Bundesamt
für Eich- und
Vermessungswesen

Final Report

Bilateral key comparison EURAMET.EM-K11.1

AC-DC Voltage Transfer Difference at Low Voltages

Jeannine Renner, Gernot Heine and Wolfgang Waldmann
BEV
Federal Office of Metrology and Surveying
Arltgasse 35, 1160 Vienna, AUSTRIA
E-mail: wolfgang.waldmann@bev.gv.at

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Content

1. Scope/Introduction

The Mutual Recognition Arrangement (MRA) state, that the metrological equivalence of national measurement standards will be determined by a set of key comparisons chosen and organized by the Consultative Committees of the CIPM working closely together with the Regional Metrology Organizations (RMO).

A regional key comparison EUROMET.EM-K11 "ac-dc voltage transfer difference at low voltages" has been conducted between National Metrology Institutes (NMI) and was finished in 2011.

During the last years the Bulgarian Institute of Metrology (BIM) extended the measurement capability for ac-dc voltage in the mV-range.

This comparison is initiated to provide confidence into the new established mV-range of BIM. The results will be linked to those of EUROMET.EM-K11 and CCEM-K11, respectively.

2. Participants and organisation

The comparison was organised in accordance with the "EURAMET Guide on Comparisons 05/2016". Bundesamt für Eich- und Vermessungswesen (BEV) in Austria has been the pilot laboratory and BIM Bulgaria has been participant.
The technical protocol of the comparison was agreed between the participants and agrees to a large extent with the technical protocol of the EUROMET.EM-K11.

BEV participated in EUROMET.EM-K11 and will be the linking laboratory.

The travelling standard was provided and characterized by the pilot laboratory. It was measured a few times at BEV before sending it to BIM and finally measured after return to BEV.

Because of the Covid19-measures it was not possible to follow the initially agreed time schedule. The actual measurement sequence is stated in table 1.

Laboratory	Measurement date
BEV	May 2020
BIM	June/July 2020
BEV	July 2020

Table 1

3. Definition of the ac-dc voltage transfer difference

The ac-dc voltage transfer difference δ of a transfer standard is defined as:

$$d = \frac{V_{ac} - V_{dc}}{V_{dc}} \qquad (1)$$

where Vac is the rms value of the ac input voltage and Vdc is the dc input voltage which, when reversed, produces the same mean output voltage of the transfer standard as Vac.

Differences are expressed in microvolt per volt (µV/V) and a positive sign signifies that more ac than dc voltage is required for the same output response.

4. The Travelling Standard

The travelling standard is a Fluke 792A thermal transfer standard, serial number 892 8001, which has amplified low voltage ranges 700 mV, 220 mV and 22 mV. At the rated input voltage the output voltage is approximately 2 V. The input connector of the standard is a type N female (The stainless steel connector saver should always be connected to the input of the Fluke 792A). The output connectors are 4 mm binding posts, female. A battery pack with connecting cable is included, as the travelling standard has to be operated on battery during measurement.

The temperature coefficients of the travelling standard are given below in table 2. The effect of temperature variations during the measurements was included as uncertainty contribution.

The ac-dc voltage transfer difference of the travelling standard may have a dependence on the power supply voltage. Hence the voltage of the battery pack should be measured a few times during the comparison, before starting and after ending the measurement. The uncertainty due to the battery pack voltage is estimated to be insignificant compared to other contributions if the battery pack included in the travelling standard is used only. It was not necessary to add a corresponding uncertainty contribution in the evaluation of the results.

In the EUROMET.EM-K11 comparison it has also been found that the ac-dc voltage transfer difference of the travelling standard has a dependence of the relative humidity. But also here the uncertainty is estimated to be insignificant compared to other contributions if the measurements are made at the recommended ambient conditions. It was not necessary to add a corresponding uncertainty contribution in the evaluation of the results. Note that the equivalent input resistance of a Fluke 792A is frequency dependent.

The temperature coefficients of the output voltage of the travelling standard with their expanded uncertainties are estimated in the table below. The estimation follows the temperature coefficients as measured by SP in the EUROMET.EM-K11 comparison. Due to Covid19 shutdown at BEV it was not possible to measure it in April 2020 as originally planned. The temperature coefficients were measured at BEV in August 2020 after return of the travelling standard. The final results of BIM were estimated under consideration of these temperature coefficients.

Voltage	Frequency	Temperature coefficient / $10^{-6}\cdot K^{-1}$	Expanded uncertainty / $10^{-6}\cdot K^{-1}$
100 mV	1 kHz	-0,4	1,1
	20 kHz	-0,6	1,2
	100 kHz	-0,6	1,2
10 mV	1 kHz	-0,4	2,1
	20 kHz	-1,8	2,7
	100 kHz	-1,5	2,5
2 mV	1 kHz	0,2	5,1
	20 kHz	-0,9	5,1
	100 kHz	-2,0	5,4

Table 2

The correction $\Delta\delta_T$ of the ac-dc transfer difference due to temperature dependence of travelling standard is:

$$\Delta\delta_T = \alpha_T \Delta T \qquad (2)$$

where

α_T is the temperature coefficient, values and uncertainties given in the table above.
ΔT is the correction for deviation of the temperature from the reference value 23 °C during the measurement (ΔT = 23 °C - *temperature during measurement)*

5. Measurements of the pilot laboratory and influence parameters

Before and after the course of the comparison the stability of the travelling standard has been monitored by the pilot laboratory. The stability of the travelling standard was found to be very good with a maximum yearly drift of < 1 µV/V at 100 kHz.

The temperature coefficient of the travelling standard was characterized at BEV after the measurements at BIM and submitted to the participant.

The participant was asked to report minimum and maximum power supply voltages during it's measuring period. The power supply voltages were found to be equal to these measured at BEV within 20 mV. This small difference was estimated to be insignificant and no correction was applied.

6. Measuring scheme

The ac-dc voltage transfer difference of the travelling standard was to be measured at the voltages 100 mV and 10 mV and at the frequencies 1 kHz, 20 kHz and 100 kHz. These are the same measuring points as in the key comparisons EUROMET.EM-K11 and CCEM-K11.

Additionally the ac-dc voltage transfer difference of the travelling standard was to be measured at the voltage of 2 mV and at the frequencies 1 kHz, 20 kHz and 100 kHz.

7. Measurement results

The results of the NMIs were reported for each measuring point as measured ac-dc transfer difference δ_i and expanded uncertainty U_i. The expanded uncertainty is obtained as the standard uncertainty of the measurand multiplied by a coverage factor k_i.

a. Drift of the travelling standard

Because of the stability of the travelling standard as seen in the measurements at BEV before and after the measurements at BIM drift effects were not taken into account.

b. Reference Value

The reference value of a measurement series is calculated from the result of the measurement and the deduction of the corrections from the PMJTC and the resistive dividers. The reference value is the mean value of the measurements at BEV before and after the measurements at BIM.

8. Report of the Comparison

a. BEV Report

See Appendix 4.

b. BIM Report

See Appendix 5.

9. Tables and graphs of reported results

a. BEV results

	d_{BEV} [µV/V]			$U(d_{BEV})$ [µV/V]		
	1 kHz	20 kHz	100 kHz	1 kHz	20 kHz	100 kHz
100 mV	11	3	34	13	13	17
10 mV	9	48	58	28	29	35
2 mV	31	58	62	61	61	68

Table 3

b. BIM results

	d_{BIM} [µV/V]			$U(d_{BIM})$ [µV/V]		
	1 kHz	20 kHz	100 kHz	1 kHz	20 kHz	100 kHz
100 mV	11	2	26	20	20	25
10 mV	10	46	51	44	49	53
2 mV	33	40	57	85	96	104

Table 4

c. Summary

A graphical representation of the results of BEV and BIM is shown in figure 1 to 3. The results show excellent agreement within the stated uncertainties.

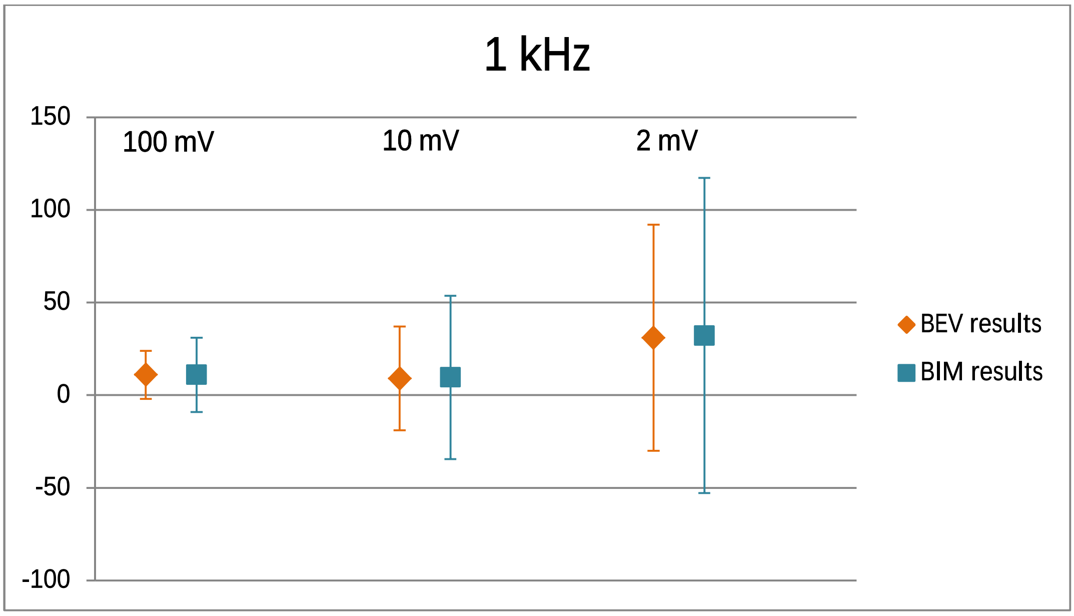


Figure 1: Results in [µV/V]

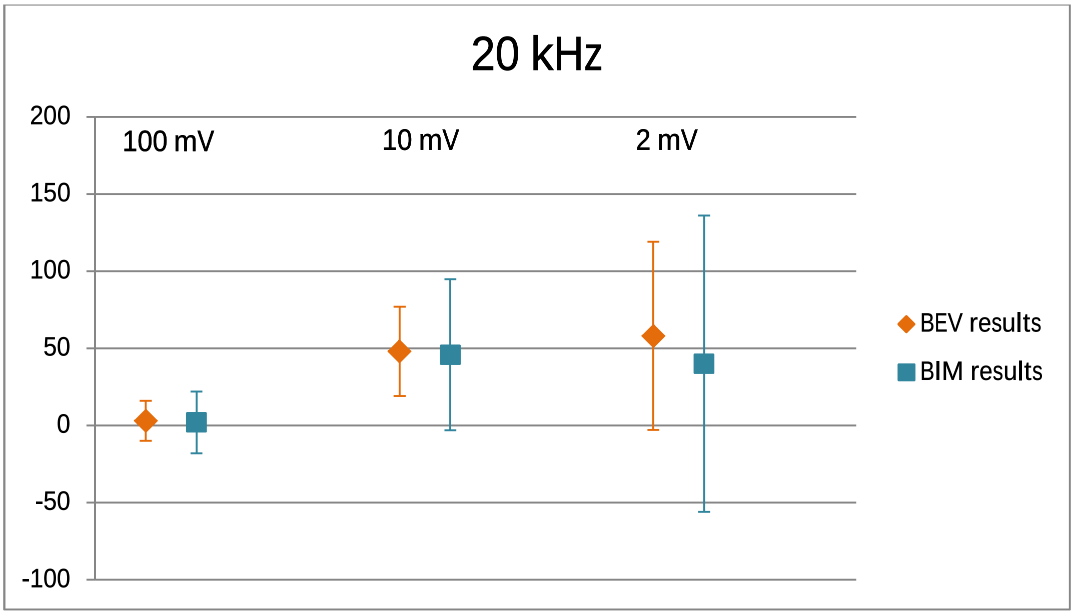


Figure 2: Results in [µV/V]

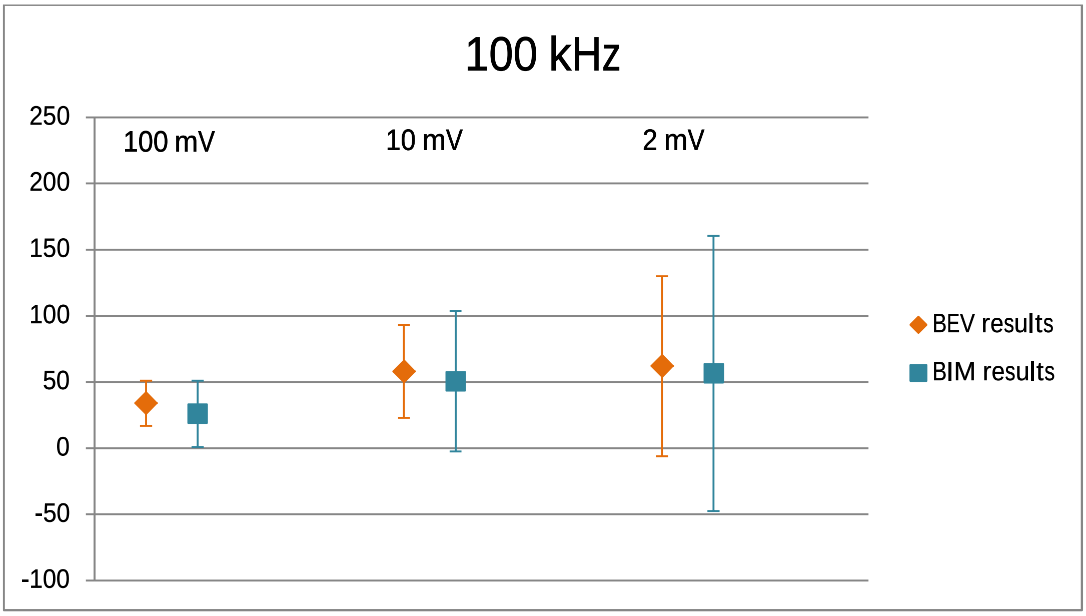


Figure 3: Results in [µV/V]

d. Degree of equivalence

See Appendix 2.

e. Linking to CCEM-K11

See Appendix 3.

f. Preparation of the final draft of the report

After the completion of draft B of the report some comments were provided by INMETRO on behalf of the CCEM-WGLF. These comments refer mainly to the representation of the decimal places and were considered in the final version of the report for the 10 mV results. For the 100 mV results the representation of "Final report of key comparison EUROMET.EM-K11 ac-dc voltage transfer difference at low voltages" was adopted for consistency reasons.

10. Circulation of the Travelling Standards

The travelling standard was measured at BEV first in March 2020 but because of the Covid19 shutdown it was measured once again in May 2020. After that it was transported to BIM in the end of May 2020. After the measurements in BIM within 1 month it was transported back to BEV and measured again in the end of July 2020 to check for eventual drift or changes during transport. Between the measurements there was one week for transportation.

11. Organisation

The pilot laboratory and coordinator for the comparison was the Federal Office of Metrology and Surveying, Austria (BEV). The travelling standard was supplied from BEV.

Each participating laboratory did cover the costs of the measurement, transportation and customs clearance. No damage occurred to the travelling standard during the comparison.
The coordinating laboratory had covered the overall costs for the organisation of the comparison.

12. Participants

BEV (pilot laboratory):

Wolfgang Waldmann
Federal Office of Metrology and Surveying
BEV
Arltgasse 35
1160 Vienna
AUSTRIA

phone: (+43) 1 21110 826350
email: wolfgang.waldmann@bev.gv.at

BIM (participating laboratory):

Radoslava Hadzhistoykova
BIM
Bulgarian Institute of Metrology
52-B, G.M.Dimitrov Blvd.,
1040 Sofia,
BULGARIA

phone: +359 878289091
fax: +359 2 9702735
email: r.hadzhistoykova@bim.government.bg

Appendix 1. Packing list

Key comparison EURAMET.EM-K11.1 “ac-dc voltage transfer difference at low voltages”

1 pc. Fluke 792A AC-DC transfer standard, S/N 892 8001.
1 pc. Fluke 792A Power pack, S/N 892 8001.
1 pc. Power pack cable.
1 pc. Power pack testing box.
1 pc. Stainless steel type N extender (should always be connected to the Fluke 792A AC-DC transfer standard).
1 pc. Shorting bar (connected to the Fluke 792A AC-DC transfer standard).
1 pc. Protective cap type N (should always be connected during transport to the Fluke 792A AC-DC transfer standard).
1 pc. Technical protocol for the key comparison EURAMET.EM-K11.1

Owner of equipment:

Federal Office of Metrology and Surveying
BEV
Arltgasse 35
1160 Vienna
AUSTRIA

Phone: (+43) 1 21110 826350
Email: wolfgang.waldmann@bev.gv.at

Appendix 2: Degree of equivalence with the reference value

The degree of equivalence *DoE* of the BIM results with the BEV reference value is calculated by

$$\boldsymbol{DoE} = \boldsymbol{\delta_{BIM}} - \boldsymbol{\delta_{BEV}} \tag{3}$$

with a standard uncertainty of

$$\boldsymbol{u}(\boldsymbol{DoE}) = \sqrt{\boldsymbol{u}^2(\boldsymbol{\delta_{BIM}}) + \boldsymbol{u}^2(\boldsymbol{\delta_{BEV}})} \tag{4}$$

and an expanded uncertainty calculated by

$$\boldsymbol{U}(\boldsymbol{DoE}) = \boldsymbol{k} \times \boldsymbol{u}(\boldsymbol{DoE}) \tag{5}$$

where a coverage factor k = 2 is used which corresponds to a coverage probability of approximately 95 % for a normal distribution.

The results are shown in table 5.

	DoE of BIM with BEV [µV/V]			*U*(*DoE*) of BIM with BEV [µV/V]		
	1 kHz	20 kHz	100 kHz	1 kHz	20 kHz	100 kHz
100 mV	0,0	-1,0	-8,0	23,9	23,9	30,2
10 mV	1	-2	-7	53	57	64
2 mV	1	-18	-5	105	114	125

Table 5

Appendix 3: Link to CCEM-K11 comparison

For the BIM measurements at 100 mV and 10 mV and frequencies of 1 kHz, 20 kHz and 100 kHz a link is given to the comparison CCEM-K11. BEV took part in the EUROMET.EM-K11 comparison which is linked to the CCEM-K11 comparison and therefore BEV degrees of equivalence *DoE* and the corresponding uncertainties were used for the calculation of the link.

In the “Final report of key comparison EUROMET.EM-K11 ac-dc voltage transfer difference at low voltages” the final results are presented as the differences of the ac-dc differences of the participating NMI and the key comparison reference value KCRV. The *DoE* and the associated uncertainties for BEV with respect to CCEM-K11 are shown in table 6.

	DoE with KCRV from CCEM-K11 for BEV [µV/V]			*U*(*DoE*) for BEV [µV/V]		
	1 kHz	20 kHz	100 kHz	1 kHz	20 kHz	100 kHz
100 mV	2,4	0,4	-2,6	12,7	14,1	18,9
10 mV	6	0	-3	38	38	46

Table 6

The corrections D between the key comparison reference value KCRV of CCEM-K11 and the EUROMET.EM-K11 comparison reference value are calculated in the report “Final report of key comparison EUROMET.EM-K11 ac-dc voltage transfer difference at low voltages” and stated in table 7. These corrections D can be used to calculate the *DoE* with respect to EUROMET.EM-K11.

	D between KCRV from CCEM-K11 and CRV from EUROMET.EM-K11 [µV/V]			$U(D)$ [µV/V]		
	1 kHz	20 kHz	100 kHz	1 kHz	20 kHz	100 kHz
100 mV	-0,7	-2,1	-6,6	1,7	2,4	3,6
10 mV	-5	-4	-10	10	10	13

Table 7

These differences and the corresponding uncertainties were used now for the evaluation of the DoE according to formula (7) and the associated uncertainties according to formula (8) of BIM with respect to the CCEM-K11 comparison (Table 8).

$$\boldsymbol{DoE_{BIM,\,CCEM}} = \boldsymbol{DoE_{BIM-BEV}} + \boldsymbol{DoE_{BEV,\,CCEM}} \tag{7}$$

$$\boldsymbol{u\left(DoE_{BIM,CCEM}\right)} = \sqrt{\boldsymbol{u^2(DoE_{BIM-BEV}) + u^2\left(DoE_{BEV,\,CCEM}\right)}} \tag{8}$$

	DoE of BIM with CCEM-K11 [µV/V]			*U*(*DoE*) of BIM with CCEM-K11 [µV/V]		
	1 kHz	20 kHz	100 kHz	1 kHz	20 kHz	100 kHz
100 mV	2,4	-0,6	-10,6	27,0	27,7	35,7
10 mV	7	-2	-10	66	69	79

Table 8

As in CCEM-K11 and in EUROMET.EM-K11 the 2 mV voltage was not included, the link was calculated for the 100 mV and the 10 mV voltages only. Nevertheless, the measurement results at 2 mV show also excellent agreement within the stated uncertainties.

Appendix 4: Report of BEV

EURAMET.EM-K11.1

AC-DC Voltage Transfer Difference at Low Voltages

BEV – Report

Institute: BEV
Federal Office of Metrology and Surveying
Arltgasse 35
A-1160 Vienna
AUSTRIA

By: Martin Garcocz, Jeannine Renner

Date: 20. September 2020

Measurements performed in August 2020

Table of content

Definition of the measurand

The ac-dc voltage transfer difference is defined as

$$d = \frac{V_{ac} - V_{dc}}{V_{dc}}$$

where V_{ac} is an rms ac voltage, and V_{dc} is a dc voltage which, when reversed, produces the same mean output response as the rms ac voltage.
Differences are expressed in microvolts per volts (μV/V) and a positive sign signifies that more ac than dc voltage was required for the same output response.

Travelling standard

The travelling standard is a Fluke 792A thermal transfer standard with an accompanied power pack. The serial number for both units is 892 8001.

BEV standards

Traceability: For AC-DC voltage transfer difference at the level of 1 volt BEV is directly traceable to PTB, Germany.
For higher and lower voltage levels BEV performs its own step-up and step-down procedures.

100 mV:
A Planar Multijunction Thermal Converter (PMJTC) ("PTC15", 90 Ohms, manufactured at IPHT, Jena, Germany) has directly been used to determine the ac-dc voltage transfer difference of the travelling standard at 100 mV.

10 mV:
A PMJTC ("PTC15") and a Resistive Voltage Divider ("RDD5", ratio 10:1, manufactured at BEV) have been used to determine the ac-dc voltage transfer difference of the travelling standard at 10 mV.

2 mV:
A PMJTC ("PTC15") and a Resistive Voltage Divider ("B200", ratio 200:1, manufactured at BEV) have been used to determine the ac-dc voltage transfer difference of the travelling standard at 2 mV.

Measurement setup

A type "N" Tee connector has been used to connect the travelling standard with the standards of BEV. It has type "N-male" connectors on all sides and was directly connected with the central measurement earth via a short cable.
The nanovoltmeters were separated from ground- connections of power supply and GPIB-connectors and grounded via the shieldings of their input - cables.
The Ground and Guard terminals of the F 792A were connected to measurement earth, the stainless steel input- connector remained always at the input and only the travelling power pack was used with the power line disconnected during the measurements.

At 100 mV and 10 mV a resistor in series with the input to the Tee connector was put in to achieve a voltage level of approx. 1.5 volts for the calibrators.

Instruments used:

Calibrators:	Fluke 5700 S.N. 6280303
	Datron 4808 S.N. 42982
Nanovoltmeters:	Keithley 2182 for PMJTC and F 792A
Resistive Divider:	“RDD 5” Resistive Voltage Divider Ratio 10:1
	“B200” Resistive Voltage Divider Ratio 200:1
GPIB-isolators:	National Instruments 140A

Transferswitch: BEV < 5ms, 1000 V, AC/DC and polarity switch
Software: BEV, C#

<u>Ambient conditions:</u>
Room temperature: 23°C ± 0.5°C
Relative Humidity: 50 % ± 10 %

Measurement procedure

The measurements have been performed automatically, controlled by a PC with a home-made software. All relevant parameters, including the sensitivity of the converter, where put into the starting sheet before the measurements.

As a preparation for the ac-dc measurements the input impedance of the travelling standard was measured and corrections for the used resistive voltage dividers calculated.
Warm-up time: more than 30 min with nominal voltage.
Fitting of the ac voltage to the mean of dc voltage of both polarities for equal output response of the TC (better than 20 µV/V).

The measurement sequence was AC1 - DC plus - DC minus - AC2. A minimum of 40 independent evaluations of the transfer difference for each compared voltage / frequency point has been performed.

After completing the measurements the software calculates mean value and standard- deviation. All single readings are stored in a text file for later corrections, if necessary.

Measurement results

The ac-dc voltage transfer difference for the travelling standard in µV/V is:

	1 kHz	20 kHz	100 kHz
100 mV	+ 11	3	34
10 mV	+ 9	+ 48	+ 58
2 mV	+ 31	+ 58	+ 62

Measurement uncertainty

The expanded measurement uncertainty in µV/V is:

	1 kHz	20 kHz	100 kHz
100 mV	13	13	17
10 mV	28	29	35
2 mV	61	61	68

Uncertainty budget for the comparison at 100 mV in µV/V:

calibration F792 100mV	PMJTC 15 norm ∞	std-dev norm 40	dc-eff. norm ∞	setup norm ∞	tee norm ∞	repeat norm ∞	temp. norm ∞	humidity norm ∞	sum k = 1 norm
1 kHz	1.7	4.1	2	3.3	0.2	1.5	1.1	0.2	6.2
20 kHz	2.5	4.1	2	3.3	0.2	1.5	1.2	0.5	6.5
100 kHZ	3	4.1	2	5.6	1	2.2	1.2	1.5	8.4

Uncertainty budget for the comparison at 10 mV in µV/V:

calibration F792 10mV	PMJTC 15 norm ∞	RDD5	loading correction	std-dev norm 40	dc-eff. norm ∞	setup norm ∞	tee norm ∞	repeat norm ∞	temp. norm ∞	humidity norm ∞	sum k = 1 norm
1 kHz	1.7	8.7	0.2	7	2	6.5	1.5	2	2.1	1.0	13.6
20 kHz	2.5	9.1	0.3	7	2	6.5	1.5	2	2.7	1.0	14.1
100 kHZ	3	11.9	0.8	7	2	8.0	4	2.5	2.5	3.0	17.5

Uncertainty budget for the comparison at 2 mV in µV/V:

calibration F792 2mV	PMJTC 15 norm ∞	B200	loading correction	std-dev norm 40	dc-eff. norm ∞	setup norm ∞	tee norm ∞	repeat norm ∞	temp. norm ∞	humidity norm ∞	sum k = 1 norm
1 kHz	1.7	15.5	0.2	22	2	6.5	1.5	10	5.1	2.0	30.1
20 kHz	2.5	16.2	0.2	22	2	6.5	1.5	10	5.1	2.0	30.5
100 kHZ	3	20.4	0.6	22	2	8.0	4	10	5.4	5.0	33.9

Temperature / Humidity - Corrections

The measured values for the temperature coefficient and the estimated values for the humidity coefficient in the frequency range 1 kHz to 100 kHz were small (< 10% of the overall uncertainty) compared to other uncertainty contributions. No correction to the ac-dc values was applied but an additional uncertainty contribution added.

Other Influence Parameters

Frequency: The frequency of the output voltage of both used calibrators was measured with and without load (standard: HP 53131 S.N.3736A24005). The deviations from the nominal frequencies were smaller than 10^{-5} and negligible for the uncertainty budget.
Power Pack: The voltage of the power pack of the travelling standard has been measured in both polarities during the comparison using the provided dummy-load.

positive Voltage:	Max: + 11.091 V	Min: + 11.082 V
negative Voltage:	Max: - 11.087 V	Min: - 11.077 V

Step-down Procedure

Before measuring the ac-dc transfer differences the divider's in- and output impedance and the input impedance of the Fluke 792A (BEV) as well as the input impedance of the travelling standard have been evaluated using a LCR bridge (Agilent 4284, S.N. 2940J11720). The corrections for loading the dividers with the used F 792A were calculated.
Then a step-down- procedure was performed by calibrating the resistive dividers "RDD5" and “B200” with the ratios 10:1 and 200:1. This has been done in the following way:

1) The BEV Fluke 792A (S.N.: 8928001); designated as “F792”, was calibrated at the level of 150 mV directly against a PMJTC ("PTC 15", 90 ohms).

δF792(150mV) = δPTC3 - δ(PTC3-F792)

Uncertainty budget for Step 1: calibration of F 792A (BEV) with PTC15 at 150 mV:

frequency	PMJTC 15 norm ∞	std-dev norm 40	dc-eff. norm ∞	Setup Norm ∞	tee norm ∞	repeat norm ∞	temp. norm ∞	humidity norm ∞	sum k = 1 norm
1 kHz	1.7	4.1	2	3.3	0.2	1.5	1.1	0.2	6.2
20 kHz	2.5	4.1	2	3.3	0.2	1.5	1.2	0.5	6.5
100 kHZ	3	4.1	2	5.6	1	2.2	1.2	1.5	8.4

2) The resistive divider “RDD 5” was connected to the input of the F792A and a PMJTC with nominal 1.5 volts ("PTC 48", 190 ohms) was used to evaluate the ac-dc transfer difference of the divider. Corrections for the used PMJTC, the 792A at 150 mV and the loading effect due to the input impedance of the 792A in parallel to the output of the divider have been applied.

δRDD5 = δF792 (150mV) - δ(PTC48) + δ(PTC48 - (F792+RDD5)) - load-corr.(F792)

Uncertainty budget for Step 2: calibration of RDD5 with 792A (BEV) and PTC48:

calibration RDD 5	PMJTC 15 norm ∞	792 at 150 mV	loading correction	std-dev norm 40	dc-eff. norm ∞	setup norm ∞	tee norm ∞	repeat norm ∞	temp. norm ∞	humidity norm ∞	sum k = 1 norm
1 kHz	1.7	6.2	0.2	4.1	2	3.3	0.2	1.5	1.1	0.2	8.7
20 kHz	2.5	6.5	0.3	4.1	2	3.3	0.2	1.5	1.2	0.5	9.1
100 kHZ	3	8.4	0.8	4.1	2	5.6	1	2.2	1.2	1.5	11.9

3) This evaluated ac-dc- transfer difference for the RDD5 was used to calibrate the travelling standard at the level of 10 mV by using the PTC15 at the level of 100 mV and the RDD5 connected to the input of the travelling standard.

δF792 (10mV) = δPTC15 - δ(PTC15-(F792+RDD5)) + δRDD5 + load-corr.(F792)

Uncertainty budget for Step 3: calibration of F 792A with PTC14 + RDD5 at a level of 10 mV:

calibration F792 10mV	PMJTC 15 norm ∞	RDD5	loading correction	std-dev norm 40	dc-eff. norm ∞	setup norm ∞	tee norm ∞	repeat norm ∞	temp. norm ∞	humidity norm ∞	sum k = 1 norm
1 kHz	1.7	8.7	0.2	7	2	6.5	1.5	2	2.1	1.0	13.6
20 kHz	2.5	9.1	0.3	7	2	6.5	1.5	2	2.7	1.0	14.1
100 kHZ	3	11.9	0.8	7	2	8.0	4	2.5	2.5	3.0	17.5

4) The evaluated ac-dc- transfer difference for the RDD5 was also used to calibrate the travelling standard at the level of 15 mV by using the PTC15 at the level of 150 mV and the RDD5 connected to the input of the travelling standard.

δF792 (15mV) = δPTC15 - δ (PTC15-(F792+RDD5)) + δRDD5 + load-corr.(F792)

Uncertainty budget for step 4:

calibration F792 15mV	PMJTC 15 norm ∞	RDD5	loading correction	std-dev Norm 40	dc-eff. norm ∞	setup norm ∞	tee norm ∞	repeat norm ∞	temp. norm ∞	humidity norm ∞	sum k = 1 norm
1 kHz	1.7	8.7	0.2	5.4	2	6.5	1.5	2	2.1	1.0	12.9
20 kHz	2.5	9.1	0.3	5.4	2	6.5	1.5	2	2.7	1.0	13.4
100 kHZ	3	11.9	0.8	5.4	2	8.0	4	2.5	2.5	3.0	16.9

5) The resistive divider “B200” was connected to the input of the F792A and a PMJTC with series resistor with nominal 3 volts ("PTC 48 + 191R") was used to evaluate the ac-dc transfer difference of the divider. Corrections for the used PMJTC, the 792A at 15 mV and the loading effect due to the input impedance of the 792A in parallel to the output of the divider have been applied.

δB200 = δF792(15mV) - δ (PTC48+191R) + δ (PTC48 - (F792+B200)) - load-corr.(F792)

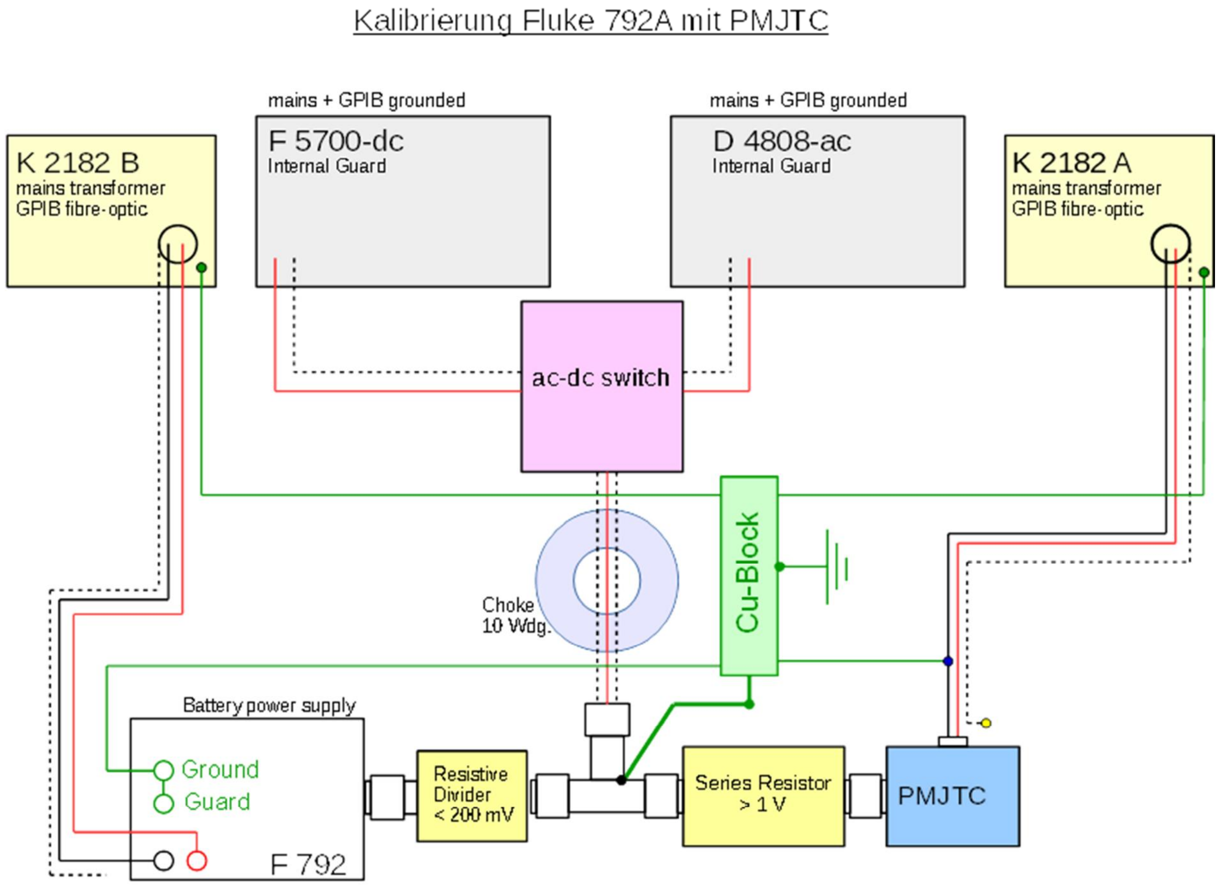
Uncertainty budget for step 5:

calibration B200	PTC48+R norm ∞	792 at 15 mV	loading correction	std-dev norm 40	dc-eff. norm ∞	setup norm ∞	tee norm ∞	repeat norm ∞	temp. norm ∞	humidity norm ∞	sum k = 1 norm
1 kHz	2.5	12.9	0.2	3.2	2	6.5	1.5	2	2.1	1.0	15.5
20 kHz	3.2	13.4	0.2	3.2	2	6.5	1.5	2	2.7	1.0	16.2
100 kHZ	3.6	16.9	0.6	3.2	2	8.0	4	2.5	2.5	3.0	20.4

6) This evaluated ac-dc- transfer difference for the divider B200 was used to calibrate the travelling standard at the level of 2 mV by using the PTC15 at the level of 400 mV and the B200 connected to the input of the travelling standard.

calibration F792 2mV	PMJTC 15 norm ∞	B200	loading correction	std-dev norm 40	dc-eff. norm ∞	setup norm ∞	tee norm ∞	repeat norm ∞	temp. norm ∞	humidity norm ∞	sum k = 1 norm
1 kHz	1.7	15.5	0.2	22	2	6.5	1.5	10	5.1	2.0	30.1
20 kHz	2.5	16.2	0.2	22	2	6.5	1.5	10	5.1	2.0	30.5
100 kHZ	3	20.4	0.6	22	2	8.0	4	10	5.4	5.0	33.9

Measurement Circuit



Appendix 5: Report of BIM

EURAMET.EM-K11.1
Bilateral Comparison
of AC-DC voltage transfer difference at low voltages

Report

Bulgarian Institute of Metrology (BIM)

Radoslava Hadzhistoykova

Bulgarian Institute of Metrology
52-B, G.M.Dimitrov Blvd.,
1797 Sofia,
BULGARIA

Date: 12.10.2020

Content

1. Introduction

BIM participated in the bilateral EURAMET comparison EURAMET.EM-K11.1, ac-dc voltage transfer difference at low voltages In June – July 2020.

The purpose of this comparison is to provide confidence into the new established mV-range of BIM. The results will be linked to those of EUROMET.EM-K11 (EUROMET Project No 464). EUROMET.EM-K11 results are linked to those of CCEM-K11.

The travelling standard is Fluke 792A AC-DC transfer standard, serial number 892 8001, which has amplified low voltage ranges 700 mV, 220 mV and 22 mV. It is compared to a low voltage reference AC-DC transfer standards of BIM.

2. Definition of the ac-dc voltage transfer difference

The AC-DC voltage transfer difference δ of a transfer standard is defined as:

$\delta = (V_{ac} - V_{dc}) / V_{dc}$

where Vac is the rms value of the AC input voltage and Vdc is the DC input voltage which, when reversed, produces the same mean output voltage of the transfer standard as Vac.

Differences are expressed in micro- volt per volt (µV/V) and a positive sign signifies that more AC than DC voltage is required for the same output response.

3. The Travelling Standard

The travelling standard is a Fluke 792A thermal transfer standard (TTS) with an accompanied power pack, both with serial number 892 8001.

4. BIM standards for low voltages and traceability

The AC-DC transfer difference at the reference voltage level is provided by PMJTC 1 V, produced by IPHT, Jena, serial No. 15B PTB/IPHT 2006. It is directly traceable to BEV, Austria with last calibration in 2016.

Step-up and step-down procedures are applied to achieve levels with higher and lower values.

The PMJTC is used directly to determine the AC-DC transfer difference of traveling standard for low voltage 200 mV.

A set of micropotentiometers (µpots), produced by SP, Sweden is used to provide traceability from 200 mV to 2 mV. Each micropotentiometer consists of a SJTC and a radial resistor, mounted in different housing. They are connected via current Tee-connector. TTS and µpots are calibrated to each other by step-down procedure, see Figure. 1. The comparison measuring points are measured in the following steps of the step-down procedure:

<u>100 mV – Step 3</u>

The reference standard is µpot 200 mV - TC1 10 mA, No TC1-0801 with resistor 20 Ω, R1-0801;

<u>10 mV – Step 9</u>

The reference standard is µpot 20 mV - TC1 10 mA, No TC1-0801 with resistor 2 Ω, R1-0803;

<u>2 mV – Step 13</u>

The reference standard is µpot 5 mV – TC2 5 mA, No TC2-0802 with resistor 1 Ω, R1-0805.

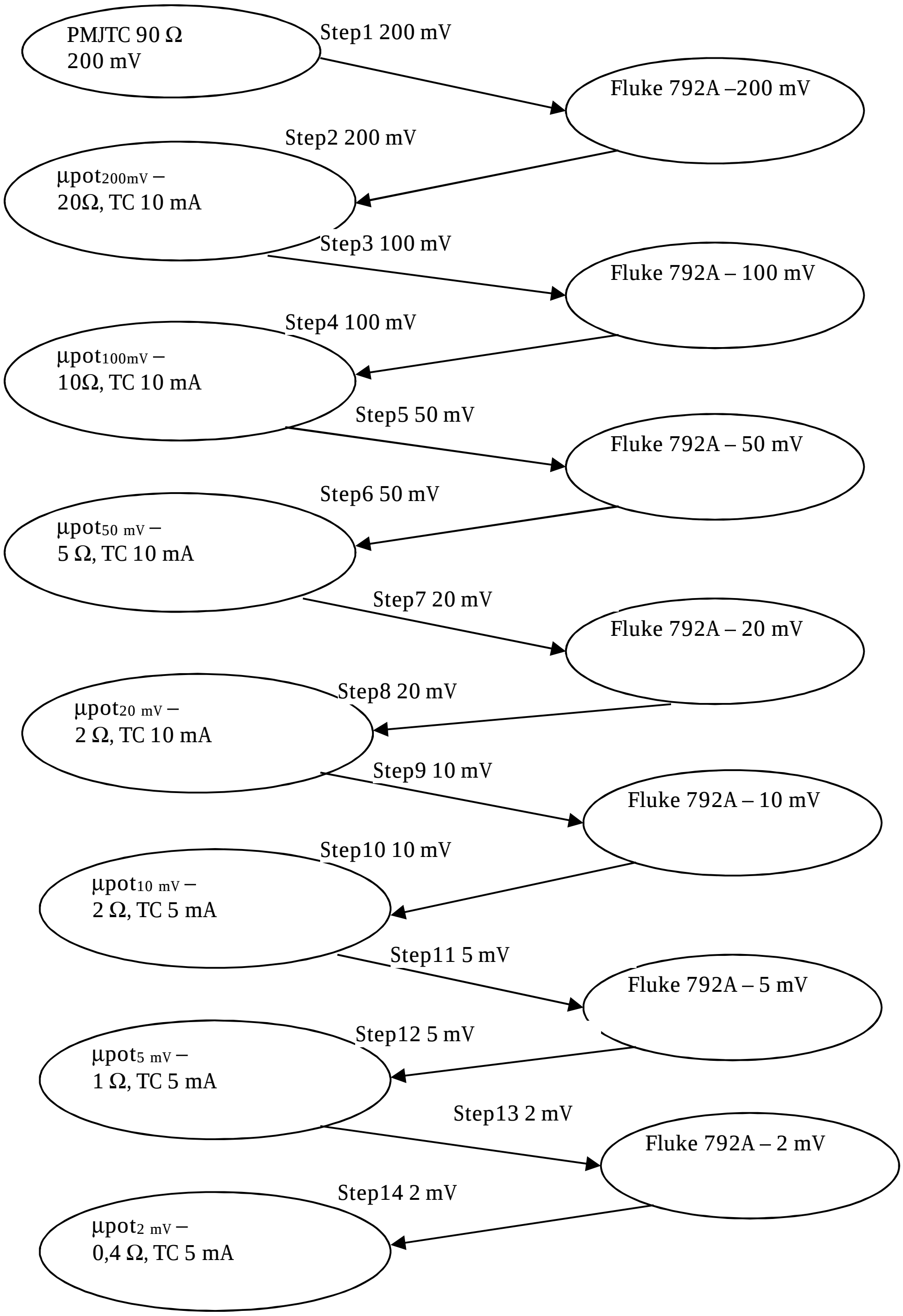


Fig.1 step-down procedure from 200 mV to 2 mV

5. Measurement setup

The comparison of the PMJTC and TTS is performed with an automated measuring system, shown in Figure 2.

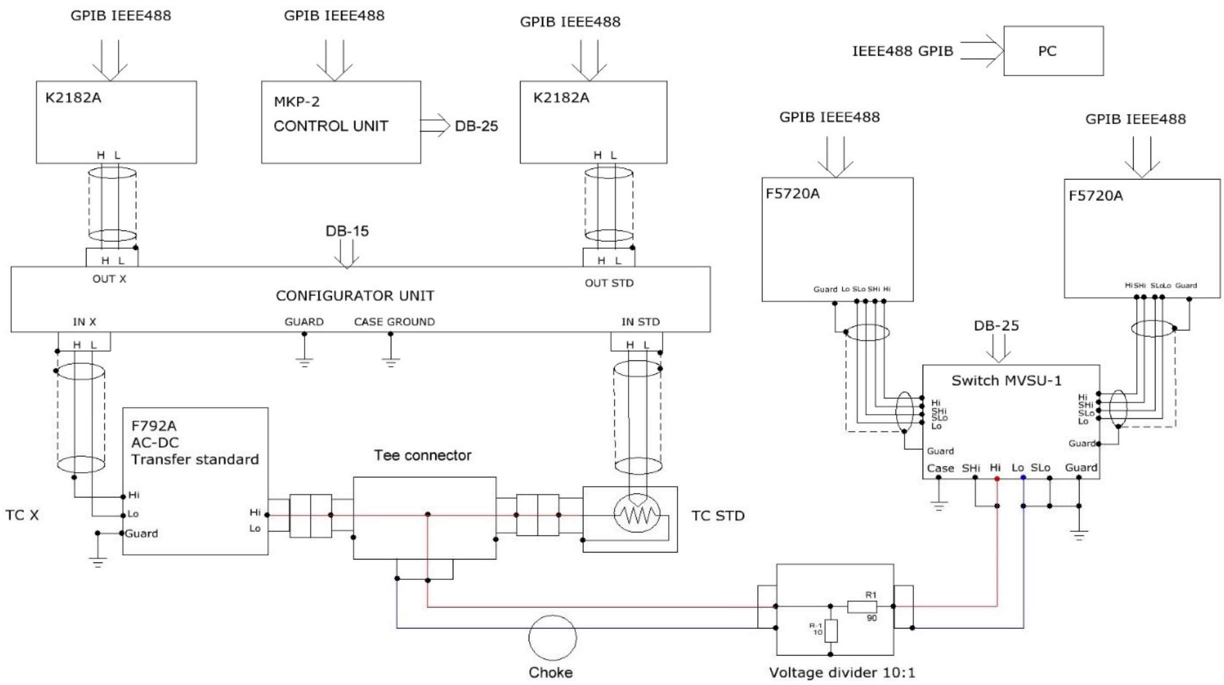
Two Fluke 5720 A calibrators are used as ac and dc sources. The AC-DC switching system, manufactured by Dr. M. Kampik, Silesian Technical University, Gliwice, Poland, consists of control unit, configurator/filters unit and relay unit, MVSU-1. The switching time is typically 2 ms. The configurator unit integrates five notch filters for low frequencies, from which 100 Hz filter is used.

The AC-DC switch is connected to the T-connector via 10:1 divider and a coaxial choke. As T connector is type N with female output connectors, it is extended with two N-N male adapters. The AC-DC transfer difference of the traveling standard is measured at the center of the T-connector as a reference plane.

The guards of Fluke 5720A sources, relay unit, configurator unit and Fluke 792A are connected to a common ground.

The LO output of Fluke 792A and the LO output of the reference standard are connected to the common guard via a Guard to LO connection in the configurator/filters unit.

The LO input of the Fluke 792A is also connected to the common ground via LO to Guard connection in the relay unit. The Ground terminal of Fluke 792A is connected additionally to Guard of the relay unit.



AC-DC voltage transfer on 200 mV

Fig.2 Automated measuring system for AC-DC transfer measurements

The set-up for this measurement is shown on Figure 3.

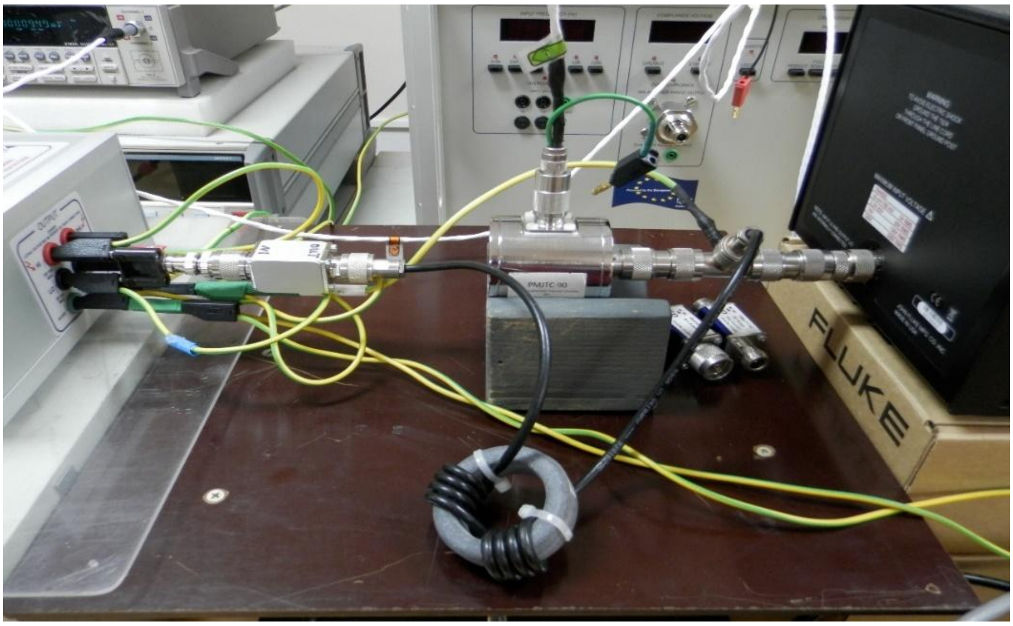
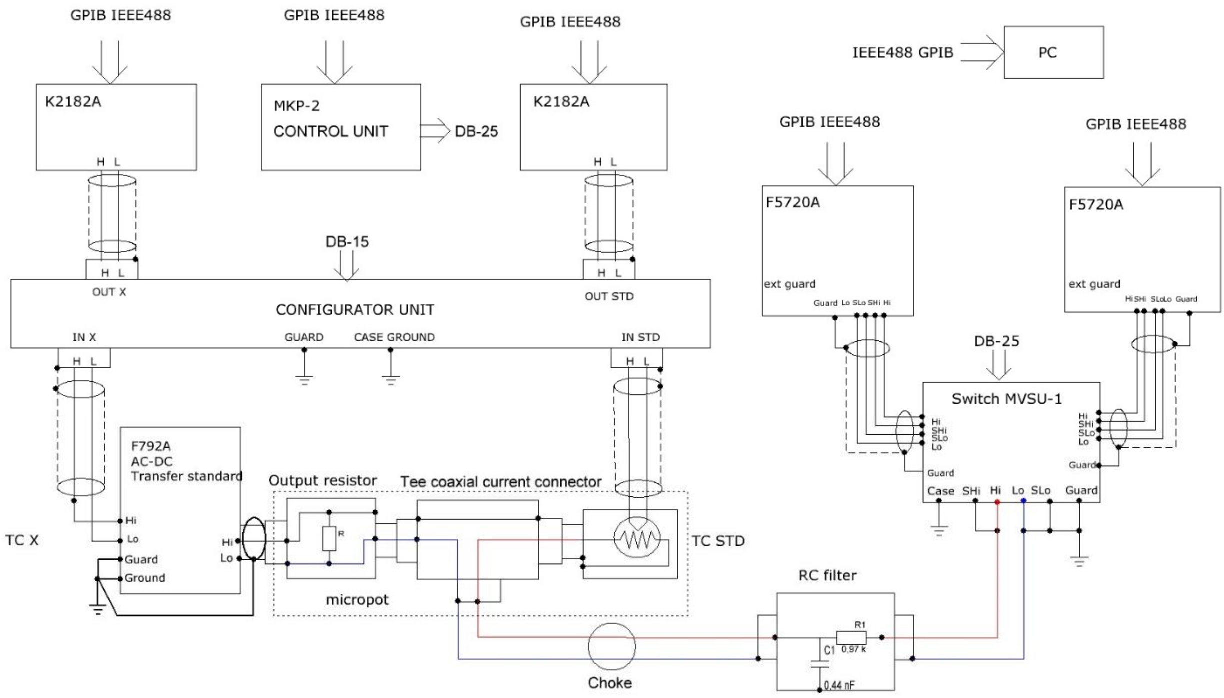


Fig. 3 200 mV calibration of TTS

The comparison of the µPots and TTS in the step-down procedure is performed with the same automated measuring system, after small modification as shown on Figure 4. In the measuring system, the radial resistor of µPot is connected directly to the input N-connector of Fluke 792A.The micropotentiometers are protected from the noise of calibrators by connecting RC-filter after the AC-DC switch. Due to the step-down procedure, the measured AC-DC transfer difference at voltages below 200 mV is at the input connector of TTS as the reference plane.



AC-DC voltage transfer from 200 mV (792A) to 2 mV (2 mV µpot)

Step 2 - 14 от "step-down" procedure

Fig.4 Automated measuring system for calibration of TTS and micropotentiometers

Figure 5 shows the set-up for this measurement.

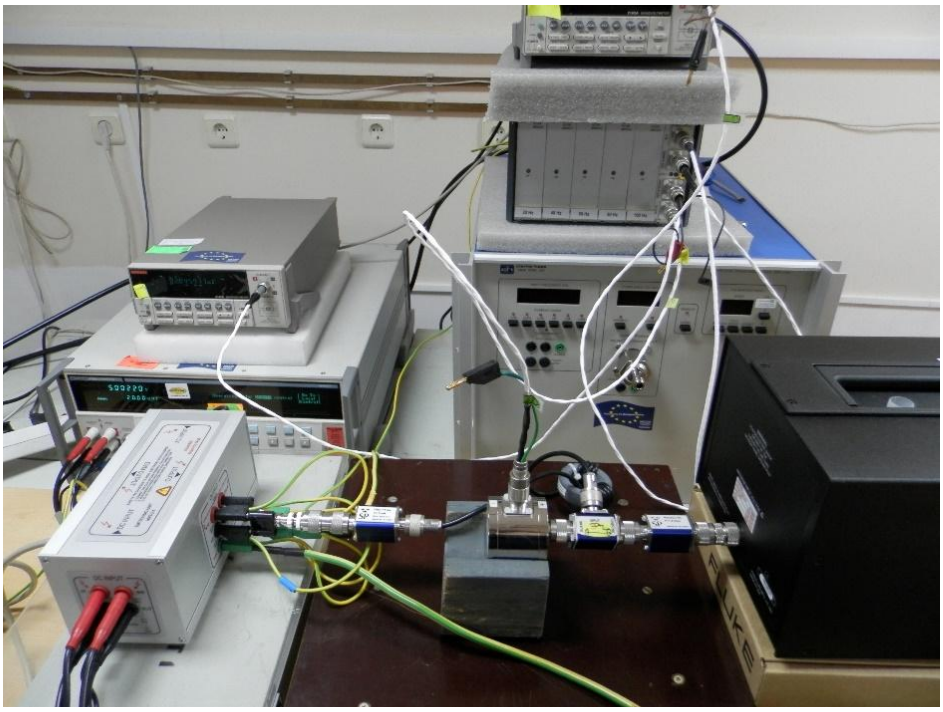


Fig.5 calibration of µpot 5 mV

6. Measurement procedure

Automated measurements are controlled by a homemade software in LabView environment. The output voltage of Fluke 792A is characterized from 200 mV to 2 mV before starting the measurements. The loading effect of 792A is measured, using RLC meter Agilent E4980A.

The measurement starts by determining the scale factors of the AC-DC transfer standards. At each frequency, the AC-voltage is adjusted to within 1.10^{-4} of the DC-voltage mean of both polarities. AC- and DC-voltage are applied consecutively and a two-channel method is used to measure output voltages of PMJTC (µpot) and Fluke 792A (TTS under test).

AC-DC standards are warmed up for 30 minutes for stabilization. The stabilization time for both PMJTC and µpot is 60 s after each switching. The measurement sequence is symmetric DC+, AC, DC-. For each measuring point minimum 3 times of 12 independent evaluations of the AC-DC transfer difference are performed.

After completing the measurements the software calculates mean value, standard deviation and AC-DC transfer difference. All single readings are stored in a text file.

Step-down procedure is performed twice - first with BIM's, and a second with BEV's TTS. In this way on the odd steps of the procedure, the differences in the values of the micropotentiometers, obtained in two different ways, can be estimated.

Also AC-DC transfer measurements between the both Fluke 792A are performed at comparison measuring points. In this way, the values of TTS under test, obtained in two different ways (triangle measurement), can be estimated.

7. Measuring conditions

The measurements are performed in a temperature and humidity controlled environment with ambient conditions:

Temperature: 23,06 °C ± 0,46 °C,

Humidity: 49 %rh ± 8 %rh.

Other Influence Parameters:

Measuring frequency of both calibrators is measured with counter CNT-91. The deviations from the nominal frequencies were smaller than 1.10^{-4} and negligible for the uncertainty budget.

The traveling standard is operated on battery during the time of the measurements.

The power pack voltage of the traveling standard is measured in both polarities during the measurements with a dummy load.

Positive Voltage:	Max: + 11.093 V	Min: + 11.085 V
Negative voltage:	Max: - 11.0878 V	Min: - 11.0802 V

8. Measurement results

Voltage	Range	Measured ac-dc voltage difference / 10^{-6} at frequency		
		1 kHz	20 kHz	100 kHz
100 mV	220 mV	11	2	26
10 mV	22 mV	10	46	51
2 mV	22 mV	32	40	57

9. Uncertainty analysis

The AC-DC transfer difference of the TTS in the step-down procedure is determined at the current ambient temperature and relative humidity. The AC-DC transfer difference of the TTS is not corrected for the error due to the temperature dependence because the room temperature is maintained within 23,0 °C ± 0,5 °C. The temperature dependence is added as uncertainty contribution to the budget, based on the temperature coefficient of TTS and the deviation from the nominal temperature. The deviation is determined using minimum and maximum values of temperature for the period of measurements.

The humidity dependence is added as uncertainty contribution, based on estimated in BEV factor for covering an eventual difference between the Fluke 792 instruments of SP and BEV.

The model equations of the measurements of the different steps in the voltage step-down procedure are described below.

Model for step 1

The measured AC-DC transfer difference, δ of the test TTS at the voltage 0,2 V is determined as:

$$\delta = \delta_{dA} + \delta_{dset-up} + \delta_s + \delta_{ld} \tag{1}$$

where:

δ_{dA} – difference between measured AC-DC differences of standard PMJTC and UUT TTS;

δ_S – AC-DC transfer difference of reference standard PMJTC;

$\delta_{dset\text{-}up}$ – AC-DC transfer difference, due to the measurement set-up

- consist of reproducibility, linearity and resolution of nanovoltmeter, scale factors, connectors and adapters, EMI, drift of the standard;

δ_{ld} – level dependence of the standard PMJTC from 1 V to 0,2 V.

Model for even steps 2,4,6,8,...

The measured AC-DC transfer difference of micropotentiometer, $\delta_{\mu pot}$ on j step determined as:

$$\delta_{\mu pot j} = \delta_{dAj} + \delta_{dset-up} + \delta_{s792\ j-1} - \delta_{z} \quad (2)$$

where:

δ_{dAj} - difference between measured AC-DC differences of standard Fluke 792A and UUT µpot;

$\delta_{dset-up}$ - AC-DC difference, due to the measurement set-up;

$\delta_{s792j-1}$ - AC-DC difference of Fluke 792A from “j-1” step

δ_{Zi} - AC-DC difference, due to loading effect.

Model for odd steps 3,5,7,9,...

The measured AC-DC transfer difference of Fluke 792A on “j”-step:

$$d_{792\mathrm{j}} = d_{\mathrm{dAj}} + d_{\mathrm{dset\text{-}up}} + d_{\mathrm{s\mu pot\ j\text{-}1}} + d_{\mathrm{sld}m\mathrm{pot\ j\text{-}1}} + d_{\mathrm{Zi}} \quad (3)$$

where:

δ_{dAj} - difference between measured AC-DC differences of standard µpot and Fluke 792A;

$\delta_{dset-up}$ - AC-DC difference due to the measurement set-up;

$\delta_{s\mu potj-1}$- AC-DC difference of standard µpot on “j-1” step;

$\delta_{sld\mu potj-1}$ - AC-DC difference, due to level dependence of µpot on “j-1” step;

δ_{Zi} - AC-DC difference due to loading effect;

For the investigation of loading effect of 792A is used RLC meter Agilent E4980A.

AC-DC difference δ_{Zi} (δ_{L2}) due to loading effect is determined as:

$$d_{\mathrm{L2}} = \frac{1}{\sqrt{1 + 2\frac{R_0}{R_{inp}} + \left(\frac{R_0}{R_{inp}}\right)^2 + w^2 C_{inp}{}^2 R_0{}^2}} - 1 \quad (4)$$

Step-down procedure
Uncertainty budgets in µV/V are:

Step No	Reference standard	Unit under test	Measured voltage	Contribution of:	Std. unc. f: 1 kHz	Std. unc. f: 20 kHz	Std. unc. f: 100 kHz	Type A or B	Distribution
1	PMJTC 15B	Fluke 792A	200 mV	AC-DC difference of standard	2,0	2,0	3,0	B	Normal
				Repeated measurement	3,8	3,6	4,0	A	Normal
				Measuring set-up:	4,4	3,6	3,1	B	Rectangular
				- reproducibility	3,7	2,7	1,9	B	Rectangular
				- resolution, linearity of the NVM and scale factors	2,0	2,0	2,0	B	Rectangular
				- EMI	1,0	1,0	1,0	B	Rectangular
				- drift of the standard	0,2	0,9	0,2	B	Rectangular
				- connectors and adapters	0,5	0,5	1,0	B	Rectangular
				Level dependence	0,1	0,5	4,5	B	Rectangular
				Temperature dependence	1,0	1,3	1,3	B	Rectangular
				Humidity dependence	0,1	0,3	0,9	B	Rectangular
				Standard unc. (k=1):	6,2	5,7	7,5		
2	Fluke 792A	µpot 200 mV	200 mV	AC-DC difference of standard	6,2	5,7	7,5	B	Normal
				Repeated measurement - standard deviation	2,6	1,7	1,5	A	Normal
				Measuring set-up $\delta_{dset-up}$:	2,5	2,5	2,6	B	Rectangular
				- reproducibility	1,0	1,0	1,0	B	Rectangular
				- resolution, linearity of the NVM and scale factors	2,0	2,0	2,0	B	Rectangular
				- EMI	1,0	1,0	1,0	B	Rectangular
				- drift of the standard	0	0	0	B	Rectangular
				- connectors and adapters	0,5	0,5	1,0	B	Rectangular
				Loading error of µpot δ_{Zi}	1,3	2,2	3,7	B	Rectangular
				Different setups	0,1	0,7	1,7	B	Rectangular
				Temperature dependence	1,0	1,3	1,3	B	Rectangular
				Humidity dependence	0,1	0,3	0,9	B	Rectangular
				Standard unc. (k=1):	7,4	6,9	9,0		
3	µpot 200 mV	Fluke 792A	100 mV	AC-DC difference of standard	7,4	6,9	9,0	B	Normal
				Repeated measurement - standard deviation	5,8	6,7	6,9	A	Normal
				Measuring set-up $\delta_{dset-up}$:	1,7	1,7	3,1	B	Rectangular
				- reproducibility	1,0	1,0	2,6	B	Rectangular
				- resolution, linearity of the NVM and scale factors	0,8	0,8	0,8	B	Rectangular
				- EMI	1,0	1,0	1,0	B	Rectangular
				- drift of the standard	0	0	0	B	Rectangular
				- connectors and adapters	0,5	0,5	1,0	B	Rectangular
				Level dependence	1,0	1,0	0,0	B	Rectangular
				Loading error of µpot δ_{Zi},	1,3	2,2	3,7	B	Rectangular
				Different setups	0,6	1,9	0,6	B	Rectangular
				Temperature dependence	1,0	1,3	1,3	B	Rectangular
				Humidity dependence	0,1	0,3	0,9	B	Rectangular
				Standard unc. (k=1):	9,8	10,2	12,5		
				Expanded unc:	20	20	25		
				Eff. deg. of freedom:	117	128	138		

Step No	Reference standard	Unit under test	Measured voltage	Contribution of:	Std. unc. f: 1 kHz	Std. unc. f: 20 kHz	Std. unc. f: 100 kHz	Type A or B	Distribution
4	Fluke 792A	µpot 100 mV	100 mV	AC-DC difference of standard	9,8	10,2	12,5	B	Normal
				Repeated measurement - standard deviation	3,1	3,7	2,7	A	Normal
				Measuring set-up $\delta_{dset-up}$:	1,3	1,2	1,8	B	Rectangular
				- reproducibility	0,5	0,1	1,0	B	Rectangular
				- resolution, linearity of the NVM and scale factors	0,4	0,4	0,4	B	Rectangular
				- EMI	1,0	1,0	1,0	B	Rectangular
				- drift of the standard	0	0	0	B	Rectangular
				- connectors and adapters	0,5	0,5	1,0	B	Rectangular
				Loading error of µpot δ_{Zi}	0,6	1,1	1,8	B	Rectangular
				Different setups	0,9	1,6	0,9	B	Rectangular
				Temperature dependence	1,0	1,3	1,3	B	Rectangular
				Humidity dependence	0,1	0,3	0,9	B	Rectangular
				Standard unc. (k=1):	10,4	11,0	13,1		
5	µpot 100 mV	Fluke 792A	50 mV	AC-DC difference of standard	10,4	11,0	13,1	B	Normal
				Repeated measurement - standard deviation	6,3	8,1	7,4	A	Normal
				Measuring set-up $\delta_{dset-up}$:	1,8	2,5	2,7	B	Rectangular
				- reproducibility	1,0	2,0	2,0	B	Rectangular
				- resolution, linearity of the NVM and scale factors	1,1	1,1	1,1	B	Rectangular
				- EMI	1,0	1,0	1,0	B	Rectangular
				- drift of the standard	0	0	0	B	Rectangular
				- connectors and adapters	0,5	0,5	1,0	B	Rectangular
				Level dependence	1,0	1,0	1,0	B	Rectangular
				Loading error of µpot δ_{Zi},	0,6	1,1	1,8	B	Rectangular
				Different setups	0	0	0	B	Rectangular
				Temperature dependance	1,0	1,3	1,3	B	Rectangular
				Humidity dependance	0,1	0,3	0,9	B	Rectangular
				Standard unc (k=1):	12,4	14,0	15,5		
6	Fluke 792A, 220 mV range	µpot 50 mV	50 mV	AC-DC difference of standard	12,4	14,0	15,5	B	Normal
				Repeated measurement - standard deviation	3,1	2,5	2,7	A	Normal
				Measuring set-up $\delta_{dset-up}$:	1,7	1,7	1,7	B	Rectangular
				- reproducibility	1,0	1,0	0,5	B	Rectangular
				- resolution, linearity of the NVM and scale factors	0,8	0,8	0,8	B	Rectangular
				- EMI	1,0	1,0	1,0	B	Rectangular
				- drift of the standard	0	0	0	B	Rectangular
				- connectors and adapters	0,5	0,5	1,0	B	Rectangular
				Loading error of µpot δ_{Zi}	0,3	0,6	0,9	B	Rectangular
				Different setups	1,2	2,2	0,4	B	Rectangular
				Temperature dependance	1,0	1,3	1,3	B	Rectangular
				Humidity dependance	0,1	0,3	0,9	B	Rectangular
				Standard unc (k=1):	12,7	14,1	15,6		

Step No	Reference standard	Unit under test	Measured voltage	Contribution of:	Std. unc. f: 1 kHz	Std. unc. f: 20 kHz	Std. unc. f: 100 kHz	Type A or B	Distribution
7	µpot 50 mV	Fluke 792A, 22 mV range	20 mV	AC-DC difference of standard	12,7	14,1	15,6	B	Normal
				Repeated measurement - standard deviation	11,3	13,7	15,9	A	Normal
				Measuring set-up $\delta_{dset-up}$:	3,2	3,2	3,3	B	Rectangular
				- reproducibility	2,0	2,0	2,0	B	Rectangular
				- resolution, linearity of the NVM and scale factors	2,2	2,2	2,2	B	Rectangular
				- EMI	1,0	1,0	1,0	B	Rectangular
				- drift of the standard	0,0	0,0	0,0	B	Rectangular
				- connectors and adapters	0,5	0,5	1,0	B	Rectangular
				Level dependence	1,0	1,0	1,0	B	Rectangular
				Loading error of µpot δ_{Zi}	0,4	0,6	0,8	B	Rectangular
				Different setups	0	0	0	B	Rectangular
				Temperature dependence	2,2	2,8	2,6	B	Rectangular
				Humidity dependence	0,6	0,6	1,7	B	Rectangular
				Standard unc. (k=1):	17,7	20,4	23,0		
8	Fluke 792A, 22 mV range	µpot 20 mV	20 mV	AC-DC difference of standard	17,7	20,4	23,0	B	Normal
				Repeated measurement - standard deviation	3,6	4,6	4,5	A	Normal
				Measuring set-up $\delta_{dset-up}$:	3,0	3,0	3,1	B	Rectangular
				- reproducibility	2,0	2,0	2,0	B	Rectangular
				- resolution, linearity of the NVM and scale factors	2,0	2,0	2,0	B	Rectangular
				- EMI	1,0	1,0	1,0	B	Rectangular
				- drift of the standard	0	0	0	B	Rectangular
				- connectors and adapters	0,5	0,5	1,0	B	Rectangular
				Loading error of µpot δ_{Zi}	0,2	0,2	0,3	B	Rectangular
				Different setups	1,2	2,5	1,7	B	Rectangular
				Temperature dependence	2,2	2,8	2,6	B	Rectangular
				Humidity dependence	0,6	0,6	1,7	B	Rectangular
				Standard unc. (k=1):	18,4	21,3	23,8		
9	µpot 20 mV	Fluke 792A, 22 mV range	10 mV	AC-DC difference of standard	18,4	21,3	23,8	B	Normal
				Repeated measurement - standard deviation	10,8	10,9	9,4	A	Normal
				Measuring set-up $\delta_{dset-up}$:	3,3	3,3	3,4	B	Rectangular
				- reproducibility	3,0	3,00	3,00	B	Rectangular
				- resolution, linearity of the NVM and scale factors	0,8	0,8	0,8	B	Rectangular
				- EMI	1,0	1,0	1,0	B	Rectangular
				- drift of the standard	0	0	0	B	Rectangular
				- connectors and adapters	0,5	0,5	1,0	B	Rectangular
				Level dependence	0	0	1	B	Rectangular
				Loading error of µpot δ_{Zi},	0,2	0,2	0,3	B	Rectangular
				Different setups	2,0	0,7	1,6	B	Rectangular
				Temperature dependence	2,2	2,8	2,6	B	Rectangular
				Humidity dependence	0,6	0,6	1,7	B	Rectangular
				Standard unc (k=1):	21,7	24,3	26,0		
				Expanded unc:	44	49	53		
				Eff. deg. of freedom:	86	77	69		

Step No	Reference standard	Unit under test	Measured voltage	Contribution of:	Std. unc. f: 1 kHz	Std. unc. f: 20 kHz	Std. unc. f: 100 kHz	Type A or B	Distribution
10	Fluke 792A, 22 mV range	µpot 10 mV	10 mV	AC-DC difference of standard	21,2	23,7	25,5	B	Normal
				Repeated measurement - standard deviation	5,8	8,0	6,3	A	Normal
				Measuring set-up $\delta_{dset\text{-}up}$:	1,2	1,2	1,5	B	Rectangular
				- reproducibility	2,0	2,0	2,0	B	Rectangular
				- resolution, linearity of the NVM and scale factors	0,5	0,5	0,5	B	Rectangular
				- EMI	1,0	1,0	1,0	B	Rectangular
				- drift of the standard	0	0	0	B	Rectangular
				- connectors and adapters	0,5	0,5	1,0	B	Rectangular
				Loading error of µpot δ_{Zi}	0,2	0,2	0,3	B	Rectangular
				Different setups	0,5	0,1	0,1	B	Rectangular
				Temperature dependence	2,2	2,8	2,6	B	Rectangular
				Humidity dependence	0,6	0,6	1,7	B	Rectangular
				Standard unc (k=1):	22,6	25,8	27,0		
11	µpot 10 mV	Fluke 792A, 22 mV range	5 mV	AC-DC difference of standard	22,6	25,8	27,0	B	Normal
				Repeated measurement - standard deviation	16,0	14,3	11,8	A	Normal
				Measuring set-up $\delta_{dset\text{-}up}$:	4,3	4,3	4,4	B	Rectangular
				- reproducibility	4,0	4,0	4,0	B	Rectangular
				- resolution, linearity of the NVM and scale factors	1,2	1,2	1,2	B	Rectangular
				- EMI	1,0	1,0	1,0	B	Rectangular
				- drift of the standard	0	0	0	B	Rectangular
				- connectors and adapters	0,5	0,5	1,0	B	Rectangular
				Level dependence	1,0	1,0	1,0	B	Rectangular
				Loading error of µpot δ_{Zi},	0,2	0,2	0,3	B	Rectangular
				Different setups	0	0	0	B	Rectangular
				Temperature dependence	2,2	2,8	2,6	B	Rectangular
				Humidity dependence	0,6	0,6	1,7	B	Rectangular
				Standard unc (k=1):	28,2	29,9	30,0		
12	Fluke 792A, 22 mV range	µpot 5 mV	5 mV	AC-DC difference of standard	28,2	29,9	30,0	B	Normal
				Repeated measurement - standard deviation	13,3	12,6	12,6	A	Normal
				Measuring set-up $\delta_{dset\text{-}up}$:	6,2	6,2	6,2	B	Rectangular
				- reproducibility	6,0	6,0	6,0	B	Rectangular
				- resolution, linearity of the NVM and scale factors	0,8	0,8	0,8	B	Rectangular
				- EMI	1,0	1,0	1,0	B	Rectangular
				- drift of the standard	0	0	0	B	Rectangular
				- connectors and adapters	0,5	0,5	1,0	B	Rectangular
				Loading error of µpot δ_{Zi}	0,1	0,1	0,2	B	Rectangular
				Different setups	0,2	5,1	2,7	B	Rectangular
				Temperature dependence	5,1	5,0	5,4	B	Rectangular
				Humidity dependence	1,2	1,2	2,9	B	Rectangular
				Standard unc (k=1):	32,2	33,5	33,7		

Step No	Reference standard	Unit under test	Measured voltage	Contribution of:	Std. unc. f: 1 kHz	Std. unc. f: 20 kHz	Std. unc. f: 100 kHz	Type A or B	Distribution
13	µpot 5 mV	Fluke 792A, 22 mV range	2 mV	AC-DC difference of standard	32,2	33,5	33,7	B	Normal
				Repeated measurement - standard deviation	22,9	30,6	36,3	A	Normal
				Measuring set-up $\delta_{dset-up}$:	15,2	15,2	15,2	B	Rectangular
				- reproducibility	15,0	15,0	15,0	B	Rectangular
				- resolution, linearity of the NVM and scale factors	2,4	2,4	2,4	B	Rectangular
				- EMI	1,0	1,0	1,0	B	Rectangular
				- drift of the standard	0	0	0	B	Rectangular
				- connectors and adapters	0,5	0,5	1,0	B	Rectangular
				Level dependence	1,0	1,0	1,0	B	Rectangular
				Loading error of µpot δ_{Zi}	0,1	0,1	0,2	B	Rectangular
				Different setups	5,3	7,1	7,1	B	Rectangular
				Temperature dependence	5,1	5,0	5,4	B	Rectangular
				Humidity dependence	1,2	1,2	2,9	B	Rectangular
				Standard unc (k=1):	42,7	48,1	52,2		
				Expanded unc:	85	96	104		
				Eff. deg. of freedom:	17	123	119		

Appendix 1. Summary of results

Key comparison EURAMET.EM-K11.1 "AC-DC voltage transfer difference at low voltages"

Please send this information by e-mail also.

Acronym of institute: BIM

Date of measurements: 24.06. -22.07.2020

Measuring result:

Voltage	Range	Measured ac-dc voltage difference / 10^{-6} at frequency		
		1 kHz	20 kHz	100 kHz
100 mV	220 mV	11	2	26
10 mV	22 mV	10	46	51
2 mV	22 mV	32	40	57

Expanded uncertainty:

Voltage	Range	Expanded uncertainty / 10^{-6} at frequency		
		1 kHz	20 kHz	100 kHz
100 mV	220 mV	20	20	25
10 mV	22 mV	44	49	53
2 mV	22 mV	85	96	104

Measuring frequency:

	Nominal frequency		
	1 kHz	20 kHz	100 kHz
Measuring frequency, kHz	1,00081	20,000105	99,999801
Expanded uncertainty, kHz	0,00041	0,000154	0,000031

Influence parameters:

	Min	Max
Ambient temperature / ºC	22,60	23,51
Relative humidity / % rh	41,1	57,3
Pos. power supply voltage / V	11,093	11,085
Neg. power supply voltage / V	11,087	11,080

Appendix 2. Summary of uncertainty budget

Key comparison EURAMET.EM-K11.1 “AC-DC voltage transfer difference at low voltages”

Please send this information by e-mail also.

Acronym of institute: Bulgarian Institute of Metrology (BIM)

Date: 12.10.2020

Remarks: All values are corrected for temperate and humidity dependence.

Uncertainty budget for measuring voltage 100 mV in µV/V:

Contribution of:	Std. unc. f: 1 kHz	Std. unc. f: 20 kHz	Std. unc. f: 100 kHz	Type A or B	Distribution
AC-DC difference of standard µV/V	7,2	6,7	8,9	B	Normal
Repeated measurement - standard deviation	5,8	6,7	6,9	A	Normal
Measuring set-up	1,7	1,7	3,1	B	Rectangular
- reproducibility	1,0	1,0	2,6	B	Rectangular
- resolution, linearity of the NVM and scale factors	0,8	0,8	0,8	B	Rectangular
- EMI	1,0	1,0	1,0	B	Rectangular
- drift of the standard	0	0	0	B	Rectangular
- connectors and adapters	0,5	0,5	1,0	B	Rectangular
Level dependence	1,0	1,0	0,0	B	Rectangular
Loading error of µpot200 mV δ_{Zi}	1,3	2,2	3,7	B	Rectangular
Different setups	0,6	1,9	0,6	B	Rectangular
Temperature dependence, µV/V	1,0	1,3	1,3	B	Rectangular
Humidity dependence	0,1	0,3	0,9	B	Rectangular
Standard unc (k=1):	9,8	10,2	12,5		
Expanded unc:	20	20	25		
Eff. deg. of freedom:	117	128	138		

Uncertainty budget for measuring voltage 10 mV in µV/V:

Contribution of:	Std. unc. f: 1 kHz	Std. unc. f: 20 kHz	Std. unc. f: 100 kHz	Type A or B	Distribution
AC-DC difference of standard	18,0	20,8	23,4	B	Normal
Repeated measurement - standard deviation	10,8	10,9	9,4	A	Normal
Measuring set-up	3,3	3,3	3,4	B	Rectangular
- reproducibility	3,0	3,00	3,00	B	Rectangular
- resolution, linearity of the NVM and scale factors	0,8	0,8	0,8	B	Rectangular
- EMI	1,0	1,0	1,0	B	Rectangular
- drift of the standard	0	0	0	B	Rectangular
- connectors and adapters	0,5	0,5	1,0	B	Rectangular
Level dependence	0	0	1	B	Rectangular
Loading error of µpot 20 mV δ_{Zi}	0,2	0,2	0,3	B	Rectangular
Different setups	2,0	0,7	1,6	B	Rectangular
Temperature dependence	2,2	2,8	2,6	B	Rectangular
Humidity dependence	0,6	0,6	1,7	B	Rectangular
Standard unc (k=1):	21,7	24,3	26,0		
Expanded unc:	44	49	53		
Eff. deg. of freedom:	86	77	69		

Uncertainty budget for measuring voltage 2 mV in µV/V:

Contribution of:	Std. unc. f: 1 kHz	Std. unc. f: 20 kHz	Std. unc. f: 100 kHz	Type A or B	Distribution
AC-DC difference of standard	31,3	32,4	32,7	B	Normal
Repeated measurement - standard deviation	22,8	30,6	36,3	A	Normal
Measuring set-up	15,2	15,2	15,3	B	Rectangular
- reproducibility	15,0	15,0	15,0	B	Rectangular
- resolution, linearity of the NVM and scale factors	2,4	2,4	2,4	B	Rectangular
- EMI	1,0	1,0	1,0	B	Rectangular
- drift of the standard	0	0	0	B	Rectangular
- connectors and adapters	0,5	0,5	1,0	B	Rectangular
Level dependence	1,0	1,0	1,0	B	Rectangular
Loading error of µpot 5 mV δ_{Zi}	0,1	0,1	0,2	B	Rectangular
Different setups	5,3	7,1	7,1	B	Rectangular
Temperature dependence	0,3	0,5	1,1	B	Rectangular
Humidity dependence	1,2	1,2	2,9	B	Rectangular
Standard unc (k=1):	42,7	48,1	52,2		
Expanded unc:	85	96	104		
Eff. deg. of freedom:	117	123	119		