Subsequent bilateral key comparison of CCEM-K2.2012.1: Comparison of Resistance Standards at 10 MΩ and 1 GΩ

TECHNICAL PROTOCOL (Draft)

2020 – 2021 Resistance Comparison among KRISS, NIST and NRC

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1. Introduction

The Mutual Recognition Arrangement (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 (CCs) of the CIPM (International Committee of Weights and Measures), the BIPM (International Bureau of Weights and Measures) and the Regional Metrology Organizations (RMOs). As part of this process, the CIPM Consultative Committee for Electricity and Magnetism (CCEM) carried out the key comparison CCEM-K2 of resistance standards at 10 MΩ and 1 GΩ. This comparison was piloted by the National Institute of Standards and Technology and approved by the CCEM for full equivalence in January 2002 [1, 2].

In subsequent years SIM [3], EURAMET [4] and APMP have each carried out a similar comparison, and the published results are linked in the KCDB of the BIPM. Since the original CCEM-K2 of 2002 many laboratories have enhanced their measurement capabilities in the ranges in question. At the meeting in 2009 the CCEM decided to repeat the CCEM-K2 comparison to improve the precision of the link between RMOs. After the National Research Council (NRC) of Canada agreed to pilot this comparison, named as CCEM-K2.2012, the comparison was done between 2012 and 2016 and the final report was published March 2020 [5]. After completing the key comparison, the KRISS considered its results are unrepresentative of supporting its Calibration Measurement Capabilities (CMC). Thus, the KRISS decided to do a subsequent bilateral comparison to link the KRISS results and uncertainties to the key comparison for the purpose of supporting its CMCs. For this comparison, the NIST and NRC, which already participated in the CCEM-K2.2012 key comparison, are participating as pilot labs.

The procedures outlined in this document should allow for a clear and unequivocal comparison of the measurement results. The protocol was prepared following the CCEM guidelines for planning, organizing, conducting and reporting key, supplementary and pilot comparisons.

2. Traveling standards

2.1 Description of the standards

As 10 MΩ and 1 GΩ travelling standards, two commercial resistors (Measurement International-model 9331 and 9331S) and two NIST-designed resistors are used.

The resistance elements of NIST resistors are hermetically sealed in metal containers. The two resistor terminations of the standards are coaxial BPO or N-Type connectors mounted on PTFE plates on the top panel of the enclosures. The resistor containers are electrically isolated from the enclosures and electrically connected to the shield of one of the coaxial connectors. This allows the resistor container of the standard to be operated either in floating mode, a grounded mode, or driven at a guard potential. The 10 MΩ standard resistor has an internal 10 kΩ thermistor temperature sensor that may be measured with a LEMO to banana plug lead in the case of large temperature effects.

2.2 Quantities to be measured at the time of each test

Resistance of the 10 MΩ and 1 GΩ standards at the following conditions:
test voltage: 10 V $\leq V_{test} \leq$ 100 V;
ambient or air bath temperature: (23 ± 1.0) °C
ambient relative humidity: (45 ± 15) %.

3. Organization

3.1 Coordinator and participants

The pilot laboratories and coordinators for the comparison are the NIST and NRC.

Coordinator of the pilot laboratory:

Dean Jarrett (NIST), e-mail: dean.jarrett@nist.gov

Carlos Sanchez (NRC), e-mail: Carlos.Sanchez@nrc-cnrc.gc.ca

The participating institutes are listed in the following table 1.

Table 1 Participants

Institute (Acronym)	Country	Contact person	Address	e-mail
Korea Research Institute of Standards and Science(KRISS)	Korea, The republic of	Kwang Min Yu	Korea Research Institute of Standards and Science, 267 Gajeong-ro, Yuseong-Gu, Daejeon 34113, Rep. of Korea	kmyu@kriss.re.kr
National Research Council (NRC)	Canada	Carlos Sanchez	1200 Montreal Road, Ottawa K1A 0R6, Ontario, Canada	Carlos.Sanchez@nrc-cnrc.gc.ca
National Institute of Standard and Technology(NIST)	United States	Dean Jarrett	NIST, 100 Bureau Drive, MS 8171, Gaithersburg, Maryland, 20899-8171 USA	dean.jarrett@nist.gov

*) These laboratories participated in CCEM.EM-2012

3.2 Time schedule

The circulation of the standards starts in October 2020 and is planned to end in March 2022. The detailed time schedule for the comparison is given in Table 2.

Table 2 Measurement schedule

Institute	Country	Time for measurements and transport
Pilot (NRC)	Canada	October 2020 to April 2021
KRISS	Republic of Korea	April to July 2021
Pilot(NIST)	United States	July to Septmember 2021
Pilot (NRC)	Canada	October to December 2021

In agreeing with the proposed circulation time schedule, each participating laboratory confirms that it is capable of performing the measurements in the limited time period allocated in the time schedule. If, for some reasons, the measurement facility is not ready or custom clearance should take too much time, the laboratory is requested to contact immediately the coordinator in the pilot laboratory.

As soon as possible after the completion of the measurements, the transport package is to be transported to the next participant and the participant should indicate that all measurements have been completed.

If unavoidable delay occurs, the coordinators shall inform the participants and may revise the time schedule.

3.3 Description of transportation

Packing list

-Two 10 MΩ standard resistors:

- NIST-designed, Serial Number: HR7549, Size: 23cm x 5.6 cm x 9 cm, Weight 1 kg
- Measurement International-model, Serial Number: 1104461

-Two 1 GΩ standard resistors:

- NIST-designed, Serial Number: HR9122, Size: 23cm x 5.6 cm x 9 cm, Weight 1 kg
- Measurement International-model, Serial Number: 1104444

4. Measurement instructions

4.1 Test before measurements

No initial tests are required. However, the ambient laboratory conditions of temperature and humidity should be maintained within the range given in section 2.2 during the measurements and for periods of at least eight hours before measurements.

4.2 Measurement performance

Pre-conditioning: Air-type standards should be conditioned to air-bath or ambient laboratory conditions, regulated at the chosen working temperature for at least 24 hours. Keep the specified voltage and do not immerse the standards in the oil.

Measurand: The resistance value of the traveling standards should be measured at DC, expressed in terms of the SI ohm.

Test voltage: 10 V $\leq V_{test} \leq$ 100 V
Temperature: (23 ± 1.0) °C
Humidity: (45 ± 15) %.

4.3 Method of measurement

The measurement method is not specified. It is assumed that every participant uses its best normal measurement process. The method and the traceability scheme are to be described in the measurement report (see below). The choice of using the ground/guard configuration is left to the participants. Section 2.1 describes the internal configuration of the ground/guard terminals in the resistance standards.

5. Uncertainty of measurement

A detailed uncertainty budget in accordance with the ISO Guide to the Expression of Uncertainty in Measurement shall be reported for one resistor of each nominal value.

To have a comparable uncertainty evaluation, principal uncertainty contributions are listed as below. Depending on the measuring methods this list may be changed:

1) Scaling procedure and/or traceability path (total at time of reference standard calibration)
2) Reference standard(s) (total due to drift, TCR, PCR, VCR)
3) Measuring apparatus (ratio, resolution, stability, gain and offset effects, configuration)
4) Leakage effects
5) Temperature variation effects
6) Typical standard deviation of a measurement set, defined as the median standard deviation value among the data sets used to calculate the final reported value.

The detailed uncertainty is to be provided; including the standard uncertainties, combined standard uncertainty and the k=2 expanded uncertainty.

6. Measurement report

Each participant is asked to submit a final printed and signed report by email within 6 weeks after completing the measurements. The report should contain at least the following:

-Description of the measuring set-up used for each level, including the ground/guard configuration;
-Traceability scheme;

-Description of the measurement procedure used for each level;

-The test voltage used for the measurements;
-The ambient conditions of the measurement: the mean temperature and humidity;
-The measurement results: Mean resistance value for every standard and the

corresponding mean date of measurement.
-A complete uncertainty budget in accordance with the principles of the ISO Guide to the Expression of Uncertainty in Measurement, including the standard uncertainty and the k=2 expanded uncertainty. Such an analysis is a prerequisite to be considered in the calculation of the comparison reference value. It is also an essential part of the final report which will appear in the BIPM Key Comparison Database.

The pilot laboratory will inform a participating laboratory if there is a substantial deviation between the results of the laboratory and the preliminary reference values. No other information will be communicated before the completion of the circulation.

7. Report of the comparison

The participants will report their measurement results to NIST. Once all measurements are completed and all the reports are received by NIST. KRISS will do the analysis and verify the results with help of the NRC and write the report. Included in the final report will be calculated values of the degree of equivalence with the reference value for each participant at each resistance level where results are submitted. The degree of equivalence between the participants will be presented in table form.

8. References

[1] R.F. Dziuba and D. G. Jarett, Final report on key comparison CCEM-K2 of resistance standards at 10 MΩ and 1 GΩ, *Metrologia*, 39, Tech. Suppl., 01001, 2002.
[2] N. F. Zhang, N. Sedransk and D. G. Jarrett, Statistical uncertainty analysis of key comparison CCEM-K2, *IEEE Trans. Instrum, Meas*. 52, 491-4, 2003.
[3] R. E Elmquist, D G Jarrett and N F Zhang, RMO comparison final report: 2006-2007 Resistance standards comparison between SIM laboratories. SIM.EM-K1, 1 Ω; SIM.EM-K2, 1 GΩ; SIM.EM-S6, 1 MΩ, *Metrologia*, 46, Tech. Suppl., 01001, 2009.
[4] Beat Jeckelmann and Markus Zeier, Final report on RMO key comparison EUROMET.EM-K2: Comparison of resistance standards at 10 MΩ and 1 GΩ, EURAßMET, *Metrologia*, 47, Tech. Suppl., 01006, 2010.
[5] Carlos Sanchez and Kai Wendler, Final report of the CCEM-K2.2012 key comparison of resistance standards at 10 MΩ and 1 GΩ, Metrologia 57 Tech. Suppl. 01006, 2020.