DIRECT JOSEPHSON ARRAY VOLTAGE COMPARISON BETWEEN NRC AND NIST

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Abstract[±]

The National Research Council's (NRC) Josephson voltage standard (JVS) has been directly compared with the compact, transportable Josephson array standard of the National Institute of Standards and Technology (NIST) at 10 V. A simplified biasing technique for both arrays has been developed for this direct comparison. The preliminary results of this comparison augment the confidence and traceability of the 7th interlaboratory comparison (ILC) of Josephson Voltage Standards (JVS) at 10 V sponsored by the National Conference of Standard Laboratories International (NCSLI).

Introduction

The 7th NCSLI JVS comparison [1] at 10 V was conducted in 2005. The details of this comparison are described elsewhere in this conference but include the measurement of four traveling Zener voltage standards by each of the participants using their own 10 V Josephson array system. A new feature of this comparison is the use of a compact JVS (CJVS), which travels to each of the four sub-pivot laboratories of this comparison. Near simultaneous measurements of the traveling Zener references are performed with the sub-pivot and CJVS measurement systems.

This feature reduces the uncertainty due to the non-linear drift of the Zener standards and instability associated with the environmental and transportability effects. As a result the uncertainty of these indirect comparisons of the sub-pivot JVS and CJVS was reduced to approximately 19 to 27 nV, a factor of 7.6 to 10.8 improvements over the 2002 ILC [2].

While the ILC results are a significant improvement, direct comparisons between two Josephson array systems can yield even smaller uncertainties by eliminating any contribution associated with the Zener reference standards. Direct array comparisons using similar nanovolt detectors have achieved uncertainties of order 3 nV [3], ten fold improvement over the indirect comparison using Zener intermediate standards.

The CJVS and most of the participants of 7th NCSLI JVS comparison use bias instrumentation (such as the JVS 1000* series Josephson system controller) from VMetrix for biasing their Josephson arrays and configuring their measurement systems. This is a convenient turn-key system that is used by most industrial laboratories and several NMIs. The instrumentation is integrated with the publicly available NISTVolt software and well suited for the calibration of Zener voltage standards or digital voltmeters (dvms). However, without significant modification, this instrumentation and software does not allow for direct comparison with another Josephson array system. The purpose of this work is to demonstrate a way to work around this shortcoming of the biasing electronics in order to perform a more direct comparison of two JVS measurement systems.

Direct Comparisons of Josephson Arrays

In the ILC comparison the CJVS and the sub-pivot JVS, including their measurement systems, were compared through substitution of an intermediate Zener voltage reference. This tests the equivalence of both systems but includes the noise contribution of the Zener voltage reference over short periods of time. However, a direct Josephson comparison only compares one Josephson array and its measurement system to a second Josephson array without its measurement system. To be fully comparable direct Josephson comparisons should really be performed twice, once with each measurement system.

It is important to note that a direct array comparison does not test the offset and repeatability of low potential reversing switches that are normally part of a JVS measurement system. Unlike Zeners, the polarity of each array can be reversed without using a reversing switch. Reversing switch offset and repeatability is embedded in an indirect comparison using Zeners and can also be evaluated by short circuit measurements.

For this summary we focus on the comparison of the NRC JVS and its measurement system with the NIST CJVS array acting as a known voltage source but without the CJVS measurement system. We hope to present results of the CJVS and its measurement system with the NRC array without its measurement system during the conference.

The NRC JVS

The NRC JVS is not based on the JVS1000* instrumentation. The details of the instrumentation and software of this system are described in [3] but only the relevant aspects will be described in this manuscript.

The NRC system has two dvms, a system dvm across the NRC array at all times and a nanovoltmeter to measure the difference voltage between the NRC array and the device under test which in this case is the CJVS array. Both the nanovoltmeter and the system dvm are HP34420A*. Data acquisition is performed by programming both the system

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

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dvm and nanovoltmeter to simultaneously acquire and internally store a burst of readings. In this way there is no IEEE bus activity during the data acquisition.

The operating voltage step of the NRC array and the NIST CJVS array, as well as the voltage difference between the two arrays can thus be determined for each individual data point. The NRC data acquisition and rejection algorithm [3] examines the sequential data stream and only accepts a particular point if the previous and next point are all within a small fraction of a step voltage. This effectively removes data, near in time, to a step transition of either Josephson array. Each of the accepted data points are then corrected for the nonlinearity of the nanovoltmeter and finally corrected to the voltage equivalent to operation of each Josephson array on a specific step.

Direct Comparisons Involving JVS 1000* Circuitry

The NIST CJVS consists of a VMetrix JVS 1000* bias instrument, a Josephson array and a cryoprobe that houses the Josephson array chip and the microwave oscillator. The microwave source is a 76.76 GHz fixed frequency oscillator that is phase locked to an external 10 MHz signal, the same signal that locks the NRC oscillator. A separate computer running a modified version of NISTVolt controls the JVS 1000*. A separate oscilloscope is used to monitor, tune and configure the CJVS before the direct comparison measurements.

During the comparison measurements the CJVS is set to the NISTVolt 'NullLoop' configuration with the reference terminals shorted and the 'NIST detector' terminals going to the NRC JVS measurement system. The CJVS bias system is disconnected so that the NRC system controls bias to both arrays and also controls the data acquisition as shown in Figure 1.

Biasing Josephson Arrays

Simultaneous biasing of both arrays is achieved by including a shorting switch in parallel with the nanovoltmeter and keeping the array without its measurement system disconnected from its bias circuitry, see Fig 1.

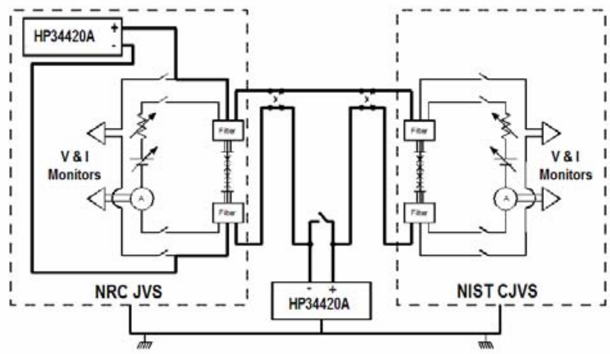

Figure 1: A simplified schematic of the direct comparison circuit of the NRC JVS measurement system and the NIST CJVS array.

With the nanovoltmeter shorted the NRC bias system biases both the NRC array and the CJVS array to the same voltage. Open circuiting the NRC bias caused both arrays to jump several steps from the bias voltage (typically ~2 mV) but both arrays remain within one step of each other. Opening the nanovoltmeter switch usually resulted in a jump between the two arrays of one or two steps. A simple manual toggle switch is used as the nanovoltmeter switch but it can be easily automated by either system.

Note that the nanovoltmeter switch has no thermal emf contributions to the measurements since it is an open circuit and not in the potential measurement loop.

Results

The nanovoltmeter readings were corrected for operation of each array on steps other than the calculated step nearest ±10 V. As well, correction was applied for the nanovoltmeter nonlinearity using a calibration against the NRC JVS of 23 points on the 10 mV range.

Twenty independent sets of polarity reversed results at 10 V indicate that

$$\text{NRC JVS} - \text{NIST CJVS} = (0.3 \pm 1.6)\ \text{nV}.$$

This is a 95% expanded uncertainty of the type A component.

The 1.6 nV uncertainty is very similar to the residual noise floor of the NRC JVS system operating at 0 V in this acquisition period.

Conclusion

Preliminary measurements indicate that the expanded Type A measurement uncertainty of the direct comparison the NRC JVS and NIST CJVS is 1.6 nV. This is a substantial reduction over comparisons using Zener references.

Other details, as well as a full uncertainty budget will be presented during the conference.

Acknowledgement

B. Wood would like to acknowledge several insightful conversations with S. Solve and D. Reymann of BIPM.

References

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