# Bilateral Comparison of 10 V Standards

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A comparison of the 10 V voltage reference standards of the BIPM and the National Metrology Laboratory (NML, Dublin, Ireland) was carried out in March 2001. Two BIPM 732B Zener diode-based travelling standards, BIPM6 and BIPM9, were transported by freight. The NML measurements were carried out at 10 V by comparison with the NML voltage standard reference. The BIPM measurements of the travelling standards were carried out by direct comparison to 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 values and uncertainties were calculated for the reference date from linear least-squares fits.

Table 1 lists the results of the 10 V comparison and the contributions to the uncertainty budget. 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 $10^8$.

In estimating the uncertainty we calculated the *a priori* uncertainty based on all known sources except that associated with the stability of the standards when transported, and compared 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 used the larger of these two estimates in calculating the final uncertainty.

In Table 1, the following elements are listed:

(1) the predicted value $U_{Z\_NML}$ 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 arising from 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 arising from 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 ($U_{Z\_NML} - U_{Z\_BIPM}$) 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).

Table 2 summarizes the uncertainties due to the BIPM measuring equipment and the maintenance and measuring equipment at the NML.

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

$$U_{\mathrm{NML}} - U_{\mathrm{BIPM}} = -0.34 \ \mu\mathrm{V}; \ u_{\mathrm{c}} = 2.3 \ \mu\mathrm{V} \text{ on } 2001/03/13,$$

where $u_{\mathrm{c}}$ is the combined standard uncertainty.

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.
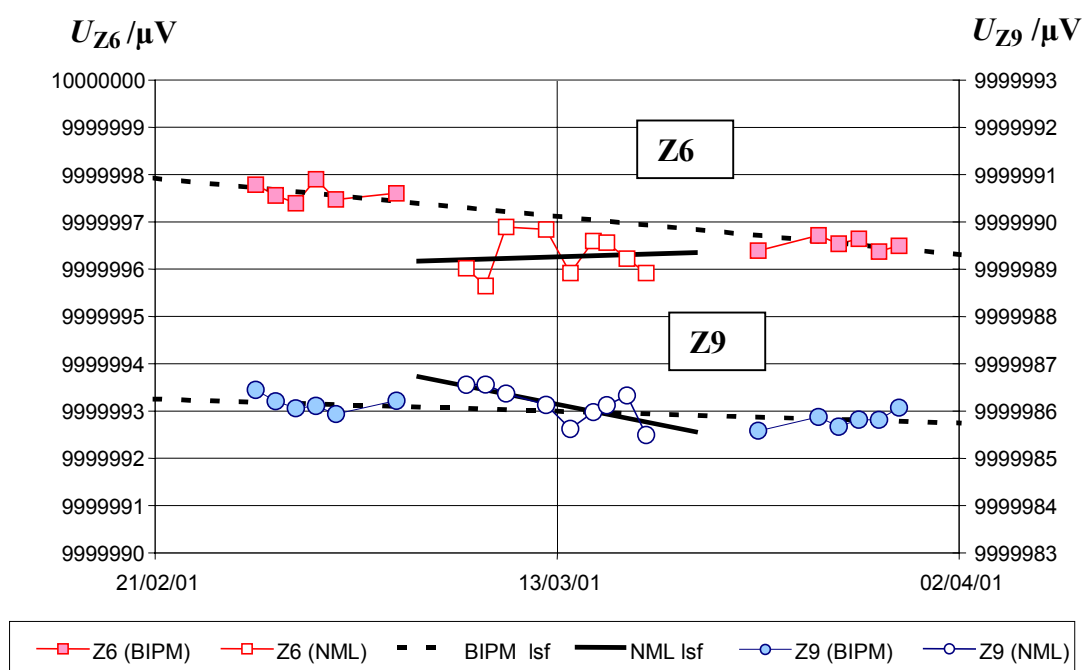


Figure 1. Voltage of BIPM6 and BIPM9 as a function of time, with linear least-squares fits to the measurements in each laboratory

Table 1. Results of the NML(Ireland)/BIPM bilateral comparison of 10 V standards using two Zener travelling standards: reference date 13 March 2001. Uncertainties are 1 $\sigma$ estimates. The uncorrelated uncertainty is $w = [r^2 + t^2 + v^2]^{1/2}$, the expected transfer uncertainty is $x = [w_6^2 + w_9^2]^{1/2}/2$ and the correlated uncertainty is $y = [s^2 + u^2]^{1/2}$.

| | | BIPM6 | BIPM9 | |
|---|---|---|---|---|
| 1 | *NML (Ireland)* $(U_{Z\_NML} - 10\ V)/\mu V$ | −3.71 | −13.87 | |
| 2 | Type A uncertainty/$\mu$V | 0.16 | 0.10 | $r$ |
| 3 | equipment uncertainty/$\mu$V | 2.3 | | $s$ |
| 4 | *BIPM* $(U_{Z\_BIPM} - 10\ V)/\mu V$ | −2.89 | −14.01 | |
| 5 | Type A uncertainty/$\mu$V | 0.10 | 0.10 | $t$ |
| 6 | equipment uncertainty/$\mu$V | 0.01 | | $u$ |
| 7 | pressure and temperature corrections uncertainty/$\mu$V | 0.11 | 0.32 | $v$ |
| 8 | $(U_{Z\_NML} - U_{Z\_BIPM})/\mu V$ | −0.82 | 0.14 | |
| 9 | uncorrelated uncertainty/$\mu$V | 0.22 | 0.35 | $w$ |
| 10 | $<U_{NML} - U_{BIPM}>/\mu V$ | −0.34 | | |
| 11 | expected transfer uncertainty/$\mu$V | 0.20 | | $x$ |
| 12 | $s_M$ of difference for 2 Zeners/$\mu$V | 0.48 | | |
| 13 | correlated uncertainty/$\mu$V | 2.3 | | $y$ |
| 14 | comparison total uncertainty/$\mu$V | 2.3 | | |

Table 2. Estimated standard uncertainties for Zener calibrations

with the BIPM equipment.

| | Uncertainty/nV |
|---|---|
| thermal EMFs | 10 |
| detector/EMI | 0.5 |
| leakage resistance | 0.3 |
| frequency | 0.3 |
| | |
| rss total | 10 |

with the NML equipment.

| | Uncertainty/$\mu$V |
|---|---|
| reference group stability | 2.2 |
| uncorrected parasitic voltages | 0.3 |
| detector | 0.5 |
| pressure and temperature | 0.02 |
| | |
| rss total | 2.3 |