

Comparison of Two Josephson Array Voltage Standard Systems Using a Set of Zener References

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Abstract

Two Josephson Array Voltage Standard Systems using different calibration algorithms are operated at the National Institute of Standards and Technology (NIST). A manual switch system is designed to make system comparisons by measuring against the 1.018 V of three Zener references. The difference of the average of the three Zener references is smaller than 1 nV.

Introduction

Josephson junction arrays have been widely used as DC voltage standards based on a relationship between voltage and frequency established by quantum physics. Although the Josephson junction provides the most accurate voltage standard available, various systematic errors could arise when a voltage standard system using a Josephson junction array along with other instruments are integrated together to provide a calibration tool for other voltage standards, such as Zener references. The common error sources are from thermal voltages within a calibration loop, leakage between array voltage leads or from these leads to ground, etc. Two Josephson voltage systems used at NIST, Gaithersburg are constructed based on different calibration algorithms. Consequently, the different hardware and software are incorporated into the two systems. An indirect comparison between the two systems was performed based on measuring a set of three Zener references to check consistency of the two systems.

Two different algorithms

For the convenience of description, we name the two Josephson junction array voltage standard systems as NIST-I and NIST-II. The basic procedure to make a voltage calibration is to measure the difference between two very close voltages with a high precision DVM. In our experiment the two voltages are from a biased array and a Zener reference. In order to cancel the thermal voltage in the loop and the DVM's zero offset it is necessary to change the polarity of the two voltages as well as the DVM polarity. The algorithm of NIST-I uses four consecutive steps shown in Fig. 1. The results of the four step measurements are averaged to obtain the Zener voltage [1]. This procedure is then repeated several times

to reduce the Type A uncertainty of the calibration. In the NIST-II algorithm, also known as NISTVolt, only Step 1 and Step 3 shown in Fig. 1 are used. The DVM polarity

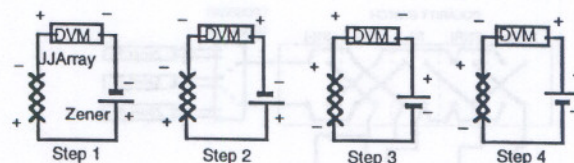


Fig. 1 The voltage calibration procedure used in NIST-I

in the calibration process is not reversed. The reason to adopt this procedure is that the repeatability of the reversing switch is often a significant source of uncertainty, adding a second reversing switch for the DVM may add to the total uncertainty. The DVM and thermal offsets and their drifts are modeled by a combined offset, V_0 , and drift rate, m . By taking N readings of DVM as Step 1, then repeating the measurements as Step 3, Step 1 and Step 3, the NIST-II program is able to make a linear fit to the data points and to calculate the Zener reference voltage, along with the combined offset, V_0 , and its drift rate, m [2].

Experimental description

The initial attempt to compare the two systems was not able to reach sub-nanovolt accuracy because of differences in the thermal voltages caused by the switches and wiring in the two systems. A manual switch system shown in Fig. 2 is designed to make an indirect comparison between the NIST-I and NIST-II systems by measuring a set of three Zener references of 1.018 V. Each system uses its own bias source, microwave source, frequency counter, and DVM. Both systems share the same switch for changing the polarity of the Zener reference and the DVM (for NIST-I only). This arrangement measures the sum of the Zener voltage and any thermal voltage existing in the circuit from the polarity switch to the Zener reference. Both systems see the identical thermal voltages from the polarity switch to the Zener references. It makes the comparison of the two complete independent systems and their associated algorithms possible.

The polarity switch and system switch used in the experiment are double pole multi-position low thermal switches. As shown in the Fig. 2, when S1 is used, the contacts of a and b are connected, as well as the contacts c and d. The thermal voltages of all switch positions were measured independently before the switch can be used in

* This work was performed in the Electricity Division, Electronics and Electrical Engineering Laboratory, Technology Administration, U.S. Department of Commerce.

the experiment. The range of the thermal voltages are within 3 nV. These thermal voltages are also very stable in the experimental environment. When S1 and S4 of the system switch are used simultaneously, the NIST-I system is connected with the polarity switch and the Zener references. The four measurement steps shown in Fig. 1 can be realized through different position combinations of the polarity switch. Similarly, S2 and S5 of the system switch connect the NIST-II to the Zener references through the polarity switch. The polarity of the Josephson junction array is changed electronically by the bias source.

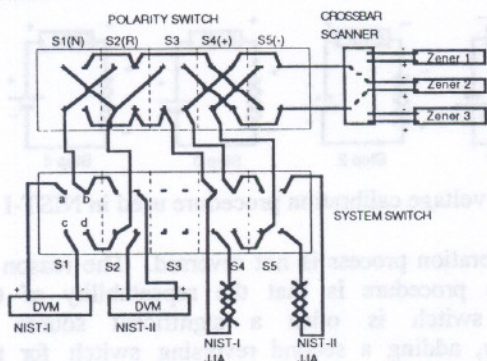


Fig. 2 A manual switch system for comparing NIST-I and NIST-II.

Results

The characteristics of the Zener reference show short term output fluctuations and long term drift. In a few minutes time, which is often the time for a Josephson voltage standard system to calibrate a Zener, the output of a Zener reference can fluctuate several tens of nanovolts at the 1.018V level. The comparison of NIST-I and NIST-II against a single Zener reference was performed in a time period of few hours to avoid the effect of long term drift of the Zener output. Fig. 3 shows the measurement results by NIST-I and NIST-II for the Zener 1.

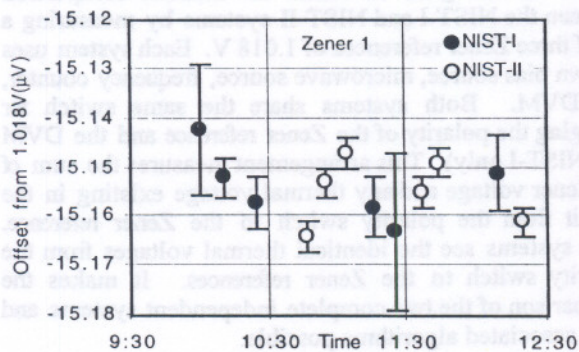


Fig. 3 Calibration results of NIST-I and NIST-II for Zener reference 1.

The sequence of the comparison was interleaved for the two systems with groups of three, two and one measurements. The average Zener output of the total six measurements from each system converged very closely to a difference of 0.9 nV. The uncertainty bar shown in the

Fig. 3 shows the Type A contribution only. The NIST-I program uses four average numbers to calculate the Type A uncertainty, while the NIST-II uses forty DVM readings to calculate the uncertainty. Measurements against the Zener 2 and Zener 3 were also done in a similar pattern.

Table 1 lists the comparison results. Columns of NIST-I and NIST-II are the Zener output from the nominal 1.018 V. Delta represents the difference between the NIST-I and NIST-II results. Six measurements were averaged for Zener 1 and Zener 2 by each system, while nine measurements were averaged for Zener 3. The difference of the average of the three Zener references measured by the NIST-I and NIST-II systems is 0.4 nV, indicating the equivalency of NIST-I and NIST-II system hardware and software under the well controlled measurement conditions. The relative uncertainty (2σ) of the averaged three Zener references measured by two systems is estimated as 1.1×10^{-8} .

	NIST-I	NIST-II	Delta	1σ
Zener 1	-15.1539	-15.1548	0.0009	0.0066
Zener 2	-29.4806	-29.4792	-0.0014	0.0100
Zener 3	-4.7274	-4.7267	-0.0007	0.0109
Average	-16.4540	-16.4536	-0.0004	0.0054

Table 1 Comparison results of three Zener references. The unit of all numbers is microvolts.

Conclusion

The consistent results of NIST-I and NIST-II systems have been achieved using a set of quiet Zener references without transporting them from one location to the other. The results also showed the equivalence of two different algorithms for the application of Josephson voltage standard systems in calibrating Zener references. The method can be used to make *in situ* system inter-comparisons to check possible problems caused by hardware defaults or to debug software for Josephson voltage standard systems.

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References

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