Bilateral Comparison of 1.018 V and 10 V Standards
between the GUM, Poland 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 Central Office of Measures (GUM, Warsaw, Poland) was carried out in May 2001. Two BIPM 732B Zener diode-based travelling standards, here called GUM 07 and GUM 10, were hand-carried by plane. The BIPM and GUM measurements were carried out at 1.018 V and 10 V using the Josephson array voltage standard (JAVS) of the laboratory. The 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 1.018 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 the 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_GUM} of each Zener, computed using a linear least squares fit to all of the data from the GUM and referenced to the mean date of the GUM'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 GUM. 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 ($U_{Z\_GUM} - U_{Z\_BIPM}$) for each Zener, and

(9) the uncorrelated part of the uncertainty;

(10) the result of the comparison, which is a weighted mean of the differences of the calibration results for the different standards. A weighted mean was chosen because Zener GUM 10 was unusually unstable during the GUM return measurements: the weight of each difference was set to be inversely proportional to the square of its 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 2 lists the same information for the 10 V comparison, apart from part (10), where the result of the comparison is the simple mean of the differences of the calibration results for the different standards.

Tables 3 and 4 summarize the uncertainties due to the measuring equipment of the GUM and of the BIPM, respectively.

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

$$U_{\mathrm{GUM(1.018\ V)}} - U_{\mathrm{BIPM(1.018\ V)}} = 0.000\ \mu\mathrm{V};\ u_{\mathrm{c}} = 0.038\ \mu\mathrm{V}\ \text{on 2001/05/07},$$

where u_{c} is the combined standard uncertainty,
and for a 10 V standard on the reference date is

$$U_{\mathrm{GUM(10\ V)}} - U_{\mathrm{BIPM(10\ V)}} = -0.06\ \mu\mathrm{V};\ u_{\mathrm{c}} = 0.13\ \mu\mathrm{V}\ \text{on 2001/05/07}.$$

The result of the 10 V comparison is very satisfactory. The result of the 1.018 V comparison is less significant because of the instability in the 1.018 V output of Zener GUM 10. Using only the result of Zener GUM 07, a difference of 1 part in 10^8 would have been obtained, the uncertainty being of the order of 3.5 parts in 10^8.

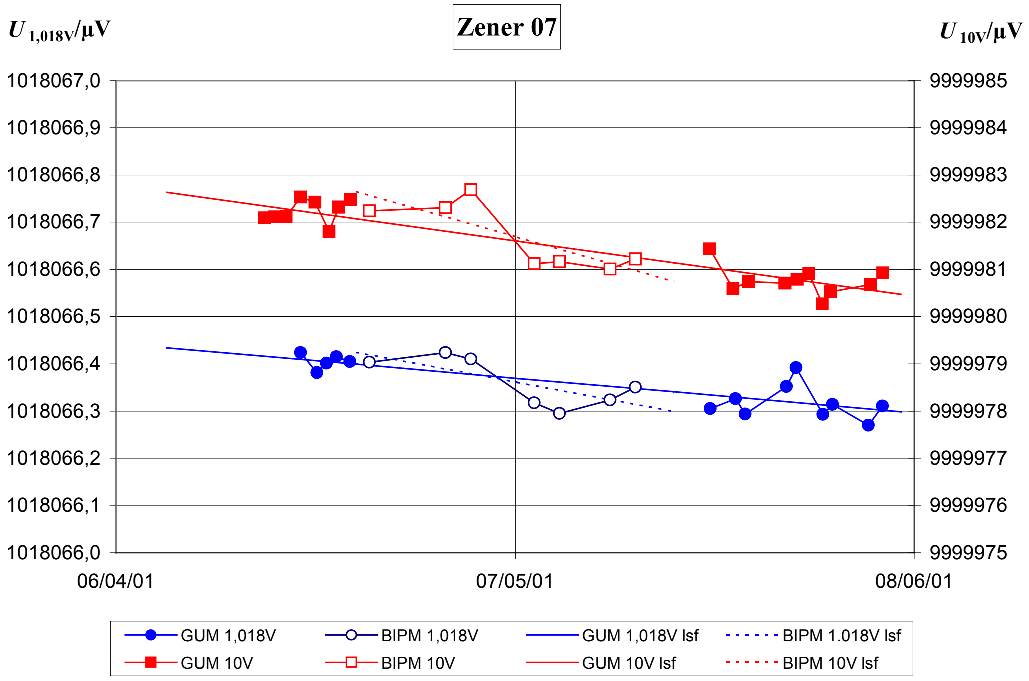

Figure 1. Voltage of GUM 07 as a function of time, with linear least-squares fits to the measurements in each laboratory

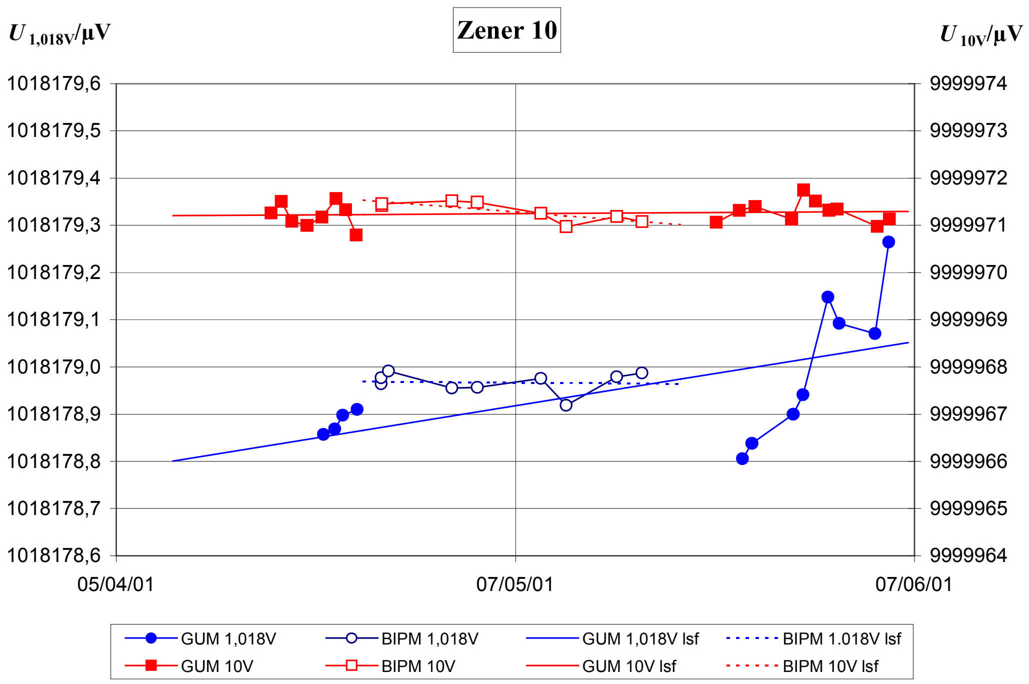

Figure 2. Voltage of GUM 10 as a function of time, with linear least-squares fits to the measurements in each laboratory

Table 1. Results of the GUM(Poland)/BIPM bilateral comparison of 1.018 V standards using two Zener travelling standards: reference date 7 May 2001. Uncertainties are 1 σ estimates. The uncorrelated uncertainty is $w = [r^2 + t^2 + v^2]^{1/2}$, the expected transfer uncertainty is $x = [w_{07}^{-2} + w_{10}^{-2}]^{-1/2}$ (corresponding to the weighted mean) and the correlated uncertainty is $y = [s^2 + u^2]^{1/2}$.

			GUM 07	GUM 10	
1	GUM	$(U_{Z\_GUM} - 1.018\ \mathrm{V})/\mu\mathrm{V}$	66.369	178.910	
2		Type A uncertainty/µV	0.010	0.044	r
3		equipment uncertainty/µV	0.030		s
4	BIPM	$(U_{Z\_BIPM} - 1.018\ \mathrm{V})/\mu\mathrm{V}$	66.360	178.967	
5		Type A uncertainty/µV	0.015	0.010	t
6		equipment uncertainty/µV	0.005		u
7	pressure and temperature	corrections uncertainty/µV	0.002	0.001	v
8		$(U_{Z\_GUM} - U_{Z\_BIPM})/\mu\mathrm{V}$	0.009	–0.057	
9		Uncorrelated uncertainty/µV	0.018	0.045	w
10		$\langle U_{GUM} - U_{BIPM} \rangle/\mu\mathrm{V}$	0.000		
11		expected transfer uncertainty/µV	0.017		x
12		s_M of difference for two Zeners/µV	0.022		
13		correlated uncertainty/µV	0.030		y
14		comparison total uncertainty/µV	0.038		

Table 2. Results of the GUM(Poland)/BIPM bilateral comparison of 10 V standards using two Zener travelling standards: reference date 7 May 2001. Uncertainties are 1 σ estimates. The uncorrelated uncertainty is $w = [r^2 + t^2 + v^2]^{1/2}$, the expected transfer uncertainty is $x = [w_{07}^2 + w_{10}^2]^{1/2}/2$ and the correlated uncertainty is $y = [s^2 + u^2]^{1/2}$.

			GUM 07	GUM 10	
1	GUM	$(U_{Z\_GUM} - 10\ \text{V})/\mu\text{V}$	–18.40	–28,75	
2		Type A uncertainty/µV	0.10	0.10	r
3		equipment uncertainty/µV	0.03		s
4	BIPM	$(U_{Z\_BIPM} - 10\ \text{V})/\mu\text{V}$	–18.32	–28.70	
5		Type A uncertainty/µV	0.17	0.10	t
6		equipment uncertainty/µV	0.01		u
7		pressure and temperature corrections uncertainty/µV	0.01	0.01	v
8		$(U_{Z\_GUM} - U_{Z\_BIPM})/\mu\text{V}$	–0.08	–0.05	
9		uncorrelated uncertainty/µV	0.20	0.14	w
10		$\langle U_{GUM} - U_{BIPM}\rangle/\mu\text{V}$	–0.06		
11		expected transfer uncertainty/µV	0.12		x
12		s_M of difference for two Zeners/µV	0.02		
13		correlated uncertainty/µV	0.03		y
14		comparison total uncertainty/µV	0.13		

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

	Uncertainty/nV	
	1.018 V	10 V
thermistor measurement	0.4	5
pressure measurement	0.4	4
thermal electromotive forces	30	30
DVM calibration	0	0
leakage resistance	1.0	10
frequency	1.0	10
Total	30	34

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

	Uncertainty/nV	
	1.018 V	10 V
thermistor measurement	0.3	4
pressure measurement	0.4	4
thermal electromotive forces	3.0	3
detector/EMI	3.0	1
leakage resistance	3.0	0
frequency	0.0	0
total	5.2	6