Bilateral Comparison of 1.018 V and 10 V Standards between the BEV (Austria) and the BIPM, April to May 2025 (part of the ongoing BIPM key comparison BIPM.EM-K11.a and b)

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Introduction

As part of the ongoing BIPM key comparison BIPM.EM-K11.a and b, a comparison of the 1.018 V and 10 V voltage reference standards of the BIPM and the *Bundesamt für Eich- und Vermessungswesen* (BEV), Wien, Austria, was carried out from April to May 2025. Two BIPM Zener diode-based travelling standards (Fluke 732B), BIPM_6 (Z6) and BIPM_I (ZI), were transported to BEV and back to BIPM by freight. In order to keep the Zeners powered during their transportation and during long measurement series, a dedicated auxiliary battery supply was designed and connected in parallel to the internal battery.

At BEV, the reference standard for DC voltage is a Programmable Josephson Voltage Standard (PJVS). The output electromotive force (EMF) of each travelling standard was measured by direct comparison with the primary standard.

At the BIPM, the output EMF of each travelling standard was calibrated before and after the measurements at BEV against the PJVS developed at the BIPM around a PTB programmable SNS (Superconductor/Normal Metal/Superconductor) array.

Results of all measurements were corrected by the BIPM for the dependence of the output voltages of the Zener standards on internal temperature and ambient atmospheric pressure.

Outline of the measuring method

BEV 1.018 V and 10 V measurements

At BEV, the primary reference standard for DC voltage measurement is a 10 V Programmable Josephson Voltage Standard (PJVS) [1] – DC Quantum Voltmeter – manufactured by *Supracon AG*[*].

This system comprises the following key components:

- Cryoprobe including Programmable Josephson junction array chip
- 70 GHz microwave synthesizer
- Current source developed by *Supracon*
- Polarity reversal switch by Supracon

A *Keithley 2182A* Nanovoltmeter (K2182A) is utilized as a differential voltmeter. This nanovoltmeter undergoes direct calibration against the Josephson standard before being employed for differential voltage measurements. The correction values for the nanovoltmeter are directly stored within the measurement program and automatically applied for subsequent measurements.

The control software “AC-supraVoltcontrol_V24-02” [1], also sourced from *Supracon*, is used for both the calibration of the *K2182A* nanovoltmeter and the calibration of the travelling standards.

Following a warm-up period of four hours for the PJVS and the Zeners being disconnected from the power line for two hours, the output voltages of the PJVS array and the BIPM travelling standards were connected in series opposition through a low thermal EMF multiplexer (polarity switch) to the *K2182A* nanovoltmeter. Then for the positive polarity measurement the two voltages were compared by measuring the difference voltage using the *K2182A* nanovoltmeter in the 10 mV range. For the measurement of the negative polarity, the Josephson output voltage was inversed by changing the polarity of the bias current through the PJVS and the output voltage of the Zener was inverted by changing the polarity of the output with the multiplexer.

Each measurement consists of 10 individual data points and the results stated in the table are the arithmetic mean of these 10 data points. Each of these 10 data points represents the mean value of 40 individual readings, with the first 20 readings taken at a positive

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[*] Certain commercial equipment, instruments, or materials are identified in this paper to facilitate understanding. Such identification does not imply recommendation or endorsement by BIPM and BEV, nor does it imply that the materials or equipment that are identified are necessarily the best available for the purpose.

polarity and the subsequent 20 readings taken at a negative polarity. The "GUARD" and "CHASSIS" output terminals were interconnected and connected to the common ground of the measurement setup.

The internal thermistor resistance was measured using a *Fluke 8588A* multimeter at the 100 kΩ range in low current mode (10 µA). The ambient conditions, including pressure, relative humidity and temperature, were recorded using a calibrated *AOIP HM30* instrument.

BIPM Measurements for 1.018 V and 10 V

The output voltage of the Zener standard to be measured was connected in series opposition to the BIPM Programmable Josephson Voltage Standard - PTB 10 V SNS array (S/N: 2013-02/4a) [2], through a low thermal EMF multiplexer [3, 4]. The binding post terminals “GUARD” and “CHASSIS” of the Zener standard were connected together and connected to a single point which is the grounding reference point of the measurement setup.

The measurements started at least two hours after the mains plug at the rear of the Zeners had been disconnected in order for the Zener internal temperature to stabilize. In this comparison, the BIPM detector was a digital nanovoltmeter *Keithley 2182A* operated on its 10 mV range. A computer was used to monitor, record the measurements, acquire the data, correct for pressure dependence, and calculate results.

The BIPM array biasing frequency was adjusted in such a way that the voltage difference between the primary and the secondary voltage standards was always below 1 µV for both nominal voltages. In such a case, the nanovoltmeter gain error doesn’t affect the measurement result and the corresponding uncertainty can also be neglected.

One individual measurement point was acquired according to the following:

1- The Zener and the BIPM array are set in their positive polarity, connected in series opposition and the detector data reading sequence starts;
2- The polarity of the detector is reversed and a reading sequence is carried out. The number of measurements is twice the number acquired in step 1;
3- The polarity of the detector is reversed again to match the conditions of step 1 and the reading sequence restarts;
4- The Zener and the BIPM array are set in their negative polarity, connected in series opposition and the detector data reading sequence starts;

5- The polarity of the detector is reversed and a reading sequence is carried out. The number of measurements is twice the number acquired in step 4;
6- The polarity of the detector is reversed again to match the conditions of step 4 and the reading sequence restarts.

The reversal of the array polarity (by reversing the bias current) is always accompanied by a reversal of the Zener voltage standard using the multiplexer. The reversal of the detector polarity is done to cancel out any internal thermal EMF with a constant drift rate.

Each data acquisition step consists of 50 preliminary measurements followed by 100 measurements. Each of these should not differ from the mean of the preliminary measurements by more than four times their standard deviation. If so, the software warns the operator with a beep. If many beeps occur, it means that the Zener output value has changed. The decision on restarting the “Data Acquisition” step in progress is based on considering the graphical representation of the measurements on the computer screen. The procedure to acquire one individual measurement point is repeated five times in a row and the mean value corresponds to one result on the graph (cf. Fig. 1, 2, 3, and 4).

Results at 10 V

Figure 1 shows the measured values obtained for the two standards by the two laboratories at 10 V. Figure 2 presents the voltage evolution of the arithmetic mean of the two standards which is used to compute the final result at 10 V. A linear least squares fit is applied to all of the individual BIPM results, and to the mean value of both transfer standards. The comparison result is the voltage difference between the mean value of the BEV measurements at the mean date of the BEV measurements (27/04/2025) and the BIPM fitted value with their the related associated uncertainties.

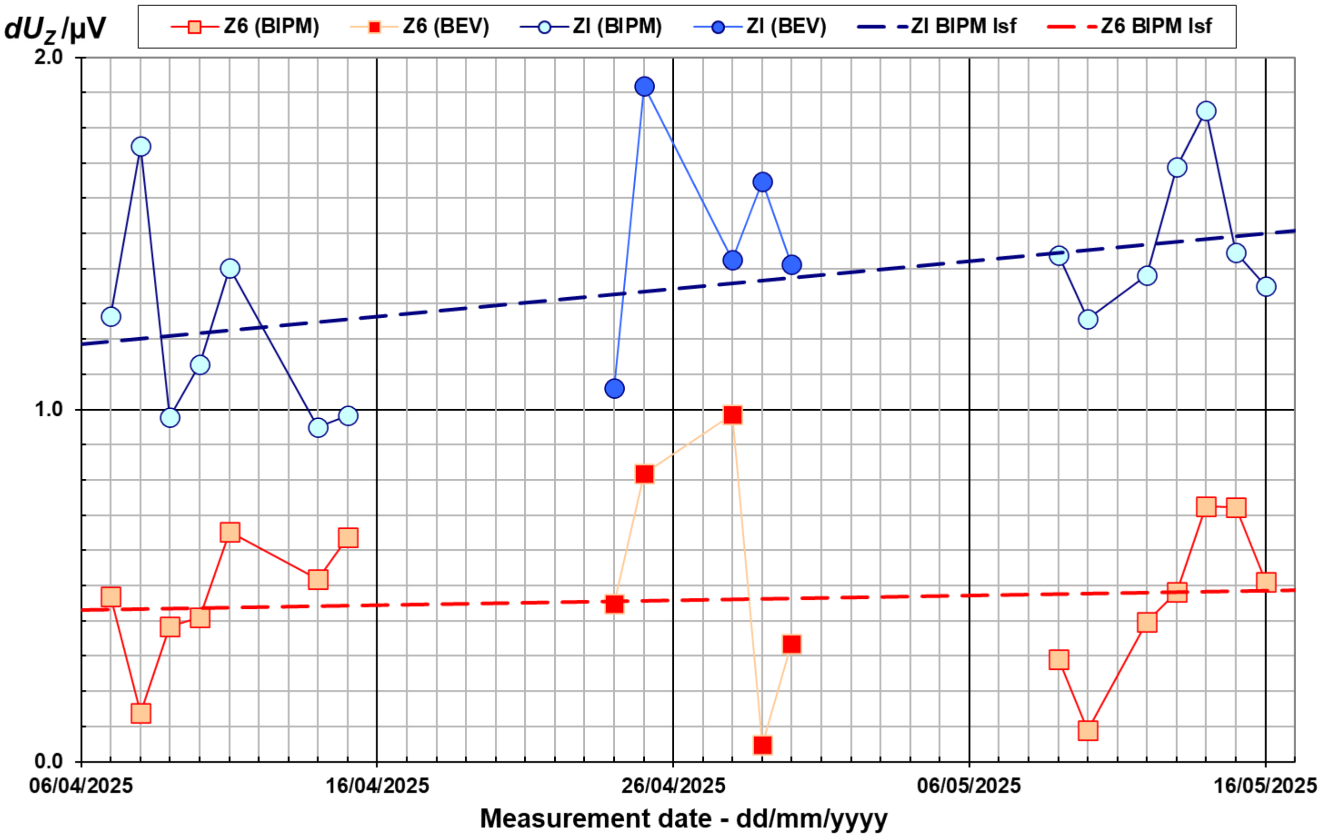

Figure 1: Voltage of Z6 (squares) and ZI (disks) at 10 V measured at both institutes (light markers for BIPM and dark markers for BEV), referred to an arbitrary offset, as a function of the measurement date with a linear least-squares fit (lsf) to the BIPM measurements**.** Temperature and pressure corrections were applied to all the measurements.

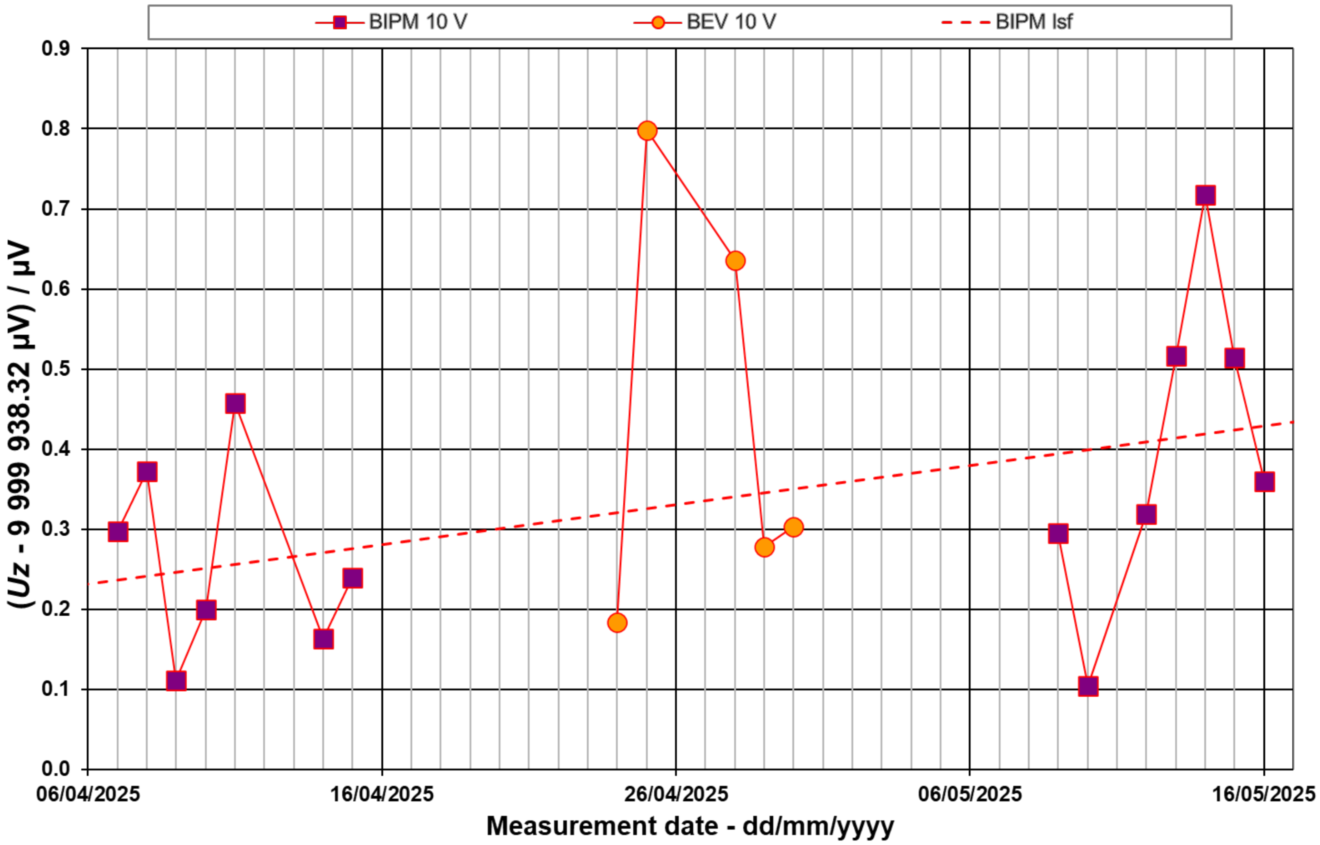

Figure 2: Voltage evolution of the arithmetic mean of the two standards at 10 V. BEV measurements are represented by disks and BIPM measurements by squares. A least-squares fit is applied to the BIPM measurements.

Uncertainty Budgets at 10 V

BIPM uncertainty budget at 10 V

Table 1 summarizes the uncertainties related to the calibration of a Zener against the PJVS at the BIPM at the level of 10 V.

Experience has shown that flicker or 1/*f* noise ultimately limits the stability characteristics of Zener standards and it is not appropriate to use the standard deviation divided by the square root of the number of observations to characterize the dispersion of measured values. For the present standards, the relative value of the voltage noise floor due to flicker noise is about 1 part in 10^8 [5]. The Type A standard uncertainty in Table 1 therefore has a lower limit of 100 nV. However, if the standard deviation of the measurements at the mean date of the participant is larger than the flicker noise floor, it is this standard deviation which is considered to be the Type A standard uncertainty.

PJVS & detector uncertainty components	**Uncertainty (nV)**	**Degrees of freedom**
Noise of the measurement loop that includes the residual thermal EMF including the residual EMF of the reversing switch (Type A)	2	
Detector gain (Type B)	negligible	∞
Leakage resistance (Type B)	4	∞
Frequency (Type B)	0.1	∞
Zener noise (Type A)	Not lower than the 1/*f* noise estimated as 100 nV, included in the comparison uncertainty budget (Table 3)	
Zener temperature correction	Included in the comparison uncertainty budget (Table 3)	10
Zener pressure correction		14

Table 1: Estimated standard uncertainties arising from the PJVS and the measurement setup for Zener calibrations with the BIPM equipment at the level of 10 V.

BEV uncertainty budget at 10 V

Tables 2 lists the uncertainties related to the calibration of the Zeners at BEV for Z6 and ZI.

Note that the uncertainty of the temperature and pressure corrections (in italics) are given as an indication only and do not contribute to the final uncertainty budget used for this comparison as they are applied by the BIPM and included in the comparison uncertainty budget (Table 3).

$u_{P,\sigma}$ is the relative uncertainty contribution of the standard deviation of one measurement.

u_{PJVS} is the relative uncertainty contribution by the Josephson system.

u_{NVM} is the relative uncertainty contribution by the nanovoltmeter's nonlinearity.

u_{LS} is the relative uncertainty contribution by the voltage error due to leakage current.

u_{Mu} is the relative uncertainty contribution by the thermal EMF of the multiplexer.

$u_{P,T}$ is the relative uncertainty contribution by the temperature coefficient of the voltage standard due to changes in environment temperature during one measurement.

$u_{P,p}$ is the relative uncertainty contribution by the pressure coefficient of the voltage standard due to changes in atmospheric pressure during one measurement.

Quantity	**Relative Uncertainty contribution**	**Type**	**Distribution**	**Degrees of freedom**	**Standard Uncertainty***
$u_{P,\sigma}$	3.19×10^{-9}	A	Normal	19	31.90 nV
u_{PJVS}	1×10^{-10}	B	Rectangular	∞	1.00 nV
u_{NVM}	1×10^{-10}	B	Rectangular	∞	1.00 nV
u_{LS}	3×10^{-11}	B	Rectangular	∞	0.30 nV
u_{Mu}	5×10^{-10}	B	Rectangular	∞	5.00 nV
$u_{P,T}$	*4×10^{-9}*	*B*	*Rectangular*	∞	*40.00 nV*
$u_{P,p}$	*4×10^{-10}*	*B*	*Rectangular*	∞	*4.00 nV*
	Combined uncertainty				39 nV
	Expanded uncertainty (*k*=2)				78 nV

Table 2: Estimated standard uncertainties for a Zener calibration with the BEV equipment at the level of 10 V for Zener Z6 and ZI.

*Note: In above column Standard Uncertainty, the factor 1/√3 for rectangular distribution is not yet included in the individual contributions shown here but only considered in propagation for the Combined uncertainty.

Uncertainty contributions for the comparison BEV/BIPM at 10 V

Table 3 lists the results and the uncertainty contributions for the comparison BEV/BIPM at 10 V.

		Results/µV		Uncertainty/µV	
		Z6	**ZI**	**Z6**	**ZI**
1	BEV (U_{BEV} – 10 V)	-71.27	-51.21		
2	Type A uncertainty			0.032	0.032
3	correlated (Type B) uncertainty			0.003	
4	BIPM (U_{BIPM} – 10 V)	-71.34	-51.35		
5	Type A uncertainty			0.100	0.100
6	correlated (Type B) uncertainty			0.004	
7	pressure and temperature correction uncertainty			0.014	0.024
8	(U_{BEV} – U_{BIPM})	0.07	0.14		
9	Total uncorrelated uncertainty			0.106	0.108
10	Total correlated uncertainty			0.005	
11	< U_{BEV} – U_{BIPM} >	**0.10**			
12	*a priori* uncertainty			0.076	
13	*a posteriori* uncertainty			0.035	
14	**comparison total standard uncertainty**			**0.08**	

Table 3: Results and uncertainties of BEV (Austria)/BIPM bilateral comparison of 10 V standards using two Zener travelling standards: reference date 27 April 2025. Standard uncertainties are used throughout.

In Table 3, the following elements are listed:

(1) the value attributed by BEV to each Zener, U_{BEV}, computed as the arithmetic mean of all data from BEV and corrected for temperature and pressure differences between both laboratories by the BIPM.
(2) BEV combined Type A uncertainty (cf. Table 2).
(3) the uncertainty component arising from the realization and maintenance of the volt at BEV: it is the quadratic combination of the Type B components of the participant uncertainty budget listed in Table 2. This uncertainty is completely correlated between the different Zeners used for the comparison.

(4-6) the corresponding quantities for the BIPM referenced to the mean date of the BEV measurements. In this case, the Type A uncertainty is limited by the flicker noise level of 100 nV.

(7) the uncertainty due to the combined effects of the pressure and temperature coefficients [6, 7] and to the differences of the mean pressures and temperatures in the participating laboratories is calculated as follows:

The uncertainty of the temperature correction $u_{T,i}$ of Zener *i* is determined for the difference ΔR_i between the mean values of the thermistor resistances measured at both institutes which is then multiplied by the uncertainty $u(c_{T,i})$ of the relative temperature coefficients of each Zener standard:

$$u_{T,i} = U \times u(c_{T,i}) \times \Delta R_i$$

where U = 10 V, $u(c_{T,Z6})$ = 0.196 × 10^{-7} / kΩ, $u(c_{T,ZI})$ = 0.353 × 10^{-7} / kΩ, ΔR_{Z6} = 0.042 kΩ and ΔR_{ZI} = 0.051 kΩ.

The same procedure is applied for the uncertainty $u_{P,i}$ of the pressure correction for the difference ΔP_i between the mean values of the pressure measured at both institutes:

$$u_{P,i} = U \times u(c_{P,i}) \times \Delta P_i$$

where U = 10 V, $u(c_{P,Z6})$ = 0.059 × 10^{-9} / hPa, $u(c_{P,ZI})$ = 0.084 × 10^{-9} / hPa,

ΔP_{Z6} = 18.8 hPa and ΔP_{ZI} = 18.9 hPa.

The uncertainties of the temperature and the pressure measurements are negligible.

(8) the difference (U_{BEV} – U_{BIPM}) for each Zener, and (9) the uncorrelated part of the uncertainty, calculated as the root sum square of lines 2, 5 and 7.

(10) the correlated part of the uncertainty, calculated as the root sum square of lines 3 and 6, for each travelling standard.

(11) the result of the comparison is the arithmetic mean of the differences of the calibration results for the different standards.

(12 and 13) the uncertainty related to the transfer, estimated by comparing the following uncertainties:

> (12) the *a priori* uncertainty, determined as the standard uncertainty of the mean, obtained by propagating the uncorrelated uncertainties for both Zeners;
>
> (13) the *a posteriori* uncertainty, which is the standard deviation of the mean of the two results.

(14) the total uncertainty of the comparison, which is the root sum square of the correlated part of the uncertainty (10) and the larger of (12) and (13).

To estimate the uncertainty related to the stability of the standards during transportation, we have calculated the "*a priori*" uncertainty of the mean of the results obtained for the two standards (also called statistical internal consistency). It consists of the quadratic combination of the uncorrelated uncertainties of each result. We compared this component to the "*a posteriori*" uncertainty (also called statistical external consistency) which consists of the experimental standard deviation of the mean of the results from the two travelling standards[*].

If the "*a posteriori*" uncertainty is significantly larger than the "*a priori*" uncertainty, we assume that a standard has changed in an unusual way, probably during their transportation. This is not the case at the 10 V output. We use the larger of these two estimates in calculating the final uncertainty.

The comparison result is presented as the difference between the value assigned to a 10 V standard by BEV, at BEV, U_{BEV}, and that assigned by the BIPM, at the BIPM, U_{BIPM}, on the reference date of the 27th of April 2025:

$$\boldsymbol{U_{\mathrm{BEV}} - U_{\mathrm{BIPM}} = 0.10\ \mu\mathrm{V}; \qquad u_{\mathrm{c}} = 0.08\ \mu\mathrm{V}}$$

where u_{c} is the combined standard uncertainty associated with the measured difference, including the uncertainty of the realization of the volt at BEV, at the BIPM, and the uncertainty related to the comparison.

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[*] With only two travelling standards, the uncertainty of the standard deviation of the mean is comparable to the value of the standard deviation of the mean itself.

Results at 1.018 V

Figure 3 shows the measured values obtained for the two standards by the two laboratories at 1.018 V and Figure 4 presents the voltage evolution of the arithmetic mean of the two standards which is used to compute the final result at 1.018 V.

A linear least squares fit is applied to the results of the BIPM, before and after the measurements at BEV, to obtain the results for both standards and their uncertainties at the mean date of the BEV measurements (27/04/2025).

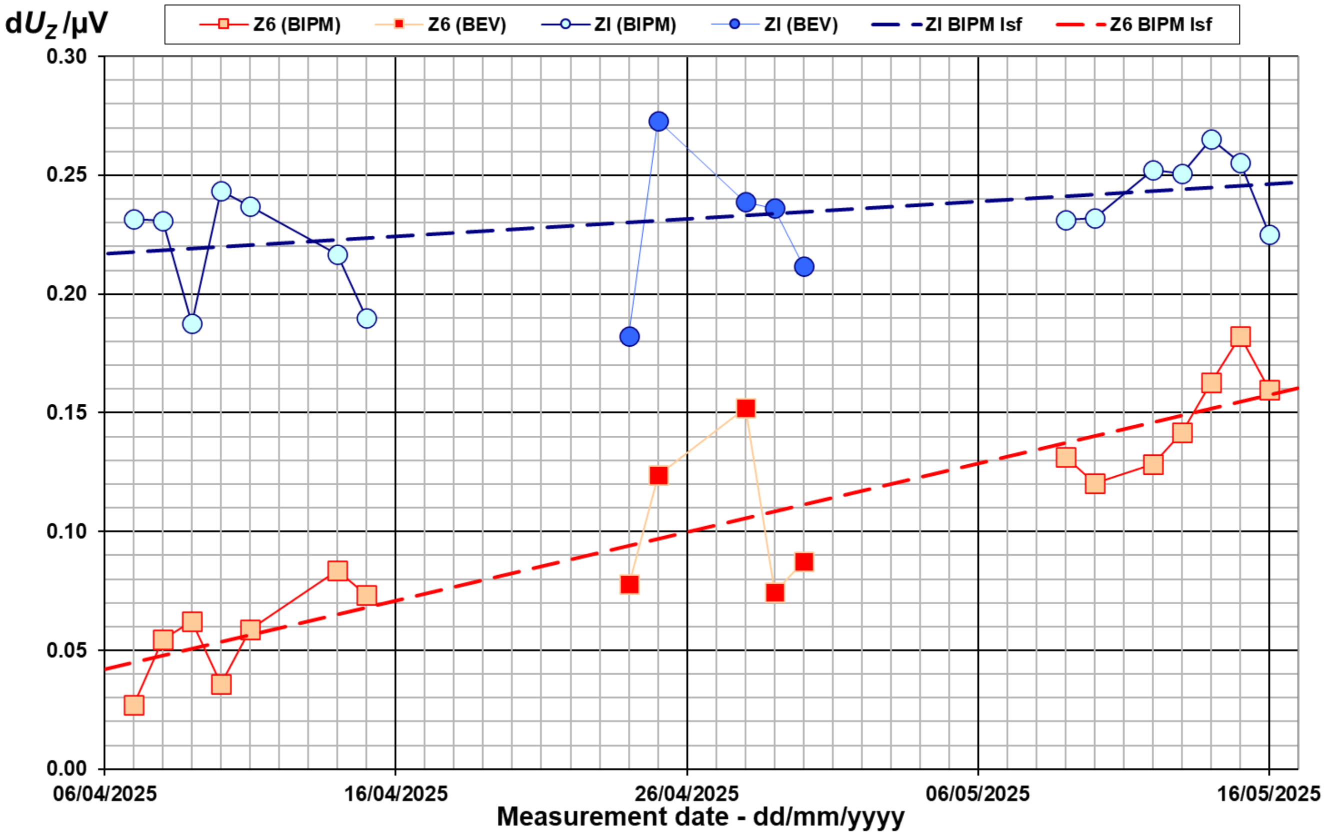

Figure 3: Voltage of Z6 (squares) and ZI (disks) at 1.018 V measured at both institutes (light markers for BIPM and dark markers for BEV), referred to an arbitrary offset, as a function of the measurement date with a linear least-squares fit (lsf) to the BIPM measurements**.**

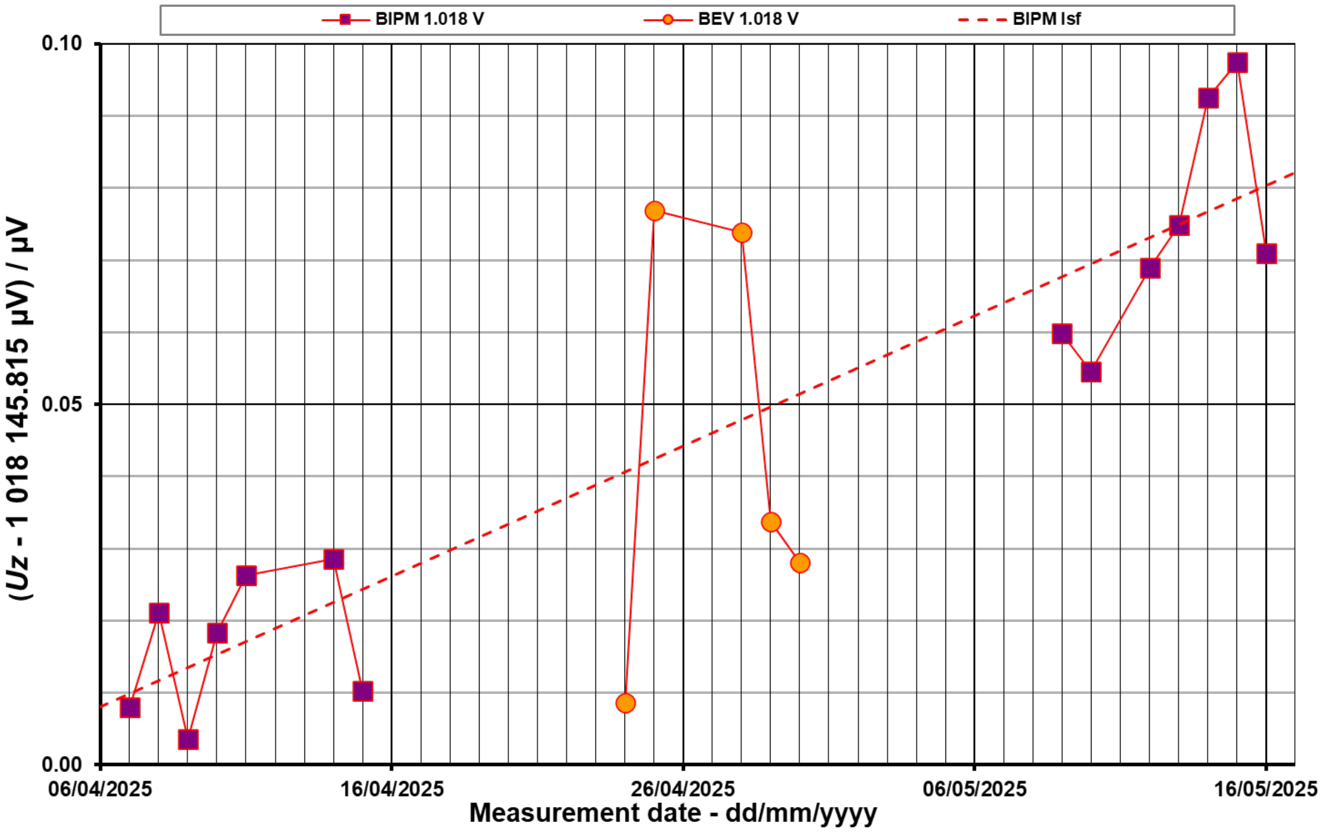

Figure 4: Voltage evolution of the arithmetic mean of the two standards at 1.018 V. BEV measurements are represented by disks and BIPM measurements by squares. A least-squares fit is applied to the BIPM measurements.

Uncertainty Budgets at 1.018 V

BIPM uncertainty budget at 1.018 V

Table 4 summarizes the uncertainties related to the calibration of a Zener against the Programmable Josephson Voltage Standard at the BIPM at the level of 1.018 V.

PJVS & detector uncertainty components	Uncertainty (nV)	Degrees of freedom
Noise of the measurement loop that includes the residual thermal EMF including the residual EMF of the reversing switch (Type A)	2	
Detector gain (Type B)	negligible	∞
Leakage resistance (Type B)	0.4	∞
Frequency (Type B)	0.01	∞
Zener noise (Type A)	Not lower than the 1/*f* noise estimated as 10 nV, included in the comparison uncertainty budget (Table 6)	
Zener temperature correction	Included in the comparison uncertainty budget (Table 6)	10
Zener pressure correction		14

Table 4: Estimated standard uncertainties arising from the PJVS and the measurement setup for Zener calibrations with the BIPM equipment at the level of 1.018 V.

BEV uncertainty budget at 1.018 V

Table 5 lists the uncertainties related to the calibration of the Zeners at BEV for Z6 and ZI. Note that the uncertainty of the temperature and pressure corrections (in italics) are given as an indication only and do not contribute to the final uncertainty budget used for this comparison as they are applied by the BIPM and included in the comparison uncertainty budget (Table 6).

$u_{P,\sigma}$ is the relative uncertainty contribution of the standard deviation of one measurement.

u_{PJVS} is the relative uncertainty contribution by the Josephson system.

u_{NVM} is the relative uncertainty contribution by the nanovoltmeter's nonlinearity.

u_{LS} is the relative uncertainty contribution by the voltage error due to leakage current.

u_{Mu} is the relative uncertainty contribution by the thermal EMF of the multiplexer.

$u_{P,T}$ is the relative uncertainty contribution by the temperature coefficient of the voltage standard due to changes in environment temperature during one measurement.

$u_{P,p}$ is the relative uncertainty contribution by the pressure coefficient of the voltage standard due to changes in atmospheric pressure during one measurement.

Quantity	Relative uncertainty contribution	Type	Distribution	Degrees of freedom	Standard Uncertainty*
$u_{P,\sigma}$	4.6×10^{-9}	A	Normal	19	4.7 nV
u_{PJVS}	9.8×10^{-10}	B	Rectangular	∞	1 nV
u_{NVM}	9.8×10^{-10}	B	Rectangular	∞	1 nV
u_{LS}	2.9×10^{-10}	B	Rectangular	∞	0.3 nV
u_{Mu}	4.9×10^{-9}	B	Rectangular	∞	5 nV
$u_{P,T}$	*1×10^{-8}*	*B*	*Rectangular*	∞	*10.18 nV*
$u_{P,p}$	*6×10^{-10}*	*B*	*Rectangular*	∞	*0.61 nV*
	Combined uncertainty				8.2 nV
	Expanded uncertainty (*k*=2)				16.3 nV

Table 5: Estimated standard uncertainties for a Zener calibration with the BEV equipment at the level of 1.018 V for Zener Z6 and ZI.

*Note: In above column Standard Uncertainty, the factor 1/√3 for rectangular distribution is not yet included in the individual contributions shown here but only considered in propagation for the Combined uncertainty.

Uncertainty contributions for the comparison BEV/BIPM at 1.018 V

Table 6 lists the results and the uncertainty contributions for the comparison BEV/BIPM at 1.018 V.

		Results/μV		**Uncertainty/μV**	
		Z6	**ZI**	**Z6**	**ZI**
1	BEV (U_{BEV} – 1.018 V)	148.120	143.598		
2	Type A uncertainty			0.005	0.005
3	correlated (Type B) uncertainty			0.003	
4	BIPM (U_{BIPM} – 1.018 V)	148.120	143.603		
5	Type A uncertainty			0.010	0.010
6	correlated (Type B) uncertainty			<0.001	
7	pressure and temperature correction uncertainty			0.001	0.004
8	($U_{\mathrm{BEV}} - U_{\mathrm{BIPM}}$)	0.000	-0.005		
9	Total uncorrelated uncertainty			0.011	0.012
10	Total correlated uncertainty			0.003	
11	$< U_{\mathrm{BEV}} - U_{\mathrm{BIPM}} >$	**-0.002**			
12	*a priori* uncertainty			0.008	
13	*a posteriori* uncertainty			0.003	
14	**comparison total standard uncertainty**			**0.009**	

Table 6: Results and uncertainties of BEV (Austria)/BIPM bilateral comparison of 1.018 V standards using two Zener travelling standards: reference date 27 April 2025. Standard uncertainties are used throughout.

In Table 6, the following elements are listed:

(1) the value attributed by BEV to each Zener U_{BEV}, computed as the arithmetic mean of all data from BEV and corrected for temperature and pressure differences between both laboratories by the BIPM.

(2) the BEV Type A uncertainty (cf. Table 5).

(3) the uncertainty component arising from the realization and maintenance of the volt at BEV: it is the quadratic combination of the Type B components of the participant uncertainty budget listed in Table 5. This uncertainty is completely correlated between the different Zeners used for the comparison.

(4-6) the corresponding quantities for the BIPM referenced to the mean date of BEV measurements. In this case, the Type A uncertainty is limited by the flicker noise level of 10 nV.

(7) the uncertainty due to the combined effects of the pressure and temperature coefficients [6, 7] and to the differences of the mean pressures and temperatures in the participating laboratories is calculated as follows:

The uncertainty of the temperature correction $u_{T,i}$ of Zener *i* is determined for the difference ΔR_i between the mean values of the thermistor resistances measured at both institutes which is then multiplied by the uncertainty $u(c_{T,i})$ of the relative temperature coefficients of each Zener standard:

$$u_{T,i} = U \times u(c_{T,i}) \times \Delta R_i$$

where U = 1.018 V, $u(c_{T,Z6})$ = 0.232 × 10^{-7} / kΩ, $u(c_{T,ZI})$ = 0.658 × 10^{-7} / kΩ, ΔR_{Z6} = 0.045 kΩ and ΔR_{ZI} = 0.052 kΩ.

The same procedure is applied for the uncertainty $u_{P,i}$ of the pressure correction for the difference ΔP_i between the mean values of the pressure measured at both institutes:

$$u_{P,i} = U \times u(c_{P,i}) \times \Delta P_i$$

where U = 1.018 V, $u(c_{P,Z6})$ = 0.052 × 10^{-9} / hPa, $u(c_{P,ZI})$ = 0.079 × 10^{-9} / hPa, ΔP_{Z6} = 18.8 hPa and ΔP_{ZI} = 18.6 hPa.

The uncertainties of the measurement of the temperature and the pressure are negligible.

(8) the difference (U_{BEV} – U_{BIPM}) for each Zener, and (9) the uncorrelated part of the uncertainty, calculated as the root sum square of lines 2, 5 and 7.

(10) the correlated part of the uncertainty, calculated as the root sum square of lines 3 and 6, for each travelling standard.

(11) the result of the comparison is the arithmetic mean of the differences of the calibration results for the different standards.

(12 and 13) the uncertainty related to the transfer, estimated by comparing the following uncertainties:

(12) the *a priori* uncertainty, determined as the standard uncertainty of the mean, obtained by propagating the uncorrelated uncertainties for both Zeners;

(13) the *a posteriori* uncertainty, which is the standard deviation of the mean of the two results.

(14) the total uncertainty of the comparison, which is the root sum square of the correlated part of the uncertainty (10) and the larger of (12) and (13).

In this case the *a priori* uncertainty is larger than the *a posteriori* uncertainty. We conclude that at 1.018 V both Zeners behaved consistently within the uncertainty of the comparison.

The result of the comparison is presented as the difference between the value assigned to a 1.018 V standard by BEV, at BEV, U_{BEV}, and that assigned by the BIPM, at the BIPM, U_{BIPM}, on the reference date of the 27th of April 2025:

$$\boldsymbol{U_{\mathrm{BEV}} - U_{\mathrm{BIPM}} = -0.002\ \mu\mathrm{V}; \qquad u_{\mathrm{c}} = 0.009\ \mu\mathrm{V}}$$

where u_{c} is the combined standard uncertainty associated with the measured difference, including the uncertainty of the realization of the volt at the BIPM and at BEV and the uncertainty related to the comparison.

Conclusion

The final result of the comparison is presented as the difference between the values assigned to DC voltage standards by BEV, at the level of 1.018 V and 10 V, at BEV, U_{BEV}, and those assigned by the BIPM, at the BIPM, U_{BIPM}, at the reference date of the 27th of April 2025.

$$\boldsymbol{U_{\mathrm{BEV}} - U_{\mathrm{BIPM}} = -0.002\ \mu\mathrm{V};\quad u_{\mathrm{c}} = 0.009\ \mu\mathrm{V},\ \text{at } 1.018\ \mathrm{V}}$$

$$\boldsymbol{U_{\mathrm{BEV}} - U_{\mathrm{BIPM}} = 0.10\ \mu\mathrm{V};\qquad u_{\mathrm{c}} = 0.08\ \mu\mathrm{V},\ \text{at } 10\ \mathrm{V}}$$

where u_{c} is the combined standard uncertainty associated with the measured difference, including the uncertainty of the realization of the volt at the BIPM and at BEV, and the uncertainty related to the comparison.

These are excellent results for both nominal voltages. The comparison results show that the voltage standards maintained by BEV and the BIPM are equivalent within their stated standard uncertainties. The recent similar comparisons performed with the cryocooled version of the *Supracon* PJVS showed small systematic errors on some of the travelling standards [8-10]. The liquid helium version of the *Supracon* PJVS doesn’t seem to exhibit such bias as the measurements made by BEV exhibited a perfect agreement with the BIPM measurements. It would be interesting to investigate this observation further.

References

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