APMP reference no. APMP.EM-K6.a

APMP International Comparison of Ac-dc Transfer Standards at the Lowest Attainable Level of Uncertainty

Final Report

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1. Scope

This comparison has offered the same range and frequencies as the key Comparison CCEM-K6a with the view of providing the National Metrology Institutes (NMIs) of the APMP member economies with an opportunity to link the values of their standards for ac-dc transfer difference to the international reference values. The comparison is part of the Global Mutual Recognition Arrangement (MRA) process.

2. Definition of the Measurand

Ac-dc transfer difference is defined as

$$\delta = \frac{U_{ac} - U_{dc}}{U_{dc}}$$

where

U_{ac} is an rms ac voltage, and

U_{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 volt (μV/V), and a positive sign signifies that more ac than dc was required for the same output response.

3. The Travelling Standard

The travelling standard was a Holt Model 11 Single-Junction Thermal Voltage Converter, Part Number 90081C, with the following nominal parameters:

Rated Input Voltage:	4V
Heater Resistance:	400 Ω
Thermocouple Resistance:	7 Ω
Output Voltage:	7 mV

The Thermal Converter was supplied with a GR type-874 adapter plate 11 Part Number 84980 and two Tee-pieces, a GR type-874 and an N-male with an N-to-GR type 874 adapter. In order to raise the confidence in the results the travelling standard had been chosen to have a relatively high magnitude of ac-dc difference (from 5 μV/V at 1 kHz to approximately 30 μV/V at 1 MHz). The participants were asked to measure the ac-dc difference of the travelling standard at 3 V and selected frequencies that included those of CCEM-K6a.

4. Measurement Conditions

* The voltage was defined at the mid-point of the Tee-piece. The participants had the option of using either or both Tee-pieces or a Tee-piece of their own however, only one set of results could be reported by each participant
* When using the GR type 874 Tee-piece supplied with the Travelling Standard, the Thermal Converter was connected to the side of the Tee-piece marked in green.
* The input and output of the Travelling Standard was always earthed to protect the insulation between the heater and the thermocouple.

5. Test Points

The ac-dc difference of the travelling standard was measured with 3 V applied at the following frequencies:

Standard: 1 kHz, 20 kHz, 100 kHz and 1 MHz,
Optional: 50 kHz and 500 kHz.

6. Reports

Each participant was asked to submit a report within one month after completing the measurements. All reports have been received and contain at least the following:

* Detailed description of the measurement setup including a drawing that can be used, if necessary, in the final report of the Comparison;
* Definition of the measurand including the Tee-piece used;
* Detailed description of the measurement procedure;
* The mean value of the results, their standard deviation and the number of measurements taken to obtain the results;
* Complete uncertainty budget in accordance with the principles of the ISO Guide to the Expression of Uncertainty in Measurement. Individual uncertainty components, the standard uncertainty and the degrees of freedom should be included.

7. Participants and the Time Schedule

The list of the participants and time schedule are shown in Tables 1 and 2. Each participant was given a time slot of 6 weeks, comprising 4 weeks for measurement and 2 weeks for transportation.

Table 1
Participants of APMP.EM-K6a

Economy	NMI	Standard, AC-DC Comparator System	Traceability
Australia	NMIA	SJTC, fully automated dual-channel	NMIA
Malaysia	NML-SIRIM	SJTC, fully automated dual-channel	NMIA
Hong Kong	SCL	MJTC, fully-automated dual-channel	NPL
Singapore	NMC	MJTC, fully automated dual-channel	PTB
India	NPL	MJTC, semi-automated dual-channel	NPLI
Germany	PTB	MJTC, fully automated differential	PTB
Chinese Taipei	CMS	MJTC, fully automated dual-channel	PTB
New Zealand	MSL	Electronic transfer std., fully automated dual-channel	NMIA
Japan	NMIJ	SJTC, fully automated dual-channel	NMIJ
Thailand	NIMT	SJTC, fully automated dual-channel	NMIA
Korea	KRISS	MJTC, semi-automated dual-channel	PTB
Viet Nam	VMI	SJTC, fully automated dual-channel	NMIA
Indonesia	KIM-LIPI	SJTC, fully automated dual-channel	NMIA
South Africa	NMISA	MJTC, fully automated dual-channel	PTB
Philippines	ITDI	SJTC, fully automated dual-channel	NMIA

Table 2
Comparison Schedule

Economy	Laboratory	Period of Measurement	Responsible Person	e-mail Address
Australia	NMIA		Ilya Budovsky	Ilya.Budovsky@nmi.gov.au
Malaysia	NML-SIRIM	15/11/2000-31/12/2000	Abdul Rashid Bin Zainal Abidin	abd.rashid_z.abidin@sirim.my
Hong Kong	SCL	1/1/2001-15/2/2001	Y.K.Yan	ykyan@itc.gov.hk.
Singapore	NMC	15/2/2001-31/3/2001	Jing Tao	jing_tao@nmc.a-star.edu.sg
Australia	NMIA	1/4/2001-15/5/2001	Ilya Budovsky	Ilya.Budovsky@csiro.au
India	NPL	15/5/2001-30/6/2001	V.K.Rustagi A.K.Govil	rustagi@csnpl.ren.nic.in
Germany	PTB	1/7/2001-15/8/2001	Manfred Klonz	Manfred.Klonz@ptb.de
Chinese Taipei	CMS	15/8/2001-30/9/2001	Wei, Yih-cheng	YihChengWei@itri.org.tw
New Zealand	IRL	1/10/2001-15/11/2001	Murray Early	m.early@irl.cri.nz
Australia	NMIA	15/11/2001-31/12/2001	Ilya Budovsky	Ilya.Budovsky@nmi.gov.au
Japan	NMIJ	1/1/2002 -15/2/2002	Hitoshi Sasaki Hirojuki Fujiki	hitoshi-sasaki@aist.go.jp fujiki@aist.go.jp
Thailand	NIMT	15/2/2002 -31/3/2002	Chalit Kumtawee Ajchara Charoensook	nimt@nimt.or.th
Korea	KRISS	1/4/2002 -15/5/2002	Sung-Won Kwon	swkwon@kriss.re.kr
Australia	NMIA	15/5/2002-15/8/2002	Ilya Budovsky	Ilya.Budovsky@csiro.au
Viet Nam	VMI	15/8/2002-30/9/2002	Nguyen Anh Son	vmi@fpt.vn
Indonesia	KIM-LIPI	1/10/2002-30/11/2002	Bumbang Suprianto	bkmkim@cbn.net.id
South Africa	NMISA	1/12/2002-15/1/2003	Moses Temba	MLTemba@csir.co.za
Australia	NMIA	15/1/2003-28/2/2003	Ilya Budovsky	Ilya.Budovsky@csiro.au
Philippines	ITDI	1/3/2003-15/4/2002	Manuel Ruiz	mmr@agham.dost.gov.ph
Australia	NMIA	15/4/2003-31/5/2003	Ilya Budovsky	Ilya.Budovsky@nmi.gov.au

8. Transportation

* The case was transported by air freight without a carnet for Customs clearance.
* The case was designed so that the Thermal Converter was transported assembled together with the adapter plate and the N-type Tee together with the N-to-GR adapter. There was no need to disassemble these parts, however the participants had to ensure good contact before taking measurements.

9. Contents of the pack

1. Thermoelement. Holt Model 11 Part Number 90081C, s/n 0943500001033
2. Adapter. Holt Model 11 Part Number 84980, s/n 0943500001037
3. Tee Piece, type 874TL
4. Tee Piece, type N. Pasternak PE9390
5. N-to-Type 874 Adapter. Pasternak PE9358
6. Output Connection Cable
7. Comparison Protocol

10. Measurement Results

It is known that the ac-dc difference of a TVC depends greatly on its input connector and the tee-adaptor used to connect it to the reference TVC. As a rule, in order to reduce this uncertainty, the test voltage is defined at the center-point of the tee adaptor. Such a definition was also adopted for the comparison described here. Two types of connector, known as Type N and GR Type 874, are commonly used in TVCs of the highest precision. The travelling standard was equipped with the latter connector. However, it was important to enable comparison of NMIs that use either type of connector in their reference TVC. For this purpose, the travelling standard was circulated with two tee adaptors, one being Type 874 and the other Type N-male with an additional N-female to Type 874 adaptor at the travelling standard end.

Prior to the start of the comparison, using methods described in [2], NMIA conducted a study of the differences that arise from the use of the travelling standard with the two circulated adaptors. These differences are presented in Table 3

Table 3

Correction δ_{874} - δ_{N+874} in μV/V at Frequencies					
1 kHz	**20 kHz**	**50 kHz**	**100 kHz**	**500 kHz**	**1 MHz**
0	**-0.3**	**-0.7**	**-1.5**	**-4**	**-6.2**

The summary of reported measurement results is given in Table 4. All results are for the Type 874 connector. The results of those participants who used Type N (NMC, MSL, NMIJ, NMISA, VMI and ITDI) have been adjusted using the corrections in Table I. Since the uncertainties of these corrections were approximately one order of magnitude less than those reported by the participants, no further adjustments were made to the reported uncertainties below.

Table 4

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Laboratory	Nominal Measurement Period	Measured Ac-dc Difference δ_{LAB} and Expanded Uncertainty (95%) U_{LAB} in μV/V											
		1 kHz		20 kHz		50 kHz		100 kHz		500 kHz		1 MHz	
		δ	U	δ	U	δ	U	δ	U	δ	U	δ	U
NMIA		**-5.0**	0.8	**-2.5**	1.9	**1.0**	4.0	**4.6**	5.0	**24.1**	12.0	**34.0**	18.0
SIRIM	15/11/2000-31/12/2000	**-5.5**	5.0	**-3.7**	7.0	**2.2**	6.0	**2.0**	8.0	**26.2**	17.0	**40.5**	27.0
SCL	1/1/2001-15/2/2001	**-10.0**	9.0	**-6.0**	9.0	**-7.0**	10.0	**-1.0**	15.0	**11.0**	33.0	**16.0**	78.0
NMC	15/2/2001-31/3/2001	**-5.1**	5.2	**-3.4**	5.2	**-0.4**	5.6	**1.1**	5.6	**7.0**	12.0	**16.8**	32.0
NMIA	1/4/2001-15/5/2001	**-5.0**	0.8	**-1.5**	1.9			**4.2**	5.0	**24.0**	12.0	**34.5**	18.0
NPLI	15/5/2001-30/6/2001	**-8.4**	4.4	**4.4**	4.6	**-3.5**	5.6	**-1.1**	6.4	**11.2**	22.8	**9.5**	26.0
PTB	1/7/2001-15/8/2001	**-5.3**	0.8	**-2.8**	0.8	**-0.6**	1.4	**1.1**	2.8	**5.4**	11.0	**8.9**	25.0
CMS	15/8/2001-30/9/2001	**-5.5**	2.0	**-3.0**	2.4	**-0.2**	2.7	**1.7**	6.7	**16.0**	16.0	**28.0**	29.0
MSL	1/10/2001-15/11/2001	**-4.4**	6.2	**-1.3**	8.4	**0.7**	12.7	**5.2**	16.3	**28.3**	33.0	**27.4**	53.4
NMIA	15/11/2001-31/12/2001	**-4.8**	0.8	**-2.2**	1.9	**1.1**	4.0	**4.4**	5.0	**22.1**	12.0	**29.7**	18.0
NMIJ	1/1/2002 - 15/2/2002	**-5.3**	1.1	**-3.1**	1.1	**0.1**	1.3	**4.2**	1.9	**22.9**	7.1	**27.7**	20.2
NIMT	15/2/2002 - 31/3/2002	**-4.7**	5.0	**-4.0**	6.0	**-1.2**	7.0	**3.0**	11.0	**29.9**	20.0	**49.7**	28.0
KRISS	1/4/2002 - 15/5/2002	**-6.6**	2.9	**-3.1**	2.9	**-0.7**	3.3	**2.1**	3.4	**12.5**	11.9	**16.1**	23.3
NMIA	15/5/2002-15/8/2002	**-4.9**	0.8	**-2.3**	1.9	**1.1**	4.0	**4.5**	5.0	**22.4**	12.0	**30.5**	18.0
VMI	15/8/2002-30/9/2002	**-4.7**	4.4	**-1.7**	6.5	**0.7**	14.1	**3.5**	16.3			**22.8**	65.0
KIM-LIPI	1/10/2002-30/11/2002	**-4.8**	5.0	**-2.9**	6.0	**0.0**	14.0	**3.1**	21.0	**17.5**	44.0	**20.8**	73.0
NMISA	1/12/2002-15/1/2003	**-3.9**	3.0	**-2.4**	3.0	**-0.1**	4.0	**1.6**	4.0	**6.1**	11.0	**7.8**	31.0
NMIA	15/1/2003-28/2/2003	**-5.0**	0.8	**-2.4**	1.9	**0.9**	4.0	**4.1**	5.0	**22.9**	12.0	**32.1**	18.0
ITDI	1/3/2003-15/4/2002	**-1.6**	8.8	**-3.0**	6.6	**1.3**	13.0	**3.5**	14.0	**120.0**	25.0	**138.8**	41.0
NMIA	1/6/2003-15/7/2003	**-5.1**	0.8	**-2.5**	1.9	**1.1**	4.0	**4.6**	5.0	**22.9**	12.0	**35.2**	18.0
NMIA Mean		**-5.0**	0.8	**-2.2**	1.9	**1.0**	4.0	**4.4**	5.0	**23.1**	12.0	**32.7**	18.0
Ref Value		**-5.2**	0.5	**-2.8**	0.6	**-0.1**	0.9	**3.3**	1.5	**18.8**	5.3	**25.6**	11.8
NMIA STD		**0.1**		**0.4**		**0.1**		**0.2**		**0.8**		**2.3**	

11. Determination of the Reference Values

The reference values for the APMP.EM-K6a have been based on the results by participants chosen with the following criteria:

1. An independent realisation of primary standards for ac-dc difference
2. The lowest values of reported uncertainties.

The following three laboratories satisfy the above criteria: NMIA [2], PTB[3, 4] and NMIJ [5].

For each frequency, the APMP.EM-K6a reference value $\delta_{REF-APMP}$ and its standard uncertainty $u_{REF-APMP}$ have been calculated from the results of these three laboratories as a weighted mean [6] given by:

$$\delta_{REF-APMP} / u^2{}_{REF-APMP} = \sum \delta_{LAB_i} / u^2{}_{LAB_i} \,,$$

where

$$1/u^2_{REF-APMP} = \sum 1/u^2_{LAB_i} .$$

Table 5
Deviation $D_{\text{LAB-APMP}}$ from APMP Reference Value and expanded uncertainty (95%) $U_{\text{LAB-APMP}}$ in μV/V

Laboratory	Deviation from APMP Reference Value $D_{LAB\text{-}APMP}$ and Expanded Uncertainty (95%) U_{LAB} in μV/V at Frequencies											
Laboratory	**1 kHz**		**20 kHz**		**50 kHz**		**100 kHz**		**500 kHz**		**1 MHz**	
	δ	U	δ	U	δ	U	δ	U	δ	U	δ	U
NMIA	**0.1**	0.6	**0.3**	1.8	**1.1**	3.9	**1.3**	4.8	**5.3**	10.7	**8.4**	13.6
SIRIM	**-0.3**	5.0	**-0.9**	7.0	**2.3**	6.1	**-1.3**	8.1	**7.4**	17.8	**14.9**	29.5
SCL	**-4.8**	9.0	**-3.2**	9.0	**-6.9**	10.0	**-4.3**	15.1	**-7.8**	33.4	**-9.6**	78.9
NMC	**0.1**	5.2	**-0.6**	5.2	**-0.3**	5.6	**-2.2**	5.8	**-11.8**	13.1	**-8.8**	34.1
NMIA	**0.1**	0.6	**1.3**	1.8			**0.9**	4.8	**5.2**	10.7	**8.9**	13.6
NPLI	**-3.2**	4.4	**7.2**	4.6	**-3.4**	5.7	**-4.4**	6.6	**-7.6**	23.4	**-16.1**	28.6
PTB	**-0.1**	0.6	**0.0**	0.5	**-0.5**	1.0	**-2.2**	2.4	**-13.4**	9.6	**-16.7**	22.0
CMS	**-0.3**	2.1	**-0.2**	2.5	**-0.1**	2.9	**-1.6**	6.9	**-2.8**	16.9	**2.4**	31.3
MSL	**0.8**	6.2	**1.5**	8.4	**0.8**	12.7	**1.9**	16.4	**9.5**	33.4	**1.8**	54.7
NMIA	**0.3**	0.6	**0.6**	1.8	**1.2**	3.9	**1.1**	4.8	**3.3**	10.7	**4.1**	13.6
NMIJ	**-0.1**	1.0	**-0.3**	0.9	**0.3**	0.9	**0.9**	1.2	**4.1**	4.7	**2.0**	16.4
NIMT	**0.5**	5.0	**-1.2**	6.0	**-1.1**	7.1	**-0.3**	11.1	**11.1**	20.7	**24.1**	30.4
KRISS	**-1.4**	2.9	**-0.3**	3.0	**-0.6**	3.4	**-1.2**	3.7	**-6.3**	13.0	**-9.5**	26.1
NMIA	**0.3**	0.6	**0.5**	1.8	**1.2**	3.9	**1.2**	4.8	**3.7**	10.7	**4.9**	13.6
VMI	**0.5**	4.4	**1.1**	6.5	**0.8**	14.1	**0.2**	16.4			**-2.8**	66.1
KIM-LIPI	**0.4**	5.0	**-0.1**	6.0	**0.1**	14.0	**-0.2**	21.1	**-1.3**	44.3	**-4.8**	74.0
NMISA	**1.3**	3.0	**0.4**	3.1	**0.0**	4.1	**-1.7**	4.3	**-12.7**	12.2	**-17.8**	33.2
NMIA	**0.2**	0.6	**0.4**	1.8	**1.0**	3.9	**0.7**	4.8	**4.1**	10.7	**6.5**	13.6
ITDI	**3.6**	8.8	**-0.2**	6.6	**1.4**	13.0	**0.2**	14.1	**101.2**	25.6	**113.2**	42.7
NMIA	**0.1**	0.6	**0.3**	1.8	**1.3**	3.9	**1.3**	4.8	**4.1**	10.7	**9.6**	13.6
NMIA Mean	**0.2**	0.6	**0.6**	1.8	**1.2**	3.9	**1.1**	4.8	**4.3**	10.7	**7.0**	13.6

The deviation of each laboratory's result from the APMP.EM-K6a reference value, $D_{LAB-APMP}$, and its Expanded Uncertainty are given in Table 5. For the three reference laboratories the correlation with the reference value has been taken into account using the formula

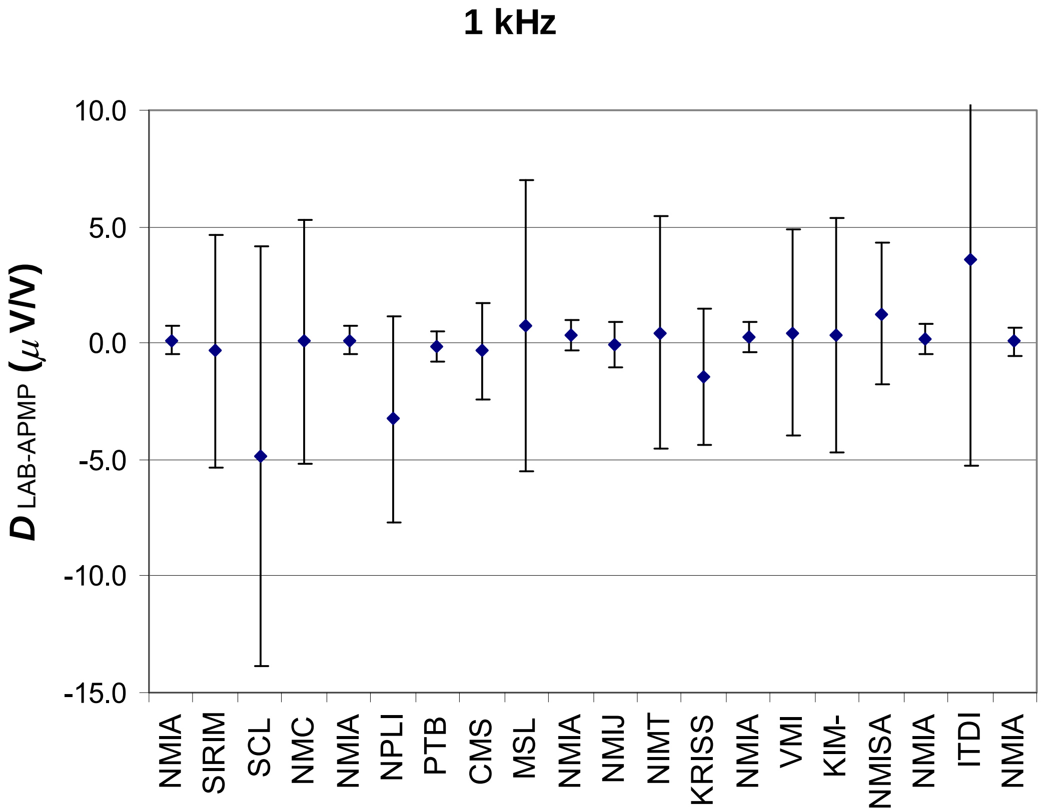
$$u^2_{\text{LAB-APMP}} = u^2_{\text{LAB}} - u^2_{\text{REF-APMP}} , \qquad (3)$$

where u_{LAB} are the uncertainties reported by the laboratory. For the remaining laboratories there is no such correlation. Therefore, for these laboratories,

$$u^2{}_{\mathrm{LAB-APMP}} = u^2{}_{\mathrm{LAB}} + u^2{}_{\mathrm{REF-APMP}} \,. \qquad (4)$$

Deviation $D_{\mathrm{LAB\text{-}APMP}}$ from APMP Reference Value and expanded uncertainties (95%) $U_{\mathrm{LAB\text{-}APMP}}$ are shown graphically below.

Deviation $D_{\mathrm{LAB\text{-}APMP}}$ from APMP reference value and expanded uncertainty at 95% confidence level $U_{\mathrm{LAB\text{-}APMP}}$ in μV/V.



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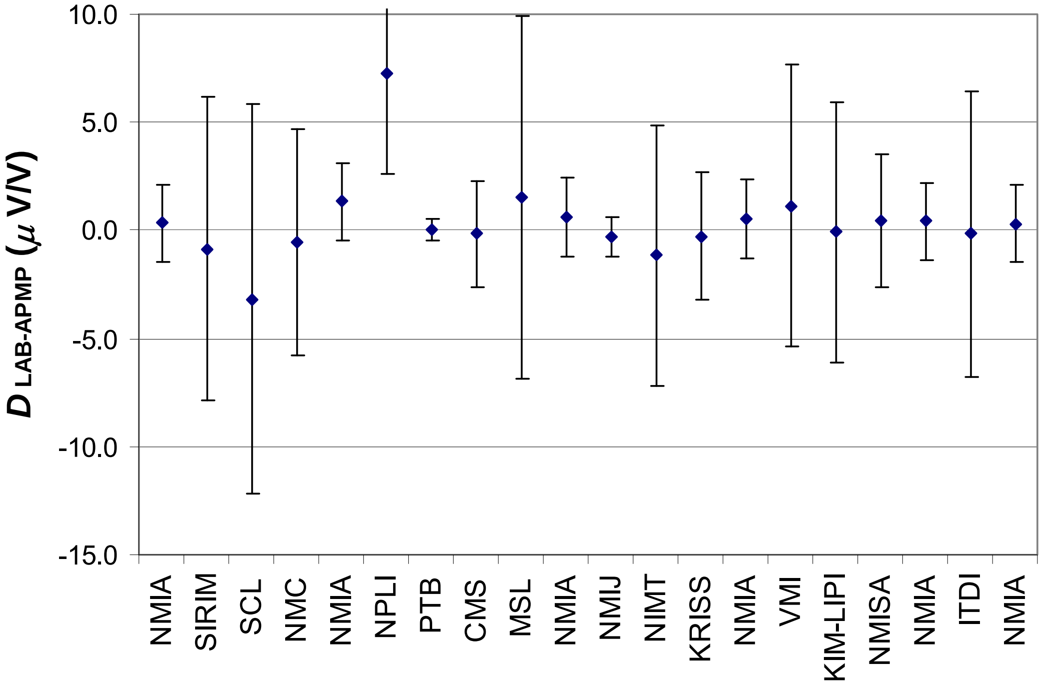
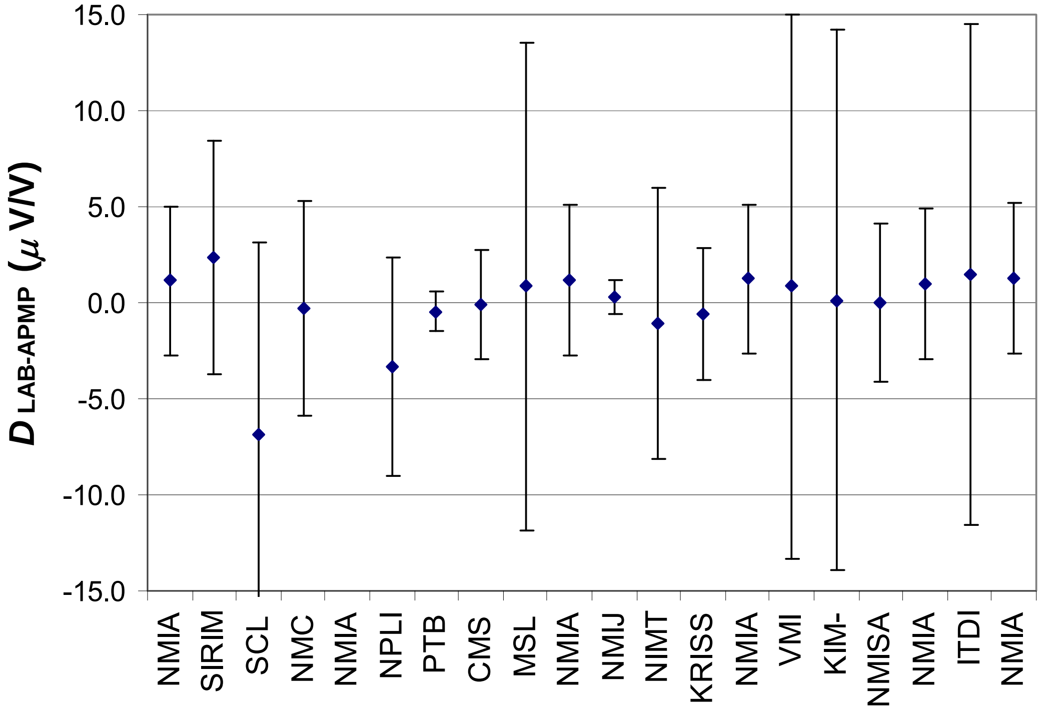
Deviation $D_{LAB\text{-}APMP}$ from APMP reference value and expanded uncertainty at 95% confidence level $U_{LAB\text{-}APMP}$ in μV/V (continued).

20 kHz

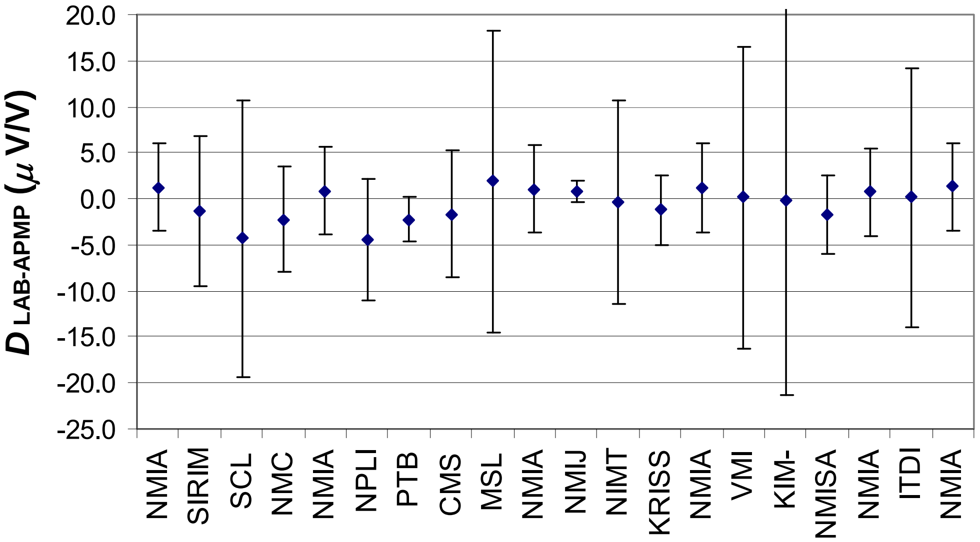


50 kHz

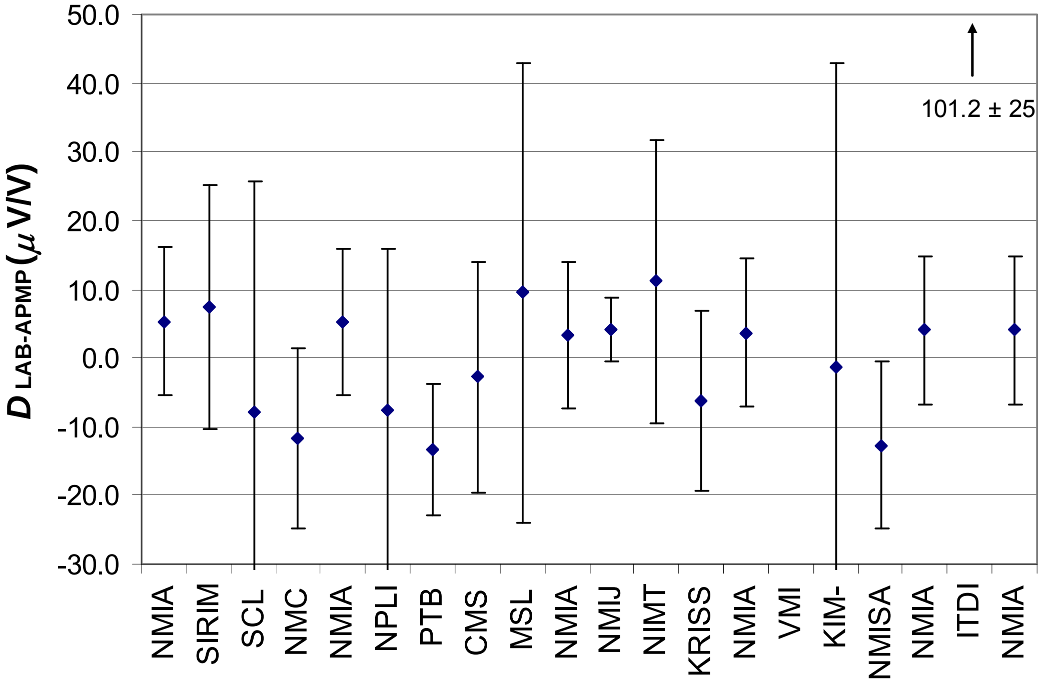


Deviation $D_{LAB-APMP}$ from APMP reference value and expanded uncertainty at 95% confidence level $U_{LAB-APMP}$ in μV/V (continued).

100 kHz



500 kHz



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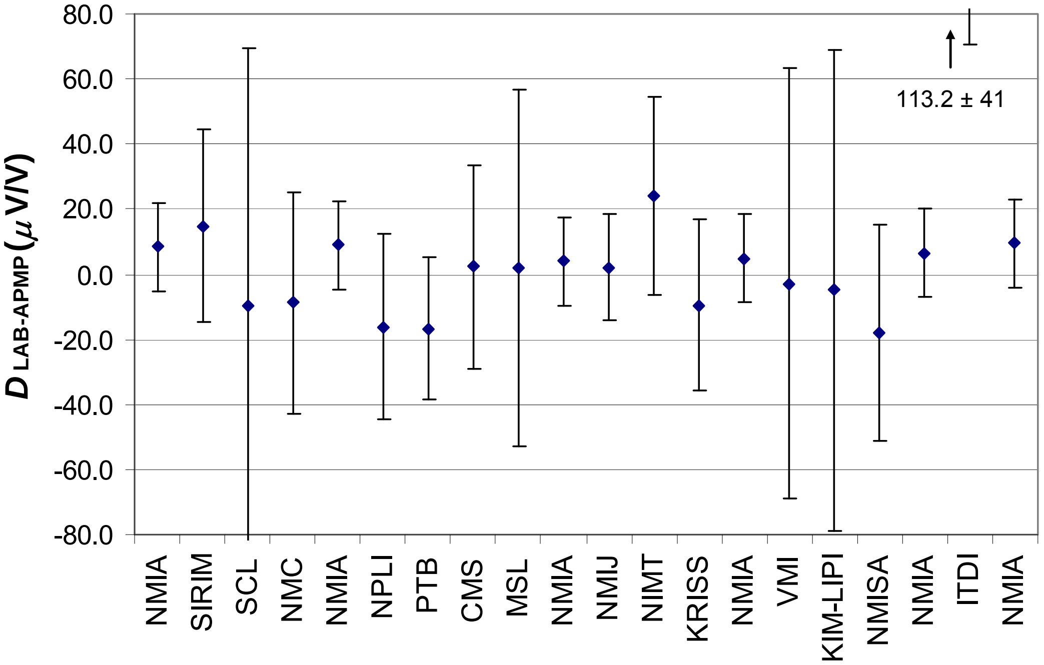
Deviation $D_{\text{LAB-APMP}}$ from APMP reference value and expanded uncertainty at 95% confidence level $U_{\text{LAB-APMP}}$ in μV/V (continued).

1 MHz



12. Linking the Results to CCEM-K6a

At the compulsory frequencies of 1 kHz, 20 kHz, 100 kHz and 1 MHz, the results of APMP.EM-K6a can be linked to CCEM-K6a through two of the three above laboratories, NMIA and PTB, that took part in both comparisons. Using their results, the difference between theAPMP.EM-K6 reference value $\delta_{\text{REF-APMP}}$ and the CCEM-K6a reference value $\delta_{\text{REF-CCEM}}$ can be expressed as follows:

$$\delta_{\text{REF-APMP}} - \delta_{\text{REF-CCEM}} = \sum w_{\text{LAB}} \left(D_{\text{LAB-CCEM}} - D_{\text{LAB-APMP}} \right), \qquad (5)$$

where $D_{\text{LAB-CCEM}}$ and $D_{\text{LAB-APMP}}$ are the deviations from CCEM-K6a and APMP.EM-K6a reference values of the linking laboratories, shown with corresponding expanded uncertainty in [1] and Table 5, respectively, and w_{LAB} is the weight calculated from:

$$w_{\text{LAB}} = \frac{\dfrac{1}{t^2_{\text{LAB-CCEM}} + t^2_{\text{LAB-APMP}} + 2r^2_{\text{LAB}}}}{\sum \dfrac{1}{t^2_{\text{LAB-CCEM}} + t^2_{\text{LAB-APMP}} + 2r^2_{\text{LAB}}}}, \qquad (6)$$

where $t_{\text{LAB-CCEM}}$, $t_{\text{LAB-APMP}}$ are transfer uncertainties caused essentially by the instability of the travelling standard and r_{LAB} is the uncertainty corresponding to imperfect reproducibility of the measurements at the laboratory in the period elapsed between the two comparisons. This uncertainty has been determined through a separate comparison held between NMIA and PTB in 2003.

Table 6
Deviation $D_{LAB-CCEM}$ from CCEM Reference Value and expanded uncertainty (95%) $U_{LAB-CCEM}$ in μV/V

Laboratory	1 kHz		20 kHz		100 kHz		1 MHz	
	$D_{LAB-CCEM}$	$U_{LAB-CCEM}$	$D_{LAB-CCEM}$	$U_{LAB-CCEM}$	$D_{LAB-CCEM}$	$U_{LAB-CCEM}$	$D_{LAB-CCEM}$	$U_{LAB-CCEM}$
NMIA	-0.2	1.5	0.1	2.2	0.2	4.6	5.2	24
PTB	0.1	0.4	0.1	1	-0.6	2	-13	24

NMIA figures in Table 6 have been adjusted by a small shift in NMIA values that occurred since participation in CCEM-K6a. The new values are the result of the study of the effect of different tee pieces mentioned above in section 2 and have been obtained by subtracting the corrections given in Table I from the values reported in [1].

The uncertainties of the link $u_{APMP-CCEM}$ have been calculated in accordance with [7] from

$$\frac{1}{u^2_{\text{APMP-CCEM}}} = \sum \frac{1}{t^2_{\text{LAB-CCEM}} + t^2_{\text{LAB-APMP}} + 2r^2_{\text{LAB}}}. \qquad (7)$$

Calculations in accordance with (5) - (7) yield the differences and expanded uncertainties given in Table 7.

Table 7
Correction $\delta_{REF-APMP}$ - $\delta_{REF-CCEM}$ and its expanded uncertainty (95%) $U_{APMP-CCEM}$ in μV/V

1 kHz		20 kHz		100 kHz		1 MHz	
δ	U	δ	U	δ	U	δ	U
-0.1	0.3	-0.2	0.9	0.4	2.0	0.7	5.0

These differences are added to the values shown in Table 5 to obtain the values of each participant's deviation $D_{LAB-CCEM}$ from the CCEM-K6a reference value.

Table 8 shows the deviation $D_{LAB-CCEM}$ from the CCEM-K6a reference value and its uncertainty. For the laboratories that did not take part in CCEM-K6a, the uncertainty has been obtained from the sum of squares of uncertainties in Tables 5 and 7.

Table8
Deviation $D_{LAB-CCEM}$ from CCEM Reference Value and expanded uncertainty (95%) $U_{LAB-CCEM}$ in μV/V

Laboratory	Deviation from CCEM-K6a Reference Value $D_{LAB-CCEM}$ and Expanded Uncertainty (95%) U_{LAB} in μV/V at Frequencies							
	1 kHz		20 kHz		100 kHz		1 MHz	
	δ	U	δ	U	δ	U	δ	U
NMIA	**-0.2**	1.5	**0.1**	2.2	**0.2**	4.6	**5.2**	24.0
SIRIM	**-0.4**	5.0	**-1.1**	7.1	**-0.9**	8.4	**15.6**	29.9
SCL	**-4.9**	9.0	**-3.4**	9.1	**-3.9**	15.2	**-8.9**	79.1
NMC	**0.0**	5.2	**-0.8**	5.3	**-1.8**	6.1	**-8.1**	34.5
NPLI	**-3.3**	4.4	**7.0**	4.7	**-4.0**	6.9	**-15.4**	29.0
PTB	**0.1**	0.4	**0.1**	1.0	**-0.6**	2.0	**-13.0**	24.0
ITRI	**-0.4**	2.1	**-0.4**	2.6	**-1.2**	7.2	**3.1**	31.7
MSL	**0.7**	6.2	**1.3**	8.5	**2.3**	16.5	**2.5**	54.9
NMIJ	**-0.1**	1.0	**-0.5**	1.3	**1.3**	2.3	**2.8**	17.1
NIMT	**0.4**	5.0	**-1.4**	6.1	**0.1**	11.3	**24.8**	30.8
KRISS	**-1.5**	3.0	**-0.5**	3.1	**-0.8**	4.2	**-8.8**	26.6
VMI	**0.4**	4.4	**0.9**	6.6	**0.6**	16.5	**-2.1**	66.3
KIM-LIPI	**0.3**	5.0	**-0.3**	6.1	**0.2**	21.2	**-4.1**	74.1
NMISA	**1.2**	3.1	**0.2**	3.2	**-1.3**	4.7	**-17.1**	33.6
ITDI	**3.5**	8.8	**-0.4**	6.7	**0.6**	14.2	**113.9**	43.0

13. Degree of Equivalence between Pairs of Laboratories

For two mutually independent laboratories *i* and *j* the degree of equivalence $D_{i,j}$ and its expanded uncertainty $U(D_{i,j})$ have been calculated as:

$$D_{i,j} = d_i - d_j \text{ , and} \tag{8}$$

$$U^2(D_{i,j}) = U^2(d_i) + U^2(d_j) - 2r_{ij}U(d_i)U(d_j), \tag{9}$$

where r_{ij} is the correlation coefficient for the results of NMI_i and NMI_j due to mutual correlation. The value of r_{ij} has been taken as zero for all pairs of laboratories, including mutually dependent laboratories. This is because, as evident from the results, the uncertainties of the laboratories that take the traceability from other NMIs are significantly larger than those of the calibration of their standards by the reference NMI. The values $D_{i,j}$ and $U(D_{i,j})$ are shown in Tables 9 to 14.

14. Conclusions

The APMP International Comparison of Ac-dc Transfer Standards at the Lowest Attainable Level of Uncertainty APMP.EM-K6a started in 2000 and concluded in 2003. The travelling standard has not been damaged and has shown excellent stability. The results submitted by the overwhelming majority of the participants lie well within the reported uncertainty. At the standard frequencies the results have been linked to those of the CCEM-K6a Key Comparison. The main results of these comparisons have been published in [8].

Since the completion of this comparisons the two reference laboratories, NMIA and PTB, have made adjustments to the values of their primary standards based on further research [9,10]. Applying the new values in the frequency range from 100 kHz to 1 MHz significantly reduces the difference to the reference value of this comparison. The uncertainties in this frequency range have also decreased. It is recommended that NMIs that are traceable to NMIA and PTB have their standards recalibrated.

Table 9
Degree of Equivalence between pairs of laboratories at 1 kHz
$D_{i,j}$ and its expanded uncertainty (95%) $U(D_{i,j})$ in μV/V

	NMIA		NML-SIRIM		SCL		NMC		NPLI		PTB		CMS	
	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$
NMIA			0.5	5.1	5.0	9.0	0.1	5.3	3.4	4.5	0.3	0.9	0.5	2.2
NML-SIRIM	-0.5	5.1			4.5	10	-0.4	7.2	2.9	6.7	-0.2	5.1	0.0	5.4
SCL	-5.0	9.0	-4.5	10			-4.9	10	-1.6	10	-4.7	9.0	-4.5	9.2
NMC	-0.1	5.3	0.4	7.2	4.9	10			3.3	6.8	0.2	5.3	0.4	5.6
NPLI	-3.4	4.5	-2.9	6.7	1.6	10	-3.3	6.8			-3.1	4.5	-2.9	4.9
PTB	-0.3	0.9	0.2	5.1	4.7	9.0	-0.2	5.3	3.1	4.5			0.2	2.2
CMS	-0.5	2.2	0.0	5.4	4.5	9.2	-0.4	5.6	2.9	4.9	-0.2	2.2		
MSL	0.6	6.3	1.1	8.0	5.6	11	0.7	8.1	4.0	7.6	0.9	6.3	1.1	6.6
NMIJ	-0.3	1.2	0.3	5.1	4.8	9.1	-0.2	5.3	3.2	4.5	0.0	1.2	0.3	2.3
NIMT	0.3	5.1	0.8	7.1	5.3	10	0.4	7.2	3.7	6.7	0.6	5.1	0.8	5.4
KRISS	-1.6	3.0	-1.1	5.8	3.4	9.5	-1.5	6.0	1.8	5.3	-1.3	3.0	-1.1	3.6
VMI	0.3	4.5	0.8	6.7	5.3	10	0.4	6.8	3.7	6.3	0.6	4.5	0.8	4.9
KIM-LIPI	0.2	5.1	0.7	7.1	5.2	10	0.3	7.2	3.6	6.7	0.5	5.1	0.7	5.4
NMISA	1.1	3.1	1.6	5.9	6.1	9.5	1.2	6.0	4.5	5.4	1.4	3.1	1.6	3.7
ITDI	3.4	8.8	3.9	10	8.4	13	3.5	10	6.8	9.9	3.7	8.8	3.9	9.1

	MSL		NMIJ		NIMT		KRISS		VMI		KIM-LIPI		NMISA		ITDI	
	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$
NMIA	-0.6	6.3	0.3	1.2	-0.3	5.1	1.6	3.0	-0.3	4.5	-0.2	5.1	-1.1	3.1	-3.4	8.8
NML-SIRIM	-1.1	8.0	-0.3	5.1	-0.8	7.1	1.1	5.8	-0.8	6.7	-0.7	7.1	-1.6	5.9	-3.9	10
SCL	-5.6	11	-4.8	9.1	-5.3	10	-3.4	9.5	-5.3	10.0	-5.2	10	-6.1	9.5	-8.4	13
NMC	-0.7	8.1	0.2	5.3	-0.4	7.2	1.5	6.0	-0.4	6.8	-0.3	7.2	-1.2	6.0	-3.5	10
NPLI	-4.0	7.6	-3.2	4.5	-3.7	6.7	-1.8	5.3	-3.7	6.3	-3.6	6.7	-4.5	5.4	-6.8	9.9
PTB	-0.9	6.3	0.0	1.2	-0.6	5.1	1.3	3.0	-0.6	4.5	-0.5	5.1	-1.4	3.1	-3.7	8.8
CMS	-1.1	6.6	-0.3	2.3	-0.8	5.4	1.1	3.6	-0.8	4.9	-0.7	5.4	-1.6	3.7	-3.9	9.1
MSL			0.9	6.3	0.3	8.0	2.2	6.9	0.3	7.6	0.4	8.0	-0.5	6.9	-2.8	11
NMIJ	-0.9	6.3			-0.6	5.1	1.4	3.1	-0.6	4.5	-0.5	5.1	-1.4	3.2	-3.7	8.9
NIMT	-0.3	8.0	0.6	5.1			1.9	5.8	0.0	6.7	0.1	7.1	-0.8	5.9	-3.1	10
KRISS	-2.2	6.9	-1.4	3.1	-1.9	5.8			-1.9	5.3	-1.8	5.8	-2.7	4.2	-5.0	9.3
VMI	-0.3	7.6	0.6	4.5	0.0	6.7	1.9	5.3			0.1	6.7	-0.8	5.4	-3.1	9.9
KIM-LIPI	-0.4	8.0	0.5	5.1	-0.1	7.1	1.8	5.8	-0.1	6.7			-0.9	5.9	-3.2	10
NMISA	0.5	6.9	1.4	3.2	0.8	5.9	2.7	4.2	0.8	5.4	0.9	5.9			-2.3	9.3
ITDI	2.8	11	3.7	8.9	3.1	10	5.0	9.3	3.1	9.9	3.2	10	2.3	9.3		

Table 10

Degree of Equivalence between Pairs of Laboratories at 20 kHz

$D_{i,j}$ and its expanded uncertainty (95%) $U(D_{i,j})$ in μV/V

	NMIA		NML-SIRIM		SCL		NMC		NPLI		PTB		CMS		MSL		NMIJ		NIMT		KRISS		VMI		KIM-LIPI		NMISA		ITDI	
	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$
NMIA			1.5	7.3	3.8	9.2	1.2	5.5	-6.6	5.0	0.6	1.9	0.8	3.1	-0.9	8.6	0.9	2.0	1.8	6.3	0.9	3.5	-0.5	6.8	0.7	6.3	0.2	3.6	0.8	6.9
NML-SIRIM	-1.5	7.3			2.3	11	-0.3	8.8	-8.1	8.4	-0.9	7.0	-0.7	7.5	-2.4	11	-0.6	7.1	0.3	9.3	-0.6	7.6	-2.0	9.6	-0.8	9.3	-1.3	7.7	-0.7	10
SCL	-3.8	9.2	-2.3	11			-2.6	10	-10.4	10	-3.2	9.0	-3.0	9.4	-4.7	12	-2.9	9.1	-2.0	11	-2.9	9.5	-4.3	11	-3.1	11	-3.6	9.5	-3.0	11
NMC	-1.2	5.5	0.3	8.8	2.6	10			-7.8	7.0	-0.6	5.3	-0.4	5.8	-2.1	9.9	-0.3	5.3	0.6	8.0	-0.3	6.0	-1.7	8.4	-0.5	8.0	-1.0	6.1	-0.4	8
NPLI	6.6	5.0	8.1	8.4	10.4	10	7.8	7.0			7.2	4.7	7.4	5.3	5.7	9.6	7.5	4.7	8.4	7.6	7.5	5.5	6.1	8.0	7.3	7.6	6.8	5.6	7.4	8.1
PTB	-0.6	1.9	0.9	7.0	3.2	9.0	0.6	5.3	-7.2	4.7			0.2	2.5	-1.5	8.4	0.3	1.0	1.2	6.1	0.3	3.0	-1.1	6.5	0.1	6.1	-0.4	3.1	0.2	6.6
CMS	-0.8	3.1	0.7	7.5	3.0	9.4	0.4	5.8	-7.4	5.3	-0.2	2.5			-1.7	8.8	0.1	2.6	1.0	6.5	0.1	3.9	-1.3	7.0	-0.1	6.5	-0.6	3.9	0.0	7.1
MSL	0.9	8.6	2.4	11	4.7	12	2.1	9.9	-5.7	9.6	1.5	8.4	1.7	8.8			1.8	8.5	2.7	10	1.8	8.9	0.4	11	1.6	10	1.1	9.0	1.7	11
NMIJ	-0.9	2.0	0.6	7.1	2.9	9.1	0.3	5.3	-7.5	4.7	-0.3	1.0	-0.1	2.6	-1.8	8.5			0.9	6.1	0.0	3.1	-1.4	6.6	-0.2	6.1	-0.7	3.2	-0.1	6.7
NIMT	-1.8	6.3	-0.3	9.3	2.0	11	-0.6	8.0	-8.4	7.6	-1.2	6.1	-1.0	6.5	-2.7	10	-0.9	6.1			-0.9	6.7	-2.3	8.9	-1.1	8.5	-1.6	6.8	-1.0	9
KRISS	-0.9	3.5	0.6	7.6	2.9	9.5	0.3	6.0	-7.5	5.5	-0.3	3.0	-0.1	3.9	-1.8	8.9	0.0	3.1	0.9	6.7			-1.4	7.2	-0.2	6.7	-0.7	4.3	-0.1	7.3
VMI	0.5	6.8	2.0	9.6	4.3	11	1.7	8.4	-6.1	8.0	1.1	6.5	1.3	7.0	-0.4	11	1.4	6.6	2.3	8.9	1.4	7.2			1.2	8.9	0.7	7.2	1.3	9.3
KIM-LIPI	-0.7	6.3	0.8	9.3	3.1	11	0.5	8.0	-7.3	7.6	-0.1	6.1	0.1	6.5	-1.6	10	0.2	6.1	1.1	8.5	0.2	6.7	-1.2	8.9			-0.5	6.8	0.1	9
NMISA	-0.2	3.6	1.3	7.7	3.6	9.5	1.0	6.1	-6.8	5.6	0.4	3.1	0.6	3.9	-1.1	9.0	0.7	3.2	1.6	6.8	0.7	4.3	-0.7	7.2	0.5	6.8			0.6	7.3
ITDI	-0.8	6.9	0.7	10	3.0	11	0.4	8	-7.4	8.1	-0.2	6.6	0.0	7.1	-1.7	11	0.1	6.7	1.0	9	0.1	7.3	-1.3	9.3	-0.1	9	-0.6	7.3		

Table 11

Degree of Equivalence between Pairs of Laboratories at 50 kHz

$D_{i,j}$ and its expanded uncertainty (95%) $U(D_{i,j})$ in μV/V

	NMIA		NML-SIRIM		SCL		NMC		NPLI		PTB		CMS		MSL		NMIJ		NIMT		KRISS		VMI		KIM-LIPI		NMISA		ITDI	
	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$
NMIA			-1.2	7.2	8.0	11	1.4	6.8	4.5	6.9	1.6	4.0	1.2	4.8	0.3	13	0.9	4.0	2.2	8.1	1.7	5.2	0.3	15	1.0	15	1.1	5.7	-0.3	14
NML-SIRIM	1.2	7.2			9.2	12	2.6	8.3	5.7	8.3	2.8	6.2	2.4	6.7	1.5	14	2.1	6.1	3.4	9.3	2.9	7.0	1.5	15	2.2	15	2.3	7.3	0.9	14
SCL	-8.0	11	-9.2	12			-6.6	11	-3.5	12	-6.4	10	-6.8	10	-7.7	16	-7.1	10	-5.8	12	-6.3	11	-7.7	17	-7.0	17	-6.9	11	-8.3	16
NMC	-1.4	6.8	-2.6	8.3	6.6	11			3.1	8.0	0.2	5.7	-0.2	6.3	-1.1	14	-0.5	5.7	0.8	9.0	0.3	6.6	-1.1	15	-0.4	15	-0.3	6.9	-1.7	14
NPLI	-4.5	6.9	-5.7	8.3	3.5	12	-3.1	8.0			-2.9	5.8	-3.3	6.4	-4.2	14	-3.6	5.7	-2.3	9.1	-2.8	6.6	-4.2	15	-3.5	15	-3.4	7.0	-4.8	14
PTB	-1.6	4.0	-2.8	6.2	6.4	10	-0.2	5.7	2.9	5.8			-0.4	3.0	-1.3	13	-0.7	1.4	0.6	7.1	0.1	3.6	-1.3	14	-0.6	14	-0.5	4.2	-1.9	13
CMS	-1.2	4.8	-2.4	6.7	6.8	10	0.2	6.3	3.3	6.4	0.4	3.0			-0.9	13	-0.3	3.0	1.0	7.6	0.5	4.5	-0.9	14	-0.2	14	-0.1	5.0	-1.5	13
MSL	-0.3	13	-1.5	14	7.7	16	1.1	14	4.2	14	1.3	13	0.9	13			0.6	13	1.9	15	1.4	13.2	0.0	19	0.7	19	0.8	13	-0.6	18
NMIJ	-0.9	4.0	-2.1	6.1	7.1	10	0.5	5.7	3.6	5.7	0.7	1.4	0.3	3.0	-0.6	13			1.3	7.1	0.8	3.5	-0.6	14	0.1	14	0.2	4.2	-1.2	13
NIMT	-2.2	8.1	-3.4	9.3	5.8	12	-0.8	9.0	2.3	9.1	-0.6	7.1	-1.0	7.6	-1.9	15	-1.3	7.1			-0.5	7.8	-1.9	16	-1.2	16	-1.1	8.2	-2.5	15
KRISS	-1.7	5.2	-2.9	7.0	6.3	11	-0.3	6.6	2.8	6.6	-0.1	3.6	-0.5	4.5	-1.4	13	-0.8	3.5	0.5	7.8			-1.4	15	-0.7	14	-0.6	5.3	-2.0	13
VMI	-0.3	15	-1.5	15	7.7	17	1.1	15	4.2	15	1.3	14	0.9	14	0.0	19	0.6	14	1.9	16	1.4	15			0.7	20	0.8	15	-0.6	19
KIM-LIPI	-1.0	15	-2.2	15	7.0	17	0.4	15	3.5	15	0.6	14	0.2	14	-0.7	19	-0.1	14	1.2	16	0.7	14	-0.7	20			0.1	15	-1.3	19
NMISA	-1.1	5.7	-2.3	7.3	6.9	11	0.3	6.9	3.4	7.0	0.5	4.2	0.1	5.0	-0.8	13	-0.2	4.2	1.1	8.2	0.6	5.3	-0.8	15	-0.1	15			-1.4	14
ITDI	0.3	14	-0.9	14	8.3	16	1.7	14	4.8	14	1.9	13	1.5	13	0.6	18	1.2	13	2.5	15	2.0	13	0.6	19	1.3	19	1.4	14		

Table 12

Degree of Equivalence between Pairs of Laboratories at 100 kHz

$D_{i,j}$ and its expanded uncertainty (95%) $U(D_{i,j})$ in μV/V

	NMIA		NML-SIRIM		SCL		NMC		NPLI		PTB		CMS		MSL		NMIJ		NIMT		KRISS		VMI		KIM-LIPI		NMISA		ITDI	
	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$
NMIA			2.4	9.4	5.4	16	3.3	7.5	5.5	8.1	3.3	5.3	2.7	8.4	-0.8	17	0.2	4.9	1.4	12	2.3	6.0	0.9	17	1.3	22	2.8	6.4	0.9	15
NML-SIRIM	-2.4	9.4			3.0	17	0.9	10	3.1	10	0.9	8.5	0.3	11	-3.2	18	-2.2	8.2	-1.0	14	-0.1	8.9	-1.5	18	-1.1	23	0.4	9.2	-1.5	16
SCL	-5.4	16	-3.0	17			-2.1	16	0.1	16	-2.1	15	-2.7	17	-6.2	22	-5.2	15	-4.0	19	-3.1	16	-4.5	22	-4.1	26	-2.6	16	-4.5	21
NMC	-3.3	7.5	-0.9	10	2.1	16			2.2	8.8	0.0	6.3	-0.6	9.0	-4.1	17	-3.1	5.9	-1.9	13	-1.0	6.9	-2.4	17	-2.0	22	-0.5	7.2	-2.4	15
NPLI	-5.5	8.1	-3.1	10	-0.1	16	-2.2	8.8			-2.2	7.0	-2.8	9.5	-6.3	18	-5.3	6.7	-4.1	13	-3.2	7.6	-4.6	18	-4.2	22	-2.7	7.8	-4.6	16
PTB	-3.3	5.3	-0.9	8.5	2.1	15	0.0	6.3	2.2	7.0			-0.6	7.3	-4.1	17	-3.1	2.6	-1.9	11	-1.0	4.4	-2.4	17	-2.0	21	-0.5	4.9	-2.4	14
CMS	-2.7	8.4	-0.3	11	2.7	17	0.6	9.0	2.8	9.5	0.6	7.3			-3.5	18	-2.5	7.0	-1.3	13	-0.4	7.8	-1.8	18	-1.4	22	0.1	8.1	-1.8	16
MSL	0.8	17	3.2	18	6.2	22	4.1	17	6.3	18	4.1	17	3.5	18			1.0	16	2.2	20	3.1	16.8	1.7	23	2.1	27	3.6	17	1.7	22
NMIJ	-0.2	4.9	2.2	8.2	5.2	15	3.1	5.9	5.3	6.7	3.1	2.6	2.5	7.0	-1.0	16			1.2	11	2.1	3.9	0.7	16	1.1	21	2.6	4.4	0.7	14
NIMT	-1.4	12	1.0	14	4.0	19	1.9	13	4.1	13	1.9	11	1.3	13	-2.2	20	-1.2	11			0.9	11.7	-0.5	20	-0.1	24	1.4	12	-0.5	18
KRISS	-2.3	6.0	0.1	8.9	3.1	16	1.0	6.9	3.2	7.6	1.0	4.4	0.4	7.8	-3.1	17	-2.1	3.9	-0.9	12			-1.4	17	-1.0	21	0.5	5.7	-1.4	15
VMI	-0.9	17	1.5	18	4.5	22	2.4	17	4.6	18	2.4	17	1.8	18	-1.7	23	-0.7	16	0.5	20	1.4	17			0.4	27	1.9	17	0.0	22
KIM-LIPI	-1.3	22	1.1	23	4.1	26	2.0	22	4.2	22	2.0	21	1.4	22	-2.1	27	-1.1	21	0.1	24	1.0	21	-0.4	27			1.5	21	-0.4	25
nmisa	-2.8	6.4	-0.4	9.2	2.6	16	0.5	7.2	2.7	7.8	0.5	4.9	-0.1	8.1	-3.6	17	-2.6	4.4	-1.4	12	-0.5	5.7	-1.9	17	-1.5	21			-1.9	15
ITDI	-0.9	15	1.5	16	4.5	21	2.4	15	4.6	16	2.4	14	1.8	16	-1.7	22	-0.7	14	0.5	18	1.4	15	0.0	22	0.4	25	1.9	15		

Table 13
Degree of Equivalence between Pairs of Laboratories at 500 kHz
$D_{i,j}$ and its expanded uncertainty (95%) $U(D_{i,j})$ in μV/V

	NMIA		NML-SIRIM		SCL		NMC		NPLI		PTB		CMS		MSL		NMIJ		NIMT		KRISS		VMI		KIM-LIPI		NMISA		ITDI	
	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$
NMIA			-3	21	12	35	16	17	12	26	18	14	7	20	-5	35	0	12	-7	23	11	17	4	11	6	46	17	16	-97	28
NML-SIRIM	3	21			15	38	19	22	15	29	21	20	10	25	-2	38	3	18	-4	27	14	22	7	18	9	48	20	22	-94	31
SCL	-12	35	-15	38			4	36	0	41	6	35	-5	37	-17	47	-12	34	-19	39	-2	36	-8	33	-7	56	5	36	-109	42
NMC	-16	17	-19	22	-4	36			-4	27	2	16	-9	21	-21	36	-16	14	-23	25	-6	19	-12	13	-11	46	1	18	-113	29
NPLI	-12	26	-15	29	0	41	4	27			6	25	-5	29	-17	41	-12	24	-19	31	-1	27	-8	23	-6	50	5	26	-109	35
PTB	-18	14	-21	20	-6	35	-2	16	-6	25			-11	19	-23	35	-17	11	-25	23	-7	16	-13	10	-12	45	-1	16	-115	27
CMS	-7	20	-10	25	5	37	9	21	5	29	11	19			-12	37	-7	18	-14	27	4	21	-3	17	-2	47	10	21	-104	31
MSL	5	35	2	38	17	47	21	36	17	41	23	35	12	37			5	34	-2	39	16	36	10	33	11	56	22	36	-92	42
NMIJ	0	12	-3	18	12	34	16	14	12	24	17	11	7	18	-5	34			-7	21	10	14	4	5	5	45	17	13	-97	26
NIMT	7	23	4	27	19	39	23	25	19	31	25	23	14	27	2	39	7	21			17	24	11	21	12	49	24	24	-90	33
KRISS	-11	17	-14	22	2	36	6	19	1	27	7	16	-4	21	-16	36	-10	14	-17	24			-6	13	-5	46	6	18	-108	29
VMI	-4	11	-7	18	8	33	12	13	8	23	13	10	3	17	-10	33	-4	5	-11	21	6	13			1	44	13	12	-101	26
KIM-LIPI	-6	46	-9	48	7	56	11	46	6	50	12	45	2	47	-11	56	-5	45	-12	49	5	46	-1	44			11	46	-103	51
NMISA	-17	16	-20	22	-5	36	-1	18	-5	26	1	16	-10	21	-22	36	-17	13	-24	24	-6	18	-13	12	-11	46			-114	28
ITDI	97	28	94	31	109	42	113	29	109	35	115	27	104	31	92	42	97	26	90	33	108	29	101	26	103	51	114	28		

Table 14
Degree of Equivalence between Pairs of Laboratories at 1 MHz
$D_{i,j}$ and its expanded uncertainty (95%) $U(D_{i,j})$ in μV/V

	NMIA		NML-SIRIM		SCL		NMC		NPLI		PTB		CMS		MSL		NMIJ		NIMT		KRISS		VMI		KIM-LIPI		NMISA		ITDI	
	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$	$D_{i,j}$	$U^2(D_{i,j})$
NMIA			-8	32	17	80	16	37	23	32	24	26	5	34	5	56	5	21	-17	33	17	29	10	67	12	75	25	36	-106	45
NML-SIRIM	8	32			25	84	24	45	31	41	32	37	13	43	13	62	13	34	-9	42	24	39	18	72	20	80	33	44	-98	52
SCL	-17	80	-25	84			-1	86	7	84	7	82	-12	85	-11	96	-12	81	-34	85	0	83	-7	103	-5	108	8	86	-123	90
NMC	-16	37	-24	45	1	86			7	44	8	41	-11	46	-11	64	-11	38	-33	46	1	43	-6	74	-4	81	9	48	-122	55
NPLI	-23	32	-31	41	-7	84	-7	44			1	36	-19	42	-18	62	-18	33	-40	42	-7	39	-13	72	-11	79	2	44	-129	51
PTB	-24	26	-32	37	-7	82	-8	41	-1	36			-19	38	-19	59	-19	27	-41	38	-7	34	-14	70	-12	77	1	40	-130	48
CMS	-5	34	-13	43	12	85	11	46	19	42	19	38			1	63	0	35	-22	44	12	41	5	73	7	80	20	46	-111	53
MSL	-5	56	-13	62	11	96	11	64	18	62	19	59	-1	63			0	57	-22	63	11	61	5	86	7	92	20	64	-111	69
NMIJ	-5	21	-13	34	12	81	11	38	18	33	19	27	0	35	0	57			-22	35	12	31	5	68	7	76	20	37	-111	46
NIMT	17	33	9	42	34	85	33	46	40	42	41	38	22	44	22	63	22	35			34	40	27	73	29	80	42	45	-89	52
KRISS	-17	29	-24	39	0	83	-1	43	7	39	7	34	-12	41	-11	61	-12	31	-34	40			-7	71	-5	78	8	42	-123	50
VMI	-10	67	-18	72	7	103	6	74	13	72	14	70	-5	73	-5	86	-5	68	-27	73	7	71			2	99	15	74	-116	79
KIM-LIPI	-12	75	-20	80	5	108	4	81	11	79	12	77	-7	80	-7	92	-7	76	-29	80	5	78	-2	99			13	81	-118	85
NMISA	-25	36	-33	44	-8	86	-9	48	-2	44	-1	40	-20	46	-20	64	-20	37	-42	45	-8	42	-15	74	-13	81			-131	54
ITDI	106	45	98	52	123	90	122	55	129	51	130	48	111	53	111	69	111	46	89	52	123	50	116	79	118	85	131	54		

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APENDIX 1. Uncertainty Budgets

NMIA

Frequency (kHz)	1-σ Uncertainty Components (μV/V)							**Expanded Uncertainty (μV/V)**
	Re.f TVC	Type A	Ref. Drift	Connectors	Meas Setup	Total	υ_{eff}	
1	0.4	0.2	0.1	0.0	0.1	0.4	78	**0.8**
20	0.9	0.2	0.2	0.1	0.1	0.9	60	**1.9**
50	1.9	0.2	0.5	0.3	0.2	2.0	60	**4.0**
100	2.3	0.2	0.5	0.8	0.3	2.5	65	**5.0**
500	5.9	0.2	0.5	1.2	0.6	6.1	60	**12.1**
1000	8.8	0.2	1.0	1.5	1.0	9.0	55	**18.1**

NML-SIRIM

Contribution	**2V Std.**	**2V to 3V transfer**	**4V NML - 3V**	**n**	**T-piece**	**Drift in 2V Std.**	**Rounding off uncertainty**	**Combined uncertainty**	**v_eff**	***k***	**U 95%**
Unit	**(ppm)**	**(ppm)**	**(ppm)**	**(ppm)**	**(ppm)**	**(ppm)**	**(ppm)**	**(ppm)**			**(ppm)**
Evaluation Type	B	A	A	A			B				
DOF, v	50	9	49	59			∞				
Frequency (Hz)											
1000	2	0.78	0.51	1	0.05	0.05	0.29	2.44	93.4	1.99	5
20000	2.5	1.77	0.58	1	0.05	0.05	0.29	3.29	61.7	2.00	7
50000	2.5	1.21	0.53	1	0.05	0.06	0.29	3.01	79.4	1.99	6
100000	3.5	1.08	0.62	1	0.1	0.1	0.29	3.86	69.8	1.99	8
500000	8.5	1.05	0.78	1	0.1	0.1	0.29	8.66	53.9	2.01	17
1000000	13.5	1.08	0.68	1	0.1	0.1	0.29	13.60	51.5	2.01	27

SCL

Test Voltage (V)	Test Freq. (Hz)	Ks (ppm/nV)	Kx (ppm/nV)	Standard Uncertainty Contributions: Type B u(Ss) (ppm)	u(Mr) (nV)	u(Nr) (nV)	u(β) (ppm)	Type A u(random) (ppm)	Combined Standard Uncertainty u(Sx) (± ppm)	Expanded Uncertainty at 95 % C.L. U (± ppm)	Coverage Factor k
3	1 k	0.13	0.13	3.5	2.9	2.9	2.9	0.4	4.58	8.98	1.96
	20 k	0.13	0.13	3.5	2.9	2.9	2.9	0.3	4.58	8.98	1.96
	50 k	0.13	0.13	4.0	2.9	2.9	2.9	0.4	4.98	9.75	1.96
	100 k	0.13	0.13	4.5	2.9	2.9	5.8	0.3	7.35	14.40	1.96
	500 k	0.13	0.13	12.0	2.9	2.9	11.5	0.3	16.66	32.66	1.96
	1 M	0.13	0.13	27.0	2.9	2.9	28.9	0.3	39.53	77.48	1.96

$$u^2(Sx) = u^2(Ss) + Ks^2u^2(Mr) + Kx^2u^2(Nr) + u^2(\beta) + u^2(random)$$

NMC

Frequency	1 kHz	20 kHz	50 kHz	100 kHz	500 kHz	1 MHz
Type A standard uncertainty (μV/V)	**0.1**	**0.1**	**0.2**	**0.2**	**0.1**	**0.3**
▪ Standard deviation (μV/V)	0.3	0.3	0.5	0.5	0.2	0.8
Type B standard uncertainty (μV/V)	**2.5**	**2.5**	**2.8**	**2.8**	**5.5**	**15.2**
▪ Reference standard (μV/V)	1.0	1.0	1.5	1.5	5.0	15.0
▪ System Set-up (μV/V)	2.3	2.3	2.4	2.4	2.4	2.6
Combined standard uncertainty (μV/V)	**2.6**	**2.6**	**2.8**	**2.8**	**5.6**	**16**
Degree of freedom	8	8	8	8	8	8

NPLI

Uncertainty budget of the ac-dc voltage transfer difference measurement in NPL, India

Standard measurement uncertainty in ppm at different frequencies

Influence quantity	1 kHz	20 kHz	50 kHz	100 kHz	500 kHz	1000k Hz	Degrees of freedom	Type A or B	Shape of distribution
Measurement data	0.4	0.5	0.3	0.4	0.4	0.5	14	A	Normal
Reference Standard	0.6	1.0	1.8	2.2	10.0	11.1	infinity	A	Normal
Measurement set up	0.5	0.5	0.5	0.5	3.0	4.0	Infinity	B	Rectangular
Connector & Tee	0	0	0	1.0	4.0	5.0	Infinity	B	Rectangular
Value of Exponent	2.0	2.0	2.0	2.0	2.0	2.0	Infinity	B	Rectangular
Combined standard uncertainty (u_δ)	2.2	2.3	2.8	3.2	11.4	13.0			
Expanded uncertainty for 95% confidence level(U)	4.4	4.6	5.6	6.4	22.8	26.0			

PTB

The model function is: $\delta_x = \delta_s + \delta_d + \delta_{con} + \delta_{calibrator}$

δ_x	AC-DC Voltage Transfer Difference of the unknown standard
δ_s	AC-DC Voltage Transfer Difference of the standard at the 3 V taken from (5)
δ_{con}	AC-DC Voltage Transfer Difference due to the different T-connectors especially at high frequencies and electromagnetic influences from outside
$\delta_{calibrator}$	AC-DC Voltage Transfer Difference with different calibrators and calibration set-ups in the step-down
δ_d	measured difference δ_d of the ac-dc transfer differences of the unknown δ_x and the known standard δ_s

Table I shows the uncertainty budget for the PTB standard at 3 V, the PMJTC at 3 V and the calibration of the travelling standard (SJTC).

Table I Uncertainty budget

influence quantity	Standard measurement uncertainty u in µV/V at the frequencies					
	1 kHz	20 kHz	50 kHz	100 kHz	500 kHz	1 MHz
$u(\delta_{TH})$	0,01	0,01	0,01	0,01	0,01	0,01
$u(\delta_{L,G,C})$	0	0,2	0,5	0,9	4,5	9,3
$u(\delta_{skin})$	0	0	0	0	1,1	4,4
$u(\delta_{con})$	0	0	0,1	0,5	1,8	2,4
$u(\delta_{LF})$	0	0	0	0	0	0
$u(\delta_s)$	**0,0**	**0,2**	**0,5**	**1,0**	**5,0**	**10,6**
$u(\delta_A)$	0,1	0,1	0,1	0,1	0,2	0,2
$u(\delta_C)$	0,2	0,2	0,2	0,2	0,2	0,2
$u(\delta_d)$	**0,2**	**0,2**	**0,2**	**0,2**	**0,3**	**0,3**
$u(\delta_{con})$	**0**	**0**	**0,1**	**0,5**	**1,8**	**2,4**
$u(\delta_{PMJTC})$	**0,2**	**0,3**	**0,5**	**1,2**	**5,3**	**11,9**
$u(\delta_{ASJTC})$	0,2	0,2	0,2	0,2	0,2	0,2
$u(\delta_{CSJTC})$	0,2	0,2	0,2	0,2	0,2	0,2
$u(\delta_{dSJTC})$	**0,3**	**0,3**	**0,3**	**0,3**	**0,3**	**0,3**
$u(\delta_{con})$	**0**	**0**	**0,1**	**0,5**	**1,8**	**2,4**
$u(\delta_{calibrator})$	**0,2**	**0,2**	**0,3**	**0,4**	**0,6**	**2,4**
$u(\delta_{SJTC})$	**0,4**	**0,4**	**0,7**	**1,4**	**5,6**	**12,2**
U (k=2)	**0,8**	**0,8**	**1,4**	**2,8**	**11**	**25**

Remarks:

$u^2(\delta_S) = u^2(\delta_{TH}) + u^2(\delta_{L,G,C}) + u^2(\delta_{skin}) + u^2(\delta_{con}) + u^2(\delta_{LF})$;

$u^2(\delta_d) = u^2(\delta_A) + u^2(\delta_C)$;

$u^2(\delta_{PMJTC}) = u^2(\delta_s) + u^2(\delta_d) + u^2(\delta_{con})$

$u^2(\delta_{dSJTC}) = u^2(\delta_{ASJTC}) + u^2(\delta_{CSJTC})$;

$u^2(\delta_{SJTC}) = u^2(\delta_{PMJTC}) + u^2(\delta_{dSJTC}) + u^2(\delta_{con}) + u^2(\delta_{calibrator})$

$U = k\, u(\delta_{SJTC})$; k is taken as 2

CMS

Source of uncertainty	Uncertainty, µV/V, 3 V test voltage at frequency					
	1 kHz	20 kHz	50 kHz	100 kHz	500 kHz	1 MHz
Random effect	0.3	0.3	0.3	0.7	1	1.3
Standard's uncertainty	0.5	0.5	0.7	1.5	4	8
Comparator's uncertainty	0.8	1.0	1.2	3	7	12
Combined standard uncertainty	1.0	1.2	1.4	3.4	8.1	15
Degrees of freedom	1000	2074	3842	4454	34437	141807
Coverage factor, k	1.96	1.96	1.96	1.96	1.96	1.96
Expanded uncertainty	2.0	2.4	2.7	6.7	16	29

MSL

Table of Uncertainty Components							
Description	Standard Uncertainty (µV/V)						Comment
	Frequency (kHz)						
	1	**20**	**50**	**100**	**500**	**1000**	
Reference Standard	3	4	6	7.5	14	20	NML Calibration of 792A (ν = 200)
Stability of Reference	0.8	1.2	1.2	1.6	8.2	16.3	Comparison with other instruments (ν = 5)
Type A, non-linear drift and meeting definition	0.1	0.2	0.2	0.2	0.2	0.3	Evaluated during measurement process (ν = 100)
Grounding	0.5	0.5	2.0	3.0	3.0	4.0	Different grounding points (ν = 5)
Measurement set-up	0.3	0.5	0.4	0.5	1.4	2.0	Changes due to variation in equipment (ν = 13)
Difference in Tee definition	0	0	0	0.1	0.2	1.0	Change from GR tee + adaptor to Type N tee (ν = 5)
Combined standard uncertainty	3.2	4.2	6.5	8.3	16.5	26.2	
Effective degrees of freedom	199	186	171	139	68	31	
Expanded uncertainty	6.2	8.4	12.7	16.3	33.0	53.4	

APMP reference no. APMP.EM-K6.a

NMIJ

Uncertainty budget of the ac-dc voltage transfer difference measurement														
			Standard measurement uncertainty u in 10^{-6} at frequencies											
influence quantity	Type	u	1kHz	degree	20kHz	degree	50kHz	degree	100kHz	degree	500kHz	degree	1MHz	degree
reference		**u(δs)**	**0.4**		**0.4**		**0.4**		**0.6**		**2.5**		**8.0**	
Thomson effect	A	u(δTha)	0.2	10	0.2	10	0.2	10	0.2	10	0.2	10	0.2	10
	B	u(δThb)	0.3	Inf.	0.3	Inf.	0.3	Inf.	0.3	Inf.	0.3	Inf.	0.3	Inf.
reactive components and skin effect	B	u(δL,C,S)	0.0	Inf.	0.0	Inf.	0.02	Inf.	0.08	Inf.	1.93	Inf.	7.7	Inf.
connectors	B	u(δcon)	0.0	11	0.08	11	0.2	11	0.5	11	1.6	11	2	11
different measurement		**u(δd)**	**0.4**		**0.4**		**0.5**		**0.7**		**2.5**		**6.2**	
standard deviation	A	u(δa)	0.3	31	0.3	31	0.3	31	0.3	31	0.3	31	0.3	31
resolution of DVM	B	u(δr)	0.16	31	0.16	31	0.16	31	0.16	31	0.16	31	0.16	31
thermal noise	B	u(δtn)	0.09	31	0.09	31	0.09	31	0.09	31	0.09	31	0.09	31
DC offset	B	u(δoff)	0.1	31	0.1	31	0.1	31	0.1	31	0.1	31	0.1	31
stability of AC output	B	u(δsta)	0.15	31	0.15	31	0.15	31	0.15	31	0.15	31	0.15	31
index measurements	B	u(δi)	0.1	31	0.1	31	0.1	31	0.1	31	0.1	31	0.1	31
Reproducibility	B	u(δR)	0.12	6	0.12	6	0.17	6	0.23	6	0.58	6	0.87	6
connectors and T	B	u(δc,T)	0.0	11	0.08	11	0.2	11	0.5	11	1.6	11	2.00	11
AC adjustment	B	u(δad)	0.0	4	0.0	4	0.0	4	0.0	4	0.0	4	0.29	4
Grounding	B	u(δG)	0.0	11	0.0	11	0.0	11	0.07	11	1.73	11	5.77	11
Standard measurement uncertainty		**u(δx) /Effective**	**0.6**	193	**0.6**	206	**0.6**	182	**0.9**	60	**3.5**	77	10.1	100
expanded uncertainty for confidence level of 95%		**U**	**1.1**		**1.1**		**1.3**		**1.9**		**7.1**		**20.2**	

Remarks: $u^2(\delta x)=u^2(\delta s)+u^2(\delta d)$

NMIT

	Repeatabilit of meas		Calibrat of Holt 20		Drift of Standard		Calibrat of Sens		Drift in Temp drift		Drift in Hum drift		Linearity of Ac-dc	
Unit	1*10^-6		1*10^-6		1*10^-6		1*10^-6		1*10^-6		1*10^-6		1*10^-6	
Dist.	Normal		Normal		Rect		Normal		Rect		Rect		Rect	
Divisor	1		2		√3		1		√3		√3		√3	
Ci	1		1		1		1		1		1		1	
Vi	9													
Freq (Hz)	Value	ur	Value	us	Valu	du	Valu	usen	Valu	ut	Valu	uhum	Value	ulin
1 k	0.11	0.11	1.8	0.9	0.80	0.5	0.1	0.1	1	0.58	1	0.58	1	0.58
20k	0.13	0.13	2.5	1.3	0.35	0.2	0.1	0.1	1	0.58	1	0.58	1	0.58
50k	0.1	0.11	5.8	2.9	0.55	0.3	0.1	0.1	1	0.58	1	0.58	1	0.58
100k	0.19	0.19	8.2	4.1	0.35	0.2	0.1	0.1	1	0.58	1	0.58	1	0.58
500k	0.4	0.37	18	9	0.45	0.3	0.1	0.1	1	0.58	1	0.58	1	0.58
1M	0.3	0.33	28	14	0.34	0.2	0.1	0.1	1	0.58	1	0.58	1	0.58

	Error of Connector		Dist and Noise		EMI and RFI		Drift in Freq settin		Roundfing off Uncert		Resolution of DMM		Stability of UUC					
Unit	1*10^-6		1*10^-6		1*10^-6		1*10^-6		1*10^-6		1*10^-6		1*10^-6					
Dist.	Normal		Rect		Rect		Normal		Rect		Rect		Rect					
Divisor	2		√3		√3		1		√3		√3		√3					
Ci	1		1		1		1		1		1		1					
Vi																		
Freq (Hz)	Valu	ucon	Valu	udis	Valu	uemi	Valu	ufreq	Valu	uro	Valu	ures	Valu	ustb	uc	neff	k	Ue 1*10^-6
1 k	1	0.58	1	0.58	1	0.58	0.2	0.2	1	0.58	1	0.58	2.3	1.3	*2.3*	2E+06	2.000	***5***
20k	1	0.58	1	0.58	1	0.58	0.4	0.4	1	0.58	1	0.58	4.3	2.5	*3.2*	3E+06	2.000	***6***
50k	1	0.58	1	0.58	1	0.58	0.4	0.4	1	0.58	1	0.58	2.6	1.5	*3.6*	1E+07	2.000	***7***
100k	1	0.58	1	0.58	1	0.58	0.7	0.7	1	0.58	1	0.58	5.0	2.9	*5.3*	6E+06	2.000	***11***
500k	1	0.58	1	0.58	1	0.58	0.7	0.7	1	0.58	1	0.58	6.0	3.5	*9.8*	4E+06	2.000	***20***
1M	1	0.58	1	0.58	1	0.58	0.6	0.6	1	0.58	1	0.58	3.2	1.8	*14.2*	3E+07	2.000	***28***

KRISS

Source of Uncertainty	Symbol	Degrees of freedom	Standard uncertainty (μV/V) (k=1)					
			1kHz	20 kHz	50 kHz	100 kHz	500 kHz	1 MHz
1. Standard TVC	u_{B1}	∞	1.4	1.4	1.6	1.6	5.9	11.6
2. Uncertainty from N value	u_N	24	0.02	0.01	0	0.01	0.04	0.05
3. Repeated measurements	u_{AP}	96	0.41	0.4	0.4	0.5	0.64	0.79
combined standard uncertainty	u_C		1.5	1.5	1.6	1.7	5.9	11.6
effective degreees of freedom	ν_{eff}		15391	16856	27744	12129	709795	######
Expanded uncertainty(k=2)	U		2.9	2.9	3.3	3.4	11.9	23.3

VMI

Componet		Applied	Type	Distribution	ν	1kHz	20kHz	50kHz	100kHz	1MHz	Note
Reference TVC (s/n: 503-2001)	$u(\delta_{Ref})$		B	Normal	30	1.2	1.6	3.4	4.6	15.5	From report
Connectors	$u(\delta_{conn})$		B	Normal	15	1	2	4	4	10	
Drift in Ref TVC /year	$u(\delta_{RefDrift})$		B	Rectangular	20	1.0	1.0	3.0	3.0	15	
ESDM	$u(\delta_{A})$		A	Normal	4	0.3	0.3	0.2	0.4	0.4	
Temperature/Humidity	$u(\delta_{T,H})$	3 V	B	Normal	20	1	2	4	4	20	
Sensitivity Calculation	$u(\delta_{n})$		B	Normal	25	0.1	0.1	0.1	0.1	0.1	$(\Delta n_x / n_x)*\delta_{iut}$
Frequence Setting	$u(\delta_{f})$		B	Normal	20	0.1	0.1	0.1	0.1	0.1	$(\Delta f / f)*\delta_{iut}$
IUT Stability	$u(\delta_{IUT\ Stab})$		B	Normal	20	0.5	0.5	1	2	10	
Rounding off values	$u(\delta_{round\ val})$		A	Rectangular	1000	0.06	0.06	0.06	0.06	0.6	
Rounding off uncertainty	$u(\delta_{round\ unc})$		A	Rectangular	1000	0.06	0.06	0.06	0.06	0.6	

KIM-LIPI

ref=A55-2v
iut=A55-3v

A55-2v certificate from NML (ppm) =>Ref.:RN 43027											
1 kHz		20 kHz		50 kHz		100 kHz		500 kHz		1 MHz	
Diff	Uncert	Diff	Uncert	Diff	Uncert	Diff	Uncert	Diff	Uncert	Diff	Uncert
2.2	2.5	5.7	3.2	10.7	6.2	15.2	8.7	35.0	19.0	48.0	30.0

	Build up results from 2v to 3v (ppm)											
	1 kHz		20 kHz		50 kHz		100 kHz		500 kHz		1 MHz	
	iutcor	iutuncert	iutcor	iutuncert	iutcor	iutuncert	iutcor	iutuncert	iutcor	iutuncert	iutcor	iutuncert
	-4.4	0.5	-6.6	0.2	-9.1	0.4	-11.4	0.4	-18.9	0.3	-24.1	0.4
ESDM =>		0.2		0.1		0.2		0.2		0.1		0.2

A55-3v corrected (ppm)											
1 kHz		20 kHz		50 kHz		100 kHz		500 kHz		1 MHz	
iutcor	iutuncert	iutcor	iutuncert	iutcor	iutuncert	iutcor	iutuncert	iutcor	iutuncert	iutcor	iutuncert
-2.2	2.5	-0.9	3.2	1.6	6.2	3.8	8.7	16.1	19.0	23.9	30.0

ref=A55-3v
iut=Holt-4v

	Build up results from 3v to 4v (ppm)											
	1 kHz		20 kHz		50 kHz		100 kHz		500 kHz		1 MHz	
	iutcor	iutuncert	iutcor	iutuncert	iutcor	iutuncert	iutcor	iutuncert	iutcor	iutuncert	iutcor	iutuncert
	-2.6	0.4	-2.0	0.4	-1.6	0.2	-0.7	0.5	1.4	0.4	-3.1	0.4
ESDM =>		0.2		0.2		0.1		0.2		0.2		0.2

	Holt-4v corrected											
	1 kHz		20 kHz		50 kHz		100 kHz		500 kHz		1 MHz	
	iutcor	iutuncert	iutcor	iutuncert	iutcor	iutuncert	iutcor	iutuncert	iutcor	iutuncert	iutcor	iutuncert
	-4.8	2.5	-2.9	3.2	0.0	6.2	3.1	8.7	17.5	19.0	20.8	30.0
iut exp unc ==>		5		6		14		21		44		73

NMISA

UNCERTAINTY BUDGET MATRIX (UBM)	Certificate No	EMC\U-0898
	Procedure No	NML-DCLF\U-0011

Reference: *Guide to the Expression of Uncertainty in Measurement* , issued by BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML - ISO 1996

Description:	Calibration of HOLT 11 SJTC Model 90081C + Adapter 84980	Type & Serial Number	0943500001033 + 0943500001037	Range:	3 V @ 1 kHz	Metrologist: M L Temba

Mathematical Model: See Procedure in the Appendix Equation (2)

Symbol	Source of Uncertainty	Associated Uncertainty Value U(Xi) +/-	Unit	+	Floor +/-	Unit	Probability Distribution (N, R, T, U)	Divisor factor	Sensitivity Coefficient Ci	Unit	Measurement Uncertainty Contribution $U_i(y)$ +/-	+	Floor +/-	Reliability (%)	Degrees of Freedom v	Remarks
	Standards and Reference Equipment (Uncorrelated)										Unit	+	Unit			
Std	Certified Systematic Uncert. of Ref MJTC 70	2.000E+00	ppm	+			Normal K = 2	2.00	1.000E+00		1.000E+00	+		100	infinite	
Dsa	Ageing of Ref	5.000E-01	ppm	+			Rectangular √3	1.73	1.000E+00		2.887E-01	+		100	infinite	Compared from previous certificate
Da	Transfer difference measurements	4.000E-01	ppm	+			Rectangular √3	1.73	1.000E+00		2.309E-01	+		100	infinite	
Dc	Connectors and T-piece	0.000E+00	ppm	+			Rectangular √3	1.73	1.000E+00		0.000E+00	+		100	infinite	See Report NML-03-0011
De	Effect of Ambient Temperature	0.000E+00	ppm	+			Rectangular √3	1.73	1.000E+00		0.000E+00	+		100	infinite	Same room temperature controlled environment
Drs	Linearity of DVM(s)	0.000E+00	ppm	+			Triangular √6	2.45	1.000E+00		0.000E+00	+		100	infinite	Using the same input and range, otherwise check std de
Drx	Linearity of DVM(x)	0.000E+00	ppm	+			Rectangular √3	1.73	1.000E+00		0.000E+00	+		100	infinite	Using the same input and range, otherwise check std de
				+								+				
				+								+				
				+								+				
				+								+				
				+								+				
Res	Resolution of Standard / Equipment (If applicable)			+								+		100		
	Standards and Reference Equipment (Correlated)										**NOTE!**		*ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED*			
				+								+				
				+								+				
				+								+				
				+								+				
	Unit Under Test / Calibration (Uncorrelated)										**NOTE!**		*ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED*			
				+								+				
				+								+				
Res	Resolution of UUT (If applicable)			+								+		100		
Data	Type "B" Evaluation Range of the results (Rectangular)			+								+		100		
	Estimated Standard Deviation (Type "A" Evaluation)	1.230E+00					Normal K = 1	1.00			0.000E+00	ESDM			11	No of Readings 12
	Unit Under Test / Calibration (Correlated)										**NOTE!**		*ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED*			
				+								+				
				+								+				
				+								+				
	TOTAL UNCERTAINTY										Unit	+	Unit			

Best Measurement Capability (Excluding UUT contribution)	Combined Uncertainty (Normal)	Level of Confidence	1.066	+	0.000	V_{eff}	infinite	Checked and Approved By:
	Expanded Uncertainty	95,45 % K = 2	2.135	+	0	k =	2.00	
Uncertainty of Measurement	Combined Uncertainty (Normal)	Level of Confidence	1.066	+	0.000	V_{eff}	infinite	
	Expanded Uncertainty	95,45 % K = 2	2.135	+	0	k =	2.00	

CSIR-National Metrology Laboratory - dc Low Frequency   0898-UBM.xls   3 V @ 1 kHz

UNCERTAINTY BUDGET MATRIX (UBM)	Certificate No	EMC\U-0898
	Procedure No	NML-DCLF\U-0011

Reference: *Guide to the Expression of Uncertainty in Measurement* , issued by BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML - ISO 1996

Description:	Calibration of HOLT 11 SJTC Model 90081C + Adapter 84980	Type & Serial Number	0943500001033 + 0943500001037	Range:	3 V @ 20 kHz	Metrologist: M L Temba

Mathematical Model: See Procedure in the Appendix Equation (2)

Symbol	Source of Uncertainty	Associated Uncertainty Value U(Xi) +/-	Unit	+	Floor +/-	Unit	Probability Distribution (N, R, T, U)	Divisor factor	Sensitivity Coefficient Ci	Unit	Measurement Uncertainty Contribution $U_i(y)$ +/-	+	Floor +/-	Reliability (%)	Degrees of Freedom v	Remarks
	Standards and Reference Equipment (Uncorrelated)										Unit	+	Unit			
Std	Certified Systematic Uncert. of Ref MJTC 70	2.000E+00	ppm	+			Normal K = 2	2.00	1.000E+00		1.000E+00	+		100	infinite	
Dsa	Ageing of Ref	5.000E-01	ppm	+			Rectangular √3	1.73	1.000E+00		2.887E-01	+		100	infinite	Compared from previous certificate
Da	Transfer difference measurements	4.000E-01	ppm	+			Rectangular √3	1.73	1.000E+00		2.309E-01	+		100	infinite	
Dc	Connectors and T-piece	0.000E+00	ppm	+			Rectangular √3	1.73	1.000E+00		0.000E+00	+		100	infinite	See Report NML-03-0011
De	Effect of Ambient Temperature	0.000E+00	ppm	+			Rectangular √3	1.73	1.000E+00		0.000E+00	+		100	infinite	Same room temperature controlled environment
Drs	Linearity of DVM(s)	0.000E+00	ppm	+			Triangular √6	2.45	1.000E+00		0.000E+00	+		100	infinite	Using the same input and range, otherwise check std de
Drx	Linearity of DVM(x)	0.000E+00	ppm	+			Rectangular √3	1.73	1.000E+00		0.000E+00	+		100	infinite	Using the same input and range, otherwise check std de
				+								+				
				+								+				
				+								+				
				+								+				
				+								+				
Res	Resolution of Standard / Equipment (If applicable)			+								+		100		
	Standards and Reference Equipment (Correlated)										**NOTE!**		*ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED*			
				+								+				
				+								+				
				+								+				
				+								+				
	Unit Under Test / Calibration (Uncorrelated)										**NOTE!**		*ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED*			
				+								+				
				+								+				
Res	Resolution of UUT (If applicable)			+								+		100		
Data	Type "B" Evaluation Range of the results (Rectangular)			+								+		100		
	Estimated Standard Deviation (Type "A" Evaluation)	1.050E+00					Normal K = 1	1.00			0.000E+00	ESDM			11	No of Readings 12
	Unit Under Test / Calibration (Correlated)										**NOTE!**		*ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED*			
				+								+				
				+								+				
				+								+				
	TOTAL UNCERTAINTY										Unit	+	Unit			

Best Measurement Capability (Excluding UUT contribution)	Combined Uncertainty (Normal)	Level of Confidence	1.066	+	0.000	V_{eff}	infinite	Checked and Approved By:
	Expanded Uncertainty	95,45 % K = 2	2.135	+	0	k =	2.00	
Uncertainty of Measurement	Combined Uncertainty (Normal)	Level of Confidence	1.066	+	0.000	V_{eff}	infinite	
	Expanded Uncertainty	95,45 % K = 2	2.135	+	0	k =	2.00	

CSIR-National Metrology Laboratory - dc Low Frequency   0898-UBM.xls   3 V @ 20 kHz

NMISA (continued)

UNCERTAINTY BUDGET MATRIX (UBM)		
	Certificate No	EMC\U-0898
	Procedure No	NML-DCLF\U-0011

Reference: *Guide to the Expression of Uncertainty in Measurement*, issued by BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML - ISO 1995

Description:	Calibration of HOLT 11 SJTC Model 90081C + Adapter 84980	Type & Serial Number	0943500001033 + 0943500001037	Range:	3 V @ 50 kHz	Metrologist: M L Temba

Mathematical Model: See Procedure in the Appendix Equation (2)

Symbol	Source of Uncertainty	Associated Uncertainty Value U(Xi) +/-	Unit	+	Floor +/-	Floor Unit	Probability Distribution (N, R, T, U)	Divisor factor	Sensitivity Coefficient Ci	Unit	Measurement Uncertainty Contribution $U_i(y)$ +/-	+	Floor +/-	Reliability (%)	Degrees of Freedom v	Remarks
	Standards and Reference Equipment (Uncorrelated)										Unit	+	Unit			
Std	Certified Systematic Uncert. of Ref MJTC 70	3.000E+00	ppm	+			Normal K = 2	2.00	1.000E+00		1.500E+00	+		100	infinite	
Dsa	Ageing of Ref	5.000E-01	ppm	+			Rectangular √3	1.73	1.000E+00		2.887E-01	+		100	infinite	Compared from previous certificate
Da	Transfer difference measurements	4.000E-01	ppm	+			Rectangular √3	1.73	1.000E+00		2.309E-01	+		100	infinite	
Dc	Connectors and T-piece	0.000E+00	ppm	+			Rectangular √3	1.73	1.000E+00		0.000E+00	+		100	infinite	See Report NML-03-0011
De	Effect of Ambient Temperature	0.000E+00	ppm	+			Rectangular √3	1.73	1.000E+00		0.000E+00	+		100	infinite	Same room temperature controlled environment
Drs	Linearity of DVM(s)	0.000E+00	ppm	+			Triangular √6	2.45	1.000E+00		0.000E+00	+		100	infinite	Using the same input and range, otherwise check std de
Drx	Linearity of DVM(x)	0.000E+00	ppm	+			Rectangular √3	1.73	1.000E+00		0.000E+00	+		100	infinite	Using the same input and range, otherwise check std de
				+								+				
				+								+				
				+								+				
				+								+				
				+								+				
Res	Resolution of Standard / Equipment (If applicable)			+								+		100		
	Standards and Reference Equipment (Correlated)										**NOTE!** *ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED*					
				+								+				
				+								+				
				+								+				
				+								+				
	Unit Under Test / Calibration (Uncorrelated)										**NOTE!** *ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED*					
				+								+				
				+								+				
Res	Resolution of UUT (If applicable)			+								+		100		
Data	Type "B" Evaluation Range of the results (Rectangular)			+								+		100		
Data	Estimated Standard Deviation (Type "A" Evaluation)	4.500E-01					Normal K = 1	1.00			0.000E+00	ESDM			11	No of Readings 12
	Unit Under Test / Calibration (Correlated)										**NOTE!** *ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED*					
				+								+				
				+								+				
				+								+				
	TOTAL UNCERTAINTY										Unit	+	Unit			

Best Measurement Capability (Excluding UUT contribution)	Combined Uncertainty (Normal)	Level of Confidence		1.545	+	0.000	V_{eff}	infinite	Checked and Approved By:
	Expanded Uncertainty	95,45 %	K = 2	3.094	+	0	k =	2.00	
Uncertainty of Measurement	Combined Uncertainty (Normal)	Level of Confidence		1.545	+	0.000	V_{eff}	infinite	
	Expanded Uncertainty	95,45 %	K = 2	3.094	+	0	k =	2.00	

CSIR-National Metrology Laboratory - dc Low Frequency 0898-UBM.xls 3 V @ 50 kHz

UNCERTAINTY BUDGET MATRIX (UBM)		
	Certificate No	EMC\U-0898
	Procedure No	NML-DCLF\U-0011

Reference: *Guide to the Expression of Uncertainty in Measurement*, issued by BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML - ISO 1995

Description:	Calibration of HOLT 11 SJTC Model 90081C + Adapter 84980	Type & Serial Number	0943500001033 + 0943500001037	Range:	3 V @ 100 kHz	Metrologist: M L Temba

Mathematical Model: See Procedure in the Appendix Equation (2)

Symbol	Source of Uncertainty	Associated Uncertainty Value U(Xi) +/-	Unit	+	Floor +/-	Floor Unit	Probability Distribution (N, R, T, U)	Divisor factor	Sensitivity Coefficient Ci	Unit	Measurement Uncertainty Contribution $U_i(y)$ +/-	+	Floor +/-	Reliability (%)	Degrees of Freedom v	Remarks
	Standards and Reference Equipment (Uncorrelated)										Unit	+	Unit			
Std	Certified Systematic Uncert. of Ref MJTC 70	3.000E+00	ppm	+			Normal K = 2	2.00	1.000E+00		1.500E+00	+		100	infinite	
Dsa	Ageing of Ref	5.000E-01	ppm	+			Rectangular √3	1.73	1.000E+00		2.887E-01	+		100	infinite	Compared from previous certificate
Da	Transfer difference measurements	4.000E-01	ppm	+			Rectangular √3	1.73	1.000E+00		2.309E-01	+		100	infinite	
Dc	Connectors and T-piece	0.000E+00	ppm	+			Rectangular √3	1.73	1.000E+00		0.000E+00	+		100	infinite	See Report NML-03-0011
De	Effect of Ambient Temperature	0.000E+00	ppm	+			Rectangular √3	1.73	1.000E+00		0.000E+00	+		100	infinite	Same room temperature controlled environment
Drs	Linearity of DVM(s)	0.000E+00	ppm	+			Triangular √6	2.45	1.000E+00		0.000E+00	+		100	infinite	Using the same input and range, otherwise check std de
Drx	Linearity of DVM(x)	0.000E+00	ppm	+			Rectangular √3	1.73	1.000E+00		0.000E+00	+		100	infinite	Using the same input and range, otherwise check std de
				+								+				
				+								+				
				+								+				
				+								+				
				+								+				
Res	Resolution of Standard / Equipment (If applicable)			+								+		100		
	Standards and Reference Equipment (Correlated)										**NOTE!** *ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED*					
				+								+				
				+								+				
				+								+				
				+								+				
	Unit Under Test / Calibration (Uncorrelated)										**NOTE!** *ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED*					
				+								+				
				+								+				
Res	Resolution of UUT (If applicable)			+								+		100		
Data	Type "B" Evaluation Range of the results (Rectangular)			+								+		100		
Data	Estimated Standard Deviation (Type "A" Evaluation)	9.000E-01					Normal K = 1	1.00			0.000E+00	ESDM			11	No of Readings 12
	Unit Under Test / Calibration (Correlated)										**NOTE!** *ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED*					
				+								+				
				+								+				
				+								+				
	TOTAL UNCERTAINTY										Unit	+	Unit			

Best Measurement Capability (Excluding UUT contribution)	Combined Uncertainty (Normal)	Level of Confidence		1.545	+	0.000	V_{eff}	infinite	Checked and Approved By:
	Expanded Uncertainty	95,45 %	K = 2	3.094	+	0	k =	2.00	
Uncertainty of Measurement	Combined Uncertainty (Normal)	Level of Confidence		1.545	+	0.000	V_{eff}	infinite	
	Expanded Uncertainty	95,45 %	K = 2	3.094	+	0	k =	2.00	

CSIR-National Metrology Laboratory - dc Low Frequency 0898-UBM.xls 3 V @ 100 kHz

NMISA (continued)

UNCERTAINTY BUDGET MATRIX (UBM)	Certificate No	EMC\U-0898
	Procedure No	NML-DCLF\U-0011

Reference: Guide to the Expression of Uncertainty in Measurement, issued by BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML - ISO 1996

Description:	Calibration of HOLT 11 SJTC Model 90081C + Adapter 84980	Type & Serial Number	0943500001033 + 0943500001037	Range:	3 V @ 500 kHz	Metrologist: M L Temba

Mathematical Model: See Procedure in the Appendix Equation (2)

Symbol	Source of Uncertainty	Associated Uncertainty Value U(Xi) +/-	Unit	+	Floor +/-	Unit	Probability Distribution (N, R, T, U)	Divisor factor	Sensitivity Coefficient Ci	Unit	Measurement Uncertainty Contribution $U_i(y)$ +/-	+	Floor +/-	Reliability (%)	Degrees of Freedom v	Remarks
Standards and Reference Equipment (Uncorrelated)											Unit	+	Unit			
Std	Certified Systematic Uncert. of Ref MJTC 70	1.000E+01	ppm	+			Normal K = 2	2.00	1.000E+00		5.000E+00	+		100	infinite	
Dsa	Ageing of Ref	5.000E-01	ppm	+			Rectangular √3	1.73	1.000E+00		2.887E-01	+		100	infinite	Compared from previous certificate
Da	Transfer difference measurements	4.000E-01	ppm	+			Rectangular √3	1.73	1.000E+00		2.309E-01	+		100	infinite	
Dc	Connectors and T-piece	0.000E+00	ppm	+			Rectangular √3	1.73	1.000E+00		0.000E+00	+		100	infinite	See Report NML-03-0011
De	Effect of Ambient Temperature	0.000E+00	ppm	+			Rectangular √3	1.73	1.000E+00		0.000E+00	+		100	infinite	Same room temperature controlled environment
Drs	Linearity of DVM(s)	0.000E+00	ppm	+			Triangular √6	2.45	1.000E+00		0.000E+00	+		100	infinite	Using the same input and range, otherwise check std de
Drx	Linearity of DVM(x)	0.000E+00	ppm	+			Rectangular √3	1.73	1.000E+00		0.000E+00	+		100	infinite	Using the same input and range, otherwise check std de
				+								+				
				+								+				
				+								+				
				+								+				
				+								+				
Res	Resolution of Standard / Equipment (If applicable)			+								+		100		
Standards and Reference Equipment (Correlated)									**NOTE!**		***ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED***					
				+								+				
				+								+				
				+								+				
				+								+				
Unit Under Test / Calibration (Uncorrelated)									**NOTE!**		***ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED***					
				+								+				
				+								+				
Res	Resolution of UUT (If applicable)			+								+		100		
Data	Type "B" Evaluation Range of the results (Rectangular)			+								+		100		
	Estimated Standard Deviation (Type "A" Evaluation)	9.800E-01					Normal K = 1	1.00			0.000E+00	ESDM			11	No of Readings 12
Unit Under Test / Calibration (Correlated)									**NOTE!**		***ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED***					
				+								+				
				+								+				
				+								+				
TOTAL UNCERTAINTY											Unit	+	Unit			

Best Measurement Capability (Excluding UUT contribution)	Combined Uncertainty (Normal)	Level of Confidence	5.014	+	0.000	V_{eff}	infinite	Checked and Approved By:
	Expanded Uncertainty	95,45 % K = 2	10.040	+	0	k =	2.00	
Uncertainty of Measurement	Combined Uncertainty (Normal)	Level of Confidence	5.014	+	0.000	V_{eff}	infinite	
	Expanded Uncertainty	95,45 % K = 2	10.040	+	0	k =	2.00	

CSIR-National Metrology Laboratory - dc Low Frequency 0898-UBM.xls 3 V @ 500 kHz

UNCERTAINTY BUDGET MATRIX (UBM)	Certificate No	EMC\U-0898
	Procedure No	NML-DCLF\U-0011

Reference: Guide to the Expression of Uncertainty in Measurement, issued by BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML - ISO 1996

Description:	Calibration of HOLT 11 SJTC Model 90081C + Adapter 84980	Type & Serial Number	0943500001033 + 0943500001037	Range:	3 V @ 1 MHz	Metrologist: M L Temba

Mathematical Model: See Procedure in the Appendix Equation (2)

Symbol	Source of Uncertainty	Associated Uncertainty Value U(Xi) +/-	Unit	+	Floor +/-	Unit	Probability Distribution (N, R, T, U)	Divisor factor	Sensitivity Coefficient Ci	Unit	Measurement Uncertainty Contribution $U_i(y)$ +/-	+	Floor +/-	Reliability (%)	Degrees of Freedom v	Remarks
Standards and Reference Equipment (Uncorrelated)											Unit	+	Unit			
Std	Certified Systematic Uncert. of Ref MJTC 70	3.000E+01	ppm	+			Normal K = 2	2.00	1.000E+00		1.500E+01	+		100	infinite	
Dsa	Ageing of Ref	5.000E-01	ppm	+			Rectangular √3	1.73	1.000E+00		2.887E-01	+		100	infinite	Compared from previous certificate
Da	Transfer difference measurements	4.000E-01	ppm	+			Rectangular √3	1.73	1.000E+00		2.309E-01	+		100	infinite	
Dc	Connectors and T-piece	0.000E+00	ppm	+			Rectangular √3	1.73	1.000E+00		0.000E+00	+		100	infinite	See Report NML-03-0011
De	Effect of Ambient Temperature	0.000E+00	ppm	+			Rectangular √3	1.73	1.000E+00		0.000E+00	+		100	infinite	Same room temperature controlled environment
Drs	Linearity of DVM(s)	0.000E+00	ppm	+			Triangular √6	2.45	1.000E+00		0.000E+00	+		100	infinite	Using the same input and range, otherwise check std de
Drx	Linearity of DVM(x)	0.000E+00	ppm	+			Rectangular √3	1.73	1.000E+00		0.000E+00	+		100	infinite	Using the same input and range, otherwise check std de
				+								+				
				+								+				
				+								+				
				+								+				
				+								+				
Res	Resolution of Standard / Equipment (If applicable)			+								+		100		
Standards and Reference Equipment (Correlated)									**NOTE!**		***ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED***					
				+								+				
				+								+				
				+								+				
				+								+				
Unit Under Test / Calibration (Uncorrelated)									**NOTE!**		***ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED***					
				+								+				
				+								+				
Res	Resolution of UUT (If applicable)			+								+		100		
Data	Type "B" Evaluation Range of the results (Rectangular)			+								+		100		
	Estimated Standard Deviation (Type "A" Evaluation)	1.300E+00					Normal K = 1	1.00			0.000E+00	ESDM			11	No of Readings 12
Unit Under Test / Calibration (Correlated)									**NOTE!**		***ONLY CHANGE BLUE CELLS - All OTHER CELLS (WHITE) ARE PROTECTED***					
				+								+				
				+								+				
				+								+				
TOTAL UNCERTAINTY											Unit	+	Unit			

Best Measurement Capability (Excluding UUT contribution)	Combined Uncertainty (Normal)	Level of Confidence	15.005	+	0.000	V_{eff}	infinite	Checked and Approved By:
	Expanded Uncertainty	95,45 % K = 2	30.047	+	0	k =	2.00	
Uncertainty of Measurement	Combined Uncertainty (Normal)	Level of Confidence	15.005	+	0.000	V_{eff}	infinite	
	Expanded Uncertainty	95,45 % K = 2	30.047	+	0	k =	2.00	

CSIR-National Metrology Laboratory - dc Low Frequency 0898-UBM.xls 3 V @ 1 MHz