IMPROVEMENTS IN THE NIST CALIBRATION SERVICE FOR THERMAL TRANSFER STANDARDS

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Abstract: We report on multiple improvements made in the calibration services offered for thermal converters and thermal transfer standards in the ac-dc Difference Standards and Measurement Techniques Project at NIST during the past year. The major improvement in this calibration is the increased efficiency made possible by the consolidation of three disparate calibration services – low voltage thermal transfer standards, low-frequency thermal converters, and RF-dc difference calibrations – into a single service. This consolidation has the immediate benefit of offering NIST calibration customers one source for ac-dc calibrations from 2 mV to 1000 V and from 10 Hz to 1 GHz. Additional benefits include lower calibration prices and reduced uncertainties at many points.

1. Introduction

For historical reasons, the calibration service for thermal converters and thermal transfer standards, including the calibration of current shunts used as thermal transfer standards, has been divided into three separate areas. First, the calibration of thermal voltage converters [TVCs] at voltages from about 250 mV to 1000 V at frequencies from 10 Hz to 1 MHz has been performed in the Fundamental Electrical Measurements (FEM) Group of the Quantum Electrical Metrology Division. Second, voltages below 250 mV at these frequencies were measured in the Applied Electrical Measurements (AEM) Group. Finally, calibrations at frequencies greater than 1 MHz were performed by the Radio Frequency Electronics Group in the Electromagnetics Division in Boulder, CO. In addition to the separation of tasks, some overlap occurred in the frequency range between 30 kHz and 1 MHz with calibrations offered at these frequencies at both the Gaithersburg and Boulder laboratories for both TVCs and micro-potentiometers, but with different uncertainties assigned to the calibrations performed at each site.

As might be expected, the inefficiencies caused by the division of tasks in the calibration services led to significant customer confusion, higher prices, and unnecessarily large uncertainties.

In an effort to increase the efficiency of the ac-dc difference calibration services, all calibrations of thermal converters and thermal transfer standards have been consolidated in the ac-dc Difference Standards and Measurement Techniques Project in the FEM Group in Gaithersburg, MD. Combining all ac-dc difference measurements (including RF-dc calibrations) into one project will result in improved customer service, lower prices due to increased efficiency, and reduced uncertainties due to technical improvements. Each part of the ac-dc Difference Calibration Service will be addressed in this paper.

2. Low-Frequency Calibration Service

The calibration service for thermal converters and current shunts in the frequency range from 10 Hz to 1 MHz has relied for many years upon traditional multijunction thermal converters (MJTCs) as primary standards [1]. These converters have input levels of 2 V to 10 V at frequencies from about 40 Hz to 10 kHz. A collection of these thermal converters constitutes the NIST primary standards for both voltage and current calibrations, and values for other NIST ac-dc standards are measured in terms of voltage build-up and build-down techniques. Although these converters are extremely good, their best performance is over a limited range of voltages

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and frequencies, making them difficult to use as everyday working standards. MJTCs, fabricated as part of a collaboration between NIST and Sandia National Laboratories, using thin-film fabrication technology have been shown to have performance equivalent to the traditional wire-based MJTCs over an expanded voltage and frequency parameter space [2]. These MJTCs have the potential to bring primary-standards performance to working standards.

We are improving the calibration service in the 10 Hz to 1 MHz frequency range by incorporating a set of these devices into our collection of working standards and using them for routine calibrations. Although nominally rated at 2 V, these devices, which are mounted in vacuum to improve their efficiencies, may be used with little loss in performance down to about 150 mV. In addition, their ˙ differences have been shown to be relatively independent of frequency from 10 Hz to 100 kHz, and their performance up to 1 MHz is quite good. Used with high-quality range resistors from our coaxial thermal converter sets, these MJTCs are proving to be excellent working standards, offering near-primary standard performance in everyday standards. This performance over the entire frequency regime will enable us to reduce our uncertainties, particularly at the extremes of frequency. In addition, the dynamic range of these devices will permit reductions in uncertainty down to 150 mV, because we will no longer need to rely on extensive voltage scaling (and accompanying increased uncertainty) to determine corrections at these low voltages. A photograph of a MJTC voltage converter is shown in Figure 1, and representative data in Figure 2.

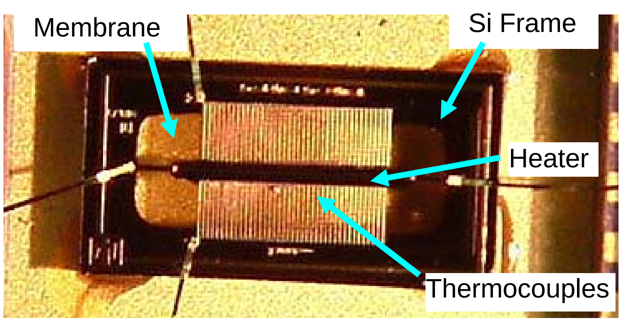

Figure 1. Photograph of thin-film MJTC voltage converter.

In addition to incorporating MJTCs into our working standards for voltage calibration, we are developing MJTCs for use as current converters for currents up to 10 A [3]. Although these devices are presently in the prototype stage, initial measurements on a 1 A device indicate that these MJTCs have exceptionally good performance at frequencies from 10 Hz to 100 kHz. We anticipate integrating these devices in parallel into modules capable of measuring currents of 10 A, and using them as working standards for ac current measurement, in the same manner as the voltage MJTCs we presently use as working standards. As with the voltage MJTCs, using MJTCs as current converters will allow us to reduce our uncertainties, particularly at the extremes of frequency. A photograph of a 1 A MJTC is shown in Figure 3 and its performance in Figure 4.

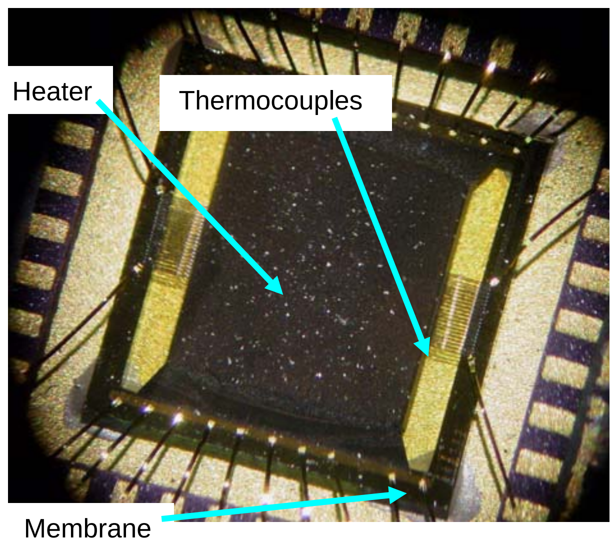

Figure 3. Photograph of 1 A thin-film MJTC current converter

3. Low-Voltage Calibration Service

Calibrations of thermal transfer standards below 250 mV from 10 Hz to 1 MHz have traditionally been performed by the AEM Group at NIST. To increase the efficiency of the calibration service for these instruments, these calibrations have been incorporated into the ac-dc Difference Standards and Measurement Techniques Project. Inclusion of these calibrations into the FEM Group will allow us to provide complete calibration of thermal transfer standards over the complete voltage range from 2 mV to 1000 V.

Although we will initially rely on low-voltage scaling performed in the AEM Group to provide characterization of thermal transfer working standards at voltages below 150 mV, we will soon reference our working standards to an intrinsic ac Josephson Voltage Standard under development in the Quantum Devices Group of the Quantum Electrical Metrology Division [4]. Recent test calibrations of a thermal transfer standard from 100 mV down to 2 mV using a prototype system demonstrated the efficacy of the system and measurement technique. Although much work remains to be done before this Josephson-based system is ready for incorporation into the calibration service, especially at frequencies above the audio region, we are confident that this system will provide a quantum reference for voltage calibrations at extremely low voltages. Coupled should be able to measure thermal transfer standards at voltages from 2 V down to 2 mV with unprecedented accuracy. The prototype system presently used at NIST in Boulder for research is being replicated at NIST in Gaithersburg, and we expect to begin using it later in the year. Preliminary measurements using the prototype system are shown in Figure 5

A block diagram of the system is shown in Figure 6. The chip itself consists of two independently biased arrays of 2560 junction each. The junctions are biased using a 15 GHz microwave signal and a 4 Mb digital pattern at 10 Gb/s. Waveforms are constructed by selecting the amplitude and harmonic phase on the 2.5 kHz pattern repetition frequency. The system produces audio frequency waveforms using a high-speed delta-sigma conversion technique [5].

4. RF-dc Difference Calibration Service

The calibration service for thermal converters at frequencies above 1 MHz was recently moved from NIST in Boulder to NIST in Gaithersburg. This service covers the measurement of thermal voltage converters, peak-to-peak detectors, thermistor mounts, and RF micropotentiometers.

At frequencies up to 100 MHz, the NIST standard thermal converters consist of thermoelements in series with appropriate range resistors; however, to provide reproducible voltage measurements at

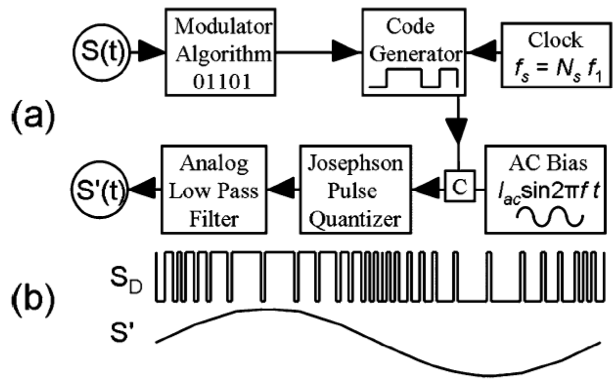

Figure 6. (a) Block diagram of a delta–sigma DAC based on bipolar pulsed Josephson junctions. S(t) is the desired waveform and S'(t) is the synthesized output waveform. (b) S_D represents a coarse bipolar bitstream signal applied in parallel with the microwave ac bias.

frequencies greater than 100 MHz, the standard TVCs have built-in Type N tee structures. The characterization of these converters is done so that the plane of reference for the measurements is at the output terminal, as shown in Figure 7 [6]

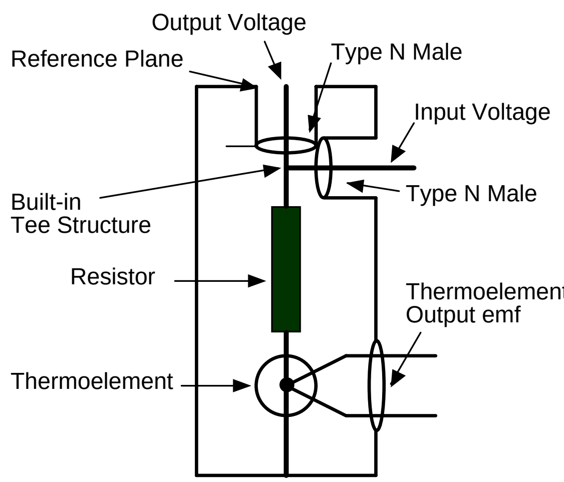

Figure 7. Diagram of high-frequency thermal converter with built in tee structure.

To characterize TVCs at frequencies above 1 MHz, a TVC is first compared to a NIST low-frequency standard at 1 MHz. It is then compared at 50 MHz and 100 MHz to a standard thermistor mount whose power response and input impedance characteristics have been determined. The ac-dc differences of the TVC at intervening frequencies are then modeled using a second-order polynomial fit with a linear term; these modeled points are then checked by direct comparison of standards. At frequencies greater than 100 MHz, the TVC is compared directly to a thermistor mount (in series with an attenuator, if necessary), and the RF voltage at the reference plane calculated n terms of the electrical parameters of the thermistor mount.

Since the RF-dc calibration service now resides in the same project as the low-frequency TVC calibrations, the interface between the two services at 1 MHz becomes much less of a problem for characterizing TVCs at high frequency, and the calibration services no longer overlap between 30 kHz and 1 MHz. This continuity of frequency ranges is expected to result in lower uncertainties at frequencies above 1 MHz, and the increased efficiency of the combined calibration service has already allowed us to reduce prices at these frequencies.

At the present time the service as established in Gaithersburg has performed TVC calibrations up to 100 MHz, but we are preparing to offer TVC calibrations to 1 GHz, consistent with the previously-established service. We are proposing to measure peak-to-peak detectors using the NIST Sampling Waveform Analyzer [7], and will begin peak-to-peak detector calibrations shortly. At this time there are no plans to actively measure RF micropotentiometers; however, we still have the necessary standards to perform these calibrations. The documentation for the entire RF-dc calibration service is not presently in compliance with NIST guidelines and we are actively working to update and publish the existing documentation.

5. Further Information

Further information about the ac-dc Difference Standards and Techniques Project, including updates on our calibration services, research, and documentation, can be found on our web site: http://www.acdc.nist.gov. Information about the calibration services, including uncertainties and fees, may be found on the NIST Technology Services Calibration Services home page: http://ts.nist.gov/ts/htdocs/230/233/calibrations/.

6. Conclusions

We have consolidated three disparate measurement services into the NIST ac-dc Difference Project. Consolidating these calibration services will at once improve our customer service by providing one point of contact for all ac-dc measurement services, reducing the number of NIST test numbers from twelve to four, and result in reduced uncertainties and lower costs for calibrations. Technically, combining the calibration services will hasten the introduction of a quantum standard for ac voltage measurements, and the development of MJTCs with improved performance at frequencies up to 100 MHz.

References

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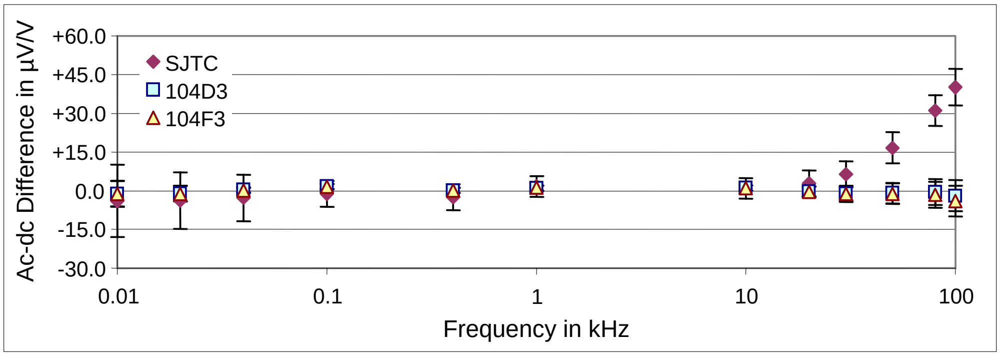

Figure 2. Performance of thin-film MJTC voltage converters relative to a single junction thermal converter. The uncertainty bars represent the expanded uncertainties for the measurement.

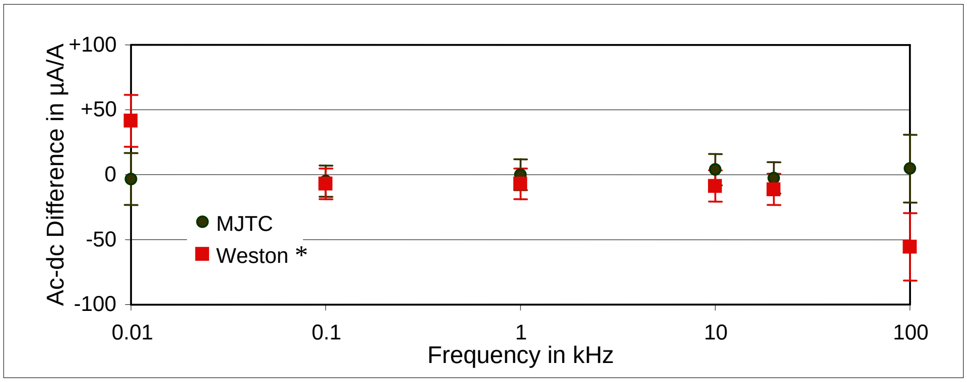

Figure 4. Comparison of the performance of the new 1 A MJTC and a traditional Weston current converter.

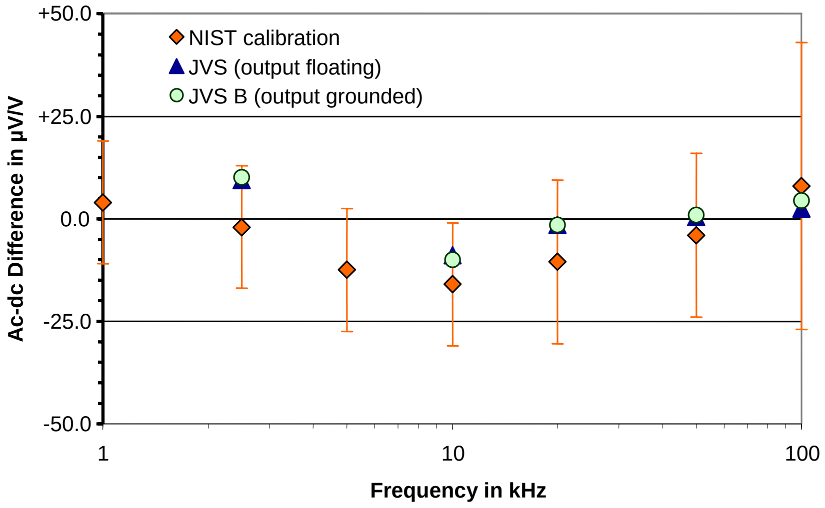

Figure 5. Preliminary results comparing the agreement between measurements made on a thermal transfer standard at 100 mV using the ac JVS and the NIST calibration of the transfer standard.

*The use of commercial names does not imply endorsement or recommendation.