

# CCE 92-05 Intercomparison of AC–DC Voltage Transfer Standards at High Frequencies (1–50 MHz)

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**Abstract**—From August 1995 to May 1998, the CCE 92-05 intercomparison of ac–dc voltage transfer standards at high frequencies was carried out. Two travel standards were measured by 15 national standards institutes. The results in the frequency range from 1 to 50 MHz show a good agreement between the majority of participants. The span of the majority of the reported ac–dc differences at 50 MHz is less than 1000  $\mu\text{V/V}$ , which is similar to a previous intercomparison but with a greater number of participants.

**Index Terms**—AC–DC transfer, intercomparison, measurement standards, thermal converters.

## I. INTRODUCTION

THE PRIMARY LF ac–dc transfer standards (up to 1 MHz) are realized by using single or multijunction thermal converters (SJTC or MJTC) [1]. The ac–dc voltage transfer difference and the corresponding uncertainty have reached the level of several tenths of  $\mu\text{V/V}$  in the audio frequency range [2]. In the high-frequency range, coaxial thermal converters (UHF-type) or calorimetric systems are commonly used as primary voltage standards [3]–[8]. Furthermore, the transfer difference and uncertainty strongly increase with frequency in this range.

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

To be able to establish a worldwide traceability for ac–dc transfer at high frequencies, the Comité Consultatif d'Electricité (CCE) decided to organize an international comparison. There had never been an extensive CCE intercomparison, only an (informal) intercomparison between six laboratories has been carried out [9]. In the meantime, the CCE has pointed out this type of intercomparison as one of the key comparisons.

## II. SCOPE OF THE INTERCOMPARISON

During the last decades, several ac–dc transfer intercomparisons have been carried out concerning the low-frequency range (up to 1 MHz) [2]. The scope of the presented comparison is to extend the frequency range up to 50 MHz with a relatively small uncertainty of the ac–dc transfer difference (see Table I).

Manuscript received July 2, 1998.

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Publisher Item Identifier S 0018-9456(99)02870-3.

TABLE I  
MEASUREMENT PARAMETERS FOR THE TWO TRAVELING STANDARDS

Standard	Input	Required frequencies	Optional frequencies
TS-HF	4 V	1, 10, 30 and 50 MHz	0,5, 70 and 100 MHz
TS-A55	3 V	1, 10, 30 and 50 MHz	0,5, 70 and 100 MHz

To cover the transition from the LF ac–dc voltage transfer to the RF voltage in 50  $\Omega$  systems, the frequency range extends over 0.5 MHz to 100 MHz.

## III. TRAVELING STANDARDS

Two traveling standards are used in the intercomparison.

- *VSL Calculable HF AC–DC Transfer Standard (TS-HF)* [3], [4]: This ac–dc standard consists of a 5-mA thermoelement in series with an (in-house) range resistor. 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 traveling 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.

### A. AC–DC Transfer Difference

The ac–dc transfer difference  $\delta$  of the traveling standards is defined as

$$\delta \equiv (V_{ac} - V_{dc})/V_{dc} \quad (1)$$

where  $V_{ac}$  is the rms value of the applied ac voltage, and  $V_{dc}$  is the mean value of the direct and reversed dc voltages, which produces the same output voltage of the standard as  $V_{ac}$ .

### B. Connectors

The middle of a Tee-connector is used as the reference plane for the ac–dc transfer measurements. Due to the fact that the input connectors are different, problems can arise due to compatibility of the connectors. Therefore, a special Tee has been provided, which has at the input a type-N female connector and at the output on one side a type-N female and on the other side a GR-874 connector.

### C. Measurement Setup

To characterize the measurement setup used for systematic errors and to be independent of the reference standards, the participants are asked to measure the two traveling standards against each other by using the supplied Tee connector. The result of this measurement can be used by the participant to have a consistency check of their measurement setup. On the other hand, these errors can be detected by the pilot laboratory when the reported ac–dc transfer differences are analyzed.

## IV. PARTICIPATING LABORATORIES

The NMi Van Swinden Laboratorium is the pilot laboratory for this intercomparison. The long-term stability of the traveling standards due to transportation was not characterized before. Therefore, the pilot laboratory has scheduled three check measurements during the intercomparison. Due to serious transportation problems, it finally ends up with five check measurements.

The participants are given in the chronological order in which they have participated.

### A. Participants

- 1) NMi Van Swinden Laboratorium (VSL), The Netherlands, C. J. van Mullem.
- 2) Physikalisch-Technische Bundesanstalt (PTB), Germany, D. Janik.
- 3) D. I. Mendeleyev Institute for Metrology (VNIIM), Russia, V. S. Alexandrov.
- 4) National Office of Measures (OMH), Hungary, A. Jakab.
- 5) Slovenian Institute of Quality and Metrology (SIQ), Slovenia, Z. Svetik and A. Razpotnik.
- 6) National Physics Laboratory (NPL), U.K., G. Jones (up to 1 MHz).
- 7) Laboratoire Central des Industries Électriques (LCIE), France, M. Valon and L. Erard.
- 8) AREPA Test & Kalibrering A/S, Denmark, T. Lippert.
- 9) Office Fédéral de Métrologie (OFMET), Switzerland, M. Flüeli.
- 10) Sverige Provnings-och Forskningsinstitut (SP), Sweden, K.-E. Rydler (up to 30 MHz).
- 11) Centro Español de Metrología (CEM), Spain, J. M. Balmisa, M. Neira, S. Ramiro, and M. Martínez.
- 12) National Institute of Standards and Technology (NIST), USA, J. Kinard and G. Free.
- 13) National Measurement Laboratory (NML), Australia, I. F. Budovsky and J. Petranovic.
- 14) National Physical Laboratory (NPLI), India, V. K. Rustagi and A. K. Govil.
- 15) Korean Research Institute of Standards and Science (KRISS), South Korea, J. H. Kim and S. W. Kwon.

## V. LABORATORY PROCEDURES AND STANDARDS

The laboratory procedures and reference standards used by the participants have been described in more or less detail in the reports. In cases when the report contains a minimum of

TABLE II  
REFERENCE STANDARDS AND MEASUREMENT  
PROCEDURE USED BY THE INSTITUTES

Institute	Primary standard $\leq 1$ MHz	Primary standard $> 1$ MHz	Measurement system
VSL	VSL HF SJTC (SJTC + 700 $\Omega$ )	VSL HF SJTC (SJTC + 700 $\Omega$ )	ac-dc transfer system (automatic)
PTB	PTB MJTC	Coaxial calorimeter (dual load type)	ac substitution system (automatic)
VNIIM	VNIIM converter (SJTC + 1 k $\Omega$ )	VNIIM converter (SJTC + 1 k $\Omega$ )	No information
OMH	OMH MJTC	Calorimetric voltage standard	ac-dc transfer system (automatic)
SIQ	EUR HF SJTC	EUR HF SJTC	RF-dc manual system
NPL	SJTC + 900 $\Omega$	not participating	ac-dc transfer system
LCIE	Holt 20 converter	Holt 20 converter	RF-dc manual system
AREPA	EUR HF SJTC	EUR HF SJTC	ac-dc transfer system (aut.)
OFMET	EUR HF SJTC	EUR HF SJTC	ac-dc transfer system (aut.)
SP	EUR HF SJTC	EUR HF SJTC	ac-dc transfer system (aut.)
CEM	MJTC (PTB-cal.) EUR HF SJTC	EUR HF SJTC	ac-dc transfer system (aut.)
NIST	NIST SJTC + 1 k $\Omega$	NIST SJTC	ac-dc transfer system (aut.)
NML	NML TC	Twin line calorimeter	Aut. Comparison system
NPLI	NPLI MJTC	Calorimetric voltage standard	Semi-aut. Comparison system
KRISS	KRISS MJTC (PTB type + cal)	RF power and impedance standard	ac-dc transfer system (aut.)

information or large ac–dc deviations have been observed, the participant has been asked to give additional information.

In most cases, the reference standards for frequencies up to 1 MHz and the higher frequencies are different. In Table II these reference standards for the two frequency ranges are given. Several European national institutes (such as OFMET, SP, CEM, SIQ, and AREPA) also use the VSL calculable HF ac–dc transfer standard (the EUR HF SJTC) as primary standard, the same type of instrument as the traveling standard TS-HF. These standards are calibrated by VSL. Other institutes use their own developed and characterized coaxial type of thermal converters or calorimetric systems as primary reference standards.

The measurement system for almost all institutes is a (semi-) automatic system to compare a traveling standard 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 institute to institute. In general,

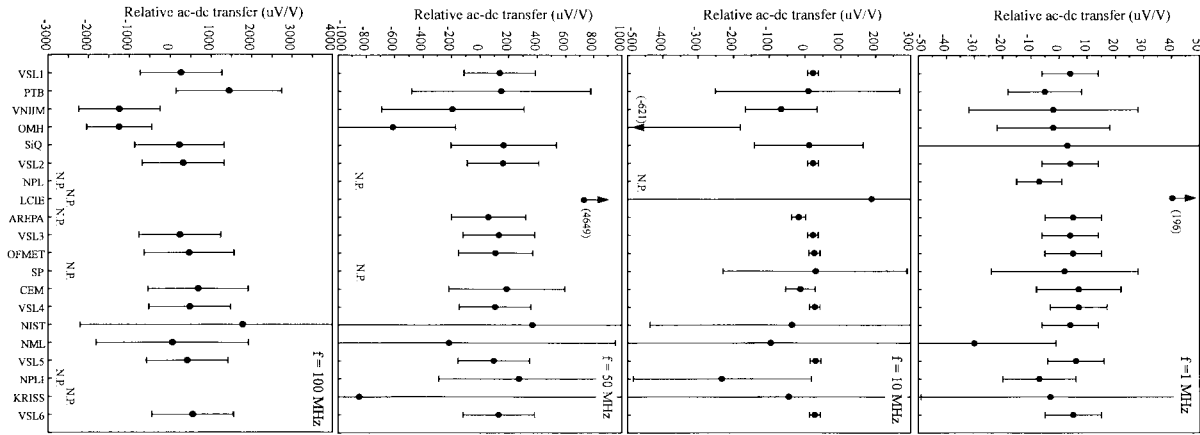


Fig. 1. Relative ac-dc transfer difference for the frequencies of (1, 10, 50, and 100) MHz for the TS-HF traveling standard (N.P.: not participating).

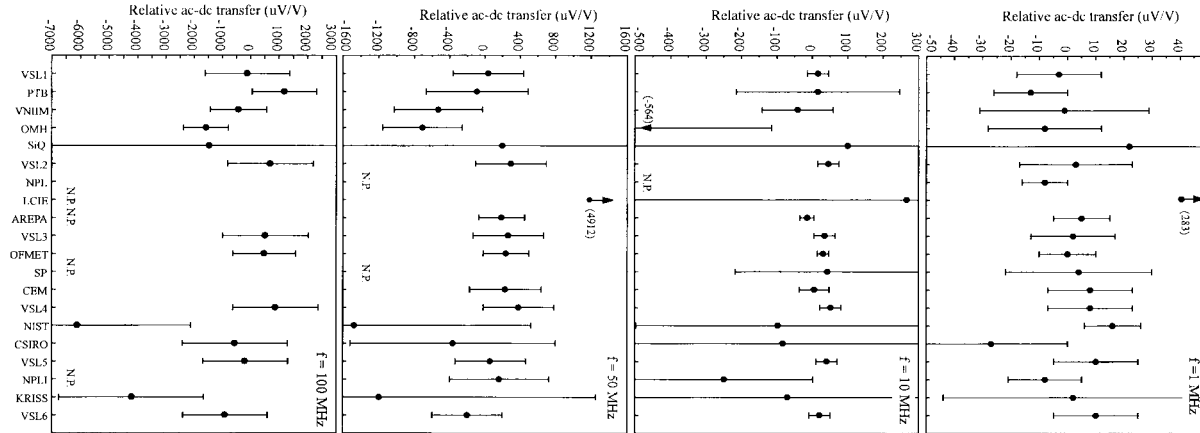


Fig. 2. Relative ac-dc transfer difference for the frequencies of (1, 10, 50, and 100) MHz for the TS-A55 traveling standard (N.P.: not participating).

measurements have been carried out in several days with 5–10 cycles per single measurement to obtain a mean value of the ac-dc transfer difference.

## VI. UNCERTAINTY STATEMENTS

The participants have been asked to report the uncertainty analysis in accordance with [10]. Most of them have provided a detailed uncertainty calculation in their report. However, some participants just reported the total uncertainty.

The type A evaluation is based on the number of measurements taken. The type B evaluation is divided into several independent contributions for which the pilot laboratory has proposed a minimum set. The main contribution is given by the reference standard used. For all institutes, this term is dominating the uncertainty calculation. Other reported uncertainty sources are the Tee connector, the measurement setup, and the reproducibility of the measurements.

From the reported uncertainty calculations, it is concluded that the determination of the uncertainty of the reference standard is essential. This part is not given in the reports but this is necessary to evaluate the uncertainties in detail to come to a worldwide agreement in the scope of a key comparison.

## VII. RESULTS OF THE INTERCOMPARISON

Figs. 1 and 2 present the results for the two traveling standards for the frequencies (1, 10, 50, and 100) MHz. The given relative ac-dc transfer is the difference between the reported value and the calculated mean value which is the average of all reported  $\delta$ 's with skipping extreme values. The uncertainty bars are the reported  $k = 1$  values.

The check measurements carried out by the pilot laboratory indicate that the TS-HF has a very stable behavior over time. However, the TS-A55 seems to be less stable but this can be caused by overloading during the intercomparison (reported at least once by a participant). Also, during a check measurement, the transfer differences of the TS-A55 showed instabilities, although they are small compared to the specified uncertainty.

The results at 1 MHz are in close agreement with each other. However, one institute is completely out of the range and another is 30  $\mu\text{V/V}$  away for the mean. The obtained results are similar to the published results for the last LF ac-dc intercomparison [2]. The scatter of the results increases with the frequency. But these deviations are mostly covered by the specified uncertainty. The overall agreement for the frequency range from 10 MHz to 50 MHz is good. In addition, for most

institutes the uncertainties are strongly increasing at 10 MHz due to the transition from LF to HF ac-dc reference standards.

Even at 100 MHz, the results show a quite good agreement. However, half of the eight presented results are obtained by using a reference standard that is based on the VSL calculable HF ac-dc standard [3], [4]. In combination with the results obtained for the other frequencies, it is concluded that there is a minimal influence of the measurement setup on the ac-dc transfer for this type of reference standard.

### VIII. CONCLUSIONS

In May 1998, the intercomparison of ac-dc voltage transfer standards at high frequencies was completed. The final results in the frequency range from 1 MHz to 50 MHz show a good agreement between the majority of participants. The calculated deviations from the mean value are covered by the specified uncertainty. The present intercomparison clearly indicates that a detailed evaluation of the uncertainty of the reference standard is necessary to come to a worldwide agreement in this field of measurements.

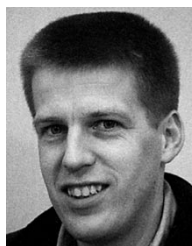
### ACKNOWLEDGMENT

All participants are gratefully thanked for their good co-operation during the running of the intercomparison and for respecting the time schedule as closely as possible.

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