Protocol for APMP Key Comparison of Electrical Resistance Standards using 1 Ω and 10 kΩ Resistors as Travelling Standards (APMP.EM.BIPM-K13)

1. Introduction

This APMP key comparison was initiated by APMP TCEM members during one of TCEM meetings in November 2021. The National Institute of Metrology (Thailand), NIMT, volunteered to pilot the key comparison. Further discussions led to identification of suitable and possible travelling measurement standards. Two air-type standard resistors, one of 1 Ω nominal and the other of 10 kΩ nominal, will be provided by NIMT for this purpose. As the pilot laboratory, NIMT will also prepare a measurement protocol, a computation of comparison results and three comparison reports namely a draft report A, a draft report B and a final report. To support the pilot laboratory, Korea Research Institute of Standards and Science, KRISS, agreed to be a co-pilot laboratory. KRISS will assist NIMT regarding technical issues including measurement values to determine drift of the travelling standards. Reference values and link to International Key Comparison values will initially be calculated through BIPM-EM-K13 measurement results of KRISS, NMIA, NMC, NIMT and EMI. Further analysis will be carried out if needed.

2. Travelling standards

The travelling standards are described in three main folds; namely, general description of the travelling standards, measurement quantities and measurement method.

2.1 Standard descriptions

Two air-type standard resistors are used as travelling standards. They are manufactured by Measurements International, MI. Model 9331/1 and 9331/10k are used. Their technical details are shown in Table I.

Table I Travelling standard technical details

Characteristics	Standard resistors	
	Nominal: 1 Ω	Nominal: 10 kΩ
Model	9331/1	9331/10 k
Tolerance	±2 ppm	±2 ppm
Stability	2.5 ppm/year	2.5 ppm/year
Maximum current	0.3162 A	0.0032 A
Temperature coefficient	$\alpha = +3.41\times10^{-7}$ °C^{-1} $\beta = -2.68\times10^{-8}$ °C^{-2}	$\alpha = -2.38\times10^{-8}$ °C^{-1} $\beta = +1.85\times10^{-9}$ °C^{-2}
Maximum voltage	0.32 V	31.62 V

2.2 Measurement quantities

Test current shall not exceed the stated values in Table I (300 mA for 1 Ω and 3 mA for 10 kΩ. Ambient or air bath temperature ranges should be within (23±2) °C. Ambient relative humidity should be within (50±15) %.

2.3 Measurement method

The APMP regional comparison reference value (RRV) will be evaluated following principles of weighted mean computation and model-data consistency test [1]. Analyses follow the principles stated below.

- KRISS, the co-pilot laboratory, will contribute three measured values.
- Drift behaviours of travelling standards will be determined from the measured values provided by KRISS.
- Each participating laboratory will have approximately two weeks (10 working days) to perform measurement. The laboratory is expected to use its own measurement method. However, laboratory is requested to provide information regarding measurement settings in Annex 3.
- Measured values to be reported to the pilot laboratory must be computed using given temperature coefficients in order to normalise the temperature to 23 °C.

3. Organisations

Organisations of the comparison are explained in three parts: pilot and co-pilot laboratories with their respected coordinators, participating laboratories and tentative measurement schedule.

3.1 Pilot laboratory and co-pilot laboratory

- Pilot laboratory and coordinator: NIMT/Mrs. Natenapit Khumthukthit (natenapit@nimt.or.th)
- Co-pilot laboratory and coordinator: KRISS/Dr. Dong-Hun Chae (dhchae@kriss.re.kr)

3.2 Participating laboratories

Laboratories registered their interest in participating in the comparison are listed in Table 2. Address and contact person of each laboratory are also listed.

Table 2 Participating laboratories

No	Country	Institute	Acronym	Contact person and details
1	Thailand	National Institute of Metrology Thailand	NIMT	**Natenapit Khumthukthit** **natenapit@nimt.or.th** 3/4-5 Moo3, Klong Ha Klong-Luang Pathum thani 12120, Thailand
2	Republic of Korea	Korea Research Institute of Standards and Science	KRISS	**Dong-Hun Chae** dhchae@kriss.re.kr 267, Gajeong-ro, Yuseong-gu, Daejeon 34113, Republic of Korea
3	Australia	National Measurement Institute Australia	NMIA	**Leigh Johnson** **leigh.johnson@measurement.gov.au** 36 Bradfield Road, West Lindfield, NSW 2070, Australia
4	Chinese Taipei	Center for Measurement Standards	CMS	**Shih-Fang Chen** **csf0317@itri.org.tw** Rm. 105, Bldg. 16, No. 321, Section 2, Kuang Fu Road, Hsinchu, 300044, Taiwan
5	Hong Kong, China	Standards and Calibration Laboratory	SCL	**Cliff Wong** **cliff.wong@itc.gov.hk** 36/F, Immigration Tower, 7 Gloucester Road, Wanchai, Hong Kong
6	Indonesia	National Measurement Standard – National Standardization Agency of Indonesia	SNSU – BSN	**Agah Faisal** **faisal@bsn.go.id** Kompleks PUSPIPTEK Gedung 420, Setu, Tangerang Selatan, Banten 15314, Indonesia
7	Malaysia	National Metrology Institute of Malaysia	NMIM	**Nirul Irwani Ishak** **nirul@sirim.my** National Metrology Institute of Malaysia, Lot PT 4803, Bandar Baru Salak Tinggi, 43900 Sepang, Selangor Darul Ehsan, Malaysia
8	Mongolia	Mongolian Agency for Standard and Metrology	MASM	**Ariuntungalag Jargal** **ariuntungalag@masm.gov.mn** Bayanzurkh district, Peace avenue-46A, 13343 Ulaan-Baatar, Mongolia

No	Country	Institute	Acronym	Contact person and details
9	New Zealand	Measurement Standards Laboratory of New Zealand	MSL	**Tim Lawson** **tim.lawson@measurement.govt.nz** 69 Gracefield Rd, Lower Hutt 5040, New Zealand
10	Philippines	National Metrology Laboratory of the Philippines	NML-ITDI	**Sabino Paulo B. Leones, Jr.** **paulo_leones@yahoo.com** Metrology Building, DOST Compound, Gen. Santos Avenue, Bicutan, Taguig City, Metro Manila, Philippines
11	Singapore	National Metrology Centre	NMC	**Chua Sze Wey** **chua_sze_wey@nmc.a-star.edu.sg** National Metrology Centre, 8 Clean Tech Loop, #01-20, Singapore 637145
12	UAE	Emirates Metrology Institute	EMI	**Jon Bartholomew** **jon.bartholomew@qcc.gov.ae** Krypto Labs Building, Masdar City. Abu Dhabi, UAE
13	Saudi Arabia	National Measurement and Calibration Center	SASO-NMCC	**Abdullah M. Alrobaish** **o.shamrani@saso.gov.sa** Prince Turki bin Abdulaziz I Road, Al-Muhammadiyah_ Riyadh, Saudi Arabia

3.3 Tentative measurement schedule

Circulation of the travelling standards will start in February 2023 and is planned to end in May 2024. Tentative measurement schedule is shown in Table 3.

Table 3 Tentative measurement loop and schedule

Loop	Laboratory	ATA Carnet	Starting date of measurements
Reference lab	KRISS, Korea	Available	February 2023
1	CMS, Chinese Taipei	Available	March 2023
	SCL, Hong Kong, China	Available	April 2023
	SNSU-BSN, Indonesia	N/A	May 2023

Loop	Laboratory	ATA Carnet	Starting date of measurements
Reference lab	KRISS, Korea	Available	August 2023
2	NIMT, Thailand	Available	End August 2023
	MSL, New Zealand	Available	September 2023
	NMIA, Australia	N/A	October 2024
	MNIM, Malaysia	Available	November 2023
	EMI, UAE	N/A	December 2023
	NML-ITDI, Philippines	Available	January 2024
	SASO-NMCC, Saudi Arabia	N/A	February 2024
	A Star, Singapore	Available	March 2023
	Mongolia	N/A	April 2024
Reference lab	KRISS, Korea	Available	May 2024

Each participating laboratory will be allowed a four-week time period to perform measurements and to manage transportation of the travelling standards. Laboratory facing unexpected difficulties in managing all activities within the four-week period must inform the delay to the coordinator immediately. The coordinator will then inform the next in-line laboratory.

3.4 Travelling standards

The travelling standards are air-type 1Ω and 10 kΩ standard resistors. They should be shipped in an protective luggage Photos of the travelling standards and their package are shown in Figure 1, Figure 2 and Figure 3 respectively.

Figure 1. 1Ω standard resistor

Figure 2. 10 kΩ standard resistor

Figure 3. Packed standard resistors in their protective luggage

Details of the travelling standard is listed in Table IV.

Table IV Travelling standards

Standard resistors	Name	Manufacturer	Type	Serial number	Unit	Owner
1 Ω	Standard Resistor	Measurements International	Air	1103855	1	NIMT
10 kΩ	Standard Resistor	Measurements International	Air	1103602	1	NIMT

3.5 Transportations and report of travelling standards arrival

Participating laboratory is responsible for all transportation costs; namely, exports, guarantee on delivery time and custom clearances. Each laboratory shall coordinate the transportation process with great care. Shipment procedure should be arranged in good time so that the travelling standards could be shipped without delay. The protective luggage together with the travelling standards should not be exposed to extreme temperatures or mechanical shocks and always remains upright. This arrangement is very important and shall be confirmed to the shipping agency.

Each laboratory is responsible for the shipping costs or hand-carryings, if they are preferable, in order to minimise possible changes in resistance. The transportation costs should be on the exporting the travelling standards to the next measuring laboratory.

The travelling standards shall be shipped in the protective luggage provided. The carnet shall be included in the transportation package.

Upon receiving the travelling standards, laboratory must inform the coordinator using the form provided in Annex 1 together with the exported MS excel data from travelling temperature and humidity recorder with described in Annex 4 and send to the coordinator via email.

After completing the measurement, the travelling standards shall be sent to the next laboratory without delay.

3.6 Unpacking, handling and packing

The following items are packed in the protective luggage which will be transported to participated laboratories. Please, check the packing list upon the arrival and departure of the travelling standards.

- Two standard resistors: one unit of 1 Ω standard resistor and one unit of 10 kΩ standard resistor
- A travelling temperature and humidity recorder

4. Measurements

The NMI should carry out the resistance measurements using normal techniques or calibration procedure used by the laboratory to provide calibration services.

The reference temperature for KRISS resistance measurements is 23 °C and the resistors are kept at this nominal temperature during the whole period of measurements at KRISS. If possible, the participating laboratory should use the same nominal temperature.

Resistors should be stored in the intended measurement temperature at least 48 hours before measurement.

The measurements are carried out with a 50 mA DC current for 1 Ω resistors and 300 μA for 10 kΩ resistors. If possible, the participating laboratory should use the same nominal currents. In order to limit power effects, nominal currents larger than 300 mA in 1 Ω and 3 mA in 10 kΩ should be avoided.

5. Reporting results

The participating laboratory is requested to submit its measurement report to the coordinator no later than 4 weeks after the end of its measurements.

6. Comparison report

The reference values and link to the Key Comparison values will initially be calculated through the BIPM-EM-K13 measurement results of KRISS, NMIA, NMC, NIMT and EMI. Further analysis will be carried out if needed. The comparisons of results and corresponding uncertainties will be reported. Degree of equivalence of each laboratory is computed using the En value.

NIMT is responsible for the preparation of the comparison report including the draft A and the draft B, whist KRISS will proofread them and provide advices following the procedure given in the document CIPM-MRA-D-05, “Measurement comparisons in the CIPM-MRA”.

7. References

[1] G. M. Cox, "The evaluation of key comparison data," Metrologia, vol. April 2005, 589-595, 2002.

8. Bibliography

1. F. Delahaye, “DC and AC techniques for resistance and impedance measurements”, *Metrologia*, **29**, 81-93, 1992.
2. T. J. Witt, “Electrical resistance standards and the quantum Hall effect”, *Rev. Sci Instrum.*, **69**, 2823-2843, 1998.

Annex 1 – Reception of travelling Standards

To: From:	National Institute of Metrology (Thailand), NIMT 3/4-5 Moo 3, Klong 5, Klong Luang, Pathumthani 12120, Thailand Tel: +66 25775100 ext. 1240 e-mail: natenapit@nimt.or.th
We confirm having received the standard	NMI: …… Name: …… Signature: …… Date: ……

resistors comparison on the date given above.
After a visual inspection:

☐ There are no apparent damages.

☐ We have detected severe damages putting the measurement results at risk. Please indicate the damages, specifying every detail and, if possible, include photos. If it is necessary use additional sheets to report it.

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Annex 2 Measurement results and corresponding uncertainties

To: From:	National Institute of Metrology (Thailand), NIMT 3/4-5 Moo 3, Klong 5, Klong Luang, Pathumthani 12120, Thailand Tel: +66 25775100 ext. 1240 e-mail: natenapit@nimt.or.th
	NMI: …… Name: …… Signature: …… Date: ……

Standard Resistor 1 Ω

Method of measurement: .....

Measurement result of 1 Ω : .....

Measurement uncertainty: .....

Quantity X_i	**Estimate** x_i	**Standard uncertainty** $u(x_i)$	**Probability distribution**	**Effective degree of freedom**	**Sensitivity coefficient** c_i	**Uncertainty contribution** $u_i(y)$
R_x						

Combined standard uncertainty: $u_c(R_x)$ = ……..

Annex 2 Measurement results and corresponding uncertainties

To: From:	National Institute of Metrology (Thailand), NIMT 3/4-5 Moo 3, Klong 5, Klong Luang, Pathumthani 12120, Thailand Tel: +66 25775100 ext. 1240 e-mail: natenapit@nimt.or.th
	NMI: …… Name: …… Signature: …… Date: ……

Standard Resistor 10 kΩ

Method of measurement: .....

Measurement result of 10 kΩ : .....

Measurement uncertainty: .....

Quantity X_i	**Estimate** x_i	**Standard uncertainty** $u(x_i)$	**Probability distribution**	**Effective degree of freedom**	**Sensitivity coefficient** c_i	**Uncertainty contribution** $u_i(y)$
R_x						

Combined standard uncertainty: $u_c(R_x)$ = ……..

Annex 3 Measurement settings

To: From:	National Institute of Metrology (Thailand), NIMT 3/4-5 Moo 3, Klong 5, Klong Luang, Pathumthani 12120, Thailand Tel: +66 25775100 ext. 1240 e-mail: natenapit@nimt.or.th
	NMI: …… Name: …… Signature: …… Date: ……

Procedure of the measuring set-up used

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Annex 4: Operation manual of datalogger

1. Plug in Datalogger to USB Port of PC.
2. Run “PDF Logger Configuration Tool.exe” (Fig.1) to configure parameters (“5 min rate*” & “Metric”).

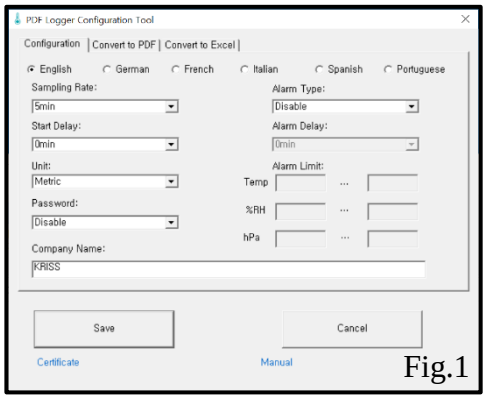

Fig.1

* Do not select “30 sec.” Logger will store data for only less than a week.

3. Press “Save” button.
4. Turn on the Logger by pressing “START/STOP” button.

(Please, replace two batteries (CR2032) before you ship the package.)

5. Press the “START/STOP” button for about 5 sec. to start recording temperature, humidity, and barometric pressure (Fig.2)*, before shipping.

Fig.2

Fig.3

6. Your will see “REC” when recording starts. (Fig.2)
7. When you get the package and you want to stop recording, press the “START/STOP” button for about 5 sec. to stop recording. (Fig.3)
8. When you want to export data, plug in Datalogger to USB Port of PC.
9. Run “PDF Logger Configuration Tool.exe”.
10. Go to either “Convert to PDF” or “Convert to Excel” window.
11. Save data in one of two formats (Fig.4 shows the exported log with raw data in PDF format).

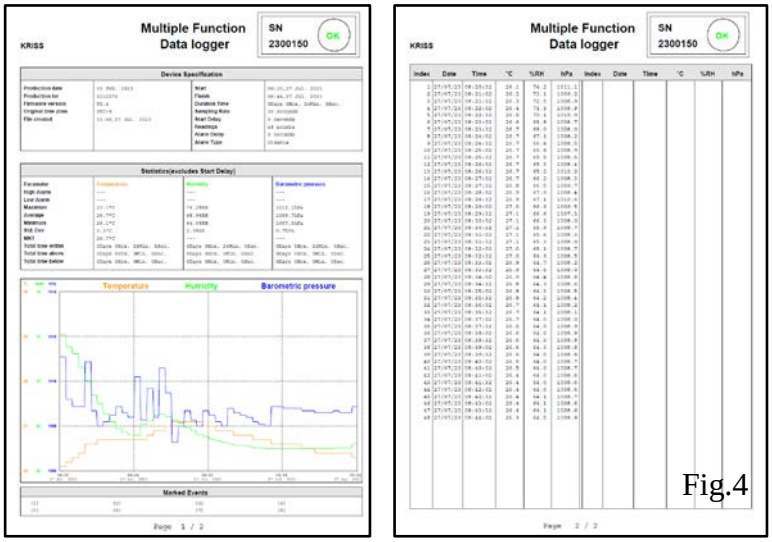

Fig.4

*Warning:
If you want to record the data, then perform from step 1 to step 3 again.
If not, you cannot start “REC” for recording.