FINAL REPORT

EUROMET project No. 690

Bilateral comparison of DC and AC voltages
BEV - NCM

W. Waldmann (BEV, pilot laboratory)
P. Aladzhem (NCM)

April 2006

1. Introduction

The main objectives of the comparison are:

- to demonstrate equivalence of metrological practice
- to contribute to acceptance of NCM in EUROMET
- to confirm the CMC of NCM in the field of DC and AC voltages
- to check the correctness of the calibration results
- to check the correct traceability of the standards

2. Travelling standard

2.1. Description of the standard

Type	Multifunctional transfer standard 4950
Manufacturer	Wavetek
Serial number	37053
Height	88 mm
Width	427 mm
Depth	487 mm
Weight	11.8 kg
Line voltage	230 V, 50 Hz

2.2. Measurement program

Measurand	Measurement value	Frequency
DC voltage	1.018 V; 10 V	
AC voltage	1 V; 10 V	44 Hz; 1 kHz; 100 kHz

Ambient conditions:

- Temperature : (23 ± 1) °C
- Relative humidity: (50 ± 15) %

3. Organization

3.1. Co-ordinator, pilot laboratory

Name: Dipl.-Ing. Wolfgang Waldmann
Address: BEV, Bundesamt fuer Eich- und Vermessungswesen,
Arltgasse 35
A-1160 Vienna, Austria
Telephone: +43 1 49110 350 Fax: +43 1 4920875
e-mail: w.waldmann@metrologie.at

3.2. Participants: BEV – Austria, NCM – Bulgaria

Name: Petya Aladzhem
Address: NCM, National Centre of Metrology,
52 B, G.M. Dimitrov Blvd.
BG-1797 Sofia, Bulgaria
Telephone: +359 02 71 02 37 Fax: +359 02 71 70 50
e-mail: ncm@sasm.orbitel.bg

3.3. Transportation and schedule

NCM was responsible for the transportation of the standard – NCM-BEV; BEV-NCM. A Bulgarian transportation firm organized the transportation.
The package was shipped by cargo plane and was accompanied by ATA carnet.

NCM had ten days (two periods of five days) and BEV had ten days (one period) available for their participation in the comparison. These periods include only the measurements. Each laboratory had three days for the transportation of the MTS 4950 Wavetek.

Time schedule

	Measurement period	Measurements done	Dispatch Date
NCM	10. 2. 03 – 14. 2. 03	DC + AC voltage	14. 2. 03
BEV	20. 2. 03 – 24. 2. 03	DC voltage	-----
BEV	25. 2. 03 – 28. 2. 03	AC voltage	28. 2. 03
NCM	03. 3. 03 – 07. 3. 03	DC + AC voltage	-----

4. Measurement Instruction

4.1. Test before measurement

In order to verify the condition of the standard "Selftest Operations" were performed following the instructions in the User handbook, section 4.

4.2. Measurement conditions and constraints

After arrival the standard was allowed to stabilize at temperature (23 ± 1) °C for one day before use.
Configuration (settings) of the Wavetek 4950:

- for DC Voltage:
  Guard: *Local*; Accuracy mode: *High*; Cert. Corrections: *off*;
  Input Zero operation before measurements at each range.
- for AC Voltage:
  Guard: *Local*; Accuracy mode: *High*; Cert. Corrections: *off*
  The measurements at 44 Hz were performed in the frequency band 36 - 44 Hz, at 1 kHz in the frequency band 0.9 - 1.1 kHz, at 100 kHz in the frequency band 90 - 110 kHz.

5. Method of measurement at NCM

5.1. Method of measurement at DC Voltage

The calibration of MTS 4950 Wavetek (further on in the text MTS) in the range 1 V at the voltage of 1.018 V and in the range 10 V with Nanoscan reference system 7003 N was performed by direct method of measurement.
The results were calculated as average value of measurements during six and seven days using the ANOVA method. This method is given in GUM, Annex H.5, p.p. 83-87 and is used to estimate "a between – day effect" in measurement. The variance of measurement results is calculated in accordance with the equation H.32.

5.2. Methods of measurement at AC Voltage

The calibration of MTS 4950 in the ranges 1 V and 10 V was performed with thermal converters A55 Fluke 1 V and 10 V using the calibrator 4808 Wavetek and the digital multimeter HP3458A. The calibration of the calibrator 4808 Wavetek was carried out simultaneously with calibration of the MTS.
The calibration of the calibrator 4808 Wavetek was performed by method of comparison with DC Voltage. The calibration of the MTS was performed with 4808 Wavetek by direct measuring method.
AC voltage from the calibrator was applied to the thermal converter and MTS at the same time. The indications of the MTS, thermal converter's output and positive and negative settings of DC Voltage of the calibrator 4808 Wavetek were recorded. The multimeter HP3458A was used for thermal converter's output readings.
For estimation of the uncertainty associated with AC actual value (connected with correction of applied AC voltage) of calibrator the correlation between corrections relevant to actual values of DC positive and negative voltage was taken into account, resulting from the fact that one and the same calibrator was used.
The result was calculated as average value of measurements during three or four days.

Configuration of the AC set up:

- Multimeter HP3458A – ACAL DCV, NDIG 6, NPLC 50, LFILT ON;
- Calibrator 4808 Wavetek – Rem sense ON;
- for the connection to the thermal converters connector QNPL type GR874 and banana adapter Pomona 1269 was used;
- warming 15 min – 30 min for thermal converter's stabilization.

6. Method of measurement at BEV

6.1. Method of measurement at DC Voltage

Calibration of MTS 4950 Wavetek in the range 1 V at the voltage of 1.018 V and in the range 10 V against the group of Zener standards (Fluke 732B) representing the National Voltage Standard (which is calibrated with the Josephson system of the BEV).

6.2. Method of measurement at AC Voltage

Calibration of MTS 4950 Wavetek in the ranges 1 V and 10 V with the AC Voltage Reference Standard Fluke 5790 (which is calibrated with the thermal converters of the BEV using a step-up and step-down method).

7. Measurement results

7.1. General

NCM measured two times:

- Measurement period 10. 2. 03 – 14. 2. 03: results indicated as d_{NCM1} with the reference date 12. 2. 03
- Measurement period 03. 3. 03 – 07. 3. 03: results indicated as d_{NCM2} with the reference date 6. 3. 03

BEV measured once:

- Measurement period 20. 2. 03 – 24. 2. 03 for DC voltage: results indicated as d_{BEV} with the reference date 22. 2. 03
- Measurement period 25. 2. 03 – 28. 2. 03 for AC voltage: results indicated as d_{BEV} with the reference date 26. 2. 03

The results d_{XXX} are stated as deviation from the nominal voltage and are denoted as a relative value (given in µV/V in the tables 7.2 and 7.3).

As the key comparison reference value (KCRV) for the measurement of DC voltage the measurement result d_{BEV} with an associated uncertainty U_{BEV} of BEV was chosen, because BEV has taken part in the following key comparisons:

- EUROMET.EM.BIPM-K11: "Comparison of 10 V DC voltage standards" [1]
- BIPM.EM-K11.a: "DC voltage: 1.018 V, Zener diode" [2]
- BIPM.EM-K11.b: "DC voltage: 10 V, Zener diode" [2]

As the comparison reference value (CRV) for the measurement of AC voltage the measurement result d_{BEV} with an associated uncertainty U_{BEV} of BEV was chosen, because BEV has taken part in the following key comparison:

- CCEM-K6.a: "Comparison of AC/DC voltage transfer standards" [3]

The value $d_{NCMmean}$ is the mean value of the results of the two measurement periods of NCM and is given by:

$$d_{NCMmean} = \frac{d_{NCM1} + d_{NCM2}}{2}$$

The degree of equivalence D_{NCM} for the participant NCM with respect to the reference value as stated above is given by:

$$D_{NCM} = d_{NCMmean} - d_{BEV}$$

with the expanded uncertainty (k = 2):

$$U_{D,NCM} = \sqrt{U_{NCM}^2 + U_{BEV}^2}$$

This calculation of the expanded uncertainty is used because NCM do not have an independent realisation of the volt.

7.2. Measurement results at DC Voltage

	Result BEV		Result NCM					
	22.2.03		12.2.03	6.3.03	mean			
Voltage	d_{BEV}	U_{BEV}	d_{NCM1}	d_{NCM2}	$d_{NCMmean}$	U_{NCM}	D_{NCM}	$U_{D,NCM}$
V	µV/V	µV/V	µV/V	µV/V	µV/V	µV/V	µV/V	µV/V
10	1.8	1.0	-1.1	-2.0	-1.6	3.4	-3.4	3.5
1.018	5.7	1.6	1.7	1.0	1.4	4.2	-4.3	4.5

7.3. Measurement results at AC Voltage

		Result BEV		Result NCM					
		26.2.03		12.2.03	6.3.03	mean			
Voltage	Frequency	d_{BEV}	U_{BEV}	d_{NCM1}	d_{NCM2}	$d_{NCMmean}$	U_{NCM}	D_{NCM}	$U_{D,NCM}$
V	kHz	µV/V	µV/V	µV/V	µV/V	µV/V	µV/V	µV/V	µV/V
10	0.044	-4.4	14	-17.0	-16.0	-16.5	17	-12.1	22.1
10	1	-9.5	13	-29.0	-29.0	-29.0	17	-19.5	21.4
10	100	65.3	25	71.0	70.0	70.5	35	5.2	43.3
1	0.044	4.8	13	-22.0	-23.0	-22.5	35	-27.3	37.3
1	1	-4.2	12	-34.0	-33.0	-33.5	29	-29.3	31.2
1	100	76.9	23	51.0	45.0	48.0	47	-28.9	52.5

8. Measurement uncertainty

8.1. Main uncertainty components

The uncertainty calculation complies with the requirements of the "Guide to the Expression of Uncertainty in Measurement (GUM)", first edition 1995, International Organisation for Standardisation (ISO), Geneva, 1993.

Considered sources of uncertainty:

DC Voltage:

- Type A
- Standards for DC Voltage
- Effect of the resolution of the measuring instruments
- EMI and relative humidity
- Uncompensated offset voltages
- Stability of the standards
- Temperature coefficient of the standards
- Drift of the standards

AC Voltage:

- Type A
- Standards for AC Voltage
- Effect of the resolution of the measuring instruments
- EMI and relative humidity
- Stability resp. short term stability of the standards
- Drift of the standards

8.2. Uncertainty Analysis

Uncertainty budgets of NCM and BEV for one measurement value of DC voltage resp. AC voltage are given in Appendix A.

9. Statement of traceability at NCM

9.1. The traceability on DC Voltage

The Nanoscan reference system 7003 N is calibrated at NCM with Reference standard 732B Fluke which is traceable via National standard to BIPM.
The calibrator 4808 Wavetek is calibrated at NCM with multimeter 1281 Wavetek, which is traceable to National Standard.

9.2. The traceability on AC Voltage

The calibrator 4808 Wavetek is calibrated at NCM with thermal converters A55 Fluke 1 V calibrated by NCM, and 10 V, which is calibrated at SP, Sweden, in 2000.

10. Statement of traceability at BEV

10.1. The traceability on DC Voltage

DC voltage is traceable to the Josephson system of the BEV. As the Josephson system is a primary standard no external traceability is necessary.

10.2. The traceability on AC Voltage

The thermal converters at 1 V-level are traceable to PTB, Germany. Other AC voltage levels are calibrated at BEV using a step-up and step-down method.

11. Evaluation of degrees of equivalance linked to BIPM.EM-K11.a and BIPM.EM-K11.b Comparisons

For the NCM measurement of DC voltage is given here a link to the comparisons BIPM.EM-K11.a “DC voltage: 1.018 V, Zener diode” and BIPM.EM-K11.b: “DC voltage: 10 V, Zener diode”, in which BEV participated.
In the Rapport BIPM-2001/03 (April 2001) [2] the final results of the comparison are presented as the differences between the values assigned to a 1.018 V and a 10 V standard by each laboratory and stated together with the combined standard uncertainty u_c (for k=1). According to the results stated in the “BIPM key comparison database” these differences are used as the degree of equivalence $D_{K11,BEV}$ and the expanded uncertainty $U_{K11,BEV} = 2 \cdot u_c$ (for k=2) of BEV as follows:

$D_{K11,BEV(10\ V)} = -0.04\ \mu V$ $\qquad$ $U_{K11,BEV(10\ V)} = 0.20\ \mu V$

$D_{K11,BEV(1.018\ V)} = -0.01\ \mu V$ $\qquad$ $U_{K11,BEV(1.018\ V)} = 0.03\ \mu V$

The same values are used now in this comparison for the evaluation of degrees of equivalence linked to BIPM.EM-K11.a and BIPM.EM-K11.b comparisons for the following reasons:

- As BEV used in the BIPM.EM-K11.a and BIPM.EM-K11.b comparisons and in this comparison the same Josephson system for measuring Zener standards, the same reproducibility of these measurements can be assumed (in the first comparison for the Zeners used as travelling standards, in this comparison for the Zeners owned by BEV which were used).

- No drift of the Josephson measurements has to be taken into account as the Josephson system is a primary standard.

Therefore the degree of equivalence $D_{K11.4,NCM}$ and the expanded uncertainty $U_{K11.4,NCM}$ of NCM with respect to the BIPM Reference Value given in the Rapport BIPM-2001/03 can be calculated as follows:

$$D_{K11.4,NCM(10\,V)} = D_{K11,BEV(10\,V)} + D_{NCM(10\,V)} = (-0.04\ \mu V) + (-34\ \mu V) = -34.04\ \mu V$$

$$U_{K11.4,NCM(10V)} = \sqrt{U^2_{K11,BEV(10V)} + U^2_{D,NCM(10V)}} = \sqrt{(0.20\,\mu V)^2 + (35\,\mu V)^2} = 35.00\,\mu V$$

$$D_{K11.4,NCM(1.018\,V)} = D_{K11,BEV(1.018\,V)} + D_{NCM(1.018\,V)} = (-0.01\ \mu V) + (-4.3\ \mu V) = -4.31\ \mu V$$

$$U_{K11.4,NCM(1.018V)} = \sqrt{U^2_{K11,BEV(1.018V)} + U^2_{D,NCM(1.018V)}} = \sqrt{(0.03\,\mu V)^2 + (4.5\,\mu V)^2} = 4.50\,\mu V$$

12. Corrective actions

As the first results of NCM failed to coincide with the reference value within the stated uncertainty of NCM, the pilot laboratory asked NCM to recalculate their values. This was done by NCM: mainly the uncertainty evaluation was recalculated and some uncertainty components were added.

13. References

[1] F. Liefrink, E.F. Dierikx and J.W. Heimeriks, “Final Report of EUROMET.EM.BIPM-K11: Comparison of 10 V Electronic Voltage Standards”, September 2002, published online in the *Key Comparison Data Base:* http://kcdb.bipm.fr

[2] W. Waldmann, D. Reymann and T. J. Witt, “Rapport BIPM-2001/03: Bilateral Comparison of 1.018 V and 10 V Standards between the BEV, Austria and the BIPM”, BIPM Publications, April 2001, published online in the *Key Comparison Data Base:* http://kcdb.bipm.fr

[3] M. Klonz, “Final Report of CCEM-K6.a: Key Comparison of AC/DC Voltage Transfer Standards at the Lowest Attainable Level of Uncertainty”, published online in the *Key Comparison Data Base:* http://kcdb.bipm.fr

Appendix A: Uncertainty budgets

A.1 Uncertainty budget of NCM for DC voltage 10 V, measuring date 12.2.03

	Quantity (unit)	Distribution	*xi*	*u(xi)*	*νi*	*ci*	*ui(y)*	*r(xi,y)*
1	mean measured value (V)	Normal	9.999974	4.84E-07	6	1	4.84E-07	0.028748
2	correction from Fluke 7003N (V)	Mixed	-0.000014	0.0000145	50	-1	-1.45E-05	-0.86126
3	drift of 7003N / for 232 days (V)	Rectangular	0	7.4754E-06	infinity	-1	-7.48E-06	-0.44402
4	resolution of 4950 (V)	Rectangular	0	2.8868E-07	infinity	1	2.887E-07	0.017147
5	uncert. due uncompens. offset voltages (V)	Normal	0.00000054	0.0000002	6	1	2E-07	0.01188
6	stability of Fluke 7003N for 7 days (V)	Rectangular	0	2.2901E-06	infinity	-1	-2.29E-06	-0.13603
7	temperature coefficient of 7003N (V)	Rectangular	0	2.2517E-07	infinity	-1	-2.25E-07	-0.01337
8	noise from 7003N (V)	Rectangular	0	3.4641E-07	infinity	-1	-3.46E-07	-0.02058
9	predictability of 7003N (V)	Rectangular	0	2.8868E-06	infinity	-1	-2.89E-06	-0.17147
10	uncert. due EMI and relative humidity (V)	Rectangular	0	1.7898E-06	infinity	-1	-1.79E-06	-0.10631
y	measured value (V)	Normal	9.99998854	1.6836E-05	90.86985			

Conf. level =	95.45%	*k* =	2.0279
Result =	**9.999989**	***U* =**	**0.000034**

A.2 Uncertainty budget of NCM for AC voltage 10 V, 44 Hz, measuring date 12.2.03

Quantity	Value	Standard Uncertainty	Degrees of Freedom	Distribution	Sensitivity Coefficient	Uncertainty Contribution
δU	268.6E-6 V	60.6E-6 V	51			
Udcavg	10.00022458 V	6.03E-6 V	56		-1.0	-6.0E-6 V
δUdcp	36.00E-6 V	5.00E-6 V	50	normal	-0.50	-2.5E-6 V
δUdcn	32.00E-6 V	5.00E-6 V	50	normal	-0.50	-2.5E-6 V
δUdcdr	0.0 V	2.27E-6 V	50	normal	-1.0	-2.3E-6 V
δac/dc	1.00E-6	6.00E-6	50	normal	-10	-60E-6 V
Unom	10.0 V					
Uavg	10.00009640 V	5.05E-6 V	47		1.0	5.1E-6 V
δUres	0.0 V	2.89E-6 V	infinity	rectangular	1.0	2.9E-6 V
δUrep	0.0	2.05E-6	infinity	rectangular	1.0	2.0E-6 V
δUshst	0.0	57.7E-6	infinity	rectangular	1.0	58E-6 V
δUem/rh	0.0	1.79E-6	infinity	rectangular	1.0	1.8E-6 V
U	9.9998278 V	83.9E-6 V	190			

Result:
Quantity: U
Value: 9.99983 V
Relative Expanded Uncertainty: 17E-6
Coverage Factor: 2.00
Coverage: 95% (t-table 95.45%)

A.3 Uncertainty budget of BEV for DC voltage 10 V, measuring date 22.2.03

Quantity X_i	**Estimate** x_i	**Standard uncertainty** $u(x_i)$	**Probability distribution/ method of evaluation(A,B)**	**Sensitivity coefficient** c_i	**Uncertainty contribution** $u_i(y)$	**Degrees of freedom** n_i
---	**µV/V**	**µV/V**	**---**	**---**	**µV/V**	**---**
$U_{DMM,reading}$	1.83	0.30	normal / A	1	0.30	100
du_{loaded}	---	0.40	rectangular / B	1	0.23	infinite
$du_{DC\text{-}reference}$	---	0.50	normal (k=2) / B	1	0.25	infinite
$du_{DMM,resolution}$	---	0.10	rectangular / B	1	0.06	infinite
$du_{thermal}$	---	0.05	rectangular / B	1	0.03	infinite
$du_{reproducibility}$	---	0.23	normal / A	1	0.23	6
$\boldsymbol{U_{DMM,result}}$	**1.83**			k = 1	0.51	129.3
				k = 2	**1.02**	

A.4 Uncertainty budget of BEV for AC voltage 10 V, 44 Hz, measuring date 26.2.03

Quantity X_i	**Estimate** x_i	**Standard uncertainty** $u(x_i)$	**Probability distribution/ method of evaluation(A,B)**	**Sensitivity coefficient** c_i	**Uncertainty contribution** $u_i(y)$	**Degrees of freedom** n_i
---	**µV/V**	**µV/V**	**---**	**---**	**µV/V**	**---**
$du_{std\text{-}DC}$	---	4.4	normal (k=2) / B	1.0	2.2	infinite
$du_{std\text{-}AC}$	---	11.0	normal (k=2) / B	1.0	5.5	infinite
$U_{DMM,reading}$	-4.4	3.0	normal / A	1.0	3.0	10
$du_{reproducibility}$	---	2.0	normal / A	1.0	2.0	5
$du_{thermal}$	---	1.4	rectangular / B	1.0	0.8	infinite
$du_{DMM,resolution}$	---	1.0	rectangular / B	1.0	0.6	infinite
$\boldsymbol{U_{DMM,result}}$	**-4.4**			k = 1	7.0	213.1
				k = 2	**14.0**	