RECENT IMPROVEMENTS AND REVISED UNCERTAINTIES IN THE NIST AC-DC DIFFERENCE CALIBRATION SERVICE FOR THERMAL TRANSFER STANDARDS*

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Abstract - This paper describes recent developments in the ac-dc difference calibration service for thermal transfer standards at the National Institute of Standards and Technology. Related developments include the revision of calibration uncertainties, with substantial reductions at many points, and an expansion of the calibration parameter space for thermal current converters and shunts. New research programs include a prototype thermal transfer standard using a superconducting temperature sensor.

1. Revised Uncertainties

This NIST calibration service covers ac-dc thermal transfer instruments at voltages from 200 mV to 1000 V, and at currents from 1 mA to 20 A, for frequencies from 5 Hz to 1 MHz. The overall uncertainties for this service have been extensively documented in the past,[1,2,3,4] however newly revised uncertainties are being established following "Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results."[5] Some of the new uncertainties have been published elsewhere.[6,7]

The characterizations of thermal transfer standards over the entire NIST parameter space are based on:

- a group of primary standards composed of multijunction thermal converters
- a high frequency extension procedure based on carefully made coaxial converters
- a low frequency extension procedure based on thermoelement modules operated at low heater temperatures
- range-to-range build-up and build-down bootstrap measurements.

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The NIST primary standards for ac-dc difference are a group of multijunction thermal converters of different designs and from different manufacturers.[3] Theoretical analysis and measurement results indicate that the ac-dc difference of these devices are very close to zero as both voltage and current converters at frequencies from a few tens of hertz to about 10 kHz. The uncertainties associated with the primary standards have been evaluated by Hermach.[2] From that analysis, the uncertainty assigned to the group of primary standards from 2 V to 10 V at 1 kHz is 0.53 µV/V for k=2.

To extend the upper frequency range, special thermal voltage converters (TVCs) with ac-dc differences nearly independent of frequency from 10 kHz to 1 MHz are characterized in terms of the primary standards at 1 kHz. The nearly flat frequency response of the special converters is used to determine the ac-dc difference of the reference and working standards up to 1 MHz. To extend the lower frequency range, selected thermoelements are assembled in cluster modules and operated at low heater temperatures in order to minimize low frequency error due to failure to thermally average the signal.[6] The reference and working sets of TVCs are constructed to have ac-dc differences nearly independent of voltage level and are characterized over the whole voltage calibration range by range-to-range build-up and build-down comparisons. A diagram of the overall process is shown in Fig. 1.

The uncertainty analysis for the NIST standards includes contributions combined by the square root of the sum-of-the-squares (RSS) method from:

- the determination of the response characteristic of the standard TVC,
- errors in the circuitry which compensates for the response characteristic,
- dc reversal error,
- ac effects in the comparator, including electromagnetic pickup and interference in the system and detector leads,
- Noise, linearity, and accuracy in the digital nanovoltmeters used as detectors,
- Stability of the signal sources,
- Voltage level dependence,
- Self-heating effects, and
- Bead error and the effect from stray capacitances.

For the calibration of customers' TVCs, additional uncertainty elements, depending on the type of converter structure, are combined by RSS with the values for the NIST standards. An example of one of the more significant improvements in the calibration uncertainties is given in Fig. 2. Not all uncertainties will improve as much as this example, but all values will be reduced somewhat.

2. Expansion of Parameter Space

Due to requests from calibration clients, work is underway to extend the calibration of transfer shunts up to 100 A and down to 100 µA. The present parameter space covers from 20 A down to 1 mA for frequencies up to 100 kHz. A preliminary study has been made of the relative performance of three types of transfer shunts up to nearly 100 A. Comparisons have also been made between the frequency coefficient of a two-stage current transformer and the transfer shunts. The results show similar agreement at the various current levels. Special test calibrations of transfer shunts will be offered at the following currents and maximum frequencies:

Current	30 A	50 A	80 A	100 A
Max. Frequency	30 kHz	30 kHz	20 kHz	10 kHz

Work is also underway to provide calibrations at 100 μA. Preliminary tests have been made on the step-down to 100 μA from 1 mA using several different shunts and voltage monitoring configurations. High resistance shunts for such low currents present special problems due to their sensitivity to stray capacitance and electromagnetic pick-up.

3. New Cryogenic Transfer Standard

The ultimate uncertainty for thermal converters is usually limited by thermal and thermoelectric effects in the heaters. Heater powers as high as a few tens of milliwatts and temperature gradients of as much as 100 K are common in some thermal converters. The resulting large temperature rises create significant temperature gradients along the heater, leading to Peltier and Thomson errors and contributing to the ac-dc difference of the device. To reduce these effects, a novel resistive superconducting, transition-edge sensor is being developed to operate with very small temperature gradients and at cryogenic temperatures where these errors are expected to be negligible.[8] This converter may also be capable of direct thermal transfer measurements at extremely low signal levels.

The new cryogenic transfer standard is based on a silicon chip containing a signal heater, trim heater, and temperature sensor all mounted on a temperature-stabilized platform. The temperature of the assembly is held constant by applying a feedback signal to the trim heater. The thermometer is a 5 Ω (normal state resistance) Nb thin-film meander line operated within its transition region of (9.187 ± 0.005) K to (9.193 ± 0.005) K. The heaters are PdAu thin-film meander lines adjacent to the detector on the silicon substrate. The resulting thermometer has a sensitivity of 1800 Ω/K at its operating temperature.

The experimental platform supporting the superconducting sensors is mounted in a cryostat cooled to 4 K by liquid He. A commercial room temperature ac resistance bridge is used to monitor the resistance of the superconducting transition edge sensor. The imbalance signal from the resistance bridge is fed to a proportional-integral-derivative controller. This controller regulates the power fed back to the trim heater to hold the sensor at a fixed temperature. Variations in the applied input signals are observed as changes in the trim heater feedback power. Preliminary ac-dc difference measurements have been made using the cryogenic device at the unusually low signal power level of 10 μW. The performance of the prototype sensor was limited by noise in the room temperature electronics and the servo systems. An improved sensor optimized for ac-dc difference measurements is under development.

4. Conclusion

The revisions of the uncertainties and expansions of the parameter space for ac-dc difference which are presently in progress will result in an improved NIST calibration service. Complete documentation of these improvements will appear in a NIST Technical Note and in the NIST Journal of Research.

References

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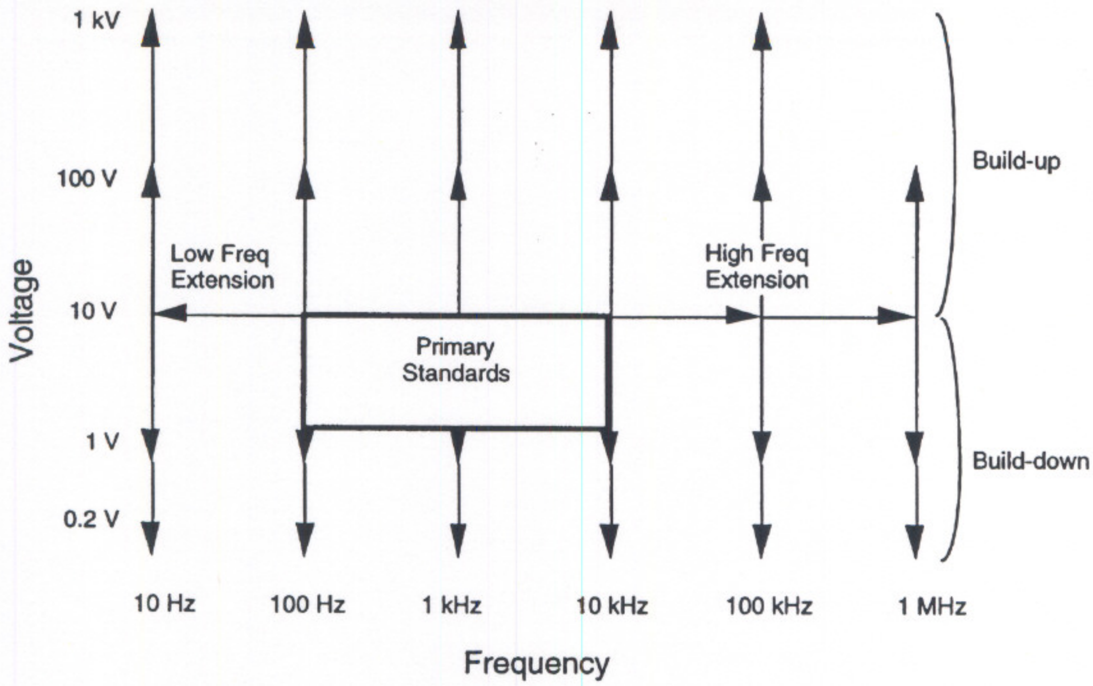

Fig. 1. Diagram of the primary standards, high and low frequency extension paths and build-up and build-down paths used to characterize standards over entire parameter space.

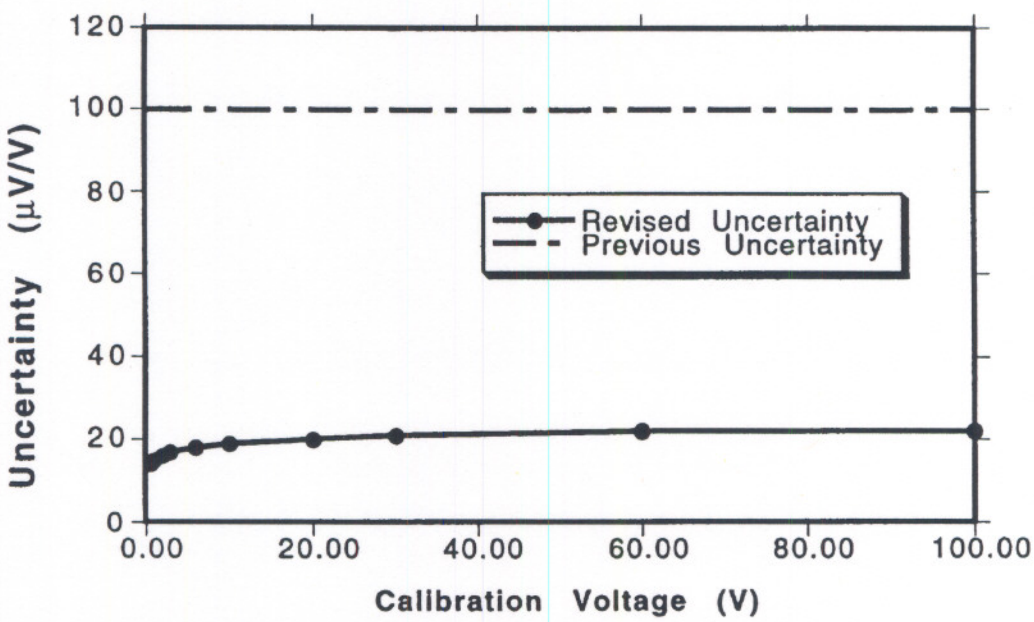

Fig. 2. Comparison of previous and revised uncertainties at 10 Hz.