Direct Comparison Between Inmetro Programmable and Conventional Josephson Voltage Standards at 10 V

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Abstract **— A 10 V Programmable Josephson Voltage Standard (PJVS) is being implemented at Inmetro, in collaboration with the National Institute of Standards and Technology (NIST). Inmetro Programmable and conventional Josephson Voltage standards have been compared at 10 V, in order to evaluate the new PJVS system. The uncertainty components are addressed and the final comparison result is** $(V_{PJVS}-V_{cJVS})/V_{cJVS}= 1.24 \times 10^{-10}$ **with a relative total combined standard uncertainty of** 2.79×10^{-10}**.**

Index Terms **— Comparison, Josephson Voltage Standard, Programmable Josephson Voltage Standard, uncertainty.**

I. INTRODUCTION

In the early 1970s, many national standards laboratories started using the Josephson Effect as the practical standard of voltage [1]. Josephson Voltage Standard (JVS) systems were developed, making the calibration of voltage standards faster and more accurate. The conventional Josephson Voltage Standard (cJVS) systems provide a voltage calculated by $V = n.f/K_J$, where n is the number of the active steps, f is the irradiated microwave frequency, $K_J = 2.e/h$ is the Josephson constant, e is the elementary charge and h is the Plank constant. Despite of using the same $K_{J\text{-}90}$ (483 597.9 GHz/V), a direct on-site comparison of JVSs is the only way to uncover sources of error in a setup dedicated to calibrating secondary voltage standards, such as Zener-diode-based standards. Considering very good controlled condition (room temperature/humidity, on battery operation), Zener standards can reach typically relative uncertainty of a few parts in 10^9. On the other hand, the limiting factor of direct Josephson comparisons is the intrinsic noise level of the detector (one part in 10^{10} typically) [2]. A comparison between the Inmetro cJVS and the NIST Compact JVS at 10 V was performed in June 2009. A link between the Inmetro and the Bureau International des Poids et Mesures (BIPM) that was established via an earlier key comparison between the NIST and the BIPM was determined to be –0.26 nV with a standard uncertainty of 1.76 nV. Inmetro 10 V PJVS implementation is ongoing. It has been directly compared to the same cJVS described above, at 10 V, in order to evaluate it.

II. JOSEPHSON VOLTAGE STANDARDS DESCRIPTION

The Inmetro cJVS system uses a Hypres 10 V Josephson chip (SIS array) mounted onto the lower WR-12 flange of a tube waveguide, inside a magnetic shield at the bottom of the cryoprobe. The array is biased by a programmable current source. The RF source is a Millitech Gunn oscillator with a central frequency at 75 GHz and a ±1 GHz mechanical tuning range. The microwave frequency is locked by an EIP-578B frequency counter. Step biasing and the connection of the DUT are operated automatically by the software NISTVolt in a computer [3].

The PJVS system uses a NIST 10 V SINIS array, mounted onto the lower side of a semirigid coaxial cable inside a magnetic shield at the bottom of a cryoprobe. This array (composed by 265,113 juntions, divided into 23 sub-arrays - SbA01 to SbA23) is biased by a National Instrument PXI programmable current source. The RF source is an Agilent E8257D PSG Microwave Analog Signal Generator. Step biasing, array monitoring and voltage generation are operated automatically by the software PJVS2011 (NIST/Metas) in a computer. The bias source is always connected (what ensures the step stability). The GPIB interface and PXI communication links with the instruments are optically isolated from the computer. An Agilent 34420 is used either as a meter (to check the PJVS system behaviour and the array curves) or as a detector. Although our chip's SbA01 to SbA07 are not functional, the sub-arrays who work allow the array to provide 10 V [4].

Both arrays are floating with respect to ground, which means the measurement ground reference point can be chosen arbitrarily. A Symmetricon 571A cesium atomic clock (electrically isolated) provides a 10 MHz reference to the RF sources. The laboratory temperature was regulated to better than ± 0,1 ^{o}C (what minimizes the thermal voltages and ensures good voltage stability during the measurements).

III. COMPARISON PROCEDURE, MEASUREMENT RESULTS AND UNCERTAINTY

A. Measurement Information

This comparison involved both PJVS and cJVS systems, using the cJVS (reference) to measure the voltage provided by the PJVS (DUT). Before connecting the two systems for comparison, the PJVS was characterized and initialized using an operating frequency of 18.72 GHz and + 2 dBm RF power of the frequency synthesizer (where the PJVS array shows a very good performance). More details can be seen in [4]. The frequency of the cJVS was fixed at 75.929 GHz. Twenty-four points were taken using the cJVS to measure the PJVS. Half of those points were taken using the DVM in the normal polarity mode and the other half using the DVM in the reversed polarity mode. Each point was calculated from four sets of DVM measurements with array polarity + - + -. Each set consisted of 10 DVM readings. A fit to those 40 data was applied, assuming a linear drift of the thermal EMFs in the measurement; the results are the best estimate of the PJVS voltage and the type A uncertainty. More details can be seen in [5].

The average time to finish a comparison was 7 min. There were no corrections made to compensate for the cryoprobe leakage, rather the leakage errors were taken into account as a Type B uncertainty. The difference between the PJVS and the cJVS is given by:

$$V_{PJVS} - V_{cJVS} = \frac{\dfrac{\sum_i D_i^+}{N_+} + \dfrac{\sum_i D_i^-}{N_-}}{2} \qquad (1)$$

where D_i^+ is the *ith* measured difference between the PJVS and the cJVS and N_+ is the number of measurements taken by the cJVS with DVM normal polarity mode, D_i^- is the *ith* difference between the PJVS and the cJVS and N_- is the number of measurements taken by cJVS with DVM reversed polarity mode.

During the data acquisition for the comparison, the laboratory temperature and its relative humidity were controlled at 22.7 °C ± 0.1 °C and at 35 % ± 1 %, respectively.

B. Uncertainty [3]

Type A uncertainty of the JVS measurements is the pooled standard deviation of the mean of all the measurements:

$$u_A^{JVS} = \sqrt{\left(u_A^{JVS+}/2\right)^2 + \left(u_A^{JVS-}/2\right)^2} \qquad (2)$$

where u_A^{JVS+} and u_A^{JVS-} is the standard deviation of the mean for data sets with normal and reversed DVM polarity modes, respectively.

The sources of Type B uncertainty are: the frequency stability of the RF sources, the cryoprobe leakage currents, and the detector gain and linearity.

Most of the effects of the detector gain and frequency stability are already contained in the Type A uncertainty. Since both arrays had their polarities reversed during the measurements, the effect of the residual thermal EMFs (i.e., non-linear drift) and electromagnetic interferences are also contained in the Type A uncertainty of the measurements. Uncertainty components related to the RF power rectification and sloped Shapiro voltage steps are considered negligible since no such physical effects were observed.

The combined Type B uncertainty is the RSS of all the components. The final reported difference between the PJVS and the cJVS is shown in Table 1, as well as the associated uncertainties.

Table 1. The difference between the Inmetro PJVS and cJVS at 10 V with associated Type A and Type B uncertainties.

V_{PJVS}-V_{cJVS} (nV)	1.24
Type A uncertainty u_A (nV)	2.42
Type B uncertainty u_B (nV)	1.39
Combined standard uncertainty u_c (nV)	2.79

V. CONCLUSION

A comparison between the Inmetro cJVS and PJVS systems was carried out in January 2012, using the cJVS to measure 10 V against the PJVS. The difference between the two JVSs at 10 V was 1.24 nV with a Combined Standard Uncertainty (CSU) of 2.79 nV, showing the new Inmetro PJVS is working properly.

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REFERENCES

[1] S. P. Benz, C. Hamilton, “Application of the Josephson Effect to Voltage Metrology”, Proceedings of the IEEE, v. 92, issue 10, pp. 1617-1629, 2004.

[2] S. Solve and R. Chayramy, “The BIPM Compact Josephson Voltage Standard,” *IEEE Trans. Instrum. Meas.,* vol. 60, no. 7, pp. 2366 – 2371, July 2011.

[3] R.P. Landim, Y. Tang, E. Afonso and V. Ferreira, “A 10 V Josephson Voltage Standard Comparison Between NIST and INMETRO as a Link to BIPM,” *IEEE Trans. Instrum. Meas.,* vol. 60, no. 7, pp. 2353 – 2358, July 2011.

[4] R.P. Landim, M. Alzamora, V. Ferreira and E. Afonso, “Inmetro 10 V Programmable Josephson Voltage Standard Implementation,” submitted to CPEM 2012 Conf. Digest.

[5] Josephson Voltage Standard, Recommended Intrinsic/Derived Standards Practice, Nat. Conf. Standards Lab. Int. Publ., Boulder, CO, 2002.