Final Report on Bilateral Comparison

COOMET.EM.BIPM-K11

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1. Introduction

In the Mutual Recognition Arrangement (MRA) it is stated that the metrological equivalence of national measurement standards will be determined by a set of key comparisons chosen and organized by the Consultative Committees of the CIPM working closely together with the Regional Metrology Organizations (RMOs). The COOMET key comparison (COOMET Project No. 530/BY/11 “Comparison of the standards of direct current voltage unit”) was carried out to link COOMET national laboratories. This comparison provides an indirect link between voltage realizations of BelGIM and BIPM through VNIIM results obtained in voltage standard key comparisons with the BIPM. The objective of this comparison is to publish in the KCDB (BIPM key comparison data base) the difference BelGIM - BIPM together with the combined uncertainty of the measurements BelGIM - VNIIM and VNIIM- BIPM.
BelGIM performed preliminary measurements of two transfer standards of type Fluke 732 B (Z1 and Z2) from 01.07.11 to 15.07.11. The comparison took place from 18.07.2011 to 05.08.2011.
Participants were requested to measure the 1.018 V and 10 V output voltages of the transfer standards. The degree of equivalence of BelGIM was evaluated from the 1.018 V and 10 V output voltage measurements on each of two transfer standards. This degree of equivalence is presented in table 4 and table 6. The results of preliminary measurements are reported in Appendix A. The uncertainty budgets are reported in Appendix B. Measurement methods and measurement results are reported in Appendix C.

2. Participants and schedule

VNIIM (pilot laboratory) and BelGIM participated in the comparison. Table 1 shows the measurements schedule.

Table 1

Institute		Country	Standard at the laboratory	Comment
BelGIM	Belarusian State Institute of Metrology	The Republic of Belarus	18.07.-22.07.2011	Z1 and Z2
VNIIM Pilot	D.I. Mendeleyev Institute for Metrology	Russia	25.07.-29.07.2011	Z1 and Z2
BelGIM	Belarusian State Institute of Metrology	The Republic of Belarus	01.08.-05.08.2011	Z1 and Z2

In the course of the comparison the transfer standards (Z1 and Z2) were transported to VNIIM by rail within 16 hours as hand luggage. Upon arrival at VNIIM the Zeners were maintained during 6 hours to ensure that the batteries are fully charged and stabilization is completed. After finishing the measurements at VNIIM, the Zeners were returned to BelGIM within 16 hours under the same conditions.

3. Transfer standards and requirements for measurements

The transfer standards were Zeners Z1 and Z2 (Fluke 732 B) belonging to BelGIM. The nominal output voltages of Z1 and Z2 were 1.018 V and 10 V. The measurements were performed with the nanovoltmeter and the Zener and the JVS connected in series opposition. The polarities of Z1 and Z2 and the laboratory voltage standard were changed. The Zeners were disconnected from the mains 220 V, 50 Hz. The body and shield of Zeners were connected to the ground. Measurement conditions including laboratory room temperature, relative humidity, and air pressure were recorded.

4. Characteristics of transfer standards

The table below lists values of transfer standards (Z1 and Z2) evaluated for the purpose of this comparison.

1	Temperature coefficient of 1,018 V voltage (k_{T11}) for Z1, ppm/kΩ	0.40; u = 0.1
2	Temperature coefficient of 1,018 V voltage (k_{T12}) for Z2, ppm/kΩ	0.30; u = 0.1
3	Temperature coefficient of 10 V voltage (k_{T21}) for Z1, ppm/kΩ	0.43; u = 0.1
4	Temperature coefficient of 10 V voltage (k_{T22}) for Z2, ppm/kΩ	0.78; u = 0.1
5	Pressure coefficient of 1.018 V voltage (k_{P11}) for the Z1, ppm /kPa	0.014; u = 0.01
6	Pressure coefficient of 1.018 V voltage (k_{P12}) for the Z2, ppm /kPa	0.016; u = 0.01
7	Pressure coefficient of 10 V voltage (k_{P21}) for the Z1, ppm /kPa	0.015; u = 0.01
8	Pressure coefficient of 10 V voltage (k_{P22}) for the Z2, ppm /kPa	0.019; u = 0.01
9	Output resistance of Z1 and Z2 at 1.018 V nominal voltage	1 kΩ

5. Measurement methods

The transfer standards were measured at BelGIM from 18.07.11 to 22.07.11 using BelGIM Josephson voltage standard (JVS) [1] and were subsequently transported to VNIIM. The measurements of transfer standards at VNIIM were performed from 25.07.11 to 29.07.11 using VNIIM JVS [2]. Then the transfer standards were returned to BelGIM for final measurements in the period from 01.08.11 to 05.08.11.
Voltage standards of BelGIM and VNIIM use 10 V Josephson arrays. The measurement is carried out by reading the difference between the voltage of transfer standard and output voltage of JVS via null detector. The transfer standard voltage is determined as a mean value of voltages measured in each polarity of JVS. 4 hours prior to the measurement and in the process of measurement the comparison, the transfer standards were disconnected from mains supply.

6. Results

a) <u>Measurement results BelGIM - VNIIM</u>

Tables 1 and 2 summarize mean value in relation to the mean measurement date at VNIIM (27.07.11), standard uncertainty u_A (type A), standard uncertainty u_B (type B) and corresponding total uncertainty u for each participant. Additionally, these tables summarize mean values of ambient temperature, pressure, and humidity for each participant.

The measurement results are plotted in figures 1 and 2.

Table 1 Results for transfer standard Z1 with temperature and pressure corrections

Institute	U_Z / μV	u_A / nV	u_B /nV	u / nV	R / kΩ	P / kPa	H / %
BelGIM	1018137.844	17	6	18	38.154	98,77	61,4
VNIIM	1018137.851	11	5	12	38.144	101,24	60,4
BelGIM	9999962.64	70	6	70	38.044	98,77	61,4
VNIIM	9999962.36	70	5	70	38.040	101,24	60,4

Table 2 Results for transfer standard Z2 with temperature and pressure corrections

Institute	U_Z / μV	u_A / nV	u_B / nV	u / nV	R / kΩ	P / kPa	H / %
BelGIM	1018163.333	12	6	14	38.154	98,77	61,4
VNIIM	1018163.337	7	5	9	38.144	101,24	60,4
BelGIM	9999963.22	78	6	78	38.044	98,77	61,4
VNIIM	9999963.53	70	5	70	38.040	101,24	60,4

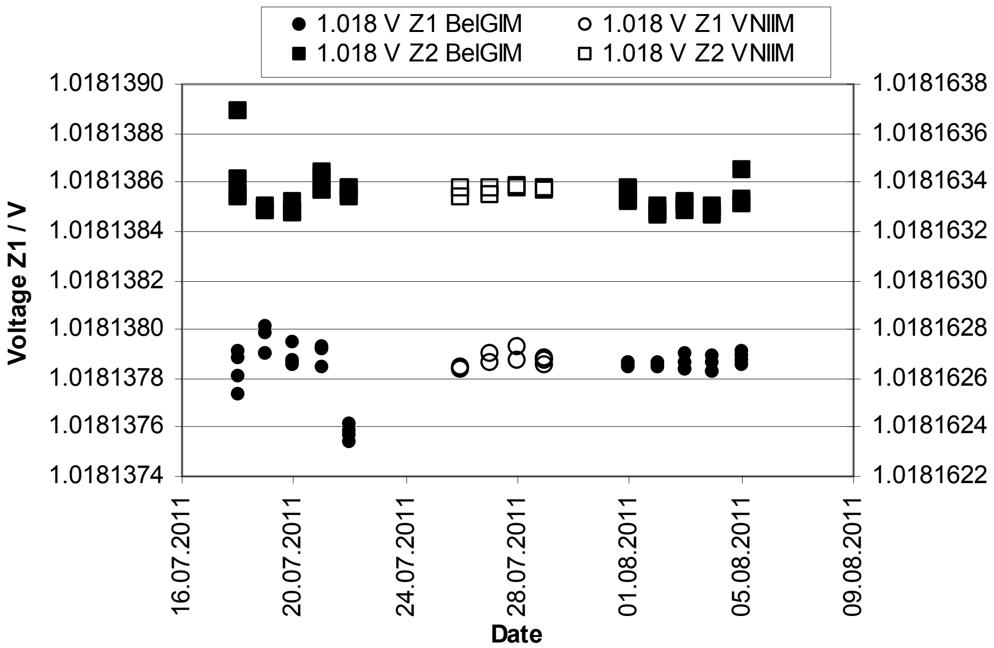

Figure 1 Results of 1.018 V voltage measurement for Z1 and Z2 in BelGIM and VNIIM without temperature and pressure corrections.

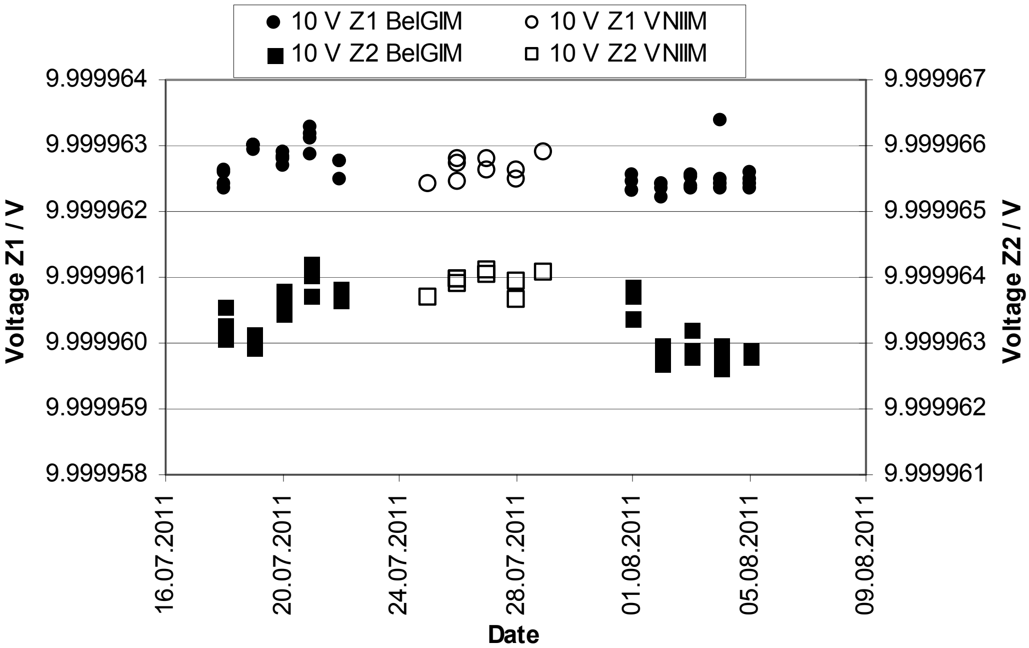

Figure 2 Results of 10 V voltage measurement for Z1 and Z2 in BelGIM and VNIIM without temperature and pressure corrections.

b) Reference value

The reference value is the BIPM voltage standard value, which is assumed to be time-independent.

c) Degree of equivalence with respect to reference value

Following the Mutual Recognition Arrangement of the CIPM (MRA), the degree of equivalence of a laboratory is expressed in terms of the difference between the laboratory's result and the reference value and the expanded uncertainty of this difference.

The difference between the BelGIM measurements and reference value was calculated as follows:

$$dU_{\text{BelGIM-BIPM}} = dU_{\text{BelGIM-VNIIM}} + dU_{\text{VNIIM-BIPM}}$$

taking into account measurements which were carried out with the use of two transfer standards and the allowance for the influence of temperature and atmospheric pressure.

Output voltage 1.018 V:

Table 3 reports the difference between the BelGIM result and the reference value $d_i = dU_{\text{BelGIM-BIPM}}$, standard uncertainty of this difference $u_{\text{LAB}} = u_{\text{BelGIM-BIPM}}$, corresponding number of degree of freedom ν_{LAB} equal to effective degree of freedom ν_{eff}, expansion factor k_{95} corresponding to a level of confidence 95 % from the Student's distribution and the expanded uncertainty $U(d_i) = k_{95} \times u(d_i)$

Table 3 Degree of equivalence

Institute	d_i / µV	u_{LAB} / µV	ν_{LAB}, ν_{eff}	k_{95}	$U(d_i)$ / µV
BelGIM	-0.005	0,035	125	1.98	0,070

Table 4. Results of the BelGIM key comparison of 1.018 V standards using Zener transfer standards: Mean Date 27 July 2011. Uncertainties are 1-σ estimates. The uncorrelated uncertainty is $w = [r^2 + t^2 + v^2]^{1/2}$, the expected transfer uncertainty is $x = [w1^{-2} + w2^{-2}]^{-1/2}$ and the correlated uncertainty is $y = [s^2 + u^2]^{1/2}$.

	Units are μV	Z1	Z2	
1	BelGIM, value (U_Z - 1018000)	137.844	163.333	
2	BelGIM, unc (A)	0.017	0.012	*r*
3	BelGIM, unc (B)	0.006		*s*
4	VNIIM, value (U_Z - 1018000)	137.883	163.376	
5	VNIIM, unc (A)	0.011	0.007	*t*
6	VNIIM, unc (B)	0.005		*u*
7	VNIIM, value (U_Z - 1018000) with temperature and pressure corrections	137.851	163.337	
8	pressure and temperature unc	0.026	0.025	*v*
9	total rss uncorr for each Zener	0.032	0.029	w =rss(r,t,v)
10	$U_{BelGIM} – U_{VNIIM}$	-0.007	-0.004	*U*
11	$U_{BelGIM} – U_{VNIIM,}$ mean	-0.006		*m*
12	expected transfer uncertainty	0.022		$x=(w1^{-2}+w2^{-2})^{-1/2}$
13	s_M of difference for 2 Zeners	0.001		*b*
14	the correlated part of the uncertainty	0.008		*y=rss(s,u)*
15	$U_{BelGIM} – U_{VNIIM,}$ uncertainty	0.023		*f =rss(y,x)*
16	$U_{VNIIM} – U_{BIPM}$, difference	0.001		*n*
17	$U_{VNIIM} – U_{BIPM}$, uncertainty	0.027		*a*
18	$U_{BelGIM} – U_{BIPM}$, difference	-0.005		*m+n*
19	$U_{BelGIM} – U_{BIPM}$, uncertainty	0.035		v= rss(f,a)
	Mean date dd/mm/yy	27/07/11		

References to Table 4:

1, 2 and 3 are the BelGIM value, type A, and type B uncertainties;

2 The stability of the Zeners can be described by flicker noise (1/f noise) with a floor value of about 0.007 μV. If the BelGIM results for Z1 from each day are used in a linear least-squares fit, the standard deviation of the residuals is 0.102 μV. With respect to the model that assumes a constant drift rate of the traveling standard, the standard deviation of the value assigned by the

BelGIM on the mean date of the VNIIM measurements, is the standard deviation of the residuals divided by the square root of the number of degrees of freedom (number of daily measurement results minus two) or about 0.017 µV, if the daily measurement values are uncorrelated. A similar argument was applied for the estimated type A uncertainty for Z2.

4, 5 and 6 are the VNIIM value, type A, and type B uncertainties.

7 is the VNIIM value corrected to the mean temperature resistance and pressure of BelGIM measurements.
Temperature resistance correction according mean difference of 0.011 kΩ is for Z1: $dUT_{Z1} = k_{T11}\times(R_{BelGIM} - R_{VNIIM})\times U_{Z1}$ = 0.004 µV;
Temperature resistance correction according mean difference of 0.008 kΩ is for Z2: $dUT_{Z2} = k_{T12}\times(R_{BelGIM} - R_{VNIIM})\times U_{Z2}$ = 0.001 µV.
Atmospheric pressure correction according difference of -2.5 kPa is
for Z1: $dUP_{Z1} = \mathrm{k}_{P11}\times(P_{BelGIM} - \mathrm{P}_{VNIIM})\times U_{Z1}$ = -0.035 µV;
for Z2: $\mathrm{dUP}_{Z2} = \mathrm{k}_{P12}\times(P_{BelGIM} - \mathrm{P}_{VNIIM})\times U_{Z2}$ = -0.040 µV;
total correction is
for Z1: (0.004)+ (-0.035)= -0.032 µV;
for Z2: (0.001)+ (-0.040)= -0.039 µV.

8 is the root-sum-square (rss) total uncorrelated uncertainty associated with the corrections for temperature resistance and pressure:
$u(Z1) = ((k_{T11}\times u(R_{Z1})\times U_{Z1})^2+(\Delta R_{Z1}\times u(k_{T11})\times U_{Z1})^2+(k_{P11}\times u(P)\times U_{Z1})^2+$
$+(\Delta P\times u(k_{P11})\times U_{Z1})^2)^{0.5}\cdot= ((0.4\times 0.011\times 1.018)^2 + (0.010\times 0.1\times 1.018)^2 +$
$+(0.014\times 0.164\times 1.018)^2 + (-2.5\times 0.01\times 1.018)^2)^{0.5}$ =0.026 µV;
$u(Z2) = ((k_{T12}\times u(R_{Z2})\times U_{Z2})^2+(\Delta R_{Z2}\times u(k_{T12})\times U_{Z2})^2+(k_{P12}\times u(P)\times U_{Z2})^2+$
$+(\Delta P\times u(k_{P12})\times U_{Z2})^2)^{0.5}\cdot= ((0.30\times 0.011\times 1.018)^2 + (0.010\times 0.1\times 1.018)^2 +$
$+(0.016\times 0.164\times 1.018)^2 + (-2.5\times 0.01\times 1.018)^2)^{0.5}$ =0.025 µV;

9 is the total uncertainty for each Zener. This is the rss of (2), (5), and (8).

10 is the comparison result from each Zener.

11 is the mean difference for two Zeners.

12 the a *priori* uncertainty, which is the standard deviation of the mean value of the results from the different Zeners, counting only the uncorrelated uncertainties of the individual results.

13 the a *posteriori* uncertainty, which is the standard deviation of the mean of the different results.

14 is the correlated part of the uncertainty. This is rss of (3) and (6).

15 the total uncertainty of the BelGIM – VNIIM comparison, which is the root-sum-square of the correlated part of the uncertainty and of the larger of (12) and (13).

16, 17 the results of VNIIM - BIPM key comparison [3].

18, 19 the results of the BelGIM key comparison

Output voltage 10 V

Table 5 reports the difference between the BelGIM result and the reference value $d_i = dU_{BelGIM\text{-}BIPM}$, standard uncertainty of this difference $u_{LAB} = u_{BelGIM\text{-}BIPM}$, corresponding number of degree of freedom ν_{LAB} equal to effective degree of freedom ν_{eff}, expansion factor k_{95} corresponding to a level of confidence 95 % from the Student's distribution and the expanded uncertainty $U(d_i) = k_{95} \times u(d_i)$

Table 5. The degree of equivalency

Institute	d_i / µV	u_{LAB} / µV	ν_{LAB}, ν_{eff}	k_{95}	$U(d_i)$ / µV
BelGIM	-0.28	0,45	125	1.98	0,88

Table 6. Results of the BelGIM key comparison of 10 V standards using Zener transfer standards: Mean Date 27 July 2011. Uncertainties are 1-σ estimates. The uncorrelated uncertainty is $w = [r^2 + t^2 + v^2]^{1/2}$, the expected transfer uncertainty is $x = [w1^{-2} + w2^{-2}]^{-1/2}$ and the correlated uncertainty is $y = [s^2 + u^2]^{1/2}$.

	Units are µV			
		Z1	Z2	
1	BelGIM, value (U_Z - 10000000)	-37.36	-36.78	
2	BelGIM, unc (A)	0.07	0.08	*r*
3	BelGIM, unc (B)	0.006		*s*
4	VNIIM, value (U_Z - 10000000)	-37.26	-35.99	
5	VNIIM, unc (A)	0.07	0.07	*t*
6	VNIIM, unc (B)	0.006		*u*
7	VNIIM, value (U_Z - 10000000) with temperature and pressure corrections	-37.59	-36.43	
8	pressure and temperature unc	0.25	0.26	*v*
9	total rss uncorr for each Zener	0.27	0.27	w =rss(r,t,v)
10	$U_{BelGIM} - U_{VNIIM}$	0.23	-0.35	*U*
11	mean $U_{BelGIM} - U_{VNIIM}$	-0.06		*m*
12	expected transfer uncertainty	0.19		$x=(w1^{-2}+w2^{-2})^{-1/2}$
13	s_M of difference for 2 Zeners	0.29		*b*
14	the correlated part of the uncertainty)	0.008		$y=rss(s,u)$
15	$U_{BelGIM} - U_{VNIIM,}$ uncertainty	0.29		$f=rss(y,b)$
16	$U_{VNIIM} - U_{BIPM}$, difference	-0.22		*n*
17	$U_{VNIIM} - U_{BIPM}$, uncertainty	0.34		*a*

18	$U_{BelGIM} – U_{BIPM}$, difference	-0.28	*m+n*
19	$U_{BelGIM} – U_{BIPM}$, uncertainty	0.45	*v*= rss(*f,a*)
	Mean date dd/mm/yy	27/07/11	

Comments to table 6:

1, 2 and 3 are the BelGIM value, type A, and type B uncertainties;

2 The stability of the Zeners can be described by flicker noise (1/f noise) with a floor value of about 0.070 µV. If the BelGIM results for Z1 from each day are used in a linear least-squares fit, the standard deviation of the residuals is 0.297 µV. With respect to the model that assumes a constant drift rate of the traveling standard, the standard deviation of the value assigned by the BelGIM on the mean date of the VNIIM measurements, is the standard deviation of the residuals divided by the square root of the number of degrees of freedom (number of daily measurement results minus two) or about 0.048 µV, if the daily measurement values are uncorrelated. As 0.048 µV is less then 0.070 µV the floor value is accepted as uncertainty type A. A similar argument was applied for the estimated type A uncertainty for Z2.

4, 5 and 6 are the VNIIM value, type A, and type B uncertainties.

7 is the VNIIM value corrected to the mean temperature resistance and pressure of BelGIM measurements.
Temperature resistance correction according mean difference of 0.011 kΩ is for Z1: $dUT_{Z1} = k_{T21}\times(R_{BelGIM} – R_{VNIIM})\times U_{Z1}$ = 0.04 µV;
Temperature resistance correction according mean difference of 0.008 kΩ is for Z2: $dUT_{Z2} = k_{T22}\times(R_{BelGIM} – R_{VNIIM})\times U_{Z2}$ = 0.03 µV.
Atmospheric pressure correction according difference of -2.5 kPa. is
for Z1: $dUP_{Z1} = \mathrm{k}_{P21}\times(P_{BelGIM} – \mathrm{P}_{VNIIM})\times U_{Z1}$ = -0.37 µV;
for Z2: $\mathrm{dUP}_{Z2} = \mathrm{k}_{P22}\times(P_{BelGIM} – \mathrm{P}_{VNIIM})\times U_{Z2}$ = -0.47 µV;
total correction is
for Z1: 0.04+ -0.37 = -0.33 µV;
for Z2: 0.03+ -0.47 = -0.44 µV.

8 is the root-sum-square (rss) total uncorrelated uncertainty associated with the corrections for temperature and pressure:
$u(\mathrm{Z1}) = ((k_{T21}\times u(R_{Z1})\times U_{Z1})^2+(\Delta R_{Z1}\times u(k_{T21})\times U_{Z1})^2+(k_{P21}\times u(\mathrm{P})\times U_{Z1})^2+$
$+(\Delta P\times u(k_{P21})\times U_{Z1})^2)^{0.5}\cdot= ((0.43\times0.011\times10)^2 + (0.010\times0.1\times10)^2 +$
$+(0.015\times0.164\times10)^2 + (-2.5\times0.01\times10)^2)^{0.5}$ =0.25 µV;
$u(\mathrm{Z2}) = ((k_{T22}\times u(R_{Z2})\times U_{Z2})^2+(\Delta R_{Z2}\times u(k_{T22})\times U_{Z2})^2+(k_{P22}\times u(\mathrm{P})\times U_{Z2})^2+$
$+(\Delta P\times u(k_{P22})\times U_{Z2})^2)^{0.5}\cdot= ((0.78\times0.011\times10)^2 + (0.010\times0.1\times10)^2 +$
$+(0.019\times0.164\times10)^2 + (-2.5\times0.01\times10)^2)^{0.5}$ =0.26 µV;

9 is the total uncertainty for each Zener. This is the rss of (2), (5), and (8).

10 is the comparison result from each Zener.

11 is the mean difference for two Zeners.

12 the a *priori* uncertainty, which is the standard deviation of the mean value of the results from the different Zeners, counting only the uncorrelated uncertainties of the individual results.

13 the a *posteriori* uncertainty, which is the standard deviation of the mean of the different results.

14 is the correlated part of the uncertainty. This is rss of (3) and (6).

15 the total uncertainty of the BelGIM – VNIIM comparison, which is the root-sum-square of the correlated part of the uncertainty and of the larger of (12) and (13).

16, 17 the results of VNIIM - BIPM key comparison [4].

18, 19 the results of the BelGIM key comparison

The final results of the comparison are presented as the differences between the values assigned to a 1.018 V and a 10 V standard by BelGIM and BIPM. The difference between the value assigned by the BelGIM at the BelGIM, U_{BelGIM}, and that assigned by the BIPM at the BIPM, U_{BIPM}, for a 1.018 V standard on the reference date is

$U_{\mathrm{BelGIM(1.018\ V)}} - U_{\mathrm{BIPM(1.018\ V)}} = -0.005\ \mu\mathrm{V}$; $u_c = 0.035\ \mu\mathrm{V}$ on 2011/07/27,

where u_c is the combined standard uncertainty,
and for a 10 V standard on the reference date is

$U_{\mathrm{BelGIM(10\ V)}} - U_{\mathrm{BIPM(10\ V)}} = -0.28\ \mu\mathrm{V}$; $u_c = 0.45\ \mu\mathrm{V}$ on 2011/07/27.

Appendix A

The results of the research of temperature and atmospheric pressure influence on the reproduced by Z1 and Z2

The research of temperature coefficients have been conducted with the use of two 732B type Zeners with the temperature range from 21 to 26 °C in the screen room. The Zeners have been disconnected from the mains and have been grounded with the special cables. One Zener has been put into the heat chamber while the second - next to it. The difference of output voltage has been measured with by nanovoltmeter Keithley 2182A. Temperature measurement has been realized near the instruments' surface with the help of laboratory thermometers. Simultaneously, there has been carried out temperature measurement of the investigated Zener on the basis of resistance of the inbuilt thermistor with the help of voltmeter 34420 Agilent.

The temperature inside the heat chamber has increased slowly with the help of a heating device with the capacity of 20 W. Averaged results of the voltage difference was registered every 4 sec. Obtained results of the research of temperature coefficients (k_T) are shown in table 1A.

On analogy, there have been conducted measurements in the process of evaluation of pressure coefficients (k_P).

Zener was placed into a sealed device in which extra pressure till 6 kPa could be produced. Averaged measurement results are presented in table 1A.

Table 1A

PMI	Output	k_T ppm/kΩ	k_P ppм/kPa
Z1	1,018 V	0.40; u = 0.1	0,014; u = 0.01
	10 V	0.43; u = 0.1	0,015; u = 0.01
Z2	1,018 V	0.30; u = 0.1	0,016; u = 0.01
	10 V	0.78; u = 0.1	0,019; u = 0.01

Appendix B

Uncertainty budgets of the participants

Uncertainty budget VNIIM, Russia

Output voltage of Z1: 1.018 V

Quantity	Uncertainty	Type	Distribution	Standard uncertainty	Sensitivity coefficient	Uncertainty Contribution	Degree of freedom
Measured voltage	9 nV	A	Normal	9 nV	1	9 nV	8
Frequency	2.4 Hz	B	rectangular	1.4 Hz	14.1 pV/Hz	0.02 nV	∞
Thermo-emf	5 nV	B	Normal	5 nV	1	5 nV	5
Leakage resistance	10Ω/200GΩ	B	rectangular	0.03 nΩ / Ω	1 V	0.03 nV	2
Nanovoltmeter	0.1nV	B	Normal	0.1 nV	1	0.1 nV	40
Total standard uncert.						10 nV	n_{eff} =12

Output voltage of Z2: 1.018 V

Quantity	Uncertainty	Type	Distribution	Standard uncertainty	Sensitivity coefficient	Uncertainty Contribution	Degree of freedom
Measured voltage	7 nV	A	Normal	7 nV	1	7 nV	8
Frequency	2.4 Hz	B	rectangular	1.4 Hz	14.1 pV/Hz	0.02 nV	∞
Thermo-emf	5 nV	B	Normal	5 nV	1	5 nV	5
Leakage resistance	10Ω/200GΩ	B	rectangular l	0.03 nΩ / Ω	1 V	0.03 nV	2
Nanovoltmeter	0.1nV	B	Normal	0.1 nV	1	0.1 nV	40
Total standard uncert.						9 нВ	n_{eff} =13

Output voltage of Z1 and Z2: 10 V

Quantity	Uncertainty	Type	Distribution	Standard uncertainty	Sensitivity coefficient	Uncertainty Contribution	Degree of freedom
Measured voltage	70 nV	A	Normal	70 nV	1	70 nV	8
Frequency	2.4 Hz	B	rectangular	1.4 Hz	14.1 pV/Hz	0.2 nV	∞
Thermo-emf	5 nV	B	Normal	5 nV	1	5 nV	5
Leakage resistance	10Ω/200GΩ	B	rectangular	0.03 nΩ / Ω	10 V	0.3 nV	2
Nanovoltmeter	0.1nV	B	Normal	0.1 nV	1	0.1 nV	40
Total standard uncert.						70 nV	n_{eff} =8

The values of the VNIIM standard parameters

Nominal frequency: 72 GHz

Resistance of the measuring circuit: 10 Ω

Leakage resistance: 200 GΩ

Typical voltage at nanovoltmeter 2 μV

Nanovoltmeter and setting	Keithley 2182, range 10 mV, rate - 1 pls, analogue filter – off, digital filter – on, meter – 14.
Measurement sequence	+/−−/+ sequence, 280 measurements for every polarity.
Typical time for sequence	2 min.

Uncertainty budget **BelGIM, the Republic of Belarus**

Output voltage of Z1: 1.018 V

Quantity	Uncertainty	Type	Distribution	Standard uncertainty	Sensitivity coefficient	Uncertainty Contribution	Degree of freedom
Measured voltage	16 nV	A	Normal	16 nV	1	16 nV	39
Frequency	1,0 Hz	B	Normal	1.0 Hz	13,6 pV/Hz	0.13 nV	300
Thermo-emf	5 nV	B	Normal	5 nV	1	5 nV	5
Leakage resistance	3Ω/100GΩ	B	Normal	0.03 nΩ / Ω	1 V	0.03 nV	11
Nanovoltmeter	7.05nV*	B	Rectangular	4.07 nV	1	4.07 nV	100
Total standard uncert.						17 nV	n_{eff} =46

Output voltage of Z2: 1.018 V

Quantity	Uncertainty	Type	Distribution	Standard uncertainty	Sensitivity coefficient	Uncertainty Contribution	Degree of freedom
Measured voltage	12 nV	A	Normal	12 nV	1	12 nV	39
Frequency	1,0 Hz	B	Normal	1.0 Hz	13.6 pV/Hz	0.13 nV	300
Thermo-emf	5 nV	B	Normal	5 nV	1	5 nV	5
Leakage resistance	3Ω/100GΩ	B	Normal	0.03 nΩ / Ω	1 V	0.03 nV	11
Nanovoltmeter	7.1 nV*	B	Rectangular	4.07 nV	1	4.07 nV	100
Total standard uncert.						14 nV	n_{eff} =58

Output voltage of Z1 and Z2: 10 V

Quantity	Uncertainty	Type	Distribution	Standard uncertainty	Sensitivity coefficient	Uncertainty Contribution	Degree of freedom
Measured voltage	70 nV	A	Normal	70 nV	1	70 nV	39
Frequency	1,0 Hz	B	Normal	1.0 Hz	134.9 pV/Hz	0.13 nV	300
Thermo-emf	5 nV	B	Normal	5 nV	1	5 nV	5
Leakage resistance	3Ω/100GΩ	B	Normal	0.03 nΩ / Ω	10 V	0.3 nV	11
Nanovoltmeter	7.1 nV*	B	Rectangular	4.07 nV	1	4.07 nV	100
Total standard uncert.						70 nV	n_{eff} =39

* no correction for the gain of the nanovoltmeter

The values of the BelGIM standard parameters

Nominal frequency:	75 GHz
Resistance of the measuring circuit:	3 Ω
Leakage resistance:	100 G Ω
Typical voltage of nanovoltmeter	235 μV
Nanovoltmeter and setting:	Keithley 2182A, range 10 mV, rate - 1 pls,
measuring procedure:	the polarity of switching +/– , 160 measurements for every polarity.
Typical time of getting the result	5 min.

Appendix C

Technical protocol and reports on the measurement techniques

C1) Technical protocol

Comparison of 1.018 V and 10 V DC Voltage Standards

COOMET.EM.BIPM-K11

Technical protocol
for the Bilateral RMO comparison between VNIIM and BELGIM,
COOMET Project 530/BY/11

1. Introduction

The Bilateral RMO Comparison will be performed at 1.018 V and 10 V levels to check the coherence of the Josephson Voltage Standards (JVS). The comparison will be performed by measuring a set of two transportable Zener diode-based references (Zeners). There will not be a direct comparison among the JVS . The comparison will take place in the BELGIM´ DC laboratory and in VNIIM´ DC laboratory planning from July to September 2011.
We consider that this comparison is similar to BIPM.EM-K11.a and BIPM.EM-K11.b

2. Purpose

The purpose of this comparison is to link the voltage reference of BELGIM (Belarussian State Institute for Standardisation and Metrology) to that of the VNIIM (D.I. Mendeleyev Institute for Metrology, Russia) in the frame of the COOMET- RMO key comparisons.

3. The standards

The BELGIM´s transfer standards to be measured are two Fluke 732B Zeners referred as:

Z1 s/n 8659701
Z2 s/n 8659702

Those Zeners have two output voltages, nominally 1.018 V and 10 V. Within this comparison, both of outputs will be measured.

To select those standards, previous measurements from BELGIM´s Zener group were made to select the two standards with lower dispersion in the measurements of 1.018 V and 10 V output voltages.

4. Powering the Zeners

The Zeners will be disconnected from the mains at least two hours before the beginning of the measurements and be reconnected to the mains at most six hours later. If the front panel LOW BAT indicator starts blinking the Zeners must be immediately connected to the mains for recharging of the battery.

When the Zeners are not in the process of measurements, they must be permanently connected to the mains (front panel AC PWR lighted).

5. Measurements schedule

There will be at least four series of measurements performed by VNIIM and at least eight series of measurements performed by BELGIM. The BELGIM start measurements, than

Zeners are delivered to VNIIM and than Zeners are delivered to BELGIM to finish measurements. Planned period of the measurements are from July to September 2011.

6. Temperature and pressure coefficients, environment conditions

The temperature, pressure and humidity of the laboratory will be measured in each measurement.

7. Uncertainties

An uncertainty budget will be given containing the different sources of uncertainty and their values.

Foreseen sources of uncertainty: realization of the voltage reference;
detector;
leakage resistance;
no compensated thermal electromotive forces;
and for each Zener: type A uncertainty.

8. Link with other comparisons

VNIIM participated in the BIPM.EM-K11.a and BIPM.EM-K11.b comparisons, and in the BIPM.EM-K10.a and BIPM.EM-K10.b comparisons, this allow us to link our comparison to the BIPM.EM-K11.a and BIPM.EM-K11.b.

9. Participant report

The BELGIM report must be sent to the VNIIM within one month from the completion of his measurements.
This report will contain:
The measurement method description and:
for each reported value:
identification of Zener;
date and time of measurement;
measured voltage;
ambient temperature, humidity, and pressure;
the Type A standard uncertainty;
an uncertainty budget with the different sources of uncertainty and their values, as:
realization of the voltage reference;
detector;
leakage resistance;
no compensated thermal electromotive forces.

10. Final report

The draft version of the final report will be issued within two months after completion of the comparison. It will be sent to BELGIM for discussion and approval. The final report will be then submitted.

11. Contact persons

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C2) BelGIM and VNIIM reports on the measurement techniques

BelGIM, the Republic of Belarus

DESCRIPTION

of the method of voltage measurement, reproduced by the Fluke 732B Zener voltage reference

BelGIM voltage standard at Josephson effect is a commercial product of SUPRACON (Jena, Germany) and is known as supraVOLTcontrol, serial number 004. The system is presented as complete 3-channel standard of voltage with the microprocessor control at Josephson effect (JVS) and allows to carry out the calibration of voltage secondary reference standards and external voltmeters.

This system has different modes of work available in the used software. For the case under consideration concerning comparison of two standards with the help of two reference standards of 732B type there has been applied the mode of work for the calibration of the secondary reference standards. This mode has been optimized for calibration of Zener voltage references, output voltage of which can be connected to JVS standard through one of three identical channels for any level of voltage (up to 10 V).

Zeners were disconnected from the mains two hours before the beginning of the measurements and were reconnected to the mains after finishing measurements in a day. For every point of measurement of the level of the output voltage of the secondary reference standard Josephson array is installed on both polarities. In order to define each of these values it is necessary to carry out 40 samples (20 for every polarity) within approximately 3 sec. In the process of this calibration the Josephson array is completely disconnected from the «ground» and from the chains of the electronic unit of JAVS standard.

Series resistance of the measuring terminals of the system makes 3 Ω, while the leakage resistance of the measuring terminals - 100 GΩ.

Presented in this document information was taken from the document «Manual on the use of the voltage standard at Josephson effect supraVOLTcontrol» by Supracon company, May, 2007.

This system includes the following elements, presented in figure B-1:

1. Cryoprobe with the 10-V Josephson array of SIS type on the basis of standard three-layer technology Nb/Al with the operational frequency approximately 75 GHz.
2. Dewar flask with liquid helium (flange 50 mm).
3. Electronic unit of JVS standard which in combination with the main computer controls the whole system and contains a special source of power for microwave attenuator and the system of connection to the Josephson array.
4. Microwave electronics which includes Gann oscillator with the frequency of 75 GHz, valve, directional coupler, mixer and attenuator, voltage-controlled.
5. Digital UHF-frequency meter EIP578 with synchronization by an external source.
6. Nanovoltmeter Keithley 2182A as a null-detector.
7. 3-channel polarity switch with special low-temperature cables of voltage supply.
8. Sensors with cables for measuring temperature, humidity and barometric pressure.
9. The host computer with the interface of IEEE standard.

The Josephson junctions array are series-connected with the high-resolution null-detector and voltage secondary reference standards. This null-detector measures the difference of voltage between the voltage secondary reference standard and quantized voltage level of the Josephson array.

As the voltage of the secondary reference standard is unknown, the system measures at first its output voltage (in 10-Volt range of the used nanovoltmeter) in order to calculate approximate voltage and the most appropriate number of step N, which should be used.

Residual voltage difference between the output voltage of the secondary reference standard and quantized voltage standard JAVS is measured within the range of nanovoltmeter 10 mV (for f = 75 GHz one step corresponds to the voltage of approximately 155 µV). If measured voltage difference is more than ±235 µV, electronic devices are set to the following step, at which Josephson voltage will be closer to the voltage of this secondary reference standard.

At every polarity of the Josephson array UHF-capacity starts with 0 mW and grows up to maximal 20 mW in order to get stable steps. In the process of this calibration the Josephson array is completely turned off from the «ground» and from the chains of electronic unit of JVS standard.

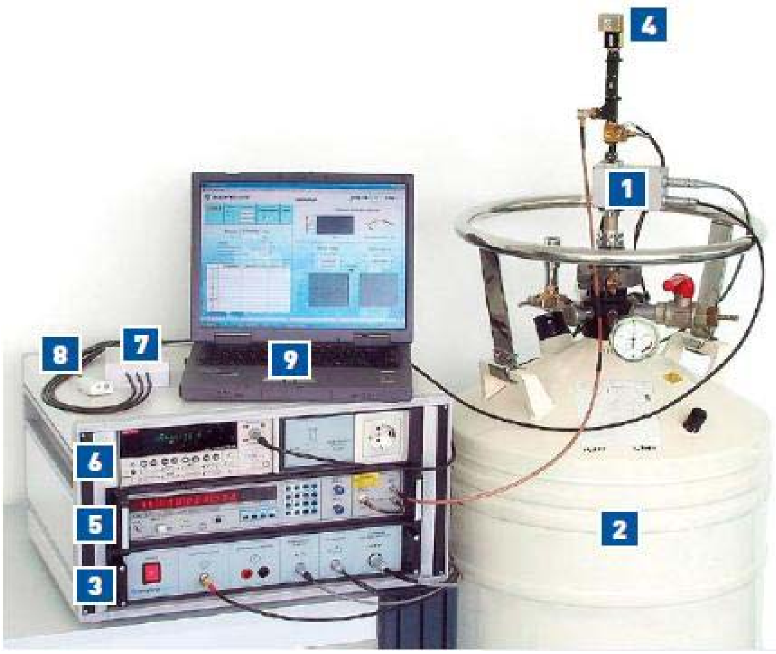

Figure B-1. Complete system of BelGIM 10-Volt standard (JVS).

Voltage measurement of the reference 732B standard
at the output «1,018 V»
PROTOCOL №1, BelGIM

Z1, serial number: 8659701

Measurement number	Date	Number of measurements	Measurement result	Standard measurement uncertainty	Temperature, °C / resistance of the control thermistor, kΩ	Atmospheric pressure, kPa	Humidity, %
1	18.07.2011	4	1.018137880	12	21.1/38.052	98.5	54.9
2			1.018137808	26	23.4/38.037	98.5	58.8
3			1.018137906	34	22.6/38.033	98.5	58.9
4			1.018137731	23	21.3/38.042	98.5	59.4
1	19.07.2011	4	1.018137979	20	23.6/38.194	98.7	68.0
2			1.018138012	14	21.0/38.192	98.7	61.3
3			1.018137902	22	23.2/38.180	98.7	68.0
4			1.018137901	17	23.0/38.171	98.7	66.6
1	20.07.2011	4	1.018137855	21	23.4/38.133	98.4	67.1
2			1.018137863	24	23.2/38.178	98.4	66.7
3			1.018137946	14	23.0/38.180	98.4	66.4
4			1.018137872	30	22.8/38.182	98.4	66.1
1	21.07.2011	4	1.018137848	27	20.6/38.290	98.0	79.2
2			1.018137920	22	22.1/38.259	98.0	74.7
3			1.018137920	14	22.3/38.249	98.0	73.8
4			1.018137924	29	22.6/38.240	98.0	72.8
1	22.07.2011	4	1.018137583	17	23.3/38.174	97.7	71.9
2			1.018137537	24	23.5/38.178	97.7	71.8
3			1.018137571	21	23.5/38.178	97.7	71.7
4			1.018137617	19	23.4/38.176	97.7	71.3

Z1, serial number: 8659701

Measurement number	Date	Number of measurements	Measurement result	Standard measurement uncertainty	Temperature, °C / resistance of the control thermistor, kΩ	Atmospheric pressure, kPa	Humidity, %
1	18.07.2011	4	9.999962619	113	21.1/38.052	98.5	54.9
2			9.999962585	111	21.3/38.037	98.5	58.8
3			9.999962409	72	22.6/38.033	98.5	58.9
4			9.999962342	103	23.2/38.042	98.5	59.4
1	19.07.2011	4	9.999962983	162	23.4/38.197	98.7	68.5
2			9.999963010	231	21.0/38.223	98.7	61.3
3			9.999962921	109	23.6/38.194	98.7	68.0
4			9.999962984	109	23.0/38.171	98.7	66.6
1	20.07.2011	4	9.999962833	115	23.0/38.180	98.4	66.4
2			9.999962893	81	23.2/38.178	98.4	66.7
3			9.999962703	117	23.4/38.178	98.4	67.1
4			9.999962810	135	21.6/38.173	98.4	63.8
1	21.07.2011	4	9.999963163	94	21.4/38.276	98.0	76.7
2			9.999962846	155	22.0/38.261	98.0	74.8
3			9.999963263	117	22.3/38.249	98.0	73.8
4			9.999963111	168	22.5/38.240	98.0	72.9
1	22.07.2011	4	9.999962471	93	23.3/38.170	97.7	71.9
2			9.999962754	108	23.5/38.180	97.7	71.8
3			9.999962745	101	23.5/38.020	97.7	71.5

Z2, serial number: 8659702

Measurement number	Date	Number of measurements	Measurement result	Standard measurement uncertainty	Temperature, °C / resistance of the control thermistor, kΩ	Atmospheric pressure, kPa	Humidity, %
1	18.07.2011	4	1.018163350	23	20,0/37.953	99.2	47
2			1.018163688	23	21,2/37.952	99.2	49.4
3			1.018163338	34	22,1/37.950	99.2	51.1
4			1.018163408	50	23,3/37.956	99.2	52.0
1	19.07.2011	4	1.018163303	18	23.6/37.962	98.7	65.8
2			1.018163283	10	23.2/38.046	98.7	66.3
3			1.018163278	14	23.3/38.025	98.7	65.8
4			1.018163279	26	23.4/38.000	98.7	65.6
1	20.07.2011	4	1.018163271	13	22.9/38.010	98.4	66.3
2			1.018163283	18	23.1/38.009	98.4	66.5
3			1.018163317	10	23.4/38.009	98.4	67.1
4			1.018163271	11	23.4/38.009	98.4	67.2
1	21.07.2011	4	1.018163364	17	21.7/38.268	98.0	75.5
2			1.018163438	21	21.7/38.268	98.0	75.5
3			1.018163421	17	22.5/38.092	98.0	73.2
4			1.018163361	11	22.6/38085	98.0	72.5
1	22.07.2011	4	1.018163379	18	23.4/38.017	97.7	72.0
2			1.018163346	27	23.4/38.023	97.7	71.8
3			1.018163341	15	23.7/38.021	97.7	71.4
4			1.018163371	29	23.9/38.015	97.7	71.0

Z2, serial number: 8659702

Measurement number	Date	Number of measurements	Measurement result	Standard measurement uncertainty	Temperature, °C / resistance of the control thermistor, kΩ	Atmospheric pressure, kPa	Humidity, %
1	18.07.2011	4	9.999963268	32	20.6/38.072	98.5	48.4
2			9.999963084	94	20.9/38.061	98.5	49.2
3			9.999963202	80	21.8/38.043	98.5	49.6
4			9.999963551	78	22.4/38.063	98.5	51.8
1	19.07.2011	4	9.999962925	57	23.6/37.962	98.7	65.8
2			9.999963142	78	23.2/38.046	98.7	66.3
3			9.999962988	133	23.3/38.025	98.7	65.8
4			9.999963041	82	23.4/38.000	98.7	65.6
1	20.07.2011	4	9.999963787	136	20.7/38.127	98.7	74.9
2			9.999963451	237	21.1/38.121	98.7	73.8
3			9.999963592	72	22.0/38.113	98.7	72.7
4			9.999963681	188	22.2/38.102	98.7	72.0
1	21.07.2011	4	9.999964162	178	21.9/38.115	98.0	75.1
2			9.999964221	129	22.2/38.107	98.0	74.3
3			9.999963741	135	22.4/38.096	98.0	73.0
4			9.999964019	74	22.4/38.094	98.0	73.3
1	22.07.2011	3	9.999963793	99	23.4/38.017	97.7	72.0
2			9.999963656	32	23.4/38.023	97.7	71.8
3			9.999963817	137	23.7/38.020	97.7	71.4

PROTOCOL №2, BelGIM

Z1, serial number: 8659701

Measurement number	Date	Number of measurements	Measurement result	Standard measurement uncertainty	Temperature, °C / resistance of the control thermistor, kΩ	Atmospheric pressure, kPa	Humidity, %
1	01.08.2011	4	1.018137860	16	23.8/38.128	98.4	68.9
2			1.018137854	15	23.7/38.131	98.4	68.9
3			1.018137858	15	23.8/38.140	98.4	69.0
4			1.018137845	17	21.7/38.139	98.4	69.0
1	02.08.2011	4	1.018137848	13	24.0/38.135	98.92	62.3
2			1.018137852	15	23.5/38.130	98.92	63.5
3			1.018137863	13	23.6/38.130	98.92	63.5
4			1.018137841	18	23.7/38.140	98.92	63.1
1	03.08.2011	4	1.018137866	17	22.0/38.17	99.46	55.3
2			1.018137839	25	23.9/38.15	98.46	55.9
3			1.018137899	8	23.8/38.10	99.52	53.4
4			1.018137836	20	23.9/38.11	99.52	52.8
1	04.08.2011	4	1.018137893	15	23.0/38.15	99.46	52.0
2			1.018137864	12	23.2/38.16	99.46	50.2
3			1.018137828	13	23.2/38.16	99.46	51.2
4			1.018137823	18	23.6/38.16	99.46	51.5
1	05.08.2011	4	1.018137874	11	23.4/38.15	99.36	53.2
2			1.018137894	16	23.7/38.15	99.36	50.6
3			1.018137907	23	23.6/38.15	99.36	50.3
4			1.018137849	15	23.1/38.15	99.36	49.3

Z1, serial number: 8659701

Measurement number	Date	Number of measurements	Measurement result	Standard measurement uncertainty	Temperature, °C / resistance of the control thermistor, kΩ	Atmospheric pressure, kPa	Humidity, %
1	01.08.2011	4	9.999962557	149	23.8/38.13	98.39	68.9
2			9.999962326	169	23.7/38.13	98.39	69.0
3			9.999962325	120	24.0/38.14	98.39	69.0
4			9.999962438	73	24.0/38.12	98.4	68.9
1	02.08.2011	4	9.999962408	87	24.0/38.12	99.06	63.5
2			9.999962414	71	24.1/38.13	99.06	63.5
3			9.999962219	109	23.6/38.14	99.06	62.7
4			9.999962362	113	23.6/38.14	99.06	62.2
1	03.08.2011	4	9.999962358	170	23.4/38.15	99.5	56.1
2			9.999962509	91	23.6/38.15	99.5	55.0
3			9.999962552	43	23.6/38.15	99.5	56.1
4			9.999962391	145	24.0/38.14	99.5	55.7
1	04.08.2011	4	9.999962476	195	23.2/38.15	99.46	52.3
2			9.999962360	102	22.7/38.15	99.46	46.6
3			9.999962418	107	23.1/38.16	99.46	50.6
4			9.999963388	154	23.5/38.16	99.46	51.6
1	05.08.2011	4	9.999962412	109	23.5/38.15	99.36	53.0
2			9.999962497	50	23.3/38.16	99.36	48.9
3			9.999962351	84	23.4/38.16	99.36	49.1
4			9.999962595	113	23.6/38.15	99.36	50.4

Z2, serial number: 8659702

Measurement number	Date	Number of measurements	Measurement result	Standard measurement uncertainty	Temperature, °C / resistance of the control thermistor, kΩ	Atmospheric pressure, kPa	Humidity, %
1	01.08.2011	4	1.018163323	15	23.7/38.013	98.4	68.9
2			1.018163371	19	23.6/38.017	98.4	69.0
3			1.018163366	17	23.6/38.019	98.4	69.0
4			1.018163325	19	23.6/38.022	98.4	68.9
1	02.08.2011	4	1.018163280	12	24.1/38.010	98.9	63.4
2			1.018163275	28	24.2/38.010	98.9	63.4
3			1.018163303	19	23.8/38.010	98.9	61.1
4			1.018163263	14	23.6/38.020	98.9	62.6
1	03.08.2011	4	1.018163319	17	22.6/38.04	99.5	55.6
2			1.018163307	14	23.8/38.03	99.5	55.9
3			1.018163301	14	23.9/38.02	99.5	55.7
4			1.018163283	9	23.6/38.01	99.5	53.5
1	04.08.2011	4	1.018163300	14	22.7/38.032	99.46	52.0
2			1.018163265	16	23.3/38.030	99.46	52.4
3			1.018163269	17	22.3/38.03	99.46	49.1
4			1.018163289	17	23.7/38.034	99.46	51.5
1	05.08.2011	4	1.018163311	18	22.9/38.00	99.36	53.3
2			1.018163326	10	23.5/38.02	99.36	53.2
3			1.018163452	9	23.7/38.02	99.36	53.2
4			1.018163307	12	24.0/38.02	99.36	52.3

Z2, serial number: 8659702

Measurement number	Date	Number of measurements	Measurement result	Standard measurement uncertainty	Temperature, °C / resistance of the control thermistor, kΩ	Atmospheric pressure, kPa	Humidity, %
1	01.08.2011	4	9,999963707	101	23,7/38,025	98,4	68,9
2			9,999963856	137	23,8/38,02	98,4	69,0
3			9,999963855	73	23,8/38,02	98,4	69,1
4			9,999963372	144	23,9/3797	98,4	69,0
1	02.08.2011	4	9.999962808	170	24.1/38.01	98.9	63.4
2			9.999962849	159	24.2/38.00	98.9	63.3
3			9.999962959	125	23.8/38.01	98.9	61.7
4			9.999962693	142	23.6/38.02	99.1	62.7
1	03.08.2011	4	9.999962810	73	22.7/38.04	99.5	55.5
2			9.999963207	306	23.8/38.03	99.5	56.0
3			9.999962787	66	24.0/38.02	99.5	55.7
4			9.999962902	156	23.6/38.00	99.46	52.6
1	04.08.2011	4	9.999962979	99	22.7/38.04	99.46	49.6
2			9.999962795	79	23.9/38.03	99.46	49.6
3			9.999962886	152	24.0/38.03	99.46	51.7
4			9.999962618	115	21.7/38.03	99.46	51.7
1	05.08.2011	4	9.999962781	170	22.7/38.02	99.36	45.9
2			9.999962870	80	23.6/38.03	99.36	49.7
3			9.999962890	150	23.7/38.03	99.36	50.0
4			9.999962833	50	23.3/38.02	99.36	49.9

VNIIM, Russia

Date of measurement: 26-29.07.11

Description of the standard and calibration method

The standard realizes voltage with frequency-to-voltage converter using Josephson array made by PTB, Germany. The output voltage is up to 10 V. The array is driven by 75 GHz frequency produced by millimeter wave generator, stability and accuracy of which depends upon the frequency-shaping circuit based on rubidium frequency reference. Zeners and EMFs are calibrated by opposite connection of their voltages and voltage of the laboratory standard. The voltage difference is read by null detector. The null detector is nanovoltmeter type Keithley 2182. During calibration, the difference between the voltages of Zener and laboratory standard does not exceed 2 µV. During calibration, the polarity of the laboratory standard and Zener under calibration is changed to avoid constant offset voltages in the comparison loop including EMFs in the measurement loop and zero drift of null detector. The description of the standard is given in [2].

Results of 1,018 V and 10 V output voltage measurements of type 732B Zener references are presented in the Table 1 VNIIM and Table 2 VNIIM.

Table 1 VNIIM Measurements of Z1 and Z2 at the output «1,018 V»

Measurement number	Date	Quantity of measurements	Measurement result, V	Standard uncertainty of the measurement result, µV	Tempe-rature		Pressure, kPa	Relative humidity, %
					kΩ	°C		
Reference standard Z1								
1	26.07.11	4	1.018137856	0.012	38.132	22.9	101.6	58
2		4	1.018137844	0.016	38.117	23.1	101.6	58
3	27.07.11	4	1.018137874	0.011	38.141	23.0	101.6	62
4		4	1.018137905	0.018	38.122	23.0	101.6	62
5	28.07.11	4	1.018137938	0.005	38.184	23.0	101.3	61
6		4	1.018137883	0.019	38.138	23.0	101.1	62
7	29.07.11	4	1.018137866	0.012	38.155	22.9	100.8	59
8		4	1.018137891	0.018	38.153	22.9	100.8	60
9		4	1.018137885	0.016	38.154	22.9	100.8	61
Reference standard Z2								
1	26.07.11	4	1.018163379	0.013	38.030	22.9	101.6	58
2		4	1.018163351	0.015	38.024	23.1	101.6	58
3	27.07.11	4	1.018163355	0.025	38.038	23.0	101.6	62
4		4	1.018163386	0.011	38.027	23.0	101.6	62
5	28.07.11	4	1.018163392	0.017	38.059	23.0	101.3	61
6		4	1.018163381	0.008	38.036	23.0	101.1	62
7	29.07.11	4	1.018163386	0.015	38.051	22.9	100.8	59
8		4	1.018163376	0.013	38.046	22.9	100.8	60
		4	1.018163380	0.017	38.047	22.9	100.8	61

Table 2 VNIIM Measurements of Z1 and Z2 at the output «10 V»

Measurement number	Date	Quantity of measurements	Measurement result, V	Standard uncertainty of the measurement result, μV	Tempe-rature		Pressure, kPa	Relative humidity, %
					kΩ	°C		
Reference standard Z1								
1	26.07.11	4	9.99996252	0.130	38.132	22.9	101.6	58
2		4	9.99996254	0.086	38.117	23.1	101.6	58
3	27.07.11	4	9.99996290	0.095	38.141	23.0	101.6	62
4		4	9.99996282	0.078	38.122	23.0	101.6	62
5	28.07.11	4	9.99996290	0.054	38.184	23.0	101.3	61
6		4	9.99996270	0.093	38.138	23.0	101.1	62
7	29.07.11	4	9.99996257	0.082	38.155	22.9	100.8	59
8		4	9.99996270	0.085	38.153	22.9	100.8	60
9		4	9.99996299	0.084	38.154	22.9	100.8	61
Reference standard Z2								
1	26.07.11	4	9.99996378	0.115	38.030	22.9	101.6	58
2		4	9.99996404	0.095	38.024	23.1	101.6	58
3	27.07.11	4	9.99996406	0.184	38.038	23.0	101.6	62
4		4	9.99996399	0.138	38.027	23.0	101.6	62
5	28.07.11	4	9.99996412	0.072	38.059	23.0	101.3	61
6		4	9.99996418	0.062	38.036	23.0	101.1	62
7	29.07.11	4	9.99996374	0.463	38.051	22.9	100.8	59
8		4	9.99996401	0.081	38.046	22.9	100.8	60
		4	9.99996416	0.118	38.047	22.9	100.8	61

7. References

[1] Supracon. Josephson Voltage Standard supraVOLTcontrol. MANUAL. 2007.

[2] V. S. Aleksandrov; A. S. Katkov; G. P. Telitchenko. New State Primary Standard and State Test Scheme for Instruments for Measuring DC Electrical Voltage and Electromotive Force. Measurement Techniques, Vol. 45, Issue 3, 2002, pp. 228-232.

[3] D. Avrons, A. Katkov, V. Krzhimovsky, D. Reymann and T.J. Witt. Bilateral Comparison of 1.018 V Standards between the VNIIM and the BIPM. Rapport BIPM-99/02.

[4] A. S. Katkov, S. Solve and M. Stock. Bilateral Comparison of 10 V Standards between the VNIIM (Russia) and the BIPM. Rapport BIPM-2007/07.