SIM.EM – S9b, 1 Ω and 10 kΩ

2012 Resistance Bilateral Comparison between SIM/COOMET Laboratories

COMPARISON FINAL REPORT

Comparison of Resistance Standards at 1 Ω and 10 kΩ between INIMET (Cuba) and INTI (Argentina)

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Introduction

The MRA states that its technical basis is a set of results obtained in a course of time through key comparisons carried out by the Consultative Committees of the CIPM, the BIPM and the Regional Metrology Organizations (RMOs).

As part of this process, INTI has participated in several key and supplemental comparisons; in particular, it has participated in SIM.EM-K1-K2-S6.

By means of procedures for linking key comparison data, a bilateral comparison will help to provide assurance of equality in measurements between the participating laboratories. With this end, the comparison SIM.EM – S9.b, 1 Ω and 10 kΩ of 1 Ω and 10 kΩ standards resistors of INIMET and INTI was carried out from March to October 2012. Two INTI standard resistors, Leeds & Northrup 1850321, nominal value 1 Ω and ESI SR104 460037 nominal value 10 kΩ were transported by freight to INIMET.

The INIMET measurements were carried out from July, 30 to August, 17, 2012 At INTI, the travelling standards were calibrated before and after the measurements at INIMET, by comparison with the other standards traceable to the quantum Hall resistance reference of INTI. Results of all measurements were corrected for deviations of the reference temperature value.

Results at 1 Ω

Figure 1 shows the measured values obtained for the 1 Ω standard L&N SN 1850321. Plotted values are corrected in temperature. A linear least squares fit is applied to the results of INTI to obtain the result for the standard and its uncertainty at the mean date of INIMET measurements.

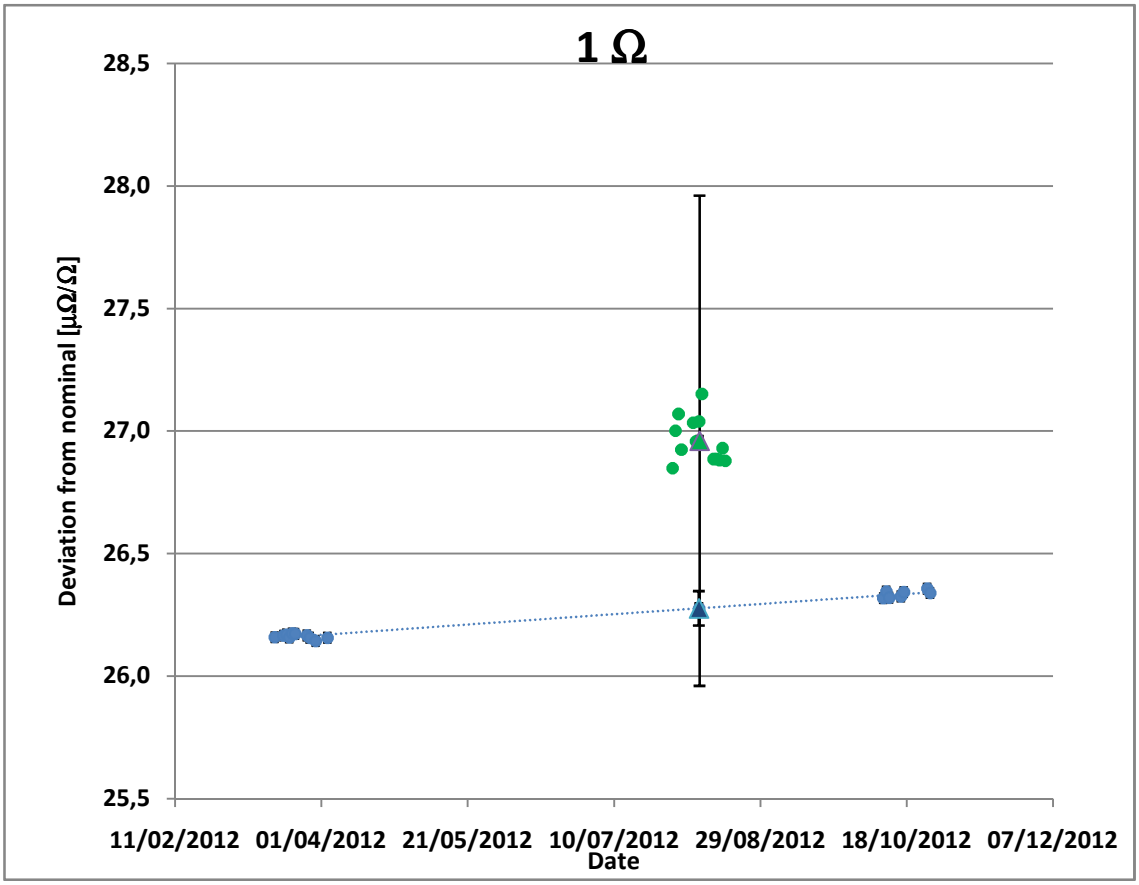


Figure 1. Resistance values obtained by INTI (in blue) and INIMET (in green) at 1 Ω. Dotted line refers to a linear least-squares fit to measurements of INTI.

The result of the comparison is presented as the difference between the value assigned to a 1 Ω standard by INTI, R_{INTI}, and that assigned by INIMET, R_{INIMET}, which for the reference date is

$$R_{INTI} - R_{INIMET} = -0.68\ \mu\Omega; \qquad u_c = 1.07\ \mu\Omega \qquad \text{on 08/08/2012},$$

where u_c is the combined standard uncertainty associated with the measured difference, including the uncertainty of the representation of the ohm at INTI and at INIMET and the uncertainty related to the comparison.

Method of measurements at INTI

All measurements were carried out with an automated DCC current comparator bridge, a commercial MI Model 6010 B. Six INTI 1 Ω standard resistors were used in this comparison, with interchange of like-value standards in the current comparator

bridge to reduce bridge ratio errors. Measurements were repeated on ten days in the first part and seven days in the last part. In the last part, INTI used two 1 Ω standard resistors in the comparison.
Measurement temperature control: The reference standards and the travel standard were measured in a silicone oil bath maintained at nominal 20.02 °C, U = 0.01 °C.
Test current: Direct current with reversal, measured at 45 mA.
Room Temperature: 22 °C, U = 1 °C
Atm Pressure : There was no pressure correction.

Traceability at INTI

The set of six 1 Ω standard resistors of INTI are measured once per year in comparison with the ESI SR104 10 kΩ standard resistors using the DCC current comparator bridge MI 6010 B and two transfer Hamon boxes of 10 Ω/step and 1 kΩ/step. In this way it is possible to scale from 10 kΩ to 1 Ω in three steps using only 1:1 relations with the bridge. The ESI SR104 resistors are calibrated against the quantum Hall resistance of INTI using a high accuracy potentiometer system. Then they are used immediately after to compare the set of 1 Ω. Each year, after six months, the 1 Ω standard resistors set are measured between them assuming that the mean value of the set is constant.

The declared uncertainties at INTI are 0.1 μΩ/Ω for 1 Ω standard resistors and 0.08 μΩ/Ω for 10 kΩ standard resistors.

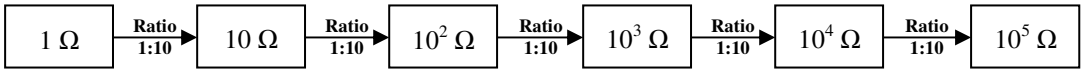
Method of measurements at INIMET

Measurements were carried out by means of an automated current comparator bridge GUILDLINE 6675A. Two INIMET 1 Ω standard resistors were used in this comparison. Measurements were repeated during three weeks, four/five days a week. Each measurement corresponds to an average of four measurements. In all cases the values of resistors were corrected at the reference temperature (20 °C)
Measurement temperature control: The reference standards and the comparison standard were measured in a mineral oil bath maintained at nominal 23.00 °C, U = 0.05 °C.
Test current: Direct current with reversal, measured at 100 mA.
Room Temperature: 23 °C, U = 2 °C

Traceability at INIMET

A set of eight 1Ω standard resistors at INIMET are certified by ONN (Oficina Nacional de Normalización). Two 1 Ω standard resistors were used in this comparison with its last calibration dated September, 29th, 2011. Dissemination of the unit in the middle range is done in the following way:

Dissemination from 1 Ω to 100 kΩ



All measurements are repeated each two years.

Uncertainties

The following tables list the uncertainty contributions of each institute for the comparison at 1 Ω. The instability of the standards during transportation was negligible, as was observed because of the difference between the standard deviations of the standard mean value calculated before and after transportation. We take into account a component of uncertainty due to the difference of the measurement temperatures between both institutes, which exceed two degrees. This uncertainty was calculated as an uncertainty in the values of the coefficients of temperature corrections, according to

$$u(c_T) = R_0 |\Delta t| u_\alpha$$

where R_0 is the value of the resistor at the INTI´s reference temperature, Δt is the difference between the reference temperatures of each institute t_{INIMET} - t_{INTI} and u_α is the uncertainty in the linear coefficient. u_β, the uncertainty in the second order coefficient of the temperature correction was negligible. Replacing with the right values

$$u(c_T) = 2.3 \times 10^{-8}\ \Omega$$

The combined total uncertainty u_C of the comparison was calculated as the root sum square of the combined standard uncertainties of both institutes and the uncertainty due to the correction of the temperature.

Table 1. Detailed uncertainty budget at INTI, 1Ω

Resistor SN 1850321 Influence factor y_i	Standard uncertainty $u(y_i)$	Distribution / method of evaluation (A, B)	Sensitivity coefficient c_i	Uncertainty contribution $u(R_i)$ [Ω]	Degrees of freedom ν_i
Scaling / traceability	1.00E-08 Ω	Rectangular/B	1	1.00E-08	50
Reference standard(s)	4.00E-08 Ω	Normal/B	1	4.00E-08	50
Temperature standard	5.00E-03 °C	Rectangular/B	7.82E-06 Ω/°C	3.91E-08	50
Measuring system	5.80E-09 Ω	Rectangular/B	1	5.80E-09	50
Typ. standard deviation	6.50E-09 Ω	Normal/A	1	6.50E-09	9
Temperature resistor	5.00E-03 °C	Rectangular/B	7.55E-06 Ω/°C	3.77E-08	50
Combined standard uncertainty and effective degrees of freedom:				8.10E-08 Ω	145
Expanded uncertainty (95% coverage factor):				**1.60E-07 Ω**	

Table 2. Detailed uncertainty budget at INIMET, 1 Ω

Resistor SN 1850321 Influence factor y_i	Standard uncertainty $u(y_i)$	Distribution / method of evaluation (A, B)	Sensitivity coefficient c_i	Uncertainty contribution $u(R_i)$ [Ω]	Degrees of freedom ν_i
Scaling / traceability	9.00E-07 Ω	Rectangular/B	1	9.00E-07	50
Reference standard(s)	5.00E-07 Ω	Normal/B	1	5.00E-07	50
Temperature standard	3.00E-08 Ω	Rectangular/B	1	3.00E-08	50
Measuring system	2.90E-07 Ω	Rectangular/B	1	2.90E-07	50
Typ. standard deviation	2.53E-08 Ω	Normal/A	1	2.53E-08	12
Temperature resistor	5.00E-03 °C	Rectangular/B	7.55E-06 Ω/°C	3.80E-08	50
Combined standard uncertainty and effective degrees of freedom:				1.07E-06 Ω	90
Expanded uncertainty (95% coverage factor):				**2.10E-06 Ω**	

Results at 10 kΩ

Figure 2 shows the measured values obtained for the 10 kΩ standard SN 460037. Plotted values are corrected in temperature. A linear least squares fit is applied to the results of INTI to obtain the result for the standard and its uncertainty at the mean date of INIMET measurements.

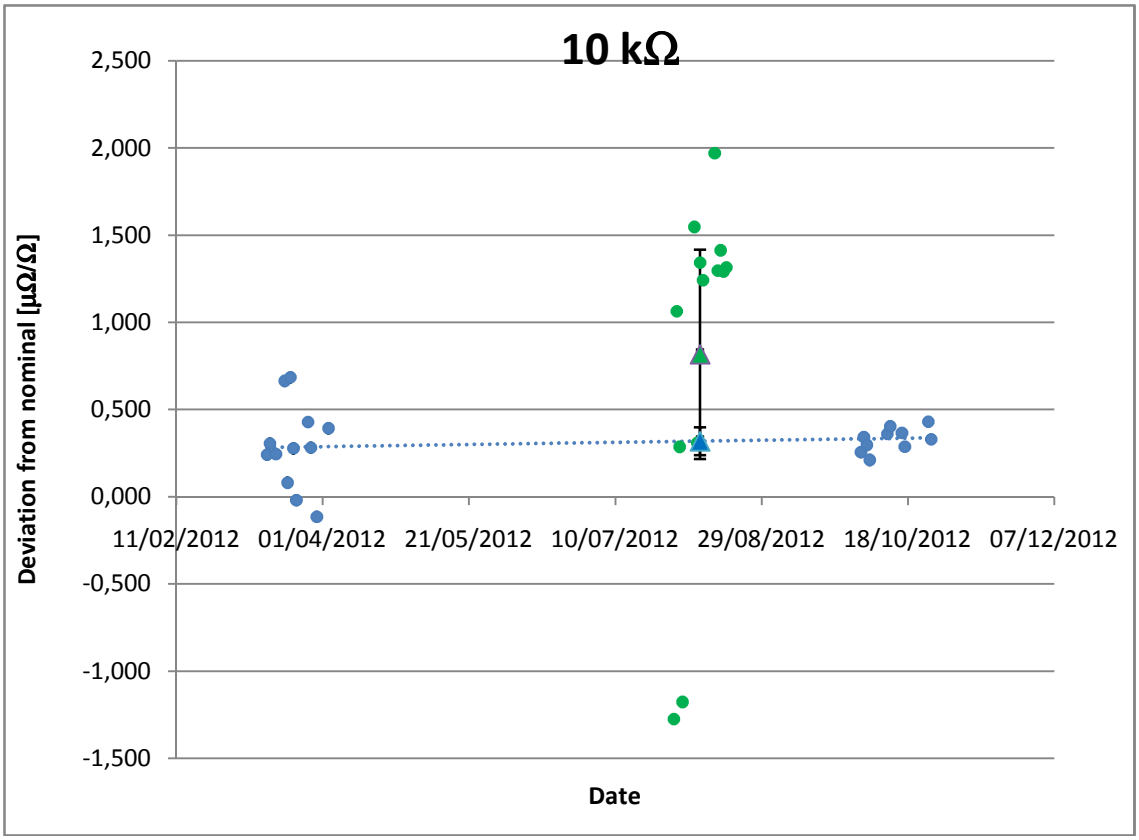


Figure 2. Resistance values obtained by INTI (in blue) and INIMET (in green) at 10 kΩ. Dotted line refers to a linear least-squares fit to measurements of INTI.

The result of the comparison is presented as the difference between the value assigned to a 10 kΩ-standard by INTI, R_{INTI}, and that assigned by INIMET, R_{INIMET}, which for the reference date is

$$R_{INTI} - R_{INIMET} = 0.005\ \Omega;\ u_c = 0.006\ \Omega \qquad \text{on 08/08/2012},$$

u_c is the combined standard uncertainty associated with the measured difference, including the uncertainty of the representation of the ohm at INTI and at INIMET and the uncertainty related to the comparison.

Method of measurements at INTI

All measurements were carried out by means ofan automated DCC current comparator bridge, a commercial MI Model 6010 B. Traceability was obtained through two 10 kΩ standard calibrated with respect to the quantum Hall effect standard of INTI and compared between them with the DCC, with interchange of like-value standards in the current comparator bridge to reduce bridge ratio errors. Measurements were

repeated on twelve days in the first part (three weeks) of INTI´s measurements and eleven days (three weeks) in the last part.
Measurement temperature control: The reference standards and the travel standard were measured at room temperature. Then the resistor values were corrected at the temperature reference, 23 ºC.
Test current: Direct current with reversal, measured at 0.3 mA.
Room Temperature: 22 ºC, U = 1 ºC
Atm Pressure: There was no pressure correction.

Traceability at INTI

Same as was explained at Results at 1 Ω.

The uncertainties at INTI are 0.1 μΩ/Ω for 1 Ω standard resistors and 0.08 μΩ/Ω for 10 kΩ standard resistors

Method of measurements at INIMET

Measurements were carried out with an automated current comparator bridge GUILDLINE 6675A. One INIMET 1 kΩ standard resistor was used in this comparison. The bridge was set up in four terminal configuration, 0.316 mA nominal current test. 10:1 measurements were repeated during three weeks, four/five days a week. Each measurement corresponds to an average of four measurements.
Measurement temperature control: The reference standard was measured in a mineral oil bath maintained at nominal 23.00 °C, U = 0.05 ºC. The comparison standard was measured at a controlled room temperature and its values were corrected at the reference temperature, 23 ºC.
Test current: Direct current with reversal, measured at 0.316 mA.
Room Temperature: 23 ºC, U = 2 ºC

Traceability at INIMET

Same as explained at Results at 1 Ω.

1 kΩ standard resistor certificate has last calibration dated October, 18th, 2011

Uncertainties

The following tables list the uncertainty contributions of each institute for the comparison at 10 kΩ. The instability of the standards during transportation was negligible, as was observed because of the difference between the mean value standard deviations of the standard calculated before and after transportation.

The combined total uncertainty u_C of the comparison was calculated as the root sum square of the combined standard uncertainties of both institutes.

Table 3. Detailed uncertainty budget at INTI, 10 kΩ

Resistor SN 460037 Influence factor y_i	Standard uncertainty $u(y_i)$	Distribution / method of evaluation (A, B)	Sensitivity coefficient c_i	Uncertainty contribution $u(R_i)$ Ω	Degrees of freedom ν_i
Scaling / traceability	2.90E-04 Ω	Rectangular/B	1	2.90E-04	50
Reference standard(s)	4.00E-04 Ω	Normal/B	1	4.00E-04	50
Temperature standard	1.00E-01 °C	Rectangular/B	8.00E-04 Ω/°C	8.00E-05	50
Measuring system	5.80E-05 Ω	Rectangular/B	1	5.80E-05	50
Typ. standard deviation	5.70E-04 Ω	Normal/A	1	5.70E-04	11
Temperature resistor	1.00E-01 °C	Rectangular/B	9.00E-04 Ω/°C	9.00E-05	50
Combined standard uncertainty and effective degrees of freedom:				7.60E-04 Ω	28
Expanded uncertainty (95% coverage factor):				**1.60E-03 Ω**	

Table 4. Detailed uncertainty budget at INIMET, 10 kΩ

Resistor SN 460037 Influence factor y_i	Standard uncertainty $u(y_i)$	Distribution / method of evaluation (A, B)	Sensitivity coefficient c_i	Uncertainty contribution $u(R_i)$ Ω	Degrees of freedom ν_i
Scaling / traceability	5.00E-03 Ω	Rectangular/B	1	5.00E-03	50
Reference standard(s)	1.30E-03 Ω	Normal/B	1	1.30E-03	50
Temperature standard	8.30E-05 Ω	Rectangular/B	1	8.30E-05	50
Measuring system	6.50E-05 Ω	Rectangular/B	1	6.50E-05	50
Typ. standard deviation	2.80E-03 Ω	Normal/A	1	2.80E-03	12
Temperature resistor	1.00E-01 °C	Rectangular/B	9.00E-04 Ω/°C	9.00E-05	50
Combined standard uncertainty and effective degrees of freedom:				5.90E-03 Ω	67
Expanded uncertainty (95% coverage factor):				**1.17E-02 Ω**	

Conclusion

The result of the comparison is presented as the difference between the value assigned to a 1 Ω standard by INTI, R_{INTI}, and that assigned by INIMET, R_{INIMET}, which for the reference date is

$$\boldsymbol{R_{INTI} - R_{INIMET} = -0.68\ \mu\Omega;} \qquad \boldsymbol{u_c = 1.07\ \mu\Omega} \qquad \textbf{on 08/08/2012},$$

and the difference between the value assigned to a 10 kΩ standard by INTI, R_{INTI}, and that assigned by INIMET, R_{INIMET}, which for the reference date is

$$\boldsymbol{R_{INTI} - R_{INIMET} = 0.005\ \Omega;} \qquad \boldsymbol{u_c = 0.006\ \Omega} \qquad \textbf{on 08/08/2012},$$

In both cases u_c is the combined standard uncertainty associated with the measured difference, including the uncertainty at INTI and at INIMET and the uncertainty related to the comparison.

These are very good results. The comparison results show that the resistance standards maintained by INTI and INIMET were equivalent, within their combined uncertainties, on the mean date of the comparison.