THE SEVENTH INTERCOMPARISON OF JOSEPHSON VOLTAGE STANDARDS IN NORTH AMERICA

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Abstract[+]

The 7th interlaboratory comparison (ILC) of Josephson Voltage Standards (JVS) at 10 V, sponsored by the National Conference of Standard Laboratories International (NCSLI), took place from April to October 2005 with 15 participating labs. NIST's traveling JVS system was used to make five comparisons with sub-pivot labs. This paper describes the protocol used for the JVS intercomparison, and the improvements achieved by the use of the transportable JVS.

Introduction

The 7th NCSLI JVS intercomparison at 10 V was carried out from April to October 2005. The same four traveling Zener voltage standards used in an earlier ILC (ILC 2002) were used as the transfer standards in ILC 2005. The 2005 JVS ILC is intended to provide participating labs with a means of comparing dc voltage measurements in order to meet accreditation or contractual requirements, and to establish reliability, confidence, and improved system operation.

A compact JVS (CJVS) was used in the 6th NCSLI JVS intercomparison in 2002 [1] to make a single comparison with the pivot lab. In 2005, NIST made *in situ* comparisons as the main pivot lab with five sub-pivot labs using the NIST CJVS. Each sub-pivot lab was responsible for making comparison measurements with three participants using the same protocol as in the NCSLI JVS ILC 2002 [2]. Use of the CJVS in the comparisons with the sub-pivot labs significantly reduced the uncertainty between NIST and the sub-pivot labs resulting from non-linear drift of the Zener standards and instability associated with the environmental and transportability effects. This made possible the detection of system errors well below the 2×10^{-8} level that is typically achievable with Zener standards alone.

Experiment Description

The 2005 NCSLI JVS intercomparison protocol divided the 15 participating laboratories into 4 groups. One laboratory in each group was the sub-pivot lab. NIST shipped the CJVS to a sub-pivot lab where an *in situ* comparison was made with the sub-pivot JVS by NIST personnel and sub-pivot lab staff. In this comparison, multiple measurements of four Fluke 732B Zener standards[‡] by the two JVS systems were interleaved so as to greatly reduce the effect of short term Zener noise and drift. After this comparison, the Zener standards were shipped to the next three laboratories for measurements and then returned to the sub-pivot lab for a second set of measurements. This 'daisy' pattern was repeated in four loops. The standard measurement procedure was the same as in ILC 2002 and consisted of 4 ± pair measurements of each of the four standards, typically performed in two days.

The CJVS was shipped back to NIST after each comparison in a sub-pivot lab. Before it was shipped to the next sub-pivot lab a direct array to array comparison between the CJVS and a programmable Josephson voltage standard (PJVS) was carried out to confirm the CJVS performance.

During the course of the third loop comparison, the batteries of all four traveling Zener standards were exhausted due to shipment delay. The comparison was halted for five weeks to allow the Zeners to stabilize. An extra sub-pivot lab was added and the schedule for comparison was modified accordingly.

Results of the CJVS Comparisons

Table 1 lists the results of the comparisons between the CJVS and the five sub-pivot labs in ILC 2005 compared to the results of ILC 2002 [2]. The differences between the CJVS and the sub-pivot labs varied from 3.5 nV to 15 nV with a 95 % confidence uncertainty of 19 nV to 27 nV at 10 V. The uncertainty improvement factor relative to ILC 2002 varies from 7.6 to 10.8.

The initial CJVS comparison with sub-pivot 1 showed a difference of 49 nV with a 95 % uncertainty of 27 nV. This apparent discrepancy was resolved when it was discovered that a leakage correction factor that was previously entered into the software of sub-pivot 1 had a misplaced decimal point. This small error of 5 parts in 10^9 would not have been detected without the improved uncertainty of the CJVS comparison.

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

Table 1. Results of the *in-situ* comparison between the CJVS and the sub-pivot labs and the improvement compared to the 2002 JVS intercomparison.

Lab	Date	Lab-CJVS (nV)	Uc (95%) (nV)	Lab-NIST (nV) in 2002	Uc (95%) (nV) in 2002	Factor 2002 / 2005
Sub-1	4/5/2005	4.7	26.8	30.0	206.0	7.7
Sub-2	5/10/2005	7.0	19.0	-41.0	206.0	10.8
Sub-3	6/7/2005	-3.5	26.8	-6.0	205.0	7.6
Sub-4	7/12/2005	-2.4	25.0	-59.0	215.0	8.6
Sub-5	8/16/2005	-15.0	24.5	0.0	205.0	8.4

Loop 1 and 2 Results

The participant lab results are analyzed as in ILC2002, that is, all measurements for a given lab are corrected for pressure dependence and reduced to a single mean voltage and mean time. The best estimate of the time dependent Zener bank mean value is taken to be a straight line drawn between the NIST CJVS values at either end of the loop – the point-to-point model. The estimated difference between each lab and the CJVS is the residual to the line. The uncertainty of this difference is estimated using results from ILC2002 on the same Zener bank and by observing the behavior of the Zener bank in the seven months before the ILC. The seven month history is used to simulate the ILC by selecting bank means at one week intervals. A straight line is drawn through points that are four weeks apart and the residuals to the intervening points are calculated. This was done for seven consecutive loops. The RMS value of all of the residuals is an estimate of the standard uncertainty of the straight line prediction over a four week interval. For the data tested, this number is 96 nV which compares favorably with the 99 nV calculated independently from the ILC2002 data [1]. The fact that the ILC2002 result includes travel effects whereas the seven month data history calculation does not, implies that travel effects and imperfect pressure corrections are a minor contribution to the total uncertainty.

Table 2 shows the Lab-NIST results for loops 1-4. Column 4 represents the standard deviation of the mean σ_m for the 16 ± pair measurements made at each lab. The uncertainty in 95 % confidence is determined from the least square sum of the ILC2002 bank uncertainty result (99 nV), and the result in column 4 multiplied by a Student *t* factor. Results for lab 2 and lab 5 are well outside the expected range for both offset and scatter. In the case of lab 5 the cause turned out to be an inadequate frequency reference for the Gunn oscillator. The cause of the discrepancy with lab 2 has not been determined.

Loop 3 and Loop 4 Results

As previously mentioned, there was a failure of battery power for all four Zeners after loop 2. In spite of allowing five weeks for the standards to stabilize, it is quite apparent from the loop 3 and loop 4 data that the standards did not achieve their previous level of stability. Thus there is no independent method of determining the uncertainty of the point-to-point model during the loop 3-4 measurements. Since there are no obvious outliers, we can use the residuals to the point-to-point model to make an estimate for the uncertainty of the model. The estimate is likely to be conservative because an individual lab's large error would cause an increase in the uncertainty of all laboratories. The resulting standard uncertainty of the model for loops 3 and 4 is 166 nV which is 67 % higher than that obtained before the battery failure.

Table 2. Results for the four measurement loops.

Lab #	Date	Lab-CJVS (nV)	Lab σ_m (nV)	U_c (95 %) (nV)
Loop 1				
1	4/11/2005	-42	17	199
2	4/18/2005	+277	175	412
3	4/26/2005	+52	12	198
Sub-1	5/2/2005	+36	28	204
Loop 2				
4	5/16/2005	-49	20	200
5	5/24/2005	-1046	86	261
Sub-2	5/31/2005	+14	12	198
Loop 3				
7	7/19/2005	-160	12	329
8	7/25/2005	-265	23	332
Sub-4	8/1/2005	-86	18	330
Loop 4				
9	8/22/2005	+160	23	332
10	9/7/2005	+181	15	330
Sub-5	9/22/2005	-52	32	335

Conclusion

The use of the CJVS in ILC2005 has improved the uncertainty of sub-pivot comparisons by about an order of magnitude to a few parts in 10^9 and also provided a more direct link to the other 10 participants in the ILC. Because the sub-pivot comparisons are made *in situ*, uncertainty from non-linear drift, transportation and environmental effects is largely eliminated. Small system errors of few parts in 10^9 can be detected and corrected with a CJVS comparison. The discovery of system problems at 3 of the 15 laboratories in the ILC 2005 demonstrates the value of intercomparisons for Josephson systems.

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References

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