Final Report **Revised: 7 October 2019**

Interamerican Metrology System (SIM)
Regional Metrology Organization (RMO)
High Value Resistance Comparison

SIM.EM-S15:

- **100 MΩ at 10 V and 100 V.**
- **100 GΩ at 100 V and 500 V.**

Member Participants:

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2018 Comparison

Pilot Laboratory: National Institute of Standards and Technology, Gaithersburg, Maryland USA

Abstract —This is a report of the results of an Interamerican Metrology System (SIM) comparison on high resistance values, performed to compare the measurement capabilities of National Institute of Standards and Technology (NIST) and (Instituto Costarrricense de Electricidad – Laboratorio Metrológico de Variables Eléctricas) ICE-LMVE and for establishing the degree of equivalence between those laboratories.
During 2018, two resistance standards were used as traveling standards for measurements in those countries, with NIST-USA acting as the pilot laboratory. Results for four measurement points are presented as errors relative to a comparison reference value together with their uncertainty.

Index Terms — Comparison, resistance, measurement error, measurement uncertainty.

1 Introduction

At the National Institute of Standards and Technology (NIST), the U.S. representation of the ohm is based on the quantum Hall effect, and it is maintained and disseminated at various resistance levels by working reference groups of standards. NIST provides a calibration service for standard resistors of nominal decade values (i.e., $R = 10^n$ where n is an integer) in the range from $10^{-5}\ \Omega$ to $10^{12}\ \Omega$. In addition, non-decade value standard resistors can be calibrated in the lower resistance ranges, near $10^3\ \Omega$ or below. To provide this wide-ranging calibration service, NIST maintains a working reference group at each nominal decade value between 1 Ω and $10^{12}\ \Omega$. The working reference groups are calibrated using special ratio techniques.

At the Instituto Costarricense de Electricidad Laboratorio Metrológico de Variables Eléctricas (ICE-LMVE), the Costa Rican representation of the ohm is based on a group of resistors, which goes for calibration to another NMI (not NIST) that uses a comparison against reference standards calibrated in terms of the quantized Hall resistance, using a potentiometric measurement bridge and a modified Wheatstone bridge. To provide the service, ICE-LMVE use a substation method through a commercial high value resistance bridge meter in the range of 1 MΩ to 100 TΩ.

The objective of this comparison is to compare the measurement capabilities of NIST and ICE-LMVE in the field of high value resistance. Since ICE-LMVE has sent their resistors to another NMI, there is no correlation between NIST and ICE-LMVE in the results of this comparison.

ICE-LMVE has been improving its resistance procedures and personnel training. This action is aimed to determine the improvement degree ICE-LMVE has achieved and support new uncertainties that ICE-LMVE will report to SIM for their inclusion in the Key Comparison Data Base (KCDB).

SIM.EM-S15 is an intercomparison of a 100 MΩ resistance standard and a 100 GΩ resistance standard. The participant institutes are listed in Table 1.

Table 1. Resistance comparison participants

Country	**Institute**	**Acronym**
Costa Rica	Instituto Costarricense de Electricidad	ICE
United States	National Institute of Standards and Technology	NIST

2 Traveling Standards

2.1 Description of the standards

The traveling standard for the SIM.EM-S15 comparison were

- Standard Resistor, 100 MΩ, S/N HR8148 Model: NIST-HR-100M
- Standard Resistor, 100 GΩ, S/N HR11232 Model: NIST-HR-100G

These resistance standards are designed as very high stability calibration laboratory standards for accurate resistance calibration in air. With a wide laboratory environment requirement from 18 °C to 28 °C, they can be used as working standards or reliable, ruggedized, transportable transfer standards.

2.2 Transport Package Description

A plastic container was filled with polyurethane foam to hold the traveling standards and equipment. NIST sent the standards via United Parcel Service (UPS) to Costa Rica and then ICE personal hand carried the standards from Costa Rica back to NIST.

2.3 Quantities to be measured

Participants measured the 100 MΩ at 10 V and 100 V; and the 100 GΩ at 100 V and 500 V; both values are presented at 23 °C.

All resistance measurements with corresponding combined standard uncertainties were reported. At least four measurements over three days for each voltage were done.

3 Organization

The National Institute of Standards and Technology (NIST) was the pilot laboratory for the SIM.EM-S15 comparison. NIST used a NIST designed 100 MΩ guarded Hamon transfer standard resistor and a 100 GΩ guarded Hamon transfer standard resistor as reference standards for the measurements. A direct substitution was used to calibrate the traveling standards. Measurements were taken on the traveling standards at both institutes.

The NIST resistance standards were measured at NIST at the beginning and end of the comparison schedule. The NIST resistance standards travelled to the ICE laboratory. ICE calibrated both resistors and sent the results to NIST.

The schedule of measurements is shown in Table 2.

Table 2. Schedule of measurements

Laboratory	Approximate measurement dates
NIST (United States)	February 22, 2018 to March 27, 2018
ICE (Costa Rica)	June 28, 2018 to August 23, 2018
NIST (United States)	November 2, 2018 to December 01, 2018

4 Pilot Laboratory Measurement Results

The pilot laboratory measurement results are listed in Table 3 and Table 4 and are shown graphically in Figure 1 and Figure 2. Results at each voltage consist only of measurements from a Dual Source Resistance Bridge using guarded Hamon Transfer Standards with substitution methods.

4.1 SIM.EM-S15 100 MΩ results

Table 3. Pilot Lab (NIST) measurements for 100 MΩ

100 Mohm HR8148				
Avg date:	**3/15/2018**	**3/16/2018**	**10/24/2018**	**10/29/2018**
Range of dates:	2/3/18-4/28/18		10/1/18-11/26/18	
Avg Temperature (°C)	23.01	23.01	23.01	23.01
Avg Relative Humidity (%)	41.9	41.6	41.6	41.7
Test Voltage (V)	10	100	10	100
Combined standard uncertainty (RSS)	0.92	0.88	0.93	0.88
Expanded uncertainty (*k*=2)	**1.8**	**1.8**	**1.9**	**1.8**
Reported value (ppm)	**-543**	**-543**	**-540**	**-540**
Reported value (ohm)	**9.99457E+07**	**9.99457E+07**	**9.99460E+07**	**9.99460E+07**

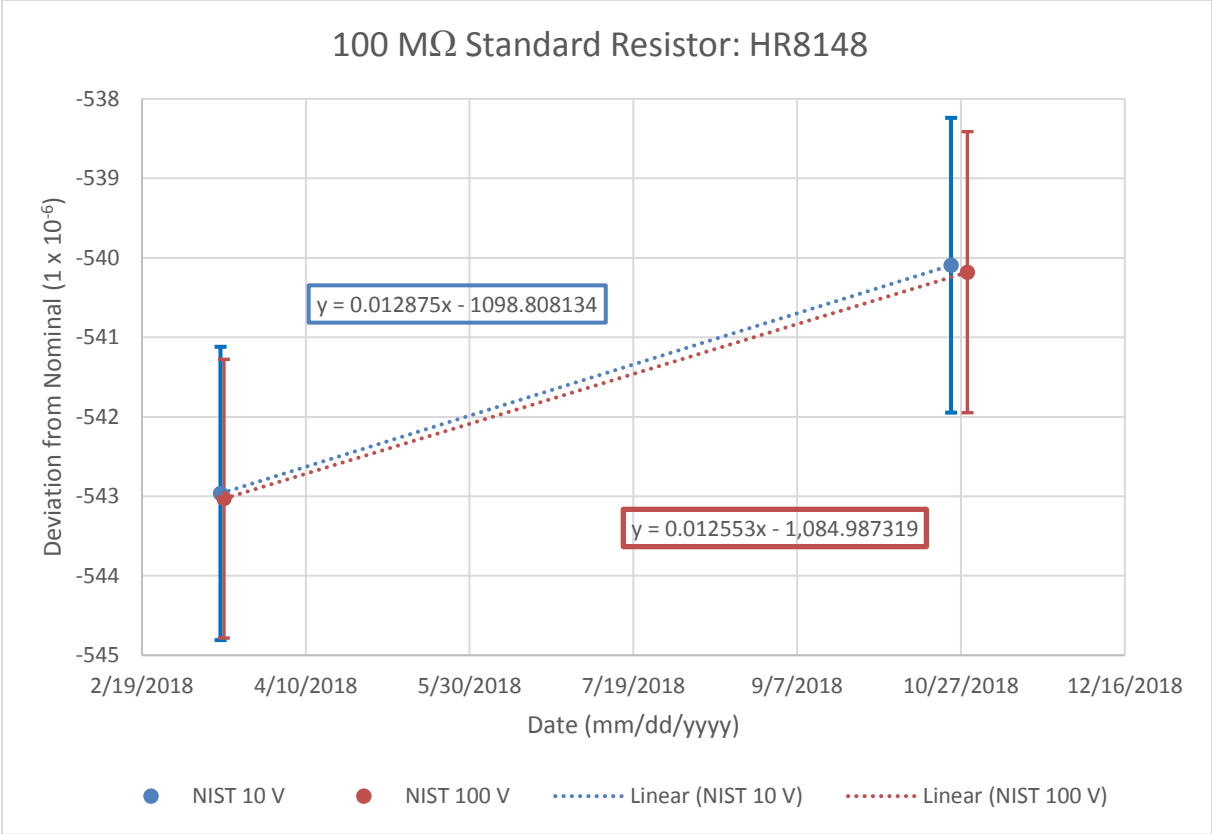

Fig. 1. Pilot laboratory measurements of NIST 100 MΩ standard resistor at 10 V and 100 V, showing the averages of the before and after measurements. The error bar on the mean value of both averages, showing expanded uncertainty (k = 2).

4.2 SIM.EM- S15 100 GΩ results

Table 4. Pilot Lab (NIST) measurements for 100 GΩ

100 Gohm HR11232				
Avg date:	**3/11/2018**	**3/11/2018**	**11/18/2018**	**11/18/2018**
Range of dates:	2/22/18 to 3/27/18		11/2/18 to 12/1/18	
Avg Temperature (°C)	23.01	23	23.01	23.01
Avg Relative Humidity (%)	36.5	36.6	40.1	40.1
Test Voltage (V)	100	500	100	500
Combined standard uncertainty (RSS)	15.22	11.66	5.51	4.89
Expanded uncertainty (k=2)	30	23	11	9.8
Reported value (ppm)	**-609**	**-616**	**-512**	**-520**
Reported value (ohm)	**9.99391E+10**	**9.99384E+10**	**9.99488E+10**	**9.99480E+10**

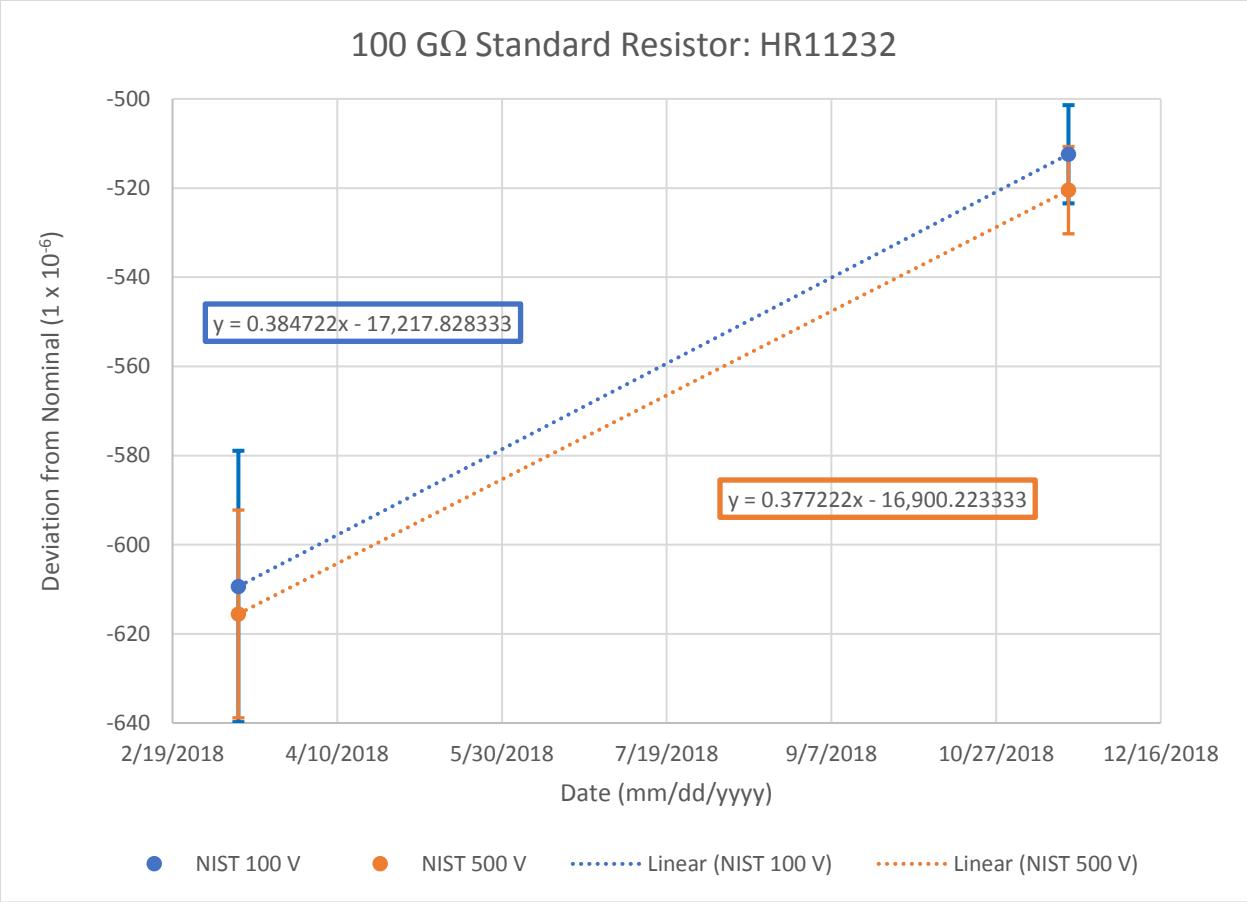

Fig. 2. Pilot laboratory measurements of NIST 100 GΩ standard resistor at 100 V and 500 V showing the averages of the before and after measurements. The error bar on the mean value of both averages, showing expanded uncertainty (k = 2).

5 Reported Results of Comparisons

The results for the participant laboratory (ICE) are reported in Table 5 and Table 6. Figure 3 and Figure 4 graphically show those results as they compare to the pilot laboratory (NIST).

5.1 SIM.EM-S15 100 MΩ results

Table 5. ICE measurements for 100 MΩ

Date (MN/DY/YR)	Resistance (MΩ)	Voltage (V)	Expanded Uncertainty μΩ/Ω (*k* = 2)
6/29/2018	99.947 3	10	
7/4/2018	99.947 2	10	
7/11/2018	99.947 1	10	
7/23/2018	99.947 4	10	
8/3/2018	99.947 2	10	
Mean (*7/14/2018*)	*99.947 2*	10	14
6/29/2018	99.947 5	100	
7/4/2018	99.947 6	100	
7/11/2018	99.947 4	100	
7/23/2018	99.947 7	100	
8/3/2018	99.947 5	100	
Mean (*7/14/2018*)	*99.947 5*	100	14

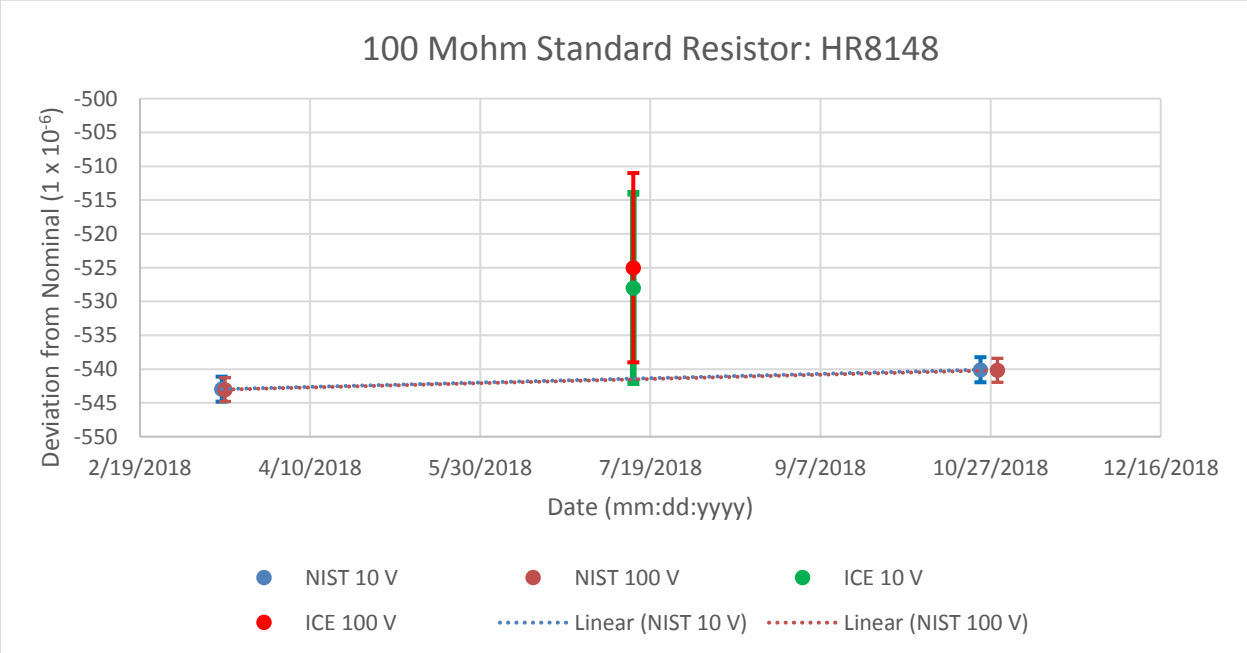

Fig. 3. Participant results of measurement of NIST 100 MΩ standard resistor at 10 V and 100 V with error bar on the mean value, showing expanded uncertainty (*k* = 2). NIST mean value corresponds to the average of before and after measurements. ICE-LMVE mean value corresponds to the average of five days of measurements.

5.2 SIM.EM- S15 100 GΩ results

Table 6. ICE measurements for 100 GΩ

Date (MN/DY/YR)	Resistance (GΩ)	Voltage (V)	Expanded Uncertainty μΩ/Ω (k = 2)
8/9/2018	99.948 5	100	
8/9/2018	99.944 4	100	
8/13/2018	99.945 2	100	
8/20/2018	99.947 9	100	
8/23/2018	99.947 9	100	
Mean (08/14/2018)	*99.946 8*	100	140
7/3/2018	99.953	500	
7/6/2018	99.952 1	500	
7/11/2018	99.953 1	500	
7/13/2018	99.954 7	500	
8/20/2018	99.952	500	
Mean (07/16/2018)	*99.953*	500	90

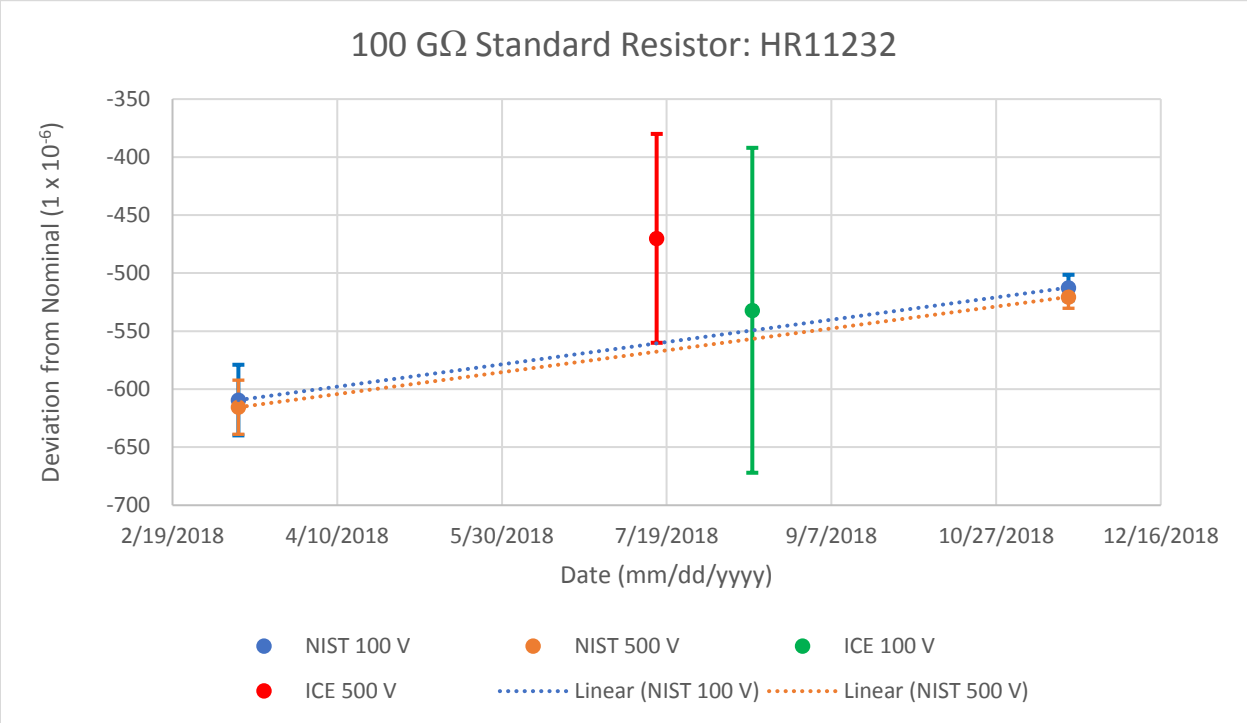

Fig. 4. Participant results of measurement of NIST 100 GΩ standard resistor at 100 V and 500 V with error bar on the mean value, showing expanded uncertainty (k = 2). NIST mean value corresponds to the average of before and after measurements. ICE-LMVE mean value corresponds to the average of five days of measurements.

6 Summary and References

This intercomparison exercise was performed with the ultimate goal of improving the measurement and calibration capabilities of the LMVE.

According to the exercise carried out, the LMVE proposes a new CMC as detailed in the attached table, which shows the improvement in the implementation of a new measurement method, based on a commercial High Resistance Meter designed to measure high resistances in the range of 1 MΩ to 100 TΩ.

The measurements were done in the *Resistor Substitution Measurements MODE*. In this mode high accuracy is obtained. The measurement of a standard of known resistor is automatically compared to a resistor under test. With this method any hardware drift and instability are taken account, consequently are corrected for the unknown resistance measurement.

Table 7. Intercomparison Results vrs CMCs

	CMCs TODAY		**SIM.EM-S15 Participation Results**	
Value	Voltage (V)	Uncertainty (PPM)	Voltage (V)	Uncertainty (PPM)
10 MΩ	1, 10, 50 & 100	30		
100 MΩ	1, 10, 50, 100, 200, 500 & 1000	50	10 & 100	14
1 GΩ	1	150		
	10, 50, 100, 200, 500 & 1000	150		
10 GΩ	1	1100		
	10	200		
	50, 100, 200, 500 & 1000	150		
100 GΩ	10, 50, 100, 200, 500 & 1000	500	100	140
			500	90

Table 8. Improvement

	CMCs TODAY		CMCs to be Upload		Improvement
Value	Voltage (V)	Uncertainty (PPM)	Voltage (V)	Uncertainty (PPM)	(%)
10 MΩ	1, 10, 50 & 100	30	1, 10, 50 & 100	14	-46.7
100 MΩ	1, 10, 50, 100, 200, 500 & 1000	50	1, 10, 50, 100, 200, 500 & 1000	30	-60.0
1 GΩ	1	150	Will be taken out of CMCs. No clients ask for this value		
	10, 50, 100, 200, 500 & 1000	150	10, 50, 100, 200, 500 & 1000	50	-50.0
10 GΩ	1	1100	Will be taken out of CMCs. No clients ask for this value.		
	10	200	Will be taken out of CMCs. No clients ask for this value.		
	50, 100, 200, 500 & 1000	150	50, 100, 200, 500 & 1000	100	-33.3
100 GΩ	10, 50, 100, 200, 500 & 1000	500	10, 50, 100, 200, 500 & 1000	150	-70.0

References

[1] ISO/IEC 17043:2010 Conformity assessment -- General requirements for proficiency testing

[2] CIPM MRA-D-05 Measurement comparisons in the CIPM MRA. Version 1.5

[3] CIPM MRA-D-04 - Calibration and Measurement Capabilities in the context of the CIPM MRA. Version 4.

Appendix A: Analysis Procedure

The bilateral comparisons consist of two related resistance comparisons between ICE and NIST. SIM.EM-S15 is a comparison of a NIST 100 MΩ standard resistor, S/N HR8148 Model: NIST-HR-100M and a NIST 100 GΩ standard resistor, S/N HR11232 Model: NIST-HR-100G. The two participant laboratories each measured both traveling standards resistors. NIST measured the traveling standards for two measurement periods, before and after ICE measured the traveling standards for one measurement period. A linear fit of the pilot laboratory (NIST) results before and after data was used to determine values on the mean dates of the ICE results.

In order to determine if ICE-LMVE is proficient for this particular measurement discipline, the normalized error (E_n) is calculated.

The E_n performance statistic is found in ISO/IEC 17043-2010 and the A2LA document "A2LA Proficiency Testing Requirements for Accredited Testing and Calibration Laboratories" and in other documents is given in equation (1):

$$|E_n| = \left| \frac{x - X}{\sqrt{U_{lab}^2 + U_{ref}^2}} \right|$$

where:

E_n = normalized error

x = participant's measurement result

X = assigned value of the artifact

U_{lab} = uncertainty of the participant's measurement results

U_{ref} = uncertainty of the reference laboratory's assigned value

The normalized error can fluctuate between a positive or negative value. If a participant gets normalized error values between -1 and +1, with an acceptable estimate of their uncertainties, it can be concluded that the laboratory has a satisfactory, reliable and competent performance.

The normalized error criterion is:

$|En| \leq 1.0$ for satisfactory performance and

$|En| > 1.0$ for unsatisfactory performance.

Note: U_{lab} and U_{ref} are both the expanded uncertainty with k = 2.

Appendix B: Analysis Results

1. Measurements for 100 MΩ standard resistor at 10 V and 100 V.

100 Mohm HR8148	NIST	NIST	NIST	NIST	Excel Date# for NIST ref value		ICE	ICE	Normalized Error	
Avg date:	3/15/2018	3/16/2018	10/24/2018	10/29/2018	07/14/2018	07/14/2018	07/14/2018	07/14/2018		
Test Voltage (V)	10	100	10	100	10 V	100 V	10 V	100 V	10 V	100 V
Quantity	**Standard Uncertainty (ppm)**		**Standard Uncertainty (ppm)**		**NIST pooled SD (Uncert, ppm)**		**Standard Uncertainty (ppm)**			
	(10V, before)	(100 V, before)	(10 V, after)	(100 V, after)	10 V	100 V	(10 V)	(100 V)		
Expanded uncertainty (*k*=2)	1.8	1.8	1.9	1.8	1.9	1.8	14	14		
					NIST value on ICE mean date(ppm)					
Reported value (ppm)	-543	-543	-540	-540	-541	-542	-528	-525	0.95	1.17
Reported value (ohm)	9.99457E+07	9.99457E+07	9.99460E+07	9.99460E+07	9.99459E+07	9.99458E+07	9.99472E+07	9.99475E+07		

2. Measurements for 100 GΩ standard resistor at 100 V and 500 V.

100 Gohm HR11232	NIST	NIST	NIST	NIST	Excel Date# for NIST ref value		ICE	ICE	Normalized Error	
Avg date:	3/11/2018	3/11/2018	11/18/2018	11/18/2018	08/14/2018	07/16/2018	08/14/2018	07/16/2018		
Test Voltage (V)	100	500	100	500	100 V	500 V	100 V	500 V	100 V	500 V
Quantity	**Standard Uncertainty (ppm)**		**Standard Uncertainty (ppm)**		**NIST pooled SD (Uncert, ppm)**		**Standard Uncertainty (ppm)**			
	(100V, before)	(500 V, before)	(100 V, after)	(500 V, after)	100 V	500 V	(100 V)	(500 V)		
Expanded uncertainty (k=2)	30	23	11	9.8	22.6	17.7	140	90		
					NIST value on ICE mean date(ppm)					
Reported value (ppm)	-609	-616	-512	-520	-549	-568	-532	-470	0.12	1.06
Reported value (ohm)	9.99391E+10	9.99384E+10	9.99408E+10	9.99480E+10	9.99451E+10	9.99432E+10	9.99468E+10	9.99530E+10		

Appendix C: Uncertainty Budgets for 100 MΩ

Table C1. ICE-LMVE 100 MΩ at 10 V Uncertainty Budget

No.	Component	Information Source	Estimated Value		Distribution	Uncertainty Value		Coverage Factor	Uncertainty Value (68.28%)	Degrees of Freedom	Sensitivity Coefficient		Contribution to uncertainty (Square)	W - S	% contribution
1	Ratio Nx/Ns	**Data**	**0.999 439 800 0**	--	---	---	--	--	---	--	---	--	**0.000E+00**	**0.000E+00**	0.000%
1.1	Repetitibity	Observation	---	--	A	0.000 001 800 0	--	1.00	0.000 001 800 0	19	100	--	3.240E-08	5.526E-17	6.654%
1.2	Resolution	Bridge	---	--	R	0.000 005 000 0	--	1.73	0.000 002 890 2	200	100	--	8.354E-08	3.489E-17	17.156%
2	6650 A Bridge Uncertainty	Bridge	---	--	N99	0.000 015 000 0	---	2.58	0.000 005 823 0	200	100	--	3.391E-07	5.749E-16	69.638%
3	**Standard Resistor (RS)**	**Calibration Certificate**	**100.003 220 000 0**	XΩ	---	---	XΩ	--	---	--	--	--	**0.000E+00**	**0.000E+00**	**0.000%**
3.1	Calibration Uncertainty	Standard	---	XΩ	N9545	0.000 300 009 7	XΩ	2.00	0.000 150 004 8	200	-1	--	2.248E-08	2.526E-18	4.616%
3.2	Stability Uncertainty	Standard	---	XΩ	R	0.000 168 005 4	XΩ/año	1.73	0.000 097 113 0	200	-1	año	9.420E-09	4.437E-19	1.935%
5	**Standard Resistor Temperature Coefficient (αs)**	**Specification**	**0.000 000 500 0**	-	**R**	**0.000 000 500 0**	-	**1.73**	**0.000 000 289 0**	**200**	**-2.58E+00**	**ºC**	**5.554E-13**	**1.543E-27**	**0.000%**
5.1	Ts	Meas	22.97	ºC	R	0.019	ºC	2.01	0.009 647 266 3	200	-5.00E-05	XΩ/ºC	2.324E-13	2.701E-28	0.000%
5.2	TNS	Calibration Certificate	23.00	ºC	No es fuente de Incertidumbre										
6	**UUT Temperature Coefficient (αX)**	**Specification**	**-0.000 001 417 0**	-	**R**	**-0.000 001 417 0**	-	**1.73**	**-0.000 000 819 1**	**200**	2.58E+00	**ºC**	**4.461E-12**	**9.950E-26**	**0.001%**
6.1	Tx	Meas	22.97	ºC	N_otro	0.019	ºC	2.01	0.009 647 266 3	200	5.00E-05	XΩ/ºC	2.324E-13	2.701E-28	0.000%
6.2	TNX	Temperature Elected	23.00	ºC	No es fuente de Incertidumbre										
7	**Standard Resistor Voltage Coefficient (δs)**	**Specification**	**0.000 000 500 0**	-	**R**	**0.000 000 500 0**	-	**1.73**	**0.000 000 289 0**	**200**	**0.00E+00**	**V**	**0.000E+00**	**0.000E+00**	**0.000%**
7.1	Vs	Meas	10.00	V	R	0.000 000 000 0	V	1.73	0.000 000 000 0	200	-5.00E-05	XΩ/V	0.000E+00	0.000E+00	0.000%
7.2	VNS	Calibration Certificate	10.00	V	No es fuente de Incertidumbre										
8	**UUT Voltage Coefficient (δX)**	**Specification**	**0.000 000 001 5**	-	**R**	**0.000 000 001 5**	-	**1.73**	**0.000 000 000 9**	**200**	0.00E+00	**V**	**0.000E+00**	**0.000E+00**	**0.000%**
8.1	Vx	Meas	10.00	V	R	0.000 000 000 0	V	1.73	0.000 000 000 0	200	1.04E+08	XΩ/V	0.000E+00	0.000E+00	0.000%
8.2	VNX	Voltage Elected	10.00	V	No es fuente de Incertidumbre										
		Rx	99.947 195 831 5	XΩ							Incertidumbre Combinada		0.00069781	Total	100.000%
											v eff		354.93		
			Rx =		99.947 195 8	MΩ	±	14.01	μΩ/Ω		Valor de k calculado		2.01		
											Incetidumbre Expandida		1.401E-03		

Table C2. ICE-LMVE 100 MΩ at 100 V Uncertainty Budget

No.	Component	Information Source	Estimated Value		Distribution	Uncertainty Value		Coverage Factor	Uncertainty Value (68.28%)	Degrees of Freedom	Sensitivity Coefficient		Contribution to uncertainty (Square)	W - S	% contribution
1	Ratio Nx/Ns	**Data**	**0.999 445 300 0**	--	---	---	--	--	---	--	---	--	**0.000E+00**	**0.000E+00**	0.000%
1.1	Repetitibity	Observation	---	--	A	0.000 000 600 0	--	1.00	0.000 000 600 0	19	100	--	3.600E-09	6.822E-19	0.689%
1.2	Resolution	Bridge	---	--	R	0.000 005 000 0	--	1.73	0.000 002 890 2	200	100	--	8.354E-08	3.489E-17	15.996%
2	6650 A Bridge Uncertainty	Bridge	---	--	N99	0.000 015 000 0	---	2.58	0.000 005 823 0	200	100	--	3.391E-07	5.749E-16	64.932%
3	**Standard Resistor (RS)**	**Calibration Certificate**	**100.003 200 000 0**	XΩ	---	---	XΩ	--	---	--	--	--	**0.000E+00**	**0.000E+00**	**0.000%**
3.1	Calibration Uncertainty	Standard	---	XΩ	N9545	0.000 600 019 2	XΩ	2.00	0.000 300 009 6	200	-1	--	8.991E-08	4.042E-17	17.216%
3.2	Stability Uncertainty	Standard	---	XΩ	R	0.000 135 004 3	XΩ/año	1.73	0.000 078 037 2	200	-1	año	6.083E-09	1.850E-19	1.165%
5	**Standard Resistor Temperature Coefficient (αs)**	**Specification**	**0.000 000 500 0**	-	**R**	**0.000 000 500 0**	-	**1.73**	**0.000 000 289 0**	**200**	**-2.56E+00**	**ºC**	**5.481E-13**	**1.502E-27**	**0.000%**
5.1	Ts	Meas	22.97	ºC	R	0.019	ºC	2.01	0.009 647 462 7	200	-5.00E-05	XΩ/ºC	2.324E-13	2.701E-28	0.000%
5.2	TNS	Calibration Certificate	23.00	ºC	No es fuente de Incertidumbre										
6	**UUT Temperature Coefficient (αX)**	**Specification**	**-0.000 001 417 0**	-	**R**	**-0.000 001 417 0**	-	**1.73**	**-0.000 000 819 1**	**200**	2.56E+00	**ºC**	**4.402E-12**	**9.691E-26**	**0.001%**
6.1	Tx	Meas	22.97	ºC	N_otro	0.019	ºC	2.01	0.009 647 462 7	200	5.00E-05	XΩ/ºC	2.324E-13	2.701E-28	0.000%
6.2	TNX	Temperature Elected	23.00	ºC	No es fuente de Incertidumbre										
7	**Standard Resistor Voltage Coefficient (δs)**	**Specification**	**0.000 000 500 0**	-	**R**	**0.000 000 500 0**	-	**1.73**	**0.000 000 289 0**	**200**	**0.00E+00**	**V**	**0.000E+00**	**0.000E+00**	**0.000%**
7.1	Vs	Meas	100.00	V	R	0.000 000 000 0	V	1.73	0.000 000 000 0	200	-5.00E-05	XΩ/V	0.000E+00	0.000E+00	0.000%
7.2	VNS	Calibration Certificate	100.00	V	No es fuente de Incertidumbre										
8	**UUT Voltage Coefficient (δX)**	**Specification**	**0.000 000 001 5**	-	**R**	**0.000 000 001 5**	-	**1.73**	**0.000 000 000 9**	**200**	0.00E+00	**V**	**0.000E+00**	**0.000E+00**	**0.000%**
8.1	Vx	Meas	100.00	V	R	0.000 000 000 0	V	1.73	0.000 000 000 0	200	1.05E+08	XΩ/V	0.000E+00	0.000E+00	0.000%
8.2	VNX	Voltage Elected	100.00	V	No es fuente de Incertidumbre										
		Rx	99.947 725 875 9	XΩ							Incertidumbre Combinada		0.00072265	Total	100.000%
											v eff		418.86		
			Rx =		99.947 725 9	**MΩ**	±	14.50	µΩ/Ω		Valor de k calculado		2.01		
											Incetidumbre Expandida		1.450E-03		

Table C3. NIST 100 MΩ Uncertainty Budget

Quantity	**Type**	**Standard Uncertainty (ppm)**		**Standard Uncertainty (ppm)**	
		(10V, before)	**(100 V, before)**	**(10 V, after)**	**(100 V, after)**
Standard Deviation	A	0.43	0.32	0.44	0.34
Scaling / Traceability	B	0.7	0.7	0.7	0.7
Reference Stds	B	0.1	0.1	0.1	0.1
Measuring Apparatus	B	0.4	0.4	0.4	0.4
Leakage Effects	B	0.05	0.05	0.05	0.05
Ambient Temperature	B	0.06	0.06	0.06	0.06
Combined standard uncertainty (RSS)		0.92	0.88	0.93	0.88
Expanded uncertainty (*k*=2)		**1.8**	**1.8**	**1.9**	**1.8**

Appendix D: Uncertainty Budgets for 100 GΩ

Table D1. ICE-LMVE 100 GΩ at 100 V Uncertainty Budget

No.	Component	Information Source	Estimated Value		Distribution	Uncertainty Value		Coverage Factor	Uncertainty Value (68.28%)	Degrees of Freedom	Sensitivity Coefficient		Contribution to uncertainty (Square)	W - S	% contribution
1	Ratio Nx/Ns	**Data**	**0.999 171 800 0**	--	---	---	--	--	---	--	---	--	**0.000E+00**	**0.000E+00**	0.000%
1.1	Repetitibity	Observation	---	--	A	0.000 055 300 0	--	1.00	0.000 055 300 0	19	100	--	3.060E-05	4.928E-11	68.520%
1.2	Resolution	Bridge	---	--	R	0.000 005 000 0	--	1.73	0.000 002 890 2	200	100	--	8.358E-08	3.493E-17	0.187%
2	6650 A Bridge Uncertainty	Bridge	---	--	N99	0.000 020 000 0	---	2.58	0.000 007 764 0	200	100	--	6.032E-07	1.819E-15	1.351%
3	**Standard Resistor (RS)**	**Calibration Certificate**	**100.035 200 000 0**	XΩ	---	---	XΩ	--	---	--	--	--	**0.000E+00**	**0.000E+00**	**0.000%**
3.1	Calibration Uncertainty	Standard	---	XΩ	N9545	0.003 901 372 8	XΩ	2.00	0.001 950 686 4	200	-1	--	3.799E-06	7.215E-14	8.506%
3.2	Stability Uncertainty	Standard	---	XΩ	R	0.001 645 579 0	XΩ/año	1.73	0.000 951 201 8	200	-1	año	9.032E-07	4.079E-15	2.023%
5	**Standard Resistor Temperature Coefficient (αs)**	**Specification**	**0.000 250 000 0**	-	**R**	**0.000 250 000 0**	-	**1.73**	**0.000 144 508 7**	**200**	**-3.16E+00**	**ºC**	**2.091E-07**	**2.187E-16**	**0.468%**
5.1	Ts	Meas	22.97	ºC	R	0.023	ºC	2.03	0.011 357 396 6	200	-2.50E-02	XΩ/ºC	8.054E-08	3.244E-17	0.180%
5.2	TNS	Calibration Certificate	23.00	ºC	No es fuente de Incertidumbre										
6	**UUT Temperature Coefficient (αX)**	**Specification**	**0.000 100 000 0**	-	**R**	**0.000 100 000 0**	-	**1.73**	**0.000 057 803 5**	**200**	3.16E+00	**ºC**	**3.346E-08**	**5.597E-18**	**0.075%**
6.1	Tx	Meas	22.97	ºC	N_otro	0.023	ºC	2.03	0.011 357 396 6	200	9.99E-05	XΩ/ºC	1.289E-12	8.302E-27	0.000%
6.2	TNX	Temperature Elected	23.00	ºC	No es fuente de Incertidumbre										
7	**Standard Resistor Voltage Coefficient (δs)**	**Specification**	**0.000 001 000 0**	-	**R**	**0.000 001 000 0**	-	**1.73**	**0.000 000 578 0**	**200**	**5.00E+03**	**V**	**8.345E-06**	**3.482E-13**	**18.687%**
7.1	Vs	Meas	150.00	V	R	0.000 000 000 0	V	1.73	0.000 000 000 0	200	-1.00E-04	XΩ/V	0.000E+00	0.000E+00	0.000%
7.2	VNS	Calibration Certificate	100.00	V	No es fuente de Incertidumbre										
8	**UUT Voltage Coefficient (δX)**	**Specification**	**-0.000 000 013 0**	-	**R**	**-0.000 000 013 0**	-	**1.73**	**-0.000 000 007 5**	**200**	-5.00E+03	**V**	**1.410E-09**	**9.944E-21**	**0.003%**
8.1	Vx	Meas	150.00	V	R	0.000 000 000 0	V	1.73	0.000 000 000 0	200	-8.86E+04	XΩ/V	0.000E+00	0.000E+00	0.000%
8.2	VNX	Voltage Elected	100.00	V	No es fuente de Incertidumbre										
		Rx	99.948 525 756 2	XΩ							Incertidumbre Combinada		0.00668269	Total	100.000%
											v eff		40.12		
			Rx =		99.948 525 8	**GΩ**	±	138.03	µΩ/Ω		Valor de k calculado		2.06		
											Incetidumbre Expandida		1.380E-02		

Table D2. ICE-LMVE 100 GΩ at 500 V Uncertainty Budget

No.	Component	Information Source	Estimated Value		Distribution	Uncertainty Value		Coverage Factor	Uncertainty Value (68.28%)	Degrees of Freedom	Sensitivity Coefficient		Contribution to uncertainty (Square)	W - S	% contribution
1	Ratio Nx/Ns	**Data**	**0.999 166 000 0**	--	---	---	--	--	---	--	---	--	**0.000E+00**	**0.000E+00**	0.000%
1.1	Repetitibity	Observation	---	--	A	0.000 032 500 0	--	1.00	0.000 032 500 0	19	100	--	1.057E-05	5.880E-12	58.979%
1.2	Resolution	Bridge	---	--	R	0.000 005 000 0	--	1.73	0.000 002 890 2	200	100	--	8.359E-08	3.494E-17	0.466%
2	6650 A Bridge Uncertainty	Bridge	---	--	N99	0.000 020 000 0	---	2.58	0.000 007 764 0	200	100	--	6.032E-07	1.819E-15	3.366%
3	**Standard Resistor (RS)**	**Calibration Certificate**	**100.035 300 000 0**	XΩ	---	---	XΩ	--	---	--	--	--	**0.000E+00**	**0.000E+00**	**0.000%**
3.1	Calibration Uncertainty	Standard	---	XΩ	N9545	0.003 901 376 7	XΩ	2.00	0.001 950 688 4	200	-1	--	3.799E-06	7.216E-14	21.197%
3.2	Stability Uncertainty	Standard	---	XΩ	R	0.002 760 974 3	XΩ/año	1.73	0.001 595 938 9	200	-1	año	2.543E-06	3.233E-14	14.188%
5	**Standard Resistor Temperature Coefficient (αs)**	**Specification**	**0.000 250 000 0**	-	**R**	**0.000 250 000 0**	-	**1.73**	**0.000 144 508 7**	**200**	**-3.16E+00**	**ºC**	**2.091E-07**	**2.187E-16**	**1.167%**
5.1	Ts	Meas	22.97	ºC	R	0.023	ºC	2.03	0.011 357 396 6	200	-2.50E-02	XΩ/ºC	8.054E-08	3.244E-17	0.449%
5.2	TNS	Calibration Certificate	23.00	ºC	No es fuente de Incertidumbre										
6	**UUT Temperature Coefficient (αX)**	**Specification**	**0.000 100 000 0**	-	**R**	**0.000 100 000 0**	-	**1.73**	**0.000 057 803 5**	**200**	3.16E+00	**ºC**	**3.346E-08**	**5.598E-18**	**0.187%**
6.1	Tx	Meas	22.97	ºC	N_otro	0.023	ºC	2.03	0.011 357 396 6	200	1.00E-04	XΩ/ºC	1.289E-12	8.304E-27	0.000%
6.2	TNX	Temperature Elected	23.00	ºC	No es fuente de Incertidumbre										
7	**Standard Resistor Voltage Coefficient (δs)**	**Specification**	**0.000 001 000 0**	-	**R**	**0.000 001 000 0**	-	**1.73**	**0.000 000 578 0**	**200**	**0.00E+00**	**V**	**0.000E+00**	**0.000E+00**	**0.000%**
7.1	Vs	Meas	500.00	V	R	0.000 000 000 0	V	1.73	0.000 000 000 0	200	-1.00E-04	XΩ/V	0.000E+00	0.000E+00	0.000%
7.2	VNS	Calibration Certificate	500.00	V	No es fuente de Incertidumbre										
8	**UUT Voltage Coefficient (δX)**	**Specification**	**-0.000 000 013 0**	-	**R**	**-0.000 000 013 0**	-	**1.73**	**-0.000 000 007 5**	**200**	0.00E+00	**V**	**0.000E+00**	**0.000E+00**	**0.000%**
8.1	Vx	Meas	500.00	V	R	0.000 000 000 0	V	1.73	0.000 000 000 0	200	-1.29E+05	XΩ/V	0.000E+00	0.000E+00	0.000%
8.2	VNX	Voltage Elected	500.00	V	No es fuente de Incertidumbre										
		Rx	99.952 978 130 0	XΩ							Incertidumbre Combinada		0.00423343	Total	100.000%
											v eff		53.65		
			Rx =		99.952 978 1	**GΩ**	±	86.75	μΩ/Ω		Valor de k calculado		2.05		
											Incetidumbre Expandida		8.671E-03		

Table D3. NIST 100 GΩ Uncertainty Budget

Quantity	**Type**	**Standard Uncertainty (ppm)**		**Standard Uncertainty (ppm)**	
		(100V, before)	**(500 V, before)**	**(100 V, after)**	**(500 V, after)**
Standard Deviation	A	14.5	10.7	3	1.6
Scaling / Traceability	B	3	3	3	3
Reference Stds	B	2	2	2	2
Measuring Apparatus	B	2	2	2	2
Leakage Effects	B	2	2	2	2
Ambient Temperature	B	0.6	0.6	0.6	0.6
Combined standard uncertainty (RSS)		15.22	11.66	5.51	4.89
Expanded uncertainty (*k*=2)		**30**	**23**	**11**	**9.8**