Final Report on Bilateral Comparison

COOMET.EM.BIPM-K11.a

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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 (RMO's). The COOMET key comparison (COOMET Project No. 342/BY/05) supplementing BIPM.EM-K11.a was carried out to link COOMET national laboratories. This comparison provides indirect link between voltage realizations of BelGIM and BIPM through VNIIM results obtained in voltage standard key comparisons with the BIPM. In the KCDB, the difference BelGIM - BIPM will be given together with the combined uncertainty of measurements BelGIM – VNIIM and VNIIM- BIPM.

BelGIM performed preliminary measurements of two transfer standards type Fluke 732 B (Z1 and Z2) from 11.01.06 to 18.04.06. The comparison took place in May 10-28, 2006.

Participants were requested to measure the 1.018 V output voltage of the transfer standards. The degree of equivalence of BelGIM was evaluated from the 1.018 V output voltage measurements on each of two transfer standards. This degree of equivalence is presented in table 3. The uncertainty budgets are reported in Appendix B. Description of 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. The dates of preliminary measurements are reported in Appendix A.
Table 1

<table>
<thead>
<tr>
<th>Institute</th>
<th>Country</th>
<th>Standard at the laboratory</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>BelGIM Belarussian State Institute of Metrology</td>
<td>Republic of Belarus</td>
<td>10.05.-15.05.2006</td>
<td>Z1 and Z2</td>
</tr>
<tr>
<td>VNIIM Pilot Mendeleyev Institute for Metrology</td>
<td>Russia</td>
<td>16.05.-19.05.2006</td>
<td>Z1 and Z2</td>
</tr>
<tr>
<td>BelGIM Belarussian State Institute of Metrology</td>
<td>Republic of Belarus</td>
<td>22.05.-28.05.2006</td>
<td>Z1 and Z2</td>
</tr>
</tbody>
</table>

In the course of comparison the transfer standards (Z1 and Z2) were transported to VNIIM by rail within 18 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 18 hours under the same conditions.

3. Transfer standards and requirements for measurements

The transfer standards were Zeners Z1 and Z2 belonging to BelGIM. The nominal output voltage of Z1 and Z2 was 1.018 V. The measurements were performed with the null detector by opposite connection and by changing polarity of Z1 and Z2 and the laboratory voltage standard. 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 controlled. During measurements at BelGIM and VNIIM the Zeners were maintained in shielded rooms.

4. Characteristics of transfer standards

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

<table>
<thead>
<tr>
<th></th>
<th>Value of temperature coefficient of 1.018 V voltage ((k_T)) for Z1</th>
<th>(-0.12 \cdot 10^{-7} \text{ V/°C}) (u_c = 0.3 \cdot 10^{-7} \text{ V/°C})</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Value of temperature coefficient of 1.018 V voltage ((k_T)) for Z2</td>
<td>(-0.11 \cdot 10^{-7} \text{ V/°C}) (u_c = 0.3 \cdot 10^{-7} \text{ V/°C})</td>
</tr>
<tr>
<td>3</td>
<td>Value of baric coefficient of 1.018 V voltage ((k_P)) for Z1 and Z2, not exceed</td>
<td>(±0.25 \cdot 10^{-7} \text{ V/kPa})</td>
</tr>
<tr>
<td>4</td>
<td>Output resistance of Z1 and Z2 at 1.018 V nominal voltage</td>
<td>1 kΩ</td>
</tr>
</tbody>
</table>

5. Measurement methods

The transfer standards were measured at BelGIM from 10.05.06 to 15.05.06 using BelGIM voltage standard and were subsequently transported to VNIIM. The measurements of transfer standards at VNIIM were performed from 16.05.06 to 19.05.06 using VNIIM voltage standard. Then the transfer standards were returned to BelGIM for final measurements in the period from 22.05.06 to 28.05.06.

BelGIM performed measurements with Josephson Voltage Standard. The BelGIM Josephson Voltage Standard uses niobium point contacts with 8 mV output voltage.
driven by 8,795 GHz frequency. Cascade resistive voltage divider (similar [1]) which is a part of the standard enables the voltage to rise up to 1.018 V level. The difference between 8 mV voltages is read by nanovoltmeter Keithley 2182 as null detector. The difference between 1,018 V voltages is read by voltmeter 3458A Hewlett Packard as null detector. Output voltage measurements were performed in each polarity.

The VNIIM voltage standard [2] uses 1 V and 10 V Josephson arrays made in PTB. The null detector is Keithley 2182 nanovoltmeter. The measurement is carried out by reading the difference between the voltage of transfer standard and output voltage of VNIIM standard via null detector. The transfer standard voltage is determined as a mean value of voltages measured in each polarity of VNIIM standard.

6. Results

a) Measurement results BelGIM-VNIIM
Tables 1 and 2 summarize mean value in relation to the mean measurement date at VNIIM (18.05.06), 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 cascade resistive voltage divider caused an increase in the uncertainty of the BelGIM standard

The measurement results are plotted in figures 1 and 2.

Table 1 Results for transfer standard Z1

<table>
<thead>
<tr>
<th>Institute</th>
<th>$U_Z$ / µV</th>
<th>$u_A$ / µV</th>
<th>$u_B$ / µV</th>
<th>$u$ / µV</th>
<th>$T$ / °C</th>
<th>$P$ / kPa</th>
<th>$H$ / %</th>
</tr>
</thead>
<tbody>
<tr>
<td>BelGIM</td>
<td>1018140,27</td>
<td>0,018</td>
<td>0,30</td>
<td>0,30</td>
<td>20.5</td>
<td>99.2</td>
<td>61</td>
</tr>
<tr>
<td>VNIIM</td>
<td>1018140,17</td>
<td>0,008</td>
<td>0,007</td>
<td>0,011</td>
<td>23.5</td>
<td>101.3</td>
<td>24</td>
</tr>
</tbody>
</table>

Table 2 Results for transfer standard Z2

<table>
<thead>
<tr>
<th>Institute</th>
<th>$U_Z$ / µV</th>
<th>$u_A$ / µV</th>
<th>$u_B$ / µV</th>
<th>$u$ / µV</th>
<th>$T$ / °C</th>
<th>$P$ / kPa</th>
<th>$H$ / %</th>
</tr>
</thead>
<tbody>
<tr>
<td>BelGIM</td>
<td>1018165,18</td>
<td>0,022</td>
<td>0,30</td>
<td>0,30</td>
<td>20.5</td>
<td>99.2</td>
<td>61</td>
</tr>
<tr>
<td>VNIIM</td>
<td>1018165,10</td>
<td>0,008</td>
<td>0,007</td>
<td>0,011</td>
<td>23.5</td>
<td>101.3</td>
<td>24</td>
</tr>
</tbody>
</table>

Figure 1 Results of voltage measurement for Z1 in BelGIM and VNIIM
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:

\[ dU_{\text{BelGIM}} = (U_{\text{BelGIM}} - U_{\text{VNIIM}}) + (U_{\text{VNIIM}} - U_{\text{BIPM}}) = dU_1 + dU_2 \]

Referring to the results of bilateral comparison of voltage standards between the VNIIM and the BIPM [3], \( dU_2 = 0.001 \, \mu V \) with standard uncertainty \( u(dU_2) = 0.027 \, \mu V \)

For the transfer standard Z1, \( dU_{\text{BelGIM}} \) is equal to 0.099 \( \mu V \). It was determined as the difference between the BelGIM mean values in relation to the VNIIM mean measurement date (18.05.06) and the VNIIM mean value, taking into consideration that \( dU_2 = 0.001 \, \mu V \).

For the transfer standard Z2, \( dU_{\text{BelGIM}} = 0.079 \, \mu V \).

The temperature correction for the difference between the mean temperatures of BelGIM and VNIIM equal to 3.0 °C was determined for Z1 as:

\[ dU_T (Z1) = k_{TZ1} (T_{\text{VNIIM}} - T_{\text{BelGIM}}) = -0.036 \, \mu V; \]  

and for Z2 as:

\[ dU_T (Z2) = k_{TZ2} (T_{\text{VNIIM}} - T_{\text{BelGIM}}) = -0.033 \, \mu V. \]  

The difference between the mean value of two transfer standards and reference value which takes into account temperature correction was calculated as follows:

\[ dU_{\text{BelGIM}} = 0.5 \cdot ((0.099 - 0.036) + (0.079 - 0.033)) \, \text{mK}B = 0.054 \, \mu V. \]
Standard uncertainty of the difference between BelGIM measurements and the reference value \(d_{\text{U BelGIM}}\) takes into account uncertainty of BelGIM measurements, uncertainty of VNIIM measurements, uncertainty of result produced by VNIIM standard in bilateral comparison and uncertainty due to temperature and pressure effects when carrying out measurements in BelGIM and VNIIM:

\[
u = (u_{\text{BelGIM-Z}}^2 + u_{\text{VNIIM-Z}}^2 + u_{\text{VNIIM-BIPM}}^2 + u_T^2 + u_P^2)^{0.5}.
\]

\[
u_T = |T_{\text{BelGIM}} - T_{\text{VNIIM}}| \cdot u (k_T) = 3 \times 0.03 = 0.09 \, \mu V;
\]

\[
u_P = 0.5|P_{\text{BelGIM}} - P_{\text{VNIIM}}| k_P/\sqrt{3} = 0.5 \times 2.1 \times 0.025/1.73 = 0.015 \, \mu V;
\]

For Z1 and Z2, \(u = (0.30^2 + 0.023^2 + 0.027^2 + 0.09^2 + 0.015^2)^{0.5} = 0.32 \, \mu V.
\]

The mean uncertainty of measurements on two Zeners was calculated as follows:

\[
u_{\text{mean}} = 0.5 / (u_{Z1}^2 + u_{Z2}^2)^{0.5} = 0.21 \, \mu V.
\]

The expanded uncertainty must be calculated at 95 % level of confidence, which requires the knowledge of the degree of freedom \(\nu\), associated with the standard uncertainty of the difference.

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

<table>
<thead>
<tr>
<th>Institute</th>
<th>(d_i , / , \mu V)</th>
<th>(u_{\text{LAB}} , / , \mu V)</th>
<th>(\nu_{\text{LAB}}, \nu_{\text{eff}})</th>
<th>(k_{95})</th>
<th>(U(d_i) , / , \mu V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BelGIM</td>
<td>0.054</td>
<td>0.21</td>
<td>33</td>
<td>2.03</td>
<td>0.43</td>
</tr>
</tbody>
</table>
Table 4  Results of the BelGIM key comparison of 1.018 V standards using Zener traveling standards: Mean Date 18 May 2006. Uncertainties are 1-σ estimates.

BelGIM voltage key comparison using traveling Zener standards Z1 and Z2.

<table>
<thead>
<tr>
<th>Units are µV</th>
<th>BelGIM value</th>
<th>VNIIM value, with temperature corrections, ( U_{VNIIM} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1018140.268</td>
<td>1018140.170</td>
</tr>
<tr>
<td>2</td>
<td>0.018</td>
<td>0.008</td>
</tr>
<tr>
<td>3</td>
<td>0.30</td>
<td>0.007</td>
</tr>
<tr>
<td>4</td>
<td>0.30</td>
<td>0.11</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>VNIIM value, with temperature corrections, ( U_{VNIIM} )</th>
<th>BelGIM value</th>
<th>VNIIM value, with temperature corrections, ( U_{VNIIM} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.062</td>
<td>0.053</td>
<td></td>
</tr>
<tr>
<td>0.21</td>
<td>0.001</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total unc for 2 Zeners</th>
<th>0.21</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>( U_{BELGIM} - U_{VNIIM} )</th>
<th>( U_{BELGIM} - U_{BIPM} )</th>
<th>( U_{VNIIM} - U_{BIPM} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.054</td>
<td>0.054</td>
<td>0.054</td>
</tr>
</tbody>
</table>

| \( \text{mean date} \) yy/mm/dd | 06/05/18 | 06/05/18 |

References to Table 4

1, 2, 3 and 4 are the BelGIM value, type A, type B and combined uncertainties;

2 The stability of the Zeners can be described by flicker noise (1/f noise) with a floor value of about 7 nV. If the BelGIM results for Z1 from each day are used in a linear least-squares fit, the standard deviation of the residuals is 0.091 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 0.018 µV, if the daily measurement values are uncorrelated. A similar argument was applied for the estimated type A uncertainty for Z2.

5, 6, 7, 8 and 9 are the VNIIM value, type A, type B and combined uncertainties.

9 is the VNIIM value corrected to the mean temperature of BelGIM measurements;

10 is the root-sum-square (rss) total uncertainty associated with the corrections for temperature and pressure.
is the total uncertainty for each Zener. This is the rss of 4, 9 and 10.

is the comparison result from each Zener.

is the mean difference for all $n (=2)$ Zeners.

is the standard uncertainty of the comparison BelGIM - VNIIM and uncertainty of the mean from the results on two Zeners.

are result of VNIIM-BIPM key comparison [3];

are calculated result of BelGIM key comparison.

7. References


BelGIM measurements of the transfer standards

Stability of Zeners

**Measurements of temperature effects on voltages realized by Z1 and Z2**

The measurements of temperature effects were carried out on two Zeners in the temperature range from 20 to 25 °C. Zeners were placed in special oven. The oven temperature was measured with a thermometer in such a way that the distance between thermometer and side of Zener was about 20 mm. Measurements were carried out using a standard similar to the National voltage standard with standard cells. The null detector was voltmeter 3458A Hewlett Packard.

The change in 1,018 V voltage was equal to \((-12 \pm 30) \cdot 10^{-9} / ^\circ C\) for Z1 and \((-11 \pm 30) \cdot 10^{-9} / ^\circ C\) for Z2.
Participant’s uncertainty budgets

Uncertainty budget of VNIIM, Russia

Output voltage of Zener reference: 1.018 V,
Output resistance of Zener reference: 1 kΩ.

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Uncertainty</th>
<th>Type</th>
<th>Probability distribution</th>
<th>Standard uncertainty</th>
<th>Sensitivity coefficient</th>
<th>Uncertainty contribution</th>
<th>Degree of freedom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured mean voltage</td>
<td>8 nV</td>
<td>A</td>
<td>normal</td>
<td>8 nV</td>
<td>1</td>
<td>8 nV</td>
<td>6</td>
</tr>
<tr>
<td>Frequency</td>
<td>24 Hz</td>
<td>B</td>
<td>rectangular</td>
<td>14 Hz</td>
<td>14.5 pV/Hz</td>
<td>0.2 nV</td>
<td>∞</td>
</tr>
<tr>
<td>thermal EMFs</td>
<td>5 nV</td>
<td>B</td>
<td>normal</td>
<td>5 nV</td>
<td>1</td>
<td>5 nV</td>
<td>5</td>
</tr>
<tr>
<td>Leakage error</td>
<td>5 nV</td>
<td>B</td>
<td>rectangular</td>
<td>3 nV</td>
<td>1</td>
<td>3 nV</td>
<td>2</td>
</tr>
<tr>
<td>Detector</td>
<td>3 nV</td>
<td>B</td>
<td>normal</td>
<td>3 nV</td>
<td>1</td>
<td>3 nV</td>
<td>40</td>
</tr>
<tr>
<td>Combined st. unc.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>11 nV</td>
</tr>
</tbody>
</table>

The estimated relative standard uncertainty at VNIIM of the 1.018 V measurements for Z1 and Z2 is therefore 11 nV/V.

Values of the laboratory

Frequency: 75 GHz
Series resistance of leads/filters: 10 Ω
Leakage resistance: 200 GΩ
Typical voltage at null detector 20 µV
Null detector and settings: Keithley 2182, 10 mV range, rate - 1 pls,
Measurement sequence +/- sequence, 280 readings of null detector each
Typical time for sequence 1 minute
### Uncertainty budget of BelGIM, Belarus

#### for Z1

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Estimate</th>
<th>Uncertainty</th>
<th>Type</th>
<th>Probability distribution</th>
<th>Standard uncertainty</th>
<th>Sensitivity coefficient</th>
<th>Uncertainty contribution</th>
<th>Degree of freedom</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X_0$</td>
<td>1.018 V</td>
<td>17 nV</td>
<td>A</td>
<td>normal</td>
<td>17 nV</td>
<td>1/1,018 V</td>
<td>$1.7 \cdot 10^{-8}$</td>
<td>26</td>
</tr>
<tr>
<td>$X_f$</td>
<td>8.795 GHz</td>
<td>17 Hz</td>
<td>B</td>
<td>rectangular</td>
<td>10 Hz</td>
<td>1/8,795 GHz</td>
<td>$0.1 \cdot 10^{-8}$</td>
<td>$\infty$</td>
</tr>
<tr>
<td>$X_R$</td>
<td>1 kΩ / 20 GΩ</td>
<td>$10 \cdot 10^{-8}$</td>
<td>B</td>
<td>rectangular</td>
<td>$3 \cdot 10^{-8}$</td>
<td>1</td>
<td>$3 \cdot 10^{-8}$</td>
<td>5</td>
</tr>
<tr>
<td>$X_{M1}$</td>
<td>0</td>
<td>2 nV</td>
<td>A</td>
<td>normal</td>
<td>2 nV</td>
<td>1/8 mV</td>
<td>$25 \cdot 10^{-8}$</td>
<td>20</td>
</tr>
<tr>
<td>$X_{M2}$</td>
<td>0</td>
<td>50 nV</td>
<td>B</td>
<td>normal</td>
<td>50 nV</td>
<td>1/1,018 V</td>
<td>$5 \cdot 10^{-8}$</td>
<td>10</td>
</tr>
<tr>
<td>$X_D$</td>
<td>0</td>
<td>15 $\cdot 10^{-8}$</td>
<td>B</td>
<td>normal</td>
<td>$15 \cdot 10^{-8}$</td>
<td>1</td>
<td>$15 \cdot 10^{-8}$</td>
<td>10</td>
</tr>
<tr>
<td>$X_T$</td>
<td>0</td>
<td>$3 \cdot 10^{-8}$</td>
<td>B</td>
<td>normal</td>
<td>$3 \cdot 10^{-8}$</td>
<td>1</td>
<td>$3 \cdot 10^{-8}$</td>
<td>20</td>
</tr>
<tr>
<td>$U$</td>
<td>1.018 V</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$30 \cdot 10^{-8}$</td>
<td>$\nu_{eff} = 33$</td>
</tr>
</tbody>
</table>

#### for Z2

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Estimate</th>
<th>Uncertainty</th>
<th>Type</th>
<th>Probability distribution</th>
<th>Standard uncertainty</th>
<th>Sensitivity coefficient</th>
<th>Uncertainty contribution</th>
<th>Degree of freedom</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X_0$</td>
<td>1.018 V</td>
<td>23 nV</td>
<td>A</td>
<td>normal</td>
<td>23 nV</td>
<td>1/1,018 V</td>
<td>$2.3 \cdot 10^{-8}$</td>
<td>26</td>
</tr>
<tr>
<td>$X_f$</td>
<td>8.795 GHz</td>
<td>17 Hz</td>
<td>B</td>
<td>rectangular</td>
<td>10 Hz</td>
<td>1/8,795 GHz</td>
<td>$0.1 \cdot 10^{-8}$</td>
<td>$\infty$</td>
</tr>
<tr>
<td>$X_R$</td>
<td>1 kΩ / 20 GΩ</td>
<td>$10 \cdot 10^{-8}$</td>
<td>B</td>
<td>rectangular</td>
<td>$3 \cdot 10^{-8}$</td>
<td>1</td>
<td>$3 \cdot 10^{-8}$</td>
<td>5</td>
</tr>
<tr>
<td>$X_{M1}$</td>
<td>0</td>
<td>2 nV</td>
<td>A</td>
<td>normal</td>
<td>2 nV</td>
<td>1/8 mV</td>
<td>$25 \cdot 10^{-8}$</td>
<td>20</td>
</tr>
<tr>
<td>$X_{M2}$</td>
<td>0</td>
<td>50 nV</td>
<td>B</td>
<td>normal</td>
<td>50 nV</td>
<td>1/1,018 V</td>
<td>$5 \cdot 10^{-8}$</td>
<td>10</td>
</tr>
<tr>
<td>$X_D$</td>
<td>0</td>
<td>$15 \cdot 10^{-8}$</td>
<td>B</td>
<td>normal</td>
<td>$15 \cdot 10^{-8}$</td>
<td>1</td>
<td>$15 \cdot 10^{-8}$</td>
<td>10</td>
</tr>
<tr>
<td>$X_T$</td>
<td>0</td>
<td>$3 \cdot 10^{-8}$</td>
<td>B</td>
<td>normal</td>
<td>$3 \cdot 10^{-8}$</td>
<td>1</td>
<td>$3 \cdot 10^{-8}$</td>
<td>20</td>
</tr>
<tr>
<td>$U$</td>
<td>1.018 V</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$30 \cdot 10^{-8}$</td>
<td>$\nu_{eff} = 33$</td>
</tr>
</tbody>
</table>

- $X_0$ - uncertainty due to reading of difference between 1.018 V voltage measurements by null-detector;
- $X_f$ - uncertainty due to instability of applied frequency;
- $X_R$ - uncertainty caused by shunting of Zener output resistance;
- $X_{M1}$ - uncertainty due to reading of difference between 8 mV voltage measurements by null-detector when the voltage rises to 1,018 V level;
- $X_{M2}$ - uncertainty of 1,018 V measurement;
- $X_D$ - uncertainty due to instability of current and gain of resistive divider;
- $X_T$ - uncertainty due to thermal EMFs in the measurement loops;
APPENDIX C

Description of measurement methods

VNIIM, Russia

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 10 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 output voltage measurements of type 732В Zener references are presented in the Table 1 VNIIM.

Table 1 VNIIM.

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BelGIM, Belarus

**Description of the standard and calibration method**

The BelGIM national voltage standard uses three sequentially connected niobium point contacts with Josephson junctions maintained in Dewar with liquid helium and driven by high-frequency voltage. The standard can realize voltage at 10.18 mV level at 8,795 GHz frequency and with the number of steps equal to 560 (F = 8,795 Hz, n = 560). Stably realized voltage of 4 mV or 8 mV which is controlled by nanovoltmeter 2182 Keithley rises up to 1,018 V level using cascade resistive voltage divider powered by 1 mA stable source. This voltage is applied to null detector and the voltage difference between the national standard and the voltage standard 732B is read. The null detector is voltmeter 3458A Hewlett Packard.

In order to avoid constant offset voltages in the comparison loop the measurements were performed in each voltage polarity. The polarity was changed with switch P309.

The cascade resistive divider may cause serious fluctuations in measurement results.

Measurements of voltages realized by 1,018 V voltage standards type 732B were carried out in the shielded room at 20.5 °C twice a day in such a way that the Zeners were disconnected from the mains supply and the systems and shields were connected to the ground. The number of counts for each measurement was not less than 10. Subsequently, the measurement results were averaged.

Results of 1,018 V output voltage measurements of type 732B Zener references are presented in the Table 2 BELGIM and Table 3 BELGIM.
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