Bilateral Comparison of 10 V Standards between the NML (Ireland) and the BIPM, March to April 2007 (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-K11.b, a comparison of the 10 V voltage reference standards of the BIPM and the National Metrology Laboratory (NML), Dublin, Ireland, was carried out from March to April 2007. Two BIPM Zener diode-based travelling standards (Fluke 732B), BIPM_8 and BIPM_9, were transported by freight to NML. The NML measurements were carried out by comparison with the mean of the NML voltage standard. The local representation of the SI unit of electric potential is maintained at the 10 V level by means of a group of twelve commercially-produced Zener diode-based electronic voltage standards, each of which has been characterized for the effects of temporal drift and environmental influences. The value ascribed to the ensemble voltage standard is the weighted mean of the values of the individual standards. The unknown EMF, of nominal value 10 V, is measured by comparison with four well-behaved standards, drawn from the group. A weighted least-squares method is used to reduce the data, which comprise the measured voltage differences and the predicted output EMFs of the reference devices.

At the BIPM, the traveling standards were calibrated with the Josephson Voltage 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. A linear least squares fit is applied to the results of both laboratories to obtain the results for both standards and their uncertainties at a common reference date.

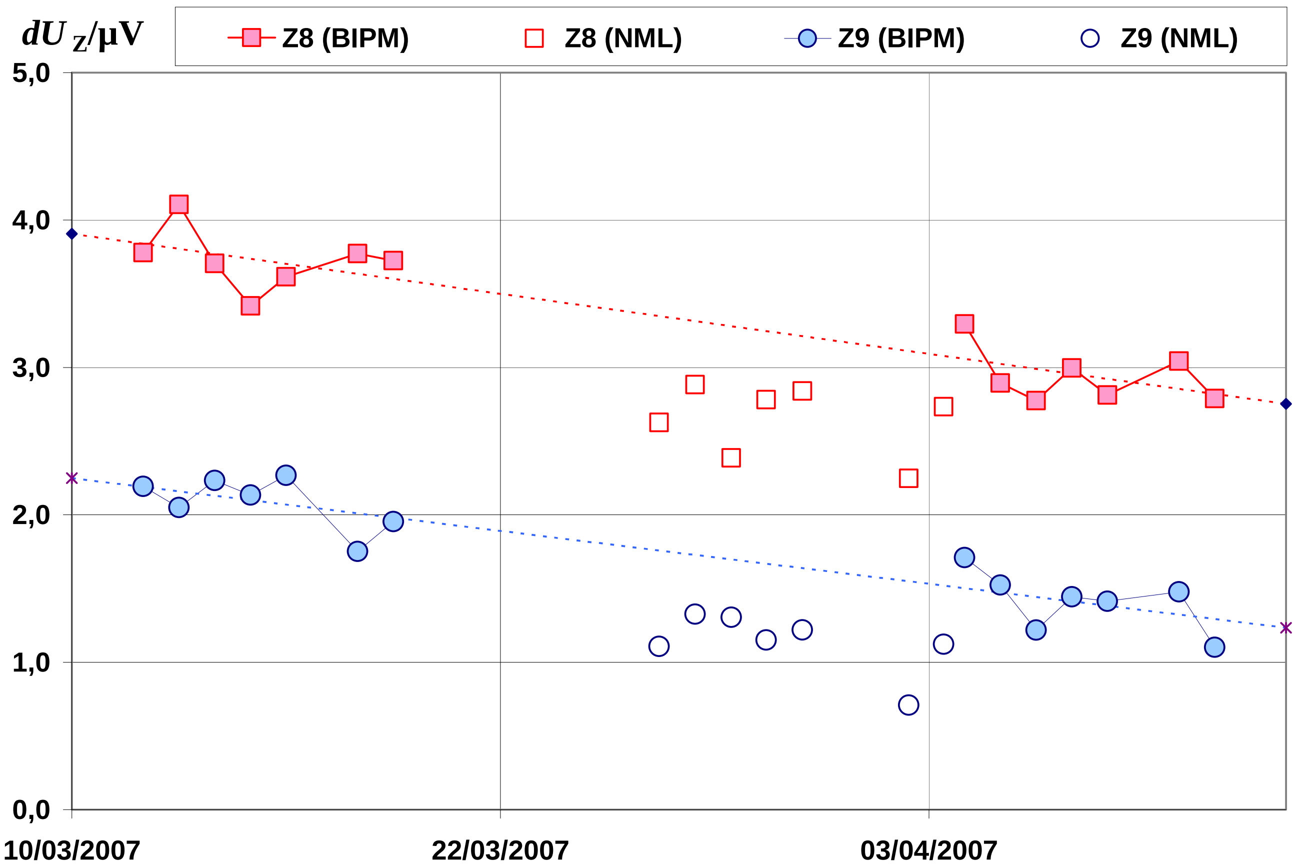

Figure 1. Voltage of BIPM_8 (Z8) and BIPM_9 (Z9) at 10 V measured at both institutes, referred to an arbitrary origin, as a function of time, with linear least-squares fit to the measurements of the BIPM.

Table 1 lists the results of the comparison and the uncertainty contributions for the comparison NML/BIPM. Experience has shown that flicker or 1/*f* noise ultimately limits 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 voltage noise floor due to flicker noise is about 1 part in 10^8.

In estimating 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 traveling standards[*]. If the *a posteriori* uncertainty is

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

significantly larger than 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, whichever is greater;
(3) the uncertainty component arising from the maintenance of the volt at the NML: this uncertainty is completely correlated between the different Zeners used for a comparison;
(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 traveling standard;
(11 and 12) the uncertainty related to the transfer, estimated by the following two methods:

(11) the *a priori* uncertainty, determined as described on page 3;

(12) the *a posteriori* uncertainty, which is the standard deviation of the mean of the two 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 2 summarizes the uncertainties related to the calibration of a Zener diode against the Josephson array voltage standard at the BIPM.

Table 3 lists the uncertainties related to the maintenance of the volt and the Zener calibration 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

$$U_{\mathrm{NML}} - U_{\mathrm{BIPM}} = -0.55\ \mu\mathrm{V};\quad u_{\mathrm{c}} = 1.40\ \mu\mathrm{V} \quad \textbf{on 2007/03/30},$$

where u_{c} is the standard uncertainty associated with the measured difference, including the uncertainty of the representation of the volt at the BIPM, based on $K_{\mathrm{J-90}}$, the uncertainty of the representation of the volt at NML, and the uncertainty related to the comparison.

This is a satisfactory result. Assuming that the probability density function of the measured difference is normal, an interval estimate, with a coverage probability of approximately 95%, may be obtained by multiplying the standard uncertainty (u_c) by a coverage factor k=2. Since this interval estimate includes the value zero, the comparison result shows that the voltage standards maintained by the NML and the BIPM were equivalent, within their stated expanded uncertainties, on the mean date of the comparison.

Table 1. Results of the NML(Ireland)/BIPM bilateral comparison of 10 V standards using two Zener traveling standards: reference date 30 March 2007. Uncertainties are 1 σ estimate.
The uncorrelated uncertainty is $w = [r^2 + t^2 + v^2]^{1/2}$, the expected transfer uncertainty is $x = ½ [w_8^2 + w_9^2]^{1/2}$, and the correlated uncertainty is $y = [s^2 + u^2]^{1/2}$, where:

r is the NML Type A uncertainty (2);
s is the NML Type B uncertainty, which is assumed to be correlated for both transfer standards (3);
t is the BIPM Type A uncertainty (5);
u is the BIPM Type B uncertainty, which is assumed to be correlated for both transfer standards (6);
v is the pressure and temperature coefficient correction uncertainty (7);
w_i is the quadratic combination of the uncorrelated uncertainties for the Zener *I* (9);
x is the expected transfer uncertainty (from the calculation of the statistical internal consistency) (11);
y is the quadratic combination of the correlated uncertainties (13).

(U_Z — 10V)

		BIPM_8	BIPM_9
1	*NML (Ireland)*(U_Z — 10V)/µV	–43.86	–45.37
2	Type A uncertainty/µV	0.10	0.10
3	correlated unc. /µV	1.39	
4	*BIPM* (U_Z — 10V)/µV	–43.27	–44.85
5	Type A uncertainty/µV	0.10	0.10
6	correlated unc./µV	0.01	
7	pressure and temperature correction uncertainty/µV	0.02	0.01
8	(U_{NML} — U_{BIPM})/µV	-0.59	-0.52
9	uncorrelated uncertainty/µV	0.14	0.14
10	< U_{NML} — U_{BIPM} >/µV	-0.55	
11	*a priori* uncertainty/µV	0.10	
12	*a posteriori* uncertainty/µV	0.03	
13	correlated uncertainty/µV	1.39	
14	comparison total uncertainty/µV	1.40	

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

	Uncertainty/µV
thermal electromotive forces	0.003
detector / electromagnetic interference	0.003
leakage resistance	0.003
frequency	0.0003
pressure correction	0.004
temperature correction	0.013
total	0.014

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