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Bilateral Comparison of 1.018 V and 10 V Standards between the NCM (Bulgaria) and the BIPM, April to June 2006 (part of the ongoing BIPM key comparisons BIPM.EM-K11.a and .b)

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Introduction

As part of the ongoing BIPM key comparisons BIPM.EM-K11a and b, a comparison of the 1.018 V and 10 V voltage reference standards of the BIPM and the National Center of Metrology (NCM), Sofia, Bulgaria, was carried out between April and June 2006.

Method

Two BIPM 732B Zener diode-based travelling standards, Z BIPM 8 (Z8) and Z BIPM B (ZB), were transported by plane to and from the NCM as hand-luggage. At the NCM, the calibration was performed using the Nanoscan reference system Fluke 7003 N, by the differential method of measurement. To minimize the influence of parasitic voltages, the differences between the voltages in positive and negative polarity were measured using a MTS 4950 Wavetek. Polarity switching of the voltage was carried out by simultaneous replacement of the cable connections of both devices. The results were calculated as the average value of the measurements in positive and negative polarity. The BIPM measurements of the travelling standards were carried out by direct comparison with the Josephson effect standard. Results of all measurements were corrected for the dependence of the output voltages on ambient temperature and pressure.

Results

Figures 1 and 2 show the measured values obtained for the two standards by the two laboratories. The values and uncertainties are calculated for the reference date from linear least-squares fits to all data from each laboratory.

Table 1 lists the results of the 1.018 V comparison and the component uncertainty contributions for the comparison NCM/BIPM. Experience has shown that flicker or 1/*f* noise dominates the stability characteristics of Zener diode 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 flicker floor voltage is about 1 part in 10^8.

Table 2 lists the corresponding information for the 10 V comparison.

In estimating the uncertainty we have calculated the *a priori* uncertainty based on all known sources except that associated with the stability of the standards when transported. We compare this with the *a posteriori* uncertainty estimated by the standard deviation of the weighted mean of the results from the two travelling standards. 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. If the *a posteriori* uncertainty is significantly different from the *a priori* uncertainty, we assume that a standard has changed in an unusual way and we use the larger of these two estimates in calculating the final uncertainty.

In Tables 1 and 2, the following elements are listed:

(1) the predicted value U_{NCM} of each Zener, computed using a linear least squares fit to all of the data from the NCM and referenced to the mean date of the NCM's measurements;
(2) the Type A uncertainty due to the instability of the Zener, computed as the standard uncertainty of the value predicted by the linear drift model, or as an estimate of the $1/f$ noise voltage level;
(3) the uncertainty component arising from the measuring equipment of the NCM: this uncertainty is completely correlated between the different Zeners used for a comparison[1];
(4-6) the corresponding quantities for the BIPM referenced to the mean date of the NCM's measurements;
(7) the uncertainty due to the combined effects of the uncertainties of the pressure and temperature coefficients and to the difference of the mean pressures and temperatures in the participating laboratories; although the same equipment is used to measure the coefficients for all Zeners, the uncertainty is dominated by the Type A uncertainty of each Zener, so that the final uncertainty can be considered as uncorrelated among the different Zeners used in a comparison;
(8) the difference ($U_{\mathrm{NCM}} - U_{\mathrm{BIPM}}$) for each Zener;
(9) the uncorrelated part of the uncertainty;
(10) the result of the comparison, which is the weighted mean of the differences of the calibration results for the different standards; using as weights the reciprocal of the square of the uncorrelated part of the uncertainty components for each travelling standard;

[1.] In fact, there is a high degree of correlation between these input quantities and we can assume a correlation coefficient of unity without significantly affecting the standard uncertainty of the result of this comparison.

(11 and 12) the uncertainty of the transfer, estimated by the following two methods: (11) the *a priori* uncertainty, which is the expected uncertainty from the different Zeners, taking into account only the uncorrelated uncertainties of the individual results; (12) the *a posteriori* uncertainty, which is the standard deviation of the weighted mean of the different results;
(13) the correlated part of the uncertainty; and
(14) the total uncertainty of the comparison, which is the root sum square of the correlated part of the uncertainty and of the larger of (11) and (12).

Table 3 summarizes the uncertainties due to the BIPM measuring equipment.
Table 4 summarizes the uncertainties due to the NCM measuring equipment.

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

$$U_{\mathrm{NCM}} - U_{\mathrm{BIPM}} = -1.39\ \mu\mathrm{V}; \qquad u_{\mathrm{c}} = 1.00\ \mu\mathrm{V} \text{ on } 2006/05/23,$$

and the difference between the value assigned to a 10 V standard by the NCM, at the NCM, U_{NCM}, and that assigned by the BIPM, at the BIPM, U_{BIPM}, for the reference date is

$$U_{\mathrm{NCM}} - U_{\mathrm{BIPM}} = -0.99\ \mu\mathrm{V}; \qquad u_{\mathrm{c}} = 4.00\ \mu\mathrm{V} \text{ on } 2006/05/23,$$

where u_{c} is the combined Type A and Type B standard uncertainty from both laboratories.

Conclusion

This is a rather satisfactory result. The differences between the values assigned to the mean voltage of the travelling standards are, at 1.018 V, within the 95% uncertainty and, at 10 V, well within the standard uncertainty associated with these differences. It should be pointed out that the individual results of both Zeners agree well. This proves that the main contribution to these differences and uncertainties relate to the maintenance conditions of the reference standards at the NCM and further such bilateral comparisons should help in improving these conditions.

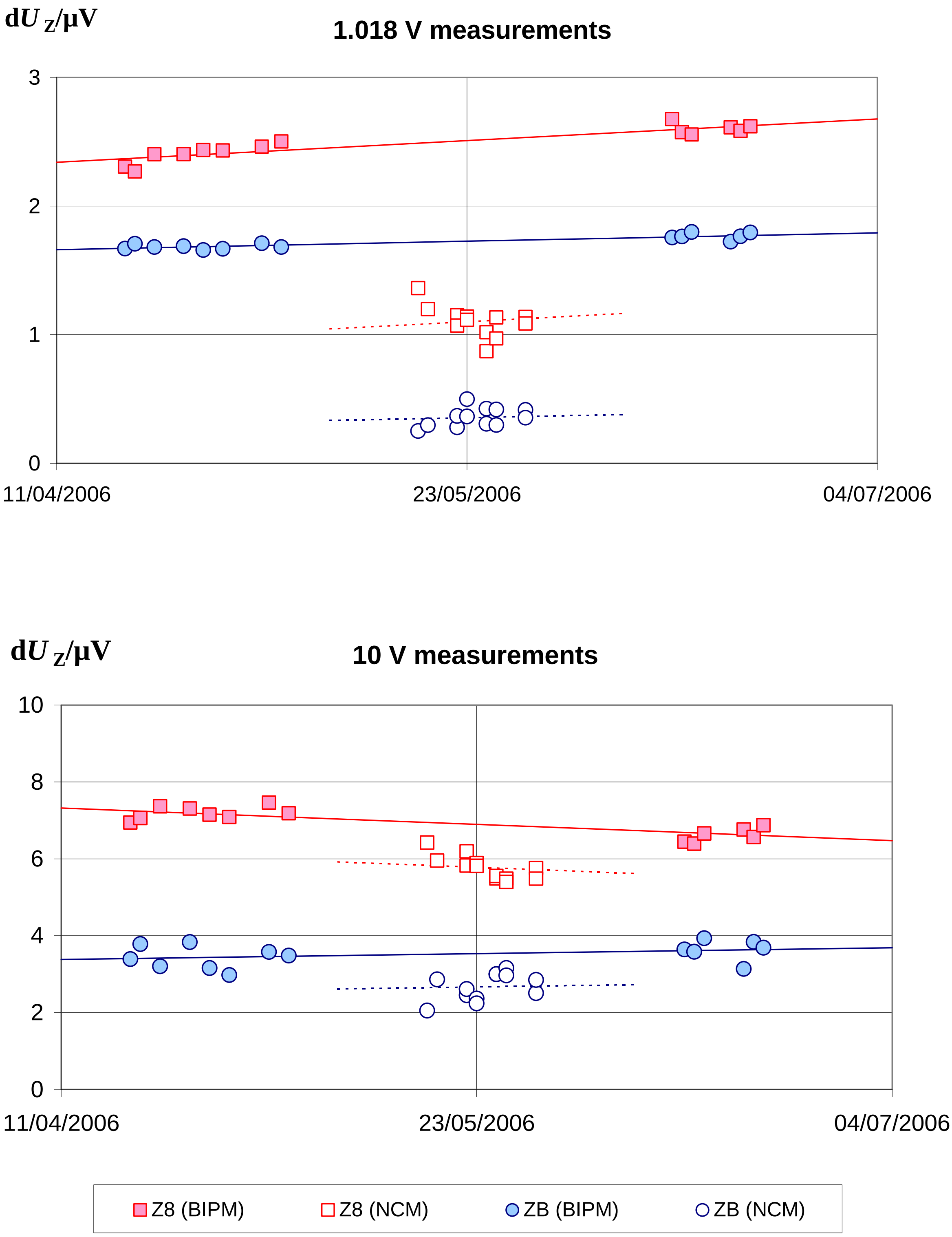

Figure 1. Voltage of Z8 and ZB at 1.018 V and 10 V as a function of time, with arbitrary voltage origins, marked with linear least-squares fits to the measurements of the BIPM.

Table 1. Results of the NCM (Bulgaria)/BIPM bilateral comparison of 1.018 V standards using two Zener travelling standards: reference date 2006/05/23. Uncertainties are 1 σ estimates. The uncorrelated uncertainty is $w = [r^2 + t^2 + v^2]^{1/2}$, the expected transfer uncertainty is $x = [w_8^{-2} + w_B^{-2}]^{-1/2}$, and the correlated uncertainty is $y = [s^2 + u^2]^{1/2}$.

		BIPM_8	BIPM_B	
1	*NCM (Bulgaria)* $(U_Z - 1.018\ \text{V})/\mu\text{V}$	165.10	123.76	
2	type-A uncertainty/µV	0.03	0.02	*r*
3	equipment uncertainty/µV	1.00		*s*
4	*BIPM* $(U_Z - 1.018\ \text{V})/\mu\text{V}$	166.51	125.13	
5	type-A uncertainty/µV	0.01	0.01	*t*
6	equipment uncertainty/µV	0.01		*u*
7	pressure and temperature corrections uncertainty/µV	0.01	0.01	*v*
8	$(U_{Z\_NCM} - U_{Z\_BIPM})/\mu\text{V}$	–1.41	–1.37	
9	uncorrelated uncertainty/µV	0.03	0.02	*w*
10	$\langle U_{NCM} - U_{BIPM}\rangle/\mu\text{V}$	–1.39		
11	expected transfer uncertainty/µV	0.04		*x*
12	σ_M of difference for two Zeners/µV	0.02		
13	correlated uncertainty/µV	1.00		*y*
14	comparison total uncertainty/µV	1.00		

Table 2. Results of the NCM (Bulgaria)/BIPM bilateral comparison of 10 V standards using two Zener travelling standards: reference date 2006/05/23. Uncertainties are 1 σ estimates. The uncorrelated uncertainty is $w = [r^2 + t^2 + v^2]^{1/2}$, the expected transfer uncertainty is $x = [w_8^{-2} + w_B^{-2}]^{-1/2}$, and the correlated uncertainty is $y = [s^2 + u^2]^{1/2}$.

			BIPM_8	BIPM_B	
1	*NCM (Bulgaria)*	$(U_Z - 10\ \text{V})$/µV	–41.23	–7.33	
2		type-A uncertainty/µV	0.10	0.10	*r*
3		equipment uncertainty/µV	4.00		*s*
4	*BIPM*	$(U_Z - 10\ \text{V})$/µV	–40.11	–6.46	
5		type-A uncertainty/µV	0.10	0.10	*t*
6		equipment uncertainty/µV	0.01		*u*
7	pressure and temperature	corrections uncertainty/µV	0.05	0.05	*v*
8		$(U_{Z\_NCM} - U_{Z\_BIPM})$/µV	–1.11	–0.87	
9		uncorrelated uncertainty/µV	0.15	0.15	*w*
10		$\langle U_{NCM} - U_{BIPM} \rangle$/µV	–0.99		
11		expected transfer uncertainty/µV	0.11		*x*
12		σ_M of difference for two Zeners/µV	0.12		
13		correlated uncertainty/µV	4.00		*y*
14		comparison total uncertainty/µV	4.00		

Table 3 Estimated standard uncertainties for Zener calibrations with the BIPM equipment.

	Uncertainty/nV	
	1.018 V	10 V
thermal EMFs	3.0	3.0
detector/EMI	3.0	0.5
leakage resistance	3.0	0.3
frequency	<0.1	0.3
pressure correction	0.4	4.0
temperature correction	0.2	7.0
total	5.4	8.6

Table 4. Estimated standard uncertainties for Zener calibrations with the NCM equipment.

	Uncertainty	
	1.018 V	10 V
reference group and comparator/µV	1.00	4.00
pressure correction/hPa	0.02	0.02
temperature correction/kΩ	0.005	0.005
Total/µV	1.00	4.00