

Final Report

BILATERAL COMPARISON OF DC VOLTAGE REFERENCES BETWEEN CENAM AND NIST

(SIM.EM.BIPM-K11.b.)

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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 -34.7 nV with an uncertainty of 43.2 nV at 95 % level of confidence.

1..INTRODUCTION

The Josephson Voltage Standard (JVS) of CENAM and the transportable Compact Josephson Voltage Standard (CJVS) of NIST were compared at the 10 V level. This comparison was held at CENAM in March 2006.

The aim of this bilateral comparison, was to check the coherence between both JVS systems and 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.

2. PARTICIPANTS AND ORGANIZATION OF THE COMPARISON

2.1 Participants

CENTRO NACIONAL DE METROLOGÍA, CENAM - MEXICO

NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY, NIST -
UNITED STATES OF AMERICA (pilot laboratory)

The NIST measurements were made by Yi-hua Tang, Dionisio Hernández and Enrique Navarrete. The CENAM measurements were made by Dionisio Hernández and Enrique Navarrete

2.2 Quantity

DC Voltage at 10 V

2.3 Comparison schedule

This comparison was carried out at CENAM from 21st to 23rd of March 2006.

2.4 Standards of the comparison

2.4.1 Secondary DC voltage standards

The used transfer standards were labeled and identified as follow:

<u>Zener</u>	<u>s/n</u>
Z1	5855103
Z2	5855201
Z3	5855203
Z4	5855303

The four electronic DC reference standards, type Fluke 732B, used as transfer standards were provided by CENAM. This set was previously selected from a group of 12 to have lower noise performance.

2.4.2 Primary DC voltage standards

CENAM JVS

The CENAM JVS is a commercial system, from the Research and Manufacturing Company⁺⁺ (RMC). The CENAM JVS was established in 1994 and has been modified with an additional RF filter. The 10V Josephson junction array (s/n JA-62/7) is from the PREMA Semiconductor GmbH⁺⁺ in Germany (1999). The JVS bias source (JBS500⁺⁺) has been modified to improve the selection of quantum voltage steps. The Gunn diode frequency is phase locked through an EIP 578B⁺⁺ counter. and a phase lock loop. The system is operated manually. An HP3458A⁺⁺ digital voltmeter (DVM) was used to measure the voltage difference between JVS and Zener standard.

NIST JVS

The transportable NIST CJVS consists of a VMetrix⁺⁺ JVS 1000 bias source, a 10 V Josephson array made by HYPRES⁺⁺, a cryoprobe that houses the Josephson array and a microwave oscillator. The microwave source is a 76,76 GHz fixed frequency oscillator that is phase locked to an external 10 MHz

⁺⁺ 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 neither by CENAM, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

signal. The system was used in the automatic mode. An Agilent 34420⁺⁺ DVM was used to measure the voltage difference between JVS and Zener standard.

2.5 Comparison organization

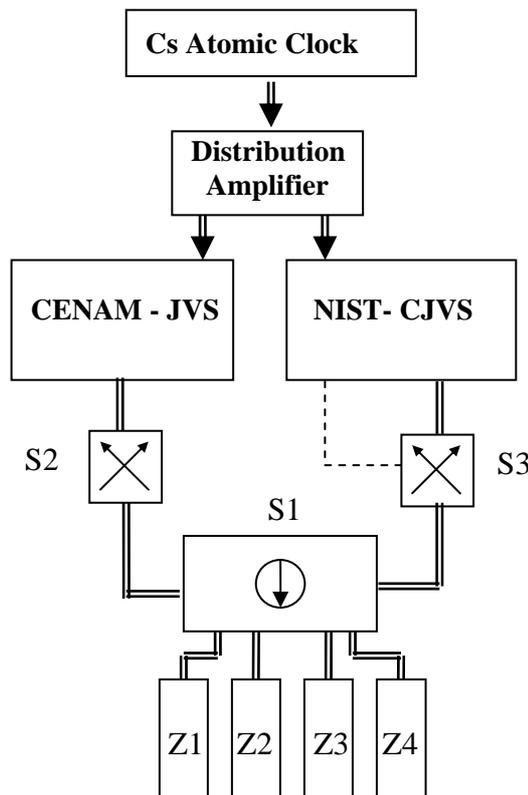
This comparison was not a direct comparison between the two JVS systems. This was made at the 10 V level by measuring four Zener references using the CENAM JVS and the transportable Compact Josephson Voltage Standard (CJVS) of NIST, in alternating way. Yi-hua Tang was at CENAM to operate the NIST CJVS during the comparison.

Before the comparison, NIST sent its transportable CJVS to CENAM,

The comparison was performed following the NIST designed protocol described in the Annex 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 Cs clock (Agilent 5071A), provided the frequency reference (10 MHz) for both systems. The atomic clock was connected to both JVS systems through a distribution amplifier and isolation transformers that were made at CENAM.

A switch box S1 allows the connection of one of the four Zeners to the desired JVS system (either NIST or CENAM) and the 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.

4. MEASUREMENTS RESULTS

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 CJVS and CENAM JVS, so that the Zener drift during the comparison could be compensated [1]. For example, 4 measurements of the first row in Table 1 generate a difference value between NIST and CENAM JVS.

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. Least-squares fit was applied to obtain the best estimate of the Zener value.

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 at 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.

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

On the first day, Zener 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 Zener were measured twice.

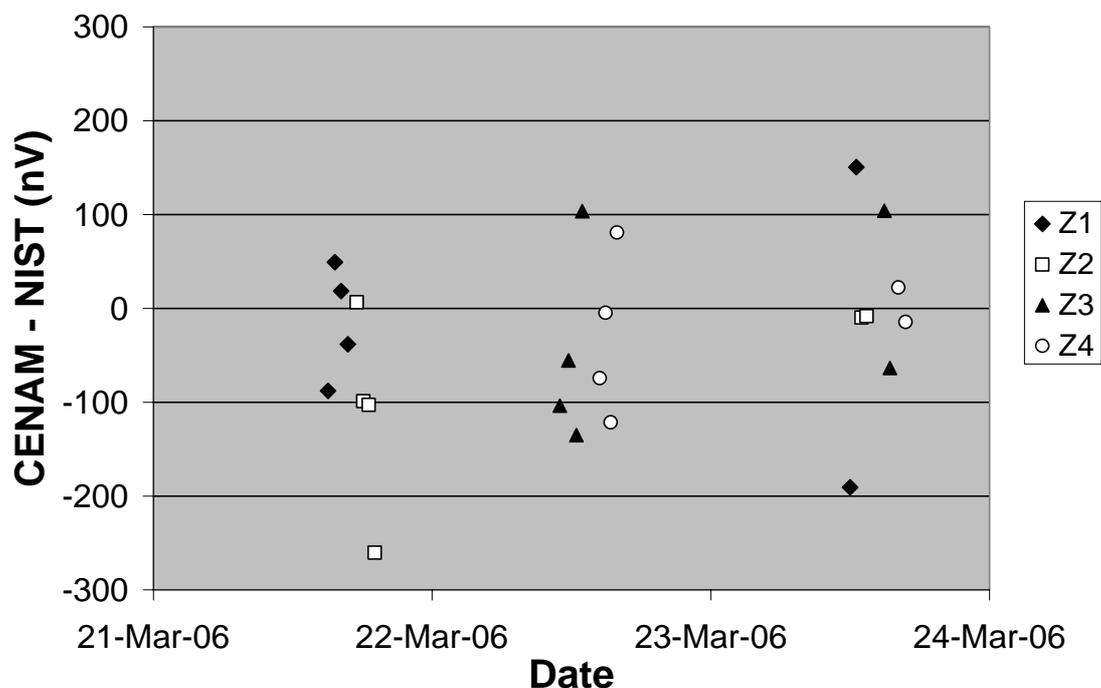


Fig. 2 Differences between the NIST and CENAM. Measurements for the four Zeners: Z1, Z2, Z3, and Z4.

5. COMPARISON UNCERTAINTY

Type A Uncertainty:

It has been pointed out [2, 3] that due to 1/f processes a sequence of measured values from the same Zener may be serial correlated. The 1/f noise floor of Zener is often the limiting factor to the uncertainty for the JVS comparison using Zeners as transfer standards. Nevertheless an analysis of the results of a comparison between NIST and Sandia National Laboratories using the same protocol as this comparison [4] showed that taking the Zener differences measured by using two JVS systems reduces the correlation of the Zener measurements. Additional ANOVA analysis and the Levenes's test showed that there were no significant statistical differences among the measurements of different Zener, and then it is justified to consider the 24 measurements of the differences as independent.

The mean difference of the 24 pairs of CENAM and NIST measurements at 10V was -34.7 nV.

Mean difference	- 34.7 nV
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Type A Uncertainty	
Standard deviation	96.8 nV
Number of measurements	24
Degrees of freedom	23
Type A Uncertainty (Standard deviation of mean)	19.8 nV

Type B Uncertainty		
Uncertainty sources	NIST	CENAM
Frequency	0.1 nV	1.2 nV
Probe leakage	0.4 nV	0.3 nV
Switch thermals + Null meter error	5.0 nV	6.9 nV
Type B uncertainty	5.0 nV	7.0 nV

Final results	
Mean difference	- 34.7 nV
Combined uncertainty (k=1)	21.6 nV
Expanded uncertainty (k = 2)	43.2 nV

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, impact due to shipping, and environmental effects from atmospheric pressure, temperature, and relative humidity, are largely eliminated.

6. RESUME OF RESULTS AND CONCLUSIONS

$d_{CENAM-NIST}$: result of measurement carried out by CENAM and NIST expressed as the difference from the NIST value;

$d_{CENAM-NIST} = (V_{CENAM} - V_{NIST})$, where "V" stands for "voltage"

$U_{CENAM-NIST}$: combined standard uncertainty of $d_{CENAM-NIST}$

$d_{CENAM-NIST}$	$U_{CENAM-NIST}$
/ nV	/ nV
-34.7	21.6

6.1 Impact of the comparison on the calibration and measurement capabilities of the participating laboratories.

No systematic errors were found in this comparison within the uncertainty of the comparison.

The uncertainty declared in the Zener calibration service at 10 V level and 95% level of confidence was 0.5 $\mu\text{V}/\text{V}$ for CENAM and 0.19 $\mu\text{V}/\text{V}$ for NIST. Both uncertainties are largely covered by the results of this comparison.

A reduction in the CENAM uncertainty for this service is possible.

REFERENCES

- [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] T.J. Witt and D. Reymann, "Using power spectra and Allan variances to characterize the noise of Zener-diode voltage standards," *IEE Proc. SCI. Meas. Technol*, Vol 147, No. 4, July 2000
- [3] T.J. Witt, Y. Tang, "Investigations of Noise in Measurements of Electronic Voltage Standards," *IEEE Trans. Instrum. And Meas.* Vol 54, No. 2, April 2005.
- [4] 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 2005.

Annexe 1. Degrees of equivalence and Linking SIM.EM.BIPM-K11.b. to BIPM.EM-K11.b

1. Degrees of equivalence

The degree of equivalence of CENAM with respect to the NIST value is given by a pair of terms:

$D_{CENAM-NIST} = d_{CENAM-NIST}$ and its expanded uncertainty ($k = 2$ at 95% level of confidence), $U_{CENAM-NIST} = 2 u_{CENAM-NIST}$, both expressed in nV.

Lab	$D_{CENAM-NIST}$	$U_{CENAM-NIST}$
	/ nV	/ nV
CENAM	- 34.7	43.2

2. Linking SIM.EM.BIPM-K11.b. to BIPM.EM-K11.b

A link between CENAM and BIPM can be established via BIPM - NIST JVS comparison performed using a set of 3 transportable Zener standards [Ref 1]. This comparison was made in 1998 and was included in the **BIPM.EM-K11.b** comparison report.

The difference between NIST and BIPM was:

$$d_{NIST-BIPM} = 0.26 \mu V$$

The uncertainty at 95% level of confidence was:

$$U_{NIST-BIPM} = 0.28 \mu V$$

The degree of equivalence of CENAM with respect to BIPM is given by a pair of terms:

$D_{CENAM-BIPM} = (d_{NIST-BIPM} + d_{CENAM-NIST})$ and its expanded uncertainty (at 95% level of confidence), $U_{CENAM-BIPM}$.

$$U_{CENAM-BIPM} = (U_{NIST-BIPM}^2 + U_{CENAM-NIST}^2)^{1/2}, \text{ both expressed in } \mu V$$

Lab	$D_{CENAM-BIPM}$	$U_{CENAM-BIPM}$
	/ μV	/ μV
CENAM	0.23	0.28

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.

[Ref. 1] 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.

Annexe 2. Protocol of the comparison

Comparison of 10 V DC Voltage References

Technical protocol for the Bilateral RMO comparison between NIST and CENAM

1. Introduction

The Bilateral RMO Comparison will be performed at 10 V level to check the coherence of the Josephson Voltage Standard (JVS). The comparison will be performed by measuring a set of four Zener diode-based references (Zeners) using the transportable NIST Compact JVS and the CENAM- JVS. There will not be a direct comparison among the JAVS. The comparison will take place in the CENAM' DC laboratory from 20th to 24th of March 2006.

2. Purpose

The purpose of this comparison is to link the voltage reference of CENAM (Centro Nacional de Mertoología) of Mexico to that of the NIST in the frame of the SIM- RMO key comparisons.

3. The standards

The CENAM's transfer standards to be measured are four Fluke 732B Zeners referred as:

Zener	s/n
Z1	5855103
Z2	5855201
Z3	5855203
Z4	5855303

Those Zeners have two output voltages, nominally 1.018 V and 10 V. Within this comparison, only the 10 V outputs will be measured.

To select those standards, previous measurements from CENAM's Zener group were made to select the four standards with lower dispersion in the measurements of 10 V output voltage.

4. Powering the Zeners

The Zeners will be disconnected from the mains at least two hours before the beginning of the measurements and be reconnected to the mains at most six hours later. If the front panel LOW BAT indicator starts blinking the Zeners must be immediately connected to the mains for recharging of the battery.

When the Zeners are not in the process of measurements, they must be permanently connected to the mains (front panel AC PWR lighted).

5. Measurements schedule

There will be five series of measurements performed by NIST and five series of measurements performed by CENAM. The NIST and CENAM measurements will be in alternating mode during the week 20th to 24th of March 2006.

6. Temperature and pressure coefficients, environment conditions

The temperature and pressure of the laboratory will be measured in each measurement.

The pressure, temperature and humidity effects will be minimized by performing the measurements in the same laboratory in alternating way. There will be no corrections for pressure, temperature and humidity.

7. Connections

During the measurements the mains plug at the rear of the Zeners will be disconnected.

8. Uncertainties

An uncertainty budget will be given containing the different sources of uncertainty and their values.

Foreseen sources of uncertainty: realization of the voltage reference
detector
leakage resistance
no compensated thermal electromotive
forces
and for each Zener: type A uncertainty

9. Participant report

The CENAM report must be sent to the NIST within one month from the completion of his measurements.

This report will contain:

The measurement method description and:

for each reported value:

identification of Zener
date and time of measurement
measured voltage
ambient temperature, humidity, and pressure
the Type A standard uncertainty;

an uncertainty budget with the different sources of uncertainty and their values, as:

realization of the voltage reference
detector
leakage resistance
no compensated thermal electromotive forces

10. Final report

The draft version of the final report will be issued within two months after completion of the comparison. It will be sent to CENAM for discussion and approval. The final report will be then submitted.

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