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Bilateral Comparison of 10 V Standards between the NML (Ireland) and the BIPM, April to June 2006 (part of the ongoing BIPM key comparison BIPM.EM-K11.b)

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As a part of the ongoing BIPM key comparison BIPM.EM-K11b, a comparison of the 10 V voltage reference standards of the BIPM and the National Metrology Laboratory (NML), Dublin, Ireland, was carried out from April to June 2006. Two BIPM 732B Zener diode-based travelling standards, BIPM_C and BIPM_D, were transported by freight. The NML measurements were carried out by comparison with the mean of the NML voltage standard. 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.

Figure 1 shows the measured values obtained for the two standards by the two laboratories. The BIPM values and uncertainties, and those of the NML are calculated for the reference date from linear least-squares fits to all data from each laboratory.

Table 1 lists the results of the comparison and the component uncertainty contributions for the comparison NML/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.

In estimating the uncertainty we have calculated the *a priori* uncertainty based on all known uncorrelated 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 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 Table 1, the following elements are listed:

(1) the predicted value U_{NML} of each Zener, computed using a linear least squares fit to all of the data from the NML and referenced to the mean date of the NML'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 NML: 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 NML'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 ($U_{NML} - U_{BIPM}$) for each Zener, and (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;
(11 and 12) the uncertainty of the transfer, estimated by the following two methods:

> (11) 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;
>
> (12) the *a posteriori* uncertainty, which is the standard deviation of the 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).

[1.] At 10 V, 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.

Table 2 summarizes the uncertainties due to the BIPM measuring equipment.

Table 3 lists the uncertainties of maintenance and measuring equipment at the NML.

The final result of the comparison is presented as the difference between the value assigned to a 10 V standard by the NML, at the NML, U_{NML}, and that assigned by the BIPM, at the BIPM, U_{BIPM}, which for the reference date is

$$U_{NML} - U_{BIPM} = 0.87\ \mu V; \qquad u_c = 1.40\ \mu V \text{ on } 2006/05/27,$$

where u_c is the combined Type A and Type B standard uncertainty from both laboratories, that is the standard uncertainty associated with the measured difference.

This is a satisfactory result. The differences between the values assigned to both traveling standards by the two laboratories are well within the standard uncertainties associated with these differences.

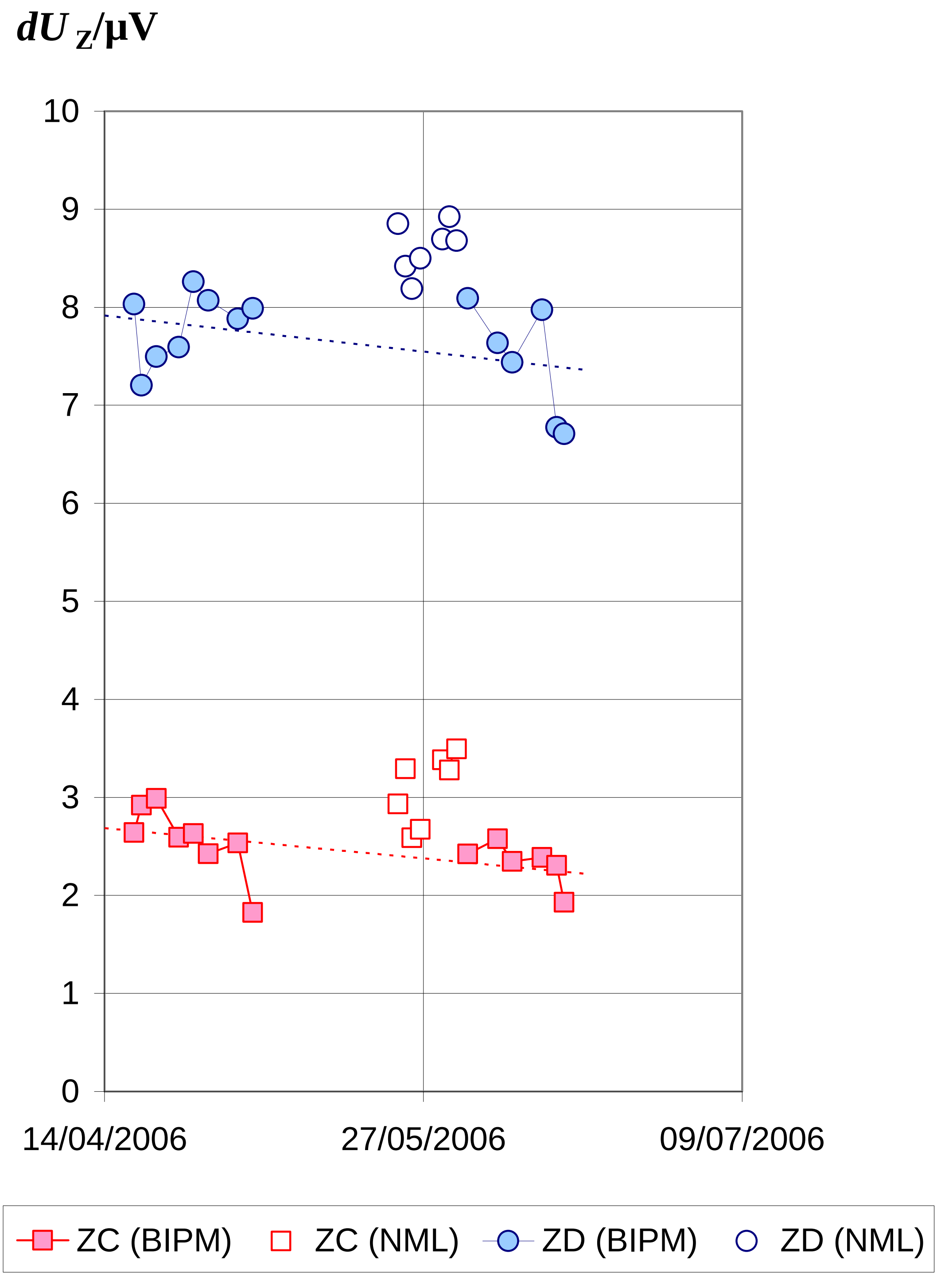

Figure 1. Voltage of BIPM_C (ZC) and BIPM_D (ZD) at 10 V, referred to an arbitrary origin, as a function of time, with linear least-squares fit to the measurements of the BIPM.

Table 1. Results of the NML(Ireland)/BIPM bilateral comparison of 10 V standards using two Zener travelling standards: reference date 27 May 2006. Uncertainties are 1 σ estimates. The uncorrelated uncertainty is $w = [r^2 + t^2 + v^2]^{1/2}$, the expected transfer uncertainty is $x = [w_8^{-2} + w_9^{-2}]^{-1/2}$, and the correlated uncertainty is $y = [s^2 + u^2]^{1/2}$.

			BIPM_C	BIPM_D	
1	*NML (Ireland)*	$(U_Z - 10\text{V})/\mu\text{V}$	–41.91	–41.39	
2		type-A uncertainty/µV	0.12	0.10	*r*
3		equipment uncertainty/µV	1.39		*s*
4	*BIPM*	$(U_Z - 10\text{V})/\mu\text{V}$	–42.63	–42.46	
5		type-A uncertainty/µV	0.10	0.14	*t*
6		equipment uncertainty/µV	0.01		*u*
7		pressure and temperature corrections uncertainty/µV	0.02	0.02	*v*
8		$(U_{Z\_NML} - U_{Z\_BIPM})/\mu\text{V}$	0.72	1.06	
9		uncorrelated uncertainty/µV	0.15	0.17	*w*
10		$\langle U_{NML} - U_{BIPM} \rangle/\mu\text{V}$	0.87		
11		expected transfer uncertainty/µV	0.12		*x*
12		s_M of difference for two Zeners/µV	0.17		
13		correlated uncertainty/µV	1.39		*y*
14		comparison total uncertainty/µV	1.40		

Table 2. Estimated standard uncertainties for Zener calibrations with the BIPM equipment.

	Uncertainty/nV
thermal electromotive forces	3
detector / electromagnetic interference	3
leakage resistance	3
frequency	0.3
pressure correction	4
temperature correction	13
total	14.1

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

	Uncertainty/µV
reference group stability and comparator	1.39
pressure correction	0.03
temperature correction	0.04
total	1.39