A TWO-WAY JOSEPHSON VOLTAGE STANDARD COMPARISON BETWEEN NIST AND NRC

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Abstract[±]

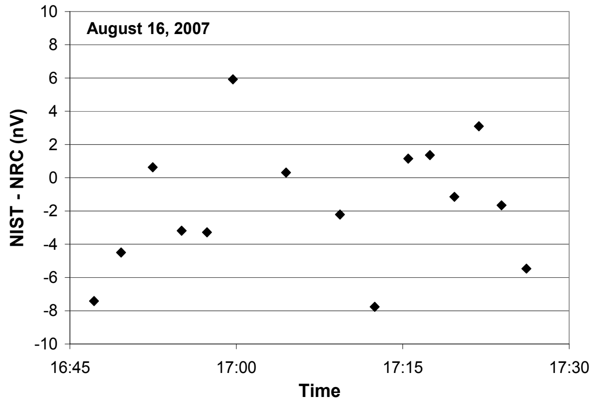
A two-way Josephson voltage standard (JVS) direct comparison between the National Institute of Standards and Technology (NIST) and the National Research Council (NRC) has been conducted. The process consists of two comparisons, one using NIST designed hardware and software and the other using NRC designed hardware and software. The results of the two comparisons are in agreement to within 0.7 nV and their mean indicates that the difference between the two JVSs at 10 V is -0.28 nV with a pooled combined uncertainty of 2.07 nV ($k = 2$).

Introduction

The NRC JVS and the NIST transportable compact Josephson array standard (CJVS) were directly compared at 10 V in 2006 [1]. The NRC JVS was used to bias both arrays in parallel. NRC designed hardware and software were used in the comparison. This paper describes a second comparison using NIST designed hardware and software. In the NIST system a battery-powered, dual bias source, the JBS100D manufactured by VMetrix[*], was used. A new module of NISTVolt© software was developed to control the measurements and reduce the data.

Direct Comparison Using the NRC Protocol

The details of the comparison using the NRC protocol are described in the reference [1] and are briefly summarized here. Simultaneous biasing of both arrays is achieved by including an automated shorting switch in parallel with the nanovoltmeter. All switching and biasing of the two arrays is controlled by the NRC software. This fully automated data collection process significantly improves the efficiency of the comparison. Data sets were acquired on two successive days, with a time period of 90 minutes for each data set. A total of 36 points were taken with no obvious distinction between the two data sets. Each point is the mean value of a pair of measurement sets with different polarities of the arrays. Each measurement set consists of 40 readings and had a mean standard deviation of approximately 2 nV. The nanovoltmeter DVM used for measuring the difference of the two arrays is always on the 10 mV range but all measurements were within ±1.2 mV. Fig. 1 shows the measurement results on the two successive days. The leakage resistance between the minus and plus leads of the NRC cryoprobe was measured to be 5.9 x 10^{11} Ω with lead resistance 2.48 Ω. The leakage resistance of the NIST CJVS cryoprobe was 4.0 x 10^{11} Ω with lead resistance 7.0 Ω. The combined correction for the difference between the NIST CJVS and the NRC JVS is 0.133 nV. The final results were corrected for the errors caused by the leakage of both cryoprobes at 10 V.



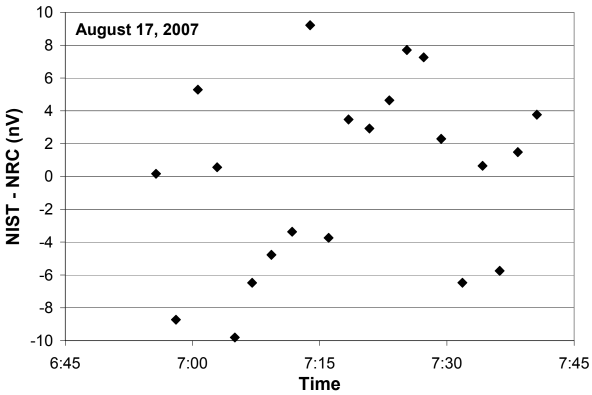


Fig.1. Measurement results from using the NRC automatic measurement system with the NIST CJVS as a voltage source.

Direct Comparison Using the NIST Protocol

Fig. 2 shows the NIST design for the comparison. The two JVS systems are connected in series opposition with the difference voltage V1-V2 connected to DVM2. DVM1 measures V1 and is used to deduce the step number of the NIST JVS. The step number of the NRC JVS is deduced from the voltage $V_{DVM1} - V_{DVM2}$. A dual battery-powered bias source is used to independently set both arrays near 10 V. If the bias reversing switch of one bias source is set to open and the shorting switch is closed, then the other bias source will bias both arrays in parallel. This is the simplest and most effective way to get both arrays onto a step at nearly identical voltages.

The bias set point, the bias reversing switches, and the DVM2 shorting switch are operated manually. Data acquisition from both DVMs is controlled by NISTVolt software. The difference between the two arrays was always controlled within the 1 mV range of DVM2. If a step jump occurred

[+] This work was performed partially at NIST in the Quantum Electrical Metrology Division, Electronics and Electrical Engineering Laboratory, U.S. Department of Commerce, not subject to copyright in the United States.

[*] Commercial equipment and materials are identified in order to adequately specify certain procedures. In no case does such identification imply recommendation or endorsement by NIST or NRC, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

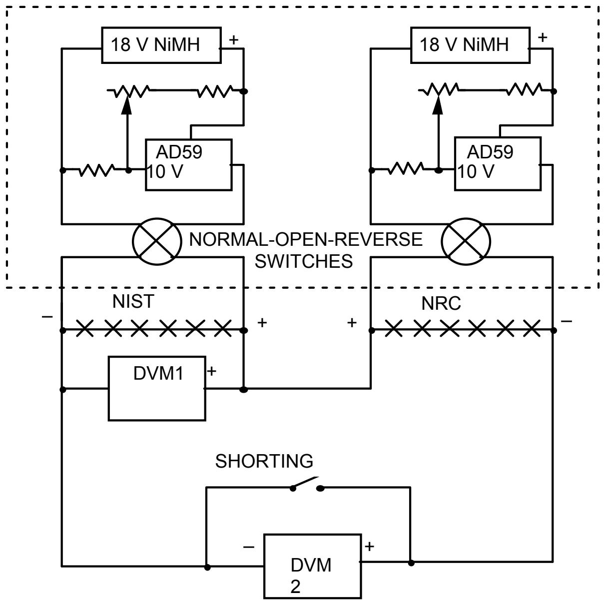


Fig. 2 The circuit used in the NIST direct comparison method.

during the measurement, causing DVM2 to change to the 10 mV range, the measurement was repeated to avoid the impact of a change in the DVM2 gain error. Note that since the two JVS systems are typically operating at different frequencies and different step numbers, the comparison parameter of interest is not the difference voltage, but the amount by which the difference voltage deviates from its theoretical value. Fig. 3 shows these results. A total of 30 points were taken. Fifteen points were taken using DVM2 with the polarity shown in Fig. 2. Then the leads of DVM2 were reversed, the sign of DVM2 data in the software was reversed, and 15 more points were taken. Each point is the result of a fit to 6 data sets using the NISTVolt software [2] with a + − + − + − sequence of array polarity. Each data set consists of 10 DVM readings. The data of Fig. 3 show a bias related to the DVM2 polarity. The final result is calculated as the mean of the two data groups of normal and reversed DVM2 polarity. Future investigation of the influence of the DVM2 polarity bias is planned. The correction for the errors caused by the leakage of both cryoprobes at 10 V was also applied to the final results.

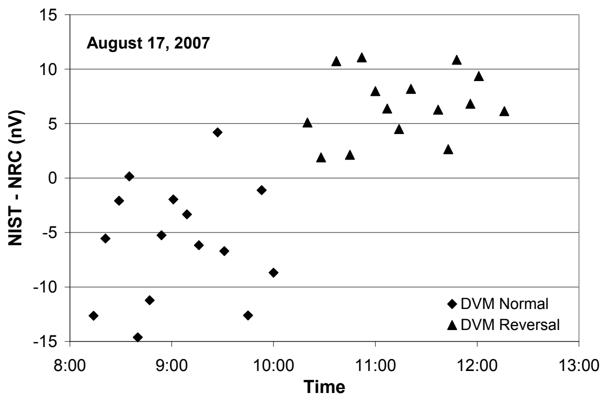


Fig.3. Measurement results from NIST measurement protocol.

Uncertainty Analysis

Table 1 lists the differences between the two JVS with the Type A uncertainties. The difference is the mean value of all the measurement differences between the two systems. The Type A uncertainty of NRC's measurements is the standard deviation of the mean of all the measurements. The Type A uncertainty of NIST's measurements is the pooled standard deviation of the mean of the normal DVM polarity and reversed DVM polarity measurement groups. Table 2 lists the Type B uncertainty of each JVS system. Table 3 lists the differences and their associated combined uncertainties. The final reported difference between NIST CJVS and NRC JVS shown in Table 3 is the mean value of the differences of the two sets of measurements with the associated uncertainty being the pooled uncertainty of the two sets of measurements.

Table 1. Differences between the two JVSs and associated uncertainties

	Made by NRC	Made by NIST
NIST- NRC (nV)	-0.66	0.10
Number of measurements	36	15
Standard Deviation (nV)	4.94	3.09
Type A uncertainty (nV)	0.82	0.80
Type B uncertainty (nV)	0.86	0.87
Combined uncertainty (nV)	1.19	1.18

Table 2. Type B uncertainty of the components of each JVS system. All of the components are in nV

	NRC	NIST
Frequency offset and noise	0.39	0.10
Leakage	0.013	0.013
Detector gain and linearity	0.45	0.60
Detector bias	0.02	0.00
Microwave power rectification	0.00	0.00
EMI	0.60	0.60
Detector offset, impedance, and noise	0.16	0.15
Uncorrected thermals	0.00	0.00
Sloped voltage steps	0.00	0.00
Type B (nV)	0.86	0.87

Table 3. The final reported difference between NIST CJVS and NRC JVS and associated expanded uncertainty ($k = 2$)

NIST - NRC (nV)	-0.28
Pooled combined uncertainty (nV)	1.04
Expanded uncertainty (nV) $k = 2$	2.07

Conclusion

Two direct 10 V comparisons were made between the NIST CJVS and NRC JVS systems using independently designed hardware and software. The two comparison methods agree to within 0.7 nV. The mean value of the difference between the two systems is -0.26 nV with an expanded combined uncertainty of 2.07 nV or relative uncertainty of 2.07 parts in 10^{10}.

References

[1] B. Wood, Y. Tang and C.A.Hamilton, "Direct Josephson Array Voltage Comparison between NRC and NIST," Digest of Conf. on Precision Electromagnetic Measurements (CPEM2006), pp. 14-15 (July 2006), July 9- July 14, 2006, Torino, Italy.

[2] "Josephson Voltage Standard, Recommended Intrinsic/Derived Standards Practice," 4th Edition, 2002, the National Conference of Standards Laboratories International publication.