Bilateral Comparison of 1.018 V and 10 V Standards
between the NML (Ireland) and the BIPM,
March 2002

by O. Power**, D. Reymann* and T. J. Witt*
*Bureau International des Poids et Mesures, F-92312 Sèvres Cedex
** National Metrology Laboratory, Glasnevin, Dublin 9, Ireland

As a part of the on-going 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 Metrology Laboratory (NML), Dublin, Ireland, was carried out in March 2002. Two BIPM 732B Zener diode-based travelling standards, BIPMA 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 with the Josephson effect standard. 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 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 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 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;
(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 mean of the differences of the calibration results for the different standards;
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).

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 3 summarizes 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 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 NML, at the NML, U_{NML}, and that assigned by the BIPM, at the BIPM, U_{BIPM}, for the reference date is

$$U_{\mathrm{NML}} - U_{\mathrm{BIPM}} = -0.106\ \mu\mathrm{V};\ u_{\mathrm{c}} = 0.455\ \mu\mathrm{V} \text{ on 2002/03/18},$$

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

$$U_{\mathrm{NML}} - U_{\mathrm{BIPM}} = +0.37\ \mu\mathrm{V};\ u_{\mathrm{c}} = 1.11\ \mu\mathrm{V} \text{ on 2002/03/10},$$

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

This is a satisfactory result. The differences between the values assigned to the travelling standards by the two laboratories are less than the standard uncertainties associated with these differences.

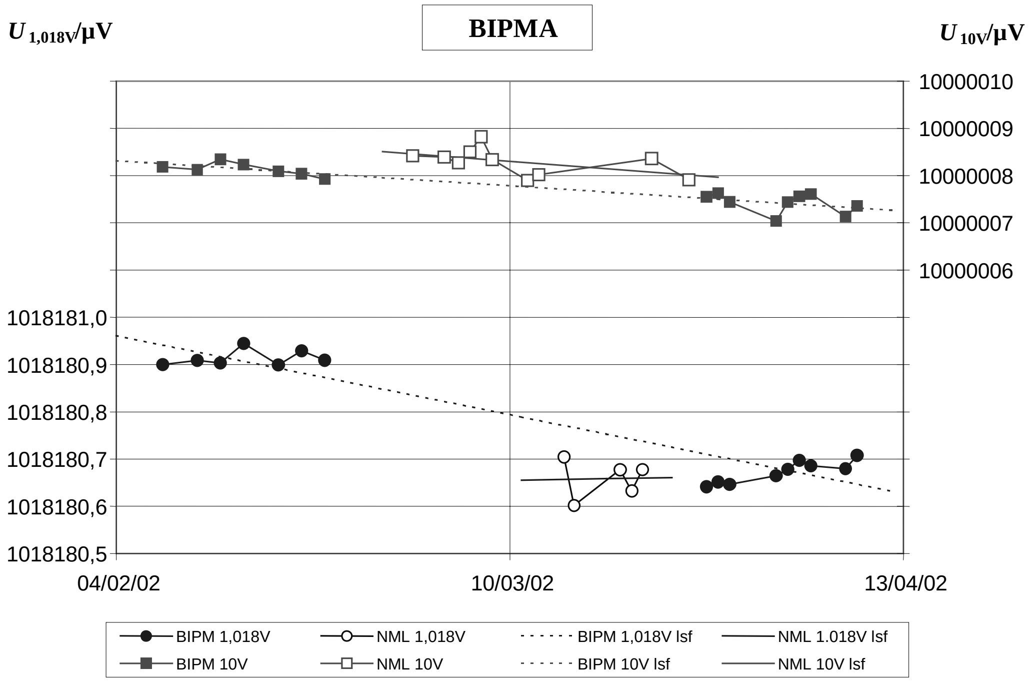

Figure 1. Voltage of BIPMA as a function of time, with linear least-squares fits (lsf) to the measurements of each laboratory

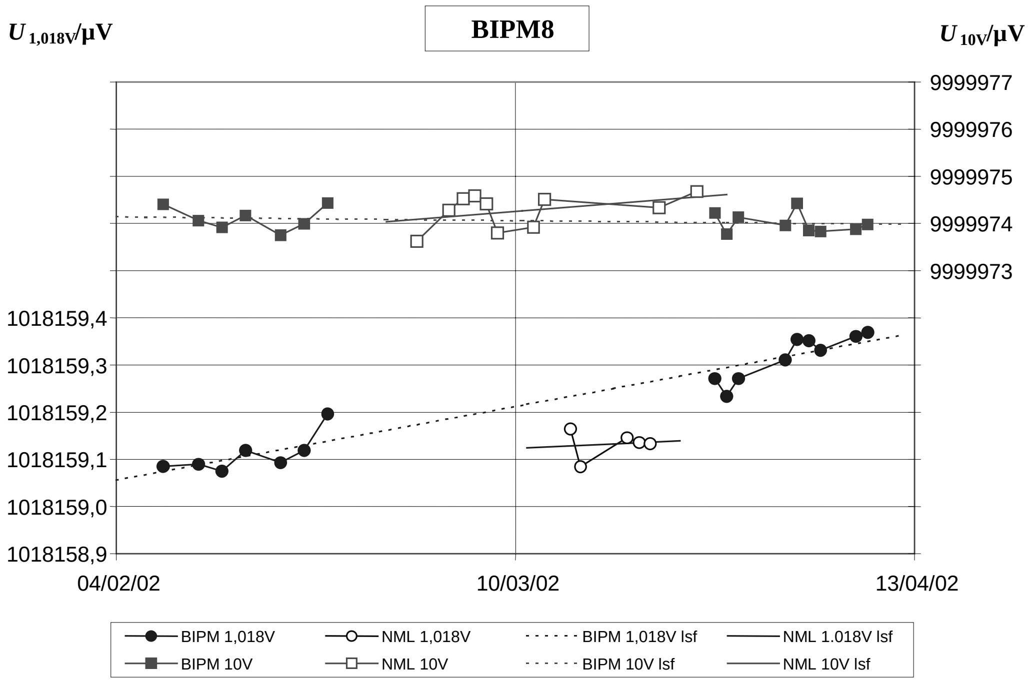

Figure 2. Voltage of BIPM8 as a function of time, with linear least-squares fits (lsf) to the measurements of each laboratory

Table 1. Results of the NML(Ireland)/BIPM bilateral comparison of 1.018 V standards using two Zener travelling standards. Reference date 18 March 2002. Uncertainties are 1 σ estimates.
The uncorrelated uncertainty is $w = [r^2 + t^2 + v^2]^{1/2}$, the expected transfer uncertainty is $x = [w_A^2 + w_8^2]^{1/2}/2$, and the correlated uncertainty is $y = [s^2 + u^2]^{1/2}$.

		BIPMA	BIPM8	
1	*NML (Ireland)* $(U_Z - 1.018\text{V})/\mu\text{V}$	180.659	159.133	
2	Type A uncertainty/µV	0.021	0.015	*r*
3	equipment uncertainty/µV	0.455		*s*
4	*BIPM* $(U_Z - 1.018\text{V})/\mu\text{V}$	180.753	159.250	
5	Type A uncertainty/µV	0.011	0.010	*t*
6	equipment uncertainty/µV	0.005		*u*
7	pressure and temperature corrections uncertainty/µV	0.005	0.010	*v*
8	$(U_{Z\_NML} - U_{Z\_BIPM})/\mu\text{V}$	–0.094	–0.118	
9	uncorrelated uncertainty/µV	0.024	0.021	*w*
10	$<U_{NML} - U_{BIPM}>/\mu\text{V}$	–0.106		
11	expected transfer uncertainty/µV	0.016		*x*
12	s_M of difference for two Zeners/µV	0.012		
13	correlated uncertainty/µV	0.455		*y*
14	comparison total uncertainty/µV	0.455		

Table 2. Results of the NML(Ireland)/BIPM bilateral comparison of 10 V standards using two Zener travelling standards. Reference date 10 March 2002. Uncertainties are 1 σ estimates. The uncorrelated uncertainty is $w = [r^2 + t^2 + v^2]^{1/2}$, the expected transfer uncertainty is $x = [w_A^2 + w_8^2]^{1/2}/2$, and the correlated uncertainty is $y = [s^2 + u^2]^{1/2}$.

		BIPMA	BIPM8	
1	*NML (Ireland)* $(U_Z - 10\text{V})/\mu\text{V}$	8.29	–25.73	
2	Type A uncertainty/µV	0.10	0.11	*r*
3	equipment uncertainty/µV	1.10		*s*
4	*BIPM* $(U_Z - 10\text{V})/\mu\text{V}$	7.77	–25.94	
5	Type A uncertainty/µV	0.10	0.10	*t*
6	Equipment uncertainty/µV	0.01		*u*
7	pressure and temperature corrections uncertainty/µV	0.02	0.06	*v*
8	$(U_{Z\_NML} - U_{Z\_BIPM})/\mu\text{V}$	0.52	0.21	
9	Uncorrelated uncertainty/µV	0.14	0.16	*w*
10	$\langle U_{NML} - U_{BIPM} \rangle/\mu\text{V}$	0.37		
11	expected transfer uncertainty/µV	0.11		*x*
12	s_M of difference for two Zeners/µV	0.15		
13	Correlated uncertainty/µV	1.10		*y*
14	comparison total uncertainty/µV	1.11		

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

	Uncertainty/nV	
	1.018 V	10 V
thermal EMFs	3	3
detector/EMI	3	0.5
leakage resistance	3	0.3
frequency	<0.1	0.3
pressure correction	0.4	4
temperature correction	0.8	4
total	5.3	6.4

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

	Uncertainty/µV	
	1.018 V	10 V
reference group stability		1.1
10 V reference standard	0.25	
comparator	0.38	
pressure correction	0.004	0.04
temperature correction	0.003	0.01
total	0.455	1.10