Final Report

APMP.EM.BIPM-K11.3

APMP Key Comparison of DC Voltage at 1.018 V and 10 V

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Abstract

A key comparison of DC voltage at 1.018 V and 10 V has been conducted from 2009 to 2011 between APMP member laboratories and the BIPM. All participants' results (except one) are within the uncertainty of comparison reference value and also within the uncertainty of the CIPM key comparison reference value of the BIPM.EM-K11.3, approximately 0.08 μV/V for 10 V and 0.2 μV/V for 1.018 V (k=2). The result of the comparison is supposed to successfully provide participating laboratories with the opportunity to compare national standards within the region, and to support participants' entries in Appendix C of the Mutual Recognition Arrangement.

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1. Introduction

At the APMP TCEM meeting, held in Jeju on 5 September 2005, KRISS proposed to organize an APMP key comparison (KC) of DC voltage. At the same meeting NMIJ, Japan kindly agreed to provide Zener standards for travelling standards. The proposal was approved by the meeting. As a preparative step for the KC, a pilot comparison between KRISS and NMIJ was also carried out in August to September, 2007 to test conditions of stabilization after transport and reported to the following TCEM meeting. This KC APMP.EM.BIPM-K11.3 covers comparison of both 1.018 V and 10 V of which the results can be linked to the KC identified by BIPM.EM-K11.a and BIPM.EM-K11.b.

1.1 The assistance of the support group

The protocol was drafted with the help of Dr. Ilya Budovsky (NMIA), TCEM chair at that time, and finalized with the help of support group; Dr. Stephane Solve (BIPM), Dr. Chiharu Urano (NMIJ) and Dr. Sze Wey Chua (NMC/A*STAR). The support group also reviewed the Draft A and Drat B of this report.

2. Participants and organization of the comparison

2.1 List of participants

Thirteen laboratories originally planned to participate in the comparison program. Eleven laboratories who finally participated in the comparison are listed in Table 2-1.

Table 2-1. List of participants.

	Organisation	**Acronym**	**State or Economy**
1	National Measurement Institute of Australia	NMIA	Australia
2	National Measurement Centre, A*STAR[*]	NMC/A*STAR	Singapore
3	Standards and Industrial Research Institute of Malaysia	SIRIM	Malaysia
4	Center for Measurement Standards	CMS	Chinese Taipei
5	Korea Research Institute of Standards and Science	KRISS	Korea
6	National Metrology Institute of Japan, AIST	NMIJ/AIST	Japan
7	National Institute of Metrology (Thailand)	NIMT	Thailand
8	BIPM	BIPM	BIPM
9	Standards and Calibration Laboratory	SCL	Hong Kong
10	D. I. Mendeleyev Institute for Metrology	VNIIM	Russia
11	Kazakhstan Institute of Metrology	KazInMetr	Kazakhstan

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[*] Formerly Standards, Productivity and Innovation Board, Singapore (SPRING)

2.2 Comparison schedule

Table 2-2. Comparison schedule.

Loop	Date of Measurement	Laboratory	Country or Economy
	8 October – 31 October, 2009	KRISS, Pilot laboratory	Korea (South)
1	8 November – 30 November, 2009	NMIA	Australia
	8 December – 31 December, 2009	NMC A*STAR	Singapore
	8 January – 31 January, 2010	KRISS, Pilot laboratory	Korea (South)
2	8 February – 28 February, 2010	NML-SIRIM	Malaysia
	8 March – 31 March, 2010	CMS	Chinese Taipei
	8April – 30 April, 2010	KRISS, Pilot laboratory	Korea (South)
3	8 May – 31 May, 2010	NMIJ	Japan
	8 June – 30 June, 2010	NIMT	Thailand
	8 July – 31 July, 2010	BIPM	BIPM
	8 August – 31 August, 2010	SCL	Hong Kong China
	8 September – 30September, 2010	KRISS, Pilot laboratory	Korea (South)
4	8 October, 2010 – 30January, 2011	BIPM	BIPM
	8 February – 28 February, 2011	VNIIM	Russia
	8 March – 31 May, 2011	KRISS, Pilot laboratory (Refresh of Batteries and ATA Carnet at NMIJ)	Korea (South)
5	19 July - 11 August, 2011	KazInMetr	Kazakhstan
	19 August – 31 August, 2011	KRISS, Pilot laboratory	Korea (South)

2.3 Organization of the comparison

The comparison schedule was initially organized in five consecutive loops (Loops 1 to 5) with one, two or four participants in each loop. The artefacts returned to the pilot laboratory, KRISS for re-checking at the end of each loop.

A period of four weeks was scheduled for each participant. Generally participants had at least two weeks and usually three weeks in which to make their measurements, depending on the time taken to receive the artefacts through the customs service in their country and allow the artefacts to be stabilized with the environment in their laboratory. The BIPM kindly helped the pilot to characterize the stability of the standards.

The traveling standards, three Zener standards (provided by NMIJ), each of which was enclosed in separate travel case were transported in a larger wood case by air cargo using an ATA Carnet for customs clearance where possible. A small thermo-hygrometer (provided by NMIJ) was also enclosed in the transport case to monitor the environmental change during transportation.

2.4 Unexpected incidents

2.4.1 Rearrangement of schedule

The comparison schedule of Table 2-2 is a result of several modifications from the original schedule. The NPLI of India, NIS of Egypt, and NMISA of South Africa cancelled their participation. As a result, the KRISS and the BIPM had to take the extra time slots of the cancelled measurements. However the extra measurements were also helpful to characterize the stability of the standards. Further modification was needed because KazInMetr of Kazakhstan was added in 2011 as the last participant. All the circulation was completed by KRISS measurement in August 2011.

2.4.2 Change of correction coefficients

In the mid of the comparison, a participant (SCL) raised a question about the large uncertainties given to the temperature coefficients which can result in a large uncertainty of temperature correction when there is a big temperature difference between a participant and the pilot. The NMIJ, who provided the travelling standards, accepted to recalculate the data and proposed to change the uncertainties of the coefficients for the three Zener standards. The new values for temperature, humidity and pressure coefficients of 10 V and 1.018 V outputs are shown in Table 4-1. Temperature, humidity and pressure coefficients of 10 V and 1.018 V outputs and their standard uncertaintiestogether with their standard uncertainties. The values were finally adopted, so the revised protocol was redistributed quickly. For all the reports which were already submitted, the new correction values were recalculated by the participant and pilot for double checking.

2.4.3 Abnormal drift of the traveling standards

It was found that the travelling standards rapidly drifted around the VNIIM measurement in February 2011 as shown in Figure 6-1. The most probable explanation for this is long exposure of the standards to the cold and dry winter weather during transportation and customs clearance from BIPM to VNIIM, and very low humidity in Russia. The recorded temperature and humidity around this time of Figure 2-1 shows that the sharp temperature valleys and the prolonged low humidity dip.

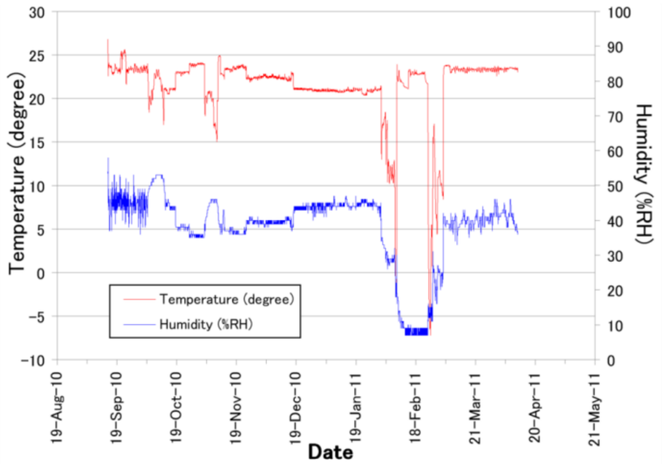


Figure 2-1. Temperature and relative humidity during transportation. Note the dip around February 2011.

3. Withdrawals of results

Because of the abnormal change of the travelling standards due to the temperature and humidity shock as described in the previous section, after discussion with VNIIM, it was decided to take the VNIIM measurement as withdrawn, although VNIIM complied with the humidity condition of the protocol. This gave us a lesson that more detailed humidity condition should have been specified in the protocol for a global circulation of the artefact standards.

4. Travelling standard and measurement instructions

4.1 Description of the standards

The travelling standards were three Fluke 732B electronic DC reference standards identified as follows:

TZS-1	s/n 6950003
TZS-2	s/n 6950002
TZS-3	s/n 6950004

The Fluke 732 B electronic DC reference standard has two output voltages, nominally 1.018 V and 10 V, respectively. Each Fluke 732B electronic DC reference standard is fixed in an upgrade-box (18.0 cm x 21.0 cm x 47.0 cm). Two additional batteries are installed inside the upgrade-box. These batteries are used to increase the working time of the internal battery of the Fluke 732B. A BNC type female connector is provided for the measurement of internal thermistor resistance. The total weight of the upgrade box (with Fluke 732B and

Figure 4-1 An upgrade-box for Fluke 732B with additional batteries inside.

batteries) is around 14 kg. Each upgrade box is packed in a wood case (27 x 27.5 x 55) cm. The two additional batteries are connected in parallel to original internal battery through MONITOR/EXT BAT IN connectors on rear panel of the 732B. It is possible to recharge all three batteries at the same time by the automatic charging circuit of the Fluke 732B.

4.2 *Quantities to be measured and conditions of measurements*

For the key comparison, DC voltage outputs 1.018 V and 10 V of the three traveling standards were measured. Since different environmental conditions are used among participating laboratories, appropriate correction of measurement results against temperature, humidity and pressure is necessary. This makes it necessary for us to prepare a set of travelling standards with the coefficient data on their environmental coefficients. The coefficient data are shown in Table 4-1. Temperature, humidity and pressure coefficients of 10 V and 1.018 V outputs and their standard uncertainties were also provided by NMIJ who provided the travelling Zener standards for this KC. The measured voltages V_{measured} should be corrected for temperature and pressure effects. The temperature effect was taken into account through the thermistor resistance R. The following formula was used to calculate the corrected voltages $V_{\mathrm{corrected}}$:

$$V_{\mathrm{corrected}} = V_{\mathrm{measured}} - \alpha_R \cdot (R - R_0) - \alpha_p \cdot (p - p_0) \qquad (1)$$

Here α_R and α_p are the temperature and pressure coefficients as given in Table 4-1, p is the ambient air pressure, and p_0 = 1013.25 hPa the reference atmospheric pressure. The reference thermistor resistances R_0 depend on the specific standard and are also given in the Table. Humidity effect of the Zener standards is known to have very slow time response [2]. In view of time schedule of comparison, the humidity effect was treated as a drift effect when reference value was calculated by interpolation between two reference measurements as in the earlier EUROMET KC [3]. The recommended measurement conditions, 23 °C and 55 % RH or below were given in the protocol. It was also recommended in the protocol that measurements should be carried out after allowing the standard to stabilize with the standard disconnected from the AC line power, and that the CHASSIS (green terminal marked as "GROUND") of the upgrade box is connected to the one point ground of the participant's measurement system.

4.3 *Measurement instructions*

After arrival in the participant's laboratory, the standards were allowed to stabilize in a temperature and, possibly, humidity controlled room for at least four days before the measurements began. The internal thermistor resistance was reported for each measurement result of output voltage. The thermistor resistances of the standards have nominal values between 38 kΩ and 40 kΩ (see Table 4-1). To avoid heating of the thermistor, the test current was not to exceed 10 µA. A small thermo-hygrometer (data logger) which records the environmental temperature and humidity during transport was enclosed in the transit case. It was recommended that the participating laboratories should use their own instrument for precise measurement of the environmental condition.

4.4 Deviations from the protocol

As already explained in 2.4.2, the uncertainties of the temperature, humidity and pressure coefficients which were finally fixed are given as follows.

Table 4-1. Temperature, humidity and pressure coefficients of 10 V and 1.018 V outputs and their standard uncertainties

Voltage	Standard	Reference thermistor resistance at R_0 (kΩ)	Temperature coefficient α_R (nVΩ^{-1})	Humidity coefficient α_H(nV%RH^{-1})	Pressure coefficient α_p(nV hPa^{-1})
10 V	TZS-1	39.65	4.3 ± 1.3	<15	17.8 ±0.7
	TZS-2	39.04	1.9 ± 0.2	<15	16.5 ± 0.5
	TZS-3	39.41	1.3 ± 0.1	<15	21.3 ± 1.1
1.018 V	TZS-1	39.65	0.3 ± 0.0	<1	2.0 ± 0.0
	TZS-2	39.04	0.2 ± 0.1	<1	1.4 ± 0.0
	TZS-3	39.41	0.2 ± 0.1	<1	2.1 ± 0.2

5. Methods of measurement and traceability

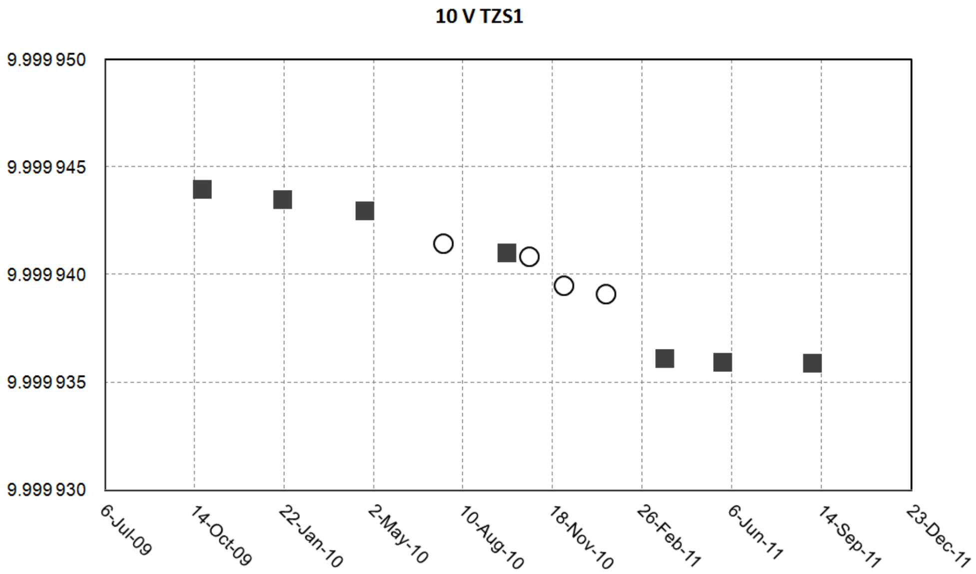
All the participants were using Josephson voltage standard for the measurements. Therefore each participant's measurement results are traceable to its own standard not to any other laboratory's. Further details of measurement systems are given in Appendix B.

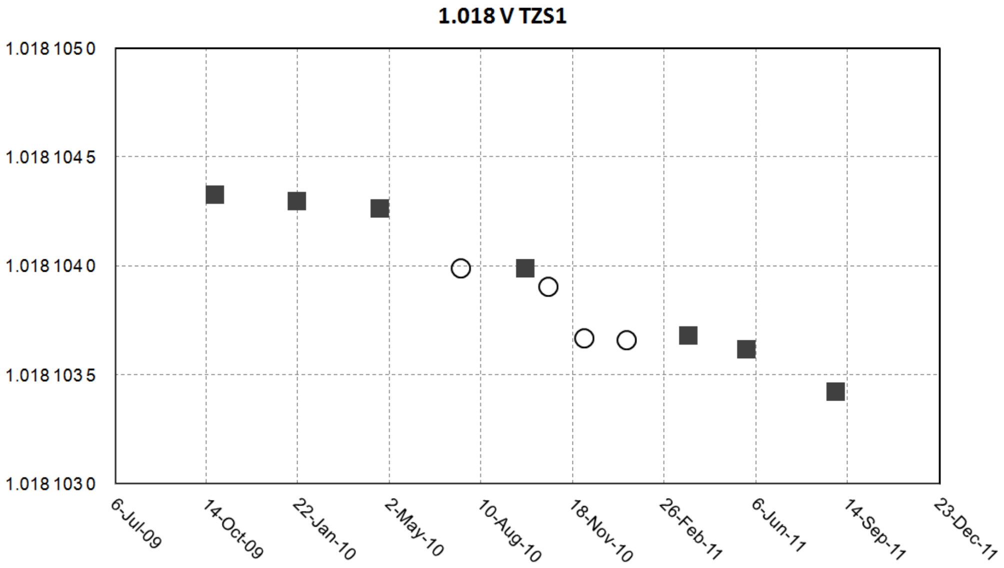
6. Measurements of the pilot laboratory and the BIPM

Measurements made by the pilot laboratory together with those by the BIPM were used to estimate the stability of the travelling standards during the course of the comparison. In order to assess only the instability with time, the temperature and pressure effect were corrected for all the measurement results.

6.1 Stability of the travelling standards

Measurements made by the pilot laboratory and by the BIPM for each travelling standard at 10 V and 1.018 V are shown in Figure 6-1. Repeated measurements of pilot laboratory (solid squares) and the BIPM (open circles) of 10 V output and 1.018 V output from the three traveling standards, where all data are represented after the correction of the local temperature and pressure effects. The abnormal jumps of some outputs around February 2011 are probably attributed to the long exposure of the traveling standards to the cold and dry weather (See 2.4.3). The stability in a shorter time scale can be seen in Figure 6-2, the BIPM measurement from October 2010 to January 2011. The Figure 6-2 shows that the travelling standard TZS2 has the smaller drift compared to the other two, TZS1 and TZS3. The typical noise width of TZS2 is about 1.5 μV for the 10 V output, and 0.2 μV for the 1.018 V output. The drifts of TZS1 and TZS3 were of opposite direction so that the average of the three travelling standards ensured improved stability for the comparison.


10 V TZS1
9.999 950
9.999 945
9.999 940
9.999 935
9.999 930
6-Jul-09
14-Oct-09
22-Jan-10
2-May-10
10-Aug-10
18-Nov-10
26-Feb-11
6-Jun-11
14-Sep-11
23-Dec-11


1.018 V TZS1
1.018 105 0
1.018 104 5
1.018 104 0
1.018 103 5
1.018 103 0
6-Jul-09
14-Oct-09
22-Jan-10
2-May-10
10-Aug-10
18-Nov-10
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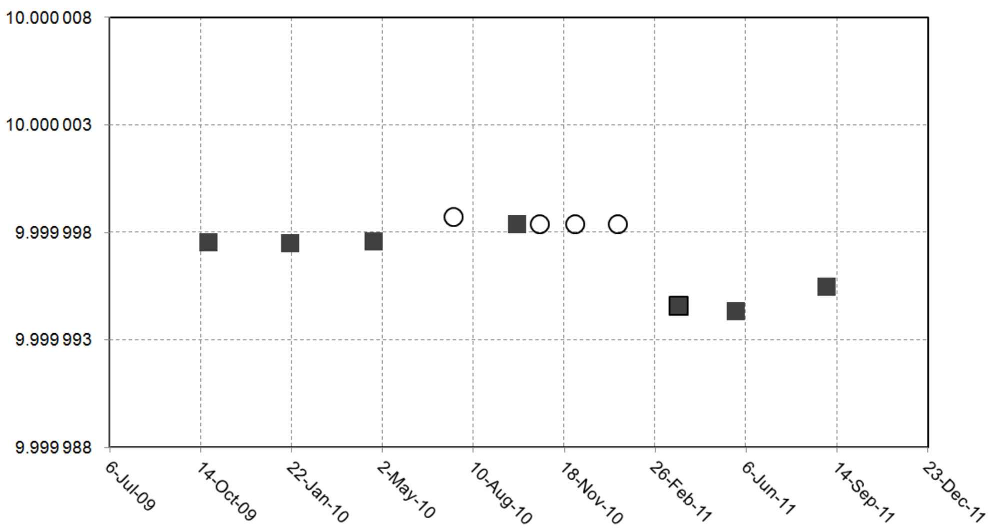
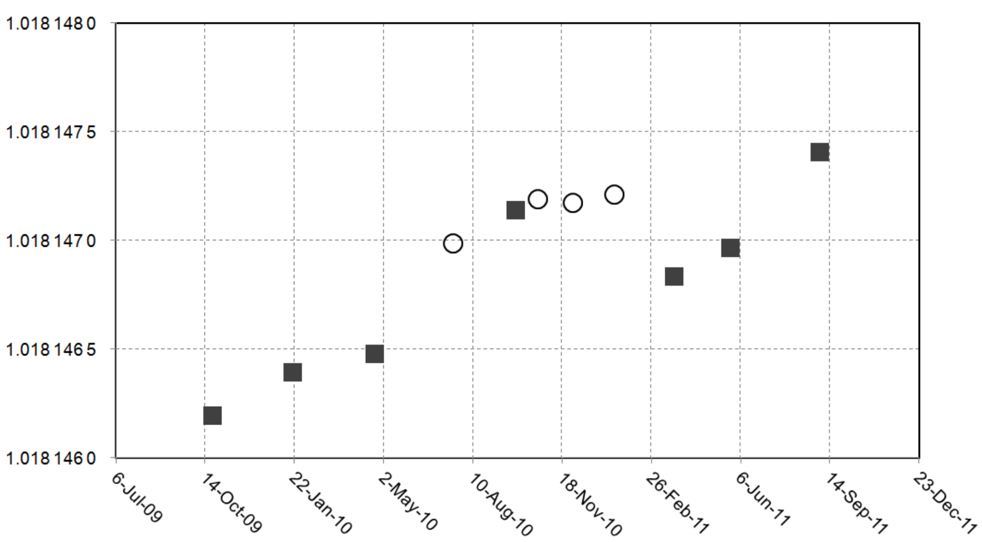
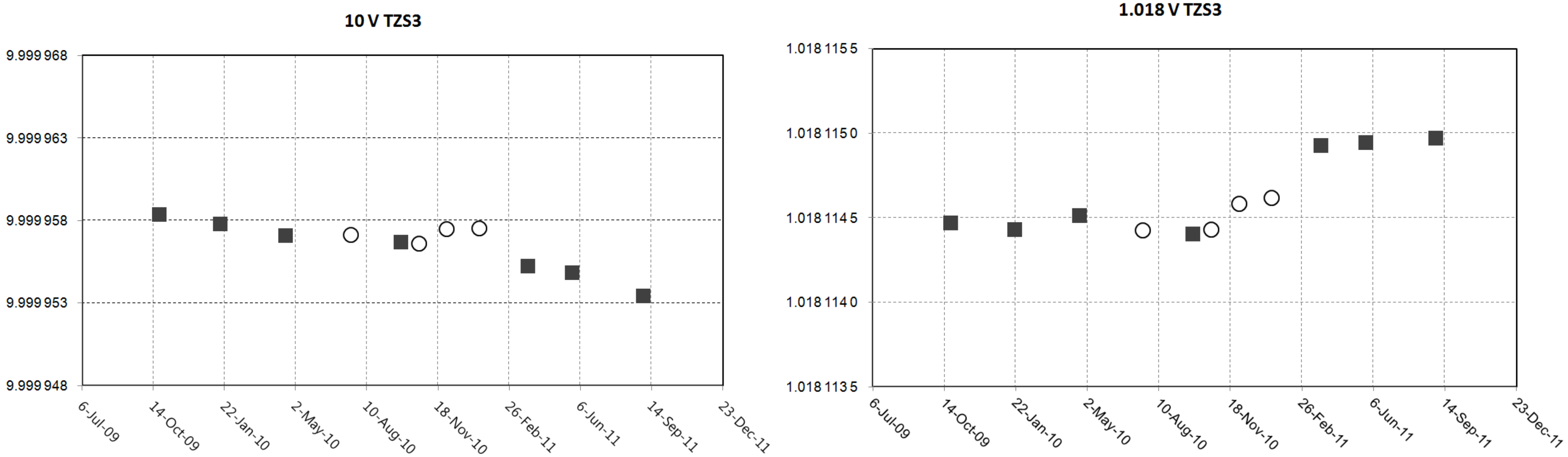
14-Sep-11
23-Dec-11



10 V TZS2

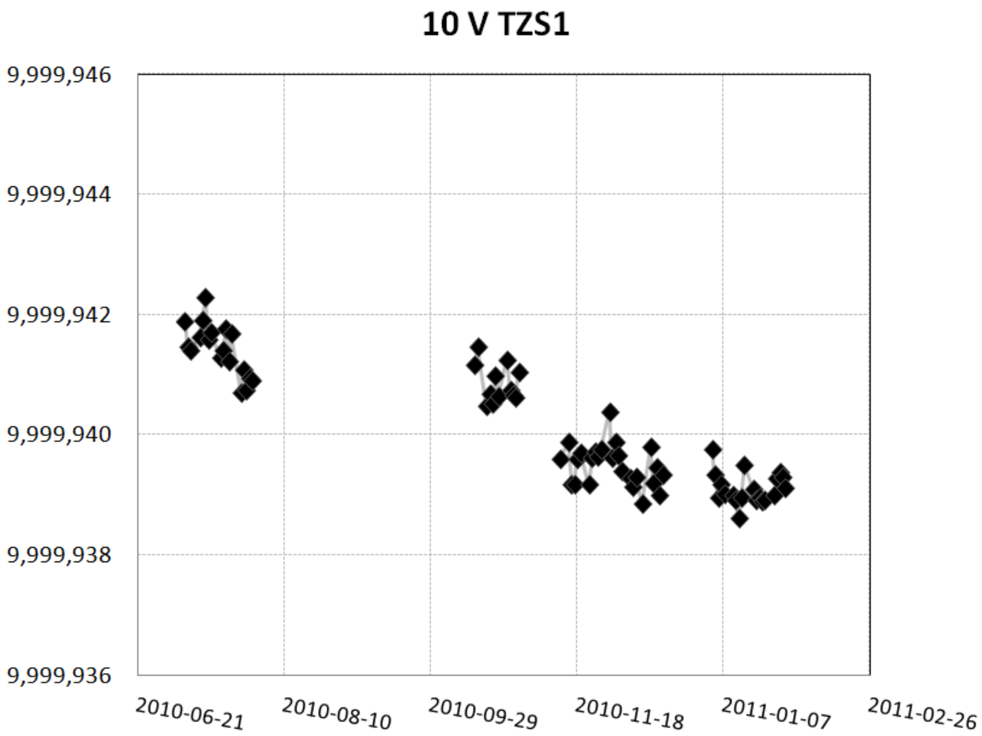


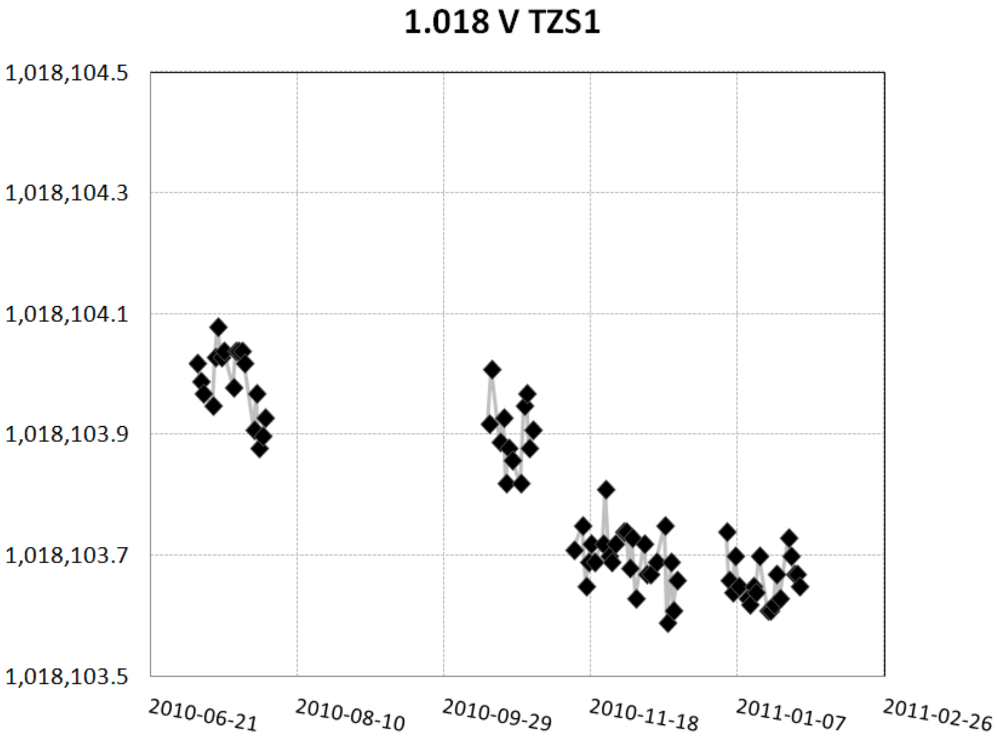
1.018 V TZS2

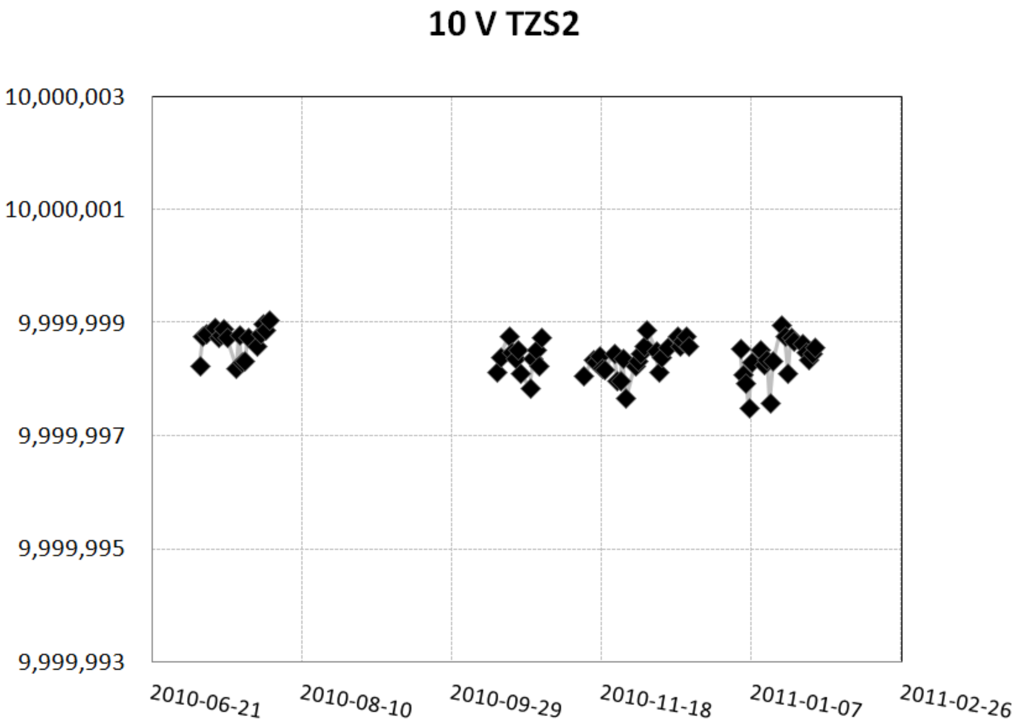

10 V TZS3

1.018 V TZS3

Figure 6-1. Repeated measurements of pilot laboratory (solid squares) and the BIPM (open circles) of 10 V output and 1.018 V output from the three traveling standards, where all data are represented after the correction of the local temperature and pressure effects. The abnormal jumps of some outputs around February 2011 are probably attributed to the long exposure of the traveling standards to the cold and dry weather (See 2.4.3).


10 V TZS1
9,999,946
9,999,944
9,999,942
9,999,940
9,999,938
9,999,936
2010-06-21
2010-08-10
2010-09-29
2010-11-18
2011-01-07
2011-02-26


1.018 V TZS1
1,018,104.5
1,018,104.3
1,018,104.1
1,018,103.9
1,018,103.7
1,018,103.5
2010-06-21
2010-08-10
2010-09-29
2010-11-18
2011-01-07
2011-02-26


10 V TZS2
10,000,003
10,000,001
9,999,999
9,999,997
9,999,995
9,999,993
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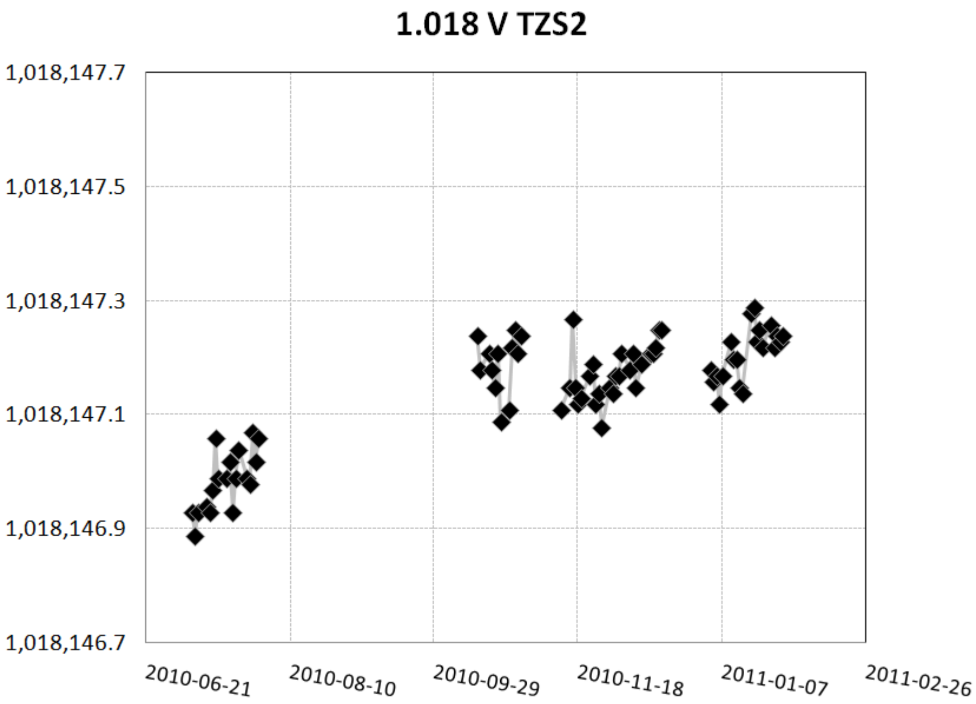
2010-08-10
2010-09-29
2010-11-18
2011-01-07
2011-02-26


1.018 V TZS2
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1,018,147.5
1,018,147.3
1,018,147.1
1,018,146.9
1,018,146.7
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2010-08-10
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2011-01-07
2011-02-26

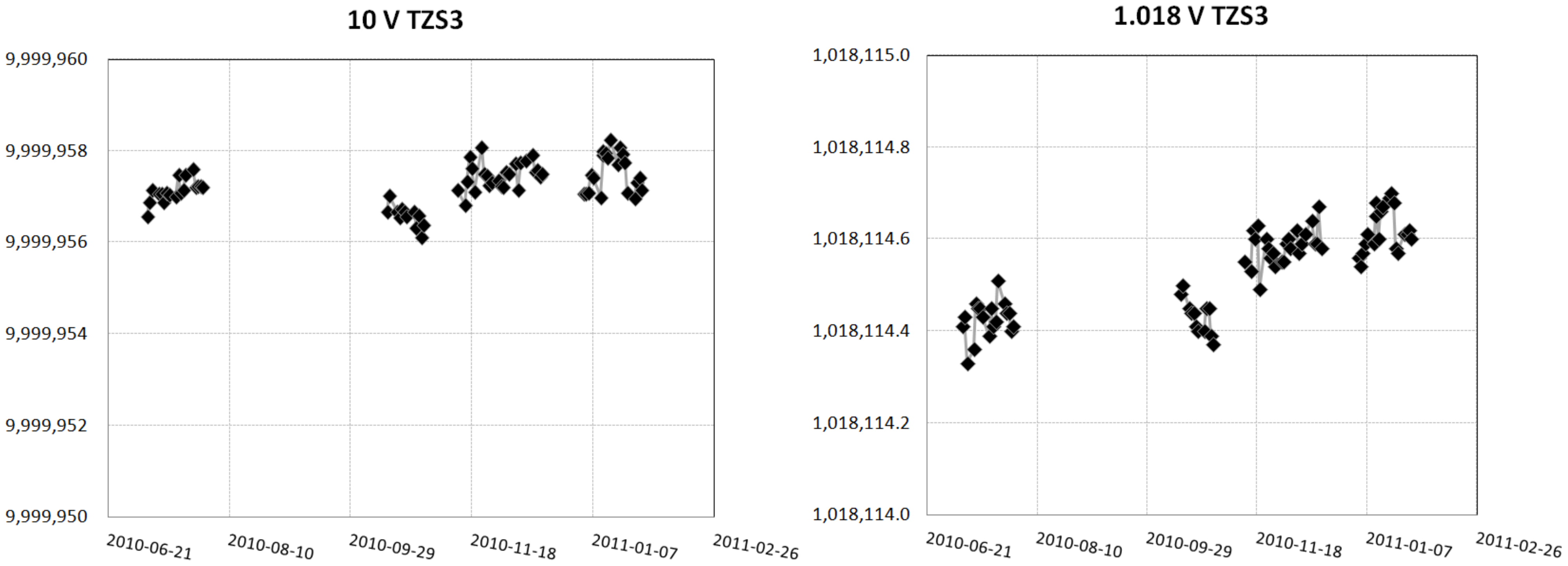

Figure 6-2. Stability of the travelling standards measured by the BIPM. Vertical axes are in μV unit.

6.2 Calculation of reference values

The KRISS measurement values after correction for the temperature and pressure effect are taken as the reference values so that the reference value at the time of a participant's measurement is determined by a interpolation of the two closest KRISS measurement values with using a linear drift model. Applying the correction already expressed in (1), the predicted reference value, $q_{i,k}$, for the i-th Zener standard at the time of the k-th participant's measurement is obtained by an interpolation with the two closest data sets of the KRISS measurements as the following equation (2);

$$q_{i,k} = \frac{t_k - t_1}{t_2 - t_1} V_{i,k,2}{}^{\mathrm{KRISS}} + \frac{t_2 - t_k}{t_2 - t_1} V_{i,k,1}{}^{\mathrm{KRISS}} \tag{2}$$

For the calculation of the uncertainties of the comparison results, we can further expand the equation (2) in terms of parameters for temperature and pressure corrections.

$$\begin{aligned}
q_{i,k} &= \frac{t_k - t_1}{t_2 - t_1} V_{i,k,2}{}^{\mathrm{KRISS}} + \frac{t_2 - t_k}{t_2 - t_1} V_{i,k,1}{}^{\mathrm{KRISS}} \\
&= q_{i,k}^0 - \frac{t_k - t_1}{t_2 - t_1}\left\{\alpha_{i,R}\left(R_{i,k,2} - R_0\right) + \alpha_{i,p}\left(p_{i,k,2} - p_0\right)\right\} - \frac{t_2 - t_k}{t_2 - t_1}\left\{\alpha_{i,R}\left(R_{i,k,1} - R_0\right) + \alpha_{i,p}\left(p_{i,k,1} - p_0\right)\right\} \\
&= q_{i,k}^0 - \alpha_{i,R}\left\{\frac{t_k - t_1}{t_2 - t_1}\left(R_{i,k,2} - R_0\right) + \frac{t_2 - t_k}{t_2 - t_1}\left(R_{i,k,1} - R_0\right)\right\} - \alpha_{i,p}\left\{\frac{t_k - t_1}{t_2 - t_1}\left(p_{i,k,2} - p_0\right) + \frac{t_2 - t_k}{t_2 - t_1}\left(p_{i,k,1} - p_0\right)\right\} \\
&= q_{i,k}^0 - \alpha_{i,R}\left\{\left(\frac{t_k - t_1}{t_2 - t_1} R_{i,k,2} + \frac{t_2 - t_k}{t_2 - t_1} R_{i,k,1}\right) - R_0\right\} - \alpha_{i,p}\left\{\left(\frac{t_k - t_1}{t_2 - t_1} p_{i,k,2} + \frac{t_2 - t_k}{t_2 - t_1} p_{i,k,1}\right) - p_0\right\} \\
&= q_{i,k}^0 - \alpha_{i,R}\left(\overline{R}_{i,k} - R_0\right) - \alpha_{i,p}\left(\overline{p}_{i,k} - p_0\right)
\end{aligned} \tag{2'}$$

where $q_{i,k}{}^0$ is the raw reference value after interpolation without the temperature or pressure correction, $\overline{R}_{i,k}$ and $\overline{p}_{i,k}$ is interpolated thermistor resistance and pressure respectively given by

$$\overline{R}_{i,k} = \frac{t_k - t_1}{t_2 - t_1} R_{i,k,2} + \frac{t_2 - t_k}{t_2 - t_1} R_{i,k,1} \tag{3}$$

$$\overline{p}_{i,k} = \frac{t_k - t_1}{t_2 - t_1} p_{i,k,2} + \frac{t_2 - t_k}{t_2 - t_1} p_{i,k,1} \tag{4}$$

t_1 is the time of the KRISS measurement preceding the k-th participant's measurement, t_2 is the time of the KRISS measurement following the k-th participant's measurement respectively, $V_{\mathrm{KRISS},\,1}$ and $V_{\mathrm{KRISS},\,2}$ are the reference values at the time t_1 and t_2 respectively. In order to avoid any correlation effect, every group of the KRISS data between k-th participant and (k+1)-th participant are divided into two parts of which the earlier part is used to calculate $q_{i,k}$, and the later part is used to calculate $q_{i,k+1}$.

6.3 Uncertainty contribution from the instability of Zeners

The uncertainty contribution from the instability of the Zener during travelling, $u(q_{i,k},)_{\mathrm{Z}}$, which includes the 1/f noise floor [5] was estimated from the KRISS and BIPM measurement results shown in Figure 6-1. With assumption of linear drift and consideration of any unknown nonlinear or hysteretic changes the maximum of the differences was taken as the standard uncertainty for the instability of the Zener. However, as all the Zeners showed the abnormal jumps around February 2011, the data were divided into two groups; before-the-jump group and after-the-jump group, consisting of 8 points, and 3 points, respectively, and providing 6 + 1 differences in total per each Zener. Thus the degree of freedom for this uncertainty is 6. The following table shows the calculated standard uncertainties.

Table 6-1. Standard uncertainty of Zener instability, $u_{\mathrm{Z},i}$ during traveling

Voltage	Standard	Standard uncertainty (nV)	Degree of freedom
10 V	TZS-1	769	6
	TZS-2	592	6
	TZS-3	459	6
1.018 V	TZS-1	138	6
	TZS-2	144	6
	TZS-3	89	6

6.4 Uncertainty contribution from the T & P correction correlations

The uncertainties of the temperature and pressure corrections are obtained from the uncertainties of temperature and pressure measurements and from the uncertainties of the coefficients given in the Table 4.1. The mathematical equation for the correction which should be substituted from the original measurement values to obtain the values at the reference condition as stated in the equation (1) can be stated as $C(R, p) = \alpha_{\mathrm{R}}\,(R - R_0) + \alpha_{\mathrm{p}}\,(p - p_0)$. The uncertainty can be expressed as $u(C) = \{\ (R - R_0)^2\, u^2(\alpha_{\mathrm{R}}) + \alpha_{\mathrm{R}}^2\, u^2(R) + (p - p_0)^2\, u^2(\alpha_{\mathrm{p}}) + \alpha_{\mathrm{p}}^2\, u^2(p)\ \}^{1/2}$. It should be noted that the corrections are made not only for the participant's but also for the KRISS' result, thus when we calculate the difference between the participant's and the KRISS' result, the uncertainty component can be correlated because the coefficients are already the same for both KRISS and participants' results. This effect will be addressed in detail in the following sections.

7. Measurement results

7.1 Mathematical model

The participants were requested to report both the original result and the corrected result to allow the pilot to double-check the calculation. The corrected results were taken as the measurement results for the comparison. Participants' measurement result for *i*-th Zener at the time of the *k*-th participant, $x_{i,k}$ is normalized as expressed in the following equation (5) by subtracting the reference value for the travelling standard, $q_{i,k}$, which is given by the interpolation of the pilot's measurements result as shown in (2),

$$d_{i,k} = V^{x}{}_{corrected,i,k} - V^{\mathrm{KR}}{}_{corrected,i,k} + \Delta V^{i}{}_{Z} = x_{i,k} - q_{i,k} + z_i \qquad (5)$$

Here we introduced a virtual term $\Delta V^{i}_{\mathrm{Z}}$ (= z_i) to represent a nonlinear deviation of the travelling standards for uncertainty expression only, although the expectation value would be zero. All the $d_{i,k}$ are averaged over all Zeners by weighted mean to obtain the averaged normalized result of the *k*-th participant, d_k,

$$d_k = \frac{\sum_{i=1}^{3} w_i d_{i,k}}{\sum_{i=1}^{3} w_i} \qquad (6)$$

As for the weighting factor, we used w_i as given by;

$$w_i = 1/\{u^2(d_{i,k}) - u_{\mathrm{s},k}{}^2\}, \qquad (7)$$

where the standard uncertainty, $u(d_{i,k})$ is the combined uncertainty of all uncertainties relevant to the $d_{i,k}$ and the $u_{\mathrm{s},k}$ is the combined uncertainty of the *k*-th participant's system and KRISS system, $\sqrt{u_{\mathrm{s},k}{}^2 + u_{\mathrm{s,KR}}{}^2}$, which is common for all Zener indices, *i*. Then the uncertainty of d_k, is calculated by

$$u^2(d_k) = \frac{1}{\sum_i w_i} + u_{\mathrm{s},k}^2 \qquad (8)$$

The uncertainty of the normalized value of the participant for *i*-th Zener, $u(d_{i,k})$ which appears in (7) may be calculated by directly differentiating (5), however it should be noted that complicated correlation terms will appear in the uncertainty expression because of the correlations between $u(x_{i,k})$ and $u(q_{i,k})$ as stated in the section 6.4. However, with the help of the equation (2’), the mathematical model (5) can be rewritten in a diagonal form as follows to avoid the correlation terms.

$$d_{i,k} = x^0{}_{i,k} - q^0{}_{i,k} - \alpha_{i,R}\left(R^x{}_{i,k} - \overline{R^q}_{i,k}\right) - \alpha_{i,p}\left(p^x{}_{i,k} - \overline{p^q}_{i,k}\right) + z_i \tag{9}$$

Here, superscript 0 stands for the original measurement data before the corrections, superscript x for the participating laboratory, superscript q for the pilot laboratory. Therefore, for example, $R^x{}_{i,k}$ means the participant’s measurement of the thermistor resistance for the i-th Zener at the time of k-th participant and $q^0{}_{i,k}$ means the interpolated value of the pilot’s measurements on the i-th Zener output before the temperature and pressure corrections. $\overline{R^q}_{i,k}$, $\overline{p^q}_{i,k}$ is the interpolated thermistor resistance and pressure of the KRISS measurement, respectively defined as (3) and (4). From (9), the uncertainty can be expressed as follow.

$$u(d_{i,k}) = \left[\begin{array}{r} u^2(x^0{}_{i,k}) + u^2(q^0{}_{i,k}) + u^2(\alpha_{i,R})\left(R^x{}_{i,k} - \overline{R^q}_{i,k}\right)^2 + \alpha_{i,R}{}^2\left\{u^2(R^x{}_{i,k}) + u^2(\overline{R^q}_{i,k})\right\} \\ + u^2(\alpha_{i,p})\left(p^x{}_{i,k} - \overline{p^q}_{i,k}\right)^2 + \alpha_{i,p}{}^2\left\{u^2(p^x{}_{i,k}) + u^2(\overline{p^q}_{i,k})\right\} + u^2(z_i) \end{array}\right]^{1/2} \tag{10}$$

Here the $u(z_i)$ is the random instability of the travelling standard, TZS-i on which the uncertainties are given in Table 6-1. Summary of the participants’ results calculated by (5), (6), (7), (8), (9) and (10) is described in the next section.

7.2 Results of the participating institutes

Participants’ final results are shown in the following tables. It should be noted that KRISS, BIPM and NMIJ have multiple participation data. (KRISS: 7 and the BIPM: 4 NMIJ: 3) For those laboratories, the first participation results were arbitrarily taken as their representing results.

7.2.1 10 V results

Table 7-1. Results of participating laboratories for the 10 V TZS-1. See text for definition of symbols.

			Participant				***Pilot***				***Difference***		
k	**Participant**	**Date**	$R^x_{1,k}$	$p^x_{1,k}$	$x_{1,k}$-10 V	$u_A(x_{1,k})$	$R^q_{1,k}$	$p^q_{1,k}$	$q_{1,k}$-10 V	$u_A(q_{1,k})$	$d_{1,k}$	$u(d_{1,k})$	$w_1^{-1/2}$
		mm/dd/yy	kΩ	hPa	μV	μV	kΩ	hPa	μV	μV	μV	μV	μV
1	**NMIA**	11/22/09	39.795	1001.7	-56.576	0.252	39.732	1009.8	-56.155	0.031	**-0.421**	**0.775**	**0.775**
2	**NMC-A*STAR**	12/21/09	39.716	1006.9	-56.845	0.060	39.777	1007.8	-56.270	0.045	**-0.575**	**0.777**	**0.777**
3	**KRISS**	01/20/10	39.758	1014.8	-56.553	0.059	39.684	1008.1	-56.525	0.040	**-0.028**	**0.779**	**0.779**
4	**NML-SIRIM**	02/16/10	39.770	1000.7	-56.933	0.068	39.721	1014.7	-56.718	0.039	**-0.216**	**0.776**	**0.776**
5	**CMS-ITRI**	03/14/10	39.708	1012.7	-57.279	0.126	39.685	1013.5	-56.708	0.056	**-0.570**	**0.781**	**0.772**
6	**NMIJ**	05/27/10	39.695	1002.2	-57.290	0.019	39.666	1005.8	-57.695	0.077	**0.405**	**0.774**	**0.774**
7	**NIMT**	06/25/10	39.683	1003.7	-57.958	0.047	39.664	1006.3	-57.993	0.062	**0.035**	**0.774**	**0.774**
8	**BIPM**	07/18/10	39.726	1007.5	-58.577	0.024	39.662	1006.7	-58.234	0.052	**-0.342**	**0.777**	**0.777**
9	**SCL**	08/23/10	39.699	992.8	-59.090	0.036	39.660	1007.3	-58.599	0.046	**-0.491**	**0.774**	**0.774**
10	**KazInMetr**	07/28/11	39.712	964.8	-65.235	0.046	39.657	996.3	-64.082	0.053	**-1.153**	**0.776**	**0.776**

Table 7-2. Results of participating laboratories for the 10 V TZS-2. See text for definition of symbols.

k	**Participant**	**Date**	***Participant***				***Pilot***				***Difference***		
			$R^x_{2,k}$	$p^x_{2,k}$	$x_{2,k}$-10 V	$u_A(x_{2,k})$	$R^q_{2,k}$	$p^q_{2,k}$	$q_{2,k}$-10 V	$u_A(q_{2,k})$	$d_{2,k}$	$u(d_{2,k})$	$w_2^{-1/2}$
		mm/dd/yy	kΩ	hPa	µV	µV	kΩ	hPa	µV	µV	µV	µV	µV
1	**NMIA**	11/22/09	39.071	1001.8	-1.994	0.155	38.942	1010.1	-1.624	0.032	**-0.370**	**0.594**	**0.594**
2	**NMC-A*STAR**	12/21/09	38.967	1006.7	-2.122	0.054	39.032	1009.2	-1.573	0.028	**-0.549**	**0.596**	**0.596**
3	**KRISS**	01/19/10	38.995	1014.6	-1.736	0.051	38.896	1007.2	-1.662	0.035	**-0.074**	**0.596**	**0.596**
4	**NML-SIRIM**	02/17/10	39.000	1001.9	-1.796	0.063	38.955	1012.8	-1.786	0.047	**-0.010**	**0.598**	**0.597**
5	**CMS-ITRI**	03/14/10	38.948	1012.3	-1.507	0.088	38.918	1012.2	-1.626	0.046	**0.120**	**0.600**	**0.588**
6	**NMIJ**	05/27/10	38.932	1001.3	-1.520	0.028	38.894	1004.8	-1.814	0.049	**0.295**	**0.595**	**0.595**
7	**NIMT**	06/25/10	38.904	1004.0	-1.240	0.041	38.892	1005.4	-1.763	0.043	**0.523**	**0.597**	**0.597**
8	**BIPM**	07/18/10	38.931	1007.6	-1.293	0.024	38.890	1005.9	-1.722	0.043	**0.429**	**0.595**	**0.595**
9	**SCL**	08/23/10	38.942	992.7	-1.200	0.038	38.886	1006.7	-1.660	0.049	**0.460**	**0.598**	**0.598**
10	**KazInMetr**	07/28/11	38.946	964.8	-5.349	0.108	38.856	997.0	-4.911	0.053	**-0.437**	**0.605**	**0.605**

Table 7-3. Results of participating laboratories for the 10 V TZS-3. See text for definition of symbols.

k	Participant	Date	*Participant*				*Pilot*				*Difference*		
			$R^x_{3,k}$	$p^x_{3,k}$	$x_{3,k}$-10 V	$u_A(x_{3,k})$	$R^q_{3,k}$	$p^q_{3,k}$	$q_{3,k}$-10 V	$u_A(q_{3,k})$	$d_{3,k}$	$u(d_{3,k})$	$w_3^{-1/2}$
		mm/dd/yy	kΩ	hPa	µV	µV	kΩ	hPa	µV	µV	µV	µV	µV
1	**NMIA**	11/22/09	39.547	1001.7	-42.034	0.317	39.404	1009.4	-41.823	0.030	**-0.211**	**0.459**	**0.459**
2	**NMC-A*STAR**	12/21/09	39.425	1006.8	-41.996	0.067	39.494	1009.1	-42.017	0.032	**0.021**	**0.462**	**0.462**
3	**KRISS**	01/19/10	39.447	1014.9	-42.339	0.029	39.359	1006.4	-42.270	0.024	**-0.069**	**0.458**	**0.458**
4	**NML-SIRIM**	02/18/10	39.450	1001.1	-42.614	0.053	39.409	1013.0	-42.603	0.010	**-0.011**	**0.460**	**0.459**
5	**CMS-ITRI**	03/14/10	39.413	1012.5	-42.760	0.116	39.375	1012.1	-42.713	0.034	**-0.047**	**0.471**	**0.456**
6	**NMIJ**	05/27/10	39.370	1001.6	-42.987	0.050	39.343	1004.2	-43.088	0.006	**0.101**	**0.459**	**0.459**
7	**NIMT**	06/25/10	39.343	1004.0	-42.743	0.063	39.337	1004.8	-43.139	0.011	**0.396**	**0.461**	**0.461**
8	**BIPM**	07/18/10	39.356	1007.6	-42.851	0.100	39.332	1005.3	-43.181	0.015	**0.331**	**0.467**	**0.467**
9	**SCL**	08/23/10	39.408	992.7	-43.280	0.029	39.325	1006.1	-43.244	0.022	**-0.036**	**0.458**	**0.458**
10	**KazInMetr**	07/28/11	39.000	965.0	-46.113	0.142	38.875	997.5	-46.023	0.054	**-0.090**	**0.482**	**0.482**

7.2.2 1.018 V results

Table 7-4. Results of participating laboratories for the 1.018 V TZS-1. See text for definition of symbols.

			Participant				*Pilot*				*Difference*		
k	**Participant**	**Date**	$R^x_{1,k}$	$p^x_{1,k}$	$x_{1,k}$ - 1.018 V	$u_A(x_{1,k})$	$R^q_{1,k}$	$p^q_{1,k}$	$q_{1,k}$ – 1.018 V	$u_A(q_{1,k})$	$d_{1,k}$	$u(d_{1,k})$	$w_1^{-1/2}$
		mm/dd/yy	kΩ	hPa	μV	μV	kΩ	hPa	μV	μV	μV	μV	μV
1	**NMIA**	11/22/09	39.795	1001.7	104.245	0.035	39.725	1012.1	104.328	0.006	**-0.083**	**0.138**	**0.137**
2	**NMC-A*STAR**	12/21/09	39.705	1005.8	104.236	0.007	39.738	1015.4	104.326	0.010	**-0.090**	**0.138**	**0.137**
3	**KRISS**	01/19/10	39.749	1015.9	104.299	0.012	39.700	1007.1	104.296	0.005	**0.002**	**0.138**	**0.138**
4	**NML-SIRIM**	02/16/10	39.770	1000.7	104.214	0.009	39.731	1012.1	104.278	0.006	**-0.064**	**0.138**	**0.135**
5	**CMS-ITRI**	03/14/10	39.708	1012.7	104.176	0.017	39.710	1010.8	104.286	0.007	**-0.111**	**0.139**	**0.133**
6	**NMIJ**	05/27/10	39.667	1000.8	104.272	0.008	39.697	1003.2	104.180	0.008	**0.092**	**0.138**	**0.138**
7	**NIMT**	06/25/10	39.676	1004.0	104.113	0.010	39.698	1003.8	104.135	0.007	**-0.022**	**0.138**	**0.138**
8	**BIPM**	07/18/10	39.729	1007.6	103.990	0.012	39.699	1004.3	104.099	0.006	**-0.109**	**0.138**	**0.138**
9	**SCL**	08/23/10	39.698	992.8	103.938	0.011	39.701	1005.0	104.044	0.007	**-0.106**	**0.138**	**0.137**
10	**KazInMetr**	07/28/11	39.712	965.0	103.267	0.090	39.676	998.2	103.492	0.010	**-0.225**	**0.165**	**0.164**

Table 7-5. Results of participating laboratories for the 1.018 V TZS-2. See text for definition of symbols.

k	Participant	Date	*Participant*				*Pilot*				*Difference*		
			$R^x_{2,k}$	$p^x_{2,k}$	$x_{2,k}$ – 1.018 V	$u_A(x_{2,k})$	$R^q_{2,k}$	$p^q_{2,k}$	$q_{2,k}$ – 1.018 V	$u_A(q_{2,k})$	$d_{2,k}$	$u(d_{2,k})$	$w_2^{-1/2}$
		mm/dd/yy	kΩ	hPa	μV	μV	kΩ	hPa	μV	μV	μV	μV	μV
1	**NMIA**	11/22/09	39.071	1001.8	146.305	0.024	38.937	1012.2	146.352	0.004	**-0.047**	**0.144**	**0.143**
2	**NMC-A*STAR**	12/21/09	38.956	1005.7	146.384	0.005	38.959	1015.7	146.426	0.006	**-0.042**	**0.144**	**0.143**
3	**KRISS**	01/19/10	39.005	1016.3	146.472	0.006	38.907	1007.3	146.414	0.006	**0.058**	**0.144**	**0.144**
4	**NML-SIRIM**	02/17/10	39.000	1001.9	146.494	0.010	38.994	1012.6	146.494	0.004	**0.000**	**0.144**	**0.141**
5	**CMS-ITRI**	03/15/10	38.948	1012.3	146.624	0.013	38.954	1011.3	146.537	0.008	**0.087**	**0.145**	**0.141**
6	**NMIJ**	05/27/10	38.921	1000.7	146.589	0.002	38.901	1003.1	146.651	0.012	**-0.062**	**0.145**	**0.145**
7	**NIMT**	06/25/10	38.902	1004.2	146.775	0.006	38.905	1003.7	146.767	0.010	**0.008**	**0.145**	**0.144**
8	**BIPM**	07/18/10	38.929	1007.6	146.985	0.010	38.908	1004.3	146.861	0.008	**0.124**	**0.145**	**0.145**
9	**SCL**	08/23/10	38.942	992.7	147.034	0.011	38.912	1005.1	147.003	0.007	**0.031**	**0.144**	**0.143**
10	**KazInMetr**	07/28/11	38.946	964.8	146.943	0.054	38.841	998.1	147.254	0.009	**-0.311**	**0.154**	**0.154**

Table 7-6. Results of participating laboratories for the 1.018 V TZS-3. See text for definition of symbols.

k	**Participant**	**Date**	***Participant***				***Pilot***				***Difference***		
			$R^x_{3,k}$	$p^x_{3,k}$	$x_{3,k}$ – 1.018 V	$u_A(x_{3,k})$	$R^q_{3,k}$	$p^q_{3,k}$	$q_{3,k}$ – 1.018 V	$u_A(q_{3,k})$	$d_{3,k}$	$u(d_{3,k})$	$w_3^{-1/2}$
		mm/dd/yy	kΩ	hPa	μV	μV	kΩ	hPa	μV	μV	μV	μV	μV
1	**NMIA**	11/22/09	39.547	1001.7	114.444	0.042	39.394	1012.0	114.456	0.003	**-0.012**	**0.089**	**0.099**
2	**NMC-A*STAR**	12/21/09	39.412	1005.5	114.459	0.009	39.417	1014.2	114.443	0.004	**0.016**	**0.090**	**0.087**
3	**KRISS**	01/20/10	39.418	1016.3	114.428	0.010	39.354	1008.6	114.496	0.008	**-0.068**	**0.094**	**0.094**
4	**NML-SIRIM**	02/18/10	39.450	1001.1	114.437	0.007	39.383	1014.9	114.458	0.010	**-0.021**	**0.090**	**0.085**
5	**CMS-ITRI**	03/15/10	39.413	1012.5	114.433	0.020	39.368	1013.4	114.489	0.008	**-0.056**	**0.092**	**0.083**
6	**NMIJ**	05/27/10	39.340	1000.7	114.509	0.005	39.325	1003.6	114.499	0.014	**0.011**	**0.090**	**0.090**
7	**NIMT**	06/25/10	39.344	1004.2	114.479	0.008	39.328	1004.0	114.477	0.011	**0.002**	**0.090**	**0.090**
8	**BIPM**	07/18/10	39.353	1007.6	114.425	0.010	39.330	1004.4	114.459	0.008	**-0.034**	**0.090**	**0.090**
9	**SCL**	08/23/10	39.408	992.7	114.412	0.012	39.333	1004.9	114.432	0.005	**-0.020**	**0.090**	**0.088**
10	**KazInMetr**	07/28/11	39.000	965.0	114.712	0.066	38.904	998.0	114.964	0.012	**-0.252**	**0.111**	**0.111**

7.2.3 Summary of 10 V and 1.018 V results

The weighted mean of the normalized results over the 3 Zeners and the uncertainty for 10 V and 1.018 V as described (6), (7), and (8) are summarized in Table 7-7.

Table 7-7. Averaged results of participating laboratories for the three TZS'. See text for definition of symbols.

k	Participant	Date	10 V		1.018 V	
			d_k	$u(d_k)$	d_k	$u(d_k)$
		mm/dd/yy	μV	μV	μV	μV
1	**NMIA**	11/22/09	**-0.298**	**0.329**	**-0.036**	**0.067**
2	**NMC-A*STAR**	12/21/09	**-0.262**	**0.331**	**-0.020**	**0.068**
3	**KRISS**	01/20/10	**-0.063**	**0.329**	**-0.022**	**0.068**
4	**NML-SIRIM**	02/18/10	**-0.048**	**0.331**	**-0.026**	**0.071**
5	**CMS-ITRI**	03/15/10	**-0.089**	**0.348**	**-0.039**	**0.074**
6	**NMIJ**	05/27/10	**0.215**	**0.329**	**0.014**	**0.067**
7	**NIMT**	06/25/10	**0.369**	**0.330**	**-0.002**	**0.067**
8	**BIPM**	07/18/10	**0.238**	**0.332**	**-0.018**	**0.067**
9	**SCL**	08/23/10	**0.032**	**0.329**	**-0.029**	**0.068**
10	**KazInMetr**	07/28/11	**-0.402**	**0.339**	**-0.261**	**0.079**

7.3 Calculation of the RMO KC reference value and its uncertainty

The APMP comparison reference values (CRV's) and their uncertainties which are calculated by weighted mean over all the participants' results should be checked before accepting them with respect to their consistency. We followed a statistical validation process suggested by [8]. The summary of the validation process is shown in Table 7-8.

Table 7-8. Grand average over all participants' results for CRV calculation.

		10 V		***1.018 V***	
		µV		µV	
Parameter	**Description**	**Value**	**Standard uncertainty**	**Value**	**Standard uncertainty**
$< d >$, $u(< d >)$	Weighted Mean	**-0.028**	**0.105**	**-0.038**	**0.022**
Parameter	**Description**	**Value**	**Remark**	**Value**	**Remark**
χ^2_{obs}	$\sum_{k=1}^{10}\left(\frac{d_k - < d >}{u_k}\right)^2$	5.10	-	9.03	-
ν	N - 1	9	DOF	9	DOF
$P(\chi^2 > \chi^2_{\mathrm{obs}})$	χ^2 Probability	83 %	> 5 %, Consistency not failed	43 %	> 5 % Consistency not failed

As we see in the Table, for both 10 V and 1.018 V, the weighted mean did not fail the consistency check, thus a Monte-Carlo simulation was not necessary to calculate the CRV [8]. Finally accepted CRV's denoted by d_{ref} are summarized in Table 7-9.

Table 7-9. APMP comparison reference value (CRV) calculation result.

10 V		***1.018 V***	
d_{ref}	**$u(d_{ref})$**	**d_{ref}**	**$u(d_{ref})$**
µV	µV	µV	µV
-0.028	**0.105**	**-0.038**	**0.022**
Remark		**Remark**	
Weighted Mean		Weighted Mean	

7.4 Degrees of equivalence

7.4.1 Degrees of equivalence of the participating institutes with respect to the comparison reference values

The RMO degrees of equivalence (DOE) of the *i*-th participant with respect to the comparison reference value (CRV) is calculated as

$$D_i^{\mathrm{R}} = d_i - d_{ref} \, . \tag{11}$$

The expanded uncertainty associated with this result, $U(D_i^{\mathrm{R}})$, is then $U(D_i^{\mathrm{R}}) = 2 \cdot u(D_i^{\mathrm{R}})$ where *the coverage factor* 2 is chosen to give approximately 95 % coverage. The standard uncertainty of the DOE is given by (12).

$$u(D_i^{\mathrm{R}}) = \sqrt{u^2(d_i) - u^2(d_{ref})} \tag{12}$$

The degrees of equivalence of the participating institutes relative to the comparison reference values are tabulated in Table 7-10 and represented graphically in Figure 7-1 and Figure 7-2.

Table 7-10. Degrees of equivalence of the participating institutes relative to the comparison reference values.

Participant	Key Comparison at 10 V		Key Comparison at 1.018 V	
	D_i^{R} (μV)	$U(D_i^{\mathrm{R}})$ (μV)	D_i^{R} (μV)	$U(D_i^{\mathrm{R}})$ (μV)
NMIA	-0.269	0.624	0.002	0.128
NMC-A*STAR	-0.234	0.628	0.017	0.130
KRISS	-0.035	0.624	0.015	0.130
NML-SIRIM	-0.019	0.627	0.012	0.134
CMS-ITRI	-0.061	0.663	-0.002	0.142
NMIJ	0.244	0.624	0.052	0.127
NIMT	0.398	0.626	0.036	0.127
BIPM	0.267	0.630	0.020	0.126
SCL	0.060	0.624	0.009	0.129
KazInMetr	-0.374	0.645	-0.223	0.153

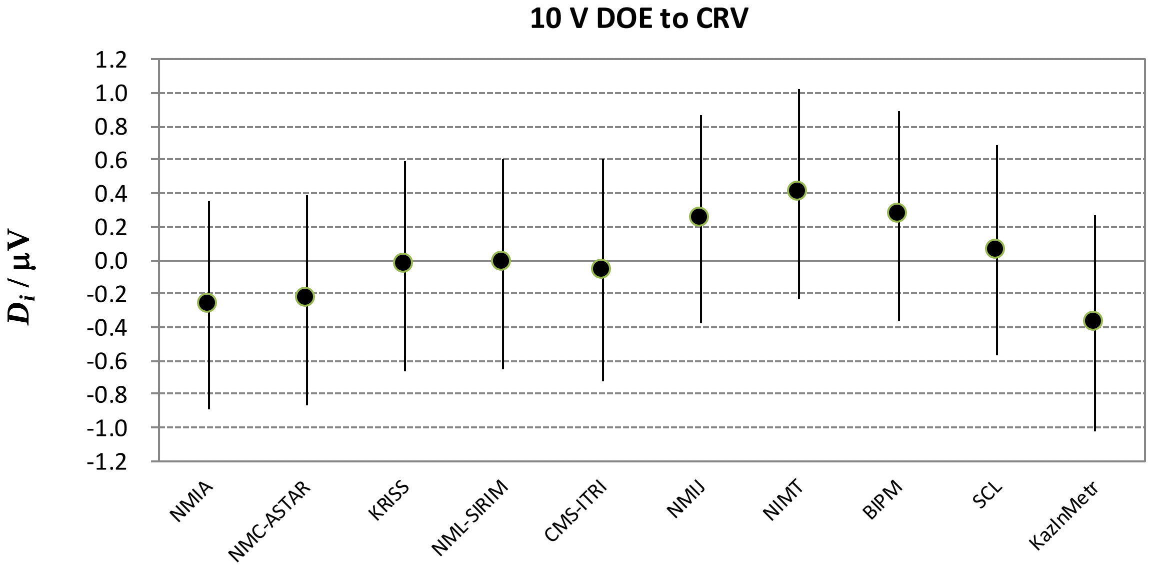

Figure 7-1. Degrees of equivalence D_i^{R} of the participating institutes (listed in participation order) at 10 V with respect to the comparison reference value. Uncertainty bars represent the expanded uncertainty $U(D_i^{\mathrm{R}})$.

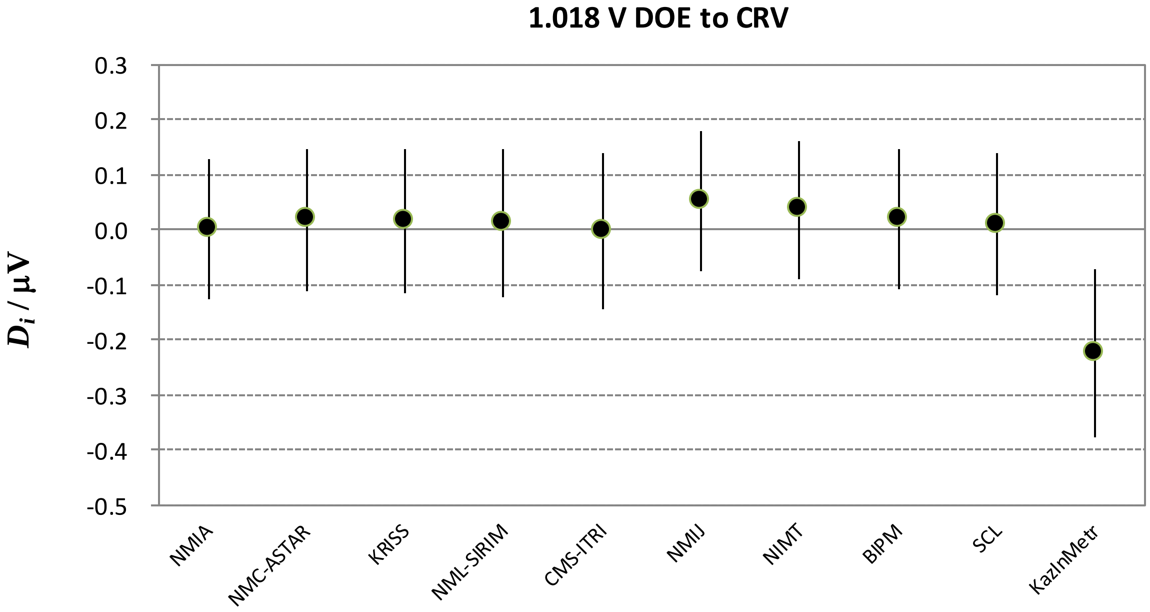

Figure 7-2. Degrees of equivalence D_i^{R} of the participating institutes (listed in participation order) at 1.018 V with respect to the comparison reference value. Uncertainty bars represent the expanded uncertainty $U(D_i^{\mathrm{R}})$

7.4.2 Pair-wise degrees of equivalence

Pair-wise degrees of equivalence of the participating institutes are calculated as:

$$D_{i,j} = d_i - d_j = x_i - q_i - \left(x_j - q_j\right). \tag{13}$$

In calculating the uncertainty associated with this result, correlations between d_i and d_j are negligible, thus standard uncertainty $u(D_{i,j})$ and the degree of freedom $\nu(D_{i,j})$ are as follows.

$$u(D_{i,j}) = \sqrt{u^2(d_i) + u^2(d_j)} \tag{14}$$

The expanded uncertainty is calculated as $U(D_{i,j}) = 2 \cdot u(D_{i,j})$. For further details of the calculation of the pair-wise degrees of equivalence refer to Appendix A.

8. Proposal for linking to BIPM.EM-K11 key comparison and degrees of equivalence

The results of APMP.EM-K11.3 can be linked to BIPM.EM-K11.3 using a method similar to that used to link EUROMET.EM.BIPM-K11.b to BIPM.EM-K11.b (see D. Reymann [9]). The link is computed using the results of the common participants which have an independent realization of the volt by means of a Josephson Array Voltage Standard. Four participants provide the links to the BIPM.EM-K11.b for 10 V: NMIA, NMC-A*STAR (Formerly SPRING), KRISS and BIPM, and three participants provide the links to the BIPM.EM-K11.a for 1.018 V: NMIA, KRISS, and BIPM.

8.1 Calculation of linking correction

Let CRV be denoted for the reference vale of this comparison and KCRV for the reference value of the BIPM.EM-K11, and Δ be the difference, CRV - KCRV. The difference, Δ is calculated on the base of the results of the linking laboratory as follows.

D_{i_L} : Result of BIPM.EM-K11 for a linking laboratory

$D_{i\_L}^{\mathbf{R}}$: Result of this RMO comparison for a linking laboratory

D_i : DOE of *i*-th participant with respect BIPM.EM-K11 KCRV

Δ_{i_L} : Difference defined by (15),

$$\Delta_{i\_L} = D_{i\_L} - D_{i\_L}^{\mathbf{R}} = (d_{i\_L}^{0} - \mathrm{KCRV}) - (d_{i\_L} - \mathrm{CRV}) \tag{15}$$

Measurements from the linking laboratories provide estimates Δ_{i_L} for the linking correction Δ, which are equivalent to CRV – KCRV. The correction Δ is then calculated as the weighted mean of the linking laboratories estimates, that is:

$$\Delta = \frac{\sum_{i\_L=1}^{4} w_{i\_L}\Delta_{i\_L}}{\sum_{i\_L=1}^{4} w_{i\_L}} \tag{16}$$

Where

$$w_{i\_L} = \frac{1}{u^2(\Delta_{i\_L})} \qquad \text{and} \qquad u^2(\Delta) = \frac{1}{\sum_{i\_L=1}^{4} w_{i\_L}}\,. \tag{17}$$

The uncertainty, $u(\Delta_{i\_L})$ associated with D_{i_L} - $D_{i\_L}{}^{\mathrm{R}}$ is calculated by (18)

$$u^2(\Delta_{i\_L}) = u^2(D_{i\_L}{}^{\mathrm{R}}) + u^2(D_{i\_L}) \tag{18}$$

The calculation results for Δ is summarized in Table 8-1.

Table 8-1. Summary of calculation results for the linking correction, Δ. All quantities are in μV unit, and the uncertainties are standard estimates (1 *s*)

Linking Lab.	**Key Comparisons at 10 V**						**Key Comparisons at 1.018 V**					
	$D_{i\_L}{}^{\mathrm{R}}$	$u(D_{i\_L}{}^{\mathrm{R}})$	D_{i_L}	$u(D_{i\_L})$	Δ_{i_L}	$u(\Delta_{i\_L})$	$D_{i\_L}{}^{\mathrm{R}}$	$u(D_{i\_L}{}^{\mathrm{R}})$	D_{i_L}	$u(D_{i\_L}{}^{-0})$	Δ_{i_L}	$u(\Delta_{i\_L})$
NMIA	-0.269	0.312	0.130	0.140	0.399	0.342	-0.002	0.064	0.028	0.026	0.028	0.069
KRISS	-0.035	0.312	-0.030	0.100	0.005	0.328	0.015	0.065	0.070	0.050	0.055	0.082
BIPM	0.267	0.315	0	0.100	-0.267	0.331	0.020	0.063	0	0.010	-0.020	0.064
NMC-A*STAR	-0.234	0.314	0.160	0.110	0.394	0.333	-	-	-	-	-	-
Weighted Mean, Δ					**0.127**		**Weighted Mean, Δ**				**0.015**	
Standard Uncertainty, *u*(Δ)					**0.167**		**Standard Uncertainty, *u*(Δ)**				**0.041**	

8.2 Degrees of equivalence with respect to BIPM.EM-K11 reference value

The degree of equivalence with respect to the KCRV of BIPM.EM.K11 for each participant of this comparison is then calculated by (19).

$$D_i = D_i^{\mathrm{R}} + \Delta \tag{19}$$

where the $D_i^{\mathbf{R}}$ values are given in Table 7-10. The uncertainty for this, $u(D_i)$ is calculated by (20).

$$u^2(D_i) = u^2(D_i^{\mathrm{R}}) + u^2(\Delta) \tag{20}$$

The degree of equivalence for each participant with respect to BIPM.EM.K11 KCRV is shown in Table 8-2, Figure 8-1, and Figure 8-2.

Table 8-2. Degrees of equivalence of the participating institutes relative to the BIPM.EM-K11 KCRV.

Participant	Key Comparison at 10 V		Key Comparison at 1.018 V	
	D_i (μV)	$U(D_i)$ (μV)	D_i (μV)	$U(D_i)$ (μV)
NMIA	-0.142	0.707	0.017	0.151
NMC-A*STAR	-0.107	0.711	0.033	0.153
KRISS	0.092	0.711	0.031	0.153
NML-SIRIM	0.108	0.710	0.027	0.157
CMS-ITRI	0.066	0.742	0.014	0.163
NMIJ	0.371	0.707	0.067	0.150
NIMT	0.525	0.709	0.051	0.151
BIPM	0.394	0.713	0.035	0.150
SCL	0.187	0.708	0.024	0.153
KazInMetr	-0.247	0.726	-0.208	0.173

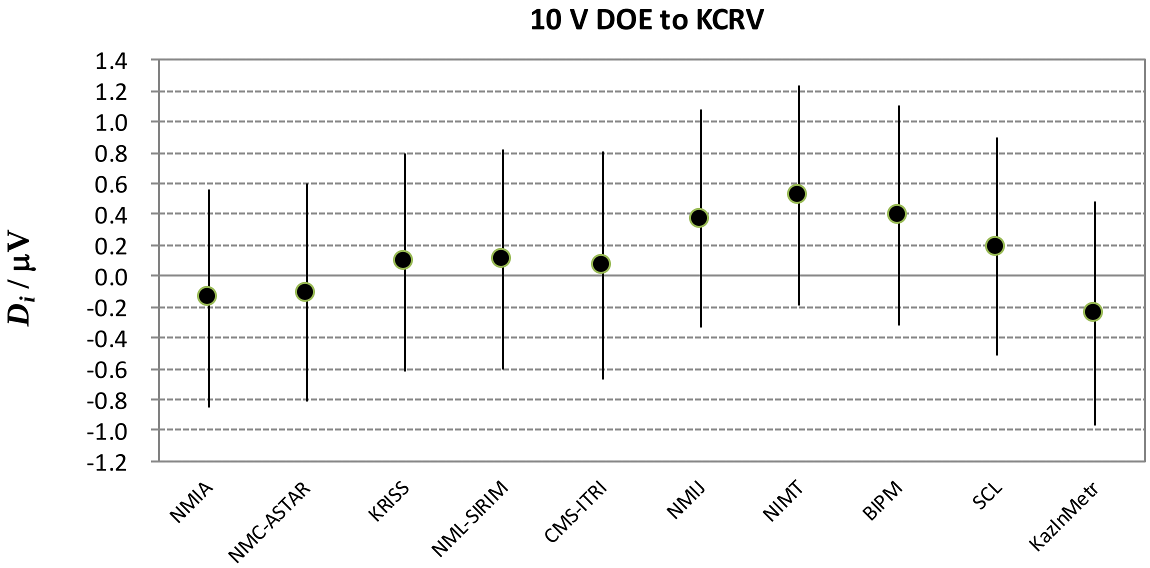

Figure 8-1. Degrees of equivalence D_i of the participating institutes (listed in participation order) at 10 V with respect to the BIPM.EM-K11.b KCRV. Uncertainty bars represent the expanded uncertainty $U(D_i)$.

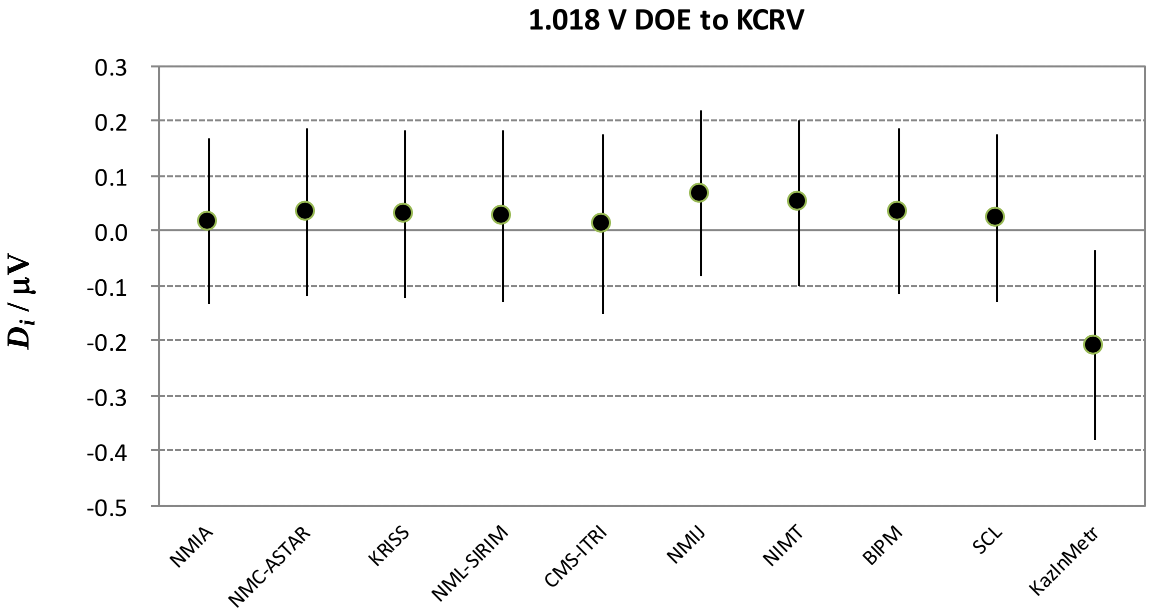

Figure 8-2. Degrees of equivalence D_i of the participating institutes (listed in participation order) at 1.018 V with respect to the BIPM.EM-K11.a KCRV. Uncertainty bars represent the expanded uncertainty $U(D_i)$.

8.3 *Pair-wise degrees of equivalence*

The pair-wise DOE, $D_{i,j}$ does not depend on the reference values because it is a difference between laboratories *i* and *j*. Thus existing degrees of equivalence of Appendix A will commonly stand for both DOEs of RMO CRV and BIPM KCRV.

9. Summary and conclusions

9.1 *Summary*

The key comparisons of DC voltage at 10 V and 1.018 V have been conducted between participating APMP member laboratories. In general there is good agreement between participating laboratories in the region for both quantities~~, although the consistency test with χ^2 probability failed for 1.018 V.~~ The measurement results are tabulated in Table 7-7, with which the RMO comparison reference value (CRV) was calculated as Table 7-9~~, where a Monte-Carlo simulation was used for 1.018 V result~~. The degrees of equivalence with respect to CRV were tabulated in Table 7-10, and represented graphically in Figure 7-1 and Figure 7-2.

9.2 *Link to the BIPM KC*

The linking correction, difference between CRV and BIPM.EM-K11 reference value (KCRV) was calculated on the basis of linking laboratories as described in section 8.2. The degrees of equivalence with respect to KCRV were tabulated in Table 8-2, and represented graphically in Figure 8-1 and Figure 8-2. It is expected that this comparison will be able to provide support for participants' entries in the MRA Appendix C.

9.3 *Impact of the comparison on the calibration and measurements capabilities of the participating laboratories*

The DOE and CMC in the BIPM KCDB for the participating institutes are compared in Table 9-1. The DOE supports CMC for most of participants with available CMC data except NMIA, KRISS, and NMIJ who claim very low uncertainties in calibration of Zeners. But it should be noted that any validation of the consistency between DOE and CMC would not be possible with this comparison because the uncertainty of this comparison is much larger than their CMC's.

Table 9-1. DOE and CMC of the participating institutes.

10 V

Lab *i* ↓	D_i	$U(D_i)$	**CMC (k=2)**
	/ 10^{-6} V		**/ 10^{-6} V**
NMIA	**-0.142**	**0.707**	**0.2**
NMC-ASTAR	**-0.107**	**0.711**	**0.5**
KRISS	**0.092**	**0.707**	**0.055**
NML-SIRIM	0.108	0.710	4
CMS-ITRI	0.066	0.742	4
NMIJ	0.371	0.707	0.03
NIMT	0.525	0.709	4
BIPM	**0.394**	**0.713**	**N.A.**
SCL	0.187	0.708	0.6
KazInMetr	-0.247	0.726	N.A.

1.018 V

Lab *i* ↓	D_i	$U(D_i)$	**CMC (k=2)**
	/ 10^{-6} V		**/ 10^{-6} V**
NMIA	**0.017**	**0.151**	**0.045**
NMC-ASTAR	0.033	0.153	0.1
KRISS	**0.031**	**0.153**	**0.02**
NML-SIRIM	0.027	0.157	0.2
CMS-ITRI	0.014	0.163	0.8
NMIJ	0.067	0.150	0.007
NIMT	0.051	0.151	0.9
BIPM	**0.035**	**0.150**	**N.A.**
SCL	0.024	0.153	0.12
KazInMetr	-0.208	0.173	N.A.

Appendices

Appendix A: Pair-wise Degrees of equivalence

Degrees of equivalence for participants of APMP.EM-K11.3 with respect to BIPM.EM-K11 are given in Table A-1 for 10 V and Table A-2 for 1.018 V.

Table A-1. Degrees of equivalence of the participating institutes relative to the BIPM.EM-K11.b KCRV (10 V).

Lab *j* →

Lab *i* ↓			**NMIA**		**NMC-ASTAR**		**KRISS**		**NML-SIRIM**		**CMS-ITRI**		**NMIJ**		**NIMT**		**BIPM**		**SCL**		**KazInMetr**	
	D_i	$U(D_i)$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$
	/ 10^{-6} V		/ 10^{-6} V		/ 10^{-6} V		/ 10^{-6} V		/ 10^{-6} V		/ 10^{-6} V		/ 10^{-6} V		/ 10^{-6} V		/ 10^{-6} V		/ 10^{-6} V		/ 10^{-6} V	
NMIA	-0.142	0.707			-0.035	1.002	-0.234	1.000	-0.250	1.002	-0.208	1.025	-0.513	1.000	-0.667	1.001	-0.536	1.004	-0.330	1.000	0.105	1.014
NMC-ASTAR	-0.107	0.711	0.035	1.002			-0.199	1.002	-0.215	1.005	-0.173	1.027	-0.478	1.002	-0.632	1.004	-0.501	1.006	-0.294	1.003	0.140	1.016
KRISS	0.092	0.707	0.234	1.000	0.199	1.002			-0.015	1.002	0.026	1.025	-0.278	1.000	-0.433	1.001	-0.301	1.004	-0.095	1.000	0.339	1.014
NML-SIRIM	0.108	0.710	0.250	1.002	0.215	1.005	0.015	1.002			0.042	1.027	-0.263	1.002	-0.417	1.004	-0.286	1.006	-0.080	1.003	0.355	1.016
CMS-ITRI	0.066	0.742	0.208	1.025	0.173	1.027	-0.026	1.025	-0.042	1.027			-0.305	1.025	-0.459	1.026	-0.327	1.029	-0.121	1.025	0.313	1.038
NMIJ	0.371	0.707	0.513	1.000	0.478	1.002	0.278	1.000	0.263	1.002	0.305	1.025			-0.154	1.001	-0.023	1.004	0.183	1.000	0.618	1.014
NIMT	0.525	0.709	0.667	1.001	0.632	1.004	0.433	1.001	0.417	1.004	0.459	1.026	0.154	1.001			0.131	1.005	0.337	1.002	0.772	1.015
BIPM	0.394	0.713	0.536	1.004	0.501	1.006	0.301	1.004	0.286	1.006	0.327	1.029	0.023	1.004	-0.131	1.005			0.206	1.004	0.640	1.018
SCL	0.187	0.708	0.330	1.000	0.294	1.003	0.095	1.000	0.080	1.003	0.121	1.025	-0.183	1.000	-0.337	1.002	-0.206	1.004			0.434	1.014
KazInMetr	-0.247	0.726	-0.105	1.014	-0.140	1.016	-0.339	1.014	-0.355	1.016	-0.313	1.038	-0.618	1.014	-0.772	1.015	-0.640	1.018	-0.434	1.014		

Table A-2. Degrees of equivalence of the participating institutes relative to the BIPM.EM-K11.a KCRV (1.018 V).

Lab *j* →

Lab *i* ↓			**NMIA**		**NMC-ASTAR**		**KRISS**		**NML-SIRIM**		**CMS-ITRI**		**NMIJ**		**NIMT**		**BIPM**		**SCL**		**KazInMetr**	
	D_i	$U(D_i)$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$	D_{ij}	$U(D_{ij})$
	/ 10^{-6} V		/ 10^{-6} V		/ 10^{-6} V		/ 10^{-6} V		/ 10^{-6} V		/ 10^{-6} V		/ 10^{-6} V		/ 10^{-6} V		/ 10^{-6} V		/ 10^{-6} V		/ 10^{-6} V	
NMIA	0.017	0.151	0	0.214	-0.015	0.215	-0.013	0.215	-0.009	0.218	0.004	0.223	-0.050	0.213	-0.033	0.214	-0.018	0.213	-0.007	0.215	0.225	0.230
NMC-ASTAR	0.033	0.153	0.015	0.215	0.000	0.216	0.002	0.216	0.006	0.219	0.019	0.224	-0.035	0.214	-0.018	0.215	-0.003	0.214	0.009	0.216	0.241	0.231
KRISS	0.031	0.153	0.013	0.215	-0.002	0.216	0.000	0.216	0.004	0.219	0.017	0.224	-0.037	0.214	-0.020	0.215	-0.005	0.214	0.007	0.216	0.239	0.231
NML-SIRIM	0.027	0.157	0.009	0.218	-0.006	0.219	-0.004	0.219	0.000	0.222	0.013	0.227	-0.040	0.217	-0.024	0.218	-0.009	0.217	0.003	0.219	0.235	0.233
CMS-ITRI	0.014	0.163	-0.003	0.223	-0.019	0.224	-0.017	0.224	-0.013	0.227	0.000	0.231	-0.053	0.222	-0.037	0.222	-0.022	0.222	-0.010	0.224	0.222	0.238
NMIJ	0.067	0.150	0.049	0.213	0.035	0.214	0.037	0.214	0.040	0.217	0.053	0.222	0.000	0.213	0.016	0.213	0.032	0.213	0.043	0.214	0.275	0.229
NIMT	0.051	0.151	0.033	0.214	0.018	0.215	0.020	0.215	0.024	0.218	0.037	0.222	-0.016	0.213	0.000	0.213	0.015	0.213	0.027	0.215	0.259	0.229
BIPM	0.035	0.150	0.018	0.213	0.003	0.214	0.005	0.214	0.009	0.217	0.022	0.222	-0.032	0.213	-0.015	0.213	0.000	0.212	0.011	0.214	0.243	0.229
SCL	0.024	0.153	0.006	0.215	-0.009	0.216	-0.007	0.216	-0.003	0.219	0.010	0.224	-0.043	0.214	-0.027	0.215	-0.011	0.214	0.000	0.216	0.232	0.231
KazInMetr	-0.208	0.173	-0.225	0.230	-0.241	0.231	-0.239	0.231	-0.235	0.233	-0.222	0.238	-0.275	0.229	-0.259	0.229	-0.243	0.229	-0.232	0.231	0.000	0.244

Appendix B: Methods of measurement

Details of the method of measurement and traceability to the SI, as reported by participants, are given below.

B.1 Method of measurement: NMIA, Australia

The voltage of each output of the instrument was measured in series opposition with a Josephson Voltage Standard (JVS). The JVS is biased using a manually operated bias supply, which remained connected to the array during the measurement. The bias supply was adjusted to obtain a null balance which remained within 500 µV during the measurement. The polarity of the instrument was reversed using a manual low-thermal reversing switch. The leads to the JVS, the reversing switch and the instrument are shielded, and the shield is connected to ground at the reversing switch. The Josephson array Dewar is shielded separately. A Keithley 182 nanovoltmeter was used as the null detector, and was set to measure without filtering. One hundred samples were taken on each polarity. The instrument was calibrated at an ambient temperature of (20 ± 1) °C, and the relative humidity of (51 ± 5) %. The atmospheric pressure was measured at the time of each test with an uncertainty of ±1.0 hPa.

TZS1: These had a mean value of 1001.7 hPa and varied from 990.5 hPa to 1017.1 hPa. The mean value of the built-in oven thermistor, measured at the time of each test with a direct current of nominally 10 µA, was (39 795 ±3) Ω, and varied from 39 774 Ω to 39 814 Ω.
TZS2: These had a mean value of 1001.8 hPa and varied from 990.5 hPa to 1017.0 hPa. The mean value of the built-in oven thermistor, measured at the time of each test with a direct current of nominally 10 µA, was (39 071 ±4) Ω, and varied from 39 040 Ω to 39 097 Ω.
TZS3: These had a mean value of 1001.7 hPa and varied from 990.5 hPa to 1016.9 hPa. The mean value of the built-in oven thermistor, measured at the time of each test with a direct current of nominally 10 µA, was (39 547 ±4) Ω, and varied from 39 518 Ω to 39 573 Ω.

During all tests the instrument was disconnected from mains power and operated on its internal battery. The waiting time after removal of mains power before starting measurements varied between 4 and 7.7 hours. This calibration is based on Test Method PM-LFS-8.2.6, and uses the value K_{J-90} = 483 597.9 GHz/V assigned to the Josephson constant on 1 January 1990.

*B.2 Method of measurement: NMC-A*STAR, Singapore*

The standards have been measured at the National Metrology Centre, A*STAR, Singapore, during the period from 11 December 2009 to 31 December 2009 according to National Metrology Centre Calibration Procedure EC1.1a and the technical protocol of APMP.EM.BIPM-K11.3. The standards were measured by comparing the output voltages directly against a Josephson Array Voltage Standard (JAVS) maintained at the National Metrology Centre. The dc voltage measurements are traceable to the SI volt via the Josephson effect, using the conventional value of the Josephson constant K_{J-90} = 483 597.9 GHz/V exactly. The uncertainty of the value of K_{J-90} in the SI system is not included in the uncertainty assessment. The measurement was carried out with the AC power disconnected from the standard at least four hours before the measurements. During the measurement, the standard was operated on internal battery power. The “GROUND” terminal is connected to the guard of the measuring system. All system components were connected to triple-shielded isolation transformers to isolate the power line network and each instrument. The general procedure was to connect the array and the standard in series opposition and measure the difference voltage with the detector voltmeter. An automatic reversal procedure follows a + - + - sequence for a total of four measurement sets. A low thermal scanner was used for polarity switching. The applied bias was off from the Josephson array during the measurement. The measurement and data acquisition were automatically controlled by software. The software targets array voltages to minimize the mean polarized null voltage (MPNV). The maximum MPNV is 2.5 mV for 10 V and 0.5 mV for 1.018 V respectively. Each data point of null voltage is the average of 3 sample points of the voltmeter.

B.3 Method of measurement: KRISS, Korea (Rep. of)

The travelling standards have been measured by KRISS calibration procedure C13-1-002-2012. The JVS of KRISS has following features. The KRISS JAVS was connected to two different current sources: the scope was powered through an isolated line (isolation transformer) while the RF equipment was referred to the standard power distribution of the shielded room.

- Type of array: 10 V SIS, manufactured by IPHT(s/n 1469-2);
- Detector: Keithley 2182, used on the 10 mV range (without any filter);
- Bias source: Homemade source based on a PTB design;
- Oscilloscope: A Tektronix 7603 oscilloscope is used to visualise the steps and to adjust the RF power level at the beginning of a series of measurements;
- Software: Homemade under Visual Basic environment;
- Frequency source stabilizer: Counter EIP 578B with locking of the frequency to the external 10 MHz reference and a stability better than ±1 Hz during the period of the comparison. The KRISS array is irradiated at a frequency around 75 GHz;
- The 10 MHz reference signal for the counter is provided by a synthetiser HP3325A which is itself referred to the 10 MHz signal coming from the reference clock.
- Thermal EMF (including array connections): approximately 500 nV– 600 nV, varies with liquid He level in reservoir;
- Total impedance of the two array measurement leads: 40 Ω or 80 Ω; this resistance includes the series resistance of a filter inserted in the two measurement leads (possible choice between two different filters).
- Leakage resistance of measurement leads: 1×10^{12} Ω.

KRISS JVS participated in BIPM.EM-K10.a in 1995, and BIPM.EM-K10.b, BIPM.EM-K11(.a & .b) in 2008.

B.4 Method of measurement: NML-SIRIM, Malaysia

The travelling standards have been measured by a Josephson voltage standard system at SIRIM.

B.5 Method of measurement: CMS-ITRI, Chinese TAIPEI

The travelling standards have been measured by a Josephson voltage standard system at CMS. The traveling standards are calibrated by using the back-to-back method. The thermal offset is eliminated by automatic switching, and we use the floating circuit such that there is no guarding or connection to the earth. The measurements are under bias-off, and the Josephson step number is tuned by JBS500 automatically such that the difference between the Josephson voltage and measured voltage is below 10 mV. It takes about 5 minutes for a single point measurement.

B.6 Method of measurement: NMIJ/AIST, Japan

The travelling standards have been measured by a Josephson voltage standard system at NMIJ. The microwave with a frequency of approximately 75 GHz, which is generated with a Gunn oscillator stabilized using a source locking microwave counter EIP578B and a Yoshida circuit, is applied to the array. The detector used for measuring a null voltage between the array and the travelling standards is a digital voltmeter, Advantest R6561, with a 1 mV range. The maximum null voltage is less than 0.5 μV. The thermal EMF between the array and the detector is canceled out by reversing the polarity of the array output and a low-thermal EMF rotary switch for the traveling standards. It takes typically 4 minutes for a (positive, negative, negative and positive) sequence. The total measurement time for 5 sets of this sequence is approximately 20 minutes.

B.7 Method of measurement: NIMT, Thailand

The DC voltages of the traveling standards were determined from the voltage differences between the voltage of Josephson Junction Voltage Standard (JJVS) which is maintained at the National Institute of Metrology (Thailand) and the voltage of the traveling standards. Both temperature and relative humidity surrounding the measuring station were controlled to be within (23±1) °C and (50±5) %RH, respectively. The traveling standards were left to stabilize in the controlled ambient condition around the measuring station for four days before any measurements were started. Additionally, the AC power line was disconnected four hours prior to the starting of measurements. The guard was connected to the earth if this connection resulted in standard deviation of reading of null meter less than 500 nV for each polarity of measurement. Otherwise, the guard and the earth would be disconnected. At one point of the system was connected to isolated ground. The Josephson Junction Voltage Standard was operated in a shielded room. The biasing was applied on the Josephson array during the measurements and the Josephson step number was adjusted manually and the maximum value of null voltage was 0.310 mV (not over 2 steps away). The nano-voltmeter model Keithley 2182A was used as null voltage with the following setting: Filter OFF and 1 PLC (MED) number of sample are set.

B.8 Method of measurement: BIPM

The output voltage of the Zener standard to be measured is connected to the BIPM Josephson Voltage Standard (in series opposition with the BIPM array) through a low thermal EMF switch. The binding post CHASSIS" of the Zener standard is connected to a single point which is the grounding reference point of the measurement setup. The measurements start after at least two hours since the mains plug at the rear of the Zeners has been disconnected. The BIPM detector consists of an EM model N1a analog nanovoltmeter whose output is connected, via an optically-coupled isolation amplifier, to a pen recorder and a digital voltmeter (DVM) which is connected to a computer. This computer is used to monitor measurements, acquire data and calculate results. Low thermal electromotive force switches are used for critical switching, such as polarity reversal of the detector input. After the BIPM array biasing frequency has been adjusted to a value where the voltage difference between the primary and the secondary voltage standards is below 0.5 μV, the nanovoltmeter is set to its 3 μV or 10 μV range to perform measurements at 1.018 V and 10 V respectively. The measurement sequence can then be carried out. Three consecutive measurement points are acquired according to the following procedure (Cf. Fig.1): Note that the polarity of the Zener follows the polarity of the array.

1- Positive array polarity and reverse position of the detector;

2- Data acquisition;

3- Positive array polarity and normal position of the detector;

4- Data acquisition;

5- Negative array polarity and reverse position of the detector;

6- Data acquisition;

7- Negative array polarity and normal position of the detector;

8- Data acquisition;

9- Negative array polarity and reverse position of the detector;

10- Data acquisition

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11- Negative array polarity and normal position of the detector;

12- Data acquisition;

13- Positive array polarity and reverse position of the detector;

14- Data acquisition;

15- Positive array polarity and normal position of the detector;

16- Data acquisition;

The reversal of the detector polarity is done to cancel out any detector offset error and internal linear thermo-electromotive forces.

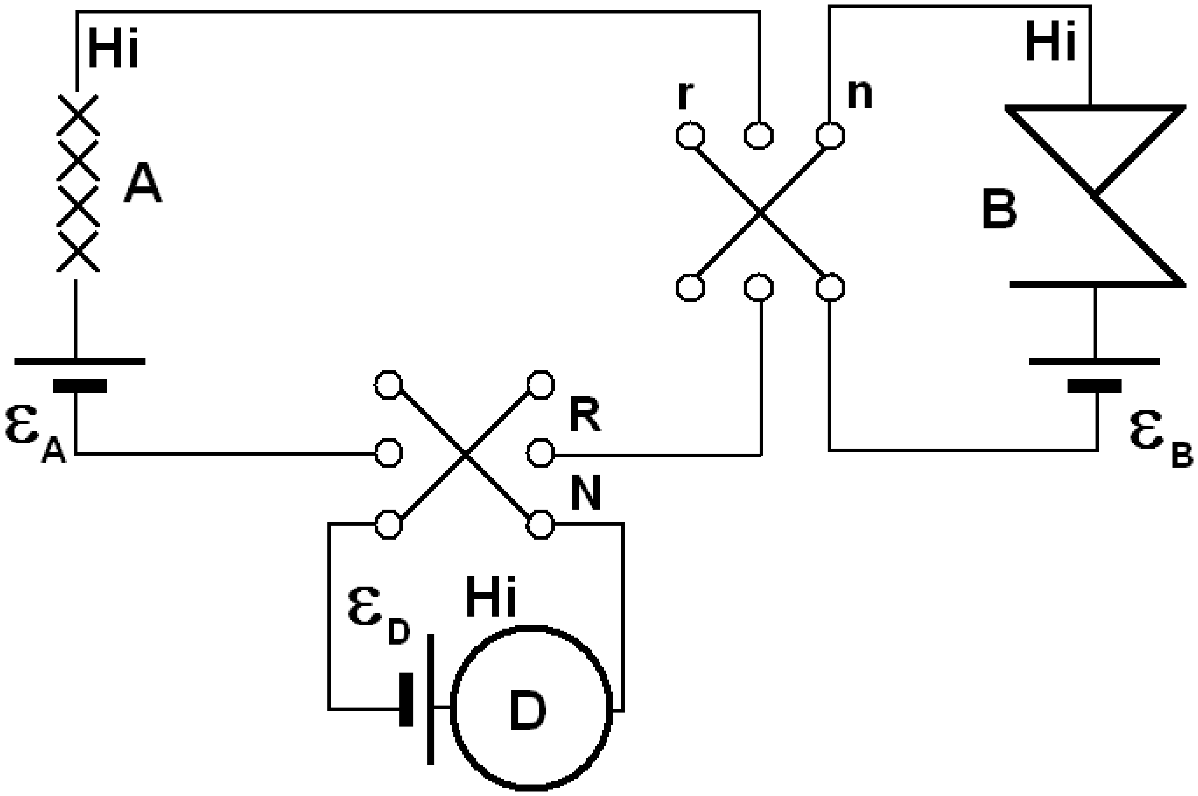

Fig. 1: Schematic of the measurement setup where the polarity reversing switches and the thermals are shown

Note that no potential reference is represented as both standards are floating from the ground during the acquisition sequence. Each "Data Acquisition" step consists of 10 preliminary points followed by 30 measurement points. Each of these should not differ from the mean of the preliminary points by more than twice their standard deviation. The "Data Acquisition" sequence lasts 25 s and is basically the time period during which the array is to stay on the selected step. The total measurement time (including polarity reversals and data acquisition) is approximately 5 minutes. This procedure is repeated three times and the mean value corresponds to one point on the graph.

B.9 Method of measurement: SCL, Hong Kong

1. System Descriptions
    - 1.1 The Josephson Array Voltage Standard (JAVS) of SCL consists of:
        - (a) Hypres 10 V Array of 20208 Nb-Al$_2$O$_3$-Nb Josephson junctions;
        - (b) Millitech Gunn-Diode with integral isolator, operating near 75 GHz;
        - (c) RMC WR12 dielectric waveguide;
        - (d) EIP 578B Source Locking Microwave Counter;
        - (e) Astro Endyne JBS500 Josephson Bias Source;
        - (f) HP 3458A digital multimeter;
        - (g) Guildline 9145A5 Low Thermal selector switch; and
        - (h) Tektronix 2225 Oscilloscope.
        - (i) Control Software: NISTVolt version 5.2.
    - 1.2 HP 5061B Cesium Beam Frequency Standard.
    - 1.3 Mensor 2103 Precision Barometric Pressure Indicator.
    - 1.4 Vaisala HM 70 Temperature/Humidity Indicator.

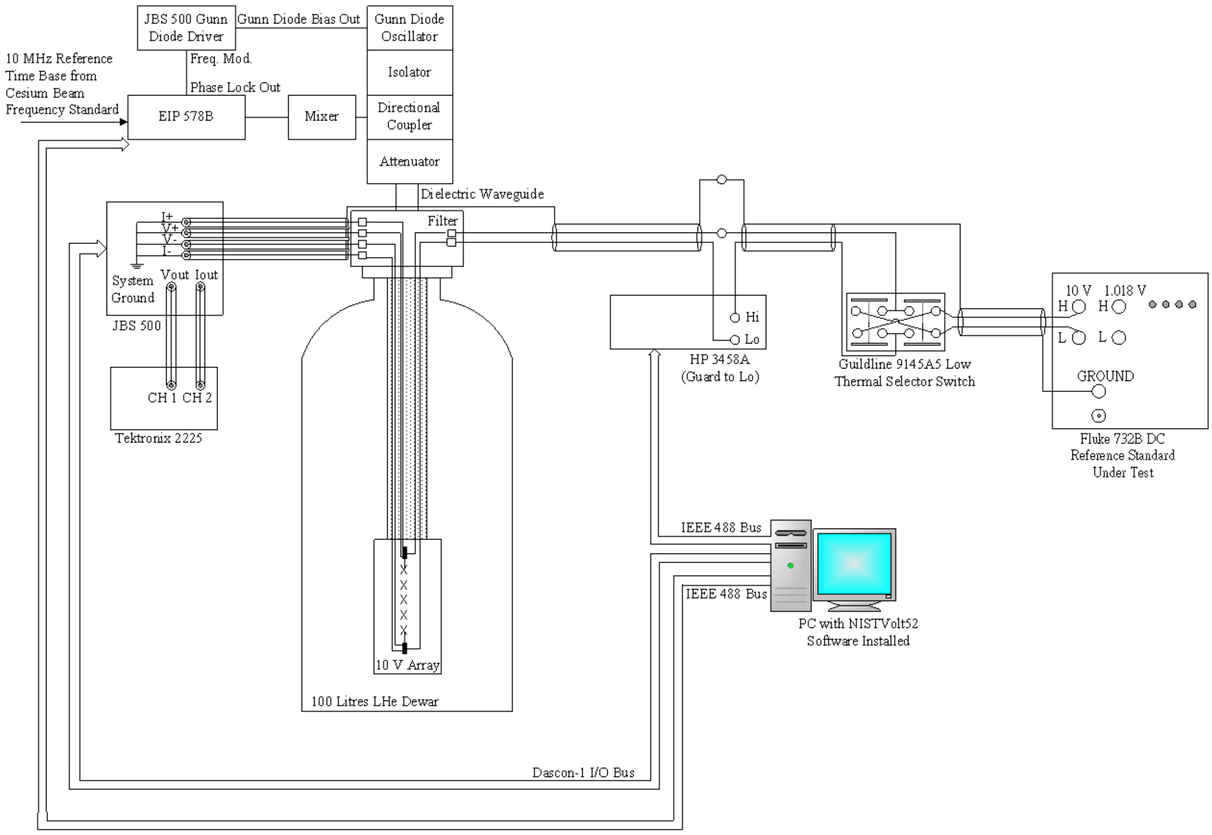

Figure 1: System Hook-up

2. Measurement Methodology

2.1 The three DC Voltage Reference Standards, Fluke 732B, were allowed to stabilize in the SCL environment from 7 to 11 August 2010 and measurements were performed from 12 August to 3 September 2010.

2.2 The three Fluke 732B were powered by an AC line power of 230 V and 50 Hz before the measurements. They were disconnected from the AC mains and powered from their internal batteries at least four hours prior to and during the measurement.

2.3 Measurements were made at ambient temperature of (23±1) °C, relative humidity of (45±8) % and 100 kPa (nominal) barometric pressure.

2.4 For each measurement, the Fluke 732B's output voltage was recorded together with other data including the time and date of measurement, the environmental temperature, relative humidity, barometric pressure and the internal thermistor resistance of the Fluke 732B.

2.5 During the measurement, the Fluke 732B's output terminals were floating from the system ground. The unit's GROUND terminal was connected to system ground, via the connection shield. Detailed connection is shown in Figure 1.

2.6 The outputs of the Fluke 732B were measured by differential method against the quantized output voltages of the Laboratory's JAVS. An HP 3458A DMM was used as a null detector for measuring the voltage difference. The microwave source of the JAVS was a Gunn diode oscillator operating at 75 GHz. The JAVS operating frequency was stabilized and monitored by an EIP 578B counter. The 10 MHz time base frequency of the counter was supplied from an HP 5061B Cesium Beam Frequency Standard. The measurement process was under computer control using the software NISTVolt 5.2.

2.7 The Josephson step number was adjusted by the NISTVolt software. The step number was selected so that the voltage difference between the array output and the Fluke 732B output was less than ±10 mV. After selected the correct step, the bias voltage was cut-off and the null voltages were recorded by the NISTVolt.

2.8 A measured value consisted of 40 measured voltage differences. A measured voltage difference was the mean of 2 DVM readings. Measurement polarities were in the pattern of "normal", "reverse", "normal", "reverse"; for elimination of the effect of the offset voltage in the system. The output voltage of the unit under test (i.e. Fluke 732B) and the offset voltage of the JAVS system were calculated based on the 40 measured values by NISTVolt 5.2 using least square method.

2.9 The output voltage of Fluke 732B was reversed using a manual operated Guildline 9145A5 low thermal switch. The array voltage was reversed by changing the polarity of the array bias voltage through the control program. The offset voltage error due to the Guildline 9145A5 switch was not corrected but treated as measurement uncertainty and included in the uncertainty budget.

2.10 The measured voltages were corrected for temperature and pressure effects in accordance with the formula stated in Section 4.3 of the Technical Protocol (ver. 9.0, Oct. 1, 2010).

2.11 The resistance of the internal thermistor was measured by an Agilent 34420A Nano volt/Micro ohm meter. Prior to the measurement, correction to meter reading(s) was determined by comparison against SCL's 10 kΩ and 100 kΩ reference standard resistors. During the measurement, the meter was configured to operate at 100 kΩ range and Low Power Mode (at which the test current applied to the thermistor has been verified to be 5 μA).

B.10 Method of measurement: KazInMetr, Kazakhstan

The system is operates in the following way: The JJ array is connected in series to a high resolution null detector and the secondary voltage standard which has to be calibrated. The null detector measures the difference voltage between the secondary voltage standard and the quantized voltage level of the JJ array chip for both polarities. The Keithley nanovoltmeter (Keithley 2182A) as null detector measures the difference voltage between the Josephson voltage standard and the secondary standard, the device under test DUT, in both polarities. With these measurements the influence of thermal voltages can be eliminated arithmetically. Twenty measurements in both polarities will be made in order to determine the difference voltage with a high accuracy. The polarity of the Josephson voltage is reversed by the polarity change of the bias current through the JJ array chip and the polarity of the DUT is reversed by the polarity reversal switch. The system uses a three channel computer-controlled polarity reversal switch, with very low thermal voltages, in order to reverse the polarity of the DUT. This reversal switch allows a simultaneous calibration of three voltages, for example 10 V, 1 V, and 1.018 V of a Fluke secondary standard. The system includes sensors for the barometric pressure and internal temperature, which are integrated in the JVS electronics unit, and for humidity and environmental temperature, which are installed in a separate small box. This box can be put on or nearby the secondary standard which should be calibrated. The data from the sensors are permanently displayed and are listed in the calibration reports. «GROUND» of the upgrade box was connected to the guard of measuring system. One point in system the guard was connected to ground.

Appendix C: Uncertainty statements

C.1 Uncertainty statement: NMIA, Australia

Zener-based Electronic Voltage Reference, Fluke Model 732B, S/N 6950001-3 (TZS-1)

Uncertainty estimate of 1.018 V output Corrected Voltage

Component	Type	Standard uncertainty (nV/V)	Degrees of Freedom
Frequency Counter Offset	B	0.10	8
Frequency Counter Resolution	B	0.00	1000
Leakage Resistances	B	3.93	2
Null Detector Gain	B	0.15	11
Uncancelled Thermals	B	13.75	4
Temperature Measurement	B	0.00	2
Temperature Coefficient	B	0.00	72
Pressure Measurement	B	0.00	2
Pressure Coefficient	B	0.00	72
Variation of Voltage Difference Measurements	A	33.87	72
Rounding of Reported Value	B	0.29	1000
Combined standard uncertainty		36.8	nV/V
Effective degrees of Freedom		67	
Coverage factor (95% Level of Confidence)		1.996	
Expanded uncertainty		74.7	nV

The combined Type B uncertainty at 1.018 V was 14.6 nV.

Uncertainty estimate of 10 V output Corrected Voltage

Component	Type	Standard uncertainty (nV/V)	Degrees of Freedom
Frequency Counter Offset	B	0.10	8
Frequency Counter Resolution	B	0.00	1000
Leakage Resistances	B	0.40	2
Null Detector Gain	B	0.02	11
Uncancelled Thermals	B	1.40	4
Temperature Measurement	B	0.07	2
Temperature Coefficient	B	18.81	73
Pressure Measurement	B	0.04	2
Pressure Coefficient	B	0.81	73
Variation of Voltage Difference Measurements	A	25.22	73
Rounding of Reported Value	B	0.29	1000
Combined standard uncertainty		31.5	nV/V
Effective degrees of Freedom		136	
Coverage factor (95% Level of Confidence)		1.978	
Expanded uncertainty		623	nV

The combined Type B uncertainty at 10 V was 189 nV.

Zener-based Electronic Voltage Reference, Fluke Model 732B, S/N 6950002 (TZS-2)

Uncertainty estimate of 1.018 V output Corrected Voltage

Component	Type	Standard uncertainty (nV/V)	Degrees of Freedom
Frequency Counter Offset	B	0.10	8
Frequency Counter Resolution	B	0.00	1000
Leakage Resistances	B	3.93	2
Null Detector Gain	B	0.15	11
Uncancelled Thermals	B	13.75	4
Temperature Measurement	B	0.05	2
Temperature Coefficient	B	3.03	73
Pressure Measurement	B	0.00	2
Pressure Coefficient	B	0.00	73
Variation of Voltage Difference Measurements	A	23.50	73
Rounding of Reported Value	B	0.29	1000
Combined standard uncertainty		27.7	nV/V
Effective degrees of Freedom		44	
Coverage factor (95% Level of Confidence)		2.015	
Expanded uncertainty		56.8	nV

The combined Type B uncertainty at 1.018 V was 14.9 nV.

Uncertainty estimate of 10 V output Corrected Voltage

Component	Type	Standard uncertainty (nV/V)	Degrees of Freedom
Frequency Counter Offset	B	0.10	8
Frequency Counter Resolution	B	0.00	1000
Leakage Resistances	B	0.40	2
Null Detector Gain	B	0.02	11
Uncancelled Thermals	B	1.40	4
Temperature Measurement	B	0.01	2
Temperature Coefficient	B	0.62	71
Pressure Measurement	B	0.03	2
Pressure Coefficient	B	0.57	71
Variation of Voltage Difference Measurements	A	15.55	71
Rounding of Reported Value	B	0.29	1000
Combined standard uncertainty		15.6	nV/V
Effective degrees of Freedom		73	
Coverage factor (95% Level of Confidence)		1.993	
Expanded uncertainty		312	nV

The combined Type B uncertainty at 10 V was 17 nV.

Zener-based Electronic Voltage Reference, Fluke Model 732B, S/N 6950004 (TZS-3)

Uncertainty estimate of 1.018 V output Corrected Voltage

Component	Type	Standard uncertainty (nV/V)	Degrees of Freedom
Frequency Counter Offset	B	0.10	8
Frequency Counter Resolution	B	0.00	1000
Leakage Resistances	B	3.93	2
Null Detector Gain	B	0.15	11
Uncancelled Thermals	B	13.75	4
Temperature Measurement	B	0.05	2
Temperature Coefficient	B	13.51	73
Pressure Measurement	B	0.10	2
Pressure Coefficient	B	2.26	73
Variation of Voltage Difference Measurements	A	41.49	73
Rounding of Reported Value	B	0.29	1000
Combined standard uncertainty		46.0	nV/V
Effective degrees of Freedom		89	
Coverage factor (95% Level of Confidence)		1.987	
Expanded uncertainty		93.0	nV

The combined Type B uncertainty at 1.018 V was 20.2 nV.

Uncertainty estimate of 10 V output Corrected Voltage

Component	Type	Standard uncertainty (nV/V)	Degrees of Freedom
Frequency Counter Offset	B	0.10	8
Frequency Counter Resolution	B	0.00	1000
Leakage Resistances	B	0.40	2
Null Detector Gain	B	0.02	11
Uncancelled Thermals	B	1.40	4
Temperature Measurement	B	0.01	2
Temperature Coefficient	B	1.38	73
Pressure Measurement	B	0.06	2
Pressure Coefficient	B	1.27	73
Variation of Voltage Difference Measurements	A	31.70	73
Rounding of Reported Value	B	0.29	1000
Combined standard uncertainty		31.8	nV/V
Effective degrees of Freedom		74	
Coverage factor (95% Level of Confidence)		1.993	
Expanded uncertainty		633	nV

The combined Type B uncertainty at 10 V was 24 nV.

*C.2 Uncertainty statement: NMC-A*STAR, Singapore*

TZS-1 1.018 V

Component	Type	Uncertainty Value	Distribution	Coverage Factor	Standard Uncertainty	Sensitive Coefficient	Uncertainty Contribution (nV)	Degree of Freedom
1. Zero offset	A	20.0 nV	normal	1	20.0 nV	1	20.0	50
2. Leakage	B	0.04 nV	rectangular	1.732	0.02 nV	1	0.02	99
3. Frequency	B	0.2 nV	rectangular	1.732	0.1 nV	1	0.1	99
4. Detector gain error	B	0.5 nV	rectangular	1.732	0.3 nV	1	0.3	99
5. Thermistor resistance	B	2.8 Ω	rectangular	1.732	1.6 Ω	0.3 nV/Ω	0.5	99
6. Thermistor coefficient	B	0.0 nV/Ω	normal	1	0.0 nV/Ω	54.9 Ω	0.0	99
7. Ambient pressure	B	0.13 hPa	t-distribution	2.0	0.07 hPa	2.0 nV/hPa	0.1	99
8. Pressure coefficient	B	0.0 nV/hPa	normal	1	0.0 nV/hPa	7.43 hPa	0.0	99
9. SDM of daily means	A	7.0 nV	normal	1	7.0 nV	1	7.0	20
JAVS system contribution, Us, (RSS of Component 1 - 4)							20	50
Zener contribution, Uz, (RSS of Component 5 - 9)							8	20
Combined standard uncertainty (RSS of U_S and U_Z)							22	61
Type-A standard uncertainty, U_A, (Component 9)							7	20
Type-B standard uncertainty, U_B, (RSS of Component 1 - 8)							20	50
Combined standard uncertainty (RSS of U_A and U_B)							22	61
Expanded Uncertainty (nV) (*k* = 2.04)							**44**	

TZS-1 10 V

Component	Type	Uncertainty Value	Distribution	Coverage Factor	Standard Uncertainty	Sensitive Coefficient	Uncertainty Contribution (nV)	Degree of Freedom
1. Zero offset	A	20.0 nV	normal	1	20.0 nV	1	20.0	50
2. Leakage	B	0.4 nV	rectangular	1.732	0.2 nV	1	0.2	99
3. Frequency	B	2.0 nV	rectangular	1.732	1.2 nV	1	1.2	99
4. Detector gain error	B	2.0 nV	rectangular	1.732	1.2 nV	1	1.2	99
5. Thermistor resistance	B	2.8 Ω	rectangular	1.732	1.6 Ω	4.3 nV/Ω	6.9	99
6. Thermistor coefficient	B	1.3 nV/Ω	normal	1	1.3 nV/Ω	65.8 Ω	85.5	99
7. Ambient pressure	B	0.13 hPa	t-distribution	2.0	0.07 hPa	17.8 nV/hPa	1.2	99
8. Pressure coefficient	B	0.7 nV/hPa	normal	1	0.7 nV/hPa	6.37 hPa	4.5	99
9. SDM of daily means	A	60.3 nV	normal	1	60.3 nV	1	60.3	20
JAVS system contribution, Us, (RSS of Component 1 - 4)							21	51
Zener contribution, Uz, (RSS of Component 5 - 9)							105	101
Combined standard uncertainty (RSS of U_S and U_Z)							107	108

Type-A standard uncertainty, U_A, (Component 9)	61	20
Type-B standard uncertainty, U_B, (RSS of Component 1 - 8)	89	112
Combined standard uncertainty (RSS of U_A and U_B)	107	108
Expanded Uncertainty (nV) (*k* = 2.02)	**217**	

Remarks:

1. Zero offset uncertainty is the combined effect of the null meter bias current, input impedance, non linearity and noise, of the uncorrected thermal voltages in the measurement loop, of the rectification of the reference frequency, and of the effect of electromagnetic interference. Zero offset uncertainty does not depend on the magnitude of the voltage measured, and it was rigorously evaluated from a set of short circuit measurements.
2. SDM = standard deviation of the mean; RSS = square root of the sum of square.
3. Thermistor coefficient uncertainty dominated both 1.018 V and 10 V in the initial estimation due to large uncertainty of the coefficients. The estimations in the tables were based on revised coefficient uncertainty values.

TZS-2 1.018 V

Component	Type	Uncertainty Value	Distribution	Coverage Factor	Standard Uncertainty	Sensitive Coefficient	Uncertainty Contribution (nV)	Degree of Freedom
1. Zero offset	A	20.0 nV	normal	1	20.0 nV	1	20.0	50
2. Leakage	B	0.04 nV	rectangular	1.732	0.02 nV	1	0.02	99
3. Frequency	B	0.2 nV	rectangular	1.732	0.1 nV	1	0.1	99
4. Detector gain error	B	0.5 nV	rectangular	1.732	0.3 nV	1	0.3	99
5. Thermistor resistance	B	2.7 Ω	rectangular	1.732	1.6 Ω	0.2 nV/Ω	0.3	99
6. Thermistor coefficient	B	0.1 nV/Ω	normal	1	0.1 nV/Ω	83.5 Ω	8.4	99
7. Ambient pressure	B	0.13 hPa	t-distribution	2.0	0.07 hPa	1.4 nV/hPa	0.1	99
8. Pressure coefficient	B	0.0 nV/hPa	normal	1	0.0 nV/hPa	7.56 hPa	0.0	99
9. SDM of daily means	A	5.4 nV	normal	1	5.4 nV	1	5.4	20
JAVS system contribution, Us, (RSS of Component 1 - 4)							20	50
Zener contribution, Uz, (RSS of Component 5 - 9)							10	107
Combined standard uncertainty (RSS of U_S and U_Z)							23	76
Type-A standard uncertainty, U_A, (Component 9)							6	20
Type-B standard uncertainty, U_B, (RSS of Component 1 - 8)							37	68
Combined standard uncertainty (RSS of U_A and U_B)							37	76
Expanded Uncertainty (nV) (*k* = 2.02)							**46**	

TZS-2 10 V

Component	Type	Uncertainty Value	Distribution	Coverage Factor	Standard Uncertainty	Sensitive Coefficient	Uncertainty Contribution (nV)	Degree of Freedom
1. Zero offset	A	20.0 nV	normal	1	20.0 nV	1	20.0	50
2. Leakage	B	0.4 nV	rectangular	1.732	0.2 nV	1	0.2	99
3. Frequency	B	2.0 nV	rectangular	1.732	1.2 nV	1	1.2	99
4. Detector gain error	B	2.0 nV	rectangular	1.732	1.2 nV	1	1.2	99
5. Thermistor resistance	B	2.7 Ω	rectangular	1.732	1.6 Ω	1.9 nV/Ω	3.0	99

6. Thermistor coefficient	B	0.2 nV/Ω	normal	1	0.2 nV/Ω	72.7 Ω	14.5	99
7. Ambient pressure	B	0.13 hPa	t-distribution	2.0	0.07 hPa	16.5 nV/hPa	1.1	99
8. Pressure coefficient	B	0.5 nV/hPa	normal	1	0.5 nV/hPa	6.51 hPa	3.3	99
9. SDM of daily means	A	53.7 nV	normal	1	53.7 nV	1	53.7	20
JAVS system contribution, Us, (RSS of Component 1 - 4)							21	51
Zener contribution, Uz, (RSS of Component 5 - 9)							56	23
Combined standard uncertainty (RSS of U_S and U_Z)							60	30
Type-A standard uncertainty, U_A, (Component 9)							54	20
Type-B standard uncertainty, U_B, (RSS of Component 1 - 8)							26	110
Combined standard uncertainty (RSS of U_A and U_B)							60	30
Expanded Uncertainty (nV) (*k* = 2.09)							**124**	

TZS-3 1.018 V

Component	Type	Uncertainty Value	Distribution	Coverage Factor	Standard Uncertainty	Sensitive Coefficient	Uncertainty Contribution (nV)	Degree of Freedom
1. Zero offset	A	20.0 nV	normal	1	20.0 nV	1	20.0	50
2. Leakage	B	0.04 nV	rectangular	1.732	0.02 nV	1	0.02	99
3. Frequency	B	0.2 nV	rectangular	1.732	0.1 nV	1	0.1	99
4. Detector gain error	B	0.5 nV	rectangular	1.732	0.3 nV	1	0.3	99
5. Thermistor resistance	B	2.8 Ω	rectangular	1.732	1.6 Ω	0.2 nV/Ω	0.3	99
6. Thermistor coefficient	B	0.1 nV/Ω	normal	1	0.1 nV/Ω	2.0 Ω	0.2	99
7. Ambient pressure	B	0.13 hPa	t-distribution	2.0	0.07 hPa	2.1 nV/hPa	0.1	99
8. Pressure coefficient	B	0.2 nV/hPa	normal	1	0.2 nV/hPa	7.77 hPa	1.6	99
9. SDM of daily means	A	8.9 nV	normal	1	8.9 nV	1	8.9	20
JAVS system contribution, Us, (RSS of Component 1 - 4)							20	50
Zener contribution, Uz, (RSS of Component 5 - 9)							9	21
Combined standard uncertainty (RSS of U_S and U_Z)							22	66
Type-A standard uncertainty, U_A, (Component 9)							9	20
Type-B standard uncertainty, U_B, (RSS of Component 1 - 8)							21	51
Combined standard uncertainty (RSS of U_A and U_B)							22	66
Expanded Uncertainty (nV) (*k* = 2.04)							**45**	

TZS-3 10 V

Component	Type	Uncertainty Value	Distribution	Coverage Factor	Standard Uncertainty	Sensitive Coefficient	Uncertainty Contribution (nV)	Degree of Freedom
1. Zero offset	A	20.0 nV	normal	1	20.0 nV	1	20.0	50
2. Leakage	B	0.4 nV	rectangular	1.732	0.2 nV	1	0.2	99
3. Frequency	B	2.0 nV	rectangular	1.732	1.2 nV	1	1.2	99

4. Detector gain error	B	2.0 nV	rectangular	1.732	1.2 nV	1	1.2	99
5. Thermistor resistance	B	2.8 Ω	rectangular	1.732	1.6 Ω	1.3 nV/Ω	2.1	99
6. Thermistor coefficient	B	0.1 nV/Ω	normal	1	0.1 nV/Ω	15.5 Ω	1.5	99
7. Ambient pressure	B	0.13 hPa	t-distribution	2.0	0.07 hPa	21.3 nV/hPa	1.4	99
8. Pressure coefficient	B	1.1 nV/hPa	normal	1	1.1 nV/hPa	6.45 hPa	7.1	99
9. SDM of daily means	A	67.4 nV	normal	1	67.4 nV	1	67.4	20
JAVS system contribution, Us, (RSS of Component 1 - 4)							21	51
Zener contribution, Uz, (RSS of Component 5 - 9)							68	21
Combined standard uncertainty (RSS of U_S and U_Z)							71	24
Type-A standard uncertainty, U_A, (Component 9)							68	20
Type-B standard uncertainty, U_B, (RSS of Component 1 - 8)							22	66
Combined standard uncertainty (RSS of U_A and U_B)							71	24
Expanded Uncertainty (nV) (*k* = 2.11)							**150**	

C.3 Uncertainty statement: KRISS, Korea (Rep. of)

The type B uncertainty of KRISS measurement system, excluding the temperature and pressure correction uncertainty :

Uncertainty Budget: 10 V Zener						
No.	Component	Distribution	c_i	$u(x_i)$nV	$\|c_i.u(x_i)\|$nV	ν_i
1	Microwave freq. (1 Hz/75 GHz)		1	0.13	0.13	500
2	Probe leakage (DWG), (0.3 Ω/10 GΩ @ 0.5 min)		1	0.3	0.30	50
3	Circuit leakage (1 k Ω/1 T Ω for 1.018 V Zener, 40 Ω/1 T Ω for 10 V Zener)		1	0.4	0.40	50
4	Thermals (incl. Reverse sw. Repeatability, Circuits)	appr. norma	1	1.93	1.93	32
5	Digital nanovoltmeter (0.5 mV reading w/Keithley 2182)	appr normal	1	2.02	2.02	50
	RSS Type B, u_B				2.84	84.93
Uncertainty Budget: 1.018 V KRISS Zener						
No.	Component	Distribution	c_i	$u(x_i)$nV	$\|c_i.u(x_i)\|$nV	ν_i
1	Microwave freq. (1 Hz/75 GHz)		1	0.013	0.01	500
2	Probe leakage (DWG), (0.3 Ω/10 GΩ @ 0.5 min)		1	0.03	0.03	50
3	Circuit leakage (1 k Ω/1 T Ω for 1.018 V Zener, 40 Ω/1 T Ω for 10 V Zener)		1	1	1.00	50
4	Thermals (incl. Reverse sw. Repeatability, Circuits)	appr. norma	1	1.93	1.93	32
5	Digital nanovoltmeter (0.5 mV reading w/Keithley 2182)	appr normal	1	2.02	2.02	50
	RSS Type B, u_B				2.97	98.59

C.4 Uncertainty statement: NML-SIRIM, Malaysia

The type B uncertainty of SIRIM JVS was declared as 29.86 nV (*k*=1) for both 10 V and 1.018 V as can be found in Appendix D.4.

Notes:

1. The Microwave frequency was synchronized to local atomic clock.
2. Cryoprobe performance is assumed to comply with manufacturer's specifications.
3. Detector resolution is determined by DMM digit (8½)

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C.5 Uncertainty statement: CMS-ITRI, Chinese TAIPEI

The type B uncertainty of travelling standard calibration was declared as 121 nV ~ 135 nV for 10 V and 41 nV for 1.018 V while the type B uncertainty associated with temperature and pressure correction to the reference condition was 15 nV to 62 nV. By assuming that total type B uncertainty consists of the correction component and measurement system component, the standard uncertainty of the measurement system was estimated to be 120 nV for 10 V and 40 nV for 1.018 V (k=1) by the pilot.

C.6 Uncertainty statement: NMIJ/AIST, Japan

Uncertainty budget (**1.018 V** / **TZS-1** / NMIJ / K11.3.a / May 27, 2010)

Quantity	Estimate	Uncertainty	Type	Probability distribution	Standard uncertainty	Sensitivity coefficient	Uncertainty contribution	Degree of freedom
Measured mean voltage	1.018 104 251 9 V	8.1 nV	A	normal	8.1 nV	1	8.1 nV	4
Frequency	76 GHz	12 Hz	B	normal	12 Hz	3 pV/Hz	0.04 nV	∞
Leakage voltage	0 nV*	0.01 nV	B	rectangular	0.006 nV	1	0.006 nV	∞
Voltage at null detector	250 nV**	5.1 nV	B	rectangular	2.9 nV	1	2.9 nV	∞
Correction for temperature effect	-0.0 nV	0.0 nV	B	rectangular	0.0 nV	1	0.0 nV	∞
Correction for pressure effect	+24.9 nV	0.0 nV	B	rectangular	0.0 nV	1	0.0 nV	∞
Corrected voltage at R0 and p0	1.018 104 276 7 V	-	-	-	-	-	8.6 nV	5
	* no correction to the measured mean voltage is applied, as the path for the leakage is unknown.							
	** typical voltage at the null detector, that is already part of the mean measured voltage.							
	Series resistance of leads/filters:		10 Ω					
	Leakage resistance:		$>10^{12}$ Ω					
	Null detector and settings:		Advantest R6561, 1 mV range, 1 s gate time, 10 samples, auto zero ON, LO terminal to the earth, analog lowpass filter with f_c = 1 kHz					
	Measurement sequence:		+/-/-/+ sequence using automatic mechanical switch; 10 readings of null detector in each polarity, bias off during measurement, null voltage <250 nV (1.018 V) or <500 nV (10 V)					
	Typical time for sequence:		4 min					
	Thermistor resistance:		R = 39.667 kΩ, R0 = 39.65 kΩ, α = 0.3 ± 0.0 nV/Ω					
	Ambient pressure:		p = 1000.82 hPa, p0 = 1013.25 hPa, α = 2.0 ± 0.0 nV/hPa					

Uncertainty budget (**1.018 V** / **TZS-2** / NMIJ / K11.3.a / May 27, 2010)

Quantity	**Estimate**	**Uncertainty**	**Type**	**Probability distribution**	**Standard uncertainty**	**Sensitivity coefficient**	**Uncertainty contribution**	**Degree of freedom**
Measured mean voltage	1.018 146 548 4 V	2.4 nV	A	normal	2.4 nV	1	2.4 nV	4
Frequency	76 GHz	12 Hz	B	normal	12 Hz	3 pV/Hz	0.04 nV	∞
Leakage voltage	0 nV*	0.01 nV	B	rectangular	0.006 nV	1	0.006 nV	∞
Voltage at null detector	250 nV**	5.1 nV	B	rectangular	2.9 nV	1	2.9 nV	∞
Correction for temperature effect	+0.0 nV	20.6 nV	B	rectangular	11.9 nV	1	11.9 nV	∞
Correction for pressure effect	+17.6 nV	0.0 nV	B	rectangular	0.0 nV	1	0.0 nV	∞
Corrected voltage at R0 and p0	1.018 146 566 0 V	-	-	-	-	-	12.5 nV	2878

* no correction to the measured mean voltage is applied, as the path for the leakage is unknown.

** typical voltage at the null detector, that is already part of the mean measured voltage.

Series resistance of leads/filters:	10 Ω
Leakage resistance:	>10^{12} Ω
Null detector and settings:	Advantest R6561, 1 mV range, 1 s gate time, 10 samples, auto zero ON, LO terminal to the earth, analog lowpass filter with f_c = 1 kHz
Measurement sequence:	+/-/-/+ sequence using automatic mechanical switch; 10 readings of null detector in each polarity, bias off during measurement, null voltage <250 nV (1.018 V) or <500 nV (10 V)
Typical time for sequence:	4 min
Thermistor resistance:	R = 38.921 kΩ, R0 = 39.04 kΩ, α = 0.2 ± 0.1 nV/Ω
Ambient pressure:	p = 1000.66 hPa, p0 = 1013.25 hPa, α = 1.4 ± 0.0 nV/hPa

Uncertainty budget (**1.018 V** / **TZS-3** / NMIJ / K11.3.a / May 27, 2010)

Quantity	**Estimate**	**Uncertainty**	**Type**	**Probability distribution**	**Standard uncertainty**	**Sensitivity coefficient**	**Uncertainty contribution**	**Degree of freedom**
Measured mean voltage	1.018 114 469 5 V	5.0 nV	A	normal	5.0 nV	1	5.0 nV	4
Frequency	76 GHz	12 Hz	B	normal	12 Hz	3 pV/Hz	0.04 nV	∞
Leakage voltage	0 nV*	0.01 nV	B	rectangular	0.006 nV	1	0.006 nV	∞
Voltage at null detector	250 nV**	5.1 nV	B	rectangular	2.9 nV	1	2.9 nV	∞
Correction for temperature effect	+0.0 nV	12.1 nV	B	rectangular	7.0 nV	1	7.0 nV	∞
Correction for pressure effect	+26.4 nV	4.3 nV	B	rectangular	2.5 nV	1	2.5 nV	∞
Corrected voltage at R0 and p0	1.018 114 495 9 V	-	-	-	-	-	9.4 nV	51

* no correction to the measured mean voltage is applied, as the path for the leakage is unknown.

** typical voltage at the null detector, that is already part of the mean measured voltage.

Series resistance of leads/filters:	10 Ω
Leakage resistance:	>10^{12} Ω
Null detector and settings:	Advantest R6561, 1 mV range, 1 s gate time, 10 samples, auto zero ON, LO terminal to the earth, analog lowpass filter with f_c = 1 kHz
Measurement sequence:	+/-/-/+ sequence using automatic mechanical switch; 10 readings of null detector in each polarity, bias off during measurement, null voltage <250 nV (1.018 V) or <500 nV (10 V)
Typical time for sequence:	4 min
Thermistor resistance:	R = 39.340 kΩ, R0 = 39.41 kΩ, α = 0.2 ± 0.1 nV/Ω
Ambient pressure:	p = 1000.69 hPa, p0 = 1013.25 hPa, α = 2.1 ± 0.2 nV/hPa

Uncertainty budget (**10 V / TZS-1** / NMIJ / K11.3.a / May 27, 2010)

Quantity	Estimate	Uncertainty	Type	Probability distribution	Standard uncertainty	Sensitivity coefficient	Uncertainty contribution	Degree of freedom
Measured mean voltage	9.999 942 706 9 V	18.7 nV	A	normal	18.7 nV	1	18.7 nV	4
Frequency	76 GHz	12 Hz	B	normal	12 Hz	30 pV/Hz	0.4 nV	∞
Leakage voltage	0 nV*	0.1 nV	B	rectangular	0.06 nV	1	0.06 nV	∞
Voltage at null detector	250 nV**	5.1 nV	B	rectangular	2.9 nV	1	2.9 nV	∞
Correction for temperature effect	-0.2 nV	101.3 nV	B	rectangular	58.5 nV	1	58.5 nV	∞
Correction for pressure effect	+196.9 nV	13.3 nV	B	rectangular	7.7 nV	1	7.7 nV	∞
Corrected voltage at R0 and p0	9.999 942 903 6 V	-	-	-	-	-	62.0 nV	486

* no correction to the measured mean voltage is applied, as the path for the leakage is unknown.

** typical voltage at the null detector, that is already part of the mean measured voltage.

Series resistance of leads/filters: 10 Ω

Leakage resistance: $>10^{12}$ Ω

Null detector and settings: Advantest R6561, 1 mV range, 1 s gate time, 10 samples, auto zero ON, LO terminal to the earth, analog lowpass filter with f_c = 1 kHz

Measurement sequence: +/-/-/+ sequence using automatic mechanical switch; 10 readings of null detector in each polarity, bias off during measurement, null voltage <250 nV (1.018 V) or <500 nV (10 V)

Typical time for sequence: 4 min

Thermistor resistance: R = 39.695 kΩ, R0 = 39.65 kΩ, α = 4.3 ± 1.3 nV/Ω

Ambient pressure: p = 1002.19 hPa, p0 = 1013.25 hPa, α = 17.8 ± 0.7 nV/hPa

Uncertainty budget (**10 V / TZS-2** / NMIJ / K11.3.a / May 27, 2010)

Quantity	Estimate	Uncertainty	Type	Probability distribution	Standard uncertainty	Sensitivity coefficient	Uncertainty contribution	Degree of freedom
Measured mean voltage	9.999 998 078 3 V	28.3 nV	A	normal	28.3 nV	1	28.3 nV	4
Frequency	76 GHz	12 Hz	B	normal	12 Hz	30 pV/Hz	0.4 nV	∞
Leakage voltage	0 nV*	0.1 nV	B	rectangular	0.06 nV	1	0.06 nV	∞
Voltage at null detector	250 nV**	5.1 nV	B	rectangular	2.9 nV	1	2.9 nV	∞
Correction for temperature effect	+0.2 nV	37.4 nV	B	rectangular	21.6 nV	1	21.6 nV	∞
Correction for pressure effect	+197.2 nV	10.4 nV	B	rectangular	6.0 nV	1	6.0 nV	∞
Corrected voltage at R0 and p0	9.999 998 275 7 V	-	-	-	-	-	36.2 nV	11

* no correction to the measured mean voltage is applied, as the path for the leakage is unknown.

** typical voltage at the null detector, that is already part of the mean measured voltage.

Series resistance of leads/filters: 10 Ω

Leakage resistance: $>10^{12}$ Ω

Null detector and settings: Advantest R6561, 1 mV range, 1 s gate time, 10 samples, auto zero ON, LO terminal to the earth, analog lowpass filter with f_c = 1 kHz

Measurement sequence: +/-/-/+ sequence using automatic mechanical switch; 10 readings of null detector in each polarity, bias off during measurement, null voltage <250 nV (1.018 V) or <500 nV (10 V)

Typical time for sequence: 4 min

Thermistor resistance: R = 38.932 kΩ, R0 = 39.04 kΩ, α = 1.9 ± 0.2 nV/Ω

Ambient pressure: p = 1001.30 hPa, p0 = 1013.25 hPa, α = 16.5 ± 0.5 nV/hPa

Uncertainty budget (**10 V / TZS-3** / NMIJ / K11.3.a / May 27, 2010)

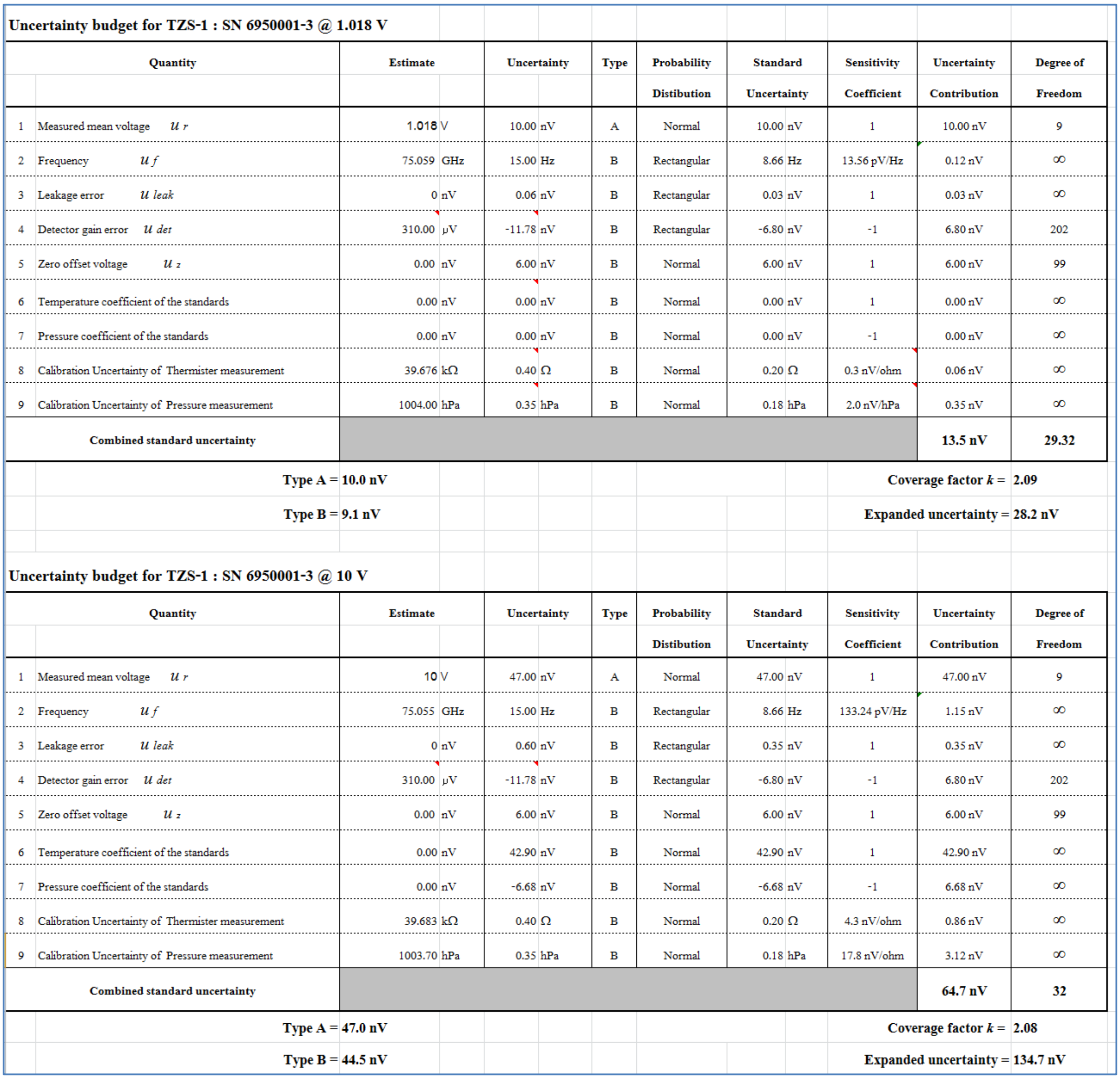
Quantity	**Estimate**	**Uncertainty**	**Type**	**Probability distribution**	**Standard uncertainty**	**Sensitivity coefficient**	**Uncertainty contribution**	**Degree of freedom**
Measured mean voltage	9.999 956 713 4 V	50.2 nV	A	normal	50.2 nV	1	50.2 nV	4
Frequency	76 GHz	12 Hz	B	normal	12 Hz	30 pV/Hz	0.4 nV	∞
Leakage voltage	0 nV*	0.1 nV	B	rectangular	0.06 nV	1	0.06 nV	∞
Voltage at null detector	250 nV**	5.1 nV	B	rectangular	2.9 nV	1	2.9 nV	∞
Correction for temperature effect	+0.1 nV	6.9 nV	B	rectangular	4.0 nV	1	4.0 nV	∞
Correction for pressure effect	+248.4 nV	22.2 nV	B	rectangular	12.8 nV	1	12.8 nV	∞
Corrected voltage at R0 and p0	9.999 956 961 8 V	-	-	-	-	-	52.0 nV	5

* no correction to the measured mean voltage is applied, as the path for the leakage is unknown.

** typical voltage at the null detector, that is already part of the mean measured voltage.

Series resistance of leads/filters:	10 Ω
Leakage resistance:	$>10^{12}$ Ω
Null detector and settings:	Advantest R6561, 1 mV range, 1 s gate time, 10 samples, auto zero ON, LO terminal to the earth, analog lowpass filter with f_c = 1 kHz
Measurement sequence:	+/-/-/+ sequence using automatic mechanical switch; 10 readings of null detector in each polarity, bias off during measurement, null voltage <250 nV (1.018 V) or <500 nV (10 V)
Typical time for sequence:	4 min
Thermistor resistance:	R = 39.370 kΩ, R0 = 39.41 kΩ, α = 1.3 ± 0.1 nV/Ω
Ambient pressure:	p = 1001.59 hPa, p0 = 1013.25 hPa, α = 21.3 ± 1.1 nV/hPa

C.7 Uncertainty statement: NIMT, Thailand



Uncertainty budget for TZS-1 : SN 6950001-3 @ 1.018 V

	Quantity		Estimate	Uncertainty	Type	Probability Distibution	Standard Uncertainty	Sensitivity Coefficient	Uncertainty Contribution	Degree of Freedom
1	Measured mean voltage	u_r	1.018 V	10.00 nV	A	Normal	10.00 nV	1	10.00 nV	9
2	Frequency	u_f	75.059 GHz	15.00 Hz	B	Rectangular	8.66 Hz	13.56 pV/Hz	0.12 nV	∞
3	Leakage error	u_{leak}	0 nV	0.06 nV	B	Rectangular	0.03 nV	1	0.03 nV	∞
4	Detector gain error	u_{det}	310.00 μV	-11.78 nV	B	Rectangular	-6.80 nV	-1	6.80 nV	202
5	Zero offset voltage	u_z	0.00 nV	6.00 nV	B	Normal	6.00 nV	1	6.00 nV	99
6	Temperature coefficient of the standards		0.00 nV	0.00 nV	B	Normal	0.00 nV	1	0.00 nV	∞
7	Pressure coefficient of the standards		0.00 nV	0.00 nV	B	Normal	0.00 nV	-1	0.00 nV	∞
8	Calibration Uncertainty of Thermister measurement		39.676 kΩ	0.40 Ω	B	Normal	0.20 Ω	0.3 nV/ohm	0.06 nV	∞
9	Calibration Uncertainty of Pressure measurement		1004.00 hPa	0.35 hPa	B	Normal	0.18 hPa	2.0 nV/hPa	0.35 nV	∞
	Combined standard uncertainty								**13.5 nV**	**29.32**

Type A = 10.0 nV **Coverage factor *k* = 2.09**

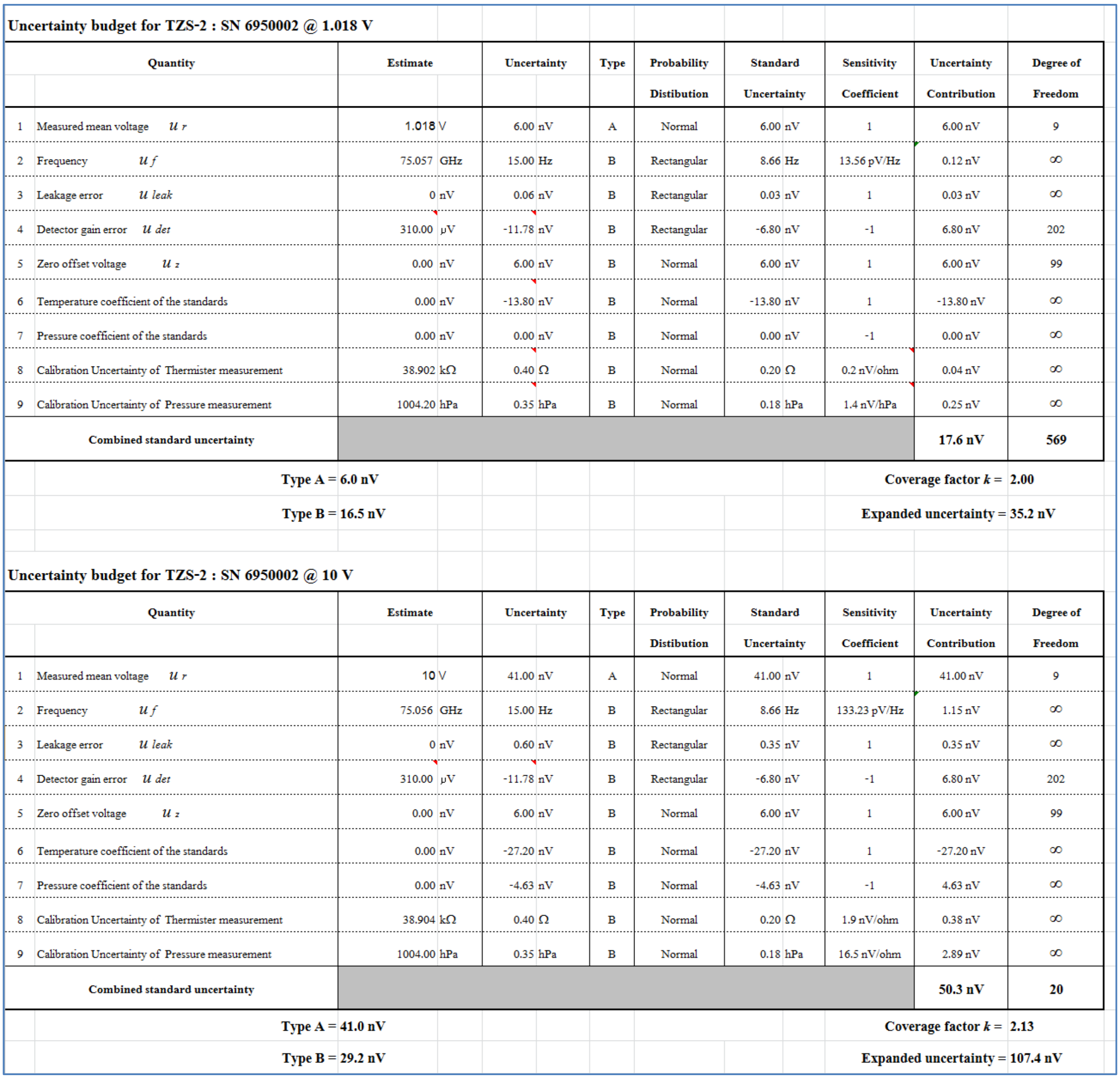
Type B = 9.1 nV **Expanded uncertainty = 28.2 nV**

Uncertainty budget for TZS-1 : SN 6950001-3 @ 10 V

	Quantity		Estimate	Uncertainty	Type	Probability Distibution	Standard Uncertainty	Sensitivity Coefficient	Uncertainty Contribution	Degree of Freedom
1	Measured mean voltage	u_r	10 V	47.00 nV	A	Normal	47.00 nV	1	47.00 nV	9
2	Frequency	u_f	75.055 GHz	15.00 Hz	B	Rectangular	8.66 Hz	133.24 pV/Hz	1.15 nV	∞
3	Leakage error	u_{leak}	0 nV	0.60 nV	B	Rectangular	0.35 nV	1	0.35 nV	∞
4	Detector gain error	u_{det}	310.00 μV	-11.78 nV	B	Rectangular	-6.80 nV	-1	6.80 nV	202
5	Zero offset voltage	u_z	0.00 nV	6.00 nV	B	Normal	6.00 nV	1	6.00 nV	99
6	Temperature coefficient of the standards		0.00 nV	42.90 nV	B	Normal	42.90 nV	1	42.90 nV	∞
7	Pressure coefficient of the standards		0.00 nV	-6.68 nV	B	Normal	-6.68 nV	-1	6.68 nV	∞
8	Calibration Uncertainty of Thermister measurement		39.683 kΩ	0.40 Ω	B	Normal	0.20 Ω	4.3 nV/ohm	0.86 nV	∞
9	Calibration Uncertainty of Pressure measurement		1003.70 hPa	0.35 hPa	B	Normal	0.18 hPa	17.8 nV/ohm	3.12 nV	∞
	Combined standard uncertainty								**64.7 nV**	**32**

Type A = 47.0 nV **Coverage factor *k* = 2.08**

Type B = 44.5 nV **Expanded uncertainty = 134.7 nV**



Uncertainty budget for TZS-2 : SN 6950002 @ 1.018 V

	Quantity	Estimate	Uncertainty	Type	Probability Distibution	Standard Uncertainty	Sensitivity Coefficient	Uncertainty Contribution	Degree of Freedom
1	Measured mean voltage u_r	1.018 V	6.00 nV	A	Normal	6.00 nV	1	6.00 nV	9
2	Frequency u_f	75.057 GHz	15.00 Hz	B	Rectangular	8.66 Hz	13.56 pV/Hz	0.12 nV	∞
3	Leakage error u_{leak}	0 nV	0.06 nV	B	Rectangular	0.03 nV	1	0.03 nV	∞
4	Detector gain error u_{det}	310.00 μV	-11.78 nV	B	Rectangular	-6.80 nV	-1	6.80 nV	202
5	Zero offset voltage u_z	0.00 nV	6.00 nV	B	Normal	6.00 nV	1	6.00 nV	99
6	Temperature coefficient of the standards	0.00 nV	-13.80 nV	B	Normal	-13.80 nV	1	-13.80 nV	∞
7	Pressure coefficient of the standards	0.00 nV	0.00 nV	B	Normal	0.00 nV	-1	0.00 nV	∞
8	Calibration Uncertainty of Thermister measurement	38.902 kΩ	0.40 Ω	B	Normal	0.20 Ω	0.2 nV/ohm	0.04 nV	∞
9	Calibration Uncertainty of Pressure measurement	1004.20 hPa	0.35 hPa	B	Normal	0.18 hPa	1.4 nV/hPa	0.25 nV	∞
	Combined standard uncertainty							**17.6 nV**	**569**

Type A = 6.0 nV

Coverage factor *k* = 2.00

Type B = 16.5 nV

Expanded uncertainty = 35.2 nV

Uncertainty budget for TZS-2 : SN 6950002 @ 10 V

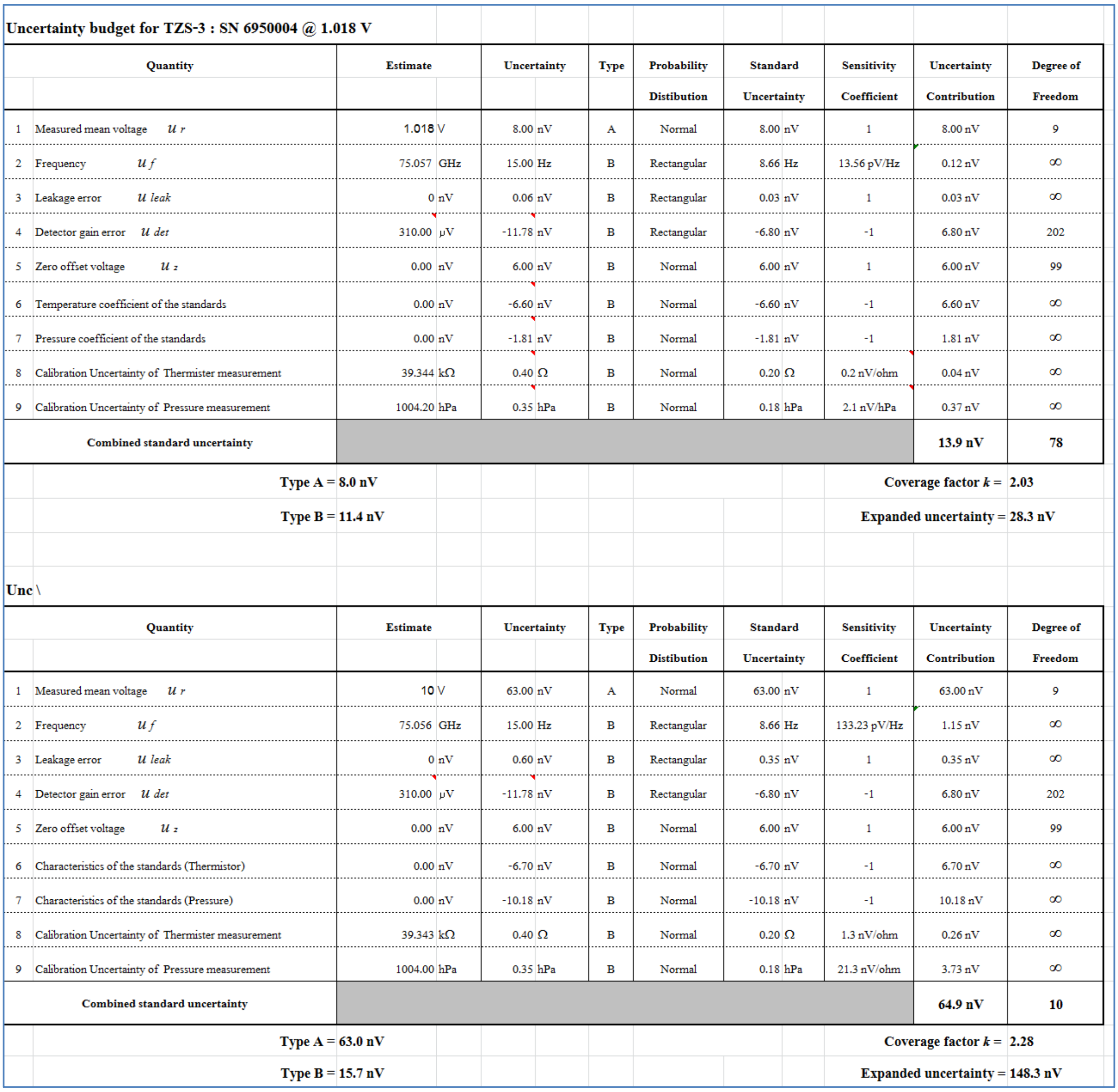
	Quantity	Estimate	Uncertainty	Type	Probability Distibution	Standard Uncertainty	Sensitivity Coefficient	Uncertainty Contribution	Degree of Freedom
1	Measured mean voltage u_r	10 V	41.00 nV	A	Normal	41.00 nV	1	41.00 nV	9
2	Frequency u_f	75.056 GHz	15.00 Hz	B	Rectangular	8.66 Hz	133.23 pV/Hz	1.15 nV	∞
3	Leakage error u_{leak}	0 nV	0.60 nV	B	Rectangular	0.35 nV	1	0.35 nV	∞
4	Detector gain error u_{det}	310.00 μV	-11.78 nV	B	Rectangular	-6.80 nV	-1	6.80 nV	202
5	Zero offset voltage u_z	0.00 nV	6.00 nV	B	Normal	6.00 nV	1	6.00 nV	99
6	Temperature coefficient of the standards	0.00 nV	-27.20 nV	B	Normal	-27.20 nV	1	-27.20 nV	∞
7	Pressure coefficient of the standards	0.00 nV	-4.63 nV	B	Normal	-4.63 nV	-1	4.63 nV	∞
8	Calibration Uncertainty of Thermister measurement	38.904 kΩ	0.40 Ω	B	Normal	0.20 Ω	1.9 nV/ohm	0.38 nV	∞
9	Calibration Uncertainty of Pressure measurement	1004.00 hPa	0.35 hPa	B	Normal	0.18 hPa	16.5 nV/ohm	2.89 nV	∞
	Combined standard uncertainty							**50.3 nV**	**20**

Type A = 41.0 nV

Coverage factor *k* = 2.13

Type B = 29.2 nV

Expanded uncertainty = 107.4 nV



Uncertainty budget for TZS-3 : SN 6950004 @ 1.018 V

	Quantity	Estimate	Uncertainty	Type	Probability Distibution	Standard Uncertainty	Sensitivity Coefficient	Uncertainty Contribution	Degree of Freedom
1	Measured mean voltage u_r	1.018 V	8.00 nV	A	Normal	8.00 nV	1	8.00 nV	9
2	Frequency u_f	75.057 GHz	15.00 Hz	B	Rectangular	8.66 Hz	13.56 pV/Hz	0.12 nV	∞
3	Leakage error u_{leak}	0 nV	0.06 nV	B	Rectangular	0.03 nV	1	0.03 nV	∞
4	Detector gain error u_{det}	310.00 μV	-11.78 nV	B	Rectangular	-6.80 nV	-1	6.80 nV	202
5	Zero offset voltage u_z	0.00 nV	6.00 nV	B	Normal	6.00 nV	1	6.00 nV	99
6	Temperature coefficient of the standards	0.00 nV	-6.60 nV	B	Normal	-6.60 nV	-1	6.60 nV	∞
7	Pressure coefficient of the standards	0.00 nV	-1.81 nV	B	Normal	-1.81 nV	-1	1.81 nV	∞
8	Calibration Uncertainty of Thermister measurement	39.344 kΩ	0.40 Ω	B	Normal	0.20 Ω	0.2 nV/ohm	0.04 nV	∞
9	Calibration Uncertainty of Pressure measurement	1004.20 hPa	0.35 hPa	B	Normal	0.18 hPa	2.1 nV/hPa	0.37 nV	∞
	Combined standard uncertainty							**13.9 nV**	**78**

Type A = 8.0 nV **Coverage factor *k* = 2.03**

Type B = 11.4 nV **Expanded uncertainty = 28.3 nV**

**Unc **

	Quantity	Estimate	Uncertainty	Type	Probability Distibution	Standard Uncertainty	Sensitivity Coefficient	Uncertainty Contribution	Degree of Freedom
1	Measured mean voltage u_r	10 V	63.00 nV	A	Normal	63.00 nV	1	63.00 nV	9
2	Frequency u_f	75.056 GHz	15.00 Hz	B	Rectangular	8.66 Hz	133.23 pV/Hz	1.15 nV	∞
3	Leakage error u_{leak}	0 nV	0.60 nV	B	Rectangular	0.35 nV	1	0.35 nV	∞
4	Detector gain error u_{det}	310.00 μV	-11.78 nV	B	Rectangular	-6.80 nV	-1	6.80 nV	202
5	Zero offset voltage u_z	0.00 nV	6.00 nV	B	Normal	6.00 nV	1	6.00 nV	99
6	Characteristics of the standards (Thermistor)	0.00 nV	-6.70 nV	B	Normal	-6.70 nV	-1	6.70 nV	∞
7	Characteristics of the standards (Pressure)	0.00 nV	-10.18 nV	B	Normal	-10.18 nV	-1	10.18 nV	∞
8	Calibration Uncertainty of Thermister measurement	39.343 kΩ	0.40 Ω	B	Normal	0.20 Ω	1.3 nV/ohm	0.26 nV	∞
9	Calibration Uncertainty of Pressure measurement	1004.00 hPa	0.35 hPa	B	Normal	0.18 hPa	21.3 nV/ohm	3.73 nV	∞
	Combined standard uncertainty							**64.9 nV**	**10**

Type A = 63.0 nV **Coverage factor *k* = 2.28**

Type B = 15.7 nV **Expanded uncertainty = 148.3 nV**

C.8 Uncertainty statement: BIPM

Table 2. Results of the BIPM in the first measurement session of APMP.EM.BIPM-K11.3 of 1.018 V standards using three Zener traveling standards: reference date 18 July 2010. Uncertainties are 1 σ estimates. The standard deviation of the mean of the BIPM daily measurement results is equal to 12 nV, 9 nV and 9 nV for TZS-1, TZS-2 and TZS-3 respectively. We consider that the Type A uncertainty can't be lower than the 1/f noise floor estimated at 10 nV.

		TZS-1	**TZS-2**	**TZS-3**
1	*BIPM* (U_Z – 1.018 V)/µV	103.99	146.98	114.43
2	Type A uncertainty/µV	0.012	0.010	0.010
3	correlated unc./µV	0.004		
4	pressure and temperature correction uncertainty/µV	0	0.010	0.012
5	uncorrelated uncertainty/µV	0.012	0.015	0.017
6	Total combined uncertainty/µV	0.013	0.015	0.017

Table 3. Estimated standard uncertainties of the BIPM JVS and measurement chain for Zener calibrations with the BIPM equipment at the level of 1.018 V without the contribution of the Zener noise and the contribution of the pressure and temperature corrections.

JVS & detector uncertainty components	Type	Uncertainty/nV
Measurement loop noise	A	3.4
nanovoltmeter accuracy	A	0.11
accuracy of the JVS RF frequency	B	0.03
Leakage resistance	B	0.03
Pressure and temperature correction	B	included in the Zener unc. budget
Zener noise	A	included in the Zener unc. budget
total		3.4

Table 5. Results of the BIPM in the first measurement session of APMP.EM.BIPM-K11.3 of 10 V standards using three Zener traveling standards: reference date 18 July 2010. Uncertainties are 1 σ estimates. The standard deviation of the mean of the BIPM daily measurement results is equal to 102 nV, 61 nV and 56 nV for TZS-1, TZS-2 and TZS-3 respectively. We consider that the Type A uncertainty can't be lower than the 1/f noise floor estimated at 100 nV.

		TZS-1	**TZS-2**	**TZS-3**
1	*BIPM* (U_Z – 10 V)/µV	-58.58	-1.29	-42.85
2	Type A uncertainty/µV	0.102	0.100	0.100
3	correlated unc./µV	0.001		
4	pressure and temperature correction uncertainty/µV	0. 128	0.021	0.036
5	uncorrelated uncertainty/µV	0.163	0.102	0.106
6	Total combined uncertainty/µV	0.163	0.102	0.106

Table 6. Estimated standard uncertainties for Zener calibrations with the BIPM equipment at the level of 10 V without the contribution of the Zener noise and the contribution of the pressure and temperature corrections.

JVS & detector uncertainty components	Type	Uncertainty/nV
Measurement loop noise	A	0.86
nanovoltmeter accuracy	A	0.11
accuracy of the JVS RF frequency	B	0.03
Leakage resistance	B	0.03
Pressure and temperature correction	B	included in the Zener unc. budget
Zener noise	A	included in the Zener unc. budget
total		0.87

C.9 Uncertainty statement: SCL, Hong Kong

Estimation of measurement uncertainty for TZS-1 (s/n: 6950001-3)

K11.3.a (1.018 V)

(i) Type A uncertainty evaluation:

Source of Uncertainty	Type	Uncertainty		Distribution	Sensitivity Coefficient		Standard Measurement	Degrees of
		Value			Value		Uncertainty (nV)	Freedom
Standard deviation of the mean value	A	4.55	nV	Normal	1		4.55	109
Random effects and noise	A	0.01	uV/V	Normal	1.018	V	10.2	39
Combined standard meas. uncertainty, u_c				Normal			11	52

(ii) Type B uncertainty evaluation:

Source of Uncertainty	Type	Uncertainty		Distribution	Sensitivity Coefficient		Standard Measurement	Degrees of
		Value			Value		Uncertainty (nV)	Freedom
DVM gain error uncertainty	B	1	uV/V	Rectangular	0.01	V	5.77	∞
Uncompensated offset voltage on switch	B	30	nV	Rectangular	1		17.3	∞
Leakage-error uncertainty	B	0.5	nV	Rectangular	1		0.289	∞
Frequency uncertainty	B	5.13	Hz	Normal	1.36E-11	V/Hz	0.070	200
Uncertainty in measuring ambient pressure	B	0.0721	hPa	Normal	2	nV/hPa	0.144	112
Uncertainty in pressure coefficient	B	0	nV/hPa	Normal	-20.477	hPa	0.0	∞
Uncertainty in measuring thermistor resistance	B	0.2451	ohm	Normal	0.3	nV/ohm	0.0735	110
Uncertainty in thermistor coefficient	B	0	nV/ohm	Normal	48	ohm	0	∞
Combined standard meas. uncertainty, u_c				Normal			18	2.5E+10

(iii) Measurement uncertainty:

Source of Uncertainty	Type	Uncertainty		Distribution	Sensitivity Coefficient		Standard Measurement	Degrees of
		Value (nV)			Value		Uncertainty (nV)	Freedom
Type A uncertainty, from (i)	A	11.0		Normal	1		11	52
Type B uncertainty, from (ii)	B	18		Normal	1		18	2.5E+10
Combined standard meas. uncertainty, u_c				Normal			**21**	690
Coverage factor, *k*							**2.0**	
Expandded measurement uncertainty, *U*							**42**	

K11.3.b (10 V)

(i) Type A uncertainty evaluation:

Source of Uncertainty	Type	Uncertainty		Distribution	Sensitivity Coefficient		Standard Measurement	Degrees of
		Value			Value		Uncertainty (nV)	Freedom
Standard deviation of the mean value	A	31.8	nV	Normal	1		31.8	108
Random effects and noise	A	0.0016	uV/V	Normal	10	V	16.0	39
Combined standard meas. uncertainty, u_c				Normal			36	150

(ii) Type B uncertainty evaluation:

Source of Uncertainty	Type	Uncertainty		Distribution	Sensitivity Coefficient		Standard Measurement	Degrees of
		Value			Value		Uncertainty (nV)	Freedom
DVM gain error uncertainty	B	1	uV/V	Rectangular	0.01	V	5.77	∞
Uncompensated offset voltage on switch	B	30	nV	Rectangular	1		17.3	∞
Leakage-error uncertainty	B	5	nV	Rectangular	1		2.887	∞
Frequency uncertainty	B	5.13	Hz	Normal	1.36E-10	V/Hz	0.70	200
Uncertainty in measuring ambient pressure	B	0.0721	hPa	Normal	17.8	nV/hPa	1.283	112
Uncertainty in pressure coefficient	B	0.7	nV/hPa	Normal	-20.477	hPa	-14.3	∞
Uncertainty in measuring thermistor resistance	B	0.2451	ohm	Normal	4.3	nV/ohm	1.0539	110
Uncertainty in thermistor coefficient	B	1.3	nV/ohm	Normal	48.7	ohm	63	∞
Combined standard meas. uncertainty, u_c				Normal			68	5.84E+08

(iii) Measurement uncertainty:

Source of Uncertainty	Type	Uncertainty		Distribution	Sensitivity Coefficient		Standard Measurement	Degrees of
		Value (nV)			Value		Uncertainty (nV)	Freedom
Type A uncertainty, from (i)	A	36.0		Normal	1		36	150
Type B uncertainty, from (ii)	B	68		Normal	1		68	5.8E+08
Combined standard meas. uncertainty, u_c				Normal			**77**	3139
Coverage factor, *k*							**2.0**	
Expandded measurement uncertainty, *U*							**154**	

Estimation of measurement uncertainty for TZS-2 (s/n: 6950002)

K11.3.a (1.018 V)

(i) Type A uncertainty evaluation:

Source of Uncertainty	Type	Uncertainty Value		Distribution	Sensitivity Coefficient Value		Standard Measurement Uncertainty (nV)	Degrees of Freedom
Standard deviation of the mean value	A	3.4	nV	Normal	1		3.4	107
Random effects and noise	A	0.01	uV/V	Normal	1.018	V	10.2	39
Combined standard meas. uncertainty, u_c				Normal			11	52

(ii) Type B uncertainty evaluation:

Source of Uncertainty	Type	Uncertainty Value		Distribution	Sensitivity Coefficient Value		Standard Measurement Uncertainty (nV)	Degrees of Freedom
DVM gain error uncertainty	B	1	uV/V	Rectangular	0.01	V	5.77	∞
Uncompensated offset voltage on switch	B	30	nV	Rectangular	1		17.3	∞
Leakage-error uncertainty	B	0.5	nV	Rectangular	1		0.289	∞
Frequency uncertainty	B	5.13	Hz	Normal	1.36E-11	V/Hz	0.070	200
Uncertainty in measuring ambient pressure	B	0.0721	hPa	Normal	1.4	nV/hPa	0.101	112
Uncertainty in pressure coefficient	B	0	nV/hPa	Normal	-20.59	hPa	0.0	∞
Uncertainty in measuring thermistor resistance	B	0.2404	ohm	Normal	0.2	nV/ohm	0.0481	110
Uncertainty in thermistor coefficient	B	0.1	nV/ohm	Normal	98	ohm	10	∞
Combined standard meas. uncertainty, u_c				Normal			21	1.8E+11

(iii) Measurement uncertainty:

Source of Uncertainty	Type	Uncertainty Value (nV)		Distribution	Sensitivity Coefficient Value		Standard Measurement Uncertainty (nV)	Degrees of Freedom
Type A uncertainty, from (i)	A	11.0		Normal	1		11.0	52
Type B uncertainty, from (ii)	B	21		Normal	1		21.0	1.8E+11
Combined standard meas. uncertainty, u_c				Normal			**24**	1178
Coverage factor, *k*							**2.0**	
Expandded measurement uncertainty, *U*							**48**	

K11.3.b (10 V)

(i) Type A uncertainty evaluation:

Source of Uncertainty	Type	Uncertainty Value		Distribution	Sensitivity Coefficient Value		Standard Measurement Uncertainty (nV)	Degrees of Freedom
Standard deviation of the mean value	A	32.2	nV	Normal	1		32.2	107
Random effects and noise	A	0.002	uV/V	Normal	10	V	20.0	39
Combined standard meas. uncertainty, u_c				Normal			38	147

(ii) Type B uncertainty evaluation:

Source of Uncertainty	Type	Uncertainty Value		Distribution	Sensitivity Coefficient Value		Standard Measurement Uncertainty (nV)	Degrees of Freedom
DVM gain error uncertainty	B	1	uV/V	Rectangular	0.01	V	5.77	∞
Uncompensated offset voltage on switch	B	30	nV	Rectangular	1		17.3	∞
Leakage-error uncertainty	B	5	nV	Rectangular	1		2.887	∞
Frequency uncertainty	B	5.13	Hz	Normal	1.36E-10	V/Hz	0.70	200
Uncertainty in measuring ambient pressure	B	0.0721	hPa	Normal	16.5	nV/hPa	1.190	112
Uncertainty in pressure coefficient	B	0.5	nV/hPa	Normal	-20.59	hPa	-10.3	∞
Uncertainty in measuring thermistor resistance	B	0.2404	ohm	Normal	1.9	nV/ohm	0.4568	110
Uncertainty in thermistor coefficient	B	0.2	nV/ohm	Normal	98	ohm	20	∞
Combined standard meas. uncertainty, u_c				Normal			29	3.63E+07

(iii) Measurement uncertainty:

Source of Uncertainty	Type	Uncertainty Value (nV)		Distribution	Sensitivity Coefficient Value		Standard Measurement Uncertainty (nV)	Degrees of Freedom
Type A uncertainty, from (i)	A	38.0		Normal	1		38	147
Type B uncertainty, from (ii)	B	29		Normal	1		29	3.6E+07
Combined standard meas. uncertainty, u_c				Normal			**48**	374
Coverage factor, *k*							**2.0**	
Expandded measurement uncertainty, *U*							**96**	

Estimation of measurement uncertainty for TZS-3 (s/n: 6950004)

K11.3.a (1.018 V)

(i) Type A uncertainty evaluation:

Source of Uncertainty	Type	Uncertainty		Distribution	Sensitivity Coefficient		Standard Measurement	Degrees of
		Value			Value		Uncertainty (nV)	Freedom
Standard deviation of the mean value	A	2.7	nV	Normal	1		2.7	109
Random effects and noise	A	0.011	uV/V	Normal	1.018	V	11.2	39
Combined standard meas. uncertainty, u_c				Normal			12	51

(ii) Type B uncertainty evaluation:

Source of Uncertainty	Type	Uncertainty		Distribution	Sensitivity Coefficient		Standard Measurement	Degrees of
		Value			Value		Uncertainty (nV)	Freedom
DVM gain error uncertainty	B	1	uV/V	Rectangular	0.01	V	5.77	∞
Uncompensated offset voltage on switch	B	30	nV	Rectangular	1		17.3	∞
Leakage-error uncertainty	B	0.5	nV	Rectangular	1		0.289	∞
Frequency uncertainty	B	5.13	Hz	Normal	1.36E-11	V/Hz	0.070	200
Uncertainty in measuring ambient pressure	B	0.0721	hPa	Normal	2.1	nV/hPa	0.151	112
Uncertainty in pressure coefficient	B	0.2	nV/hPa	Normal	-20.59	hPa	-4.1	∞
Uncertainty in measuring thermistor resistance	B	0.2433	ohm	Normal	0.2	nV/ohm	0.0487	110
Uncertainty in thermistor coefficient	B	0.1	nV/ohm	Normal	-1.8	ohm	-0.18	∞
Combined standard meas. uncertainty, u_c				Normal			19	2.7E+10

(iii) Measurement uncertainty:

Source of Uncertainty	Type	Uncertainty		Distribution	Sensitivity Coefficient		Standard Measurement	Degrees of
		Value (nV)			Value		Uncertainty (nV)	Freedom
Type A uncertainty, from (i)	A	12.0		Normal	1		12	51
Type B uncertainty, from (ii)	B	19		Normal	1		19	2.7E+10
Combined standard meas. uncertainty, u_c				Normal			**22**	576
Coverage factor, *k*							**2.0**	
Expandded measurement uncertainty, *U*							**44**	

K11.3.b (10 V)

(i) Type A uncertainty evaluation:

Source of Uncertainty	Type	Uncertainty		Distribution	Sensitivity Coefficient		Standard Measurement	Degrees of
		Value			Value		Uncertainty (nV)	Freedom
Standard deviation of the mean value	A	23.2	nV	Normal	1		23.2	109
Random effects and noise	A	0.0017	uV/V	Normal	10	V	17.0	39
Combined standard meas. uncertainty, u_c				Normal			29	147

(ii) Type B uncertainty evaluation:

Source of Uncertainty	Type	Uncertainty		Distribution	Sensitivity Coefficient		Standard Measurement	Degrees of
		Value			Value		Uncertainty (nV)	Freedom
DVM gain error uncertainty	B	1	uV/V	Rectangular	0.01	V	5.77	∞
Uncompensated offset voltage on switch	B	30	nV	Rectangular	1		17.3	∞
Leakage-error uncertainty	B	5	nV	Rectangular	1		2.887	∞
Frequency uncertainty	B	5.13	Hz	Normal	1.36E-10	V/Hz	0.70	200
Uncertainty in measuring ambient pressure	B	0.0721	hPa	Normal	21.3	nV/hPa	1.536	112
Uncertainty in pressure coefficient	B	1.1	nV/hPa	Normal	-20.58	hPa	-22.6	∞
Uncertainty in measuring thermistor resistance	B	0.2433	ohm	Normal	1.3	nV/ohm	0.3163	110
Uncertainty in thermistor coefficient	B	0.1	nV/ohm	Normal	-2.3	ohm	-0.23	∞
Combined standard meas. uncertainty, u_c				Normal			29	1.39E+07

(iii) Measurement uncertainty:

Source of Uncertainty	Type	Uncertainty		Distribution	Sensitivity Coefficient		Standard Measurement	Degrees of
		Value (nV)			Value		Uncertainty (nV)	Freedom
Type A uncertainty, from (i)	A	29.0		Normal	1		29	147
Type B uncertainty, from (ii)	B	29		Normal	1		29	1.4E+07
Combined standard meas. uncertainty, u_c				Normal			**41**	587
Coverage factor, *k*							**2.0**	
Expandded measurement uncertainty, *U*							**82**	

C.10 Uncertainty statement: KazInMetr, Kazakhstan

TZS-1	**1,018 V**	**Quantity**	**Uncertainty**	**Type**	**Probability distribution**	**Standard uncertainty**	**Sensitivity coefficient**	**Uncertainty contribution**	**Degree of freedom**
		Measured mean voltage	90 nV	A	normal	90 nV	1	90 nV	14
		Frequency	1.7E-10	B	rectangular	9.9E-11	1.018 V	0.1 nV	1000
		thermal EMFs	5 nV	B	normal	5nV	1	5 nV	5
		Leakage error	100 pA	B	normal	100 pA	10 Ω	1 nV	2
		Detector	6 nV	B	normal	6 nV	1	6 nV	50
		Ambient pressure	1hPa	B	rectangular	0,6 hPa	2,0 nV/hPa	1,2 nV	10
		Thermistor resistance	5,0 Ω	B	rectangular	2,9 Ω	0,3 nV/Ω	0,9 nV	10
		Pressure coefficient	0 nV/hPa	B	normal	0	48,3 hPa	0 nV	5
		Termistor coefficient	0 nV/Ω	B	normal	0	60 Ω	0 nV	5
		Type B unc.						8 nV	
		uc						90 nV	n_{eff} =14
		U						181 nV	

TZS-1	**10 V**	**Quantity**	**Uncertainty**	**Type**	**Probability distribution**	**Standard uncertainty**	**Sensitivity coefficient**	**Uncertainty contribution**	**Degree of freedom**
		Measured mean voltage	46 nV	A	normal	46 nV	1	46 nV	14
		Frequency	1.7E-10	B	rectangular	9.9E-11	1.018 V	0.1 nV	1000
		thermal EMFs	5 nV	B	normal	5nV	1	5 nV	5
		Leakage error	100 pA	B	normal	100 pA	10 Ω	1 nV	2
		Detector	6 nV	B	normal	6 nV	1	6 nV	50
		Ambient pressure	1hPa	B	rectangular	0,58 hPa	17,8 nV/hPa	10,3 nV	10
		Thermistor resistance	5,0 Ω	B	rectangular	2,9 Ω	4,3 nV/Ω	12,4 nV	10
		Pressure coefficient	0,7 nV/hPa	B	normal	0,7 nV/hPa	48,3 hPa	33,8 nV	5
		Termistor coefficient	1,3 nV/Ω	B	normal	1,3 nV/Ω	60 Ω	78,0 nV	5
		Type B unc.						87 nV	
		uc						98 nV	n_{eff} =12
		U						197 nV	

TZS-2	**1,018 V**	**Quantity**	**Uncertainty**	**Type**	**Probability distribution**	**Standard uncertainty**	**Sensitivity coefficient**	**Uncertainty contribution**	**Degree of freedom**
		Measured mean voltage	54 nV	A	normal	54 nV	1	54 nV	14
		Frequency	1.7E-10	B	rectangular	9.9E-11	1.018 V	0.1 nV	1000
		thermal EMFs	5 nV	B	normal	5nV	1	5 nV	5
		Leakage error	100 pA	B	normal	100 pA	10 Ω	1 nV	2
		Detector	6 nV	B	normal	6 nV	1	6 nV	50
		Ambient pressure	1hPa	B	rectangular	0,6 hPa	1,4 nV/hPa	0,8 nV	10
		Thermistor resistance	5,0 Ω	B	rectangular	2,9 Ω	0,2 nV/Ω	0,6 nV	10
		Pressure coefficient	0 nV/hPa	B	normal	0	48,3 hPa	0 nV	5
		Termistor coefficient	0,1 nV/Ω	B	normal	0.1	90 Ω	9,0 nV	5
		Type B unc.						12 nV	
		uc						55 nV	n_{eff} =15
		U						111 nV	

TZS-2	**10 V**	**Quantity**	**Uncertainty**	**Type**	**Probability distribution**	**Standard uncertainty**	**Sensitivity coefficient**	**Uncertainty contribution**	**Degree of freedom**
		Measured mean voltage	108 nV	A	normal	108 nV	1	108 nV	14
		Frequency	1.7E-10	B	rectangular	9.9E-11	1.018 V	0.1 nV	1000
		thermal EMFs	5 nV	B	normal	5nV	1	5 nV	5
		Leakage error	100 pA	B	normal	100 pA	10 Ω	1 nV	2
		Detector	6 nV	B	normal	6 nV	1	6 nV	50
		Ambient pressure	1hPa	B	rectangular	0,58 hPa	16,5 nV/hPa	9,5 nV	10
		Thermistor resistance	5,0 Ω	B	rectangular	2,9 Ω	1,9 nV/Ω	5,5 nV	10
		Pressure coefficient	0,5 nV/hPa	B	normal	0,5 nV/hPa	48,3 hPa	24,2 nV	5
		Termistor coefficient	0,2 nV/Ω	B	normal	0,2 nV/Ω	90 Ω	18,0 nV	5
		Type B unc.						33 nV	
		uc						113 nV	n_{eff} =17
		U						226 nV	

TZS-3	1,018 V	Quantity	Uncertainty	Type	Probability distribution	Standard uncertainty	Sensitivity coefficient	Uncertainty contribution	Degree of freedom
		Measured mean voltage	66 nV	A	normal	66 nV	1	66 nV	14
		Frequency	1.7E-10	B	rectangular	9.9E-11	1.018 V	0.1 nV	1000
		thermal EMFs	5 nV	B	normal	5nV	1	5 nV	5
		Leakage error	100 pA	B	normal	100 pA	10 Ω	1 nV	2
		Detector	6 nV	B	normal	6 nV	1	6 nV	50
		Ambient pressure	1hPa	B	rectangular	0,6 hPa	2,1 nV/hPa	1,2 nV	10
		Thermistor resistance	5,0 Ω	B	rectangular	2,9 Ω	0,2 nV/Ω	0,6 nV	10
		Pressure coefficient	0,2 nV/hPa	B	normal	0,2 nV/hPa	48,3 hPa	9,7 nV	5
		Termistor coefficient	0,1 nV/Ω	B	normal	0,1 nV/Ω	410 Ω	41,0 nV	5
		Type B unc.						43 nV	
		uc						79 nV	n_{eff} =20
		U						157 nV	

TZS-3	10 V	Quantity	Uncertainty	Type	Probability distribution	Standard uncertainty	Sensitivity coefficient	Uncertainty contribution	Degree of freedom
		Measured mean voltage	142 nV	A	normal	142 nV	1	142 nV	14
		Frequency	1.7E-10	B	rectangular	9.9E-11	1.018 V	0.1 nV	1000
		thermal EMFs	5 nV	B	normal	5nV	1	5 nV	5
		Leakage error	100 pA	B	normal	100 pA	10 Ω	1 nV	2
		Detector	6 nV	B	normal	6 nV	1	6 nV	50
		Ambient pressure	1hPa	B	rectangular	0,58 hPa	21,3 nV/hPa	12,3 nV	10
		Thermistor resistance	5,0 Ω	B	rectangular	2,9 Ω	1,3 nV/Ω	3,8 nV	10
		Pressure coefficient	1,1 nV/hPa	B	normal	1,1 nV/hPa	48,3 hPa	53,1 nV	5
		Termistor coefficient	0,1 nV/Ω	B	normal	0,1 nV/Ω	410 Ω	41,0 nV	5
		Type B unc.						69 nV	
		uc						158 nV	n_{eff} =20
		U						316 nV	

Appendix D: Summary of Participants' Measurements

D.1 Summary of Measurements: NMIA, Australia

TZS1 s/n 695001(_3)

10 V

NMI	Mean Date	Temp (oC)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
NMIA	2009-11-22 9:45 PM	20.2	39.795	1001.7	74	9.999 943 841	9.999 943 424	188	252	189	315.0	135.8	630.0

1.018 V

NMI	Mean Date	Temp (oC)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
NMIA	2009-11-22 9:45 PM	20.2	39.795	1001.7	73	1.018 104 265	1.018 104 245	0.0	34.5	14.6	37.46	66.8	74.92

TZS2 s/n 695002

10 V

NMI	Mean Date	Temp (oC)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
NMIA	2009-11-22 2:35 PM	20.2	39.071	1001.8	72	9.999 997 873	9.999 998 006	8	155	17	155.9	72.6	311.9

1.018 V

NMI	Mean Date	Temp (oC)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
NMIA	2009-11-22 2:35 PM	20.2	39.071	1001.8	74	1.018 146 295	1.018 146 305	3.1	23.9	14.9	28.16	44.3	56.33

TZS3 s/n 695004

10 V

NMI	Mean Date	Temp (oC)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
NMIA	2009-11-22 2:35 PM	20.2	39.547	1001.7	74	9.999 957 900	9.999 957 966	19	317	24	317.9	73.8	635.8

1.018 V

NMI	Mean Date	Temp (oC)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
NMIA	2009-11-22 2:35 PM	20.2	39.547	1001.7	74	1.018 114 447	1.018 114 444	13.9	42.2	20.2	46.79	89.2	93.57

*D.2 Summary of Measurements: NMC-A*STAR, Singapore*

TZS1 s/n 695001(_3)

10 V

NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
NMC	2009-12-21	23.5	39.716	1006.88	21	9.999 943 324	9.999 943 155	85.7	60.3	88.3	107	108	214

1.018 V

NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
NMC	2009-12-21	23.7	39.705	1005.82	21	1.018 104 237	1.018 104 236	0	7	20	21	61	42

TZS2 s/n 695002

10 V

NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
NMC	2009-12-21	23.5	38.967	1006.74	21	9.999 997 633	9.999 997 878	14.9	53.7	25.2	59	30	119

1.018 V

NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
NMC	2009-12-21	23.8	38.956	1005.69	21	1.018 146 357	1.018 146 384	8.4	5.4	21.7	22	76	45

TZS3 s/n 695004

10 V

NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
NMC	2009-12-21	23.5	39.425	1006.8	21	9.999 957 887	9.999 958 004	7.3	67.4	21.5	71	24	141

1.018 V

NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
NMC	2009-12-21	23.8	39.412	1005.48	21	1.018 114 443	1.018 114 459	1.6	8.9	20.1	22	66	44

D.3 Summary of Measurements: KRISS, Korea (Rep. of)

The type B uncertainties in the table are the type B uncertainty of the measurement system only, excluding the uncertainties of temperature and pressure correction.

TZS1	s/n 695001(_3)												
10 V													
NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2.1)
KRISS	2010/1/20	21.7	39.758	1014.8	59	9.999 943 937	9.999 943 447	141.8	58.9	2.8	154	32	307
1.018 V													
NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
KRISS	2010/1/19	21.7	39.749	1015.9	66	1.018 104 334	1.018 104 299	1.8	11.5	3.0	12	78	24
TZS2	s/n 695002												
10 V													
NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
KRISS	2010/1/19	21.7	38.995	1014.6	60	9.999 998 201	9.999 998 264	15.5	50.9	2.8	53	67	107
1.018 V													
NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
KRISS	2010/1/19	21.7	39.005	1016.3	66	1.018 146 469	1.018 146 472	1.2	6.3	3.0	7	105	14
TZS3	s/n 695004												
10 V													
NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2.1)
KRISS	2010/1/19	21.7	39.447	1014.9	60	9.999 957 744	9.999 957 661	13.1	29.2	2.8	32	84	64
1.018 V													
NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
KRISS	2010/1/20	21.8	39.418	1016.3	60	1.018 114 439	1.018 114 428	3.0	10.2	3.0	11	73	22

D.4 Summary of Measurements: NML-SIRIM, Malaysia

The type B uncertainties in the table are the type B uncertainty of the measurement system only, excluding the uncertainties of temperature and pressure correction.

s/n 695001(_3)

Mean Date	Temp (^{o}C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
2010-02-16 3:15 PM	22.7	39.77	1000.69	12	9.999 943 359	9.999 943 067	50.82	68.28	29.86	90.2	34	180.4

Mean Date	Temp (^{o}C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
2010-2-16 1:05 PM	22.7	39.77	1000.69	12	1.018 104 225	1.018 104 214	3.92	9.19	29.86	31.5	1512	63.0

s/n 695002

Mean Date	Temp (^{o}C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
2010-2-17 1:21 PM	23.2	39.00	1001.91	12	9.999 997 937	9.999 998 204	25.20	63.37	29.86	74.5	21	148.9

Mean Date	Temp (^{o}C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
2010-2-17 5:24 PM	23.2	39.00	1001.91	12	1.018 146 469	1.018 146 494	1.98	9.86	29.86	31.51	1148	63.0

s/n 695004

Mean Date	Temp (^{o}C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
2010-2-18 12:43 PM	23.1	39.45	1001.11	12	9.999 957 184	9.999 957 386	38.83	52.78	29.86	72.01	38	144.0

Mean Date	Temp (^{o}C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
2010-2-18 3:17 PM	23.1	39.45	1001.11	12	1.018 114 421	1.018 114 437	5.52	6.52	29.86	31.06	20000	62.1

D.5 Summary of Measurements: CMS-ITRI, Chinese TAIPEI

TZS1	s/n 695001(_3)												
10 V													
NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2.1)
CMS	2010/3/15	23.0+-1.5	39.71	1012.7	8	9.999 942 962	9.999 942 721	62	126	135	185	32	389
1.018 V													
NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
CMS	2010/3/15	23.0+-1.5	39.71	1012.7	8	1.018 104 192	1.018 104 176	3	17	41	45	343	90
TZS2	s/n 695002												
10 V													
NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
CMS	2010/3/15	23.0+-1.5	38.95	1012.3	8	9.999 998 303	9.999 998 493	21	88	122	151	60	302
1.018 V													
NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
CMS	2010/3/15	23.0+-1.5	38.95	1012.3	8	1.018 146 604	1.018 146 624	8	13	41	44	918	88
TZS3	s/n 695004												
10 V													
NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2.1)
CMS	2010/3/15	23.0+-1.5	39.41	1012.5	8	9.999 957 227	9.999 957 240	15	116	121	168	30	353
1.018 V													
NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
CMS	2010/3/15	23.0+-1.5	39.41	1012.5	8	1.018 114 432	1.018 114 433	3	20	41	46	195	92

D.6 Summary of Measurements: NMIJ/AIST, Japan

TZS1	s/n 695001(_3)												
10 V													
NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
NMIJ	2010-5-27 5:21 PM	22.9	39.695	1002.19	5	9.999 942 707	9.999 942 904	59	18.7	59.1	61.98790205	486	123.9758041
							9.999 942 904						
1.018 V													
NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2.6)
NMIJ	2010-5-27 2:15 PM	23.1	39.667	1000.82	5	1.018 104 252	1.018 104 277	0	8.1	2.9	8.603487665	5	22.36906793
							1.018 104 277						
TZS2	s/n 695002												
10 V													
NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2.2)
NMIJ	2010-5-27 4:14 PM	22.9	38.932	1001.3	5	9.999 998 078	9.999 998 276	22.4	28.3	22.6	36.21670885	11	79.67675947
							9.999 998 276						
1.018 V													
NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
NMIJ	2010-5-27 3:36 PM	23.1	38.921	1000.66	5	1.018 146 548	1.018 146 566	11.9	2.4	12.2	12.43382483	2878	24.86764967
							1.018 146 566						
TZS3	s/n 695004												
10 V													
NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2.6)
NMIJ	2010-5-27 4:44 PM	23.0	39.37	1001.59	5	9.999 956 713	9.999 956 962	13.4	50.2	13.7	52.03585302	5	135.2932179
							9.999 956 962						
1.018 V													
NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
NMIJ	2010-5-27 3:02 PM	22.9	39.34	1000.69	5	1.018 114 469	1.018 114 496	7.4	5	8	9.433981132	51	18.86796226

D.7 Summary of Measurements: NIMT, Thailand

TZS1	s/n 6950001(_3)												
10 V													
NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
NIMT	2010-6-25 12:00 PM	23.6	39.683	1003.7	10	9.999 942 014	9.999 942 042	43.4	47	44.5	64.7	32	134.6
1.018 V													
NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
NIMT	2010-6-25 12:00 PM	23.4	39.676	1004	10	1.018 104 102	1.018 104 113	0.0	10	9.1	13.5	29.32	28.3
TZS2	s/n 6950002												
10 V													
NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
NIMT	2010-6-25 12:00 PM	23.5	38.904	1004	10	9.999 998 349	9.999 998 760	27.6	41	29.2	50.3	20	107.2
1.018 V													
NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
NIMT	2010-6-25 12:00 PM	23.4	38.902	1004.2	10	1.018 146 735	1.018 146 775	13.8	6	16.5	17.6	569	35.1
TZS3	s/n 6950004												
10 V													
NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
NIMT	2010-6-25 12:00 PM	23.5	39.343	1004	10	9.999 956 973	9.999 957 257	12.2	63	15.7	64.9	10	148.0
1.018 V													
NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
NIMT	2010-6-25 12:00 PM	23.5	39.344	1004.2	10	1.018 114 447	1.018 114 479	6.8	8	11.4	13.9	78	28.3

D.8 Summary of Measurements: BIPM

TZS1	s/n 695001(_3)												
10 V													
NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
BIPM	2010-07-18		39.726	1007.5			9.999 941 423	128	102	127	163		326
1.018 V													
NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
BIPM	2010-07-18		39.729	1007.6			1.018 103 990	0	12	4	13		25
TZS2	s/n 695002												
10 V													
NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
BIPM	2010-07-18		38.904	1007.6			9.999 998 707	21	100	21	102		204
1.018 V													
NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
BIPM	2010-07-18		38.9291	1007.6			1.018 146 984	10	10	11	15		30
TZS3	s/n 695004												
10 V													
NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
BIPM	2010-07-18		39.356	1007.6			9.999 957 151	36	100	36	106		212
1.018 V													
NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
BIPM	2010-07-18		39.353	1007.6			1.018 114 425	12	10	14	17		34

D.9 Summary of Measurements: SCL, Hong Kong

TZS1 s/n 695001(_3)

10 V

NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
SCL	2010-08-23		39.699	992.8			9.999 940 910	65	36		77		154

1.018 V

NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
SCL	2010-08-23		39.698	992.8			1.018 103 938	0	11		21		42

TZS2 s/n 695002

10 V

NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
SCL	2010-08-23		38.942	992.7			9.999 998 800	22	38		48		96

1.018 V

NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
SCL	2010-08-23		38.942	992.7			1.018 147 034	0	11		24		48

TZS3 s/n 695004

10 V

NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
SCL	2010-08-23		39.408	992.7			9.999 956 720	23	29		41		82

1.018 V

NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
SCL	2010-08-23		39.408	992.7			1.018 114 412	4	12		22		44

D.10 Summary of Measurements: KazInMetr, Kazakhstan

TZS1	s/n 695001(_3)												
10 V													
NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
KazInMetr	2011-07-28		39.712	964.8			9.999 934 765	87	46		98		196
1.018 V													
NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
KazInMetr	2011-07-28		39.712	965			1.018 103 267	2	90		91		182
TZS2	s/n 695002												
10 V													
NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
KazInMetr	2011-07-28		38.946	964.8			9.999 994 651	32	108		113		226
1.018 V													
NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
KazInMetr	2011-07-28		38.942	992.7			1.018 146 943	0	54		55		110
TZS3	s/n 695004												
10 V													
NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
KazInMetr	2011-07-28		39	965			9.999 953 887	68	142		158		316
1.018 V													
NMI	Mean Date	Temp (°C)	Mean Thermistor Resistance (kohm)	Mean Pressure (hPa)	Number of measurements	Average of Measured Value (V)	Corrected Averaged Value (V)	Uncertainty of Correction (nV, k=1)	Type A (nV)	Type B (nV)	Combined Std. Unc. (nV)	Deg. Of freedom	Expanded Unc. (k=2)
KazInMetr	2011-07-28		39.408	992.7			1.018 114 712	42	66		79		158

Appendix E: References

[1] Mutual Recognition Arrangement "Mutual Recognition of National Measurement Standards and of Calibration and Measurement Certificates Issued by National Metrology Institutes - Arrangement Drawn up by the International Committee of Weights and Measures under the Authority Given to it in the Metre Convention." http://www.bipm.org/utils/en/pdf/mra_2003.pdf 15 January 2007.

[2] L.X. Liu et al, "APMP Comparison of DC voltage," Report APMP-IC-6-95, 2001.

[3] F. Liefrink et al, "Comparison of 10 V Electronic Voltage Standards," Final Report: EUROMET project no. 429, September 2002.

[4] Witt T. J. "Pressure coefficient of some Zener diode-based electronic voltage standards," IEEE Trans. Instrum. Meas., Vol. 48, No. 2, 1999, pp. 329-332.

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[6] Thomas J. Witt,"Key Comparisons in Electricity: Case Studies from the BIPM,"APMP TCEM MEETING, 5 September 2005.

[7] Guideline Guidelines for CIPM key comparisons 1 March 1999 With modifications by the CIPM, in October 2003, available on-line from BIPM KCDB..

[8] M. G. Cox, "The evaluation of key comparison data," Metrologia, **39**, 589-595 (2002).

[9] D. Reymann, "Link between the comparison EUROMET.EM.BIPM-K11.b and the ongoing comparison BIPM.EM-K11.b," available on-line from BIPM KCDB.

[10] Evaluation of Measurement Data —Guide to the Expression of Uncertainty in Measurement, JCGM 100: 2008, 1st edition, Sep. 2008.

Appendix F: Comparison protocol

The comparison protocol is given below.

Technical Protocol

Key comparison APMP.EM.BIPM-K11.3: 10 V and 1.018 V DC VOLTAGE

Ver.9.6 (June 30, 2011)

CONTENTS

1. INTRODUCTION

At the APMP TCEM meeting, held in Jeju on 5 September 2005, KRISS proposed to organize an APMP key comparison (KC) of 10 V and 1.018 V DC voltage. At the same meeting NMIJ, Japan kindly agreed to provide Zener standards for traveling standards. The proposal was approved by the meeting. As a preparative step for the KC, a pilot comparison between KRISS and NMIJ was carried out in August to September, 2007 to test conditions of stabilization after transport and to check the uncertainty contributions due to the transport. This KC APMP.EM.BIPM-K11.3 covers comparison of both 1.018 V and 10 V which corresponds to KCs identified by BIPM.EM-K11.a and BIPM.EM-K11.b.

2. TRAVELING STANDARDS

3.1 General requirements

The traveling standard should have good stability of its output voltages during transportation. To reduce the consequences of any unexpected behavior of the traveling standards, several Zener standards are usually used [1]. Since different environmental conditions are used among participating labs, appropriate correction of measurement results against temperature, humidity and pressure is necessary. This makes it necessary for us to prepare a set of traveling standards with data on their environmental coefficients. Humidity effect of the Zener standards is known to have very slow time response [2]. In view of time schedule of comparison, the humidity effect will be treated as a drift effect when reference value is calculated by interpolation between two reference measurements as in the earlier EUROMET KC [3].

Characteristics of the standards

In Table 1 an overview is given of the temperature and pressure coefficients of the output voltages U_{measured} of the traveling standards as determined by NMIJ. The temperature effect is expressed in terms of the environmental temperature (α_T) and in terms of the oven thermistor resistance (α_R). The coefficient α_R will be used to make corrections for temperature effects (see measurement procedure).

Table 3: Temperature, humidity and pressure coefficients of 10 V and 1.018 V outputs.
(The uncertainties are stated in terms of combined standard uncertainty, 1 sigma)

Standard	Output	Reference thermistor resistance at R_0 (kΩ)	Temperature coefficient α_R (nV Ω^{-1})	Humidity coefficient α_H(nV %RH^{1})	Pressure coefficient α_p (nV hPa^{-1})
TZS-1	10 V	39.65	4.3 ± 1.3	<15	17.8 ± 0.7
TZS-2	10 V	39.04	1.9 ± 0.2	<15	16.5 ± 0.5
TZS-3	10 V	39.41	1.3 ± 0.1	<15	21.3 ± 1.1
TZS-1	1.018 V	39.65	0.3 ± 0.0	<1	2.0 ± 0.0
TZS-2	1.018 V	39.04	0.2 ± 0.1	<1	1.4 ± 0.0
TZS-3	1.018 V	39.41	0.2 ± 0.1	<1	2.1 ± 0.2

The resistance of the oven temperature thermistor will be used as an indicator for the temperature of the Zener standards.

3.2 Description of standards

The traveling standards, three Fluke 732B electronic DC reference standards, have identification as follows:

TZS-1	s/n 6950003
TZS-2	s/n 6950002
TZS-3	s/n 6950004

The Fluke 732 B electronic DC reference standard has two output voltages, nominally 1.018 V and 10 V, respectively. Within the comparison, both the 10 V and the 1.018 V output will be measured. Each Fluke 732B electronic DC reference standard is fixed in an upgrade-box (18.0 cm x 21.0 cm x 47.0 cm) (Fig. 1). Two additional batteries are installed inside the upgrade-box. These batteries are used to increase the working time of the internal battery of the Fluke 732B. A BNC type female connector is provided for the measurement of internal thermistor resistance (**see ‘Measuring the internal thermistor resistance’ in Clause 4.2**). The total weight of the upgrade box (with Fluke 732B and batteries) is around 14 kg. Each upgrade box is packed in a transportation case (27 x 27.5 x 55) cm. The two additional batteries are connected in parallel to MONITOR/EXT BAT IN connectors on rear panel of the 732B. These batteries are attached to the Fluke 732B inside of the Upgrade box. Note that the internal battery is already fixed in the original position inside of the Fluke 732B. It is possible to recharge all three batteries at the same time by the automatic charging circuit of the Fluke 732B.

Fig. 1: An upgrade-box with Fluke 732B and additional batteries

3.3 Quantities to be measured

DC voltage outputs 1.018 V and 10 V for the three standards.

3.4 Method of computation of the KCRV

Time drift of the traveling standards will be characterized using results of the Pilot Laboratory and BIPM. The difference between participant’s result and the interpolated time drift will be calculated. Robust evaluation [4] using median of the difference can be used for computation of the KCRV for this comparison.

3. ORGANIZATION

3.1 Coordinator and members of the support group

Coordinator:

The KRISS will coordinate the comparison and act as reference laboratory.

Address for correspondence	Address for dispatching the standards
Kyu-Tae Kim KRISS PO Box 102, Yuseong 305-600 Daejeon, KOREA (Rep. of)	Kyu-Tae Kim Div. Physical Metrology KRISS, Yuseong 305-340 Daejeon, KOREA (Rep. of)
Tel.: +82 42 868 5157 +82 42 868 5168 Fax: +82 42 868 5018 E-mail: ktkim@kriss.re.kr	Tel.: +82 42 868 5157 +82 42 868 5168 Fax: +82 42 868 5018 E-mail: ktim@kriss.re.kr

Support group:

Support group consists of following members;

Korea Research Institute of Standards and Science (KRISS), Kyu-Tae Kim
National Metrology Institute of Japan (NMIJ), Chiharu Urano
Bureau International des Poids Mesures (BIPM), Stephane Solve
National Metrology Centre (NMC/A*STAR), Sze Wey Chua

3.2 Participants

A participating laboratory that joins this Key Comparison (KC) is required to accept the following duties

- Prompt communication with pilot lab regarding the transport information, status of the standards and measurement report via both email and FAX.
- The transport standard should be handled carefully and be stored in a stabilized environment where relative humidity should be below 55 % R.H.
- Participating lab should fully recharge the transit battery and built-in operation battery (see 'Powering the standard' in Clause 3.5) before starting measurement.
- The sending lab is responsible for choosing an express delivery agent that provides a tracking number, with a facility for a real time web-check for the transportation status on the way to the next destination.
- The sending lab should arrange and pay the charge (incl. insurance) for the door-to-door transportation of the standard to the next scheduled lab.

List of participants

National Metrology Institute of Japan (NMIJ),
Michitaka Maruyama
E-mail:m-maruyama@aist.go.jp

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Kyu-Tae Kim
E-mail: ktkim@kriss.re.kr

3.3 Time schedule

The comparison will be organized as Table 2.

Table 4: Time schedule

Year	Date of Measurement	Laboratory	Country or Economy
2009	8 October – 31 October	KRISS, Pilot laboratory	Korea (South)
	8 November – 30 November	NMIA	Australia
	8 December – 31 December	NMC A*STAR	Singapore
2010	8 January – 31 January	KRISS, Pilot laboratory	Korea (South)

	8 February – 28 February	NML-SIRIM	Malaysia
	8 March – 31 March	CMS	Chinese Taipei
	8 April – 30 April	KRISS, Pilot laboratory	Korea (South)
	8 May – 31 May	NMIJ	Japan
	8 June – 30 June	NIMT	Thailand
	8 July – 31 July	BIPM	BIPM
	8 August – 31 August	SCL	Hong Kong China
	8 September – 30 September	KRISS, Pilot laboratory	Korea (South)
	8 October – 30 January	BIPM	BIPM
2011	8 February – 28 February	VNIIM	Russia
	8 March – 31 May	KRISS, Pilot laboratory (Refresh of Batteries and ATA Carnet)	Korea (South)
	8 June – 11 July	NMISA	South Africa
	19 July - 11 August	KazInMetr	Kazakhstan
	19 August – 31 August	KRISS, Pilot laboratory	Korea (South)
	8 September - 30 September	NIS	Egypt
	8 October – 30 October	KRISS, Pilot laboratory	Korea (South)

If unforeseen circumstances prevent a laboratory from carrying out the measurements within the time allocated, it should send the standards as originally scheduled without delay to the next laboratory in the schedule. Afterwards, the laboratory may be allowed to carry out the measurements before the end of the KC.

3.4 Transportation

The standards will normally be accompanied by an ATA carnet. Each participant is expected to ship using express door-to-door delivery service or to hand-carry the standard to deliver it to the next scheduled laboratory.

Because the standards should always be in the “IN CAL” state, both during transit and measurement, quick and safe transport is essential . Prompt communication with pilot laboratory should be ensured by the participating laboratory regarding the transport information and status of the standards via both email and FAX.

Every arrival and departure of the standards must be communicated to the pilot laboratory and the next scheduled laboratory using the forms that are attached in the Appendix C of this protocol.

Two or three weeks will be allowed for each participant to keep the standards in his (her) laboratory. This period includes recharging of the operation batteries, stabilization to the laboratory environment, and the measurements. **The standards must be sent to the next laboratory according to the schedule (Table 2), even if the laboratory could not finish all measurements.** If the receiver could pick up the standards from the customs earlier than the schedule, the laboratory will be able to have more measurement days. **One week is allocated as the maximum period for the door-to-door transportation of the standards to the next participant**. Both the receiver laboratory and the sender laboratory should report promptly to the pilot laboratory about the transportation. If any delay is expected, the sender and the receiver should promptly contact the pilot laboratory that will give specific instructions.

Please be sure to fully recharge the standards before sending them.

If any participants want to hand-carry the standards by themselves, they may arrange the transportation taking responsibility of the traveling cost. In this case, the transportation information of the standards should be reported to the pilot laboratory.

3.5 Unpacking, handling, packing

The traveling standards should be handled carefully. Extreme temperature, humidity or pressure changes as well as violent mechanical shocks must be avoided.

Package

The package contains the following items:

- Fluke 732B electronic DC reference standard s/n 6950003 AIST ref. 00AB6277
- Fluke 732B electronic DC reference standard s/n 6950002 AIST ref. 00AB6278
- Fluke 732B electronic DC reference standard s/n 6950004 AIST ref. 00AB6280
- SUNJEM 9600A upgrade boxes (incl. batteries) (3x)
- Transit cases (3x) AIST ref. 00AF7410 AIST ref. 00AF7411 AIST ref. 00AF7412
- Reusable wooden box which can contain the three transit cases
- Fluke 732B instruction manual
- AC line power cord (3x)
- TR-72U datalogger for temperature and humidity s/n 00E609
- ATA carnet (732B:JY950,000.-, Carry box: JY100,000.-, TR-72U JY30,000.-, 9600A JY800,000,- cord :JY1,200.- , each)

When the package arrives at your laboratory, fill the “Receiving-the-standard form” in Appendix C and send it to pilot by both email and FAX.

When you are preparing the package for sending, fill the “Shipping-the-standard checklist form” in the Appendix C and put it in the envelope for the next lab in line.

Powering of the standard

As soon as the standards arrive at the laboratory, each Fluke 732B must be supplied from the AC power line so that the attached batteries are fully charged with the self-contained automatic charger. **Be sure to check each AC line voltage selector at the rear of the Fluke 732B before connecting the AC power cable. Be careful not to supply higher than rated voltage to the Fluke 732B! The full recharge will take about half of the transit time.** If any problems are encountered in charging the transit batteries, this must be immediately reported to the pilot laboratory, which will give specific instructions.

After measurements on each working day, the standards must continuously receive uninterrupted voltage from the AC line power overnight or on weekend to fully recharge the standards for next day measurements. At least half of total battery operation time is required to recharge the Fluke 732B. The front panel **AC PWR** indicator lights when the standard is connected to the AC line power.

During measurements, the Fluke 732B should be disconnected from the AC line power. If the internal battery voltage drops low, the front panel **LOW BAT** indicator will start blinking. Then the standard must be plugged into the AC line power immediately to allow the battery to be recharged. The **IN CAL** indicator must be lit “on” during the whole comparison. In any case that the indicator is found to be “off”, the laboratory should report immediately to the pilot laboratory, which will give specific instructions.

In order to simplify the charging process, all the additional batteries in the ‘Upgrade box’ are permanently connected in parallel to the internal battery of the Fluke 732B, so that no other charging devices are required. By connecting the power cable to the ‘Upgrade Box’ the self-contained automatic charger of the Fluke 732B will do work of charging.

Front panel indicators

AC PWR
The AC PWR indicator lights whenever the standard is connected to AC line power (e.g. 220 V, 60 Hz). **Be sure to adjust each AC line voltage selector at the rear of the Fluke 732B before connecting the AC power cable. Be careful not to supply higher than rated voltage to the Fluke 732B!**

- **IN CAL**
  The IN CAL indicator goes out after excessive drops in battery operating voltage or gross changes in oven temperature.
  If the IN CAL indicator doesn’t light, you must immediately contact the pilot laboratory, which will give specific instructions how to proceed.

- **CHARGE**
  The CHARGE indicator lights on when the standard is connected to the AC line power and the internal battery is in the charging mode. When the battery is near full charge, the CHARGE indicator goes off.

- **LOW BAT**
  The LOW BAT indicator blinks when approximately 5 hours of battery operation time remains. The standard can keep its internal oven at normal temperature for at least 7 days with the help of permanently attached three batteries.
  When LOW BAT blinks, plug the Fluke 732B into the AC line power immediately to avoid extinguishing the IN CAL indicator. The battery is recharged in about half of the used time with the self-contained automatic battery charger.

3.6 Failure of the traveling standard

In case of any damage or malfunctioning of the standards, the participating laboratory must report immediately to the pilot laboratory. If the standards happen to be cooled because of a delay in customs clearance at receiving laboratory's country, additional uncertainty for the thermal hysteresis will be imposed to the uncertainty of the standards.

3.7 Financial aspects, insurance

The sending laboratory is responsible for choosing an express delivery agent, who is capable of providing a tracking number, which will enable a real time web-check of the transportation status on the way to the next destination (door-to-door).
The sending laboratory should pay the charge for the transportation (incl. insurance: 430,000 ¥ per each Fluke 732B) of the standard to the next laboratory.
In case the prepared ATA carnet is not accepted in the participant's economy, the customs duty, if applicable, on his/her border should be paid by the participating laboratory.

4. MEASUREMENT INSTRUCTIONS

4.1 Tests before measurements

Precautions

- Do not short the outputs.
- Make sure not to disconnect the standard from the AC line power for too long.
- Avoid extreme temperature, humidity or pressure changes as well as violent impacts.

Stabilization of the standards

After arrival in the participant's laboratory, the standards should be allowed to stabilize in a temperature and, possibly, humidity controlled room for at least four days before the measurements can begin.
The traveling standard should be handled carefully and be stored in a stabilized environment where relative humidity should be below 55 %.

Powering of the standard during the measurements

When not carrying out measurements, the standards must be connected continuously to the AC line power. Measurement can be carried out after full charge, i.e., after charge indicator turns off.
Measurements should be carried out with the standard disconnected from the AC line power. To allow the standard to stabilize, measurements should not begin any sooner than 4 hours after disconnecting the standard from the AC line power. Connect the AC line after finishing the measurements to recharge the standards. (See **'LOW BAT' in Clause 3.5)**

In addition to the battery-operated measurements, measurements can be made (and submitted to the pilot laboratory) with the standards connected to the AC line power. Notice that connection to the AC line power during measurement will probably have consequences for the connection of guard and/or ground.

4.2 Measurement Performance

Guarding

Assuming that you carry out the voltage measurements with the Fluke 732B's disconnected from the AC line power, instead of the internal GUARD binding post of the Fluke 732B, the CHASSIS (green terminal marked as "GROUND") of the upgrade box should be connected to the guard of your measuring system. At one point in your system the guard should be connected to ground.

Measuring the internal thermistor resistance

The internal thermistor resistance must be reported for each measurement result of output voltage. The thermistor resistances of the standards have nominal values between 38 kΩ and 40 kΩ (see Table 1). To avoid heating of the thermistor, the test current should **not exceed 10 µA**. This implies that most DMMs can not be used in their 100 kΩ range or auto-range setting.

Environmental conditions

The ambient temperature, humidity and pressure must be measured. Corrections must be made for temperature and pressure effects (see next section). Recommended measurement conditions are 23 °C and below 55 %RH.

During transport and stay at the participant's laboratory, the environmental temperature and humidity will be recorded by the data-logger in transit case to check any extreme change in environment. However, please use your own measurement instruments to report more precisely the temperature, relative humidity, and atmospheric pressure during your measurement.

4.3 Method of measurement

Making corrections for temperature and pressure effects

The measured voltages U_{measured} should be corrected for temperature and pressure effects. The temperature effect is taken into account through the thermistor resistance R. The following formula should be used to calculate the corrected voltages $U_{\mathrm{corrected}}$:

$$U_{\mathrm{corrected}} = U_{\mathrm{measured}} - \alpha_{\mathrm{R}} \cdot (R - R_0) - \alpha_{\mathrm{p}} \cdot (p - p_0),$$

where α_{R} and α_{p} are the temperature and pressure coefficients as given in Table 1, p is the ambient air pressure, and p_0 = 1013.25 hPa the reference air pressure. The reference thermistor resistances R_0 depend on the specific standard and are given in Table 1.

Obviously, the uncertainties of both the thermistor resistance measurement and the air pressure measurement contribute to the total uncertainty of measurement.

5. UNCERTAINTY OF MEASUREMENT

5.1 Main uncertainty components, including sources and typical values

The uncertainty calculations must comply with the requirements of the 'Guide to the Expression of Uncertainty in Measurement' (issued by the International Organization for Standardization, first edition 1993, ISBN 92-67-10188-9). Foreseen sources of uncertainty:

- Type A
- DVM or null-detector gain-error uncertainty
- Uncertainty due to irreversibility of scanner or switch
- Leakage-error uncertainty
- Uncertainty due to uncompensated offset voltages
- Microwave-frequency uncertainty
- Uncertainty due to EMI
- Calibration uncertainty of measurement equipment (e.g., for measuring the thermistor resistance, pressure, etc.)

This is not a complete list and should be extended with uncertainty contributions that are specific for the participant's measurement system.

5.2 Scheme to report the uncertainty budget

See Appendix B and Chapter 6

6. MEASUREMENT REPORT

Software

The participant's report must be sent to the pilot laboratory within two months from the completion of his measurements. Reports should be submitted electronically, using the following software:

- Word 2003 or later version for the report including the participant's results
- Excel 2003 or later version for the raw data and detailed uncertainty budget

Contents of report

The report must contain:

- **The results of the measurement**
  For each reported value the following information must be provided using the form attached in Appendix:
  - identification of standard
  - method of measurement
  - date and time of measurement
  - waiting time before starting measurement after disconnect AC line from the Fluke 732B
  - measured voltage
  - thermistor resistance
  - ambient temperature, humidity, and pressure
  - values of correction for temperature and pressure effects
  - measured voltage corrected for temperature and pressure effects
  - the Type A standard uncertainty
  - the Type B standard uncertainty
  - combined standard uncertainty

- the expanded uncertainty of measurement (confidence level of appr. 95 %)
- effective degrees of freedom

- **Uncertainty budget and calculation**
  The uncertainty analysis should include a list of all sources of Type B uncertainty, together with the associated standard uncertainties as well as their evaluation method. For clarity, it is recommended to present the uncertainty budget in the form of a table (see, e.g., chapter 4 of the EA-4/02 document 'Expression of the Uncertainty of Measurement in Calibration').
  For each reported value, the expanded uncertainty of measurement and the coverage factor *k* must be given for confidence level of approximate 95 %.

- **Description of the method of measurement**
  This includes information on:
  - the method applied for correction of offset voltages (manual or automatic switching, reversal of null-detector or not, etc.)
  - the method applied for guarding and shielding, and connection to earth
  - method applied for biasing the Josephson array (bias on or off during measurement)
  - method for Josephson step number adjustment and maximum value of null voltage
  - 'bandwidth' of the voltage measurement (null-detector analog or digital filtering, number of samples, averaging, etc.)

- **A statement of traceability**
  This is only required if the national standard is not considered to be a primary standard.

7. REPORT OF THE COMPARISON

The draft version of the final report will be issued within four months after completion of the comparison. The draft report will be sent to the participants and will be discussed. The whole procedure will be based on the CCEM Guidelines document WGLF/2007-12.

REFERENCES

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[3] F. Liefrink et al, "Comparison of 10 V Electronic Voltage Standards," Final Report: EUROMET project no. 429, September 2002.

[4] J.W. Mueller, "Possible Advantages of a Robust Evaluation of Comparisons," J. Res. Natl. Inst. Stand. Technol. **105**, 551, 2000.

[5] EA-4/02 "Expression of the Uncertainty of Measurement in Calibration".

APPENDIX A: List of participants

- **National Metrology Institute of Japan (NMIJ)**
- **Contact person: Michitaka Maruyama**

Address for correspondence	Address for dispatching the standards
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- **National Metrology Institute of Australia (NMIA)**
- **Contact person: Ernst Louis Marais**

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- **Contact person: Abdul Rashid B. Zainal Abidin**

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- **The Government of the Hong Kong Special Administrative Region**

Standard and Calibration Laboratory (SCL)

- **Contact person: Dennis Lee**

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- **Center for Measurement Standards (CMS)**
- **Contact person: Chun-feng Huang**

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- **Contact person: Surachet Puemchalad and Sittisak Pimsut**

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- **BIPM**
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- **Contact person: Seksembayev Nurlan**

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- **Pilot lab: Korea Research Institute of Standards and Science**
- **Contact person: Kyu-Tae Kim**

Address for correspondence	Address for dispatching the standards
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APPENDIX B: Forms for Summary Report

K11.3.a (1.018 V)

Identification of standard	TZS1	TZS2	TZS3
Method of measurement			
Date and time of measurement (from to)			
Measured voltage (V)			
Thermistor resistance (ohm)/ Ambient temperature (^{o}C)			
Humidity (% R.H.)/ Pressure (hPa)			
Corrected voltage at R_0 and p_0 (V)			
Number of measurements			
Type A standard uncertainty (nV)			
Type B standard uncertainty (nV)			
Combined standard uncertainty (nV)			
Expanded uncertainty (nV)			
Coverage factor k			
Effective degrees of freedom			

K11.3.b (10 V)

Identification of standard	TZS1	TZS2	TZS3
Method of measurement			
Date and time of measurement (from to)			
Measured voltage (V)			
Thermistor resistance (ohm)/ Ambient temperature (^{o}C)			
Humidity (% R.H.)/ Pressure (hPa)			
Corrected voltage at R_0 and p_0 (V)			
Number of measurements			
Type A standard uncertainty (nV)			
Type B standard uncertainty (nV)			
Combined standard uncertainty (nV)			
Expanded uncertainty (nV)			
Coverage factor k			
Effective degrees of freedom			

APPENDIX C: Forms for Transportation Report

(See next pages)

APMP.EM.BIPM-K11.3 COMPARISON

Shipping-the-standard form No 1

(Send this form to the pilot as soon as you have shipped the standard)

Date …………….. **Pages**……………..(including this one)

TO	**Dr. Kyu-Tae KIM** **KRISS, Daejeon, KOREA** FAX: + 82 42 8685018, E-mail: ktkim@kriss.re.kr
FROM	

Comments on the behavior of the standard:

The standard has been shipped to the address:

Shipped on: ***Date***…………… ***Time*** …………….

Means of transport: ***Airplane*** ☐ ***Other*** ………….

Carrier:

Comments on shipment (include tracking number):

APMP.EM.BIPM-K11.3 COMPARISON

Shipping-the-standard form No 2

(Send this form to both the pilot and the lab next in line, as soon as you have shipped the standard)

Date …………….. **Pages**……………..(including this one)

TO

FROM

Comments on the behavior of the standard:

The standard has been shipped to the address:

Shipped on: ***Date***…………… ***Time*** …………….

Means of transport: ***Airplane*** ☐ ***Other*** …………..

Carrier:

Comments on shipment (include tracking number):

APMP.EM.BIPM-K11.3 COMPARISON fax

8. Receiving-the-standard form

(Send this form to the pilot laboratory as soon as you receive the standard)

Date …………….. **Pages**……………..(including this one)

TO	**Kyu-Tae Kim** **KRISS, Daejon, KOREA** **FAX: +82 42 868 5018**
FROM	

Arrival at the lab: *Date* ……… *Time*……………

IN CAL lamp	***ON*** ☐	***Off*** ☐
LOW BAT lamp	***Blinks*** ☐	***Off*** ☐
Was the TR-72U datalogger for temperature and humidity working well?	***Yes*** ☐	***No*** ☐
Was the package damaged? ***Comments:***	**Yes** ☐	**No** ☐
Was the standards damaged? ***Comments:***	**Yes** ☐	**No** ☐
Was all the material available, following the receiving checklist?	**Yes** ☐	**No** ☐

Comments:

APMP.EM.BIPM-K11.3 COMPARISON

Shipping-the-standard checklist form.

(While you are making the package ready, check that all material is included)

Are these items in the package?

9.	YES ☐	NO ☐
10.		
Three Fluke 732B's with upgrade box		
Digital thermometer	YES ☐	NO ☐
Digital hygrometer	YES ☐	NO ☐
Fluke732B instruction manual	YES ☐	NO ☐
ATA Carnet	YES ☐	NO ☐
Sealed envelopes for laboratories next in line in your circulation loop	YES ☐	NO ☐

Recharge of the batteries:

Did you fully recharge the operation batteries? YES ☐ NO ☐

Please, when the package is ready, seal it in the most convenient way for you in order to prevent unauthorised access to the instrument. Refer to the pilot laboratory co-ordinator if you need further information.

Checked by ____________________________________

Date ____________________________________