SIM.EM – S10

RMO COMPARISON FINAL REPORT

High value resistance comparison with two-terminal cryogenic current comparators

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1. Introduction

This work presents a supplementary comparison of high value resistance standard performed during 2012 and January 2013. It was performed following the guidelines presented in a document about measurement comparisons in the CIPM MRA [1]. The purpose of this task was to compare the high resistance cryogenic current comparator scaling of the participating institutes, National Institute of Standards and Technology – U.S.A. (NIST), Centro Nacional de Metrología – Mexico (CENAM), Instituto Nacional de Tecnología Industrial – Argentina (INTI), all of which are members of the Sistema Interamericano de Metrología (SIM) Regional Metrology Organization.

All the measurements of this comparison were performed with two-terminal Cryogenic Current Comparators (CCC) [2]. They were developed in a frame of an international cooperation project during the years 2007 and 2008. This project includes the participating institutes and the National Measurement Institute of Australia (NMI).

2. Participating Laboratories

The following table shows the participated institutes and the average date of measurement. The pilot laboratory (NIST), measured the resistors three times closing loops with each participating institute.

Average date	National Metrology Institute	Institute
August 2012	National Institute of Standards and Technology (Pilot), U. S. A.	NIST
October 2012	Centro Nacional de Metrología, México.	CENAM
November 2012	National Institute of Standards and Technology (Pilot), U. S. A.	NIST
December 2012	Instituto Nacional de Tecnología Industrial, Argentina.	INTI
January 2013	National Institute of Standards and Technology (Pilot), U. S. A.	NIST

3. Traveling standards

In order to provide a complete evaluation of the systems and redundancy at each resistance level [3], two traveling standards of each decade value between 1 MΩ and 1 GΩ were selected. These resistors were NIST-constructed hermetically sealed standards [4] or commercial film-type standards of similar construction and quality.

The standard resistors were selected by the pilot laboratory. They must have low and linear drift, low temperature coefficient and negligible time constant. This last point is crucial because the bridge must invert voltage polarity at intervals of about 10 s to 50 s in order to reduce the effect of low frequency drift in the SQUID voltage. Typical values of delay time between voltage inversion and measurement are between 4 and 30 s. In order to reduce high frequency noise and the standard deviation of measurements, resistors with nominal value bigger than 1 MΩ were equipped with coaxial connectors. Resistor manufacturers[1], models and temperature coefficients are detailed in Table 2.

Manufacturer	Model	Nominal value	Alpha [μΩ/K]	Beta [$\mu\Omega/K^2$]
Fluke	742A-1M	1 MΩ	0.209	-0.008
Fluke	742A-1M	1 MΩ	0.086	-0.040
MIL	9331G/10M	10 MΩ	1.283	
MIL	9331G/10M	10 MΩ	0.779	
MIL	9331G/100M	100 MΩ	2.482	
Guildline	9336	100 MΩ	5.103	
NIST	NIST HR 1G	1 GΩ	25.032	
NIST	NIST HR 1G	1 GΩ	29.550	

Table 2: specification of the traveling standard resistors.

4. Description of the transport package

A heavy plastic shipping container was filled with plastic foam for protection of the comparison standards. The transport case contained the eight standard resistors and a recorder of temperature and relative humidity. This recorder was used to monitor the environmental conditions during transport.

5. Measurement procedures and instruction

Measurements were performed at direct current with a two-terminal cryogenic current comparator using the methods developed in the cooperative project. These methods are described in Appendix A. The measurement results are expressed in terms of the conventional value of the von Klitzing constant. The scaling process starts with a quantized Hall resistance (QHR) standard maintained in each of the respective laboratories or 10 kΩ standard resistors measured with respect to the QHR. In this comparison, each institute has an independent resistance realization. The standards were conditioned in an air-bath or at ambient laboratory conditions for at least 24 h, the inner temperature of the resistors were not measured in any case. The results were adjusted for the temperature deviation using the TCR of each standard. All the resistors where measured at 10 V, with exception of the 1 MΩ resistors at INTI that were measured at 5 V due limitation in the system. No voltage correction was applied in any resistor. Measurements were repeated at least four times during the period allocated to the participating laboratory, approximately three to four weeks. Environmental conditions and standard deviation was recorded at each measurement.

6. Measurement results

The corrected measurement value, expanded uncertainty and medium date of measurement of each NMI for traveling standards are listed below. The uncertainty budget for each NMI is shown in Appendix B.

[1] Commercial equipment may be identified in this paper to specify the experimental procedure adequately. Such identification is not intended to imply recommendation or endorsement, or that the equipment is necessarily the best available for the purpose.

1 MΩ standard – SN: 8409005

Medium date	Value [MΩ]	NMI	U (k=2) [μΩ/Ω]
17-Aug-12	1.00000433	NIST	0.13
11-Oct-12	1.00000445	CENAM	0.25
20-Nov-12	1.00000480	NIST	0.13
20-Dec-12	1.00000453	INTI	0.27
27-Jan-13	1.00000487	NIST	0.13

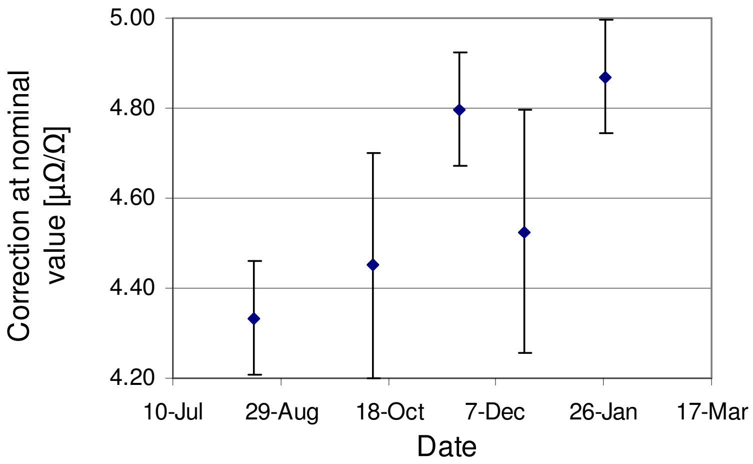


Figure 1: measurement chart to the standard resistor 8409005.

1 MΩ standard – SN: 8409007

Medium date	Value [MΩ]	NMI	U (k=2) [μΩ/Ω]
17-Aug-12	1.00000250	NIST	0.13
11-Oct-12	1.00000257	CENAM	0.25
20-Nov-12	1.00000280	NIST	0.13
20-Dec-12	1.00000263	INTI	0.26
27-Jan-13	1.00000275	NIST	0.13

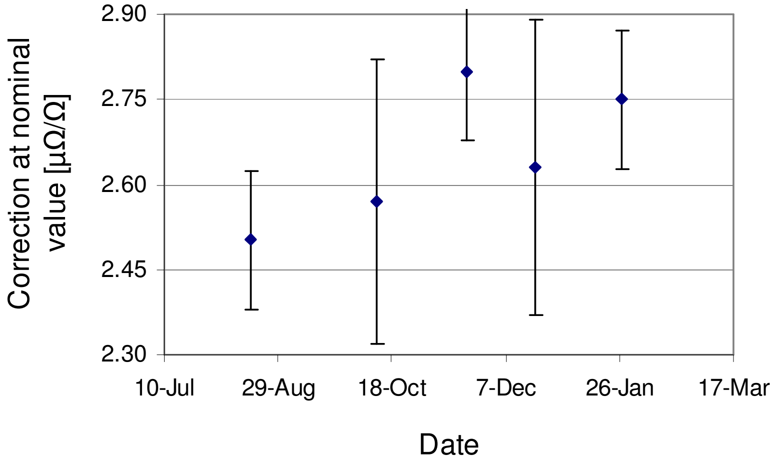


Figure 2: measurement chart to the standard resistor 8409007.

10 MΩ standard – SN: 1100955

Medium date	Value [MΩ]	NMI	U (k=2) [μΩ/Ω]
6-Aug-12	10.0000921	NIST	0.18
26-Oct-12	10.0001067	CENAM	0.54
20-Nov-12	10.0000978	NIST	0.18
19-Dec-12	10.0001017	INTI	0.45
27-Jan-13	10.0001083	NIST	0.18

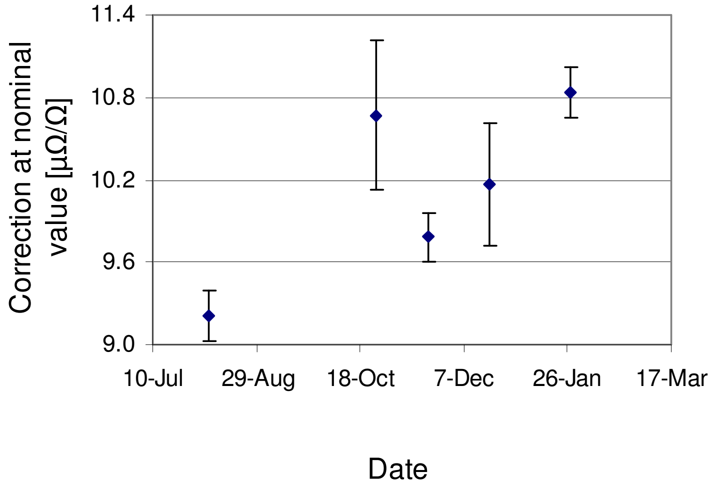


Figure 3: measurement chart to the standard resistor 1100955.

10 MΩ standard – SN: 1100956

Medium date	Value [MΩ]	NMI	U (k=2) [μΩ/Ω]
3-Aug-12	10.0000995	NIST	0.14
26-Oct-12	10.0001150	CENAM	0.52
20-Nov-12	10.0001075	NIST	0.14
20-Dec-12	10.0001102	INTI	0.39
26-Jan-13	10.0001150	NIST	0.14

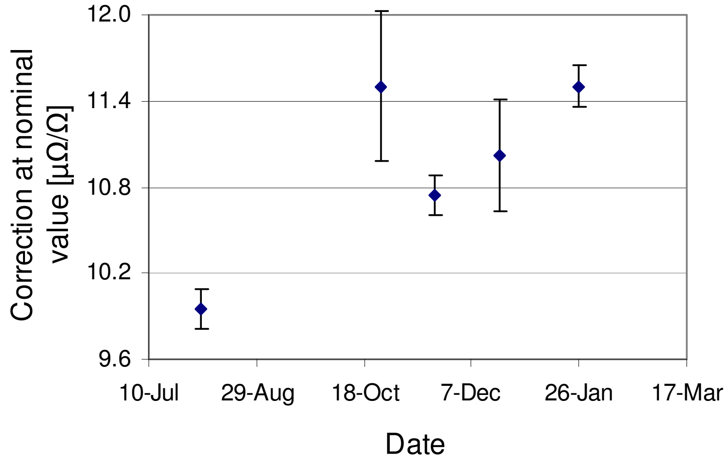


Figure 4: measurement chart to the standard resistor 1100956.

100 MΩ standard – SN: 1100587

Medium date	Value [MΩ]	NMI	U (k=2) [μΩ/Ω]
5-Aug-12	100.00164	NIST	0.4
28-Oct-12	100.00181	CENAM	1.2
21-Nov-12	100.00179	NIST	0.4
20-Dec-12	100.00156	INTI	1.0
27-Jan-13	100.00200	NIST	0.4

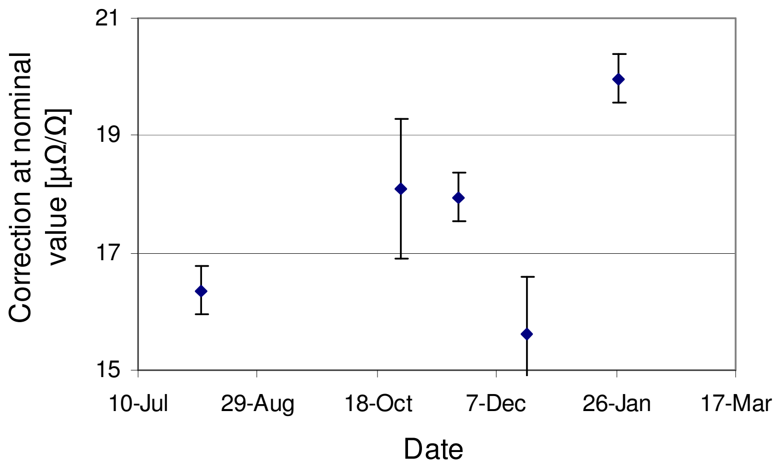


Figure 5: measurement chart to the standard resistor 1100587.

100 MΩ standard – SN: 69318

Medium date	Value [MΩ]	NMI	U (k=2) [μΩ/Ω]
5-Aug-12	100.00341	NIST	0.6
28-Oct-12	100.00362	CENAM	1.6
20-Nov-12	100.00352	NIST	0.6
20-Dec-12	100.00349	INTI	1.7
26-Jan-13	100.00376	NIST	0.6

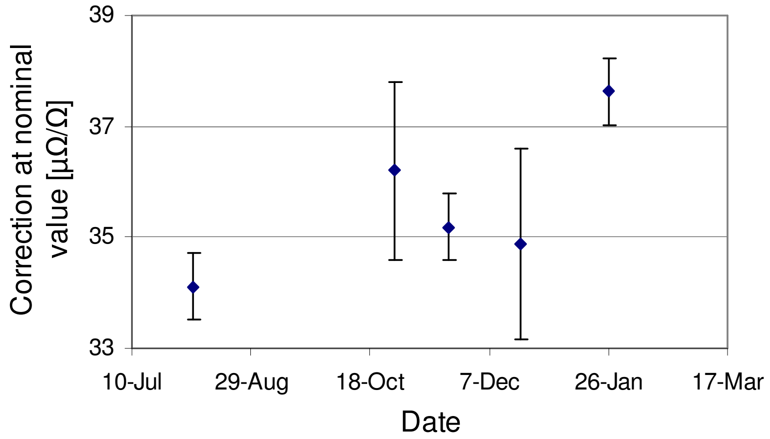


Figure 6: measurement chart to the standard resistor 69318.

1 GΩ standard – SN: HR9107

Medium date	Value [GΩ]	NMI	U (k=2) [μΩ/Ω]
6-Aug-12	0.999725	NIST	4
30-Oct-12	0.999732	CENAM	9
20-Nov-12	0.999742	NIST	4
19-Dec-12	0.999730	INTI	7
27-Jan-13	0.999750	NIST	4

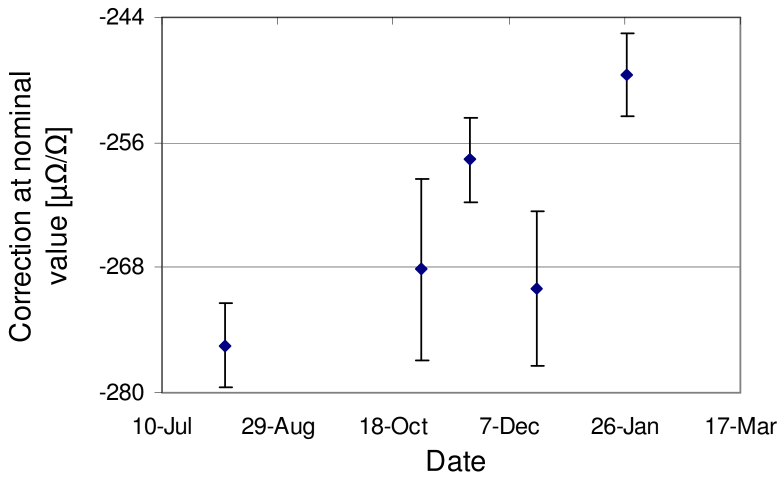


Figure 7: measurement chart to the standard resistor HR9107.

1 GΩ standard – SN: HR9203

Medium date	Value [GΩ]	NMI	U (k=2) [μΩ/Ω]
6-Aug-12	0.999358	NIST	4
1-Nov-12	0.999361	CENAM	8
20-Nov-12	0.999369	NIST	4
20-Dec-12	0.999355	INTI	7
27-Jan-13	0.999369	NIST	4

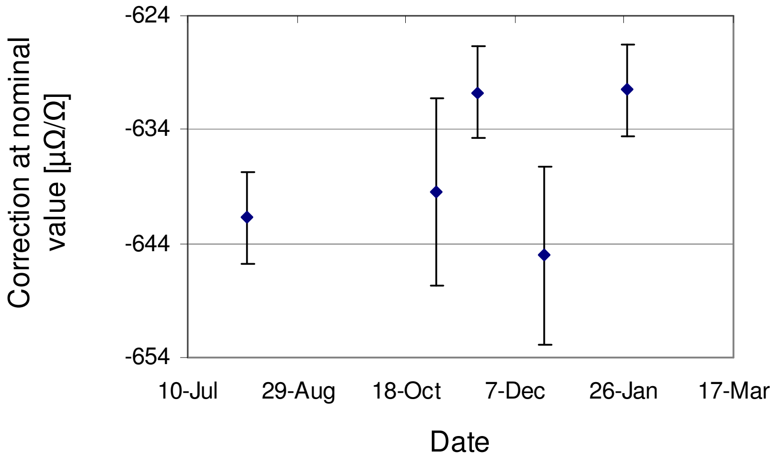


Figure 8: measurement chart to the standard resistor HR9203.

7. Reported results of comparisons

The statistical analysis of this comparison followed closely that employed for key comparison CCEM-K2 [3-5]. First, a linear trend was calculated from the measurements of the pilot laboratory using a least squares algorithm. Next, the resistor trend values at the average date of measurement of each institute were estimated and differences between these and the measured values for each institute were calculated. At each resistance level two differences were obtained and they were combined with a weighted sum, with more weight given to that resistor with less residual variance in the linear estimation. An uncertainty was calculated from the combined differences and was used to calculate the relative weight of each institute. The comparison reference value (CRV) was calculated as a weighted sum of the combined differences. Finally, the degree of equivalence was obtained subtracting the CRV to the combined difference.

Following the comparison reference value, its uncertainty and the degree of equivalence with respect to the CRV are included.

Results at 1 MΩ

Comparison reference value: -0.031 Ω.
Expanded uncertainty of CRV: 0.11 Ω.
Degree of equivalence with respect to the CRV:

NMI	[μΩ/Ω]	U (k=2) [μΩ/Ω]
CENAM	-0.06	0.30
INTI	-0.16	0.32
NIST	0.03	0.06

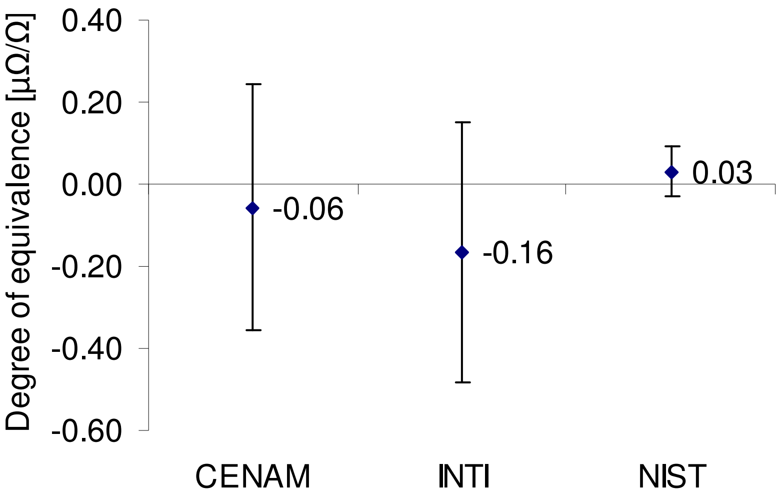


Figure 9: degree of equivalence with respect to the CRV at 1 MΩ level.

Results at 10 MΩ

Comparison reference value: 0.53 Ω.
Expanded uncertainty of CRV: 1.64 Ω.
Degree of equivalence with respect to the CRV:

NMI	[μΩ/Ω]	U (k=2) [μΩ/Ω]
CENAM	0.81	0.58
INTI	-0.15	0.50
NIST	-0.05	0.08

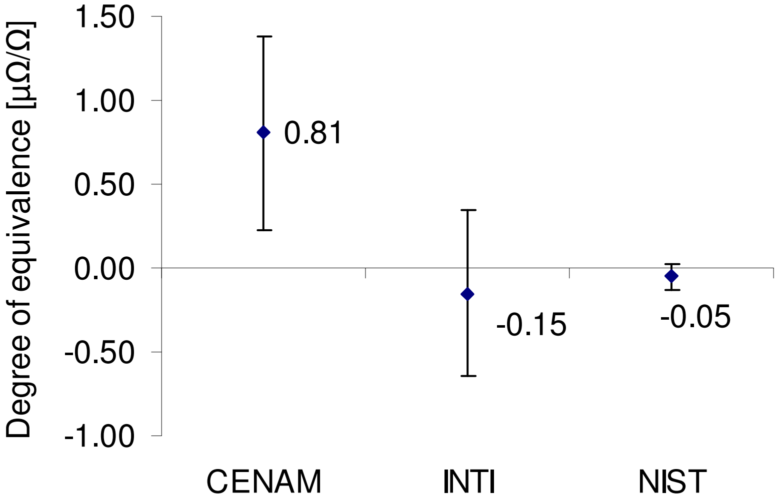


Figure 10: degree of equivalence with respect to the CRV at 10 MΩ level.

Results at 100 MΩ

Comparison reference value: -20.4 Ω.
Expanded uncertainty of CRV: 54.1 Ω.
Degree of equivalence with respect to the CRV:

NMI	[μΩ/Ω]	U (k=2) [μΩ/Ω]
CENAM	0.6	1.7
INTI	-2.7	1.8
NIST	0.2	0.3

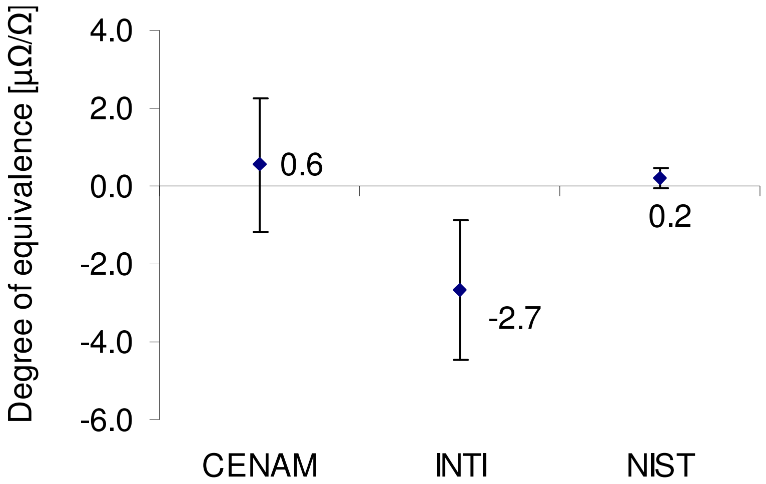


Figure 11: degree of equivalence with respect to the CRV at 100 MΩ level.

Results at 1 GΩ

Comparison reference value: -3244 Ω.
Expanded uncertainty of CRV: 3417 Ω.
Degree of equivalence with respect to the CRV:

NMI	[μΩ/Ω]	U (k=2) [μΩ/Ω]
CENAM	-2.6	8.0
INTI	-11.8	7.8
NIST	3.2	2.3

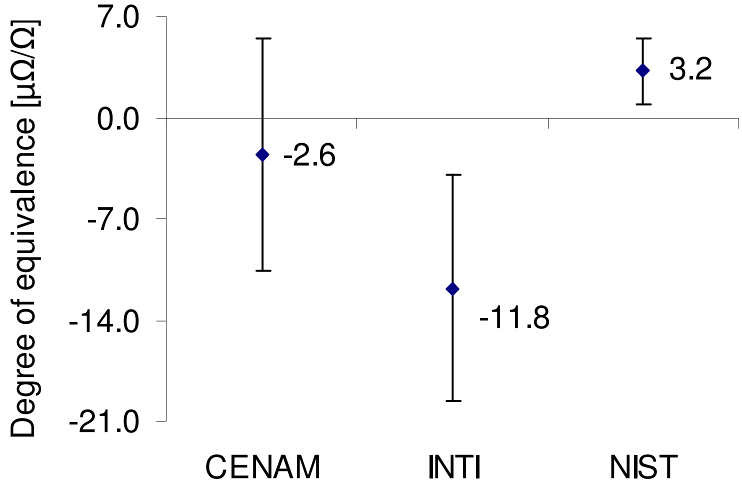


Figure 12: degree of equivalence with respect to the CRV at 1 GΩ level.

8. References

[1] *Measurement comparisons in the context of the CIPM MRA*, CIPM MRA-D-05, 2012.

[2] M. E. Bierzychudek and R. E. Elmquist, "Uncertainty evaluation in a two-terminal cryogenic current comparator," *IEEE Trans. Instrum. Meas.,* vol. 58, no. 4, pp. 1170 – 1175, April 2009.

[3] N. F. Zhang, N. Sedransk and D. Jarrett, "Statistical uncertainty analysis of key comparison CCEM-K2", *IEEE Trans. Instrum. Meas.,* vol. 52, no. 2, pp. 491-494, April 2003.

[4] R. Dziuba, D. Jarrett, L. Scott and A. Secula, "Fabrication of high-value standard resistors", *IEEE Trans. Instrum. Meas.*, vol. 48, no. 2, pp. 333-337, April 1999.

[5] R. F. Dziuba and D. G. Jarrett, *CCEM-K2 Key Comparison of Resistance Standards at 10* MΩ *and 1* GΩ, Jul. 2001. [Online]. Available: http://kcdb.bipm.org/appendixB/appbresults/ccem-k2/ccem-k2_final_report.pdf.

Appendix A

HRCCC Instructions

May 2013

Bridge connections

Particulars connections have to be performed to the measurement of the coil resistance and voltage source. They are explained next.

- The HRCCC electronic has to be connected to the PC via a KEITHLEY relay board.
- The front channel of the high accuracy multimeter has to be connected to the BNC-OUT.
- The SQUID controller (BNC-SIGNAL OUT) has to be connected to the HRCCC electronics (BNC-SQUID). Also, the BNC-DETECTOR can be connected to an oscilloscope.

Calibration of coil and lead resistances

The proposed method uses the multimeter 3458A. It is also possible to use a more accurate system, such as the MI-6010 bridge. In tests at NIST the DMM method gave equivalent results, after the ACAL procedure.

Setup

1. Perform the ACAL procedure in the DVM.
2. Source and feedback switches in "off" position.
3. Source voltage knob in 10 V position (or other HIGH RANGE). This removes the diode protection in parallel to the coils.
4. CCC cable connected to "CCC" LEMO connector on electronics unit.
5. DMM cable connected to "R-CCC" LEMO connector.
6. 4-wire connection to DMM rear panel, red connected to input binding post and green connected to Ohm Sense.

CCC connections

1. One coil must be shorted at the resistor connection point.
2. For four-terminal resistors, make a short using same-side V&I terminals.
3. Otherwise, short the leads as close as possible to the resistor.
4. For 100 kΩ and below, measure winding resistance at each resistor.

Measurements

1. Select "Winding Res" on the CCC Setup page.
2. Set range and delay for automatic DMM measurements.
3. Enter the information to identify the "winding" and "resistor".
4. Run until result is stable (best if start with 3100 turn winding – lower resistance windings may induce heating when measured).
5. Results are stored in "QCoilLeadRes.csv" file in "CCC data" folder.

Examples:

1. Primary 3100 turn lead, DMM range 10 kΩ; make 20 measurements with 10 s delay for the shorted leads at one terminal of 1 MΩ resistor.
2. Secondary 31 turn lead; DMM range 100 Ω; make 10 measurements for each resistor, measured with the short formed inside the resistor if they are 4-

terminal type, so the correction is accurate. For all higher values, the lead resistance for the 1 MΩ resistor may be used.

The CCC may cause trapped flux in the SQUID when coil resistances are measured. To remove trapped flux, turn down the SQUID Bias to zero and press the heater button for about five seconds, then adjust the Bias for maximum signal.

Connection to the measurement of the voltage source

Connect the resistors for measurement and connect the potential (Green) terminals of the RCCC cable to the back of the DVM (voltage inputs). Using the Red terminals in the main measurement to sense the voltage will cause an error, because there is a voltage drop in the CCC leads.

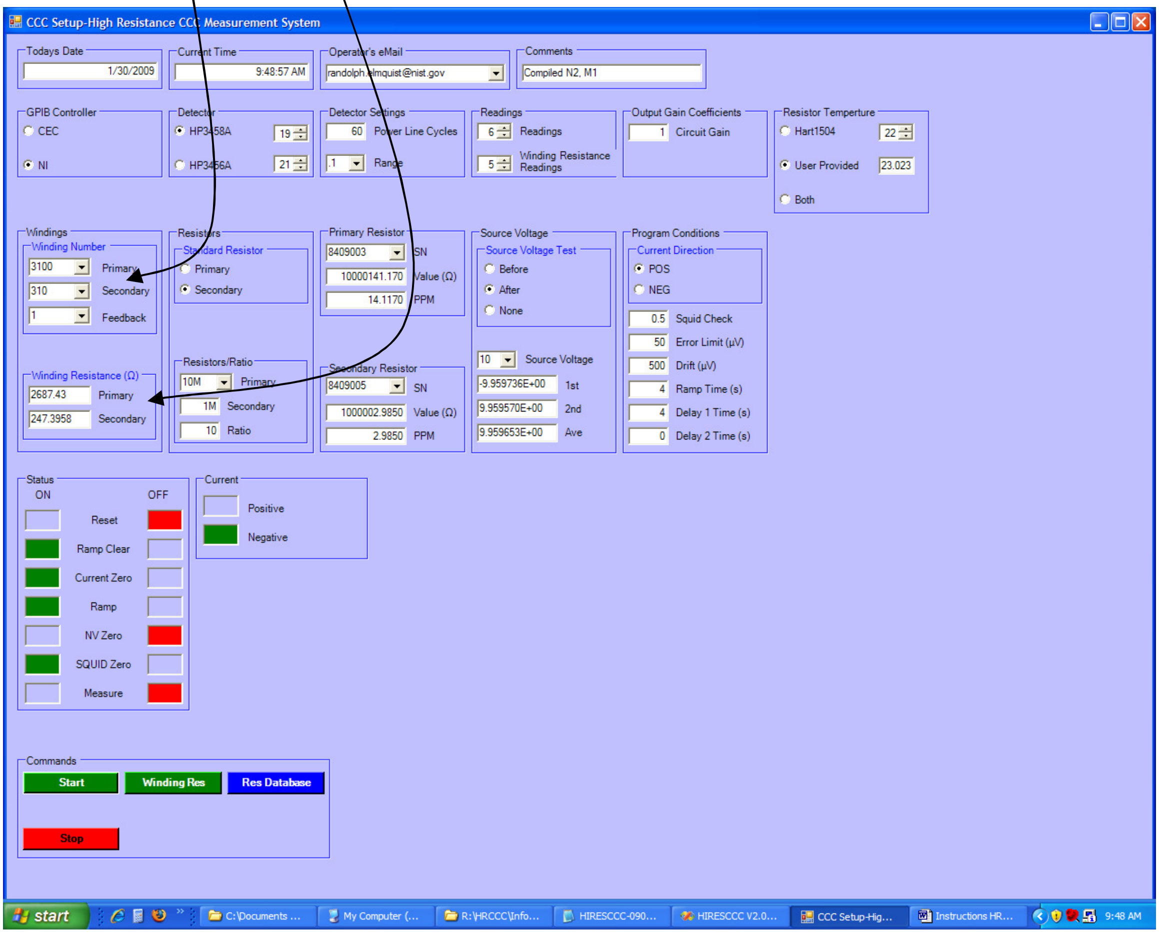
Turning on the Electronics Unit

1. Unplug the battery charger, either at the wall or at the unit.
2. Turn off the Charger switch, and turn on the Feedback and Source switches.
3. If the CCC cable is disconnected from the unit, it is best to turn the source and feedback off before reconnecting the CCC cable. The SQUID noise is sometimes increased otherwise, and turning the unit off and then on will eliminate this noise.
4. The yellow LEDs that show the status of the Integrator Zero and Reset conditions of the unit should be lit when the source is turned on. The green LED (POS) that shows the direction of the source voltage should be lit. The red LED that indicates the voltage range (High Range) should be lit if the voltage is set to 1.1 V, 5 V, or 10 V.
5. The BNC cable marked DVM should connect to the front voltage input of the DVM.

Program setup

The CCC is operated using a compiled program written in Visual Basic. When the program is activated it opens the Setup Screen shown below.

Some of the content in the drop-down boxes is read from a configuration file, MEGCCC3100IIStartForm.cfg. For example, this file is read at startup to fill the contents of the drop-down boxes labeled “Windings” and “Winding Resistance”.

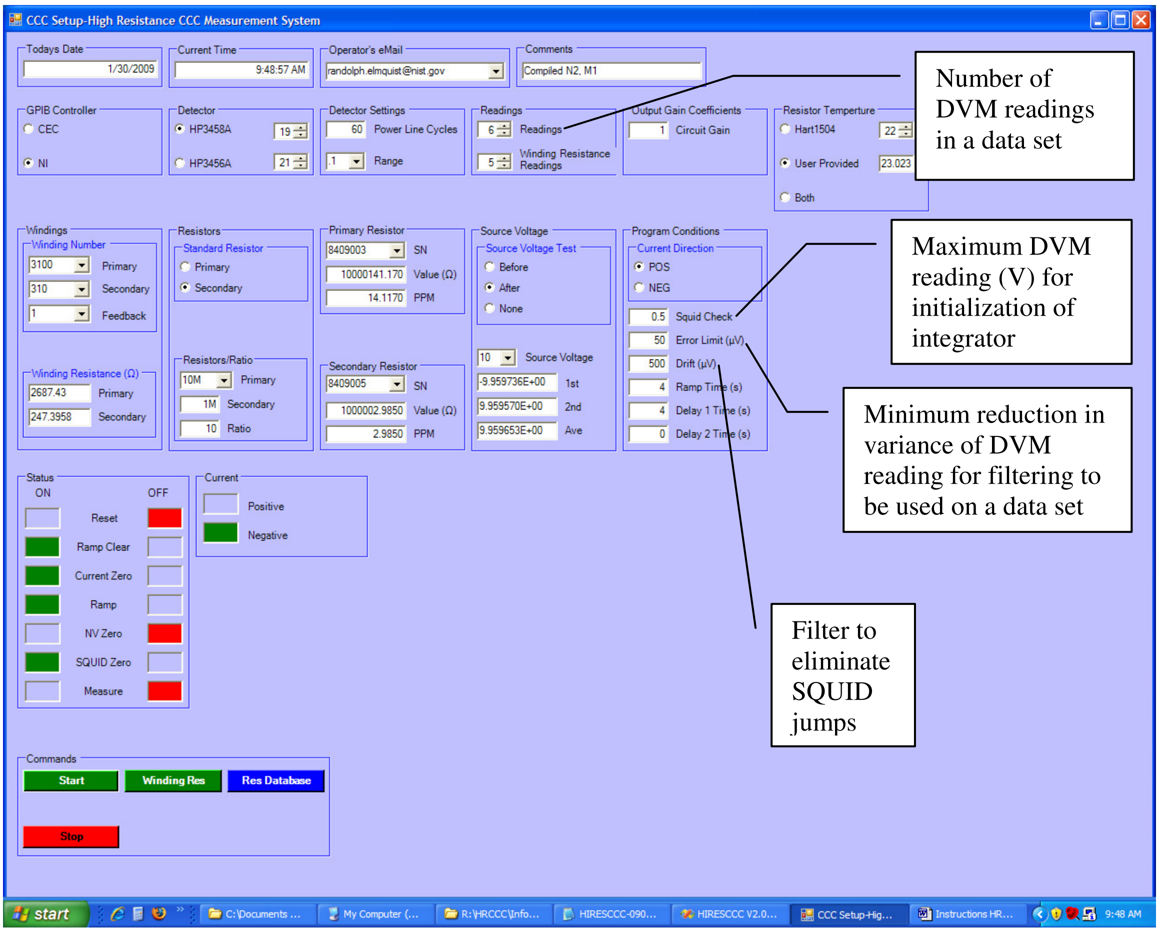


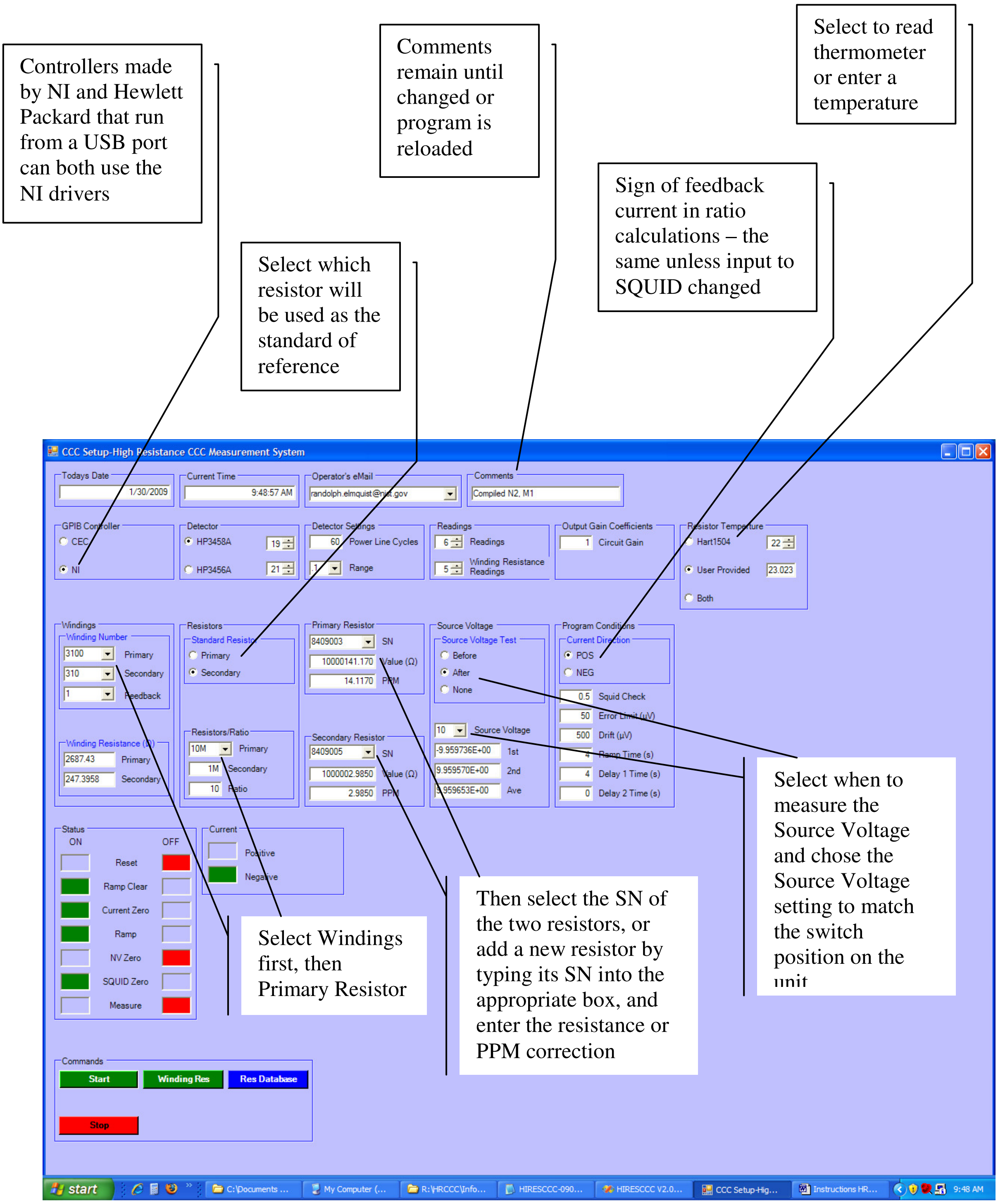
Some boxes on this form can be modified by entering values or text. When the measurement is complete, the latest entry in these boxes is saved in the configuration file or in the resistor database.

Winding resistance values depend on the winding that is selected. Whenever the user changes these values, the new values will be saved in the configuration file after the measurement is completed. The number of DMM readings “Readings”, “Detector Settings”, and “Program Conditions” are also saved and will be loaded the next time the measurement runs, even if the program is reloaded.

The "Program Conditions" box controls the data-taking process and run-time analysis. The "SQUID Check" value is the maximum offset of the integrator output voltage (DMM voltage reading) for the first reading after the integrator is zeroed. This checks that the SQUID was zeroed at the start of the run.

Two settings that control automatic filtering of the data are the "Error Limit" and "Drift". The analysis calculates the variance of the set of DVM readings (number of readings set by "Current Readings") and compares it to the variance calculated with one fewer reading (eliminating the reading with largest residual). This difference is compared to the "Error Limit" – if the variance is reduced by more than the "Error Limit", that reading is eliminated. This can continue until the remaining number of readings is two. The "Drift" variable is used when comparing the first and last data sets of the four sets of DVM readings that go into the resistance calculation. If the change from set 1 to set 4 is twice the level set by the "Drift" variable, then set 1 and set 2 are thrown out. Set 3 and set 4 become the new set 1 and set 2. This is intended to eliminate data that includes a flux jump in the SQUID, but also could eliminate data where the SQUID is drifting rapidly.



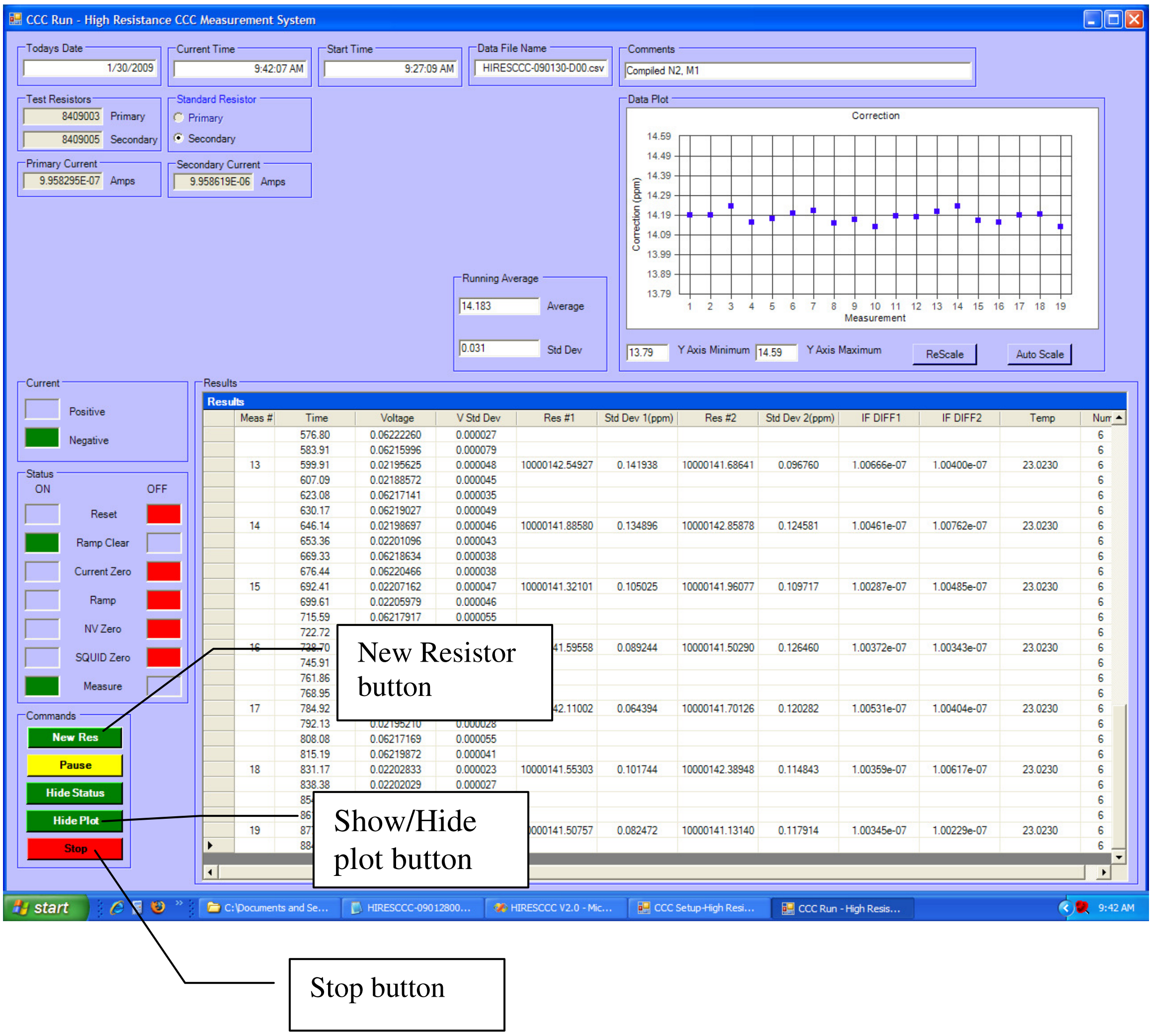


Once the setup process is complete for the measurement, press the “Start” button. You will be prompted to connect and disconnect the DMM rear-panel cable that measures the bridge voltage if you selected the “Before” option in the “Source Voltage Test” area of the “Setup” screen. It is important that the source voltage is stable, so the source should be turned on at least ten minutes before the bridge voltage is measured. When voltage calibration is complete, the measurement screen will appear over the “Setup” screen.

Measurement (Run) Screen

A message box will prompt you to engage and zero the SQUID flux-lock as this screen loads. Once the SQUID feedback is locked (zero voltage out of the SQUID) the data sequence begins. It will run until the user clicks the “New Resistor” button or the “Stop” button. Both commands will allow the program to run until the source voltage goes to zero at a current reversal. At that time, a red box appears with the message that the sequence is complete.

Display the data in graphical form by clicking the “Show Plot” button. The scale will depend on the resistor value, winding number, and source voltage level. The scale should allow all data to show on the plot unless there is drift or excess noise. The “Auto Scale” button below the plot increases or decreases the scale so that all data is on scale, with a minimum of 1 μΩ/Ω full-scale. New max/min values can also be entered manually.

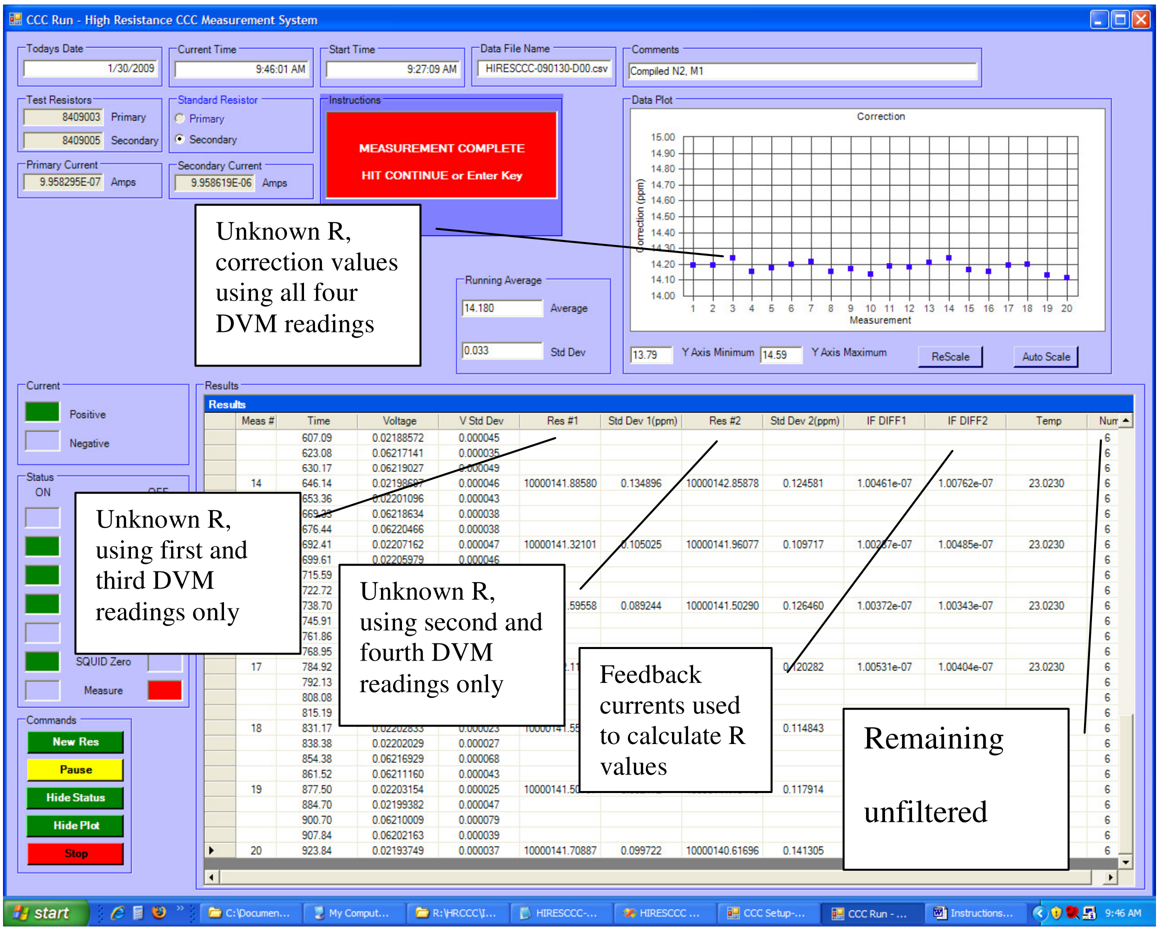


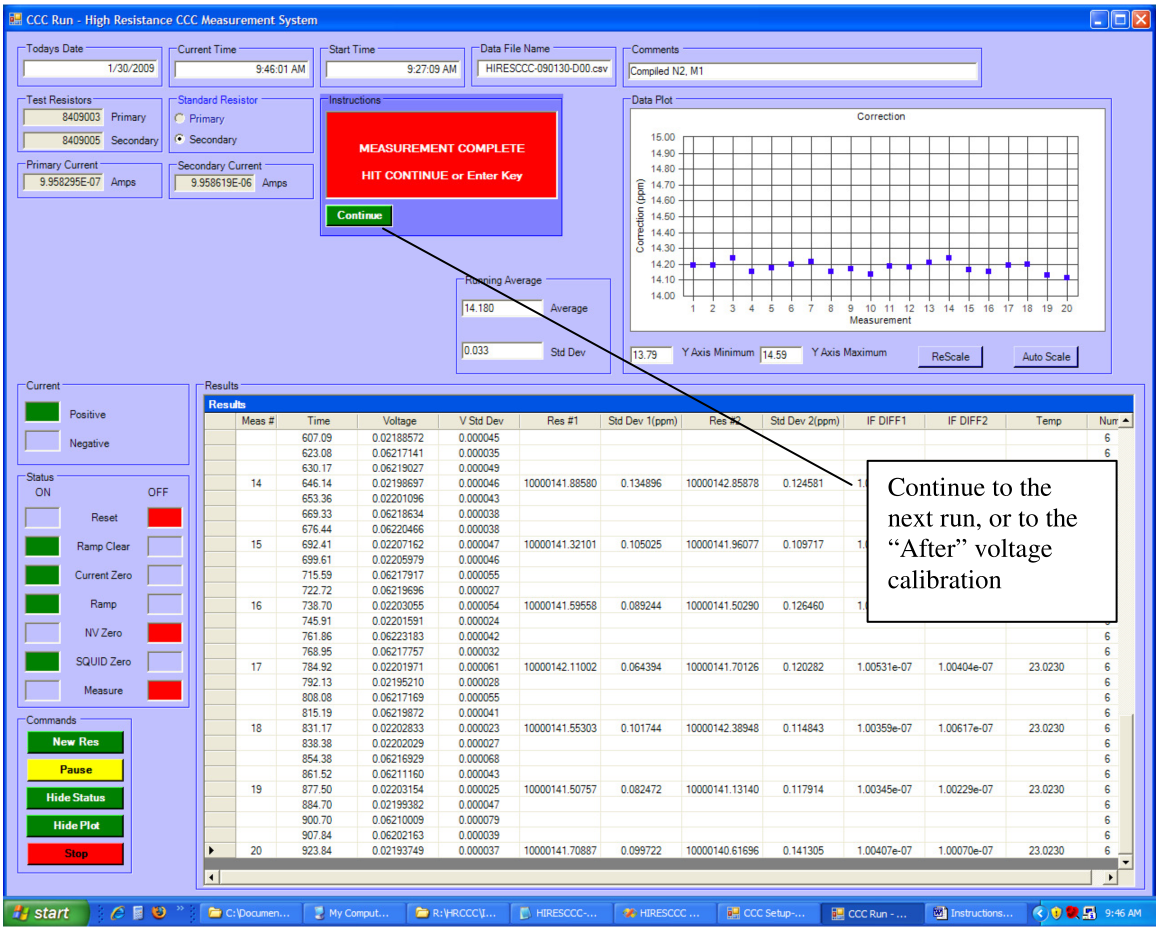
The next screenshot shows the "Run" screen when the run is completed, after "New Resistor" was selected. It shows the effect of the "Auto Scale" button on the plot of the data set. Note this is the same data set shown on the last page.

The program pauses at the end of the run, after "New Resistor" is clicked and the source voltage is zeroed, to allow you to review the data set and delete points if necessary. If a data point is excessively noisy, double-clicking on that data point on the graph will mark that point and it will be omitted from the average and standard deviation calculated for the run. The selected point or points will be shown in red. "Auto Scale" makes all of the data points visible, so that extreme points can be viewed and discarded.

The "Test Resistors" box, "Standard Resistor" box and many other fields on the Run page cannot be altered, and are for your information only.

Additional user comments can be added in the box on the Run screen. These will be appended to the comment from the Setup screen, but this comment field does not carry over to the next run. The comments on the setup screen carry over until they are changed.





When the "Continue" button is pressed, the program completes the data set, making "After" voltage calibrations if necessary. The data set is stored in two files with differing levels of compression. Any deleted points will be marked in the data files, and the average values and standard deviations exclude these points.

Charging the batteries

When the charger switch on the back panel is turned on, all of the lines from the batteries are disconnected from the circuits and the other switches. The battery charger circuits are connected to the batteries, and a LED light connected to one of the 6 V lines that leads to a charger will come on. This LED is also on if the battery chargers are connected to the 115 V power line.

To charge the batteries, turn the Source and Feedback switches to the off position, and turn on the Charger switch. The chargers are designed to sense the condition of the batteries when the AC power is first turned on. After turning on the Charger switch connect the power cord to the fused receptacle on the back panel. The fuse should be a 1.5 A or less slow-blow fuse. The batteries that are used to power the feedback and source circuits have a common ground that is connected to the electronics enclosure. The communications circuit is isolated from this common ground, except when the 6 V battery is being charged.

Be sure to supply power at 110 V to 120 V, using a step-down transformer if necessary.

Appendix B

In this appendix the budget uncertainty to each resistor and institute is shown.

Serial number: 8409005
Nominal value: 1 MΩ

CENAM - Mexico *Influence factor y_i*	**Standard uncertainty** *$u(y_i)$*	**Distribution /method of evaluation** *Method/(A, B)*	**Sensitivity coefficient** *c_i*	**Uncertainty contribution** *$u(R_i)$* [μΩ/Ω]	**Degrees of freedom** *v_i*
Scaling / traceability [μΩ/Ω]	0.100	Normal/B	1	0.100	∞
Reference standard(s) [μΩ/Ω]	0.002	Normal/B	1	0.002	∞
Measuring apparatus [μΩ/Ω]	0.070	Rectangular/B	1	0.070	∞
Reference temperature [ºC]	0.083	Normal/B	0.209 μΩ/Ω per ºC	0.017	∞
Standard deviation [μΩ/Ω]	0.011	Normal/A	1	0.011	20
Repeatability [μΩ/Ω]	0.015	Normal/B	1	0.015	5
Temperature correction [μΩ/Ω per ºC]	0.006	Normal/B	0.1 ºC	0.001	∞
Combined standard uncertainty and effective degrees of freedom:				0.125	∞
Expanded uncertainty (95 % coverage factor):				**0.249 μΩ/Ω**	

NIST - USA *Influence factor y_i*	**Standard uncertainty** *$u(y_i)$*	**Distribution /method of evaluation** *Method/(A, B)*	**Sensitivity coefficient** *c_i*	**Uncertainty contribution** *$u(R_i)$* [μΩ/Ω]	**Degrees of freedom** *v_i*
Scaling / traceability [μΩ/Ω]	0.025	Normal/B	1	0.025	∞
Reference standard(s) [μΩ/Ω]	0.025	Normal/B	1	0.025	50
Measuring apparatus [μΩ/Ω]	0.010	Normal/B	1	0.010	∞
Reference temperature [ºC]	0.050	Normal/B	0.209 μΩ/Ω per ºC	0.010	∞
Standard deviation [μΩ/Ω]	0.008	Normal/A	1	0.008	22
Repeatability [μΩ/Ω]	0.049	Normal/B	1	0.049	22
Temperature correction [μΩ/Ω per ºC]	0.006	Normal/B	0.02 ºC	0.000	∞
Combined standard uncertainty and effective degrees of freedom:				0.063	∞
Expanded uncertainty (95 % coverage factor):				**0.125 μΩ/Ω**	

INTI - Argentina *Influence factor* y_i	**Standard uncertainty** $u(y_i)$	**Distribution /method of evaluation** *Method/(A, B)*	**Sensitivity coefficient** c_i	**Uncertainty contribution** $u(R_i)$ [μΩ/Ω]	**Degrees of freedom** v_i
Scaling / traceability [μΩ/Ω]	0.045	Normal/B	1	0.045	∞
Reference standard(s) [μΩ/Ω]	0.008	Normal/B	1	0.008	∞
Measuring apparatus [μΩ/Ω]	0.114	Normal/B	1	0.114	∞
Reference temperature [ºC]	0.107	Normal/B	0.209 μΩ/Ω per ºC	0.022	∞
Standard deviation [μΩ/Ω]	0.048	Normal/A	1	0.048	3
Repeatability [μΩ/Ω]	0.024	Normal/B	1	0.024	3
Temperature correction [μΩ/Ω per ºC]	0.006	Normal/B	1 ºC	0.006	∞
Combined standard uncertainty and effective degrees of freedom:				0.136	**64**
Expanded uncertainty (95 % coverage factor):				**0.272 μΩ/Ω**	

Serial number: 8409007
Nominal value: 1 MΩ

CENAM - Mexico *Influence factor* y_i	**Standard uncertainty** $u(y_i)$	**Distribution /method of evaluation** *Method/(A, B)*	**Sensitivity coefficient** c_i	**Uncertainty contribution** $u(R_i)$ [μΩ/Ω]	**Degrees of freedom** v_i
Scaling / traceability [μΩ/Ω]	0.100	Normal/B	1	0.100	∞
Reference standard(s) [μΩ/Ω]	0.002	Normal/B	1	0.002	∞
Measuring apparatus [μΩ/Ω]	0.070	Rectangular/B	1	0.070	∞
Reference temperature [ºC]	0.045	Normal/B	0.086 μΩ/Ω per ºC	0.004	∞
Standard deviation [μΩ/Ω]	0.011	Normal/A	1	0.011	20
Repeatability [μΩ/Ω]	0.019	Normal/B	1	0.019	5
Temperature correction [μΩ/Ω per ºC]	0.006	Normal/B	0.1 ºC	0.001	∞
Combined standard uncertainty and effective degrees of freedom:				0.124	∞
Expanded uncertainty (95 % coverage factor):				**0.248 μΩ/Ω**	

NIST - USA *Influence factor* y_i	**Standard uncertainty** $u(y_i)$	**Distribution /method of evaluation** *Method/(A, B)*	**Sensitivity coefficient** c_i	**Uncertainty contribution** $u(R_i)$ [μΩ/Ω]	**Degrees of freedom** v_i
Scaling / traceability [μΩ/Ω]	0.025	Normal/B	1	0.025	∞
Reference standard(s) [μΩ/Ω]	0.025	Normal/B	1	0.025	50
Measuring apparatus [μΩ/Ω]	0.010	Normal/B	1	0.010	∞
Reference temperature [ºC]	0.050	Normal/B	0.086 μΩ/Ω per ºC	0.004	∞
Standard deviation [μΩ/Ω]	0.006	Normal/A	1	0.006	22
Repeatability [μΩ/Ω]	0.048	Normal/B	1	0.048	22
Temperature correction [μΩ/Ω per ºC]	0.006	Normal/B	0.02 ºC	0.000	∞
Combined standard uncertainty and effective degrees of freedom:				0.061	∞
Expanded uncertainty (95 % coverage factor):				**0.122 μΩ/Ω**	

INTI - Argentina *Influence factor* y_i	**Standard uncertainty** $u(y_i)$	**Distribution /method of evaluation** *Method/(A, B)*	**Sensitivity coefficient** c_i	**Uncertainty contribution** $u(R_i)$ [μΩ/Ω]	**Degrees of freedom** v_i
Scaling / traceability [μΩ/Ω]	0.045	Normal/B	1	0.045	∞
Reference standard(s) [μΩ/Ω]	0.008	Normal/B	1	0.008	∞
Measuring apparatus [μΩ/Ω]	0.114	Normal/B	1	0.114	∞
Reference temperature [ºC]	0.107	Normal/B	0.086 μΩ/Ω per ºC	0.009	∞
Standard deviation [μΩ/Ω]	0.036	Normal/A	1	0.036	3
Repeatability [μΩ/Ω]	0.016	Normal/B	1	0.016	3
Temperature correction [μΩ/Ω per ºC]	0.006	Normal/B	1 ºC	0.006	∞
Combined standard uncertainty and effective degrees of freedom:				0.129	**69**
Expanded uncertainty (95 % coverage factor):				**0.258 μΩ/Ω**	

Serial number: 1100955
Nominal value: 10 MΩ

CENAM - Mexico *Influence factor y_i*	**Standard uncertainty** $u(y_i)$	**Distribution /method of evaluation** *Method/(A, B)*	**Sensitivity coefficient** c_i	**Uncertainty contribution** $u(R_i)$ [μΩ/Ω]	**Degrees of freedom** v_i
Scaling / traceability [μΩ/Ω]	0.130	Normal/B	1	0.130	∞
Reference standard(s) [μΩ/Ω]	0.100	Normal/B	1	0.100	∞
Measuring apparatus [μΩ/Ω]	0.020	Rectangular/B	1	0.020	∞
Reference temperature [ºC]	0.043	Normal/B	1.283 μΩ/Ω per ºC	0.055	∞
Standard deviation [μΩ/Ω]	0.059	Normal/A	1	0.059	50
Repeatability [μΩ/Ω]	0.195	Normal/B	1	0.195	7
Temperature correction [μΩ/Ω per ºC]	0.050	Normal/B	0.1 ºC	0.005	∞
Combined standard uncertainty and effective degrees of freedom:				0.268	∞
Expanded uncertainty (95 % coverage factor):				**0.536 μΩ/Ω**	

NIST - USA *Influence factor y_i*	**Standard uncertainty** $u(y_i)$	**Distribution /method of evaluation** *Method/(A, B)*	**Sensitivity coefficient** c_i	**Uncertainty contribution** $u(R_i)$ [μΩ/Ω]	**Degrees of freedom** v_i
Scaling / traceability [μΩ/Ω]	0.025	Normal/B	1	0.025	∞
Reference standard(s) [μΩ/Ω]	0.025	Normal/B	1	0.025	50
Measuring apparatus [μΩ/Ω]	0.010	Normal/B	1	0.010	∞
Reference temperature [ºC]	0.050	Normal/B	1.283 μΩ/Ω per ºC	0.064	∞
Standard deviation [μΩ/Ω]	0.008	Normal/A	1	0.008	19
Repeatability [μΩ/Ω]	0.050	Normal/B	1	0.050	19
Temperature correction [μΩ/Ω per ºC]	0.050	Normal/B	0.02 ºC	0.001	∞
Combined standard uncertainty and effective degrees of freedom:				0.090	∞
Expanded uncertainty (95 % coverage factor):				**0.179 μΩ/Ω**	

INTI - Argentina *Influence factor* y_i	**Standard uncertainty** $u(y_i)$	**Distribution /method of evaluation** *Method/(A, B)*	**Sensitivity coefficient** c_i	**Uncertainty contribution** $u(R_i)$ [μΩ/Ω]	**Degrees of freedom** v_i
Scaling / traceability [μΩ/Ω]	0.123	Normal/B	1	0.123	∞
Reference standard(s) [μΩ/Ω]	0.022	Normal/B	1	0.022	∞
Measuring apparatus [μΩ/Ω]	0.020	Normal/B	1	0.020	∞
Reference temperature [ºC]	0.107	Normal/B	1.283 μΩ/Ω per ºC	0.137	∞
Standard deviation [μΩ/Ω]	0.108	Normal/A	1	0.108	4
Repeatability [μΩ/Ω]	0.005	Normal/B	1	0.005	4
Temperature correction [μΩ/Ω per ºC]	0.050	Normal/B	1 ºC	0.050	∞
Combined standard uncertainty and effective degrees of freedom:				**0.222**	**52**
Expanded uncertainty (95 % coverage factor):				**0.445 μΩ/Ω**	

Serial number: 1100956
Nominal value: 10 MΩ

CENAM - Mexico *Influence factor* y_i	**Standard uncertainty** $u(y_i)$	**Distribution /method of evaluation** *Method/(A, B)*	**Sensitivity coefficient** c_i	**Uncertainty contribution** $u(R_i)$ [µΩ/Ω]	**Degrees of freedom** v_i
Scaling / traceability [µΩ/Ω]	0.130	Normal/B	1	0.130	∞
Reference standard(s) [µΩ/Ω]	0.100	Normal/B	1	0.100	∞
Measuring apparatus [µΩ/Ω]	0.020	Rectangular/B	1	0.020	∞
Reference temperature [ºC]	0.027	Normal/B	0.779 µΩ/Ω per ºC	0.021	∞
Standard deviation [µΩ/Ω]	0.056	Normal/A	1	0.056	50
Repeatability [µΩ/Ω]	0.190	Normal/B	1	0.190	7
Temperature correction [µΩ/Ω per ºC]	0.050	Normal/B	0.1 ºC	0.005	∞
Combined standard uncertainty and effective degrees of freedom:				0.259	∞
Expanded uncertainty (95 % coverage factor):				**0.518 µΩ/Ω**	

NIST - USA *Influence factor* y_i	**Standard uncertainty** $u(y_i)$	**Distribution /method of evaluation** *Method/(A, B)*	**Sensitivity coefficient** c_i	**Uncertainty contribution** $u(R_i)$ [µΩ/Ω]	**Degrees of freedom** v_i
Scaling / traceability [µΩ/Ω]	0.025	Normal/B	1	0.025	∞
Reference standard(s) [µΩ/Ω]	0.025	Normal/B	1	0.025	50
Measuring apparatus [µΩ/Ω]	0.010	Normal/B	1	0.010	∞
Reference temperature [ºC]	0.050	Normal/B	0.779 µΩ/Ω per ºC	0.039	∞
Standard deviation [µΩ/Ω]	0.008	Normal/A	1	0.008	21
Repeatability [µΩ/Ω]	0.044	Normal/B	1	0.044	21
Temperature correction [µΩ/Ω per ºC]	0.050	Normal/B	0.02 ºC	0.001	∞
Combined standard uncertainty and effective degrees of freedom:				0.070	∞
Expanded uncertainty (95 % coverage factor):				**0.140 µΩ/Ω**	

INTI - Argentina *Influence factor* y_i	**Standard uncertainty** $u(y_i)$	**Distribution /method of evaluation** *Method/(A, B)*	**Sensitivity coefficient** c_i	**Uncertainty contribution** $u(R_i)$ [μΩ/Ω]	**Degrees of freedom** v_i
Scaling / traceability [μΩ/Ω]	0.123	Normal/B	1	0.123	∞
Reference standard(s) [μΩ/Ω]	0.022	Normal/B	1	0.022	∞
Measuring apparatus [μΩ/Ω]	0.020	Normal/B	1	0.020	∞
Reference temperature [ºC]	0.107	Normal/B	0.779 μΩ/Ω per ºC	0.083	∞
Standard deviation [μΩ/Ω]	0.100	Normal/A	1	0.100	3
Repeatability [μΩ/Ω]	0.030	Normal/B	1	0.030	3
Temperature correction [μΩ/Ω per ºC]	0.050	Normal/B	1 ºC	0.050	∞
Combined standard uncertainty and effective degrees of freedom:				0.191	33
Expanded uncertainty (95 % coverage factor):				**0.388 μΩ/Ω**	

Serial number: 1100587
Nominal value: 100 MΩ

CENAM - Mexico *Influence factor y_i*	**Standard uncertainty** $u(y_i)$	**Distribution /method of evaluation** *Method/(A, B)*	**Sensitivity coefficient** c_i	**Uncertainty contribution** $u(R_i)$ [μΩ/Ω]	**Degrees of freedom** v_i
Scaling / traceability [μΩ/Ω]	0.250	Normal/B	1	0.250	∞
Reference standard(s) [μΩ/Ω]	0.160	Normal/B	1	0.160	∞
Measuring apparatus [μΩ/Ω]	0.100	Rectangular/B	1	0.100	∞
Reference temperature [ºC]	0.025	Normal/B	2.482 μΩ/Ω per ºC	0.062	∞
Standard deviation [μΩ/Ω]	0.400	Normal/A	1	0.400	35
Repeatability [μΩ/Ω]	0.300	Normal/B	1	0.300	9
Temperature correction [μΩ/Ω per ºC]	0.100	Normal/B	0.1 ºC	0.010	∞
Combined standard uncertainty and effective degrees of freedom:				0.593	∞
Expanded uncertainty (95 % coverage factor):				**1.187 μΩ/Ω**	

NIST - USA *Influence factor y_i*	**Standard uncertainty** $u(y_i)$	**Distribution /method of evaluation** *Method/(A, B)*	**Sensitivity coefficient** c_i	**Uncertainty contribution** $u(R_i)$ [μΩ/Ω]	**Degrees of freedom** v_i
Scaling / traceability [μΩ/Ω]	0.025	Normal/B	1	0.025	∞
Reference standard(s) [μΩ/Ω]	0.025	Normal/B	1	0.025	50
Measuring apparatus [μΩ/Ω]	0.100	Normal/B	1	0.100	∞
Reference temperature [ºC]	0.050	Normal/B	2.482 μΩ/Ω per ºC	0.124	∞
Standard deviation [μΩ/Ω]	0.049	Normal/A	1	0.049	16
Repeatability [μΩ/Ω]	0.120	Normal/B	1	0.120	16
Temperature correction [μΩ/Ω per ºC]	0.100	Normal/B	0.02 ºC	0.002	∞
Combined standard uncertainty and effective degrees of freedom:				0.209	∞
Expanded uncertainty (95 % coverage factor):				**0.418 μΩ/Ω**	

INTI - Argentina *Influence factor y_i*	Standard uncertainty *$u(y_i)$*	Distribution /method of evaluation *Method/(A, B)*	Sensitivity coefficient *c_i*	Uncertainty contribution *$u(R_i)$* [µΩ/Ω]	Degrees of freedom *v_i*
Scaling / traceability [µΩ/Ω]	0.126	Normal/B	1	0.126	∞
Reference standard(s) [µΩ/Ω]	0.137	Normal/B	1	0.137	∞
Measuring apparatus [µΩ/Ω]	0.157	Normal/B	1	0.157	∞
Reference temperature [ºC]	0.107	Normal/B	2.482 µΩ/Ω per ºC	0.266	∞
Standard deviation [µΩ/Ω]	0.256	Normal/A	1	0.256	3
Repeatability [µΩ/Ω]	0.120	Normal/B	1	0.120	3
Temperature correction [µΩ/Ω per ºC]	0.100	Normal/B	1 ºC	0.100	∞
Combined standard uncertainty and effective degrees of freedom:				**0.469**	**30**
Expanded uncertainty (95 % coverage factor):				**0.959 µΩ/Ω**	

Serial number: 69318
Nominal value: 100 MΩ

CENAM - Mexico *Influence factor* y_i	**Standard uncertainty** $u(y_i)$	**Distribution /method of evaluation** *Method/(A, B)*	**Sensitivity coefficient** c_i	**Uncertainty contribution** $u(R_i)$ [μΩ/Ω]	**Degrees of freedom** v_i
Scaling / traceability [μΩ/Ω]	0.250	Normal/B	1	0.250	∞
Reference standard(s) [μΩ/Ω]	0.160	Normal/B	1	0.160	∞
Measuring apparatus [μΩ/Ω]	0.100	Rectangular/B	1	0.100	∞
Reference temperature [ºC]	0.027	Normal/B	5.103 μΩ/Ω per ºC	0.138	∞
Standard deviation [μΩ/Ω]	0.484	Normal/A	1	0.484	35
Repeatability [μΩ/Ω]	0.542	Normal/B	1	0.542	8
Temperature correction [μΩ/Ω per ºC]	0.100	Normal/B	0.1 ºC	0.010	∞
Combined standard uncertainty and effective degrees of freedom:				0.803	∞
Expanded uncertainty (95 % coverage factor):				**1.606 μΩ/Ω**	

NIST - USA *Influence factor* y_i	**Standard uncertainty** $u(y_i)$	**Distribution /method of evaluation** *Method/(A, B)*	**Sensitivity coefficient** c_i	**Uncertainty contribution** $u(R_i)$ [μΩ/Ω]	**Degrees of freedom** v_i
Scaling / traceability [μΩ/Ω]	0.025	Normal/B	1	0.025	∞
Reference standard(s) [μΩ/Ω]	0.025	Normal/B	1	0.025	50
Measuring apparatus [μΩ/Ω]	0.100	Normal/B	1	0.100	∞
Reference temperature [ºC]	0.050	Normal/B	5.103 μΩ/Ω per ºC	0.255	∞
Standard deviation [μΩ/Ω]	0.060	Normal/A	1	0.060	17
Repeatability [μΩ/Ω]	0.100	Normal/B	1	0.100	17
Temperature correction [μΩ/Ω per ºC]	0.100	Normal/B	0.02 ºC	0.002	∞
Combined standard uncertainty and effective degrees of freedom:				0.300	∞
Expanded uncertainty (95 % coverage factor):				**0.600 μΩ/Ω**	

INTI - Argentina *Influence factor y_i*	**Standard uncertainty** $u(y_i)$	**Distribution /method of evaluation** *Method/(A, B)*	**Sensitivity coefficient** c_i	**Uncertainty contribution** $u(R_i)$ [μΩ/Ω]	**Degrees of freedom** v_i
Scaling / traceability [μΩ/Ω]	0.126	Normal/B	1	0.126	∞
Reference standard(s) [μΩ/Ω]	0.137	Normal/B	1	0.137	∞
Measuring apparatus [μΩ/Ω]	0.157	Normal/B	1	0.157	∞
Reference temperature [ºC]	0.107	Normal/B	5.103 μΩ/Ω per ºC	0.546	∞
Standard deviation [μΩ/Ω]	0.461	Normal/A	1	0.461	3
Repeatability [μΩ/Ω]	0.322	Normal/B	1	0.322	3
Temperature correction [μΩ/Ω per ºC]	0.100	Normal/B	1 ºC	0.100	∞
Combined standard uncertainty and effective degrees of freedom:				0.827	23
Expanded uncertainty (95 % coverage factor):				**1.715 μΩ/Ω**	

Serial number: HR9107
Nominal value: 1 GΩ

CENAM - Mexico *Influence factor y_i*	**Standard uncertainty** $u(y_i)$	**Distribution /method of evaluation** *Method/(A, B)*	**Sensitivity coefficient** c_i	**Uncertainty contribution** $u(R_i)$ [μΩ/Ω]	**Degrees of freedom** v_i
Scaling / traceability [μΩ/Ω]	0.600	Normal/B	1	0.600	∞
Reference standard(s) [μΩ/Ω]	0.140	Normal/B	1	0.140	∞
Measuring apparatus [μΩ/Ω]	1.000	Rectangular/B	1	1.000	∞
Reference temperature [ºC]	0.024	Normal/B	25.032 μΩ/Ω per ºC	0.600	∞
Standard deviation [μΩ/Ω]	3.470	Normal/A	1	3.470	40
Repeatability [μΩ/Ω]	2.130	Normal/B	1	2.130	8
Temperature correction [μΩ/Ω per ºC]	0.700	Normal/B	0.1 ºC	0.070	∞
Combined standard uncertainty and effective degrees of freedom:				4.337	∞
Expanded uncertainty (95 % coverage factor):				**8.673 μΩ/Ω**	

NIST - USA *Influence factor y_i*	**Standard uncertainty** $u(y_i)$	**Distribution /method of evaluation** *Method/(A, B)*	**Sensitivity coefficient** c_i	**Uncertainty contribution** $u(R_i)$ [μΩ/Ω]	**Degrees of freedom** v_i
Scaling / traceability [μΩ/Ω]	0.080	Normal/B	1	0.080	∞
Reference standard(s) [μΩ/Ω]	0.025	Normal/B	1	0.025	50
Measuring apparatus [μΩ/Ω]	1.000	Normal/B	1	1.000	∞
Reference temperature [ºC]	0.050	Normal/B	25.032 μΩ/Ω per ºC	1.252	∞
Standard deviation [μΩ/Ω]	0.484	Normal/A	1	0.484	19
Repeatability [μΩ/Ω]	1.230	Normal/B	1	1.230	19
Temperature correction [μΩ/Ω per ºC]	0.700	Normal/B	0.02 ºC	0.014	∞
Combined standard uncertainty and effective degrees of freedom:				2.081	∞
Expanded uncertainty (95 % coverage factor):				**4.162 μΩ/Ω**	

INTI - Argentina *Influence factor y_i*	**Standard uncertainty** *$u(y_i)$*	**Distribution /method of evaluation** *Method/(A, B)*	**Sensitivity coefficient** *c_i*	**Uncertainty contribution** *$u(R_i)$* [μΩ/Ω]	**Degrees of freedom** *v_i*
Scaling / traceability [μΩ/Ω]	0.244	Normal/B	1	0.244	∞
Reference standard(s) [μΩ/Ω]	0.266	Normal/B	1	0.266	∞
Measuring apparatus [μΩ/Ω]	1.562	Normal/B	1	1.562	∞
Reference temperature [ºC]	0.107	Normal/B	25.032 μΩ/Ω per ºC	2.681	∞
Standard deviation [μΩ/Ω]	1.816	Normal/A	1	1.816	4
Repeatability [μΩ/Ω]	0.321	Normal/B	1	0.321	4
Temperature correction [μΩ/Ω per ºC]	0.700	Normal/B	1 ºC	0.700	∞
Combined standard uncertainty and effective degrees of freedom:				3.694	48
Expanded uncertainty (95 % coverage factor):				**7.428 μΩ/Ω**	

Serial number: HR9203
Nominal value: 1 GΩ

CENAM - Mexico *Influence factor y_i*	**Standard uncertainty** $u(y_i)$	**Distribution /method of evaluation** *Method/(A, B)*	**Sensitivity coefficient** c_i	**Uncertainty contribution** $u(R_i)$ [μΩ/Ω]	**Degrees of freedom** v_i
Scaling / traceability [μΩ/Ω]	0.600	Normal/B	1	0.600	∞
Reference standard(s) [μΩ/Ω]	0.140	Normal/B	1	0.140	∞
Measuring apparatus [μΩ/Ω]	1.000	Rectangular/B	1	1.000	∞
Reference temperature [ºC]	0.025	Normal/B	29.550 μΩ/Ω per ºC	0.740	∞
Standard deviation [μΩ/Ω]	2.970	Normal/A	1	2.970	40
Repeatability [μΩ/Ω]	2.341	Normal/B	1	2.341	7
Temperature correction [μΩ/Ω per ºC]	0.700	Normal/B	0.1 ºC	0.070	∞
Combined standard uncertainty and effective degrees of freedom:				4.089	∞
Expanded uncertainty (95 % coverage factor):				**8.178 μΩ/Ω**	

NIST - USA *Influence factor y_i*	**Standard uncertainty** $u(y_i)$	**Distribution /method of evaluation** *Method/(A, B)*	**Sensitivity coefficient** c_i	**Uncertainty contribution** $u(R_i)$ [μΩ/Ω]	**Degrees of freedom** v_i
Scaling / traceability [μΩ/Ω]	0.080	Normal/B	1	0.080	∞
Reference standard(s) [μΩ/Ω]	0.025	Normal/B	1	0.025	50
Measuring apparatus [μΩ/Ω]	1.000	Normal/B	1	1.000	∞
Reference temperature [ºC]	0.050	Normal/B	29.550 μΩ/Ω per ºC	1.478	∞
Standard deviation [μΩ/Ω]	0.477	Normal/A	1	0.477	17
Repeatability [μΩ/Ω]	0.960	Normal/B	1	0.960	17
Temperature correction [μΩ/Ω per ºC]	0.700	Normal/B	0.02 ºC	0.014	∞
Combined standard uncertainty and effective degrees of freedom:				2.085	∞
Expanded uncertainty (95 % coverage factor):				**4.171 μΩ/Ω**	

INTI - Argentina *Influence factor y_i*	**Standard uncertainty** *$u(y_i)$*	**Distribution /method of evaluation** *Method/(A, B)*	**Sensitivity coefficient** *c_i*	**Uncertainty contribution** *$u(R_i)$* [μΩ/Ω]	**Degrees of freedom** *v_i*
Scaling / traceability [μΩ/Ω]	0.244	Normal/B	1	0.244	∞
Reference standard(s) [μΩ/Ω]	0.266	Normal/B	1	0.266	∞
Measuring apparatus [μΩ/Ω]	1.562	Normal/B	1	1.562	∞
Reference temperature [ºC]	0.107	Normal/B	29.550 μΩ/Ω per ºC	3.164	∞
Standard deviation [μΩ/Ω]	1.460	Normal/A	1	1.460	3
Repeatability [μΩ/Ω]	0.007	Normal/B	1	0.007	3
Temperature correction [μΩ/Ω per ºC]	0.700	Normal/B	1 ºC	0.700	50
Combined standard uncertainty and effective degrees of freedom:				3.899	63
Expanded uncertainty (95 % coverage factor):				**7.792 μΩ/Ω**	