CCE Intercomparison of AC–DC Transfer Standards

Jan P. M. de Vreede

Abstract—A worldwide intercomparison is described covering both ac voltage and ac current measurements in the frequency range from 40 Hz to 1 MHz. Results are consistent within 10–20 ppm at low voltage and frequency, but differ by up to 100 ppm at high voltage and frequency. For currents of tens of milliamperes the results are consistent within 40 ppm.

I. INTRODUCTION

The traceability of ac quantities is becoming more important with the introduction of advanced measurement equipment capable of covering wide ranges in both frequency and amplitude. Modern electronic equipment now requires accuracy of national standards at a level between 1 and 10 ppm.

Thermal converters are usually used at national standards laboratories as basic standards, at a level of a few volts, currently up to at least 1 MHz. For higher voltages, series resistors are used to extend the range of the standard.

A small-scale intercomparison between four national standards laboratories (IMM, ETL, NBS, and NPL) was organized under the auspices of the Comité Consultatif d’Electricité (CCE) in the seventies. The results were published in 1980 [1]. Because of the high degree of consistency (of the order of 10 ppm) the CCE decided to organize a large-scale intercomparison for ac quantities with the Van Swinden Laboratorium (VSL) as pilot laboratory.

The scope of the comparison was to cover the usual range of ac–dc standards available at national standards laboratories. Hence, a frequency range from 40 Hz up to 1 MHz has been chosen, as well as higher voltages. This paper describes the results of this intercomparison in which a total of 13 laboratories from all over the world participated.

II. ORGANIZATION OF THE INTERCOMPARISON

The intercomparison is divided into two main rounds, one confined to western Europe and one extending worldwide. The first round was carried out under a contract with BCR (Community Reference Bureau, part of the Commission of the European Communities) from 1981 to 1986. During this period the transfer standards were returned to VSL twice for checking and repair. The devices were hand-carried.

The second round started after writing the intermediate BCR report [2] and after an upgrading of the VSL facilities. This round covers the period from 1988 to the beginning of 1992. The transfer devices were returned twice to VSL for intermediate measurements and were transported using standard air-freight procedures.

III. TRAVELING DEVICES

As VSL did not have sufficient traveling standards available, both the National Physical Laboratory (NPL, UK) and the National Bureau of Standards (NBS, US, now National Institute of Standards and Technology (NIST)) provided the necessary standards. A set of seven traveling standards has been identified to cover the voltage range between 10 and 1000 V and the current range from 10 to 30 mA. In Table I the measurement voltage/current and frequencies are indicated, as well as those for the earlier comparison [1].

A. Stability of the Traveling Devices

The thermal elements are rather fragile and therefore the method of transport has been a point of concern. In the first round the items were hand-carried (i.e., transported under the care of laboratory personnel). In practice, the actual handling during measurements led to most of the damage. In the second round, where air-freight handling was unavoidable, the first transport package was not sufficiently rigid to permit secure transport and some components were damaged. After that there was only one incident of damage. The following is a summary of the problems with the devices. PTB found poor electrical insulation between heater and thermocouple in the 10-mA converter (replaced by NPL before VSL-82). LCIE experienced a failure of the 30-mA converter: VSL replaced it with a 30-mA device (10 mA + shunt). SMB experienced a break-down of the 5-mA converter which effectively terminated the measurements on the 10 V to 300 V ranges (replaced by VSL before last measurements of the first round). The 1000-V converter failed at VNIIM.

IV. LABORATORY PROCEDURES AND STANDARDS

In the guidelines for the intercomparison the basic setup is detailed using the supplied GR874 Tee-connector for connecting the ac and dc source to the laboratory standard and to the traveling standard (they have either a GR874 or a GR900 connector; for the latter an adapter has been supplied). The quantity to be measured is the ac–dc difference of the traveling standards at the reference plane.
TABLE I
TRANSFER STANDARDS AND MEASUREMENT PARAMETERS: (IN BRACKETS: ORIGIN OF DEVICE; UNDERLINED FREQENCIIES ALSO USED IN [1])

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Range resistor</th>
<th>Thermal element</th>
<th>Measurement frequencies (kHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 V</td>
<td>1.9 kΩ (NPL)</td>
<td>5 mA (NPL)</td>
<td>0.040, 20, 50, 100, 1000</td>
</tr>
<tr>
<td>30 V</td>
<td>6 kΩ (NPL)</td>
<td>5 mA (NPL)</td>
<td>0.040, 20, 50, 100</td>
</tr>
<tr>
<td>100 V</td>
<td>20 kΩ (NPL)</td>
<td>5 mA (NPL)</td>
<td>0.040, 20, 50, 100</td>
</tr>
<tr>
<td>300 V</td>
<td>60 kΩ (NBS)</td>
<td>5 mA (NPL)</td>
<td>0.040, 20, 50, 100</td>
</tr>
<tr>
<td>1000 V</td>
<td></td>
<td>Integrated device (NBS)</td>
<td>0.040, 20, 50</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Current</th>
<th>Thermal element</th>
<th>Measurement frequencies (kHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 mA</td>
<td>10 mA (NPL)</td>
<td>0.040, 20, 50, 100</td>
</tr>
<tr>
<td>30 mA</td>
<td>30 mA (NPL)</td>
<td>0.040, 20, 50, 100</td>
</tr>
</tbody>
</table>

Accessories:
GR874 Tee connector
GR874-GR900 adaptor
The accessories have been chosen to fit the usual connector types

A. Participating Laboratories and Personnel

In this section the participating laboratories, the personnel directly involved in the comparison and some special features of the laboratory setup are given (more details about the facilities of the west European laboratories are found in [2] and its references). Also indicated in the text by "**" are those laboratories which participated in the earlier comparison [1]. In Table II the time schedule is presented as well as when the "breakdown" in a traveling device occurred.

National Physical Laboratory (NPL**), Teddington, U.K.: B. R. D. Knight, P. Martin

Instead of a simple interpolation per cycle of ac and dc signals a software program is used to obtain one complete fit for the whole set of cycles within one run. A measurement system with source instability compensation is used. The standards are similar to the traveling devices.

Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany: M. Klonz

The measuring devices are used in combination with another thermal element in order to compensate for drift. The dc-input into the latter element is adjusted to maintain a null reading between the two thermal element outputs. This adjusted dc voltage is used as measurement result in the measurements. The references are multijunction thermal converters (MJTC; nominal 3-V input; developed at PTB by Klonz [4]). They are very well evaluated for both voltage and current transfer. For 30 mA a single junction thermal element with built-in shunt is used after having been calibrated against a MJTC.

Istituto Elettrotecnico Nazionale Galileo Ferraris (IEN), Torino, Italy: F. Cabiati

A differential measurement system is used for measuring the output of one converter and the difference between
A new measurement facility (using differential voltage measurement) is used for this intercomparison. All standards (having type-N connectors) are 10 mA thermal converters housed in an almost cubic cylinder. A group of six converters forms the reference group of which the average is assumed to be zero (based upon pair difference measurements of each combination). The 30-mA converter is compared to a set of three 10-mA converters connected in parallel.

Commonwealth Scientific and Industrial Research Organization (CSIRO), Lindfield, Australia: K. G. Kujath

Standards are based upon a set containing single-junction converters which have been extensively analyzed in the past. The working group references are commercial items which are compared to the basic group by using a build-up chain over the full voltage range (1–1000 V) from 57 Hz to 100 kHz. At 1 MHz a successful comparison was carried out between calculation (using material information) and a calorimetric method.

In each output channel a Lindeck potentiometer with nulling detector is used followed by an A/D-converter. 4–6 runs, each of 10 measurements, are performed during a period of three months (The laboratory standards have been attached an equal number of runs to each side of the Tee-junction).

National Research Council (NRC), Ottawa, Canada: R. F. Clark

The reference standards are 1-V calorimetric TVC’s [5] with commercial working standards used in the intercomparison. Measurements have carried out at below nominal rating. Three runs have been made. No measurements have been carried out below 50 kHz.

National Institute of Standards and Technology (NIST **), Gaithersburg, USA: J. Kinard

A set of eight MJTC’s is used as NIST set with an average ac–dc difference of less than 0.5 ppm between 30 Hz and 10 kHz. Buildup, standards, and uncertainties (2σ) are described in [6]. Different setups have been used. A weighted average is used as final result, except for 1000 V. The ambient temperature varied between 22 and 27°C, but no influence on the results has been observed.

Amt für Standardisierung, Meßwesen und Warenprüfung (ASMW), Berlin, Germany: G. Schliestedt

A MJTC of 10 mA and a SJTC of 2.5 mA combined with range resistors are used as standards. The set of standards include a manually operated transfer switch between the two sources (dc and ac). The measurement system is equipped with UHF connectors and hence a different reference plane is used. Up to 100 kHz the influence of this change in reference plane is assumed to be negligible.

The measurements were performed before the German unification. ASMW is now integrated with PTB.
The standards are multijunctions (in air) housed coaxially in a metal cylinder. Metal-dielectric thin-film resistors are used to extend the range from 10 to 1000 V. For 1 MHz and 10 V a single junction TE and resistor is used. A special amplifier is used for the current ac–dc transfer.

The laboratory reference is maintained at fixed output amplitude for both ac and dc. In the laboratory definition of the ac–dc difference the numerator has the opposite sign compared to other results. The pilot laboratory has converted these data to obtain a consistent set for all participants.


Because VSL as pilot laboratory has regularly made measurements during the last decade, the evolution in its transfer standards and its measuring facilities can be shown in the description of the setups used in rounds 1 and 2. In the first round commercially obtained units (calibrated at NBS) were used as standards with SJTC “home-made” devices as working standards (5-mA TE plus range resistors in home-made configurations). For current measurements a group of 5 mA (different mounted with low dc-reversal error) TE’s are used and are given a zero difference. In the second round the standards have changed and are now MJTC’s obtained from PTB, but mounted in a cylindrical housing. These have been used directly as voltage and current standards. An evaluation of the standards was undertaken after the first round, because there seemed to be some systematic deviations in the VSL standards. This was confirmed with the new MJTC’s. Hence, in the second round the values from the new standards are used (leading to incremental variations in the VSL results between round 1 and 2). At the end of 1991, a new evaluation had taken place for the MJTC, resulting in a change of less than 2 ppm. The newly developed 1 MHz HF ac/dc converters (with calculable ac–dc transfer) were used [7]. The basic measuring setup includes a fully automated transfer system, with built-in facilities to obtain settings for the compensation parameters.

The output signals were processed differently in each round. In the first round, a system was used in which converter output and difference output (using pre-amplification to a normal DMM) were obtained in sequence. In the second round, part of the measurements has been performed using a new setup with direct readout of two DMMs with sufficient resolution after amplification. The remainder of the measurements were performed using the older system. Altogether it has resulted in a more stable measuring facility.
Fig. 1. AC-DC difference for the 10-V standard as measured by each laboratory (vertical bars refer to stated total uncertainty). (a) 40 Hz. (b) 20 kHz. (c) 50 kHz. (d) 100 kHz. (e) 1 MHz.
Fig. 2. AC-DC difference and total uncertainty (vertical bar: $1\sigma$) for the 30-V standard as measured by each laboratory. (a) 40 Hz. (b) 20 kHz. (c) 50 kHz. (d) 100 kHz.

Fig. 3. AC-DC difference and total uncertainty (vertical bar: $1\sigma$) for the 100-V standard as measured by each laboratory. (a) 40 Hz. (b) 20 kHz. (c) 50 kHz. (d) 100 kHz.
Fig. 3. (Continued.)

Fig. 4. AC-DC difference and total uncertainty (vertical bar: 1σ) for the 300 V standard as measured by each laboratory: (a) 40 Hz. (b) 20 kHz. (c) 50 kHz. (d) 100 kHz.
Fig. 5. AC-DC difference and total uncertainty (vertical bar: 1σ) for the 1000-V standard as measured by each laboratory: (a) 40 Hz. (b) 20 kHz. (c) 50 kHz.

Fig. 6. AC-DC difference and total uncertainty (vertical bar: 1σ) for the 10-mA standard as measured by each laboratory. (a) 40 Hz. (b) 20 kHz. (c) 50 kHz. (d) 100 kHz.
VI. CONCLUSIONS

From the data obtained in this intercomparison it seems that ac–dc transfer measurements for voltage are in agreement to within some 10 ppm for the lower ranges (up to 100 V) and within the audio range (up to 20 kHz). The agreement degrades to some 50–100 ppm over the full amplitude range and up to 100 kHz. At 1 MHz larger discrepancies became evident. For current measurements the results are even more promising with agreement within 5–40 ppm.

The long time span has reduced the value of the intercomparison. A number of laboratories have already asked for a possible re-measurement, because they have improved their facilities significantly. Therefore, a new intercomparison is needed in this field. Although lessons should be taken from this comparison before starting a new round, limited comparisons running in parallel with
TABLE III
SUMMARY OF RESULTS COMPILLED OVER ALL PARTICIPANTS FOR EACH TRANSFER STANDARD

<table>
<thead>
<tr>
<th>Standard 10 V</th>
<th>Frequency (kHz)</th>
<th>Average (ppm)</th>
<th>Std. devn. (ppm)</th>
<th>Min. (ppm)</th>
<th>Max. (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.04</td>
<td>3.9</td>
<td>3.0</td>
<td>-1.5</td>
<td>9.0</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>-0.7</td>
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<td>-6</td>
<td>5.2</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>-2.8</td>
<td>5.0</td>
<td>-15.5</td>
<td>8.7</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>-4.6</td>
<td>8.9</td>
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<td>1000</td>
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<td>60.1</td>
<td>-498*</td>
<td>25</td>
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(*not included in calculation)

<table>
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<tr>
<th>Standard 30 V</th>
<th>Frequency (kHz)</th>
<th>Average (ppm)</th>
<th>Std. devn. (ppm)</th>
<th>Min. (ppm)</th>
<th>Max. (ppm)</th>
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<td>3.5</td>
<td>-2.7</td>
<td>10.2</td>
</tr>
<tr>
<td></td>
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<td>-11.4</td>
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</tr>
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<td>6.4</td>
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<td>4.0</td>
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<tr>
<td></td>
<td>100</td>
<td>-15.7</td>
<td>10.0</td>
<td>-34.1</td>
<td>8.7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Standard 100 V</th>
<th>Frequency (kHz)</th>
<th>Average (ppm)</th>
<th>Std. devn. (ppm)</th>
<th>Min. (ppm)</th>
<th>Max. (ppm)</th>
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<tbody>
<tr>
<td></td>
<td>0.04</td>
<td>4.7</td>
<td>3.6</td>
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<td>13.2</td>
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<td>-38.7</td>
<td>-10.3</td>
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<tr>
<td></td>
<td>100</td>
<td>-42.4</td>
<td>21.4</td>
<td>-73.5</td>
<td>-13.0</td>
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<table>
<thead>
<tr>
<th>Standard 300 V</th>
<th>Frequency (kHz)</th>
<th>Average (ppm)</th>
<th>Std. devn. (ppm)</th>
<th>Min. (ppm)</th>
<th>Max. (ppm)</th>
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</thead>
<tbody>
<tr>
<td></td>
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<td>3.6</td>
<td>3.9</td>
<td>-3.1</td>
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<td>-42.4</td>
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<table>
<thead>
<tr>
<th>Standard 1000 V</th>
<th>Frequency (kHz)</th>
<th>Average (ppm)</th>
<th>Std. devn. (ppm)</th>
<th>Min. (ppm)</th>
<th>Max. (ppm)</th>
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<tbody>
<tr>
<td></td>
<td>0.04</td>
<td>-0.5</td>
<td>7.2</td>
<td>-17.0</td>
<td>11.6</td>
</tr>
<tr>
<td></td>
<td>20</td>
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<td>50</td>
<td>-56.4</td>
<td>37.0</td>
<td>-126.3</td>
<td>-4.0</td>
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<table>
<thead>
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<th>Standard 10 mA</th>
<th>Frequency (kHz)</th>
<th>Average (ppm)</th>
<th>Std. devn. (ppm)</th>
<th>Min. (ppm)</th>
<th>Max. (ppm)</th>
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<tr>
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<td>3.0</td>
<td>-9.3</td>
<td>-0.4</td>
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<td></td>
<td>50</td>
<td>-6.5</td>
<td>5.5</td>
<td>-17.1</td>
<td>1.7</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>-9.1</td>
<td>7.1</td>
<td>-36.1</td>
<td>2.7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Standard 30 mA</th>
<th>Frequency (kHz)</th>
<th>Average (ppm)</th>
<th>Std. devn. (ppm)</th>
<th>Min. (ppm)</th>
<th>Max. (ppm)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>0.04</td>
<td>-9.3</td>
<td>5.1</td>
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<td>6.1</td>
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<tr>
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<td>6.1</td>
<td>-16.4</td>
<td>6.5</td>
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<td>13.5</td>
<td>22.0</td>
<td>-15.5</td>
<td>44.6</td>
</tr>
</tbody>
</table>

TABLE IV
SUMMARY OF TYPE A UNCERTAINTY RELATIVE TO TYPE B UNCERTAINTY FOR A NUMBER OF STANDARDS

<table>
<thead>
<tr>
<th>Voltage (V)</th>
<th>Frequency (kHz)</th>
<th>Type A Uncertainty (ppm)</th>
<th>Type B Uncertainty (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.04</td>
<td>≤0.1</td>
<td>≤0.1</td>
</tr>
<tr>
<td>20</td>
<td>≤0.1-0.7</td>
<td>≤0.1</td>
<td>≤0.1-0.3</td>
</tr>
<tr>
<td>100</td>
<td>0.1-1.0</td>
<td>≤0.1-0.5</td>
<td>≤0.1-0.2</td>
</tr>
<tr>
<td>Current</td>
<td>10 mA</td>
<td>0.1-1.0</td>
<td>0.1-0.5</td>
</tr>
</tbody>
</table>

some linkage (e.g., a laboratory participating in more than one comparison) might be a good alternative. Altogether, the intercomparison provides unprecedented information about the worldwide measuring capability of the national standards laboratories and the consistency of their results, thereby establishing the necessary basis for mutual recognition of calibration certificates.

ACKNOWLEDGMENT

The author would like to thank Dr. C. J. P. M. Harmans for organizing the first round of this comparison, J. J. Schmitt and J. T. Dessens for carrying out the measurements at VSL, and all participants for providing the details of their measurements.

REFERENCES


