Key comparison CCEM-K6.c of

AC-DC voltage transfer standards

at selected frequencies between 1 MHz and 100 MHz

Final report

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Abstract

From August 1995 to September 1998, the CCEM-K6.c Key Comparison (which started as the CCE 92-05 comparison) of ac-dc voltage transfer standards at selected high frequencies between 1 MHz and 100 MHz was carried out. Subsequently, from December 1998 until mid 2000, some participants carried out additional measurements.
Two travelling standards were measured by 15 national standard institutes. The results at all selected frequencies in the range from 1 MHz to 100 MHz show a good agreement between most of participants. The agreement at 1 MHz is within 10 µV/V for most of the participants. The span of the majority of the reported ac-dc differences at 50 MHz is less than 0.6 mV/V, which is similar to a previous comparison but with more participants. Even at 100 MHz, most obtained results are within a span of 3 mV/V, which is considered to be a good agreement.

Note:
The CCEM has agreed to a simplified analysis of the results of CCEM-K6.c but this comparison and its analysis should not be taken a model for future comparisons.

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1. Background and summary of key comparison CCEM-K6.c

This summary endeavors to put this comparison in the present context of key comparisons organized by the Consultative Committee on Electricity and Magnetism (CCEM). It is meant to explain why the methods of organizing and carrying out the comparison differed significantly from the present rules for key comparisons based on the CIPM Mutual Recognition Arrangement (MRA) of October 1999 and the accompanying Guidelines for CIPM Key Comparisons [1].

In June 1992 the Consultative Committee on Electricity (CCE, later renamed CCEM) agreed CCE comparison 92-5 of single junction thermal voltage converters at frequencies between 1 MHz and 50 MHz and at a voltage of 4 V with the Nederlands Meetinstituut, Van Swinden Laboratorium (NMi-VSL) as pilot laboratory. Between October 1994 and February 1995 the NMi-VSL characterized the travelling standards; in August 1995 a “European loop” of the comparison began. For practical purposes, the European loop included participants in a technically identical comparison called EUROMET project 348 as well as participants in CCE 92-5. Present CIPM key comparison rules require finishing a CCEM comparison before carrying out regional metrology organization (RMO) comparisons with the same travelling standards. They also require that the CCEM and RMO comparisons be linked, usually through the participation of several laboratories in both comparisons. In the present case, EUROMET project 348 and CCEM-K6.c are linked through the repeated measurements of the pilot laboratory.

In March 1997 the European loop finished and the “worldwide loop” began. Customs problems were encountered, causing a delay in the transportation of the standards from the U.S.A. to Canada. In order to maintain the original schedule, it was decided to postpone the participation of the National Research Council (NRC-INMS) of Canada to the end of the comparison. Therefore, NRC participated in September 1998. Preliminary results of the comparison were presented at the Conference on Precision Electromagnetic Measurements in July 1998 [2], [3]. Under present rules the pilot laboratory is not allowed to present the comparison results in public before all participants have completed their measurements and the draft A comparison report has been agreed by all participants. In January 1999 the National Physical Laboratory, U.K., (NPL-UK), participated a second time, after having completed its facilities for measuring between 10 MHz and 100 MHz. The National Measurement Laboratory of Australia (CSIRO-NML), whose first participation in the comparison took place in August 1997, participated for a second time, in October 1999, following changes in its apparatus and techniques. Under present rules institutes are not allowed to participate in the original comparison after public presentation of the comparison results but the CCEM accepts that in these particular circumstances, which took place before the signing of the MRA and the formulation of the CIPM key comparison guidelines, these two comparisons can be considered as subsequent bilateral comparisons.

Another peculiarity of this comparison is that, beginning with the characterization measurements at the NMi-VSL, measurements were carried out at some optional frequencies. A total of twelve participants measured at 100 MHz and the CCEM agrees with the participants’ request to include this frequency in the final results.

In some respects this comparison is similar to key comparison CCEM-K6.a of ac-dc transfer at low frequency [4]. In the latter case the CCEM also explicitly accepted to include so many participants from the EUROMET region, and to consider the second participation of some institutes as subsequent bilateral comparisons. Besides, the CCEM is aware that significant correlations exist between the results of institutes using essentially identical basic reference standards. Since the correlation coefficients between these institutes have not been determined, explicit values of degrees of equivalence between participants cannot be presented in the comparison report. At its meeting of September 2002, the CCEM agreed to make similar exceptions in the case of CCEM-K6.c.

The key comparison has 15 participants, who, of course, are also members of the Meter Convention. A total of 17 laboratories applied for participation in the comparison, but two participants have withdrawn: SIQ, Slovenia and Telecom, Finland.

2. Introduction

At low frequencies (up to 1 MHz) the primary ac-dc transfer standards are realised using Single or Multi Junction Thermal Converters (SJTC or MJTC) [5]. The ac-dc voltage transfer difference and the corresponding uncertainty have decreased to the level of several µV/V in the audio frequency range [6]. In the high frequency range (1 MHz to 100 MHz or more) coaxial thermal converters (UHF-type) or calorimetric systems are commonly used as primary ac-dc voltage standards [7]-[12]. Furthermore, the transfer difference and uncertainty strongly increase with frequency in this range.

In instrumentation, significant progress has been made in ac calibration and measurement equipment. An added option of modern calibrators is the so-called wideband option, which generates or measures ac voltage in the MHz range with relatively high accuracy.

To be able to establish worldwide traceability for ac-dc transfer at high frequencies, the Comité Consultatif d'Électricité et Magnétisme (CCEM) decided to organize an international comparison. There has never been an extensive CCEM comparison in this range, only an (informal) comparison between six laboratories has been carried out in 1993 [13]. In the meantime, the CCEM has designated this type of comparison as one of its key comparisons.

3. Scope of the comparison

3.1. Definition of the measurand

The ac-dc transfer difference δ of the travelling standards is defined as:

$$\delta = \frac{V_{\mathrm{ac}} - V_{\mathrm{dc}}}{V_{\mathrm{dc}}} \qquad \textbf{(1)}$$

where V_{ac} is the root-mean-square (rms) value of the applied ac voltage, and V_{dc} is the direct voltage which, when reversed, produces the same mean output voltage of the standard as V_{ac}.

In this comparison, two travelling standards were used. The participants have also been asked to compare both standards against each other, using the T-connector provided with the standards. The result of this measurement can be used by the participants to have a consistency check of their measuring set-ups. Systematic deviations in the participant's set-up or problems with the travelling standards can be detected by the pilot laboratory when the reported ac-dc transfer differences are analysed.

$$\delta_{\mathrm{A55\text{-}HF}} = \delta_{\mathrm{A55}} - \delta_{\mathrm{HF}} \qquad \textbf{(2)}$$

3.2. Definition of the frequency range

During the last decades, several ac-dc transfer comparisons have been carried out concerning the low frequency range, up to 1 MHz, one of them as a CCEM key comparison [6]. The scope of the presented comparison is to extend the frequency range up to 100 MHz (see Table 1). This range covers the transition from the LF ac-dc voltage transfer to the RF voltage in 50 Ω systems. The 0.5 MHz and 1 MHz point are included to create an overlap with the CCEM-K6.a comparison [4].

Table 1 Measurement parameters for the two travelling standards.

Standard	Input	Mandatory frequencies (MHz)	Optional frequencies (MHz)
TS-HF	4 V	1, 10, 30, 50 and 100*)	0.5 and 70
TS-A55	3 V	1, 10, 30, 50 and 100*)	0.5 and 70
TS-HF vs. TS-A55	3 V		0.5, 1, 10, 30, 50, 70 and 100

*) Initially 100 MHz was considered as an optional frequency, but later, some of the participants proposed to include 100 MHz as a required frequency. The CCEM has accepted this proposal.

4. Travelling standards

4.1. Description of the standards

Two travelling standards were used in the comparison:
- *NMi-VSL Calculable HF ac-dc transfer standard (TS-HF)* [7], [8]

This ac-dc standard consists of a 5 mA thermoelement in series with a range resistor made by the NMi-VSL for this purpose. This combination has a nominal input voltage of 4 V and a corresponding output voltage of 7 mV. The standard is equipped with a type-N male input connector.
- *Fluke A55 thermal converter (TS-A55)*

A commercial Fluke A55 3 V thermal converter is used as the second travelling standard which is equipped with a GR-874 input connector. It has a nominal input voltage of 3 V and also a 7 mV output voltage.

4.2. Connectors and reference plane

The middle of a T-connector defines the reference plane for the ac-dc transfer measurements. Using different input connectors can cause connector compatibility problems. Therefore, an asymmetrical T-connector was provided with an N (female) connector on one side and a GR-874 connector on the other side.

5. Participating laboratories

The NMi Van Swinden Laboratorium is the pilot laboratory for this comparison. The effect of transportation on the long-term stability of the travelling standards had not been characterized before beginning the comparison. The pilot laboratory therefore initially scheduled three check measurements during the comparison. However, serious transportation problems arose during the comparison and additional comparisons were subsequently added at the end of the main comparison. All of this has led to the need for additional check measurements so that a total of seven check measurements was carried out by the pilot laboratory.

NRC-INMS had been scheduled in the main comparison after NIST. Custom problems between the U.S.A. and Canada caused a delay in the transport of the standards. In order to maintain the original schedule, it was decided to postpone the NRC participation to the end of the comparison. After this, additional bilateral comparisons were carried out; the NPL-UK asked to participate a second time, but now at frequencies above 1 MHz and the NML-CSIRO requested a subsequent bilateral comparison after taking actions to improve its measurements [17] following its first measurements in August 1997.

The participants are listed below in the chronological order in which they have participated:

1. Nederlands Meetinstituut - Van Swinden Laboratorium (NMI-VSL),
   The Netherlands, C.J. van Mullem.
2. Physikalisch-Technische Bundesanstalt (PTB),
   Germany, M. Klonz and D. Janik.
3. D.I. Mendeleyev Institute For Metrology (VNIIM),
   Russia, G.P. Telitchenko, V.M. Baikov.
4. National Office of Measures (OMH),
   Hungary, A. Török, A. Jakab.
5. National Physical Laboratory (NPL-UK1),
   United Kingdom, G. Jones (up to 1 MHz).
6. Bureau National de Métrologie - Laboratoire National d'Essais (BNM-LNE)[1],
   France, M. Valon and L. Erard.
7. AREPA Test & Kalibrering A/S (AREPA),
   Denmark, T. Lippert.
8. Swiss Federal Office of Metrology and Accreditation (METAS)[2],
   Switzerland, M. Flüeli.
9. SP Sverige Provnings- och Forskningsinstitut (SP),
   Sweden, K.-E. Rydler (up to 30 MHz).
10. Centro Español de Metrologia (CEM),
    Spain, J.M. Balmisa, M. Neira, S. Ramiro, and M. Martínez
11. National Institute of Standards and Technology (NIST),
    U.S.A., J. Kinard and G. Free.
12. Commonwealth Scientific and Industrial Research Organisation -
    National Measurement Laboratory (CSIRO-NML1),
    Australia, I.F. Budovsky and J. Petranovic.
13. National Physical Laboratory (NPLI),
    India, V.K. Rustagi and A.K. Govil.
14. Korean Research Institute of Standards and Science (KRISS),
    South Korea, J.H. Kim and S.W. Kwon.
15. National Research Council -
    Institute for National Measurement Standards (NRC-INMS),
    Canada, P.S. Filipski.

[1] BNM-LCIE (Bureau National de Métrologie - Laboratoire Central des Industries Electriques) at the time of the measurements

[2] OFMET (Office Fédéral de Métrologie) at the time of the measurements

Subsequent bilateral comparisons

5. National Physical Laboratory (NPL-UK2),
   United Kingdom, G. Jones (above 1 MHz).
12. Commonwealth Scientific and Industrial Research Organisation -
   National Measurement Laboratory (CSIRO-NML2),
   Australia, I.F. Budovsky and S. Grady.

Note: In this report, the laboratories are referred to by the acronyms as given in the list above. For laboratories which have performed more than one series of measurements (NMi-VSL, NPL-UK and CSIRO-NML), a sequential number is added to the acronym to specify which series of measurements is referred to.

Table 2 Reference standards and measurement procedure used by the institutes (independent realisations of the reference standard are printed in bold on a green background).

Institute	Primary standard <= 1 MHz	Primary standard => 10 MHz	Measurement system
NMI-VSL	**VSL HF SJTC (SJTC + 700 Ω)**	**VSL HF SJTC (SJTC + 700 Ω)**	ac-dc transfer system (automatic)
PTB	**PTB MJTC**	**PTB Calorimetric voltage standard**	ac-dc transfer system (automatic)
VNIIM	**VNIIM converter (SJTC + 1 kΩ)**	**VNIIM converter (SJTC + 1 kΩ)**	ac-dc transfer system (manual)
OMH	OMH MJTC	**Calorimetric voltage standard**	ac-dc transfer system (automatic)
NPL-UK	**SJTC + 900 Ω**	EUR HF SJTC	ac-dc transfer system
BNM-LNE	Holt 20 converter	Holt 20 converter	RF-dc manual system
AREPA	EUR HF SJTC	EUR HF SJTC	ac-dc transfer system (automatic)
METAS	EUR HF SJTC	EUR HF SJTC	ac-dc transfer system (automatic)
SP	MJTC (PTB-cal.)	EUR HF SJTC	ac-dc transfer system (automatic)
CEM	MJTC (PTB-cal.) EUR HF SJTC	EUR HF SJTC	ac-dc transfer system (automatic)
NIST	**NIST SJTC + 1 kΩ**	**NIST SJTC**	ac-dc transfer system (automatic)
CSIRO-NML	**NML TC**	**Twin line calorimeter**	Aut. Comparison system
NPL-I	**NPLI MJTC**	**Calorimetric voltage standard**	Semi-aut. Comparison System
KRISS	KRISS MJTC (PTB type +cal)	**RF power and impedance standard**	ac-dc transfer system (automatic)
NRC-INMS	**NRC Calorimetric voltage standard**	**NRC Calorimetric voltage standard**	ac-dc transfer system (automatic)

6. Laboratory procedures and standards

The laboratory procedures and reference standards used by the participants have been described in more or less detail in the measurement reports, which the participants provided to the pilot laboratory. In cases where the report contained insufficient information or if unusually large ac-dc deviations were reported, the participant was asked to give additional information.

In most of the participating laboratories the reference standards for frequencies up to 1 MHz are different from those used at higher frequencies. Table 2 lists the reference standards used by the participants for the two frequency ranges. Six European national institutes (NMi-VSL, METAS, SP, CEM, AREPA, and NPL-UK) use the calculable HF ac-dc transfer standard (the EUR HF SJTC), fabricated by the NMi-VSL, as their primary standard. One of these instruments was also used as the travelling standard (TS-HF). All of these standards used by the participants in this comparison were initially calibrated by NMi-VSL. Other institutes use different primary reference standards. These are either coaxial types of thermal converters or calorimetric systems. All independent realisations are printed in bold on a green background in Table 2.

Almost all participants use an automatic or semi-automatic system to compare the travelling standards against their reference standard. In general, the ac-dc measurement consists of an input signal sequence dc+, ac, dc-, ac, dc+, etc.. Some institutes use a two-step method to determine the ac-dc difference, first the ac-ac(ref) measurement and second the ac(ref)-dc measurement. The reference frequency is chosen between 1 kHz and 100 kHz. The outputs of the standards are read simultaneously. Depending on the system, this is done directly by DVM’s and/or the difference between the two standards to be compared is taken. The number of measurements differs from one institute to another. In general, measurements were carried out on several days with 5 to 10 cycles per single measurement to obtain a mean value of the ac-dc transfer difference.

7. Uncertainty statements

The participants have been asked to report the uncertainty analysis in accordance with the Guide to the Expression of Uncertainty in Measurement [14]. Most have provided a detailed uncertainty calculation in their report. However, some participants just reported the total uncertainty in their first version of the measurement report. Additionally, they provided more detailed budgets after being requested to do so by the pilot laboratory.

In July 2000, the participants were asked to present their uncertainty budgets according to a format as specified by the pilot laboratory. Only two institutes didn’t reply completely and their budgets have been directly reproduced from the received measurement reports. The complete set of uncertainty budgets of all the participants is found in Appendix D.

From the reported uncertainty calculations, it was concluded that the determination of the uncertainty of the reference standard is essential for the determination of the total uncertainty. Most of the participants didn't provide any detailed information about the uncertainty of their reference standard in their measurement report. The support group of this comparison, however, insisted that such information should be provided, at least by those participants of which the results have been used to determine the key comparison reference values as discussed in the next section. In February 2003, those laboratories have been asked to provide additional information about the uncertainty in their reference standard. These extended uncertainty budgets have been reported in Appendix E. One participant, NIST, has not been able to trace back this information after such a long time, for its measurements above 1 MHz. NIST reported that these facilities and reference standards have been changed after the participation in the comparison. The information about the previous system is no longer available. As an exception to the CIPM key comparison rules, in this comparison, NIST has not been excluded and the results have been included in the calculation of the reference values, as discussed in the next chapter. One positive result of this comparison is that for the first time the uncertainty budgets are under detailed and open discussion. This is a widely acknowledged benefit of this comparison.

8. Analysis of the measurement results

8.1. Corrections

The measurement results obtained by the participants were sent to the pilot laboratory. For each travelling standard and for each frequency, the result is reported as a value, δ_i, and an expanded uncertainty, U_i. The expanded uncertainty is obtained from the combined standard uncertainty, u_i, multiplied by a coverage factor, k_i. All participants used a coverage factor $k_i = 2$.

During the course of the comparison, the pilot laboratory performed several measurements on the travelling standards. Only one measurement result of the pilot laboratory is taken as the actual participation of NMi-VSL to this comparison; this is the first measurement, indicated by NMi-VSL1. All other measurements of the pilot laboratory are only used to monitor the long-term stability of the standards.

Before the results of the participants can be compared, some corrections have to be applied.

The travelling standard TS-HF has been broken once during the comparison. The instrument was repaired but this has resulted in a shift of its ac-dc transfer difference. Measurement results obtained after this accident are corrected for this step. The pilot laboratory has determined the step, δ_{step}, at all measurement frequencies. The travelling standard was measured shortly before the break down during one of the normally scheduled checks and, of course, measured again after the repair. Based on these measurements, an uncertainty, u_{step}, was determined for each value of δ_{step}. This uncertainty is added to the reported uncertainties of all participants, before and after the step occurred. The complete characterisation took one month.

The travelling standards used in this comparison hadn't been extensively characterised before the start of the comparison. From experience with similar standards, no serious problems were expected with regard to the behaviour of the standards. At the end of the comparison, the behaviour of the standards was analysed by looking at the measurements from the pilot laboratory. For both standards, at each frequency, a linear fit was calculated through the measurements of the pilot laboratory. The slope of this linear fit is considered to be a measure for the drift of the standard. The root mean squared (rms) deviation of the pilot's results from the linear fit is chosen to be an estimate of the uncertainty in the drift, u_{drift}, and at the same time, it is a measure of the consistency of the measurements. Here, a remarkable difference is observed between the two travelling standards. The deviations from the linear fit are significantly larger for TS-A55. This behaviour is not only seen in the results of the pilot laboratory, but also in the results from the other participants. It is reasonable to assume that the difference in behaviour is mainly caused by the type of input connector of the standards. It is commonly known that the contacts made by the GR-874 connector of TS-A55 do not reproduce as good as the contacts from the N connector of TS-HF. Furthermore, one participant reported that TS-A55 had been slightly overloaded during the measurements. As a result of this, TS-A55 may have become less stable. For these two reasons, it was decided that this report should be based only on the results of TS-HF. The results of TS-A55, given in Appendix B, have been worked out in a similar way as for the TS-HF converter.

Drift corrections, δ_{drift}, have been calculated for all participants at each measured frequency. These values are determined at the average measurement date of the participant.

The corrected results, δ_{ic}, are now found from:

$$\delta_{ic} = \delta_i + \delta_{\text{step}} + \delta_{\text{drift}} \tag{3}$$

with a combined uncertainty, u_{ic}:

$$u_{ic} = \sqrt{u_i^2 + u_{\text{step}}^2 + u_{\text{drift}}^2} \tag{4}$$

The results of TS-HF at the mandatory frequencies are given in Table 3 to Table 7. The corrected values δ_{ic} are also plotted in Figure 1 to Figure 5. The results of TS-HF at the optional frequencies are presented in Appendix A. The results of TS-A55 are given in Appendix B and the measurements of TS-A55 versus TS-HF are shown in Appendix C.

8.2. Calculation of the key comparison reference value

After having applied the corrections, the results from the participants are compared to find the level of agreement. For this purpose, a key comparison reference value (KCRV), δ_R, has been determined for each of frequencies included in this comparison. The results of participants to be included in the calculation of the KCRV have to meet the following criteria:

- The results are obtained from an independently realised reference standard. This means that correlated results, such as those derived from reference standards calibrated at NMI-VSL or PTB, do not contribute to the KCRV. For the pilot laboratory, only one measurement result is taken as the contribution to the key comparison reference value: NMI-VSL1.

- The results yielded an ac-dc transfer difference consistent with the other independent realisations. The presence of outliers is tested by an approach as proposed in [15]. A robust estimate of the standard deviation σ of the underlying distribution is obtained by using the median of absolute deviations (MAD), defined by:

  $$\sigma \approx S(\text{MAD}) \equiv 1.4826 \cdot \mathit{median}_i \left\{ \left| \delta_{ic} - \delta_{\text{med}} \right| \right\} \tag{5}$$

  where δ_{med} is the median of the independent results δ_{ic}, and the factor of 1.4826 is a normalisation factor that produces the correct estimate of σ for Gaussian error distributions. A value of δ_{ic} which differs from the median by more than 2.5 times S(MAD) will be considered an outlier. So, if:

  $$\left| \delta_{ic} - \delta_{\text{med}} \right| > 2.5 \cdot S(\text{MAD}) \tag{6}$$

  the point δ_{ic} is identified as an outlier.

- The results are given with an acceptable uncertainty supported by a sound uncertainty budget. This was already discussed in chapter 7.

According to equation (6), the following independent results were identified as outliers: OMH at 10 MHz and 30 MHz; KRISS at 50 MHz and 100 MHz; NPL-I at 100 MHz.

The reference value of a comparison should be the best possible estimate of the measurand being tested. There are several possibilities on how to determine a reference value. The most straightforward way, would be using the arithmetical mean of the results meeting the criteria as mentioned above. However, such an approach would only be justified if all these participants have reported uncertainties of the same order of magnitude. In this comparison, at some frequencies, differences in reported uncertainties of two orders of magnitude are observed. Therefore, the participants in this comparison have decided that the key comparison reference value, δ_R, should be taken as the weighted mean of the TS-HF results, δ_{ic}, meeting the criteria mentioned above:

$$\delta_R = \frac{\sum_{i=1}^{N} w_i \delta_{ic}}{\sum_{i=1}^{N} w_i} \quad \textbf{(7)}$$

The weight, w_i, for each laboratory, i, is found from the inverse of the squared standard uncertainty:

$$w_i = \frac{1}{u_{\delta ic}^2} \quad \textbf{(8)}$$

The uncertainty of the key comparison reference value, u_R, is calculated as experimental standard deviation of the average of the results meeting the above mentioned criteria:

$$u_R = \frac{1}{\sqrt{\sum_{i=1}^{N} w_i}} \quad \textbf{(9)}$$

The expanded uncertainty, U_R, is given by:

$$U_R = k_R \cdot u_R \quad \textbf{(10)}$$

where the coverage factor k_R = 2 is used to obtain a confidence level of approximately 95 % (see Appendix G).

The KCRV's, δ_R, and their expanded uncertainties, U_R, for TS-HF at the mandatory frequencies are given on the bottom lines of Table 3 to Table 7. In these tables, laboratories whose results have been included in the KCRV, are indicated by an asterisk (*) in the first column. For these laboratories, the last column of the table shows the percentage of contribution to the KCRV.

In Figure 1 to Figure 5 the KCRV is shown as a solid line and the expanded uncertainty is indicated by dashed lines. Participants contributing to the KCRV are indicated by blue diamonds; participants not contributing to the KCRV are indicated by red squares; the characterisation measurements of the pilot laboratory are indicated by green triangles. Some of the results may be out of the scale of the graph. In those cases, the values can be found in the corresponding table.

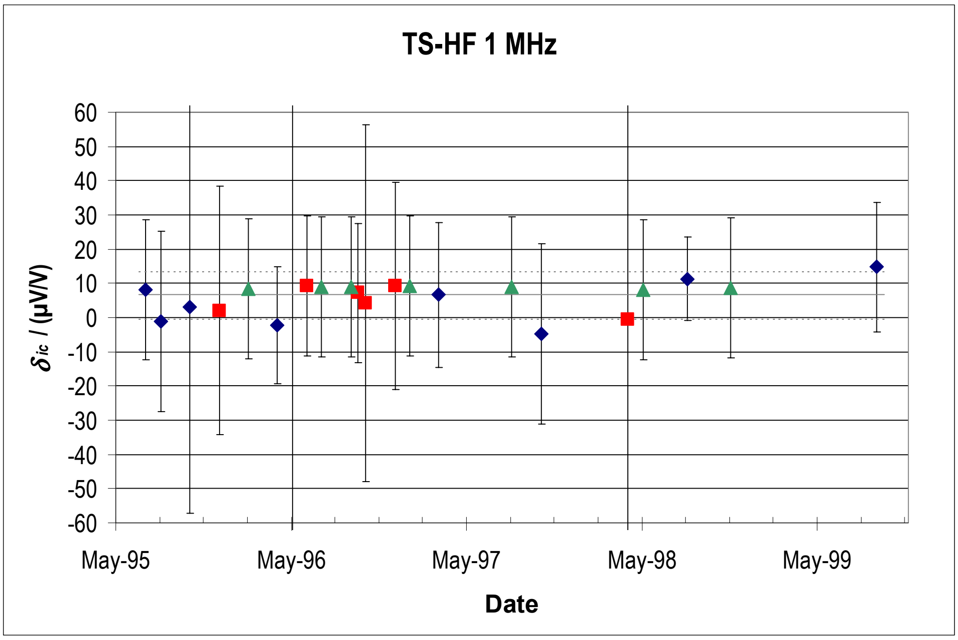

Figure 1 Corrected values of the results, δ_{ic}, and expanded uncertainties, U_{ic}, at 1 MHz. (blue diamonds: participants included in the reference value; the red squares: not included in the reference; green triangles: characterisation measurements of the pilot laboratory.) The solid line shows the reference value, δ_R, and the dashed lines indicate the expanded uncertainty, U_R in the reference value.

Table 3 Measurement results, uncertainties, corrections and the percentage of contribution to the reference value for TS-HF at 1 MHz. The reference value and its expanded uncertainty are given at the bottom line. (Laboratories indicated with * contribute to the reference value).

	Lab	Date	δ_i (µV/V)	u_i (µV/V)	δ_{step} (µV/V)	u_{step} (µV/V)	δ_{drift} (µV/V)	u_{drift} (µV/V)	δ_{ic} (µV/V)	$U_{\delta ic}$ (µV/V)	Contr. to δ_R (%)
*	NMI-VSL1	Aug-95	8.2	10.0	0.0	2.1	0.0	0.4	8.2	20.5	11.5
*	PTB	Sep-95	-1.0	13.0	0.0	2.1	0.0	0.4	-1.0	26.4	7.0
*	VNIIM	Nov-95	2.9	30.0	0.0	2.1	0.0	0.4	2.9	60.2	1.3
	OMH	Jan-96	2.0	18.0	0.0	2.1	0.1	0.4	2.1	36.3	
	NMI-VSL2	Mar-96	8.4	10.0	0.0	2.1	0.1	0.4	8.5	20.5	
*	NPL-UK1	May-96	-2.3	8.3	0.0	2.1	0.1	0.4	-2.2	17.2	16.4
	BNM-LNE	Jun-96	200.0	450.0	0.0	2.1	0.2	0.4	200.2	900.0	
	AREPA	Jul-96	9.0	10.0	0.0	2.1	0.2	0.4	9.2	20.5	
	NMI-VSL3a	Aug-96	8.8	10.0	0.0	2.1	0.2	0.4	9.0	20.5	
	NMI-VSL3b	Oct-96	8.9	10.0	-0.1	2.1	0.2	0.4	9.0	20.5	
	METAS	Oct-96	7.0	10.0	-0.1	2.1	0.2	0.4	7.2	20.5	
	SP	Nov-96	4.0	26.0	-0.1	2.1	0.2	0.4	4.2	52.2	
	CEM	Jan-97	9.0	15.0	-0.1	2.1	0.3	0.4	9.2	30.3	
	NMI-VSL4	Feb-97	9.0	10.0	-0.1	2.1	0.3	0.4	9.2	20.5	
*	NIST	Apr-97	6.4	10.4	-0.1	2.1	0.3	0.4	6.6	21.2	10.7
	NMI-VSL5	Sep-97	8.6	10.0	-0.1	2.1	0.4	0.4	9.0	20.5	
*	NPL-I	Nov-97	-5.0	13.0	-0.1	2.1	0.4	0.4	-4.6	26.4	7.0
	KRISS	May-98	-1.0	46.0	-0.1	2.1	0.5	0.4	-0.5	92.1	
	NMI-VSL6	Jun-98	7.8	10.0	-0.1	2.1	0.6	0.4	8.2	20.5	
*	NRC-INMS	Sep-98	10.8	5.7	-0.1	2.1	0.6	0.4	11.3	12.2	32.5
	NMI-VSL7	Dec-98	8.0	10.0	-0.1	2.1	0.7	0.4	8.6	20.5	
	NPL-UK2	Jan-99									
*	CSIRO-NML2	Oct-99	14.0	9.2	-0.1	2.1	0.8	0.4	14.7	18.9	13.5
	δ_R , U_R								6.6	7.0	

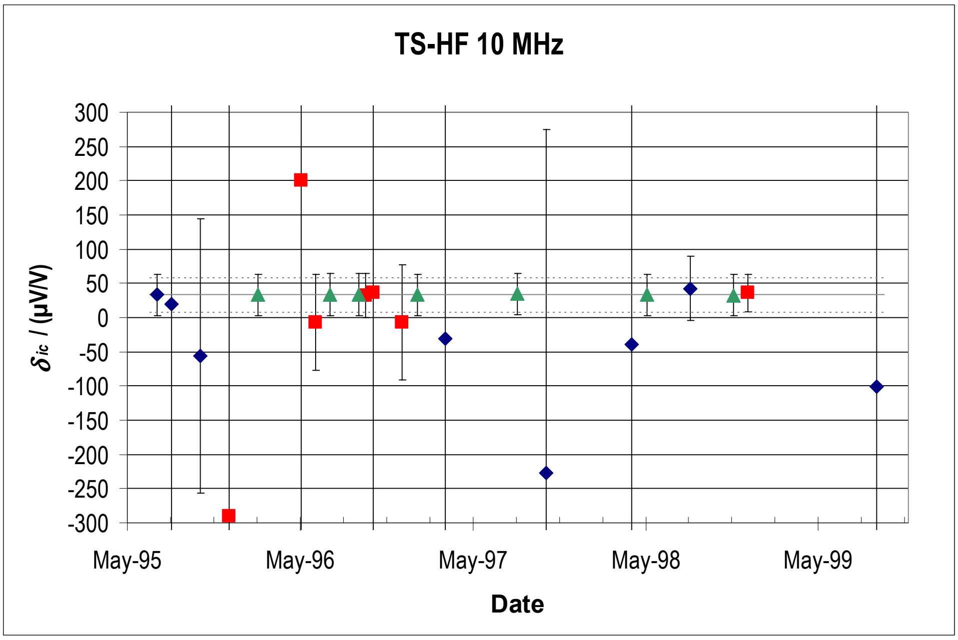

Figure 2 Corrected values of the results, δ_{ic}, and expanded uncertainties, U_{ic}, at 10 MHz.
(blue diamonds: participants included in the reference value; the red squares: not included in the reference; green triangles: characterisation measurements of the pilot laboratory.) The solid line shows the reference value, δ_R, and the dashed lines indicate the expanded uncertainty, U_R in the reference value.

Table 4 Measurement results, uncertainties, corrections and the percentage of contribution to the reference value for TS-HF at 10 MHz. The reference value and its expanded uncertainty are given at the bottom line. (Laboratories indicated with * contribute to the reference value).

	Lab	Date	δ_i (µV/V)	u_i (µV/V)	δ_{step} (µV/V)	u_{step} (µV/V)	δ_{drift} (µV/V)	u_{drift} (µV/V)	δ_{ic} (µV/V)	$U_{\delta ic}$ (µV/V)	Contr. to δ_R (%)
*	NMI-VSL1	Aug-95	33.1	15.0	0.0	2.1	0.0	0.7	33.1	30.3	68.4
*	PTB	Sep-95	20.0	260.0	0.0	2.1	0.0	0.7	20.0	520.0	0.2
*	VNIIM	Nov-95	-56.0	100.0	0.0	2.1	0.0	0.7	-56.0	200.0	1.6
	OMH	Jan-96	-290.0	580.0	0.0	2.1	0.1	0.7	-289.9	1160.0	
	NMI-VSL2	Mar-96	32.9	15.0	0.0	2.1	0.1	0.7	33.0	30.3	
	NPL-UK1	May-96									
	BNM-LNE	Jun-96	200.0	500.0	0.0	2.1	0.2	0.7	200.2	1000.0	
	AREPA	Jul-96	-7.0	35.0	0.0	2.1	0.2	0.7	-6.8	70.1	
	NMI-VSL3a	Aug-96	33.3	15.0	0.0	2.1	0.2	0.7	33.5	30.3	
	NMI-VSL3b	Oct-96	30.6	15.0	2.7	2.1	0.2	0.7	33.5	30.3	
	METAS	Oct-96	29.0	16.0	2.7	2.1	0.2	0.7	31.9	32.3	
	SP	Nov-96	33.0	260.0	2.7	2.1	0.2	0.7	35.9	520.0	
	CEM	Jan-97	-10.0	42.0	2.7	2.1	0.3	0.7	-7.1	84.1	
	NMI-VSL4	Feb-97	30.1	15.0	2.7	2.1	0.3	0.7	33.1	30.3	
*	NIST	Apr-97	-34.1	400.0	2.7	2.1	0.3	0.7	-31.1	800.0	0.1
	NMI-VSL5	Sep-97	31.7	15.0	2.7	2.1	0.4	0.7	34.8	30.3	
*	NPL-I	Nov-97	-230.0	251.0	2.7	2.1	0.4	0.7	-226.9	502.0	0.2
*	KRISS	May-98	-43.1	2433.0	2.7	2.1	0.5	0.7	-39.9	4866.0	0.0
	NMI-VSL6	Jun-98	30.0	15.0	2.7	2.1	0.5	0.7	33.2	30.3	
*	NRC-INMS	Sep-98	39.4	23.1	2.7	2.1	0.6	0.7	42.7	46.4	29.2
	NMI-VSL7	Dec-98	29.3	15.0	2.7	2.1	0.6	0.7	32.6	30.3	
	NPL-UK2	Jan-99	33.0	13.5	2.7	2.1	0.6	0.7	36.3	27.4	
*	CSIRO-NML2	Oct-99	-105.0	303.0	2.7	2.1	0.8	0.7	-101.5	606.0	0.2
	δ_R , U_R								33.5	25.1	

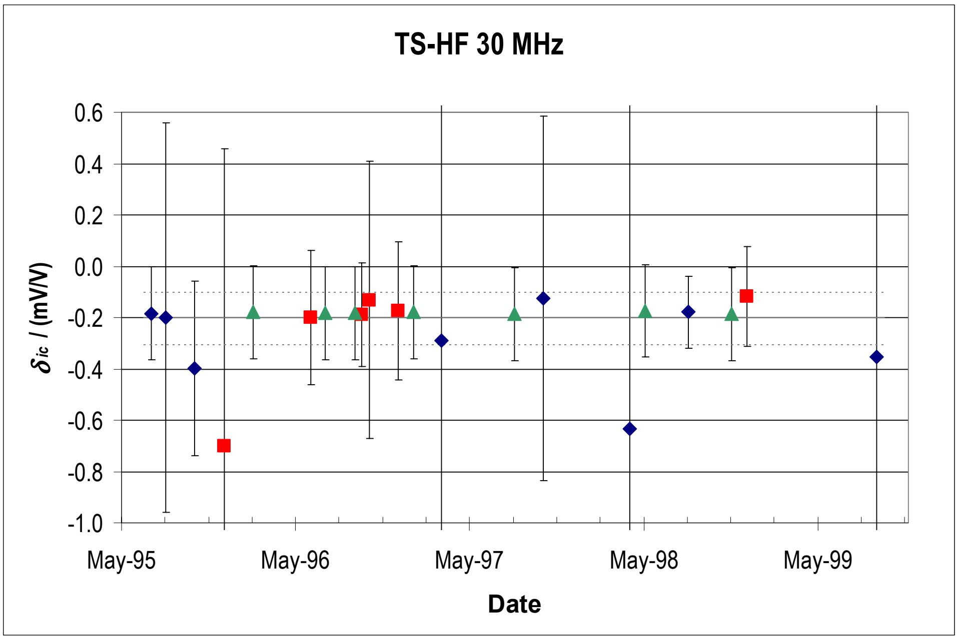

Figure 3 Corrected values of the results, δ_{ic}, and expanded uncertainties, U_{ic}, at 30 MHz.
(blue diamonds: participants included in the reference value; the red squares: not included in the reference; green triangles: characterisation measurements of the pilot laboratory.) The solid line shows the reference value, δ_R, and the dashed lines indicate the expanded uncertainty, U_R in the reference value.

Table 5 Measurement results, uncertainties, corrections and the percentage of contribution to the reference value for TS-HF at 30 MHz. The reference value and its expanded uncertainty are given at the bottom line. (Laboratories indicated with * contribute to the reference value).

	Lab	Date	δ_i (mV/V)	u_i (mV/V)	δ_{step} (mV/V)	u_{step} (mV/V)	δ_{drift} (mV/V)	u_{drift} (mV/V)	δ_{ic} (mV/V)	$U_{\delta ic}$ (mV/V)	Contr. to δ_R (%)
*	NMI-VSL1	Aug-95	-0.184	0.090	0.000	0.009	0.000	0.004	-0.184	0.181	32.0
*	PTB	Sep-95	-0.200	0.380	0.000	0.009	0.000	0.004	-0.200	0.760	1.8
*	VNIIM	Nov-95	-0.398	0.170	0.000	0.009	0.000	0.004	-0.398	0.341	9.1
	OMH	Jan-96	-0.700	0.580	0.000	0.009	0.000	0.004	-0.700	1.160	
	NMI-VSL2	Mar-96	-0.178	0.090	0.000	0.009	-0.001	0.004	-0.178	0.181	
	NPL-UK1	May-96									
	BNM-LNE	Jun-96	2.900	0.700	0.000	0.009	-0.001	0.004	2.899	1.400	
	AREPA	Jul-96	-0.200	0.130	0.000	0.009	-0.001	0.004	-0.201	0.261	
	NMI-VSL3a	Aug-96	-0.182	0.090	0.000	0.009	-0.001	0.004	-0.183	0.181	
	NMI-VSL3b	Oct-96	-0.153	0.090	-0.028	0.009	-0.001	0.004	-0.183	0.181	
	METAS	Oct-96	-0.160	0.100	-0.028	0.009	-0.001	0.004	-0.190	0.201	
	SP	Nov-96	-0.102	0.270	-0.028	0.009	-0.001	0.004	-0.132	0.540	
	CEM	Jan-97	-0.144	0.135	-0.028	0.009	-0.001	0.004	-0.174	0.271	
	NMI-VSL4	Feb-97	-0.150	0.090	-0.028	0.009	-0.001	0.004	-0.179	0.181	
*	NIST	Apr-97	-0.261	0.800	-0.028	0.009	-0.001	0.004	-0.291	1.600	0.4
	NMI-VSL5	Sep-97	-0.156	0.090	-0.028	0.009	-0.002	0.004	-0.186	0.181	
*	NPL-I	Nov-97	-0.096	0.355	-0.028	0.009	-0.002	0.004	-0.126	0.710	2.1
*	KRISS	May-98	-0.604	2.436	-0.028	0.009	-0.002	0.004	-0.635	4.872	0.0
	NMI-VSL6	Jun-98	-0.143	0.090	-0.028	0.009	-0.003	0.004	-0.174	0.181	
*	NRC-INMS	Sep-98	-0.148	0.069	-0.028	0.009	-0.003	0.004	-0.179	0.139	54.1
	NMI-VSL7	Dec-98	-0.155	0.090	-0.028	0.009	-0.003	0.004	-0.186	0.181	
	NPL-UK2	Jan-99	-0.087	0.097	-0.028	0.009	-0.003	0.004	-0.119	0.195	
*	CSIRO-NML2	Oct-99	-0.321	0.764	-0.028	0.009	-0.004	0.004	-0.353	1.528	0.4
	δ_R , U_R								-0.201	0.102	

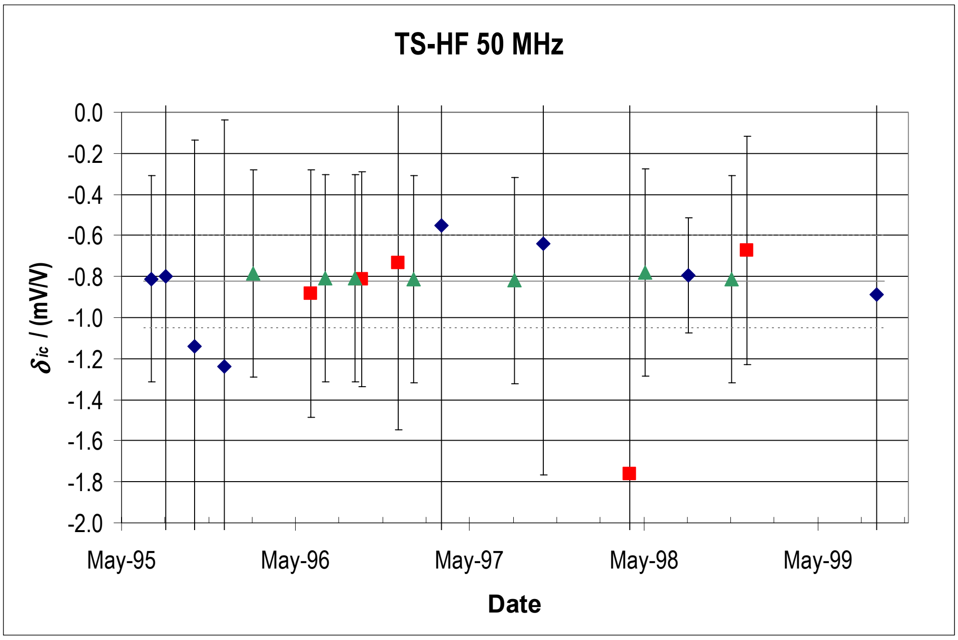

Figure 4 Corrected values of the results, δ_{ic}, and expanded uncertainties, U_{ic}, at 50 MHz.
(blue diamonds: participants included in the reference value; the red squares: not included in the reference; green triangles: characterisation measurements of the pilot laboratory.) The solid line shows the reference value, δ_R, and the dashed lines indicate the expanded uncertainty, U_R in the reference value.

Table 6 Measurement results, uncertainties, corrections and the percentage of contribution to the reference value for TS-HF at 50 MHz. The reference value and its expanded uncertainty are given at the bottom line. (Laboratories indicated with * contribute to the reference value).

	Lab	Date	δ_i (mV/V)	u_i (mV/V)	δ_{step} (mV/V)	u_{step} (mV/V)	δ_{drift} (mV/V)	u_{drift} (mV/V)	δ_{ic} (mV/V)	$U_{\delta ic}$ (mV/V)	Contr. to δ_R (%)
*	NMI-VSL1	Aug-95	-0.811	0.250	0.000	0.027	0.000	0.014	-0.811	0.504	19.8
*	PTB	Sep-95	-0.800	0.630	0.000	0.027	0.001	0.014	-0.799	1.261	3.2
*	VNIIM	Nov-95	-1.141	0.500	0.000	0.027	0.002	0.014	-1.139	1.002	5.0
*	OMH	Jan-96	-1.240	0.600	0.000	0.027	0.003	0.014	-1.237	1.202	3.5
	NMI-VSL2	Mar-96	-0.788	0.250	0.000	0.027	0.004	0.014	-0.784	0.504	
	NPL-UK1	May-96									
	BNM-LNE	Jun-96	3.700	0.550	0.000	0.027	0.005	0.014	3.705	1.102	
	AREPA	Jul-96	-0.890	0.300	0.000	0.027	0.006	0.014	-0.884	0.603	
	NMI-VSL3a	Aug-96	-0.816	0.250	0.000	0.027	0.006	0.014	-0.809	0.504	
	NMI-VSL3b	Oct-96	-0.686	0.250	-0.130	0.027	0.007	0.014	-0.808	0.504	
	METAS	Oct-96	-0.690	0.260	-0.130	0.027	0.007	0.014	-0.812	0.524	
	SP	Nov-96									
	CEM	Jan-97	-0.612	0.406	-0.130	0.027	0.009	0.014	-0.733	0.814	
	NMI-VSL4	Feb-97	-0.693	0.250	-0.130	0.027	0.009	0.014	-0.813	0.504	
*	NIST	Apr-97	-0.432	2.000	-0.130	0.027	0.010	0.014	-0.551	4.000	0.3
	NMI-VSL5	Sep-97	-0.703	0.250	-0.130	0.027	0.013	0.014	-0.820	0.504	
*	NPL-I	Nov-97	-0.525	0.563	-0.130	0.027	0.014	0.014	-0.641	1.128	3.9
	KRISS	May-98	-1.648	2.447	-0.130	0.027	0.017	0.014	-1.761	4.894	
	NMI-VSL6	Jun-98	-0.669	0.250	-0.130	0.027	0.018	0.014	-0.781	0.504	
*	NRC-INMS	Sep-98	-0.684	0.137	-0.130	0.027	0.019	0.014	-0.795	0.281	63.5
	NMI-VSL7	Dec-98	-0.705	0.250	-0.130	0.027	0.021	0.014	-0.814	0.504	
	NPL-UK2	Jan-99	-0.563	0.276	-0.130	0.027	0.021	0.014	-0.671	0.555	
*	CSIRO-NML2	Oct-99	-0.785	1.226	-0.130	0.027	0.026	0.014	-0.889	2.453	0.8
	δ_R , U_R								-0.825	0.224	

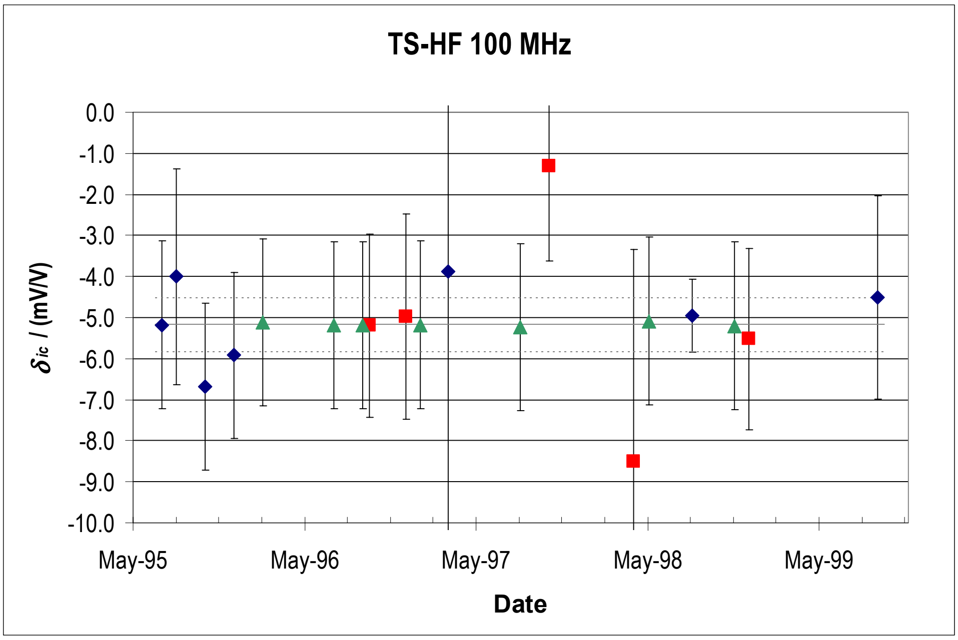

Figure 5 Corrected values of the results, δ_{ic}, and expanded uncertainties, U_{ic}, at 100 MHz. (blue diamonds: participants included in the reference value; the red squares: not included in the reference; green triangles: characterisation measurements of the pilot laboratory.) The solid line shows the reference value, δ_R, and the dashed lines indicate the expanded uncertainty, U_R in the reference value.

Table 7 Measurement results, uncertainties, corrections and the percentage of contribution to the reference value for TS-HF at 100 MHz. The reference value and its expanded uncertainty are given at the bottom line. (Laboratories indicated with * contribute to the reference value).

	Lab	Date	δ_i (mV/V)	u_i (mV/V)	δ_{step} (mV/V)	u_{step} (mV/V)	δ_{drift} (mV/V)	u_{drift} (mV/V)	δ_{ic} (mV/V)	$U_{\delta ic}$ (mV/V)	Contr. to δ_R (%)
*	NMI-VSL1	Aug-95	-5.180	1.000	0.000	0.194	0.000	0.047	-5.180	2.039	10.3
*	PTB	Sep-95	-4.000	1.300	0.000	0.194	0.001	0.047	-3.999	2.630	6.2
*	VNIIM	Nov-95	-6.687	1.000	0.000	0.194	0.004	0.047	-6.683	2.039	10.3
*	OMH	Jan-96	-5.920	0.990	0.000	0.194	0.007	0.047	-5.913	2.020	10.6
	NMI-VSL2	Mar-96	-5.127	1.000	0.000	0.194	0.009	0.047	-5.117	2.039	
	NPL-UK1	May-96									
	BNM-LNE	Jun-96									
	AREPA	Jul-96									
	NMI-VSL3a	Aug-96	-5.206	1.000	0.000	0.194	0.016	0.047	-5.190	2.039	
	NMI-VSL3b	Oct-96	-4.591	1.000	-0.615	0.194	0.019	0.047	-5.187	2.039	
	METAS	Oct-96	-4.600	1.100	-0.615	0.194	0.019	0.047	-5.195	2.236	
	SP	Nov-96									
	CEM	Jan-97	-4.381	1.230	-0.615	0.194	0.023	0.047	-4.973	2.492	
	NMI-VSL4	Feb-97	-4.588	1.000	-0.615	0.194	0.024	0.047	-5.179	2.039	
*	NIST	Apr-97	-3.282	4.000	-0.615	0.194	0.027	0.047	-3.870	8.010	0.7
	NMI-VSL5	Sep-97	-4.648	1.000	-0.615	0.194	0.034	0.047	-5.229	2.039	
	NPL-I	Nov-97	-0.741	1.130	-0.615	0.194	0.036	0.047	-1.320	2.295	
	KRISS	May-98	-7.943	2.576	-0.615	0.194	0.044	0.047	-8.514	5.167	
	NMI-VSL6	Jun-98	-4.517	1.000	-0.615	0.194	0.046	0.047	-5.086	2.039	
*	NRC-INMS	Sep-98	-4.390	0.396	-0.615	0.194	0.050	0.047	-4.955	0.886	54.9
	NMI-VSL7	Dec-98	-4.642	1.000	-0.615	0.194	0.054	0.047	-5.203	2.039	
	NPL-UK2	Jan-99	-4.965	1.087	-0.615	0.194	0.055	0.047	-5.525	2.210	
*	CSIRO-NML2	Oct-99	-3.952	1.223	-0.615	0.194	0.067	0.047	-4.500	2.478	7.0
	δ_R , U_R								-5.160	0.656	

9. Degree of equivalence

In the MRA the estimation of the degree of equivalence is used to express the agreement between pairs of participating laboratories or between a laboratory and the KCRV.

During the drafting of the final report on the key comparison CCEM-K6.a, the correlations between participants have been extensively discussed. From this discussion [4] it is stated by the CCEM WGKC/2001-20*: "The WGKC of the CCEM judges that significant correlations exist among the results of participants whose reference standard of ac-dc difference is based on calibration carried out by another participating laboratory. Although these correlations have a profound effect on the uncertainty of the degrees of equivalence between pairs of NMI's, a sufficiently accurate evaluation of covariance terms has not been identified. Consequently this appendix B entry of the KCDB does not include explicit values and uncertainties of degrees of equivalence among pairs of participants."* In stead, only the degrees of equivalence of participants with the reference value, D_i, are presented. In the September 2002 meetings of the CCEM Working Group on Key Comparisons and the CCEM itself, it was agreed to allow applying the same simplified presentation of the results of CCEM-K6.c.

The values of the degrees of equivalence with the reference value D_i are given by:

$$D_i = \delta_{ic} - \delta_R \qquad \textbf{(11)}$$

For participants who are not included in the KCRV the expanded uncertainty U_i in D_i is:

$$U_i = k_D \cdot \sqrt{u_{\delta ic}^2 + u_R^2} \qquad \textbf{(12)}$$

In case the laboratory contributes to the KCRV the expanded uncertainty U_i is given by:

$$U_i = k_D \cdot \sqrt{u_{\delta ic}^2 - u_R^2} \qquad \textbf{(13)}$$

In equations (12) and (13) k_D = 2 (see Appendix G).

The degree of equivalence D_{ij} between any pair of laboratories *i* and *j* is given by:

$$D_{ij} = D_i - D_j \qquad \textbf{(14)}$$

The correlation coefficients between pairs of laboratories have not been evaluated. Therefore, the expanded uncertainty U_{ij} in D_{ij} can only be roughly estimated, ignoring all correlations:

$$U_{ij} = \sqrt{U_{\delta ic}^2 + U_{\delta jc}^2} \qquad \textbf{(15)}$$

where $U_{\delta ic}$ and $U_{\delta jc}$ are derived from equation (4) multiplied by the coverage factor k = 2.

The degrees of equivalence, D_i, and their expanded uncertainties, U_i, for TS-HF at the mandatory frequencies, are shown in Figure 6 to Figure 10. These values are also presented in the corresponding tables: Table 8 to Table 12.
The degrees of equivalence for TS-HF at optional frequencies are given in Appendix A, and for TS-A55 at all frequencies in Appendix B.

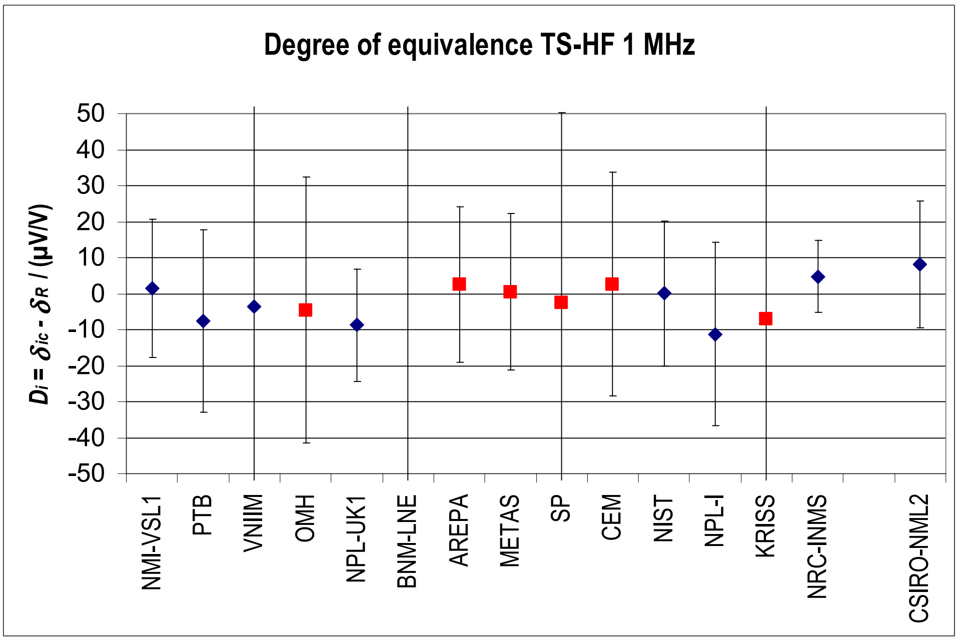

Figure 6 Degree of equivalence with the key comparison reference value at 1 MHz with the corresponding expanded uncertainties (k = 2). (blue diamonds: included in the KCRV; red squares: not included in the KCRV)

Table 8 Values of the degree of equivalence with the reference value at 1 MHz with the corresponding expanded uncertainties (k = 2). Participants indicated with (*) are included in the KCRV.

	Lab	D_i (µV/V)	U_i (µV/V)
*	NMI-VSL1	1.6	19.2
*	PTB	-7.6	25.4
*	VNIIM	-3.7	59.8
	OMH	-4.5	36.9
*	NPL-UK1	-8.8	15.7
	BNM-LNE	193.5	900.0
	AREPA	2.6	21.6
	METAS	0.5	21.6
	SP	-2.5	52.6
	CEM	2.6	31.1
*	NIST	0.0	20.1
*	NPL-I	-11.3	25.4
	KRISS	-7.2	92.4
*	NRC-INMS	4.7	10.0
*	CSIRO-NML2	8.1	17.6

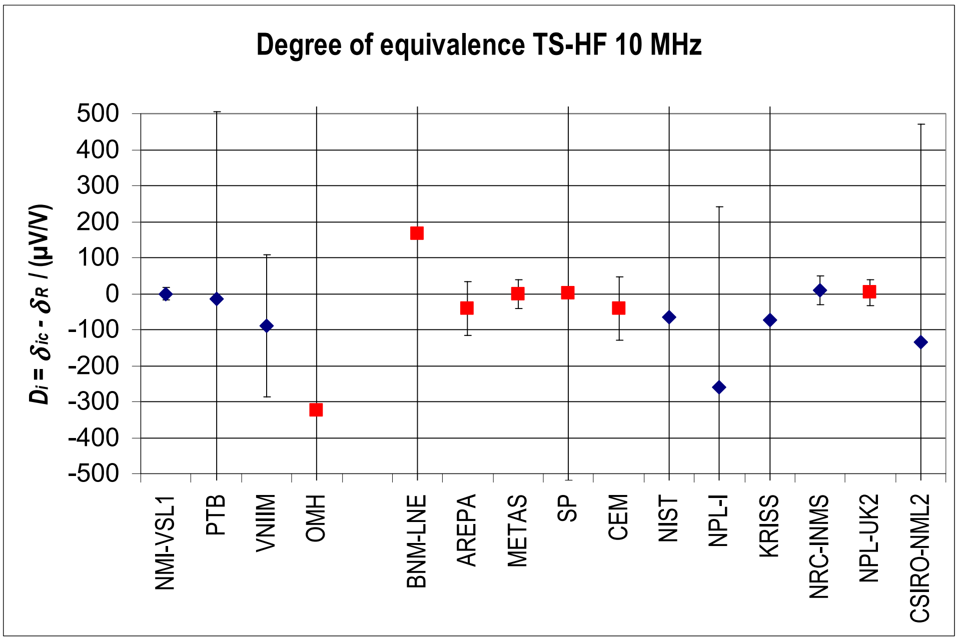

Figure 7 Degree of equivalence with the key comparison reference value at 10 MHz with the corresponding expanded uncertainties (k = 2). (blue diamonds: included in the KCRV; red squares: not included in the KCRV)

Table 9 Values of the degree of equivalence with the reference value at 10 MHz with the corresponding expanded uncertainties (k = 2). Participants indicated with (*) are included in the KCRV.

	Lab	D_i (µV/V)	U_i (µV/V)
*	NMI-VSL1	-0.4	17.0
*	PTB	-13.5	519.4
*	VNIIM	-89.4	198.5
	OMH	-323.4	1160.3
	BNM-LNE	166.7	1000.3
	AREPA	-40.3	74.5
	METAS	-1.6	40.9
	SP	2.4	520.6
	CEM	-40.5	87.8
*	NIST	-64.6	799.6
*	NPL-I	-260.4	501.4
*	KRISS	-73.4	4865.9
*	NRC-INMS	9.2	39.0
	NPL-UK2	2.8	37.1
*	CSIRO-NML2	-135.0	605.5

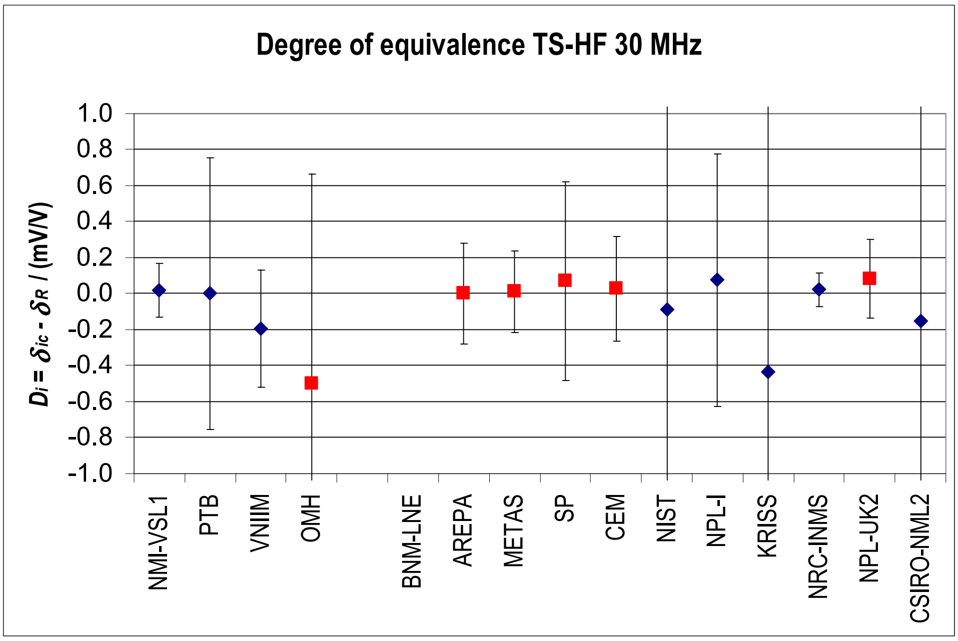

Figure 8 Degree of equivalence with the key comparison reference value at 30 MHz with the corresponding expanded uncertainties (k = 2). (blue diamonds: included in the KCRV; red squares: not included in the KCRV)

Table 10 Values of the degree of equivalence with the reference value at 30 MHz with the corresponding expanded uncertainties (k = 2). Participants indicated with (*) are included in the KCRV.

	Lab	D_i (mV/V)	U_i (mV/V)
*	NMI-VSL1	0.017	0.149
*	PTB	0.001	0.753
*	VNIIM	-0.197	0.325
	OMH	-0.499	1.165
	BNM-LNE	3.100	1.404
	AREPA	0.000	0.280
	METAS	0.012	0.226
	SP	0.070	0.550
	CEM	0.027	0.290
*	NIST	-0.090	1.597
*	NPL-I	0.075	0.703
*	KRISS	-0.433	4.871
*	NRC-INMS	0.022	0.094
	NPL-UK2	0.083	0.221
*	CSIRO-NML2	-0.152	1.525

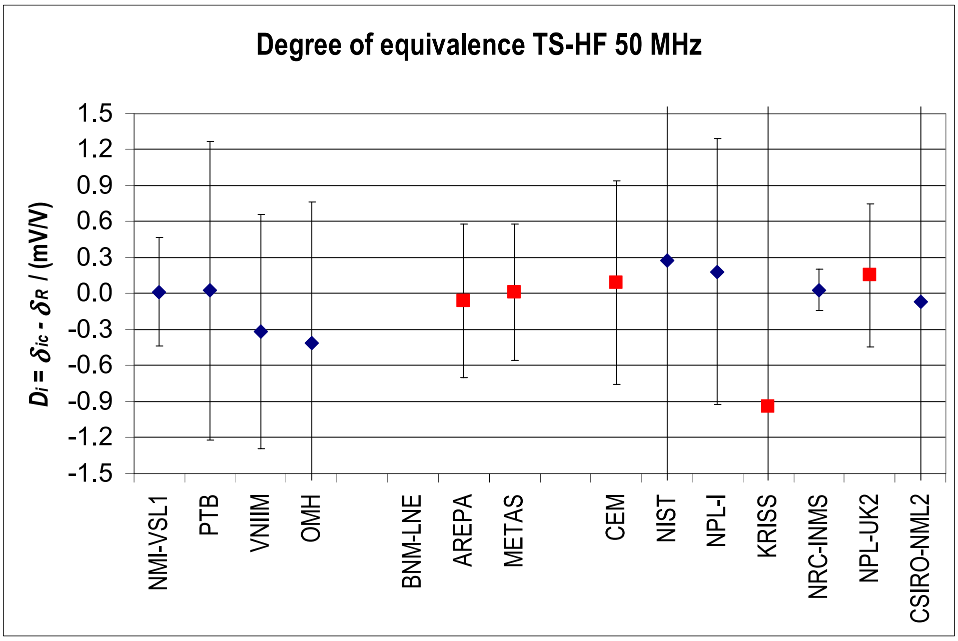

Figure 9 Degree of equivalence with the key comparison reference value at 50 MHz with the corresponding expanded uncertainties (k = 2). (blue diamonds: included in the KCRV; red squares: not included in the KCRV)

Table 11 Values of the degree of equivalence with the reference value at 50 MHz with the corresponding expanded uncertainties (k = 2). Participants indicated with (*) are included in the KCRV.

	Lab	D_i (mV/V)	U_i (mV/V)
*	NMI-VSL1	0.013	0.451
*	PTB	0.025	1.241
*	VNIIM	-0.315	0.976
*	OMH	-0.413	1.180
	BNM-LNE	4.530	1.124
	AREPA	-0.060	0.643
	METAS	0.012	0.570
	CEM	0.092	0.845
*	NIST	0.273	3.994
*	NPL-I	0.184	1.105
	KRISS	-0.936	4.900
*	NRC-INMS	0.030	0.170
	NPL-UK2	0.153	0.599
*	CSIRO-NML2	-0.064	2.442

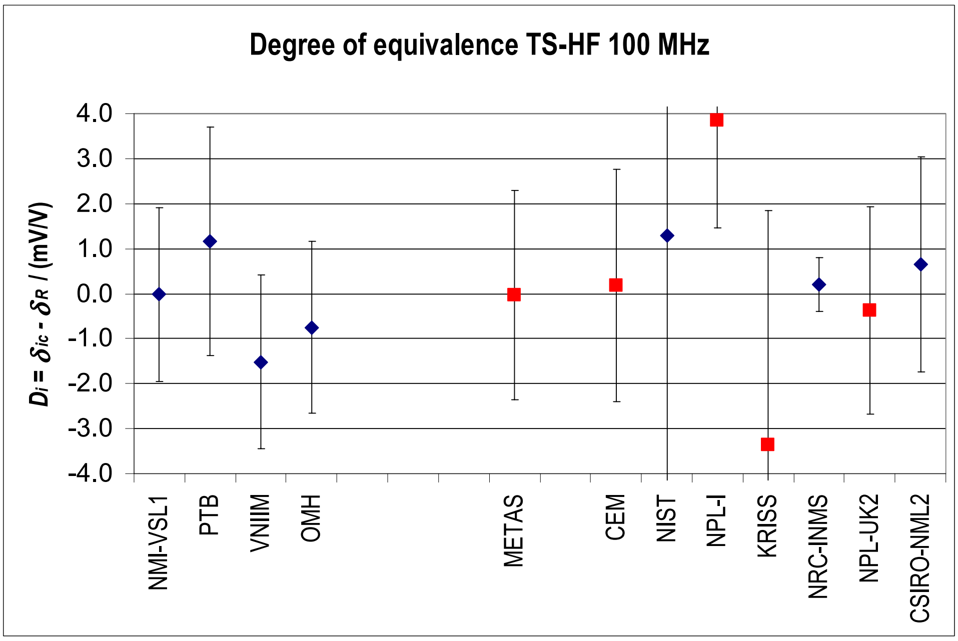

Figure 10 Degree of equivalence with the key comparison reference value at 100 MHz with the corresponding expanded uncertainties (k = 2). (blue diamonds: included in the KCRV; red squares: not included in the KCRV)

Table 12 Values of the degree of equivalence with the reference value at 100 MHz with the corresponding expanded uncertainties (k = 2). Participants indicated with (*) are included in the KCRV.

	Lab	D_i (mV/V)	U_i (mV/V)
*	NMI-VSL1	-0.021	1.931
*	PTB	1.161	2.547
*	VNIIM	-1.523	1.931
*	OMH	-0.754	1.910
	METAS	-0.036	2.330
	CEM	0.187	2.577
*	NIST	1.290	7.983
	NPL-I	3.840	2.387
	KRISS	-3.354	5.209
*	NRC-INMS	0.205	0.595
	NPL-UK2	-0.365	2.306
*	CSIRO-NML2	0.660	2.390

10. Discussion of the results of the key comparison

The goal of this comparison is to establish the degree of equivalence between laboratories for AC-DC voltage transfer measurements at the highest level of accuracy. Therefore, the participants and the support group of this comparison agreed that the determination of this degree of equivalence should be based on a consistent set of measurement results. In the analysis of the results it has been found that the results of TS-A55 are less consistent than those of TS-HF in the sense that the uncertainties in the reference values are larger and the deviations from the reference value are larger for TS-A55. Therefore, it has been agreed that the degrees of equivalence in the comparison should be based only the results of TS-HF. The results of TS-HF have been found to be sufficiently reliable for this purpose. (The results of TS-A55 have been presented in Appendix B).

At all frequencies, it has been observed that the BNM-LNE results have a large deviation from the KCRV's compared to other participants and at some frequencies the expanded uncertainties do not overlap with the reference value. After the comparison results had been shown to all participants, BNM-LNE informed the pilot laboratory that their reported results consider the connector of the travelling standard as the reference plane, while all other participants (following the protocol) used the center of the T-connector as the reference plane. For this reason, the results of BNM-LNE should not be compared directly with the other results. BNM-LNE is recommended to determine corrections for this shift of the reference plane. After applying these corrections, the BNM-LNE results can be compared with the other results.

Disregarding the results of BNM-LNE, there is a very good agreement between the results of the participants at all frequencies. Except for NPL-I at 100 MHz, all reported results are in agreement with the KCRV's within the reported expanded uncertainties.

At 1 MHz, 13 out of 15 participants have a deviation from the KCRV of less than 10 µV/V. The results and uncertainties published in the CCEM-K6.a LF ac-dc key comparison [4] at 1 MHz are of the same order of magnitude. So, there is a good agreement between the two comparisons. It has to be noted that some participants reported uncertainties different by a factor of two for the two comparisons without an explanation. They may have used different facilities or reference standards in these comparisons.

At 10 MHz, the deviations from the KCRV are less than 100 µV/V for 11 out of 15 participants. At frequencies above 1 MHz some of the laboratories change to another type of independent realisation: from thermal converters to a calorimetric voltage standard. This is the case for PTB, OMH, CSIRO-NML and NPL-I. For these laboratories, the uncertainties are significantly larger than for laboratories using a thermal converter as an independent reference standard. The difference in the uncertainties is typically about a factor of 10. It is remarkable that the uncertainty of NRC-INMS, using a calorimetric standard, is of the same order of magnitude as laboratories using thermal converters.

At 30 MHz, the deviations from the KCRV are less than 0.20 mV/V for 12 out of 15 participants.

SP didn't report any results at frequencies above 30 MHz, because these facilities were not available or operational at the time of the comparison.

At 50 MHz, the deviations from the KCRV are less than 0.30 mV/V for 12 out of 14 participants.

BNM-LNE and AREPA didn't report results above 50 MHz.

At 100 MHz, the deviations from the KCRV are less than 1.5 mV/V for 10 out of 12 participants.

So, in general, there is a good agreement between the reported results at all frequencies. Although there are some differences in the reported uncertainties, the level of agreement between the independent participants doesn't seem to be influenced significantly by the type of realisation of the reference standards. In other words, there is a good agreement between reference standards based on thermal voltage converters and calorimetric voltage standards.

For 10 MHz and above, the results of 6 out of 15 participants are obtained by using a reference standard which is based on the NMi-VSL calculable HF ac-dc standard [7], [8]. The agreement between these participants is close at all frequencies, and the reported uncertainties are all of the same order of magnitude. It is therefore concluded that the influence of the measurement set-up on the total uncertainty of the ac-dc transfer for this type of reference standard is relatively small [16].

As mentioned in chapter 7, NIST was not able to present the detailed uncertainty budget of the reference at frequencies above 1 MHz. Under the current CIPM rules for key comparisons, any results without a detailed uncertainty budget wouldn't be acceptable to be included a comparison report. However, as an exception to the CIPM rules, the CCEM has allowed that in this case, the NIST results above 1 MHz can be included in the report. Even more, since the contributions of the NIST results to the KCRV's are relatively small, the NIST results have not been excluded from the calculations of the KCRV's. Nevertheless, NIST is recommended to demonstrate its capabilities of its new facilities in another (bilateral) comparison, in which the results should be supported by a sound and detailed uncertainty budget. (In the mean time, an additional comparison [18] between NRC, NIST, PTB and NMi-VSL with another type of travelling standard has been carried out which confirmed the results of the present comparison but the results are not included in the present report.)

VNIIM has revised its uncertainty budget after the results of this comparison had been presented to the participants. Under the present CIPM rules for key comparisons, participants are not allowed to change their uncertainty budget after the results have been seen by all participants. The pilot laboratory has studied the changes in the uncertainty budget and is convinced that VNIIM has gained better insight in its uncertainty contributions and that the revised uncertainty budget contains more details than the first. As an exception to the CIPM rules for key comparison, the CCEM has allowed that these changes can be included in the comparison report.

The results for the TS-A55 are comparable to the TS-HF results. For the same reason as mentioned above, the BNM-LNE results for TS-A55 cannot be compared with the other results. Except for NPL-I at 100 MHz, all reported results agree with the reference values within the reported uncertainties. The typical deviations from the reference value are larger for TS-A55 than for TS-HF. This difference is mainly attributed to the input connectors of the standards. The TS-A55 has a GR-874 and the TS-HF an N-type input connector. At frequencies above 1 MHz, for a few participants the deviations from the reference values for TS-HF and TS-A55 do not quite match (see Appendix C). It is expected that this is caused by the use of (T-) adapters (and especially the deviation of its electrical length for different connectors) to connect the travelling standard to the reference plane in the measurement set-up [19]. In most cases, the difference is within the reported uncertainty for the measurement of TS-A55 versus TS-HF. However, participants for which the uncertainty doesn't cover the difference in the results are recommended to review their uncertainties, to be sure that none of the contributions have been underestimated.

In this comparison, the CCEM has allowed several exceptions from the CIPM rules and guidelines for key comparisons. These exceptions are given by the CCEM on a case-by-case basis. Therefore, in this respect, this report should not be used as a general model for reports of CCEM key comparisons.

11. Conclusions

In 1998, the measurements of the CCE 92-05 comparison of ac-dc voltage transfer standards at high frequencies were completed. This comparison was later identified as the CCEM-K6.c key comparison. The report gives the results of 15 participants, one participant withdrew his results and another one didn't report any results.

The comparison was carried out with two travelling standards. The results of one of these standard were found to be more reliable than those of the other standard. Therefore, the final results of this comparison are only based on the most reliable travelling standard.

The KCRV's in this comparison are calculated as the weighted mean of the results of participants using an independent realisation of a reference standard. Results identified as outliers do not contribute to the KCRV. The degree of equivalence with the KCRV has been determined for all participants at each measured frequency. For all frequencies in the range from 1 MHz to 100 MHz, there is a good agreement between the results of most participants. Except for a few cases, the calculated deviations from the reference values are covered by the reported expanded uncertainty.

The uncertainties in the measurements are mainly determined by the uncertainties in the reference standards of the participants.

12. Lessons learned

In the area of (key) comparisons, many things have changed since the start of this comparison. It is commonly recognized that the introduction of rules and guidelines for comparison has brought more structure in comparisons and has improved the quality of the results. Nevertheless, at the end of a project it is always useful to look back at the positive and negative aspects that have been experienced during the course of the project. Therefore, the authors have summarized some lessons that have been learned that could be useful for future coordinators and participants in comparisons.

Coordination:
- The coordinator should be familiar with the CIPM guidelines for comparisons and the GUM.
- It is recommended that *at least two persons*:
- are involved in the coordination of the comparison,
- know the actual status of the comparison and
- are capable of performing the measurements for the comparison,

just in case one of them becomes ill or decides to leave the department.
- The pilot laboratory should avoid replacement of the coordinator during the course of a comparison.

Project management:
- The project leader (pilot laboratory) should have tools to enforce the participants to handle in agreement with the protocol as they committed to do. (In the worst case, a participant could be excluded from the comparison.)
- Make back-up copies of paper and electronic documents.
- It is recommended that the pilot laboratory starts with the analysis of the results as soon as the first results come in. This avoids surprises at the end and besides, the complete results will be available almost immediately after the last participant has reported his results.

Protocol:
- The protocol should *not* be changed *after* the comparison has started. Therefore, the protocol should be carefully written.
- Describe/provide a format for reporting results
- Describe/provide a format for reporting the uncertainty budget
- The pilot laboratory should *not* accept other formats
- Give a list of uncertainty contributions that have to be included
- Clearly describe the required level of detail for the uncertainty budgets.
- Limit the number of measurement points and/or items to be measured to a reasonable minimum.
- All participants should respect the protocol. If, in the measurements or in the reporting of the results, a participant does not follow the protocol, this participant should be excluded from the comparison.

Schedule:
- Try to complete the measurements within about 12 to 18 months.
- The analysis of the result and writing of the draft reports will take another 6 to 12 months.
- Don't allow additional entries after the schedule has been approved by the participants.
- If a participant is not able to complete the mandatory measurements within the time that was agreed in the schedule, the pilot laboratory should not allow extra time for this participant. The comparison should go on as scheduled. Even more, this participant should not be allowed to retry performing the measurements at the end of the comparison, because this will delay the completion of the comparison. If this participant wants to retry, a supplementary comparison should be organized.

Travelling standard and its transport:
- The behaviour of the travelling standard should be studied before the comparison starts. It is not useful to use two (or more) standards if one is significantly less stable than the other.
- A back-up travelling standard should be readily available.
- Use a suitable package
- Be aware of all customs regulations that may raise difficulties during shipment of the standard(s).
- The pilot laboratory should always know where the travelling strandard is. Therefore, communication before and after shipment is very important.

Reporting of the measurement results:
- Participants should report their results within the given time limit.
- Participants should report their results in a single, complete and comprehensible document, rather than sending incoherent bits and pieces of information to the pilot laboratory.
- Upon receipt of a measurement report from a participant, the pilot laboratory should check as soon as possible that the report contains all required information in the required formats. If not, the participant should be informed immediately, giving the participant another chance to provide the required information within the agreed time limit.
- Reporting more than one measurement value for a single measurement quantity is unacceptable. If, by using different methods or different set-ups, a participant obtains more than one measurement value for the same measurement quantity, *the participant* should decide which of the measurement values is taken as the result for this comparison. This decision should not be made by the *pilot laboratory*. It is also the authors' opinion that the result of a participant should not be based on the (weighted) mean of measurement values obtained by different measurement methods or set-ups. The "best measurement capability" of a national measurement institute should be based on *one* method of measurement performed on *one* specified set-up.

Analysis of the results:
- The participants should agree on a method of analysis of the results before the start of the comparison. (This is now included in the guidelines for key comparisons, but in practice, this doesn't always happen.)

13. Acknowledgement

All participants are gratefully thanked for the good co-operation during the running of the comparison and for respecting the time schedule as closely as possible. The pilot laboratory appreciates the effort of the participants for the completion of this comparison as a key comparison. The members of the support group of the comparison, Dr. Manfred Klonz, Mr. Karl-Erik Rydler and Dr. Thomas Witt, are acknowledged for their valuable advice, comments, remarks and constructive criticism during the completion of this report. Within NMi-VSL, the authors wish to thank our colleagues Joop Dessens and Oswin Kerkhof for their support, contributions and useful discussions in this comparison.
The results of this key comparison are valuable; especially the fact that the uncertainty budgets are discussed among the experts in the fields of ac-dc transfer and RF voltage.
Due to extensive discussion on the way to present the results of a key comparison in the field of ac-dc transfer difference the drafting of the report of this key comparison has been significantly delayed but has consequently improved the quality of the report.

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A. Appendix: Results of TS-HF at optional frequencies

In this comparison, the frequencies 0.5 MHz and 70 MHz have been selected as optional frequencies. Several participants have reported results at these frequencies. These results for travelling standard TS-HF are reported here below. For the calculations of the results, the same approach is used as for the mandatory frequencies.

A.1. Calculation of the results

For each optional frequency, the result is reported as a value, δ_i, and an expanded uncertainty, U_i. The expanded uncertainty is obtained from the combined standard uncertainty, u_i, multiplied by a coverage factor, k_i. All participants used a coverage factor $k_i = 2$.

Only one measurement result of the pilot laboratory is taken as the actual participation of NMi-VSL to this comparison; this is the first measurement, indicated by NMi-VSL1. All other measurements of the pilot laboratory are only used to monitor the behaviour of the standards.

The travelling standard TS-HF has been broken once during the comparison. The instrument was repaired but this has resulted in a shift of its ac-dc transfer difference. Measurement results obtained after this accident are corrected for this step. The pilot laboratory has determined the step, δ_{step}, at all measurement frequencies. The travelling standard was measured shortly before the break down during one of the normally scheduled checks and, of course, measured again after the repair. Based on these measurements, an uncertainty, u_{step}, was determined for each value of δ_{step}. This uncertainty is added to the reported uncertainties of all participants, before and after the step occurred.

At the end of the comparison, the behaviour of the standards was analysed by looking at the measurements from the pilot laboratory. At each frequency, a linear fit was calculated through the measurements of the pilot laboratory. The slope of this linear fit is considered to be a measure for the drift of the standard. The root mean squared (rms) deviation of the pilot's results from the linear fit is chosen to be an estimate of the uncertainty in the drift, u_{drift}.

Drift corrections, δ_{drift}, have been calculated for all participants at each measured frequency. These values are determined at the average measurement date of the participant.

The corrected results, δ_{ic}, are now found from:

$$\delta_{ic} = \delta_i + \delta_{\text{step}} + \delta_{\text{drift}} \qquad \textbf{(A - 1)}$$

with a combined uncertainty, u_{ic}:

$$u_{ic} = \sqrt{u_i^2 + u_{\text{step}}^2 + u_{\text{drift}}^2} \qquad \textbf{(A - 2)}$$

The results of TS-HF at the optional frequencies are given in Table A 1 and Table A 2. The corrected values δ_{ic} are also plotted in Figure A 1 and Figure A 2.

After having applied the corrections, the results from the participants can be compared with each other to find the level of agreement. For this purpose, a reference value, δ_R, has to be determined for each optional frequency in this comparison. The results of participants to be included in the calculation of δ_R have to meet the following criteria (as described in detail in section 8.2):

- obtained from an independently realised reference standard,
- yielded an ac-dc transfer difference consistent with the other independent realisations and,
- given with an acceptable uncertainty supported by a sound uncertainty budget.

For the pilot laboratory, only one measurement result is taken as the contribution to the reference value: NMI-VSL1.

The following independent results have been identified as outliers: NPL-I at 0.5 MHz; KRISS at 70 MHz.

The participants in this comparison have decided that the reference value, δ_R, should be taken as the weighted mean of the results, δ_{ic}, meeting the criteria mentioned above:

$$\delta_R = \frac{\sum_{i=1}^{N} w_i \delta_{ic}}{\sum_{i=1}^{N} w_i} \qquad \textbf{(A - 3)}$$

The weight, w_i, for each laboratory, i, is found from the inverse of the squared standard uncertainty:

$$w_i = \frac{1}{u_{\delta ic}^2} \qquad \textbf{(A - 4)}$$

The uncertainty of the reference value, u_R, is calculated as experimental standard deviation of the average of the results meeting the above mentioned criteria:

$$u_R = \frac{1}{\sqrt{\sum_{i=1}^{N} w_i}} \qquad \textbf{(A - 5)}$$

The expanded uncertainty, U_R, is given by:

$$U_R = k_R \cdot u_R \qquad \textbf{(A - 6)}$$

where the coverage factor k_R = 2 is used to obtain a confidence level of approximately 95 %.

The values of δ_R, and their expanded uncertainties, U_R, for TS-HF at the optional frequencies are given on the bottom lines of Table A 1 and Table A 2. In these tables, laboratories whose results have been included in the δ_R, are indicated by an asterisk (*) in the first column. For these laboratories, the last column of the table shows the percentage of contribution to the reference value. The results are plotted in Figure A 1 and Figure A 2. Some of the results may be out of the scale of the graph. In those cases, the values can be found in the corresponding table.

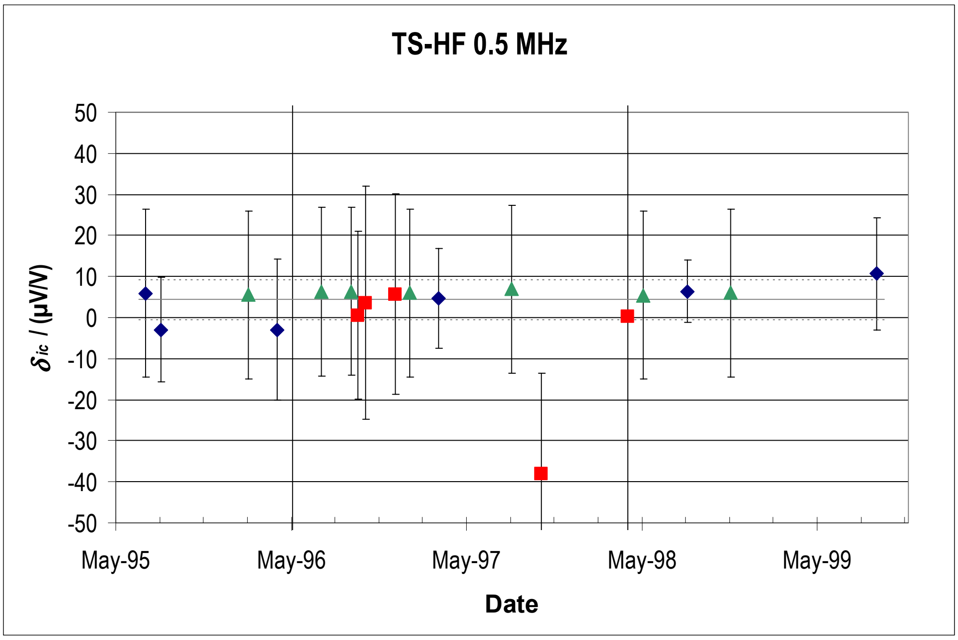

Figure A 1 Corrected values of the results, δ_{ic}, and expanded uncertainties, U_{ic}, at 0.5 MHz. (blue diamonds: participants included in the reference value; the red squares: not included in the reference; green triangles: characterisation measurements of the pilot laboratory.) The solid line shows the reference value, δ_R, and the dashed lines indicate the expanded uncertainty, U_R in the reference value.

Table A 1 Measurement results, uncertainties, corrections and the percentage of contribution to the reference value for TS-HF at 0.5 MHz. The reference value and its expanded uncertainty are given at the bottom line. (Laboratories indicated with * contribute to the reference value).

	Lab	Date	δ_i (µV/V)	u_i (µV/V)	δ_{step} (µV/V)	u_{step} (µV/V)	δ_{drift} (µV/V)	u_{drift} (µV/V)	δ_{ic} (µV/V)	$U_{\delta ic}$ (µV/V)	Contr. to δ_R (%)
*	NMI-VSL1	Aug-95	5.9	10.0	0.0	2.1	0.0	0.5	5.9	20.5	5.8
*	PTB	Sep-95	-3.0	6.0	0.0	2.1	0.0	0.5	-3.0	12.8	14.8
	VNIIM	Nov-95									
	OMH	Jan-96									
	NMI-VSL2	Mar-96	5.3	10.0	0.0	2.1	0.2	0.5	5.5	20.5	
*	NPL-UK1	May-96	-3.2	8.3	0.0	2.1	0.3	0.5	-2.9	17.2	8.2
	BNM-LNE	Jun-96	300.0	650.0	0.0	2.1	0.3	0.5	300.3	1300.0	
	AREPA	Jul-96									
	NMI-VSL3a	Aug-96	6.0	10.0	0.0	2.1	0.4	0.5	6.3	20.5	
	NMI-VSL3b	Oct-96	6.8	10.0	-0.8	2.1	0.4	0.5	6.4	20.5	
	METAS	Oct-96	1.0	10.0	-0.8	2.1	0.4	0.5	0.6	20.5	
	SP	Nov-96	4.0	14.0	-0.8	2.1	0.4	0.5	3.6	28.3	
	CEM	Jan-97	6.0	12.0	-0.8	2.1	0.5	0.5	5.7	24.4	
	NMI-VSL4	Feb-97	6.3	10.0	-0.8	2.1	0.5	0.5	6.0	20.5	
*	NIST	Apr-97	4.9	5.7	-0.8	2.1	0.6	0.5	4.6	12.1	16.4
	NMI-VSL5	Sep-97	7.1	10.0	-0.8	2.1	0.7	0.5	7.0	20.5	
	NPL-I	Nov-97	-38.0	12.0	-0.8	2.1	0.8	0.5	-38.0	24.4	
	KRISS	May-98	0.0	26.0	-0.8	2.1	1.0	0.5	0.1	52.2	
	NMI-VSL6	Jun-98	5.3	10.0	-0.8	2.1	1.0	0.5	5.4	20.5	
*	NRC-INMS	Sep-98	6.1	3.1	-0.8	2.1	1.1	0.5	6.3	7.6	42.0
	NMI-VSL7	Dec-98	5.6	10.0	-0.8	2.1	1.2	0.5	6.0	20.5	
	NPL-UK2	Jan-99									
*	CSIRO-NML2	Oct-99	10.0	6.5	-0.8	2.1	1.5	0.5	10.6	13.7	12.8
	δ_R , U_R								4.5	4.9	

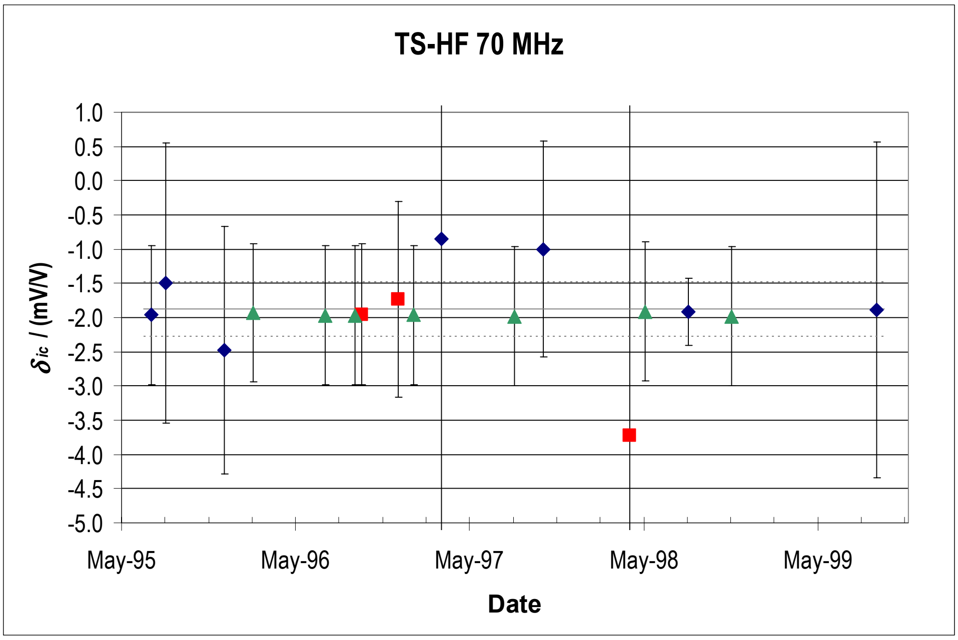

Figure A 2 Corrected values of the results, δ_{ic}, and expanded uncertainties, U_{ic}, at 70 MHz. (blue diamonds: participants included in the reference value; the red squares: not included in the reference; green triangles: characterisation measurements of the pilot laboratory.) The solid line shows the reference value, δ_R, and the dashed lines indicate the expanded uncertainty, U_R in the reference value.

Table A 2 Measurement results, uncertainties, corrections and the percentage of contribution to the reference value for TS-HF at 70 MHz. The reference value and its expanded uncertainty are given at the bottom line. (Laboratories indicated with * contribute to the reference value).

	Lab	Date	δ_i (mV/V)	u_i (mV/V)	δ_{step} (mV/V)	u_{step} (mV/V)	δ_{drift} (mV/V)	u_{drift} (mV/V)	δ_{ic} (mV/V)	$U_{\delta ic}$ (mV/V)	Contr. to δ_R (%)
*	NMI-VSL1	Aug-95	-1.964	0.500	0.000	0.082	0.000	0.025	-1.964	1.015	15.3
*	PTB	Sep-95	-1.500	1.020	0.000	0.082	0.001	0.025	-1.499	2.047	3.8
	VNIIM	Nov-95									
*	OMH	Jan-96	-2.480	0.900	0.000	0.082	0.006	0.025	-2.474	1.808	4.8
	NMI-VSL2	Mar-96	-1.938	0.500	0.000	0.082	0.008	0.025	-1.929	1.015	
	NPL-UK1	May-96									
	BNM-LNE	Jun-96									
	AREPA	Jul-96									
	NMI-VSL3a	Aug-96	-1.982	0.500	0.000	0.082	0.014	0.025	-1.968	1.015	
	NMI-VSL3b	Oct-96	-1.702	0.500	-0.280	0.082	0.017	0.025	-1.965	1.015	
	METAS	Oct-96	-1.690	0.510	-0.280	0.082	0.017	0.025	-1.953	1.034	
	SP	Nov-96									
	CEM	Jan-97	-1.474	0.710	-0.280	0.082	0.020	0.025	-1.734	1.430	
	NMI-VSL4	Feb-97	-1.704	0.500	-0.280	0.082	0.021	0.025	-1.963	1.015	
*	NIST	Apr-97	-0.596	2.900	-0.280	0.082	0.024	0.025	-0.853	5.803	0.5
	NMI-VSL5	Sep-97	-1.730	0.500	-0.280	0.082	0.030	0.025	-1.980	1.015	
*	NPL-I	Nov-97	-0.754	0.785	-0.280	0.082	0.032	0.025	-1.002	1.579	6.3
	KRISS	May-98	-3.476	2.463	-0.280	0.082	0.039	0.025	-3.718	4.929	
	NMI-VSL6	Jun-98	-1.670	0.500	-0.280	0.082	0.040	0.025	-1.910	1.015	
*	NRC-INMS	Sep-98	-1.680	0.228	-0.280	0.082	0.044	0.025	-1.916	0.487	66.6
	NMI-VSL7	Dec-98	-1.747	0.500	-0.280	0.082	0.047	0.025	-1.980	1.015	
	NPL-UK2	Jan-99									
*	CSIRO-NML2	Oct-99	-1.669	1.224	-0.280	0.082	0.059	0.025	-1.890	2.454	2.6
	δ_R , U_R								-1.871	0.397	

A.2. Degrees of equivalence

The values of the degrees of equivalence with the reference value D_i are given by:

$$D_i = \delta_{ic} - \delta_R \qquad \textbf{(A - 7)}$$

For participants who are not included in the reference value the expanded uncertainty U_i in D_i is:

$$U_i = k_D \cdot \sqrt{u_{\delta ic}^2 + u_R^2} \qquad \textbf{(A - 8)}$$

In case the laboratory contributes to the reference value the expanded uncertainty U_i is given by:

$$U_i = k_D \cdot \sqrt{u_{\delta ic}^2 - u_R^2} \qquad \textbf{(A - 9)}$$

In equations (A-8) and (A-9), k_D =2.

The degrees of equivalence, D_i, and their expanded uncertainties, U_i, for TS-HF at the optional frequencies, are shown in Figure A 3 and Figure A 4. These values are also presented in the corresponding tables: Table A 3 and Table A 4.

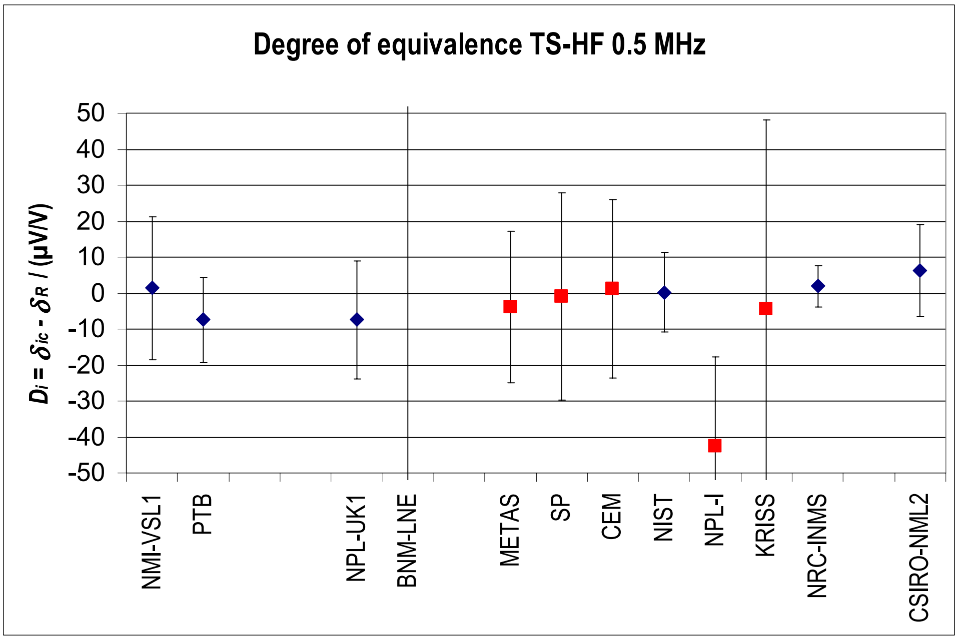

Figure A 3 Degree of equivalence with the reference value at 0.5 MHz with the corresponding expanded uncertainties (k = 2). (blue diamonds: included in the δ_R; red squares: not included in the δ_R)

Table A 3 Values of the degree of equivalence with the reference value at 0.5 MHz with the corresponding expanded uncertainties (k = 2). Participants indicated with * are included in the δ_R.

	Lab	D_i (µV/V)	U_i (µV/V)
*	NMI-VSL1	1.4	19.9
*	PTB	-7.4	11.8
*	NPL-UK1	-7.4	16.4
	BNM-LNE	295.8	1300.0
	METAS	-3.9	21.1
	SP	-0.9	28.8
	CEM	1.2	24.9
*	NIST	0.2	11.1
	NPL-I	-42.5	24.9
	KRISS	-4.3	52.4
*	NRC-INMS	1.9	5.8
*	CSIRO-NML2	6.2	12.8

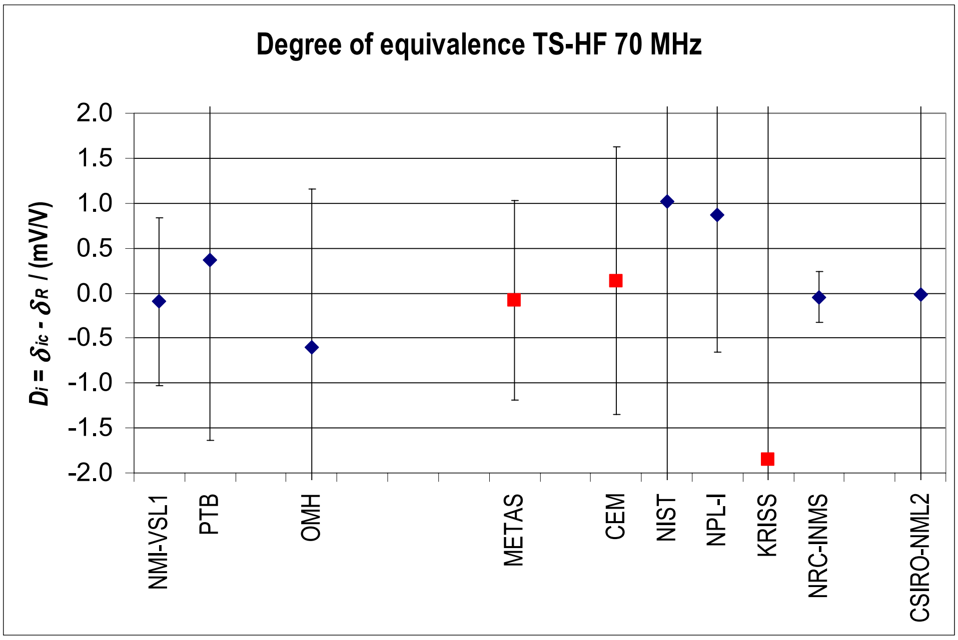

Figure A 4 Degree of equivalence with the reference value at 70 MHz with the corresponding expanded uncertainties (k = 2). (blue diamonds: included in the δ_R; red squares: not included in the δ_R)

Table A 4 Values of the degree of equivalence with the reference value at 70 MHz with the corresponding expanded uncertainties (k = 2). Participants indicated with * are included in the δ_R.

	Lab	D_i (mV/V)	U_i (mV/V)
*	NMI-VSL1	-0.093	0.934
*	PTB	0.373	2.008
*	OMH	-0.603	1.764
	METAS	-0.082	1.108
	CEM	0.137	1.484
*	NIST	1.019	5.789
*	NPL-I	0.869	1.529
	KRISS	-1.846	4.945
*	NRC-INMS	-0.045	0.281
*	CSIRO-NML2	-0.019	2.422

B. Appendix: Results of TS-A55

In this comparison, two different standards were used as travelling standards: TS-HF and TS-A55. During the analysis of the results, it was observed that the results of TS-A55 are less consistent than those of TS-HF. The TS-A55 results of the pilot laboratory show an rms deviation from the calculated linear drift which is typically about 10 times (between 2 and 20 times) larger than for the TS-HF results. Similarly, the results of the participants also show a larger deviation from the linear drift in the case of TS-A55. Furthermore, one participant reported that TS-A55 had been slightly overloaded during the measurements. As a result of this, TS-A55 may have become less stable. For these reasons, it was decided that the official results of this comparison should only be based on the results of TS-HF. Nevertheless, the reported results for TS-A55 have been analysed as well and are shown in this appendix. For this analysis the same approach was used as for TS-HF.

B.1. Calculation of the results

For each frequency, the result for TS-A55 is reported as a value, δ_i, and an expanded uncertainty, U_i. The expanded uncertainty is obtained from the combined standard uncertainty, u_i, multiplied by a coverage factor, k_i. All participants used a coverage factor $k_i = 2$.

Only one measurement result of the pilot laboratory is taken as the actual participation of NMi-VSL to this comparison; this is the first measurement, indicated by NMi-VSL1. All other measurements of the pilot laboratory are only used to monitor the behaviour of the standards.

The travelling standard TS-A55 has not been broken during the comparison and no steps or jumps have been observed in its behaviour. Therefore, the step correction, δ_{step}, and its uncertainty, u_{step}, can be set to zero for TS-A55 at all measurement frequencies.

At the end of the comparison, the behaviour of the standards was analysed by looking at the measurements from the pilot laboratory. At each frequency, a linear fit was calculated through the measurements of the pilot laboratory. The slope of this linear fit is considered to be a measure for the drift of the standard. The root mean squared (rms) deviation of the pilot's results from the linear fit is chosen to be an estimate of the uncertainty in the drift, u_{drift}. Drift corrections, δ_{drift}, have been calculated for all participants at each measured frequency. These values are determined at the average measurement date of the participant.

The corrected results, δ_{ic}, are now found from:

$$\delta_{ic} = \delta_i + \delta_{\text{step}} + \delta_{\text{drift}} \tag{B - 1}$$

with a combined uncertainty, u_{ic}:

$$u_{ic} = \sqrt{u_i^2 + u_{\text{step}}^2 + u_{\text{drift}}^2} \tag{B - 2}$$

The results of TS-A55 are given in Table B 1 to Table B 7. The corrected values δ_{ic} are also plotted in Figure B 1 to Figure B 7.

After having applied the corrections, the results from the participants can be compared with each other to find the level of agreement. For this purpose, a reference value, δ_R, has to be determined for each frequency in this comparison. The results of participants to be included in the calculation of δ_R have to meet the following criteria (as described in detail in section 8.2):

- obtained from an independently realised reference standard,
- yielded an ac-dc transfer difference consistent with the other independent realisations and,
- given with an acceptable uncertainty supported by a sound uncertainty budget.

For the pilot laboratory, only one measurement result is taken as the contribution to the reference value: NMI-VSL1.
One independent result has been identified as an outlier: NPL-I at 0.5 MHz.

The participants in this comparison have decided that the reference value, δ_R, should be taken as the weighted mean of the results, δ_{ic}, meeting the criteria mentioned above:

$$\delta_R = \frac{\sum_{i=1}^{N} w_i \delta_{ic}}{\sum_{i=1}^{N} w_i} \qquad \textbf{(B - 3)}$$

The weight, w_i, for each laboratory, i, is found from the inverse of the squared standard uncertainty:

$$w_i = \frac{1}{u_{\delta ic}^2} \qquad \textbf{(B - 4)}$$

The uncertainty of the reference value, u_R, is calculated as experimental standard deviation of the average of the results meeting the above mentioned criteria:

$$u_R = \frac{1}{\sqrt{\sum_{i=1}^{N} w_i}} \qquad \textbf{(B - 5)}$$

The expanded uncertainty, U_R, is given by:

$$U_R = k_R \cdot u_R \qquad \textbf{(B - 6)}$$

where the coverage factor k_R = 2 is used to obtain a confidence level of approximately 95 %.

The values of δ_R, and their expanded uncertainties, U_R, for TS-A55 are given on the bottom lines of Table B 1 to Table B 7. In these tables, laboratories whose results have been included in the δ_R, are indicated by an asterisk (*) in the first column. For these laboratories, the last column of the table shows the percentage of contribution to the reference value. The results are plotted in Figure B 1 to Figure B 7. Some of the results may be out of the scale of the graph. In those cases, the values can be found in the corresponding table.

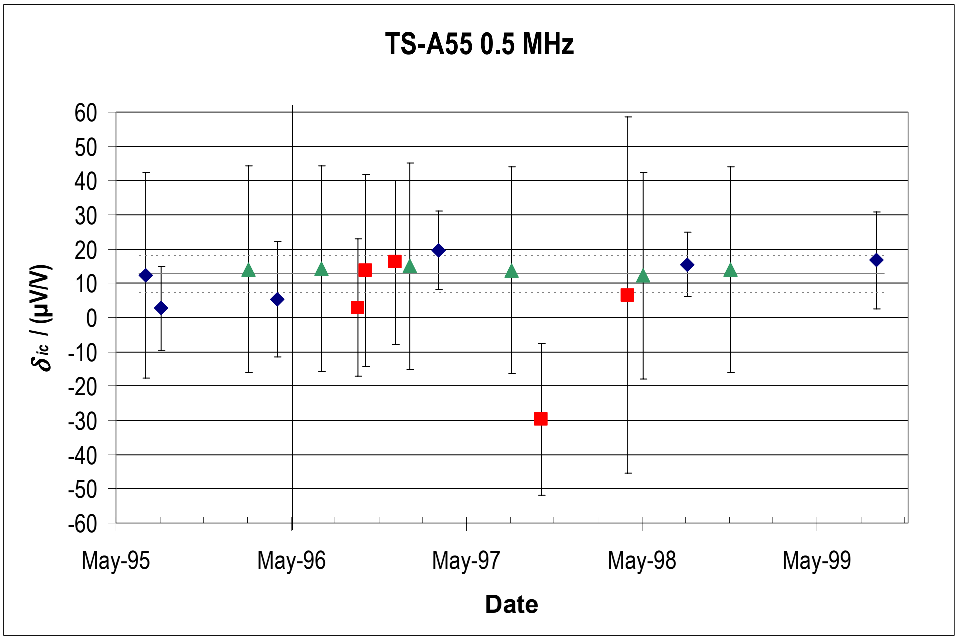

Figure B 1 Corrected values of the results, δ_{ic}, and expanded uncertainties, U_{ic}, at 0.5 MHz. (blue diamonds: participants included in the reference value; the red squares: not included in the reference; green triangles: characterisation measurements of the pilot laboratory.) The solid line shows the reference value, δ_R, and the dashed lines indicate the expanded uncertainty, U_R in the reference value.

Table B 1 Measurement results, uncertainties, corrections and the percentage of contribution to the reference value for TS-A55 at 0.5 MHz. The reference value and its expanded uncertainty are given at the bottom line. (Laboratories indicated with * contribute to the reference value).

	Lab	Date	δ_i (µV/V)	u_i (µV/V)	δ_{step} (µV/V)	u_{step} (µV/V)	δ_{drift} (µV/V)	u_{drift} (µV/V)	δ_{ic} (µV/V)	$U_{\delta ic}$ (µV/V)	Contr. to δ_R (%)
*	NMI-VSL1	Aug-95	12.3	15.0	0.0	0.0	0.0	1.0	12.3	30.1	3.1
*	PTB	Sep-95	3.0	6.0	0.0	0.0	-0.3	1.0	2.7	12.2	19.2
	VNIIM	Nov-95									
	OMH	Jan-96									
	NMI-VSL2	Mar-96	16.2	15.0	0.0	0.0	-2.0	1.0	14.2	30.1	
*	NPL-UK1	May-96	7.9	8.3	0.0	0.0	-2.6	1.0	5.3	16.7	10.2
	BNM-LNE	Jun-96	300.0	650.0	0.0	0.0	-2.9	1.0	297.1	1300.0	
	AREPA	Jul-96									
	NMI-VSL3a	Aug-96	17.7	15.0	0.0	0.0	-3.4	1.0	14.3	30.1	
	METAS	Oct-96	7.0	10.0	0.0	0.0	-4.1	1.0	2.9	20.1	
	SP	Nov-96	18.0	14.0	0.0	0.0	-4.3	1.0	13.7	28.1	
	CEM	Jan-97	21.0	12.0	0.0	0.0	-4.9	1.0	16.1	24.1	
	NMI-VSL4	Feb-97	20.2	15.0	0.0	0.0	-5.2	1.0	15.0	30.1	
*	NIST	Apr-97	25.4	5.7	0.0	0.0	-5.7	1.0	19.7	11.5	21.4
	NMI-VSL5	Sep-97	21.0	15.0	0.0	0.0	-7.1	1.0	13.9	30.1	
	NPL-I	Nov-97	-22.0	11.0	0.0	0.0	-7.7	1.0	-29.7	22.1	
	KRISS	May-98	16.0	26.0	0.0	0.0	-9.4	1.0	6.6	52.0	
	NMI-VSL6	Jun-98	21.9	15.0	0.0	0.0	-9.7	1.0	12.2	30.1	
*	NRC-INMS	Sep-98	26.1	4.6	0.0	0.0	-10.6	1.0	15.5	9.4	32.0
	NMI-VSL7	Dec-98	25.4	15.0	0.0	0.0	-11.4	1.0	14.0	30.1	
	NPL-UK2	Jan-99									
*	CSIRO-NML2	Oct-99	31.0	7.0	0.0	0.0	-14.3	1.0	16.7	14.2	14.2
	δ_R , U_R								13.0	5.3	

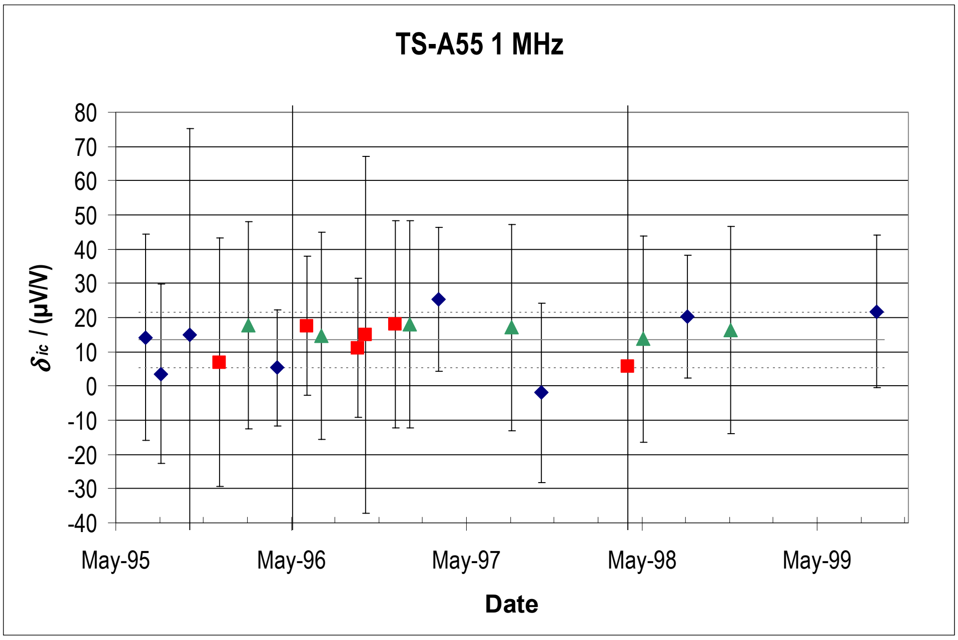

Figure B 2 Corrected values of the results, δ_{ic}, and expanded uncertainties, U_{ic}, at 1 MHz. (blue diamonds: participants included in the reference value; the red squares: not included in the reference; green triangles: characterisation measurements of the pilot laboratory.) The solid line shows the reference value, δ_R, and the dashed lines indicate the expanded uncertainty, U_R in the reference value.

Table B 2 Measurement results, uncertainties, corrections and the percentage of contribution to the reference value for TS-A55 at 1 MHz. The reference value and its expanded uncertainty are given at the bottom line. (Laboratories indicated with * contribute to the reference value).

	Lab	Date	δ_i (µV/V)	u_i (µV/V)	δ_{step} (µV/V)	u_{step} (µV/V)	δ_{drift} (µV/V)	u_{drift} (µV/V)	δ_{ic} (µV/V)	$U_{\delta ic}$ (µV/V)	Contr. to δ_R (%)
*	NMI-VSL1	Aug-95	14.2	15.0	0.0	0.0	0.0	1.8	14.2	30.2	7.2
*	PTB	Sep-95	4.0	13.0	0.0	0.0	-0.4	1.8	3.6	26.2	9.6
*	VNIIM	Nov-95	16.3	30.0	0.0	0.0	-1.2	1.8	15.1	60.1	1.8
	OMH	Jan-96	9.0	18.0	0.0	0.0	-2.0	1.8	7.0	36.2	
	NMI-VSL2	Mar-96	20.6	15.0	0.0	0.0	-2.8	1.8	17.8	30.2	
*	NPL-UK1	May-96	9.0	8.3	0.0	0.0	-3.6	1.8	5.4	17.0	23.0
	BNM-LNE	Jun-96	300.0	450.0	0.0	0.0	-4.1	1.8	295.9	900.0	
	AREPA	Jul-96	22.0	10.0	0.0	0.0	-4.5	1.8	17.5	20.3	
	NMI-VSL3a	Aug-96	19.5	15.0	0.0	0.0	-4.9	1.8	14.7	30.2	
	METAS	Oct-96	17.0	10.0	0.0	0.0	-5.9	1.8	11.1	20.3	
	SP	Nov-96	21.0	26.0	0.0	0.0	-6.1	1.8	14.9	52.1	
	CEM	Jan-97	25.0	15.0	0.0	0.0	-6.9	1.8	18.1	30.2	
	NMI-VSL4	Feb-97	25.3	15.0	0.0	0.0	-7.3	1.8	18.0	30.2	
*	NIST	Apr-97	33.4	10.4	0.0	0.0	-8.1	1.8	25.3	21.1	14.9
	NMI-VSL5	Sep-97	27.2	15.0	0.0	0.0	-10.1	1.8	17.1	30.2	
*	NPL-I	Nov-97	9.0	13.0	0.0	0.0	-11.0	1.8	-2.0	26.2	9.6
	KRISS	May-98	19.0	46.0	0.0	0.0	-13.4	1.8	5.6	92.1	
	NMI-VSL6	Jun-98	27.5	15.0	0.0	0.0	-13.8	1.8	13.7	30.2	
*	NRC-INMS	Sep-98	35.2	8.8	0.0	0.0	-15.0	1.8	20.2	17.9	20.5
	NMI-VSL7	Dec-98	32.5	15.0	0.0	0.0	-16.2	1.8	16.3	30.2	
	NPL-UK2	Jan-99									
*	CSIRO-NML2	Oct-99	42.0	11.0	0.0	0.0	-20.3	1.8	21.7	22.3	13.3
	δ_R , U_R								13.5	8.1	

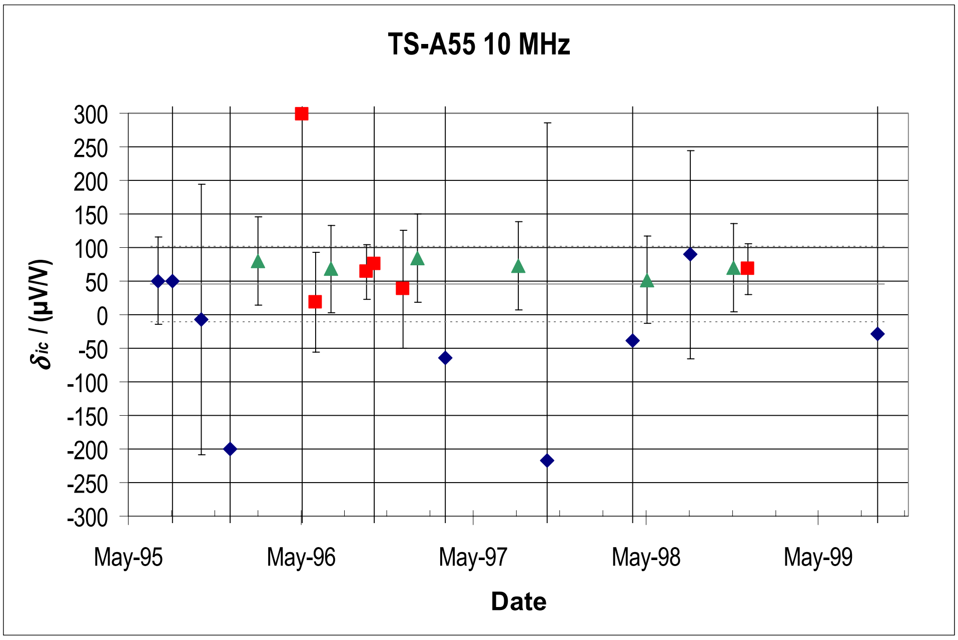

Figure B 3 Corrected values of the results, δ_{ic}, and expanded uncertainties, U_{ic}, at 10 MHz. (blue diamonds: participants included in the reference value; the red squares: not included in the reference; green triangles: characterisation measurements of the pilot laboratory.) The solid line shows the reference value, δ_R, and the dashed lines indicate the expanded uncertainty, U_R in the reference value.

Table B 3 Measurement results, uncertainties, corrections and the percentage of contribution to the reference value for TS-A55 at 10 MHz. The reference value and its expanded uncertainty are given at the bottom line. (Laboratories indicated with * contribute to the reference value).

	Lab	Date	δ_i (µV/V)	u_i (µV/V)	δ_{step} (µV/V)	u_{step} (µV/V)	δ_{drift} (µV/V)	u_{drift} (µV/V)	δ_{ic} (µV/V)	$U_{\delta c}$ (µV/V)	Contr. to δ_R (%)
*	NMI-VSL1	Aug-95	50.7	30.0	0.0	0.0	0.0	12.9	50.7	65.3	74.6
*	PTB	Sep-95	50.0	230.0	0.0	0.0	-0.1	12.9	49.9	460.7	1.5
*	VNIIM	Nov-95	-6.5	100.0	0.0	0.0	-0.3	12.9	-6.8	201.7	7.8
*	OMH	Jan-96	-200.0	580.0	0.0	0.0	-0.5	12.9	-200.5	1160.3	0.2
	NMI-VSL2	Mar-96	80.5	30.0	0.0	0.0	-0.7	12.9	79.8	65.3	
	NPL-UK1	May-96									
	BNM-LNE	Jun-96	300.0	500.0	0.0	0.0	-1.0	12.9	299.0	1000.3	
	AREPA	Jul-96	20.0	35.0	0.0	0.0	-1.1	12.9	18.9	74.6	
	NMI-VSL3a	Aug-96	69.3	30.0	0.0	0.0	-1.2	12.9	68.2	65.3	
	METAS	Oct-96	65.0	16.0	0.0	0.0	-1.4	12.9	63.6	41.1	
	SP	Nov-96	77.0	260.0	0.0	0.0	-1.5	12.9	75.5	520.6	
	CEM	Jan-97	40.0	42.0	0.0	0.0	-1.7	12.9	38.3	87.9	
	NMI-VSL4	Feb-97	86.0	30.0	0.0	0.0	-1.8	12.9	84.2	65.3	
*	NIST	Apr-97	-63.0	400.0	0.0	0.0	-2.0	12.9	-65.0	800.4	0.5
	NMI-VSL5	Sep-97	75.6	30.0	0.0	0.0	-2.4	12.9	73.1	65.3	
*	NPL-I	Nov-97	-215.0	251.0	0.0	0.0	-2.6	12.9	-217.6	502.7	1.3
*	KRISS	May-98	-35.2	2432.0	0.0	0.0	-3.2	12.9	-38.4	4864.1	0.0
	NMI-VSL6	Jun-98	55.1	30.0	0.0	0.0	-3.3	12.9	51.7	65.3	
*	NRC-INMS	Sep-98	92.9	76.5	0.0	0.0	-3.6	12.9	89.3	155.2	13.2
	NMI-VSL7	Dec-98	74.0	30.0	0.0	0.0	-3.9	12.9	70.1	65.3	
	NPL-UK2	Jan-99	72.0	13.5	0.0	0.0	-4.0	12.9	68.0	37.3	
*	CSIRO-NML2	Oct-99	-23.0	303.0	0.0	0.0	-4.9	12.9	-27.9	606.5	0.9
	δ_R , U_R								46.1	56.4	

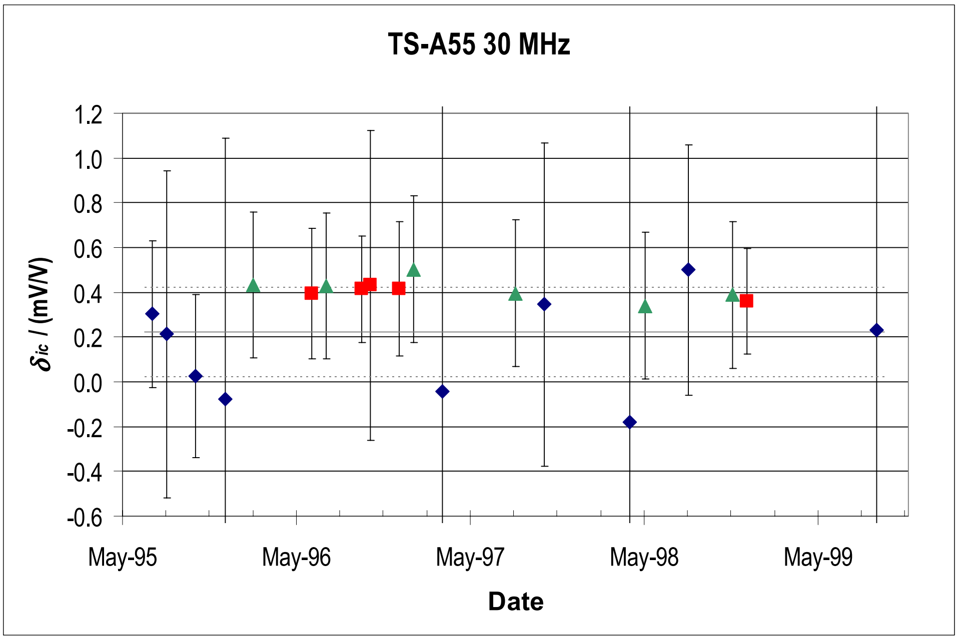

Figure B 4 Corrected values of the results, δ_{ic}, and expanded uncertainties, U_{ic}, at 30 MHz. (blue diamonds: participants included in the reference value; the red squares: not included in the reference; green triangles: characterisation measurements of the pilot laboratory.) The solid line shows the reference value, δ_R, and the dashed lines indicate the expanded uncertainty, U_R in the reference value.

Table B 4 Measurement results, uncertainties, corrections and the percentage of contribution to the reference value for TS-A55 at 30 MHz. The reference value and its expanded uncertainty are given at the bottom line. (Laboratories indicated with * contribute to the reference value).

	Lab	Date	δ_i (mV/V)	u_i (mV/V)	δ_{step} (mV/V)	u_{step} (mV/V)	δ_{drift} (mV/V)	u_{drift} (mV/V)	δ_{ic} (mV/V)	$U_{\delta ic}$ (mV/V)	Contr. to δ_R (%)
*	NMI-VSL1	Aug-95	0.303	0.150	0.000	0.000	0.000	0.065	0.303	0.327	36.7
*	PTB	Sep-95	0.210	0.360	0.000	0.000	0.002	0.065	0.212	0.732	7.3
*	VNIIM	Nov-95	0.019	0.170	0.000	0.000	0.007	0.065	0.026	0.364	29.6
*	OMH	Jan-96	-0.090	0.580	0.000	0.000	0.012	0.065	-0.078	1.167	2.9
	NMI-VSL2	Mar-96	0.417	0.150	0.000	0.000	0.016	0.065	0.433	0.327	
	NPL-UK1	May-96									
	BNM-LNE	Jun-96	3.400	0.700	0.000	0.000	0.023	0.065	3.423	1.406	
	AREPA	Jul-96	0.370	0.130	0.000	0.000	0.026	0.065	0.396	0.291	
	NMI-VSL3a	Aug-96	0.401	0.150	0.000	0.000	0.028	0.065	0.429	0.327	
	METAS	Oct-96	0.380	0.100	0.000	0.000	0.034	0.065	0.414	0.239	
	SP	Nov-96	0.397	0.340	0.000	0.000	0.035	0.065	0.432	0.692	
	CEM	Jan-97	0.374	0.135	0.000	0.000	0.040	0.065	0.414	0.300	
	NMI-VSL4	Feb-97	0.460	0.150	0.000	0.000	0.042	0.065	0.502	0.327	
*	NIST	Apr-97	-0.089	0.800	0.000	0.000	0.047	0.065	-0.042	1.605	1.5
	NMI-VSL5	Sep-97	0.338	0.150	0.000	0.000	0.059	0.065	0.396	0.327	
*	NPL-I	Nov-97	0.283	0.355	0.000	0.000	0.063	0.065	0.346	0.722	7.5
*	KRISS	May-98	-0.259	2.435	0.000	0.000	0.077	0.065	-0.182	4.872	0.2
	NMI-VSL6	Jun-98	0.260	0.150	0.000	0.000	0.079	0.065	0.339	0.327	
*	NRC-INMS	Sep-98	0.414	0.272	0.000	0.000	0.087	0.065	0.501	0.560	12.5
	NMI-VSL7	Dec-98	0.296	0.150	0.000	0.000	0.094	0.065	0.389	0.327	
	NPL-UK2	Jan-99	0.264	0.097	0.000	0.000	0.096	0.065	0.360	0.234	
*	CSIRO-NML2	Oct-99	0.114	0.764	0.000	0.000	0.117	0.065	0.231	1.534	1.7
	δ_R , U_R								0.224	0.198	

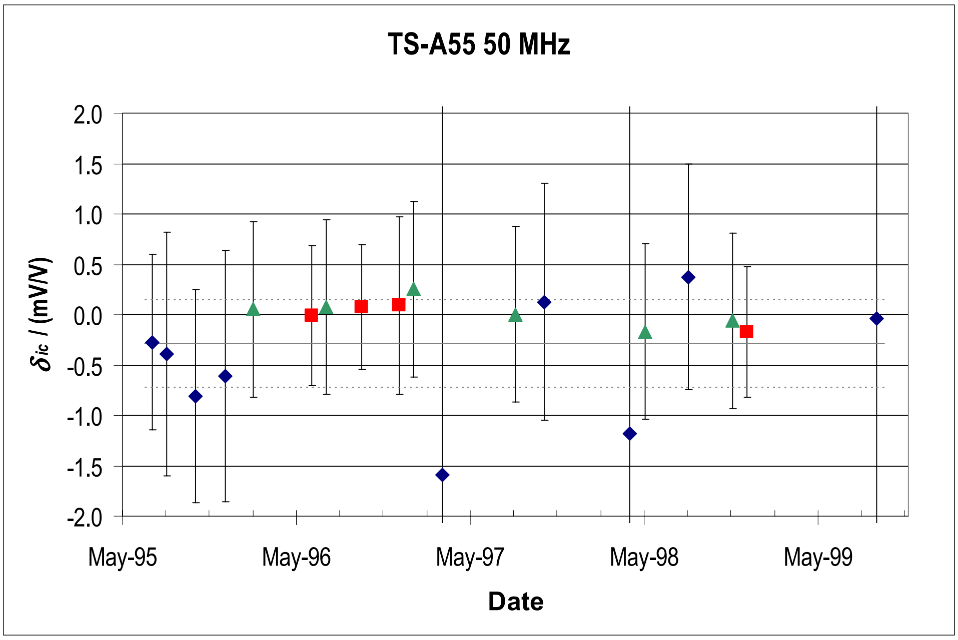

Figure B 5 Corrected values of the results, δ_{ic}, and expanded uncertainties, U_{ic}, at 50 MHz. (blue diamonds: participants included in the reference value; the red squares: not included in the reference; green triangles: characterisation measurements of the pilot laboratory.) The solid line shows the reference value, δ_R, and the dashed lines indicate the expanded uncertainty, U_R in the reference value.

Table B 5 Measurement results, uncertainties, corrections and the percentage of contribution to the reference value for TS-A55 at 50 MHz. The reference value and its expanded uncertainty are given at the bottom line. (Laboratories indicated with * contribute to the reference value).

	Lab	Date	δ_i (mV/V)	u_i (mV/V)	δ_{step} (mV/V)	u_{step} (mV/V)	δ_{drift} (mV/V)	u_{drift} (mV/V)	δ_{ic} (mV/V)	$U_{\delta c}$ (mV/V)	Contr. to δ_R (%)
*	NMI-VSL1	Aug-95	-0.273	0.400	0.000	0.000	0.000	0.172	-0.273	0.871	24.8
*	PTB	Sep-95	-0.400	0.580	0.000	0.000	0.010	0.172	-0.390	1.210	12.8
*	VNIIM	Nov-95	-0.841	0.500	0.000	0.000	0.030	0.172	-0.811	1.058	16.8
*	OMH	Jan-96	-0.660	0.600	0.000	0.000	0.051	0.172	-0.609	1.248	12.0
	NMI-VSL2	Mar-96	-0.014	0.400	0.000	0.000	0.071	0.172	0.056	0.871	
	NPL-UK1	May-96									
	BNM-LNE	Jun-96	4.600	0.550	0.000	0.000	0.101	0.172	4.701	1.153	
	AREPA	Jul-96	-0.120	0.300	0.000	0.000	0.111	0.172	-0.009	0.692	
	NMI-VSL3a	Aug-96	-0.045	0.400	0.000	0.000	0.121	0.172	0.077	0.871	
	METAS	Oct-96	-0.070	0.260	0.000	0.000	0.146	0.172	0.076	0.624	
	SP	Nov-96									
	CEM	Jan-97	-0.078	0.406	0.000	0.000	0.172	0.172	0.094	0.882	
	NMI-VSL4	Feb-97	0.070	0.400	0.000	0.000	0.182	0.172	0.253	0.871	
*	NIST	Apr-97	-1.788	2.000	0.000	0.000	0.202	0.172	-1.586	4.015	1.2
	NMI-VSL5	Sep-97	-0.249	0.400	0.000	0.000	0.252	0.172	0.003	0.871	
*	NPL-I	Nov-97	-0.147	0.563	0.000	0.000	0.273	0.172	0.126	1.177	13.5
*	KRISS	May-98	-1.510	2.445	0.000	0.000	0.332	0.172	-1.177	4.902	0.8
	NMI-VSL6	Jun-98	-0.513	0.400	0.000	0.000	0.343	0.172	-0.170	0.871	
*	NRC-INMS	Sep-98	0.002	0.531	0.000	0.000	0.373	0.172	0.375	1.117	15.0
	NMI-VSL7	Dec-98	-0.463	0.400	0.000	0.000	0.403	0.172	-0.060	0.871	
	NPL-UK2	Jan-99	-0.585	0.276	0.000	0.000	0.414	0.172	-0.171	0.651	
*	CSIRO-NML2	Oct-99	-0.539	1.226	0.000	0.000	0.504	0.172	-0.035	2.476	3.1
	δ_R , U_R								-0.282	0.433	

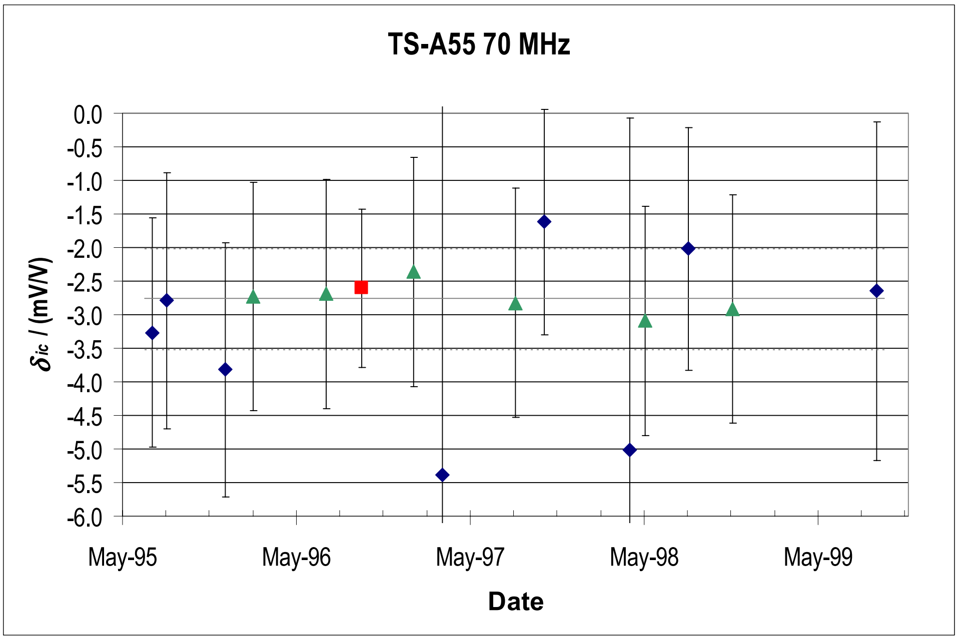

Figure B 6 Corrected values of the results, δ_{ic}, and expanded uncertainties, U_{ic}, at 70 MHz. (blue diamonds: participants included in the reference value; the red squares: not included in the reference; green triangles: characterisation measurements of the pilot laboratory.) The solid line shows the reference value, δ_R, and the dashed lines indicate the expanded uncertainty, U_R in the reference value.

Table B 6 Measurement results, uncertainties, corrections and the percentage of contribution to the reference value for TS-A55 at 70 MHz. The reference value and its expanded uncertainty are given at the bottom line. (Laboratories indicated with * contribute to the reference value).

	Lab	Date	δ_i (mV/V)	u_i (mV/V)	δ_{step} (mV/V)	u_{step} (mV/V)	δ_{drift} (mV/V)	u_{drift} (mV/V)	δ_{ic} (mV/V)	$U_{\delta ic}$ (mV/V)	Contr. to δ_R (%)
*	NMI-VSL1	Aug-95	-3.269	0.800	0.000	0.000	0.000	0.294	-3.269	1.704	19.3
*	PTB	Sep-95	-2.810	0.910	0.000	0.000	0.019	0.294	-2.791	1.912	15.3
	VNIIM	Nov-95									
*	OMH	Jan-96	-3.910	0.900	0.000	0.000	0.092	0.294	-3.818	1.893	15.6
	NMI-VSL2	Mar-96	-2.855	0.800	0.000	0.000	0.129	0.294	-2.727	1.704	
	NPL-UK1	May-96									
	BNM-LNE	Jun-96									
	AREPA	Jul-96									
	NMI-VSL3a	Aug-96	-2.911	0.800	0.000	0.000	0.221	0.294	-2.690	1.704	
	METAS	Oct-96	-2.870	0.510	0.000	0.000	0.266	0.294	-2.604	1.177	
	SP	Nov-96									
	CEM	Jan-97									
	NMI-VSL4	Feb-97	-2.694	0.800	0.000	0.000	0.332	0.294	-2.362	1.704	
*	NIST	Apr-97	-5.760	2.900	0.000	0.000	0.368	0.294	-5.392	5.830	1.6
	NMI-VSL5	Sep-97	-3.284	0.800	0.000	0.000	0.460	0.294	-2.824	1.704	
*	NPL-I	Nov-97	-2.118	0.785	0.000	0.000	0.497	0.294	-1.621	1.676	19.9
*	KRISS	May-98	-5.625	2.457	0.000	0.000	0.606	0.294	-5.019	4.949	2.3
	NMI-VSL6	Jun-98	-3.717	0.800	0.000	0.000	0.625	0.294	-3.092	1.704	
*	NRC-INMS	Sep-98	-2.700	0.856	0.000	0.000	0.680	0.294	-2.020	1.809	17.1
	NMI-VSL7	Dec-98	-3.652	0.800	0.000	0.000	0.735	0.294	-2.916	1.704	
	NPL-UK2	Jan-99									
*	CSIRO-NML2	Oct-99	-3.567	1.224	0.000	0.000	0.919	0.294	-2.648	2.518	8.8
	δ_R , U_R								-2.760	0.748	

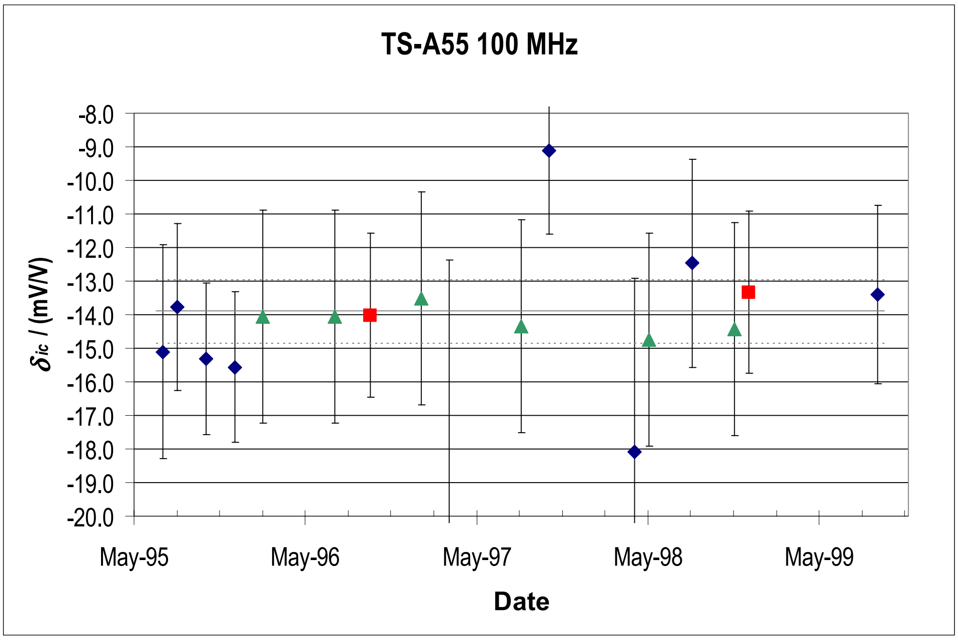

Figure B 7 Corrected values of the results, δ_{ic}, and expanded uncertainties, U_{ic}, at 100 MHz. (blue diamonds: participants included in the reference value; the red squares: not included in the reference; green triangles: characterisation measurements of the pilot laboratory.) The solid line shows the reference value, δ_R, and the dashed lines indicate the expanded uncertainty, U_R in the reference value.

Table B 7 Measurement results, uncertainties, corrections and the percentage of contribution to the reference value for TS-A55 at 100 MHz. The reference value and its expanded uncertainty are given at the bottom line. (Laboratories indicated with * contribute to the reference value).

	Lab	Date	δ_i (mV/V)	u_i (mV/V)	δ_{step} (mV/V)	u_{step} (mV/V)	δ_{drift} (mV/V)	u_{drift} (mV/V)	δ_{ic} (mV/V)	$U_{\delta c}$ (mV/V)	Contr. to δ_R (%)
*	NMI-VSL1	Aug-95	-15.102	1.500	0.000	0.000	0.000	0.519	-15.102	3.174	8.9
*	PTB	Sep-95	-13.800	1.130	0.000	0.000	0.034	0.519	-13.766	2.487	14.5
*	VNIIM	Nov-95	-15.408	1.000	0.000	0.000	0.101	0.519	-15.308	2.253	17.6
*	OMH	Jan-96	-15.730	0.990	0.000	0.000	0.167	0.519	-15.563	2.235	17.9
	NMI-VSL2	Mar-96	-14.286	1.500	0.000	0.000	0.233	0.519	-14.053	3.174	
	NPL-UK1	May-96									
	BNM-LNE	Jun-96									
	AREPA	Jul-96									
	NMI-VSL3a	Aug-96	-14.461	1.500	0.000	0.000	0.400	0.519	-14.061	3.174	
	METAS	Oct-96	-14.500	1.100	0.000	0.000	0.482	0.519	-14.018	2.432	
	SP	Nov-96									
	CEM	Jan-97									
	NMI-VSL4	Feb-97	-14.106	1.500	0.000	0.000	0.601	0.519	-13.505	3.174	
*	NIST	Apr-97	-21.099	4.000	0.000	0.000	0.666	0.519	-20.433	8.067	1.4
	NMI-VSL5	Sep-97	-15.175	1.500	0.000	0.000	0.833	0.519	-14.343	3.174	
*	NPL-I	Nov-97	-10.027	1.130	0.000	0.000	0.899	0.519	-9.128	2.487	14.5
*	KRISS	May-98	-19.195	2.545	0.000	0.000	1.097	0.519	-18.098	5.195	3.3
	NMI-VSL6	Jun-98	-15.882	1.500	0.000	0.000	1.131	0.519	-14.751	3.174	
*	NRC-INMS	Sep-98	-13.700	1.466	0.000	0.000	1.232	0.519	-12.468	3.109	9.3
	NMI-VSL7	Dec-98	-15.770	1.500	0.000	0.000	1.331	0.519	-14.439	3.174	
	NPL-UK2	Jan-99	-14.700	1.087	0.000	0.000	1.365	0.519	-13.335	2.409	
*	CSIRO-NML2	Oct-99	-15.072	1.221	0.000	0.000	1.663	0.519	-13.409	2.653	12.7
	δ_R , U_R								-13.877	0.946	

B.2. Degrees of equivalence

The values of the degrees of equivalence with the reference value D_i are given by:

$$D_i = \delta_{ic} - \delta_R \quad \textbf{(B - 7)}$$

For participants who are not included in the reference value the expanded uncertainty U_i in D_i is:

$$U_i = k_D \cdot \sqrt{u_{\delta ic}^2 + u_R^2} \quad \textbf{(B - 8)}$$

In case the laboratory contributes to the reference value the expanded uncertainty U_i is given by:

$$U_i = k_D \cdot \sqrt{u_{\delta ic}^2 - u_R^2} \quad \textbf{(B - 9)}$$

In equations (B-8) and (B-9) k_D = 2.

The degrees of equivalence, D_i, and their expanded uncertainties, U_i, for TS-A55 are shown in Figure B 8 to Figure B 14. These values are also presented in the corresponding tables: Table B 8 to Table B 14.

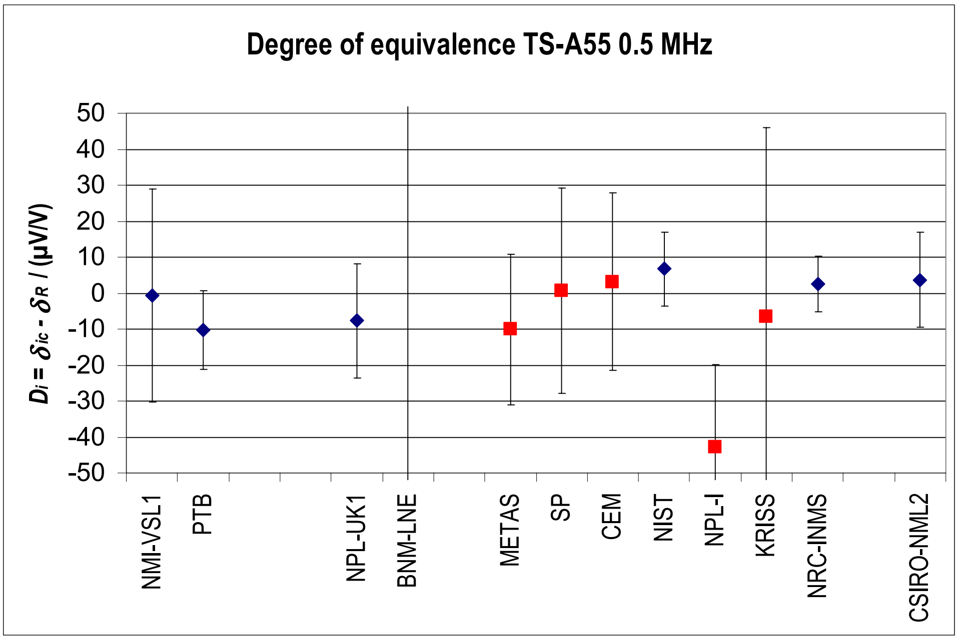

Figure B 8 Degree of equivalence with the reference value at 0.5 MHz with the corresponding expanded uncertainties (k = 2). (blue diamonds: included in the δ_R; red squares: not included in the δ_R)

Table B 8 Values of the degree of equivalence with the reference value at 0.5 MHz with the corresponding expanded uncertainties (k = 2). Participants indicated with * are included in the δ_R.

	Lab	D_i (µV/V)	U_i (µV/V)
*	NMI-VSL1	-0.7	29.6
*	PTB	-10.3	10.9
*	NPL-UK1	-7.7	15.9
	BNM-LNE	284.1	1300.0
	METAS	-10.1	20.8
	SP	0.7	28.6
	CEM	3.1	24.7
*	NIST	6.7	10.2
	NPL-I	-42.7	22.7
	KRISS	-6.4	52.3
*	NRC-INMS	2.5	7.8
*	CSIRO-NML2	3.7	13.1

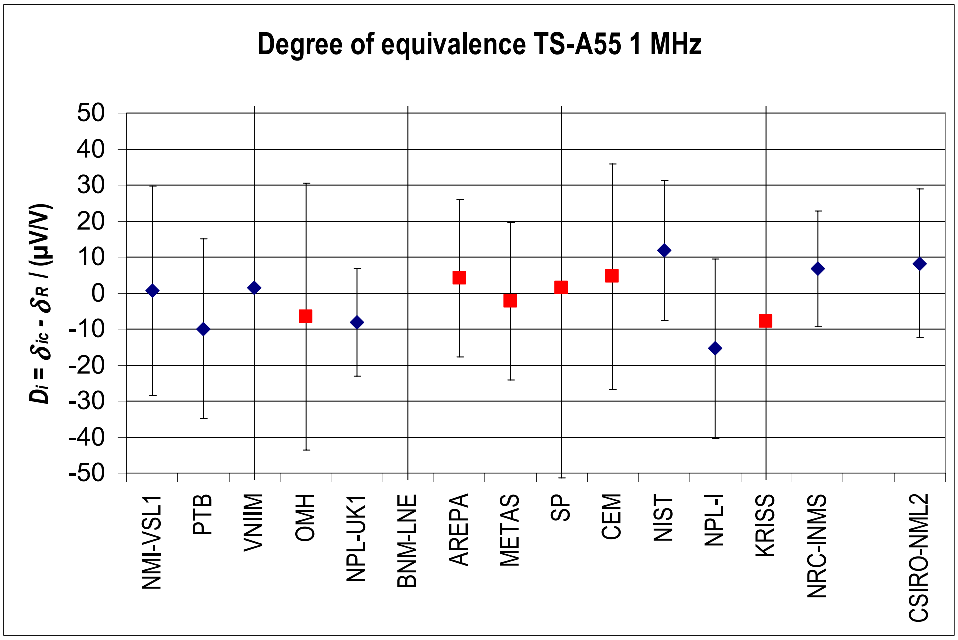

Figure B 9 Degree of equivalence with the reference value at 1 MHz with the corresponding expanded uncertainties (k = 2). (blue diamonds: included in the δ_R; red squares: not included in the δ_R)

Table B 9 Values of the degree of equivalence with the reference value at 1 MHz with the corresponding expanded uncertainties (k = 2). Participants indicated with * are included in the δ_R.

	Lab	D_i (µV/V)	U_i (µV/V)
*	NMI-VSL1	0.7	29.1
*	PTB	-9.9	24.9
*	VNIIM	1.6	59.5
	OMH	-6.5	37.1
*	NPL-UK1	-8.1	14.9
	BNM-LNE	282.4	900.0
	AREPA	4.0	21.9
	METAS	-2.4	21.9
	SP	1.4	52.7
	CEM	4.6	31.3
*	NIST	11.8	19.4
*	NPL-I	-15.5	24.9
	KRISS	-7.9	92.4
*	NRC-INMS	6.7	16.0
*	CSIRO-NML2	8.2	20.7

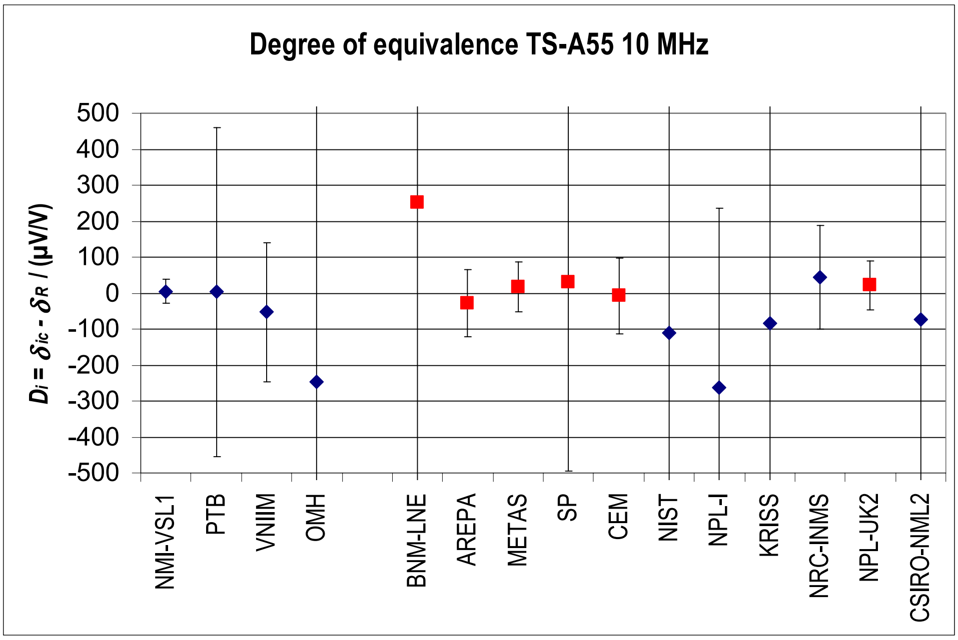

Figure B 10 Degree of equivalence with the reference value at 10 MHz with the corresponding expanded uncertainties (k = 2). (blue diamonds: included in the δ_R; red squares: not included in the δ_R)

Table B 10 Values of the degree of equivalence with the reference value at 10 MHz with the corresponding expanded uncertainties (k = 2). Participants indicated with * are included in the δ_R.

	Lab	D_i (µV/V)	U_i (µV/V)
*	NMI-VSL1	4.7	32.9
*	PTB	3.8	457.3
*	VNIIM	-52.9	193.6
*	OMH	-246.6	1158.9
	BNM-LNE	253.0	1001.9
	AREPA	-27.1	93.5
	METAS	17.5	69.8
	SP	29.5	523.7
	CEM	-7.7	104.4
*	NIST	-111.0	798.4
*	NPL-I	-263.7	499.5
*	KRISS	-84.5	4863.7
*	NRC-INMS	43.2	144.5
	NPL-UK2	21.9	67.6
*	CSIRO-NML2	-73.9	603.9

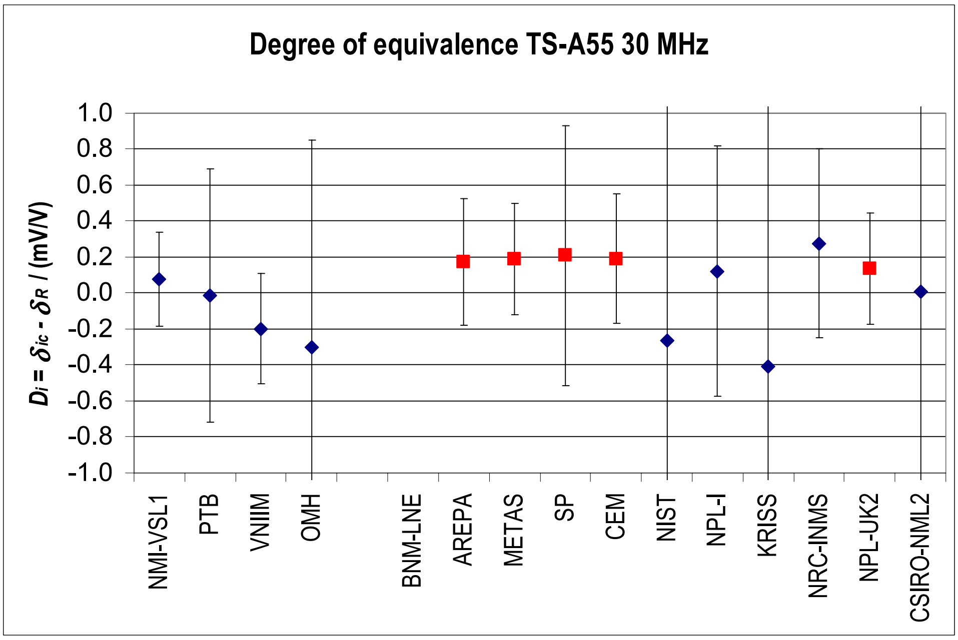

Figure B 11 Degree of equivalence with the reference value at 30 MHz with the corresponding expanded uncertainties (k = 2). (blue diamonds: included in the δ_R; red squares: not included in the δ_R)

Table B 11 Values of the degree of equivalence with the reference value at 30 MHz with the corresponding expanded uncertainties (k = 2). Participants indicated with * are included in the δ_R.

	Lab	D_i (mV/V)	U_i (mV/V)
*	NMI-VSL1	0.079	0.260
*	PTB	-0.012	0.704
*	VNIIM	-0.198	0.306
*	OMH	-0.302	1.150
	BNM-LNE	3.200	1.420
	AREPA	0.172	0.352
	METAS	0.190	0.311
	SP	0.208	0.720
	CEM	0.190	0.360
*	NIST	-0.266	1.593
*	NPL-I	0.122	0.694
*	KRISS	-0.405	4.868
*	NRC-INMS	0.277	0.523
	NPL-UK2	0.136	0.307
*	CSIRO-NML2	0.007	1.521

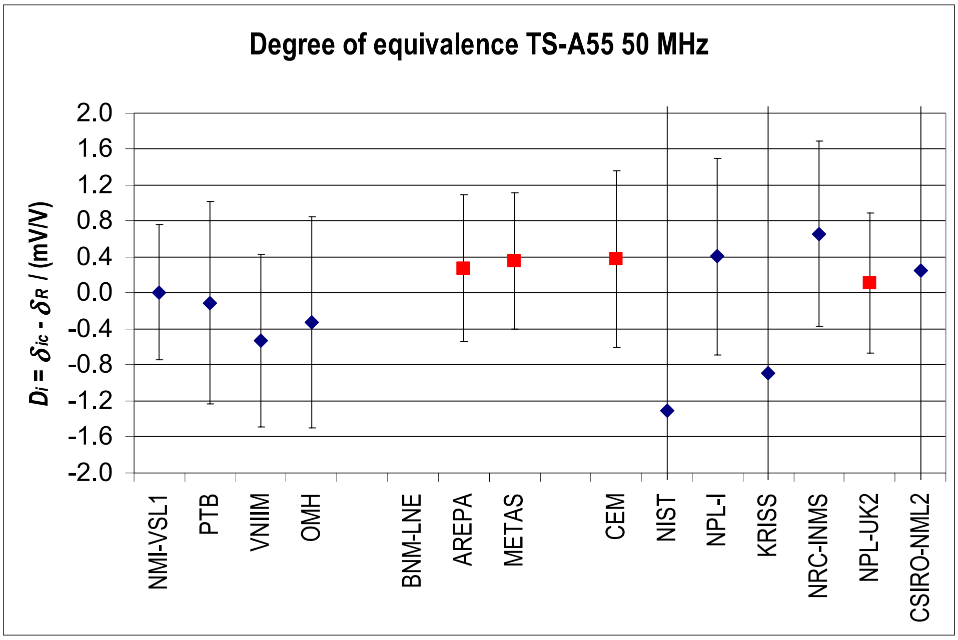

Figure B 12 Degree of equivalence with the reference value at 50 MHz with the corresponding expanded uncertainties (k = 2). (blue diamonds: included in the δ_R; red squares: not included in the δ_R)

Table B 12 Values of the degree of equivalence with the reference value at 50 MHz with the corresponding expanded uncertainties (k = 2). Participants indicated with * are included in the δ_R.

	Lab	D_i (mV/V)	U_i (mV/V)
*	NMI-VSL1	0.010	0.756
*	PTB	-0.107	1.130
*	VNIIM	-0.529	0.965
*	OMH	-0.327	1.171
	BNM-LNE	4.983	1.231
	AREPA	0.273	0.816
	METAS	0.358	0.759
	CEM	0.376	0.983
*	NIST	-1.304	3.991
*	NPL-I	0.408	1.095
*	KRISS	-0.895	4.883
*	NRC-INMS	0.657	1.030
	NPL-UK2	0.111	0.782
*	CSIRO-NML2	0.247	2.438

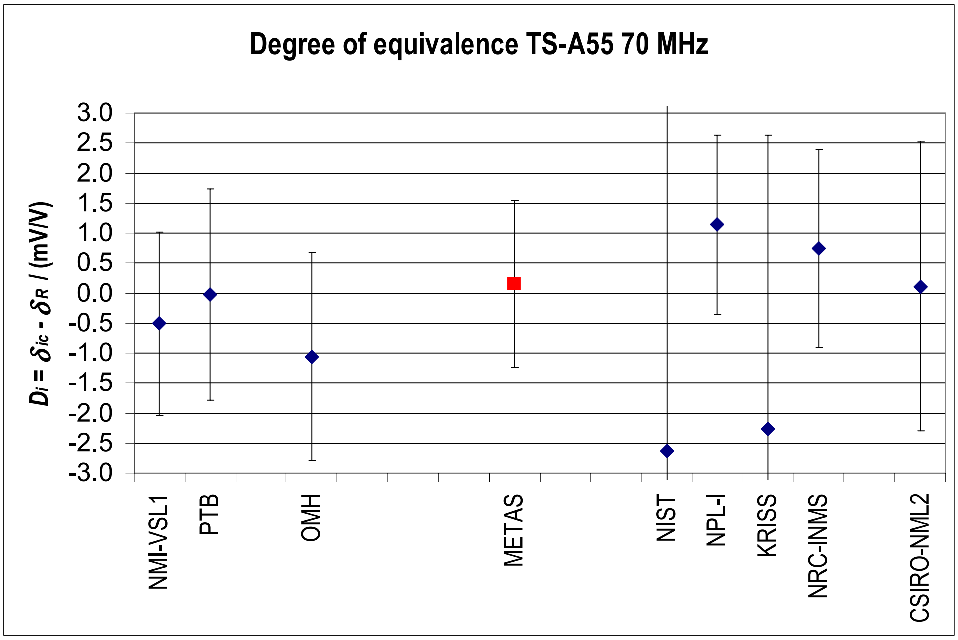

Figure B 13 Degree of equivalence with the reference value at 70 MHz with the corresponding expanded uncertainties (k = 2). (blue diamonds: included in the δ_R; red squares: not included in the δ_R)

Table B 13 Values of the degree of equivalence with the reference value at 70 MHz with the corresponding expanded uncertainties (k = 2). Participants indicated with * are included in the δ_R.

	Lab	D_i (mV/V)	U_i (mV/V)
*	NMI-VSL1	-0.509	1.531
*	PTB	-0.032	1.760
*	OMH	-1.058	1.739
	METAS	0.156	1.395
*	NIST	-2.632	5.781
*	NPL-I	1.138	1.500
*	KRISS	-2.259	4.892
*	NRC-INMS	0.740	1.647
*	CSIRO-NML2	0.111	2.404

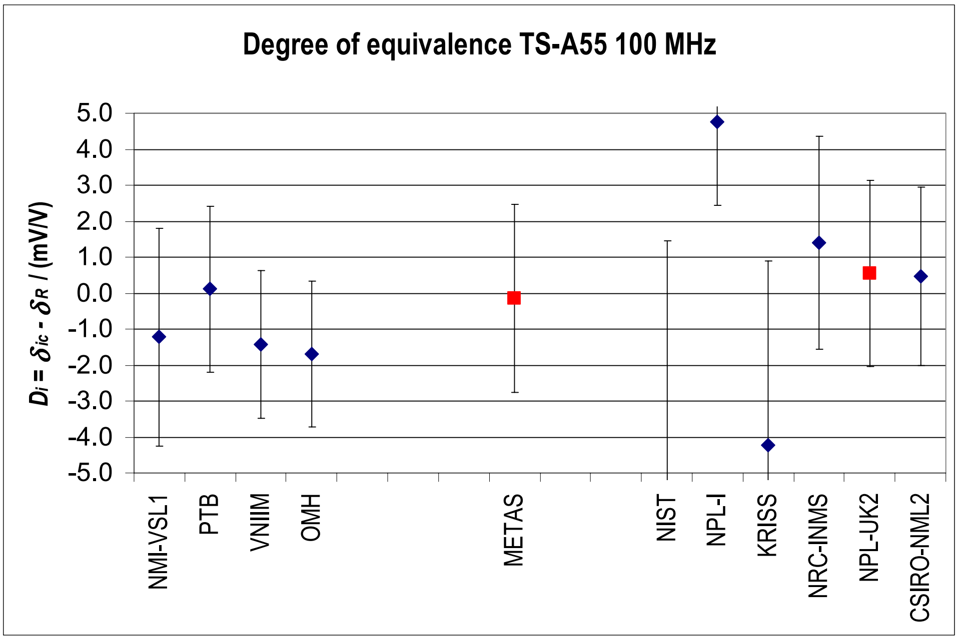

Figure B 14 Degree of equivalence with the reference value at 100 MHz with the corresponding expanded uncertainties (k = 2). (blue diamonds: included in the δ_R; red squares: not included in the δ_R)

Table B 14 Values of the degree of equivalence with the reference value at 100 MHz with the corresponding expanded uncertainties (k = 2). Participants indicated with * are included in the δ_R.

	Lab	D_i (mV/V)	U_i (mV/V)
*	NMI-VSL1	-1.225	3.030
*	PTB	0.111	2.300
*	VNIIM	-1.431	2.045
*	OMH	-1.686	2.025
	METAS	-0.141	2.610
*	NIST	-6.556	8.011
*	NPL-I	4.749	2.300
*	KRISS	-4.221	5.108
*	NRC-INMS	1.409	2.962
	NPL-UK2	0.542	2.588
*	CSIRO-NML2	0.468	2.479

C. Appendix: Results of TS-A55 versus TS-HF

The protocol of this comparison asks the participants also to measure both travelling standards against each other, using the special T-connector that is supplied with the travelling standards. Although, this measurement is optional, it should be considered a useful exercise for the participants to check the consistency of their measuring system and for the pilot laboratory to check the behaviour of the standards with respect to each other.

C.1. Calculation of the results

For frequency, the result is reported as a value, δ_i, and an expanded uncertainty, U_i. The expanded uncertainty is obtained from the combined standard uncertainty, u_i, multiplied by a coverage factor, k_i. All participants used a coverage factor $k_i = 2$.

Only one measurement result of the pilot laboratory is taken as the actual participation of NMi-VSL to this comparison; this is the first measurement, indicated by NMi-VSL1. All other measurements of the pilot laboratory are only used to monitor the behaviour of the standards.

The travelling standard TS-HF has been broken once during the comparison. The instrument was repaired but this has resulted in a shift of its ac-dc transfer difference. Of course, this shift of TS-HF is directly reflected in the measurements of TS-A55 versus TS-HF. Measurement results obtained after this accident are corrected for this step. The pilot laboratory has determined the step, δ_{step}, at all measurement frequencies. The travelling standard was measured shortly before the break down during one of the normally scheduled checks and, of course, measured again after the repair. Based on these measurements, an uncertainty, u_{step}, was determined for each value of δ_{step}. This uncertainty is added to the reported uncertainties of all participants, before and after the step occurred.

In the analysis of these results, no corrections are made for the drift of the travelling standards, so δ_{drift} and u_{drift} are set to zero.

The corrected results, δ_{ic}, are now found from:

$$\delta_{ic} = \delta_i + \delta_{\text{step}} + \delta_{\text{drift}} \qquad \textbf{(C - 1)}$$

with a combined uncertainty, u_{ic}:

$$u_{ic} = \sqrt{u_i^2 + u_{\text{step}}^2 + u_{\text{drift}}^2} \qquad \textbf{(C - 2)}$$

The results of TS-A55 vs. TS-HF at all measurement frequencies are given in Table C 1 to Table C 7. The corrected values δ_{ic} are also plotted in Figure C 1 to Figure C 7.

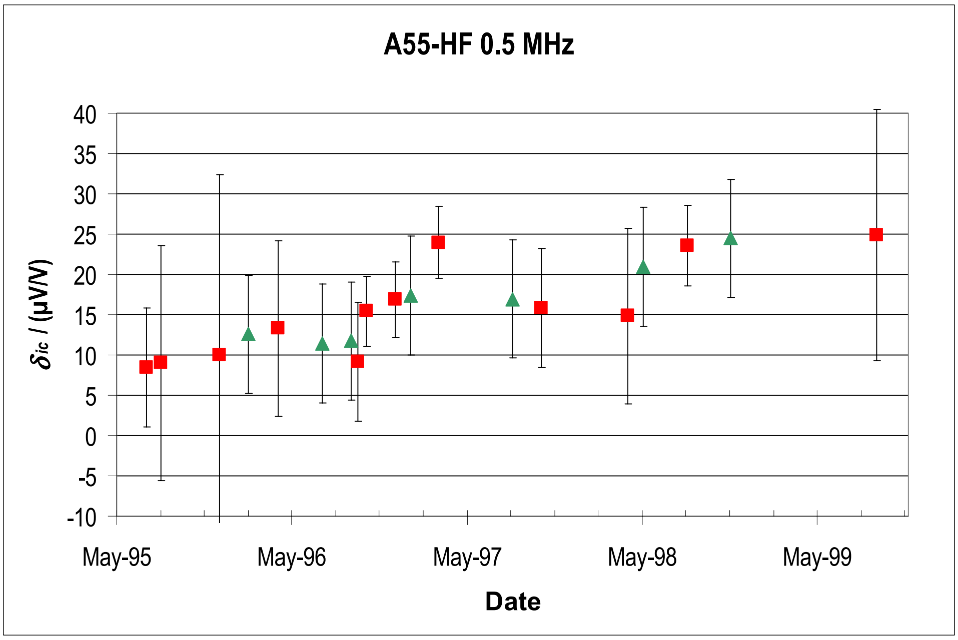

Figure C 1 Corrected measurement results of TS-A55 versus TS-HF at 0.5 MHz with the expanded uncertainties (k = 2). (Red squares: participants; green triangles: characterisation measurements of the pilot laboratory)

Table C 1 Values of the measurement results δ_i and corrections δ_{step} of TS-A55 versus TS-HF at 0.5 MHz with their standard uncertainties (k = 1), and the corrected results δ_{ic} with their expanded uncertainties $U_{\delta ic}$ (k = 2). There are no corrections applied for the drift of the standards.

Lab	Date	δ_i (µV/V)	u_i (µV/V)	δ_{step} (µV/V)	u_{step} (µV/V)	δ_{drift} (µV/V)	u_{drift} (µV/V)	δ_{ic} (µV/V)	$U_{\delta ic}$ (µV/V)
NMI-VSL1	Aug-95	8.5	3.0	0.0	2.1	0.0	0.0	8.5	7.3
PTB	Sep-95	9.0	7.0	0.0	2.1	0.0	0.0	9.0	14.6
VNIIM	Nov-95								
OMH	Jan-96	10.0	11.0	0.0	2.1	0.0	0.0	10.0	22.4
NMI-VSL2	Mar-96	12.6	3.0	0.0	2.1	0.0	0.0	12.6	7.3
NPL-UK1	May-96	13.3	5.0	0.0	2.1	0.0	0.0	13.3	10.9
BNM-LNE	Jun-96								
AREPA	Jul-96								
NMI-VSL3a	Aug-96	11.4	3.0	0.0	2.1	0.0	0.0	11.4	7.3
NMI-VSL3b	Oct-96	10.9	3.0	0.8	2.1	0.0	0.0	11.8	7.3
METAS	Oct-96	8.3	3.0	0.8	2.1	0.0	0.0	9.1	7.3
SP	Nov-96	14.6	0.4	0.8	2.1	0.0	0.0	15.4	4.3
CEM	Jan-97	16.0	1.0	0.8	2.1	0.0	0.0	16.8	4.7
NMI-VSL4	Feb-97	16.5	3.0	0.8	2.1	0.0	0.0	17.4	7.3
NIST	Apr-97	23.1	0.7	0.8	2.1	0.0	0.0	23.9	4.5
NMI-VSL5	Sep-97	16.1	3.0	0.8	2.1	0.0	0.0	16.9	7.3
NPL-I	Nov-97	15.0	3.0	0.8	2.1	0.0	0.0	15.8	7.3
KRISS	May-98	14.0	5.0	0.8	2.1	0.0	0.0	14.8	10.9
NMI-VSL6	Jun-98	20.1	3.0	0.8	2.1	0.0	0.0	21.0	7.3
NRC-INMS	Sep-98	22.7	1.3	0.8	2.1	0.0	0.0	23.5	5.0
NMI-VSL7	Dec-98	23.6	3.0	0.8	2.1	0.0	0.0	24.5	7.3
NPL-UK2	Jan-99								
CSIRO-NML2	Oct-99	24.0	7.5	0.8	2.1	0.0	0.0	24.8	15.6

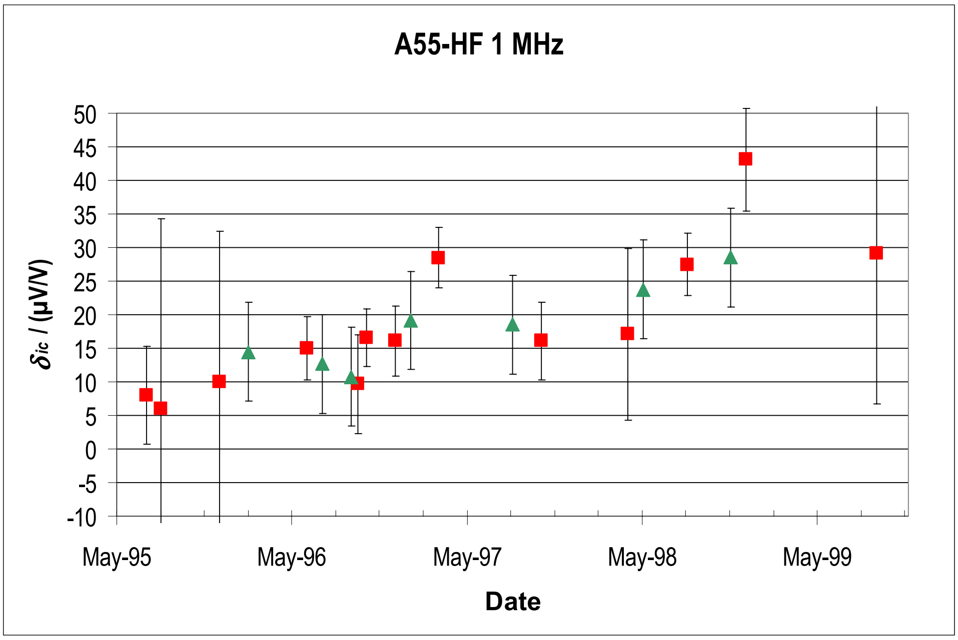

Figure C 2 Corrected measurement results of TS-A55 versus TS-HF at 1 MHz with the expanded uncertainties (k = 2). (Red squares: participants; green triangles: characterisation measurements of the pilot laboratory)

Table C 2 Values of the measurement results δ_i and corrections δ_{step} of TS-A55 versus TS-HF at 1 MHz with their standard uncertainties (k = 1), and the corrected results δ_{ic} with their expanded uncertainties $U_{\delta ic}$ (k = 2). There are no corrections applied for the drift of the standards.

Lab	Date	δ_i (µV/V)	u_i (µV/V)	δ_{step} (µV/V)	u_{step} (µV/V)	δ_{drift} (µV/V)	u_{drift} (µV/V)	δ_{ic} (µV/V)	$U_{\delta ic}$ (µV/V)
NMI-VSL1	Aug-95	8.0	3.0	0.0	2.1	0.0	0.0	8.0	7.3
PTB	Sep-95	6.0	14.0	0.0	2.1	0.0	0.0	6.0	28.3
VNIIM	Nov-95								
OMH	Jan-96	10.0	11.0	0.0	2.1	0.0	0.0	10.0	22.4
NMI-VSL2	Mar-96	14.4	3.0	0.0	2.1	0.0	0.0	14.4	7.3
NPL-UK1	May-96								
BNM-LNE	Jun-96								
AREPA	Jul-96	15.0	1.0	0.0	2.1	0.0	0.0	15.0	4.7
NMI-VSL3a	Aug-96	12.7	3.0	0.0	2.1	0.0	0.0	12.7	7.3
NMI-VSL3b	Oct-96	10.7	3.0	0.1	2.1	0.0	0.0	10.8	7.3
METAS	Oct-96	9.6	3.0	0.1	2.1	0.0	0.0	9.7	7.3
SP	Nov-96	16.5	0.3	0.1	2.1	0.0	0.0	16.6	4.3
CEM	Jan-97	16.0	1.5	0.1	2.1	0.0	0.0	16.1	5.2
NMI-VSL4	Feb-97	19.1	3.0	0.1	2.1	0.0	0.0	19.1	7.3
NIST	Apr-97	28.4	0.8	0.1	2.1	0.0	0.0	28.5	4.5
NMI-VSL5	Sep-97	18.4	3.0	0.1	2.1	0.0	0.0	18.5	7.3
NPL-I	Nov-97	16.0	2.0	0.1	2.1	0.0	0.0	16.1	5.8
KRISS	May-98	17.0	6.0	0.1	2.1	0.0	0.0	17.1	12.7
NMI-VSL6	Jun-98	23.7	3.0	0.1	2.1	0.0	0.0	23.8	7.3
NRC-INMS	Sep-98	27.4	0.9	0.1	2.1	0.0	0.0	27.5	4.6
NMI-VSL7	Dec-98	28.4	3.0	0.1	2.1	0.0	0.0	28.5	7.3
NPL-UK2	Jan-99	43.0	3.2	0.1	2.1	0.0	0.0	43.1	7.7
CSIRO-NML2	Oct-99	29.0	11.0	0.1	2.1	0.0	0.0	29.1	22.4

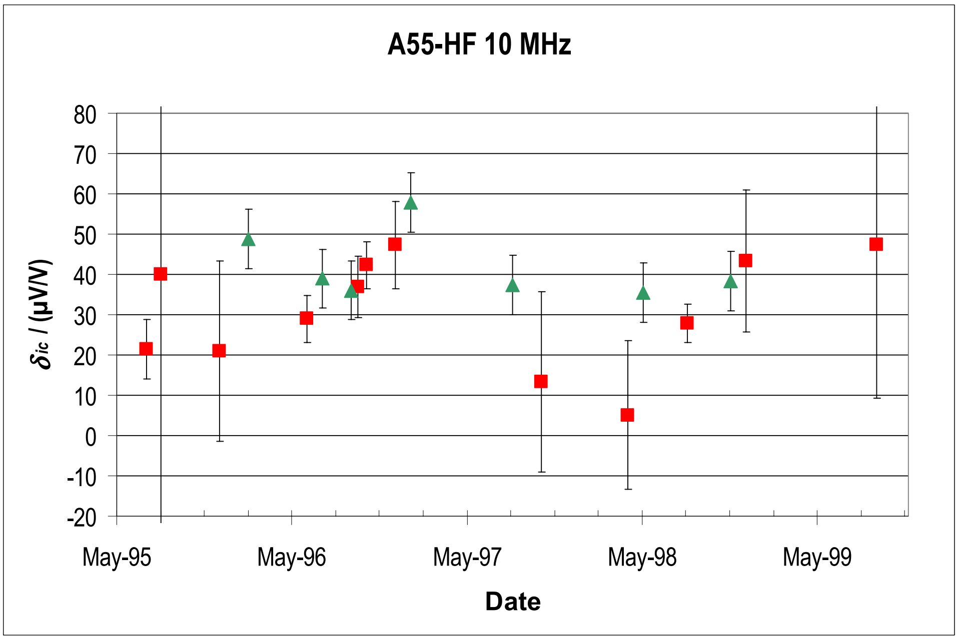

Figure C 3 Corrected measurement results of TS-A55 versus TS-HF at 10 MHz with the expanded uncertainties (k = 2). (Red squares: participants; green triangles: characterisation measurements of the pilot laboratory)

Table C 3 Values of the measurement results δ_i and corrections δ_{step} of TS-A55 versus TS-HF at 10 MHz with their standard uncertainties (k = 1), and the corrected results δ_{ic} with their expanded uncertainties $U_{\delta ic}$ (k = 2). There are no corrections applied for the drift of the standards.

Lab	Date	δ_i (µV/V)	u_i (µV/V)	δ_{step} (µV/V)	u_{step} (µV/V)	δ_{drift} (µV/V)	u_{drift} (µV/V)	δ_{ic} (µV/V)	$U_{\delta ic}$ (µV/V)
NMI-VSL1	Aug-95	21.4	3.0	0.0	2.1	0.0	0.0	21.4	7.3
PTB	Sep-95	40.0	270.0	0.0	2.1	0.0	0.0	40.0	540.0
VNIIM	Nov-95								
OMH	Jan-96	21.0	11.0	0.0	2.1	0.0	0.0	21.0	22.4
NMI-VSL2	Mar-96	48.8	3.0	0.0	2.1	0.0	0.0	48.8	7.3
NPL-UK1	May-96								
BNM-LNE	Jun-96								
AREPA	Jul-96	29.0	2.0	0.0	2.1	0.0	0.0	29.0	5.8
NMI-VSL3a	Aug-96	38.9	3.0	0.0	2.1	0.0	0.0	38.9	7.3
NMI-VSL3b	Oct-96	38.7	3.0	-2.7	2.1	0.0	0.0	36.1	7.3
METAS	Oct-96	39.6	3.1	-2.7	2.1	0.0	0.0	36.9	7.5
SP	Nov-96	45.0	2.0	-2.7	2.1	0.0	0.0	42.3	5.8
CEM	Jan-97	50.0	5.0	-2.7	2.1	0.0	0.0	47.3	10.9
NMI-VSL4	Feb-97	60.5	3.0	-2.7	2.1	0.0	0.0	57.9	7.3
NIST	Apr-97								
NMI-VSL5	Sep-97	40.1	3.0	-2.7	2.1	0.0	0.0	37.4	7.3
NPL-I	Nov-97	16.0	11.0	-2.7	2.1	0.0	0.0	13.3	22.4
KRISS	May-98	7.8	9.0	-2.7	2.1	0.0	0.0	5.1	18.5
NMI-VSL6	Jun-98	38.1	3.0	-2.7	2.1	0.0	0.0	35.4	7.3
NRC-INMS	Sep-98	30.5	1.0	-2.7	2.1	0.0	0.0	27.8	4.7
NMI-VSL7	Dec-98	41.1	3.0	-2.7	2.1	0.0	0.0	38.4	7.3
NPL-UK2	Jan-99	46.0	8.6	-2.7	2.1	0.0	0.0	43.3	17.7
CSIRO-NML2	Oct-99	50.0	18.9	-2.7	2.1	0.0	0.0	47.3	38.0

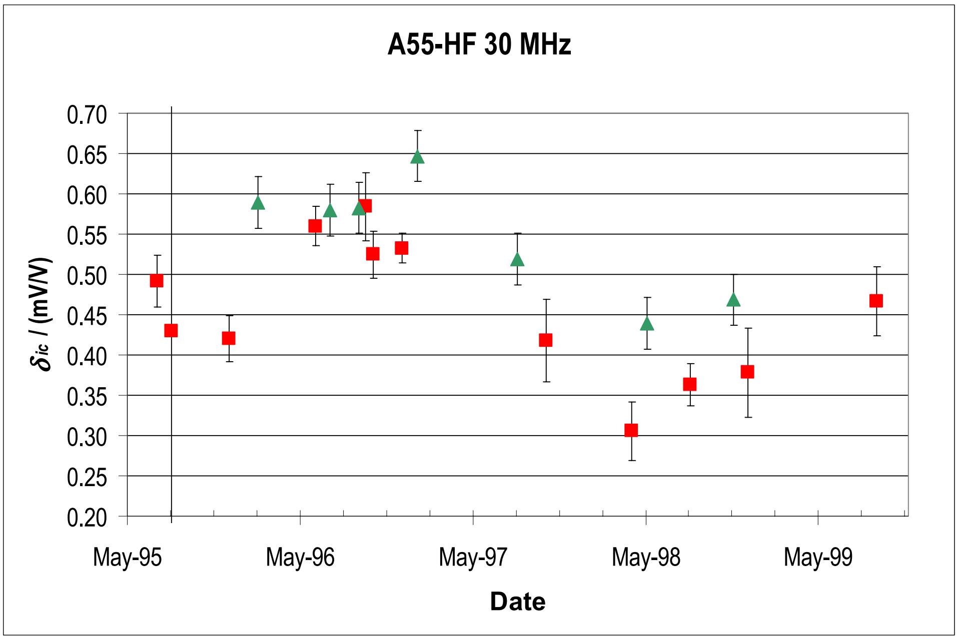

Figure C 4 Corrected measurement results of TS-A55 versus TS-HF at 30 MHz with the expanded uncertainties (k = 2). (Red squares: participants; green triangles: characterisation measurements of the pilot laboratory)

Table C 4 Values of the measurement results δ_i and corrections δ_{step} of TS-A55 versus TS-HF at 30 MHz with their standard uncertainties (k = 1), and the corrected results δ_{ic} with their expanded uncertainties $U_{\delta ic}$ (k = 2). There are no corrections applied for the drift of the standards.

Lab	Date	δ_i (mV/V)	u_i (mV/V)	δ_{step} (mV/V)	u_{step} (mV/V)	δ_{drift} (mV/V)	u_{drift} (mV/V)	δ_{ic} (mV/V)	$U_{\delta ic}$ (mV/V)
NMI-VSL1	Aug-95	0.492	0.013	0.000	0.009	0.000	0.000	0.492	0.032
PTB	Sep-95	0.430	0.400	0.000	0.009	0.000	0.000	0.430	0.800
VNIIM	Nov-95								
OMH	Jan-96	0.420	0.011	0.000	0.009	0.000	0.000	0.420	0.029
NMI-VSL2	Mar-96	0.589	0.013	0.000	0.009	0.000	0.000	0.589	0.032
NPL-UK1	May-96								
BNM-LNE	Jun-96								
AREPA	Jul-96	0.560	0.008	0.000	0.009	0.000	0.000	0.560	0.024
NMI-VSL3a	Aug-96	0.580	0.013	0.000	0.009	0.000	0.000	0.580	0.032
NMI-VSL3b	Oct-96	0.554	0.013	0.028	0.009	0.000	0.000	0.583	0.032
METAS	Oct-96	0.556	0.019	0.028	0.009	0.000	0.000	0.584	0.042
SP	Nov-96	0.496	0.011	0.028	0.009	0.000	0.000	0.524	0.029
CEM	Jan-97	0.504	0.001	0.028	0.009	0.000	0.000	0.532	0.018
NMI-VSL4	Feb-97	0.618	0.013	0.028	0.009	0.000	0.000	0.647	0.032
NIST	Apr-97								
NMI-VSL5	Sep-97	0.491	0.013	0.028	0.009	0.000	0.000	0.519	0.032
NPL-I	Nov-97	0.389	0.024	0.028	0.009	0.000	0.000	0.417	0.051
KRISS	May-98	0.277	0.016	0.028	0.009	0.000	0.000	0.305	0.037
NMI-VSL6	Jun-98	0.411	0.013	0.028	0.009	0.000	0.000	0.439	0.032
NRC-INMS	Sep-98	0.335	0.009	0.028	0.009	0.000	0.000	0.363	0.026
NMI-VSL7	Dec-98	0.440	0.013	0.028	0.009	0.000	0.000	0.469	0.032
NPL-UK2	Jan-99	0.350	0.026	0.028	0.009	0.000	0.000	0.378	0.055
CSIRO-NML2	Oct-99	0.438	0.019	0.028	0.009	0.000	0.000	0.466	0.043

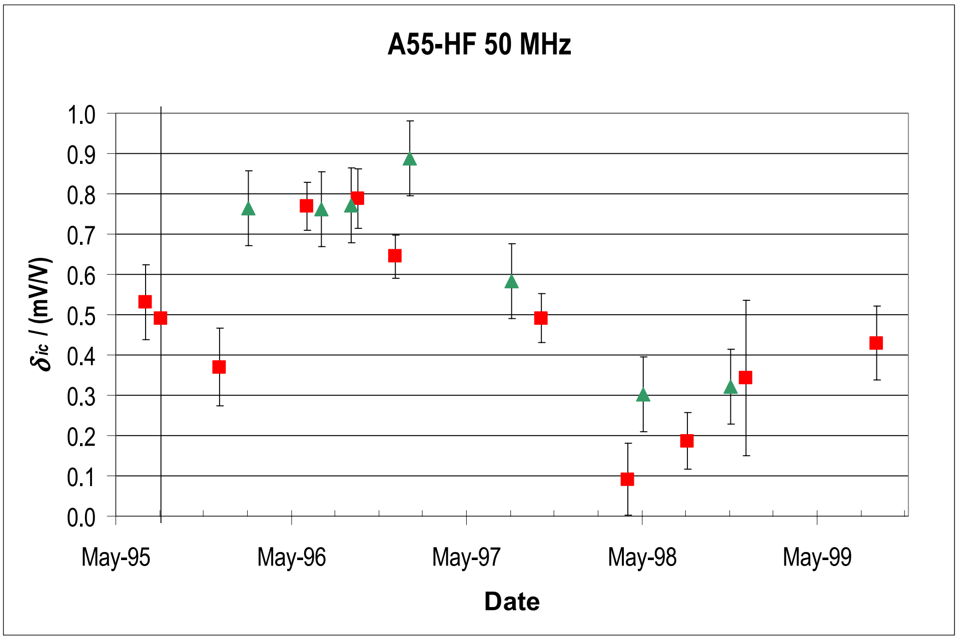

Figure C 5 Corrected measurement results of TS-A55 versus TS-HF at 50 MHz with the expanded uncertainties (k = 2). (Red squares: participants; green triangles: characterisation measurements of the pilot laboratory)

Table C 5 Values of the measurement results δ_i and corrections δ_{step} of TS-A55 versus TS-HF at 50 MHz with their standard uncertainties (k = 1), and the corrected results δ_{ic} with their expanded uncertainties $U_{\delta ic}$ (k = 2). There are no corrections applied for the drift of the standards.

Lab	Date	δ_i (mV/V)	u_i (mV/V)	δ_{step} (mV/V)	u_{step} (mV/V)	δ_{drift} (mV/V)	u_{drift} (mV/V)	δ_{ic} (mV/V)	$U_{\delta ic}$ (mV/V)
NMI-VSL1	Aug-95	0.530	0.038	0.000	0.027	0.000	0.000	0.530	0.093
PTB	Sep-95	0.490	0.680	0.000	0.027	0.000	0.000	0.490	1.361
VNIIM	Nov-95								
OMH	Jan-96	0.370	0.040	0.000	0.027	0.000	0.000	0.370	0.096
NMI-VSL2	Mar-96	0.765	0.038	0.000	0.027	0.000	0.000	0.765	0.093
NPL-UK1	May-96								
BNM-LNE	Jun-96								
AREPA	Jul-96	0.770	0.013	0.000	0.027	0.000	0.000	0.770	0.060
NMI-VSL3a	Aug-96	0.762	0.038	0.000	0.027	0.000	0.000	0.762	0.093
NMI-VSL3b	Oct-96	0.641	0.038	0.130	0.027	0.000	0.000	0.771	0.093
METAS	Oct-96	0.658	0.025	0.130	0.027	0.000	0.000	0.788	0.073
SP	Nov-96								
CEM	Jan-97	0.515	0.002	0.130	0.027	0.000	0.000	0.645	0.054
NMI-VSL4	Feb-97	0.759	0.038	0.130	0.027	0.000	0.000	0.888	0.093
NIST	Apr-97								
NMI-VSL5	Sep-97	0.453	0.038	0.130	0.027	0.000	0.000	0.583	0.093
NPL-I	Nov-97	0.362	0.015	0.130	0.027	0.000	0.000	0.492	0.062
KRISS	May-98	-0.038	0.036	0.130	0.027	0.000	0.000	0.092	0.089
NMI-VSL6	Jun-98	0.173	0.038	0.130	0.027	0.000	0.000	0.302	0.093
NRC-INMS	Sep-98	0.057	0.023	0.130	0.027	0.000	0.000	0.187	0.071
NMI-VSL7	Dec-98	0.192	0.038	0.130	0.027	0.000	0.000	0.322	0.093
NPL-UK2	Jan-99	0.213	0.093	0.130	0.027	0.000	0.000	0.343	0.193
CSIRO-NML2	Oct-99	0.300	0.037	0.130	0.027	0.000	0.000	0.430	0.091

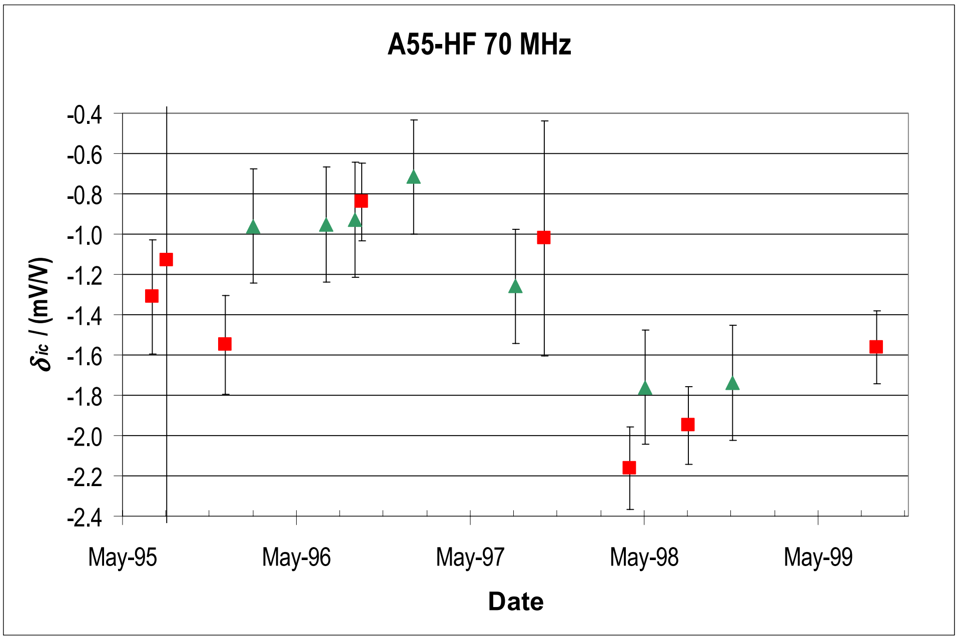

Figure C 6 Corrected measurement results of TS-A55 versus TS-HF at 70 MHz with the expanded uncertainties (k = 2). (Red squares: participants; green triangles: characterisation measurements of the pilot laboratory)

Table C 6 Values of the measurement results δ_i and corrections δ_{step} of TS-A55 versus TS-HF at 70 MHz with their standard uncertainties (k = 1), and the corrected results δ_{ic} with their expanded uncertainties $U_{\delta ic}$ (k = 2). There are no corrections applied for the drift of the standards.

Lab	Date	δ_i (mV/V)	u_i (mV/V)	δ_{step} (mV/V)	u_{step} (mV/V)	δ_{drift} (mV/V)	u_{drift} (mV/V)	δ_{ic} (mV/V)	$U_{\delta ic}$ (mV/V)
NMI-VSL1	Aug-95	-1.311	0.116	0.000	0.082	0.000	0.000	-1.311	0.284
PTB	Sep-95	-1.130	1.090	0.000	0.082	0.000	0.000	-1.130	2.186
VNIIM	Nov-95								
OMH	Jan-96	-1.550	0.090	0.000	0.082	0.000	0.000	-1.550	0.244
NMI-VSL2	Mar-96	-0.960	0.116	0.000	0.082	0.000	0.000	-0.960	0.284
NPL-UK1	May-96								
BNM-LNE	Jun-96								
AREPA	Jul-96								
NMI-VSL3a	Aug-96	-0.953	0.116	0.000	0.082	0.000	0.000	-0.953	0.284
NMI-VSL3b	Oct-96	-1.209	0.116	0.280	0.082	0.000	0.000	-0.929	0.284
METAS	Oct-96	-1.120	0.050	0.280	0.082	0.000	0.000	-0.840	0.192
SP	Nov-96								
CEM	Jan-97								
NMI-VSL4	Feb-97	-0.997	0.116	0.280	0.082	0.000	0.000	-0.717	0.284
NIST	Apr-97								
NMI-VSL5	Sep-97	-1.538	0.116	0.280	0.082	0.000	0.000	-1.258	0.284
NPL-I	Nov-97	-1.301	0.280	0.280	0.082	0.000	0.000	-1.021	0.584
KRISS	May-98	-2.441	0.062	0.280	0.082	0.000	0.000	-2.161	0.206
NMI-VSL6	Jun-98	-2.040	0.116	0.280	0.082	0.000	0.000	-1.760	0.284
NRC-INMS	Sep-98	-2.230	0.049	0.280	0.082	0.000	0.000	-1.950	0.191
NMI-VSL7	Dec-98	-2.018	0.116	0.280	0.082	0.000	0.000	-1.738	0.284
NPL-UK2	Jan-99								
CSIRO-NML2	Oct-99	-1.841	0.037	0.280	0.082	0.000	0.000	-1.561	0.180

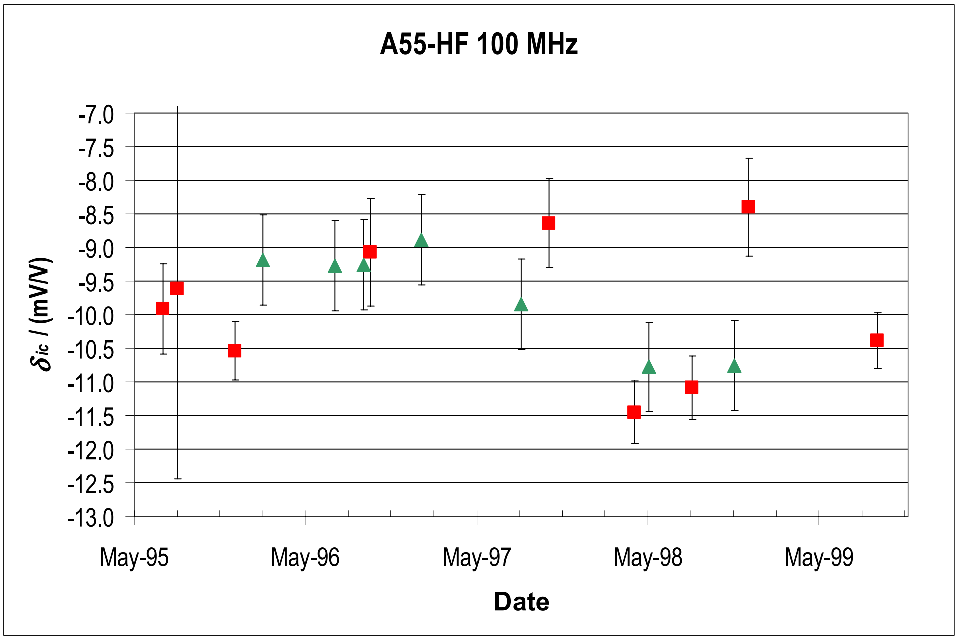

Figure C 7 Corrected measurement results of TS-A55 versus TS-HF at 100 MHz with the expanded uncertainties (*k* = 2). (Red squares: participants; green triangles: characterisation measurements of the pilot laboratory)

Table C 7 Values of the measurement results δ_i and corrections δ_{step} of TS-A55 versus TS-HF at 100 MHz with their standard uncertainties (*k* = 1), and the corrected results δ_{ic} with their expanded uncertainties $U_{\delta ic}$ (*k* = 2). There are no corrections applied for the drift of the standards.

Lab	Date	δ_i (mV/V)	u_i (mV/V)	δ_{step} (mV/V)	u_{step} (mV/V)	δ_{drift} (mV/V)	u_{drift} (mV/V)	δ_{ic} (mV/V)	$U_{\delta ic}$ (mV/V)
NMI-VSL1	Aug-95	-9.917	0.274	0.000	0.194	0.000	0.000	-9.917	0.671
PTB	Sep-95	-9.620	1.400	0.000	0.194	0.000	0.000	-9.620	2.827
VNIIM	Nov-95								
OMH	Jan-96	-10.540	0.100	0.000	0.194	0.000	0.000	-10.540	0.436
NMI-VSL2	Mar-96	-9.185	0.274	0.000	0.194	0.000	0.000	-9.185	0.671
NPL-UK1	May-96								
BNM-LNE	Jun-96								
AREPA	Jul-96								
NMI-VSL3a	Aug-96	-9.265	0.274	0.000	0.194	0.000	0.000	-9.265	0.671
NMI-VSL3b	Oct-96	-9.869	0.274	0.615	0.194	0.000	0.000	-9.254	0.671
METAS	Oct-96	-9.690	0.350	0.615	0.194	0.000	0.000	-9.075	0.800
SP	Nov-96								
CEM	Jan-97								
NMI-VSL4	Feb-97	-9.495	0.274	0.615	0.194	0.000	0.000	-8.880	0.671
NIST	Apr-97								
NMI-VSL5	Sep-97	-10.457	0.274	0.615	0.194	0.000	0.000	-9.842	0.671
NPL-I	Nov-97	-9.255	0.269	0.615	0.194	0.000	0.000	-8.640	0.663
KRISS	May-98	-12.066	0.131	0.615	0.194	0.000	0.000	-11.451	0.468
NMI-VSL6	Jun-98	-11.393	0.274	0.615	0.194	0.000	0.000	-10.778	0.671
NRC-INMS	Sep-98	-11.700	0.130	0.615	0.194	0.000	0.000	-11.085	0.467
NMI-VSL7	Dec-98	-11.367	0.274	0.615	0.194	0.000	0.000	-10.752	0.671
NPL-UK2	Jan-99	-9.017	0.311	0.615	0.194	0.000	0.000	-8.402	0.732
CSIRO-NML2	Oct-99	-11.000	0.072	0.615	0.194	0.000	0.000	-10.385	0.413

C.2. Consistency of the participants' measurements

By combining the results of TS-A55 vs. TS-HF and the individual measurement of TS-A55 and TS-HF for each participant according to Figure C 8, an impression is obtained of the consistency of the measurements of this participant.

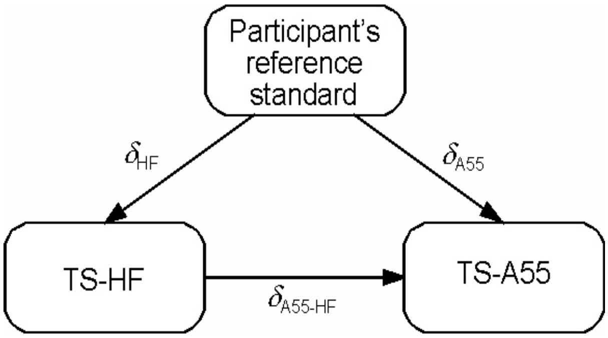

Figure C 8 Triangle consistency check

In Figure C 8:
δ_{HF} is the measurement of TS-HF against the laboratory's reference standard,
δ_{A55} is the measurement of TS-A55 against the laboratory's reference standard,
δ_{A55-HF} is the measurement of TS-A55 against TS-HF.

In this discussion, the values of δ_{HF} and δ_{A55-HF} have been corrected for the δ_{step}, but none of the measurement values have been corrected for δ_{drift}.

From δ_{HF} and δ_{A55} the difference (δ_{A55}-δ_{HF}) can be calculated. The difference $\delta_{calc-meas}$ between this calculated value and the measured value δ_{A55-HF} is an indication of the (in)consistency of the participant's measurements.

$$\delta_{\text{calc}-\text{meas}} = (\delta_{\text{A55}} - \delta_{\text{HF}}) - \delta_{\text{A55}-\text{HF}} \quad \textbf{(C - 3)}$$

The results of the measured value of δ_{A55-HF}, U_{A55-HF}, the calculated value (δ_{A55} - δ_{HF}) and $\delta_{calc-meas}$ at all measurement frequencies are given in Table C 8 to Table C 14. The values $\delta_{calc-meas}$ are also plotted in Figure C 9 to Figure C 15. The uncertainty bars represent U_{A55-HF}, which is not the same as the actual uncertainty in $\delta_{calc-meas}$.

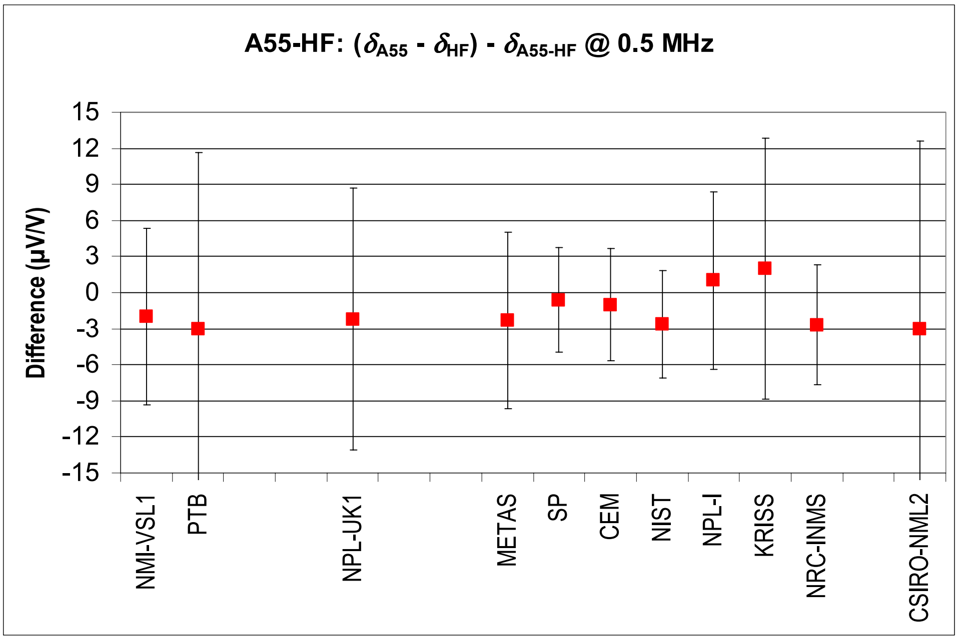

Figure C 9 Consistency of the measurements at 0.5 MHz expressed as the difference δ_{A55} - δ_{HF} as obtained from separate measurements of TS-A55 and TS-HF, compared with a direct measurement $\delta_{A55\text{-}HF}$ of TS-A55 versus TS-HF. The uncertainty bars indicate the reported expanded uncertainties for the measurement of $\delta_{A55\text{-}HF}$, $U_{A55\text{-}HF}$.

Table C 8 Measured and calculated values of TS-A55 versus TS-HF and the difference between the calculated and measured value for each participant at 0.5 MHz. The "T" column indicates whether or not the participant has used the special T-connector supplied with the travelling standards to compare both standards against each other. (Y: the supplied T-connector was used; N: the supplied T-connector was not used; ?: the participant didn't report which T-connector was used.)

Lab	Measured $\delta_{A55\text{-}HF}$ (µV/V)	$U_{A55\text{-}HF}$ (µV/V)	Calculated δ_{A55}-δ_{HF} (µV/V)	$\delta_{calc\text{-}meas}$ (µV/V)	T
NMI-VSL1	8.5	7.3	6.5	-2.0	Y
PTB	9.0	14.6	6.0	-3.0	?
NPL-UK1	13.3	10.9	11.1	-2.2	?
METAS	9.1	7.3	6.8	-2.3	Y
SP	15.4	4.3	14.8	-0.6	N
CEM	16.8	4.7	15.8	-1.0	Y
NIST	23.9	4.5	21.3	-2.6	N
NPL-I	15.8	7.3	16.8	1.0	Y
KRISS	14.8	10.9	16.8	2.0	Y
NRC-INMS	23.5	5.0	20.8	-2.7	Y
CSIRO-NML2	24.8	15.6	21.8	-3.0	Y

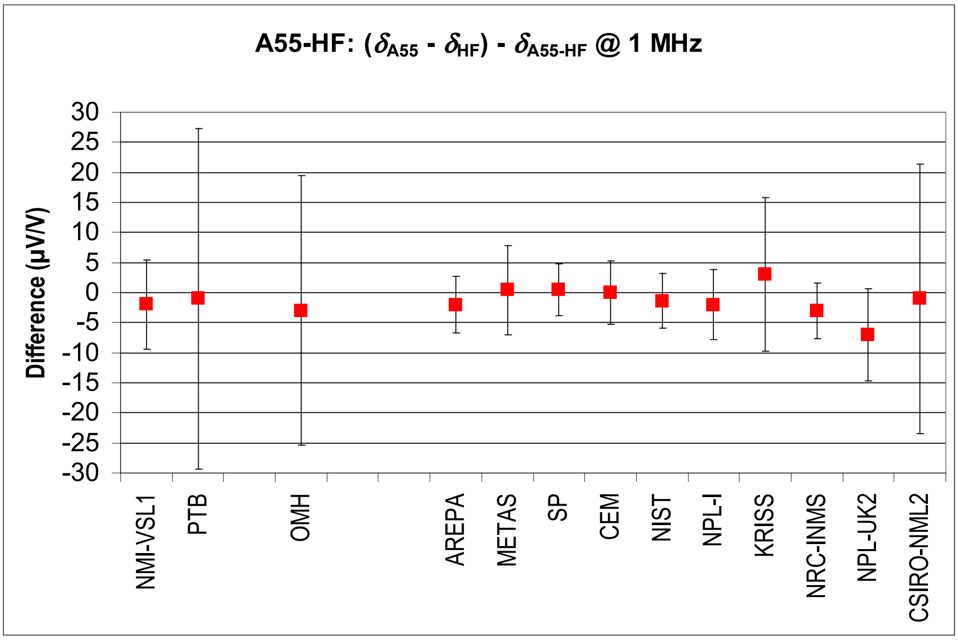

Figure C 10 Consistency of the measurements at 1 MHz expressed as the difference δ_{A55} - δ_{HF} as obtained from separate measurements of TS-A55 and TS-HF, compared with a direct measurement $\delta_{A55\text{-}HF}$ of TS-A55 versus TS-HF. The uncertainty bars indicate the reported expanded uncertainties for the measurement of $\delta_{A55\text{-}HF}$, $U_{A55\text{-}HF}$.

Table C 9 Measured and calculated values of TS-A55 versus TS-HF and the difference between the calculated and measured value for each participant at 1 MHz. The "T" column indicates whether or not the participant has used the special T-connector supplied with the travelling standards to compare both standards against each other. (Y: the supplied T-connector was used; N: the supplied T-connector was not used; ?: the participant didn't report which T-connector was used.)

Lab	Measured $\delta_{A55\text{-}HF}$ (µV/V)	$U_{A55\text{-}HF}$ (µV/V)	Calculated δ_{A55}-δ_{HF} (µV/V)	$\delta_{calc\text{-}meas}$ (µV/V)	T
NMI-VSL1	8.0	7.3	6.0	-2.0	Y
PTB	6.0	28.3	5.0	-1.0	?
OMH	10.0	22.4	7.0	-3.0	Y
AREPA	15.0	4.7	13.0	-2.0	Y
METAS	9.7	7.3	10.1	0.4	Y
SP	16.6	4.3	17.1	0.5	N
CEM	16.1	5.2	16.1	0.0	Y
NIST	28.5	4.5	27.1	-1.4	N
NPL-I	16.1	5.8	14.1	-2.0	Y
KRISS	17.1	12.7	20.1	3.0	Y
NRC-INMS	27.5	4.6	24.5	-3.0	Y
NPL-UK2	43.1	7.7	36.1	-7.0	?
CSIRO-NML2	29.1	22.4	28.1	-1.0	Y

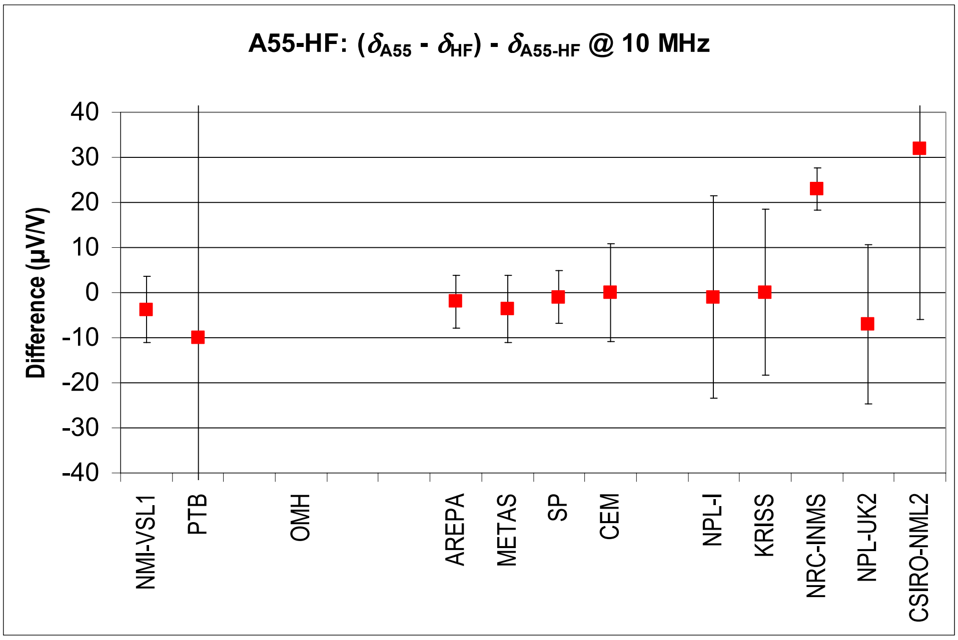

Figure C 11 Consistency of the measurements at 10 MHz expressed as the difference δ_{A55} - δ_{HF} as obtained from separate measurements of TS-A55 and TS-HF, compared with a direct measurement $\delta_{A55\text{-}HF}$ of TS-A55 versus TS-HF. The uncertainty bars indicate the reported expanded uncertainties for the measurement of $\delta_{A55\text{-}HF}$, $U_{A55\text{-}HF}$.

Table C 10 Measured and calculated values of TS-A55 versus TS-HF and the difference between the calculated and measured value for each participant at 10 MHz. The "T" column indicates whether or not the participant has used the special T-connector supplied with the travelling standards to compare both standards against each other. (Y: the supplied T-connector was used; N: the supplied T-connector was not used; ?: the participant didn't report which T-connector was used.)

Lab	Measured $\delta_{A55\text{-}HF}$ (µV/V)	$U_{A55\text{-}HF}$ (µV/V)	Calculated δ_{A55}-δ_{HF} (µV/V)	$\delta_{calc\text{-}meas}$ (µV/V)	T
NMI-VSL1	21.4	7.3	17.7	-3.8	Y
PTB	40.0	540.0	30.0	-10.0	?
OMH	21.0	22.4	90.0	69.0	Y
AREPA	29.0	5.8	27.0	-2.0	Y
METAS	36.9	7.5	33.3	-3.6	Y
SP	42.3	5.8	41.3	-1.0	N
CEM	47.3	10.9	47.3	0.0	Y
NPL-I	13.3	22.4	12.3	-1.0	Y
KRISS	5.1	18.5	5.2	0.1	Y
NRC-INMS	27.8	4.7	50.8	23.0	Y
NPL-UK2	43.3	17.7	36.3	-7.0	?
CSIRO-NML2	47.3	38.0	79.3	32.0	Y

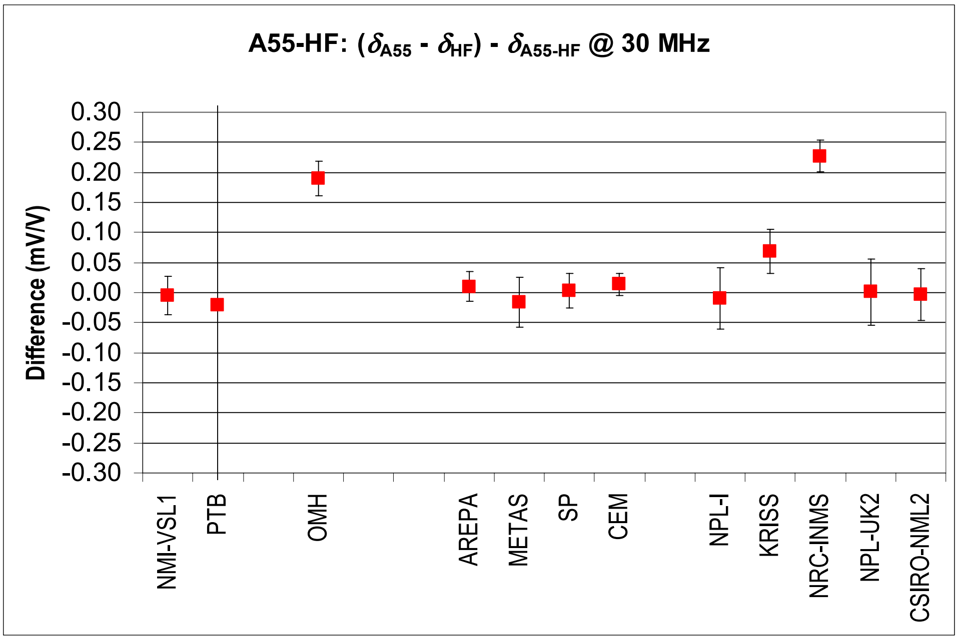

Figure C 12 Consistency of the measurements at 30 MHz expressed as the difference δ_{A55} - δ_{HF} as obtained from separate measurements of TS-A55 and TS-HF, compared with a direct measurement $\delta_{A55\text{-}HF}$ of TS-A55 versus TS-HF. The uncertainty bars indicate the reported expanded uncertainties for the measurement of $\delta_{A55\text{-}HF}$, $U_{A55\text{-}HF}$.

Table C 11 Measured and calculated values of TS-A55 versus TS-HF and the difference between the calculated and measured value for each participant at 30 MHz. The "T" column indicates whether or not the participant has used the special T-connector supplied with the travelling standards to compare both standards against each other. (Y: the supplied T-connector was used; N: the supplied T-connector was not used; ?: the participant didn't report which T-connector was used.)

Lab	Measured $\delta_{A55\text{-}HF}$ (mV/V)	$U_{A55\text{-}HF}$ (mV/V)	Calculated δ_{A55}-δ_{HF} (mV/V)	$\delta_{calc\text{-}meas}$ (mV/V)	T
NMI-VSL1	0.492	0.032	0.486	-0.005	Y
PTB	0.430	0.800	0.410	-0.020	?
OMH	0.420	0.029	0.610	0.190	Y
AREPA	0.560	0.024	0.570	0.010	Y
METAS	0.584	0.042	0.568	-0.016	Y
SP	0.524	0.029	0.527	0.003	N
CEM	0.532	0.018	0.546	0.014	Y
NPL-I	0.417	0.051	0.407	-0.010	Y
KRISS	0.305	0.037	0.374	0.068	Y
NRC-INMS	0.363	0.026	0.590	0.227	Y
NPL-UK2	0.378	0.055	0.379	0.001	?
CSIRO-NML2	0.466	0.043	0.463	-0.003	Y

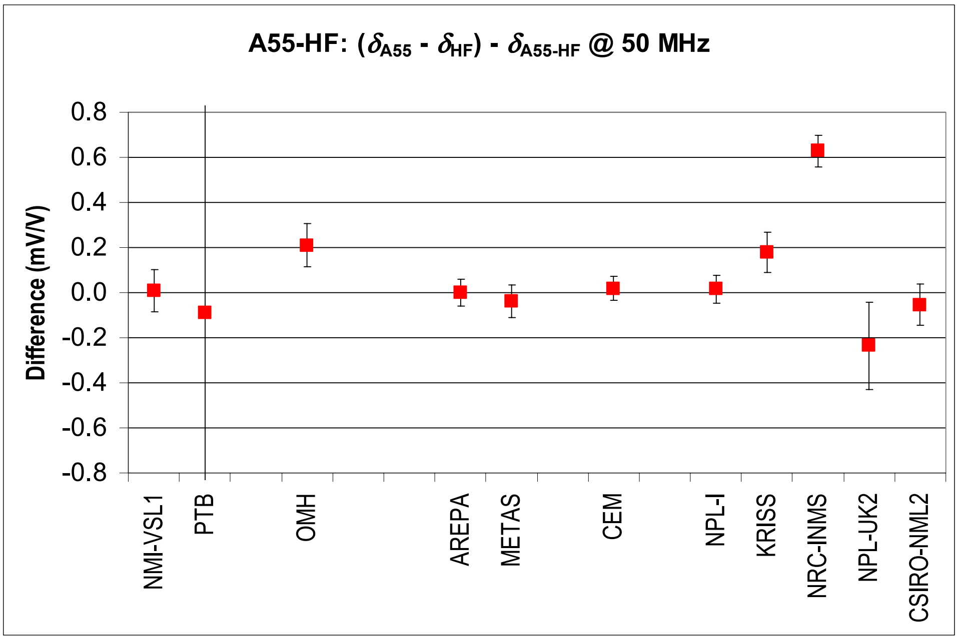

Figure C 13 Consistency of the measurements at 50 MHz expressed as the difference δ_{A55} - δ_{HF} as obtained from separate measurements of TS-A55 and TS-HF, compared with a direct measurement $\delta_{A55\text{-}HF}$ of TS-A55 versus TS-HF. The uncertainty bars indicate the reported expanded uncertainties for the measurement of $\delta_{A55\text{-}HF}$, $U_{A55\text{-}HF}$.

Table C 12 Measured and calculated values of TS-A55 versus TS-HF and the difference between the calculated and measured value for each participant at 50 MHz. The "T" column indicates whether or not the participant has used the special T-connector supplied with the travelling standards to compare both standards against each other. (Y: the supplied T-connector was used; N: the supplied T-connector was not used; ?: the participant didn't report which T-connector was used.)

Lab	Measured $\delta_{A55\text{-}HF}$ (mV/V)	$U_{A55\text{-}HF}$ (mV/V)	Calculated δ_{A55}-δ_{HF} (mV/V)	$\delta_{calc\text{-}meas}$ (mV/V)	T
NMI-VSL1	0.530	0.093	0.538	0.008	Y
PTB	0.490	1.361	0.400	-0.090	?
OMH	0.370	0.096	0.580	0.210	Y
AREPA	0.770	0.060	0.770	0.000	Y
METAS	0.788	0.073	0.750	-0.038	Y
CEM	0.645	0.054	0.664	0.019	Y
NPL-I	0.492	0.062	0.508	0.016	Y
KRISS	0.092	0.089	0.268	0.177	Y
NRC-INMS	0.187	0.071	0.815	0.629	Y
NPL-UK2	0.343	0.193	0.108	-0.235	?
CSIRO-NML2	0.430	0.091	0.376	-0.054	Y

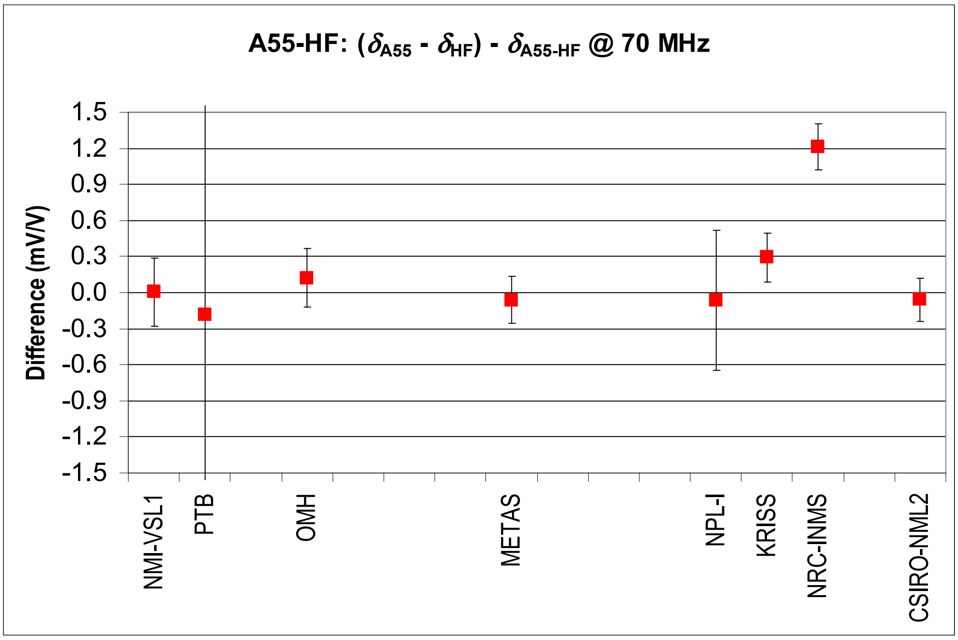

Figure C 14 Consistency of the measurements at 70 MHz expressed as the difference δ_{A55} - δ_{HF} as obtained from separate measurements of TS-A55 and TS-HF, compared with a direct measurement δ_{A55-HF} of TS-A55 versus TS-HF. The uncertainty bars indicate the reported expanded uncertainties for the measurement of δ_{A55-HF}, U_{A55-HF}.

Table C 13 Measured and calculated values of TS-A55 versus TS-HF and the difference between the calculated and measured value for each participant at 70 MHz. The "T" column indicates whether or not the participant has used the special T-connector supplied with the travelling standards to compare both standards against each other. (Y: the supplied T-connector was used; N: the supplied T-connector was not used; ?: the participant didn't report which T-connector was used.)

Lab	Measured δ_{A55-HF} (mV/V)	U_{A55-HF} (mV/V)	Calculated δ_{A55}-δ_{HF} (mV/V)	$\delta_{calc-meas}$ (mV/V)	T
NMI-VSL1	-1.311	0.284	-1.305	0.006	Y
PTB	-1.130	2.186	-1.310	-0.180	?
OMH	-1.550	0.244	-1.430	0.120	Y
METAS	-0.840	0.192	-0.900	-0.060	Y
NPL-I	-1.021	0.584	-1.084	-0.063	Y
KRISS	-2.161	0.206	-1.868	0.293	Y
NRC-INMS	-1.950	0.191	-0.740	1.210	Y
CSIRO-NML2	-1.561	0.180	-1.618	-0.057	Y

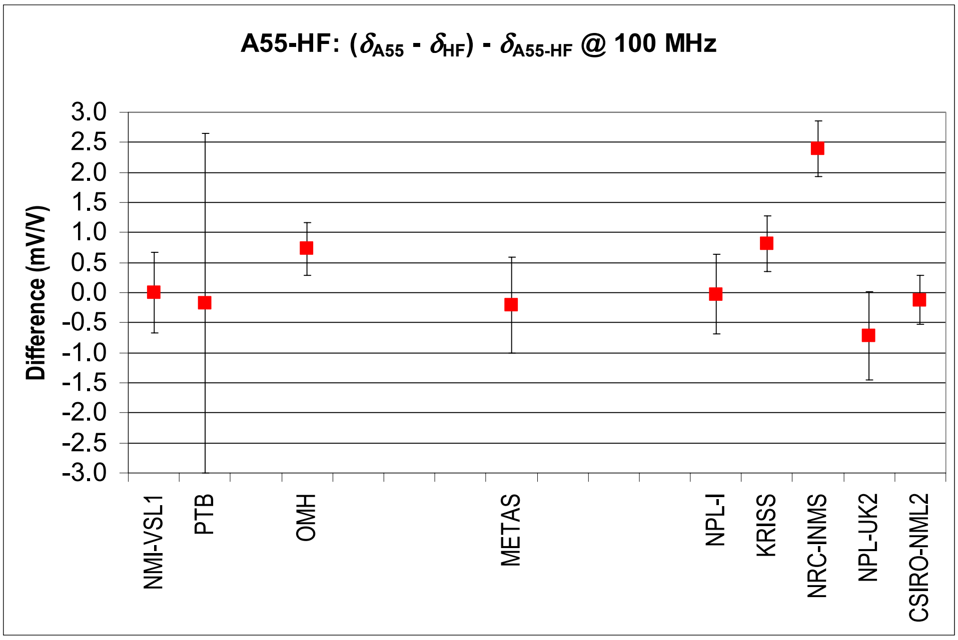

Figure C 15 Consistency of the measurements at 100 MHz expressed as the difference δ_{A55} - δ_{HF} as obtained from separate measurements of TS-A55 and TS-HF, compared with a direct measurement $\delta_{A55\text{-}HF}$ of TS-A55 versus TS-HF. The uncertainty bars indicate the reported expanded uncertainties for the measurement of $\delta_{A55\text{-}HF}$, $U_{A55\text{-}HF}$.

Table C 14 Measured and calculated values of TS-A55 versus TS-HF and the difference between the calculated and measured value for each participant at 100 MHz. The "T" column indicates whether or not the participant has used the special T-connector supplied with the travelling standards to compare both standards against each other. (Y: the supplied T-connector was used; N: the supplied T-connector was not used; ?: the participant didn't report which T-connector was used.)

Lab	Measured $\delta_{A55\text{-}HF}$ (mV/V)	$U_{A55\text{-}HF}$ (mV/V)	Calculated δ_{A55}-δ_{HF} (mV/V)	$\delta_{calc\text{-}meas}$ (mV/V)	T
NMI-VSL1	-9.917	0.671	-9.922	-0.005	Y
PTB	-9.620	2.827	-9.800	-0.180	?
OMH	-10.540	0.436	-9.810	0.730	Y
METAS	-9.075	0.800	-9.285	-0.210	Y
NPL-I	-8.640	0.663	-8.671	-0.031	Y
KRISS	-11.451	0.468	-10.637	0.814	Y
NRC-INMS	-11.085	0.467	-8.695	2.390	Y
NPL-UK2	-8.402	0.732	-9.120	-0.718	?
CSIRO-NML2	-10.385	0.413	-10.505	-0.120	Y

C.3. Discussion of the consistency results

It is noted that we should be very careful when drawing conclusions from the results in Figure C 9 to Figure C 15. If the triangle of Figure C 8 doesn't close within the given uncertainties, it is still not clear where this inconsistency comes from. Even the measurement reports from the participants do not always provide sufficient information to answer this question.

At least one participant, NRC-INMS, informed the pilot laboratory that the differences in the results had been investigated by additional measurements. The reference standard used at NRC-INMS has an N-type connector. So, TS-HF was measured with a symmetrical T-connector and TS-A55 was measured with the NRC asymmetrical T-connector. TS-HF vs. TS-A55 was measured with the T-connector that was provided by the pilot laboratory. It was suspected that the differences that were found resulted from using two different asymmetrical T-connectors to measure TS-A55. The electrical lengths of both T-connectors were measured on a vector network analyzer and corrections were calculated for both T-connector. After applying these corrections the agreement between the different measurements was much better.

Other participants which observed inconsistencies are also recommended to investigate the reason for these discrepancies, if they haven't done this so far.

On the other hand, participants for which the consistency triangle of Figure C 8 closes within the given uncertainties, should realize that systematic deviations may still exist. For example, if a participant measures δ_{A55} and $\delta_{\mathrm{A55\text{-}HF}}$ with the same asymmetrical T-connector, the triangle can be consistent, but there can be a systematic deviation in the measurement of TS-A55 due to the asymmetry of the T-connector.

D. Appendix: Uncertainty budgets of the participants

Institute: NMI-VSL

Remarks: Measurement period during the comparison as pilot laboratory.
Uncertainties in μV/V.
The values of contributions for which a rectangular distribution is assumed, are given as the half width of the probability interval. Values of contributions for which a normal (gaussian) distribution is assumed are given as standard uncertainties (*k* = 1).

Travelling standard: TS-HF

Contribution of:	Unc. f: 1 MHz	Unc. f: 10 MHz	Unc. f: 30 MHz	Unc. f: 50 MHz	Unc. f: 100 MHz	Type A or B	Shape
St. dev. of measurement	1	1	1	1	1	A	Normal
Reference standard	10	15	90	250	1000	B	Normal
Measurement set-up	2	2	10	25	250	B	Rect
Connectors	1	1	6	20	100	B	Rect
Reproducibility	1	2	5	20	50	B	Rect

Total unc (k=1):	10	15	90	250	1000
Expanded unc (k=2):	20	30	180	500	2000

Travelling standard: TS-A55

Contribution of:	Unc. f: 1 MHz	Unc. f: 10 MHz	Unc. f: 30 MHz	Unc. f: 50 MHz	Unc. f: 100 MHz	Type A or B	Shape
St. dev. of measurement	2	2	2	2	2	A	Normal
Reference standard	10	15	90	250	1000	B	Normal
Measurement set-up	10	20	100	250	500	B	Rect
Connectors	10	40	150	400	1500	B	Rect
Reproducibility	5	10	100	250	1000	B	Rect

Total unc (k=1):	15	30	150	400	1500
Expanded unc (k=2):	30	60	300	800	3000

Institute: PTB

Remarks: Values in µV/V
The values of contributions for which a rectangular distribution is assumed, are given as the half width of the probability interval. Values of contributions for which a normal (gaussian) distribution is assumed are given as standard uncertainties (*k* = 1).

Travelling standard: TS-HF (4V)

Contribution of:	Unc. f: 1 MHz	Unc. f: 10 MHz	Unc. f: 30 MHz	Unc. f: 50 MHz	Unc. f: 100 MHz	Type A or B	Shape
st. dev. of measurement	5	10	30	20	50	A	gauss
reference standard	12	250	360	570	1000	B	gauss
measurement set-up	2	50	110	220	900	B	rect.
connectors	3	100	200	400	1100	B	rect.
....							
....							
....							

total unc (k=1):	13	260	380	630	1300
Expanded unc (k=2):	26	520	760	1260	2600

Travelling standard: TS-A55 (3V)

Contribution of:	Unc. f: 1 MHz	Unc. f: 10 MHz	Unc. f: 30 MHz	Unc. f: 50 MHz	Unc. f: 100 MHz	Type A or B	Shape
st. dev. of measurement	5	20	30	60	180	A	gauss
reference standard	12	220	330	510	800	B	gauss
measurement set-up	2	50	110	220	900	B	rect.
connectors	3	100	200	400	1000	B	rect.
....							
....							
....							

total unc (k=1):	13	230	360	580	1130
Expanded unc (k=2):	26	460	720	1160	2260

Institute: VNIIM

Remarks: Revised uncertainty budget 22/01/1999
Values in µV/V
All uncertainty contributions are expressed as standard uncertainties (k = 1)

Travelling standard: TS-HF

Contribution of: ppm(10^{-6})	Unc. f: 1 MHz	Unc. f: 10 MHz	Unc. f: 30 MHz	Unc. f: 50 MHz	Unc. f: 100 MHz	Type A or B	Shape
st. dev. Of measurement	0.8	1.7	6	20	60	A	normal
reference standard	29	99	160	492	985	B	uniform
measurement set-up	4	4	10	10	10	B	uniform
T-connector	5	10	50	75	150	B	uniform
change in external conditions..........	2	4	4	4	4	B	uniform
....							
....							

total unc (k=1):	30	100	170	500	1000
expanded unc (k=2):	60	200	340	1000	2000

Travelling standard: TS-A55

Contribution of: ppm(10^{-6})	Unc. f: 1 MHz	Unc. f: 10 MHz	Unc. f: 30 MHz	Unc. f: 50 MHz	Unc. f: 100 MHz	Type A or B	Shape
st. dev. Of measurement	2.9	3	3	5	10	A	normal
reference standard	29	99	160	492	985	B	uniform
measurement set-up	4	4	10	10	10	B	uniform
T-connector	5	10	50	75	150	B	uniform
change in external conditions	2	4	4	4	4	B	uniform
....							
....							

total unc (k=1):	30	100	170	500	1000
expanded unc (k=2):	60	200	340	1000	2000

Institute: OMH

Remarks: The calibrations are valid in the reference plane of the supplied T-connector
Values in µV/V
All uncertainty contributions are expressed as standard uncertainties (k = 1)

Travelling standard: TS-HF

Contribution of:	Unc. f: 1 MHz	Unc. f: 10 MHz	Unc. f: 30 MHz	Unc. f: 50 MHz	Unc. f: 100 MHz	Type A or B	Shape
st. dev. of measurement	1	30	30	30	30	A	normal
reference standard	15	580	580	590	984	B	
measurement set-up	10	40	40	40	100	B	
Connectors	Included in line of measurement set-up						
....							
....							
....							

total unc (k=1):	18	580	580	600	990
expanded unc (k=2):	36	1160	1160	1200	1980

Travelling standard: TS-A55

Contribution of:	Unc. f: 1 MHz	Unc. f: 10 MHz	Unc. f: 30 MHz	Unc. f: 50 MHz	Unc. f: 100 MHz	Type A or B	Shape
st. dev. of measurement	1	30	30	30	30	A	normal
reference standard	15	580	580	590	984	B	
measurement set-up	10	40	40	40	100	B	
Connectors	Included in line of measurement set-up						
....							
....							
....							

total unc (k=1):	18	580	580	600	990
expanded unc (k=2):	36	1160	1160	1200	1980

Institute: NPL-UK1

Remarks: Frequencies 1 MHz and below
Values in µV/V
The values of contributions for which a rectangular distribution is assumed, are given as the half width of the probability interval. Values of contributions for which a normal (gaussian) distribution is assumed are given as standard uncertainties (*k* = 1).

Travelling standard: TS-HF

Contribution of:	Unc. f: 1 MHz	Unc. f: 10 MHz	Unc. f: 30 MHz	Unc. f: 50 MHz	Unc. f: 100 MHz	Type A or B	Shape
st. dev. of measurement	1.1					A	Gauss
reference standard @ 1kHz	2					B	RECT
freq. dependence of the standard	14					B	RECT
measurement set-up	2					B	RECT
....							

total unc (k=1):	8.3				
expanded unc (k=2):	17				

Travelling standard: TS-A55

Contribution of:	Unc. f: 1 MHz	Unc. f: 10 MHz	Unc. f: 30 MHz	Unc. f: 50 MHz	Unc. f: 100 MHz	Type A or B	Shape
st. dev. of measurement	1.1					A	GAUS
reference standard @ 1kHz	2					B	RECT
freq. dependence of the standard	14					B	RECT
measurement set-up	2					B	RECT
....							

total unc (k=1):	8.3				
expanded unc (k=2):	17				

Institute: NPL-UK2

Remarks: Frequencies 10 MHz and above
Values in μV/V
All uncertainty contributions are expressed as standard uncertainties (k = 1)

Travelling standard: TS-HF

Contribution of:	Unc. f: 1 MHz	Unc. f: 10 MHz	Unc. f: 30 MHz	Unc. f: 50 MHz	Unc. f: 100 MHz	Type A or B	Shape
st. dev. of measurement		0.5	3.3	12.5	50	A	Gauss
reference standard		10	90	250	1000	A	Gauss
measurement set-up		5.8	1.3	34.6	69.3	B	RECT
connectors		2.3	23.1	63.5	248	B	RECT
Allowance for drift in Standard		2.9	26	72	289	B	RECT
Voltage dependence of stanadards		5.8	11.5	57.7	173	B	RECT
....							

total unc (k=1):		13.5	97.2	276.5	1087
expanded unc (k=2):		27	195	553	2174

Travelling standard: TS-A55

Contribution of:	Unc. f: 1 MHz	Unc. f: 10 MHz	Unc. f: 30 MHz	Unc. f: 50 MHz	Unc. f: 100 MHz	Type A or B	Shape
st. dev. of measurement		0.6	2.8	8	53	A	GAUS
reference standard		10	90	250	1000	A	Gauss
measurement set-up		5.8	1.3	34.6	69.3	B	RECT
connectors		2.3	23.1	63.5	248	B	RECT
Allowance for drift in Standard		2.9	26	72	289	B	RECT
Voltage dependence of stanadards		5.8	11.5	57.7	173	B	RECT
....							

total unc (k=1):		13.5	97.2	276.5	1087
expanded unc (k=2):		27	195	553	2174

Institute: BNM-LNE

Remarks: All uncertainties are given in µV/V
All uncertainty contributions are expressed as standard uncertainties (k = 1)

Travelling standard: TS-HF

Contribution of:	Unc. f: 1 MHz	Unc. f: 10 MHz	Unc. f: 30 MHz	Unc. f: 50 MHz	Unc. f: 100 MHz	Type A or B	Shape
St. dev. of measurement	50	50	50	50		A	Gauss.
Reference standard	280	280	400	400		B	Gauss.
Voltage meas.	30	30	30	30		B	Gauss.
Ref. standard drift	200	300	400	200		B	Rect.
Detector sensibility	50	50	50	50		B	Rect.
Reversibility	50	50	50	50		B	Rect.
Voltage interpolation	10	10	10	10		B	Rect.

Total unc (k=1):	450	500	700	550	
Expanded unc (k=2):	900	1000	1400	1100	

Travelling standard: TS-A55

Contribution of:	Unc. f: 1 MHz	Unc. f: 10 MHz	Unc. f: 30 MHz	Unc. f: 50 MHz	Unc. f: 100 MHz	Type A or B	Shape
St. dev. of measurement	50	50	50	50		A	Gauss.
Reference standard	280	280	400	400		B	Gauss.
Voltage meas.	30	30	30	30		B	Gauss.
Ref. standard drift	200	300	400	200		B	Rect.
Detector sensibility	50	50	50	50		B	Rect.
Reversibility	50	50	50	50		B	Rect.
Voltage interpolation	10	10	10	10		B	Rect.

Total unc (k=1):	450	500	700	550	
Expanded unc (k=2):	900	1000	1400	1100	

Institute: AREPA

Remarks: Reference Standard: VSL SJTC EUR-53
Values in µV/V
The values of contributions for which a rectangular distribution is assumed, are given as the half width of the probability interval. Values of contributions for which a normal (gaussian) distribution is assumed are given as standard uncertainties (*k* = 1).

Travelling standard: TS-HF

Contribution of:	Unc. f: 1 MHz	Unc. f: 10 MHz	Unc. f: 30 MHz	Unc. f: 50 MHz	Unc. f: 100 MHz	Type A or B	Shape
St. dev. of measurement	1	1	5	6		A	Gaus.
Reference standard	5	10	90	250		B	Gaus.
Measurement set-up	10	15	30	100		B	Uniform
Connectors	10	50	150	200		B	Uniform
....							
....							
....							

Total unc (k=1):	10	35	130	300	
Expanded unc (k=2):	20	70	260	600	

Travelling standard: TS-A55

Contribution of:	Unc. f: 1 MHz	Unc. f: 10 MHz	Unc. f: 30 MHz	Unc. f: 50 MHz	Unc. f: 100 MHz	Type A or B	Shape
St. dev. of measurement	2	3	15	6		A	Gaus.
Reference standard	5	10	90	250		B	Gaus.
Measurement set-up	10	15	30	100		B	Uniform
Connectors	10	50	150	200		B	Uniform
....							
....							
....							

Total unc (k=1):	10	35	130	300	
Expanded unc (k=2):	20	70	260	600	

Institute: METAS

Remarks: All uncertainties in µV/V
"Measurement set-up" and "connectors" components grouped in one contribution.
The values of contributions for which a rectangular distribution is assumed, are given as the half width of the probability interval. Values of contributions for which a normal (gaussian) distribution is assumed are given as standard uncertainties (*k* = 1).
Compiled by Marc Flüeli.

Travelling standard: TS-HF

Contribution of:	Unc. f: 1 MHz	Unc. f: 10 MHz	Unc. f: 30 MHz	Unc. f: 50 MHz	Unc. f: 100 MHz	Type A or B	Shape
St. dev. Of measurement	0.2	0.2	1.7	5.3	21	A	N, 1s
Reference standard	10	15	90	250	1000	B	N, 1s
Measurement set-up							
Connectors							
Measurement set-up and connectors	5	5	10	30	100	B	R
Error on sensitivity of thermal converter	0	3	20	60	250	B	R
....							

Total unc (k=1):	11	16	100	260	1100
expanded unc (k=2):	22	32	200	520	2200

Travelling standard: TS-A55

Contribution of:	Unc. f: 1 MHz	Unc. f: 10 MHz	Unc. f: 30 MHz	Unc. f: 50 MHz	Unc. f: 100 MHz	Type A or B	Shape
St. dev. Of measurement	0.4	1.1	5.1	11	38	A	N, 1s
Reference standard	10	15	90	250	1000	B	N, 1s
Measurement set-up							
Connectors							
Measurement set-up and connectors	5	5	10	30	100	B	R
Error on sensitivity of thermal converter	1	5	50	100	550	B	R
....							

Total unc (k=1):	11	16	100	260	1100
expanded unc (k=2):	22	32	200	520	2200

"N" stands for *Normal Distribution* and "R" for *Rectangular Distribution*

Institute: SP

Remarks: Values in μV/V
All uncertainty contributions are expressed as standard uncertainties (k = 1)

Travelling standard: TS-HF

Contribution of:	Unc. f: 1 MHz	Unc. f: 10 MHz	Unc. f: 30 MHz	Unc. f: 50 MHz	Unc. f: 100 MHz	Type A or B	Shape
st. dev. Of measurement	0.4	0.4	1			A	normal
reference standard	25	250	250			B	normal
measurement set-up	2	4	12			B	Rectang
Connectors	0.2	20	150			B	Rectang
....							
....							
....							

total unc (k=1):	26	260	270		
Expanded unc (k=2):	52	520	540		

Travelling standard: TS-A55

Contribution of:	Unc. f: 1 MHz	Unc. f: 10 MHz	Unc. f: 30 MHz	Unc. f: 50 MHz	Unc. f: 100 MHz	Type A or B	Shape
st. dev. Of measurement	0.2	2	9			A	normal
reference standard	25	250	250			B	normal
measurement set-up	2	4	12			B	Rectang
connectors	0,5	45	380			B	Rectang
....							
....							
....							

total unc (k=1):	26	260	340		
expanded unc (k=2):	52	520	680		

Institute: CEM

Remarks: Values in µV/V
Nº 12 Measurements for each point
All uncertainty contributions are expressed as standard uncertainties (k = 1)

Travelling standard: TS-HF

Contribution of:	Unc. f: 1 MHz	Unc. f: 10 MHz	Unc. f: 30 MHz	Unc. f: 50 MHz	Unc. f: 100 MHz	Type A or B	Shape
st. dev. of measurement	1	1	1	1	12	A	
reference standard	5	10	90	250	1000	B	Normal
measurement set-up	10	35	80	250	600	B	Rectang.
Connectors	________	________	________	________	________	_____	________
connectors and lines	10	20	60	200	400	B	Rectang.
....							
....							

total unc (k=1):	15	42	135	406	1230
expanded unc (k=2):	30	84	270	812	2460

Travelling standard: TS-A55

Contribution of:	Unc. f: 1 MHz	Unc. f: 10 MHz	Unc. f: 30 MHz	Unc. f: 50 MHz	Unc. f: 100 MHz	Type A or B	Shape
st. dev. of measurement	1	4	1	2	________	A	
reference standard	5	10	90	250	________	B	Normal
measurement set-up	10	35	80	250	________	B	Rectang.
Connectors	________	________	________	________	________	_____	________
connectors and lines	10	20	60	200	________	B	Rectang.
....							
....							

total unc (k=1):	15	42	135	406	________
expanded unc (k=2):	30	84	270	812	________

Institute: NIST (Gaithersburg)

Remarks: 1 MHz
Values in µV/V
All uncertainty contributions are expressed as standard uncertainties (k = 1)

Travelling standard: TS-HF and TS-A55

1 MHz Uncertainties (µV/V of applied voltage)	
Type A contribution	0.80
Type B contributions	
Primary standard MJTCs	0.25
Stability of standards	0.20
Comparator system for transfer to reference TVC	0.20
Voltage step-up, each step	0.20
Two steps	0.20
Thermoelement model	3.00
Transimpedance of resistor	5.00
Current standing wave	5.00
Tee and connector standing wave ratio	3.00
Frequency extension	3.00
Connector reproducibility	3.00
Skin effect	3.00
Comparator system	2.00
Voltage step-down, each step	2.00
Two steps	2.00
Root-sum-of-squares (k=1)	10.39
Expanded unc (k=2)	**20.8**

Institute: NIST (Boulder)

Remarks: RF part (> 1 MHz)
Values in µV/V
All uncertainty contributions are expressed as standard uncertainties (k = 1)

Travelling standard: TS-HF

Contribution of:	Unc. f: 1 MHz	Unc. f: 10 MHz	Unc. f: 30 MHz	Unc. f: 50 MHz	Unc. f: 100 MHz	Type A or B	Shape
st. dev. of measurement		6	14	16	46	A	Normal
reference standard		346	692	1732	3872	B	Rect.
measurement set-up		200	400	1000	1000	B	Rect.
connectors							
Drift							
....							
....							

total unc (k=1):		400	800	2000	4000
expanded unc (k=2):		800	1600	4000	8000

Travelling standard: TS-A55

Contribution of:	Unc. f: 1 MHz	Unc. f: 10 MHz	Unc. f: 30 MHz	Unc. f: 50 MHz	Unc. f: 100 MHz	Type A or B	Shape
st. dev. of measurement		5	13	20	61	A	Normal
reference standard		346	692	1732	3872	B	Rect.
measurement set-up		200	400	1000	1000	B	Rect.
connectors							
Drift							
....							
....							

total unc (k=1):		400	800	2000	4000
expanded unc (k=2):		800	1600	4000	8000

Institute: CSIRO-NML2

Remarks: LF department; measurements at 1 MHz
Values in µV/V
All uncertainty contributions are expressed as standard uncertainties (k = 1)

Travelling standard: TS-HF

Contribution of:	Unc. f: 1 MHz	Unc. f: 10 MHz	Unc. f: 30 MHz	Unc. f: 50 MHz	Unc. f: 100 MHz	Type A or B	Shape
st. dev. of measurement	0.1					A	Normal
reference standard	8.8					A	Normal
measurement set-up	1.0					B	Rect.
connectors	1.5					B	Rect.
Drift	2.0					B	Rect.
....							
....							

total unc (k=1):	9.2				
expanded unc (k=2):	18.4				

Travelling standard: TS-A55

Contribution of:	Unc. f: 1 MHz	Unc. f: 10 MHz	Unc. f: 30 MHz	Unc. f: 50 MHz	Unc. f: 100 MHz	Type A or B	Shape
st. dev. of measurement	0.1					A	Normal
reference standard	8.8					A	Normal
measurement set-up	1.0					B	Rect.
connectors	5.0					B	Rect.
Drift	4.0					B	Rect.
....							
....							

total unc (k=1):	10.9				
expanded unc (k=2):	21.8				

Institute: CSIRO-NML2

Remarks: Values in µV/V
Frequencies > 1 MHz
All uncertainty contributions are expressed as standard uncertainties (k = 1)
Submitted by Stephen Grady

Travelling standard: TS-HF

Contribution of:	Unc. f: 1 MHz	Unc. f: 10 MHz	Unc. f: 30 MHz	Unc. f: 50 MHz	Unc. f: 100 MHz	Type A or B	Shape
St. dev. of measurement		0.5	0.5	0.7	3.5	A	Normal
Reference standard		302.4	763.8	1225.6	1220.7	B	Normal
Measurement set-up		5.8	5.8	5.8	5.8	B	Rect
Connectors		17.7	17.7	35.4	70.7	B	U
....							
....							
....							

Total unc (k=1):		303	764	1226	1223
Expanded unc (k=2):		606	1528	2452	2446

Travelling standard: TS-A55

Contribution of:	Unc. f: 1 MHz	Unc. f: 10 MHz	Unc. f: 30 MHz	Unc. f: 50 MHz	Unc. f: 100 MHz	Type A or B	Shape
St. dev. of measurement		3.4	4.6	7.1	11.9		Normal
Reference standard		302.0	763.6	1225.2	1218.6		Normal
Measurement set-up		17.7	17.7	35.4	70.7		U
Connectors							
....							
....							
....							

Total unc (k=1):		303	764	1226	1221
Expanded unc (k=2):		605	1528	2451	2441

Institute: NPL-I

Remarks: Uncertainty contribution is in µV/V
All uncertainty contributions are expressed as standard uncertainties (k = 1)

Travelling Standard: TS-HF

Contribution of	Unc. 1.0 MHz	Unc. 10 MHz	Unc. 30 MHz	Unc. 50 MHz	Unc. 100 MHz	Type A or B	Shape of distribution
st. dev. of measurement	2	8	5	4	13	A	Normal
reference standard	11	250	350	550	1003	B	Normal
measurement set up	5	10	30	50	100	B	Rectangular
connectors	3	10	20	40	100	B	Rectangular
value of exponent	2	2	2	2	2	B	Rectangular
Tee & connector SWR	3	15	50	100	500	B	U shaped

total unc. (k=1)	13	251	355	563	1130
Expanded unc. (k=2)	26	502	710	1126	2260

Travelling Standard: TS-A55

Contribution of	Unc. 1 MHz	Unc. 10 MHz	Unc. 30 MHz	Unc. 50 MHz	Unc. 100 MHz	Type A or B	Shape of distribution
st. dev. of measurement	1	9	4	4	7	A	Normal
reference standard	11	250	350	550	1003	B	Normal
measurement set up	5	10	30	50	100	B	Rectangular
connectors	3	10	20	40	100	B	Rectangular
value of exponent	2	2	2	2	2	B	Rectangular
Tee & connector SWR	3	15	50	100	500	B	U shaped

total unc. (k=1)	13	251	355	563	1130
expanded unc. (k=2)	26	502	710	1126	2260

Institute: KRISS

Remarks: Values in μV/V
Measurements at 1 MHz
All uncertainty contributions are expressed as standard uncertainties (k = 1)
Submitted by Sung-Won Kwon (Electricity Group)

Travelling standard: TS-HF

Contribution of:	Unc. f: 1 MHz	Unc. f: 10 MHz	Unc. f: 30 MHz	Unc. f: 50 MHz	Unc. f: 100 MHz	Type A or B	Shape
st. dev. of measurement	0.3					A	normal
reference standard	45					B	normal
reasurement set-up	1.6					B	rectangular
Discrepany due to different reference standards	5.3					B	rectangular

Total unc (k=1):	46				
Expanded unc (k=2):	92				

Travelling standard: TS-A55

Contribution of:	Unc. f: 1 MHz	Unc. f: 10 MHz	Unc. f: 30 MHz	Unc. f: 50 MHz	Unc. f: 100 MHz	Type A or B	Shape
St. dev. of measurement	0.2					A	normal
Reference standard	45					B	normal
Measurement set-up	1.6					B	rectangular
Discrepany due to different reference standards	5.3					B	rectangular

total unc (k=1):	46				
expanded unc (k=2):	92				

Institute: KRISS

Remarks: Values in µV/V
Frequencies > 1 MHz
All uncertainty contributions are expressed as standard uncertainties (k = 1)
Submitted by Jeong Hwan Kim (Electromagnetics Group)

Travelling standard: TS-HF

Contribution of:	Unc. f: 1 MHz	Unc. f: 10 MHz	Unc. f: 30 MHz	Unc. f: 50 MHz	Unc. f: 100 MHz	Type A or B	Shape
st. dev. of measurement		10	10	15	72	A	normal
reference standard		2433	2435	2444	2544	B	rectangular
measurement set-up		10	10	10	10	B	rectangular
Connectors repeatability + system drift		29	58	116	405	B	rectangular

total unc (k=1):		2433	2436	2447	2576
expanded unc (k=2):		4866	4872	4894	5152

Travelling standard: TS-A55

Contribution of:	Unc. f: 1 MHz	Unc. f: 10 MHz	Unc. f: 30 MHz	Unc. f: 50 MHz	Unc. f: 100 MHz	Type A or B	Shape
st. dev. of measurement		11	27	65	180	A	normal
reference standard		2432	2434	2442	2512	B	rectangular
reasurement set-up		9	9	9	9	B	rectangular
Connectors repeatability + sytem drift		29	58	116	405	B	rectangular

total unc (k=1):		2432	2435	2445	2545
expanded unc (k=2):		4864	4870	4890	5090

Reference standard for TS-A55 (KRISS - continued)

Contribution of:	Unc. f: 1 MHz	Unc. f: 10 MHz	Unc. f: 30 MHz	Unc. f: 50 MHz	Unc. f: 100 MHz	Type A or B	Shape
effective efficiency of thermistor mount		360	343	326	358	B	normal
parallel resistance of thermistor mount		2400	2400	2400	2400	B	rectangular
DC substitution power meas.		30	30	30	30	B	rectangular
voltage reference plane		21	63	109	240	B	rectangular
difference from two thermistor mounts		90	97	116	123	B	rectangular
std. dev. of measurement		4	1	4	30	A	normal
measurement set-up		10	10	10	10	B	rectangular
Connector repeatability + system drift		29	58	116	405	B	rectangular
standard transfer from lower TVC's		120	170	239	428	B	rectangular

total unc (k=1):		2432	2434	2442	2512
expanded unc (k=2):		4864	4868	4884	5024

Reference standard for TS-HF (KRISS - continued)

Contribution of:	Unc. f: 1 MHz	Unc. f: 10 MHz	Unc. f: 30 MHz	Unc. f: 50 MHz	Unc. f: 100 MHz	Type A or B	Shape
effective efficiency of thermistor mount		360	343	326	358	B	normal
parallel resistance of thermistor mount		2400	2400	2400	2400	B	rectangular
DC substitution power meas.		30	30	30	30	B	rectangular
voltage reference plane		21	63	109	240	B	rectangular
difference form two thermistor mounts		90	97	116	123	B	rectangular
std. dev. of measurement		10	1	2	15	A	normal
measurement set-up		10	10	10	10	B	rectangular
Connector repeatability + system drift		29	58	116	405	B	rectangular
standard transfer form lower TVC's		140	183	259	588	B	rectangular

total unc (k=1):		2433	2435	2444	2544
expanded unc (k=2):		4866	4870	4888	5088

Institute: NRC-INMS

Remarks: TS-HF Test voltage: 3.85 V, Working Std.: NRC TVC#6e, Tee: NRC N/N/N #3,
TS-A55 Test voltage: 2.8 V, Working Std.: VSL TS-HF, Tee: NRC GR874/N/BNC
All uncertainty contributions are expressed as standard uncertainties (*k* = 1)
Results are given in μV/V

Travelling standard: TS-HF

Contribution of:	Unc. f: 1 MHz	Unc. f: 10 MHz	Unc. f: 30 MHz	Unc. f: 50 MHz	Unc. f: 100 MHz	Type A or B	Shape
St. dev. of measurement	0.1	0.1	0.1	0.1	0.4	A	Normal
Working standard	5.7	23.1	68.8	136.8	392.7	A+B	Normal
Comparator drift	0.4	0.4	1.4	3.0	8.5	B	Rect.
Drift correction	0.1	0.2	0.7	1.8	9.1	B	Rect.
NRC tee assymetry	0.1	0.2	3.0	8.9	37.2	B	Rect.
Exponent n ref TVC	0.1	0.6	1.5	2.3	2.2	B	Rect.
Exponent n test TVC	0.1	0.2	0.9	3.9	25.3	B	Rect.

Total unc (k=1):	5.7	23.1	68.9	137.3	395.5
expanded unc (k=2):	12	46	14*10	28*10	79*10

Travelling standard: TS-A55

Contribution of:	Unc. f: 1 MHz	Unc. f: 10 MHz	Unc. f: 30 MHz	Unc. f: 50 MHz	Unc. f: 100 MHz	Type A or B	Shape
St. dev. of measurement	0.0	0.0	0.4	0.3	0.1	A	Normal
Working standard	5.7	23.1	68.9	137.3	227.8	A+B	Normal
Comparator drift	0.6	0.4	0.3	0.4	0.9	B	Rect.
Drift correction	0.1	0.1	0.5	1.2	17.3	B	Rect.
NRC Tee asymmetry	6.6	72.9	263.1	512.9	1406.2	B	Rect.
Contact repetition	0.0	0.8	7.6	21.1	84.4	B	Rect.
Exponent n ref. TVC	0.1	0.2	0.9	3.9	25.3	B	Rect.
Exponent n tst. TVC	0.2	0.5	2.4	0.0	79.0	B	Rect.

Total unc (k=1):	8.8	76.5	272.1	531.4	1465.6
Expanded unc (k=2):	18	15*10	54*10	$11*10^2$	$29*10^2$

E. Appendix: More detailed uncertainty budgets

From the reported uncertainty calculations as given in Appendix D, it was concluded that the determination of the uncertainty of the reference standard is essential for the determination of the total uncertainty. Most of the participants didn't provide any detailed information about the uncertainty of their reference standard in their measurement report; only KRISS included these details in the original uncertainty budget. The support group of this comparison, however, insisted that such information should be provided, at least by those participants of which the results have been used to determine the key comparison reference values. In February 2003, those laboratories have been asked to provide additional information about the uncertainty in their reference standard. These extended uncertainty budgets have been reported here below.

NIST reported that, after such a long time, this information could not be traced back for their measurements at the frequencies of 10 MHz and above. The NIST measuring system has been modified in the meantime and the information of the previous system is no longer available.

In Appendix E, the quantity $u(\delta_{\text{total}})$ is the combined standard uncertainty associated with the measurement of the travelling standard in the participating laboratory. It is calculated as the root-sum-square of the preceding contributions in each column.

Note 1: All uncertainty contributions are expressed as standard uncertainties (k = 1).

Note 2: The pilot laboratory has observed small discrepancies between the uncertainty budgets in this appendix and the budgets given in appendix D. The pilot laboratory has not inquired about the reasons for these discrepancies. Since the differences are quite small, it is assumed that they result from either rounding errors or from the fact that participants were not able to trace back the exact information. It should be clear that these differences have no influence on the results of this comparison, because for the calculations only the uncertainty data as presented in appendix D has been used.

Institute: NMI - VSL
Country: Netherlands
Remarks:
Reference standard: VSL HF SJTC + 700 Ω

		Standard measurement uncertainty *u* in µV/V at the frequencies					
u	**influence quantity**	1 MHz	10 MHz	30 MHz	50 MHz	100 MHz	Type A or B and Distribution
	Thermal converter						
$u(\delta_{TH})$	Thermoelectric effects						
$u(\delta_{L,G,C})$	reactive components and dielectric losses in heater and connecting leads						
$u(\delta_{skin})$	skin effect and proximity effect in heater and connecting leads						
$u(\delta_{con})$	input and T-connectors standing wave						
$u(\delta_{LEV})$	current level effect in the heater						
	Resistor + thermal converter						
$u(\delta_{Th})$	Thermo-electric effects	1	1	1	1	1	B / Rect.
$u(\delta_{Mech})$	Mechanical parameters	2	5	40	100	400	B / Rect.
$u(\delta_{Elect})$	Electrical parameters	2	5	40	100	400	B / Rect.
$u(\delta_{Con})$	Model for T and N connector	1	1	10	50	150	B / Rect.
$u(\delta_{SJTC})$	Model for the SJTC	1	1	10	50	150	B / Rect.
$u(\delta_{Model})$	Comparison model vs. measurements	6	10	60	150	600	B / Rect.
	Voltage step-up or step-down						
$u(\delta_A)$	comparator system						
$u(\delta_C)$	comparator system						
$u(\delta_{con})$	input and T-connectors standing wave						
	Comparison of the travelling SJTC standard						
$u(\delta_A)$	Standard deviation in the measurement	1	1	1	1	1	A / Norm.
$u(\delta_C)$	comparator system	2	2	10	25	250	B / Rect.
$u(\delta_{con})$	input and T-connectors standing wave	1	1	6	20	100	B / Rect.
$u(\delta_{rep})$	Reproducibility	1	2	5	20	50	B / Rect.
$u(\delta_{total})$	**total uncertainty (k=1)**	**7**	**13**	**85**	**221**	**894**	
U	**expanded uncertainty (k=2)**	**20**	**30**	**180**	**500**	**2000**	

Institute: PTB
Country: Germany
Remarks:
Reference standard: Multijunction Thermal Converter at 1 MHz

		Standard measurement uncertainty *u* in µV/V at the frequencies					
u	**influence quantity**	1 MHz	10 MHz	30 MHz	50 MHz	100 MHz	Type A or B and Distribution
	Thermal converter						
$u(\delta_{TH})$	Thermoelectric effects	0.01					B-Norm
$u(\delta_{L,G,C})$	reactive components and dielectric losses in heater and connecting leads	9.3					B-Norm
$u(\delta_{skin})$	skin effect and proximity effect in heater and connecting leads	4.4					B-Norm
$u(\delta_{con})$	input and T-connectors standing wave	2.4					B-Norm
$u(\delta_{LEV})$	current level effect in the heater	0					B-Norm
	Resistor + thermal converter						
$u(\delta_{L,G,C})$	reactive components and dielectric losses in resistor and connecting leads	na					
$u(\delta_{skin})$	skin effect and proximity effect in resistor and connecting leads	na					
$u(\delta_{stand})$	current standing wave	na					
$u(\delta_{con})$	input and T-connectors standing wave	na					
	Voltage step-up or step-down						
$u(\delta_{A})$	comparator system	0.2					A-Norm
$u(\delta_{C})$	comparator system	0.2					B-Norm
$u(\delta_{con})$	input and T-connectors standing wave	2.4					B-Norm
	Comparison of the travelling SJTC standard						
$u(\delta_{A})$	comparator system	0.2					A-Norm
$u(\delta_{C})$	comparator system	0.2					B-Norm
$u(\delta_{con})$	input and T-connectors standing wave	2.4					B-Norm
$u(\delta_{calib})$	use of different ac sources	2.4					B-Norm
$u(\delta_{total})$	**total uncertainty (k=1)**	**12.2**					
U	**expanded uncertainty (k=2)**	**25**					

Institute: PTB
Country: Germany
Remarks:
Reference standard: 3 Volt (TS-A55) traceable to calorimetric voltage standard

		Standard measurement uncertainty *u* in µV/V at the frequencies					
u	**influence quantity**	1 MHz	10 MHz	30 MHz	50 MHz	100 MHz	Type A or B and Distribution
$u(\delta_{AC})$	**Primary AC standard**		13	13	13	13	B-Norm
	Calorimetric voltage standard						
$u(\delta_{Pow})$	Calorimetric rf power/ac power		100	150	300	600	B-Norm
$u(\delta_{Imp})$	rf/ac impedance		175	280	400	800	B-Norm
$u(\delta_{Stab})$	Stability of p. voltage std.		80	100	150	300	B-Rect.
$u(\delta_{ConStd})$	Ref. plane and connector		50	80	150	250	B-Rect.
	Transfer v. standard to TVC						
$u(\delta_{Comsys})$	comparator system		20	35	65	70	A
$u(\delta_{ConTC})$	Ref. plane and connector		30	60	100	200	B-Rect.
	Voltage step-up or step-down						
$u(\delta_{Step})$	Step-up procedure		30	50	120	160	B-Rect.
$u(\delta_{Comsys})$	comparator system		20	40	80	120	A
	Calibration						
$u(\delta_{Comsys})$	comparator system		20	30	60	100	A
$u(\delta_{ConTC})$	Ref. plane and connector		30	50	80	180	B-Rect.
$u(\delta_{total})$	**total uncertainty (k=1)**		**230**	**360**	**580**	**1 130**	
U	**expanded uncertainty (k=2)**		**460**	**720**	**1 160**	**2 260**	

Institute: VNIIM
Country: Russia
Remarks:
Reference standard: PNTE-2 № 211 (SJTC + 1 kΩ)

		Standard measurement uncertainty *u* in µV/V at the frequencies					
u	**influence quantity**	1 MHz	10 MHz	30 MHz	50 MHz	100 MHz	Type A or B and Distribution
	Thermal converter						
$u(\delta_{TH})$	Thermoelectric effects	2	2	2	2	2	B, uniform
$u(\delta_{L,G,C})$	reactive components and dielectric losses in heater and connecting leads	2	20	50	100	250	B, uniform
$u(\delta_{skin})$	skin effect and proximity effect in heater and connecting leads	4	15	20	30	50	B, uniform
$u(\delta_{con})$	input and T-connectors standing wave	4	4	10	10	10	B, uniform
$u(\delta_{LEV})$	current level effect in the heater	4	4	4	4	4	B, uniform
	Resistor + thermal converter						
$u(\delta_{L,G,C})$	reactive components and dielectric losses in resistor and connecting leads	22	89	140	450	920	B, uniform
$u(\delta_{skin})$	skin effect and proximity effect in resistor and connecting leads						
$u(\delta_{stand})$	current standing wave						
$u(\delta_{con})$	input and T-connectors standing wave	4	15	20	30	50	B, uniform
	Voltage step-up or step-down						
$u(\delta_A)$	comparator system						
$u(\delta_C)$	comparator system						
$u(\delta_{con})$	input and T-connectors standing wave						
	Comparison of the travelling SJTC standard						
$u(\delta_A)$	comparator system	4	4	10	10	10	A, normal
$u(\delta_C)$	comparator system	4	4	10	10	10	A, normal
$u(\delta_{con})$	input and T-connectors standing wave	5	10	50	75	150	B, uniform
$u(\delta_{calib})$	use of different ac sources						
$u(\delta_{total})$	**total uncertainty (k=1)**	**25**	**98**	**160**	**469**	**968**	
U	**expanded uncertainty (k=2)**	**50**	**190**	**320**	**940**	**1936**	

Institute: OMH
Country: Hungary
Remarks: The calibration is valid in the reference plane of the supplied Special T connector
Reference standard: Guildline 7000/10 MJTC at 1MHz, and OMH made Calorimetric standard at higher frequencies

		Standard measurement uncertainty *u* in µV/V at the frequencies						
u	**influence quantity**	1 MHz	10 MHz	30 MHz	50 MHz	70 MHz	100 MHz	Type A or B and Distribution
$u(\delta_{AC})$	**Reference AC/DC voltage standard at specified low frequencies**	15	15	15	15	15	15	B, normal
$u(\delta_{ACsetup})$	measurement setup	10	10	10	10	10	10	B, rectangular
	Calorimetric voltage standard							
$u(\delta_{Stab})$	Stability of voltage standard		130	130	130	330	330	B, rectangular
	Voltage transformation correction							
$u(\delta_{Tr})$	Voltage transformation measurement		440	440	440	440	440	B, normal
$u(\delta_{LevelTr})$	Level dependence of voltage transformation		5	50	130	250	470	B, rectangular
$u(\delta_{ImpTr})$	Unc. due to impedance difference between absorber resistor and level meter used for transformation measurements		290	290	290	580	580	B, rectangular
$u(\delta_{ConTr})$	connector loss and transformation		200	200	200	330	330	B, rectangular
	Transfer of calorimetric standard to TVC							
	Voltage step-up							
	Calibration							
$u(\delta_{Stddev})$	standard deviation		30	30	30	30	30	A, normal
$u(\delta_{Comsys})$ $u(\delta_{ConTC})$	comparator system, including Ref. plane and connector		40	40	40	40	40	B, rectangular
$u(\delta_{total})$	**total uncertainty (k=1)**	**18**	**580**	**580**	**600**	**900**	**990**	
U	**expanded uncertainty (k=2)**	**36**	**1160**	**1160**	**1200**	**1800**	**1980**	
	Rounded values	**36**	**1200**	**1200**	**1200**	**1800**	**2000**	

Institute: **NPL-UK1**
Country: **UK**
Remarks:
Reference standard: **NPL standard for 1 MHz (VSL standard calibrated by VSL above 1 MHz)**

		Standard measurement uncertainty *u* in µV/V at the frequencies					
u	**influence quantity**	1 MHz	10 MHz	30 MHz	50 MHz	100 MHz	Type A or B and Distribution
	Thermal converter						
$u(\delta_{TH})$	Thermoelectric effects						
$u(\delta_{L,G,C})$	reactive components and dielectric losses in heater and connecting leads	4					B, rectangular
$u(\delta_{skin})$	skin effect and proximity effect in heater and connecting leads	4					B, rectangular
$u(\delta_{con})$	input and T-connectors standing wave	4					B, rectangular
$u(\delta_{LEV})$	current level effect in the heater	-					
	Resistor						
$u(\delta_{L,G,C})$	reactive components and dielectric losses in resistor and connecting leads	4					B, rectangular
$u(\delta_{skin})$	skin effect and proximity effect in resistor and connecting leads	4					B, rectangular
$u(\delta_{stand})$	current standing wave						
$u(\delta_{con})$	input and T-connectors standing wave	4					B, rectangular
	Voltage step-up or step-down						
$u(\delta_{A})$	comparator system	1					
$u(\delta_{C})$	comparator system						
$u(\delta_{con})$	input and T-connectors standing wave	4					B, rectangular
	Total for reference standard	10.6					B, normal, above 1 MHz uncertainties from VSL certificate
	Comparison of the travelling SJTC standard						
$u(\delta_{A})$	comparator system	1					A, normal
$u(\delta_{C})$	comparator system						
$u(\delta_{con})$	input and T-connectors standing wave	4					B, rectangular
$u(\delta_{calib})$	use of different ac sources						
$u(\delta_{total})$	**total uncertainty (k=1)**	**11.4**					
U	**expanded uncertainty (k=2)**	**22.8**					

Institute: **NIST, Gaithersburg**
Country: **USA**
Remarks: The components of the uncertainty evaluated by statistical means are designated Type A components. Type B components in the uncertainty table are estimated from rectangular distributions* with limits ±b. The Type B entries in the table are the equivalent standard deviations of that distribution, equal to b/√3.

Reference standard: MJTC were used as primary standards at audio frequency. Frequency extension was done using SJTC mounted with range resistors in coaxial enclosures.

		Standard measurement uncertainty *u* in µV/V at the frequencies					
u	**influence quantity**	1 MHz	10 MHz	30 MHz	50 MHz	100 MHz	Type A or B and Distribution*
	Thermal converter						
$u(\delta_p)$	Primary standard MJTCs	0.25					Type B
$u(\delta_{ss})$	Stability of standards	0.20					Type B
$u(\delta_{cr})$	Comparator system for transfer to reference TVC	0.20					Type B
$u(\delta_{tm})$	Thermoelement model	3.00					Type B
$u(\delta_{su,1})$	Voltage step-up, each step	0.20					Type B
	Two steps	0.20					Type B
	Resistor + thermal converter						
$u(\delta_{tr})$	Transimpedance of resistor	5.00					Type B
$u(\delta_{skin})$	skin effect and proximity effect in resistor and connecting leads	3.00					Type B
$u(\delta_{stand})$	current standing wave	5.00					Type B
$u(\delta_{con})$	input and T-connectors standing wave	3.00					Type B
	Frequency extension up to 100 kHz	3.00					Type B
	Voltage step-up or step-down						
$u(\delta_{su,2})$	Voltage step-down, each step	2.00					Type B
$u(\delta_{su,2})$	Two steps	2.00					Type B
$u(\delta_{con})$	Connector reproducibility	3.00					Type B
	Comparison of the travelling SJTC standard						
$u(\delta_{ct})$	comparator system	2.00					Type B
$u(\delta_{sd})$	Standard deviation	0.80					Type A
$u(\delta_{total})$	**total uncertainty (k=1)**	**10.39**					
U	**expanded uncertainty (k=2)**	**20.78**					

Institute: **NIST, Boulder**
Country: **USA**
Remarks: The uncertainty budget is difficult to determine because the measurement system was poorly documented. Since this comparison a new measurement system has been built, new standards have been characterised, and new uncertainties are used in our calibrations.

Reference standard: SJTC + resistor-reference standard

		Standard measurement uncertainty *u* in µV/V at the frequencies					
u	**influence quantity**	1 MHz	10 MHz	30 MHz	50 MHz	100 MHz	Type A or B and Distribution
	Thermal converter						
$u(\delta_{TH})$	Thermoelectric effects						
$u(\delta_{L,G,C})$	reactive components and dielectric						
$u(\delta_{skin})$	skin effect and proximity effect in						
$u(\delta_{con})$	input and T-connectors standing wave						
$u(\delta_{LEV})$	current level effect in the heater						
	Resistor + thermal converter						
$u(\delta_{L,G,C})$	reactive components and dielectric losses in resistor and connecting leads						
$u(\delta_{skin})$	skin effect and proximity effect in resistor and connecting leads						
$u(\delta_{stand})$	current standing wave						
$u(\delta_{con})$	input and T-connectors standing wave						
	Voltage step-up or step-down						
$u(\delta_{A})$	comparator system						
$u(\delta_{C})$	comparator system						
$u(\delta_{con})$	input and T-connectors standing wave						
	Comparison of the travelling SJTC standard						
$u(\delta_{A})$	Reference Standard		346	692	1732	3872	B, rectangular
$u(\delta_{C})$	comparator system random error		200 6	400 14	1000 16	1000 46	B, rectangular A
$u(\delta_{con})$	input and T-connectors standing wave						
$u(\delta_{calib})$	use of different ac sources						
$u(\delta_{total})$	**total uncertainty (k=1)**		**400**	**799**	**2000**	**3999**	
U	**expanded uncertainty (k=2)**		**799**	**1599**	**4000**	**7999**	

Institute: NPL-I
Country: India
Remarks:
Reference standard: Multijunction Thermal Converter
Travelling Standard: TS-HF

		Standard measurement uncertainty *u* in µV/V at the frequencies					
u	**Influence quantity**	1 MHz	10 MHz	30 MHz	50 MHz	100 MHz	Type A or B and Distribution
	Thermal converter						
$u(\delta_{TH})$	Thermoelectric effects	0*	-	-	-	-	
$u(\delta_{L,G,C})$	Reactive components and dielectric losses in heater and connecting leads	9	-	-	-	-	B: Rectangular
$u(\delta_{skin})$	skin effect and proximity effect in heater and connecting leads	3	-	-	-	-	B: Rectangular
$u(\delta_{con})$	input and T-connectors standing wave	5	-	-	-	-	B: Rectangular
$u(\delta_{LEV})$	current level effect in the heater	2	-	-	-	-	A: Rectangular
	Resistor + thermal converter[(a)]						
$u(\delta_{L,G,C})$	Reactive components and dielectric losses in resistor and connecting leads						
$u(\delta_{skin})$	skin effect and proximity effect in resistor and connecting leads						
$u(\delta_{stand})$	current standing wave						
$u(\delta_{con})$	input and T-connectors standing wave						
	Voltage step-up or step-down[(b)]						
$u(\delta_{A})$	comparator system						
$u(\delta_{C})$	comparator system						
$u(\delta_{con})$	input and T-connectors standing wave						
	Comparison of the travelling SJTC standard						
$u(\delta_{A})$	Std. dev. of measurement	2	-	-	-	-	A: Normal
$u(\delta_{C})$	comparator system	5	-	-	-	-	B: Rectangular
$u(\delta_{con})$	input and T-connectors standing wave	4	-	-	-	-	B: Rectangular
$u(\delta_{exponent})$	Value of exponent	2	-	-	-	-	B: Rectangular
$u(\delta_{total})$	**total uncertainty (k=1)**	**13**					
U	**expanded uncertainty (k=2)**	**26**					

- We have taken it zero because it is PSI make MJTC

(a) This is not required as we have used 3 volt MJTC for comparison
(b) This is also not required as we have used 3 volt MJTC for comparison

Institute: **NPL-I**
Country: **India**
Remarks:
Reference standard: **3 volt thermal converter traceable to calorimetric reference standard**
Travelling Standard: **TS-HF**

		Standard measurement uncertainty *u* in µV/V at the frequencies					
u	**influence quantity**	1 MHz	10 MHz	30 MHz	50 MHz	100 MHz	Type A or B and Distribution
$u(\delta_{AC})$	**ReferenceAC/DC voltage [(a)] standard at specified low frequencies**						
	Calorimetric voltage standard						
$u(\delta_{Pow})$	Calorimetric rf /dc power	-	200	250	400	600	B: Normal
$u(\delta_{Imp})$	rf/dc impedance	-	50	100	200	350	B: Normal
$u(\delta_{Stab})$	Stability of voltage standard	-	10	20	50	100	B: Rectangular
$u(\delta_{ConStd})$	Reference plane and connector[(a)]	-	-	-	-	-	B: Rectangular
	Transfer of calorimetric standard to TVC						
$u(\delta_{Comsys})$	comparator system	-	10	30	50	100	B: Rectangular
$u(\delta_{ConTC})$	Reference plane and connector	-	15	50	100	500	B: Rectangular
	Voltage step-up (two steps)						
$u(\delta_{Step})$	Step-up procedure	-	100	150	210	350	B: Rectangular
$u(\delta_{Comsys})$	comparator system	-	10	30	50	100	B: Rectangular
$u(\delta_{Step})$	Step-up procedure	-	100	150	210	350	B: Rectangular
$u(\delta_{Comsys})$	comparator system	-	10	30	50	100	B: Rectangular
	Calibration						
$u(\delta_{Comsys})$	comparator system	-	10	30	50	100	B: Rectangular
$u(\delta_{ConTC})$	Ref. plane and connector	-	15	50	100	500	B: Rectangular
$u(\delta_{exp})$	Value of exponent	-	2	2	2	2	B: Rectangular
$u(\delta_{meas})$	Std. dev. of measurement	-	8	5	4	13	A: Normal
$u(\delta_{total})$	**total uncertainty (k=1)**		**252**	**355**	**566**	**1130**	
U	**expanded uncertainty (k=2)**		**504**	**710**	**1132**	**2260**	

(a) This is not required as we are using rf/dc substitution.

Institute: **NRC-INMS**
Country: **Canada**
Remarks:
Reference standard: **Calorimetric Thermal Voltage Converter CTVC#7, SJTC NRCTVC#6e**
Travelling standard: **VSL TS-HF Test Voltage: 3.85 V**

		Standard measurement uncertainty *u* in µV/V at the frequencies					
u	**influence quantity**	1 MHz	10 MHz	30 MHz	50 MHz	100 MHz	Type A or B and Distribution
$u(\delta_{AC})$	**ReferenceAC/DC voltage standard at specified low frequencies**	0.2	Note: NRC MJTC Primary Standard of AC/DC difference, at 1 kHz , 1 V				A+B n
$u(\delta_{Step})$	Comparison with SJTC Working Standard	0.2					A n
	Calorimetric voltage standard („calculable“)						
$u(\delta_{Mech})$	Mechanical dimensions	0	1	7	19	74	B u
$u(\delta_{Design})$	Design variations	4.6	14	58	88	280	B u
$u(\delta_{Rad})$	Radiation losses	2	6	6	6	6	B u
$u(\delta_{Stab})$	Internal solder connections	2	6	10	13	20	B u
$u(\delta_{TCorr})$	Thermal corrections	0.1	1.2	6.3	12.3	24.4	B u
$u(\delta_{Comp})$	Intercomparisons with other CTVCs	0.8	3	5	6	10	B u
	Transfer of calorimetric standard to VSL TS-HF						
$u(\delta_{Comp})$	Comparison standard deviation	0.1	0.1	0.1	0.1	0.4	A n
$u(\delta_{Comsys})$	Comparator system	0.4	0.4	1.4	3	8.5	B u
$u(\delta_{CorrDrift})$	Drift correction	0.1	0.2	0.7	1.8	9.1	B u
$u(\delta_{ConTC})$	Ref. plane Tee asymmetry	0.1	0.2	3.0	8.9	37.2	B u
$u(\delta_{n\ ref})$	Comparison/n-meas reference	0.1	0.6	1.5	2.3	2.2	B u
$u(\delta_{n\ test})$	Comparison/n-meas test	0.1	0.2	0.9	3.9	25.2	B u
	TS-HF VSL **Calibration Result Uncertainty**						
$u(\delta_{total})$	**total uncertainty (k=1)**	**5.7**	**23.1**	**68.9**	**137.3**	**395.5**	**A+B n**
U	**expanded uncertainty (k=2)**	**12**	**47**	**$14*10^1$**	**$28*10^1$**	**$79*10^1$**	**A+B n**

n – uncertainty distribution assumed normal
u - uncertainty distribution assumed rectangular

Institute: **CSIRO-NML2**
Country: **Australia**
Remarks: The last value of $u(\delta_A)$ represents the estimate of the drift in the travelling standard during measurement.
Reference standard: **NML Single-Junction Thermal Voltage Converter**
Travelling standard: **TS-HF EUR54**

		Standard measurement uncertainty *u* in µV/V at the frequencies					
u	**influence quantity**	1 MHz	10 MHz	30 MHz	50 MHz	100 MHz	Type A or B and Distribution
	Thermal converter						
$u(\delta_{TH})$	Thermoelectric effects	0.3					
$u(\delta_{L,G,C})$	reactive components and dielectric losses in heater and connecting leads	5.4					
$u(\delta_{skin})$	skin effect and proximity effect in heater and connecting leads	4.6					
$u(\delta_{con})$	input and T-connectors standing wave	5.2					
$u(\delta_{LEV})$	current level effect in the heater	0.0					
	Resistor + thermal converter						
$u(\delta_{L,G,C})$	reactive components and dielectric losses in resistor and connecting leads						
$u(\delta_{skin})$	skin effect and proximity effect in resistor and connecting leads	-					
$u(\delta_{stand})$	current standing wave	-					
$u(\delta_{con})$	input and T-connectors standing wave	-					
	Voltage step-up or step-down						
$u(\delta_A)$	comparator system	-					
$u(\delta_C)$	comparator system	-					
$u(\delta_{con})$	input and T-connectors standing wave	-					
	Comparison of the travelling SJTC standard						
$u(\delta_A)$	comparator system	2.0					
$u(\delta_C)$	comparator system	0.0					
$u(\delta_{con})$	input and T-connectors standing wave	1.5					
$u(\delta_{calib})$	use of different ac sources	1.0					
$\boldsymbol{u(\delta_{total})}$	**total uncertainty (k=1)**	**9.2**					
U	**expanded uncertainty (k=2)**	**18.4**					

Institute: **CSIRO-NML2**
Country: **Australia**
Remarks: $u(\delta_{therm})$ is the estimate due to thermal losses in calorimeter.
Reference standard: **NML Twin Joule Voltage Calorimeter**
Travelling standard: **TS-A55**

		Standard measurement uncertainty *u* in µV/V at the frequencies					
u	**influence quantity**	1 MHz	10 MHz	30 MHz	50 MHz	100 MHz	Type A or B and Distribution
$u(\delta_{AC})$	**ReferenceAC/DC voltage standard at specified low frequencies**						
	Calorimetric voltage standard						
$u(\delta_{Pow})$	Calorimetric rf /ac power		120	248	376	374	B Rect
$u(\delta_{Imp})$	rf/ac impedance		275	721	1165	1157	B Rect
$u(\delta_{Stab})$	Stability of voltage standard		27	39	20	19	A Norm
$u(\delta_{ConStd})$	Reference plane and connector		13	13	25	50	B Rect
$u(\delta_{therm})$	Thermal Losses		3	10	14	22	B Rect
	Transfer of calorimetric standard to TVC						
$u(\delta_{Comsys})$	comparator system		-	-			
$u(\delta_{ConTC})$	Reference plane and connector		-	-			
	Voltage step-up						
$u(\delta_{Step})$	Step-up procedure		6	6	6	6	B Rect
$u(\delta_{Comsys})$	comparator system		15	15	29	60	B Norm
	Calibration						
$u(\delta_{Comsys})$	comparator system		3	5	7	12	A Norm
$u(\delta_{ConTC})$	Ref. plane and connector		18	18	35	71	B Rect
$u(\delta_{total})$	**total uncertainty (k=1)**		**304**	**764**	**1226**	**1221**	
U	**expanded uncertainty (k=2)**		**608**	**1528**	**2452**	**2442**	

F. Appendix: Summary of key comparison CCEM-K6.c

A summary is given of the results and the degrees of equivalence with the key comparison reference values for the measurements of TS-HF at the mandatory frequencies.

For all mandatory frequencies in this comparison the degree of equivalence, D_i with respect to the key comparison reference value, δ_R is found from:

$$D_i = \delta_{ic} - \delta_R$$

The expanded uncertainty U_i is given by:

$$U_i = 2 \cdot \sqrt{u_{\delta ic}^2 + u_R^2}$$

for participants that do not contribute to δ_R.

For participants included in the reference value:

$$U_i = 2 \cdot \sqrt{u_{\delta ic}^2 - u_R^2}$$

The degree of equivalence, D_{ij} between any pair of participating laboratories is:

$$D_{ij} = D_i - D_j$$

The expanded uncertainty, U_{ij} in D_{ij} is roughly estimate by:

$$U_{ij} = \sqrt{U_{\delta ic}^2 + U_{\delta jc}^2}$$

ignoring all correlations between participants *i* and *j*.

The Working Group on Key Comparisons of the CCEM judges that significant correlations exist among the results of participants whose reference standard of ac-dc difference is based on calibration carried out by another participating laboratory. Although these correlations have a profound effect on the uncertainty of the degrees of equivalence between pairs of NMI's, a sufficiently accurate evaluation of covariance terms has not been identified. Consequently this appendix B entry of the KCDB does not include explicit values and uncertainties of degrees of equivalence among pairs of participants.

CCEM-K6.c Key comparison of AC-DC voltage transfer standards at selected frequencies between 1 MHz and 100 MHz

Measurand: AC-DC voltage transfer difference

Measurement frequency: 1 MHz

Nominal voltage: 4 V

The key comparison reference value, δ_R, is chosen to be the weighted mean of independent results, δ_{ic}, that have not been identified as outliers. The weight of each participant is proportional to its inversed squared uncertainty, $u_{\delta ic}$, in this result. At 1 MHz, the results of 8 independent participants have been used in the calculation of δ_R. The expanded uncertainty U_R of δ_R is the standard uncertainty of the weighted mean multiplied by a coverage factor k_R = 2.

δ_R = 6.6 µV/V and U_R = 7.0 µV/V.

Table F 1. Results at 1 MHz. Corrected measurement results δ_{ic} of the participants with the expanded uncertainties (k = 2), $U_{\delta ic}$. Degrees of equivalence D_i with respect to the KCRV and the expanded uncertainty (k = 2) U_i. Participants indicated with (*) contributed to the reference value.

	Lab	Date	δ_{ic}	$U_{\delta ic}$	D_i	U_i
			(mV/V)	(mV/V)	(mV/V)	(mV/V)
*	NMI-VSL1	Aug-95	0.008	0.020	0.002	0.019
*	PTB	Sep-95	-0.001	0.026	-0.008	0.025
*	VNIIM	Nov-95	0.00	0.06	0.00	0.06
	OMH	Jan-96	0.00	0.04	0.00	0.04
*	NPL-UK1	May-96	-0.002	0.017	-0.009	0.016
	BNM-LNE	Jun-96	0.2	0.9	0.2	0.9
	AREPA	Jul-96	0.009	0.020	0.003	0.022
	METAS	Oct-96	0.007	0.020	0.001	0.022
	SP	Nov-96	0.00	0.05	0.00	0.05
	CEM	Jan-97	0.009	0.030	0.003	0.031
*	NIST	Apr-97	0.007	0.021	0.000	0.020
*	NPL-I	Nov-97	-0.005	0.026	-0.011	0.025
	KRISS	May-98	0.00	0.09	-0.01	0.09
*	NRC-INMS	Sep-98	0.011	0.012	0.005	0.010
*	CSIRO-NML2	Oct-99	0.015	0.019	0.008	0.018

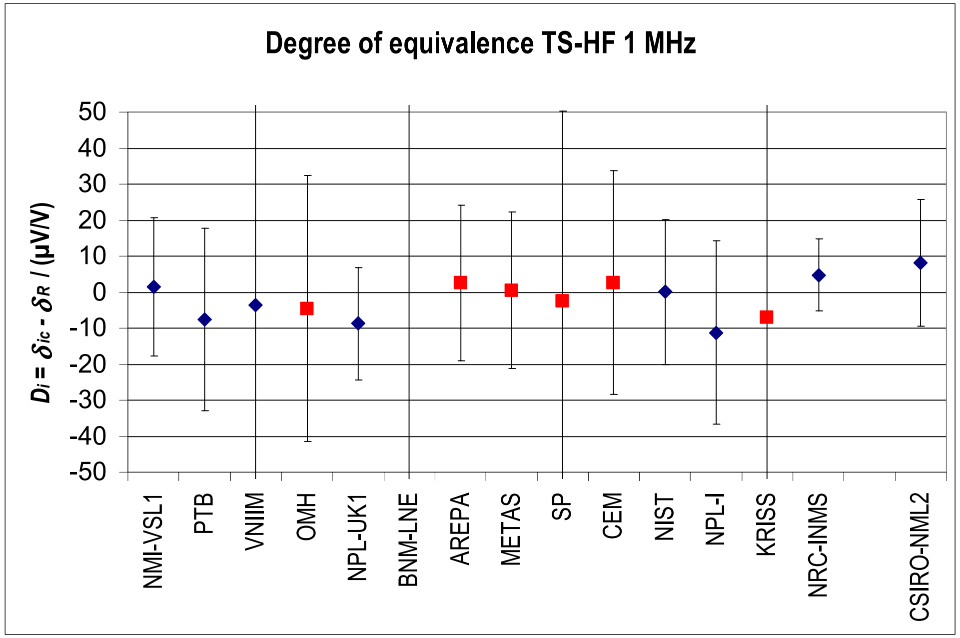

Figure F 1. Degree of equivalence with the reference value and the expanded uncertainty for the AC-DC voltage transfer difference at 1 MHz.
(Blue diamonds: included in δ_R; red squares: not included in δ_R)

CCEM-K6.c Key comparison of AC-DC voltage transfer standards at selected frequencies between 1 MHz and 100 MHz

Measurand: AC-DC voltage transfer difference
Measurement frequency: 10 MHz
Nominal voltage: 4 V

The key comparison reference value, δ_R, is chosen to be the weighted mean of independent results, δ_{ic}, that have not been identified as outliers. The weight of each participant is proportional to its inversed squared uncertainty, $u_{\delta ic}$, in this result. At 10 MHz, the results of 8 independent participants have been used in the calculation of δ_R. The expanded uncertainty U_R of δ_R is the standard uncertainty of the weighted mean multiplied by a coverage factor k_R = 2.
δ_R = 34 µV/V and U_R = 25 µV/V.

Table F 2. Results at 10 MHz. Corrected measurement results δ_{ic} of the participants with the expanded uncertainties (k = 2), $U_{\delta ic}$. Degrees of equivalence D_i with respect to the KCRV and the expanded uncertainty (k = 2) U_i. Participants indicated with (*) contributed to the reference value.

	Lab	Date	δ_{ic}	$U_{\delta ic}$	D_i	U_i
			(mV/V)	(mV/V)	(mV/V)	(mV/V)
*	NMI-VSL1	Aug-95	0.033	0.030	0.000	0.017
*	PTB	Sep-95	0.0	0.5	0.0	0.5
*	VNIIM	Nov-95	-0.06	0.20	-0.09	0.20
	OMH	Jan-96	-0.3	1.2	-0.3	1.2
	BNM-LNE	Jun-96	0.2	1.0	0.2	1.0
	AREPA	Jul-96	-0.01	0.07	-0.04	0.07
	METAS	Oct-96	0.03	0.03	0.00	0.04
	SP	Nov-96	0.0	0.5	0.0	0.5
	CEM	Jan-97	-0.01	0.08	-0.04	0.09
*	NIST	Apr-97	0.0	0.8	-0.1	0.8
*	NPL-I	Nov-97	-0.2	0.5	-0.3	0.5
*	KRISS	May-98	0	5	0	5
*	NRC-INMS	Sep-98	0.04	0.05	0.01	0.04
	NPL-UK2	Jan-99	0.04	0.03	0.00	0.04
*	CSIRO-NML2	Oct-99	-0.1	0.6	-0.1	0.6

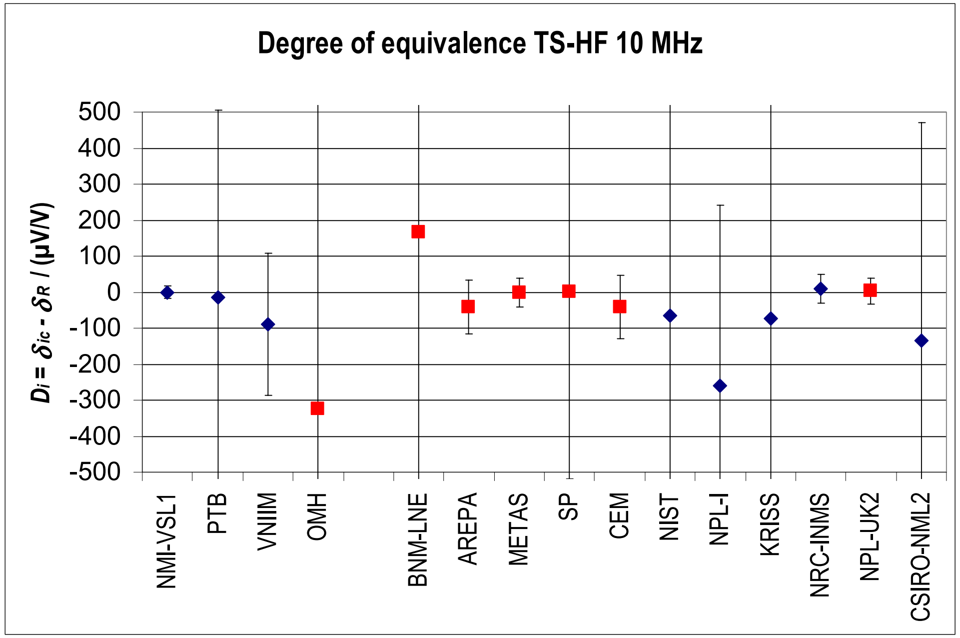

Figure F 2. Degree of equivalence with the reference value and the expanded uncertainty for the AC-DC voltage transfer difference at 10 MHz.
(Blue diamonds: included in δ_R; red squares: not included in δ_R)

CCEM-K6.c Key comparison of AC-DC voltage transfer standards at selected frequencies between 1 MHz and 100 MHz

Measurand: AC-DC voltage transfer difference
Measurement frequency: 30 MHz
Nominal voltage: 4 V

The key comparison reference value, δ_R, is chosen to be the weighted mean of independent results, δ_{ic}, that have not been identified as outliers. The weight of each participant is proportional to its inversed squared uncertainty, $u_{\delta ic}$, in this result. At 30 MHz, the results of 8 independent participants have been used in the calculation of δ_R. The expanded uncertainty U_R of δ_R is the standard uncertainty of the weighted mean multiplied by a coverage factor k_R = 2.
δ_R = -0.20 mV/V and U_R = 0.10 mV/V.

Table F 3. Results at 30 MHz. Corrected measurement results δ_{ic} of the participants with the expanded uncertainties (k = 2), $U_{\delta ic}$. Degrees of equivalence D_i with respect to the KCRV and the expanded uncertainty (k = 2) U_i. Participants indicated with (*) contributed to the reference value.

	Lab	Date	δ_{ic} (mV/V)	$U_{\delta ic}$ (mV/V)	D_i (mV/V)	U_i (mV/V)
*	NMI-VSL1	Aug-95	-0.18	0.18	0.02	0.15
*	PTB	Sep-95	-0.2	0.8	0.0	0.8
*	VNIIM	Nov-95	-0.4	0.3	-0.2	0.3
	OMH	Jan-96	-0.7	1.2	-0.5	1.2
	BNM-LNE	Jun-96	2.9	1.4	3.1	1.4
	AREPA	Jul-96	-0.20	0.26	0.00	0.28
	METAS	Oct-96	-0.19	0.20	0.01	0.23
	SP	Nov-96	-0.1	0.5	0.1	0.6
	CEM	Jan-97	-0.17	0.27	0.03	0.29
*	NIST	Apr-97	-0.3	1.6	-0.1	1.6
*	NPL-I	Nov-97	-0.1	0.7	0.1	0.7
*	KRISS	May-98	-1	5	0	5
*	NRC-INMS	Sep-98	-0.18	0.14	0.02	0.09
	NPL-UK2	Jan-99	-0.12	0.20	0.08	0.22
*	CSIRO-NML2	Oct-99	-0.4	1.5	-0.2	1.5

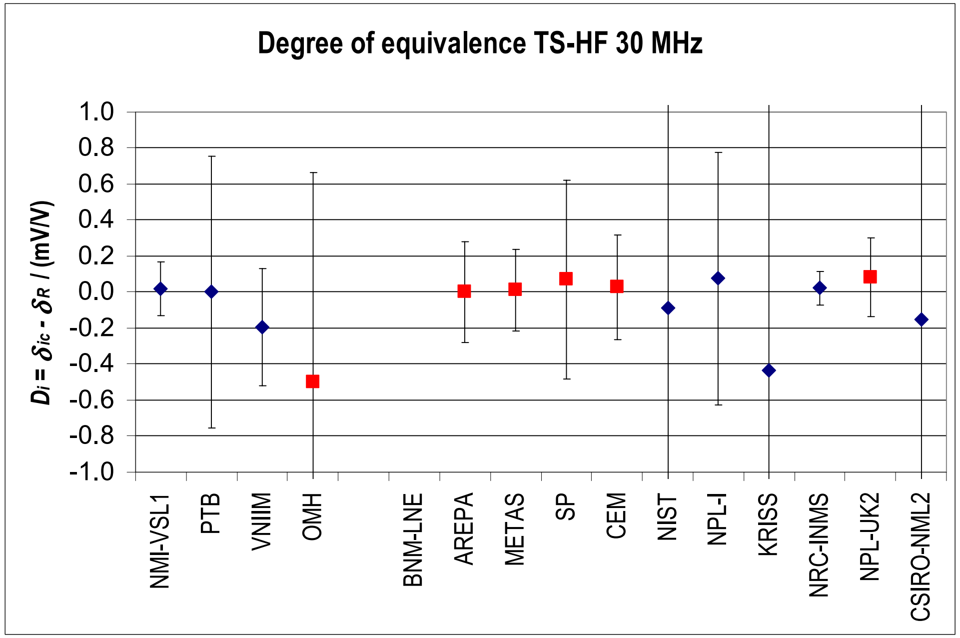

Figure F 3. Degree of equivalence with the reference value and the expanded uncertainty for the AC-DC voltage transfer difference at 30 MHz.
(Blue diamonds: included in δ_R; red squares: not included in δ_R)

CCEM-K6.c Key comparison of AC-DC voltage transfer standards at selected frequencies between 1 MHz and 100 MHz

Measurand: AC-DC voltage transfer difference

Measurement frequency: 50 MHz

Nominal voltage: 4 V

The key comparison reference value, δ_R, is chosen to be the weighted mean of independent results, δ_{ic}, that have not been identified as outliers. The weight of each participant is proportional to its inversed squared uncertainty, $u_{\delta ic}$, in this result. At 50 MHz, the results of 8 independent participants have been used in the calculation of δ_R. The expanded uncertainty U_R of δ_R is the standard uncertainty of the weighted mean multiplied by a coverage factor k_R = 2.

δ_R = -0.83 mV/V and U_R = 0.22 mV/V.

Table F 4. Results at 50 MHz. Corrected measurement results δ_{ic} of the participants with the expanded uncertainties (k = 2), $U_{\delta ic}$. Degrees of equivalence D_i with respect to the KCRV and the expanded uncertainty (k = 2) U_i. Participants indicated with (*) contributed to the reference value.

	Lab	Date	δ_{ic}	$U_{\delta ic}$	D_i	U_i
			(mV/V)	(mV/V)	(mV/V)	(mV/V)
*	NMI-VSL1	Aug-95	-0.8	0.5	0.0	0.5
*	PTB	Sep-95	-0.8	1.3	0.0	1.2
*	VNIIM	Nov-95	-1.1	1.0	-0.3	1.0
*	OMH	Jan-96	-1.2	1.2	-0.4	1.2
	BNM-LNE	Jun-96	3.7	1.1	4.5	1.1
	AREPA	Jul-96	-0.9	0.6	-0.1	0.6
	METAS	Oct-96	-0.8	0.5	0.0	0.6
	CEM	Jan-97	-0.7	0.8	0.1	0.8
*	NIST	Apr-97	-1	4	0	4
*	NPL-I	Nov-97	-0.6	1.1	0.2	1.1
	KRISS	May-98	-2	5	-1	5
*	NRC-INMS	Sep-98	-0.79	0.28	0.03	0.17
	NPL-UK2	Jan-99	-0.7	0.6	0.2	0.6
*	CSIRO-NML2	Oct-99	-0.9	2.5	-0.1	2.4

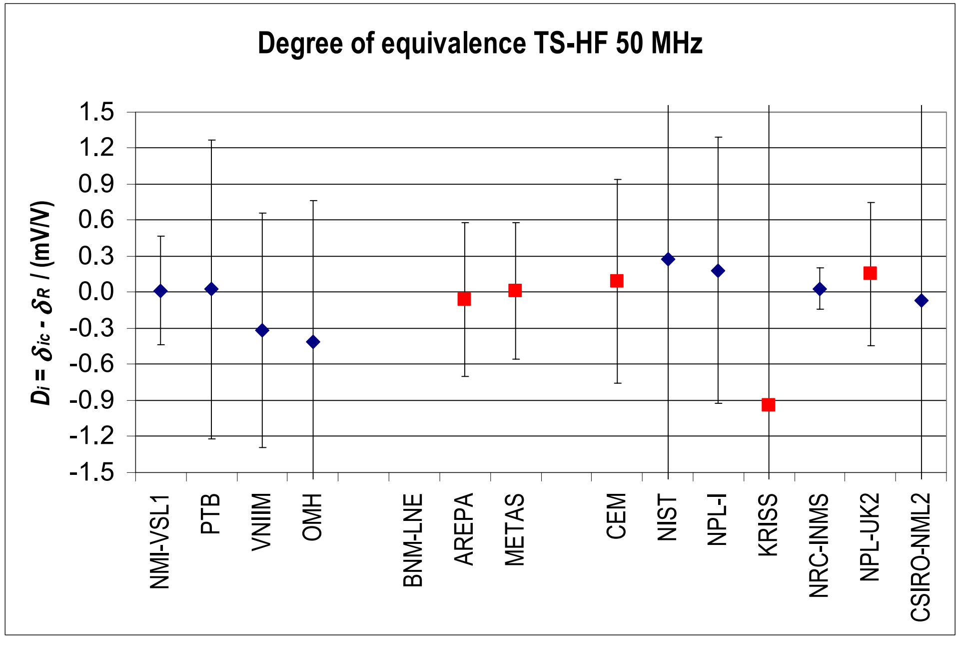

Figure F 4. Degree of equivalence with the reference value and the expanded uncertainty for the AC-DC voltage transfer difference at 50 MHz.
(Blue diamonds: included in δ_R; red squares: not included in δ_R)

CCEM-K6.c Key comparison of AC-DC voltage transfer standards at selected frequencies between 1 MHz and 100 MHz

Measurand: AC-DC voltage transfer difference

Measurement frequency: 100 MHz

Nominal voltage: 4 V

The key comparison reference value, δ_R, is chosen to be the weighted mean of independent results, δ_{ic}, that have not been identified as outliers. The weight of each participant is proportional to its inversed squared uncertainty, $u_{\delta ic}$, in this result. At 100 MHz, the results of 7 independent participants have been used in the calculation of δ_R. The expanded uncertainty U_R of δ_R is the standard uncertainty of the weighted mean multiplied by a coverage factor k_R = 2.

δ_R = -5.16 mV/V and U_R = 0.66 mV/V.

Table F 5. Results at 100 MHz. Corrected measurement results δ_{ic} of the participants with the expanded uncertainties (k = 2), $U_{\delta ic}$. Degrees of equivalence D_i with respect to the KCRV and the expanded uncertainty (k = 2) U_i. Participants indicated with (*) contributed to the reference value.

	Lab	Date	δ_{ic}	$U_{\delta ic}$	D_i	U_i
			(mV/V)	(mV/V)	(mV/V)	(mV/V)
*	NMI-VSL1	Aug-95	-5.2	2.0	0.0	1.9
*	PTB	Sep-95	-4.0	2.6	1.2	2.5
*	VNIIM	Nov-95	-6.7	2.0	-1.5	1.9
*	OMH	Jan-96	-5.9	2.0	-0.8	1.9
	METAS	Oct-96	-5.2	2.2	0.0	2.3
	CEM	Jan-97	-5.0	2.5	0.2	2.6
*	NIST	Apr-97	-4	8	1	8
	NPL-I	Nov-97	-1.3	2.3	3.8	2.4
	KRISS	May-98	-9	5	-3	5
*	NRC-INMS	Sep-98	-5.0	0.9	0.2	0.6
	NPL-UK2	Jan-99	-5.5	2.2	-0.4	2.3
*	CSIRO-NML2	Oct-99	-4.5	2.5	0.7	2.4

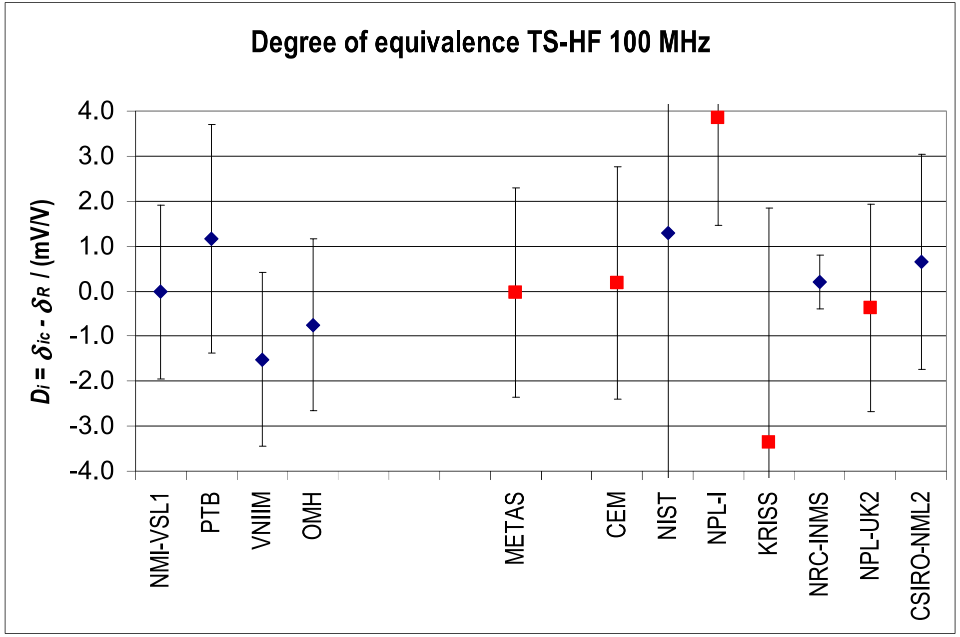

Figure F 5. Degree of equivalence with the reference value and the expanded uncertainty for the AC-DC voltage transfer difference at 100 MHz.
(Blue diamonds: included in δ_R; red squares: not included in δ_R)

G. Appendix: Degrees of freedom

In chapter 8, §8.2, a coverage factor k_R = 2 is used to calculate the expanded uncertainty in the key comparison reference values (KCRV's). To determine the value of k_R, knowledge is required about the effective degrees of freedom of the KCRV, ν_R. Therefore, the effective degrees of freedom ν_i of the results from participants included in the KCRV are also required. Unfortunately, most participants didn't report their ν_i, because this wasn't explicitly asked for in the comparison protocol. However, all participants have reported the number of measurements (*n*) and in Appendix D and E it can be seen that all participants have used $k_i = 2$ to calculate their expanded uncertainties. The pilot laboratory has analyzed the data to verify that k_i = 2 can be justified for all participants included in the KCRV.

Starting from the uncertainty budgets in Appendix D, a separation is made between contributions derived from type A evaluations, u_A, and contributions from type B evaluations, u_B. For all participants at all frequencies, $u_B \gg u_A$. So, it is to be expected that ν_i will be determined by the degrees of freedom related to u_B.

The degrees of freedom ν_A related to u_A are (*n*-1). For the different participants, *n* has values between 10 and 180.

For the degrees of freedom ν_B related to u_B, it is more difficult to make a reasonable estimate. Therefore, two different approaches will be shown. In all uncertainty budgets there are several type B contributions. Some of them are assumed to have a uniform (rectangular) probability distribution and others are assumed to have a normal probability distribution. A typical example of the latter one is the uncertainty in the reference standard. In Appendix E, the uncertainty in the reference standard is given in more detailed (type B) contributions. Most of these detailed contributions are assumed to have uniform distributions, but the convolved distribution of the combined uncertainty of the reference standard can often be approximated by a normal distribution.

Approach (1)
The uncertainty in a parameter that contributes to the measurement result is often given by limits within which the value of this parameter will be. The distribution of the values of this parameter is often unknown and therefore taken as uniform. However, the limits within which the parameter is expected to be are usually well known. Therefore, the degrees of freedom for uncertainty contributions evaluated by specified limits are often taken to be infinite (∞). If the degrees of freedom for all individual type B contributions are estimated to be ∞, ν_B for the combined type B contribution will also be ∞.

If the total combined uncertainty $u_{\delta ic}$ is given by:

$$u_{\delta ic} = \sqrt{u_A^2 + u_B^2}$$

the effective degrees of freedom ν_i for participant *i* is found from the Welch-Satterthwaite equation [1]:

$$\nu_i = \frac{u_{\delta ic}^4}{\dfrac{u_A^4}{\nu_A} + \dfrac{u_B^4}{\nu_B}}$$

With this approach, in the worst case (PTB at 1 MHz), $\nu_i \approx 500$. This means that for all participants included in the KCRV, $2.000 < k_i \leq 2.005$.

Approach (2)
The first approach assumes that the limits of parameter values in a type B evaluation are well known, but unfortunately this is not always the case. The number of degrees of freedom is a measure for the accuracy of an uncertainty contribution. Equation (G.3) in Annex G of the GUM [1], shows how the degrees of freedom can be estimated from the relative uncertainty in an uncertainty contribution:

$$\nu_b \approx \frac{1}{2}\left(\frac{\Delta u(x_b)}{u(x_b)}\right)^{-2}$$

where the quantity in brackets is the relative uncertainty in $u(x_b)$ and $u(x_b)$ is the uncertainty in a parameter x_b.
Suppose that for all type B uncertainty contribution $\Delta u(x_b)/u(x_b)$ = 15 % (which is a very conservative estimate), then all values of ν_b become 22.
The effective degrees of freedom ν_B from the combined type B contributions is now found from:

$$\nu_B = \frac{u_B^4}{\sum_b \frac{(u(x_b))^4}{\nu_b}}$$

If u_B is not dominated by one single contribution of $u(x_b)$, then typically $\nu_B > 30$. ν_i is again found from the same formula as given above. So in this case, for each participant $\nu_i > 30$ and thus $2.000 \le k_i \le 2.087$.

Approach (1) is rather common practice when making an uncertainty budget, while approach (2) can be considered as a very conservative estimate. The differences in the k_i values from both approaches are small. So, it can be concluded that if, in this report, we use $k_i = 2$ instead of the actual value of k_i, the relative error in the expanded uncertainty of a participant will be less than 5 %.

The next step is to find ν_R which is required to determine k_R. From §8.2 the calculation of the KCRV, δ_R, and its uncertainty u_R are repeated here:

$$\delta_R = \sum_{i=1}^{N} g_i \cdot \delta_{ic}$$

where δ_{ic} are the lab results, N is the number participants included in the KCRV and g_i is defined as:

$$g_i = \frac{w_i}{\sum_{i=1}^{N} w_i}$$

and

$$w_i = \frac{1}{u_{\delta ic}^2}.$$

The uncertainty in KCRV is given by:

$$u_R = \sqrt{\sum_{i=1}^{N}\left((g_i \cdot u_{\delta ic})^2\right)} = \frac{1}{\sqrt{\sum_{i=1}^{N} \frac{1}{u_{\delta ic}^2}}}.$$

The number of effective degrees of freedom ν_R is now easily found from the Welch-Satterthwaite formula by taking into accounting the different weights g_i:

$$\nu_R = \frac{u_R^4}{\sum_{i=1}^{N} \frac{(g_i \cdot u_{\delta ic})^4}{\nu_i}}$$

In the case of approach (1), $\nu_R > 10^5$, and k_R is very close to 2.
For approach (2), $50 < \nu_R < 170$, and $2.015 < k_R < 2.051$.

From this we conclude that by using $k_R = 2$ instead of the actual value of k_R, even under conservative assumptions, the error in the expanded uncertainty in the KCRV is expected to be less than 3 %.

From the conclusions mentioned above, it can easily be seen that, in chapter 9, it is also reasonable to use a coverage factor $k_D = 2$ for the expanded uncertainty U_i in the degrees of equivalence with the reference value D_i.

[1] "Guide to the expression of uncertainty in measurement", first published in 1993, by BIPM/IEC/IFCC/ISO/IUPAP/OIML.

H. Appendix: Technical protocol

CCE comparison 92-05

AC/DC transfer devices at high frequencies (1-50 MHz)

Instructions for Participants

1. Scope

During the last decades, several AC/DC transfer comparisons have been carried out concerning the low frequency range, below 1 MHz. The scope of this comparison is to extend the frequency range up until 50 MHz with a relative small uncertainty of the AC/DC transfer.

2. Definition of the comparison

The AC/DC transfer difference of a thermal converter (δ) is defined as:

$$\delta = \frac{V_{\mathrm{ac}} - V_{\mathrm{dc}}}{V_{\mathrm{dc}}}$$

where: V_{ac} is the rms value of the applied ac voltage;
V_{dc} is the mean value of the direct and reversed dc voltages, which produce the same output voltage of the converter as V_{ac}.

3. The travelling standards

Two travelling standards are supplied:
- A VSL Calculable HF AC/DC transfer standard
- A Fluke A55 thermal converter

1) VSL Calculable HF AC/DC transfer standard (TS-HF)
A calculable HF AC/DC standard of VSL design (EUROMET project 223) is used as one of the standards. It consists of a 5 mA current thermoelement in series with a range resistor. The standard is equipped with a type-N male connector at the input. The main specifications are:

Input voltage:	4 V
Output voltage:	7 mV (at nominal input voltage)
Input resistance:	800 Ω (nominal)
Output resistance:	7 Ω (nominal)

2) Fluke A55 thermal converter (TS-A55)

A commercial Fluke A55-3V thermal converter is used as the other travelling standard. This device is equipped with a GR-874 connector at the input. The main specifications are:

Input voltage:	3 V
Output voltage:	7 mV (at nominal input voltage)
Input resistance:	600 Ω (nominal)
Output resistance:	8 Ω (nominal)

Connectors

The middle of a T-connector is used as reference plane for the AC/DC transfer measurements. Due to the fact that the input connectors are different for both standards, problems can arise due to compatibility of the connectors with the measurement equipment. Therefore, a special T (serial number N/N/874 3) is provided, which has at the input a type-N female connector and at the output on one side a type-N female connector and on the other side a GR-874 connector.

Two output adapters are also supplied, which connect the output of the standards to banana plugs.

4. Measuring conditions

The participating laboratories are asked to follow their usual measurement procedure to their best measurement capabilities in respect to the allowed time frame (1 month) for the comparison. Important remarks to be mentioned are:

- The reference plane for this calibration is the central plane of a T-connector. The T-connector chosen has to be reported for each travelling standard.
- The input and the output of the transfer devices have to be earthed in order to protect the insulation between the heater and the thermocouple.
- The measuring frequency has a significant influence on the AC/DC transfer, the accuracy and stability of the frequency should be reported.

5. Measuring scheme

1) Calibration of the separate travelling standards

The AC/DC transfer difference δ of the travelling standards has to be measured at its nominal input voltage if possible. The measurement frequencies are given in table below with four required frequencies and the other three are optional.

f_{meas} (MHz)	1	10	30	50
Optional (MHz)	0,5	70	100	

2) Calibration of the two travelling standards against each other (if possible)

If it is possible with the existing set-up, an ac/dc measurement at the four frequencies (1, 10, 30 and 50 MHz) is required of both travelling standards at **the nominal input voltage of 3 V**. In this case the measured ac/dc transfer difference between both standards should be reported.

6. Uncertainty statements

The measurements should be performed at the lowest possible uncertainty level. A detailed uncertainty analysis for the measurements has to be reported in accordance with the GUIDE TO EXPRESSION OF UNCERTAINTY IN MEASUREMENT, first published in 1993 by BIPM/IEC/IFCC/ ISO/IUPAP/OIML, based on the RECOMMENDATION INC-1 (1980) of the working group and the CIPM on the Statement of Uncertainties, English version published in Metrologia 17 (1981), p. 73. Participants are asked to evaluate Type A and B standard uncertainties, and to report them separately. At the end the standard measurement uncertainty should be stated. All uncertainties should be given at a confidence level of 63% (1 σ).

7. Report

After carrying out the measurements, each participating laboratory should send a report to the pilot laboratory within one month including the form ‘Results of CCE 92-05 Comparison’. Short response time is necessary to check the status of the standards and to finish the comparison in the shortest time frame possible.
The report should contain at least:

- A detailed description of the measurement set-up including some drawings, which can be used in the final report and a publication of the results;
- A detailed description of the measurement procedure;
- The mean measurement value and the statistical spread of the AC/DC transfer difference of the standards for each frequency measured, together with the number of measurements to produce this mean value;
- A detailed uncertainty budget in accordance with the GUIDE TO EXPRESSION OF UNCERTAINTY IN MEASUREMENT, first published in 1993 by BIPM/IEC/IFCC/ ISO/IUPAP/OIML.
  See also the form ‘Uncertainty budget of the CCE 92-05 comparison’, which is attached to this instruction set;
- The form ‘Results of CCE 92-05 Comparison’.

8. Transportation and customs

The devices should be (hand-) carried by car, train or plane as it appears the safest for the devices. **For air-cargo or parcel service, the transporting case should be surrounded by a larger case filled with foam to protect the transporting case.**
Inside the European Union no custom papers are necessary. So, an EU loop will be organized first. For all the participants outside the European Union, an ATA-carnet will be provided, if applicable.

9. Circulation time schedule

The time schedule will be arranged when the list of participating laboratories is completed. To finish the comparison within the shortest time frame possible, only one month is allowed for each participant, which also includes the transportation time. The definitive time schedule is attached to this instruction.

10. Organisation

The pilot laboratory for the comparison is the NMi Van Swinden Laboratorium (VSL). The travelling standards will be (or have been) dispatched from VSL at the end of August 1995 and will return after the completion of each loop. The number of loops is determined at 5, three within Europe and two as a Worldwide loop.
It is the responsibility of the participating laboratory to inform the next participant in advance to arrange the transportation of the standards to him, and to inform the pilot laboratory about the date of transportation.

11. Contact person

If there are any questions concerning the comparison, the contact person at the pilot laboratory is:

Dr. Cees van Mullem
Nederlands Meetinstituut
Van Swinden Laboratorium
Schoemakerstraat 97
P.O. Box 654
2600 AR Delft
The Netherlands

Telephone: + 31 15 2 69 15 00
Telefax: + 31 15 2 61 29 71
E-mail: CvanMullem@nmi.nl

Results of CCE 92-05 Comparison

On this form, the participant is kindly requested to present an overview of the results of his/her measurements on the transfer standards, it means the number of measurements (# meas.), the average of the transfer difference (δ) and the corresponding total uncertainty (σ_t) expressed as a 1σ value. (It can be handwritten.)

Institute:

Date:

Remarks:

Travelling standard: TS-HF

frequency (MHz)	0.5 *(optional)*	1	10	30	50	70 *(optional)*	100 *(optional)*
# meas.							
δ (ppm)							
σ_t (ppm)							

Travelling standard: TS-A55

frequency (MHz)	0.5 *(optional)*	1	10	30	50	70 *(optional)*	100 *(optional)*
# meas.							
δ (ppm)							
σ_t (ppm)							

Also, the measurement results of the TS-HF versus the TS-A55 can be put on this form with:

δ is the measured $\delta_{DUT}-\delta_{REF}$;
σ_m is the standard deviation of the measurements.

Travelling standards: **TS-HF versus TS-A55**
REFERENCE: ....
DUT: ....

frequency (MHz)	0.5 *(optional)*	1	10	30	50	70 *(optional)*	100 *(optional)*
# meas.							
δ (ppm)							
σ_t (ppm)							

Uncertainty budget of the CCE 92-05 comparison

This form can be used as an example to determine and to express the uncertainty of the measurements. It can be filled in (handwritten) or put in an appendix of your report on a form like this one. You can add your own sources of uncertainty; this is just an example.
Our main goal is to have a uniform presentation of the uncertainty budget and corresponding an easy comparison between the results of the different institutes. Thank you in advance for your cooperation.

Institute:
Date:
Remarks:

Travelling standard: TS-HF

Contribution of:	Unc. f: MHz	Unc. f: MHz	Unc. f: MHz	Unc. f: MHz	Type A or B	Shape of distribution
st. dev. of measurement						
reference standard						
measurement set-up						
connectors						
....						
....						
....						

total uncertainty (1σ):				

Travelling standard: TS-A55

Contribution of:	Unc. f: MHz	Unc. f: MHz	Unc. f: MHz	Unc. f: MHz	Type A or B	Shape of distribution
st. dev. of measurement						
reference standard						
measurement set-up						
connectors						
....						
....						
....						

total uncertainty (1σ):				

Participation in the CCE Comparison 92-05
AC/DC Transfer devices at high frequencies (1-50 MHz)

Institute:

Address:

Country:

Person to contact:

Telephone:

Telefax:

E-mail (if available):

Please indicate your answer by crossing the appropriate box and adding any further comments:

☐ We are not interested in the participation of this comparison.

☐ We wish to participate in the CCE comparison 92-05.

To help us to arrange the time schedule, please indicate which periods in 1995 and 1996 are unacceptable for you to perform the measurements:

and which is the preferred period:

Please return this form to:

Dr. Cees van Mullem
Nederlands Meetinstituut
Van Swinden Laboratorium
PO Box 654
2600 AR Delft
The Netherlands
Telephone: 31 15 691500
Telefax: 31 15 612971