Comparison of 1.018 V and 10 V Standards between the VMI (Socialist Republic of Vietnam) and the KRISS (Republic of Korea)

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ABSTRACT

A comparison of DC voltage standards between the Korea Research Institute of Standards and Science (KRISS) and the Vietnam Metrology Institute (VMI) has been carried from 2 July to 17 August of 2012. The comparison was made at the 1.018 V and the 10 V level by measuring two Zener references which were hand-carried for a quick transfer between the two laboratories. The difference between the measurements was -0.9 μV with an uncertainty of 1.5 μV at 95 % level of confidence for the 10 V level, 0.0 μV with an uncertainty of 0.2 μV at 95 % level of confidence for the 1.018 V level.

1. INTRODUCTION

The Voltage Standard of Vietnam Metrology Institute (VMI) and the Josephson Voltage Standard (JVS) of Korea Research Institute of Standards and Science (KRISS) were compared at both 10 V and 1.018 V level with using Transportable Zener Voltage Standards (TVS) from June to August 2012.

The aim of this bilateral comparison in the frame of the APMP- Regional Metrology Organization (APMP-RMO) Key Comparisons, was to check the coherence between the two NMI's voltage standards and to link the voltage reference of VMI to that of KRISS and to that of the Bureau International des Poids et Mesures (BIPM) using the results of the JVS KRISS-BIPM comparison performed in February 2008, according to the BIPM.EM-K11 key comparison. Other main targets of this comparison are to check the correct traceability of the VMI standards and the correctness of the calibration results and to confirm the proposed CMC values of VMI in the field of DC voltage.

This comparison was approved by the Low Frequency Working Group (WGLF) of the Consultative Committee for Electricity and Magnetism (CCEM) and registered in the Comité International des Poids et Mesures (CIPM) Key Comparison Database (KCDB) as APMP.EM.BIPM-K11.4**.**

2. PARTICIPANTS AND ORGANIZATION OF THE COMPARISON

2.1 Participants

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2.2 Quantity

DC Voltage at 10 V and 1.018 V

2.3 Comparison schedule

This comparison was carried out from 2 July to 17 August of 2012, started several days late, but completed as originally scheduled.

2.4 Comparison organization

The comparison was organized as Table 1.

Table 1. Comparison schedule

Year	Date of Measurement	Laboratory	Country or Economy
2012	2 July – 6 July	KRISS, Pilot laboratory	Korea (Rep. of)
	12 July – 27 July	VMI	Vietnam
	3 August – 17 August	KRISS, Pilot laboratory	Korea (Rep. of)

3. TRAVELLING STANDARD AND MEASUREMENT INSTRUCTION

3.1 Description of the standards

The adopted travelling standards, Zener voltage standards, were labeled as DC reference standards Fluke 732B, and identified as follows:

Zener	s/n
TZS-K	6270008 (KRISS)
TZS-V	7135019 (VMI)

The two Zener voltage standards were provided by KRISS and VMI, respectively, and carefully hand-carried by a VMI researcher to minimize transportation time and the effect of environmental condition changes during transportation. The temperature and pressure coefficients were characterized using KRISS JVS during the period from 21 May to 27 June of 2012 prior to the first comparison measurement. The result is shown in Table 2. The temperature effect is expressed in terms of the resistance of internal oven thermistors (α_R).

Table 2. Temperature and pressure coefficients of 10 V and 1.018 V outputs.

(The uncertainties are stated in terms of combined standard uncertainty with $k = 1$)

Standard	Output	Reference thermistor resistance R_0 (kΩ)	Temperature coefficient α_R (nV Ω^{-1})	Reference pressure P_0 (hPa)	Pressure coefficient α_P (nV hPa^{-1})
TZS-K	10 V	38.650	1.4 ± 0.2	998.00	30 ± 11
TZS-V	10 V	38.650	3.1 ± 0.2	998.00	37 ± 8
TZS-K	1.018 V	38.650	-0.27 ± 0.03	998.00	-7.4 ± 1.3
TZS-V	1.018 V	38.650	0.29 ± 0.02	998.00	0.7 ± 0.6

The measurement results for the temperature and pressure coefficient characterization are shown in Figs. 1 and 2.

3.2 Quantities to be measured and conditions of measurement

DC voltage outputs 1.018 V and 10 V for the two standards were measured. The results will be linked to BIPM.EM-K11.a and BIPM.EM -K11.b, respectively. Due to the limited number of available TZS's, a careful and quick transport by hand-carrying was attempted successfully. The ambient temperature, humidity and pressure must be measured. Corrections must be made for temperature and pressure effect. The effect of humidity to the Zener standards is known to have very slow time response [1]. In consideration of the quick time schedule of the comparison, the humidity effect can be treated as a time drift effect when the reference value is calculated by interpolation between two reference measurements as in the case of an earlier EUROMET KC [2].

3.3 Measurement instructions

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 humidity controlled room for at least two days before the measurements can begin.

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 2 hours after disconnecting the standard from the AC line power. Connect the AC line after finishing the measurements to recharge the standards. *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.

Guarding

It is assumed that you carry out the voltage measurements with the Fluke 732B’s disconnected from the AC line power. Both standards are kept floating. To reduce external noise, the GUARD of the Fluke 732B should be connected to ground potential of the measurement system andCHASSIS GROUND of the Fluke 732B should be disconnected.

Measuring the internal thermistor resistance

The internal thermistor resistance must be reported so that a temperature correction can be made. 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). It is recommended that the measurement conditions in both laboratories are similar and in this case preferably 23 ^{o}C and 45 % (R.H.), the conditions at KRISS.

3.4 Deviations from the protocol

A blind test method was unintentionally adopted for comparison, where the Josephson calibration result was hidden by using incorrect Josephson step number, and disclosed by recalculation with the correct step number after all measurements were completed. Finally, it helped to reinforce the transparency and reliability of the comparison even though the KRISS measurement was done in the presence of VMI staff at KRISS.

4. METHODS OF MEASUREMENTS

VMI NATIONAL VOLTAGE STANDARD

The NATIONAL VOLTAGE STANDARD of VMI is a group of 3 Zener reference modules (Model 7000). This incorporate a 7000N Nanoscan Module that provides one 10 V Average Output, one 1 V Divided Output and one 4-wire buffered 10 V Output, together with a measurement scan controller, a null detector, and a fiber-optic based RS232 interface to a PC. Each 7000 Zener reference module provides a 1.018 V Output also. VMI NATIONAL VOLTAGE STANDARD has been made traceable to the SI through yearly calibration (KRISS) using a Zener voltage standard (Fluke 732B). For 10 V measurement, internal detector with a manufacturer's software was used which is available only for 10 V calibration. For 1.018 V measurement, Nanovolt meter Agilent 34420A was used as a detector to find the potential difference between VMI's national standards and travelling standard. Both measurement circuits were partly shielded but not grounded. Only chassis' of both detectors were automatically grounded via power line cables. Isolation between any instrument terminals and ground is estimated to be higher than 20 GΩ according to the manufacturer's specifications.

KRISS JVS

The JVS of KRISS has following features.

- 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.

5. REPEATED MEASUREMENTS OF THE PILOT INSTITUTE, BEHAVIOUR OF THE TRAVELLING STANDARDS

Prior to the comparison, the behavior of the traveling standards has been investigated, especially the temperature coefficients and the pressure coefficients at KRISS. Fig. 1 shows the measurements for the temperature coefficients evaluation. Fig. 2 shows the measurements for the pressure coefficients evaluation. In order to evaluate the temperature coefficients, the temperature variation was made in the vicinity of the reference thermistor resistance of 38.650 kΩ. Only 3 thermistor resistance points (R_1, R_2, R_3 in the order of measurement sequence) were taken to calculate the temperature coefficient, resulting in a large uncertainty as shown in the Table 2. The uncertainty was calculated according to the following mathematical model.

$$\alpha_R = \frac{\bar{V}_2 - \left\{\bar{V}_1 + \bar{V}_3\right\}/2}{R_2 - \left\{(R_1 + R_3)/2\right\}} \qquad (5\text{-}1)$$

where $\bar{V}_i$ was defined as average of voltages measured at temperature R_i, and R's represent thermistor resistances corresponding to the temperature settings.

Then the uncertainty of the temperature coefficient is given by;

$$u^2(\alpha_R) = \frac{u\left(\bar{V}_2\right)^2 + \left\{u\left(\bar{V}_1\right)^2 + u\left(\bar{V}_3\right)^2\right\}/4}{\left[R_2 - \left\{(R_1 + R_3)/2\right\}\right]^2} + \left\{\bar{V}_2 - \left(\bar{V}_1 - \bar{V}_3\right)/2\right\}^2 \frac{u\left(R_2\right)^2 + \left\{u\left(R_1\right)^2 + u\left(R_3\right)^2\right\}/4}{\left[R_2 - \left\{(R_1 + R_3)/2\right\}\right]^4}$$

$$\therefore u(\alpha_R) \approx \alpha_R \sqrt{\frac{u\left(R_2\right)^2 + \left\{u\left(R_1\right)^2 + u\left(R_3\right)^2\right\}/4}{\left[R_2 - \left\{(R_1 + R_3)/2\right\}\right]^2}} \qquad (5\text{-}2)$$

where we assumed that the influences of uncertainties of the voltage measurements are negligibly small compared to those of the uncertainties of resistance measurements.

All V_i's are independent to each other, thus the Welch-Satterwaite equation [3] says that the corresponding degree of freedom is;

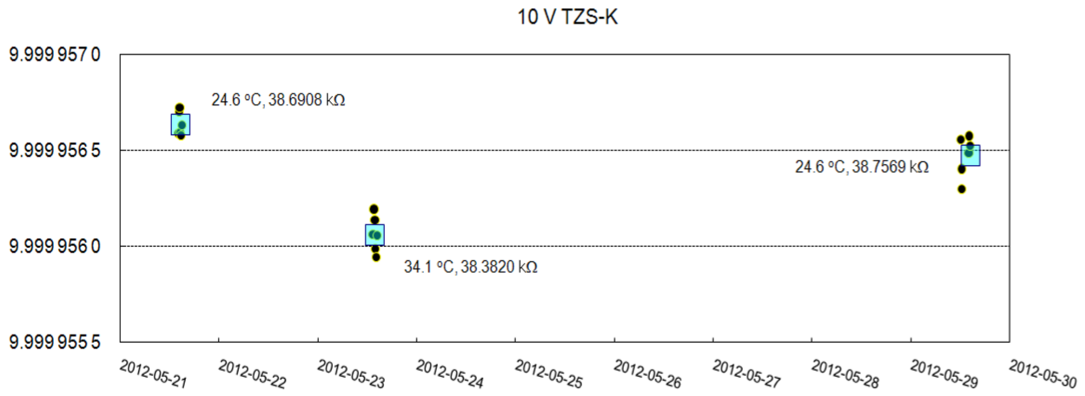
$$\begin{aligned} \nu_R &= \frac{\left\{u\left(R_2\right)^2 + u\left(R_1\right)^2/4 + u\left(R_3\right)^2/4\right\}^2}{\frac{u\left(R_2\right)^4}{3} + \frac{\left\{u\left(R_1\right)^2/4\right\}^2}{3} + \frac{\left\{u\left(R_3\right)^2/4\right\}^2}{3}} \\ &\simeq 3\frac{\left\{1.5u\left(R_1\right)^2\right\}^2}{1.125u\left(R_1\right)^4} = 6 \end{aligned} \qquad (5\text{-}3)$$

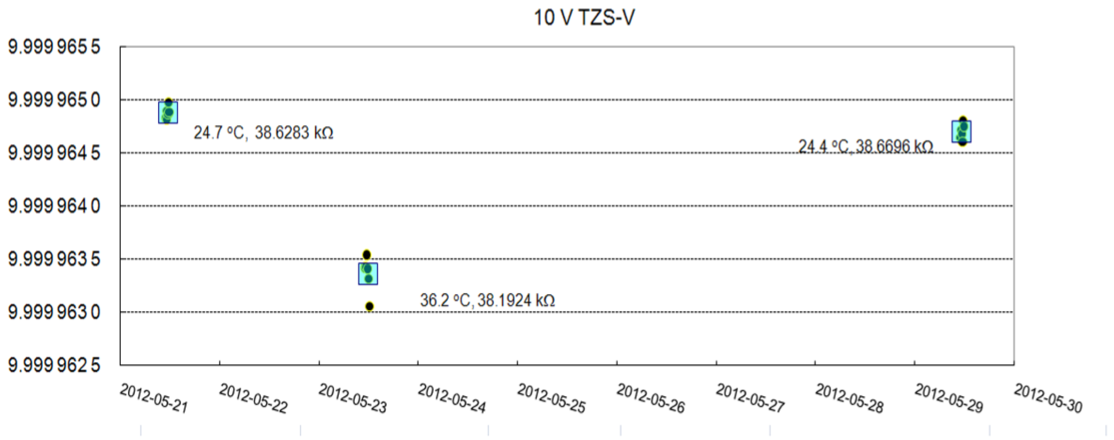
where we assumed that all V_i's have the same variation characteristics.

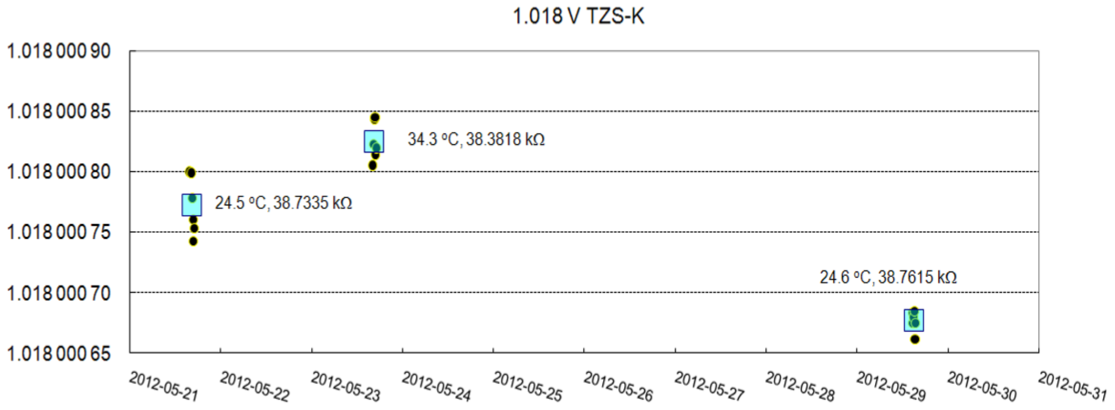
The relative magnitudes of temperature correction values were smaller than $6\text{x}10^{-8}$, so were the uncertainty contributions from the temperature coefficients with respect to overall uncertainty levels of this comparison. For pressure coefficients, we used a linear regression analysis in the commonly available software to obtain the values given in the Table 2. We found that there were no significant differences in the results between the 3 points-method and the linear regression method. Using the coefficients of the Table 2, the corrected voltage, V_i, to be taken as the corresponding NMI's measurement result (i: VMI or KRISS), is calculated from the measured voltage, $V_i^{(0)}$ according to the following equation.

$$\begin{aligned} V_i &= V_i^{(0)} + \Delta V_T + \Delta V_P \\ &= V_i^{(0)} - \alpha_R\,(R - R_0) - \alpha_P\,(P - P_0) \end{aligned} \tag{5-4}$$

Where R denotes the thermistor resistance and P denotes the atmospheric pressure.







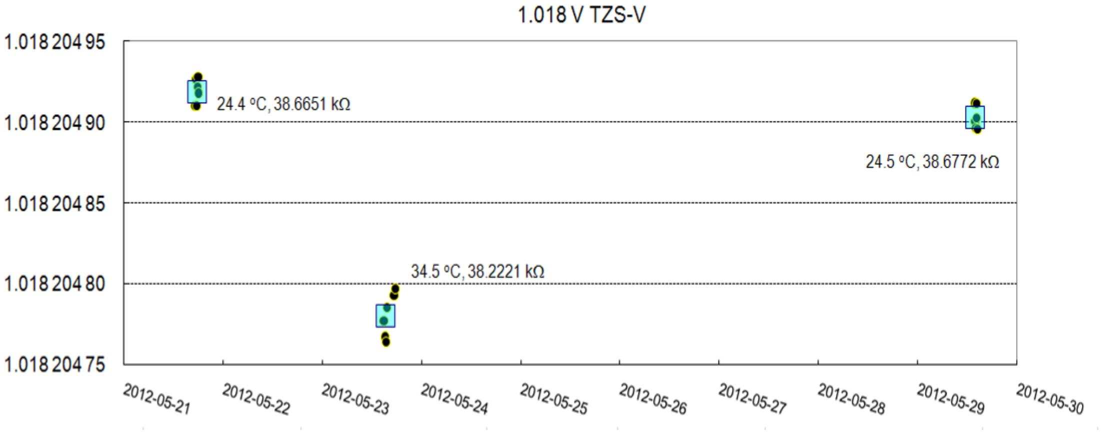
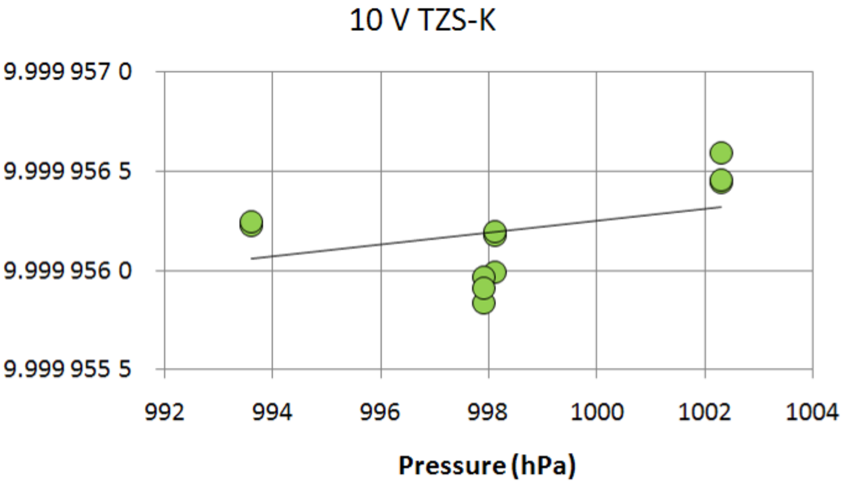
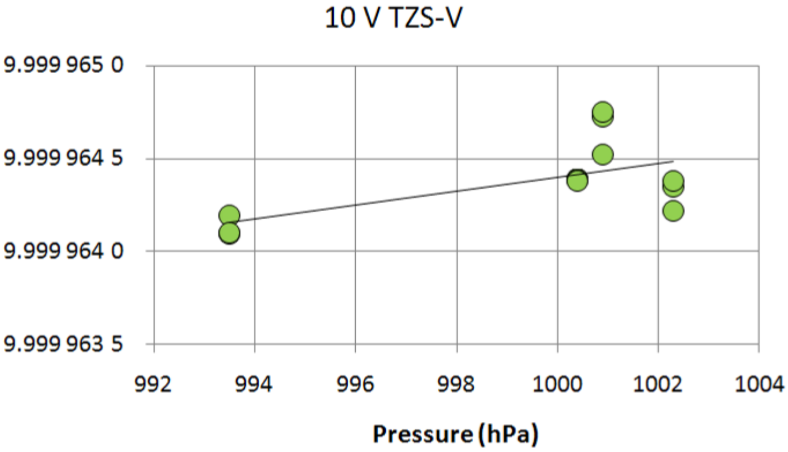
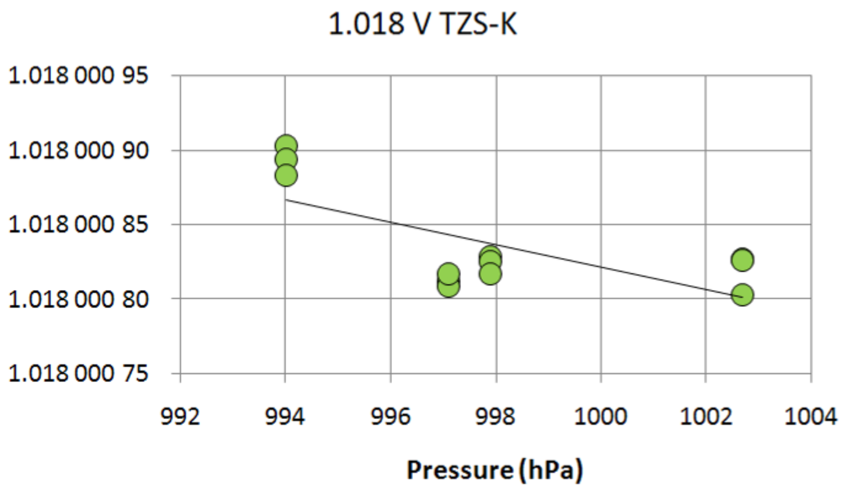


Fig. 1. Measurement data for temperature coefficient evaluation.
Squares are average of each group. (X-axis: Date, Y-axis: Output voltage(V))







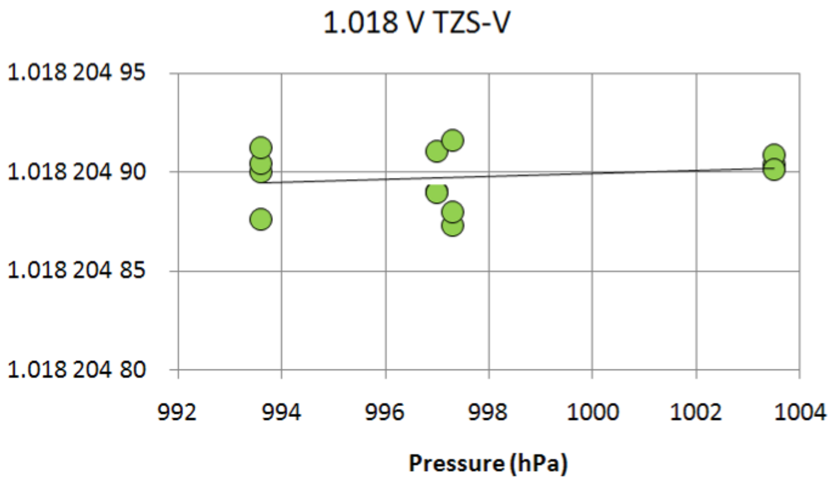
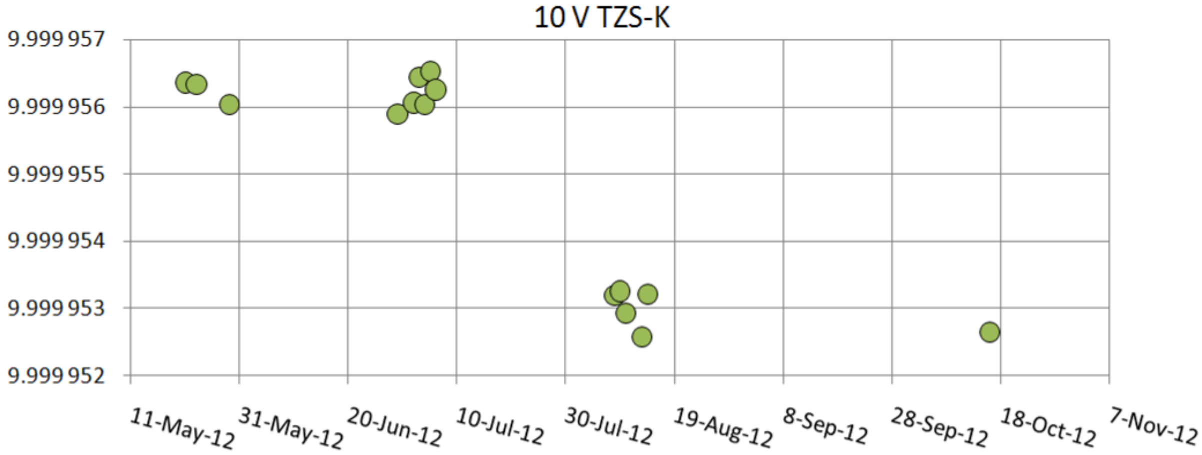


Fig. 2. Measurement data for pressure coefficient evaluation. The solid line of each graph denotes a straight line fitted to the data.

The time drift behavior of the traveling standards is shown in Fig. 3, where measurement results by KRISS are plotted. The last points of 10 V TZS-K and 1.018 V TZS-K in Fig. 3 which are a follow-up measurement after finishing all comparison measurements are found to be a little deviated from the previous trend. This means that unknown transportation effect, presumably from a big humidity change happened during the TZS's traveling. But the comparison period was so short with respect to the time constant of the humidity effect that we could assume that an approximately linear drift model is applicable for this comparison.


10 V TZS-K
9.999 957
9.999 956
9.999 955
9.999 954
9.999 953
9.999 952
11-May-12
31-May-12
20-Jun-12
10-Jul-12
30-Jul-12
19-Aug-12
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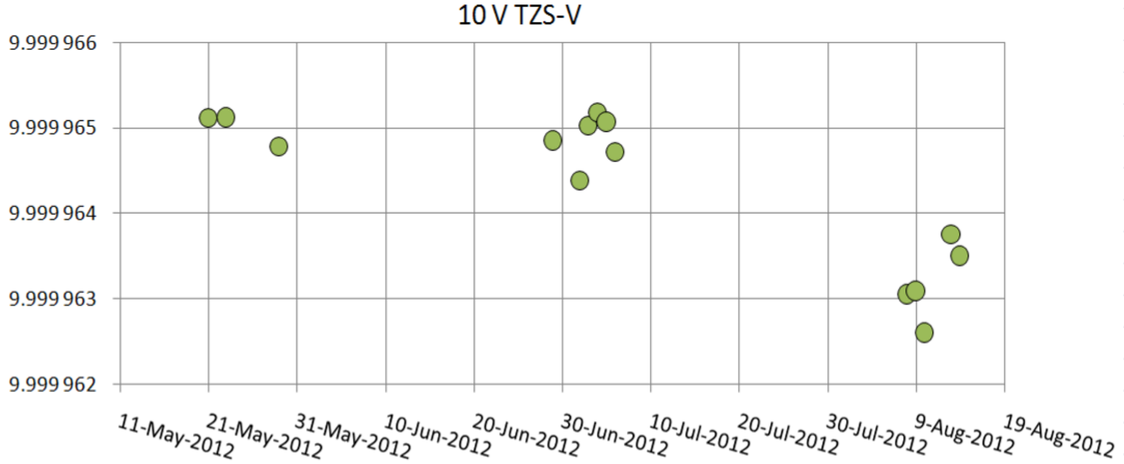
28-Sep-12
18-Oct-12
7-Nov-12


10 V TZS-V
9.999 966
9.999 965
9.999 964
9.999 963
9.999 962
11-May-2012
21-May-2012
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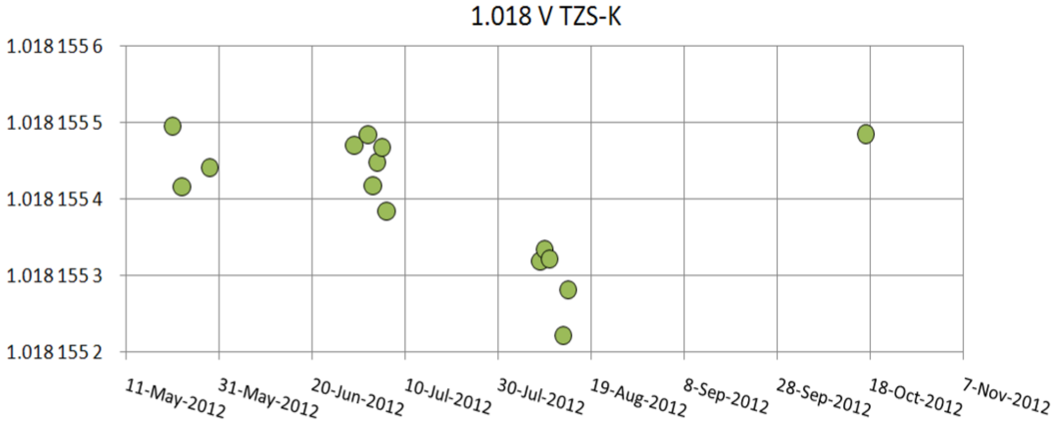
9-Aug-2012
19-Aug-2012


1.018 V TZS-K
1.018 155 6
1.018 155 5
1.018 155 4
1.018 155 3
1.018 155 2
11-May-2012
31-May-2012
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18-Oct-2012
7-Nov-2012

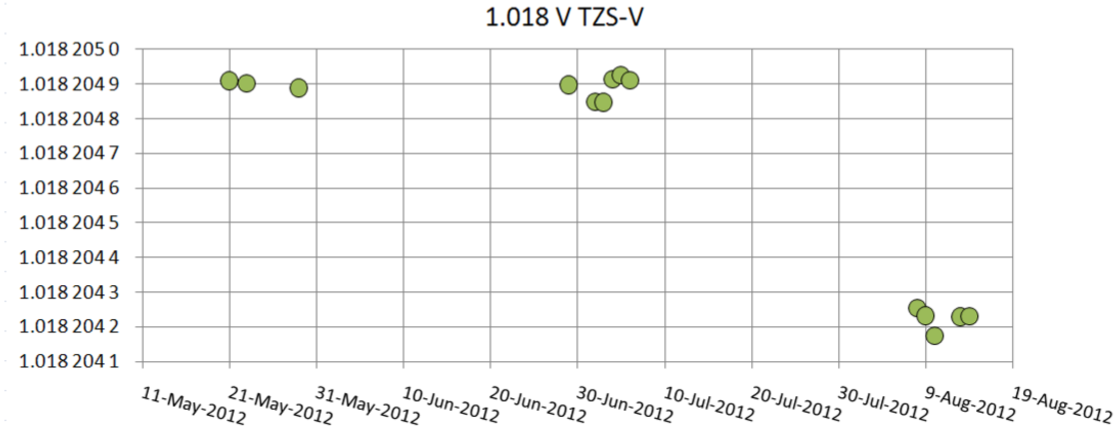


Fig. 3. Time drift behavoir of the traveling standards measured at KRISS.

6. MEASUREMENTS RESULTS

The comparison measurement results are shown in Table 3 and are plotted in Fig. 4, where the temperature and pressure effect already corrected with using the coefficients given in Table 2.

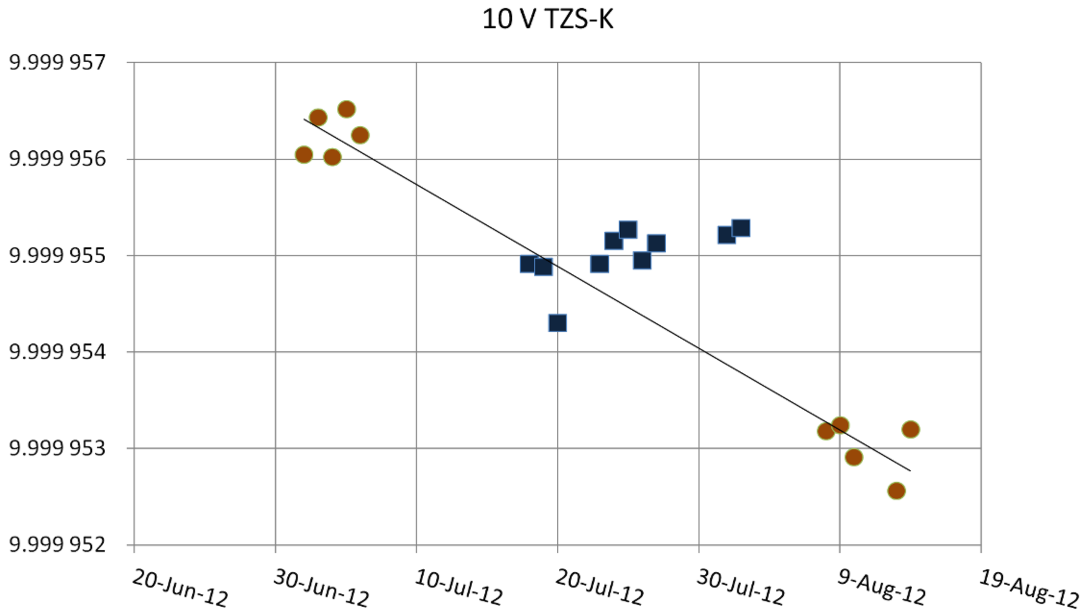
Table 3. comparison measurement result. Shaded rows denote KRISS results, white rows denote VMI results.

Date	Temp (°C)	Rel. Humidity (%)	Pressure (hPa)	Thermistor (Mohm)	Mean Value (V)	Std. Deviation (nV)	Corrected Value (V)
10 V TZS-K							
2-Jul-12	23.7	53.0	994.8	0.0387786	9.999 956 139	083	9.999 956 057
3-Jul-12	25.1	43.5	990.9	0.0387104	9.999 956 313	044	9.999 956 443
4-Jul-12	25.0	48.0	994.9	0.0387136	9.999 956 025	119	9.999 956 029
5-Jul-12	24.7	47.5	996.7	0.0387361	9.999 956 604	049	9.999 956 523
6-Jul-12	24.8	46.5	988.6	0.0387217	9.999 956 072	224	9.999 956 254
18-Jul-12	25.9	51.7	998.9	0.0385069	9.999 954 745	296	9.999 954 917
19-Jul-12	26.5	56.7	1,000.5	0.0385209	9.999 954 782	187	9.999 954 887
20-Jul-12	26.2	57.1	1,002.4	0.0385304	9.999 954 271	084	9.999 954 308
23-Jul-12	26.3	47.5	993.3	0.0385657	9.999 954 660	086	9.999 954 920
24-Jul-12	25.5	51.4	992.7	0.0386282	9.999 954 969	079	9.999 955 159
25-Jul-12	25.1	57.6	995.9	0.0386413	9.999 955 198	153	9.999 955 274
26-Jul-12	25.5	54.6	998.9	0.0386232	9.999 954 941	132	9.999 954 952

27-Jul-12	25.1	53.7	998.6	0.0386595	9.999 955 166	189	9.999 955 134
1-Aug-12	25.3	61.8	998.7	0.0386395	9.999 955 227	140	9.999 955 220
2-Aug-12	25.9	59.9	998.3	0.0386177	9.999 955 252	131	9.999 955 288
8-Aug-12	25.9	42	997.4	0.0386675	9.999 953 194	067	9.999 953 187
9-Aug-12	23.4	43	996.5	0.03877185	9.999 953 374	098	9.999 953 248
10-Aug-12	23.35	46.5	997.85	0.0387609	9.999 953 069	190	9.999 952 918
13-Aug-12	23.9	41	992.15	0.0387364	9.999 952 517	063	9.999 952 571
14-Aug-12	22.7	48	997.65	0.03883125	9.999 953 452	038	9.999 953 209
10 V TZS-V							
2-Jul-12	23.9	47.0	995.3	0.0387146	9.999 963 986	060	9.999 963 886
3-Jul-12	24.7	42.5	990.7	0.0386727	9.999 964 322	109	9.999 964 522
4-Jul-12	24.6	42.5	994.3	0.0386784	9.999 964 626	095	9.999 964 677
5-Jul-12	24.8	45.5	996.8	0.0386610	9.999 964 558	014	9.999 964 570
6-Jul-12	25.3	43.5	989.0	0.0386544	9.999 963 896	085	9.999 964 216
18-Jul-12	24.8	47.2	1,000.7	0.0385488	9.999 964 347	195	9.999 964 561
19-Jul-12	26.0	50.1	1,003.6	0.0385014	9.999 964 188	107	9.999 964 441
20-Jul-12	25.9	52.1	1,003.4	0.0384723	9.999 965 097	078	9.999 965 450
23-Jul-12	27.0	44.3	996.0	0.0384596	9.999 964 516	191	9.999 965 181
24-Jul-12	25.6	52.5	994.2	0.0385736	9.999 964 648	134	9.999 965 027
25-Jul-12	25.1	56.3	996.4	0.0385909	9.999 964 523	135	9.999 964 764
26-Jul-12	25.3	56.7	999.3	0.0385910	9.999 964 434	200	9.999 964 568
27-Jul-12	25.1	56.2	999.6	0.0385911	9.999 964 809	170	9.999 964 934
1-Aug-12	25.2	64.4	999.1	0.0386652	9.999 964 697	254	9.999 964 610
2-Aug-12	25.8	62.0	999.2	0.0385939	9.999 964 281	144	9.999 964 410
8-Aug-12	26.2	50	997.2	0.0386045	9.999 962 382	105	9.999 962 552
9-Aug-12	23.45	46.5	996.35	0.0387168	9.999 962 737	057	9.999 962 591
10-Aug-12	23.95	46	997.1	0.0387227	9.999 962 298	105	9.999 962 106
13-Aug-12	23.55	41	992.7	0.0387178	9.999 963 265	090	9.999 963 251

14-Aug-12	23.8	45	997.4	0.0387494	9.999 963 288	070	9.999 963 002
1.0181 V TZS-K							
2-Jul-12	23.8	44.5	992.9	0.0387770	1.018 155 488	010	1.018 155 485
3-Jul-12	24.5	44.0	990.3	0.0387393	1.018 155 451	042	1.018 155 418
4-Jul-12	24.5	46.0	994.5	0.0387452	1.018 155 449	013	1.018 155 448
5-Jul-12	25.1	45.0	996.9	0.0387213	1.018 155 457	028	1.018 155 468
6-Jul-12	24.6	46.0	988.2	0.0387386	1.018 155 434	025	1.018 155 385
18-Jul-12	25.8	51.6	998.9	0.0385142	1.018 155 695	038	1.018 155 665
19-Jul-12	26.2	56.6	1,000.0	0.0385264	1.018 155 340	084	1.018 155 322
20-Jul-12	25.8	57.2	1,002.1	0.0385543	1.018 155 690	083	1.018 155 695
23-Jul-12	25.9	47.5	993.2	0.0385642	1.018 155 556	058	1.018 155 497
24-Jul-12	25.7	51.5	992.5	0.0386196	1.018 155 347	140	1.018 155 298
25-Jul-12	26.1	57.5	995.6	0.0386434	1.018 155 667	076	1.018 155 647
26-Jul-12	25.5	54.5	998.8	0.0386258	1.018 155 574	094	1.018 155 574
27-Jul-12	25.2	55.4	997.3	0.0386412	1.018 155 269	216	1.018 155 261
31-Jul-12	25.4	61.6	997.8	0.0386371	1.018 155 653	105	1.018 155 648
1-Aug-12	26.1	58.3	996.7	0.0386124	1.018 155 811	092	1.018 155 791
8-Aug-12	24.7	49	996.59	0.0387000	1.018 155 316	021	1.018 155 319
9-Aug-12	23.3	48.5	996.2	0.0387351	1.018 155 325	015	1.018 155 335
10-Aug-12	23.5	45.5	996.8	0.0387296	1.018 155 309	027	1.018 155 322
13-Aug-12	23.1	42.5	992.35	0.0387549	1.018 155 236	033	1.018 155 222
14-Aug-12	23.6	45	997.4	0.0387192	1.018 155 268	013	1.018 155 282
1.0182 V TZS-V							
2-Jul-12	25.1	46.5	991.4	0.0386564	1.018 204 846	009	1.018 204 849
3-Jul-12	25.7	49.0	990.2	0.0386480	1.018 204 841	007	1.018 204 847
4-Jul-12	25.3	47.0	994.2	0.0386396	1.018 204 908	014	1.018 204 913
5-Jul-12	25.8	42.0	996.8	0.0386354	1.018 204 920	011	1.018 204 925
6-Jul-12	24.7	50.5	988.0	0.0386759	1.018 204 912	007	1.018 204 911

18-Jul-12	24.8	47.2	1,000.6	0.0385512	1.018 204 504	009	1.018 204 531
19-Jul-12	26.0	50.1	1,002.2	0.0385236	1.018 204 495	055	1.018 204 528
20-Jul-12	25.9	52.1	1,002.5	0.0384897	1.018 204 487	020	1.018 204 530
23-Jul-12	27.0	44.3	995.8	0.0384612	1.018 204 500	017	1.018 204 556
24-Jul-12	25.6	52.5	994.0	0.0385716	1.018 204 503	057	1.018 204 529
25-Jul-12	25.1	56.3	996.3	0.0385914	1.018 204 462	030	1.018 204 480
26-Jul-12	25.3	56.7	999.4	0.0386012	1.018 204 513	013	1.018 204 526
27-Jul-12	25.2	54.4	997.9	0.0386128	1.018 204 503	057	1.018 204 514
31-Jul-12	25.5	61.2	996.1	0.0386055	1.018 204 519	052	1.018 204 534
1-Aug-12	26.2	58.1	995.1	0.0385771	1.018 204 481	049	1.018 204 504
8-Aug-12	25.5	39	996.6	0.0386019	1.018 204 239	013	1.018 204 254
9-Aug-12	23.1	48.5	995.55	0.0388004	1.018 204 273	009	1.018 204 232
10-Aug-12	23.15	47.5	995.95	0.0387984	1.018 204 216	015	1.018 204 174
13-Aug-12	22.9	45	992.4	0.0388086	1.018 204 271	015	1.018 204 228
14-Aug-12	23.2	44	997.4	0.0387962	1.018 204 273	038	1.018 204 231



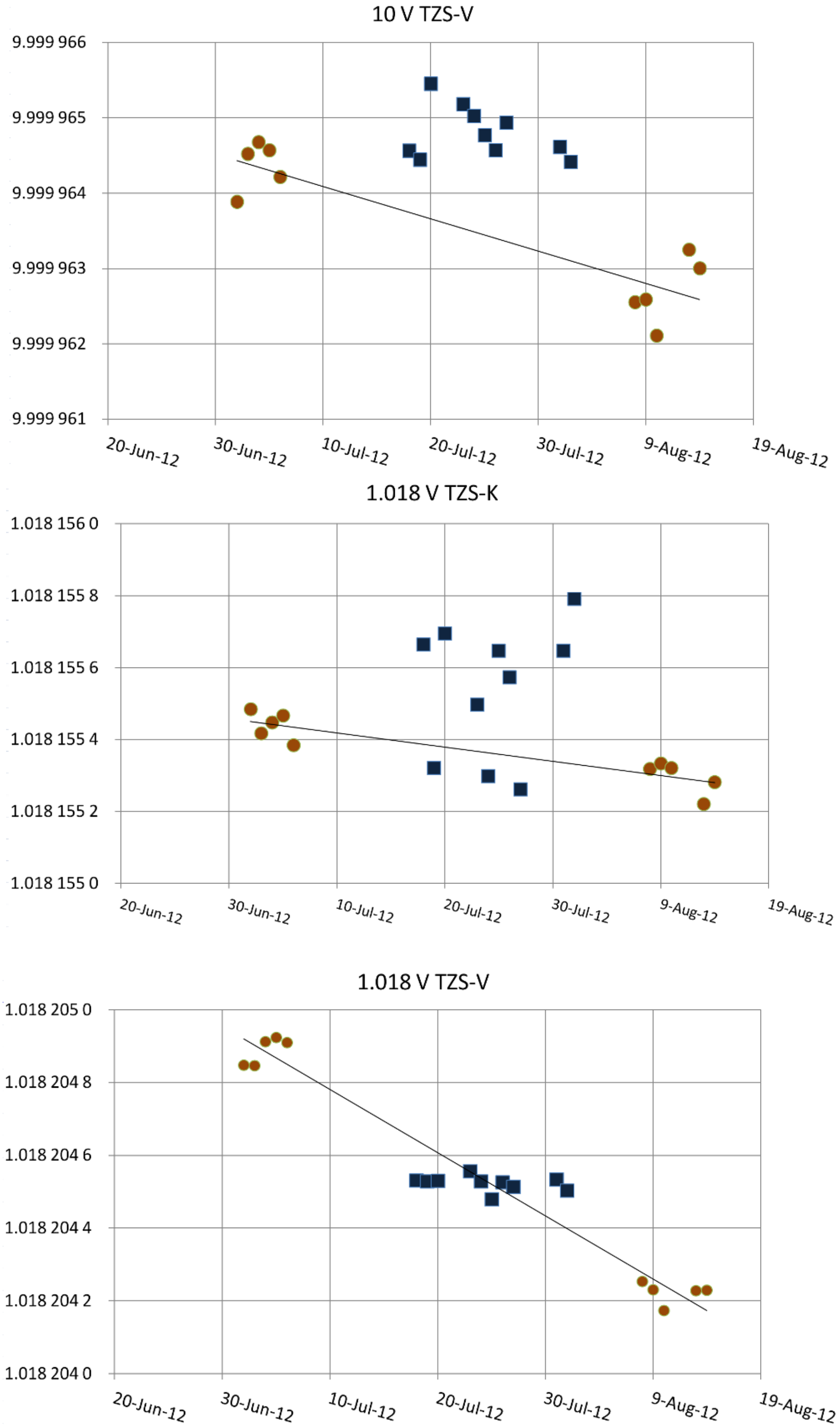


Fig. 4. Comparison measurement results after all corrections, where squares are VMI results and circles are KRISS results. The solid line of each graph denotes a straight line fitted to the KRISS data.

The summary of measurement results are listed in Table 4.

Table 4. Measured values and differences between VMI and KRISS.

	VMI Measurement, V_{VMI} /V	$u(V_{\mathrm{VMI}})$ /μV	ν_VMI	*KRISS Measurement,* V_{KRISS} /V	$u(V_{\mathrm{KRISS}})$ / μV	ν_KRISS	*Uncertainty due to stability of traveling standard,* u_T/ μV	ν_T	*Difference,D* V_{VMI} - V_{KRISS} (μV)	*Standard Uncertainty of D* / μV	ν_{eff}
TZS-K, 10 V	9.999 955 006	1.04	81	9.999 954 493	0.110	14	0.29	8	0.513	1.083	90
TZS-V, 10 V	9.999 964 779	1.04	82	9.999 963 456	0.197	8	0.45	8	1.339	1.059	64
TZS-K, 1.018 V	1.018 155 540	0.285	27	1.018 155 362	0.017	9	0.038	8	0.178	0.286	27
TZS-V, 1.018 V	1.018 204 523	0.112	197	1.018 204 533	0.027	8	0.058	8	-0.010	0.115	78

The KRISS measurements were made both before and after the VMI measurement. The two measurement data sets were used to calculate an expected value at the time of VMI measurement. The KRISS measurement value of Table 4 is the expected value at the average time of VMI measurement which was calculated by a linear regression fit from the two sets of KRISS measurements. The uncertainty budget of VMI measurement is given in Table 6, and the uncertainty budget of KRISS measurement is given in Table 7. The uncertainty of thermals is estimated from thermal effects of reverse switch and circuits. The uncertainty from digital nanovoltmeter is from a nonlinearity effect of the meter gain at the measurement points within a usual range of -1 mV~1 mV, as a result, the convolution of the gain nonlinearity distribution and the measurement point distribution becomes a Gaussian-like distribution, where the gain nonlinearity was estimated by statistical regression (type A) in our case, and the measurement points was assumed as a rectangular distribution (type B). The uncertainty due to the temperature correction has two components; the term by coefficient, $u(\alpha_R)$ $(\langle R\rangle - R_0)$, and the term by thermistor resistance, $\alpha_R\, u(R)$.

Both terms were estimated by a standard deviation of typical measurement data. Similarly, the uncertainty due to pressure can be estimated, we found that the uncertainty by pressure measurement is negligibly small so only the coefficient term can be included in the budget table. The uncertainty of KRISS measurement value at column $u(V_{\mathrm{KRISS}})$ of Table 3 is given by RSS (root sum square) of standard uncertainty of the linear regression, u_{reg} and type B standard uncertainty of KRISS measurement, u_{B}.

$$u(V_{\mathrm{KRISS}}) = \sqrt{{u_{\mathrm{reg}}}^2 + {u_{\mathrm{B}}}^2} \tag{6-1}$$

$$u_{reg} = s\sqrt{\frac{1}{n} + \frac{\left(t-\bar{t}\right)^2}{\sum_{j=1}^{n}\left(t_j-\bar{t}\right)^2}} \tag{6-2}$$

where t is the average time of VMI measurement, $\bar{t}$ is the mean of all j-th measurement time, t_j, n is the number of total data used for the regression, s is standard deviation of the regression given by the following expression,

$$s = \sqrt{\sum_{j=1}^{n}\frac{\left(V_j - V_{\mathrm{exp}}(t_j)\right)^2}{n-2}} \tag{6-3}$$

where $V_{\mathrm{exp}}(t_j)$ is the calculated expected value by the linear regression at time t_j. The next column, u_{T} is for the uncertainty due to the possible nonlinear change of the traveling standard during the comparison period. The standard deviation of all the KRISS measurement data from the regression fit was taken as the u_{T}. The standard uncertainty of D, the difference $V_{\mathrm{VMI}} - V_{\mathrm{KRISS}}$, was calculated by RSS of $u(V_{\mathrm{VMI}})$, $u(V_{\mathrm{KRISS}})$, u_{T}. The degree of freedom was calculated by Welch-Satterthwaite equation.[3] As we have two D's for each voltage level and the standard uncertainty is not uniform, a weighted mean approach was chosen to calculate the final difference and the associated uncertainty. The inverses of standard variations (square of standard uncertainties of the Table 4) were used as the weighting factors. The final result is described in Table 5.

Table 5. Comparison result between VMI and KRISS.

	D / μV	u / μV	ν	U / μV
10 V	0.935	0.757	154	1.486
1.018 V	0.017	0.107	105	0.212

D : Difference in measurement result between VMI and KRISS, $\boldsymbol{V_{VMI} - V_{KRISS}}$
u : Combined standard uncertainty of ***D***
U: Expanded uncertainty of at 95 % confidence level

Table 6. Uncertainty budget of VMI measurements after corrections of temperature and pressure ($V_{\mathrm{VMI}} = V^{(0)}_{\mathrm{VMI}} + \Delta V_T + \Delta V_P$)

(a) 10 V of TZS-K

No.	Component	Distribution	c_i	$u(x_i)$ V	$\lvert c_i\, u(x_i)\rvert$ V	ν_i
1	Uncertainty of VMI Standard	Normal	1	8.98×10^{-7}	8.98×10^{-7}	50
1-1		Uncorrelated	1	8.98×10^{-7}	8.98×10^{-7}	50
1-2		Correlated - Nanovolt meter (1 mV Range)	1	1.36×10^{-8}	1.36×10^{-8}	50
2	Drift of VMI standard	Rectangular	1	5.08×10^{-7}	5.08×10^{-7}	50
3	Repeatability (Type A)	Normal	1	9.32×10^{-8}	9.32×10^{-8}	9
4	Nanovolt meter (1 mV Range)	Rectangular	1	1.36×10^{-8}	1.36×10^{-8}	50
5	Temperature Correction - Coefficient	*t*	1	1.13×10^{-8}	1.13×10^{-8}	6
6	Temperature Correction - Thermistor *R*	*t*	1	4.53×10^{-8}	4.53×10^{-8}	3
7	Pressure correction - Coefficient	*t*	1	2.03×10^{-9}	2.03×10^{-9}	10
u_c					1.04×10^{-6}	81
k					1.99	
U					2.06×10^{-6}	

(b) 10 V of TZS-V

No.	Component	Distribution	c_i	$u(x_i)$ V	$\lvert c_i\, u(x_i)\rvert$ V	ν_i
1	Uncertainty of VMI Standard	Normal	1	8.98×10^{-7}	8.98×10^{-7}	50
1-1		Uncorrelated	1	8.98×10^{-7}	8.98×10^{-7}	50
1-2		Correlated - Nanovolt meter (1 mV Range)	1	1.36×10^{-8}	1.36×10^{-8}	50
2	Drift of VMI standard	Rectangular	1	5.08×10^{-7}	5.08×10^{-7}	50
3	Repeatability (Type A)	Normal	1	1.16×10^{-7}	1.16×10^{-7}	9
4	Nanovolt meter (1 mV Range)	Rectangular	1	1.36×10^{-8}	1.36×10^{-8}	50
5	Temperature Correction - Coefficient	*t*	1	1.82×10^{-8}	1.82×10^{-8}	6
6	Temperature Correction - Thermistor *R*	*t*	1	6.74×10^{-8}	6.74×10^{-8}	3
7	Pressure correction - Coefficient	*t*	1	1.25×10^{-8}	1.25×10^{-8}	10
u_c					1.04×10^{-6}	82
k					1.99	
U					2.07×10^{-6}	

(c) 1.018 V of TZS-K

No.	Component	Distribution	c_i	$u(x_i)$ V	$\lvert c_i\, u(x_i)\rvert$ V	ν_i
1	Uncertainty of VMI Standard	Normal	1	8.30x10^{-8}	8.30x10^{-8}	77
1-1		Uncorrelated	1	7.38x10^{-8}	7.38x10^{-8}	50
1-2		Correlated - Nanovolt meter (10 mV Range)	1	2.48x10^{-8}	2.48x10^{-8}	50
1-3		Correlated - Leakage	1	2.89x10^{-8}	2.89x10^{-8}	50
2	Drift of VMI standard	Rectangular	1	3.44x10^{-8}	3.44x10^{-8}	50
3	Repeatability (Type A)	Normal	1	5.89x10^{-8}	5.89x10^{-8}	9
4	Nanovolt meter (100 mV Range)	Rectangular	1	2.36x10^{-7}	2.36x10^{-7}	50
5	Leakage	Rectangular	1	2.89x10^{-8}	2.89x10^{-8}	50
6	Temperature Correction - Coefficient	*t*	1	1.68x10^{-9}	1.68x10^{-9}	6
7	Temperature Correction - Thermistor *R*	*t*	1	8.73x10^{-9}	8.73x10^{-9}	3
8	Pressure correction - Coefficient	*t*	1	9.23x10^{-10}	9.23x10^{-10}	10
u_c					2.85x10^{-7}	27
k					2.06	
U					5.86x10^{-7}	

(d) 1.018 V of TZS-V

No.	Component	Distribution	c_i	$u(x_i)$ V	$\lvert c_i\, u(x_i)\rvert$ V	ν_i
1	Uncertainty of VMI Standard	Normal	1	8.30x10^{-8}	8.30x10^{-8}	77
1-1		Uncorrelated	1	7.38x10^{-8}	7.38x10^{-8}	50
1-2		Correlated - Nanovolt meter (10 mV Range)	1	2.48x10^{-8}	2.48x10^{-8}	50
1-3		Correlated - Leakage	1	2.89x10^{-8}	2.89x10^{-8}	50
2	Drift of VMI standard	Rectangular	1	3.44x10^{-8}	3.44x10^{-8}	50
3	Repeatability (Type A)	Normal	1	6.42x10^{-9}	6.42x10^{-9}	9
4	Nanovolt meter (10 mV Range)	Rectangular	1	2.48x10^{-8}	2.48x10^{-8}	50
5	Leakage	Rectangular	1	2.89x10^{-8}	2.89x10^{-8}	50
6	Temperature Correction - Coefficient	*t*	1	1.83x10^{-9}	1.83x10^{-9}	6
7	Temperature Correction - Thermistor *R*	*t*	1	5.87x10^{-9}	5.87x10^{-9}	3
8	Pressure correction - Coefficient	*t*	1	1.26x10^{-11}	1.26x10^{-11}	10
u_c					1.12x10^{-7}	197
k					1.972	
U					2.21x10^{-7}	

Table 7. Uncertainty budget of KRISS measurements after corrections of Temperature, pressure, and time drift

(a) 10 V of TZS-K

No.	Component	Distribution	Type	c_i	$u(x_i)$ V	$\|c_i.u(x_i)\|$ V	ν_i
1	$\boldsymbol{u}_{\mathbf{reg}}$	*t*	A	1	9.20 x10^{-8}	9.20 x10^{-8}	8
2	Microwave freq. (~1 Hz/75 GHz)	Rectangular	B	1	1.3 x10^{-10}	1.3 x10^{-10}	500
3	Probe leakage (~0.3 Ω/10 GΩ @ 0.5 min)	Rectangular	B	1	3.0 x10^{-10}	3.0 x10^{-10}	50
4	Circuit leakage (~40 Ω/1 T Ω)	Rectangular	B	1	4.0x10^{-10}	4.0 x10^{-10}	50
5	Thermals (incl. Rev. Sw. Repeatability, Circuits)	Appr. Normal	A	1	1.93 x10^{-9}	1.93 x10^{-9}	32
6	Digital nanovoltmeter (±1 mV reading w/Keithley 2182)	Appr. Normal	A&B	1	2.02 x10^{-9}	2.02 x10^{-9}	50
7	Temperature Correction - Coefficient	Appr. Normal	A	1	1.55 x10^{-8}	1.55 x10^{-8}	6
8	Temperature Correction - Thermistor	Appr. Normal	A	1	4.67 x10^{-8}	4.67 x10^{-8}	3
9	Pressure Correction - Coefficient	Appr. Normal	A	1	3.42 x10^{-8}	3.42 x10^{-8}	10
u_c (V)						1.10 x10^{-7}	14
k						2.16	
***U*(V)**						2.37 x10^{-7}	

(b) 10 V of TZS-V

No.	Component	Distribution	Type	c_i	$u(x_i)$ V	$\|c_i.u(x_i)\|$ V	ν_i
1	$\boldsymbol{u}_{\mathbf{reg}}$	*t*	A	1	1.95 x10^{-7}	1.95 x10^{-7}	8
2	Microwave freq. (~1 Hz/75 GHz)	Rectangular	B	1	1.30 x10^{-10}	1.30 x10^{-10}	500
3	Probe leakage (~0.3 Ω/10 GΩ @ 0.5 min)	Rectangular	B	1	3.0 x10^{-10}	3.0 x10^{-10}	50
4	Circuit leakage (~40 Ω/1 T Ω)	Rectangular	B	1	4.0x10^{-10}	4.0 x10^{-10}	50
5	Thermals (incl. Rev. Sw. Repeatability, Circuits)	Appr. Normal	A	1	1.93 x10^{-9}	1.93 x10^{-9}	50
6	Digital nanovoltmeter (±1 mV reading w/Keithley 2182)	Appr. Normal	A&B	1	2.02 x10^{-9}	2.02 x10^{-9}	50
7	Temperature Correction - Coefficient	Appr. Normal	A	1	7.17 x10^{-9}	7.17 x10^{-9}	6
8	Temperature Correction - Thermistor	Appr. Normal	A	1	3.13 x10^{-8}	3.13 x10^{-8}	3
9	Pressure Correction - Coefficient	Appr. Normal	A	1	2.47 x10^{-8}	2.47 x10^{-8}	10
u_c (V)						1.97 x10^{-7}	8
k						2.31	
***U*(V)**						4.53 x10^{-7}	

(c) 1.018 V of TZS-K

No.	Component	Distribution	Type	c_i	$u(x_i)$ V	$\|c_i.u(x_i)\|$ V	ν_i
1	$\boldsymbol{u}_{\mathbf{reg}}$	*t*	A	1	1.67 x10^{-8}	1.67 x10^{-8}	8
2	Microwave freq. (~1 Hz/75 GHz)	Rectangular	B	1	1.30 x10^{-11}	1.3 x10^{-11}	500
3	Probe leakage (~0.3 Ω/10 GΩ @ 0.5 min)	Rectangular	B	1	3.0 x10^{-11}	3.0 x10^{-11}	50
4	Circuit leakage (~1 k Ω/1 T Ω)	Rectangular	B	1	1.0 x10^{-9}	1.0 x10^{-9}	50
5	Thermals (incl. Rev. Sw. Repeatability, Circuits)	Appr. Normal	A	1	1.93 x10^{-9}	1.93 x10^{-9}	50
6	Digital nanovoltmeter (±1 mV reading w/Keithley 2182)	Appr. Normal	A&B	1	2.02 x10^{-9}	2.02 x10^{-9}	50
7	Temperature Correction - Coefficient	Appr. Normal	A	1	2.56 x10^{-9}	2.56 x10^{-9}	6
8	Temperature Correction - Thermistor	*t*	A	1	8.88 x10^{-9}	8.88 x10^{-9}	3
9	Pressure Correction - Coefficient	*t*	A	1	4.73 x10^{-9}	4.73 x10^{-9}	10
$\boldsymbol{u}_{\mathbf{c}}$ **(V)**						1.74 x10^{-8}	9
k						2.26	
***U*(V)**						3.93 x10^{-8}	

(d) 1.018 V of TZS-V

No.	Component	Distribution	Type	c_i	$u(x_i)$ V	$\|c_i.u(x_i)\|$ V	ν_i
1	$\boldsymbol{u}_{\mathbf{reg}}$	*t*	A	1	2.71 x10^{-8}	2.71 x10^{-8}	8
2	Microwave freq. (~1 Hz/75 GHz)	Rectangular	B	1	1.30 x10^{-11}	1.30 x10^{-11}	500
3	Probe leakage (~0.3 Ω/10 GΩ @ 0.5 min)	Rectangular	B	1	3.0 x10^{-11}	3.0 x10^{-11}	50
4	Circuit leakage (~1 k Ω/1 T Ω)	Rectangular	B	1	1.0 x10^{-9}	1.0 x10^{-9}	50
5	Thermals (incl. Rev. Sw. Repeatability, Circuits)	Appr. Normal	A	1	1.93 x10^{-9}	1.93 x10^{-9}	50
6	Digital nanovoltmeter (±1 mV reading w/Keithley 2182)	Appr. Normal	A&B	1	2.02 x10^{-9}	2.02 x10^{-9}	50
7	Temperature Correction - Coefficient	Appr. Normal	A	1	9.67 x10^{-10}	9.67 x10^{-10}	6
8	Temperature Correction - Thermistor	*t*	A	1	6.32 x10^{-9}	6.32 x10^{-9}	3
9	Pressure Correction - Coefficient	*t*	A	1	2.34 x10^{-9}	2.34 x10^{-9}	10
$\boldsymbol{u}_{\mathbf{c}}$ **(V)**						2.72 x10^{-8}	8
k						2.31	
***U*(V)**						6.28 x10^{-8}	

7. SUMMARY AND CONCLUSIONS

7.1 Summary

The degree of equivalence between VMI and KRISS is summarized as follows,

10 V: $D = V_{\mathrm{VMI}} - V_{\mathrm{KRISS}} = 0.9\ \mu\mathrm{V}$, $U(D) = 1.5\ \mu\mathrm{V}$ (approximately 95 %, $k = 2$)

1.018 V: $D = V_{\mathrm{VMI}} - V_{\mathrm{KRISS}} = 0.0\ \mu\mathrm{V}$, $U(D) = 0.2\ \mu\mathrm{V}$ (approximately 95 %, $k = 2$)

7.2 Link to the BIPM KC

Pilot lab KRISS has following DOE (Degree of Equivalence) with respect to the BIPM KC (BIPM.EM-K11.a & b) reference value. [4]

10 V: $d_{\mathrm{KRISS}} = -31\ \mathrm{nV}$, $U(d_{\mathrm{KRISS}}) = 200\ \mathrm{nV}$

1.018 V: $d_{\mathrm{KRISS}} = 70\ \mathrm{nV}$, $U(d_{\mathrm{KRISS}}) = 100\ \mathrm{nV}$

The DOE of VMI with respect to the BIPM KCRV is given by the following equation

$$d_{\mathrm{VMI}} = D - d_{\mathrm{KRISS}}$$

The uncertainty is given by

$$u^2(d_{\mathrm{VMI}}) = u^2(D) + u^2(d_{\mathrm{KRISS}})$$

Therefore the d_{VMI} value and the expanded uncertainty ($k = 2$) are as follows:

10 V: $d_{\mathrm{VMI}} = 1.0\ \mu\mathrm{V}$, $U(d_{\mathrm{VMI}}) = 1.5\ \mu\mathrm{V}$

1.018 V: $d_{\mathrm{VMI}} = 0.1\ \mu\mathrm{V}$, $U(d_{\mathrm{VMI}}) = 0.2\ \mu\mathrm{V}$

7.3 Impact of the comparison on the calibration and measurements capabilities of the participating laboratories.

The two NMI’s results agreed well. No systematic errors were found in this comparison. VMI is planning to submit the CMC (Calibration and Measurement Capability) for MRA (Mutual Recognition Arrangement) related to electrical quantities.

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[3] JCGM 100:2008 (GUM 1995 with minor corrections) Evaluation of measurement data - Guide to the expression of uncertainty in measurement.

[4] S. Solve et al., “Bilateral comparison of 1.018 V and 10 V standards between the KRISS (Republic of Korea) and the BIPM, February 2008 (part of the ongoing BIPM key comparison BIPM.EM-K11.a and b),” Metrologia, vol. 45, 01007, 2008.

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APPENDIX

Comparison protocol attached.

Technical Protocol APMP.EM.BIPM-K11.4

Bilateral comparison of DC Voltage between KRISS and VMI

CONTENTS

1. INTRODUCTION

This bilateral key comparison between KRISS, Korea (South) and VMI, Vietnam has been organized by KRISS (pilot) in response to VMI's request for RMO comparison in DC voltage of 1.018 V and 10 V by transporting Zener voltage standards. An RMO KC for this APMP.EM.BIPM-K11.3 (pilot: KRISS) started in 2009. Circulation of the traveling standards is finished and the comparison is now in Draft A report preparation stage. This bilateral comparison is, therefore, a separate RMO KC. The protocol of this KC, K11.4 follows the protocol of the K11.3 with two minor differences: 1) The traveling standards, 2) Post evaluation of pressure coefficient of the traveling standard. The corresponding CCEM KC's are BIPM.EM-K11.a (1.018 V) and BIPM.EM-K11.b (10 V). The link of VMI result to the KCRV will be based on the KRISS result in BIPM.EM-K11.a & b, 2008.

2. TRAVELING STANDARDS

2.1 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,[1] two Zener standards (Fluke 732B) are used; one provided from KRISS, the other provided from VMI. Although the environmental conditions between the two labs are similar, appropriate uncertainty evaluation for temperature, humidity and pressure effect is necessary. This makes it necessary for us to prepare a set of traveling standards with data on their environmental coefficients.

Temperature correction

Temperature coefficients of the traveling Zener standards has been characterized at KRISS and shown in Table 1.

Pressure correction

Considering the atmospheric pressure conditions are almost same between the two labs and to save time from protocol approval and to carrying out measurements, the pressure coefficient will be evaluated right after all comparison measurements are finished at KRISS. Then the blank in the last column in the Table 1 will be filled out and included in the final report.

Humidity correction

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].

2.2 Description of standards

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

TZS-K	s/n 6270008
TZS-V	s/n 7135019

The Fluke 732 B electronic DC reference standard has two output voltages, nominally 1.018 V and 10 V, respectively. The traveling standard should be handled carefully and be stored in a stabilized environment where relative humidity is between 40 % and 55 % R.H.

Characteristics of the standard 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 KRISS. 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 1: 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})	Reference pressure (hPa)	Pressure coefficient α_p (nV hPa^{-1})*
TZS-K	10 V	38.650	1.4 ± 0.2	998.00	30 ± 11
TZS-V	10 V	38.650	3.1 ± 0.2	998.00	37 ± 8
TZS-K	1.018 V	38.650	-0.27 ± 0.03	998.00	-7.4 ± 1.3
TZS-V	1.018 V	38.650	0.29 ± 0.02	998.00	0.7 ± 0.6

* As for the blank if this column, see 2.1.

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

2.3 Quantities to be measured

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

3. ORGANIZATION

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3.3 Time schedule

The comparison will be organized as Table 2.

Table 2: Time schedule

Year	Date of Measurement	Laboratory	Country or Economy
2012	22 June – 6 July	KRISS, Pilot laboratory	Korea (South)

	12 July – 27 July	VMI	Vietnam
	3 August – 17 August	KRISS, Pilot laboratory	Korea (South)

3.4 Transportation

Travelling standard should be hand-carried carefully during the transportations between 2 laboratories to avoid internal battery discharge during a prolonged customs clearance time and to avoid abrupt change of environmental condition (temperature, humidity, pressure). It is because the traveling standard has not been fully evaluated of its temperature, humidity and pressure coefficient.

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, the measurements and reporting the result to the pilot lab.

Because the standards should always be in the "IN CAL" state, during transit as well as measurement, quick and safe transport is essential.

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 always avoided.

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 internal 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 transport time.

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 and transportation. **Be sure to fully recharge the standards before packing them.** 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.

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 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!

- **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. **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.

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 humidity controlled room for at least two days before the measurements can begin.

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 2 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. The standards are kept floating. To reduce external noise, the GUARD of the Fluke 732B should be connected to ground potential of the measurement system, CHASIS GROUND of the Fluke 732B should be kept in no connection.

Measuring the internal thermistor resistance

The internal thermistor resistance must be reported so that temperature correction can be made. 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 μ A**. 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 ℃ and 45 %RH.

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 $U_{\text{corrected}}$:

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

where α_{R} and α_{p} are the temperature and pressure coefficients as given in Table 1, p is the ambient air pressure, p_0 = 1010.00 hPa is the reference air pressure, and R_0 = 38.650 kΩ is the reference thermistor resistance.

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, JCGM 100 :2008). 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 A and
Chapter 6

6. MEASUREMENT REPORT

VMI’s report must be sent to both the pilot laboratory and the TCEM chair within two days from the completion of measurements and before transporting to the next lab (KRISS).

6.1 Software

Reports should be submitted electronically, using the following software:

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

6.2 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.)*

** Standard used is Josephson Voltage standard system*

7. REPORT OF THE COMPARISON

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

REFERENCES

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

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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.

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

APPENDIX A: Forms for Summary Report

10 V:

Identification of standard	TZS-K	TZS-V
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		

1.018 V:

Identification of standard	TZS-K	TZS-V
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		