Rapport BIPM-2000/02

Bilateral Comparison of 1.018 V and 10 V Standards between the NML, Ireland and the BIPM,

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A comparison of the 1.018 V and 10 V voltage reference standards of the BIPM and the National Metrology Laboratory, (NML), Dublin, Ireland, was carried out in April 2000. Two BIPM 732B Zener diode-based travelling standards, BIPM7 and BIPM8, were transported by freight. The NML measurements were carried out at 10 V by comparison with the mean of the NML voltage standard. A precision potentiometer was then used to scale between 10 V and 1.018 V to measure the 1.018 V outputs of the Zeners in terms of a 10 V reference standard. The BIPM measurements of the travelling standards were carried out by direct comparison to the Josephson effect standard or (1) at 10 V by dividing the 10 V outputs to 1.018 V by means of a resistive divider and comparing the divided voltages to the electromotive force of a standard cell, and (2) at 1.018 V by direct comparison to the electromotive force of a standard cell using a potentiometer. Results of all measurements were corrected for the dependence of the output voltage on ambient temperature and pressure.

Figures 1 and 2 show 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.

Table 1 lists the results of the 1.018 V 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 of the mean 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 same 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 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_{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 predicted value from the linear drift model, or an estimate of the $1/f$ noise voltage level;
(3) the uncertainty component due to the measuring equipment of the NML. This uncertainty is completely correlated between the different Zeners used for a comparison;
(4-6) the corresponding quantities for the BIPM;
(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 ($U_{\mathrm{NML}} - U_{\mathrm{BIPM}}$) 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 as Zener BIPM7 was unusually unstable during the NML measurements; the weight is proportional to the inverse of the square of the type-A uncertainty;
the uncertainty of the transfer, estimated by 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).

Table 3 summarises the uncertainties due to the BIPM measuring equipment.

Table 4 lists the uncertainties of maintenance and measuring equipment at the NML.

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

$$U_{\mathrm{NML}} - U_{\mathrm{BIPM}} = -\,0.15\ \mu\mathrm{V}; \qquad u_{\mathrm{c}} = 0.46\ \mu\mathrm{V} \text{ on } 2000/04/19,$$

and 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}, for the reference date is

$$U_{\mathrm{NML}} - U_{\mathrm{BIPM}} = -\,1.7\ \mu\mathrm{V}; \qquad u_{\mathrm{c}} = 2.4\ \mu\mathrm{V} \text{ on } 2000/04/11,$$

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

This is a satisfactory result. The difference between the values assigned to the travelling standards by the two laboratories is less than the standard uncertainty associated with the difference.

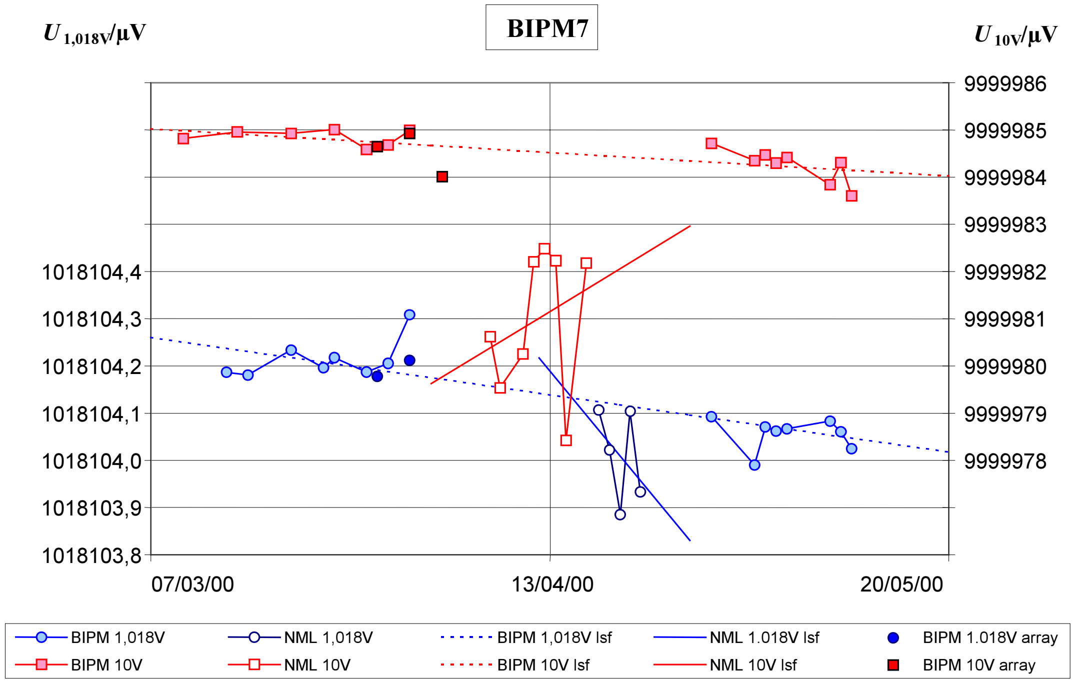

Figure 1. Voltage of BIPM7 vs time with linear least-squares fits (LSF) to the measurements of each laboratory

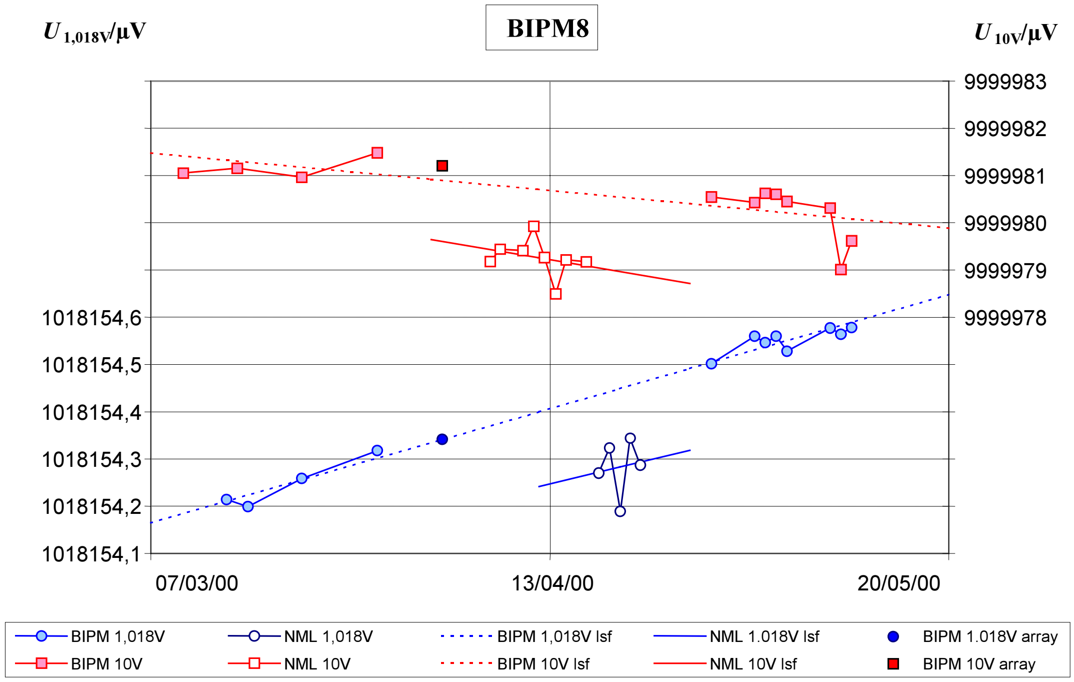

Figure 2. Voltage of BIPM8 vs time with linear least-squares fits (LSF) to the measurements of each laboratory

Table 1. Results of the NML(Ireland)/BIPM bilateral comparison of 1.018 V standards using two Zener travelling standards: mean date 19 April 2000. Uncertainties are 1-σ estimates. The uncorrelated uncertainty is $w=[r^2+t^2+v^2]^{1/2}$, the expected transfer uncertainty is $x=[w_7^{-2}+w_8^{-2}]^{-1/2}$ and the correlated uncertainty is $y=[s^2+u^2]^{1/2}$.

		BIPM7	BIPM8	
1	NML (Ireland) $(U_Z - 1.018\text{V})$/µV	104.010	154.283	
2	type-A uncertainty/µV	0.047	0.031	r
3	equipment uncertainty/µV	0.46		s
4	BIPM $(U_Z - 1.018\text{V})$/µV	104.117	154.448	
5	type-A uncertainty/µV	0.013	0.010	t
6	equipment uncertainty/µV	0.010		u
7	Pressure and temperature corrections uncertainty/µV	0.026	0.013	v
8	$(U_{Z\_NML} - U_{Z\_BIPM})$/µV	-0.107	-0.166	
9	uncorrelated uncertainty/µV	0.055	0.035	w
10	$<U_{NML} - U_{BIPM}>$/µV	-0.147		
11	Expected transfer uncertainty/µV	0.029		x
12	S_M of difference for 2 Zeners/µV	0.027		
13	correlated uncertainty/µV	0.46		y
14	comparison total uncertainty/µV	0.46		

Table 2. Results of the NML(Ireland)/BIPM bilateral comparison of 10 V standards using two Zener travelling standards: mean date 11 April 2000. Uncertainties are 1-σ estimates. The uncorrelated uncertainty is $w=[r^2+t^2+v^2]^{1/2}$, the expected transfer uncertainty is $x=[w_7^{-2}+w_8^{-2}]^{-1/2}$ and the correlated uncertainty is $y=[s^2+u^2]^{1/2}$.

		BIPM7	BIPM8	
1	NML (Ireland) $(U_Z - 10V)/\mu V$	-19.01	-20.74	
2	type-A uncertainty/μV	0.56	0.14	r
3	equipment uncertainty/μV	2.30		s
4	BIPM $(U_Z - 10V)/\mu V$	-15.46	-19.29	
5	type-A uncertainty/μV	0.10	0.13	t
6	equipment uncertainty/μV	0.10		u
7	pressure and temperature corrections uncertainty/μV	0.13	0.24	v
8	$(U_{Z\_NML} - U_{Z\_BIPM})/\mu V$	-3.54	-1.44	
9	uncorrelated uncertainty/μV	0.58	0.31	w
10	$<U_{NML} - U_{BIPM}>/\mu V$	-1.67		
11	expected transfer uncertainty/μV	0.27		x
12	s_M of difference for 2 Zeners/μV	0.65		
13	correlated uncertainty/μV	2.30		y
14	comparison total uncertainty/μV	2.39		

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

	1.018 V		10 V	
	Josephson	Potentiometer	Josephson	Comparator
	value/nV	value/nV	value/nV	value/nV
thermal EMFs	2	2	2	2
detector/EMI	5	5	0.5	10
leakage resistance	5	5	0.3	10
frequency	<0.1		0.3	
reference cell		5		50
potentiometer/comparator		5		85
total	7.4	10	2.1	100

Table 4: estimated standard uncertainties for Zener calibrations with the NML equipment.

	1.018 V	10 V
	value/µV	value/µV
reference group stability		2.2
10 V Reference standard	0.25	
uncorrected parasitic voltages		0.3
detector		0.5
comparator	0.38	
pressure and temperature	0.01	0.02
rss total	0.46	2.3