JOSEPHSON VOLTAGE STANDARDS COMPARISON BETWEEN CENAM AND NIST AT 10 V LEVEL

*Dionisio Hernández, *Enrique Navarrete, *David Avilés, **Yi-hua Tang

*Centro Nacional de Metrología (CENAM)
km 4,5 carretera a los Cues, El Marqués, Querétaro, MÉXICO
Telephone: + (442) 211-0500, email: dhernand@cenam.mx

**National Institute of Standards and Technology (NIST)
Gaithersburg, MD 20899, USA
Telephone: + (301) 975-4691, email: yi-hua.tang@nist.gov

Abstract: A comparison of Josephson Voltage Standards (JVS) between the National Institute of Standards and Technology (NIST) and the Centro Nacional de Metrología (CENAM) held at CENAM from 21st to 23rd of March 2006 is reported. The comparison was made at the 10 V level by measuring four Zener references using the JVS of CENAM and the transportable Compact Josephson Voltage Standard (CJVS) of NIST. The difference between the measurements was -38 nV with an uncertainty of 42 nV at 95 % level of confidence.

1. INTRODUCTION

The Josephson Voltage Standard (JVS) of CENAM and the transportable CJVS of NIST[+] were compared at the 10 V level at CENAM, from March 21-23, 2006.

The purpose of this comparison is to link the voltage reference of CENAM to that of NIST in the frame of the Inter-American Metrology System – Regional Metrology Organization (SIM-RMO) Key Comparisons and to that of the Bureau International des Poids et Mesures (BIPM) using the results of the JVS NIST-BIPM Comparison performed in 1998.

This comparison was approved by the Low Frequency Working Group (WGLF) of the Consultative Committee for Electricity and Magnetism (CCEM) and registered in the Comité International des Poids et Mesures (CIPM) Key Comparison Database (KCDB) as SIM.EM.BIPM-K11.b.

The comparison was performed following the protocol designed by NIST, by measuring a set of four Zener diode-based references using the transportable CJVS of NIST and the JVS of CENAM, in an alternating sequence.

CENAM provided the four Zener standards used as transfer standards (serial numbers 5855103, 5855201, 5855203 and 5855303), which were previously selected from a group of 12 to have lower dispersion.

2. EXPERIMENT DESCRIPTION

2.1 CENAM JVS

The CENAM JVS is a commercial system, from the Research and Manufacturing Company[++] (RMC), which was established in 1994 and has been modified with an additional RF filter. The 10V Josephson junction array is from the PREMA Semiconductor GmbH[++] in Germany. The JVS bias source has been modified to improve the selection of quantum voltage steps. The system is operated manually. An HP3458A[++] digital voltmeter (DVM) was used as the null detector.

2.2 NIST JVS

The NIST CJVS consists of a VMetrix JVS 1000 bias source, a Josephson array, a cryoprobe that houses the Josephson array, and a microwave oscillator. The microwave source is a 76,76 GHz

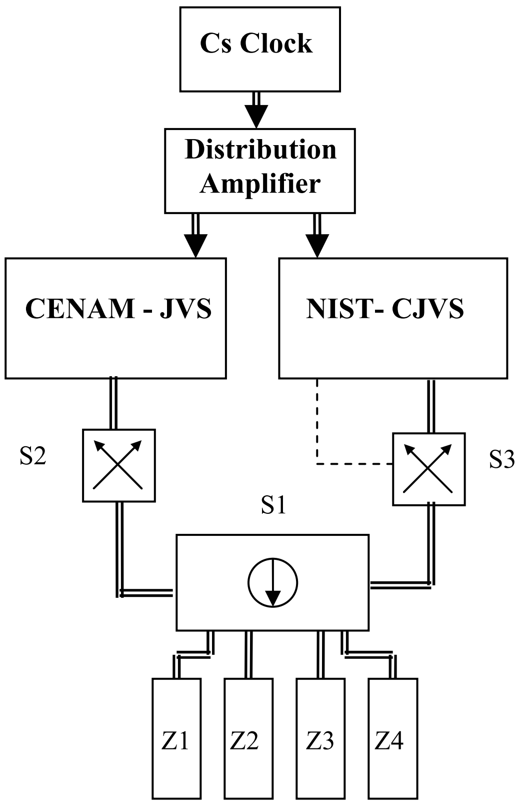
[+] This work was performed partially at NIST in the Quantum Electrical Metrology Division, Electronics and Electrical Engineering Laboratory, Technology Administration, U.S. Department of Commerce, not subject to copyright in the United States.

[++] Certain commercial equipment, instruments, or materials are identified in this report in order to facilitate understanding. Such identification does not imply recommendation or endorsement by NIST, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

fixed frequency oscillator that is phase locked to an external 10 MHz signal. The system was used in the automatic mode. A HP34420 DVM was used as the null detector.

2.3 COMPARISON SETUP

The comparison set up is shown in Figure 1.



S1 – Switch Box to select JVS, Zener and Polarity
S2 - Manual Reversal Switch
S3 - Automatic Reversal Switch

Fig. 1 *Experimental setup*

CENAM's atomic clock, a high performance Agilent 5071A, provided the frequency reference (10 MHz) for both systems. The atomic clock was connected to the JVS systems through a distribution amplifier and isolation transformers that were made at CENAM.

A switch box S1 allows connection of one of the four Zeners to the desired JVS system (either NIST or CENAM) and selection of Zener polarity (plus or minus). The switch is a C4 Series rotary switch made by Electroswitch.

CENAM used a manual low thermal rotary switch S2 to reverse the polarity of the connected Zener, while NIST used an automatic low thermal switch S3.

3. MEASUREMENTS

The Zeners were kept floating. No GUARD or CHASSIS GROUND was connected.

Each Zener was disconnected from the AC power two hours before the measurements.

Thermal emfs were checked before the comparison by measuring a short circuit. The values for the thermal emfs were a few nanovolts for both systems.

The measurement sequence, listed in Table 1, was designed to have the same mean time (within a few minutes) for a pair of Zener measurements (positive and negative polarities) made by the NIST and CENAM JVSs, so that the Zener drift during the comparison could be compensated.

Table 1 *Measurement sequence for each Zener (selected using the switch box S1), the JVS (NIST or CENAM), and polarities (+ or -).*

NIST+	CENAM+	CENAM-	NIST-
CENAM+	NIST+	NIST -	CENAM-

Each CENAM measurement was taken in 4 groups of 12 single measurements for each group following the sequence (+, -, -, +). The polarity was reversed using the manual switch S2 as shown in Figure 1. A three-parameter, least-squares fit was applied to obtain the best estimate of the Zener value [1].

Each NIST measurement was taken similarly, except the 4 groups followed the sequence (+, -, +, -). The polarity was reversed using the automatic switch S3.

No pressure or temperature corrections were necessary because the measurements were made at the same place and the same mean time. The total time for a comparison of one pair of Zener measurements by the CENAM JVS and the NIST CJVS was approximately 30 minutes. During this short time, the environmental conditions in the lab were stable and the Zener variation associated with the environmental conditions was insignificant.

Figure 2 shows that the differences between the NIST and CENAM measurements were all less than 300 nV.

On the first day, Zeners Z1 and Z2 were measured four times, on the second day Z3 and Z4 were measured four times, and on the third day the four Zeners were measured twice.

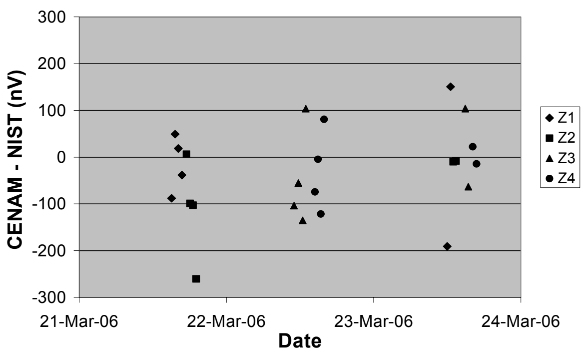


Fig. 2 *Differences between the NIST and CENAM measurements for the four Zeners: Z1, Z2, Z3, and Z4.*

4. RESULTS AND CONCLUSIONS

The mean difference of the 24 pairs of CENAM and NIST measurements at 10 V was -38 nV. The expanded uncertainty of the comparison between CENAM and NIST using a Zener transfer is expressed as the standard deviation of the mean multiplied by Student t factor in Table 2.

Table 2 *Results of the CENAM and NIST JVS comparison at 10 V using the CJVS*

Mean difference (nV)	-38,2
Standard deviation (nV)	100,4
Number of measurements	24
Degrees of freedom	23
Standard deviation of mean (nV)	20,5
Student t (95%)	2,07
Expanded Uncertainty (95 %) (nV)	42,4

The contribution of Type B uncertainty from both JVS systems is included in the expanded uncertainty [1]. This can be seen from the following simple model.

$$Y_{NIST} = True_1 + \varepsilon \qquad (1)$$

$$Y_{CENAM} = True_2 + \gamma \qquad (2)$$

where Y_{NIST} equals the +/- combined Zener value measured by the NIST CJVS during a measurement sequence and Y_{CENAM} equals the corresponding +/- combined Zener value that was measured by the CENAM JVS. $True_1$ and $True_2$ are the actual values of the Zener during the respective +/- sequences, which will be functions of time, and ε and γ are the errors attributable to the respective JVS systems for the +/- measurement sequences. The difference value is given by

$$Diff = (True_2 - True_1) + (\gamma - \varepsilon) \qquad (3)$$

The variance of $Diff$ is, assuming independence of terms, given by

$$Var(Diff) = Var(True_2) + Var(True_1) + \sigma_\gamma^2 + \sigma_\varepsilon^2 \qquad (4)$$

where we expect that $Var(True_2) = Var(True_1)$ so that

$$Var(Diff) = 2Var(True) + \sigma_\gamma^2 + \sigma_\varepsilon^2 \qquad (5)$$

Here, $2Var(True)$ is the variability contributed by the Zener and σ_γ^2 and σ_ε^2 are the variability's contribution from the two JVS systems, which are estimated by their zero offset uncertainties.

The uncertainty using the 24 pairs of Zener measurements was 42 nV at the 95 % level of confidence or a relative uncertainty of 4,2 X 10^{-9}. The uncertainties of most JVS comparisons using the protocol of the Measurement Assurance Program (MAP), in which Zeners are used as transfer standards for two JVS systems in different locations, are in the range of a few parts in 10^8. The improvement made in this comparison is due to the implementation of the NIST CJVS in the comparison, so that the uncertainty contributions associated with Zener non-ideal behavior, such as non-linear drift, shipping, and environmental effects from atmospheric pressure, temperature, and relative humidity, are largely eliminated.

A link between CENAM and BIPM in voltage measurement can be established via BIPM - NIST JVS comparison in 1998 using a set of 3 transport Zener standards [3]. Table 3 lists the combined results of the CENAM - NIST JVS comparison and the NIST - BIPM JVS comparison for the link between CENAM and BIPM. The difference between CENAM and BIPM is found to be 0,22 μV with an expanded uncertainty of 0,28 μV in 95 % confidence. The uncertainty is dominated by the NIST - BIPM uncertainty, which predates development of the CJVS and is hence dominated by the poor long-term behavior of Zener transport standards.

Table 3 *JVS measurement equivalence between CENAM and BIPM via comparisons of CENAM to NIST and NIST to BIPM*

	Difference (μV)	Uncertainty (μV) (95%)
NIST - BIPM	0,26	0,28
CENAM - NIST	-0,038	0,042
CENAM - BIPM	0,22	0,28

REFERENCE

[1] “Josephson Voltage Standard,” Recommended Intrinsic / Derived Standards Practice RISP-1 4th Edition, published by the National Conference of Standards Laboratories International (NCSLI), Boulder, CO, 2002.

[2] Y. Tang, S.L. Kupferman, and M.T. Salazar, “An evaluation of two methods for comparing Josephson voltage standards of two laboratories,” *IEEE Trans. Instrum. Meas*. Vol.54, pp 398-403, February 2002.

[3] T.J. Witt, D. Reymann, Y. Tang and C.A. Hamilton, “Bilateral Comparison of 10 V Standards between the NIST, Gaithersburg, the NIST, Boulder, and the BIPM,” Rapport BIPM-99/07.