EURAMET.EM-S41

DC voltage

Bilateral Comparison KIM-LIPI / LNE

Final Report

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2 December 2014

Abstract: This report describes a bilateral comparison of DC voltage standards organised within the frame of the EU-Indonesia Trade Support Program II n° APE12-06b between LNE, France and KIM-LIPI, Indonesia. This bilateral comparison registered in the KCDB as EURAMET.EM-S41 was piloted by LNE. LNE participated in EUROMET comparison N° 429, designated EUROMET.EM.BIPM-K11 thus providing the link between KIM-LIPI results and CCEM-K11. This report includes the measurement results from the participants and information about their calibration methods for measurements of 1,018 V and 10 V.

Content

Supplementary Comparison EURAMET EM-S41 Bilateral comparison of DC voltage reference standards (1,018 V and 10 V)

1 INTRODUCTION

The comparison is organised within the EU-Indonesia Trade Support Programme II, Sub-project Number APE12-06b, “Improvement of traceability of Metrology and Calibration measurements of Puslit KIM”.
Two National Metrology Institutes took part in this comparison: LNE (France) and KIM-LIPI (Indonesia). LNE is acting as the pilot laboratory and in this function is responsible for providing the travelling standard, the evaluation of the measurement results and the final report.

The objective of this comparison is to compare the measurement capabilities of the two National Metrology Institutes for 2 values of DC voltage : 1,018 V and 10 V.

The comparison is linked to EUROMET comparison n° 429, also designated EUROMET.EM.BIPM-K11, by the participation of LNE to this comparison. It is aimed to validate the competence of the KIM-LIPI to measure accurately DC voltage within their KCDB and/or accreditation uncertainties.

This bilateral comparison was registered in the KCDB as EURAMET.EM-S41 in May 2014.

The comparison is accomplished in accordance with the EURAMET Guidelines on Conducting Comparisons and CCEM Guidelines for Planning, Organising, Conducting and Reporting Key, Supplementary and Pilot Comparisons.

2 DEFINITION OF THE MESURAND

The quantity to be measured is the value of the DC voltage delivered by the travelling standard.

Quantities to be measured are:
$V_{1.018}$: voltage of nominal value equal to 1,018 V;
V_{10}: voltage of nominal value equal to 10 V.

Participants were asked to measure and report additional quantities:
T_{ext}: the temperature (°C) of the environment where the standard is measured;
R_{th}: the resistance of the internal thermoresistor of the standard.

3 TRAVELLING STANDARD

3.1 DESCRIPTION OF THE STANDARD

The travelling standard is a Zener diode standard Fluke 732A s/n 5240001 with the following specifications:

Nominal value of the outputs:	1 V - 1,018 V and 10 V
Stability per month:	(10 V output) : ± 0,5 ppm/month
Output impedance:	1 mΩ for 10 V output and 1 kΩ for 1,018 V.

The device was chosen with respect to stability and repeatability prior to the start of the comparison.

3.2 CHARACTERIZATION OF THE STANDARDS

3.2.1 Time dependence

Measurements were performed prior to the comparison.
The short time stability was evaluated and still remains lower than 0,12 µV for 1,018 V output and 0,2 µV for 10 V output.
The drift was also estimated to be lower than 3 µV/V per year for 1,018 V output and 5 µV/V per year for 10 V output.

Considering the short period for the comparison, the behaviour of the Zener output voltages could be assumed to be linear between each value measured by the LNE.

3.2.2 Effect of temperature

Measurements were performed in the past at 20° C and 23° C. The effect of the temperature was estimated to be lower than 0,13 µV/V/°C for 1,018 V output and - 0,05 µV/V/°C for 10 V output. This effect could be considered as negligible.

4 DESCRIPTION OF THE INTERLABORATORY COMPARISON AND ORGANIZATION

4.1 ORGANIZATION OF THE INTERLABORATORY COMPARISON

The comparison was organized and controlled by the pilot laboratory. The comparison started at LNE, where the zener diode standard was calibrated and characterized. The standard was sent to KIM-LIPI where it was also calibrated. The standard was then returned to LNE. Finally the standard was re-calibrated by LNE and the results from both laboratories were compared.

The travelling standard was transported in the original case and protected from mechanical shocks, vibration by plane. The travel box contained the following items:

- Zener reference standard (in condition of Real Panel switch OFF).
- Operating instructions of the travelling standard.

4.2 COORDINATOR AND PARTICIPANTS OF THE COMPARISON

Coordinator: Isabelle Blanc, isabelle.blanc.@lne.fr
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Participants:

Pilot laboratory: Laboratoire national de métrologie et d'essais, LNE,
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Participant: KIM-LIPI:
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4.3 TIME SCHEDULE

The circulation was scheduled between May 2014 and September 2014.
Preliminary measurements were performed at LNE in November 2013 for the qualification of the standard.

The original measurements were taken from calibrations performed from April 14th to June 5th 2014. The zener diode was sent to KIM-LIPI, Indonesia, on June 6th.

The time to transportation was longer than expected. The calibrations planned in July 2014 at KIM-LIPI were postponed and measurements were performed at KIM-LIPI from August 5th to August 29th 2014.

At the receipt at KIM-LIPI, the IN CAL indicator didn't light. The pilot laboratory was informed and specific instructions were given and executed before proceeding to the calibrations.

The zener diode was carried back to LNE on September 17th 2014. It was receipt at LNE on October 8th 2014. The final measurements were performed at LNE from October 10th to November 5th 2014.

The preliminary report from KIM-LIPI was received by LNE on September 20th, 2014. The final report of the comparison was sent on November 2014.

4.4 INSTRUCTIONS

A copy of the complete measurement instructions sent to the participating laboratory is given in Appendix A.

The measurements were performed under the following conditions (Tab 1), where R_{th} is the value of the internal thermistor resistance of the Zener diode standard.

Lab.	Date	R_{th} (Ω)	u (R_{th}) (Ω)	Temperature (°C)	ΔT (°C)	Relative Humidity (%)
LNE	10-10 to 05-11	4461,131	0,410	23	0,5	45
KIM-LIPI	05-08 to 29-08	4469,357	1,000	23,6	0,1	65
LNE	14-04 to 05-06	4464,948	0,500	23	0,5	45

Tab 1 – Measurement conditions (internal thermistor resistance value associated to its uncertainty and environmental conditions of the room where the standard is measured)

5 METHOD OF MEASUREMENTS

5.1 LNE METHOD

5.1.1 Method

The voltage difference between the DC reference and the travelling standard is measured with a digital nanovoltmeter. The measurement is performed in two steps by using another Zener diode which is used as a tare.

In the first step the tare is compared to the set of calibrated reference standards. The EMF E_T of the tare is then given by:

$$E_T = E_{ref} - V_{ref}$$

where:

- E_{ref} is the mean value of the EMF of the set of reference standards;
- V_{ref}, the mean value of voltages measured by the nanovoltmeter in the first step.

In the second step, the standard to be calibrated is then compared to the tare. The EMF E_X of the unknown standard is given by:

$$E_X = E_T + V_X = E_{ref} + \left(V_X - V_{ref}\right)$$

where V_X is the voltage measured by the nanovoltmeter in the second step.

A series of measures is repeated every day during a period of 3 to 4 weeks.

5.1.2 Reference standards and source of traceability

The reference standards are a set of four zener diode standards calibrated against LNE's JAVS with a periodicity of 3 months for 1,018 V output and 6 months for 10 V output. The references of these standards are:

- FLUKE 732B s/n 6465007;
- FLUKE 732B s/n 6470002;
- FLUKE 732B s/n 6440001;
- FLUKE 732B s/n 6295011.

The nanovoltmeter is a KEITHLEY type 182 s/n 554965 calibrated with a periodicity of 12 months.

5.2 KIM-LIPI

5.2.1 Method

The measurement is carried out based on a comparison method using a group reference standard of zener diode. The difference value between zener standard and travelling standard is recorded using a nanovolt-meter. Each difference value is obtained through a Forward and Reverse measurement which is done and operated manually using a low thermal scanner. The acquisition interval of data recording is arranged for 1 minute.
The measurement is carried out in condition of the system is powered by the AC line power and the CHASSIS was disconnected from the GUARD.

5.2.2 Reference standards and source of traceability

The reference group is consisting of the following standard instruments: Fluke 732B s/n 8440012, Fluke 732B s/n 8440013, Fluke 732B s/n 8440014, Fluke 732B s/n 8440015 and Fluke 7001N s/n 941254611.

The reference standard value was obtained through a prediction process based on calibration results against $PJVS_{KIM}$ (Programmable Josephson Voltage System) recorded from October, 2006 to November, 2010.

6 CHARACTERIZATION OF THE REFERENCE VALUE

6.1 DETERMINATION OF THE COMPARISON REFERENCE VALUE

The comparison reference value, E_{ref}, has been determined as the linear interpolated value between the first and final measurements performed at LNE.

The value reported by LNE is an average value of measurements that were performed during 3 to 4 weeks. The day-to-day fluctuations in the zener output voltages are taken into account in the uncertainty budget.

6.2 REFERENCE VALUE OF THE COMPARISON

As a slight drift is observed for the traveling standard between values measured by LNE in April-June 2014 and those measured October-November 2014, an interpolated value between the first and the final measurements performed at LNE taking into account the dates of measurement has been chosen as the reference value for the comparison. Expressions of the reference value E_{ref} and its standard uncertainty $u[E_{ref}]$ are:

$$E_{ref} = \frac{E(t_2) - E(t_1)}{t_2 - t_1}.(t - t_2) + E(t_2)$$

$$u[E_{ref}] = \frac{1}{t_2 - t_1}.\{(t_2 - t)^2.u^2[E(t_1)] + (t - t_1)^2.u^2[E(t_2)]$$
$$+ 2.(t_2 - t).(t - t_1).r[E(t_1), E(t_2)].u[E(t_1)].u[E(t_2)]\}^{1/2}$$

where:

- t_1 is the date of the first measurement at LNE;
- t_2, the date of the final measurement at LNE;
- t, the date of measurement at KIM-LIPI;
- $r[E(t_1),E(t_2)]$, the correlation coefficient between $E(t_1)$ and $E(t_2)$ taken equal to 1.

The reference value $E_{ref-comp}$ for the comparison associated with its expanded uncertainty (k = 2) u ($E_{ref-comp}$) is given in Tab 2.

Voltage	1,018 V	10 V
$E_{ref-comp}$	1,01800638	10,0001863
$u(E_{ref-comp})$	0,00000068	0,0000067

Tab 2: Reference value associated with its expanded uncertainty (k = 2) expressed in volts

7 MEASUREMENT RESULTS

Participants were asked to provide estimates of standard uncertainties, the effective degrees of freedom and the combined standard uncertainty. The uncertainty budgets provided by the participants can be found in Appendix B.

The measurement results and their associated expanded uncertainties can be found in Tab 3 to 4. Each table is followed by a graphical illustration of the reported results and the corresponding reference values (Fig 1 to 2).

7.1 1,018 V OUTPUT

Lab.	Date	E_X (V)	$u(E_X)$ (V)	Standard deviation (µV)
LNE	14-04 to 05-06-14	1,0180073	0,0000006	0,07
KIM-LIPI	05-08 to 29-08-14	1,0181828	0,0000023	1,16
LNE	15-10 to 05-11-14	1,0180058	0,0000006	0,05

Tab 3: Results for 1 V output

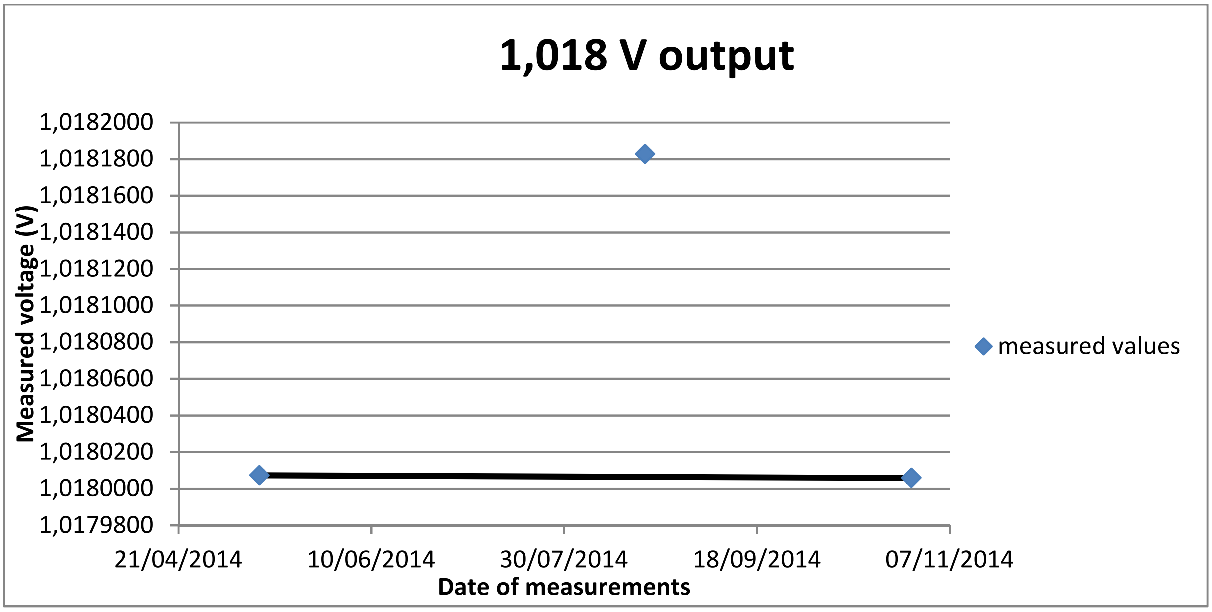

Fig 1: Results for 1 V output

7.2 10 V OUTPUT

Lab.	Date	E_X (V)	$u(E_X)$ (V)	Standard deviation (µV)
LNE	14-04 to 05-06-14	10,0001849	0,0000060	0,2
KIM-LIPI	05-08 to 29-08-14	9,999764	0,000035	17,59
LNE	10-10 to 05-11-14	10,0001873	0,0000060	0,2

Tab 4: Results for 10 V output

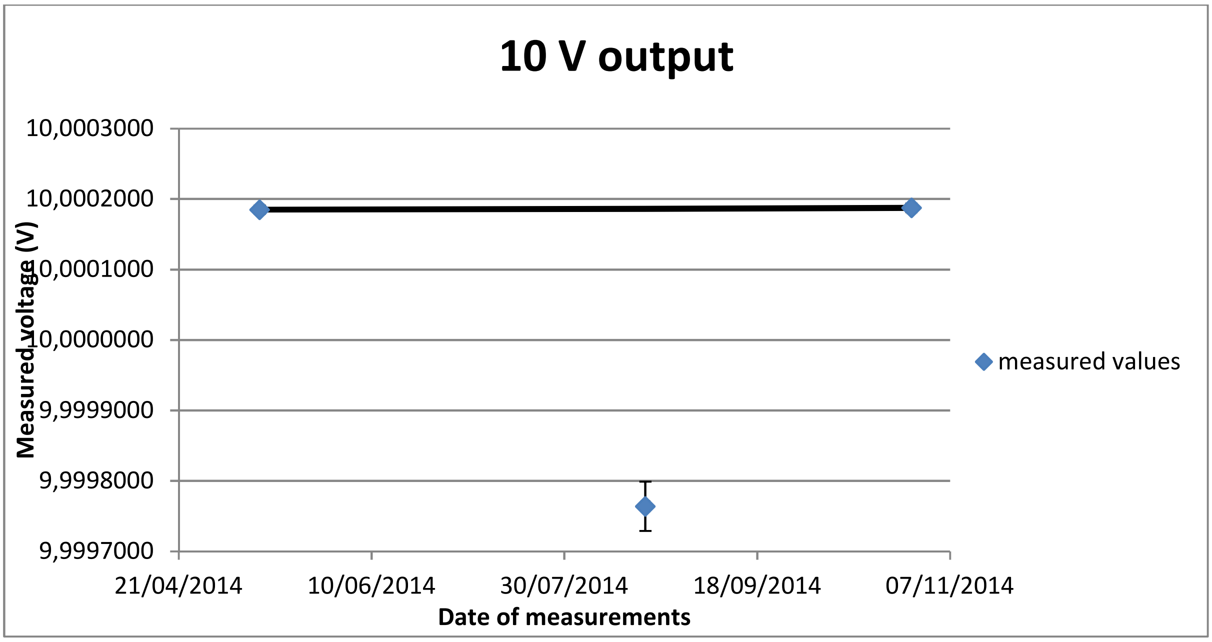

Fig 2: Results for 10 V output

8 DEGREES OF EQUIVALENCE OF KIM LIPI

8.1 DEGREES OF EQUIVALENCE (DOE) BETWEEN LNE AND KIM-LIPI

The values and the uncertainties reported by both laboratories are used in the calculation of the DoE. The degree of equivalence (DoE) between LNE and KIM-LIPI is summarized as follows:

$$D = E_{KIM-LIPI} - E_{ref}$$

with an expanded uncertainty

$$U[D] = \sqrt{U^2[E_{KIM-LIPI}] + U^2[E_{ref}]}$$

where $E_{KIM-LIPI}$ and E_{ref} are respectively the value of the voltage of the traveling standard measured by KIM-LIPI and the reference value.

The computed values for the degree of equivalence between LNE and KIM-LIPI are given in Tab 5.

Voltage	1,018 V	10 V
D	0,0001764	-0,000422
U [*D*]	0,0000024	0,000036

Tab 5: Degrees of equivalence between KIM-LIPI and LNE associated to the expanded uncertainties (k = 2) in absolute value expressed in volts.

A large deviation of results of KIM-LIPI from the comparison reference value, exceeding 75 times the expanded uncertainty at 1,018 V and 12 times the expanded uncertainty at 10 V, is observed. This indicates that one major source of error at least has not been identified at KIM-LIPI. As a consequence the calculated value of the degree of equivalence has no meaning.

8.2 LINK TO THE CCEM KEY COMPARISON

The link with CCEM comparisons will only make sense when the source of error has been identified and corrected or taken into account in the uncertainty budget.

9 CONCLUSION

From April 2014 to November 2014 a bilateral comparison has been organized between KIM-LIPI (Indonesia) and LNE (France) acting as the pilot laboratory. The objective of this comparison was to compare the measurement capabilities of the two National Metrology Institutes for 2 values of DC voltage : 1,018 V and 10 V. A large deviation of measurement results of KIM-LIPI from the comparison reference values (measurement results of LNE) greatly exceeding the expanded uncertainty associated with measurement results has been observed.

10 APPENDICES

Appendix A – Instructions
Appendix B – Uncertainty budget
Appendix C – Corrective actions

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APPENDIX A - Instructions

BILATERAL COMPARAISON of a DC reference standard

TECHNICAL PROTOCOL

1. Introduction

The comparison is organised within the EU-Indonesia Trade Support Programme II, Sub-project Number APE12-06b, "Improvement of traceability of Metrology and Calibration measurements of Puslit KIM".
The comparison is linked to the corresponding EUROMET comparison N° 429.
Two National Metrology Institutes take part in this comparison: LNE (France) and KIM-LIPI (Indonesia).
LNE is acting as the pilot laboratory and in this function is responsible for providing the travelling standard, the evaluation of the measurement results and the final report.
The comparison will be accomplished in accordance with the EURAMET Guidelines on Conducting Comparisons and CCEM Guidelines for Planning, Organising, Conducting and Reporting Key, Supplementary and Pilot Comparisons.

2. Participants and organization

2.1. The travelling standard is a Zener diode standard Fluke 732A.

2.2. Specifications

Nominal value of the outputs:	1 V; 1,018 V and 10 V.
Stability per month:	10 V output): ± 0,5 ppm/month.
Output impedance:	1 mΩ for 10 V output, 1 kΩ for 1,0 V and 1,018 V.
Dimensions of the case:	80 mm x 60 mm x 40 mm.
Total mass Approx.:	30 kg.

2.3. Powering the standard

If not carrying out measurements on the standards, **the standards must continue to receive uninterrupted voltage from the AC line power** (230 V, 50 Hz). Check that the front panel **AC PWR** indicator lights when the standard is connected to the AC line power.

During measurements, the standard should be operated at its internal battery, i.e., disconnected from the AC line power. If the battery voltage drops low, the front panel LOW BAT indicator starts blinking and the standard must be plugged into the AC line power immediately to allow for recharging of the battery and to avoid extinguishing the IN CAL indicator.

Front panel indicators

- **AC PWR**
  The AC PWR indicator lights whenever the standard is connected to AC line power (230 V, 50 Hz).
- **IN CAL**
  The IN CAL indicator goes out after excessive drops in battery operating voltage or gross changes in oven temperature.
  If the IN CAL indicator doesn't light, you must immediately contact the pilot laboratory, which will give specific instructions how to proceed.
- **CHARGE**
  The CHARGE indicator lights when the standard is connected to the AC line power and the internal battery is in the charging mode. When the battery is near full charge, the CHARGE indicator goes off.
- **LOW BAT**
  The LOW BAT indicator blinks when approximately 5 hours of battery operation time remains.
  When LOW BAT blinks, plug the standard into the AC line power immediately to avoid extinguishing the IN CAL indicator. The battery is recharged in less than 24 hours with the self-contained automatic battery charger.

3. Quantities to be measured

- $V_{1.018}$*: voltage at the output 1,018 V;*
- V_{10}*: voltage at the output 10 V;*
- T_{ext}: the temperature (°C) of the environment where the standard is measured.

4. Measurement instructions

Precautions

- Do not short the output voltages.
- Make sure not to disconnect the standard from the AC line power for too long a period.
- Avoid extreme temperature, humidity or pressure changes as well as violent impacts.

Stabilization of the standards

After arrival in the participant's laboratory, the standards should be allowed to stabilise in a temperature and, possibly, humidity controlled room for at least three days before use. Don't place the standards too close to each other, this to avoid heating of the standards.

Powering of the standard during the measurements

When not carrying out measurements, the standards must be connected continuously to the AC line power.
Measurements should be carried out with the standard operated at its internal battery, i.e. disconnected from the AC line power. To allow the standard for stabilization, battery-operated measurements should not start any sooner than 2 hours after disconnection of the standard from the AC line power. Restrict the disconnection to 6 hours or less.
In addition to the battery-operated measurements, measurements can be made (and submitted to the pilot laboratory) with the standards connected to the AC line power. Notice that connection to the AC line power during measurement will (probably) have consequences for the connection of guard and/or ground.

Guarding

Assuming that you carry out the voltage measurements with the standards disconnected from the AC line power, the front panel GUARD binding post should be connected to the guard of your measuring system and to the front panel CHASSIS binding post. At one point in your system the guard should be connected to ground.
If measuring while the standards are powered by the AC line power, the CHASSIS must be disconnected from the GUARD to avoid earth loops.

The measurements should be performed under the following conditions:
- Temperature of the environment: 23°C ± 2°C;
- Relative humidity: between 30 % and 70 %.

5. Reporting of results

A report should be sent to the pilot laboratory within one month after the measurements are completed. The report should include:
- Description of the measurement method;
- The reference standard;
- The traceability to the SI;
- The results of the quantities to be measured (list of section 3);
- The associated standard uncertainties, the effective degrees of freedom and the expanded uncertainties;

The environment conditions must also be reported.

6. Uncertainty of measurement

The uncertainty must be calculated following the ISO “Guide to the expression of uncertainty in measurement” (GUM) and the complete uncertainty budget must be reported.

7. Transportation

The travelling standard must be transported in the original case and protected from mechanical loads, vibration etc. for transport by plane.

The travel box contains the following items:
- Zener reference standard;
- Operating instructions of the travelling standard (this document).

8. CONTACT

Pilot Laboratory : Laboratoire national de métrologie et d'essais (LNE)
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APPENDIX B - UNCERTAINTY BUDGET

LNE uncertainty budget

The EMF of the standard under test is given by equation:

$$E_X = E_T + V_X = E_{ref} + \left(V_X - V_{ref}\right) \text{ or more exactly:}$$

$$E_X = E_T + V_X = E_{ref} + \left(V_X - V_{ref}\right) + c$$

where *c* is a correction due to errors linked with set-up.

The uncertainty u(E_X) of E_X can then be computed from relation:

$$u^2(E_X) = u^2\left(E_{ref}\right) + u^2(V_X) + u^2\left(V_{ref}\right) - 2u(V_X)u\left(V_{ref}\right)r(V_X, V_{ref}) + u^2(c)$$

where $r(V_X, V_{ref})$ is the correlation coefficient between V_X and V_{ref}. In the worst case $r(V_X, V_{ref}) = -1$ and relation above becomes:

$$u^2(E_X) = u^2\left(E_{ref}\right) + u^2(V_X) + u^2\left(V_{ref}\right) + 2u(V_X)u\left(V_{ref}\right) + u^2(c)$$

Detailed values of the uncertainty budget for both outputs are given in Tab B1 to B2.

1,018 V output						
Quantity	**Standard uncertainty**	**Probability distribution /method of evaluation (A,B)**	**Sensitivity coefficient**	**Uncertainty contribution (nV)**	**Degree of freedom**	
X_i	$u(x_i)$		c_i	$u(E_i)$	υ_i	
calibration uncertainty of zener diode standards (against Josephson eff	30 nV	norm/type B	1	30,0	inf	
drift of zener diode standards	60 nV	rect/type B	1	60,0	inf	
stability of the reference standards during a measurement cycle	12 nV	rect/type B	1	12,0	inf	
calibration uncertainty of the nanovoltmeter	6 nV	norm/type B	2	12,0	inf	
drift of the nanovoltmeter	6 nV	rect/type B	2	12,0	inf	
temperature on the nanovoltmeter	4 nV	U/type B	2	8,0	inf	
linearity on the nanovoltmeter	3 nV	rect/type B	2	6,0	inf	
resolution of the nanovoltmeter (1 nV)	0,3 nV	rect/type B	2	0,6	inf	
stray EMF	30 nV	rect/type B	2	60,0	inf	
stability of the tare during a measurement cycle	12 nV	rect/type B	1	12,0	inf	
leakage resistances	0 nV	rect/type B	1	-	inf	
common mode	0,1 nV	rect/type B	1	0,1	inf	
effect of measurement current	4 nV	rect/type B	1	4,0	inf	
effect of input current of the nanovoltmeter	0 nV	rect/type B	1	-	inf	
effect of stray AC currents	6 nV	rect/type B	1	6,0	inf	
noise of the nanovolmeter	6 nV	rect/type B	1	6,0	inf	
repeatability	70 nV	norm/type A	1	70,0	15	
	Combined standard uncertainty			117		
	Effective degrees of freedom			inf		
	Expanded uncertainty (k=2)			0,23	µV	

Tab B1 – uncertainty budget for 1,018 V output

10 V output							
Quantity	**Standard uncertainty**		**Probability distribution /method of evaluation (A,B)**	**Sensitivity coefficient**	**Uncertainty contribution (nV)**	**Degree of freedom**
X_i	$u(x_i)$			c_i	$u(E_i)$	υ_i
calibration uncertainty of zener diode standards (against Josephson eff	300	nV	norm/type B	1	300,0	inf
drift of zener diode standards	585	nV	rect/type B	1	585,0	inf
stability of the reference standards during a measurement cycle	60	nV	rect/type B	1	60,0	inf
calibration uncertainty of the nanovoltmeter	10	nV	norm/type B	2	20,0	inf
drift of the nanovoltmeter	6	nV	rect/type B	2	12,0	inf
temperature on the nanovoltmeter	6	nV	U/type B	2	12,0	inf
linearity on the nanovoltmeter	3	nV	rect/type B	2	6,0	inf
resolution of the nanovoltmeter (1 nV)	0,3	nV	rect/type B	2	0,6	inf
stray EMF	30	nV	rect/type B	2	60,0	inf
stability of the tare during a measurement cycle	60	nV	rect/type B	1	60,0	inf
leakage resistances	0	nV	rect/type B	1	-	inf
common mode	0,1	nV	rect/type B	1	0,1	inf
effect of measurement current	4	nV	rect/type B	1	4,0	inf
effect of input current of the nanovoltmeter	0	nV	rect/type B	1	-	inf
effect of stray AC currents	6	nV	rect/type B	1	6,0	inf
noise of the nanovolmeter	6	nV	rect/type B	1	6,0	inf
repeatability	200	nV	norm/type A	1	200,0	18
	Combined standard uncertainty				693	
	Effective degrees of freedom				inf	
	Expanded uncertainty (k=2)				1,4	µV

Tab B2 – uncertainty budget for 1 V output

For the purpose of this comparison, the uncertainties will be enlarged to 0,6 µV/V (k=2).

KIM-LIPI uncertainty budget

Detailed values of the uncertainty budget for both outputs are given in Tab B3 to B4.

1 V output

Uncertainty budget and BMC estimation

Artefact	Standard Cell JF-732A
Method	Comparison
Ref. Standard:	Standard Cell Group
Uncert. Equation	$u_i(x)^2 = u_1(x)^2+u_2(x)^2+u_3(x)^2+u_4(x)^2+u_5(x)^2+u_6(x)^2$

Meas point 1.018 V

Uncert Component	Unit	Distribution	Symbol	$U_{exp.}$	Cov. Factor	DoF/vi	Std. Uncert/ui	Sens. Coeff/ci	$c_i.u_i$	$(c_i.u_i)^2$	$(c_i.u_i)4/vi$	
Repeatability	µV	Normal	$u_1(X)$	0.05	4.12	16	0.01	1	0.01	0.00	0.00	
Ref. Std.	µV	Normal	$u_2(X)$	2.09	2.05	24	1.02	1	1.02	1.03	0.04	
nanoVM Std.	µV	Rect	$u_3(X)$	0.50	3.46	1E+99	0.14	1	0.14	0.02	0.00	
Scanner	µV	Rect	$u_4(X)$	0.01	2.00	60	0.01	1	0.01	0.00	0.00	
Ref. Drift	µV	Rect	$u_6(X)$	1.1	2.00	60	0.54	1	0.54	0.29	0.00	
Leak. Cable	µV	Rect	$u_7(X)$	0.05	1.73	1E+99	0.03	1	0.03	0.00	0.00	
									Sums	1.34	0.05	
									$U_{combine}$	1.16		
										ν_{eff}	39	
										$C.F_{95\% CL}$	2.02	
										$U_{95\%}$	**2.34**	µV

Tab B3 – uncertainty budget for 1,018 V output

10 V output

Uncertainty budget and BMC estimation

Artefact	Standard Cell JF-732A
Method	Comparison
Standard	Standard Cell Group JF-732B(4), JF-7001(1)
$U_{Equation}$	$u_i(x)^2 = u_1(x)^2+u_2(x)^2+u_3(x)^2+u_4(x)^2+u_5(x)^2+u_6(x)^2$

Meas. point 10 V

Uncert source	Unit	Distribution Type	Symbol	$U_{exp.}$	Cov. Factor	DoF/νi	Std. Uncert/ ui	Sens. Coeff/ ci	$c_i.u_i$	$(c_i.u_i)^2$	$(c_i.u_i)4/vi$	
Repeatability	µV	Normal	$u_1(X)$	0.08	4.1	16.0	0.01871149	1	0.02	0.00	0.00	
Ref. Std.	µV	Normal	$u_2(X)$	28.24	2	60.0	14.1199537	1	14.12	199.37	662.49	
nanoVM Std.	µV	Rect	$u_3(X)$	3.46	3.46	1E+99	1	1	1.00	1.00	0.00	
Scanner	µV	Rect	$u_4(X)$	0.01	2.00	60.0	0.007	1	0.01	0.00	0.00	
Ref. drift	µV	Rect	$u_6(X)$	20.87	2.00	6E+01	10.435	1	10.44	108.89	197.61	
Leak.Cable	µV	Rect	$u_6(X)$	0.0005	1.73	1E+99	0.00028868	1	0.00	0.00	0.00	
									Sums	309.26	8.6E+02	
									$U_{combine}$	17.59		
										ν_{eff}	111	
										$C.F_{95\% CL}$	1.98	
										$U_{95\%}$	**34.85**	µV

Tab B4 – uncertainty budget for 10 V output

APPENDIX C – Corrective actions

1. Non-conformity and first investigations

The period of implementation of the ILC was from April 2014 to November 2014, while the KIM-LIPI Lab took measurements in August 2014.

The ILC report of December 2014 stated that a large deviation of results of KIM-LIPI from the comparison reference value, exceeding 75 times the expanded uncertainty at 1,018 V and 12 times the expanded uncertainty at 10 V, is observed.

For the purpose, the reference standard dc voltage value of KIM-LIPI was traceable to F. 7000 (SN 941254641) which was last calibrated on February 23, 2011. Correction of the deviation of the calibration value was applied by estimating drift. This corrected reference value was passed down to a group of 5 individual dc voltage standards and next the value of this group was derived to calibrate ILC artefacts (Fig C1). The process of transferring the value of the dc voltage standard that was used as a reference to a group was done with the power supply disconnected to the power line grid while the disseminating of the value of a group to the ILC artefact was carried out with the power supply connected to the power line grid.

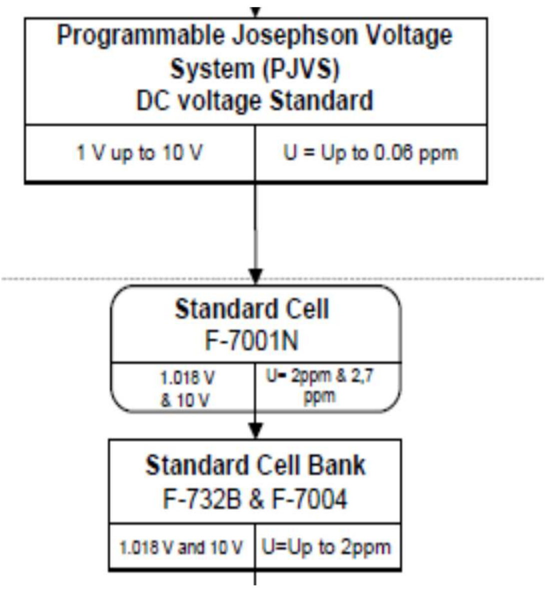


Fig C1 - DC voltage traceability chart

2. Identification of potential causes

Potential causes are identified:

a) The standard dc voltage that was referred to had a calibrated value by Josephson Voltage Standard of NMIJ as of May 24th, 2007. And the next calibrated value was by the KIM-LIPI Programmable Josephson Voltage System (PJVS), each as of: February 1st of 2010, May 21st of 2010, June 1st of 2010, and February 23rd of 2011. Calibrated values by PJVS KIM-LIPI considered that would have been too long if used in August 2014. Although corrections were made based on the estimation of the drift but the values might be not valid.
b) The process of transferring the value of a standard dc voltage that was used as a reference to a group was carried out with the power supply independent of the power line grid while the disseminating of the value of the group to the ILC artefact was carried out with the power supply connected to the grid. It is feared that there was a ground loop that causes systematic errors in measurement.

c) The supervisor of Electrical Metrology Laboratory of KIM-LIPI was concerned about the influence of an internal battery. The internal battery of the dc voltage reference standard might be weak and should be replaced after a lifetime. The battery might distort the value of the dc voltage reference standard.

d) This might be an error in using mathematical formula in evaluating two different stages of the standard dc voltage that was used as a reference to a group, and from a group to ILC artefacts.

3. Actions

Some actions were planned to overcome the non-conformity:

a) Calibrate the standard dc voltage that is the reference, namely F.7000 (SN: 941254641) to another NMI or to BIPM.

b) Calculate the effect of the ground loop by comparing the measurement results when the power supply is connected to the grid and when the power supply is separated from the grid.

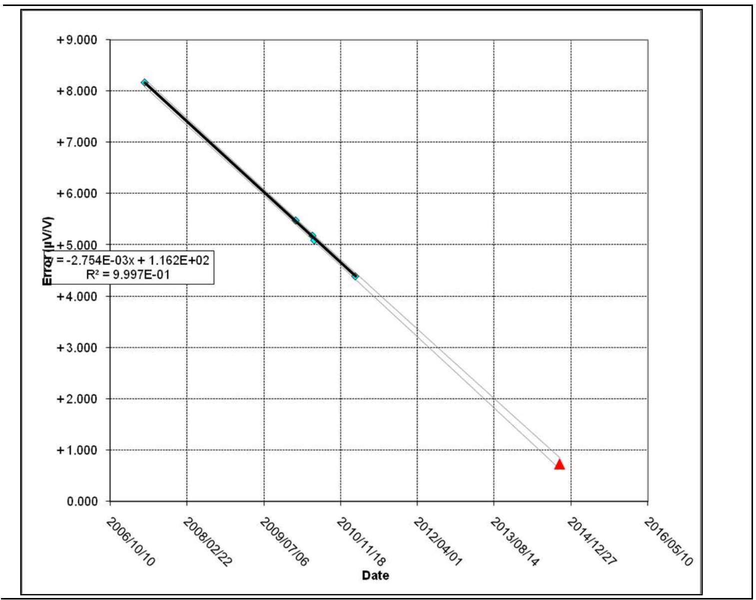
c) Observe the duration of a cycle of the measurement for both 1,018 V and 10 V respectively and compare it to the cycle of recharging the internal battery. The aim is to check whether the duration of measurment cycle is less than to the duration of recharging cycle, to make sure the zener diode inside the dc voltage reference standard keep maintained in hot codition.

d) Check the calculation of the calibration values for the two different stages as mentioned earlier.

4. Implementation and results of the action plan

a) Calibration of the reference dc voltage standard, F.7000 (SN: 941254641) to BIPM France was performed on September 14th of 2015. The calibration results for both of 1,018 V and 10 V are respectively (1,017 999 678 ± 0,000 000 010) V and (9,999 894 46 ± 0,000 000 10) V. Meanwhile these values are compared to the expected values obtained taken into account the drift effect estimated by linear regression from previous calibration values obtained by KIM-LIPI between May 2007 and February 2011. The expected results for both of 1.018 V and 10 V are respectively (1,017 999 8 ± 0,000 002 2) V and (9,999 890 ± 0,000 035) V.

Date	Output voltage (V)
24.05.2007	1,018 008 314
01.02.2010	1,018 005 579
21.05.2010	1,018 005 276
01.06.2010	1,018 005 185
23.02.2011	1,018 004 470



Date	Output voltage (V)
24.05.2007	9,999 979 265
01.02.2010	9,999 950 124
21.05.2010	9,999 946 895
01.06.2010	9,999 946 596
23.02.2011	9,999 939 520

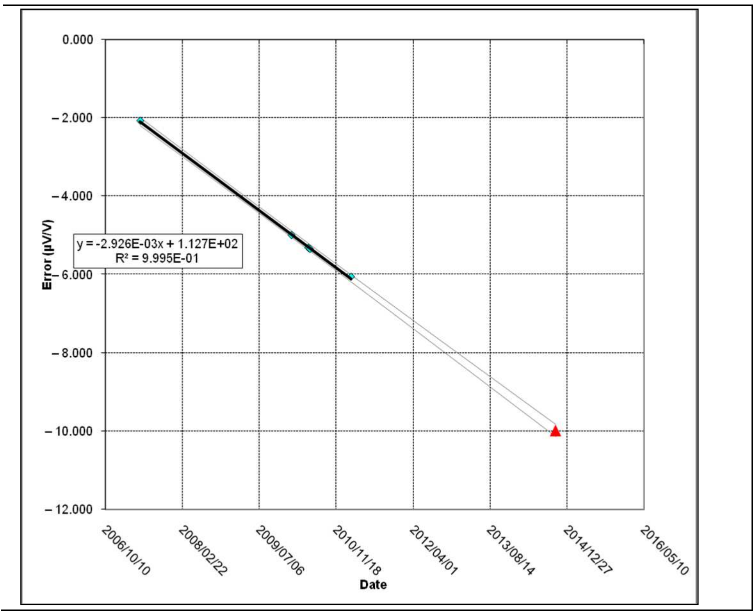


Fig C2 – Time dependence of Reference standard (F7000)

The values are in agreement within the combined uncertainty. This result shows the PJVS KIM-LIPI can be valid to disseminate both of reference values of 1,018 V and 10 V and also the corrections of the drift estimated by linear regression.

b) The results of measurements are compared when the power was connected to the power line and when the power was released from the power line. A minor contribution is noticed when compared to each of the combined uncertainties obtained, namely 0,077 µV for 1,018 V and 0,93 µV for 10 V dc voltages.

c) The duration of the measurement process using the internal battery has been observed. The measurement process required at most 2 hours to finish the opposition method among the group of dc voltage standard and the ILC artefact. Meanwhile the internal battery was not drain out for 6 hours until the indicator of LOW CHARGE litting red. This ensures the zener diode was maintained at hot condition.

d) The first stage was arranged such both the reference dc voltage standard of F7000 (SN: 941254641) used to transfer the reference value and the group of dc voltage standards, which consisted of Fluke 732B-S/N: 8440012, Fluke 732B-S/N : 8440013, Fluke 732B-S/N : 8440014, Fluke 732B-S/N : 8440015 and Fluke 7001N-S/N : 941254611, connected as described in Figure C3.

The group value was evaluated using the relation (1):

$$T_G = T_{REF} + \frac{1}{5}\sum_{i}^{5}\left(\overline{RVS - FWD}\right)_i \qquad (1)$$

where :

T_G	:	The assigned group value transferred from the reference dc voltage standard
T_{REF}	:	The reference dc voltage standard value estimated from the linear drift estimation respective to each date.
FWD	:	The DVM reading for the forward opposition method (back-to-back method)
RVS	:	The DVM reading for the reverse opposition method (back-to-back method)

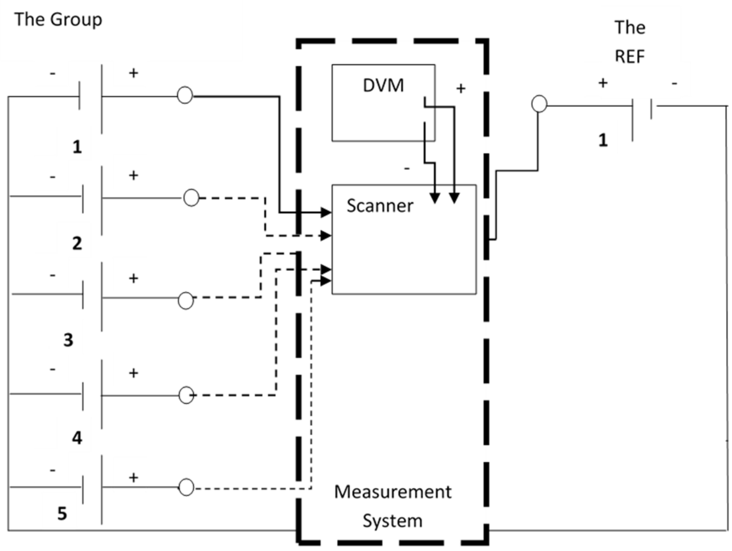


Fig C3 - The diagram of the opposition method -First stage

The second stage was arranged such both the artefact of ILC of F-732A (SN: 5240001) worked as UUT and the group of dc voltage standards were connected as described in Figure C4.

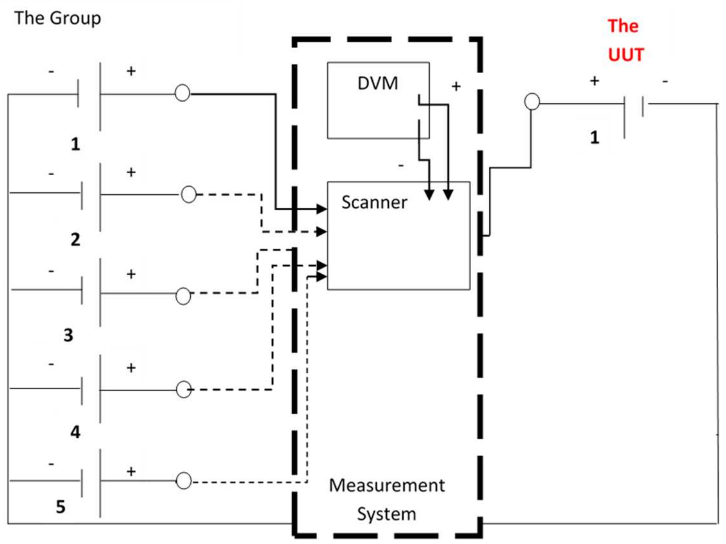


Fig C4 - The diagram of the opposition method - Second stage

The UUT value was evaluated using the relation (2) :

$$T_{UUT} = T_G + \frac{1}{5}\sum_{i}^{5}\left(\overline{FWD - RVS}\right)_i \qquad (2)$$

where :

T_{UUT}	:	The unknown value calibrated against the assigned group value
T_G	:	The assigned group value transferred from the reference dc voltage standard
FWD	:	The DVM reading for the forward opposition method (back-to-back method)
RVS	:	The DVM reading for the reverse opposition method (back-to-back method)

Both of two stages were done 17 times every working day from August 5th of 2014 to August 29th of 2014. The reported values would be the average of the 17 measuring values.

Instead using relation (2), the value of the device to be calibrated was calculated with the relation (3):

$$T_{UUT} = T_G + \frac{1}{5}\sum_{i}^{5}\left(\overline{RVS - FWD}\right)_i \qquad (3)$$

This relation (3) is found to be wrong since the position of the UUT was putted on the right hand of the figure replacing the position of the REF at the first stage without any more arrangements, neither to the middle nor to the left hand of the figure.

The recalculation of the measurement results of the ILC travelling standard, F-732A (SN: 5240001), using correct mathematical equations provides (1,018 005 9 ± 0,000 002 3) V and (10,000 184 ± 0,000 035) V respectively for both nominal values of 1,018 V and 10 V.
This result is proposed by KIM-LIPI to make a corrective action to the non-conformity values on the report of EURAMET.EM-S41.

5. Evaluation of corrected results

Considering that the following results should be reported by KIM-LIPI:

(1,018 005 9 ± 0,000 002 3) V for 1,018 V output,
(10,000 184 ± 0,000 035) V for 10 V output,

then, the degrees of equivalence (DoE) between LNE and KIM-LIPI should be (Tab C1):

Voltage	1,018 V	10 V
D	-0,5	-2,3
U [D]	2,4	36,0

Tab C1: Degrees of equivalence between KIM-LIPI and LNE associated to the expanded uncertainties (k = 2) in absolute value expressed in µV.

For 10 V output, the reported DoE of LNE with respect to the EUROMET.EM.BIPM-K11 is as follows [1] [2]:

$$d_{LNE} = 0{,}35\ \mu V, \quad U(d_{LNE}) = 0{,}59\ \mu V \quad (k=2)$$

The DoE of KIM-LIPI with respect to the BIPM KCRV is given by the following equation:

$$d_{KIM\text{-}LIPI} = D + d_{LNE}$$

The uncertainty is given by:

$$u^2(d_{KIM\text{-}LIPI}) = u^2(D) + u^2(d_{LNE}) + u^2(d_s)$$

where $u(d_s)$ is an additional uncertainty component associated to an eventual drift of the LNE standard in the time interval between the CCEM and the KIM-LIPI comparison. This component has been considered as negligible.

Therefore the $d_{KIM\text{-}LIPI}$ value and the expanded uncertainty (k = 2) are as follows:

$$d_{KIM\text{-}LIPI} = -1{,}9\ \mu V \qquad U_{(dKIM\text{-}LIPI)} = 36\ \mu V$$

As conclusion, the degree of equivalence of KIM-LIPI with KCRV for 10 V could be established with the proposed corrective actions and then it is consistent with the associated uncertainty.

References
[1] *F. Liefrink and al., Final Report, EUROMET project no. 429 also designated EUROMET.EM.BIPM-K11 - Key Comparison of 10 V Electronic Voltage Standards*

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