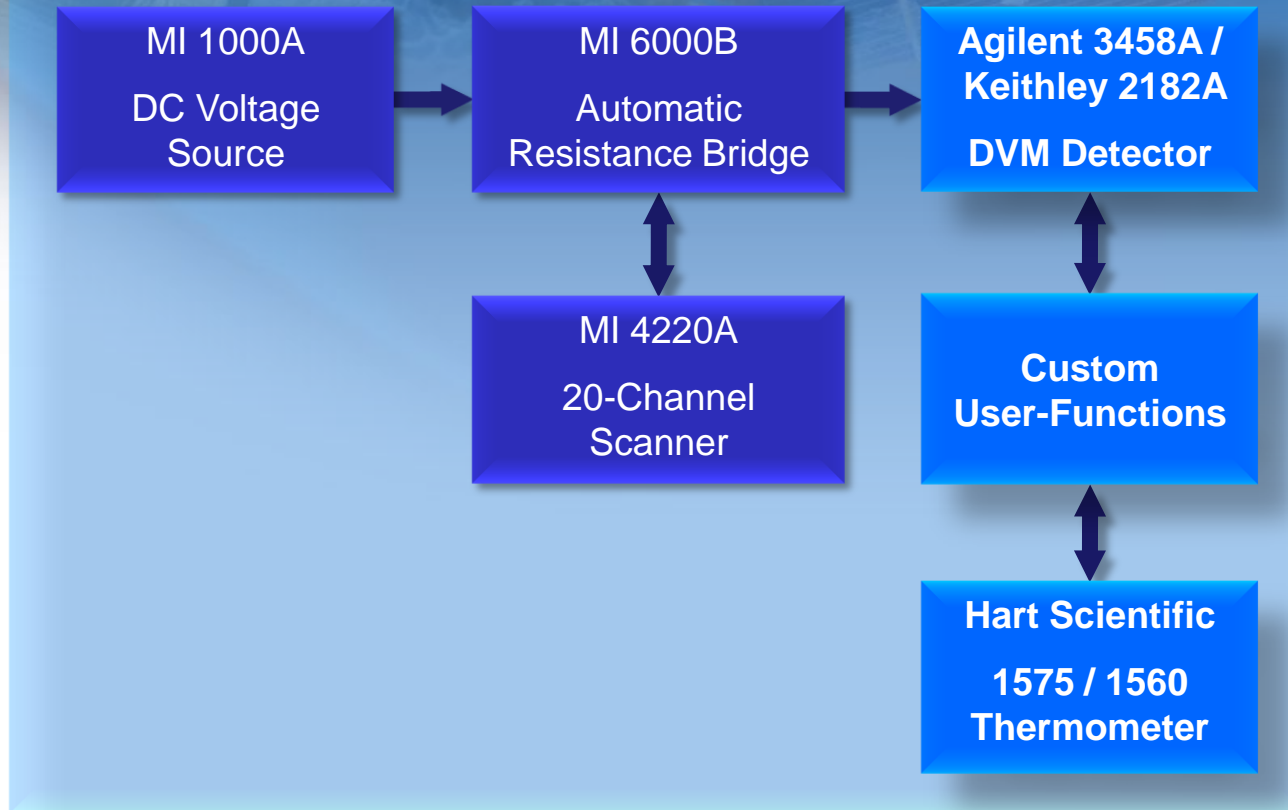
## Measurement Results Overview

- Reduced MI-Recommended Settings For *Settle Time* And *Number Of DVM Readings* By Half
- Cut Execution Times Nearly 50% From Those In Previous Table Without Increasing Measurement Noise Or Offset In Resistance Measurement Through  $10^8\Omega$
- Measurements Were Made With Keithley-Supplied 2182A Cable With Acceptable Results; However, The System Could Not Support Such Dramatic Reductions In *Settle Time*
- All Measurements Were Made Using Laboratory-Grade Low-Capacitance Cabling. Lesser Grade Cabling Will Not Achieve The Same Performance, Especially With Reduced Settings

## Measurement Results Overview

- Reduced MI-Recommended Settings For *Settle Time* And *Number Of DVM Readings* By Half
- Cut Execution Times Nearly 50% From Those In Previous Table Without Increasing Measurement Noise Or Offset In Resistance Measurement Through  $10^8\Omega$
- Measurements Were Made With Keithley-Supplied 2182A Cable With Acceptable Results; However, The System Could Not Support Such Dramatic Reductions In *Settle Time*
- All Measurements Were Made Using Laboratory-Grade Low-Capacitance Cabling. Lesser Grade Cabling Will Not Achieve The Same Performance, Especially With Reduced Settings (**...Or during an earthquake**)

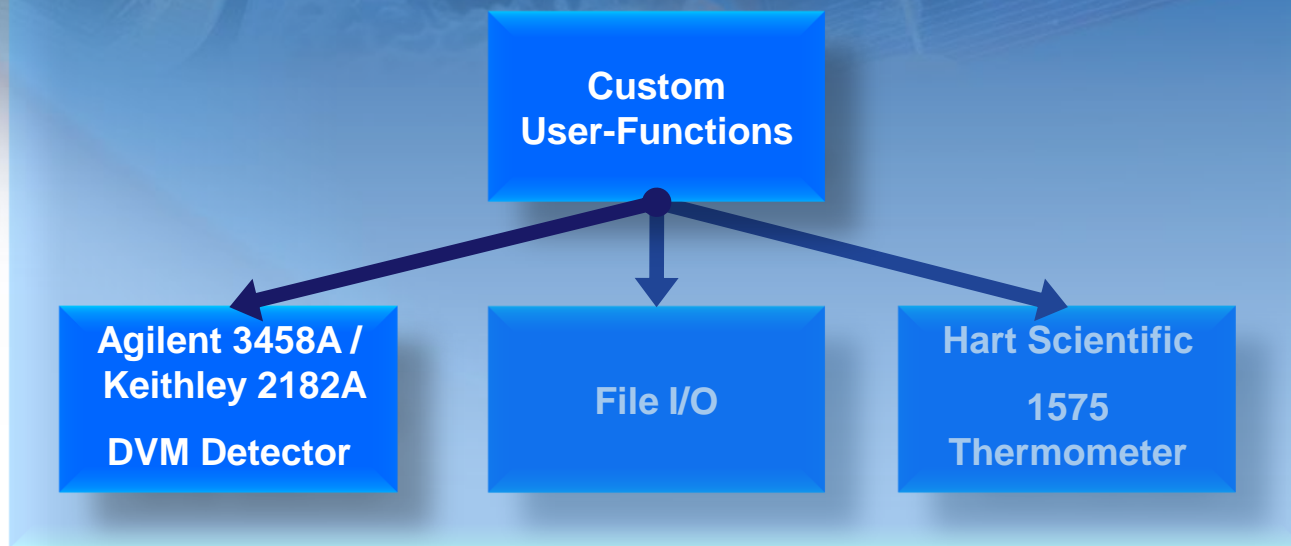
## 6000B Software Package



- 6000B Software Functionality Extended Through **Custom User-Functions**
- User-Functions Compiled As A Dynamically Linked Library (.DLL)
- Up to 20 User Functions Possible



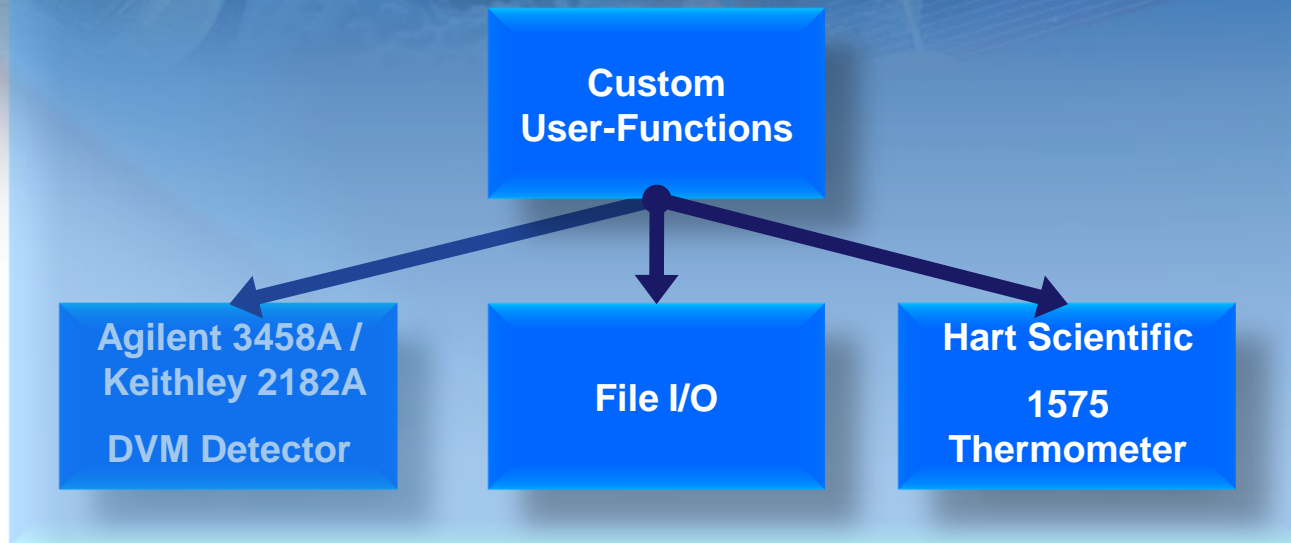
## 6000B Software Package



### Keithley Custom User-Functions

- DVM Detector Utilities
  - 3458A: ACAL DCV
  - 2182A: ACAL LVL

## 6000B Software Package



### Keithley Custom User-Functions

#### Hart SuperThermometer

- Temperature Measure [Start]
- Temperature Measure [Stop]
- Measurement Parameters Configured Through .INI File (Plain Text)
- Continuously Samples Rs And Rx Temperatures During Resistor Characterization
- Returns Temperature Measurement Statistics

# Screenshots of User Functions

**System DVM | ACAL Function**

**System DVM Info:**

Manufacturer:  Rev.:

Model:  Internal Temp.:

Serial:  Last ACAL Temp.:

**Operation Status**

SELF-TEST [PASSED]  
 ACAL LOW-LVL  
 ERROR CHECK

6/10/2011 4:44 PM

**Hart Scientific 1575 | Stop Temperature Measurements**

**Current Measurements**

CH1 [S/N: 3104]	CH2 [S/N: 602]
<b>23.7384 C</b>	<b>22.3804 C</b>
AVERAGE: 23.7374 C	AVERAGE: 22.5199 C
STDEV: 0.0005 C	STDEV: 0.2006 C
MAX: 22.7384 C	MAX: 22.8295 C
MIN: 22.7367 C	MIN: 22.2187 C
SPREAD: 0.0018 C	SPREAD: 0.6108 C
Probe Number: 11	Probe Number: 5

**SAMPLING**

Sample Mode: ALT	Number of Samples: 1
Conversion Time: 10 sec.	Filter Type: Single-pole
Sample Interval: 10 sec.	Filter Reset Threshold: 0.1
Integration Time: 10 sec.	Filter Response Time: 60 sec.

**CURRENT STATUS: RUN**

**Stopping in 8 sec.**

6/9/2011 4:50 PM

# Example Temperature Log File

```

HS1575-3.log - Notepad
File Edit Format View Help
HART SCIENTIFIC 1575
START TIME: 6/8/2011 8:24:42 AM

CH 1 [S/N: 3104]
AVERAGE: 22.7449 C
STDEV: 0.0011 C
MIN: 22.7429 C
MAX: 22.7467 C
SPREAD: 0.0038 C

CH 2 [S/N: 602]
AVERAGE: 22.8749 C
STDEV: 0.0039 C
MIN: 22.8669 C
MAX: 22.8826 C
SPREAD: 0.0156 C

STOP TIME: 6/8/2011 8:43:34 AM

HART SCIENTIFIC 1575
START TIME: 6/8/2011 9:04:09 AM

CH 1 [S/N: 3104]
AVERAGE: 22.7494 C
STDEV: 0.0007 C
MIN: 22.7483 C
MAX: 22.7505 C
SPREAD: 0.0021 C

CH 2 [S/N: 602]
AVERAGE: 22.8559 C
STDEV: 0.0035 C
MIN: 22.8496 C
MAX: 22.8623 C
SPREAD: 0.0127 C

STOP TIME: 6/8/2011 9:21:33 AM

HART SCIENTIFIC 1575
    
```

Temperature System  
Start And Stop  
Times Are Logged

# Example User Function Usage

6000B Program Selection & Creation

Program File: 1 G OHM ILC    Load File    Save File    Active Program: P1

---

**Elements**

	Resistors	Settle (s)	Readings	# Mmts	# Stats
M1	mR10 mR12 L	60	15	6	5
M2	mR1 mR2 L	45	10	6	5
M3	mR2 mR3 L	50	15	6	5
M4	mR3 mR4 L	45	10	6	5
M5	mR10 mR3 L	60	15	6	5
M6	mR12 mR20 L	70	15	6	5

Type	Time	Description
W1		U9 Temperature Meas. [Start]
W2		U10 Temperature Meas. [Stop]
W3		U11 System DVM [ACAL]
W4		U12
Cal	6000B Calibration	U13

**Programs**    Clear Program

	1	2	3	4	5	6
P1	T1					
P2						
P3						
P4						
P5						
P6						
P7						
P8						
P9						
P10						
P11						
P12						

User Functions GPIB Addresses: Bath 16, Pressure 24

**Tasks**    Clear Task

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
T1	U11	Cal	U9	M1	U10										
T2															
T3															
T4															
T5															



# Example User Function Usage

6000B Program Selection & Creation

Program File: 1 G OHM ILC    Load File    Save File    Active Program: P1

**Elements**

	Resistors	Settle (s)	Readings	# Mmts	# Stats
M1	mR10 mR12 L	60	15	6	5
M2	mR1 mR2 L	45	10	6	5
M3	mR2 mR3 L	50	15	6	5
M4	mR3 mR4 L	45	10	6	5
M5	mR10 mR3 L	60	15	6	5
M6	mR12 mR20 L	70	15	6	5

Type	Time	Description
W1		U9 Temperature Meas. [Start]
W2		U10 Temperature Meas. [Stop]
W3		U11 System DVM [ACAL]
W4		U12
Cal	6000B Calibration	U13

User Functions GPIB Addresses: Bath 16, Pressure 24

**Programs**    Clear Program

	1	2	3	4	5	6
P1	T1					
P2						
P3						
P4						
P5						
P6						
P7						
P8						
P9						
P10						
P11						
P12						

**Tasks**    Clear Task

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
T1	U11	Cal	U9	M1	U10										
T2															
T3															
T4															
T5															



# Summary

- Keithley 2182A Successfully Implemented In The Measurements International 6000B Automatic Resistance Bridge
- Results Independently Verified (PT, ILC)
- Significant Speed Increases Can Be Realized – Experiment To Determine ‘Safe’ Settings
- Automation Increased Through Custom User Functions
- Ability To Use Agilent 3458A Or Keithley 2182A In The System Increases System Throughput And Laboratory Efficiency

# Acknowledgements

## Special Thanks To:

- Measurements International for providing technical assistance as well as help in validation
- Sergio Lopez-Carmona (Keithley Instruments) for technical assistance
- Dean Crist (Keithley Instruments) for assistance in collecting test data