Improvements in the NIST Ac-dc Difference Calibration Service for Low-Voltage Thermal Transfer Standards

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Abstract

We report the preliminary results of a project to improve the NIST calibration service for low-voltage thermal transfer standards. Central to this project is the direct comparison of the low-voltage ranges of a thermal transfer standard to an intrinsic ac standard. The combination of a new intrinsic standard for ac waveforms, a scaling procedure using multijunction thermal converters (MJTCs), and the relocation of the calibration service to the Fundamental Electrical Measurements Group will result in a significant improvement in both the uncertainties and turnaround times for thermal transfer standard calibrations at low voltages.

1. Introduction

The primary standards for ac-dc difference metrology at NIST are a set of wire MJTCs, all of which have input voltage levels of about 2 V to 10 V [1]. To determine the values of the NIST reference standards at lower voltages, a step-down process is used, wherein a lower voltage range is measured at full scale against a higher voltage range used at somewhat less than full scale. To scale from the 2 V primary standard to the 100 mV standard requires three scaling steps, a transfer at 250 mV to the reference thermal voltage converter (TVC) used by the Applied Measurements Group, and then one more step to realize 100 mV [2]. As the ac-dc difference is generally dependent on input voltage level, particularly at very low frequencies and at frequencies above about 20 kHz, the uncertainty of each step in the scaling process must reflect this level dependence, as well as the uncertainties associated with the measurement process itself. The resulting uncertainties grow quite rapidly so that at 100 mV, the standard NIST uncertainty is 15 μV/V at 1 kHz and 150 μV/V at 1 MHz, both about a factor of five greater than the uncertainties at 2 V. As may be expected, the situation is much worse at lower voltages. These uncertainties no longer meet the requirements of several traditional NIST calibration customers.

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In addition to the performance issues described above, thermal voltage converters have historically been calibrated by two separate groups at NIST, depending on the input voltage level requested by the customer. The Fundamental Electrical Measurements (FEM) Group has been responsible for calibrating TVCs over the voltage range from 250 mV to 1000 V, while the Applied Electrical Measurements (AEM) Group is responsible for TVC calibrations at input voltages from 1 mV to 250 mV. Most TVCs are intended for use in only one of these voltage regimes, so this has rarely been a problem for customers of the NIST TVC calibration services. However, with the introduction of high-performance, multirange thermal transfer standards that are capable of being measured over the entire range of voltages, this splitting of responsibility has affected the overall quality of the NIST TVC calibration service.

To respond to the requirements of calibration customers for better performance at low voltages, we are working to introduce a prototype intrinsic standard into the calibration service, initially as a check on our scaling techniques, and subsequently to establish an intrinsic standard at the millivolt level. We are also evaluating thin-film MJTCs as single standards over the range from 2 V to 150 mV. To improve our customer service, the Fundamental Electrical Measurements Group is assuming all responsibility for calibrating multirange thermal transfer standards. These actions will lead to an improved service for customers of the NIST TVC calibration program.

2. Intrinsic Standard for Ac Metrology

Work has been underway for several years to develop an intrinsic standard for ac voltage [3]. This ac Josephson Voltage Standard (ACJVS) is presently capable of producing both ac and dc voltages up to about 170 mV_{rms}. The most recent ACJVS chip design has been optimized for operation at 100 mV_{rms} and utilizes two Josephson arrays of 2180 junctions each. This device has recently been used to measure a thermal transfer standard at 100 mV_{rms} using both arrays, and also at 50 mV using each array separately. Preliminary results of these measurements are shown in Table 1. A more complete description of the ACJVS system and measurements of operating margins and ac-dc differences are presently separately in [4]. Although the uncertainty analysis has not yet been completed for the ACJVS, it is anticipated that the uncertainties of this intrinsic standard will be significantly smaller than those calculated using the traditional step-down process. This measurement represents the first time an intrinsic ac voltage standard has been used as an integral part of a calibration service for ac voltage at any National Metrology Institute. Despite the fact that the ACJVS is only in its prototype stage, we consider these results as extremely promising, and believe that this system will make a major contribution to the low-voltage TVC calibration service at NIST in the near future.

Table 1. Agreement between the ac-dc difference of a NIST thermal transfer standard measured by the ACJVS and measured using traditional ac-dc difference techniques in μV/V. The uncertainties represent the $k = 2$ uncertainties of the thermal transfer standard.

Frequency (kHz)	Both Arrays	Left Array	Right Array
1.25	+3.0 ± 15	+4.0 ± 15	+4.0 ± 15
2.5	-0.5 ± 15	-0.5 ± 15	-1.5 ± 15
5	+1.3 ± 15	-1.5 ± 15	+1.5 ± 15

In addition to the long-term plan to use the ACJVS to provide a quantum-based voltage reference, we are also using thin-film MJTCs to calibrate thermal transfer standards on their low-voltage ranges [5]. These MJTCs are designed to have full-scale input voltages of 2 V; however, due to their extremely high efficiency they are usable for calibration purposes down to 150 mV. These devices have been shown to exhibit negligible variations in ac-dc difference with changes in input voltage over the audio frequency range, making it possible to use the same MJTC from 2 V down to 150 mV, and skipping the intervening steps. This procedure will greatly improve the uncertainties at 150 mV, as we can eliminate the stepwise addition of uncertainties for our standards.

3. Calibration Service for Multirange Thermal Transfer Standards

In order to assume responsibility for the calibration of multirange thermal transfer standards at voltages less than 250 mV, we must first demonstrate that the Ac-dc Difference Standards and Techniques Project has the ability to match the performance of the Applied Electrical Measurements Group. In fact, the reference standard for these calibrations is a 250 mV TVC that the FEM group calibrates for the AEM Group. This reference value is then propagated to lower voltages by traditional scaling techniques, using both multirange thermal transfer standards and micropotentiometers.

The first step in establishing the calibration service for low voltages in the FEM Group was to have a reference thermal transfer standard calibrated by the AEM Group and then to calibrate the same standard using the systems and standards in the FEM Group. In addition, a recent international intercomparison at 10 mV and 100 mV has been used to form a measurement triangle between three thermal transfer standards. One of the thermal transfer standards in this triangle has also been used to test the ACJVS, as described above.

Preliminary data for the intercomparison between a thermal transfer standard calibrated by the AEM Group and the FEM Group is shown in Table 2.

Table 2. Comparison of measurements on a thermal transfer standard performed by the FEM Group and the AEM Group. The uncertainties shown are the uncertainties of the two calibration services combined using $U_c = \frac{1}{\sqrt{2}}\left(U_{FEM}^2 + U_{AEM}^2\right)^{1/2}$ and are $k = 2$.

Voltage Range	Applied Voltage	Ac-dc Difference (µV/V)							
mV	mV	1 kHz		20 kHz		100 kHz		1 MHz	
Group:		FEM	AEM	FEM	AEM	FEM	AEM	FEM	AEM
22	10	+23	+25	+11	+21	+3	-7	-98	-153
Uncertainty (µV/V):		44		45		54		146	
220	100	+5	+4	+1	+2	+32	+33	+188	+194
Uncertainty (µV/V):		12		14		23		68	

From Table 2, it is clear that the two measurement processes agree exceptionally well with 100 mV applied to the 220 mV range of the thermal transfer standard. With 10 mV applied to the 22 mV range, the agreement is well within the combined uncertainties of the measurement processes up to 100 kHz. Although the agreement is somewhat poorer at 1 MHz, it is still within the combined uncertainties of the measurements. The very good agreement between the groups adds confidence in the ability of the FEM Group to take the responsibility for these measurements.

As a further check on the agreement of the calibration process, the FEM Group measured a thermal transfer standard that was part of an international intercomparison at 100 mV on its 220 mV range. Using two NIST thermal transfer standards to measure the traveling standard, and then measuring the NIST standards against each other allows us to form a measurement triangle (Figure 1) where the sum of the ac-dc differences around the triangle would measure zero if the instruments and measurement processes were perfect. The failure of the triangle to close at 100 mV is shown in Table 3. Again, the excellent closure suggests that the measurement processes of the FEM Group is in excellent control, and adds additional confidence for FEM calibration service.

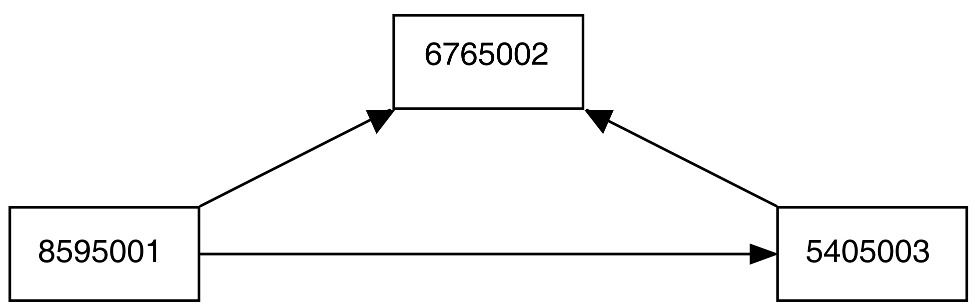

Figure 1. Triangle used to determine consistency of measurement system in the FEM Group. The numbers represent the serial numbers of the thermal transfer standards.

Table 3. Closure of the measurement triangle between three thermal transfer standards. Uncertainties are $k = 2$.

Voltage Range	Applied Voltage	Failure of the triangle to close (μV/V)			
mV	mV	1 kHz	20 kHz	100 kHz	1 MHz
220	100	+3 ± 12	+1 ± 14	+3 ± 23	-1 ± 68

4. Conclusions

Work is underway in the Quantum Electrical Metrology Division at NIST to address our customers' requirements for improvements in the low-voltage calibration service for thermal transfer standards. These requirements demand improvements in both the technical aspect of the calibration service, and in the structure of the service. To address the technical requirements for greater accuracy, we are working to integrate a prototype intrinsic ac standard, based on Josephson Junction arrays, into the routine calibration service, and to use MJTCs as working standards over the voltage range from 2 V to 150 mV. We are also working to improve customer service by moving the responsibility for the calibration service from the Applied Electrical Measurements Group to the Fundamental Electrical Measurements Group. Preliminary results using the ACJVS to measure a thermal transfer standard indicates that this intrinsic standard shows great promise for increasing the accuracy of ac-dc difference calibrations in the millivolt range. The excellent agreement between thermal transfer standard calibrations conducted in the AEM Group and FEM Group indicates that the responsibility for this calibration service can be placed in the FEM Group. Both of these efforts will make the calibration service a much more efficient service while strengthening it's world-class technical activities.

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6. References

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