

INTERCOMPARISON OF NIST, NPL, PTB, AND VSL
THERMAL VOLTAGE CONVERTERS FROM 100 KHZ TO 1 MHZ

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Abstract

Coaxial, thermal voltage converters (TVC's) have been hand-carried between NIST, NPL, PTB, and VSL for intercomparison of ac-dc difference from 100 kHz to 1 MHz. This paper briefly describes the methods and underlying principles on which ac-dc difference determinations are based in each laboratory and gives the results of the intercomparisons.

Introduction

Thermal voltage converters form the primary and working standards at the four participating laboratories for ac-dc difference, and hence ac voltage, in the 100 kHz to 1 MHz frequency range. An intercomparison of the ac-dc differences of TVCs in this range is particularly informative because the methods and hardware used by the four laboratories differ significantly. The agreement between methods adds considerable additional confidence to the process. NIST acted as the pilot laboratory for this intercomparison.

Methods of Individual Laboratories

National Institute of Standards and Technology (NIST). A group of multijunction thermal converters (MJTC's) has been established as the NIST primary standards for ac-dc difference. For these MJTC's constructed with bifilar heaters, thermoelectric and other errors have been shown theoretically and experimentally to be below the 0.5 ppm level in the range 30 Hz to 10 kHz from 2 V to 10 V [1]. The fact that these MJTC's were the result of various fabrication techniques over some period of years, improves the confidence in this group.

The extension of the frequency range from 10 kHz up to 1 MHz was achieved using two techniques employing several TVC's containing cylindrical, deposited-carbon resistors mounted coaxially with 5 or 10 mA thermoelements [2]. Firstly, 5- to 25-V TVC's were made with geometries and electrical characteristics expected to have nearly zero residual reactance and to be nearly frequency independent up to 1 MHz. Intercomparisons of nearly identical structures with different range resistors demonstrated frequency flatness of ± 5 ppm out to 100 kHz and of ± 10 ppm out to 1 MHz.

Secondly, the major ac-dc difference contributions from each structural element or region of TVC's similar to those described above were theoretically and experimentally analyzed up to 100 MHz. These contributions were: voltage standing-wave in the input connector, transimpedance of the series resistor, current standing-wave in the thermoelement, and skin effect. Examination of both range dependent and range independent contributions confirmed ac-dc differences at 1 MHz to be < 10 ppm. The methods of intercomparison are described in [2].

National Physical Laboratory (NPL). The foundation of all ac-dc transfer measurements at NPL is a collection of MJTC's [3] obtained from a variety of sources. Single-junction thermal converters (SJTC's) are selected and calibrated in the current mode by comparison with an appropriate MJTC in the mid-frequency range where the errors in MJTC's are known to be small. The errors introduced by extrapolating the response of the SJTC up to 1 MHz are estimated and form a major contribution to the uncertainty of the measurements. Calculations of the parasitic inductive and capacitive properties of 1 k Ω metal film resistors mounted in relatively large cylindrical enclosures show that these effects produce negligible errors, even at 1 MHz. Various versions of suitable structures have been described, e.g. [4], and are widely used for transfer measurements. The combination of such a resistor with a 5 mA or 10 mA SJTC provides a transfer standard rated at 5 or 10 V.

Comparison of standard and test items is carried out using a highly automated digital system which models the operation of an analog bridge [5]. The two signal outputs are amplified and digitized by high resolution DMM's. Sequences of 13 measurements are collected with the signal being switched between ac and dc sources in accordance with a specific pattern. Arithmetical manipulation of the data allows the results to be largely independent of drifts in the devices and supplies.

Physikalisch-Technische Bundesanstalt (PTB). At the PTB multijunction thermal converters have been developed as basic standards for ac-dc voltage transfer over the entire frequency range from 10 Hz to 1 MHz [6,7]. Transfer differences caused by thermoelectric effects, which are present to some degree in nearly all thermal converters, as well as frequency-dependent transfer differences in the audio-frequency range, are negligible in the PTB MJTC. At higher frequencies the frequency-dependent change of the input impedance of the heater circuit is responsible for ac-dc differences.

The bifilar heater, the intermediate leads, and the coaxial connector up to the reference plane of the tee connector have been taken into consideration. The heater resistance with its residual inductance, capacitance, and dielectric losses; the intermediate leads with residual impedance, skin effect, and proximity effect; and the connector circuit with resistance, skin effect, and dielectric losses have been measured or estimated as far as possible, and the transfer differences calculated for different heater resistances. As an experimental check, the differences among the various MJTC's have been measured. Quite good agreement between calculated and measured differences was obtained which gives considerable confidence to the correctness of the method.

For frequencies up to 100 kHz, a 190- Ω MJTC (2.3 V) has been chosen as a reference standard. For this resistance, the effect of residual capacitances and dielectric losses

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are just compensated by inductance, skin and proximity effects within the MJTC. Only the connector contribution is left, and it has been measured using a MJTC as a reference placed directly at the pins without a connector.

As the skin effect increases with frequency squared, such a MJTC has a transfer difference of 92 ppm at 1 MHz. Therefore a MJTC with higher heater resistance is preferable, and a 700- Ω MJTC (5.6 V) is taken as a reference standard. For higher voltages, series resistors and 190- Ω MJTC's are combined and characterized in a step-up procedure.

Van Swinden Laboratory (VSL). In the VSL the ac-dc difference standards between 100 kHz and 1 MHz have been developed on the basis of calculable HF ac-dc standards which are useful up to 30 MHz [8]. Recently a new set of standards was constructed with smaller ac-dc differences above 1 MHz [9].

Up to 100 kHz a set of multijunction thermal converters of PTB design and mounted in VSL-built housings are used as references [6]. These converters are considered to be nearly independent of frequency up to 100 kHz. The calculable converters and the PTB MJTC's have been compared to confirm the validity of a number of assumptions in the calculation for low frequencies. Within the combined uncertainties, both types of converters give the same results up to 100 kHz.

As standards for this intercomparison, one MJTC, two old style HF TVC's, and one new HF TVC were used. All of the standards were provided with type-N male connectors and the plane of reference for all the VSL measurements was the symmetry plane of a type-N tee connector. The measurement system was an updated version of the VSL system described in [10]. In the updated system the individual thermal converter outputs are amplified by a factor of 100 and then the difference is amplified again by 500. The overall VSL uncertainty is estimated on the basis of the above mentioned analyses and internal comparisons of 2- to 4-V TVC's in the range 100 kHz to 1 MHz.

Transfer Standards and Results

The transfer standards used in this intercomparison were TVC's of three basic types. The first type consisted of commercially manufactured, coaxial, 5- & 10-V TVC's containing UHF-pattern thermoelements, internal shield structures, and conventional series resistors. The partial results given in Fig. 1 for 200 kHz, 500 kHz, and 1 MHz are for these commercial TVC's. The second transfer standard was a VSL constructed coaxial, 5-V TVC containing a thin, straight wire for the series resistor. The third type was a PTB constructed MJTC with a 700- Ω , bifilar heater. The commercial TVC's and the PTB MJTC were mounted with type-874 connectors. The VSL TVC had a type-N connector. The 100 kHz results include values for all three types of TVC's. All measurements were referenced to the center of a type-874 tee structure.

The results from each laboratory were averaged to produce a representative value for that laboratory at each frequency. The representative values, or deviations, for all laboratories at each frequency were averaged, and these values are plotted in Fig. 1 as relative to the overall average which is indicated by zero ac-dc difference.

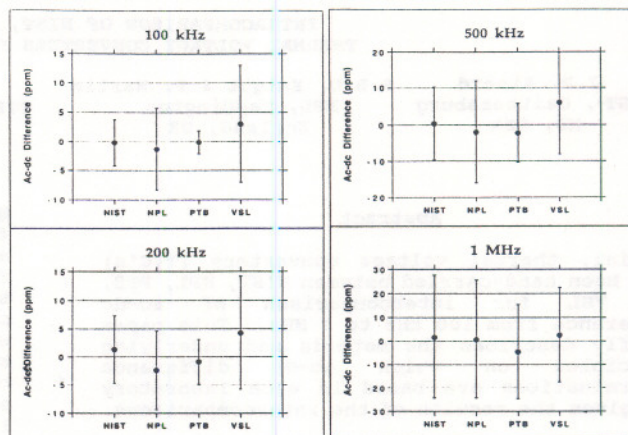


Fig. 1. Partial results of intercomparison with the overall average indicated as zero ac-dc difference, see Results Section for details. Where given, error bars represent $\pm 2\sigma$.

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